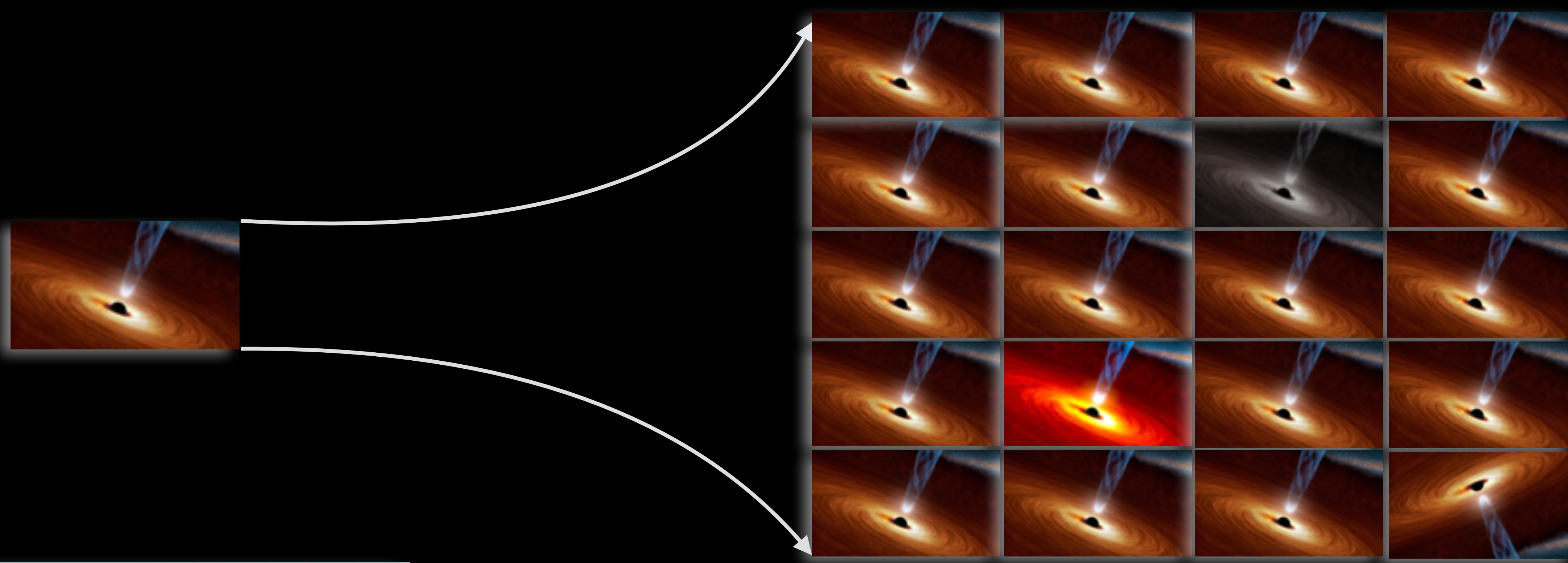
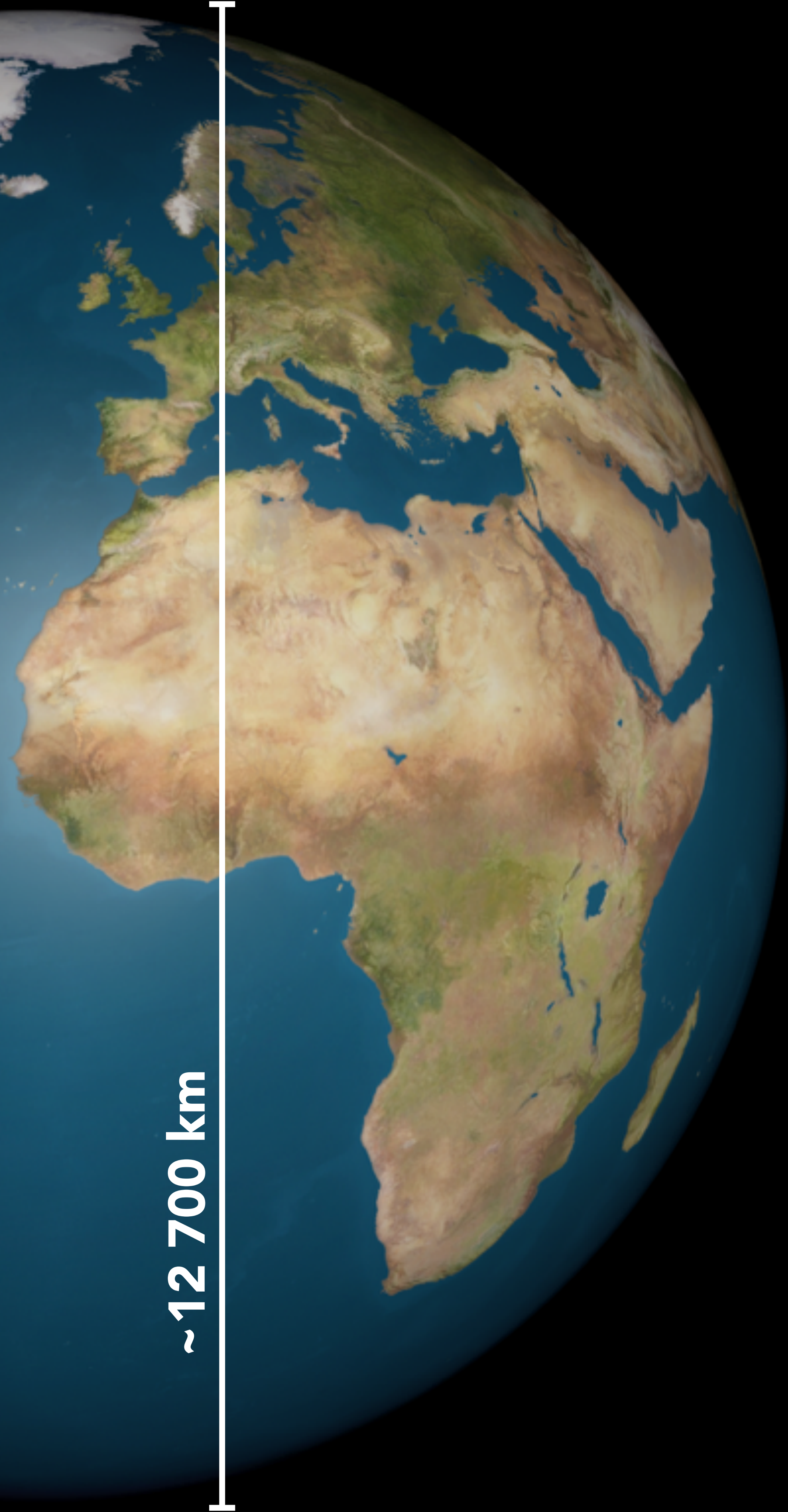
VLBI opportunities with AAMID

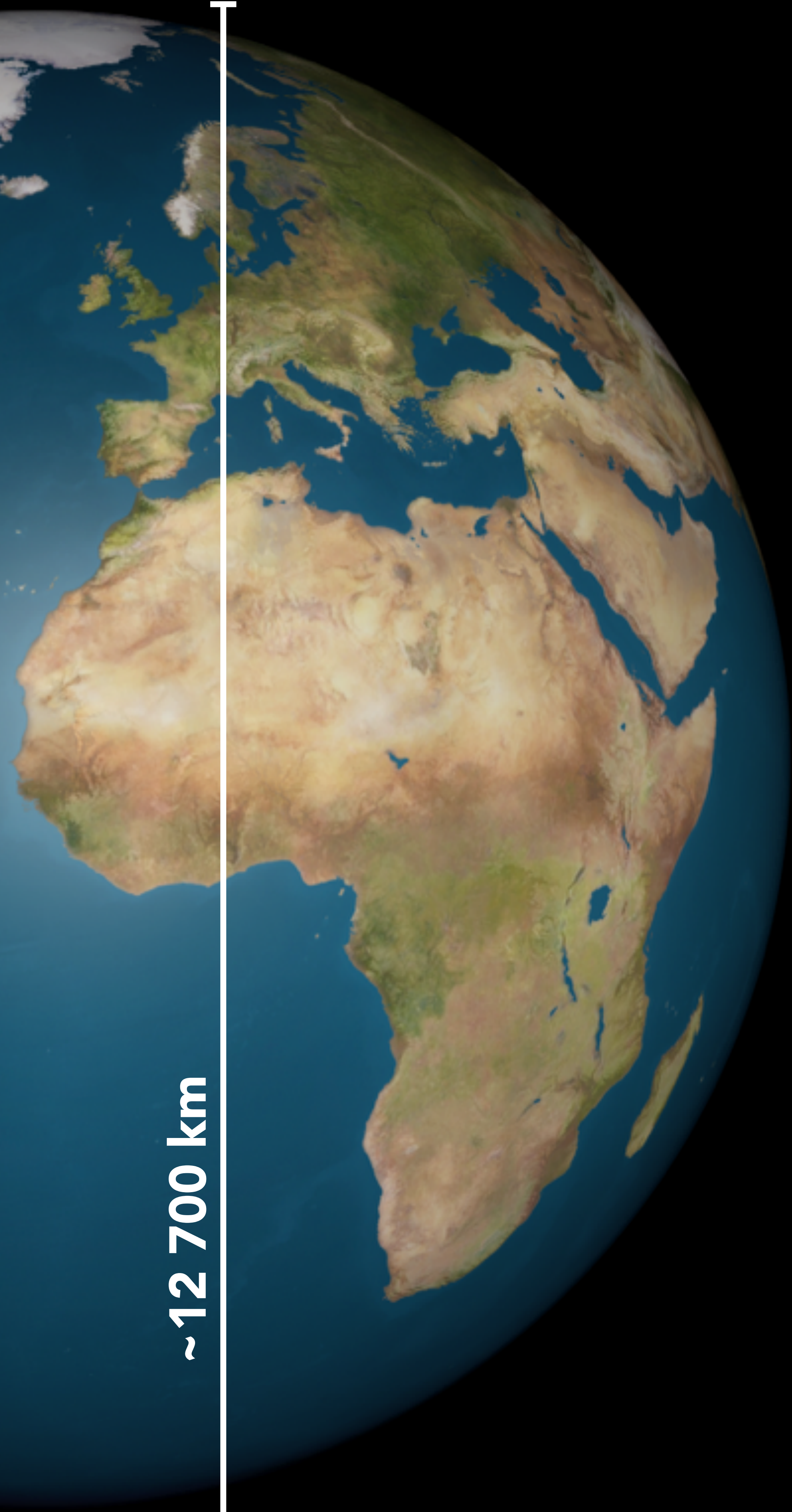


Roger Deane
Rhodes University



the power of VLBI

- unique parameter space: (sub-mas resolution)
- filters high brightness temperature emission
- impressive history of high impact results, mostly on single objects



