Radio Interferometry intro

3S24 – Session RA-01b

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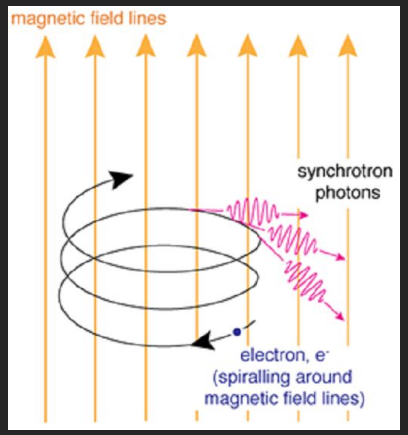
Outline

I. Review
   i. Radio emission processes
   ii. Interferometry
   iii. 1-D Fourier Transform
   iv. 2-D Fourier Transform

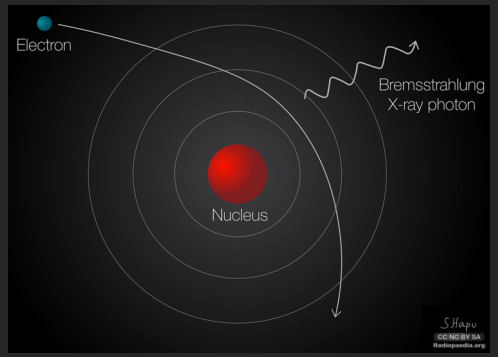
II. Radio Interferometry
   i. Working principles
   ii. An example of synthesis imaging

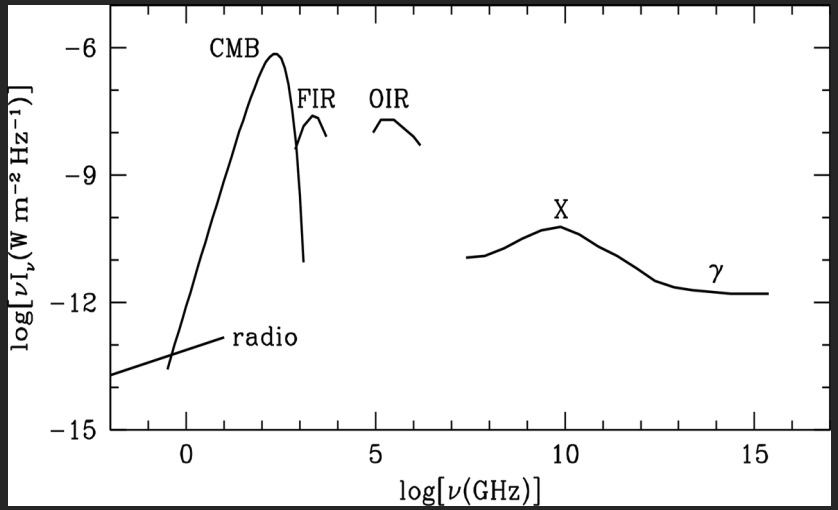
Radio Emission Processes

Synchrotron radiation
(Accelerated electron in magnetic field)

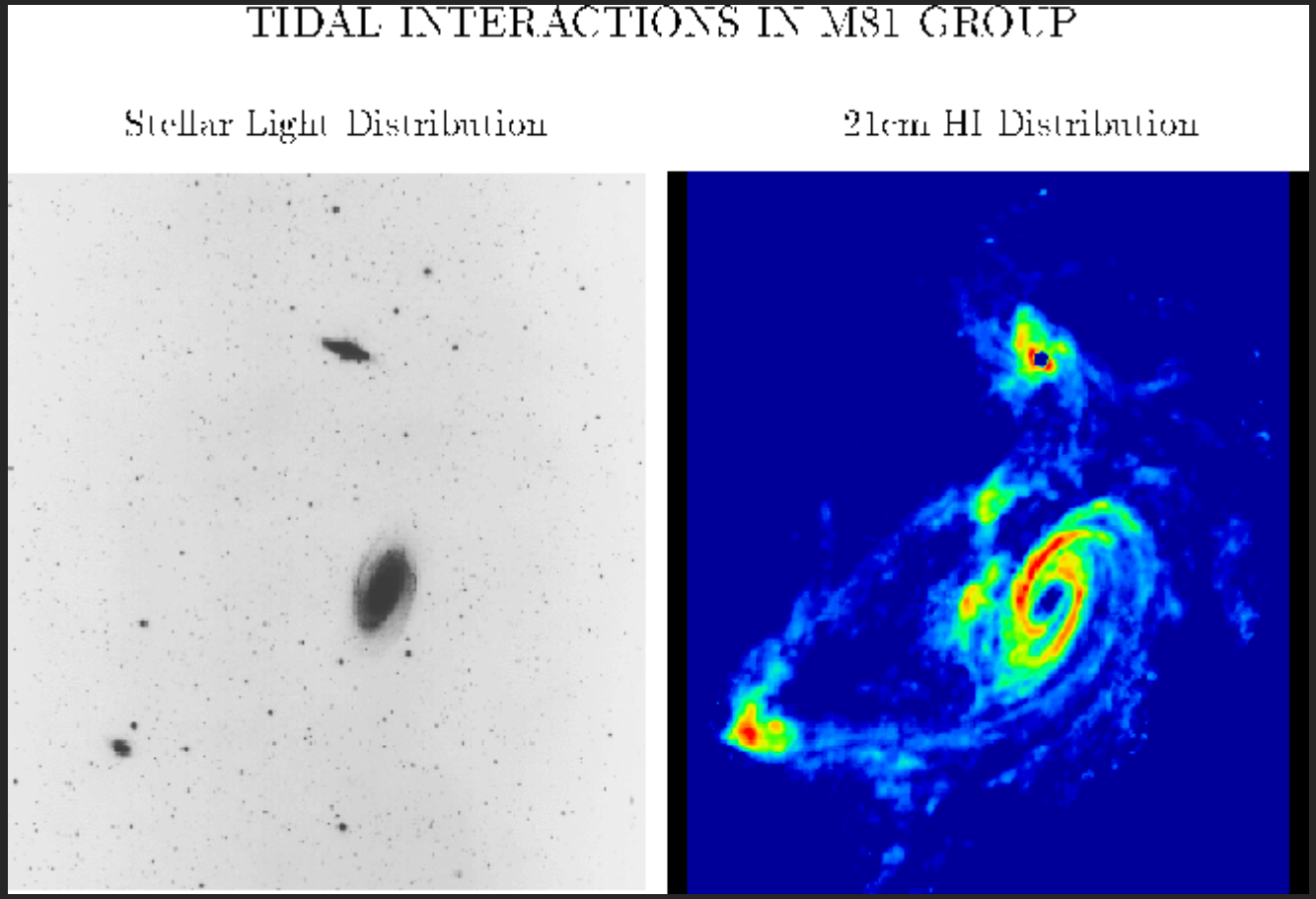


Free-free radiation
(Bremsstrahlung/braking)



