SKA-VLBI Use Cases & uGMRT

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JIVE

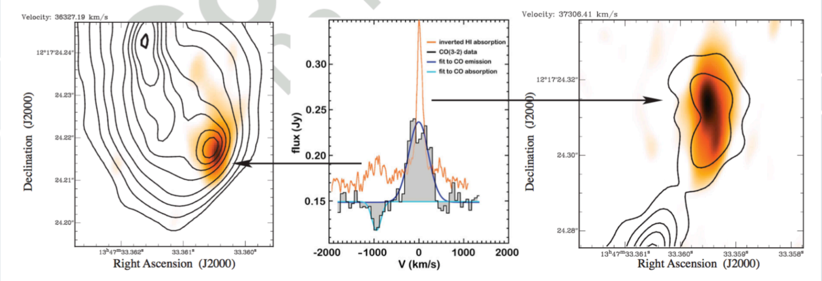
The European VLBI Network

- ➢ **Combining some of the most powerful telescopes in the world:**
- ➢ **To detect extremely weak signals, and image them at the highest detail**

- Central data processor and data archives at JIVE
- The EVN Software Correlator (SFXC) flexible operations: real-time e-VLBI, continuum, spectral line, pulsar binning, fast transients, multiple phase-centres

Tied-array in a VLBI network

Global-VLBI follow-up of a young radio source in 4C12.50, showing signs of jet-driven outflows of atomic and molecular gas (Morganti et al. 2013, Science, 341, 1082)



- WSRT in the EVN (till a few years ago): 93m equivalent, single tied-array beam
  - ➔ Ef 100m - WSRT provided the most sensitive, shortest EVN spacing

  (short spacings sensitivity, also including the 76m Lovell Telescope, was a major advantage over the VLBA for certain projects)
- Other advantages: calibration (amplitude, polarization) of VLBI data + complementary science

  (WSRT transient follow-up with the EVN; WSRT HI results follow-up at milliarcsecond resolution; great results but not fully exploited…)
- Disadvantages: very limited the Field of View!!!

The unique experience with WSRT-EVN (great successes, but also realizing some missed opportunities) was a main driving factor behind pushing the SKA-VLBI idea within JIVE.

Science example 1: HI detection limits

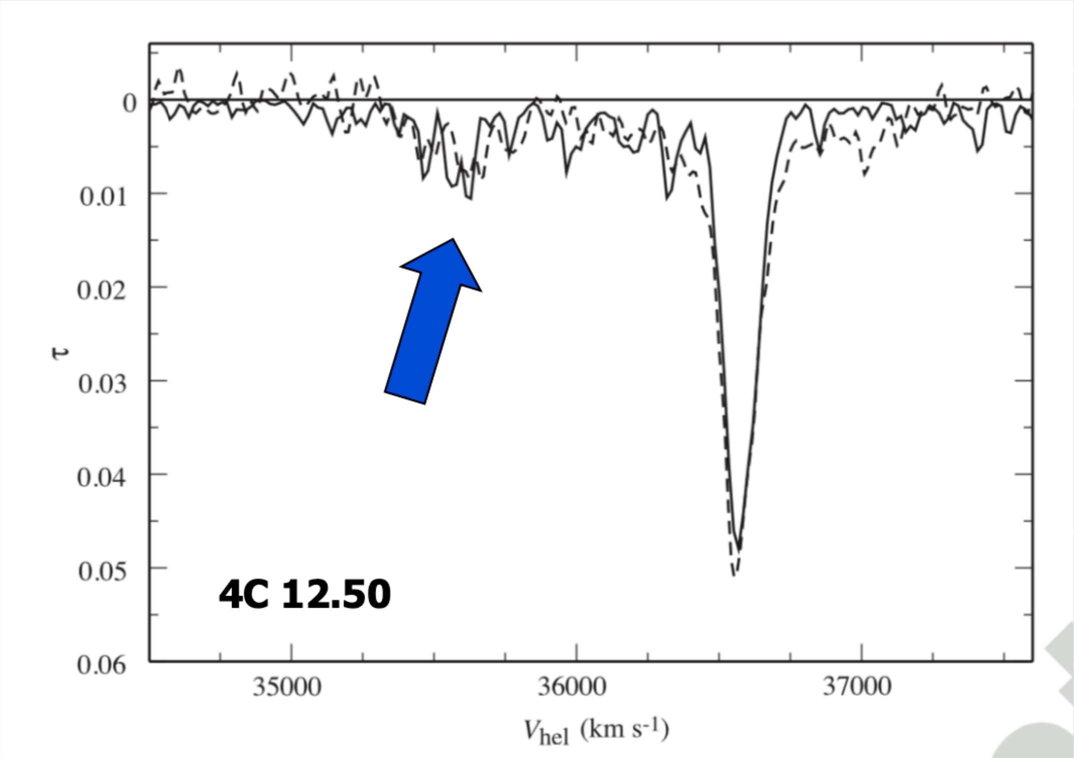
- When we target HI absorption on tens of pc scales, the continuum emission is in the mJy/beam regime – challenging!

