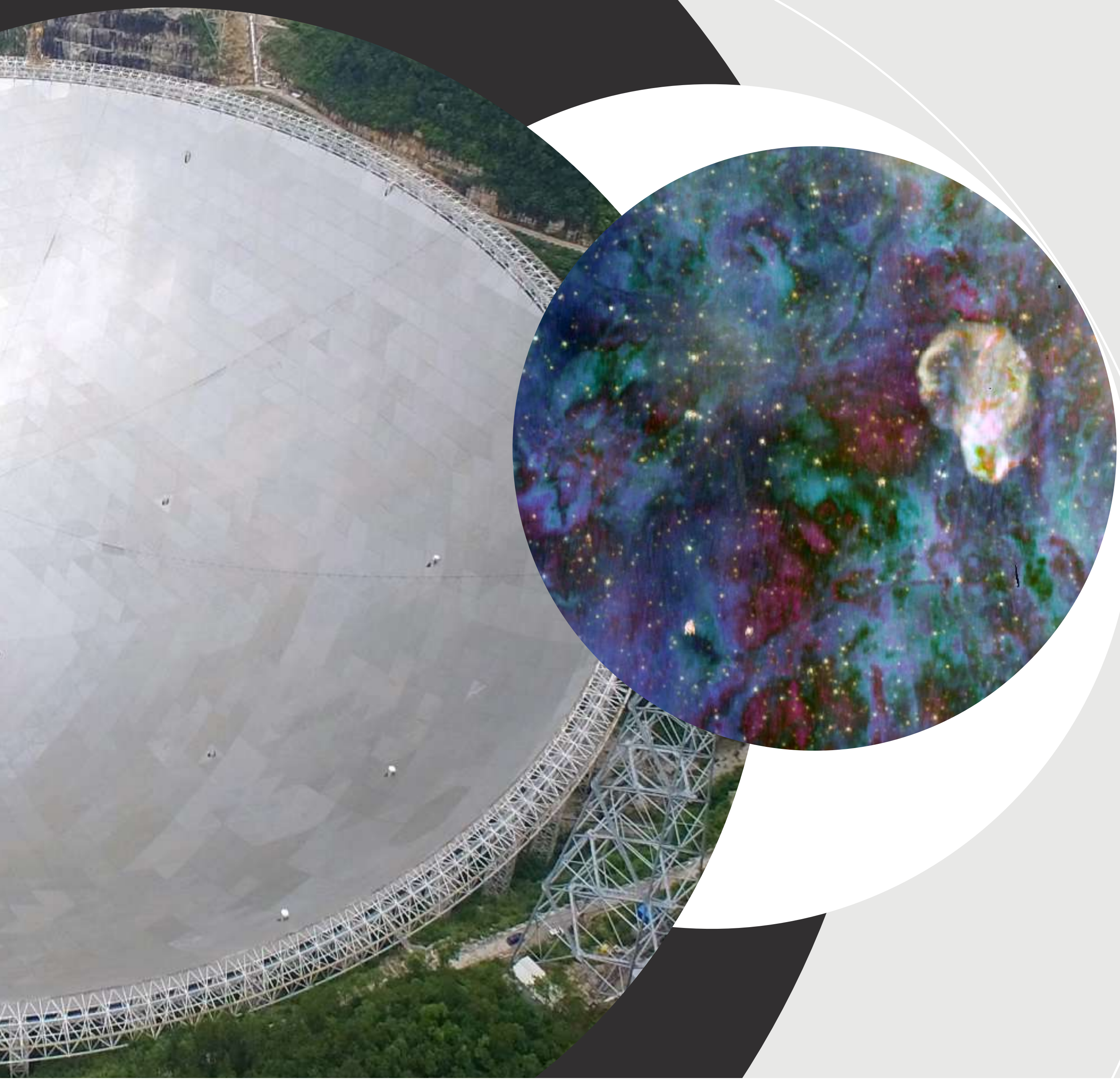


DUNLAP INSTITUTE
for ASTRONOMY & ASTROPHYSICS

Single Dish Radio Astronomy

ATCA Radio Summer School

September 25, 2017
Jennifer West

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

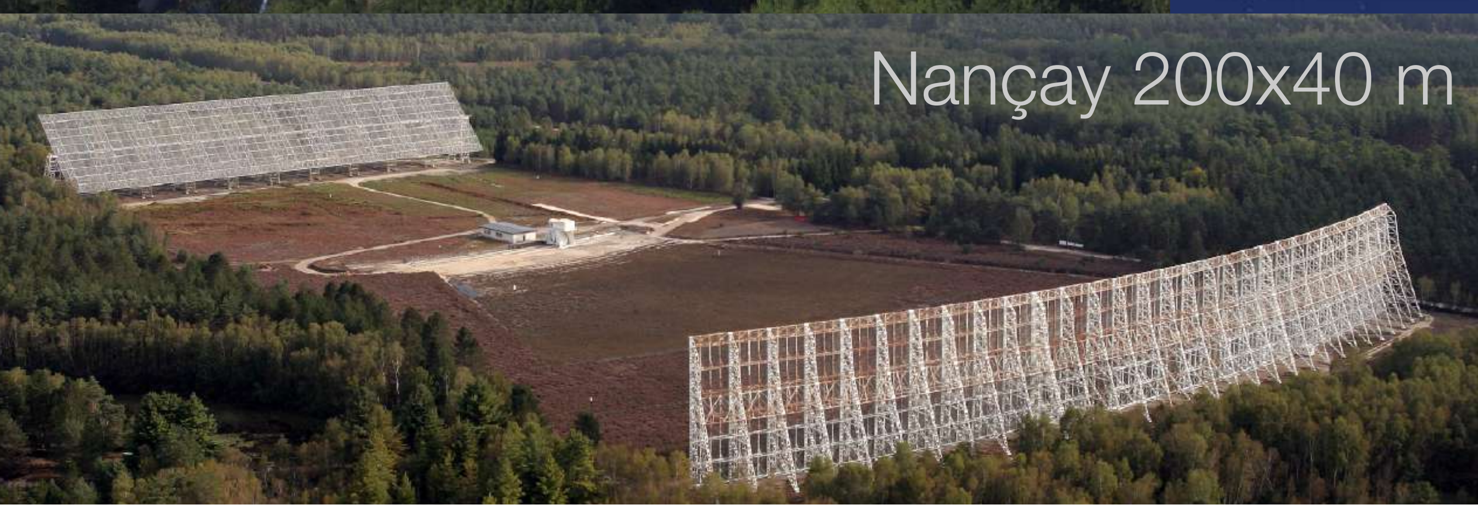
Outline

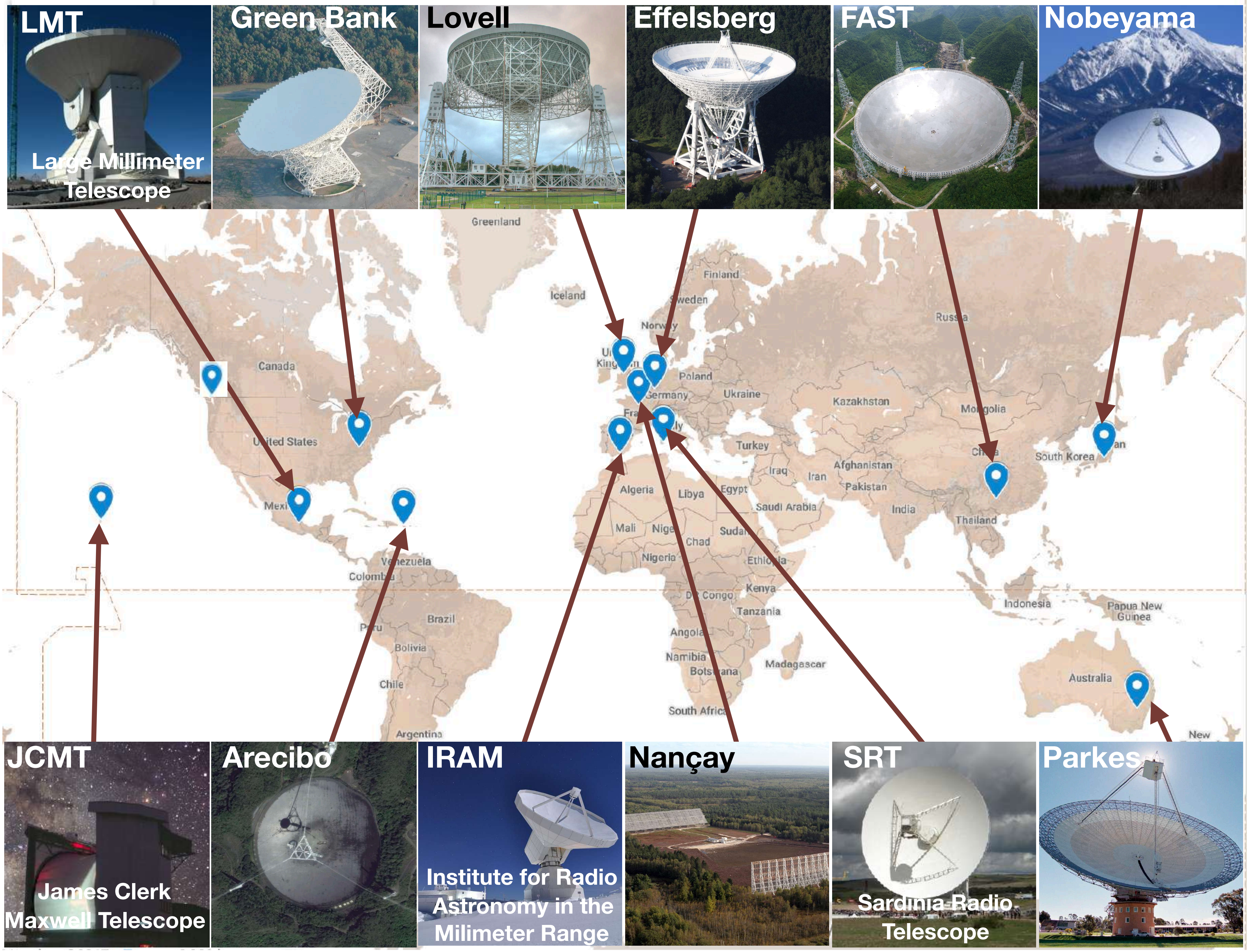
- What is a single dish radio telescope?
- Challenges of single dish astronomy
- Science with single dish telescopes
- Is there still a place for it single dish astronomy an era of big arrays?

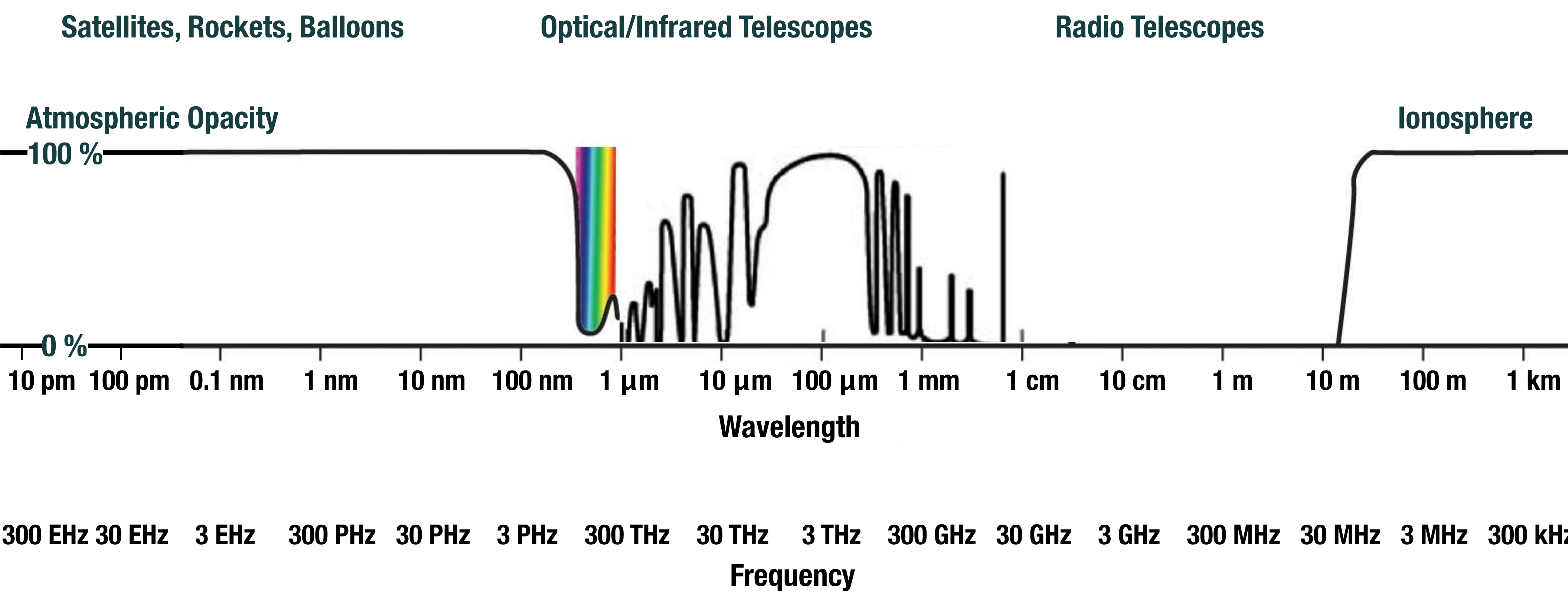

Effelesberg 100 m

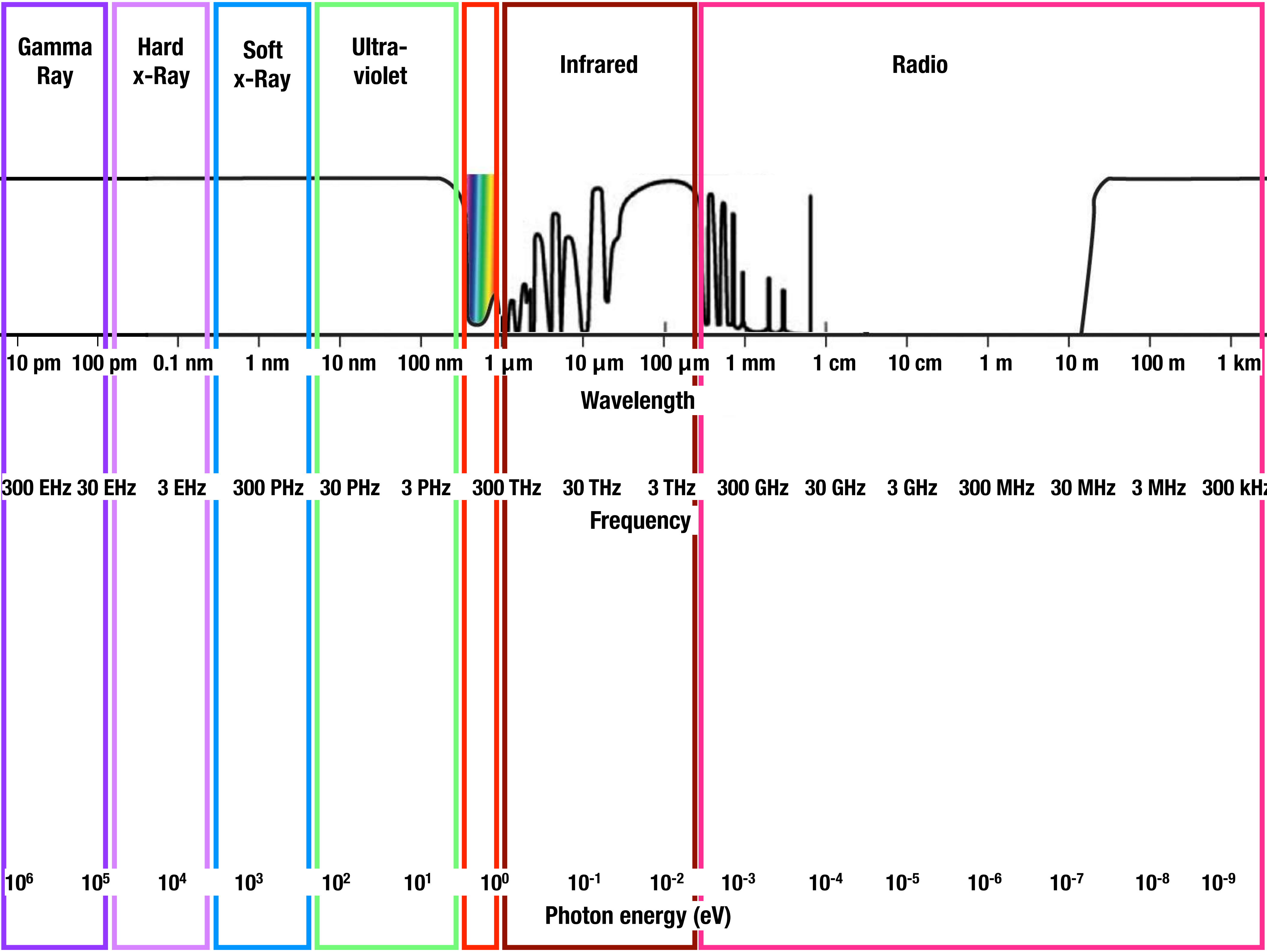

FAST 500 m


IRAM 30 m

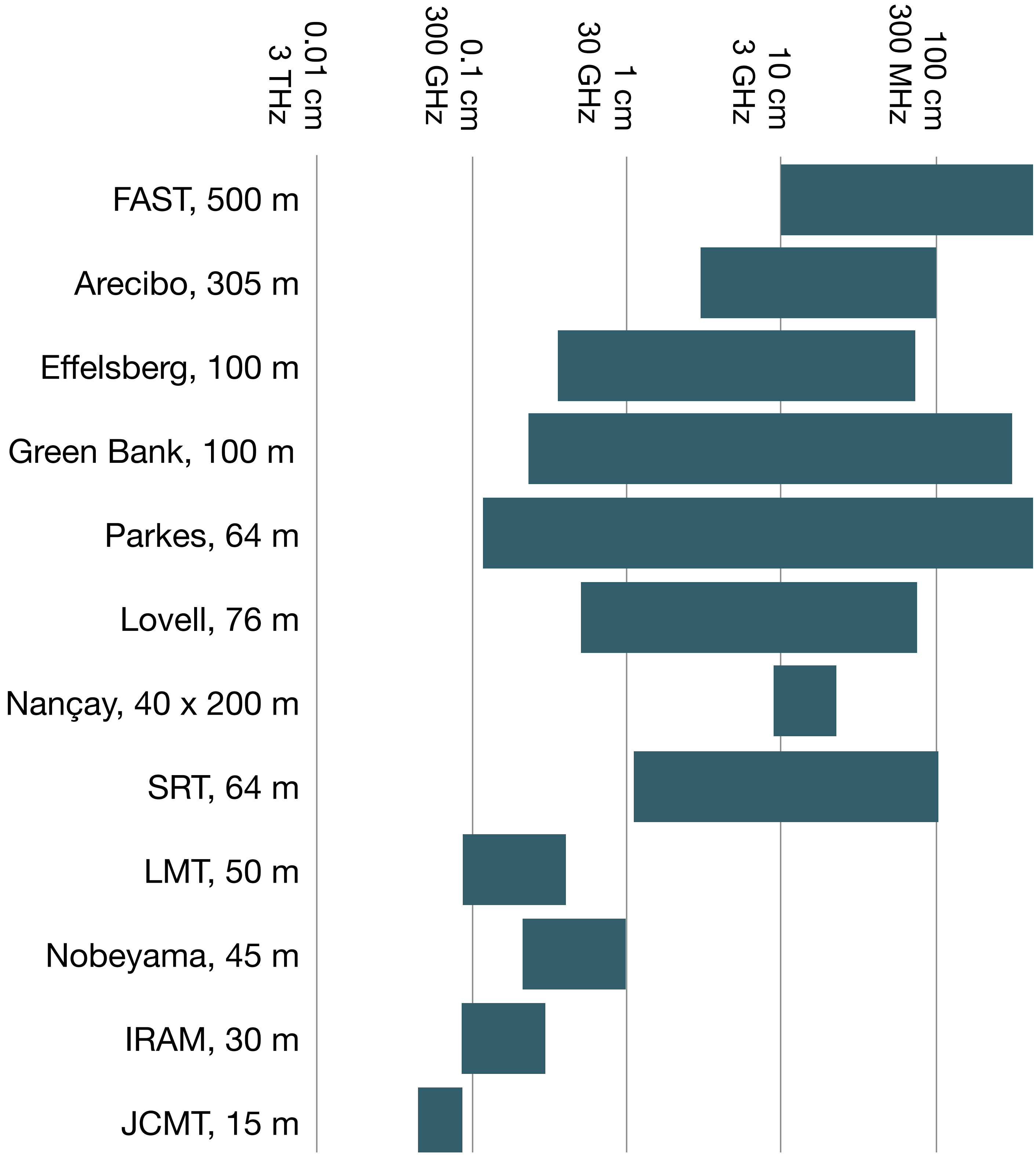

Nançay 200x40 m


LMT
Large Millimeter Telescope
Green Bank
Lovell
Effelsberg
FAST
Nobeyama
JCMT
James Clerk Maxwell Telescope
Arecibo
IRAM
Institute for Radio Astronomy in the Milimeter Range
Nançay
SRT
Sardinia Radio Telescope
Parkes