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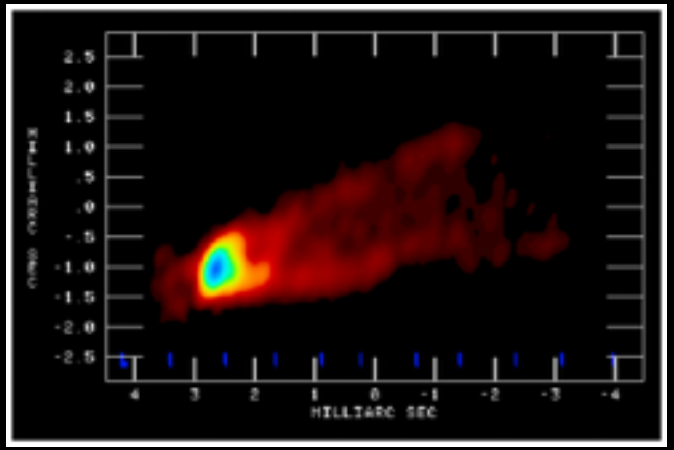
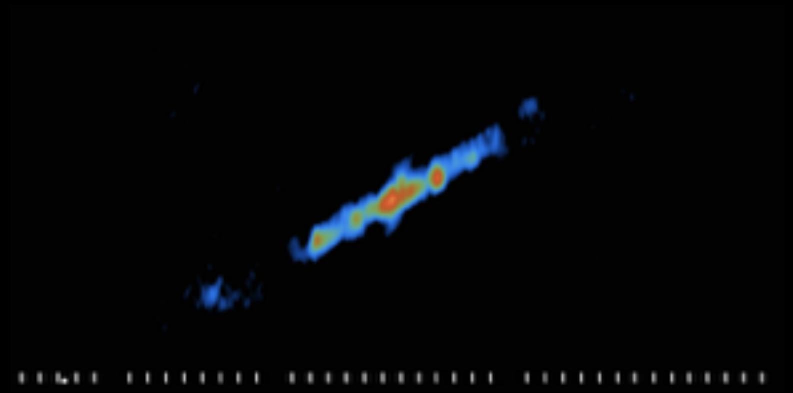
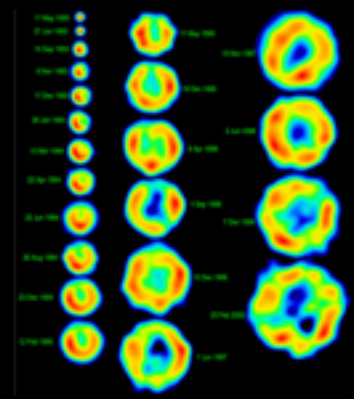


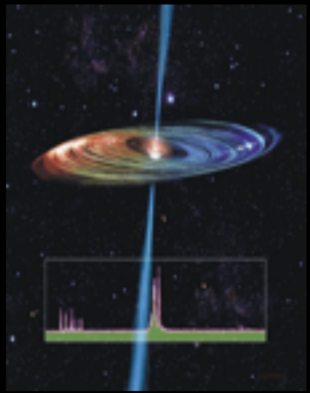
M87 jet, Craig Walker



micro-quasar SS433,
Mioduszewski et al., NRAO/AUI/NSF



SN1993J expansion,
Bartel et al. 2000



Hubble Constant from water masers,
MCP consortium

the future of VLBI

- for cm-VLBI to continue to make major contributions in the next decade, it must move to large-scale surveys

“From black-belt specialism to main-stream astrophysics”
Malcolm Longair, JIV-ERIC Symposium, April 2015

- by default, this requires pushing to larger field-of-view

talk overview

science enabled by AAMID baselines >> SKA1-MID

will focus on breath of science opportunities

some caveats / practical considerations

AAMID-VLBI opportunities overlap with SKA2

Relative timing of roll out not considered

I've tried to capture what a Memo 100 dense AA would do best in terms of VLBI

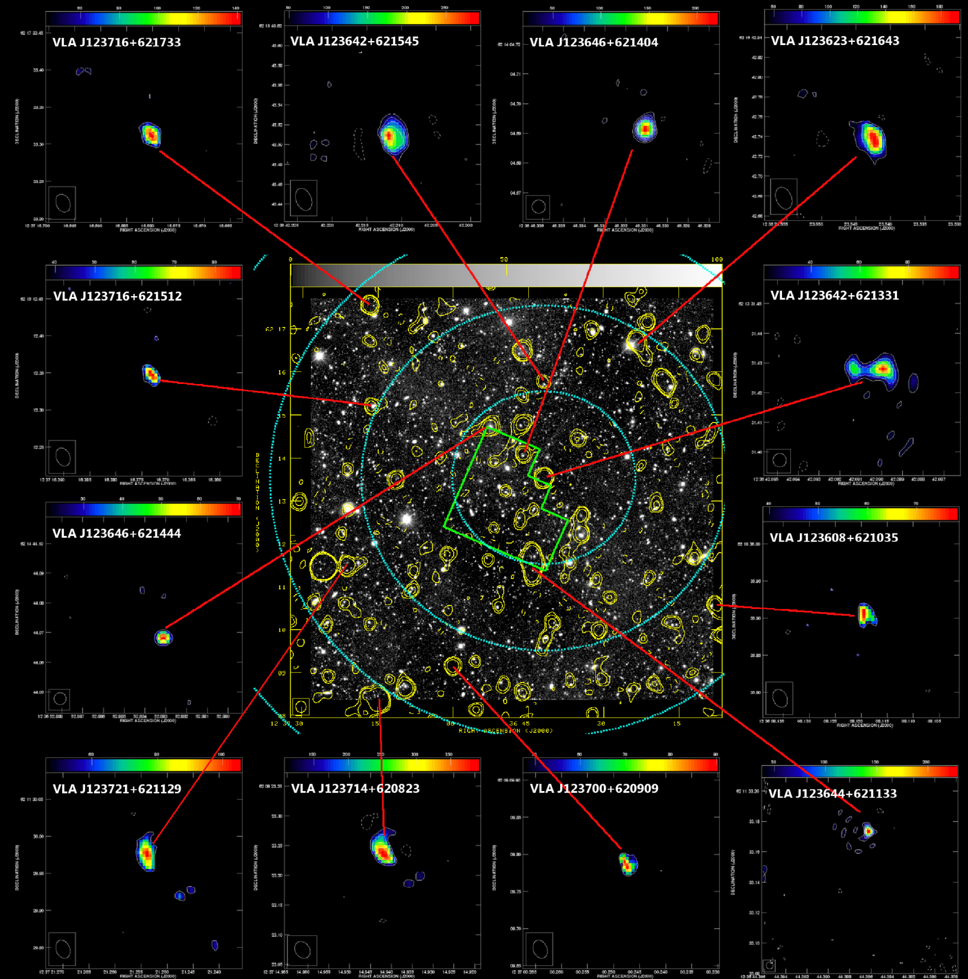
Costs of any kind have been ignored

AAMID-VLBI advantages

- wide FoV
- unique frequency coverage for VLBI (sans SKA2)
- pointing agility (=rapid followup + survey efficiency)
- multi-directional (using different modes)

wide-field VLBI surveys

- pioneered by Mike Garrett among others (strong lenses & HDF-N)
- game-changers include software correlation and multi-phase centre capability (Deller et al. 2007, Morgan et al. 2011)
- Extragalactic fields with VLBI coverage include:
  HDF-N + GOODS-North, Lockman Hole,
  Chandra DFS, Bootes
- mostly at L-band; sensitivities in ~10-100 μJy/b regime



Chi, Bartel & Garrett 2013

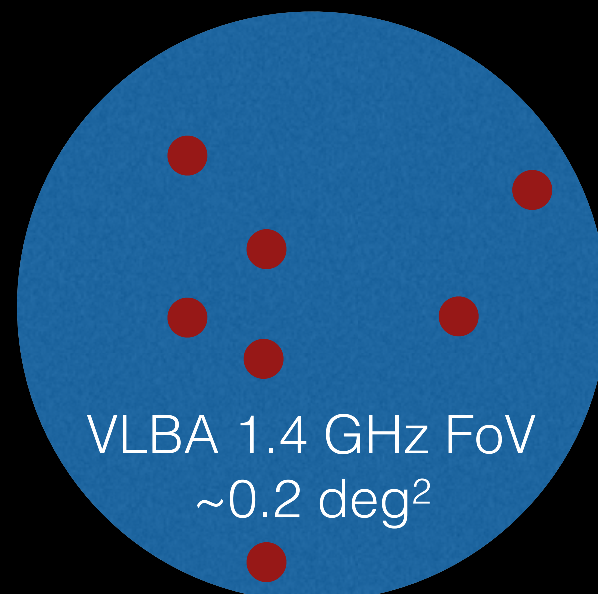
wide-field VLBI surveys

traditional VLBI

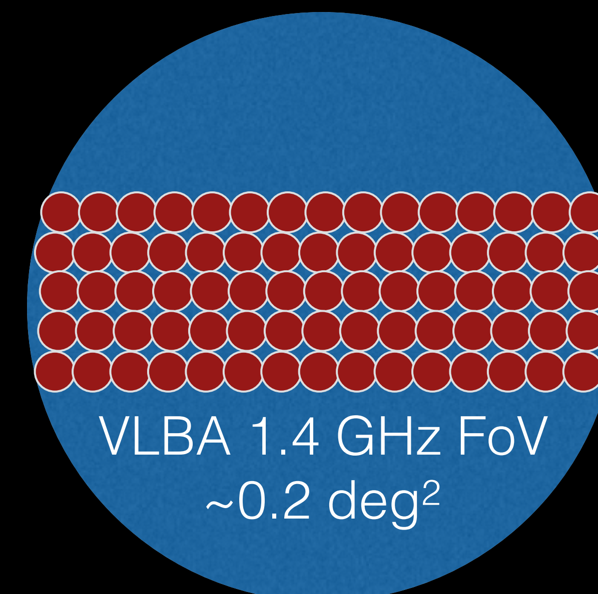
for processed FoV ~0.2 $arcmin^2$
8 hour run ~ 10 GB