Line detection sensitivity
(10hr integration, 0.5 MHz channel, ~100 km/s):

~60 μJy/beam full EVN
~1.5x lower with uGMRT
~2x with SKA1-MID or FAST
~8x with uGMRT+SKA1-MID+FAST

Detectable opacity for 10 mJy/beam continuum, 7σ
$\tau_{\text{min, peak}}$ = 0.05 (EVN only); <0.01 (global SKA-VLBI)

The figure shows $\tau \sim S_{\text{line}}/S_{\text{cont}}$ estimated from WSRT assuming unresolved continuum – true opacities were higher, those can be measured form VLBI maps.



Dashed line: WSRT spectrum; black line: global VLBI

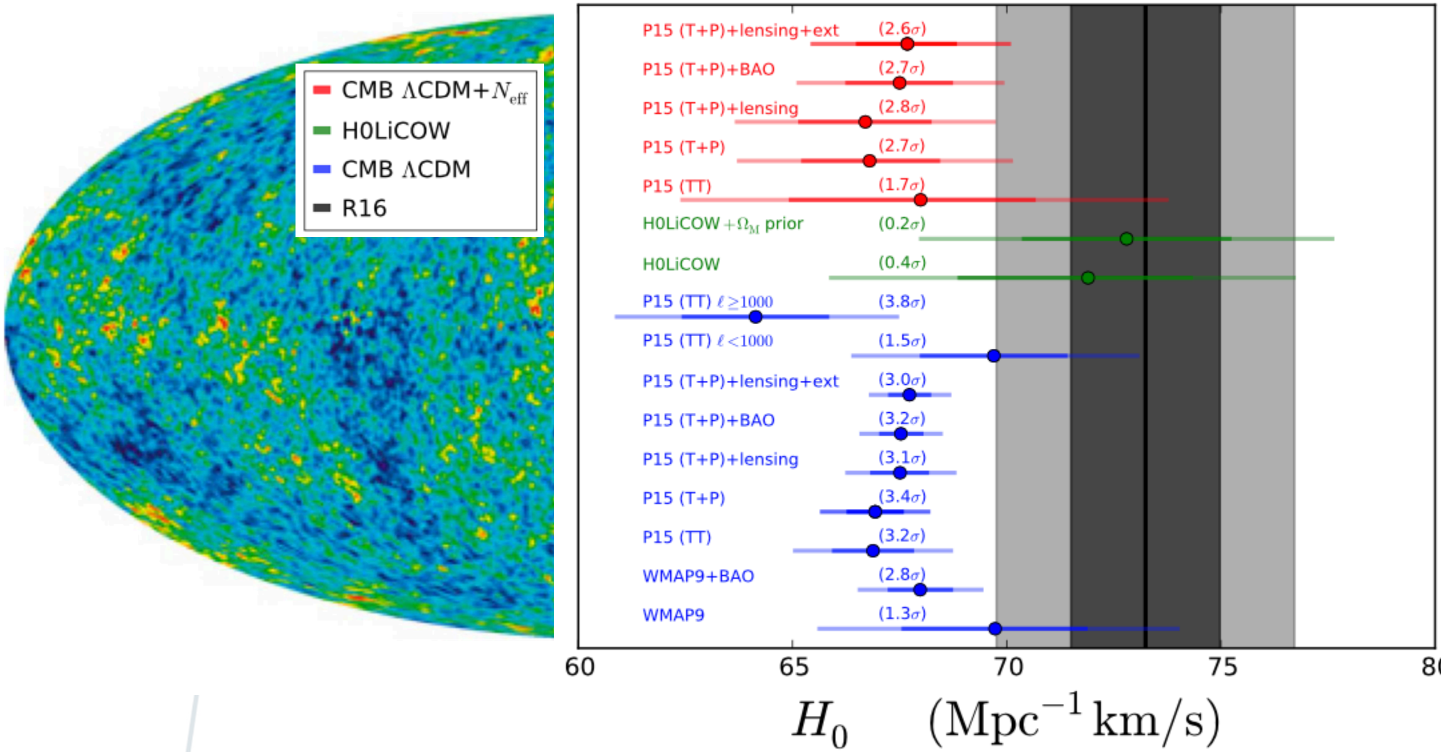
Science example 1: HI column densities

