VLBI with Mopra: 2016 - 2018

John Dickey
with slides from
Simon Ellingsen, Jim Lovell,
Jamie McCallum, Lucia Plank,
& Stas Shabala (UTAS)

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The point of this talk:

1. It would be a serious degradation of the current **Long Baseline Array** (LBA) if we lose Mopra.
2. If we could use Mopra for VLBI roughly 6 months/year there would be a lot of new things to try!

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Mopra will support Australian and international VLBI for astronomy, astrometry, and geodesy.

- Astronomy through **the LBA**, open access through peer reviewed proposals (CSIRO-CASS review, TAC and scheduling) operated by UTAS and CSIRO including Mopra since 1990s
- Astrometry through LBA proposals to find new frame-defining sources

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- Geodesy through the AuScope array, operated by UTas, funded by AuScope and Geoscience Australia (constructed NCRIS)
- The AuScope array supports the International VLBI Service for Geodesy and Astrometry ~ 100 days per year (requires dual S-X collinear receivers)
- The AuScope array also observes for ~150 days per year in Austral sessions (flexible frequency and schedule)

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Flexible VLBI Scheduling with Mopra and the AuScope Array

For astronomical VLBI, Mopra relieves the pressure due to limited Parkes receiver changes.

Mopra would allow better use of Tidbinbilla 70m short blocks.

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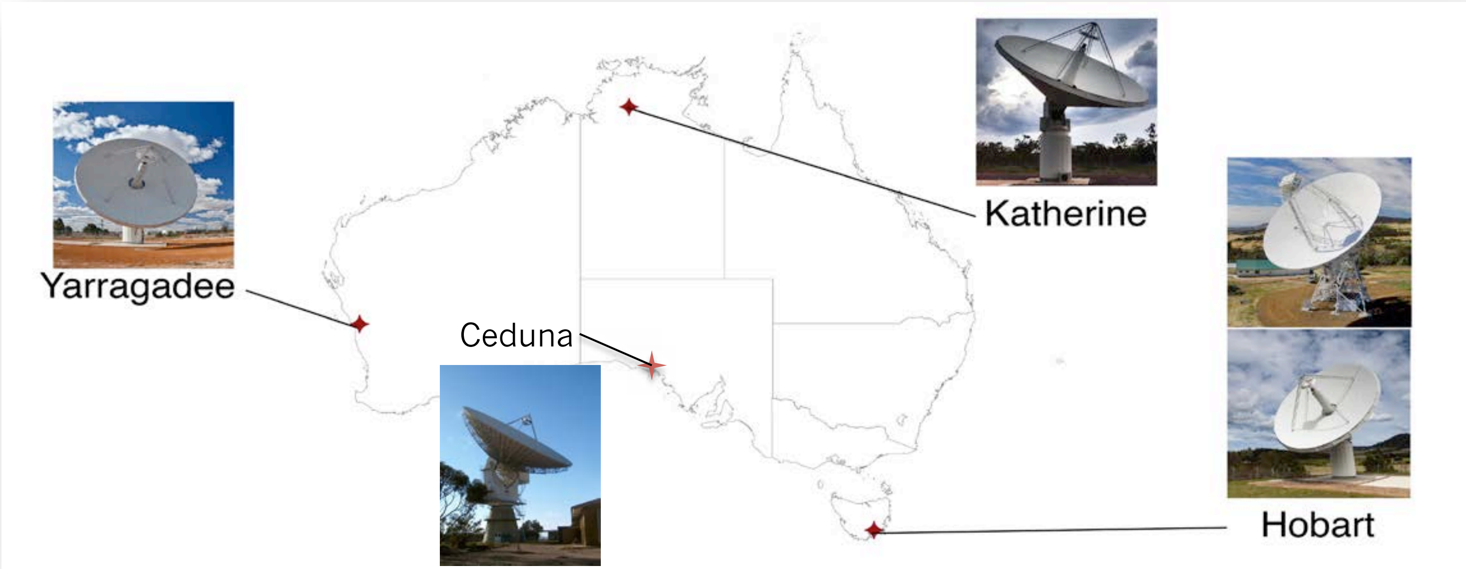
The UTas VLBI Array



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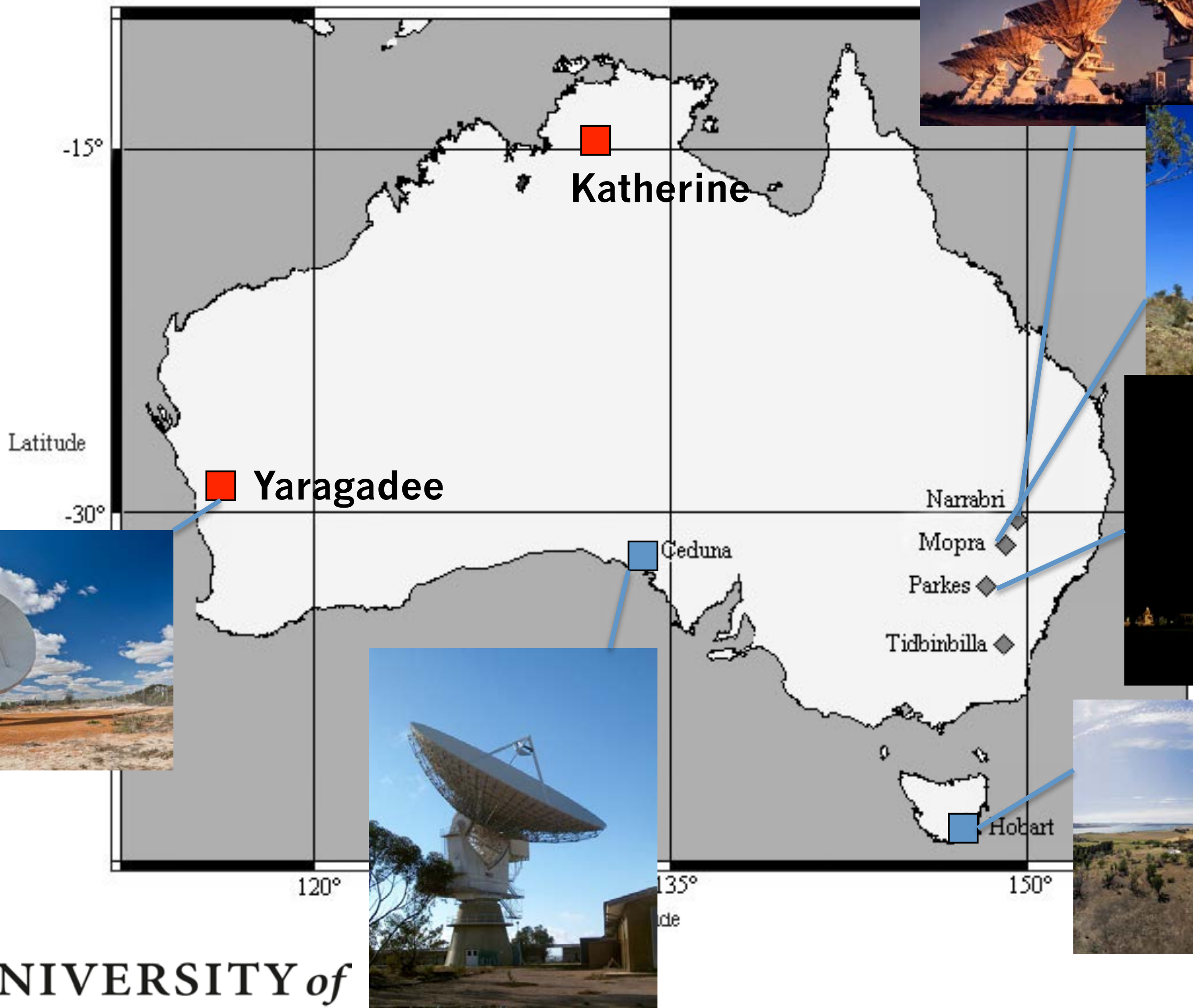
The LBA 2015



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Astronomical VLBI with the LBA is the only way to study milli-arc-sec structure and motions in sources south of $\delta = -30^{o}$ (southern limit of the VLBA, EVN, EAVN).

Much of the Milky Way and all the Magellanic Clouds can only be studied with the LBA if VLBI resolution is needed.

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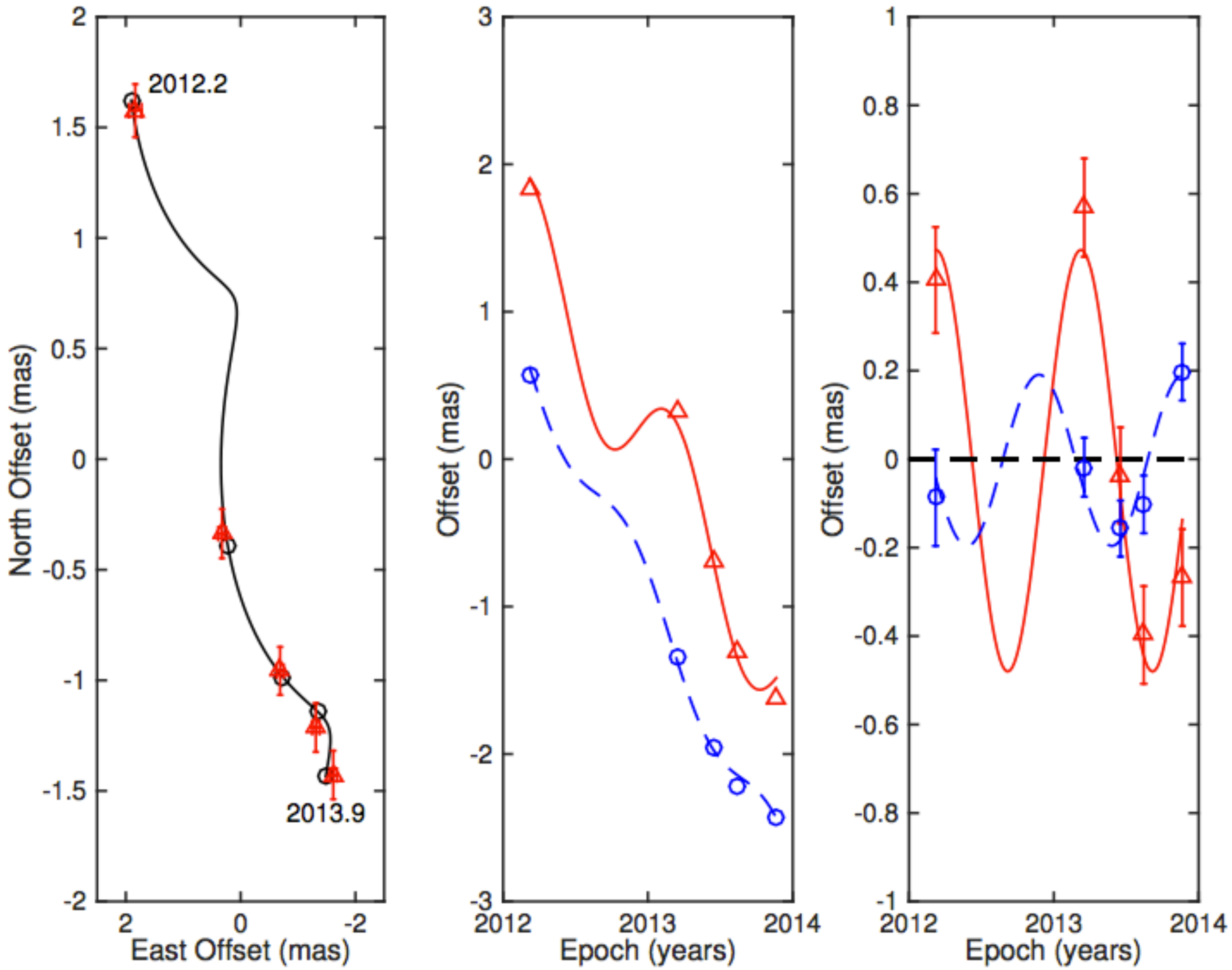
Structure of the Milky Way

Trigonometric parallax of G339.88-1.26

Krishnan et al. 2015, ApJ 805, 129 (UTas student working with Simon Ellingsen and Mark Reid).



