Principles of Interferometry – III

Parkes Radio Astronomy School 2009

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Outline

Mosaicing with interferometers

- Nyquist sampling
- Image formation

Combining with single-dish data

- The short spacing problem
- Image .v. Fourier plane combination

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Bibliography

- Ekers & Rots (1979) Image Formation, IAU Coll 49, 61.
- Cornwell (1988) A&A, 202, 316.
- Cornwell (1989) ASPC 6.
- Cornwell, Holdaway & Uson (1993) A&A, 271, 697.
- Sault, Staveley-Smith & Brouw (1996) A&A Suppl., 120, 375.
- Holdaway (1998) ASPC 180, ch.20.
- Gueth & Guilloteau (2000) ASPC 217, 291.
- Sault & Killeen, miriad manual, ch.21.
- Subrahmanyan (2004) MNRAS, 348, 1208.
- Bhatnagar, Golap & Cornwell (2005) ASPC 347, 96
- Bunn & White (2007) ApJ, 655, 21.

ICRAR

Mosaicing with Interferometers

Noun

mosaic (plural mosaics)

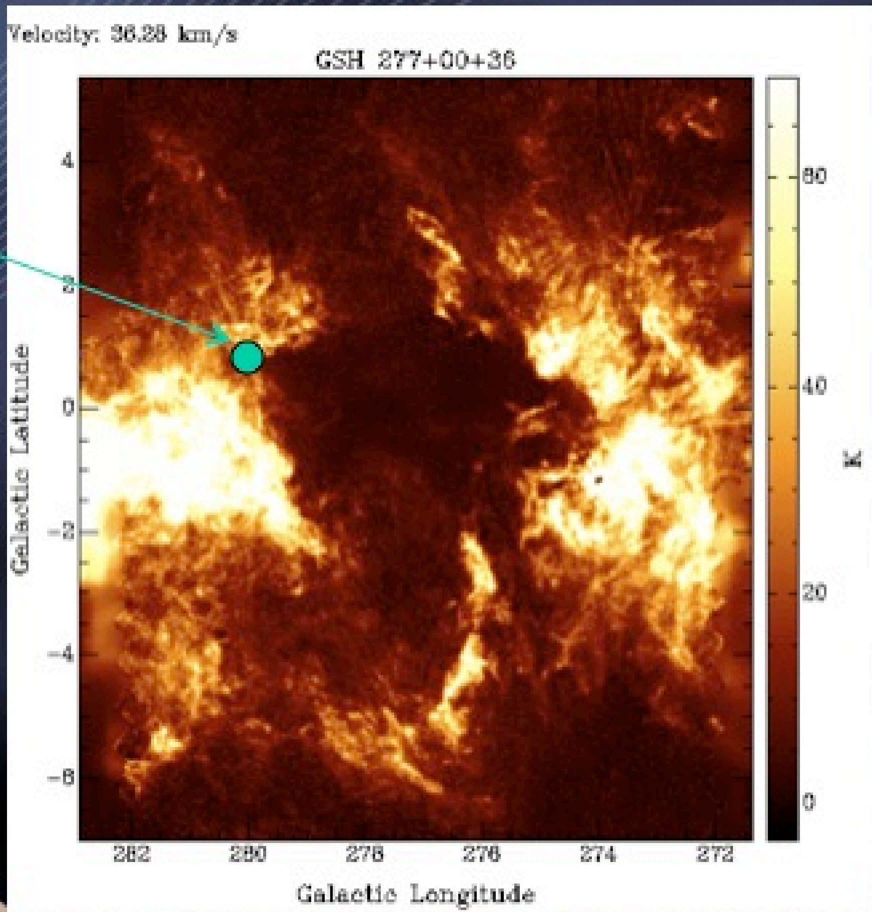
source: wiktionary

1. A piece of artwork created by placing colored squares (usually tiles) in a pattern so as to create a picture.
2. (genetics) An individual composed of two or more cell lines of different genetic or chromosomal constitution, but from the same zygote.
3. (botany) A viral disease of plants.
4. A composite picture made from overlapping photographs.

Why mosaic?

Mosaicing is necessary to create an image larger than the field-of-view of the telescope:

