

# Polarization, Faraday rotation, and the ionosphere

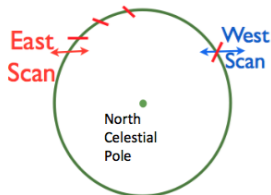
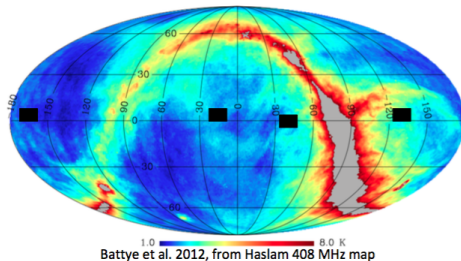
Niels Oppermann



**CITA**  
**ICAT**

Canadian Institute for  
Theoretical Astrophysics  
L'Institut Canadien  
d'astrophysique théorique

# The GBT intensity mapping survey



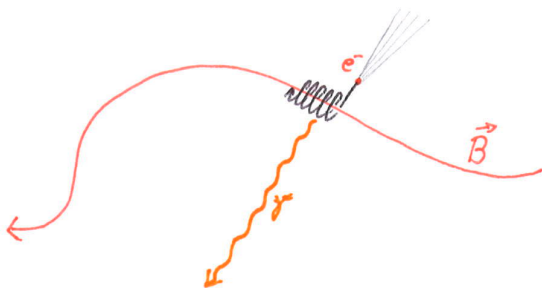
Scans 'position switched', all azimuth to control ground spill.

$$\nu = 700 \text{ MHz} - 900 \text{ MHz}$$

$$z = 0.6 - 1.0$$

all these pictures stolen from Kiyoo

# Synchrotron radiation



for  $n_{\text{CRE}}(E) \propto E^{-\gamma}$ :

$$P(\lambda) \propto \lambda^{\frac{\gamma-1}{2}} \int dz n_{\text{CRE}} B_{\perp}^{\frac{\gamma+1}{2}} e^{2i(\arctan(\frac{B_y}{B_x}) + \frac{\pi}{2})}$$

# Why is polarization interesting?

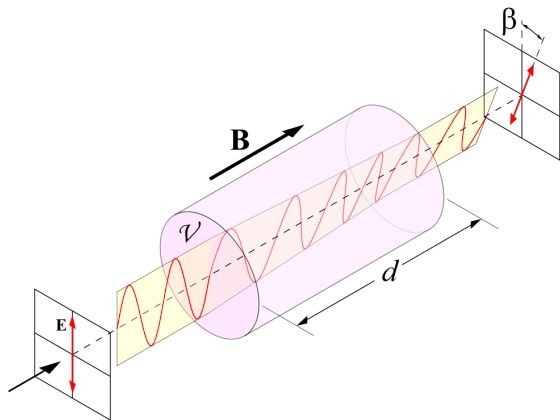
- ▶ Learn about  $B$ -fields
- ▶ Learn about various constituents of the ISM
- ▶ May leak into total intensity

## Parallactic rotation

Rotate the telescope w.r.t. the sky by an angle  $\theta$

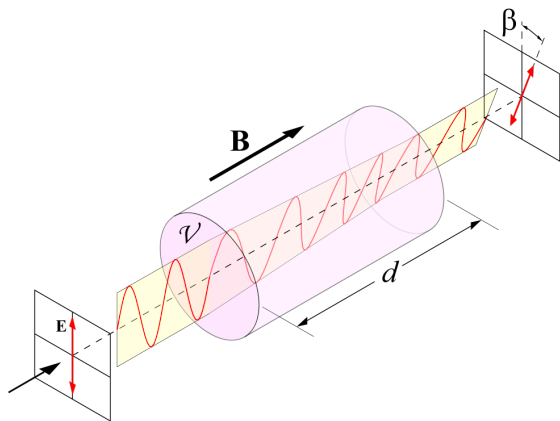
$$\begin{pmatrix} Q \\ U \end{pmatrix}_{\text{tel}} = \begin{pmatrix} \cos 2\theta & \sin 2\theta \\ -\sin 2\theta & \cos 2\theta \end{pmatrix} \begin{pmatrix} Q \\ U \end{pmatrix}_{\text{sky}}$$

# Faraday rotation



$$d\beta \propto \lambda^2 n_e B_r dr$$
$$\Rightarrow \beta \propto \lambda^2 \int_{r_{\text{source}}}^0 (1+z)^{-2} n_e B_r dr$$

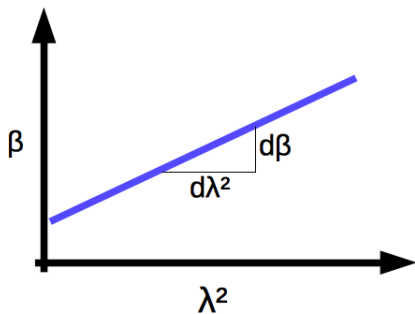
# Faraday rotation



$$\text{Faraday depth: } \phi \propto \int_{r_{\text{source}}}^0 (1+z)^{-2} n_e B_r dr$$
$$\beta = \phi \lambda^2$$

# Faraday rotation

if  $B$ -fields in front of emission:

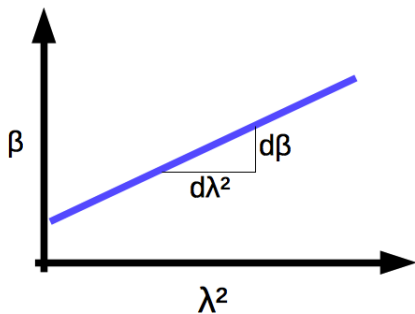


$$\phi = \text{RM} = \frac{d\beta}{d\lambda^2}$$



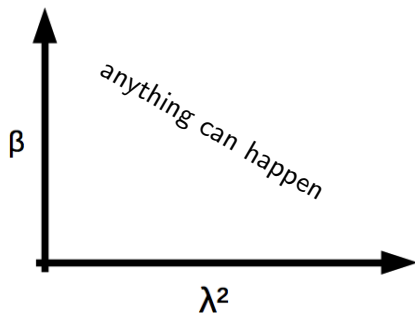
# Faraday rotation

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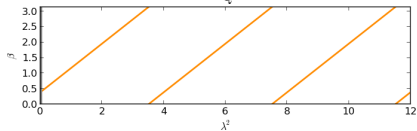
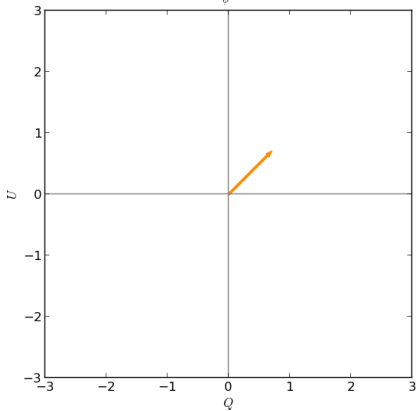
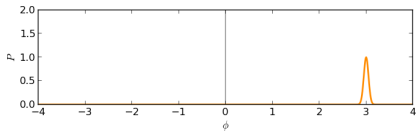
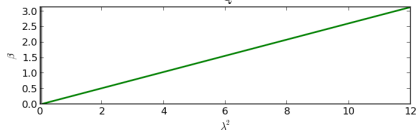
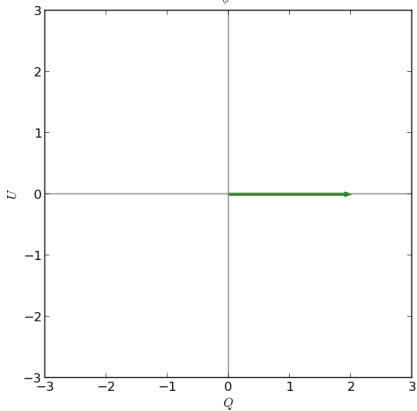
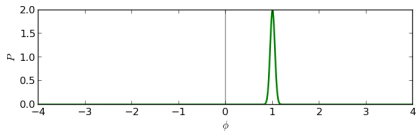


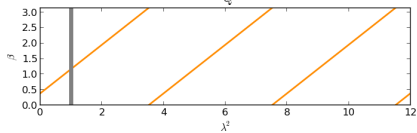
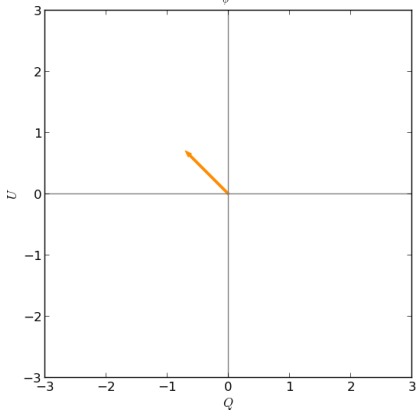
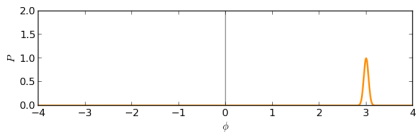
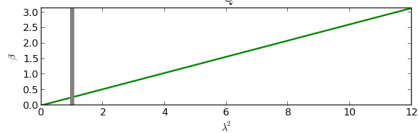
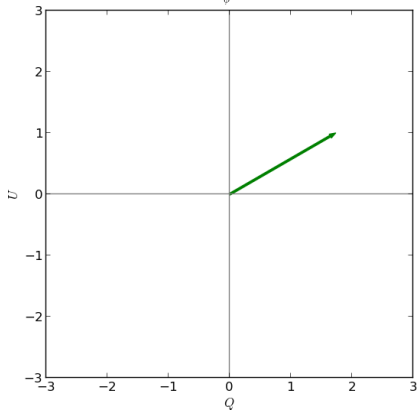
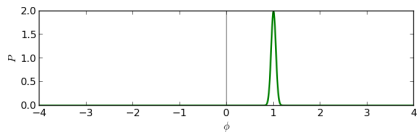
$$\phi = \text{RM} = \frac{d\beta}{d\lambda^2}$$

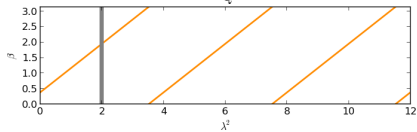
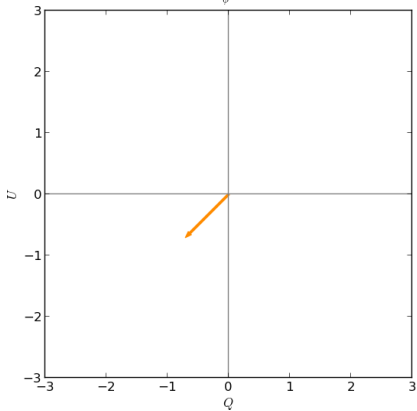
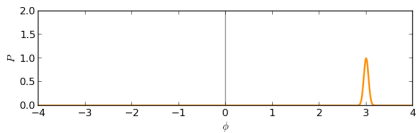
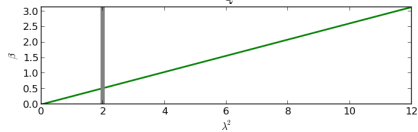
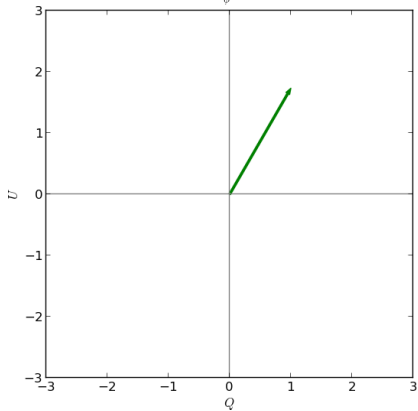
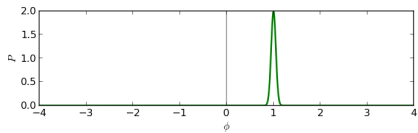
if  $B$ -fields and emission mixed:

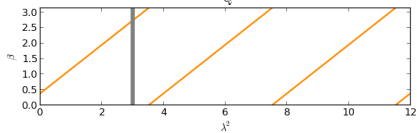
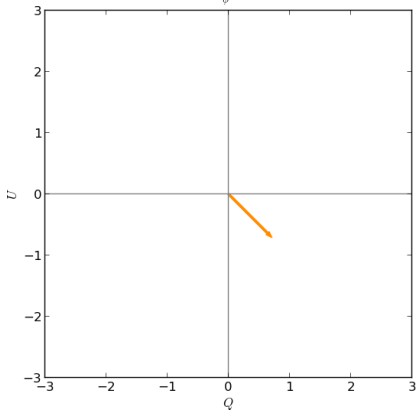
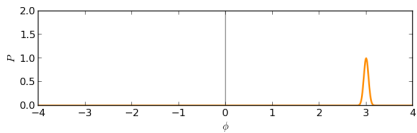
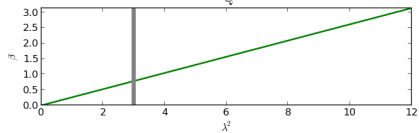
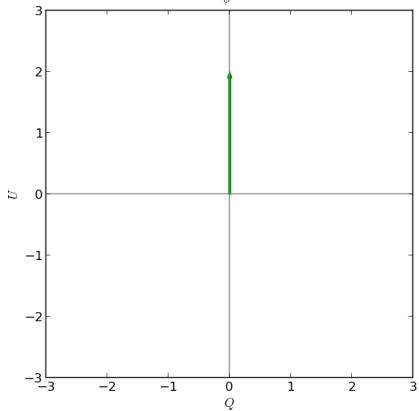
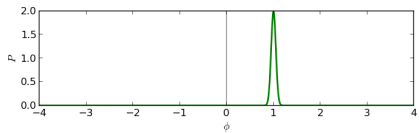


