CASA VLBI | WORKSHOP 2020

2-6 November 2020

Future of VLBI

Cristina García Miró

JUMPING JIVE
Joint Institute for VLBI
ERIC

CASA
Common Astronomy Software Applications

RadioNet

JIVE

JIVE

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CASA-VLBI Workshop

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Future of VLBI

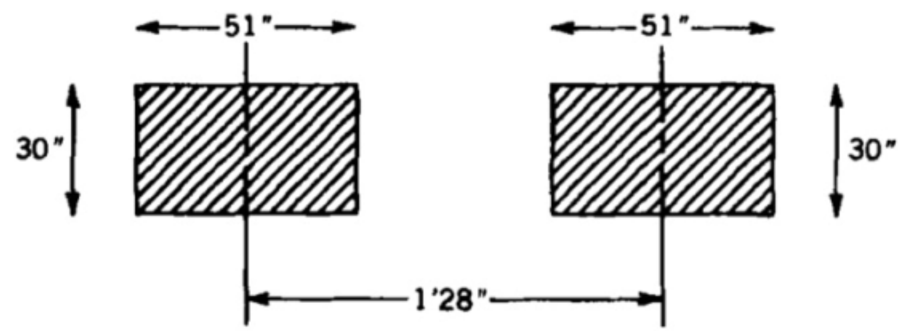
Cristina García Miró
SKA-VLBI scientist - JIVE

Future of VLBI

- What we get from VLBI right now
- Where we are heading to…
- The future of VLBI in the SKA era
- Key Science Projects with SKA-VLBI

VLBI evolution

First image of a
radio source:
Cygnus A



Jennison & Das Gupta (1953)

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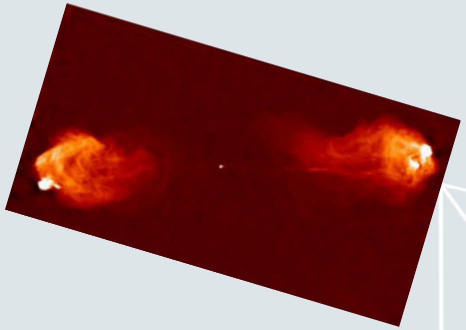

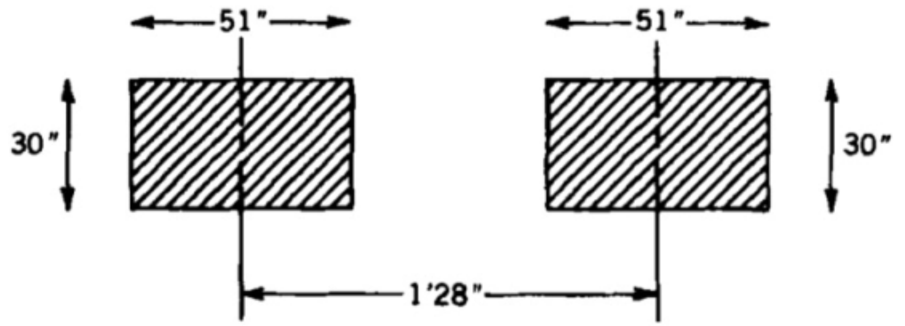

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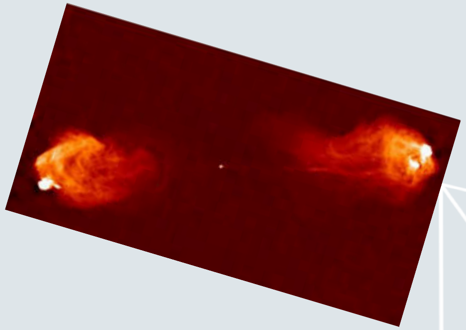

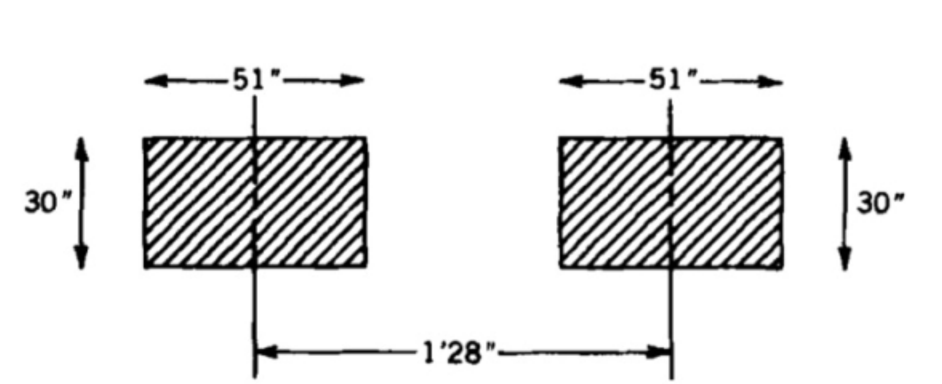

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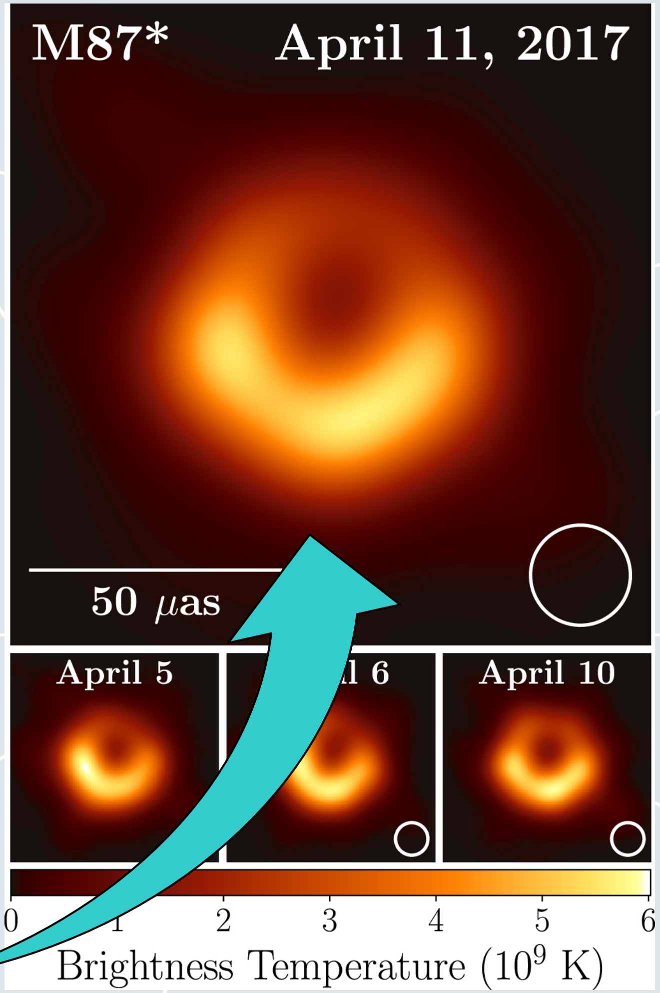

EHT Collaboration 2019a

VLBI evolution

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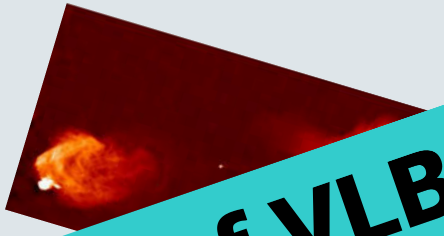
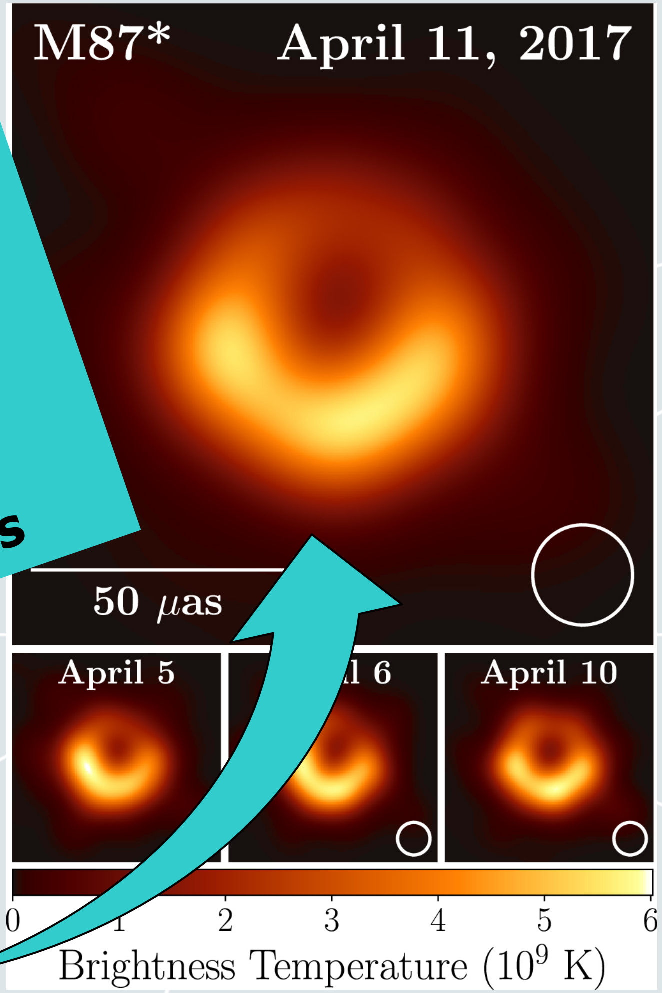


& Das Gupta (1953)

50 years of VLBI!
Closure phases & amp
Self-calibration
Phase referencing
CLEAN
Advanced calibration
& processing techniques



EHT Collaboration 2019a

What we get from VLBI right now?

Credit: A. Lobanov

- **Angular resolution:** ~10-30 μas (RadioAstron @22GHz, EHT @230GHz)
- **Dynamic range:** ~100:1
- **Spatial dynamic range:** ~1000:1 (EVN+e-MERLIN), limited by uv-coverage
- **Positional accuracy:** ~100 μas (absolute), ~50 μas (relative)
- **Field of View:** from arcsec to 10's arcmin

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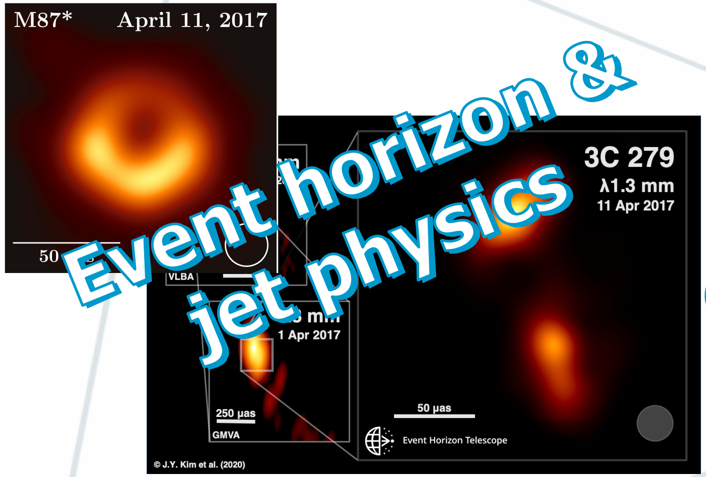
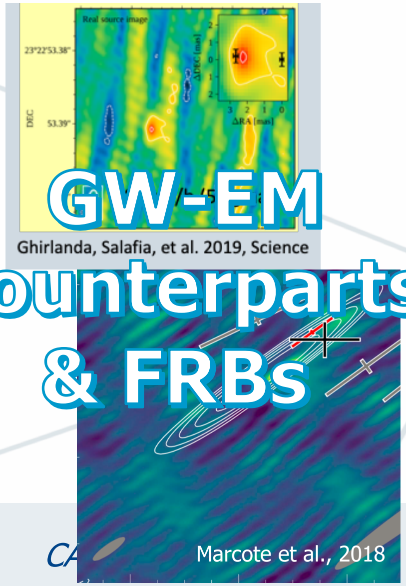
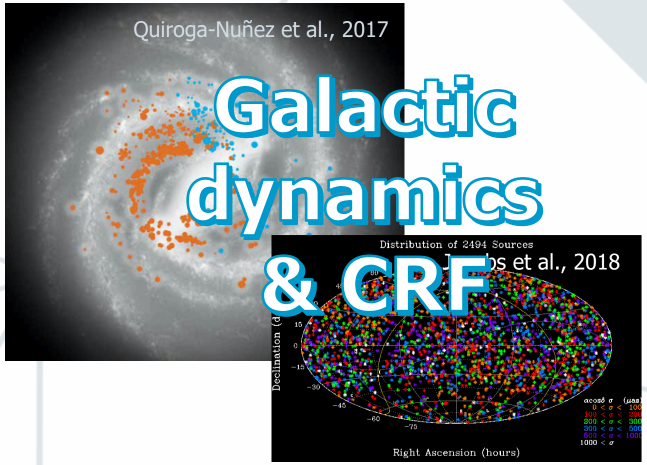
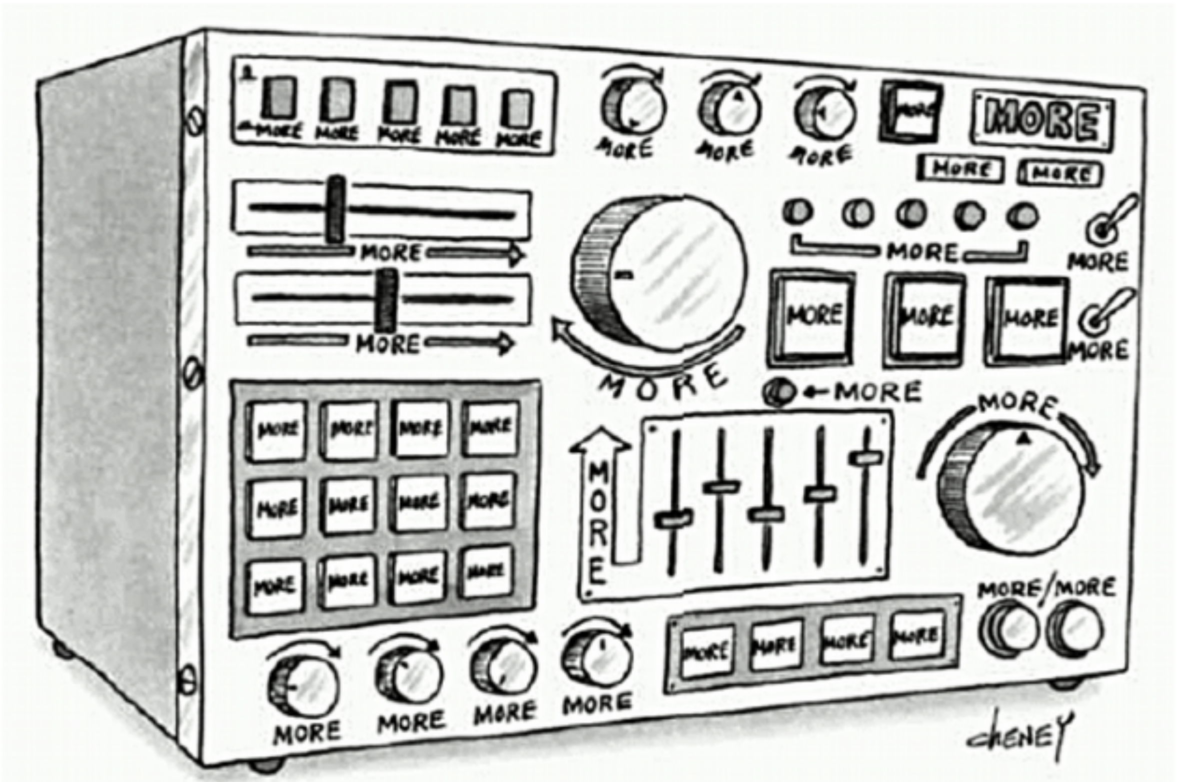
PLENTY OF SCIENCE BEING ADDRESSED!!!







BUT do we need more?



The New Yorker

BUT do we need more?

VLBI20-30: a scientific roadmap for the next decade

The future of the European VLBI Network

Editors: Tiziana Venturi, Zsolt Paragi & Michael Lindqvist

https://arxiv.org/ftp/arxiv/papers/2007/2007.02347.pdf

JIVE
Joint Institute for VLBI
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EUROPEAN VLBI NETWORK

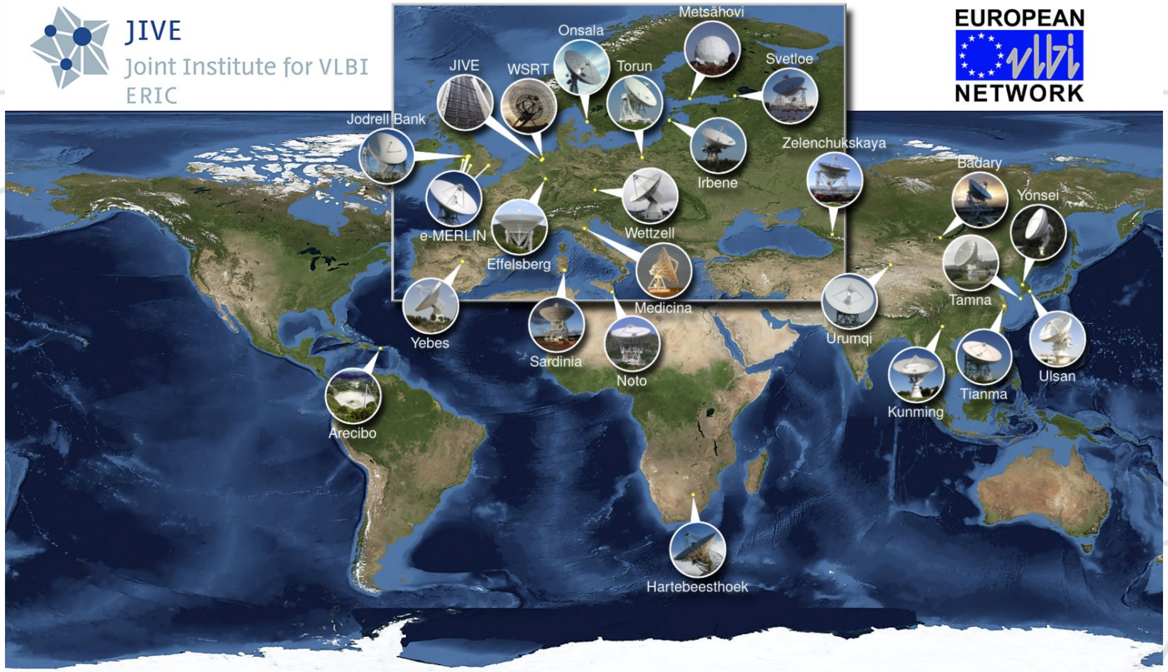


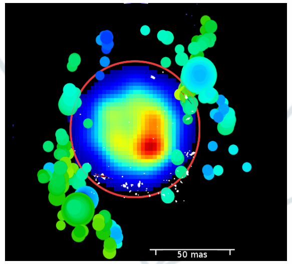
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

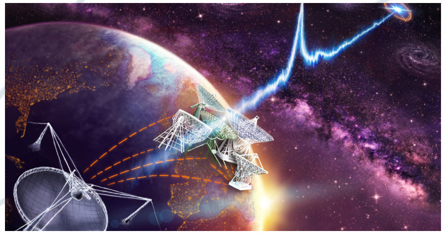
Endorsed by the EVN Consortium Board of Directors

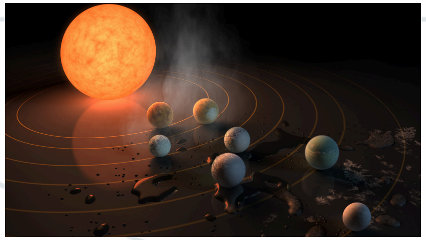
- **EU JUMPING JIVE project** deliverable
- Role of EVN/VLBI in future astronomy landscape
- ~200 pages in 7 chapters, 80 authors, and **8 key science goals** for VLBI in the next decade

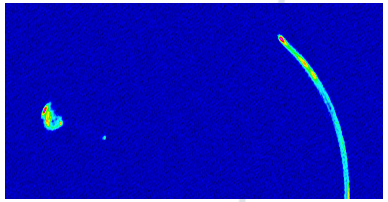
BUT do we need more?

EVN/VLBI 8 key science goals:









- What is the nature of **dark matter and dark energy**?
- When and how did the first **black holes** formed?
- How do **relativistic jets** form? What is their impact on the host galaxy?
- What is the physics of explosions following **gravitational wave events**?
- What are the elusive **fast radio bursts**?
- Are we alone?
- How was the **Milky Way born**?
- How do **stars form**? How do they impact the environment at their death?

AND…

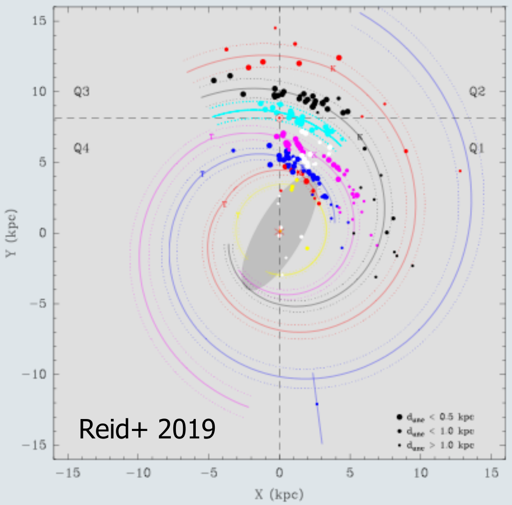
- Technical priorities for the next decade
- **Synergies**

How do we get more?

