Wide Field Imaging

CASS Radio School

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1 October, 2015

Wide-field ~~problems~~ solutions!

The antenna's primary beam

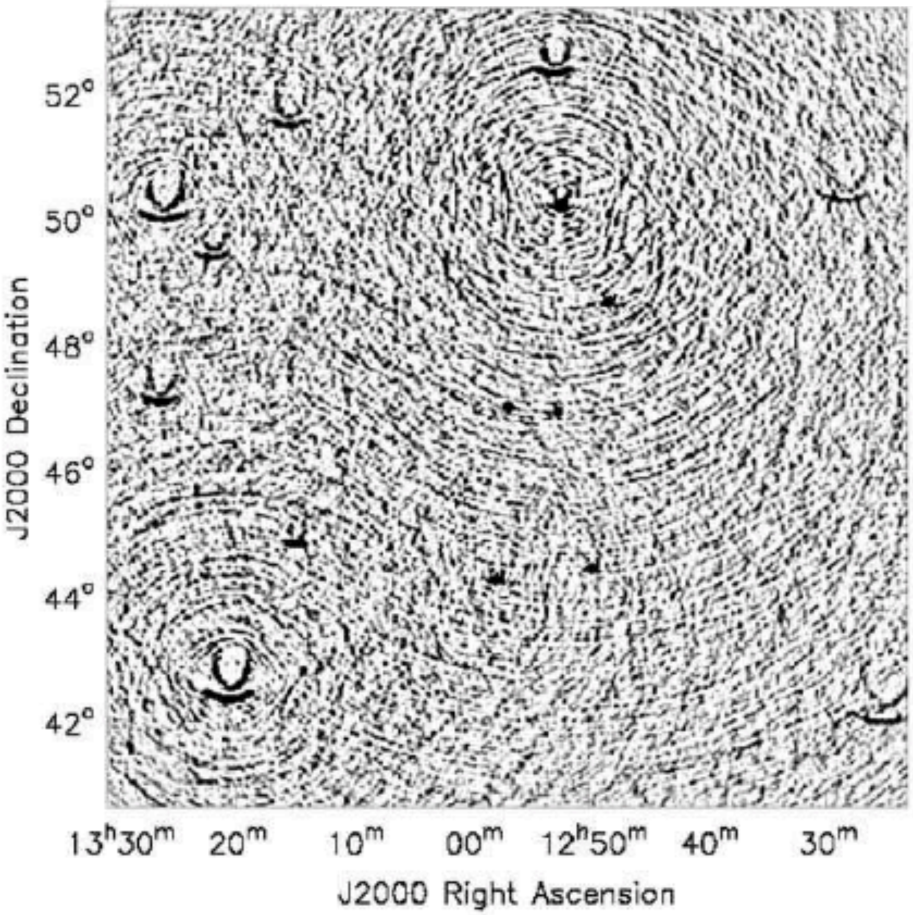
- mosaicking

Non-coplanar baselines

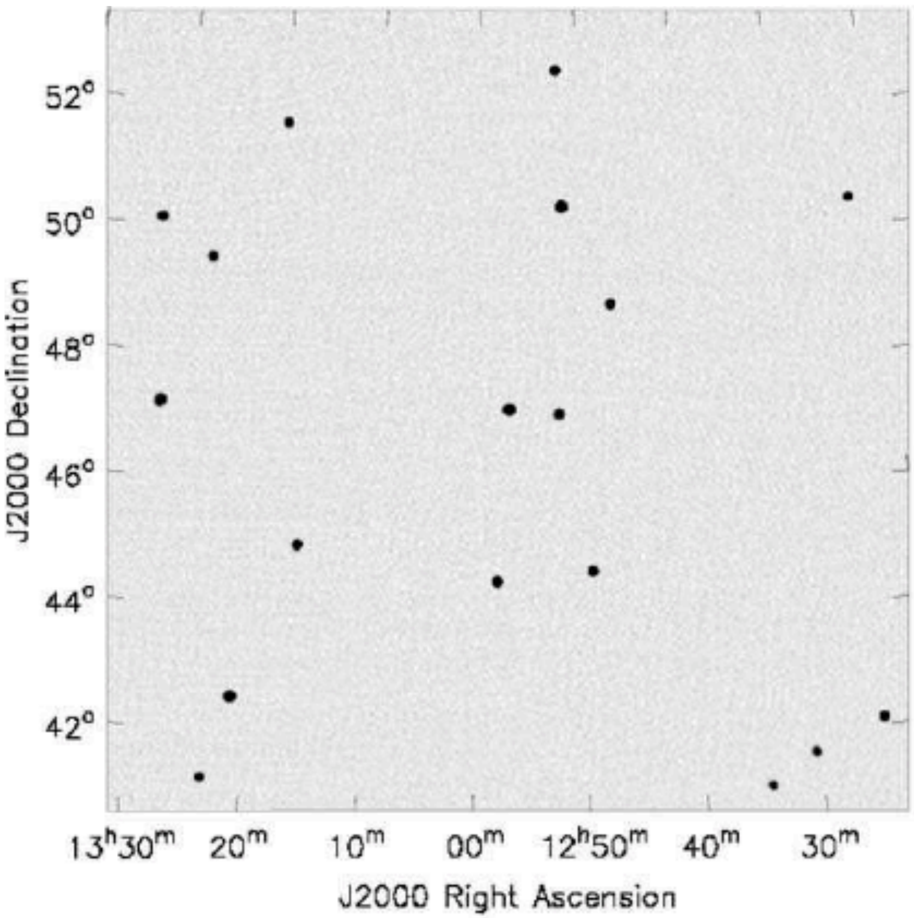
- faceting
- warped snapshots
- w-projection
- w-stacking
- w-snapshots
- 3-d DFT