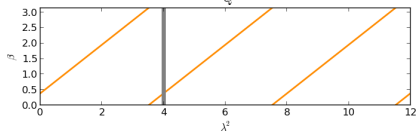
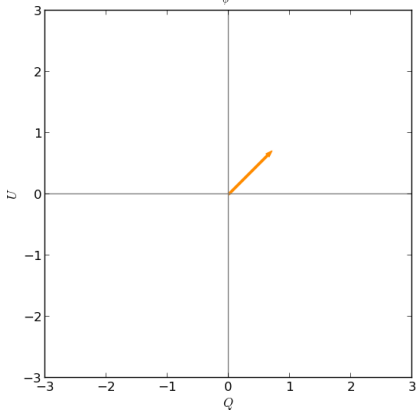
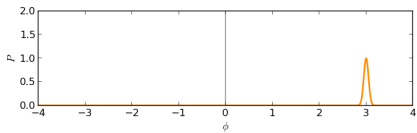
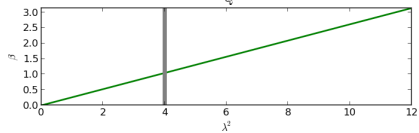
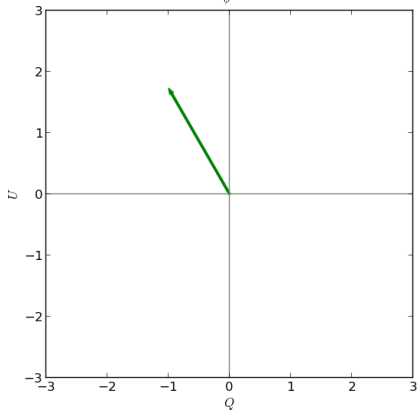
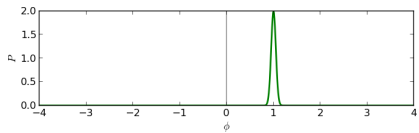
Use  $Q(\lambda)$ ,  $U(\lambda)$ ,  $I(\lambda)$ ,  
RM synthesis, ...

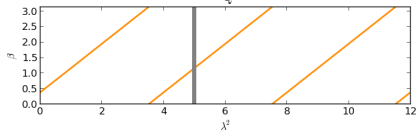
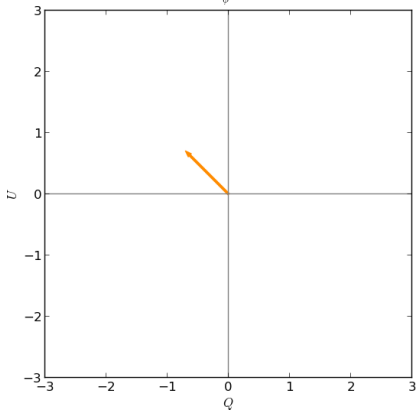
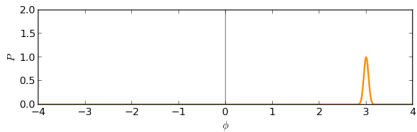
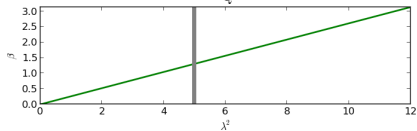
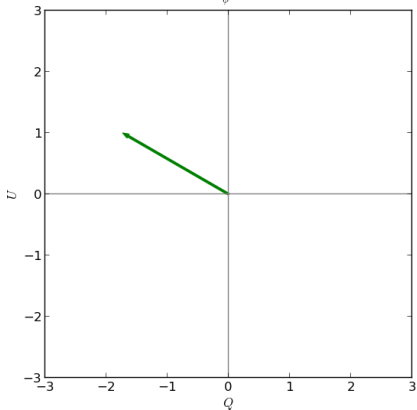
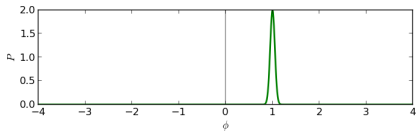


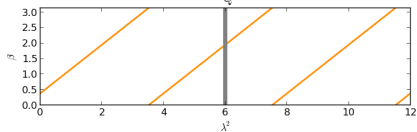
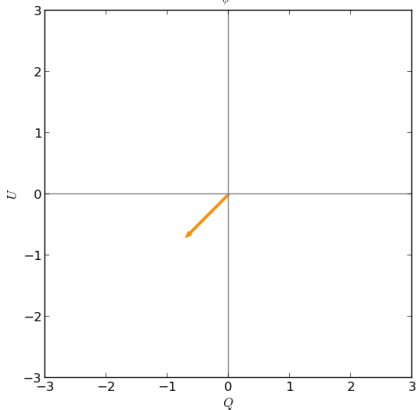
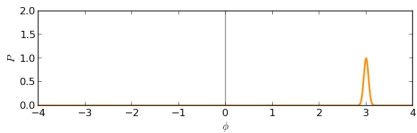
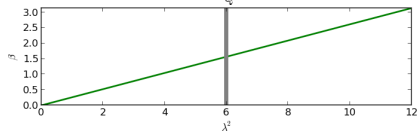
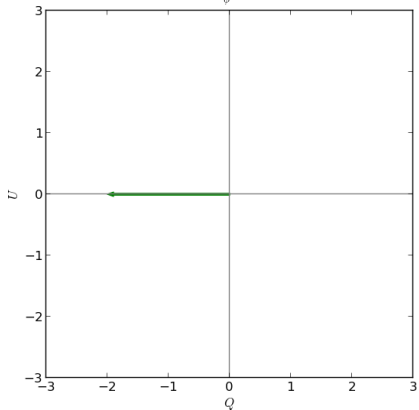
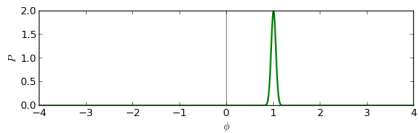




