Mosaicing -> Overlapping Fields

Surveys for point sources
Serpens 3 mm continuum:
G192.16 CO(J=1-0) outflow:

How big is “BIG”?

- Bigger than the Primary Beam: $\theta_p/D$ Full Width Half Max
- Bigger than what the shortest baseline can measure:
  Largest angular scale in arcsec, $\theta_{LAS} = 91,000/B_{short}$
  - VLA short baselines can recover 80% flux on $1/5 \theta_p/D$ Gaussian; 50% on $1/3 \theta_p/D$ Gaussian
  - CLEAN can do well on a $1/2 \theta_p/D$ Gaussian
  - MEM can still do well on a high SNR $1/2 \theta_p/D$ Gaussian
- Lack of short baselines often become a problem before source structure is larger than the primary beam:
  Mosaicing is almost always about Total Power!

An Example

- Assume a model brightness distribution: $I(x)$
- Simulated visibilities are given by:
  $$ V(u) = \int (A(x - x_p) I(x)) e^{-2\pi i u \cdot x} dx $$
- Estimate of brightness distribution at a single pointing is:
  $$ I_{recon}(x) / A(x - x_p) $$
- Need more pointings!
An Example: Simulated Data

I(x)
Raw model brightness distribution

I(x) \cdot B(x)
Image smoothed with 6" Gaussian (VLA D config. resolution at 15 GHz)

An Example: Simulated Data

\text{Primary beam used for simulations}

A(x - x_p) I(x) \cdot B(x)

Model multiplied by primary beam & smoothed with 6" Gaussian. Best we can hope to reconstruct from single pointing.

An Example: Reconstructed Simulated Data

\text{Visibilities constructed with thermal Gaussian noise. Image Fourier transformed \& deconvolved with MEM}

I_{\text{recon}}(x)

I_{\text{recon}}(x) / A(x - x_p)

Primary beam-corrected image. Blanked for beam response < 10% peak. Need to Mosaic!

Effective uv coverage – How Mosaicking Works

\text{Single dish: scan across source, Fourier transform image to get information out to dish diameter, D:}

Ekers \& Rots (1979): One visibility = linear combination of visibilities obtained from patches on each antenna:

But, can’t solve for N unknowns (Fourier information on many points between b-D \& b+D) with only one piece of data (a single visibility measurement). Need more data!

Example: Simulated Mosaic

\text{Try 9 pointings on simulated data. We could deconvolve each field separately \& knit together in a linear mosaic using:}

I_{\text{mos}}(x) = \sum_i A(x - x_i) I(x)

\text{But, Cornwell (1985) showed that one can get much better results \by using all the data together to make a single image through joint deconvolution.}

In practice, if spacings close to the dish diameter can be measured (b \sim D), then the “effective” Fourier plane coverage in a mosaic allows us to recover spacings up to about 1/2 a dish diameter. Still need Total Power.
An Example: Reconstructed Simulated Data

Nine VLA pointings deconvolved via a non-linear mosaic algorithm (AIPS VTESS). No total power included.

Same mosaic with total power added.

Interferometers & Single Dishes

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<td>IRAM</td>
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Mosaics in Practice

W75 N molecular outflow, CO(J=1-0). (Stark, Shepherd, & Testi 2002)

17 OVRO pointings deconvolved via a non-linear mosaic algorithm (MIRIAD mosmem). No total power included.

Non-Linear Joint Deconvolution

- Find dirty image consistent with ALL data. Optimize global $\chi^2$.

$$\chi^2 = \sum_p \frac{|V(u,v) - \hat{V}(u,v)|^2}{\sigma^2(u,v)}$$

The gradient of $\chi^2$ w.r.t. the model image tells us how to change the model so $\chi^2$ is reduced:

$$\nabla \chi^2 = -2 \sum_p A(x-x_p) \left[ \frac{\hat{V}(u,v) - V(u,v)}{\sigma(u,v)} \right]$$

Residual image for pointing $p$

- Like a mosaic of the residual images; use to steer optimization engine like non-linear deconvolver MEM. AIPS: vte & utess

Mosaics in Practice

Crab Nebula at 8.4 GHz. (Cornwell, Holdaway, & Uson 1993).

