

Cosmic magnetism revealed through Faraday rotation

Niels Oppermann



CITA
ICAT

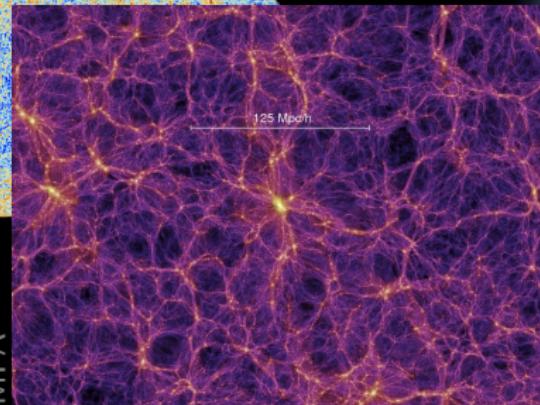
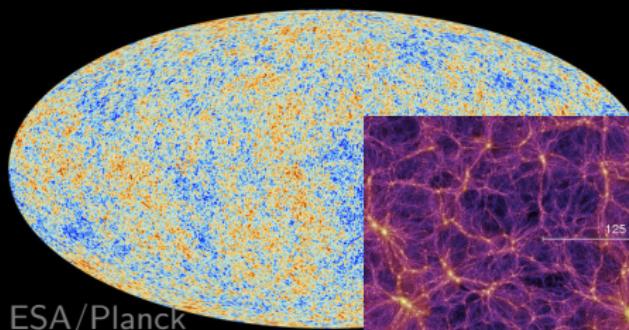
Canadian Institute for
Theoretical Astrophysics

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d'astrophysique théorique

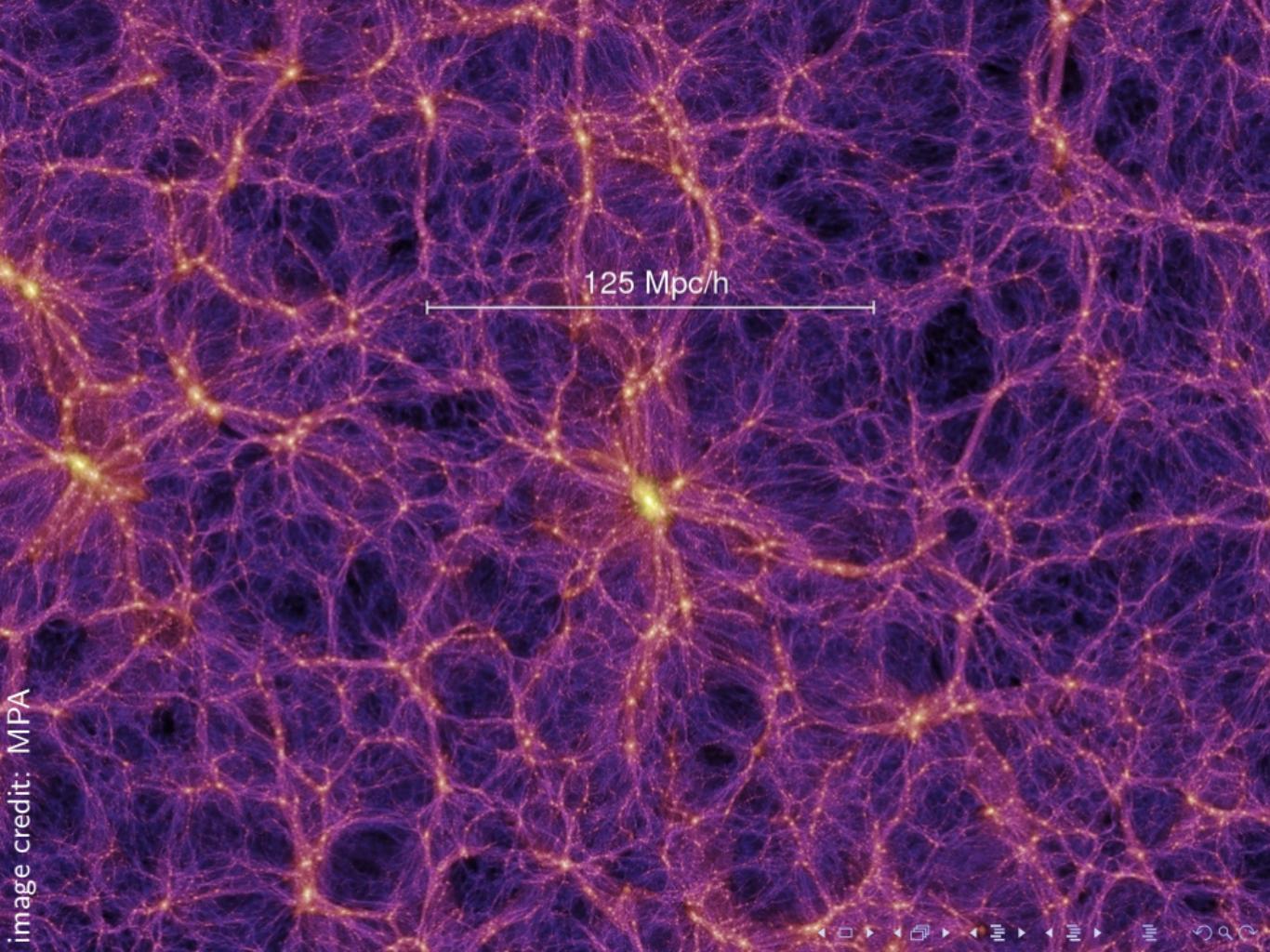
with: Valentina Vacca, Henrik Junklewitz, Torsten Enßlin
Bryan Gaensler, Dominic Schnitzeler, Jeroen Stil, Ann Mao, Jo-Anne Brown,

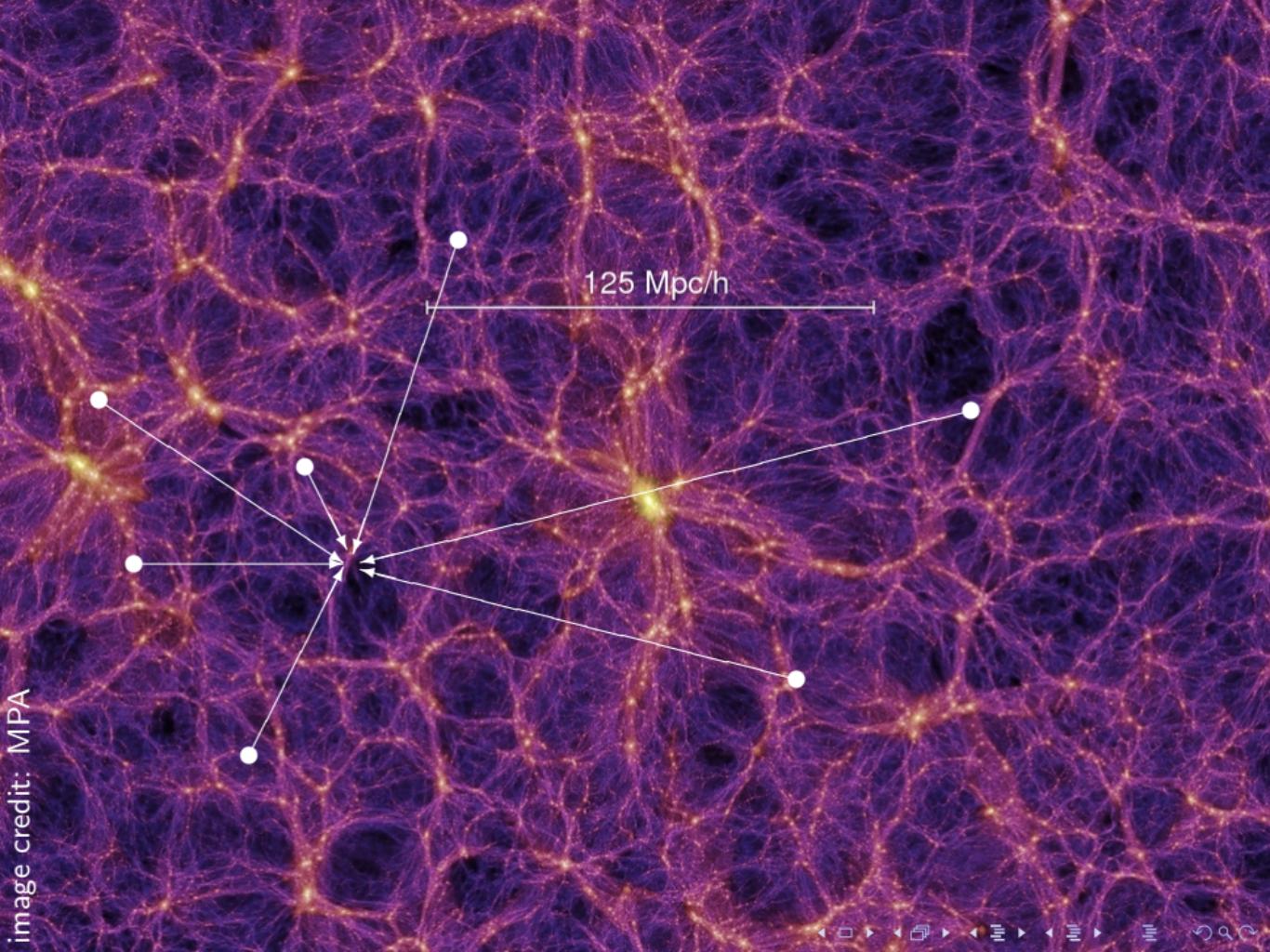
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Bonn, 2015-07-20

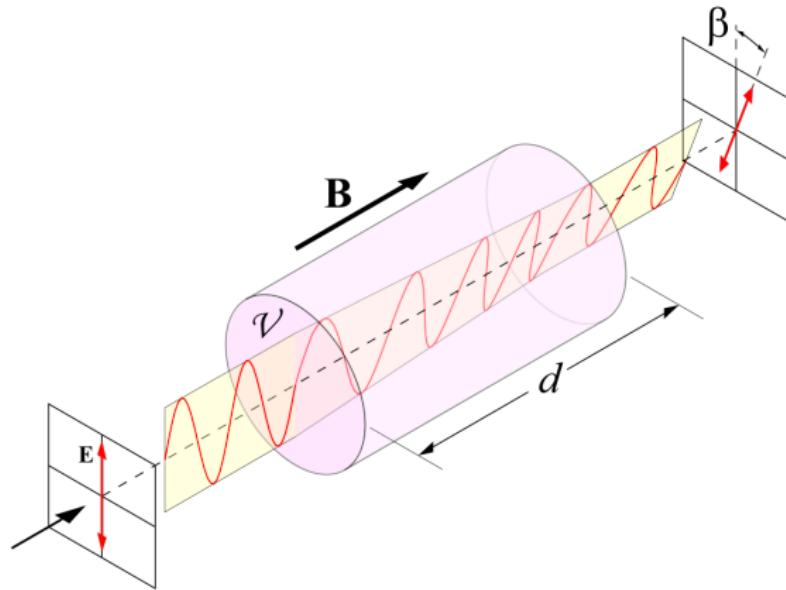


NASA/JPL-Caltech





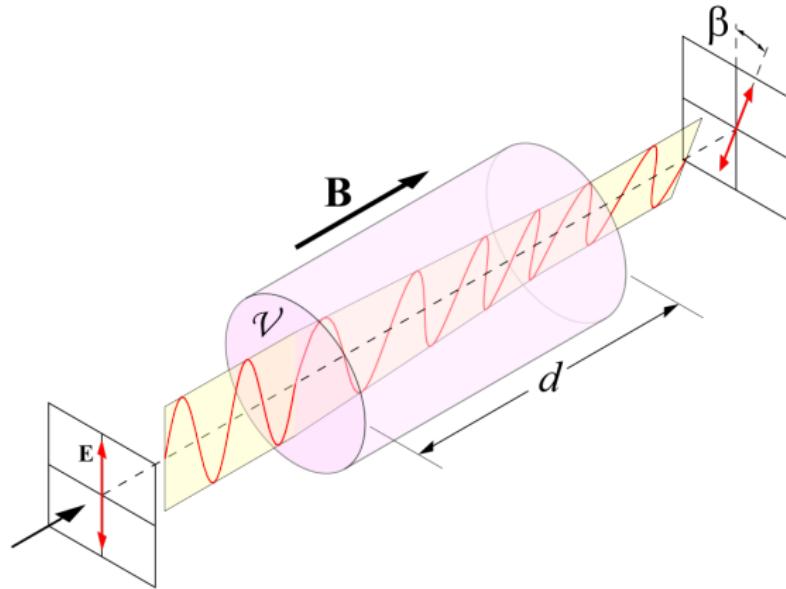
Faraday rotation



$$d\beta \propto \lambda^2 n_e B_r dr$$

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

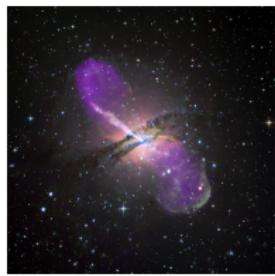
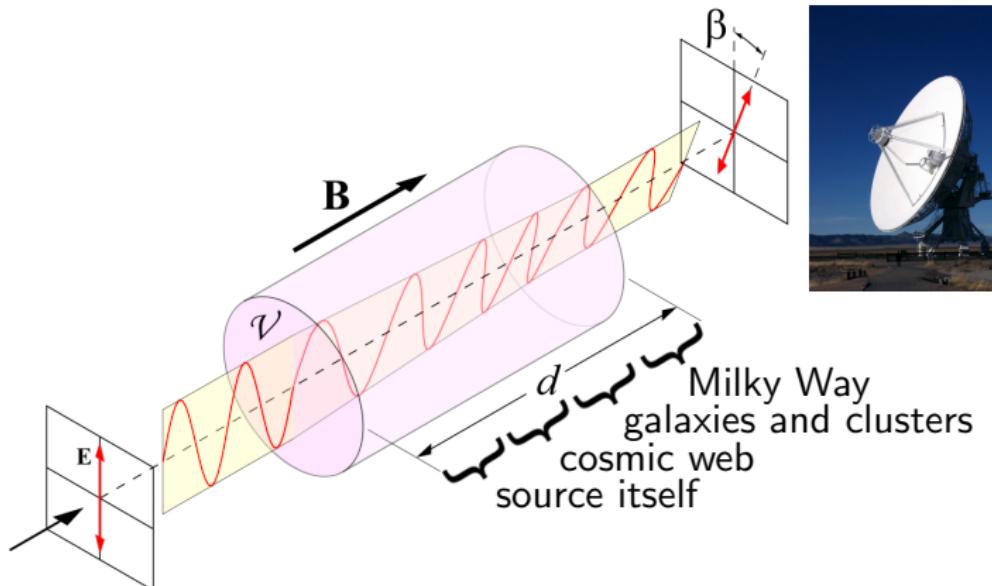
Faraday rotation



