The structure and motions of the Milky Way & Local Group

Simon Ellingsen

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Overview

- Science :
  - Astrometry and Very Long Baseline Interferometry.
  - The structure of the Milky Way.
  - Motion of the Local Group and "near-field" cosmology.
- Technical
  - Is VLBI part of SKA phase 1?.... Yes!
 - Assumptions and likely practical limitations

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Astronomy vs. Astrophysics

- What is the difference between astronomy and astrophysics?

"Actually they all look alike to me."

Studies of the Milky Way and Group

Astrometry with VLBI

- With the ATCA absolute positions are accurate to around 0.4'' and relative positions to around 0.05''.

- VLBI gives intrinsic resolution around 3 orders of magnitude greater.

- State of the art VLBI astrometry at centimetre wavelengths can achieve absolute accuracies of 0.000005'' (5 µas).

- If we were to take a football and place it on the Moon that would have an angular size of ~150 µas

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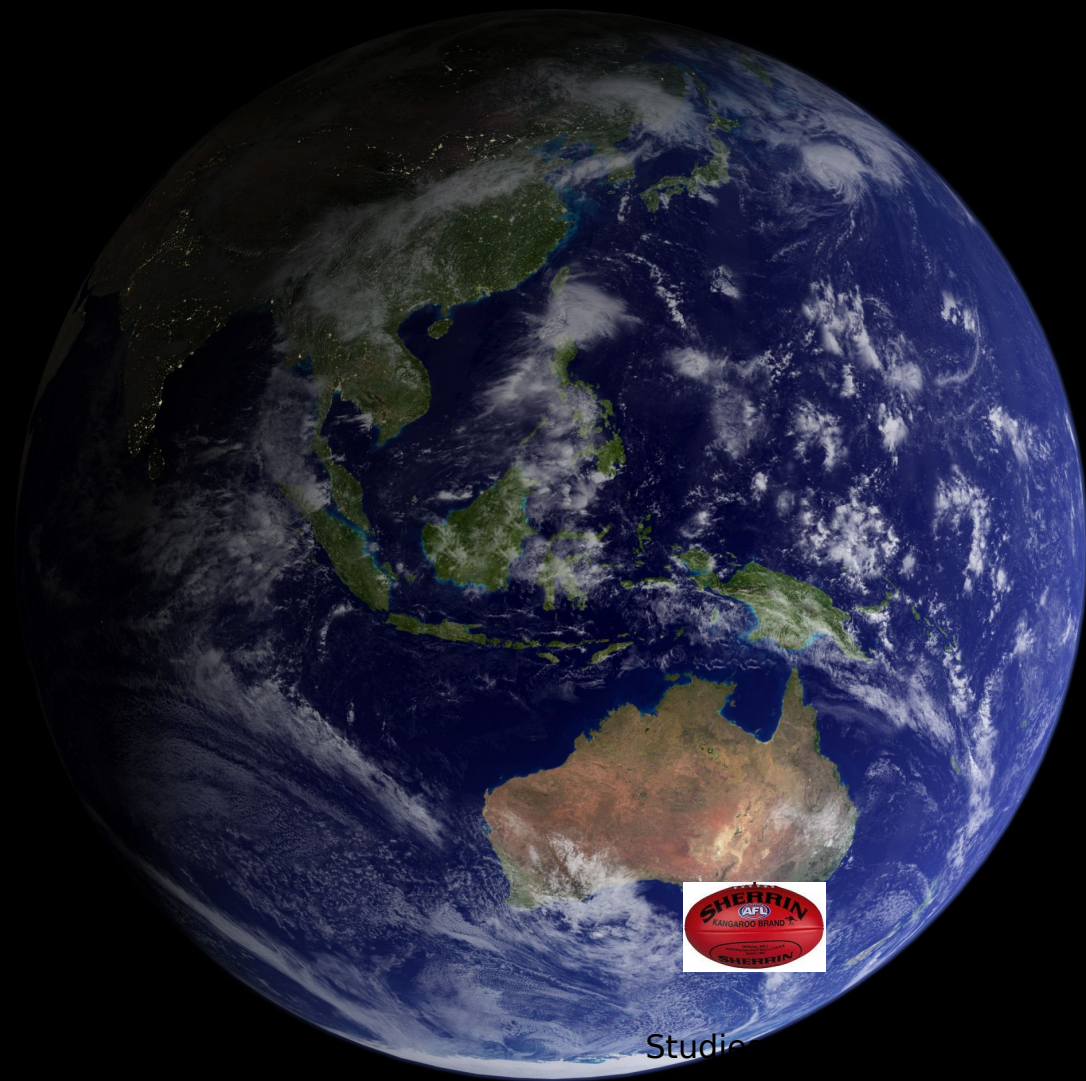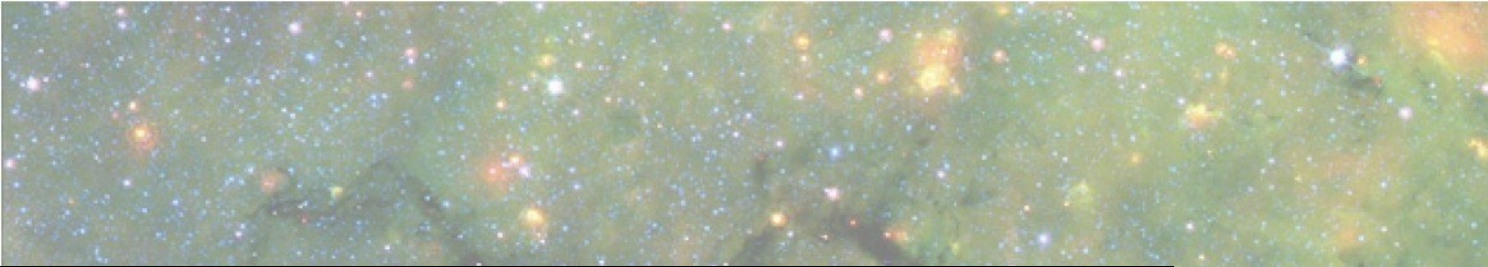
At the distance of the moon an angular size of 5 μas corresponds to a linear scale of < 1 mm.

