WIDE-FIELD IMAGING IN CLASSIC AIPS

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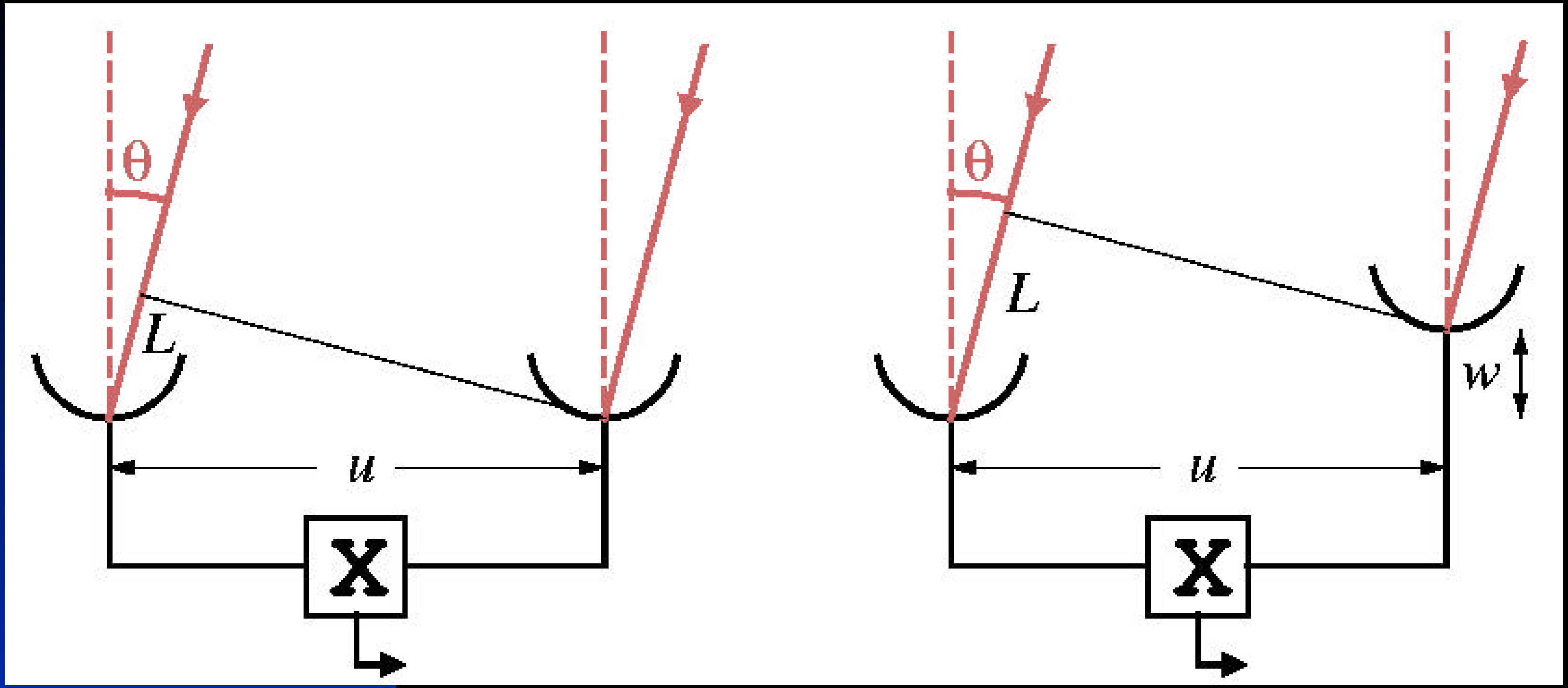
The problem



Non-coplanar array has w term in the equation for phase

$$\phi_l = 2\pi u l = 2\pi u \sin\theta$$
$$\phi_r = 2\pi\left[w(\cos\theta - 1) + u\sin\theta\right]$$
$$\phi_r = 2\pi\left[ul + w(\sqrt{1 - l^2} - 1)\right]$$