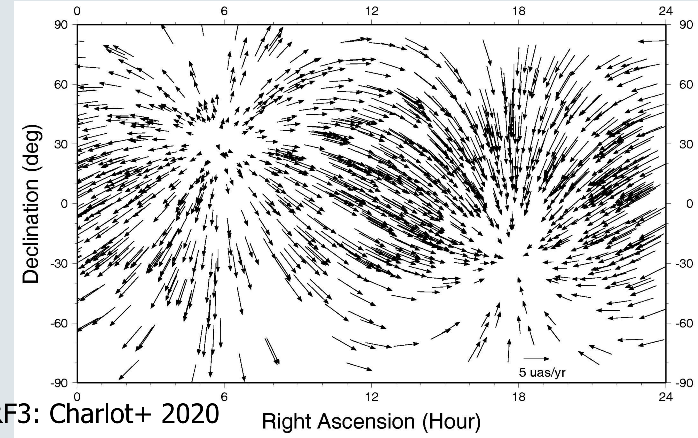
- Ultra-precise relative astrometry
- Extreme angular resolutions: Space-VLBI
- Wide-field imaging
- Imaging at very low frequencies
- Imaging with higher fidelity and sensitivity

Credit: Rioja & Dodson 2020

Ultra-precise relative astrometry



High-mass star forming regions parallaxes with VLBI observations of methanol masers



ICRF3: Charlot+ 2020

Apparent proper motion of extragalactic objects due to secular aberration drift ~ 5μas/yr

- Precise positions, distances and motions → **VLBI provides highest accuracy and precision**
- **Goal:** ultra-precise astrometry (~μas = x10 better) for large and complete surveys with next generation instruments – SKA, ngVLA
- **Astrometry calibration:** Special observational and analytical techniques that preserve the astrometric information (🚫 selfcal): remove delay contributions from instrumental and atmospheric propagation effects → reach the interferometer **thermal noise limit:**

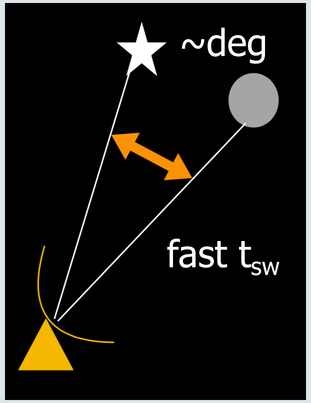
$$\Delta_{pos} \propto FWHM_{beam}/SNR_{ph}$$

- Standard phase calibration techniques for **imaging faint or extended targets**

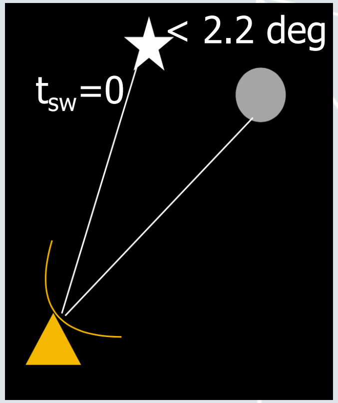
Ultra-precise relative astrometry

Credit: Rioja & Dodson 2020
Images credit: Y. K. Choi

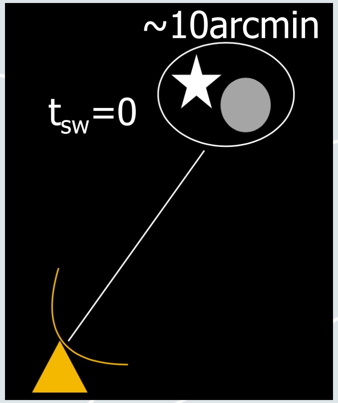
- **Standard phase calibration techniques:**



Conventional phase referencing (PR): ≤43GHz



Dual-beam phase referencing (@VERA)



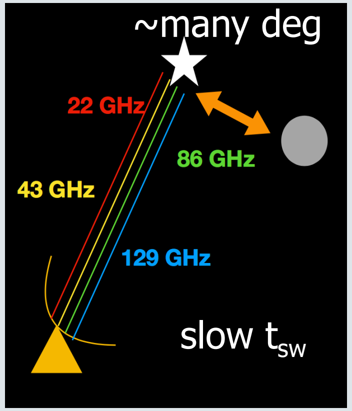
In-beam phase referencing: lower freq

- **Advanced astrometric calibration methods:** troposphere (Geoblocks & differential phase delay) and ionosphere (group delay correction, phase fitting & ICE-blocks)

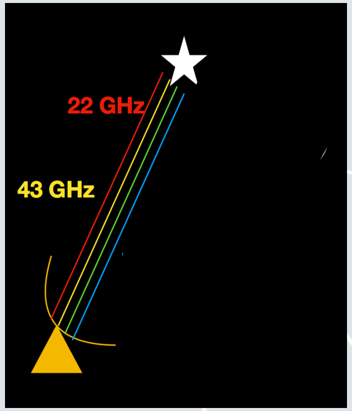
Ultra-precise relative astrometry

Credit: Rioja & Dodson 2020
Images credit: Y. K. Choi

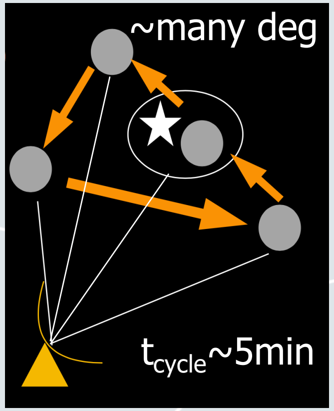
➢ **Next generation astrometric calibration techniques:**



Source Frequency Phase referencing (SFPR):
Frequency phase transfer
mm-VLBI astrometry: coherence times ~h @130GHz
Simultaneous freqs @KVN



Multi-Frequency Phase referencing (MFPR)
Frequency agility @VLBA
+ ICE-blocks between 1.3-22GHz



MultiView and **in-beam MultiView**:
For low and high frequencies
Multi-beam (minimum 3 cal)

→ **10 μas for high and low frequencies** (DR ~100:1)

Credit: Rioja & Dodson 2020
Images credit: Y. K. Choi

Ultra-precise relative astrometry

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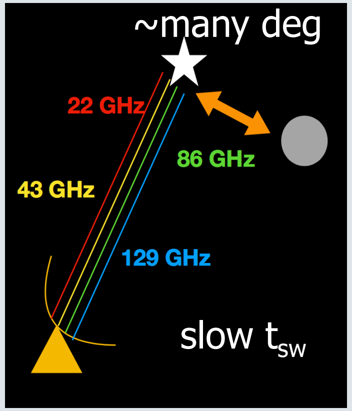

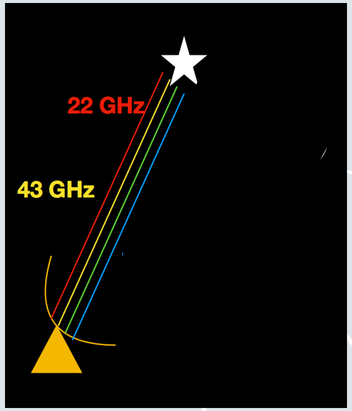

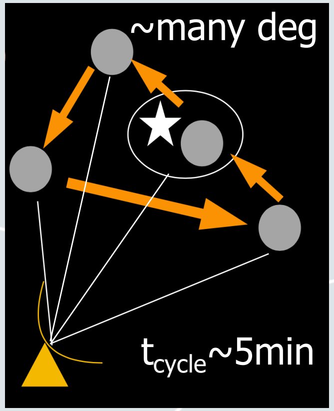

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Next generation instruments (DR 1000:1, wide bandwidths, large FoV – PAF in single dish & multiple tied-array beams in antenna arrays)

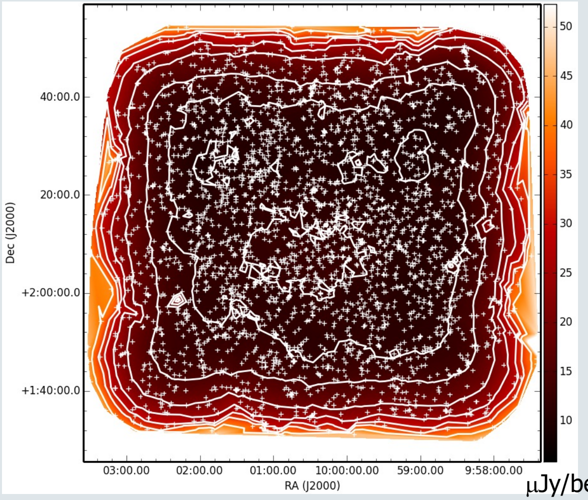
→ Reach thermal limit: **ultra-precise astrometry > 6GHz (1 μas)** and enable **precise astrometry for much lower frequencies**

Extreme angular resolutions: space mm-VLBI

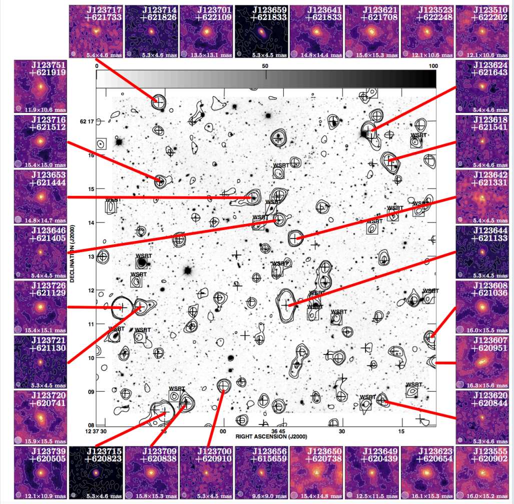
THEZA space-mm VLBI concept (Gurvits+ 2019).
Figure credits: BH simulations – Monika Mościbrodzka+ 2014 & Freek Roelofs. Beabudai Design.

- Space-borne radio interferometer freq ≥300GHz
- Ultra-sharp angular resolution down to μas and sub-μas
- ~orders of magnitude improvement in resolution and dynamic range
- **Breakthrough in high-resolution studies with high quality imaging:** to directly image the event horizon in supermassive black holes, physics of jets at launching sites, binary AGNs, time and X-ray domain synergies, megamasers, protoplanetary disks, exoplanets and SETI.

Wide-field VLBI imaging



Sensitivity map of VLBA-COSMOS project @1.4GHz 2 deg^2, Herrera Ruiz+ 2017



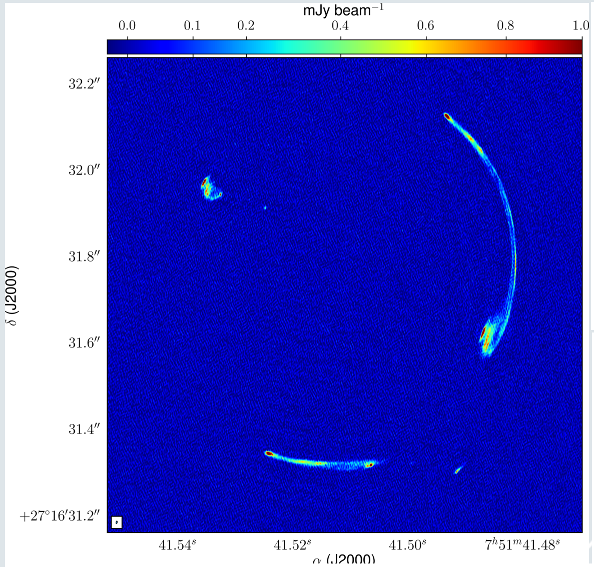
GOODS-N field, EVN @1.6GHz 160 arcmin^2
699 phase centres, Radcliffe+ 2018

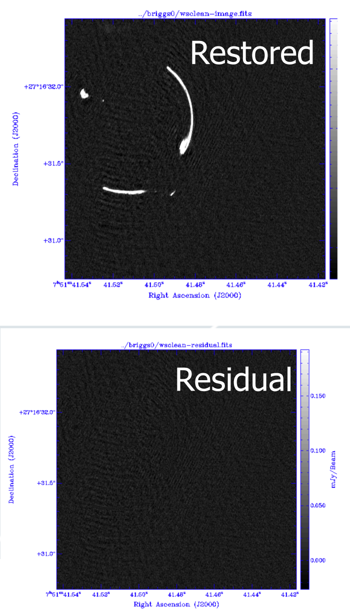
- **VLBI as a survey instrument**
- **FoV:** up to ten's arcmin (~30k x 30k images)
- **Software correlators** not limited by spectral and temporal resolution (reduce time and bandwidth smearing) & allow for **correlation with multiple phase centres**
- Wide-field advanced calibration techniques: a combination of in-beam phase referencing and **Multi-Source Self-Calibration (MSSC)** and primary beam corrections → **μJy regime**
- Application to **multi-beam telescopes** with multiple phase-centres (tied-array beams on targeted sources) and single dish antennas with **PAFs**.
- Application to **direction-dependent calibration** (atmospheric inhomogeneities and primary beam variations across FoV) defining isoplanatic facets.

Wide-field VLBI imaging

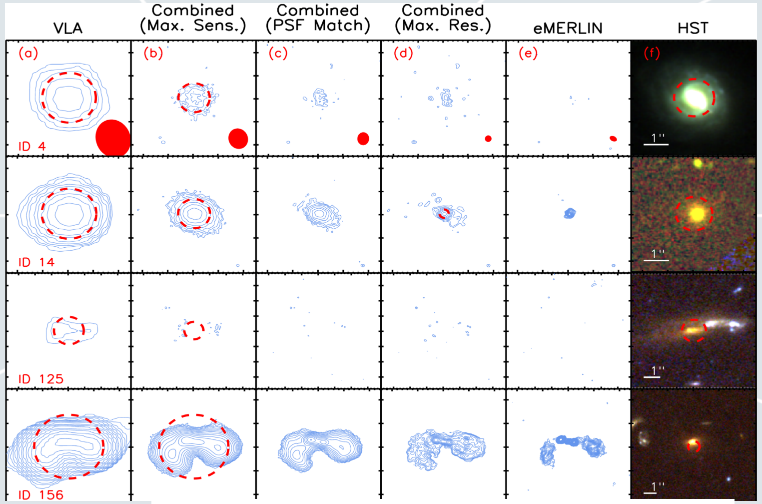
- **Multi-scale cleaning** (Cornwell 2008, Rich+ 2008): complex and extended structure (delta + gaussian functions with scale determined every minor iteration) **vs. compressed sensing** (for accurate models, e.g. EHT)
- **w-projection** (Cornwell+ 2008)**:** spherical geometry of large arrays and FoV, PSF changes over the image (Cotton-Schwab algorithm)
- **Automatic scale-dependent masking**: diffuse structures
- **Multi-frequency deconvolution:** takes spectral variation into account during deconvolution
- **Image Domain Gridding (IDG)** + correction of DD effects (a-term), 30k x 30k images
- **Parallel cleaning** larger images subdivided and cleaned independently

→ **WSClean** (Offringa+ 2014): w-stacking clean





SHARP program, Spingola+ 2018 with WSClean automasking

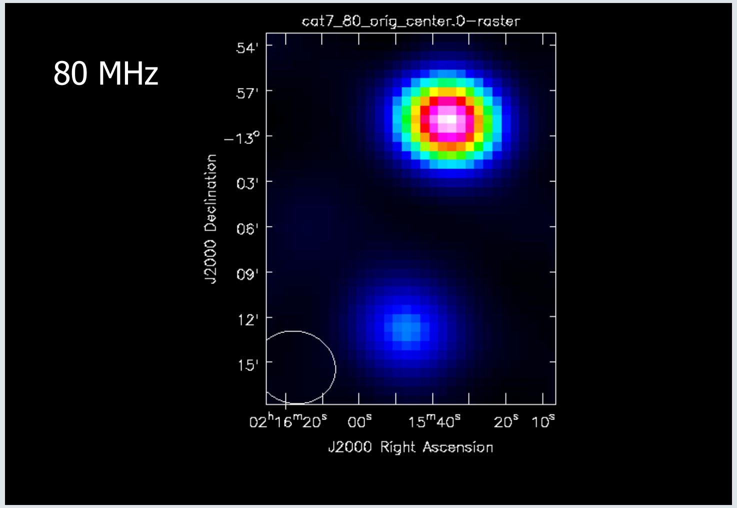


e-MERGE survey, Muxlow+ 2020 with WSClean, w-stacking for e-MERLIN large FoV, merge data sets from different arrays

Imaging at very low frequencies

- **Direction-Dependent effects** mainly due to ionosphere at lower freqs
  → affects position (**shifts**), and brightness (**defocusing**), with significant temporal fluctuations (can also affect polarization angle)

Credit: Rioja 2018



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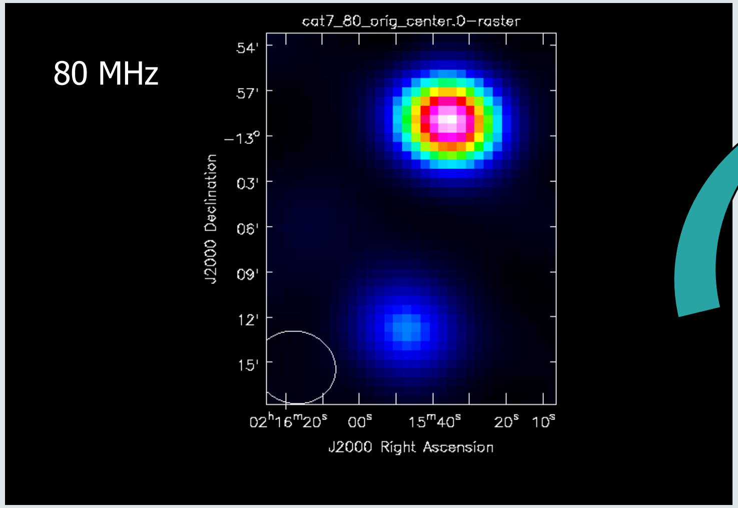
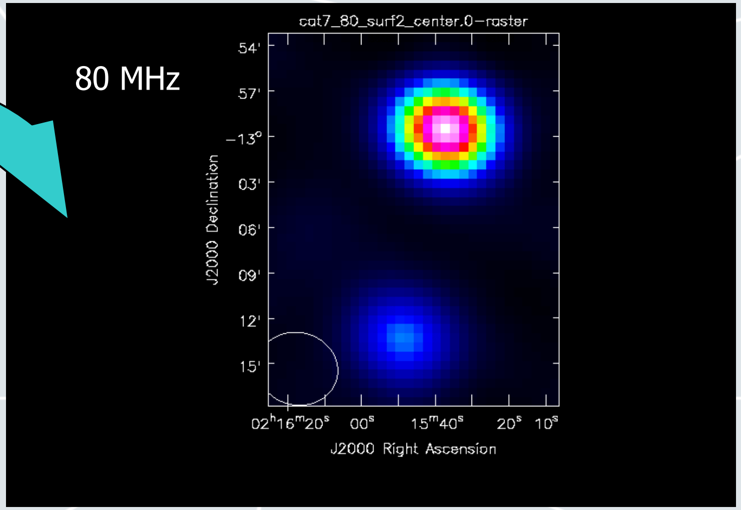


LEAP calibration for MWA
Rioja+ 2018

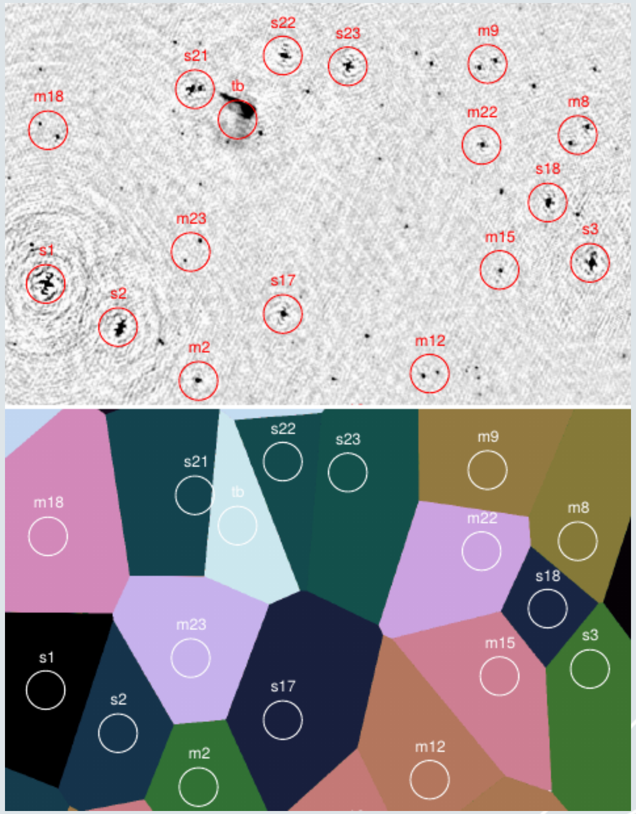


- **LEAP:** real-time phase calibration in visibility domain, using frequency smearing as an efficient directional filter, better performance for longer baselines, no need an sky model
- Corrects for both shift and defocusing
- Applicable to **SKA1-LOW tied-array real-time beamforming** (pulsars + VLBI beams)
- LEAP + WSClean → **wide FoV with DDE corrected images**

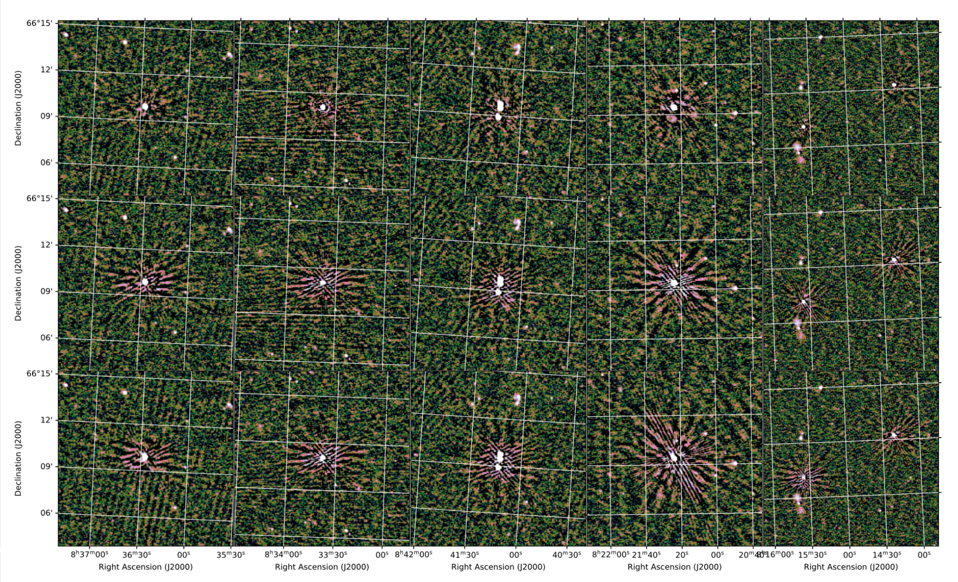
Imaging at very low frequencies

Other solutions for DDE's:

- Image in small "facets" where DDE's are constant: LOFAR facet calibration (van Weeren+ 2016)
- Probabilistic model for inferring ionospheric phase screens: Albert+ 2020, 2019



LOFAR facet calibration: each facet self-calibrated independently, isoplanatic, high resolution + dynamic range (van Weeren+ 2016)



DDE in regions far from calibrators improved with TEC screens –top row- (Albert+ 2019, 2020)

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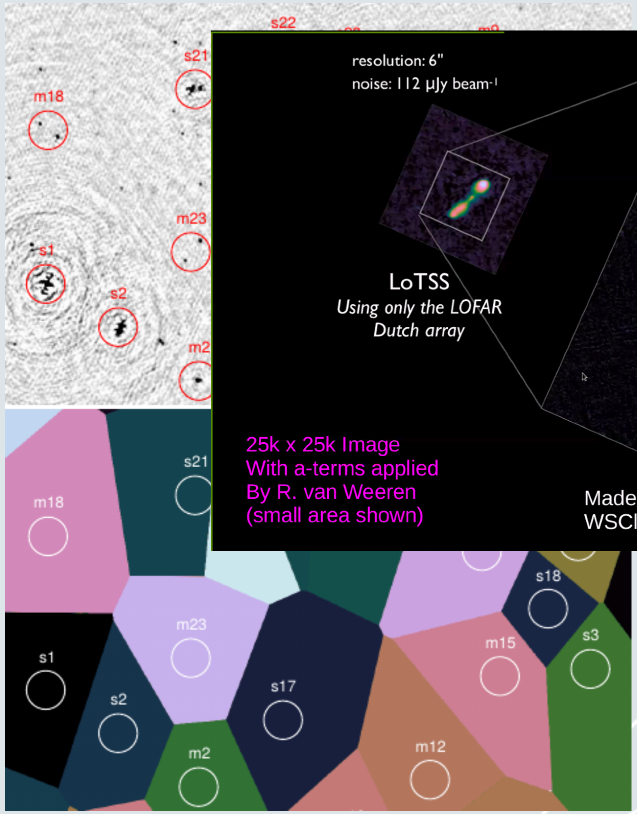

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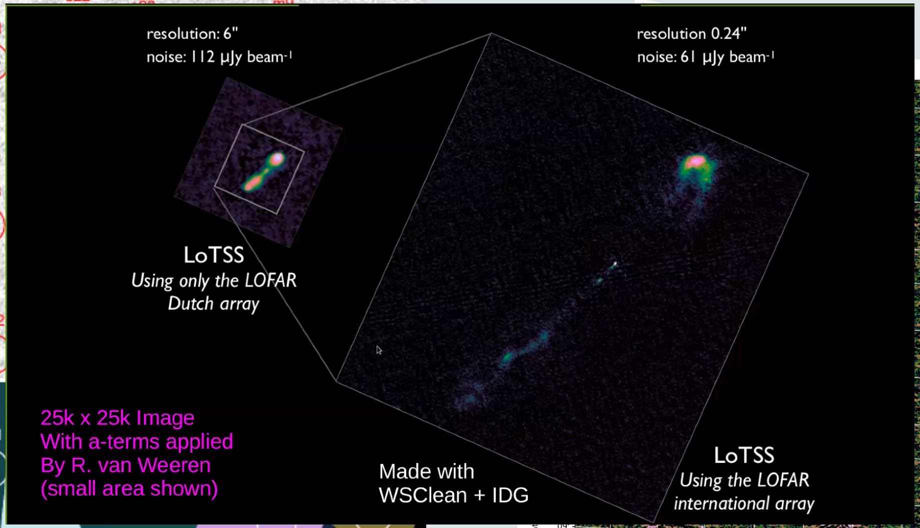