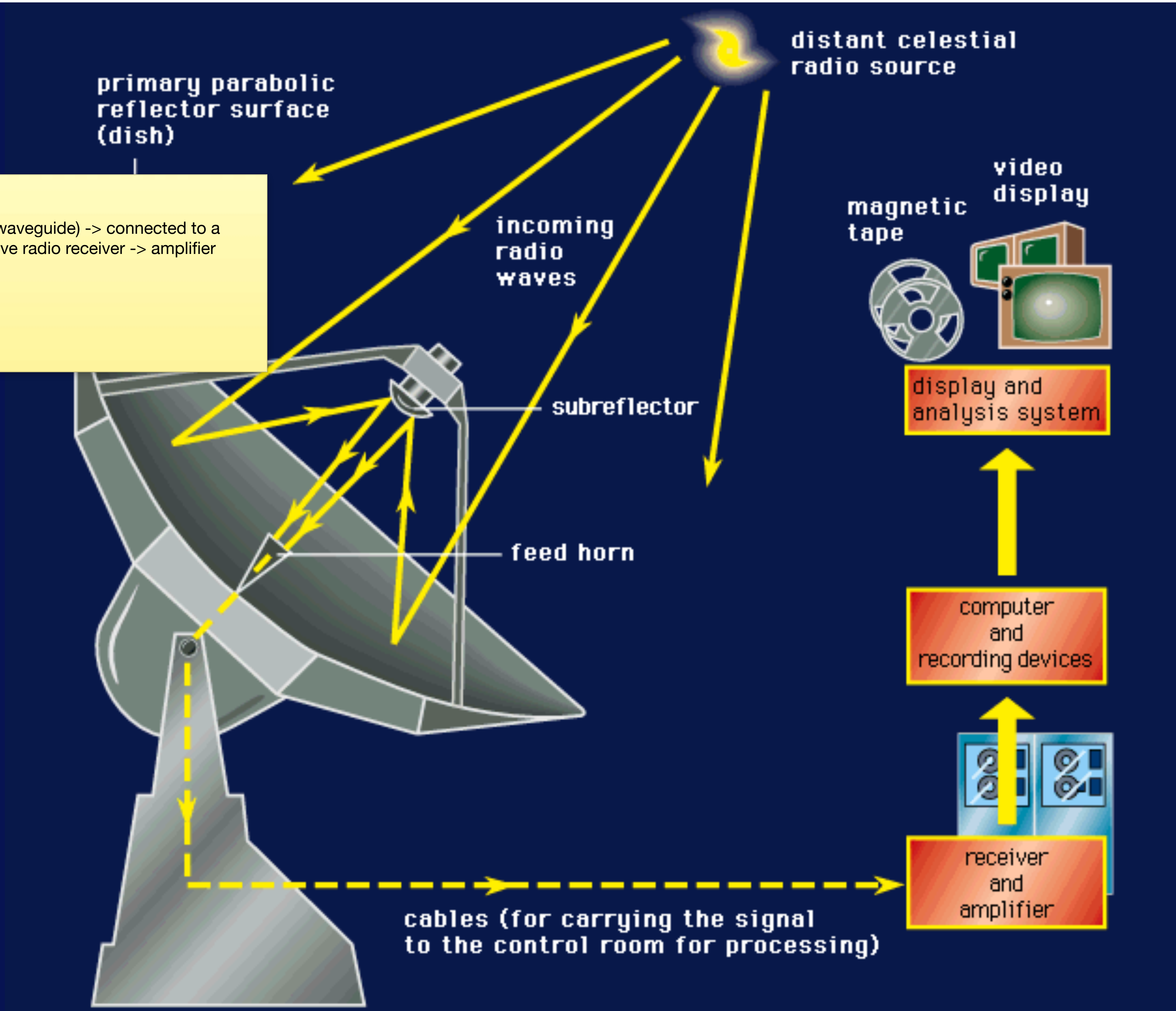

Satellites, Rockets, Balloons
Optical/Infrared Telescopes
Radio Telescopes
Atmospheric Opacity
Ionosphere
100 %
0 %
10 pm
100 pm
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
300 EHz
30 EHz
3 EHz
300 PHz
30 PHz
3 PHz
300 THz
30 THz
3 THz
300 GHz
30 GHz
3 GHz
300 MHz
30 MHz
3 MHz
300 kHz
Frequency



Gamma Ray
Hard x-Ray
Soft x-Ray
Ultra-violet
Infrared
Radio
10 pm
100 pm
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
300 EHz
30 EHz
3 EHz
300 PHz
30 PHz
3 PHz
300 THz
30 THz
3 THz
300 GHz
30 GHz
3 GHz
300 MHz
30 MHz
3 MHz
300 kHz
Frequency
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
Photon energy (eV)

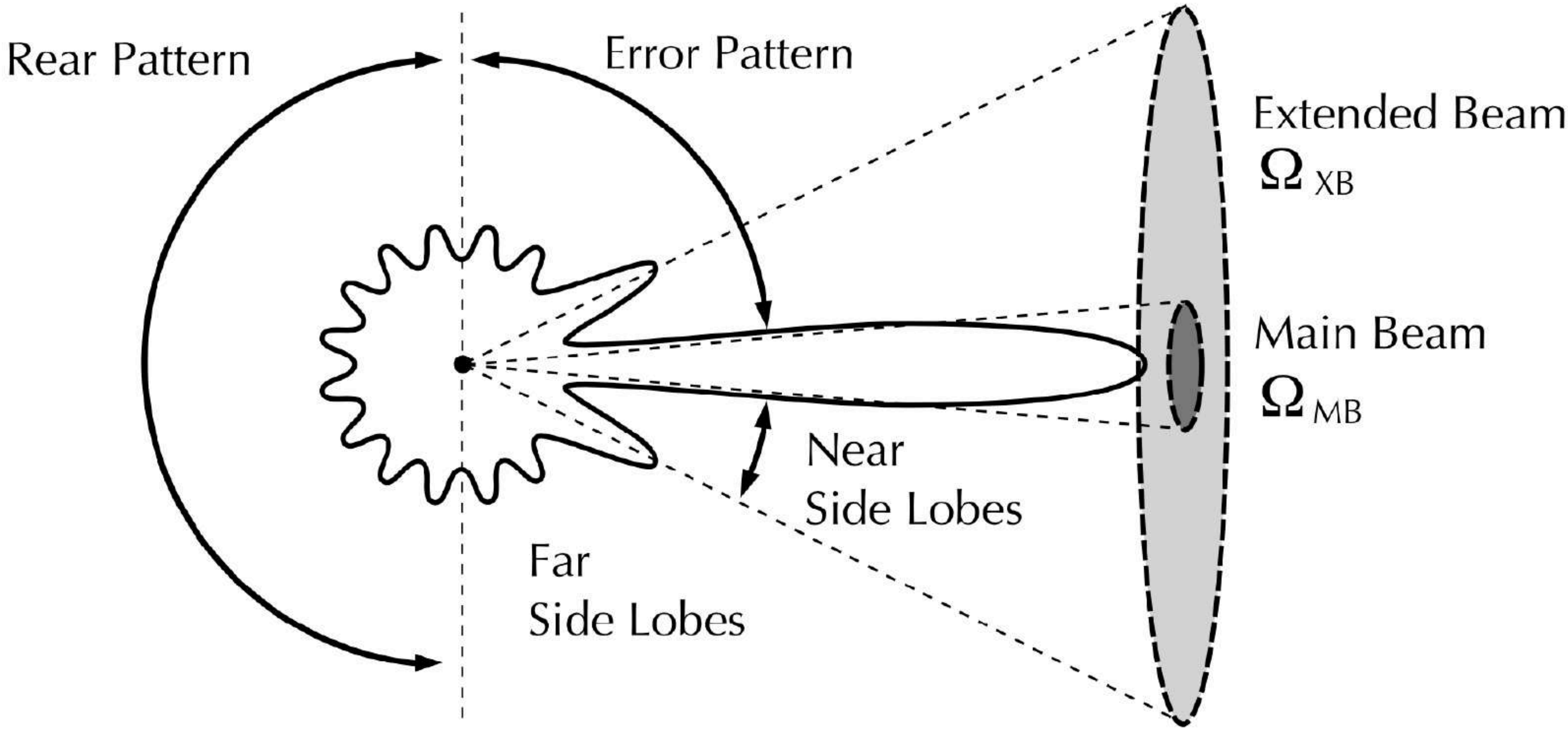


0.01 cm
3 THz
0.1 cm
300 GHz
1 cm
30 GHz
10 cm
3 GHz
100 cm
300 MHz
FAST, 500 m
Arecibo, 305 m
Effelsberg, 100 m
Green Bank, 100 m
Parkes, 64 m
Lovell, 76 m
Nançay, 40 x 200 m
SRT, 64 m
LMT, 50 m
Nobeyama, 45 m
IRAM, 30 m
JCMT, 15 m



feed (waveguide) -> connected to a sensitive radio receiver -> amplifier

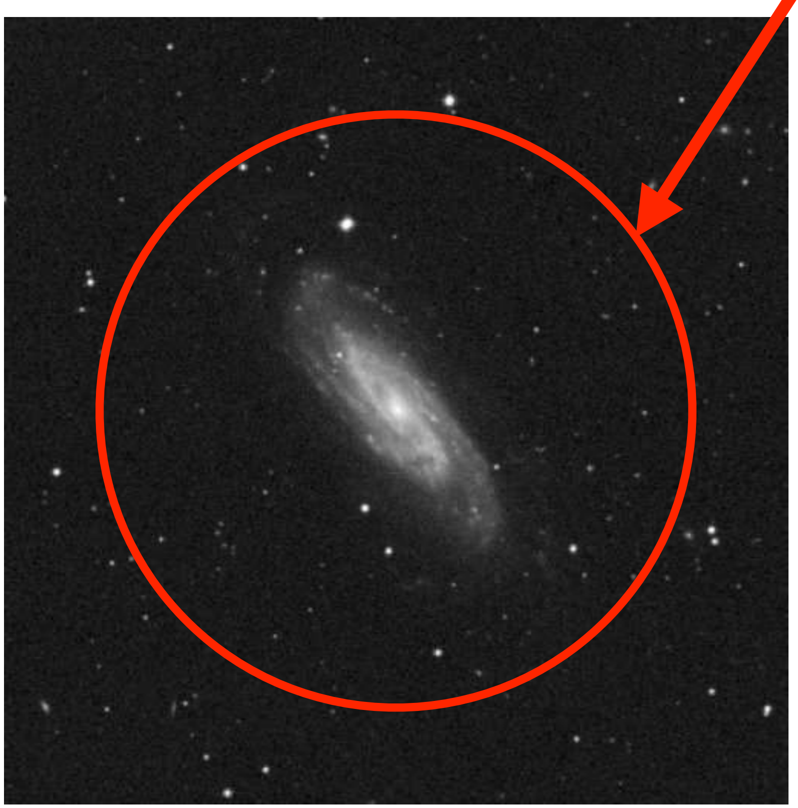
http://abyss.uoregon.edu/~js/glossary/radio_telescope.html



Upcoming: multi-beam receivers

Purcell 2006, Rohlfs & Wilson 2004

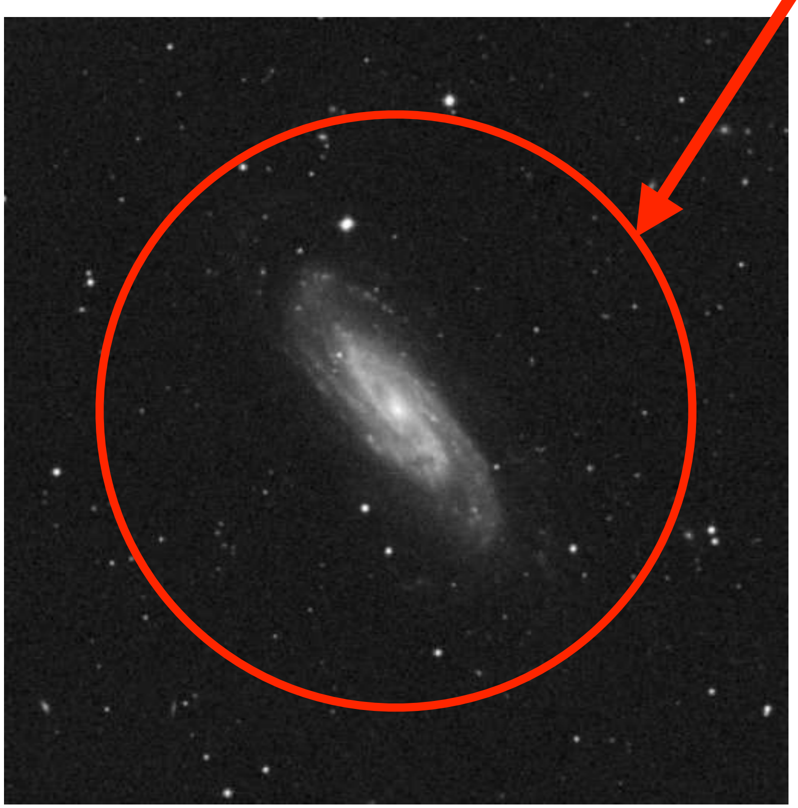
Beam size for
Green Bank 100 m



NGC3198
Palomar Digital Sky Survey

0.25°

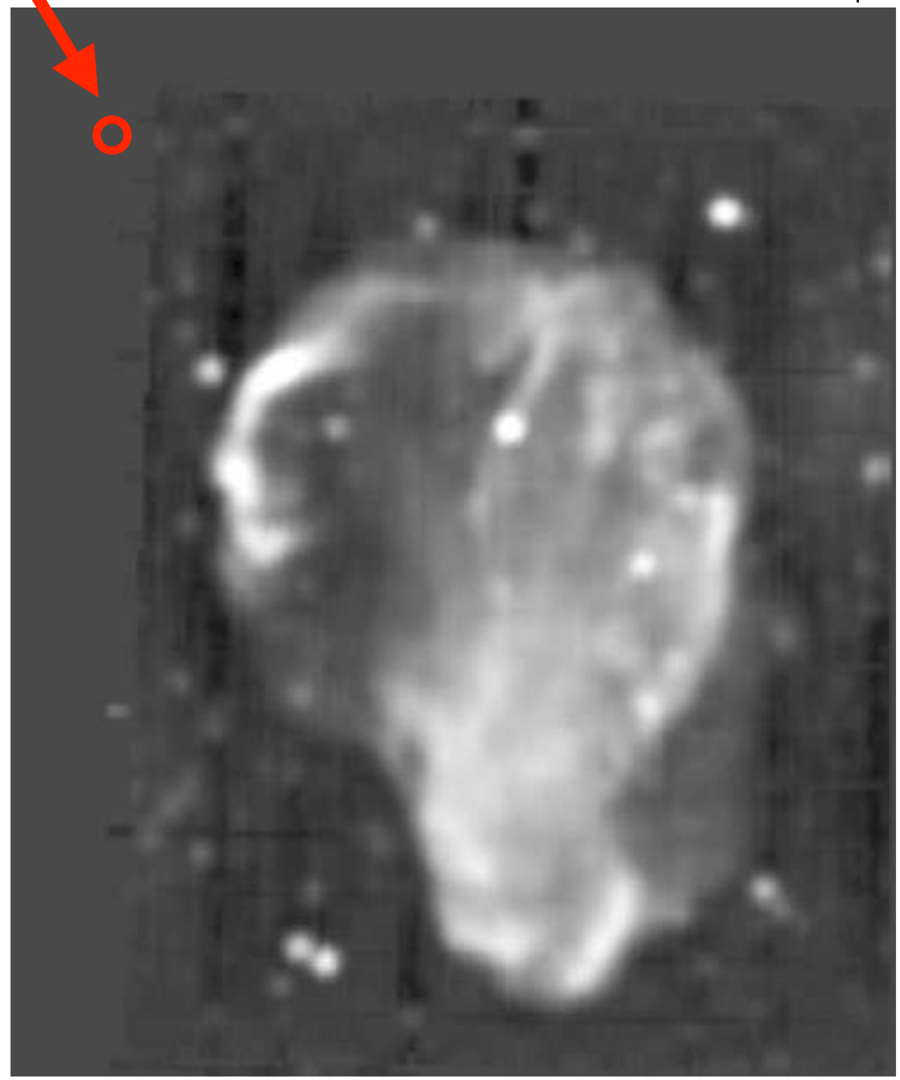
Beam size for
Green Bank 100 m



NGC3198
Palomar Digital Sky Survey

0.25°

Cygnus Loop (supernova remnant)
Green Bank Telescope

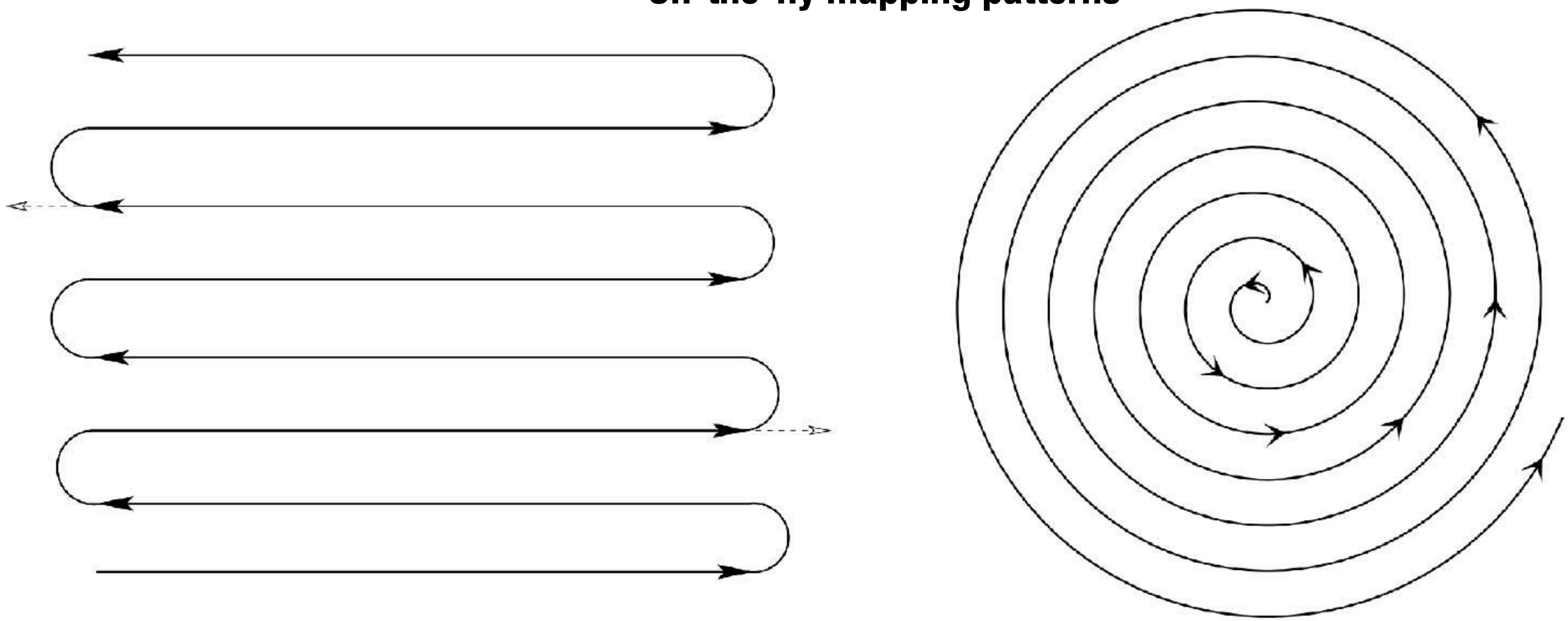


5°

Mapping

- On-the-fly mapping
- Drift scanning

On-the-fly mapping patterns



Magnum+ 2007

Challenge: Resolution

Whirlpool Galaxy, M51
Palomar Digital Sky Survey

$\theta \sim \lambda / D$

Optical Resolution
$\theta \sim 1''$

How Big?

Wavelength	Frequency	Diameter required for 1″ resolution
500 nm	600 THz	10 cm
1 μm	300 THz	0.2 m
1 mm	300 GHz	200 m
1 cm	30 GHz	2 km
10 cm	3 GHz	20 km
1 m	300 MHz	200 km
10 m	30 MHz	2000 km

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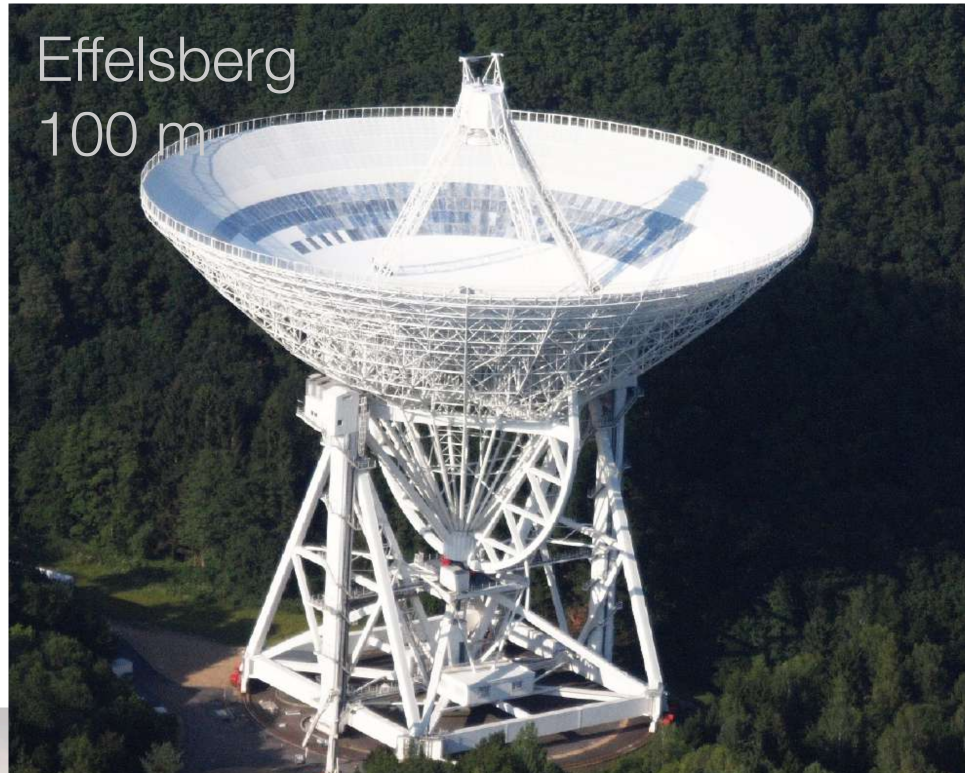
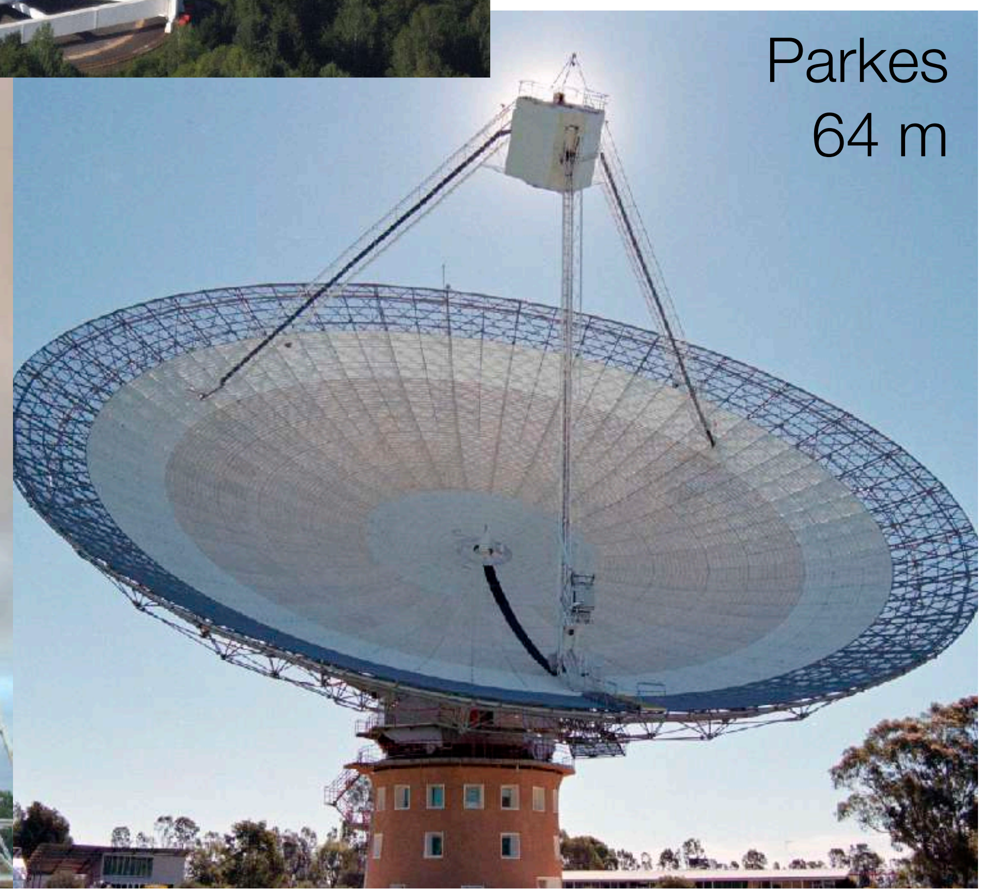
A bit of an engineering challenge!

