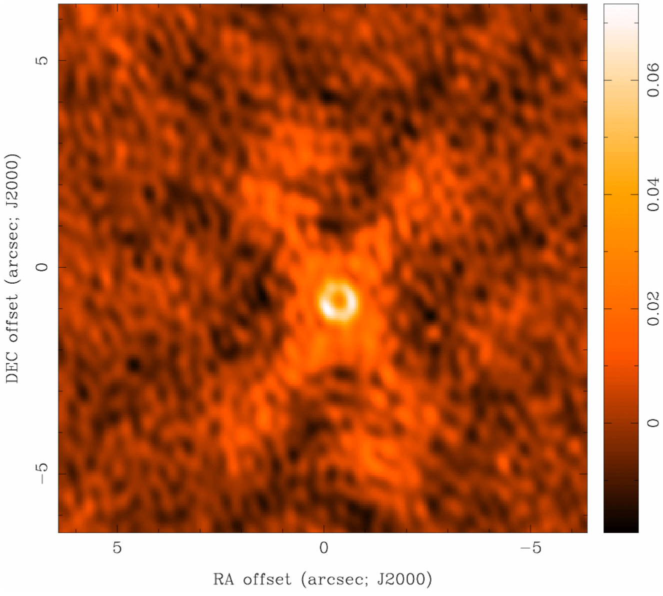
A Crash Course in Radio Astronomy and Interferometry:
4. Deconvolution Techniques

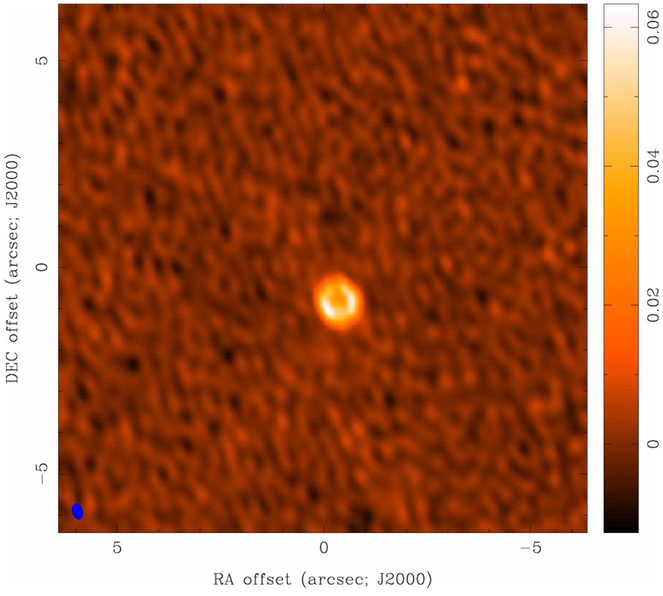
James Di Francesco
National Research Council of Canada
North American ALMA Regional Center – Victoria

(thanks to S. Dougherty, C. Chandler, D. Wilner & C. Brogan)

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)


dirty image


"CLEAN" image

Deconvolution Algorithms

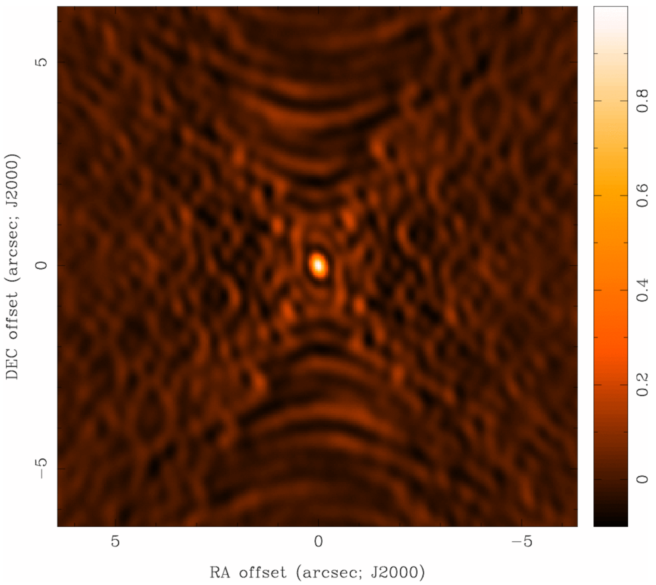
- Deconvolution:
  - uses non-linear techniques effectively interpolate/extrapolate samples of $V(u,v)$ into unsampled regions of the (u,v) plane
  - aims to find a **sensible** model of $I(x,y)$ compatible with data
  - requires *a priori* assumptions about $I(x,y)$

