VLBI Working Group: SKA-VLBI key science areas

Zsolt Paragi et al.
Joint Institute for VLBI ERIC (JIVE)

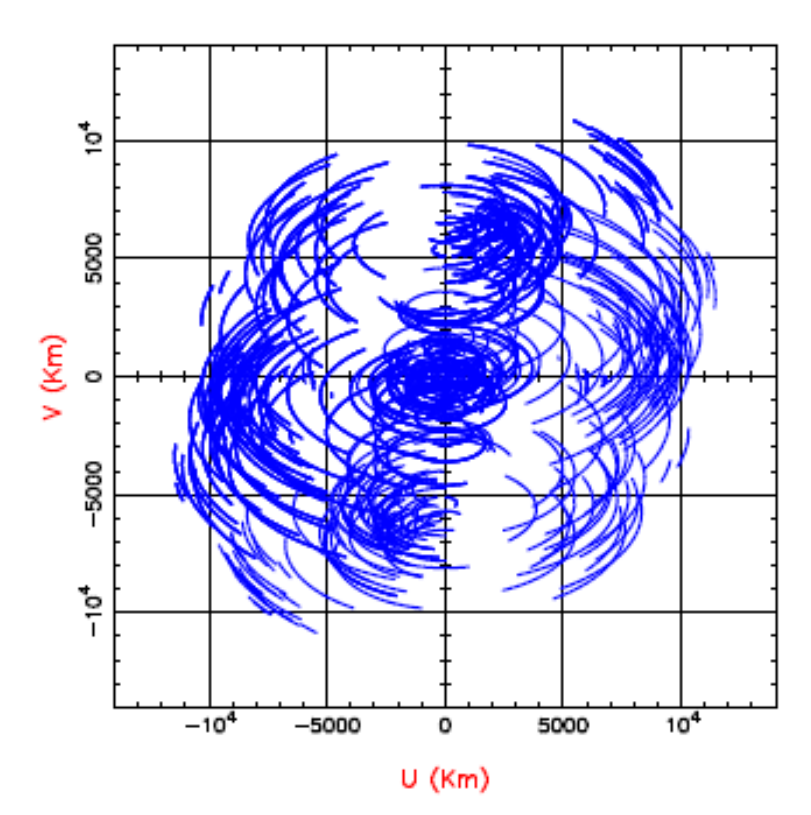
SKA-VLBI Working Group

- Evolved from VLBI focus group
- Formal WG since June 2015
  co-chairs : Cormac Reynolds (ICRAR)
  Zsolt Paragi (JIVE)
  SKA contact: Jimmy Green

"VLBI WG is interested mainly in the technique" – WRONG!

We are fully science-driven.

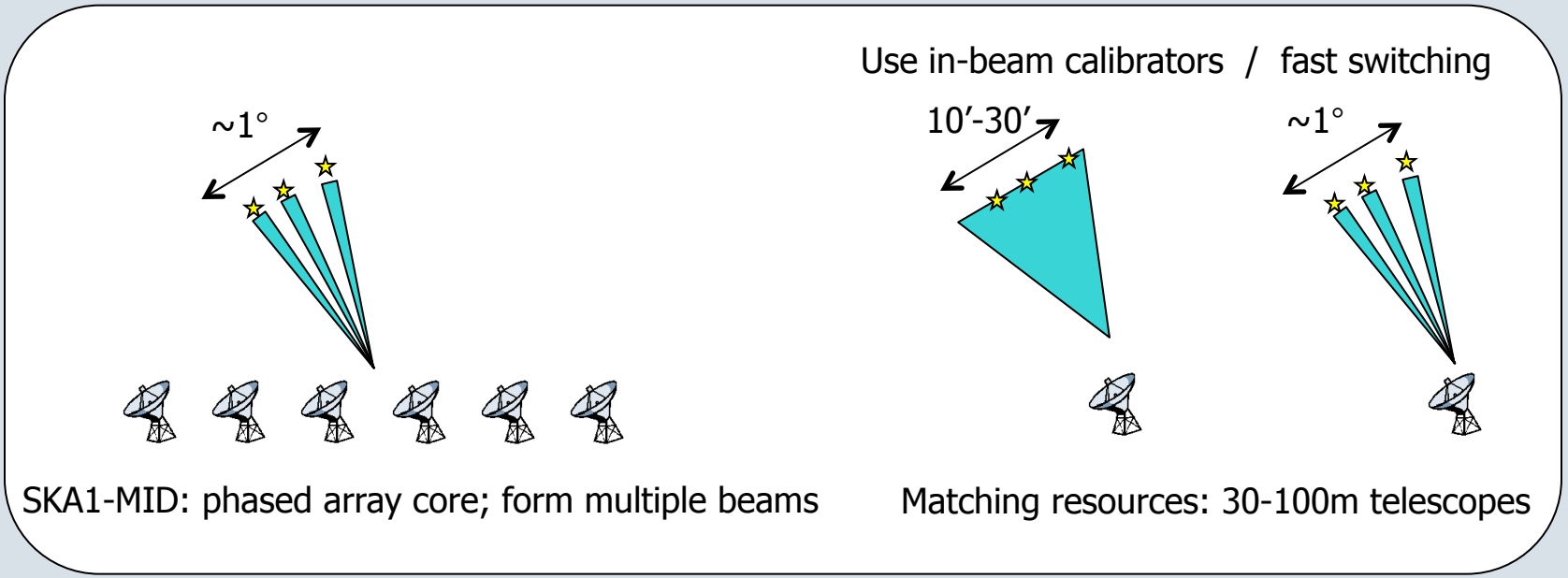
VLBI with the Square Kilometre Array



Ultra-sensitive VLBI allowing access to the Galactic Centre and the southern sky

"Very Long Baseline Interferometry with the SKA", Paragi et al. 2015, SKA Science book

How to do SKA-VLBI (Phase I.)