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

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

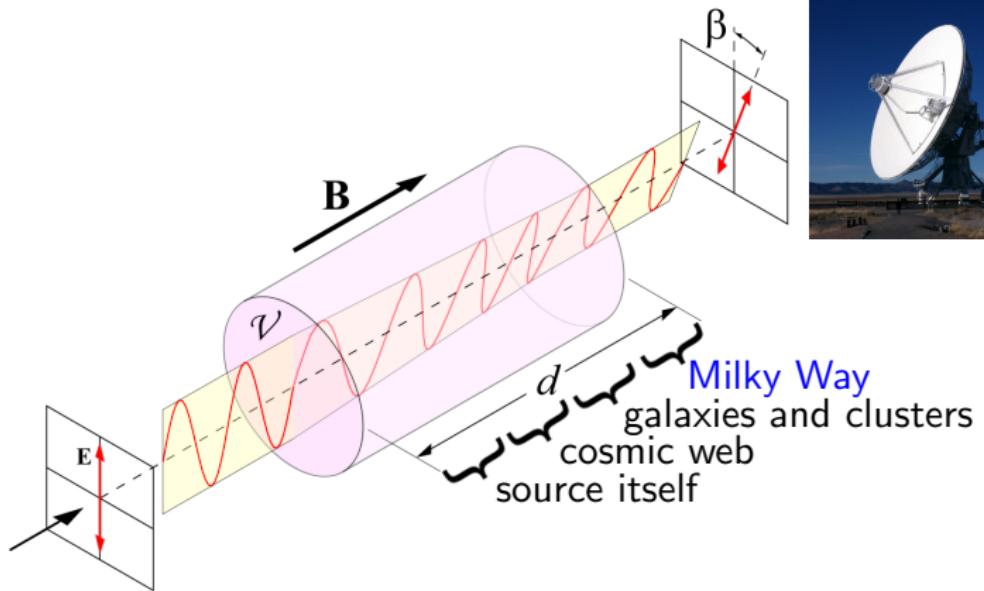
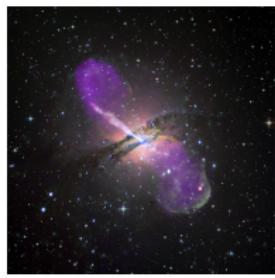
Faraday rotation



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

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

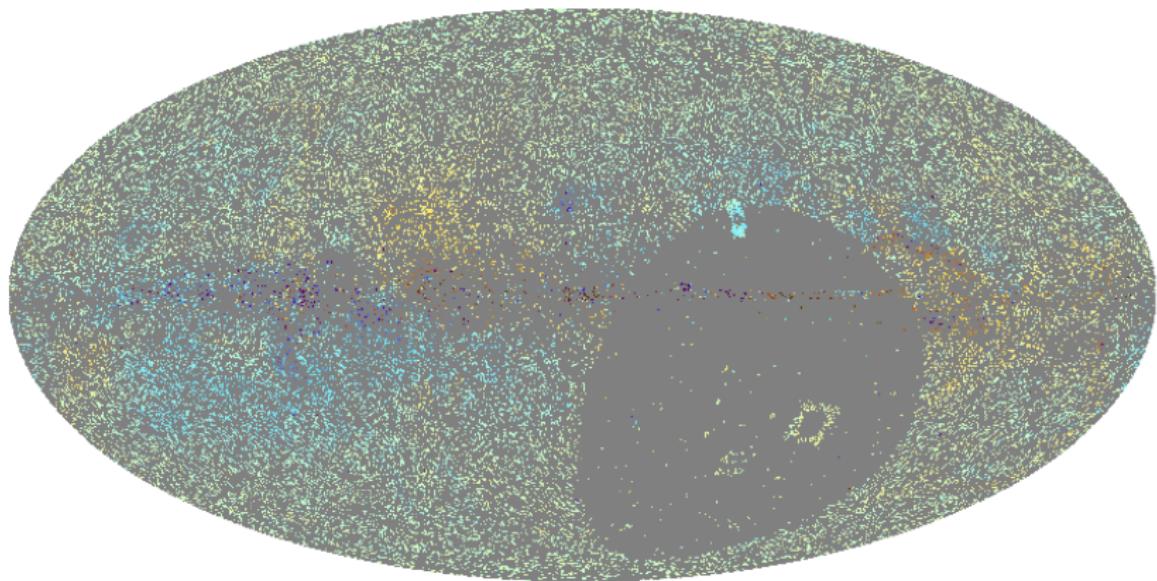
Extracting the Galactic contribution



Galactic Faraday depth:

$$\phi_{\text{MW}} \propto \int_{r_{\text{MilkyWay}}}^0 (1+z)^{-2} n_e B_r dr$$

$$d = \phi_{\text{MW}} + \phi_{\text{extragalactic}} + n$$



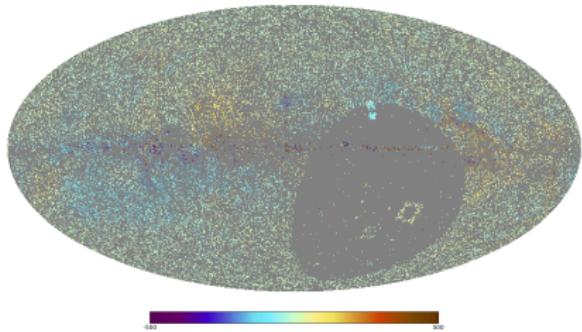
-500 500

$\gtrsim 40\,000$ data points

$$d = \phi_{\text{MW}} + \phi_{\text{extragalactic}} + n$$

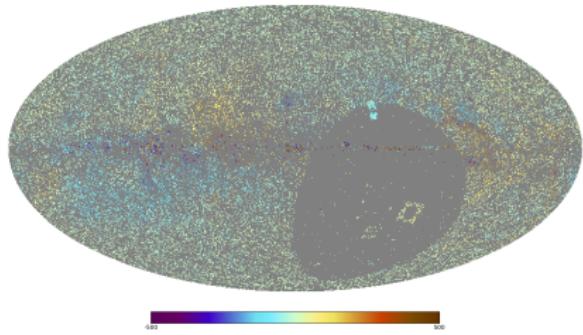
Challenges

- ▶ Regions without data
- ▶ Galactic/extragalactic split unknown
- ▶ Uncertain uncertainties



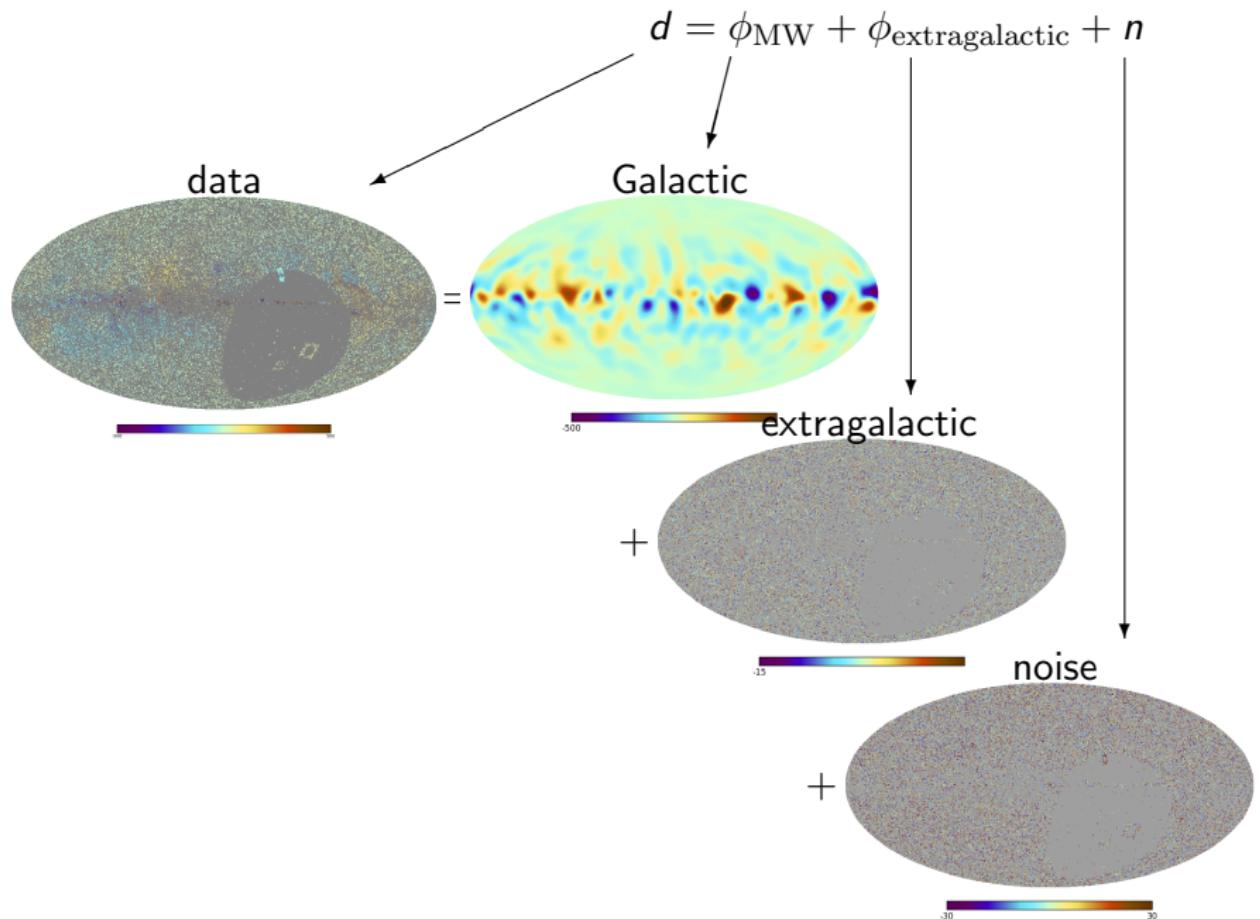
$$d = \phi_{\text{MW}} + \phi_{\text{extragalactic}} + n$$