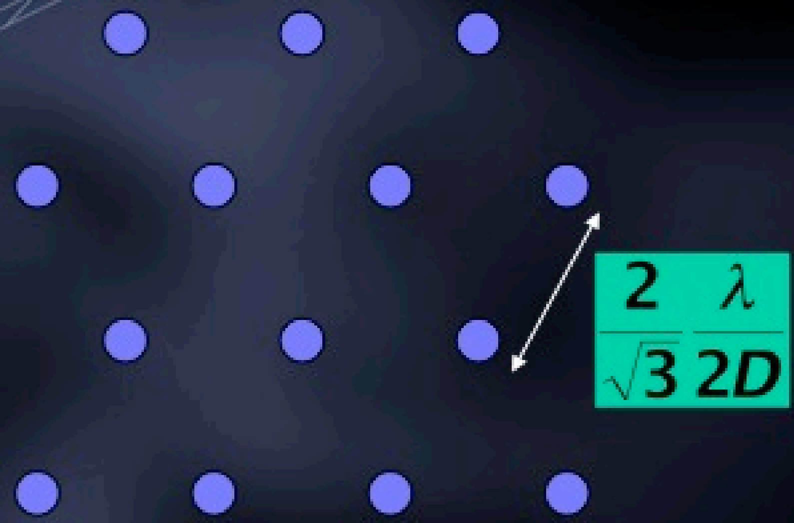
ATCA primary beam



McClure-Griffiths

Nyquist sampling of sky

D is dish diameter



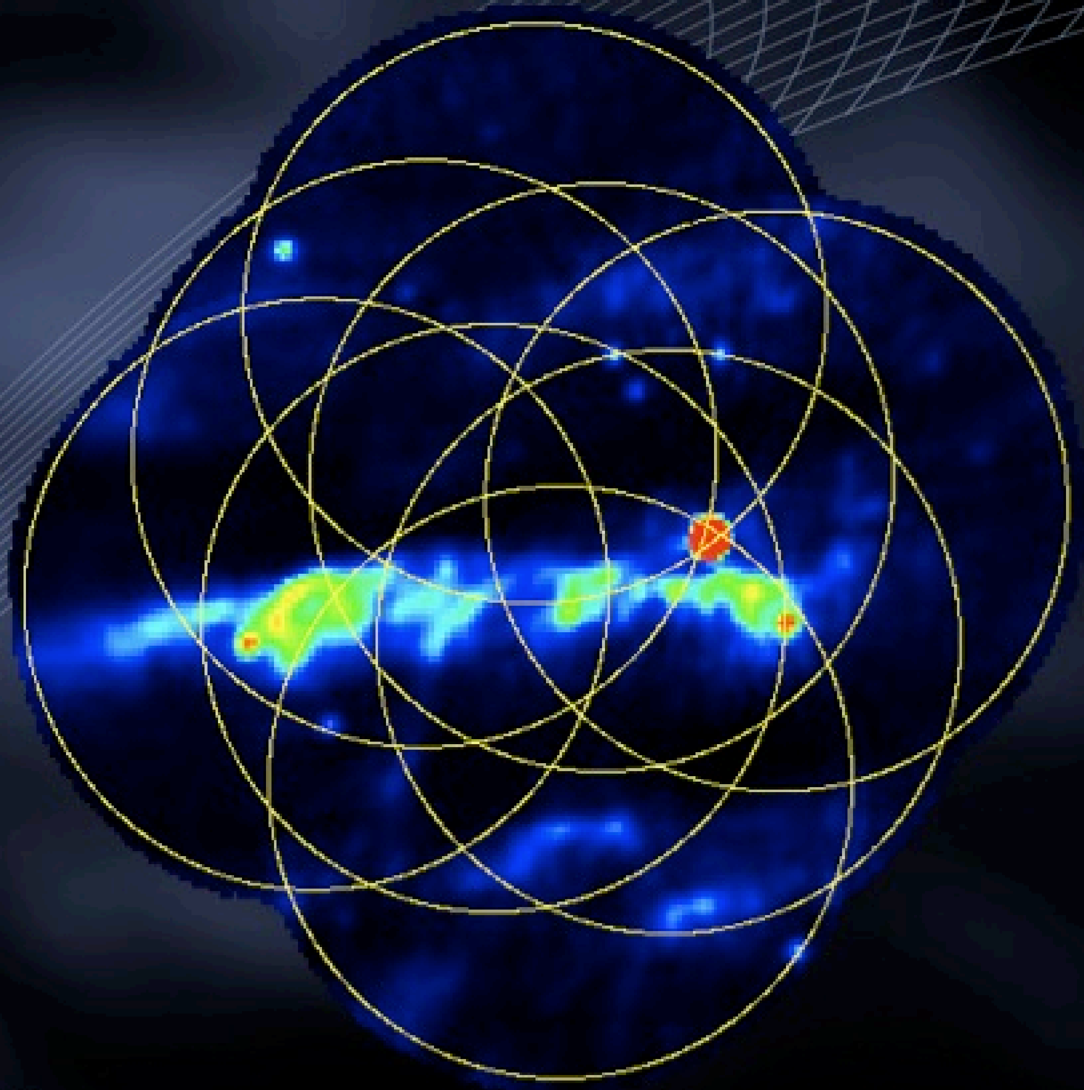
Rectangular grid

$\Delta\theta$ = 16.5’ at 21cm at ATCA

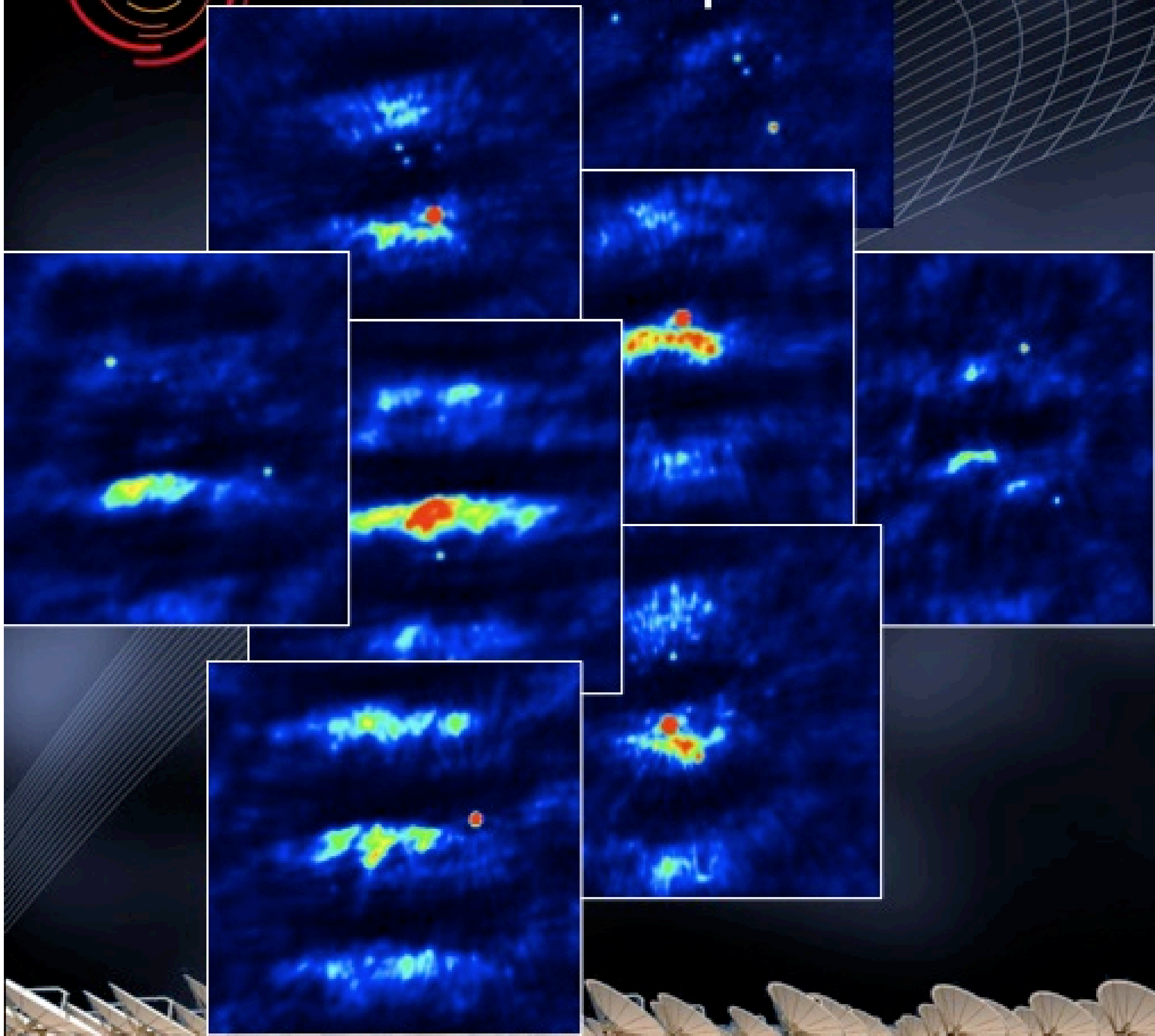
Hexagonal grid

$\Delta\theta$ = 19.0’ at 21cm at ATCA

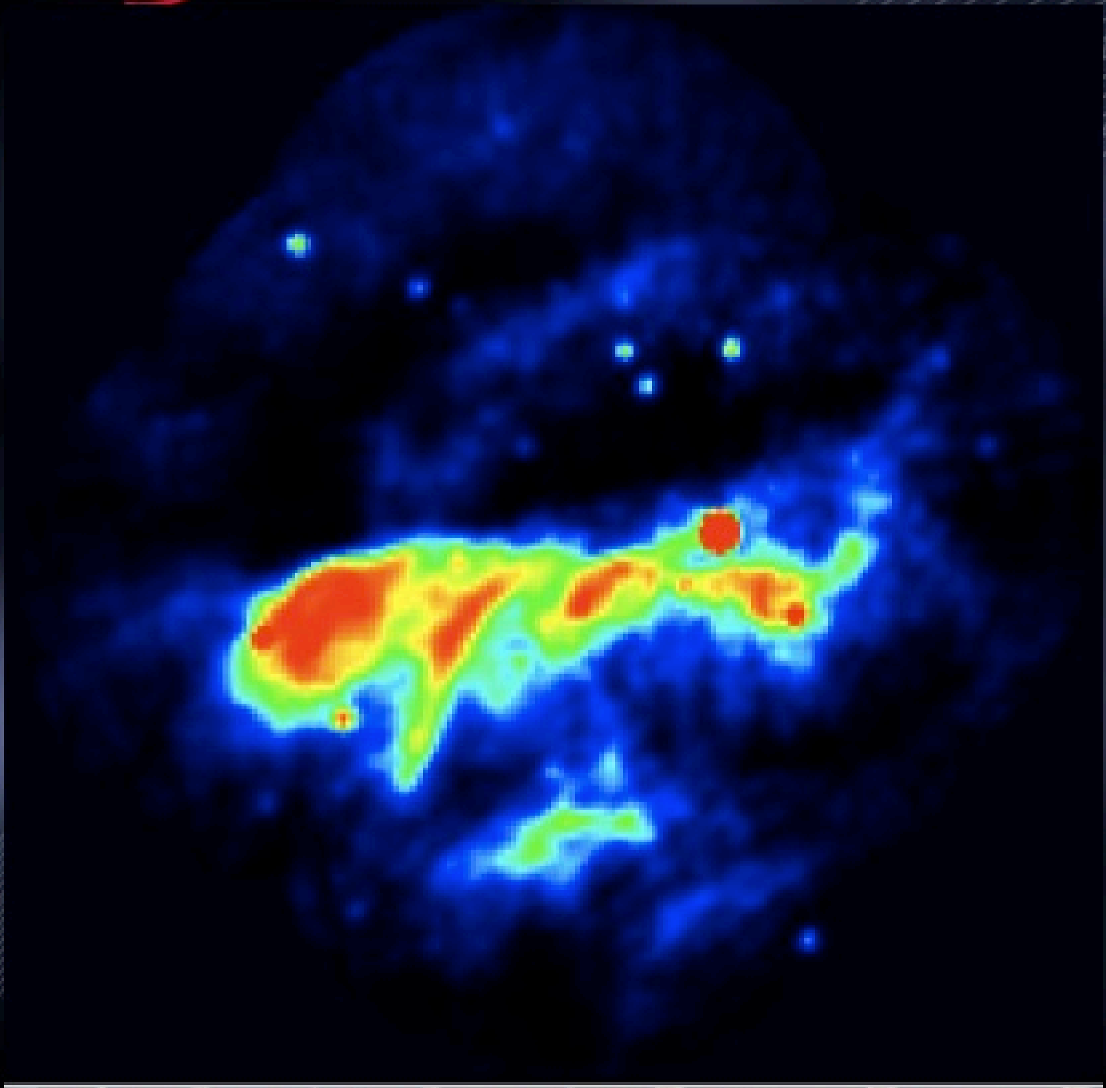
Step I: observe different pointings



Step 2: make individual images



Step 3: make combined image



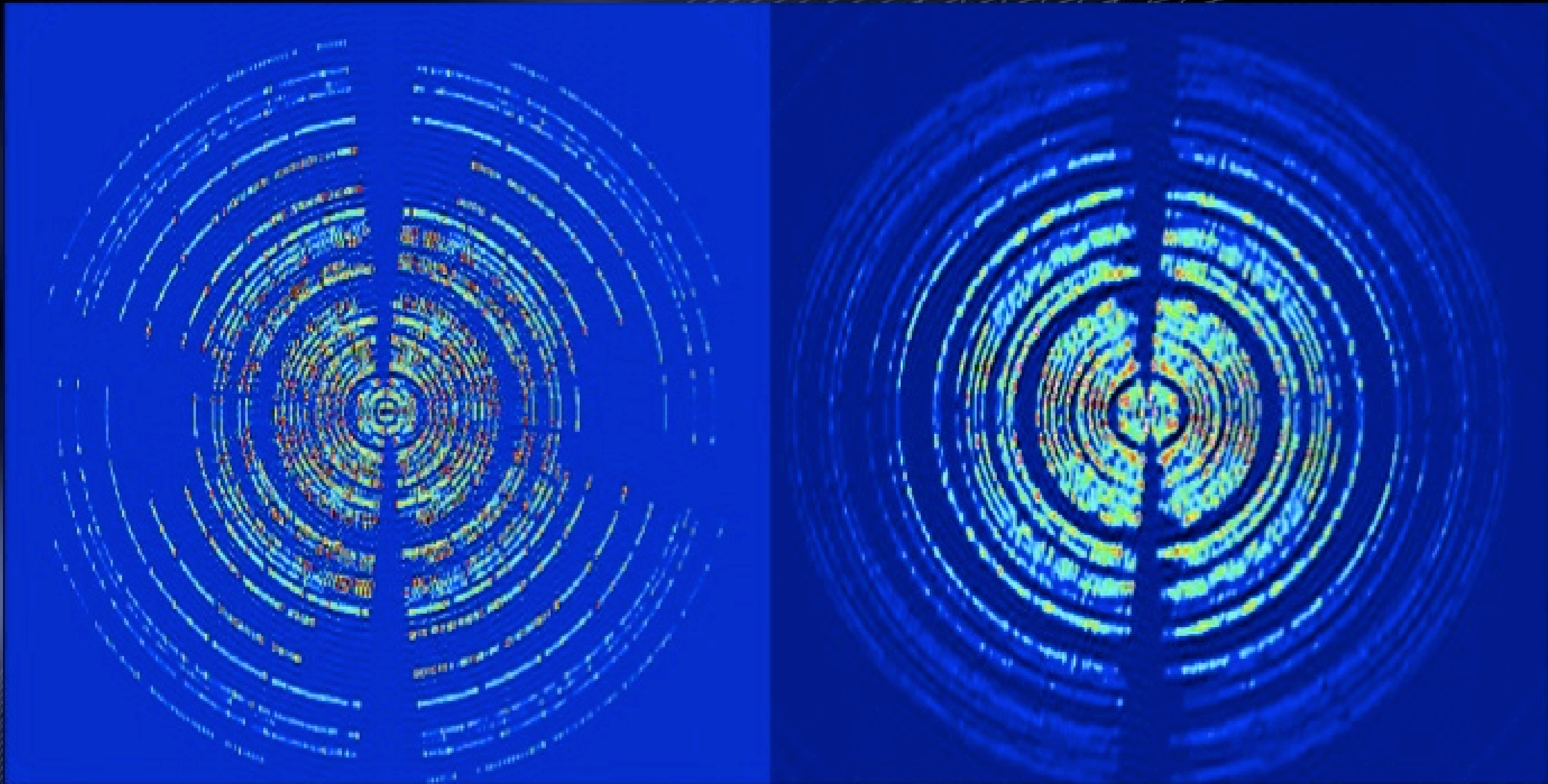
Mosaicing equation:

$$I_t(\mathbf{x}) = W(\mathbf{x}) \frac{\sum_i P(\mathbf{x}-\mathbf{x}_i) I_i(\mathbf{x})}{\sum_i P^2(\mathbf{x}-\mathbf{x}_i)}$$

P is primary beam response; I_i are the individual images.

Also applies to FPAs

Comparison of *u-v* coverage



Individual

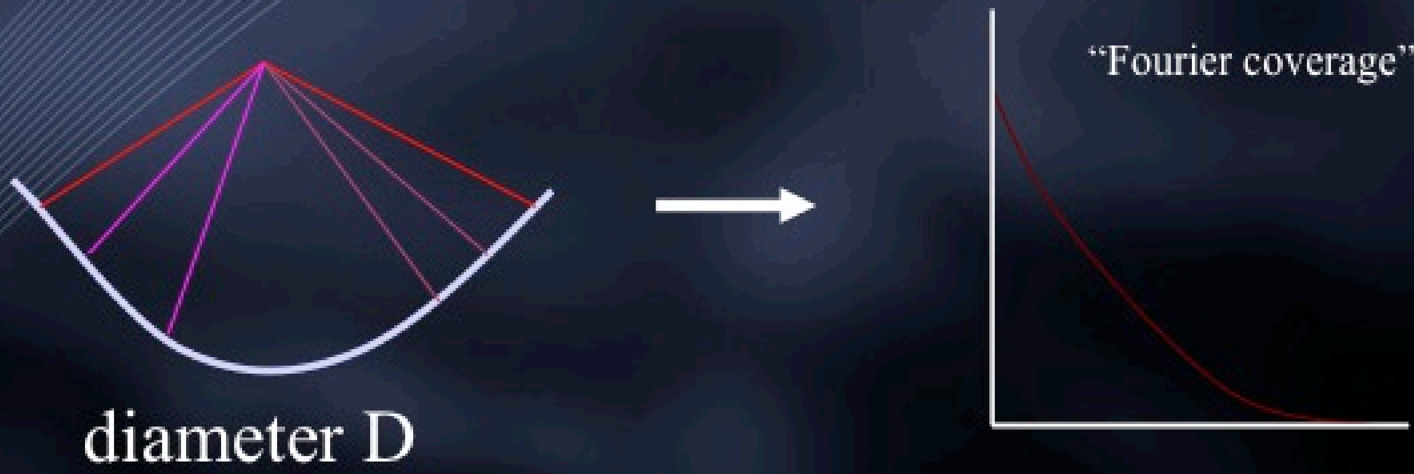
Extra *u-v* coverage in radial and azimuthal direction

