Cosmic magnetism revealed through Faraday rotation

Niels Oppermann

in collaboration with:
V. Vacca, T. Enßlin (MPA, Munich)
B. Gaensler (Dunlap, Toronto)
J. Stil, J.-A. Brown (UofC, Calgary)
H. Junklewitz, D. Schnitzeler (AIfA/MPIfR, Bonn)
and others

NORDITA workshop, Stockholm, 2015-06-26

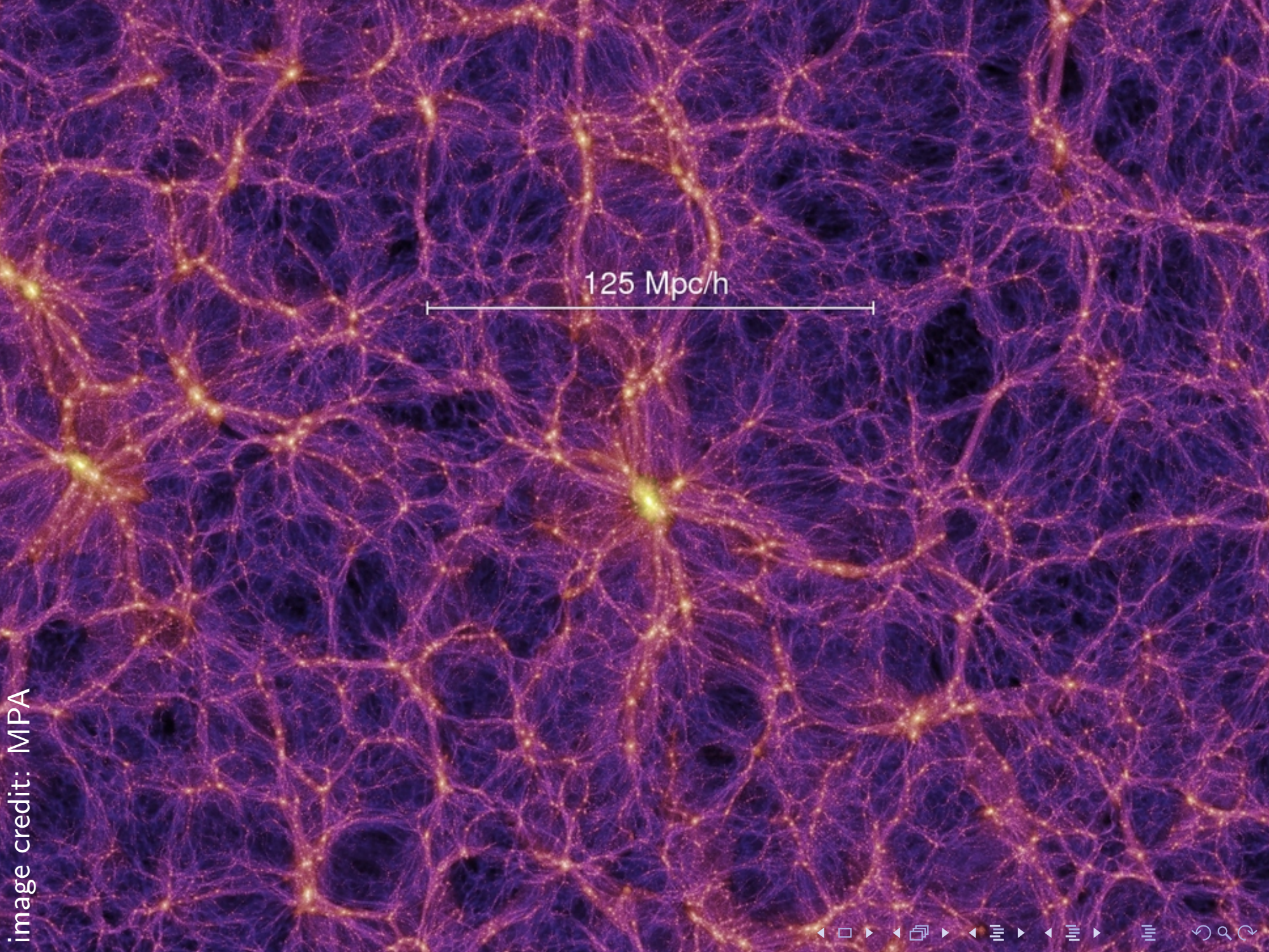


image credit: MPA

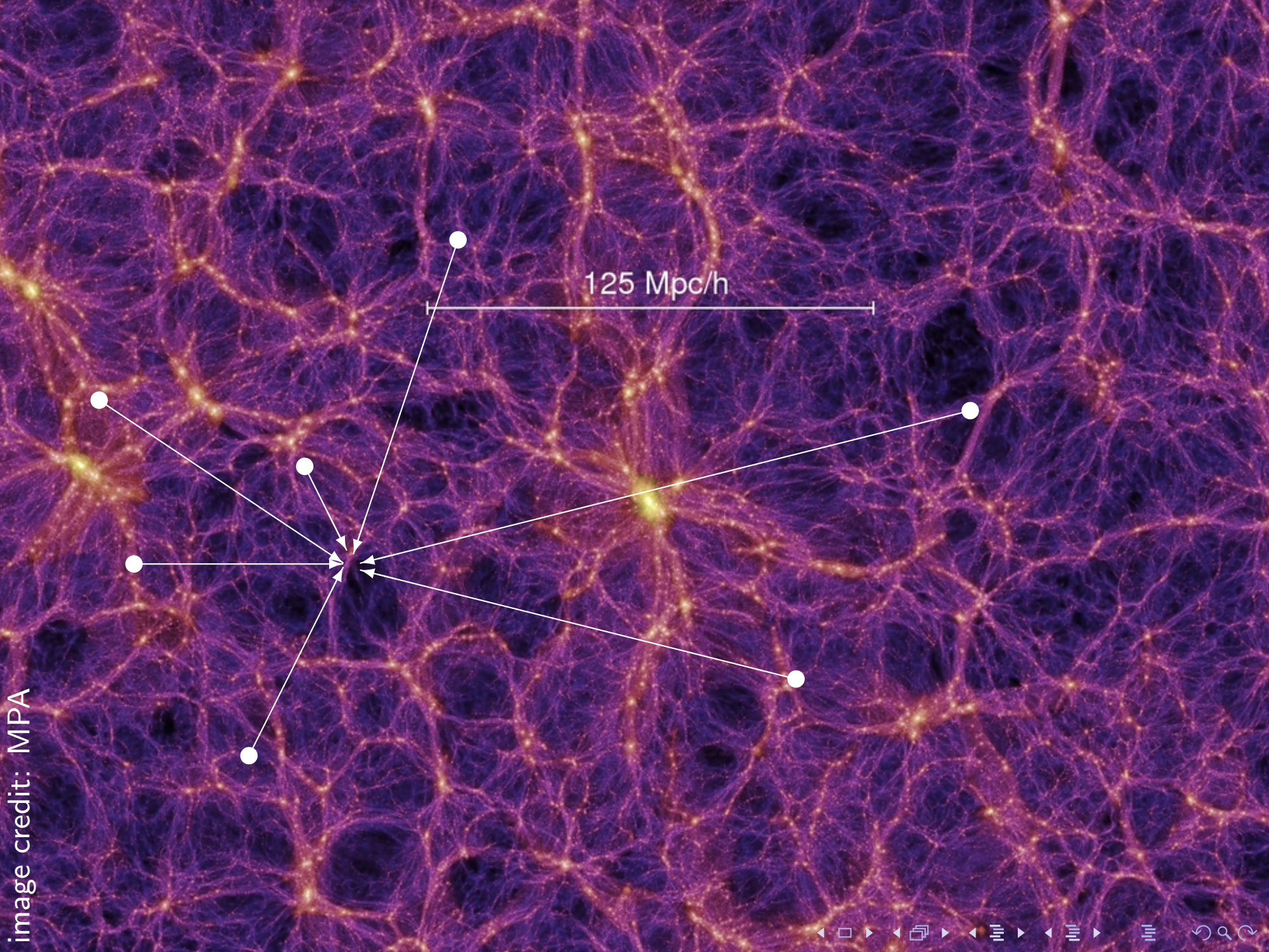
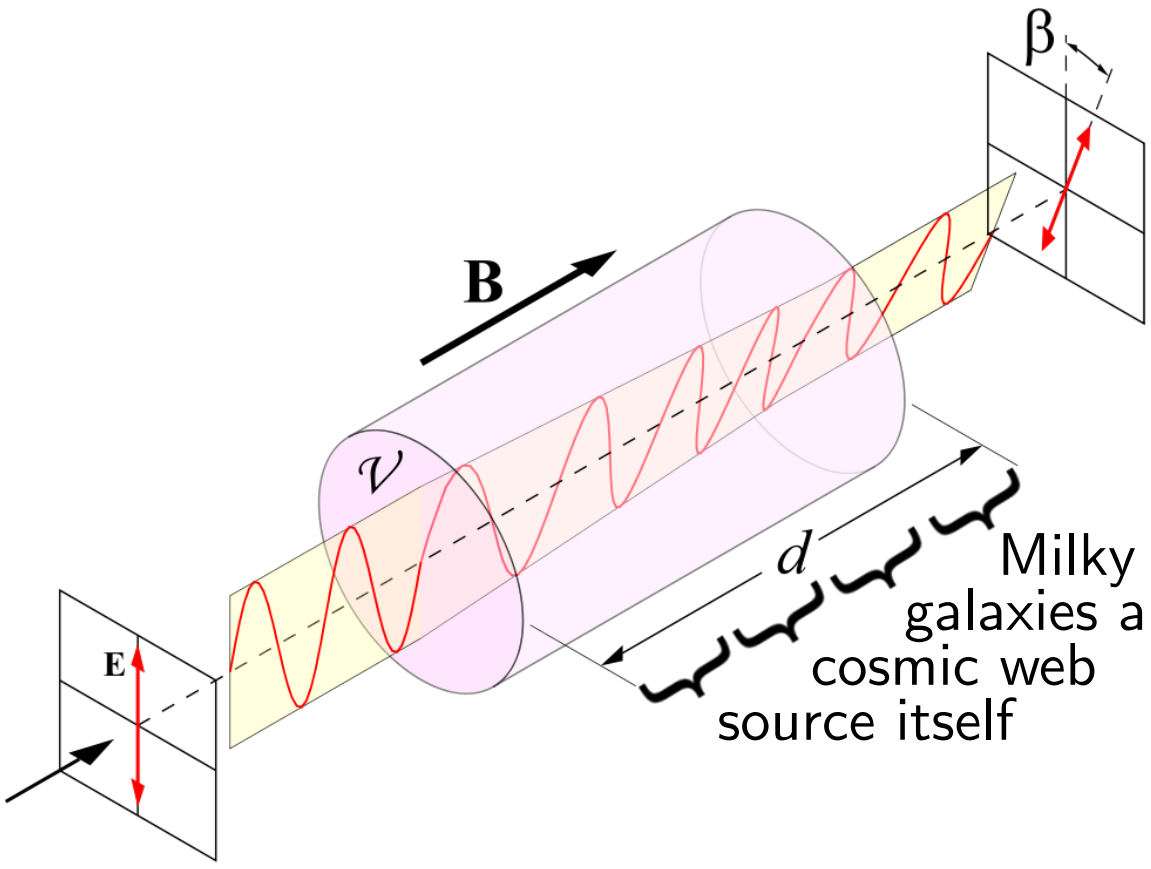
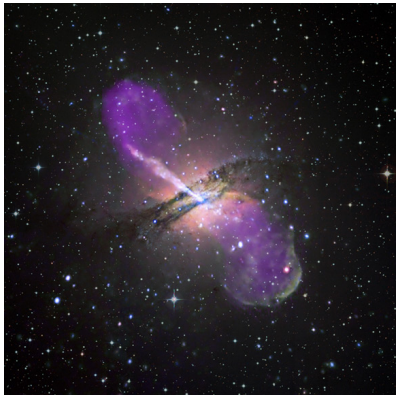


