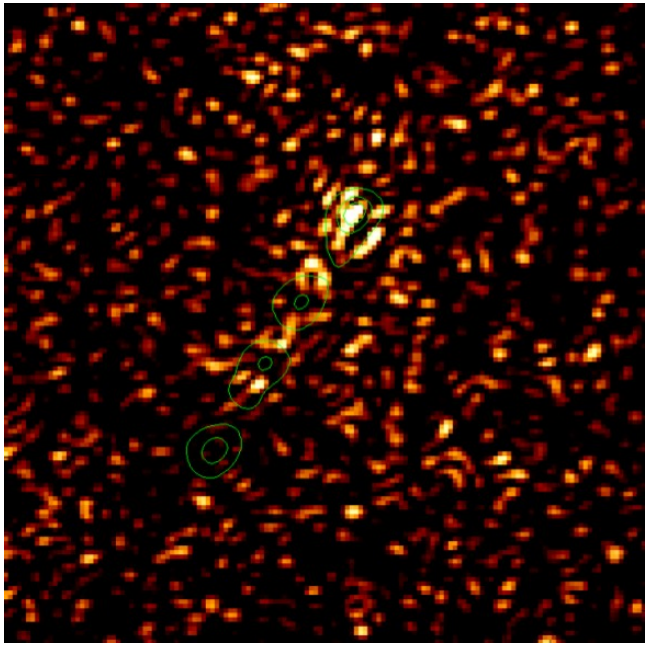
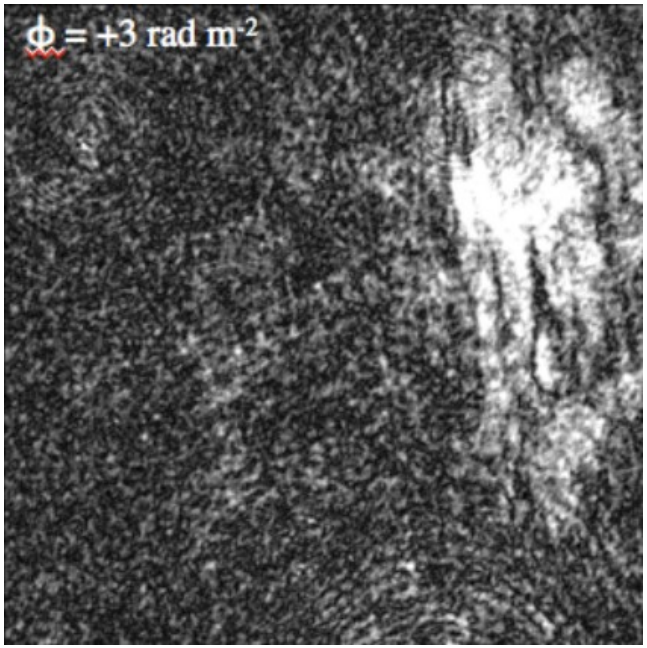
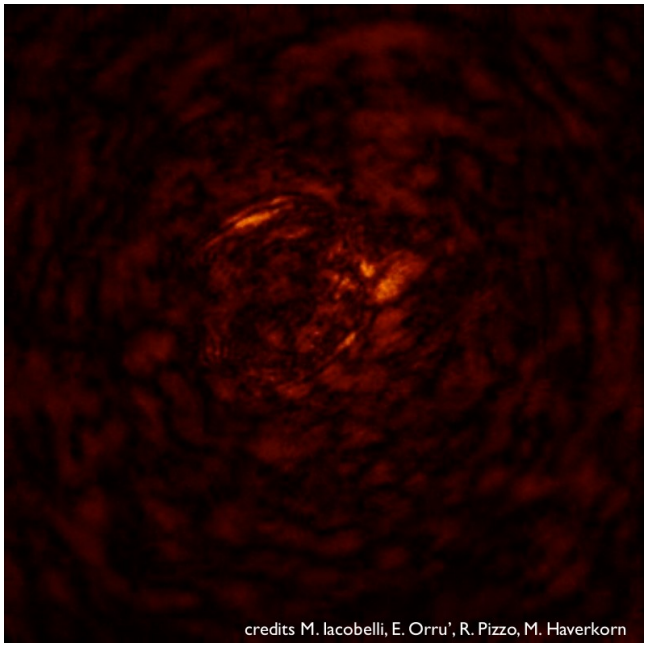
Magnetic Fields in 3D: Polarization results from LOFAR







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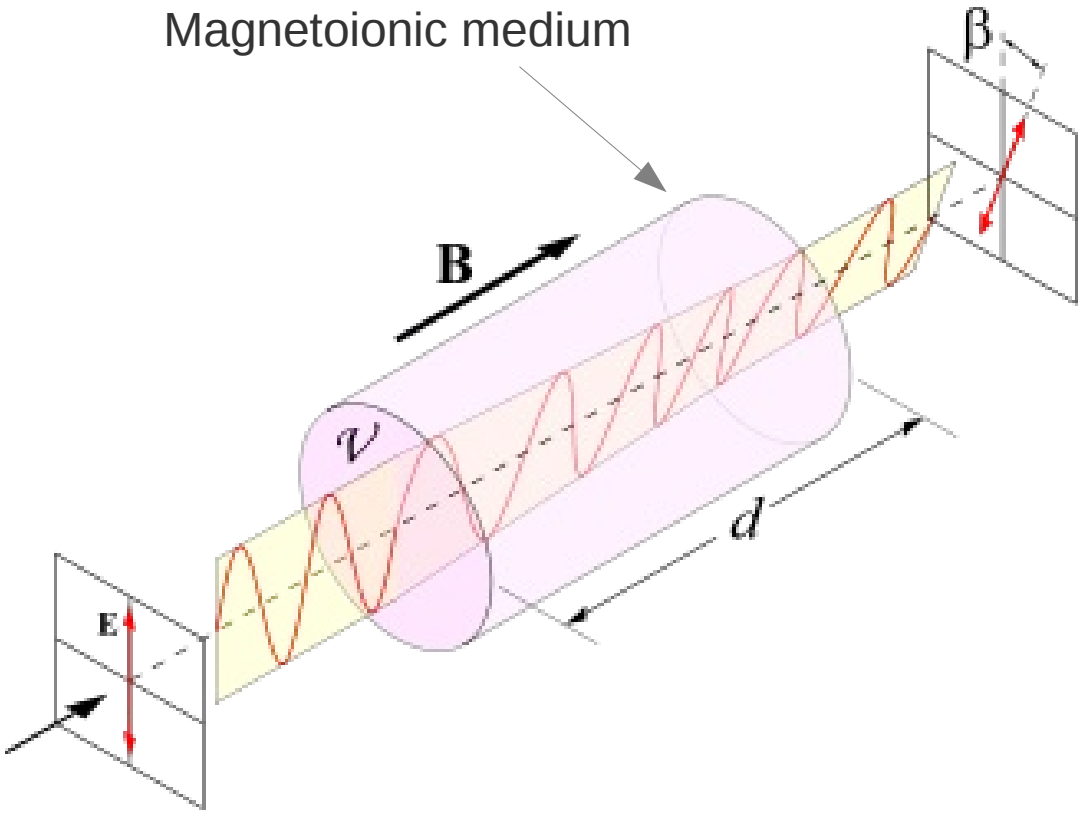
Max-Planck-Institut für Astrophysik

