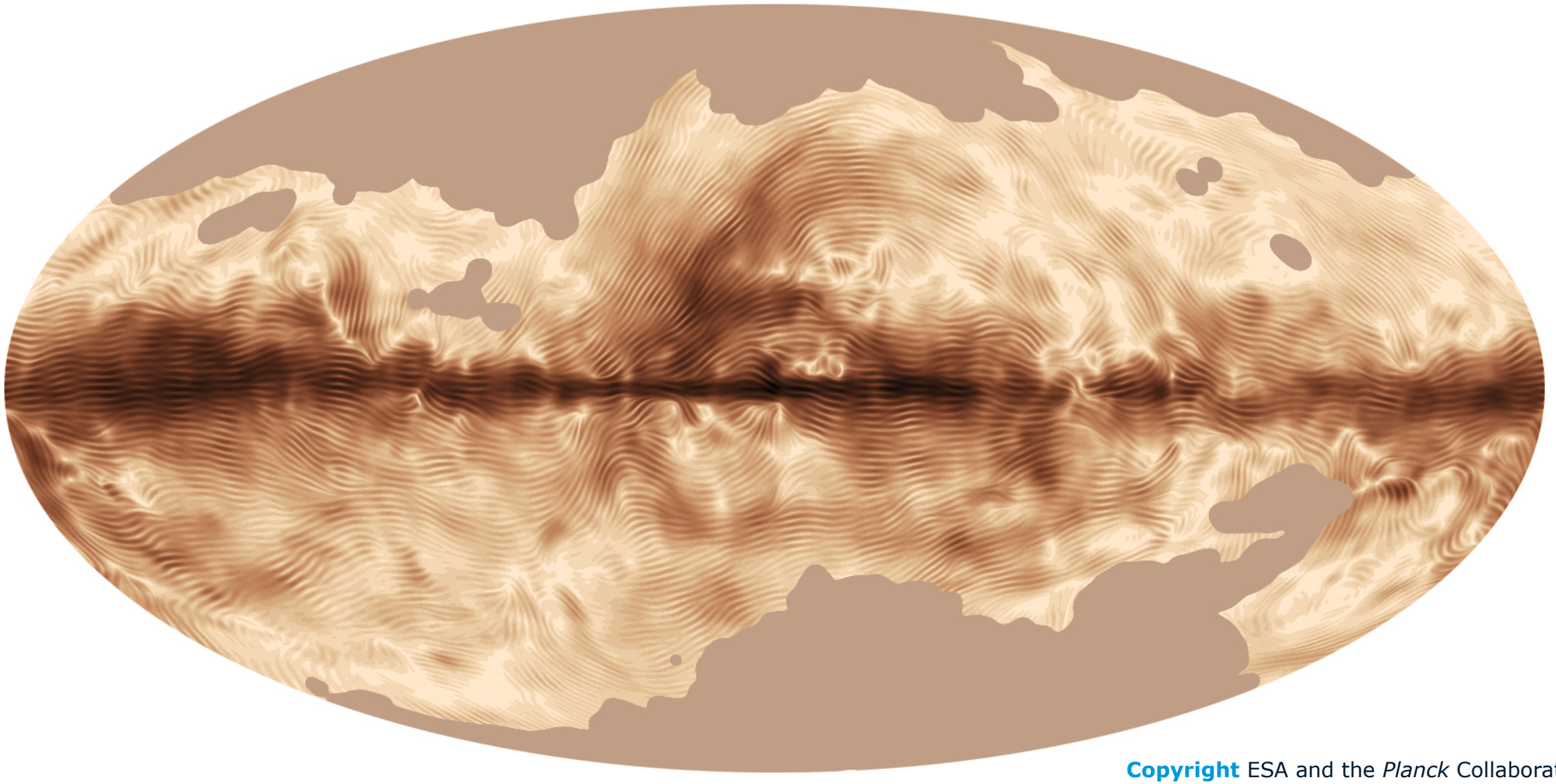
Polarized thermal emission from Galactic dust, as seen by Planck



F. Levrier (LERMA / ENS Paris et Observatoire de Paris)
on behalf of the *Planck* collaboration

Université Laval, 14 Mai 2014

esa

planck

cnes

agenzia spaziale italiana

NASA

cnrs

DTU Space
National Space Institute

Science & Technology Facilities Council

INAF ISTITUTO NAZIONALE DI ASTROFISICA

CSIC
Consejo Superior de Investigaciones Científicas

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

National Research Council of Italy

CSA ASC

DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.

UK SPACE AGENCY

MAX-PLANCK-GESELLSCHAFT

HFI PLANCK
a look back to the birth of Universe

PLANCK LFI

IAS orsay

IAP

INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA DI BOLOGNA

Aalto University

California Institute of Technology

ioa

KICC Kavli Institute for Cosmology Cambridge

Cavendish Astrophysics

University of Cambridge

Cardiff University
Prifysgol Caerdydd

irfu
cea
saclay

CEFCA

CESR

CITA–ICAT

IASF

cnrs INSU
Observer & comprendre

cnrs IN2P3
Les deux infinis

ipac

Helsinki Institute of Physics

Istituto di Astrofisica di Canarias

IFCA
Instituto de Física de Cantabria

Imperial College London

Università degli Studi di Milano

NÉEL institut

IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

ISDC
Data Centre for Astrophysics

JPL

Laboratoire de l'Accélérateur Linéaire

l'Observatoire de Paris — LERMA

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

The University of Manchester

MilliLab

Max-Planck-Institut für Astrophysik

NUI Maynooth
Ollscoil na hÉireann Má Nuad

INAF
Osservatorio Astronomico di Padova

University of Oxford

Dipartimento di Fisica
Sapienza
Università di Roma

Science & Technology Facilities Council
Rutherford Appleton Laboratory

University degli Studi di Roma Tor Vergata

Osservatorio Astronomico Trieste

UBC

UC
Universidad de Cantabria

UCSB

ma per seguir virtute e canoscenza
SISSA

Leland Stanford Junior University

ALMA

ESO

US
University of Sussex

Haverford

Scuola Normale Superiore di Pisa

esa

University of Helsinki

Universidad de Granada

Universitas Ostoliensis

Université de Genève

University of Toronto

Université de Paris-Sud XI

Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo"

asdc
ASI Science Data Center

The first Planck papers in polarization

Planck intermediate results. XIX.
An overview of the polarized thermal emission from Galactic dust
Planck Collaboration
arXiv:astro-ph 1405.0871

Planck intermediate results. XX.
Comparison of polarized thermal emission from Galactic dust with simulations of MHD turbulence
Planck Collaboration
arXiv:astro-ph 1405.0872

Planck intermediate results. XXI.
Comparison of polarized thermal emission from Galactic dust at 353 GHz with optical interstellar polarization
Planck Collaboration
arXiv:astro-ph 1405.0873

Planck intermediate results. XXII.
Frequency dependence of thermal emission from Galactic dust in intensity and polarization
Planck Collaboration
arXiv:astro-ph 1405.0874

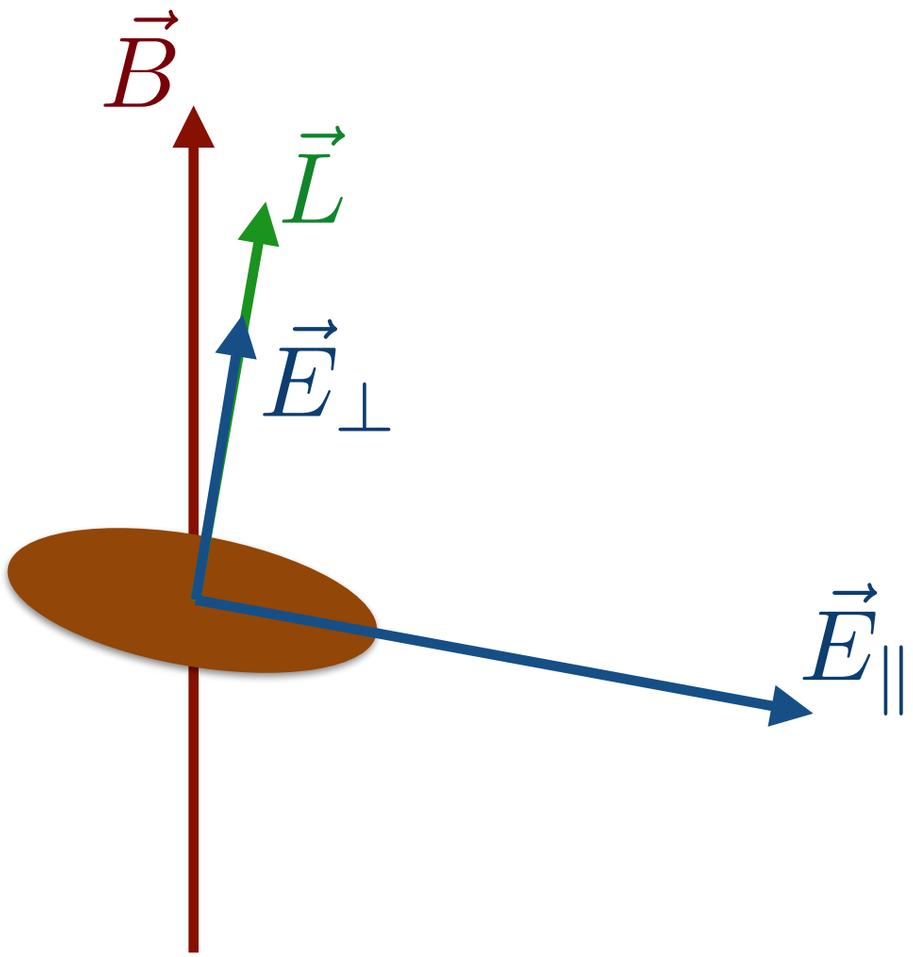
Submitted to A&A April 28
Published on arXiv May 5