Magnitude of the problem

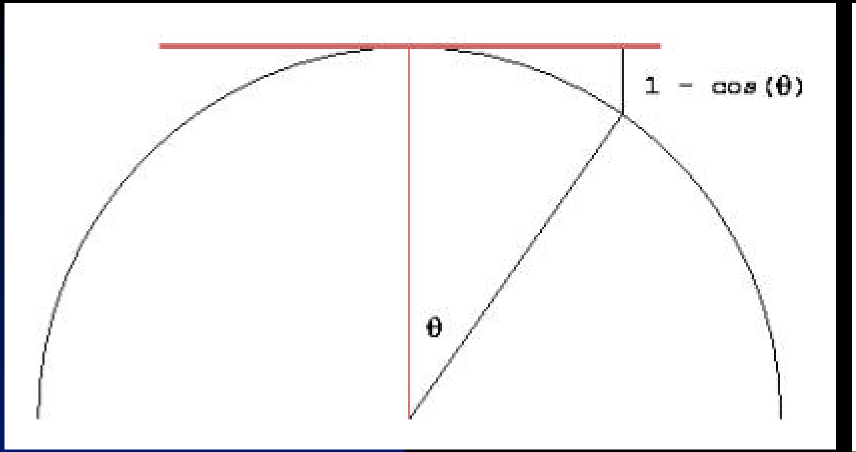
$$V(u,v,w) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(l,m)\exp^{-2\pi i\left[ul+vm+w(\sqrt{1-l^2-m^2}-1)\right]} \frac{dl\,dm}{\sqrt{1-l^2-m^2}}$$

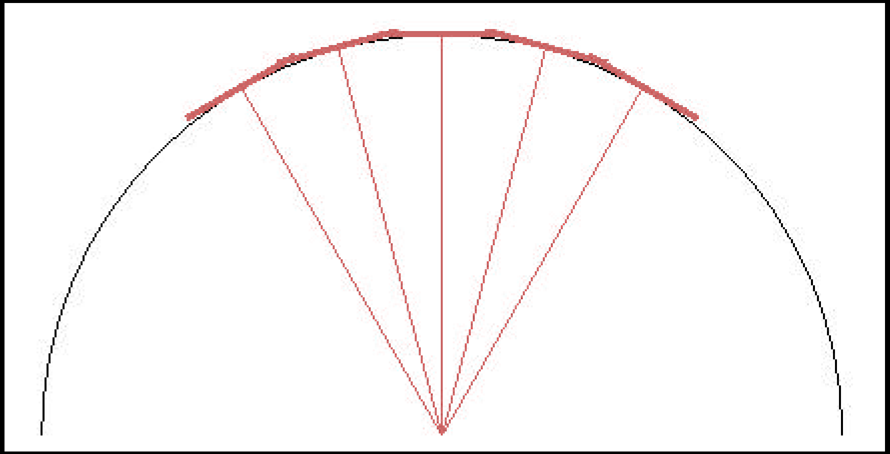
Approximation of worst phase error leads to limit on full facet diameter, all angles in same units.

$$\begin{aligned}\phi_{\rm error} &\simeq \pi(l^2+m^2)w \\ w &\leq D_{\rm max} \simeq 1/\theta_b \\ \phi_{\rm error} &< \phi_{\rm Emax} \\ \theta_{\rm facet} &< \sqrt{\theta_b\,\phi_{\rm Emax}}\end{aligned}$$

Note that synthesized beamwidth and single-dish beam size are both proportional to wavelength, making this limitation more serious at longer wavelengths.

The solution





- Left: single large field develops large phase errors away from the center
- Right: multiple small facets approximate the sphere with greatly reduced phase errors
- Requires re-computation of (u,v,w) and adjustment of visibility phases for each facet

