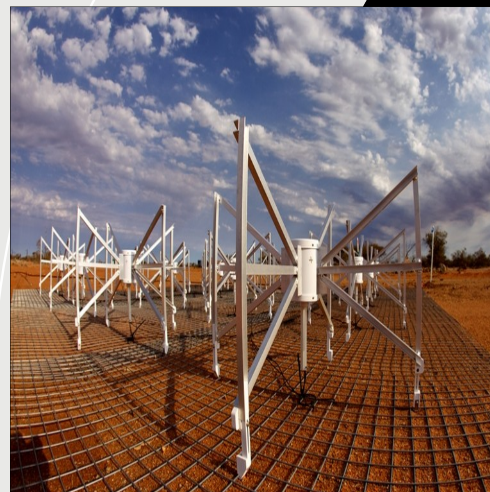
Modern Interferometers

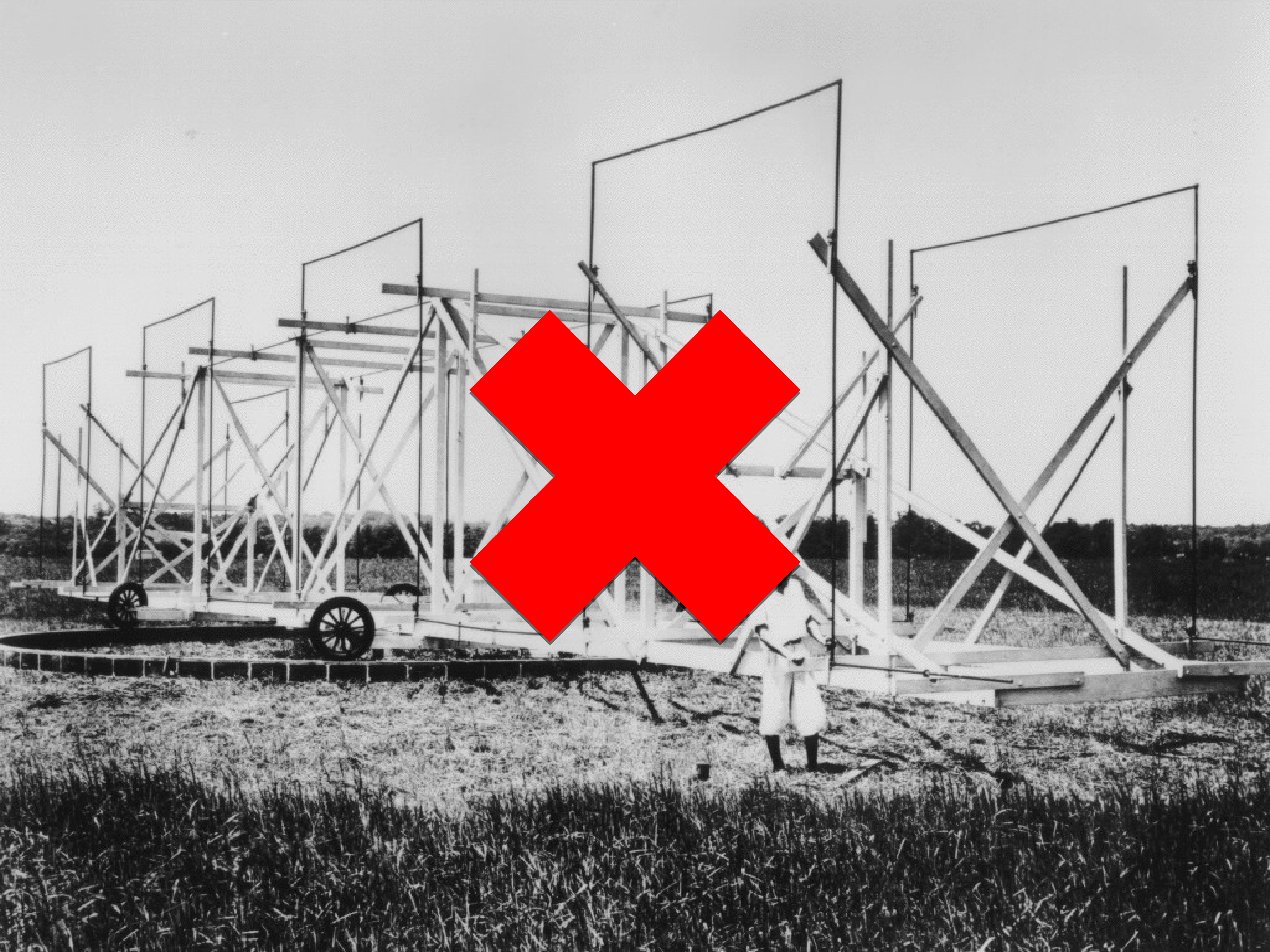


Joe Callingham

Kenyan Radio Astronomy School (Unit 4)
28th of May 2018

UNIVERSITY

Fantastic Interferometers and Where to Find Them



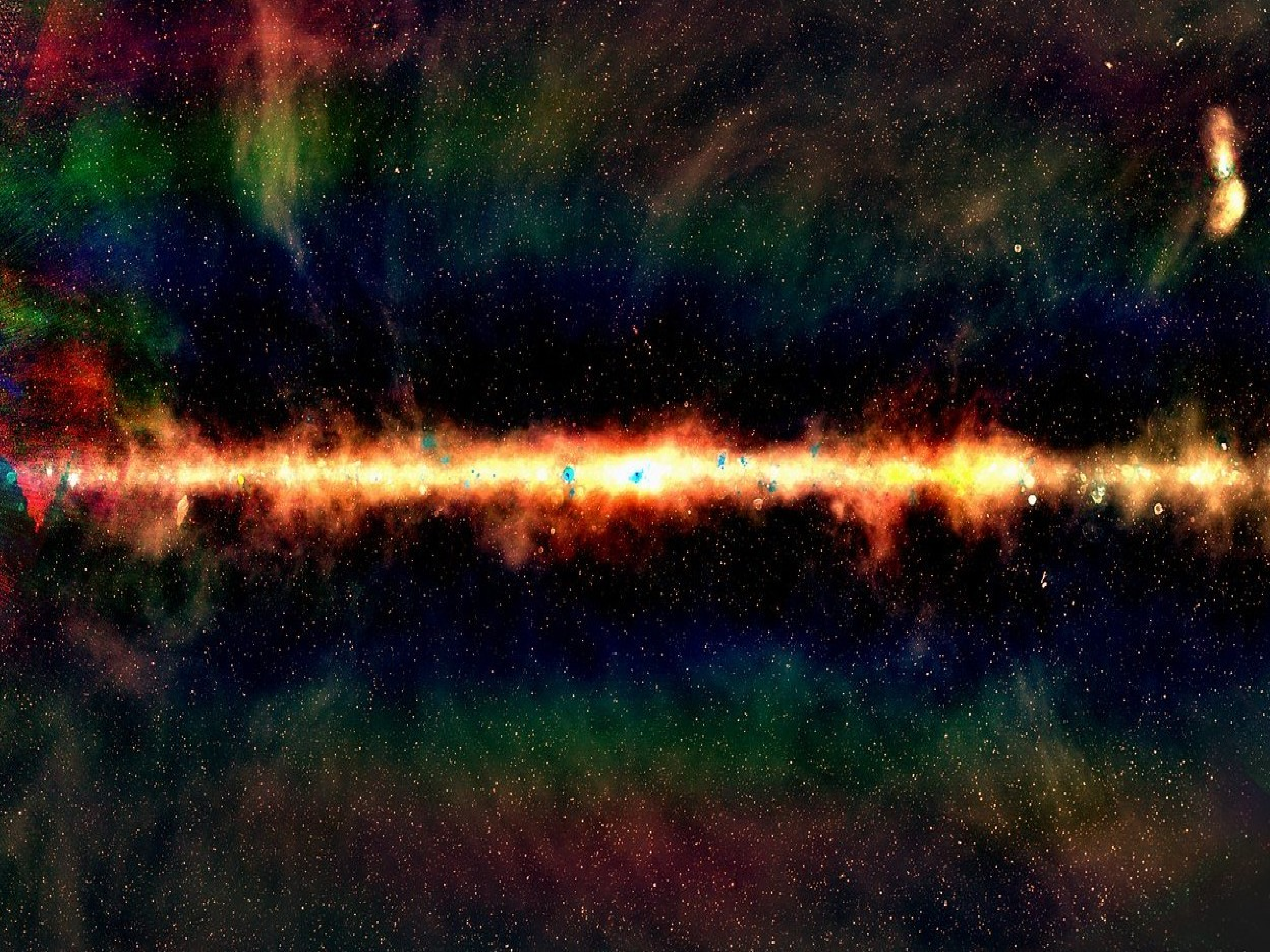

MAYBE JUST...
A LITTLE BIT...?
imgflip.com

What makes an interferometer "modern"?

› Advancements in information, dish, and antenna technology now allow:

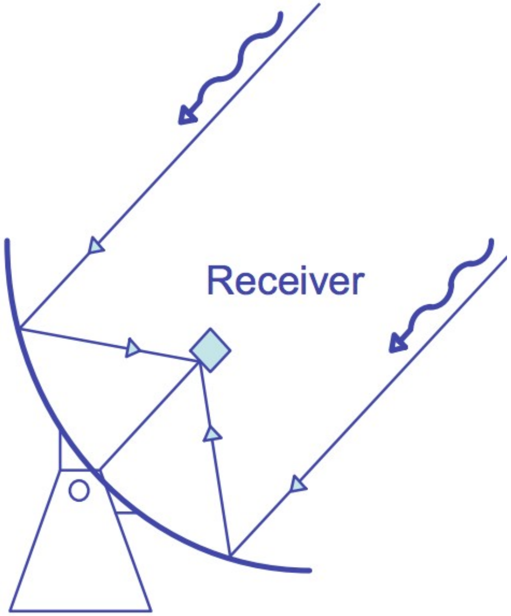
1. Aperture arrays (or phased-array feeds)
2. Highly accurate dish shapes for sub-mm observing
3. Complex and high-computing power backends

› Advancements in signal processing now allow much wider bandpasses (e.g. ATCA went from a bandwidth of 128 MHz to 2 GHz, JVLA now at 4 GHz).



Single Pixel Feed

- Only sampling a single pixel of the focal plane with all radiation focused onto single receiving element.
- Old technology that has been tried and tested on the JVLA, ATCA, etc



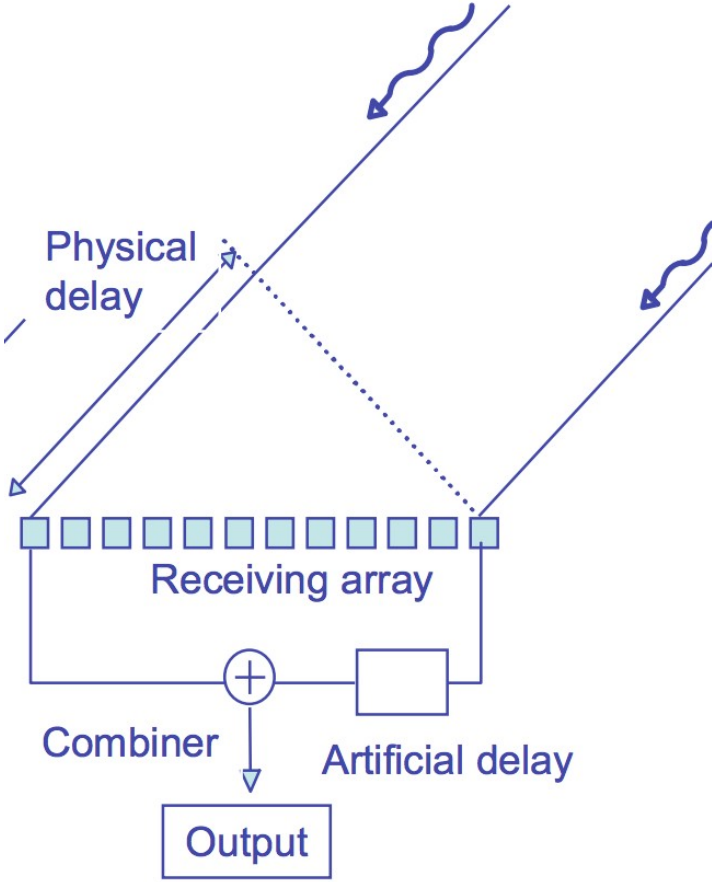
Parabolic reflector
(mechanical)

Aperture Array

- Why have a dish at all?
- Sample the whole wavefront by introducing electronic delays
- Number of elements *n* needed to sample an aperture area *A*?

