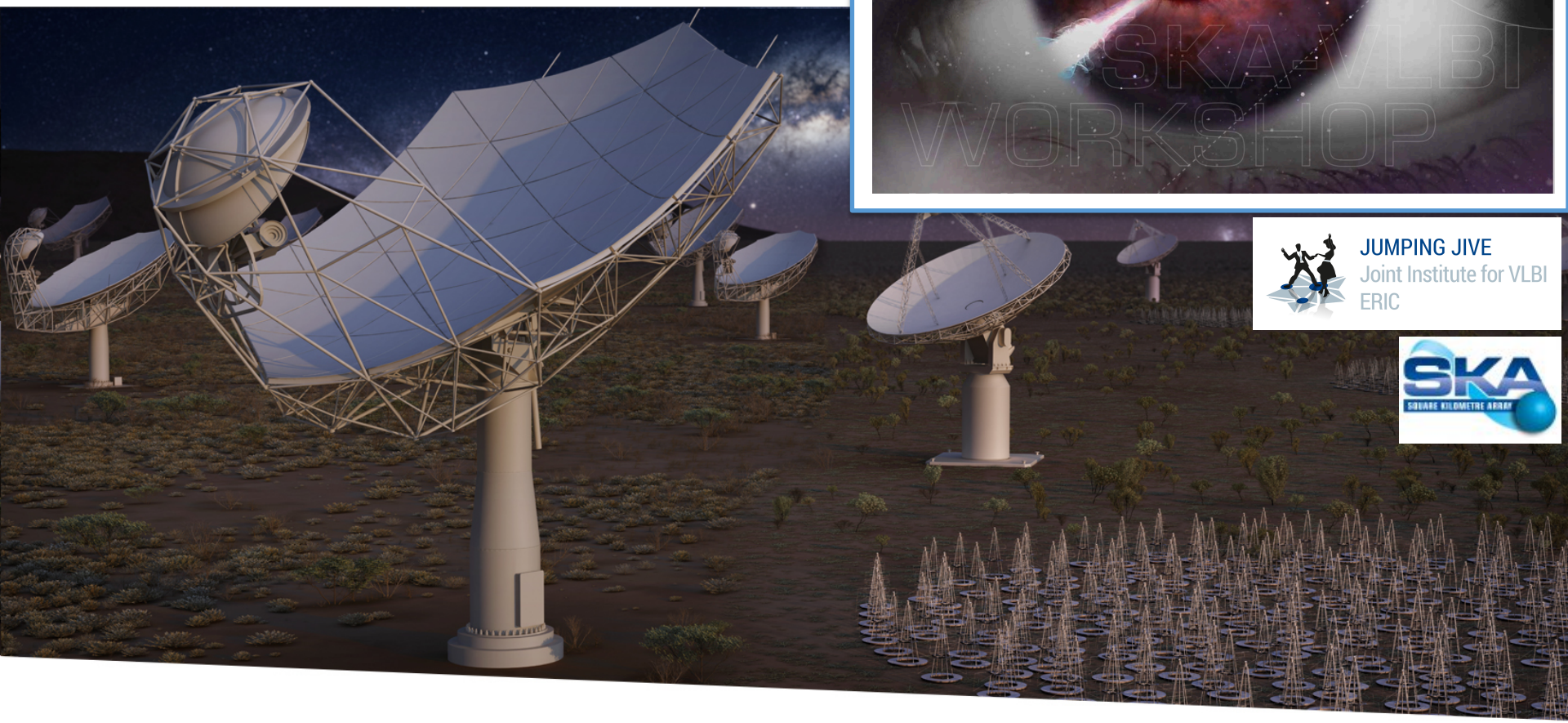
SKA-VLBI capacity and technique



SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

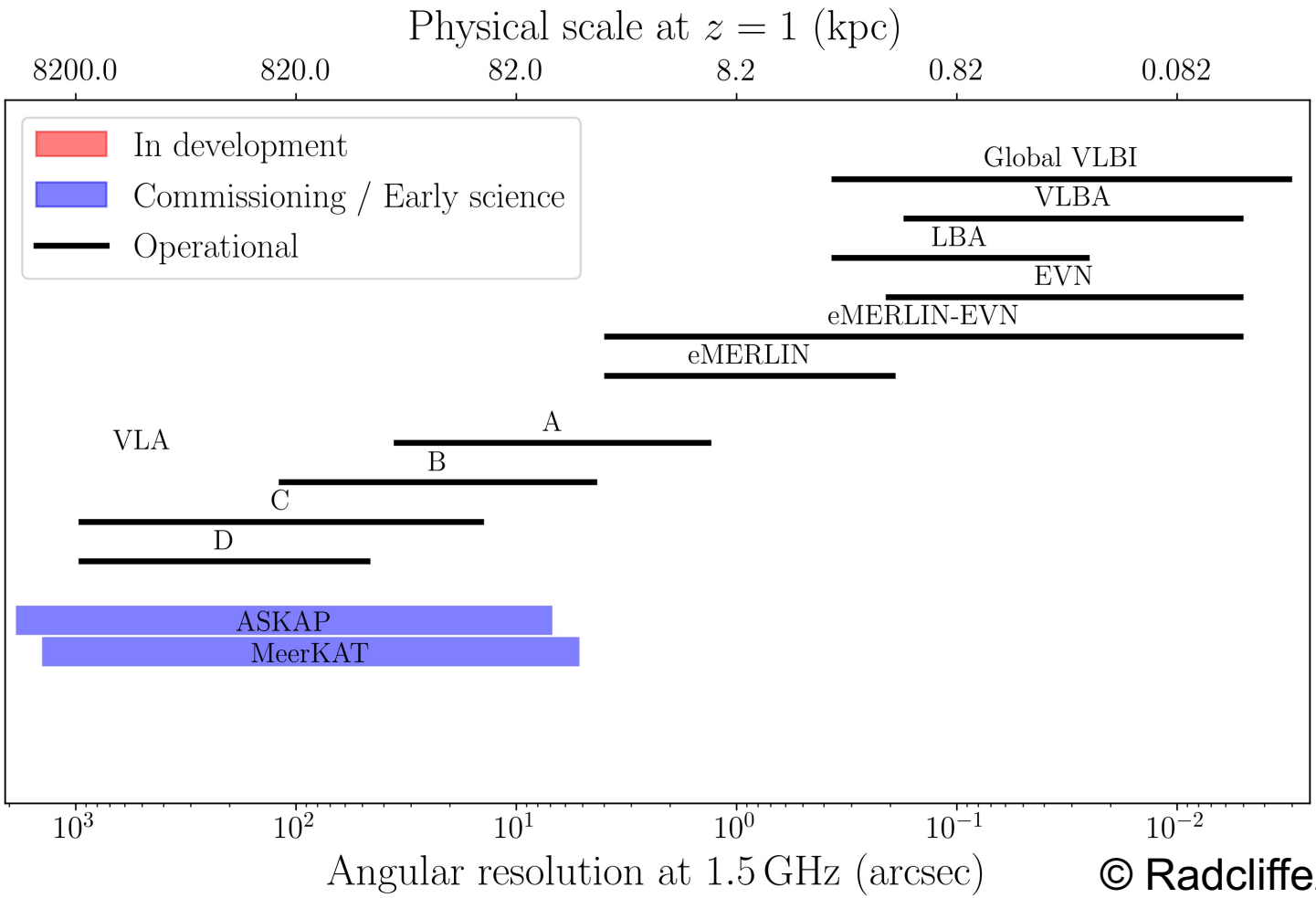
Cristina Garcia Miro / Tao An

JUMPING JIVE Project / SKA VLBI SW

miro@jive.eu JIVE / SHAO

SKA-VLBI:

broadest angular resolution



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SKA-VLBI:

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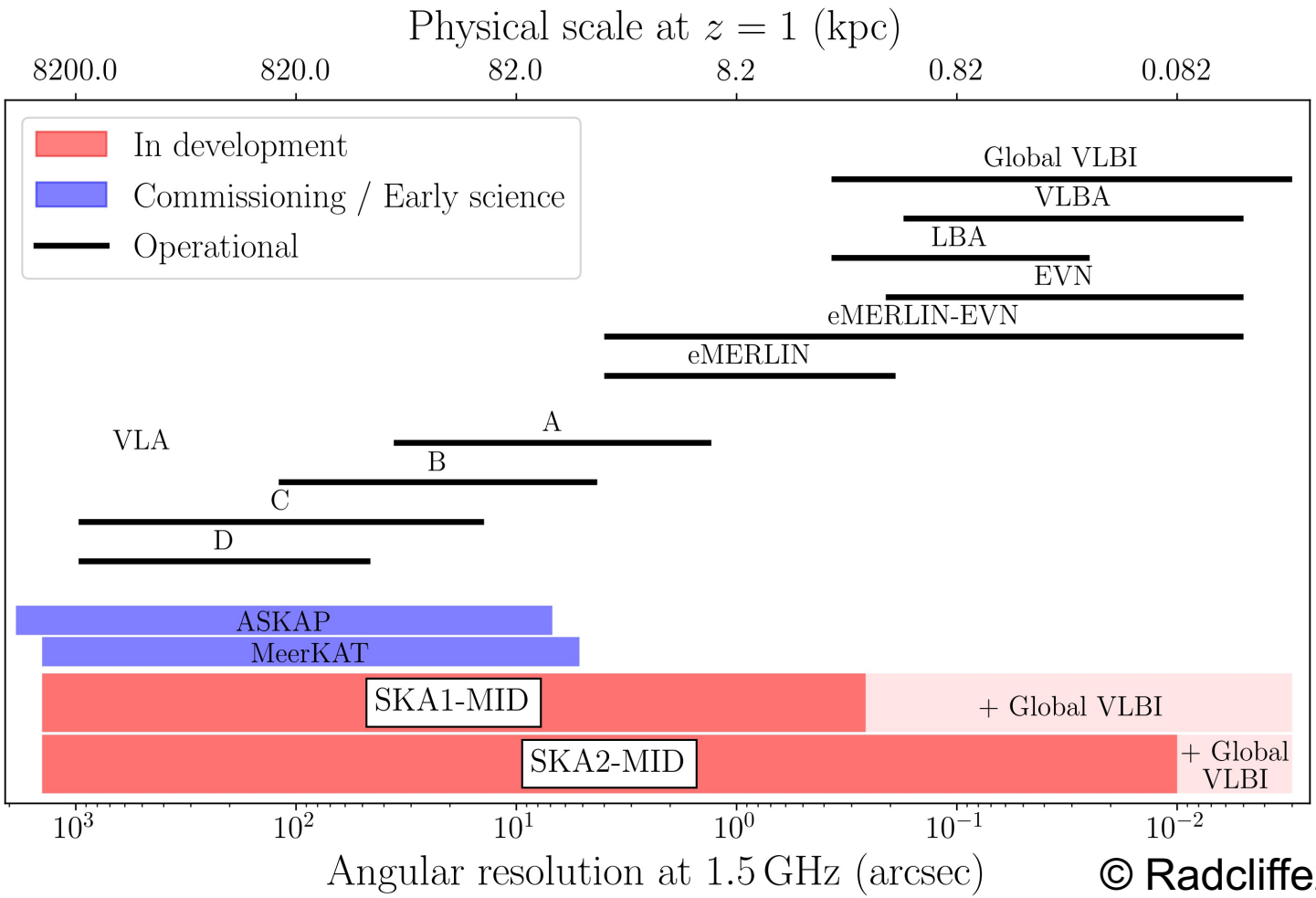

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SKA-VLBI:

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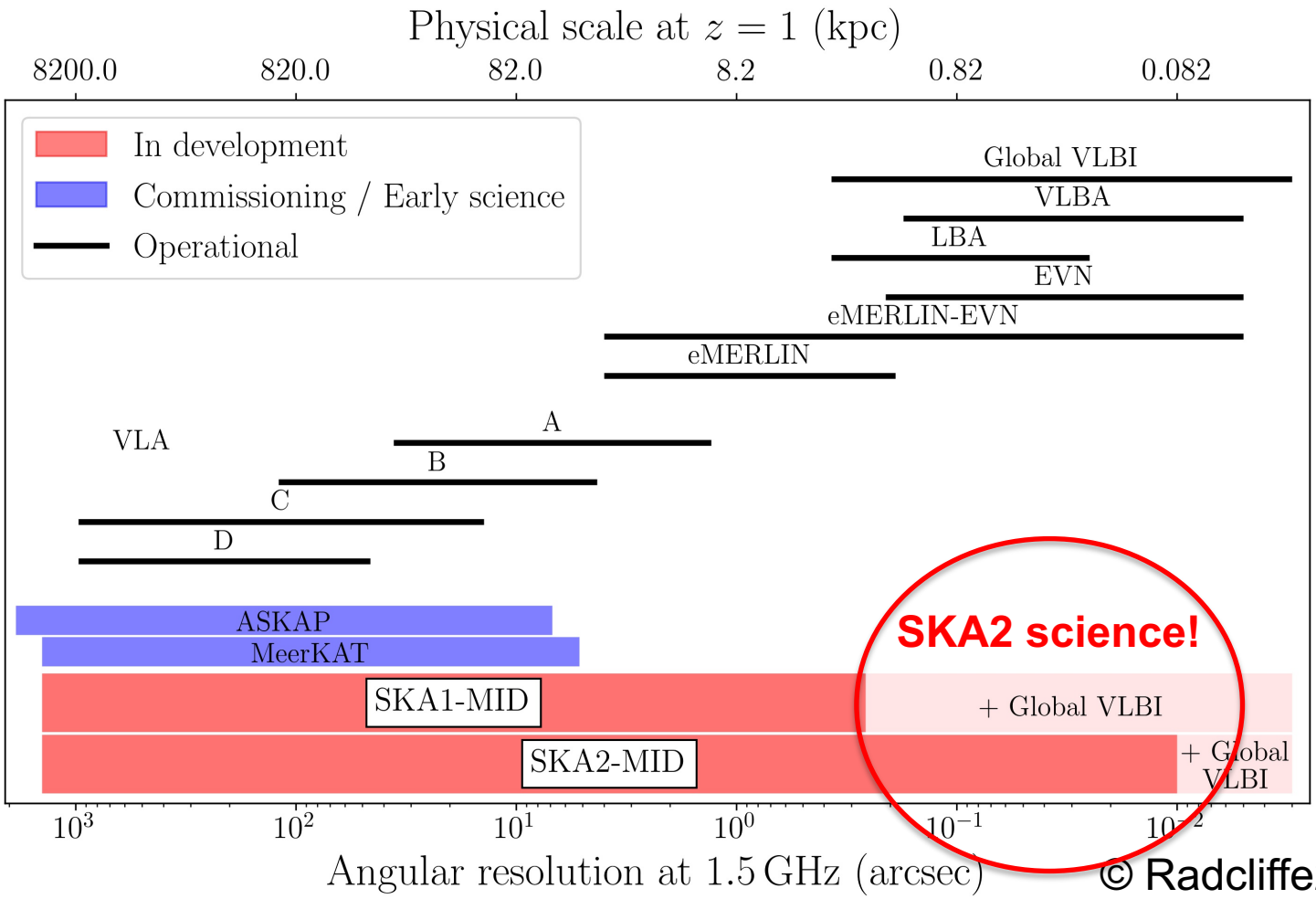

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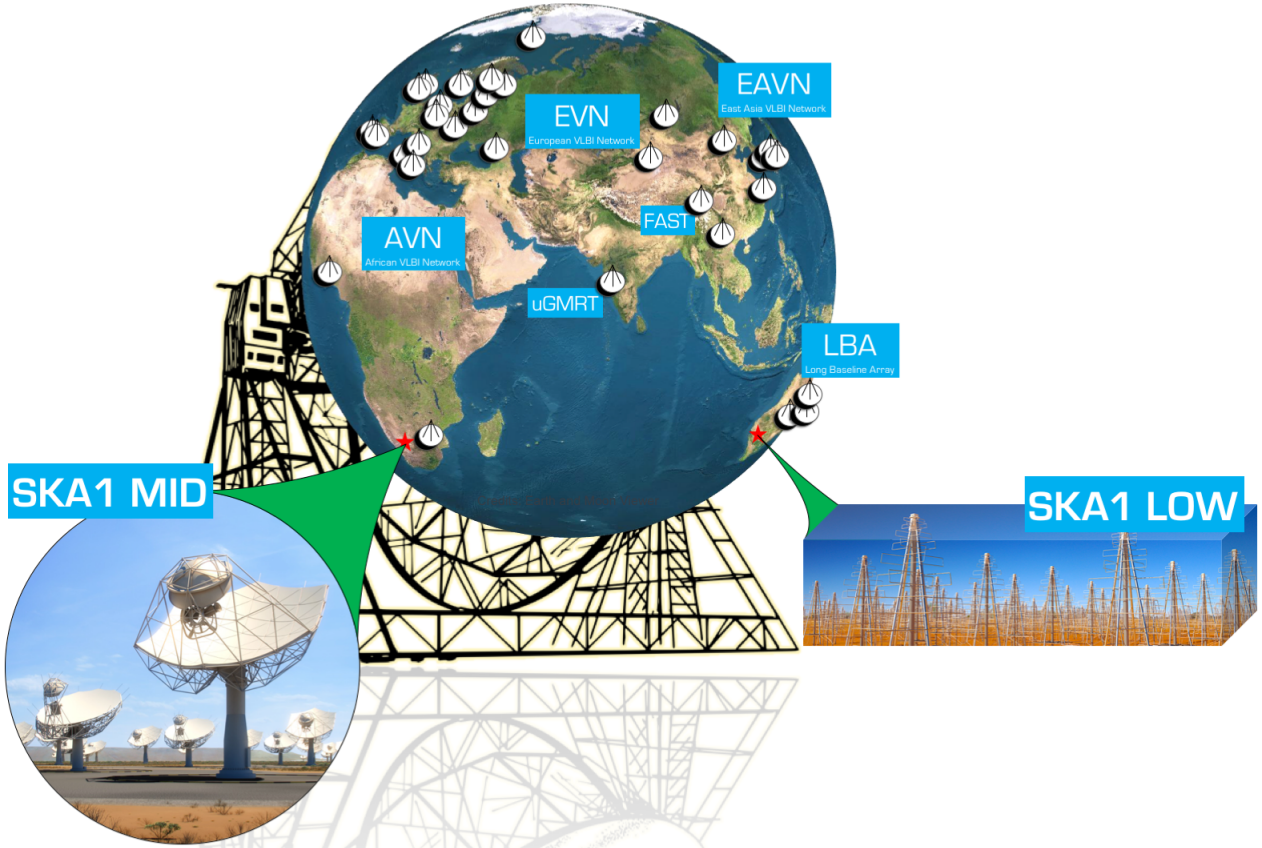
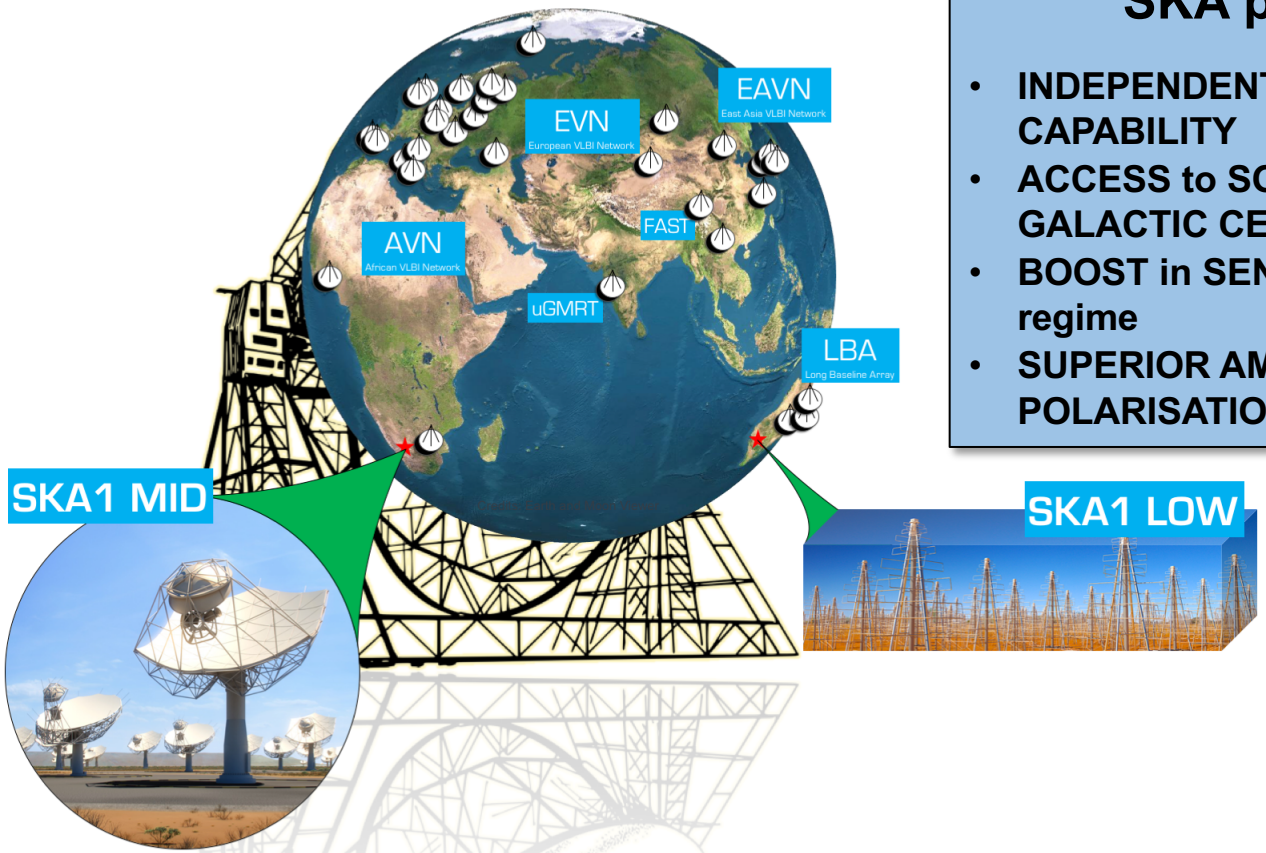
SKA-VLBI


EAVN
East Asia VLBI Network
EVN
European VLBI Network
FAST
AVN
African VLBI Network
uGMRT
LBA
Long Baseline Array
SKA1 MID
SKA1 LOW

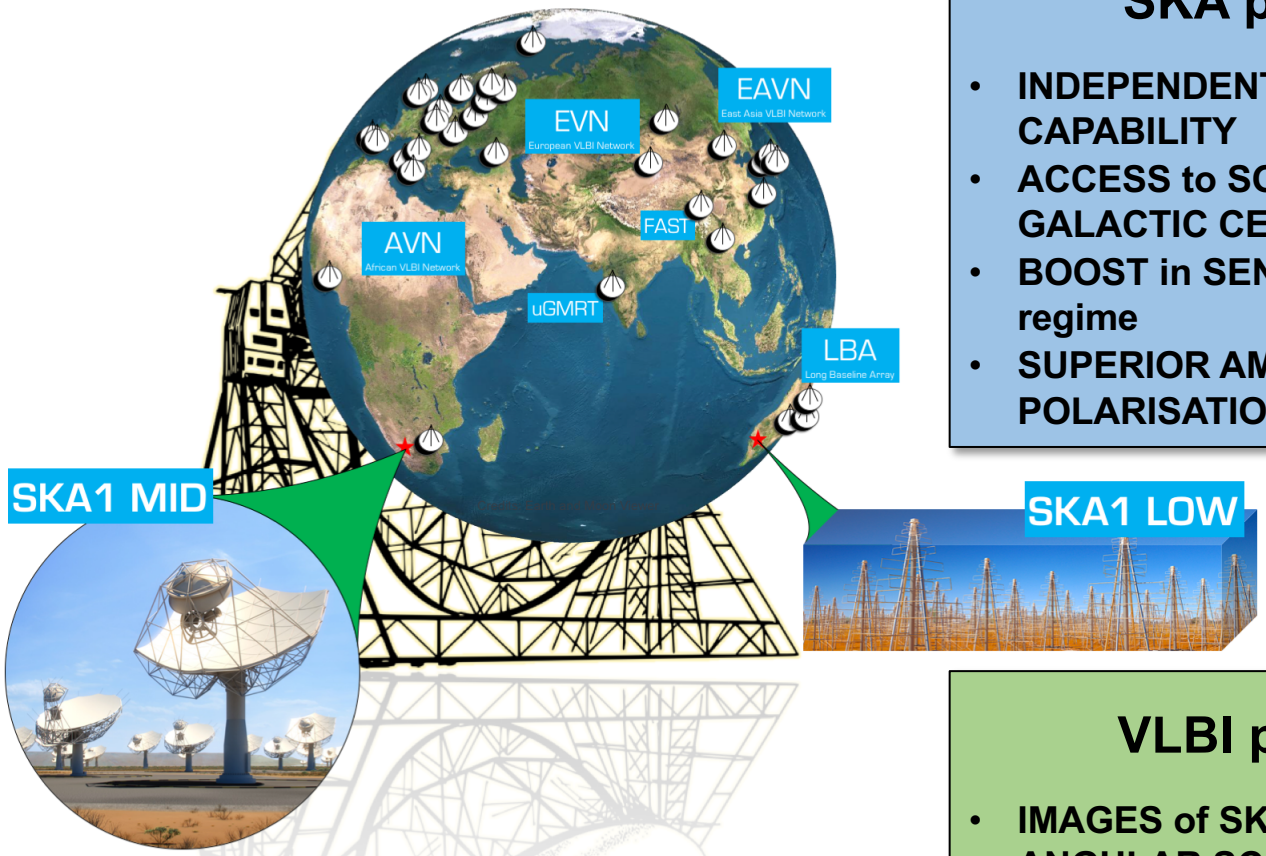
SKA-VLBI



SKA provides …

- INDEPENDENT MULTI-BEAM CAPABILITY
- ACCESS to SOUTHERN SKIES and GALACTIC CENTER
- BOOST in SENSITIVITY to µJy regime
- SUPERIOR AMPLITUDE and POLARISATION CALIBRATION

SKA-VLBI



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VLBI provides …

- IMAGES of SKY at BROAD RANGE of ANGULAR SCALES RESOLUTIONS
- HIGH RESOLUTION for SKA HPSOs
- INDEPENDENT COMMISIONING TOOL and EARLY PUBLIC RELATIONS OPPORTUNITIES
- AN ENTHUSIASTIC USER COMMUNITY

SKA-VLBI Science

SKA-VLBI Science

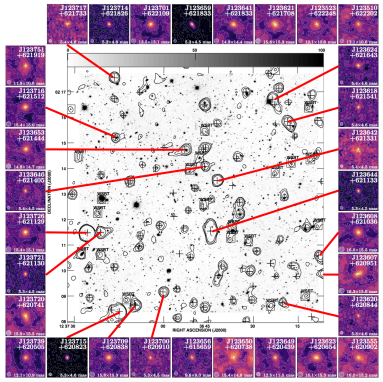
- ✓ JUMPING JIVE 2nd deliverable: Portfolio of Science Cases
- ✓ SKA VLBI Science Working group support
- ✓ Outcomes inform the SKA-VLBI operational model and KSPs

VLBI with SKA1-MID:

6 science cases updated (from SKA1 scientific use cases doc.)