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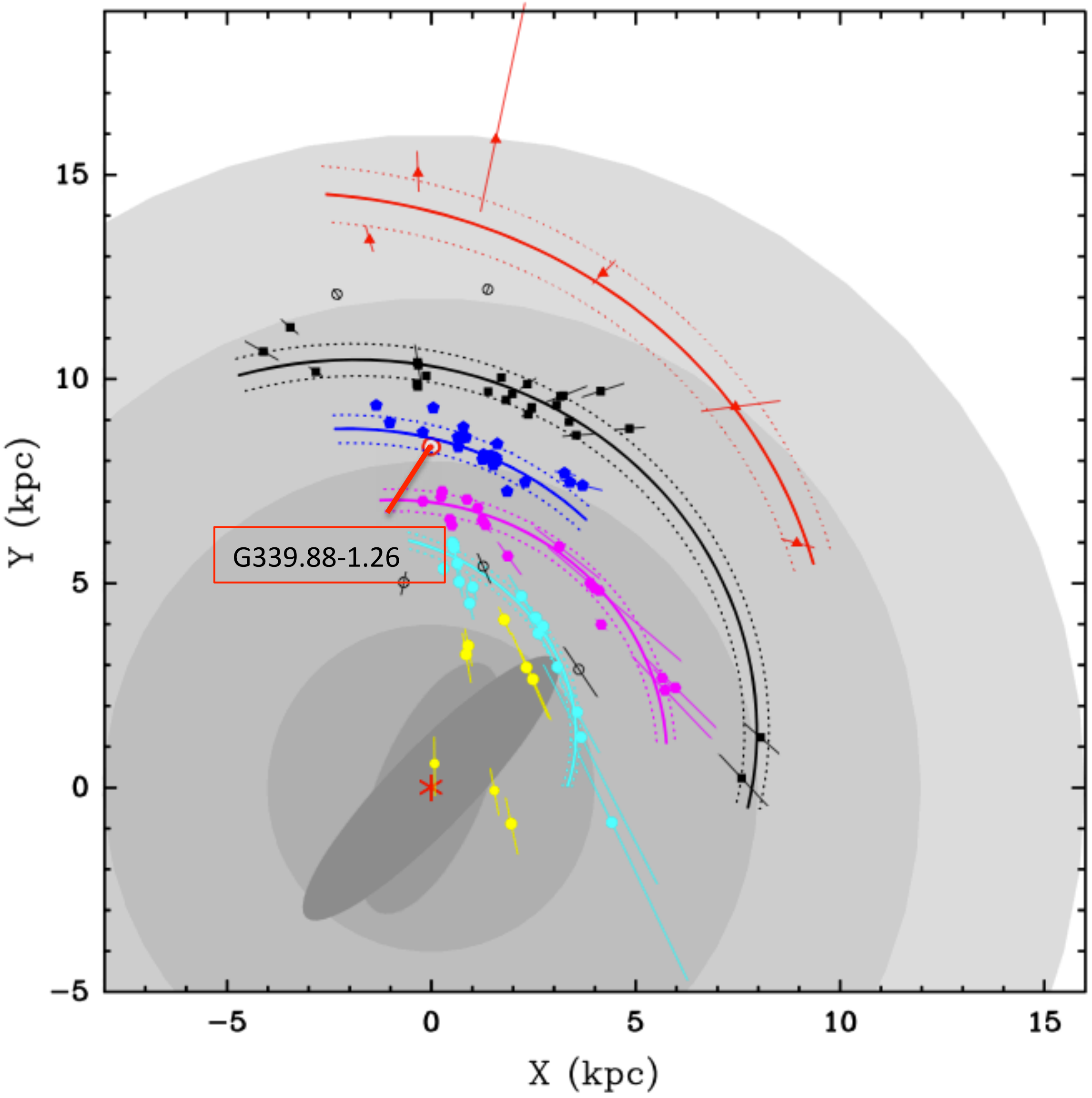
Spiral arm structure of the Milky Way from trigonometric parallax.

$R_0 = 8.34 \pm 0.16$ kpc

$\Theta_0 = 240 \pm 8$ kms^{-1}

Reid et al. 2014, ApJ, **783**, 130



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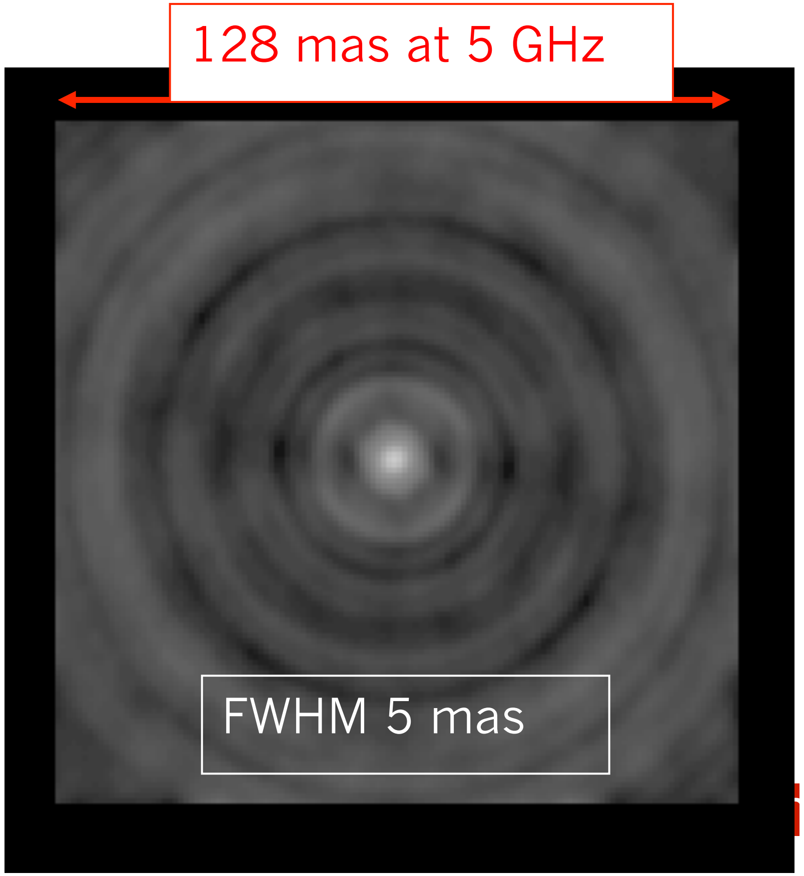
Note: GAIA will not be able to observe distant star forming regions (optical radiation is obscured by interstellar dust).

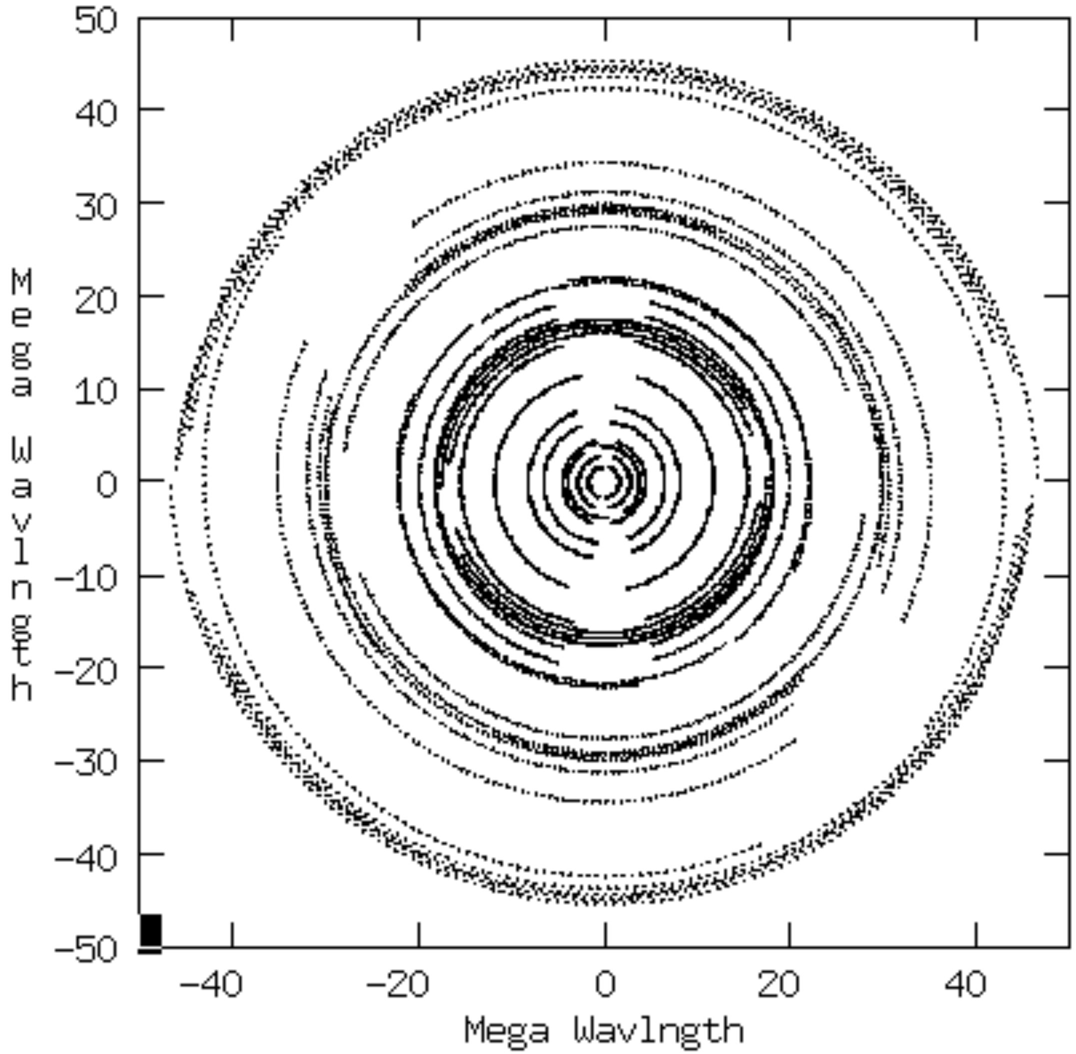
In the GAIA era there is much **greater** need for a southern hemisphere VLBI capability.

Mopra provides the shortest baselines in the LBA. Without Mopra the LBA will lose sensitivity for structure larger than about 100 mas.

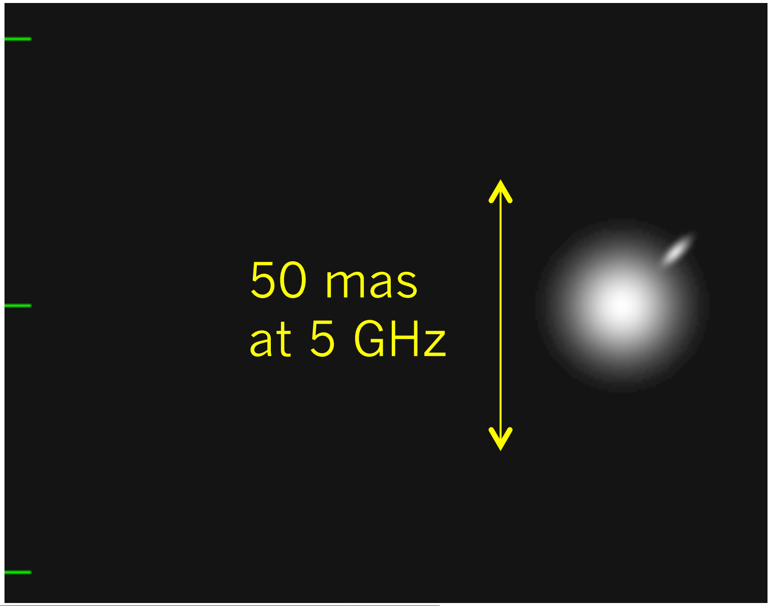
The Eight Element LBA, with

- Parkes
- Narrabri (1 elt)
- Mopra
- Tidbinbilla
- Hobart
- Ceduna
- Yarragadee
- Katherine

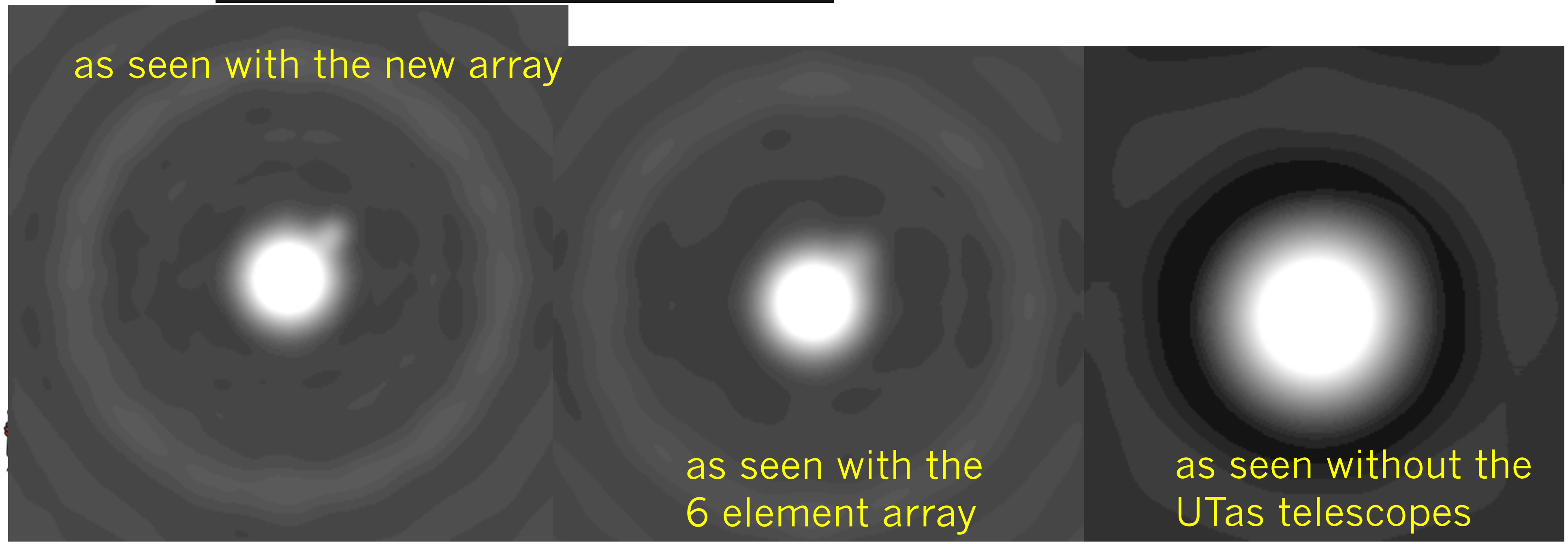




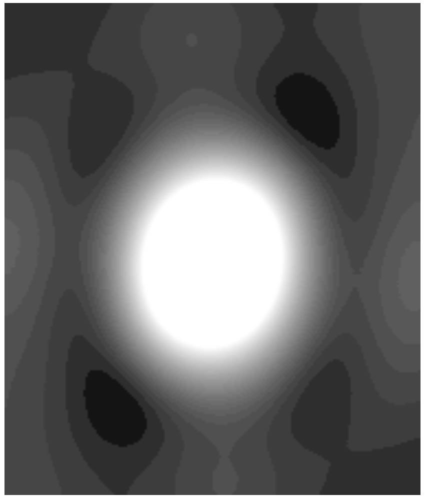
Observing a synthetic source at δ = -88° with UVCON:



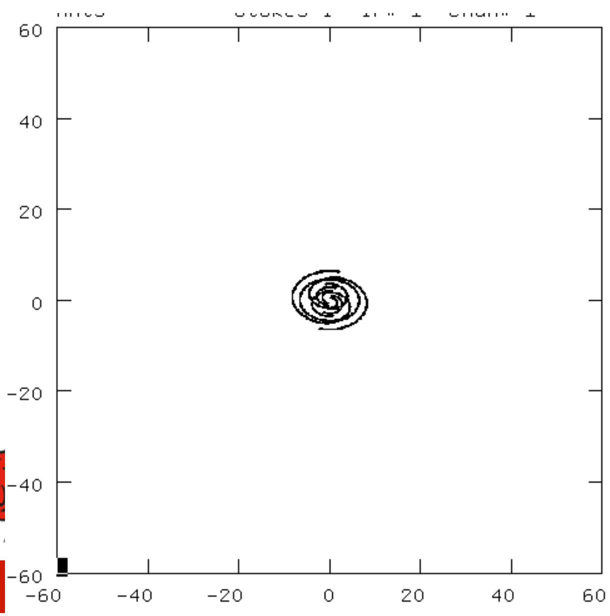
peak flux ratio = 0.37
total flux ratio = 0.034

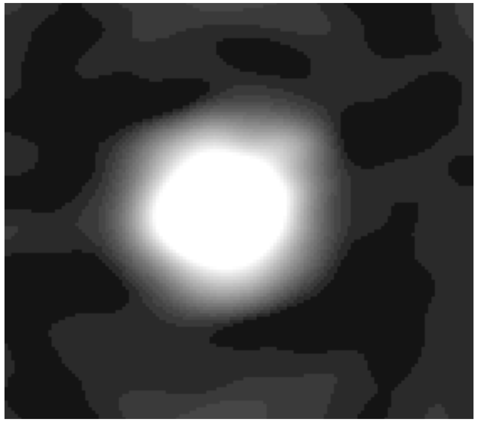


Things are not so nice at declination -45° ...

