Mosaicing

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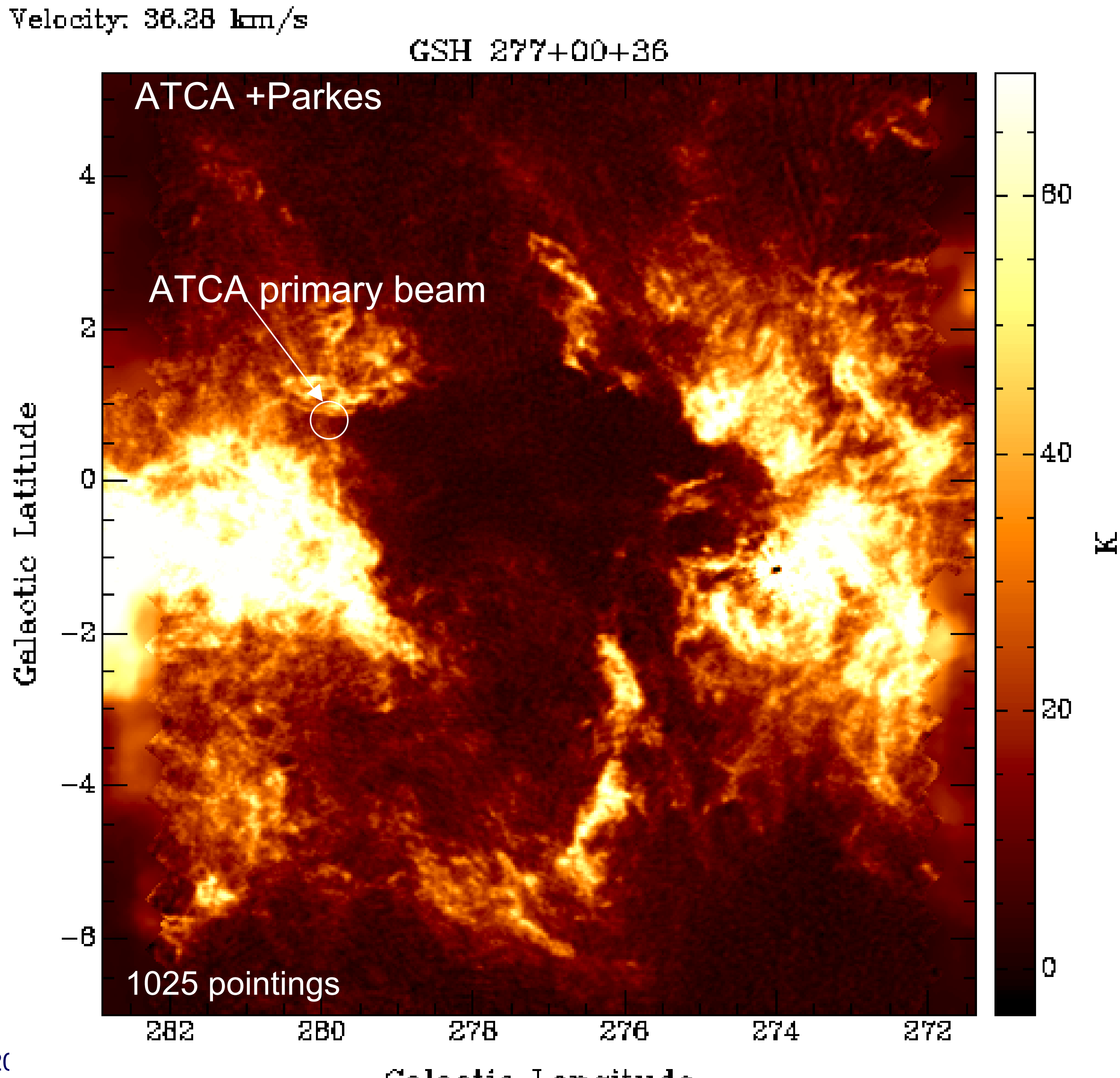
What is Mosaicing?

- In the real world -
  - Mosaic - /mO-'zA-ik/ *noun* **1.** a picture or decoration made of small pieces of stone, glass, etc., of different colours, inlaid to form a design. **2.** the process of producing it. **3.** something resembling a mosaic in composition. **4.** *Aerial Surveying* an assembly of aerial photographs taken vertically and matched in such a way as to show a continuous photographic representation of an area (**mosaic map**). **8.** composed of diverse elements combined. (ref. Macquarie Dictionary)
- In our world (astronomy) -
  - A large image created from many subimages (note: it's actually better than that!)