Mosaic

Mosaicing Fundamentals

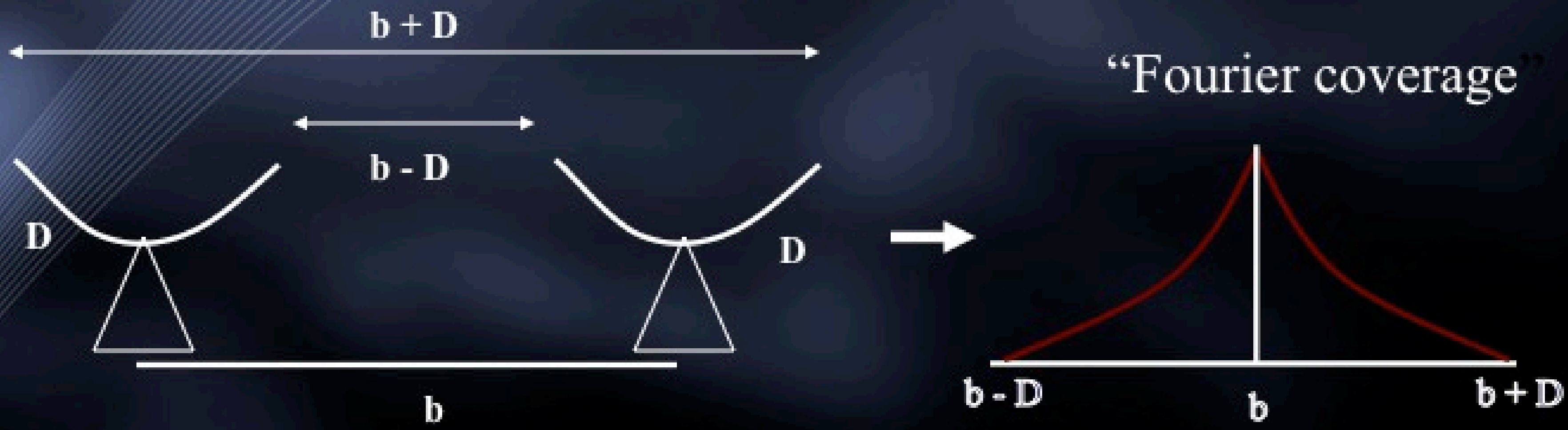
Background theory:

- Ekers & Rots (1979) pointed out that one can think of a single dish as a collection of sub-interferometers.

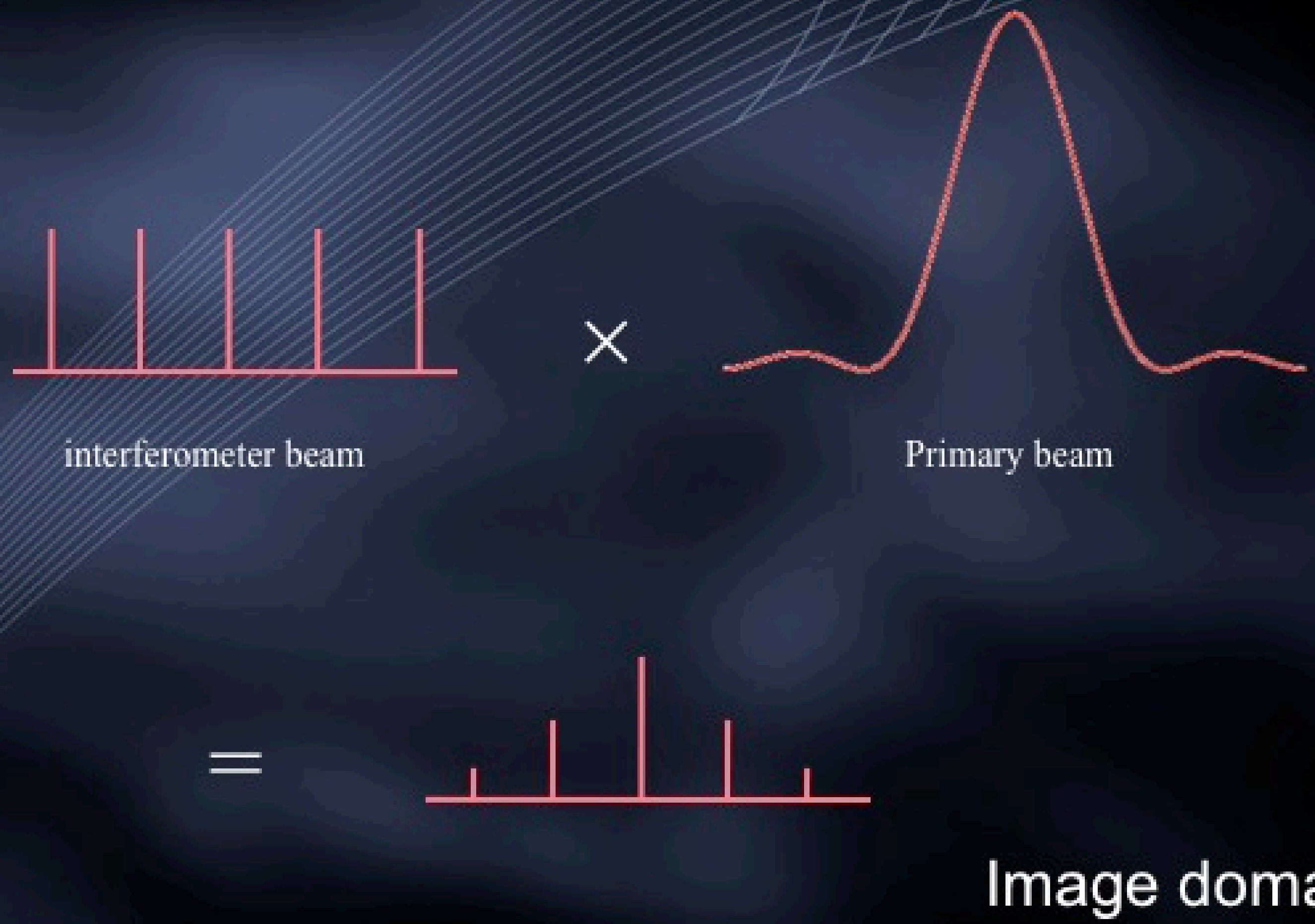


Mosaicing Fundamentals

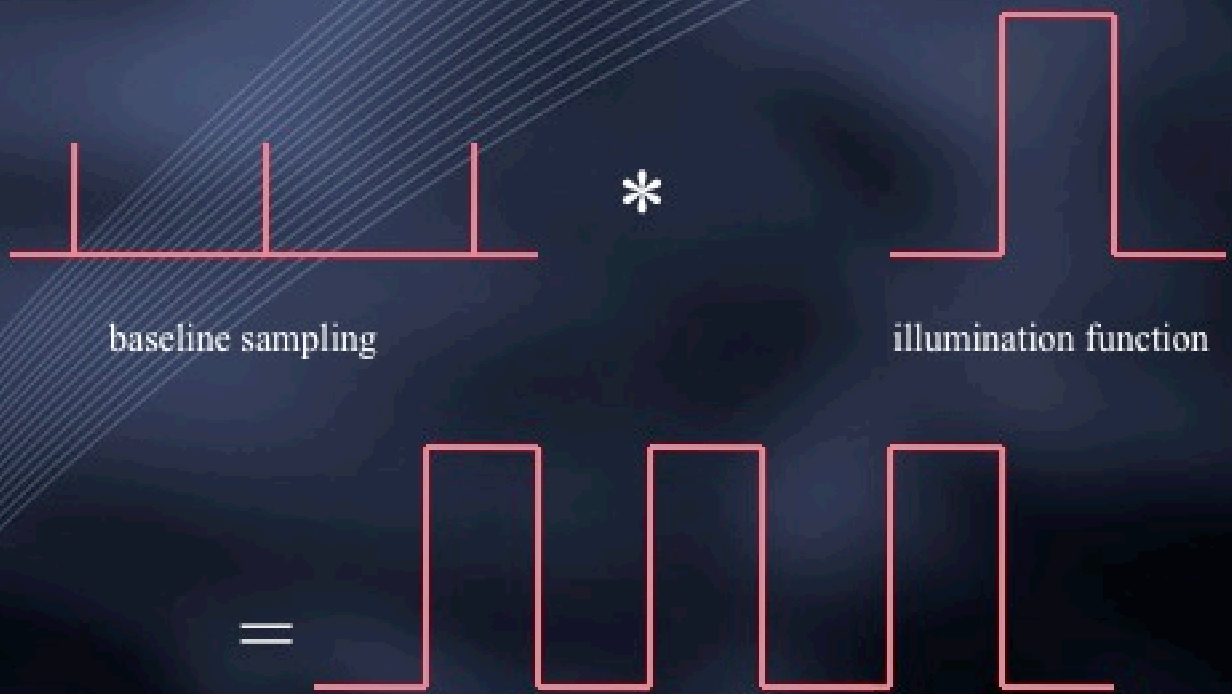
Extending this formalism to interferometers shows that an interferometer doesn't just measure angular scales $\theta = \lambda / b$ it actually measures $\lambda / (b - D) < \theta < \lambda / (b + D)$



Why is *u-v* coverage improved?



Why is *u-v* coverage improved?



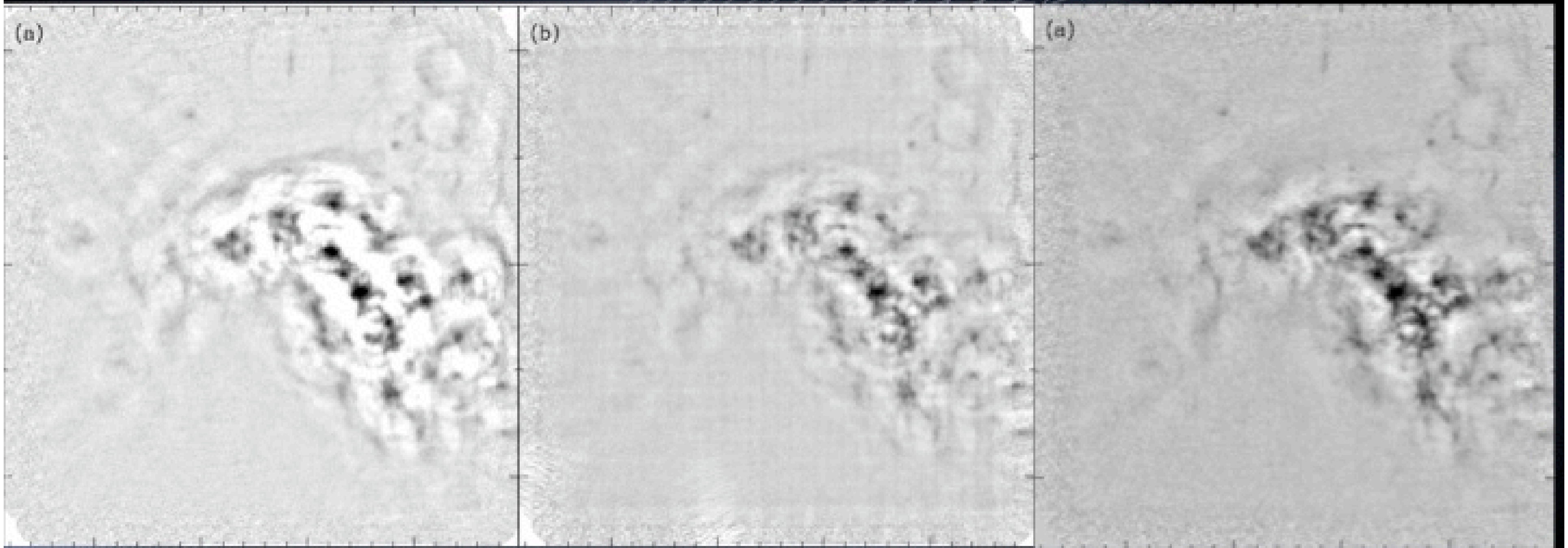
Fourier domain

Ways to combine multiple pointings

- Combine DIRTY images, then deconvolve with spatially-variant beam
- DECONVOLVE, then combine images*
- Jointly deconvolve DIRTY images
- MEM/CLEAN/MS etc.
- See miriad/casa manuals

*potential loss of information

Examples (SMC)



Dirty image

Linear mosaic of deconvolved images

Joint deconvolution

Complications

Planarity

- Exact projection no problem with co-planar arrays; w-axis distortion over wide fields will occur with non-planar arrays.

