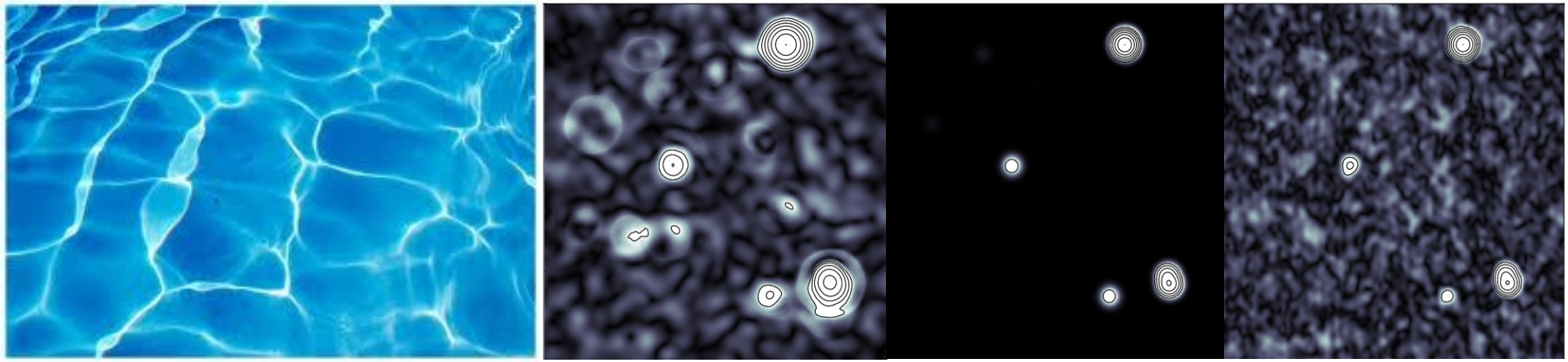
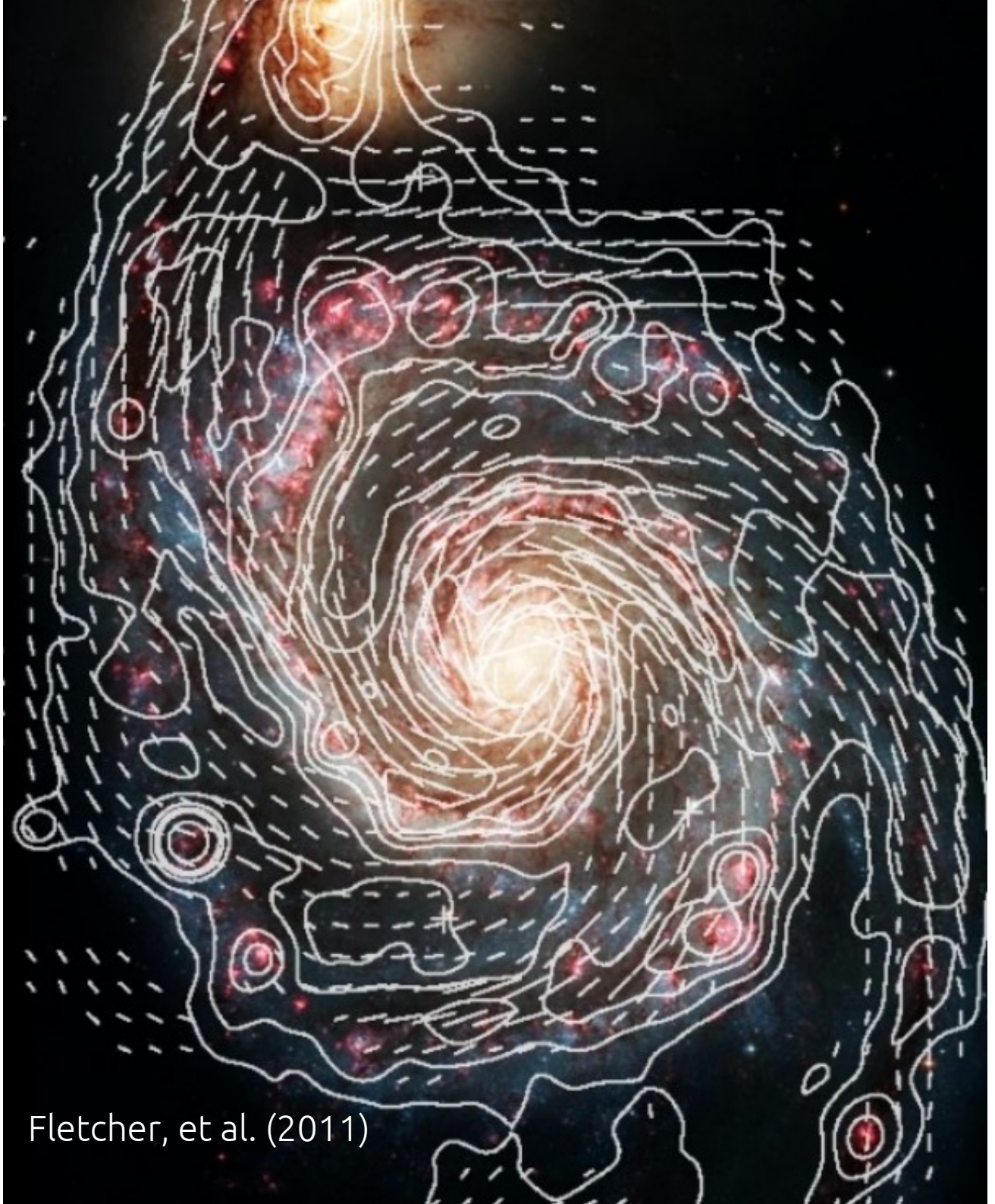
A new view of magnetic fields: Faraday caustics and Faraday Synthesis

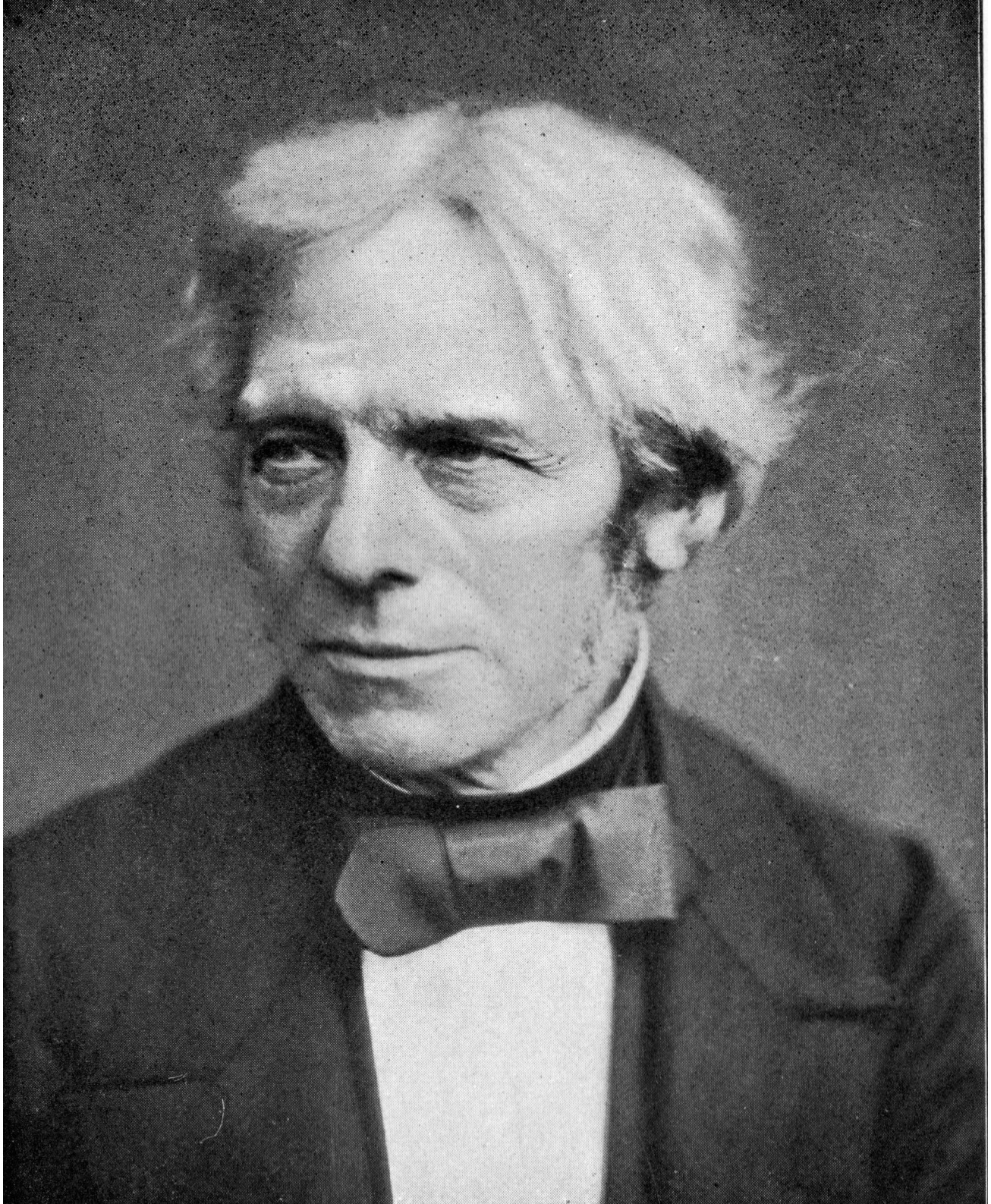


Michael Bell – MPA Garching
with Torsten Enßlin
and Henrik Junklewitz

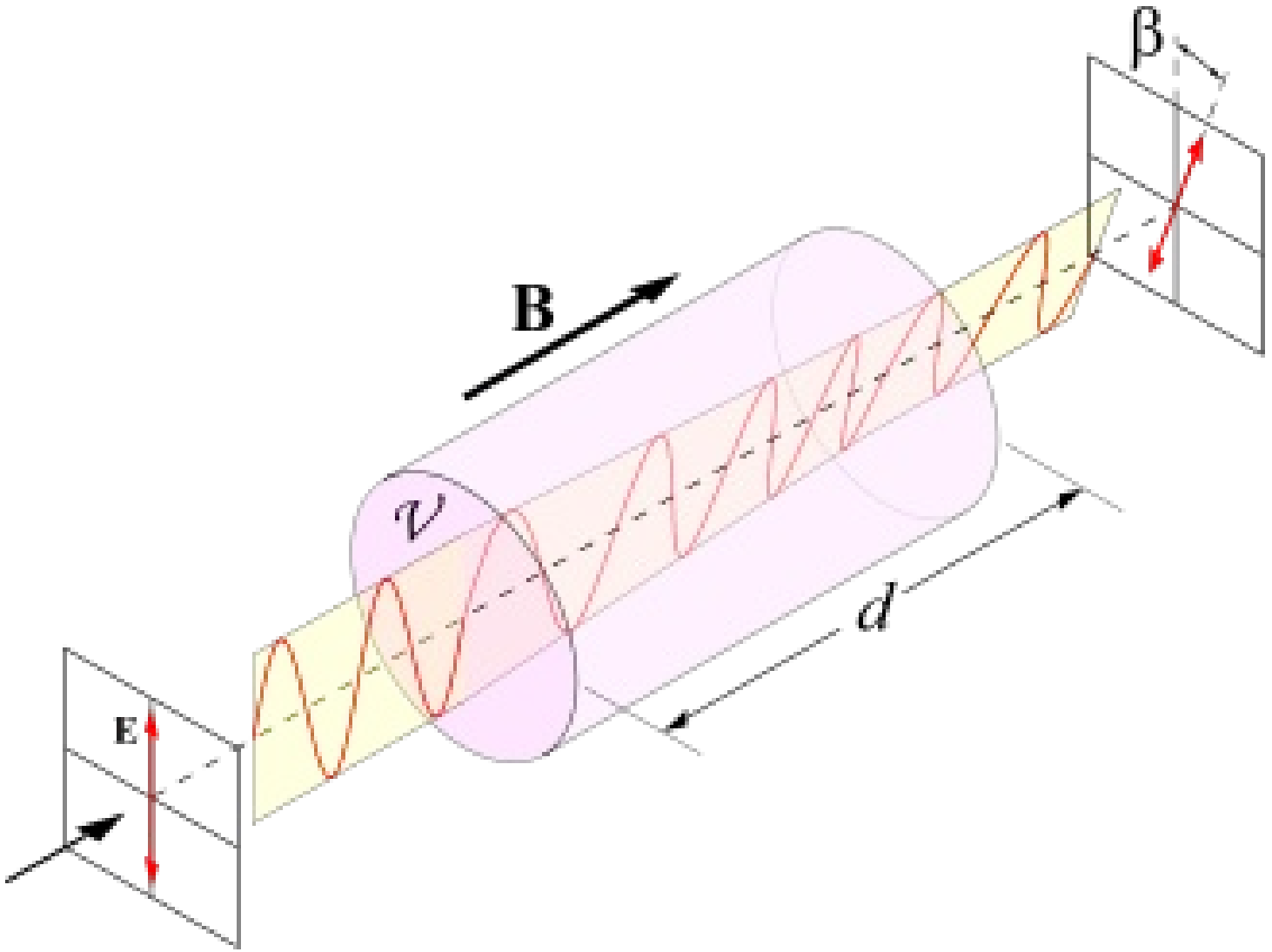
Max-Planck-Institut
für Astrophysik



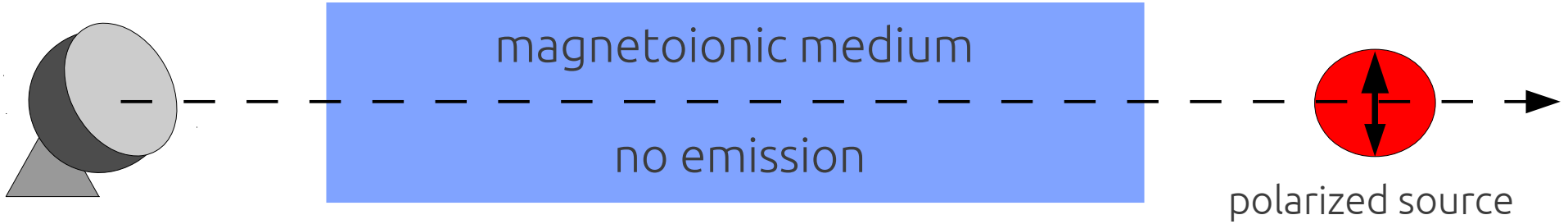
Fletcher, et al. (2011)



Faraday Rotation



Faraday Rotation



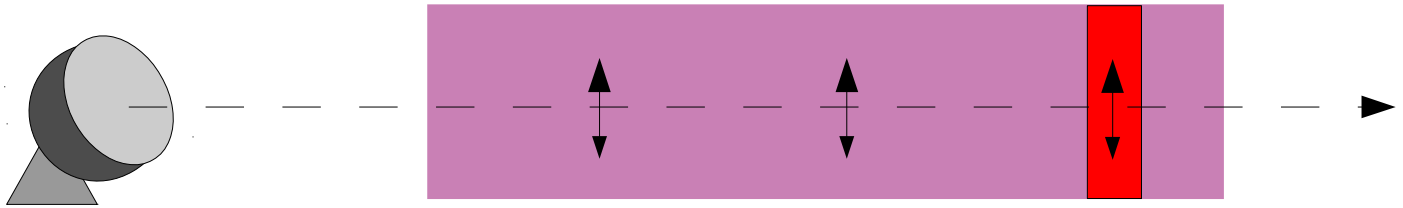
$$\chi = \chi_0 + \varphi \lambda^2$$

polarization angle

$$\varphi \propto \int_{here}^{there} dz\, n_e\, B_z$$

Faraday depth

Mixed rotating and emitting media



dz

recall

$$\chi = \chi_0 + \varphi\lambda^2$$

$$\varphi \propto \int_{here}^{there} n_e B_z \, d\, z$$

$$P(z)\,dz = p(z)\,e^{2i\chi_0}\,dz$$

$$P(\lambda^2) = \int_0^\infty P(z)\,e^{2i\varphi\lambda^2}\,dz$$

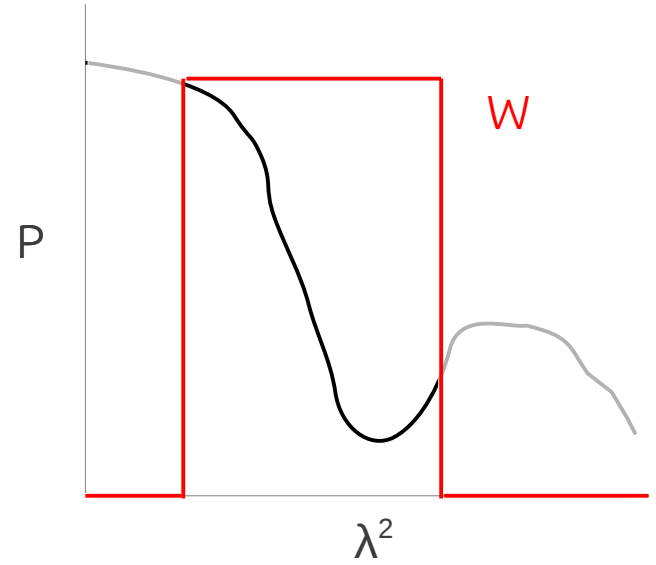
$$P(z)\,dz = F(\varphi)\,d\,\varphi$$

$$P(\lambda^2) = \int_{-\infty}^{\infty} d\,\varphi F(\varphi)\,e^{2i\varphi\lambda^2}$$

Faraday spectrum
i.e. Pol. Intensity per unit Faraday depth

Burn (1966)

RM Synthesis
see Brentjens & de Bruyn (2005)

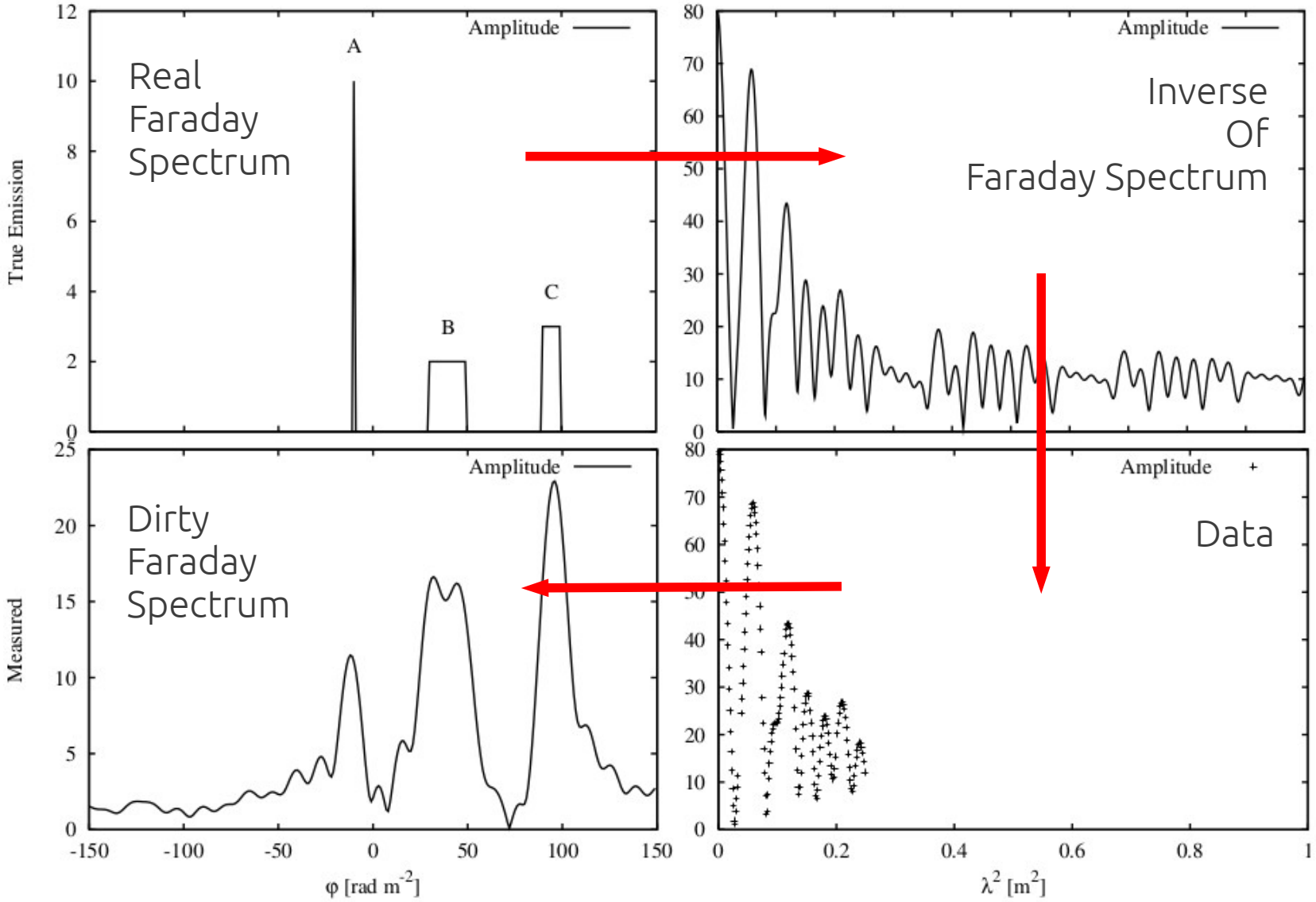


$$F'(\varphi) = FT[W\,P(\lambda^2)] = F(\varphi) * R(\varphi)$$

$$R(\varphi) = FT[W(\lambda^2)]$$ "Point spread function"