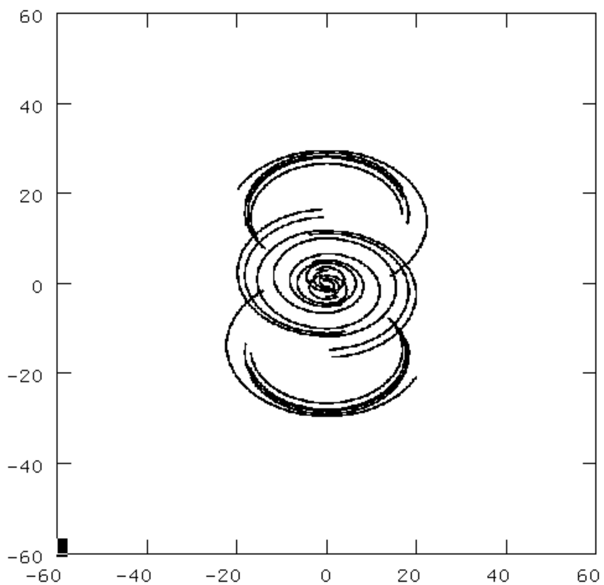


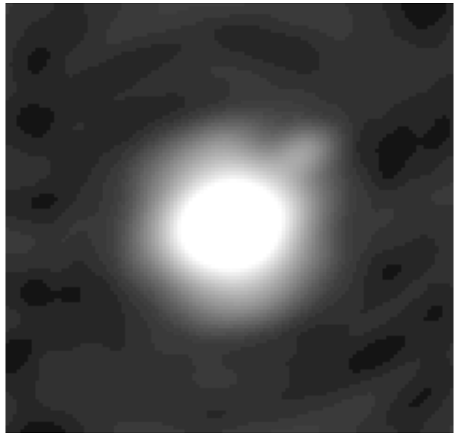
4 element array



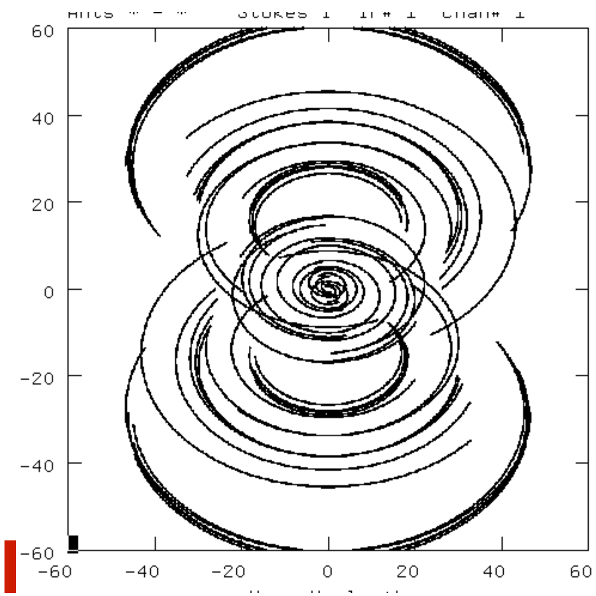


6 element array





8 element array



Next: Geodetic VLBI

The AuScope array (3 x 12m dishes at Hobart, Yarragadee, and Katherine) was built through NCRIS to provide southern hemisphere data to the IVS (International VLBI Service for astrometry and geodesy).

The goal is to maintain the accuracy of GPS and other navigational satellite systems through continuous measurement of the Earth Orientation Parameters (EOPs).

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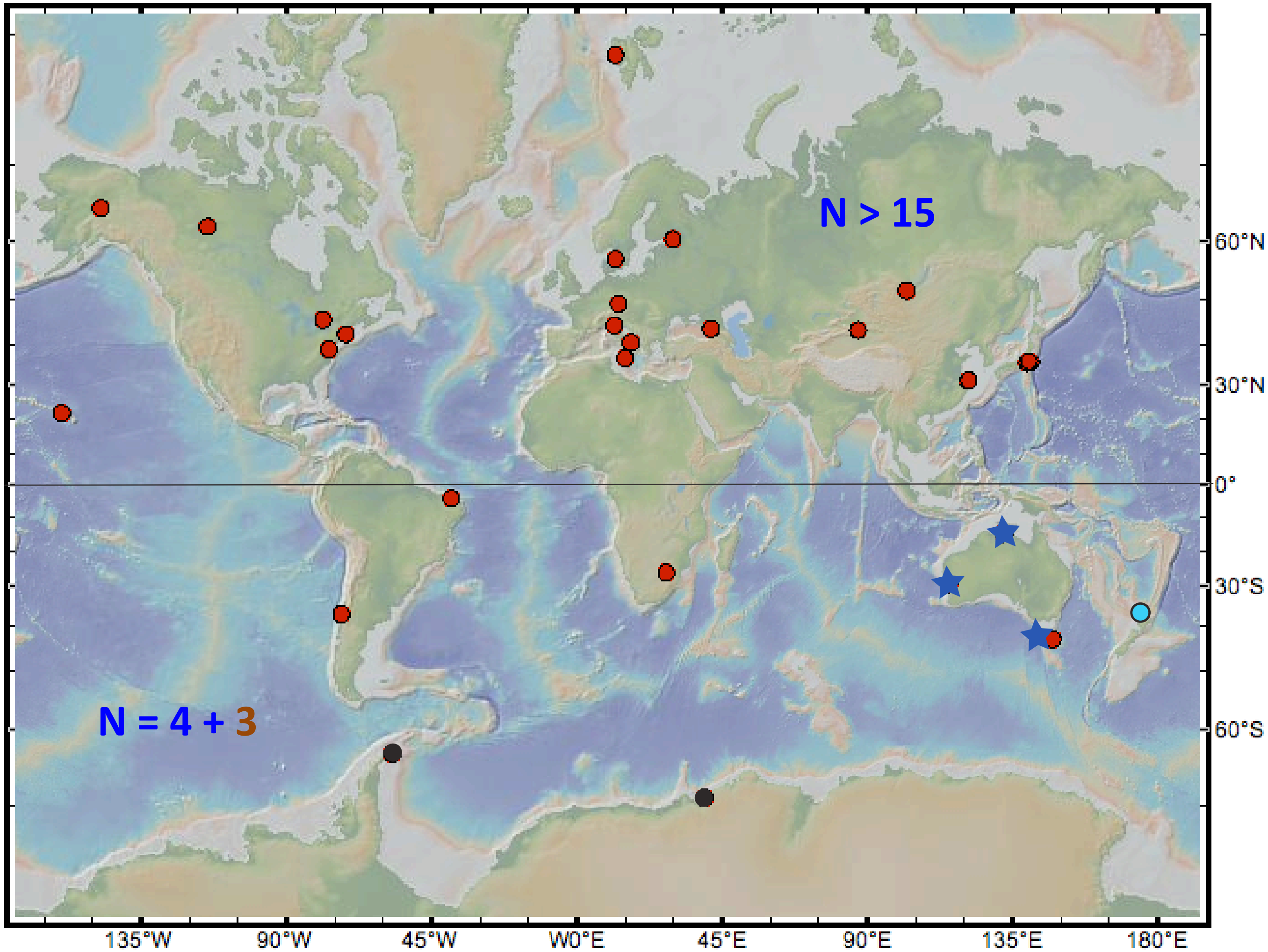
International VLBI Service