Real-time or "e-shipping" transfer to data processor centre (e.g. JIVE)

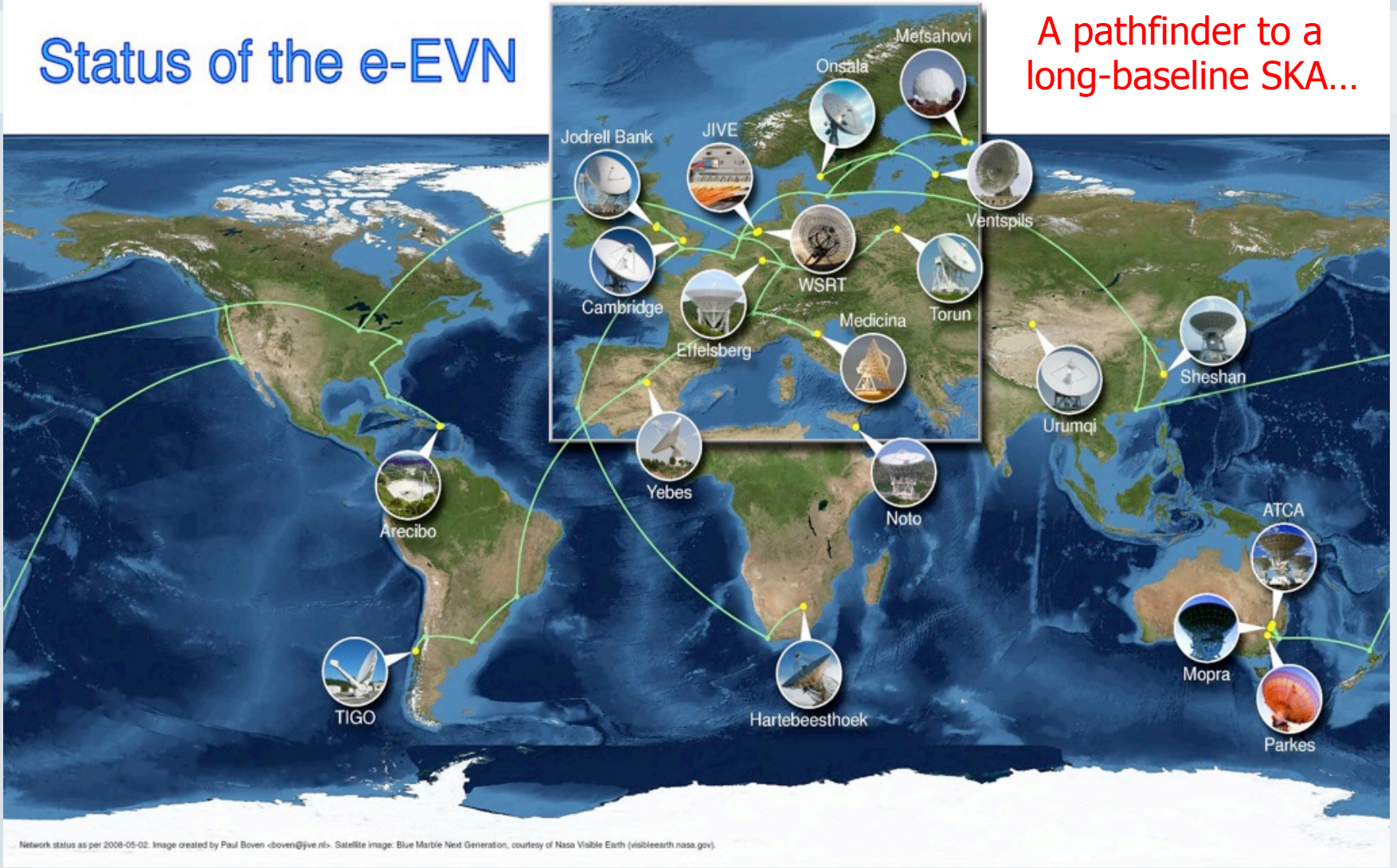
- SKA1-MID baselines up to 120-150 km
- SKA-VLBI baselines up to ~10000 km

→ a range of angular scales, but, a limited number VLBI phase-centres

- Full SKA goal: all angular scales, mas imaging of the full FoV

Status of the e-EVN

A pathfinder to a long-baseline SKA…



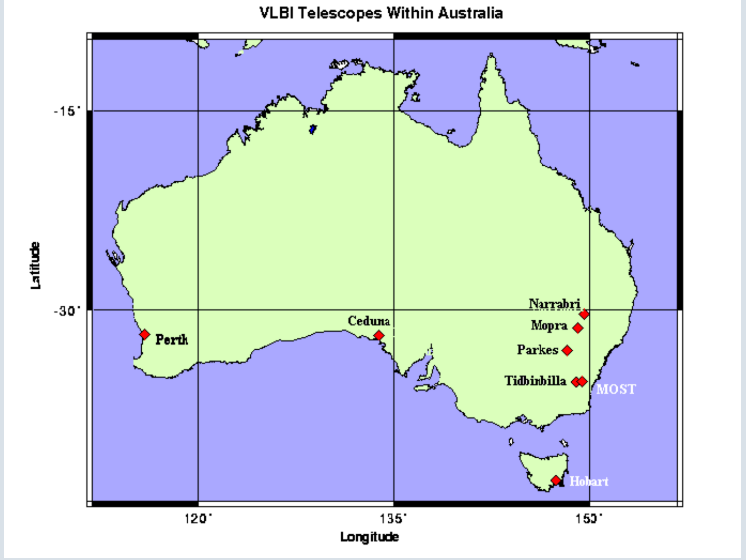
The basic principle of realtime e-VLBI correlation on global scales have been demonstrated in EXPReS/NEXPReS projects (2006-2013)

Matching resources / operations

- European VLBI Network (EVN)
- Long Baseline Array (LBA)
- African VLBI Network (AVN)
- Individual telescopes from CVN/JVN/ KVN…

We need an operational plan!

- Agreements with correlator centres
- Agreements with networks for fixed observing sessions + OOS
- Proposals / Scheduling / Support / Archiving / Data rights?
- Through a revived *Global VLBI Working Group*?

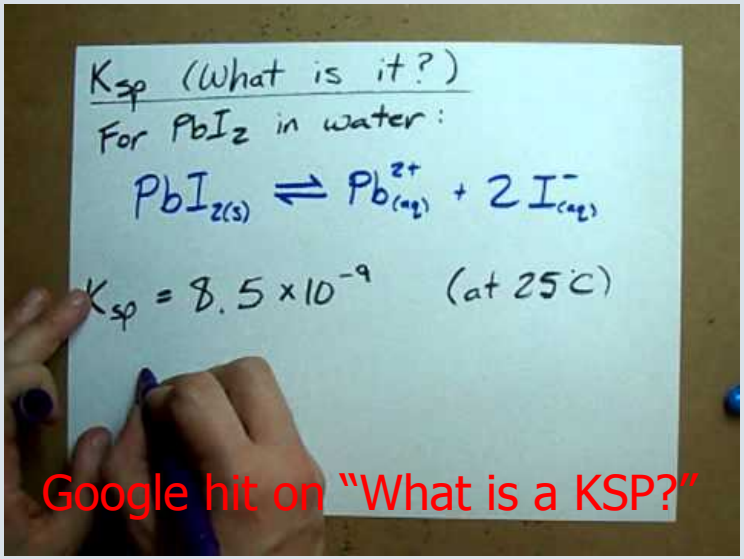


"What is a Key Science Project?"