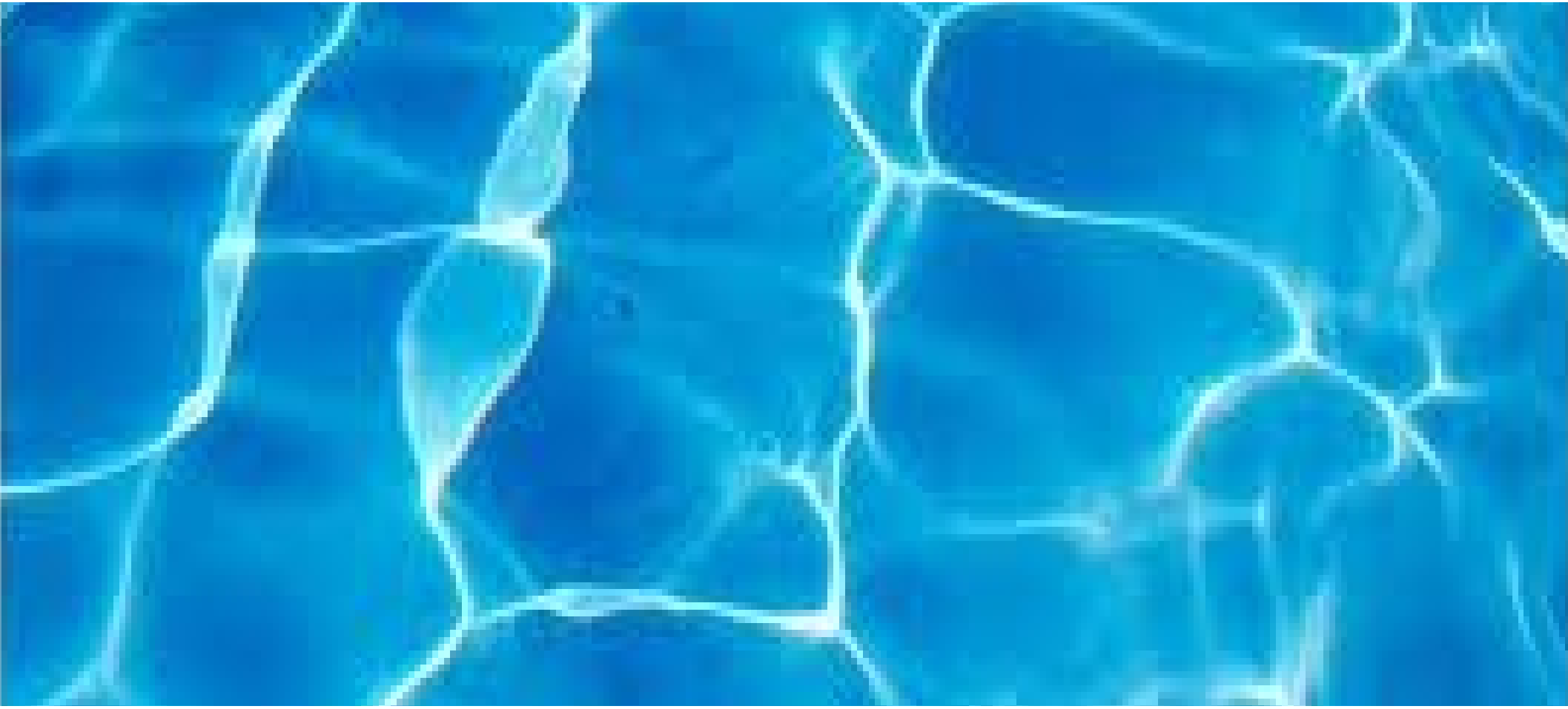
RM Synthesis

see Brentjens & de Bruyn (2005)

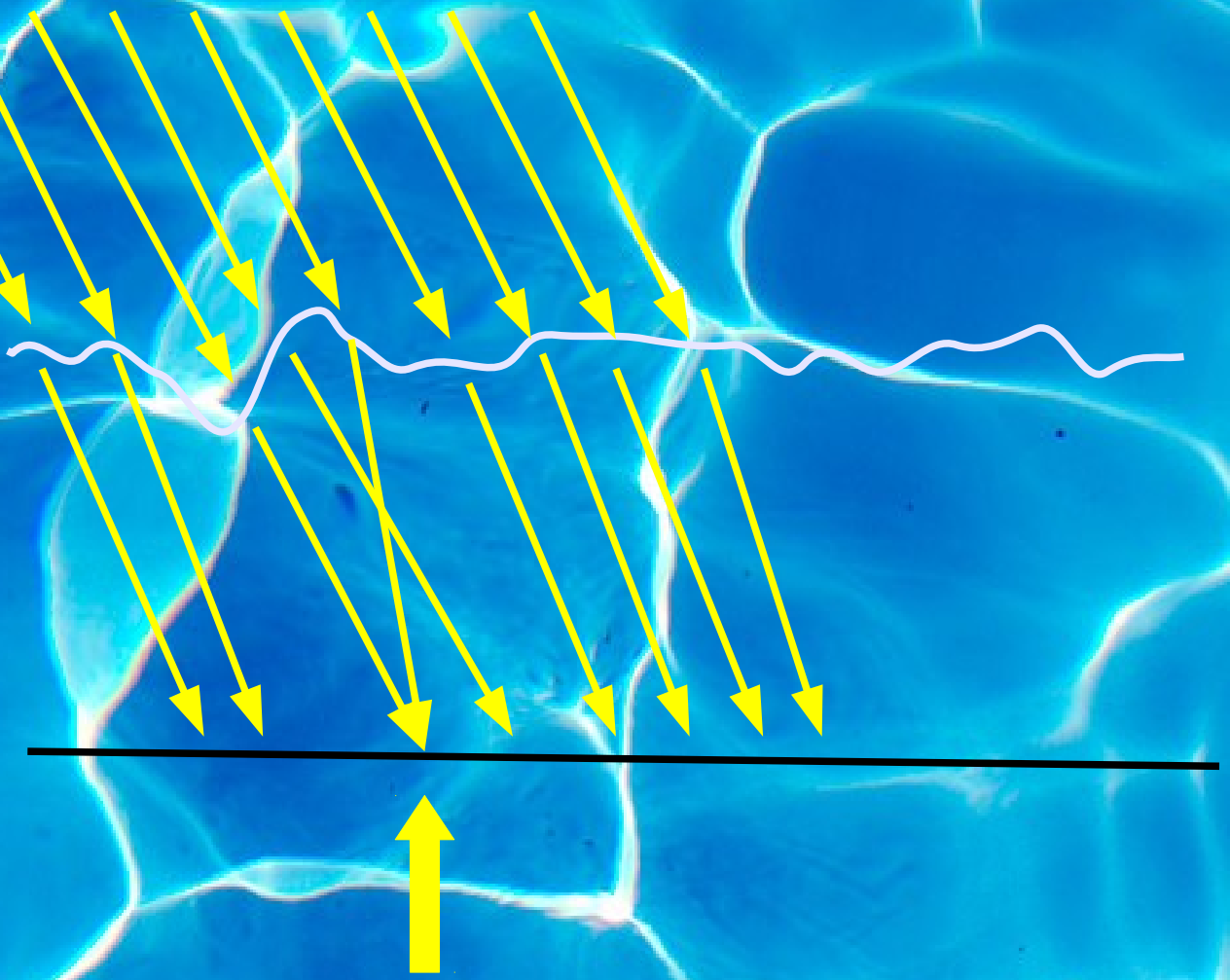


Faraday Caustics

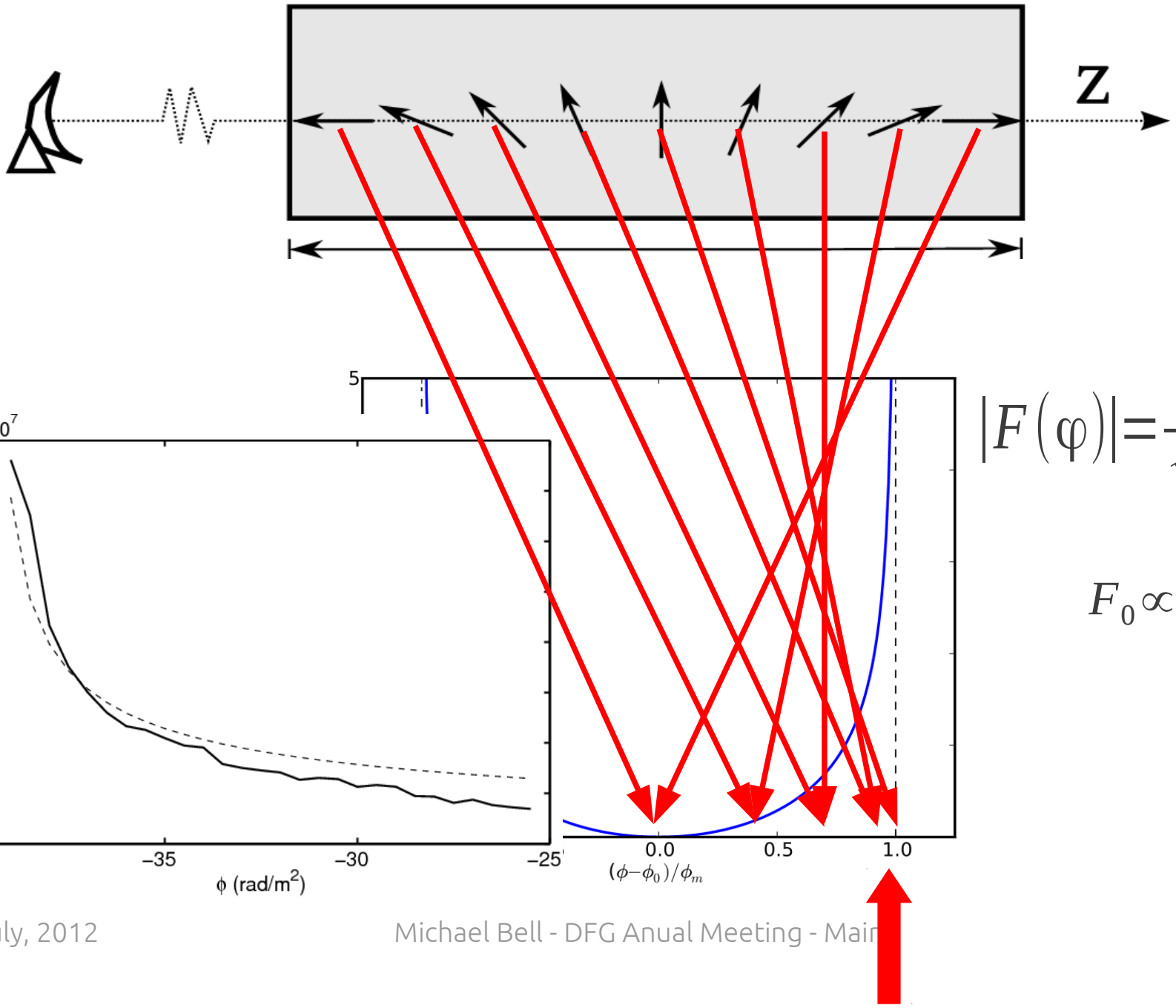
Singularities in the Faraday spectrum and their utility as probes of magnetic field properties



Optical caustics



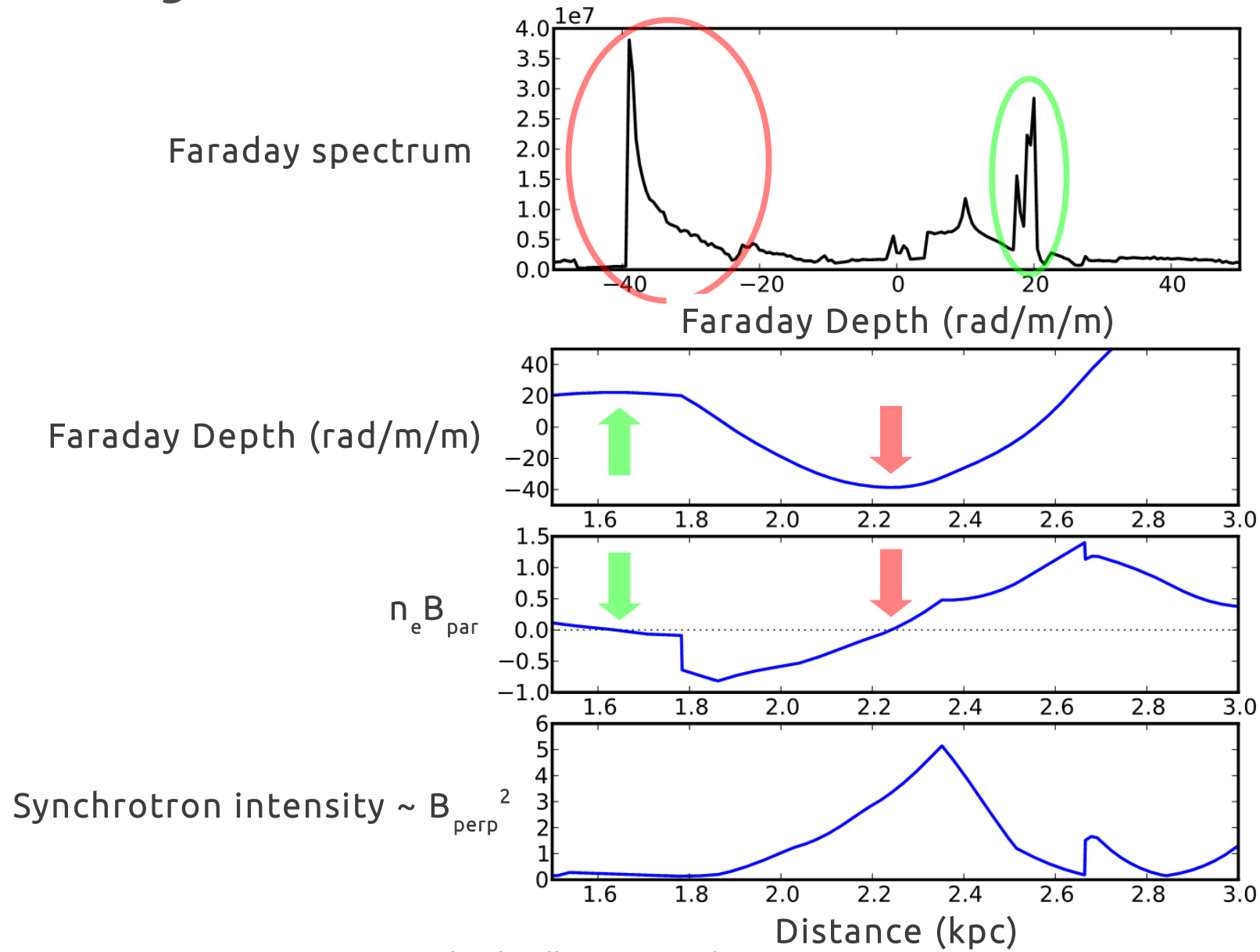
Faraday Caustics



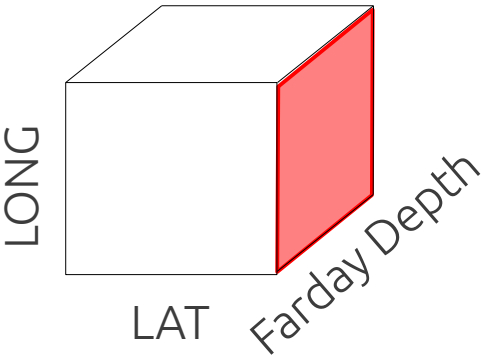
$$|F(\varphi)| = \frac{F_0}{\sqrt{\varphi - \varphi_0}}$$

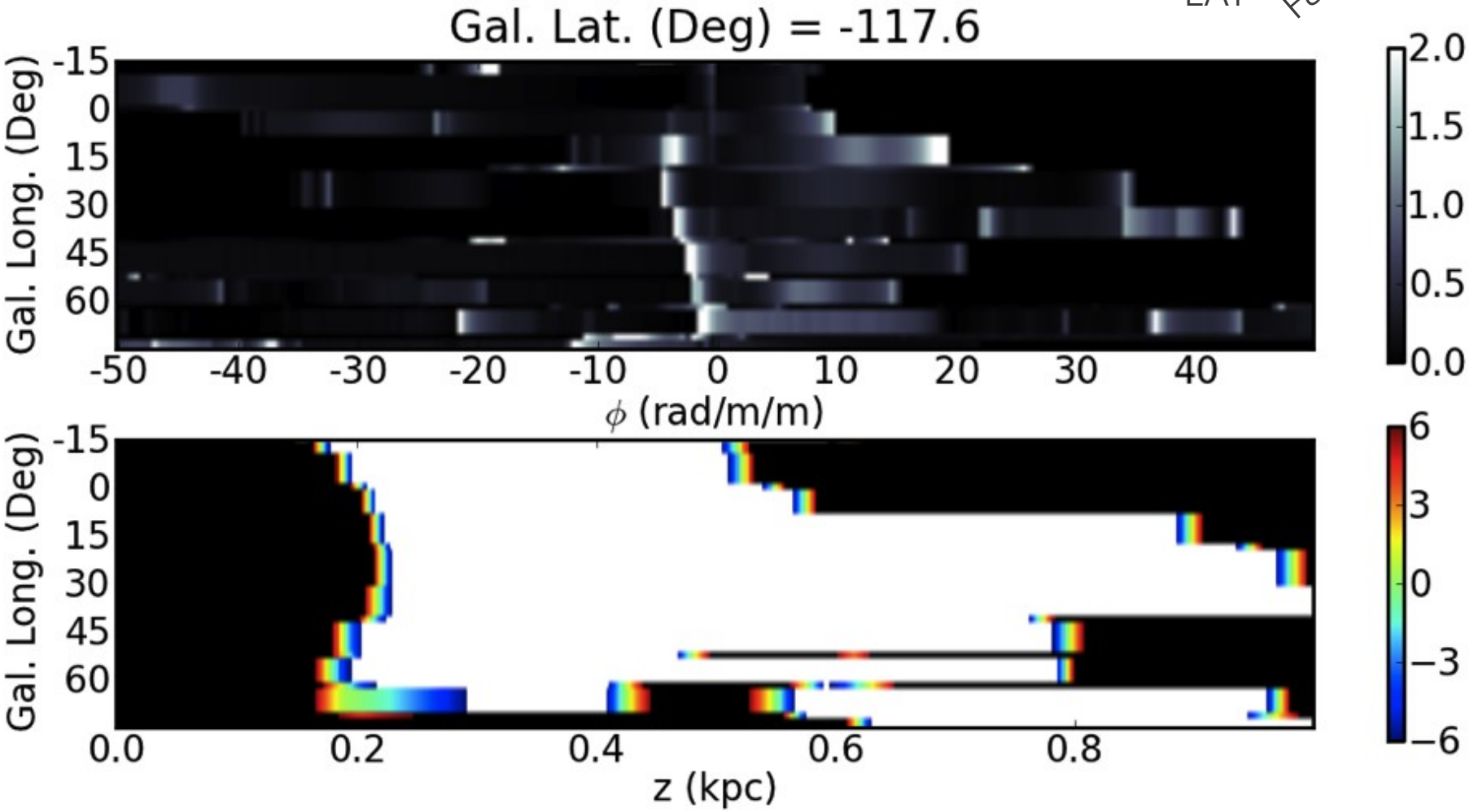
$$F_0 \propto \frac{1}{\sqrt{n_e B'_z}}$$