Steerable dishes





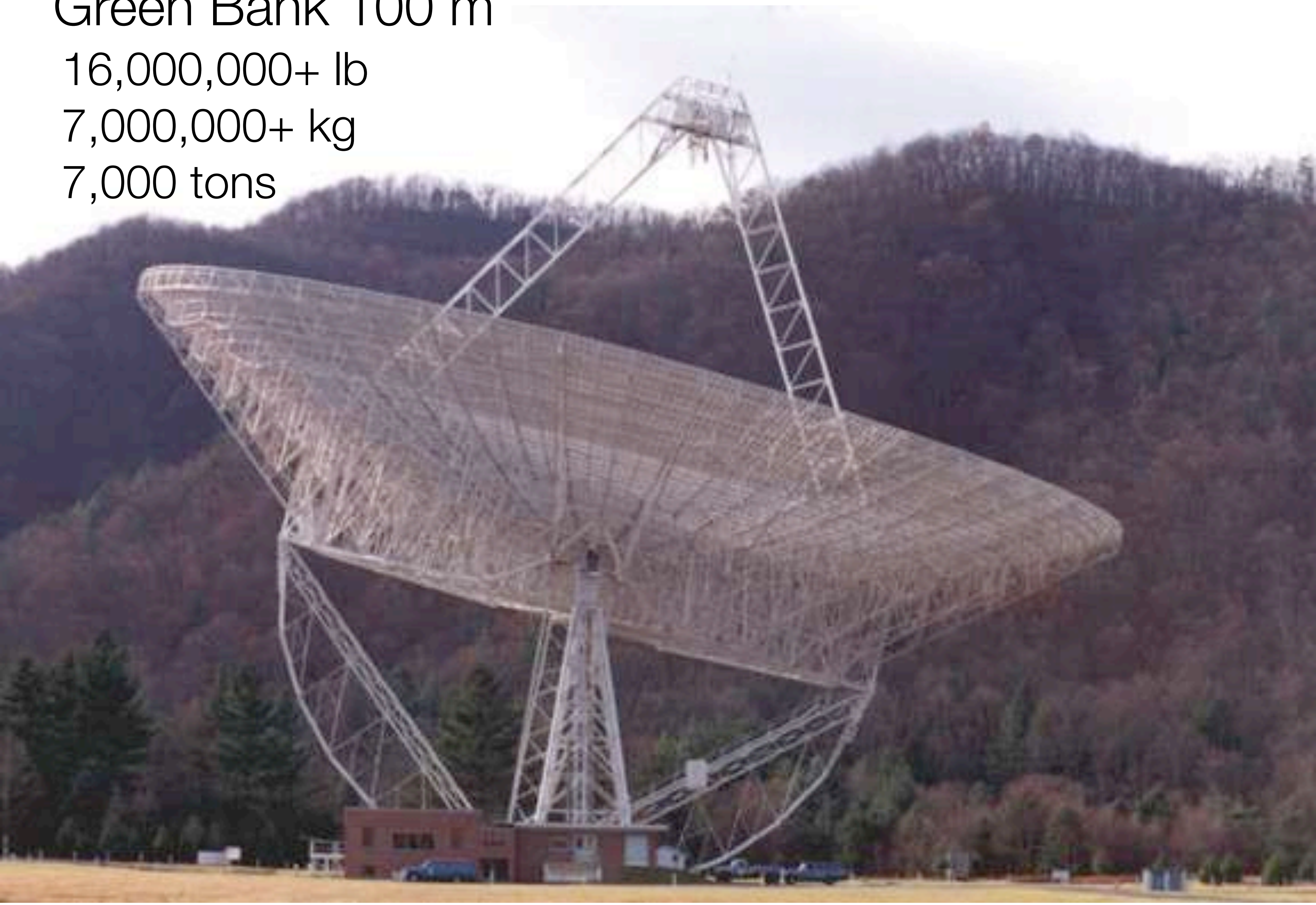
Green Bank 100 m

Green Bank 100 m

16,000,000+ lb

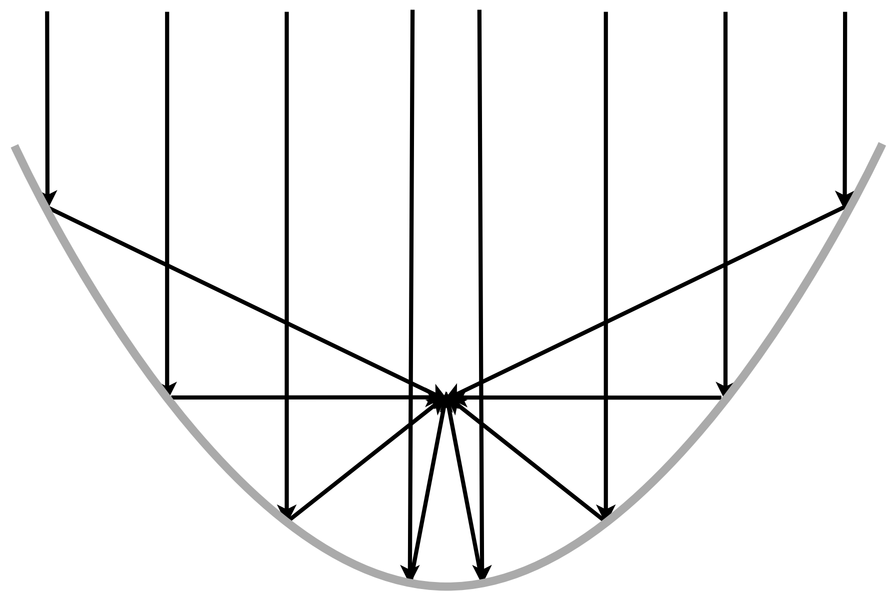
7,000,000+ kg

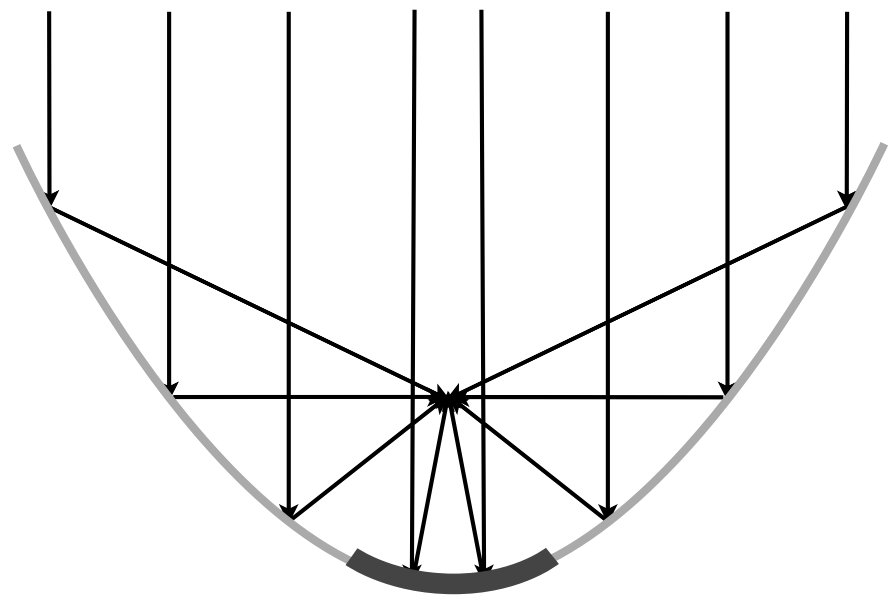
7,000 tons

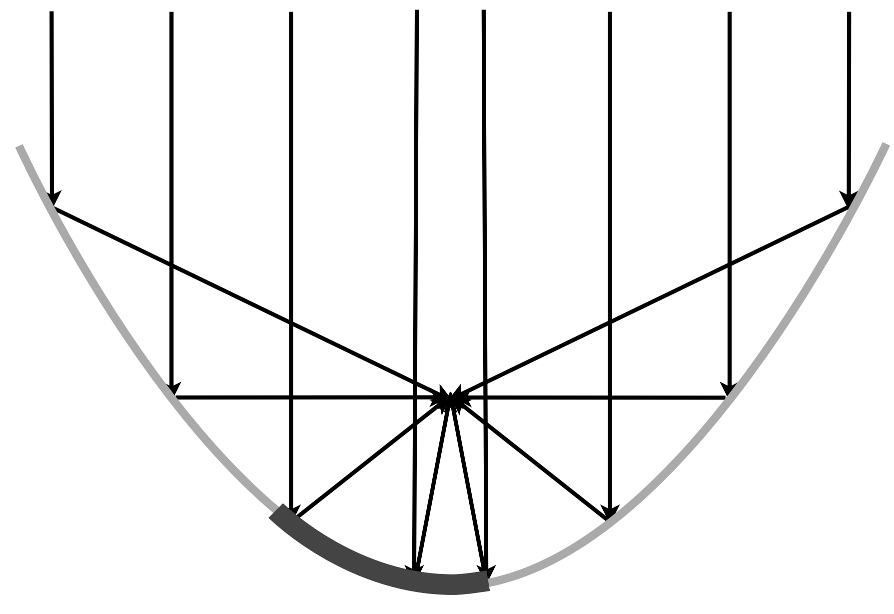


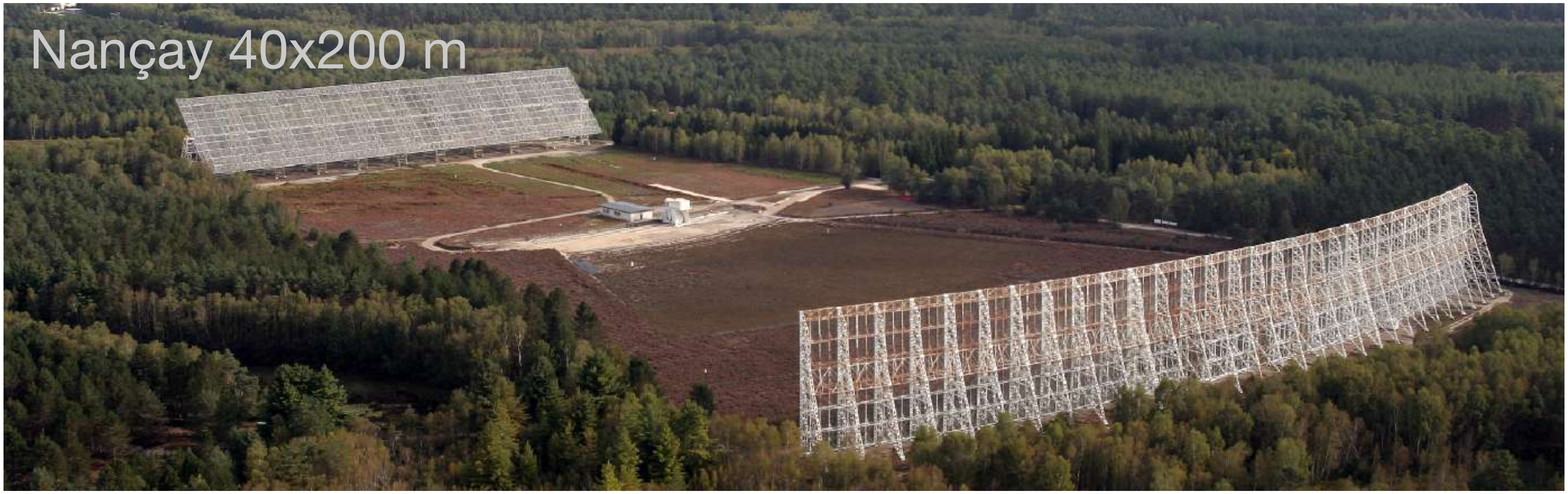
Green Bank 100 m

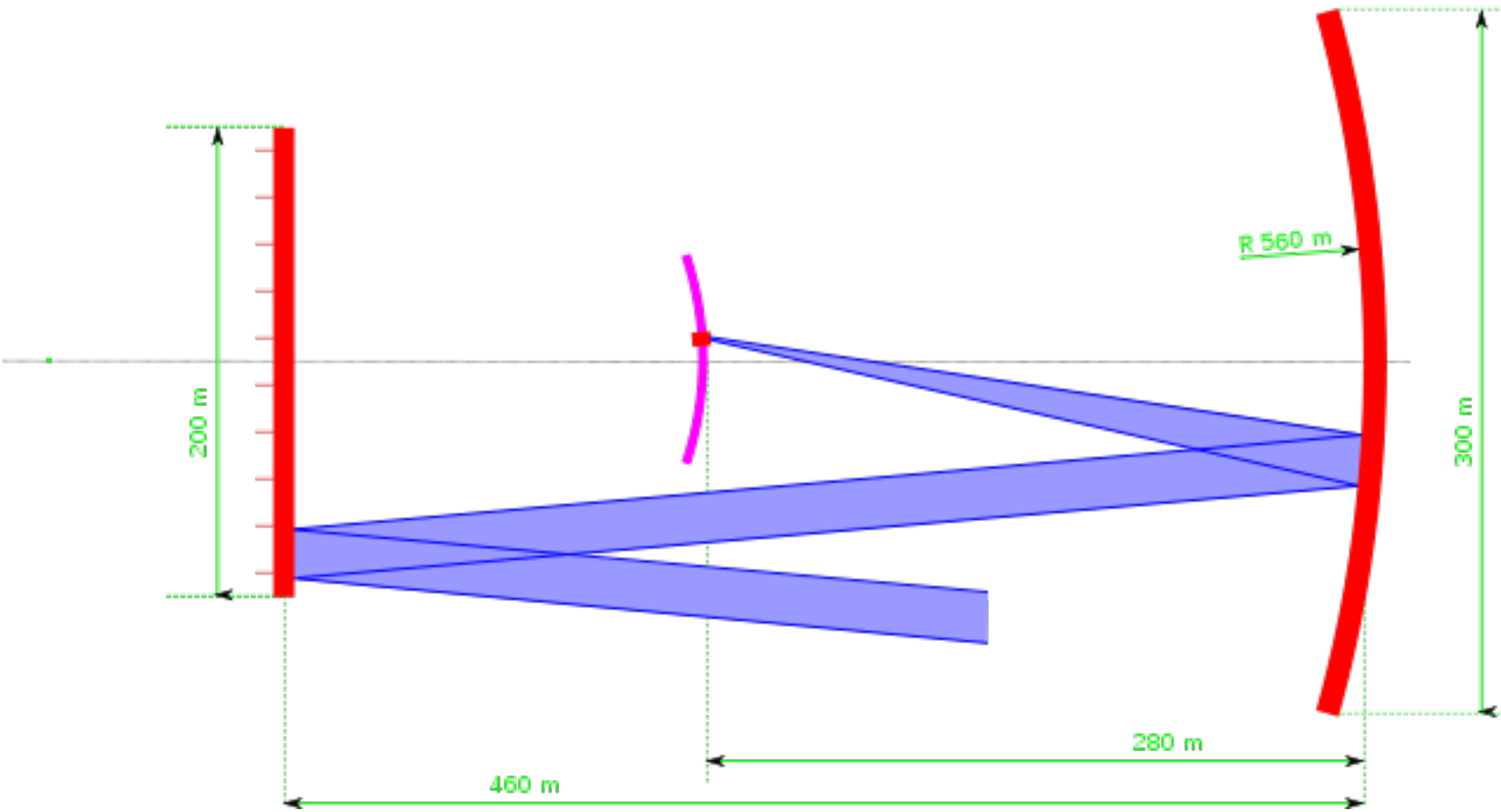
Green Bank 100 m








Nançay 40x200 m

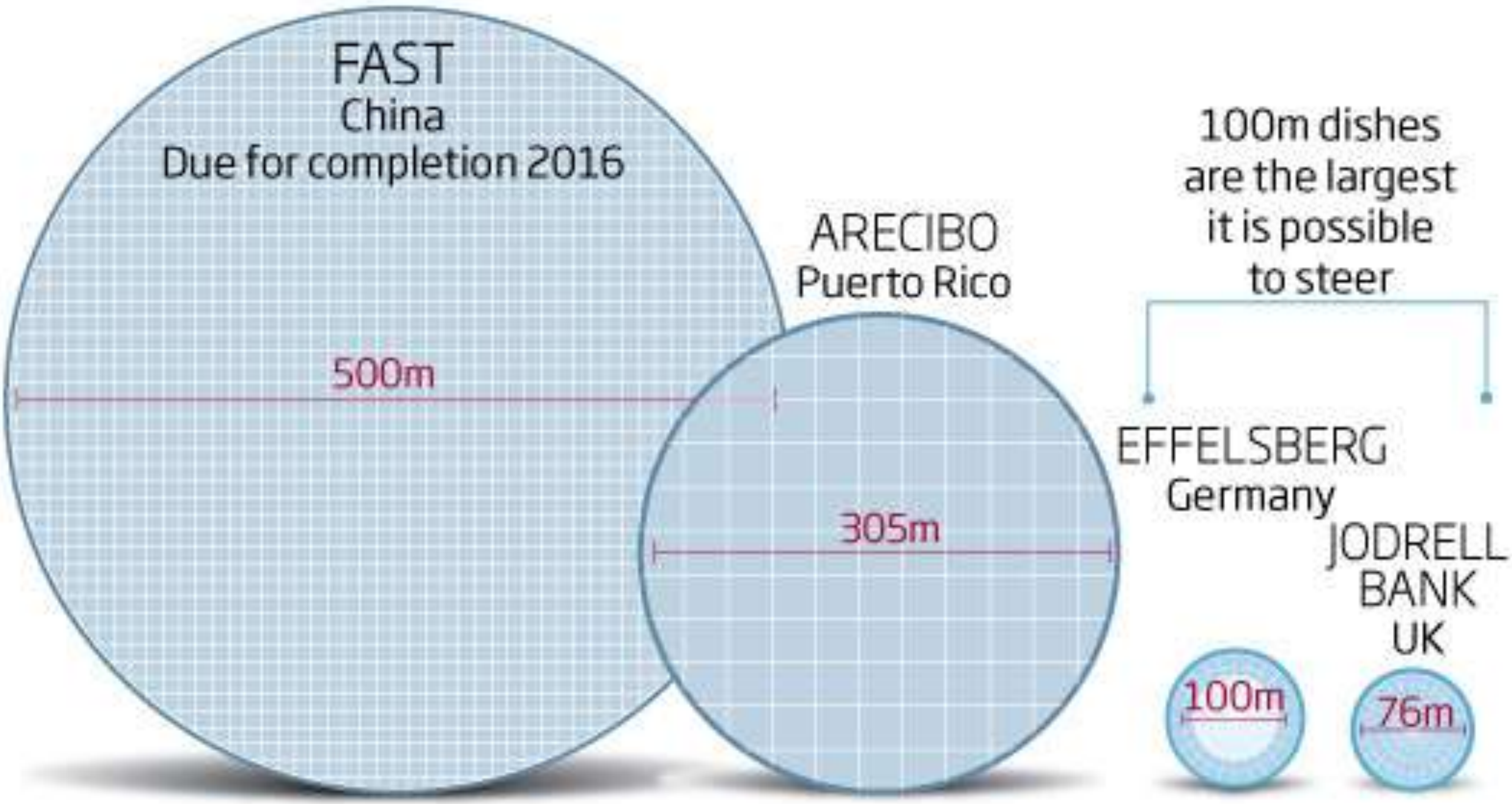

R 560 m
200 m
300 m
280 m
460 m

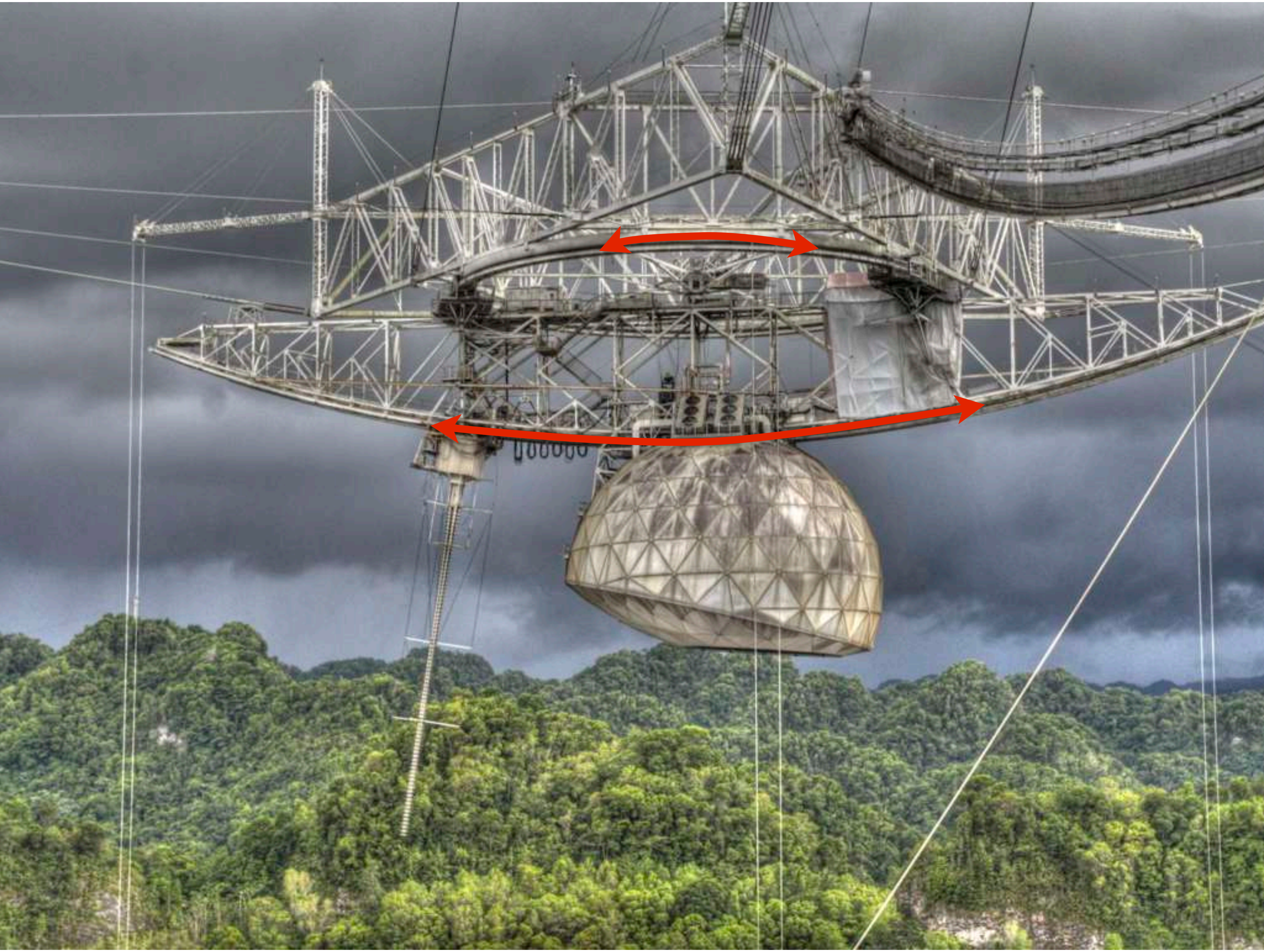

Five-hundred-meter Aperture
Spherical radio Telescope (FAST)


