EUROPEAN VLBI NETWORK

BIENNIAL REPORT 2013–2014

Produced on behalf of the European VLBI Network:

http://www.evlbi.org/

Max-Planck-Institut für Radioastronomie, Bonn

Compiled and edited by Richard Porcas

April 2016

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Introduction from the CBD Chair

I am delighted to introduce this latest European VLBI Network Biennial Report. EVN annual or biennial reports have been published since 1997 and have charted the growth of the network in many areas, including the participation of new observatories, technical advances and new observing capabilities.

The period 2013–2014 has been very eventful for the EVN. During this time we have successfully acquired a new EVN Associate Member – the Korean VLBI Network. The 3 telescopes of the KVN provide very useful additional long baselines at our highest frequencies, thus consolidating the truly Global nature of the EVN.

All member institutes are continually investing in new equipment but this period has seen the spectacular addition of two new large telescopes; the 65 m telescope at Tianma, near Shanghai, and the 64 m Sardinia Radio Telescope reinforce the EVN as the world's most sensitive VLBI facility.

Sensitivity for continuum observations has also been greatly enhanced by the introduction of digital VLBI backends, with the *DBBC* being increasingly deployed in the EVN, making observations at 2 Gbps possible.

We have seen some novel observing modes, notably *Out-of-Session* observing, initially introduced to provide EVN ground–array support for the Russian Space–VLBI project RadioAstron. And other possibilities – transient-triggered interrupts in realtime e–VLBI runs and joint observing with the Australian LBA – have been introduced.

The centre of EVN astronomical decision making lies in the Program Committee, of course. Here we have seen the replacement of 3 of its external members, and the welcome addition of an observatory member from the Institute of Applied Astronomy in St. Petersburg.

Also of importance was the change of all 3 EVN officers (Program Committee Chair, Technical and Operations Group Chair and Scheduler). These officers shoulder much of the burden of ensuring that the EVN continues as a superb astronomical facility, and I express my heartfelt appreciation for all the work they have done.

Our traditional, biennial EVN Symposium was held in October 2014, at Cagliari in Sicily. Some 133 participants attended this 4–day event, from all over the world, with 70 oral and 50 poster contributions. A highlight was, naturally, a visit to the new 64 m Sardinia Radio Telescope.

At the end of this period, on the 12th December 2014, the process of transforming JIVE into a European Research Infrastructure Consortium (ERIC) came to fruition, with the formal signing of the Decision by the European Commission.

Let me end by expressing my thanks to all the technical and operational staff at our EVN institutes who have contributed continuously to making the EVN work: the observing and technical friends, telescope schedulers and, of course, the correlator and user support groups at JIVE. And finally, many thanks to Richard Porcas who compiled and edited this report.

Anton Zensus

Chair, EVN Consortium Board of Directors
(July 2013–June 2015)

EVN CONSORTIUM BOARD OF DIRECTORS

The EVN is governed by a Consortium, founded in 1984 following 4 years of EVN observing made under less formal arrangements. The Directors of EVN Member Institutes form the Consortium Board of Directors (CBD). A list of Board membership during 2013–2014 is given below.

Table 1: **The EVN Consortium Board of Directors, 2013–2014**

Rafael Bachiller		National Astronomical Observatory, Madrid
Do-Young Byun	(from January 2014)	Korea Astronomy & Space Science Institute, Daejeon
Fernando Camilo	(until August 2014)	Arecibo Observatory
Michael Nolan	(from August 2014)	Arecibo Observatory
Luigina Feretti		Institute of Radio Astronomy, Bologna
Simon Garrington	**Chair** until June 2013	Jodrell Bank Observatory
Mike Gaylard	(until August 2014)	Hartebeesthoek Radio Astronomy Observatory
Ludwig Combrinck	(from August 2014)	Hartebeesthoek Radio Astronomy Observatory
Xiaoyu Hong		Shanghai Observatory
Alexander Ipatov		Institute of Applied Astronomy, St. Petersburg
Krzysztof Katarzynski		Toruń Centre for Astronomy
Hans Olofsson		Onsala Space Observatory
Torben Schueler		Geodetic Observatory Wettzell
Merja Tornikoski	(until June 2014)	Aalto University, Helsinki
Joni Tammi	(from July 2014)	Aalto University, Helsinki
Huib van Langevelde		Joint Institute for VLBI in Europe, Dwingeloo
Rene Vermeulen		ASTRON, Netherlands Institute for Radio Astronomy, Dwingeloo
Na Wang		Xinjiang Astronomical Observatory
Anton Zensus	**Chair** from July 2013	Max Plank Institute for Radio Astronomy, Bonn

EVN CBD Meetings: The CBD meets twice per year to discuss EVN activities, to make EVN policy decisions and to appoint EVN Officers (Chairs of the Program Committee and Technical & Operations Group, and the Scheduler), and members of the Program Committee. Meetings are attended by the EVN Officers and also by representatives of EVN observing partner organizations (e.g. NRAO and RadioAstron), and other individuals who may be invited to address topical meeting agenda points. The locations and dates of CBD meetings during 2013–2014 are given below.

Table 2: **CBD Meetings held during 2013–2014**

Jodrell Bank Observatory	16 April 2013
ASTRON/JIVE, Dwingeloo (see Figure 1)	12 November 2013
Onsala Space Observatory	13 May 2014
Institute of Radio Astronomy, Bologna	5 November 2014

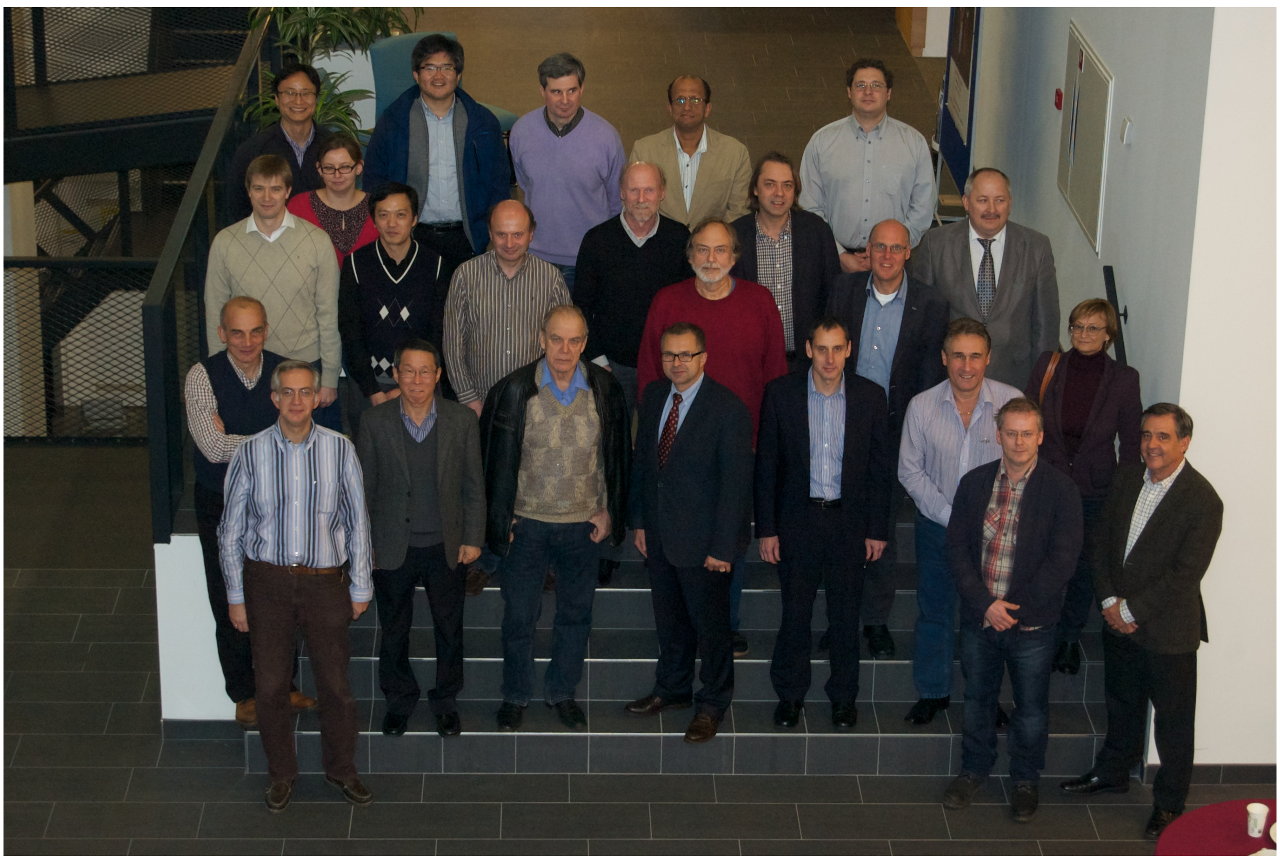


Figure 1: Participants in the Dwingeloo CBD meeting, November 2013

PROGRAM COMMITTEE REPORT

The EVN Program Committee (PC) consists of 13 voting members, 9 drawn from the EVN institutes and 4 *at large* representatives from other European institutes. In addition the EVN Scheduler attends PC meetings as a non–voting member. Members typically serve on the committee for a period of around 2-3 years, and are then replaced by other representatives invited by the EVN CBD.

EVN PC meetings: The PC meets three times a year, typically around a month after each proposal deadline, to discuss recent proposals received, to allocate a grade to each successful proposal, and to provide detailed feedback to each PI. Meeting locations and dates are given below.

Table 1: **PC Meetings during 2013–2014**

Bologna	13th March 2013	Trimester 13A
Gothenburg	2nd July 2013	Trimester 13B
Granada	6th November 2013	Trimester 13C
Valencia	14th March 2014	Trimester 14A
Toruń	1st July 2014	Trimester 14B
Bologna	6th November 2014	Trimester 14C

For the consideration of Global VLBI proposals, independent grades are provided by NRAO. In addition, voting members from NRAO join the PC meetings for extended discussions. Target of Opportunity proposals received outside formal deadlines are circulated to PC members by the PC Chair, grades and feedback being returned to the PI typically within a few days.

The PC membership through 2013–14 is listed below, including other representatives (non-voting) who contribute to the EVN PC's process.

Table 2: **List of members of the EVN PC and their roles.**

VOTING MEMBERS	**INSTITUTE**	**ROLE**
Anna Bartkiewicz	Toruń, PL	PC member
Angela Bazzano	INAF, Rome, IT	PC *at-large* member from 01/05/14
Bob Campbell	JIVE, Dwingeloo, NL	PC member; EVN correlator representative
Sandor Frey	FOMI, Budapest, HU	PC *at-large* member from 01/01/14
Marcello Giroletti	INAF-IRA, Bologna, IT	PC member
Liz Humphreys	ESO, Garching, DE	PC *at-large* member from 01/01/14
Michael Lindqvist	Onsala Space Observatory, SE	PC member; (**Chair** from 01/01/15)
Andrei Lobanov	MPIfR, Bonn, DE	PC member
Tom Muxlow	JBCA/e-MERLIN, Manchester, UK	PC member; **Chair** from 01/06/11-31/12/14
Alexey Melnikov	Saint Petersburg, RU	PC member from 01/01/14
Antonis Polatidis	ASTRON, Dwingeloo, NL	PC member
Zhi-Qiang Shen	Shanghai Observatory, CN	PC member
Jose Carlos Guirado	University of Valencia, ES	PC *at-large* member until 30/04/14
Miguel Perez-Torres	IAA-Granada, ES	PC *at-large* member
Nektarios Vlahakis	University of Athens, GR	PC *at-large* member until 31/11/13
SCHEDULERS		
Richard Porcas	MPIfR, Bonn, DE	EVN Scheduler until 31/12/13
Alastair Gunn	JBCA/e-MERLIN, Manchester, UK	EVN Scheduler from 01/01/14
NRAO		
Mark Reid	CfA, USA	NRAO Review committee Chair
Mark Claussen	NRAO, USA	VLBA/VLA Scheduler

Proposal statistics: The EVN operates an open–sky observing policy with proposals scheduled into 3 main observing sessions per year, plus regular (∼monthly) additional e–VLBI days. With the expansion of the array to include additional Russian and Asian antennas, submitted EVN astronomical proposal totals nearly doubled in 6 years – dominated by increases in proposed conventional disk–based EVN time. Proposal statistics from 2006 to 2014 are shown in Figure 2. Since the peak in proposal numbers in 2012, the numbers of conventional proposals and the total hours requested have subsided somewhat – however the total requested *network time* (EVN and RadioAstron hours requested within conventional sessions) has steadily increased, showing that we are now receiving fewer, but larger and more complex conventional disk–based proposals. (As of November 2015, the total number of hours requested in 2015 has recovered to more than the total requested at the peak in 2013.) The typical over–subscription rate, (hours requested)/(hours approved), still stands at ∼2.2.

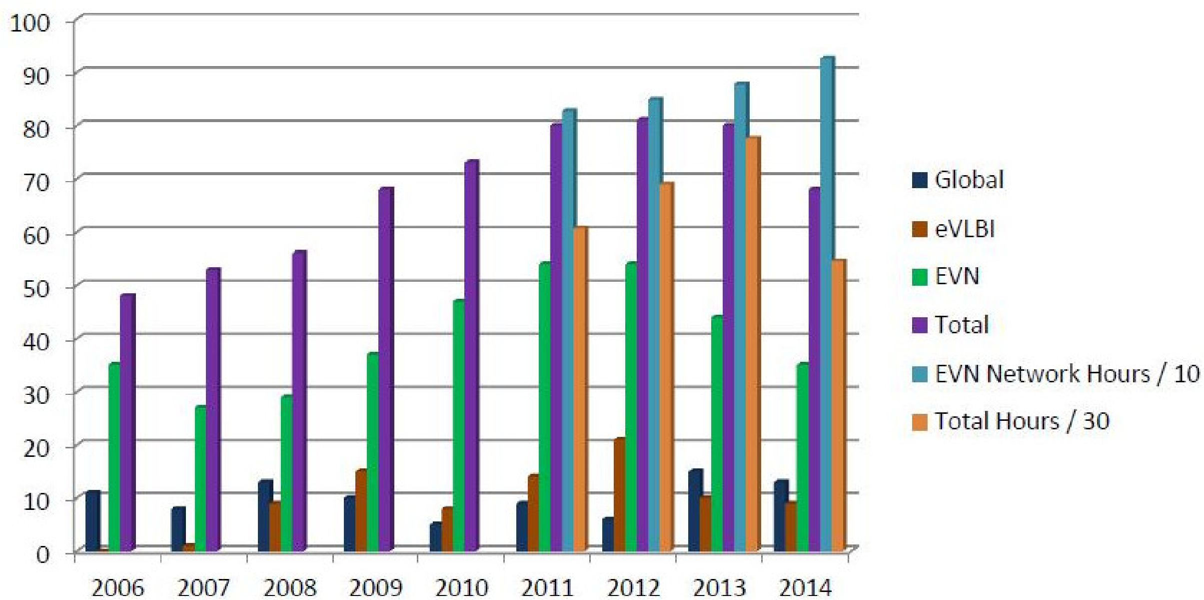


Figure 2: Total **numbers of proposals** submitted between 2006 and 2014 (purple), subdivided into EVN–alone (disk-recording; green), e–VLBI (dark brown) and Global (dark blue). From 2011 to 2014 the **total numbers of hours** proposed is also given (light brown), with "EVN Network Hours" (all observations within advertized sessions and runs) given separately (light blue).

Requested Science Research Areas and Observing Bands: There is a large international pool of users of the EVN and Global VLBI array which stretches significantly beyond the EVN member institutes and countries. Although the majority of PIs are based within Europe, a significant and growing number of EVN users are found worldwide. However, the reasearch areas proposed through 2013–2014 did not differ significantly from those reported in the previous biennial report, although there are variations between individual Trimesters. The dominant research areas still remain those of AGN/QSO, Radio Galaxies/Jets, and Star/Stellar Evolution which account for typically 60% or more of proposals received. Consequently, the requested frequency bands are likewise dominated by these research areas resulting in large numbers of proposals requesting the 18/21 cm and 6 cm bands. However, the remaining bands are still well populated with proposal requests (see Figures 3 and 4 for proposal statistics for 2010–2014.)

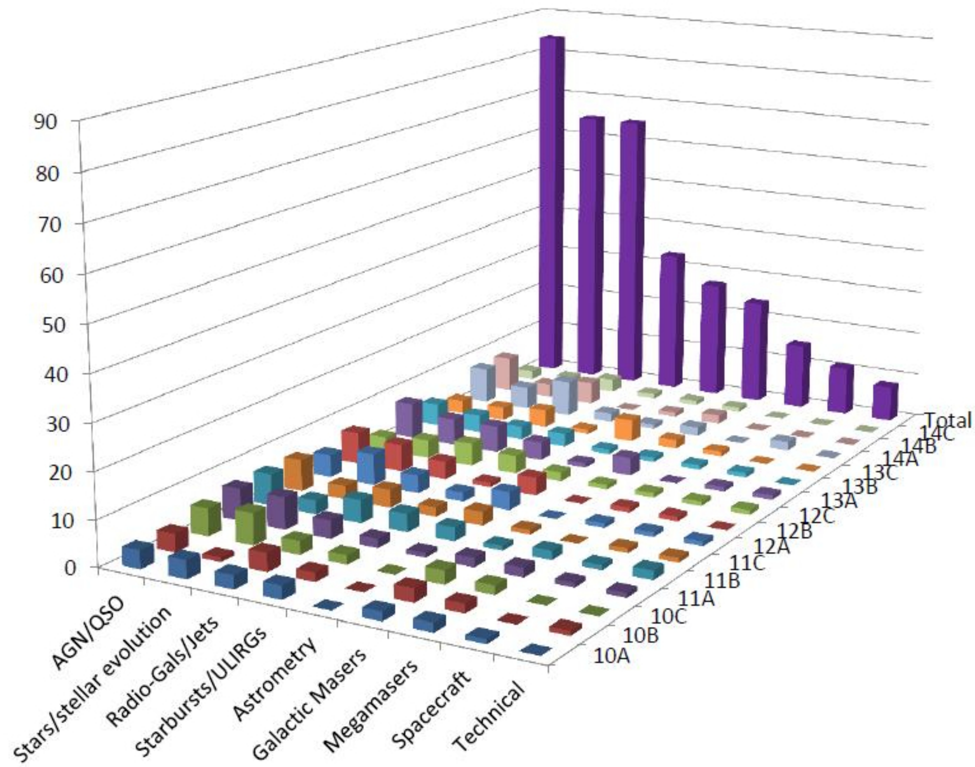


Figure 3: The distribution of scientific categories for proposals submitted from 2010 to 2014.

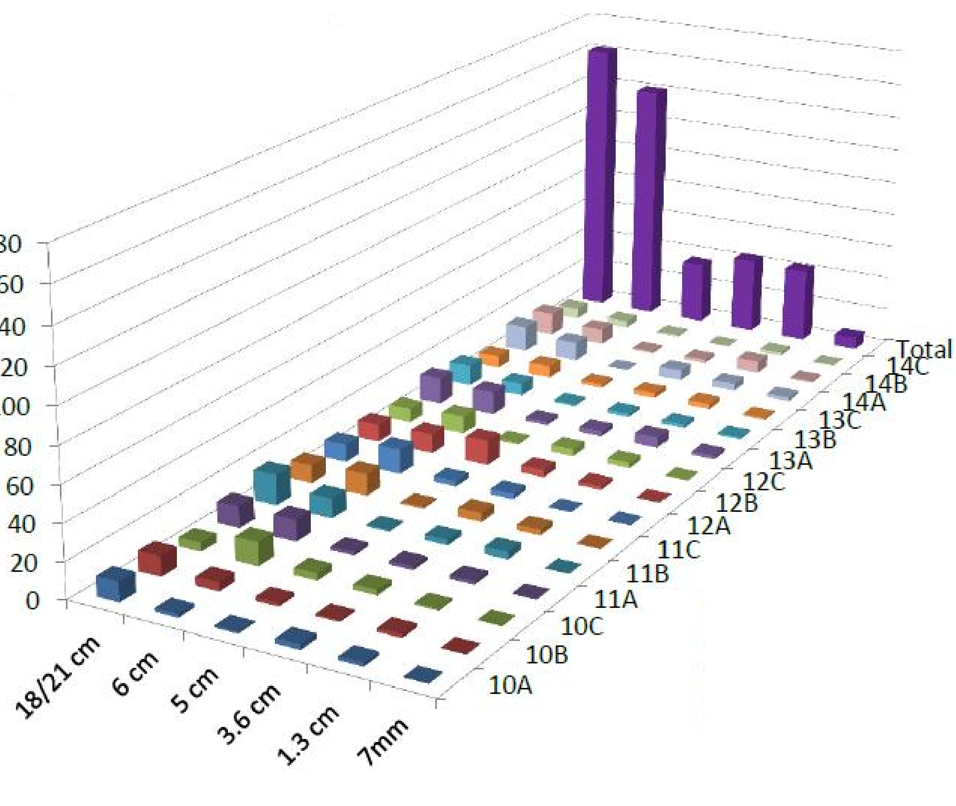


Figure 4: The distribution of requested wavebands for proposals submitted from 2010 to 2014.

TECHNICAL AND OPERATIONS GROUP REPORT

The Technical and Operations Group (TOG) is made up of the personnel at EVN stations who provide the technical and operational expertise for operating the telescopes as a VLBI array. They are also responsible for advising the EVN CBD on all aspects of technical and operational issues relevant to the reliability and performance of the network. The TOG is also the body which implements technical and operational upgrades across the network. Michael Lindqvist of Onsala Space Observatory chaired the TOG 2013–2014 (vice–chair Arpad Szomoru of JIVE).

TOG Meetings: There were three meetings during 2013–2014, all supported by RadioNet3 (funded from the European Community's seventh Framework Programme under RadioNet3–FP7). Reports from the meetings are available on the EVN web–site. The locations and dates of the meetings are given below.

Table 1: **TOG Meetings held during 2013–2014**

MPIfR, Bonn, Germany (see Figure 5)	April 10–12, 2013
Wettzell, Germany	January 23–24, 2014
Cagliari, Italy	October 5–6, 2014

Figure 5: Participants in the Bonn TOG meeting, April 2013

TOG activities: The main emphasis during the period of this report was maintaining the high level of performance achieved in the previous years, improving the reliability of the operation as a whole, and the quality of the network calibration. The roll–out and site testing of the Digital Base–Band Converter (DBBC) Version 2 continued in the reporting period. The number of stations with tested DBBC (and other digital systems) is such that 2 Gbps in operation will be possible in 2015.

Significant points to be noted are:

- Toruń and Medicina are available at 22 GHz since Session 1/2013
- Urumqi and Shanghai have installed new dual–polarisation S/X band receivers since Session 1, 2013
- All the e–VLBI experiments are now correlated using SFXC
- There were first e–VLBI fringes to Irbene on 19 March 2013
- The maximum data rate for Global projects was increased from 0.5 Mbps to 1 Gbps
- Most EVN stations have started to use *jive5ab* (a control program for Mark5 recorders) also for disk recording
- The 64 m Sardinia Radio Telescope (SRT) showed its first fringes at 22 GHz on January 27, 2014, with the Medicina antenna. SRT participated in the NMEs as an EVN station in EVN session 1 2014 at 18, 5, and 1.3 cm. Fringes were found at 18 and 1.3 cm.
- The new 65 m radio telescope near Shanghai, Tianma65, participated in all EVN session 1 2014 NMEs at 18, 6 and 5 cm. Fringes were found with the station at all these bands both through analogue and DBBC backends.
- The three KVN stations join the EVN array as regular EVN stations. They participated in all NMEs and participated in user experiments from session 2, 2014.
- Flexbuff recording (in parallel with standard recording) has been tested (partly) successfully since 2014
- From 2013 a trial implementation of EVN outside of standard session observing, in which time was reallocated from within the standard disk sessions, has been explicitly devoted to RadioAstron A01 proposals. From the 1st June 2014 deadline, this Out–of–Session observing time (up to a maximum of 144 hours/year), was available to all proposals
- An exploratory agreement with the Australian Long Baseline Array (LBA) began to make some time available for simultaneous scheduling with the EVN, thus enabling the possibility of joint LBA/EVN observations
- The pool of spare parts for the DBBC2 was started
- The automated generic e–VLBI trigger class was developed during 2014. It will be introduced to the community in 2015
- The calibration of the amplitude of the observed interference fringes could be improved even further; occasionally some stations show calibration errors of more than 10%

SCHEDULERS REPORT

The EVN Scheduler plans EVN observing sessions and runs, scheduling observations approved by the EVN Program Committee according to their grades and taking into account the many logistical constraints. Richard Porcas (MPIfR) was the Scheduler up to December 2013; Alastair Gunn (Jodrell Bank) was appointed Scheduler by the CBD from January 2014.

EVN Observing Periods: There were 3 *Standard Sessions* in each of 2013 and 2014, each nominally lasting 3 weeks. There were also 10 24h *e–VLBI* observing runs in each year.

A new observing opportunity – *Out–of–Session (OoS)* observing – was introduced in 2014, initially to accommodate EVN observations together with the Russian Space VLBI program **RadioAstron**.

The EVN also responds to a limited number of *Target–of–Opportunity (ToO)* proposals, where the need for urgent scheduling forces a rapid and unscheduled proposal review. In 2013–14 12 ToO projects were observed with 16 observations for a total of 151 hours. ToO observations can often be accommodated in the standard sessions or e–VLBI runs, but some require *ad hoc* scheduling outside of these periods.

Because a single approved project may request more than one observation the total number of *user observations* exceeds the number of observed *projects*. In addition calibration and performance–monitoring observations (NMEs) are counted as observations in this report, unless otherwise stated. Details and statistics for the various observing periods are given in the following individual sections. Below is a summary of EVN observing time scheduled in 2013–2014.

Standard sessions	1502 hours	239 observations (156 user observations from 70 projects)
e–VLBI runs	353 hours	54 user observations, including 6 *ToO* and 12 *short obs.*
OoS observations	155 hours	11 user observations from 4 projects
ToO *adhoc* **observations**	74 hours	6 user observations from 6 projects

Standard Sessions 2013-14: Table 1 summarises the dates of the 6 standard sessions and the observing wavelengths used. “LENGTH” is the time between the start of the first observation and the end of the last; “EFFICIENCY” is the ratio of the total time scheduled to the LENGTH.

TABLE 1 - EVN SESSIONS 2013-2014

SESSION	OBSERVING DATES	LENGTH (days)	EFFICIENCY (%)	WAVELENGTHS (cm)	PROJECTS SCHEDULED
2013-1	21 February - 14 March	21.6	52.7	6 1.3 5 3.6 18	15
2013-2	23 May - 13 June	20.9	52.3	6 5 18/21 3.6 1.3	17
2013-3	16 October - 05 November	20.0	48.2	1.3 6 18/21 90 3.6	16
2014-1	20 February - 11 March	19.2	48.0	18 5 6 1.3	14
2014-2	29 May - 19 June	20.6	59.3	18 0.7 6 5 90 1.3	16
2014-3	16 October - 05 November	20.0	44.9	5 0.7 6 18/21 3.6	13

Table 2 (page 12) gives a breakdown of the number of observations (N-OBS) in various categories, the size of the recording (T-BYTES) and correlators use. GLOBAL observations are those made together with the VLBA and/or GBT and/or VLA.

TABLE 2 - DETAILS OF EVN SESSIONS 2013-2014

	SESSSION 2013-I			SESSSION 2013-II			SESSSION 2013-III		
	N-OBS	HOURS	T-BYTES	N-OBS	HOURS	T-BYTES	N-OBS	HOURS	T-BYTES
TOTAL	43	273.2	734.3	44	263.0	763.1	38	220.5	758.5
EVN-only	26	283.2	653.8	28	215.0	712.6	21	154.0	680.2
GLOBAL	4	32.0	25.8	1	13.0	3.0	2	28.5	21.5
Short Obs.	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	13	38.0	54.7	15	35.0	47.5	15	38.0	56.8
Correlator:									
EVN JIVE	33	203.9	682.0	34	194.0	673.6	27	154.0	723.0
Bonn	3	28.0	52.3	3	24.0	89.5	1	15.0	18.7
VLBA	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
e-VLBI JIVE	2	18.3		2	25.0		2	8.0	
ASC Moscow	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
CAL-only	5	23.0		5	20.0		5	18.0	
User projects:									
Continuum	25	187.2	657.5	21	163.0	699.9	19	152.0	681.8
Spectral line	5	48.0	22.1	8	65.0	15.7	2	14.0	14.3
Pulsar	0	0.0	0.0	0	0.0	0.0	2	16.5	5.6
MERLIN	0			2			4		
Arecibo	0			4			3		
VLBA	1			1			1		
GBT	0			0			1		
VLA	0			0			0		
Robledo	2			0			2		
Goldstone	0			0			0		
RadioAstron	0			0			4		

	SESSSION 2014-I			SESSSION 2014-II			SESSSION 2014-III		
	N-OBS	HOURS	T-BYTES	N-OBS	HOURS	T-BYTES	N-OBS	HOURS	T-BYTES
TOTAL	36	221.5	728.5	44	292.5	765.8	34	231.5	800.4
EVN-only	21	165.0	627.7	18	176.0	596.7	13	102.0	398.4
GLOBAL	3	22.5	49.0	11	74.5	111.7	8	94.5	356.2
Short Obs.	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	12	34.0	51.8	15	42.0	57.4	13	35.0	45.8
Correlator:									
EVN JIVE	29	171.0	711.8	38	259.0	747.6	28	173.5	628.7
Bonn	1	11.5	16.7	1	13.5	18.2	0	0.0	0.0
VLBA	0	0.0	0.0	0	0.0	0.0	2	42.0	171.7
e-VLBI JIVE	2	21.0		0	0.0		0	0.0	
ASC Moscow	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
CAL-only	4	18.0		5	20.0		4	16.0	
User projects:									
Continuum	18	143.5	622.6	15	167.5	681.6	18	175.0	745.6
Spectral line	5	34.0	8.5	10	73.0	20.4	3	21.5	9.0
Pulsar	1	10.0	45.6	4	10.0	6.4	0	0.0	0.0
MERLIN	4			5			0		
Arecibo	0			6			0		
VLBA	0			11			7		
GBT	0			1			4		
VLA	0			4			5		
Robledo	1			1			0		
Goldstone	0			0			1		
RadioAstron	1			1			1		

Figure 6 shows the amount of time observed in standard sessions in 2013 and 2014 at each EVN observatory (identified by their standard station codes – see page 2), and EVN affiliate Robledo (Ro).

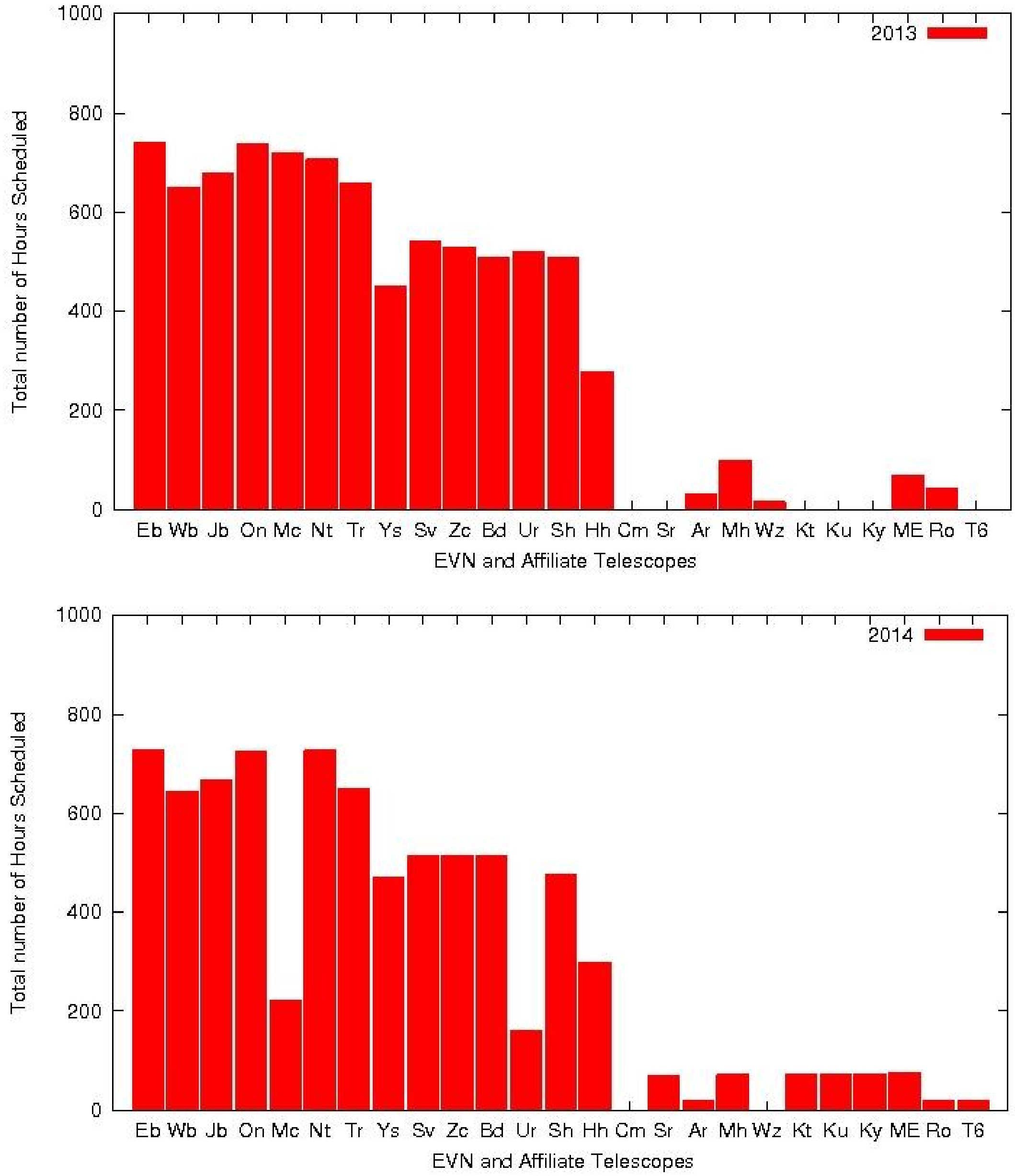


Figure 6: Total number of hours scheduled by telescope: **(top)** 2013, **(bottom)** 2014

A few features of these plots may be noted: There were no observations at Cambridge (Cm) due to the replacement of the radio links and the upgrade to e–MERLIN. Medicina (Mc) suffered a telescope breakage in 2014 (see station report, page 24) and could not observe for some sessions. Urumqi (Ur) began a major upgrade in 2014 (see station report, page 38) and could not observe in the later part of the year. The KVN (Kt, Ku, Ky), the new 64 m Sardinia Radio Telescope (Sr) and the new Shanghai 65 m telescope at Tianma (T6) only started EVN observing in 2014.

Figure 7 shows the amount of time scheduled for user projects in 2013 and 2014, broken down by wavelength (x–axis) and observation type (colours). As for earlier years, 6 cm and 18/21 cm remain the "workhorse" observing bands. The 5 cm band is used exclusively for observing maser lines of methanol and excited OH. Observations at 7 mm, and 30, 50 and 90 cm are rarely requested.