Bandwidth

- Dealing with dual frequency-dependence of primary beam and sky can be problematic.

Primary Beam and Pointing

- Good beam model needed; high dynamic range may require pointing self-calibration.

Doppler

- Doppler corrections are dependent on time and position, so not strictly applicable in visibility domain.

Off-axis

- Off-axis calibration and polarimetry often poor for radio telescopes.

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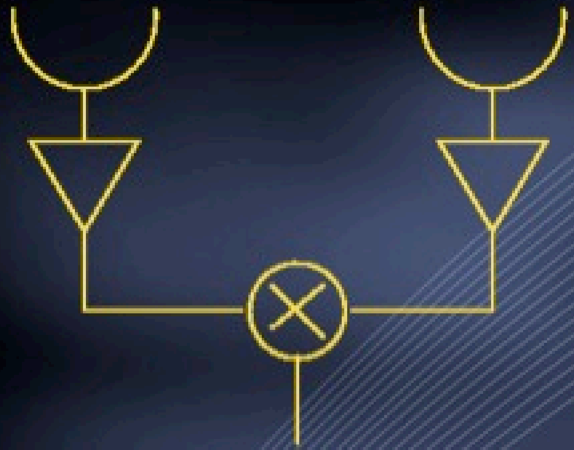
Merging Interferometer and Single-Dish Data

+

Single-dish/interferometer analogy -I



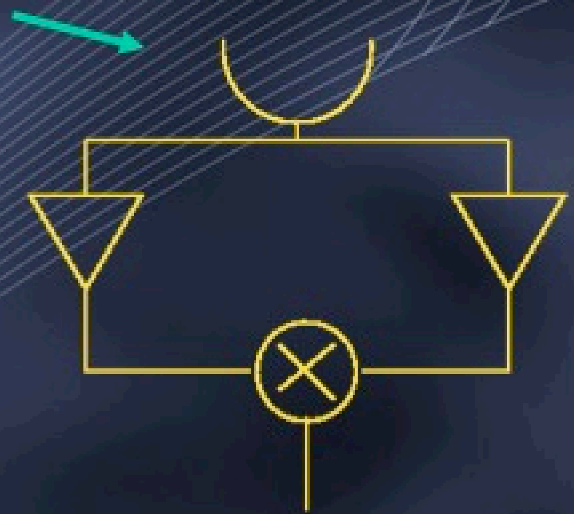
Interferometer:

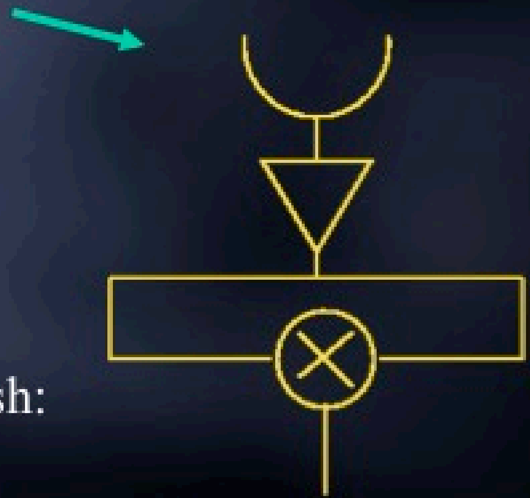
Asymmetric cross-correlations

$C_{ij}(\tau) \neq C_{ij}(-\tau)$

⇔

Complex visibilities $V(\nu)$





Single dish:

Symmetric auto-correlations

⇔

Real visibilities

Bibliography

Stanimirovic (2002) ASP Conf. Series 278

Sault & Killeen (2003) Miriad Users Manual

Holdaway (1999) ASP Conf. Series 180

Other work (partial list): Adler et al. (1992, ApJ, 392, 497); Bajaja & van Albada (1979, A&A, 75, 251); Cornwell, Holdaway & Uson (1993, A&A, 271, 697); Roger et al. (1984, PASA, 5, 560); Schwartz & Wakker (1991, ASP Conf. Ser. 19); Vogel et al. (1984, ApJ, 283, 655); Wilner & Welch (1994, 427, 898); Ye, Turtle & Kennicutt (1991, MNRAS, 249, 722); Kurono et al. (2009, PASJ, 61, 873)

The short (zero)-spacing problem

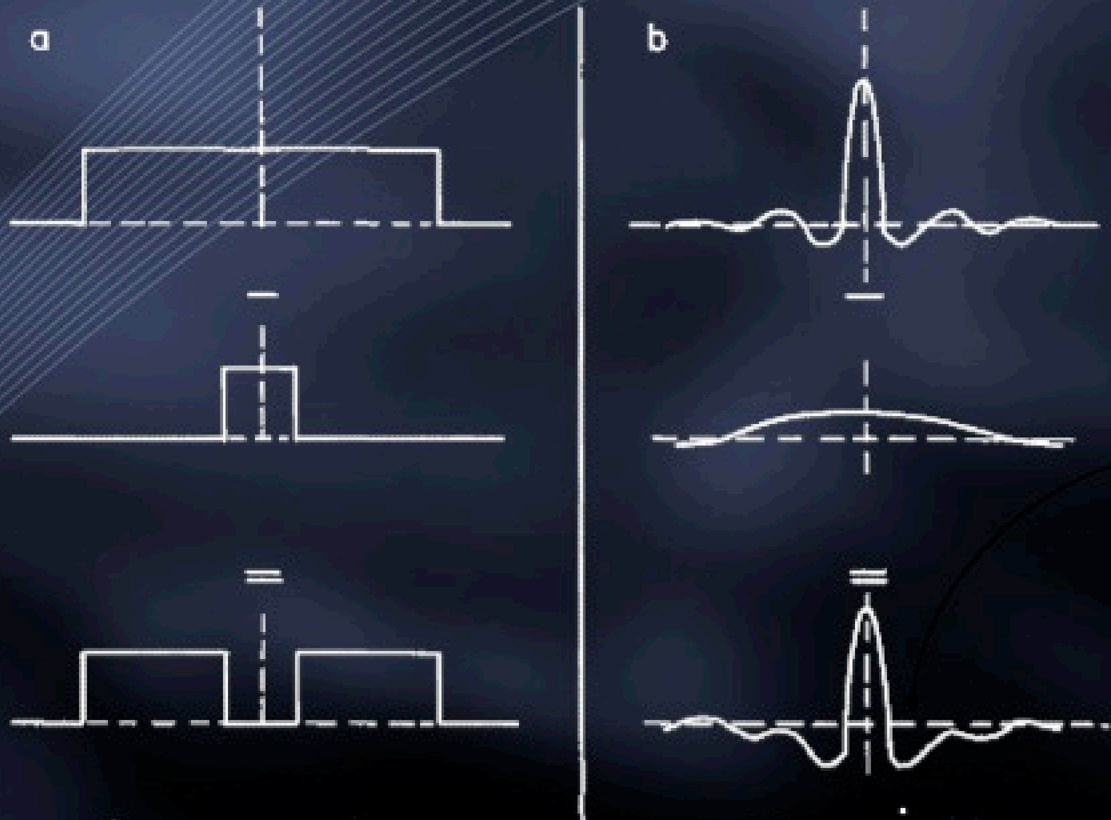
UV plane | PSF

Braun & Walterbos (1985)