image credit: MPA

Faraday rotation

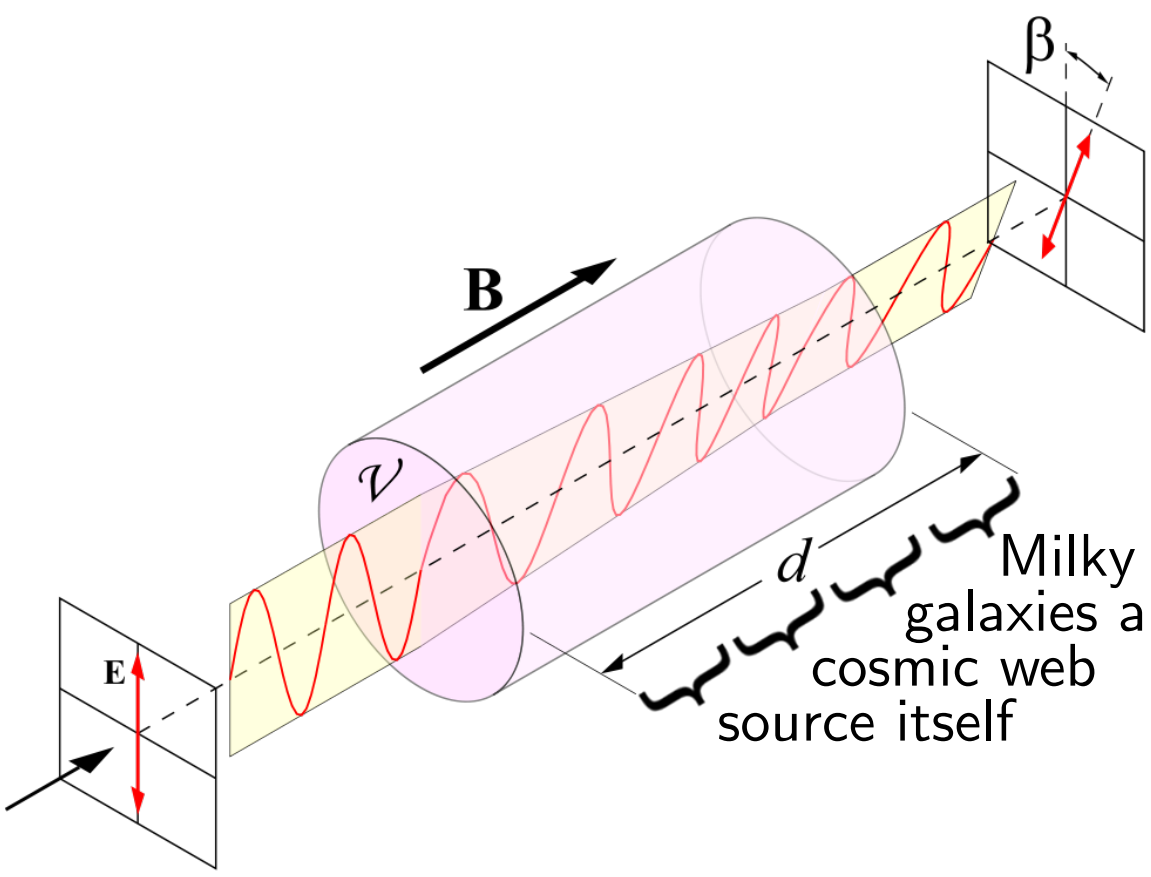


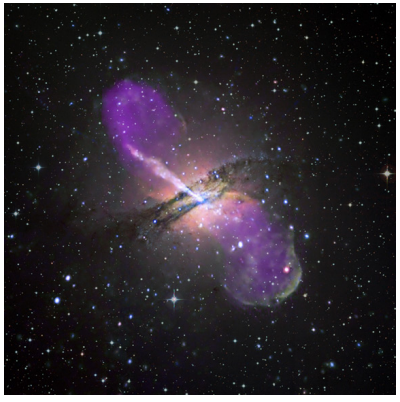


Faraday depth: $\phi \propto \int_{r_{\mathrm{source}}}^{0} (1+z)^{-2}\, n_{\mathrm{e}}\, B_r\, \mathrm{d}r$

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

Faraday rotation

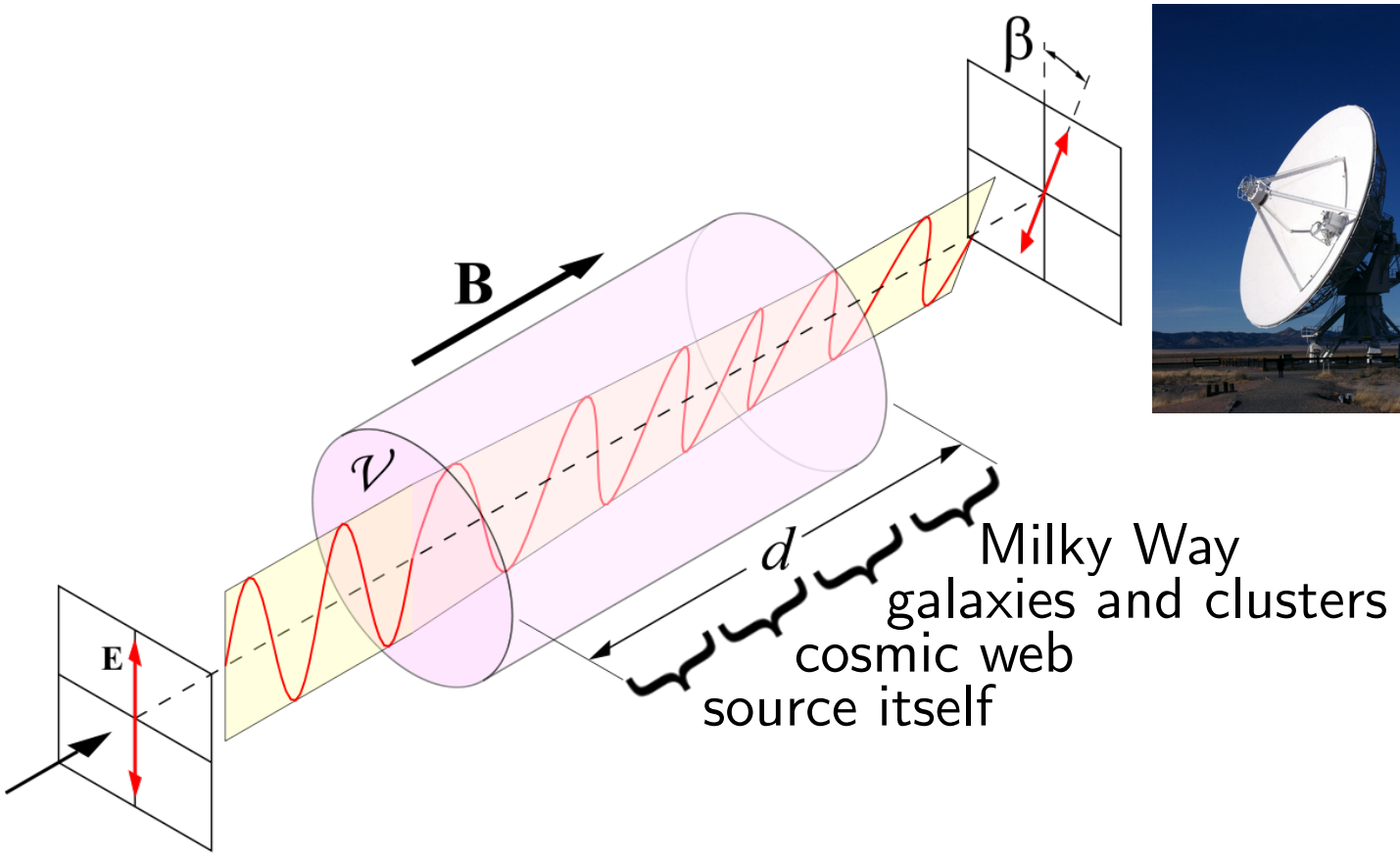


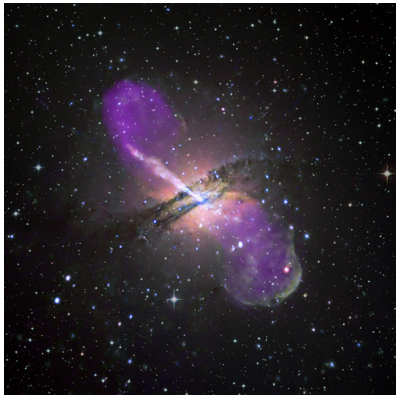


Faraday depth: $\phi \propto \int_{r_{\rm source}}^{0} (1+z)^{-2}\, n_{\rm e}\, B_r\, {\rm d}r$

$$\phi = \phi_{\rm MW} + \phi_{\rm other\ galaxies} + \phi_{\rm clusters} + \phi_{\rm filaments} + \phi_{\rm sheets} + \phi_{\rm voids} + \phi_{\rm source}$$