GLOW Annual meeting – Bielefeld – June, 2012

Conclusions

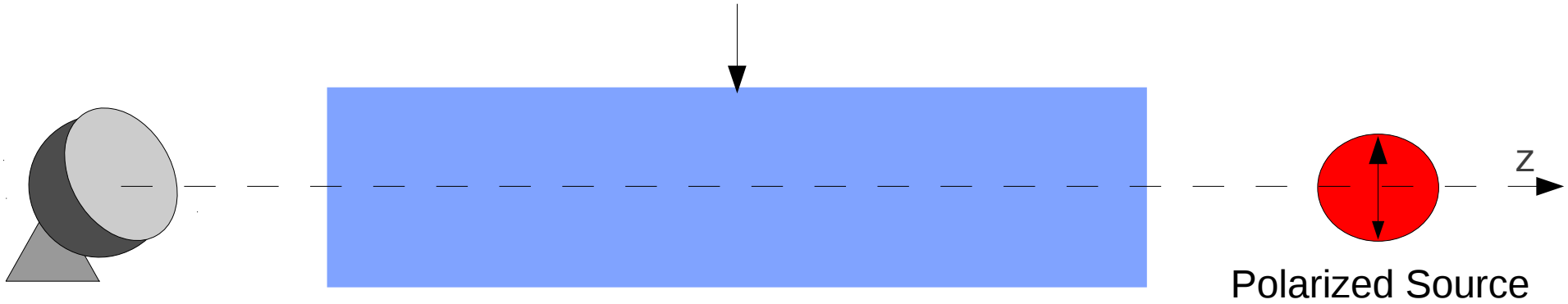
- We can detect polarization w/ LOFAR!
- But we can't do science with the results... yet.
- Data reduction software is (mostly) in place.
- The calibration procedure is still unclear. WIP

Faraday Rotation



Magnetoionic Medium – No emission

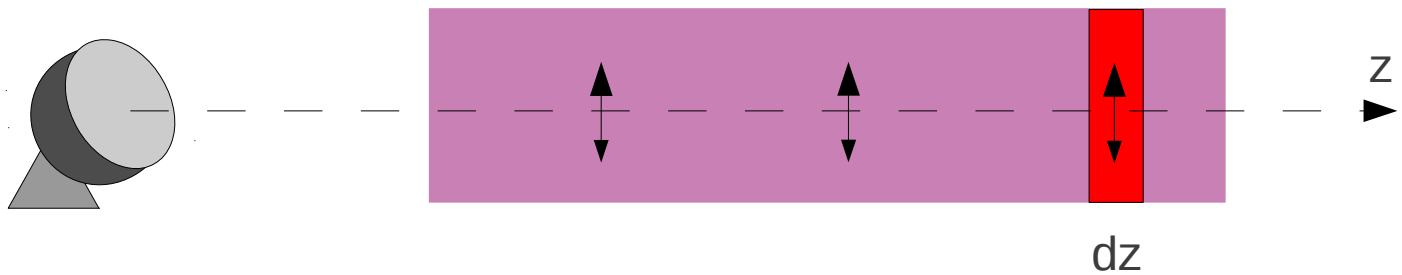
"Faraday screen"



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

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

Faraday Depth



recall

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

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

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

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

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

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

(Burn ,1966)

F(φ) = polarization per Faraday depth = ***Faraday Spectrum***

To invert we use RM synthesis (Brentjens & de Bruyn, 2005)

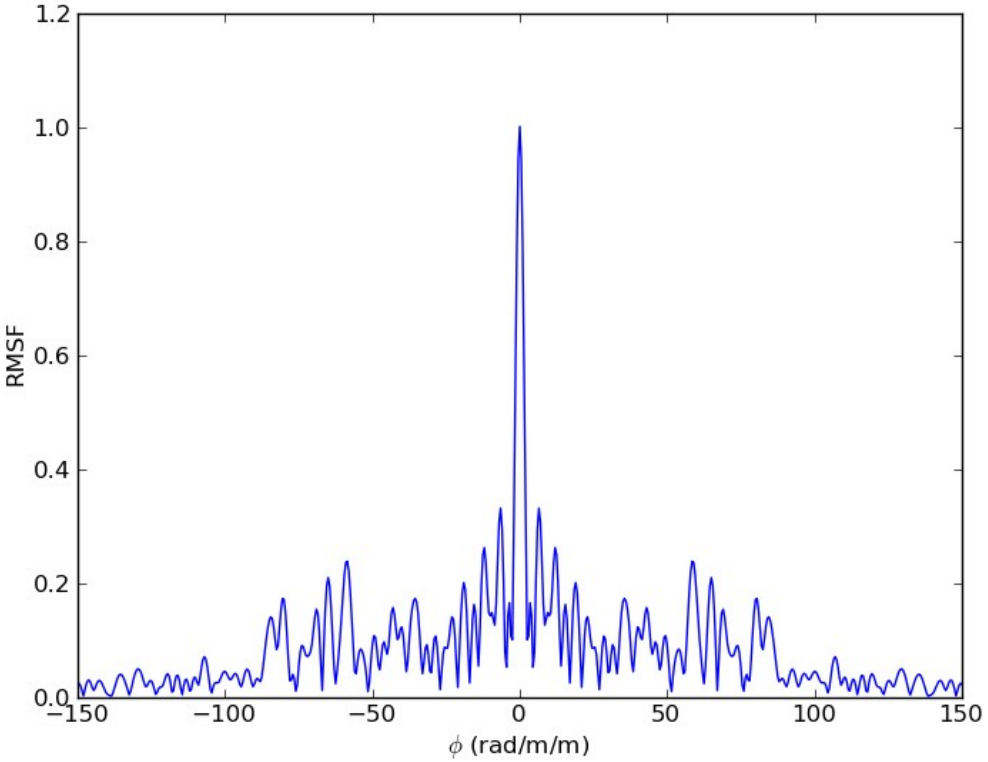
RM Synthesis

- To really invert...

$$F'(\varphi)=\int_{-\infty}^{\infty} d\lambda^2 S(\lambda^2) P(\lambda^2) e^{-2i\varphi\lambda^2} = R(\varphi) * F(\varphi)$$

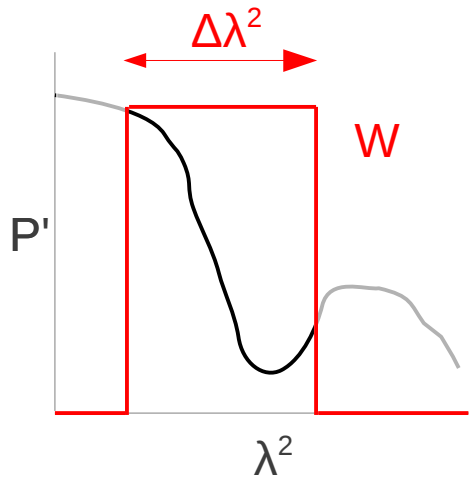
- Just like synthesis imaging, we have a PSF

$$R(\varphi)=\int_{-\infty}^{\infty} d\lambda^2 S(\lambda^2) e^{-2i\varphi\lambda^2}$$