to process full FoV (i.e. 0.2 deg^2):
8 hour run > 100 TB

multi-phase centre VLBI



7 phase centres
8 hour run ~ 7 x 10 GB



75 phase centres
8 hour run ~ 75 x 10 GB

GOODS-North VLBA survey

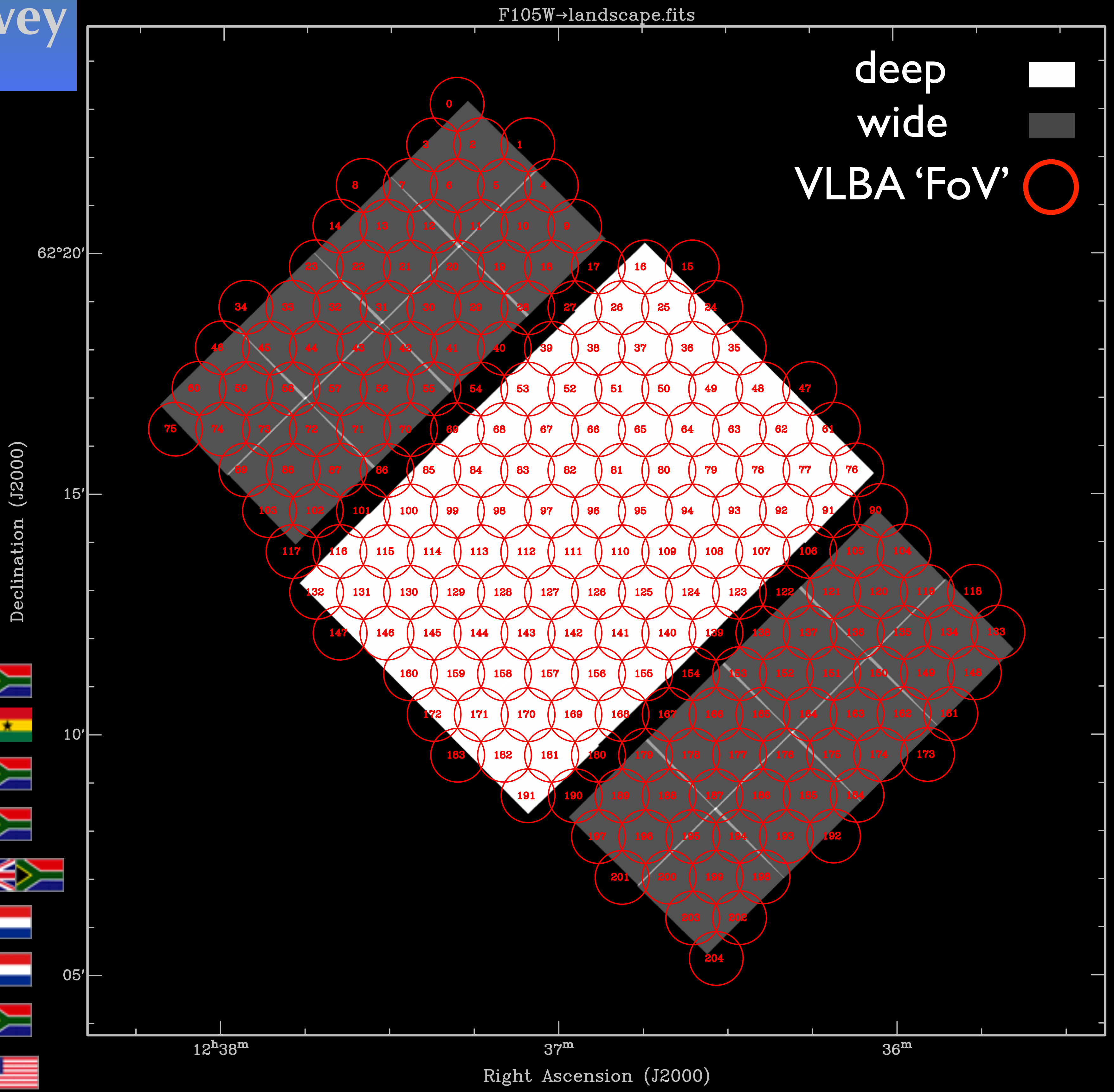
10 μJy/beam, 160 $arcmin^2$

deep HST legacy field

4 Terabytes of visibility data

205 phase centres

~0.6 Terapixels



Team:

Roger Deane (PI, Rhodes)
Alexander Akoto-Danso
Oleg Smirnov (Rhodes)
Gianni Bernardi (Rhodes)
Matt Jarvis (Oxford/UWC)
Zsolt Paragi (JIVE)
Mike Garrett (ASTRON)
Tom Mauch (SKA-SA)
Stephen Bourke (Caltech)
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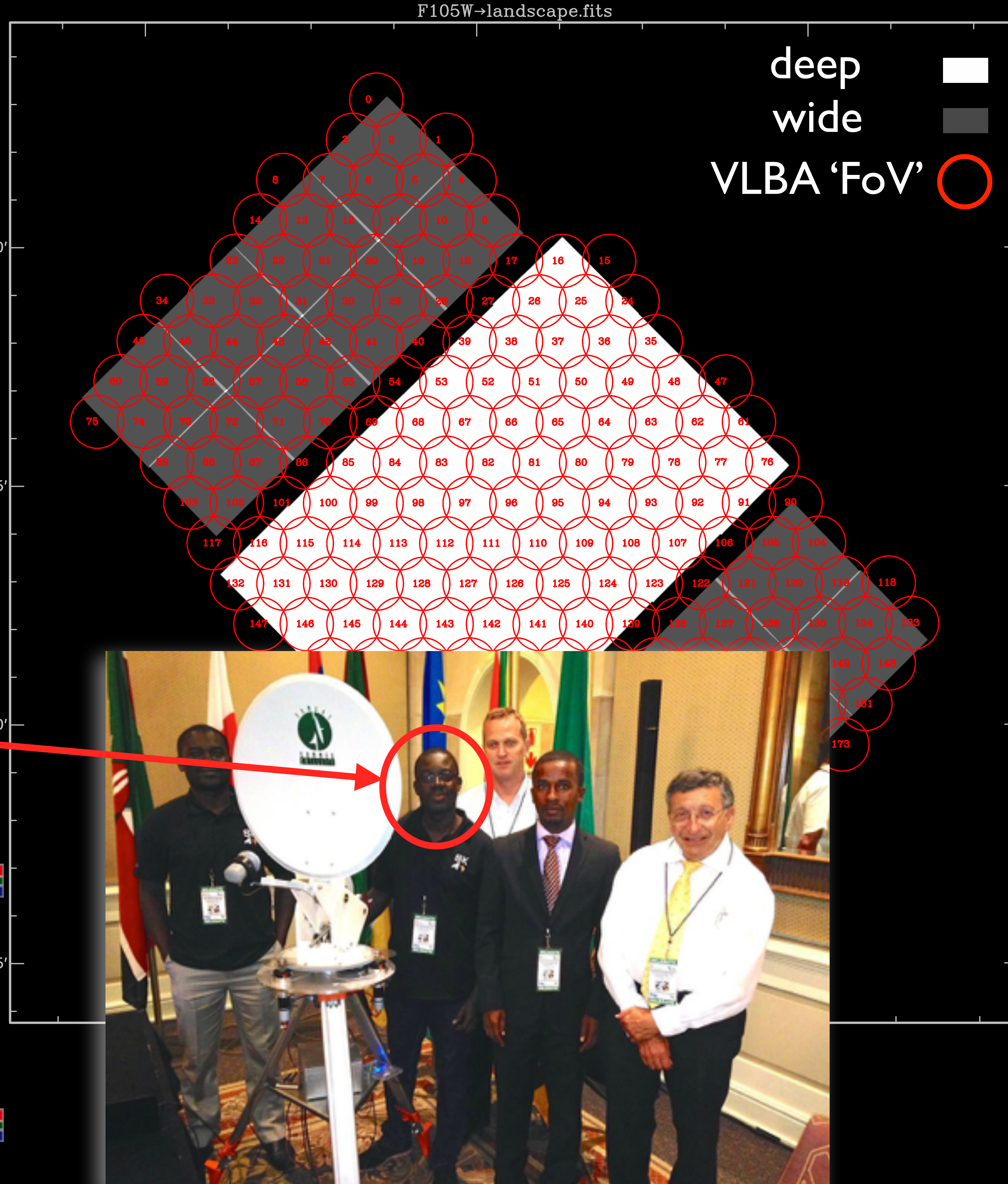

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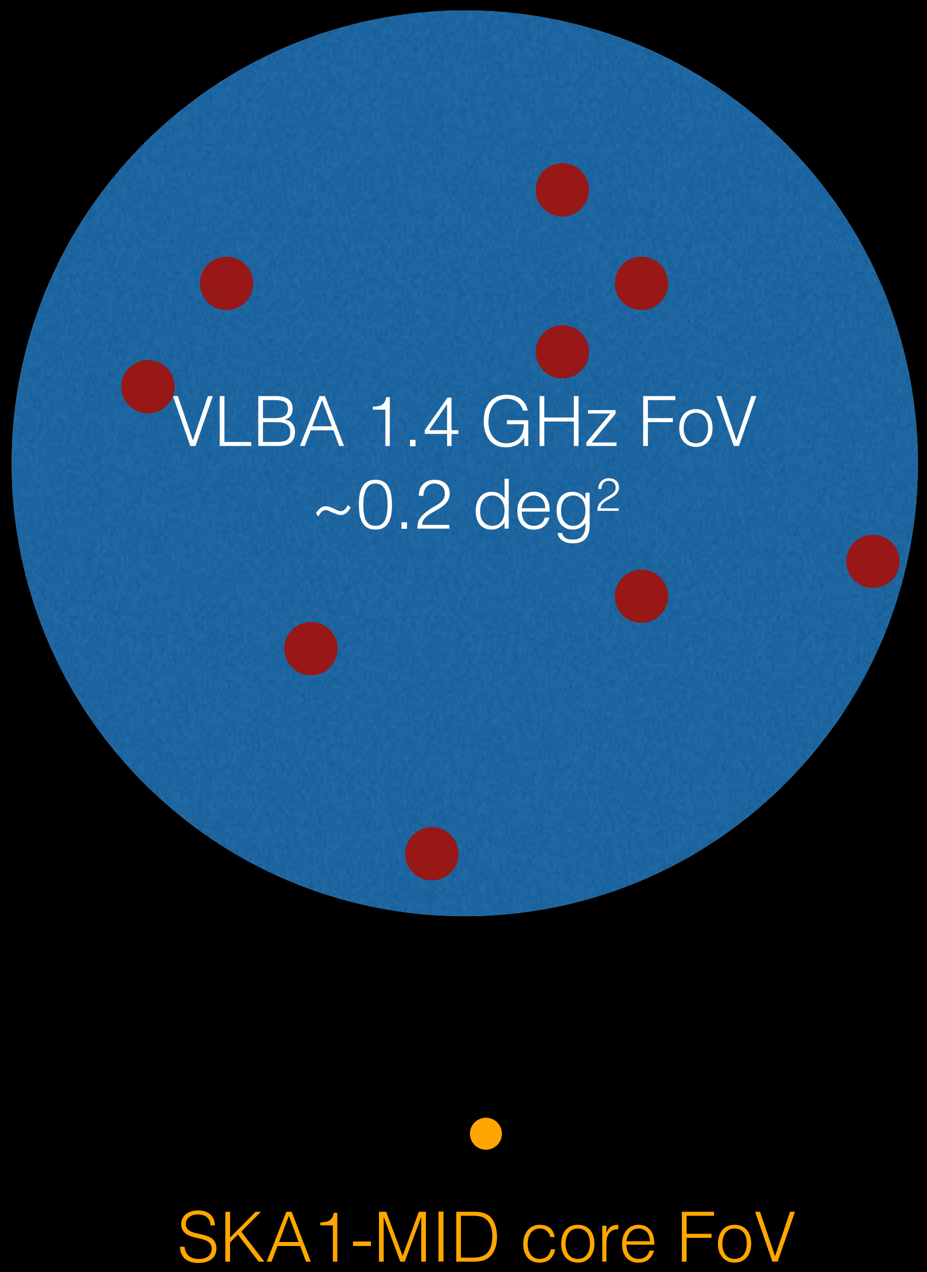
SKA-VLBI surveys

- phased up SKA1-MID core will not provide a wide FoV for SKA-VLBI (~ 1 sq. arcmin)
- could be increased using phased-up sub-arrays, but still << outer VLBI stations FoV
- given the above and high demand for VLBI time in SKA Key Science projects, it's seems unlikely that there signinificant time for wide-field SKA(1-MID)-VLBI surveys
- AAMID stations (including demonstrator) could used with AVN + EVN dishes to carry out wide-field 1.4 GHz surveys