Non-coplanar baselines

undesired result



desired result



(Cornwell+2008)

Non-coplanar baselines

$$V_\nu(u,v,w) = \iint \frac{I_\nu(l,m)}{\sqrt{1-l^2-m^2}} e^{-2i\pi[ul+vm+w(\sqrt{1-l^2-m^2}-1)]} dl dm$$

The direction cosines (l,m,n) are projections of the unit direction vector ***s*** onto the (u,v,w) axes

$$l = \cos(\alpha)$$

$$m = \cos(\beta)$$

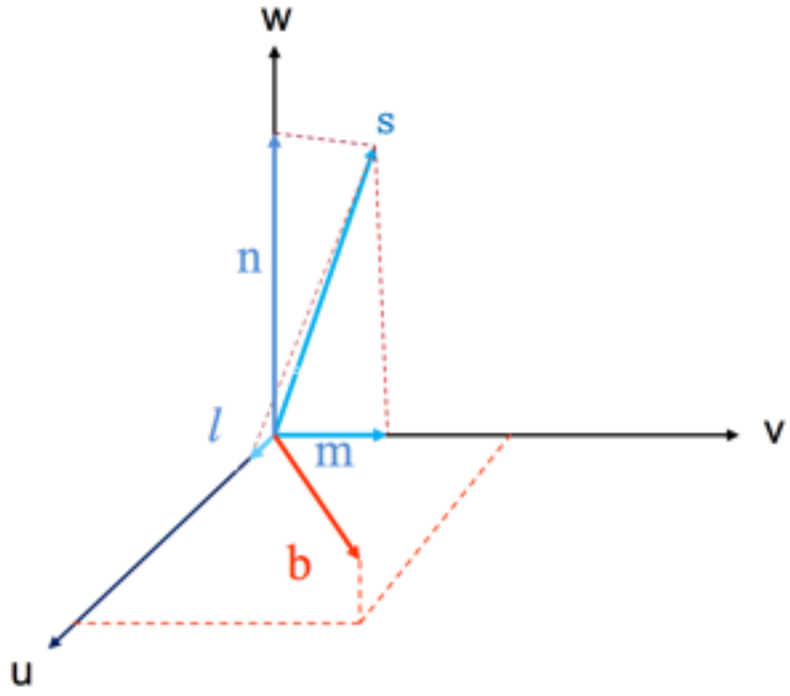
$$n = \cos(\theta) = \sqrt{1-l^2-m^2}$$

(sky)

And baseline vector

$$\mathbf{b} = (\lambda \mathrm{u}, \lambda \mathrm{v}, \lambda \mathrm{w})$$

(array)



Non-coplanar baselines

$$V_\nu(u,v,w) = \iint \frac{I_\nu(l,m)}{\sqrt{1-l^2-m^2}} e^{-2i\pi[ul+vm+w(\sqrt{1-l^2-m^2}-1)]} dl dm$$

We would prefer the form

$$V_\nu(u,\mathrm{v}) = \iint I_\nu(l,m) e^{-i2\pi(ul+\mathrm{v}m)}\, dl dm \quad : \quad I_\nu(l,m) \Leftrightarrow V(u,\mathrm{v})$$

This requires one of:

$l^2 + m^2 << 1$ or $w << \sqrt{u_{\max}^2 + v_{\max}^2}$

(small FOV) **(approx. coplanar)**

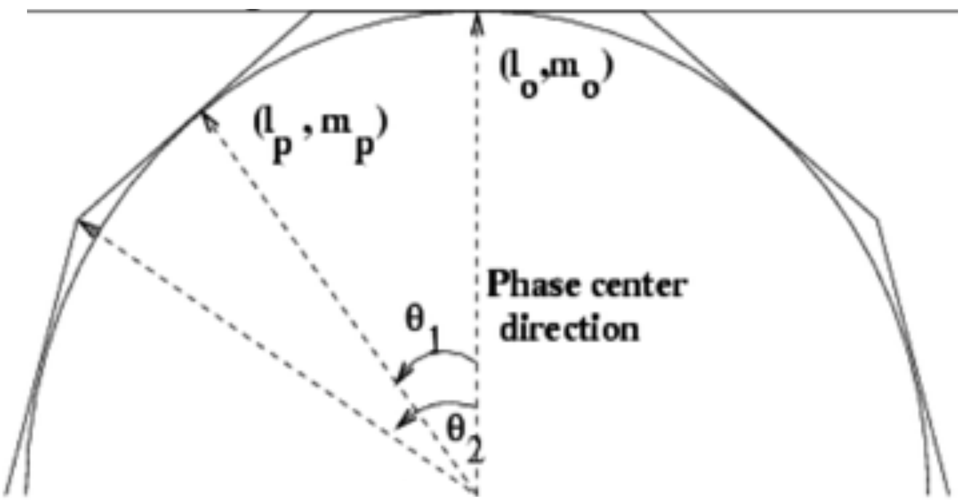
Polyhedron imaging (faceting)

Approximate the celestial sphere as a collection of 'tangent planes'