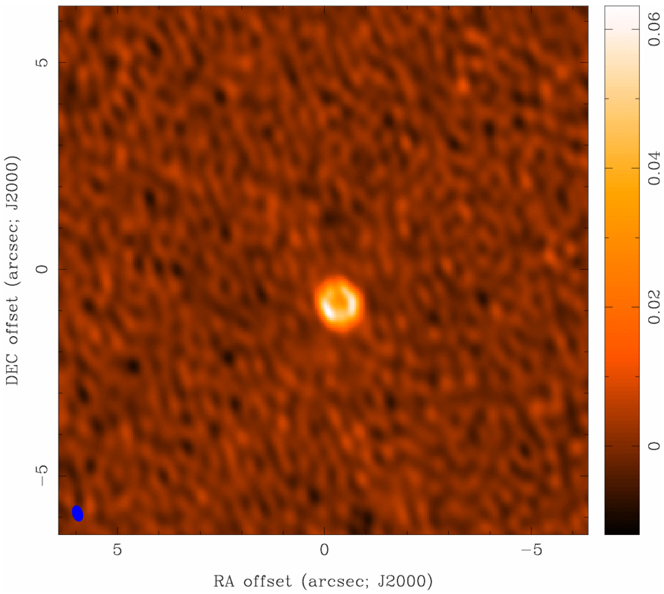
- CLEAN (Högbom 1974) is most common algorithm in radio astronomy
  - *a priori* assumption: $I(x,y)$ is a collection of point sources
  - variants for computational efficiency, extended structure

- 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 ($g \sim 0.05\text{-}0.3$)
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





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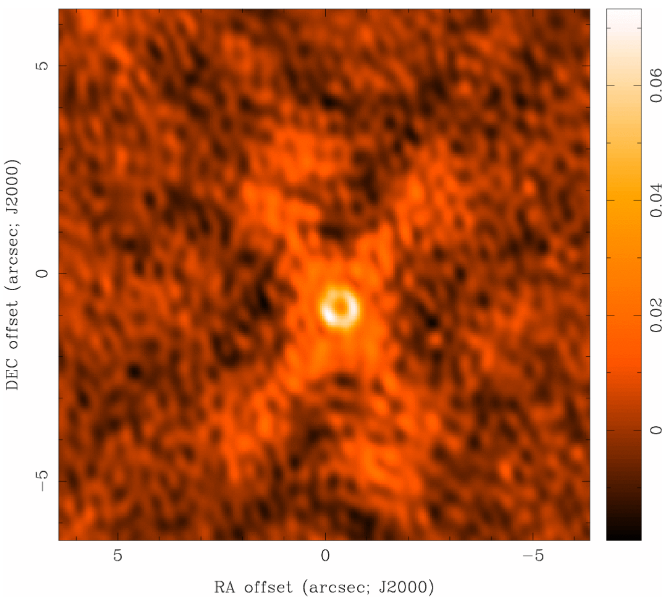
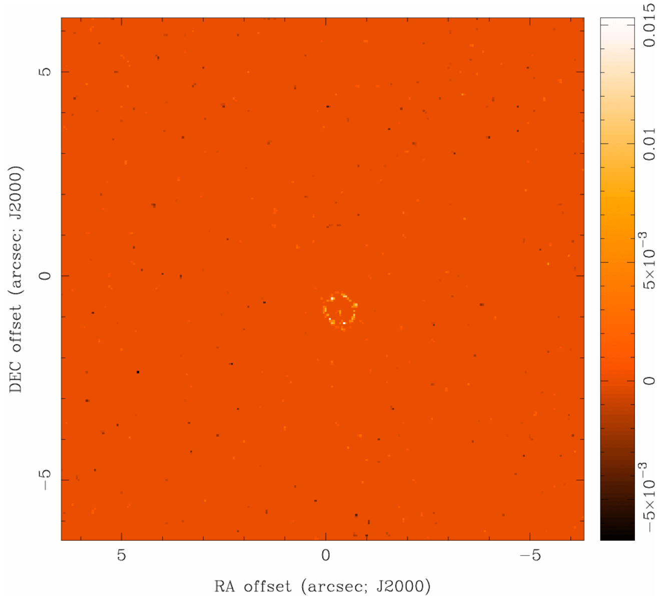
* Stopping criteria = N x rms (if noise limited), or I^{max}/N (if dynamic range limited), where N is some arbitrarily chosen value

