A short history of Mopra

A tale of MUM & SIS, their MOPS & MUG, FUDD, VSOP & TOAD

Phil Edwards | Head of Science Operations

10 December 2015

Outline

- First Light and first science
- 3mm SIS
- VLBI and VSOP
- Huygens
- New receivers at 15mm, 3mm, 7mm
- MOPS
- Remote observing
- Disasters
- New operating models

Much of this covered in Urquhart et al 2010, PASA.

First light

Construction of the wheel-on-track telescope (Cooper et al. 1992) was completed in November 1991, with the first astronomical observations being made as part of a VLBI session the following week and one of these -- Cen A -- reported in Tingay et al. (1998).

TABLE 1

LOG OF VLBI OBSERVATIONS

Epoch (1)	Frequency (GHz) (2)	Array/Format (3)	Antennas (4)	Base./Clos. (5)	*T* (hr) (6)
1988 Nov 10......	2.3	S/II	AT, MP, D43, D45, PA, HO, AS, HH	19/24	12
1991 Mar 6	8.4	S/II	AT, D43, PA, HO	6/4	11
1991 Nov 24......	8.4	S/II	AT, MP, D43, PA, HO	10/10	11
1992 Mar 26......	8.4	S/II	AT, MP, D43, D45, PA, HO, HH	14/16	10
1992 Nov 22......	8.4	S/II, III	AT, MP, D43, PA, HO, PR15, HH	19/21	12

My own first visit to Mopra was November 1992…

The Australia Telescope Overview (June 1992)

Frater, Brooks and Whiteoak:

“The Compact Array, Mopra antenna and Parkes radio telescope can be linked together to form the Australia Telescope Long Baseline Array. … Ultimately, correlation will be possible at Narrabri.”

“Apart from its use in the Long Baseline Array, the Parkes radio telescope will continue to be used for ‘stand-alone’ operation. In addition, it is planned to outfit the Mopra antenna for wide-band (700 MHz) operation at 115 GHz; at this frequency its only competitor in the Southern hemisphere will be the 14-m Swedish-ESO Submillimetre Telescope (SEST) in Chile.”

ATNF Annual Report 1993

Now that the Australia Telescope is fully operational we have to make sure we maintain a vigorous development program to maintain it as a world-class facility.

One of the key thrusts in international radio astronomy is the push towards shorter (millimetre) wave lengths.

We expect to rejoin the international community in this field when the Mopra Telescope begins operations at 3mm in 1994, but since Australia has no suitable sites for high quality observations at short millimetre wavelengths it is not clear that further development in this area will be our best strategy.

Such issues need to be vigorously debated in the coming years.

Single dish science

In its first years, Mopra was used for VLBI and single-dish observations at centimetre wavelengths (e.g., HI observations of Koribalski, Johnston & Otrupcek 1994).

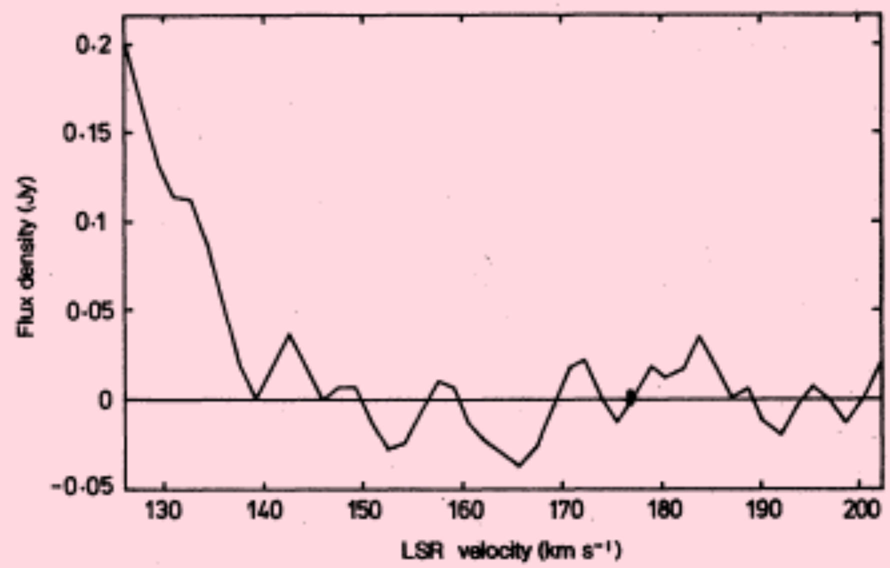
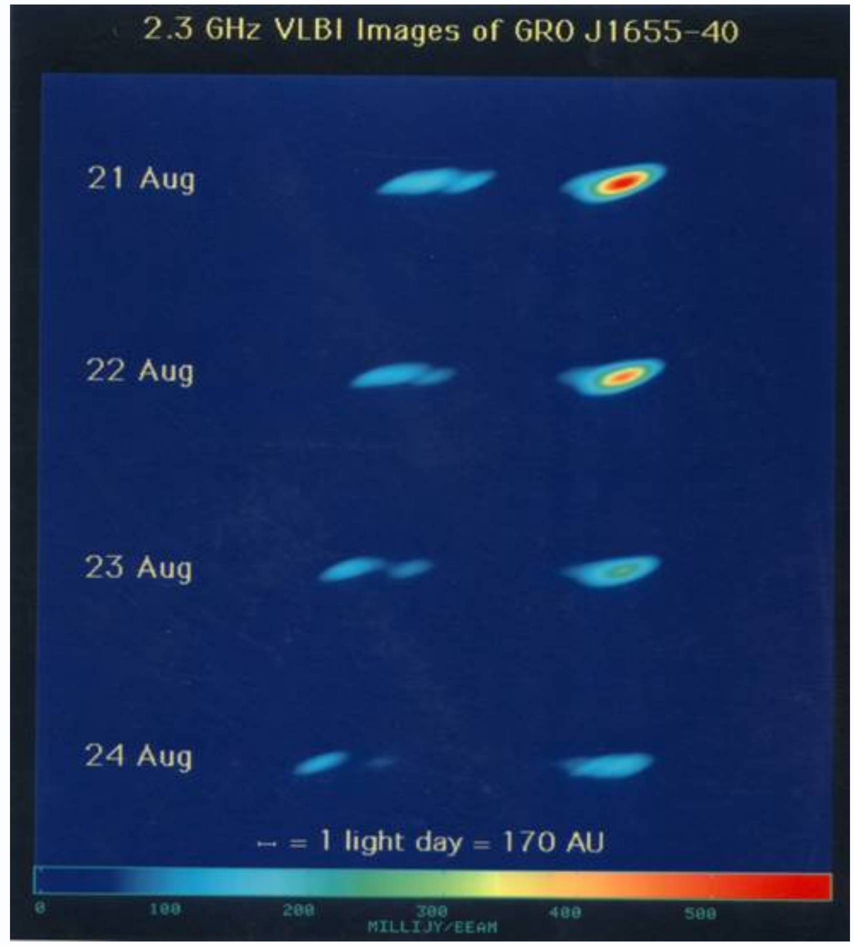