Faraday rotation

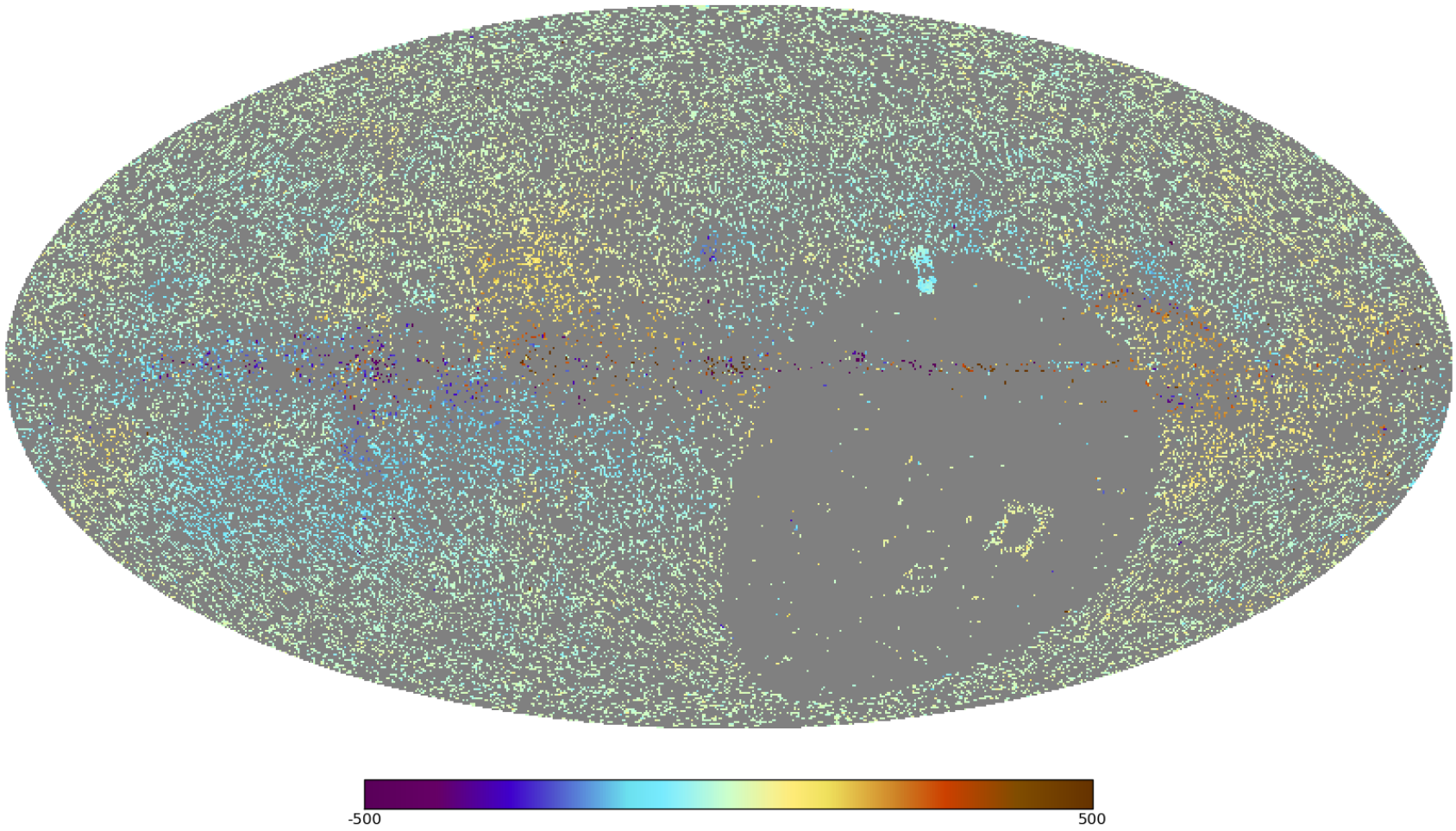




Faraday depth: $\phi \propto \int_{r_{\rm source}}^{0} (1+z)^{-2}\, n_{\rm e}\, B_r\, {\rm d}r$

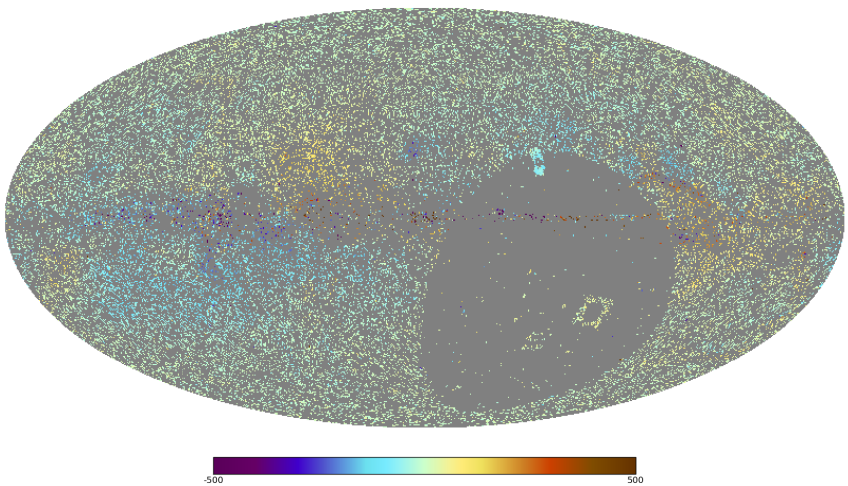
$$\phi = \phi_{\rm MW} + \phi_{\rm extragalactic}$$

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



$\gtrsim$ 40 000 data points

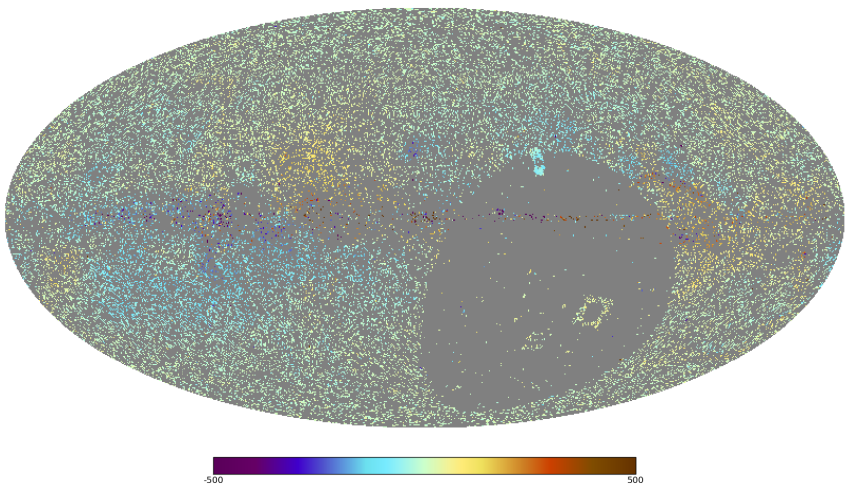
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$



Challenges

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

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



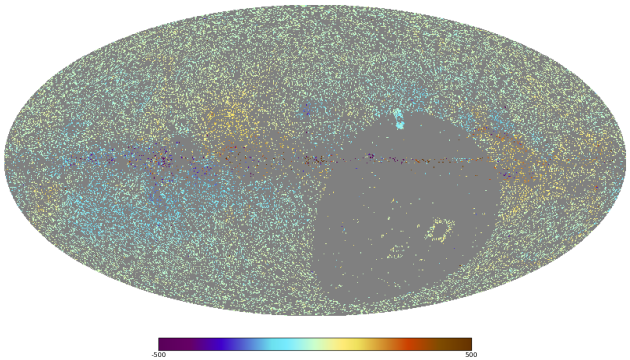
Challenges

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

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

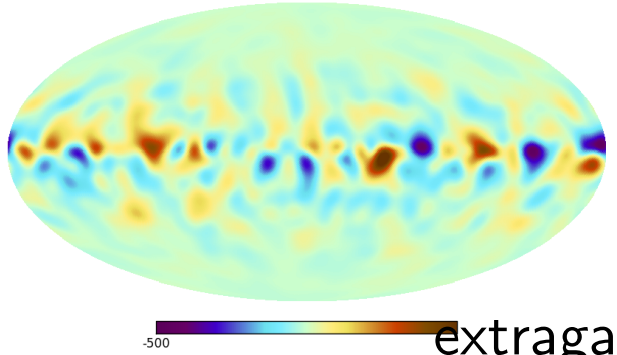
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$

data



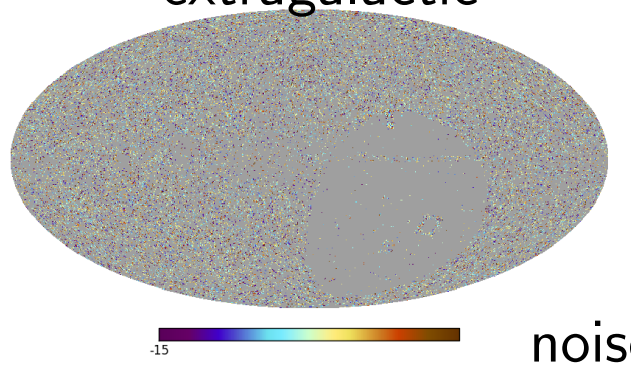
=

Galactic



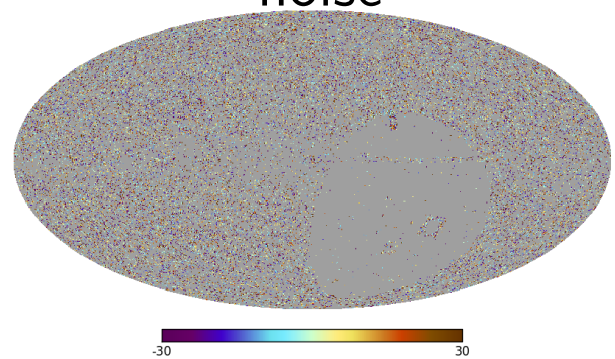
+

extragalactic



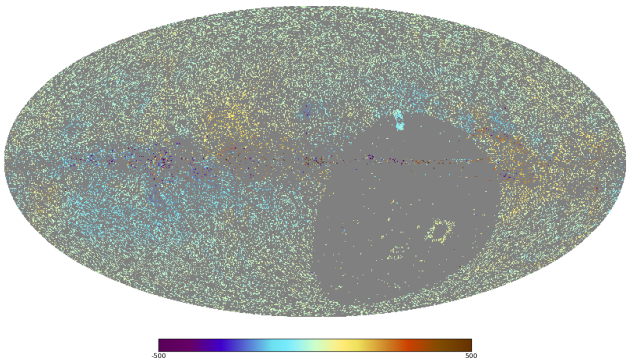
+

noise



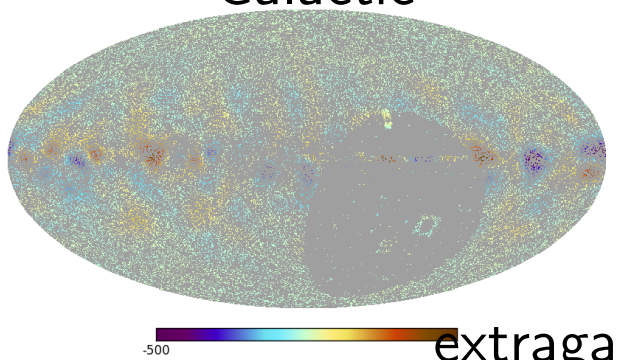
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$

