Advanced imaging techniques

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Recap: Imaging

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

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- But, we do not measure $V(u, v)$ for all values of u and v.

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- But, we do not measure $V(u,v)$ for all values of u and v.
- So, we define a window function $W(u,v)$

$$\mathrm{I}_{\mathrm{Obs}}(l,m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W(u,v)\ V_{\mathrm{True}}(u,v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \qquad (2)$$

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$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)\ V(u, v)] \tag{3}$$

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Deconvolution

- From the previous slide,

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)] \circledast \mathcal{F}^{-1}[V(u, v)] \tag{5}$$

  - $\mathcal{F}^{-1}[W(u, v)]$ is called "dirty beam"
  - $\mathrm{I}_{\mathrm{Obs}}(l, m)$ is called the "dirty image"
  - $\mathcal{F}^{-1}[V(u, v)]$ is the "true sky"

- The "dirty image" is the "true sky" convolved by the "dirty beam".

- To get the "true" sky image $\rightarrow$ we deconvolve our "dirty image" with the "dirty beam"

Non co-planar baselines

- The 2D Fourier transform assumes a small field of view.

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \qquad (6)$$

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$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{6}$$

- In its full glory, $\mathrm{V}_{\mathrm{True}}$ and $\mathrm{I}_{\mathrm{True}}$ are related as

$$\mathrm{V}_{\mathrm{True}}(u, v, w) = \int \int \frac{\mathrm{I}_{\mathrm{True}}(l, m)}{\sqrt{1 - l^2 - m^2}}\ \mathrm{e}^{-i2\pi(ul+vm+w(\sqrt{1-l^2-m^2}-1))}\ \mathrm{d}l\ \mathrm{d}m \tag{7}$$

- $\mathrm{V}_{\mathrm{True}}$ and $\mathrm{I}_{\mathrm{True}}$ do not form a Fourier transform pair!

Non co-planar baselines

- Two solutions:
  1. **Facetting**
     - Split the sky into sub-images (or facets)
     - Small field approximation holds in each facet
     - Fourier pair in each facet
     - In CASA **clean**, use **gridmode='widefield', facets=**N

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Non co-planar baselines

- Two solutions:

1. **Facetting**
   - ★ Split the sky into sub-images (or facets)
   - ★ Small field approximation holds in each facet
   - ★ Fourier pair in each facet
   - ★ In CASA **clean**, use **gridmode='widefield', facets=**N
2. **W-projection**
   - ★ Commonly used solution.
   - ★ See Cornwell et al (2011)
   - ★ In CASA **clean**, use **gridmode='widefield', wprojplanes=-1**

$$\mathrm{V}_{\mathrm{True}}(u, v, w) * \mathrm{e}^{-i2\pi w(\sqrt{1-l^2-m^2}-1)} = \int\int \frac{\mathrm{I}_{\mathrm{True}}(l, m)}{\sqrt{1-l^2-m^2}}\ \mathrm{e}^{-i2\pi(ul+vm)}\ \mathrm{d}l\ \mathrm{d}m \qquad (8)$$

W-projection

- Near the pointing center → no noticeable difference.

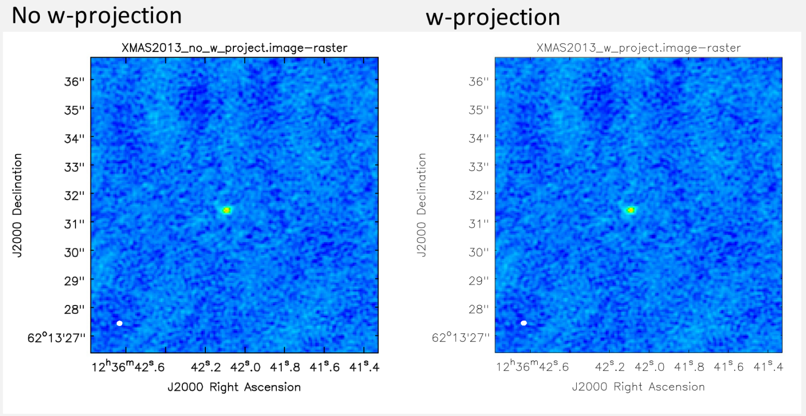

Image credit: Jack Radcliffe

W-projection

- Away from the pointing center.

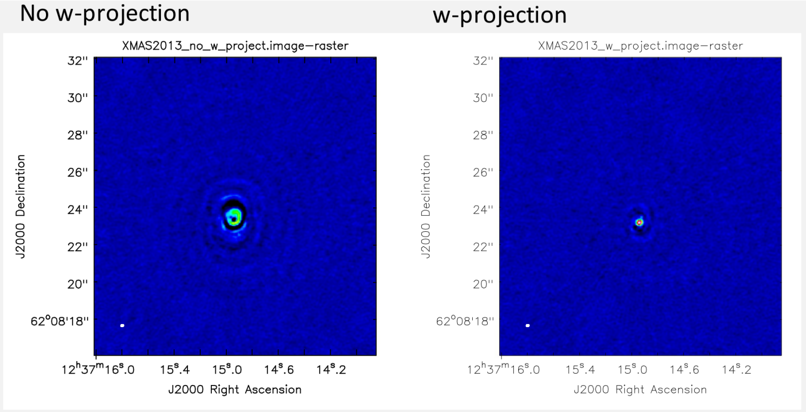

Image credit: Jack Radcliffe

Multi-scale CLEAN

- Classic CLEAN $\rightarrow$ collection of delta functions.

Multi-scale CLEAN

- Classic CLEAN → collection of delta functions.
- Multi-scale CLEAN → collection of (Gaussian) kernels with different scales.

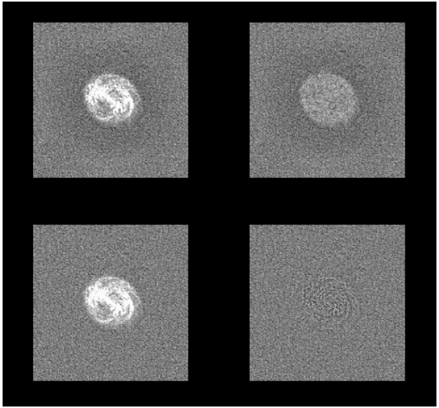

Image: Cornwell (2008)

Multi-scale CLEAN

- In CASA **clean()**, for example use "multiscale=[0,1,5,15]".

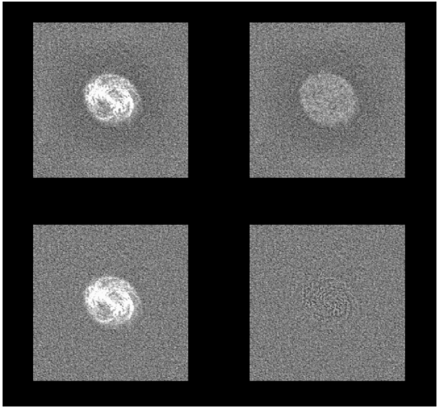

Image: Cornwell (2008)

Wideband deconvolution

- CLEAN does not account for spectral variations within the band.

Wideband deconvolution

- CLEAN does not account for spectral variations within the band.

See demonstration

Other advanced techniques

- Direction-dependent calibration – See science talk.
- W-stacking
- Auto-masking & auto-thresholding – Offringa & Smirnov (2017)
- A-projection
- Compressed sensing
- ...