Figure 2. H I spectrum in the direction of Sgr I at the same position as Fig. 1. Here, a much smaller velocity range from about +130 to +200 km s^{-1} has been selected to enhance the area around the systemic velocity of Sgr I (v_{LSR} = 148 km s^{-1}). A first-order baseline has been subtracted in the displayed area. The channel width is 3.3 km s^{-1} after Hanning smoothing has been applied. No H I has been detected around the systemic velocity of Sgr I or any other velocity outside the Galactic emission.

GRO J1655-40 Superluminal motion

Relativistic motion in a nearby bright X-ray source

S. J. Tingay[*†], D. L. Jauncey[‡], R. A. Preston[†], J. E. Reynolds[‡], D. L. Meier[†], D. W. Murphy[†], A. K. Tzioumis[‡], D. J. McKay[‡], M. J. Kesteven[‡], J. E. J. Lovell[§], D. Campbell-Wilson[#], S. P. Ellingsen[§], R. Gough[‡], R. W. Hunstead[#], D. L. Jones[†], P. M. McCulloch[§], V. Migenes[‡], J. Quick[‖], M. W. Sinclair[‡] & D. Smits[‖]



Project Phoenix

In 1995, the telescope was used together with the Parkes 64-m telescope as part of Project Phoenix, which observed 209 solar-type stars over the frequency range 1.2–3.0 GHz to search for possible narrow-band transmissions from extra-terrestrial life (Tarter 1997).

The Mopra 20/13 cm feed and receiver was modified from the(ATCA) design to improve performance over the wider Project Phoenix range — changes which later enabled Mopra to support VLBI observations during the descent of the Huygens probe through the atmosphere of Titan.

FUDD

SETI News

Finding the Aliens with a FUDD

Seth Shostak

Our own radio, television, and radar transmissions often interfere with the sensitive receivers scientists use to search for extraterrestrial signals. To minimize the disruption caused by Earth-bound radio sources, Project Phoenix will use *two* radio antennas in its search for cosmic company. The tandem telescopes will screen out terrestrial interference by means of a sophisticated piece of electronics known as a Follow Up Detection Device, or FUDD.

A somewhat simplified description of FUDD function is given in the figure:

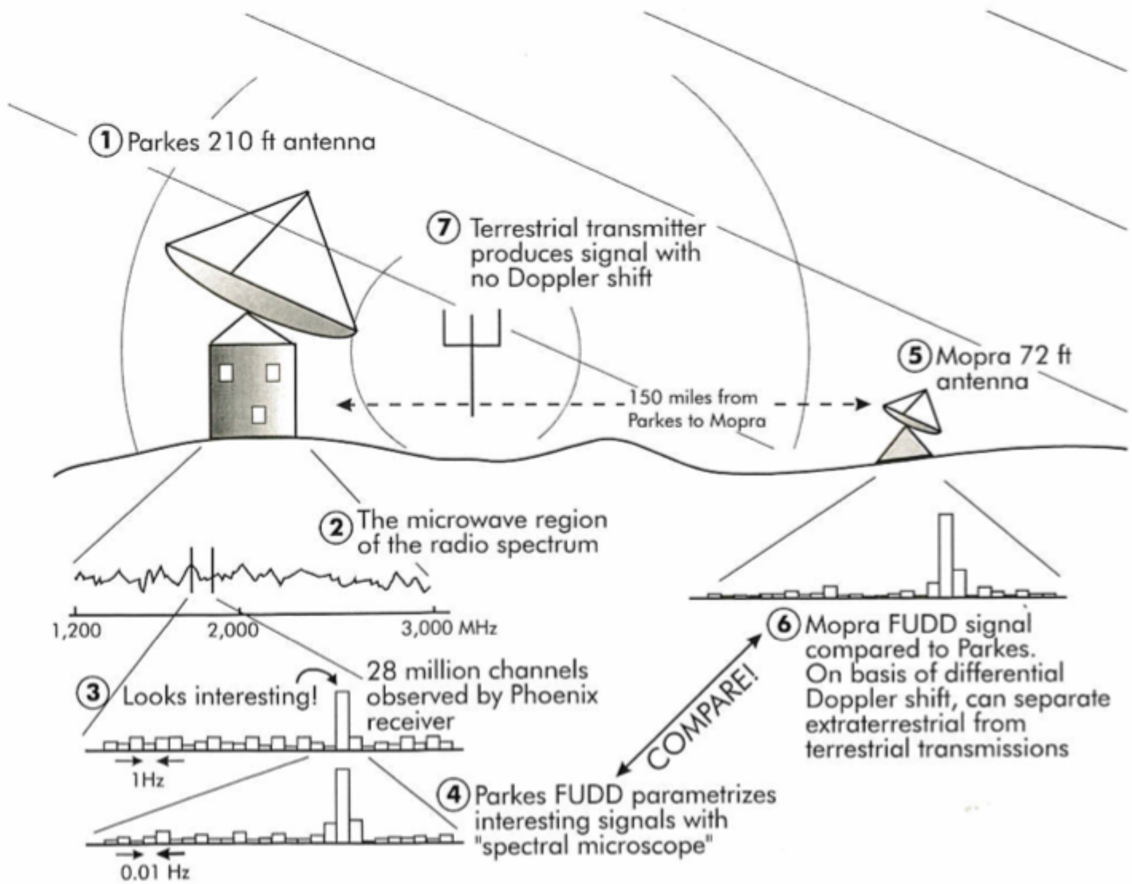
advising where on the radio dial we can find his signals, Project Phoenix will search nearly two billion channels, from 1,200 to 3,000 MHz.

3. The receivers "listen" to 28 million channels simultaneously. Each channel is typically 1 Hz wide, or five million times narrower than a television channel. If a strong signal is found in one of these channels, the news is passed on to the

JOHN MASTERSON - ATNF

The Mopra Telescope.

Project Phoenix



The Down-Under Report on Mopra

Kelvin Wellington

Why Mopra? What is Mopra? Tell you in a minute. First some history.

The first short run of the NASA SETI targeted search at Arecibo in October, 1992 suffered greatly from local interference. Chasing this interference to check that it wasn't a *bona fide* SETI signal cost lots in observing efficiency.

To overcome this, the good people from the SETI Institute went back to the drawing board and introduced the smart idea of using a second, remotely-located telescope to immediately follow-up any interesting candidate signals found by the main telescope.

This is a crucial step forward in technique. Besides saving main telescope time

Kel Wellington with Phoenix system engineer Bud Hill.

the unenviable job of overseeing all the things to be done at Mopra. And there were many. Site security was one worry, so we decided to put in some slow-scan TV cameras and send the images over the ISDN phone links to Narrabri. (Now we can watch the

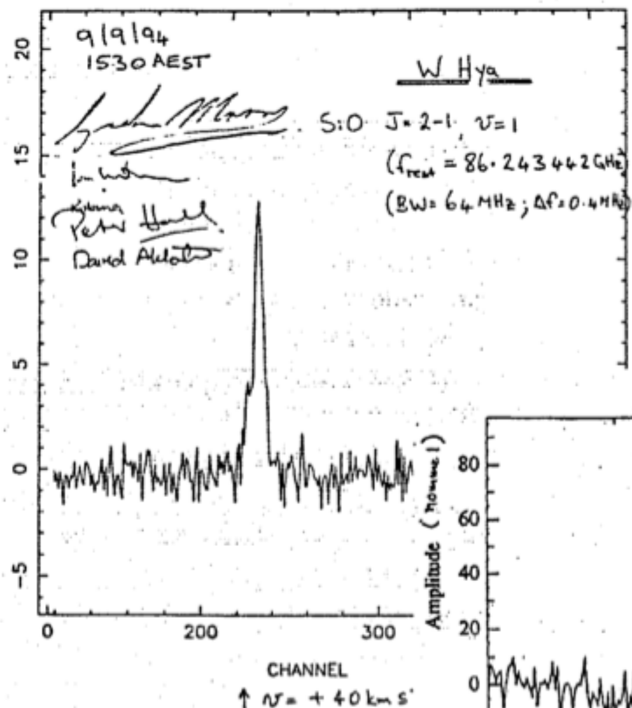
receivers and feeds. Originally designed only to go to 2.3 GHz, it was no mean feat to push them up to 3.0 GHz. And then we had to ensure that there was an uninterruptable power supply so that the telescope could be stowed in an emergency.

Last but not least we were very lucky that Robina Otrupcek was keen to move to nearby Coonabarabran and take on the job of telescope friend. Now when a computer crashes and needs resetting, or we realize we forgot to switch something on, Robina can do it and save someone an 8 hour round trip from Parkes.