5 μas - That is smaller than a bee's endophallus!

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Structure of the Milky Way

- Objects in the Milky Way are nearby :
  - Great for sensitivity and resolution.
  - But uncertainties in distance are a major issue.
- With VLBI accurate distances have been measured to more than 100 star formation regions.
- The first trigonometric parallax to a southern star formation has recently been measured (Krishnan et al. 2015, ApJ in press ; arXiv:1503.05917).
- A concerted effort is required to "catch-up" to the north prior to SKA1-MID coming online.

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Structure of the Milky Way

Trigonometric parallax of G339.88-1.26

Krishnan et al. 2015, ApJ in press ; arXiv:1503.05917

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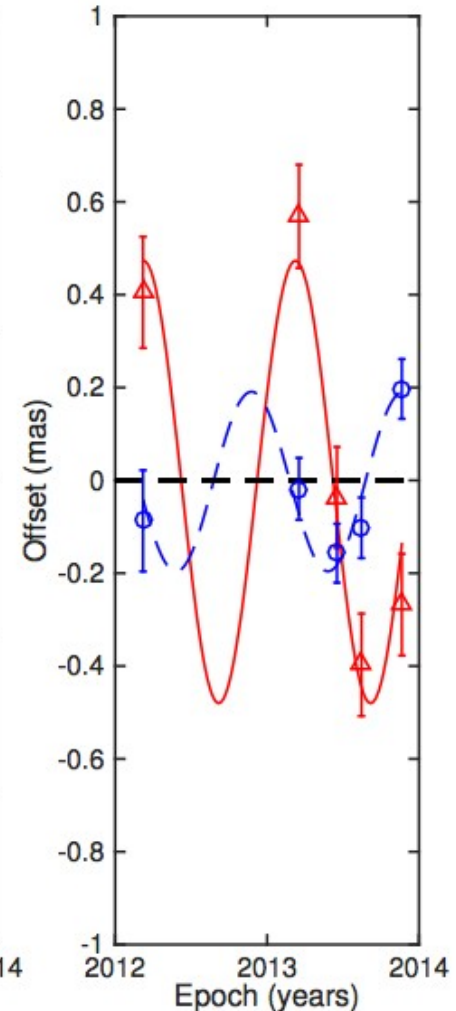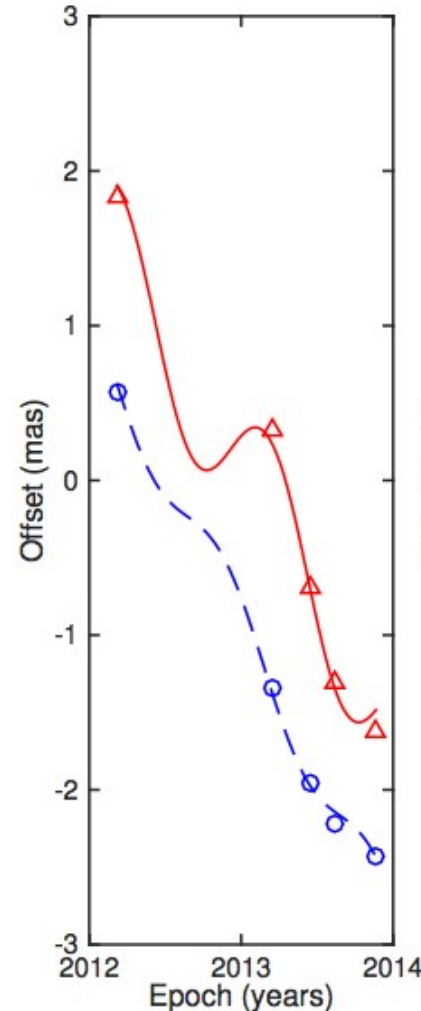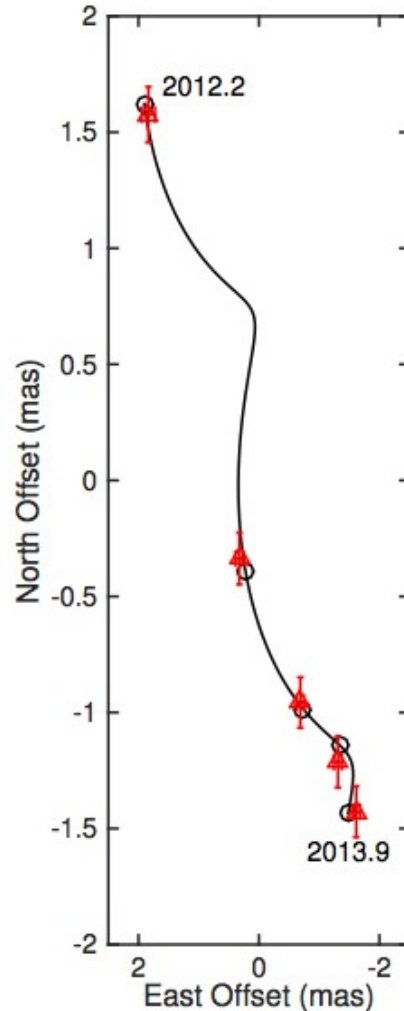
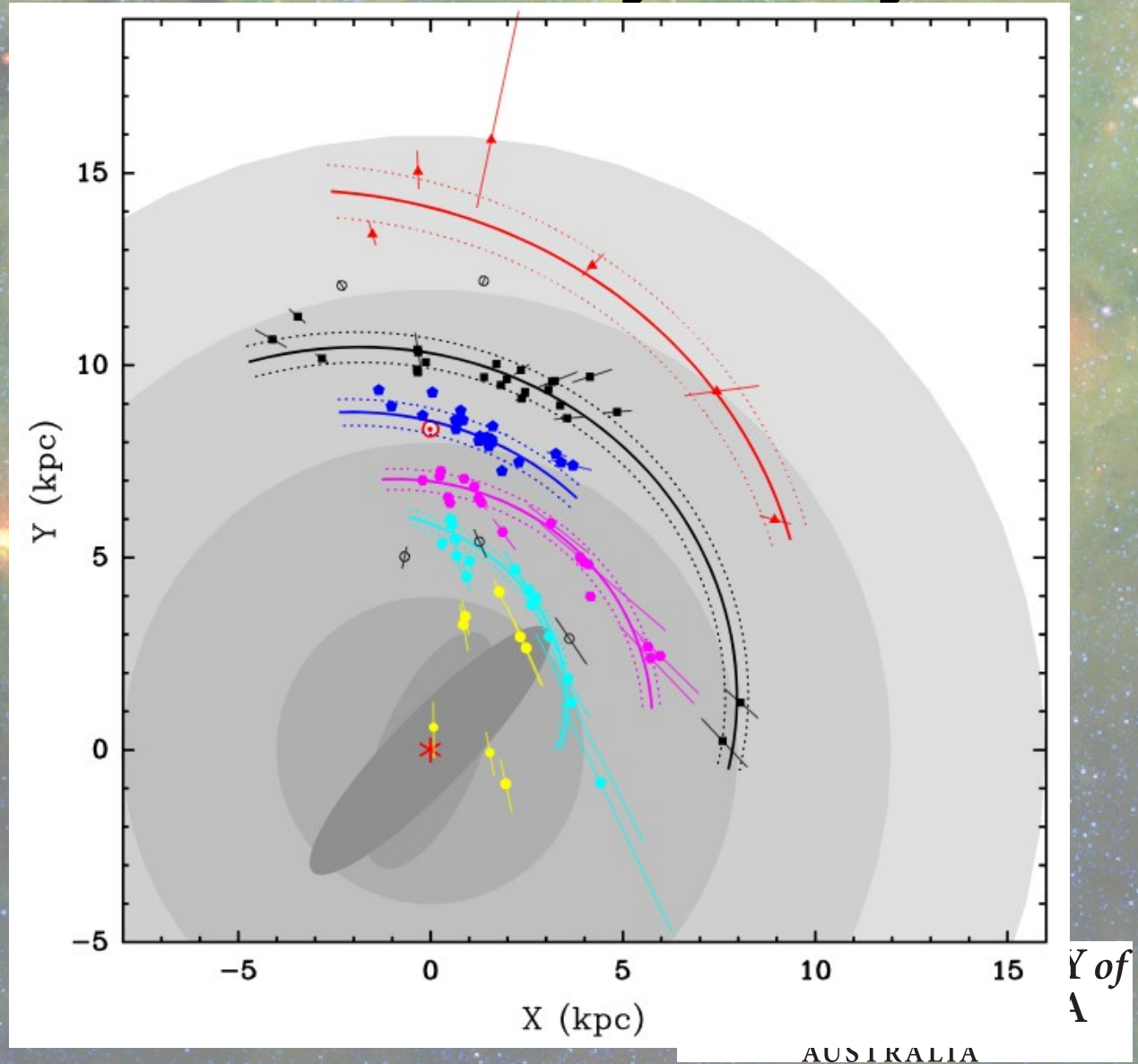# Structure of the Milky Way