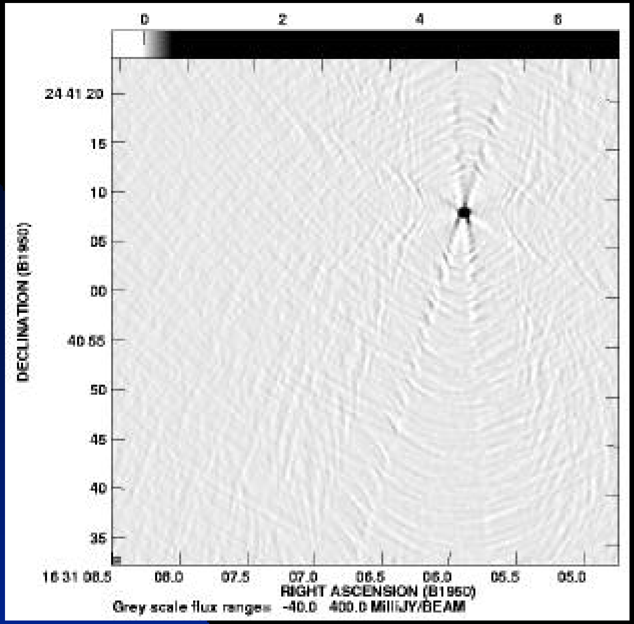
Implementation details

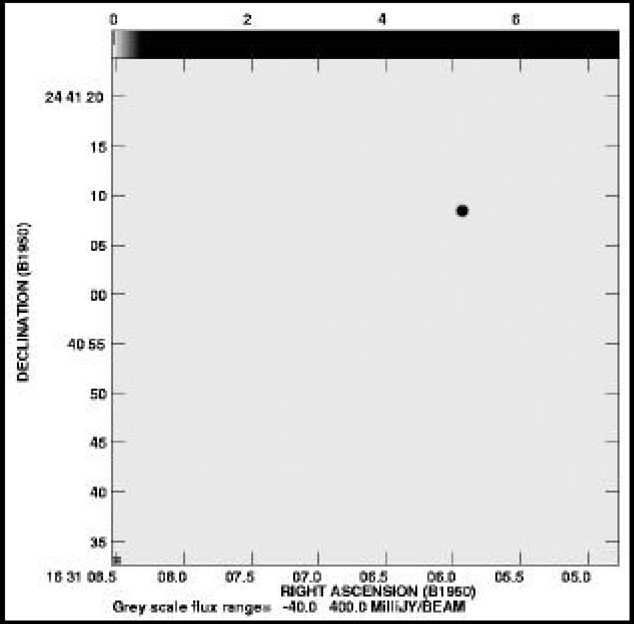
- Imaging: rotate (x,y,z) of facet center by inverse matrix, rotate each (u,v,w) by forward matrix for gridding with phase shift by product of rotated vectors
- DFT component subtraction: (x,y,0) in facet rotated by forward matrix and then subtracted from input data
- Gridded component subtraction: rotate (x,y,z) of facet center by inverse matrix, rotate each (u,v,w) by forward matrix, subtract gridded model, rotate each (u,v,w) by inverse matrix before writing back out.
- Requires separate synthesized beam for each facet
- Cotton/Schwab/Clark Clean done one facet at a time
- “OVERLAP 2” mode: subtract the components of current facet before imaging and Cleaning next strongest facet

Usage

- SETFC: task to recommend cell and image sizes, placement of facets and default Clean windows
- CHKFC: task to make image of facets and Clean windows written by SETFC
- IMAGR: task to image and Clean the facets
- FLATN: task to regrid the facets from IMAGR and CHKFC onto a single image
- CALIB: task to improve the calibration of the data using the full model in the multiple facets
- Numerous other tasks use these models too

Costs and benefits





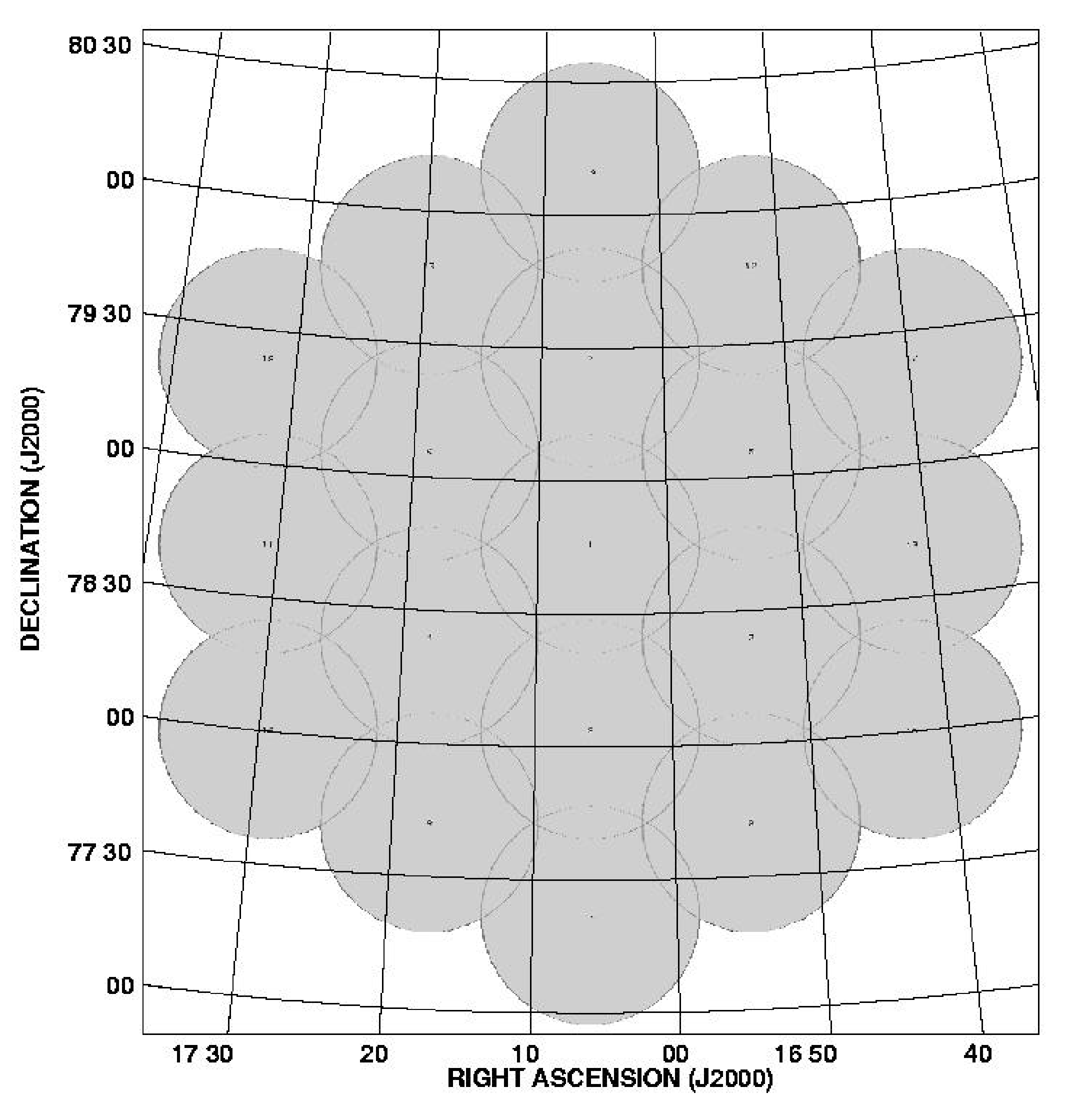
- Left: source phase corrected to facet center only
- Right: phases and (u,v,w) corrected for facet center shift. Both images Cleaned and displayed equally.
- Cost: 1 % in cpu when not needed, speeds Clean when it is needed
- Weighting best only for center facet