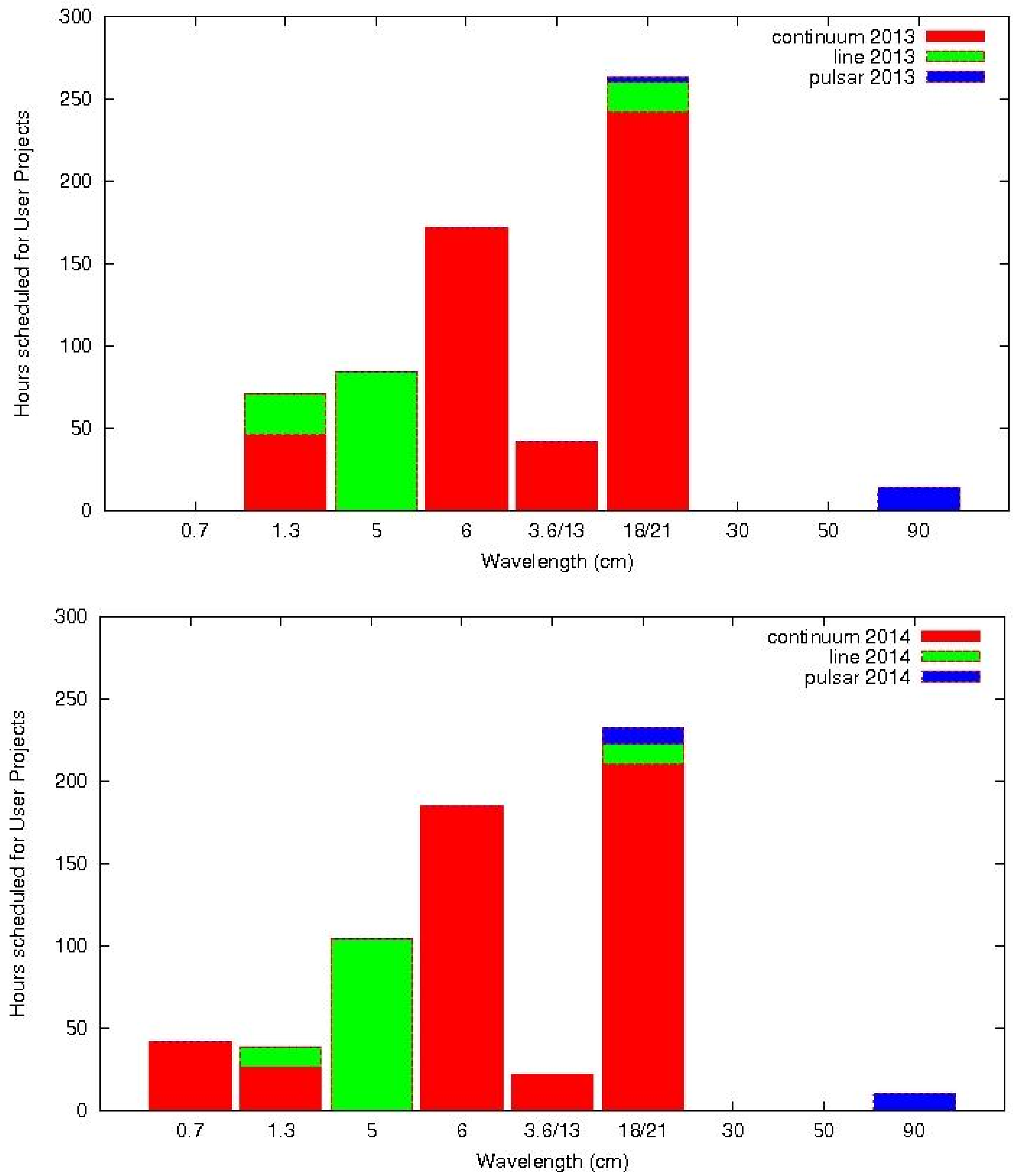


Figure 7: Total number of hours scheduled for user projects by wavelength: **(top)** 2013, **(bottom)** 2014

e–VLBI Runs: Details of the amount of time used and wavelengths observed in e–VLBI runs in 2013–2014 are shown in Table 3. In addition to *Normal* and *ToO* projects, an additional class of *short observations* is supported (<2 hours each) which have the character of service observations (e.g. checking a calibrator source for future observing) and may be approved by application to the EVNPC Chair (see Table 4). Occasionally a proposal which cannot be scheduled in a normal EVN session is modified for observing in an e-VLBI run (type "Disk"); there were none during 2013–2014.

There is also a class of e–VLBI proposals which are "scheduled" but observing is only triggered at short notice (1 day) when some "trigger criteria" are met (e.g. target is in a flaring state). Only one such *Trigger Proposal* was activated in 2013–2014

TABLE 3 - EVN e-VLBI RUNS 2013-2014

				e-VLBI PROPOSAL TYPE					
SESSION	DATE	WAVELENGTH	HOURS	Normal	Short	Disk	ToO	Trigger	
13e01	15JAN13	6cm	17h	2	2	0	0	2 sched	0 trig
13e02	05FEB13	6cm	3h	1	0	0	0	2 sched	0 trig
13e03	19MAR13	6cm	15h	3	1	0	0	2 sched	0 trig
13e04	16APR13	18cm	24h	2	1	0	0	1 sched	0 trig
13e05	02MAY13	6cm	16h	2	2	0	0	2 sched	0 trig
13e06	18JUN13	6cm	22h	3	1	0	0	2 sched	1 trig
13e07	17SEP13	6cm	19h	3	0	0	0	1 sched	0 trig
13e08	08OCT13	18cm	12h	2	0	0	0	0 sched	
13e09	12NOV13	6cm	18h	0	0	0	2	1 sched	0 trig
13e10	03DEC13	6cm	24h	3	0	0	0	2 sched	0 trig
14e01	14JAN14	18cm	18h	1	0	0	0	1 sched	0 trig
14e02	18FEB14	6cm	24h	1	1	0	1	0 sched	
14e03	25MAR14	6cm	24h	2	0	0	1	0 sched	
14e04	15APR14	18cm	18h	1	0	0	0	0 sched	
14e05	28APR14	6cm	24h	1	1	0	1	0 sched	
14e06	24JUN14	6cm	24h	1	0	0	1	0 sched	
*14e07	16SEP14	18cm	0h						
14e08	08OCT14	18cm	24h	1	0	0	0	0 sched	
14e09	18NOV14	6cm	24h	1	1	0	0	2 sched	0 trig
14e10	02DEC14	18cm	21h	1	2	0	0	0 sched	

* Session 14e07 was cancelled due to multiple telescope failures

TABLE 4 - e-VLBI SHORT OBSERVATIONS 2013-2014

CODE	SUBMITTED	LAM	HOURS	OBSERVED
RSP07	11Oct12	6cm	2h	15Jan13 e1301
RSF07	09Jan13	6cm	2h	16Jan13 e1301
RSP08A	25Feb13	6cm	2h	19Mar13 e1303
RSP08B		18cm	2h	16Apr13 e1304
RSC01	05Mar13	6cm	2h	18Jun13 e1306
RSL02	04Apr13	6cm	2h	03May13 e1305
RSG05	09Apr13	6cm	2h	03May13 e1305
RSL03	04Feb14	18cm	4h	18Feb14 e1402
RSP09	07Apr14	6cm	2h	29Apr14 e1405
RSG06	16Oct14	18cm	3h	02Dec14 e1410
RSC02	22Oct14	6cm	2h	18Nov14 e1409
RSP10	28Nov14	18cm	3h	02Dec14 e1410

Out–of–Session Observations: Details of this new class of observations are shown in Table 5. These are all joint EVN+RadioAstron observations from RadioAstron Key Science Proposals. Most were correlated at the MPIfR correlator in Bonn.

TABLE 5 - EVN OUT-OF-SESSION OBSERVATIONS

DATE yymmdd	WAVELENGTH (cm)	SOURCE	PROGRAM	CORRELATOR	HOURS
130921	1.3 + 6	3C84	KSP - nearby AGN	Bonn	14
130929	18	BLLAC	KSP - AGN polarization	Bonn	18
131110	1.3	BLLAC	KSP - AGN polarization	Bonn	16
140101	18 + 90	P B0329+54	KSP - pulsars	ASC	13
140110	1.3 + 6	0836+710	KSP - AGN physics	Bonn	18
140118	1.3	3C273	KSP - AGN polarization	Bonn	12
140204	1.3 + 6	M87	KSP - nearby AGN	Bonn	15
140404	1.3	OJ287	KSP - AGN polarization	Bonn	15
140421	1.3 + 6	3C345	KSP - AGN physics	Bonn	18
140430	1.3 + 6	3C373	KSP - AGN physics	Bonn	8
141226	1.3	1642+690	KSP - AGN physics	Bonn	8

Target-of-Opportunity Observations: Details are given in Table 6.

TABLE 6 - EVN TARGET-OF-OPPORTUNITY OBSERVATIONS 2013-2014

PROPOSAL		SCHEDULING					
Date	Topic		lambda	time	date	session	mode
10May12	Blazar TXS 0536+145 in flaring state	C	1.3cm	3h	27Feb13	EVN-I	disk
		D	1.3cm	3h	11Jun13	EVN-II	disk
		E	1.3cm	3h	17Oct13	EVN-III	disk
12Mar13	High-energy flare in the Crab Nebula		18cm	12h	24Mar13	adhoc	disk
29Apr13	Bright outburst in GRB 130427A		6cm	12h	03May13	adhoc	evlbi
22May13	Outburst in Seyfert NGC 2617		18cm	7h	07Jun13	EVN-II	evlbi
06Jul13	Size of nearby GRB 130702A		6cm	12h	15Jul13	adhoc	evlbi
22Jul13	SN 2013df in NGC 4414		1.3cm	12h	31Aug13	adhoc	evlbi
01Nov13	outburst in XTE J1908+094	A	6cm	8h	08Nov13	adhoc	evlbi
		B	6cm	9h	12Nov13	e1309	evlbi
05Nov13	Millisecond pulsar J1023+0038		6cm	8h	13Nov13	e1309	evlbi
24Jan14	Type Ia SN2014J in M82	A	18cm	18h	03Feb14	adhoc	evlbi
		B	18cm	14h	18Feb14	e1402	evlbi
13Mar14	Core localisation in XTE J1908+094		6cm	8h	26Mar14	e1403	evlbi
08Apr14	Jet of ULX Holmberg II X-1		6cm	18h	28Apr14	e1404	evlbi
18May14	SN2014bc in M106		6cm	4h	24Jun14	e1406	evlbi

EVN OBSERVATORY REPORTS

National Astronomy and Ionosphere Center, Puerto Rico, USA

ARECIBO OBSERVATORY

During the period 2013–2014 the Arecibo 305 m *William E. Gordon Telescope* participated in 167 VLBI observations in total, including 21 EVN–related runs, covering EVN and Global Network disk-recording, and EVN e–VLBI observations, and some common observation with the Russian space antenna, RadioAstron. However, Arecibo's major co-observing with RadioAstron takes place via several independent proposals. In these two years, 122 sessions were conducted under that arrangement.

VLBI hardware/software: The digital backend, RDBE, and the Mark5C recorder were integrated with the 305–m telescope in April 2013. Considerable help was received from the world community of VLBI experts. Since then, it has been used in the *PFB* mode for most HSA observations.

12 m phase-referencing antenna (see Fig. 8): During the summer of 2013, a GUI was constructed by the REU student, Stefen Mellem under the supervision of Prakash Atreya and Luis Quintero, with inputs from Tapasi Ghosh. This is able to control two sets of RDBEs and Mark5C's regardless of the origin of their IF signal. Using this software, and the single IF/LO chain to the X–band receiver of the 12 m antenna designed by Dana Whitlow & Anthony Ford, tests are being conducted to record drift data from the 12 m antenna. Full commissioning of the 12 m will begin as soon as all the systems have been integrated. VLBI phase-referencing tests using the 12 m and the 305 m telescope will begin subsequently, in coordination with the VLBA at X–band. In future, the 12 m antenna needs to be equipped with a wide–band receiver in order to cover all frequency ranges usually used for VLBI observations.

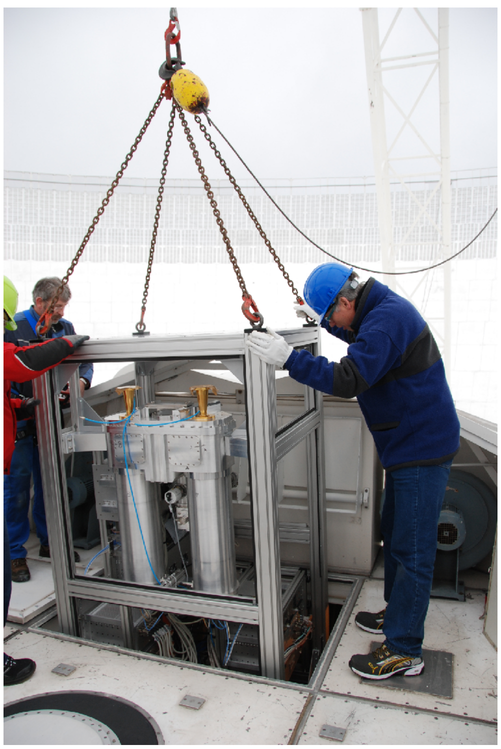
Figure 8: Arecibo 12 m phase-referencing antenna

Max-Planck-Institut für Radioastronomy, Bonn, Germany

EFFELSBERG RADIO OBSERVATORY

New receiver: In January 2014 a new K–band receiver was installed in the secondary focus cabin. It is a double horn system with a frequency range of 18–26 GHz, and will replace the old 1.3 cm VLBI receiver (21.7–24.4 GHz). The receiver was tested successfully for VLBI in EVN fringe test observations in June 2014. Fringes to the rest of the array showed a comparable to slightly better SNR than with the old receiver. The system is not finally calibrated yet, and also the IF system is not fully completed. The work was expected to be finished in November 2014, when it will become the main K–band receiver for VLBI observations.

The new receiver will be also used for continuum and spectroscopy observations. For spectroscopy the system will be equipped with 28 FFTS cards with 64k channels that can either cover the whole 8 GHz band in two polarizations or be used in a zoom mode for high resolution observations.



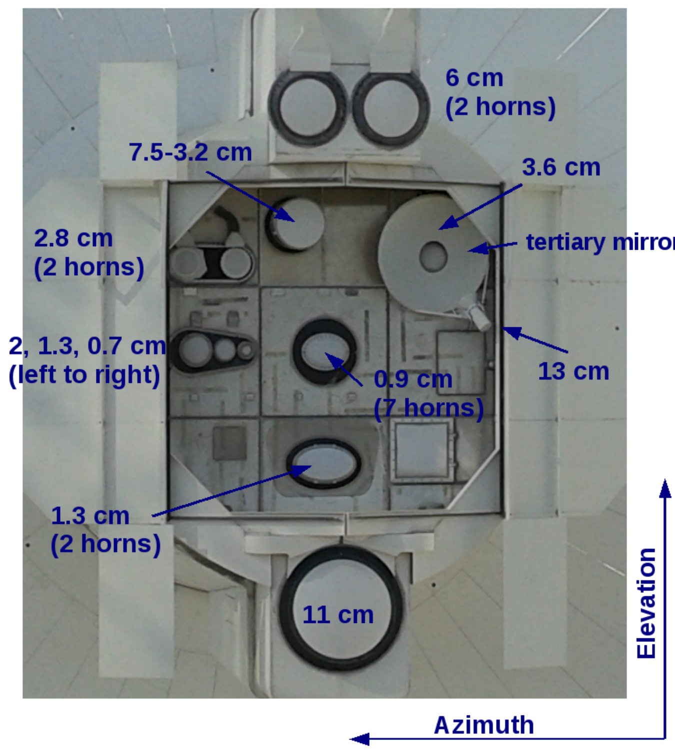


Figure 9: **Left:** Installing the new K–band receiver (photo: C.Kasemann) **Right:** Secondary focus feed arrangement

4 Gbps e–VLBI demonstration: Effelsberg participated in a successful 4 Gbps e–VLBI demo on September 18th 2013, which was organized for the final review of NEXPReS at JIVE. The observations were done at X–band using 16x32 MHz channels in dual polarization. The data was recorded on a Mark5C and in parallel sent to JIVE for real–time correlation. Fringes were obtained between Effelsberg, Metsähovi and Yebes.

Digital backends and recorders: Effelsberg is a full member of the EVN but also takes part in regular Global 3mm VLBI Array (GMVA) and High Sensitivity Array (HSA) observations, and occasional geodetic VLBI runs. To ensure full compatibility for all VLBI observations both DBBC and RDBE backends have been continually maintained and updated.

a) DBBC: In February 2013 a new Field System version allowed the implementation of true continuous calibration, which is now in use for the Effelsberg DBBC. This has allowed an overdue update of our *rxg* files. *Perl* code to perform calibration in 80 Hz continuous–cal mode was written. This produces files in *tsm* and *antabfs* format. (However, it will not work with on–off cal, or for DBBC units which have only two ADCs.)

In late summer 2013 the software on all VLBI equipment was updated.
The DBBC now uses software version 104 for all digital down–converter (*DDC*) observations which allows measurements of Tsys and Tcal with higher resolution to be made, and should further improve the calibration.
Field System release 9.11.4 was installed, which should be more robust against funny global schedules with lots of different modes and different VLBI backends and recorder combinations.
The Mark5B+ recorder was updated to *SDK 9.2*, and all e–VLBI and disk recordings are now done with the same software, namely *jive5ab* from JIVE.

During the e–VLBI test time on 28 April 2014 Effelsberg tested new *DDC* firmware/software that provides a better–shaped 16 MHz band pass. The previous firmware effectively limited the bandwidth to 13.5 MHz, but the new software provides a nearly flat bandpass over the whole 16 MHz range. The e–VLBI test was successful and the new bandpass shapes significantly improve the SNR of the correlated data. In addition the new software provides 32 MHz tunable BBCs and thereby allows more flexible frequency settings at stations for recording rates of up to 2 Gbps, compared to the fixed frequency channels in polyphase filter–bank (*PFB*) mode.

b) RDBE: Most receivers at Effelsberg provide an IF signal ranging from 500–1000 MHz and can therefore be connected to the RDBEs directly. However the 18/21 cm and 13 cm receivers only provide a narrow band IF signal ranging from 80–220 MHz. In summer 2013 the RDBEs were connected to an IF switch box and an IF up–converter for the narrow band IFs, which allows one to automatically switch between the different IF systems at Effelsberg. Thus the RDBEs can be used with all the available VLBI receivers at Effelsberg, including S/X–band geodetic configurations.

In 2013 a Field System facility to control the RDBEs was added as station code, initially to support 2 Gbps observations with the VLBA and GBT as part of the High Sensitivity Array (HSA), using the (*PFB*) mode. Calibration files are produced in *tsm* format. The Effelsberg RDBE code has also been installed at Arecibo. In January 2014 further developments resulted in a successful demonstration of a *DDC* mode (*DDC–4*, single RDBE) for HSA observations, and was used in a number of subsequent HSA observations using either 4x128 MHz at 2 Gbps or 4x32 MHz at 512 Mbps.

In 2014 a new software–switch was installed in the RDBE rack to combine the two data streams from the 2 RDBEs into a single Mark5C recorder. It uses the same main board as the Mark6 recorders, provides four 10GE connectors and uses NRAO's soft–switch software. Initial zero baseline tests against the DBBC in various modes showed very low rates of data loss: about 0.005% for data rates of 1 Gbps and 0.05% for 2 Gbps. Two *DDC–8* mode fringe test observations in July and September 2014 were successful and showed good fringes in various modes and frequency settings. The Effelsberg RDBE system now supports all modes that are available at the VLBA and GBT:
PFB mode at 2 Gbps and *DDC–4* and *DDC–8* modes at bandwidths between 1 and 128 MHz per channel, with a maximum recording rate of 2 Gbps. Observations in *PFB* mode will have Mark5B formatted data and all *DDC* observations will provide multi–threaded VDIF data.

BONN CORRELATOR

The Bonn VLBI correlator is jointly operated by the MPIfR, IGG (University of Bonn) and the BKG (Frankfurt) within the MPIfR Division of VLBI Technologie, with Walter Alef as Division Head; the friend of VLBI is now Alessandra Bertarini. All VLBI observations are processed using the DiFX software correlator running on a compute cluster. The correlator is equipped with 15 Mark 5 units which can all play back Mark 5(A, B or C) data. Correlated data is archived in raw format and FITS–IDI. The raw correlated data can also be exported to the Haystack HOPS software where fringe–fitting for geodesy and mm–VLBI is available.

The PIMA fringe–fitting software (http://astrogeo.org/pima) has been installed to ease the problem of fringe–fitting RadioAstron data. PIMA allows a fringe–rate acceleration term to be fitted.

EVN Correlation: The Bonn correlator was chosen for the following EVN projects observed in 2013–2014:

Observation	Code	Wavelength	Project
2013 EVN–1	EM097A	6	X-ray blazars
2013 EVN–1	GK047A/B	18	RadioAstron ESP: 0642+449
2013 EVN–2	EM097B	6	X-ray blazars
2013 EVN–2	EM107A	21	M31 gas
2013 EVN–2	EM107B	21	M31 gas
2013 EVN–2	GL038A	18	RadioAstron KSP: 0836+71
OoS-A130921	GS032A/B	1.3 + 6	RadioAstron KSP: 3C84
OoS-A120930	GA030A	18	RadioAstron KSP: BLLac
OoS-A131110	GA030B	1.3	RadioAstron KSP: BLLac
OoS-A140110	GL038A/B	1.3 + 6	RadioAstron KSP: 0836+710
OoS-A140118	GA030C	1.3	RadioAstron KSP: 3C273
OoS-A140204	GS032C	1.3 + 6	RadioAstron KSP: M87
2014 EVN–1	GA030D	1.3	RadioAstron KSP: 3C279
OoS-A140404	GA030E	1.3	RadioAstron KSP: OJ287
OoS-A140421	GL038D/E	1.3 + 6	RadioAstron KSP: 3C345
OoS-A140430	GL038F	1.3 + 6	RadioAstron KSP: 3C273
2014 EVN–2	GS032D	18	RadioAstron KSP: M87
OoS-A141226	GL042A	1.3	RadioAstron KSP: Jets in AGN

Mark 5 disk modules: 17 new Mark 5 disk modules and 136 4TB disks were procured, assembled, and brought into circulation on behalf of ASC Moscow. This increased the EVN pool by 544 TB to compensate for EVN modules blocked by RadioAstron observations.

Correlator renewal: The present HPC cluster was erected in 2007/2008 and will be replaced in 2015. The correlator room has been rebuilt at the end of 2014 to make space for Mark 6 recorders of which 6 were procured in 2014. Mark 6 recorders are able to record up to 16 Gbps each and are an ideal complement to the DBBC3.

DBBC3: The DBBC3 (a RadioNet3 JRA) has been developed in collaboration with Noto/INAF and OSO (see also reports on pages 26 and 34). At the end of 2014 prototype boards were available as planned. It is expected that the first field tests will take part in early summer 2015. The DBBC3 will feature one to four sampling boards each of which can sample up to 4 GHz of bandwidth in one chunk with output data–rates of up to 16 Gbps per data stream. The DBBC3 will deliver 64 Gbps for the EHT and 32 Gbps for the EVN.

National Research Foundation, South Africa

HARTEBEESTHOEK RADIO ASTRONOMY OBSERVATORY

Hartebeesthoek now routinely operates two VLBI–capable antennas, the original 26 m equipped with multiple receivers and the newer 15 m (see Fig. 10 left) with a co–axial S/X receiver, and providing the possibility of simultaneous operation of both. This has been made possible by the introduction of two DBBC recording terminals along with additional Mark5B+ recorders, which were commissioned over this period and should hopefully result in sustained reliability going forward.

Disks and e–VLBI: The data volume of disk–based experiments recorded continued to grow. Hence the observatory contributed some 64 TB of recording media to the EVN pool during 2013 in the form of 4 new 16 TB diskpacks, with a further 160 TB (5 x 32 TB) for 2014 due to be added in early 2015. Additionally the 26–m antenna continued to participate as a fully–fledged member of the EVN e–VLBI array at 1024 Mbps via a dedicated layer 2 light–path over a 10GE fibre connection. It has also been used extensively in support of the RadioAstron AGN survey program, which also made use of the ability to switch receiver on–the–fly afforded by the flexibility of the new DBBC terminals.

Receivers: In April 2014 a new dual–polarisation cryogenic K–band receiver (see Fig. 10 right) was added to the 26 m receiver complement. Work on quantifying the 26 m antenna performance at K–band is ongoing, including development of a new controller for the secondary reflector positioner and the measurement of a new pointing model to match,

Geodesy: The 15 m antenna meanwhile took over a significant fraction of the observatory's geodetic VLBI workload, including a series of new additional southern hemisphere experiments. It has also participated extensively in scintilation experiments making use of the VLBI recording equipment to Doppler track spacecraft carrier signals. Furthermore, during 2014 the observatory secured funding for the purchase of a new VGOS–capable fast–slewing 13 m class antenna, the construction of which is expected to be completed by mid 2017.

Sadly this period also marked the unexpected passing of our observatory director Dr. Michael (Mike) Gaylard, the first Hartebeesthoek member of the JIVE board, after a prolonged illness. He will be sorely missed.

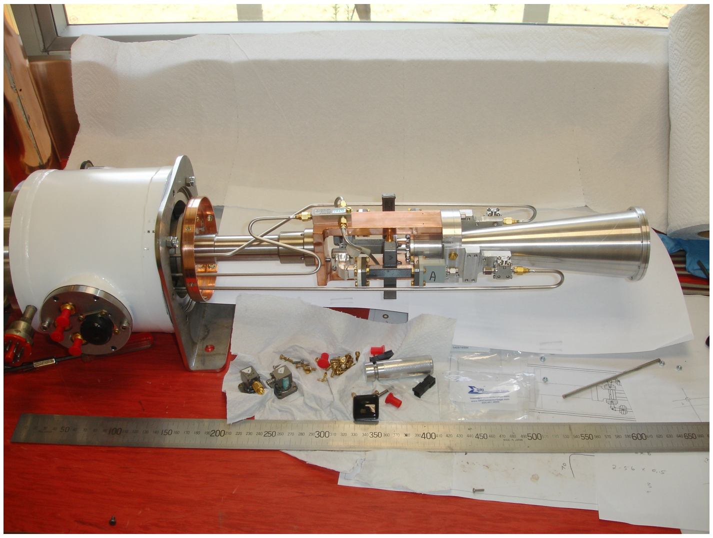


Figure 10: **Left:** 15 m telescope (26 m in background) **Right:** New 22 GHz cryogenic receiver

Institute of Applied Astronomy, Russian Academy of Sciences,

St.Petersburg, Russian Federation

QUASAR VLBI NETWORK

The Institute of Applied Astronomy (IAA) of the Russian Academy of Sciences is the host institution for the QUASAR VLBI network, consisting of three VLBI stations: Svetloe (Sv), Zelenchukskaya (Zc) and Badary (Bd). Each station is equipped with a 32 m fully–steerable radio telescope RT–32 and co–located GPS/GLONASS, DORIS (Bd) and SLR systems.

Personnel: Alexander Ipatov (Director)   Dmitry Ivanov (Technical friend)
Mikhail Kharinov (VLBI friend and Scheduler)

Observations: During the period 2013–2014 the QUASAR network performed geodetic and astrophysical VLBI observations for domestic programs (IAA weekly 24–h EOP and daily e–VLBI 1–h UT sessions) and international projects with our partners: IVS, EVN and RadioAstron. The 32 m radio telescopes at Sv, Zc and Bd participated in 6 EVN sessions at L, C, X and K–bands with a total duration of 120 days. In addition the QUASAR network radio telescopes have been used for a number of 24 h IVS experiments: Sv (107), Zc (85, including 15 for CONT14), Bd (84, including 15 for CONT14). Also a total of 32.3 days of telescope time was scheduled for RadioAstron observations.

Receivers: All QUASAR radio telescopes RT–32 are equipped with receivers in the following bands: L, S, C, X and K. The installation of a two-channel cryogenic receiver unit for K–band at Sv was finished in 2013 March. Upgrades of K–band cryogenic units are also planned for Zc and Bd. One new unit is waiting in Bd for installation.

During the EVN 2013 Session 2 there was a problem with the C–band cryogenic system at Sv station, so the experiments were carried out with warm C–band receivers. The state of the Sv C–band receiver RCP channel was unstable until October 2014. The C–band frontend was temporarily replaced with a new uncooled unit with an LNA. The repaired cooled unit of the RCP channel was restored in November 2014.

Field System: Release 9.10.4 is used at all QUASAR stations.

Backends: From February 2012 the IAA data acquisition system R1002M is fully functional at all QUASAR stations and used in all VLBI observations, including IVS, EVN, RadioAstron and domestic programs.

Recording systems: Mark5B+ is the data recording system at all QUASAR stations. In May 2014 the Mark5B+ software was upgraded to SDK 9.3.

Disk purchase: The QUASAR network as a single EVN member should provide at least 150 TB to the EVN disk pool. In 2011–2012 the IAA purchased 160 TB (20 packs of 8 TB). Thus the QUASAR network fulfilled the EVN requirement for the minimum necessary amount of disk modules. No new disk packs were purchased in this reporting period.

H-masers: Since July 2011 new Active Hydrogen Masers VCH–1003M were put into operation at all the stations of the QUASAR network. The H–maser VCH–1003M is a modern, high-performance maser with a low phase–noise option. It uses the latest technologies, including Stand–alone Auto Cavity Tuning (no external reference required), remote IP control, monitoring and self-diagnostics.

Another two Active Hydrogen Masers VCH-1005 (old models) are in reserve at Sv and Zc.

Antenna Upgrades: A number of tasks to improve the antenna design were carried out at all QUASAR radio telescopes. The center sector of the antenna sub-reflector was replaced at Sv (2013 June 18–19), Zc (2013 April 22–25) and Bd (2013 August 4–5); this improves the antenna efficiency at K–band to 0.4 (at maximum). All tachogenerators were replaced with new generation ones at Sv (2013 April 2–4). Geodetic measurements on a local network were conducted in Zc (2014). Geodetic measurements on RT–32 were carried out in Bd (2014 May), Sv (2014 September 3–14) and Zc (2014). The restoration of corrosion–resistant paint on the antennas were conducted in Bd (2014 June–August) and started in Zc (2014 September).

IAA CORRELATOR CENTER

The IAA Correlator Center performs regular processing of the domestic geodetic and astrometric observations, and astronomical observations.

The general tool for geodetic VLBI data processing is the Astrometric Radiointerferometric Correlator (ARC), the XF hardware correlator based on FPGA technology. ARC is equipped with 6 Mark 5B playback terminals and supports a maximum data rate of 1 Gbps from each station.

The main tool for astronomical VLBI data processing at the IAA is the DiFX software correlator. In 2013–2014 DiFX was located on a Sun Fire X4450 Server utilizing two virtual machines under VMware control. 32 Mbps data is processed in 1.5 times slower than real-time. In late 2014 it was moved to a new HPC hybrid blade-server cluster. Performance improvement was great but not completely estimated, since DiFX is restricted to only computing 60 cores (4 nodes). 2 Gbps data processing speed is about 3 times faster than real-time.

In addition to processing 1.35 and 18 cm wavelength spectral line observations of radio sources, DiFX now has the additional task of testing new VGOS antennas (see Figure 11). VLBI data from the observatories were transferred by Internet directly to the IAA server. IAA has a 1 Gbps link; all the observatories have links which allowed nightly usage with the following speeds: Svetloe 100 Mbps; Zelenchukskaya and Badary 450 Mbps.

Figure 11: New 13.2 m VGOS antennas. **Left:** Badary. **Right:** Zelenchukskaya (with RT-32 in background)

Institute of Radio Astronomy, Bologna, INAF, Italy

MEDICINA STATION

System Upgrades: During the period 2013–2014 work continued on developing and renewing the antenna system. At the end of 2010 INAF provided special funding to renew many parts of the antenna, including:

1. Replace all the helium pipeline and add a new cryogenic compressor
2. Replace the coaxial cable links between receivers and the antenna control room with optical fibers
3. Replace the antenna elevation rack and pinion and refurbish the reduction gears
4. Substitute the old antenna lift with a new one
5. Replace the old subreflector drivers and motors rewrite the whole control software
6. Paint the antenna
7. Buy a new H–Maser

Our aim was to manage this maintenance keeping loss of astronomical experiments as low as possible. In 2011–2012 we completed item 1, 2 and 7 and in 2013–2014 we completed item 3,4 and 5.

Starting from the beginning of 2014 we use analog fiber optics links to send the converted band (IF) of the receivers to the control room of the antenna. This is important in order to maintain equalization of the large IF band provided.

A major failure occurred in the first week of April 2014. A break of the azimuth wheel bearing and shaft (see Figure 12) forced us to stop all antenna activities until this was repaired (completed at the end of June). Due to this failure and to the activities mentioned above the antenna was not available until December 2014.

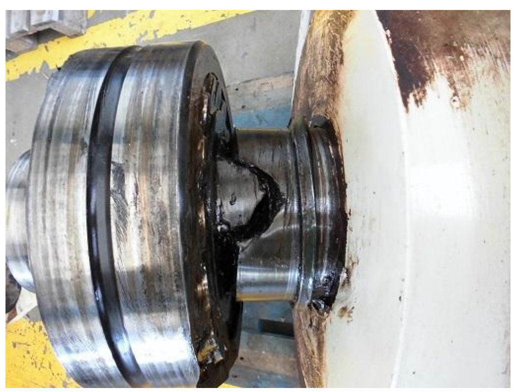


Figure 12: The broken azimuth wheel shaft

DBBC and recording: Since the end of 2014 Medicina has switched to the new VLBI data acquisition system MK5C+DBBC and using FILA10G. It is also possible to use MK5B+ mode. The old MK4 system is being retired. At the end of 2014 the amount of disk capacity is 296TB.

e–VLBI: Medicina has a network connection of 10 Gbps and performs e–VLBI experiment routinely.

Space VLBI: Since the end of 2011 Medicina participates in Radioastron observations.

Receiver development: In mid–2014 we started the design of a new receiver. It will be a dual feed system in the band 13.5–18 GHz. The receiver group is also working to provide SRT with more receivers. A single feed in the band 4.2–5.6 GHz and a 19–pixel multifeed system in the band 33–50 GHz are under construction.

NOTO STATION

Telescope upgrade: The mechanical parts for enabling frequency agility were installed in the Noto telescope in summer 2014 and the receivers will be gradually modified for relocating into new mechanical positions. At the same time the vertex room has been refurbished and the telescope surface cleaned and re–painted.

Receivers: The new environment will accommodate the following receivers in the secondary focus: **Q, K and C–bands**, and the **methanol line**.

The primary focus receiver was greatly modified in order to reduce its weight. It supports **S, X, L and P bands** in dual polarization but is uncooled. As the P, L and S bands are sampled at sky frequencies, a new set of coaxial cables will be required for the installation.