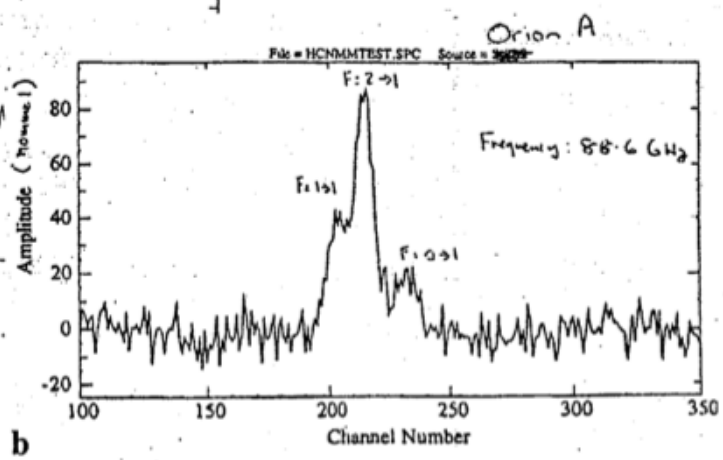
After all this preparation the Phoenix team of John Dreher, Bud Hill, Alan Patrick and Ken Smolek wheeled in their FUDD system. All observations can now be controlled and processed at

First light at 3mm

AT News



a



b

Millimetre-wave astronomy comes to Siding Spring Mountain

These are the very first mm-wave results using the 22 m Mopra radio telescope on Siding Spring Mountain. The Mopra telescope has for some time been available for VLBI and stand-alone cm-wave observations. However, recent receiver developments (discussed later in this issue) now provide the option of observing in the band 85-115 GHz. Initial tests of the antenna surface, the pointing ability and the receiver's performance all show encouraging signs for future mm-wave astronomy.

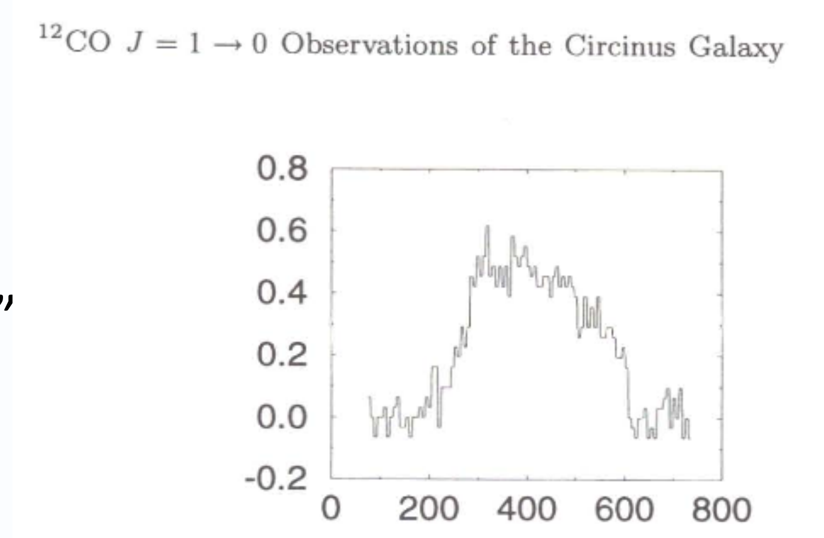
In the adjacent figures we show both: a) the first 86.2 GHz observation of the well-known SiO maser source W Hydra made with the Mopra telescope on 9 September 1994, and b) the first HCN observation at 88.6 GHz of Orion A.

First 3mm observations

A 3-mm SIS receiver was tested on the antenna in late 1994, with the feed illuminating the central solid-panelled 15m of the dish, and astronomical 3-mm observations began in August the following year, e.g., "Observations of the $^{57}Fe^{+23}$ hyperfine transition in clusters of galaxies" by Liang et al.

and

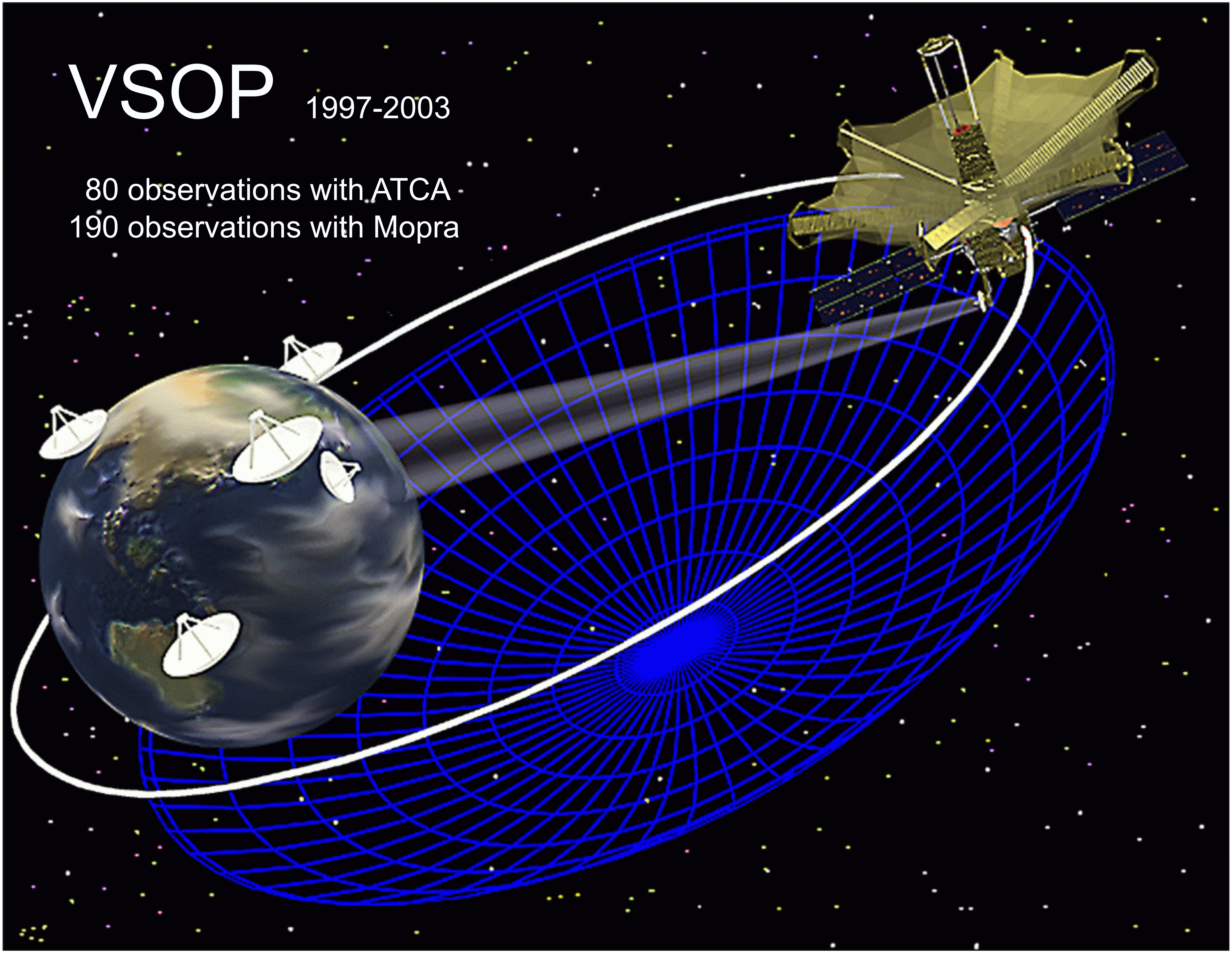
"^{12}CO J = 1 - 0 observations of the Circinus galaxy using the Mopra 22m radio telescope" by Elmouttie et al.