data



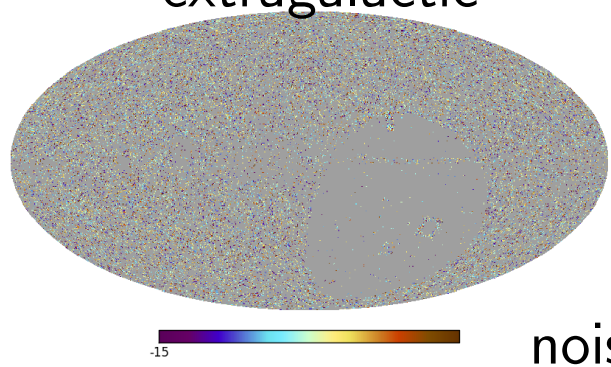
=

Galactic



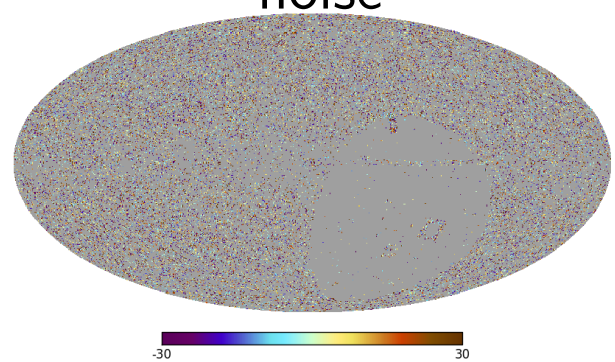
+

extragalactic



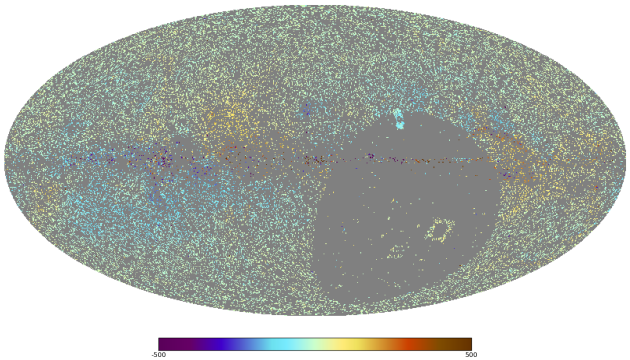
+

noise



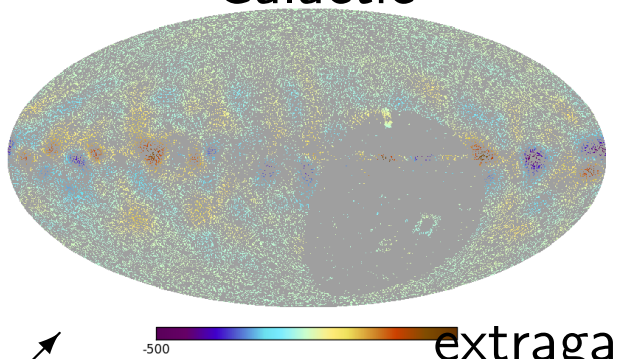
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$

