Imaging concepts (uv-coverage, weighting, clean)

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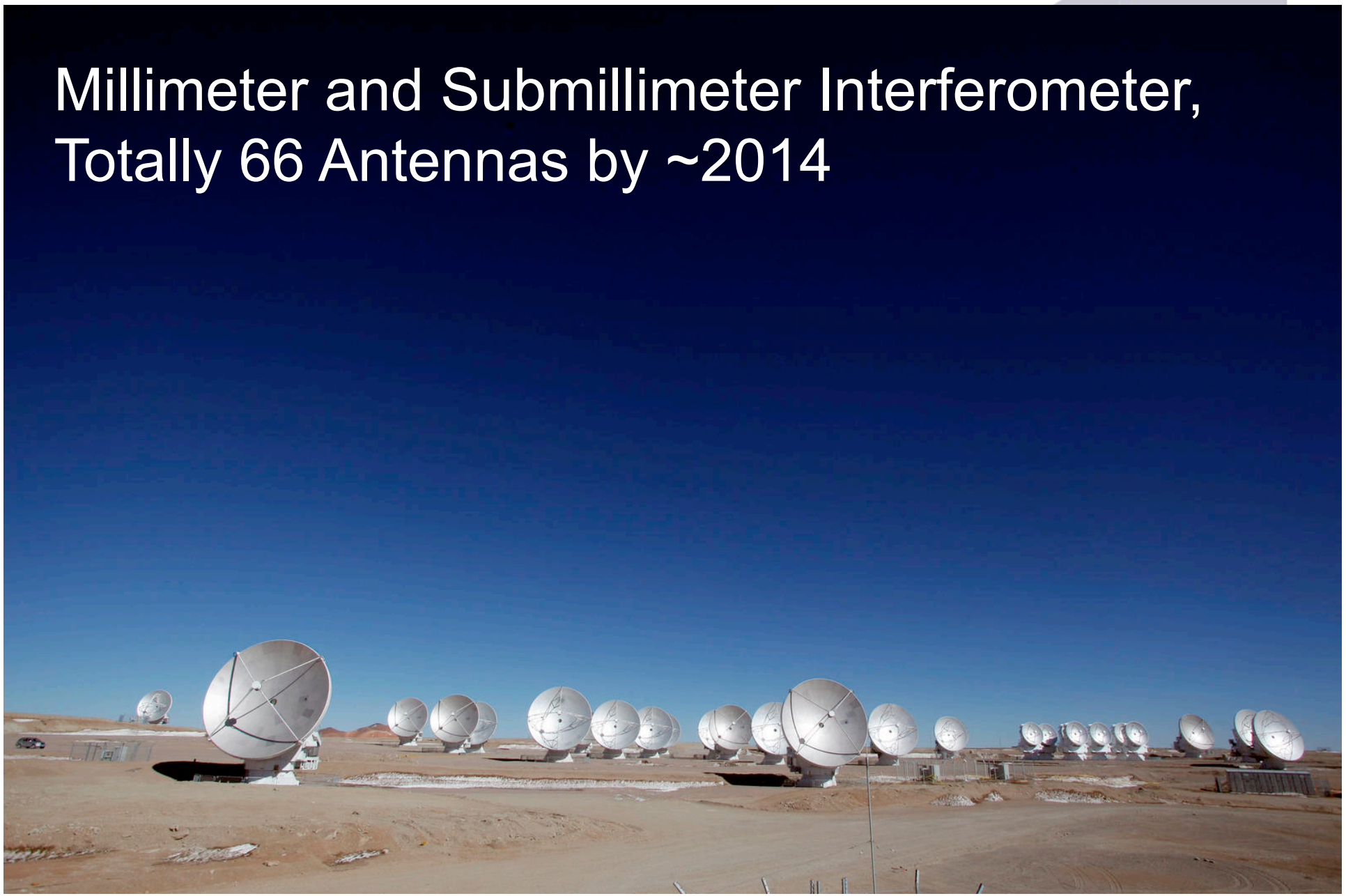
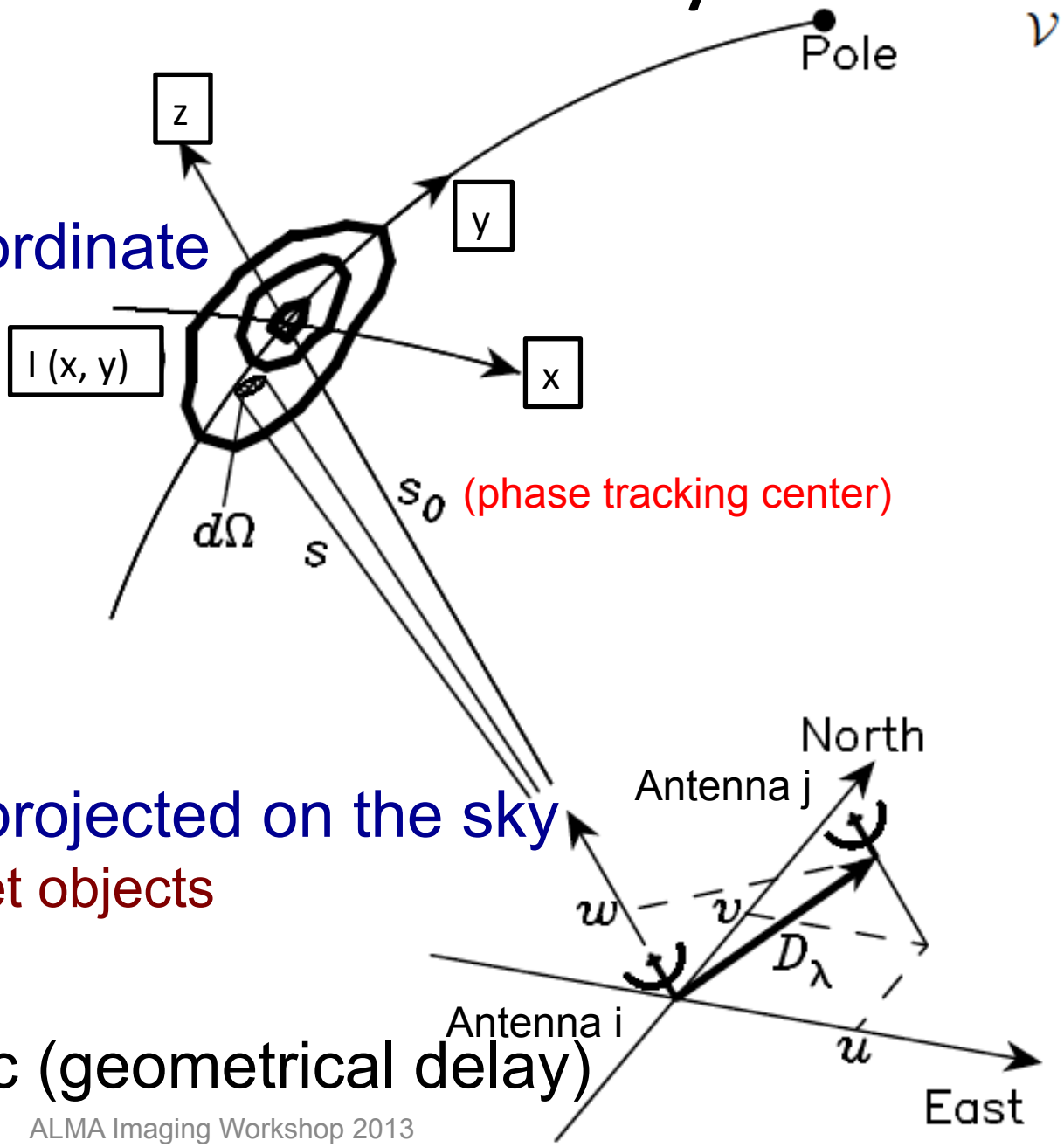
ALMA