$$N_{\mathrm{HI}} = 1.8\times10^{18}\, T_{\mathrm{spin}}\, \tau_{\mathrm{peak}}\, FWHM_{\mathrm{line}} \quad \rightarrow \quad 10^{20}\ \mathrm{cm}^{-2}$$

(100 K; <0.01; 100 km/s) (4.6 × 10^{21} cm^{-2} in 4C12.50)

- Will need additional sensitive elements in the VLBI network like uGMRT, SKA1-MID and FAST to push these limits further!

SKA-VLBI Science example II: "The H_0 trouble"



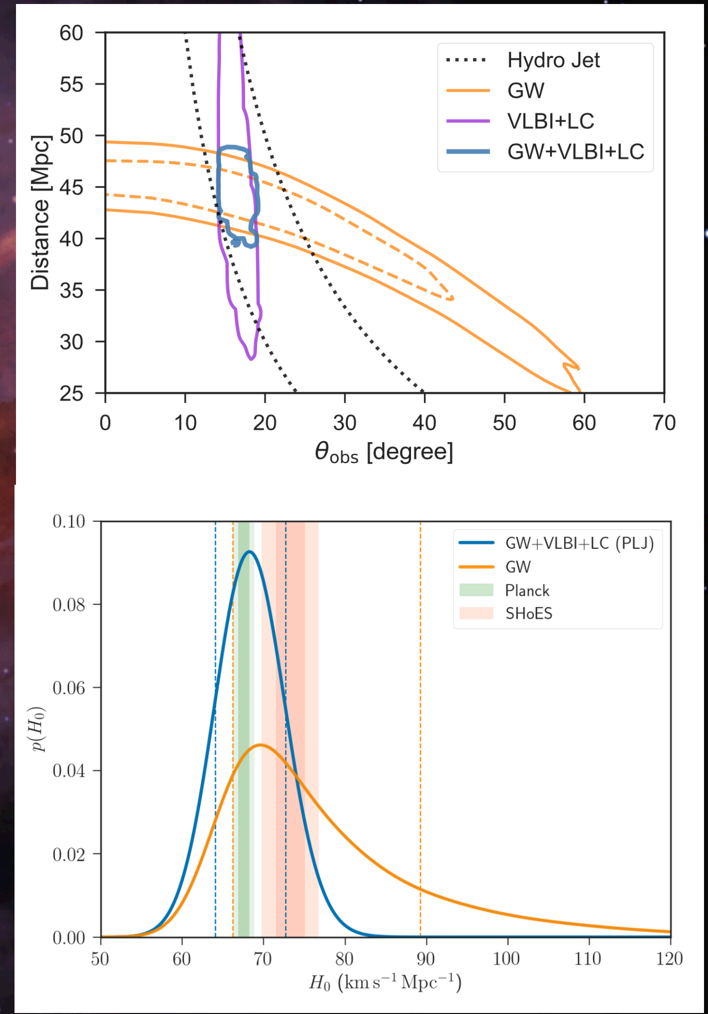
Bernal et al. (2016)

- **There is a discrepancy between the various CMB solutions and the local H_0 measurement from SN Ia data, at the 3σ level**
- **GW standard sirens could help, but solutions are degenerate with viewing angle ➔ VLBI can help resolve that!**