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

Not just star formation!

- The major uncertainty in the tests of GR from the Hulse-Taylor binary pulsar are due to Galactic motion.
  - Improved Galactic motion parameters result in a factor of 3 reduction in the uncertainty of the orbital decay measurement.
- The distance to the Pleiades is important for stellar evolution. Recent VLBI parallax distances (Melis et al. 2014, Sci, **345**, 1029) are 10% higher than Hipparcos.

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Motion of the Local Group

- Are the Magellanic Clouds on their first passage of the Milky Way?

- The Magellanic Clouds and other local group members provide a unique opportunity for studying hierarchical structure formation.

- VLBI can measure the proper motion of objects in the Magellanic Clouds to an accuracy of better than 50 μas/year

- With SKA1-mid sensitivity we will be able to detect around 100 objects in the MC and much better measure the CoM motions
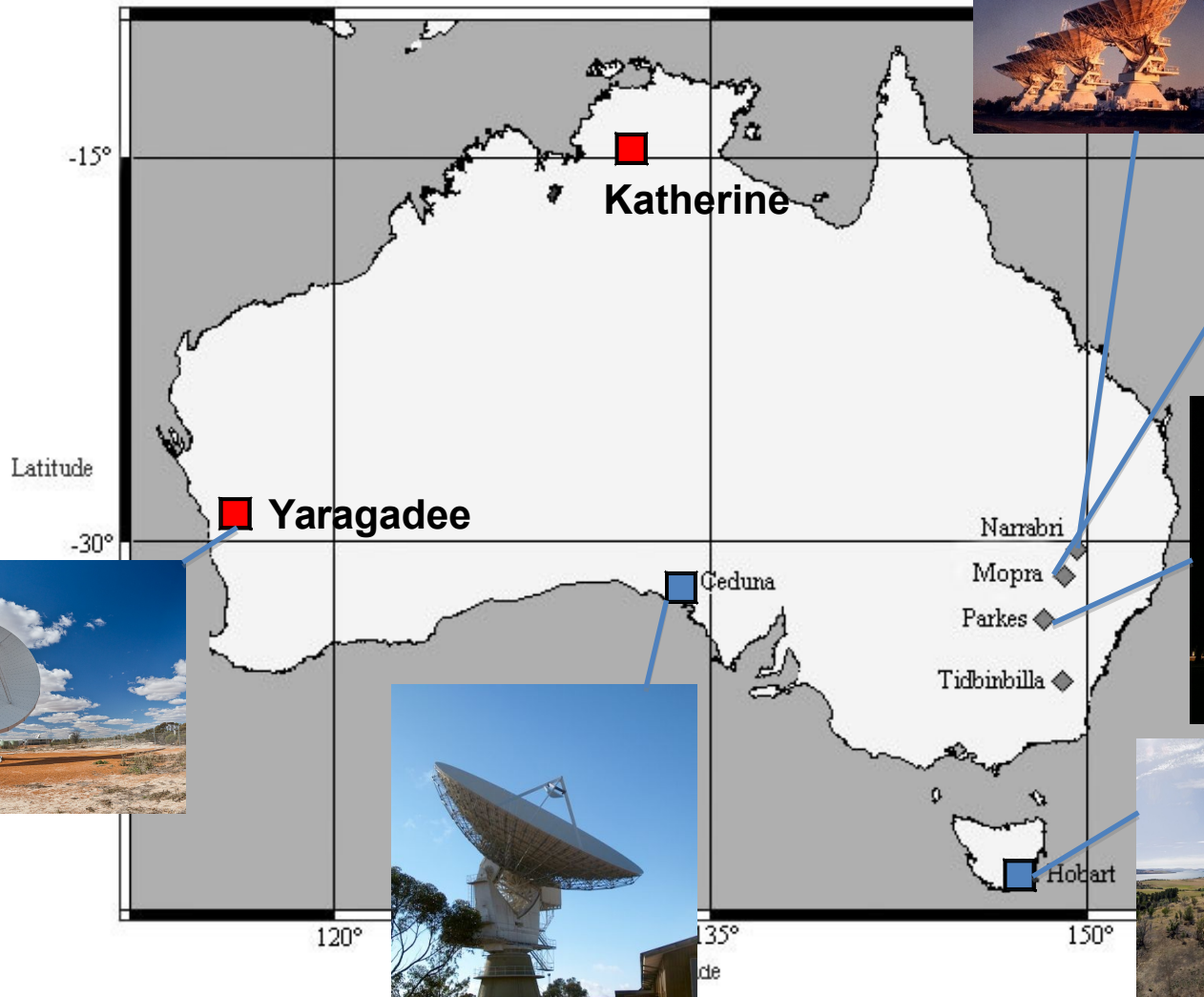
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VLBI and the SKA

- The first science from an ASKAP antenna was VLBI (Tzioumis et al. 2010).

- Also the first science from the Warkworth 30m antenna (Petrov et al. 2015, PASP in press; arXiv:1502.06802).

