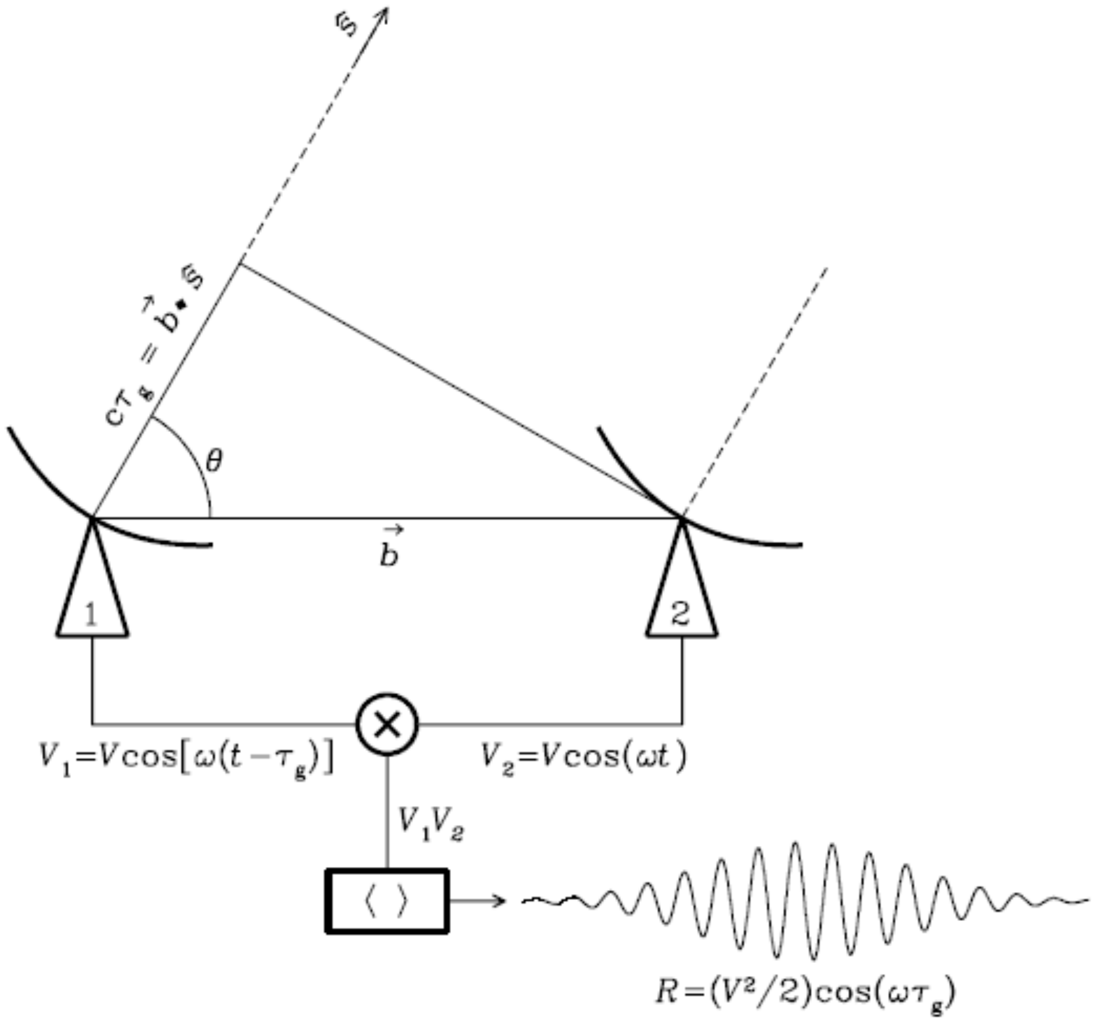
Radio Interferometry

- Two-element interferometry
- Visibilities
- Aperture synthesis
- Imaging considerations

Two-element Interferometer

- Correlate and integrate the signals from two antenna separated by baseline, *b,* pointing at the same source
- Produces an interference fringe



- The term modulating the fringes $\cos(\omega\tau_g)$ can be rewritten using

$$\omega = 2\pi\nu \qquad \text{and} \qquad \tau_g = \frac{b\cos\theta}{c} = \frac{\vec{b}\cdot\hat{s}}{c}$$

to become

$$\cos\left(2\pi\nu\frac{\vec{b}\cdot\hat{s}}{c}\right) = \cos\left(2\pi\frac{\vec{b}}{\lambda}\cdot\hat{s}\right) = \cos\left(2\pi\vec{b}_\lambda\cdot\hat{s}\right)$$

where $\vec{b}_\lambda$ is the baseline measured in wavelengths representing a *spatial frequency*

Complex Visibility

- For an extended source we must integrate over solid angle and the response of the interferometer can then be written as

$$V_\nu = \int I_\nu(\hat{s})\mathrm{e}^{\left(-i\,2\,\pi\vec{b}_\lambda\cdot\hat{s}\right)}d\Omega$$

where this *visibility* is a complex number that can be expressed in terms of *amplitude* and *phase*