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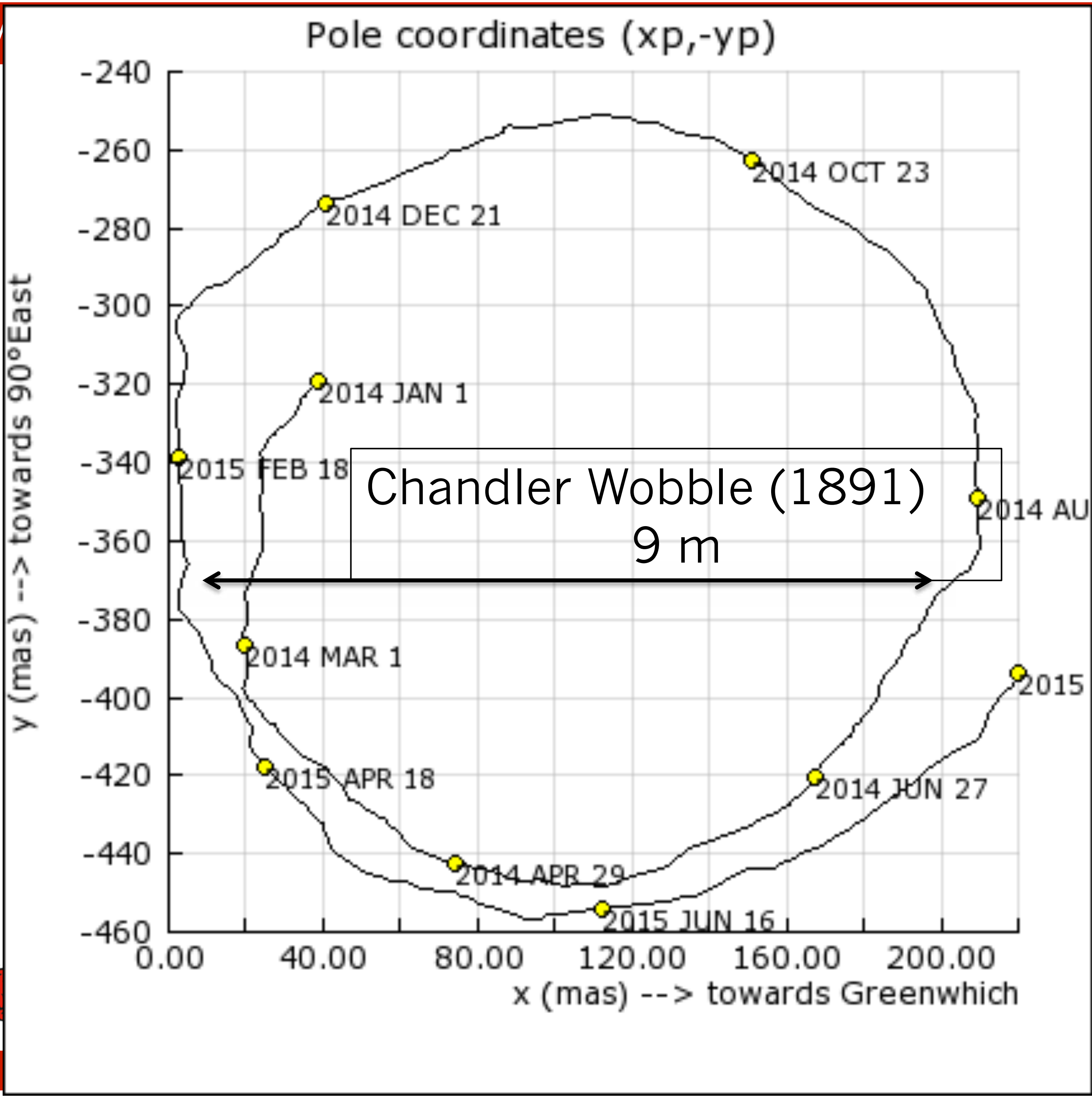
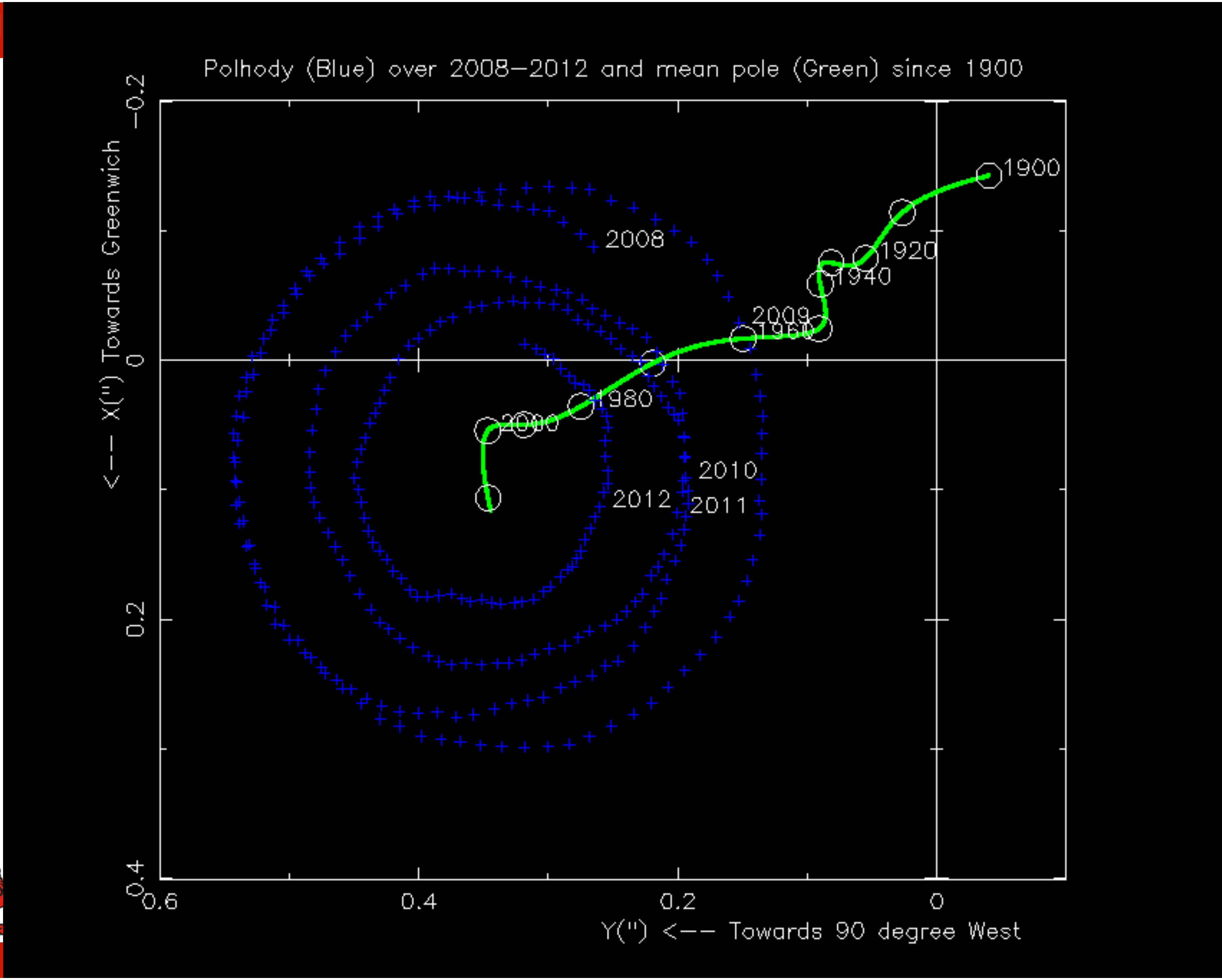
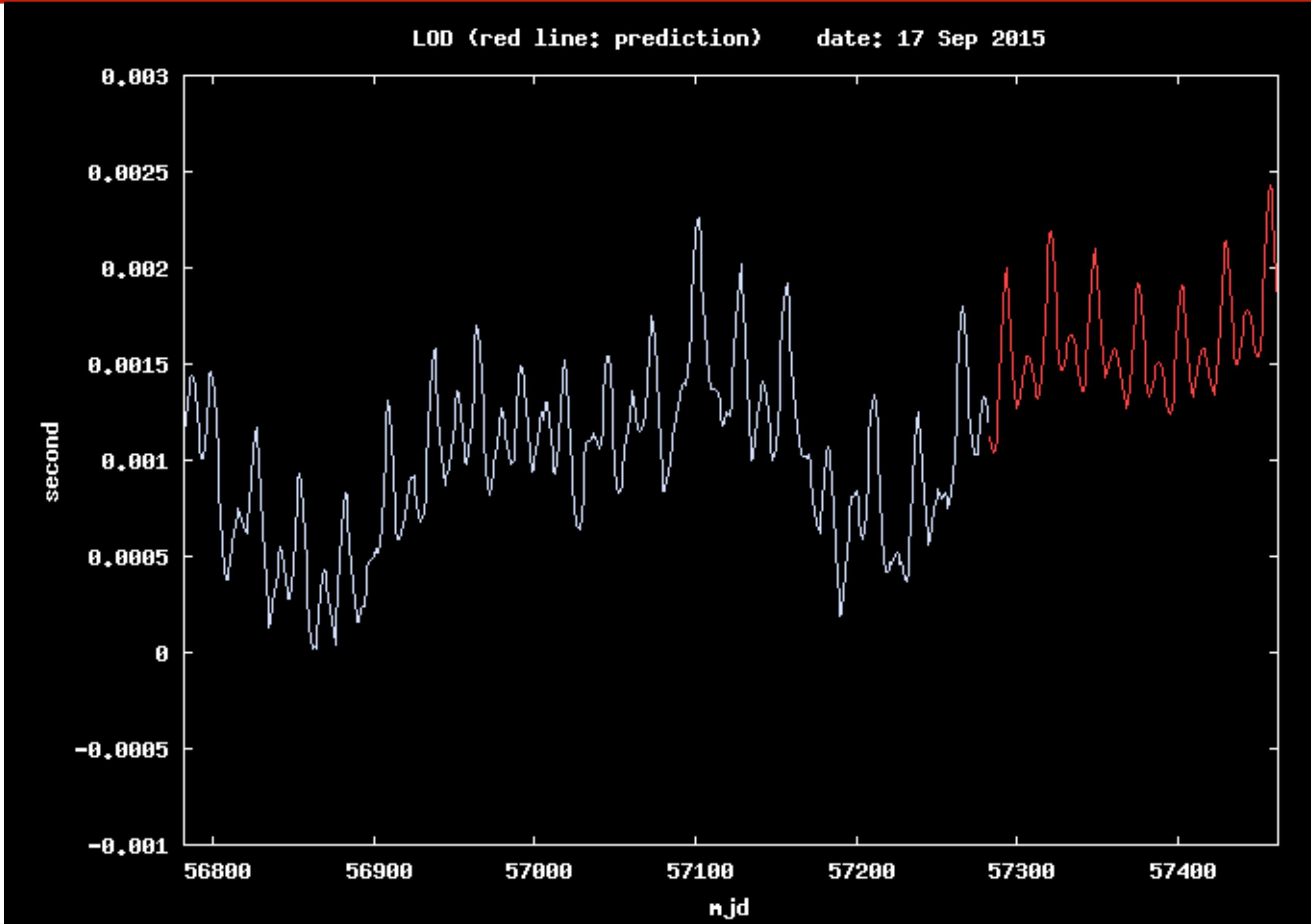


Motion of the earth's polar axis (north) measured on the sky, relative to extragalactic radio sources.

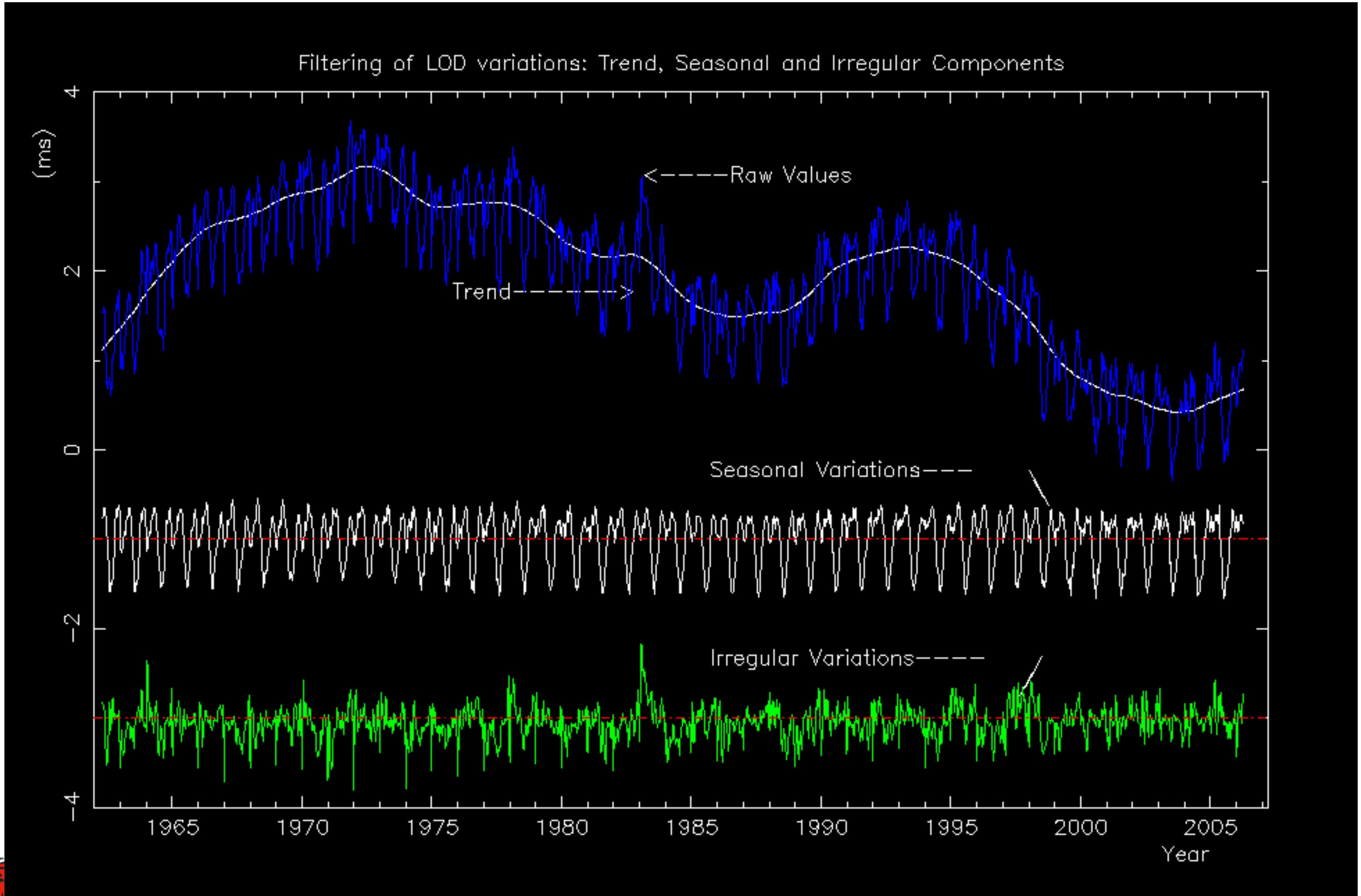
1 mas ~ 10^{-9} of a circle (one 4-millionth of a degree)
~ 3 cm on the earth's surface

M


Polhody (Blue) over 2008–2012 and mean pole (Green) since 1900
<–– X('') Towards Greenwich
Y('') <–– Towards 90 degree West
−0.2
0
0.2
0.4
0.6
0.4
0.2
0
1900
1920
1940
1960
1980
2000
2008
2009
2010
2011
2012



The length of a day varies by a few hundred micro-seconds each day. This is partly predictable, partly unpredictable.


Filtering of LOD variations: Trend, Seasonal and Irregular Components
(ms)
4
2
0
−2
−4
<-----Raw Values
Trend-------->
Seasonal Variations---
Irregular Variations----
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

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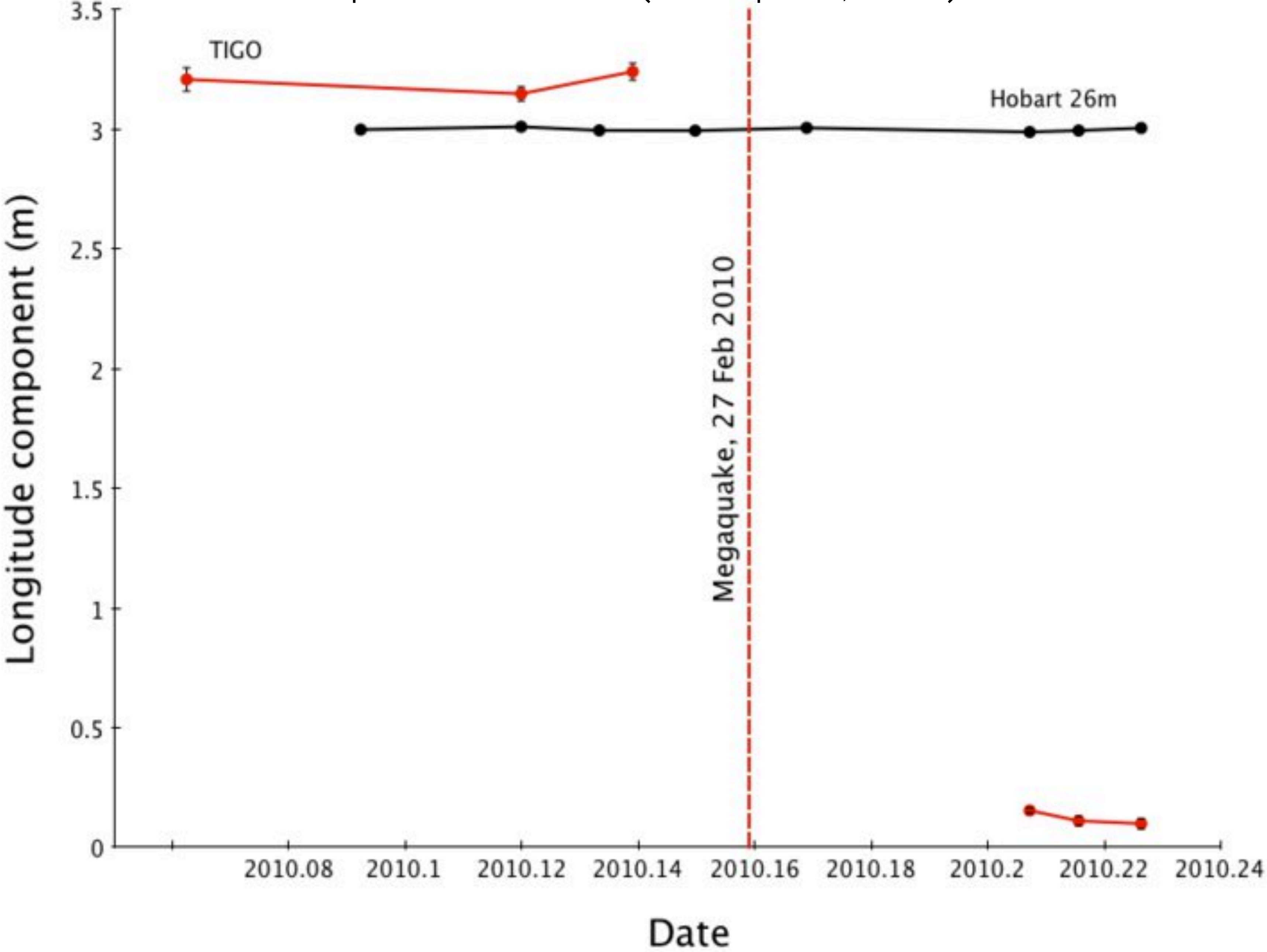
IVS measured position of TIGO (Conception, Chile) vs. Hobart



The AuScope Array has opened the Southern sky to the IVS.