Millimeter and Submillimeter Interferometer,
Totally 66 Antennas by ~2014

Interferometric Coordinate System

x, y: Sky Spatial Coordinate



u, v: ``Baseline D_λ'' projected on the sky

→ ``rotate'' as the target objects rotate on the sky.

$\tau_g = w / c = D_\lambda \cdot s_0 / c$ (geometrical delay)

Data we obtain with ALMA are ``Visibility (u,v)'',
Fourier-Transform of Source Images I (x,y)

Visibility: $$V(u,v) = \iint I(x,y)\exp\{-2\pi i(ux+vy)\}dxdy$$

x, y: Sky Spatial Coordinate.
u, v: Baseline Vectors projected on the sky.

V (u,v) is wave, and so
consists of amplitude and phase

See ``Synthesis Imaging in Radio Astronomy II", and ``Interferometry and Synthesis in Radio Astronomy"

Visibility Calibration

- Visibility: $V(u,v) = \iint I(x,y)\exp\{-2\pi i(ux+vy)\}dxdy$
- In ideal case,

$$V_{obs} = V_{source}$$

- But, in reality,

$$V_{obs} \neq V_{source} \Rightarrow V_{obs} = G \cdot V_{source}$$

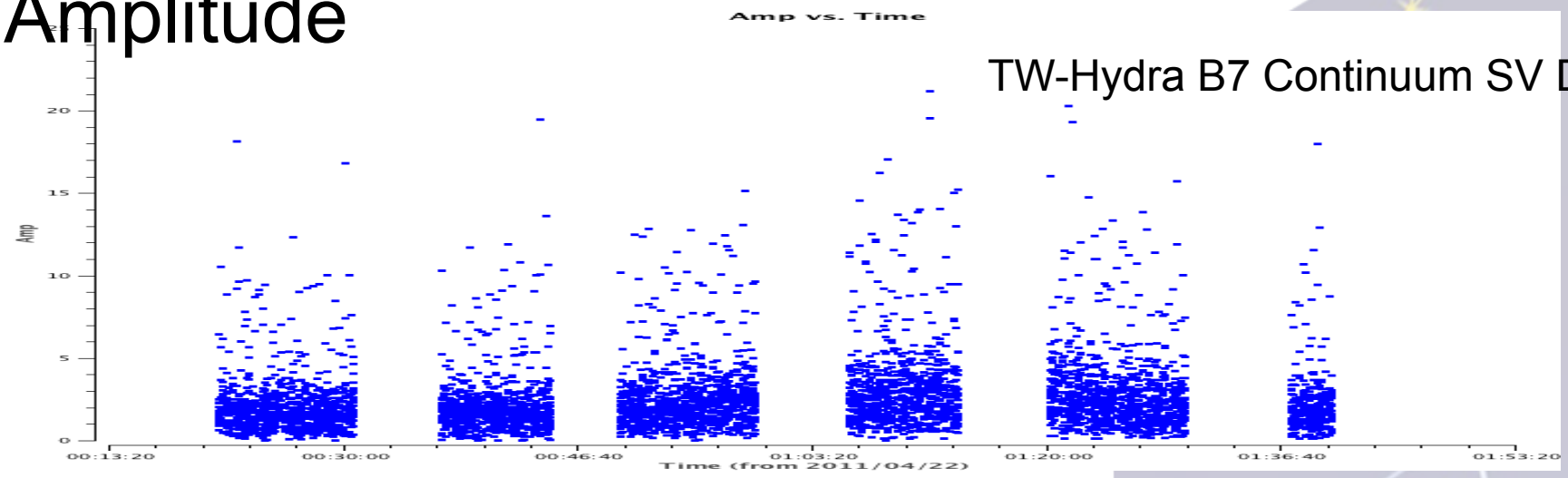
Need another term "*G*" (gain) to compensate the atmospheric/instrumental effects.

- "Calibration" is a process to derive this "*G*" and recover the true visibility.

ALMA Data Archive provides the fully calibrated visibility data!!

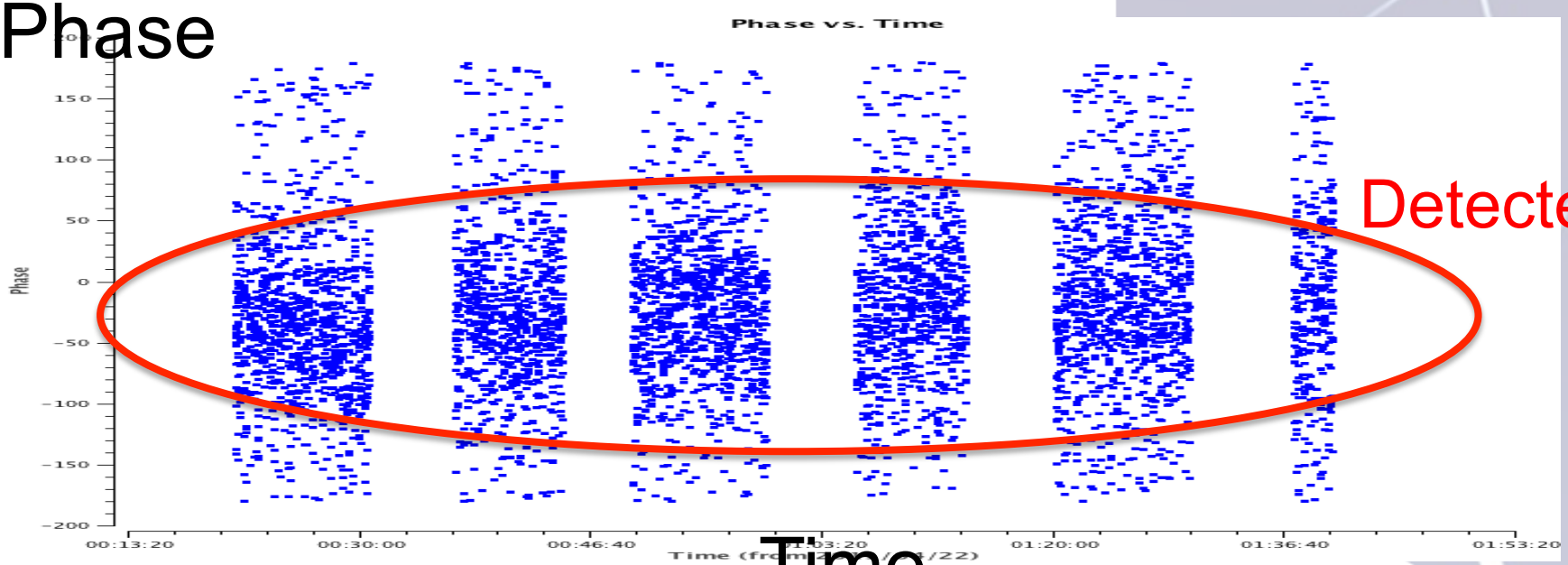
ALMA Visibility Data

Amplitude



TW-Hydra B7 Continuum SV Data

Phase



Detected!!