CLEAN

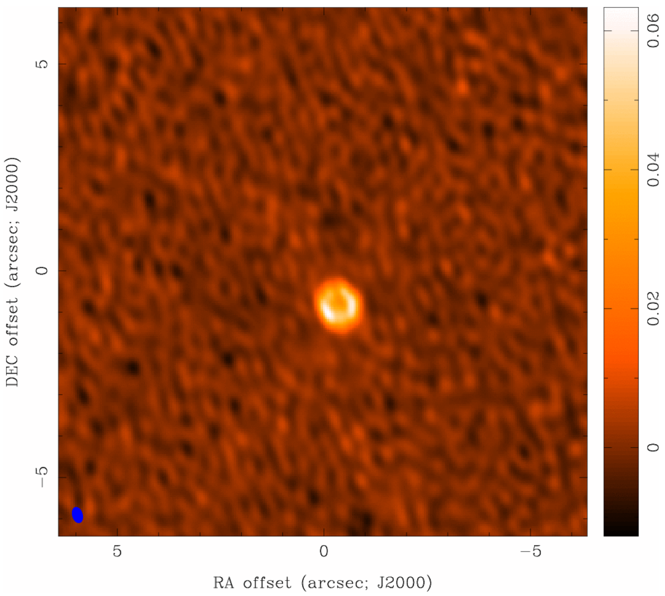
$I^D(x,y)$

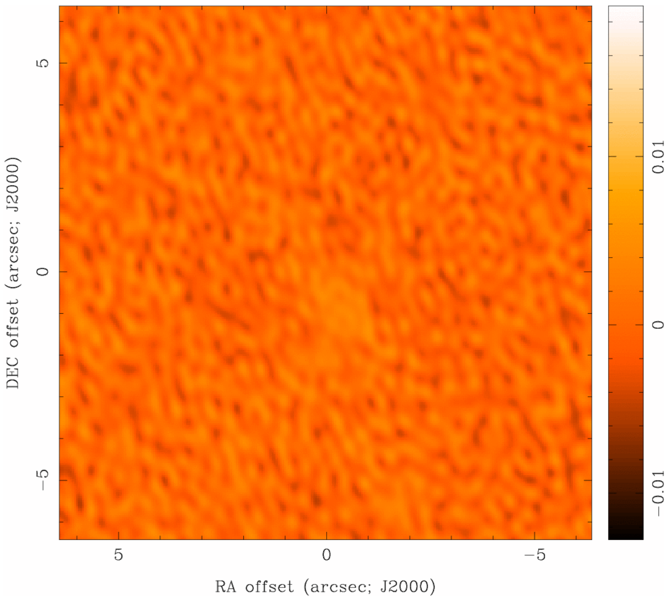




CLEAN
model

restored
image





residual
map

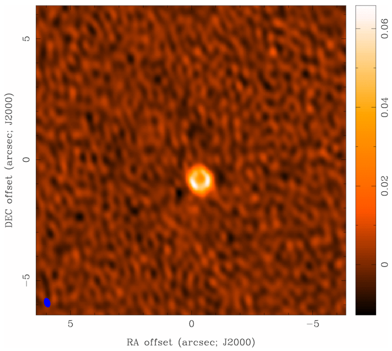
“Restored” Images

- 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