Restrict the FOV of each plane such that $l^2 + m^2 << 1$

Phase shift and recompute **(u,v,w)** for each plane

Project and combine the images onto a 2-d plane



$$N_{poly} \approx 2\theta^2_{FoV} \frac{B_{max}}{\lambda_{max}}$$

Note: uv-faceting algorithms are also viable

W-projection

$$V_\nu(u,v,w) = \iint \frac{I_\nu(l,m)}{\sqrt{1-l^2-m^2}} e^{-2i\pi[ul+vm+w(\sqrt{1-l^2-m^2}-1)]} dldm$$

factor out

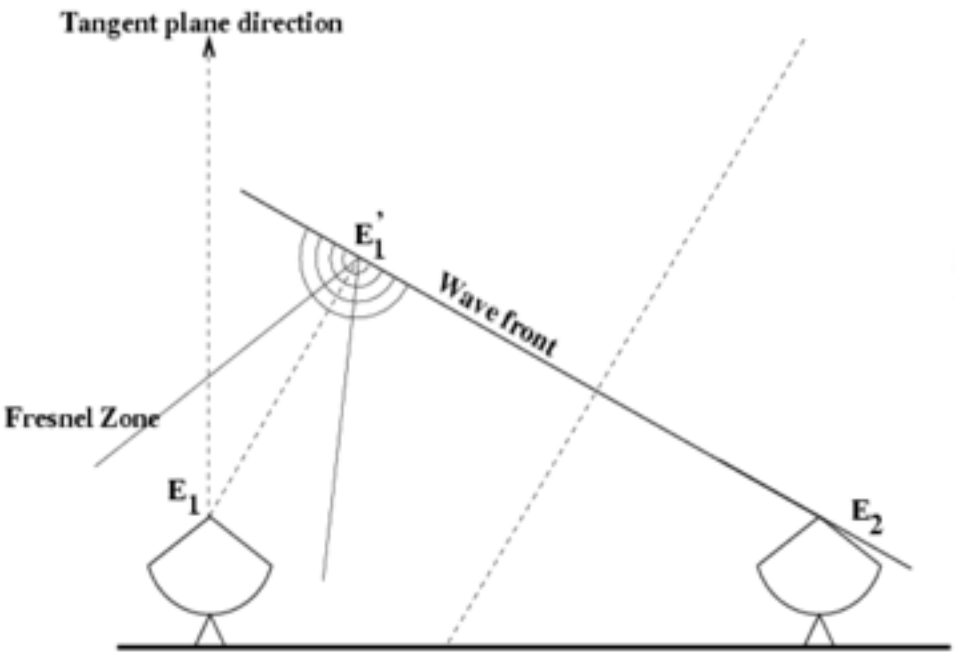
$$G(l,m,w) = e^{-2\pi i w(\sqrt{1-l^2-m^2}-1)}$$

such that

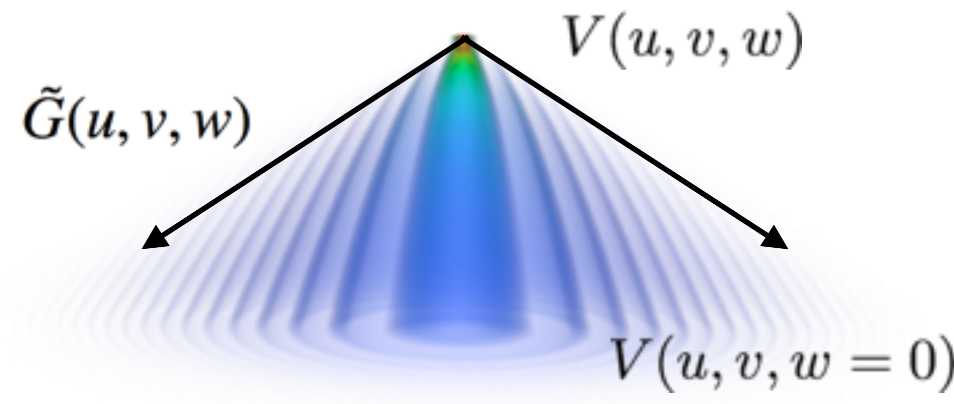
$$V(u,v,w) = \tilde{G}(u,v,w) * V(u,v,w=0)$$

W-projection

The w-term introduces a Fresnel phase screen



We can use ***G*** tp project each visibility onto the ***w***=0 plane



and Fourier transform to produce a single dirty image to deconvolve

Other non-coplanar solutions

w-stacking: partition data in ***w***, apply ***G*** in the image plane (multiplication)

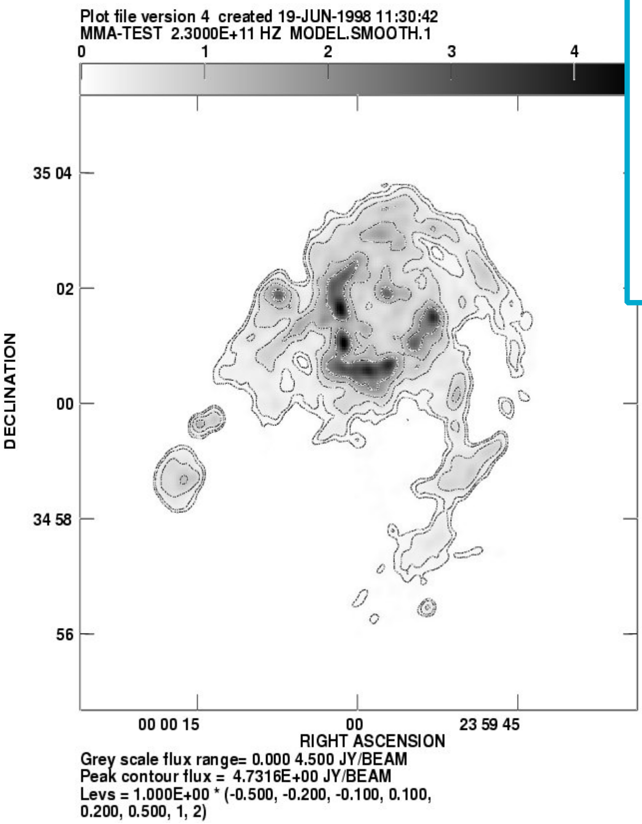
warped snapshots: modify (***l,m***) using functions of the zenith and parallactic angles for each snapshot, then coordinate transform the distorted image

w-snapshot: express ***w*** as a best fit plane with residuals **Δ*w*** projected with ***G***.