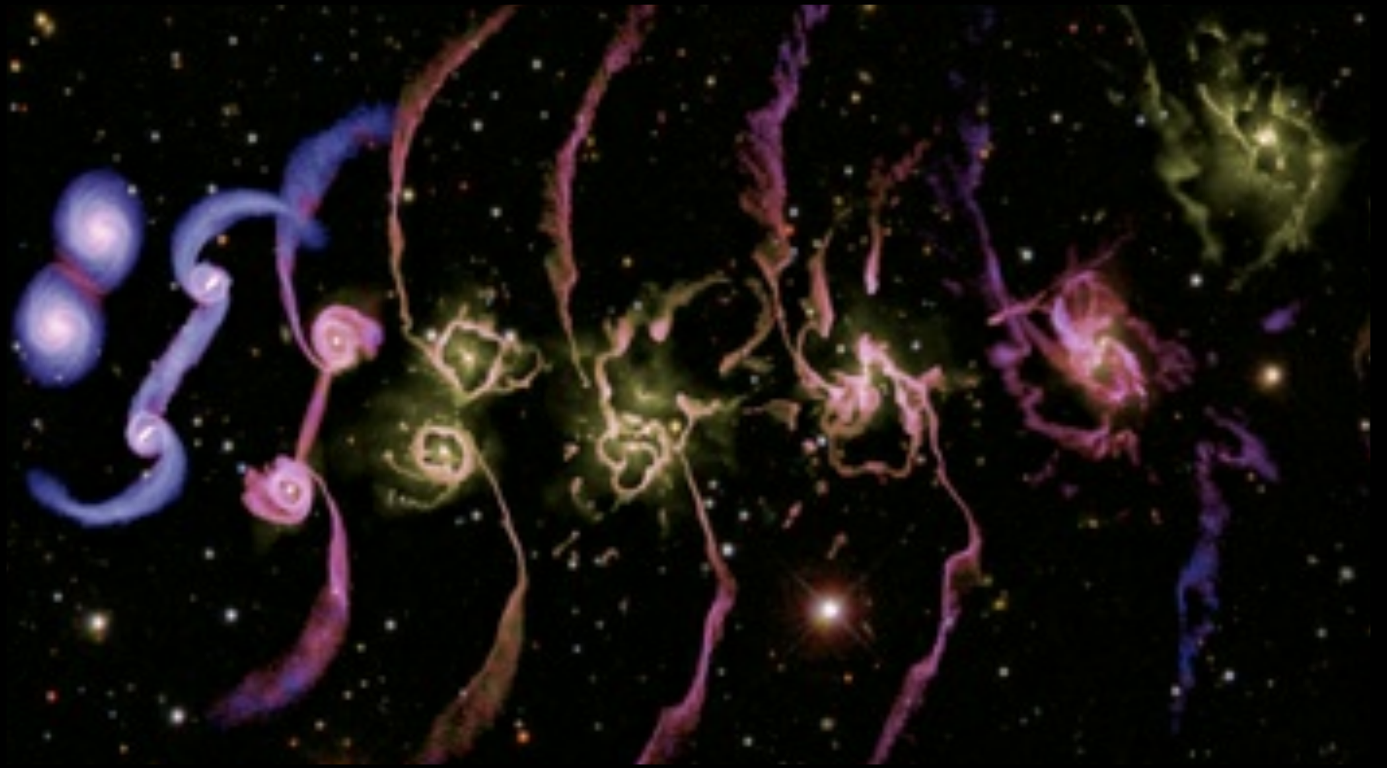


why do wide-field (>> 1 deg^2), low frequency (< 1.5 GHz) VLBI?

galaxy evolution

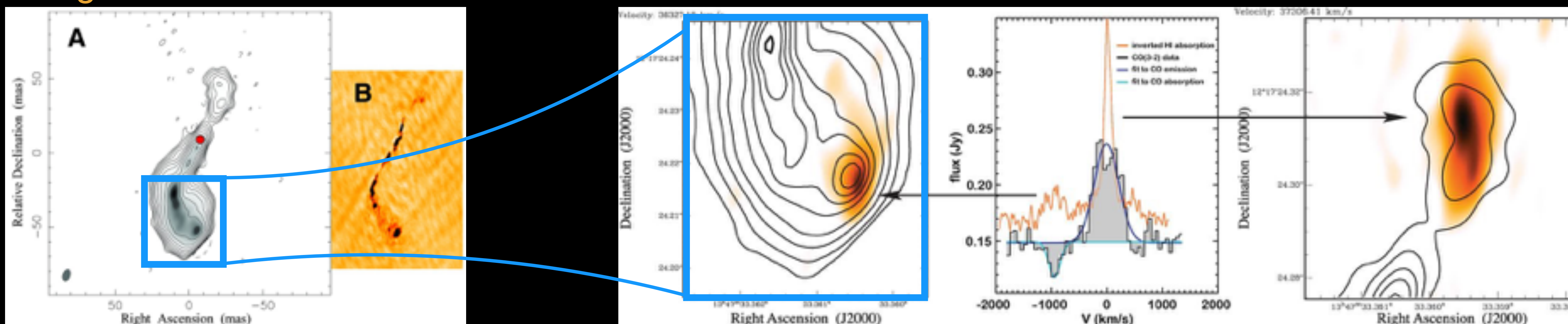
the need for large, unbiased samples

- AGN/SF separation
- obscured/Compton thick AGN
- understanding jet triggering
- AGN feedback



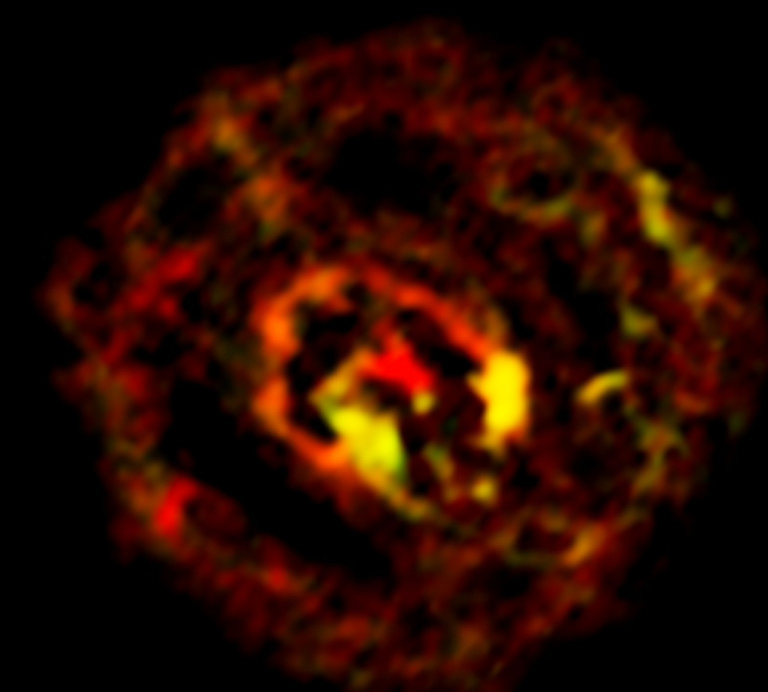
mechanical feedback

Morganti et al. 2013



HI-discovered outflow

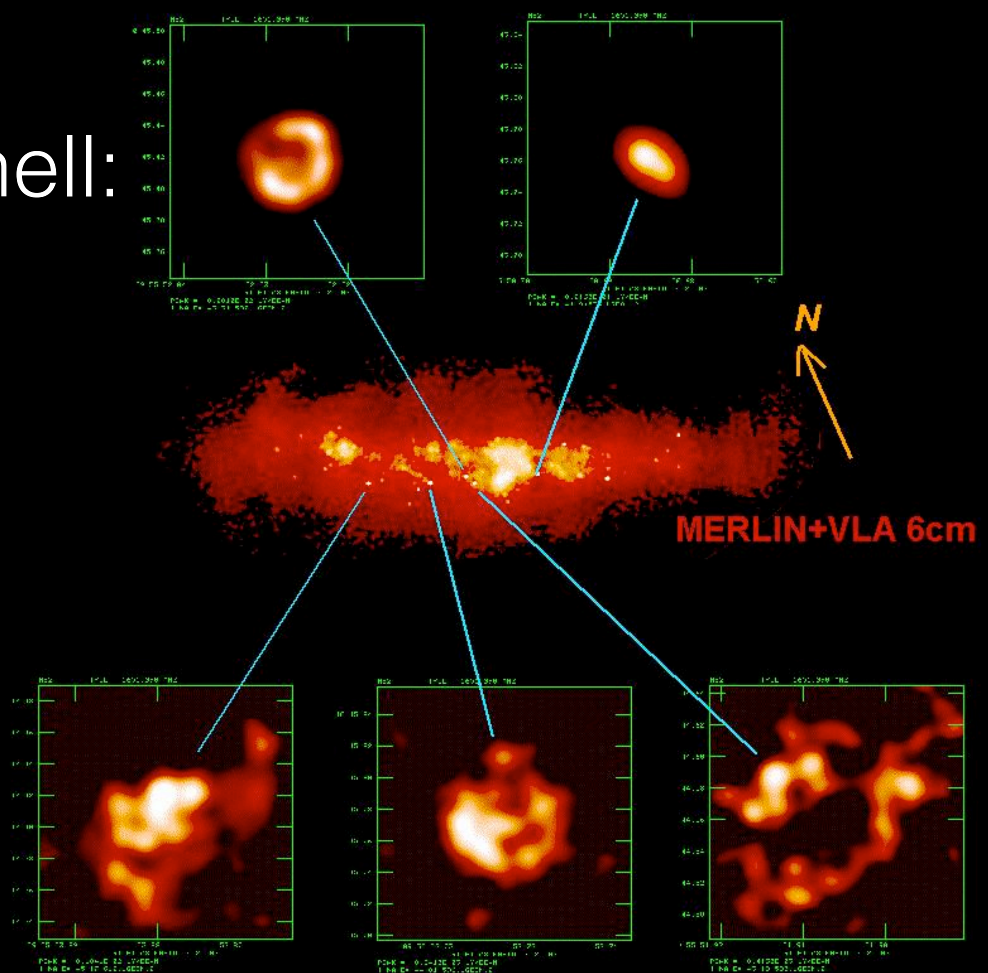
CO-discovered outflow



Combes et al. 2013 (0.5” resolution)

