Non Coplanar Radio Imaging Arrays and Computing Efficiency

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- Modern radio synthesis arrays can produce VERY LARGE data sets (e.g. EVLA = ~1000 xVLA)
- Efficient use of computing hardware vital.
- Existing techniques developed in a single threaded world
- Single processor speeds no longer increasing
- Faster = parallel
- We must rethink techniques for a parallel world

Non Coplanar Radio Imaging Arrays and Computing Efficiency

- Most radio imaging arrays use earth rotation to improve spatial frequency coverage
- Two dimensional array rotated into three dimensions
- Have “resolution” in three directions
- Universe outside of solar system in far field, i.e. is projected onto celestial sphere.
- Will discuss dealing with 3-D aspects

Imaging in 3 dimensions

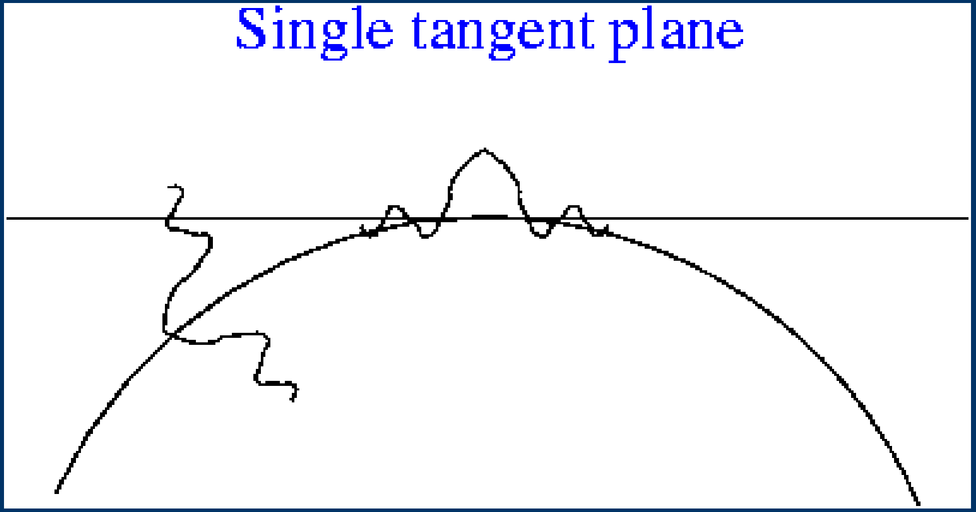
- Known as coplanarity or “W” problem
- Possibilities:
  - Full 3 D imaging and project to celestial sphere
    VERY expensive
  - Ignore, project to single 2D tangent plane
    Limited field of view
  - Multiple 2D tangent planes
    Slow deconvolution
  - Include effects of wave propagation in imaging
    Expensive
  - Multiple planes projected onto common plane
- Consider variations on multiple tangent planes

Imaging and Deconvolution

- Spatial frequency plane incompletely sampled.
- Use zero for data not measured.
- Derived “dirty” image convolution of sky with psf
- Need nonlinear deconvolution.
- “CLEAN” most popular, decompose image into points or Gaussians.
  - Select initial components in “minor” cycle
  - High accuracy subtraction from data, “major” cycle
  - Reimage residual data to residual images
  - Repeat to convergence.

Single tangent plane

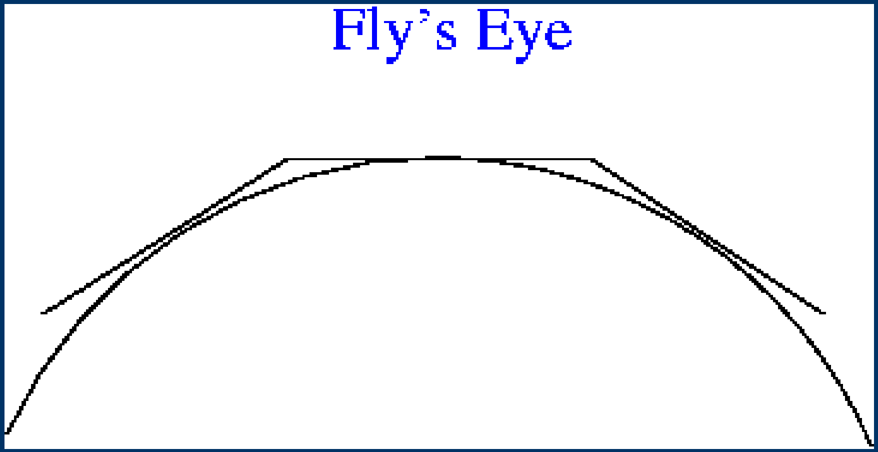
- Traditional approach for limited field of view
- Far from tangent point, resolution in z direction becomes less than distance from celestial sphere