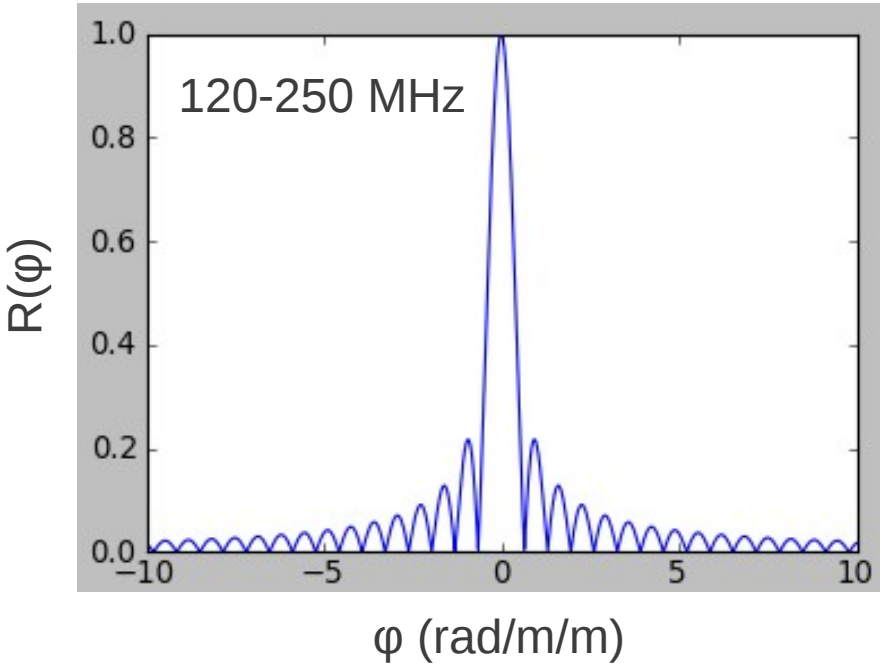
RM Synthesis

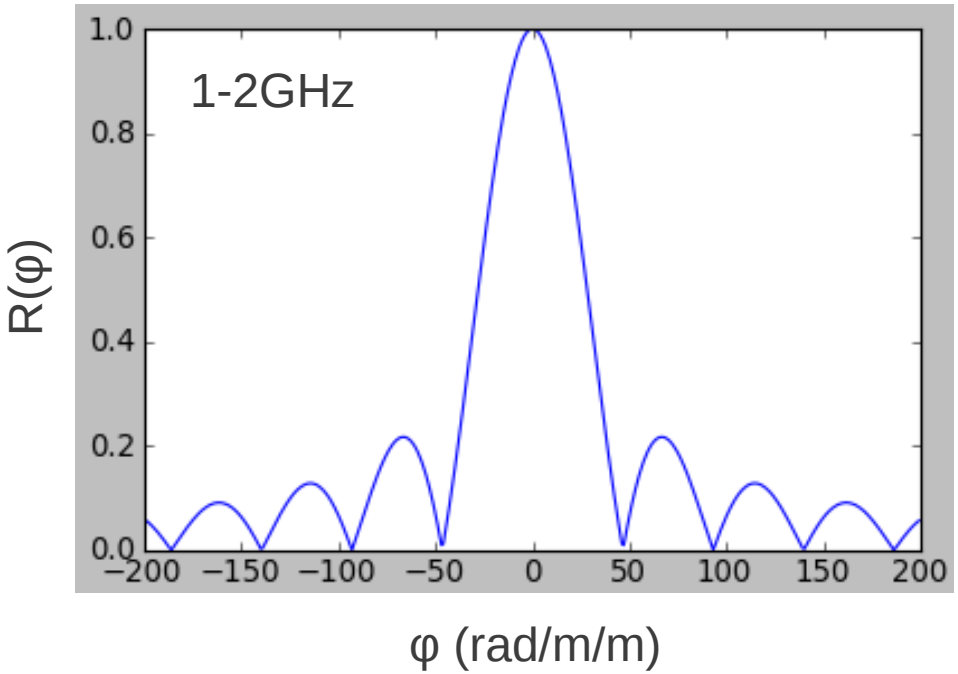
PSF & Resolution



φ resolution

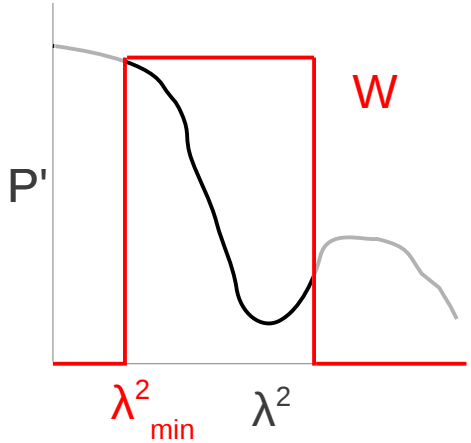
$$\delta\varphi \propto \frac{1}{\Delta\lambda^2}$$





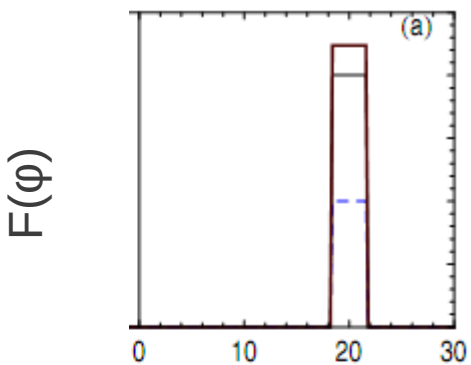
RM Synthesis

Max. scale



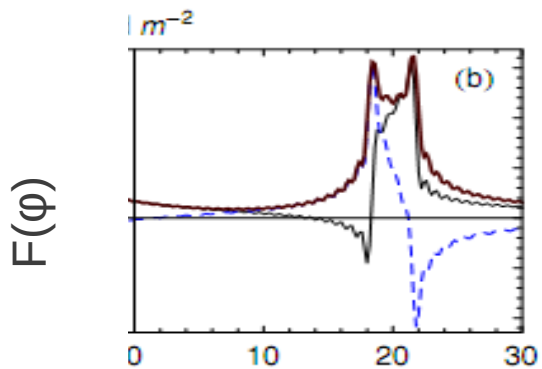
$$Max.\,\varphi\,scale \propto \frac{1}{\lambda^2_{min}}$$