Time

Finite Visibility Sampling

Ideally:

$V(u,v) = \iint I(x,y) \exp\{-2\pi i (ux+vy)\} \, dxdy$

In reality: $V'(u,v) = S(u,v) \, V(u,v)$

$S(u,v) = 1$ or 0 (observed or not observed)

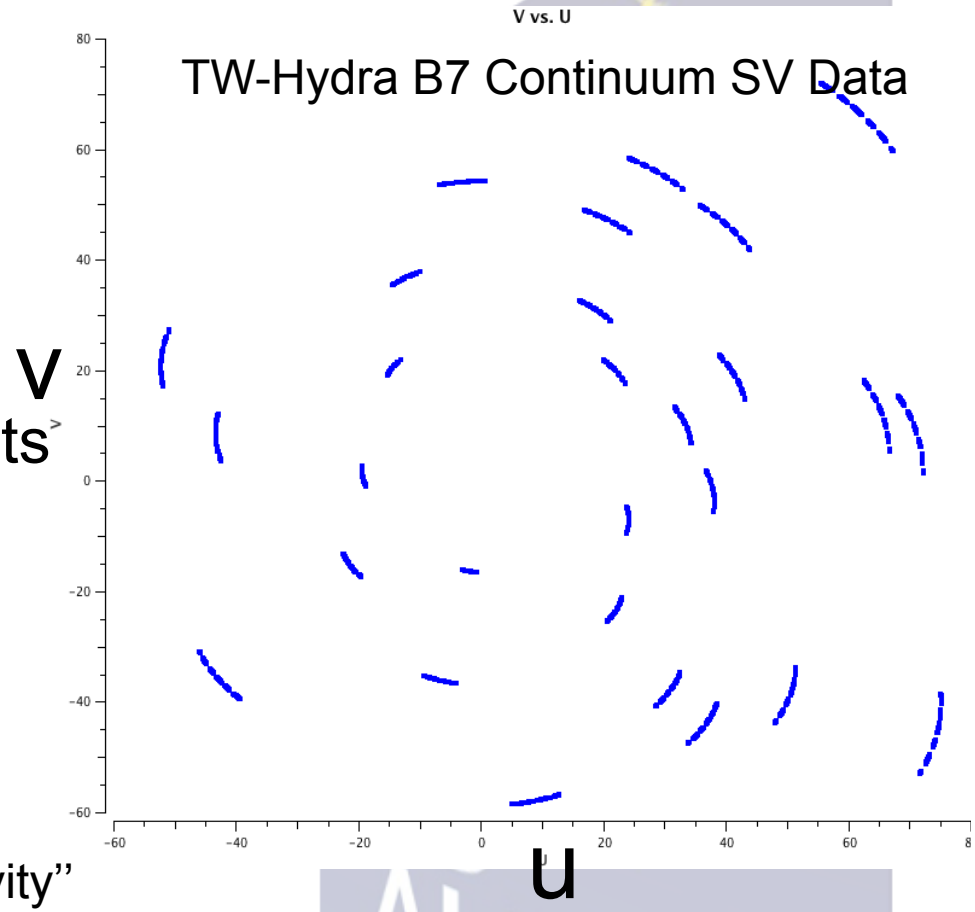
→ Sampling Function or ``uv coverage''

→Fourier-Transform of $V'(u,v)$ is NOT Real $I(x, y)$, but we call it Dirty Map $I_D(x,y)$

uv coverage

Traces the observed spatial Fourier components, following the Earth rotation.

Only discrete Fourier components can be observed, depending on the number of baselines.
→ Need some ``interpolation''.



In particular, there is always a ``central cavity'' where any interferometer can never be observed, because the baseline length shorter than the dish size can never be achieved.
→ Need extrapolation!!