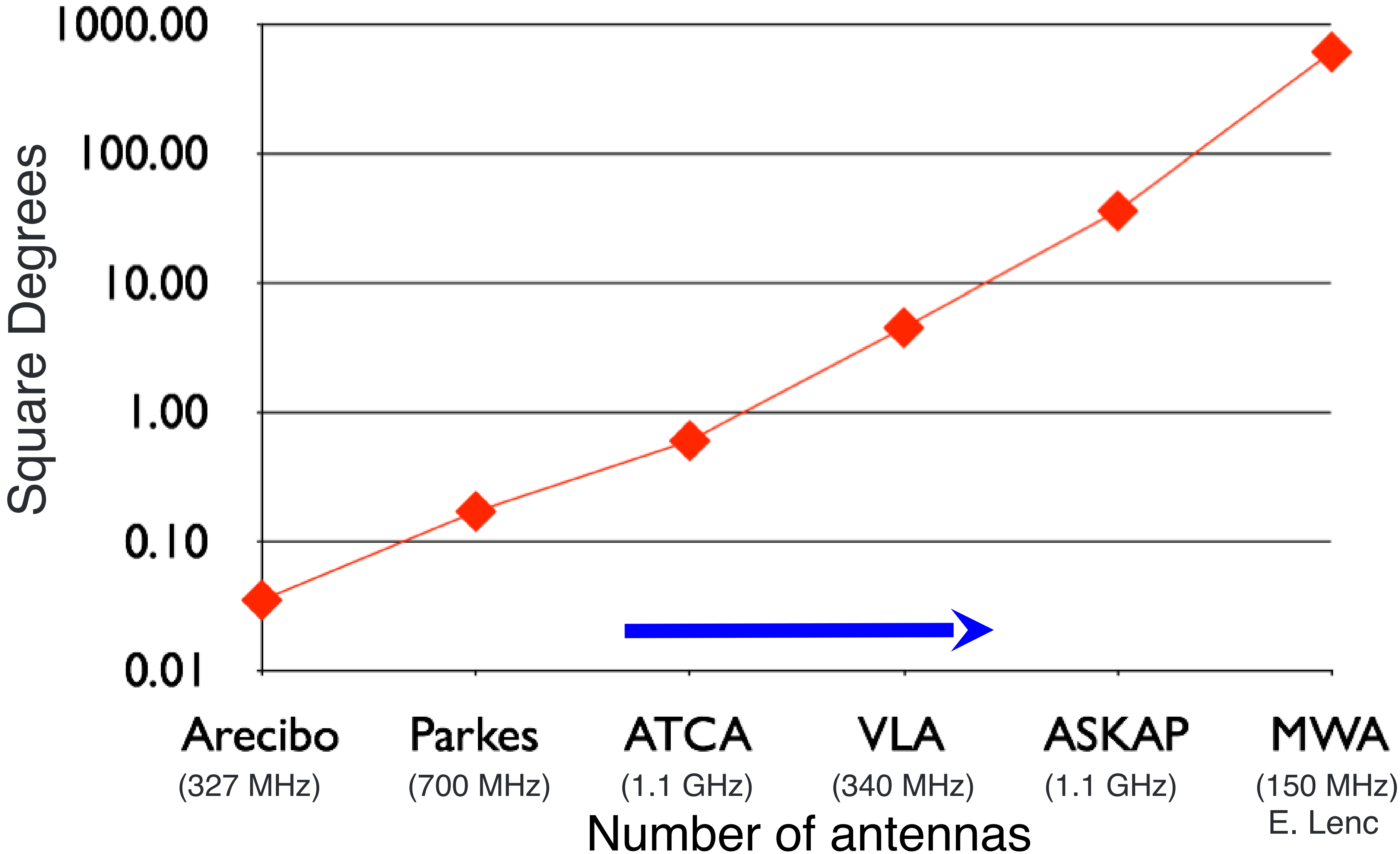
$$n \propto A / (\lambda/2)^2$$

- So for a 100m aperture and λ ~ 20cm, $n = 10^4$! Electronics cost too high for a long time.

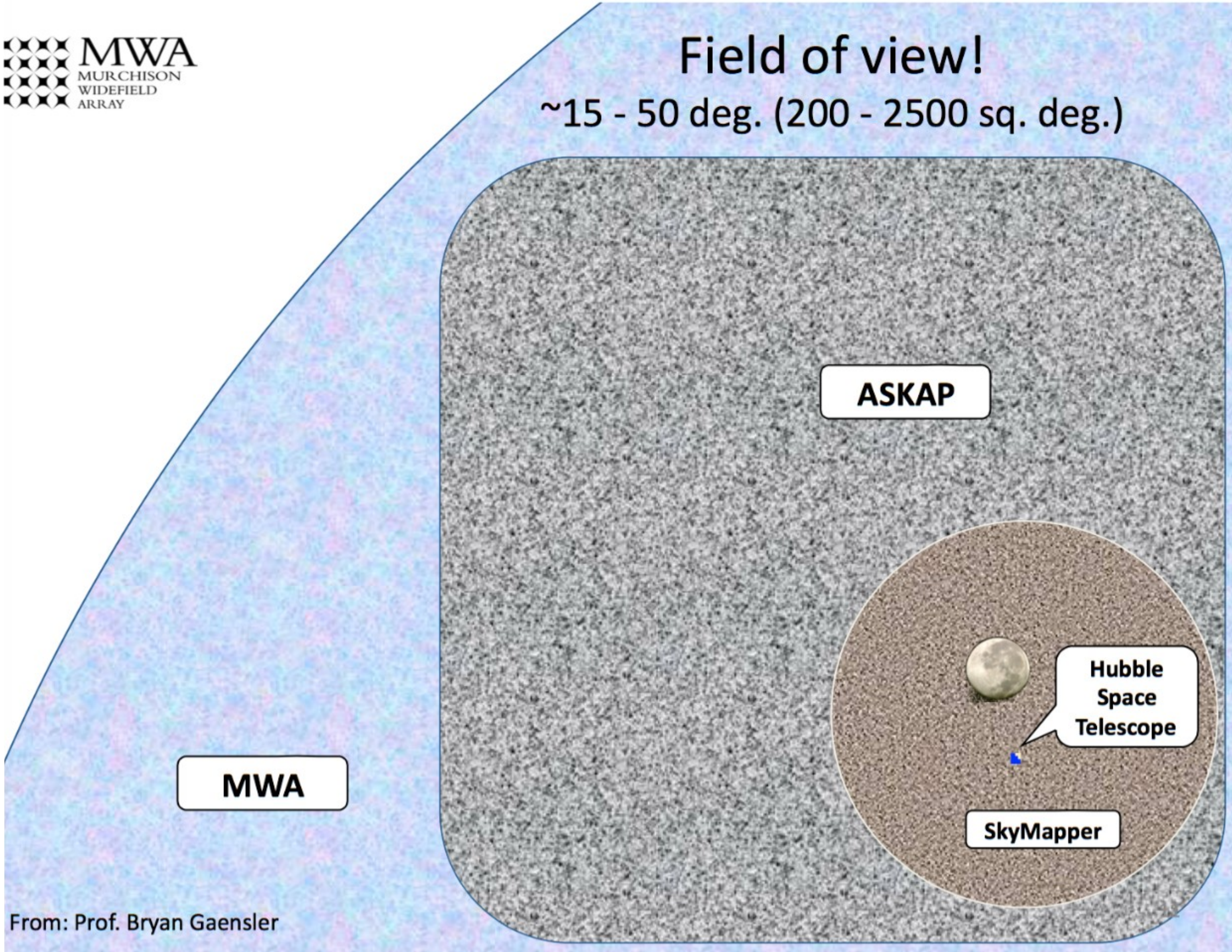


Aperture Array (electronic)

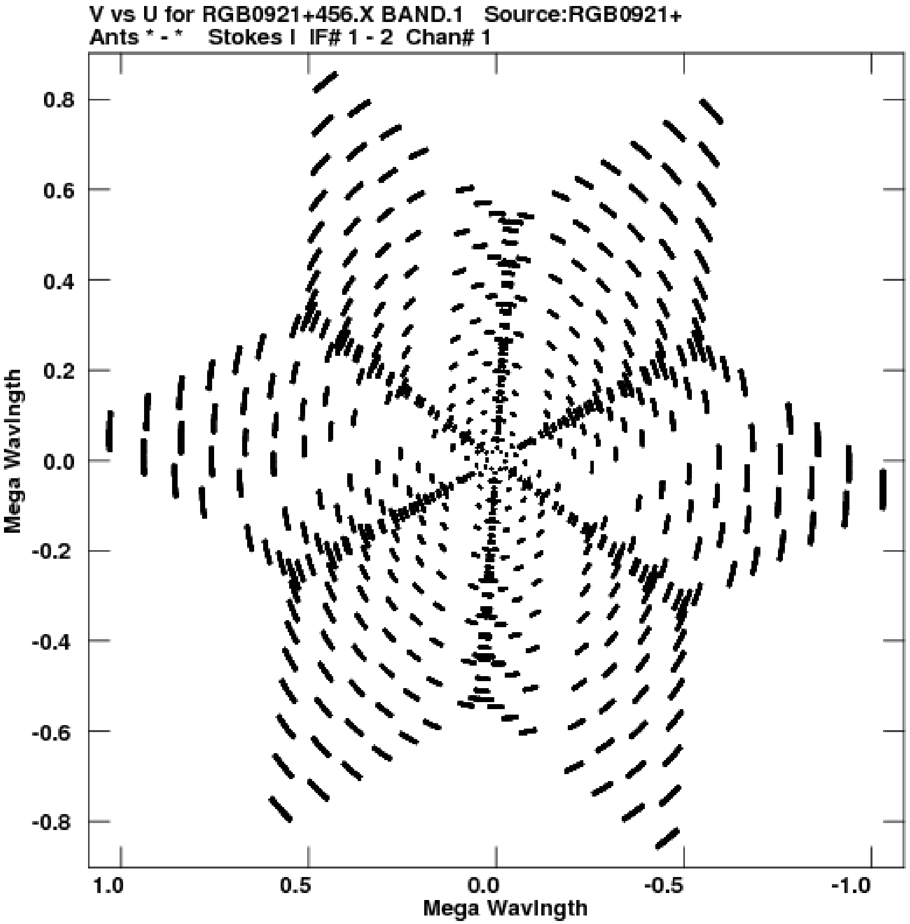
Eye on the Sky

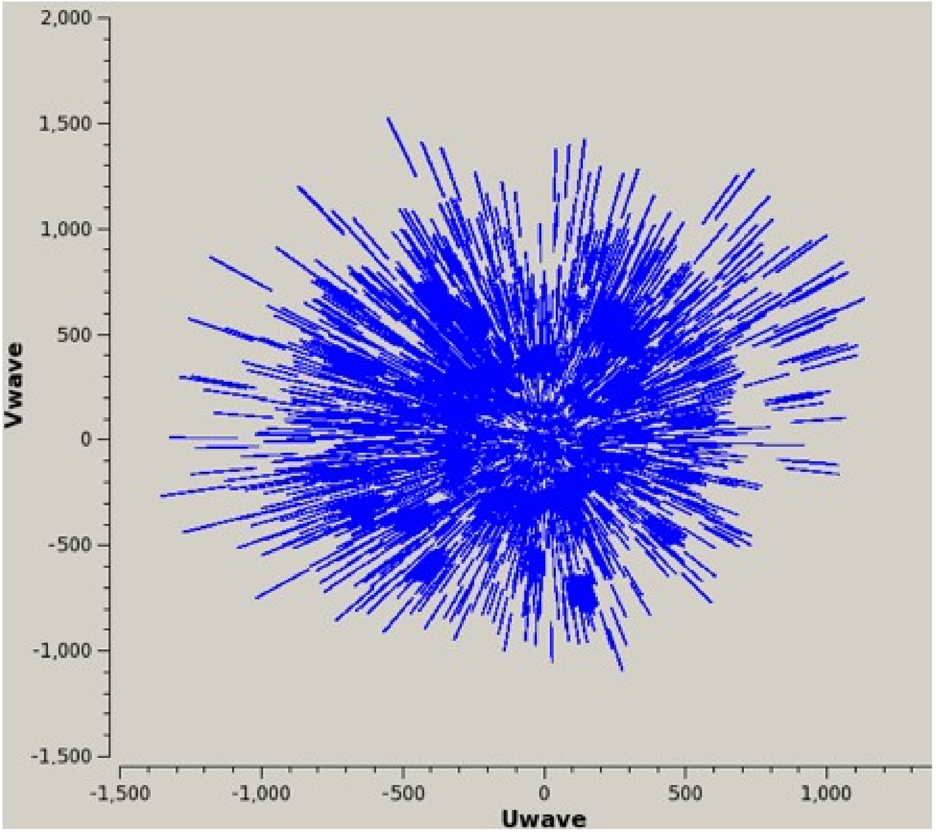


One eye to see them all



Amazing uv-coverage





VLA

MWA

Wish you had a dish?

