Probing the interstellar magnetic field with LOFAR

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Zandvoort, 2015

Outline

- Introduction
- Investigation of magnetic field with RM synthesis technique
- Behavior of RM in ionosphere and ISM
- Results and Discussion

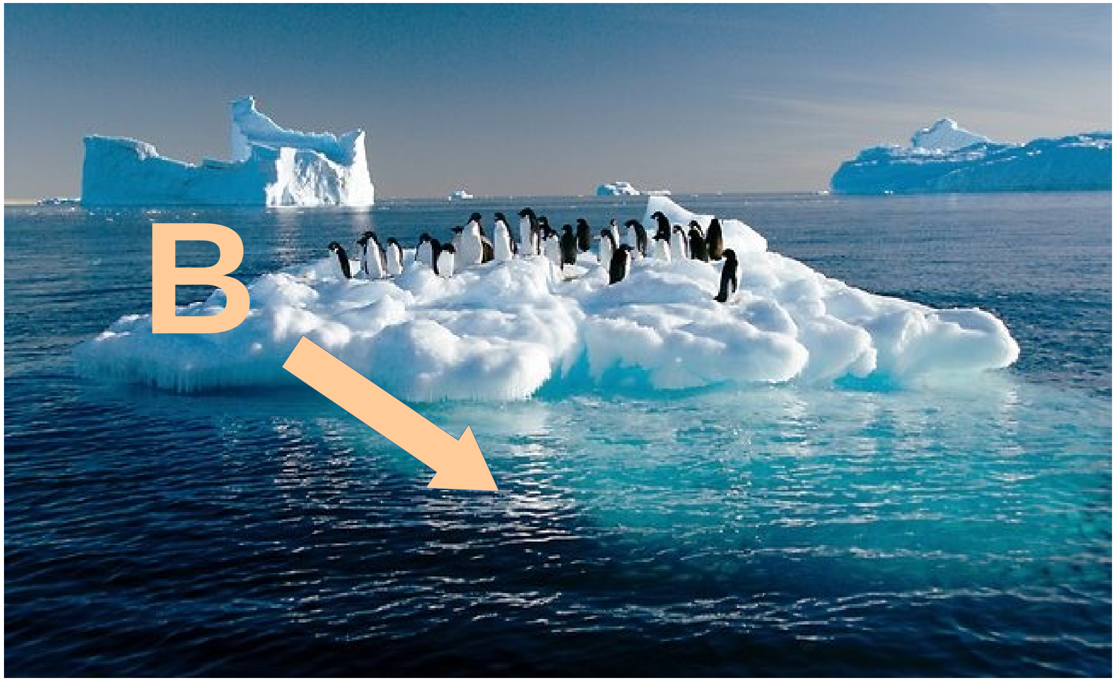
The role of Magnetism in the Universe

In Cosmology:

- Origin of magnetism (e.g. via RM of CMB)
- Role in birth of first star and galaxies

In everyday astrophysics:

- Dynamics of cosmic rays
- Extremes of dynamo theory
- Physics of active galaxies and SMBHB
- Influence on formation processes of stars, supernovae explosions



Credit: Bryan Gaensler

Different ways of magnetic field investigation

- Optical starlight polarization $B\perp(\textit{orientaton}, \textit{but not direction})$
- Synchrotron emission/polarization
- Zeeman splitting $B//(\textit{really high magnetic fields})$

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- Optical starlight polarization $B \perp (orientaton, but\ not\ direction)$
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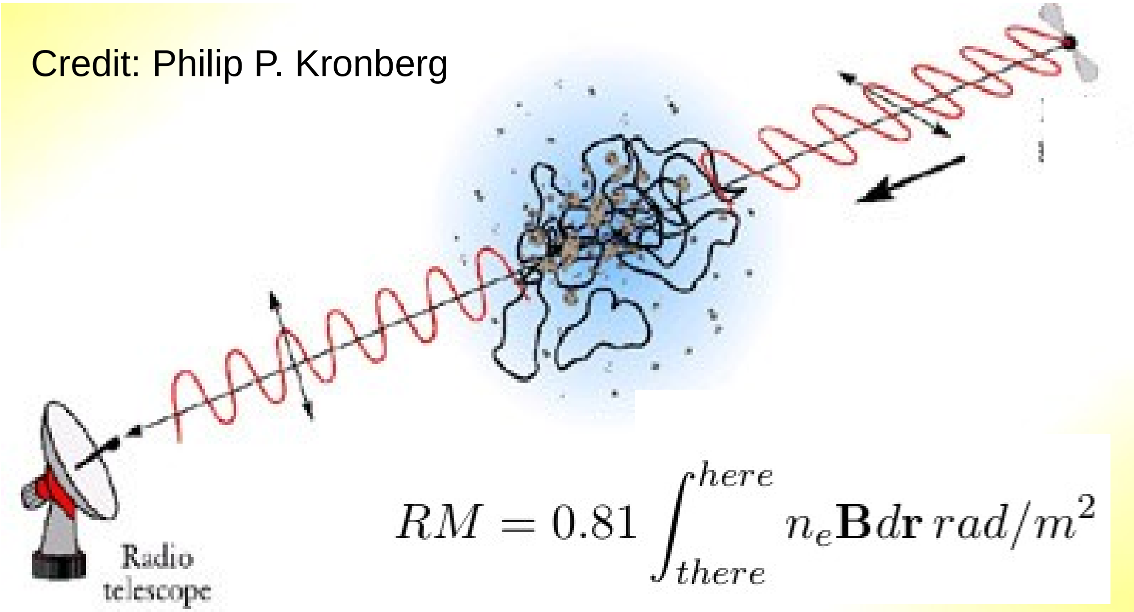
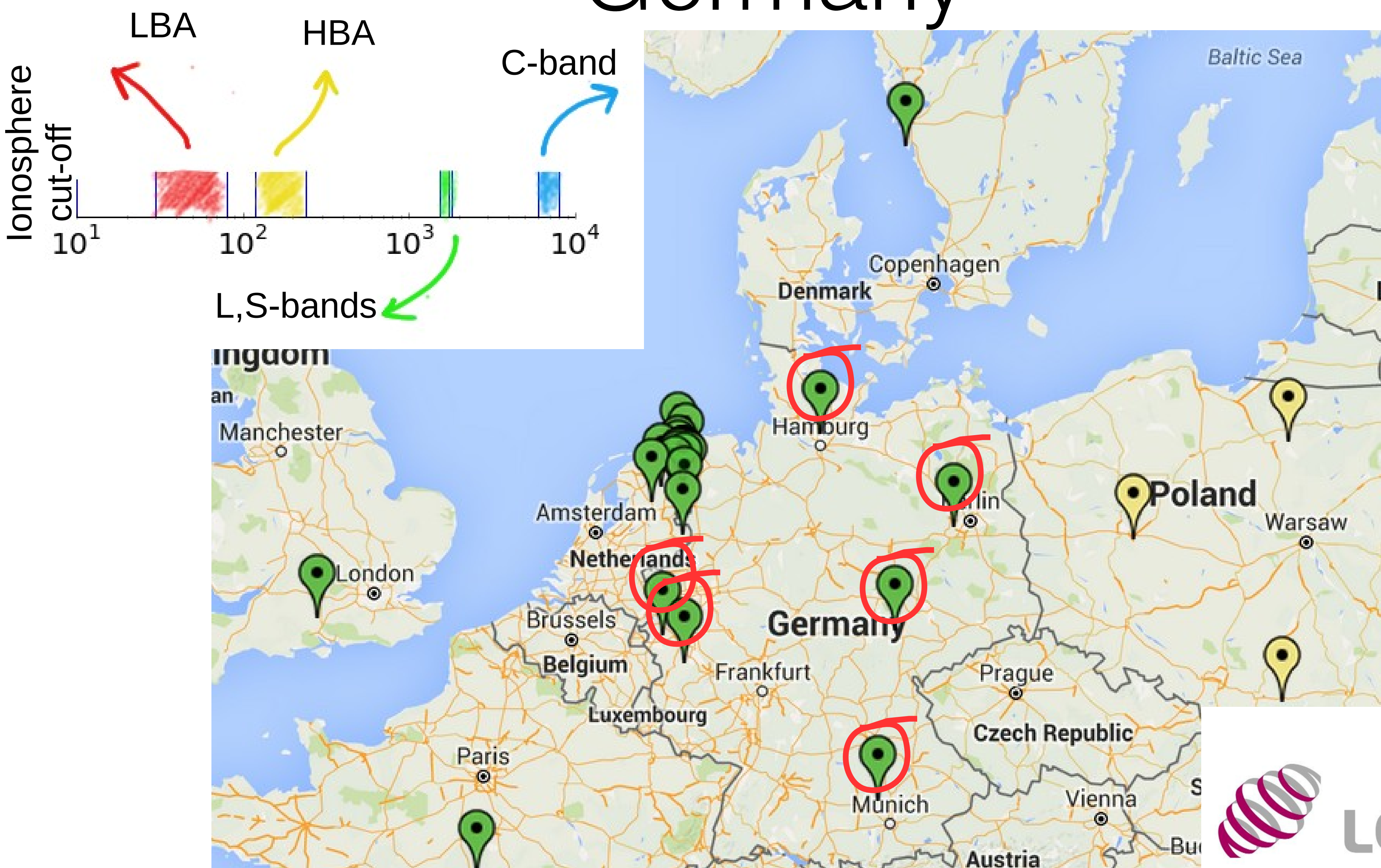
- Faraday rotation $\psi = \psi_0 + RM\lambda^2$