Example field

- VLA D array 20-cm wavelength continuum
- Observed with only 1 channel in 50 MHz, multiple narrower channels would be better
- Facet size rules allow a single facet to cover well beyond the half-power point of the single-dish beam pattern
- Imaged over a larger area of necessity – 19 central facets used plus one on a 3C source
- Data on Abell 2256 from Tracy Clarke and Torsten Ensslin

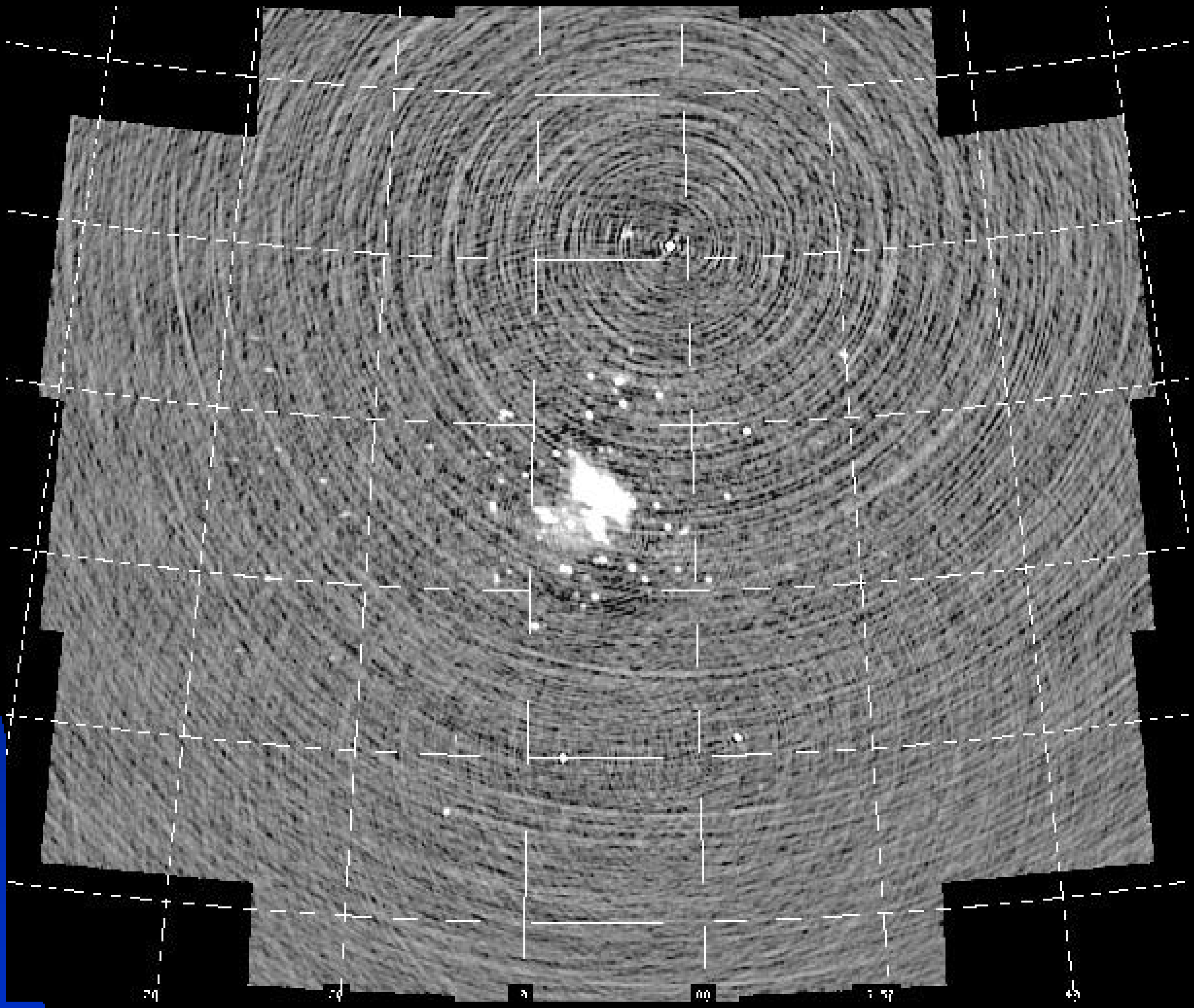
Facet selection illustrated

Output of CHKFC after FLATN. The facet numbers are shown in the center of the default circular Clean windows. Note the large area covered – each facet covers ~40 arc minutes while the primary beam to half power is only 30. These facet centers and Clean windows are then used by IMAGR.



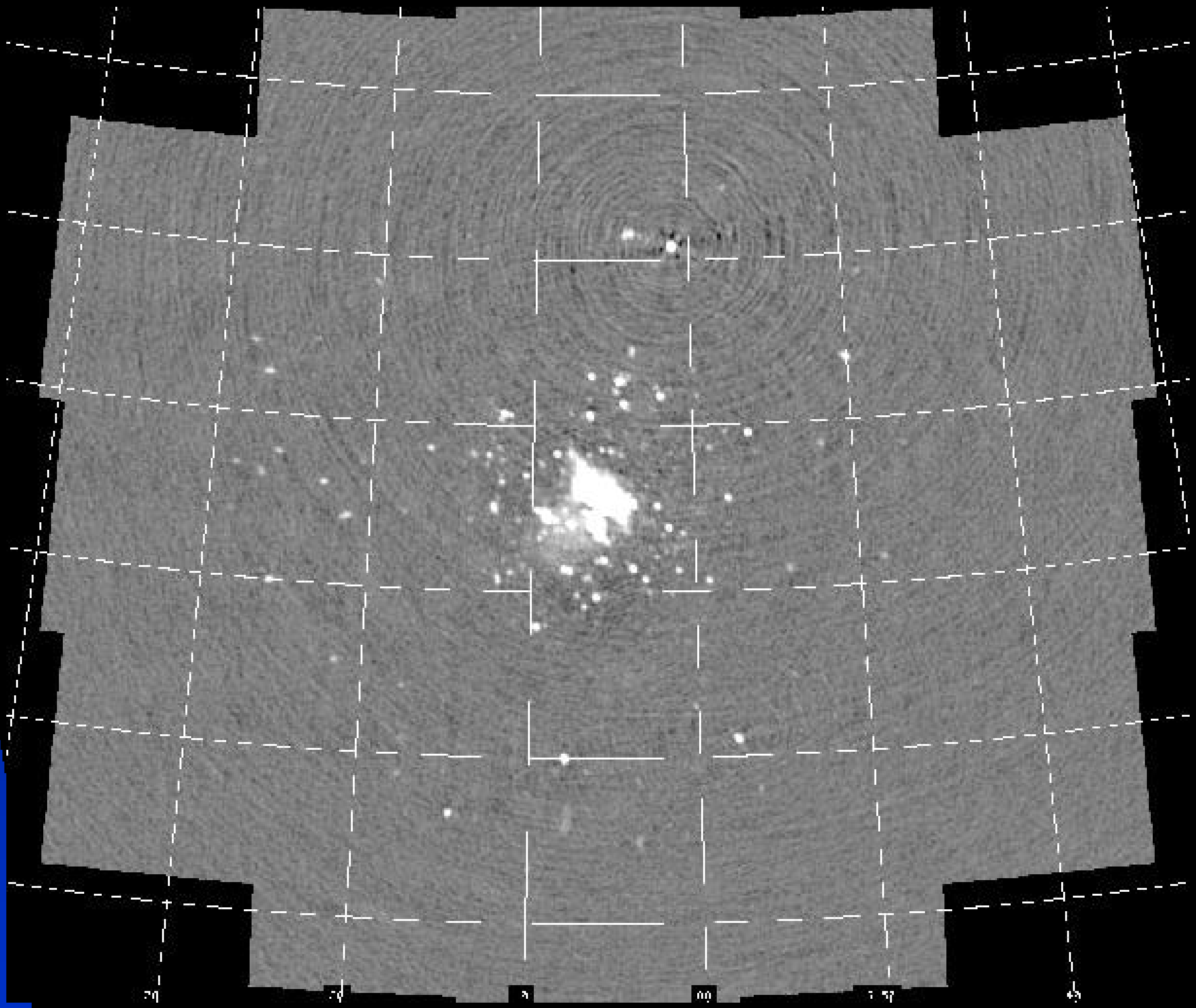
Why Clean the large area?