Data to be released in the fall

Talk outline

- **Polarized submillimetre dust emission**
- **The Planck mission**
- **The large-scale view of polarized dust emission**
- **Statistical comparison with MHD simulations**
- **Comparison with optical polarization in extinction**
- **Frequency dependence of polarized dust emission**

Polarized thermal emission from dust



Aspherical dust grains :
Emissivities larger along long axis

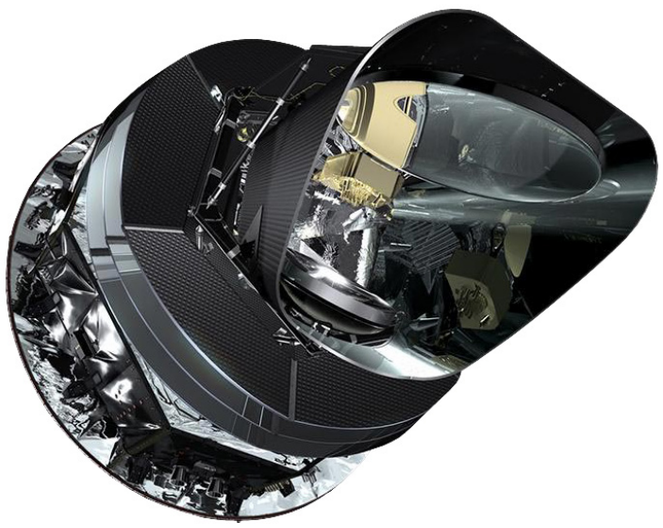
Rotating dust grains :
Angular momentum *L* aligns with *B*

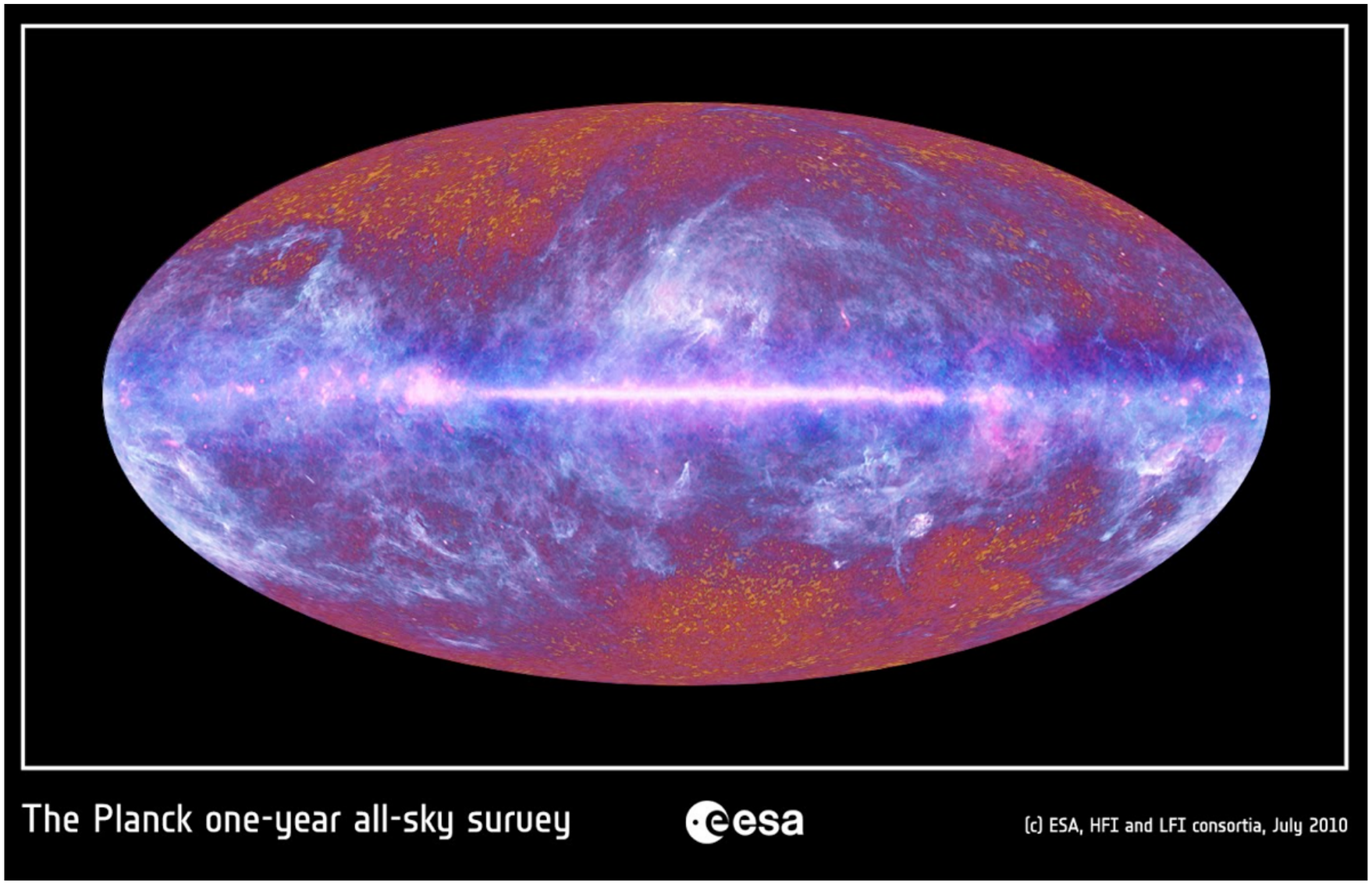
Polarized thermal dust emission gives information on :

- Dust optical properties and composition
- Magnetic field topology

Stein 1966, Andersson 2012, Draine & Fraisse 2009, Hoang & Lazarian 2008, Martin 1975, 2007