SKA continuum surveys

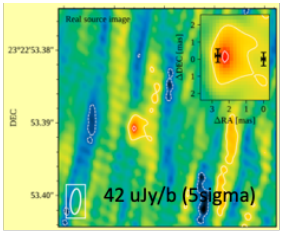
Adding high angular resolution to SKA surveys: **Giroletti et al.**



Radcliffe et al., 2018

Transients

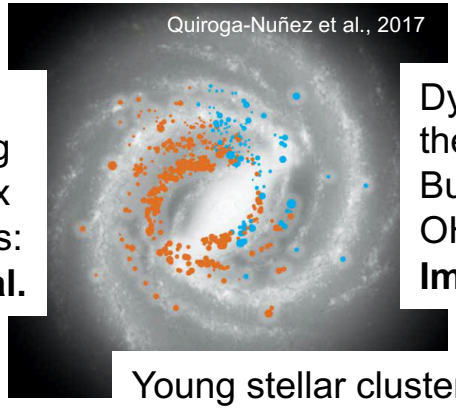
Resolving (ultra)-relativistic outflows with SKA-VLBI: **Paragi et al.**



Ghirlanda, Salafia, et al. 2019, Science

Our Galaxy, Astrometry and CoL

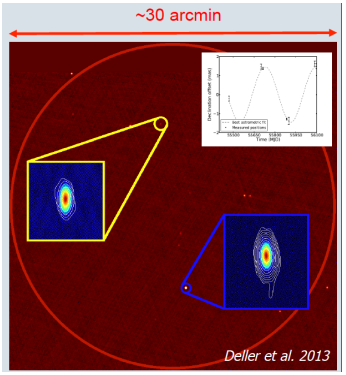
Galactic structure using maser parallax measurements: **Ellingsen et al.**



Dynamics of the Galactic Bulge using OH masers: **Imai et al.**

Young stellar cluster deep field: **Hoare et al.**

Pulsars, Astrometry



Parallax measurements of SH pulsars: **Deller et al.**

VLBI with SKA1-MID:

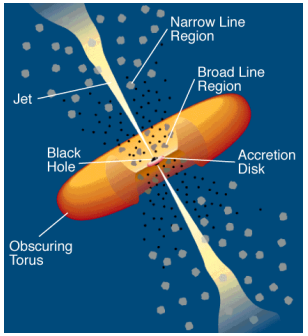
16 new science cases!

JUMPING JIVE
Joint Institute for VLBI ERIC

AGNs (6)

Polarimetric survey of a big AGN sample: **Agudo et al.**

Chasing merged and merging SMBH: **Anton et al.**

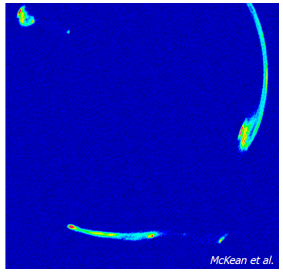


Intermediate mass black holes: **Mezcua et al.**

HI absorption in high-z radio AGN: **Morganti et al.**

Extremely high-z AGNs: **Perger et al.**

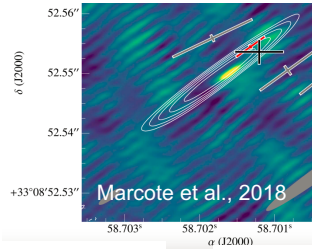
Strong gravitational lensing: **McKean et al.**



Transients (4)

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

ULXs in the local Universe: **Middleton et al.**



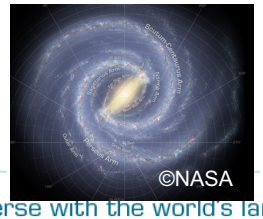
Superflares on low-mass stars: **Villadsen et al.**

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

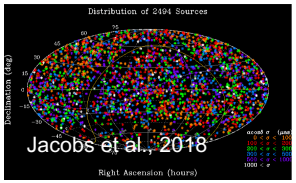
Astrometry (4)

Continuum sources in star forming regions: **Dzib et al.**

Ultra-precise astrometry to the MCs: **Rioja et al.**



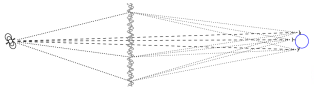
Gaia counterparts. **Charlot et al.**

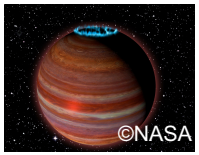


Radio and Gaia tie with radio stars: **Zhang et al.**

Stars, planets and ISM (2)

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





Radio emission from massive exoplanets: **Gawronski et al.**

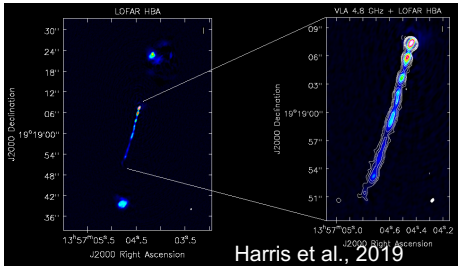
VLBI with SKA1-LOW:

7 new science cases!

JUMPING JIVE
Joint Institute for VLBI ERIC

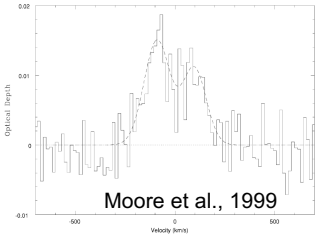
Galaxies and AGN

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



Harris et al., 2019

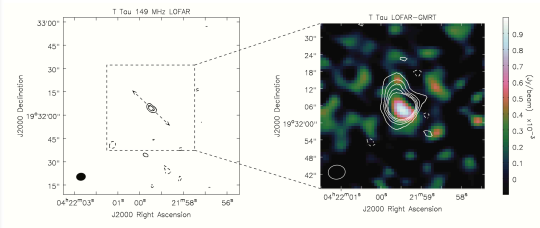
HI absorption at high z: **Gupta et al.**



Moore et al., 1999

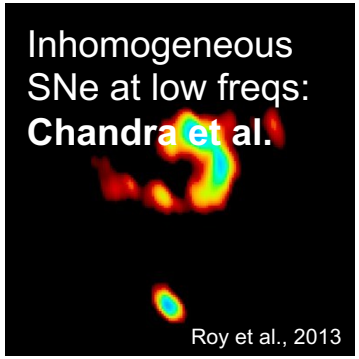
Transients

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



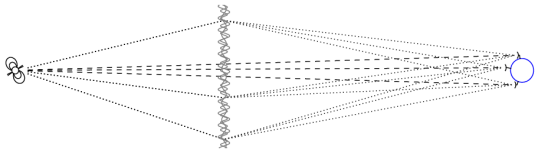
Coughlan et al., 2017

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

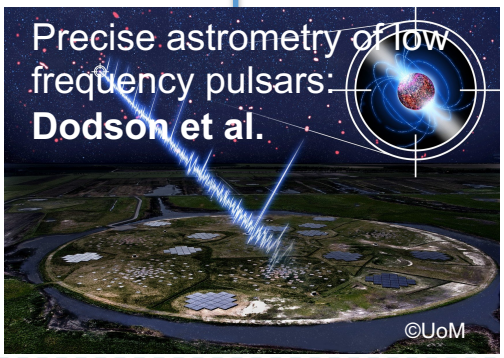

Roy et al., 2013

Pulsars and ISM

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



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


©UoM

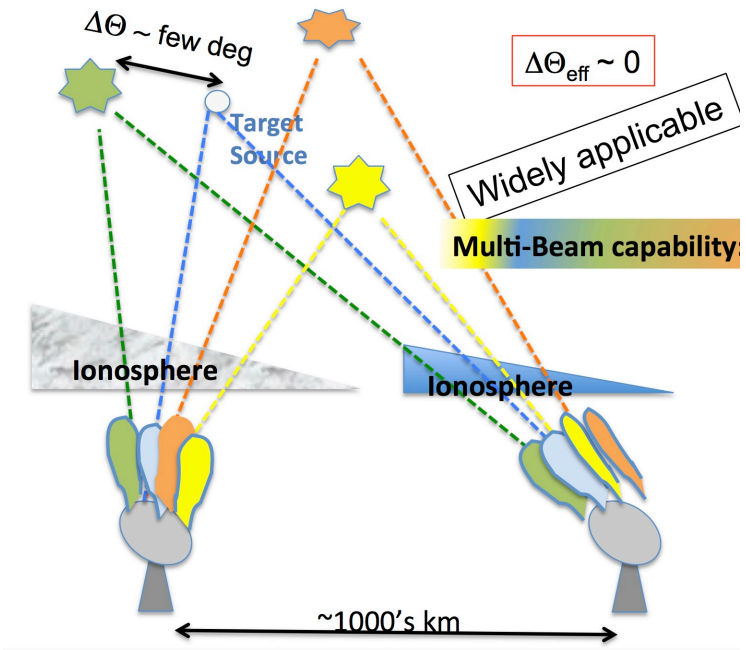
Stars, Planets, Astrometry

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


©NASA

VLBI with SKA1-LOW and SKA1-MID: 1 new science case

Multi-view astrometry with SKA-VLBI:
Rioja et al.



Rioja et al., 2018

1 microarcsec relative astrometric precision!

VLBI with SKA: key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations

typically the core

VLBI with SKA: key operational concepts

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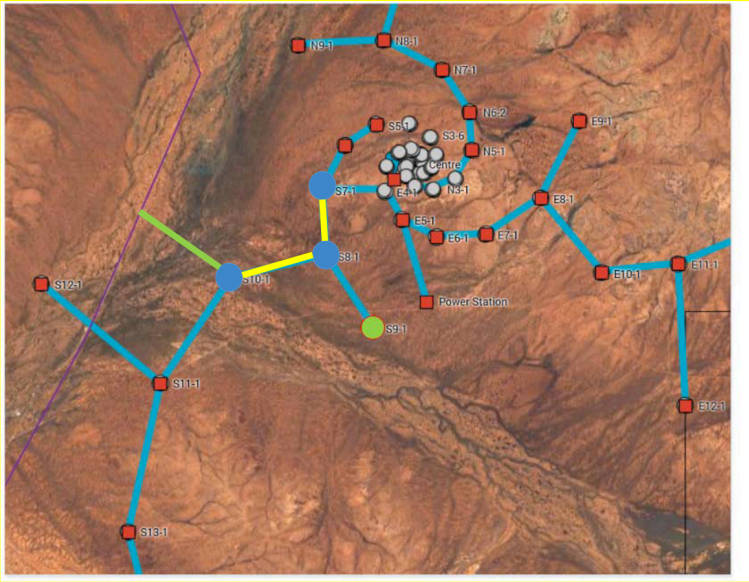
Independent subarrays:
different purposes, up to 16