Arecibo 300 m

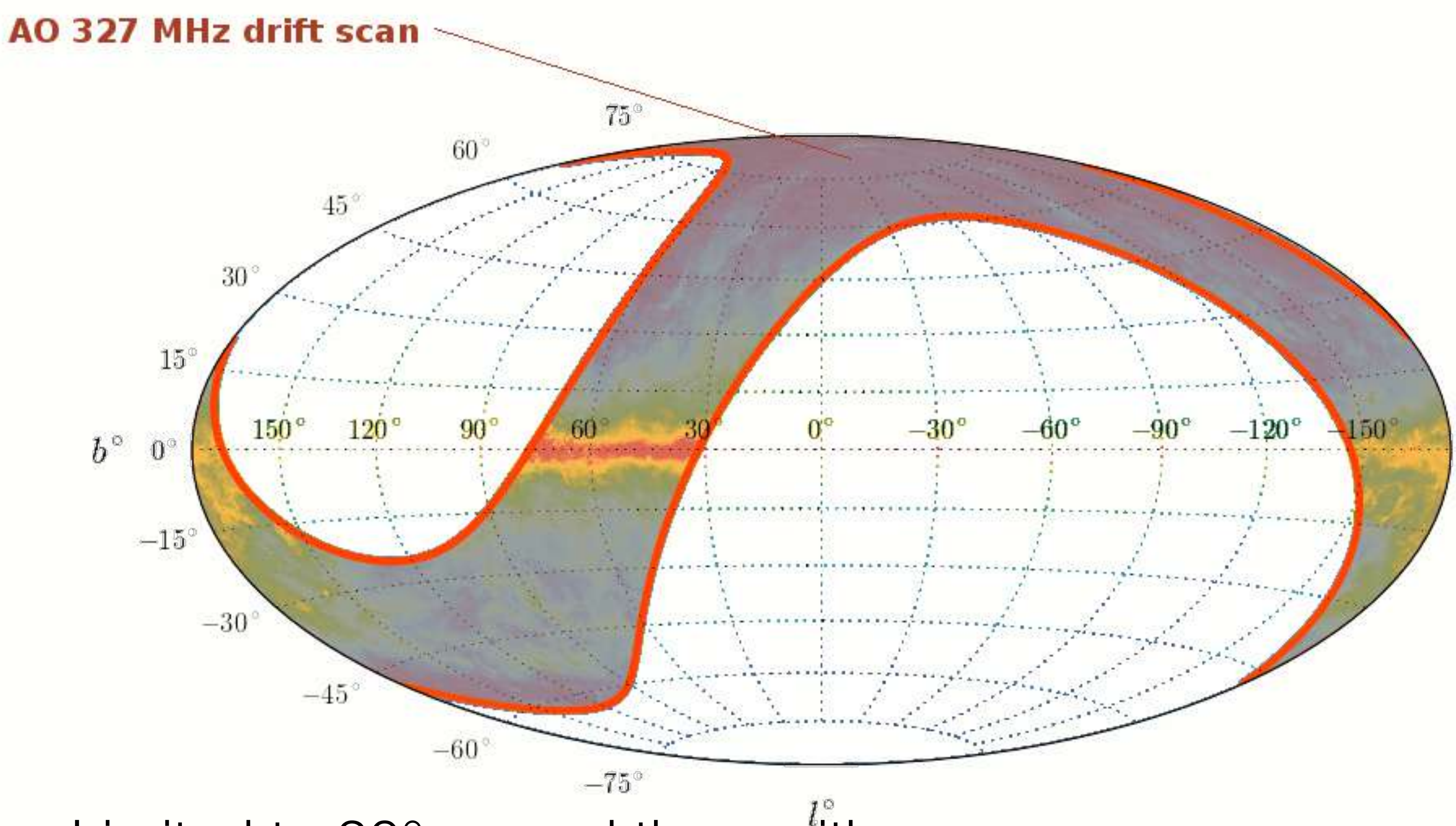
Telescopes go large

Radio astronomy will get a big boost with FAST, the world's most sensitive radio telescope

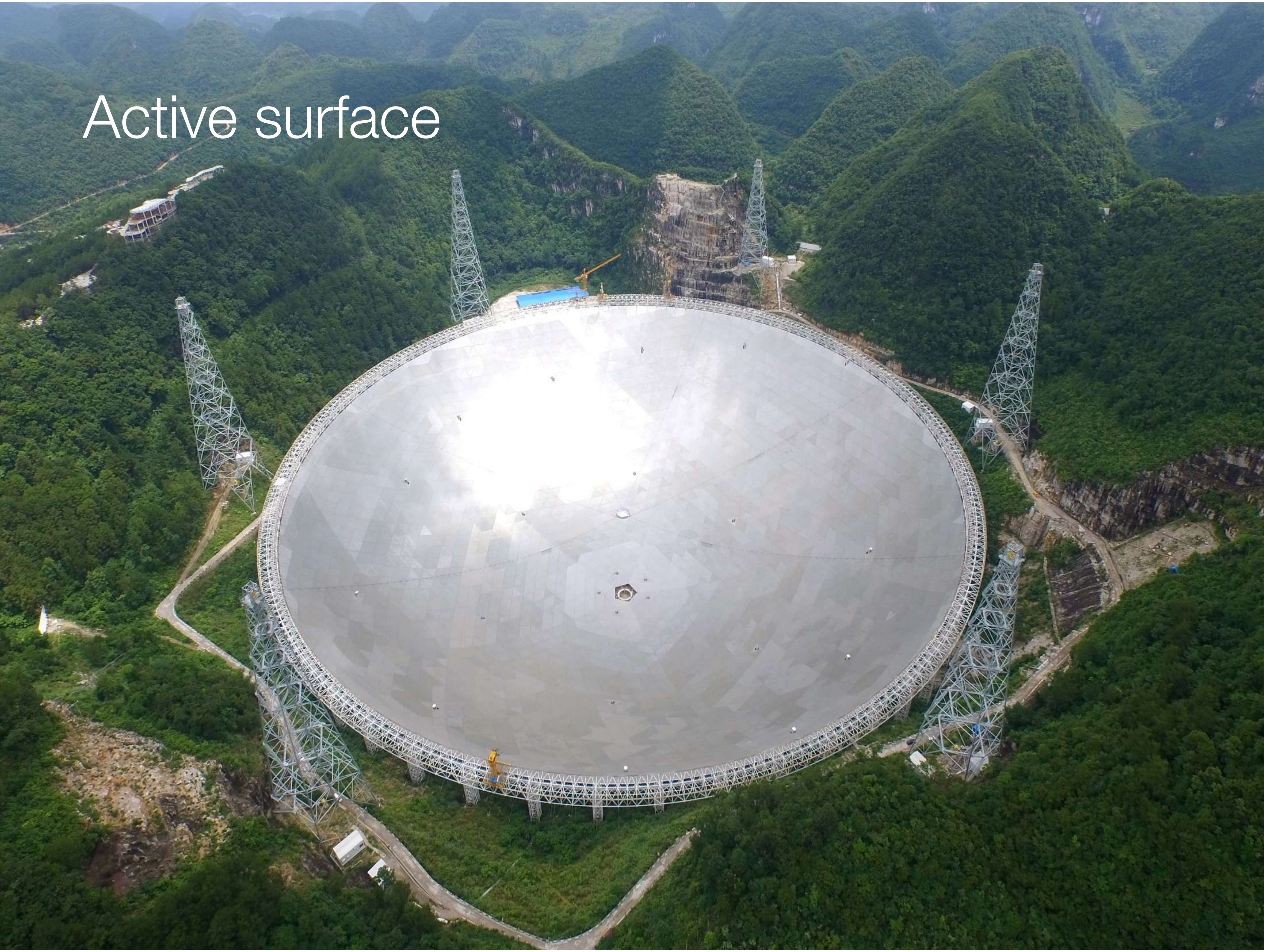




Arecibo Sky



Limited to 20° around the zenith


Active surface

How Big?

Wavelength	Frequency	Diameter required for 1″ resolution
500 nm	600 THz	10 cm
1 μm	300 THz	0.2 m
1 mm	300 GHz	200 m
1 cm	30 GHz	2 km
10 cm	3 GHz	20 km
1 m	300 MHz	200 km
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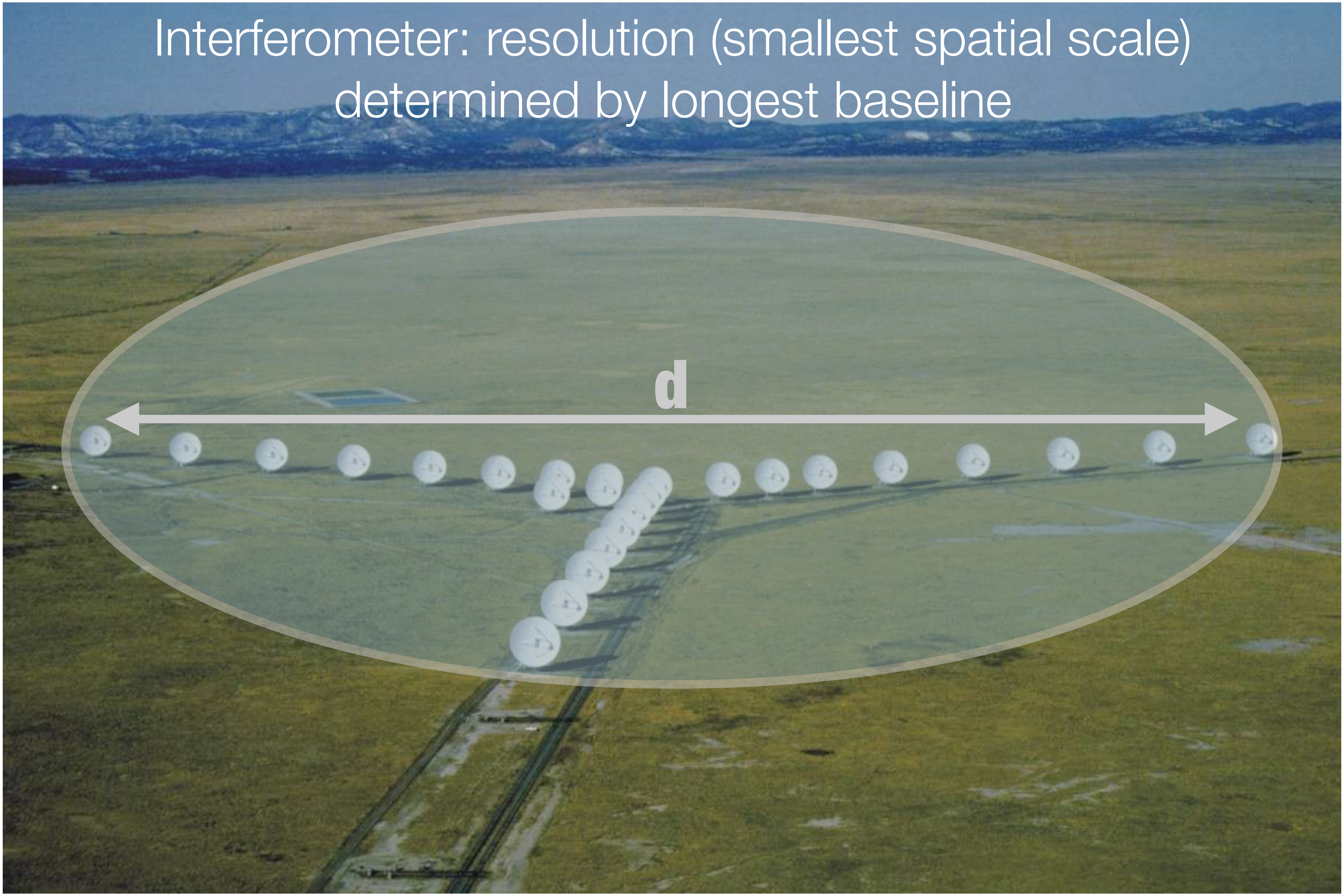
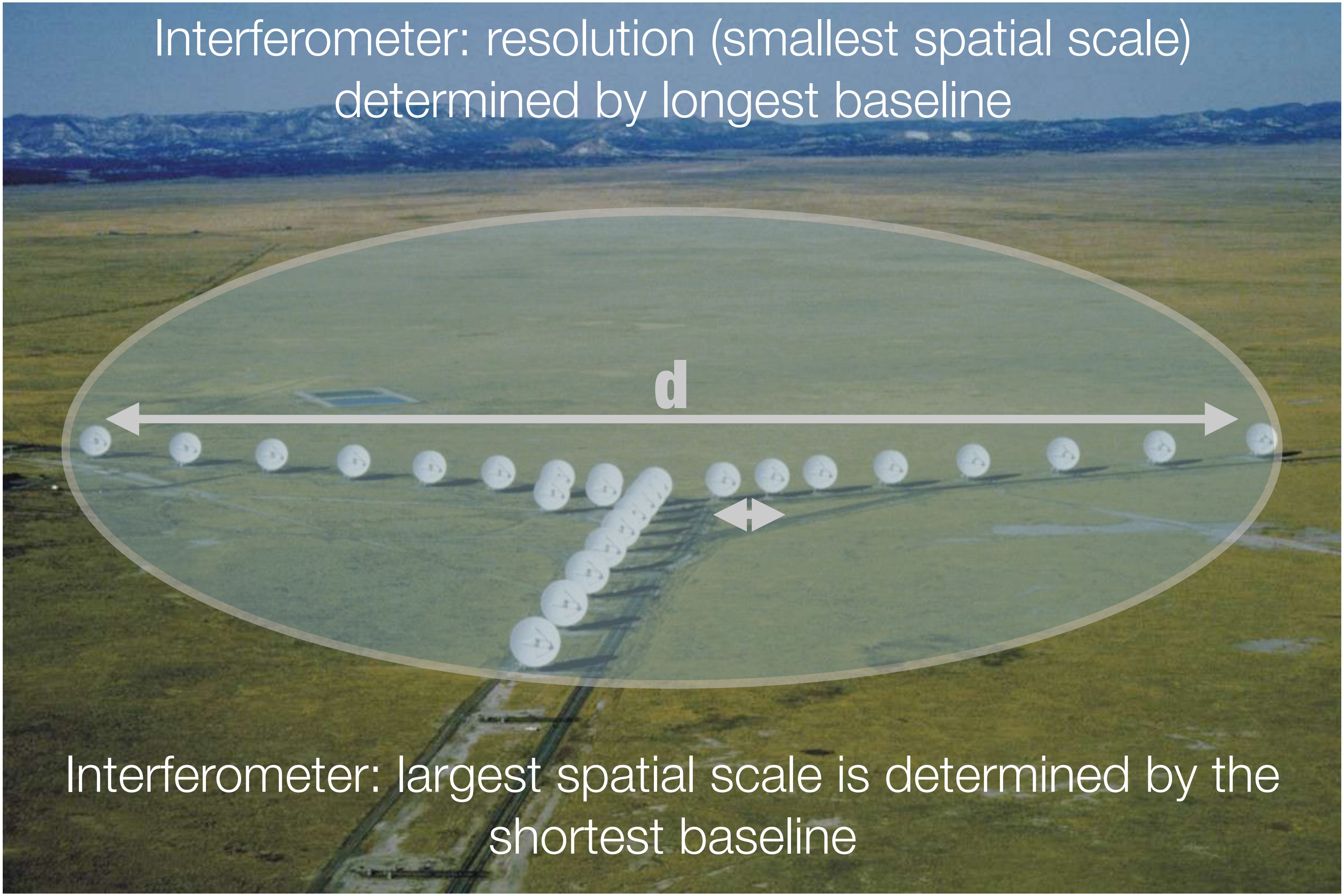
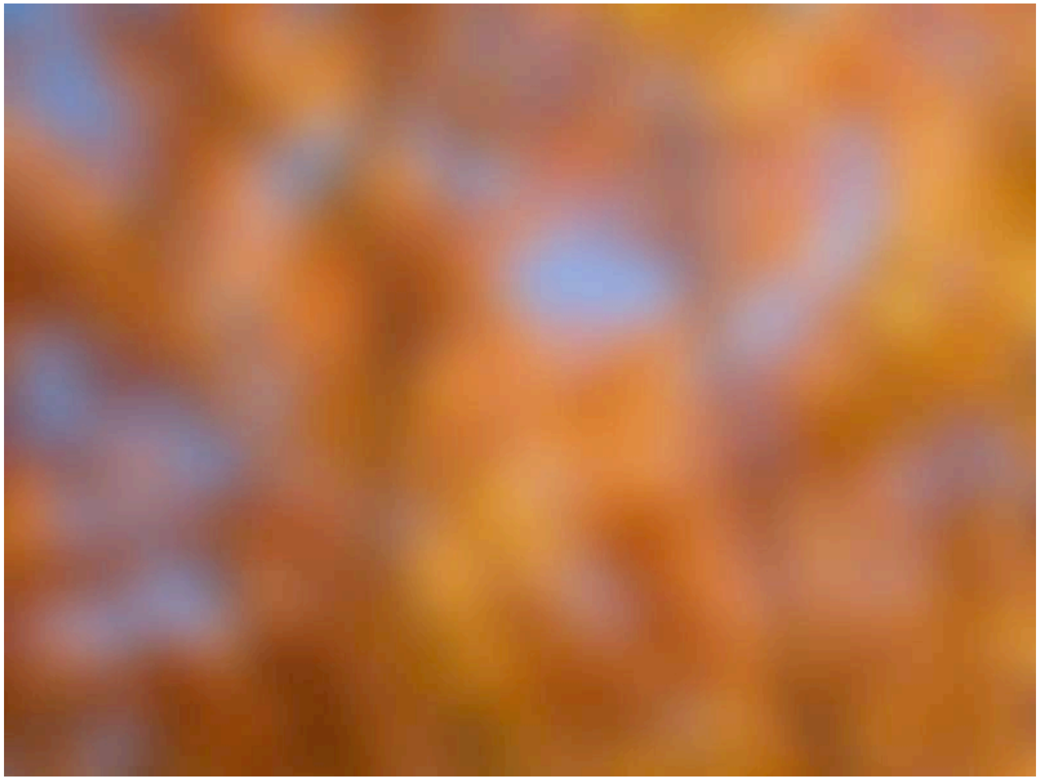
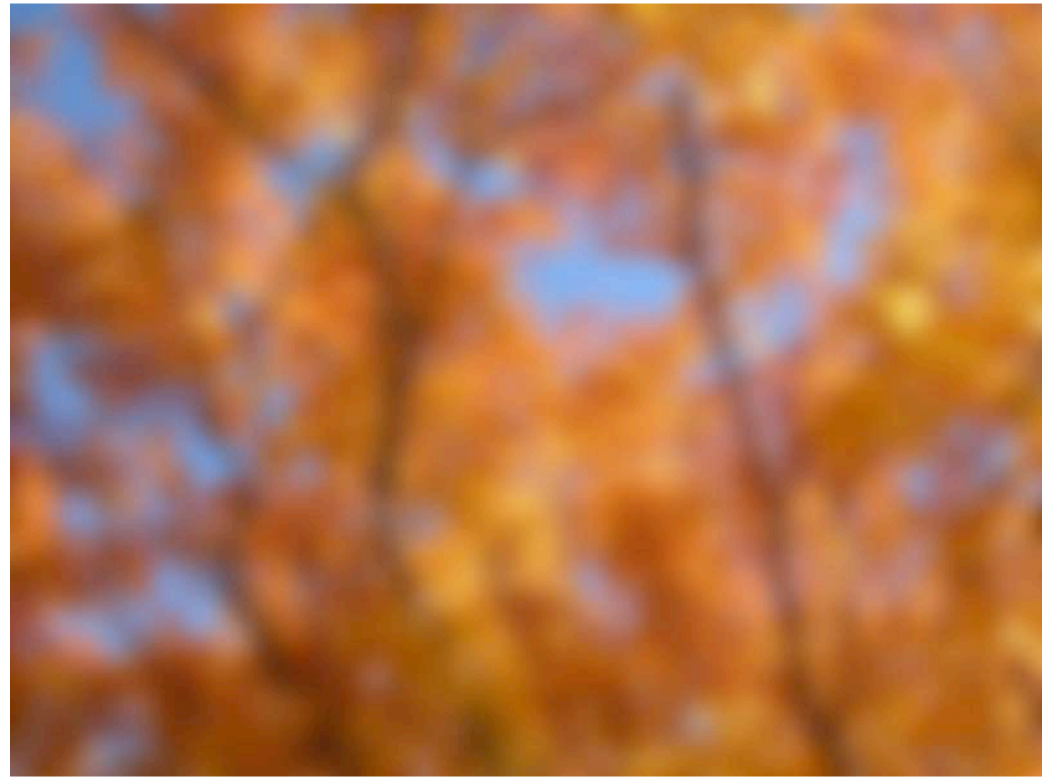
Alternatives to single dishes: Interferometers