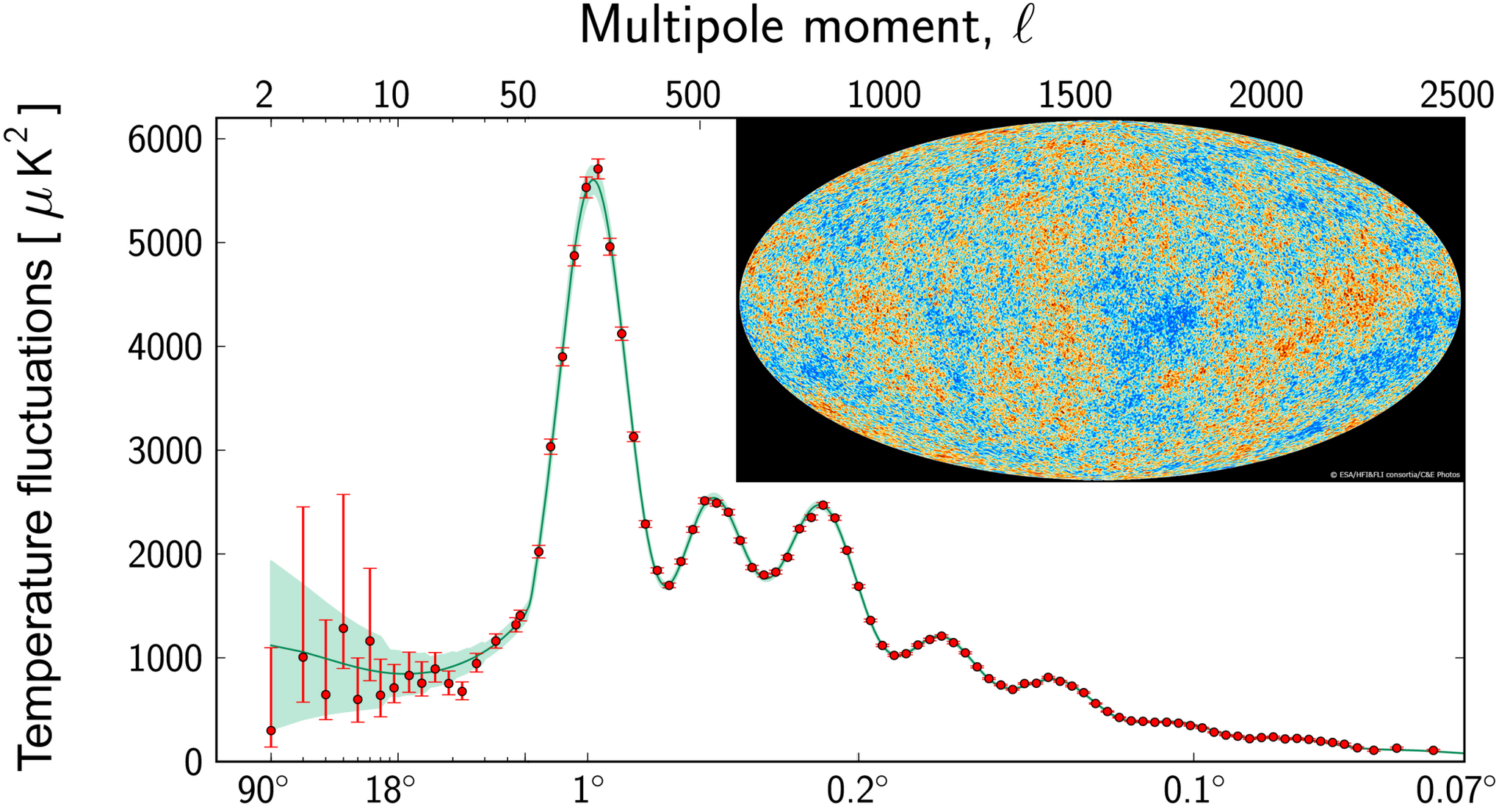
The Planck mission



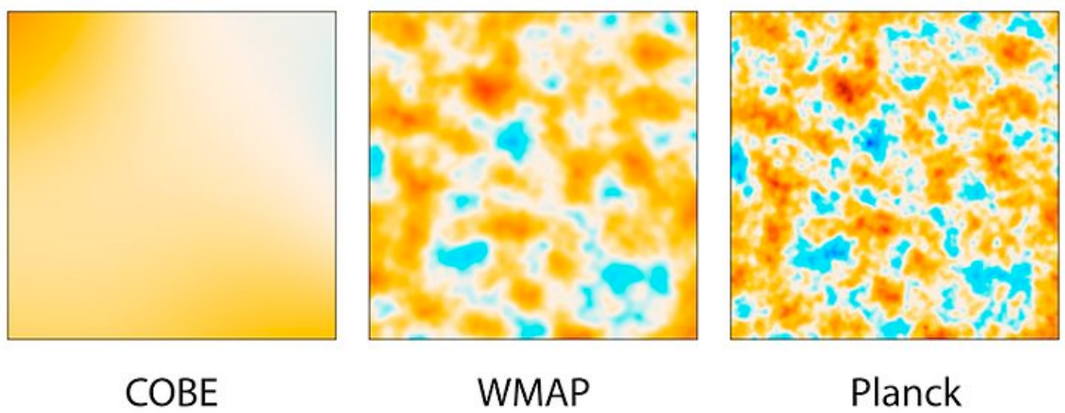


- 2009-2012 space mission
- Measurement of CMB anisotropies
- Mapping of the cold, dusty Milky Way
- Polarization : Galactic dust, primordial gravitational waves

Planck 2013 results : Cosmology



Parameter	*Planck*+WP+highL	
	Best fit	68% limits
$\Omega_b h^2$	0.022069	0.02207 ± 0.00027
$\Omega_c h^2$	0.12025	0.1198 ± 0.0026
$100\theta_{MC}$	1.04130	1.04132 ± 0.00063
τ	0.0927	$0.091^{+0.013}_{-0.014}$
n_s	0.9582	0.9585 ± 0.0070
$\ln(10^{10} A_s)$	3.0959	3.090 ± 0.025

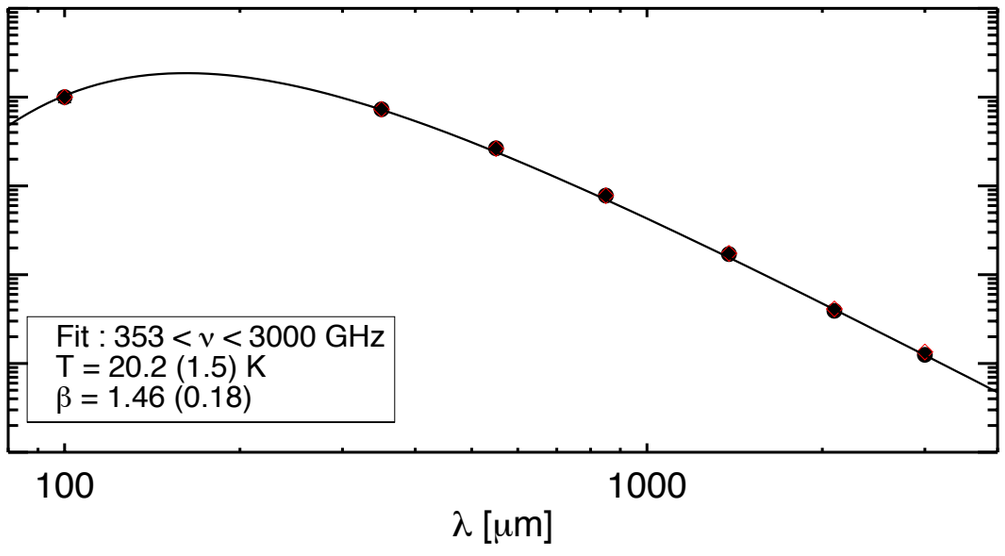


Planck 2013 results. XVI.

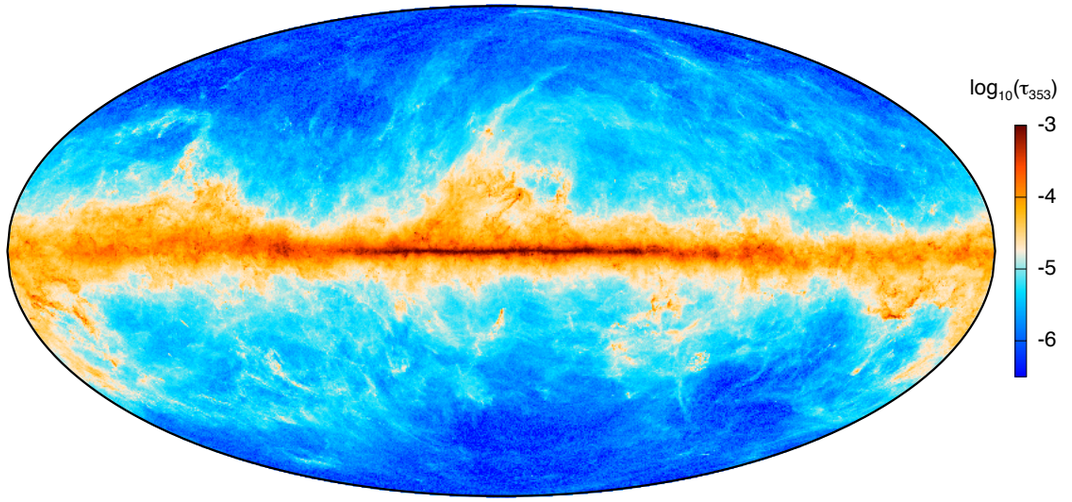
Planck 2013 results : Galactic dust emission

Modified Black-body fit

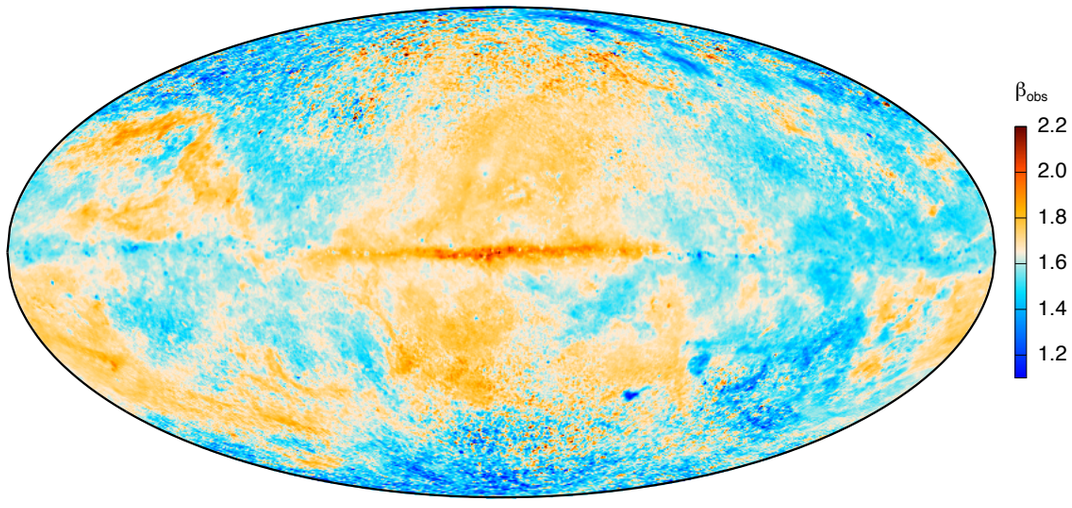
$$I_\nu = \tau_{\nu_0} B_\nu(T_{\rm obs}) \left(\frac{\nu}{\nu_0}\right)^{\beta_{\rm obs}}$$