3-d DFT: invert the 3-d coherence function;   treat the physical emission as a spherical surface inside a 3-d image

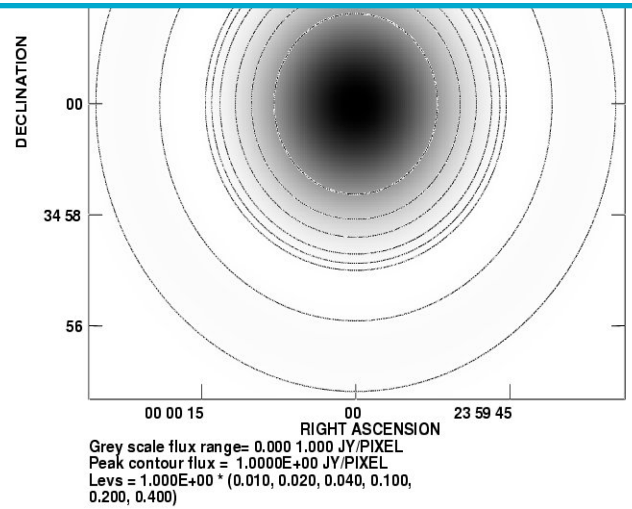
The effect of the antenna primary beam

true source

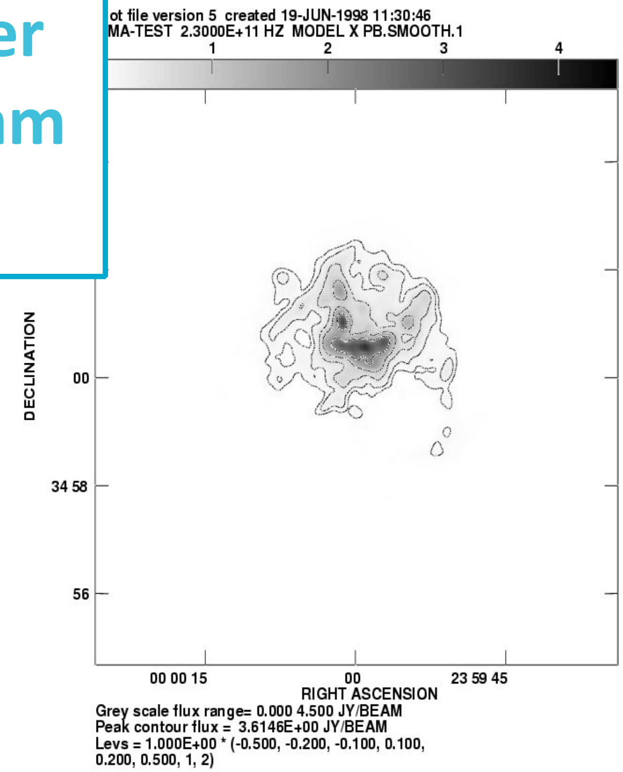


primary beam

Imaging sources larger than the primary beam requires mosaicking



apparent image



(Image credit: T.J. Cornwell)

Different approaches to mosaic observing

Alternate between a set of pointings with a traditional (single pixel) receiver

Observe multiple directions simultaneously with a multi-beam receiver

Continuously scan your telescope (OTF)

Keep your telescope fixed and let the sky drift

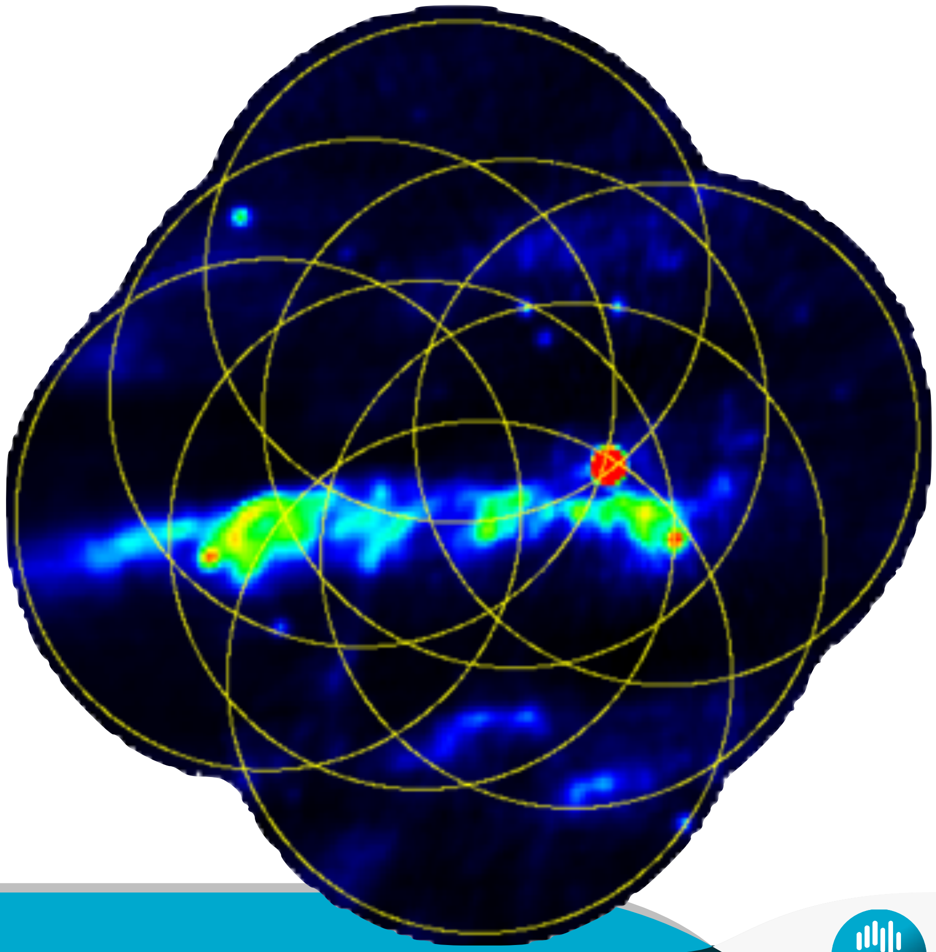
Different approaches to mosaic observing