$$V = A\mathrm{e}^{-\mathrm{i}\phi}$$

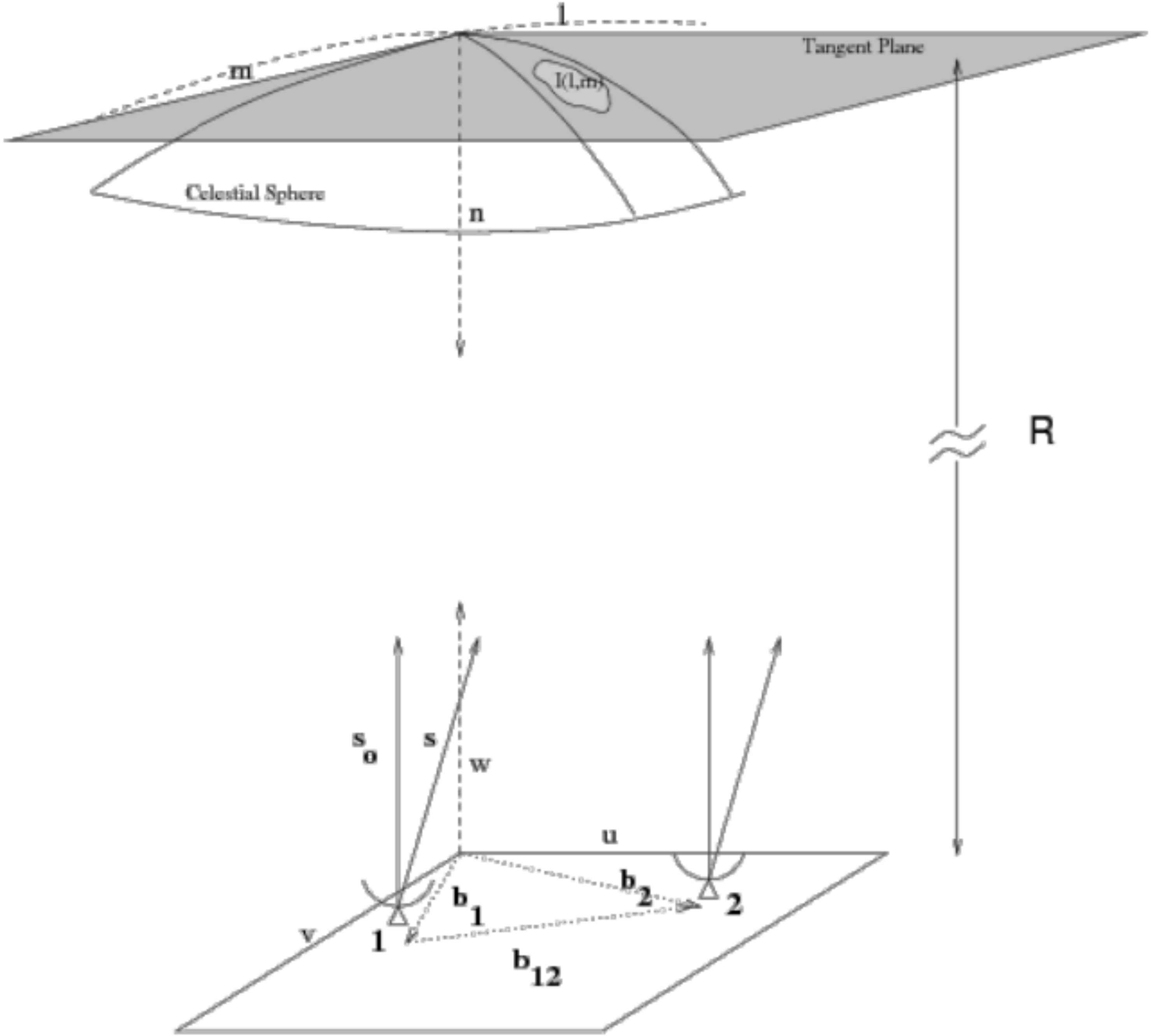
uv plane

- In 2D we can define a plane perpendicular to the source direction in which to define the baseline vector in terms of spatial frequency co-ordinates *u* and *v*, i.e.

$$\vec{b}_{\lambda} = u + v$$

- And the source position unit vector is defined by direction cosines projected on the *uv* plane

$$\hat{s} = l + m$$



l
m
Tangent Plane
I(l,m)
Celestial Sphere
n
R
s
o
s
w
u
b
2
b
1
v
1
2
b
12

- The visibility now becomes

$$V_\nu(u,v) = \int I_\nu(l,m) \mathrm{e}^{(-i 2\pi(ul+vm))} dl dm$$

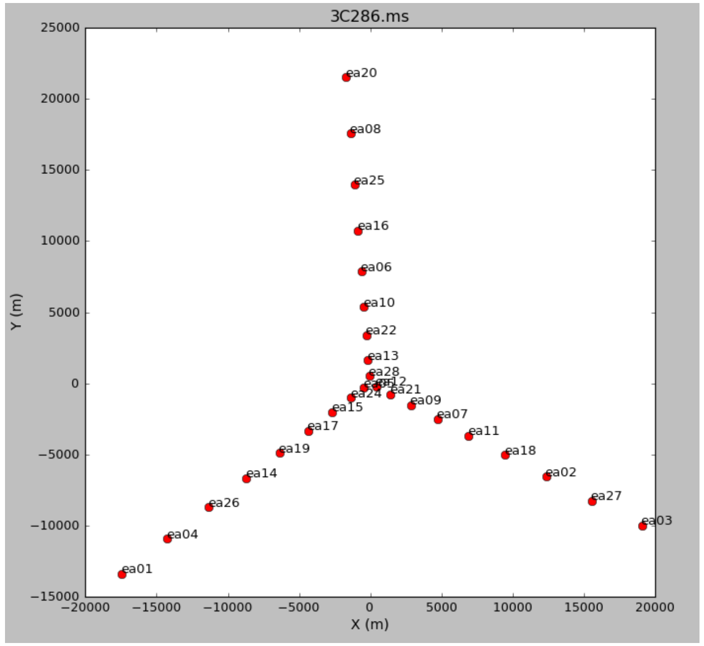
which is the Fourier transform of the intensity distribution