GW+VLBI constraint on H_0

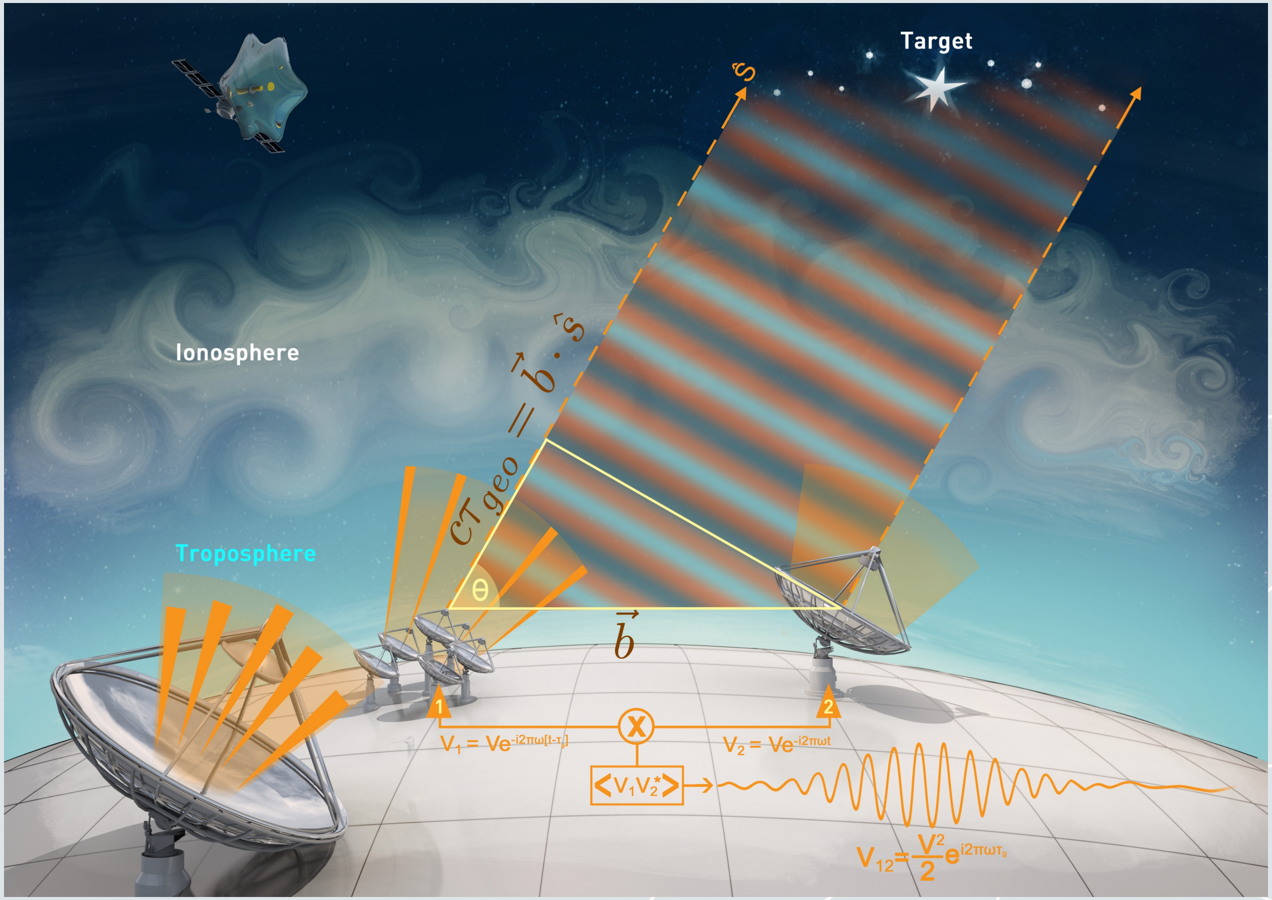
Beabudai Design

Hotokezaka et al. (2019)



- **It takes 10 BNS mergers with EM counterparts to constrain H_0 at 5%, 200 for 1%**
  (Sathyaprakash et al. 2019, Astro2020 Science White Paper on binary mergers)