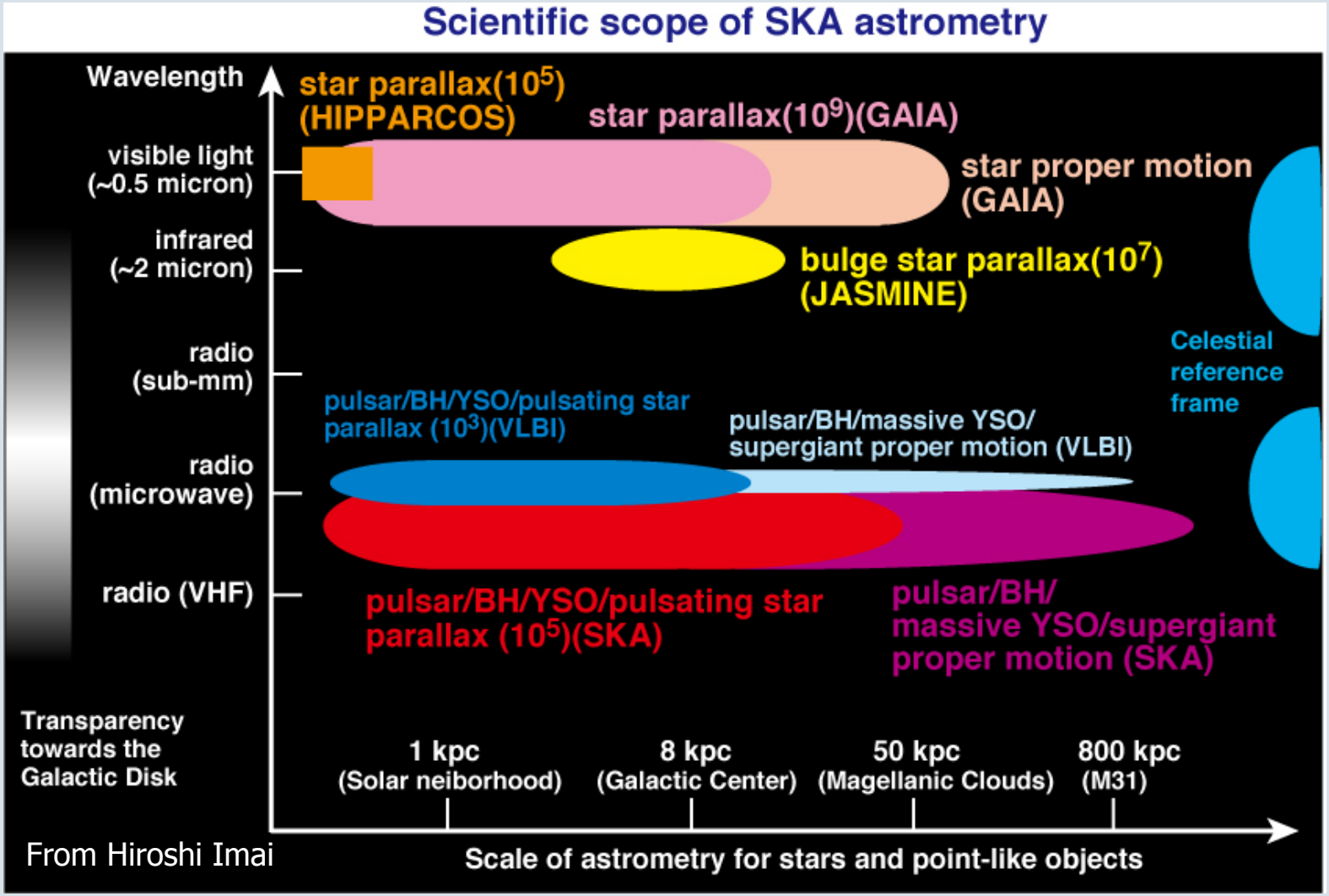
- What fraction of time SKA1-MID will dedicate to VLBI?
- How many hours of support will come from other networks?
- Min. 240h/yr EVN & LBA support should be possible, making it >1000h for 5yr duration (KSP domain, but not per science proposals)
- African VLBI Network (AVN) may support even more, but only a few telescopes will be there initially

We require a number of observing classes:

- KSPs, GOTs, TOOs, "OOS" (not TOO, but time coordinated with other facilities for multi-band projects), triggered, and commensal observations
- Will be part of our KSPs absorbed by other groups of the relevant scientific interest?



SKA-VLBI Astrometry!