Faraday Caustics

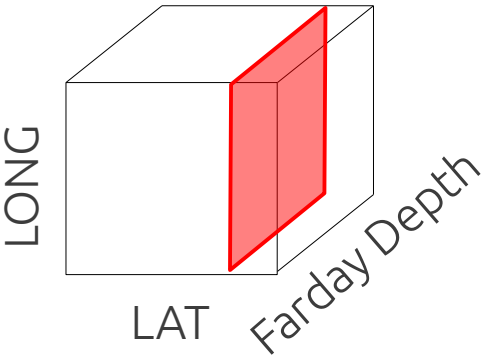


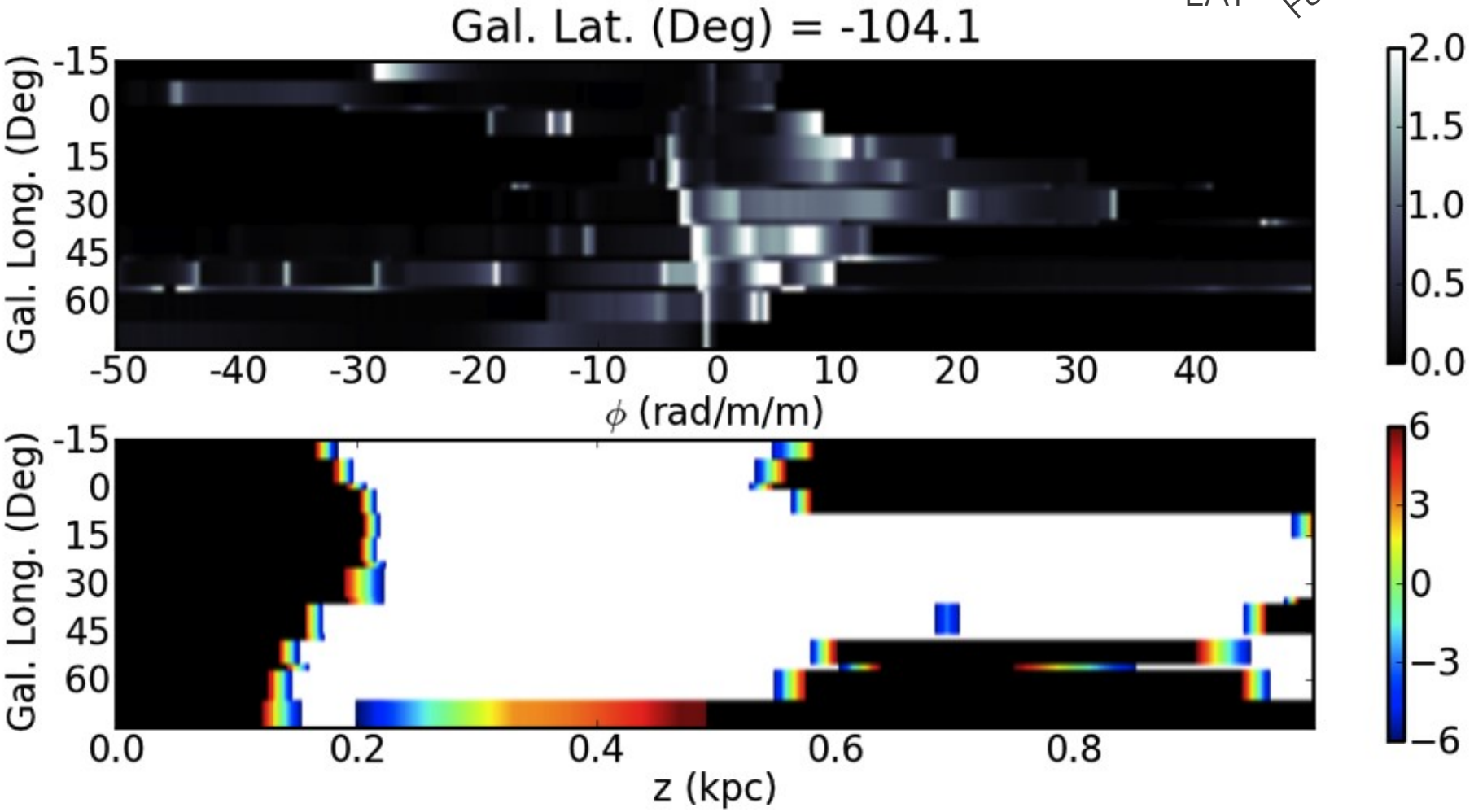
3D Structure



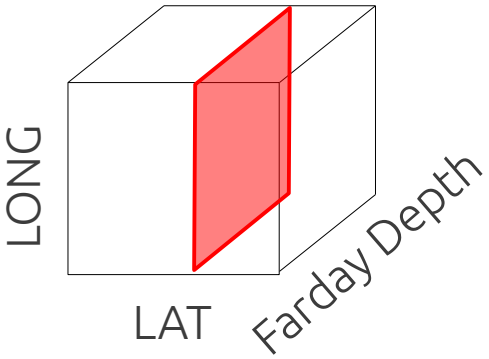


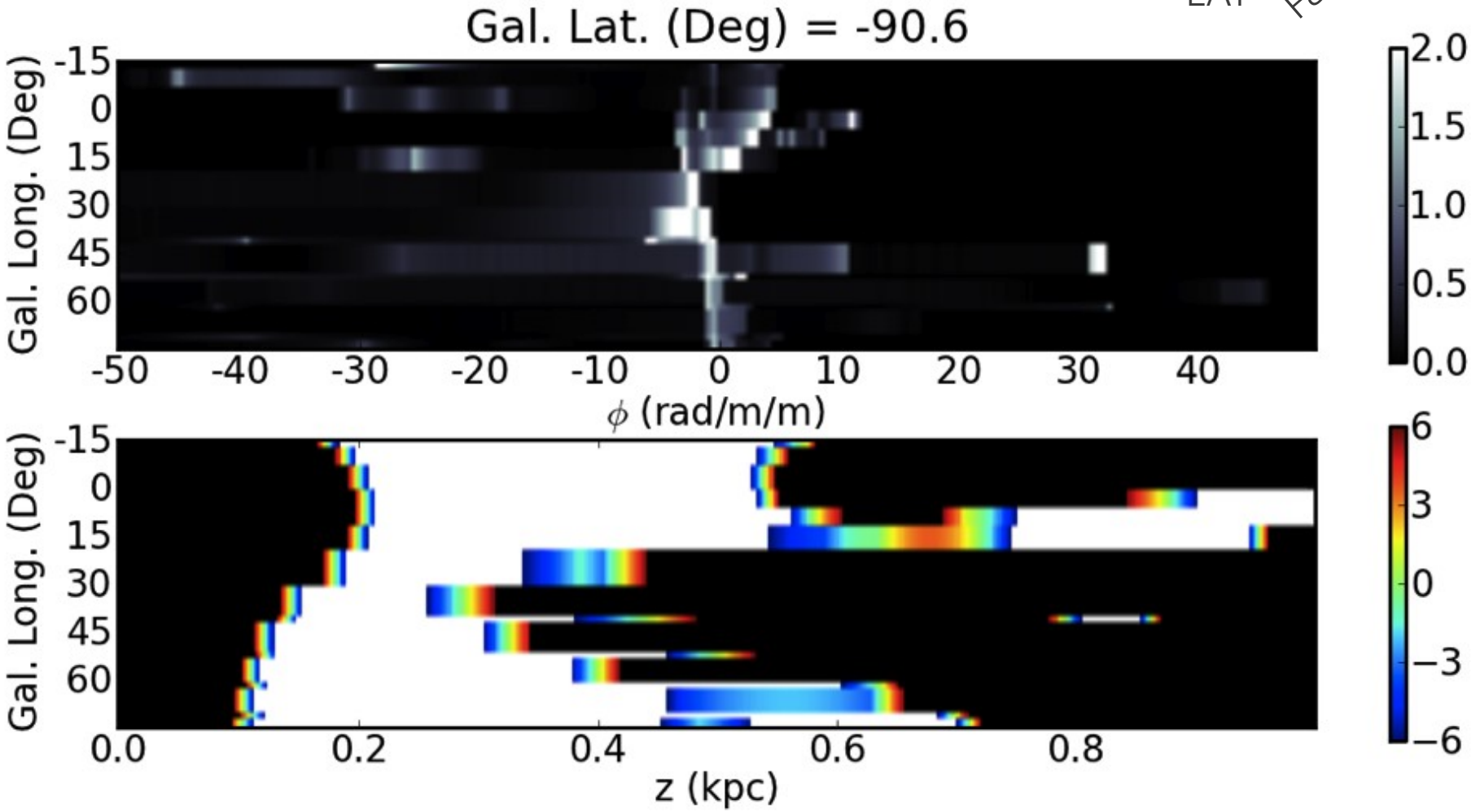
3D Structure



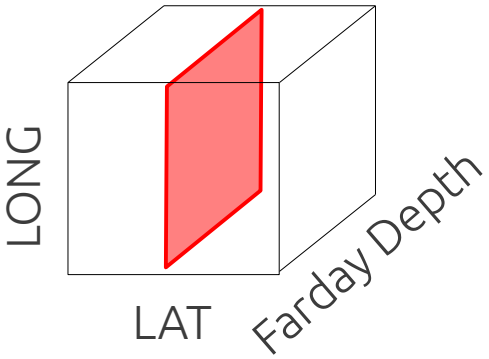


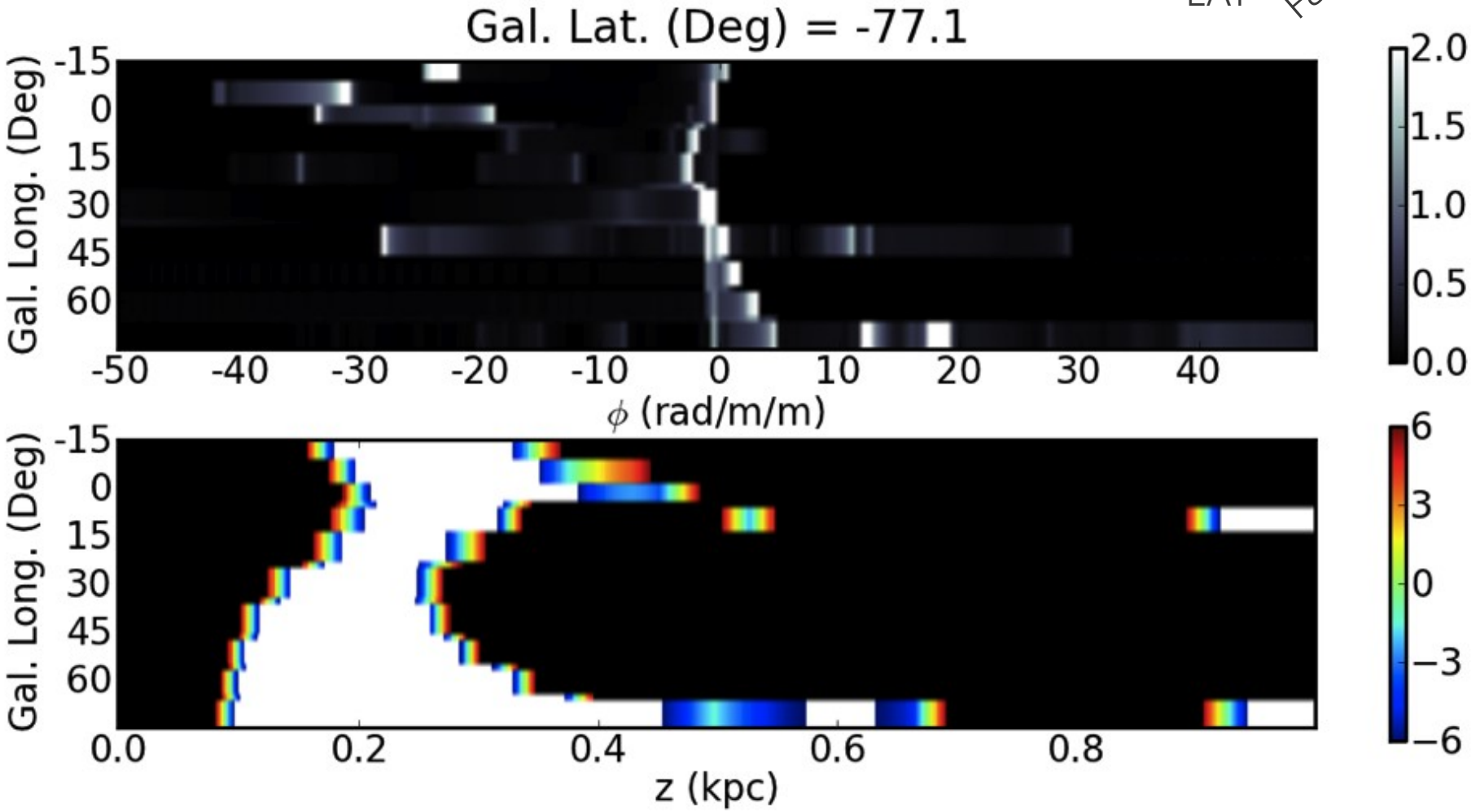
3D Structure



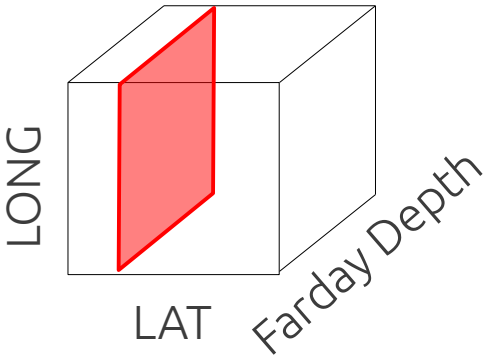


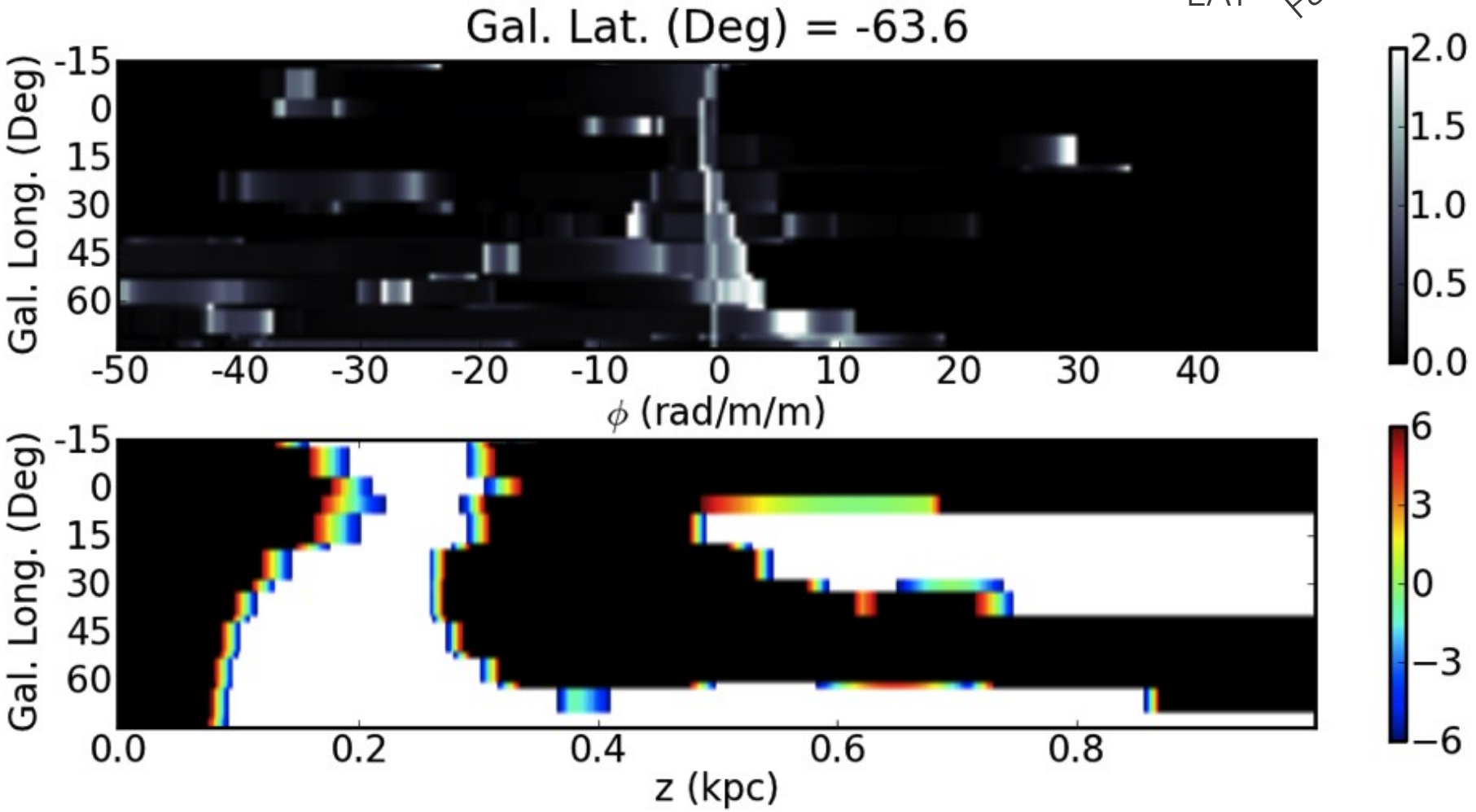
3D Structure



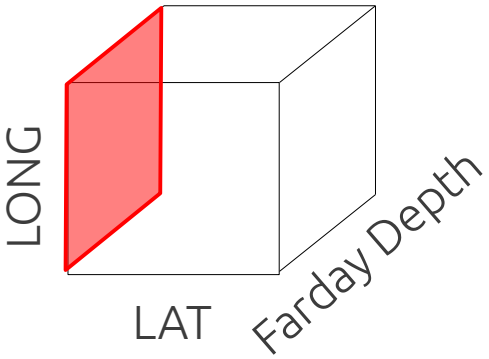


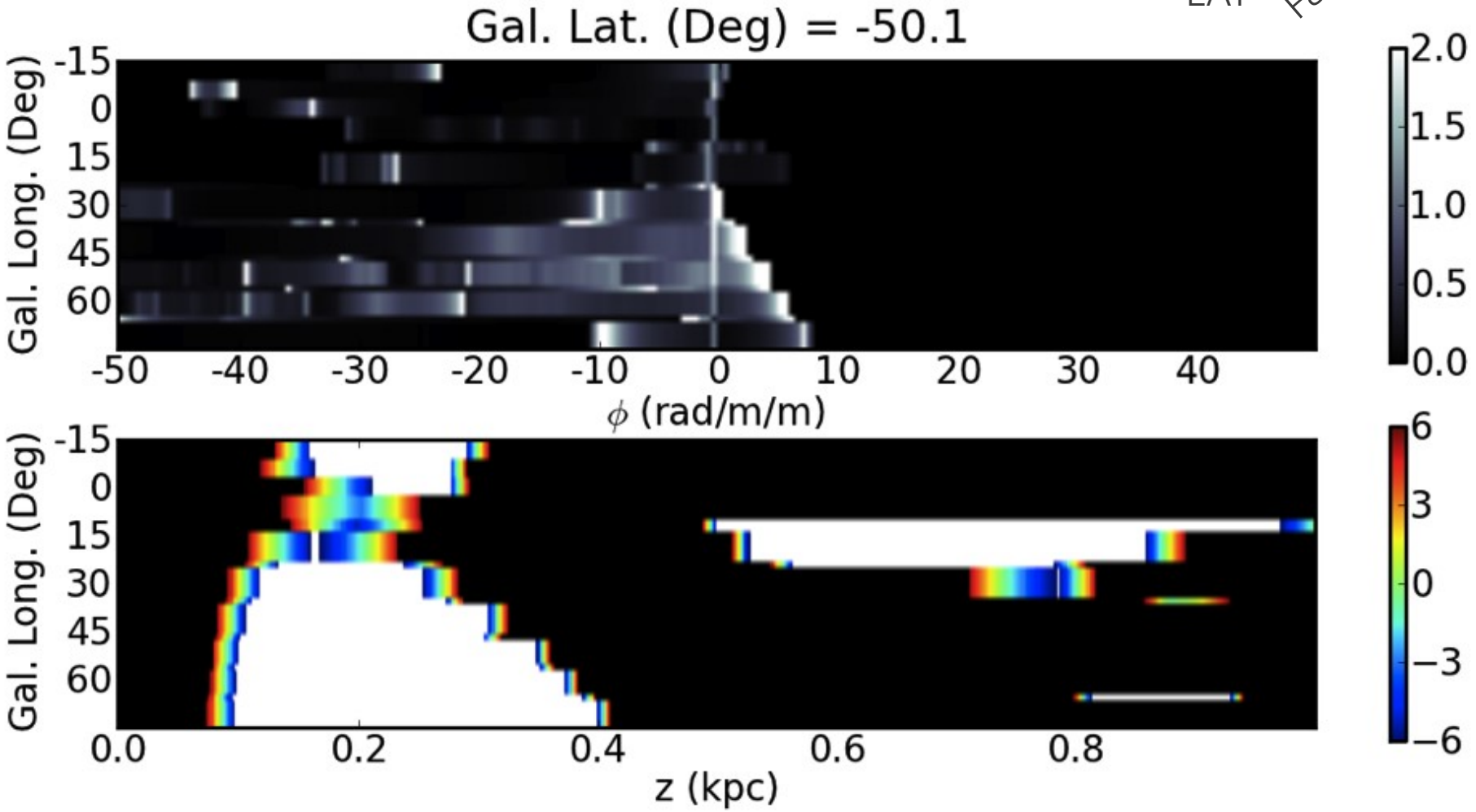
3D Structure



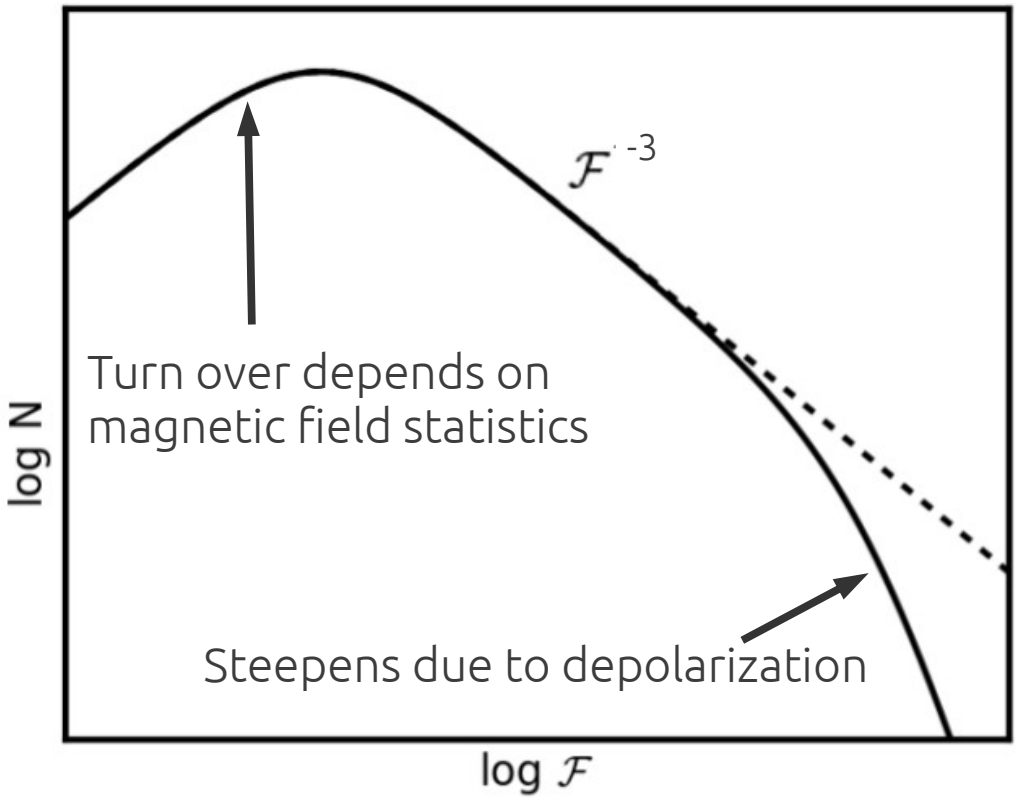


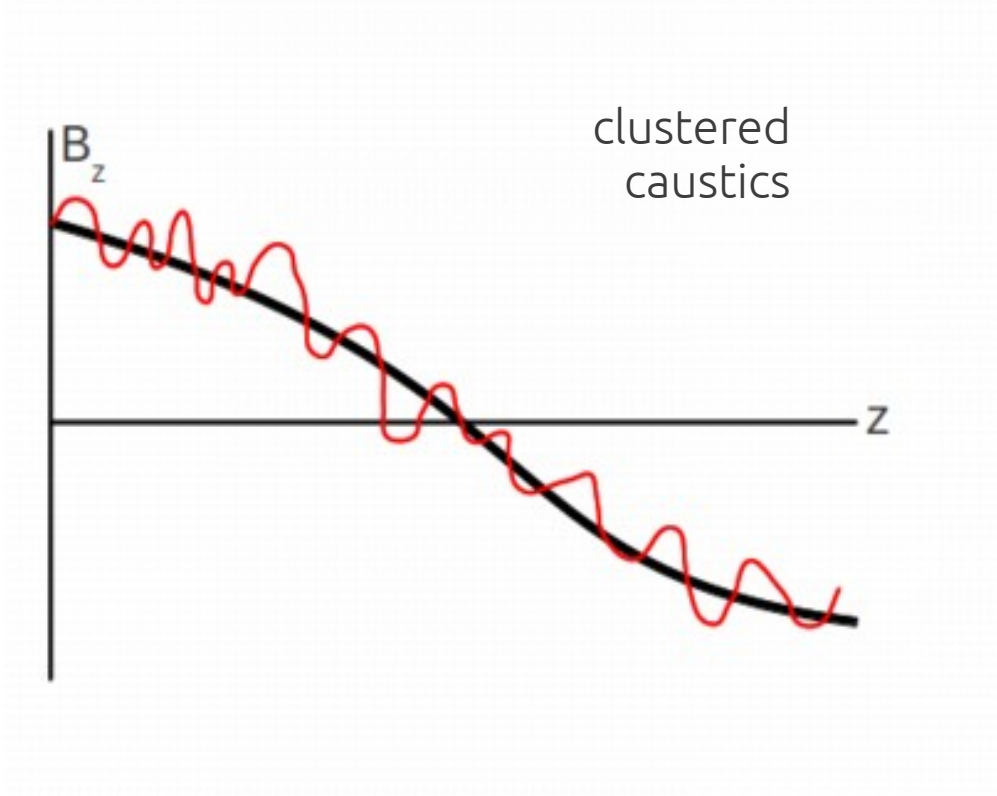
3D Structure



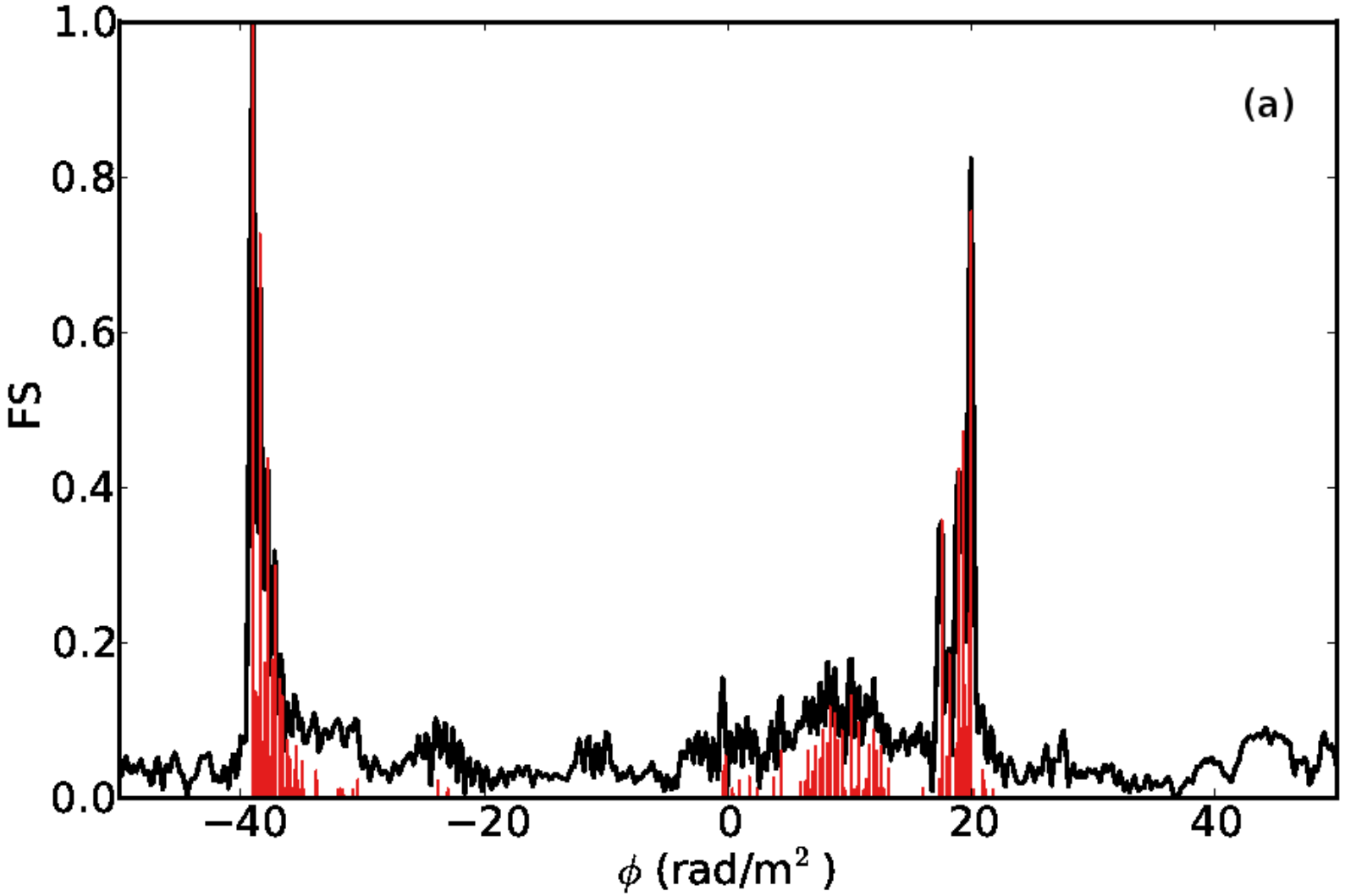


Statistics


$\mathcal{F}^{-3}$
Turn over depends on
magnetic field statistics
Steepens due to depolarization
log N
log $\mathcal{F}$