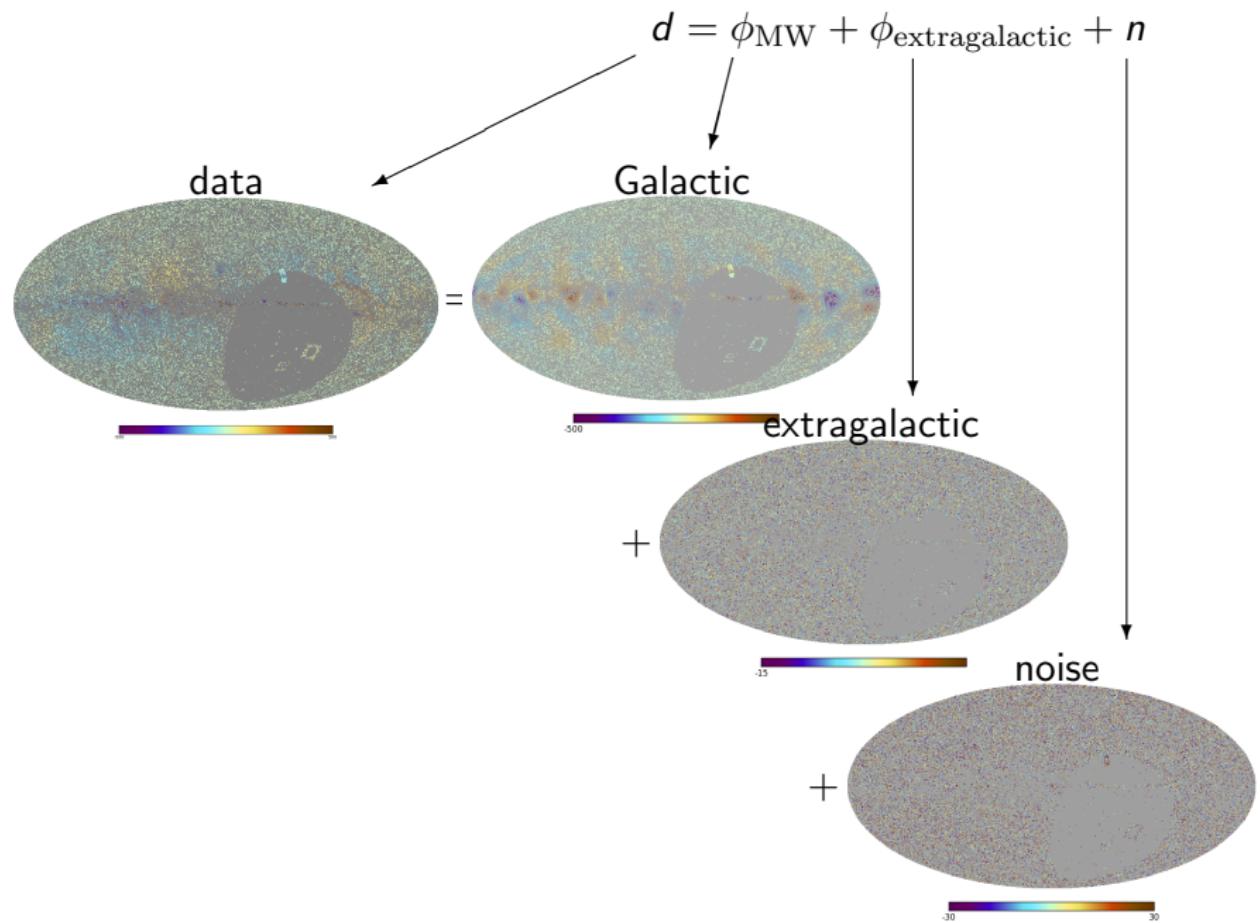
Challenges

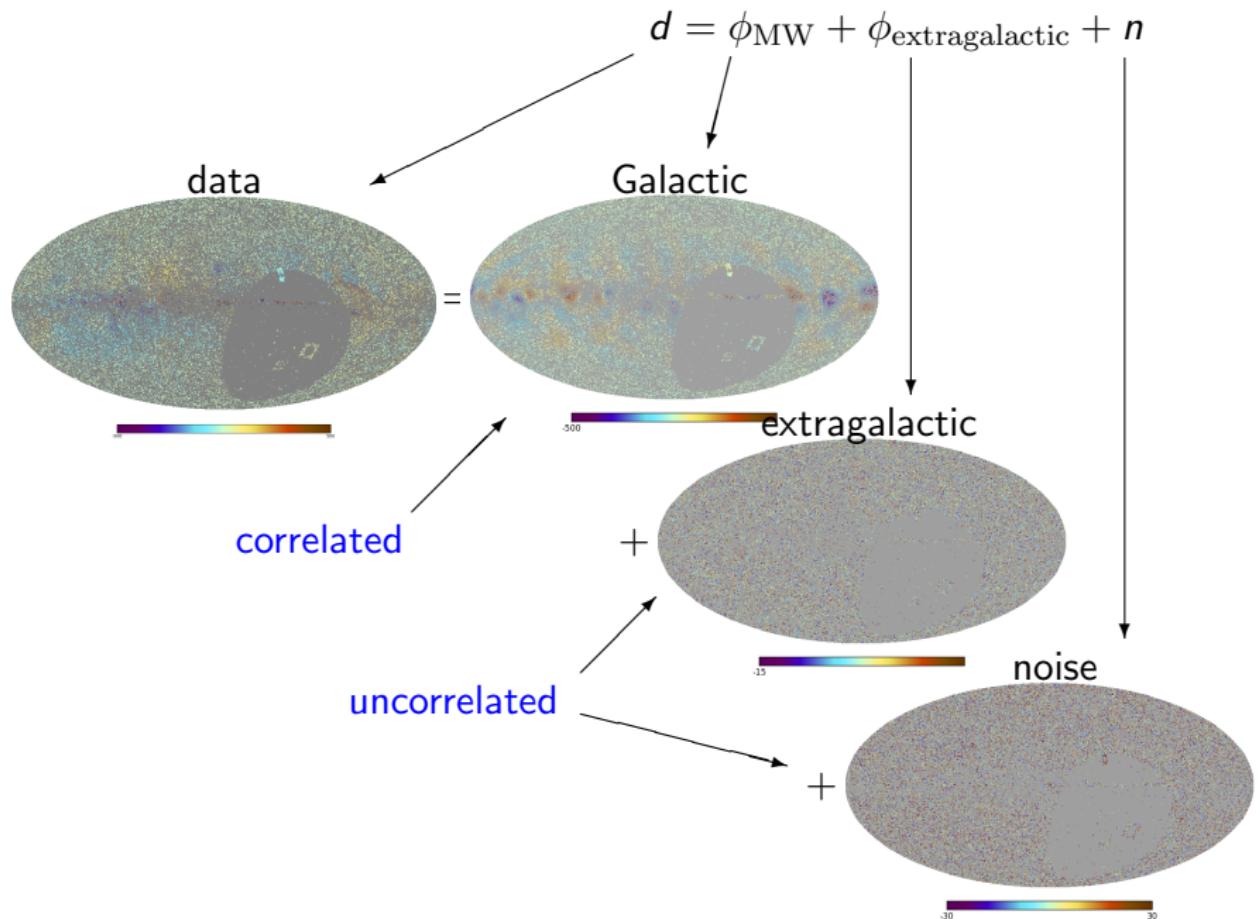


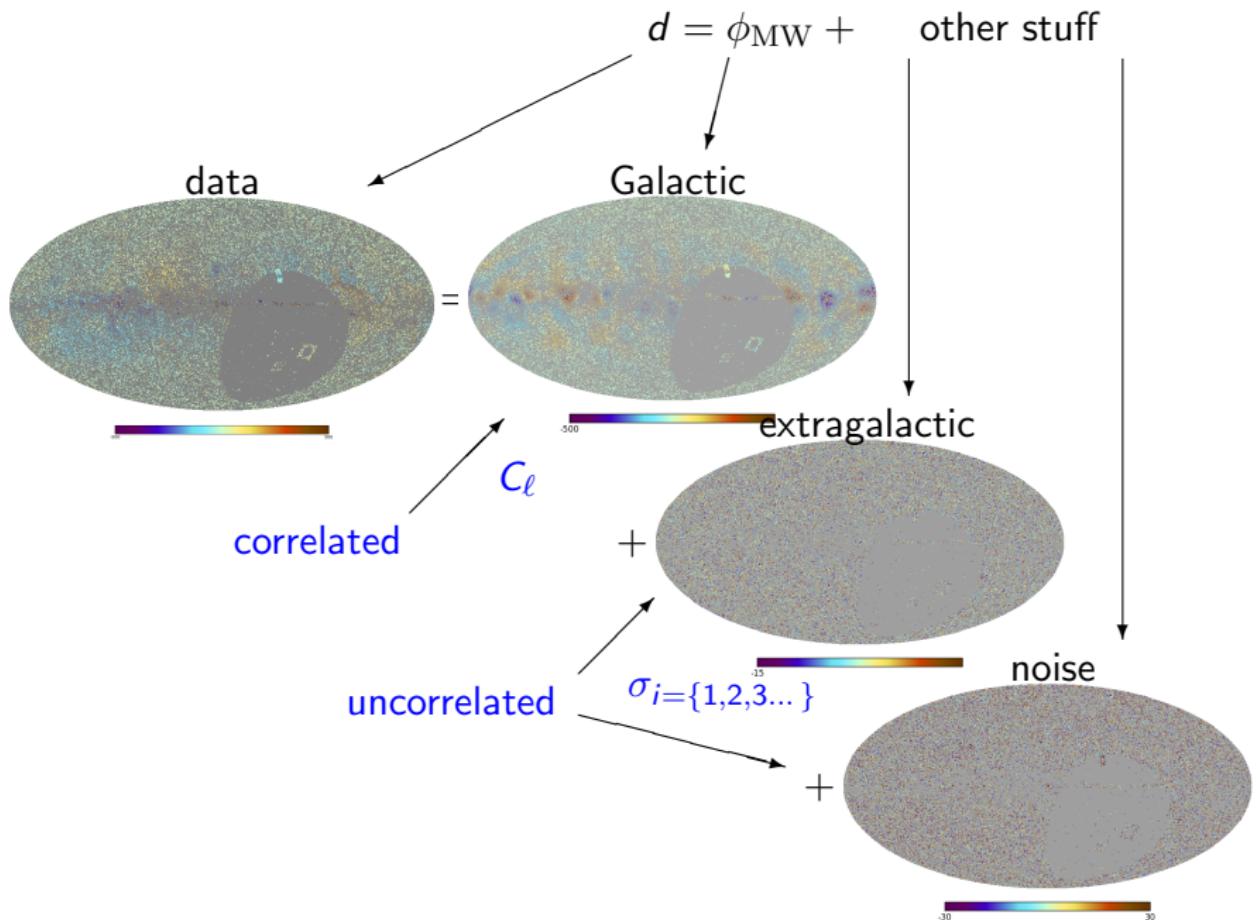
- ▶ Regions without data
- ▶ Galactic/extragalactic split unknown
- ▶ Uncertain uncertainties
 - ▶ $n\pi$ ambiguity
 - ▶ multiple components along a LOS
 - ▶ ionosphere
 - ▶ ...