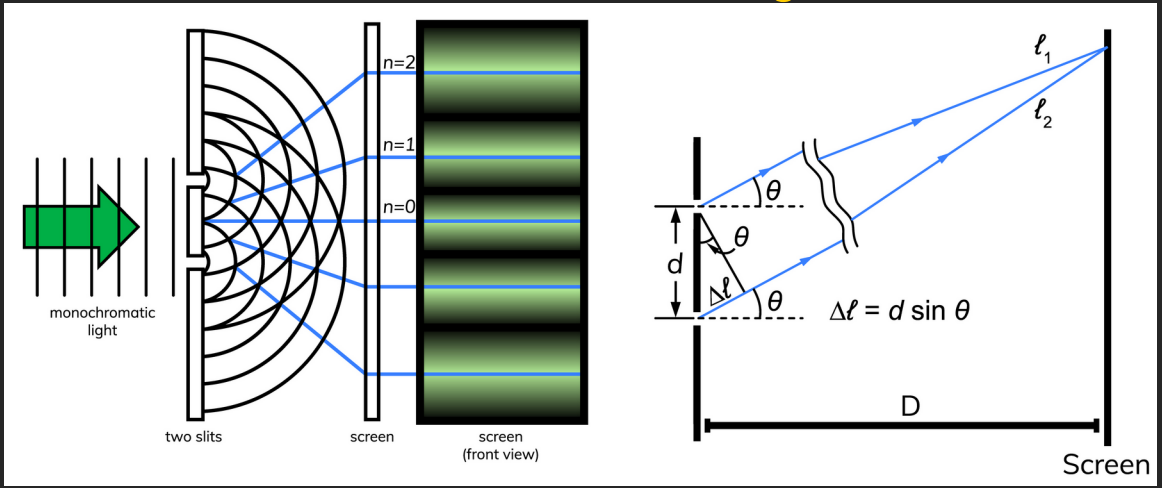


Radio sees thing optical cannot

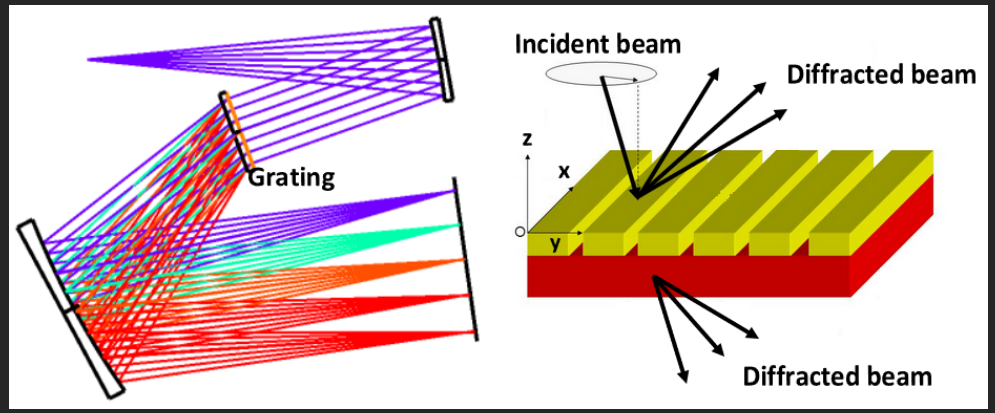


http://www.aoc.nrao.edu/intro/m81mosaic.gif

Young's Double Slit Experiment
Diffraction Grating



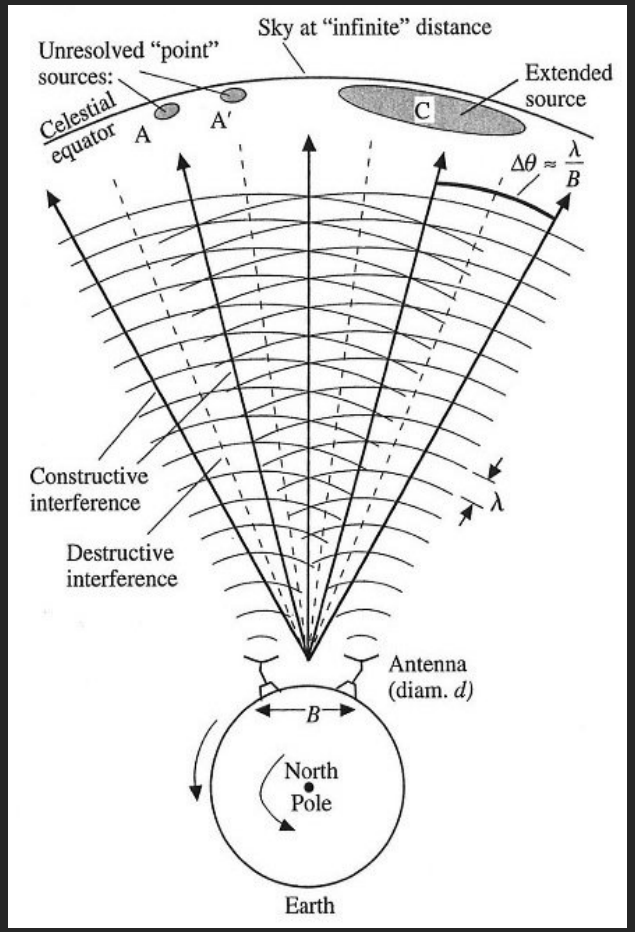
https://www.wizeprep.com/textbooks/undergrad/physics/4027/sections/2574458



For separating EM radiation into different wavelength (or colors)

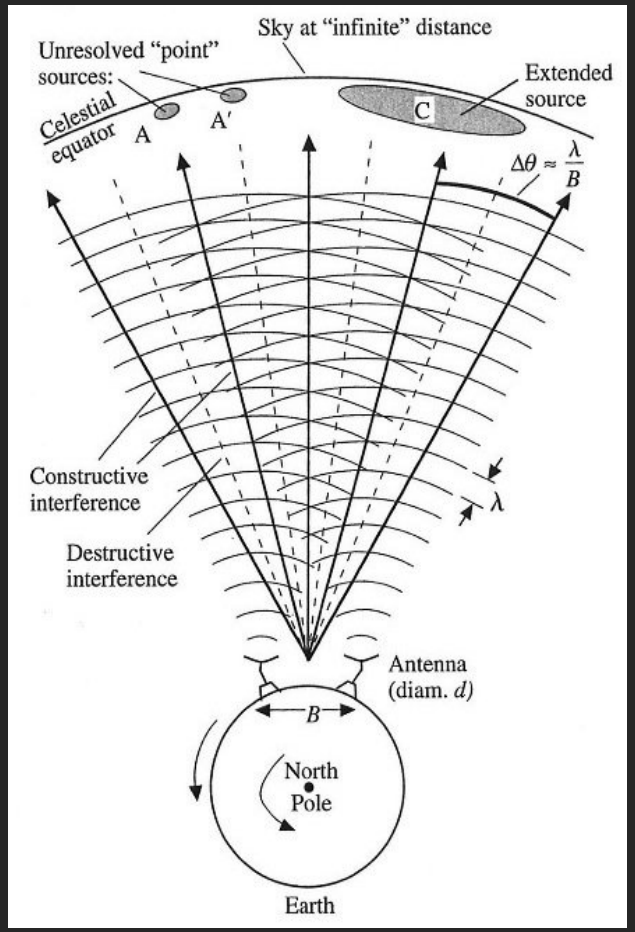
https://www.linkedin.com/pulse/versatile-grating-design-analysis-zemax-opticstudio-haifeng-ding/

Optical & Radio interferometry



DOI: 10.13140/RG.2.1.3546.3529

Optical & Radio interferometry



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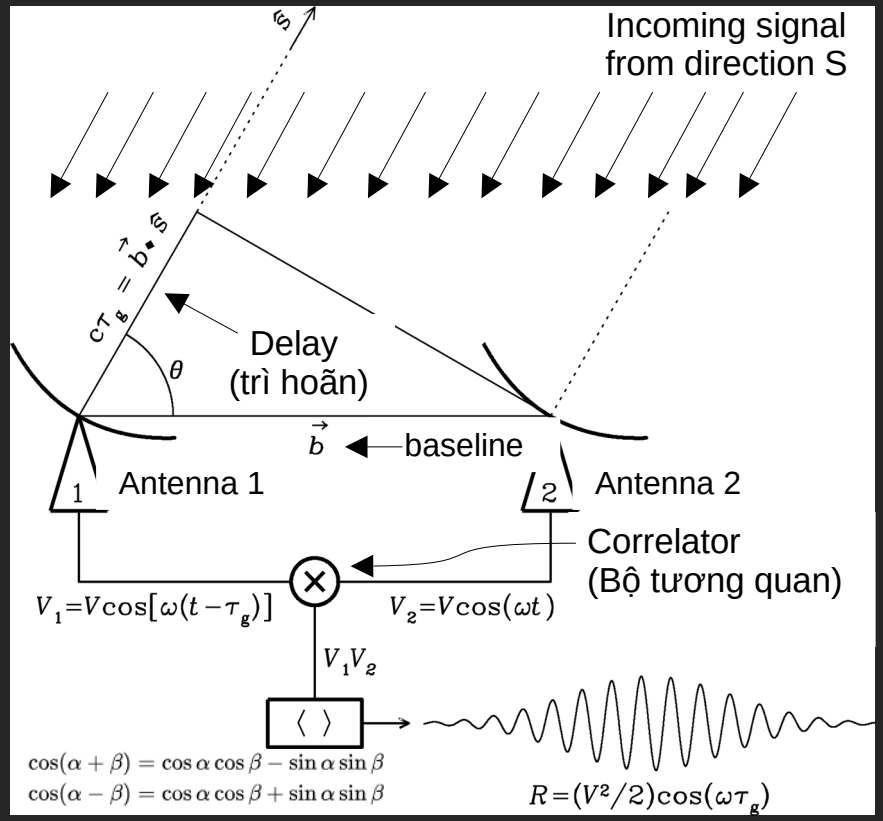
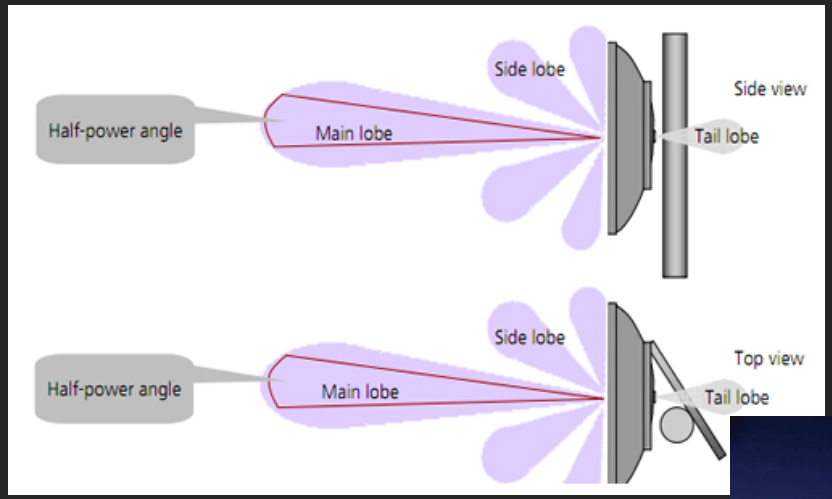
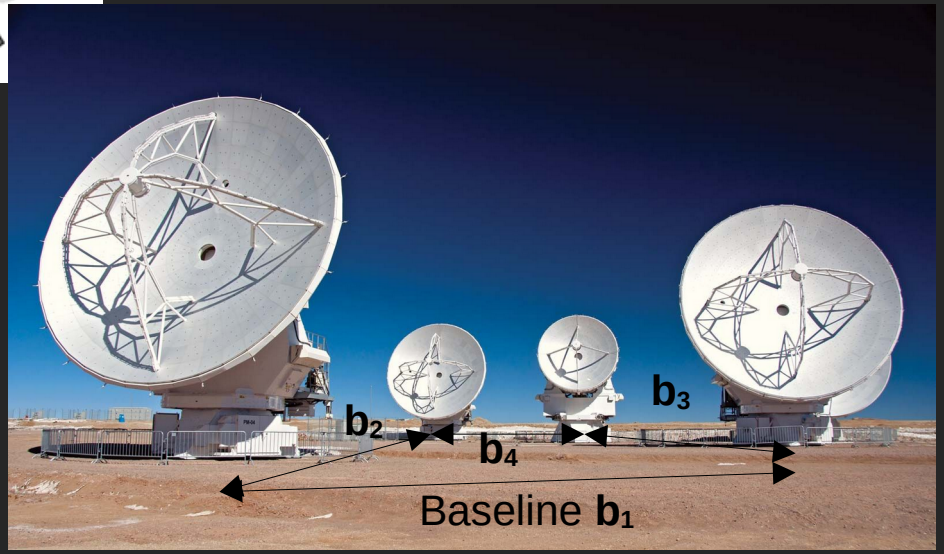