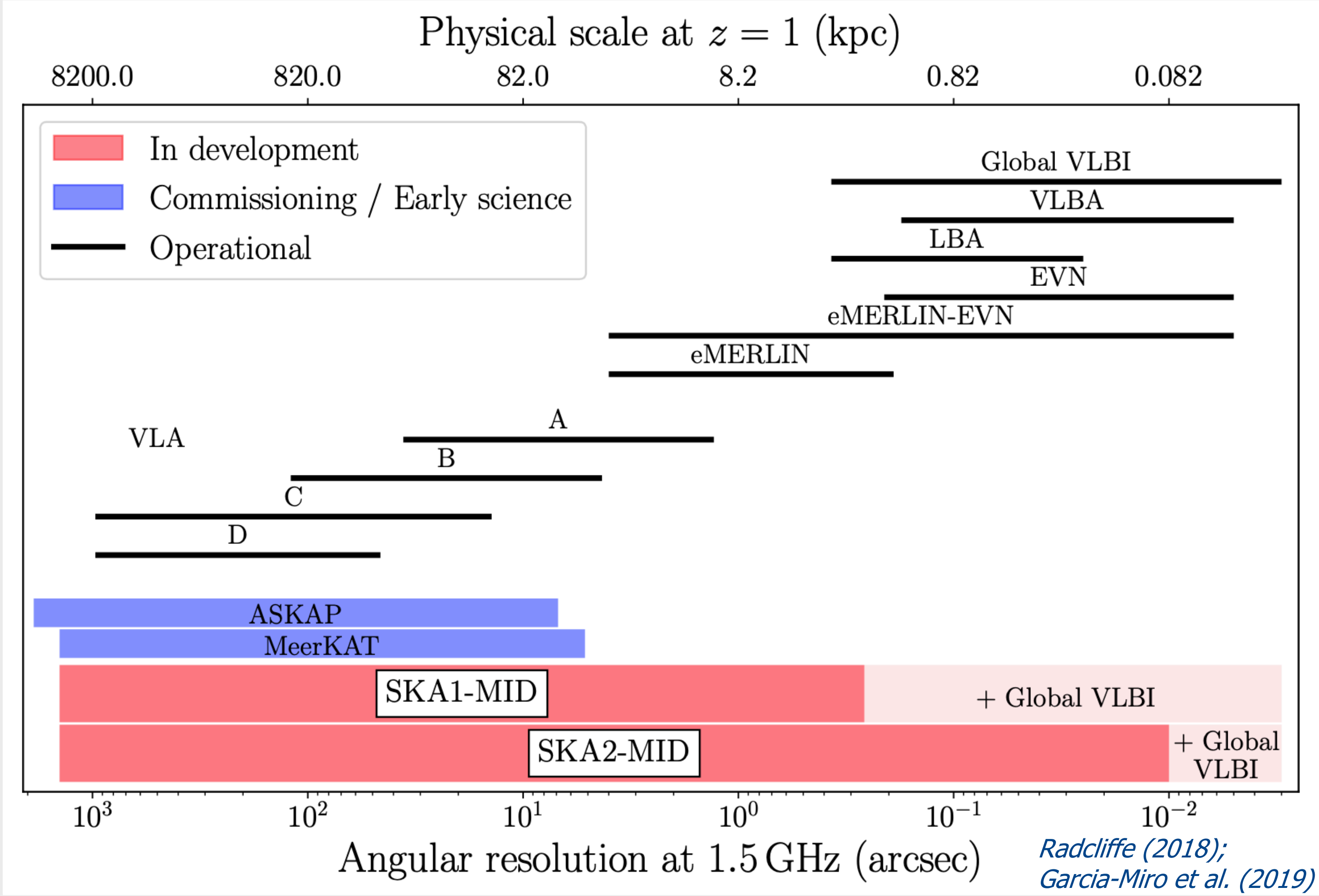
VLBI with the SKA?



Rioja & Dodson (2020)

- **Strong science driver is** *ultra-precise astrometry (~1 µas; e.g. Paragi et al. 2015)*
- **Requires n>4 SKA1-MID beams** *(L1 requirements now aligned with design capabilities)*
  - *Phasing up limits the field of view, but several tied array beams can be produced in the dish primary FoV*
  - *Allows for multiple mJy—10mJy-level calibrators within ~10s arcmin*