ideal

Central hole

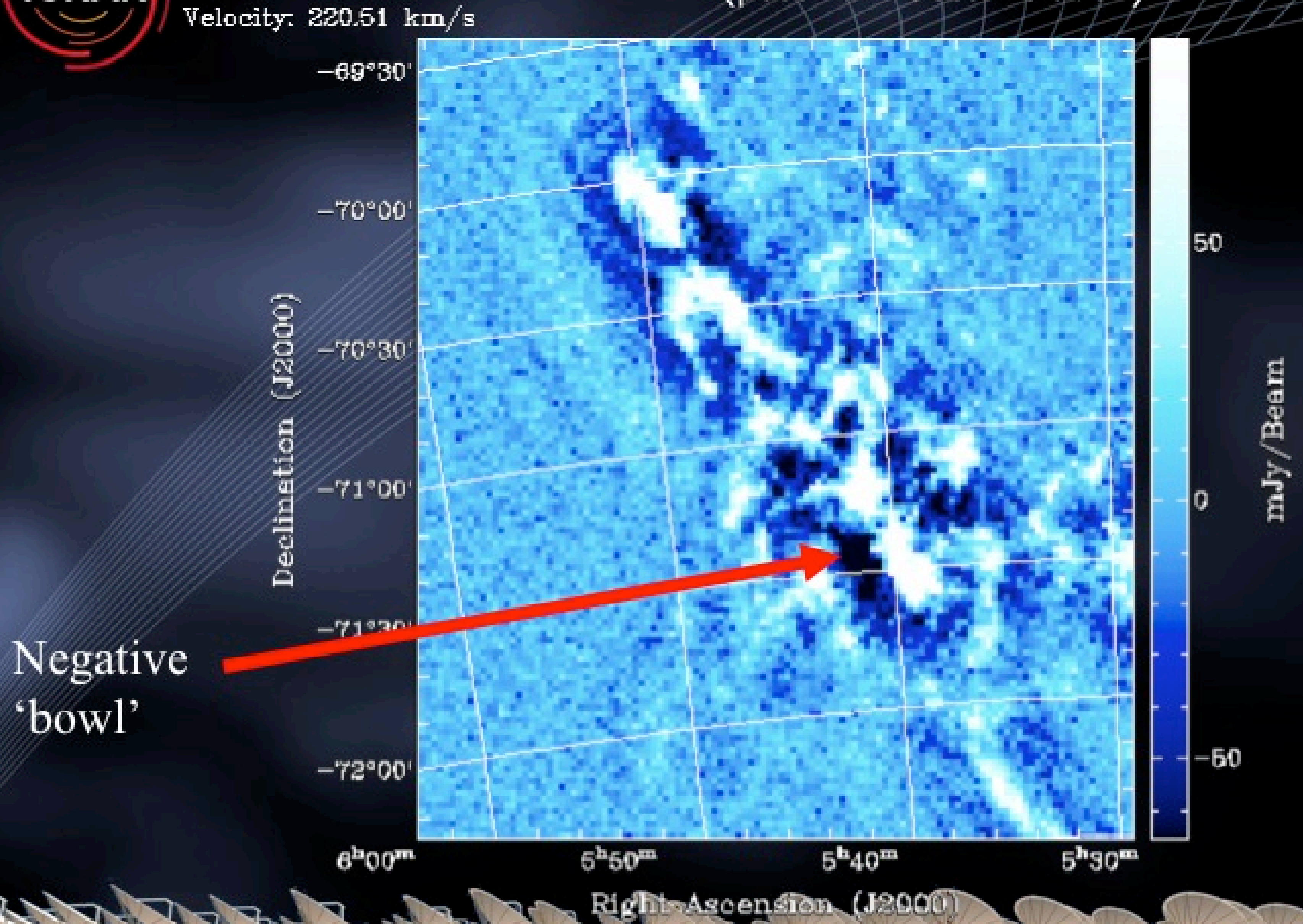
Typical interferometer



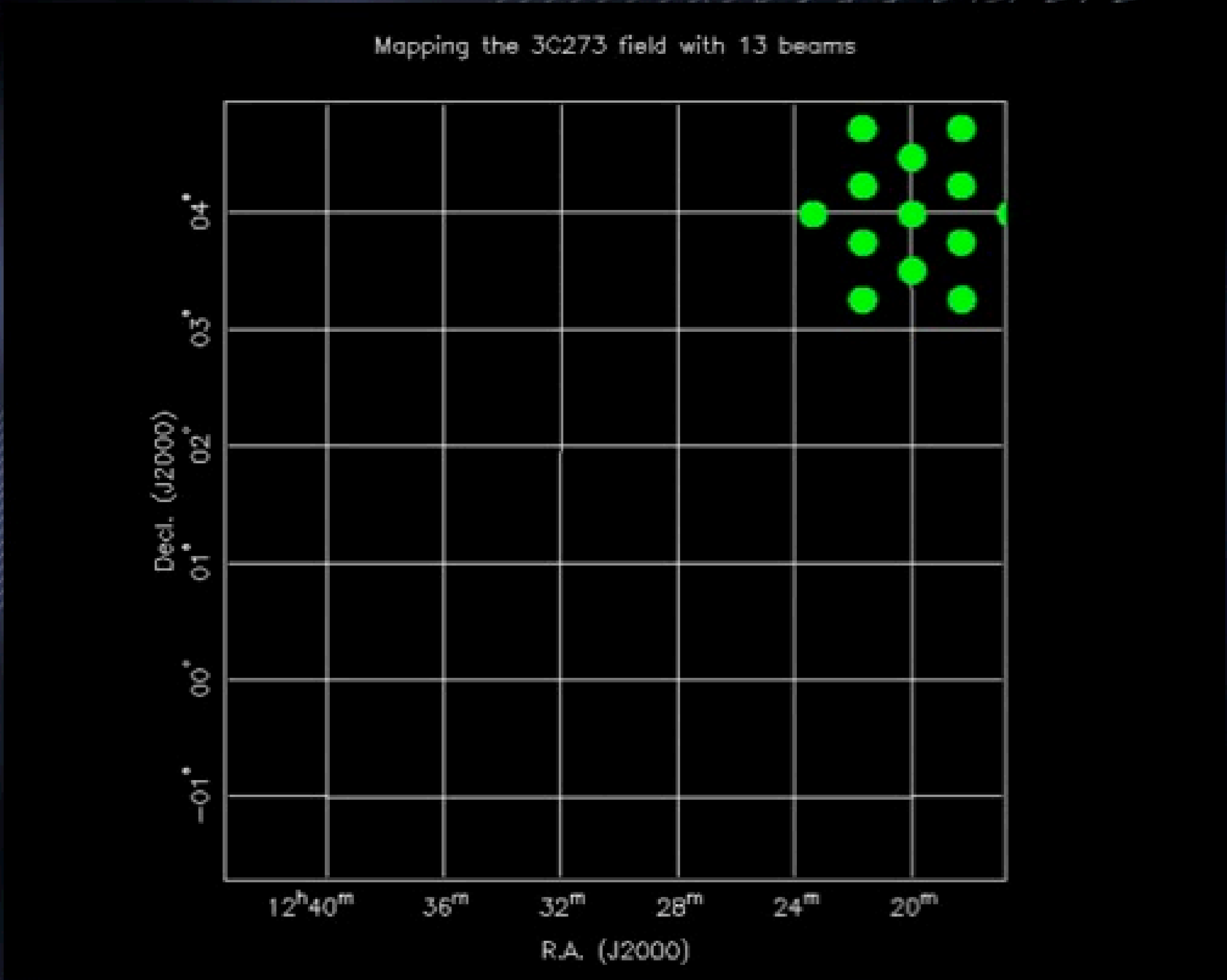
Negative 'bowl'

HI in the E-arm of the LMC (ATCA 4x750 m)

(post-MEM deconvolution)



Parkes multibeam data aquisition



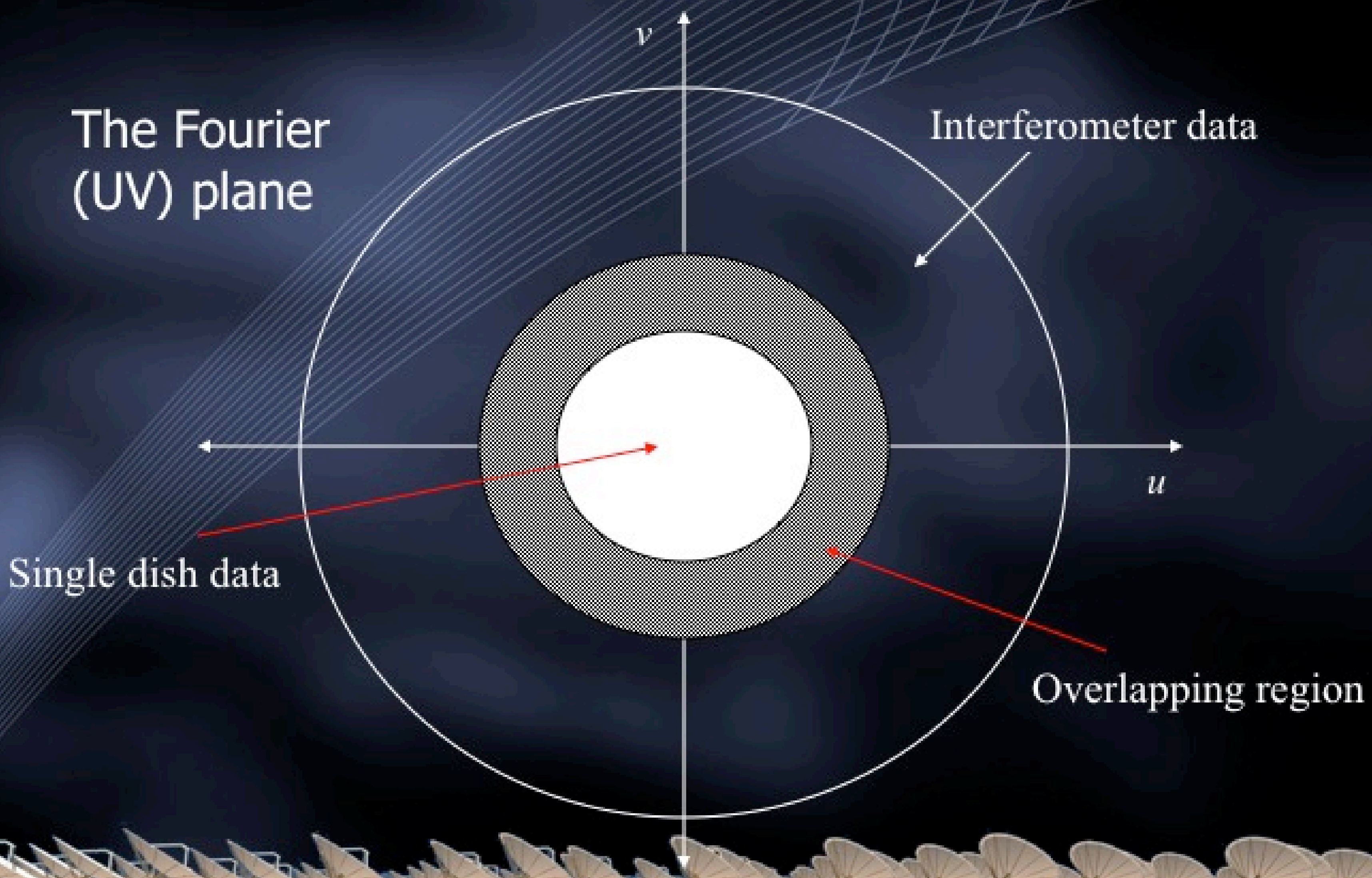
Many ways to combine

- Combine data in IMAGE plane
- Combine data in FOURIER plane
- Combine DIRTY images, then deconvolve
- DECONVOLVE, then combine images*
- Jointly deconvolve DIRTY images

*Most single-dish maps won't need deconvolution

Merging interferometer and single-dish data

The Fourier (UV) plane



Combination in Image Plane

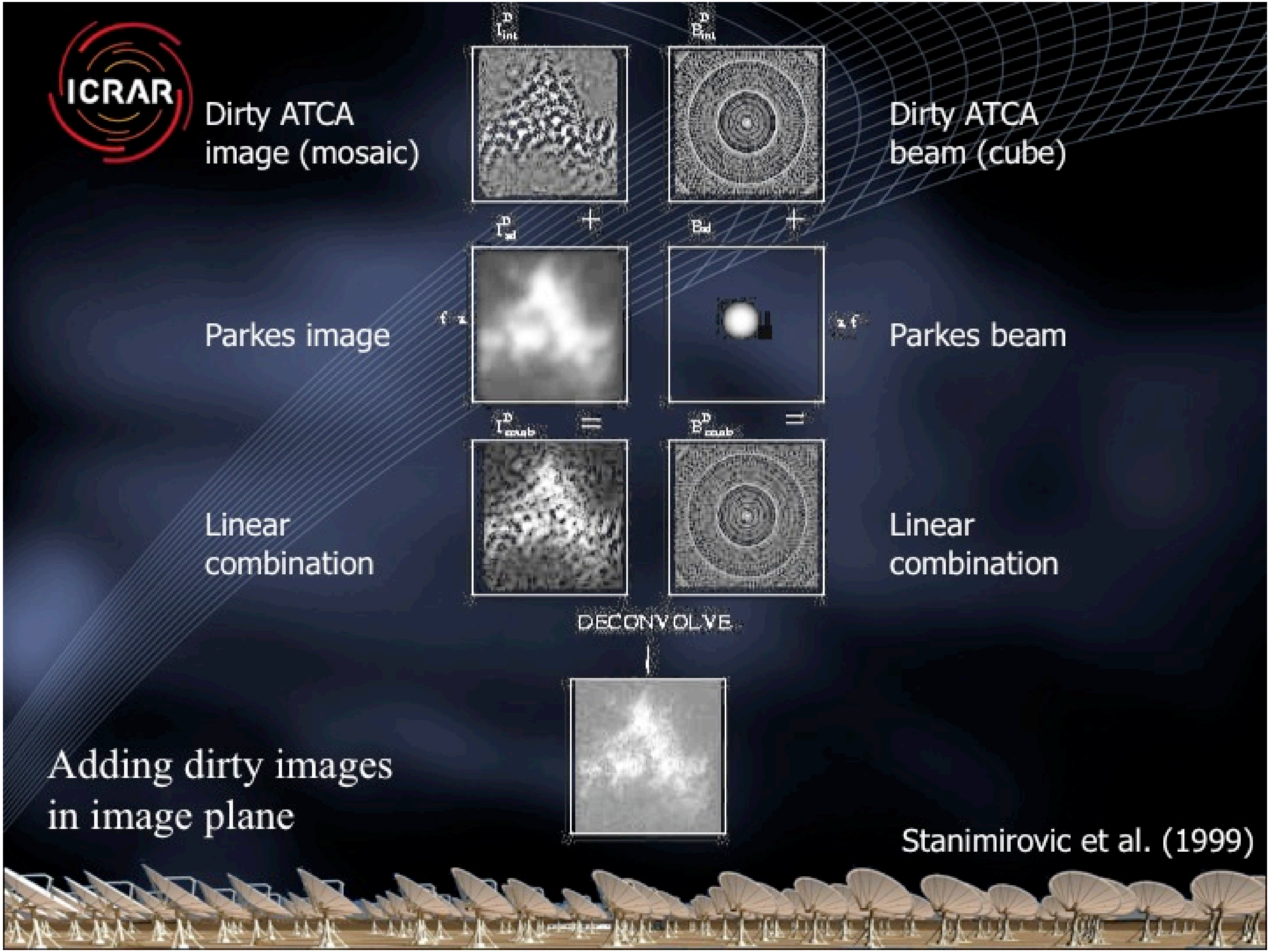
(Stanimirovic et al. 1999)