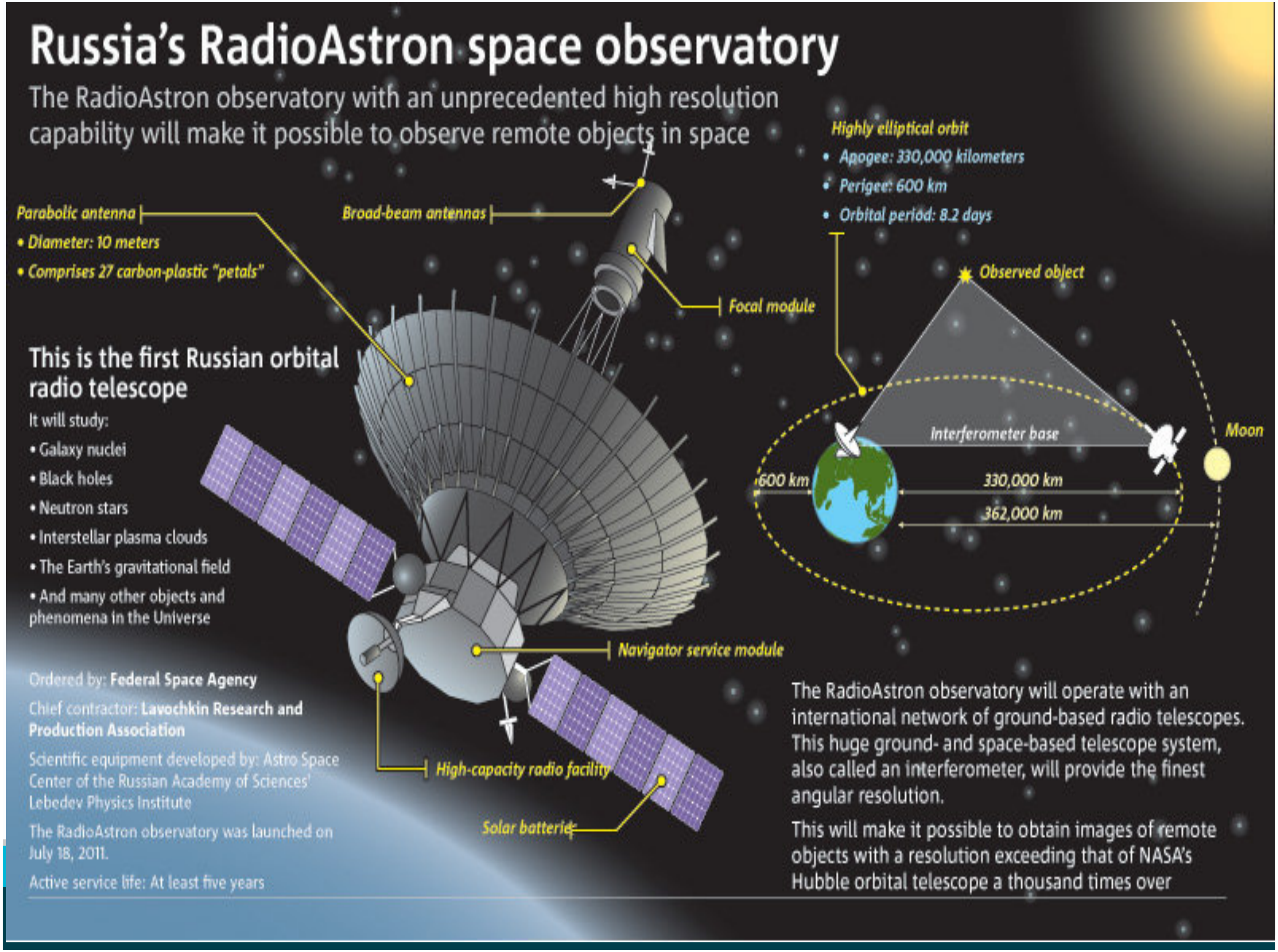


The addition of 12mm

A 12-mm receiver was constructed for Mopra in 1996, primarily to support space VLBI observations with the HALCA satellite as part of the VLBI Space Observatory Programme (Hirabayashi et al. 2000).