VLBI with SKA: key operational concepts

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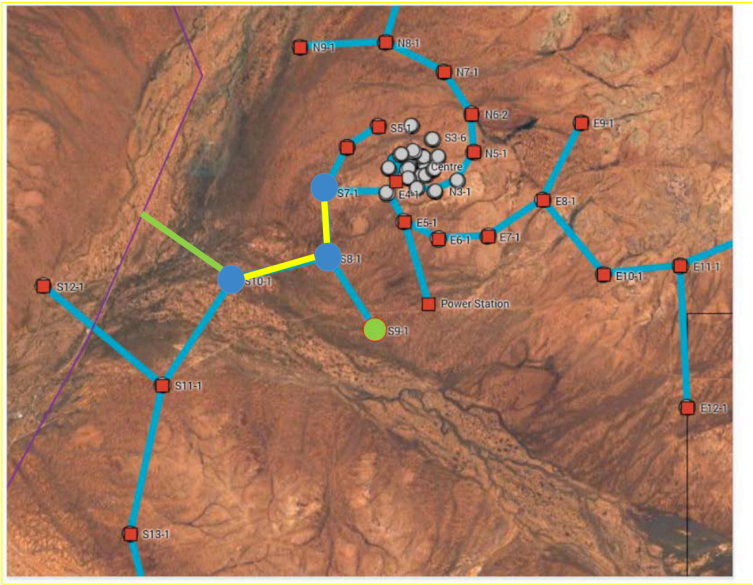
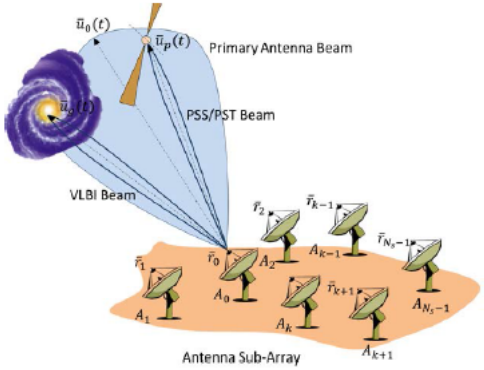


Simultaneous/commensal observing modes:
Imaging (continuum, spectral line and fast imaging for slow transients)
Non-Imaging (PSS, PST, transient buffer and VLBI)



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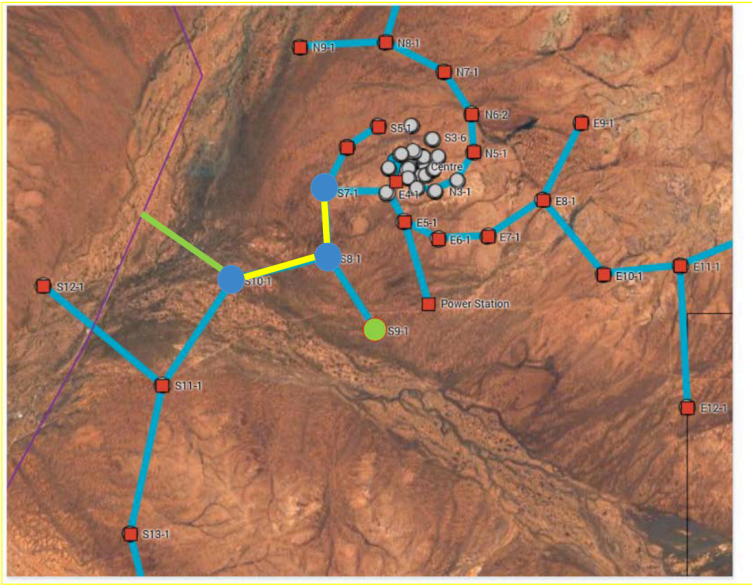

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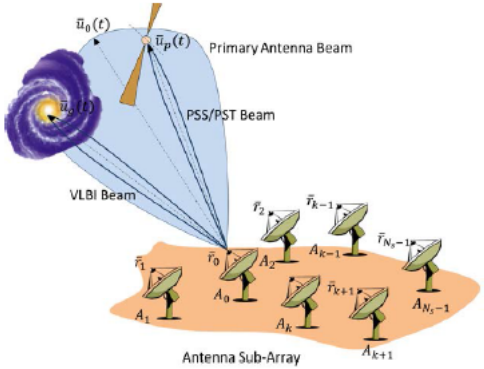
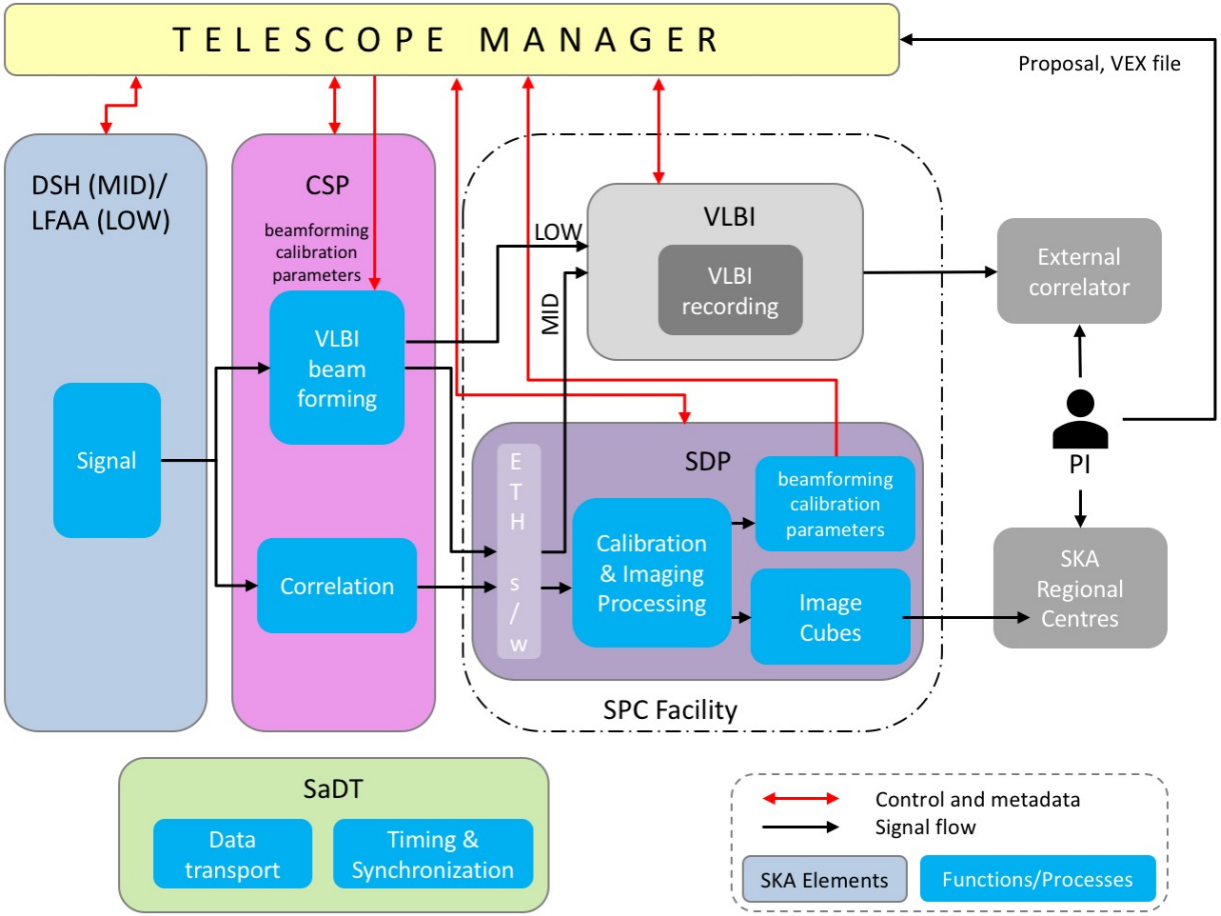


Independent multi-beam capability
within each subarray (in scan boundaries)

SKA1 VLBI technical implementation



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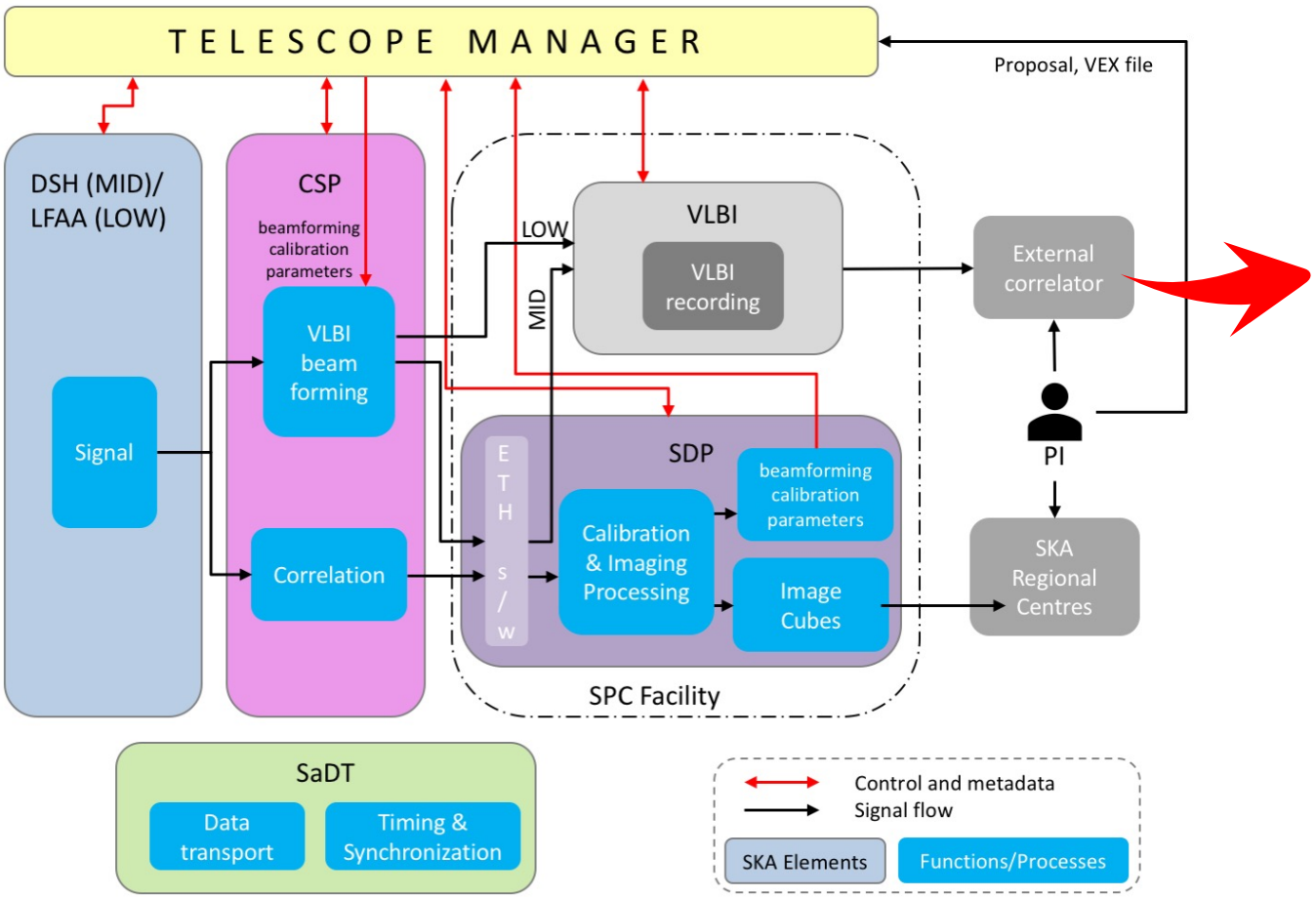
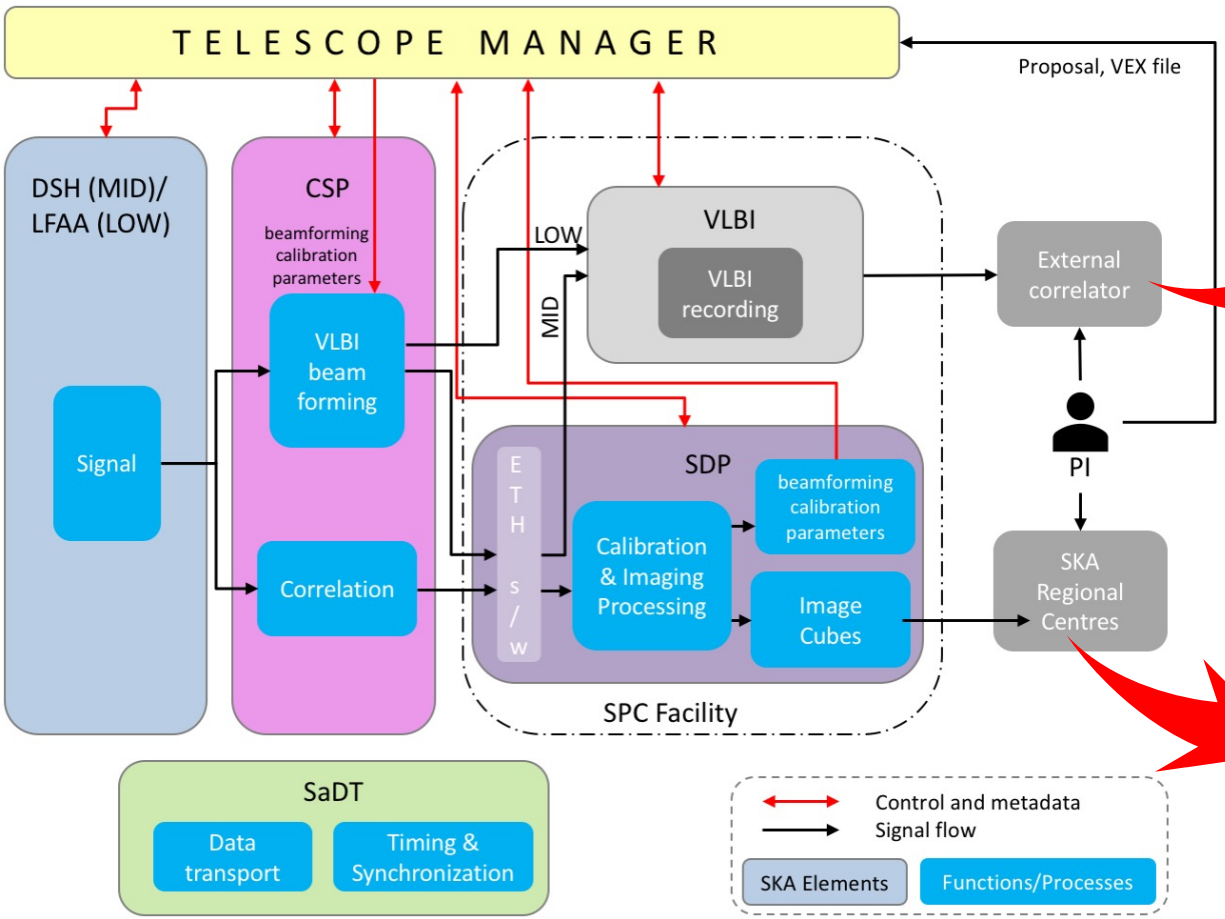