Combined image: $I_{tot} = w_{int} I_{int} + w_{sd} f_{sd} I_{sd}$

Weights

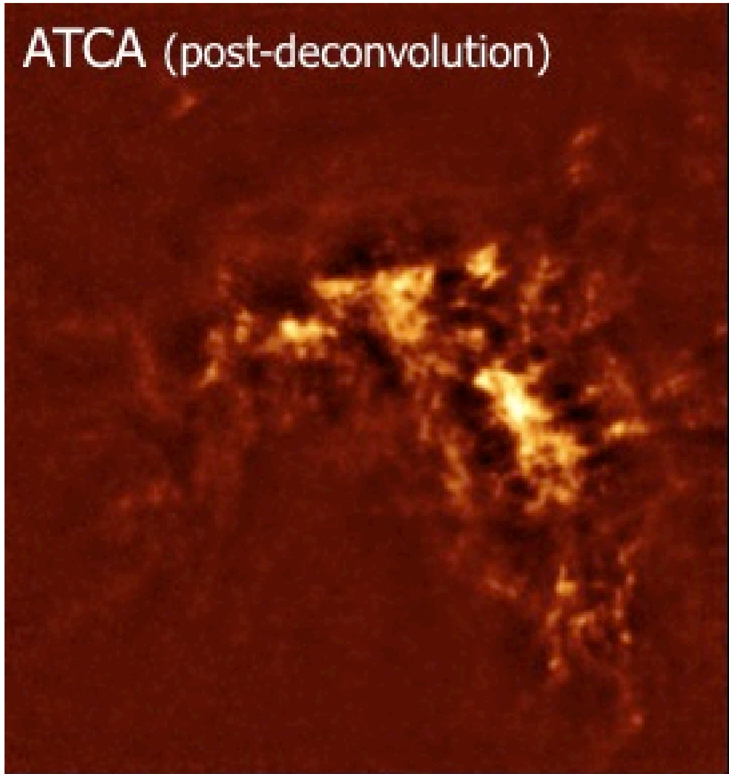
$$w_{int} = \frac{\Omega_{sd}}{\Omega_{int} + \Omega_{sd}}$$

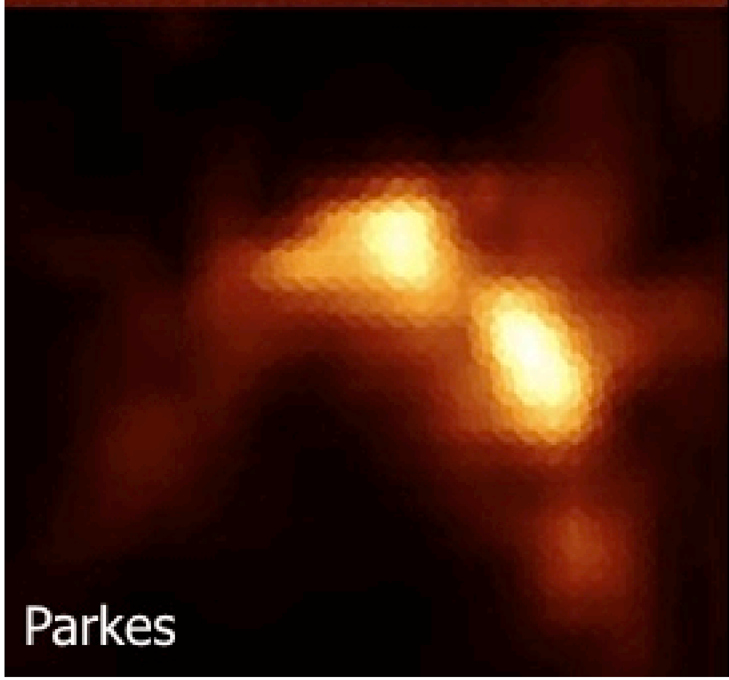
$$w_{sd} = \frac{\Omega_{int}}{\Omega_{int} + \Omega_{sd}}$$

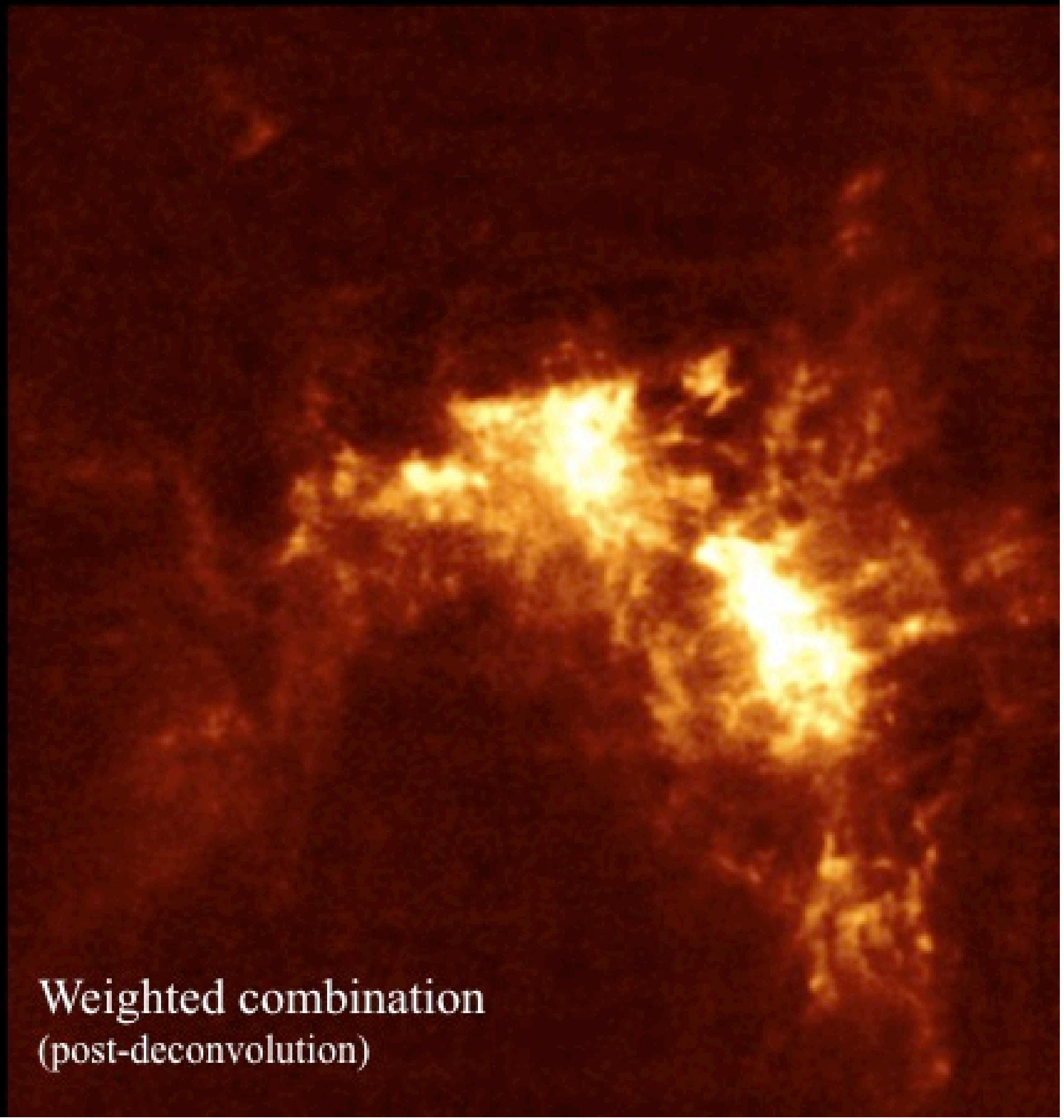

ICRAR
Dirty ATCA image (mosaic)
Dirty ATCA beam (cube)
Parkes image
Parkes beam
Linear combination
Linear combination
DECONVOLVE
Adding dirty images in image plane
Stanimirovic et al. (1999)

Adding deconvolved images in image plane: SMC in HI at V_h=130 km/s

(Stanimirovic et al 1999)







Combination in Fourier plane

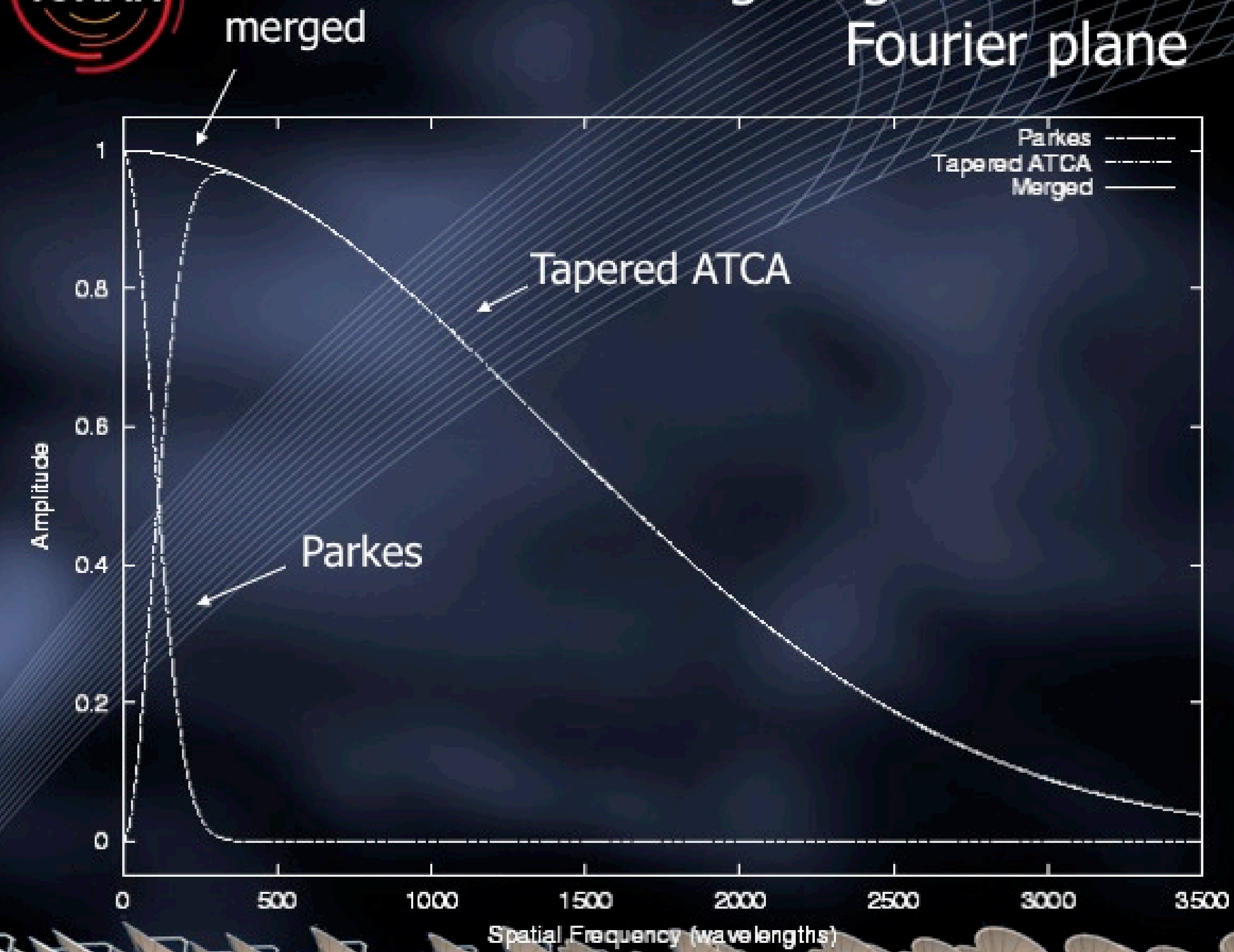
Appropriately weight data in overlap region