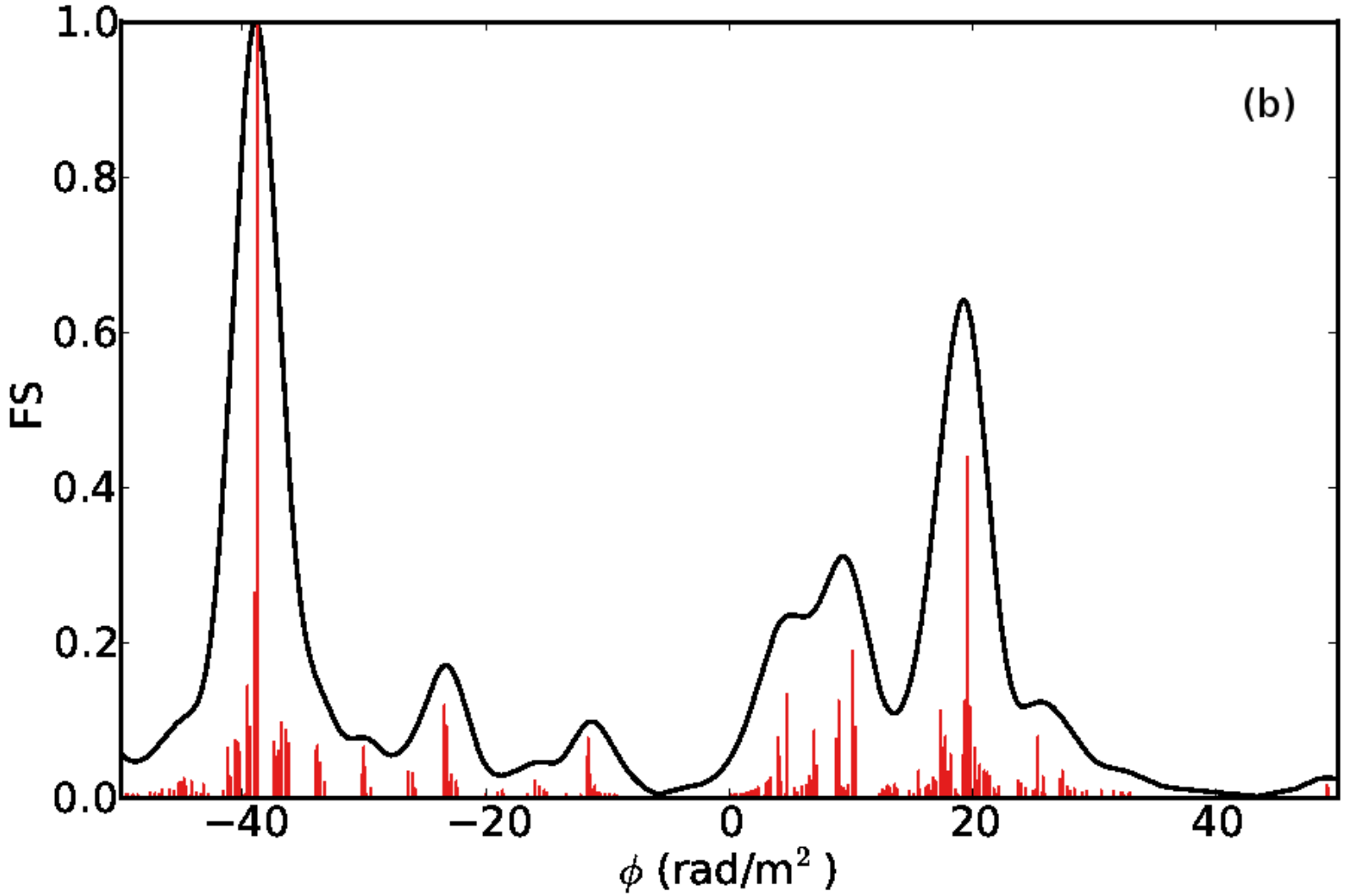

B_z
z
clustered
caustics

Appearance



110 to 250 MHz, similar to the LOFAR high band antennas

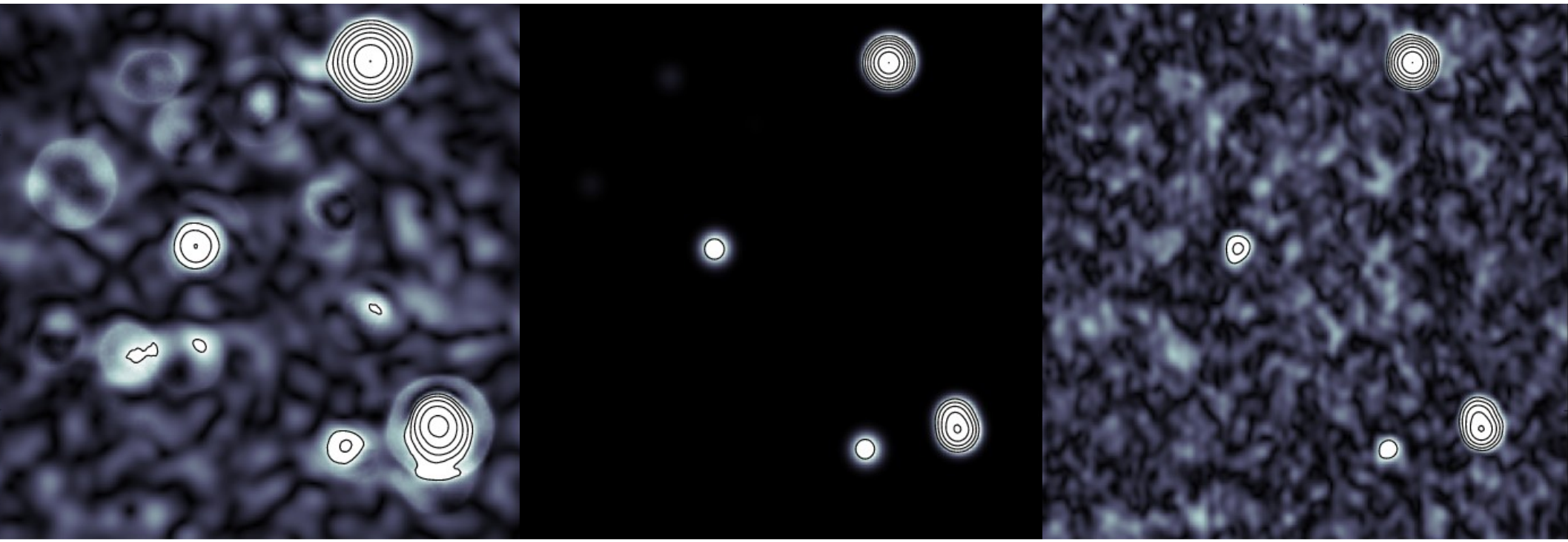
Appearance

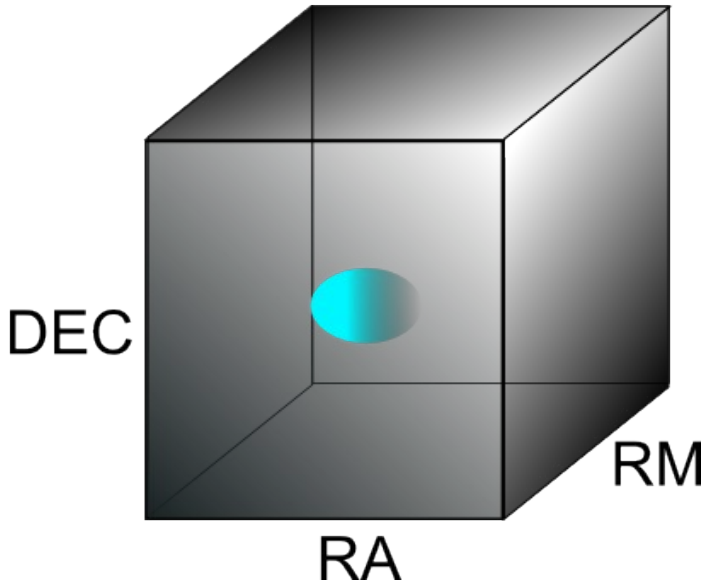


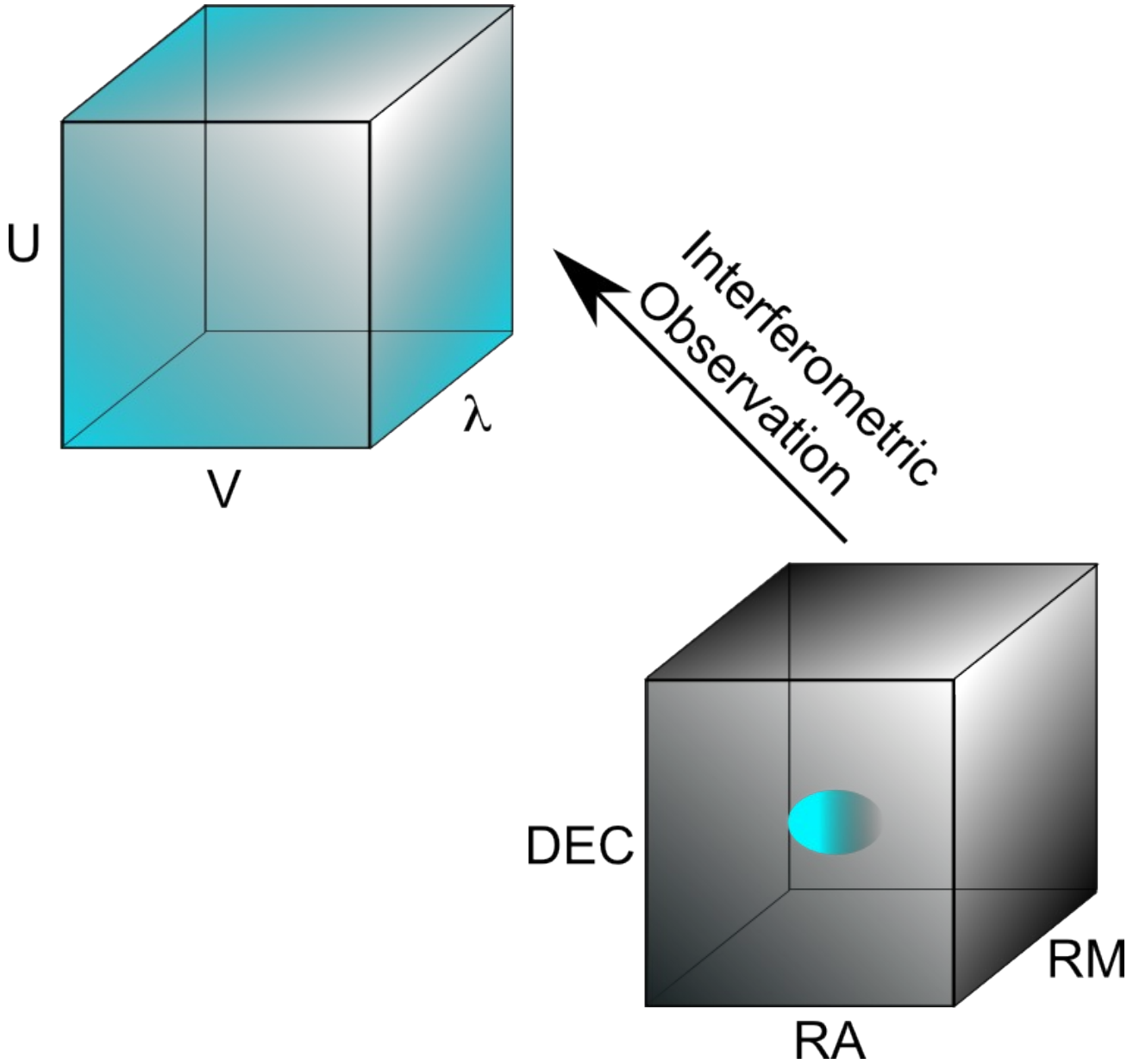
300 to 900 MHz similar to the low frequency portion of the GMIMS survey

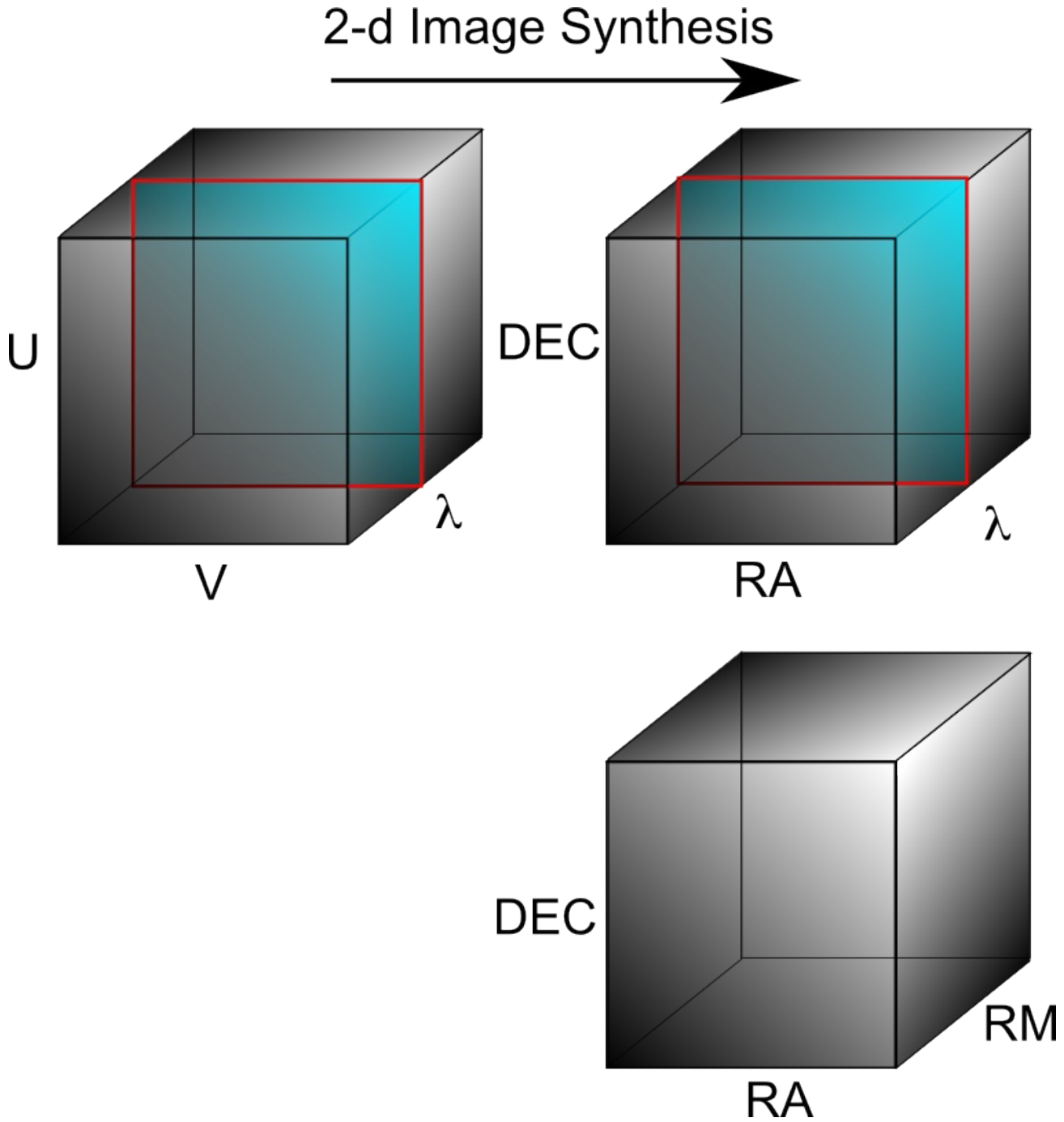
Faraday Synthesis

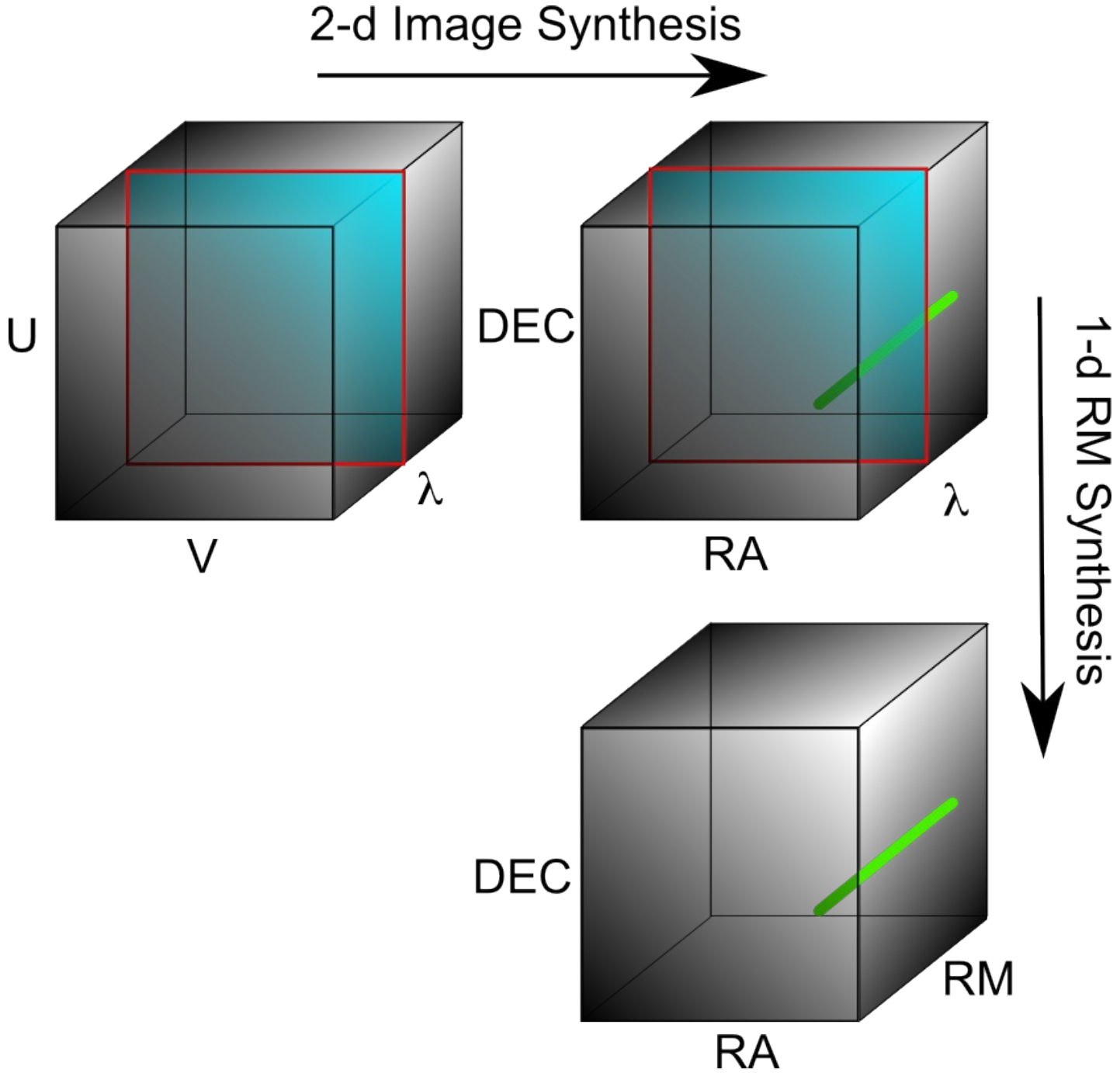
The synergy of aperture and rotation measure synthesis