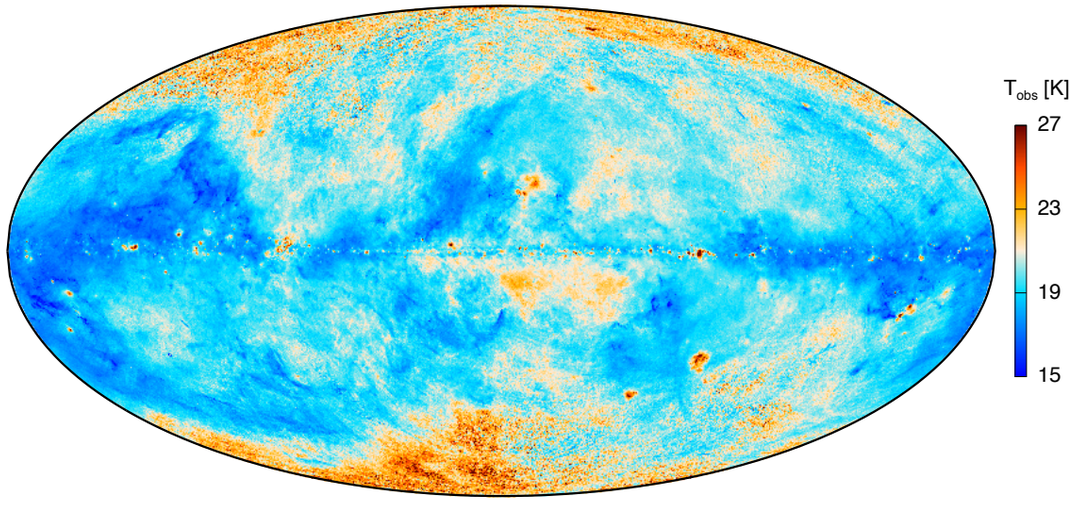
τ_{353}



$\beta_{\rm obs}$

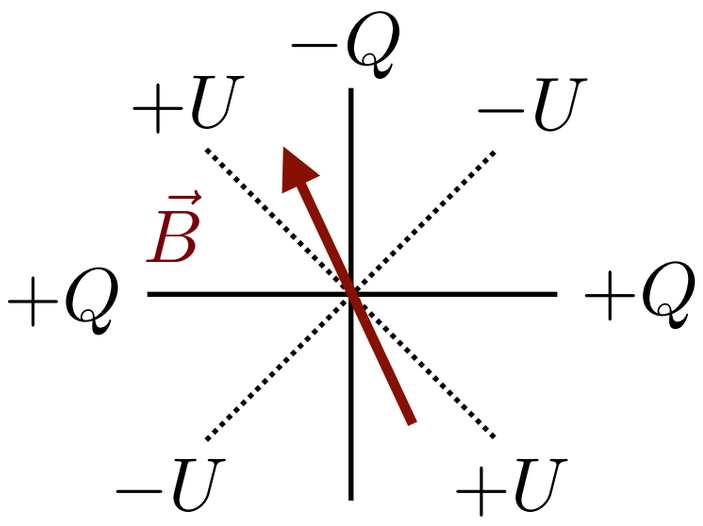


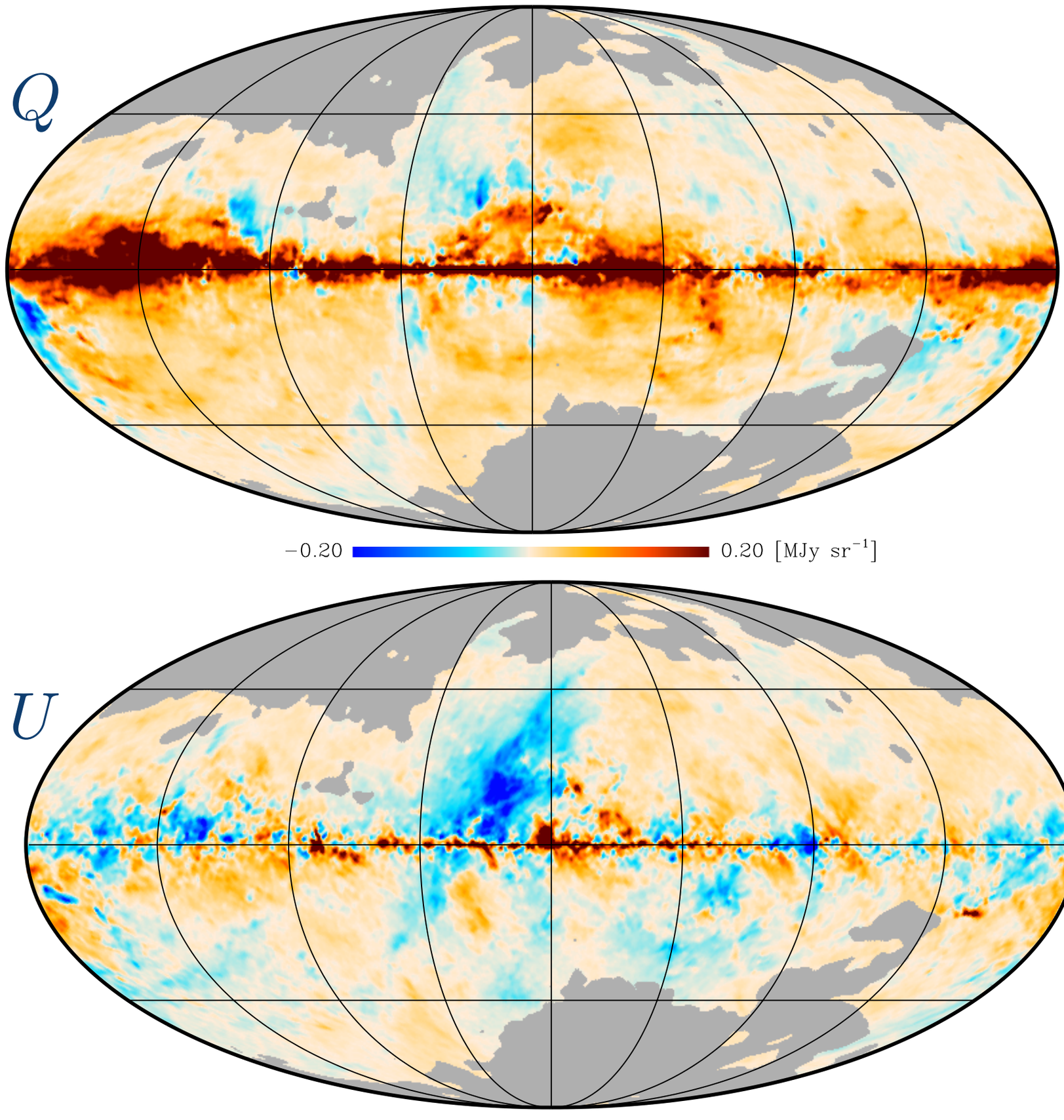
$T_{\rm obs}$



Planck 2013 results. XI.