- VLBI requirements are modest :
  - A correlator mode to "tie" the array.
  - A suitable time/frequency standard (e.g. H-maser).
  - A recorder.
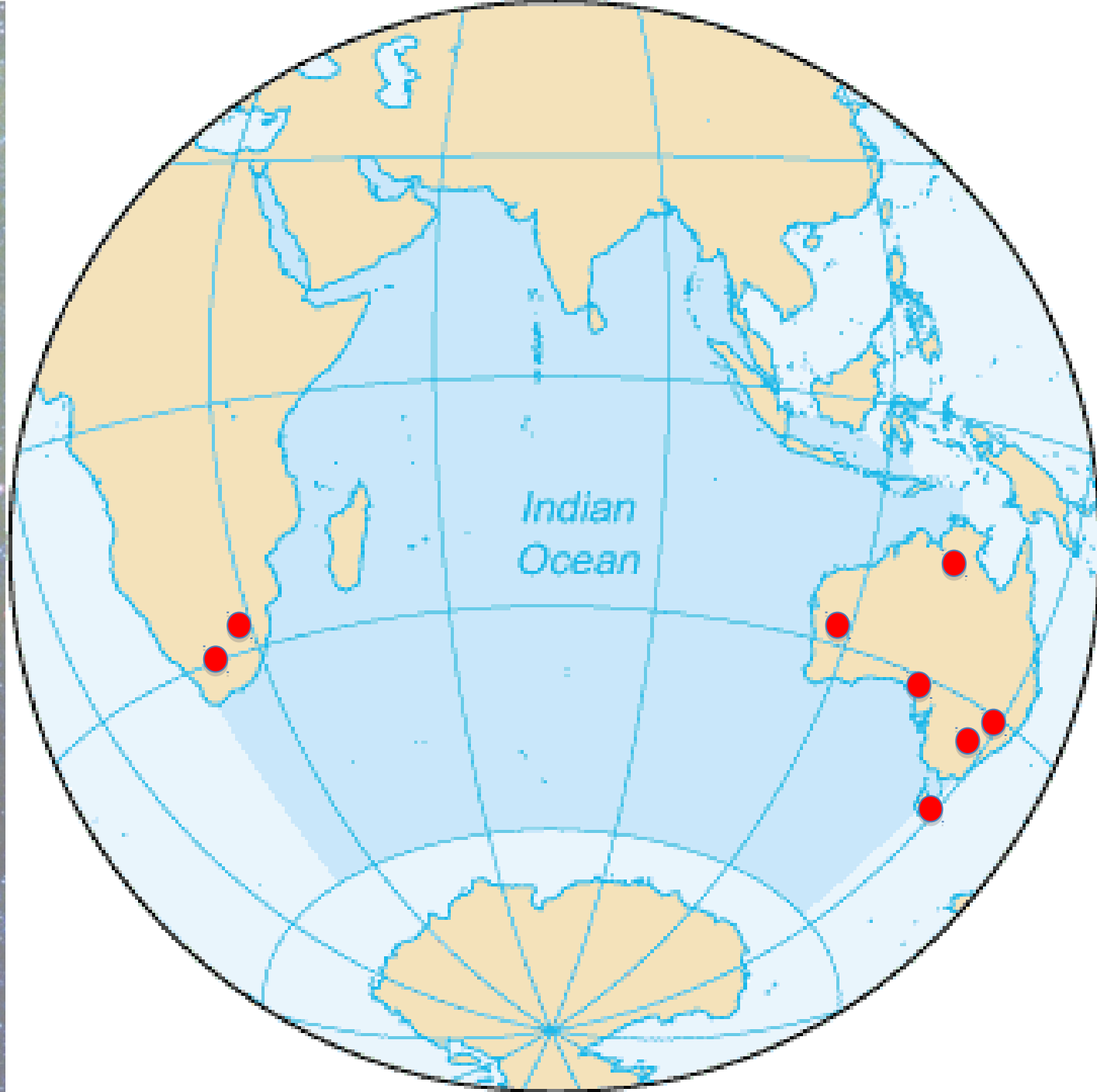
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SKA1-MID VLBI Astrometry

- It currently takes 1 day of array time (over 1 year) to measure a parallax (incl. calibration overheads).

- With SKA1-MID this drops to 4 hrs per source (after re-baselining).

- With this integration time you *also* get improved astrometric accuracy because in-beam phase calibration becomes practical.

- It will be possible to do tomography of nearby spiral arms with SKA1-MID (1% distance at 2 kpc) :
  - Complementary to magnetism and HI studies

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VLBI Telescopes in Australia

Katherine

Yaragadee

Ceduna

Narrabri

Mopra

Parkes

Tidbinbilla

Hobart

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SKA1-MID and VLBI

- Hartebeesthoek regularly participates in LBA observations, but limited mutual visibility and a lack of intermediate baselines Australia-Africa provide challenges.

- With SKA1-MID in South Africa we will see similar issues. Establishing intermediate sites as part of AVN developments would enhance science capabilities.

- SKA1-MID will open up the possibility of in-beam phase referencing at 5 cm wavelength for some sources and at SKA2 sensitivity it will be possible for all sources.

- For more details on the assumptions see Green et al. and Loinard et al. in the SKA science book (arXiv:1504.00485 and arXiv:1412.6481 respectively).

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Conclusions

- VLBI between SKA1-MID (or parts of it) and the LBA will provide opportunities for early SKA science.

- East-west baselines are important for parallax measurements.

- Our knowledge of the scale and structure of the Milky Way impacts a broad range of astrophysics.

- Having SKA antennas at remote sites in Africa and beyond will maximise the science return from VLBI with the SKA.

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