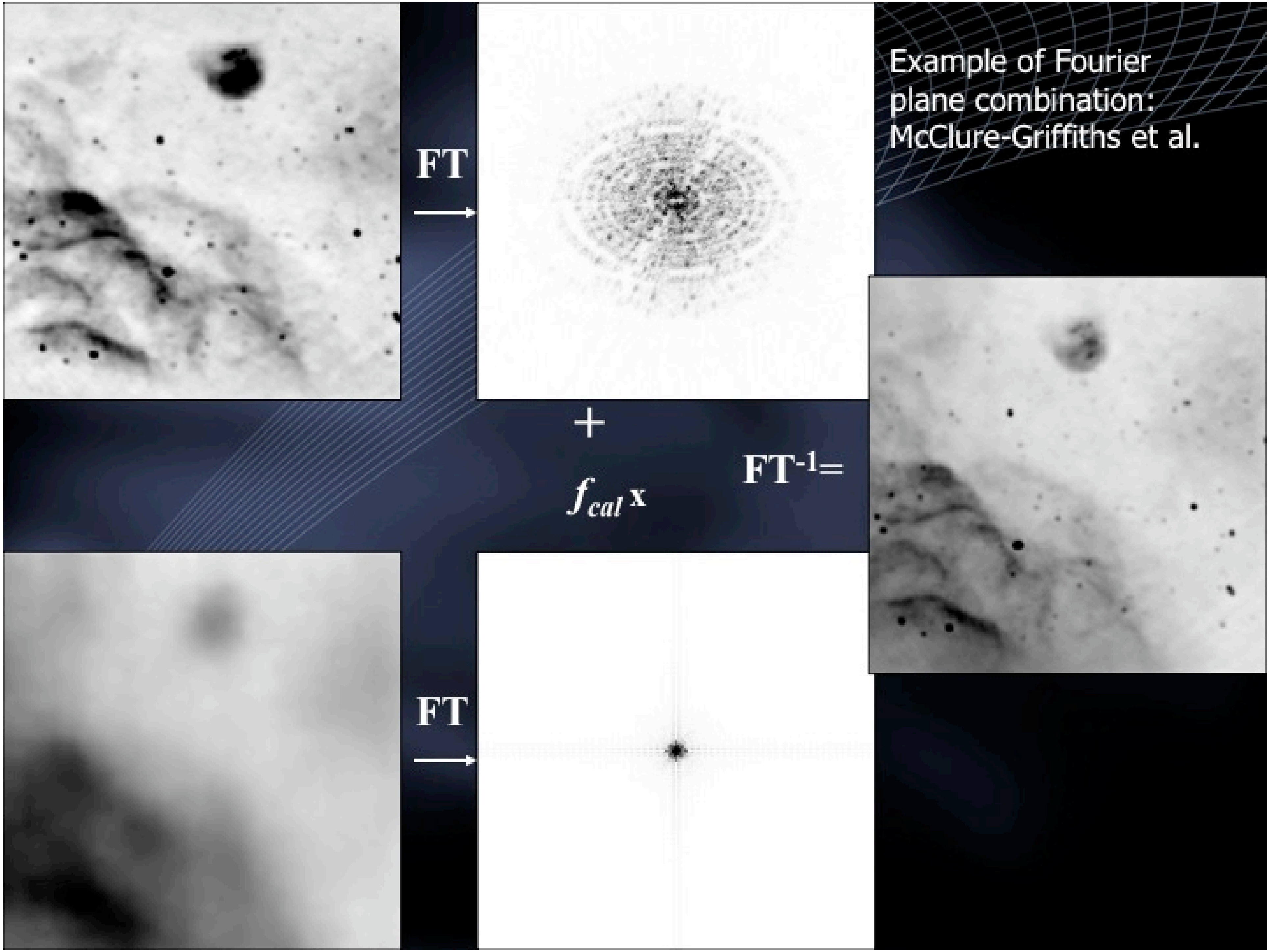
- E.g. taper interferometer Fourier-plane data with transform of SD beam
- Multiply SD Fourier-plane data with transform of interferometer beam

Adjust flux density scales (relative calibration)

Add in Fourier plane!

Weighting function in Fourier plane




Example of Fourier plane combination: McClure-Griffiths et al.
FT
+
f_cal x
FT^-1=
FT

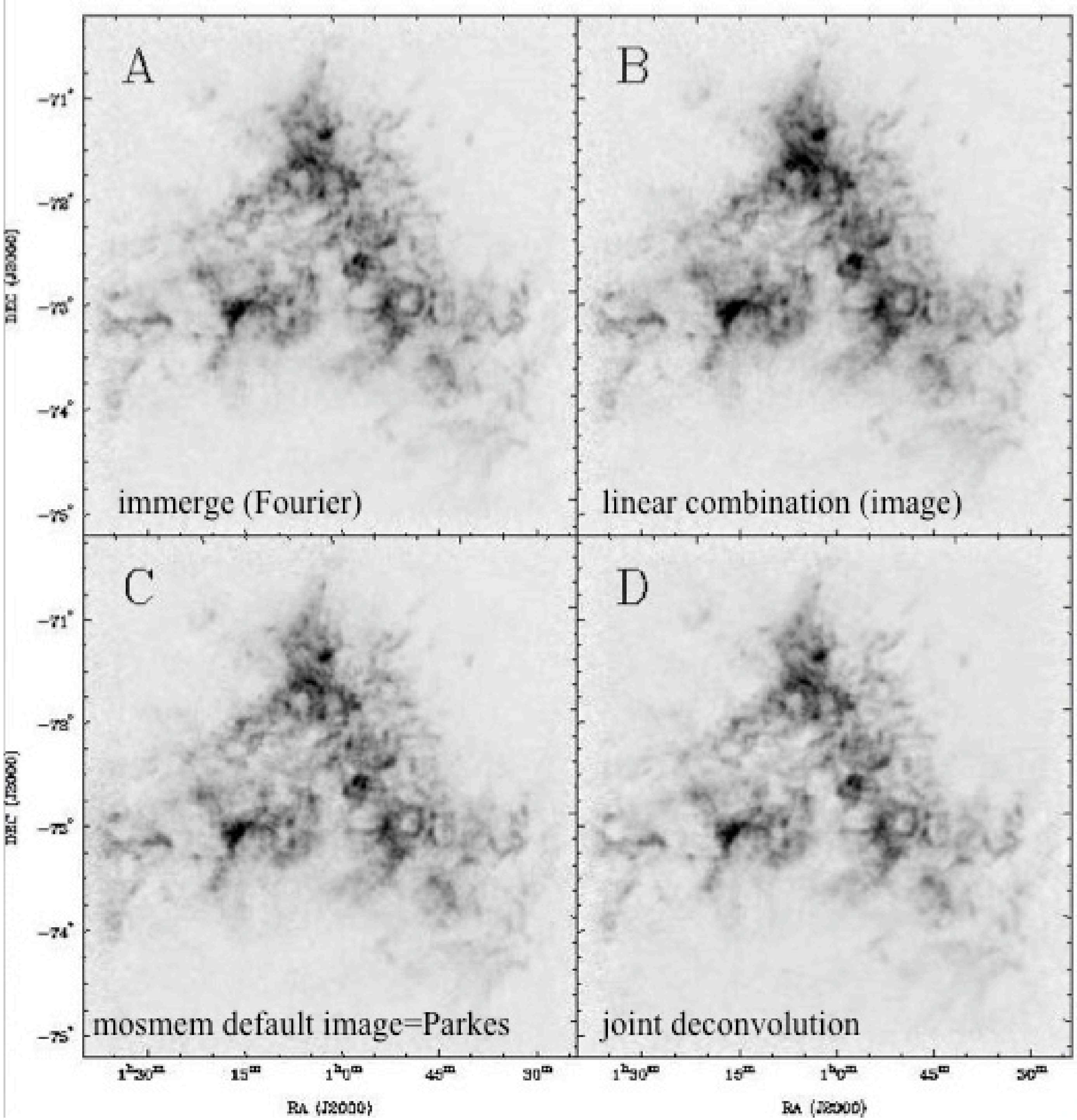
Joint deconvolution

Maximize "entropy": $$\aleph = -\sum_i I_i \ln\left(\frac{I_i}{M_i e}\right)$$

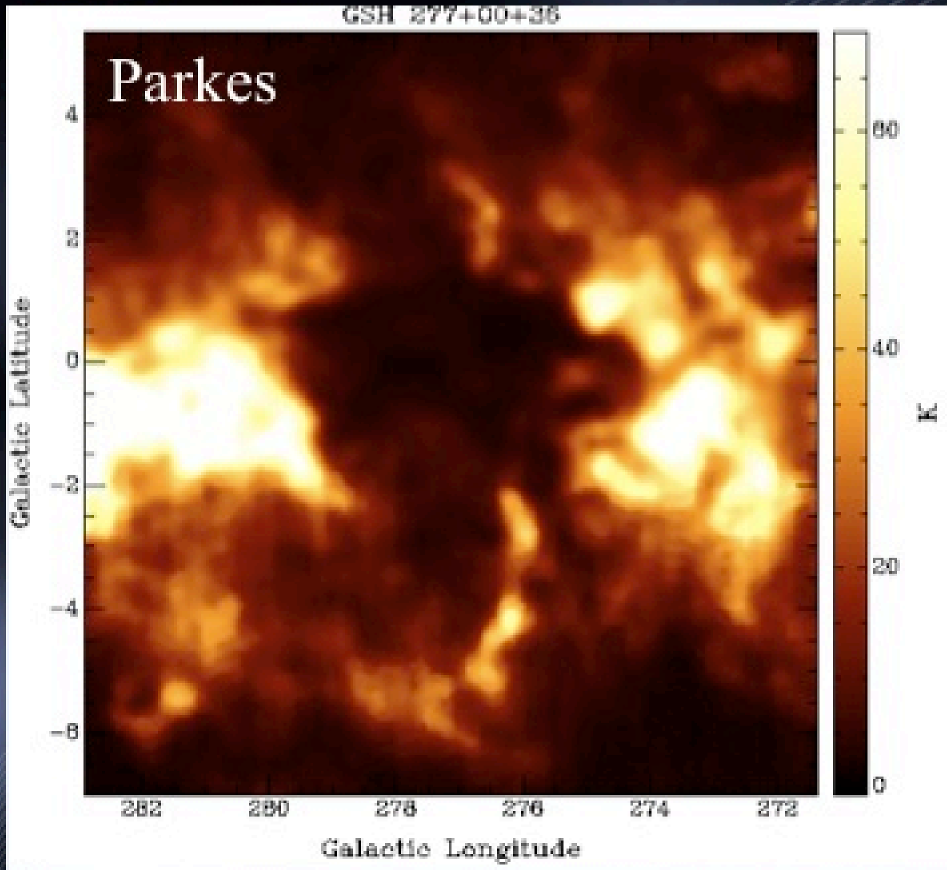
Subject to (1) $$\sum_i \left\{ I^D_{\mathrm{int}} - B_{\mathrm{int}} * I \right\}^2_i < N\sigma^2_{\mathrm{int}}$$