Horizontal and vertical resolution about a single tangent plane

Multiple tangent planes

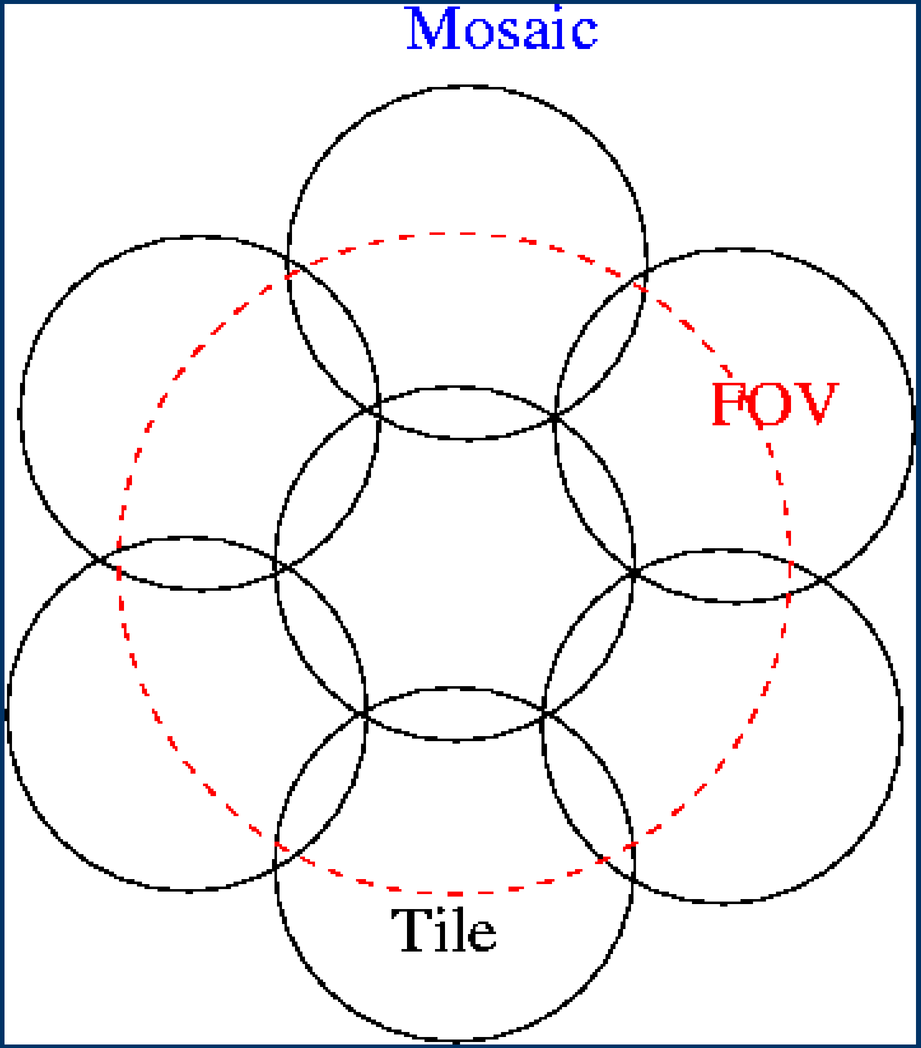
- Tile field of view with tangent planes sufficiently close to celestial sphere