The AuScope VLBI Array: 2010 - 2015

- **3 x 12m telescopes. Small, fast to meet VLBI2010 specifications**
- **Room temperature SX Receivers, 3500 Jy = noise temperature x Gain**
- **DBBC2, Mark5B+ digital backend and disk recording**
- **Operations centre at UTAS for controlling all telescopes**
- **Correlation at Curtin Uni (WA) until Sep 2015 for Austral sessions**
- **Scheduling and analysis capability in collaboration with TUWien**

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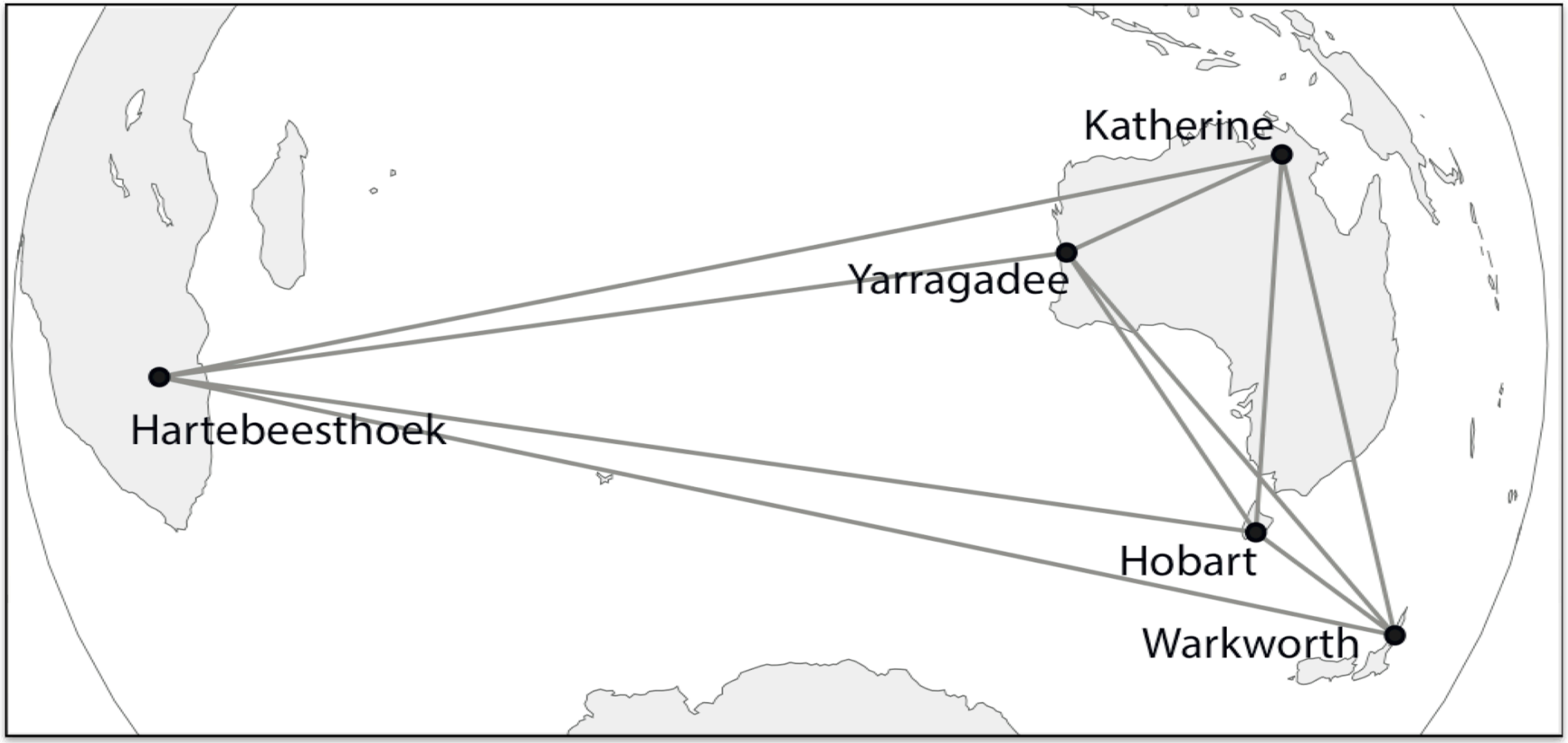
Austral VLBI 2015



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Austral VLBI 2015

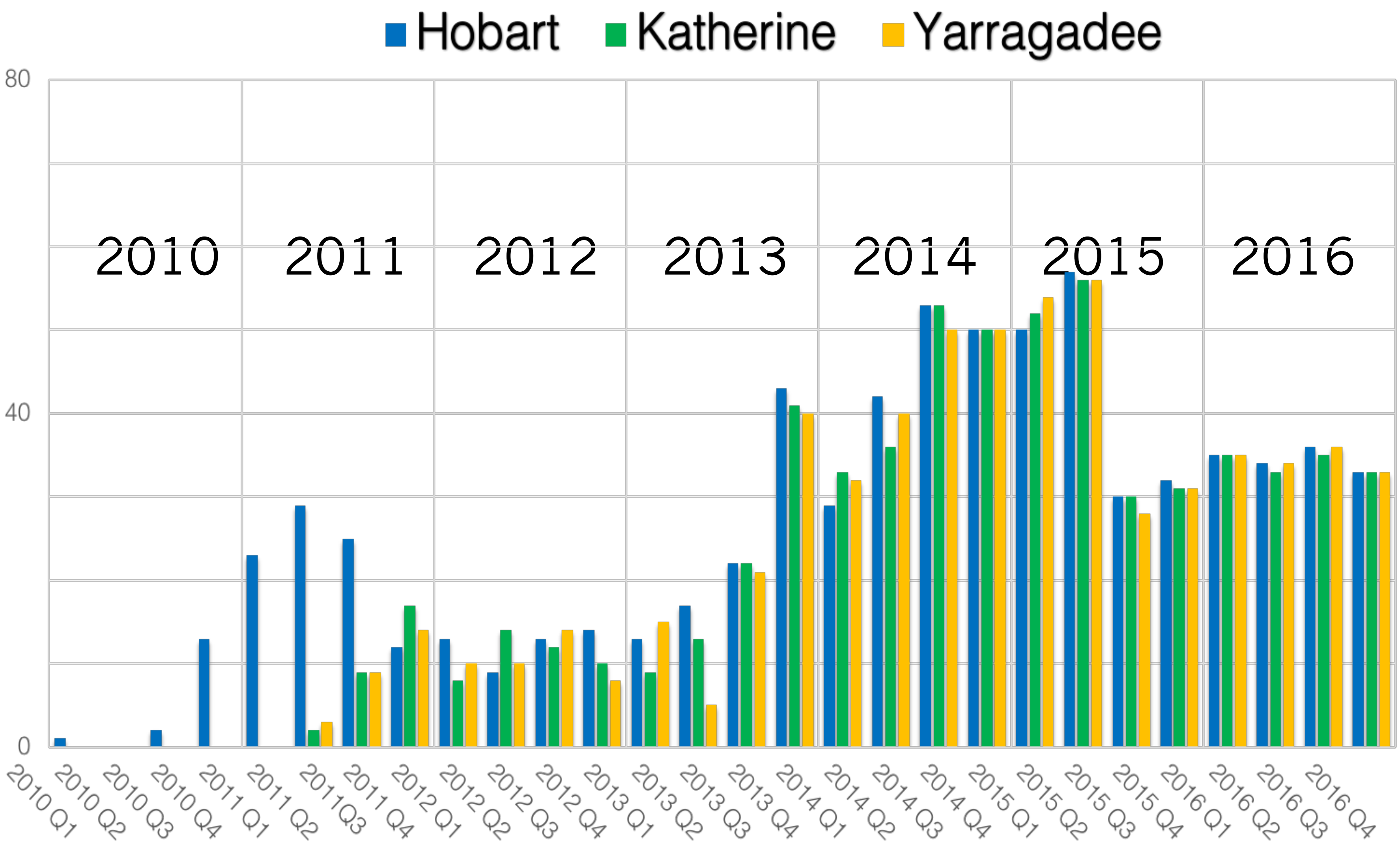
IVS observations (~100 days per year), plus

120 days per year AUSTRAL (7/2014 to 6/2015)

AuScope (100%) + Warkworth (50%) + Hart15 (50%)

Aims:

- 11 days of astrometry to monitor and enhance the southern hemisphere celestial reference frame (~6 sessions including Parkes 64m);
- 184 days of geodesy to improve the southern hemisphere terrestrial reference frame and the baseline time series;
- 4 x 15-day CONT-like sessions to densify the time series and investigate a range of observing strategies.