Cleaned image, allowing Clean to find components only in the center facet. Note the sources farther out in the primary beam and in its first outer sidelobe (down ~18 db). The distant sources compromise the science on this cluster unless they are also imaged correctly.



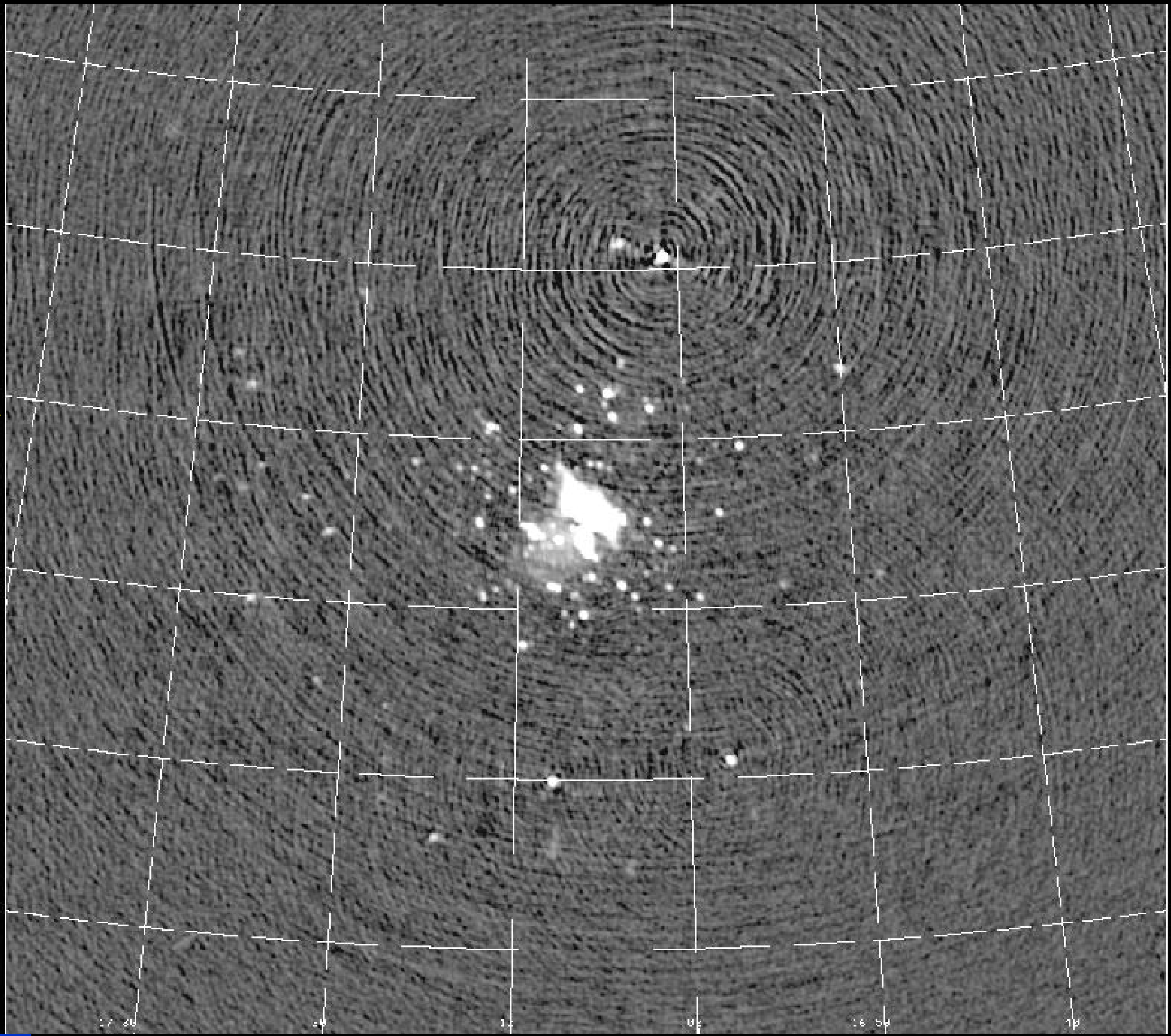
Results if one does

Same field Cleaned over all facets with OVERLAP 2 mode. The improvement in the main source area is considerable. The strong source in the outer sidelobe has been Cleaned rather well, but residual calibration, beam, and pointing effects remain.