All the parts for the new broadband **1–15 GHz** receiver have been purchased and their assembly started at the end of 2014. Such a receiver will be used for VGOS observations. Due to the wide illumination angle at prime focus, for testing it will be adapted to the antenna optics with a tertiary mirror placed in the top of the vertex.

The **22 GHz receiver** was upgraded to operate with 4 GHz bandwidth for use with the new DBBC3 broadband backend.

H–Maser: A new maser has been installed. The old EFOS–5 has been modified and will operate in parallel, providing a useful comparison of time standards. However, it could cease operating at any time. Additional instrumentation and equipment to distribute the time and frequency reference signals have been installed, so the new atomic clock station is able to provide a much improved, reliable, continuous service.

Network and e–VLBI: The network connection has been upgraded to 10 Gbps. This is necessary for observations of experiments at 4 Gbps, now possible with the backend network FILA10G interface (DBBC–to–network).

A new 10G network infrastructure has been installed in the station in order to join the 10G router to the digital backend, including the equipment placed in the vertex room. The new acquisition system DBBC3 operates with multi–40G links and will be placed in the antenna vertex room and connected to the control room and external network through a set of optical fibres.

The DBBC2 system is now the main VLBI backend and has additional new observing modes; it has completely replaced the old MK4 teminal. The Ethernet interface FILA10G is available with the latest transfer modes (VDIF, CT VDIF), so with the the 10G network connection, 4 Gbps and 8 Gbps e–VLBI experiments are possible with Noto.

SARDINIA STATION

In addition to the general astronomical validation of the SRT, validation of VLBI operations has been performed. During EVN session 1, 2014 SRT successfully participated in the first NMEs and fringe–tests and subsequently took part (on a shared–risk basis) in an increasing numbers of EVN and RadioAstron experiments.

VLBI Technical Developments:

1) integration of the VLBI Field System into the SRT *NURAGHE* control system
2) installing the latest firmware on the DBBC2+FILA10G VLBI backend, testing and calibration
3) installing Conduant, Haystack and JIVE firmware on the Mk5C recorder, and testing
4) purchase of 128TB of disk space to contribute to the EVN disk pool
5) purchase of DBBC spare parts together with other EVN stations

VLBI staff members: Carlo Migoni (VLBI friend), Andrea Melis (VLBI technical friend)

DBBC3 DEVELOPMENT

The new DBBC3L backend prototype for 32 Gbps observations was realised in collaboration with MPI (Bonn) and OSO (Onsala) under the Radionet3 framework (see also reports on pages 20 and 34). In the implementation for EVN the new backend is capable to process two IFs 4 GHz wide. The first use is planned with the wide band 22 GHz. In the maximum implementation is capable to produce 128 Gbps processing eight 4 GHz IFs.


Figure 13: **Left:**The DBBC3L prototype for EVN at 32Gbps **Right:** The FILA40G prototype

An additional unit part of the DBBC3 is the FILA40G units that is able to perform 10GE and 40GE packets handling and disposes of a pool of disks to record up to 32 Gbps in flexbuff mode.

AntArr Project: The project called AntArr is a new application of the DBBC3. A group of antennas operating at low frequencies, in the range from 10 MHz to 1000 MHz, are phased up for VLBI. Moreover dedicated elements can be added to reach still lower frequencies to observe the range down to kHz frequencies. The DBBC3 manages the array operations in a selected portion of the band and the main characteristic is to synthesize a beam with an innovative approach. The final product of the array is a single station standard VLBI data stream for correlation with other antennas, or a synthesized beam for pulsar observations. Some antenna and array prototypes have been realized and are under test at two locations: the Noto station and on the Etna volcano.

University of Manchester, England

JODRELL BANK OBSERVATORY

Jodrell Bank Observatory performed a total of 188 EVN experiments during 2013–2014. Sixty-seven experiments at 18/21cm, 59 at 6cm, 33 at 5cm, 21 at 1.3cm and 8 at 90cm were scheduled to use Jodrell Bank's Lovell and Mk2 antennas. Twenty–two of these experiments were designated joint EVN/e–MERLIN observations although e–MERLIN observations were not always performed simultaneously with the EVN. A total of 1227.5h of telescope time was scheduled for EVN observations during 2013–2014. This consisted of 736.5h on the Lovell and 491h on the Mk2. In terms of waveband this was 492.5h at 18/21cm, 381h at 6cm, 204h at 5cm, 119.5h at 1.3cm and 30.5h at 90cm. The total reported data loss at the telescope for 2013-2014 was 96h13m (7.8%), i.e. a success rate of 92.2%.

In addition to regular EVN sessions, in the period 2013–2014 JBO telescopes contributed a further 494h during a total of 19 e–VLBI observations, 133h for EVN out-of-session observations (all in support of RadioAstron) and 23h for two target-of-opportunity observations.

Apart from wind, which is the main cause of lost data, failures impacting VLBI observations during this period included warming receivers, occasional swapped polarisations, LO multiplier failures, backup power generator failures, critical failures of antenna control software and occasional recorder problems. Shortly before the May/June 2014 session, the Lovell telescope suffered a major azimuth bogie failure which resulted in all 18cm observations originally planned for the Lovell being performed with the Mk2 telescope. The remnants of Hurricane Gonzalo hitting the UK in October 2014 led to several days of disruption to observations. Although this period saw continued upheaval due to the replacement of much of the JBO observing infrastructure for e–MERLIN commissioning (see below), the observing statistics remained positive.

e–MERLIN Developments: The February/March 2013 EVN session was the first where VLBI used the e–MERLIN IF chain and subsequently new LO schemes for all observations. This was also the first EVN session where simultaneous observations were made with home station VLBI and the e–MERLIN array, giving a common telescope but not a common baseline in the joint observations. This demonstrated that the e–MERLIN observing system is now able to successfully import and observe using standard VEX files.

A major e–MERLIN correlator software development was started in 2014 which requires testing before another attempt is made to detect fringes between e–MERLIN and the EVN. In the meantime, the old interface hardware and phase rotator system for analogue Cambridge was decommissioned.

Digital Baseband Converter: Jodrell Bank took delivery of a DBBC during July 2014 and this was quickly integrated into the observing system (see Figure 14). Test observations were performed in Session III 2014 and fringes were obtained at C– and L–band during both the fringe–test and NME observations. Operations were moved to the Mark 5B/DBBC system by the end of 2014 although the Mark 5A/Mk4 system was initially retained for e–VLBI observations for a short period. To allow e–VLBI with the other Mark5 unit a dual port adapter was installed and a newer Linux/SDK4 test system installed. This has proven workable but requires other network stations to switch to the same system. At present e–VLBI has now moved to the Mark5B along with recording. *Core 2* boards have been ordered for the DBBC to allow future 2Gbps recording tests and operations. It will require a Mark5 upgrade to 5B+ which is an Amazon card plus VSI interface. The VLBA rack will be decommissioned around the time of the JBO control building refurbishment in 2016 whilst the Mk4 rack will be retained for the immediate future for support purposes.

Figure 14: The VLBI racks including new DBBC unit

Korea Astronomy and Space Science Institute, South Korea

KOREAN VLBI NETWORK

The Korean VLBI Network (KVN: http://kvn.kasi.re.kr) is the first VLBI network in Korea operated by the Korea Astronomy and Space Science Institute (KASI). The KVN consists of three 21 m–diameter radio telescopes which are located in Seoul (Yonsei University), Ulsan (University of Ulsan) and Jeju island (Tamna University). The baseline lengths are in the range of 305–476 km. The KVN has a unique receiving system which enables simultaneous observations to be made in 22, 43, 86 and 129 GHz bands.

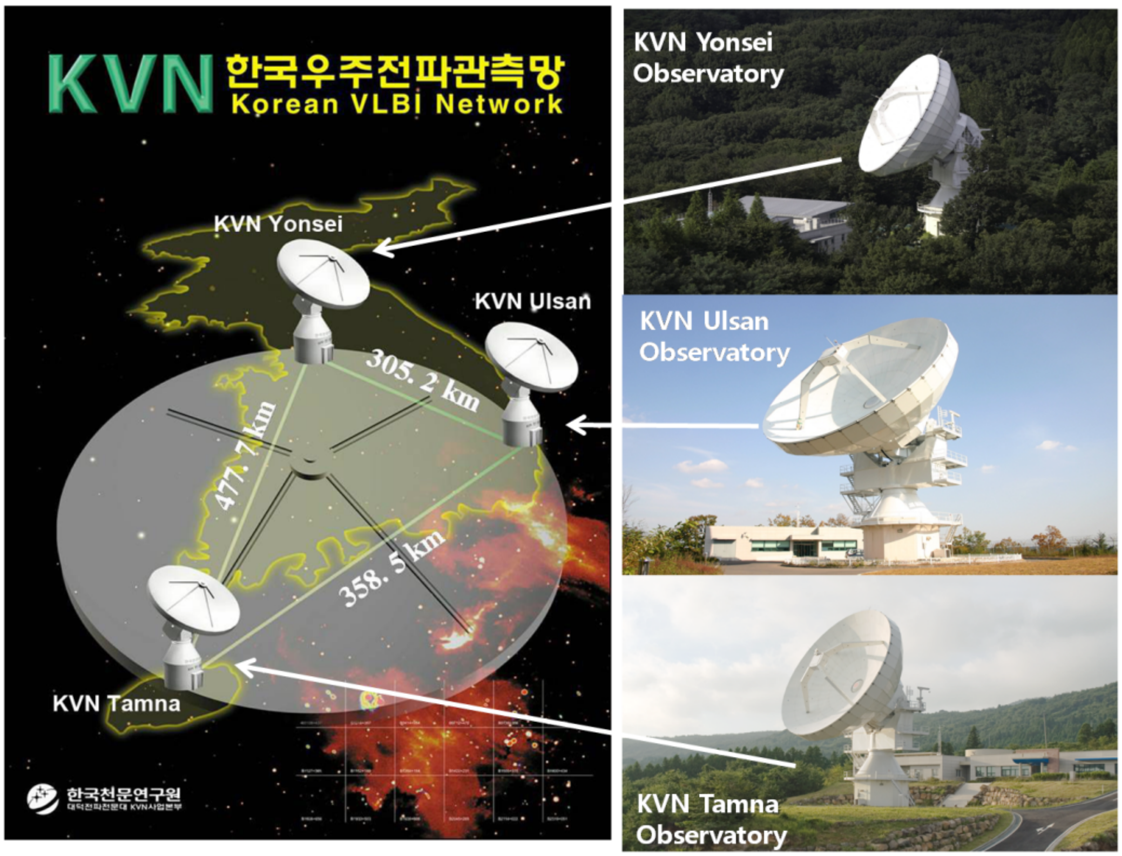


Figure 15: The Korean VLBI Network

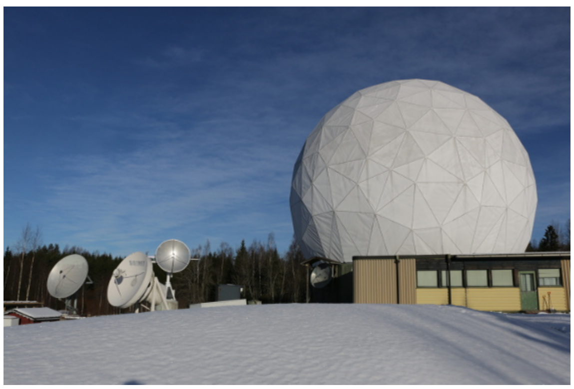
EVN observations (2013–2014): After a few years of discussion, fringe tests and participation in EVN CBD meetings as an observer, the KVN became an Associate Member of the EVN at the start of 2014. The KVN participated in 14 EVN observations at 1.3 cm and 7 mm wavelengths during 2013–2014. Most observations were successful apart from a few recording errors and weather–related problems.

System Upgrade Activities: The KVN has Mark5B, Mark5B+ and Mark6 recorders for VLBI operations. Because of the limited 1 Gbps data rate of the digital filter, Mark5B is used for most observations. Recently we purchased Fila10G and Mark6 units to support 8 Gbps operations (4 x 2 Gbps) and succeeded in getting first 8 Gbps fringes on the Yonsei–Ulsan baseline.

Aalto University, Finland

METSÄHOVI RADIO OBSERVATORY

Metsähovi Radio Observatory (MRO) is located on the premises of Aalto University at Metsähovi, Kylmälä, Finland about 35 km from the university campus. MRO has operated a 13.7 m radio telescope since 1974. The telescope radome and surface panels were replaced in 1992–1994. The current surface accuracy is 0.1 mm (rms) and the drive speed is 1.2 degrees per second. Metsähovi is known for its long–term quasar monitoring. Astronomical VLBI observations are carried out with receivers at 22, 43 and 86 GHz. An S/X receiver, owned by the Finnish Geodetic Institute (FGI), is used for Geodetic VLBI observations (RHC polarization only). MRO also does spacecraft tracking observations.



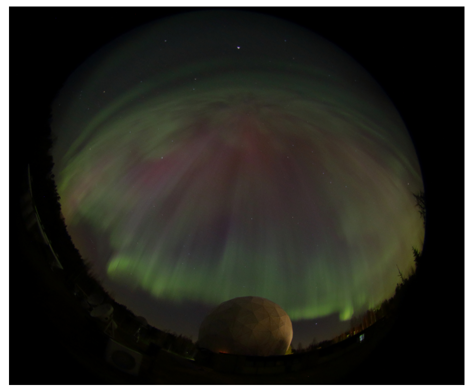


Figure 16: **Left:** Metsähovi in winter. **Right:** Aurora borealis over Metsähovi. (Photos: Merja Tornikoski)

EVN operations: In 2013 MRO participated in all 3 EVN sessions at 22 GHz. In 2014 MRO took part in EVN sessions I and II at 22 GHz and session III at 43 GHz. MRO staff giving operational support in 2013–2014 at MRO are listed below:

Table 1: Operational support in MRO during 2013–2014.

Name	Position	Responsibility
Dr. Juha Kallunki	Laboratory manager	VLBI equipment, NEXPReS
M.Sc.(tech.) Petri Kirves	Operations engineer	Receivers
M.Sc.(tech.) Ari Mujunen	Laboratory manager	NEXPReS
Dr. Elizaveta Rastorgueva-Foi	VLBI friend (2013)	VLBI observations (2013)
Tomi Salminen	Research assistant (1–6/2013)	NEXPReS
D.Sc.(tech.) Minttu Uunila	Postdoctoral researcher, IVS on–site technical contact, VLBI friend (2014)	VLBI equipment, IVS observations, EVN scheduling & observations (2014)

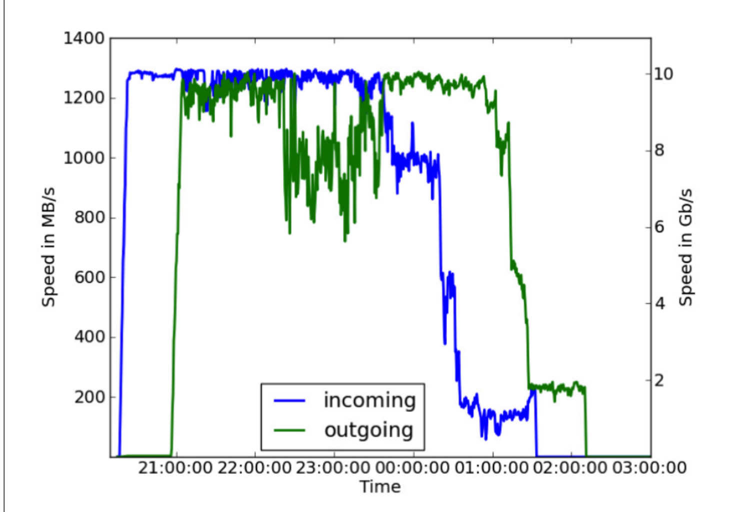
Receivers: Both S/X and 22 GHz receivers were operational during 2013–2014. The LO of the X–band receiver was repaired in 1/2014 at Metsähovi. Continuous calibration was implemented and tested in the lab for the 22 GHz receiver, and will be used in the near future. The 43 GHz receiver has been operational since 2014, even though its polarizations have been swapped. The new 86 GHz receiver has been suffering from instability issues and will most likely be repaired during 2015.

H–masers: In 2014 we purchased two Kvarz H–masers via Russian debt conversion, which will arrive to MRO in January, 2015.

BBC/DBBC status: Our old analog BBCs have now been decommisioned. We switched to using a DBBC + Mark5B+ combo in June 2013. We ordered a DBBC from Hat–Lab, and it arrived in September, 2012, with a standalone FILA10G which works nicely. DBBC boards were repaired at MPIfR Bonn in 1/2014 by M. Wunderlich.

FlexBuff DEVELOPMENT

Summary: We have developed a new DAQ system, the *FlexBuff*, using COTS components during the NEXPReS project and its *work package 8* (WP8). We participated successfully in the NEXPReS 4G demonstration using *FlexBuff* and Fila10G on September 18, 2013, and got fringes. We also recorded with our *FlexBuff* in parallel during the Q–band NME and user experiment in EVN session III 2014.



Network throughput of the 10 Gbps interfaces during the test with a 30 second time resolution

Figure 17: Network throughput of the 10 Gbps interfaces.

WP8, originally titled *Provisioning High–Bandwidth, High–Capacity Networked Storage on Demand* but shortened to *FlexBuff*, explored ways to implement on–demand networked storage to match the multi–Gbps bandwidth and Petabyte–class capacity requirements of VLBI in a distributed manner. Additionally, it addressed the use of such high–capacity storage systems for future data archives.

The objective of WP8 was to determine the best practical combination of commercially–available technologies which serves the needs of evolving, multi–Gbps high rate data acquisition and processing. This includes determining both the most suitable hardware and operating system architecture and the most applicable user software architecture which can support multiple simultaneous high–speed input and output streams. The VLBI application is a forerunner in being able to fully exploit this unique capability when recording local real–time telescope data at a given station while providing access to previously made recordings. Work during *P3* in WP8 *FlexBuff* concentrated on testing and verification of the *vlbi–streamer* data acquisition application software running on generic, commercially available Linux platforms. Several test *FlexBuff* systems were (and are) available at partner sites, representing a wide variety of COTS Linux platforms, including several instances of both kinds of systems recommended in WP8 hardware study *D8.2* and also hardware RAID systems at partner INAF and computing–centre nodes at partner PSNC. *vlbi–streamer* software was exercised on all of them and it showed remarkable capability of adapting to the varying environments, still retaining its high–rate performance.

Integration tests (as designed in *D8.8*) were performed on March 28, 2013, and subsequently reported in *D8.10*. Meanwhile, work on new features brought the *vbs_fs* FUSE filesystem capability to *vlbi–streamer*, enabling easier integration of *FlexBuff* with any other data–consumer Linux application, thus enabling e.g. unmodified software correlators to run also on *FlexBuff* Linux nodes. Related to this work, INAF also published a report on Linux filesystem performance which was not originally included in the DoW but was highly inspired by the tests they performed with *vlbi–streamer* running on their test systems. Now *vlbi–streamer* is integrated to JIVE's *jive5ab*. (See also report on page 34.)

Chalmers University of Technology, Sweden

ONSALA SPACE OBSERVATORY

Operations: The Onsala Space Observatory (OSO) telescopes continued during 2013 and 2014 to play a full role within the global observing program for astronomical VLBI. In total 9 astronomical VLBI–sessions (6 EVN sessions and 3 global mm–VLBI sessions) were conducted. OSO is also regularly involved in e–VLBI sessions (typically 10 24–hour sessions per year) within the EVN. In addition, the Onsala 20 m telescope has been used for 42 and 39 (including CONT14) geodetic VLBI experiments in 2013 and 2014, respectively, as part of the observing program of the International VLBI Service for Geodesy and Astrometry (IVS).

VLBI staff: Since February 2009 Rüdiger Haas has been the Technology Development Center's Representative in the Directing Board of the IVS and is also the IVS delegate to the Directing Board of the International Earth Rotation and Reference Frames Service (IERS). Rüdiger is the chairman of the European VLBI Group for Geodesy and Astrometry (EVGA).
Michael Lindqvist is the OSO representative on the EVN Program Committee and was also Chairman of the EVN Technical and Operations Group (TOG) from January 2012 to December 2014.

20 m Telescope Radome Replacement: One of the most dramatic events of 2014 at the observatory was the replacement of the radome of the 20 m telescope (see Figure 18). The old radome was installed in 1975 at the same time as the 20 m telescope was erected by an American company ESSCO. The radome's function is to protect the telescope from the weather and from solar radiation. It has survived well over its guaranteed lifetime due to the overpressure inside the radome, which has smoothed the vibrations of the panels, and careful maintenance over the years. Nevertheless, the material of the radome had deteriorated to the extent that the installation of a new one was unavoidable. The only reasonable solution was to buy a new radome identical to the old one from ESSCO and to have it installed by the same company. After discussions with the company it was agreed on an installation procedure where a top cap consisting of 50 panels is changed in one go and the remaining 570 panels were changed one by one. This procedure limited the time when the telescope was exposed to open air to a minimum. The installation started on 11th August 2014 and was finished by the end of September. The new radome has slightly better transmission properties for radio waves than the original one and will also dry up much faster after rain.

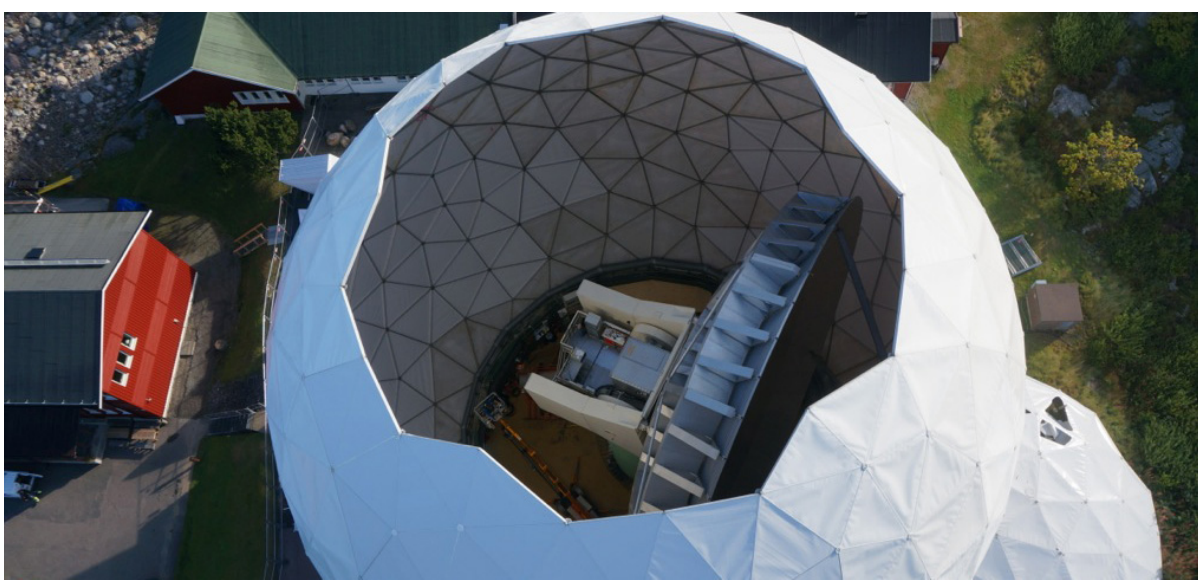


Figure 18: The top cap removed from the OSO 20 m telescope radome.

Receiver Developments: During 2013 a new **L/C–band (6 cm/18 cm wavelength)** receiver was built and installed on the 25 m telescope, to be used primarily for VLBI. The L–band channel uses the same components as the previous, decommissioned receiver, while for the C–band channel the room–temperature polarizer was replaced with a cryogenic Ortho–Mode Transition (OMT) purchased from NRAO, combined with a commercial 90–degree hybrid to achieve circular polarization. The new receiver reduced the noise figure at 5 GHz for the 25 m telecope from 1300 Jy to 700 Jy and also gave improved polarization performance.

The current **S–band (2.3 GHz band)** receiver, mostly used for geodetic VLBI, has only a single circular polarization channel. It was decided to upgrade the receiver to dual circular polarization. A low noise amplifier was purchased from the Spanish company TTI. The cryogenic box accommodating the LNAs for X– and S–band was modified for integration of a new polarization channel and the new S–band LNA. The performance of the receiver (excluding warm part) was verified in the lab and the receiver was installed back on the telescope in November 2013.

During 2014 design work on a **4–12.5 GHz** cryogenic receiver for the Onsala 20 m telescope was begun. Geodetic VLBI observations at the 20 m telescope are currently conducted with a dual S/X band system with 250 MHz bandwidth. The S–band (centred at 2.3 GHz) channel uses an offset horn and a tertiary reflector that has a small dichroic window through which the X–band (centred at 8.4 GHz) horn observes. One of the limitations of this system, both for astronomy and geodesy VLBI, is that the current S– and X–band feeds do not allow for an extension of the observing bandwidth beyond 250 MHz. A new wider–band S–band dual polarization system was built in 2014 and will likely be installed during 2015. The present narrow X–band receiver can likewise be replaced by a new broadband 4–12.5 GHz dual polarization receiver. Furthermore, at present C–band (5 GHz) astronomical VLBI observations are possible only with the 25 m antenna but some experiments are cancelled due to strong winds; the new receiver system will allow us to perform these observations even in bad weather conditions using the radome–enclosed 20 m telescope. Since the geometry of the 20 m telescope is designed for mm–wave optics, designing a horn feed for wide bandwidth covering the relatively low frequency range of 4–12.5 GHz is very challenging. During 2014 a design study was ordered and delivered by British Aerospace Systems (Australia). The delivered design will have high sensitivity and can be implemented at relatively low cost. A decision about building and deploying such a new receiver will be made during 2015.

Digital backends: The old Mk4 backend was phased out during 2014 after the successful commissioning of an additional VLBI system (DBBC2+Mark5). With two such systems deployed OSO is now able to observe routinely in VLBI mode with the 20 m and 25 m telescopes simultaneously; this means that, e.g. geodesy and astronomy VLBI projects can be run at the same time, removing scheduling clashes. Additionally, we have installed a new flexible computer–controlled IF distribution unit. This unit allows us to connect the VLBI recording rack to either of the receivers on the 20 m and 25 m antennas using the two DBBC2 units in various configurations.

Hydrogen Maser: During 2013 we purchased a new hydrogen maser. The one it replaced was more than 20 years old, had had a serious failure in 2012 and was beyond its useful lifetime. The procurement process for a new H–maser was started in early 2013 with the contract going to the Russian company Kvarz. The maser was delivered and put into operation in August 2013.

TECHNICAL R&D

NEXPReS: The EU funded NEXPReS project concluded successfully at the end of June 2013. NEXPReS made significant improvements to the EVN and pioneered high–bandwidth, high–capacity networked storage on demand. A successful demonstration of 4 Gbps e–VLBI capability was made on September 18, 2013 as part of the final review of the project, using five telescopes of the EVN (including the Onsala 20 m telescope). The international review panel, nominated by the EC, rated the third and final year of NEXPReS with the highest grade of 'excellent'.

DIVA: OSO continued the work within the EU RadioNet3 Joint Research Activity *Developments for VLBI in Astronomy* (DIVA) during 2013 and 2014. This project has two parts, and OSO is involved in both. The first concerns the development of a broadband feed and low–noise amplifier (LNA) package for VLBI, in collaboration with MPIfR (Germany), ASTRON (the Netherlands), and IAF Fraunhofer (Germany). MPIfR and ASTRON are developing the design of state–of–art LNAs, and the MMIC (Monolithic Microwave Integrated Circuit) chips for the LNAs will be processed at IAF Fraunhofer. OSO has the responsibility of integrating the LNAs with a broadband feed and performing the sensitivity tests. During 2014 the design was completed and the feed to be used for the tests was manufactured.

The second part of DIVA involves the design and testing of the third generation of a digital back-end system, DBBC3 + FILA40G (see also reports on pages 20 and 26). The FILA40G, which has been designed at OSO, combines four individual 8 Gb/s data streams from the DBBC3, performs some processing on them as needed before either transmitting the resulting streams via a 40 GbE interface, writing to disk, or a combination of both. The FILA40G will also acts as a timekeeper for the DBBC. Software for the FILA40G is currently being finalised, with test observations using the DBBC3 + FILA40G planned for spring 2015. The aim is to fully implement digitally all the functionality required of a complete 32 Gb/s VLBI backend for the EVN and for the future geodetic VLBI system VGOS (VLBI2010 Global Observing System).

Phased–array Correlator Mode: OSO staff have also been involved in the development of a phased–array mode for the JIVE software correlator. In this mode the signals from all stations in an experiment are summed coherently rather than being correlated. The main application of this is time–domain pulsar studies such as pulsar timing and pulsar searching experiments. Compared to single dish observations the increased signal to noise obtained from the phased–array mode yields higher precision timing information and allows for the detection of weaker pulsations. A disadvantage is that the synthesized beam of the phased–array is very small. To overcome this limitation a multiple phase centre capability for this modeis under development.

FlexBuff Development: OSO has also during 2014 been heavily involved in the implementation and testing of the so–called FlexBuff, the next recording system for the EVN (see also report on page 31). Data are recorded locally on the FlexBuff unit and later transferred over the internet to the correlator. Converting from disk shipping to such disk–less operations has many significant operational advantages; stations such as Onsala using such equipment do not need to bother with changing and shipping disk packs and data transfers can be done practically automatically. Furthermore no disk packs need to be distributed from the correlator to each station before each observing session. Operationally such a system also allows significant sub–sets of the astronomical or geodetic VLBI networks to produce results in (near) real time.

Shanghai Astronomical Observatory, Chinese Academy of Sciences, P. R. China

SHESHAN and TIANMA STATIONS

The **SESHAN** 25 m radio telescope was built in 1986 and has observing bands at 1.3, 3.6/13, 5, 6 and 18 cm wavelengths. It has been a full member of the EVN since 1993. Sheshan participated in the EVN sessions in February, June and October 2013. As one of the monitoring stations it was also involved in the quasi–real–time VLBI tracking of the lunar satellite of the Chinese Lunar Exploration Program *Chang'E-2*. Since 2012 January the tracking mission was scheduled on average one or two days per week.

There were no fringes detected in the EP075G & N13L2 observations in the 2013 June session. We also missed EVN observations ER030B, EI012B & ER030C in the 2013 October session because of *Chang'E-3* tracking. Sheshan participated in the 2014 February and June sessions at 18, 6, 5, and 1.3 cm bands.

Update and current status of equipments: A new pcal unit for S/X band was installed in December 2012 in Sheshan station. The pcal is injected before the LNA and after the feed. The pcal unit's input is 10 MHz from the H–Maser. The pulse intervals can be adjusted by the FS to 500 KHz, 1 MHz, 2 MHz, 5 MHz or 10 MHz. It is mostly used in the 1 MHz mode.

We have upgraded the MarK 5B+ Firmware Version to 16.31 (API 11.25, SDK 9.2), in order to be compatible with 16TB SATA modules. A problem in time synchronization for Mark 5B+: Mark5B formatter time is 1 second later than GPS time.

In 2014 we purchased hardware to assemble 5 SATA packs of 16TB. They were available for the session 2015-II.

Personnel Changes of Sheshan VLBI Station: Qinghui Liu replaced Qingyuan Fan as the Chief Engineer of the Shanghai VLBI station.

e–VLBI: More than 20 EVN e–VLBI experiments were carried out in 2012–2013 with the Sheshan station at a data rate of 512 Mbps. In 2014 the Sheshan 25 m observed at an increased data rate of 1024 Mbps for each e–VLBI session and more than 12 EVN e–VLBI experiments were carried out in 2014.

The **TIANMA** station ("TIANMA65") is located about 6 km west of the Sheshan 25 m radio telescope. Construction of the Tianma 65 telescope started in early 2009, and the majority of the mechanical system was completed in October 2012. On December 2, 2013 the telescope passed the acceptance evaluation. The Tianma radio telescope was designed as a multifunctional facility, conducting research in astrophysics, geodesy and astrometry, as well as space science. By the end of 2014, Tianma 65 had been equipped with five cryogenic receiver systems (L, C, S/X, Ku). It is expected that another three high–frequency cryogenic receiver systems (K, Ka, Q) will be completed in 2015.

CDAS and DBBC2 have been installed at the Tianma station for the VLBI terminal. The Tianma 65 m radio telescope participated in fringe test observations in the 2014 February and June sessions at 18, 6 and 5 cm bands using the CDAS & DBBC2. All systems worked well in these observations.

Figure 19: The Tianma 65 m radio telescope

Prospects: For EVN sessions in 2015, Sheshan 25 m & Tianma 65 will participate in L–, C– and X–band observations.

Toruń Centre for Astronomy, Nicolaus Copernicus University, Poland

TORUŃ STATION

Disc-based EVN and RadioAstron Sessions

Toruń Station (Tr) participated in all six regular EVN sessions scheduled in the reporting period 2013–2014 at the wavelengths of 21, 18, 6, 5 and 1.3 cm (186 experiments in total). About 30 EVN projects were affected by minor failures. The main issues causing those were: antenna controller failure, hang-up of the control system, wrong LO setting, or operator's fault. Four experiments were not carried out due to a serious breakdown of telescope control electronics and one gave no fringes to Tr because of wrong LO setting.

Since January 2013, Tr has been participating in the VLBI observations at L–, C–, and K–bands for the RadioAstron mission. In the reporting period, Tr was scheduled in 1057 such experiments. About 10% of them could not be carried out because of various technical problems.

Figure 20: Toruń 32 m radio telescope (photo courtesy P. Wolak)

e-VLBI

Tr took part in all except one e-VLBI scheduled experiments (both regular and ToO) and occasional test observations outside the schedules. We did not participate in one project because of major failure of telescope elevation drive. We completely failed in one of the ToO experiments due to difficulties with formatter synchronization.

Personnel Changes

As of 1st October 2013, Paweł Wolak joined the technical team of Toruń station replacing Magdalena Kunert-Bajraszewska. Prof. Andrzej Kus, formerly Head of TRAO and later Director of Centre for Astronomy, retired as of 30th September 2014. Marcin Gawroński joined the technical team as of 1st October 2014. Krzysztof Katarzyński, the Head of TRAO in the reporting period, stepped down at the end of 2014, and Andrzej Marecki replaced him as of 1st January 2015.

Hardware

In July 2013, a power outage resulted in a failure of setup-and-monitoring system of our 20-years-old EFOS15 frequency standard. Since then, although the maser itself works fine, we cannot monitor its parameters nor can we adjust its frequency so that the drift of about 1.6 μs/day cannot be corrected for any more. Beginning with the May/June 2014 EVN session, observations at Tr are carried out using Mark5B recorder and DBBC unit that replaced analogue BBCs.

Xinjiang Astronomical Observatory (formerly **Urumqi Astronomical Observatory**), **Chinese Academy of Sciences, P. R. China**

NANSHAN STATION

Operations

In 2013 Nanshan station carried our most of the scheduled EVN observations including Out–of–Session RadioAstron VLBI observations. In 2014 most EVN and IVS observations were compromised by our stage I reconstruction work (see below). Since 2013 July Nanshan, together with other Chinese VLBI Network stations at Shanghai and Kunming, become a member of the East-Asia VLBI Network (EAVN). This network includes the Korean VLBI Network, the Japanese VLBI Network and VERA. The current common bands of EAVN are X and K. Several fringe tests between Chinese and Korean/Japanese stations have been successful.