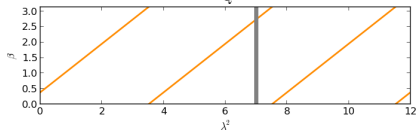
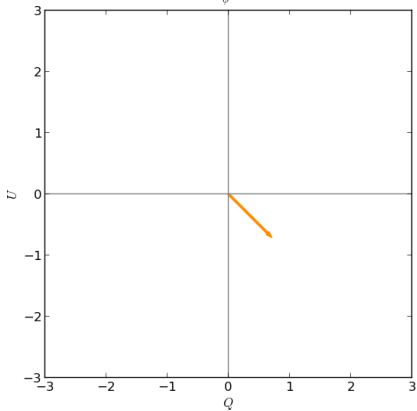
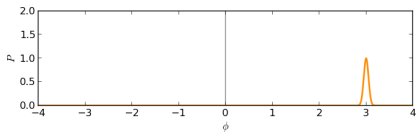
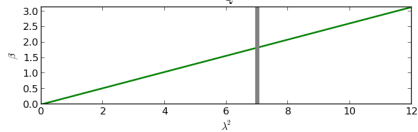
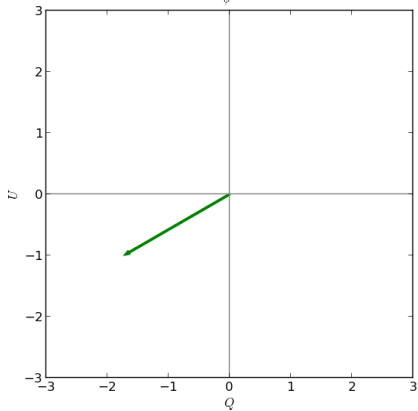
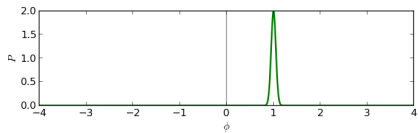


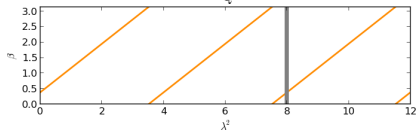
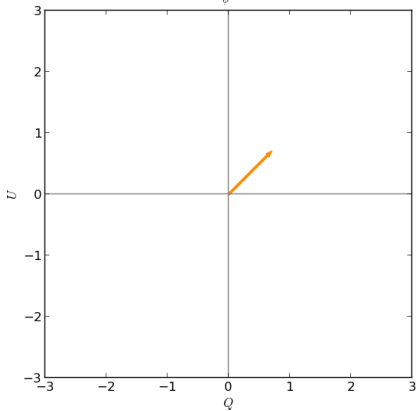
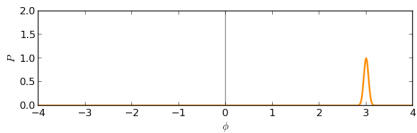
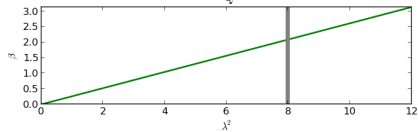
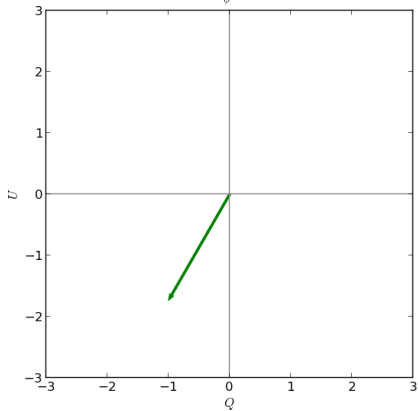
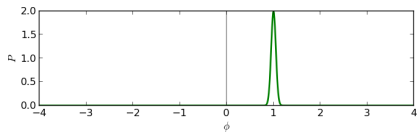


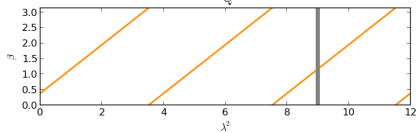
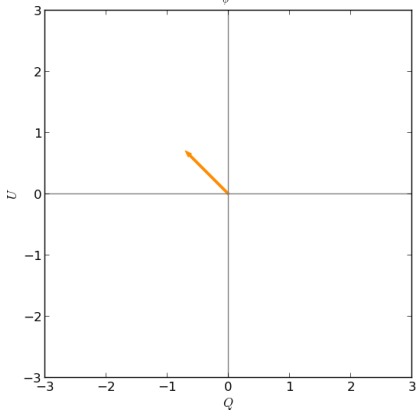
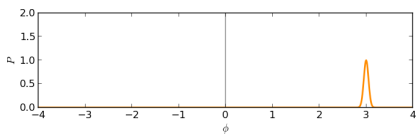
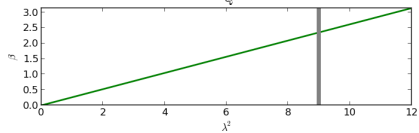
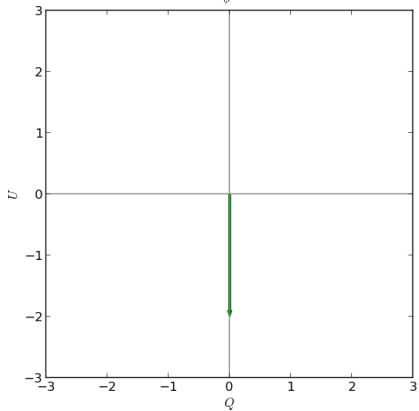
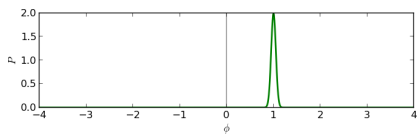