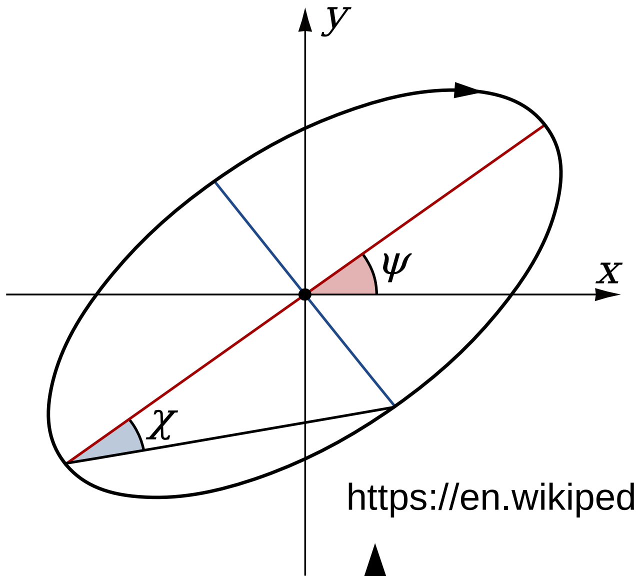


$$RM = 0.81 \int_{there}^{here} n_e \mathbf{B} d\mathbf{r}\ rad/m^2$$

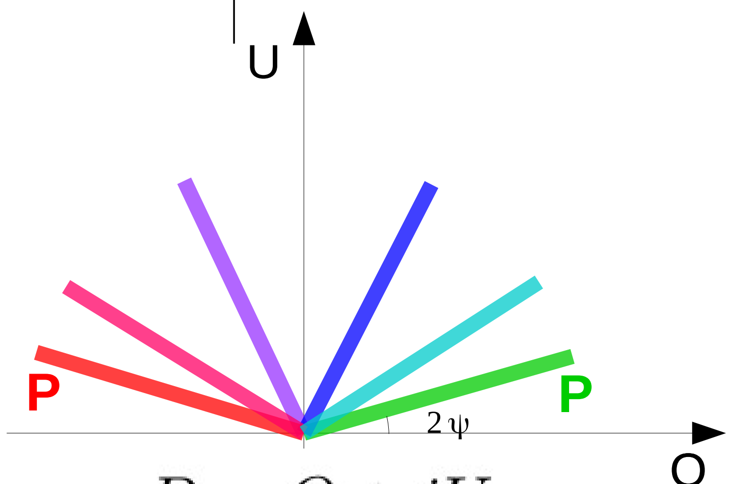
GLOW: LOFAR found shelter in Germany



RM synthesis: brief theory



https://en.wikipedia.org



$$P = Q + iU$$

$$\psi = \psi_0 + RM\lambda^2$$

$$RM = 0.81 \int_{there}^{here} n_e \mathbf{B} d\mathbf{r}\, rad/m^2$$

$$E_x, E_y, \delta$$

$$\Downarrow$$

$$I(\lambda^2)$$

$$Q(\lambda^2) = Icos(2\chi)cos(2\psi) = I_L cos(2RM\lambda^2)$$

$$U(\lambda^2) = Icos(2\chi)sin(2\psi) = I_L sin(2RM\lambda^2)$$

$$V(\lambda^2) = Isin(2\chi)$$

Burn 1966, Brentjens and de Bruyn 2005

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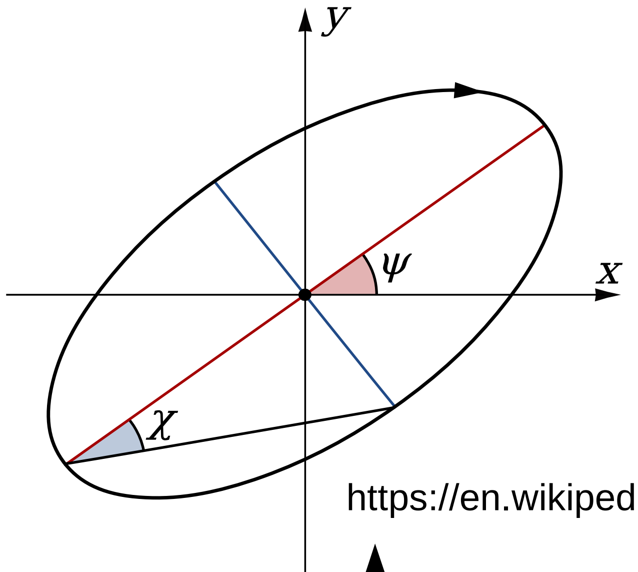

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$$RM = 0.81 \int_{there}^{here} n_e \mathbf{B} d\mathbf{r} \, rad/m^2$$