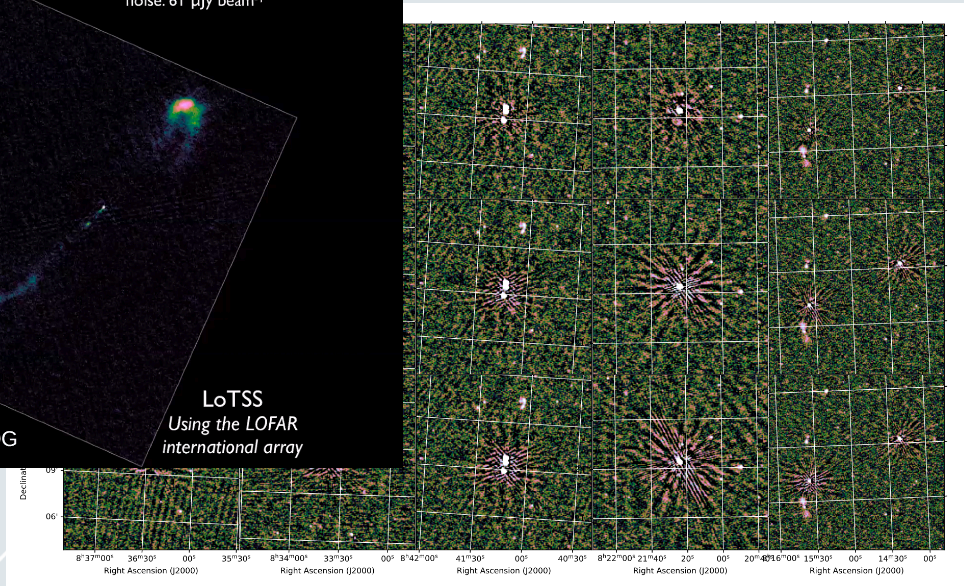

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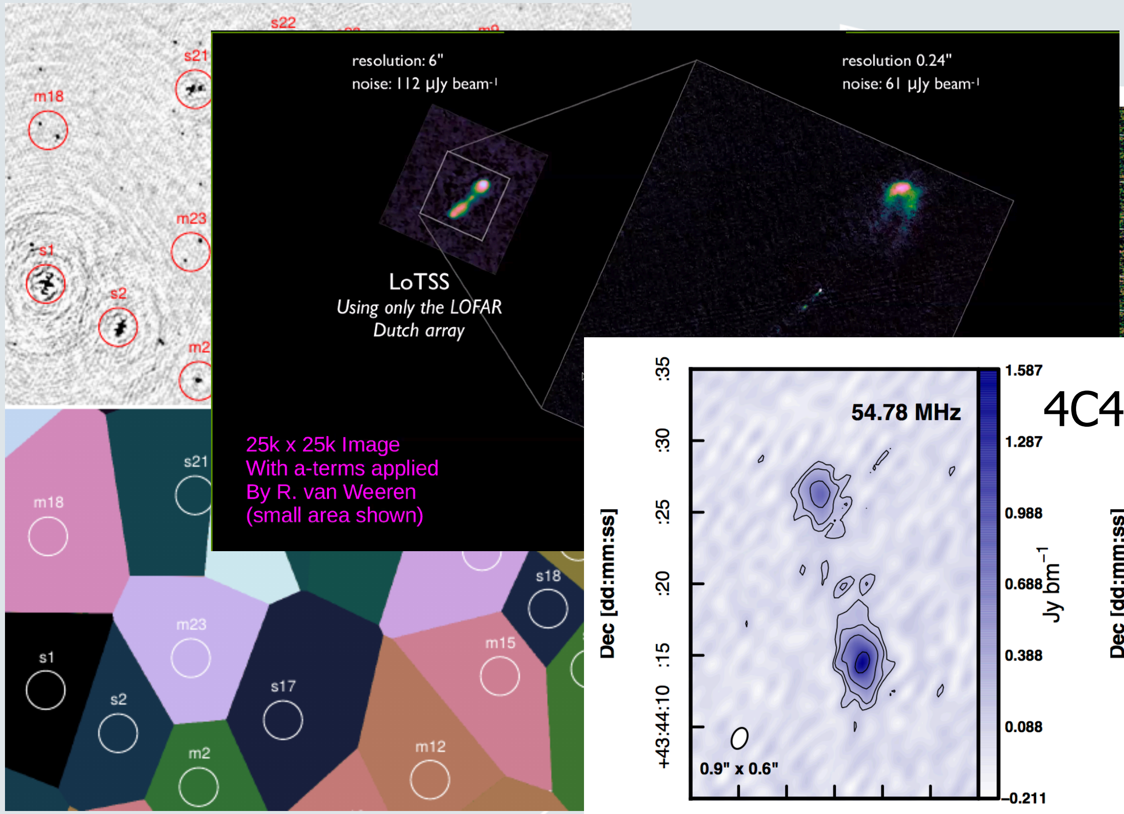

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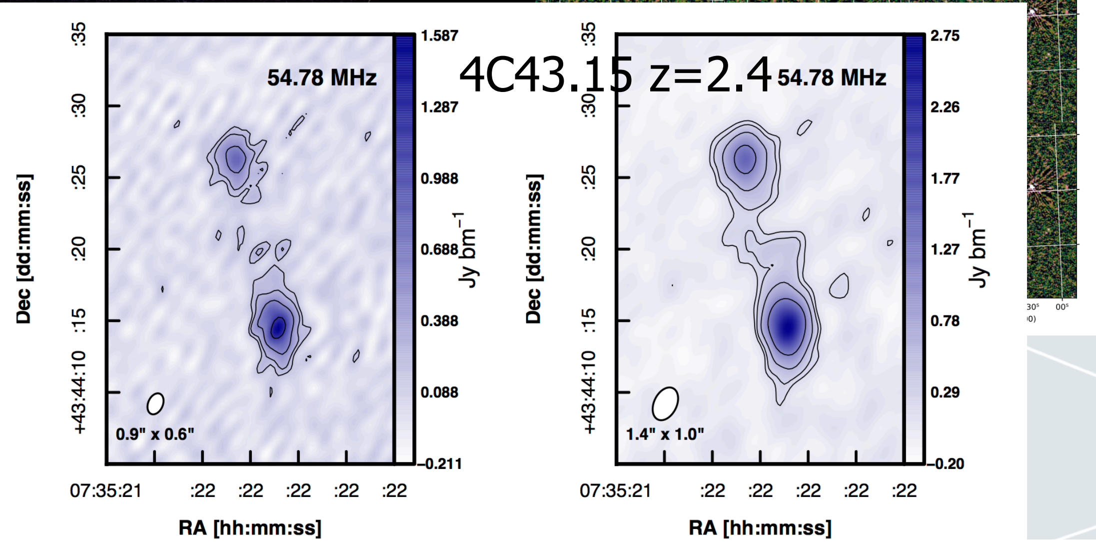


Record for highest spatial resolution at freq <100MHz –solve for TEC before selfcal- (Morabito+ 2016)

Imaging with higher fidelity & sensitivity

Credit: Venturi+ 2020

Technical enhancements

- Broadband receivers ~4-8GHz: improve sensitivity + instantaneous coverage + improve observation efficiency + good polarisation response (e.g. BrandEVN)
- Increase data rates x4: data storage and connectivity, data correlation
- Extend the frequency coverage to higher (e.g. triple band receivers) and lower frequencies (<1GHz), increase number of antennas with these frequencies
- New additions to the networks: uv-coverage improvement, specially in the southern direction for SKA synergies (more on this in a sec…)
- Extend FoV (e.g. PAFs) and align with "survey-modes" in other astronomical facilities
- Enhance software correlator to cope with previous upgrades, telescopes with multiple beams (e.g. SKA, PAFs), new observing modes (e.g. fast transients and pulsar processing modes)…

Imaging with higher fidelity & sensitivity

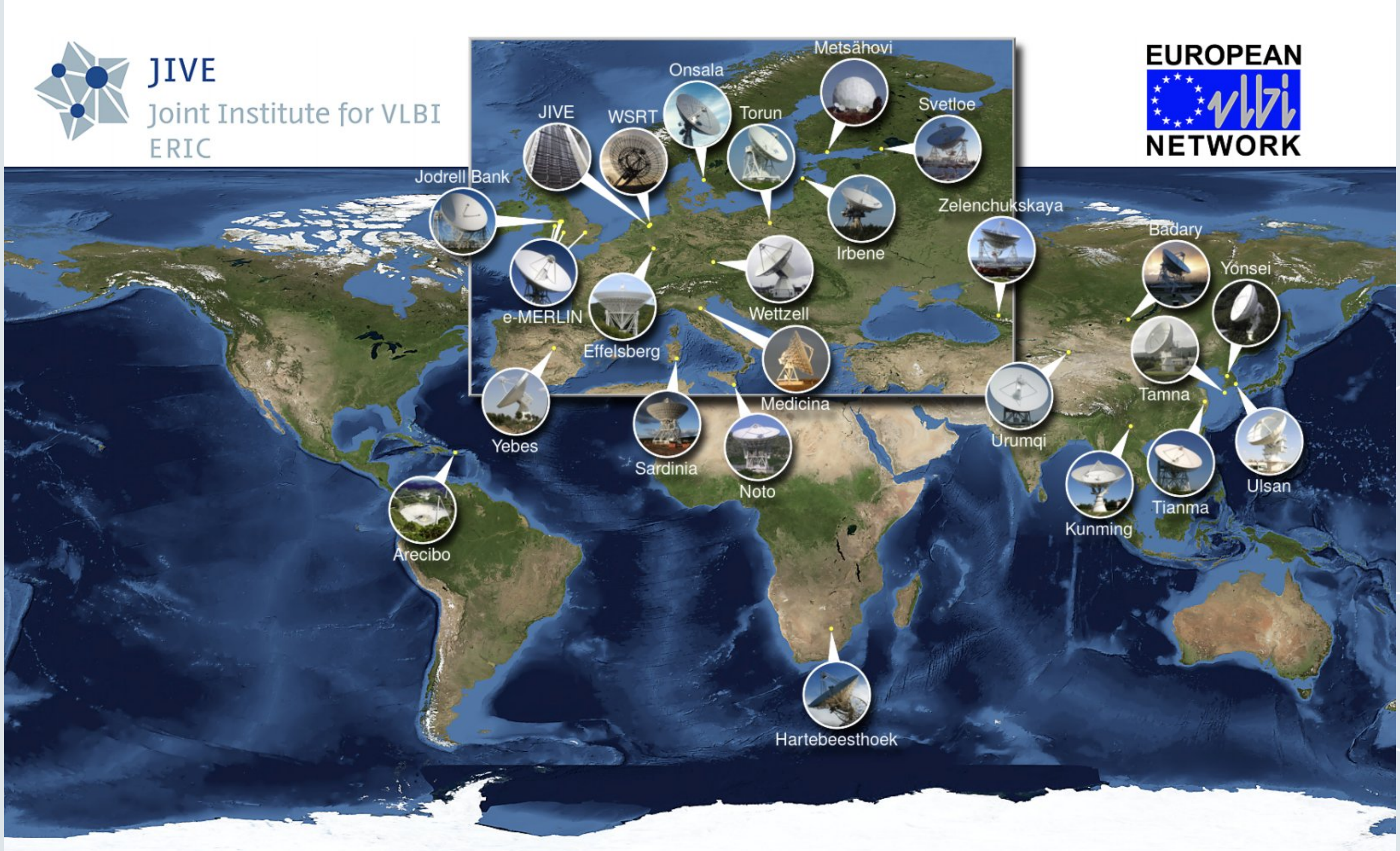


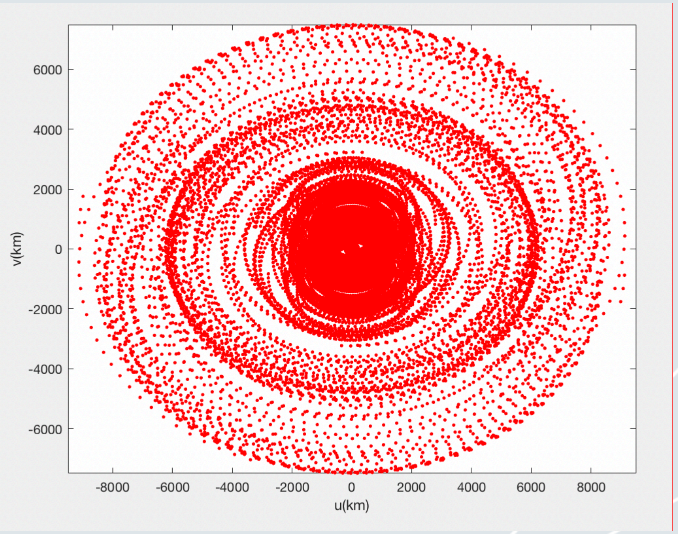
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Imaging with higher fidelity & sensitivity

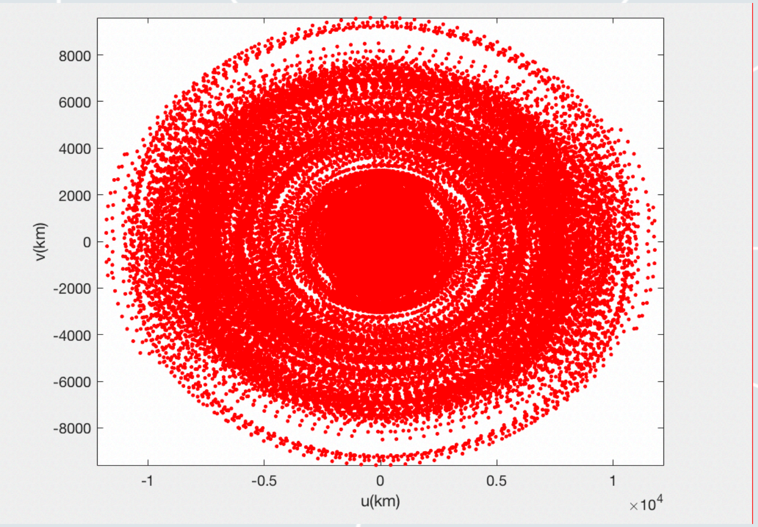
Credit: Conway, 2008

EVN + e-MERLIN baselines: excellent spatial dynamic range 8000km to 6km i.e >1000:1

- with many times VLA sensitivity
- Global VLBI promotes as VLA-like coverage
- + Multi-Frequency Synthesis (MFS) basically complete uv coverage!



uv-coverage of **EVN and *e*-MERLIN** with 18 stations total. Single frequency and 2 Gbps (256 MHz or 5% b/w)

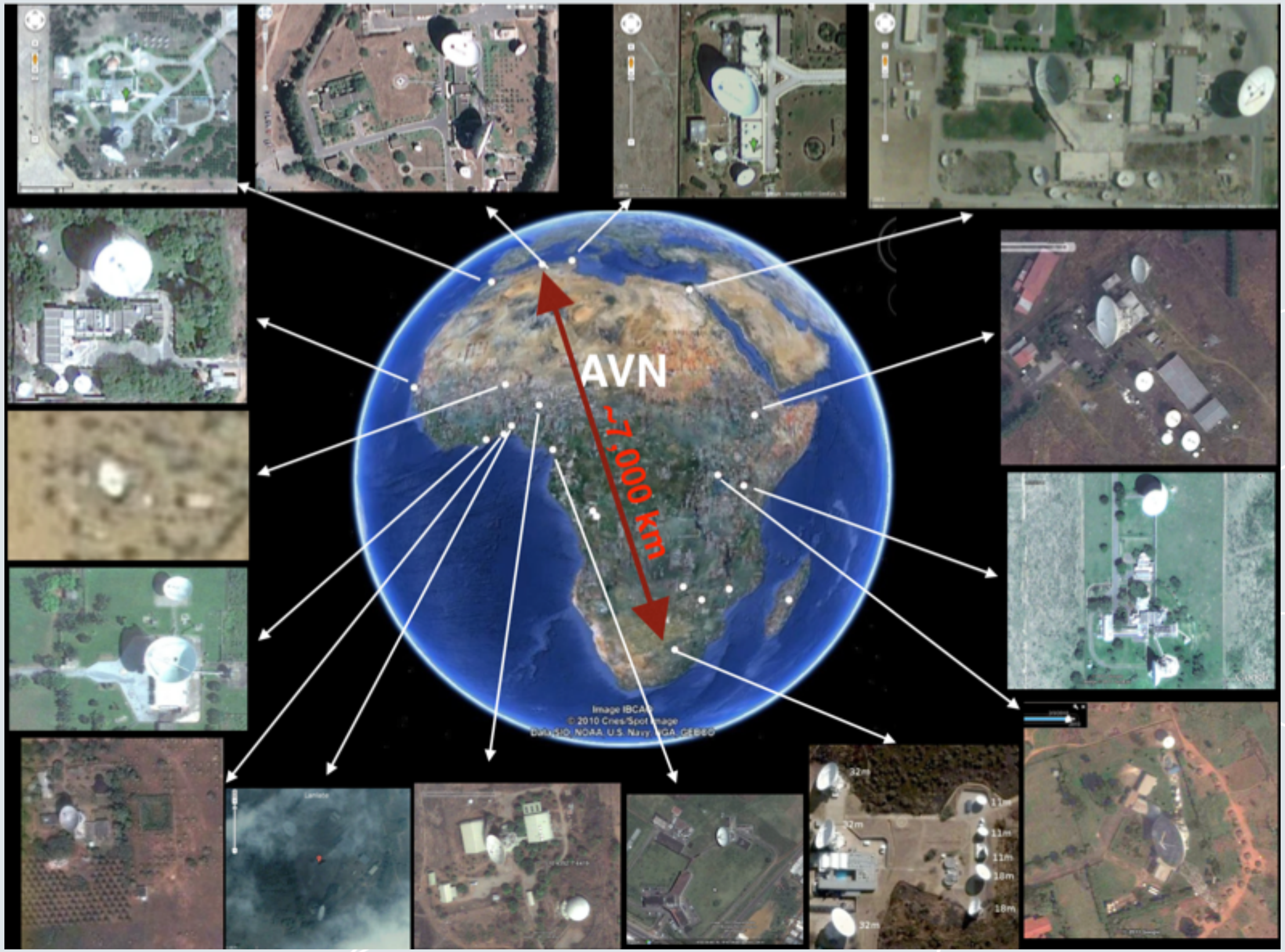


Global VLBI *uv*-coverage with 30 stations world-wide. Single frequency and 2 Gbps (256 MHz or 5% b/w)

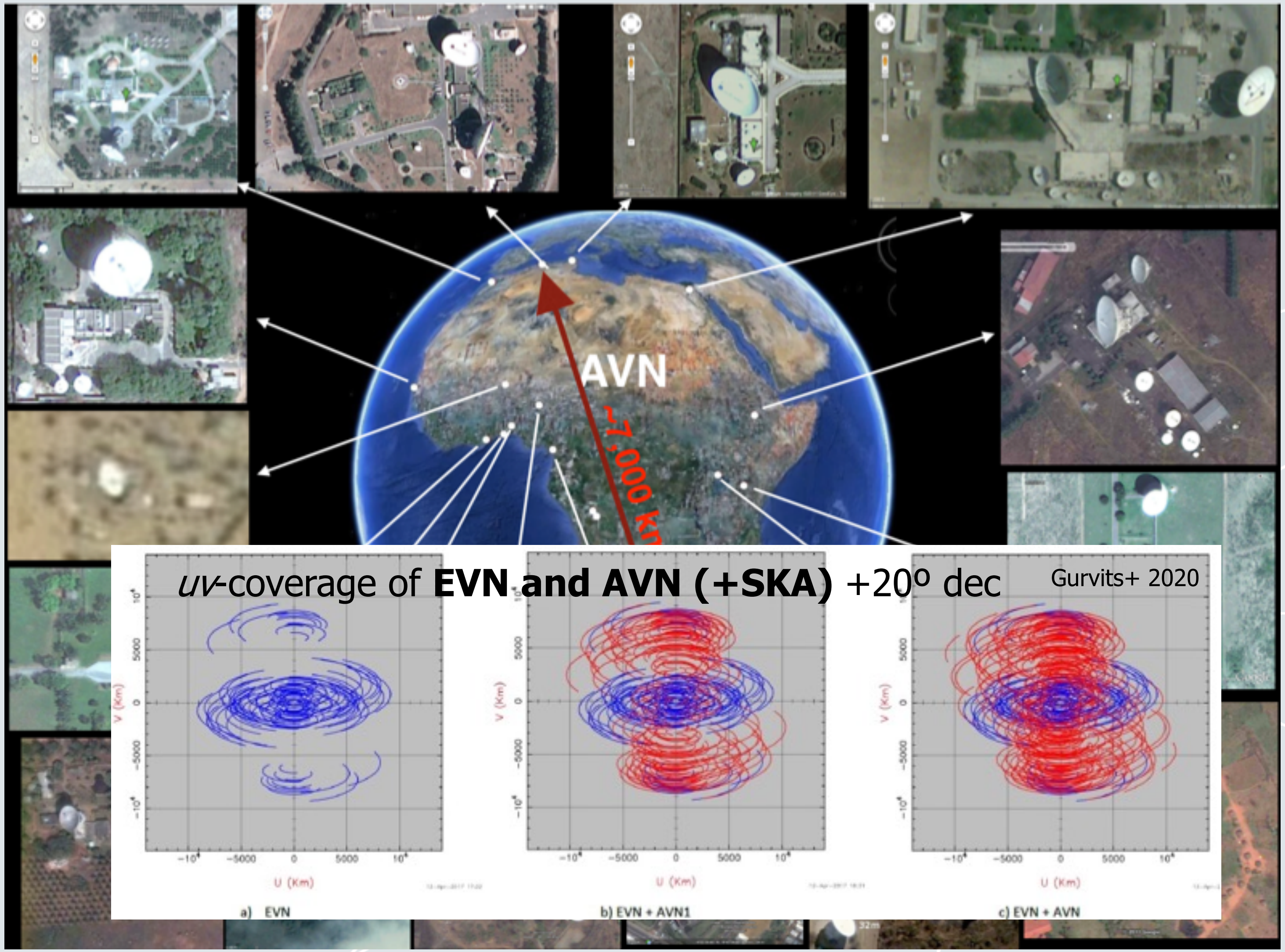
Imaging with higher fidelity & sensitivity

Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

The African VLBI Network



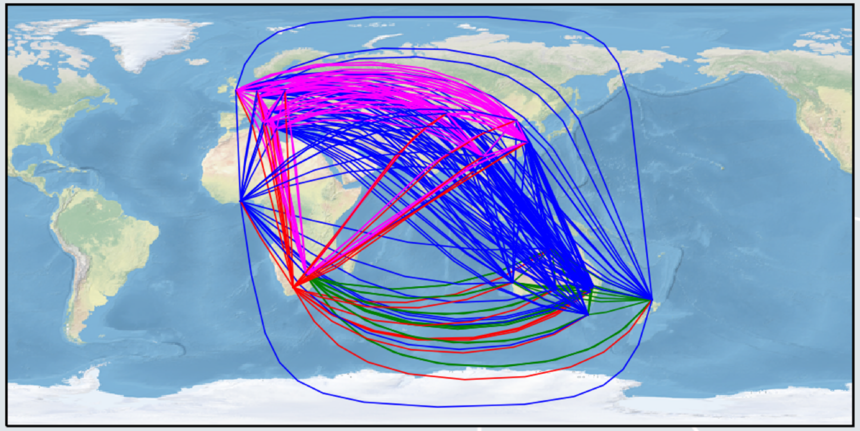
The African VLBI Network

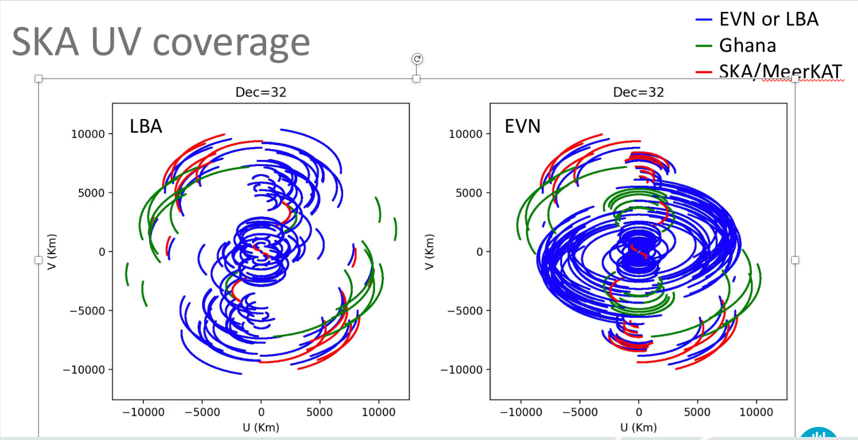


Imaging with higher fidelity & sensitivity

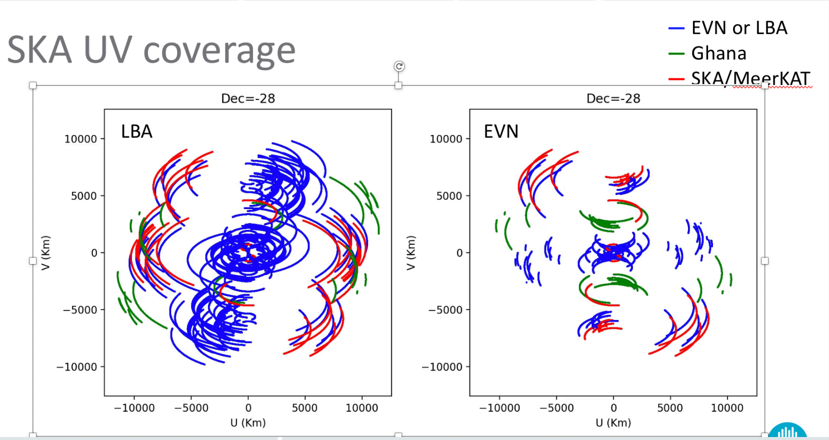
Credit: Phillips 2019

Global VLBI: LBA + EVN + EAVN + AVN (Ghana) + MeerKAT





Global VLBI *uv*-coverage +30º dec



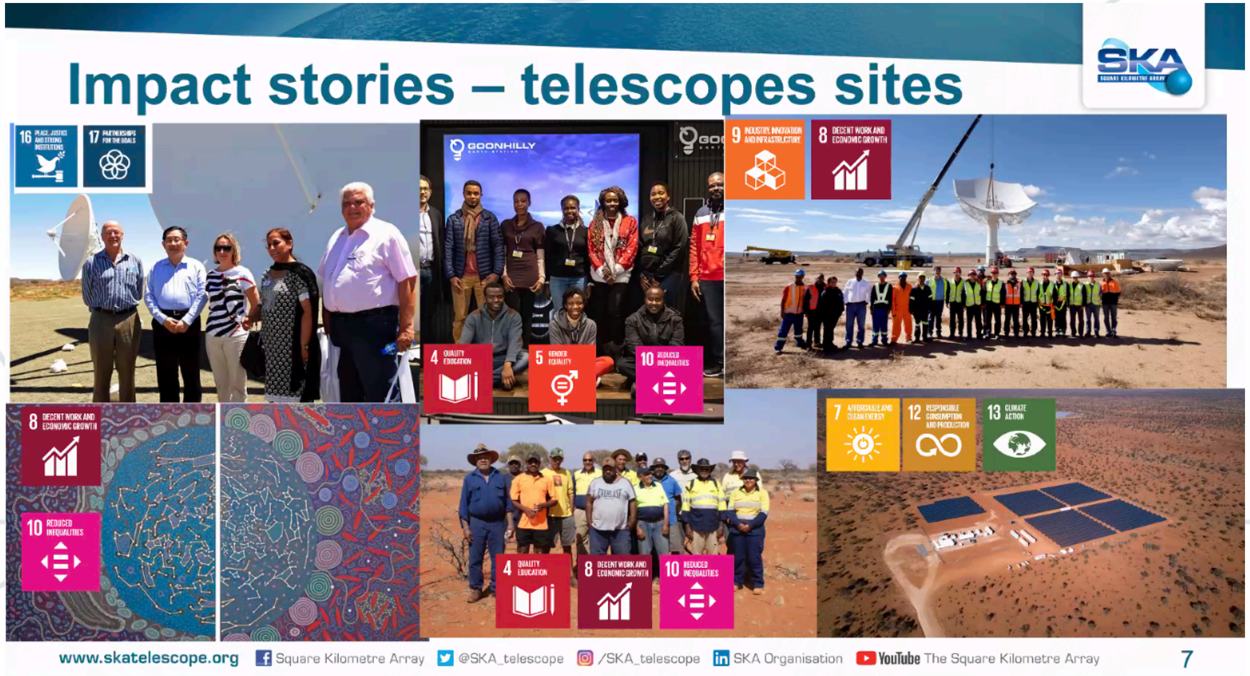
Global VLBI *uv*-coverage -30º dec

VLBI sustainable development

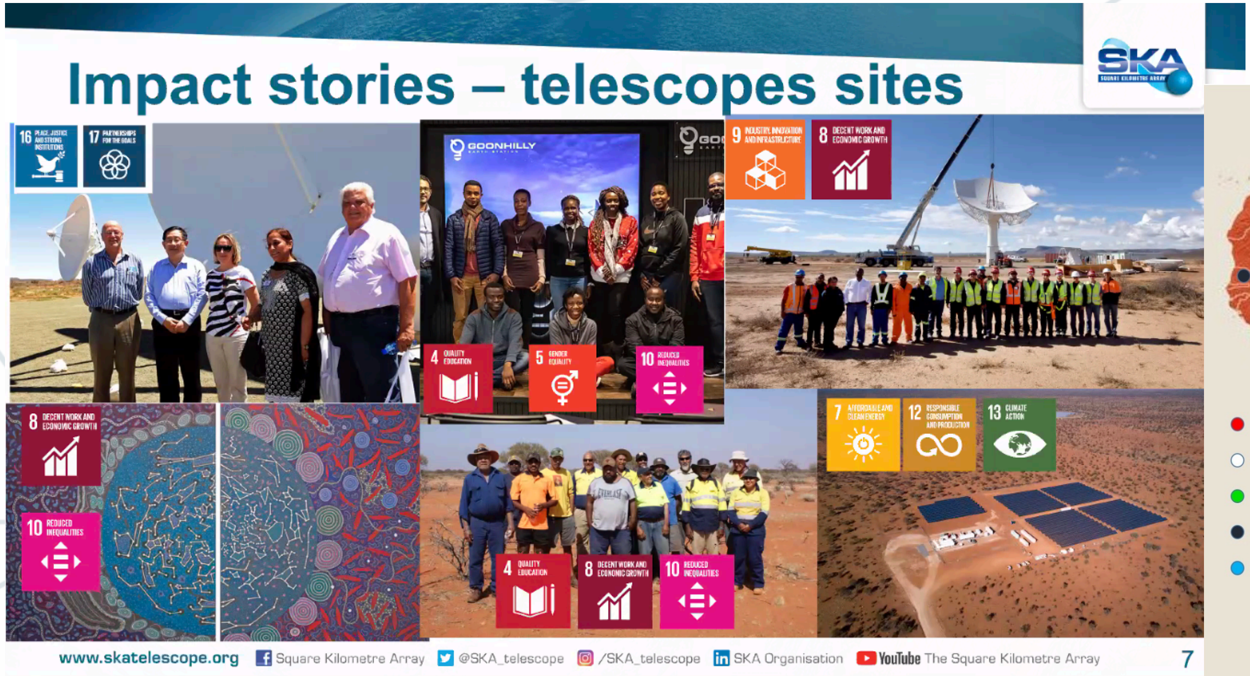
VLBI sustainable development?

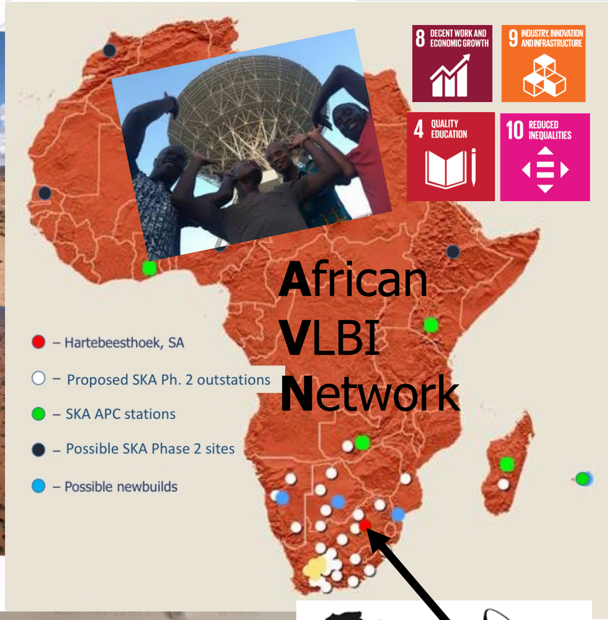
Credit: mShopper´s mind Propulsion Labs

SKA & VLBI sustainable development

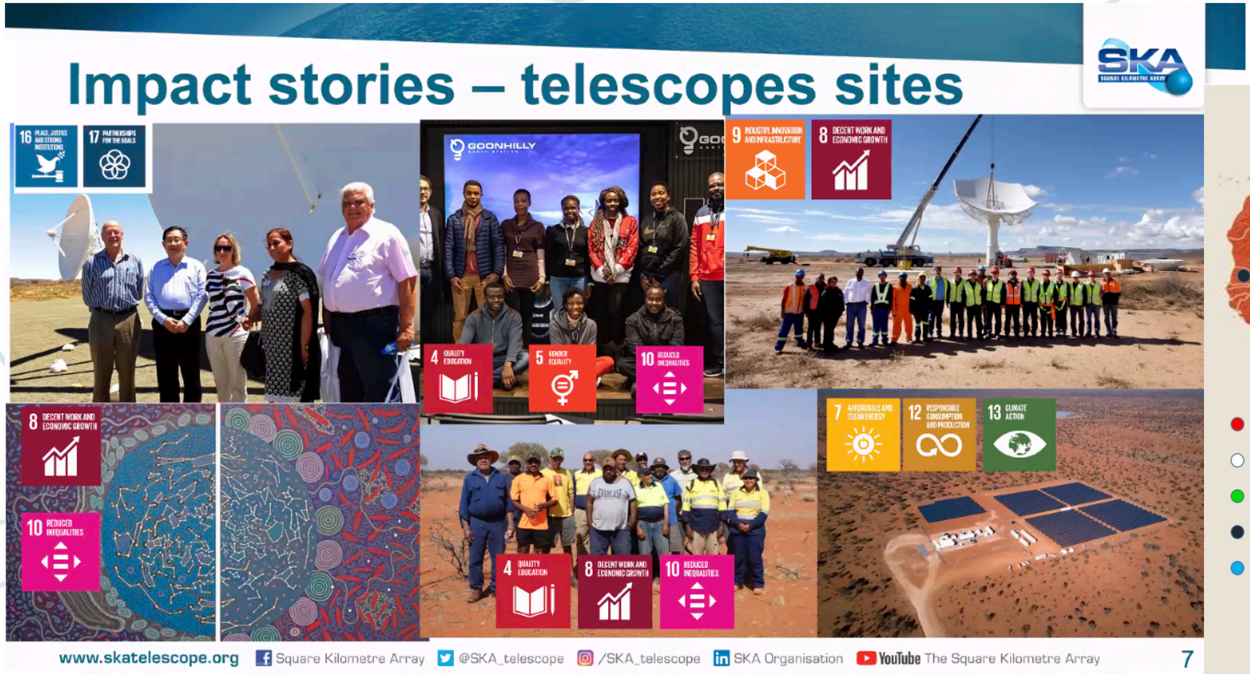


SKA & VLBI sustainable development

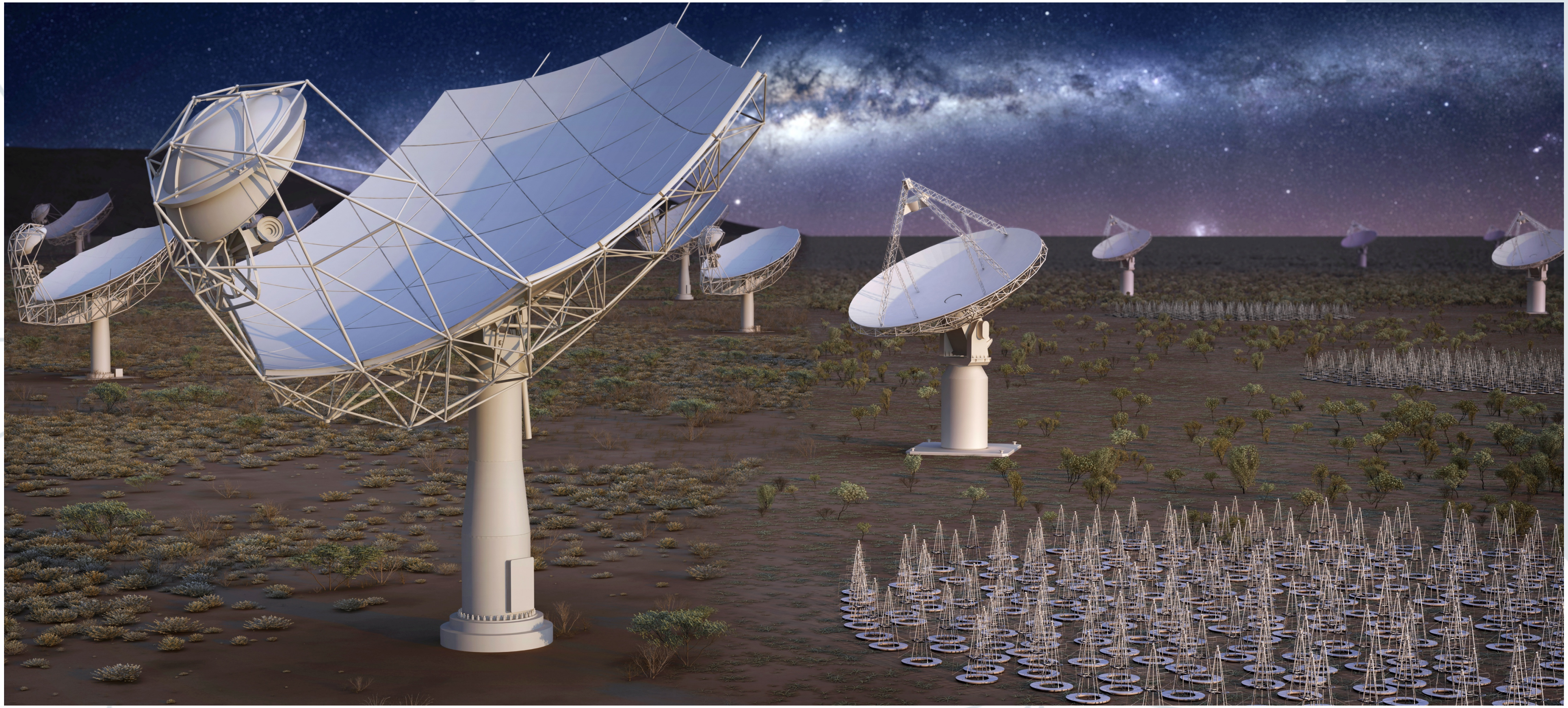




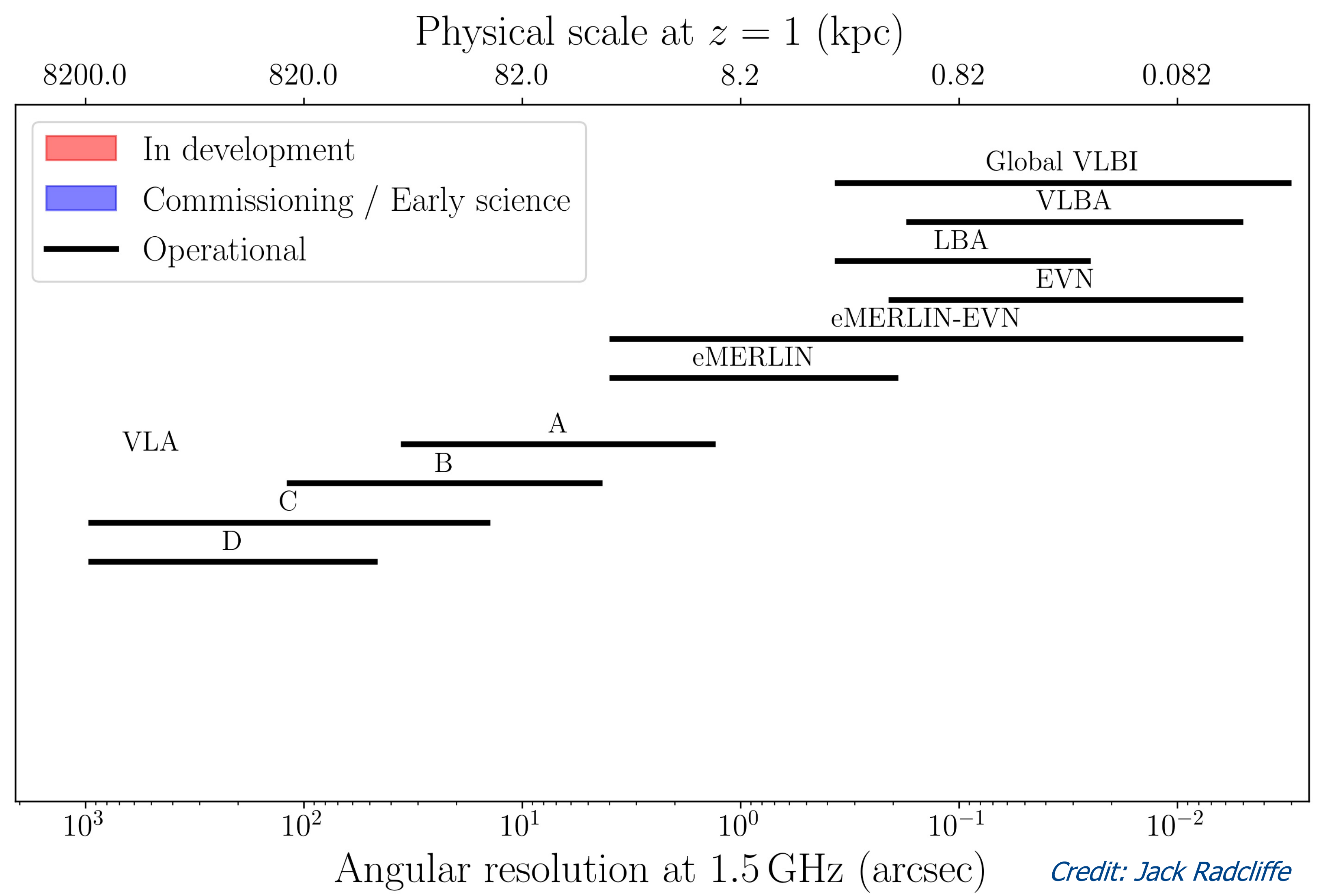
SKA & VLBI sustainable development



The future of VLBI in the SKA era

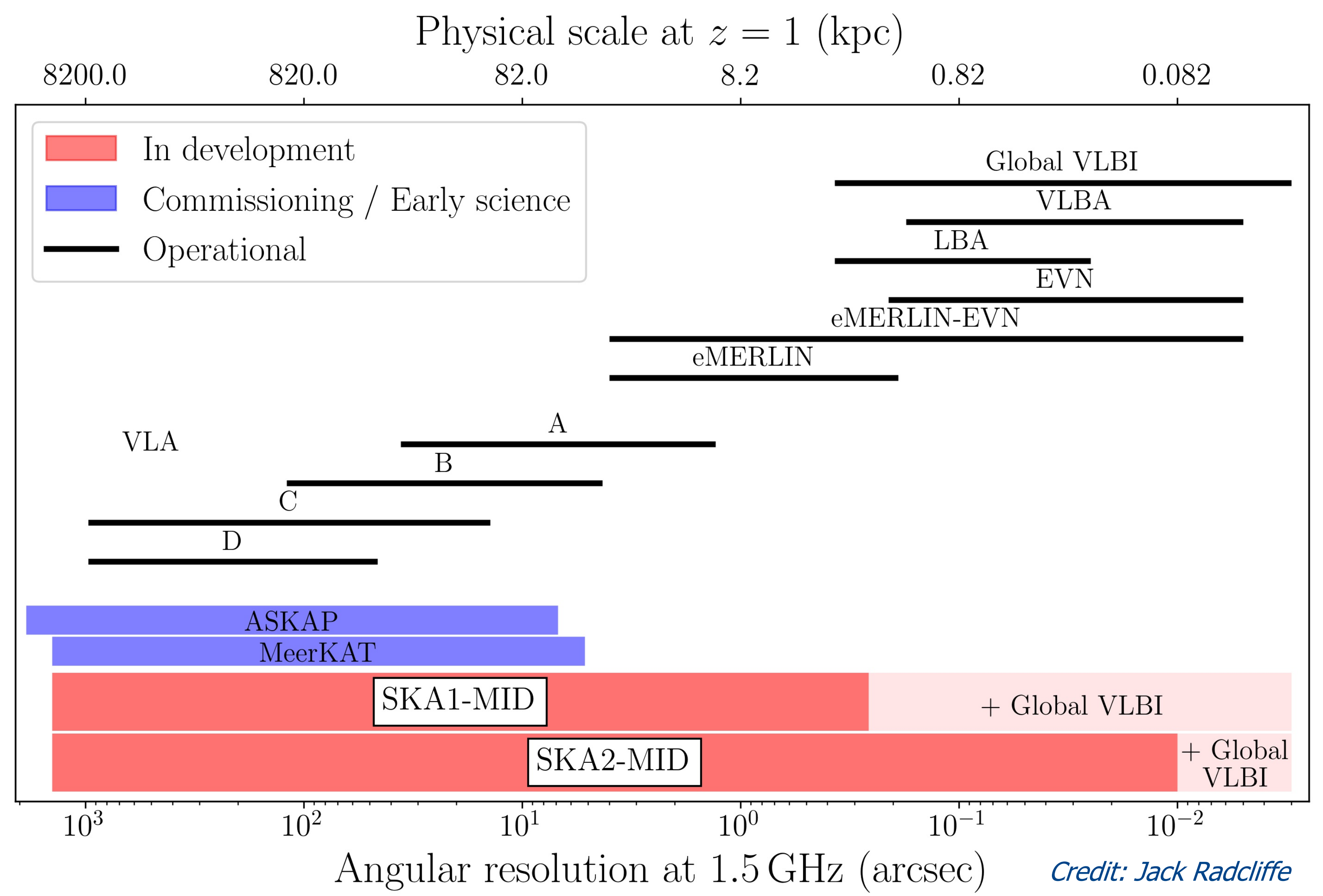


Why VLBI with the SKA?



Credit: Jack Radcliffe

Why VLBI with the SKA?