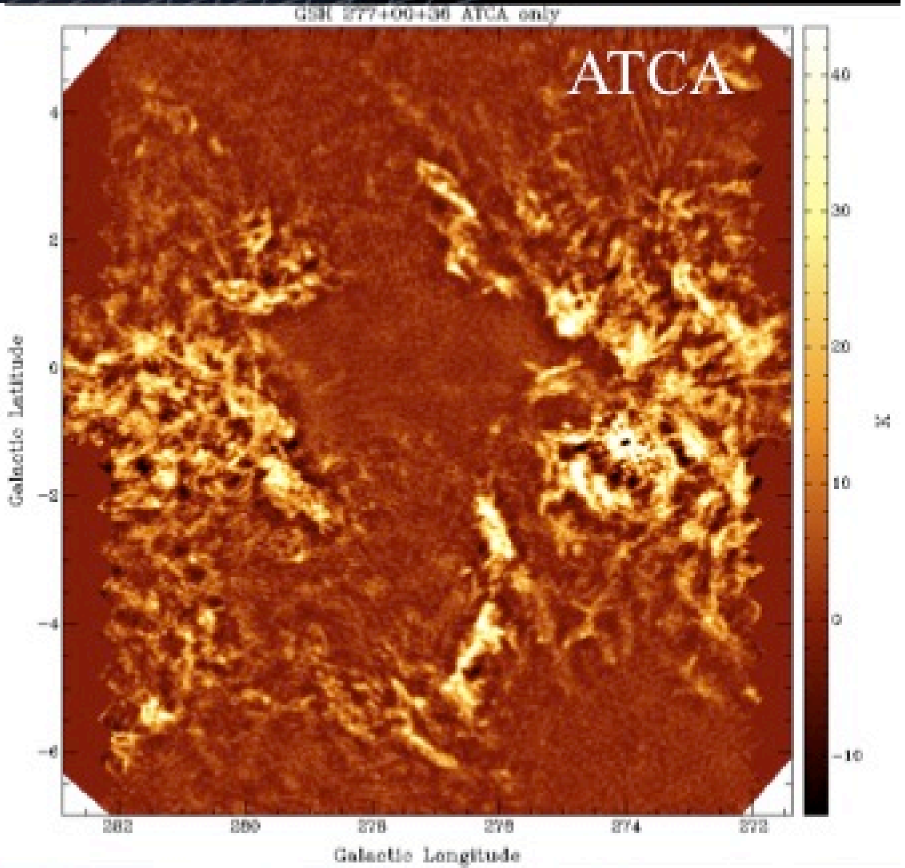
(2) $$\sum_i \left\{ I^D_{sd} - \frac{B_{sd} * I}{f_{sd}} \right\}^2_i < M\sigma^2_{sd}$$

This may be the best approach for Mopra+ATCA data

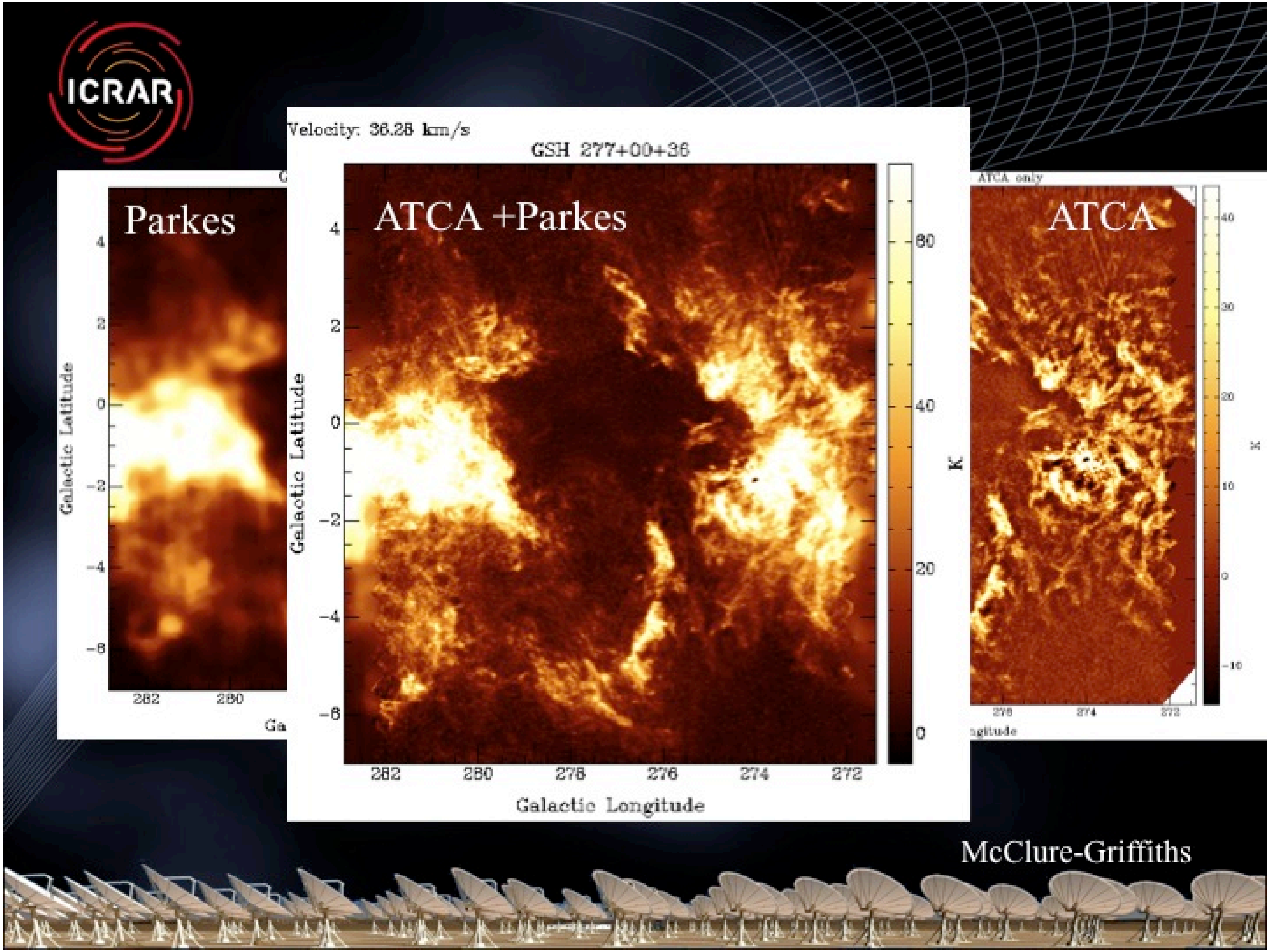


Comparing different methods using the SMC in HI at 169 km/s (Stanimirovic 2002)

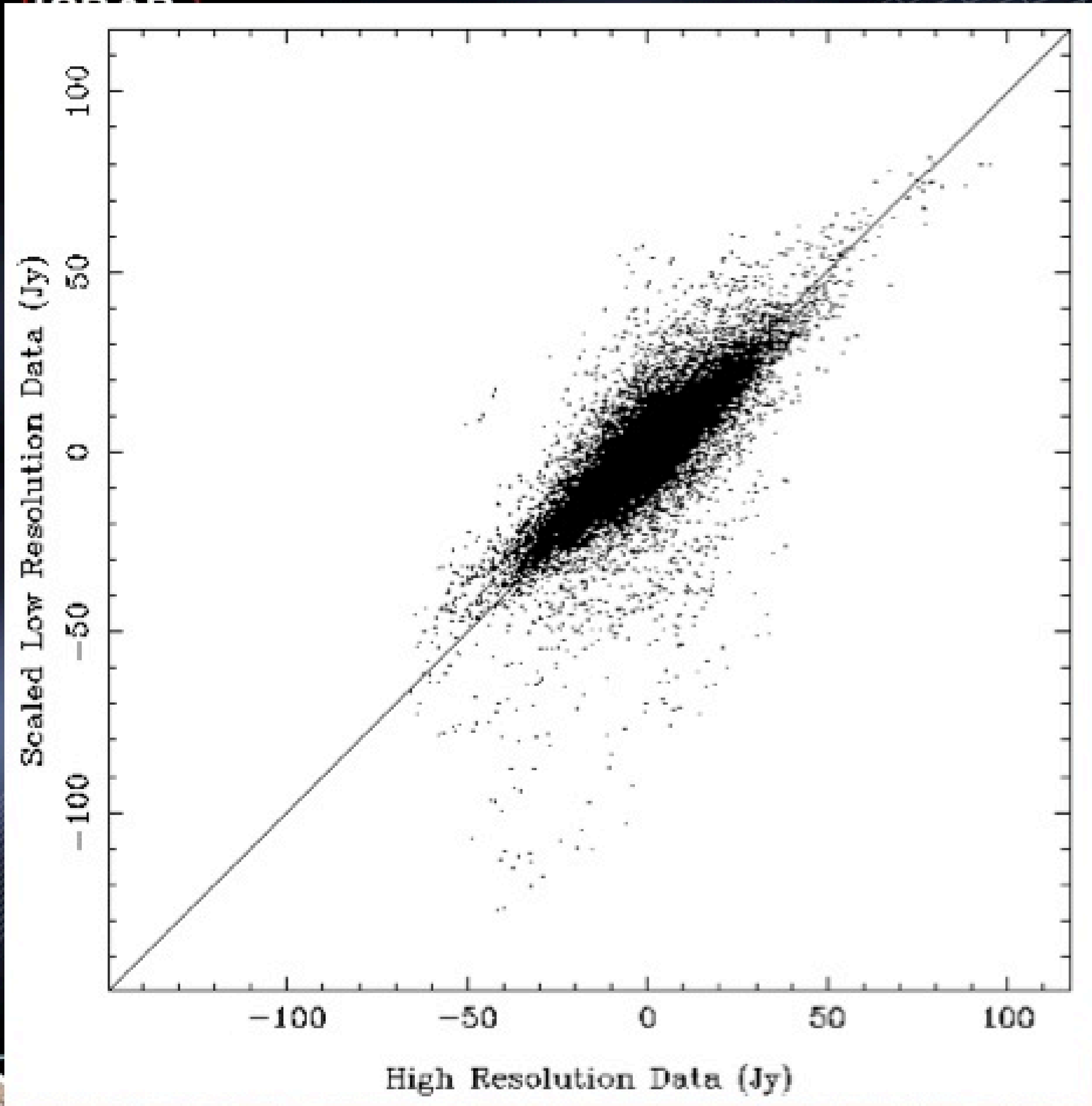




McClure-Griffiths


ICRAR
Velocity: 36.28 km/s
GSH 277+00+36
Parkes
ATCA +Parkes
ATCA
ATCA only
Galactic Latitude
Galactic Longitude
K
McClure-Griffiths

Check you understand your calibration



Relative scaling of data in overlap region from immerge
(120-170λ 130-200 km/s HI in SMC)

Summary

- Mosaicing essential for wide fields; *modus operandi* for ASKAP.
- Single-dish data essential if your image has large-scale structure approaching the interferometer primary beam size.
- Parkes+ATCA: excellent combination 1-20 GHz; Mopra+ATCA at 80-115 GHz (but challenging).
- For mosaicing and single dish combination, linear Fourier plane combination mostly works well (miriad tasks invert and immerge).

FPA footprint (APERTIF)