Dirty Map, Dirty Beam

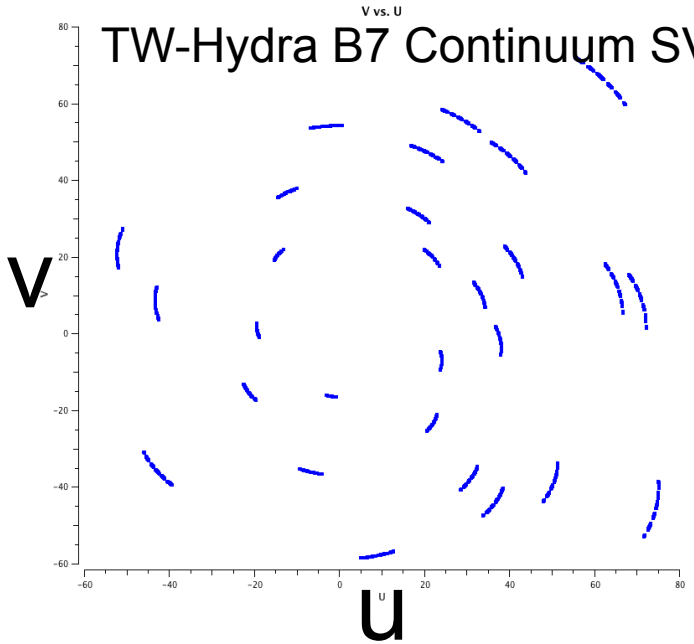
$\mathbf{V'}(\mathbf{u},\mathbf{v}) = \mathbf{S}(\mathbf{u},\mathbf{v})\mathbf{V}(\mathbf{u},\mathbf{v})$
Where $\mathbf{V}(\mathbf{u},\mathbf{v})$ is the true visibility, $\mathbf{S}(\mathbf{u},\mathbf{v})$ the sampling function, and $\mathbf{V'}(\mathbf{u},\mathbf{v})$ the sampled visibility.

The visibility is related to the image via
$\mathbf{V}(\mathbf{u},\mathbf{v}) = \mathbf{FT}(\mathbf{I}(\mathbf{x}, \mathbf{y}))$

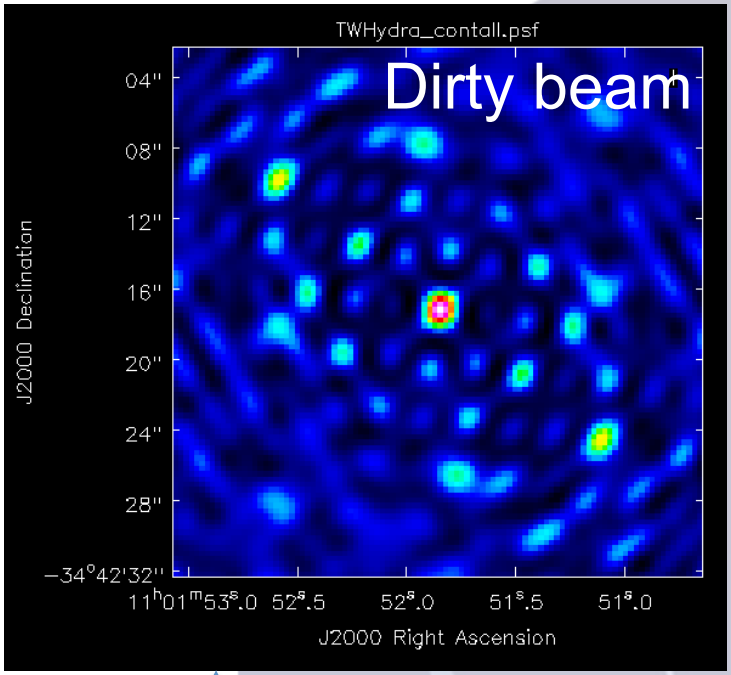
If we take the IFT of $\mathbf{V'}(\mathbf{u},\mathbf{v})$ then using the convolution theorem
$\mathbf{IFT}(\mathbf{V'}) = \mathbf{IFT}(\mathbf{S}) * \mathbf{FT}(\mathbf{V})$
where * indicates convolution

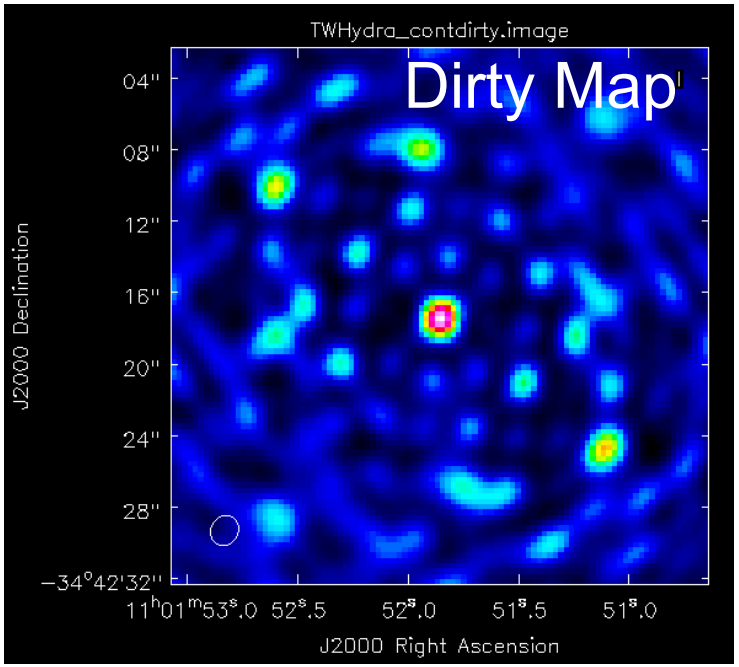
$\mathbf{IFT}(\mathbf{V'}) = \mathbf{B}(\mathbf{x}, \mathbf{y}) * \mathbf{I}(\mathbf{x}, \mathbf{y})$
where $\mathbf{B}(\mathbf{x}, \mathbf{y}) = \mathbf{IFT}(\mathbf{S}(\mathbf{u},\mathbf{v}))$ is the 'dirty beam' and * is convolution.