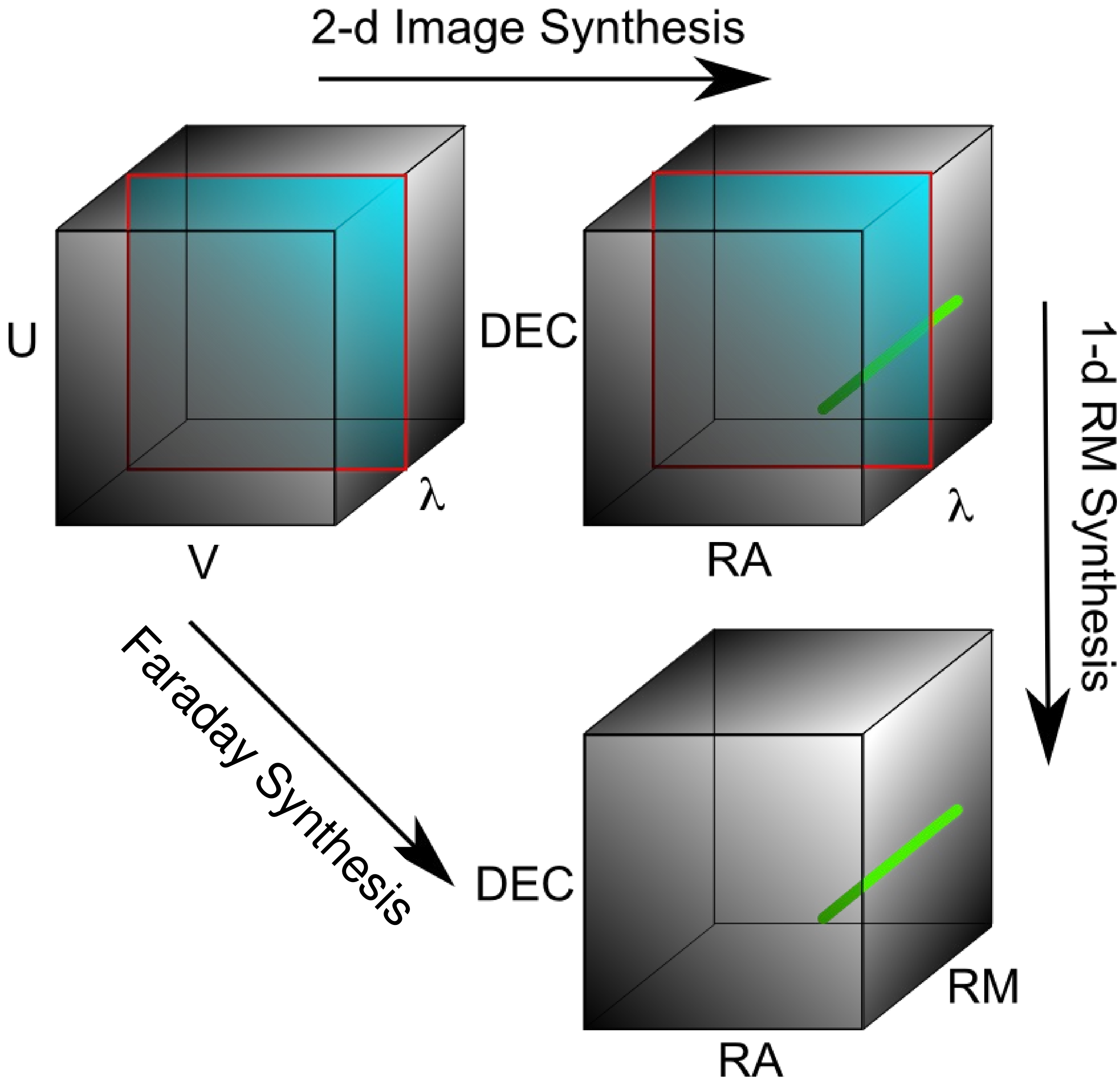


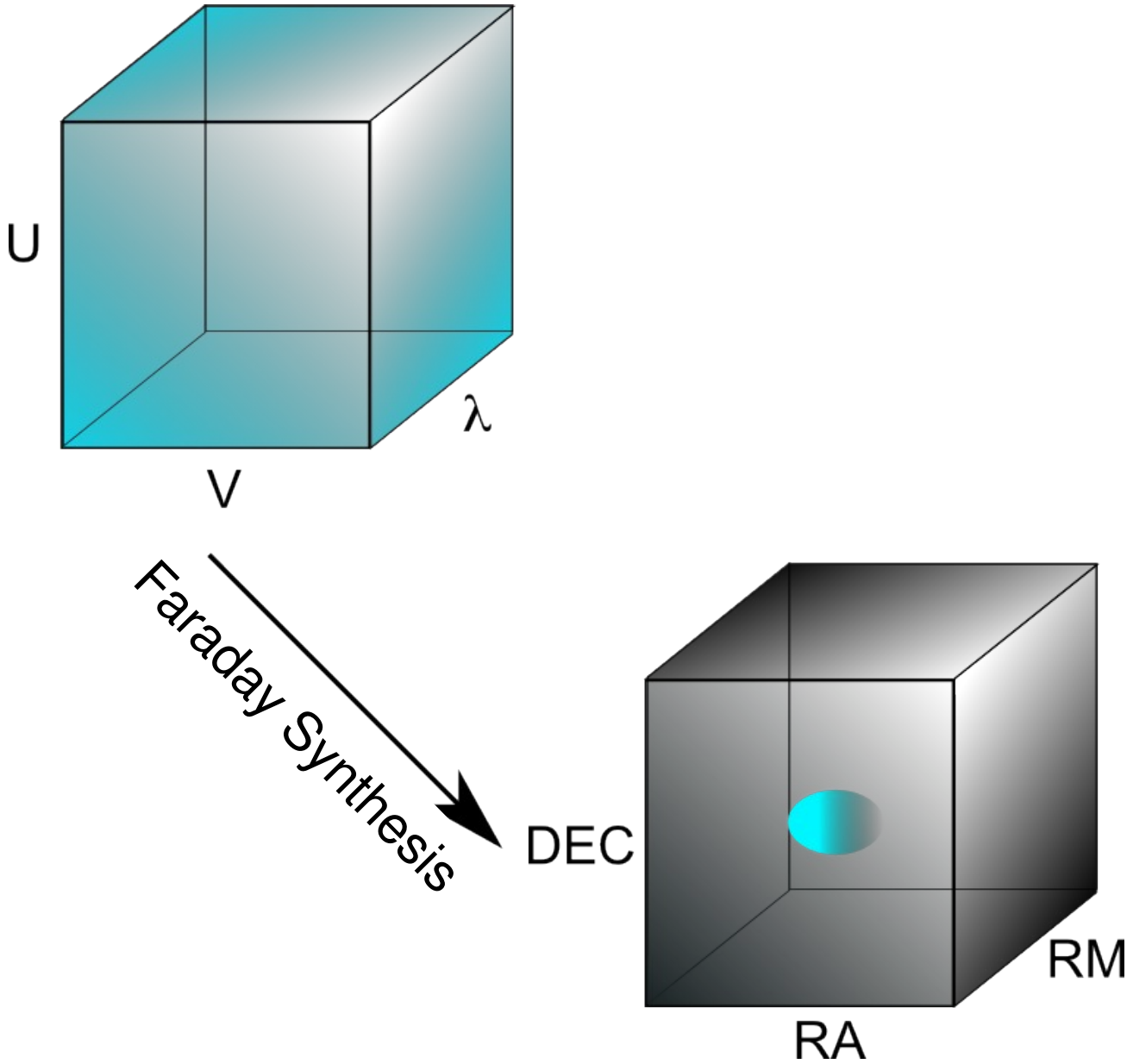

DEC
RM
RA


U
V
λ
Interferometric
Observation
DEC
RA
RM

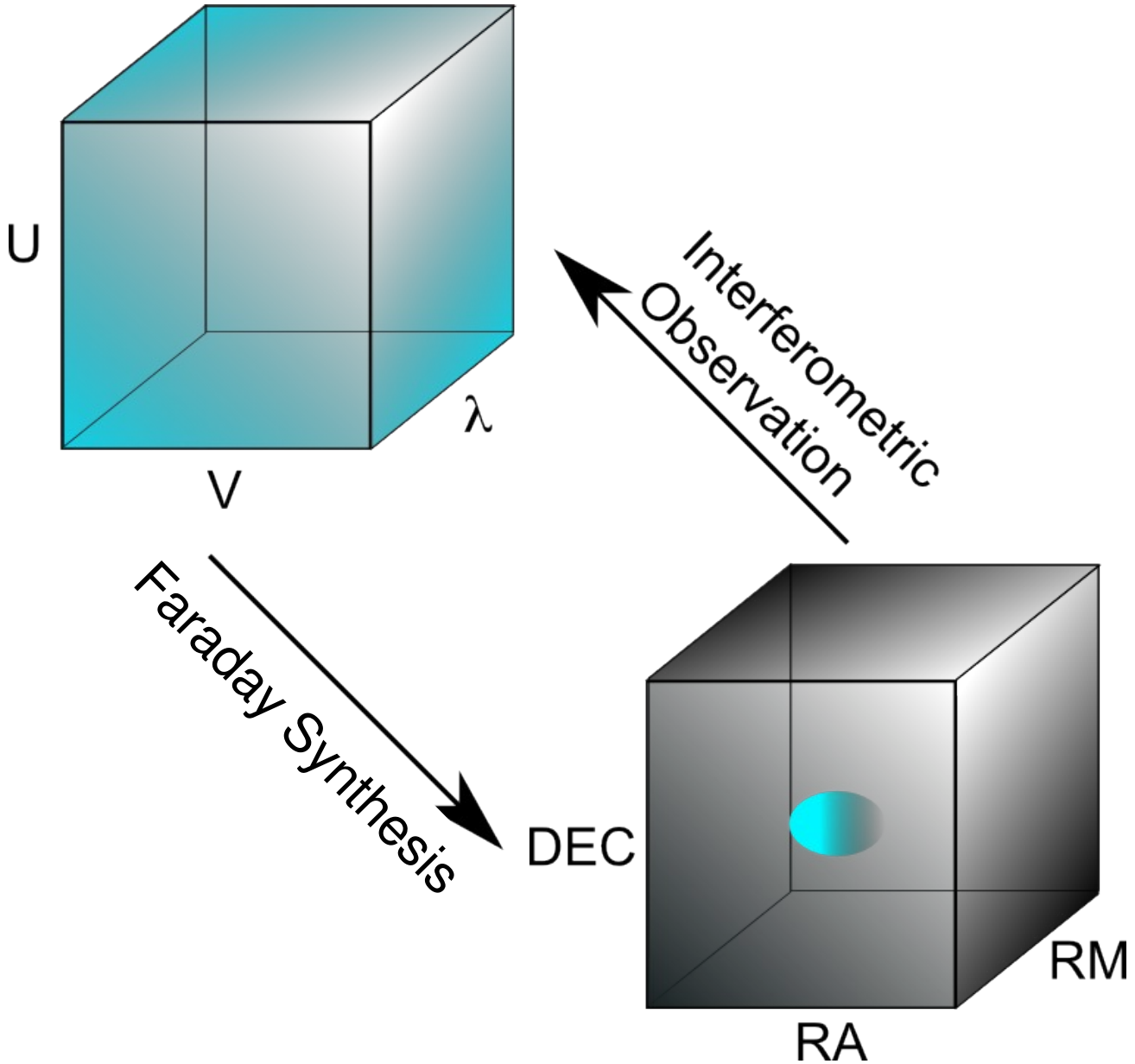

2-d Image Synthesis
U
V
λ
DEC
RA
λ
DEC
RA
RM


2-d Image Synthesis
U
V
λ
DEC
RA
λ
1-d RM Synthesis
DEC
RA
RM


2-d Image Synthesis
U
V
λ
DEC
RA
λ
1-d RM Synthesis
Faraday Synthesis
DEC
RA
RM


U
λ
V
Faraday Synthesis
DEC
RM
RA

Faraday Synthesis

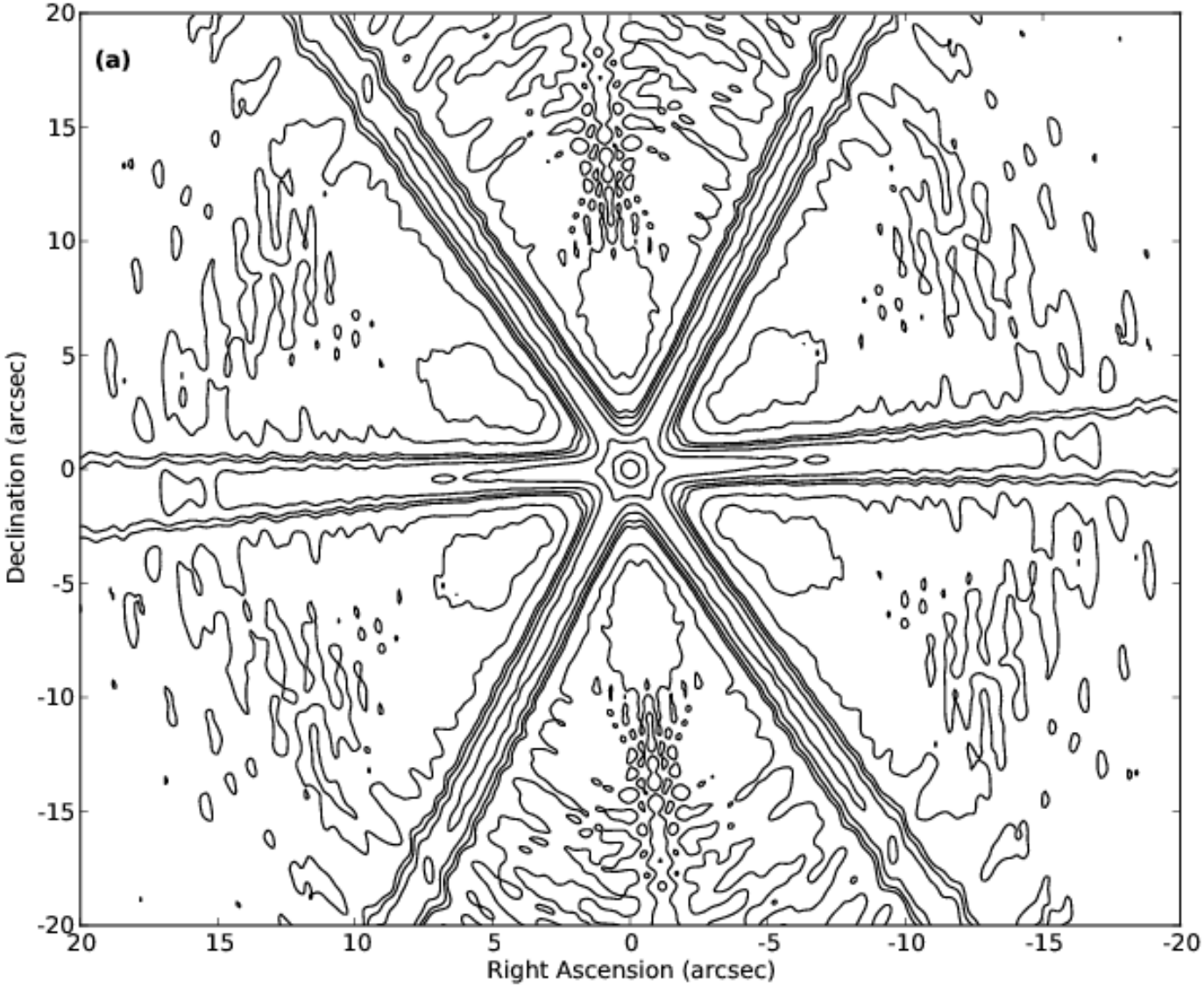


Faraday synthesis

$$PSF_{3D} \stackrel{?}{=} PSF_{sky} * PSF_{RM}$$