$$d = \phi_{\text{MW}} + \phi_{\text{extragalactic}} + n$$

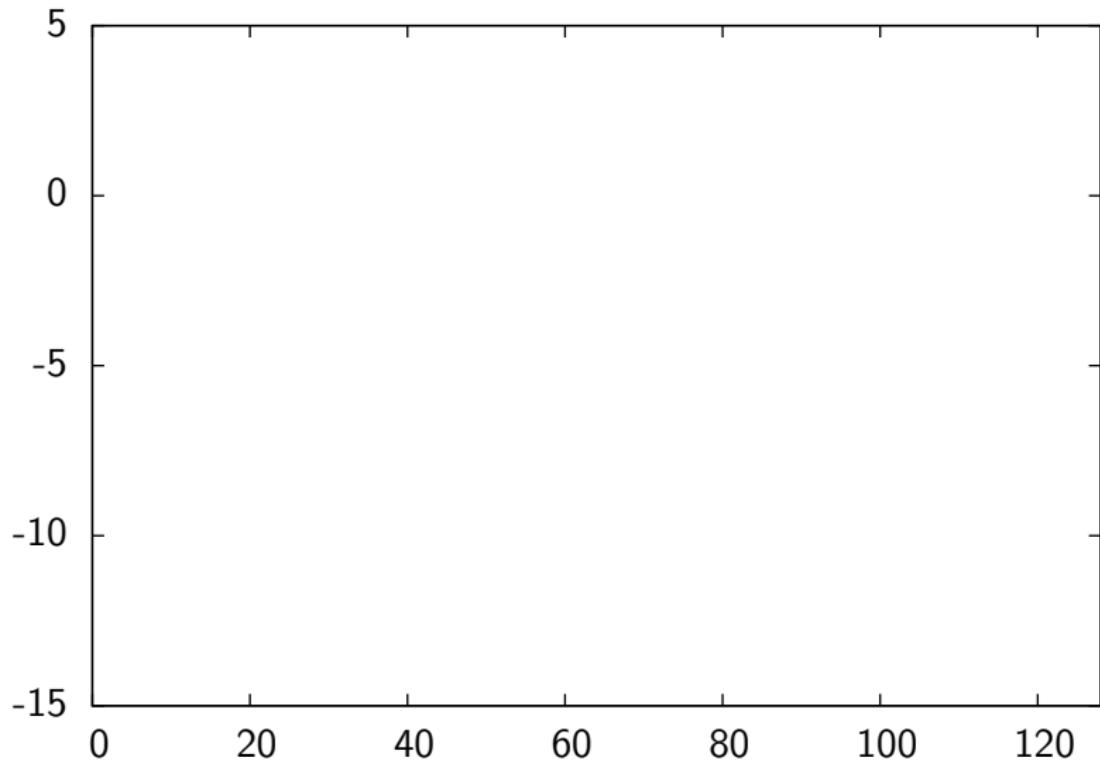




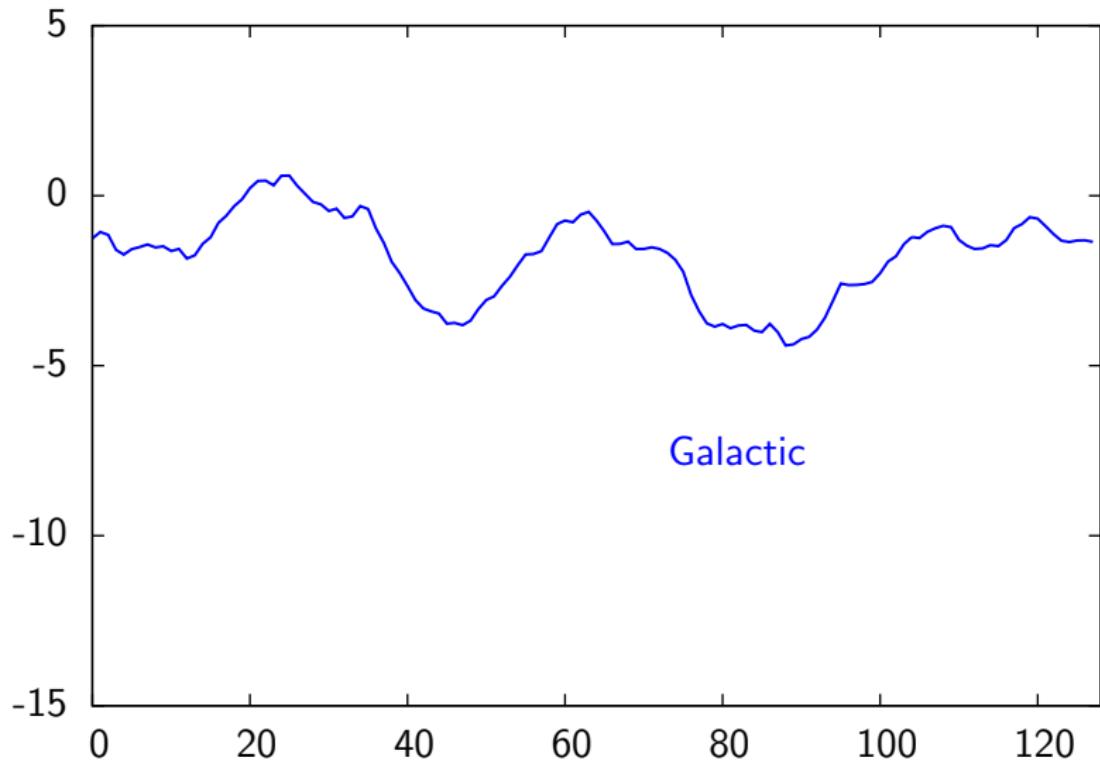




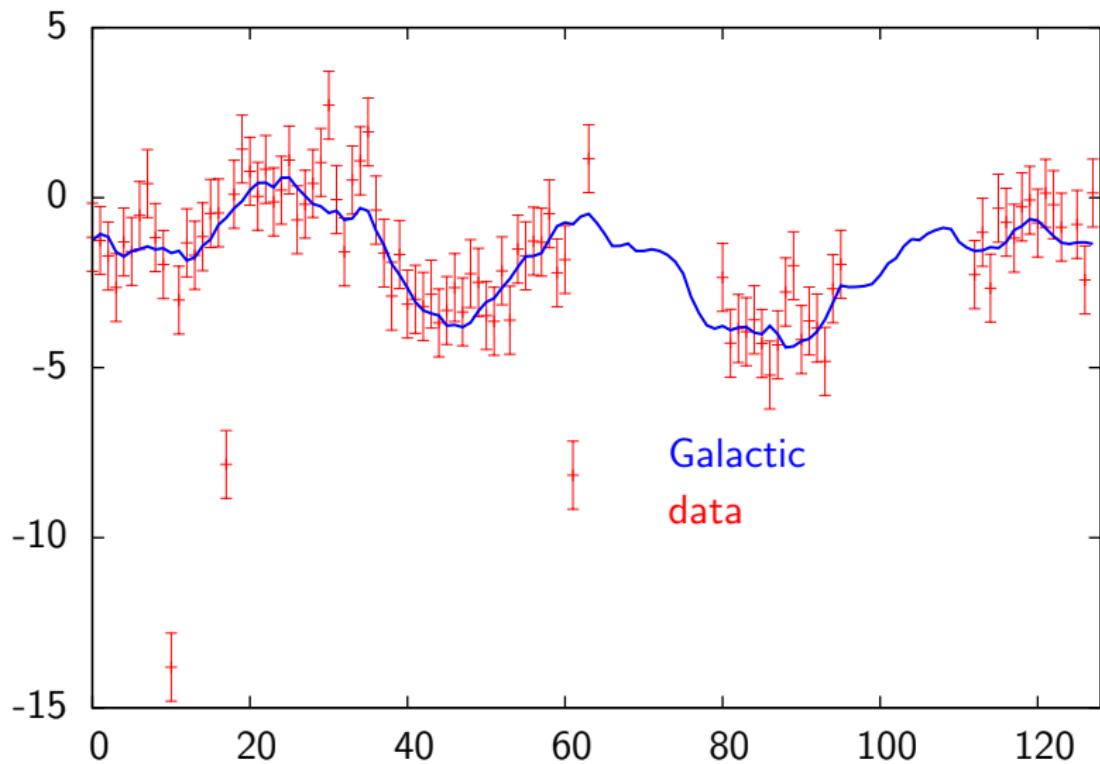
1D example



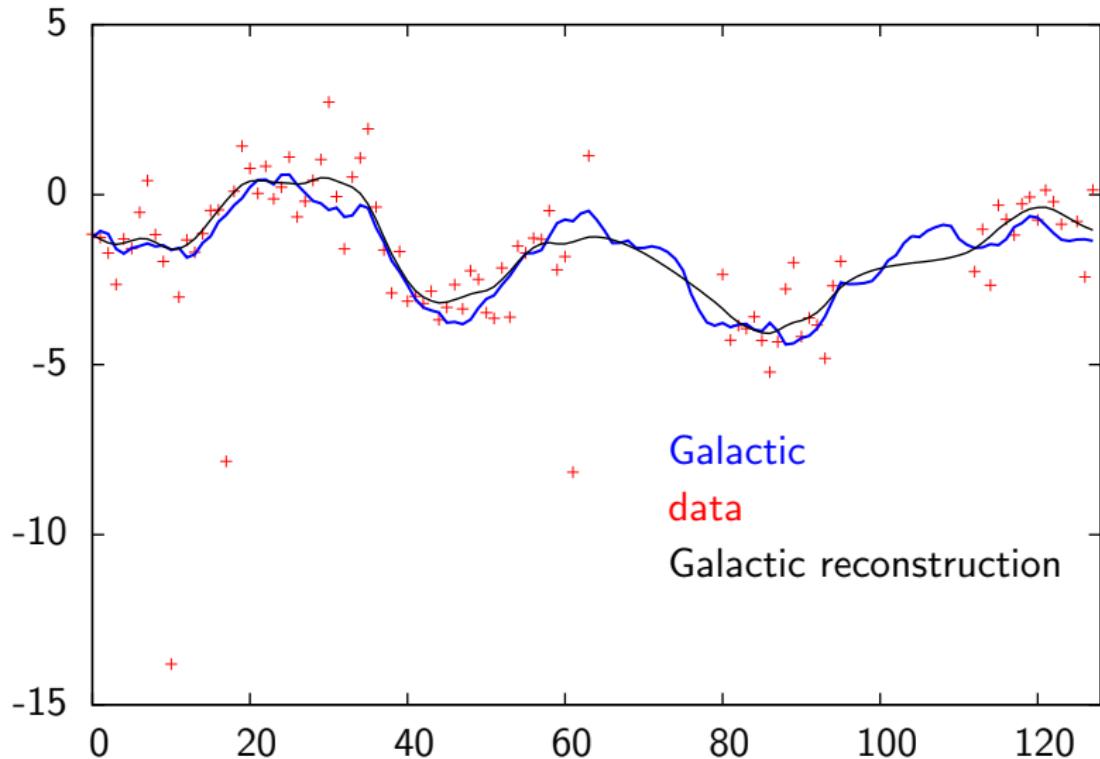
1D example



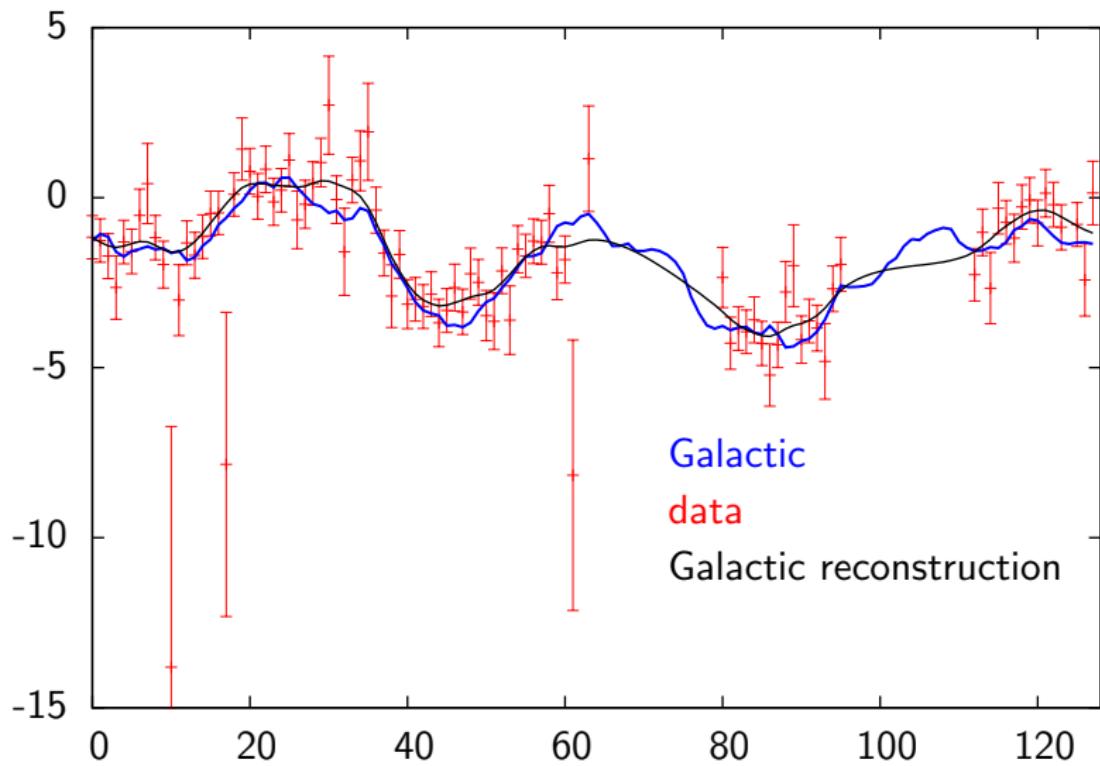
1D example



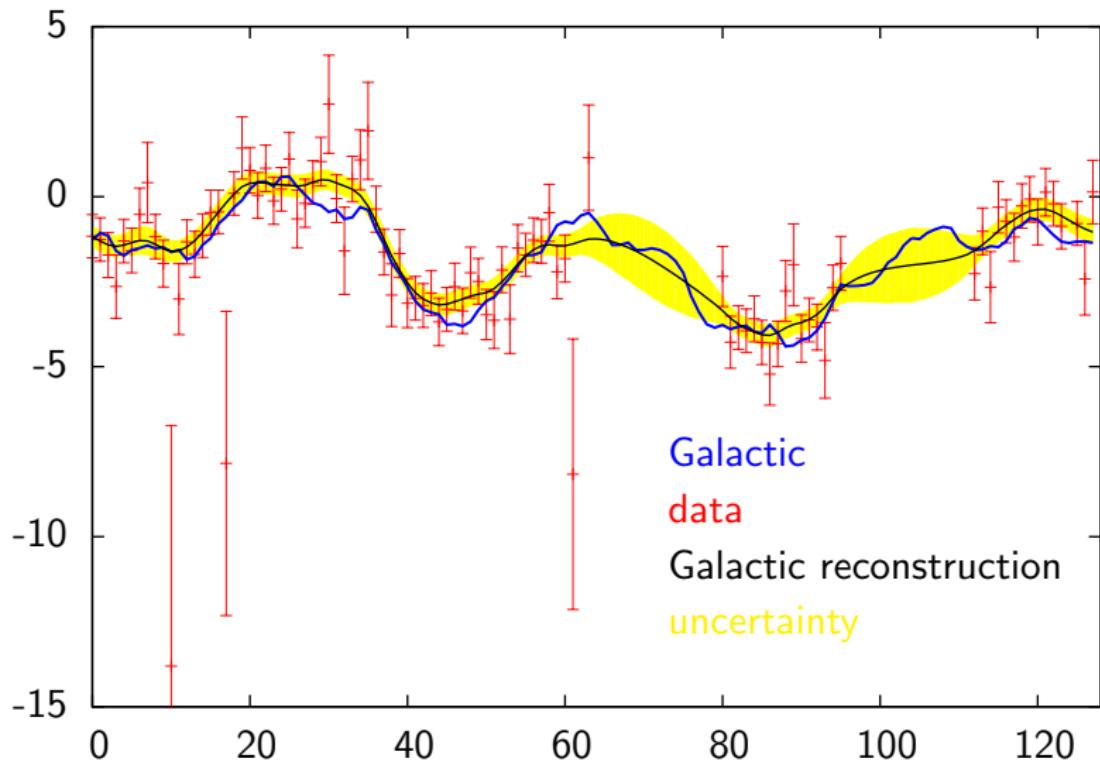
1D example



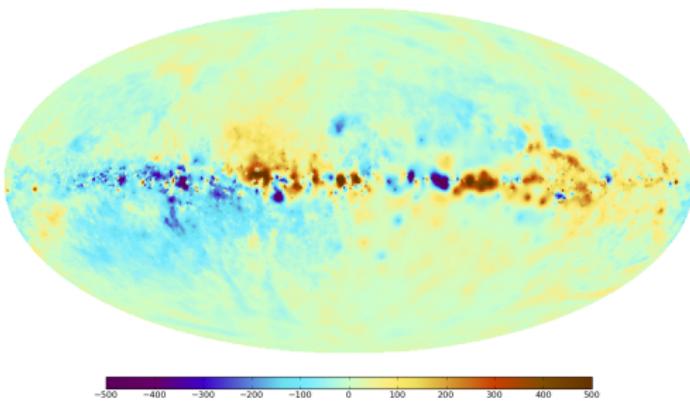
1D example



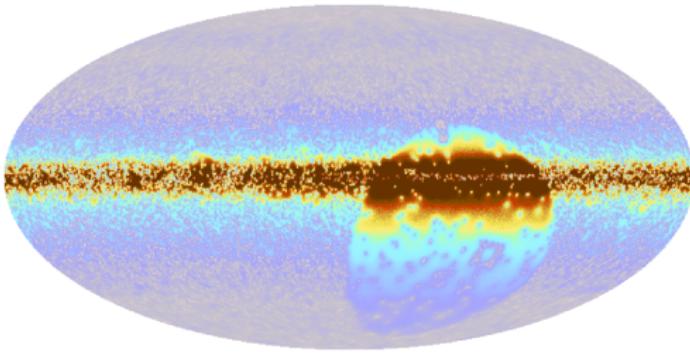
1D example



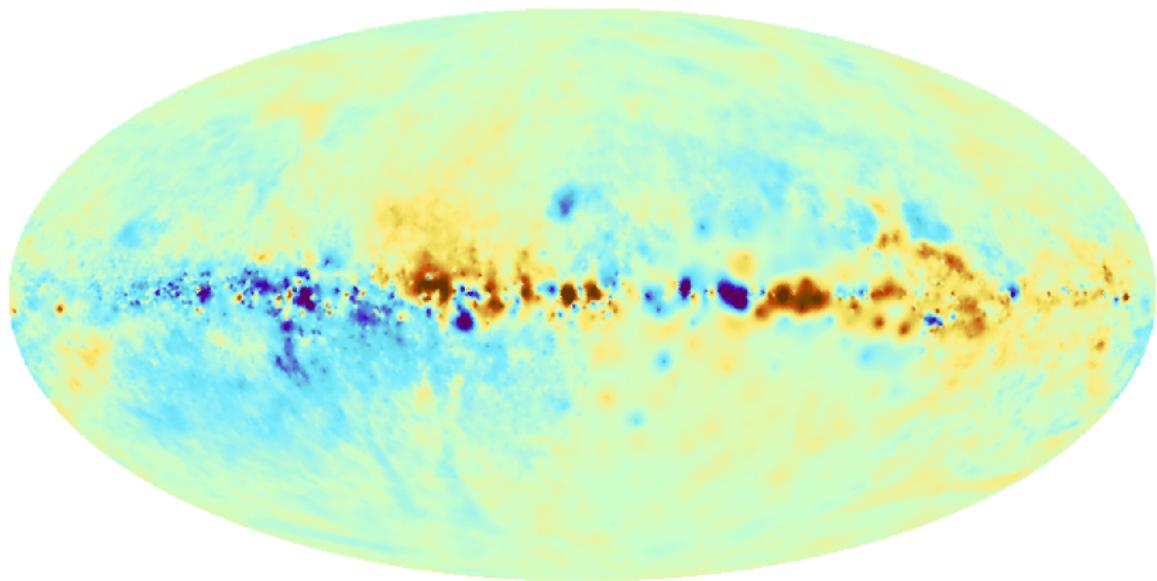
Galactic Faraday depth