SKA-VLBI
high angular resolution images

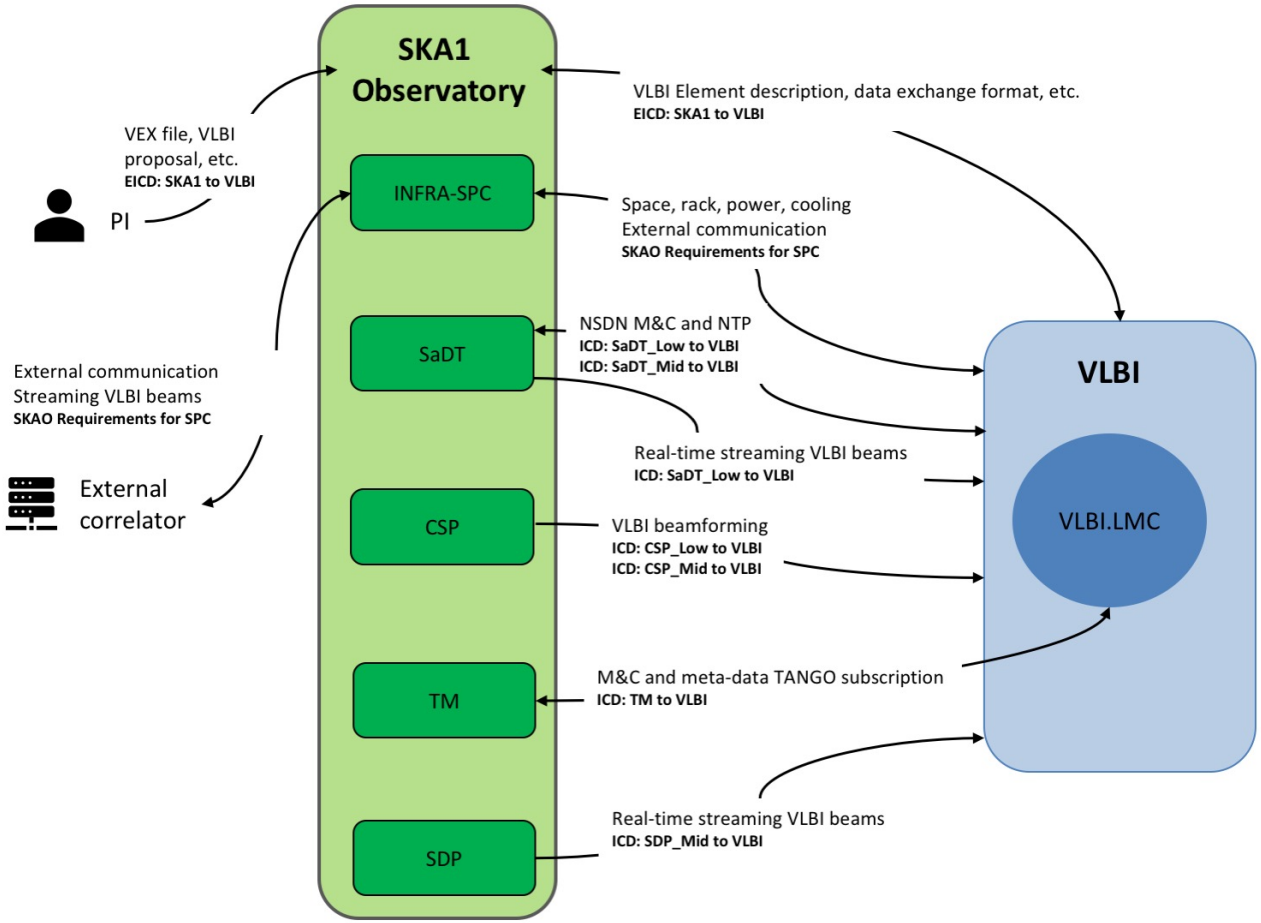
SKA1 VLBI technical implementation



SKA-VLBI high angular resolution images

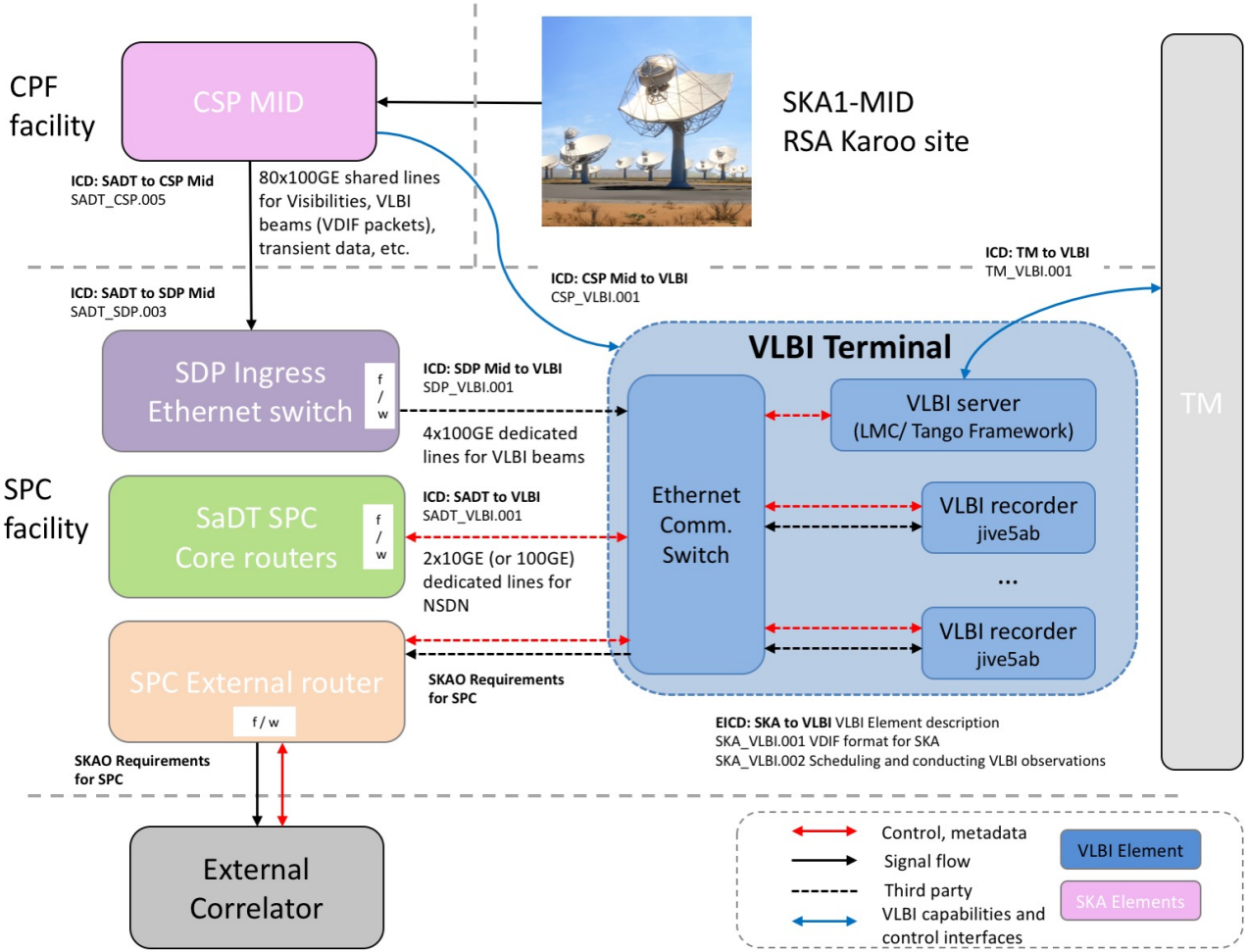
SKA image cubes (continuum and spectral line, from same subarray)

SKA1 VLBI technical implementation



- ✓ **JUMPING JIVE 1st deliverable:** "Details on VLBI Interfaces to SKA Consortia"
- ✓ **Revision of Level 1 VLBI requirements** (CDR outcomes, CSP assumptions, VLBI SWG inputs).

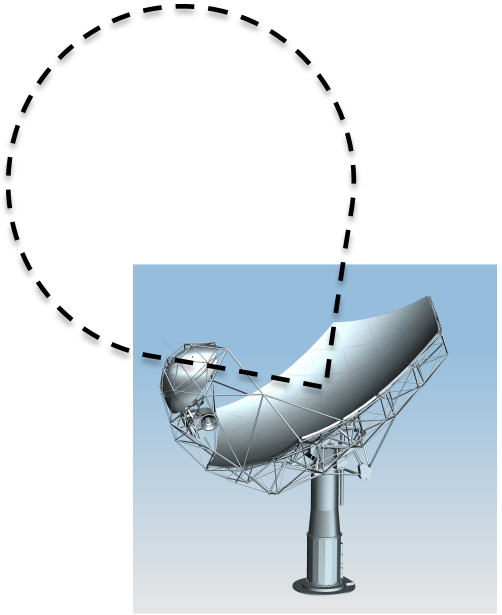
SKA1 VLBI technical implementation



SKA-VLBI with SKA1-MID

VLBI with SKA1-MID:

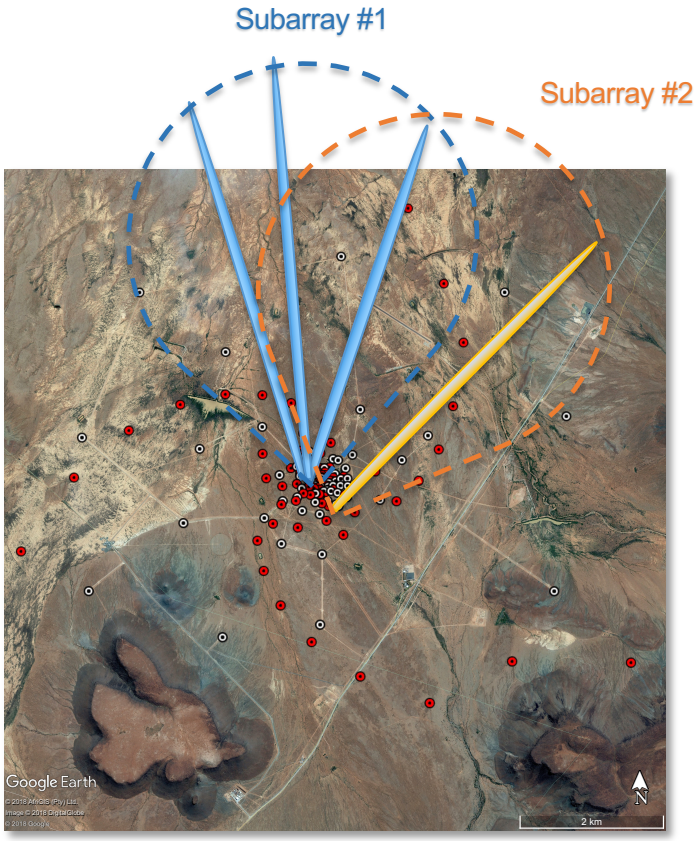
All observing modes simultaneously within a subarray with bandwidth sacrifice



SKA1-MID Antenna

Antenna Beam

133+64



SKA1-MID "subarray/array"