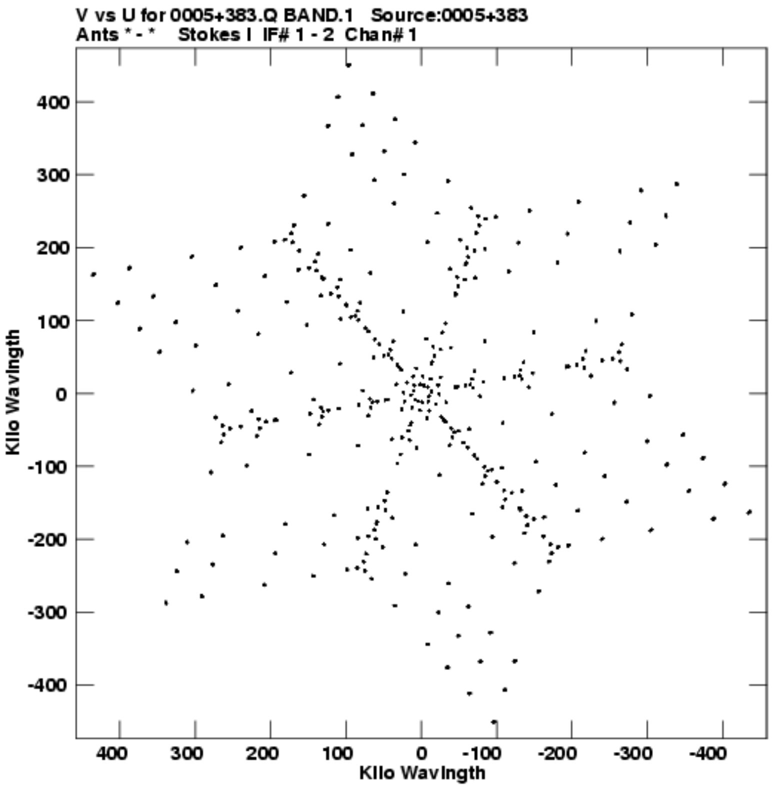
- Hence the intensity distribution can be recovered from the inverse Fourier transform of the visibilities

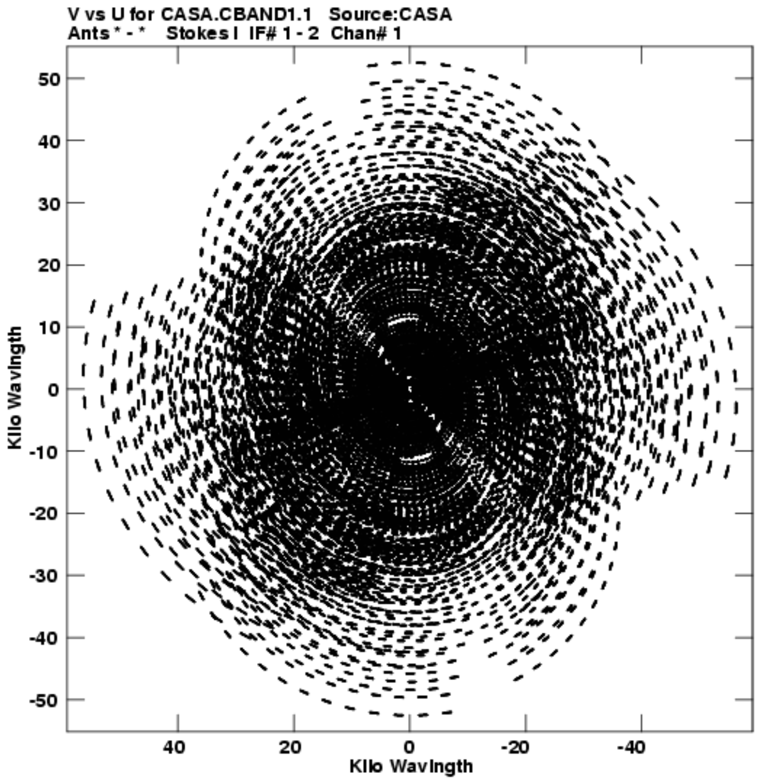
$$I_\nu(l,m) = \int V_\nu(u,v) \mathrm{e}^{(i 2\pi(ul+vm))} du dv$$