Aperture Arrays

- Low cost.
- Variable collecti
- Large field-of-view.
- Used at low-frequencies.
- Non-uniform directional response.
- Poorly understood beam pattern.

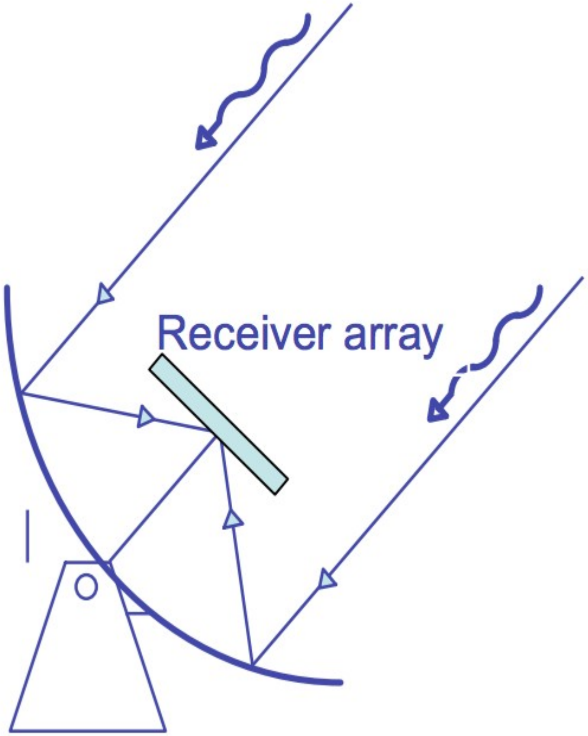
Dishes

- ng area ($\sim A_{geo}$).
- Small field-of-view.
- Used at high-frequencies.
- Uniform directional response.
- Well understood beam pattern.

John McKean

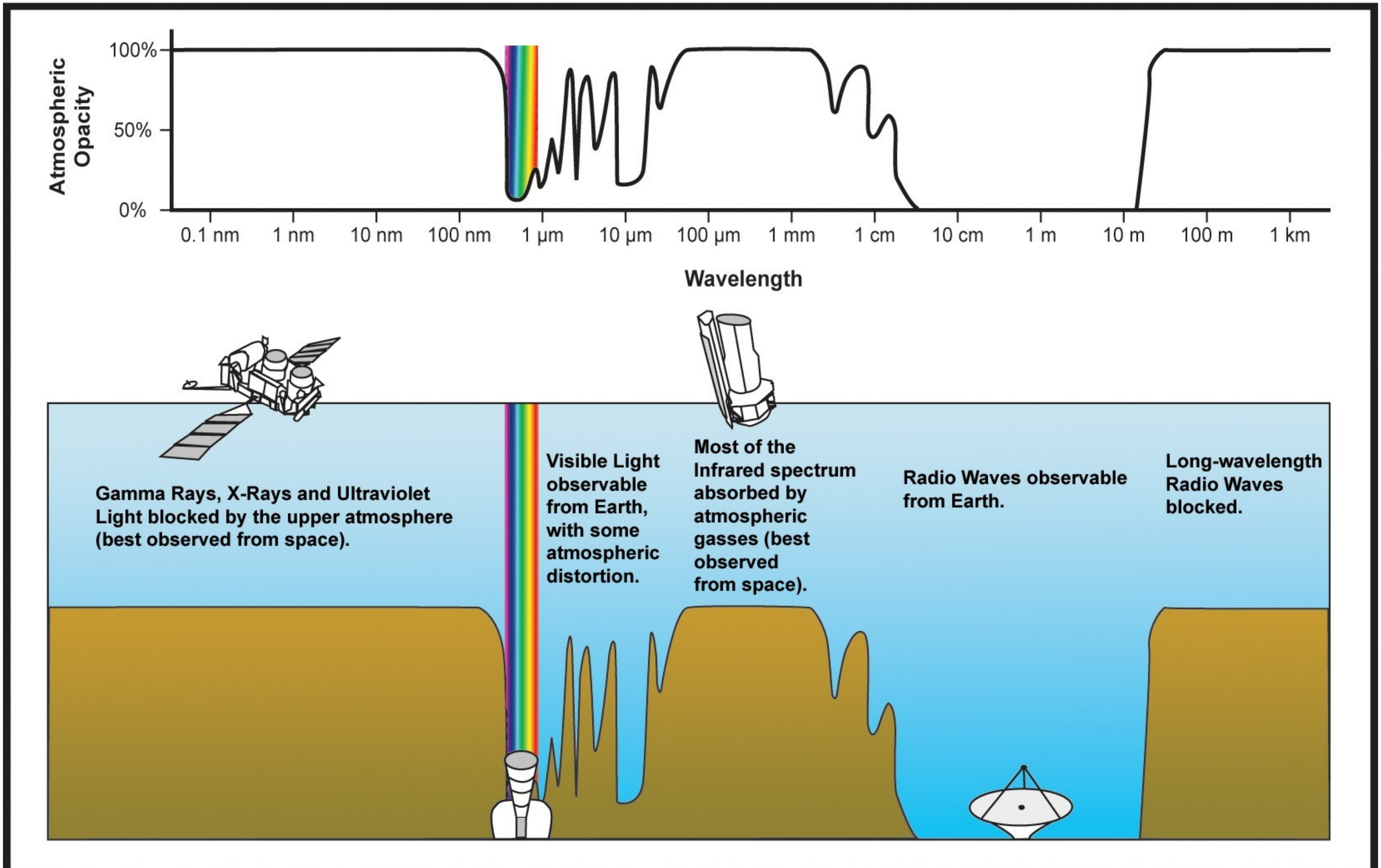
Phased Array Feed (PAF)

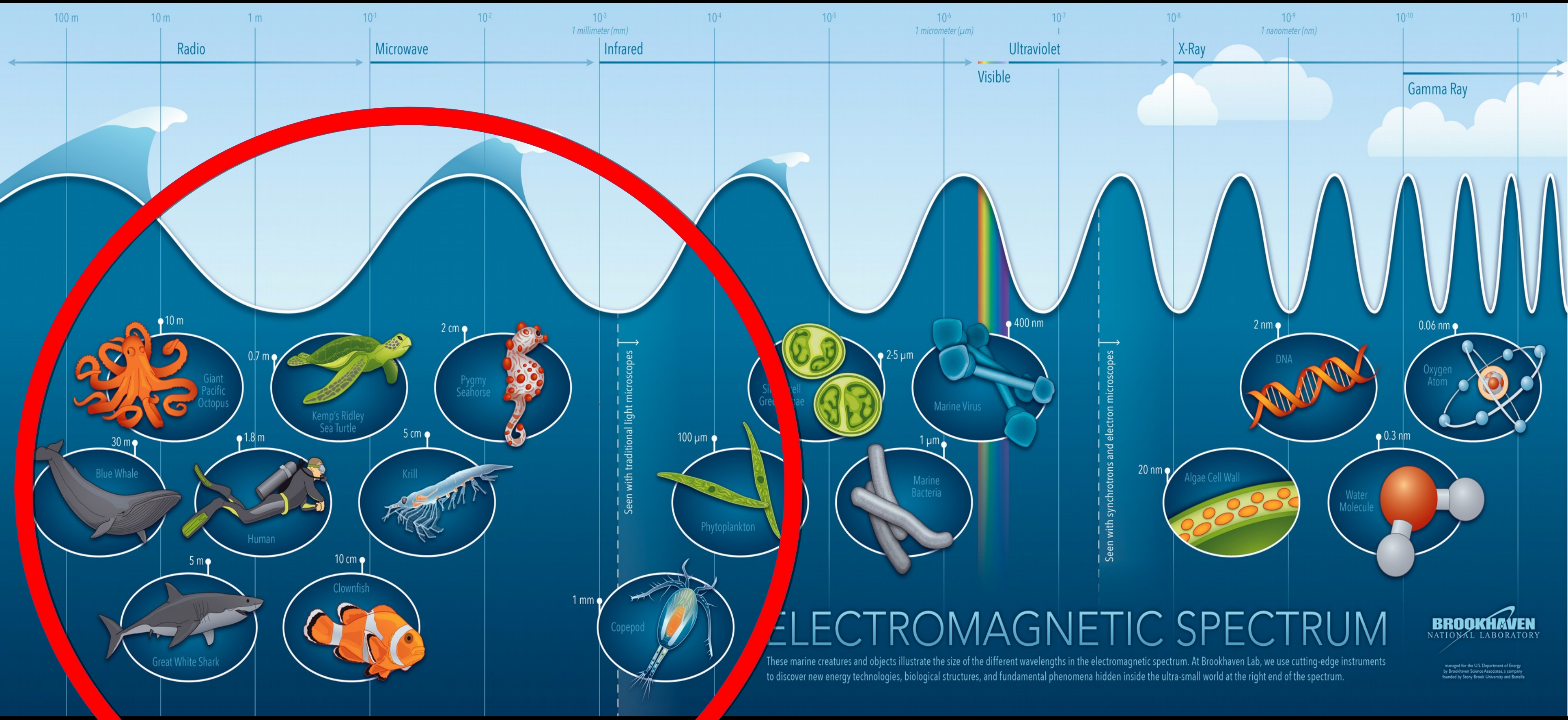
- Put an aperture array at the focal point, able to fully sample
- Ability to beam form, such as changing the beam pattern and beam weight
- Increase FoV, great for high survey speed



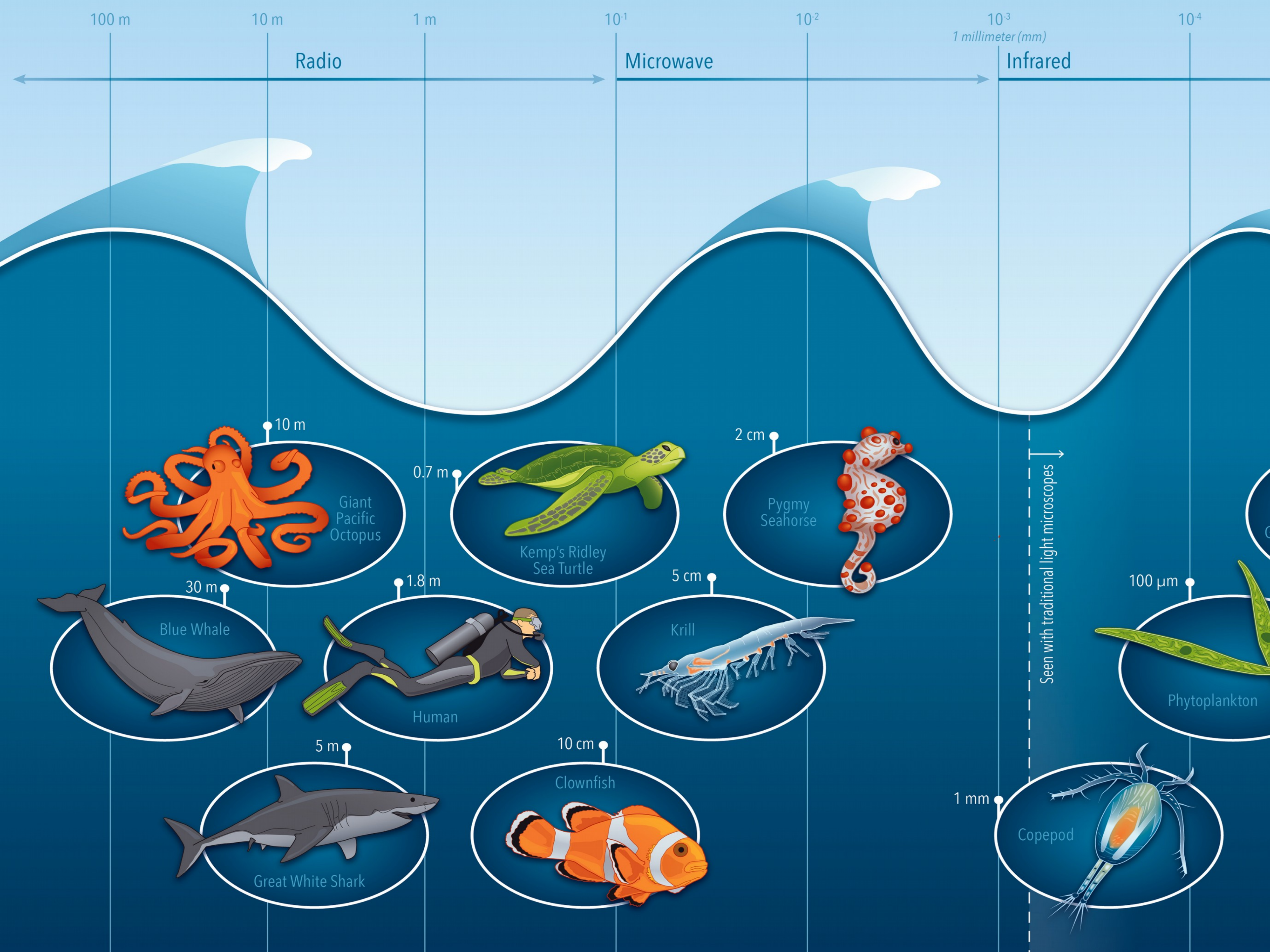
Parabolic reflector with array feed
(hybrid: mechanical & electronic)