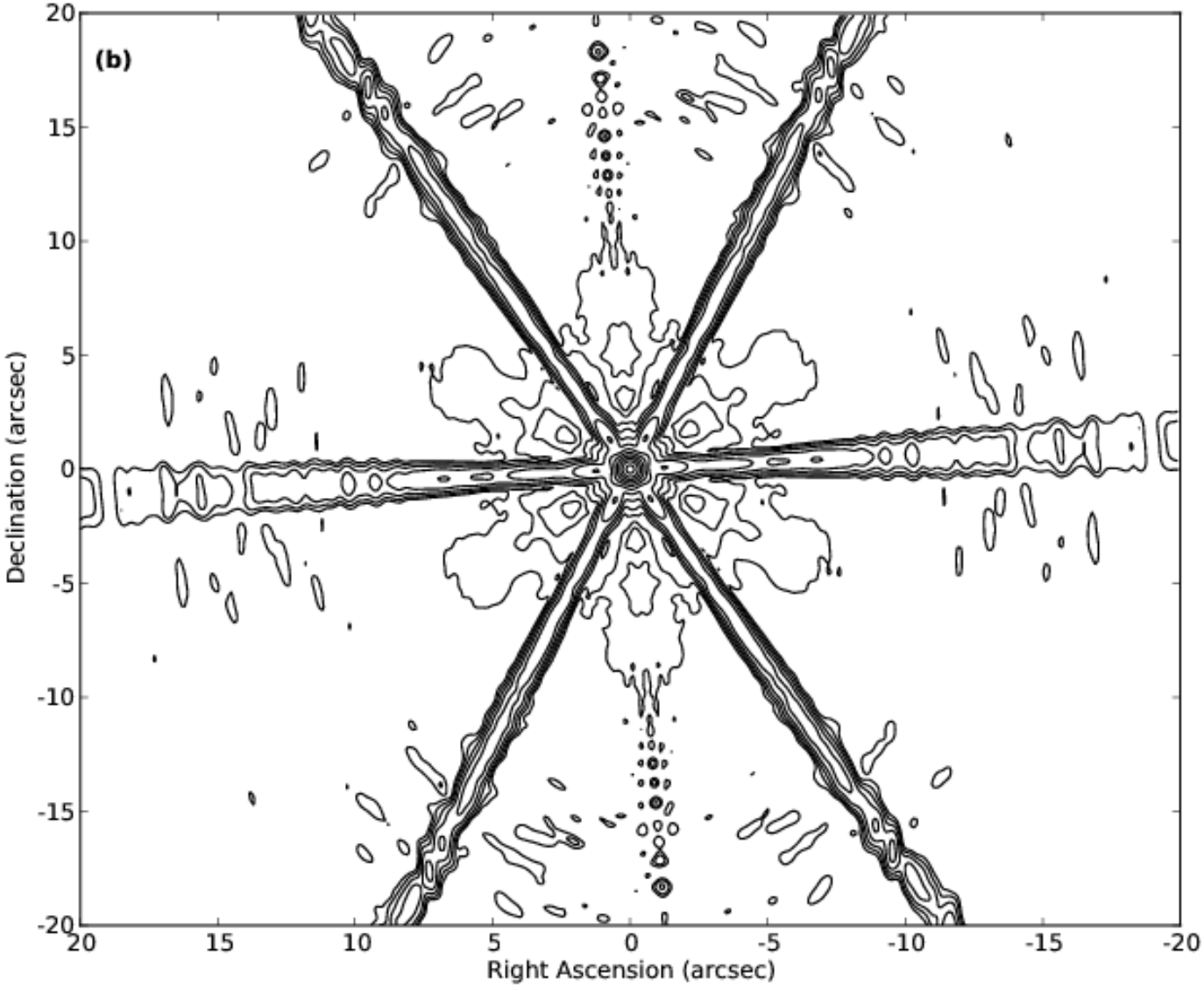
3D Dirty Beam

Image plane, Faraday depth = 0 rad/m^2



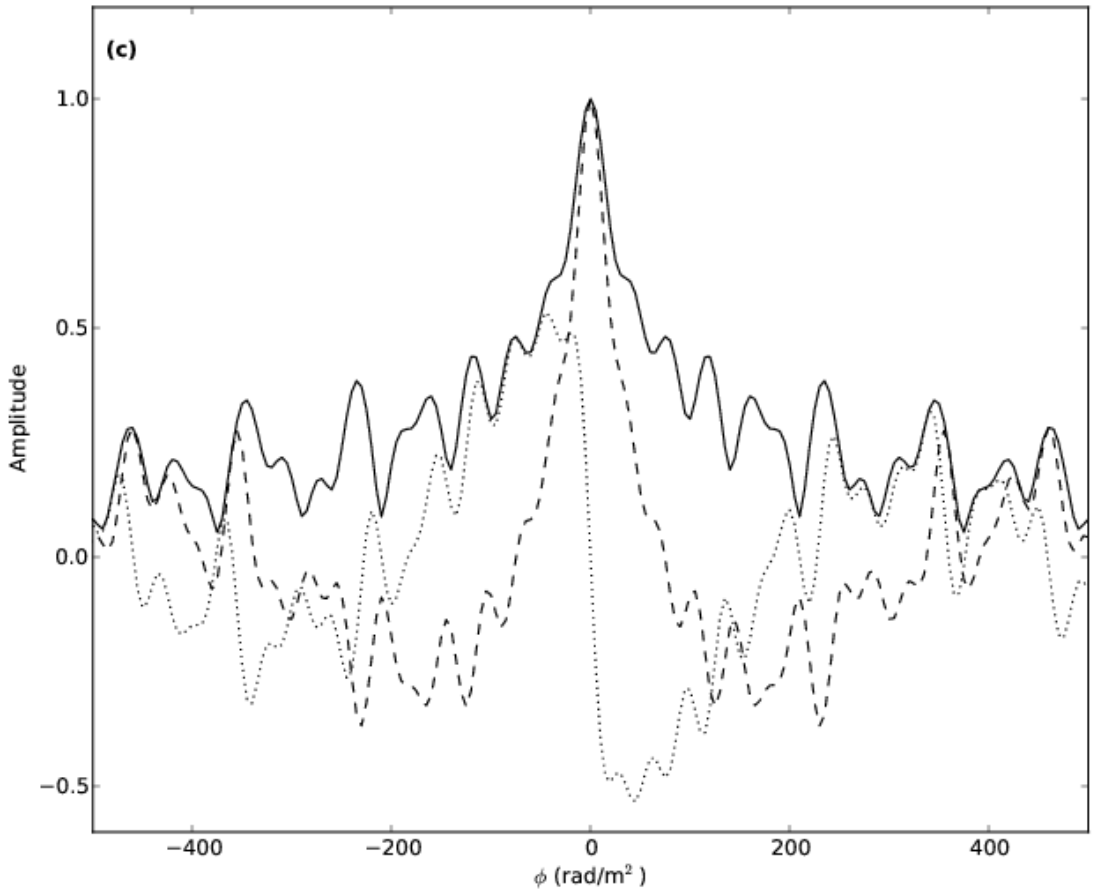
3D Dirty Beam

Image plane, Faraday depth = 50 rad/m^2



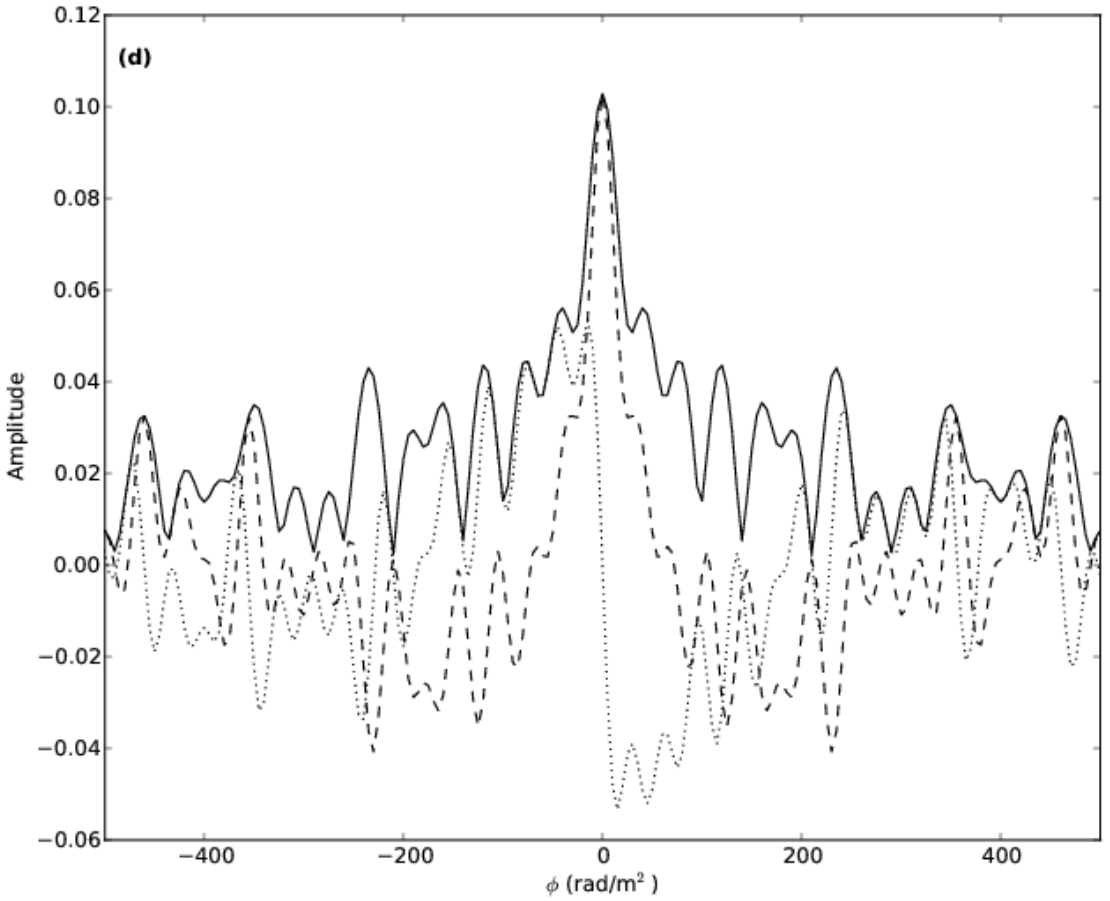
3D Dirty Beam

Faraday depth axis, phase center

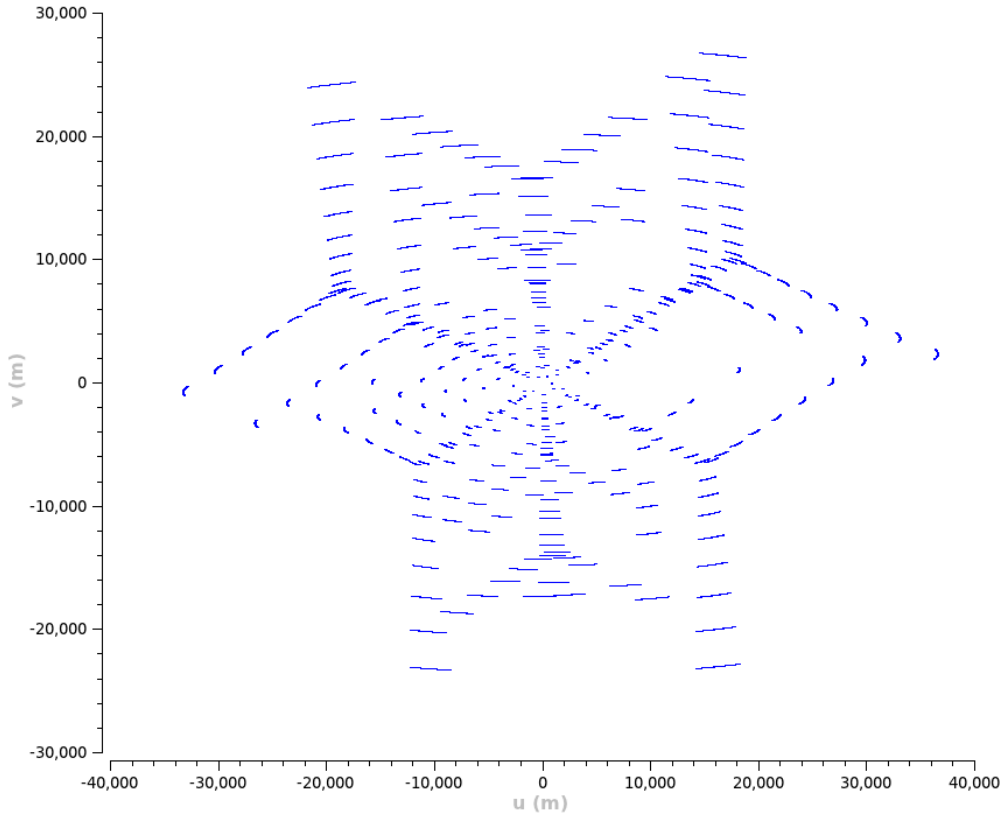


3D Dirty Beam

Faraday depth axis, off-center



Mock Observations

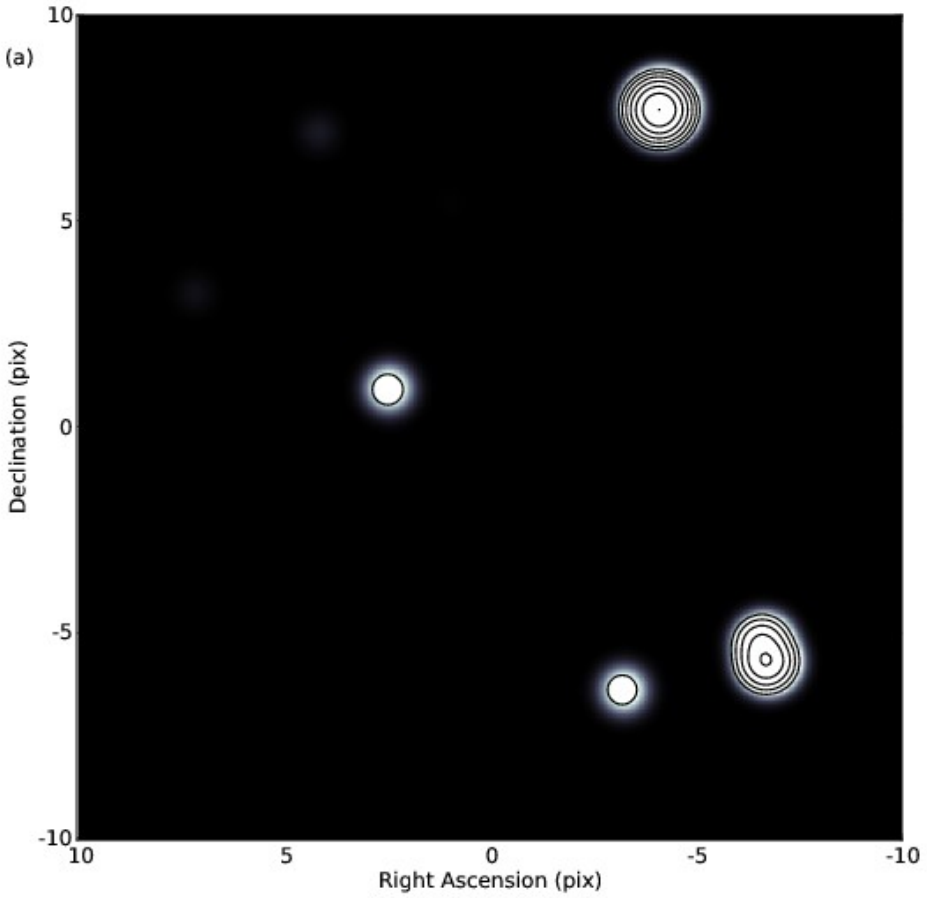


30 point sources
random locations
random fluxes (0.06 - 64 Jy)