"Fly's eye" mosaic of tangent planes

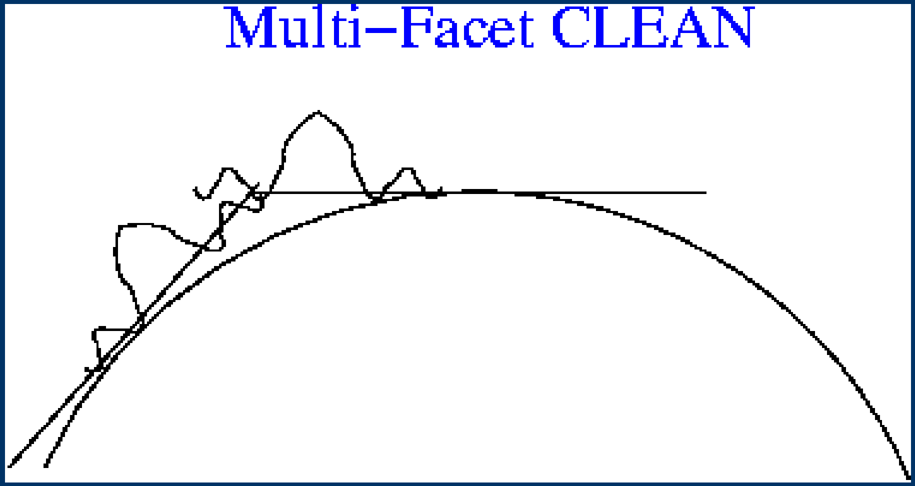
Mosaic of tangent planes

Cover field of view with overlapping facets



Multiple tangent planes, cont'd

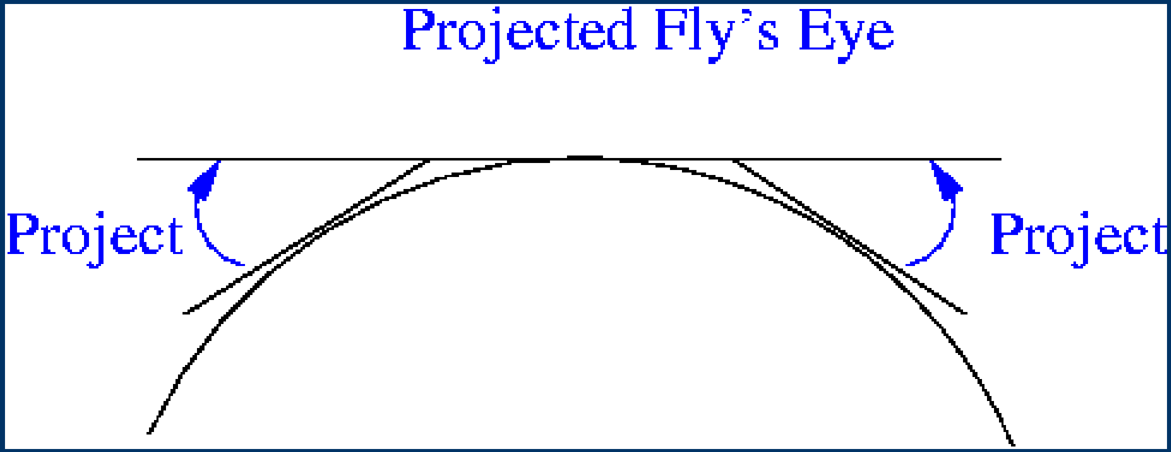
- All data used to form all tiles, more computing but easily parallelizable.
- Complication is in deconvolution, psf in one facet cannot predict sidelobe response in another.



- Each facet must be CLEANed in separate major cycle = slow.

Projection onto Common Plane

- Can project facet to common tangent plane in image formation at no additional cost.



- Psf in one facet good approximation of psf in adjacent facet.
- Multiple facets can have parallel minor cycles.

Image and CLEAN using a Common Tangent Plane

- All facets with significant emission can be processed in same minor cycles.
- This results in fewer major cycles
- Only facets with CLEANable emission need be imaged each major cycle.
- Implemented in Obit package (http://www.cv.nrao.edu/~bcotton/Obit.html)

Real world: wide bandwidth

- To improve sensitivity, modern arrays use wide bandwidth
- Spectrum not constant across field of view
- Must solve for spectrum
- Antenna pattern varies with frequency
- Split data into frequency bins – coupled deconvolution

Real world: Extended sources

- Extended source difficult to model with delta fn.
- Several potential solutions but consider "multi-resolution CLEAN"
- Model sky with combination of delta fns. and Gaussians
- Multiple versions of each facet with a variety of spatial frequency tapers

Real world: Sky mostly empty

- Sometimes more beam areas in image than independent data.
- Support a powerful constraint on deconvolution
- Must locate regions of emission as deconvolution proceeds.