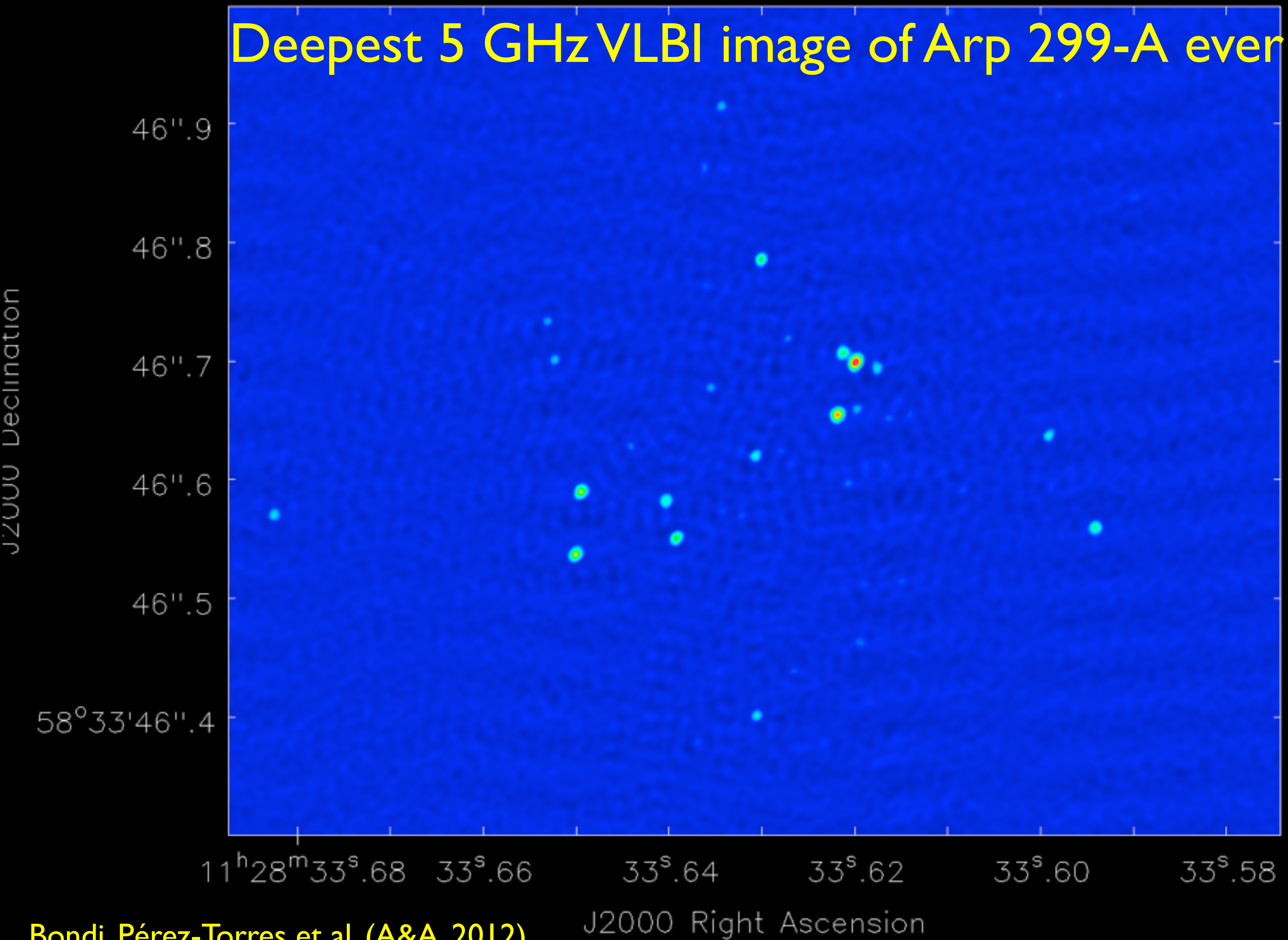
radio supernovae

- direct measurement of high mass star formation rate in nearby galaxies
- morphological modelling of expansion shell:
    - trace physics of explosion
    - probe local ISM environment



JBCA M82 monitoring group

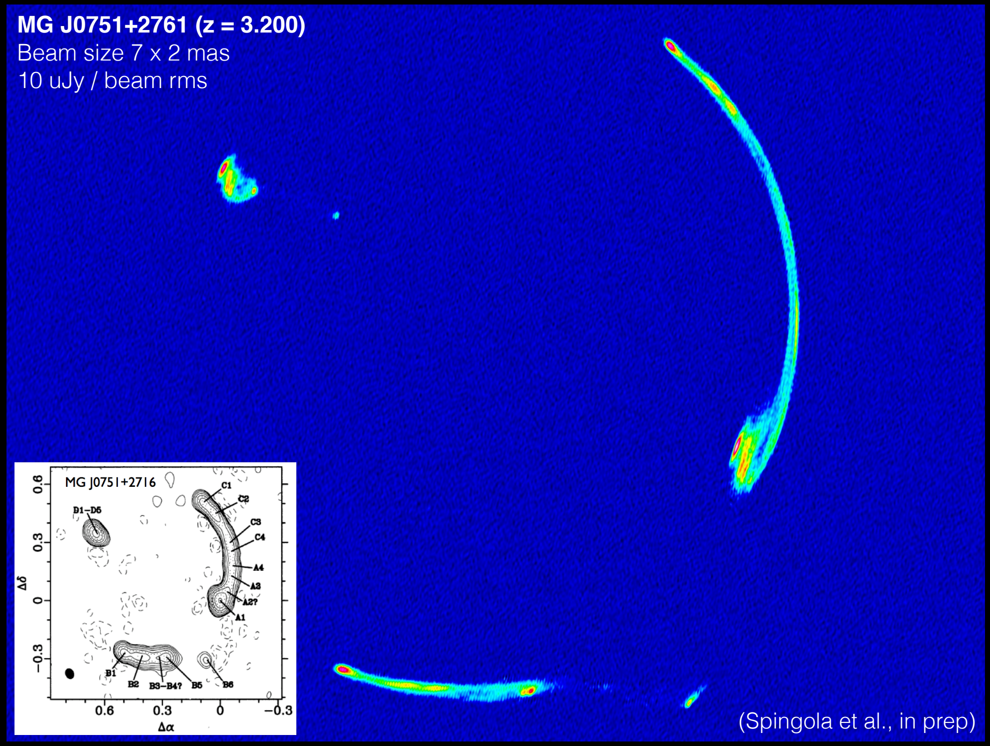
Deepest 5 GHz VLBI image of Arp 299-A ever



Bondi, Pérez-Torres et al. (A&A, 2012)

strong gravitational lensing

- unbiased probe of dark matter substructure
- VLBI is at the forefront (SHARP collaboration)
- SKA could discover 10^5 lenses, many of which could be near-full Einstein rings

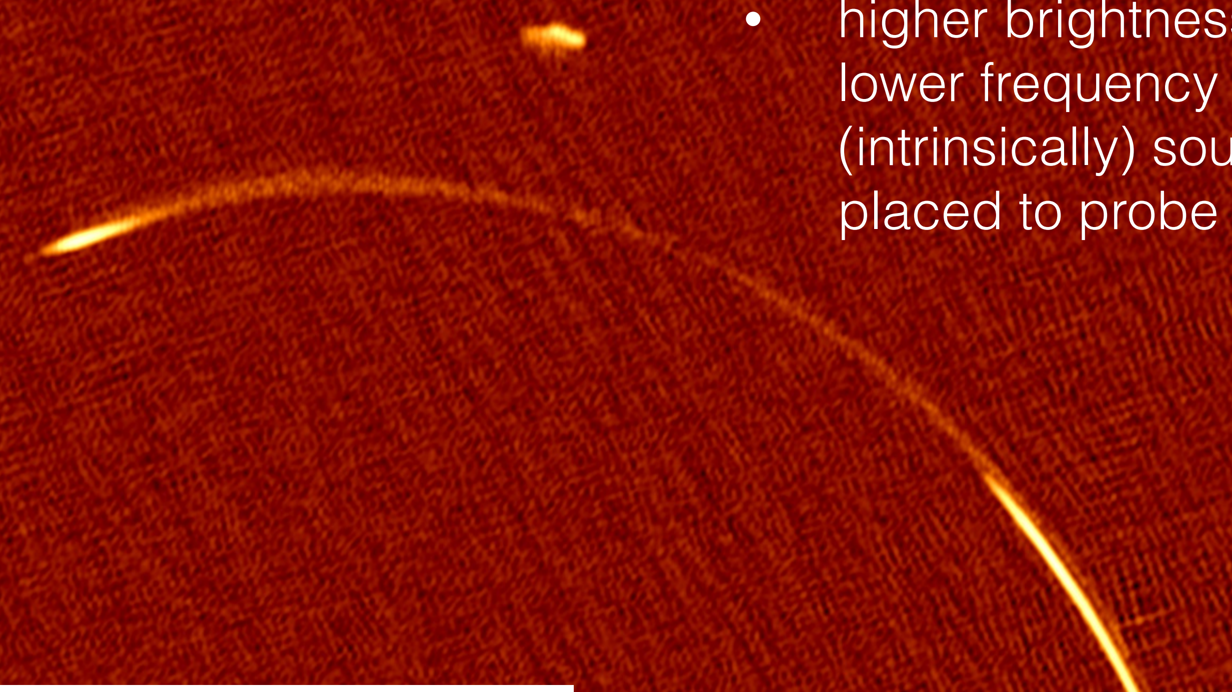


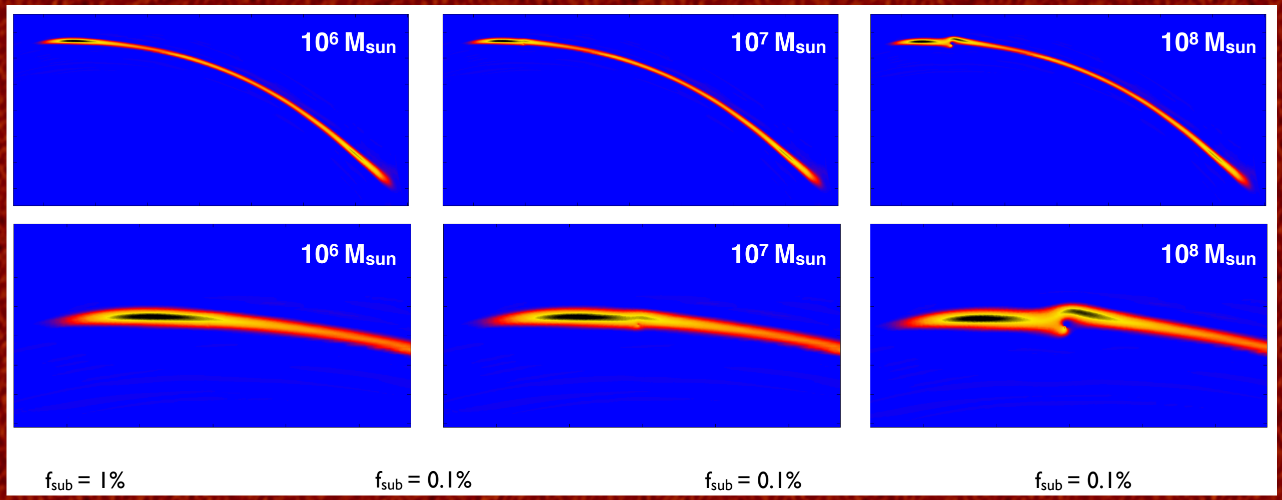
JVAS B1938+666 (z = 2.056)