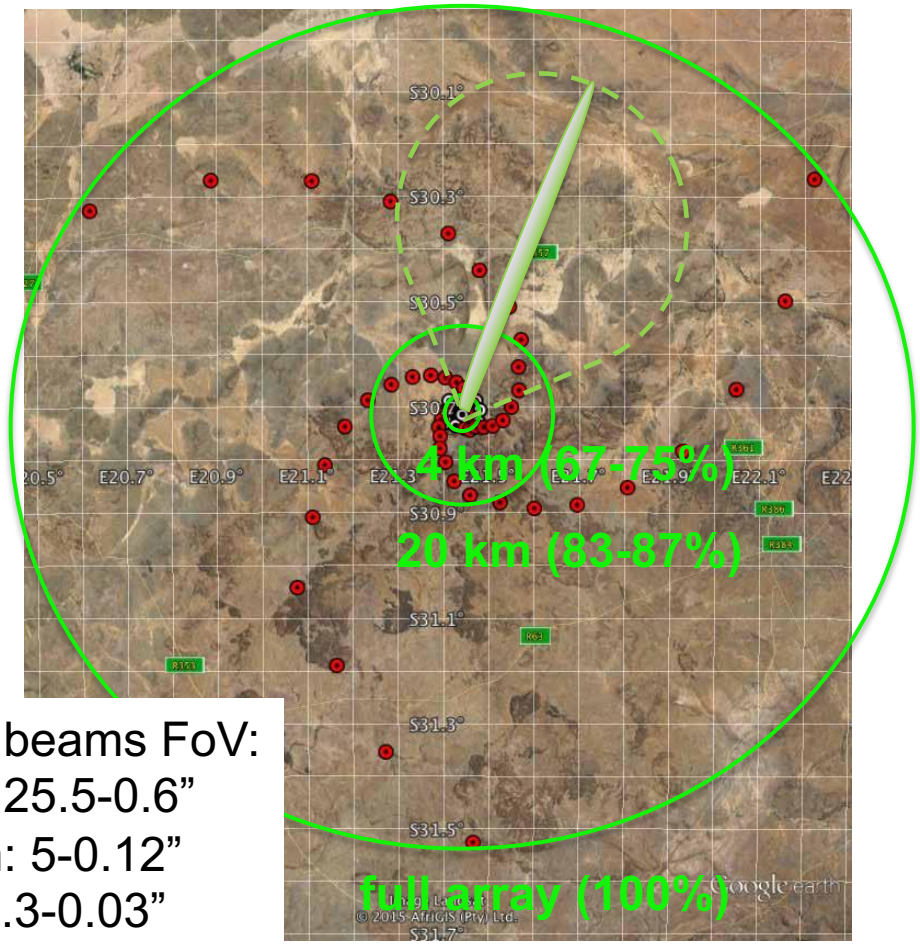
Correlation:

- ✓ ***Normal visibilities, zoom*** *(100-3 MHz, 6 kHz - 190 Hz)*
- ✓ ***VLBI coarse visibilities:*** *200 kHz*

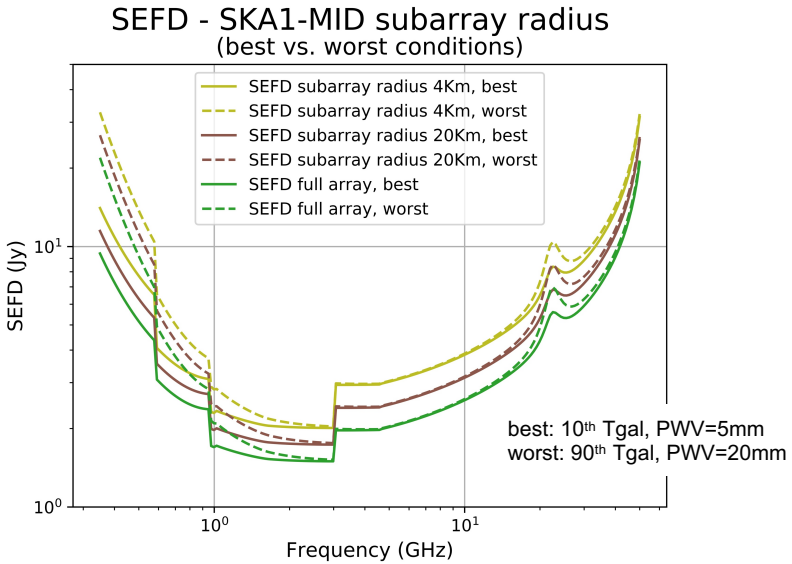
Tied-array beams:

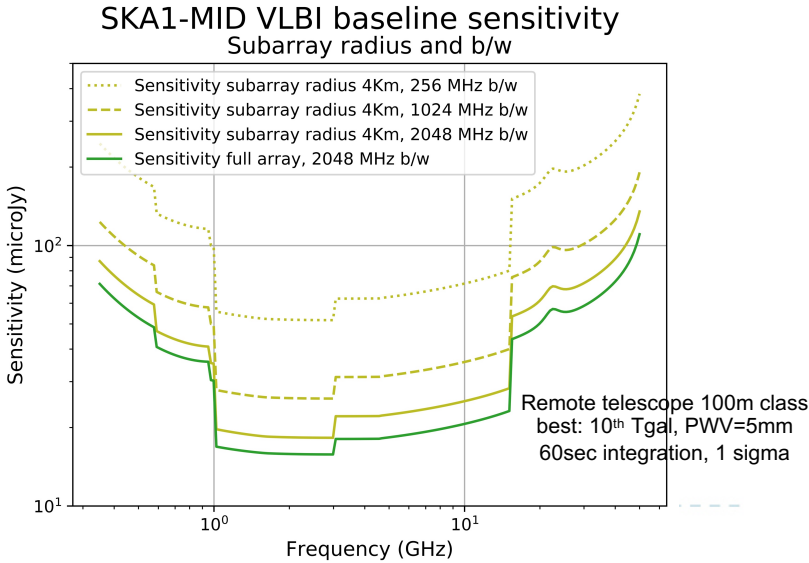
- ✓ ***4 VLBI beams*** *but up to 52 beams max per subarray (200 MHz b/w), from any subarray size*
- ✓ ***Each VLBI beam:*** *dual-pol real channels (1-128 & 200 MHz, 2-16 bits, Nyquist)*
- ✓ *RFI flagging/excision and polarisation correction*
- ✓ *1500 for* ***Pulsar Search PSS***
- ✓ *16 for* ***Pulsar Timing PST***

VLBI with SKA1-MID: configurations

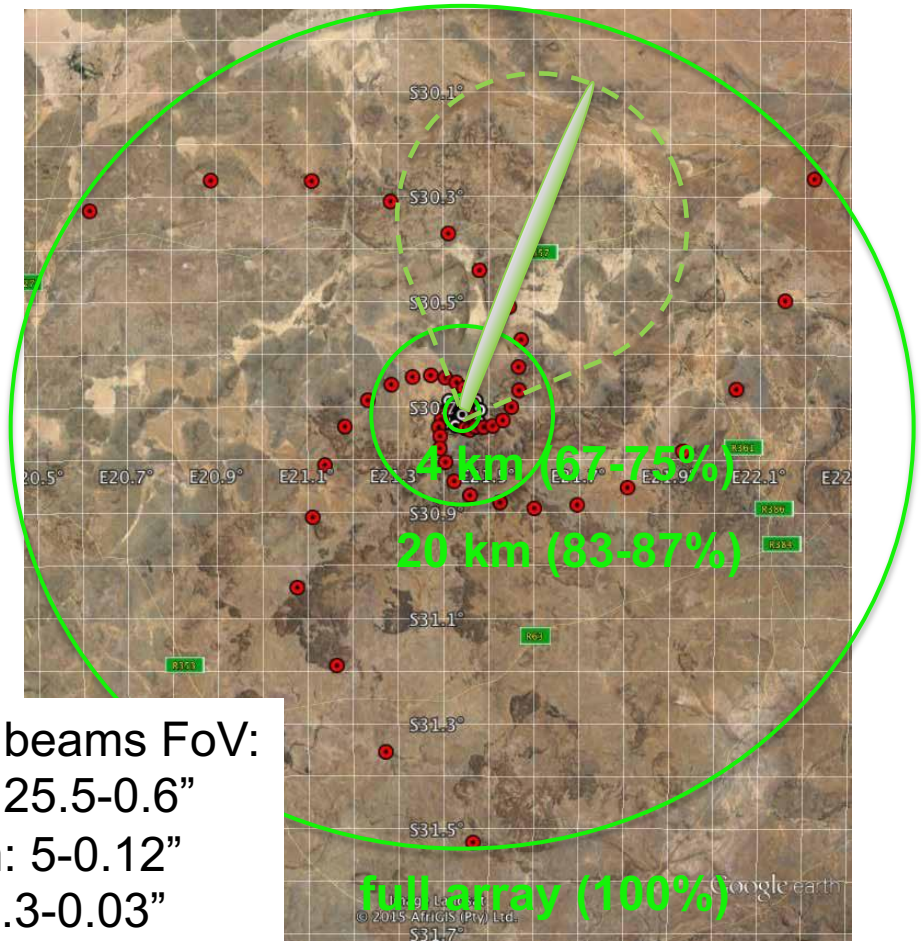


VLBI beams FoV:
4km: 25.5-0.6”
20km: 5-0.12”
full: 1.3-0.03”





VLBI with SKA1-MID: configurations



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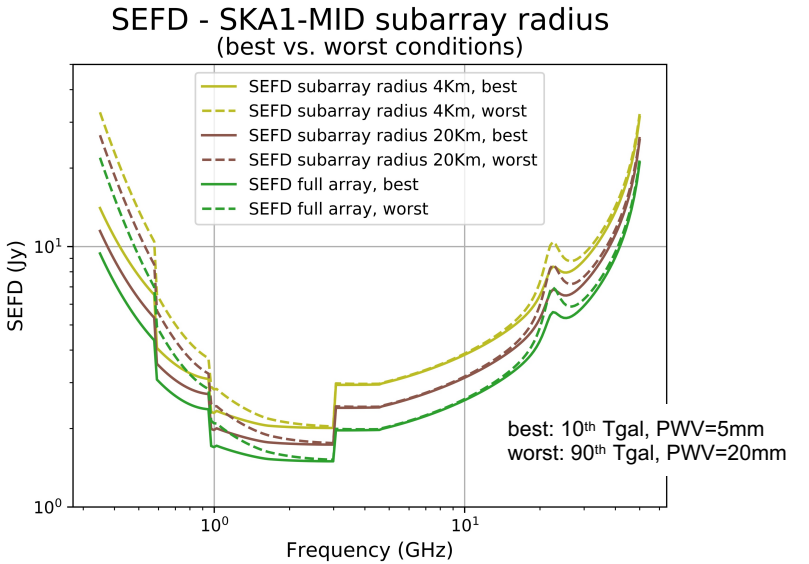

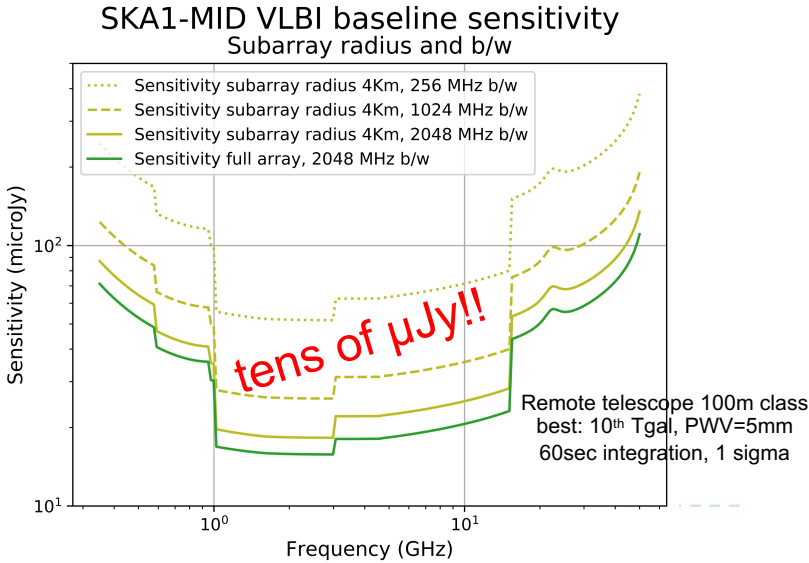

Simultaneous Observing with SKA1-MID: limited by processing resources (26+1 FSP=Frequency Slice Processor)

Band	VLBI + coarse Vis	Imaging	PSS	PST	Zoom
Band 1 (0.35-1.05GHz)	**4beams full (700MHz)** (8 FSP)	Full (4 FSP)	1500b 300MHz (8 FSP)	16b full (4 FSP)	2 (2 FSP)
	4b 600MHz (6 FSP)	Full (4 FSP)	1500b 300MHz (8 FSP)	16b full (4 FSP)	4 (4 FSP)
Band 2 (0.95-1.76GHz)	**4beams full (810MHz)** (10 FSP)	Full (5 FSP)	1500b 300MHz (8 FSP)	16b 600 MHz (3 FSP)	⊘
	4b 600MHz (6 FSP)	Full (5 FSP)	1500b 300MHz (8 FSP)	16b full (5 FSP)	2 (2 FSP)
Band 5a/b (4.6-8.5GHz & 8.3-15.3GHz)	2beams 5GHz (26 FSP)	⊘	⊘	⊘	⊘
	4beams 2.5GHz (26 FSP)	⊘	⊘	⊘	⊘
	4beams 600MHz (6 FSP)	512MHz (3 FSP)	1500b 300MHz (8 FSP)	16b 512 MHz (3 FSP)	6 (6 FSP)