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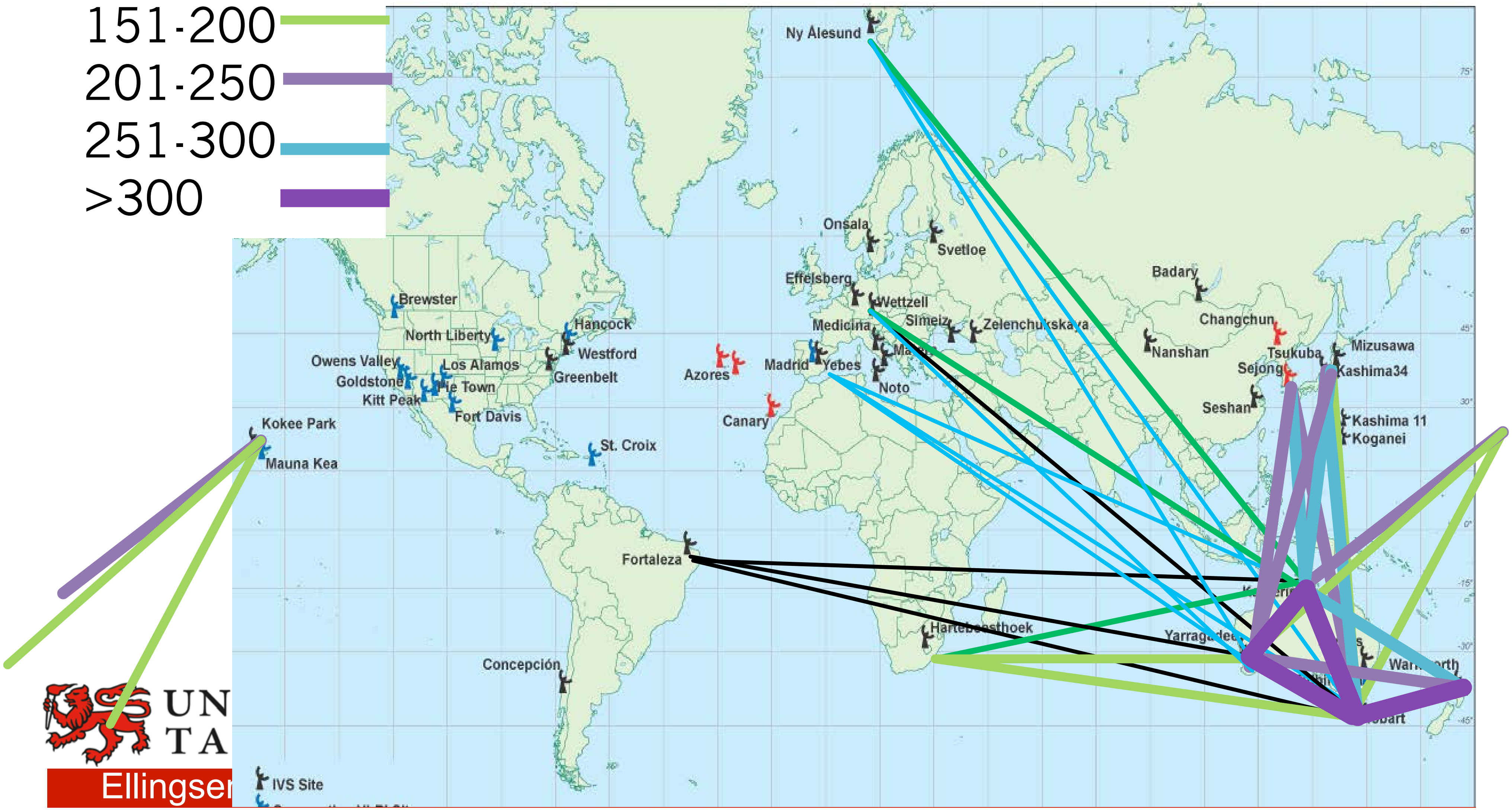
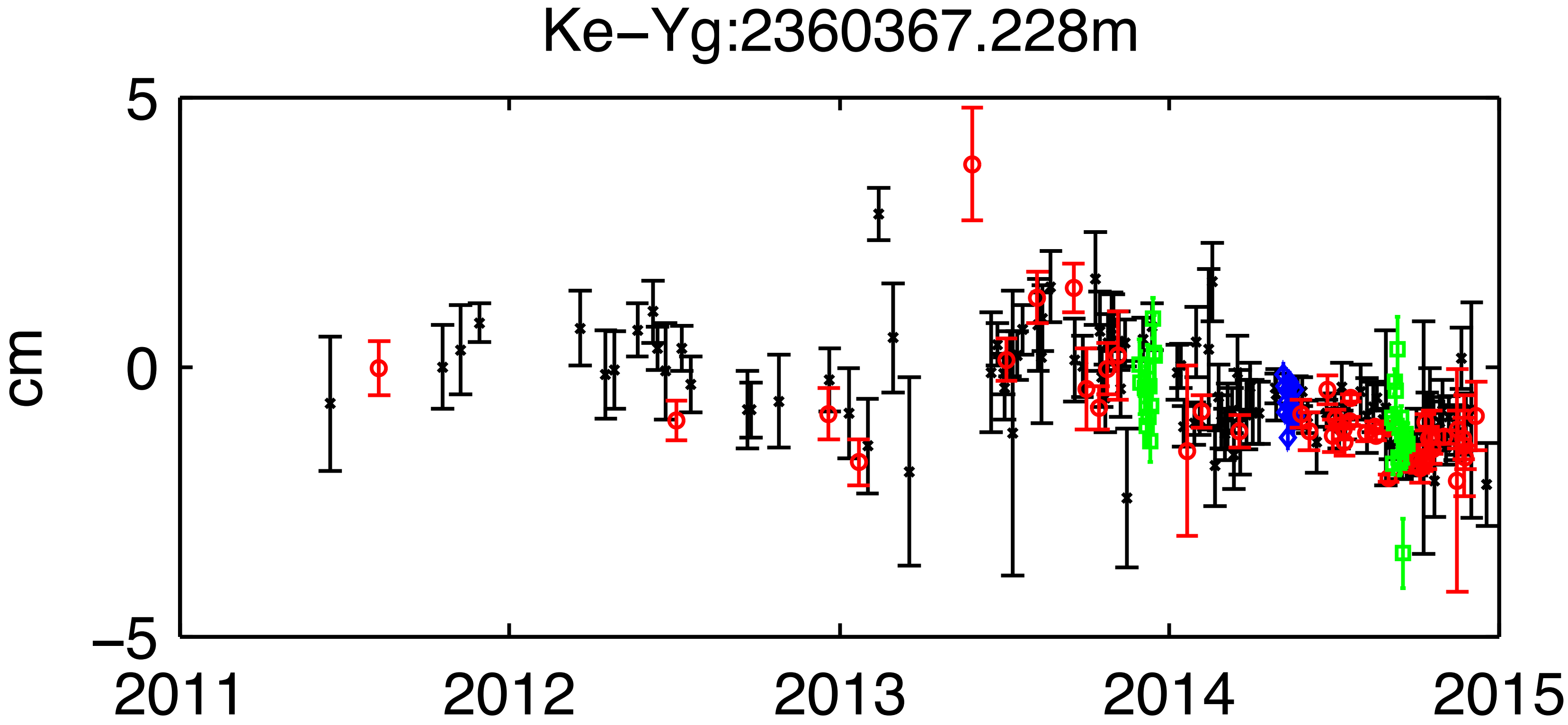
Links to Asia-Oceania VLBI network stations are important. R1714: number of observations

0-50	black
51-100	light blue
101-150	green
151-200	light green
201-250	lilac
251-300	teal
>300	purple



Dense time-series

- Identify systematics, trends on shorter timescales
- Comparison of GNSS and VLBI



= R1/R4

= CONT14

= AUST

= AUST Cont

From Plank et al 2015. IAG Symposia (REFAG), accepted

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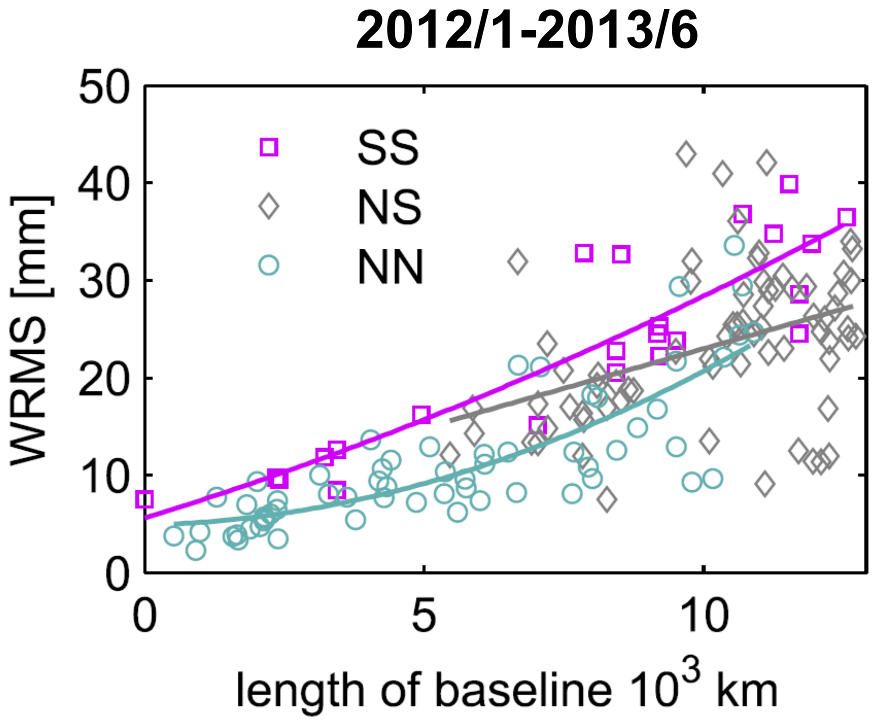
Better Results in the South

Baseline lengths from IVS R1 & R4 sessions ***[Plank et al., Adv Space Res 2015]***



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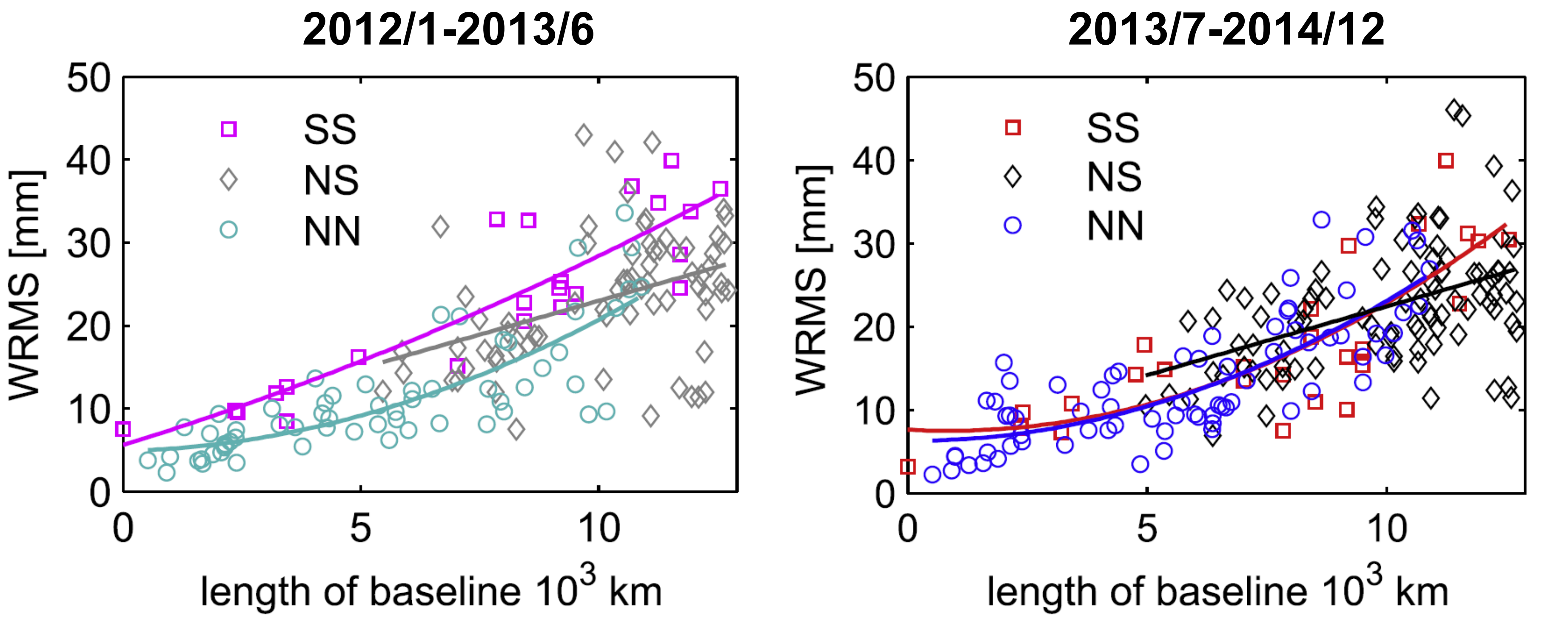

The addition of more southern stations has significantly improved the results!

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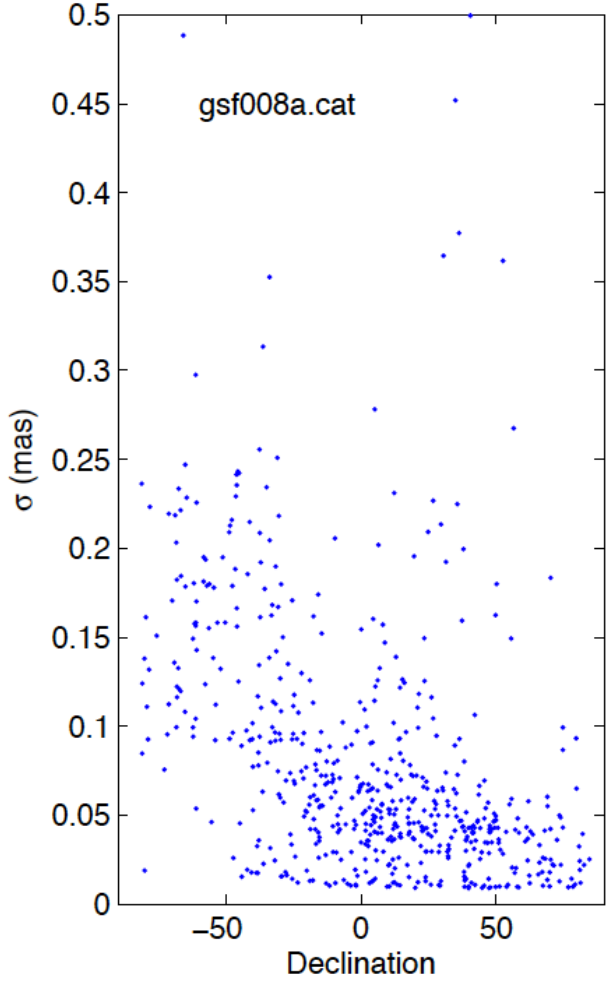
Astronomical VLBI can improve the quality of geodetic VLBI by flagging sources that have jets on the sub-mas scale.

This is critical for using the International Celestial Reference Frame (ICRF).

Southern Quasars



ICRF2: 3414 sources (mostly quasars) (Ma et al. 2009, IERS Tech. Note 35)

Southern hemisphere sources have much lower positional stability

- Fewer observations (√N effect)
- Systematics (quasar structure)

Also there are a lot fewer of them (good or bad)!