Observe a grid of pointings with a traditional (single pixel) receiver

++ most commonly supported

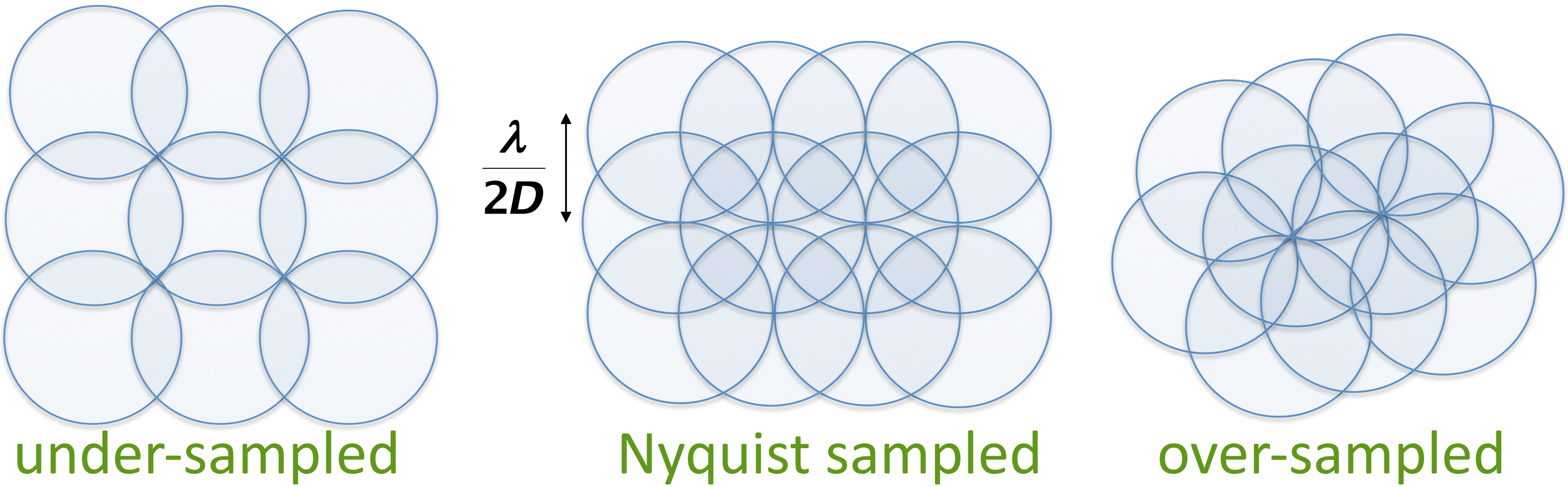
++ relatively easy to process

— overhead can be large due to slewing and settling



Different approaches to mosaic observing

Observe a grid of pointings with a traditional (single pixel) receiver



Different approaches to mosaic observing

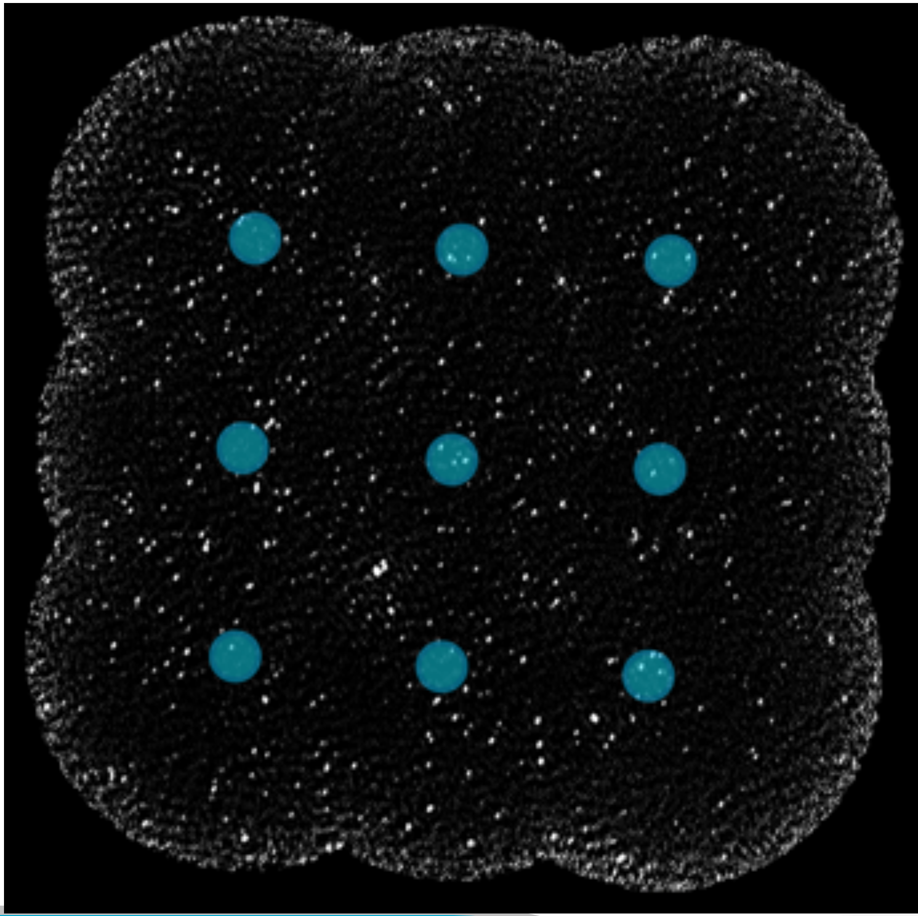