Telescope Upgrade: The Nanshan 25 m telescope reached its design lifetime limit in 2013. The scheduled upgrade program took place in 2014. The optical geometry has been modified to match the active subreflector and the support frame had been restructured with steel-pipe elements. The aimed surface accuracy is 0.15 mm which is to make future 3 mm observations feasible. The climate-restricted construction period on the mountain plateau of Tianshan is only about a half year, so the reconstruction comes in two stages. In stage I all parts above the elevation wheel will be rebuilt; in stage II the lower parts will be refurbished including azimuth track readjustment. The alidade and all the receivers and terminals remain the same. We expect a significant improvement of the reflector surface accuracy after the reconstruction, so in the feed cabin we have reserved a room for a 7 mm receiver. The secondary focus room is designed to accommodate fixed multi–band feeds and a movable sub–reflector. To fully utilize the height of the elevation bearing as well as to compensate the new big feed hole, we increase the antenna diameter to 26 m. Stage I was finished in October 2014 and the new 26 m telelscope is able to work for S/X-band VLBI observations for a scheduled lunar exploration mission. However the new front end is not ready for full astronomical VLBI observation at present. Since September 2014 the new telescope took part in several IVS VLBI observations. We are hoping to get the new VLBI phase center determined soon with these observations.

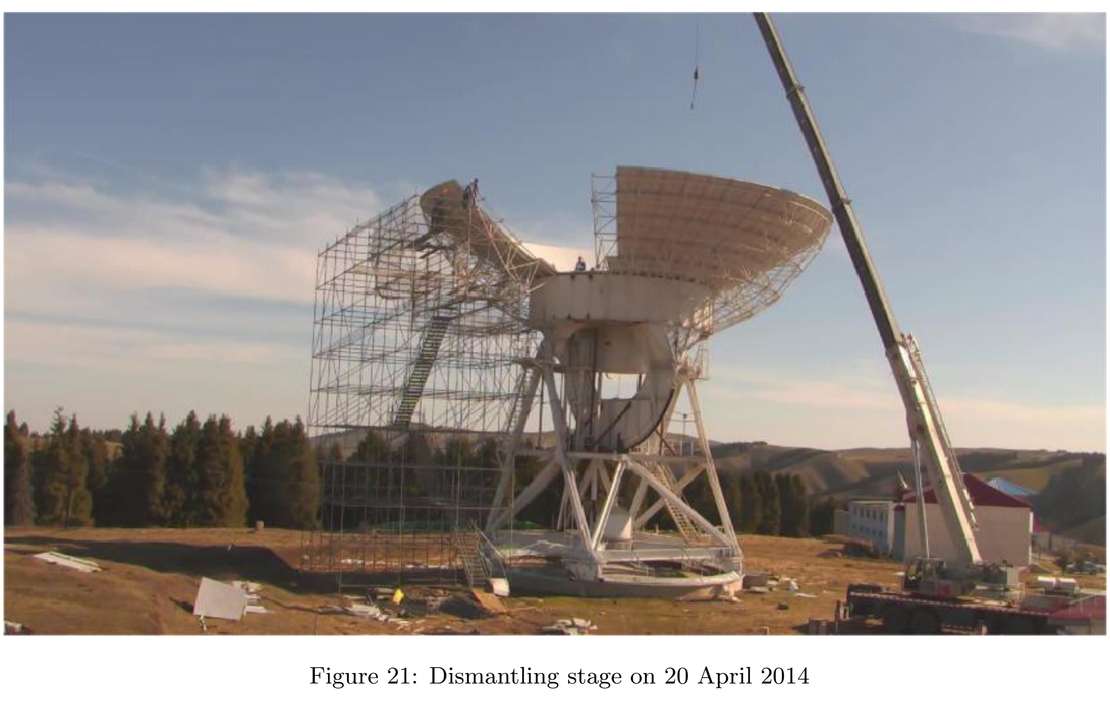


Figure 21: Dismantling stage on 20 April 2014

Figure 22: Hoisting stage on 31 July 2014

In addition to the new dish and many refinements in both hardware control panels and software control systems, we have made two significant improvements to the feed cabin and the secondary reflector designs. The new feed cabin is larger and designed to accommodate all L/S/C/X/K/Q-band feeds and all receivers at different bands simultaneously placed in the focal plane. We employ a hexapod platform on the secondary reflector so we can just move the secondary reflector to choose the observing feed rather than moving the feeds in the cabin.

Up to the end of 2014 no astronomical measurements have been done to determine new parameters such as gain curves, pointing errors and beam maps. Secondary reflector adjustment has not been fully optimized, which also makes the pointing more complicated. All these calibration observations have lower priority than the following-up stage II reconstruction in mid–2015. For VLBI our FS machine version is now multiplexed for different experiment requirements.

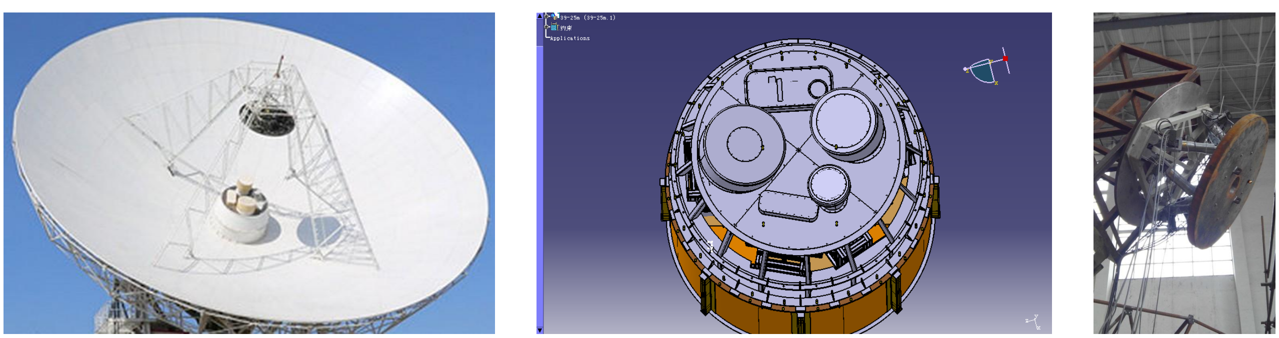


Figure 23: The new 26 m dish, new feed cabin design and secondary reflector Stewart platform

Digital backends: Since our analogue BBCs have been frequently found faulty in EVN observations, we are planning to migrate to digital backends in a couple of years. CDAS is currently a robust digital converting system that we have employed at Nanshan mainly for CVN experiments. DBBC2 and RDBE2 units have been ordered and we expect them to be installed in late 2015 for future EVN and IVS observations respectively.

Disk packs: Nanshan now has new VSN assignments for its VLBI diskpacks since the renaming of our institute. In our new disk inventory, *XAO#1XXX* is for ASTRO modules, *XAO#0XXX* is for GEO modules and *XAO#TXXX* is for local testing modules; the interface character # will be **-** for IDE modules and + for SATA modules.

ASTRON, Netherlands Institute for Radio Astronomy, Dwingeloo

WESTERBORK SYNTHESIS RADIO TELESCOPE (WSRT)

Operations: The WSRT participated in all EVN sessions of 2013 and 2014 as well as scheduled and Target–of–Opportunity e–VLBI observations. In general observations were very successful; only 1.8% (22.4 of 1237 observing hours) were lost due to backend or diskpack problems during EVN sessions. The WSRT did not participate in the e–VLBI sessions of October and December 2014, due to a problem with the maser, and commitments to a TV broadcast, respectively.

The WSRT also participated in RadioAstron Space–VLBI observations, both under the auspices of EVN projects as well as RadioAstron projects submitted to the WSRT Programme Commitee. RadioAstron observations outside of EVN sessions were recorded on disk packs and data were subsequently sent via FTP to the server in Moscow.

APERTIF developments: During this period, prototype evaluation, early commissioning and preliminary engineering work for the installation of the APERTIF system were ongoing. Thus the WSRT tied–array used a variable number of telescopes for VLBI observations. Until the first quarter of 2013, 13 telescopes were used, since one of the telescopes was used for DIGESTIF (the development prototype of the APERTIF phased–array feed). After EVN session 2/2013 11 telescopes participated in the array as APERTIF prototype frontends were installed and tested on the remaining 3 telescopes. From the middle of 2014 refurbishment and mechanical upgrades of successive telescopes brought the number available in the tied array to 8–9 for each session. As previously, at 5 cm WSRT used only a single telescope equiped with the specially modified 5 cm receiver.

Technical Developments: During 2013 and 2014 WSRT continued using the dedicated digital VLBI backend (the Tied–Array former *TADUmax*) and the Mark 5 terminal. A DBBC was purchased in late 2014 to replace *TADUmax* in the era of APERTIF.

New diskpacks were assembled and made available to the EVN pool.

ASTRON staff roles in EVN activities: Rene Vermeulen represented ASTRON at the EVN CBD Meetings and took over as vice–chair of the Consortium from 1st July, 2013. Antonis Polatidis was ASTRON's representative on the EVN PC.

Figure 24: The image shows a partial view of the WSRT array, characteristic of the activities during 2014. The telescope in the foreground is part of the 3–dish array commissioning the prototype APERTIF frontends. The telescope in the middle is being refurbished, as part of the upgrade to APERTIF, while the other 3 telescopes (along with others, not seen here) are taking part in a VLBI observation.

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GEODETIC OBSERVATORY WETTZELL

The 20 m radio telescope in Wettzell (RTW) is an essential component of the Geodetic Observatory Wettzell (Fundamentalstation Wettzell, FSW). It is collocated with other space geodetic techniques at Wettzell, such as Laser Ranging Systems, receivers for the Global Navigation Satellite System, a large laser gyroscope and several complementary local systems for time and frequency, meteorology, hydrology and seismic. In this reporting period the BKG also ran the Transportable Integrated Geodetic Observatory (TIGO) in Concepción/Chile in cooperation with Chilean partners. Additionally it operates the German Antarctic Receiving Station (GARS) at O'Higgins base, together with the German Space Center (DLR) and the Institute for Antarctic Research Chile (INACH). Following an official inauguration on April 26th 2013, the the new TWIN radio Telescope Wettzell (TTW) began first operational test sessions in August.

20 m telescope operations: The 20 m RTW mainly supports the activities of the International VLBI Service for Astrometry and Geodesy. Activities with other partners include astronomical observations and spacecraft tracking for the EVN. In the period 2013–2014 RTW tracked the spacecraft missions Venus and Mars Express (e.g. a Phobos fly–by) and RadioAstron for the EVN for 208 hours, and additionally observed astronomical projects (VLBA102, EFO26, etc.) for 96 hours.

Upgrade of the 20 m RTW: Maintenance days are scheduled for regular system improvements. However, as the components of the RTW servo system had worn with age it was possible to commission a replacement of the whole system, and to upgrade it to a similar, modern technique as installed in the Twin telescopes. The upgrade was performed from July to September 2013, and included:

- replacement of the gears for the azimuth and elevation axes, with new AC–servos and a completely digital control system
- reconfiguring the cable wrap
- re–writing software to support the classic tracking modes, and additional satellite tracking possibilities and modes which reduce the power consumption for the slewing between the sources with optimal acceleration behaviour
- polishing and varnishing of the complete surfaces of the reflector and the sub–reflector
- new controller for the reflector heating to improve the de–icing of the reflector
- replacement of the dewar to increase the maintenance intervals of the cryo system
- upgrades and repairs were also necessary for the Mark4 data acquisition rack

Recorders and Backends: A focus was laid on work to bring the Digital Baseband Converter (DBBC) into regular operations. As a preferred solution the ADS3000+ from Japan was established and tested (also in preparation of the O'Higgins upgrades). Several test data were correlated in Bonn to check the functionality and quality (especially in combination with the Twin operation tests). Additionally new CoMo boards were installed to upgrade to a standard version of the equipment. The development is still in progress.

The NASA Field System is updated to the latest available version 9.11.6 to enable the DBBC connectivity. Upgrade of station specific software is still in progress. The goal is the homogenization with the TWIN control software. Additionally the Mark5 systems were tested with the new *jive5ab* from JIVE. The software should become the basis for transfer of the data to the new TWIN control room in real–time while the scans are recorded.

Use of the EVN–PC for e-Transfer was continuously extended. In addition, e–Transfer for the 24h–sessions to the correlators in Bonn, Haystack, Washington and Tsukuba was routinely used with up to 600 Mbit per second. A combination of the Mark5 software *fuseMk5* and the communication protocol *Tsunami* on a regular Mark5B system is used.

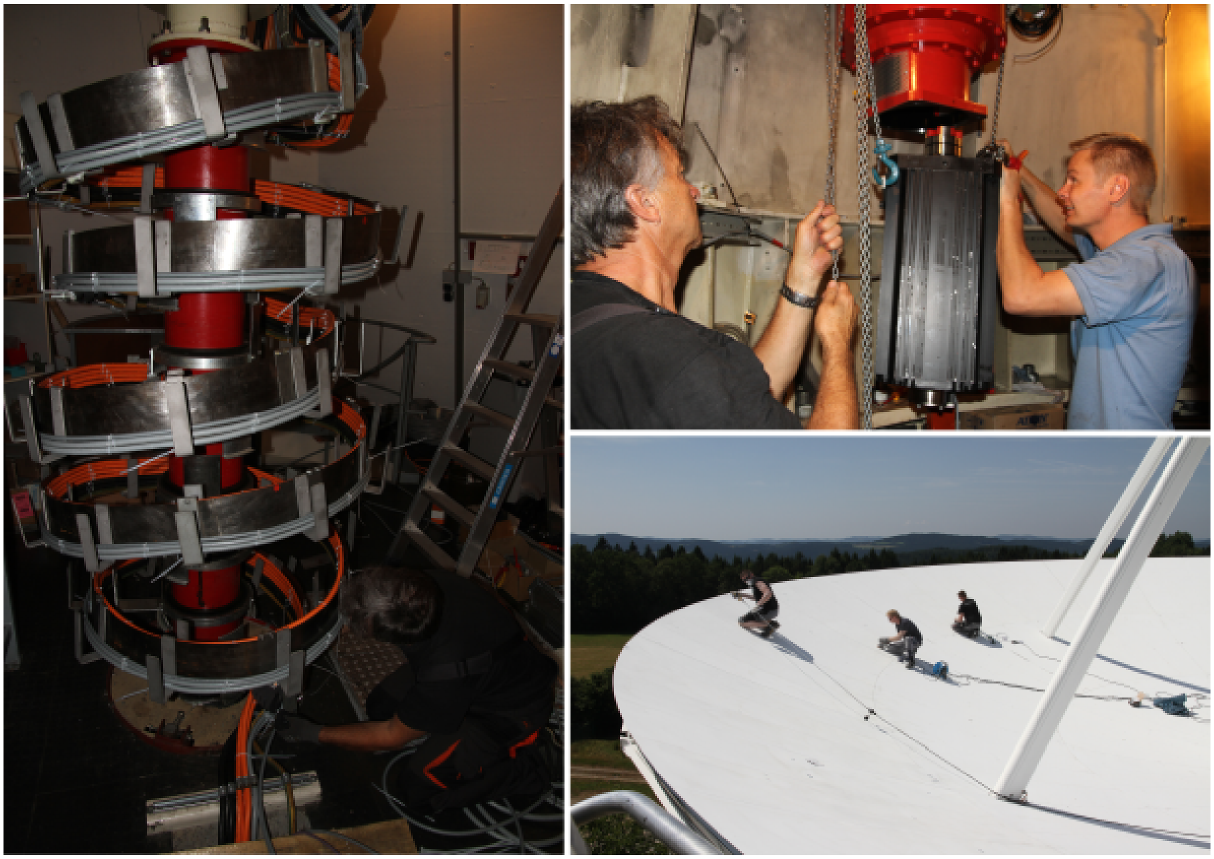


Figure 25: Wettzell RTW upgrade: **left** the new arrangement of the cable wrap with servo, power and coax cables **right top** finishing the gear drives and installing the new AC motors **right bottom** new coating and painting of the dish surface

Participation in the *NEXPReS* project: The remote control software *e–RemoteCtrl* was also extended, mainly by the Technical University Munich. The development was funded in task 3 of work package 5 of the *Novel EXplorations Pushing Robust e–VLBI Services (NEXPReS)* project and was organized in cooperation with the MPIfR. New features were established, in close cooperation with the developers of the NASA field system and with other test sites. The AuScope network in Australia and Wettzell already use the software routinely.

The new TWIN radio Telescope Wettzell (TTW): The Twin Telescope Wettzell project is Wettzell's realization of a complete VGOS conformity. The mechanical system is completely functional on both antennas. The control system was updated with the same safety features as the 20 m RTW.

The new tri–band horn was put into operation. Quality checks together with the company Vertex Antennentechnik GmbH demonstrated the very good performance of the feed horn in combination with the antenna for S– and X–band. The new control room was completely set up to control both Twin telescopes and the older 20 m antenna. Additionally connections to the TIGO telescope and the AuScope telescopes in Australia were established. The receiving and data acquisition systems for the northern antenna (TTW1) is ready for first VGOS tests with S–/X–/Ka setups.

An official inauguration of the Twin telescopes, with international guests, took place on April 26th 2013. The first test sessions were performed in August when TTW1 joined the regular INT3 session together with the 20 m antenna. To test different digital baseband converters one session used the Japanese ADS3000 system, while another used the DBBC. The scans were correlated in Bonn and showed good results.

TTW1 started its operational test phase with regular Monday–INTENSIVE observations. About 190 observation hours were recorded in 2014. The scans were correlated in Bonn and analyzed by the analysis group in Bonn and with a separate software in Wettzell. The X–band performance is excellent with an efficiency of over 80% at a system temperature of 30 K over the bandwidth of 6.4 to 9.6 GHz. The position repeatability is also quite good for X–band. The S–band suffers from RFI, so that it is not ideal for use in the analysis. Filters should reduce this problem. The Ka–band performance was tested with a spectrum analyzer and a calibration source and shows suitable results, which need to be verified again after the new tri–band–receiver and up–down converter hardware is installed in 2015.

Figure 26: The new TWIN radio telescopes Wettzell

Eleven–feed tests: The broadband feed horn (Eleven–feed) for the second telescope TTW2 (south tower, Ws) arrived in Wettzell and was tested here. The feed was built by Omnisys in Göteborg, Sweden. The Chalmers University in Göteborg measured the radiation patterns and the data of the coherence and cross–polarization. It was finished in Agust 2014 after some updates of the gold coating, which originally led to worse system temperatures in higher frequencies. In September 2014, the factory approval in Sweden showed that the results of the test measurements completely meet the specifications. After the feed was delivered to Wettzell, the system temperatures could be verified, so that the shipment to Mirad in Switzerland could be arranged. There it will be tested again and mounted into the feed cone. The already available feed patterns look quite promising. However, a mismatch in the conversion of the digital 3D–drawings caused a mechanical misalignment between feed mounting and cone. This error shifts the final delivery in the timeline to a later date. It should then be used with another broadband up–downconverter rack in combination with a DBBC3 and a FILA10G connection to a Mark6 or a FlexBuf–system.

National Astronomical Observatory, National Geographical Institute, Spain

YEBES OBSERVATORY

The National Geographical Institute (IGN, Ministry of Development in Spain) is the host institution for the National Astronomical Observatory (OAN) and the Yebes Observatory (CAY), and operates a 40 m radio telescope which participates in EVN observing sessions at frequencies above 2 GHz.

VLBI Staff: The IGN Yebes Observatory representative at the CBD was Rafael Bachiller as director of OAN. The technical VLBI friend was Pablo de Vicente and as such attended TOG meetings as Yebes Observatory representative, and Francisco ("Paco") Colomer was coordinator of projects and VLBI activities.

Observations: IGN Yebes Observatory continued playing an important role in VLBI observations during 2013 and 2014. Its big size dish (40 m diameter), together with its receivers that work at 7 different frequency bands (2.2, 5, 6.6, 8, 22, 43 and 87 GHz) and its reliability, guarantees its importance in the VLBI networks.

In this period the 40 m radio telescope took part in 9 VLBI astronomical sessions (6 EVN sessions and 3 global mm VLBI sessions), 92 24–hour geodetic observations, including CONT14 campaign, 6 e–VLBI astronomical observations and 451 RadioAstron experiments.

During 2013 a serious problem with the cable wrap system was discovered. This problem prevented the antenna from being used for two months, although this period was outside the main astronomical sessions. The repair work lasted several months and by the end of 2013 all issues were solved.

Backends and Recorders: IGN purchased one DBBC in 2009 that was delivered in 2010 to Yebes Observatory. This unit has been used for tests, like the 4 Gbps e–VLBI test in 2012, using 2 CORE2 boards. However it was discovered that it did not work correctly with 4 CORE2 boards. The equipment was sent several times to MPIfR in Bonn for repair and its problems were finally solved in May 2014. Local tests to debug the problem were performed before and after May 2014. The later tests involved doing one EVN session in parallel with the VLBA4 terminal. In addition, approximately 15 geodetic sessions were performed in parallel with the VLBA4 terminal. After such extensive checks the VLBA4 terminal was discontinued as the main VLBI backend by the end of 2014. The third 2014 EVN session was observed with the DBBC2.

Two more DBBC2 units were purchased in 2013 and delivered in 2014. They were acquired for the two 13.2 m RAEGE antennas at Yebes (see below) and Santa María. These two backends were also checked taking part in geodetic parallel sessions with the 40 m radio telescope. Together with the DBBC2, two more Mark5B+ recorders were purchased and delivered for the 13.2 m antennas. By the end of 2014 Yebes had three Mark5B+ recorders and one Mark5C on loan from JIVE. All the equipment was tested by the end of 2014.

The first Mark5B+ stopped working due to a failure in the main board. A spare board was bought and mounted. However it could only work with a single CPU, contrary to what had happened before the fault. A second board exists as spare at Yebes.

During this period Yebes Observatory brought 72 TB of disk space for the EVN pool (4 disk-packs of 16 TB each, and 1 disk-pack of 8 TB).

New 22/45 GHz receiver: In 2013 a dual polarization 22/45 GHz receiver was installed in the 40 m receiver cabin. The cryostat was shared by both receivers, although it was not possible to observe both frequencies simultaneously. The time needed to switch between these frequency bands was around 15 seconds and was performed automatically.

The antenna was tested and measured at 45 GHz and the software required was developed. The antenna efficiency was >30% and had an almost flat dependence with elevation.

Fringes between Yebes and the KVN: On June 14th 2013 a VLBI experiment at 22 and 43 GHz was undertaken by the Yebes 40 m radio telescope in Spain and the 3 radio telescopes of the Korean VLBI Network: Yonsei, Ulsan and Tamna. The observation spanned 1.5 hours and alternated between scans at 22 and 43 GHz. The target was the compact source NRAO150, with a bandwidth of 128 MHz divided into 8 intermediate frequencies and with both circular polarizations. Data was recorded on Mark5B systems at 1024 Mbps at all stations, and transferred after the experiment by Internet to a DiFX software correlator in Korea.

The correlation required no special effort, once the correct Mark5B channel mapping was found for Yebes. It was run on POLARIS, the KVN computing cluster dedicated for DiFX correlation. Post–correlation processing involved fringe fitting to find the residual delays (with AIPS task FRING) and amplitude scaling with the nominal SEFD values of the different antennas (with AIPS task CLCOR).

Fringes were found at 22 and 43 GHz in all IFs and for all stations. These are the first fringes from the new Q–band system at Yebes, and follow hot on the heels of the Yebes single–dish first light. This result opened the possibility to perform VLBI observations at 43 GHz with very long baselines between Europe and Korea, and validates the equipment and receivers at this frequency for the telescopes that took part in the observation. The longer term goal is to implement simultaneous multifrequency recording at Yebes, in a similar fashion to that done in the KVN, at these and higher frequencies. This would allow phase stabilized global mm–VLBI, using the calibration at the lower frequencies.

RAEGE 13.2 m Yebes telescope: In 2013 the commissioning of the new Yebes 13.2 m radio telescope for the Atlantic Network of Geodynamical and Space Stations (RAEGE) was started. A three–band receiver (S, X and Ka–bands) was installed. Hardware and software issues were identified and solved during 2013 and 2014, and the main parameters of the antenna determined. Efficiency was 70% at X–band and SEFD 1250 Jy at S and X–band. First fringes (at X–band) with the 13.2 m were obtained in 2014 during a geodetic experiment. The antenna is controlled with a software system similar to that at the 40 m radio telescope. It is also equipped with a DBBC2 and a Mark5B+ recorder. The goal is to install a broadband receiver for IVS VGOS by the end of 2015.

Figure 27: 13.2 m RAEGE radio telescope at Yebes, with 40 m telescope in background

REPORT FROM THE

JOINT INSTITUTE FOR VLBI IN EUROPE (JIVE)

EVN OPERATIONS

Production Correlation Statistics: All experiments during this period, both disk–based and e–VLBI, were correlated on the EVN software correlator at JIVE (SFXC). The increased capabilities of SFXC have enabled EVN PIs to pursue new kinds of experiments which were previously unimaginable.

Tables 1 and 2 summarize projects observed, correlated, distributed, and released in 2013 and 2014. They list the number of experiments as well as the network hours and correlator hours for both user and test/NME experiments. Here, correlator hours are the network hours multiplied by any multiple correlation passes required. This definition carries over to SFXC, even though it may run faster or slower than real time. Because of its enhanced capabilities, multiple correlator passes for SFXC occur only for phase–referenced spectral–line observations (separate *continuum* and *line* passes) and for pulsar observations requiring different gating/binning configurations.

Table 1: Summary of projects observed, correlated, distributed, and released in 2013.

	User Experiments			Test & Network Monitoring		
	N	Ntwk_hr	Corr_h	N	Ntwk_hr	Corr_h
Observed	107	776	891	25	82	84
Correlated	114	817	957	32	99	101
Distributed	120	849	977	27	91	91
Released	129	924	1068	24	89	89
e-EVN experiments	40	250.5	250.5			
e-EVN ToOs	7	58.5	58.5			

Table 2: Summary of projects observed, correlated, distributed, and released in 2014.

	User Experiments			Test & Network Monitoring		
	N	Ntwk_hr	Corr_h	N	Ntwk_hr	Corr_h
Observed	90	786	828	24	71	71
Correlated	80	688	740	19	56	56
Distributed	77	666	715	26	68	68
Released	80	676	723	26	74	74
e-EVN experiments	22	216	216			
e-EVN ToOs	5	61.5	61.5			

Highlights from observing sessions:

Session 1/2013: A target–of–opportunity observation of the Crab nebula following an outburst was the first to use the pulsar gating/binning capability to excise pulsar emission (SFXC also returns the pulse interval outside of the defined gate as a separate output).

Session 2/2013: Preliminary tests of global–array Gbps observations using the RDBE back–end in its digital down–converter (*DDC*) personality on VLBA stations were conducted at 18, 6, and 1.3 cm.

Session 1/2014: The first fringes at JIVE from the Sardinia Radio Telescope (18 cm) and the new Tianma 65m telescope (18, 6, 5 cm) came in network monitoring experiments (NMEs). The new JPL/DSN digital back–end at Robledo was used in its first user experiment. The first experiment requiring both pulsar gating/binning and multiple phase–centers (not for multiple pulsars) ran; this was also the first to use the new SFXC phased–array mode to assist in the gate fitting stages.

Session 2/2014: Global VLBI observations returned, following the shift of VLBA/GBT telescopes to the NRAO RDBE back–end. Some of these were at 1 Gbps, which required correlation of different channelizations (NRAO: 8x 32 MHz, EVN: 16x 16 MHz). This session was the most complicated yet encountered, with 9 large experiments (from 3 proposals) requiring new features on unprecedented scales. Four comprised a wide–field spectral–line experiment, producing 5.3 TB of output FITS files; these were the first to use integration times other than 2^n s (shifting from 0.25 s to 0.35 s saved about 2.1 TB in output FITS–file size, while maintaining a satisfactory time–smearing field of view). Another 4 required coherent de–dispersion for the target millisecond pulsar. Finally, one is proving to be our first massively multiple phase–center correlation (699 targets, compared with the previous high of about 50). Processing of the latter two groups is still on–going at the end of 2014.

Session 3/2014: the first global observations at Gbps including the JVLA using its new WIDAR correlator, which required some iterations with Socorro to design the optimal set–ups.

e–VLBI Sessions: In 2013, the first e–VLBI fringes from the Irbene telescope came during the March e–EVN day. Noto achieved a full Gbps data–rate, removing the need for channel–dropping. Arecibo provides a data–rate of 512 Mbps, regardless of the local time. In 2014 Sheshan achieved a full Gbps data–rate, removing the need to treat them as a 1–bit sampling station.

EVN Observing Statistics: Figure 28 shows the evolution of annual EVN network hours since 2004 (in global observations, EVN hours do not count periods with no participating EVN stations). The contribution of e–EVN observations is represented by the green shaded area and that of the new category of regularly–scheduled out–of–session (OoS) observations by the red shaded area. Note that not all of the disk–based experiments were correlated at JIVE.

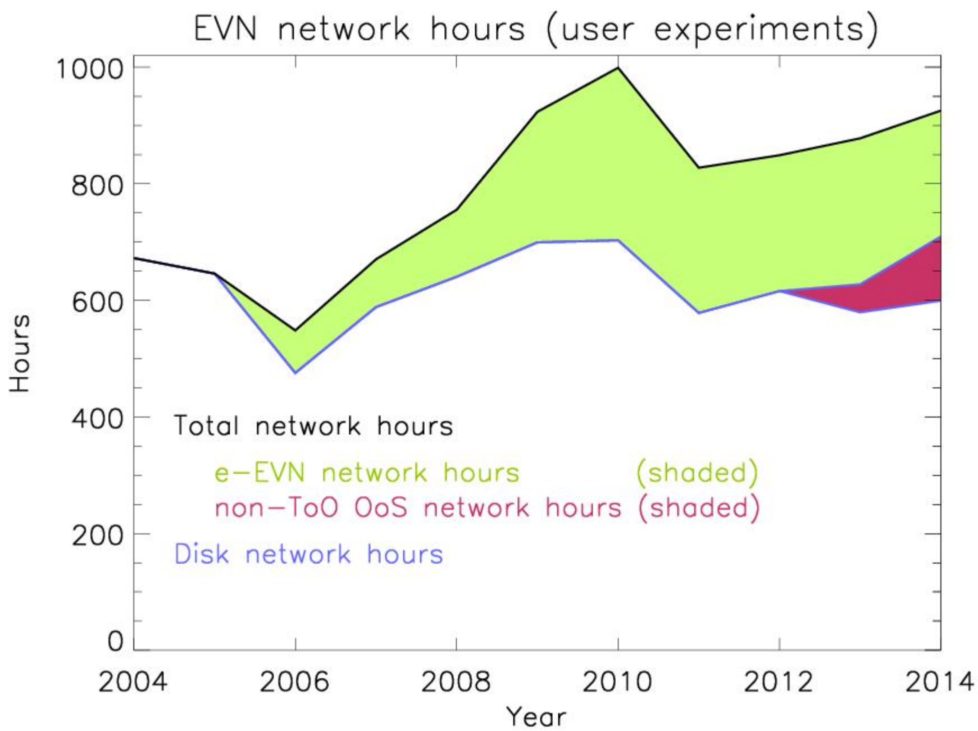


Figure 28: Annual EVN network hours, with the contribution of e–EVN observations shown by the green shaded area and of regular out–of–session observations by the red shaded area.

Figure 29 focuses on the e–EVN experiments, showing a division of annual observing hours into different categories: ToOs, triggered observations, short ($\leq$2 hr) observations, experiments proposed for disk recording but conducted in e–VLBI (after consultation with the PI), and the standard e–EVN observations. The fall–off of standard e–EVN hours in 2014 can be attributed to fewer in–session e–EVN observations, which have typically taken place on weekends when the QUASAR stations were not able to participate – this situation changed by session 2/2014. By their nature, all e–EVN observations correlate at JIVE.

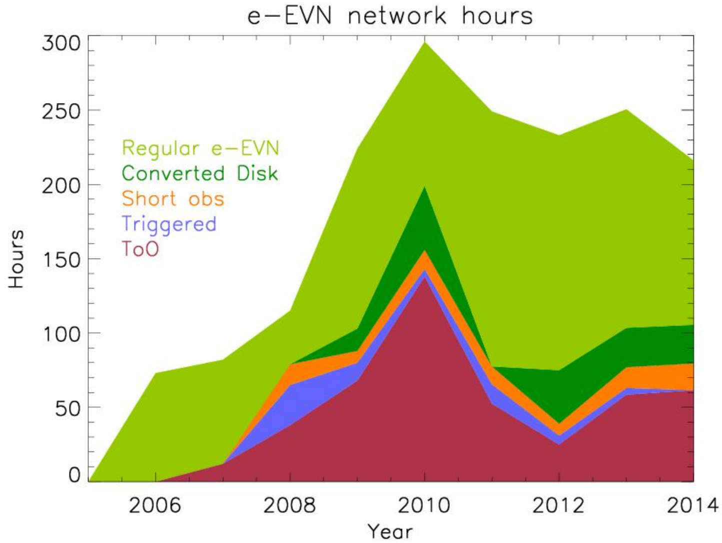


Figure 29: Division of annual e–EVN network hours into categories

Correlator Queue: Figure 30 presents the size of the correlator queue at different stages in the processing cycle, showing a snapshot of the status at the end of each week. The red line plots the number of correlator hours that remain to be correlated. The blue line plots the number of correlator hours whose data remain to be distributed to the PI. The green line plots the number of correlator hours associated with recording media that have yet to be released back to the pool (in practice, release occurs prior to the following session, leading to a blockier pattern for the green line). The flat red line at the end of 2014 represents a period of SFXC development for specific requirements of the unusual session 2/2014 experiments prior to any session 3/2014 observations being ready to correlate.

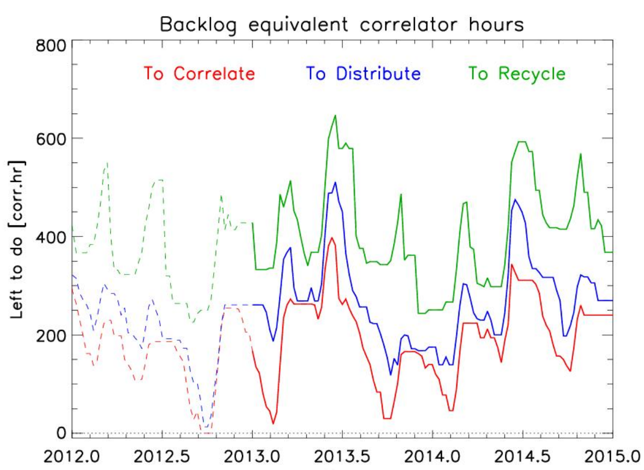


Figure 30: Size of various correlator queues, measures in correlator hours.

e–VLBI Statistics: The duration of e–EVN target–of–opportunity observations was up over the previous biennial period (120 hr vs 78 hr). The total number of e–EVN hours was slightly down (466.5 hr vs, 482 hr). Over the biennial period, 31.4% of the observed EVN network hours in experiments correlated at JIVE were e–EVN observations, also slightly down from the previous period (34%). The QUASAR stations' participation in EVN observations on weekends starting from session 2/2014 explains the slight decrease in total e–EVN numbers. A feature in SFXC was developed to allow array–composition changes in the middle of running correlation job. This has removed the need to restart the correlator during e–EVN observations when stations come in / go out of the array.

