Magnetic fields seen through Faraday rotation – from the Milky Way to cosmic scales

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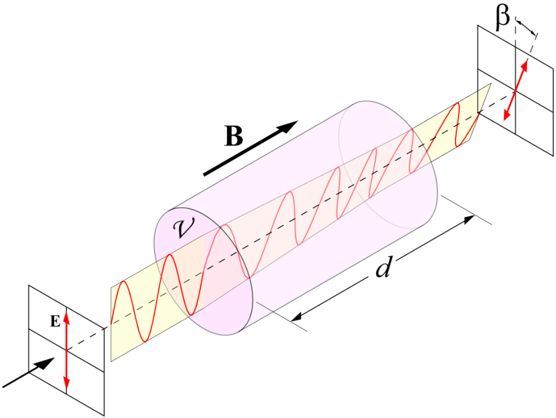
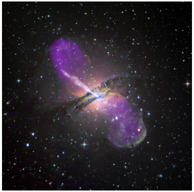
. . .

Cosmic Magnetic Fields, Krakow, 2014-10-21

Faraday rotation

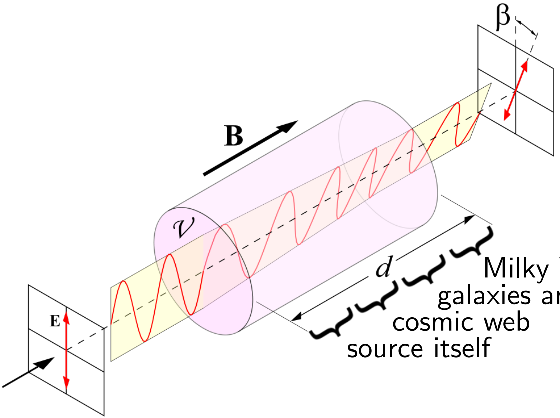


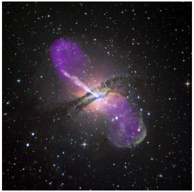


Faraday depth: $\phi \propto \int_{r_{\mathrm{source}}}^{0} (1+z)^{-2}\; n_{\mathrm{e}}\, B_r \,\mathrm{d}r$

$$\beta = \phi \lambda^2$$

Faraday rotation





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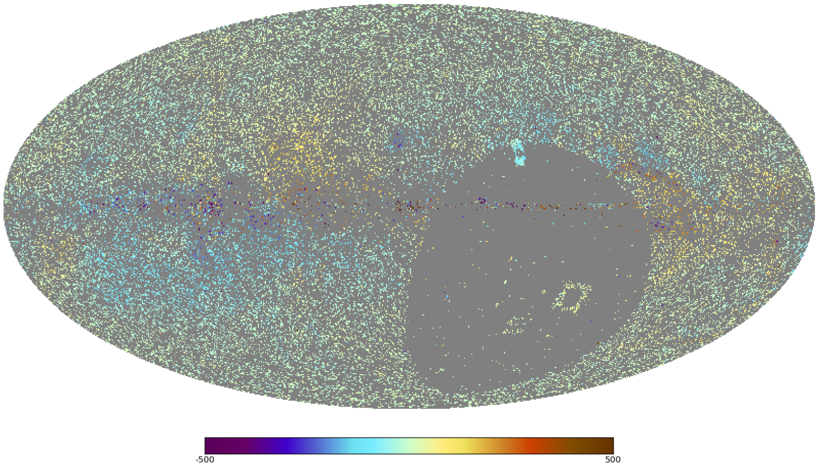
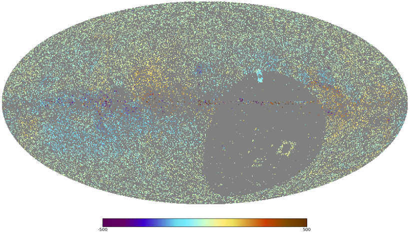


$\gtrsim 40\,000$ data points



Challenges

- Regions without data
- Galactic/extragalactic split unknown
- Uncertain error bars

$$d = \phi_{\mathrm{g}} + \phi_{\mathrm{e}} + n$$

Wiener filter:

$$\hat{\phi}_{\mathrm{g}} = G\,(G + E + N)^{-1}\,d$$
$$\hat{\phi}_{\mathrm{e}} = E\,(G + E + N)^{-1}\,d$$
$$\hat{n} = N\,(G + E + N)^{-1}\,d$$