Observe using a multi-beam receiver

++ survey speed increases N_{beam}

++ overhead decreases

++ UV coverage increases

— beams can not be too closely packed

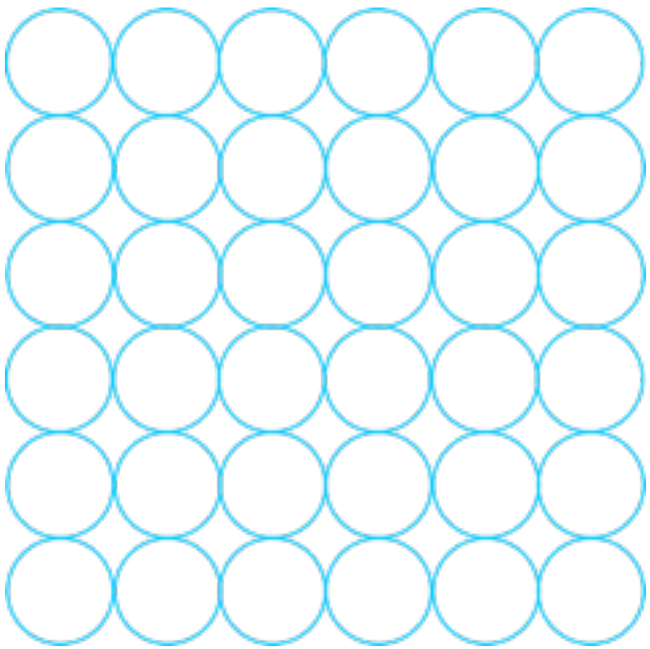


(Image credit: I. Heywood)

Different approaches to mosaic observing

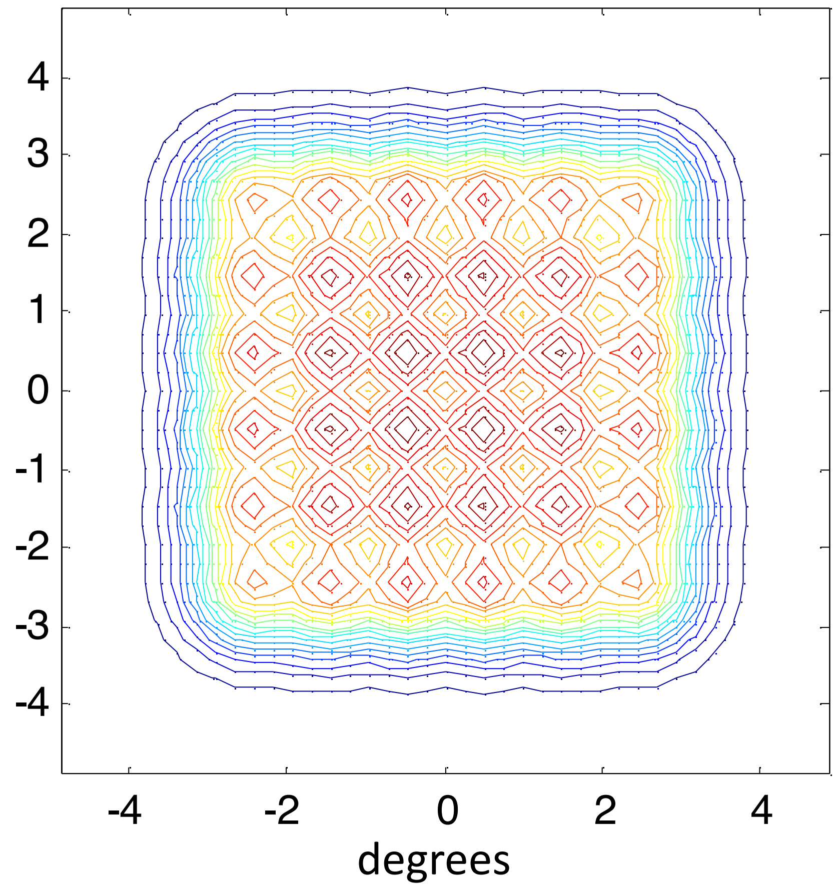
Observe using a multi-beam receiver

36 beams



Instantaneous 30 deg^2 FOV

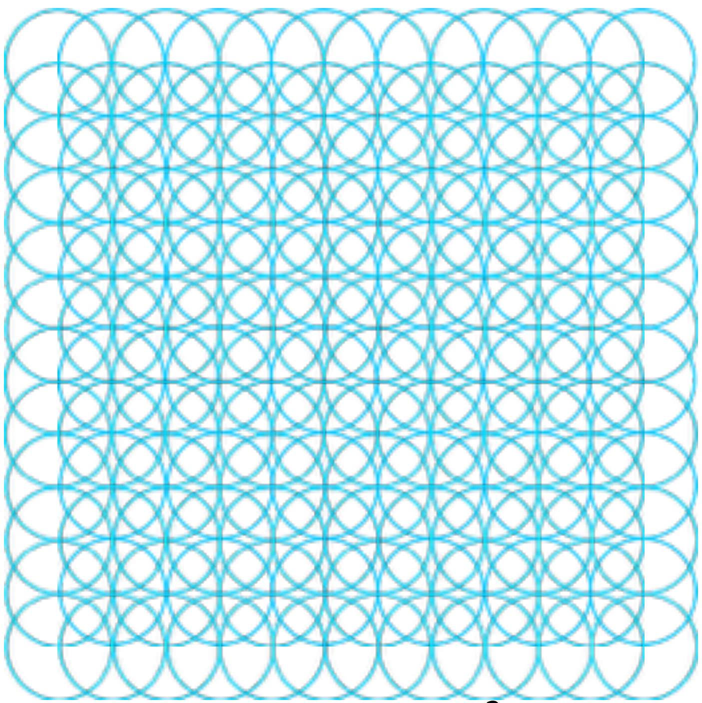
Sensitivity (5% contours)