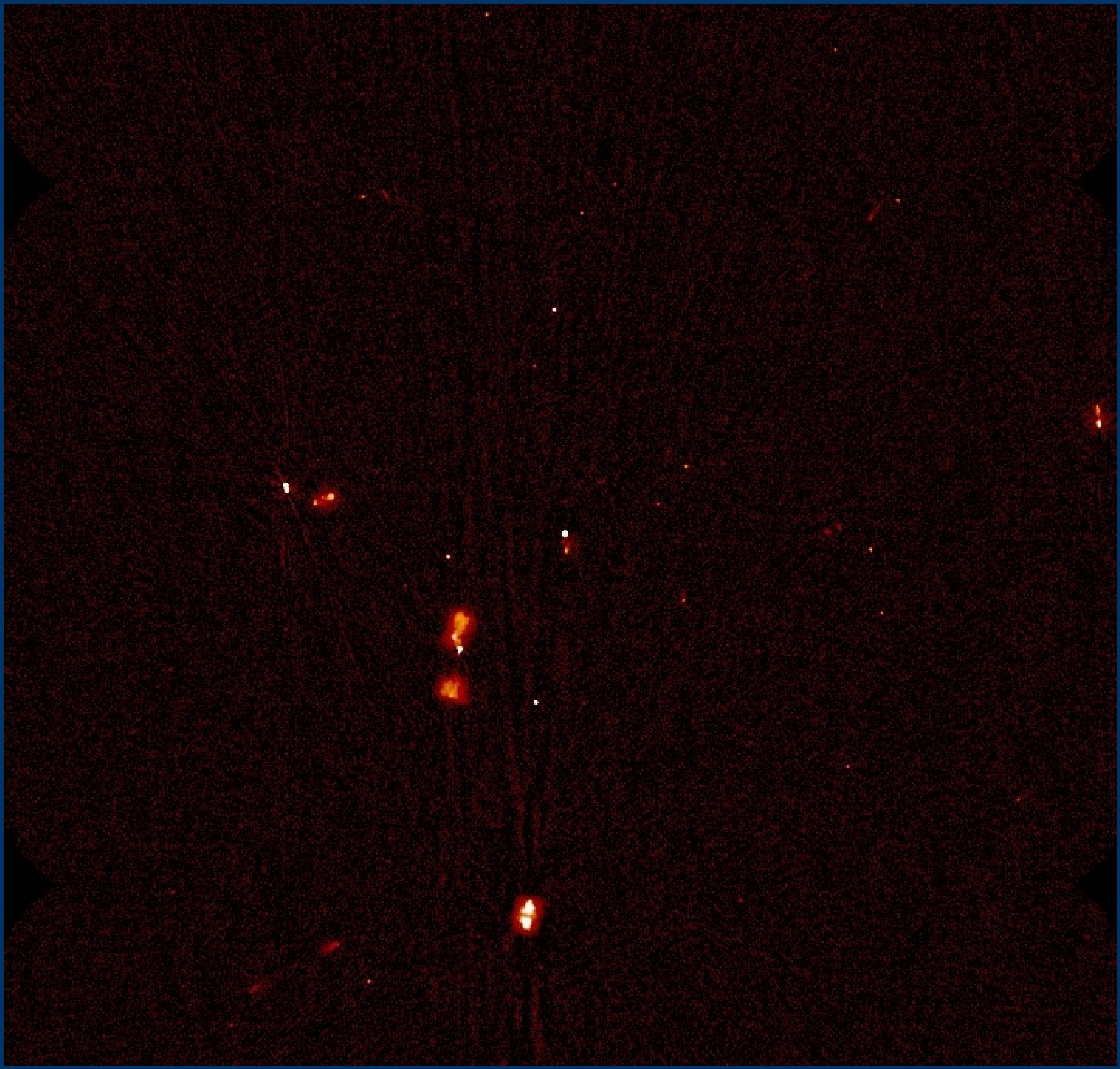
Real world: Antenna pattern

- Off axis feeds give “beam squint” ⇨ orthogonal polarization beams not co aligned on sky
- Blockage in aperture gives asymmetries in antenna pattern.
- With az-el mounts, pattern rotates on sky
- Can make corrections when calculating response to model
- Pattern a function of frequency

Example:

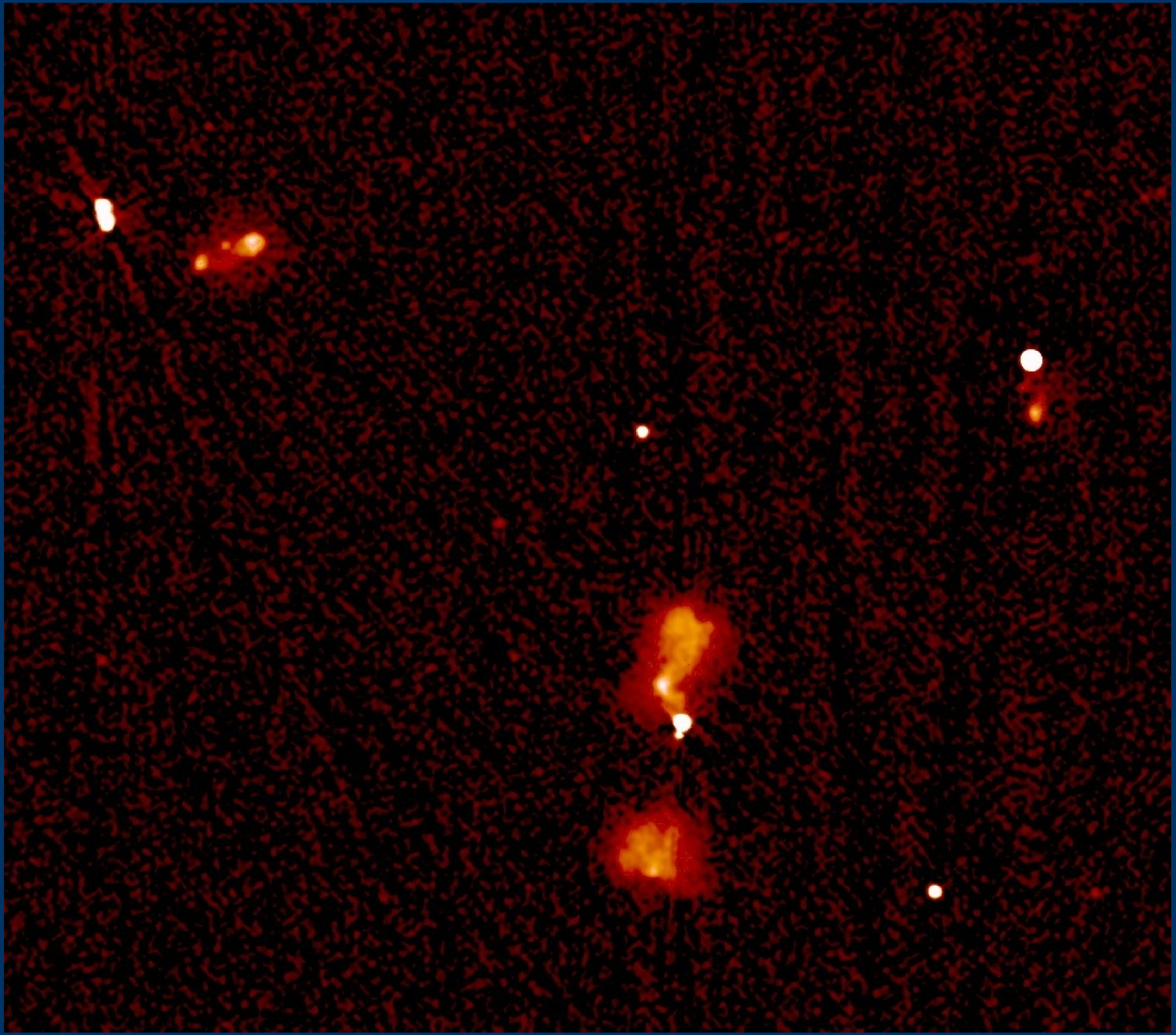
- EVLA 1-2 GHz observations of weak calibrator
- 50% of emission in background
- ~ 10 min total in B configuration (4”)
- Image (Obit/MFBeam) with:
  - Projected Fly's eye – 39 facets
  - Wideband
  - Widefield with beam corrections
  - Multi resolution (2)
- Resultant dynamic range >20,000:1
  - Residual artifacts likely pointing errors

Example EVLA field



Square root stretch, clipped at 1.5 mJy
RMS = 28 μJy

EVLA example closeup



Timing tests

- Test data ~10 min and problem fits in memory
- Duplicate 32 times and turn off baseline dependent time averaging (5x)
- Equivalent ~450 Gbyte dataset
- Reduce scale of imaging problem
- I/O to fast RAID system
- Compare runs with and without projected Fly's eye

test	Run time (hr)	CPU/real	max threads
w/o projection	88.31	0.79	1
w/o projection	38.22	1.87	8
w/projection	73.78	0.95	1
w/ projection	19.78	3.46	8

Conclusion

- Projected Fly's Eye gives substantial performance improvement for multicore process on large datasets.

Future Improvements

- Copy all CLEAN components to common image for single Gridded model calculation.