$$E_x, E_y, \delta$$

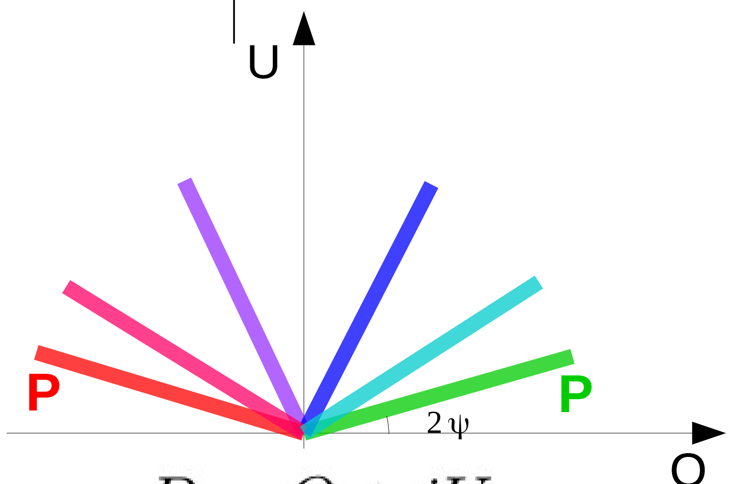
↓

$$I(\lambda^2)$$

$$Q(t) = I cos(2\chi) cos(2\psi) = I_L cos(2\omega t)$$

$$U(t) = I cos(2\chi) sin(2\psi) = I_L sin(2\omega t)$$

$$V(\lambda^2) = I sin(2\chi)$$



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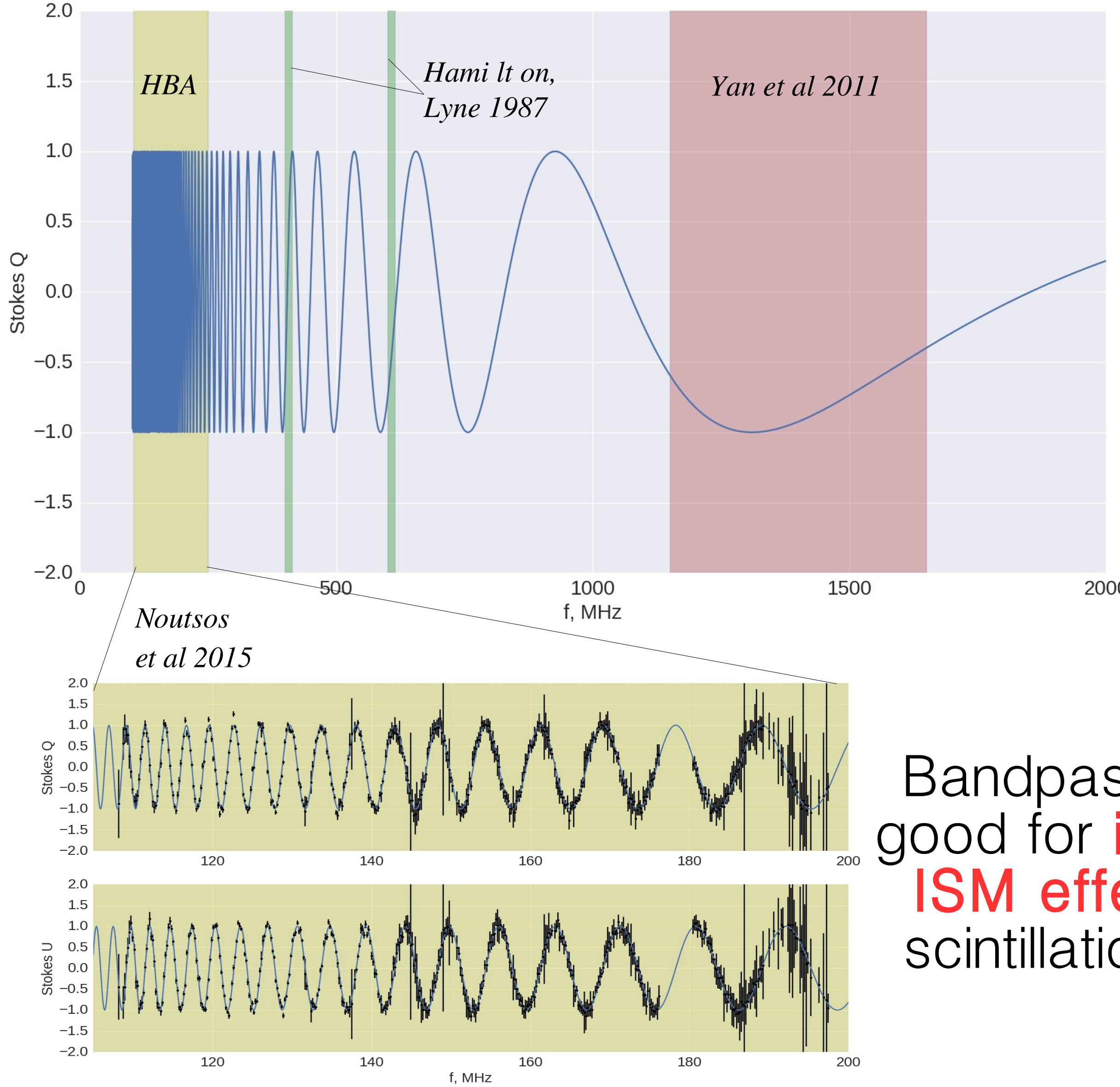
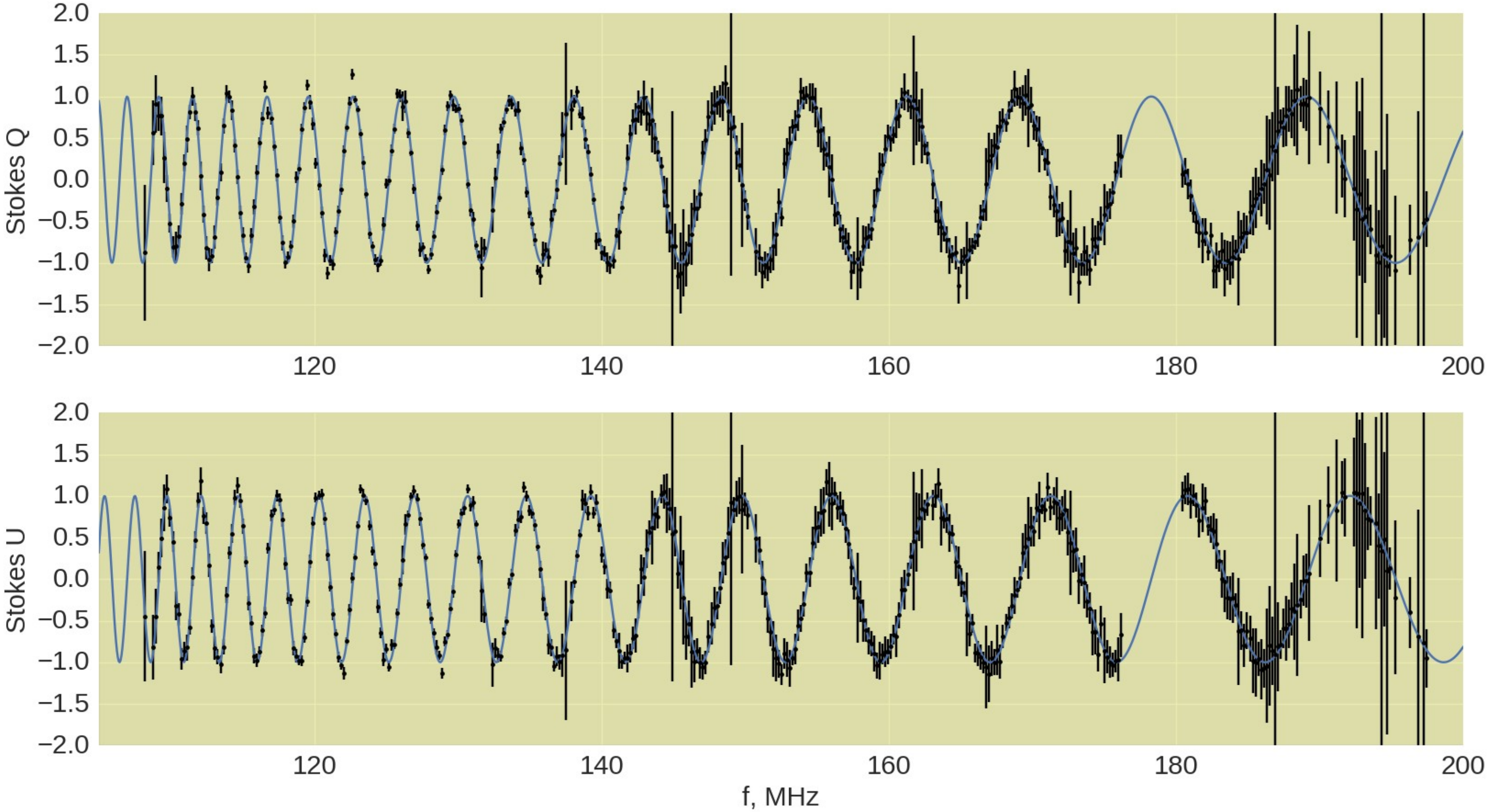
Q and U Stokes: examples