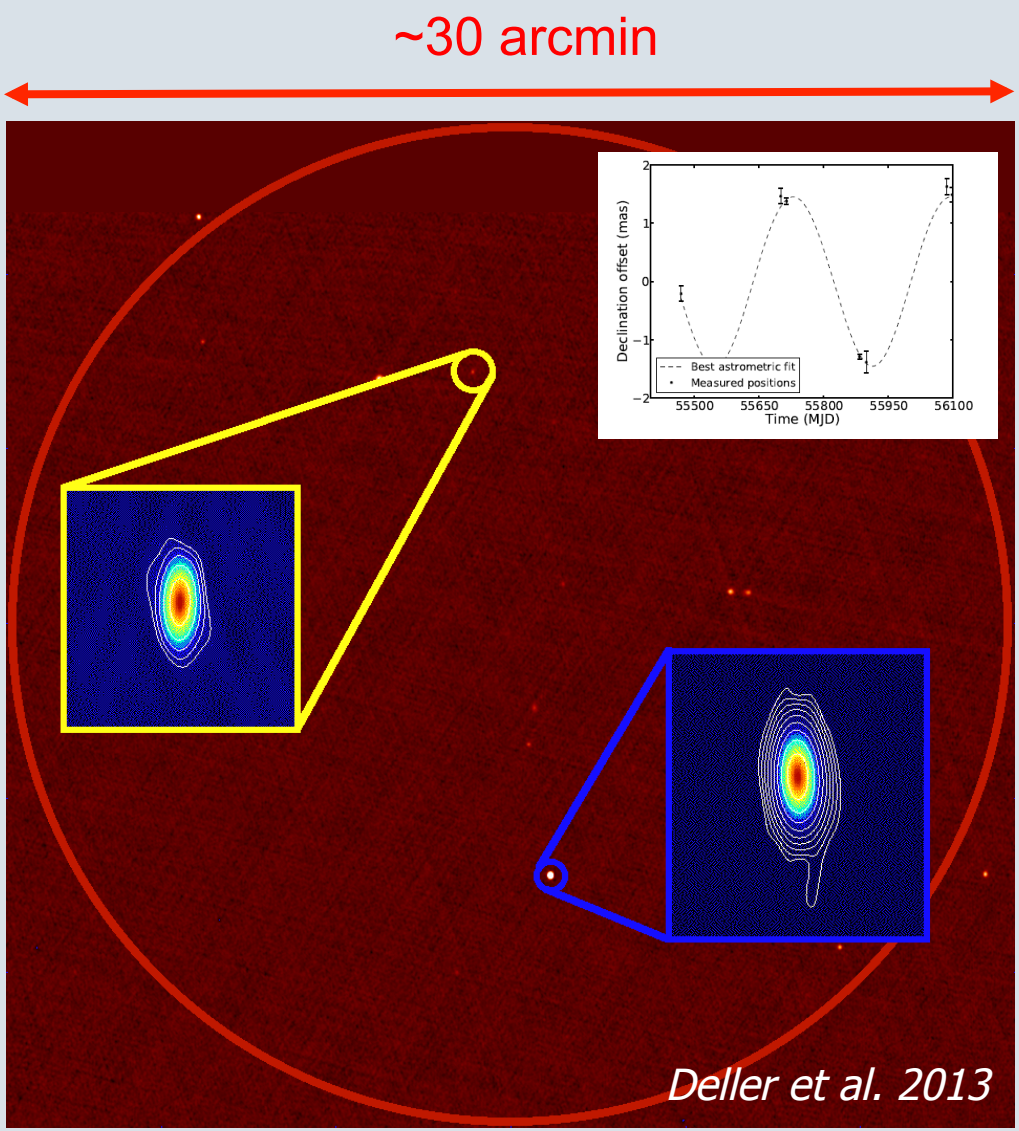


Synergy with GAIA

SKA-VLBI Astrometry: Pulsars

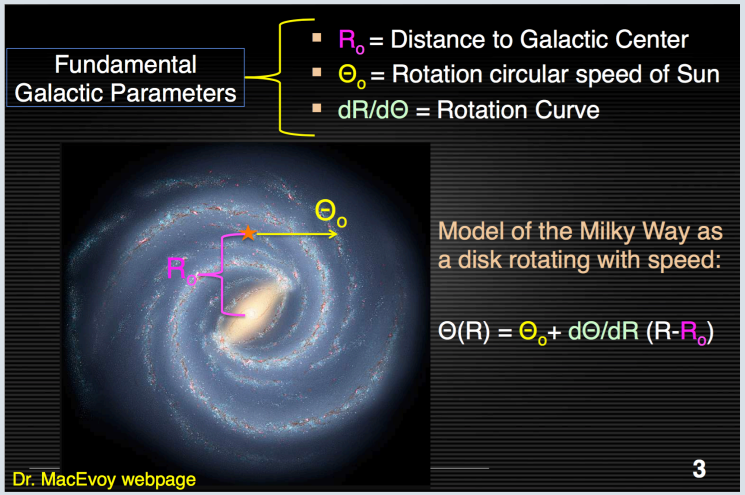
- Multi-beam calibration: ~10 μas regime
- 800 hours, band 2 (some band 5)
- 8 epochs/src over 18 months, fixed times
- Simultaneous EVN, LBA, Hartebeesthoek and SKA1-MID
- SKA1-MID local interferometer data
- Science use case (*Deller et al.*):

"Parallax measurements of millisecond pulsars to obtain precision astrometry (position, proper motion and parallax), which will be used to improve the pulsar timing model for the system. This will enable improved strong-field tests of gravity, one of the key SKA science goals (*Shao et al., 2015*). Other science benefits include studying the neutron star equation of state and better modeling the Galactic electron density distribution (*Han et al. 2015, Tauris et al. 2015, Janssen et al. 2015*)."

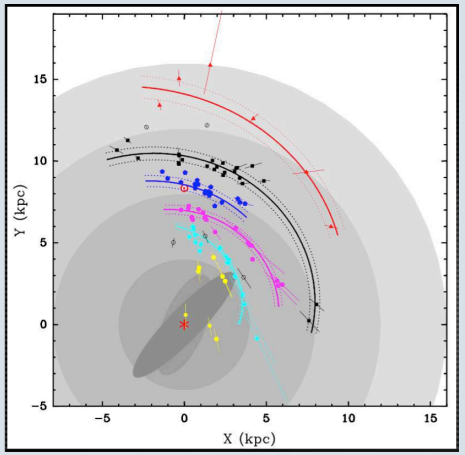


SKA-VLBI Astrometry: Stars / star clusters

- Multi-beam calibration: ~10 μas regime
- xxx hours, band 5 (not fully developed case; target numbers are more realistic for SKA2)
- proper motion and parallax of 500 stars, fixed times
- Methanol maser for high-mass stars / but also continuum for low-mass star clusters
- Simultaneous EVN, LBA, Hartebeesthoek and SKA1-MID
- Science cases:
  - 3D tomography of spiral arms (*Hoare et al.*)
  - GAIA parallax check/calibration (*Zhang et al.*) and more science… (*Paragi et al. 2015*)
- Compatible with GP SKA1-MID survey?



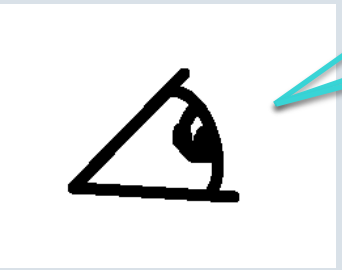
This would be a extension of the Bessel Project (*Reid et al.*) that had the aim of determining the Fundamental Galactic Parameters (above) and the structure of the spiral arms in the Milky Way (below)



Reid et al. 2014

3D tomography of spiral arms

Influence of the density wave



ISM

DW

t_{evol}

Old (10^6 yr) (**non-thermal continuum sources**)

Medium (10^5 yr) (**OH masers/ RRL sources**)

Young (10^4 yr) (**CH_3OH masers**)