Different approaches to mosaic observing

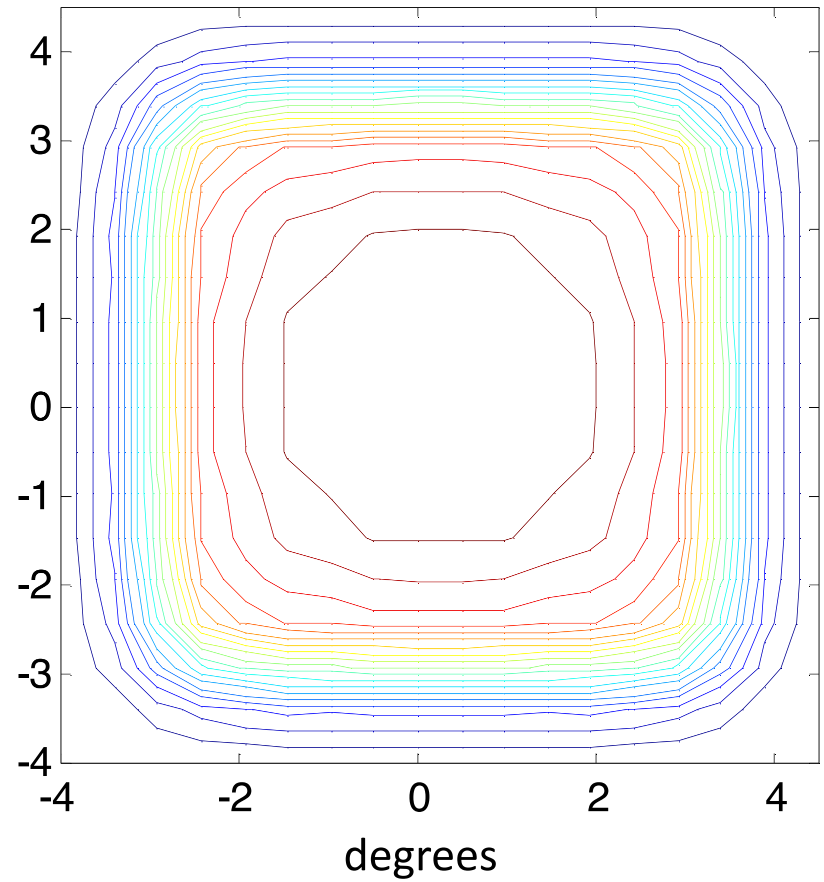
Observe using a multi-beam receiver

36 beams + 4x interleaving



Instantaneous 30 deg^2 FOV

Sensitivity (5% contours)

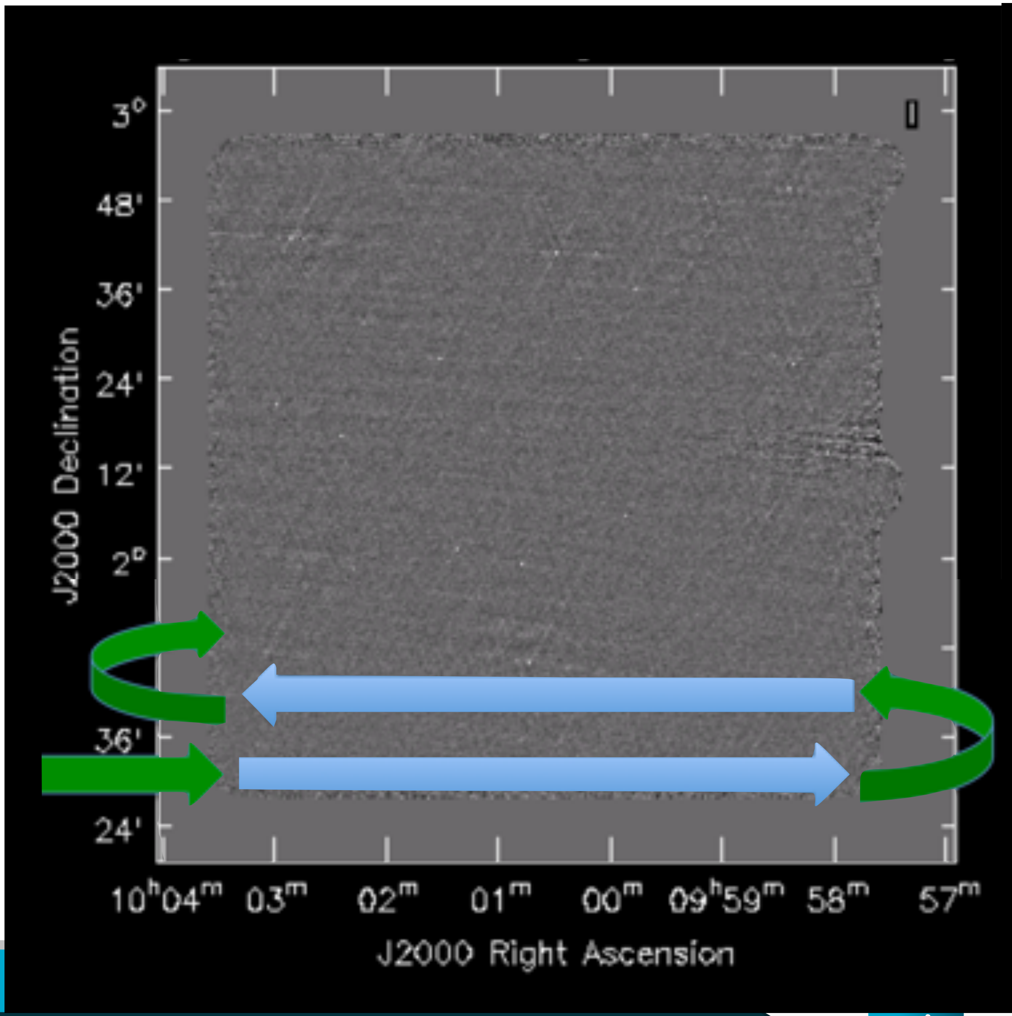


Different approaches to mosaic observing

Continuously scan your telescope (OTF)