Model F Distribution



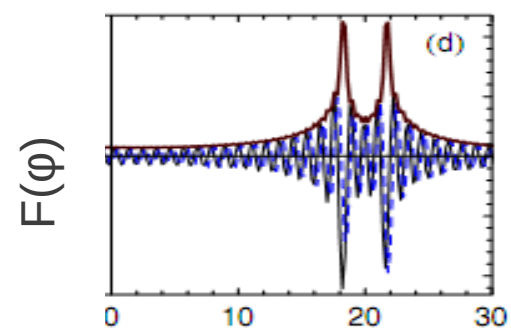
φ (rad/m/m)

$\lambda^2 > 0\ m^2$



φ (rad/m/m)

$0.6\ m^2 < \lambda^2 < 2.5\ m^2$

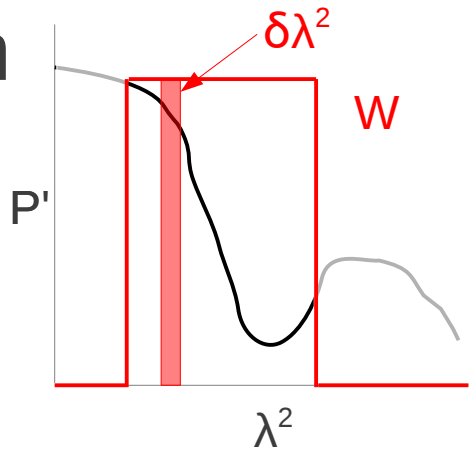


φ (rad/m/m)

Frick et al (2009)

RM Synthesis

- 3rd parameter: Max. Faraday depth
  - Essentially bandwidth depol.
  - Limits averaging options



- LOFAR & RM Synthesis
  - Great resolution: ~1 rad/m/m or better
  - Narrow channels mean sensitivity to high RMs
  - Not sensitive to resolved structure

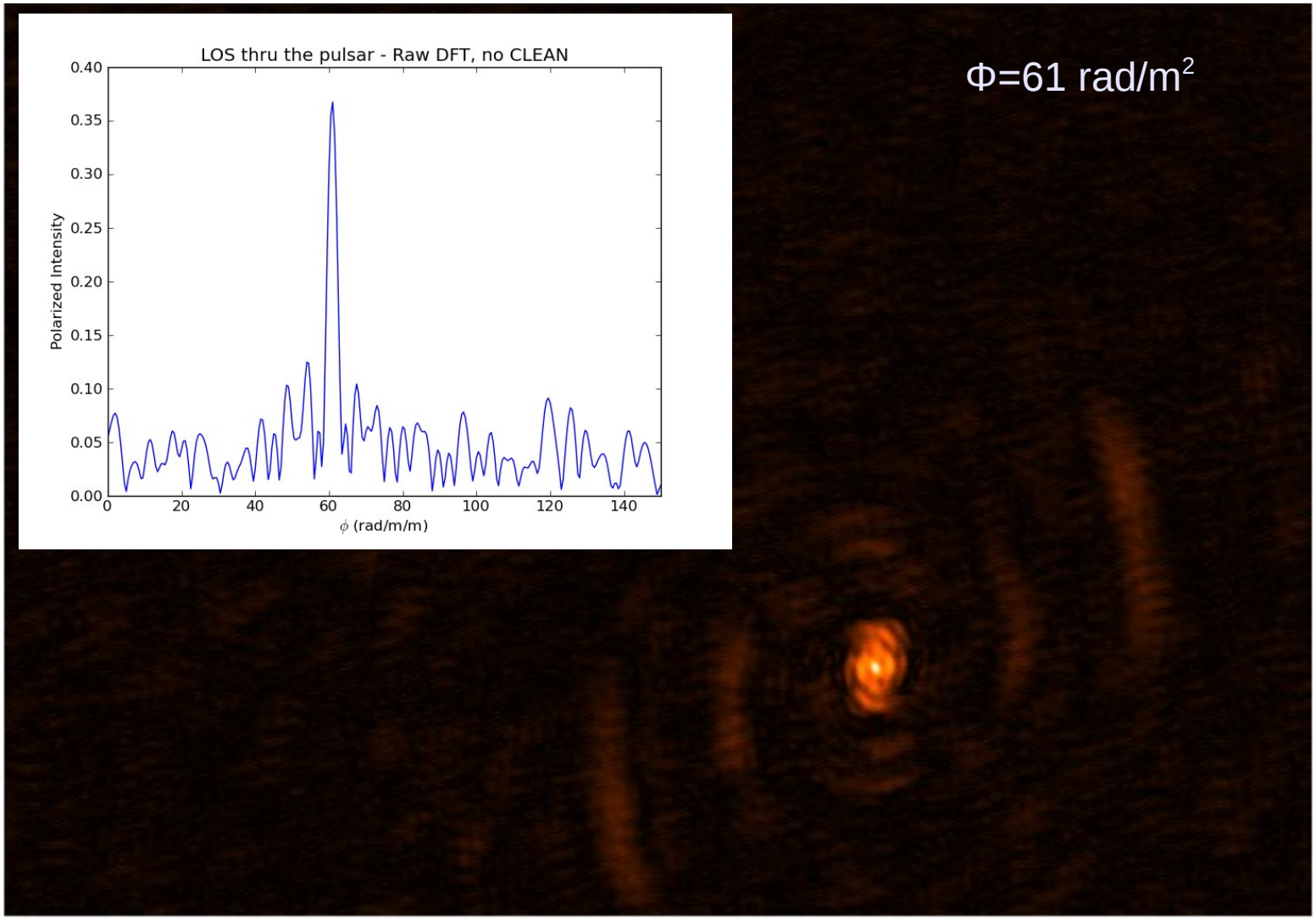
```
mrbell@lce024:~$ /home/mrbell/code/rmclean/rmsynthesis.py -h
Usage: rmsynthesis.py <input parameter file>

Options:
  --version             show program's version number and exit
  -h, --help            show this help message and exit
  -p, --plot_rmsf       Plot the RMSF as soon as it is computed.
  -V, --stokes_v        Produce a Stokes V cube after reading the fits files.
  -s, --separate_stokes
                        Indicate that the Stokes Q and U input images are
                        stored in         separate FITS files.
  -f, --freq_last       Indicate that NAXIS4 is the frequency axis.
  -r, --rest_freq       Indicate that the frequency for an image is given in
                        the RESTFREQ header keyword.
```

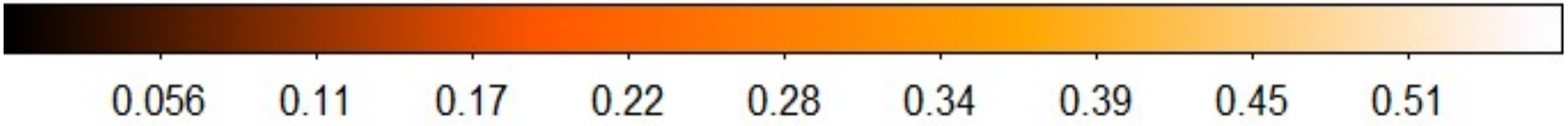
- /home/mrbell/code/rmclean/rmsynthesis.py executable
  /home/mrbell/code/rmclean/rmsynth.par example parset
  /home/mrbell/code/rmclean/README documentation