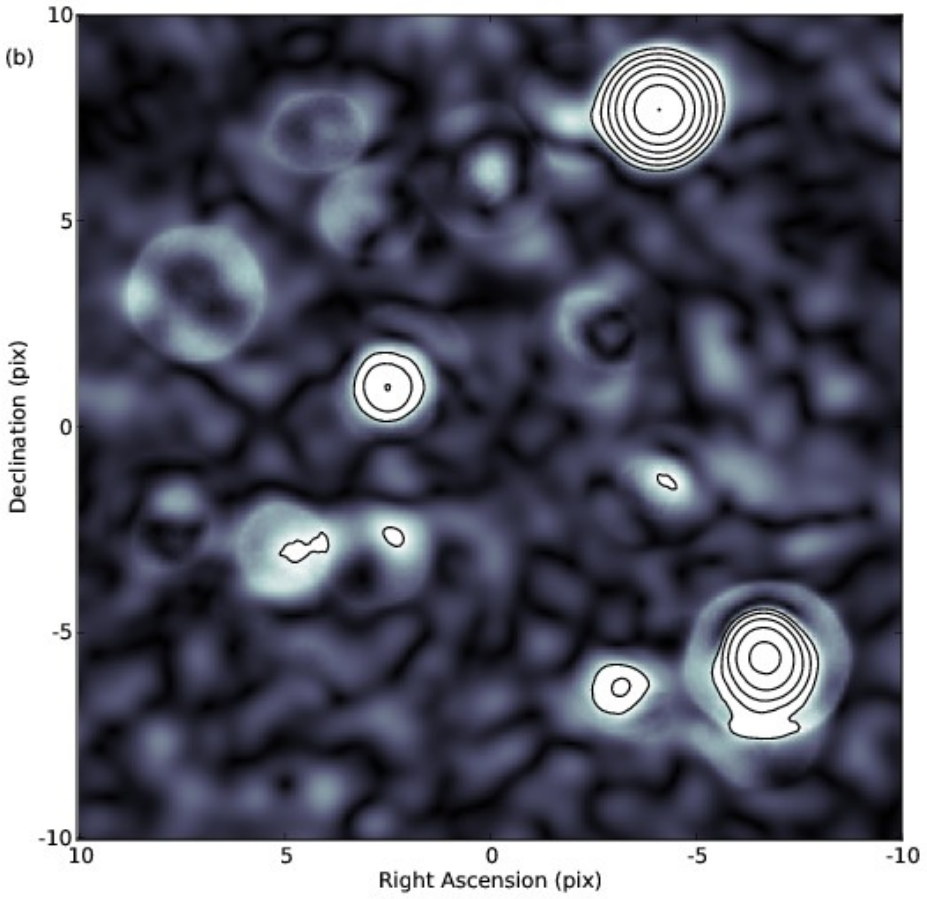
“observed” with the VLA
1-4 GHz (x64 channels)

Gaussian white noise, ~10Jy

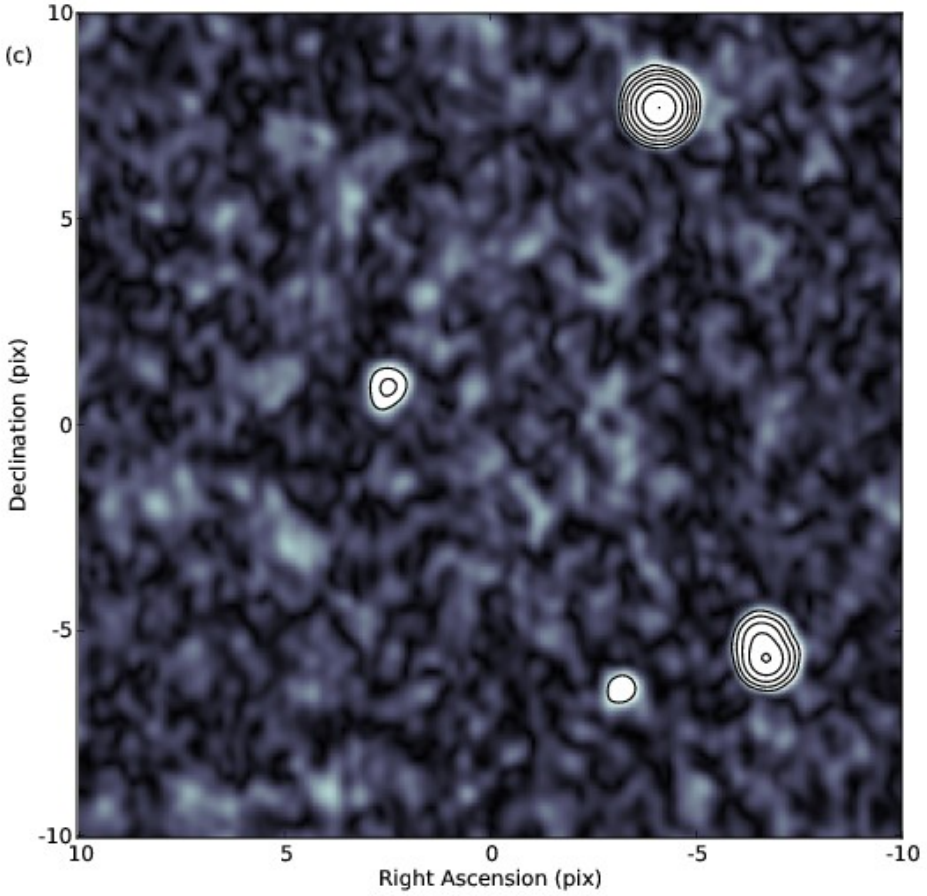
Model



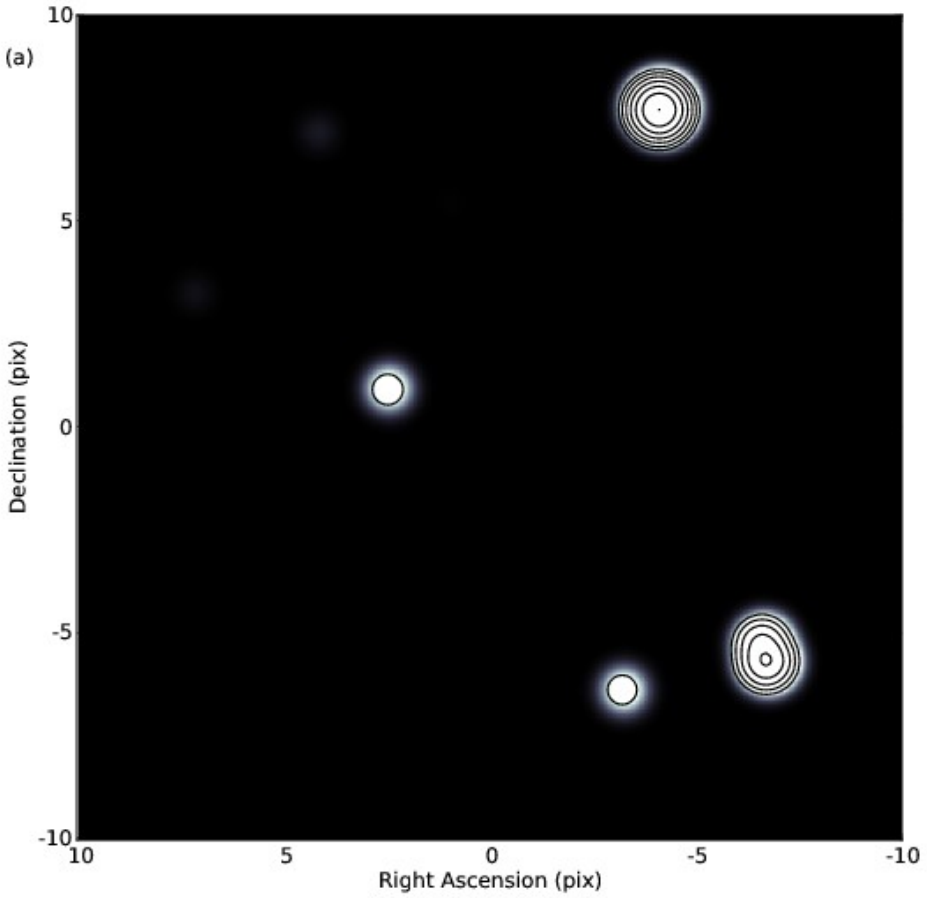
Aperture + RM Synthesis



Faraday synthesis

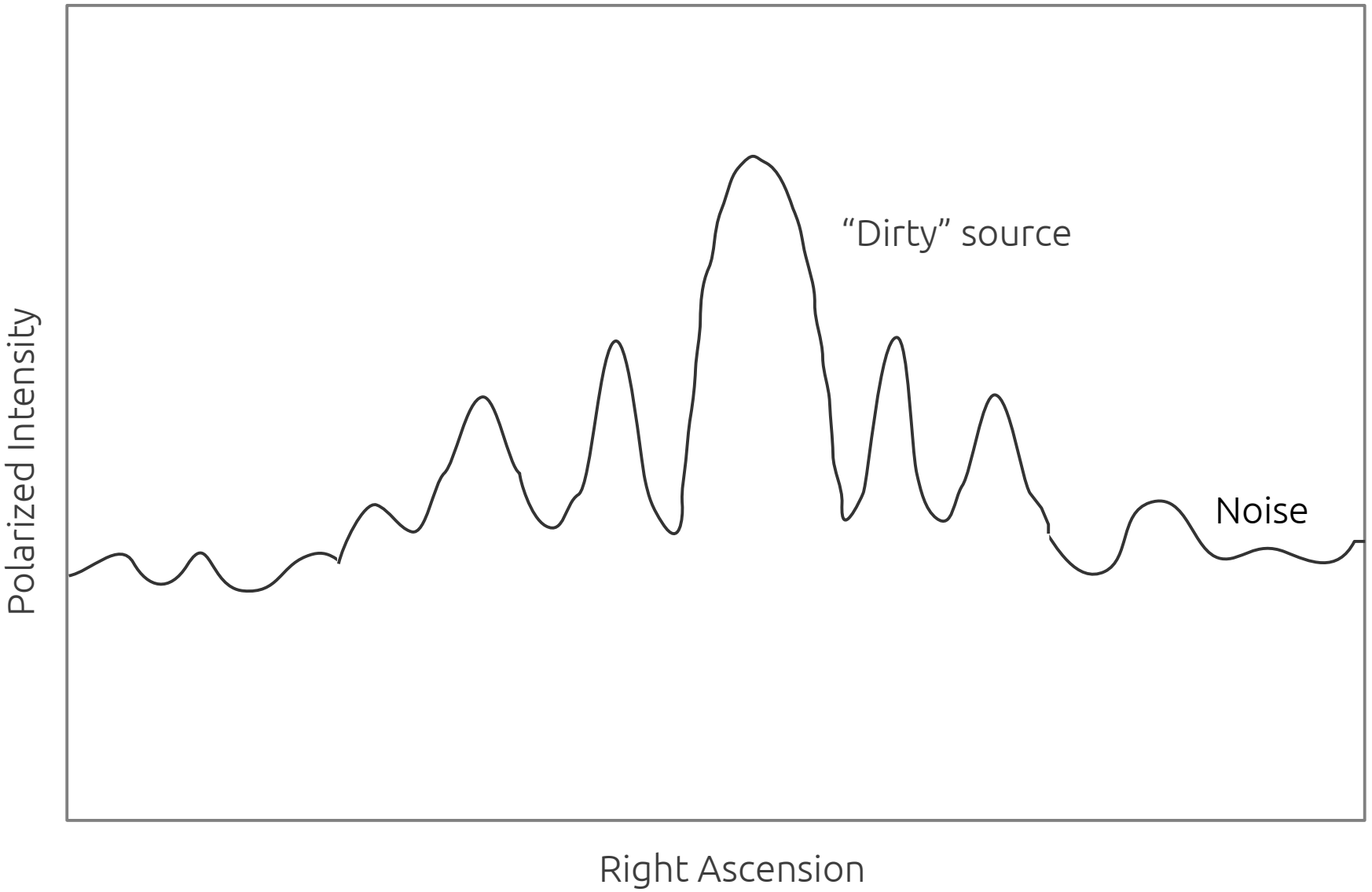


Model



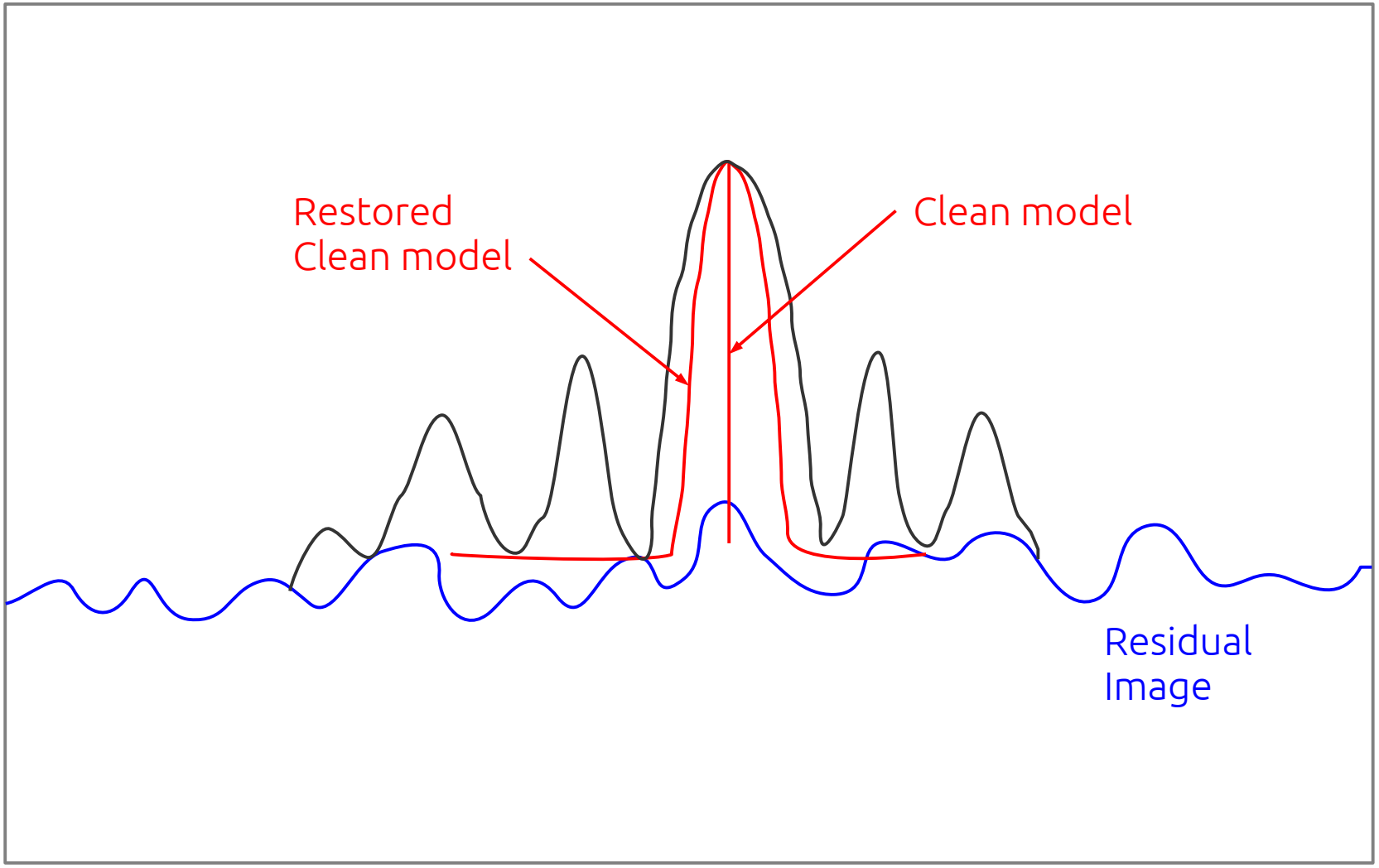
Why the artifacts?

