Faraday Synthesis

The synergy of aperture and rotation measure synthesis

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with T. Enßlin - MPA

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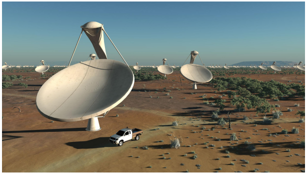
Outline

Next generation radio astronomy



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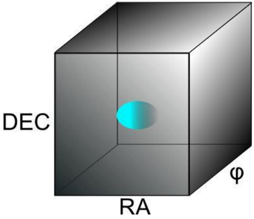
  - Probe the mangetic fields between source and observer

Evolving the technique



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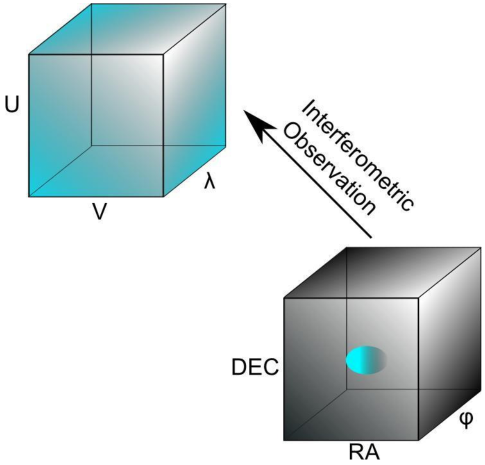

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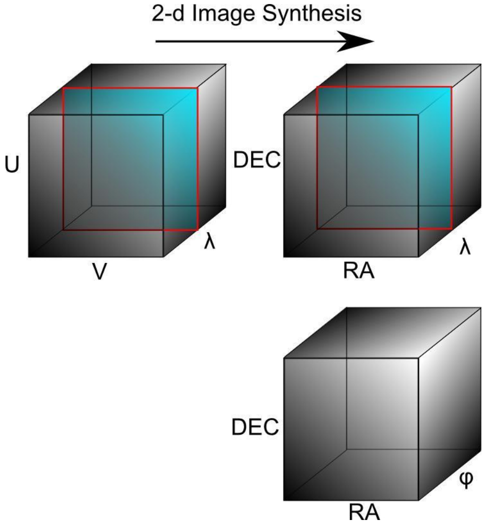

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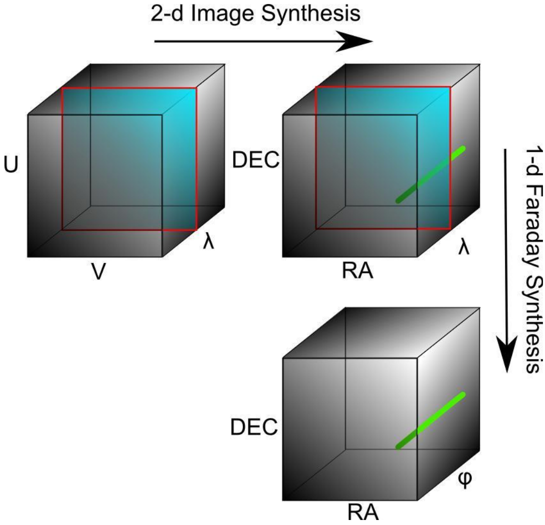

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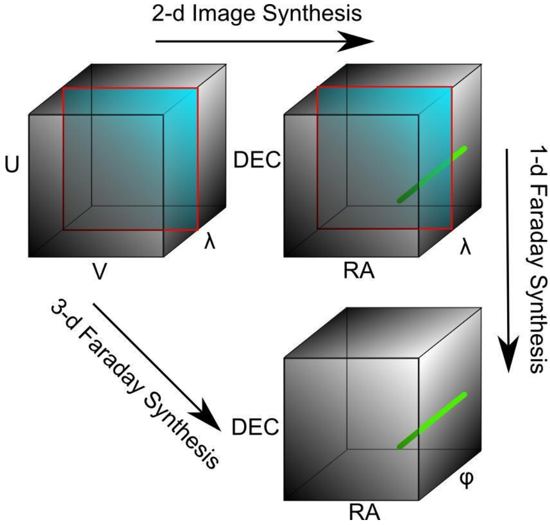