data



=

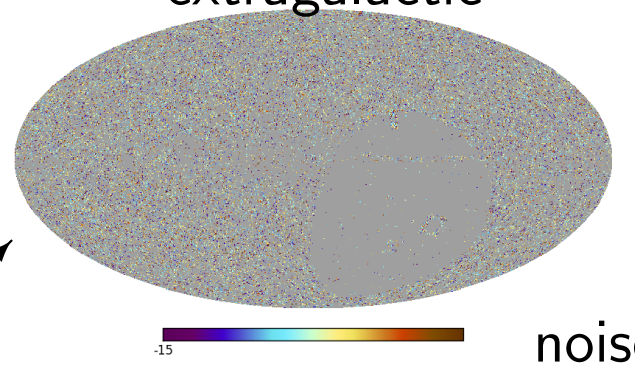
Galactic



correlated

+

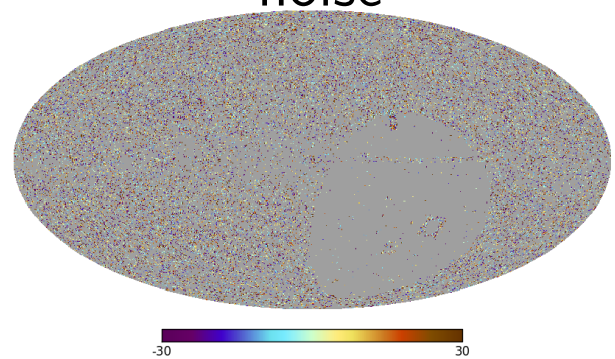
extragalactic

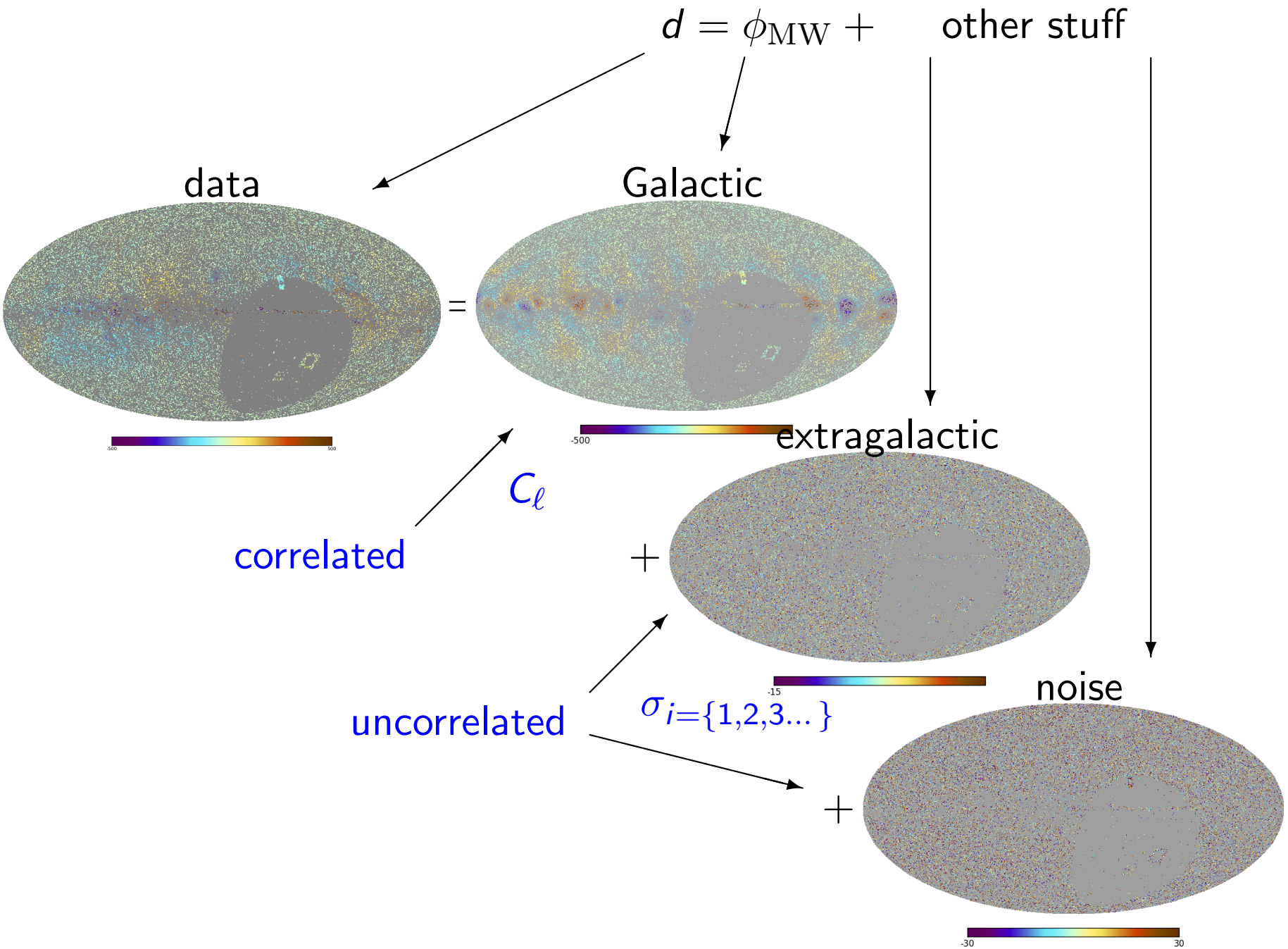


uncorrelated

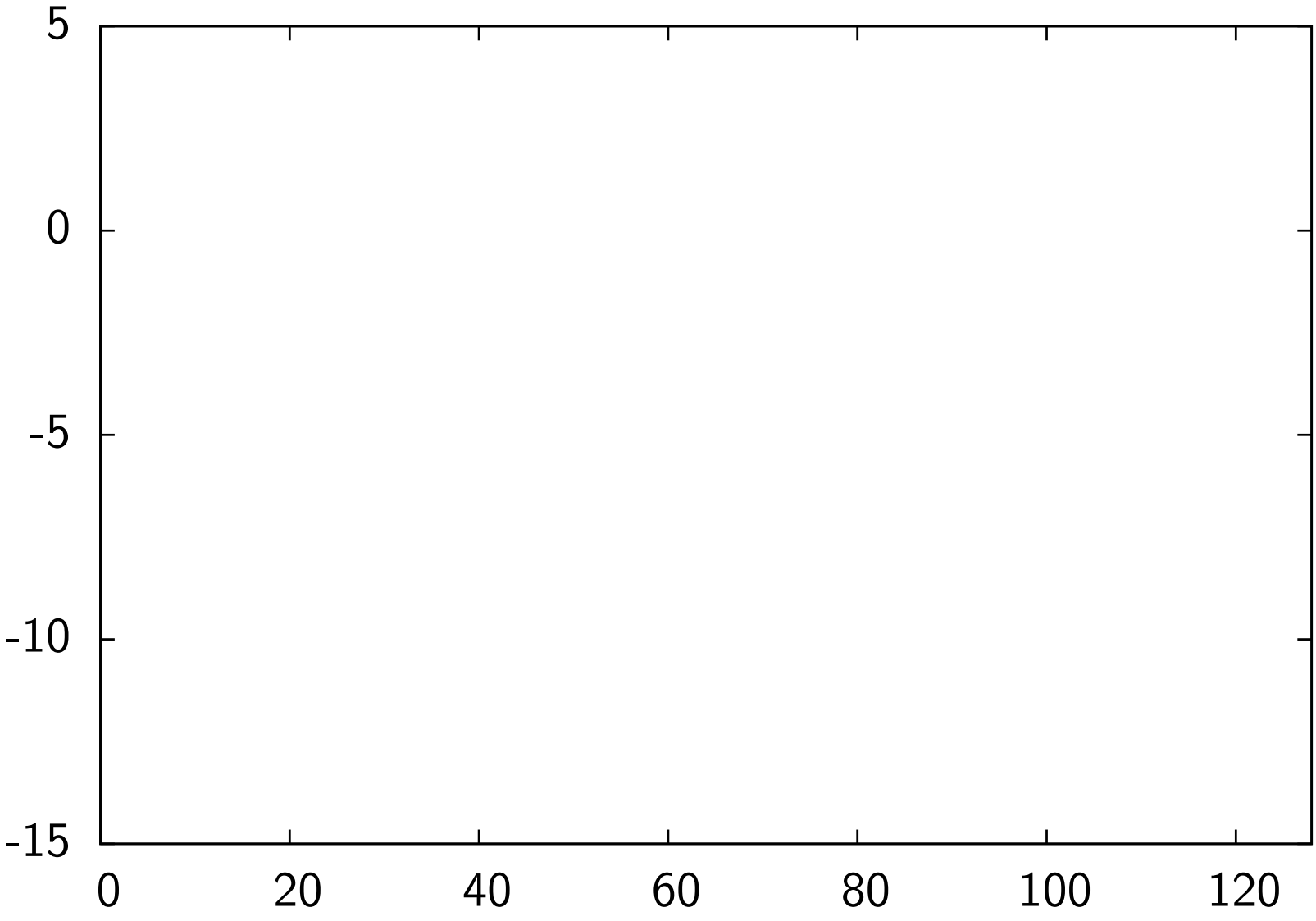
+

noise



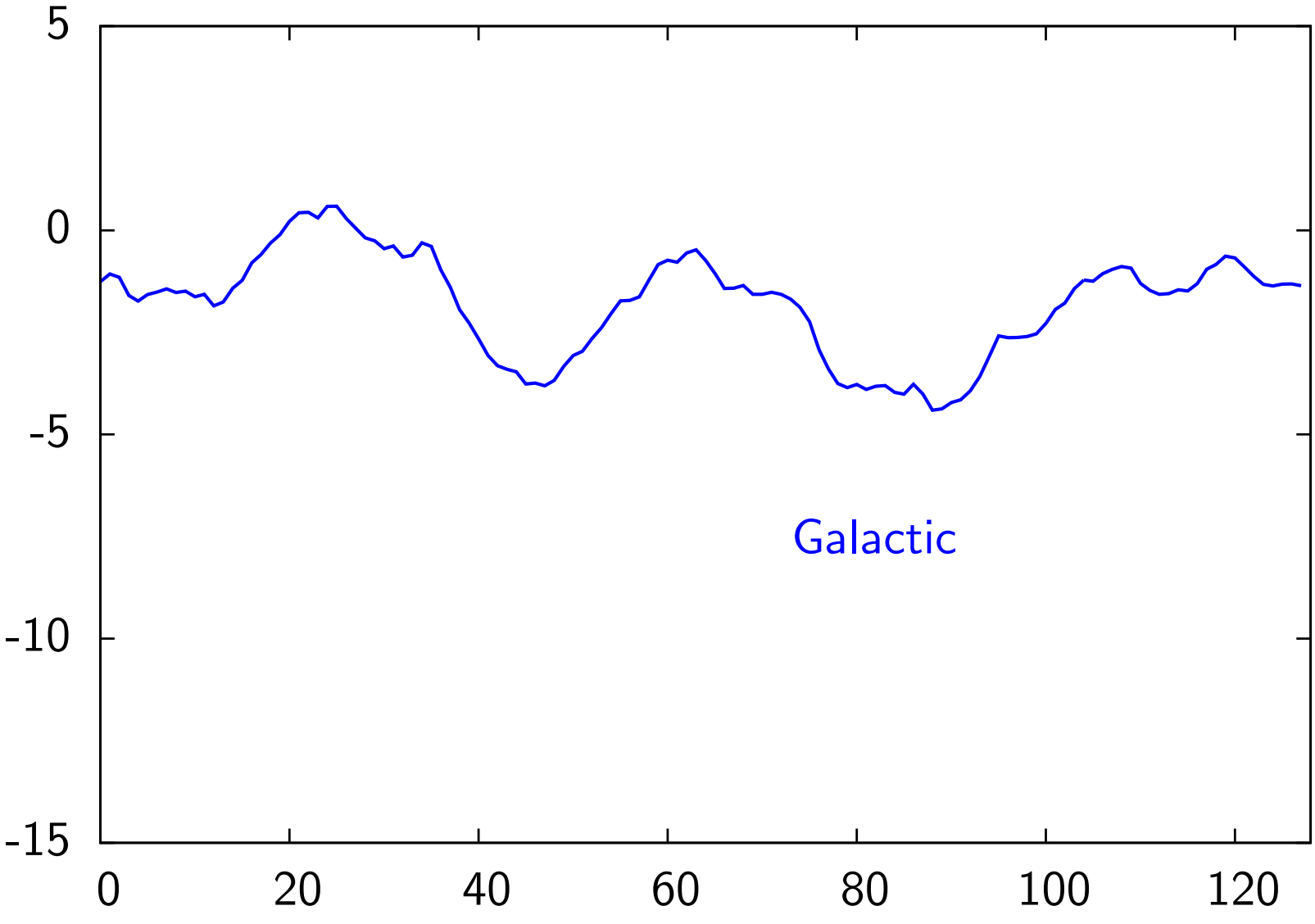

$d = \phi_{\rm MW} +$
other stuff
data
Galactic
=
-500
extragalactic
C_ℓ
correlated
+
-15
uncorrelated
$\sigma_{i=\{1,2,3...\}}$
noise
+
-30
30