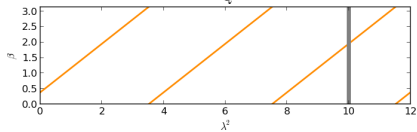
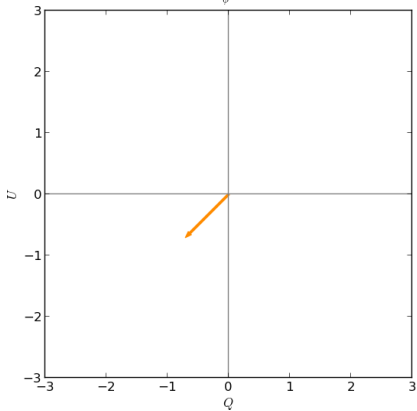
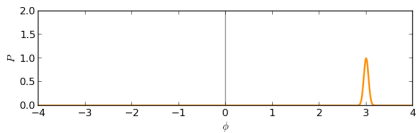
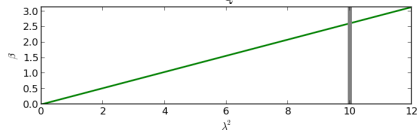
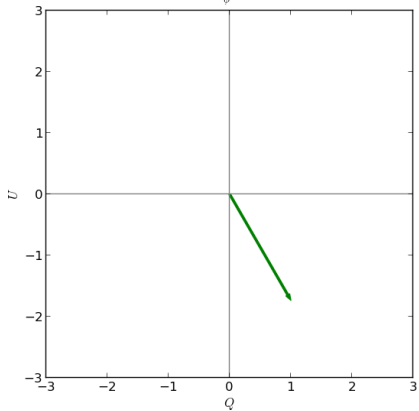
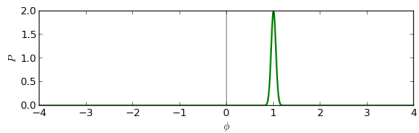


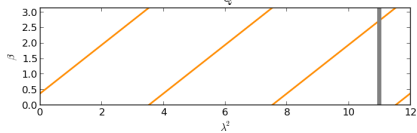
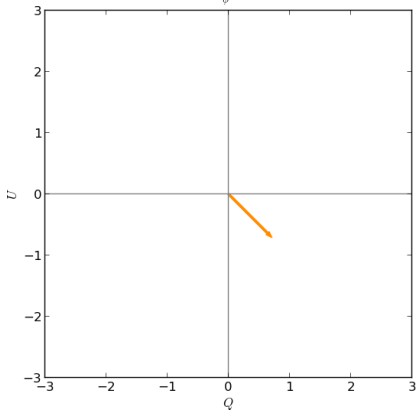
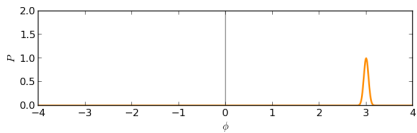
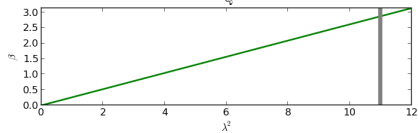
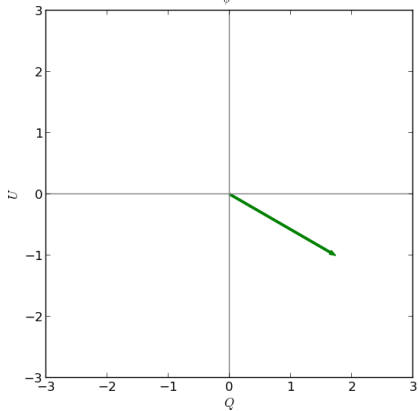
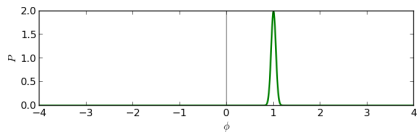


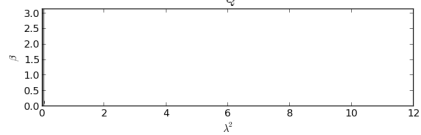
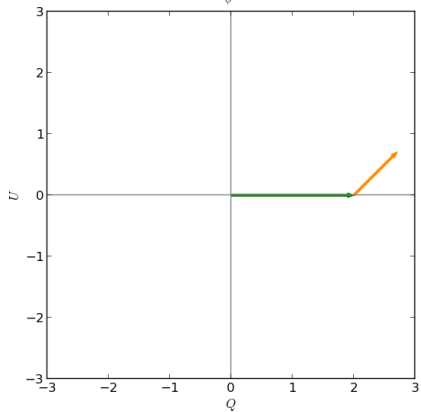
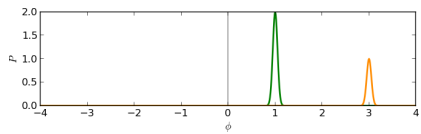


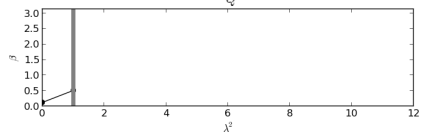
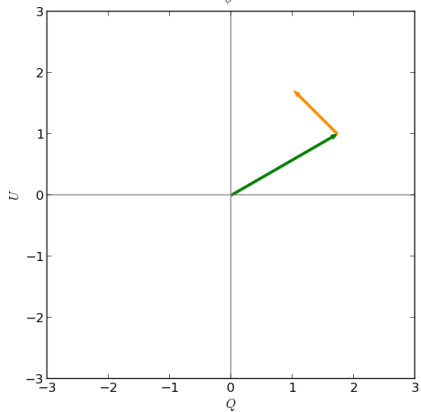
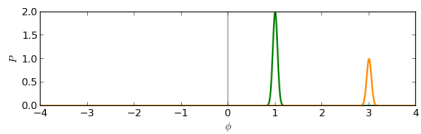


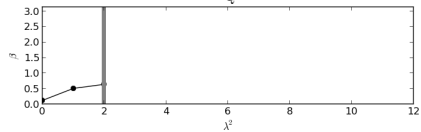
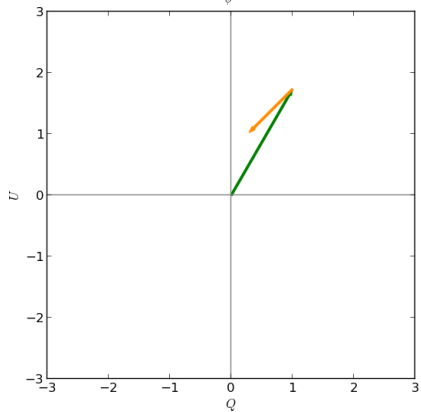
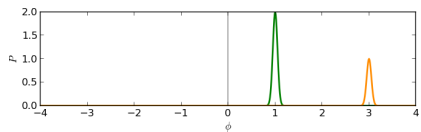




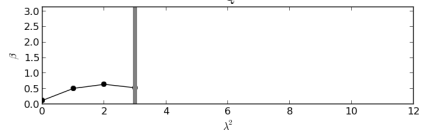
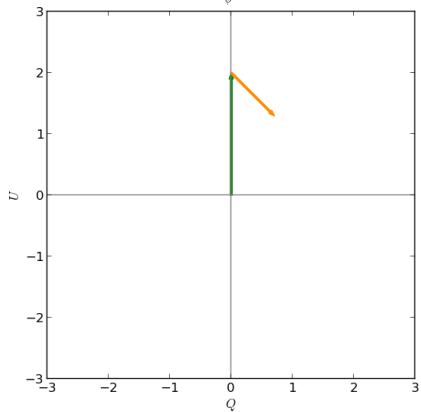
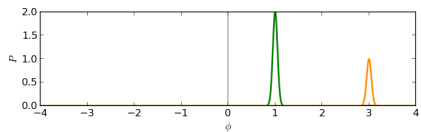