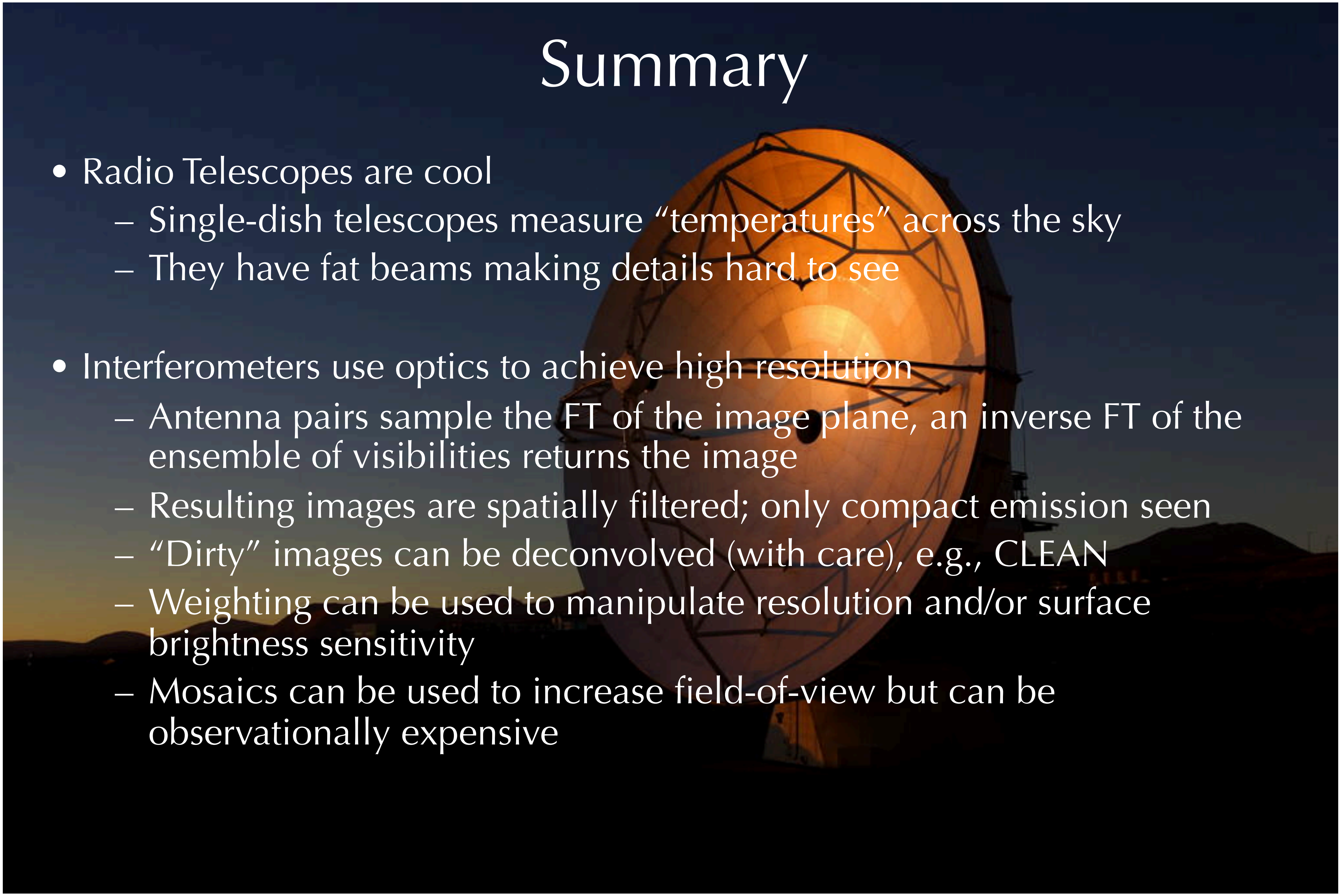
- *“dynamic range”*
  - ratio of peak brightness to rms noise in a region void of emission (common in astronomy)
  - an easy to calculate lower limit to the error in brightness in a non-empty region



- *“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