1D example



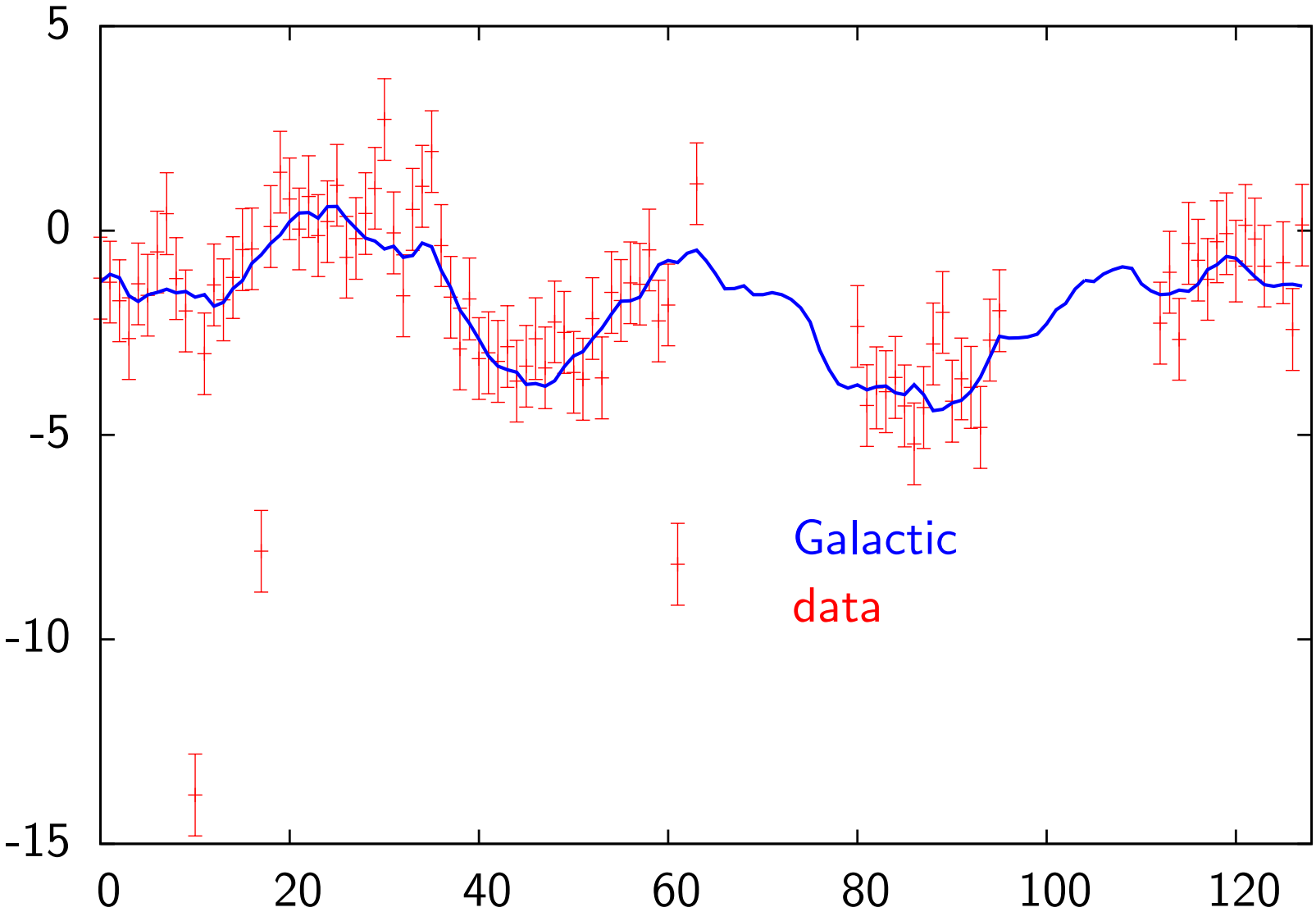
NO et al., PRE, 2011; arXiv:1107.2384

1D example



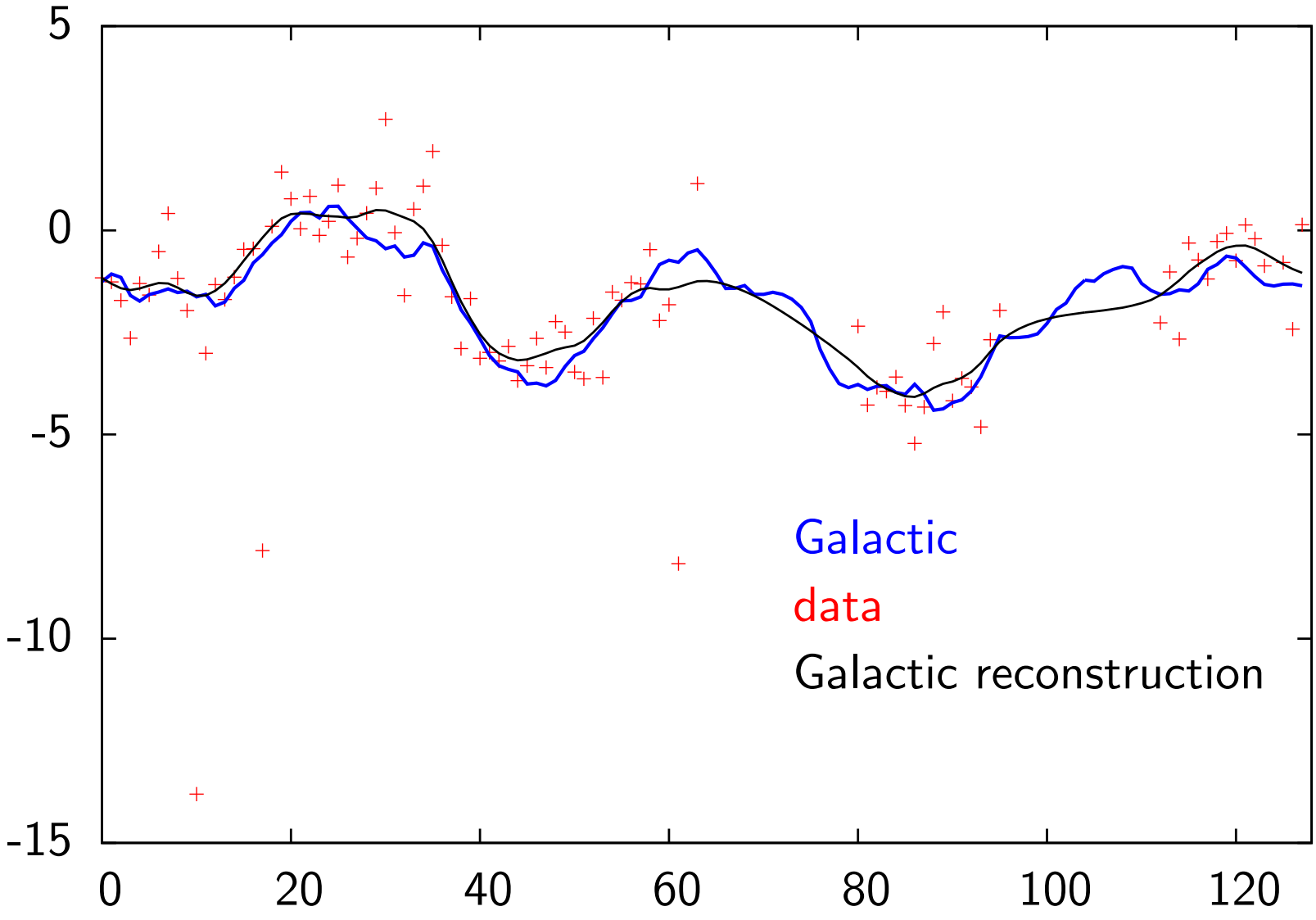
NO et al., PRE, 2011; arXiv:1107.2384

1D example



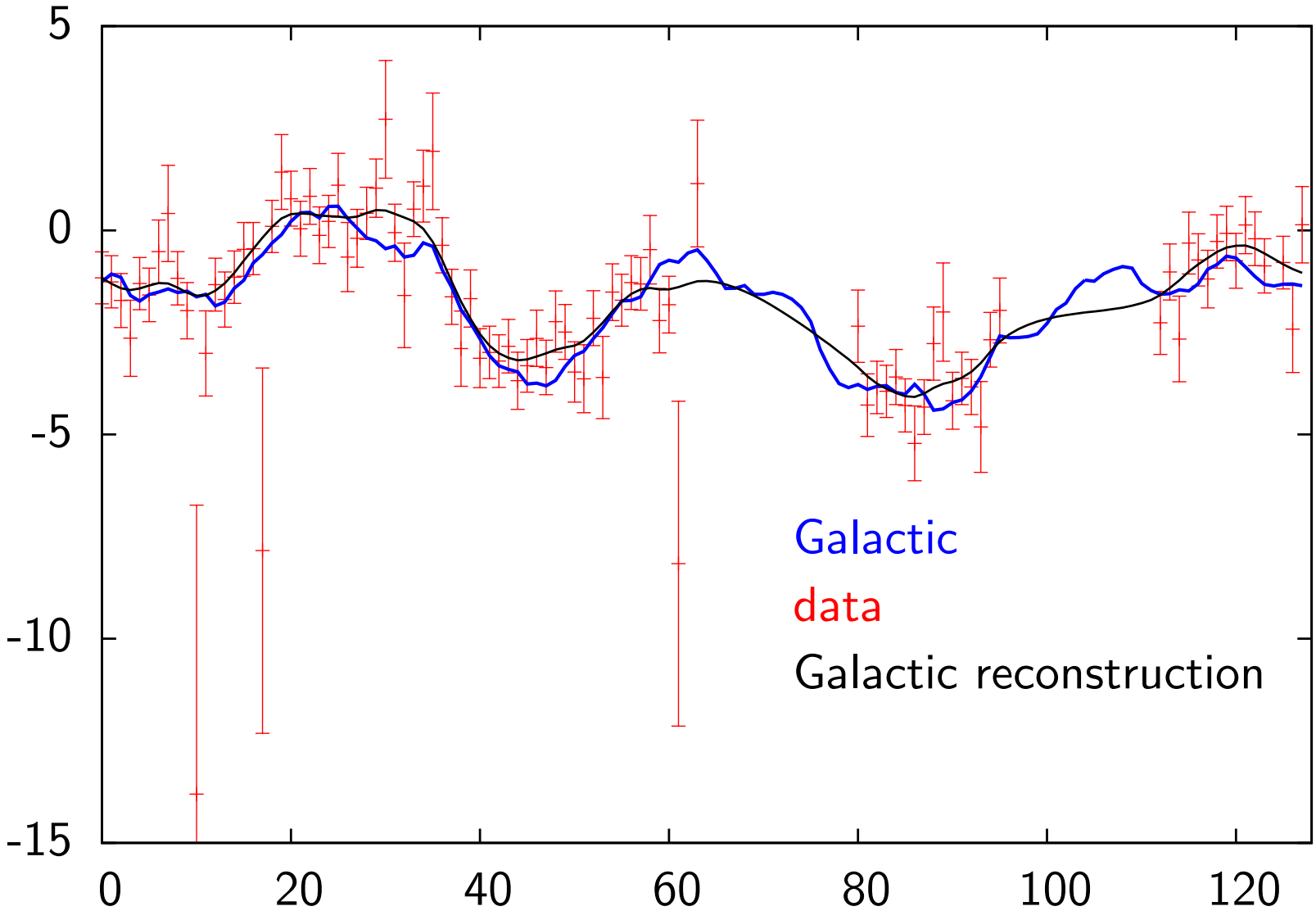
NO et al., PRE, 2011; arXiv:1107.2384

1D example



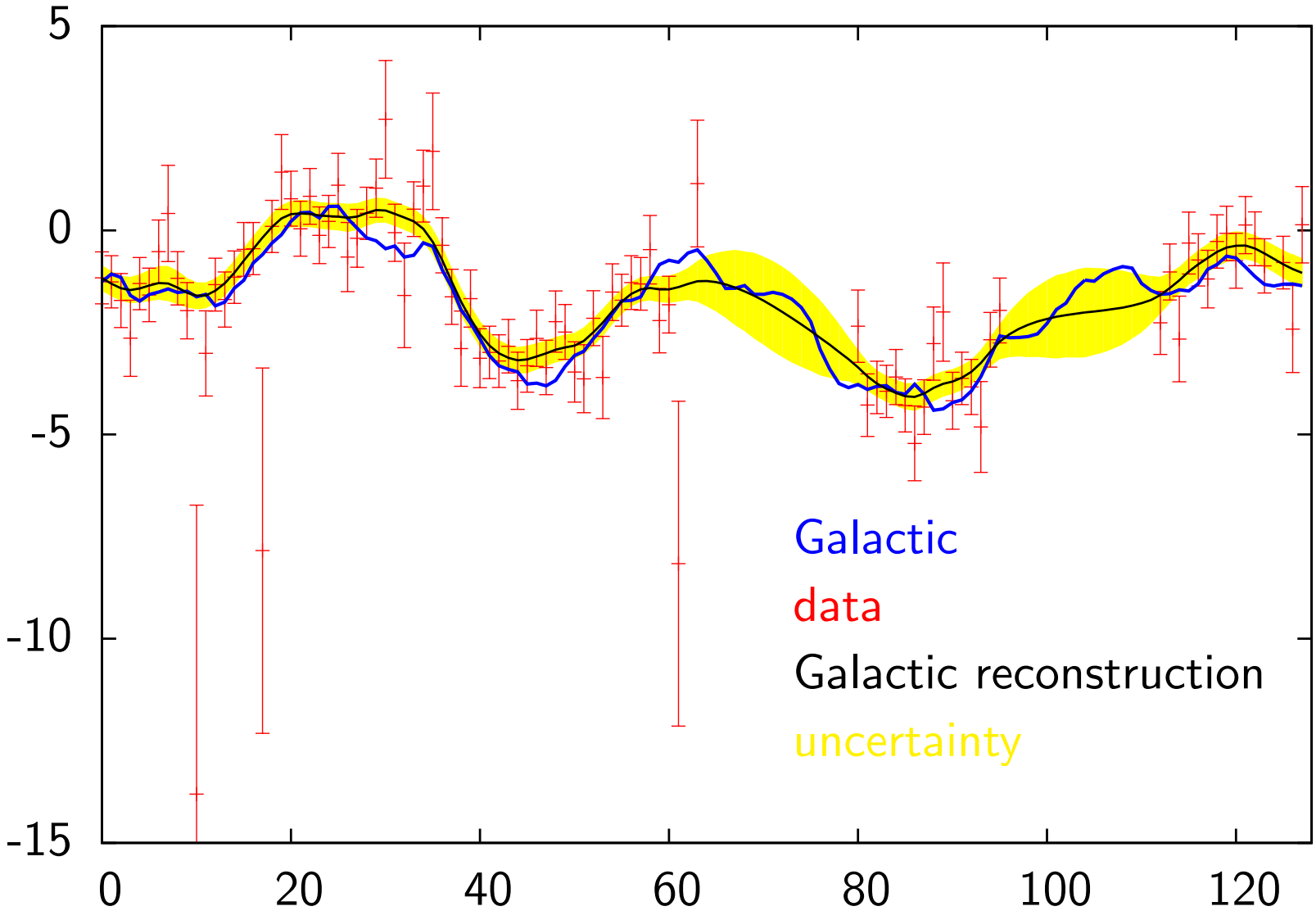
NO et al., PRE, 2011; arXiv:1107.2384

1D example



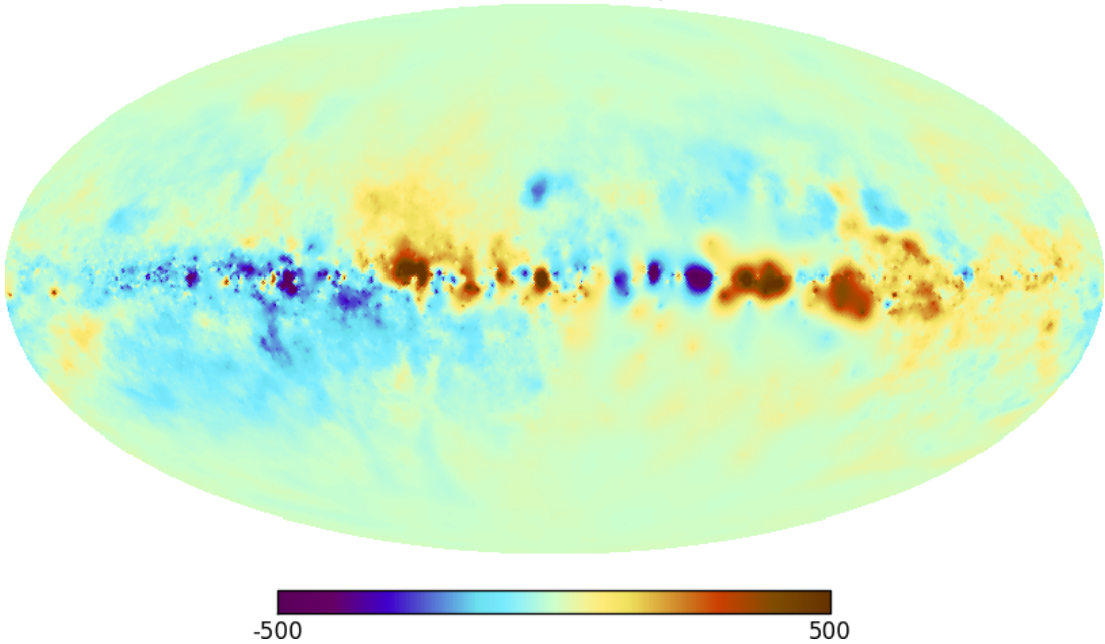
NO et al., PRE, 2011; arXiv:1107.2384

1D example

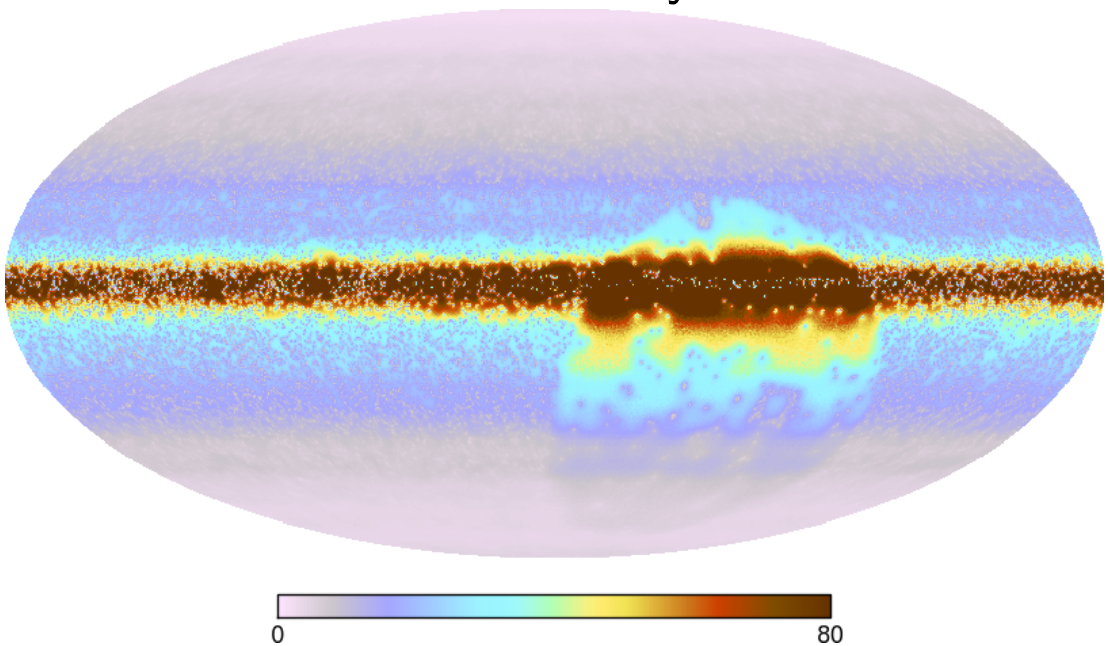


NO et al., PRE, 2011; arXiv:1107.2384

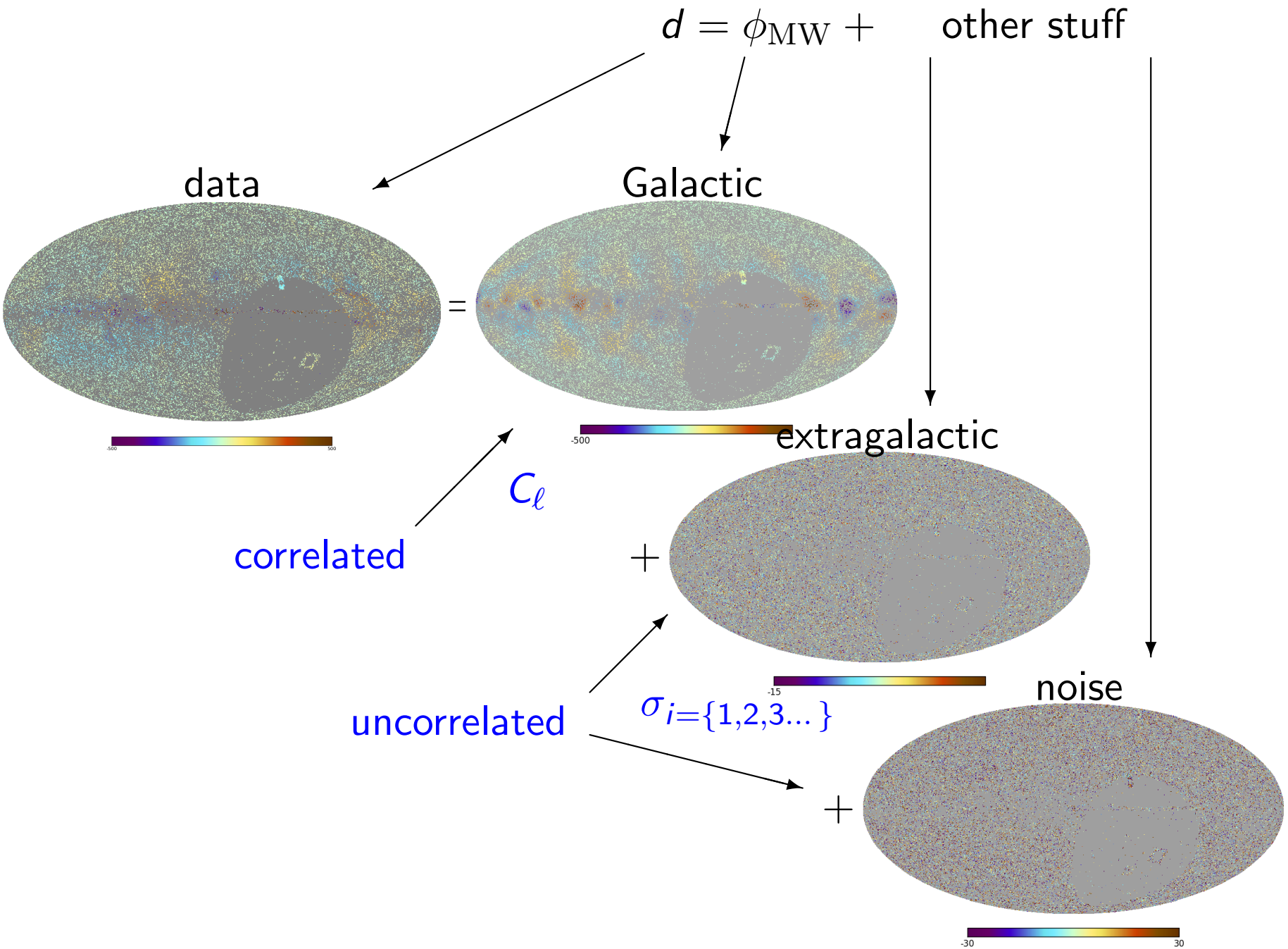
Galactic Faraday depth



uncertainty

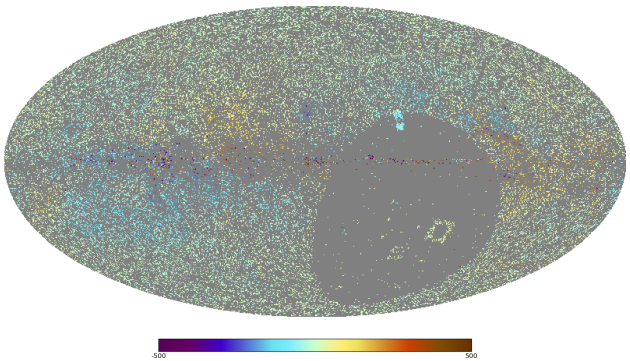