uncertainty

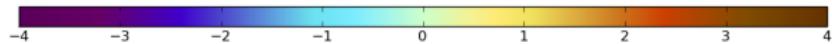
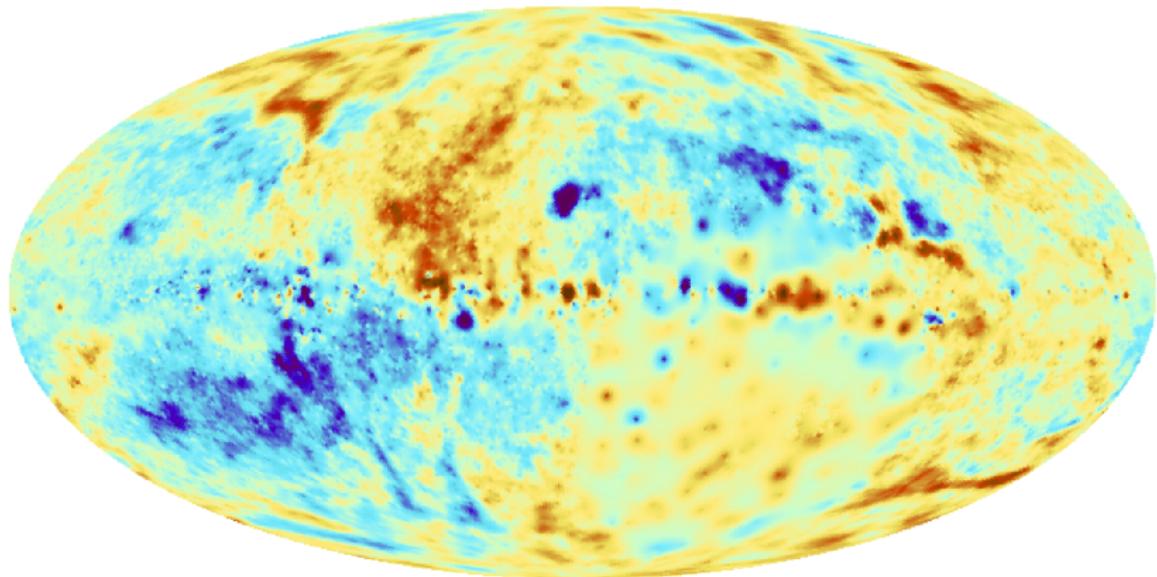


Galactic Faraday depth



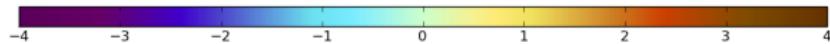
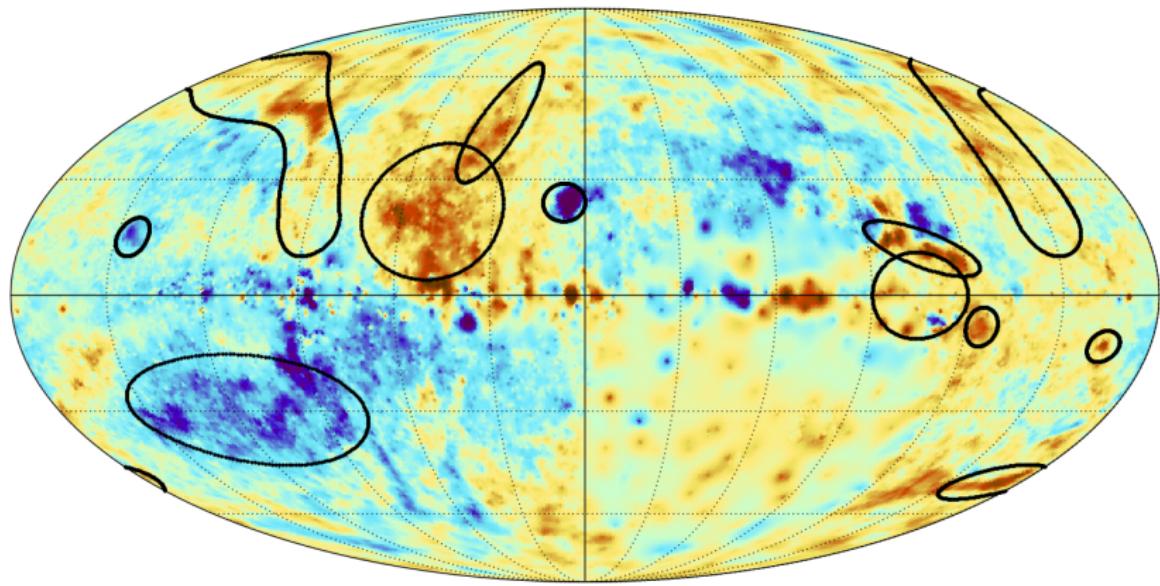
NO et al., A&A, 2012/2015; arXiv:1111.6186/1404.3701

rescaled Galactic Faraday depth



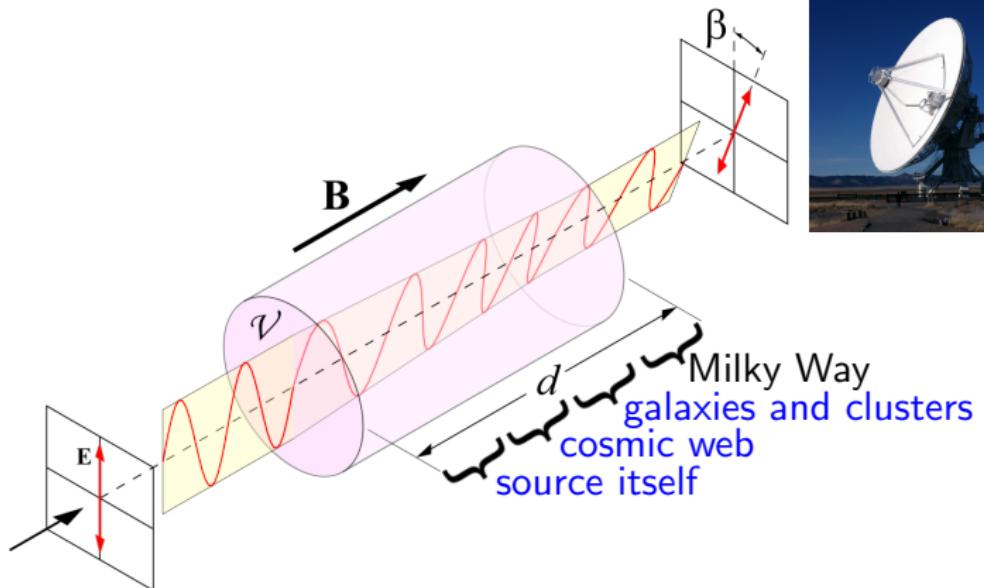
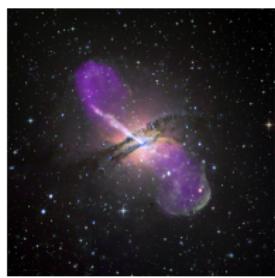
NO et al., A&A, 2012/2015; arXiv:1111.6186/1404.3701

rescaled Galactic Faraday depth



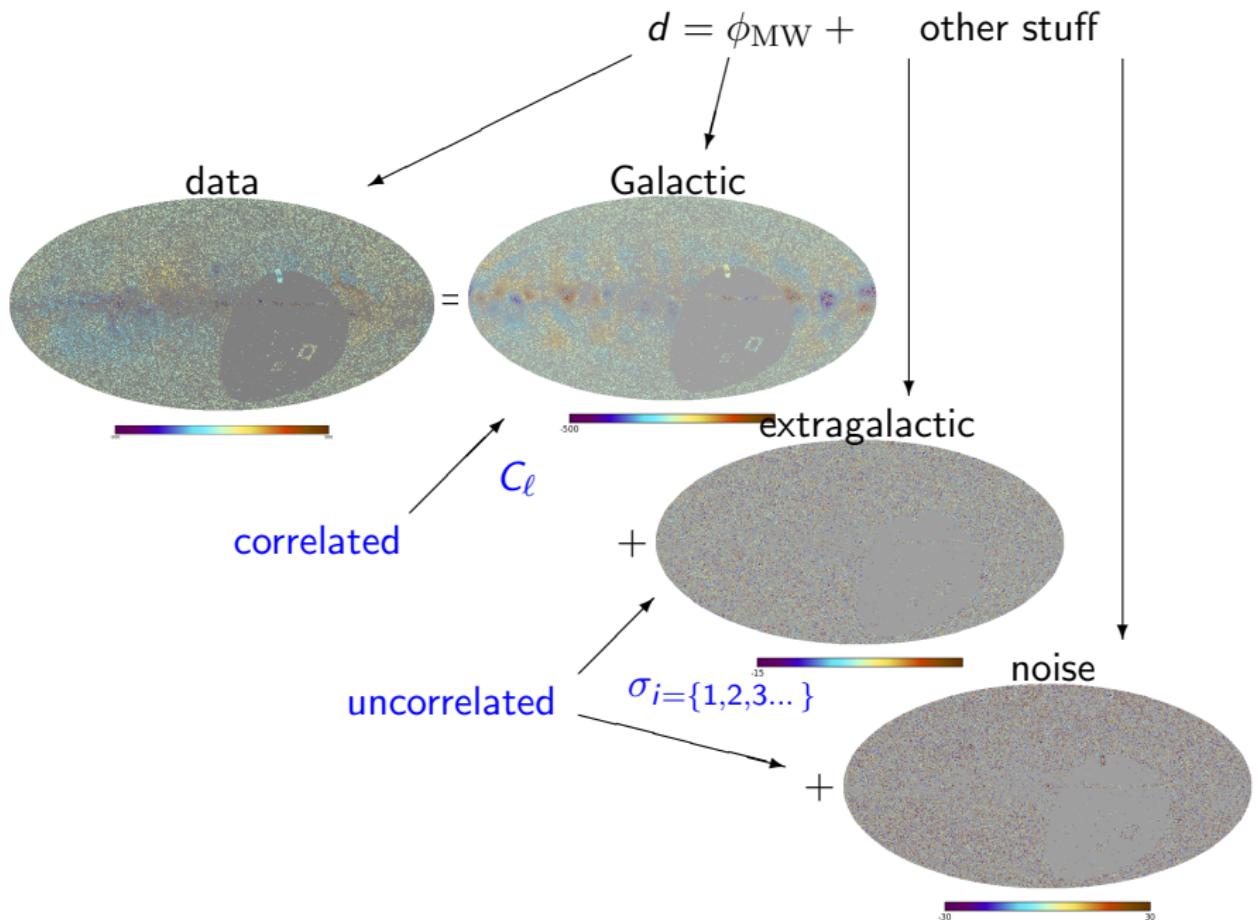
NO et al., A&A, 2012/2015; arXiv:1111.6186/1404.3701