1D Dirty image



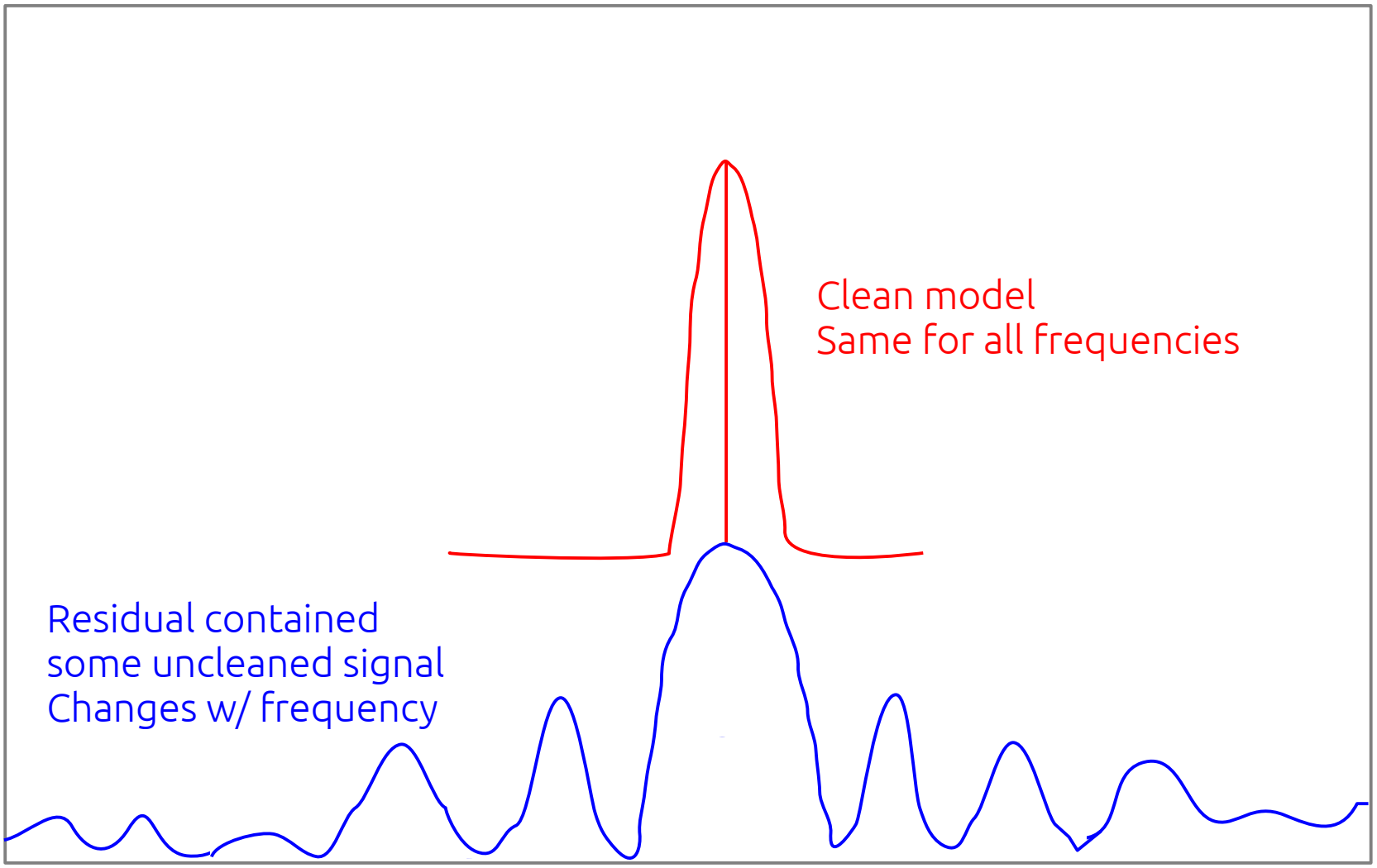
Why the artifacts?

Cleaning a single frequency



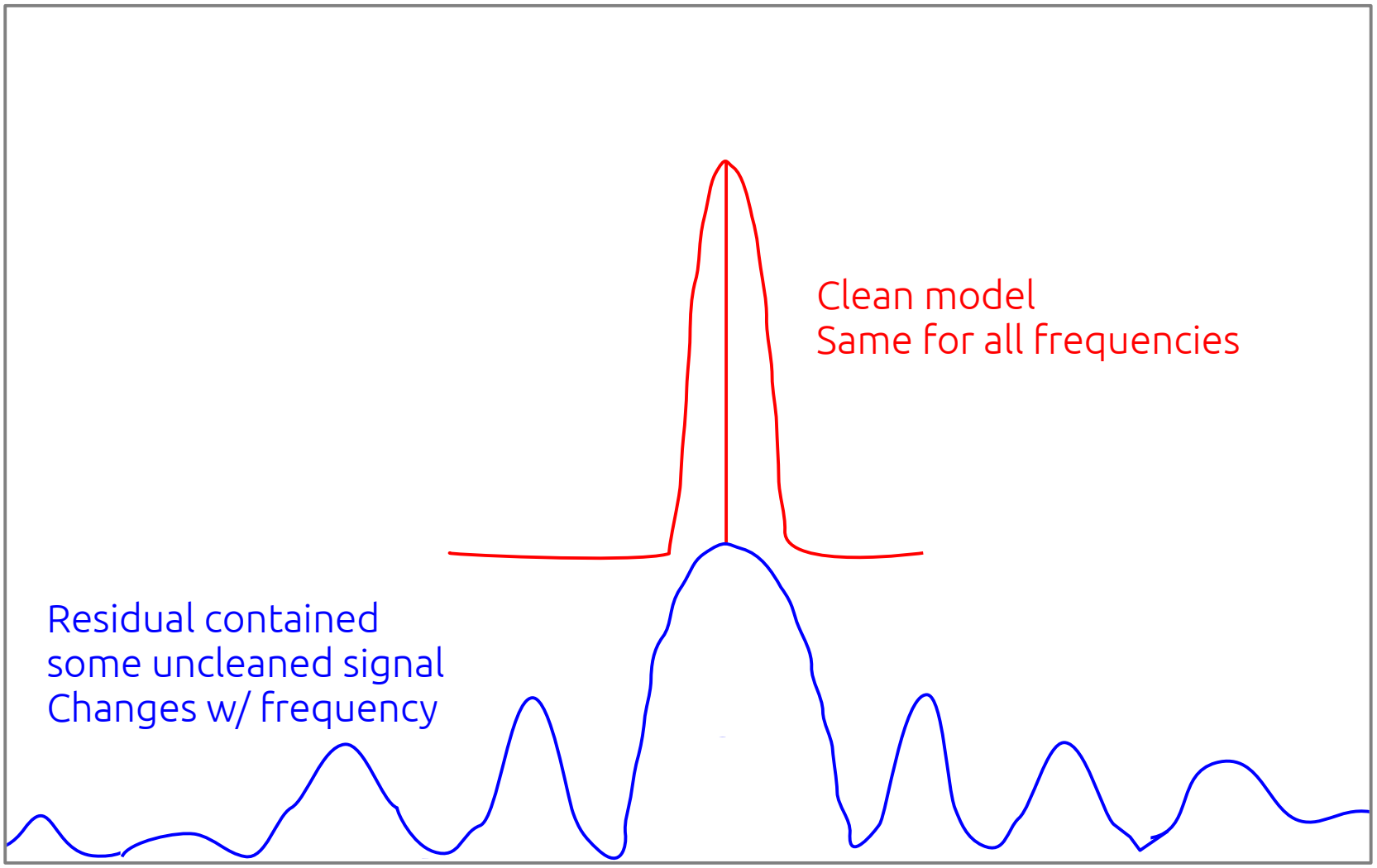
Why the artifacts?

After combining multiple frequencies

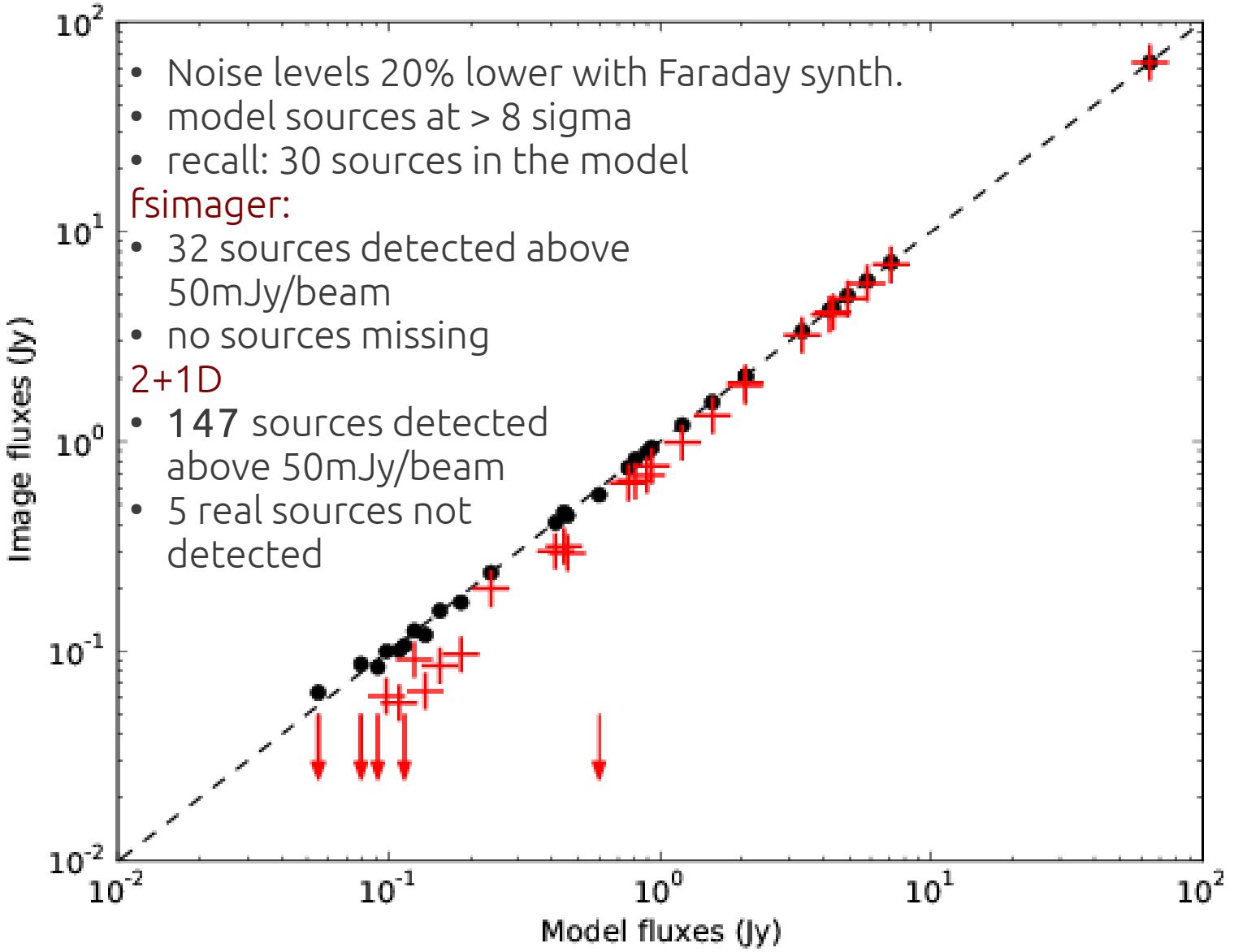


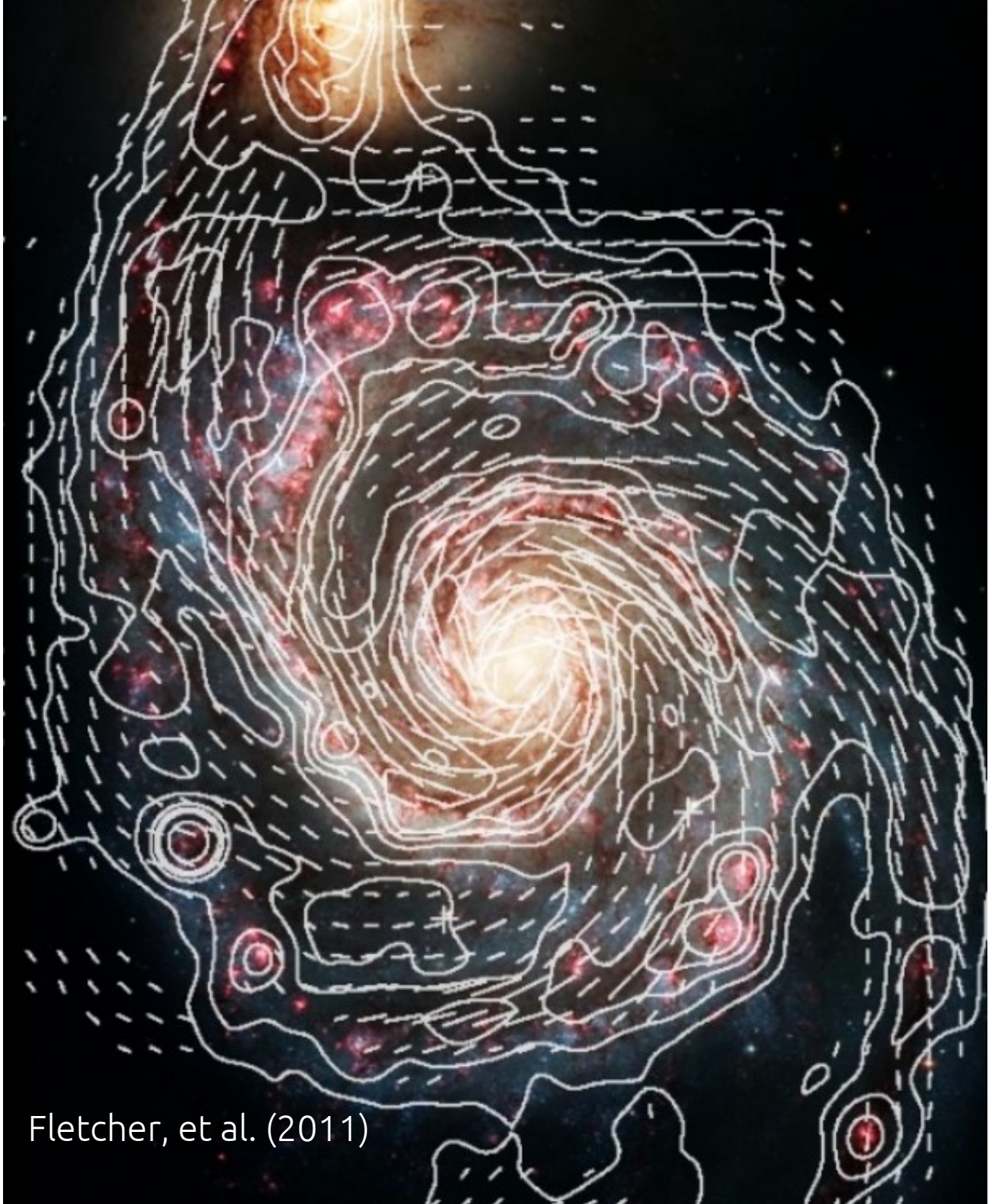
Why the artifacts?

After combining multiple frequencies



Flux recovery



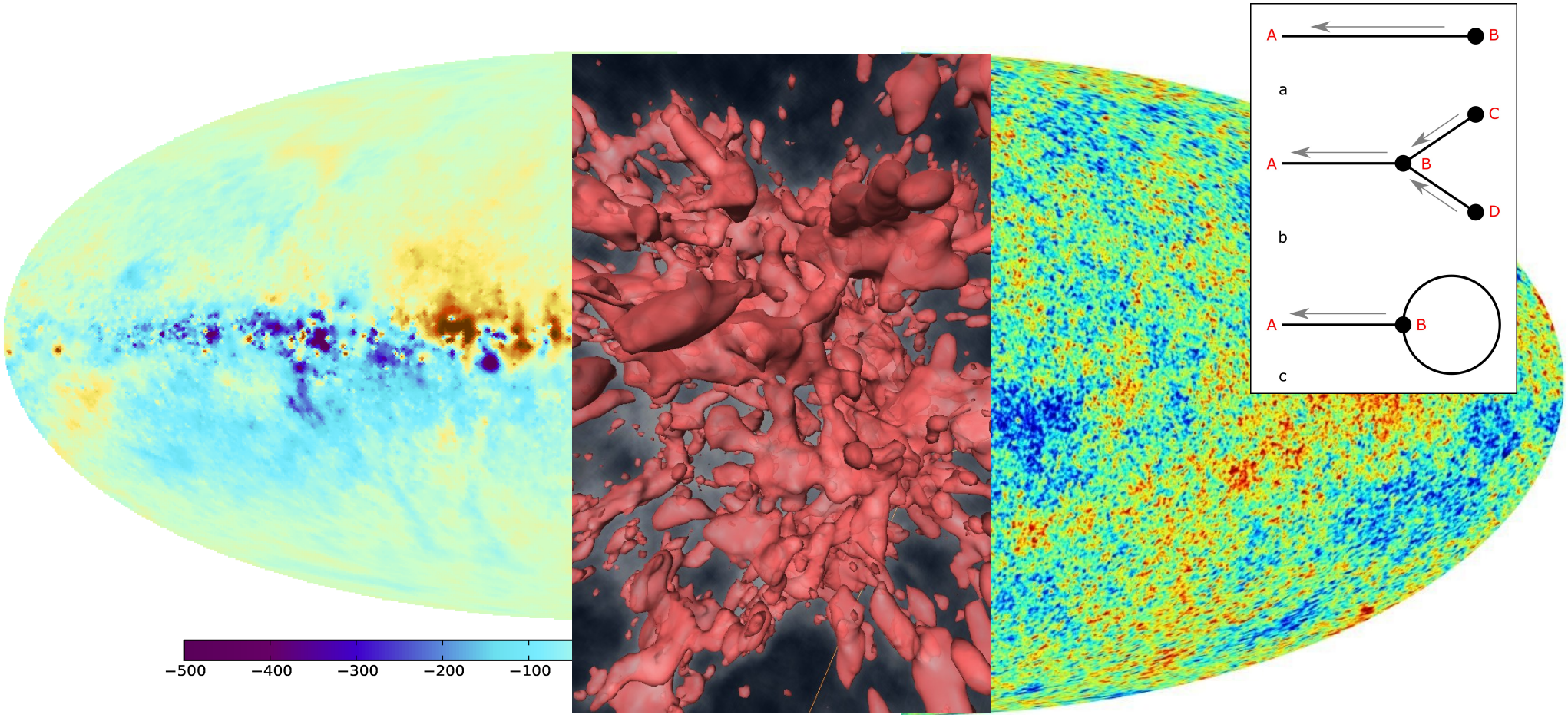


Fletcher, et al. (2011)

de Bruyn & Brentjens (2005)

Information Field Theory

Extended critical filter and more...



www.mpa-garching.mpg.de/ift

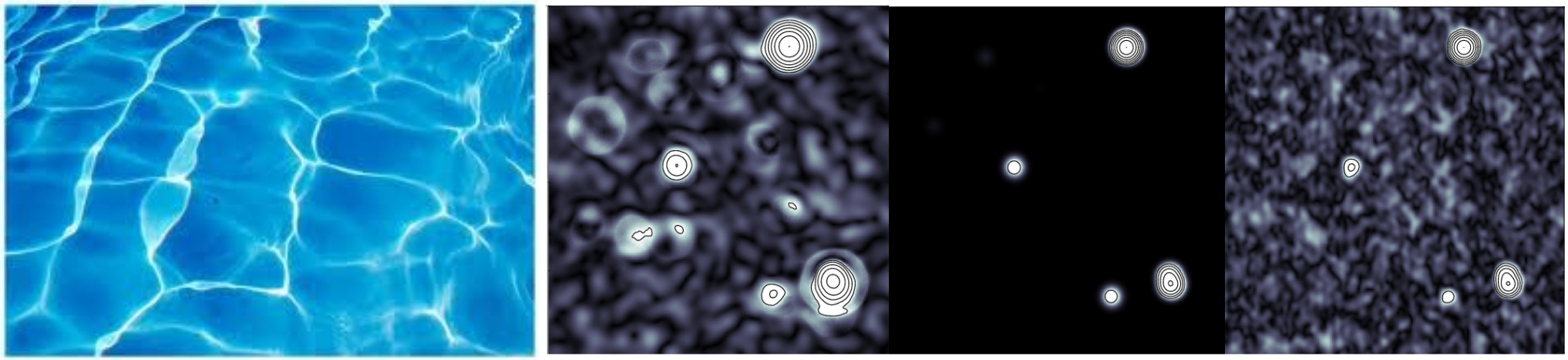
Faraday Caustics Summary

- Strong “spikes” in Faraday spectra
- Mark reversals of LOS B-field
- Are sheets in 3D Faraday spectrum
- Reveal properties of magnetic turbulence

Faraday synthesis summary

- Improves upon aperture + RM synthesis
  - Better fidelity
  - Less noise and better noise statistics
  - Higher resolution
  - Computationally cheaper (in principle)
- Provides a solid framework for building 3D imaging algorithms
- Being considered for POSSUM & CHANGES

Thank you!



Faraday caustics: Singularities in the Faraday spectrum and their utility as probes of magnetic field properties
Bell, Junklewitz & Enßlin, A&A 535, A85 (2011)

Faraday synthesis: The synergy of aperture and rotation measure synthesis
Bell & Enßlin A&A 540, A80 (2012)