A Crash Course in Radio Astronomy and Interferometry: 4. Deconvolution Techniques

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Deconvolution

- difficult to do science on dirty image
- deconvolve $b(x,y)$ from $I^D(x,y)$ to recover $I(x,y)$
- information is missing, so be careful! (there’s noise, too)
Deconvolution Algorithms

- **Deconvolution:**
  - uses non-linear techniques effectively interpolate/extrapolate samples of \( V(u,v) \) into unsampled regions of the \((u,v)\) plane
  - aims to find a **sensible** model of \( I(x,y) \) compatible with data
  - requires *a priori* assumptions about \( I(x,y) \)

- **CLEAN (Högbom 1974)** is most common algorithm in radio astronomy
  - *a priori* assumption: \( I(x,y) \) is a collection of point sources
  - variants for computational efficiency, extended structure

- deconvolution requires knowledge of beam shape and image noise properties (usually OK for aperture synthesis)
  - atmospheric seeing can modify effective beam shape
  - deconvolution process can modify image noise properties
Basic CLEAN Algorithm

1. Initialize
   - a residual map to the dirty map
   - a CLEAN component list
2. Identify strongest feature in residual map as a point source
3. Add a fraction $g$ (the loop gain) of this point source to the clean component list ($g \sim 0.05-0.3$)
4. Subtract the fraction $g$ times $b(x,y)$ from residual map
5. If stopping criteria* not reached, go back to step 2 (an iteration), or...
6. Convolve CLEAN component (cc) list with an estimate of the main dirty beam lobe (i.e., the “CLEAN beam”) and add residual map to make the final “restored” image

* Stopping criteria = $N \times$ rms (if noise limited), or $I_{\text{max}}/N$ (if dynamic range limited), where $N$ is some arbitrarily chosen value
Deconvolution

CLEAN

$I^D(x,y)$

restored image

CLEAN model

residual map
“Restored” Images

• CLEAN beam size:
  – natural choice is to fit the central peak of the dirty beam with elliptical Gaussian
  – unit of deconvolved map is Jy per CLEAN beam area
    (= intensity, can convert to brightness temperature)
  – minimize unit problems when adding dirty map residuals
  – modest super resolution often OK, but be careful

• photometry should be done with caution
  – CLEAN does not conserve flux (extrapolates)
  – extended structure missed, attenuated, distorted
  – phase errors (e.g. seeing) can spread signal around
Measures of Image Quality

- "dynamic range"
  - ratio of peak brightness to rms noise in a region void of emission (common in astronomy)
  - an easy to calculate lower limit to the error in brightness in a non-empty region

- "fidelity"
  - difference between any produced image and the correct image
  - a convenient measure of how accurately it is possible to make an image that reproduces the brightness distribution on the sky
  - need a priori knowledge of correct image to calculate

  - fidelity image = input model / difference
  - fidelity is the inverse of the relative error
Summary

- Radio Telescopes are cool
  - Single-dish telescopes measure “temperatures” across the sky
  - They have fat beams making details hard to see

- Interferometers use optics to achieve high resolution
  - Antenna pairs sample the FT of the image plane, an inverse FT of the ensemble of visibilities returns the image
  - Resulting images are spatially filtered; only compact emission seen
  - “Dirty” images can be deconvolved (with care), e.g., CLEAN
  - Weighting can be used to manipulate resolution and/or surface brightness sensitivity
  - Mosaics can be used to increase field-of-view but can be observationally expensive