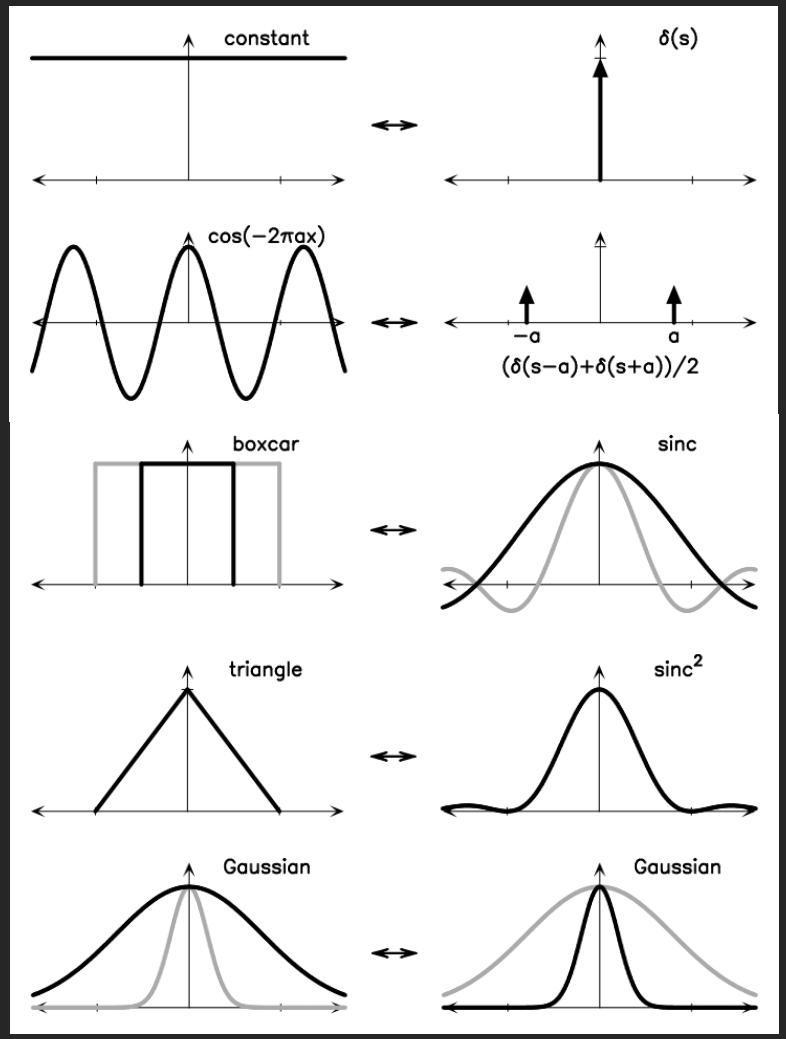
https://www.cv.nrao.edu/~sransom/web/Ch3.html

Antenna beam pattern





1-D Fourier Transform



See IC/DAQ
(Wed, 7/24)
Fourier transform
(time ↔ freq)

Fourier forward transform:

$$F(s) \equiv \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i s x}\, dx,$$

Fourier inverse transform:

$$f(x) \equiv \int_{-\infty}^{\infty} F(s)\, e^{2\pi i s x}\, ds,$$

$$e^{i\phi} = \cos\phi + i \sin\phi \qquad i \equiv \sqrt{-1}$$

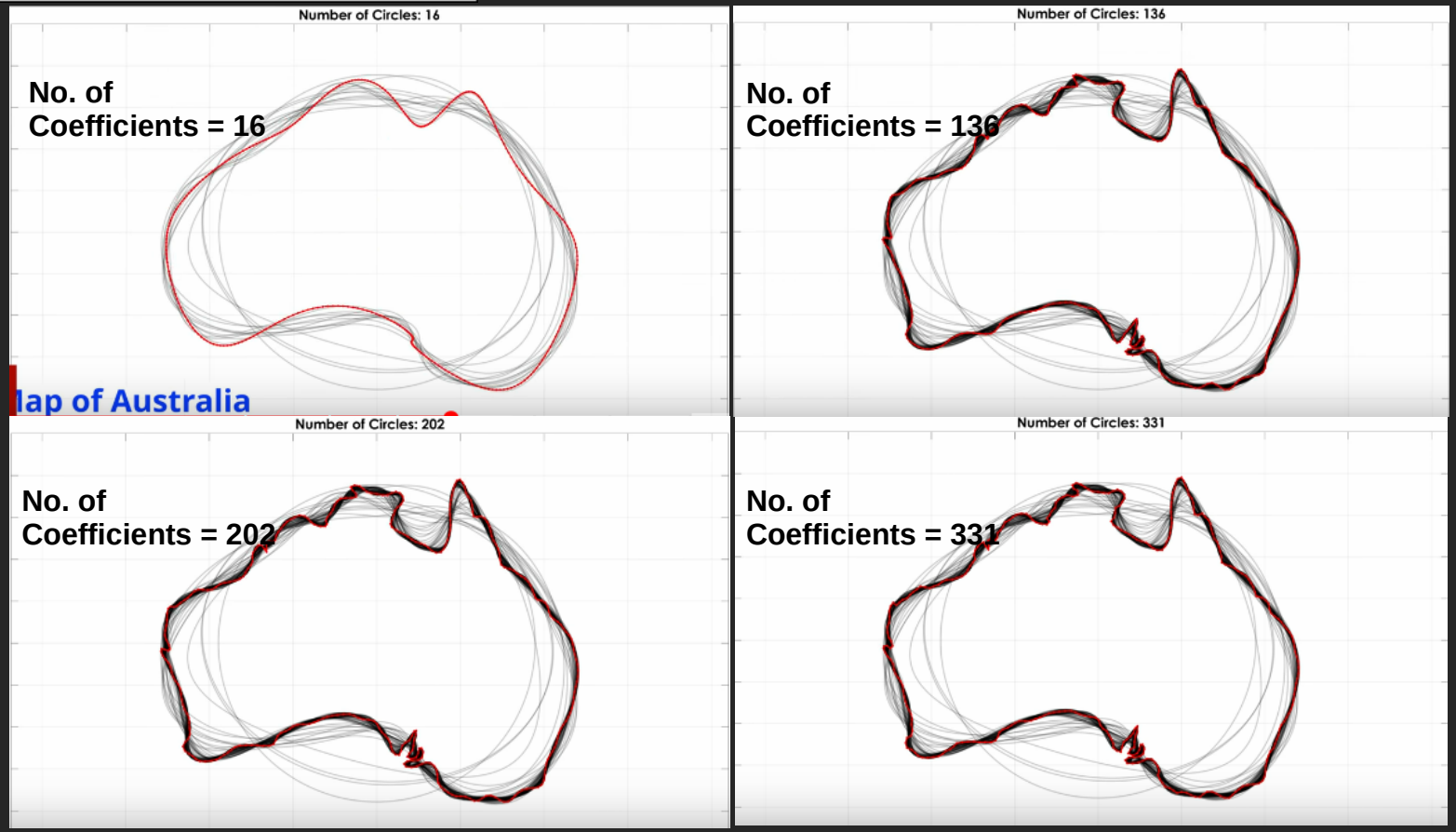
2-D Fourier Transform

Continuous Fourier

$$F(s) \equiv \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i s x}\, dx,$$

Discrete Fourier transfo

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi \frac{k}{N} n}$$



https://youtu.be/2gIl6Thgkdk?si=qFeuMPkV-nvpMpg1

Fourier forward transform:

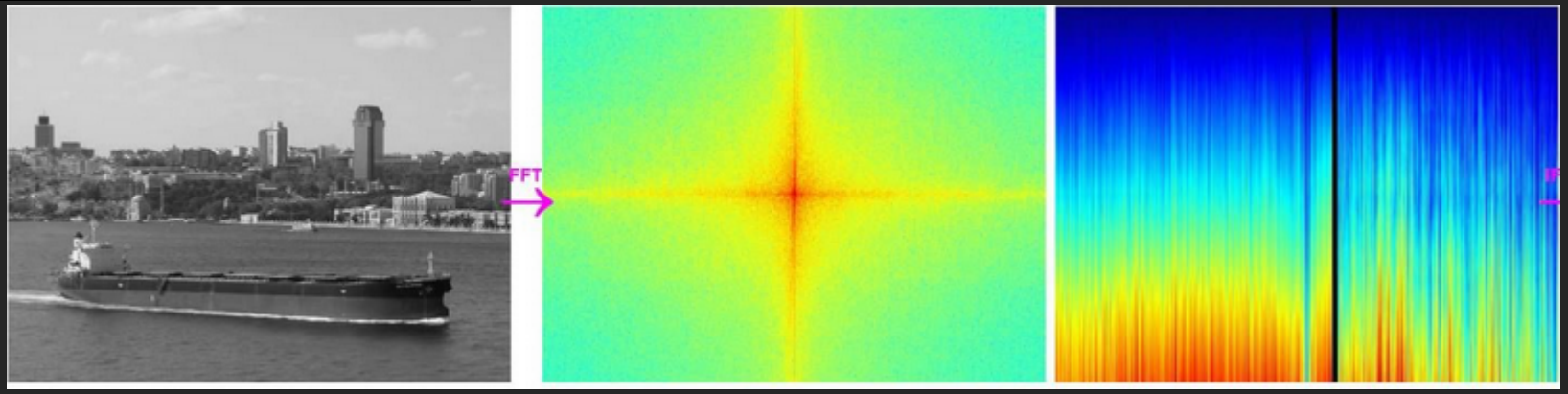
$$F(s) \equiv \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i s x}\, dx,$$

2-D Fourier Transform

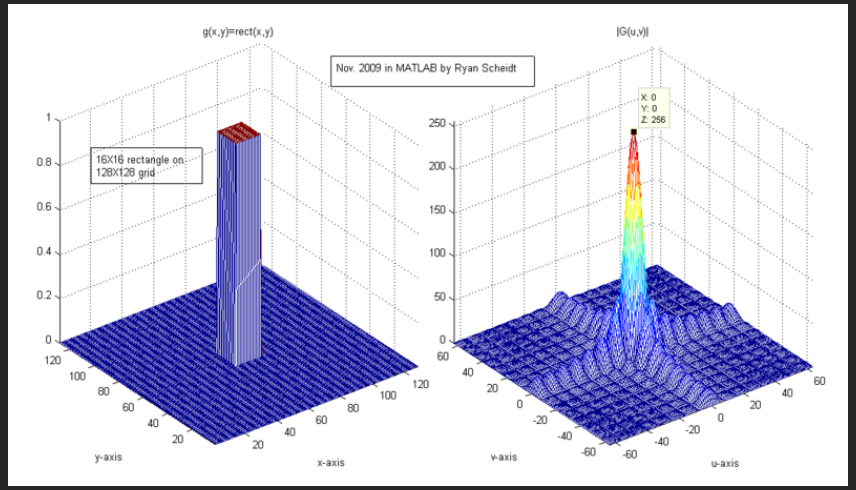
Fourier Transform Magnitude

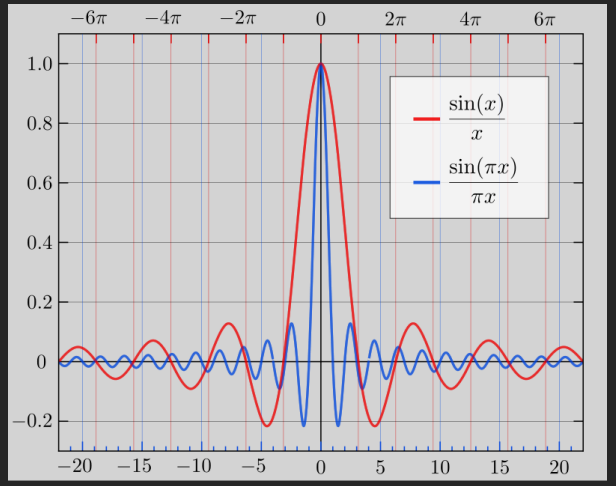
Complex number

Fourier Transform Phase



2D Sinc function



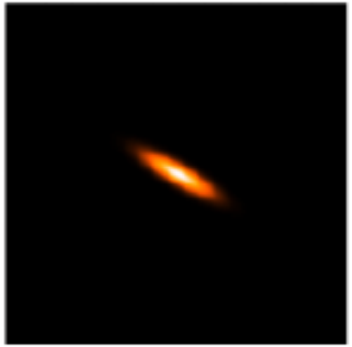


2D Fourier Transform Pairs

T(x,y)

Amp{V(u,v)}

elliptical Gaussian

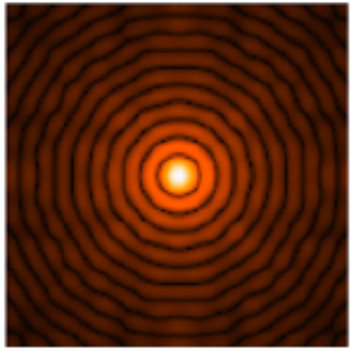


$\rightleftarrows$

elliptical Gaussian

Disk

$\rightleftarrows$



Bessel

sharp edges result in many high spatial frequencies

Sky brightness <-> Interferometric Visibilities
2D *F.T.*

$\vec{b} \cdot \hat{s} / \lambda$

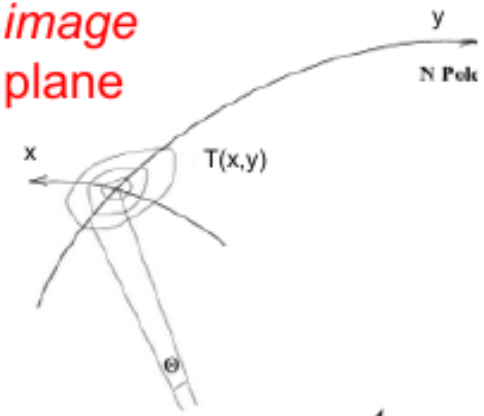
Fourier space/

$$V(u,v) = \int\int T(x,y) e^{2\pi i(ux+vy)} dx dy$$

Image space/

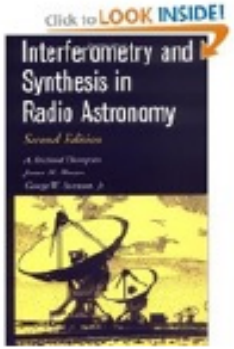
$$T(x,y) = \int\int V(u,v) e^{-2\pi i(ux+vy)} du dv$$

image plane



uv plane

(for more info, see e.g. Thompson, Moran & Swenson)