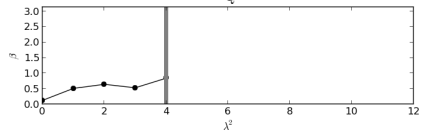
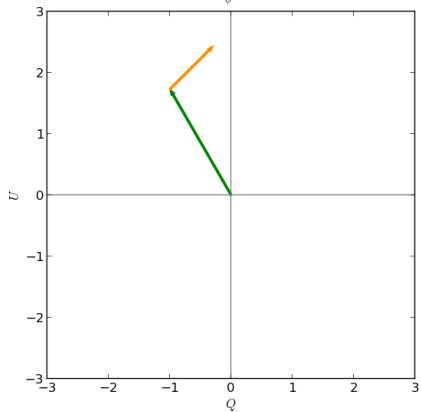
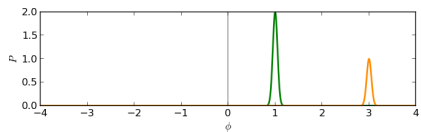


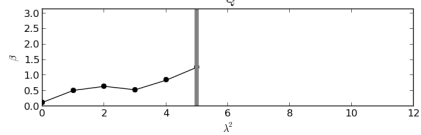
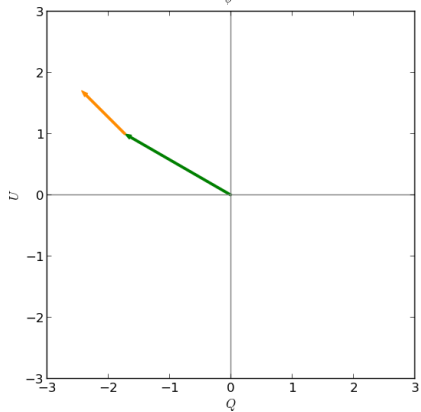
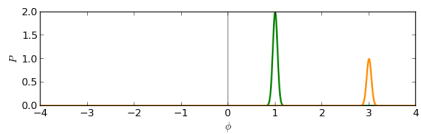


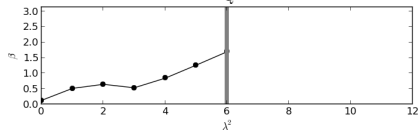
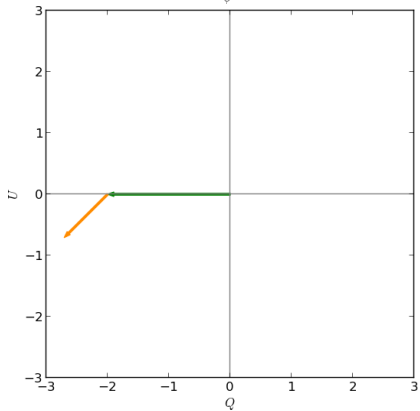
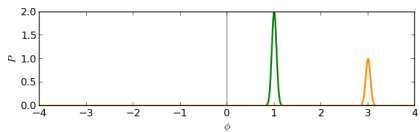


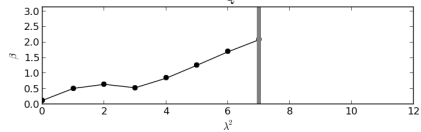
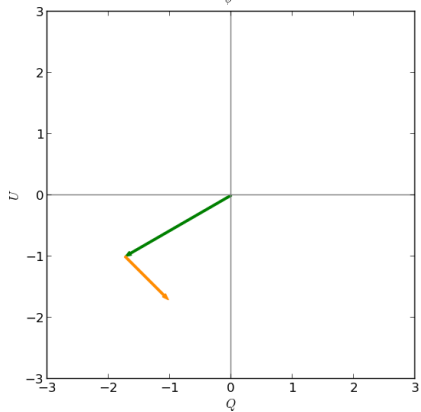
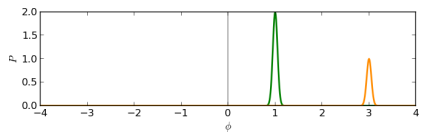


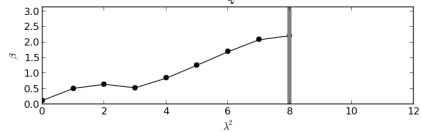
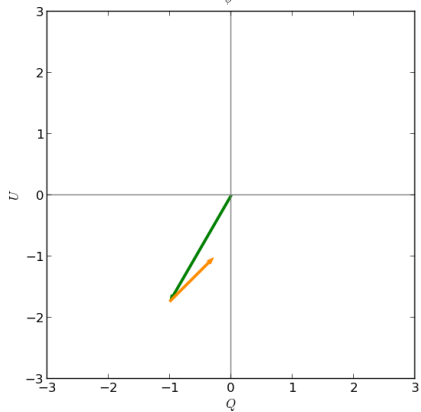
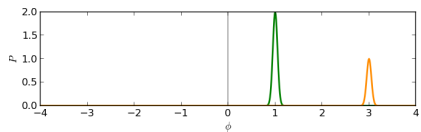


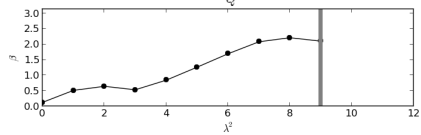
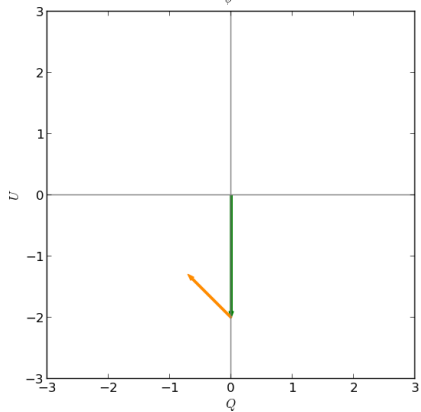
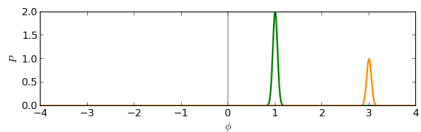