d_{evol}

$$\Delta V = d_{evol} / t_{evol}$$

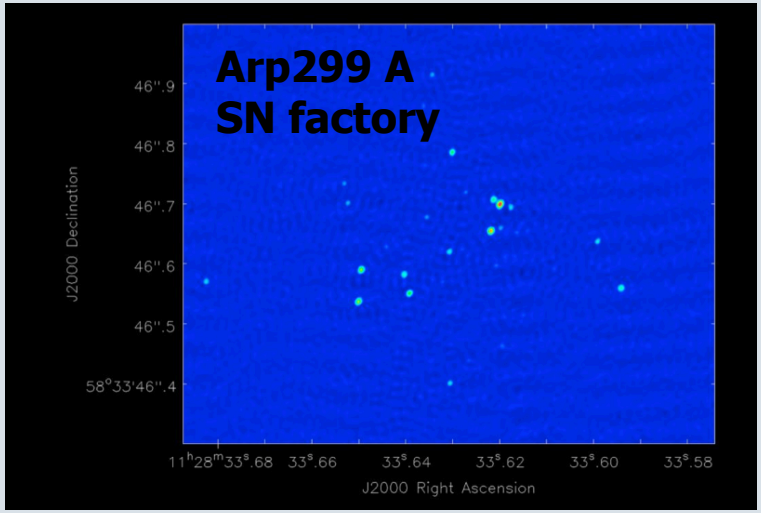
From Hiroshi Imai

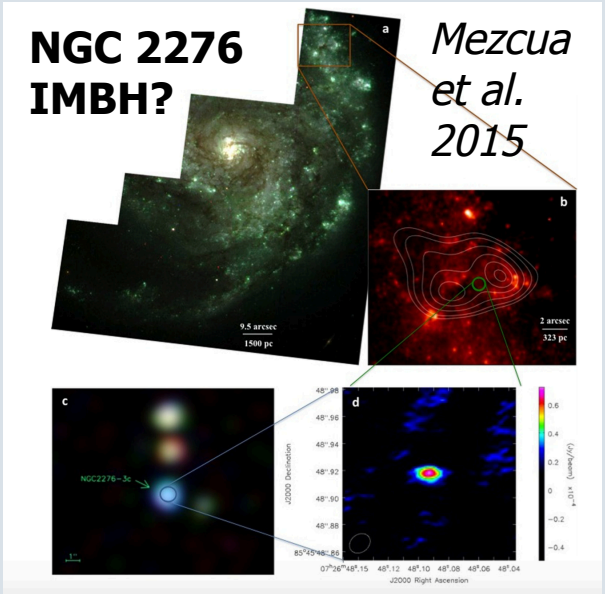
Extragalactic continuum: VLBI Galaxy Survey

- Multi-beam = multiple targets; will require fast switching of n beams to observe ~10*n sources
- xxx hours, band 5 (not fully developed case)
- May target ~100 sources in a shallow survey (~100 μJy population, with n=4)
- Deep observations to target ~10 μJy population in a few hours run requires n>>4
- Simultaneous EVN, LBA, Hart, SKA1-MID
- Science cases:
  - **AGN/SF** (*Prandoni et al. SWG*)
  - dual/multiple SMBH (*Deane et al. 2014*)
  - IMBH (e.g. *Mezcua et al. 2015*)
  - LIRG/ULIRG (*Alberdi et al.*) etc. etc.

For z>0.1 SKA1-MID resolution is not sufficient to differentiate between AGN/SF scenarios for nuclear starbursts/LLAGN

- Targeted + piggybacking on continuum survey deep field?





Transients: Explosive phenomena

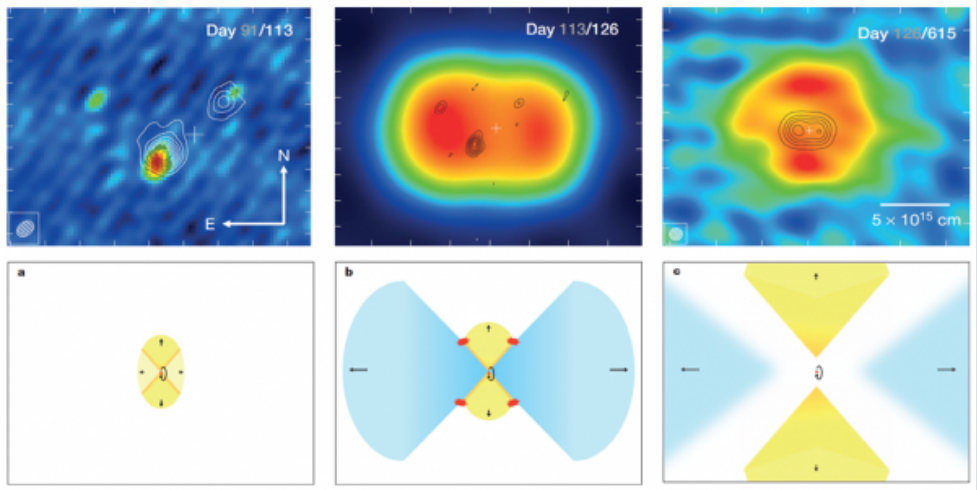
- Target of Opportunity / triggered
- 1000 hours, band 5
- Multiple visits of targets on days/months/yrs
- Flexible coordination with other facilities
- Simultaneous EVN, LBA, Hart, SKA1-MID
  (Would highly benefit from a developed AVN)
- Science cases:
  - **Galactic:** CV, BHXRB, magnetar etc.
  - **Extragalactic:** SNe, GRB, TDE etc.

  1) Unified view of accretion on all mass/scales and source types

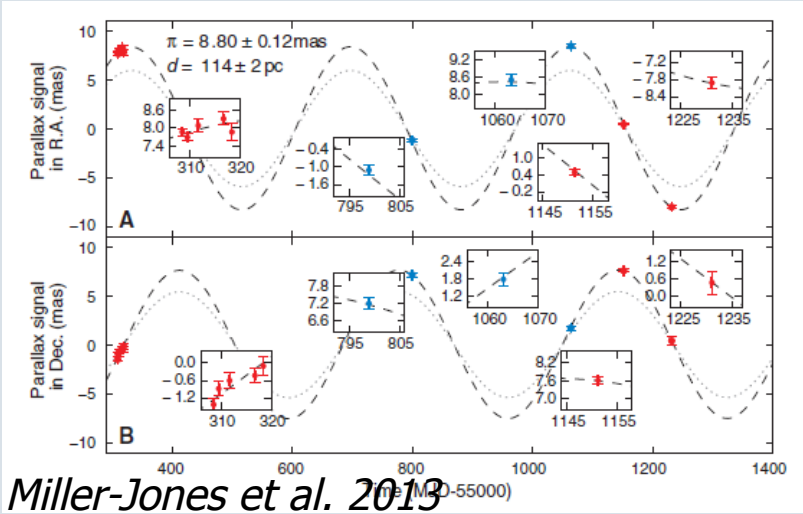
  2) Pristine jet formation in AGN

  3) Probing IMF of MBH population
- Targeted + piggybacking on SKA1-MID transient follow-up KSP?