Credit: Jack Radcliffe

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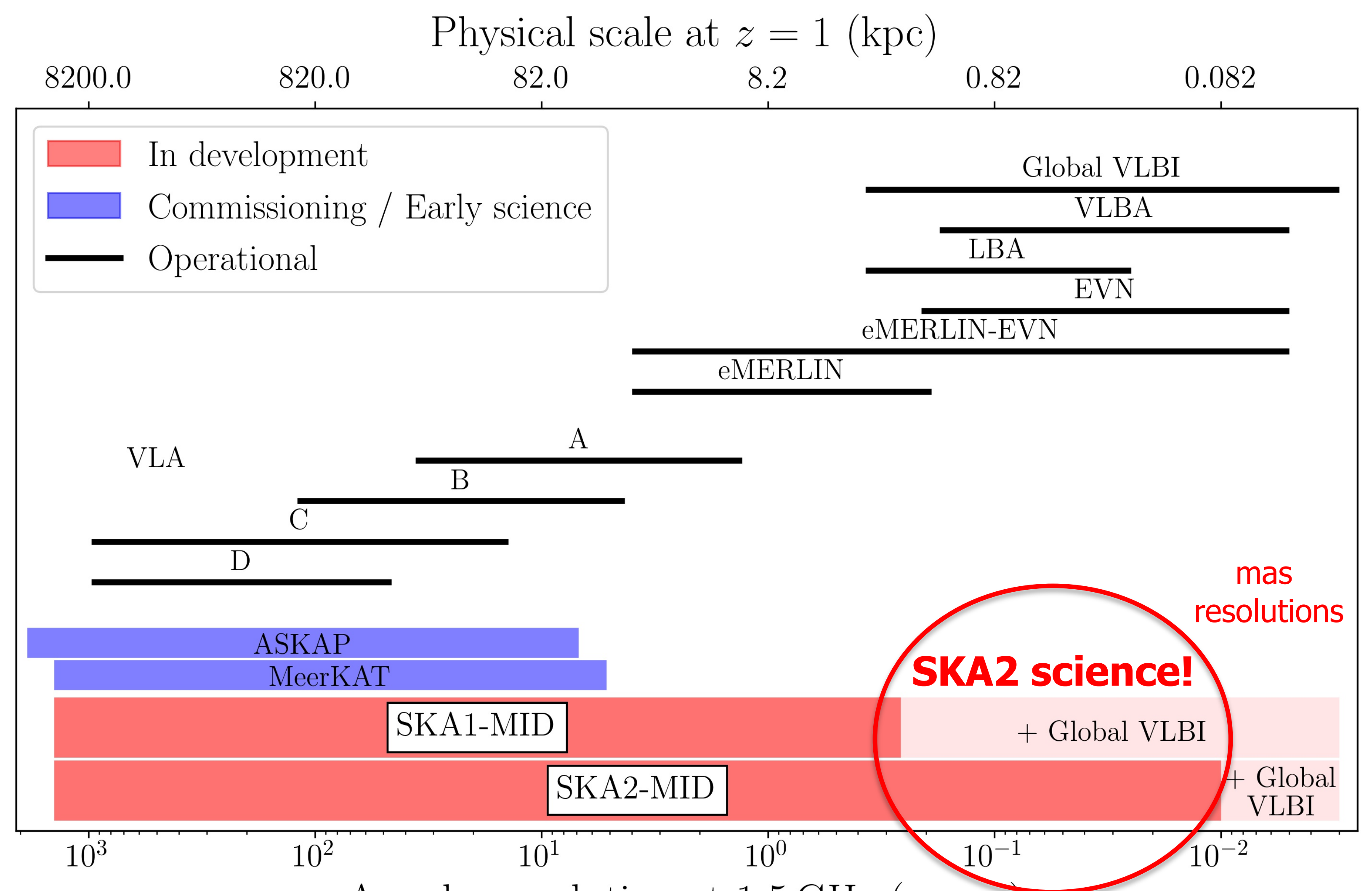


Credit: Jack Radcliffe

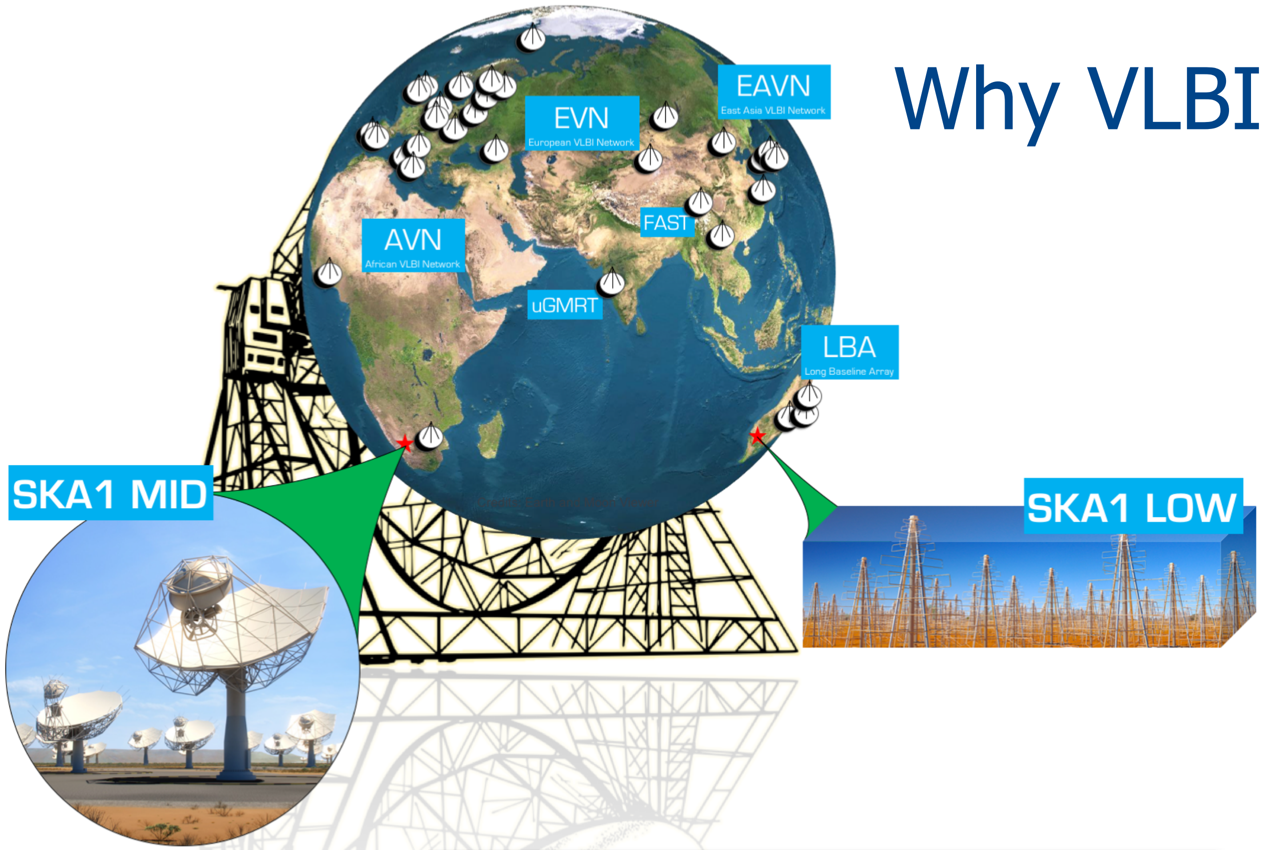
Why VLBI with the SKA?

Why VLBI with the SKA?

SKA provides …

- Independent MULTI-BEAM CAPABILITY
- BOOST in SENSITIVITY to μJy regime
- Access to SOUTHERN SKIES and GC
- COMMENSALITY with other observing modes
- Superior AMPLITUDE & POLARISATION calibration
- Pristine RF environments and state of the art RFI detection/excision

Why VLBI with the SKA?



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VLBI provides …

- Images of sky at BROAD RANGE of ANGULAR SCALES
- mas resolution for SKA HPSOs
- Independent COMMISIONING TOOL and early PR OPPORTUNITIES
- AN ENTHUSIASTIC USER COMMUNITY

JUMPING JIVE Project

*"**J**oining up **U**sers for **M**aximizing the **P**rofile, the **I**nnovation and **N**ecessary **G**lobalization of **JIVE**"*

European Union's H2020 research and innovation programme under grant agreement No 730884

JUMPING JIVE Project

JUMPING JIVE
Joint Institute for VLBI
ERIC

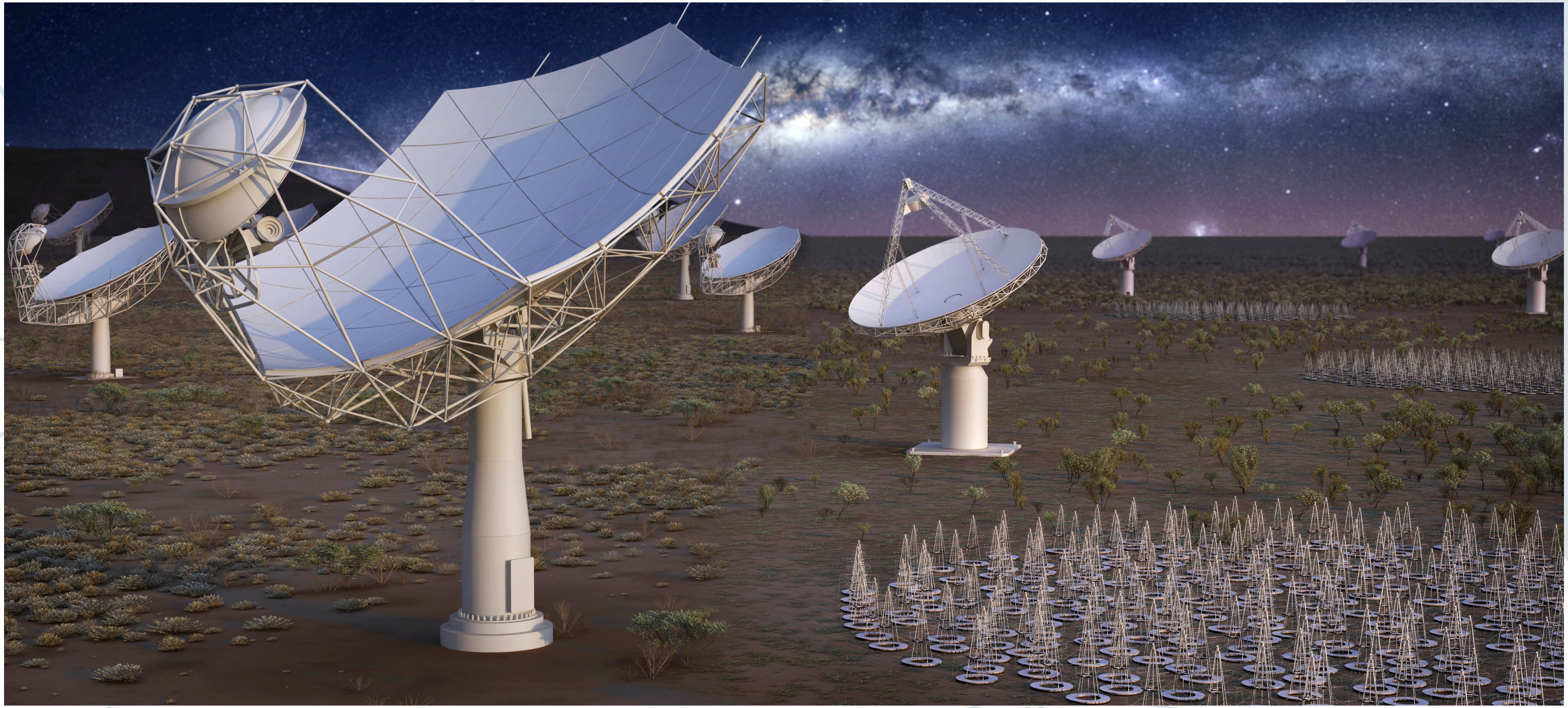
"Joining up Users for Maximizing the Profile, the Innovation and Necessary Globalization of JIVE"

European Union's H2020 research and innovation programme under grant agreement No 730884

Work package 10: "VLBI with the SKA"

- Provide support for SKA integration and operations within the VLBI arrays
- Led by Zsolt Paragi (JIVE) and Antonio Chrysostomou (SKAO)
- SKA-VLBI project scientist Cristina García-Miró (SKAO - currently at JIVE)

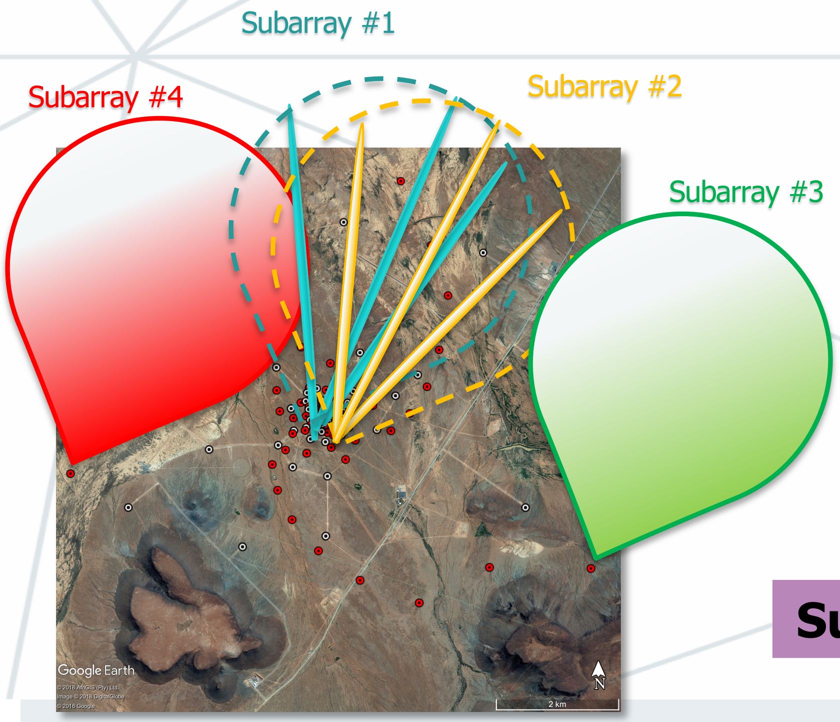
How we do VLBI with the SKA?



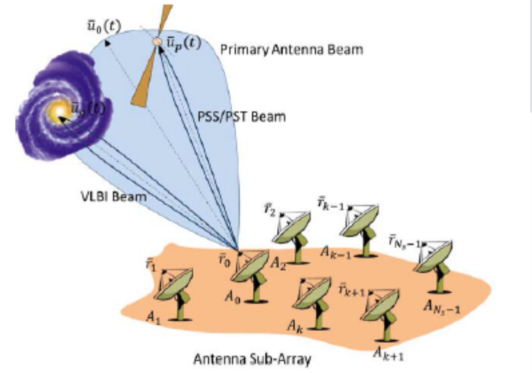
VLBI with SKA1: key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations
typically the core **+ individual SKA1 antennas or stations** short uv-spacings

Independent subarrays:
different purposes, up to 16



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

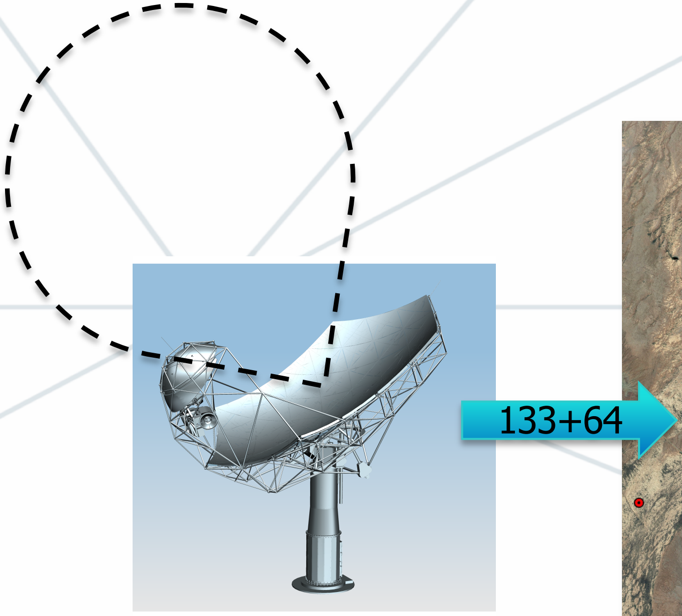


Independent multi-beam capability
within each subarray (in scan boundaries)

Support from a SKA-VLBI Consortium

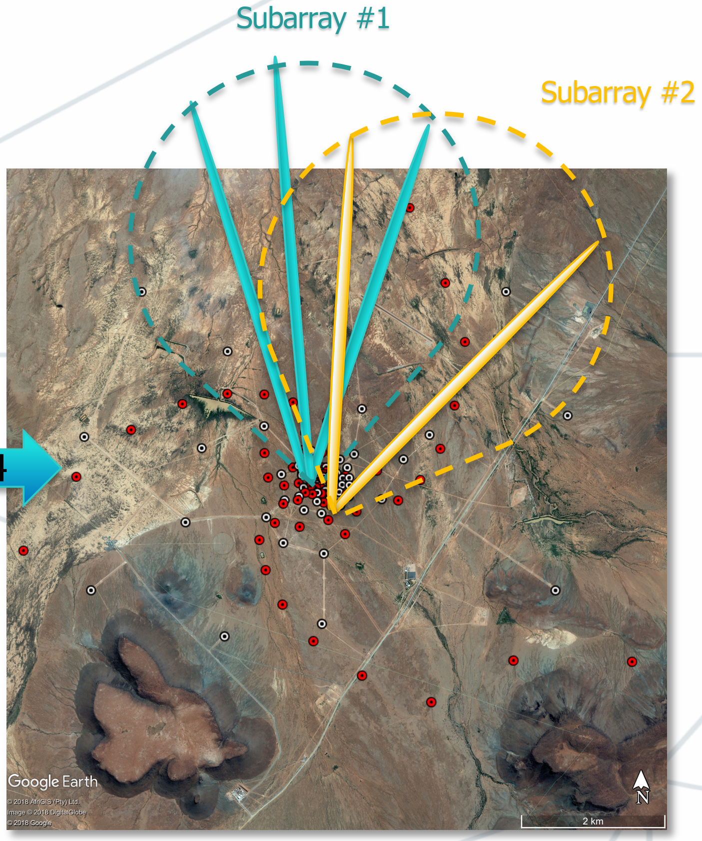
VLBI with SKA1-MID:

all observing modes within a subarray with bandwidth sacrifice



SKA1-MID
Antenna

Antenna Beam



SKA1-MID
"array/subarray"

Correlation:

- ✓ ***Normal visibilities, zoom*** (100-3 MHz, 6 kHz-190 Hz)
- ✓ ***VLBI coarse visibilities:*** 200 vs. 13 kHz

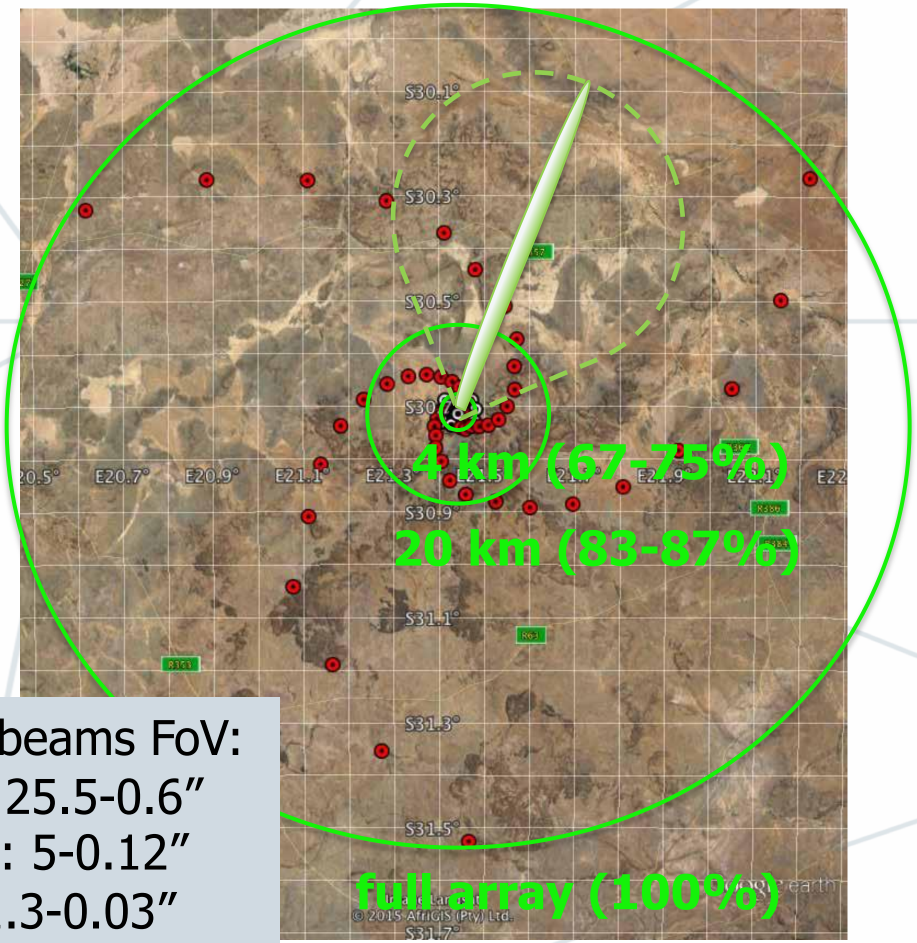
Tied-array beams:

- ✓ ***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***

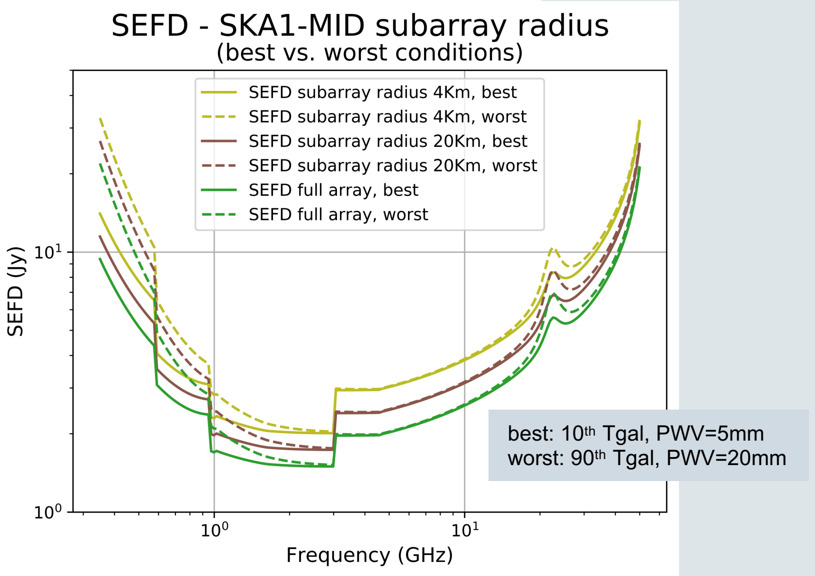
Transients:

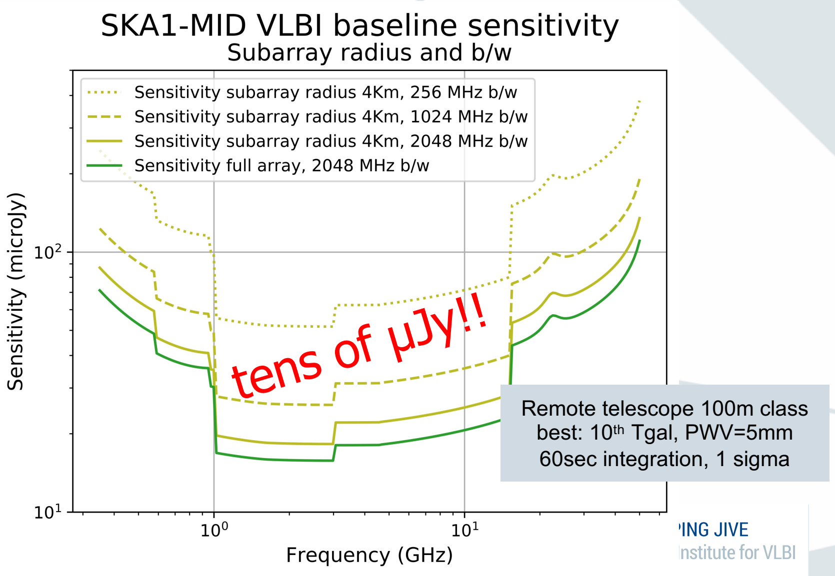
- ✓ ***Transient buffer*** (2x300 MHz search windows: -2,+60 sec, every 62 sec)
- ✓ ***Fast imaging pipeline for slow transients*** (>1sec)