- Features:
  - Reads in sets of FITS files (MUST HAVE 4 AXES! RA, Dec., Freq., Stokes)
  - Performs RM synthesis w/ or w/out RMCLEAN
  - Variable channel weighting
  - Written mainly in python, but with important bits written in C, so it's still fast

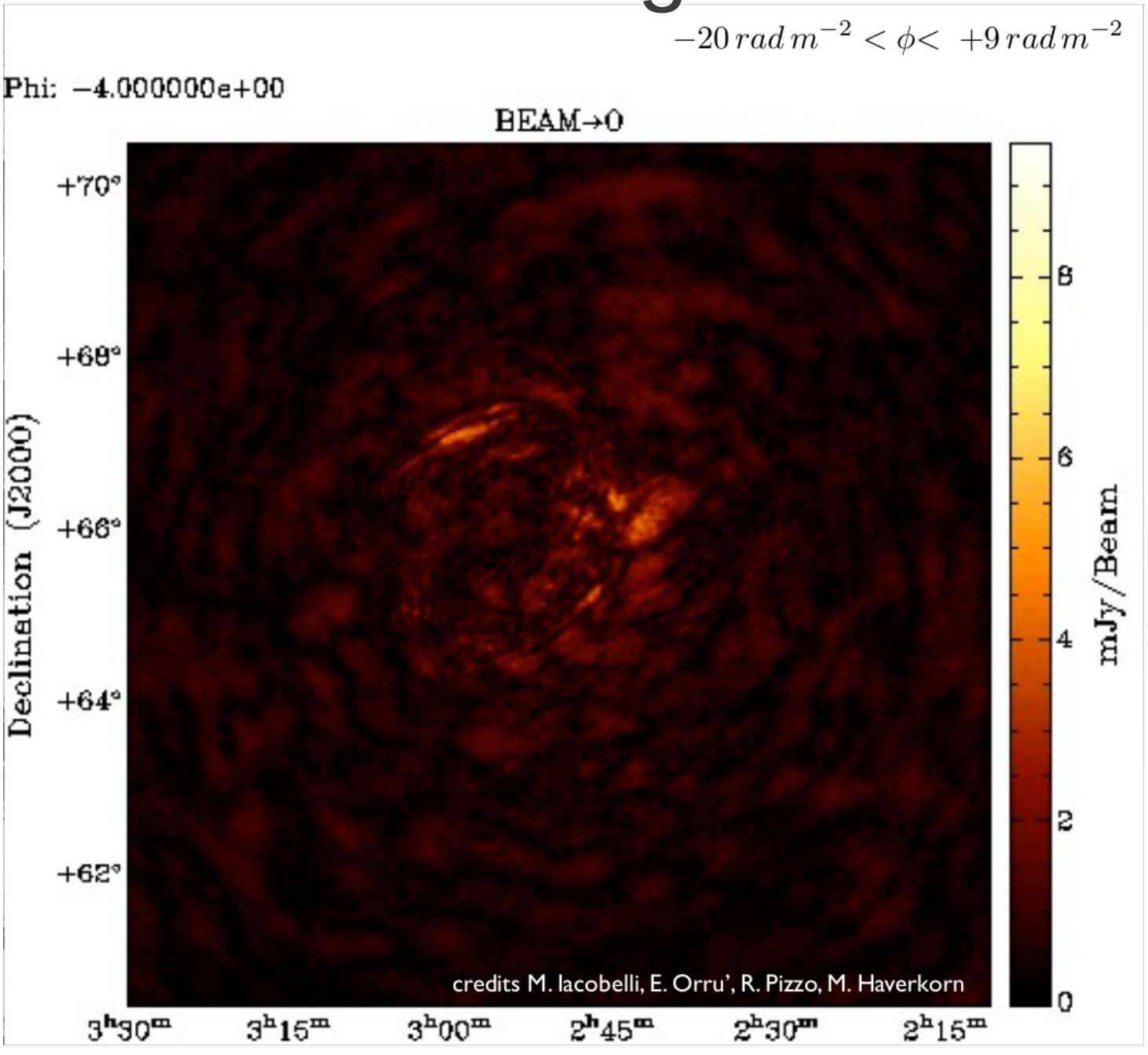
LOFAR Results

PSR J0218

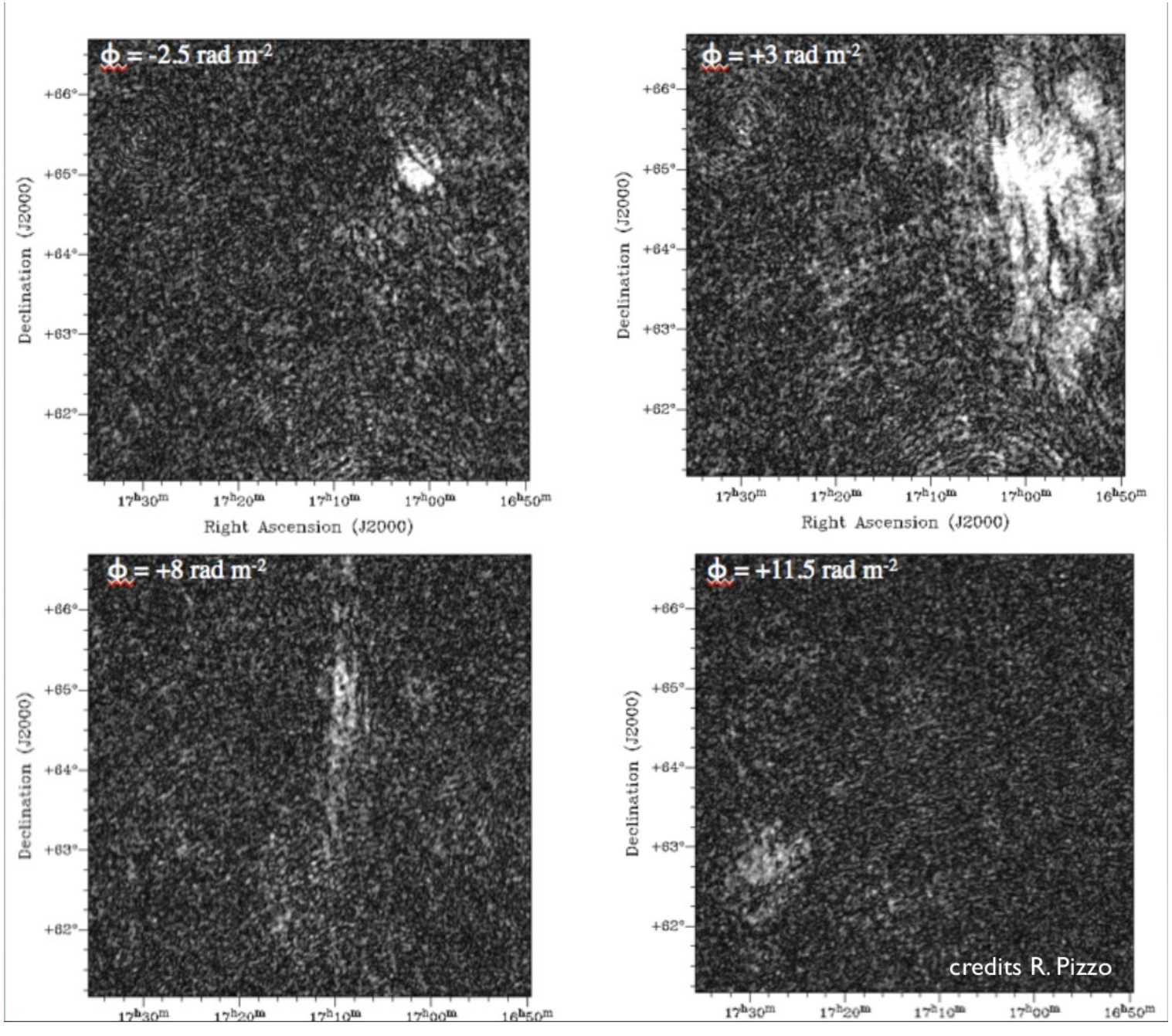

LOS thru the pulsar - Raw DFT, no CLEAN
Polarized Intensity
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
20
40
60
80
100
120
140
ϕ (rad/m/m)
Φ=61 rad/m^2