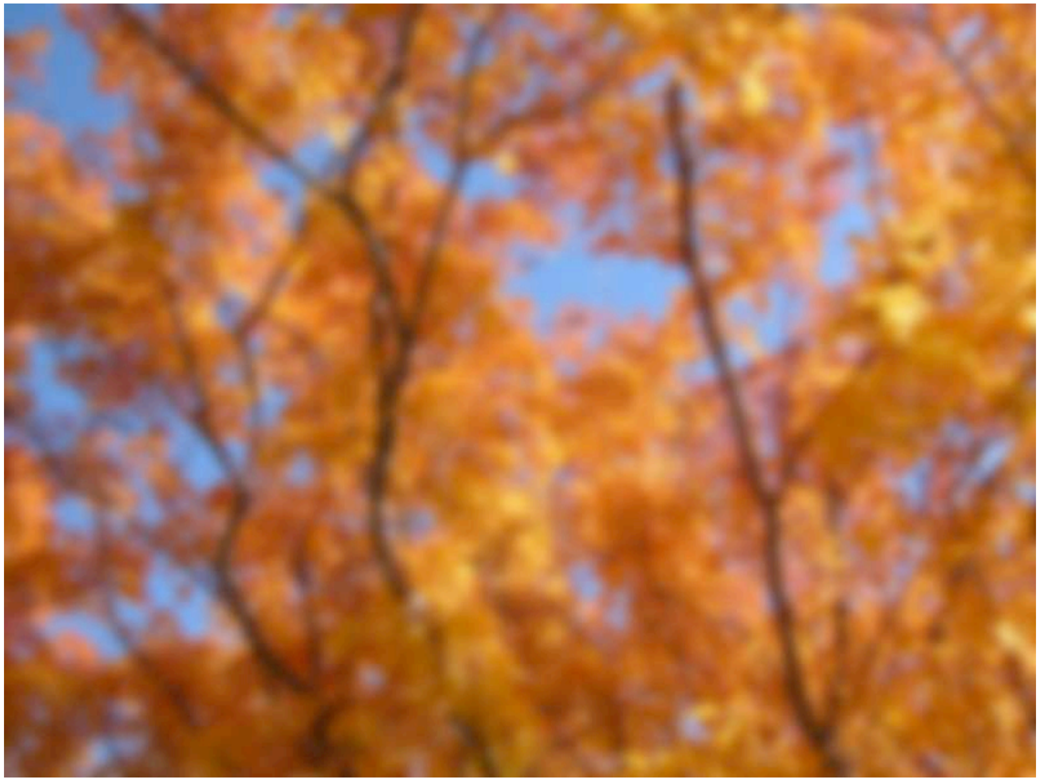

Interferometer: resolution (smallest spatial scale)
determined by longest baseline
d

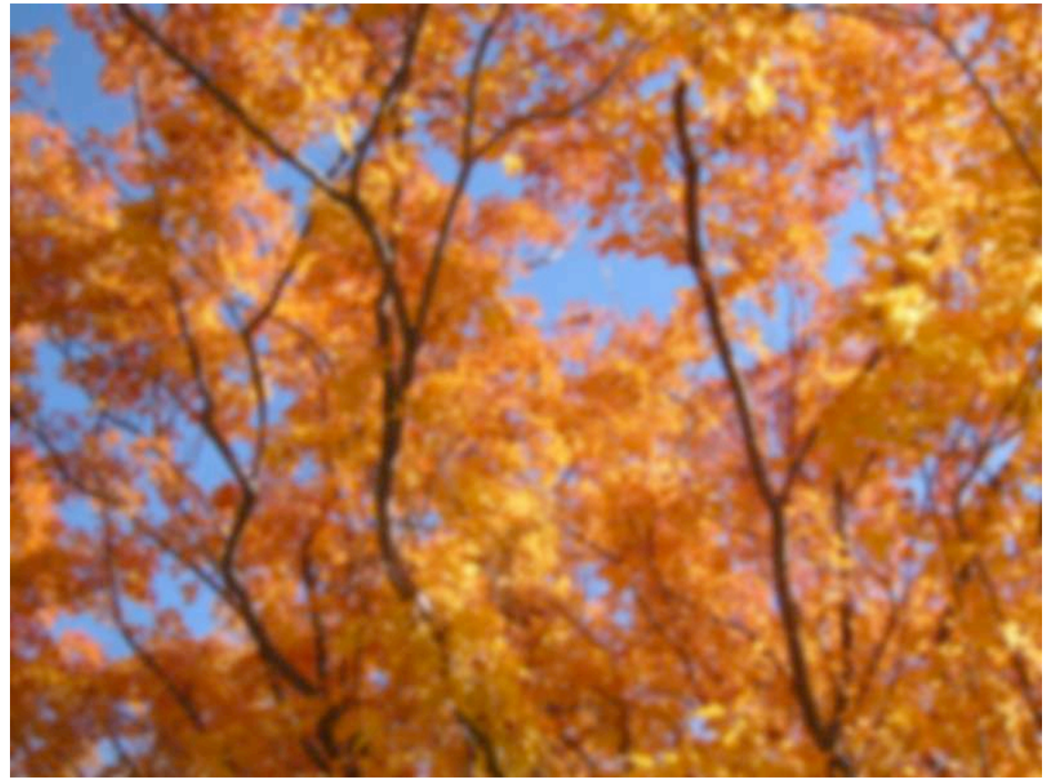

Interferometer: resolution (smallest spatial scale) determined by longest baseline
d
Interferometer: largest spatial scale is determined by the shortest baseline



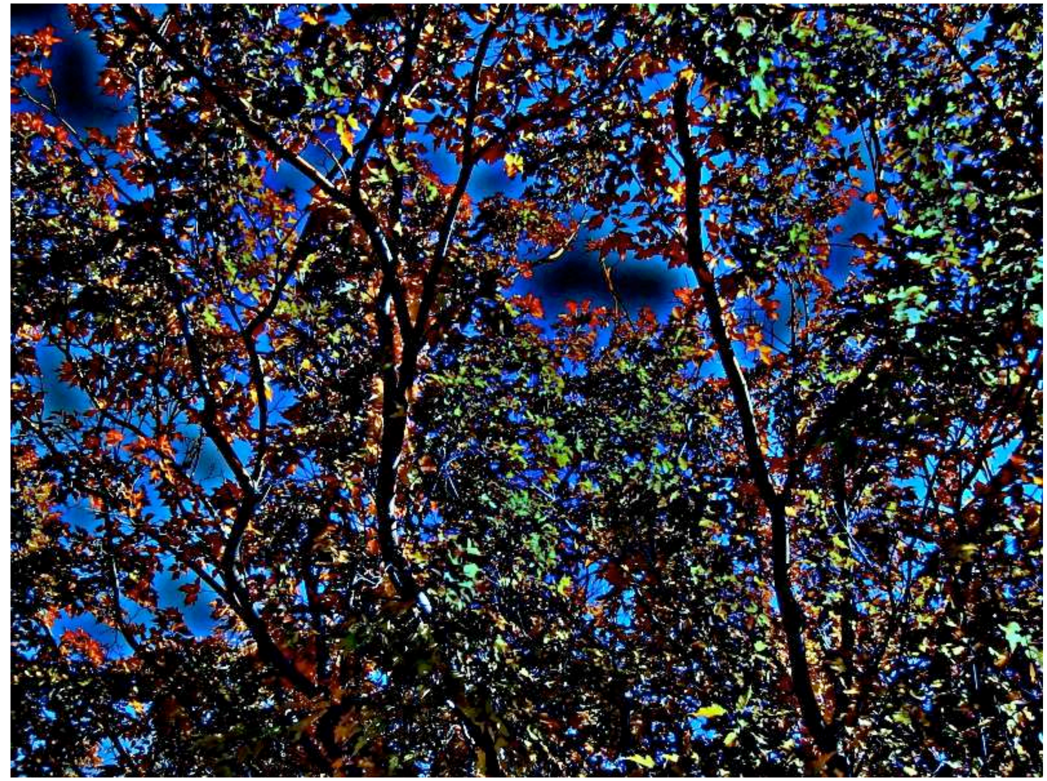


Low frequency spatial scales: short baselines





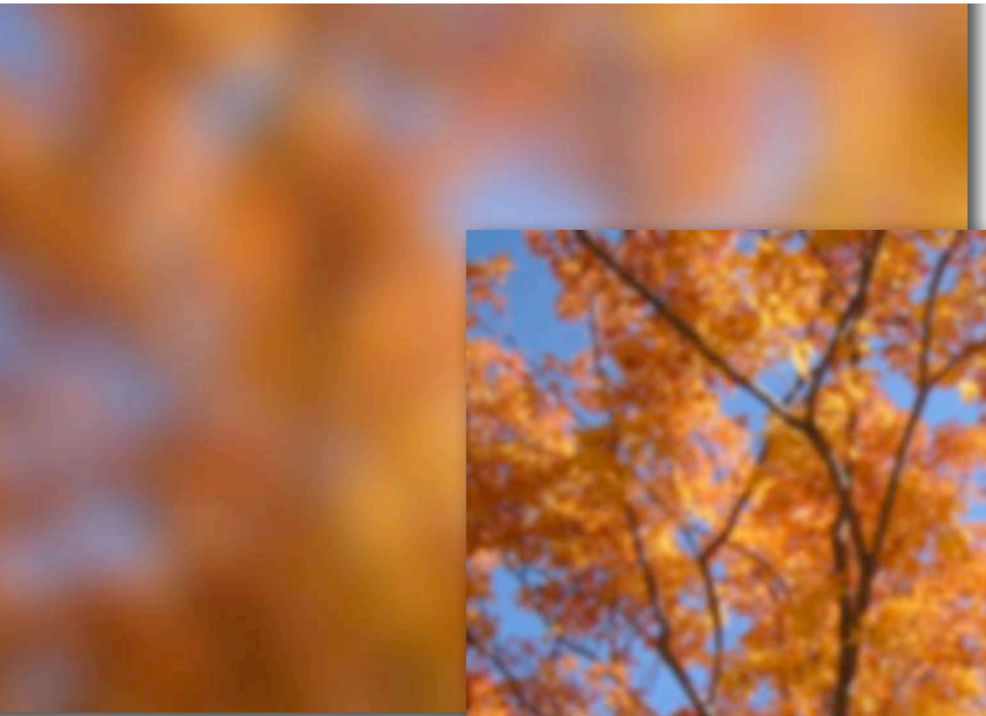
Mid frequency spatial scales: intermediate baselines

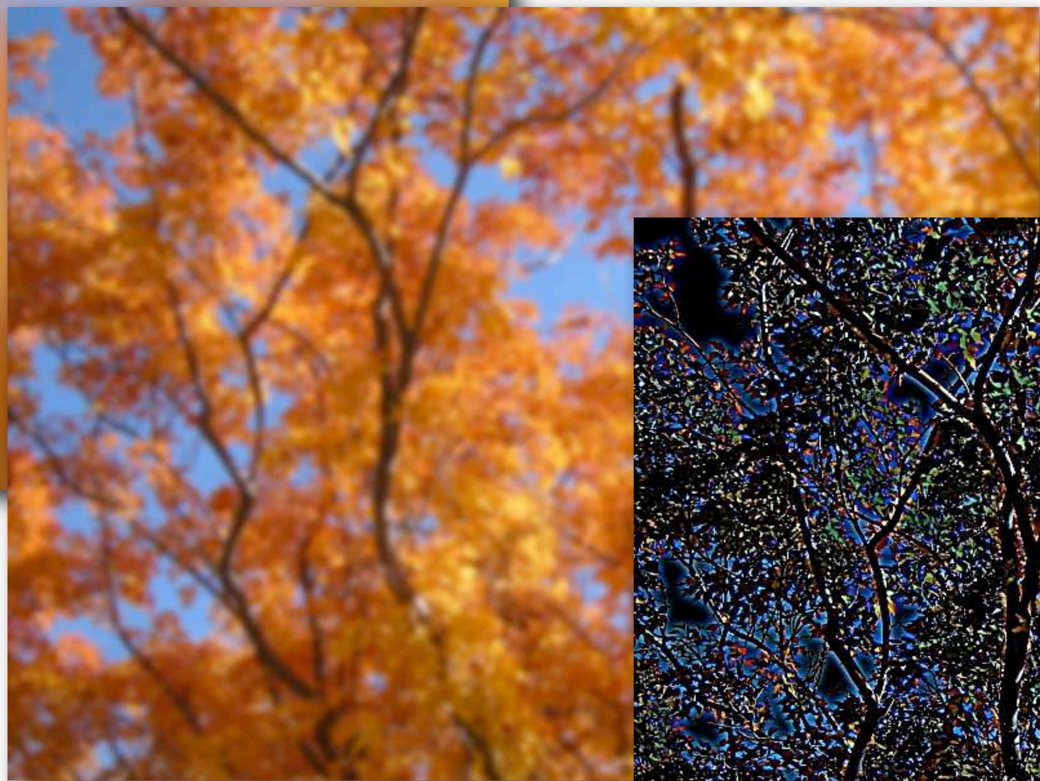


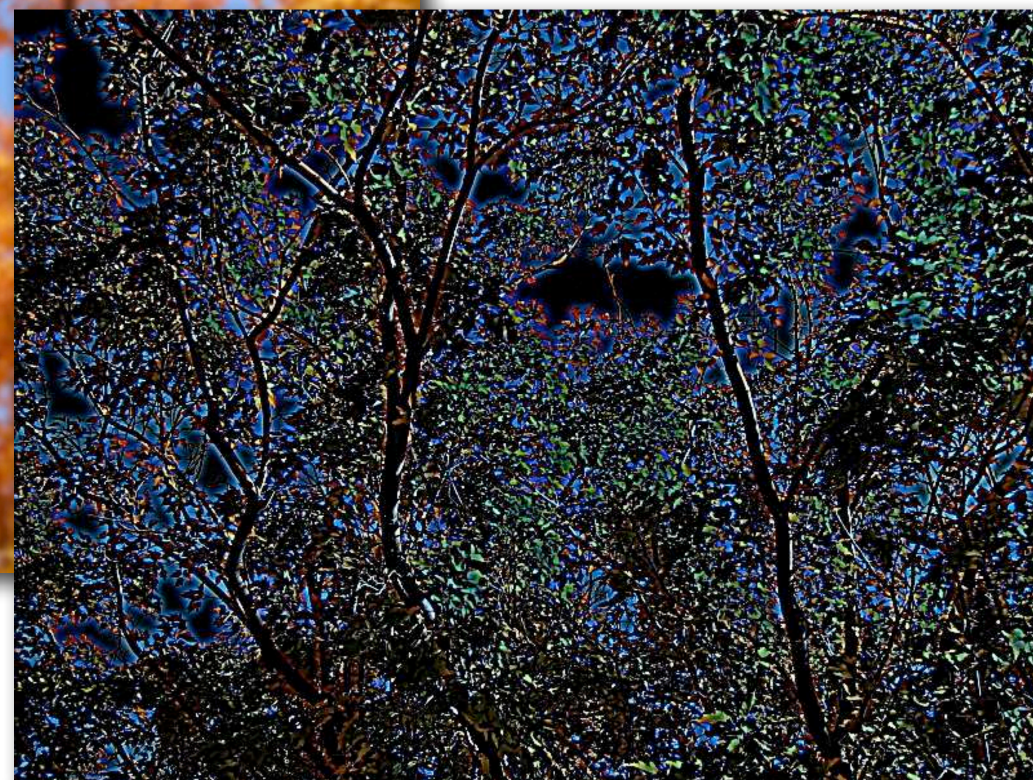
Mid frequency spatial scales: intermediate baselines


High frequency spatial scales: long baselines

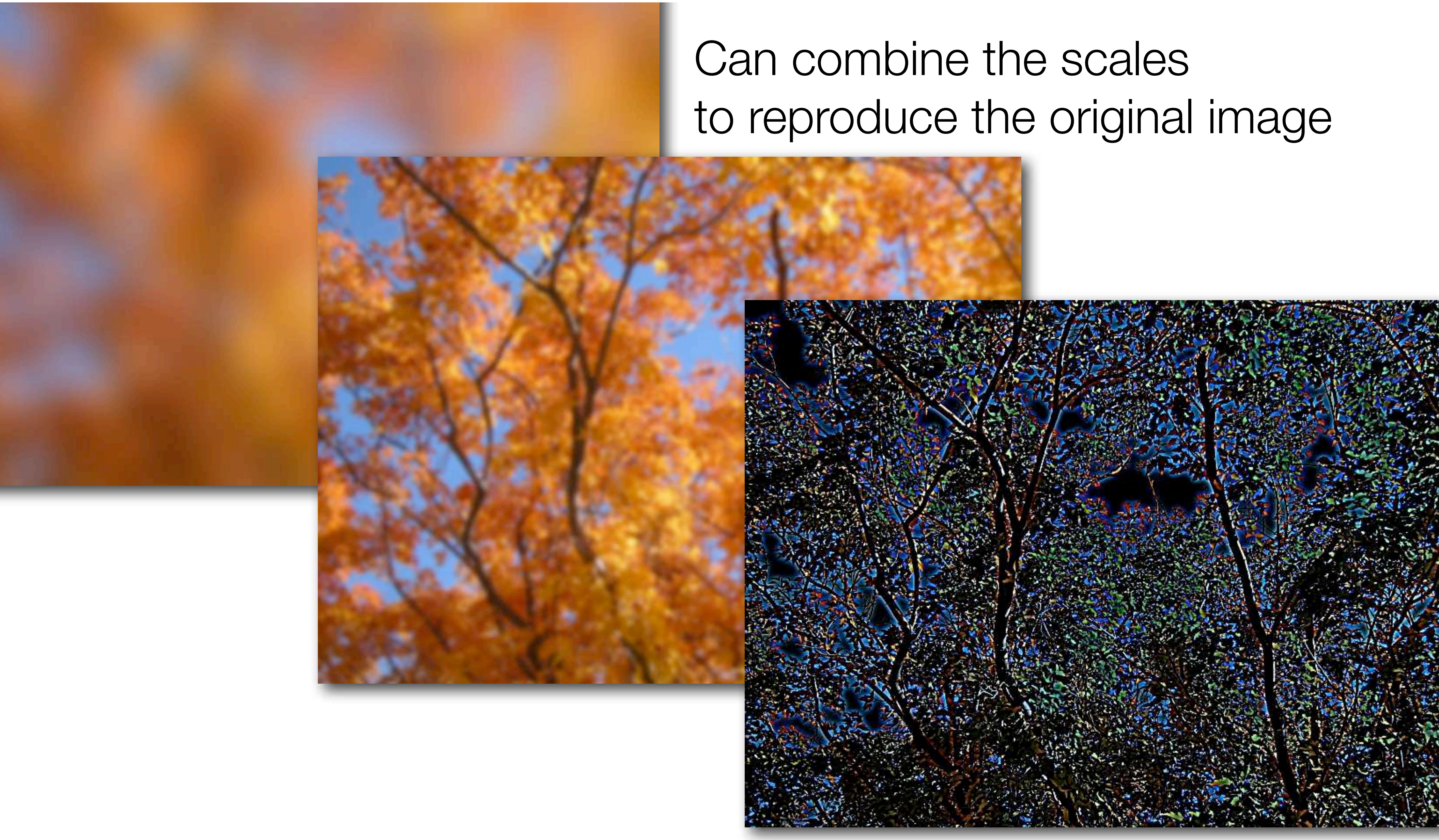
Can combine the scales
to reproduce the original image







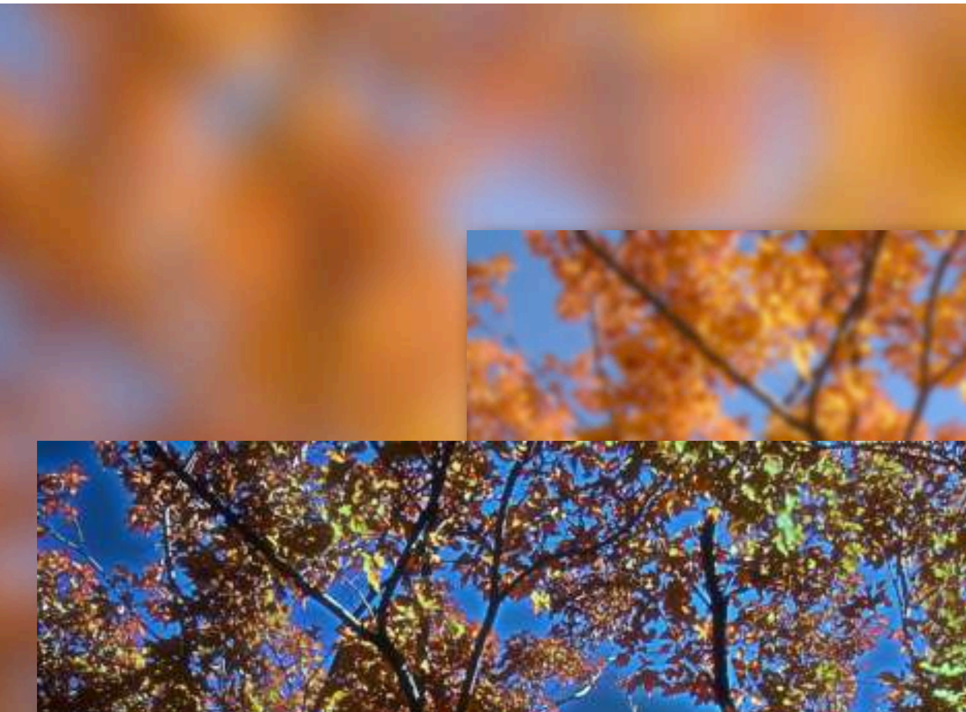
Can combine the scales
to reproduce the original image

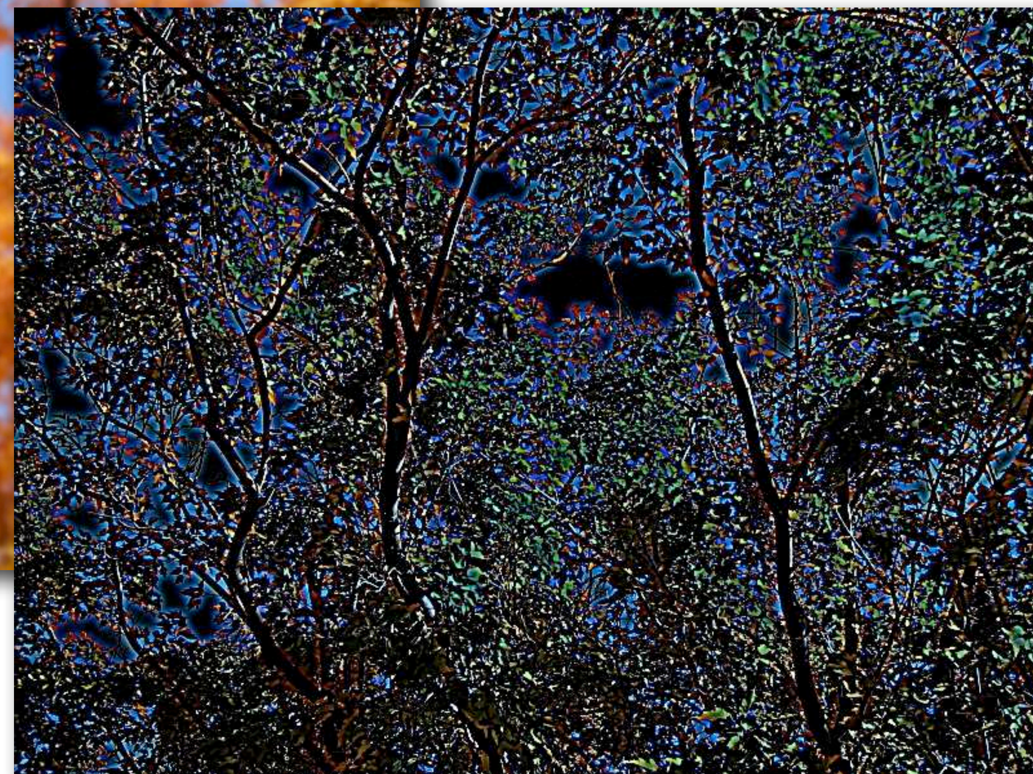


It is possible to approximate the image by using only some of the information.