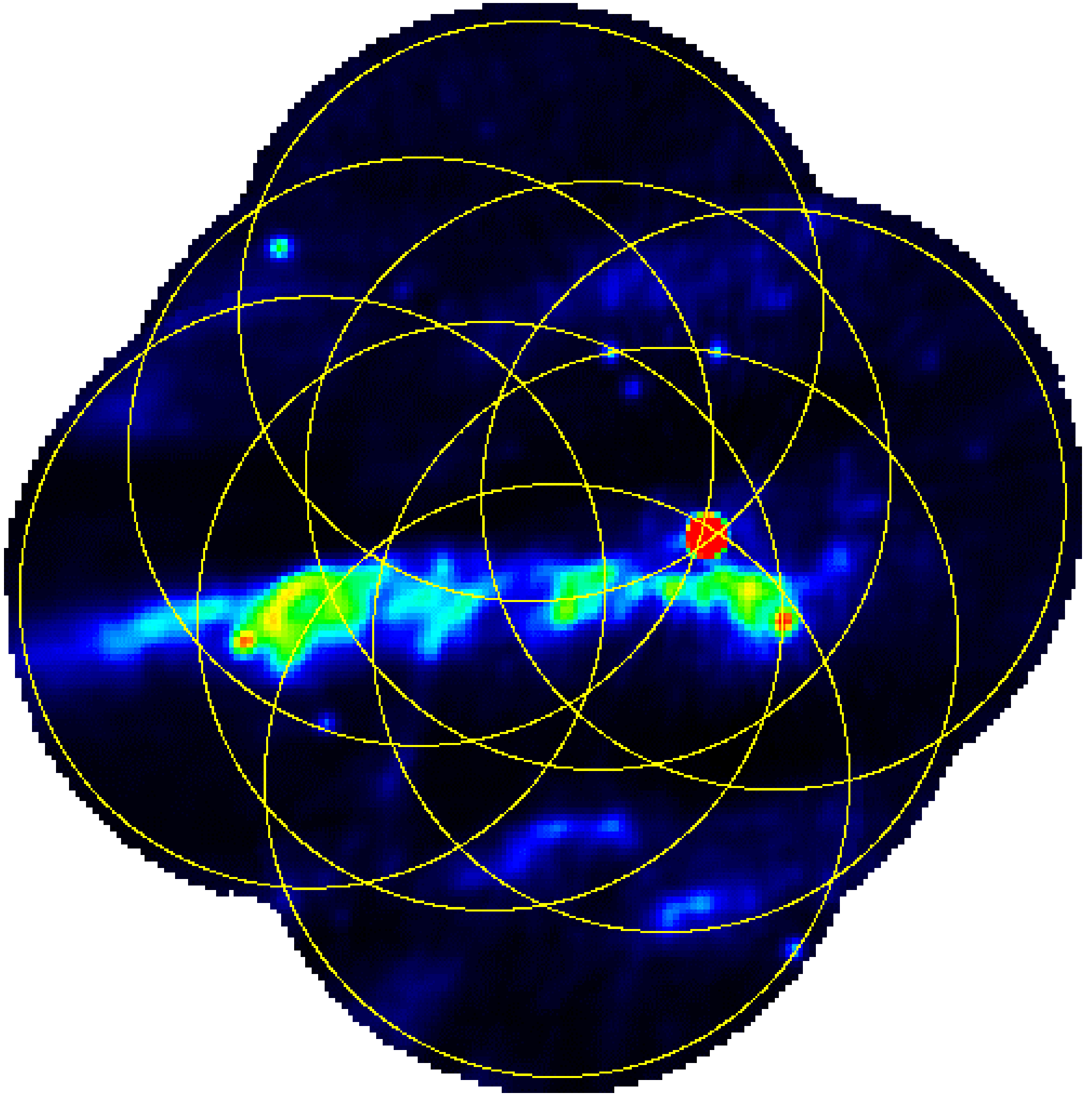
Why Mosaic?

- Wide-field imaging:
  - Interested in source that is larger than primary beam, $\theta > \lambda / D$
- Large scale structure
  - Interested in structure on scales larger than that sampled by the shortest baseline: $\theta > \lambda / b_{min}$