Stokes Q and U

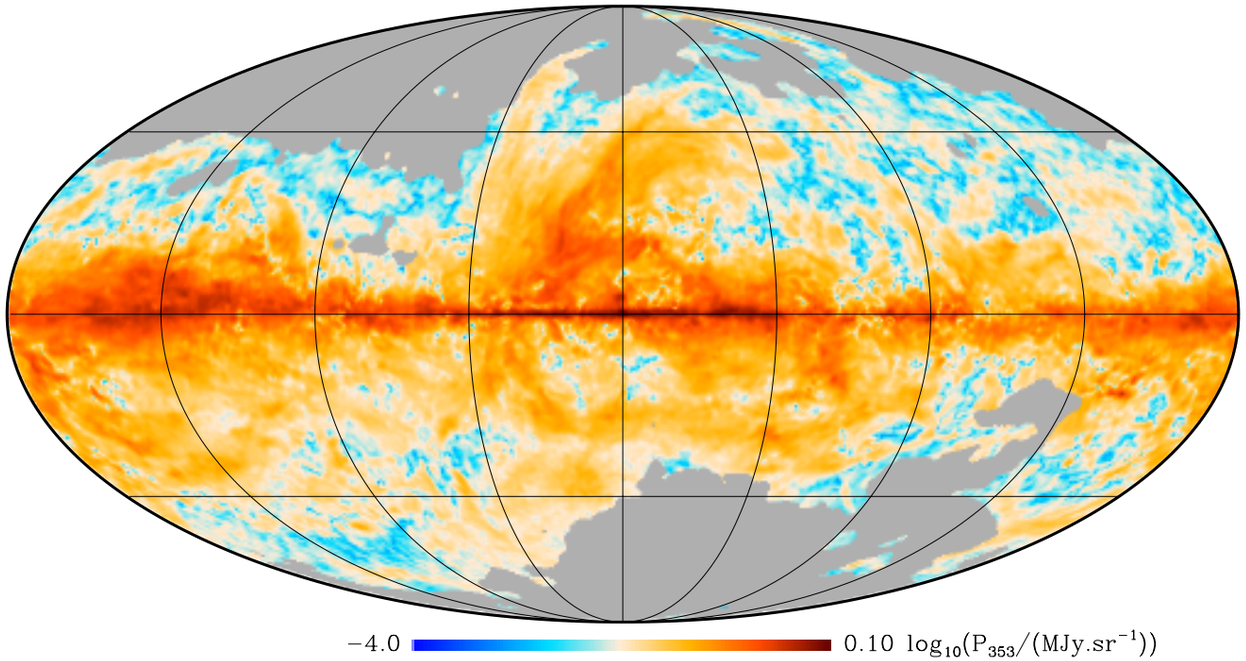




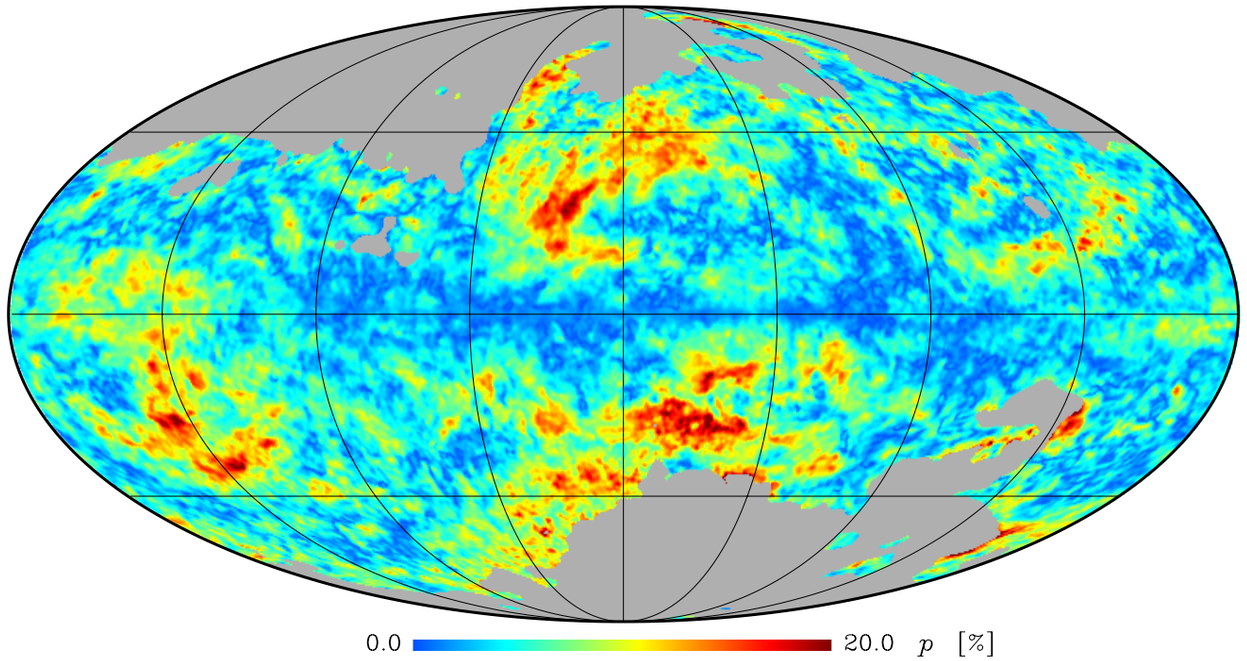
Planck intermediate results. XIX.

Polarized intensity and polarization fraction

$$P = \sqrt{Q^2 + U^2}$$



$$p = P/I$$

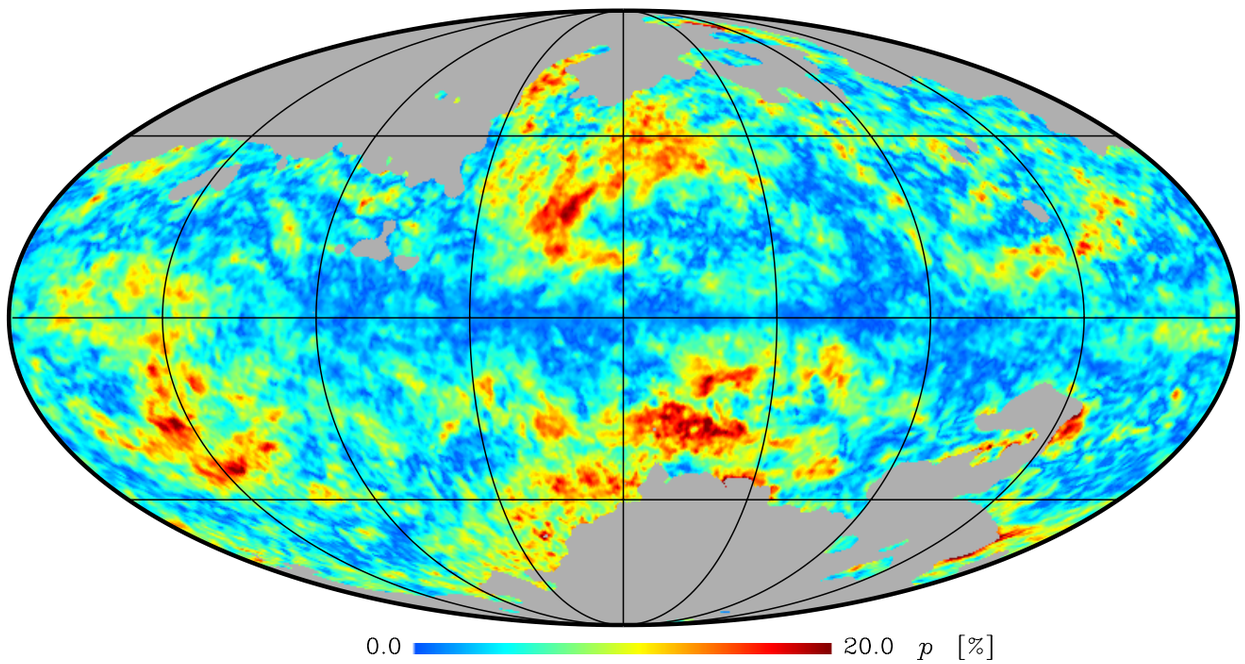


- Low polarization fractions in the Galactic Plane
- Some highly polarized regions (Fan/Auriga, Aquila Rift,…)
- Thin filamentary regions of low polarization

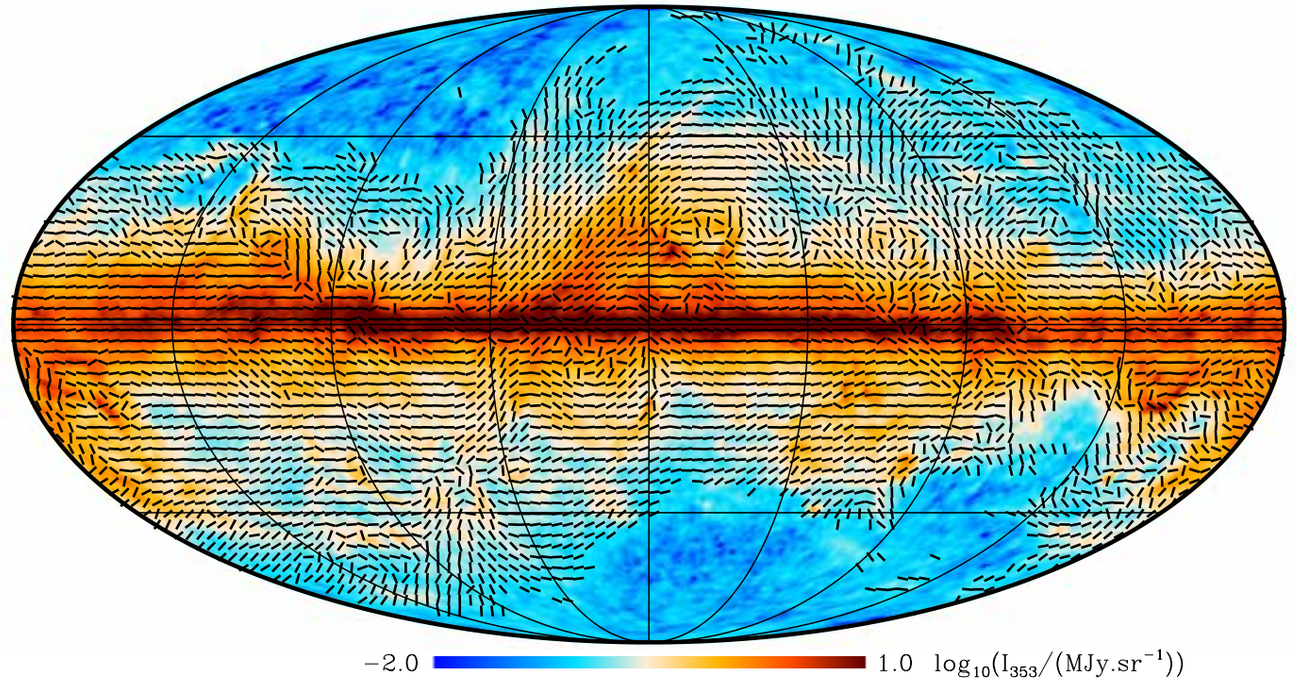
Planck intermediate results. XIX.