FTP Fringe Tests: Automatic–ftp fringe tests continue to be included in all network monitoring experiments (NMEs) at the beginning of each new frequency sub–session within EVN sessions, or as a separate fringe–test observation when the NME does not appear first in the schedule or falls well outside working hours. Under the control of sched and the field system, a specified portion of a scan is sent directly to the SFXC cluster at JIVE. Use of ftp transfer and near–real–time correlation permits stations that don't have a full e–VLBI connection to participate. Correlation results go to a web page available to all the stations, showing baseline amplitude and phase across the band as well as autocorrelations and sampler–statistics. These ftp fringe tests continue to be successful in identifying telescope problems and helping to safeguard user experiments by allowing the station friends to take care of any such problems before the actual astronomical observations begin.

Disk–pack Logistics and Infrastructure: The foundations of disk–pack shipping requirements have remained the same from the previous biennial period, with the addition of some new considerations that can tend towards less efficient pack usage. Session 2/2014 was the first to require more than 1000 TB of disk–packs to be used across the participating stations. Remaining the same are the guidelines that:

- EVN stations should buy two sessions' worth of disks, hence the disk–pack flux should balance over a 2-session interval.
- NRAO stations require pre–positioning the difference between what they will observe in globals to be correlated at JIVE (or Bonn) and what EVN stations will observe in globals to be correlated in Socorro.
- The sets of packs for observations destined for correlation in different places should be distinct from each other.

New considerations include:

- The new class of EVN out–of–session (OoS) observations, which can raise a trade–off between rapid shipping of packs and fully using the available space. So far such OoS observations have comprised relatively low data–rate RadioAstron+EVN/global observations (12 hr needs only 1.4 TB). The load for OoS observations between two sessions should be distributed along with the packs for the preceding session.
- NRAO and KVN stations want only the more modern SATA packs for recording, which establishes an effective minimum–size per each of their stations of 6-8 TB.

There were serious problems encountered in delivering packs to the QUASAR stations in the initial sessions of 2013. In session 1/2013, the three telescopes (Svetloe, Zelenchukskaya, Badary) missed 2, 7, 5 user experiments (and 2, 3, 2 NMEs) due to lack of packs. Following discussion with IAA, the total distribution was split into multiple shipments, each of no more than 6 packs, spaced a few days apart, and the delivery was shifted from a parcel company to a freight company. By session 3/2013, the difficulties seem to have been overcome.

JIVE began to exploit e–shipping operationally in 2014, initially focusing on the lower data–rate OoS observations and as a means to transfer data to another correlator from misdirected disk packs. If there is enough space at the correlator, e–shipping avoids the need to physically send disk–packs before and after correlation, and also permits a more direct experiment–based recycling.

Astronomical Capabilities of the SFXC: The principal features that astronomers can exploit in their experiments include essentially unlimited spectral resolution, multiple phase–center correlation, and pulsar gating/binning. These capabilities are described in detail in the previous biennial report, and they continue to see further development. There were 6 observations using pulsar gating/binning during this biennial period, 4 of which required the development of coherent de—dispersion of the pulse. In incoherent de-dispersion, each frequency point in the correlation gets its own time offset to undo the frequency–based dispersion the pulsar's signal accumulates traveling through the interstellar medium. For pulsars with large dispersion measures and short pulses/pulse–widths, there may arise conflicting requirements: the number of frequency points would need to be large to maintain a negligible residual dispersion in each frequency point, but would simultaneously need to be small to keep the time–span associated with the samples in the FFT below the desired temporal resolution. Coherent de–dispersion avoids such situations by applying a chirp function directly to the sampled data before correlation. In order to apply coherent de–dispersion, an FFT the size of the dispersion time across a subband in units of the sampling interval is required. For the observations driving development of the coherent de–dispersion, this FFT was 4 million points, which required further development of controls in the operating GUI for managing the number of processes running per SFXC node in order to avoid memory–usage problems.

There were 24 observations using multiple phase–center correlation This approach performs an "internal" correlation with a very large number of frequency points and a very small integration time (typically $\geq$8k frequency points and integration times $<$10 ms), but then outputs only subsets of this initial wide field using more traditional values for frequency points and integration times.

The most significant new development in this biennial period was the return of global VLBI observations, with the VLBA stations and the Green Bank telescope using NRAO's digital back–end, RDBE, in a "personality" that permits BBC tunability. The JVLA with its new WIDAR correlator also returned to global observations. For these NRAO stations as described, only eight channels are available, so observations at 1 Gbps required 32 MHz channels at NRAO stations, while the EVN stations retained their maximum channel BW of 16 MHz. Thus the ability to correlate mixed–bandwidths was developed on SFXC. In this case, the wider channels are split to match the narrower ones. Implicit in this new feature is the ability to correlate lower– and upper–sideband channels with each other. With the RDBE back–ends, VLBA stations no longer provide the TSYS section in *exp*cal.vlba files. Instead, JIVE developed programs to extract system temperature from the effects of the 80 Hz noise–diode modulation in their sampler statistics in SFXC output.

A spectral–zooming mode was developed, in which only a portion of an observed channel is correlated. This enables higher spectral resolution without a corresponding increase in the size of the output FITS files. This mode is a subset of the mixed–BW correlation capability, in that an observed channel is split into a smaller frequency range based on an external specification: in the mixed–BW case, as defined by some other station's observed channel; here based on a user–specified frequency range.

A *phased-array* mode for SFXC was developed, in which calibration information derived in AIPS following an initial correlation is fed back into the correlator to augment the a priori model. This permits "summing" the individual stations or cross–correlations to provide a data–set with time–resolution on the order of the sampling interval on a virtual telescope having an equivalent area to the sum of the areas of the participating stations. This capability has been used for EVN+GBT observations of pulsars in a globular cluster; the phased–array summed data–set can in turn be used with standard pulsar search/timing programs.

The first LO offsets (small enough to permit remaining frequency overlap with other stations) since SFXC took over production correlation occurred. The means to compensate for such incidents was developed for SFXC, and is more flexible than the similar capability was in the MkIV correlator: such LO offsets in more than one station can be handled (because the fringe rotation in SFXC is strictly station–based, as opposed to the MkIV in which the fringe rotation was applied to the "first" station of each baseline taken separately).

Digital Backends: The transition from the analog mark4/vlba4 formatters to the DBBC digital back–ends has almost finished. At the beginning of this biennial period, only Effelsberg was using the DBBC in user experiments. During 2013–4, Onsala, Noto, Toruń, Yebes, Metsahovi, and Hartebeesthoek successfully tested their DBBCs through parallel–recording in NMEs, and had shifted over to DBBC–only observations by the end of this biennial period. The new stations Tianma 65m and the Sardinia Radio Telescope used DBBC back–ends from their initial test observations (Tianma65 can also use the CDAS back–end). All EVN/global observations continue to use the DBBC in the *DDC* personality, to maintain BBC–tuning capabilities compatible with the previous analog back–ends.

Robledo also shifted to the new DSN digital back–end, the DSN VLBI Processor (DVP), during this biennial period. The DVP outputs VDIF data, in a fixed number of channels (32) regardless of the observing schedule. For 1 Gbps observations, this means that Robledo observes at 2 Gbps (32x 16MHz). SFXC can handle this by assigning 16 extra channels to Robledo, which are read from the disk–pack but which are not correlated. Parallel–recordings (DVP along with the existing mark4 back–end) were conducted in some observations in session 3/2013. DVP was used exclusively for user experiments in 2014. There were a few iterations of liaison between JIVE and Bonn, and later between JIVE and Haystack, to help with their DiFX correlators' ability to interpret recordings from the DVP back–end in a *geo* mode.

Initial tests of global–VLBI observations including VLBA stations using their new digital RDBE back–ends in its *DDC* personality were conducted in session 2/2013 at 512 Mbps and 1 Gbps. The LO selection for the RDBE systems is somewhat limited; they can use only upper Nyquist zone (512–1024 MHz above/below the LO) and there are "cross–over" frequencies at 128 MHz from the bottom and top ends of their 512 MHz IF range that a individual BBC cannot cross. These extra considerations led to some adjustments in the standard 1 Gbps frequency ranges for globals for some of the standard bands. Global user experiments returned in session 2/2014.

New EVN Telescopes: Two new large telescopes, the Sardinia Radio Telescope and the Tianma 65m telescope, made their first EVN observations in session 1/2014. Figure 31 shows amplitude and phase versus frequency for the baselines between these new stations and Effelsberg, together with the baselines to Effelsberg from their closest EVN neighbour.

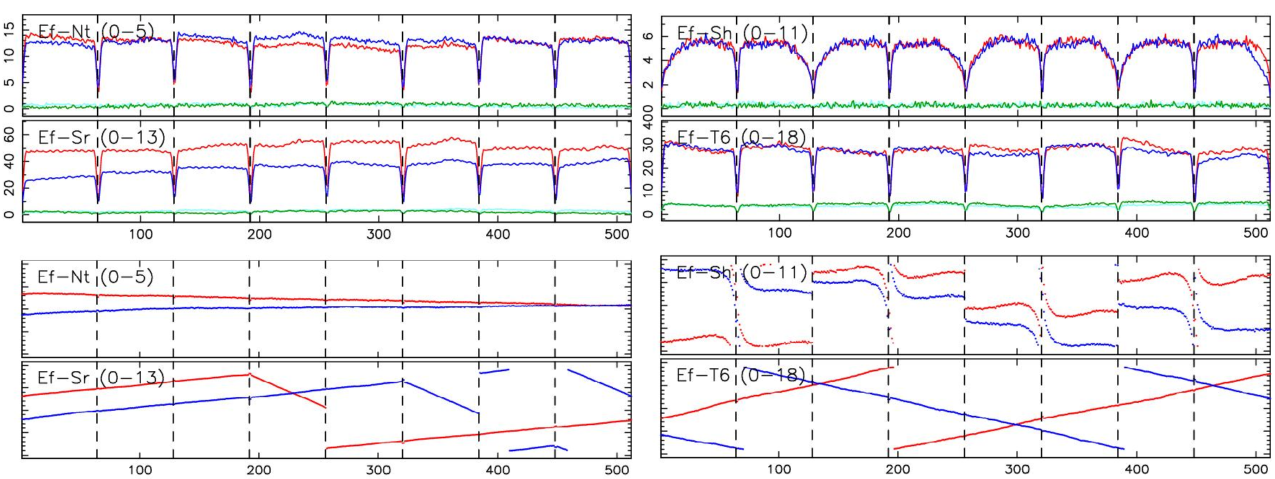


Figure 31: **Left:** Amplitude and phase vs. frequency on the baselines from Effelsberg to Noto and the new Sardinia Radio telescope (Sr), from the session 1/2014 L–band NME, N14L1. **Right:** Amplitude and phase vs. frequency on the baselines from Effelsberg to Sheshan25 (Sh) and the new Tianma 65m telescope (T6), here using a DBBC backend, from the session 1/2014 L–band NME, N14L1.

EVN USER SUPPORT

EVN Archive: The EVN Archive at JIVE provides web access to the station feedback, standard plots, pipeline results, and FITS files for experiments correlated at JIVE. Public access to the FITS files themselves and derived source–specific pipeline results is governed by the EVN Archive Policy – the complete raw FITS files and pipeline results for sources identified by the PI as “private” have a one–year proprietary period (6 months for target of opportunity observations), starting from the distribution of the last epoch resulting from a proposal. PIs can access proprietary data via a password arranged with JIVE. PIs receive a one–month warning prior to the expiration of their proprietary period.

The total size of the FITS files in the archive at the end of 2014 was 23.9 TB (a 9.2 TB gain in this biennial period); Figure 32 shows the growth of the FITS–file size in the EVN archive size over time. A marked surge in the Archive size can be seen at the end of 2014, as the first of the data from the large experiments from session 2/2014 were populating the Archive. In anticipation of faster growth under SFXC, another 26 TB of disk space was added to the server hosting the Archive, bringing the total to a dedicated 48 TB, with another 11 TB that can be shared with the pipeline work area.

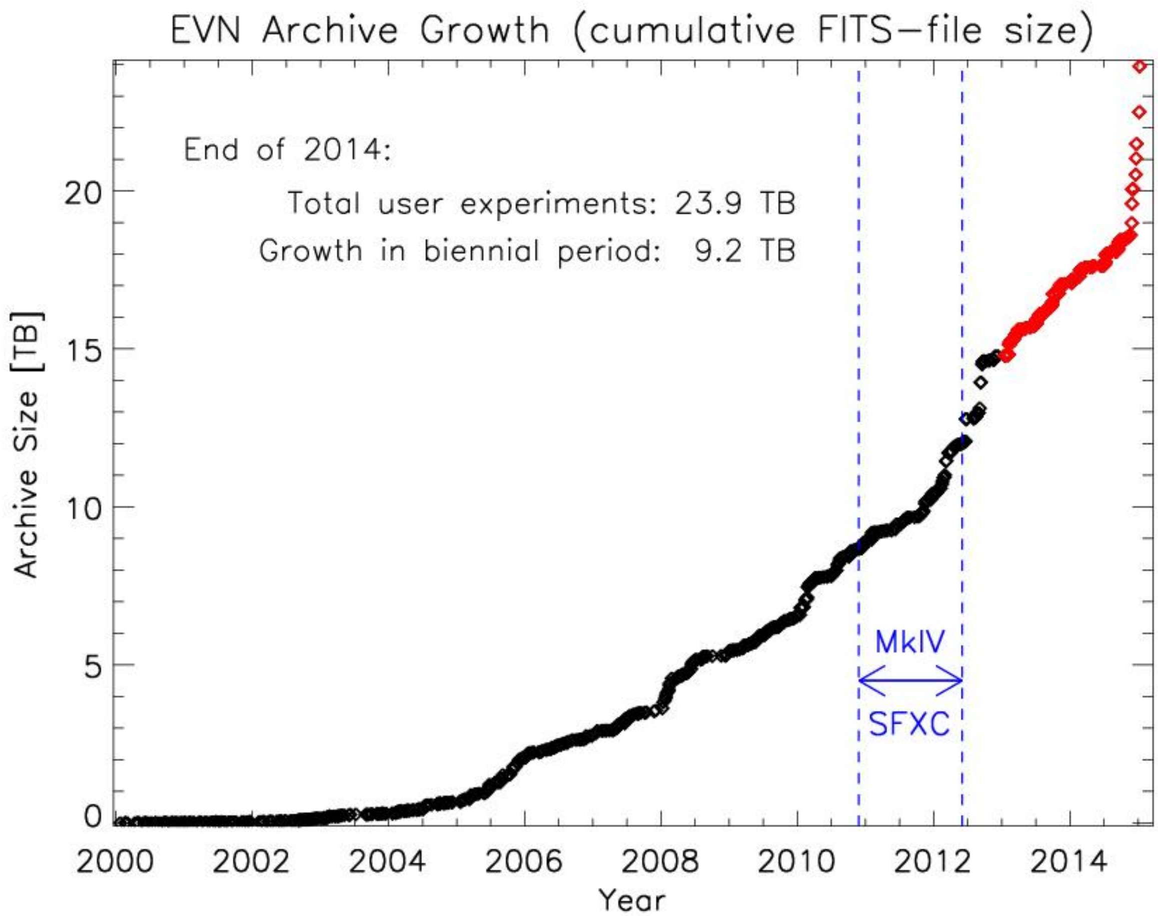


Figure 32: Growth in the size of FITS files in the EVN archive. Experiments archived in this biennial period are plotted in red. Vertical blue lines mark the dates of archiving the first data from SFXC correlation and the last data from MkIV correlation (of a disk-based observation).

EVN pipeline: The EVN pipeline runs under ParselTongue (a Python interface to classic AIPS), and the pipeline scripts are available from the JIVE wiki. The pipeline itself was modified to accept ANTAB information for VLBA stations derived from the 80 Hz continuous–cal extractor rather than from the (legacy) *vlba.cal* files for individual observations.

Scheduling assistance: The science operations and support group continues to contact all PIs once the block schedule is made public to ensure they know how to obtain help with their scheduling, and to check over schedules posted to the VLBEER server prior to stations down–loading them in order to minimize the chance of preventable errors in the observations themselves. There were 7 first–time EVN PIs in 2013 and another 8 in 2014. (There were an additional 4 first–time PIs associated with EVN/global+RadioAstron experiments, but those are scheduled centrally by the RadioAstron Mission Scheduling Team). During this biennial period, in which EVN stations have been making the transition to digital back–ends on their own independent time–scales, this scheduling help has also included providing PIs with template *setini* blocks and station catalogs appropriate to their specific experiment(s) and the version of sched that they were using – each session presented a unique configuration of back–ends and patching preferences at the various EVN stations, a situation that is continuing to evolve at the end of 2014.

EVN Proposal Tool: There were three sets of modifications to the EVN–specific portion of the NorthStar Proposal Tool over this biennial period. First, to augment the merger of the EVN+MERLIN and e–EVN observing classes, the possibility of having an e–EVN observation within a global proposal was also added. Thus one or more e–EVN epochs can be requested on an observation basis within any proposal. Second, a new row to the array–selection box was added for *EVN stations with individual limitations*, to handle the case of a single station having multiple antennas, either of which could be used but with one of them being the primary choice at a given frequency – the non–primary one would be listed in this row, while the primary is listed in the regular *EVN* row. Also included in this new row is Hartebeesthoek (declination limits), Cambridge used outside of eMERLIN, and Wettzell. New links into the help pages were added to explain the list of stations appearing in this new row. Finally, to support the new EVN out–of–session policy, the means was added to specify whether any part of the proposal would require OoS observing, which if selected would open a further dialog box to provide criteria for a minimally–required array composition (a similar box allowing specification of specific date ranges was already present in the NorthStar tool).

TECHNICAL OPERATIONS and R & D

End of the MarkIV Correlator: An era came to an end with the demise of the MarkIV hardware correlator, after many years of near–continuous operation. The correlator was dismantled, and nearly all correlator boards were shipped to Hawaii, to serve as spare parts for the SMA.

Figure 33: Mark IV correlator boards waiting for shipment

The SFXC software correlator was relocated to the correlator room, to take advantage of the excellent cooling in this room and to minimise ambient noise for the operators (Figure 34). This involved a fairly extensive re–organisation of the local network. In view of the large maintenance costs, the fire extinguisher installation, there to protect the once–irreplacable MarkIV correlator, was dismantled. As part of the construction of the new wing of the Dwingeloo building, the general cooling system was re–designed, which necessitated the replacement of the cooling machine in the JIVE correlator room.

Figure 34: SFXC cluster in its new environment

Hardware Developments and Upgrades: The Mark5 units at JIVE performed reliably as always. Early 2013 one unit was sent to Toruń, to help with the debugging of their new DBBC, running both an analogue and a digital system in parallel during several EVN sessions.

Together with ASTRON engineers the archive backup machine, located in one of the Faraday cages at the WSRT, was upgraded to a total of 38 TB of disk space, with the option for additional expansion. The backup machine is used as a daily mirror of the EVN archive located at the JIVE headquarters in Dwingeloo.

The twin Solaris servers used for many years as correlator control machines were replaced by a clustered virtual machine pair. All essential services like DNS and LDAP are hosted by these machines. Most databases used by the control system have been migrated to a replicated dual–master MySQL setup. A replicating LDAP server pair was also built for centralized, secure authentication.

EVN Software Correlator at JIVE (SFXC): At the end of 2012 additional hardware was bought for the SFXC cluster at JIVE, bringing the number of cores to 384, on a total of 40 nodes. This enabled the correlation, in real–time, of 13 stations at 1 Gbps. Since that time, all operational correlation, both recorded and real–time, has been done on the SFXC.

Development of new features and improvements continued at a rapid pace:

• support for mixed bandwidth correlation was completed and tested

• VDIF support was improved and tested with backends that actually produce VDIF data, such as the JVLA WIDAR correlator and the new NASA JPL digital backend

• spectral averaging was improved, keeping the natural labelling of the frequency bins and correctly accounting for the windowing function being used

• spectral masking was implemented in order to increase the S/N of observations that have a sparse signal in the frequency domain, such as spacecraft observations

• switched power extraction was implemented in order to derive system temperatures for stations that have 80 Hz noise injection

• positive delays are now supported, needed in particular for RadioAstron data which can have such delays in certain parts of its orbit. As an additional benefit this prevents the crashing of the correlator during e–VLBI when stations are scheduled while the source is still below the horizon.

• a beam fitting program was developed to obtain the primary antenna beams of the EVN stations, based on a series of deliberate mispointing around a known source. As more EVN stations provide this information, the quality of wide–field EVN observations will improve

• the phased array mode was made operational

• support for coherent de–dispersion was added

Besides all this, the SVN repository holding the SFXC code was made public, basic end–user documentation was written, and VEX support was further improved. The functionality to accommodate triggered observations (pioneered in the NEXPReS project) was finalized and tested. A few insitutes have downloaded and installed the SFXC code base. The Korean VLBI Network started experimenting with the phased array mode, and at Shanghai Astronomical Observatory SFXC is also being tried. Close contact is maintained with the DIFX community, making sure that solutions to specific problems can be used by both correlator implementations.

The JIVE UniBoard Correlator (JUC): Although the FPGA–based UniBoard project, a Joint Research Activity in RadioNet FP7, ended in 2012, work on the JUC continued. Early 2013 an internal review of the correlator design was held, which did not reveal any major show–stoppers. Many firmware modules were added and/or modified, adding support for dual polarisations and lower side–bands, increasing the size of the delay/phase coefficient registers, adding the second derivative delay coefficient. As larger datasets with more stations were processed, many new and interesting bugs were found and fixed. A new front node control module was written to handle the 32 MHz subbands that are needed for 2 and 4 Gbps EVN observations, but not yet tested.

In September 2014 an external review of the complete UniBoard correlator system, including both firmware and control software, was held. The review panel consisted of Prof. Dr. A. Baudry (chair), Prof. B. Klein, Dr. A. Deller and Dr. P. Harrison. Overall, the report of the panel was very positive, with, among others, the explicit advice to continue funding the further development of the JUC.

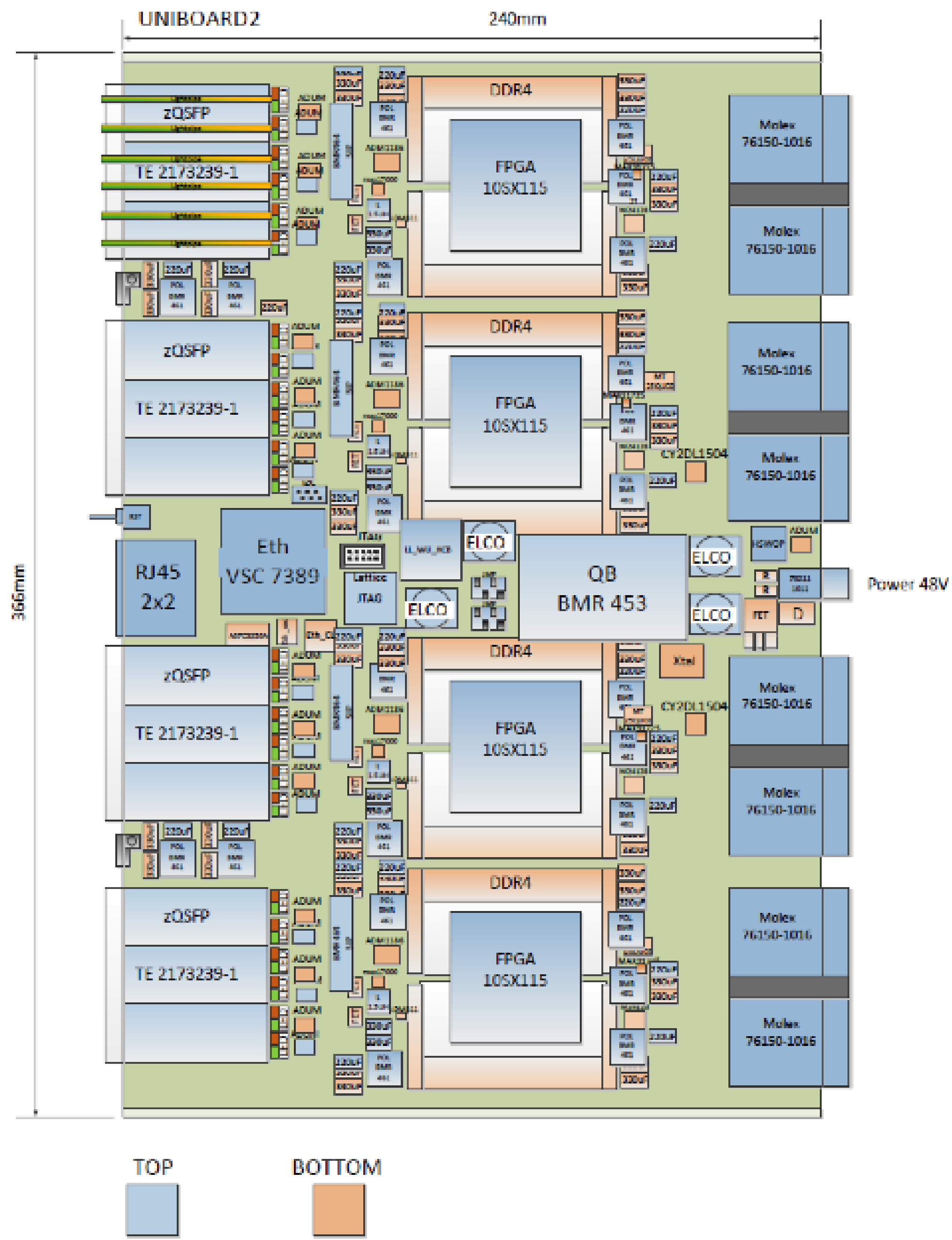


Figure 35: High-level design of UniBoard

UniBoard2: UniBoard2, a Joint Research Activity in RadioNet3, kicked off in July 2012. As in UniBoard, the intention was to develop a high–performance FPGA–based computing platform, with a number of demanding applications. The UniBoard2 project timeline however straddled two FPGA technologies, 28 and 20 nm, to which later was added 14 nm, through the collaboration between the Intel and Altera companies. To make a platform that could be a serious contender for any SKA–related instrumentation, one would have to use the very latest technology.

As a consequence, the decision was made to delay the choice of technology as long as possible. In the summer of 2013 it became clear that the 20 nm devices would become available in time for the project, and moreover, that some of the planned 14 nm devices would be pin–compatible, allowing easy future upgrades of the board. After many project–wide discussions, a design was decided upon that would have four Altera Arria10 FPGAs in one singe column. The decision was also made to create a break–out board using a new transceiver–based momory technology called *Hybrid Memory Cube*, offering far higher bandwidth and density than DDR memory modules. In the course of 2014 the hardware design took shape, and internal and external design reviews were held in June and December. Technology–independent versions of DDR, transceiver, and flash memory interfaces were developed, allowing these modules to be used for both UniBoard and UniBoard2, and potentially other boards. A design document was written showing how the EVN correlator firmware could be mapped onto UniBoard2.

jive5AB: In 2013 the first official version of *jive5AB* came out that could be used as a drop–in replacement of MIT Haystack's Mark5A, Dimino and drs programs, fully integrated with the NASA Field System. Among its many features it makes automated fringe checks possible, without interrupting the ongoing science observations (at least, for Mark5 units equipped with Amazon boards). While originally intended for use with Mark5 only, its functionality also came to include *FlexBuff* recording. The FlexBuff is a VLBI data recording system developed through the NEXPReS project, which allows simultaneous recording/transmitting of data at very high speeds. With its large storage capacity, it is possible to record an entire EVN session at the station, streaming the data to the correlator in near–real time, and thereby removing the need to ship disk packs altogether.

A data transfer program called *m5copy* was developed which, rather than copying the data iteself, drives a source and destination instance of jive5AB. *m5copy* provides a choice between the (reliable) TCP and UDT transfer protocols, and makes it possible to move nearly any kind of data in any format from any medium to another. Since its release in December 2013, the program has seen a rapid uptake in the VLBI community.

Other software developments: A new release of *ParselTongue* came out in January 2014. Support for parallel running of more AIPS tasks was added, faster file creation made possible, bugs fixed. Obit installation was simplified by stripping functionality that is not needed by ParselTongue, and the installation process on MacOS was considerably improved using Homebrew. Some work was done on using ParselTongue with the Swift parallel scripting language, supporting the work done for the Hilado work package in RadioNet3. This work aims at optimizing data processing pipelines by avoiding unnecessary reprocessing of data when processing parameters are changed.

Work on the BlackHoleCam (BHC) project started with an analysis of the available astronomical software packages, and their suitability for the BHC pipeline. This resulted in the selection of *CASA* as the packet of choice. An inventory was made of the steps involved in mm–VLBI data processing, and a collaboration was started with the *MeqTrees* team in South Africa to develop simulations based on earlier work for LOFAR and ongoing work for the Event Horizon Telescope project.

Towards 4 Gbps VLBI: The NEXPReS project ended in 2013. The final review took place in Dwingeloo and featured a live 4 Gbps demo, recording and transmitting data to the correlator in real time at up to 4 Gbps from five telescopes: Onsala (Sweden), Metsahovi (Finland), Effelsberg (Germany), Yebes (Spain) and Hartebeesthoek (South Africa). This was to showcase the progress that VLBI had made through NEXPReS.

While in some ways a repeat of the demo of the previous year, most of the hardware, firmware and software was completely new. But in spite of a number of mishaps, such as the failure of a production run of Fila10G boards and the complete lack of any opportunity for testing all this new hard– and software until one week before the review, the demo went very well, with fringes to four out of five stations. And although phase closure could not be shown, the panel was sufficiently impressed and awarded the project the rating of “excellent”.

Figure 36: Tense moments during the NEXPReS final review demo.

SPACE SCIENCE

VLBI and space science: The Space Science and Innovative Applications (SpaSIA) group continued developments of two space–oriented applications, the near–field VLBI for multi–disciplinary scientific applications as well as support to the operational (RadioAstron) and design studies of prospective Space VLBI missions.

The near–field VLBI technique allows researchers to determine five of the six state–vector components of target sources (spacecraft) with high accuracy. The interest of the planetary and space science communities to this technique translates into an enlargement of the user base of VLBI facilities.

Over the reporting period of 2013–14, the SpaSIA group continued developing several key components of the near–field VLBI technique. These include all steps of spacecraft VLBI tracking experiments, from planning to post–processing. In particular, the team has developed and tested a set of software tools that allow efficient scheduling of near–field VLBI tracking experiments and pipelining of single–dish data in order to estimate the radial Doppler–shift of the spacecraft signal. Working with the Technical Operations and R&D group at JIVE and the Department of Astrodynamics and Space Missions at Delft University of Technology, the group helped upgrade SFXC with a set of modules specific for near–field VLBI processing. These modules include the correlator delay model tested in VLBI experiments on targets at distances from several astronomical units (e.g. Mars Express) down to Earth satellites (e.g., RadioAstron).

Planetary Radio Interferometry and Doppler Experiment (PRIDE): The Planetary Radio Interferometry and Doppler Experiment is based on the near–field VLBI developments described above. In 2012 PRIDE was selected and in 2014 adopted as a part of the science payload of the ESA's mission JUICE (Jupiter Icy Moons Explorer). The experiment is designed as an enhancement of the science output of the mission by means of exploiting the available onboard instrumentation and the infrastructure of Earth–based radio astronomy facilities.

PRIDE will provide additional measurements in the areas of prime focus for other JUICE experiments. In certain applications its deliverables are unique. The latter is most obvious in the astrometric domain where PRIDE can provide precise estimates of the spacecraft celestial position directly in the ICRF frame thus enabling precise determination of the celestial mechanics parameters of the Jovian satellites. All scientific applications of PRIDE are based on two measurables: the lateral (transverse) celestial position of spacecraft and its radial velocity (Doppler). The former is the main outcome of VLBI tracking of spacecraft, while the latter is an inevitable ad hoc product of VLBI tracking.

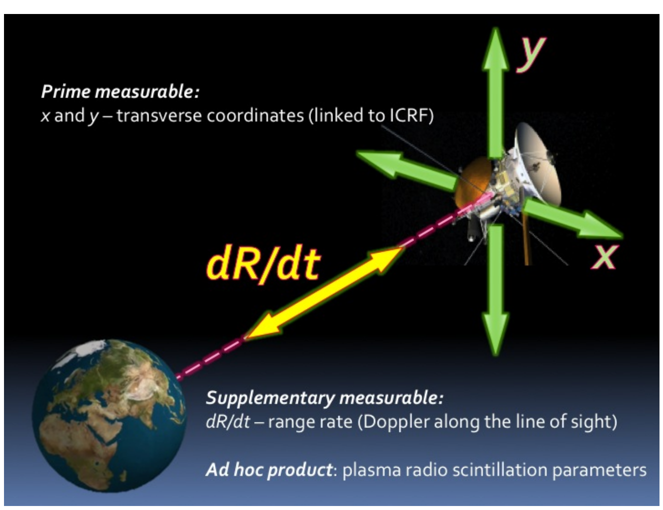


Figure 37: PRIDE-JUICE measurable

Space VLBI: RadioAstron: After completion of the in–orbit checkout period in the beginning of 2012, the Space VLBI mission RadioAstron began implementation of its Early Science Programme, Key Science Programmes and regular PI–led science experiments. The SpaSIA group at JIVE took part in all three stages of the science operations of the RadioAstron mission. The special task addressed by the group dealt with enhancements of the RadioAstron orbit determination by conducting PRIDE–style tracking of the spacecraft. It has been shown that PRIDE tracking can enhance orbit determination (as is necessary for particularly demanding long–baseline experiments), enabling sub–nanosecond delay model predictions (Figure 38). After completion of verification tests, SFXC has been declared available for correlating user–led RadioAstron experiments.