Covariance matrices:

$$G_{(\ell,m),(\ell',m')} = \delta_{\ell\ell'}\,\delta_{mm'}\,C_\ell$$
$$E_{ij} = \delta_{ij}\,\sigma_{\mathrm{e}}^2$$
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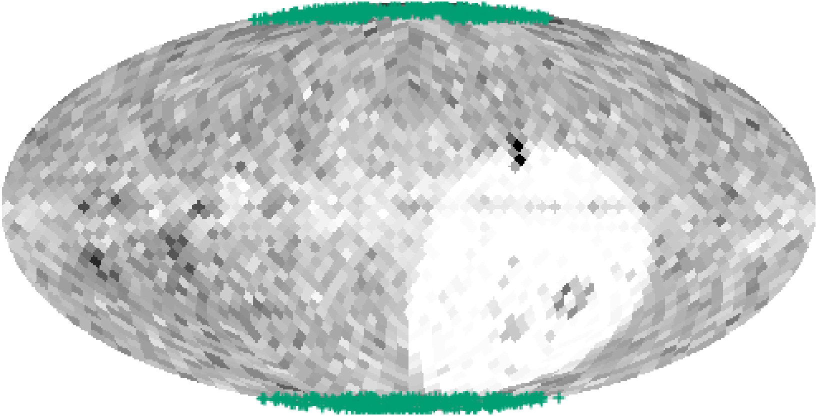
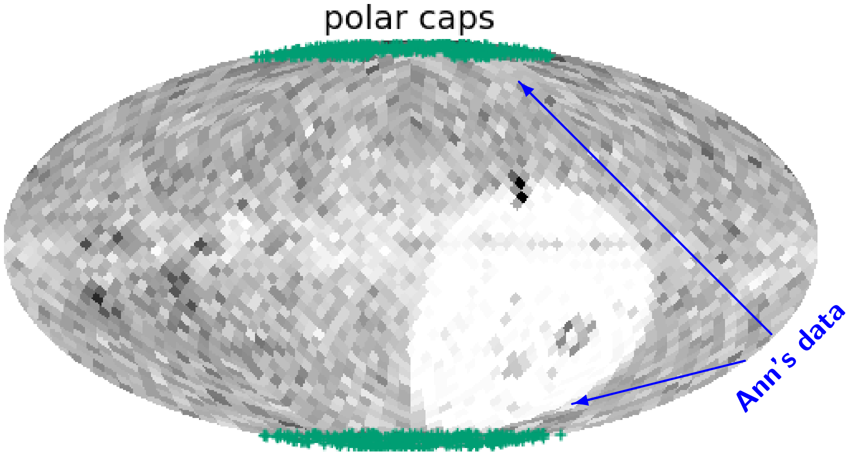
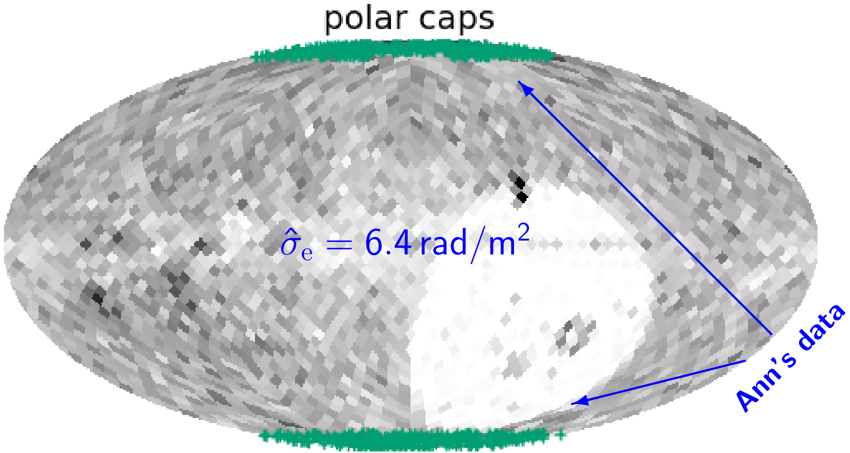
idea: find subset of data for which $\eta_i \equiv 1$