Interferometers: each baseline detects only a particular spatial scale - image is not necessarily (usually) complete.

Can combine the scales
to reproduce the original image

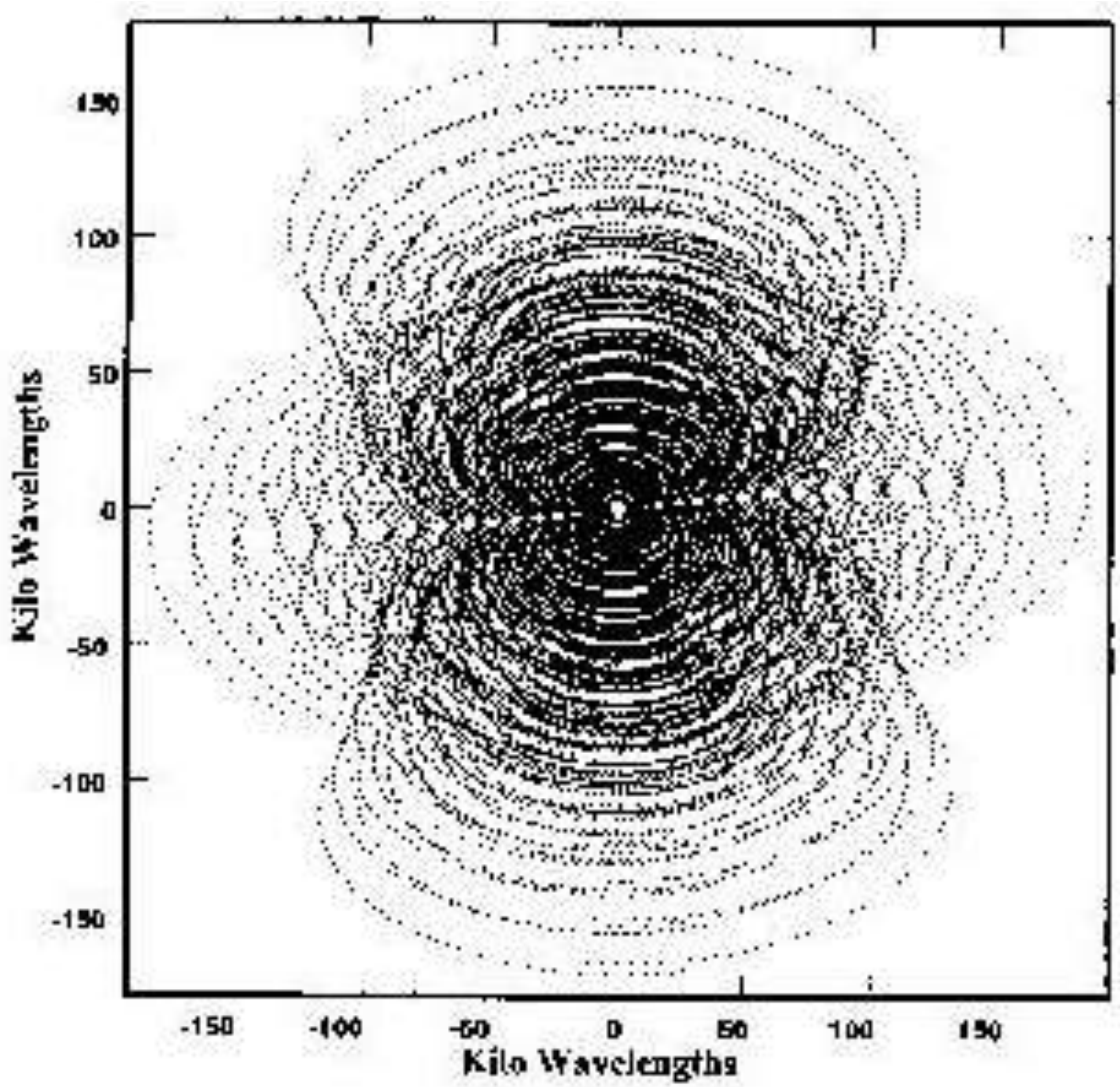


It is possible to approximate the image by using only some of the information.

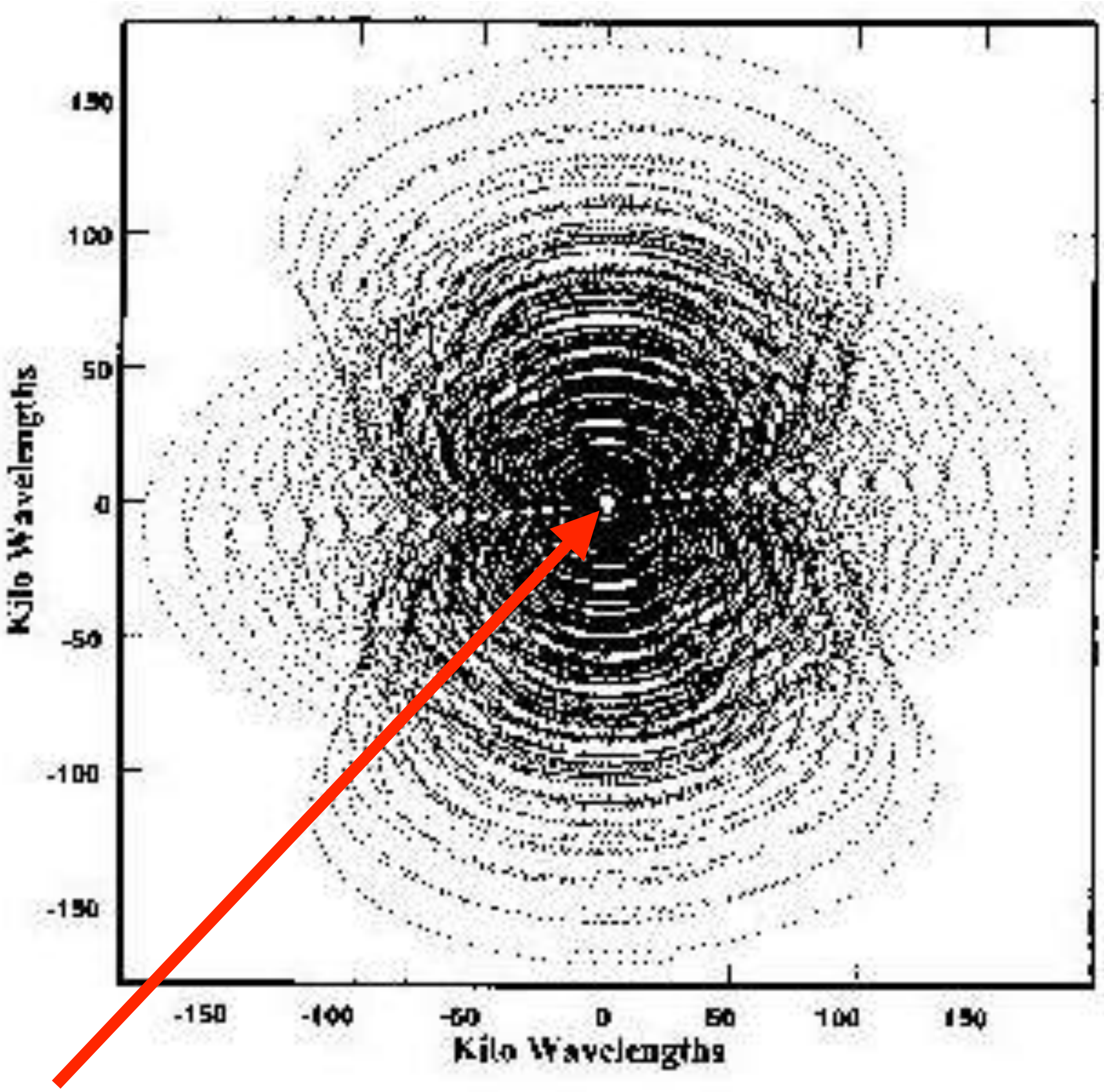
Interferometers: each baseline detects only a particular spatial scale - image is not necessarily (usually) complete.

Interferometer
measures
Fourier transform
of an image



Stanimirovic 2002

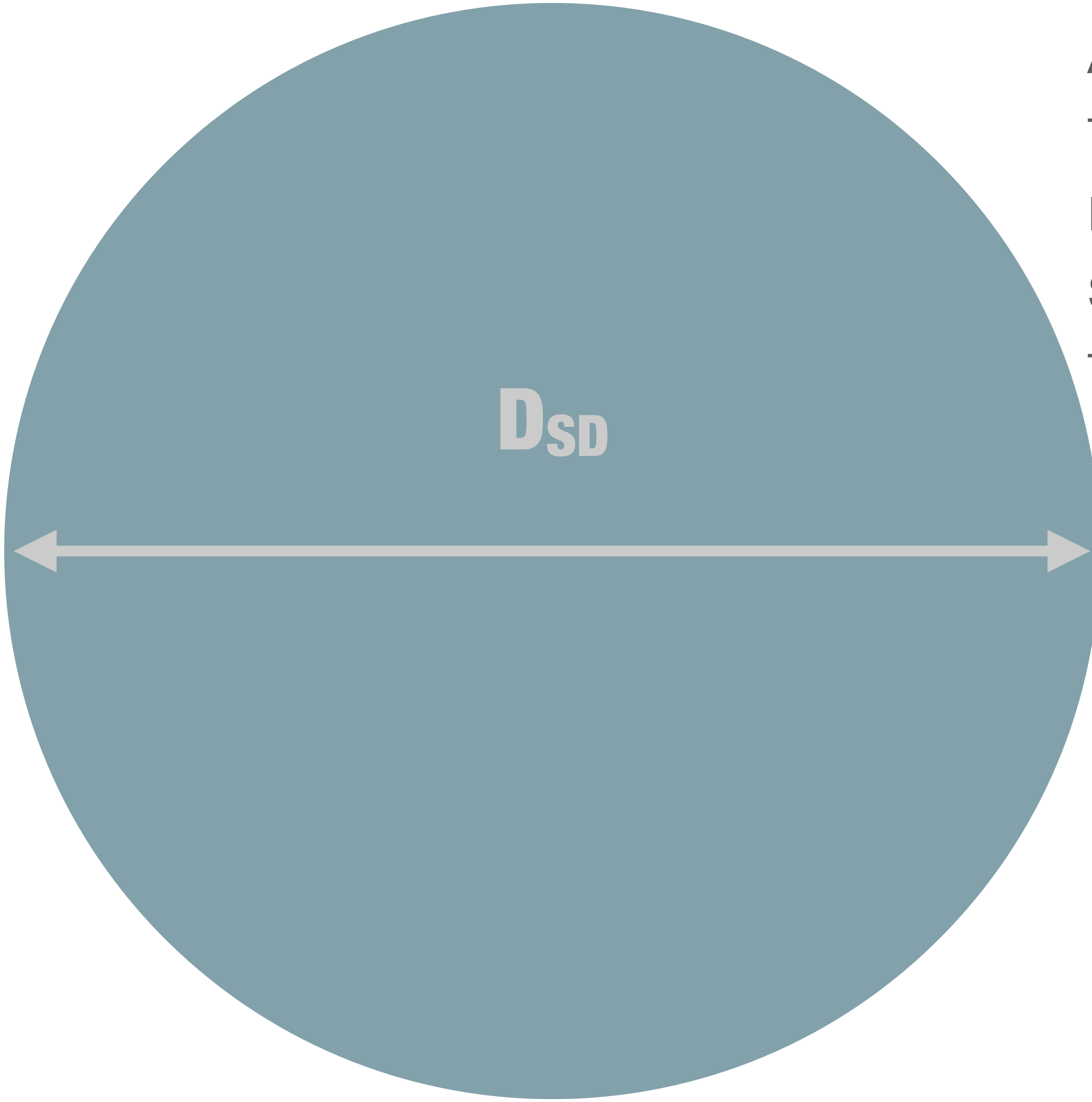
Interferometer measures Fourier transform of an image



Stanimirovic 2002

Gap at the centre of the uv-domain: the diameter of the single dish in the interferometer is smaller than the minimum baseline

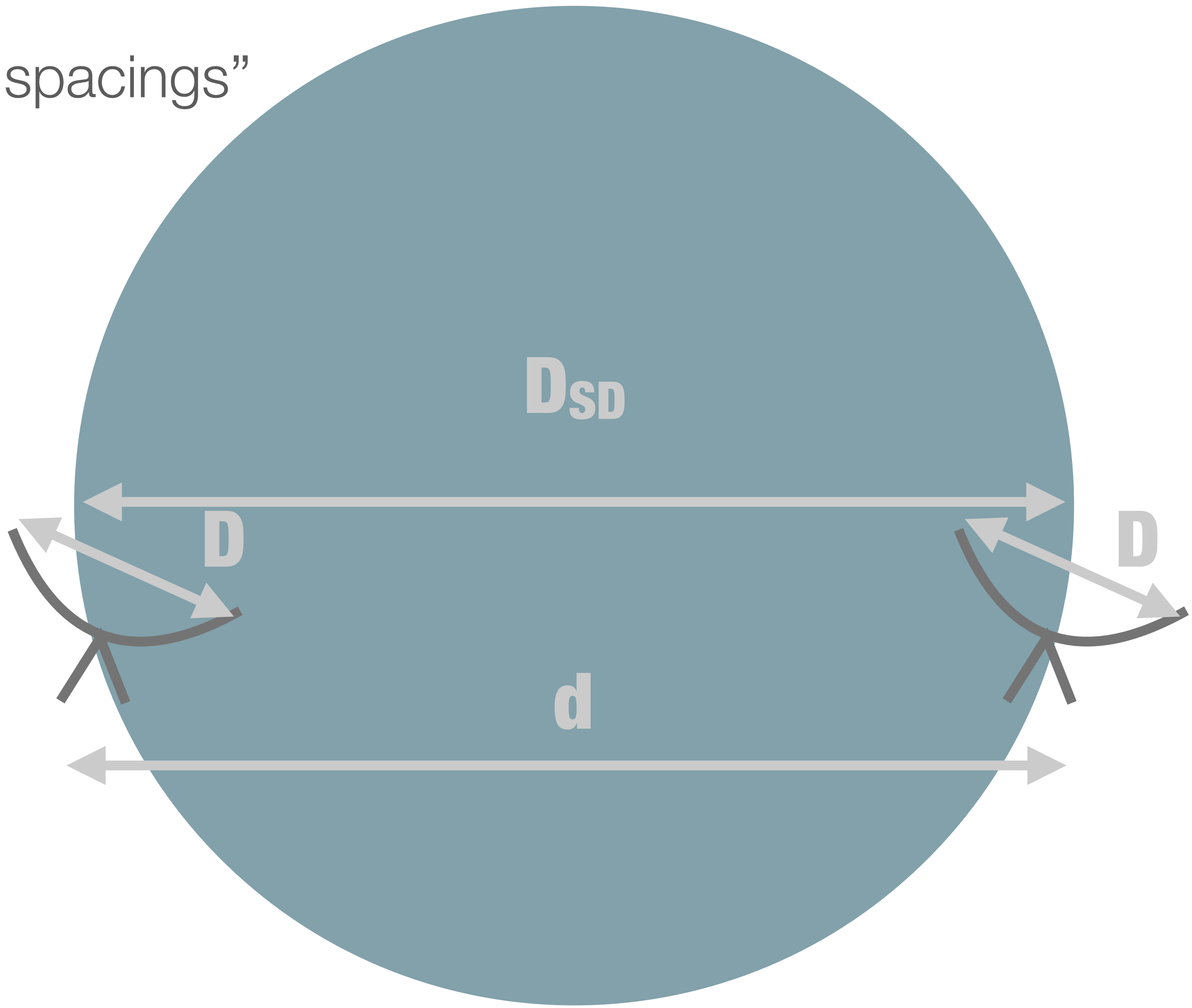
Single dish: Resolution (smallest spatial scale) determined by diameter.



Aperture is filled so not missing low spatial frequencies!

Use a single dish to fill in the missing information for an interferometer.