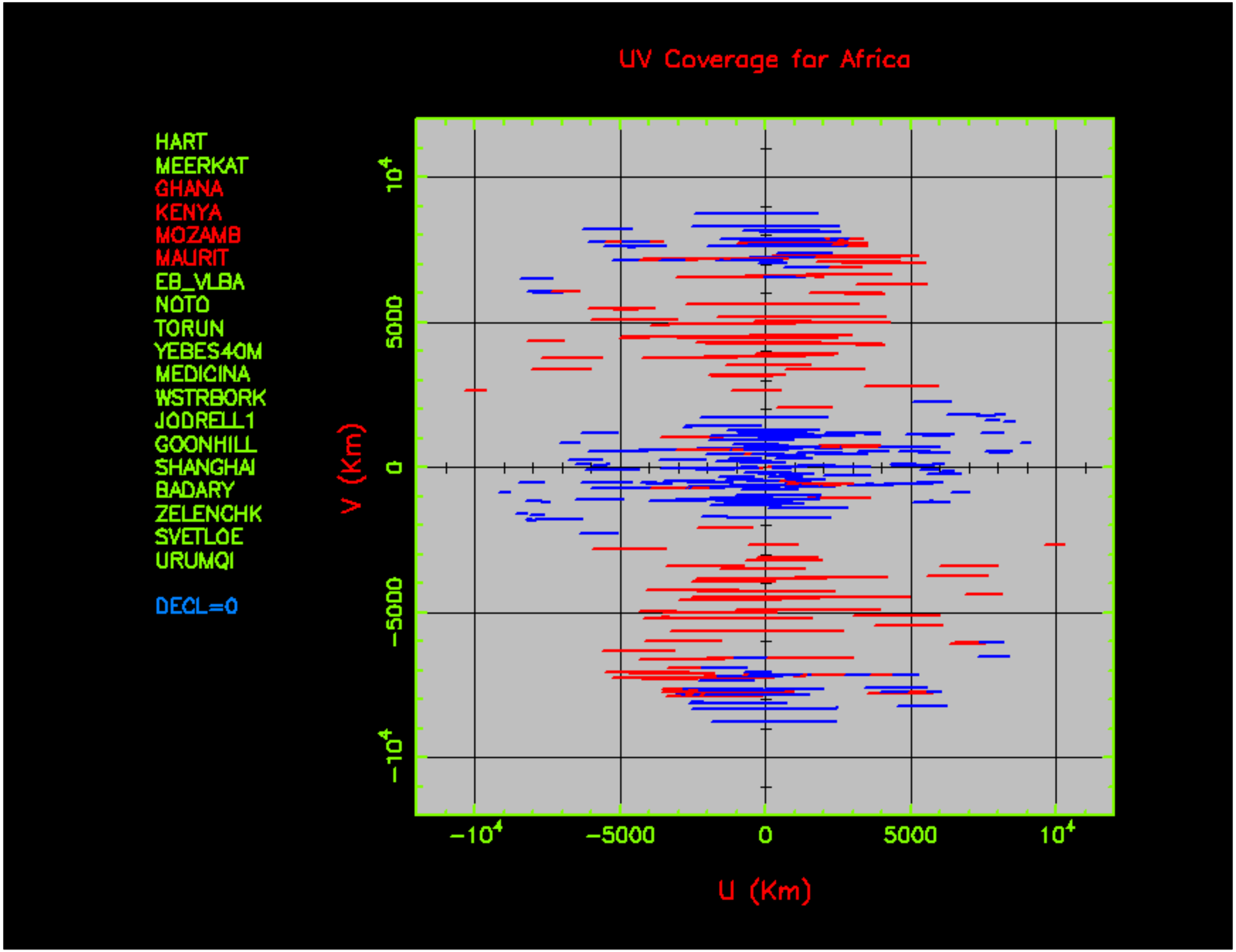
Aperture Synthesis

- One short integration with a single baseline at one wavelength gives one point in the *uv* plane
- The Earth's rotation will complete a track in the *uv* plane
- N telescopes gives N(N-1) baselines
- Wider bandwidth fills the gaps in the *uv* plane


3C286.ms
Y (m)
X (m)
ea20
ea08
ea25
ea16
ea06
ea10
ea22
ea13
ea28
ea21
ea24
ea15
ea09
ea07
ea17
ea11
ea19
ea18
ea14
ea02
ea26
ea27
ea04
ea03
ea01


V vs U for 0005+383.Q BAND.1 Source:0005+383
Ants * - * Stokes I IF# 1 - 2 Chan# 1
Kilo Wavlngth
Kilo Wavlngth

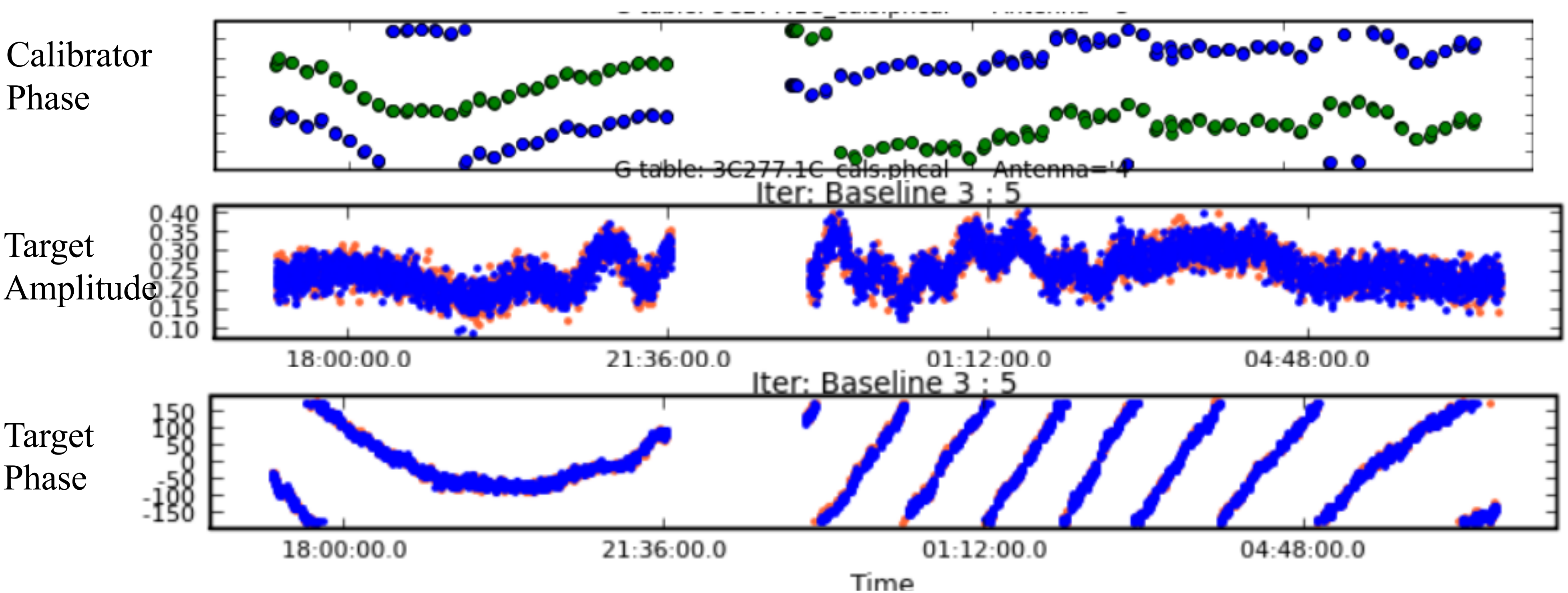

V vs U for CASA.CBAND1.1 Source:CASA
Ants * - * Stokes I IF# 1 - 2 Chan# 1
Kilo Wavlngth
Kilo Wavlngth