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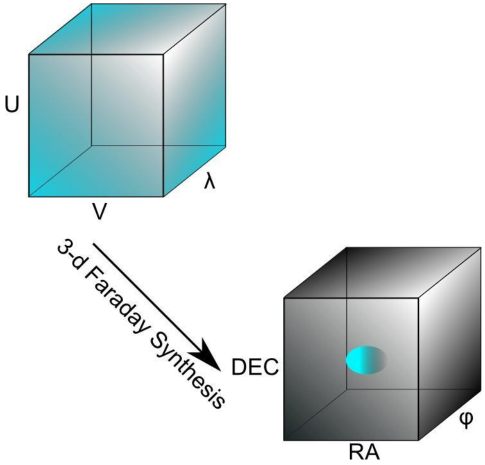

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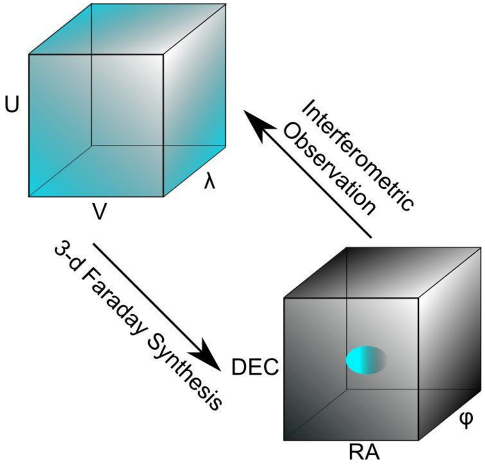

Interferometry

Van Cittert–Zernike theorem

$$V(u,v,\nu) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} dl\, dm\, \mathscr{I}(l,m,\nu) e^{-2\pi i (ul+vm)} = \mathscr{F}_{2D}\left[\mathscr{I}\right]$$

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$$\widehat{V}(u,v,\nu) = S\mathscr{F}_{2D}\left[A(l,m,\nu)\mathscr{I}(l,m,\nu)\right]$$

Imaging the sky

$$\begin{aligned}\mathscr{I}_D(l,m,\nu) &= \mathscr{F}_{2D}^{-1}\left[\widehat{V}(u,v,\nu)\right] \\ &= B(l,m,\nu) * [A(l,m,\nu)\mathscr{I}(l,m,\nu)]\end{aligned}$$

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- Sky brightness convolved with $B = \mathscr{F}_{2D}^{-1}[S]$
- B is nasty, so deconvolution is required (e.g. CLEAN)

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- $P(l, m, \lambda^2) = \int_{-\infty}^{\infty} d\phi \, F(l, m, \phi) \, e^{2i\phi\lambda^2} = \mathscr{F}_{1D}\left[F(l, m, \phi)\right]$

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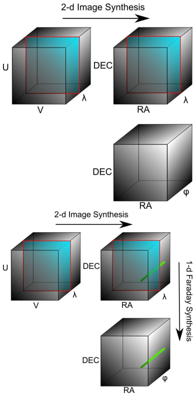
see Brentjens & de Bruyn, 2005

$$
\begin{aligned}
F_D(l,m,\phi) &= \mathscr{F}_{1D}^{-1}\left[S(l,m,\lambda^2)P(l,m,\lambda^2)\right] \\
&= F(l,m,\phi) * B(l,m,\phi)
\end{aligned}
$$

RM Synthesis

- 2D imaging of Stokes Q and U at each λ^2
  - 2D deconvolution with limited sensitivity !!
  - UV coverage varies with frequency !!
- Stack images, perform RM synthesis along each LOS
  - UV tapering and a uniform restoring beam used to make up for varying UV coverage
  - Deconvolve again (e.g. RMCLEAN - *Heald* et al., 2009)



Putting it all together

- Aperture synthesis, Stokes Q
  - $\widehat{V_Q} = S\mathscr{F}_{2D}\left[AQ\right]$
- RM synthesis
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- $A(l,m,\lambda^2) = \mathscr{F}_{1D}[a(l,m,\phi)]$

3D Imaging

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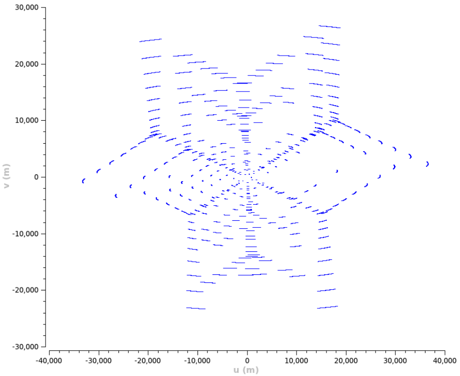
- The 3D dirty image is a convolution between
  - The Faraday spectrum, F
  - The 3D beam (PSF), B
  - The primary beam, transformed into Faraday space, i.e. $a(l, m, \phi)$

fsimager

- fsimager - Faraday synthesis imaging software
  - Written in Python, plus some Cython for speed
  - Gridding & imaging
  - Deconvolution via a 3D Clark CLEAN algorithm
- Only the basics for now...
  - No beam corrections, widefield imaging, etc.
  - Everything resides in memory, which severely limits the image size