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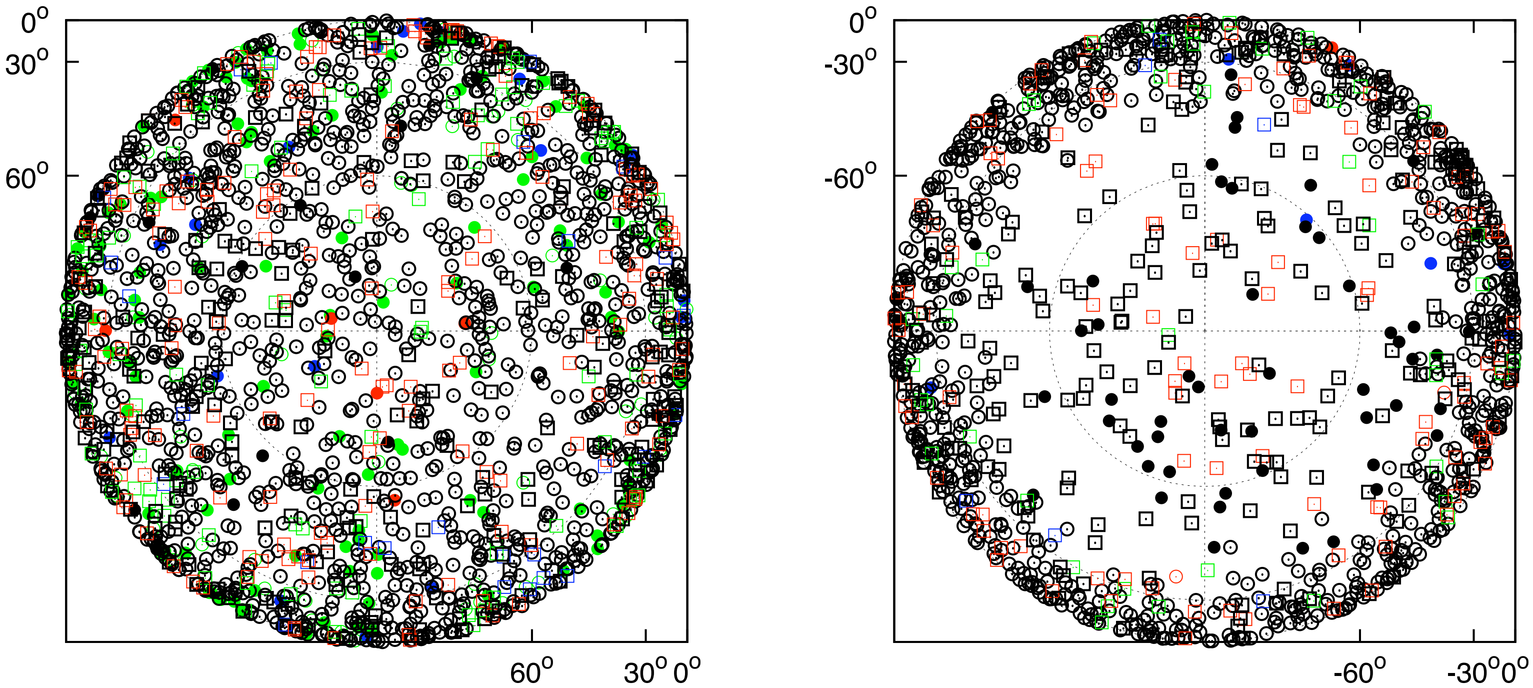
ICRF2 – quasar quality

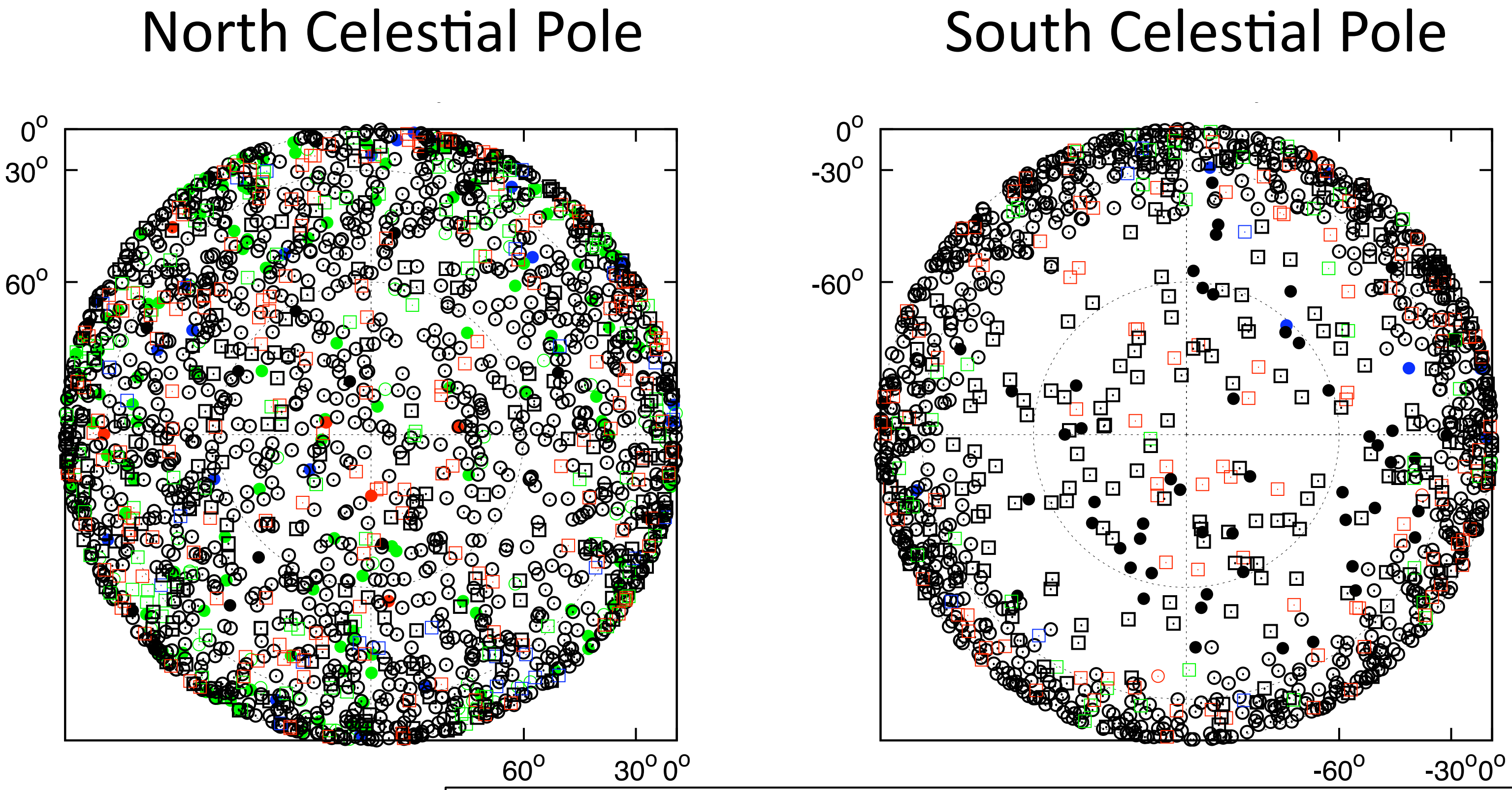
North Celestial Pole

South Celestial Pole



UTAS

ICRF2 – quasar quality



astrophysics → Structure Index

geodesy → Baseline error (mm)

	Good	Maybe	Bad
Structure Index	< 1.5	1.5 – 3	> 3
Baseline error (mm):	0.5	0.5 – 3	>3

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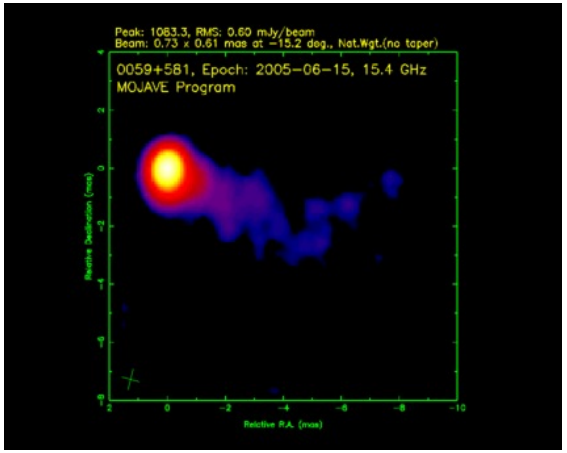
UTAS

Uncooperative quasars

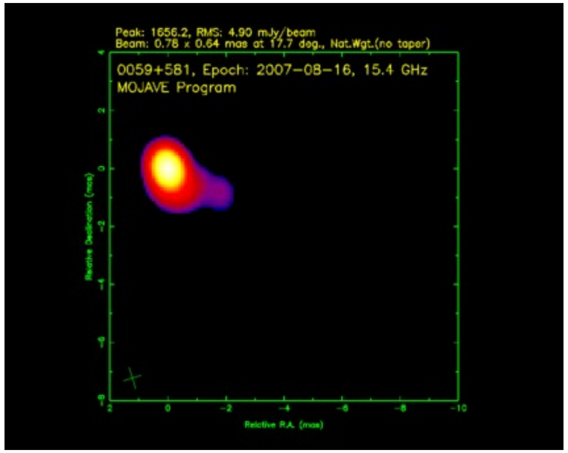
What you want them to be
- ✧ Bright point sources
- ✧ Fixed in space and time

What they are
- ✧ Supermassive black holes
- ✧ Jets ➔ structure
- ✧ Evolve on human timescales (months / years)

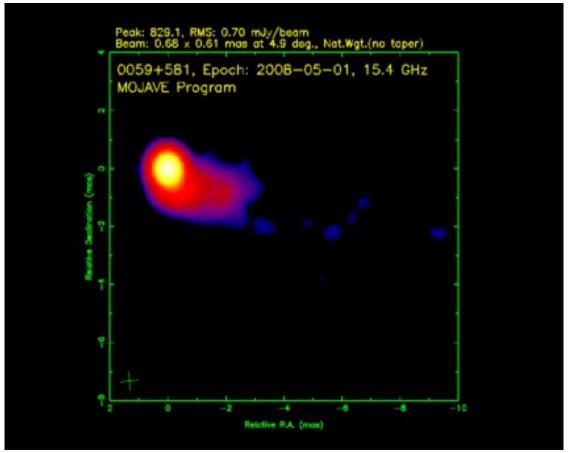
2005



2007



2008



Lister et al. (2009)

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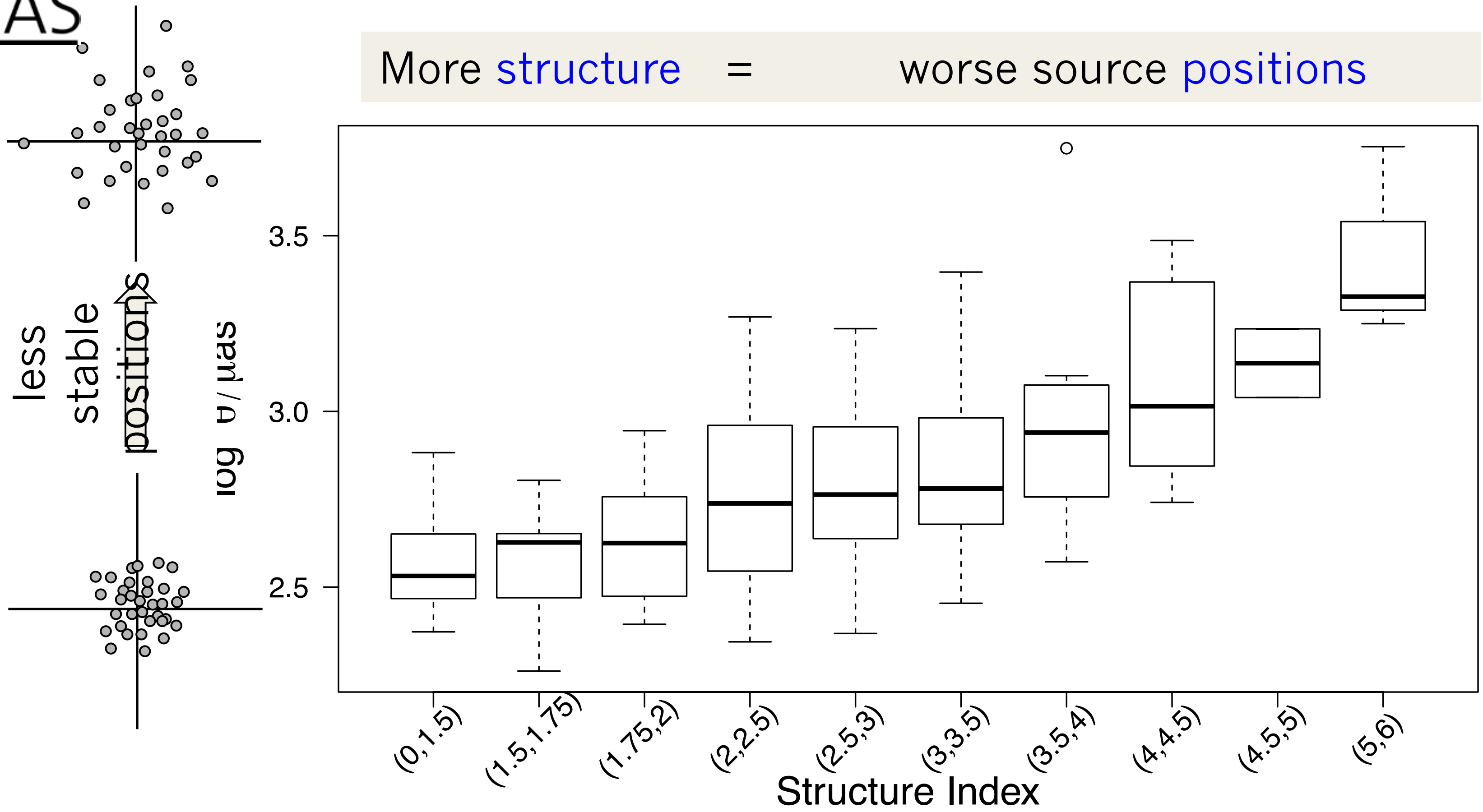
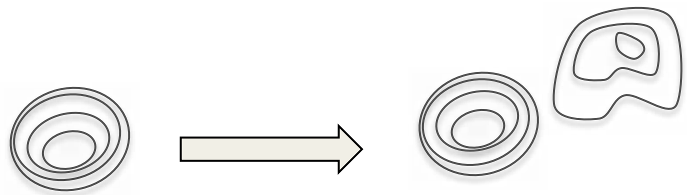
UTAS

Source structure : effects on CRF

Schaap et al. 2013, MNRAS, 434, 585

More structure = worse source positions





more structure

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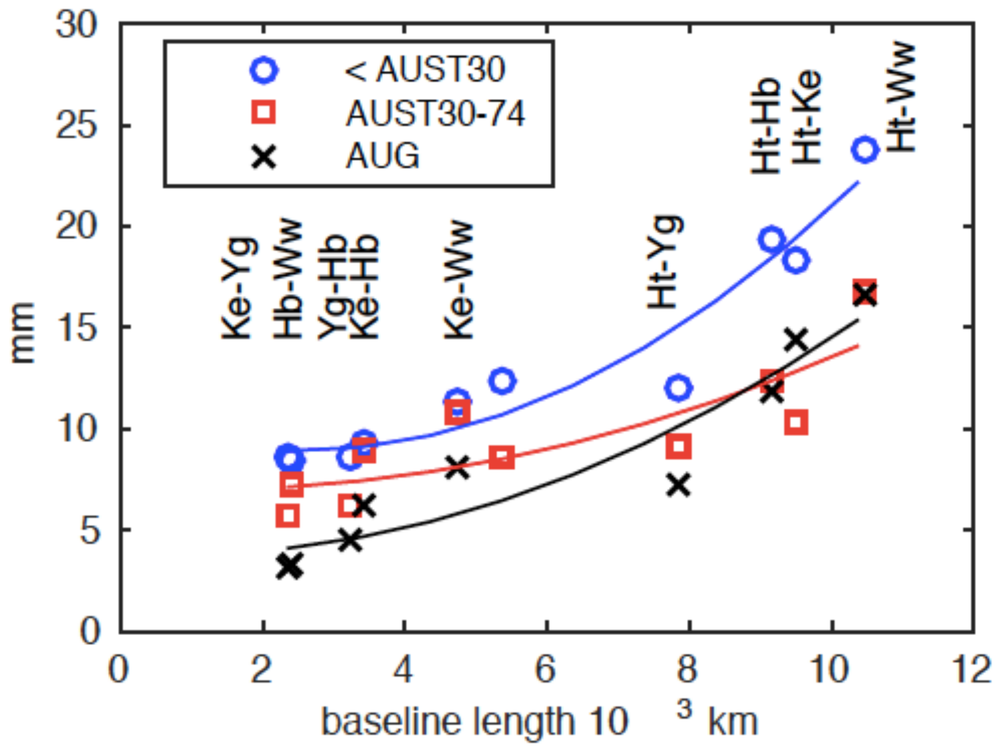
Scheduling Optimisation

Scheduling strategy changed after AUST30. Stronger sources and algorithm changes gave a 2 x increase in scans per day.