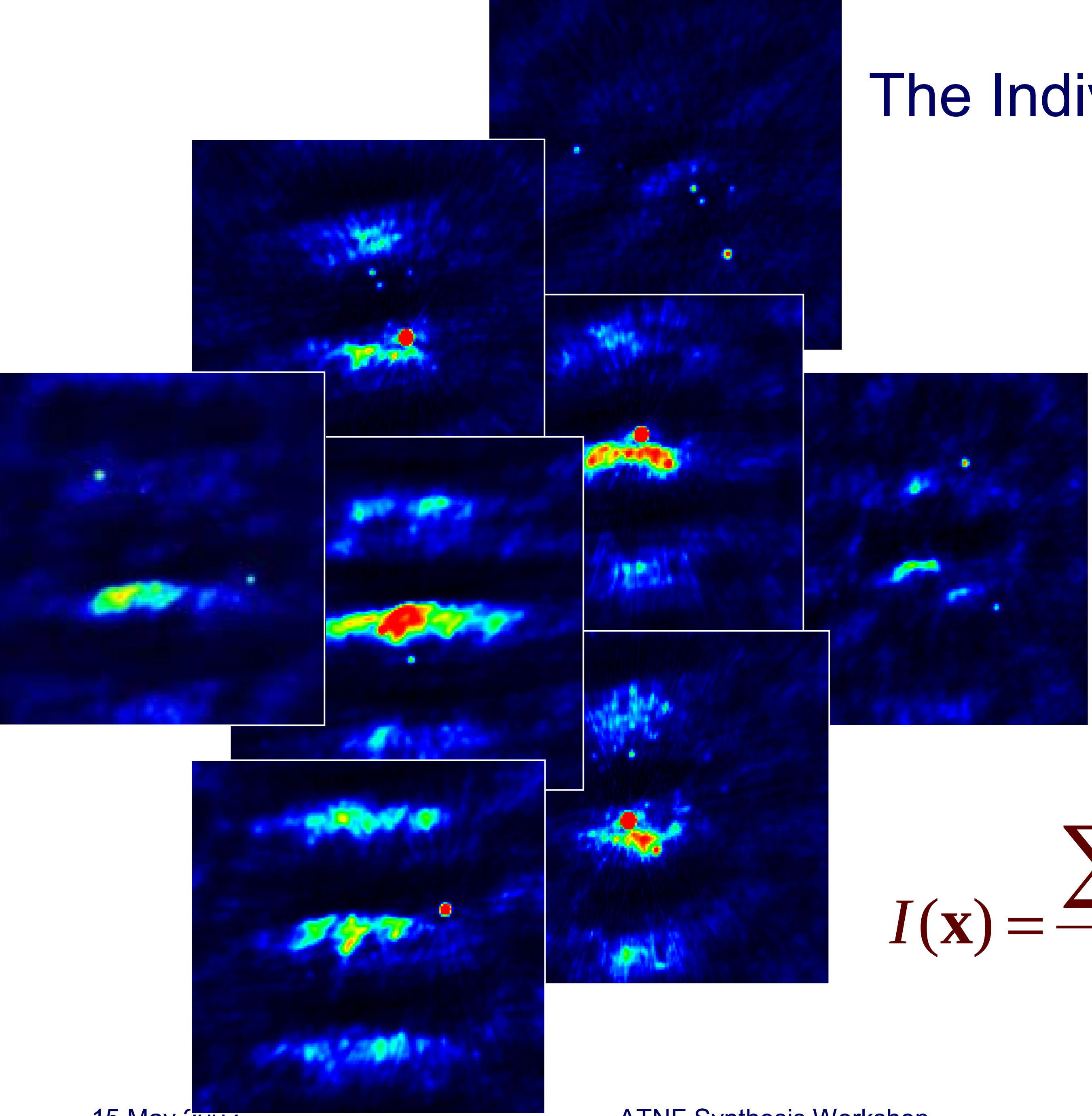


Velocity: 36.28 km/s
GSH 277+00+36
ATCA +Parkes
ATCA primary beam
1025 pointings
4
2
0
−2
−4
−6
Galactic Latitude
282
280
278
276
274
272
Galactic Longitude
60
40
20
0
K