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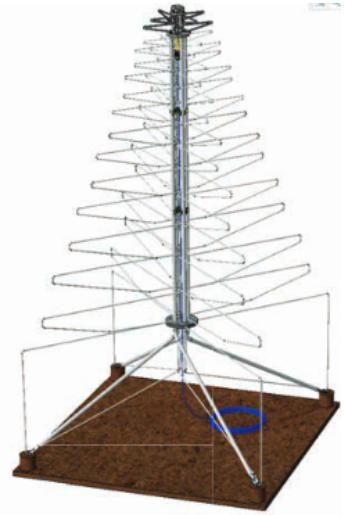
Band	VLBI + coarse Vis	Imaging	PSS	PST	Zoom
Band 1 (0.35-1.05GHz)	**4beams full (700MHz)** (8 FSP)	Full (4 FSP)	1500b 300MHz (8 FSP)	16b full (4 FSP)	2 (2 FSP)
	4b 600MHz (6 FSP)	Full (4 FSP)	1500b 300MHz (8 FSP)	16b full (4 FSP)	4 (4 FSP)
Band 2 (0.95-1.76GHz)	**4beams full (810MHz)** (10 FSP)	Full (5 FSP)	1500b 300MHz (8 FSP)	16b 600 MHz (3 FSP)	⊘
	4b 600MHz (6 FSP)	Full (5 FSP)	1500b 300MHz (8 FSP)	16b full (5 FSP)	2 (2 FSP)
Band 5a/b (4.6-8.5GHz & 8.3-15.3GHz)	2beams 5GHz (26 FSP)	⊘	⊘	⊘	⊘
	4beams 2.5GHz (26 FSP)	⊘	⊘	⊘	⊘
	4beams 600MHz (6 FSP)	512MHz (3 FSP)	1500b 300MHz (8 FSP)	16b 512 MHz (3 FSP)	6 (6 FSP)
	⊘	**Full (26 FSP)**	⊘	⊘	⊘

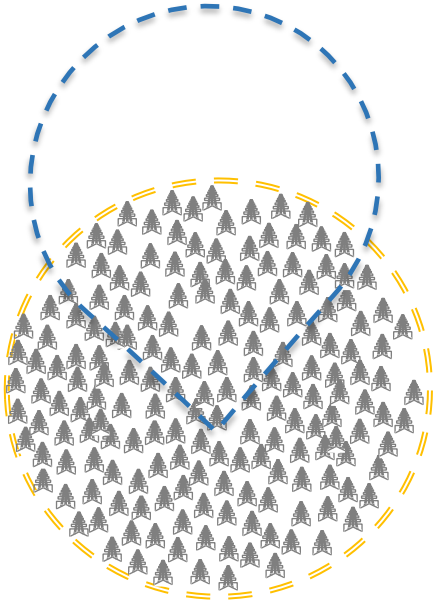
SKA-VLBI with SKA1-LOW

VLBI with SKA1-LOW: 50-350 MHz

All observing modes simultaneously:
for each subarray, for each station beam



256



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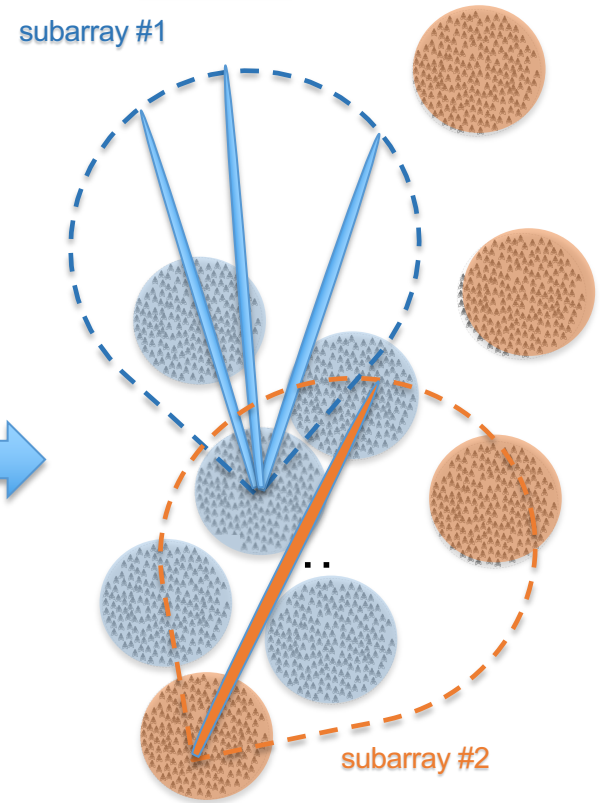


SKA1-LOW Antenna/Receptor

Antenna Beam

SKA1-LOW *"Station"*

Station Beam
300 MHz b/w

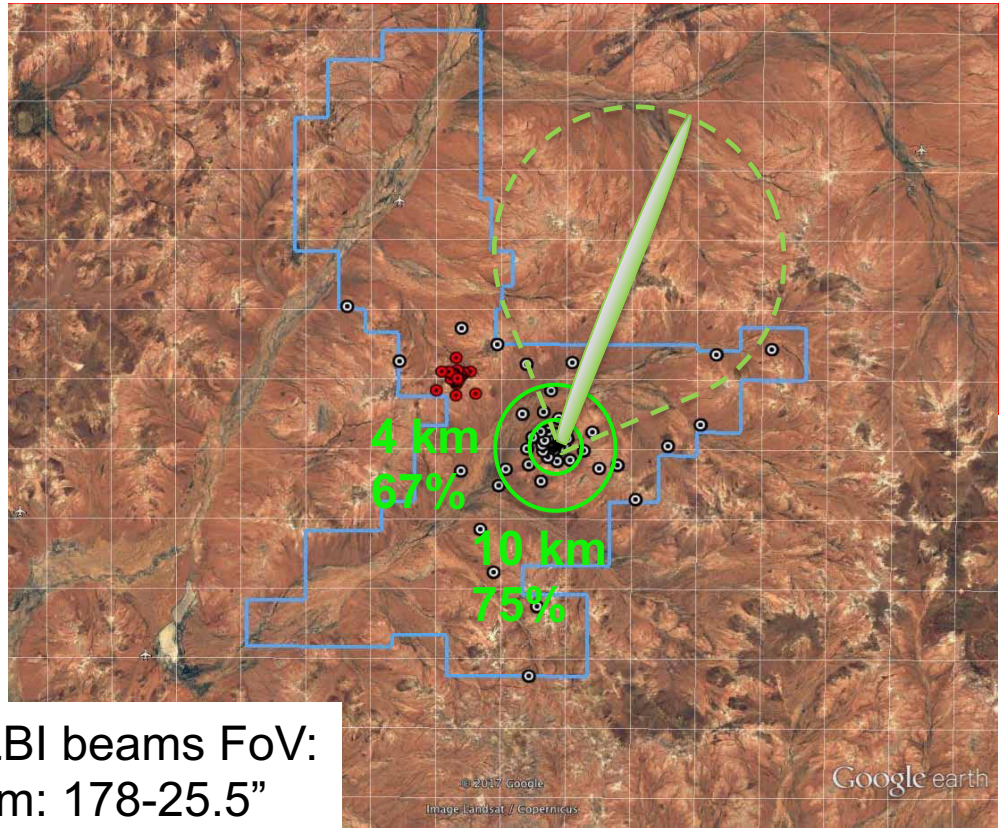
SKA1-LOW "subarray"

Correlation: normal and zoom
(14.4 kHz - 5.4kHz - 226 Hz)

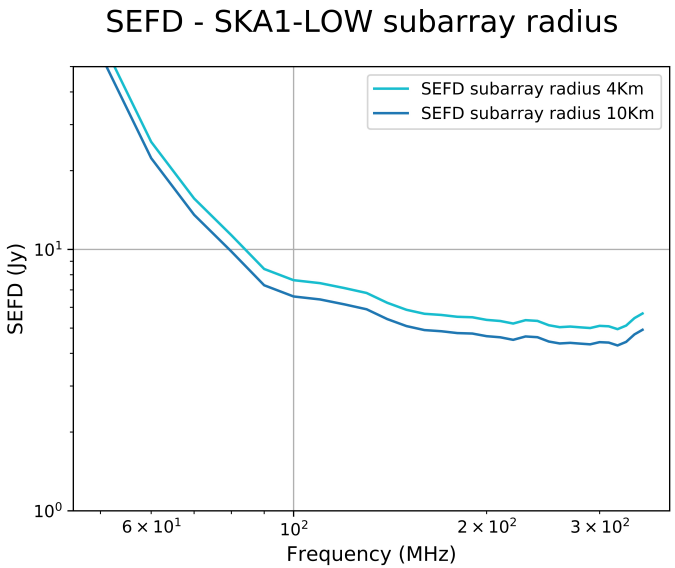
Tied-array beams from 20 Km diameter subarray:

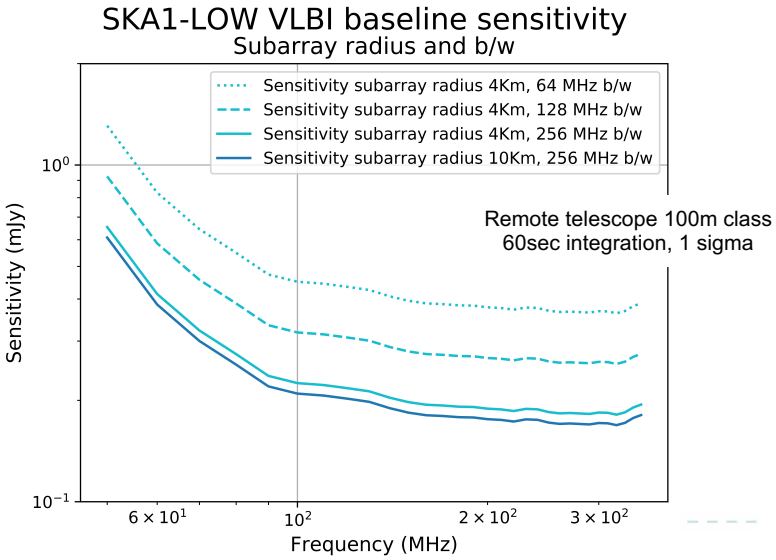
- ✓ ***4 VLBI beams*** *(in total)*
- ✓ *500 for* ***Pulsar Search PSS***
- ✓ *16 for* ***Pulsar Timing PST***

VLBI with SKA1-LOW: configurations

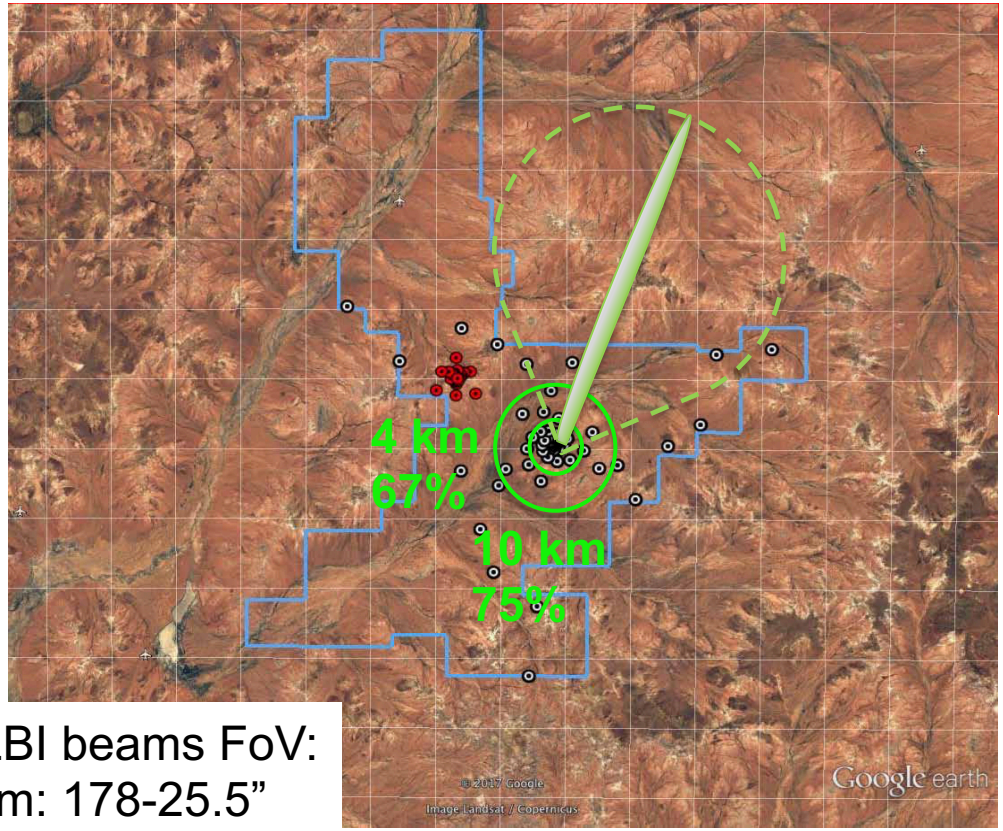


VLBI beams FoV:
4km: 178-25.5”
10km: 71-10”