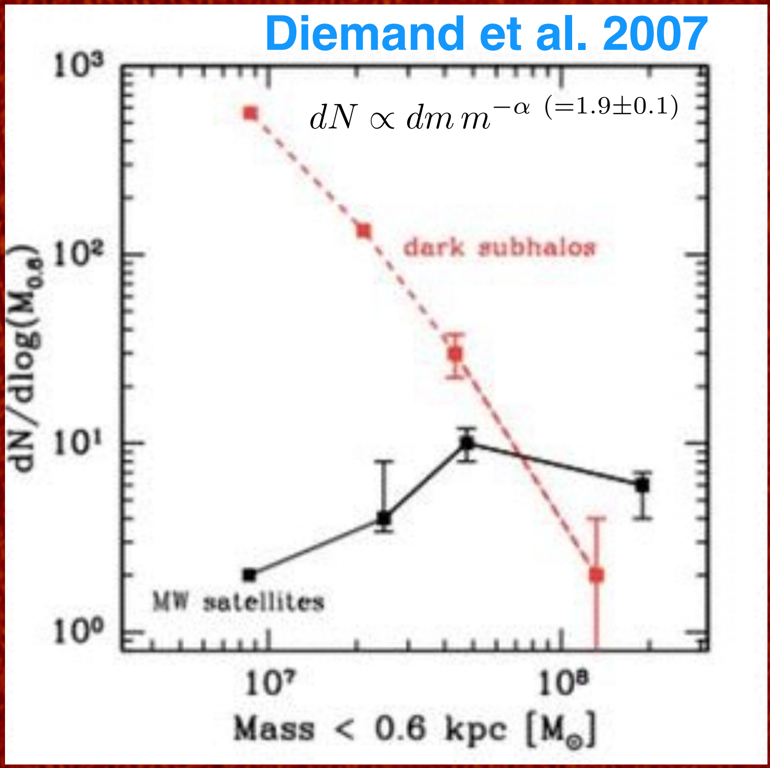
Beam size 4 x 2 mas

30 uJy / beam rms

- higher brightness temperature sensitivity of lower frequency VLBI will detect larger (intrinsically) sources and could be better placed to probe dark matter sub-structure



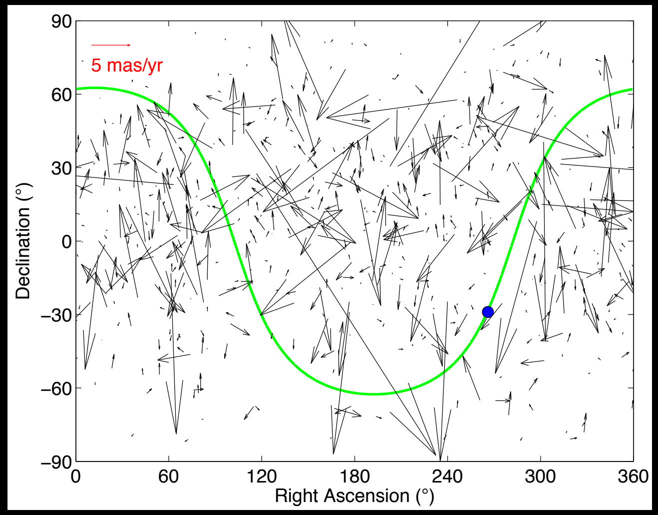




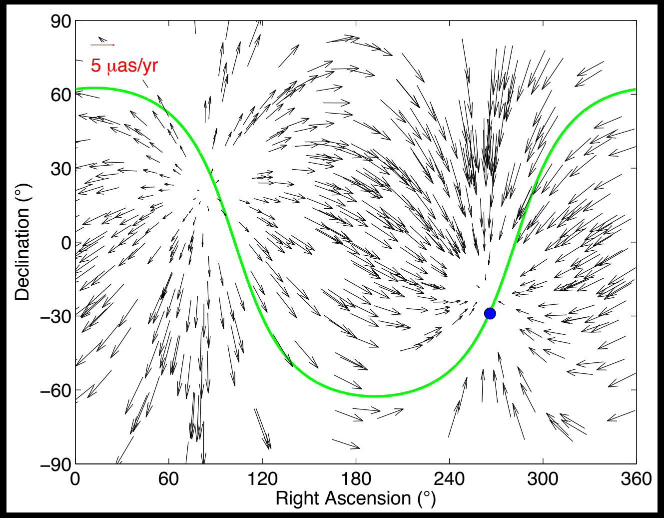
(McKean et al., in prep)

gravitational waves

QSO proper motions



best-fit dipole



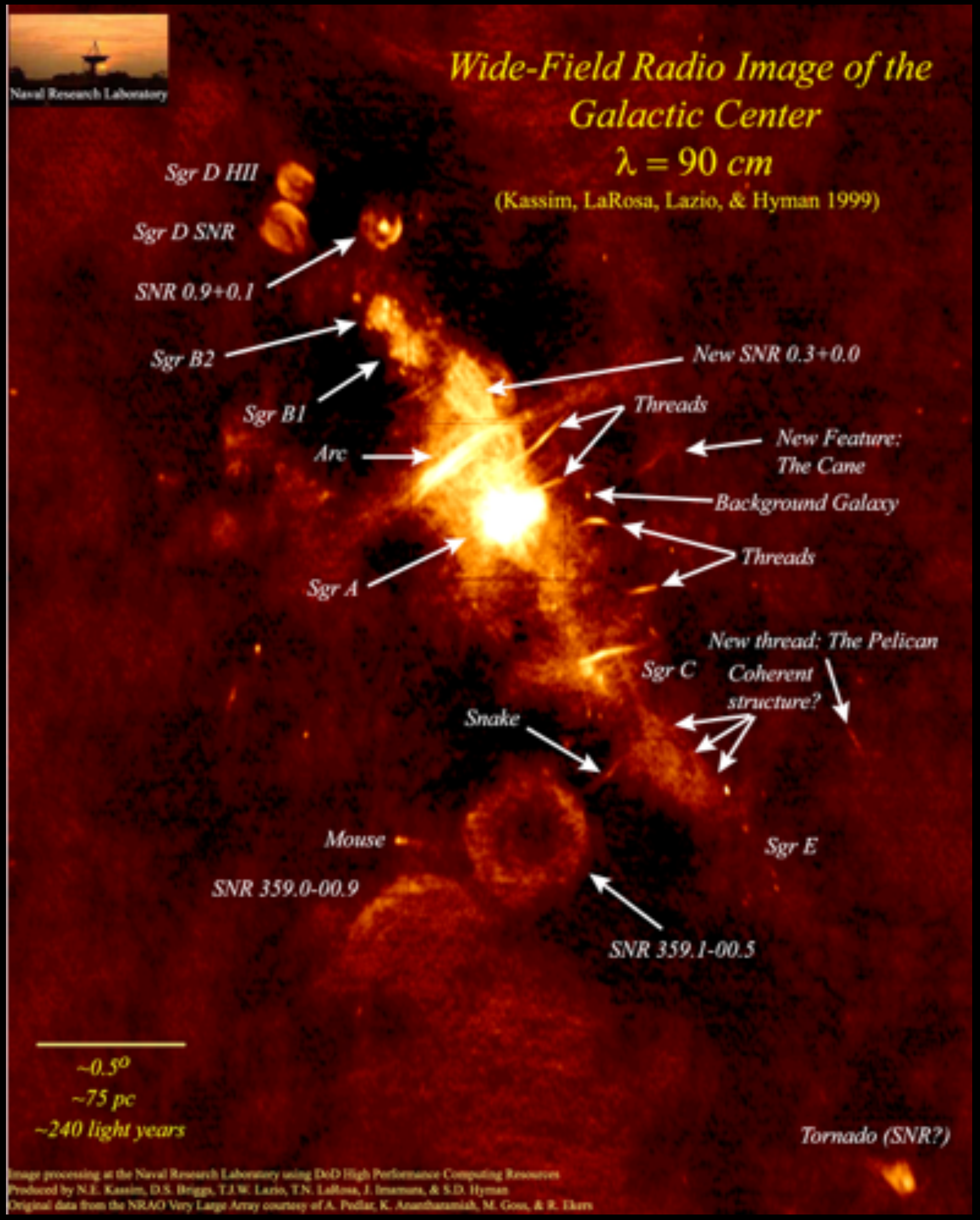
Titov+2011

- stochastic superposition of gravitational waves causes a systematic quadrupolar shift in distant quasar positions (Gwinn+1997, Jaffe 2004, Titov+2011)
- could probe GW frequency range: 1/(obs cadence) to 1/(Hubble time)
- or could probe anisotropic Hubble parameter
- wide FoV + rapid repointing + increased source counts at low freq + southern hemisphere = ideal for this
- bootstrap off of relative vs absolute astrometry
- lower freq = higher astrometric uncertainty, but simpler source structure
- another window on the gravitational Universe

Galactic centre monitoring

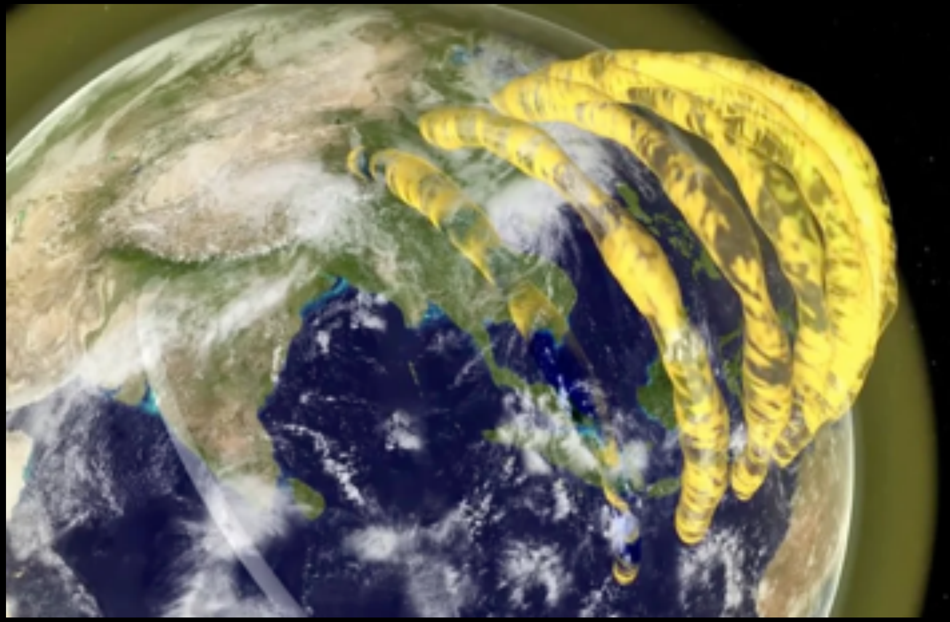
(and super-resolution from ISM scattering)

- GC is a complex region
- Sgr A* itself is highly variable
- AAMID-VLBI monitoring could enable mapping ISM electron density towards GC, accretion events of Sgr A*, SNe
- contemporaneous monitoring with multi-wavelength campaigns (e.g. Event Horizon Telescope, Chandra)



ionosphere

- $\Phi_{iono} \propto \lambda^2$
- 3D mapping of plasma "tubes" in the ionosphere by MWA (Loi et al. 2015)
- AAMID-VLBI would probe structure and dynamics of the ionosphere on longer baselines