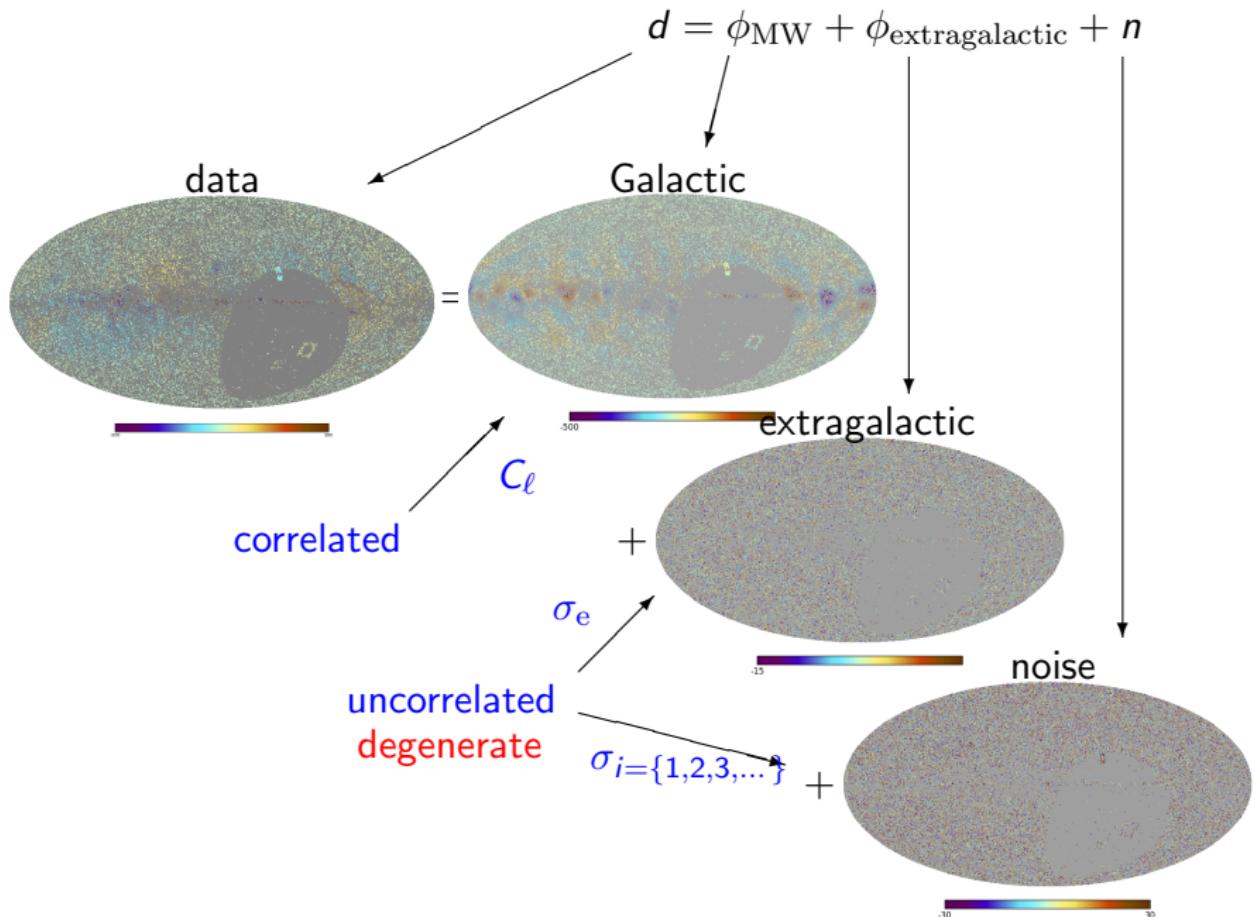
Extracting the extragalactic contribution

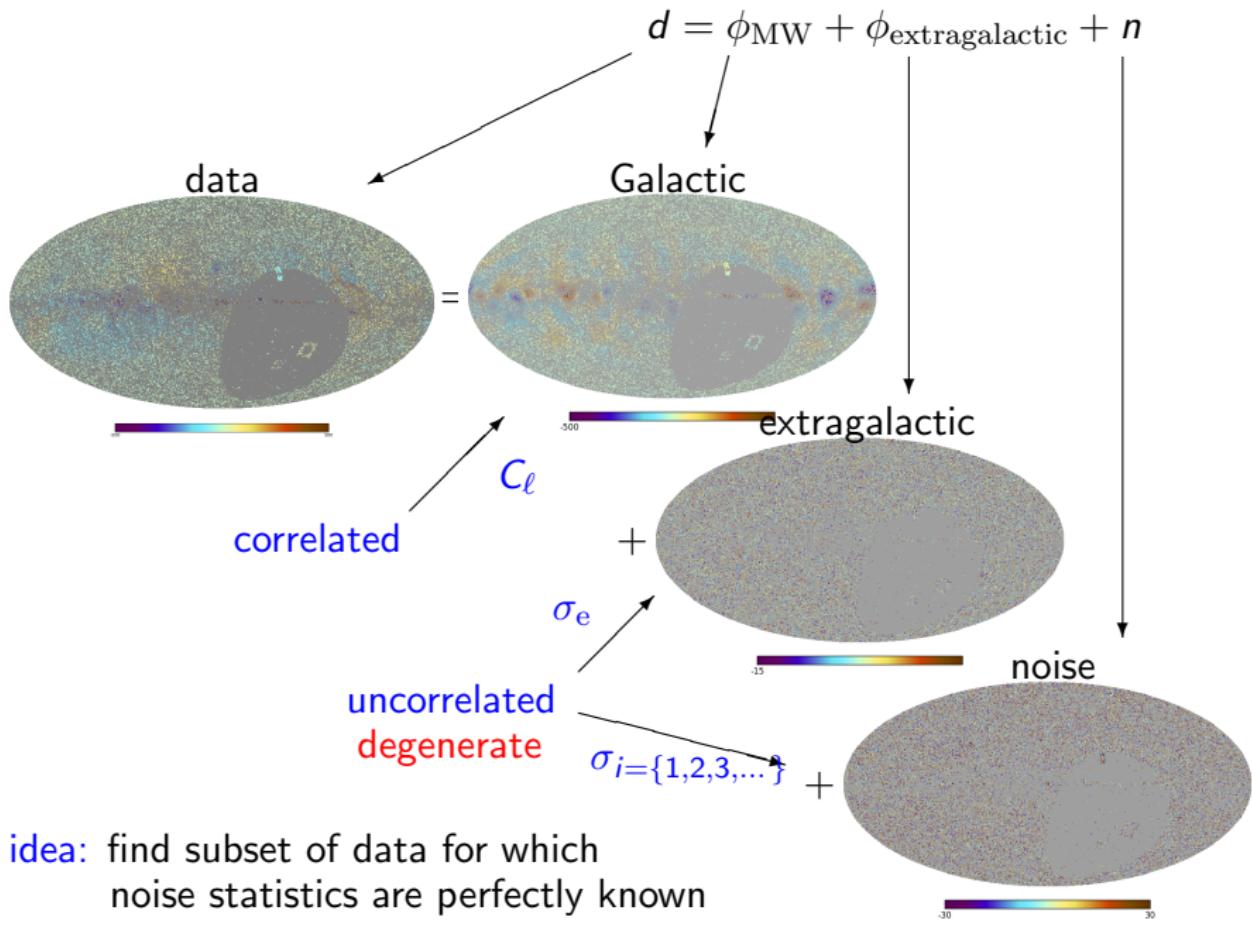


extragalactic Faraday depth:

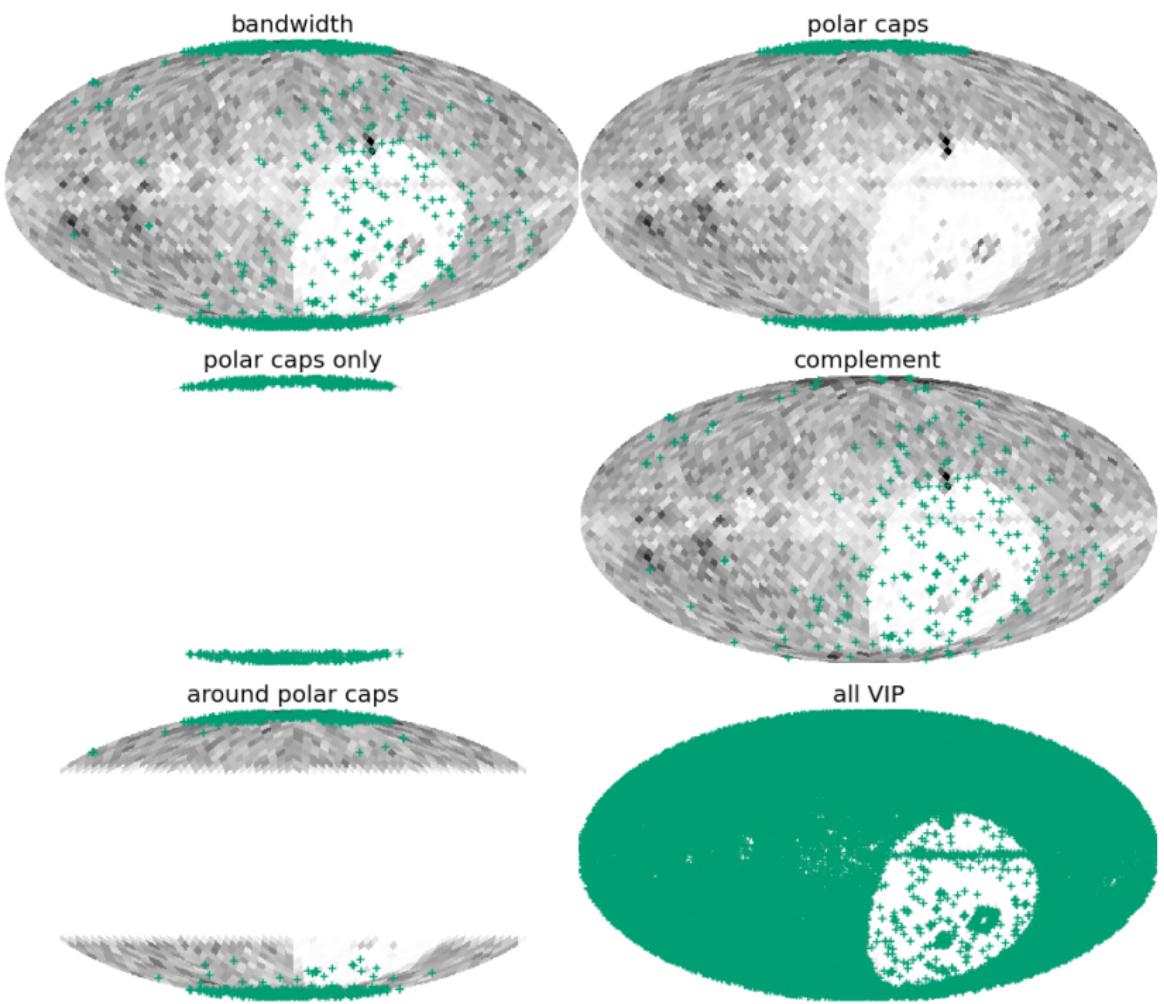
$$\phi_{\text{extragalactic}} \propto \int_{r_{\text{source}}}^{r_{\text{MilkyWay}}} (1+z)^{-2} n_e B_r dr$$