Mosaicing: Individual Approach

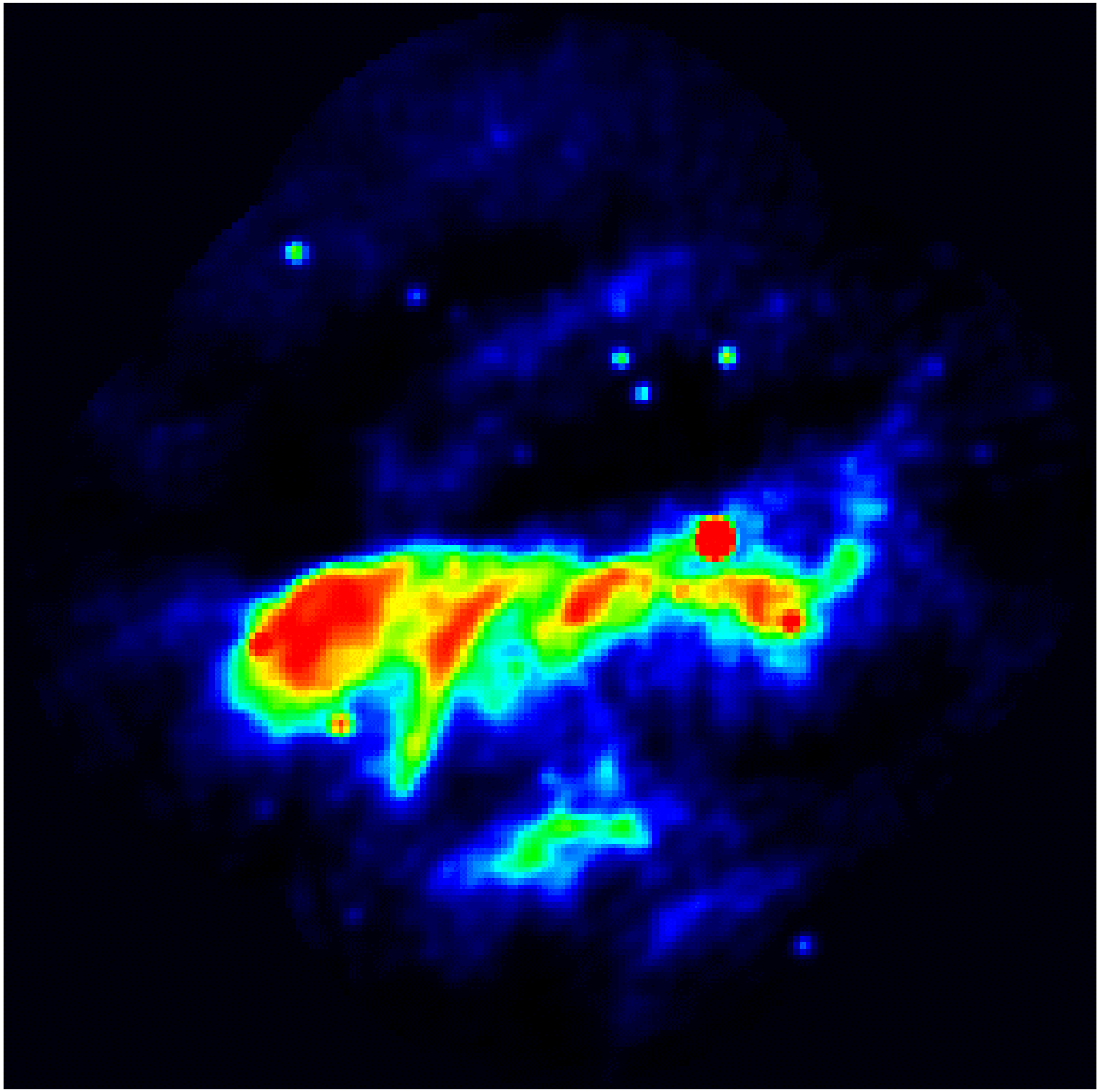


The Individual Approach



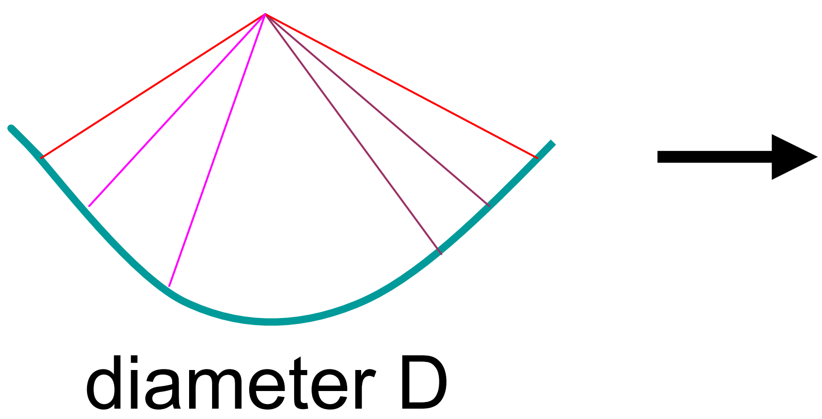
$$I(\mathbf{x}) = \frac{\sum_p A(\mathbf{x}-\mathbf{x}_p) I_p(\mathbf{x})}{\sum_p A^2(\mathbf{x}-\mathbf{x}_p)}$$

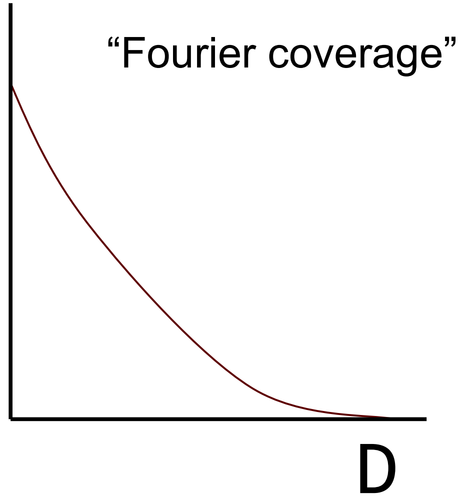
You can do better!



Mosaicing Fundamentals

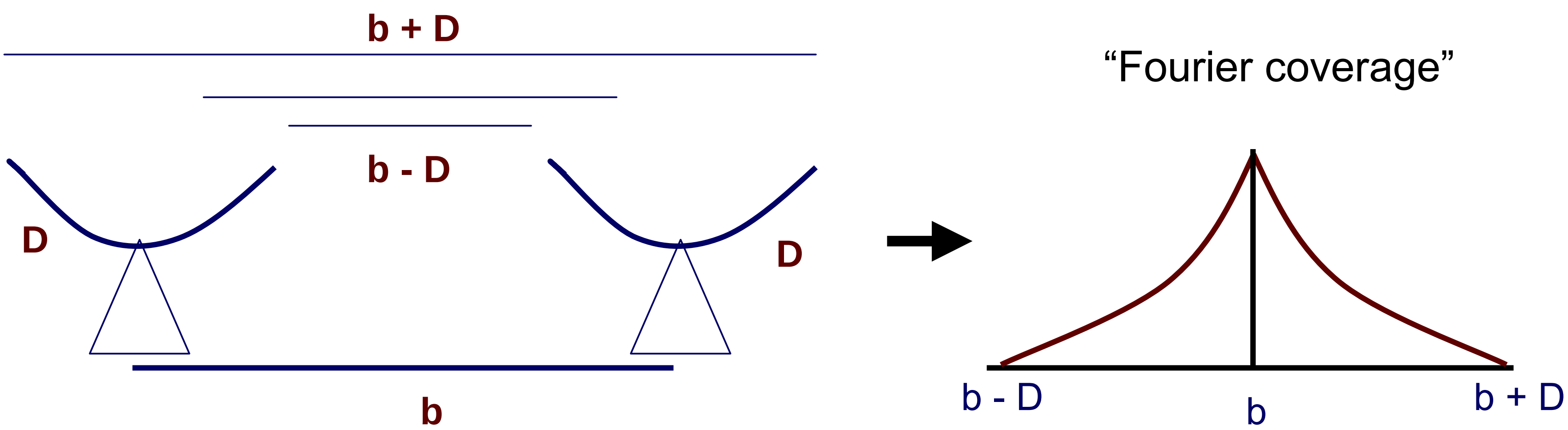
- Background theory:
  - Ekers & Rots (1979) pointed out that one can think of a single dish as a collection of sub-interferometers.