Nova Mon 2012 *(Chomiuk et al. 2014)*



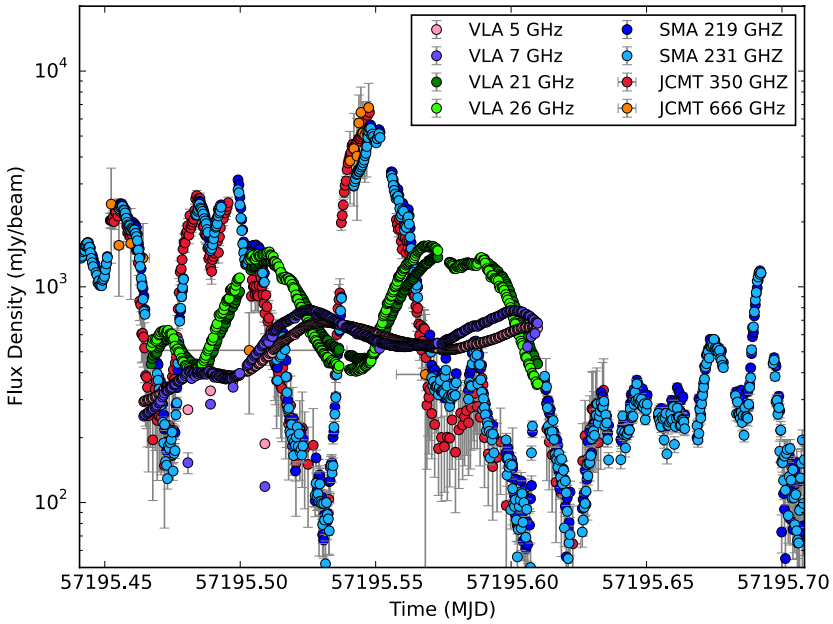
SS Cyg – probing accretion physics

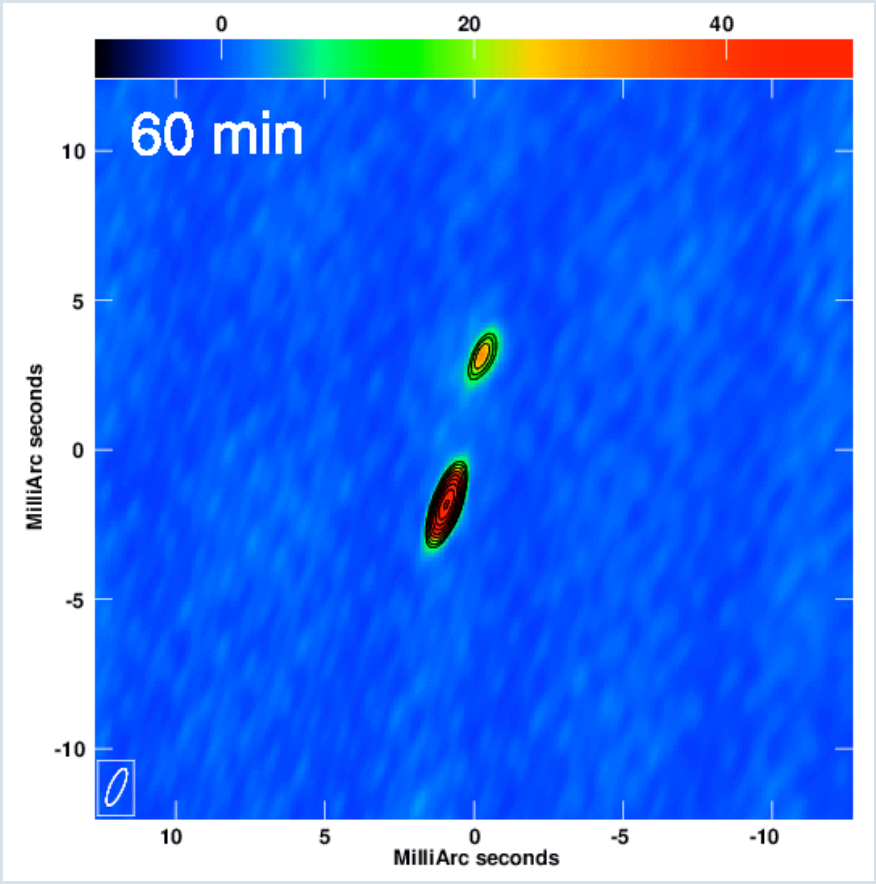


Miller-Jones et al. 2013

Transients: Explosive phenomena

V404 Cyg *(Miller-Jones, Tetarenko, Sivakoff et al., in prep.)*

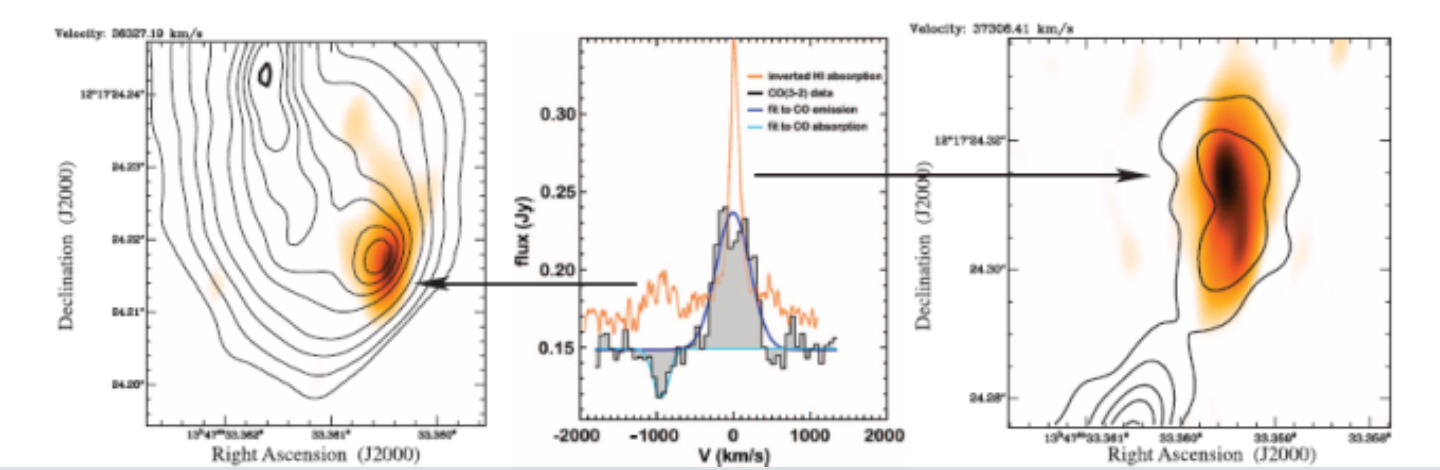




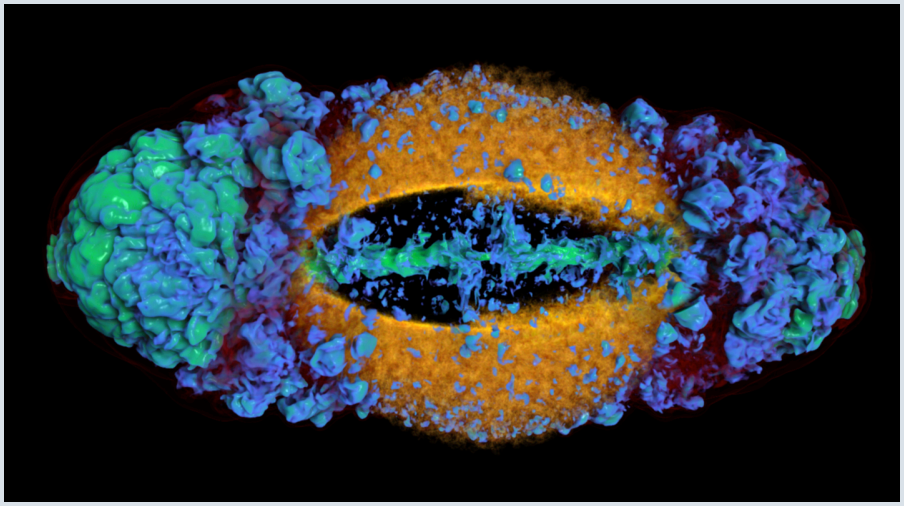
We often need VLBI resolution to map the ejecta!