Bandpass is particularly good for **investigation of ISM effects** (DM, RM, scintillations, scattering)

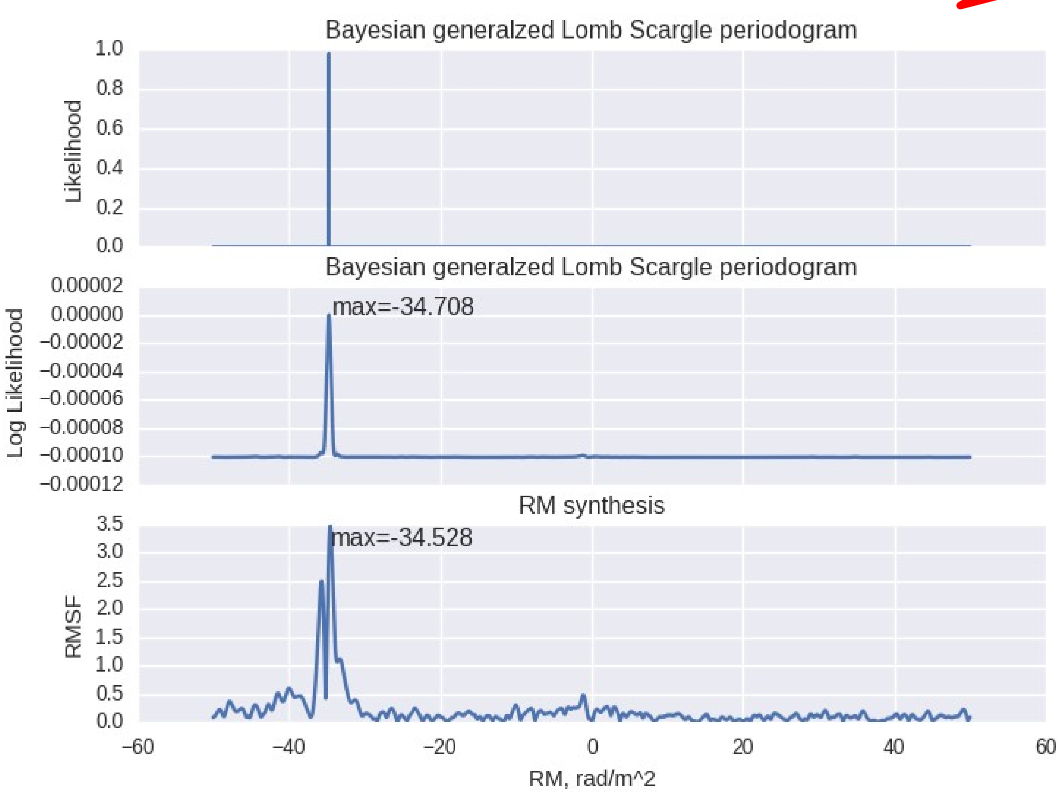
Q and U Stokes: examples



Bayesian LSP vs RM synthesis

- Works with unevenly sampled data
- Accounts for error bars
- Correct estimation of the error

Results for J2219+4754,
RM ~ -34 rad/m^2



Bretthorst 2001, Mortier

$$P(RM|data) \sim \int P(RM, A, B, \gamma_{\mathfrak{I}}, \gamma_{\mathfrak{R}}|data)\, dA\, dB\, d\gamma_{\mathfrak{R}}\, d\gamma_{\mathfrak{I}}$$

Posterior probability

Discrete Fourier transform

$$S(RM) \sim \left(\sum P(\lambda^2) \exp(-2 RM \lambda^2)\right)^2$$

Burn 1966, Brentjens and de Bruyn 2005

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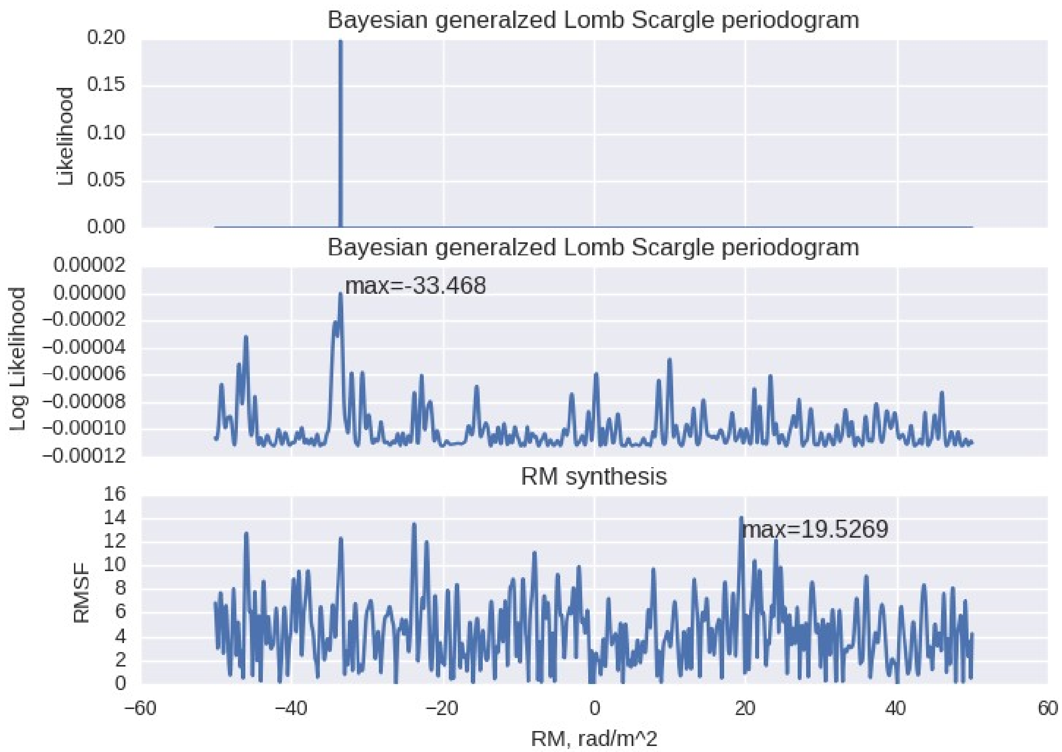