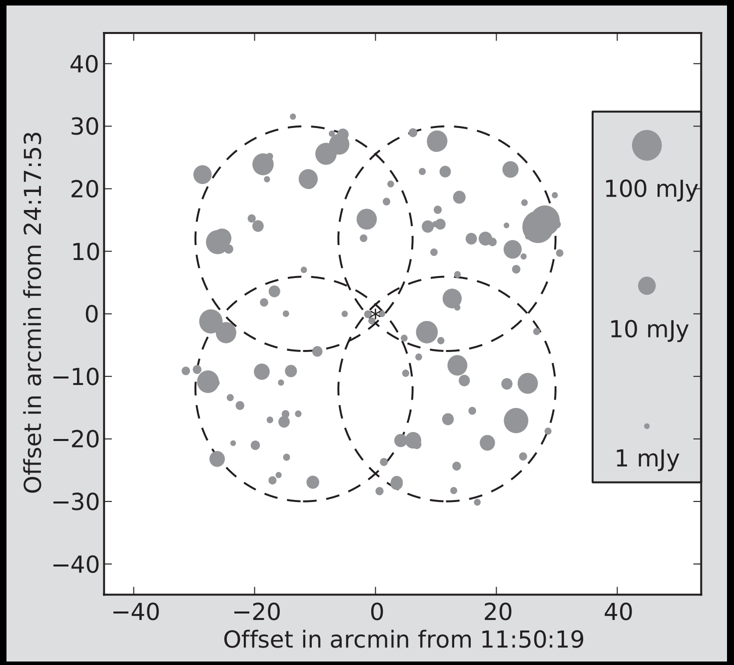
further AAMID-VLBI advantages:

rapid pointing agility (=efficiency)

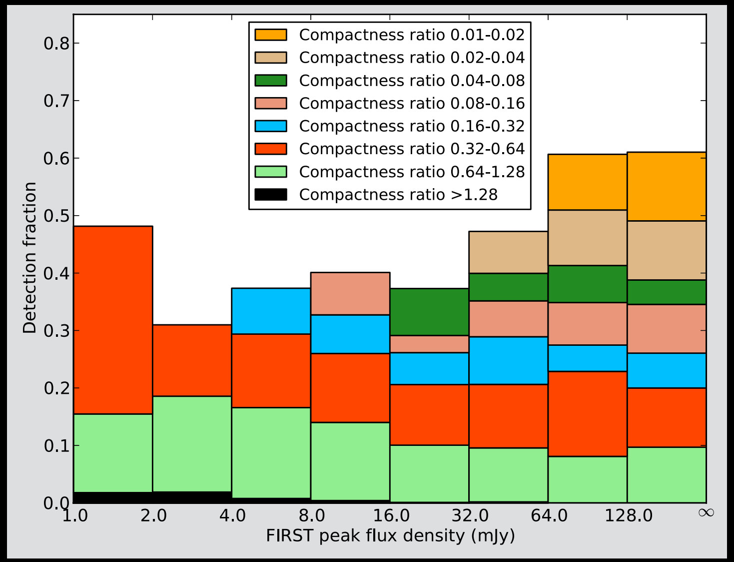
survey efficiency should be factored in to overall "survey speed" (for targeted surveys in particular)

- if you're limited by Fourier coverage, not sensitivity, require short scans over a range of hour angles
- if repointing can be done within seconds, one could perform dynamic scheduling with a granularity of seconds (as done with ALMA to a degree)
- this would enable many additional targeted surveys to be "squeezed in"
- some examples:

Deller & Middelburg 2014



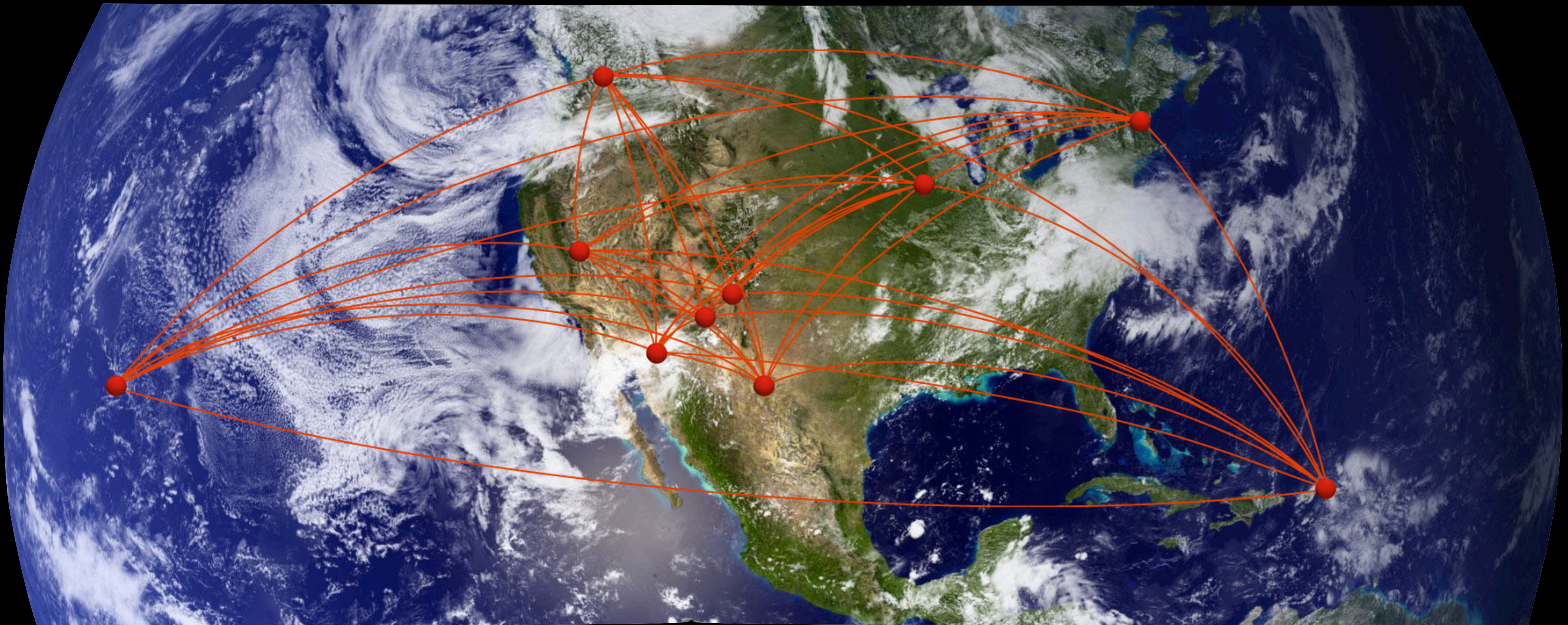
- > 20,000 FIRST selected sources observed in filler time
- multi-phase centre technique near bright calibrators
- > 4,300 detections in the 1-100 mJy range
- prospects good for in-beam calibrators for SKA-VLBI



VLBA survey of post-merger galaxies

- 91 ‘car-crash’ galaxies (SDSS/FIRST-selected)
- 61 hours with VLBA at 5 GHz (~3 mas resolution)
- ~30-50 μJy/b per target ($L_{5GHz,5\sigma} > 10^{23}$ W/Hz)

- **primary science:**
  - ✦ search for binary black holes
  - ✦ jet triggering in mergers



further AAMID-VLBI / “Dream Machine” advantages:

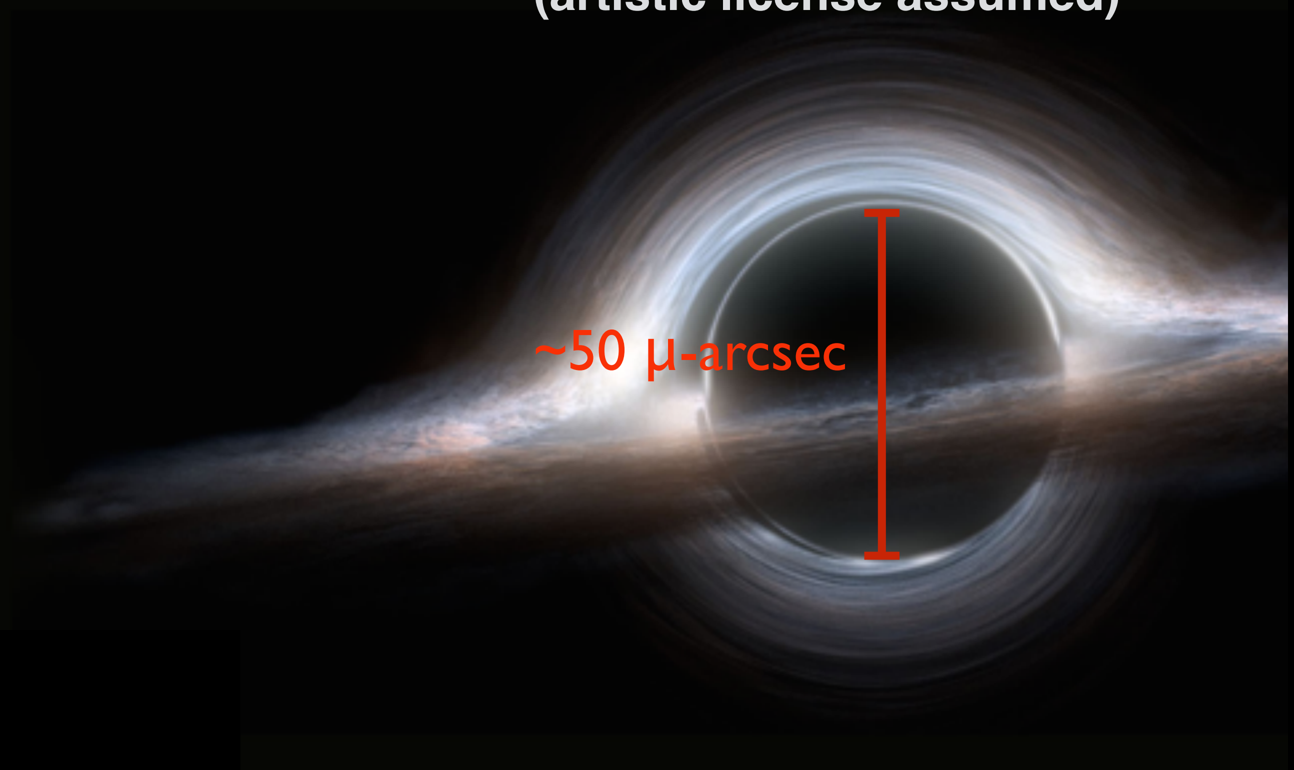
transients

- as per JP and Joeri talks, expect to spatially resolve transient phenomena and/or pinpoint ***within*** a host galaxy
- could be triggered in seconds or serendipitously on target — turn VLBI into a discovery machine
- examples include:
    - localising FRBs within their host galaxies (if extragalactic)
    - resolving explosive outflows (relativistic SNe, long-GRBs)
    - pin-pointing Tidal Disruption Events (TDEs) and flaring Intermediate Mass Black Holes (IMBHs)