HI (targeted): AGN forming their galaxies

- AGN jet pushing out neutral (HI) and molecular gas in 4C12.50
- Large collecting area: sensitive for spectral line VLBI!



Morganti et al. 2013, Science, 341, 1082, 2013



Artist's impression: Ajay Limaye
From: Alexander Y. Wagner wepage

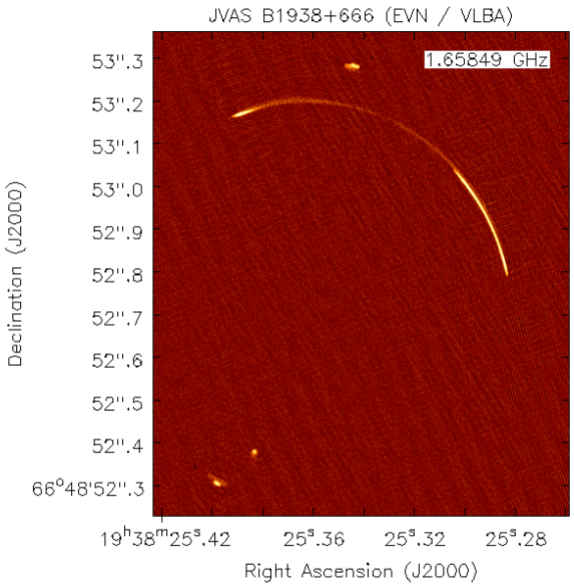
- Realistic 3D simulations show that jets (but also winds from AGN and SF) are capable of clearing gas from the inner regions of a galaxy, especially for a clumpy medium

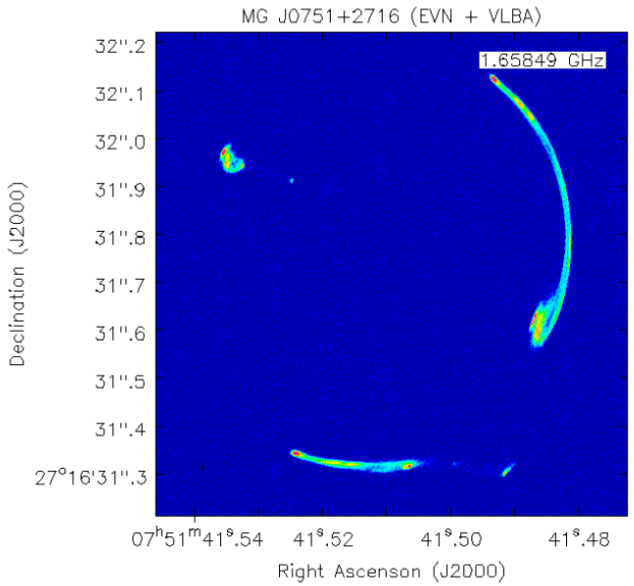
Continuum extragalactic (targeted)

Testing models for dark mater with lensed arcs

Extended gravitational arcs found through the dedicated SKA lensing survey will detect ~10^6 M_{sun} dark matter haloes (Segue 1 MW dwarf at redshift ~1)

1. What is the shape of the dark matter halo mass function (power-law, turnover mass)?
2. Is it consistent with a CDM / WDM model for dark matter?
3. Needs VLBI capability





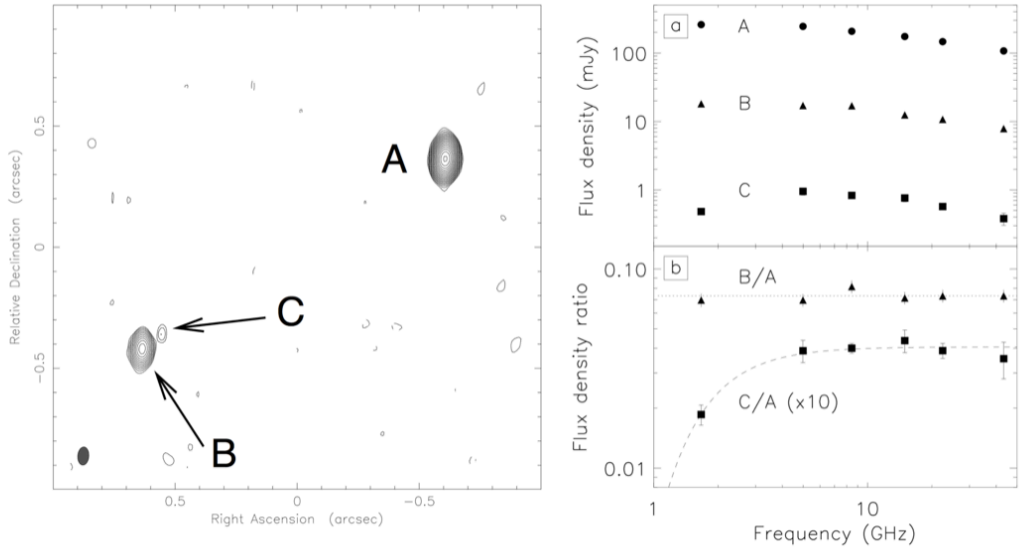
John McKean
3 slides

Continuum extragalactic (targeted)

Testing BH mass function / scaling relations

Central images of gravitational lenses are sensitive inner mass profile and central supermassive black hole mass.

1. How does the black hole mass function / scaling relations vary with galaxy type?
2. Unique method to measure BH masses in quiescent galaxies at redshift ($z < 1$) at 0.5 dex precision.
3. Needs multi-frequency VLBI capability (to resolve central images and distinguish from lens galaxy AGN emission).