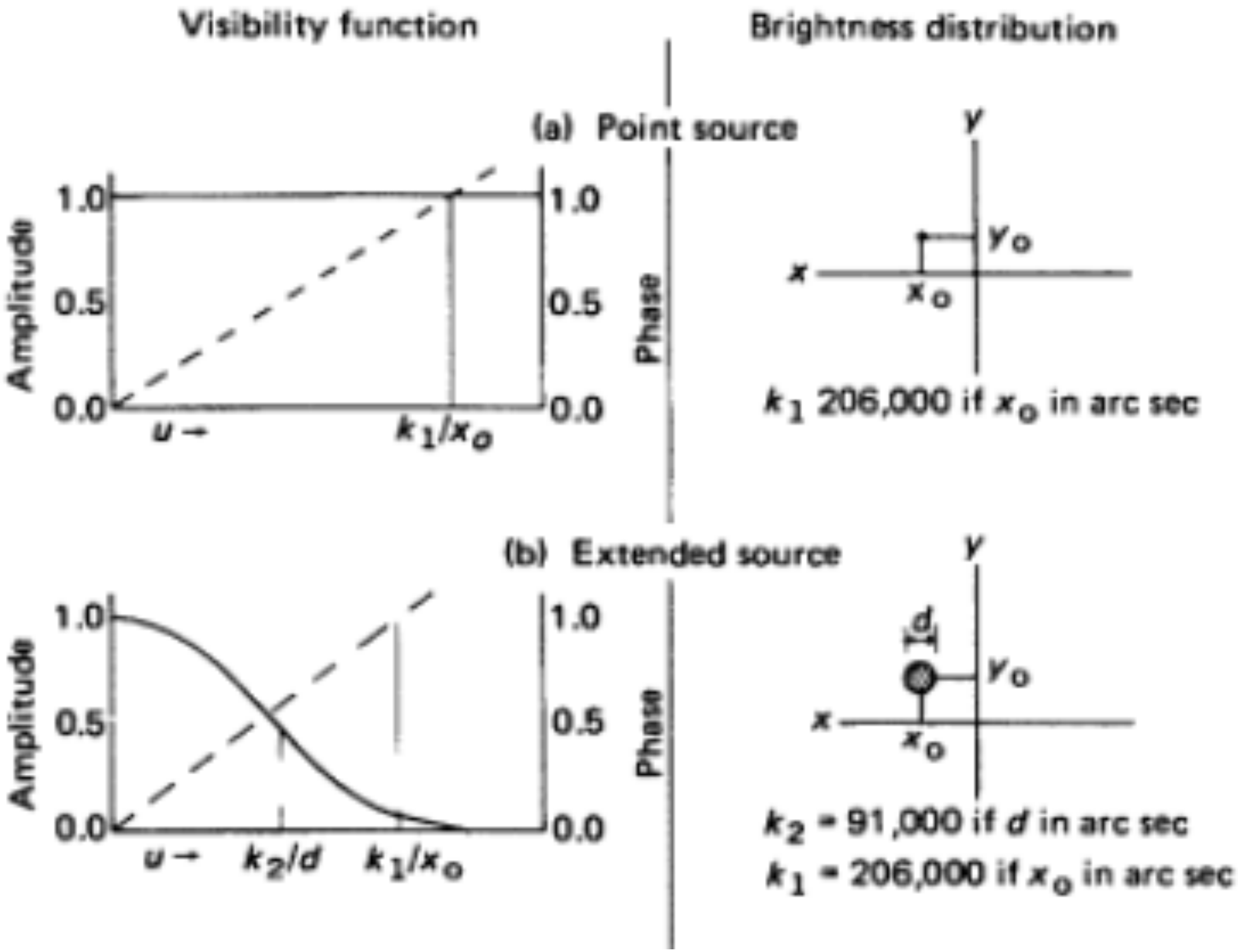
UV Coverage for Africa
HART
MEERKAT
GHANA
KENYA
MOZAMB
MAURIT
EB_VLBA
NOTO
TORUN
YEBES40M
MEDICINA
WSTRBORK
JODRELL1
GOONHILL
SHANGHAI
BADARY
ZELENCHK
SVETLOE
URUMQI
DECL=0
V (Km)
U (Km)
10^4
5000
0
−5000
-10^4

Calibration

- The effects of the atmosphere on the amplitude and phase are corrected by regular observations of a nearby, bright, point source e.g. a quasar