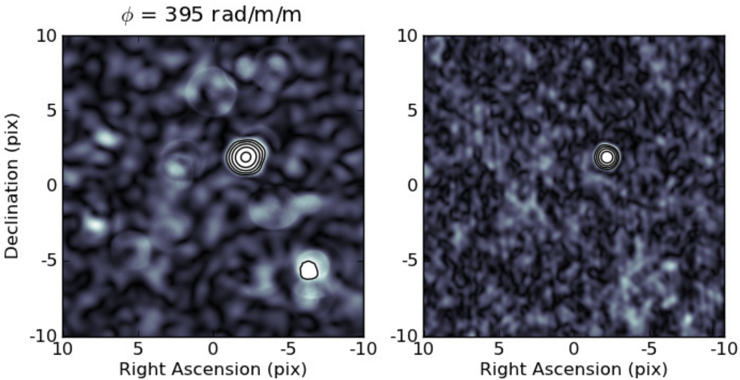
Mock observations

- 30 point sources
  - Random locations
  - Random fluxes (0.06 - 64 Jy)
- "Observed" with the VLA from 1-4 GHz (x64 channels)
- Added Gaussian white noise, $\sigma = 10$ Jy



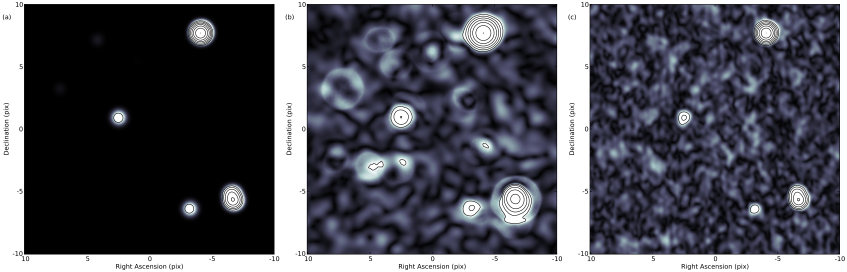
Results

Side by side comparison



Results

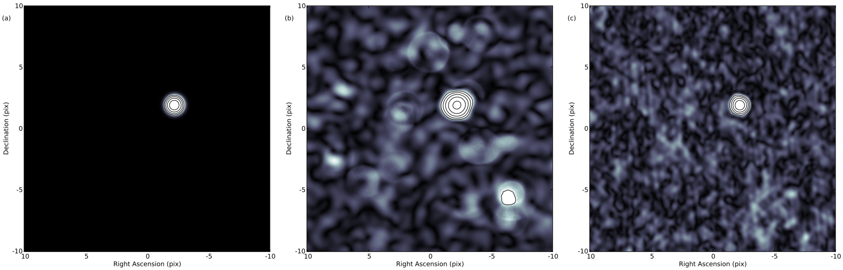
$$\phi = 68 \text{ rad/m}^2$$



Model - 2+1D - fsimager

Results

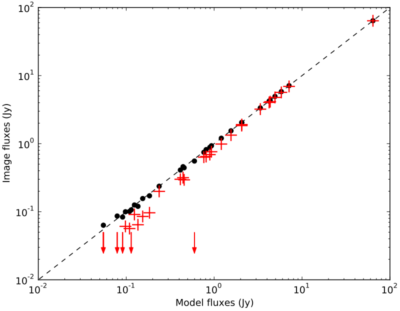
$$\phi = 395 \text{ rad/m}^2$$



Model - 2+1D - fsimager

Results

- Noise levels about the same @~ 5 mJy/Beam
- Model sources at 10σ and higher
- *Recall:* 30 sources in the model
- `fsimager`:
  - 32 sources detected above 50 mJy/Beam
  - No sources missing
- 2+1D
  - 147 sources detected above 50 mJy/Beam
  - 5 real sources not detected



`dots = Faraday synthesis`

`crosses = Aperture + RM synthesis`

Summary

- Faraday synthesis improves on aperture + RM synthesis
  - Improveded fidelity
  - Higher resolution
  - Less computationally expensive (in principle)
- Provides a solid framework for building new image reconstruction algorithms
- A production implementations is needed!