VLBI with SKA1-MID: configurations



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





SKA1-MID simultaneous observing:

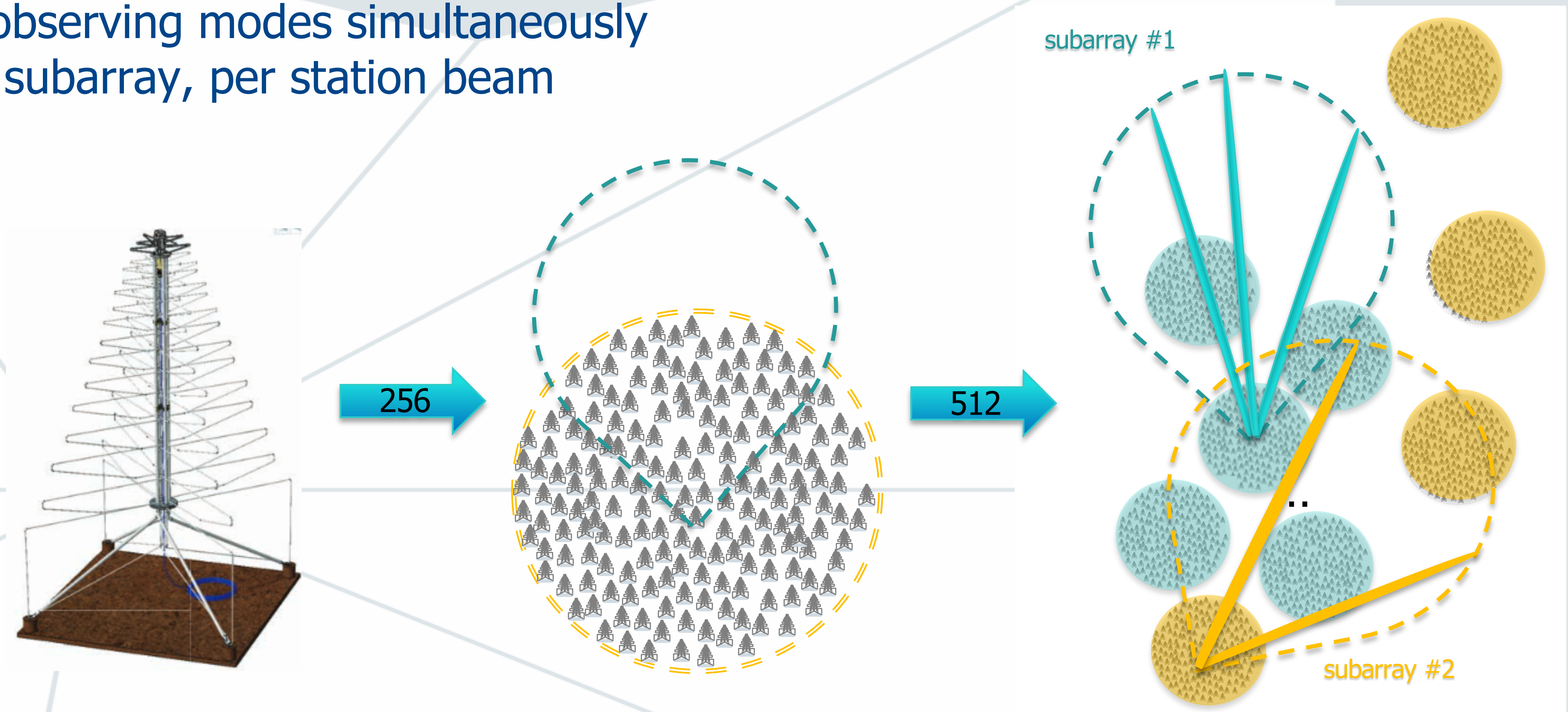
limited by processing resources (26+1 FSP=Frequency Slice Processor)

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)	2/4beams 5/2.5GHz (26 FSP)	🚫	🚫	🚫	🚫
	4beams 600MHz (6 FSP)	512MHz (3 FSP)	1500b 300MHz (8 FSP)	16b 512 MHz (3 FSP)	6 (6 FSP)
	14beams 500MHz (21 FSP)	500MHz (3 FSP)			3.1MHz (1 FSP)
	🚫	**Full (26 FSP)**	🚫	🚫	🚫

VLBI with SKA1-LOW: 50-350 MHz

All observing modes simultaneously per subarray, per station beam

SKA1-LOW "subarray"



SKA1-LOW Antenna/Receptor

Antenna Beam

SKA1-LOW *"Station"*

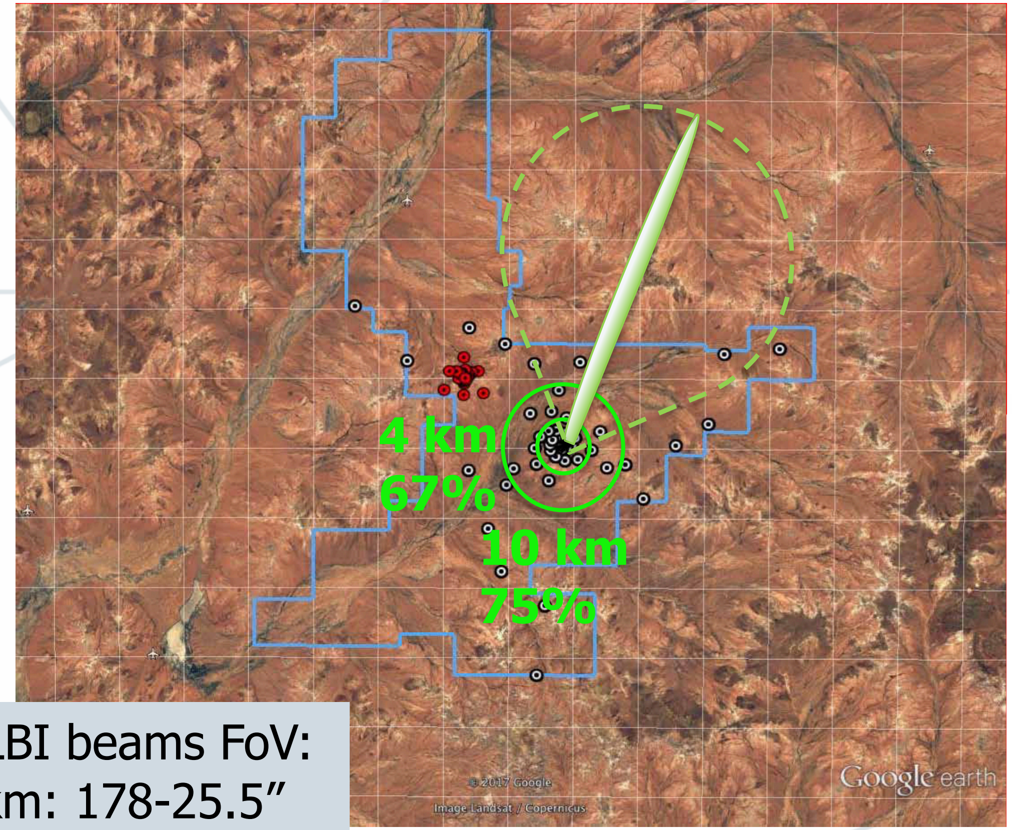
Station Beam
300 MHz b/w

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

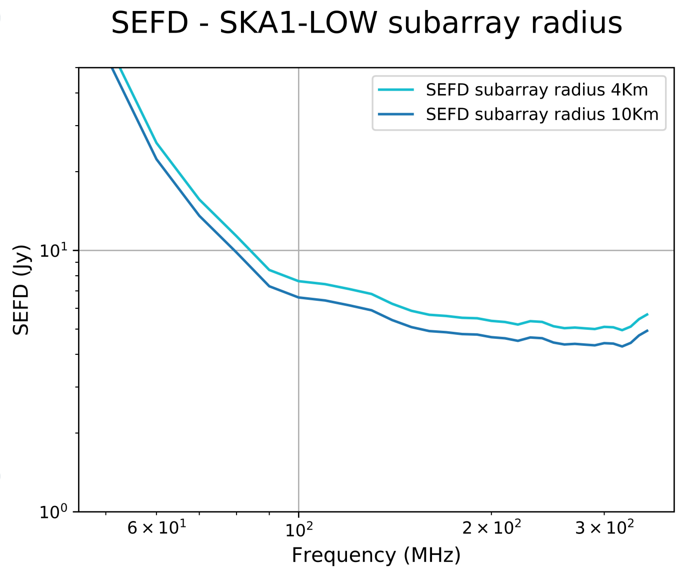
Tied-array beams from 20 Km diameter subarray:
- ✓ ***4 VLBI beams*** *(in total)*
- ✓ *500 for **Pulsar Search PSS***
- ✓ *16 for **Pulsar Timing PST***

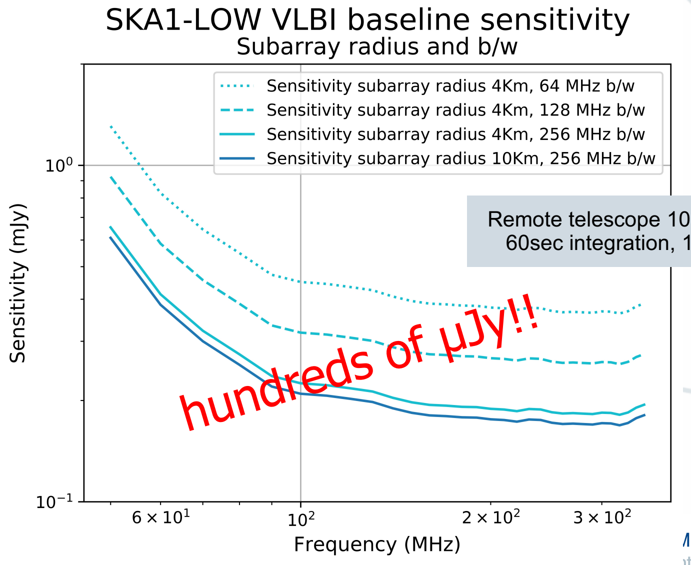
Transients:
- ✓ ***Transient buffer*** *(*300 MHz search windows, 900 sec, every 45min)
- ✓ ***Fast imaging pipeline for slow transients*** (>1sec)

VLBI with SKA1-LOW: configurations

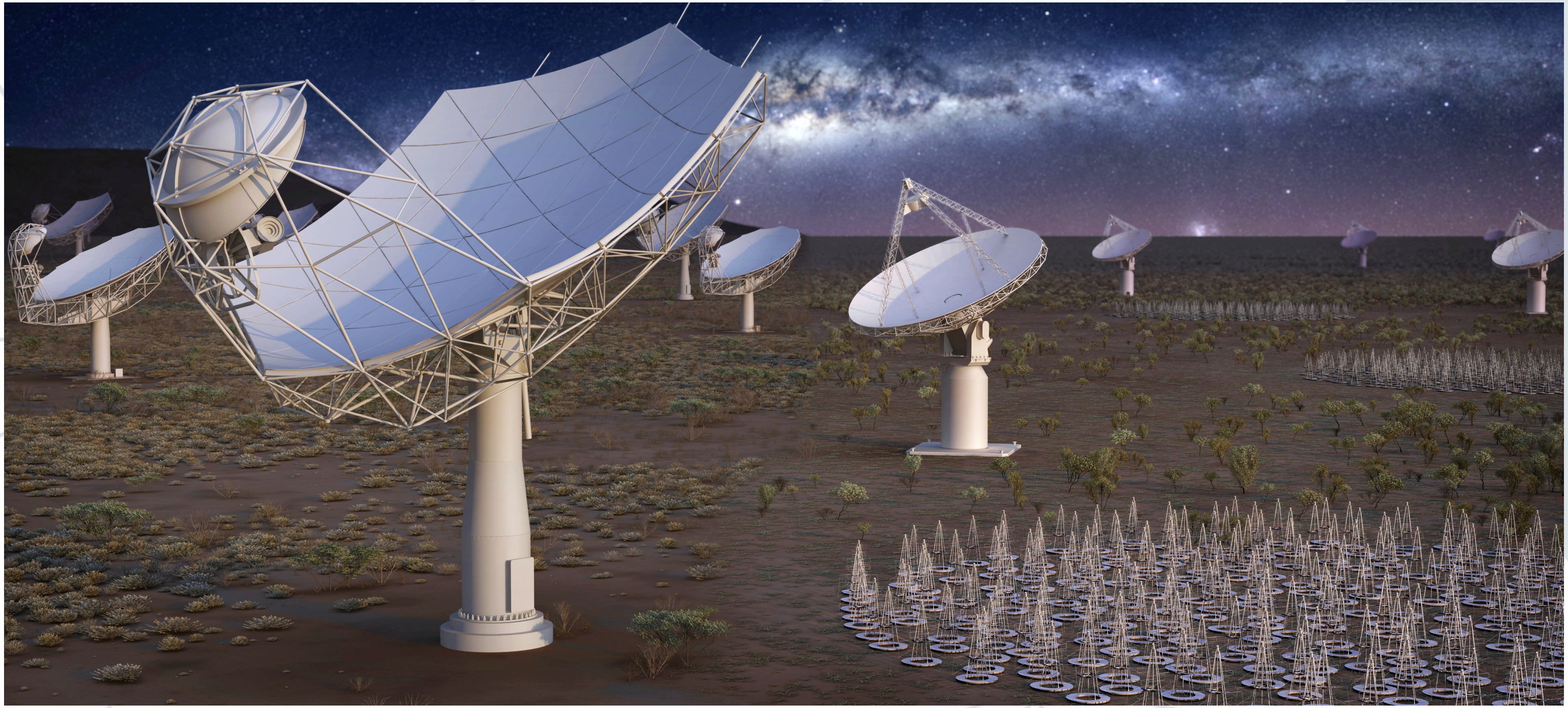


VLBI beams FoV:
4km: 178-25.5”
10km: 71-10”



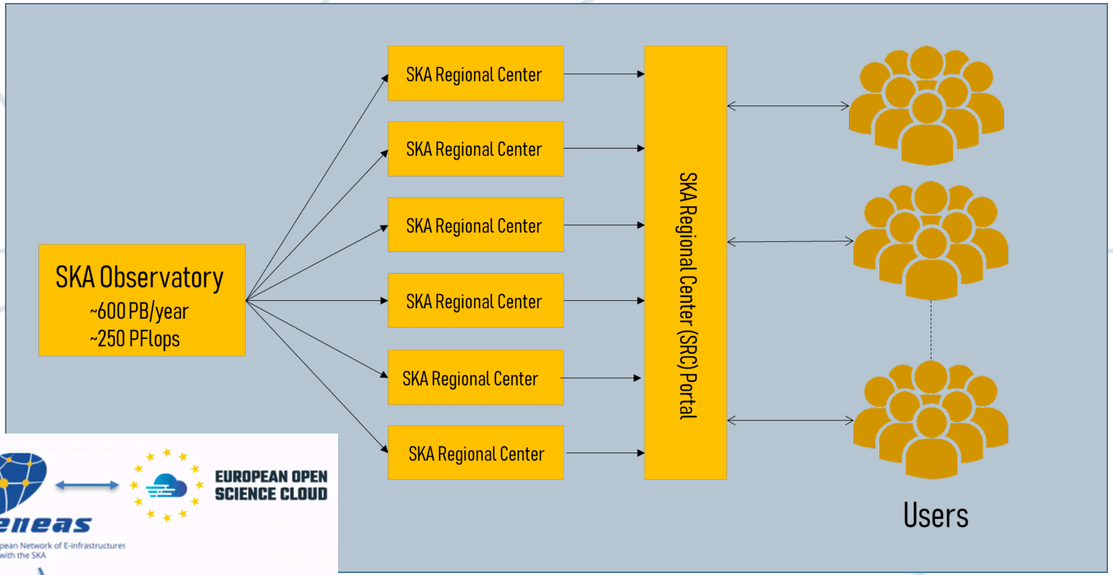


SKA1 Observatory model



SKA1 Observatory: a global research infrastructure

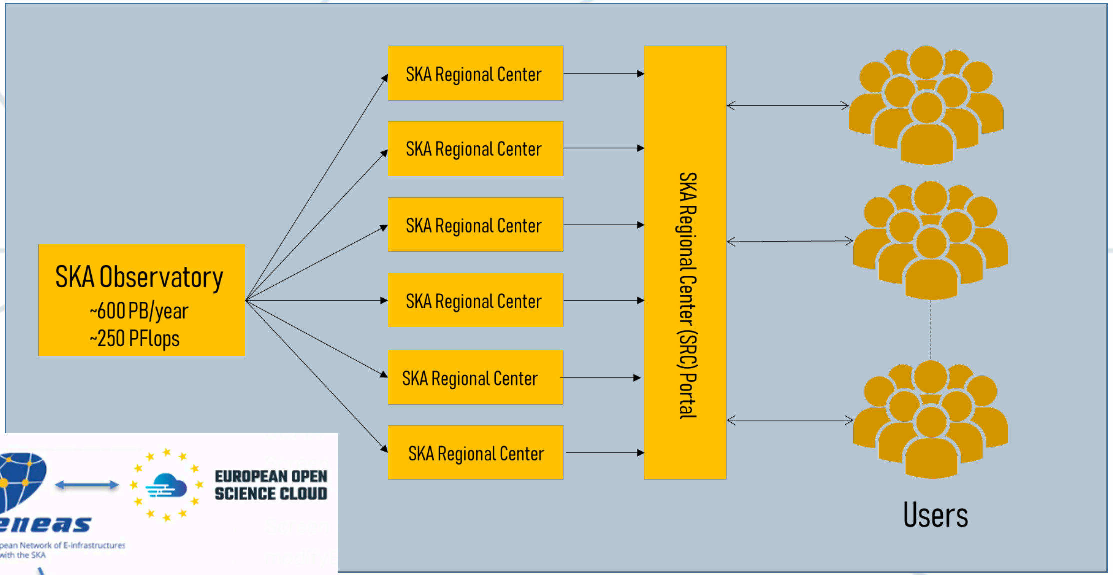
SKA Regional Centres tiered model



- SKA image cubes with ~TB size, ~2^{16} frequency channels → **SKA science-ready data products** (forget SKA visibilities!)
- Distributed network of **SKA Regional Centres**: subsets of SKA archive, processing and post-processing capability, distribution of data and user support, **open science model**
- **SKA Data Challenges:** build new culture on radio astronomy post-processing and analysis.

SKA1 Observatory: a global research infrastructure

SKA Regional Centres tiered model



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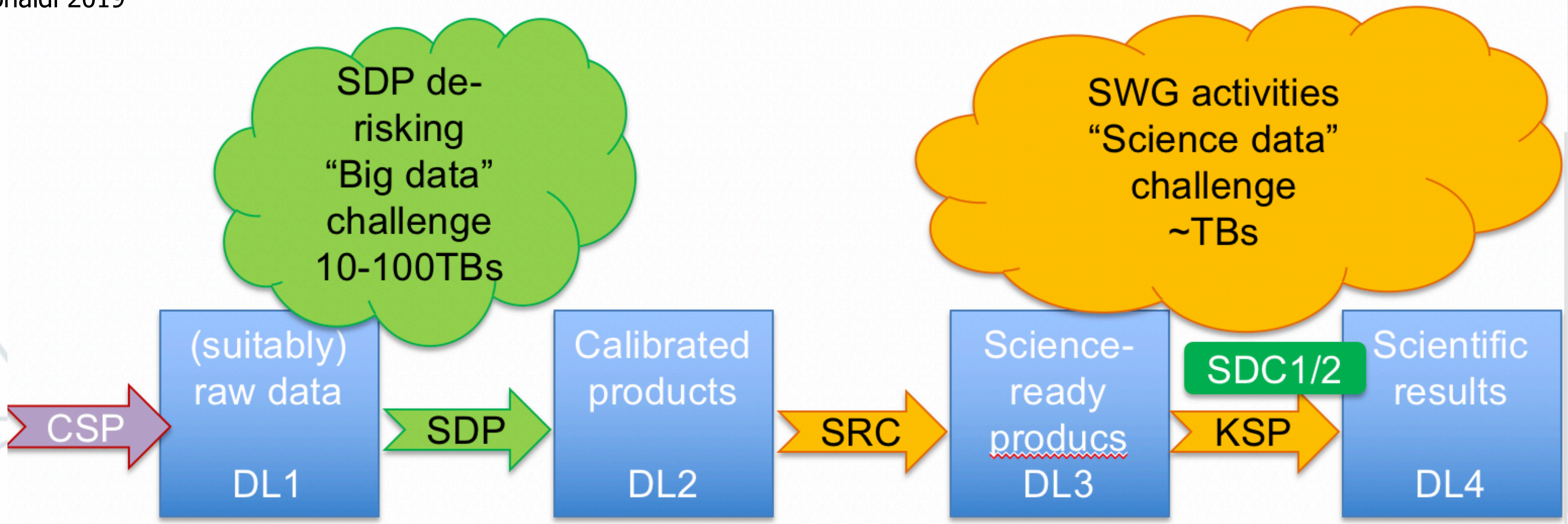
- **SKA Data Challenges:** build new culture on radio astronomy post-processing and analysis.

New culture into the VLBI world!