Amplitude vs Baseline plots



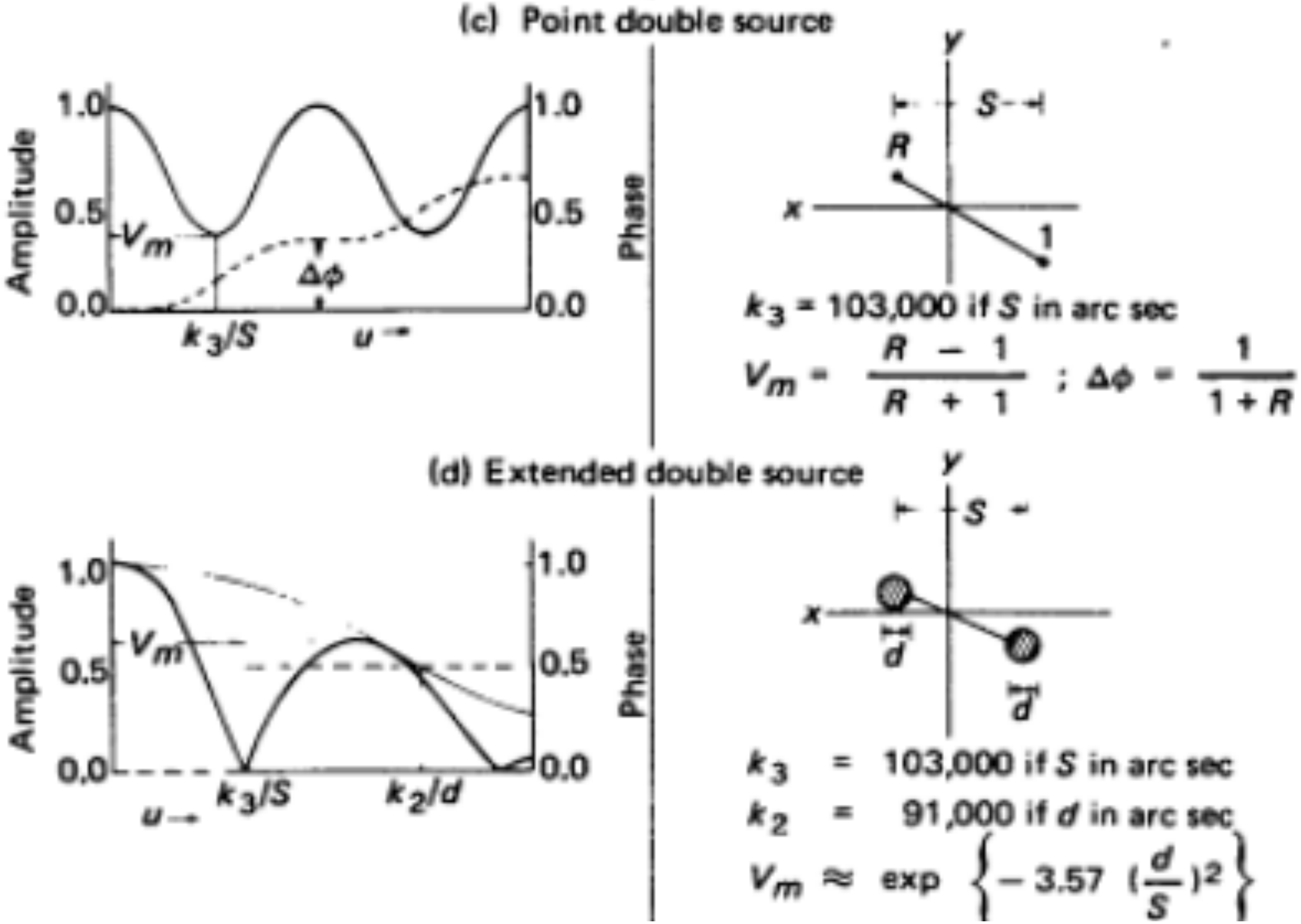


Figure 16–1. The visibility functions for various brightness distribution models (reproduced from Fomalont & Wright 1974; © Springer, Berlin).

Image Fidelity

- Maximum baseline determines the resolution or synthesised beam

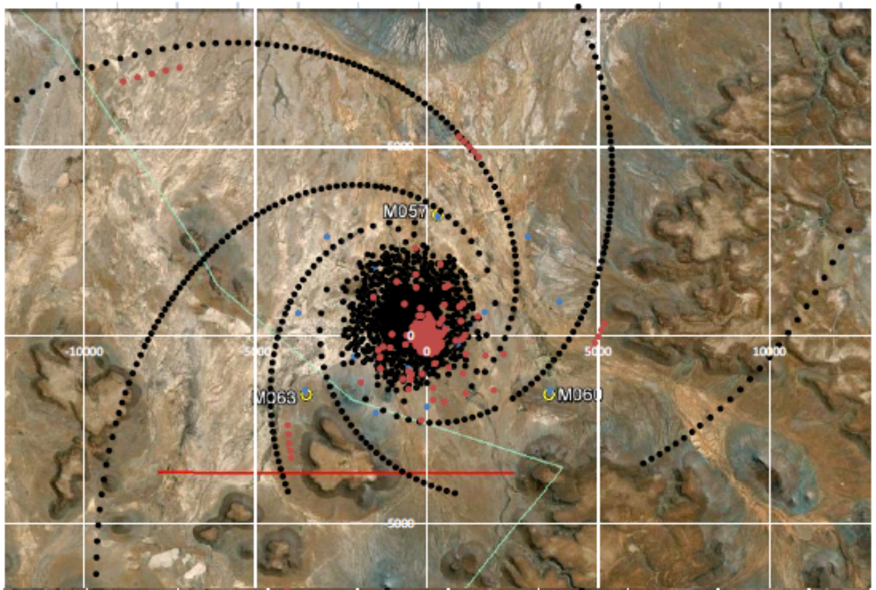
$$\theta_{beam} \approx \frac{\lambda}{b_{\max}}$$

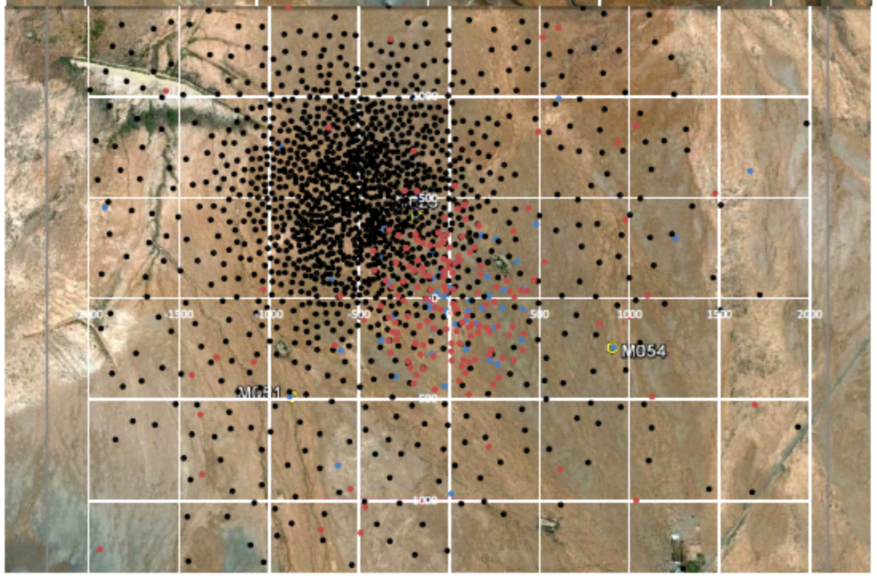
- Minimum baseline determines the largest angular scale that the interferometer can image