The radio sky

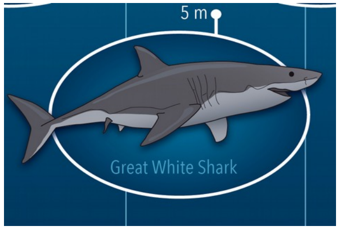




100 m
10 m
1 m
10⁻¹
10⁻²
10⁻³
1 millimeter (mm)
10⁻⁴
10⁻⁵
10⁻⁶
1 micrometer (μm)
10⁻⁷
10⁻⁸
10⁻⁹
1 nanometer (nm)
10⁻¹⁰
10⁻¹¹
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
10 m
Giant Pacific Octopus
0.7 m
Kemp's Ridley Sea Turtle
2 cm
Pygmy Seahorse
30 m
Blue Whale
1.8 m
Human
5 cm
Krill
5 m
Great White Shark
10 cm
Clownfish
Seen with traditional light microscopes
100 μm
Phytoplankton
1 mm
Copepod
2-5 μm
400 nm
Marine Virus
1 μm
Marine Bacteria
Seen with synchrotrons and electron microscopes
2 nm
DNA
0.06 nm
Oxygen Atom
20 nm
Algae Cell Wall
0.3 nm
Water Molecule
ELECTROMAGNETIC SPECTRUM
These marine creatures and objects illustrate the size of the different wavelengths in the electromagnetic spectrum. At Brookhaven Lab, we use cutting-edge instruments to discover new energy technologies, biological structures, and fundamental phenomena hidden inside the ultra-small world at the right end of the spectrum.
BROOKHAVEN
NATIONAL LABORATORY



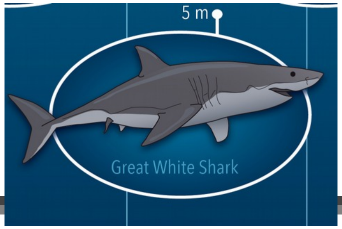
100 m
10 m
1 m
10^{-1}
10^{-2}
10^{-3}
1 millimeter (mm)
10^{-4}
Radio
Microwave
Infrared
10 m
Giant Pacific Octopus
0.7 m
Kemp's Ridley Sea Turtle
2 cm
Pygmy Seahorse
Seen with traditional light microscopes
30 m
Blue Whale
1.8 m
Human
5 cm
Krill
100 µm
Phytoplankton
5 m
Great White Shark
10 cm
Clownfish
1 mm
Copepod

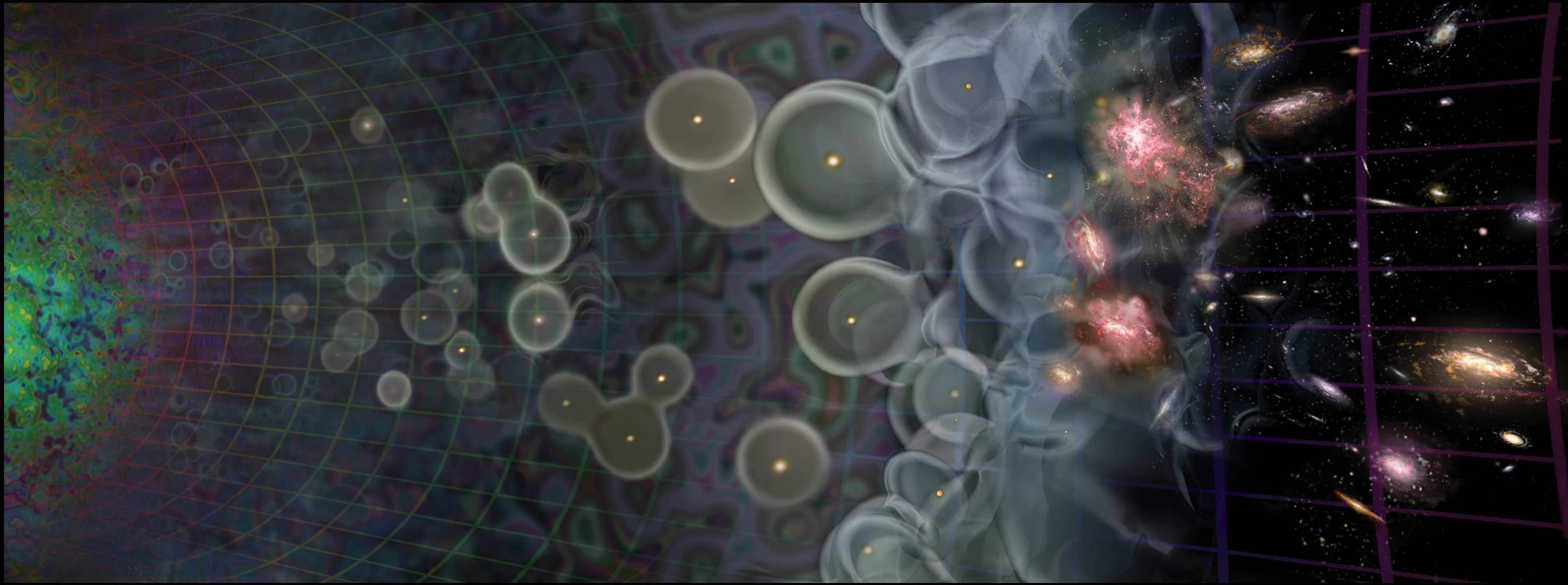


Low Radio Frequency Sky

BACK TO THE FUTURE: THE MWA

All the sky!

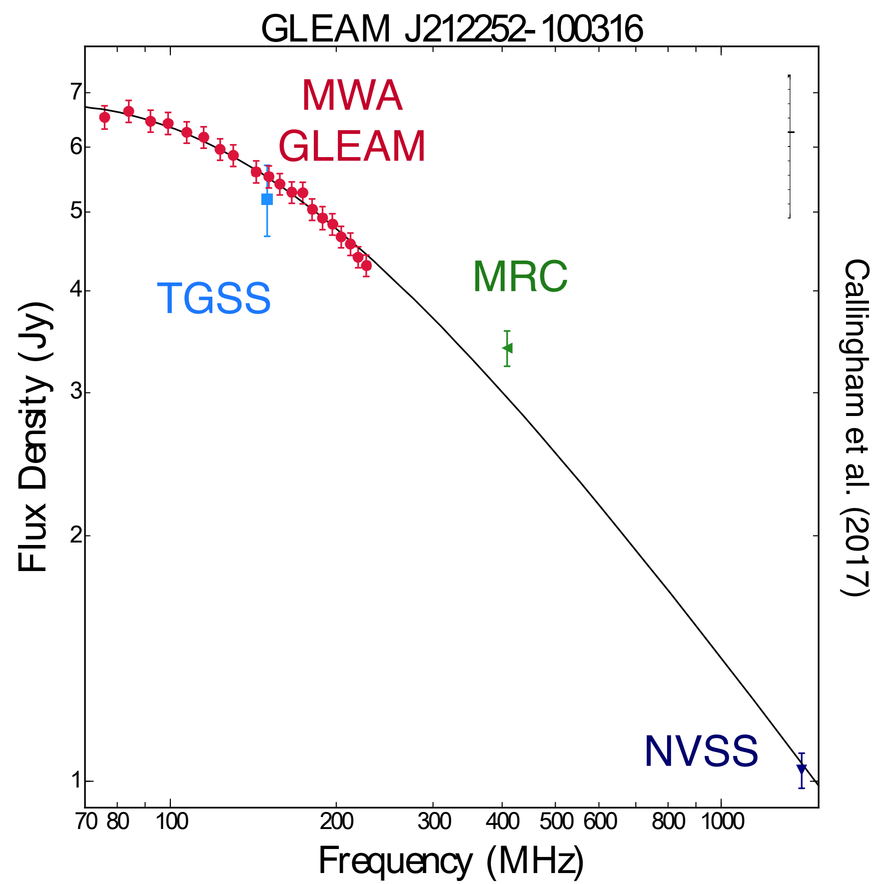




- When did reionization happen?
- How fast did it happen?
- What were the sources of reionization (stars? galaxies?)

The SED Revolution with GLEAM

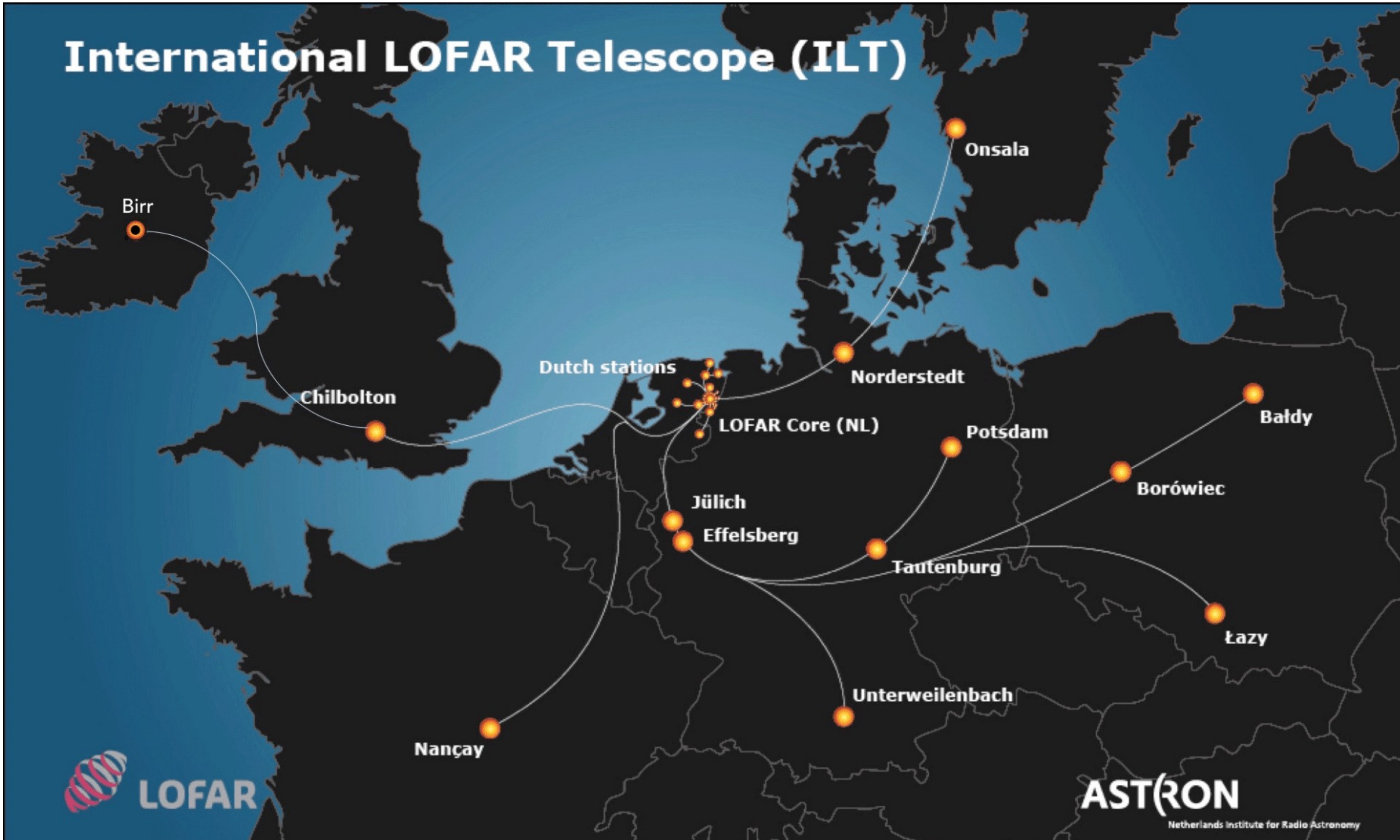
- MWA GLEAM survey (Hurley-Walker, Callingham et al. 2017)
  - 305,615 sources over 59% of the sky at 2’ resolution, σ ~ 10 mJy
  - every source: 20 fluxes spanning 72 – 231 MHz