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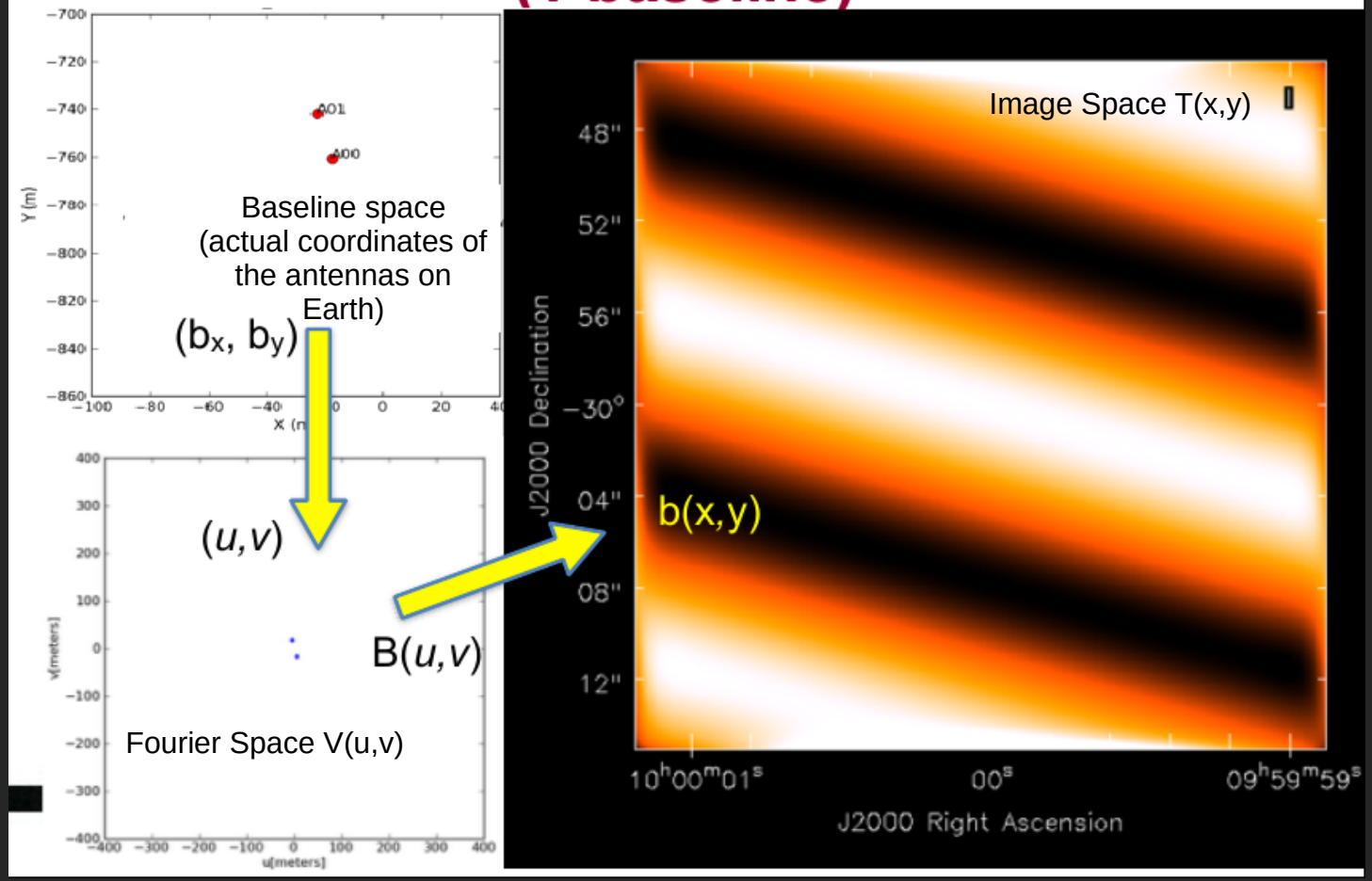
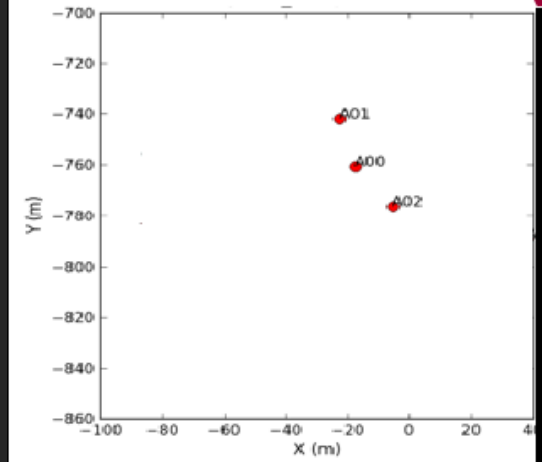
18

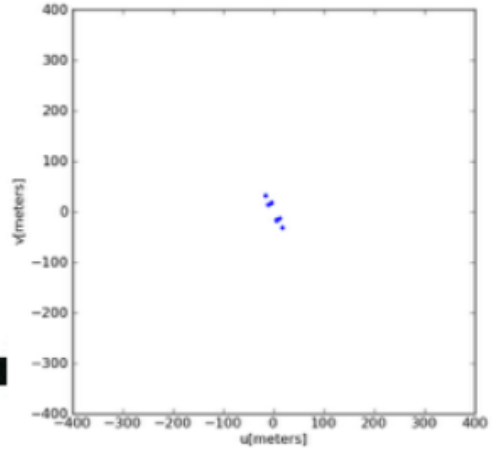
https://science.nrao.edu/facilities/alma/naasc-workshops/nrao-cd-ru17/InterfBasics_Rice.pdf

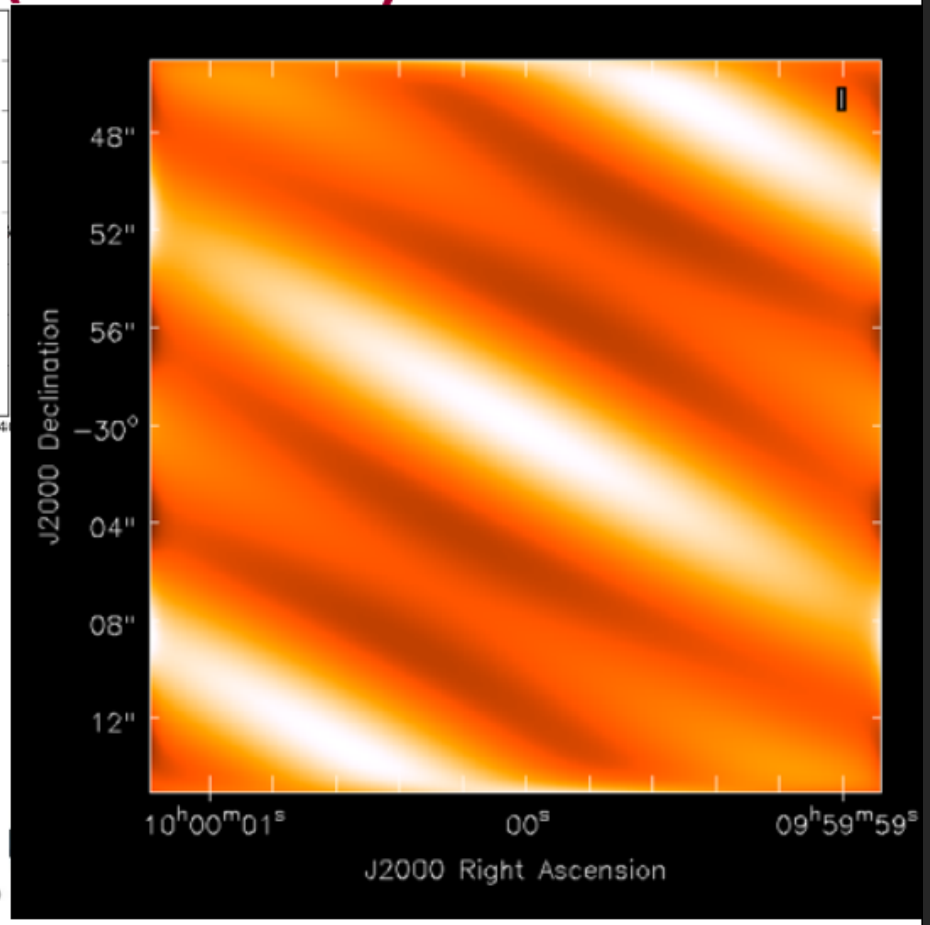
Example: Dirty Beam with 2 Antennas (1 baseline)



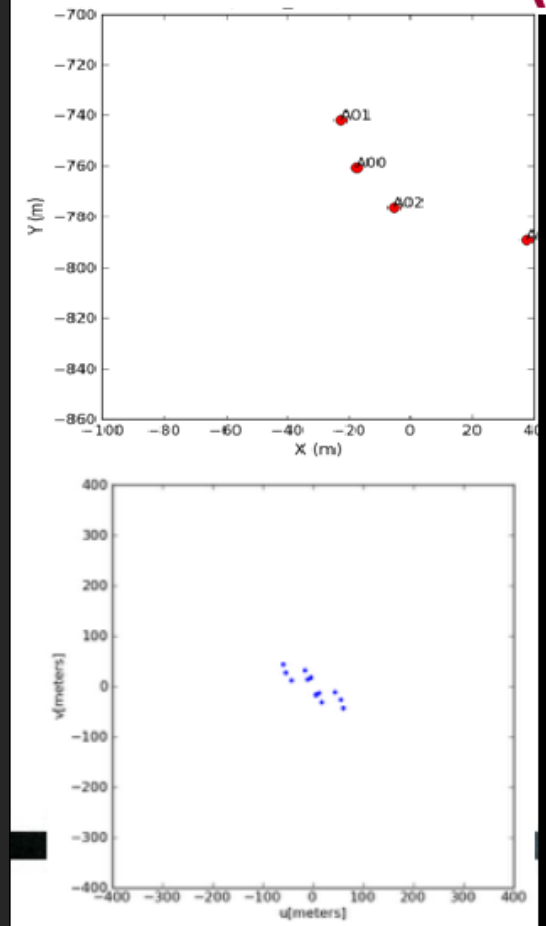
Example: Dirty Beam with 3 Antennas (3 baselines)