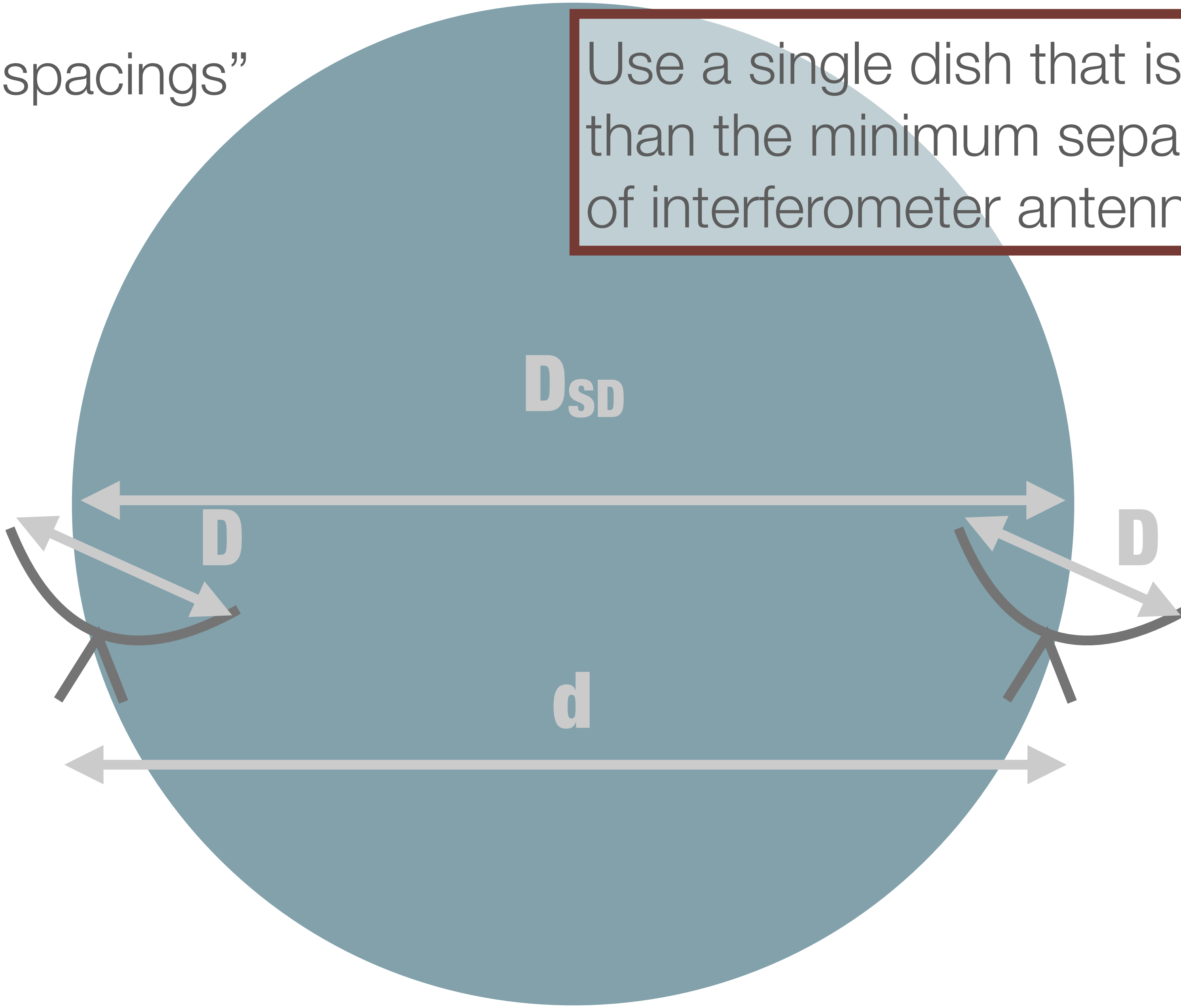
“Zero spacings”

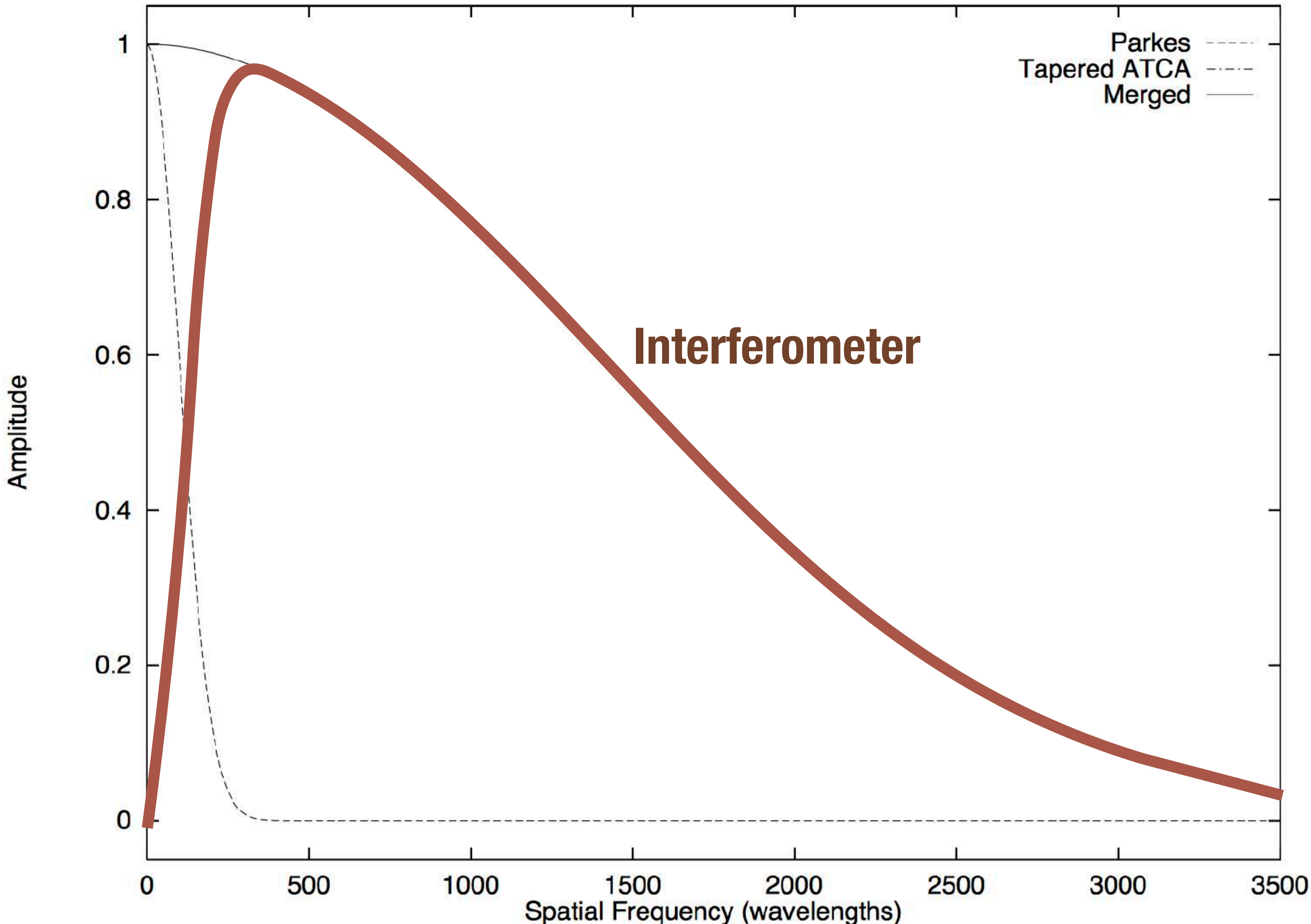


Use a single dish to fill in the missing information for an interferometer.

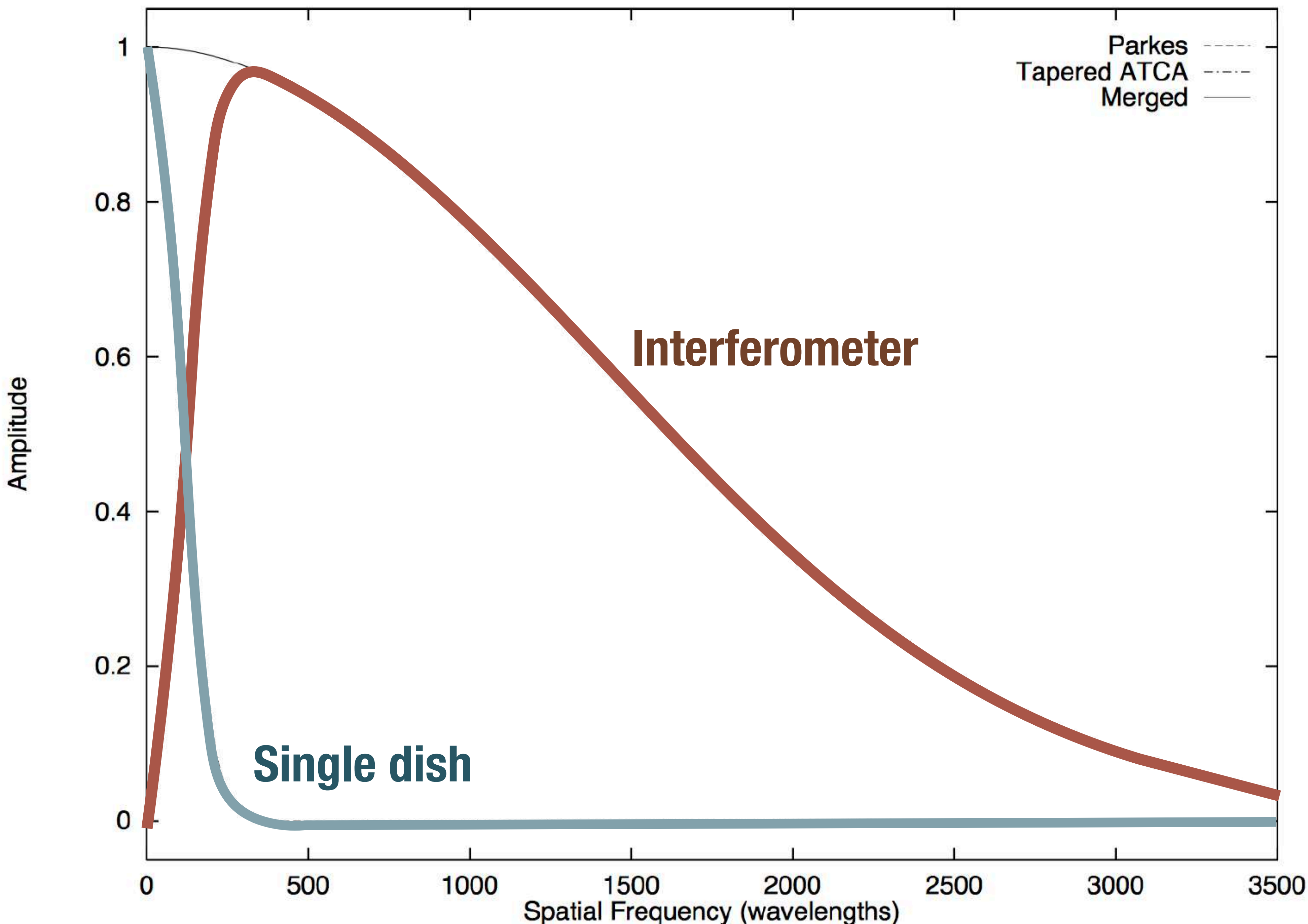
“Zero spacings”

Use a single dish that is larger than the minimum separation of interferometer antennas

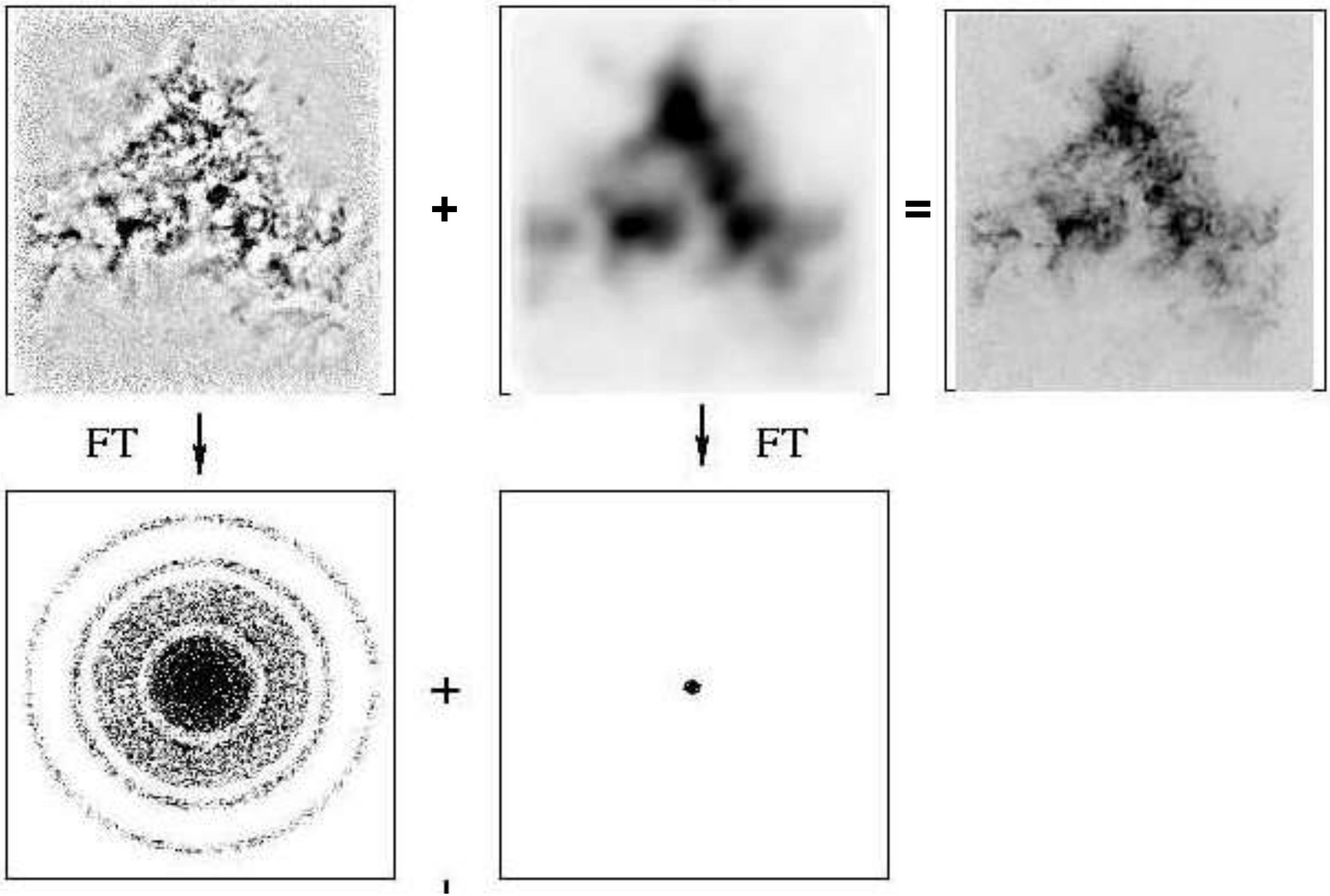




Stanimirovic 2002

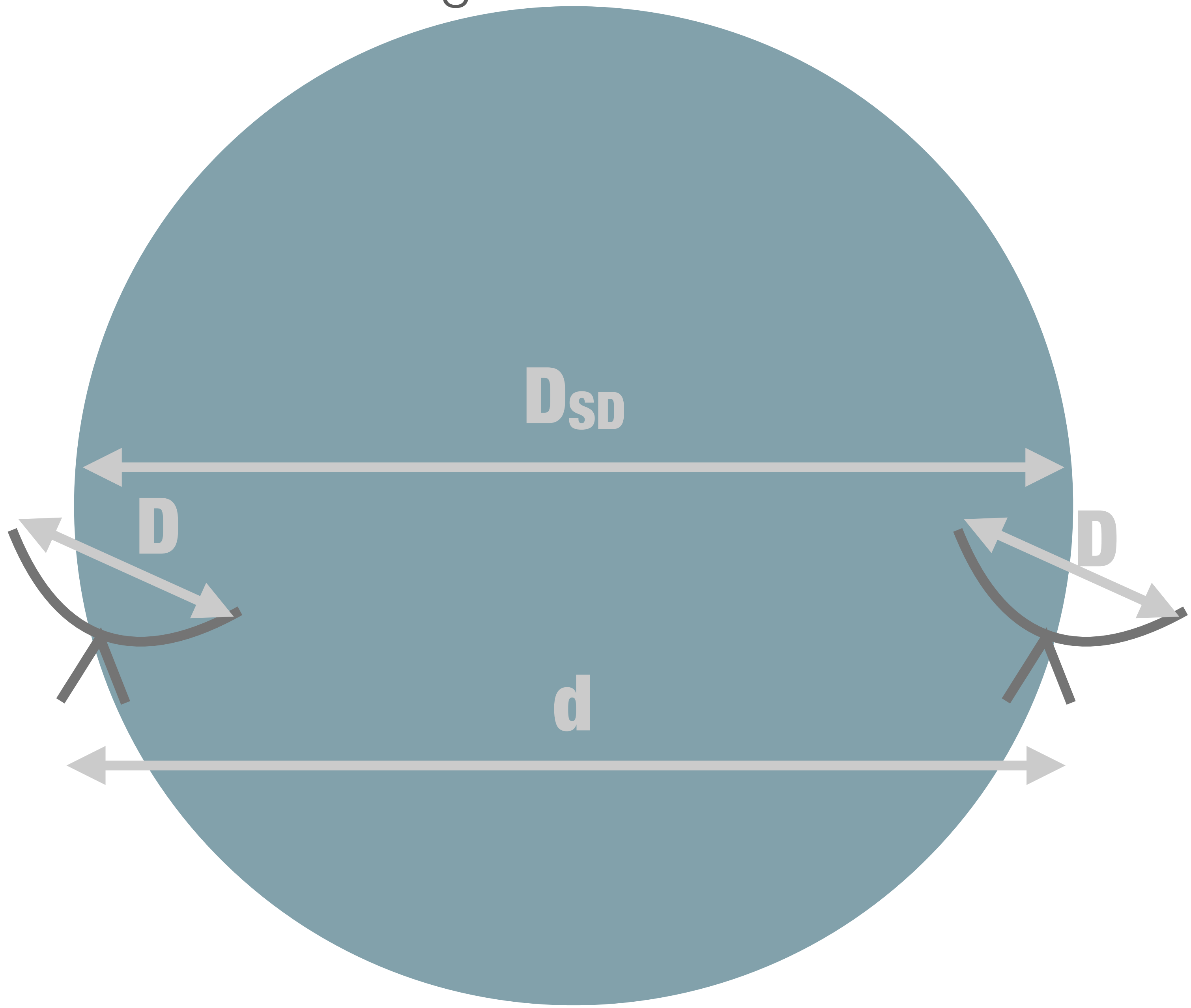


Stanimirovic 2002



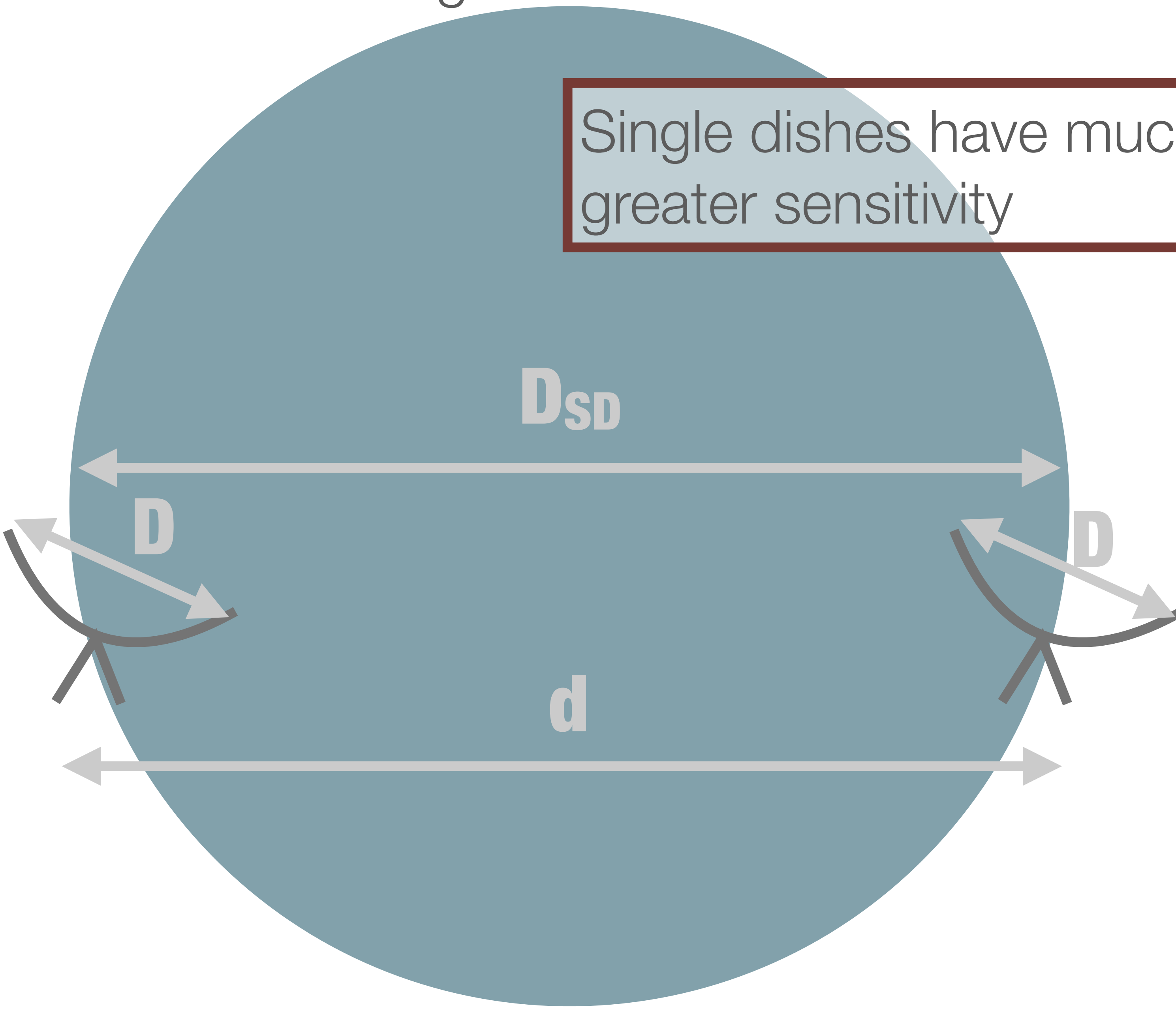
Stanimirovic 2002

Single dish: Sensitivity is determined by the collecting area
Interferometer: Sensitivity is determined by the sum of the collecting areas of the dishes



Single dish: Sensitivity is determined by the collecting area
Interferometer: Sensitivity is determined by the sum of the collecting areas of the dishes

Single dishes have much greater sensitivity



Noise Characteristics

- Interferometer uses many dishes
  - Signal in each dish is correlated but
  - Noise in each dish is uncorrelated -> averages out
- Single dishes do not have this benefit
  - single-dishes can be severely affected by instrumental fluctuations

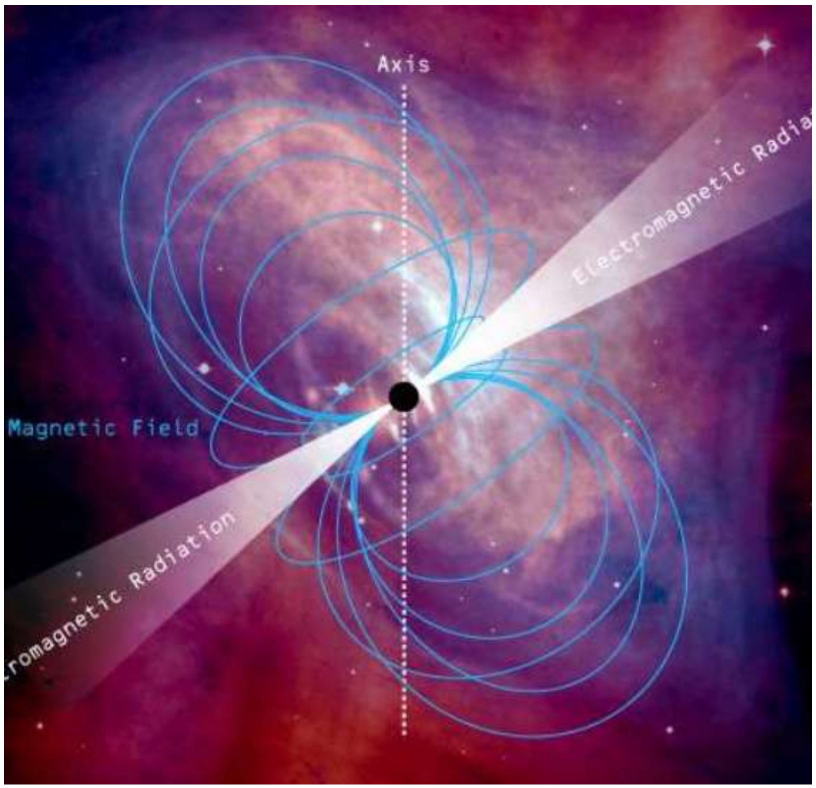
What do we measure?