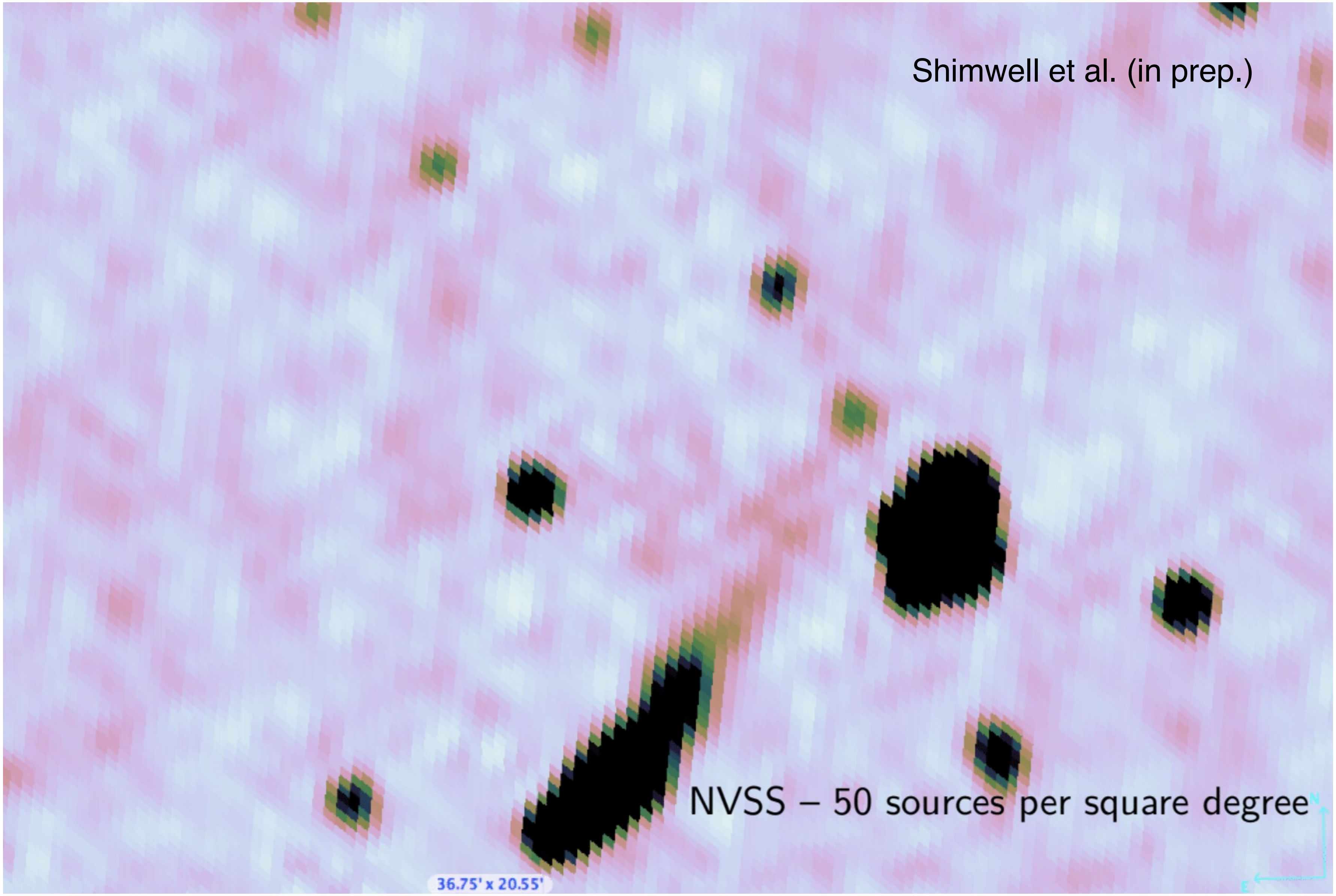
LOFAR

- Two telescopes really (78 MHz bandwidth):
  - HBA (110 - 180, and 210 - 240 MHz)
  - LBA (10 - 90 MHz)

LOFAR – long baselines

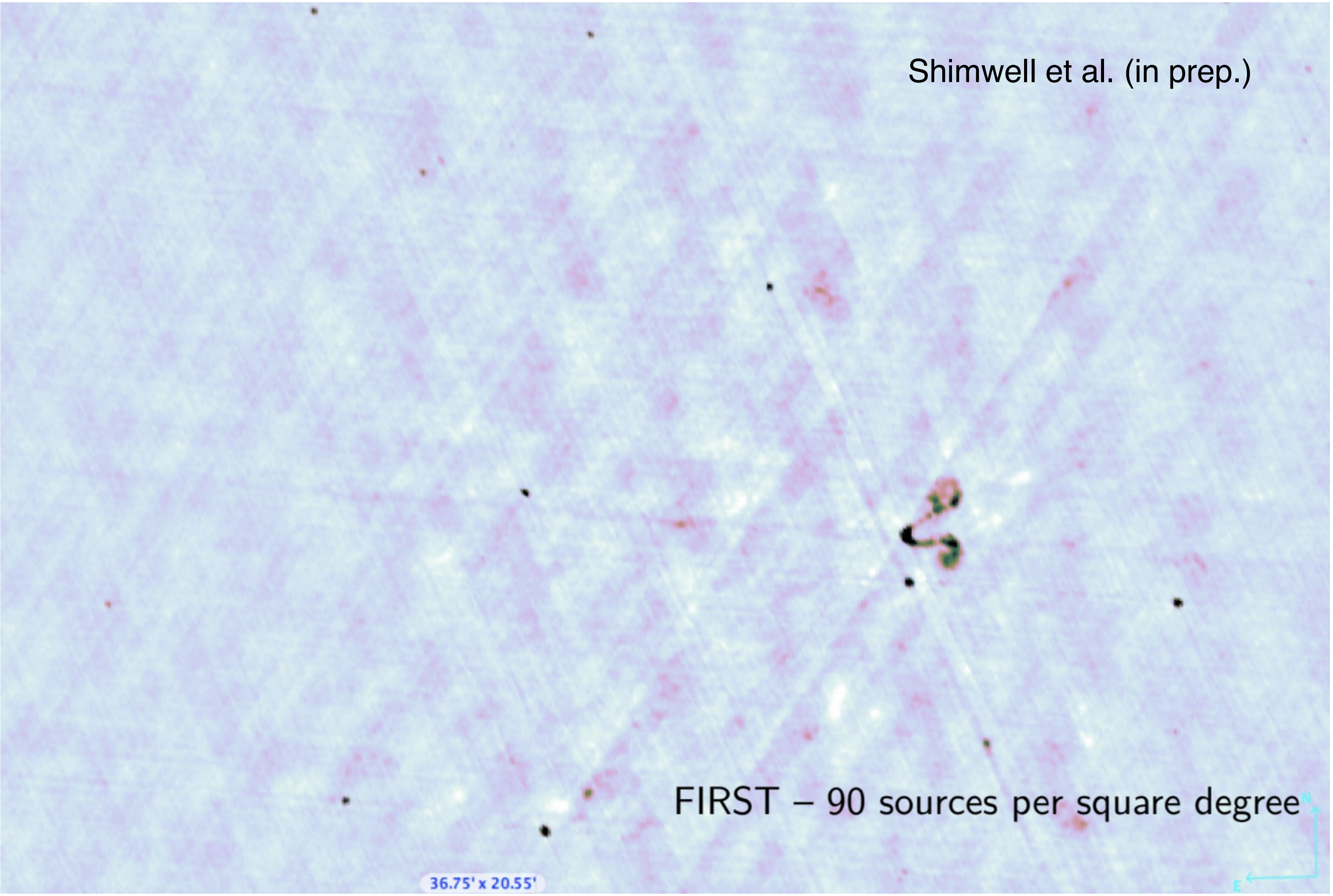


LoTSS

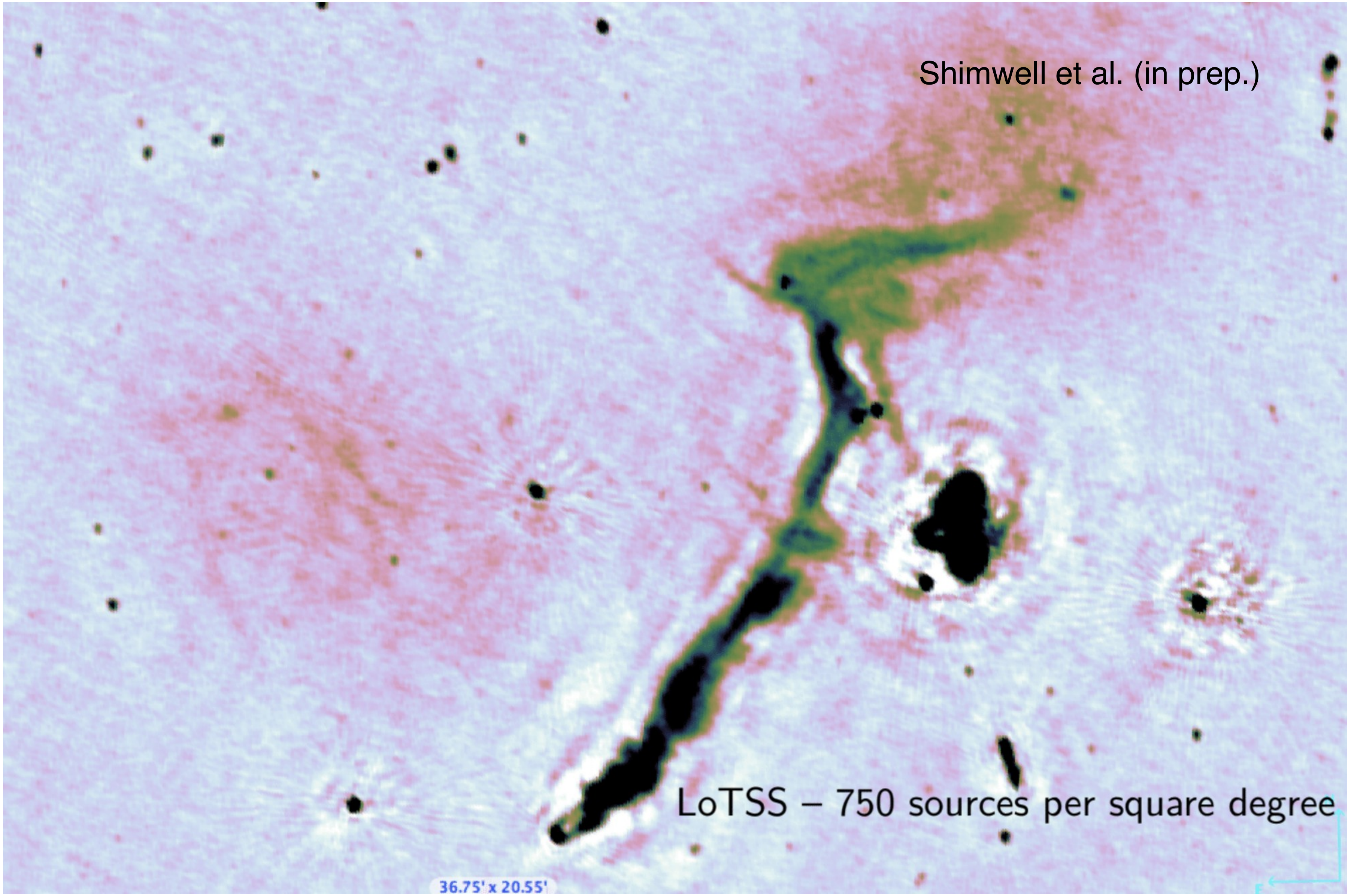


Shimwell et al. (in prep.)
NVSS – 50 sources per square degree
36.75' x 20.55'

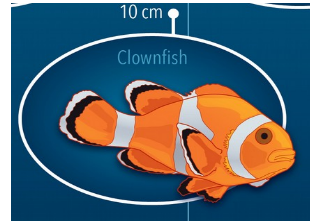
LoTSS


Shimwell et al. (in prep.)
FIRST – 90 sources per square degree
36.75' x 20.55'

LoTSS


Shimwell et al. (in prep.)
LoTSS – 750 sources per square degree
36.75' x 20.55'