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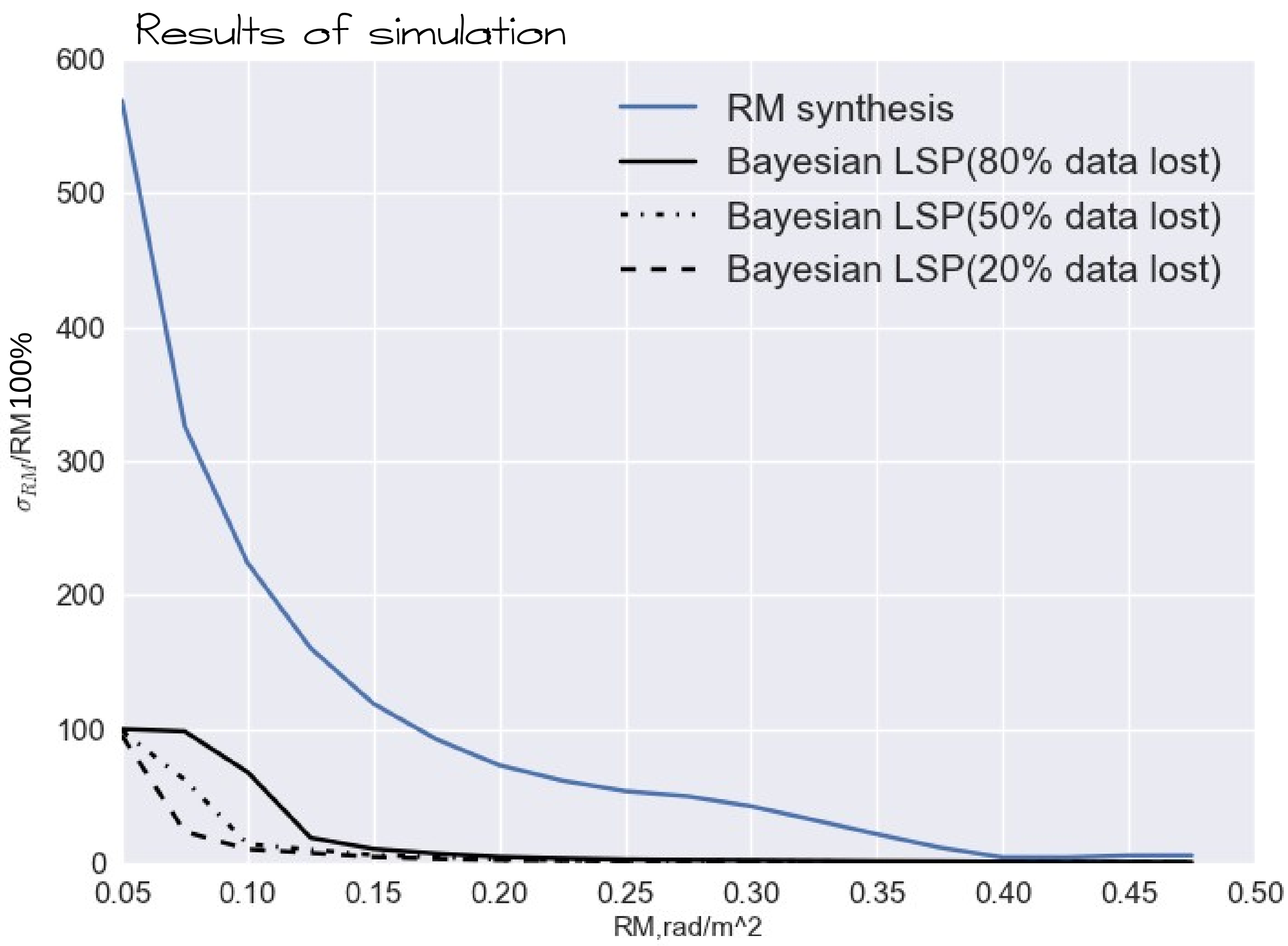
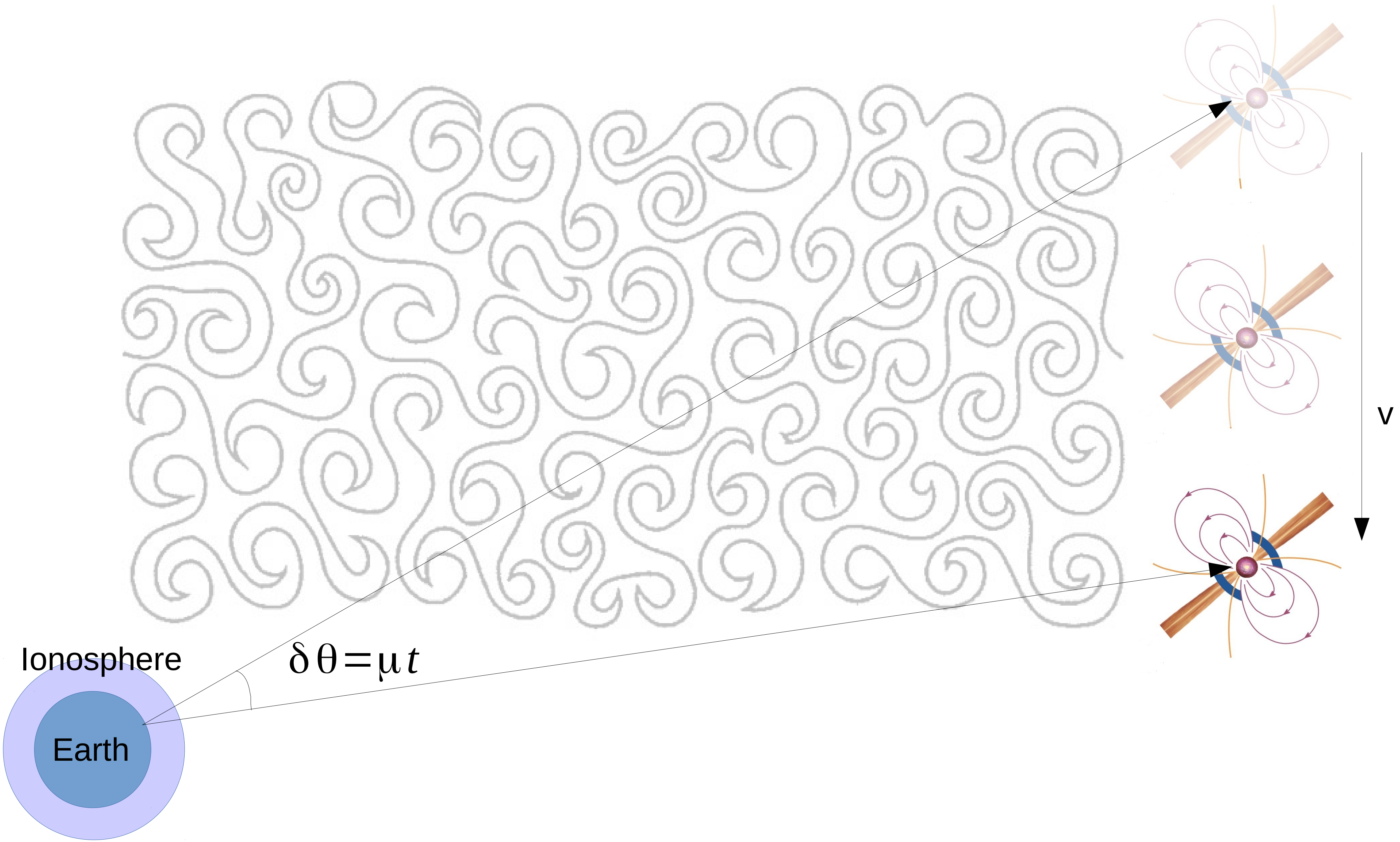


To do:

Determine significance of the pick!

Schnitzeler et al, in prep.