Relation among the uv, Dirty Beam, and Dirty Map



IFT

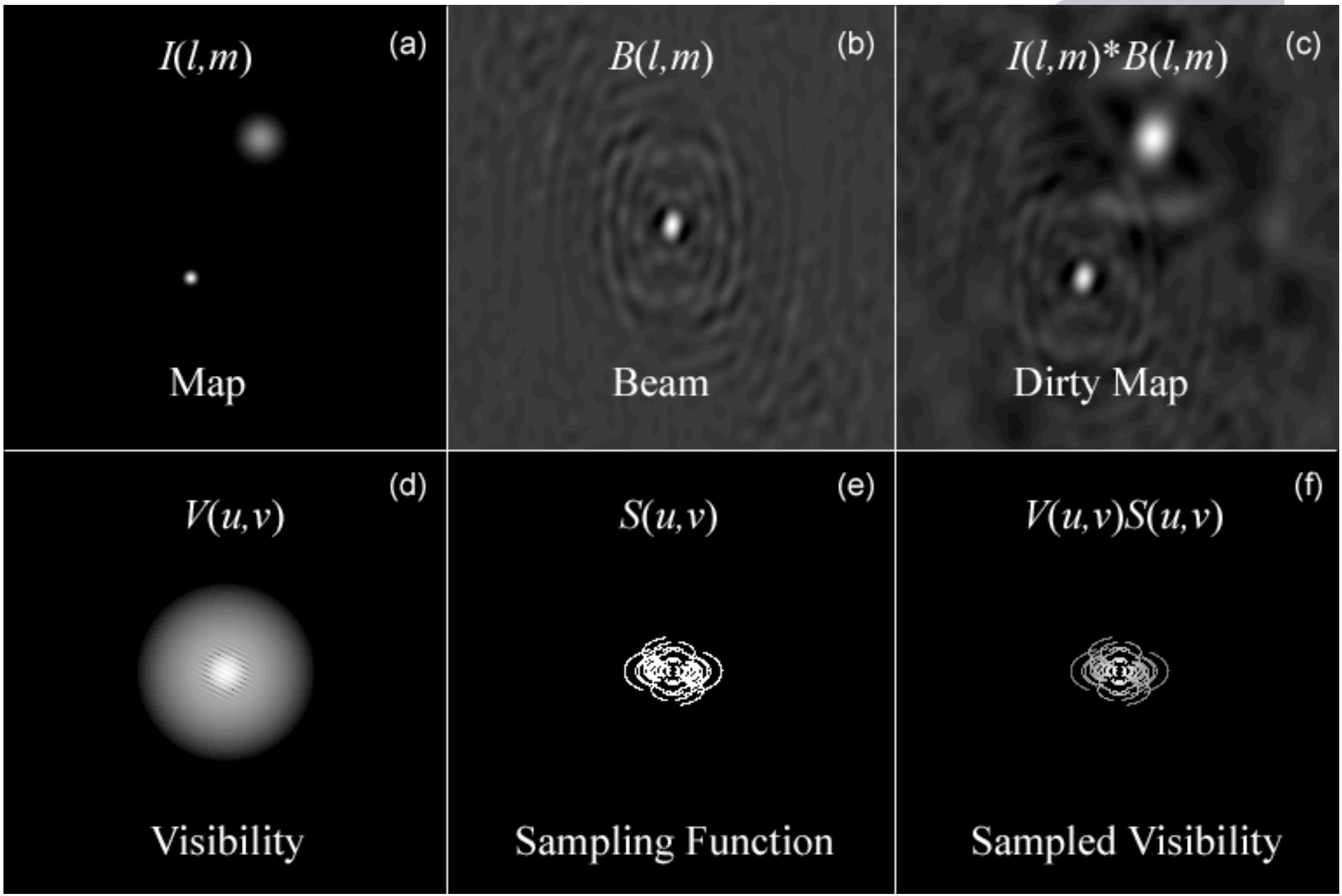




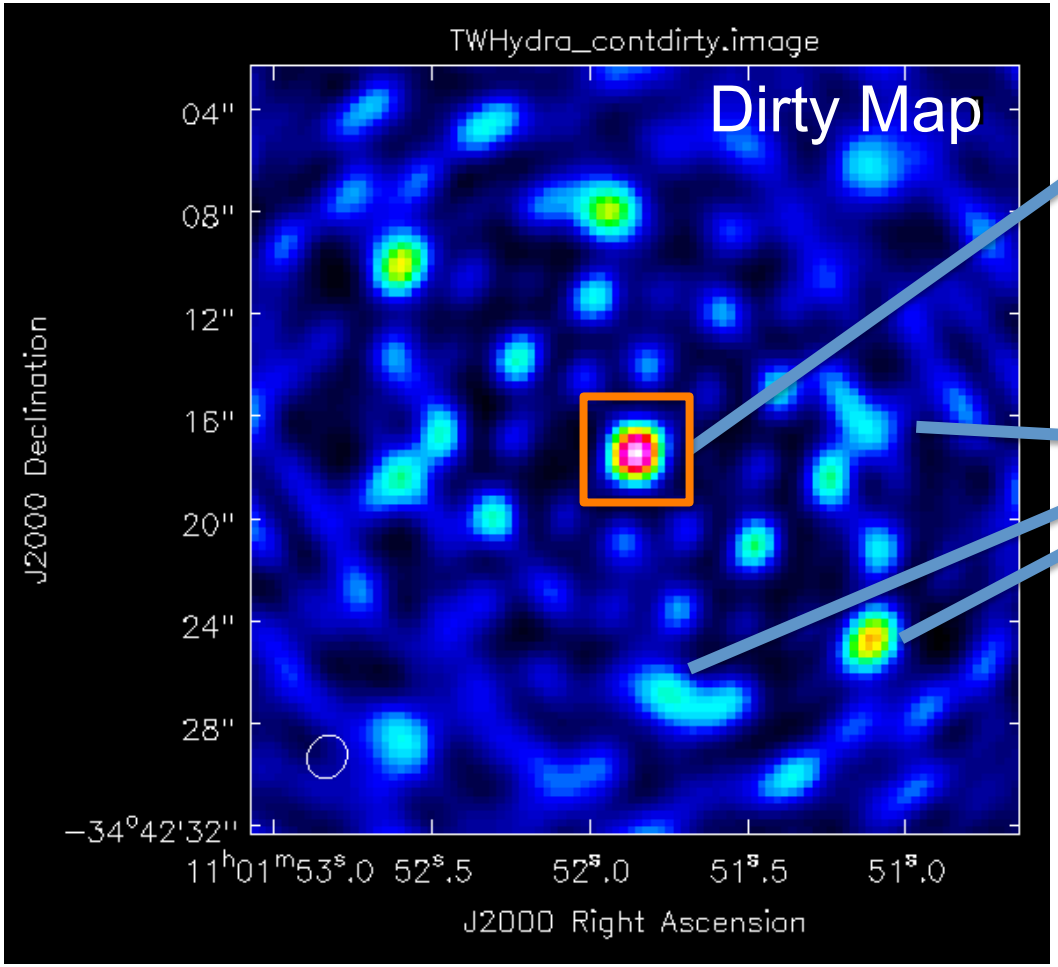
$*$ Convolution

``True'' Image

From http://web.njit.edu/~gary/728/Lecture6.html by Prof. Dale E. Gary (NJIT)