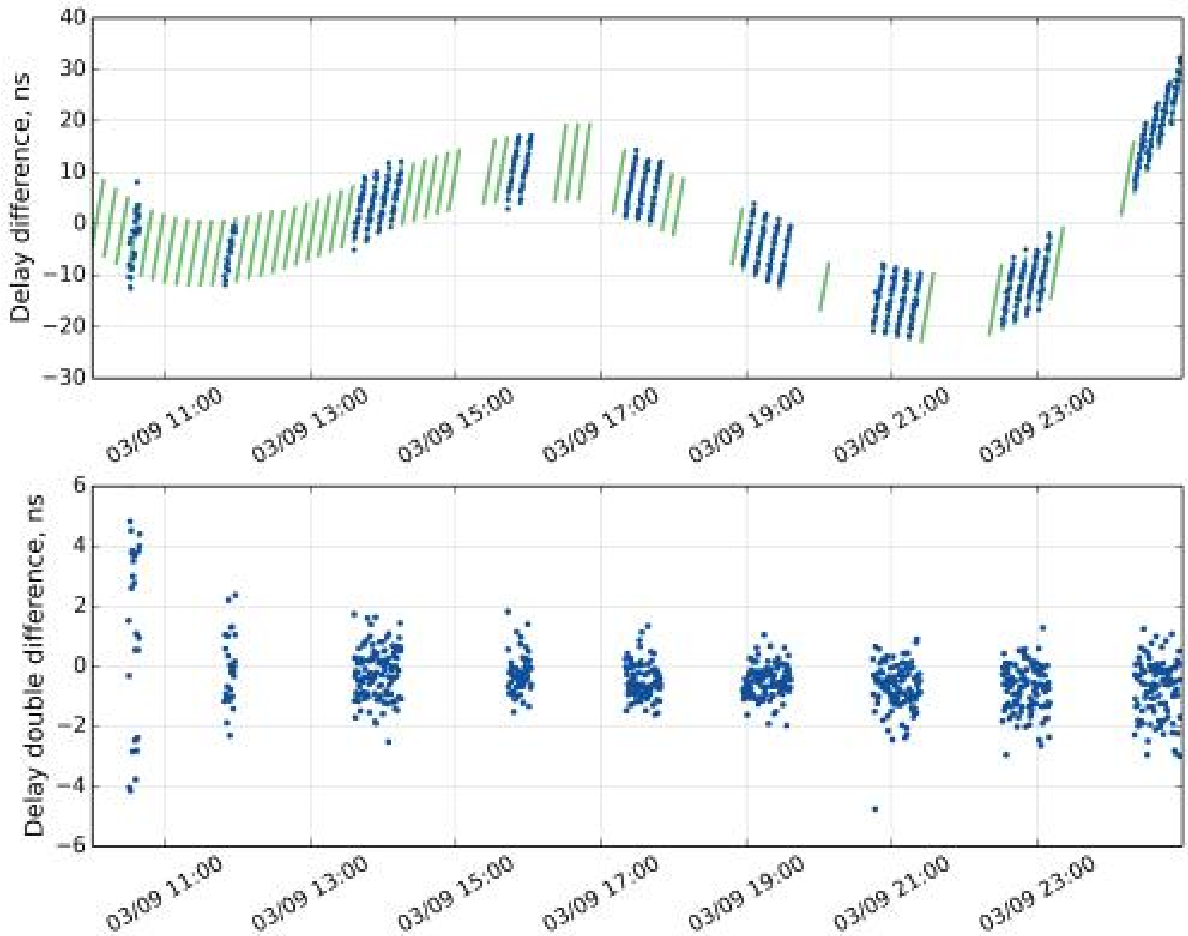


Figure 38: Improved versus nominal orbital solution: difference in measured residual delays (blue dots) in modeled delays (green dots) (top), and their double difference (bottom), for the baseline Effelsberg–RadioAstron in experiment GK047A.

EVN–RELATED MEETINGS AND CONFERENCES

12th EVN Symposium and Users Meeting, Cagliari, Sardinia

The Istituto di Radioastronomia (IRA) di Bologna and the Osservatorio Astronomico di Cagliari (OAC) of the Istituto Nazionale di Astrofisica (INAF) hosted the 12th European VLBI Network Symposium and Users Meeting. The conference was held from 7th to 10th of October, 2014 at the Hotel Regina Margherita, in the center of Cagliari. The latest scientific results and technical developments from VLBI and, in particular, e–VLBI and space–VLBI (RadioAstron) were reported. The timing of this meeting coincided with the first successful observational tests of the 64 m Sardinia Radio Telescope (SRT) within the EVN, and with a number of results from new and upgraded radio facilities around the globe, such as e–MERLIN, ALMA, and the SKA pathfinders. The symposium was attended by 133 participants from all over the world, with the Asian community represented by more than 20 colleagues. The program of the meeting consisted of 70 oral contributions (including 8 invited speakers) and 50 posters, covering a very wide range of VLBI topics in both galactic and extragalactic astrophysics (e.g., AGN, stellar evolution from birth to death, astrometry, and planetary science) as well as technological developments and future international collaborations.

Figure 39: Participants in the EVN Symposium visit the Sardinia Radio Telescope

The scientific program also included a visit to the SRT and the EVN Users Meeting, where astronomers provided useful feedback on various matters regarding EVN operations. The symposium received financial support from the European Commission FP7 RadioNet3 project.

The Conference Proceedings, published online in Proceedings of Science, are available at:
http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=230

EGU and IVS Training School on VLBI for Geodesy and Astrometry, Espoo, Finland

Metsähovi Radio Observatory (MRO) and the Finnish Geodetic Institute (FGI) hosted a European Geosciences Union (EGU) and IVS Training School on VLBI for Geodesy and Astrometry on March 2–5, 2013. The aim of the school is to convey knowledge to the next generation researchers who will work with the next generation VLBI system for Geodesy and Astrometry. The program of the school covered all major aspects of today's VLBI system and the next generation VLBI system: technical aspects, observations, correlation, data analysis, and the interpretation of results. A report on the school can be found at: ftp://ivscc.gsfc.nasa.gov/pub/annual-report/2013/pdf/spcl-wg6.pdf

21st Meeting of the European VLBI Group for Geodesy and Astrometry (EVGA), Espoo, Finland

MRO and FGI also organized the 21st EVGA Meeting and 14th IVS Analysis Workshop on March 5–8, 2013. The scope of the EVGA meeting covered all aspects of geodetic and astrometric VLBI including hardware, correlation, analysis, and both scientific and technological results. The Analysis Workshop was devoted purely to discussions of the operational aspects of data analysis in the framework of IVS.

Fifth European Radio Interferometry School (ERIS), JIVE, Dwingeloo

The 5th European Radio Interferometry School (ERIS) was held from 9–13 September 2013 in Dwingeloo, organised jointly by ASTRON and JIVE. No less than 95 students were introduced to the concepts and practices of all major radio astronomy facilities. This is an important aspect of the RadioNet programme that is fostering the European radio community.

Figure 40: Bob Campbell capturing the students attention at the ERIS.

Second International VLBI Technology Workshop, Jeju, S. Korea

The Korea Astronomy and Space Science Institute (KASI) hosted the 2nd International VLBI Technology Workshop (IVTW) from 9–12 October 2013. The workshop was held at the International Convention Center, Jeju, South Korea near KVN Tamna station. IVTW–2013 kept a focus on e–VLBI and had special sessions on Time and Frequency Standards in the e–VLBI era and Wideband instrumental calibration systems.

Figure 41: Participants in the 2nd International VLBI Technology Workshop

Workshop on "Multi-Frequency VLBI Studies of AGN Core-Shift", Daejeon, S.Korea

A workshop on *Multi-Frequency VLBI Studies of AGN Core-Shift* was held in KASI from 18–19 December 2014. It focused on the methods to observe core–shifts and science implications of these observations, with a particular emphasis on the contributions that simultaneous multi–frequency VLBI would provide.

Figure 42: Participants of the Workshop on AGN core–shifts

Third International VLBI Technology Workshop, Groningen/Dwingeloo

The 3rd International VLBI Technology Workshop, hosted by JIVE, was held in Groningen and Dwingeloo from 10–13 November 2014. These meetings bring together Global experts who discuss all the technology advances relevant for VLBI data acquisition and correlation. With nearly 100 participants this was the largest meeting so far. Besides covering many topics in VLBI, one whole day was devoted to time and frequency transfer, with invited speakers from several metrology institutes. On the final morning an EVN–NREN meeting took place, sponsored by GEANT.

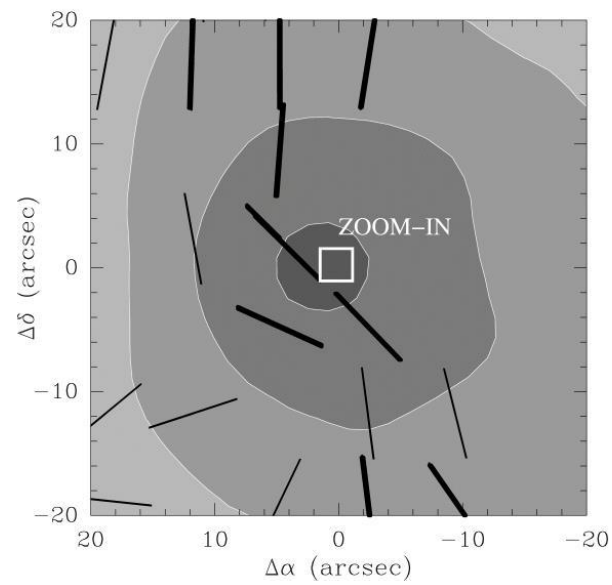
Figure 43: Participants of the 3rd International VLBI Technology Workshop

SELECTED EVN SCIENTIFIC RESULTS

GALACTIC SOURCES

The magnetic field at milliarcsecond resolution around IRAS 20126+4104

EVN observations (project code: **ES066**) have been used to determine the morphology of the magnetic field on AU scales around the massive young stellar object (YSO) IRAS20126+4104 by observing the polarized emission of the 22 GHz water masers and the 6.7 GHz methanol masers. The orientation of the magnetic field derived from the masers agrees with the S–shaped morphology seen on larger scales by using the dust-polarized emission at 350 μm.



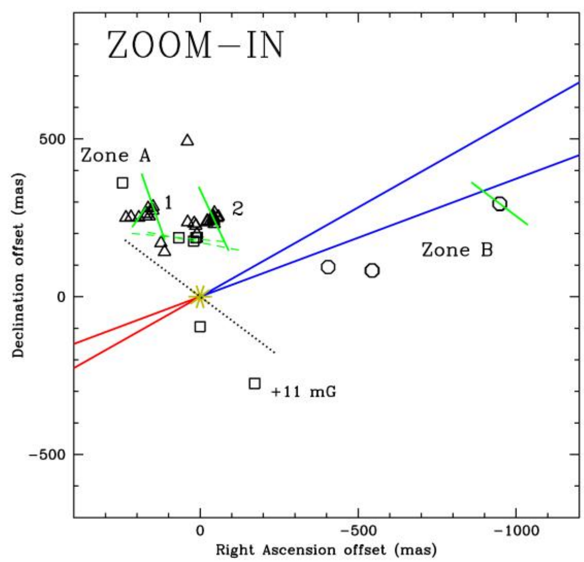


Figure 44: **Left:** The black bars represent the magnetic field direction in the young stellar object YSO IRAS20126+4104, determined from the polarized dust emission at 350 μm, with the continuum emission shown in grey scales in the background. The white box indicates the position of the right panel. **Right:** methanol (triangles), OH (squares), and water (octagons) masers in IRAS20126+4104. The gold asterisk represents the B0.5 protostar, while the dotted line represents the Keplerian disk of 1000 AU. The red and blue lines indicate the red- and blue-shifted lobes of the jet, respectively. The thick green segments represent the magnetic field direction determined from the polarized methanol and water maser emissions. The green dashed segments represent the magnetic field direction determined from the linearly polarized emission of OH masers (Edris et al. 2005, A&A, 434, 213).

Published in: **Surcis, G. et al. 2014: A&A 563, 30**

Polarization observations of methanol maser emission in YSOs

Despite the recognized importance of magnetic fields in the formation of low–mass stars their role in the formation of high–mass stars is still under debate. A long–term EVN program (project code: **ES066**) has been undertaken to make polarization observations of the 6.7 GHz methanol maser emission in young stellar objects (YSOs) (see e.g. Fig. 45).

Further observations (project code: **ES072**) have been made of the magnetic field morphology towards 8 new massive YSOs. These sources are part of a large sample of massive YSOs, the so–called flux–limited sample composed of 31 sources. A preliminary statistical analysis of the results obtained from the first 19 sources reveals evidence that the magnetic fields around massive YSOs are preferentially oriented along the molecular outflow.

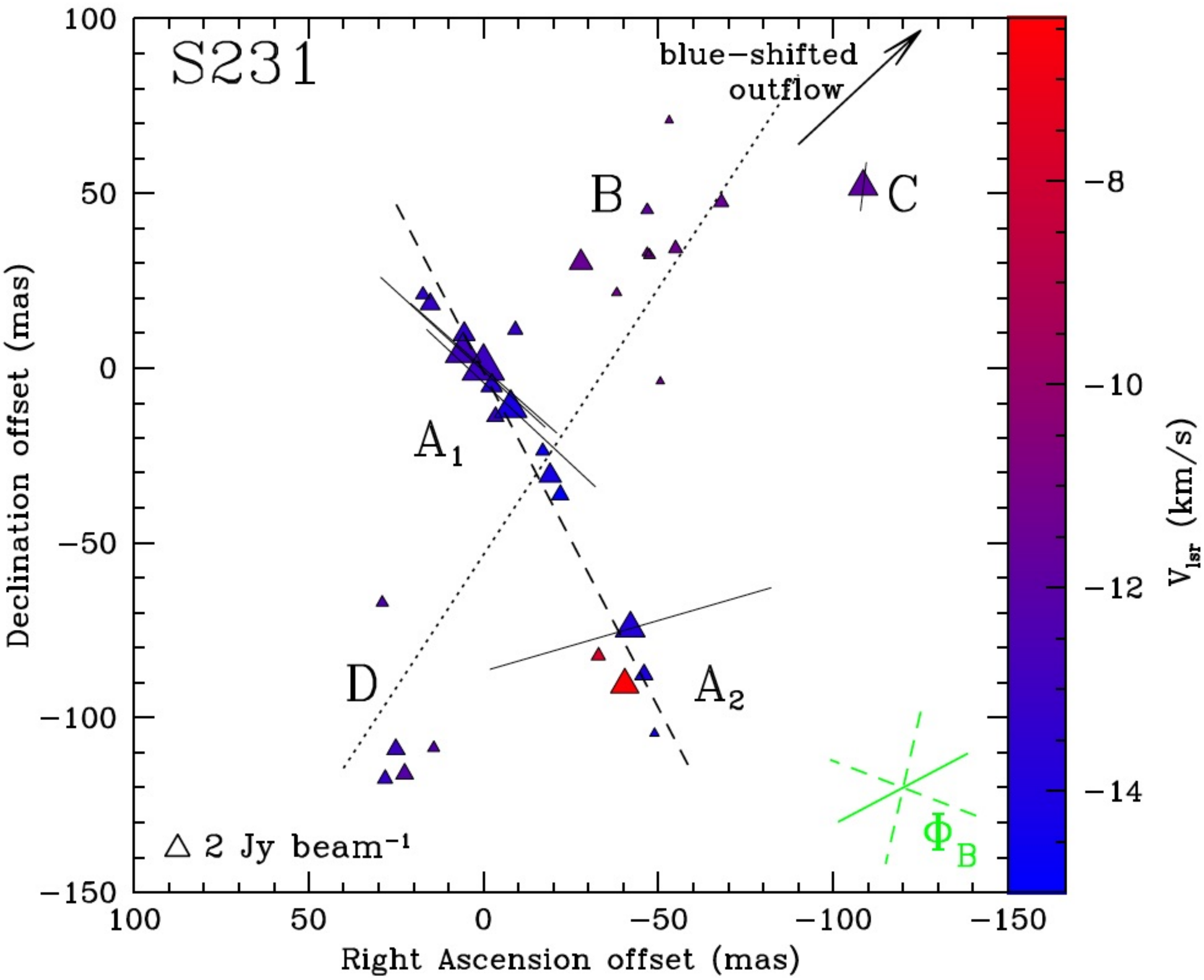


Figure 45: A view of the methanol masers features detected in the massive star forming region S231. The solid black lines represent the linear polarisation vectors of the methanol maser feature. The magnetic field is perpendicular to the linear polarisation vector.

Published in: **Surcis, G. et al. 2013: A&A 556, 73**

Published in: **Surcis, G. et al. 2014: A&A 565, L8**

EVN observations of 6.7 GHz methanol masers in clusters of massive YSOs

A study has been made of high–mass star–forming regions associated with both 6.7 GHz methanol and 4.5 μm mid–infrared (MIR) emission, which likely traces outflows from massive young stellar objects (MYSO). The objectives were to determine the milliarcsecond morphology of the maser emission and to examine if it is related to a single or several MIR counterparts in the clusters of MYSOs. EVN observations (project code: **EB043**) were carried out with near simultaneous 32 m Toruń observations in a 2.1 arcmin field. Maps were obtained with mas angular resolution that showed diversity of methanol emission morphology: a linear distribution (e.g., G37.753-00.189), a ring–like (G40.425+00.700), and a complex one (e.g., G45.467+00.053). The maser emission is usually associated with the strongest MIR counterpart in the clusters; no maser emission was detected from other MIR sources in the EVN field of view. The maser source luminosity seems to correlate with the total luminosity of the central MYSO. Although the EVN resolves out a significant part of the maser emission, the morphology is still well determined. This indicates that the majority of maser components have compact cores.

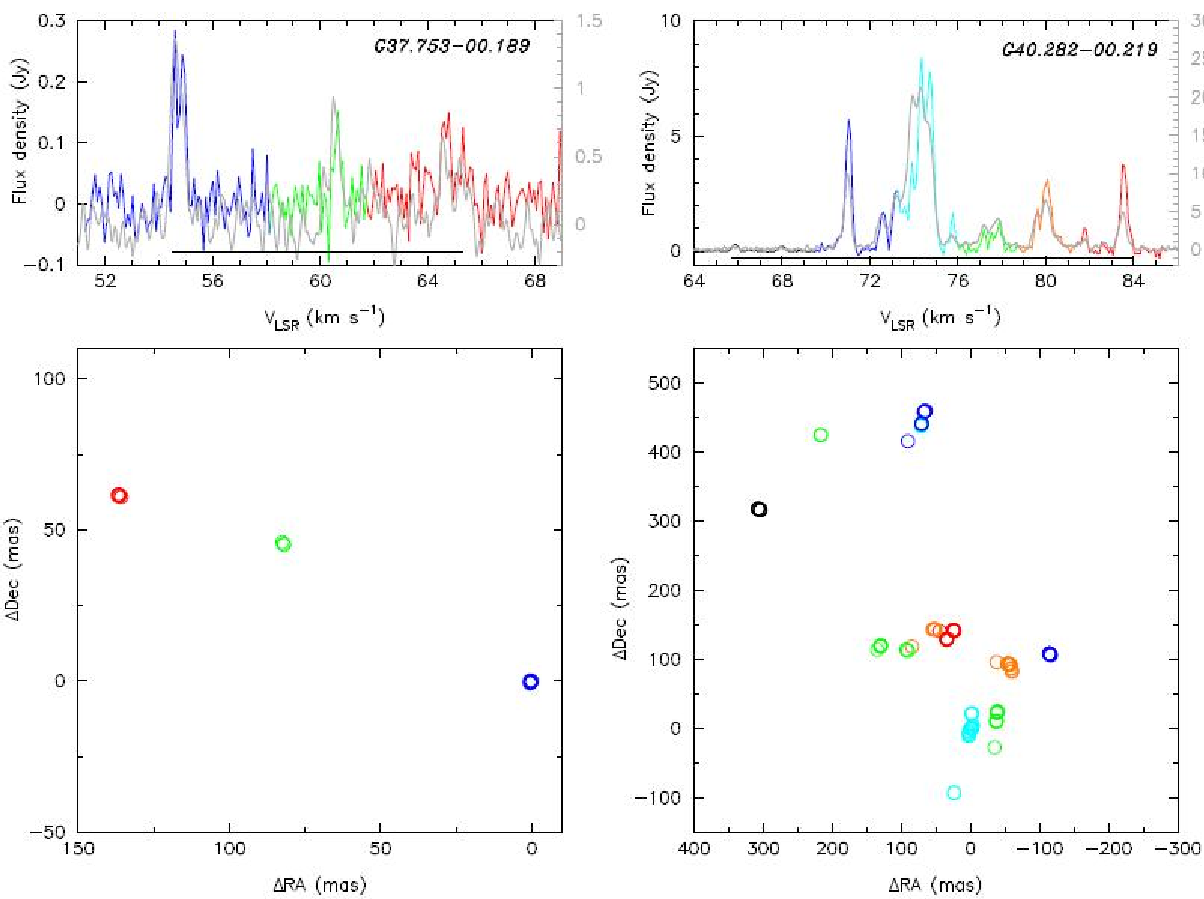


Figure 46: Example spectra and maps of 6.7 GHz methanol masers detected using the EVN. The colours of circles relate to the LSR velocities as shown in the spectra. The grey lines show the Toruń 32 m dish spectra. The flux density scales are shown separately for the EVN (**left**) and Toruń (**right**). The thin bars under the spectra show the LSR velocity ranges of spots displayed.

Published in: **Bartkiewicz, A. et al. 2014: A&A 564, 110**

A multiple system of high–mass YSOs surrounded by disks in NGC 7538 IRS1

The EVN has been used to observe NGC7538 IRS1 (at 2.7 kpc) in the 6.7 GHz maser line of methanol, which is a typical signpost of high–mass star formation. Four observing epochs spanning eight years (project code: **ES063**) were used to measure positions, proper motions, line–of–sight velocities and accelerations of methanol masers. These measurements provided 3D kinematics and dynamics of circumstellar gas on scales from tens to a thousand AU. Compelling evidence is found that NGC7538 IRS1 is forming a multiple system of high–mass young–stars surrounded by disks. Data modelling enabled identifying quasi–Keplerian rotation around a 25 $M_\odot$ star and a thick disk containing 16 $M_\odot$ around a nearby protostar. These measurements are critical to test theoretical models of accretion for massive stars.

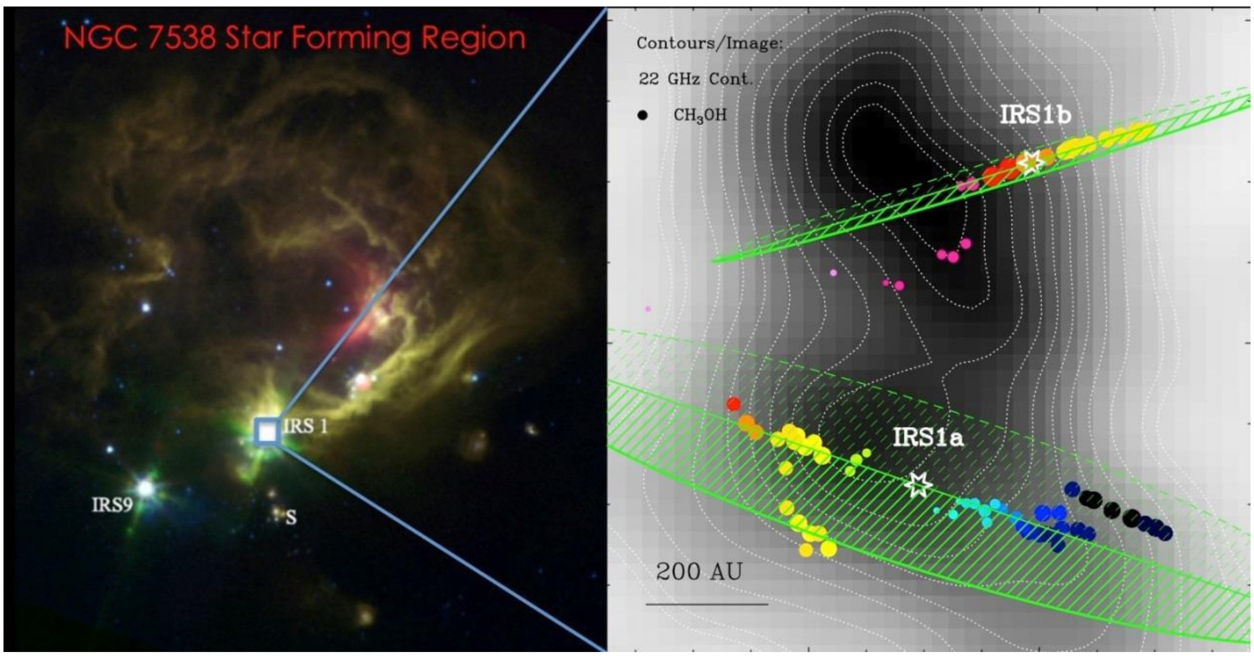


Figure 47: The NGC7538 Star Forming Region (2.7 kpc). **Left:** Three–colour IRAC image in the mid–infrared from the Spitzer Space Observatory. **Right:** 6.7 GHz methanol maser emission spots (filled circles) observed with the EVN overlaid on the 22 GHz continuum map imaged with the VLA (black image and white contours). Colors denote line–of–sight velocities, with blue indicating blue–shifted emission and red indicating red–shifted emission. The sizes of the circles scale with the flux density. The ellipses represent the disk planes surrounding the two young stars IRS1a and IRS1b, resolved by the EVN, with the solid lines indicating the near–side and the dashed lines the far–side of the disks.

Published in: **Moscadelli, L. & Goddi, C. 2014: A&A 566, A150**

EVN observations of the γ–ray flare in the classical nova V959 Mon

On 19th June 2012 the *Fermi* γ–ray Space Telescope detected emission from the classical nova V959 Mon, lasting for 12 days. EVN e–VLBI Target of Opportunity observations (project codes: **RO005 and RO006**) were made in September and October 2012. It was found that the ejecta from this nova (see Fig 48) are shaped by the motion of the binary system; some gas is being expelled rapidly along the poles as a wind from the white dwarf, while denser material has drifted out along the equatorial plane, propelled by orbital motion. At the interface between the equatorial and polar regions the observed synchrotron emission is indicative of shocks and relativistic particle acceleration, thereby also pinpointing the location of the γ–ray production. Binary shaping of the nova ejecta and associated internal shocks are expected to be widespread among novae, explaining why many novae are γ–ray emitters.

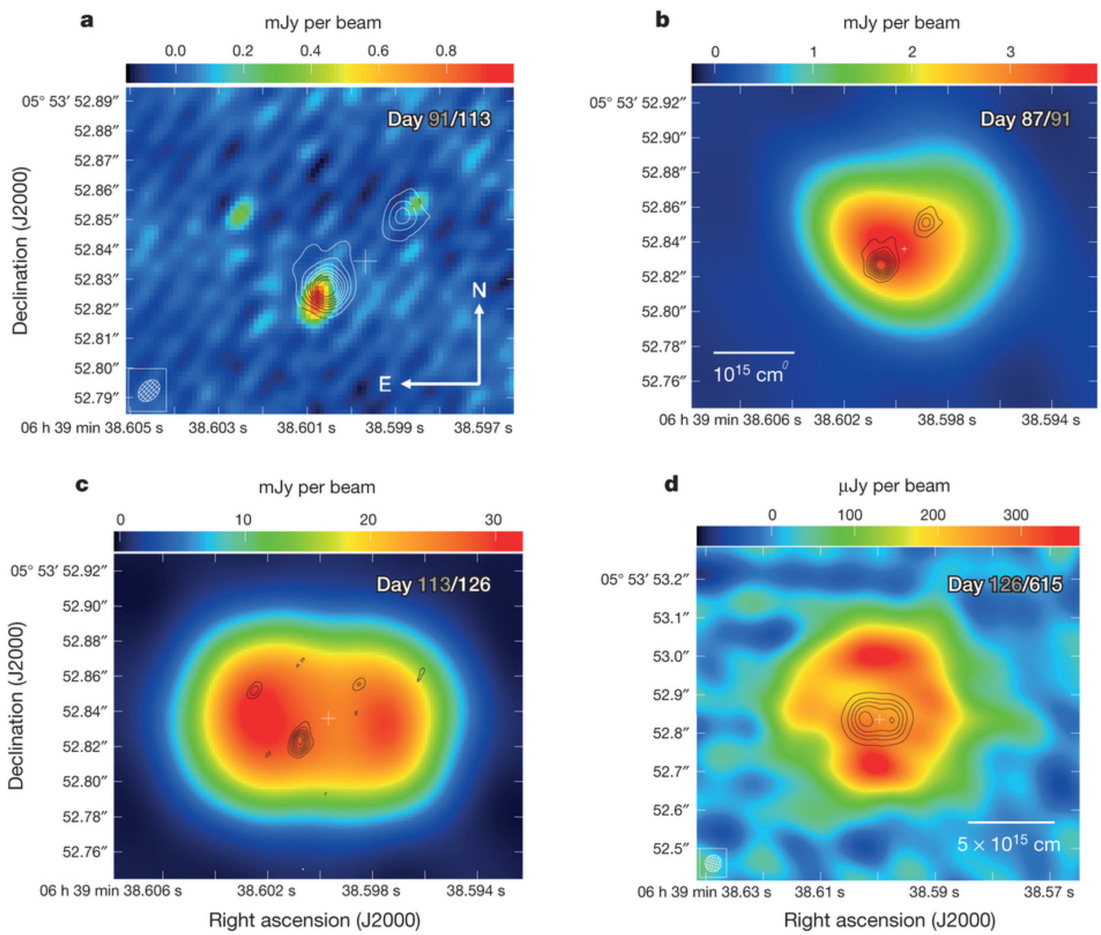


Figure 48: Radio imaging of V959 Mon. (a) The EVN images at age 91 days (contour lines) and 113 days (in colour) after the γ–ray discovery. These images show the compact radio knots expanding diagonally. (b) e–MERLIN image of the ejecta from the nova explosion (in colour) from 87 days after discovery with the EVN contours from day 91 superimposed. (c) The same components as (b) but this time imaged with the VLA 126 days after discovery (in colour) and EVN at day 113 (contours). (d) VLA image after 615 days (in colour) with contours from the day 16 image which shows how the nova ejecta has expanded and how the major axis of the radio emission flips from E–W (horizontal in image c) to N–S. Scale bars assume a distance of 1.5 kpc and the white cross is the presumed location of the central binary system.

Published in: **Chomiuk, L. et al. 2014: Nature 514, 339**

VLBI proper motion and parallax of the γ–ray millisecond pulsar PSR J0218+4232

PSR J0218+4232 is a millisecond pulsar (MSP) with a flux density of 0.9 mJy at 1.4 GHz. It is very bright in the high–energy X–ray and γ–ray domains. An astrometric program using the EVN at 1.6 GHz (project code: **EY015**) has been conducted to measure its proper motion and parallax. A model–independent distance would help constrain the pulsar's γ–ray luminosity. Detections of the MSP were achieved with signal–to–noise ratios of at least 37 in all 5 epochs. The EVN–derived proper motion value has significantly improved upon those arising from long–term pulsar–timing observations. The EVN parallax determination was 0.16 +/- 0.09 mas. This was the first trigonometric parallax measurement based soley on EVN observations for any pulsar. This parallax also provided the first model–independent distance estimate for this pulsar, with a corresponding 3–sigma lower–limit of d = 2.3 kpc. The derived distance suggests that PSR J0218+4332 may be among the most energetic γ–ray MSPs known to date. The high observed luminosity could pose challenges to the conventional outer–gap and slot–gap models.

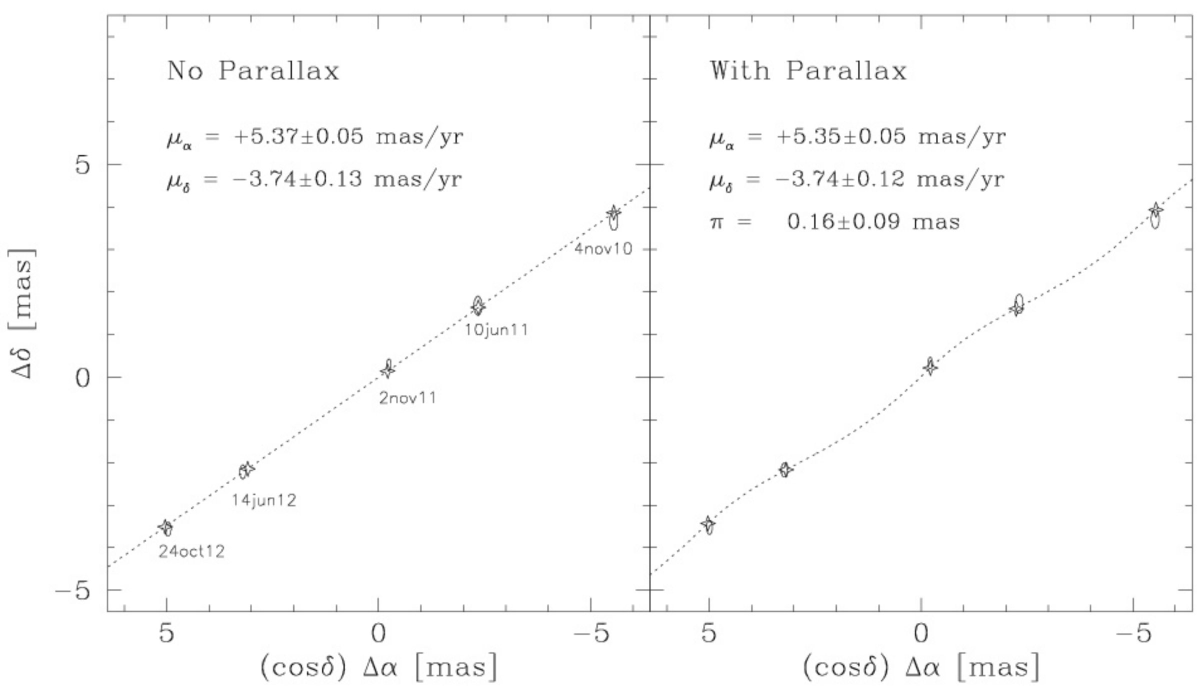


Figure 49: Astrometric fit to the motion of the milli–second pulsar J0218+4232 as observed by the EVN. The ellipses show the positional uncertainty at each epoch, the dotted line represents the modeled motion on the sky, and the star symbols mark the modeled position at each epoch. The **left** panel includes only proper motion in the model, while the **right** panel also includes parallax.

Published in: **Du, Y. et al. 2014: ApJ 782, L38**

Precision astrometry of pulsars and other compact radio sources in M15

M15 is a massive globular cluster that is known to contain some pulsars and a radio–loud low–mass X–ray binary. Multi–epoch astrometric EVN observations have been conducted (project code: **GV020**) to trace the kinematics and variability of compact radio sources in M15. Proper motions of two pulsars, including the double neutron star system M15C, and the LMXB were determined. Two previously unknown compact sources were detected, whose kinematics point to their not being in M15. Brightness variability was seen in M15C (disappearing in epochs 5–6 and re–appearing in epoch 7, accompanied by a slight offset in the pulse phase), which may be a consequence of geodetic precession, as the spin axis of the "visible" neutron star shifts due to coupling with its partner, initially moving the beamed emission out of our line of sight and later returning a different component of the emission cone back into it. The LMXB brightened by a factor of about 2.5 in the third epoch and showed a double–lobe structure with a separation on the order of 140 AU, suggesting that it underwent an outburst during the three months between epochs 2-3 (and recovered before epoch 4) . Finally, the lack of central faint emission after stacking all epochs (rms about 3.3 μJy/beam), together with the "fundamental plane" of black hole activity relating radio and X–ray luminosity to mass, places an upper limit to the mass of a putative intermediate–mass black hole in the center of M15 of $< 500\,M_{\odot}$.