++ overhead greatly decreases

— processing can be challenging



COSMOS field
13A-362 (Myers)
C-band 1hr SB
4.2-5.2 + 6.5-7.5GHz
2 square degrees
OTF scans in RA
432 phase centers

Imaging of mosaic observations

Separately image and deconvolve each pointing

Separately image and jointly deconvolve the pointings

Jointly image and deconvolve the pointings

Fit a single model to the data from all pointings

Imaging of mosaic observations

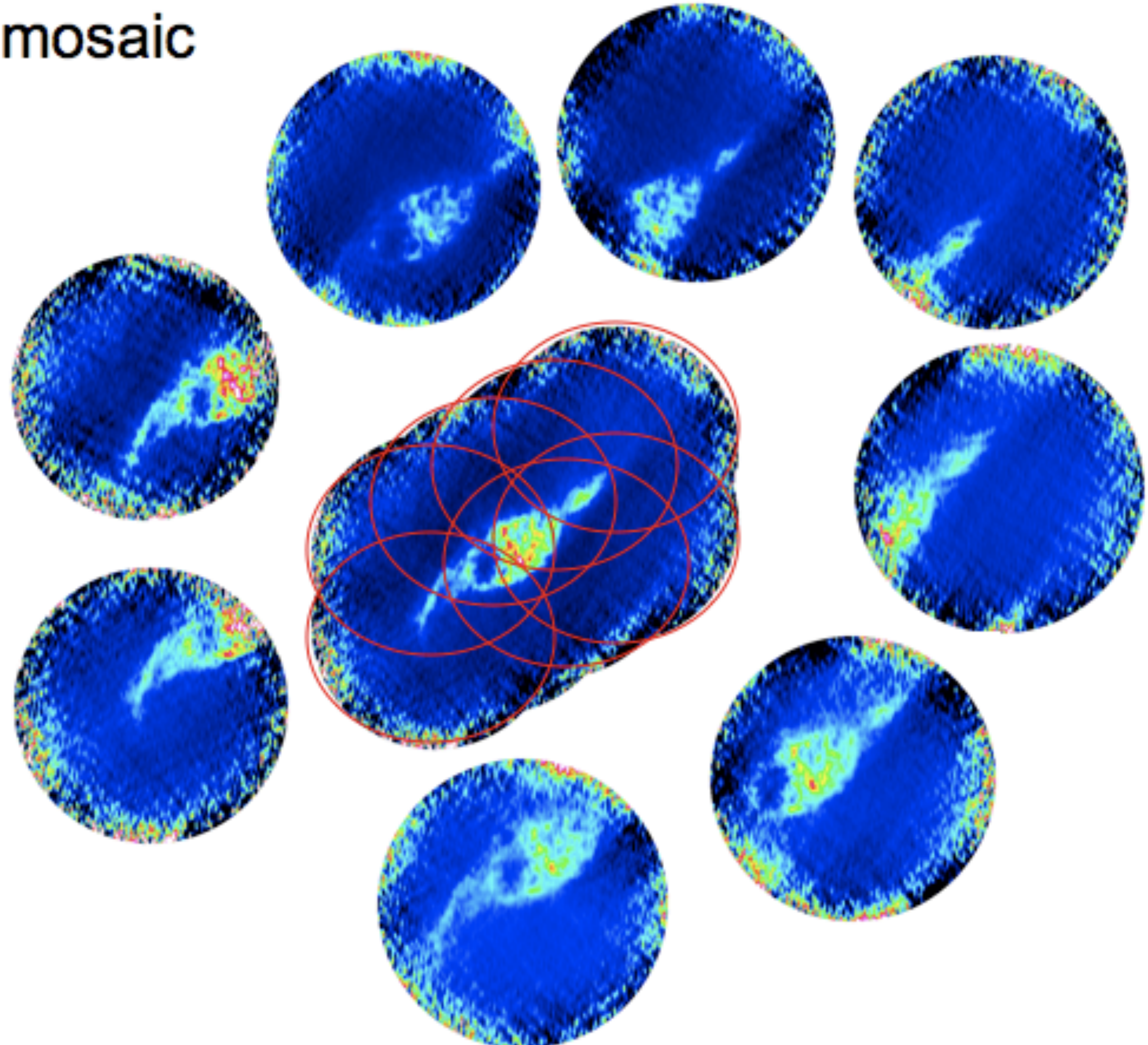
Separately image and deconvolve each pointing individually

the ***linear mosaic*** of the individual images

$$I(\vec{x}) = \frac{\sum_i A(\vec{x} - \vec{x}_i)\, I_i(\vec{x})}{\sum_i A^2(\vec{x} - \vec{x}_i)}$$

ATCA HI mosaic

(de Blok et al.)



Imaging of mosaic observations

Separately image and jointly deconvolve the pointing

- create dirty images for each pointing
- form a linear mosaic of dirty images
- calculate the position-dependent PSF
- deconvolve the mosaic

Imaging of mosaic observations

Jointly image and deconvolve the pointings

- use primary beam (A-projection) in the gridding kernel
- use the Fourier shift theorem for different pointings
- combine all of the pointings onto a single UV grid
- deconvolve the mosaic

Imaging of mosaic observations

Fit a single model to the data from all pointings

- Maximum Entropy
- Compressed Sensing

Thank you

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