Polarization fraction and polarization angle

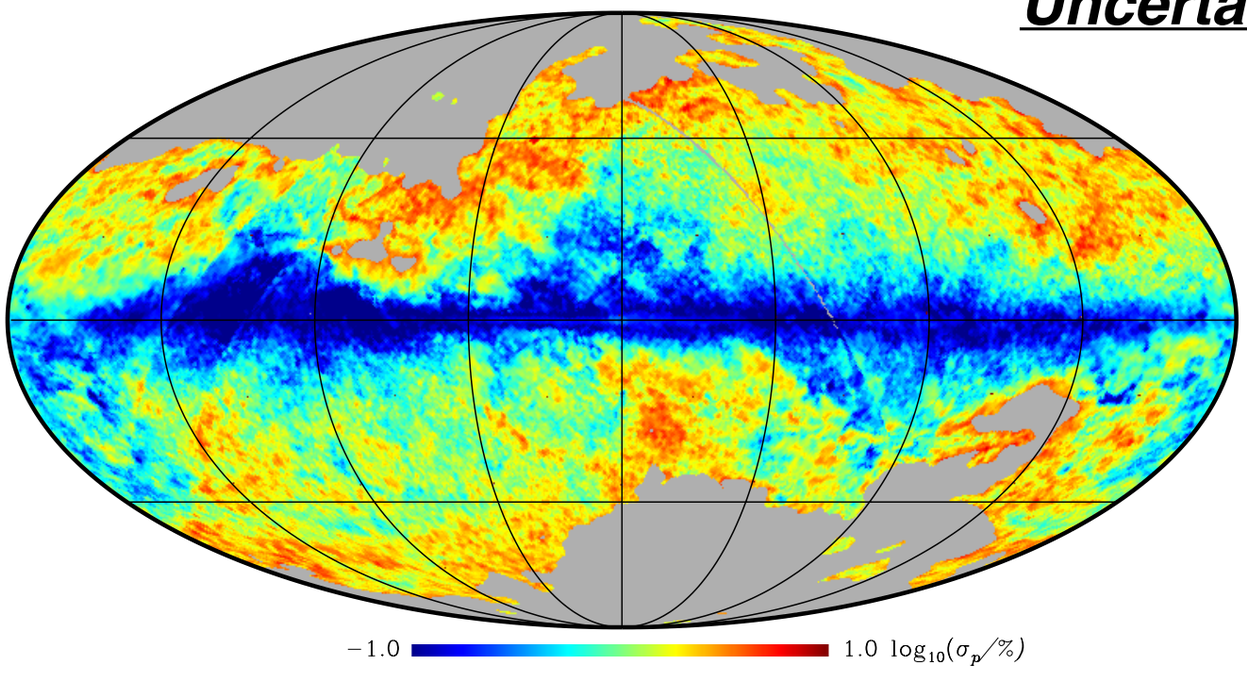
$$p = \frac{P}{I}$$

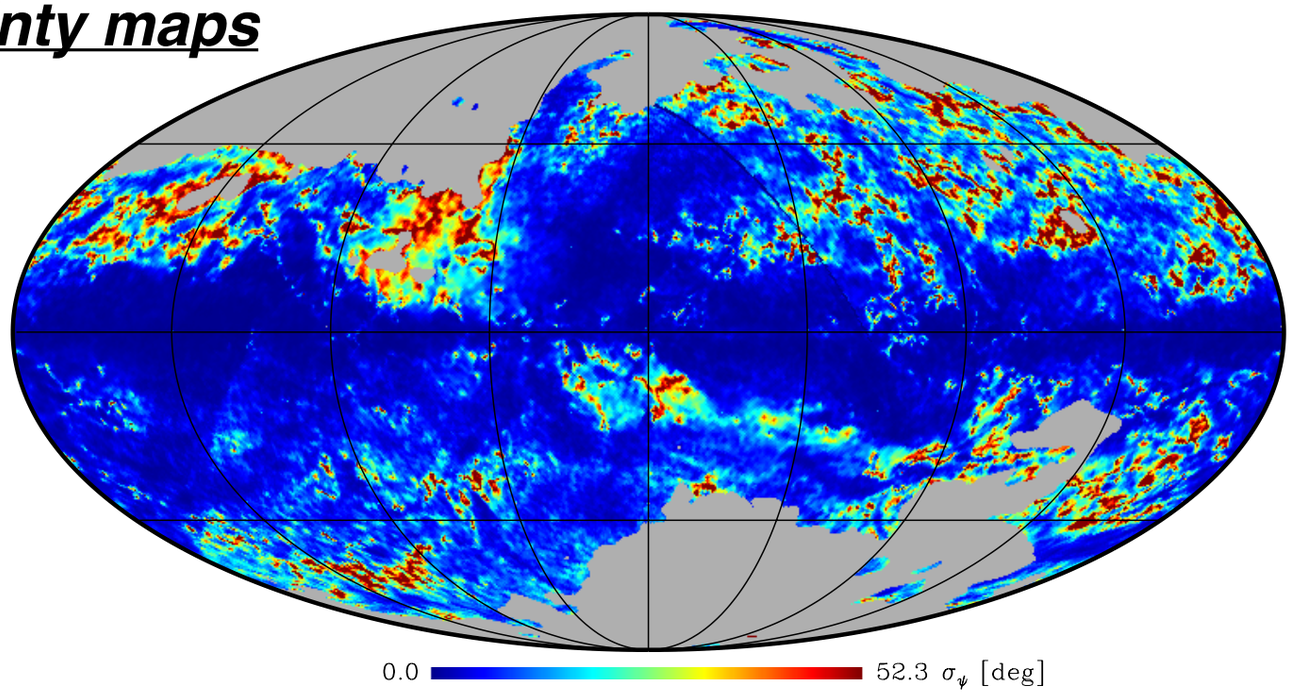


$$\psi = \frac{1}{2}\mathrm{atan}(U, Q)$$



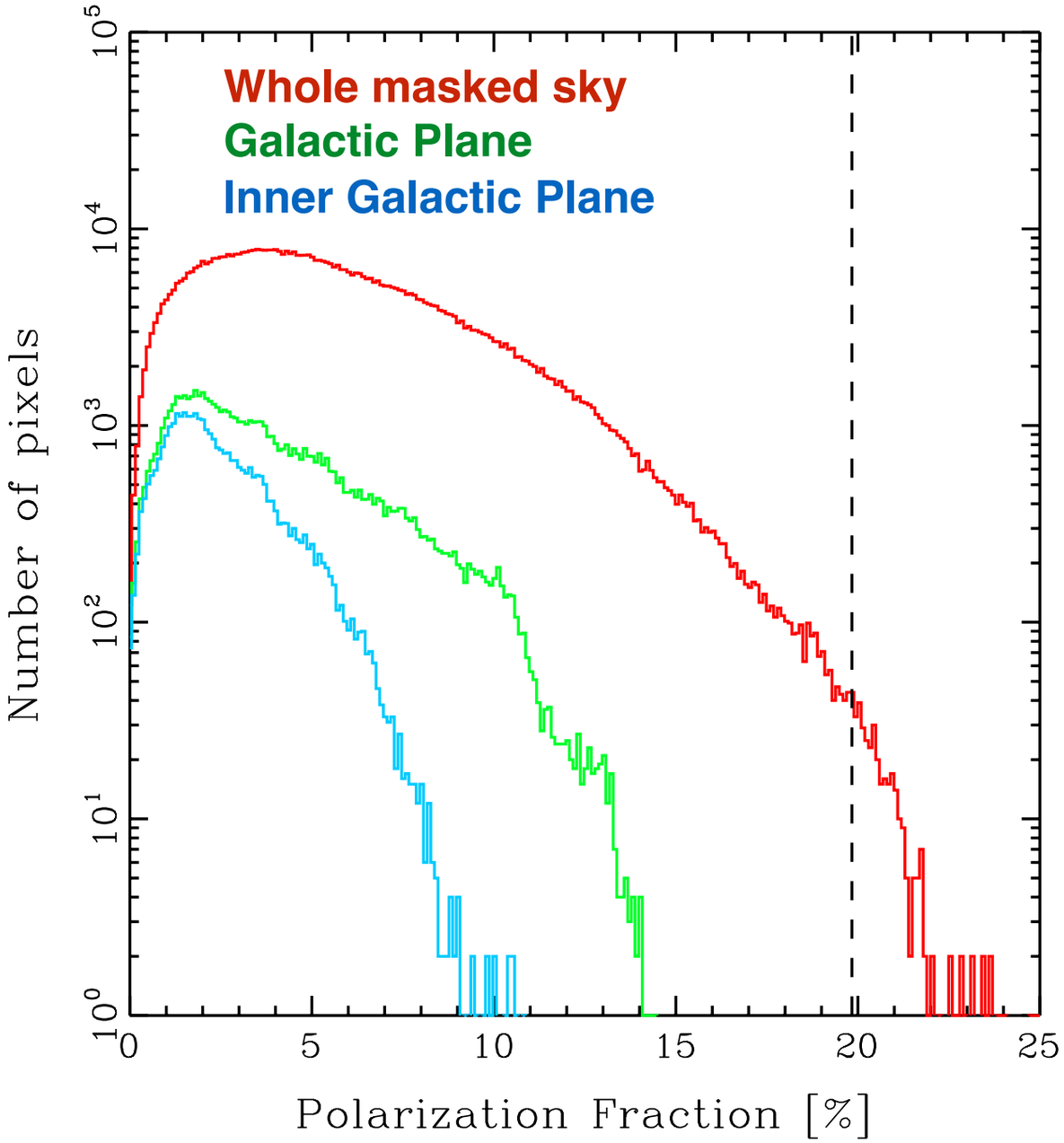
Uncertainty maps



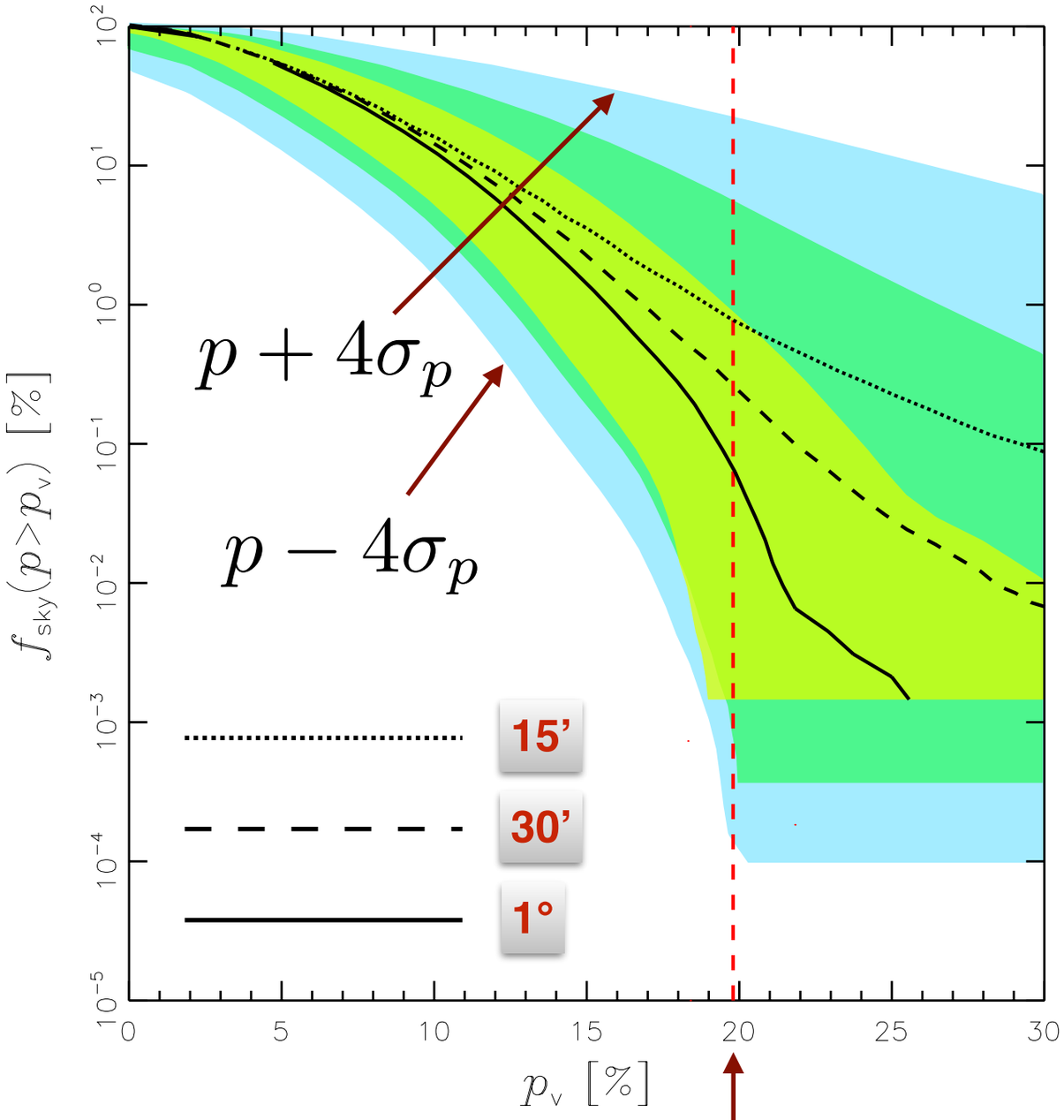


Planck intermediate results. XIX.

Maximum polarization fraction