VLBI with SKA1-LOW: configurations



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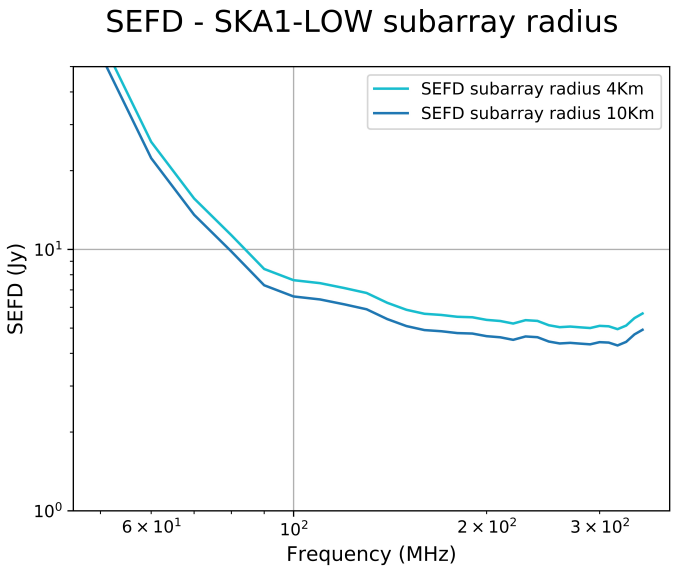
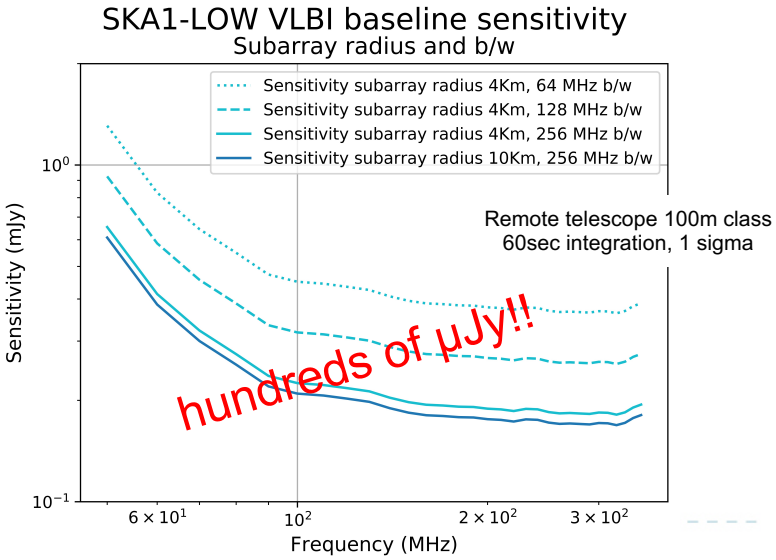
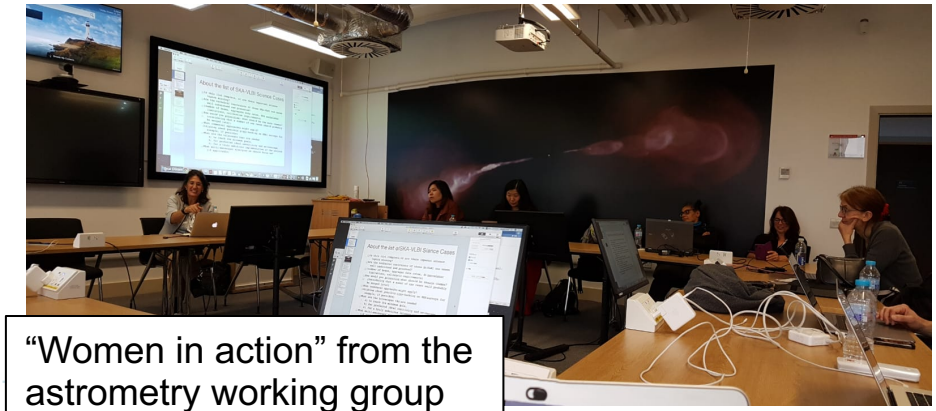




- ✓ **65 scientist from 18 countries**
- ✓ **Workshops sessions:** AGN, transients, pulsars and FRBs, high precision stellar astrometry and prospects for SKA-VLBI including African telescopes
- ✓ SKA-VLBI **data challenges**
- ✓ Four working groups to discuss **SKA-VLBI Key Science Projects**



"Women in action" from the astrometry working group

SKA-VLBI Conclusions

SKA-VLBI Conclusions

- ✓ **VLBI is an observing mode** of the SKA Observatory
- ✓ CSP design compatible with **VLBI standards & networks**
- ✓ SKA-VLBI System level solution ready, it can be applied to **SKA precursors**
- ✓ The SKA-VLBI community supports enthusiastically
- ✓ Let's start cutting-edge VLBI science with SKA precursors: MeerKAT-VLBI, (MK+)-VLBI, ASKAP-VLBI…

SKA-VLBI capacity and technique

JUMPING JIVE
Joint Institute for VLBI ERIC

SKA
SQUARE KILOMETRE ARRAY

SQUARE KILOMETRE ARRAY

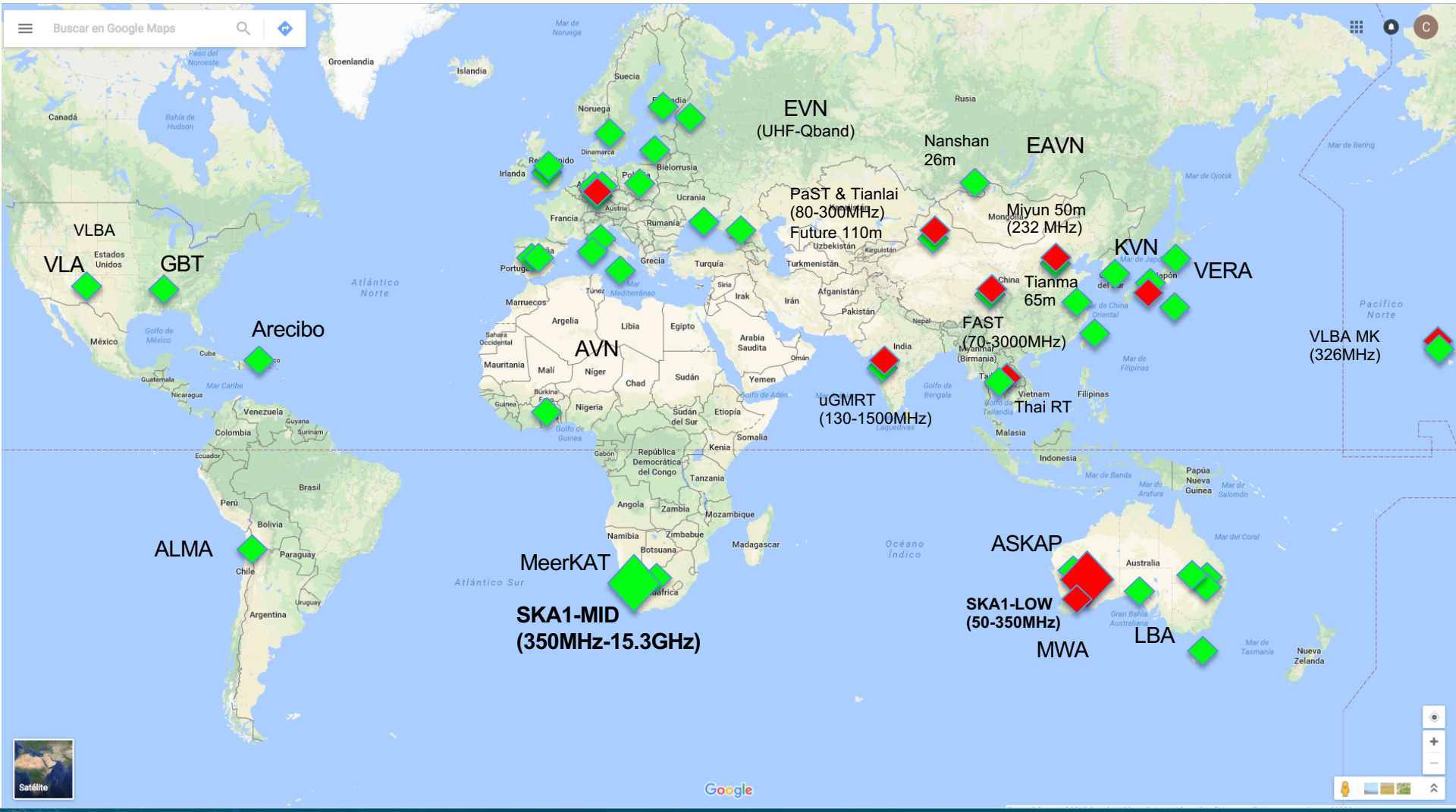
Exploring the Universe with the world's largest radio telescope

Cristina Garcia Miro / Tao An
JUMPING JIVE Project / SKA VLBI SW
miro@jive.eu JIVE / SHAO

JUMPING JIVE
Joint Institute for VLBI ERIC

VLBI with SKA:

Global VLBI network



JUMPING JIVE
Joint Institute for VLBI ERIC

SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

uGMRT
(130MHz-1500MHz)

SKA1-MID

SKA1-LOW

Table 2: Common visible time in hours for the SKA sites with other array elements

South African SKA										
Dec	W. Aus.	JP	CN	NZ	CL	USA-HI	USA-NM	USA-PR	Europe	uGMRT
+45°	0.0	2.2	**5.4**	0.0	0.0	0.0	1.5	**3.6**	**5.4**	3.0
+30°	0.0	2.7	**7.6**	0.0	0.4	0.0	1.8	**4.4**	**8.0**	6.0
+15°	0.0	2.7	**7.3**	0.0	2.3	0.0	1.8	**4.8**	**9.4**	7.0
0°	0.8	2.5	**6.8**	0.6	**3.7**	0.0	1.7	**5.0**	**9.1**	7.0
−15°	2.0	2.1	**6.3**	1.9	**4.9**	0.0	1.4	**5.1**	**7.8**	7.5
−30°	3.0	1.2	**5.4**	3.1	**6.2**	0.0	0.0	**5.2**	3.0	7.0
−45°	**4.0**	0.0	0.0	**5.2**	**7.9**	0.0	0.0	**5.2**	0.0	6.5
−60°	**5.5**	0.0	0.0	**11.8**	**11.6**	0.0	0.0	0.0	0.0	0.0
−75°	**12.9**	0.0	0.0	**24.0**	**24.0**	0.0	0.0	0.0	0.0	0.0
−90°	**24.0**	0.0	0.0	**24.0**	**24.0**	0.0	0.0	0.0	0.0	0.0
Western Australian SKA										
Dec	ZA	JP	CN	NZ	CL	USA-HI	USA-NM	USA-PR	Europe	uGMRT
+45°	0.0	**5.3**	**5.3**	0.0	0.0	**4.0**	1.3	0.0	**5.3**	5.0
+30°	2.0	**7.9**	**7.9**	3.2	0.0	**4.8**	1.7	0.0	**4.5**	7.0
+15°	3.5	**8.6**	**9.2**	**5.2**	0.0	**5.1**	1.7	0.0	3.8	7.5
0°	**4.5**	**8.5**	**6.7**	**6.6**	0.0	**5.3**	1.6	0.0	3.2	8.0
−15°	**5.5**	**7.8**	**8.3**	**7.8**	0.4	**5.4**	1.3	0.0	2.3	8.5
−30°	**9.0**	**5.1**	**6.2**	**9.1**	1.9	**5.5**	0.8	0.0	0.4	6.0
−45°	**7.7**	0.0	0.0	**10.8**	**5.2**	**5.4**	0.0	0.0	0.0	6.0
−60°	**11.5**	0.0	0.0	**14.1**	**11.7**	**5.1**	0.0	0.0	0.0	0.0
−75°	**24.0**	0.0	0.0	**24.0**	**24.0**	0.0	0.0	0.0	0.0	0.0
−90°	**24.0**	0.0	0.0	**24.0**	**24.0**	0.0	0.0	0.0	0.0	0.0

Key: W. Aus.: Western Australia; ZA: South Africa; JP: Japan, CN: Eastern China; NZ: New Zealand; CL: Chile (latitude of former TICO site); USA-HI: Hawaii; USA-NM: New Mexico; USA-PR: Puerto Rico; Europe: Id.