polar caps




polar caps
Ann's data


polar caps
$\hat{\sigma}_{\mathrm{e}} = 6.4\,\mathrm{rad}/\mathrm{m}^2$
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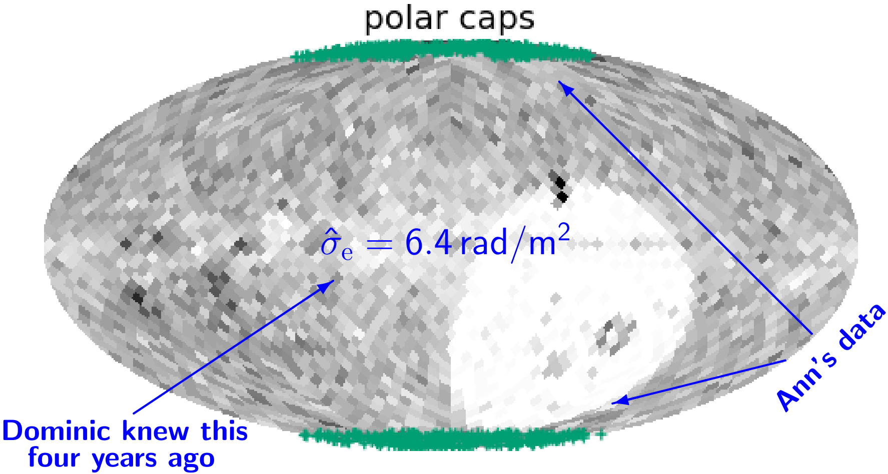
polar caps
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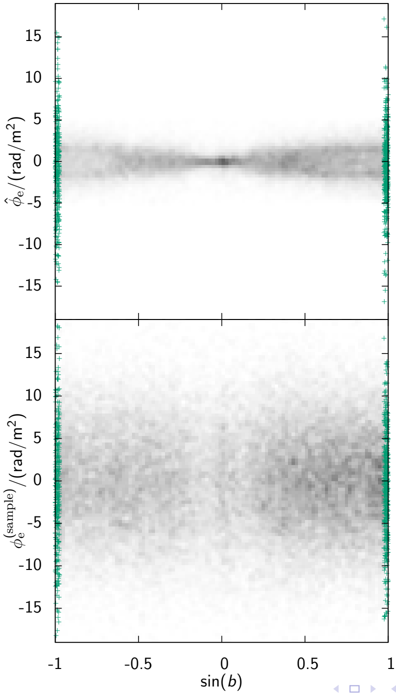
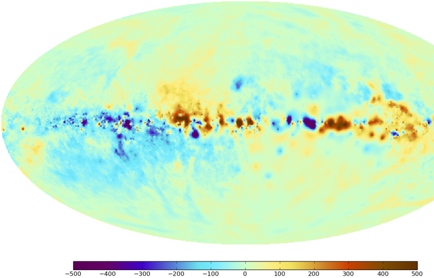
Ann's data
Dominic knew this four years ago

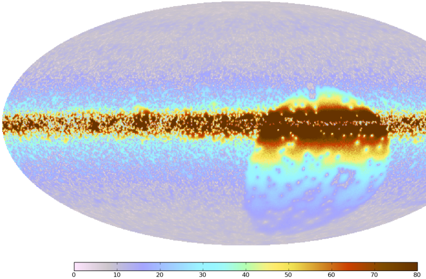


15
10
5
0
-5
-10
-15
$\hat{\phi}_e/(\mathrm{rad/m^2})$
$\phi_e^{(\mathrm{sample})}/(\mathrm{rad/m^2})$
-1
-0.5
0
0.5
1
sin(b)

Galactic Faraday depth



uncertainty



What is the extragalactic contribution?

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$$E_{ij} = \delta_{ij}\,\left(\sigma^{(\mathrm{source})2} + \sigma_i^{(\mathrm{cluster})2} + \sigma_i^{(\mathrm{filament})2} + \sigma_i^{(\mathrm{void})2}\right)$$