Mosaicing Fundamentals

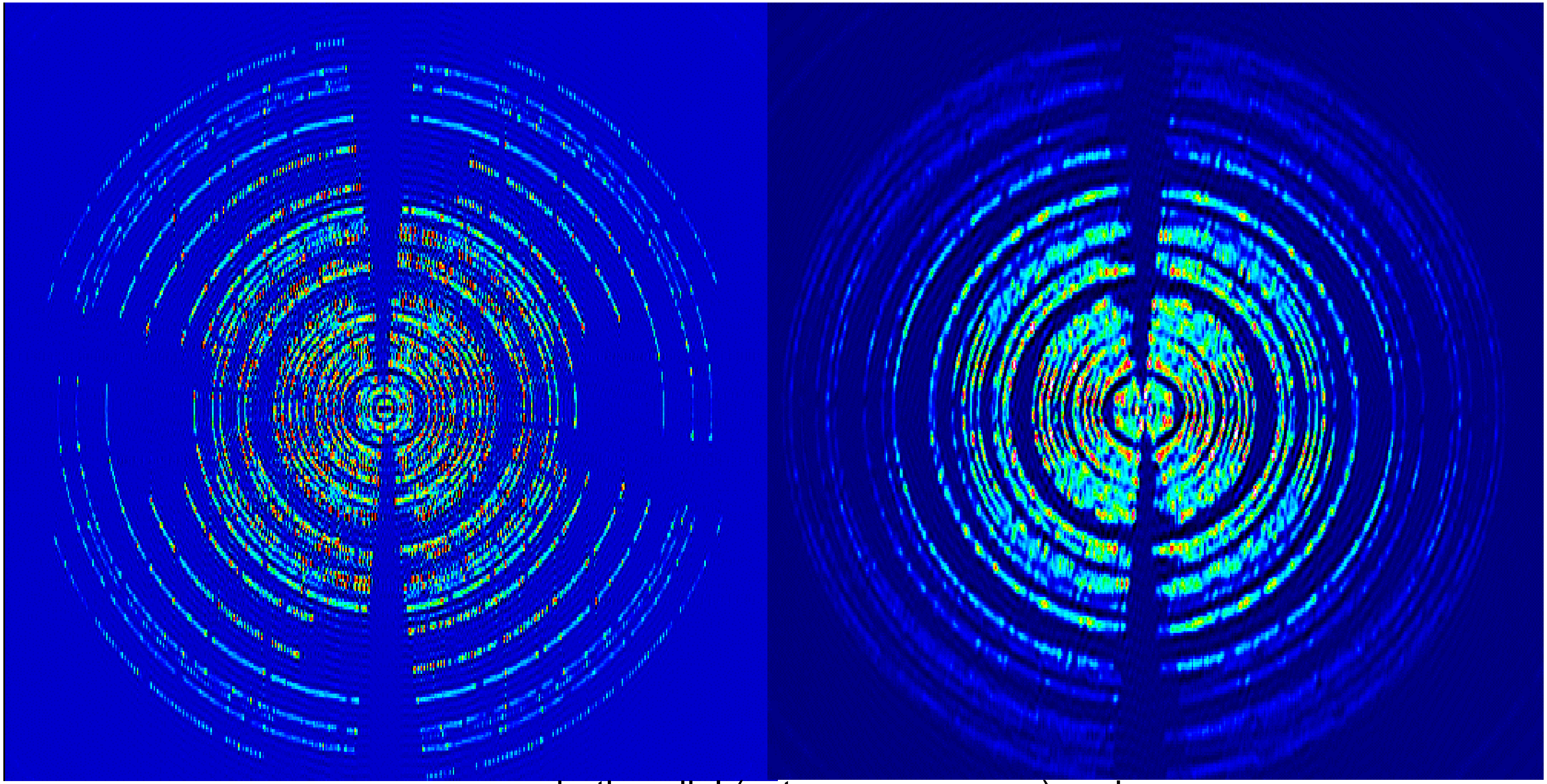
- Extended this formalism to interferometers to show that an interferometer doesn't just measure angular scales $\theta = \lambda / b$ it actually measures $\lambda / (b - D) < \theta < \lambda / (b + D)$



Mosaicing Fundamentals

- But you can't get all that extra info from a single visibility
  - Same as with a single dish, you have to scan to get the extra "spacings"
- Ekers & Rots showed that you can recover this extra information by scanning the interferometer
- The sampling theorem states that we can gather as much information by sampling the sky with a regular, Nyquist spaced grid

Comparison of *u-v* coverage



Individual

both radial (extra *u-v* coverage) and azimuthal (adjacent pointings)improvement

Joint

The Joint Approach

- Form a linear combination of the individual pointings, p:

$$I(\mathbf{x}) = W(\mathbf{x}) \frac{\sum_p A(\mathbf{x}-\mathbf{x}_p) I_p(\mathbf{x}) / \sigma_p^2}{\sum_p A^2(\mathbf{x}-\mathbf{x}_p) / \sigma_p^2}$$

- Here σ_p is the noise variance of an individual pointing and A(**x**) is the primary response function of an antenna
- W(**x**) is a weighting function that suppresses noise amplification at the edge of mosaic

Sault, Brouw, & Staveley-Smith (1996)