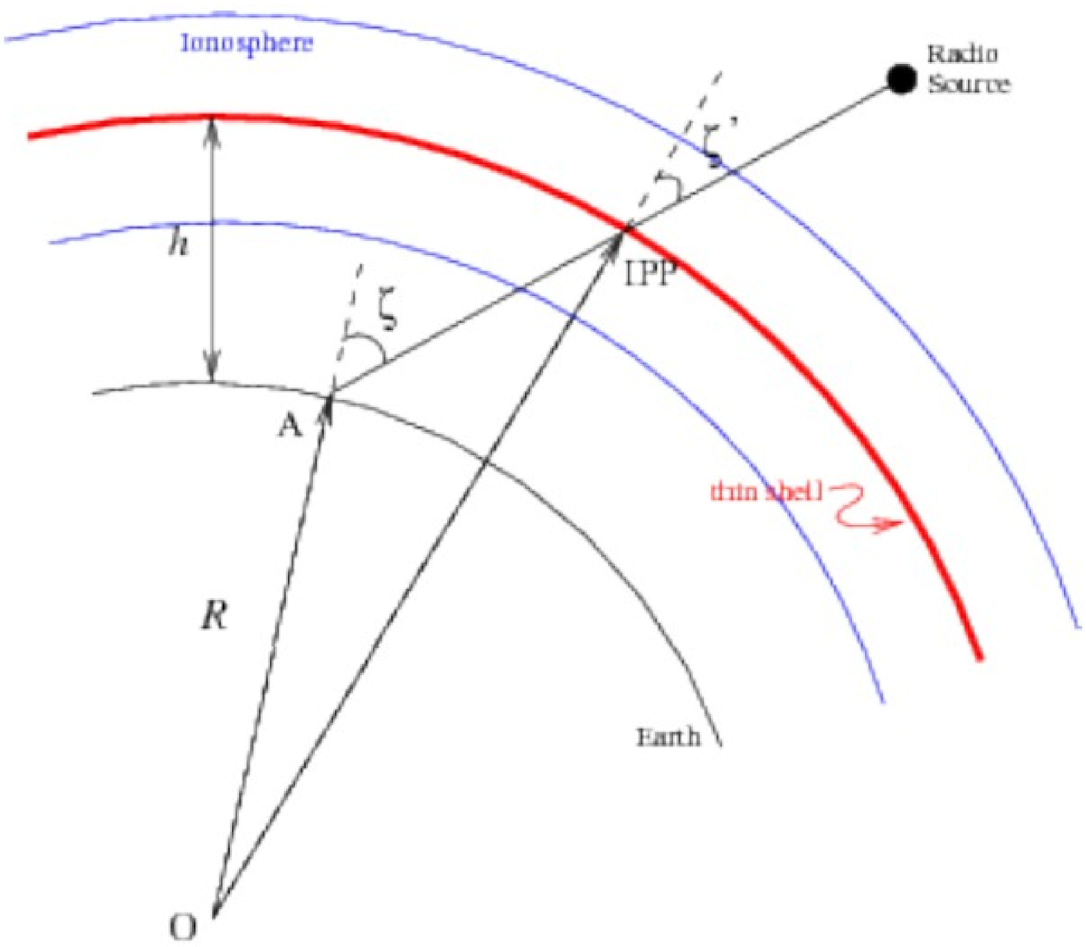
Sources of RM variations



Sources of RM variations

- For ionosphere we are using ionFR script with ROBR data ★★★★★★★★★★

http://sourceforge.net/projects/ionfr/, Sotomayor-Beltran et al, 2013



Sources of RM variations

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- For ISM we assume red noise energy wavenumber spectrum for both magnetic field and electron density

$$E_n = C_n^2 (\frac{k}{k_0})^\alpha$$

$$E_B = C_B^2 (\frac{k}{k_0})^\beta$$

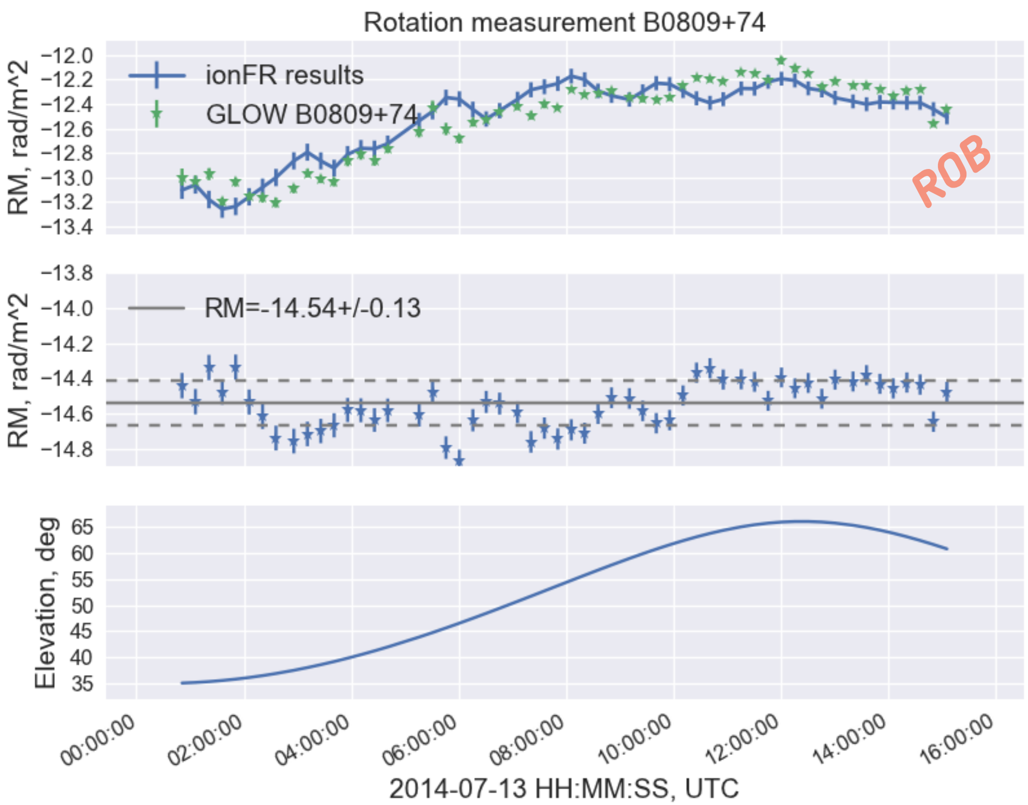
$$D_{RM}(\delta t) =< [RM(t) - RM(t+\delta t)]^2$$