SKA1 Observatory: SKA data challenges

Credit: Bonaldi 2019



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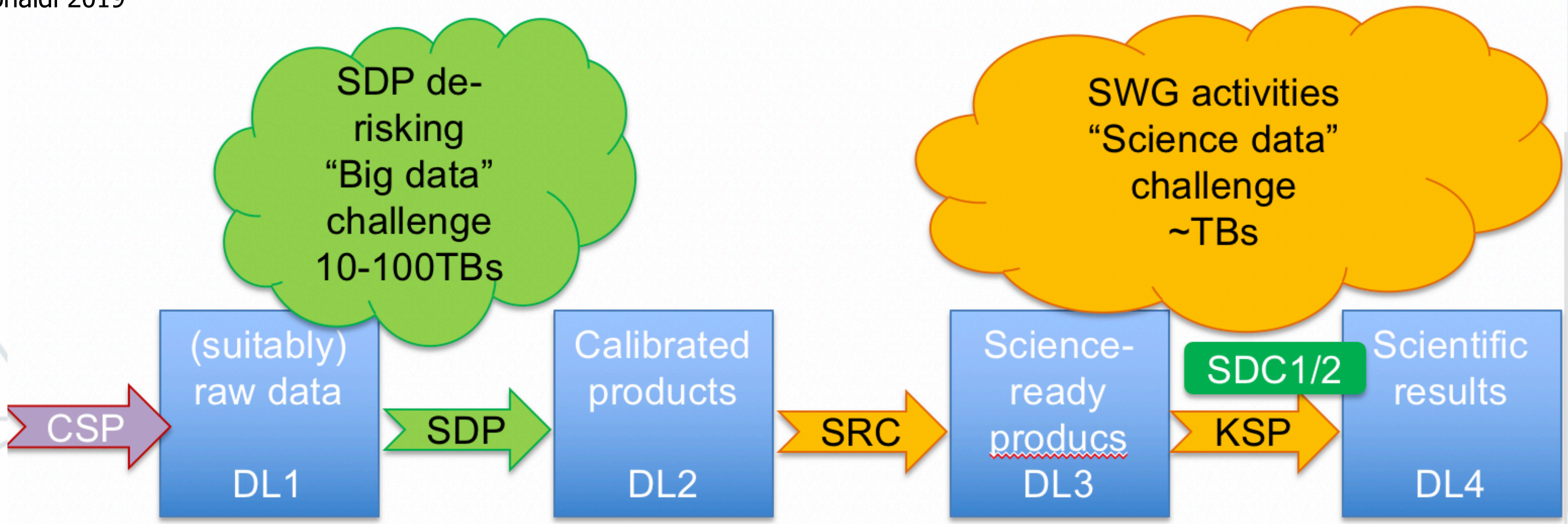
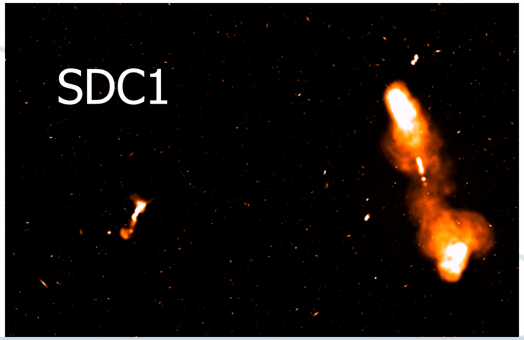


SKA Data Challenges:

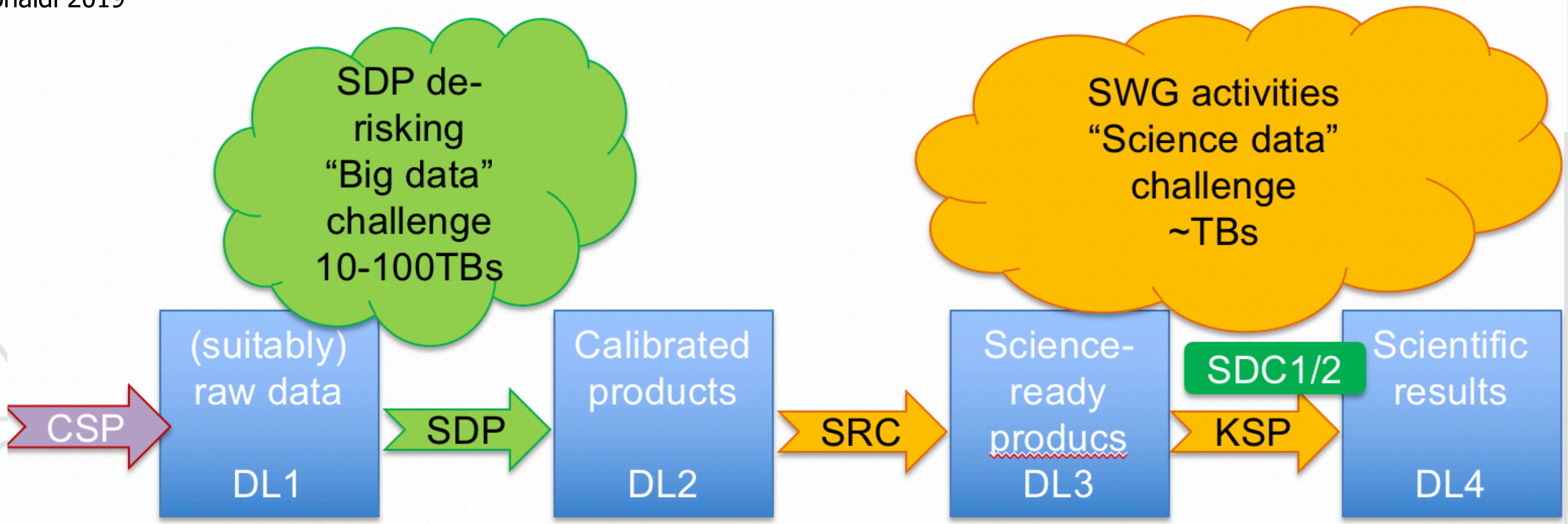
- Image plane, deconvolved with benign dirty beam, very deep confusion limited, large number of sources
- Efficient methods for source finding, characterisation and classification



10M sources, 32kx32k pixels and 4GB size, 3 frequencies (560 MHz, 1.4 GHz, 9.2 GHz) and 3 depths (8h, 100h, 1000h), 9 groups Bonaldi+ 2020

SKA1 Observatory: SKA data challenges

Credit: Bonaldi 2019



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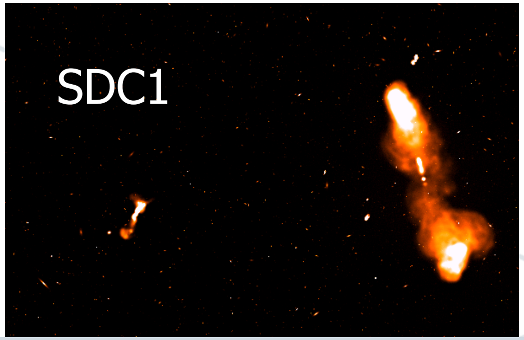

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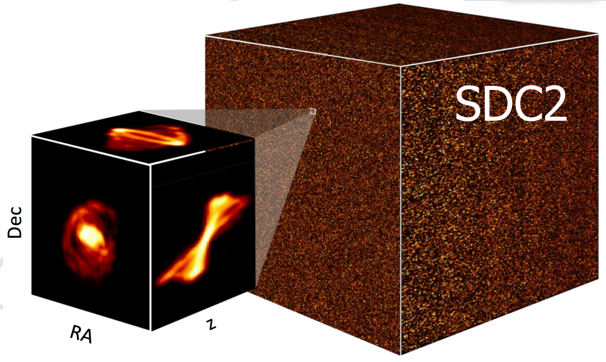
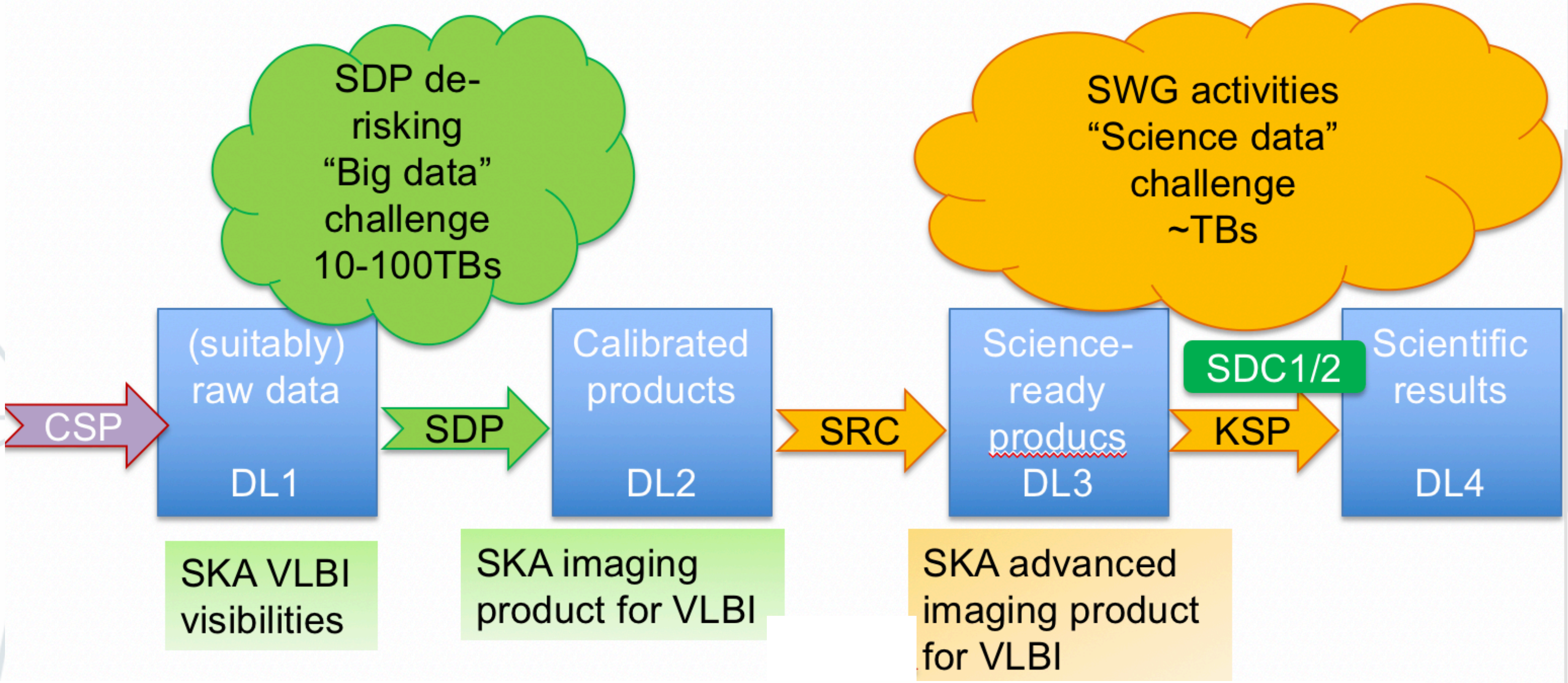
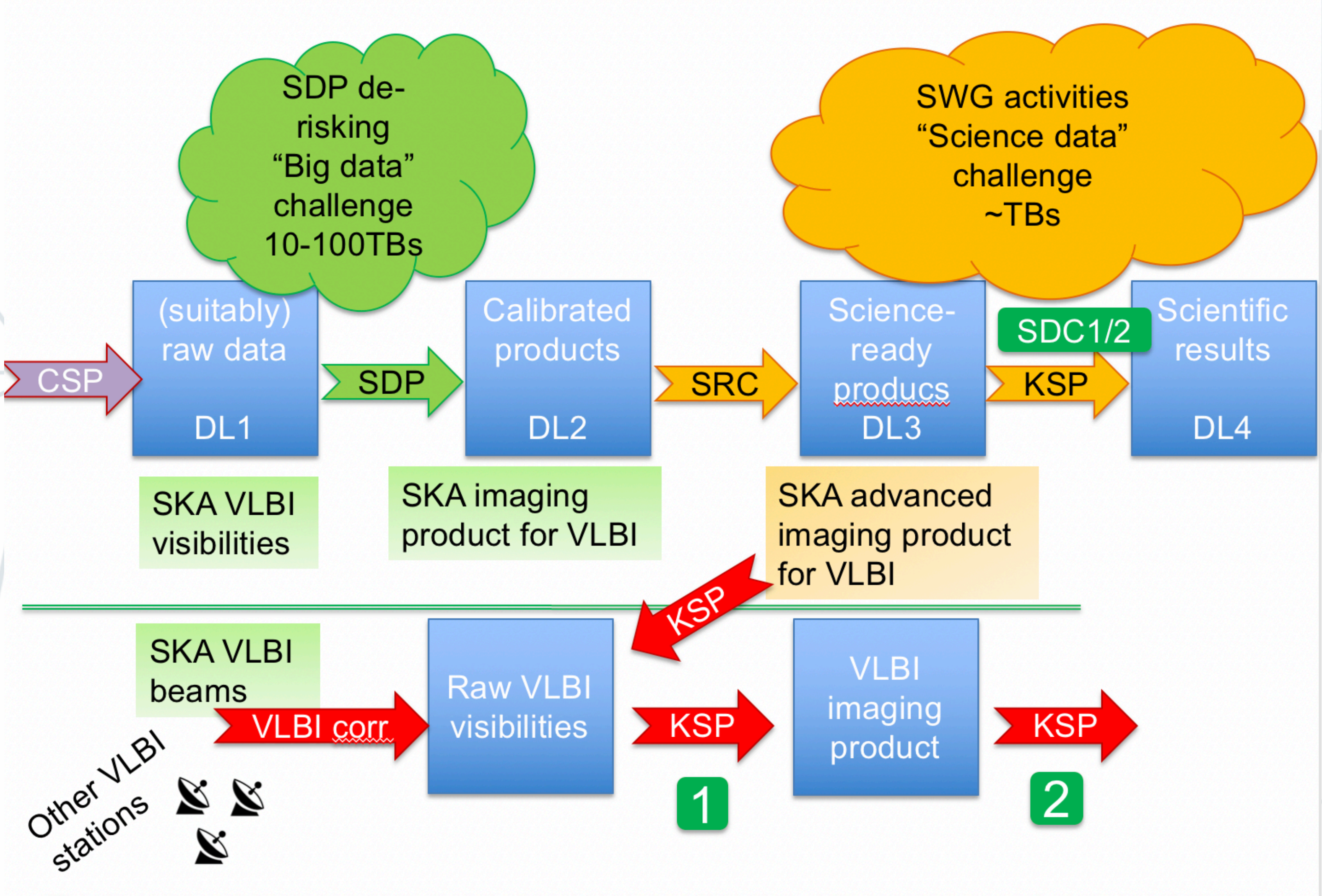


HI imaging product ~TB, 20 deg^2 FoV, z=0.24-0.5, 7 arcsec/30 kHz, 2000h simulated 10^6 HI galaxies + 10^7 continuum sources, about 30 teams with HPC facilities access

SKA1 Observatory: SKA data challenges for VLBI



SKA1 Observatory: SKA data challenges for VLBI



What SKA-VLBI can do for your science?

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What SKA-VLBI can do for your science?

SKA-VLBI Science Working Group

Chairs: Tao An & Cormac Reynolds

Previous chair: Zsolt Paragi

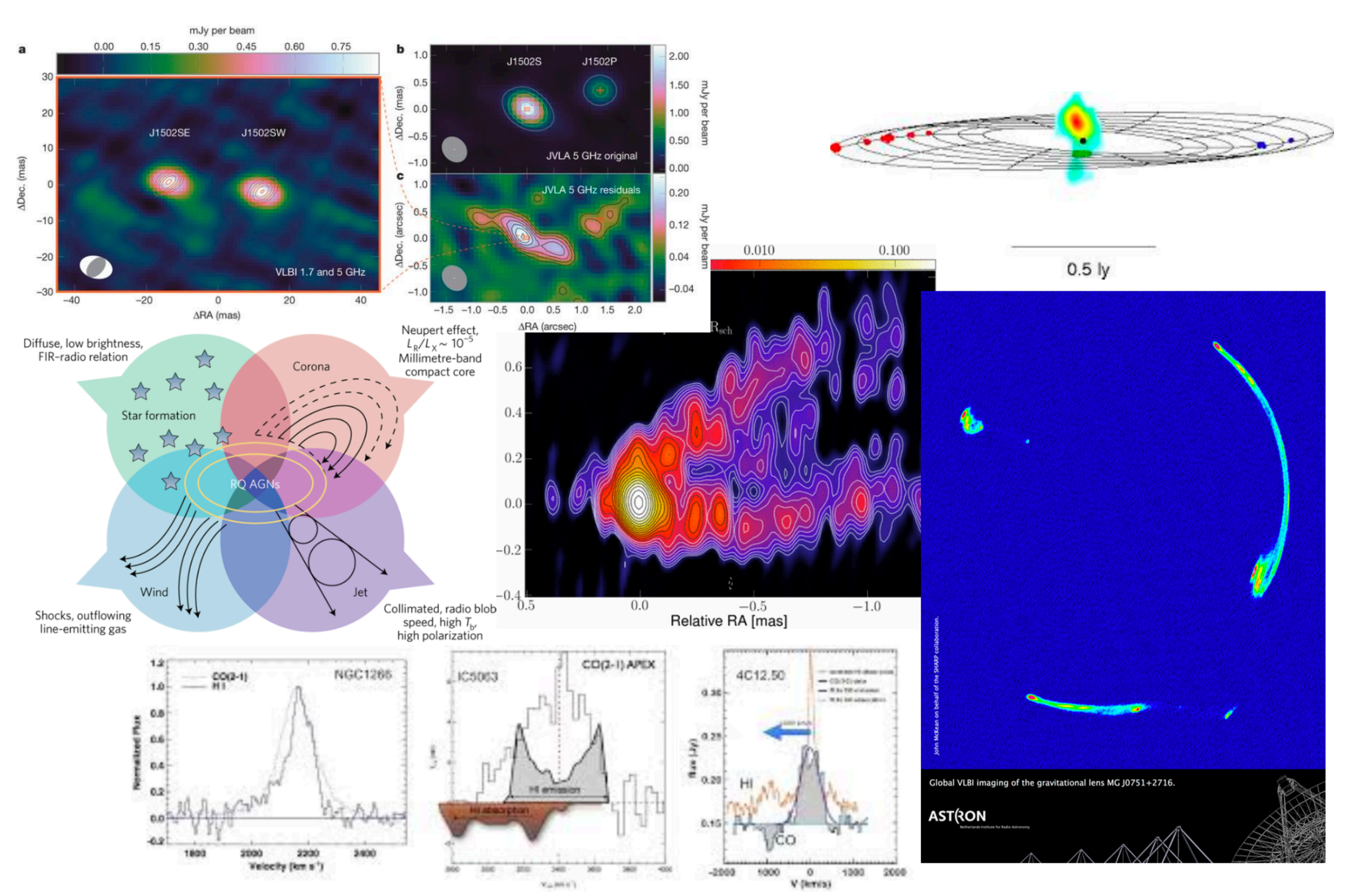
What SKA-VLBI can do for your science?

SKA-VLBI KEY SCIENCE PROJECTS WORKING GROUPS

- **Active Galactic Nuclei**
  - Leah Morabito (Durham U.)
  - John McKean (ASTRON/RuG)
- **Stars / Astrometry**
  - Maria Rioja (ICRAR-UWA/CSIRO; OAN)
  - Hiroshi Imai (Kagoshima U.)
- **Transients**
  - Manisha Caleb (U. Manchester)
  - Zsolt Paragi (JIVE)
- **Pulsars**
  - Dana Simard (U. Toronto)
  - Franz Kirsten (OSO)

What SKA-VLBI can do for your science?

GALAXIES and AGNs: Key Science Themes



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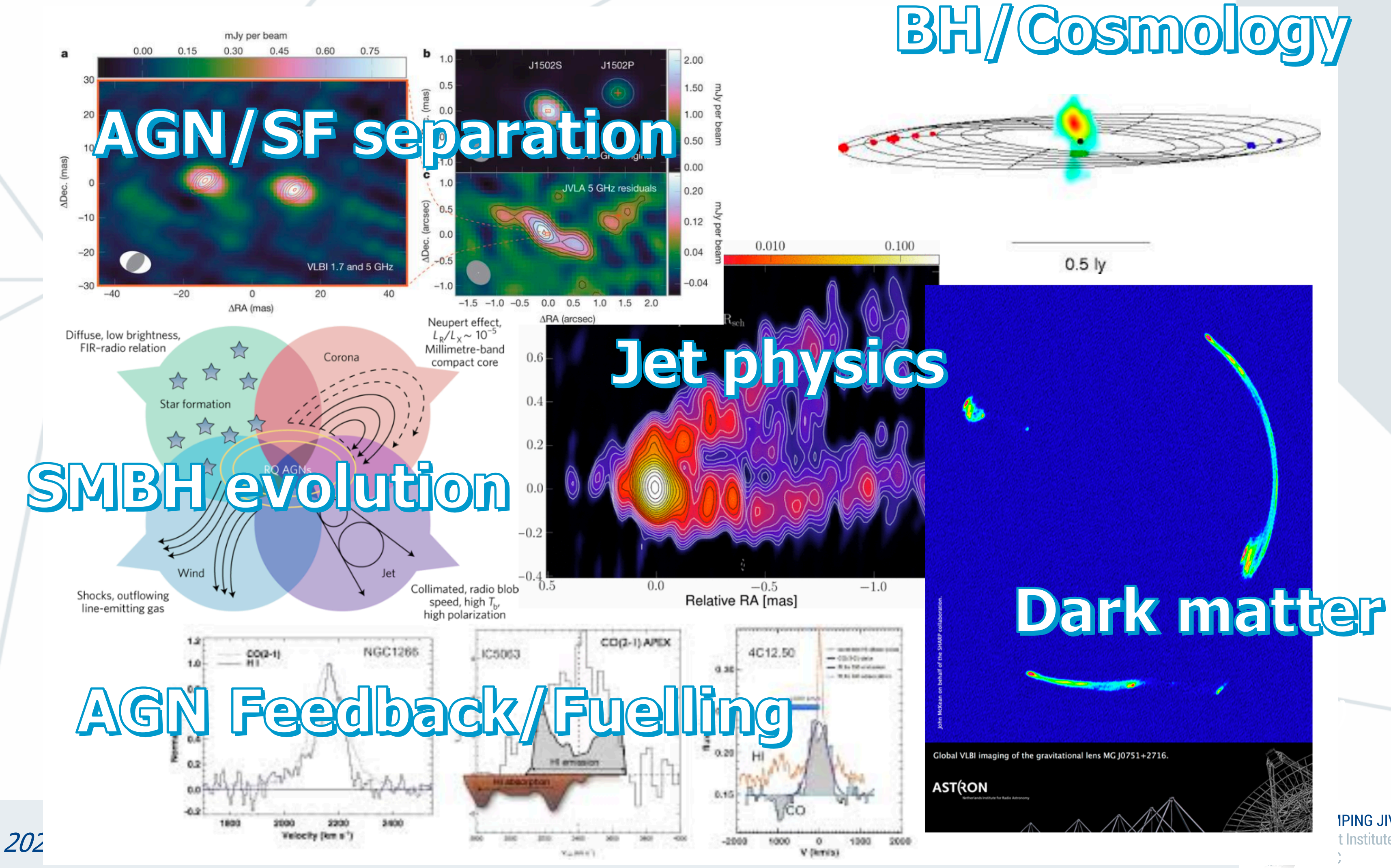
GALAXIES and AGNs: Key Science Themes

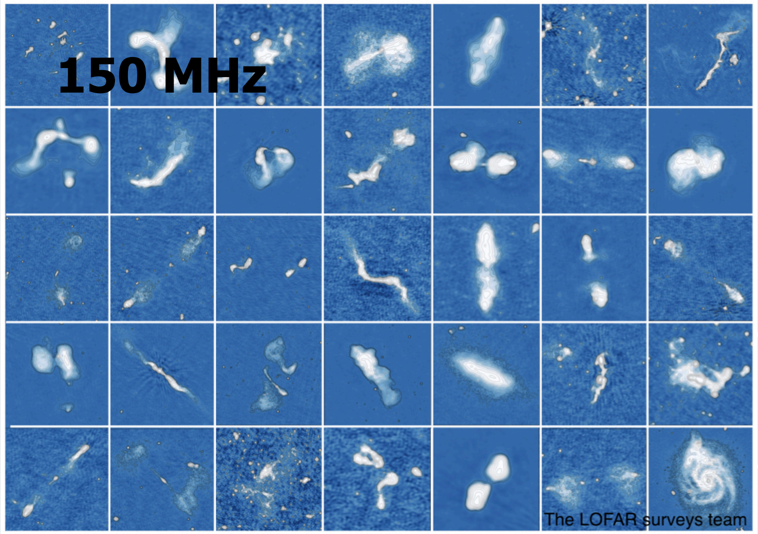


What SKA-VLBI can do for your science?

GALAXIES and AGNs

AGNs at lower frequencies
(MHz regime):

LoTSS - LOFAR Two-metre Sky Survey



Shimwell et al. 2019, Williams et al. 2019,
Duncan et al. 2019; Special volume A&A Feb 2019

SKA1-LOW - VLBI

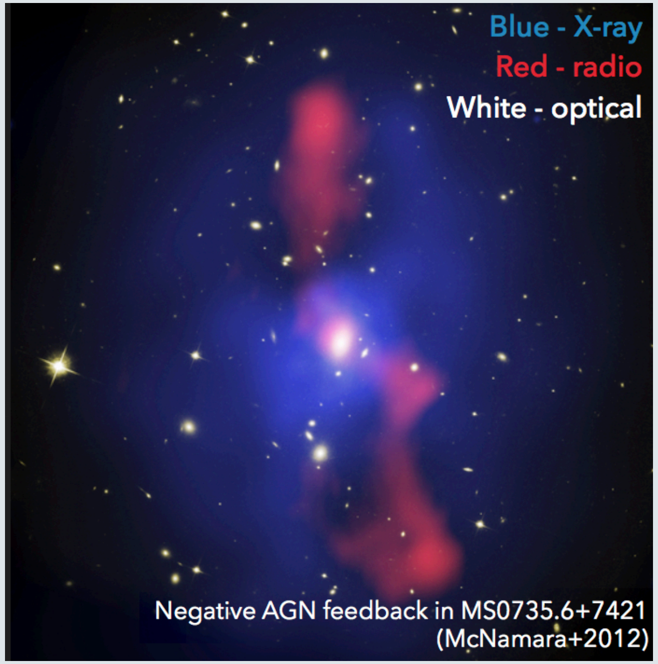
high resolution + sensitivity + low freqs

Unique probe for AGN science

- **AGN/SF** disentanglement
- **FRI vs. FRII** characterisation
- **Radio loud AGN:** physics of hot-spots (spectral modelling)
- **Radio quiet AGN:** origin of radio emission, core identification and small scale jets or winds, gravitationally lensed galaxies
- Build a sample of resolved **high-z AGN**

What SKA-VLBI can do for your science?