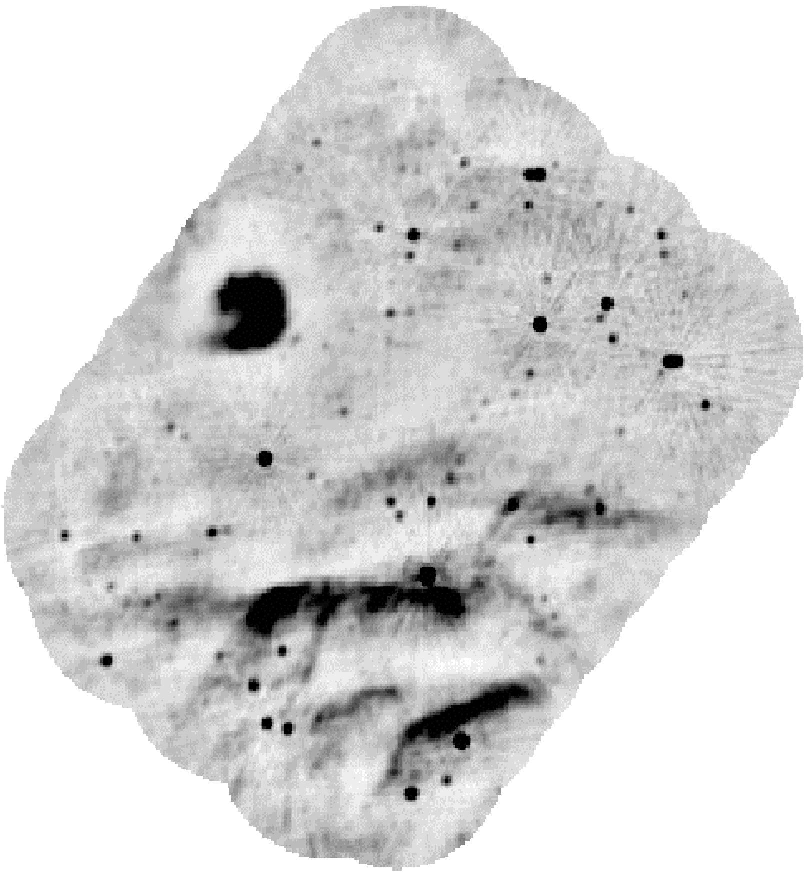
Mosaicing: Joint Approach

- Joint dirty beam depends on antenna primary beam:

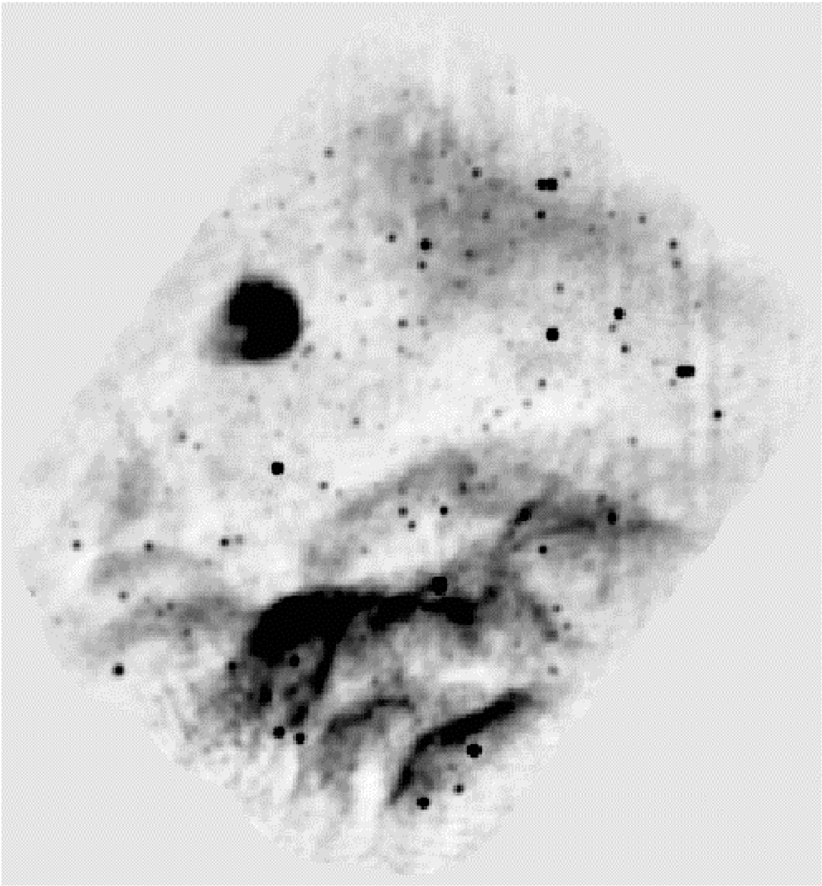
$$B(\mathbf{x};\mathbf{x}_0) = W(\mathbf{x}) \frac{\sum_p A(\mathbf{x}_0 - \mathbf{x}_p) B_p(\mathbf{x} - \mathbf{x}_0) / \sigma_p^2}{\sum_p A^2(\mathbf{x} - \mathbf{x}_p) / \sigma_p^2}$$

- Use all *u-v* data from all points simultaneously
  - Extra info gives a better deconvolution