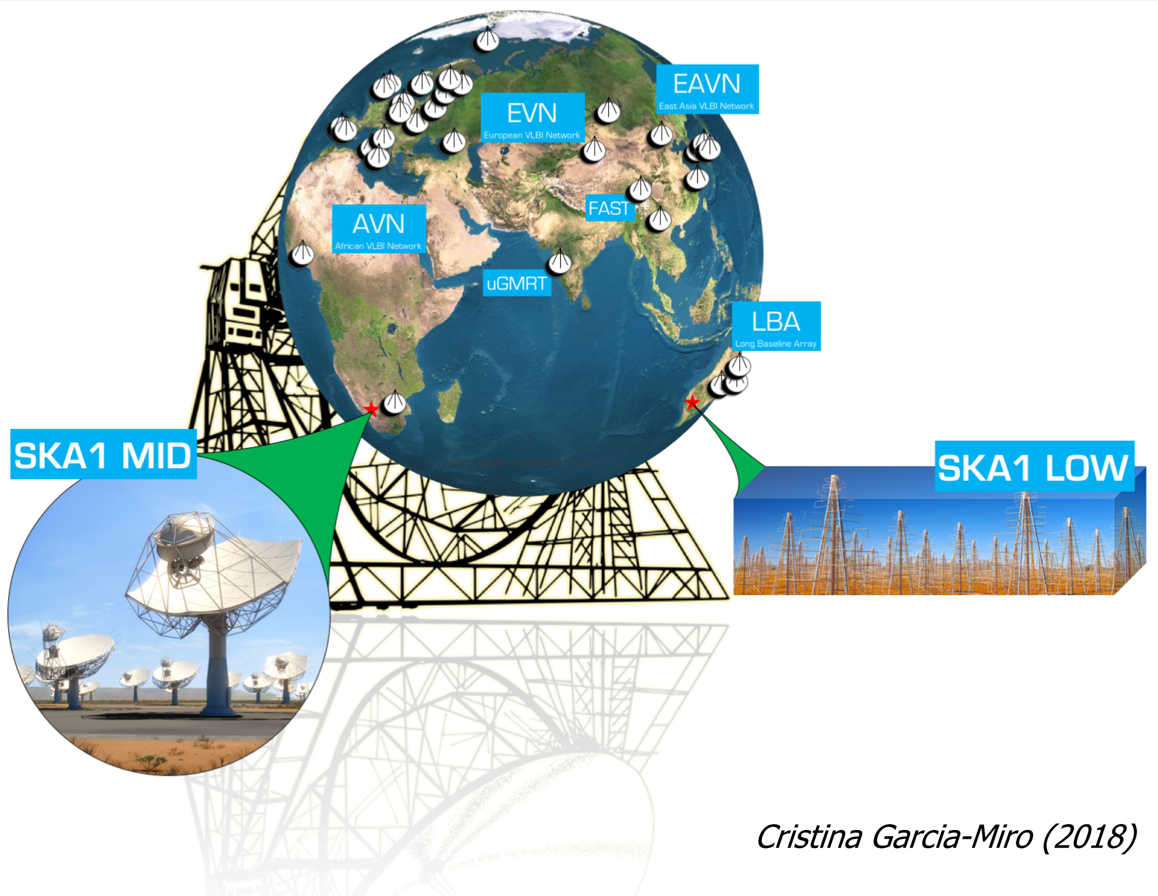
Range of angular/spatial scales probed



Radcliffe (2018); Garcia-Miro et al. (2019)

- ➢ **Allowing for unique science** *(Godfrey et al. 2012, Paragi et al. 2015, JJ D10.3-4)*
- ➢ **Bootstrapping SKA calibration** *(tying flux scales; polarization PA)*
  - – the uGMRT could also do this if VLBI + interferometer work simultaneously!
  - – alternatively, VLBI recording of core + several other antennas could be considered