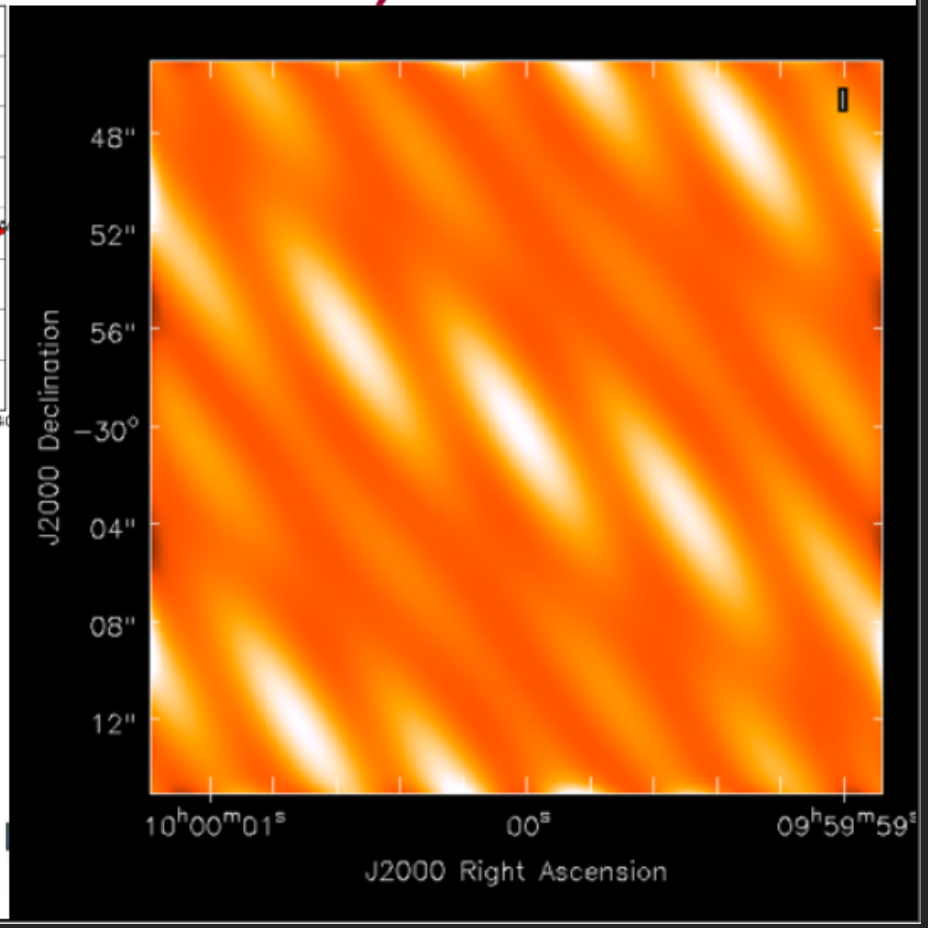




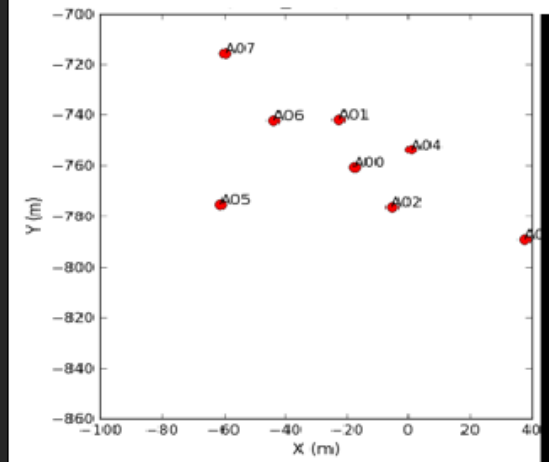


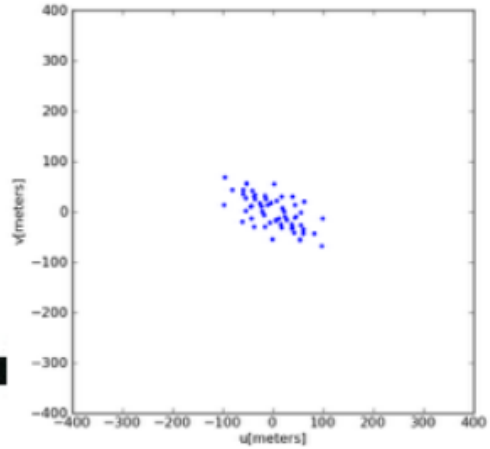
Example: Dirty Beam with 4 Antennas (6 baselines)

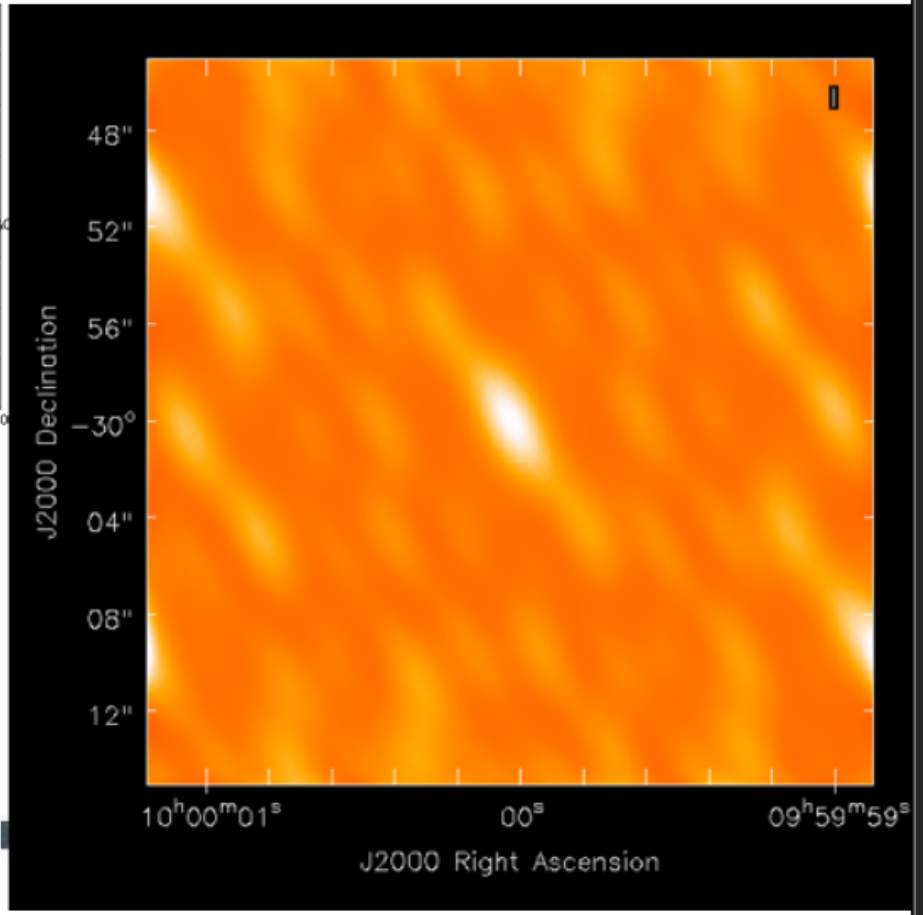




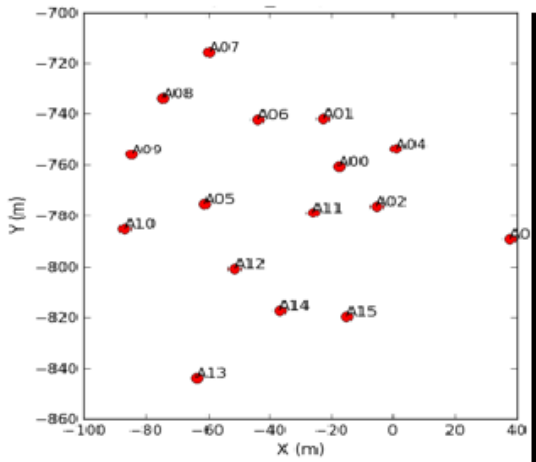
Example: Dirty Beam with 8 Antennas (28 baselines)