0.056
0.11
0.17
0.22
0.28
0.34
0.39
0.45
0.51

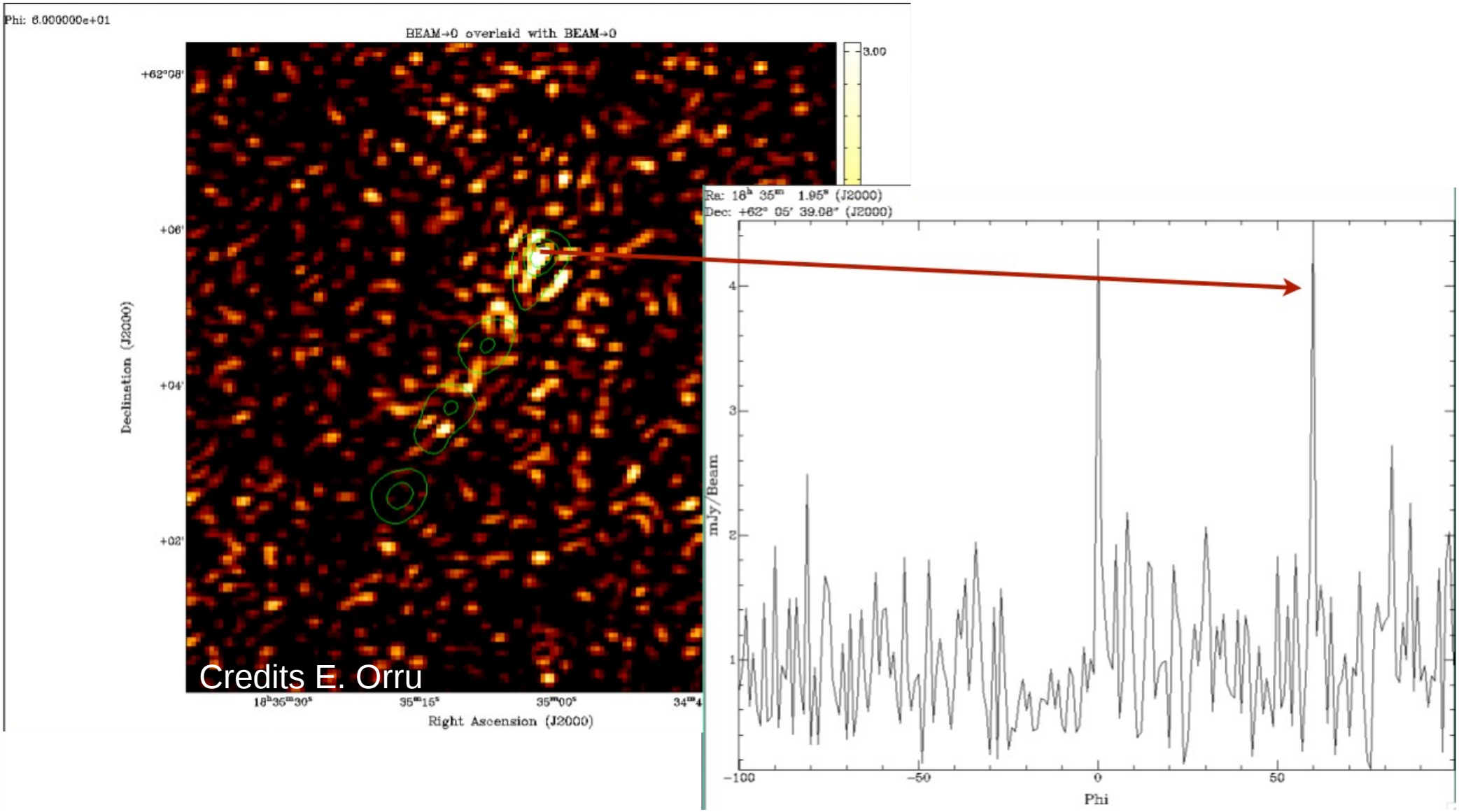
Fan Region


$-20\,rad\,m^{-2} < \phi < +9\,rad\,m^{-2}$
Phi: −4.000000e+00
BEAM→0
+70°
+68°
+66°
+64°
+62°
Declination (J2000)
3h30m
3h15m
3h00m
2h45m
2h30m
2h15m
8
6
4
2
0
mJy/Beam
credits M. Iacobelli, E. Orru', R. Pizzo, M. Haverkorn

Abell 2255


Φ = -2.5 rad m-2
Φ = +3 rad m-2
Φ = +8 rad m-2
Φ = +11.5 rad m-2
Declination (J2000)
Right Ascension (J2000)
+66°
+65°
+64°
+63°
+62°
17h30m
17h20m
17h10m
17h00m
16h50m
credits R. Pizzo