The compromised performance of the HALCA 12-mm receiver (Kobayashi et al. 2000) resulted in Mopra support for the VSOP mission being at 1.6 and 4.9 GHz (e.g., Scott et al. 2004; Dodson et al. 2008), however the 'VSOP' 12-mm receiver was used in a number of other Long Baseline Array VLBI observations (e.g., "A Warped Accretion Disk and Wide-Angle Outflow in the Inner Parsec of the Circinus Galaxy", Greenhill et al. 2003).


VSOP
1997-2003
80 observations with ATCA
190 observations with Mopra


Russia's RadioAstron space observatory
The RadioAstron observatory with an unprecedented high resolution capability will make it possible to observe remote objects in space
Parabolic antenna
• Diameter: 10 meters
• Comprises 27 carbon-plastic "petals"
Broad-beam antennas
Focal module
Highly elliptical orbit
• Apogee: 330,000 kilometers
• Perigee: 600 km
• Orbital period: 8.2 days
Observed object
Interferometer base
Moon
600 km
330,000 km
362,000 km
This is the first Russian orbital radio telescope
It will study:
• Galaxy nuclei
• Black holes
• Neutron stars
• Interstellar plasma clouds
• The Earth's gravitational field
• And many other objects and phenomena in the Universe
Navigator service module
High-capacity radio facility
Solar batteries
Ordered by: Federal Space Agency
Chief contractor: Lavochkin Research and Production Association
Scientific equipment developed by: Astro Space Center of the Russian Academy of Sciences' Lebedev Physics Institute
The RadioAstron observatory was launched on July 18, 2011.
Active service life: At least five years
The RadioAstron observatory will operate with an international network of ground-based radio telescopes. This huge ground- and space-based telescope system, also called an interferometer, will provide the finest angular resolution.
This will make it possible to obtain images of remote objects with a resolution exceeding that of NASA's Hubble orbital telescope a thousand times over

UNSW upgrades

UNSW funded the replacement of the outer perforated panels of the dish in 1999 with solid panels, and the receiver optics were modified to illuminate the full 22 m.

Several rounds of holography using a 30-GHz satellite beacon were used to reduce the surface RMS error from 270 µm in 1999 to 180 µm in 2004.

The 3-mm SIS receiver was the main receiver used for single-dish observing during this period, and the telescope was characterised by Ladd et al. (2005).

On-the-fly mapping

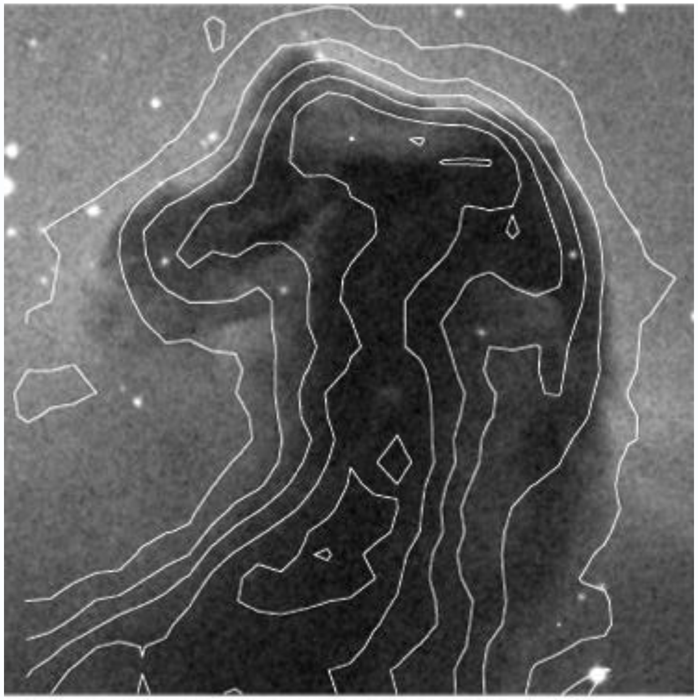
OTF mapping became possible in 2004 as a result of

(1) adjustment of the surface panels and subreflector to produce a more symmetric beam pattern at 3 mm,

(2) installation of a new antenna control computer (ACC) that can handle shorter cycle-times, and

(3) development of software to facilitate rapid scanning, schedule file preparation and processing of OTF data into spectral cubes.

Major contributions made by Tony Wong, Mike Kesteven and Mark Calabretta



Huygens

On 14 January 2005 the European Space Agency (ESA) Huygens probe descended on to the surface on Saturn's moon, Titan.

At 3:30 am, Chris grabbed the disks from the ATCA and jumped in a taxi to Narrabri airport. A charter plane flew him back to Sydney via Coonabarabran and Parkes airports, collecting the Parkes and Mopra data en route. Nine NRENs collaborated to give us a dedicated door-to-door gigabit connection from Marsfield to JIVE.