Published in: **Kirsten, F. et al. 2014: A&A 565, A43**

The annual parallax of cataclysmic binary system AM Herculis using e–VLBI

AM Her is the prototype, and first discovered member, of the class of *polars*. These are a type of cataclysmic variable where the white dwarf magnetic field is strong enough to direct the flow of accretion onto its magnetic pole(s). In order to make a new, more precise distance estimate for AM Her, a new astrometric survey using EVN e–VLBI at 5 GHz was conducted. Multi–epoch phase–referencing observations (project code: **EG069**) started in December 2012 and were performed during a 12-month period. AM Her was detected at all epochs of observation. With the addition of two archival VLA observations, a new parallax estimate ($\pi = 11.30 \pm 0.35$ mas, d = 88.5 ± 2.8 pc) was made (Fig. 50).

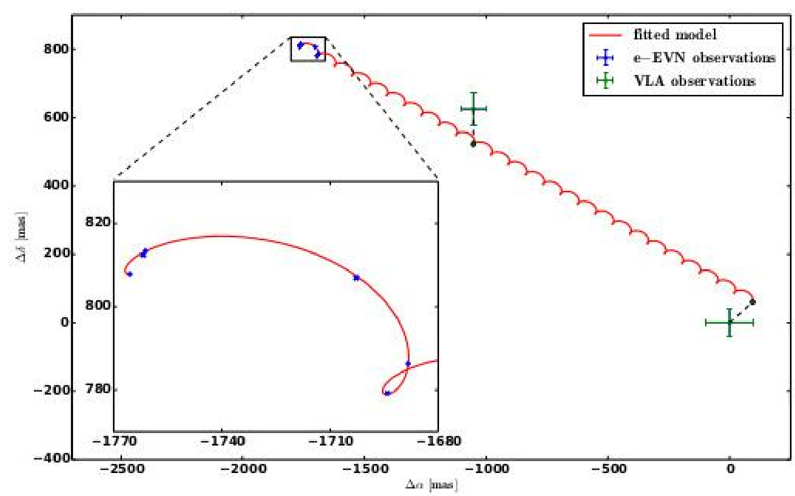


Figure 50: A comparison of the EG069 astrometric measurements with the model of the annual parallax and proper motion. The figure shows position offsets of AM Her relative to the first epoch observations.

Published in: **Rycyk, G. et al. 2014: PoS (EVN 2014) 106**

Pulsar scattering in space and time

Scattering by plasma density fluctuations in the interstellar medium has two effects that can be studied with radio–astronomical observations. (i) Strong scattering produces many sub–images (or speckles) by effectively deflecting the radiation along different paths in the "scattering screen". These images cannot be resolved with standard techniques but appear as angular scatter–broadening and can be quantified with VLBI. (ii) The different paths correspond to different travel times, so that signals will also be spread in time, which can be detected in the case of pulsars as (temporal) pulse broadening. The ratio of the strength of both effects depends on distances and can thus be used to determine the location of the scattering screen, provided that the assumption of having only one thin screen is valid.

A new approach applied in a recent global VLBI experiment compares the two effects not only after integrating over all sub–images, but tries to measure the scattering delay as a function of the deflection angle (or *vice versa*). For a given delay (seen as part of the scattered pulse profile) a narrow ring should be seen, whose size grows with the square root of the delay. In this way it can be tested if the thin–screen scenario, on which this expectation is based, is valid, or if more complicated geometries have to be considered.

In project **GW022** a number of pulsars were observed with five EVN stations, the VLBA and Arecibo. A number of correlation passes with DiFX were necessary to first produce a data set integrated over the pulse profile (weighted to maximise SNR) as basis for the phase calibration. The same calibration was then applied to binned correlations, i.e. many data sets for a number of bins within the pulse profile, corresponding to a range of scattering delays.

Early results for one pulsar (see Fig.51) show that the observed scattered pulse profile does indeed depend on the baseline length. Short baselines (large scales) show the widest profiles, which include the longest delays. On longer baselines the profile becomes narrower because only the inner parts of the scattering disk with the smallest deflection angles (and smaller delays) can be seen. It is even found that on longer baselines the profile (as a visibility) becomes negative for certain delay ranges, which is expected for ring–like structures that grow with delay. A more continuous distribution of scattering material between the pulsar and the observer would instead produce growing circular Gaussian structures without negative visibilities. Such models can be ruled out already, but more detailed conclusions have to wait for further analysis.

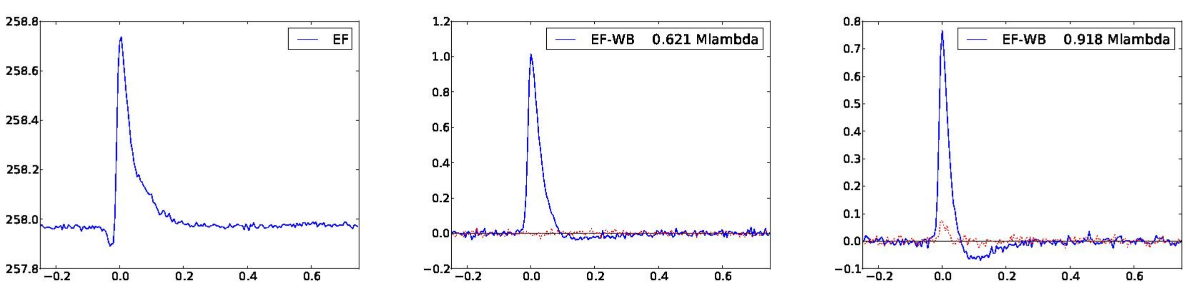


Figure 51: Pulse profiles of B1815-14 observed at 1.4 GHz (**left**) in autocorrelation (Effelsberg) and (**centre** and **right**) on 2 baselines with resolutions 0.621 kλ and 0.918 kλ, for one scan of about 15 min. The real part is shown in solid blue, the imaginary part in dotted red. The negative pre–pulse dip in the left plot results from digitisation non–linearities and dispersion.

Published in: **Wucknitz, 0. 2013: PoS (11th EVN Symposium) 049**

The NGC 3341 minor merger: a panchromatic view of the AGN in a dwarf companion

NGC 3341 is a nearby ($z = 0.027$) disturbed system consisting of a minor merger between a giant disc galaxy ($M_B = 20.3$ mag) and two low–mass dwarf companions within the galaxy disc. While spectroscopic data confirmed the physical association between the three objects, an investigation on the presence of supermassive black holes and of associated nuclear activity was missing. In combination with SDSS, Chandra and EVLA data, EVN e–VLBI observations at 1.6 and 5 GHz (project code: **RSP008**) were made to explore the nature of the components of NGC 3341 (see Figure 52). The high angular resolution provided by the EVN resolves out the radio emission seen with the VLA, favouring a multi–wavelength scenario in which the nucleus is a star–forming region.

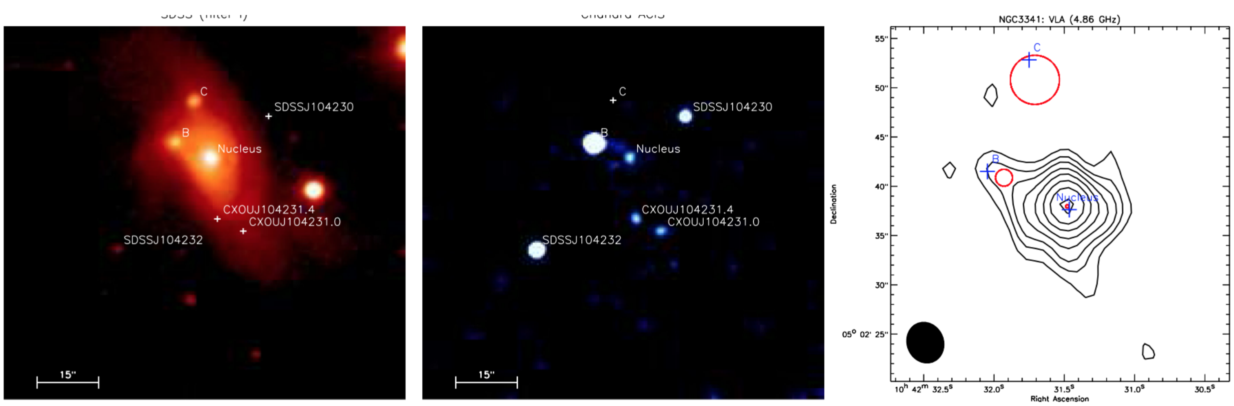


Figure 52: NGC3341 images: **Left:** optical (SDSS i filter); **Center:** X–rays (Chandra, 0.2–8 kev); **Right:** radio (EVLA, 5 GHz). The EVN data resolve out the radio emission down to a level of 21 μJy beam^{-1} at 5 GHz.

Published in: **Bianchi, S. et al. 2013: MNRAS 435, 2335**

Constraints on the progenitor system and the environs of SN2014J from deep radio observations

Deep EVN e–VLBI (project codes: **RP023, EP092**) and e–MERLIN observations have been made of the Type Ia SN 2014J in the nearby galaxy M82. These observations, along with JVLA observations of SN 2011fe, are among the most sensitive radio studies of Type Ia supernovae. By combining data and a proper modeling of the radio emission, the mass–loss rate from the progenitor system of SN 2014J has been constrained to $< 7.0 \times 10^{-10}\, M_\odot$ per year. Assuming that the medium around the supernova is uniform, then the density of the ISM is less than $1.3\,\mathrm{cm}^{-3}$, which is the most stringent limit for the (uniform) density around a Type Ia supernova. These deep upper limits favour a double–degenerate (DD) scenario involving two white dwarf (WD) stars for the progenitor system of SN 2014J, as such systems have less circumstellar gas than these upper limits. By contrast, most single–degenerate (SD) scenarios, i.e., the wide family of progenitor systems where a red giant, main–sequence, or sub-giant star donates mass to an exploding WD, were ruled out by the observations. Although a SD scenario might pass observational tests, and there are uncertainties in the modeling of the radio emission, the evidence from SNe 2011fe and 2014J points in the direction of a DD scenario for both.

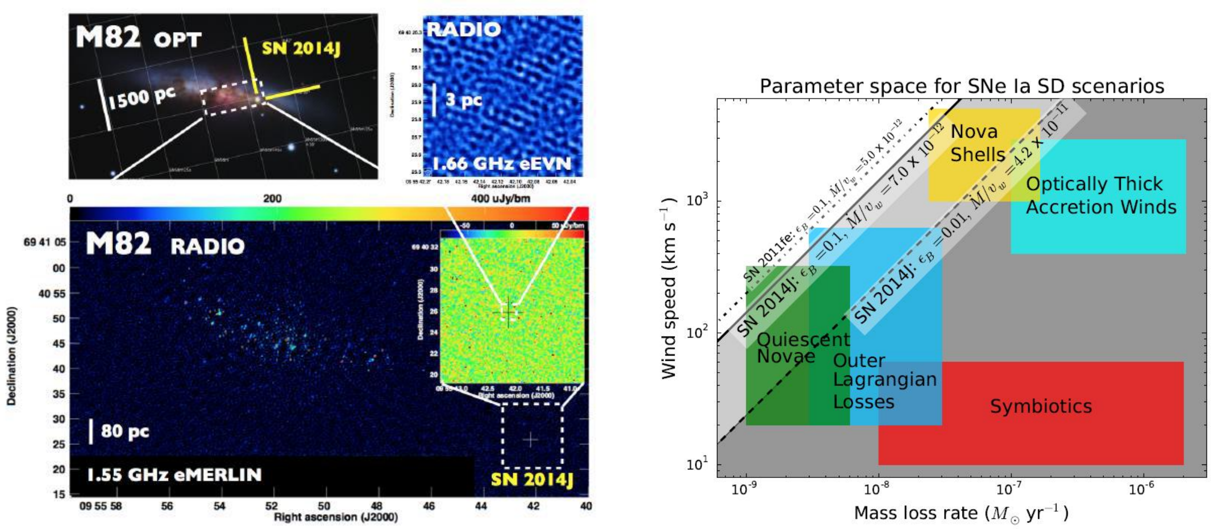


Figure 53: **Left:** EVN e–VLBI and e-Merlin images of the region surrounding SN 2014J, and an optical image of the host galaxy M82. **Right:** Constraints on the parameter space (wind speed vs. mass–loss rate) for single degenerate scenarios in the case of SN 2014J. Mass–loss scenarios falling into the grey shaded areas should have been detected by the deep radio observations, and therefore are ruled out for SN 2014J. A reassessed limit for SN 2011fe (dash–dotted line) for the same choice of parameters as the solid line for SN 2014J is also shown for comparison. These constraints leave room only for quiescent nova emission as a viable alternative among the SD scenarios for SN 2011fe.

Published in: **Pérez-Torres, M. et al. 2014: ApJ 792, 38**

Black hole lightning due to particle acceleration at sub–horizon scales

IC 310 is a peculiar radio galaxy located in the outskirts of the Perseus cluster at $z = 0.189$. In November 2012 MAGIC (Major Atmospheric Gamma–ray Imaging Cherenkov) revealed an outburst of very high energy (VHE) γ–rays from this object, characterized by unprecedented brightness and rapidity. Near–simultaneous EVN data (project code: **EE009**, Fig. 54) greatly help to constrain the allowed ranges of orientation and velocity parameters. With these constraints the γ–ray emission region size and the possible particle acceleration mechanisms have been determined. This could be pulsar–like, with acceleration by the electric field across a magnetospheric gap at the base of the radio jet. These results are unprecedented in the field of particle acceleration in relativistic jets, and they have been the subject of several press releases throughout Europe.

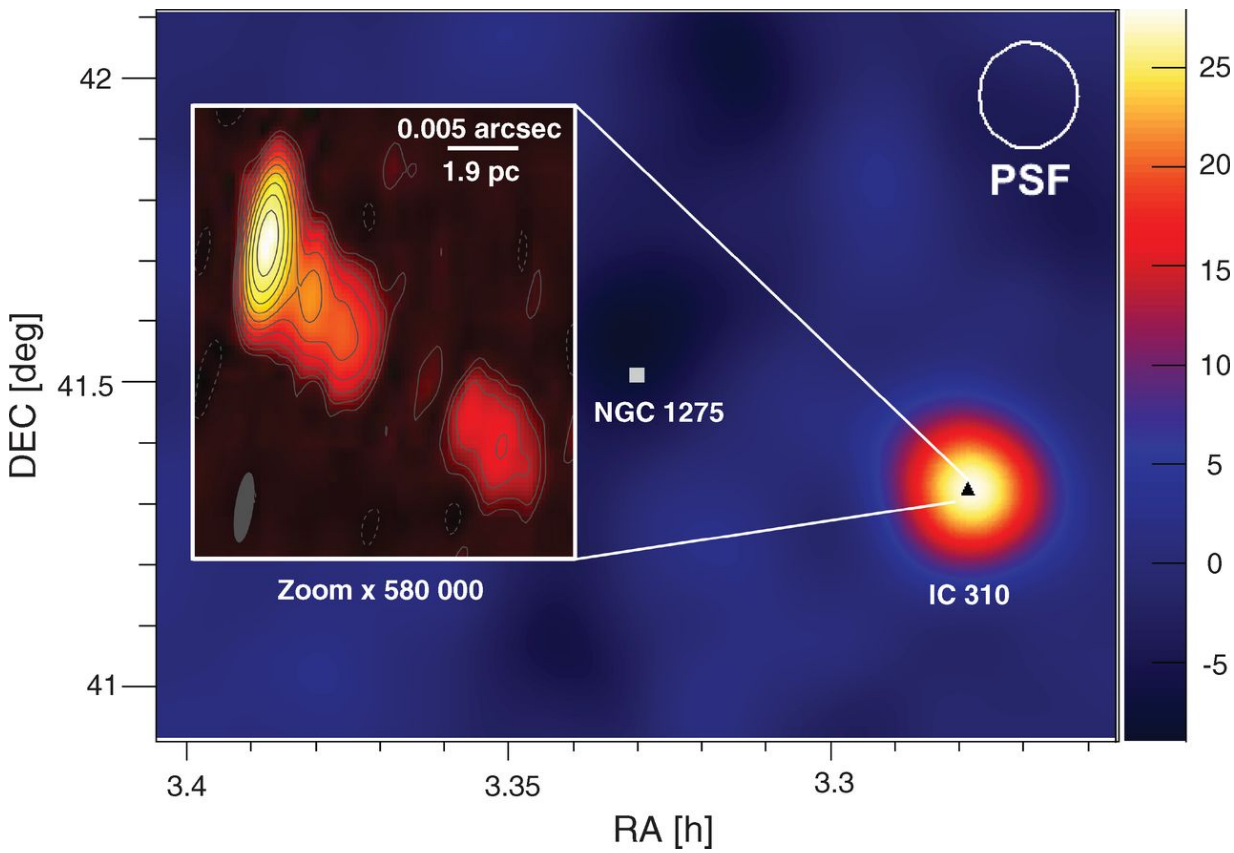


Figure 54: **Background image:** significance map of the Perseus cluster in γ–rays observed on the night of 12/13 November 2012 with the MAGIC telescopes. **Inset:** EVN radio jet image of IC 310 at 5.0 GHz obtained on 29 October 2012. Contour lines (and the colour scale associated with them) increase logarithmically by factors of 2, starting at 3 times the noise level.

Published in: **Aleksic, J. et al. 2014: Science 346, 1080**

Things that go bump in the night: the curious case of NGC 660

An analysis has been made of observations of the LINER galaxy NGC 660. NGC 660 was found to have increased in radio flux over the period 2008–2013. Observations with the EVN (project codes: **EA054, EA055**) and with e–MERLIN were made to investigate the source at the smallest possible scales. A core–jet structure is detected in the nucleus, providing evidence for (re–)started nuclear activity. From an in–depth analysis of archival observations at a range of frequencies and resolutions it is confirmed that this is a new radio source, with an age of at most a decade. Further EVN observations have been obtained in October 2014, and follow–up with e–MERLIN is ongoing. Chandra data has also been analysed but this did not have enough counts to confirm the AGN nature of the source. WHT service time optical spectroscopy was obtained in late November 2014 and is being analyzed.

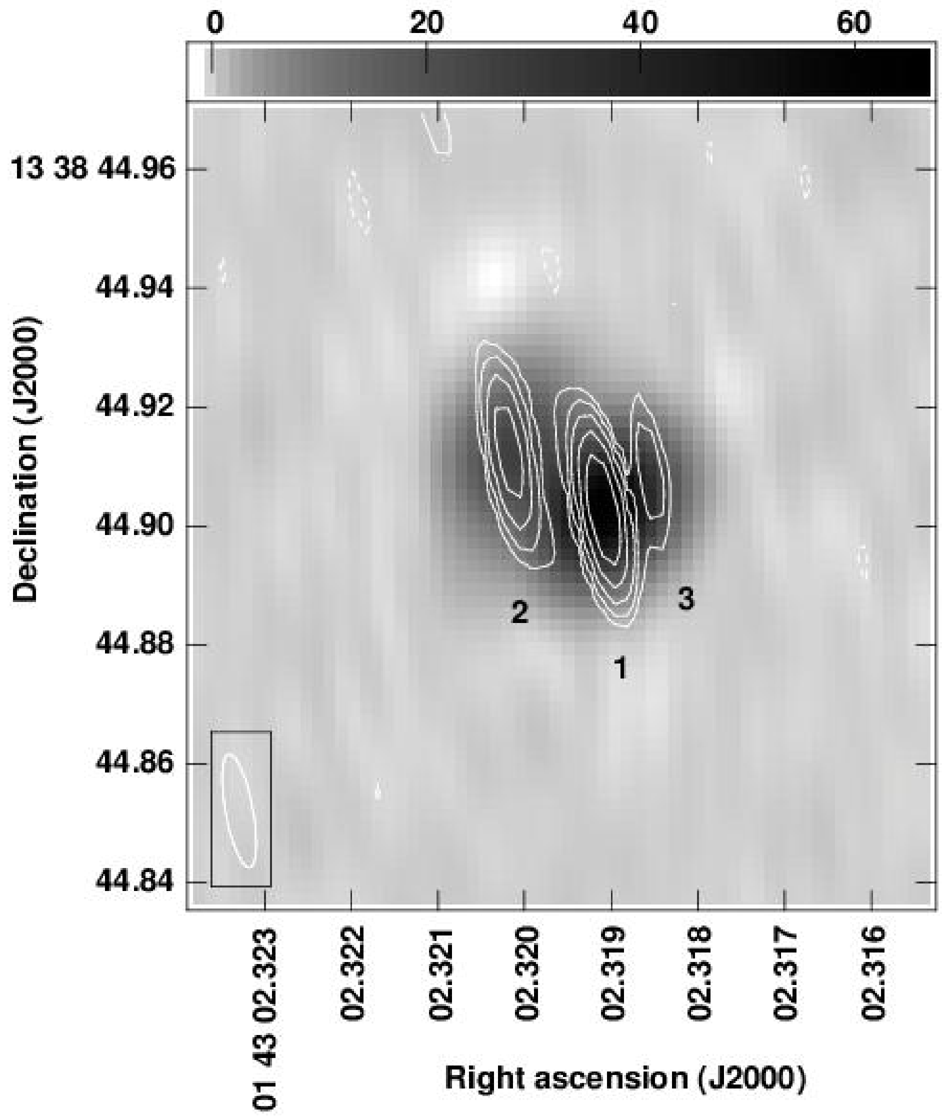


Figure 55: EVN image of the central region of NGC 660, showing recent nuclear activity.

Published in: **Argo, K. et al. 2014: PoS (12th EVN Symposium) 06**

EVN searches for intermediate–mass black holes in ultraluminous X–ray sources

EVN observations of compact radio emission in extragalactic ultraluminous X-ray sources (ULX) have been combined with data from the HST, *Chandra*, and the VLA in order to understand better the nature of these enigmatic objects. Most of the scenarios proposed to explain the ULX assume that they are powered by accretion on to a black hole (BH), with the expected BH masses ranging from 10 to $10^4\,M_\odot$. The upper bound of the BH mass signifies the elusive class of intermediate mass black holes (IMBH) believed to be remnants from the early epochs of BH formation in the Universe. VLBI detections of compact radio emission in the ULX provide accurate locations of these objects within their host galaxies and allow estimates of the ULX BH mass to be made and searching for the IMBH in galaxies.

Dedicated EVN and VLA studies of 12 ULX objects performed at 1.6 and 5 GHz have provided strong evidence for the presence of IMBH in at least 2 of the systems studied (N5457–X9 and N2276–3c). One of these (N4449–X1) is clearly associated with a supernova remnant. Upper limits on compact radio emission have been placed in the remaining 9 ULX.

The EVN observations at 1.6 GHz (project code: **EM095**) of N5457-X9 (Fig. 56) reveal compact radio emission with a flux density of 0.12 mJy and brightness temperature $T_B > 8 \times 10^4$ K, coincident with the *Chandra* X–ray position within 0.6 arcsec. The compact source has a physical size of ∼1 pc, suggesting that there are 2 radio components present in the area around this source: an extended thermal component, as revealed by single–dish and VLA radio observations, and a compact non–thermal component. Combining the radio detection with the *Chandra* and *Swift* measurements yields a BH mass in the range of $10^{5.9} - 10^{6.6}\,M_\odot$.

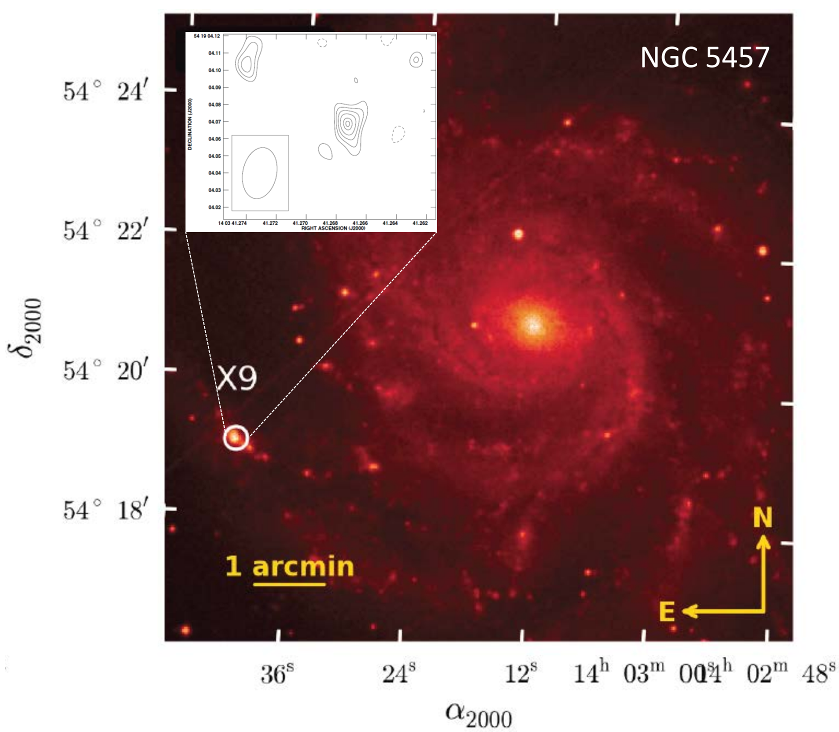


Figure 56: Optical DSS image of the galaxy NGC 5457 and the location of the ULX source N5457–X9 detected with *Chandra* (marked by the *Chandra* error circle for this object). The inset shows a 1.6 GHz EVN image of ULX N5457–X9 made at the *Chandra* position. The contours are (–3, 3, 3.5, 4, 4.5, 5 and 5.2) times the off–source rms noise of 19 μJy beam^{-1}. The restoring beam size is 30 × 20 mas, with the major axis oriented along a position angle of –11°.

Published in: **Mezcua, M. et al. 2013: MNRAS 436, 1546**

1.6 GHz EVN observations of the supernova remnant SNR 4449−1 (project code: **EM072**), made as part of an investigation of radio counterparts of ultraluminous X-ray sources, have revealed the intricate structure of the evolved radio emission in the remnant (Fig. 57). The observations confirmed earlier identifications of this object with a supernova remnant (SNR). The 1.6 GHz image yields accurate estimates of the size (0.0422×0.0285 arcsec or 0.8×0.5 pc) and age (∼55 yr) of SNR 4449−1. With a total flux of 6.1 ± 0.6 mJy measured in the EVN image, the historical lightcurve of the source can be well represented by a power–law decay with a power index of -1.19 ± 0.07. The SNR exhibits a decline rate of the radio emission of $2.2 \pm 0.1\%\,\mathrm{yr}^{-1}$ and a radio luminosity of $1.74 \times 10^{35}\,\mathrm{erg\,s}^{-1}$.

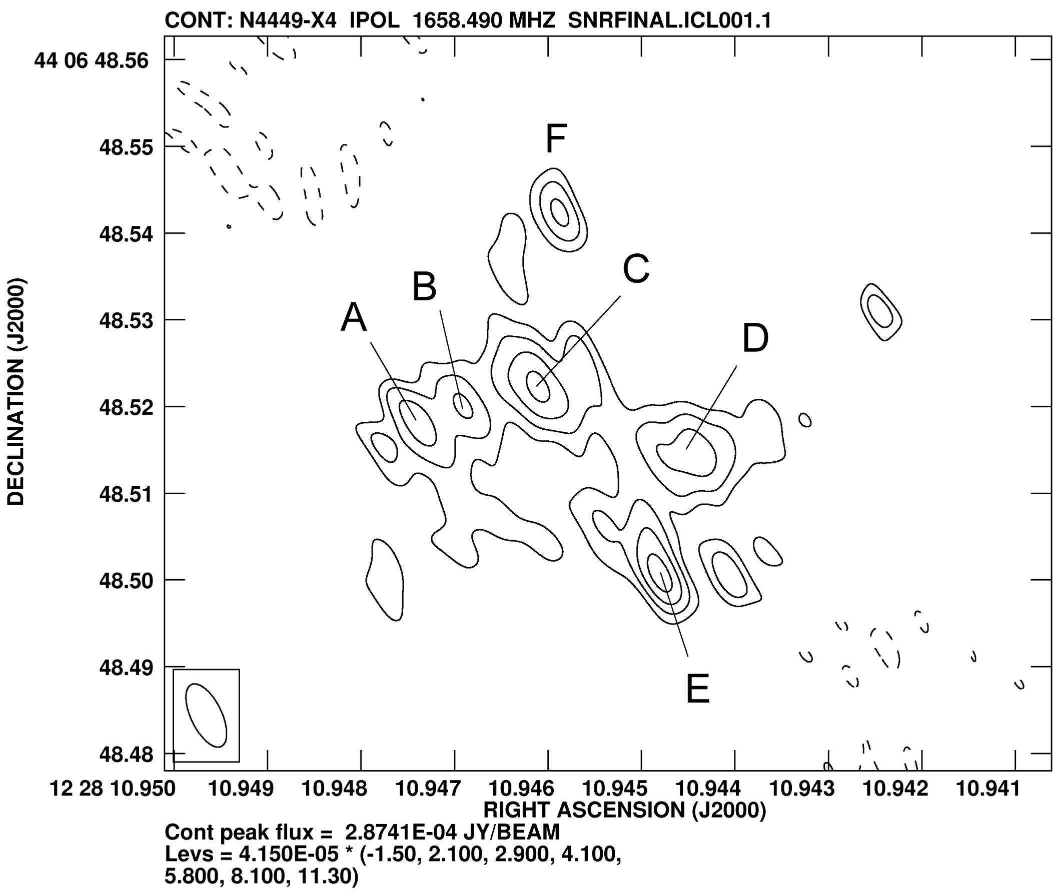


Figure 57: Resolved radio structure of the SNR in NGC 4449 using the EVN at 1.6 GHz. The rms noise off–source is $42\,\mu\mathrm{Jy\,beam}^{-1}$. Contours start at -1.5 times the rms and increase with factors of $\sqrt{2}$. The six components detected are labeled A, B, C, D, E, and F. The brightness peak of the map corresponds to component E and is $0.287\,\mathrm{mJy\,beam}^{-1}$. The dimensions (full width at half maximum) of the restoring beam are 7.9×3.5 mas, with the major axis of the beam oriented along a position angle of 25.8°. North is up and East is to the left.

Published in: **Mezcua, M. et al. 2013: MNRAS 436, 2454**

Radio jets clearing the way through a galaxy: watching feedback in action

An analysis of global HI spectral–line VLBI data on 4C12.50 (project code: **GM062**) has been made. The goal was to study the spatial distribution of the outflowing natural gas in this young AGN, which is one of the best known ultra–luminous infrared galaxy (ULIRG). The neutral gas has a strong feedback on the ISM, and this feedback plays a key role in galaxy evolution. A previously known HI absorption feature in the direction of the northern counter–jet was detected, as well as a broad (∼1000 km/s in velocity) HI component that was not seen at 10 mas resolutions before; the latter coincided with the termination point of the southern, approaching jet. A significant part of the absorption comes from a compact cloud that is seen in projection to be co–spatial with the hot–spot observed earlier in radio continuum. There is also a faint and diffuse component that extends at least 50 pc around and in front of the southern lobe. These observations showed that the radio plasma drives the outflow and removes gas from the central regions in 4C12.50, and that jet–driven outflows can play a relevant role in feedback mechanisms in radio-loud AGN.

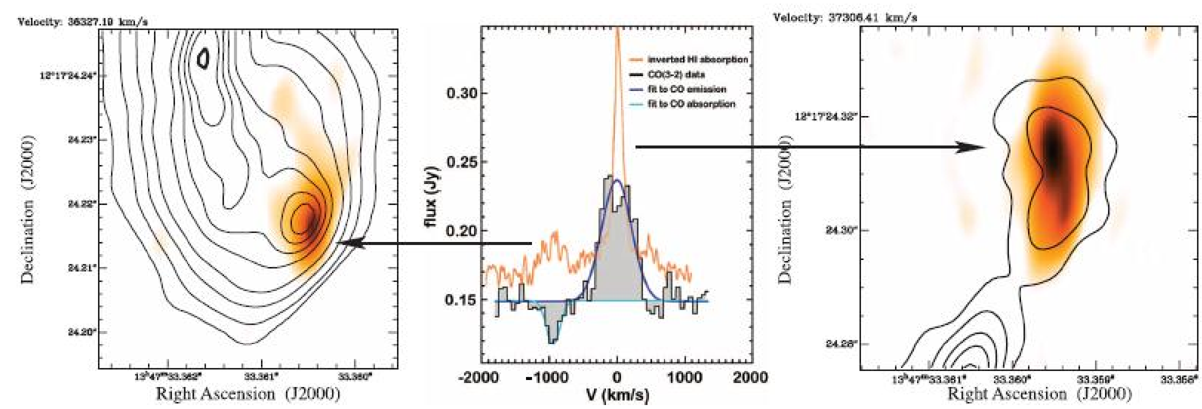


Figure 58: Total intensity (contours) and HI absorption (colours) in the approaching southern jet–lobe (**left**) and on the counter–jet side (**right**) of 4C12.50. The inset in the middle shows the HI (orange) and CO (from mm observations by another group, in grey) absorption profiles.

Published in: **Morganti, R. et al. 2013: Science 341, 1082**

As the sensitivity of radio telescopes has improved, it has become increasingly clear that many radio quiet (RQ) AGNs are not radio silent at all. However, the origin of radio emission in RQ AGNs still remains unclear and it could be ascribed to a low–power jet, to free–free emission from a molecular torus, a disc wind or the X–ray corona itself. Building on previous work the first systematic study at VLBI spatial resolutions of a complete sample of RQ local Seyfert galaxies has been made, with the purpose of characterizing statistically the physical properties of the sub–pc cores and the incidence of associated jet/outflow structures. In this work, sensitive EVN observations (project codes: **EG037, EG040**) have provided a fundamental resource to establish a detection rate of sub–pc scale cores as high as $\sim 75\%$, with varied morphology and interesting distributions of brightness temperatures, spectral indexes, radio–to–X–ray flux ratios and radio–to–BH mass (Fig. 59). While more observations will certainly be useful to clarify the details of the overall picture, the current results already point to a significant presence of jets and outflowing features, and to a possible dichotomy between type 1 and type 2 AGNs in terms of emission mechanisms, with free–free absorption more important in the latter.