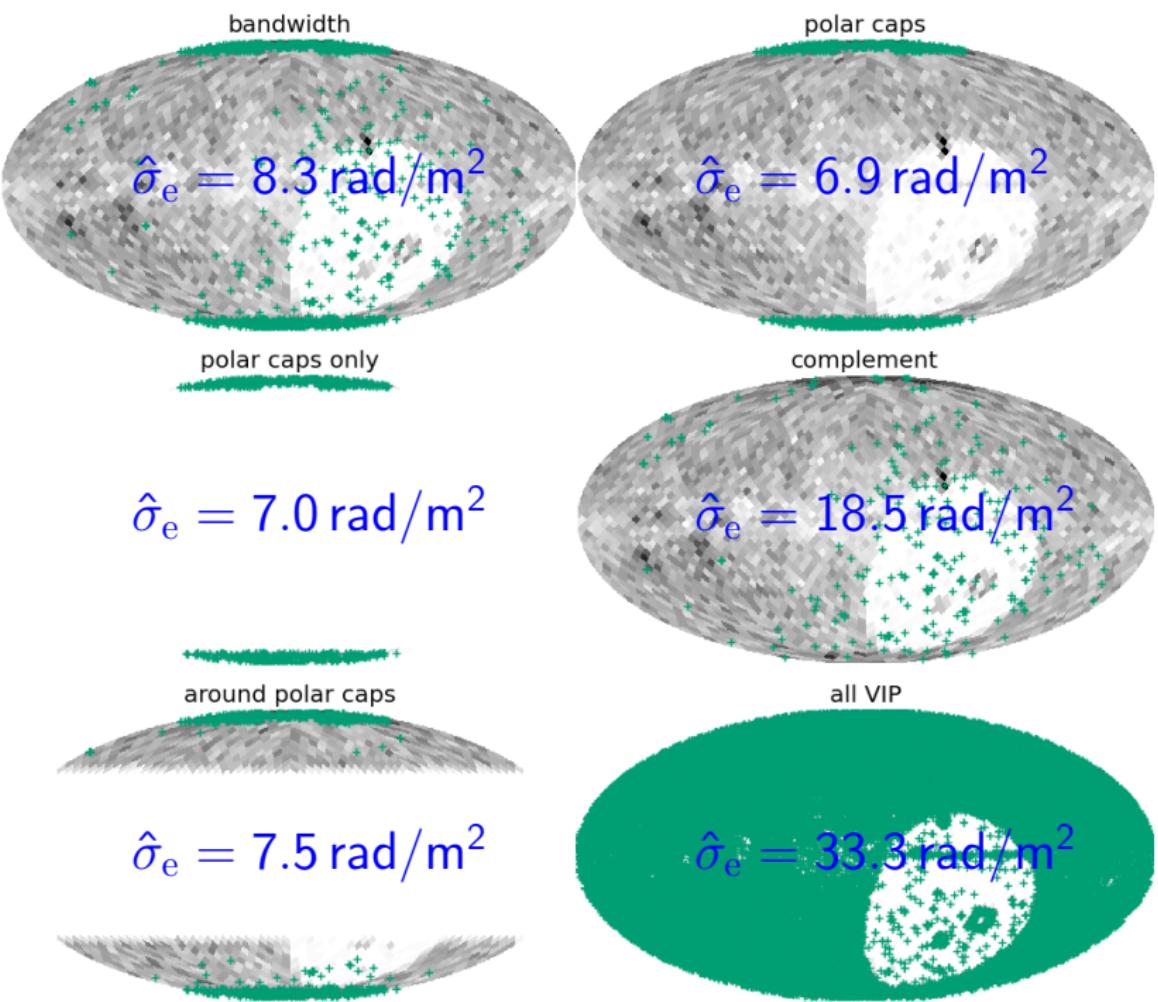




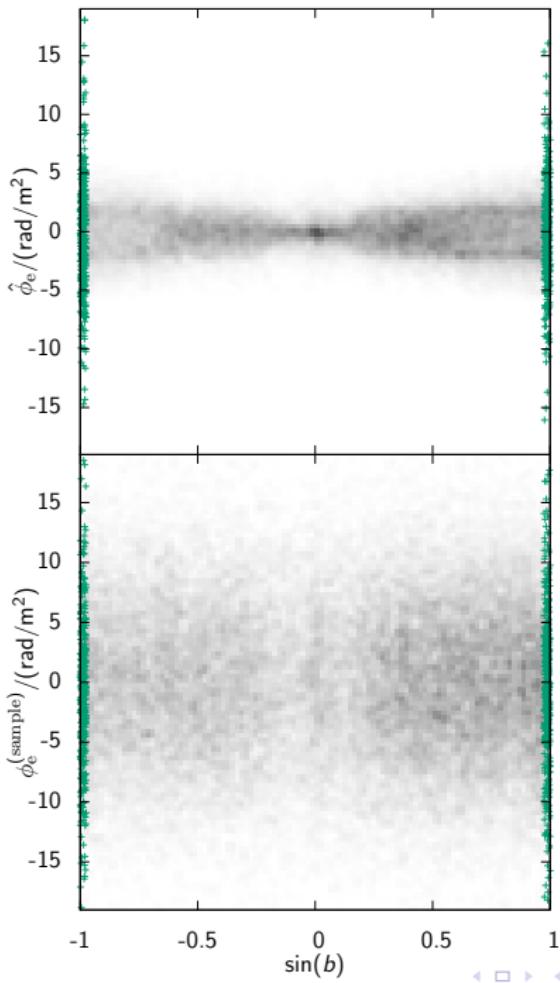


idea: find subset of data for which noise statistics are perfectly known

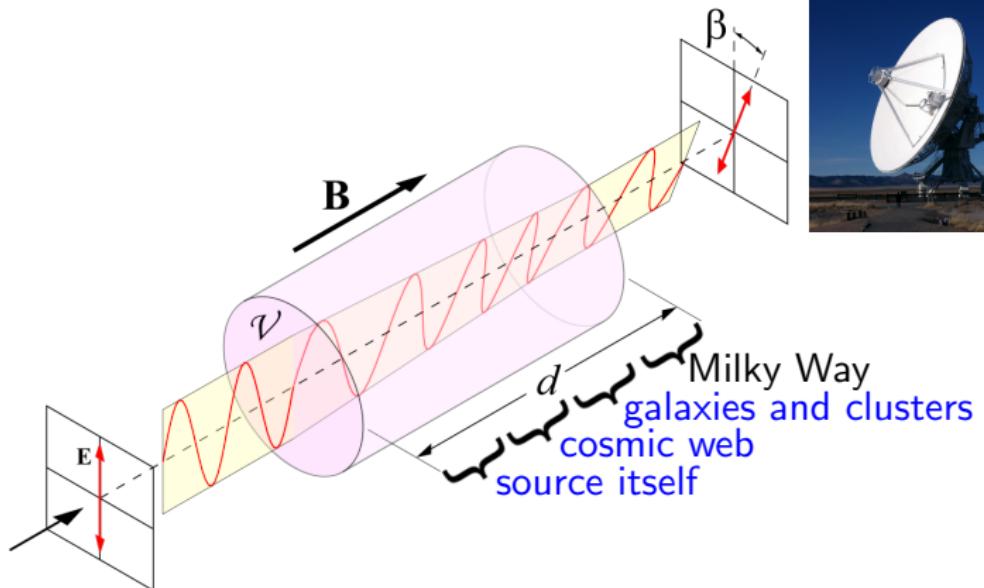
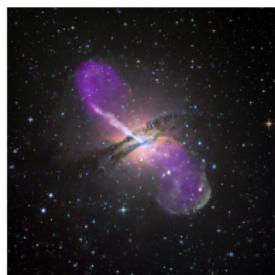




estimate
consistent with data

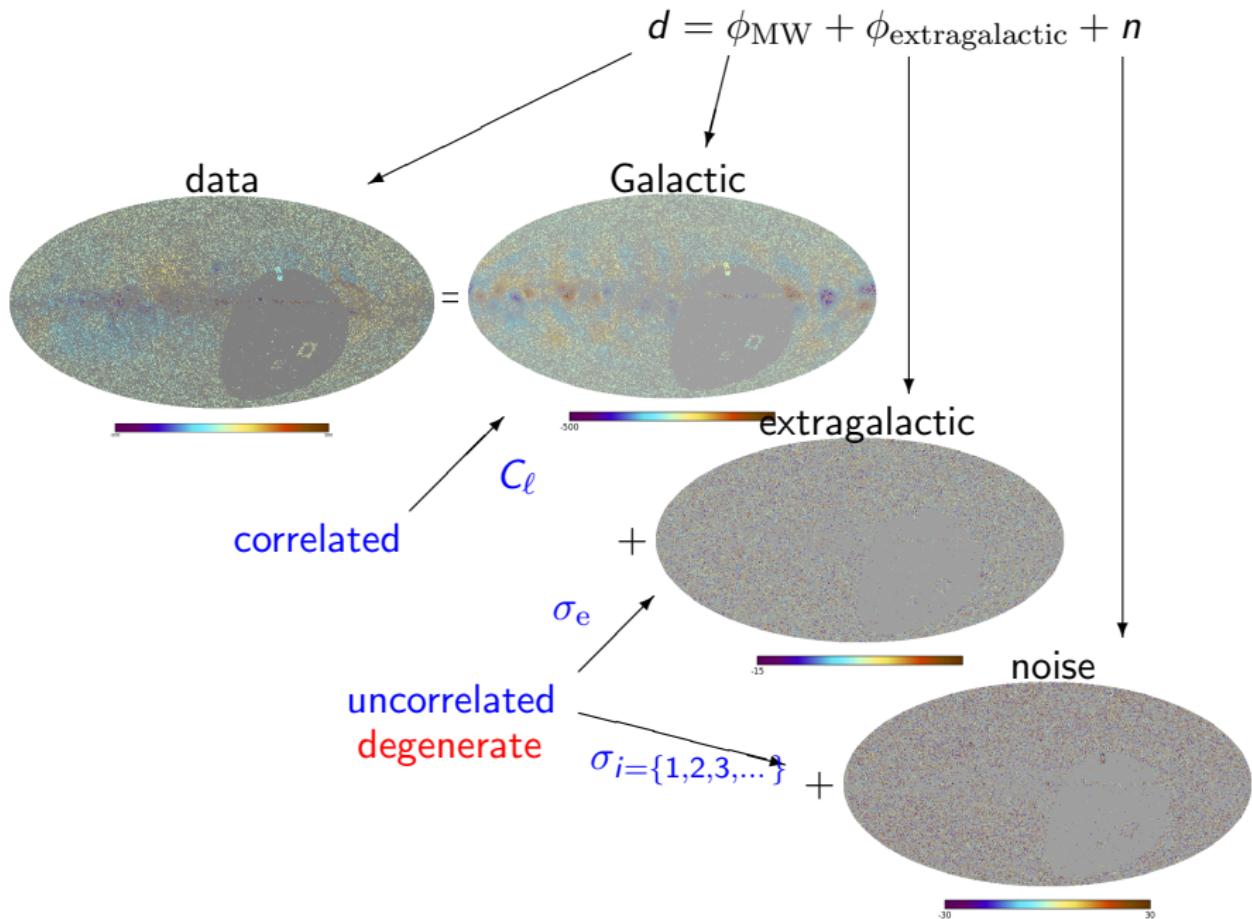


What is the extragalactic contribution?



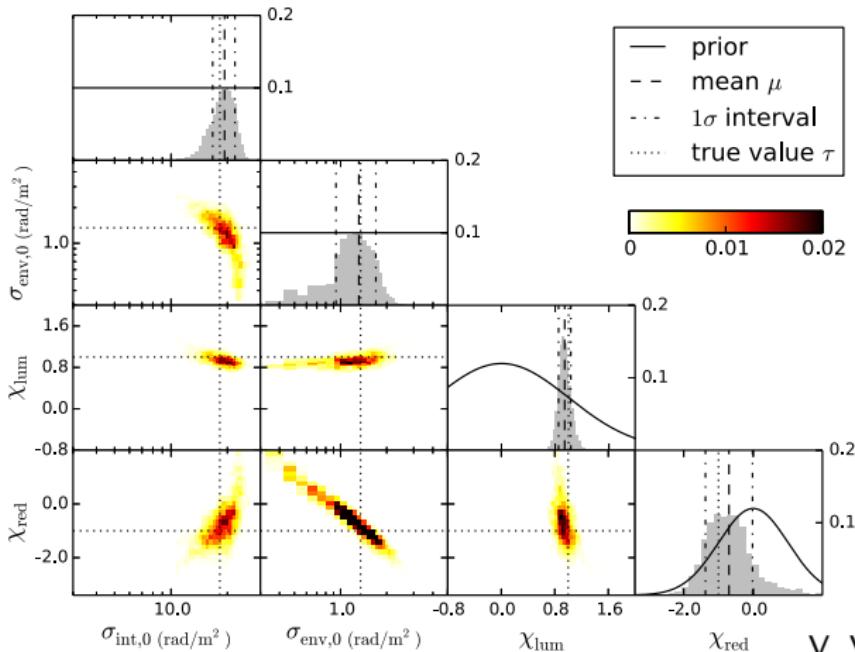
extragalactic Faraday depth:

$$\phi_{\text{extragalactic}} \propto \int_{r_{\text{source}}}^{r_{\text{MilkyWay}}} (1+z)^{-2} n_e B_r dr$$



$$\sigma_{\text{e},i}^2 \propto \left(\frac{L}{L_0}\right)^{\chi_{\text{lum}}} \frac{\sigma_{\text{int}}^2}{(1+z_i)^4} + \frac{D_i}{D_0} \sigma_{\text{env}}^2$$

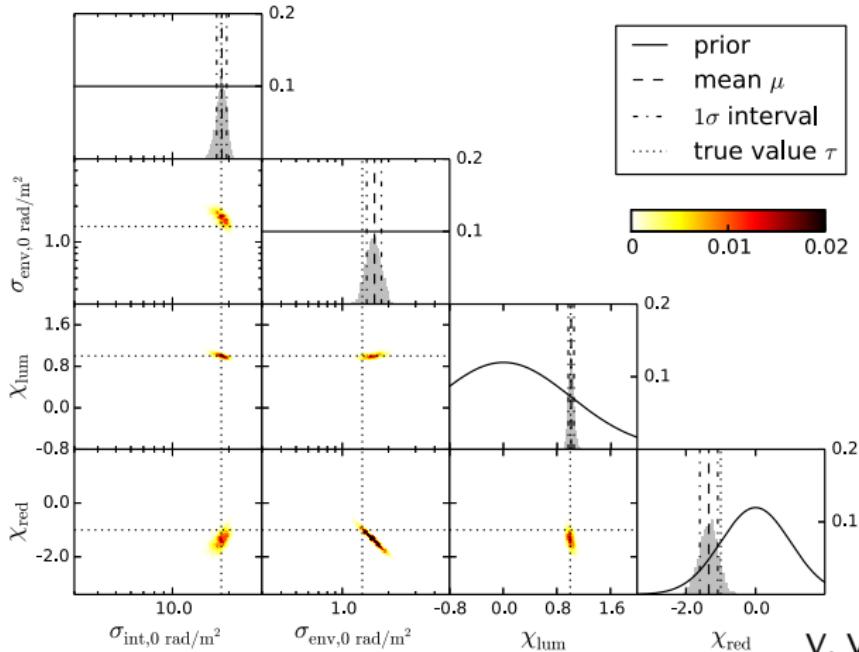
$$D_i = \int_0^{z_i} \frac{c}{H(z)} (1+z)^{4+\chi_{\text{red}}} dz$$



4003 lines of sight

$$\sigma_{\text{e},i}^2 \propto \left(\frac{L}{L_0}\right)^{\chi_{\text{lum}}} \frac{\sigma_{\text{int}}^2}{(1+z_i)^4} + \frac{D_i}{D_0} \sigma_{\text{env}}^2$$

$$D_i = \int_0^{z_i} \frac{c}{H(z)} (1+z)^{4+\chi_{\text{red}}} dz$$



41632 lines of sight

Summary

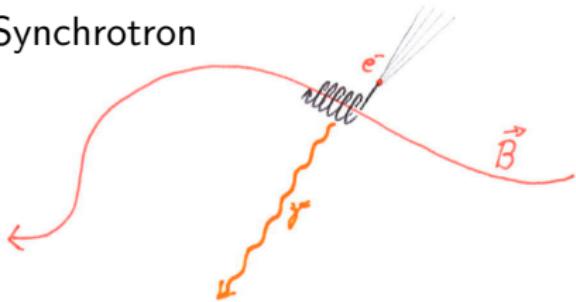
- ▶ Galactic contribution (correlated) can be separated from rest (uncorrelated)
- ▶ Rest can be separated statistically into extragalactic and noise
- ▶ Uncertainties are large and should not be ignored