NO et al., A&A, 2012/2015; arXiv:1111.6186/ arXiv:1404.3701


$d = \phi_{\rm MW} +$
other stuff
data
Galactic
=
-500
extragalactic
C_ℓ
correlated
+
-15
uncorrelated
$\sigma_{i=\{1,2,3...\}}$
noise
+
-30
30

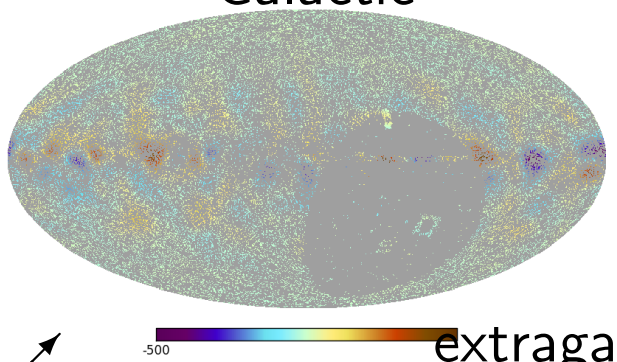
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$

data

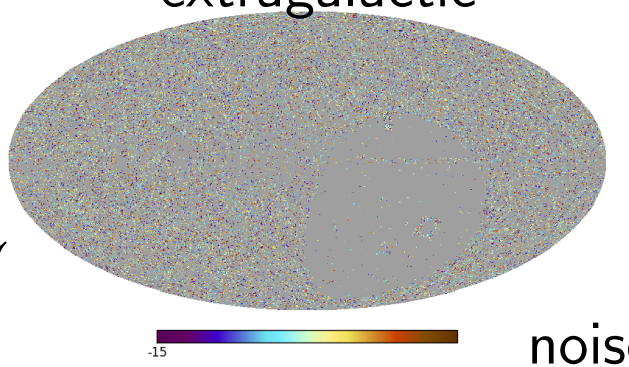


=

Galactic



extragalactic



correlated

C_ℓ

+

σ_{e}

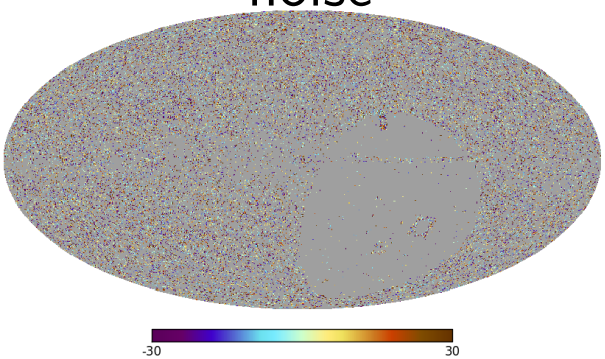
uncorrelated

degenerate

$\sigma_{i=\{1,2,3,\ldots\}}$

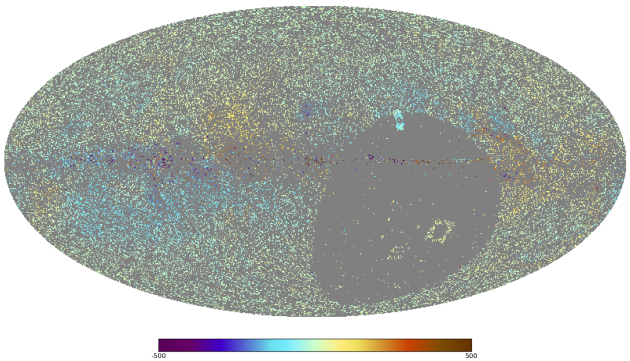
noise

+



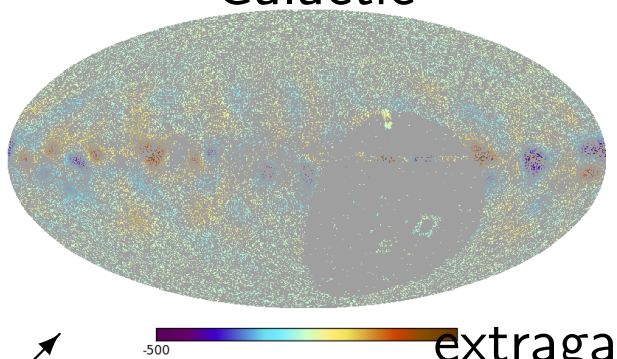
$$d = \phi_{\mathrm{MW}} + \phi_{\mathrm{extragalactic}} + n$$