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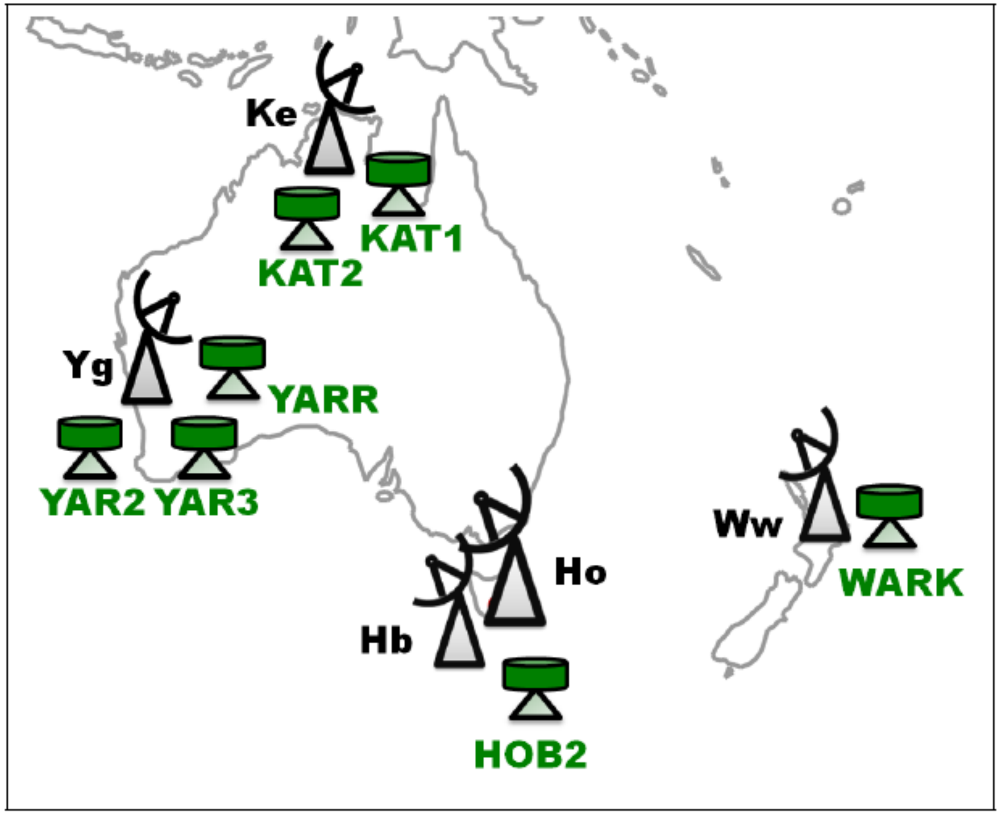
Inter-technique Ties

High cadence time series (2011-2015) allows for a unique comparison between VLBI and GNSS baselines

Inter-technique ties are a major issue for the ITRF



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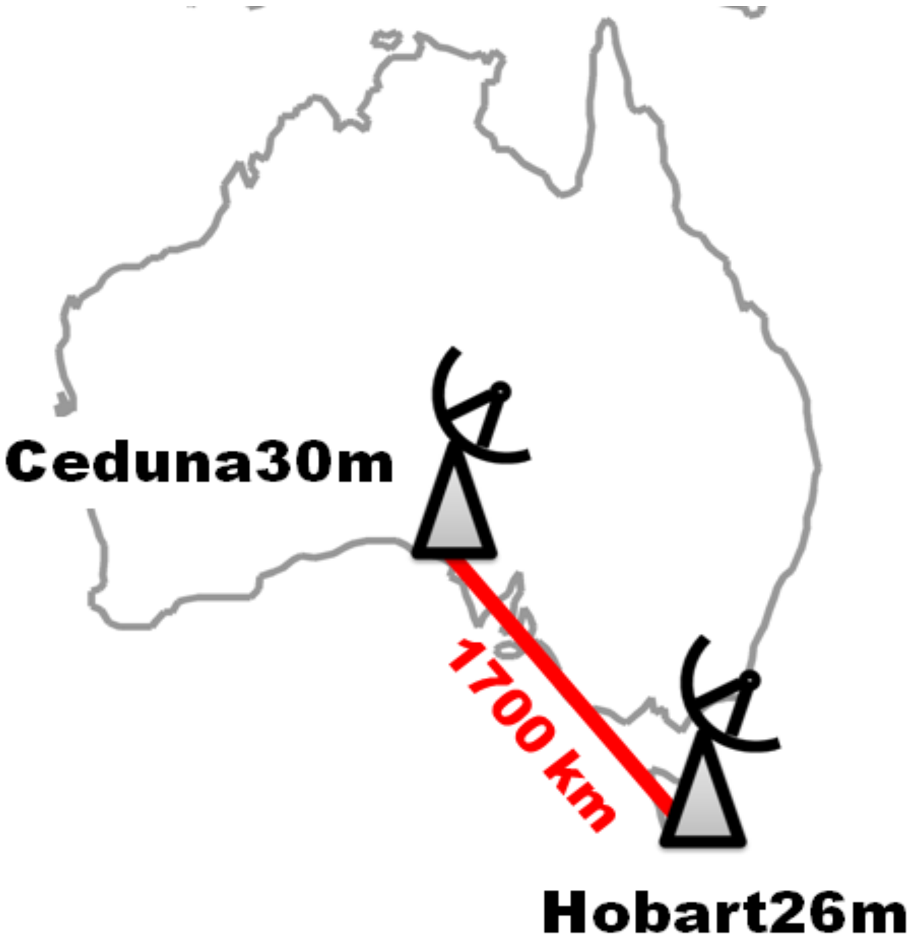
VLBI Satellite Tracking



‘Proof of concept’

Single baseline

L-band receivers

GPS & GLONASS satellites

3 successful sessions (2-4 hours)

From scheduling to analysis

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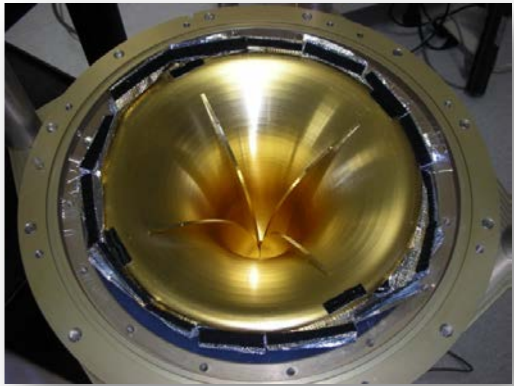
What Next for AuScope?



Bringing AuScope closer to VGOS

Broadband upgrade to 3 AuScope telescopes:

Callisto feeds, new DBBC3 systems, Mark6 or Flexbuf

Trial source structure mitigation strategies:

- Avoid/flag scans when a baseline resolves the jet
- Sidereal scheduling trials
- Variability monitoring (feedback)

Further scheduling optimisation tests with ViEVS and eRemoteCtrl

Trial shared operations

AUSTRAL is back, 12 per year, SHAO correlation, Thanks!

More twin (sibling) telescope trials with Hobart 12m and 26m

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Thanks to our Geodesy collaborators:

Jim Lovell, Jamie McCallum, Lucia Plank, Elizaveta Rastorgueva-Foi, Stas Shabala : *University of Tasmania*

David Mayer, Johannes Böhm : *Technical University of Vienna*

Oleg Titov : *Geoscience Australia*

Jonathan Quick : *Hartebeesthoek Radio Astronomy Observatory*

Stuart Weston, Sergei Gulyaev, Tim Natusch : *Auckland University of Technology*

Cormac Reynolds, Hayley Bignall : *Curtin University*

Jing Sun : *Shanghai Astronomical Observatory*

Alexander Neidhardt : *Technical University of Munich*

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The point of this talk:

1. It would be a serious degradation of the current **Long Baseline Array** (LBA) if we lose Mopra.
2. If we could use Mopra for VLBI roughly 6 months/year there would be a lot of new things to try!

http://users.on.net/~cdadsl/livepages/webcams.html

Thanks!

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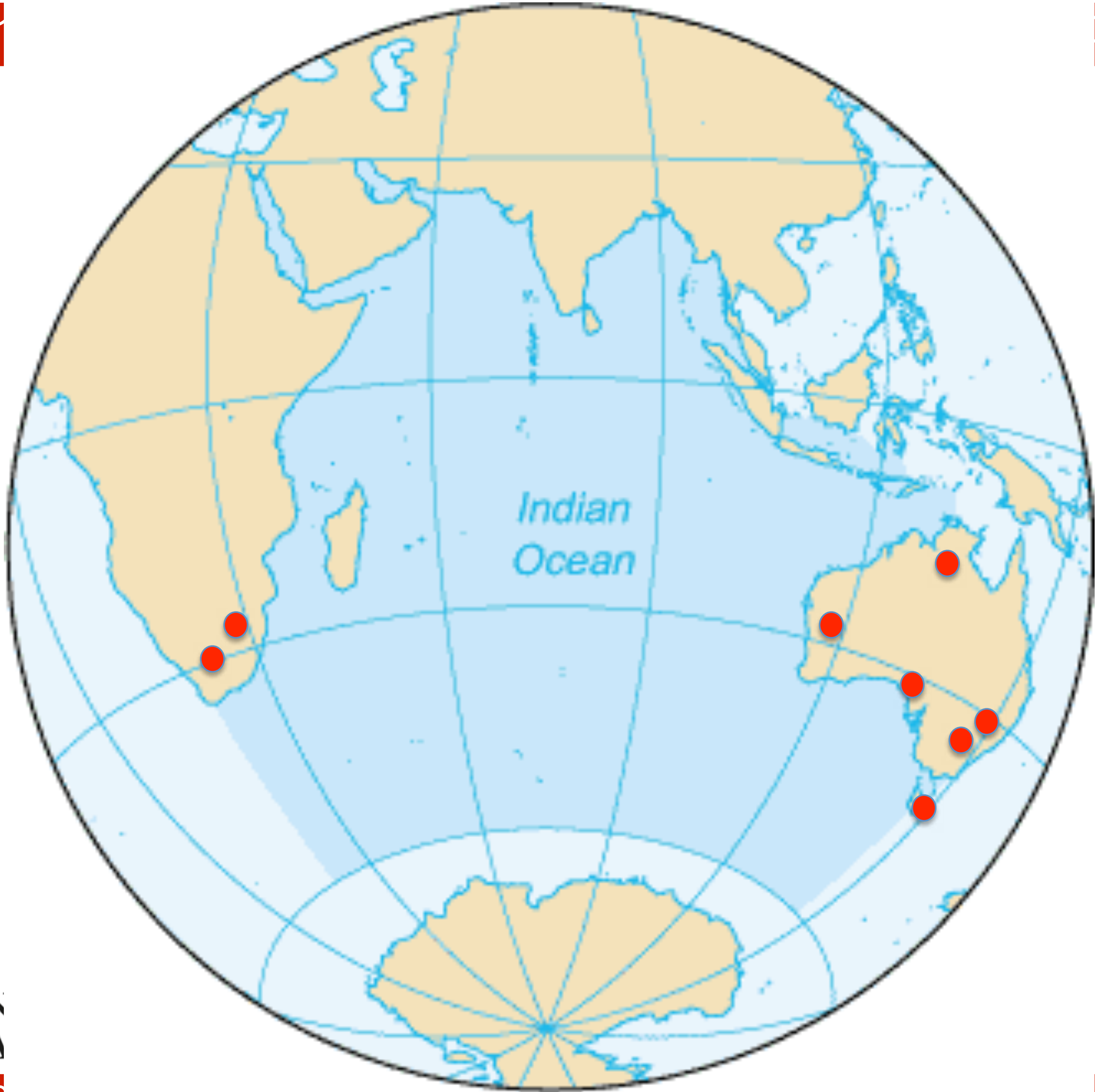

Ellingsen, Lovell, McCallum, Plank, Shabala, Dickey
and Local Group

The Next Step: VGOS

The VLBI Global Observing System

Next Generation Geodetic VLBI Technology

- Continuous operations
- Centralised remote operations
- **Broad** bandwidths and high data rates (2.5 to 14 GHz)
- Fast data turnaround
- Feedback:
  - Closing the loop from scheduling to analysis to scheduling
  - During observations: Dynamic scheduling
- Most effective use of sites with twin telescopes

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