VLA + Total power from a VLBA antenna

Joint Deconvolution (Sault et al. 1996)

- Dirty images from each pointing are linearly mosaiced. An image-plane weighting function is constructed that results in constant thermal noise across the image (source structure at the edge of the sensitivity pattern is not imaged at full flux).

- Dirty beams stored in a cube. $\chi^2(x)$ residual image is formed and used in MEM and CLEAN-based deconvolution algorithms.

- Final images restored using model intensity & residuals. MIRIAD: invert, mosmem or mosdi, restore
Linear Mosaic of Dirty Images with Subsequent Joint Deconvolution

- Limited dynamic range (few hundred to one) due to position dependent PSF. AIPS: Bess
- This can be fixed by splitting the deconvolution into major and minor cycles. Then subtracting the believable deconvolved emission from the data and re-mosaicing the residual visibilities. AIPS++ imager

Challenges:
- Low declination source,
- bright point sources,
- faint extended emission.

ATCA L band mosaic, 11 fields, deconvolved with AIPS++, multi-scale clean.

G75.78 star forming region in CO(J=1-0)

Kitt Peak 12m image convolved with BIMA primary beam, converted to uv data with sampling density similar to BIMA uv coverage, scaled & combined with BIMA data, inverted with a taper, joint deconvolution (MIRIAD).

Linear Mosaic + Joint Deconvolution with Major/Minor Cycles

- Dirty images from each pointing are linearly mosaiced.
- Approximate point spread function is created common to all pointings. Assures uniform PSF across mosaic.
- Image deconvolved until approx. PSF differs from true PSF for each pointing by specified amount. Model is subtracted from the observed data (in visibility or image plane) to get residual image. Iterations continue until peak residual is less than cutoff level.
- AIPS++ deconvolution algorithms are input function to imager: mem, clean, msclenae, msclene simultaneously cleans N different component sizes to recover compact & extended structure.

Adding in total power

Total power obtained from a single dish telescope can be:
- Added in uv plane (MIRIAD: invert). Single dish image must be Fourier transformed to create simulated uv coverage:
  Example: HI in the SMC.
- “Feathered” together after images are made (AIPS++ image.feather, MIRIAD: immerge)
  If there is sufficient uv overlap between interferometer and single dish data (VLA+GBT, OVRO/BIMA+IRAM, ATCA+Parkes):
  Examples: MIRIAD: Galactic center CS(2-1), AIPS++:Orion.

Caution: if the single dish pointing accuracy is poor, then the combined image can be significantly degraded. The only single dish that can produce images of similar quality to what an interferometer can produce is the GBT.

Linear Image “Feathering” - immerge

If there is significant overlap in uv-coverage: images can be “feathered” together in the Fourier plane.

MIRIAD immerge tapers low spatial frequencies of mosaic interferometer data to increase resolution while preserving flux. Can taper interferometer data to compensate.
MIRIAD mosaic of the SMC

ATCA observations of HI in the SMC. Dirty mosaic, interferometer only.

Deconvolved mosaic, interferometer only. Stamimirovic et al. (1999).

MIRIAD mosaic of the SMC

Total power image from Parkes. Interferometer plus single dish feathered together (immerge).

Stanimirovic et al. (1999).

CS(2-1) Near the Galactic Center

OVRO mosaic, 4 fields. Deconvolved with MEM.

OVRO+IRAM 30m mosaic using MIRIAD immerge feather algorithm. Lang et al. 2001.

Ionized Gas (8.4 GHz) in the Orion Nebula

GBT On-the-fly map of the large field. (AIPS++). 90" resolution.

VLA mosaic of central region, 9 fields. Deconvolved with MEM in AIPS++. 8.4" resolution.


Dissimilar resolution is a problem in all total power combo techniques currently available – plans to develop multi-scale SD+interferometer deconvolution in AIPS++!

Good Mosaic Practice

- Point in the right place on the sky.
- Nyquist sample the sky: pointing separation $\approx \lambda/2D$
- Observe extra pointings in a guard band around source.
- If extended structure exists, get total power information. Have good $uv$ overlap between single dish and interferometer (big single dish w/ good pointing/low sidelobes & short baselines).
- Observe short integrations of all pointing centers, repeat mosaic cycle to get good $uv$ coverage and calibration until desired integration time is achieved.
- For VLA: Either specify each pointing center as a different source or use //OF (offset) cards to minimize set up time.