data

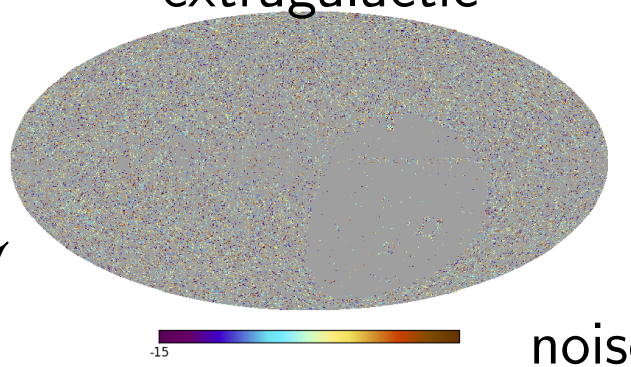


=

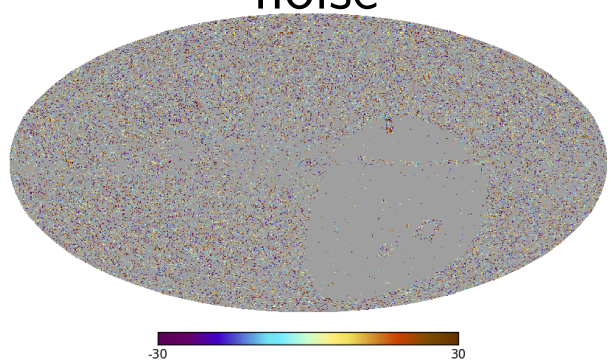
Galactic



extragalactic



noise



correlated

C_ℓ

uncorrelated

degenerate

σ_{e}

$\sigma_{i=\{1,2,3,\ldots\}}$

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

Results:

- $\sigma_{\mathrm{e}} \lesssim 7\,\mathrm{rad/m^2}$
- constraints on extragalactic contributions for individual sources very weak

What magnetic fields is this due to?

Results:

- $\sigma_{\rm e} \lesssim 7\,{\rm rad/m^2}$
- constraints on extragalactic contributions for individual sources very weak

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

Results:

- $\sigma_{\rm e} \lesssim 7\,{\rm rad/m^2}$
- constraints on extragalactic contributions for individual sources very weak

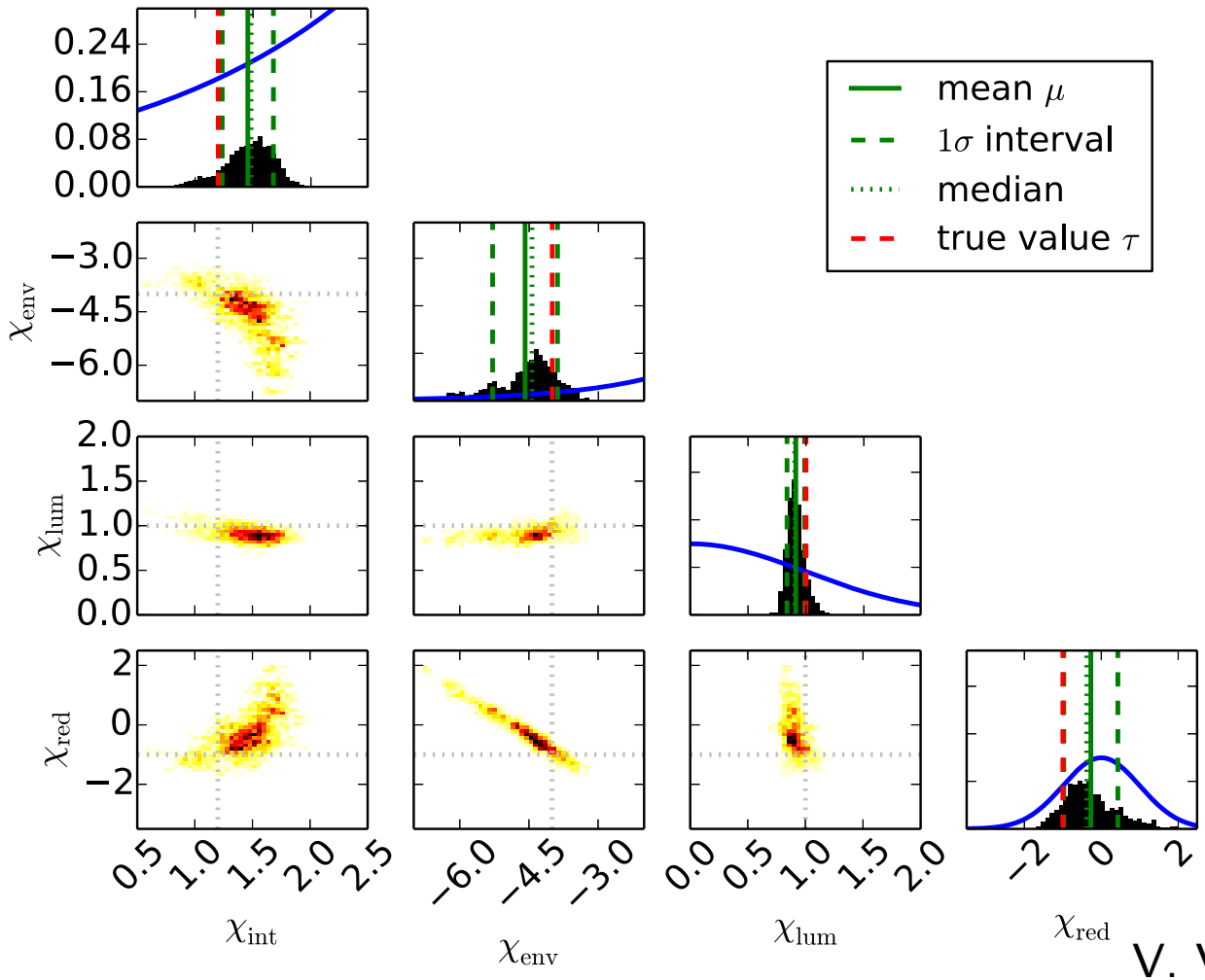
Next step:

- $\sigma_{\rm e} = \sigma_{\rm e}$(objects on the line of sight, source properties, etc.)

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

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

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

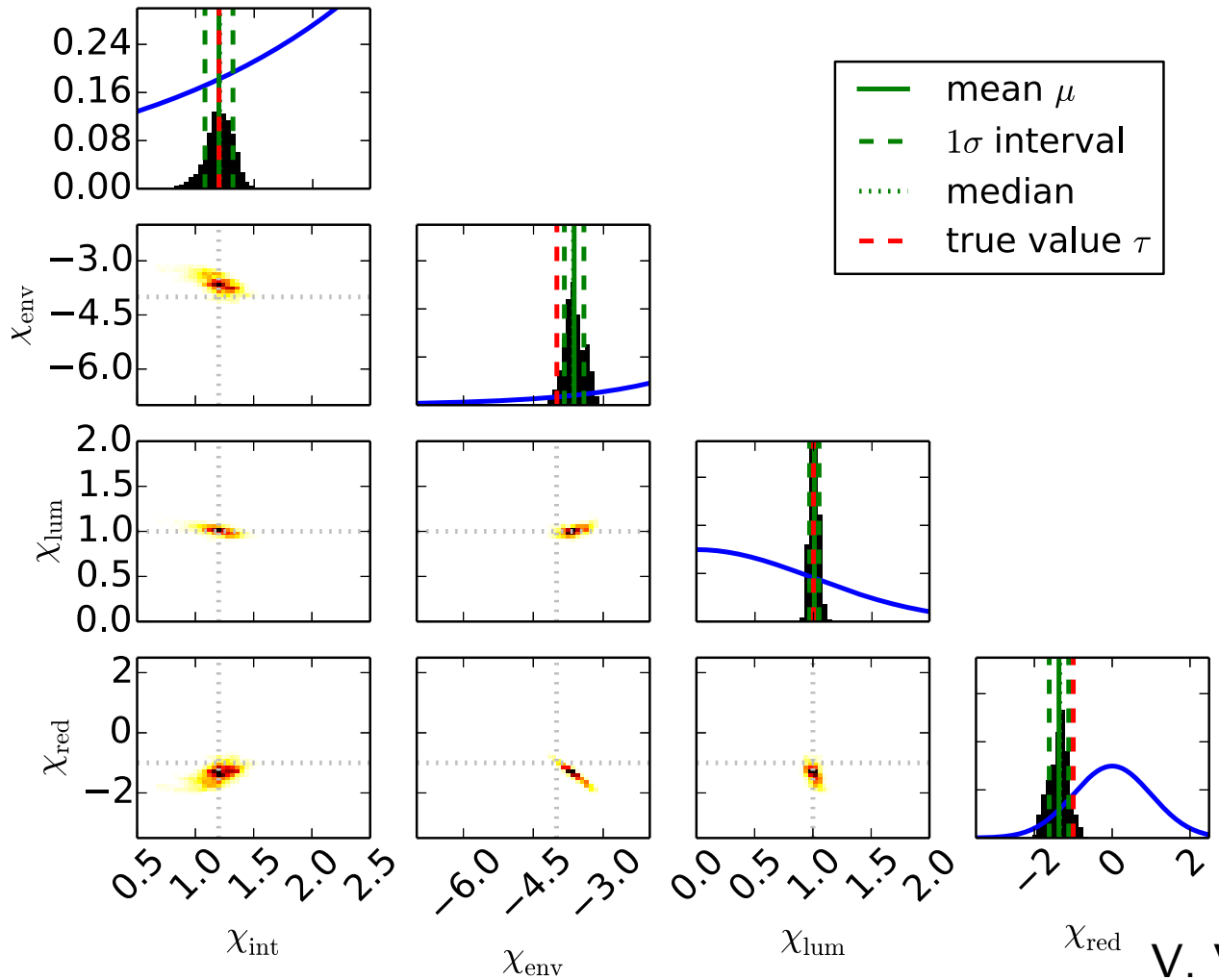


4003 lines of sight

V. Vacca, NO, et al., in prep.

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

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



41632 lines of sight

V. Vacca, NO, et al., in prep.

Summary

- Galactic contribution (correlated) can be separated from rest (uncorrelated)
- Rest can be separated statistically into extragalactic and noise
- Extragalactic contributions contain information on B-fields on cosmic scales
- Uncertainties are large and need to be understood

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