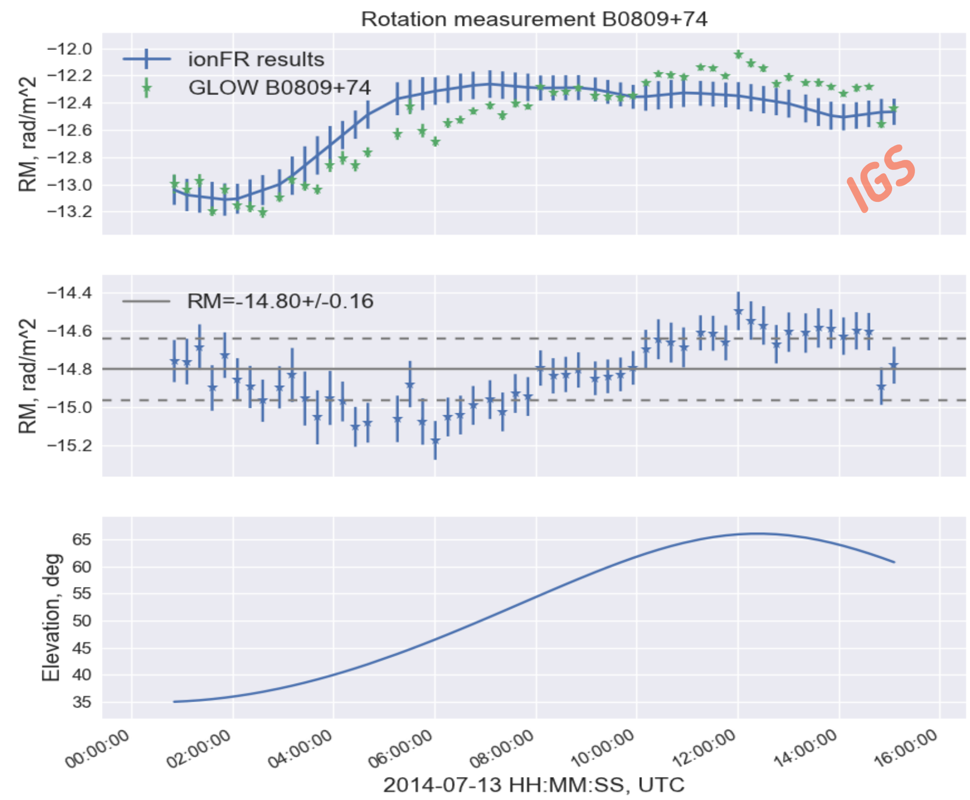
Minter, Sapngler 1996, Haverkorn 2008

$$C_{RM}(\delta t) =< [RM(t) RM(t+\delta t)] >$$

Leonardo Da Vinci

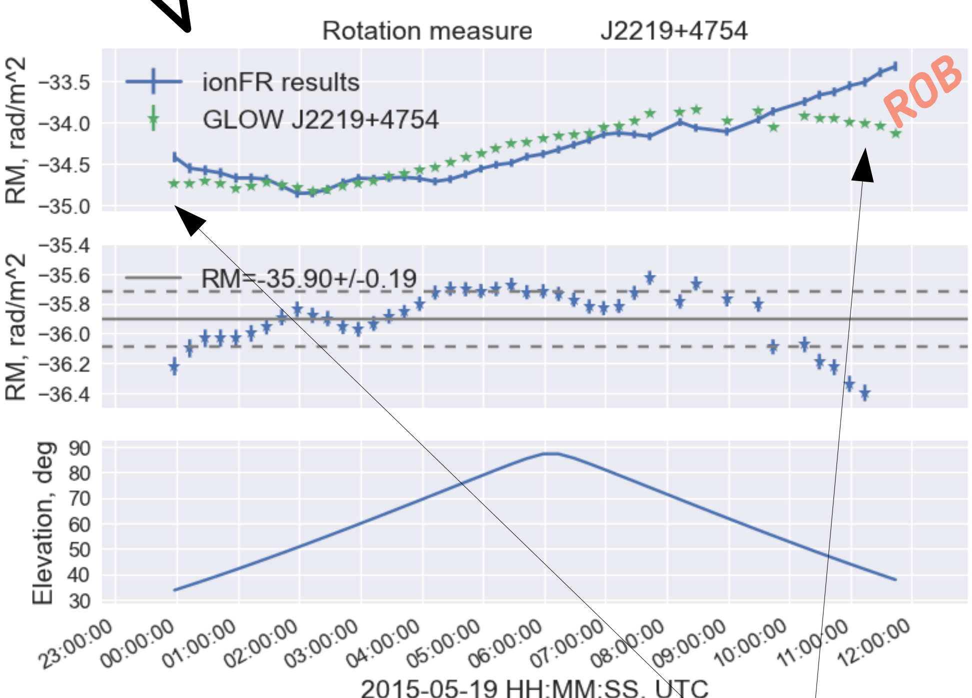
IonFR implementation





IonFR implementation

After calibration



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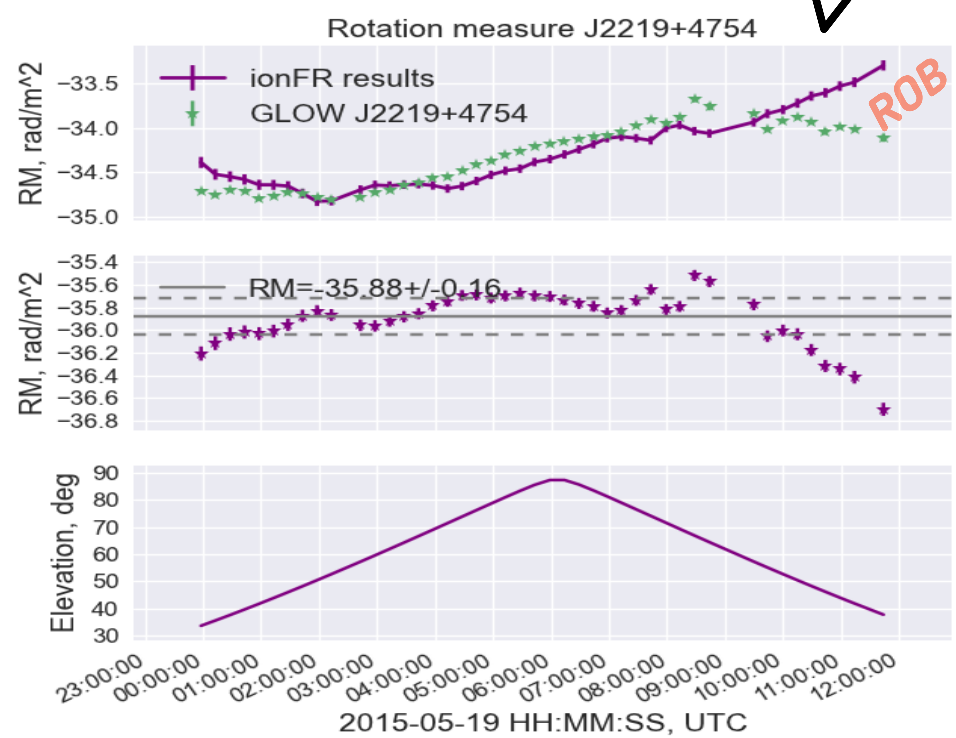
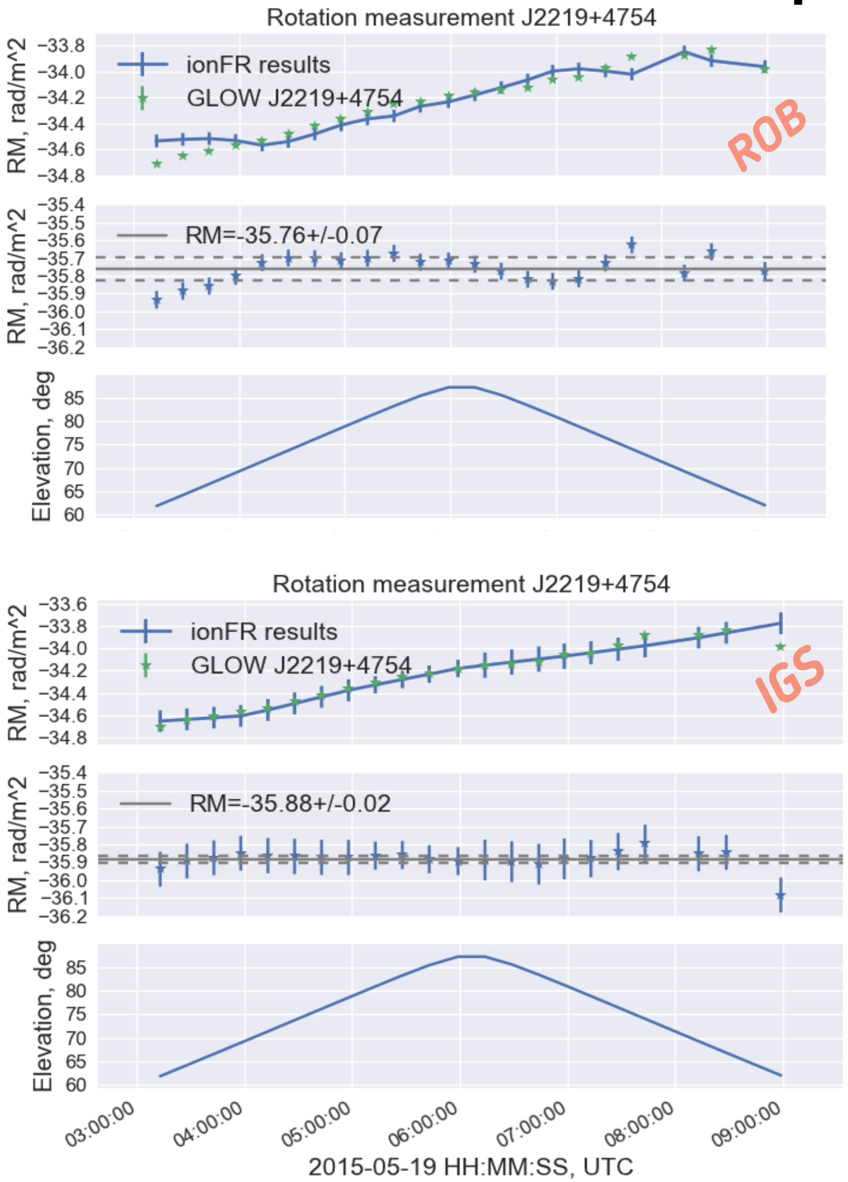