JUMPING JIVE WP10: VLBI with the SKA



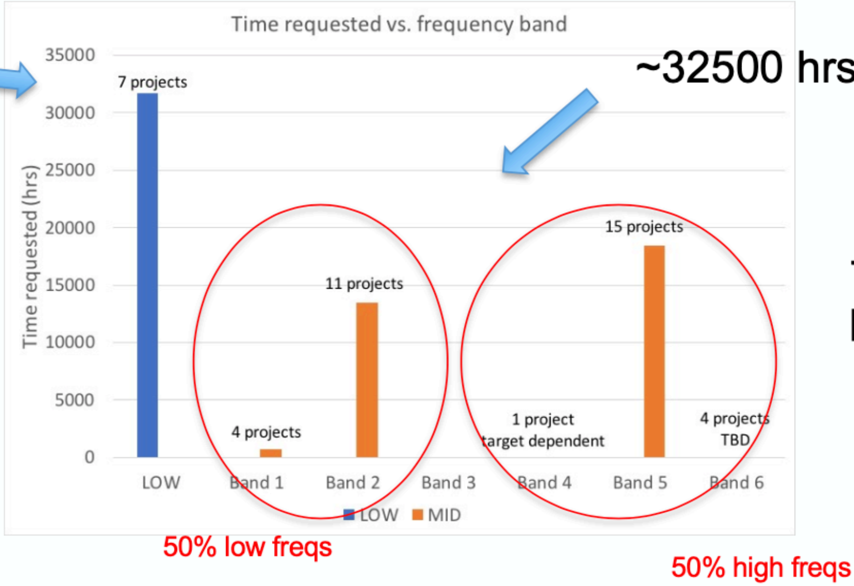
Project deliverables

- *D10.1 Details on VLBI Interfaces to SKA Consortia*
- *D10.2 Operational model for inclusion of SKA in Global VLBI*
- *D10.3 Portfolio of SKA-VLBI Science Cases*
- *D10.4 Key Science Projects*

- **High SNR brings source parametrization to another regime, given low-level systematics, i.e. excellent calibration –** Improved resolving power!
  (1% ➔1/10th beam: cf. Natarajan et al. 2017; Paragi et al. 2019)

SKA-VLBI Science Use Cases vs. frequency

~31700 hrs

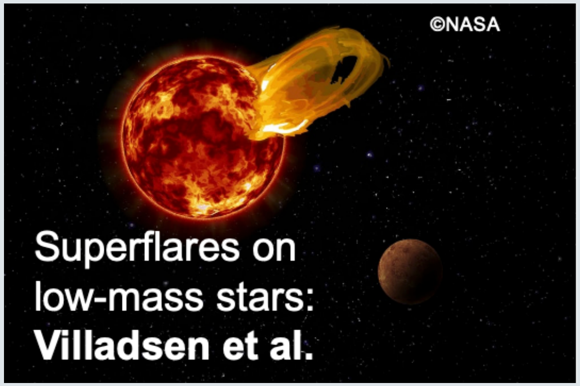


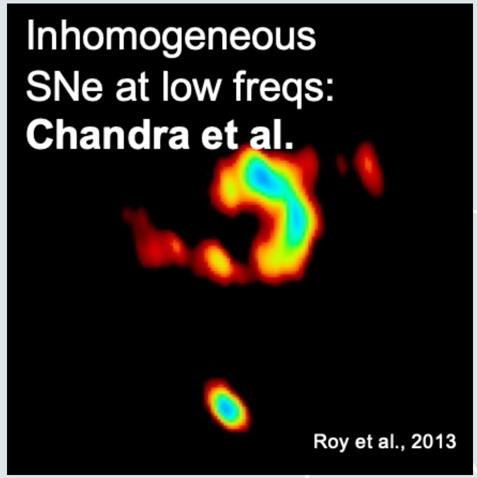
~32500 hrs

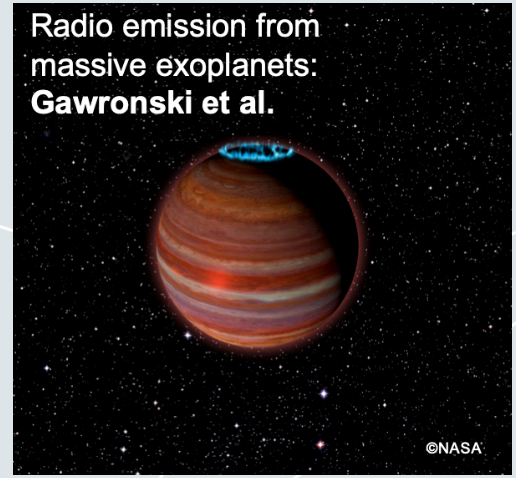
+8 MID dual-band projects

- ➢ Note projects could allocate all SKA1 telescope KSP time for several years! SKA1 telescopes will have limited time for VLBI – opportunity for uGMRT?
- ➢ **More than half of the projects are in the L-band or below!**
- ➢ All projects require multiple beams, but primary objectives in certain cases may be achievable with a single beam with less precision