Stuck in the middle - ASKAP

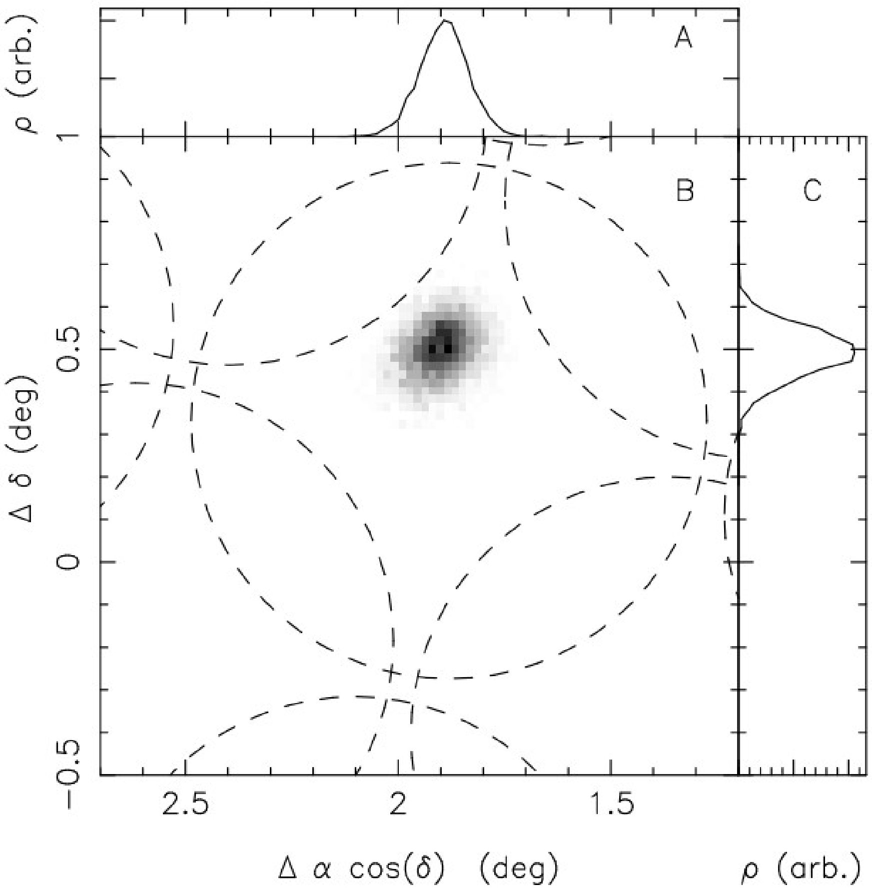


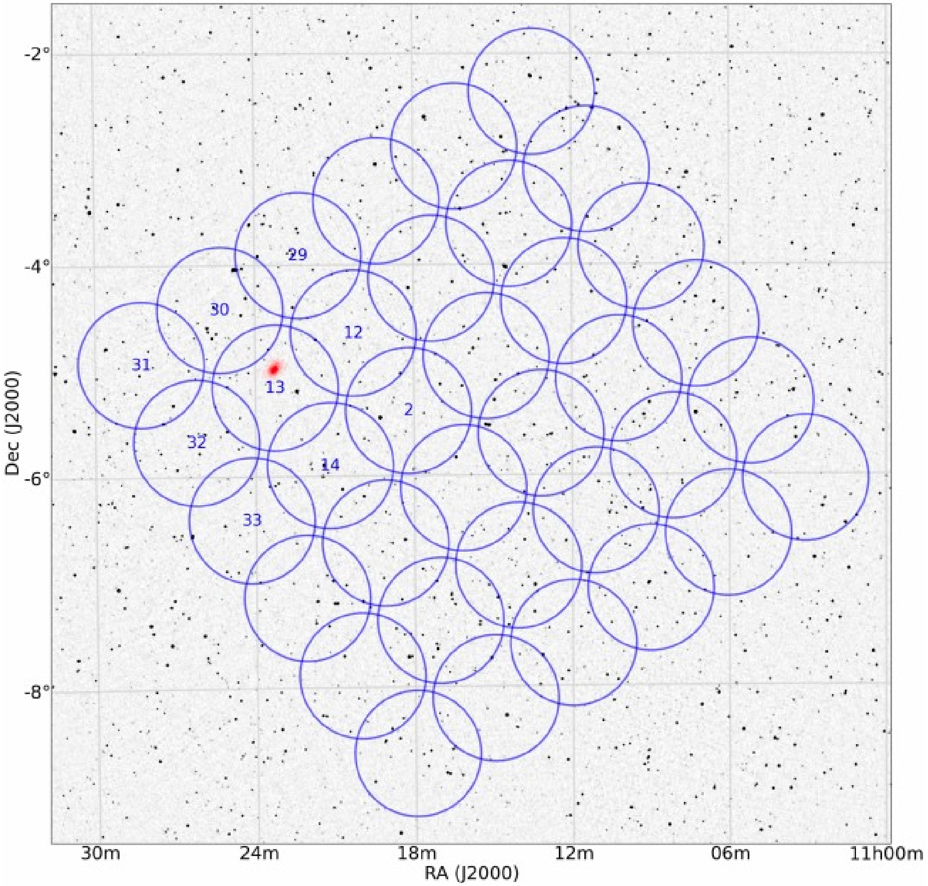
ASTRON

- 36 x 12 m dishes sensitive between 0.7 to 1.8 GHz (300 MHz bandwidth)
- Early science underway now!
- Surveys, surveys, surveys
- Survey speed set by
  - Number of pixels/beams N_b
  - Beam area Ω_b
  - Bandwidth B
  - Collecting area A_{eff}
  - System Temp T_{sys}

$$\mathrm{SVS} \propto N_{\mathrm{b}}\, \Omega_{\mathrm{b}}\, B\, \left(A_{\mathrm{eff}}/T_{\mathrm{sys}}\right)^2$$

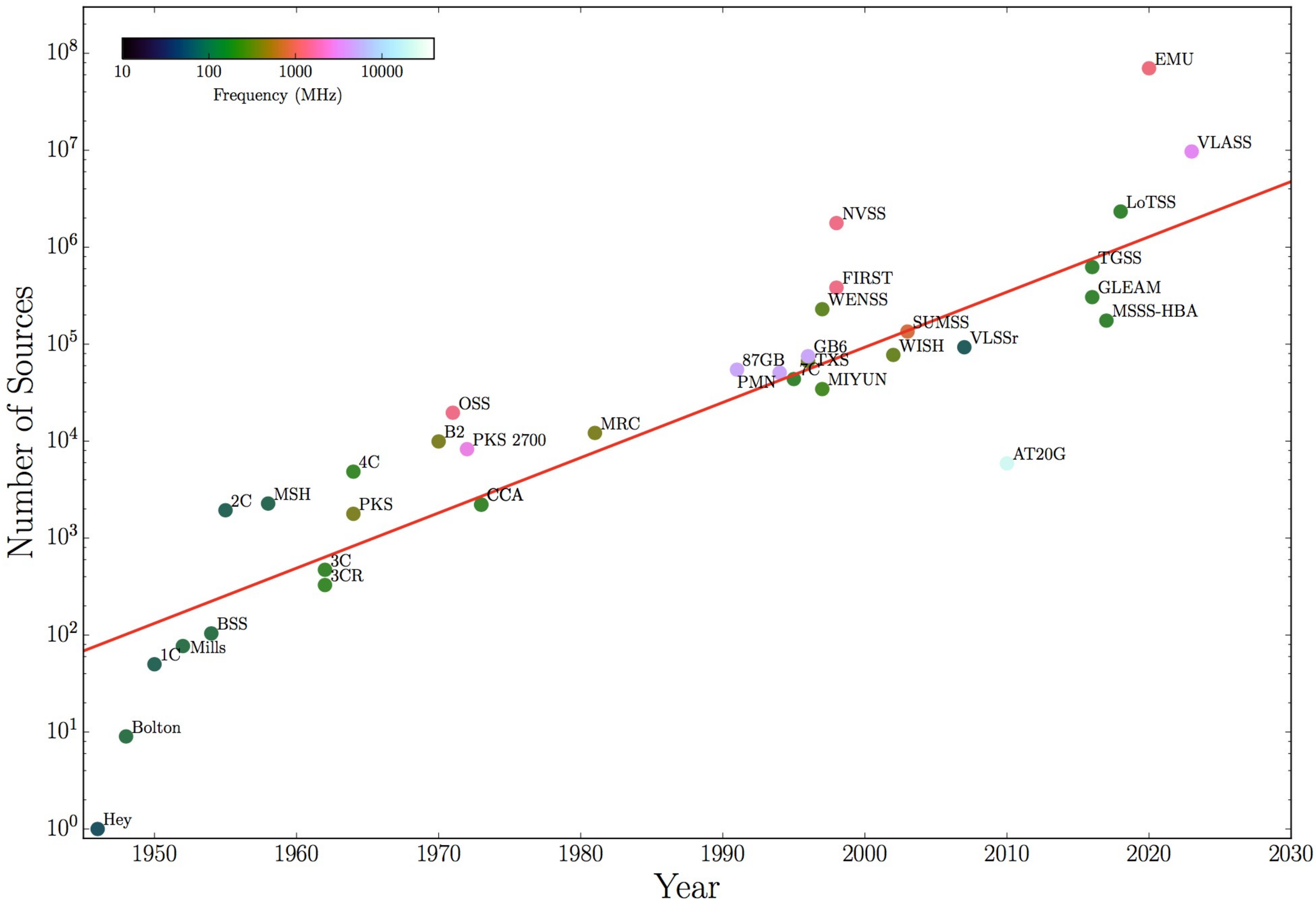
Stuck in the middle - ASKAP





Bannister et al. (2017)

Stuck in the middle - ASKAP

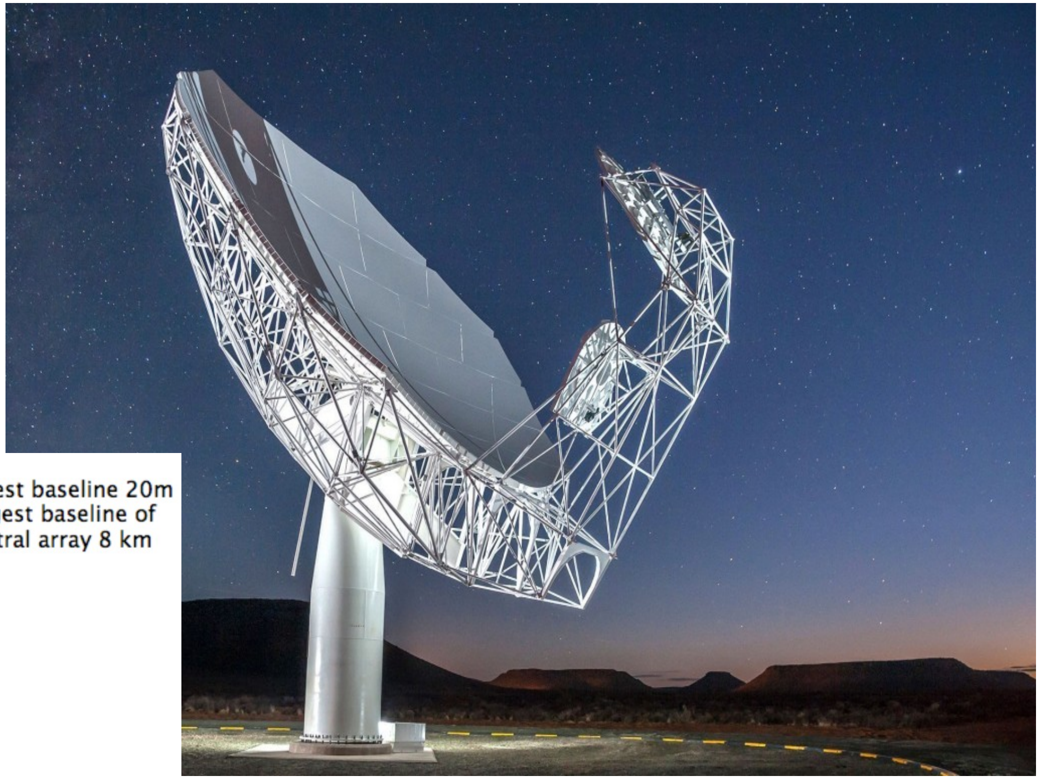


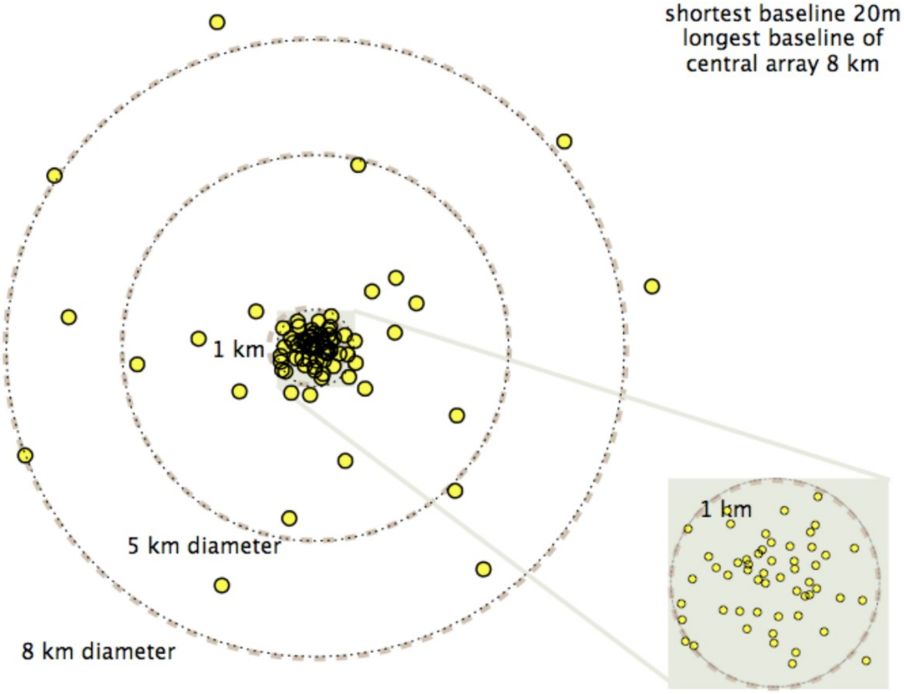
Stuck in the middle - Apertif

› 14 x 25 m dishes sensitive between 1.0 to 1.8 GHz (300 MHz bandwidth)