1° resolution

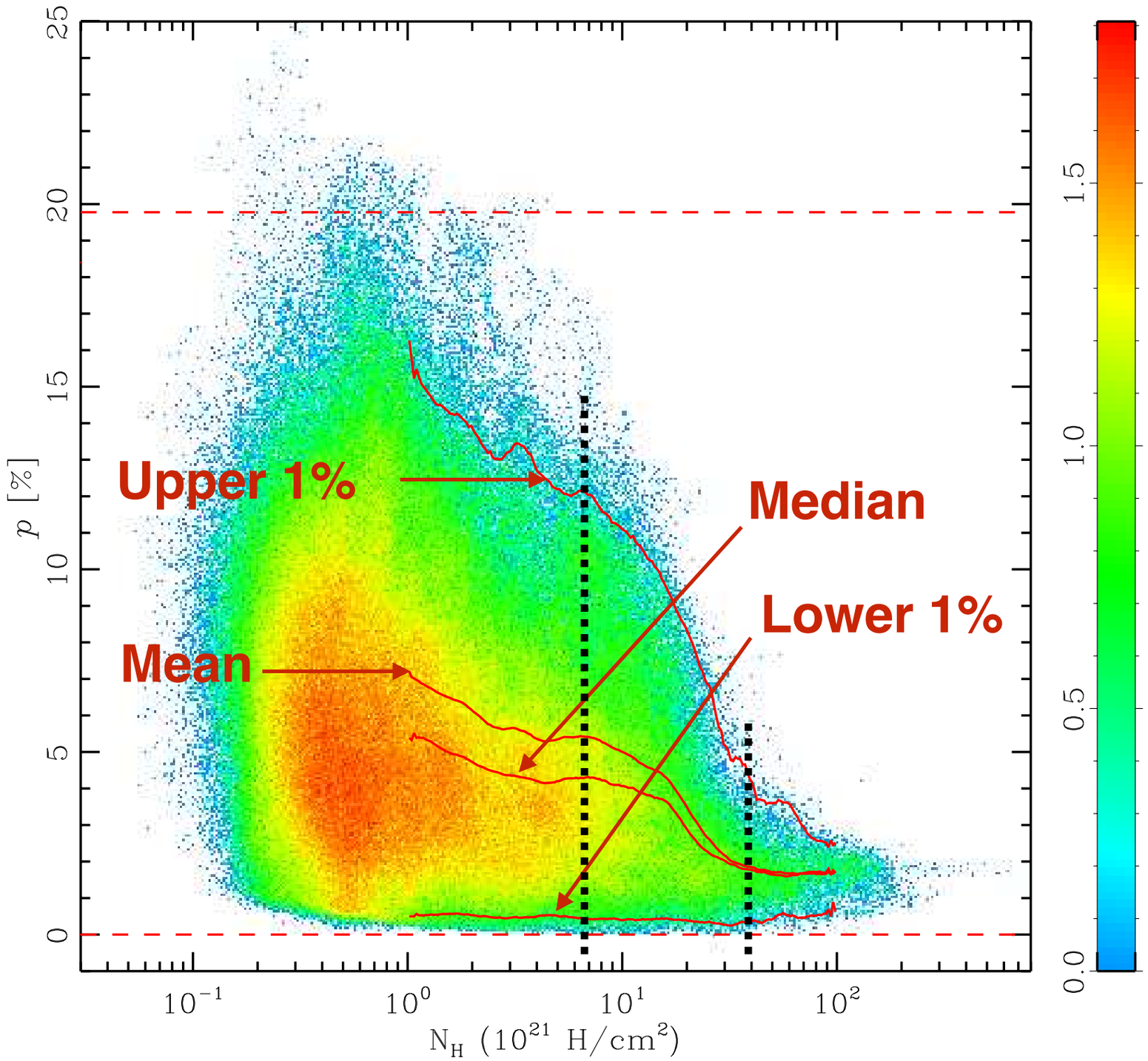


$p_{\max} = 19.8\%$

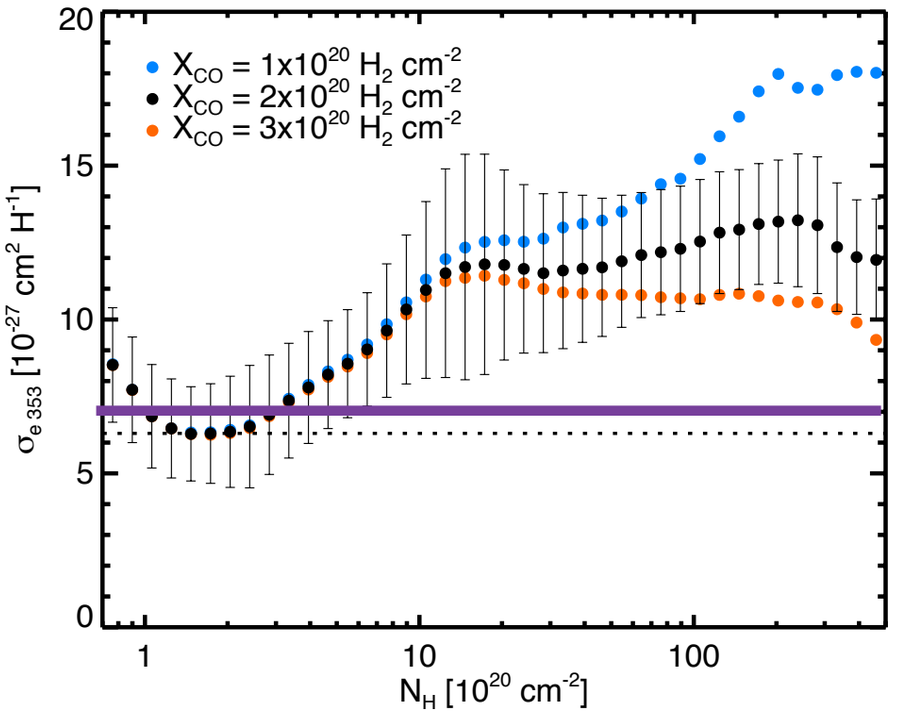
Intrinsic polarization fraction of dust at least 20%

Planck intermediate results. XIX.

Polarization fraction versus column density



$$N_{\rm H} = 1.42 \times 10^{26} \times \tau_{353}\,{\rm cm}^{-2}$$



Planck 2013 results. XI.