GALAXIES and AGNs



SKA1-MID - VLBI

high resolution + sensitivity + multiple beams

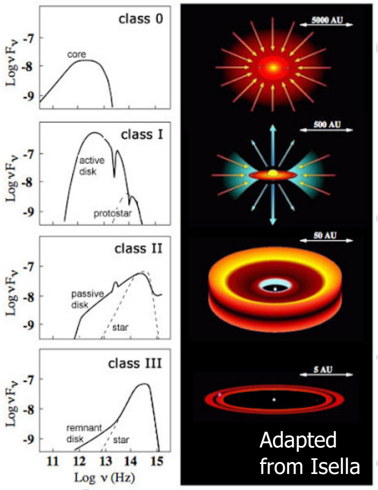
- How is the VLBI sky at < **µJy sensitivities**?
- **SKA deep-field surveys** with targeted SKA-VLBI beams to extract radio/AGN science commensally

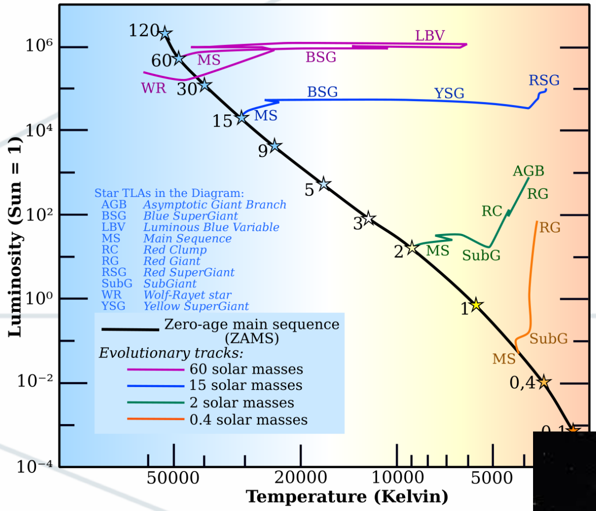
Plenty of science to exploit!

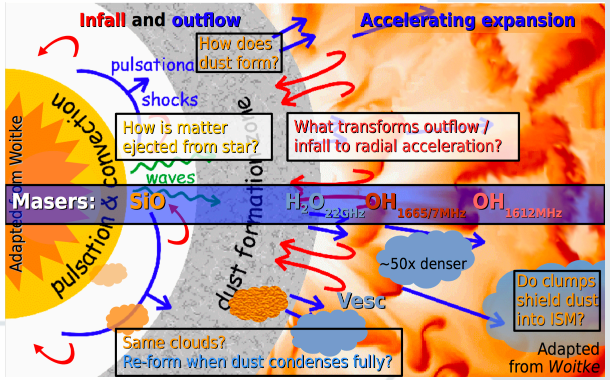
- Co-evolution → **Feedback** between SMBH and host galaxy
- Radio emission traces both **SF/AGN activity**
- The VLBI method detects the largest number of AGN: **VLBI wide-field surveys for AGN finder**
- **but also for:** SMBH binaries, gravitational lenses, radio SNe, LLAGN…

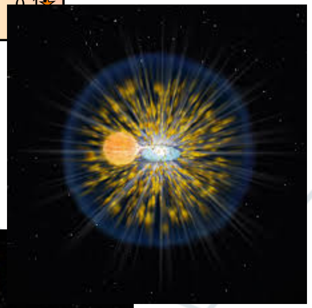
What SKA-VLBI can do for your science?

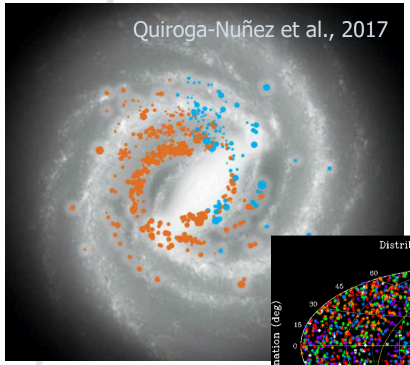
STARS/ Astrometry: Key Science Themes

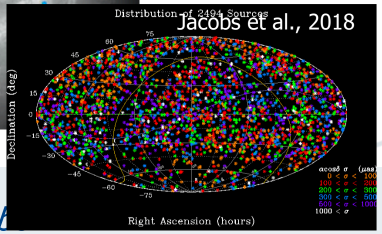


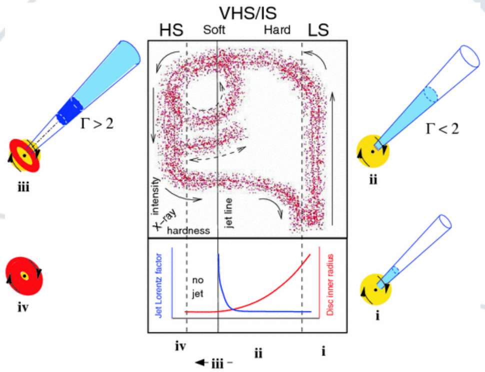








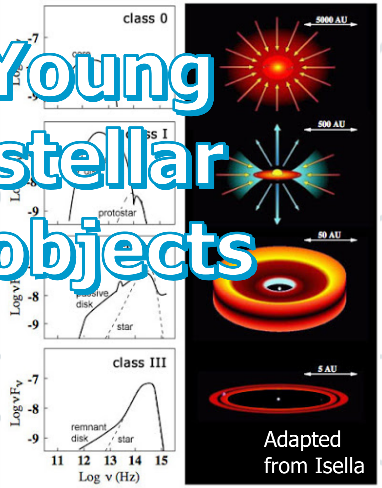




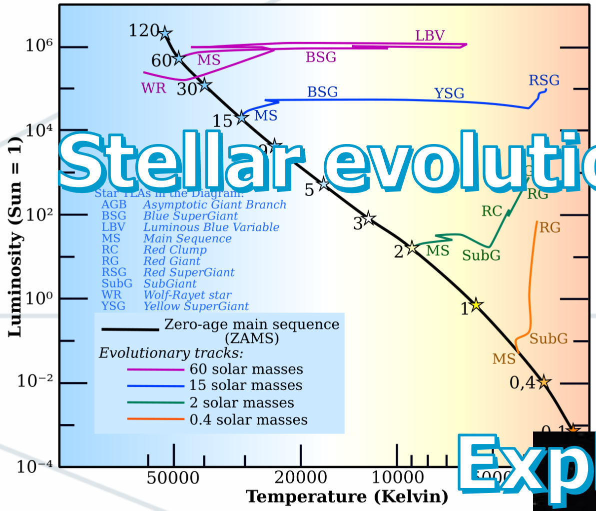
What SKA-VLBI can do for your science?

STARS/ Astrometry: Key Science Themes

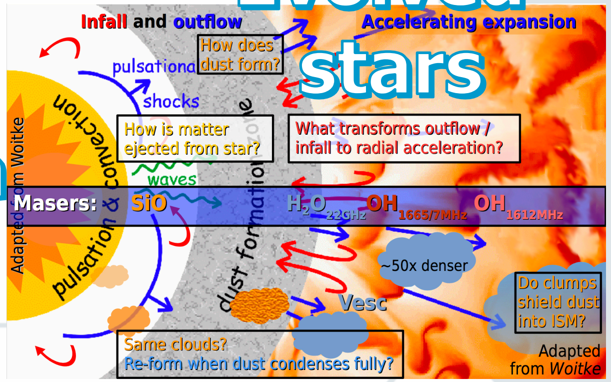
Young stellar objects



Stellar evolution

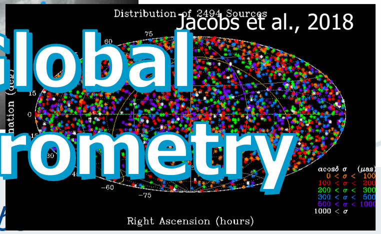


Evolved stars



Dynamics clusters/ local galaxies

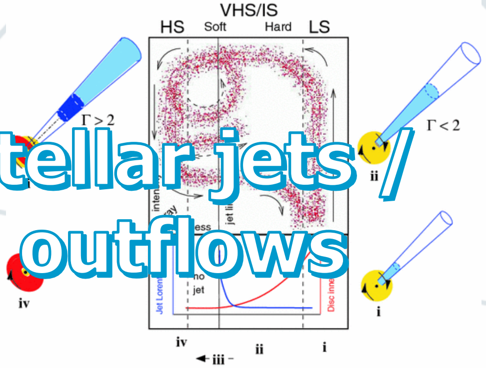
Global Astrometry



Explosions / novas

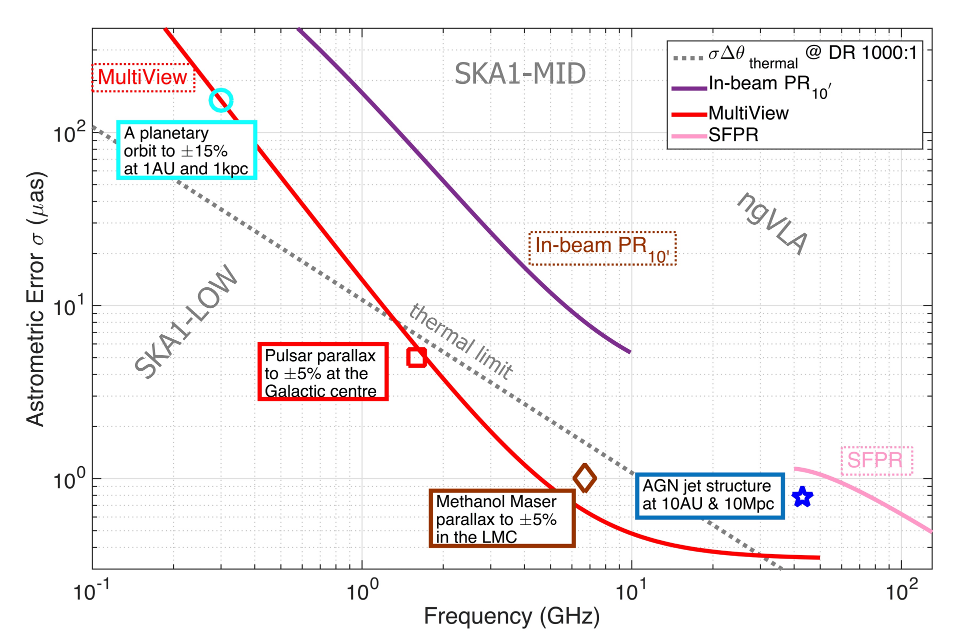
Flares / exoplanets

Stellar jets / outflows



What SKA-VLBI can do for your science?

STARS/ Astrometry



Rioja & Dodson, 2020

SKA-VLBI

Most powerful tool for astrometry (distances + proper motions + positions + multiple beams)

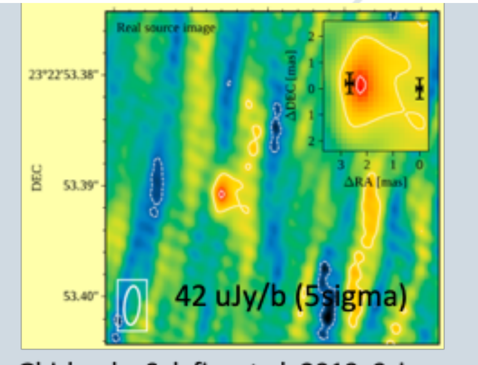
- **New phase calibration techniques: "MultiView"** (Rioja+ 2017)
  for >6GHz → 1μas

Ultimate astrometric accuracy + dramatic increase of # targets (large and complete surveys) → → new discoveries!

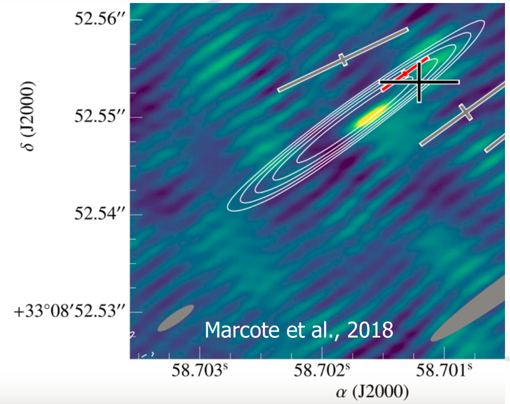
(exoplanets orbits, geometric parallaxes up to 100 kpc, pulsar parallaxes in the galactic centre, methanol masers parallaxes in LMC, AGN launching jets scales…)

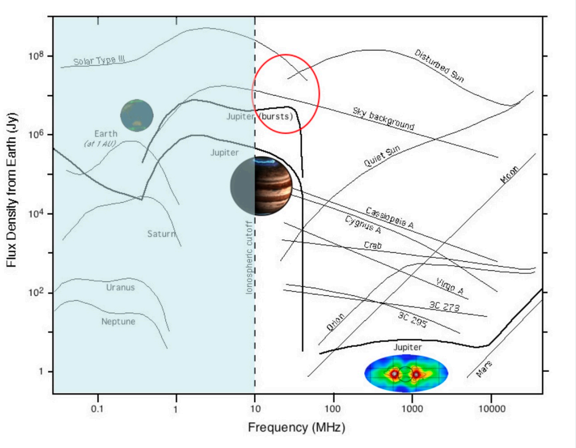
What SKA-VLBI can do for your science?

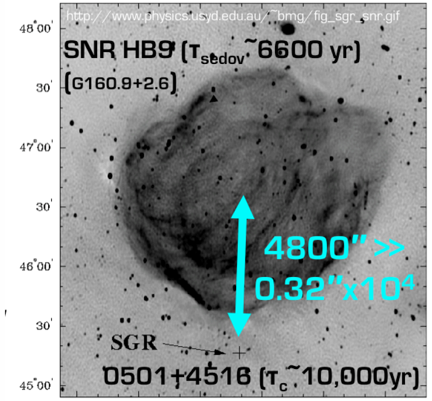
TRANSIENTS/PULSARS:
Key Science Themes



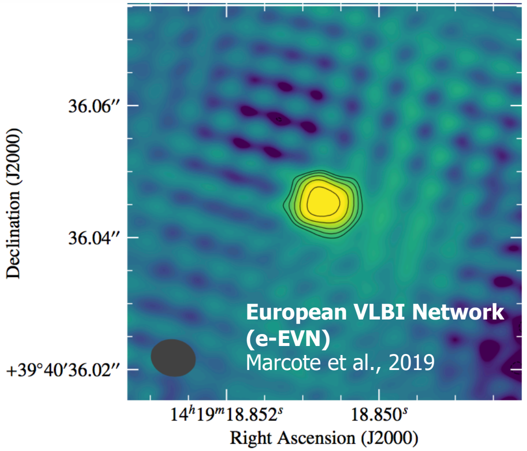
Ghirlanda, Salafia, et al. 2019, Science

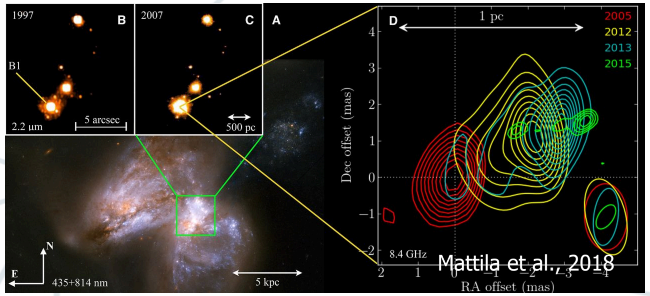






Chandra upper limit of 0.32"/yr may reject this progenitor (Mong & Ng 18, assuming D=5kpc)

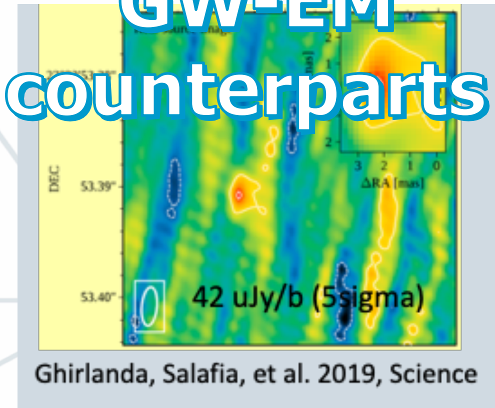




What SKA-VLBI can do for your science?

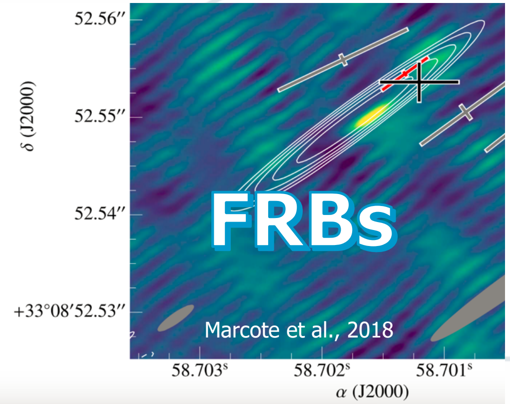
TRANSIENTS/PULSARS:
Key Science Themes

GW-EM counterparts



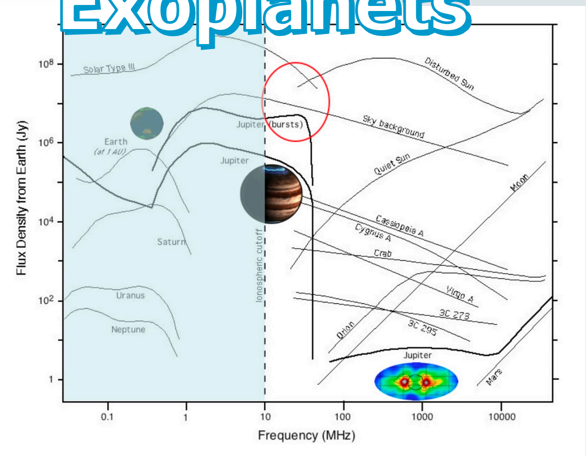
Ghirlanda, Salafia, et al. 2019, Science

FRBs

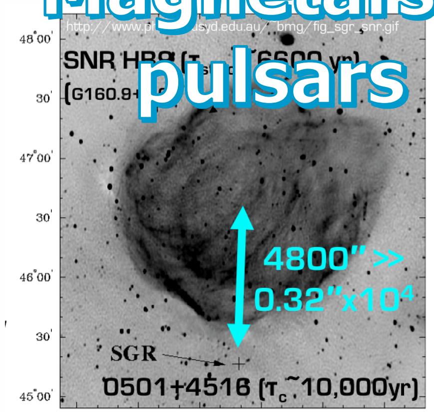


Marcote et al., 2018

Exoplanets

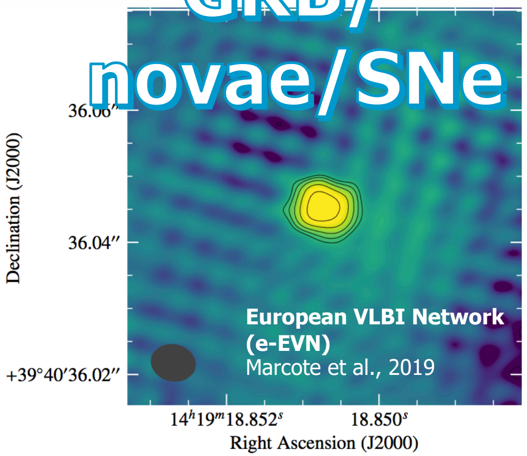


Magnetars/ pulsars



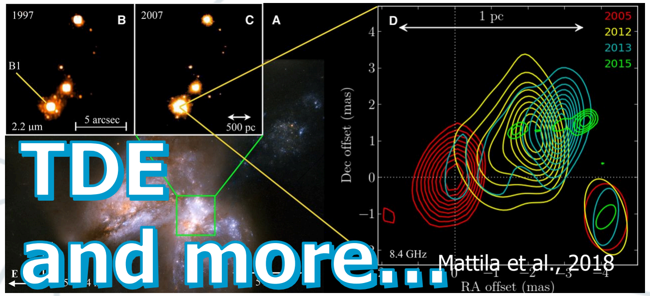
Chandra upper limit of 0.32″/yr may reject this progenitor (Mong & Ng 18, assuming D=5kpc)

GRB/ novae/SNe



European VLBI Network (e-EVN)
Marcote et al., 2019

TDE and more...

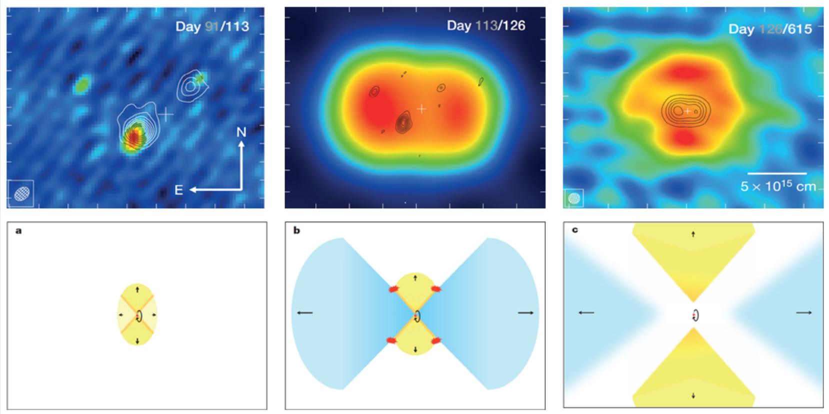


Mattila et al., 2018

What SKA-VLBI can do for your science?

TRANSIENTS/PULSARS

e-EVN, JVLA, VLBA, e-Merlin



Chomiuk et al., Nature, 514, 339, 2014

SKA-VLBI to measure very accurately:

Source expansion / apparent jet speed

proper motions /

distances (parallaxes)

- **Faint synchrotron radio transients in the local Universe** d $\leq$ 200Mpc (z ~ 0.05)
  Faint collimated ejecta can be resolved within weeks!
  proper motions in the ~1 μas regime
- **GW astronomy:** SKA-VLBI sensitivities and excellent calibration needed for resolving mildly relativistic outflows, long-term radio afterglows (BNS mergers, long-GRBs, etc.)
- **FRBs:** SKA-VLBI for progenitor environments and high-z localisations.
- **Exoplanets:** orbital motions will be detectable with SKA-VLBI.
- **Magnetars:** SKA-VLBI reaches the GC and covers a very large galactic volume for proper motion measurements.

The VLBI Future is ......

The VLBI Future is YOU

- A01550985 Iñaki Palestino Díaz
- Aaron Golden
- abiggs
- Agnieszka Kobak
- Akshatha Gopinath
- alejandro mus
- Agnieszka Kobak
- Ajith Sampath
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- alejandro mus
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- Roo

- sravani vaddi
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- Xi Yan
- yan sun

- Pratik Dabhade
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- Romana Grossova
- Roo

- Thalia Traianou
- Tuomas Savolainen
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- Willem
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- Willem
- Xi Yan
- yan sun
- Zhixuan
- Prahesti Husnindriani
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- Zsolt Paragi

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Future of VLBI

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