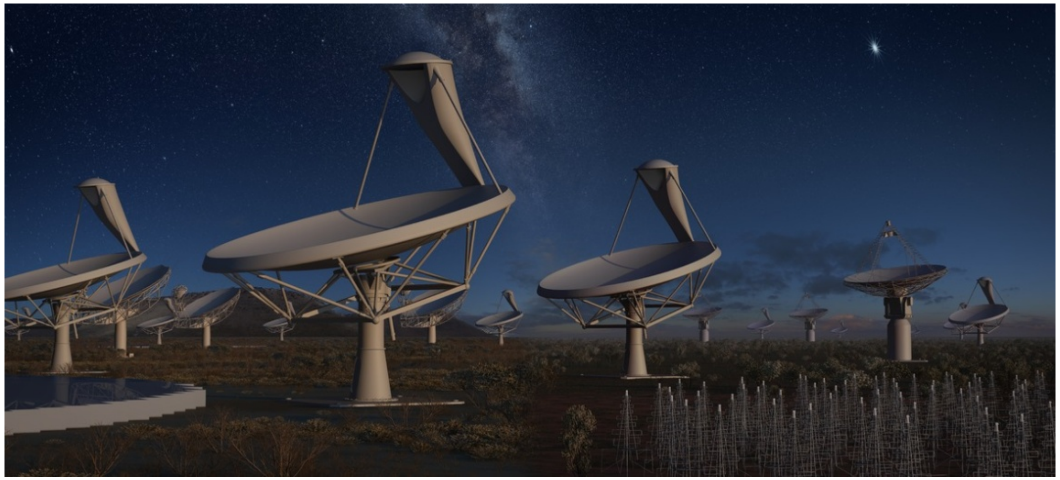
$$\theta_{LAS} \approx \frac{\lambda}{b_{\min}}$$

- Emission at spatial frequencies larger than θ_{LAS} are not detected
- Often leads to *missing flux* issues
- Need to fill in missing short spacing information
- Image fidelity is determined by number of antenna in the array
- SKA with 3000 dishes and baselines from 30 m to 5000 km will solve many of these problems