- **How bright?**
  - Sensitivity
  - Polarization?
- **Where?**
  - Astrometric calibration
  - Angular resolution

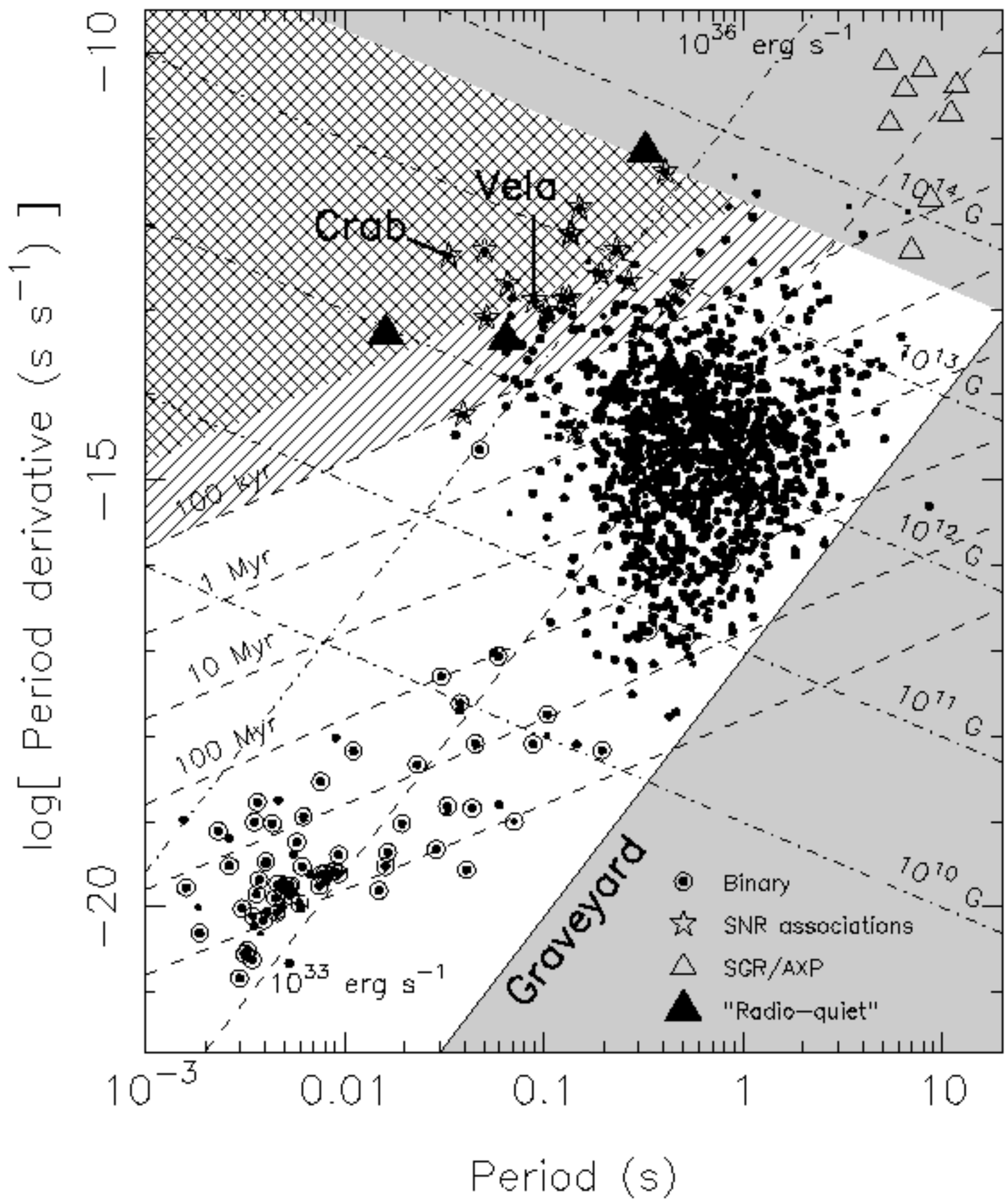
Important considerations: How long will it take?
How much computing power?

- **Do they change?**
  - With time
    - Time resolution
    - Duration
  - With frequency
    - Spectral resolution
    - Frequency range
  - **All of the above?!**

Pulsars

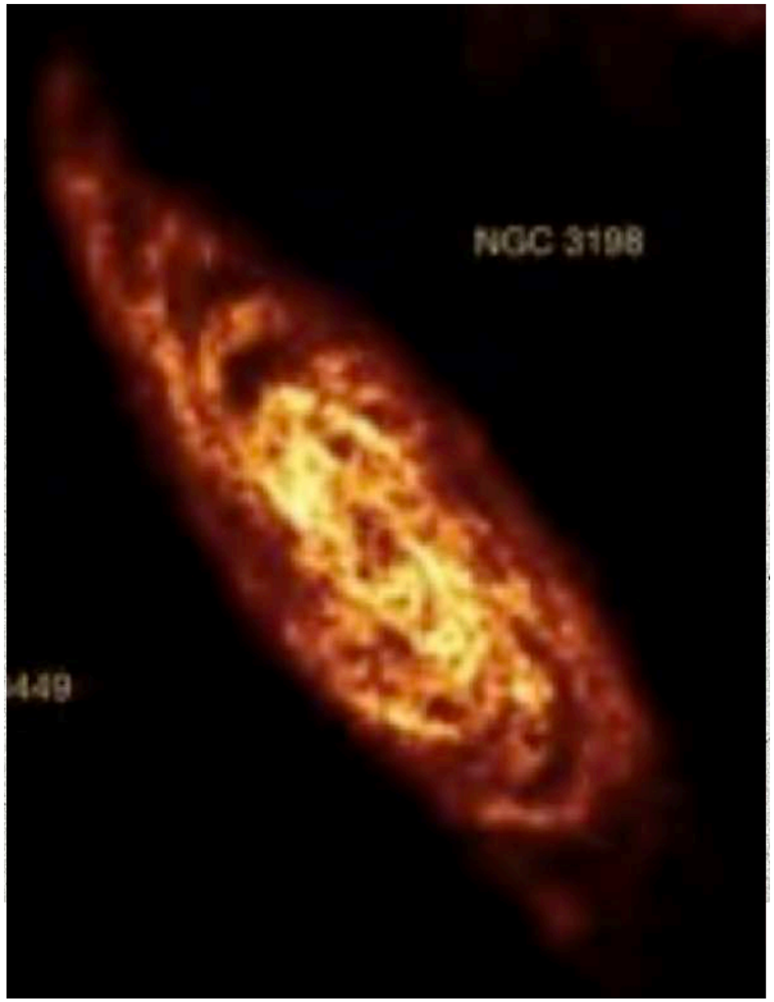


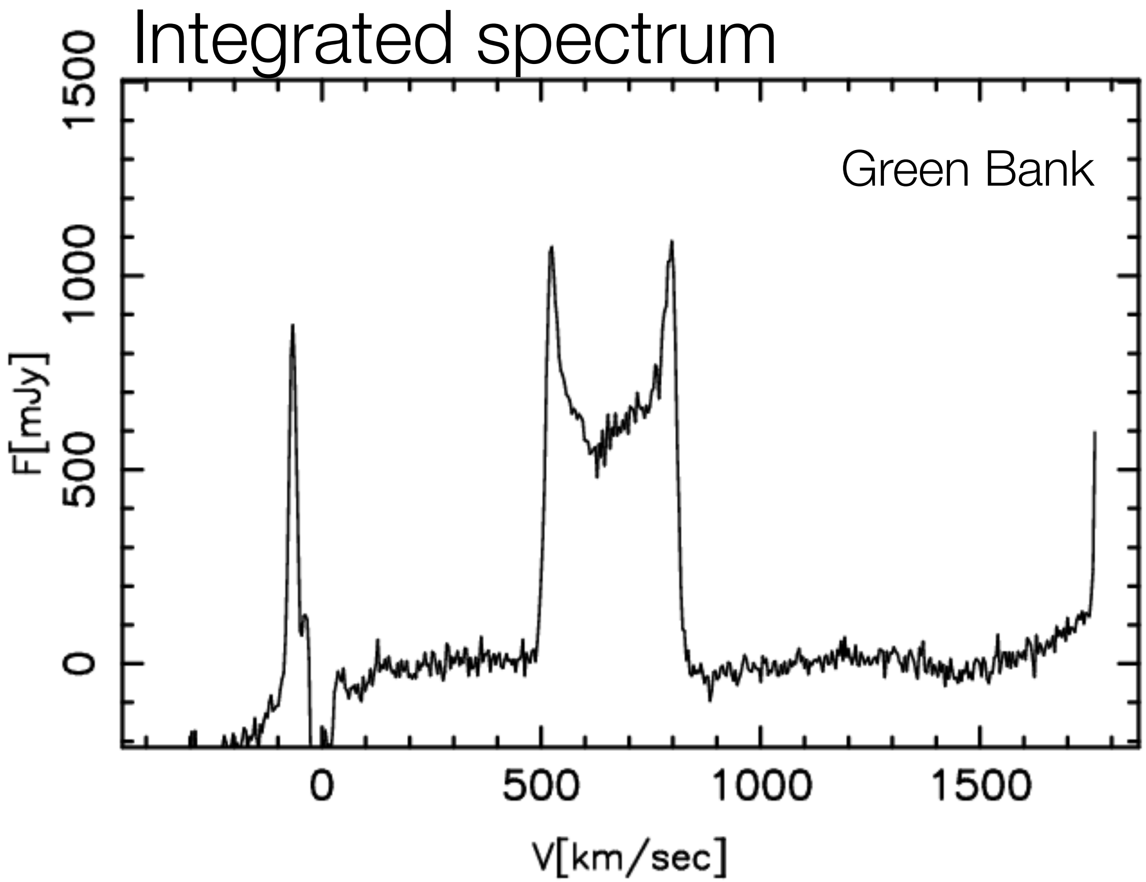
High time resolution, sensitivity, and frequency resolution



Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer

Extra-galactic

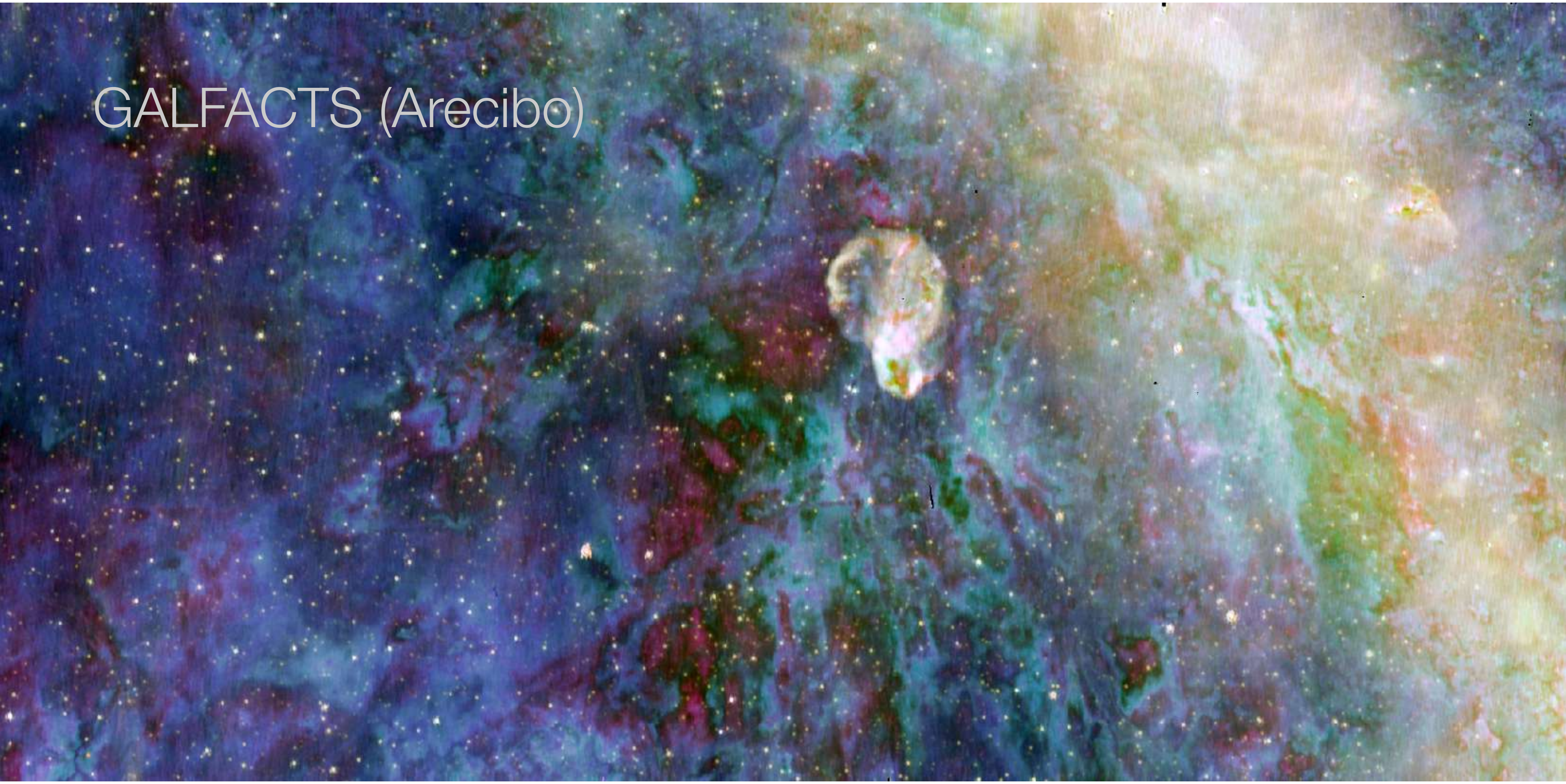




Springob+2005 (NED)

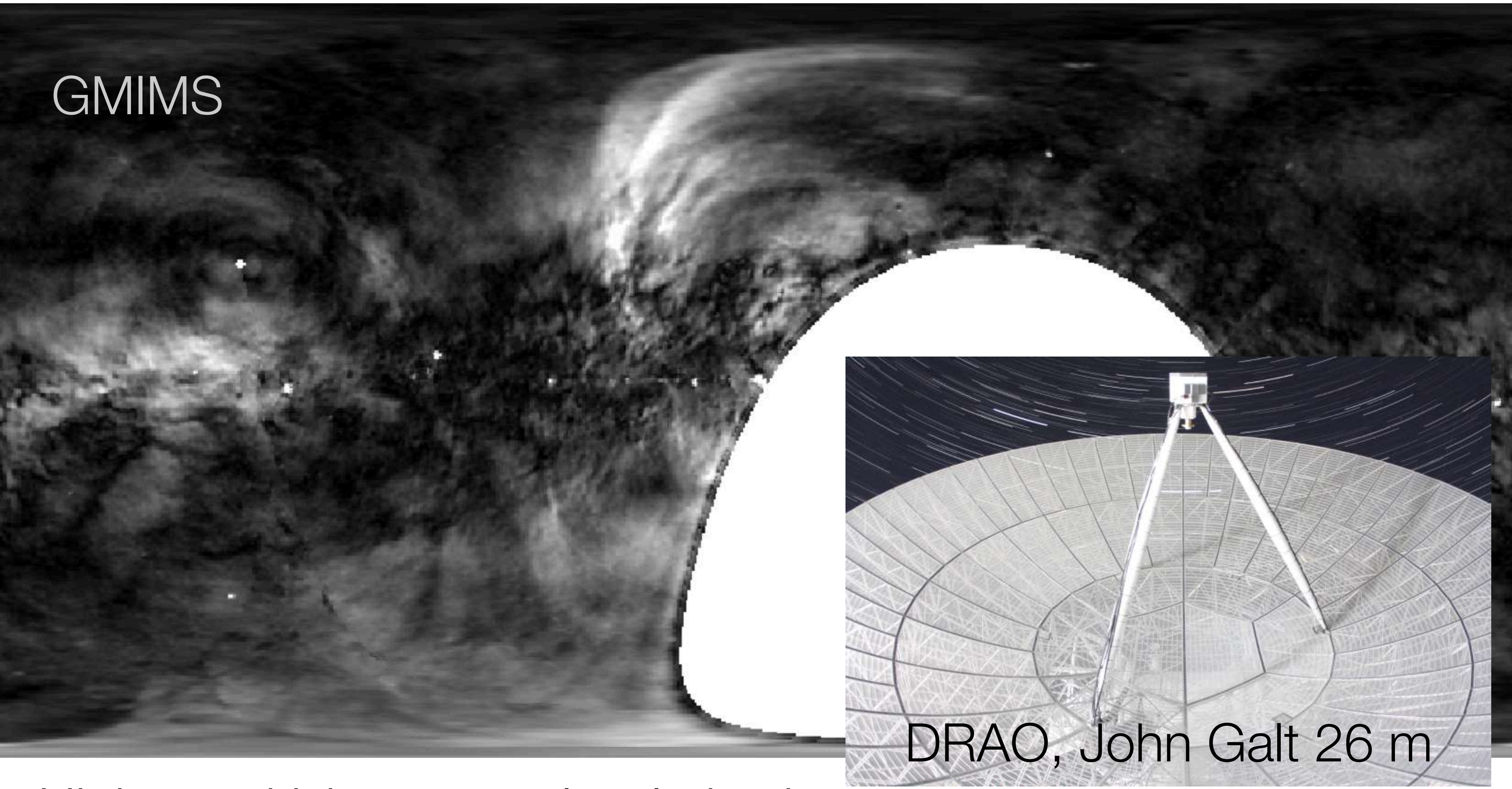
Dozens of maps with interferometers vs thousands of integrated spectra with single dishes

Diffuse Galactic Emission



High sensitivity spectral-polarization

Diffuse Galactic Emission

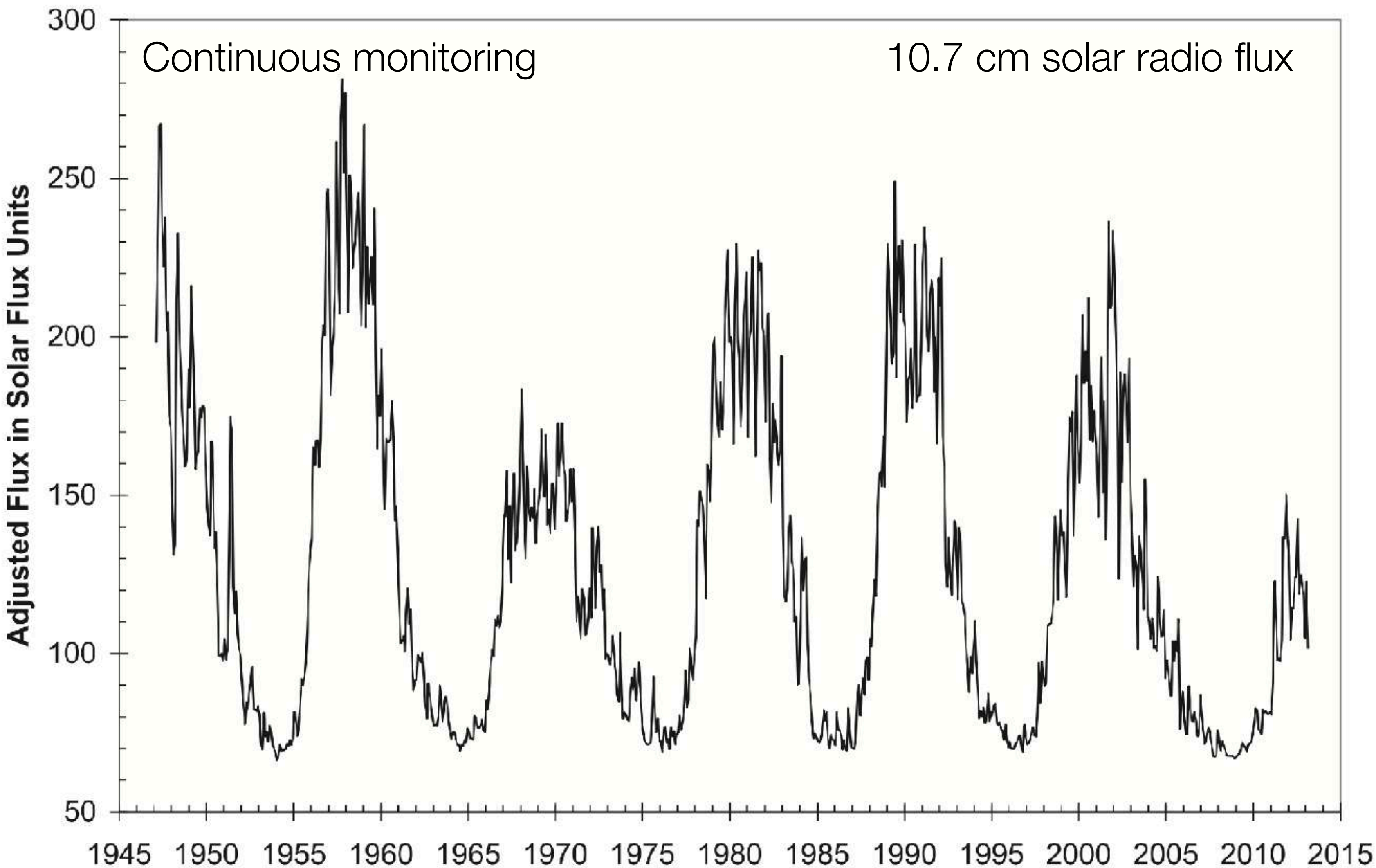


High sensitivity spectral-polarization

Solar system studies - Radar

Asteroid 2014 HQ124, Arecibo (+Goldstone transmitter)

Solar observations



Tapping, 2013

SETI/Breakthrough Listen

- searching stars and galaxies for radio signals
- needs sensitivity to detect "Earth-leakage" levels of radio transmission from stars within 5 parsecs
    - can detect a transmitter of the same power as a common aircraft radar from the 1,000 nearest stars
- began in January 2016
- $100 million in funding

Single dish science - strengths

- Studying point-like sources
- Mapping large scale structures - quickly
- High time and frequency resolution (pulsars)
- Radar mapping

Single Dishes: pros and cons

- Higher sensitivity to extended structure
- Higher mapping speed
- More telescopes
- Only need one receiver for each frequency and simpler electronics
- Easier to upgrade, install other instruments (e.g., transmitter)
- Needed to supplement arrays (zero spacings)

- Poorer angular resolution
- More affected by instrumental variations of gain and noise
- Complex and costly physical structure
- Not as scalable (can't add more antennas)


Thank you