Figure 2: A tired-looking Tasso Tzioumis handing over Mopra observatory data disks to Chris Phillips at Coonabrraban airport in the early hours of the morning. Photo: Liz Cutts

MMIC receivers, 2005-2008

Upgrading and expanding the suite of mm receivers with Indium Phosphide (InP) High Electron Mobility Transistor (HEMT) Monolithic Microwave Integrated Circuits (MMICs) low-noise amplifiers:

- 3-mm SIS receiver replaced in 2005 with new 76–117 GHz receiver,
- addition of a 12-mm receiver in 2006 (16–28 GHz),
- new 7-mm receiver in 2008 covering (30–50 GHz)

Physically, the three receivers are mounted in a single dewar.

MOPS

First light with the UNSW Mopra Spectrometer (MOPS) was on 22 May 2006, on Orion KL. MOPS is a broadband digital filter bank with four over-lapping sub-bands, each with a bandwidth of 2.2GHz providing a total of 8.3GHz of continuous bandwidth. Both a wideband mode and a zoom mode, with up to 16 zooms are available.

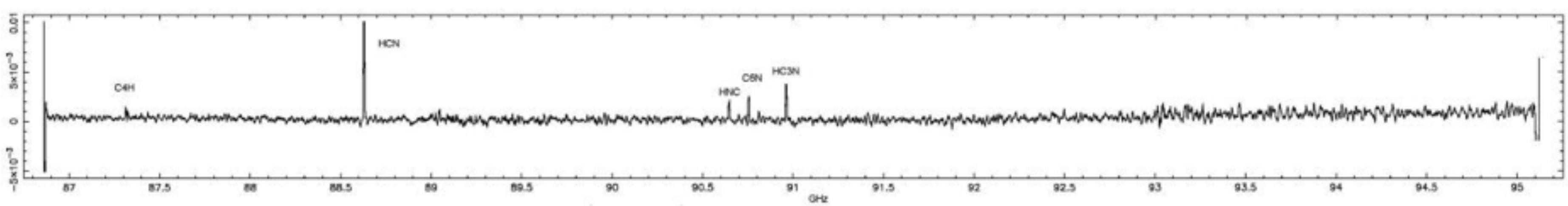


Figure 1: An example spectrum from 87 - 95 GHz, taken using the new broadband MOPS system towards the carbon star and its circumstellar envelope, IRC+10216. A few of the important lines are clear even from only 200 sec on-source. The full spectrum, taken in seven, 8 GHz-wide bands and extending from 74 to 118 GHz, would span 1.85 metres!

Remote Observing

Photo: Shaun Amy

Dion Lewis at the *Trachyte* terminals in the Narrabri control room.

Photo: Jorge Pineda

Annie Hughes on the phone from Mopra

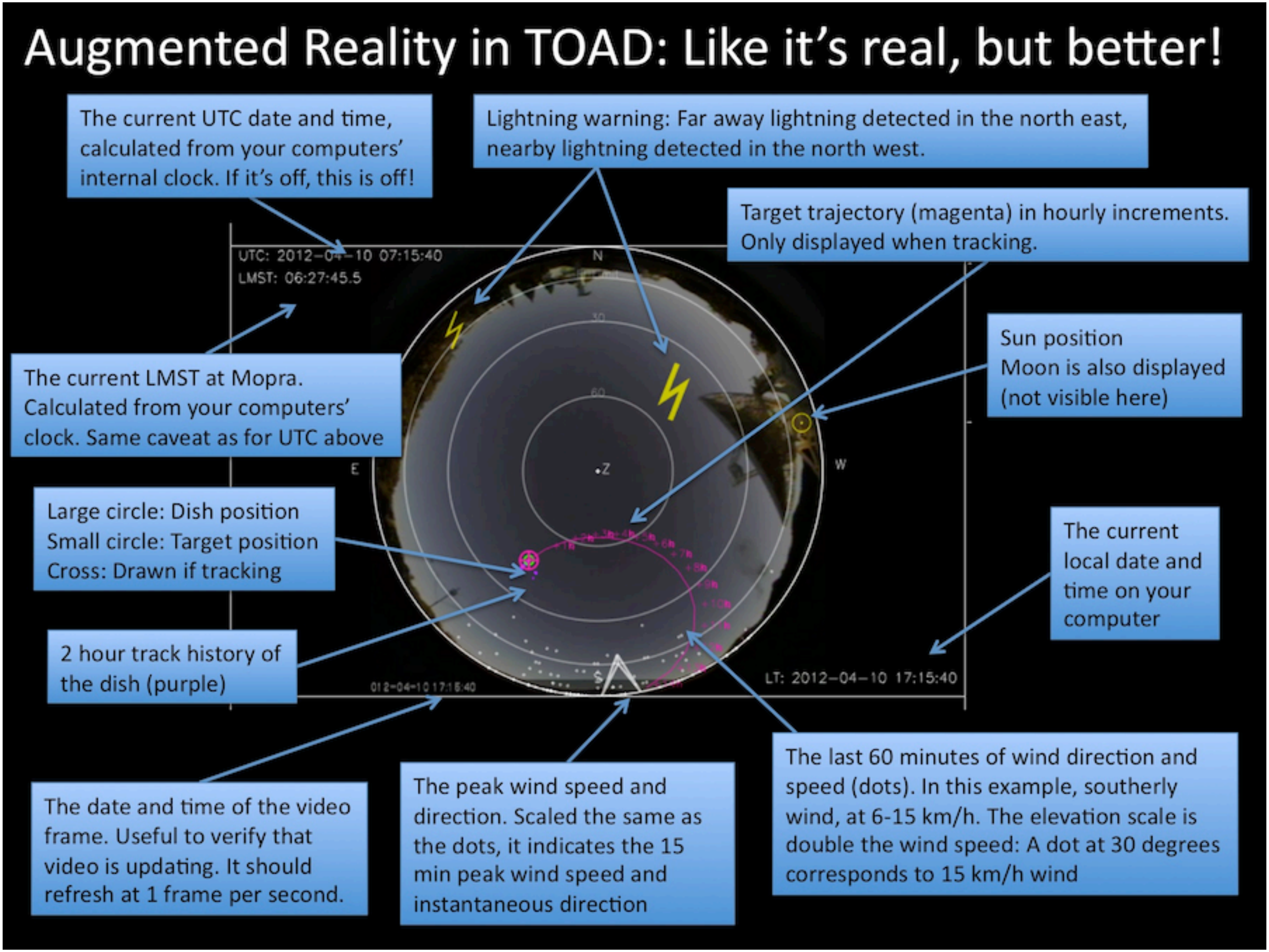
Mopra remote observing from ATCA started August 2006