Stuck in the middle - MeerKAT

- 64 x 14 m dishes sensitive between 0.6 to 1.8 GHz and 8 to 14 GHz (4 GHz bandwidth)
- 8 km longest baseline
- Operational early 2018



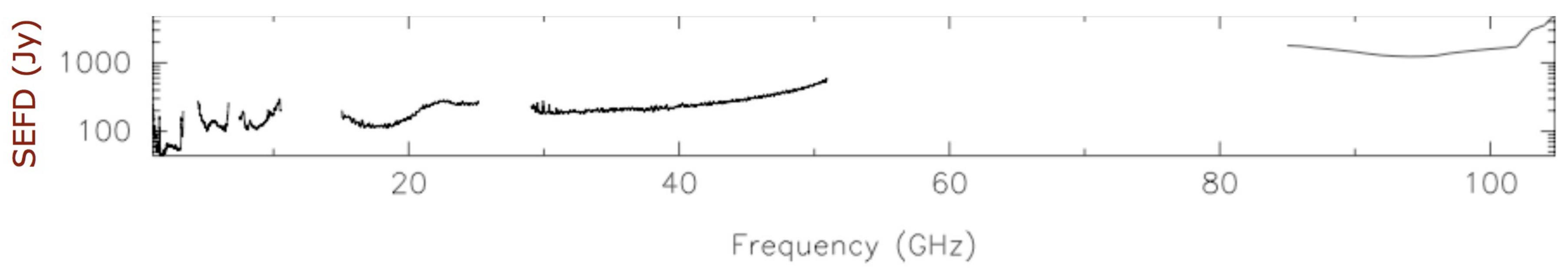


Old School Cool - JVLA

- 27 x 25 m antennas (36 km longest baseline)
- 230 MHz to 50 GHz (4 GHz bandwidth)
- Focused on followup of sources rather than widefield surveys (with obvious exceptions of NVSS and FIRST)
- Most prolific radio telescope in terms of published papers
- Heavily oversubsribed

Old School Cool - ATCA

- “VLA of the south” with 6 x 25 m antennas (longest baseline of 6 km)
- Excellent frequency coverage of 1 to 100 GHz with 2 x 2 GHz bandwidth

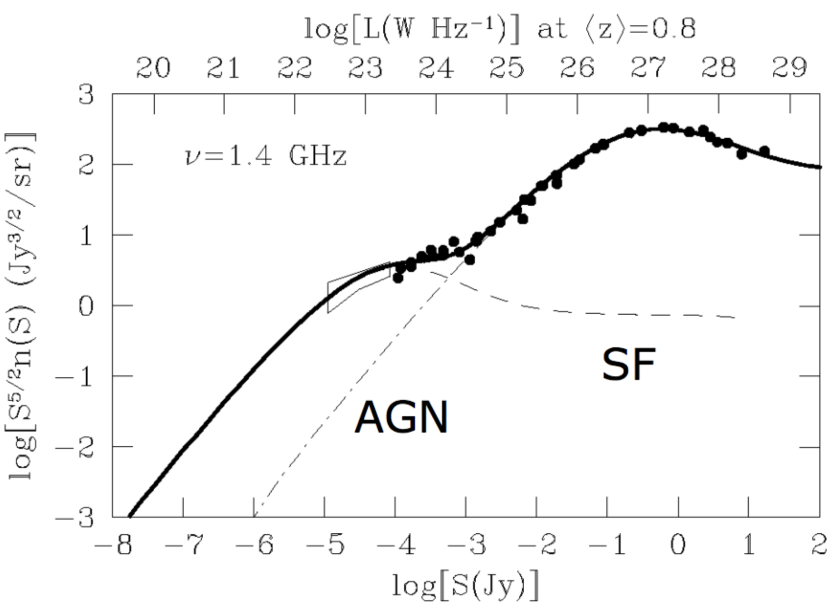


What science with these instruments?

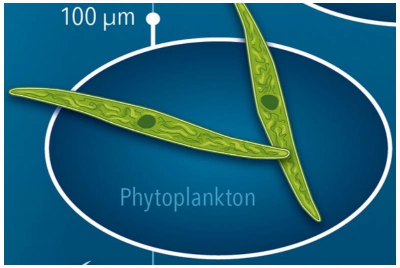
- uJy level sensitivity will allow investigations of,

  i) the star-forming population (radio-FIR correlation).

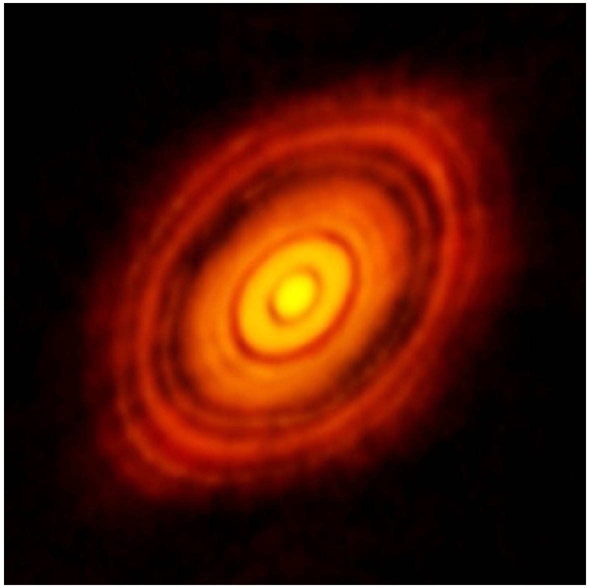
  ii) radio quiet-AGN.



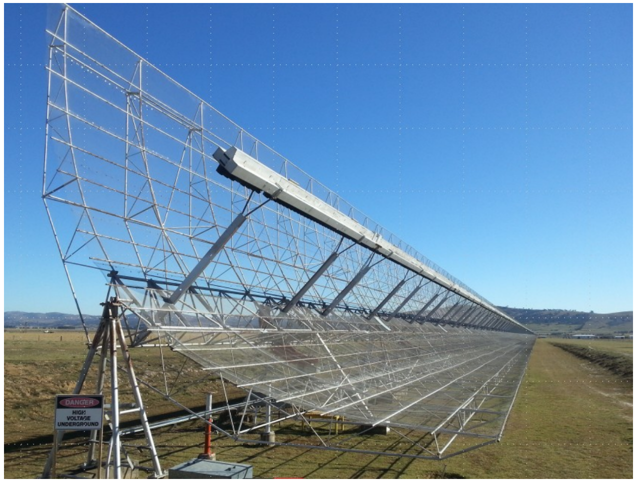
The sub-mm sky



- Interferometer of the next generation
- 54 x 12 m dishes (maximum baseline of 15 km)
- 85 GHz to 1 THz
- Dominated by dust emission (not synchrotron) – different science goals (often)

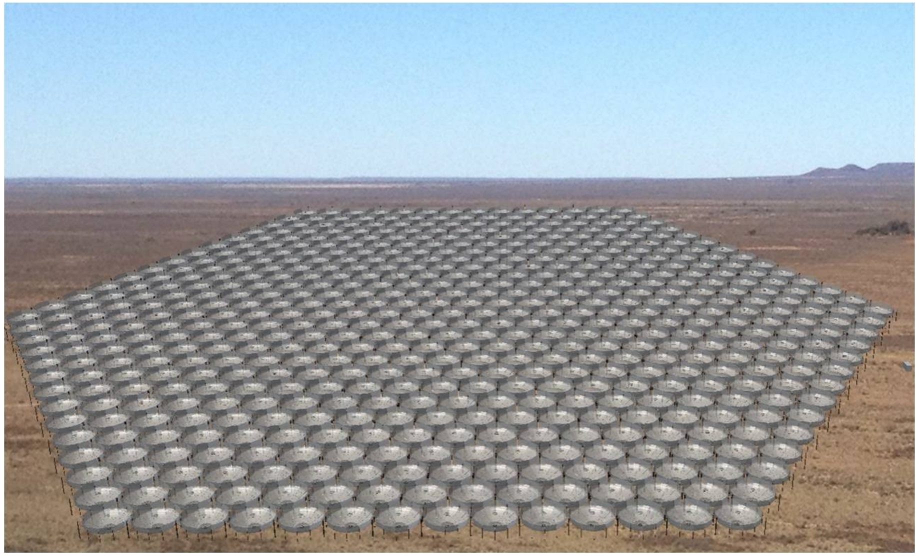


“Experimental” interferometers



UTMOST

CHIME



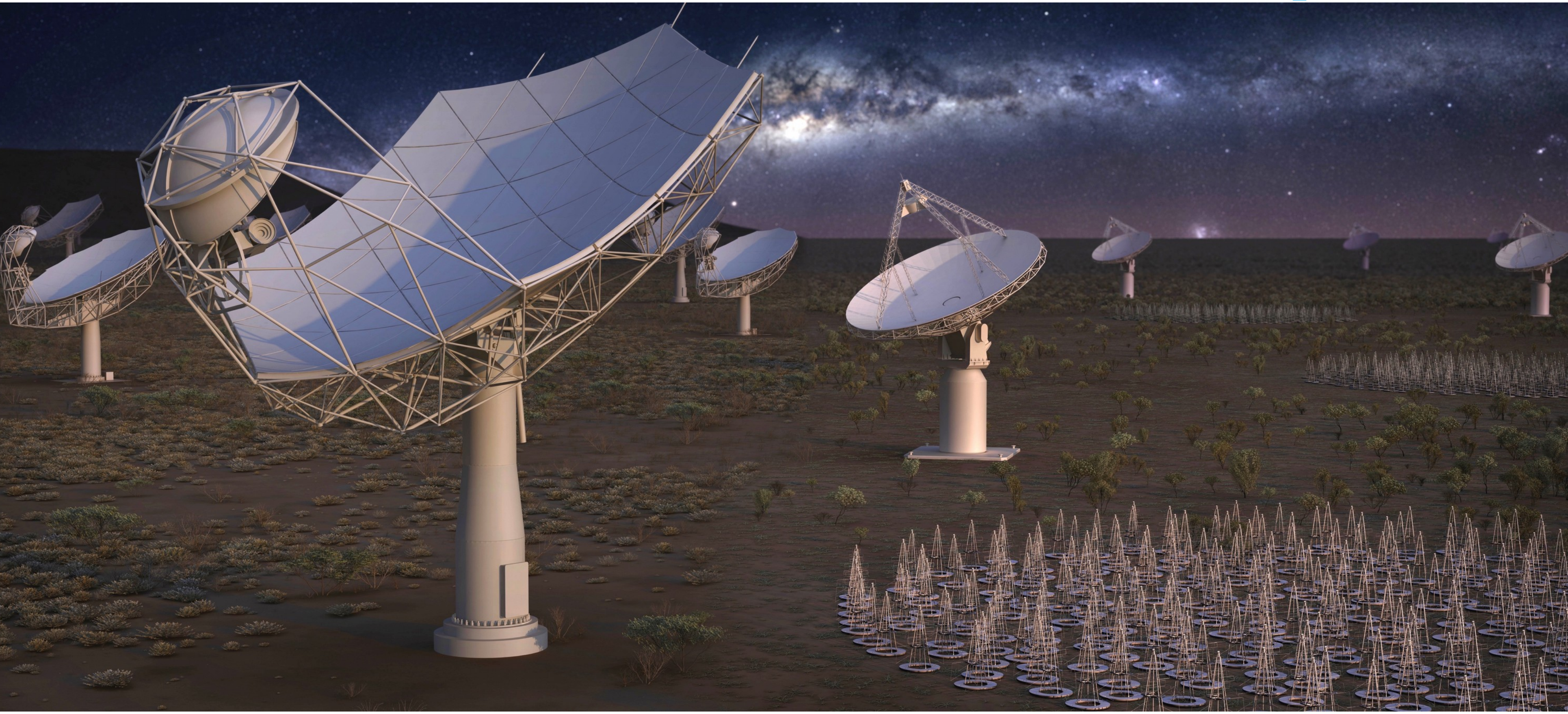
HERA

LWA

VLBI

EVN, VLBA, e-Merlin (all can achieve milliarcsecond resolution at GHz freq)