Were 3D facets really needed?

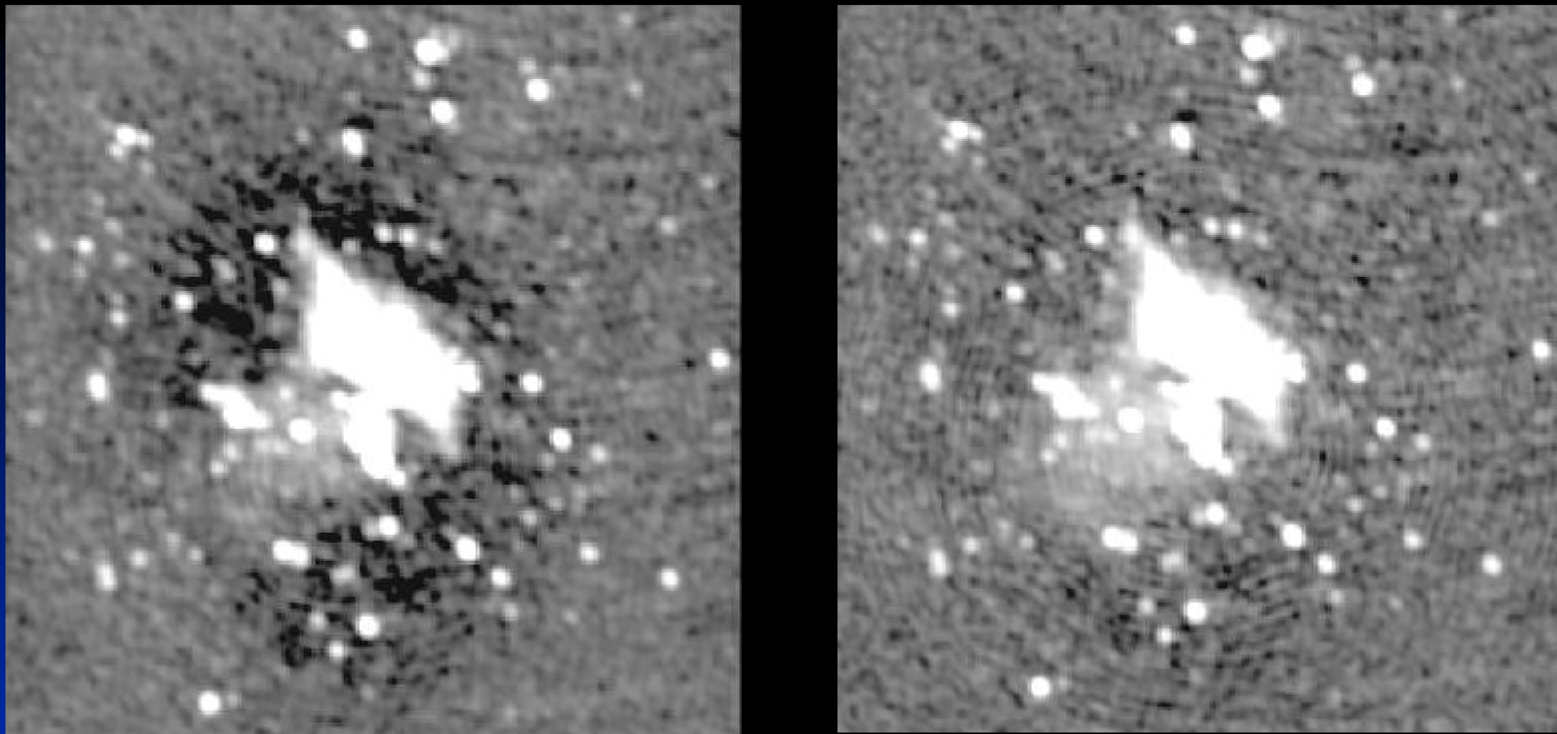
Single large facet imaged and Cleaned with no geometrical corrections. Note remaining unCleaned sidelobes and defects all of which are worse than in the 3D multiple-facet image. Note also several sources in the second outer sidelobe of the single-dish beam.



Multi-scale Clean

- IMAGR implements a multiple resolution form of Clean suggested by my ancient experiments and recent work by Holdaway & Cornwell.
- The multiple facets are used to Clean full resolution images of each facet with a point model plus tapered images of each facet with one or more Gaussian source component models.
- Cotton/Schwab Clean is used to subtract the model visibilities in the uv plane and then re-image.
- Various “steering” options are employed to reduce the tendency to favor the lowest resolution (since it integrates over the greatest flux).