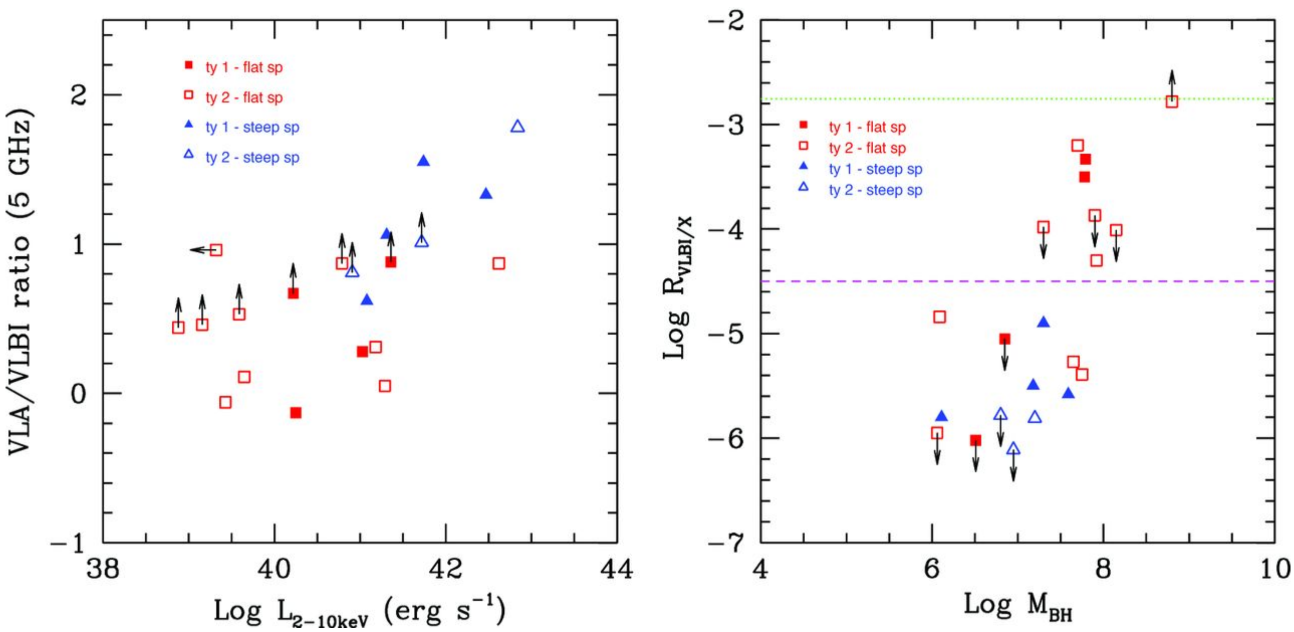


Figure 59: **Left:** VLA to VLBI flux ratio versus 2–10 keV unabsorbed luminosity. **Right:** R_X versus BH mass. The magenta dashed line represents the $R_X = -4.5$ division between RL and RQ AGN and the green dotted line represents $R_X = -2.755$, derived previously for LLAGN.

Published in: **Panessa, F., & Giroletti, M. 2013: MNRAS 432, 1138**

The radio core of the luminous infrared galaxy NGC 4418

An analysis has been made of archival EVN and MERLIN data (program code: **EB019**) of the core of the galaxy NGC 4418, which is one of the most obscured luminous infrared galaxies (LIRGs) in the nearby Universe. This nucleus contains a rich molecular gas environment, has an unusually high ratio of infrared–to–radio luminosity, and is either powered by a compact starburst or an active galactic nucleus (AGN). The VLBI–scale nuclear radio structure of NGC 4418 was found to consist of eight compact (< 49 mas, i.e. < 8 pc) features spread within a region of 250 mas, (41 pc). An inverted spectral index $\alpha \geq 0.7$ ($S_\nu \propto \nu^\alpha$) was fitted to the compact radio emission. The complex morphology and inverted spectrum of the detected compact features is evidence against the hypothesis that an AGN alone is powering the nucleus of NGC 4418. The compact features could be super star clusters with intense star formation, and their associated free–free absorption could then naturally explain both their inverted radio spectrum and the low radio–to–IR ratio of the nucleus. In order to power the radio emission via electrons accelerated in supernovae the required star formation rate per unit area is extreme. This star formation density is close to the observational limit expected for a well–mixed thermal/non–thermal plasma and is also close to the limit of what can be physically sustained dynamically.

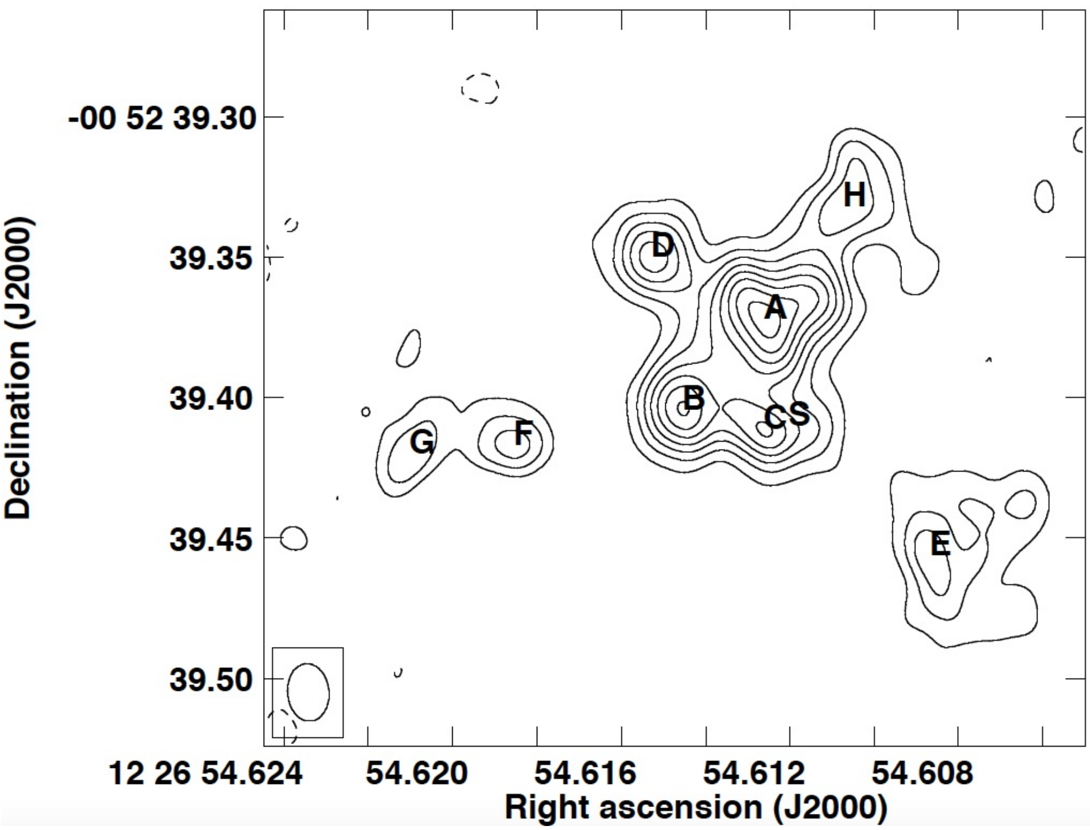


Figure 60: The EVN and MERLIN 5 GHz image of NGC 4418. There are eight compact features labelled from A to H. Label S corresponds to the published 860 μm continuum peak position. The rms noise is 90 μJy/beam and the clean beam is 20.6 x 14.8 mas.

Published in: **Varenius, E. et al. 2014: A&A 566, 15**

M 87 radio brightening

A monitoring project on the radio galaxy M 87 (project codes: **EG063, EH027**) has continued, following the success of previous years. This monitoring is carried out in collaboration with other radio arrays, such as the VLBI Exploration of Radio Astrometry (VERA) in Japan, and high and very–high energy observations by instruments such as the *Fermi* γ–ray satellite and Very High Energy (VHE) imaging atmospheric Cherenkov telescopes. The main aim is the determination of the site of high energy emission in the M 87 jet which, thanks to its proximity, is an ideal laboratory to study relativistic jets in AGNs in general. An enhancement of the VHE flux took place in 2012 and the VERA and EVN data indicate that during this episode the most likely location for the VHE flare was the radio core, rather than the jet feature HST–1. The monitoring has further continued and new, exciting results are expected in the coming years.

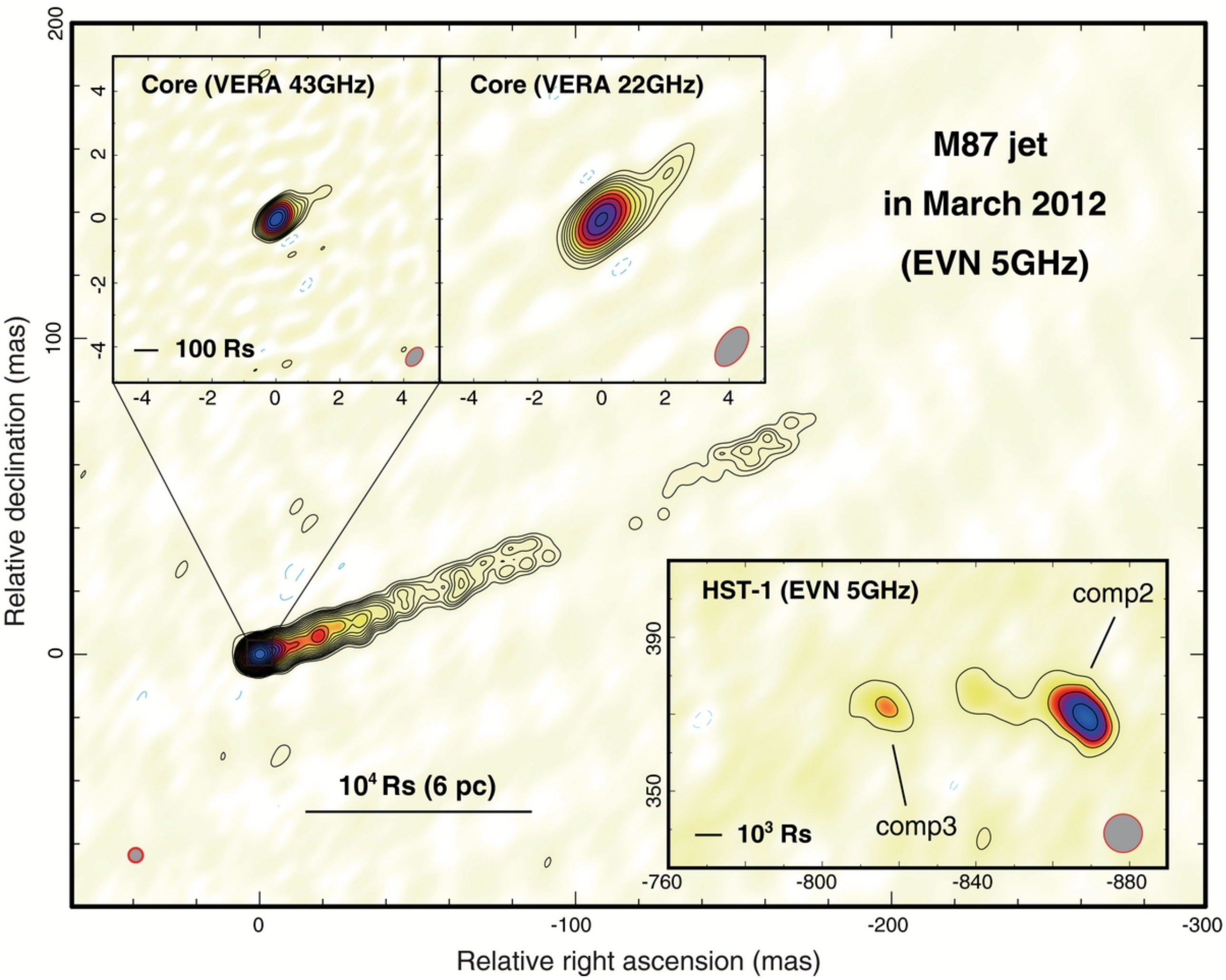


Figure 61: VLBI images of the M 87 jet during the elevated VHE γ–ray state in 2012 March. The main (background) image was obtained with the EVN at 5 GHz. The bottom right inset indicates a close–up view toward the HST–1 region. The upper–left two insets show VERA images for the core at 22 and 43 GHz. For the EVN images, circular Gaussian beams of 4.5 and 10 mas are used for the main structure, and the HST–1 close up, respectively.

Published in: **Hada, K. et al. 2014: ApJ 788, 165**

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The radio source TXS 0536+145 is associated with a flat spectrum radio quasar at redshift 2.69. On 2012 March 22 it was observed during a γ–ray flare by the Large Area Telescope on board the *Fermi* satellite. The flaring episode triggered a multi–wavelength campaign, from radio to X–rays, aimed at confirming the association of the γ–ray source with the low–energy counterpart. The observed multiband variability allowed a secure identification of the γ–ray source with the high–z blazar TXS 0536+145 to be made, which becomes the γ–ray flaring blazar at the highest redshift observed so far, with an apparent isotropic peak luminosity of $6.6\times10^{49}\,\mathrm{erg\,s^{-1}}$.

EVN high angular resolution observations at 22 GHz (project code **RO004**) were able to resolve the initial part of the jet at 0.5 mas from the core (Fig. 62). The radio light curve obtained on the basis of multi–epoch observations shows an increase of the flux density about 4 months after the γ–ray flare, suggesting the presence of opacity effects. The flux and spectral variability is observed only in the core region, while no significant variability is present in the jet component. The core spectrum turned out to be inverted when the flux density reached the maximum in the radio band. Similarly, in γ–rays a harder–when–brighter behaviour was observed. Despite the harder spectrum, no significant emission above 10 GeV is observed. At the redshift of TXS 0536+145 the flux attenuation due to the Extragalactic Background Light (EBL) should be observable below 10 GeV, leading to a curvature of the spectrum. However, due to the poor statistics it is not possible to test if the observed curvature is related to the EBL attenuation, to the Klein–Nishina effect, or if it is intrinsic to the spectrum of the source.

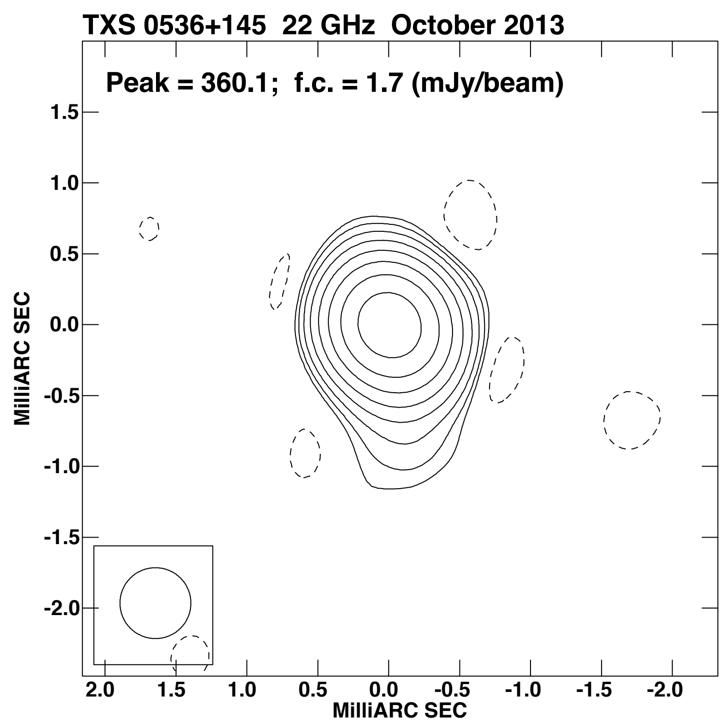


Figure 62: EVN image of TXS 0536+145 at 22 GHz. The image is restored with a circular Gaussian of FWHM = 0.5 mas, plotted in the bottom–left corner. The peak flux density is 360.1 mJy beam^{-1} and the first contour level 1.7 mJy beam^{-1}, which corresponds to 3 times the off–source noise level. Contour levels increase by factors of 2.

Published in: **Orienti, M. et al. 2014: MNRAS 444, 3040**

The parsec–scale structure of GPS radio sources

GHz–peaked spectrum (GPS) radio sources are thought to represent an early stage in the individual radio source evolution. In these objects the radio emission is totally confined within the innermost region of the host galaxy where jet–cloud interaction may take place as suggested by the high fraction of asymmetric GPS sources. The high resolution of Global VLBI (project code: **GD001**) allowed the morphology of 10 sources from a GPS sample to be determined. The combination of these data and earlier 1.7 GHz observations allows the spectral index distribution across the source structure to be studied, and an unambiguous determination of the nature of each component to be made. In 7 sources core components with a flat or inverted spectrum were detected. In six sources the radio emission has a two–sided morphology and comes mainly from steep–spectrum extended structures, like lobes, jets and hotspots. In three out of the six sources with a two–sided structure the flux density arising from the lobes is asymmetric, and the brightest lobe is the one closest to the core, suggesting that the jets are expanding in an inhomogeneous ambient medium which may influence the source growth (see Fig. 63). The interaction between the jet and the environment may slow down the source expansion and enhance the luminosity due to severe radiative losses, likely producing an excess of CSS radio sources in flux density limited samples.

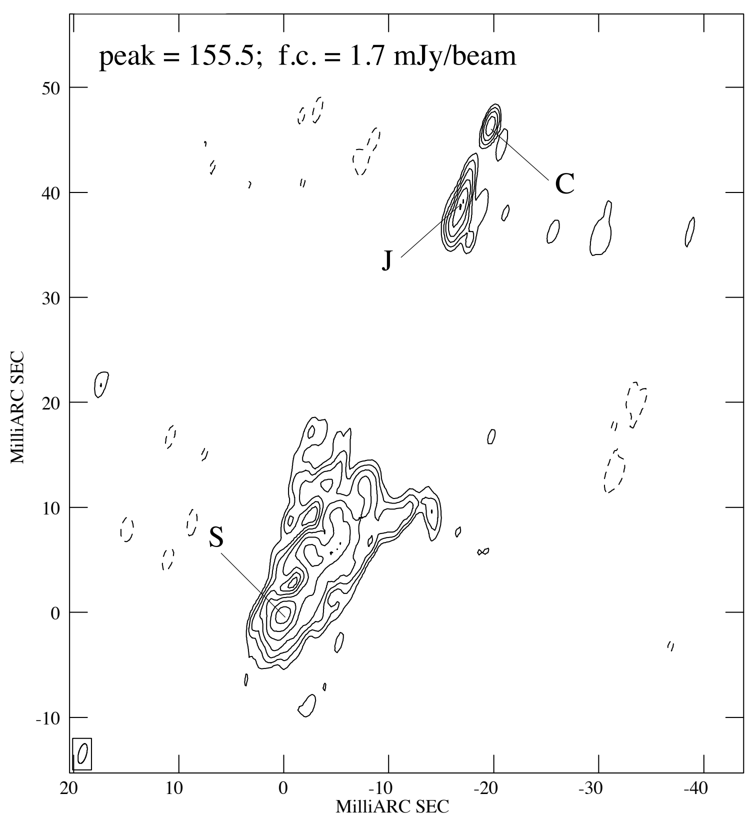


Figure 63: 0428+205: global VLBI image at 5 GHz. The restoring beam is 1.9 mas×0.75 mas in p.a.-15°, and is plotted in the bottom left corner; the peak flux density is 155.5 mJy beam^{-1}. The first contour level is 1.7 mJy beam^{-1}, which is three times the off–source noise level; contour levels increase by factors of 2. From the spectral analysis, it is suggested that the core, C, is the northern component, which accounts for 29 mJy (i.e. 1.2% of the total VLA flux density), while the elongated component J is likely the main jet. The southern lobe, S, is dominated by a compact component, likely the hotspot, located about 50 mas ($\sim$175 pc) from the core.

Published in: **Dallacasa, D. et al. 2013: MNRAS 433, 147**

EVN observations of BAL quasars

Broad absorption line quasars (BAL QSOs) are objects presenting hints of fast outflows in their UV/optical spectrum, manifested as broad absorption features in the blue–wing of emission lines such as C IV and Mg II. They constitute ~15% of the QSO population, and can be even more rare among radio–loud (RL) QSOs. Two main scenarios have been proposed to explain the BAL phenomenon, one considering orientation as a key factor to account for the observed BAL QSO fraction and another proposing a youth scenario in which the QSO is still expelling a shell of dust, which would be responsible for the absorption features.

Radio emission can be used to test these two scenarios, permitting an estimate to be made of the orientation of the jet, and the age of the radio phase. An observational campaign has been made on a sample of 25 RL BAL QSOs and 31 comparison RL non–BAL QSOs. The 11 brightest objects were also proposed for VLBI observations, in order to map the pc–scale structure and interpret the morphology. Among these the 4 faintest were observed with the EVN at 5 GHz to take advantage of its great sensitivity. The telescopes at Darnhall and Knockin from the MERLIN array were also included. A total bandwidth of 32 MHz was used and an average on–source time of about 2 hours was obtained. The resulting typical angular resolution was 5 mas.

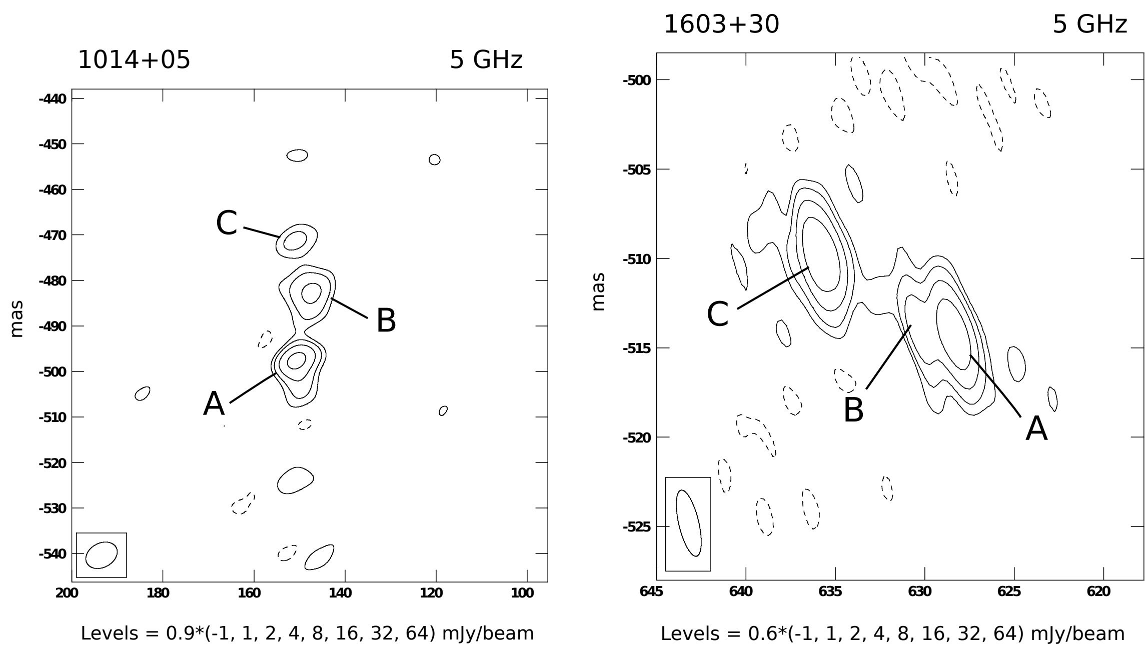


Figure 64: Two of the BAL QSOs resolved with the EVN. Levels are 3σ multiples, according to the legend.

Three of the 4 objects observed with the EVN showed a resolved structure (see Fig. 64 for 2 examples), one as a core–jet, and the others more complex ones. Different orientation must be considered to account for the different morphologies observed and the fact that some were not resolved suggests that a young radio age is present in some cases. Some sources showed a considerable drop of flux density with respect to arcsecond scale measurements. This could suggest different radio phases, with possible restarting scenarios. Also, linear sizes span from a few pc to several kpc, again not suggesting a particularly young, compact radio phase. As found by other authors, a mixed scenario is necessary to explain the BAL QSOs class of objects, observational evidence not preferring one of those proposed.

Published in: **Bruni, G. et al. 2013: A&A 554, A94**

Twin supermassive black hole candidates in the brightest cluster galaxy of RBS 797

The radio–loud brightest cluster galaxy (BCG) at the center of the cool core cluster RBS 797 is known to exhibit a misalignment of its 5 GHz radio emission observed at different VLA resolutions, with the innermost kpc–scale jets being almost orthogonal to the radio lobes which extend for tens of kpc filling the X–ray cavities seen by Chandra (Figure 65, left). The different radio directions may be caused by rapid jet reorientation due to interaction with a secondary supermassive black hole (SMBH), or to the presence of two AGN, probably in a merging phase, which are emitting radio jets in different directions (Figure 65, centre).

Since no information on the pc–scale radio properties is available in the literature, an explorative program was performed to assess the detectability of the BCG in RBS 797 at VLBI resolution and to study its nuclear region. A test observation was made on 3 May, 2013 (project code **RSG05**) in a 6 cm e–VLBI run with a subset of the EVN. The total time spent on the target was about 1 hour. As is evident from the 5 GHz EVN map (Figure 65, right), two compact components were clearly detected. The results from a visibility model–fit with two Gaussian components indicate that both components are compact and smaller than the observing beam. There are two possible scenarios for the origin and nature of the EVN double source, and both interpretations are consistent with the presence of a SMBH binary system.

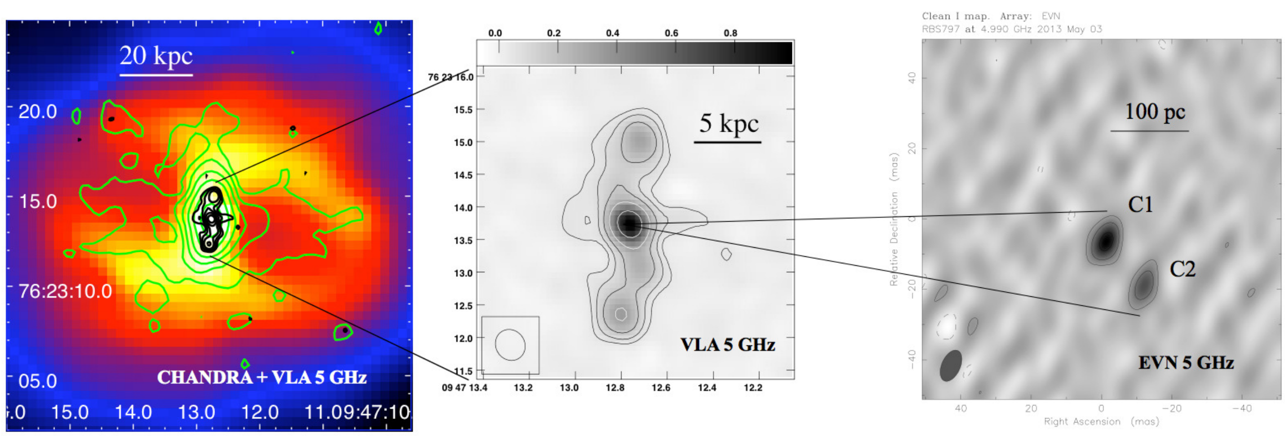
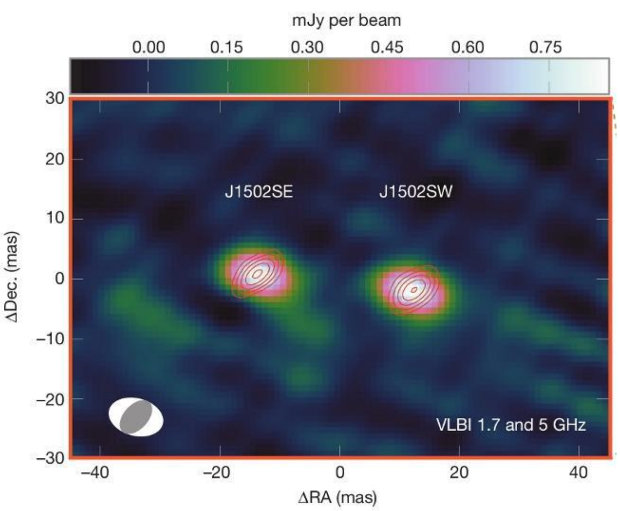


Figure 65: **Left**: The 5 GHz VLA contours of RBS 797, imaged at different resolutions, are overlaid onto the Chandra image of the central region of the cluster. Green contours: 5 GHz VLA map at 1.4×1.3 arcsec resolution; the rms noise is 0.01 mJy beam^{-1} and the contour levels start at 3σ, increasing by factors of 2. Black contours: see caption centre panel. **Centre**: 5 GHz VLA map at 0.5×0.4 arcsecond resolution (the beam is shown in the lower–left corner). The rms noise is 0.01 mJy beam^{-1} and the contour levels start at 0.04 mJy beam^{-1}, increasing by factors of 2. **Right**: 5 GHz EVN map of the BCG in RBS 797 at a resolution of 9.4 × 5.3 mas^2 in P.A. 24° (the beam is shown to the lower–left). The rms noise is 36 μJy beam^{-1} and the peak flux density is 0.53 mJy beam^{-1}. The contours levels start at 3σ and increase by factors of 2.

Published in: **Gitti, M. et al, 2013: A&A, 557, L14**

A close–pair binary in a distant triple supermassive black hole system

Finding binary, and even multiple supermassive black holes is of great importance because these systems have played an important role in forming galaxies in the early Universe, and they are a potential source of gravitational wave radiation as well. The EVN is particularly well suited for this quest, since its unprecedented angular resolution allows us to resolve the closest pairs of SMBH candidates. The detection of a small–separation compact double source within the system J1502+1115 has now been reported, from observations with the EVN (project codes: **ED035, ED039**). This system was already known to host a wider separation dual–SMBH. The compact structures and the observed flat spectra pointed to the presence of an inner dual active galactic nucleus (AGN) in a rare type of triple–SMBH system (there are only a handful of suspected candidates known), with a separation of only 140 parsec for the inner pair. This finding needs to be confirmed by further observations, because another group claimed that the VLBI structure might instead indicate a peculiar Compact Symmetric Object (CSO), a pair of compact radio lobes from a single, young active galactic nucleus. In any case, J1502+1115 remains a high–profile target for sensitive VLBI observations. The orbital motion of very small separation binary black holes may be imprinted onto their large–scale jets, twisting them into a helical or corkscrew–like shape. So even though black holes may be so close together that our telescopes cannot resolve them, their twisted jets may help locating these systems with future very sensitive instruments like the Square Kilometre Array.



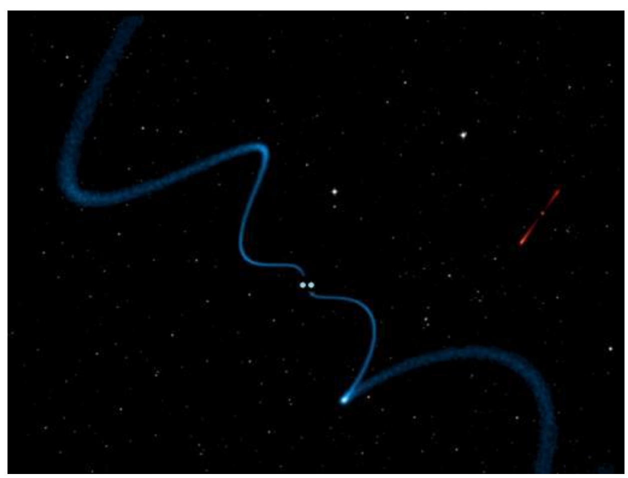


Figure 66: **Left:** EVN 1.7 GHz image (contours) overlaid on the EVN 5 GHz image (colour scale) of the close pair of candidate supermassive black holes in J1502+1115. **Right:** a sketch of spiral jets from a close pair of black holes in a triple SMBH system.

Published in: **Deane, R. et al. 2014: Nature 551, 57**

VLBI observations of J2228+0110 and other field sources in multiple–phase–centre mode

A patch of sky in the SDSS Stripe 82 region has been observed at 1.6 GHz using the EVN (project code: **EG057**). This was one of the early EVN science projects to fully exploit the multi–phase–centre capability of the SFXC software correlator. There are 15 known mJy/sub–mJy radio sources in the target field defined by the primary beam size of a typical 30 m–class EVN radio telescope. The source of particular interest was a recently identified high–redshift radio quasar: J222843.54+011032.2 (J2228+0110) at a redshift of z = 5.95. The aim was to investigate the mas–scale properties of all the VLBI–detectable sources within this primary beam area with a diameter of 20 arcmin. The source J2228+0110 was detected with a brightness temperature $\mathrm{Tb} > 10^8$ K, as expected for a high–redshift radio–loud AGN. In addition, two other target sources were also detected, one of them with no redshift information. Their brightness temperature values ($\mathrm{Tb} > 10^7$ K) suggest a non–thermal synchrotron radiation origin for their radio emission. The detection rate of 20% is broadly consistent with other wide–field VLBI experiments carried out recently. Accurate equatorial coordinates of the three detected sources were also derived using the phase–referencing technique.

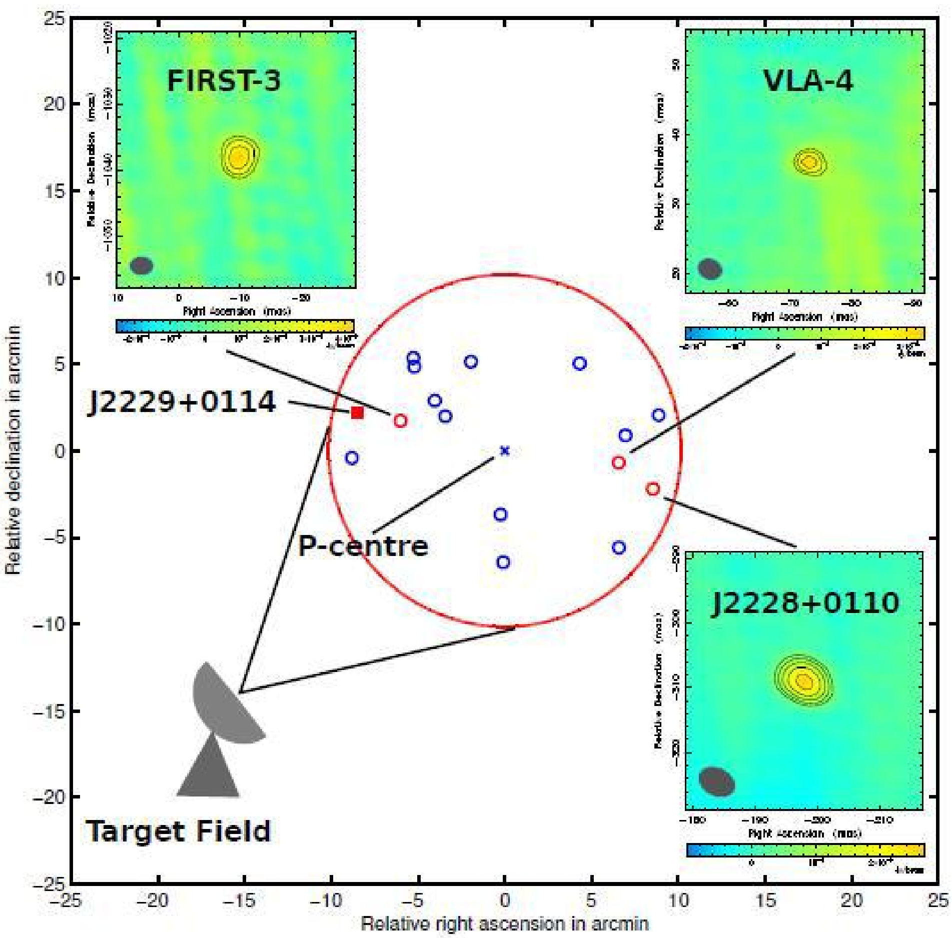


Figure 67: EVN detection of the high–redshift quasar J2228+0110 and another 2 sources with the multi–phase–centre correlation technique. The label "P-centre" marks the pointing centre of the 9 smaller telescopes working in the in–beam mode and the primary phase centre. The source J2229+0114 marked with a filled square served as the in–beam phase calibrator. The large circle is the primary beam size (FWHM) of a 32 m antenna at 1.6 GHz.

Published in: **Cao, H. et al. 2014: A&A 563, 111**

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