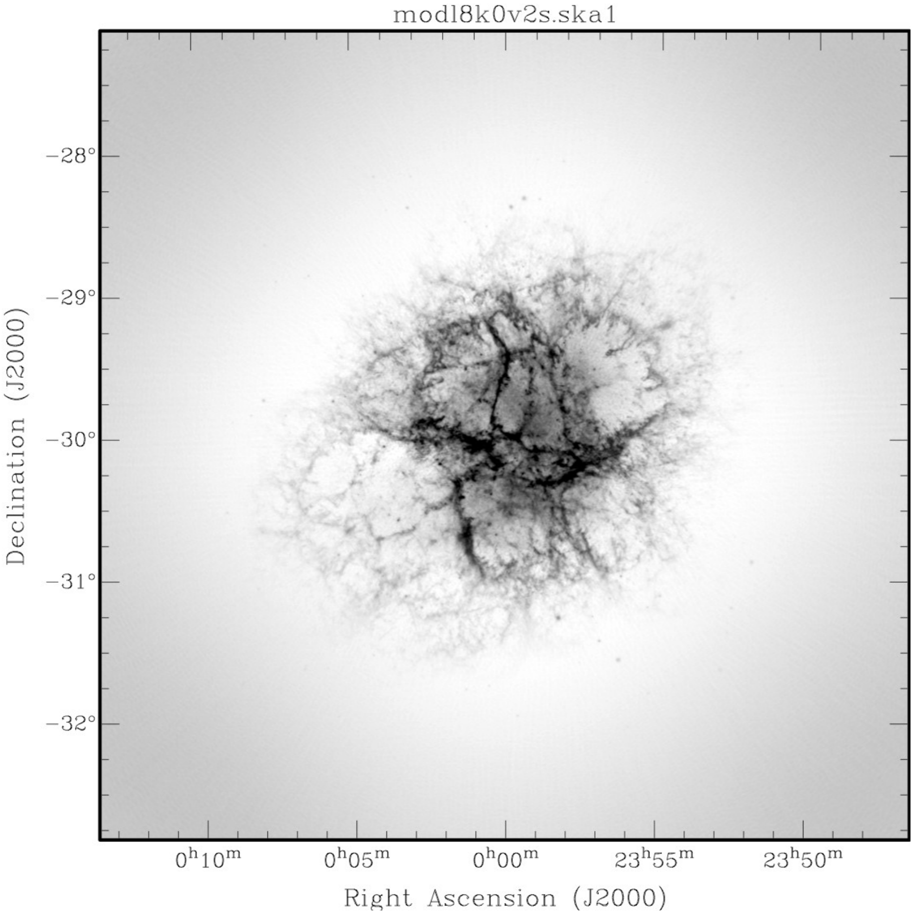
The future – SKA-low and SKA-mid

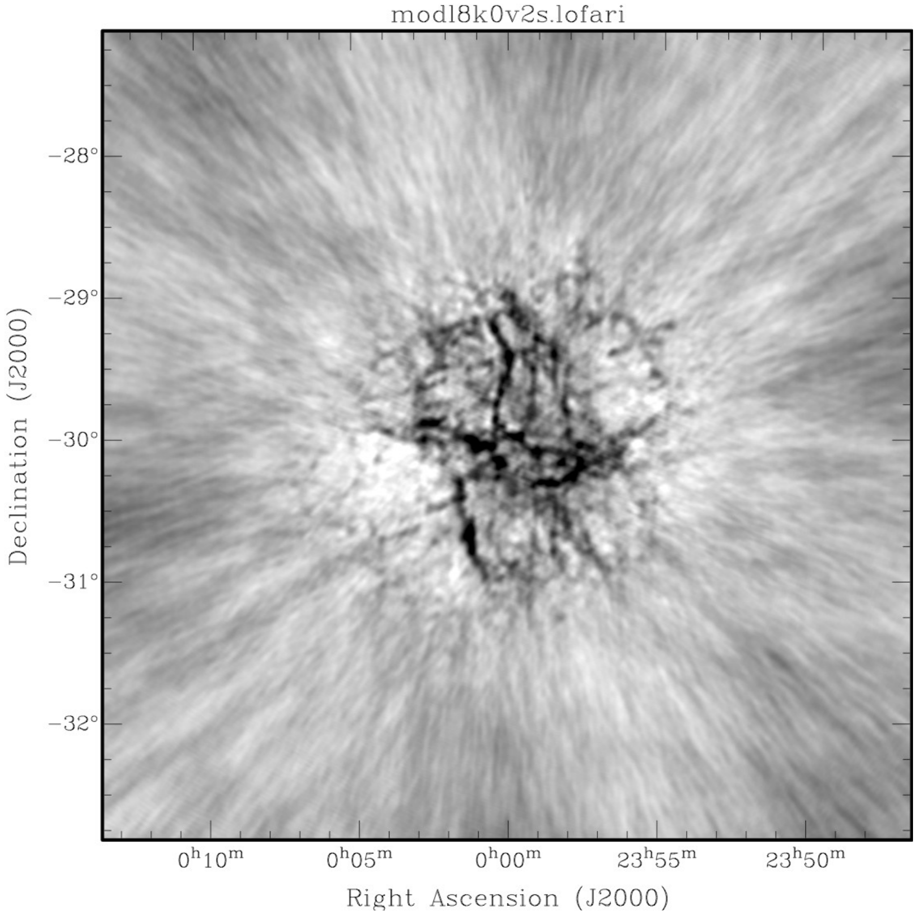


- SKA-Low (50 to 350 MHz) - 130000 dipole antennas making it 8 x more sensitive than LOFAR

- SKA-mid (1 GHz to 14 GHz) - 130 x 15 m offset Gregorian dishes + 64 MeerKAT dishes (194 in total). 5 x more sensitive than the JVLA. 4 x better resolution than the JVLA

Image Quality Comparison

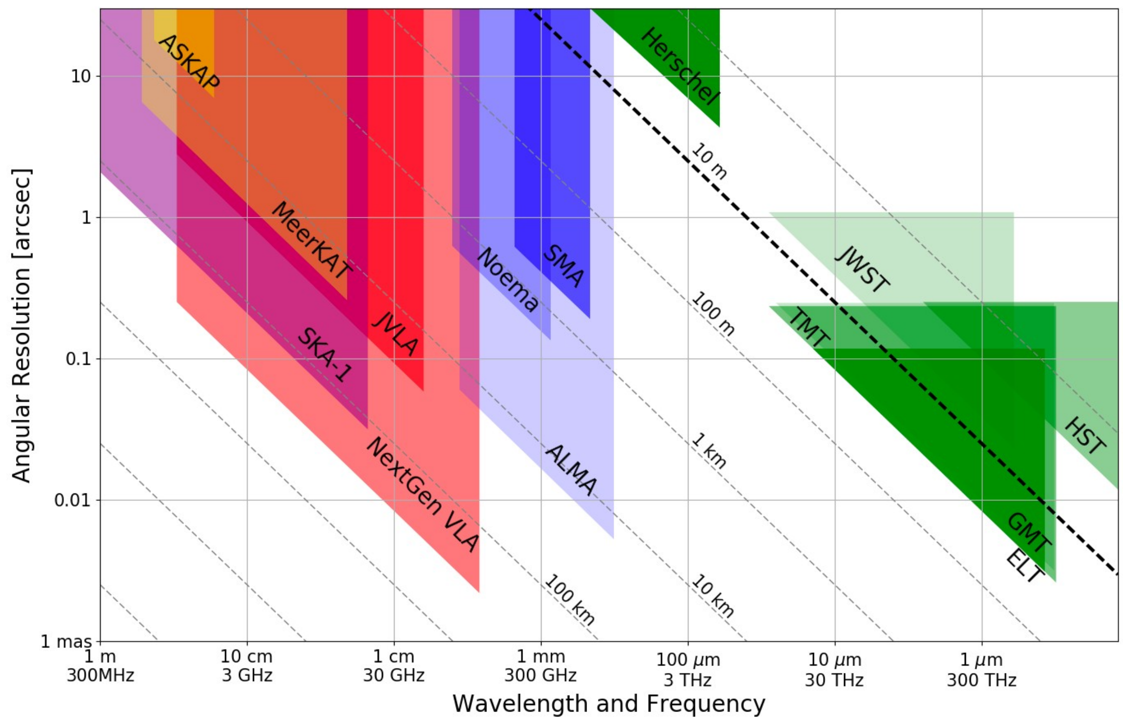




- Single SKA1-Low snap-shot compared to LOFAR-INTL snap-shot

The future - ngVLA

- 10 times the collecting area of JVLA and ALMA
- science operations from 1.2 to 116 GHz. Bridge ‘gap’ between SKA and ALMA
- 10x longer baselines (300 km) that yield mas-resolution,
- a dense antenna core on km-scales for low surface brightness imaging.




QUIZ

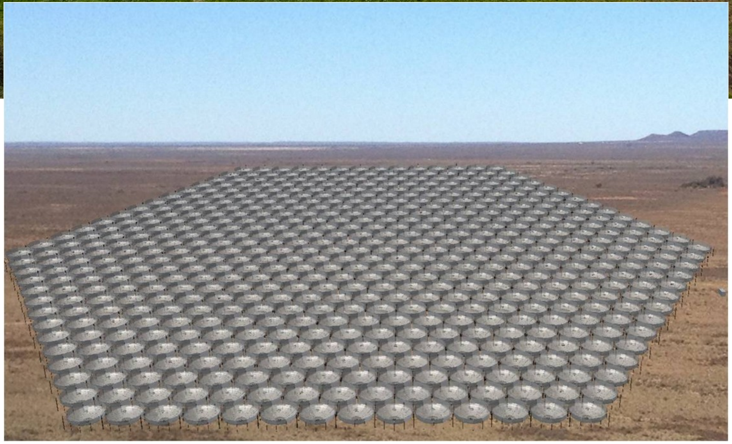
QUIZ!

ASTRON

- You want to get a spectrum of a star-forming galaxy to understand the non-thermal and thermal contribution. It is located in the Southern Hemisphere. Which telescope should you use?

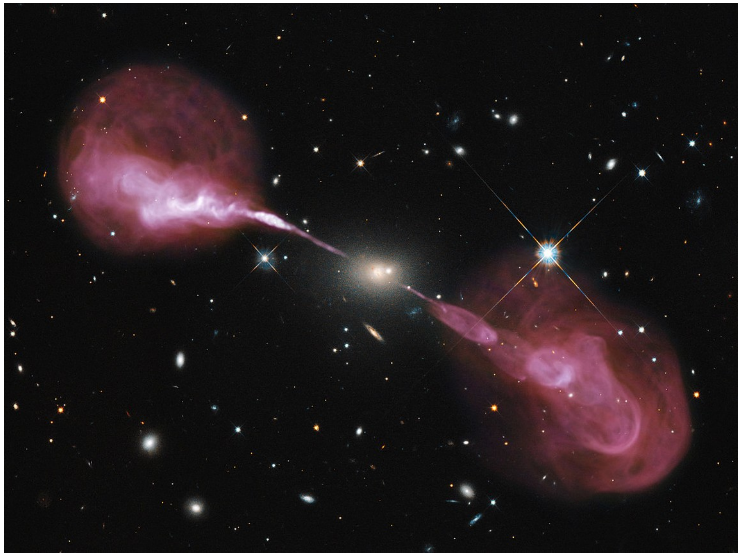
QUIZ!

› You want to detect the EoR. Which telescope?



QUIZ!

› You want to be able to study the (very intricate) knots in the lobes and jets of Hercules A. Which telescope should you use?



QUIZ!

› You want to model the composition of HI gas in galaxies out to a redshift of ~0.5. Which telescope is ideal to use?

Summary

- Complete zoo of modern interferometers.
- The next generation tools will use phase-arrays or correlate hundreds of antennas.
- You don't know where the next advance will come from!
- Lots of science questions still to be solved and you will help solve them using the best interferometers ever made.