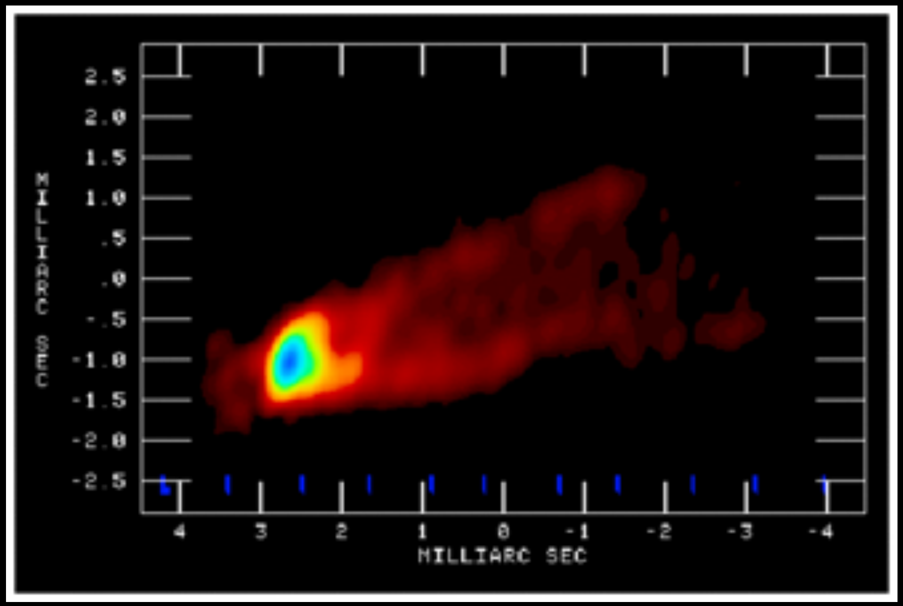
technical spin-offs from mm-VLBI

- in contrast to cm-VLBI's push to wide field surveys, mm-VLBI is being driven by the quest to measure the black hole shadows of two sources: M87 and Sgr A*

Attempting to measure something like this:
(artistic license assumed)



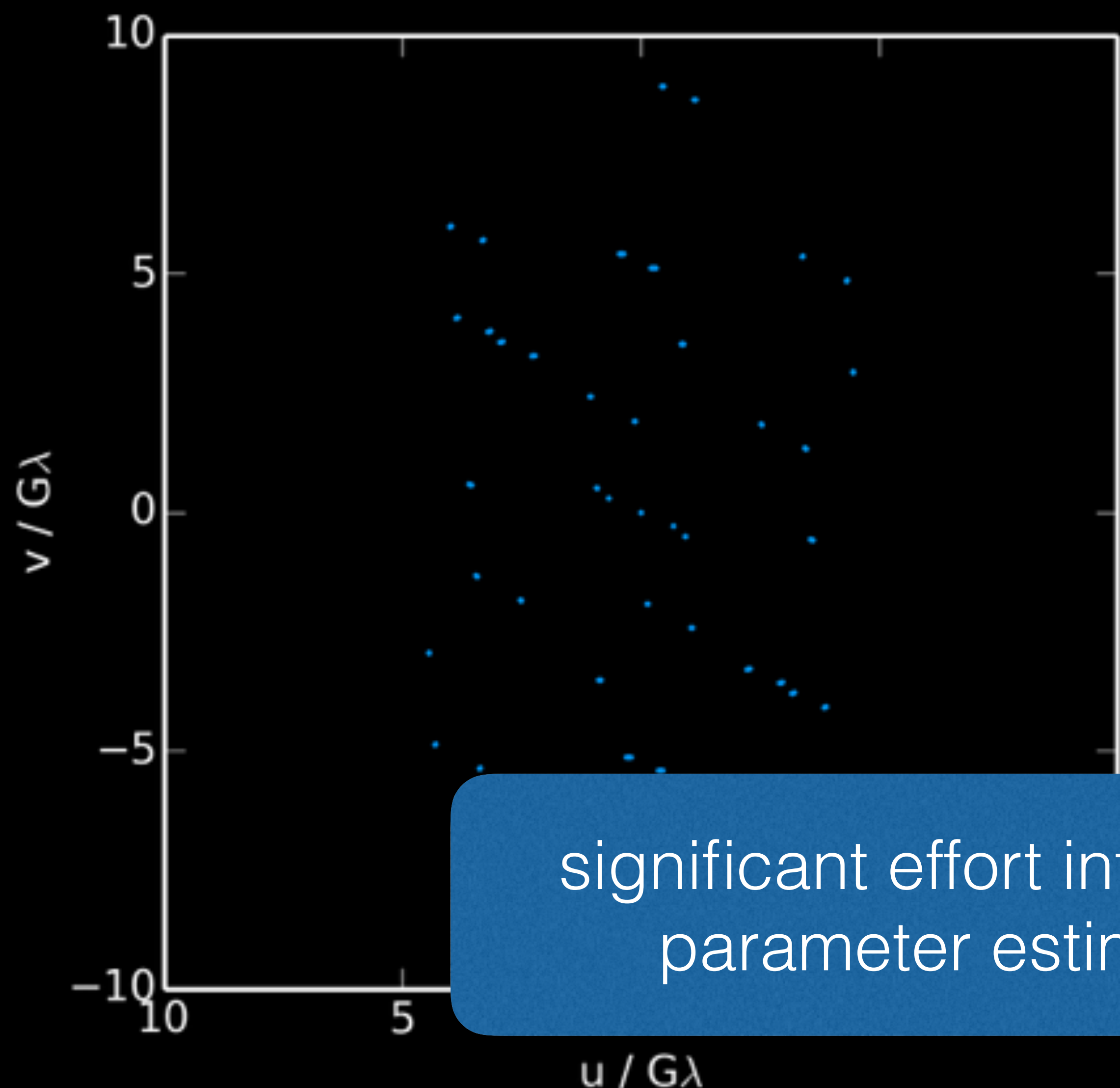
when state-of-the-art mm-VLBI imaging is this:



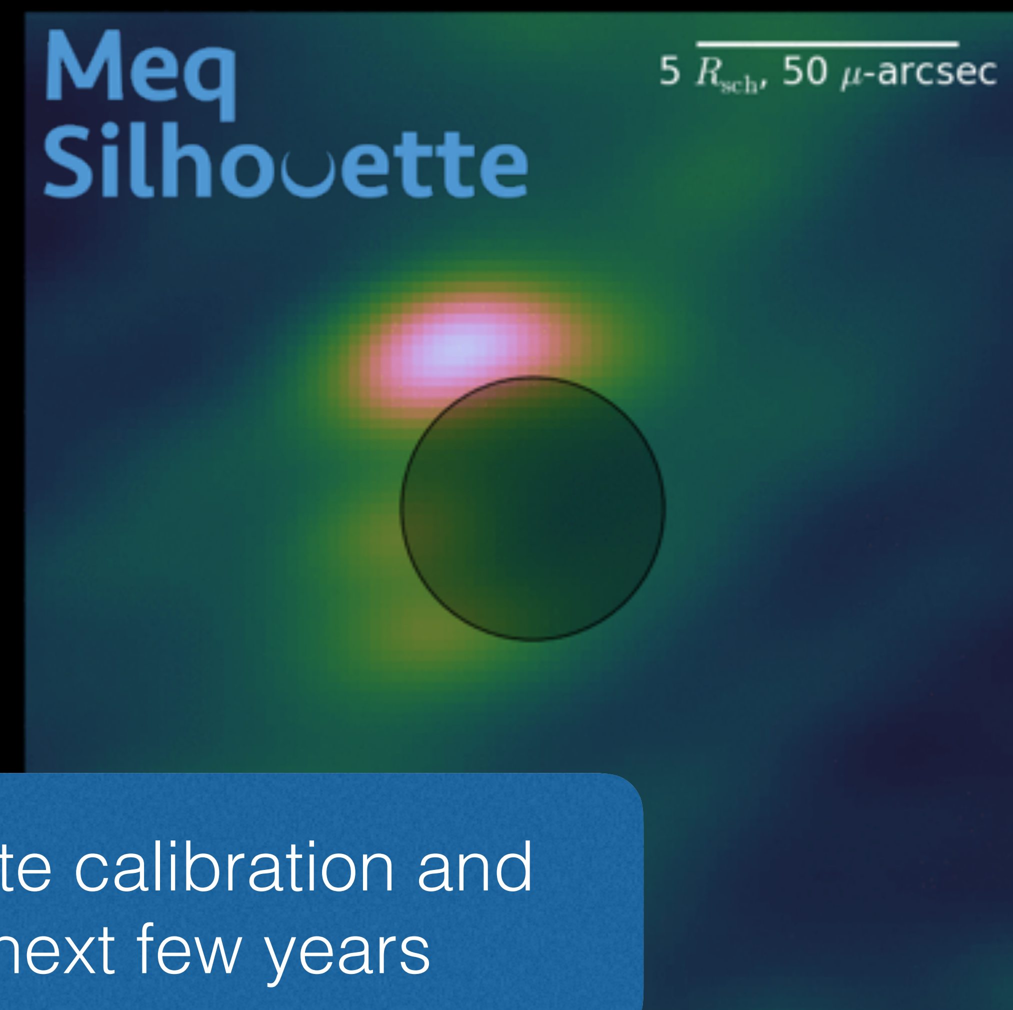
M87 jet with VLBA @ 43 GHz, credit: Craig Walker

EHT (230 GHz) snapshots of orbiting hotspot around Sgr A*

uv-coverage: 200 sec integrations, 2 hour run

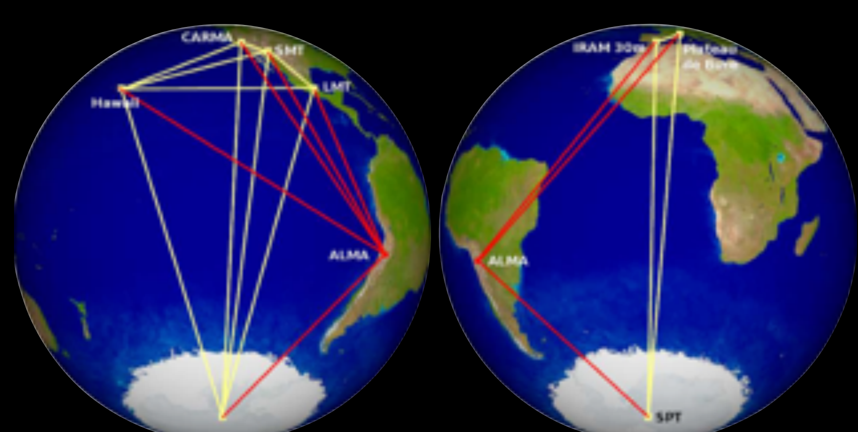


interferometric snapshots



significant effort into accurate calibration and parameter estimation in next few years

Blecher, Deane, Bernardi & Smirnov, in prep.



credit: R. Tilanus

original hotspot models from
Monika Moscibrodzka

summary

- VLBI enhances/enables most key SKA science projects
- Wide-field VLBI is here and SKA-VLBI will greatly enhance this, however, not in step with arcsec-resolution surveys
- Including AAMID demonstrator/core in into AVN/EVN would be highly beneficial to wide-field VLBI L-band surveys
- If the AAMID-VLBI “dream machine” is built, the FoV, frequency range and pointing agility will enable large-scale (astro)physics programmes simply not possible with any other facilities
- AAMID-VLBI post-processing would benefit from the significant effort being put into wide-field imaging, correlation windowing functions, variable source modelling, ionospheric calibration, etc.