SKA

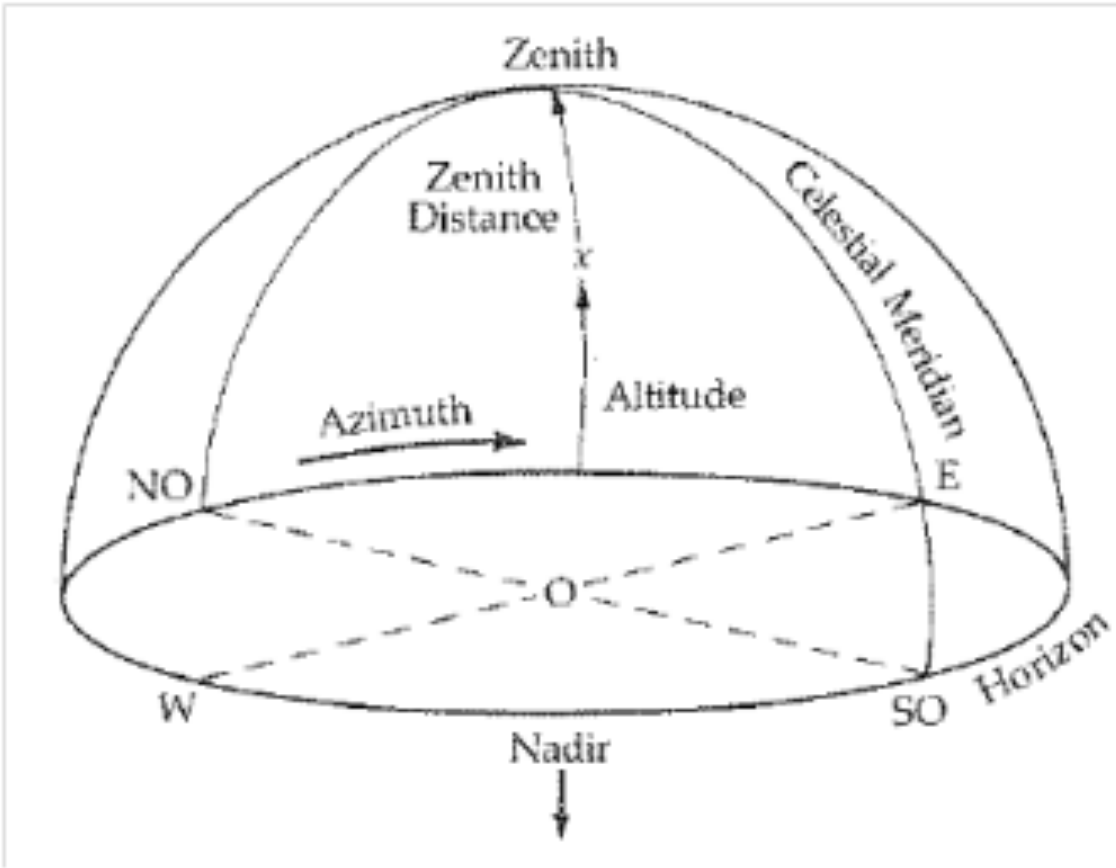

M057
M063
M060
-10000
-5000
0
5000
10000

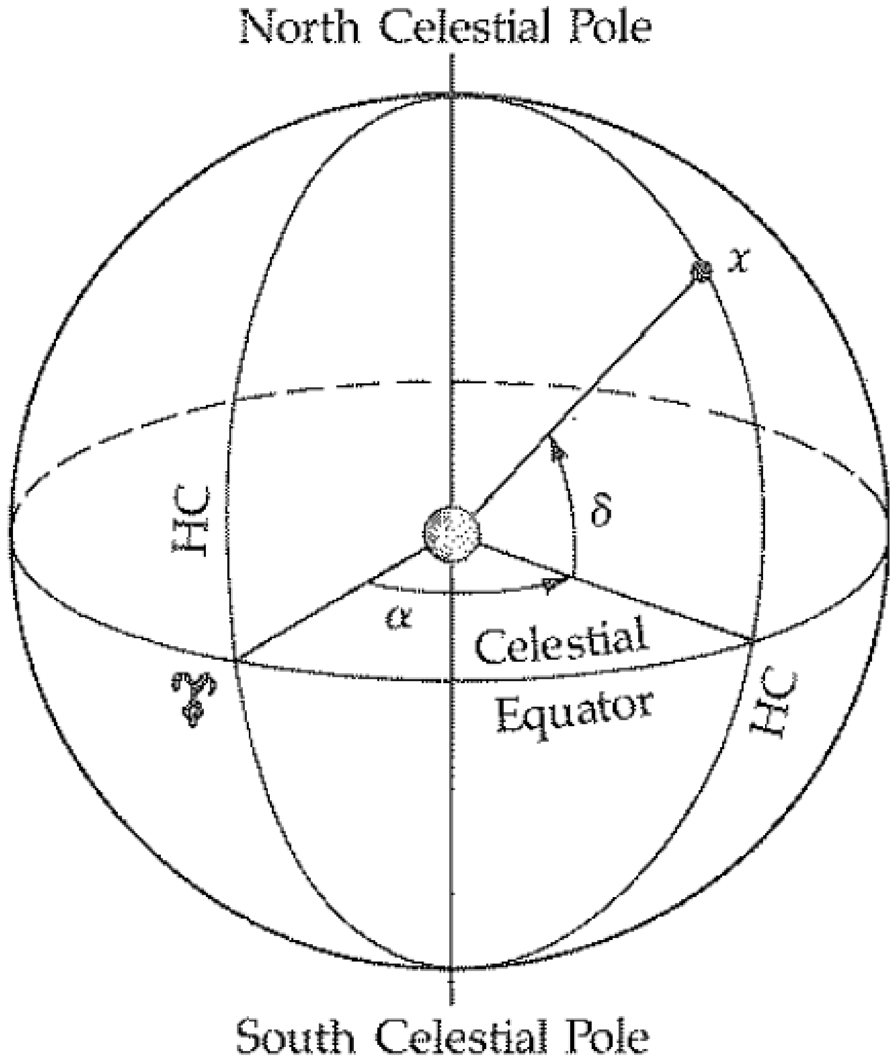

M054
-1500
-1000
-500
500
1000
1500
2000

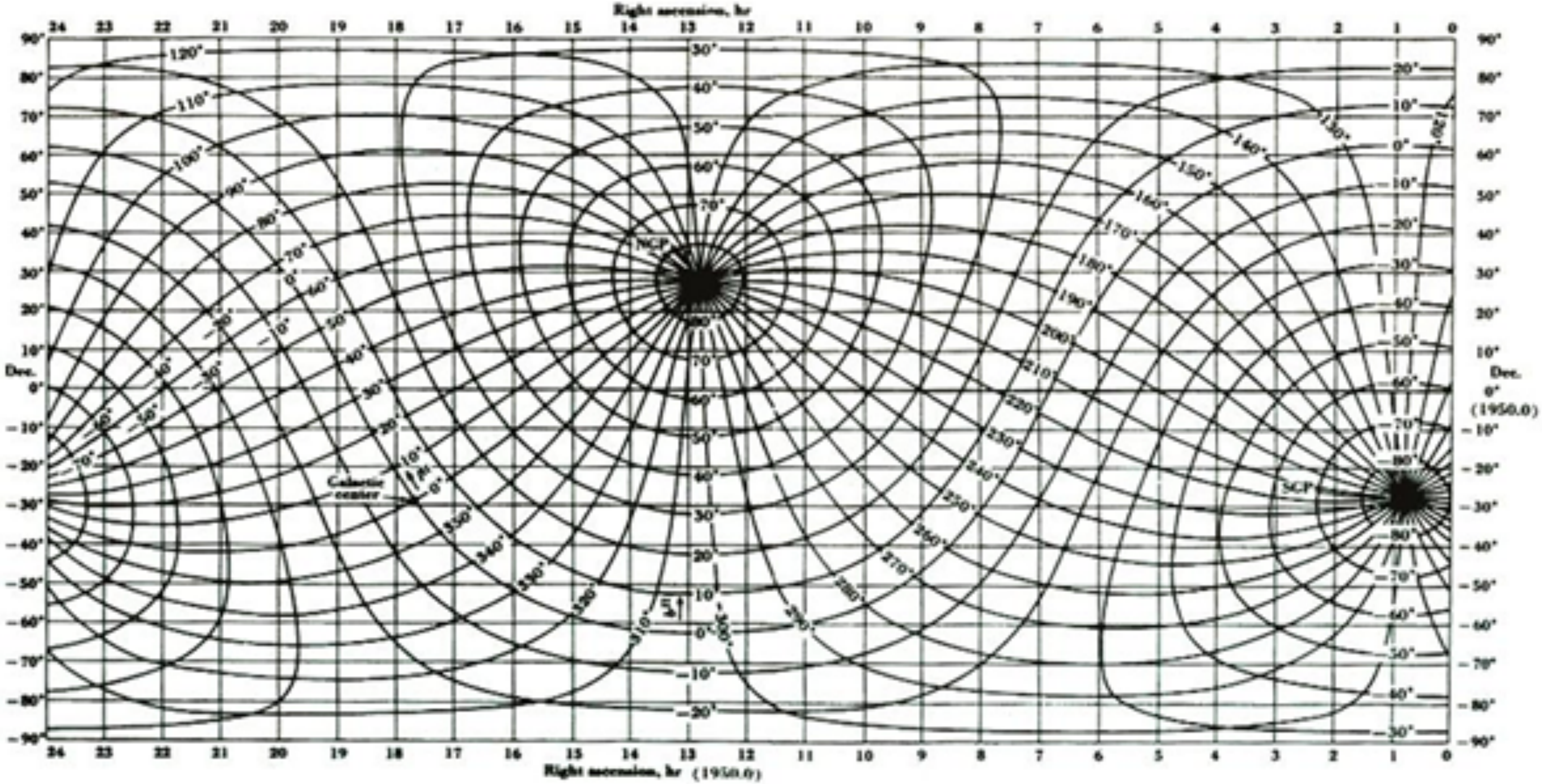


Summary

- Interferometers observe the Fourier transform of the intensity distribution on the sky
- Only sensitive to a limited range of spatial frequencies
- SKA will be a massive leap forward


Zenith
Zenith Distance
x
Celestial Meridian
Azimuth
Altitude
NO
E
O
W
SO
Horizon
Nadir


North Celestial Pole
x
HC
δ
α
Celestial Equator
HC
South Celestial Pole


Right ascension, hr
Dec.
Dec.
(1950.0)
NGP
SGP
Galactic center
Right ascension, hr (1950.0)