Single layer model can't be used

IonFR implementation



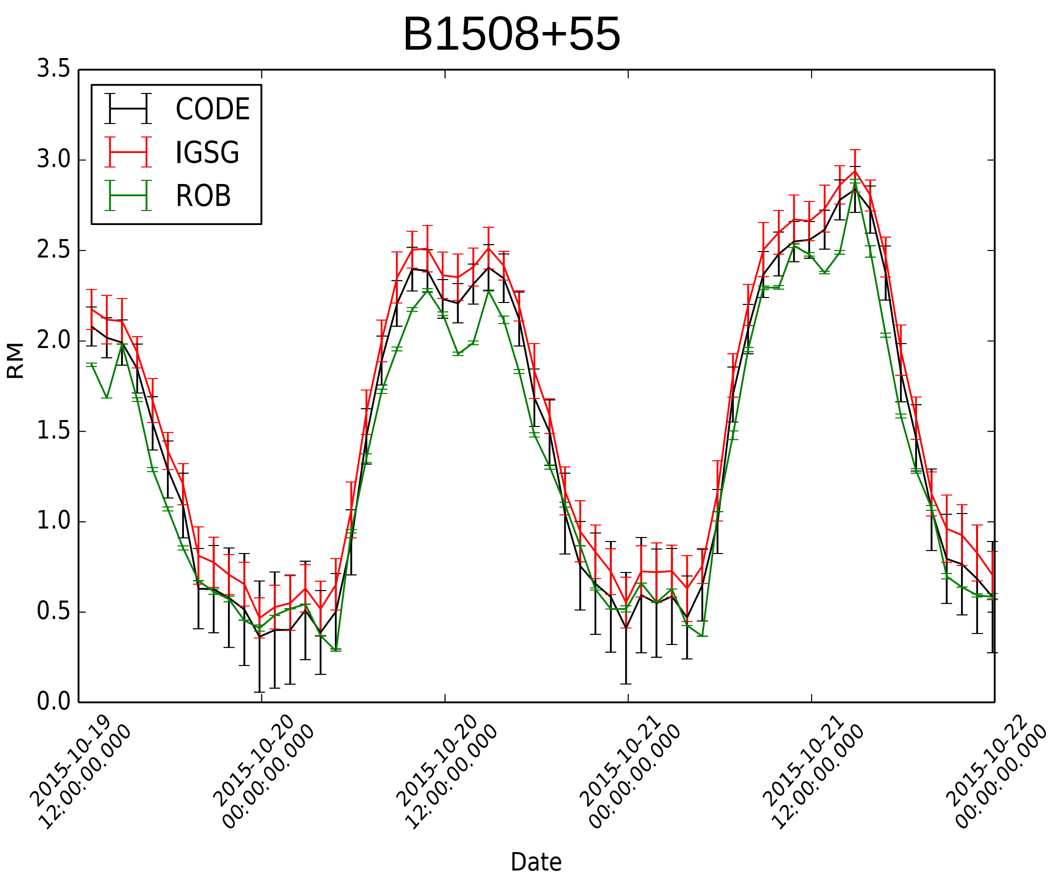
- Single layer model fails at low elevations
- Features of unmodeled ionospheric variations

To do:

More accurate investigation of ROB ionospheric maps for correct error bars

Determination of RM with likelihood analysis in the presence of red noise

IonFR implementation



By C. Tiburzi

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To do:

More accurate investigation of ROB ionospheric maps for correct error bars

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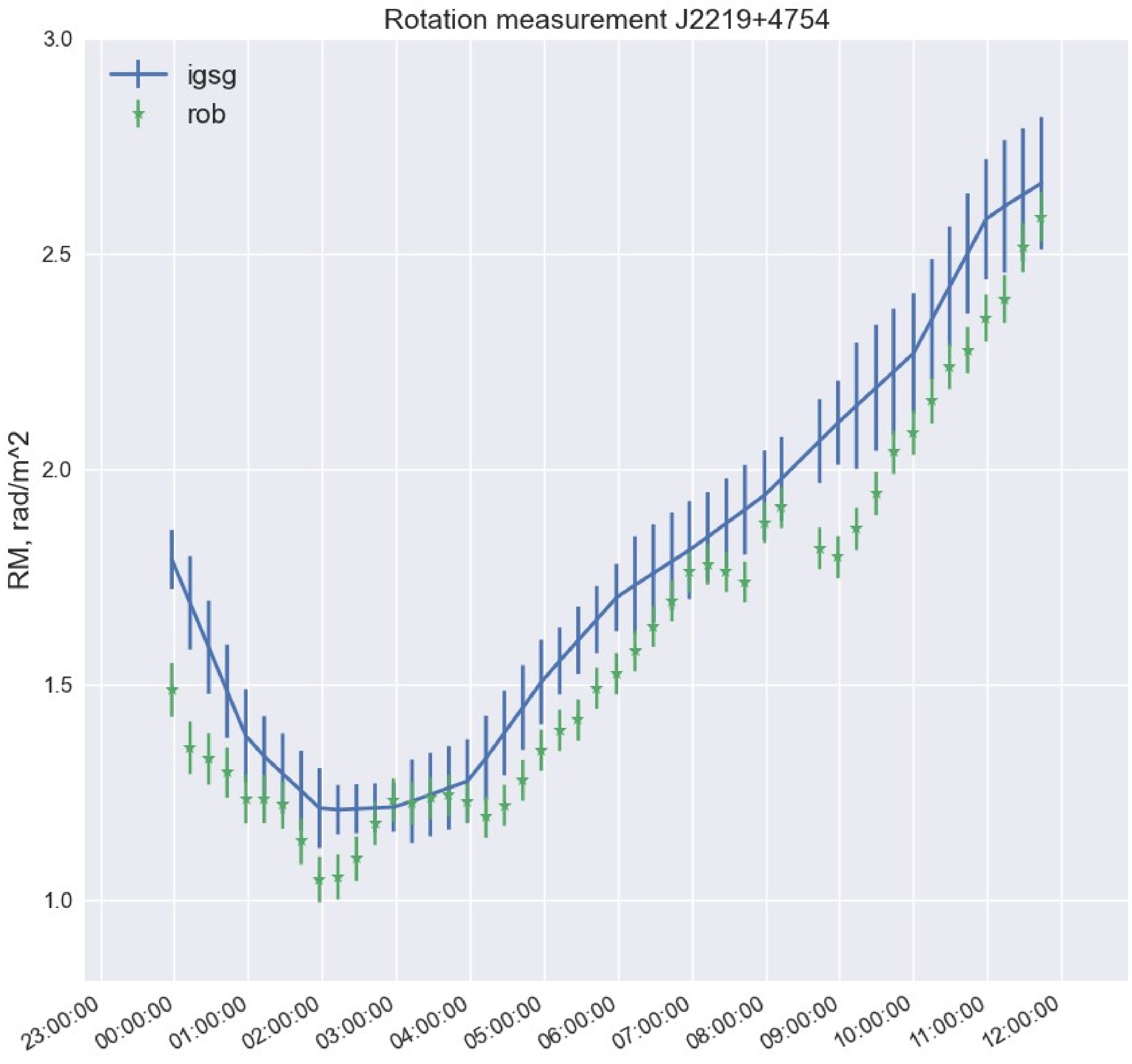
Conclusions

- We are using GLOW observations from sufficiently polarized pulsars to investigate the variations of RM
- Variations could be the result of proper motion of the pulsar, the line of sight of which will intersect different parts of ISM
- Variations are believed to show red-noise component in the spectrum


Thank you for
attention!



Rotation measurement J2219+4754
igsg
rob
RM, rad/m^2
3.0
2.5
2.0
1.5
1.0
23:00:00
00:00:00
01:00:00
02:00:00
03:00:00
04:00:00
05:00:00
06:00:00
07:00:00
08:00:00
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