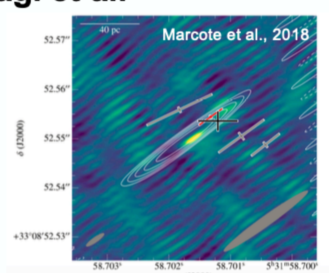
Examples for SKA1-MID



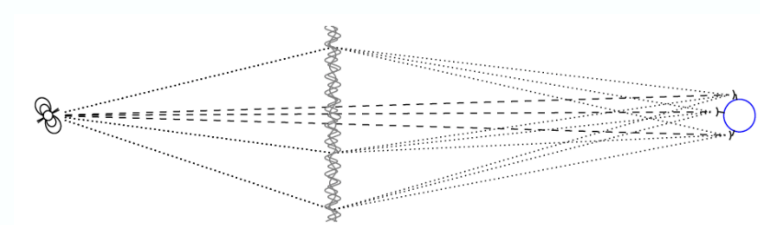




FRBs and their hosts: **Paragi et al.**



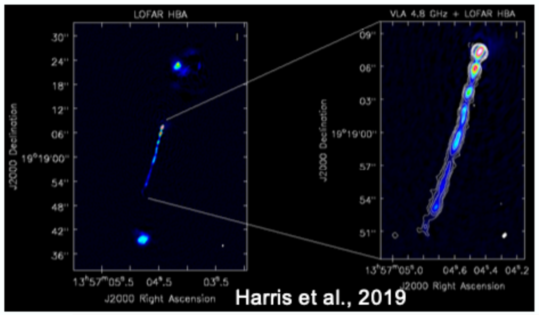
Pulsar scintillometry with SKA1-MID: **Kirsten et al.**



SKA1-LOW VLBI projects

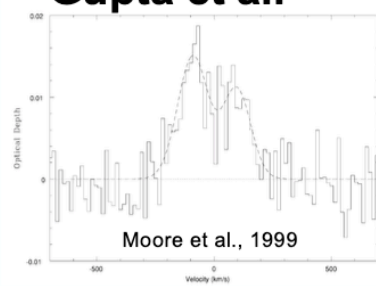
Galaxies and AGN

AGN physics at very low freqs: **Morabito et al.**



Harris et al., 2019

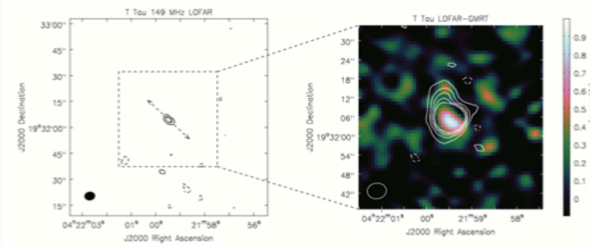
HI absorption at high z: **Gupta et al.**



Moore et al., 1999

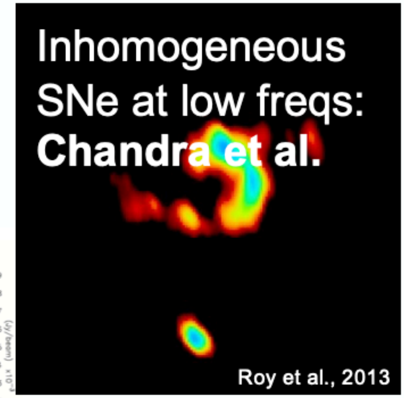
Transients

Jets from low mass YSO at very low frequencies: **Ainsworth et al.**



Coughlan et al., 2017

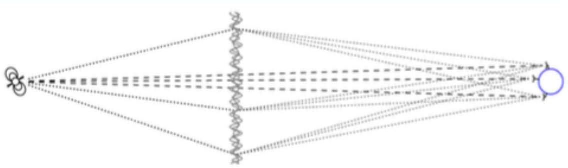
Inhomogeneous SNe at low freqs: **Chandra et al.**



Roy et al., 2013

Pulsars and ISM

Pulsar scintillometry at very low freqs: **Kirsten et al.**



Stars, Planets, Astrometry

Precise astrometry of low frequency pulsars: **Dodson et al.**

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Precise astrometry for exoplanets detection: **Guirado et al.**

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Summary

- **uGMRT will play an important role in global VLBI**
- **In particular for some SKA-VLBI projects, it could be a proxy for SKA1-MID (with certain limitations)**
- **For SKA-LOW VLBI projects uGMRT is fundamental**
- **Flexible operations are required (mixed VLBI/interferometer/pulsar observing modes)**
- **Use Cases documentation available at:**

http://www.skatelescope.org/wp-content/uploads/2019/10/JJ-WP10deliverable10.3.pdf

At your service!

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