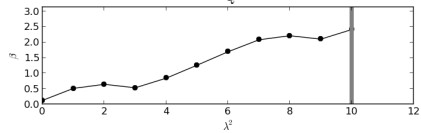
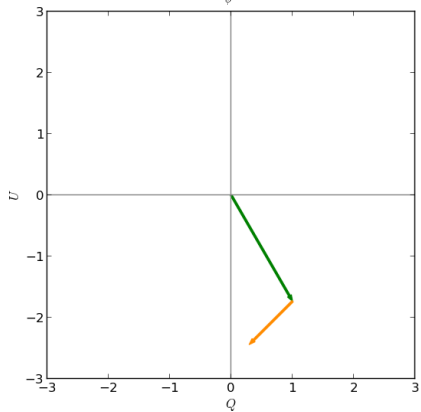
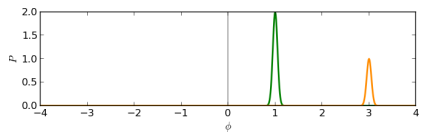




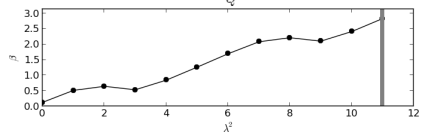
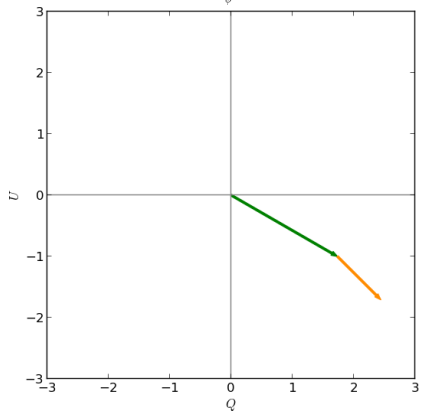
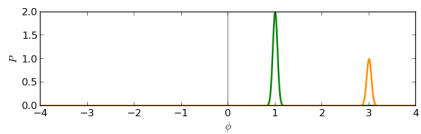






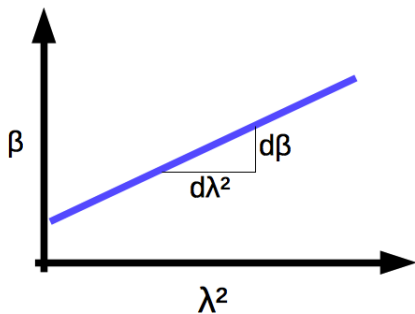






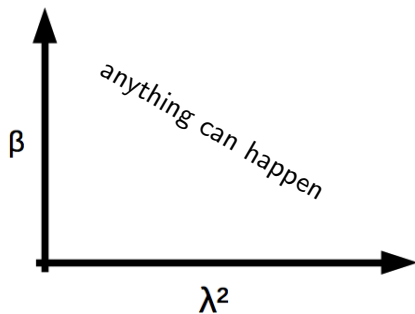
# Faraday rotation

if  $B$ -fields in front of emission:



$$\phi = \text{RM} = \frac{d\beta}{d\lambda^2}$$

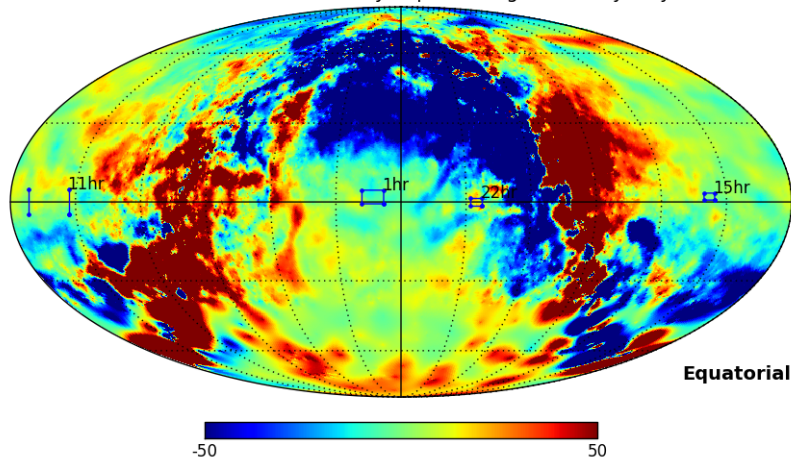
if  $B$ -fields and emission mixed:



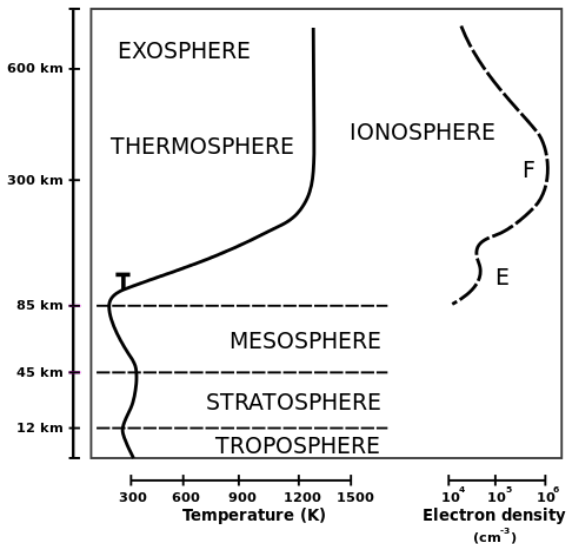
Use  $Q(\lambda)$ ,  $U(\lambda)$ ,  $I(\lambda)$ ,  
RM synthesis,...

# Faraday rotation

GBT fields in total Faraday depth through the Milky Way



# Ionosphere



# Ionosphere

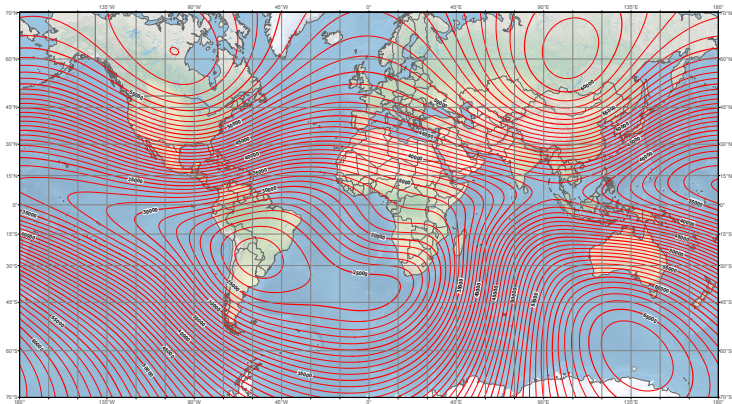
Idea: Regard ionospheric Faraday rotation as additional parallactic rotation:

$$\begin{pmatrix} Q \\ U \end{pmatrix}_{\text{tel}} = \begin{pmatrix} \cos 2(\theta - \beta) & \sin 2(\theta - \beta) \\ -\sin 2(\theta - \beta) & \cos 2(\theta - \beta) \end{pmatrix} \begin{pmatrix} Q \\ U \end{pmatrix}_{\text{sky}}$$

$$\beta \propto \lambda^2 \int_{\text{LOS}} n_e \vec{B} \cdot d\vec{r}$$

# Earth's magnetic field

**US/UK World Magnetic Model - Epoch 2015.0**  
**Main Field Total Intensity (F)**

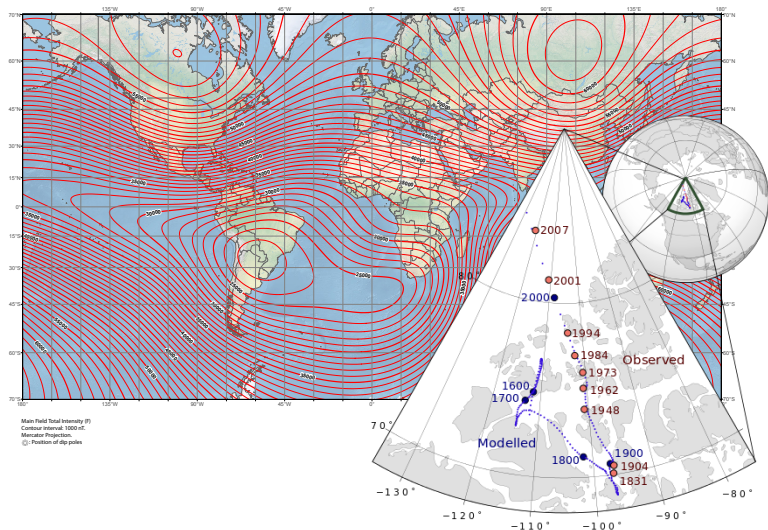


Main Field Total Intensity (F)  
Contour interval: 2000-G.  
Mercator Projection.  
⊙: Position of dip poles.

Map developed by NOAA/NGDC & CRES  
<http://ngdc.noaa.gov/gemmag/WMM>  
Map reviewed by NEA and BGS  
Published December 2014

# Earth's magnetic field

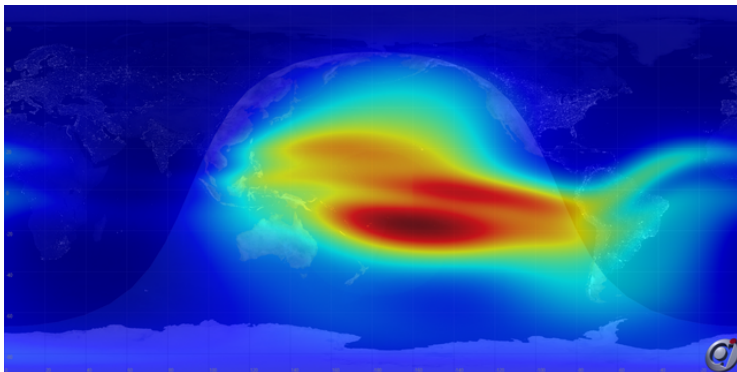
US/UK World Magnetic Model - Epoch 2015.0  
Main Field Total Intensity (F)



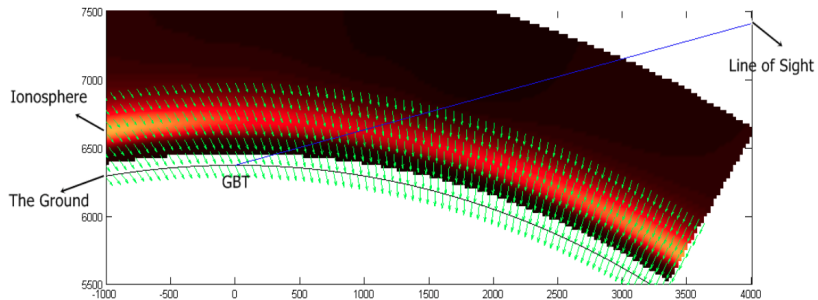
# Electron column density



# Electron column density



# Electron density in 3D

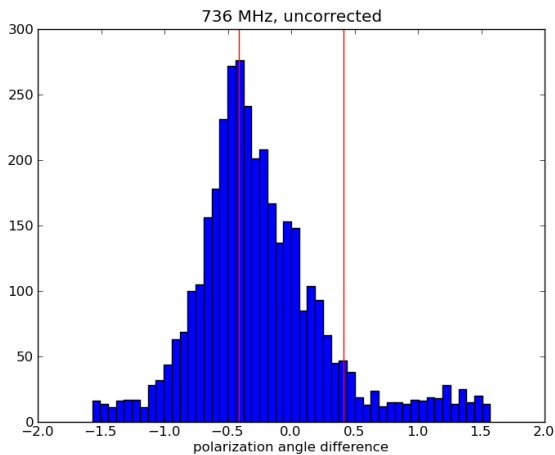


model and plot due to Yu-Wei Liao

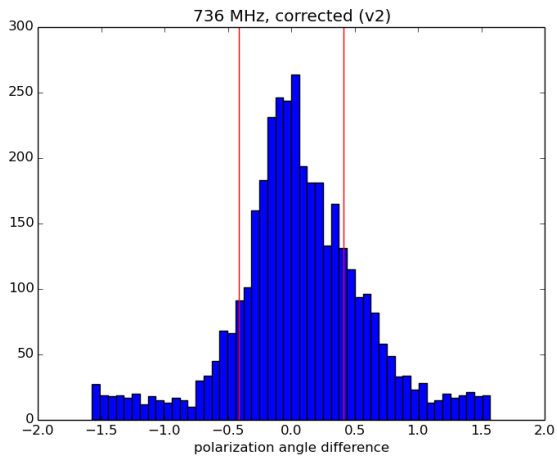
# Models for ionospheric Faraday rotation

- ▶ ionFR (used in LOFAR)
- ▶ K. Smith's model (used in CHIME)
- ▶ Tony Willis' model (DRAO)
- ▶ Victor's model (used by us)
- ▶ ...

# Does the correction work?



# Does the correction work?



# Summary

Polarization is a **nuisance** (for cosmology).

Polarization is **helpful** (for everything else).

Faraday rotation is a **nuisance** (distorts polarization).

Faraday rotation is **helpful** (LOS component of  $B$ -field).

Ionospheric rotation is a **nuisance** (but we can correct it).

Ionospheric rotation could be **helpful** (rotates telescopes for us).