Point versus multi-scale: Facet 1

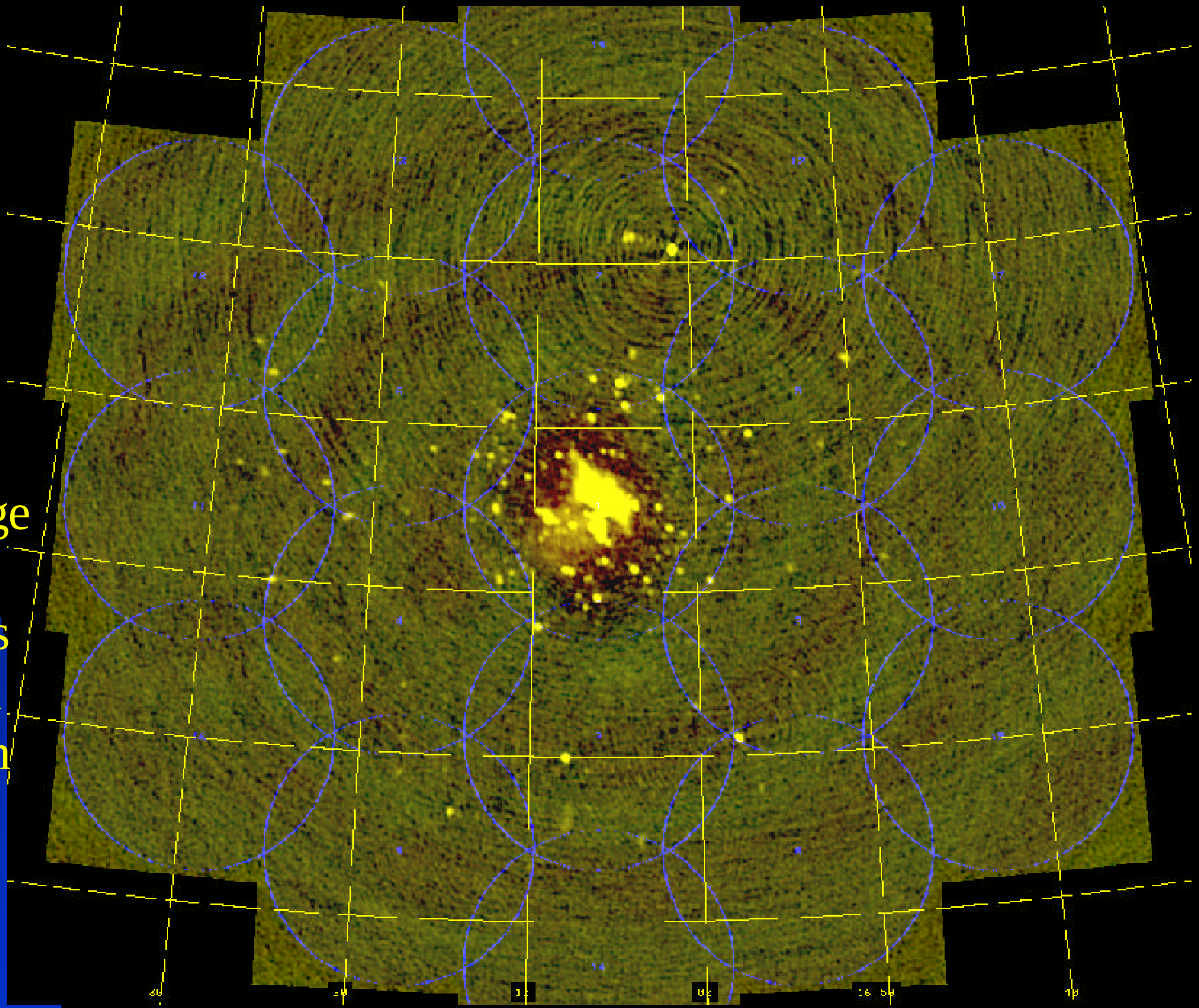


- Point-source model only Clean (left) leaves a negative “bowl” around and in the cluster due to absence of very short-spacing data.
- Multi-scale Clean (right) reduces this effect.

Point versus multi-scale: Full image

Blue:
facet image,
Green:
point image,
Red:
Multi-scale image

Note: grating rings of inner “bowl” in point-model Clean



Summary

- All matters presented here should be well known, although imaging beyond the primary beam and multi-scale Clean require more study.
- Classic AIPS has made these algorithms available to a wide range of users on a variety of computers. Multiple facets with multiple source models are supported in all data modeling used in calibration, editing, and display.
- Multiple facets each tangent to the celestial sphere are a good way to solve the 3D or non -coplanar array problem at surprisingly little cost.
- Wide-field imaging is needed at longer wavelengths to reduce the effects of interfering sources.
- Cleaning with multiple sizes of component model can reduce effects of missing short spacings and large diameter sources.