All results at

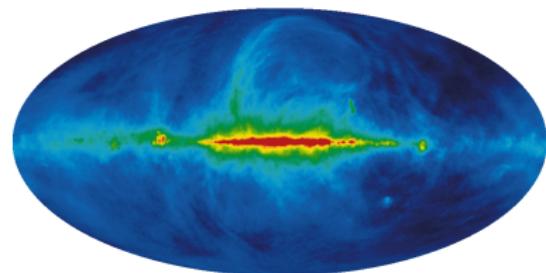
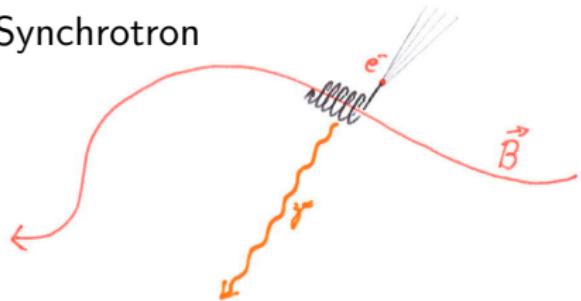
<http://www.mpa-garching.mpg.de/ift/faraday/>

BACKUP

Synchrotron

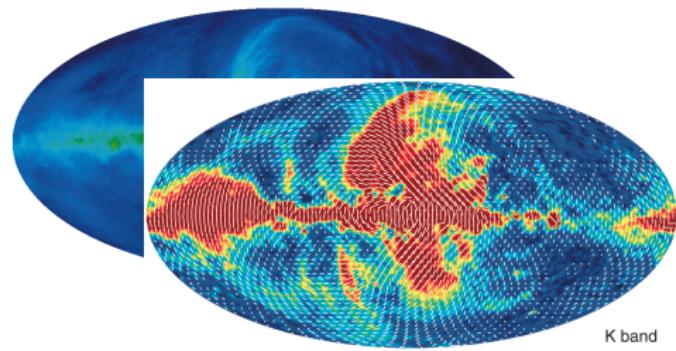
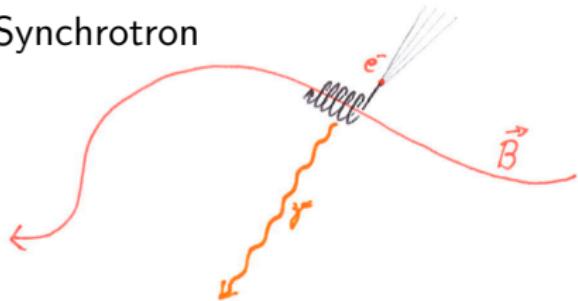


Synchrotron



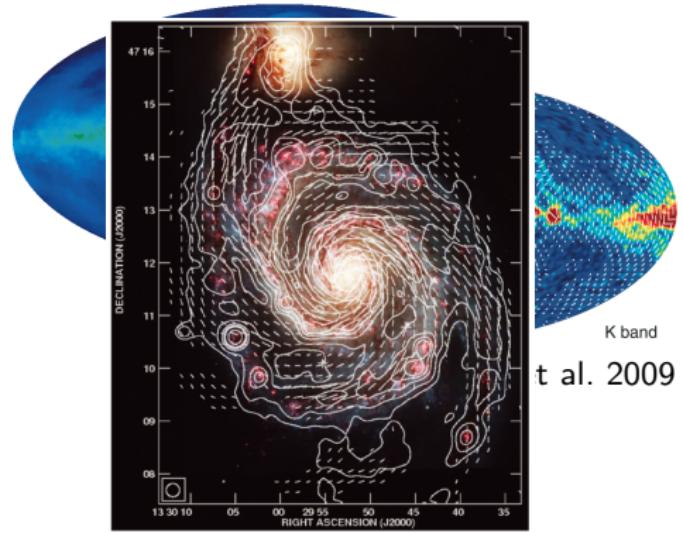
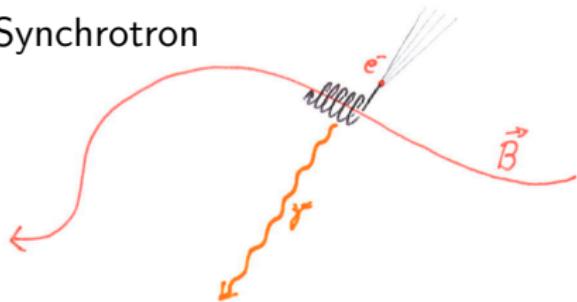
Haslam et al. 1981

Synchrotron



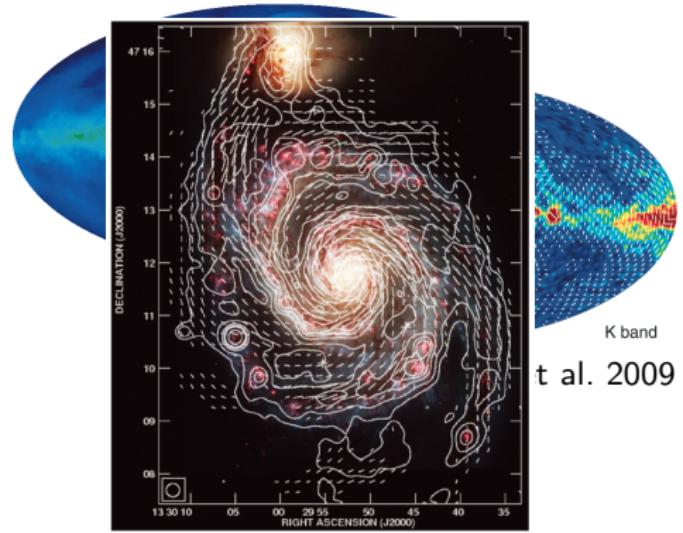
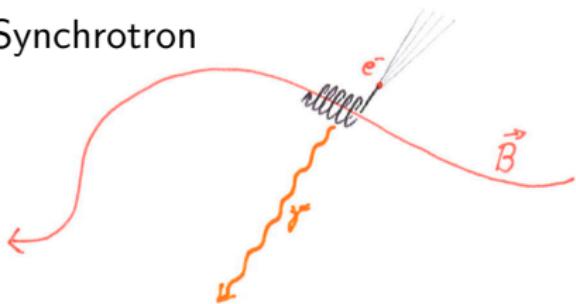
Hinshaw et al. 2009

Synchrotron

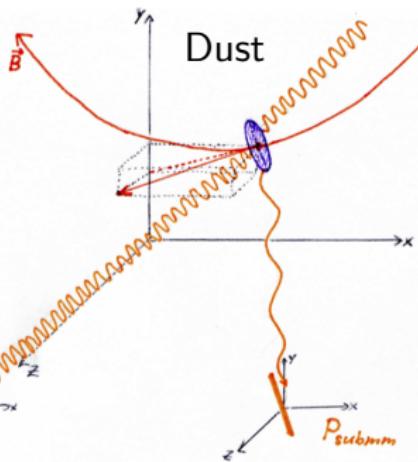


Fletcher et al. 2011

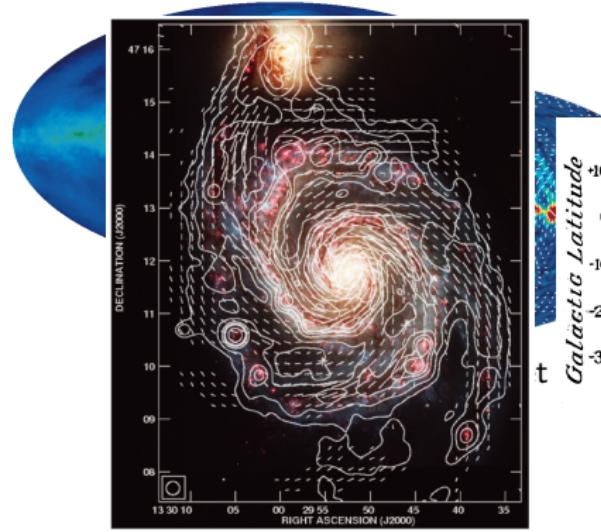
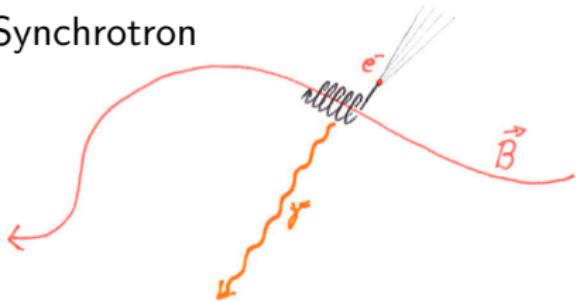
Synchrotron



Fletcher et al. 2011

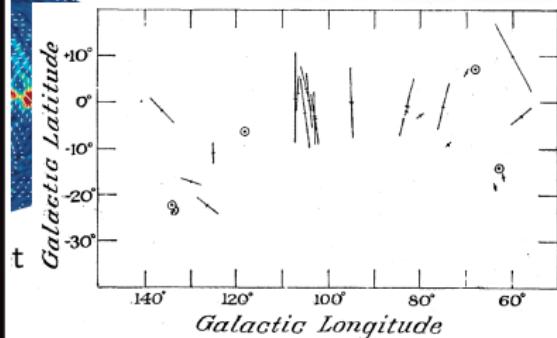
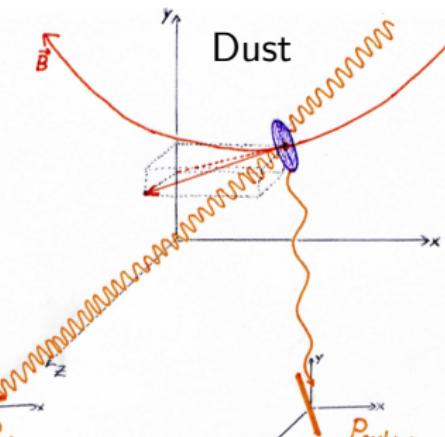


Synchrotron

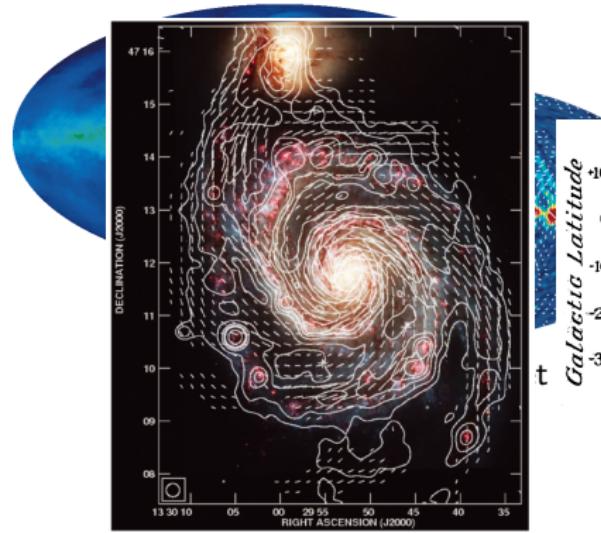
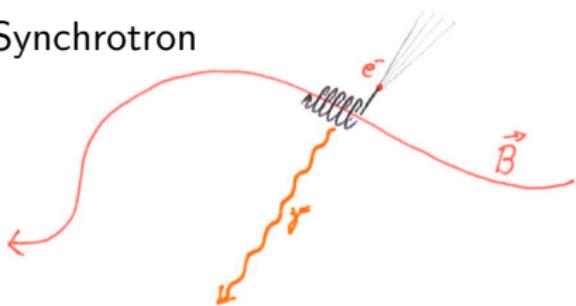


Fletcher et al. 2011

Hall 1949

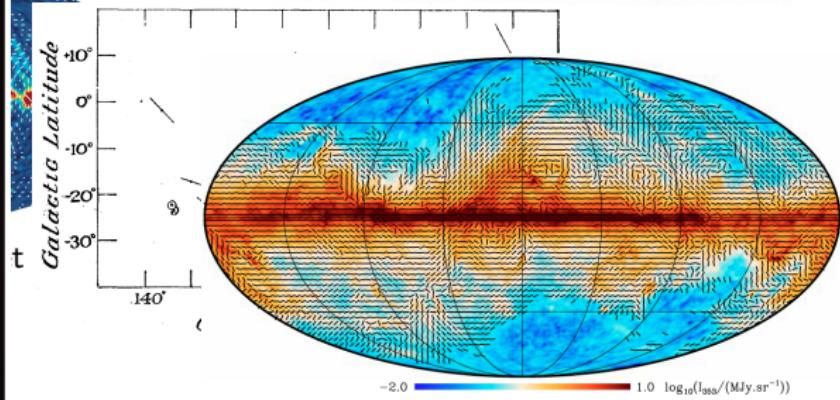
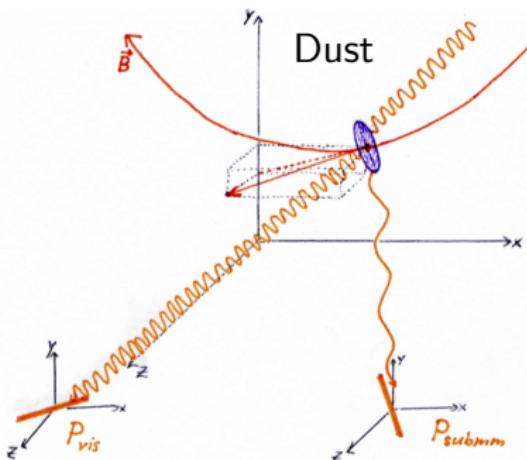


Synchrotron



Fletcher et al. 2011

Dust



Planck Collaboration Int. XIX (2014)