Remote observing (ii)

Mopra observing soon after became possible from anywhere for qualified observers.

Balt's arrival in June 2007 was quickly followed by a suite of tools including TOAD to assist observers.

The Mopra sky camera was finally added in 2011.


Augmented Reality in TOAD: Like it's real, but better!
The current UTC date and time, calculated from your computers' internal clock. If it's off, this is off!
Lightning warning: Far away lightning detected in the north east, nearby lightning detected in the north west.
Target trajectory (magenta) in hourly increments. Only displayed when tracking.
UTC: 2012-04-10 07:15:40
LMST: 06:27:45.5
N
E
W
Z
Sun position
Moon is also displayed
(not visible here)
The current LMST at Mopra. Calculated from your computers' clock. Same caveat as for UTC above
Large circle: Dish position
Small circle: Target position
Cross: Drawn if tracking
The current local date and time on your computer
2 hour track history of the dish (purple)
LT: 2012-04-10 17:15:40
The date and time of the video frame. Useful to verify that video is updating. It should refresh at 1 frame per second.
The peak wind speed and direction. Scaled the same as the dots, it indicates the 15 min peak wind speed and instantaneous direction
The last 60 minutes of wind direction and speed (dots). In this example, southerly wind, at 6-15 km/h. The elevation scale is double the wind speed: A dot at 30 degrees corresponds to 15 km/h wind

MUMs, MUGs and QRHs

The first Mopra User Manual was put together by Jill Rathborne, Michael Murphy and Jung-Kyu Lee. The 2002 version, with additional work by Lucyna Kedziora-Chudczer, is still available

http://newt.phys.unsw.edu.au/astro/mopra/mum/manual.html

Other versions of the Mopra User Guide came and went: the final version is Balt's Quick Reference Handbook

An incomplete list of other CSIRO staff who have provided Mopra support over the years includes Robina Otrupcek, Juergen Ott, Tony Wong, Stuart Robertson, Erik Muller, Dion Lewis, Nadia Lo, Kate Brooks, James Urquhart, all Narrabri staff and many Marsfield staff (Graeme Carrad, Warwick Wilson, Tasso Tzioumis …).

UNSW Mopra Support

Indra Bains, Ramesh Balasubramanyam, Michael Burton, Paolo Calisse, Neil Crighton, Maria Cunningham, Steve Curran, Tamara Davis, Jess Dempsey, Gary Derragopian, Bruce Fulton, Marton Hidas, Tracey Hill, Paul Jones, Lucyna Kedziora-Chudczer, Ned Ladd, Jung-Kyu Lee, Steve Longmore, Vincent Minier, Michael Murphy, Michael Pracy, Cormac Purcell, Jill Rathborne, Stuart Robertson, Angie Schultz, John Shobbrook, Patricia Sparks, John Storey, Tony Travouillion, Andrew Walsh

Disasters (i)

"Another even more spectacular event happened at Mopra near midnight on 12 January 2006: Mopra received a major lightning strike. A broad range of Mopra systems were damaged in the event and these are being assessed and repaired. The damage caused some electronics chips to explode while wires fused and the cryogenics systems failed. As of writing the Mopra uninterruptible power supply has yet to be brought back online and receiver health is yet to be tested. At present this event is not expected to have a major impact on VLBI or the start of the millimetre season."

ATNF News no 58 Oct 2006.

CSIRO

Disasters (ii)

SkyCam

http://www.youtube.com/watch?v=WlHP9J1UPrs

Mopra bushfire, January 2013

Change in operating model

- A call for expressions of interest, released in November 2011, solicited interest in operating the Mopra beyond October 2012.
- Funding was secured to operate the Mopra Telescope for three years, commencing in October 2012. Mopra operations will initially be supported by NAOJ and UNSW/Adelaide consortium.
- Mopra observing started with a block on UNSW/Adelaide time on May 7th.
- In return for their contributions to operating costs, UNSW was allocated 12 weeks/yr and 8 weeks/yr, with ~5 weeks/yr remaining for National Facility (single-dish and VLBI) use.
- These agreements ended at the end of October 2015

Thank you

Division/Unit Name
Presenter Name
Presenter Title

t +61 2 9123 4567
e firstname.surname@csiro.au
w www.csiro.au/lorem

Division/Unit Name
Presenter Name
Presenter Title

t +61 2 9123 4567
e firstname.surname@csiro.au
w www.csiro.au/lorem