CLEAN

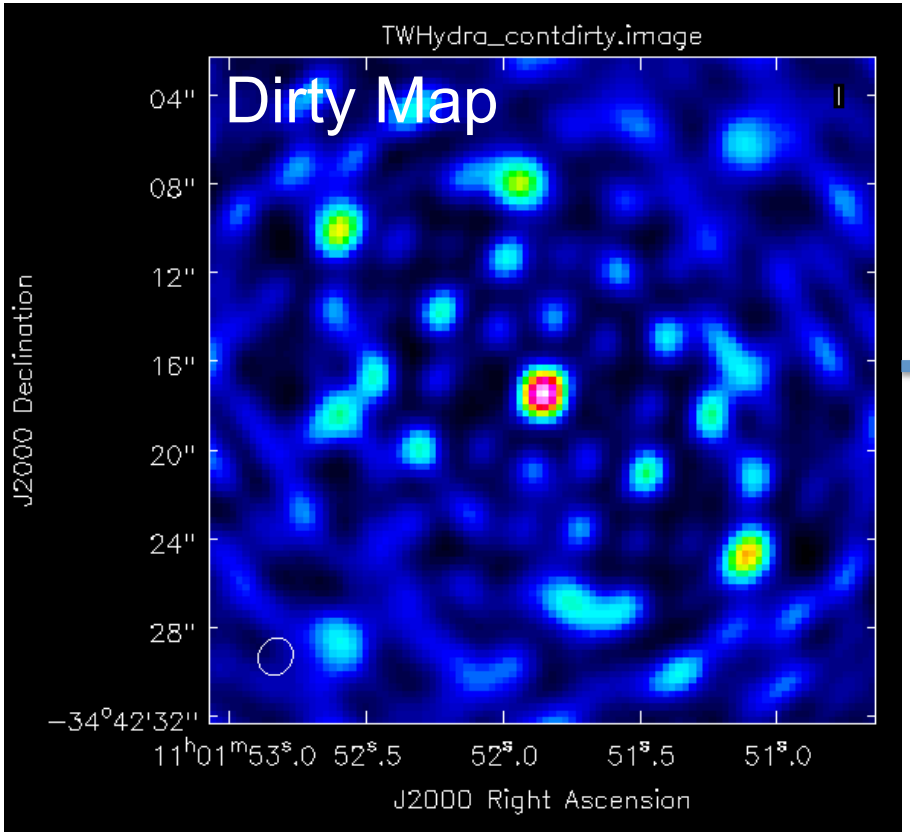


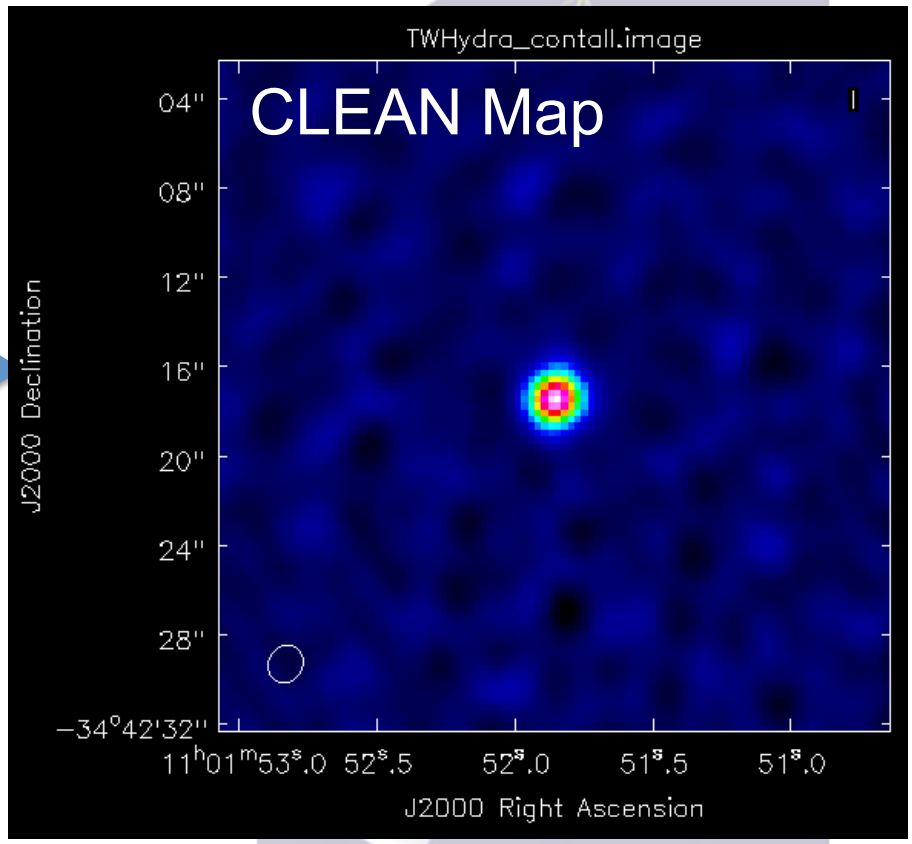
Real Emission
(Circumstellar Disk)

``Sidelobes''

Specify the real emission (putting ``CLEAN BOX''),
and remove sidelobes!!

After CLEAN





Successfully remove the sidelobes, and recover the real emission!

Note: This is equivalent to interpolation & extrapolation of the uv sampling.

CLEAN More Specifically
→ Kameno-san's website

http://milkyway.sci.kagoshima-u.ac.jp/~kameno/AIPS-Difmap/Lecture/CLEAN.swf

Tapering, Weighting, Robust Parameters

$$I_D(x, y) = \Sigma_k S(u,v)\, V(u,v) \exp\{2\pi i\,(ux+vy)\}$$

You can put weighting to the sampling function as;

$$I_D(x, y) = \Sigma_k T(u,v)\, D_k\, S(u,v)\, V(u,v) \exp\{2\pi i\,(ux+vy)\}$$

$T(u,v) = \exp[-(u^2 + v^2)/l^2]$

Where *l* is a measure of the width of the Gaussian taper.

$D_k = 1$ Natural weighting = 2

Robust parameter *r*

$D_k = 1/N(k)$ Uniform weighting =-2

Then just do clean….

Natural v.s. Uniform

Natural weighting adopts all the *uv* data points equally, thus ensure the highest sensitivity.
→ Weak lines, or extended components

Uniform weighting put the weight uniformly over the entire *uv* distance, thus ensure the highest spatial resolution.
→ High-resolution continuum, or strong line Imaging,

In reality, you play the robust parameter to get the best compromise.