Mosaicing Example



Linear Mosaic of individual pointings

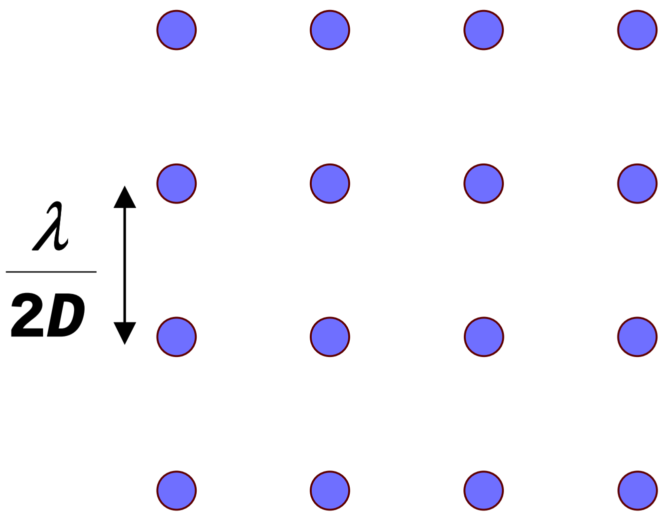


Joint Imaging and Deconvolution

Mosaicing: Comparison

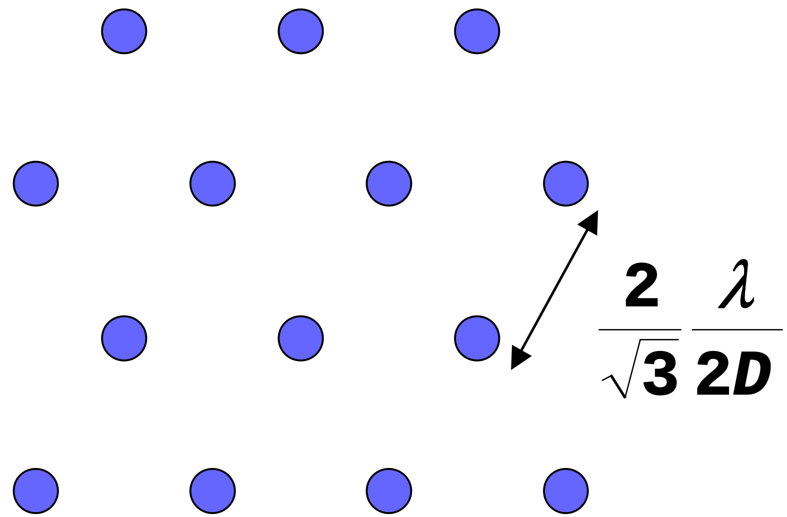
- Individual approach:
  - Disadvantages:
    - Deconvolution non-linear (cleaning bowl)
    - Overlap regions noisy (primary beam shape)
  - Advantage:
    - Not susceptible to deconvolution errors due to poor primary model, so good for high-resolution, high-dynamic range images
- Joint Approach:
  - Advantages:
    - Uses all u-v info -> better beam
    - More large-scale structure
  - Disadvantage:
    - Requires a good model for the primary beam

Mosaicing in Practice



Rectangular grid

$\theta = 16.5'$ at 21cm at ATCA



Hexagonal grid

$\theta = 19.0'$ at 21cm at ATCA

Complete *u-v* sampling

- One baseline measures region in *u-v* plane with size 2*D*
- Want adjacent samples to be completely independent
- At transit, the time between independent points is $\tau = (86400 / 2\pi)(2D / L)$ sec, where *D* = antenna diameter, *L* = longest baseline
- Nyquist sampling for N pointings: dwell time is $\tau / 2N$ sec
- E.g. for 7 pointings, 352m: 2 min, 750m: ~ 60 s

Mosaicing Practicalities

- Sensitivity concerns
  - Time per pointing reduced, but adjacent pointings contribute so for a fixed time observation the total noise is $\sigma_t \sim \sigma_p \sqrt{n}/1.4$, where n is the number of pointings
- Mosaicing requires a good model of the primary beam
  - Generally okay for the ATCA
- Pointing errors can significantly impact your mosaic
  - Pointing errors are first order in mosaics (only second order in single pointing obs of sources smaller than primary beam)
  - Solution: do reference pointing at higher frequencies

Mosaicing at the ATCA

Schedule file:

```
Source : GCa                Observer : nmm-g          Project_id : C596
         RA : 17:21:08.004
        Dec : -31:15:59.87  1Frequency : 1420.00       2Frequency : 1384.00
      Epoch : J2000.        1Bandwidth : 4.00          2Bandwidth : 128.00
    CalCode :               1Line Mode : ON            2Line Mode : OFF
Scan length : 00:40:00.0        1Start : 0
     Envflg : 0                  1Stop : 0
     Sctype : MOSAIC          1Hanning : OFF
   Pointing : GLOBAL
       Mode : STANDARD
  Averaging : 1
  Dual Freq : ON
PtCtrOffset : 0,0
Config file : FULL_4_1024-128
---------------------------------------------------------------------------
   TimeCode : REL
        Lst : 22:39:00.0        Defcat : at
Scan number : 26            Sched file : c596-gc-a
  0.9 min drive from (-114.,  39.) to (-114.,  23.).  Wrap is N
---------------------------------------------------------------------------
```

Points to file at$mosaic:GCa.mos

Integer # of mosaic cycles until t>scan length

Mosaic scan type

Mosaicing at the ATCA

Mosaic File: GCa.mos:

```
# Mosaic file for field GCa
# reference position: 17:21:08.004, 31:15:59.87
#   dRA          dDec        ncyc   name
    0.00000     0.00000       6   $GCa_001
   -0.16690     0.30100       6   $GCa_002
   -0.55401     0.32910       6   $GCa_003
   -0.71867     0.63072       6   $GCa_004
   -1.10420     0.66056       6   $GCa_005
   -1.26667     0.96276       6   $GCa_006
    0.22047     0.27416       6   $GCa_007
    0.05323     0.57482       6   $GCa_008
   -0.33285     0.60215       6   $GCa_009
   -0.49787     0.90344       6   $GCa_010
   ….
```

< 9 char
Miriad expects "_n"