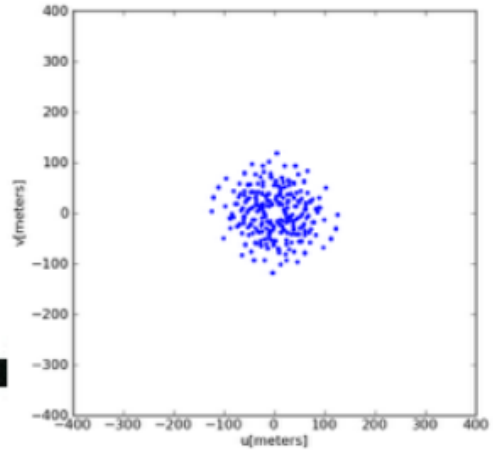


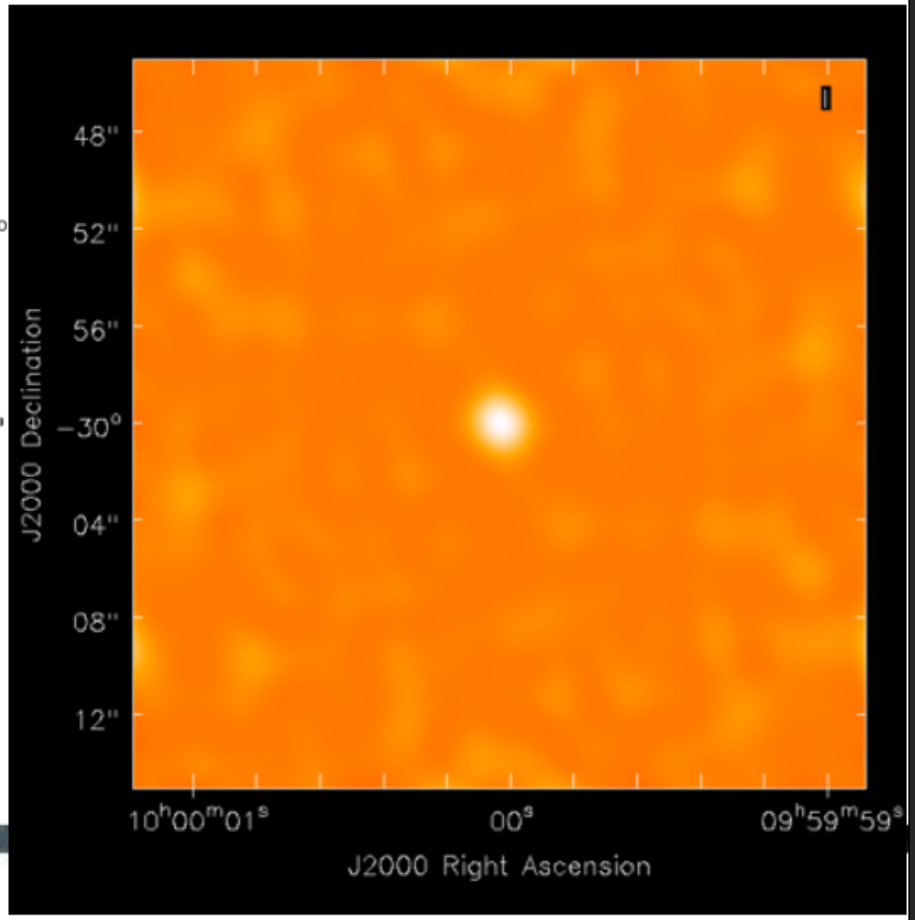




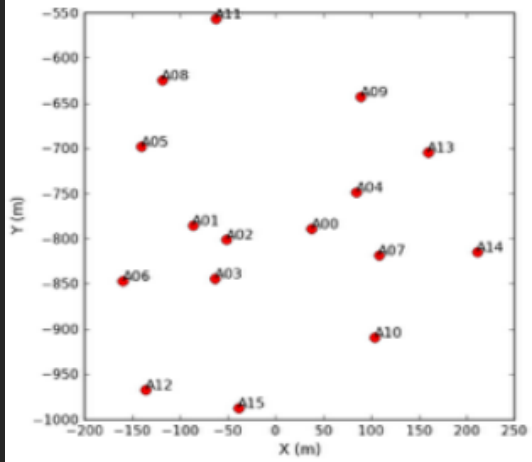
16 Antennas – Compact Configuration

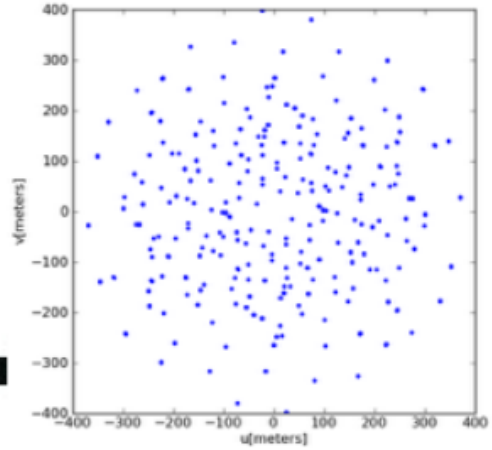


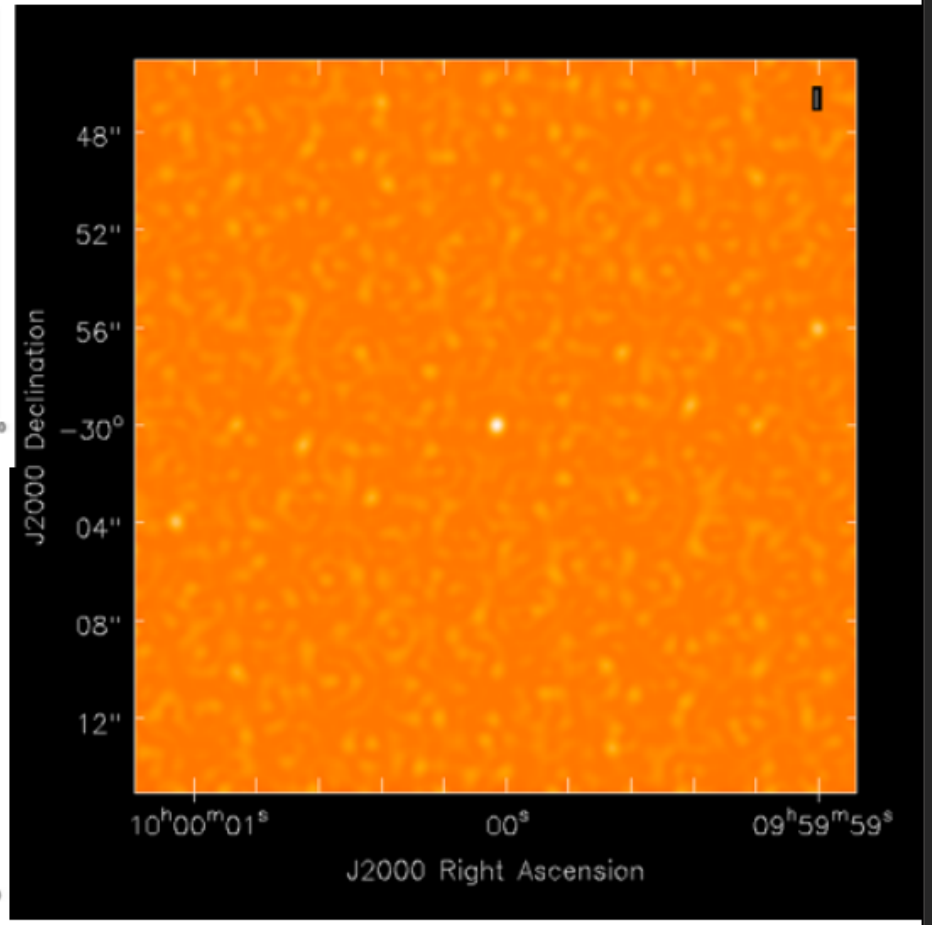




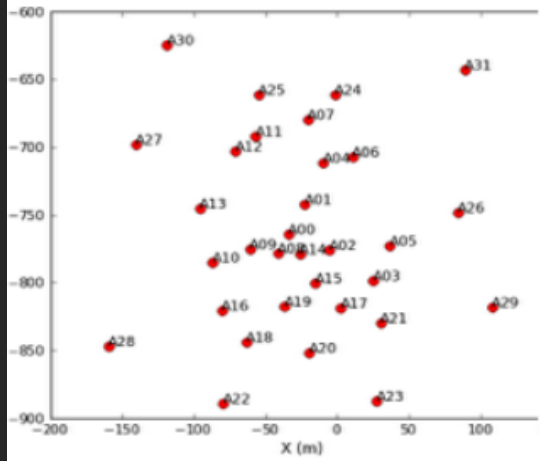
16 Antennas – Extended Configuration

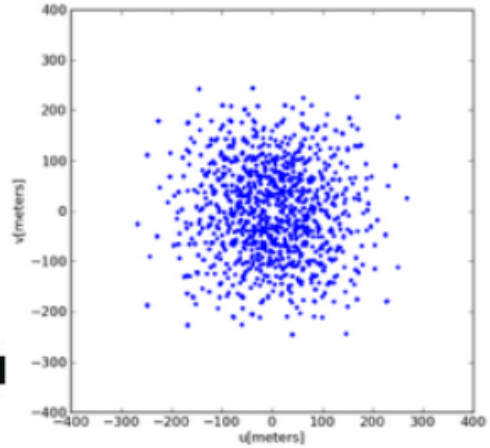


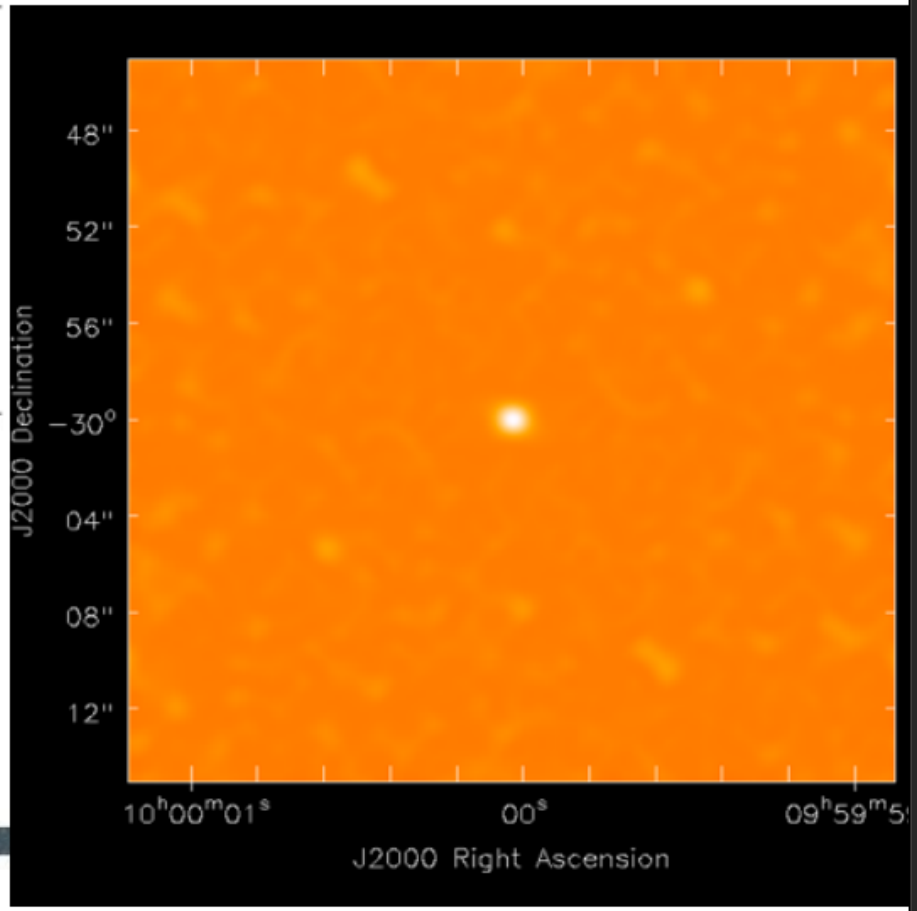




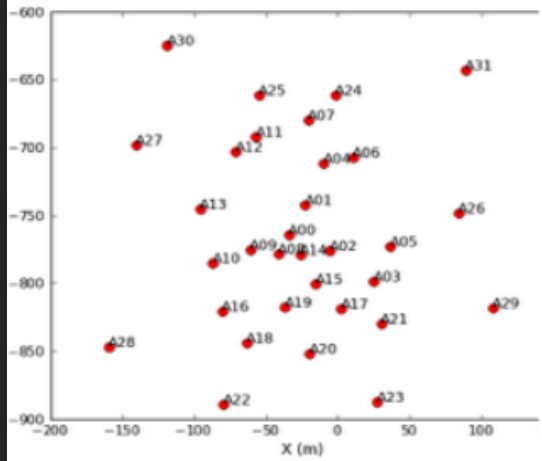
32 Antennas – Instantaneous

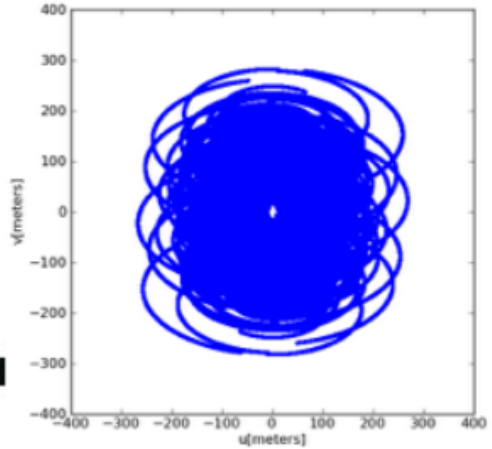


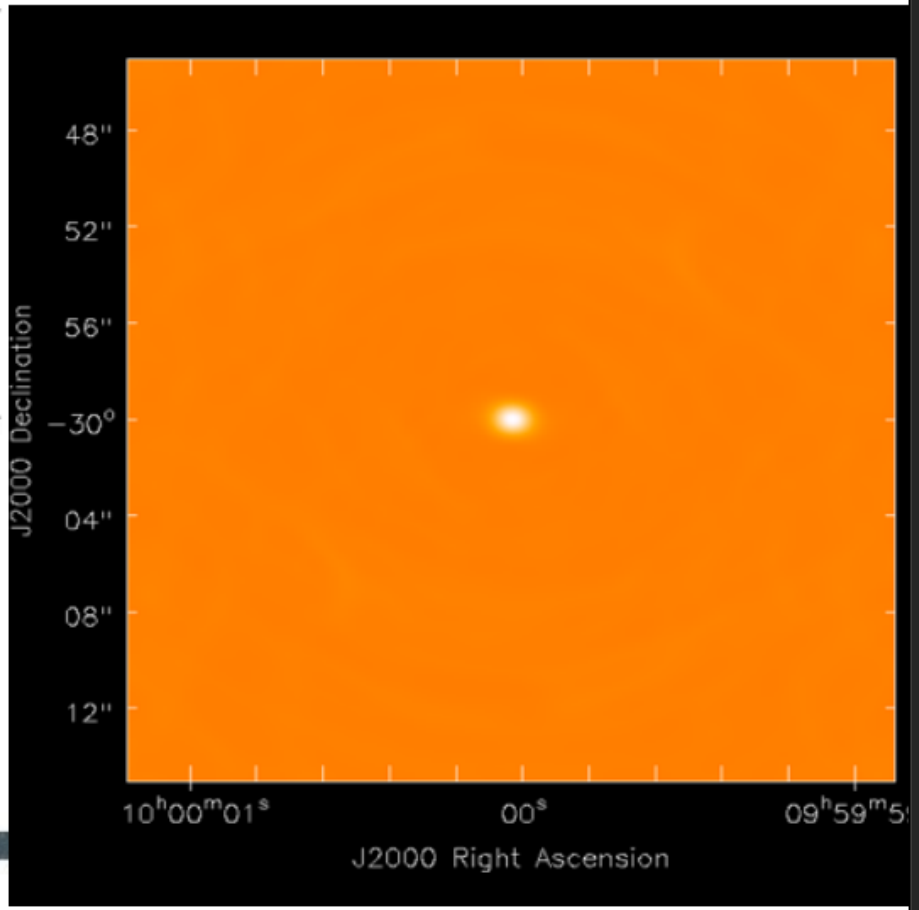




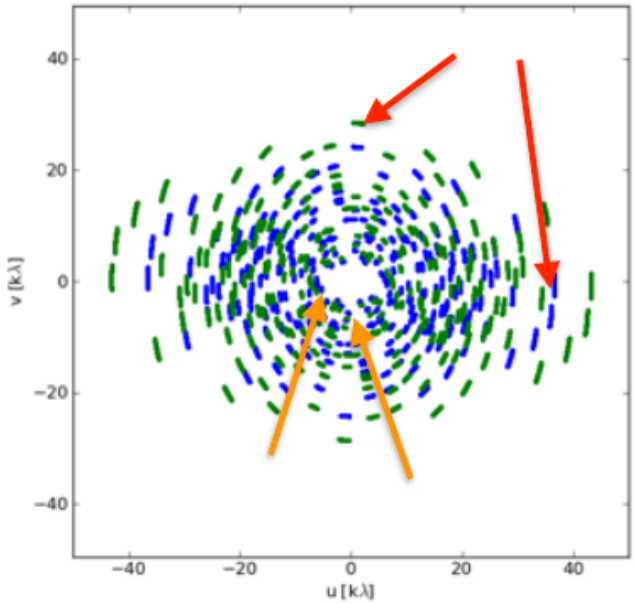
32 Antennas, 8 hrs - Earth Rotation Synthesis

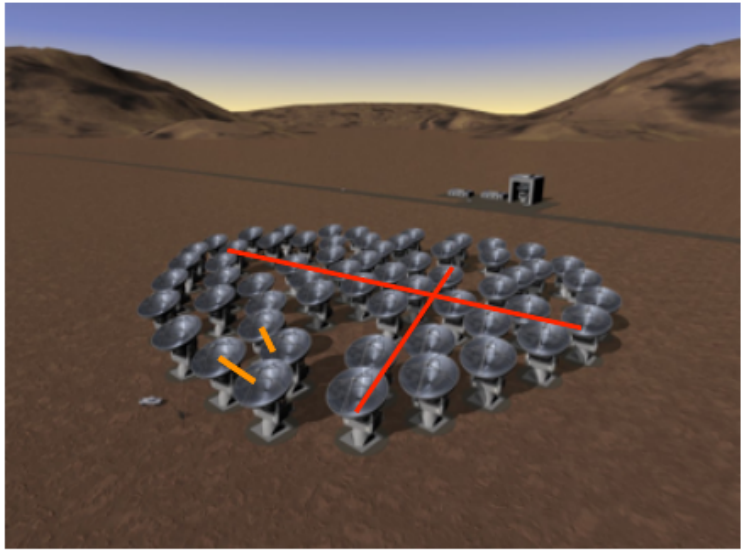






uv-coverage





Short baselines: small uv-distance, low angular frequencies, i.e. extended emission
Long baselines: large uv-distance, high angular frequencies, i.e. small-scale emission
uv-coverage with many “holes” gives dirty beams with pronounced sidelobes

Characteristic Angular Scales

Angular resolution:

- $\sim \lambda/b_{max}$, where b_{max} is the longest baseline

Largest angular scale:

- $\sim \lambda/b_{min}$, where b_{min} is the shortest baseline

An interferometer is sensitive to a range of angular sizes

$$\lambda/b_{max} < \theta < \lambda/b_{min}$$

Emission on angular scales > λ/b_{min} is missed by the interferometer!

Field of view (= "Primary Beam") of a single pointing:

- $\sim \lambda/D$, where D is the diameter of the telescope
- If sources are more extended than the FOV, it can be observed using multiple pointing centers in a mosaic

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36