Double Double Radio Galaxy

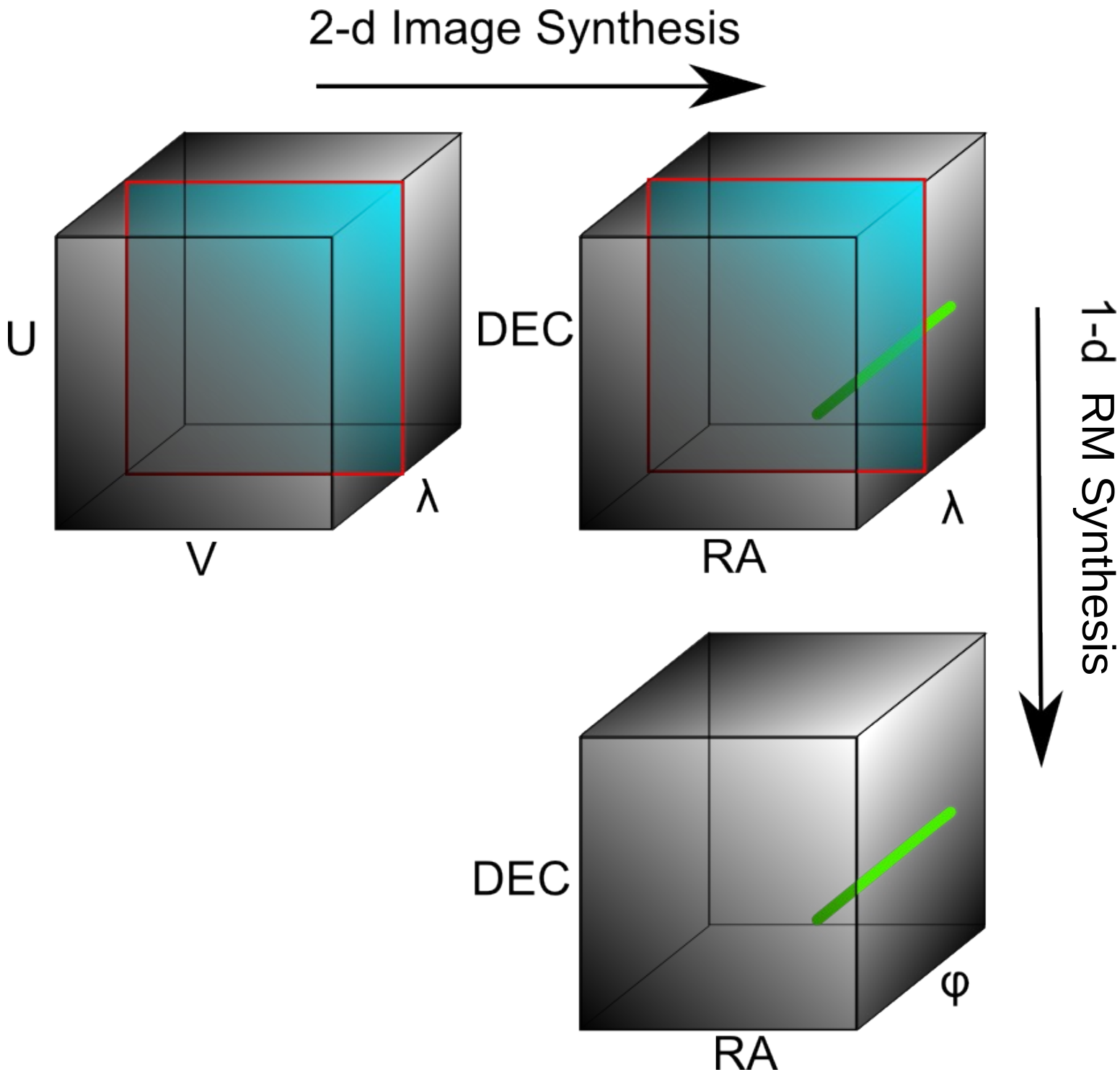


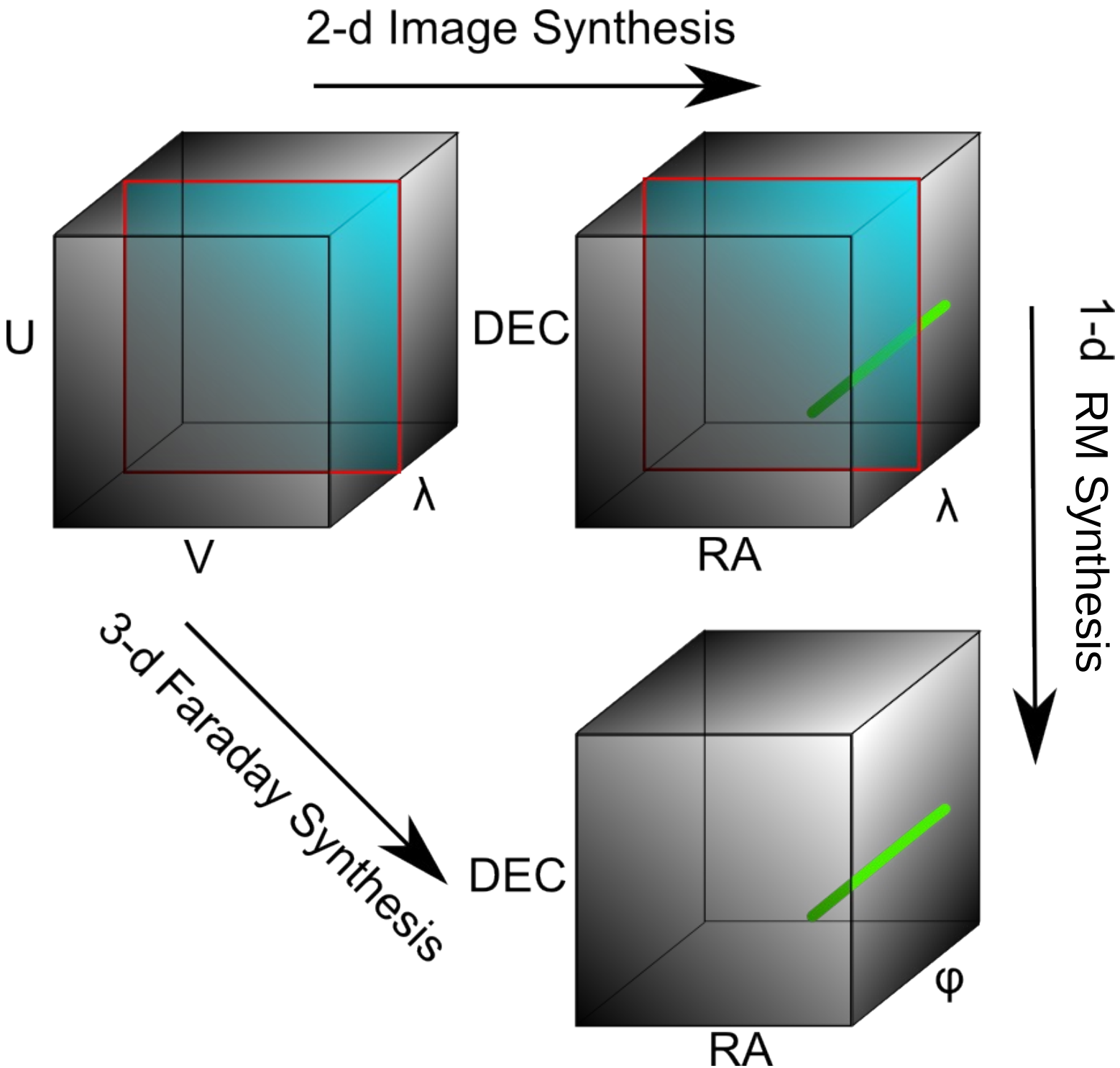
Credits E. Orru

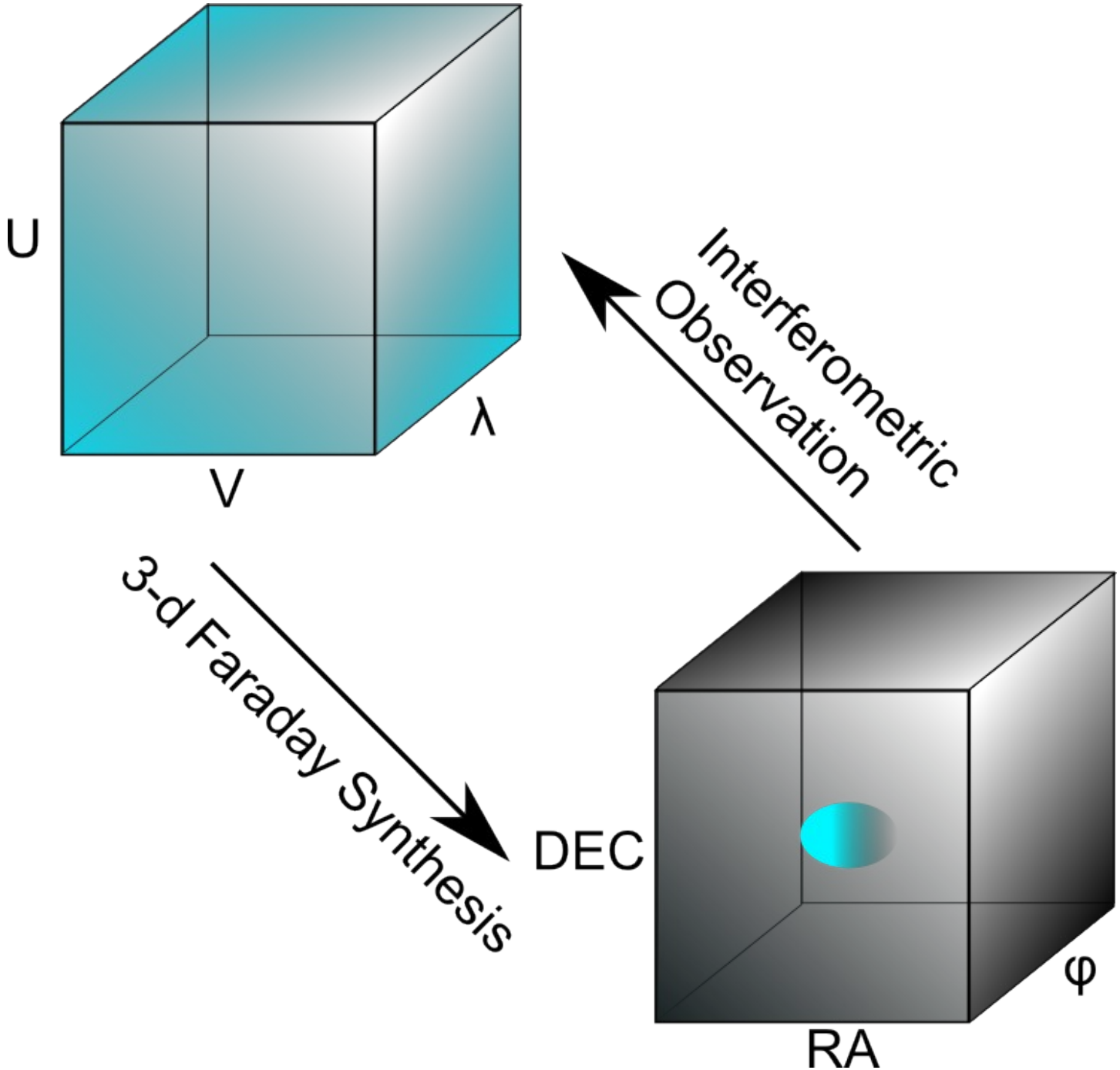
Future plans

TODO

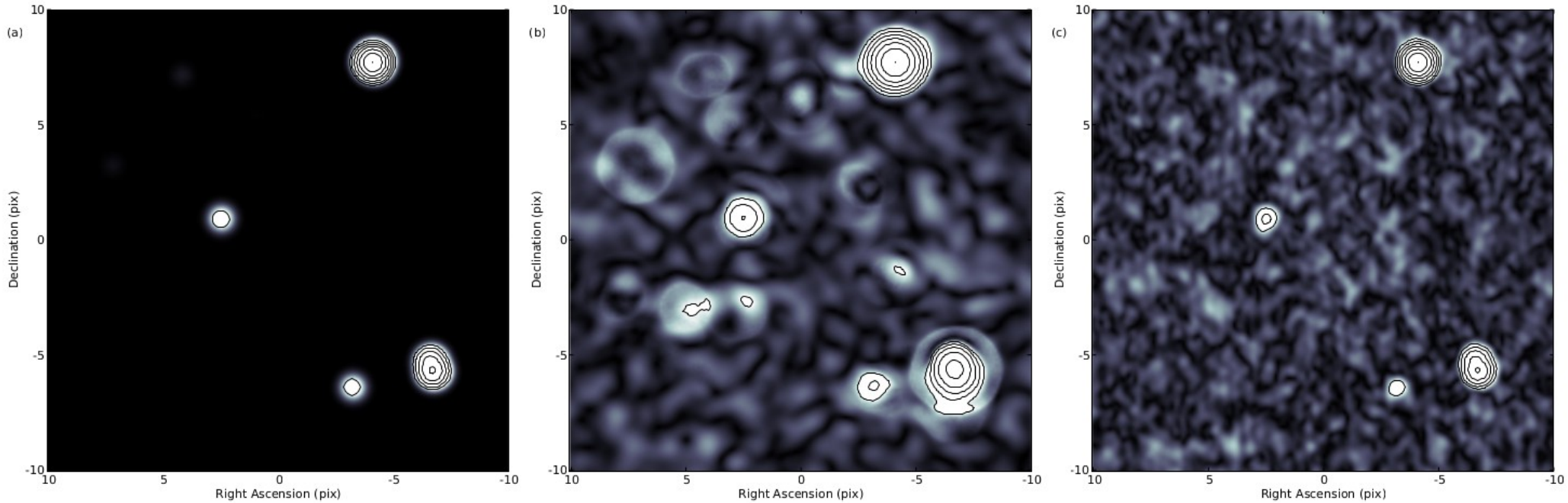
- Commissioning, commissioning, commissioning
- Improve current rmsynthesis.py code
  - Parallelize
  - Wider file I/O support (LOFAR image pipeline format)
  - Mask support
- Specify “training data”
  - Test algorithms & understand their limits
  - Working together with POSSUM


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


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


U
V
λ
Interferometric
Observation
3-d Faraday Synthesis
DEC
RA
φ

Faraday Synthesis



Bell & Enßlin, A&A, Volume 540, A80 (2012), arXiv:1112.4175

Conclusions

- We can detect polarization w/ LOFAR!
- We can't do science with the results... yet.
- All of the software is (mostly) in place.
- The calibration procedure is unclear. WIP