Degrees of polar rotation:
1hr of RA = +15 deg

Making and Cleaning an Image in MIRIAD

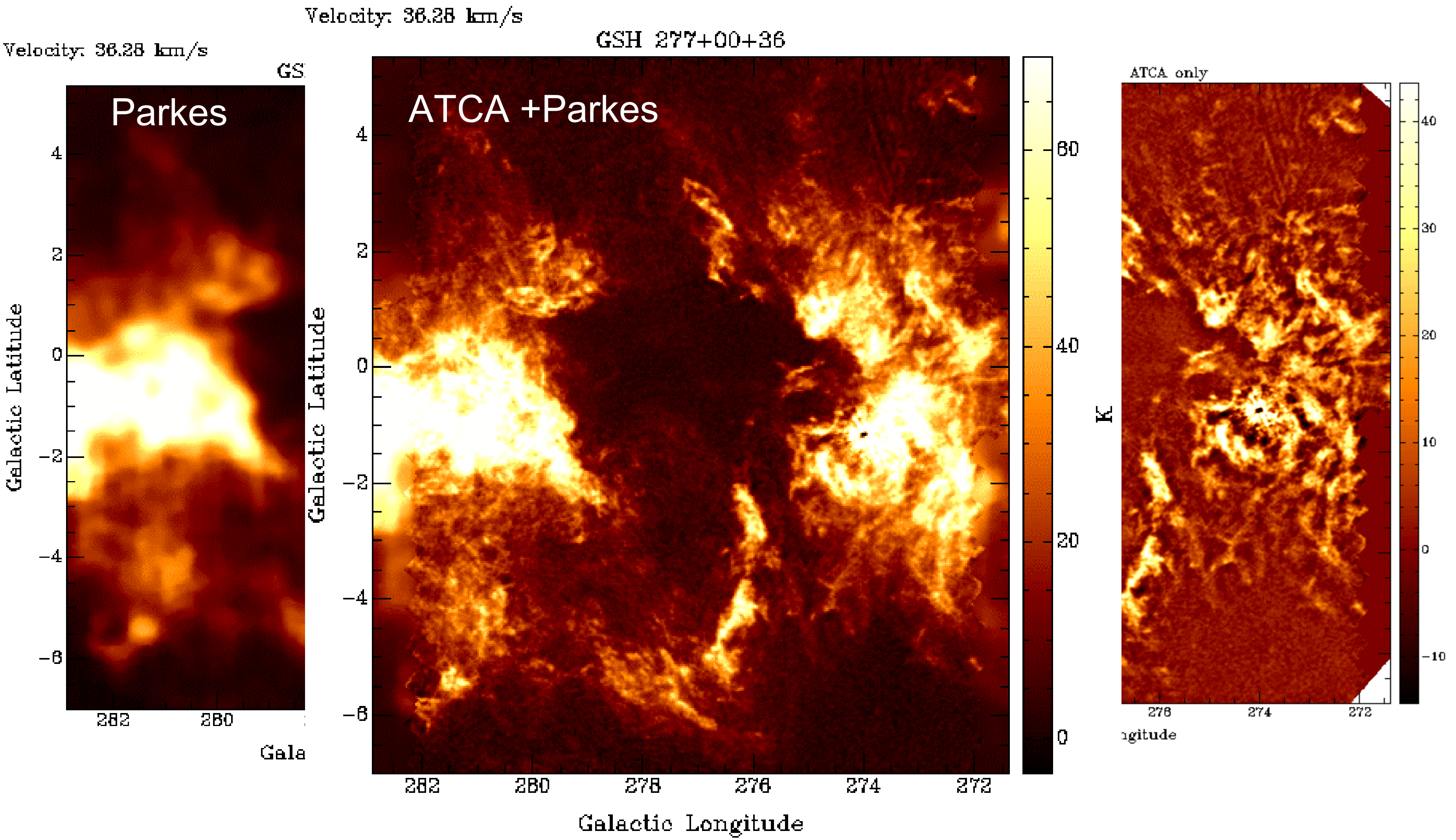
- Treat the field as one source (i.e. don't split it into components) and calibrate
- Make the image with *invert*, use "*options=mosaic,double*"
  - Your beam will be multi-plane, each plane is the beam for an individual pointing
- Deconvolve:
  - Usually use maximum entropy task *mosmem* (or *pmosmem*, for polarization), which is good at recovering large scale flux
  - Alternatively: use clean algorithm *mossdi*
- Restoring with *restor*

Other mosaicing software

- Classic AIPS:
  - LTESS (linear)
  - VTESS, UTESS (non-linear)
- AIPS++
  - part of IMAGER tool
  - has MEM and clean variations
  - also has “Mosaicwizard”

Summary

- Mosaicing is essential for wide-field imaging
  - Allows you to image an area larger than the primary beam
    - When imaging at 3mm, where the primary beam is ~ 30”, chances are good you’ll need to mosaic
  - Allows you to recover information on angular scales larger than $\theta > \lambda/b_{min}$
  - Improves *u-v* coverage
- Mosaicing is easy!



Maybe you'll want to add single dish, too…

Literature

- Ekers & Rots (1979), IAU Coll 49, 61
- Cornwell (1988), A&A, 202, 316
- Cornwell, Holdaway & Uson (1993), A&A, 271, 697
- Sault, Staveley-Smith, Brouw (1996), A&A Sup, 120, 375
- Holdaway (1998), ASP Conf 180, Ch. 20
- Sault & Killeen, Miriad manual, Ch. 21