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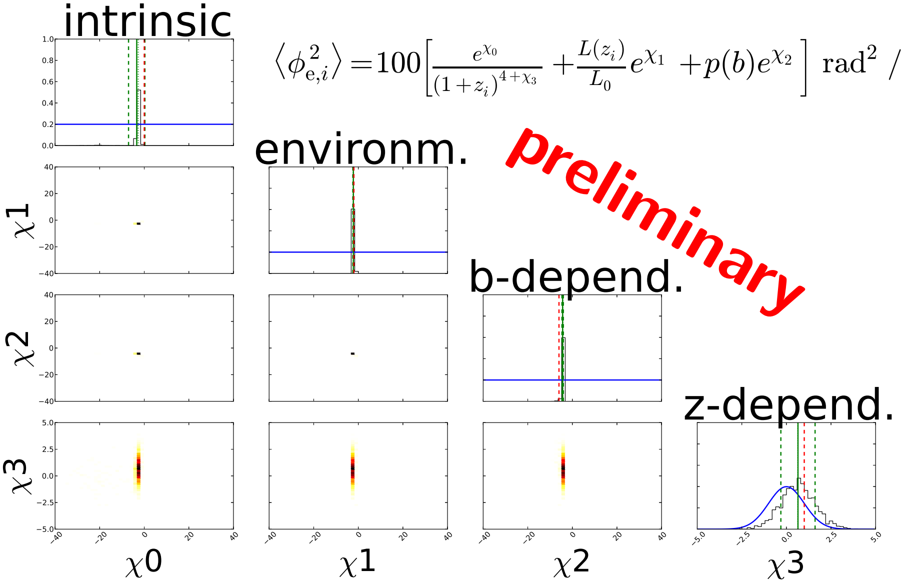
$$E_{ij} = \delta_{ij}\,\left(\frac{\mathrm{e}^{\chi_0}}{(1+z_i)^{4+\chi_3}} + \mathrm{e}^{\chi_1}\,L(z_i) + p(b)\,\mathrm{e}^{\chi_2}\right),$$
$$L(z_i) \propto \int_0^{r(z_i)} \frac{\mathrm{d}r}{(1+z(r))^4}$$

Simulation

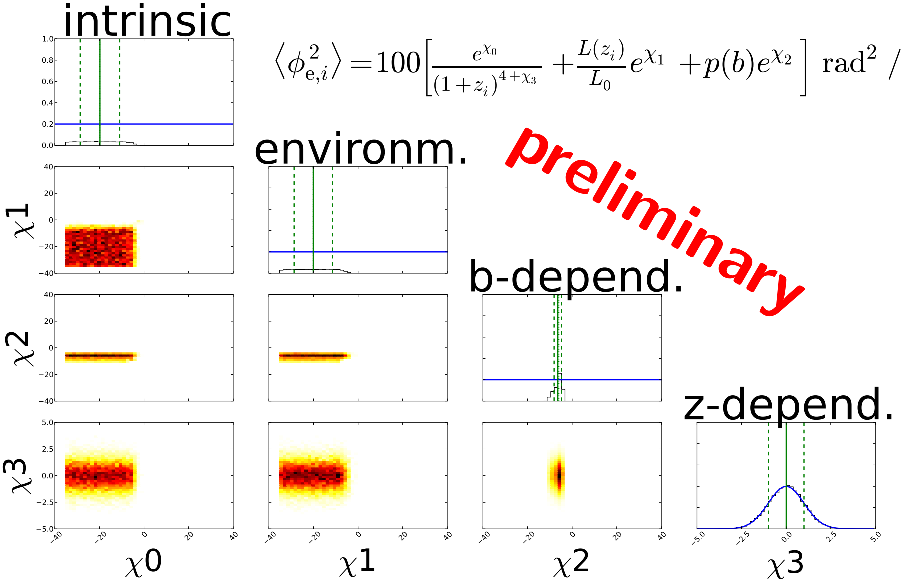
$$\left\langle \phi_{\mathrm{e},i}^2 \right\rangle = 100\left[\frac{e^{\chi_0}}{(1+z_i)^{4+\chi_3}} + \frac{L(z_i)}{L_0} e^{\chi_1} + p(b) e^{\chi_2}\right] \mathrm{rad}^2\ /\mathrm{m}^4$$



plots courtesy of Valentina Vacca

Real data

$$\langle \phi_{\mathrm{e},i}^2 \rangle = 100\left[\frac{e^{\chi_0}}{(1+z_i)^{4+\chi_3}} + \frac{L(z_i)}{L_0} e^{\chi_1} + p(b) e^{\chi_2}\right] \mathrm{rad}^2 / \mathrm{m}^4$$



plots courtesy of Valentina Vacca

Summary

- Galactic contribution (correlated) can be separated from rest (uncorrelated)
- Rest can be separated statistically into extragalactic and noise
- Uncertainties are large and should not be ignored

All results at
http://www.mpa-garching.mpg.de/ift/faraday/