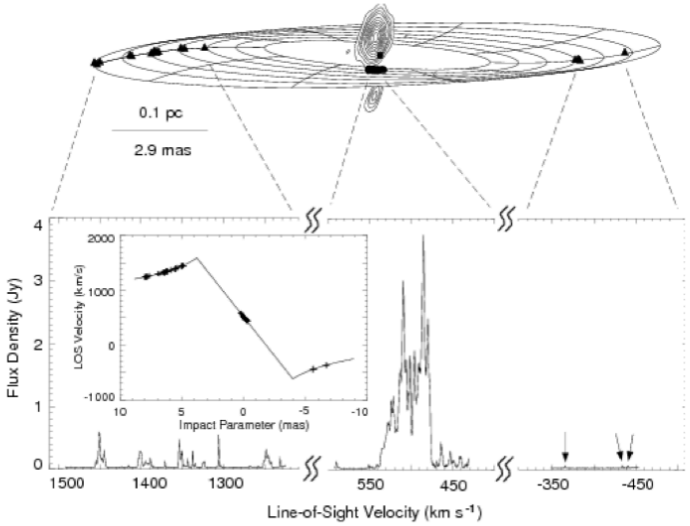


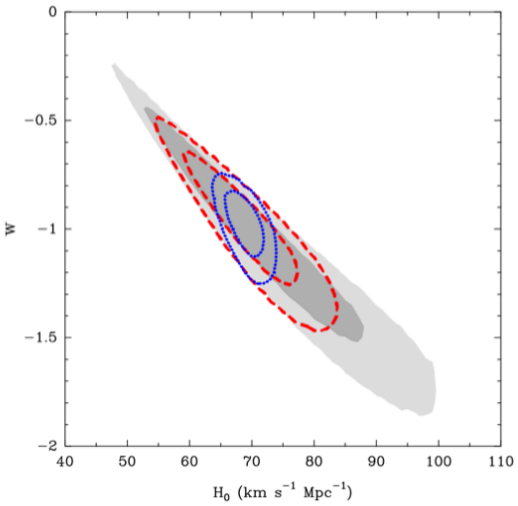
Extragalactic maser (targeted)

Testing models for dark energy with water masers

22.245 GHz water search to find MM systems at z < 3.45 (with Band5+)

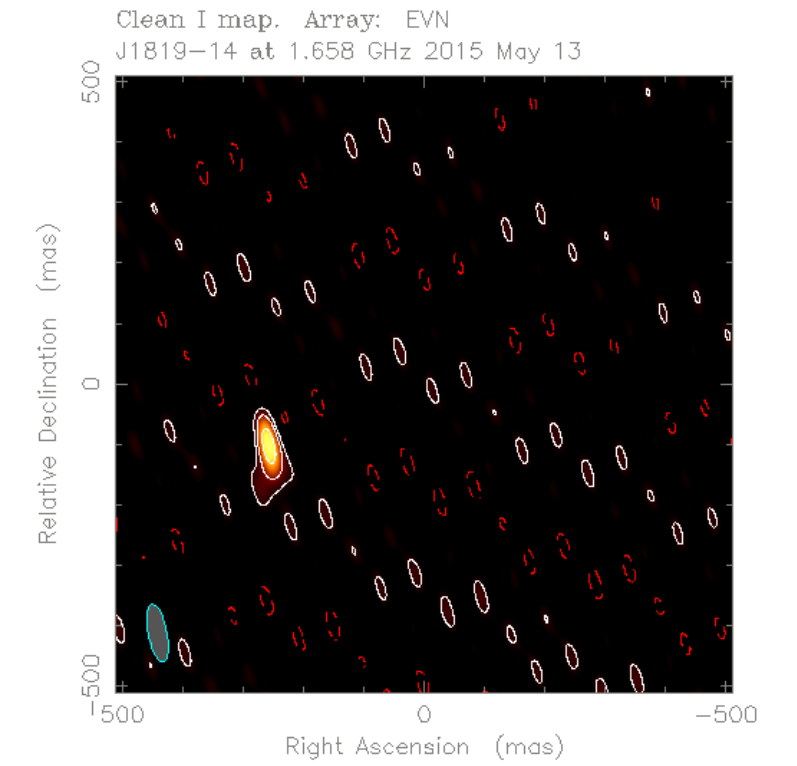
1. How does the black hole mass function / scaling relations vary with galaxy mass / type (black hole mass precision ~10%)?
2. What is dark energy?
3. Needs VLBI capability (with high frequency component)

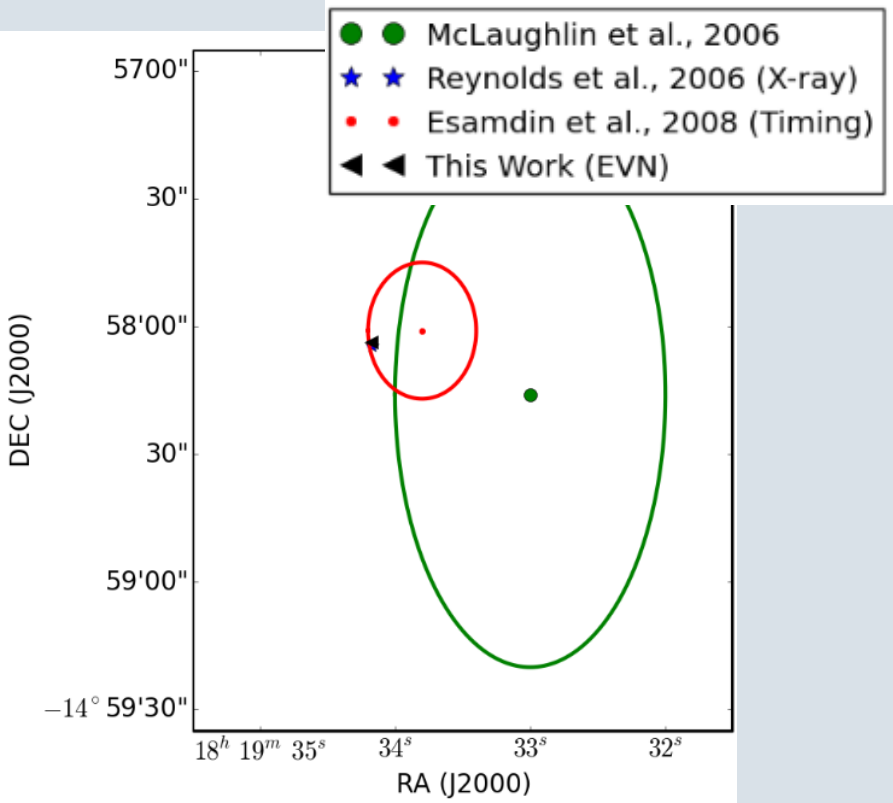




SKA-VLBI localization of FRBs?

Single pulse e-EVN image of RRAT J1819-1458
(note this mode of observation requires buffering/recording VLBI voltage data)





Paragi/Wen/Keimpema/Siemion et al.; preliminary)