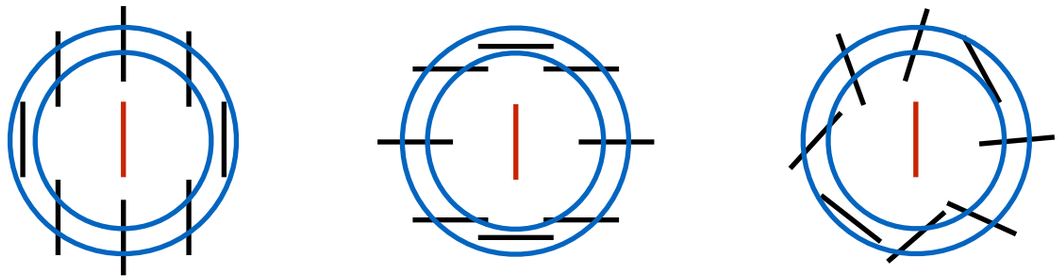
Two to three regimes of p decrease with $N_{\rm H}$

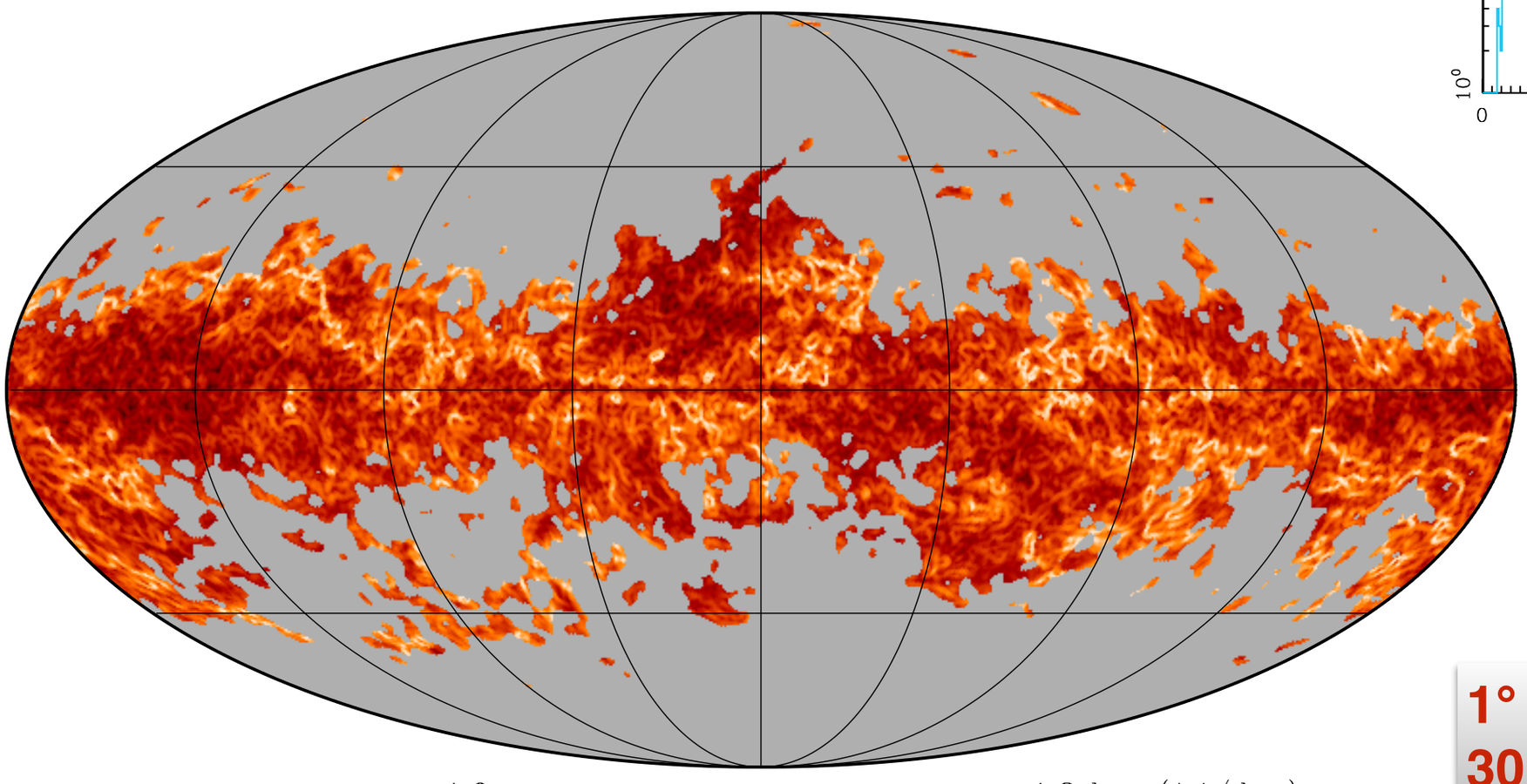
Planck intermediate results. XIX.

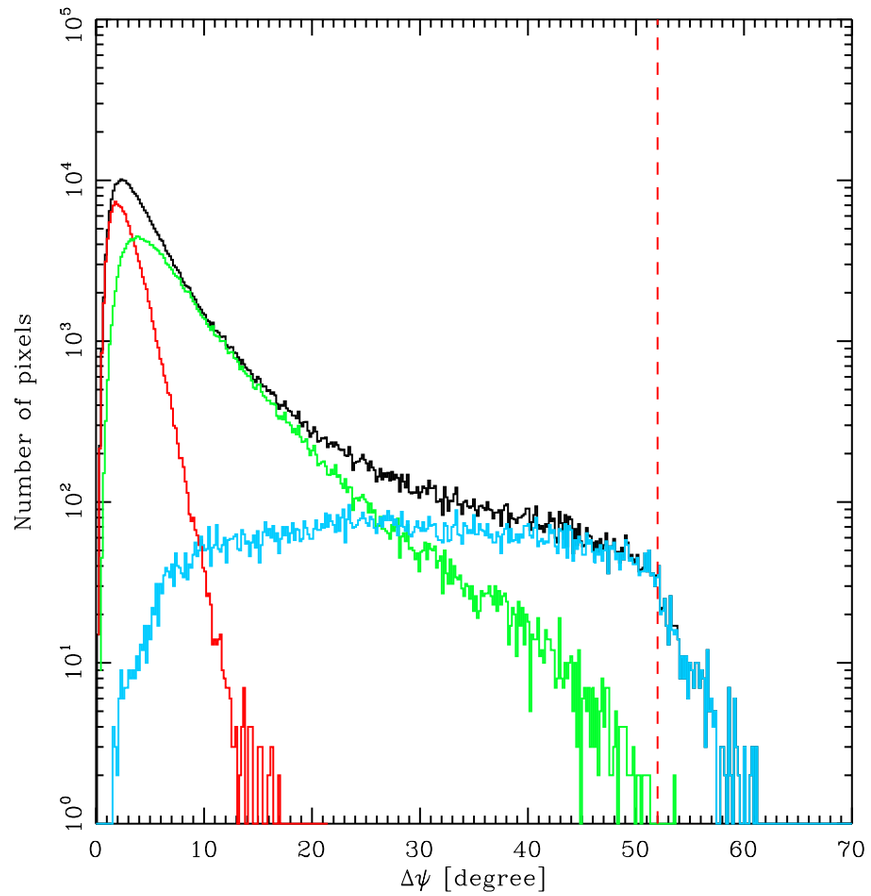
Polarization angle dispersion function

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi\left(\mathbf{r}\right) - \psi\left(\mathbf{r}+\mathbf{l}_i\right)\right]^2$$

$\Delta\psi = 0$ $\quad$ $\Delta\psi = \pi/2$ $\quad$ $\Delta\psi = \pi/\sqrt{12}$







Whole masked sky

$p > 5\%$

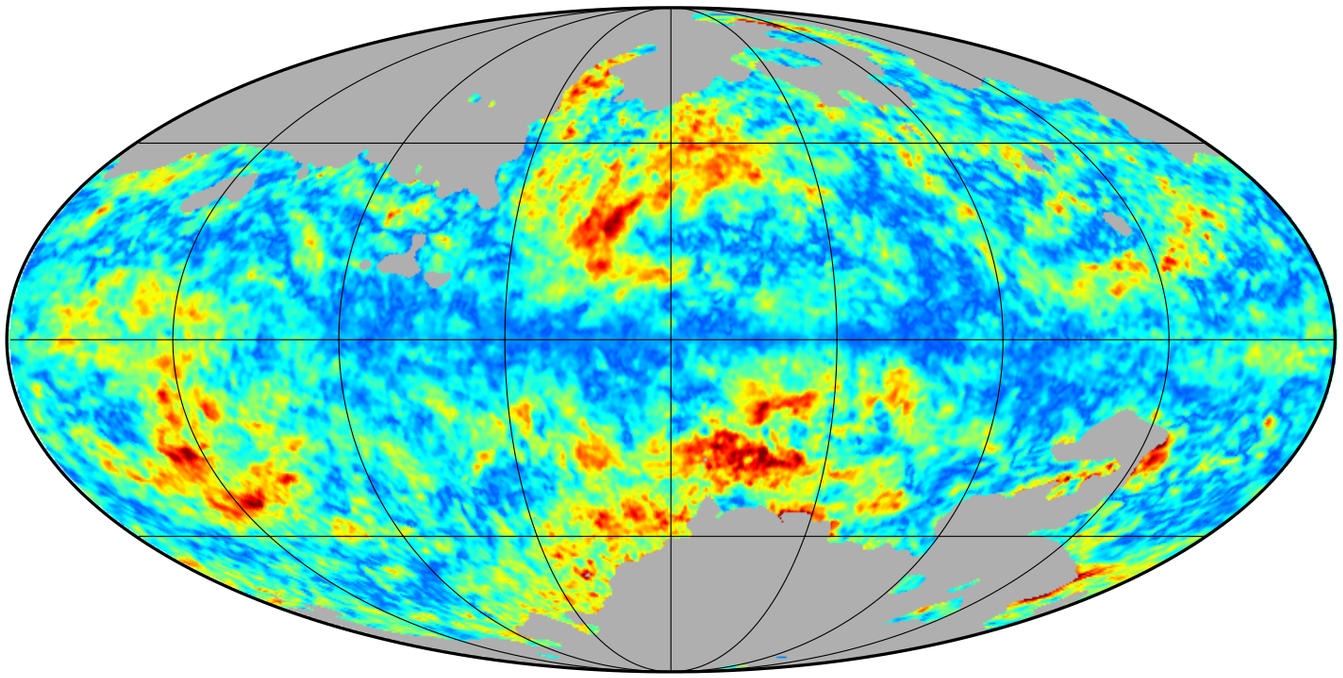
$5\% > p > 1\%$

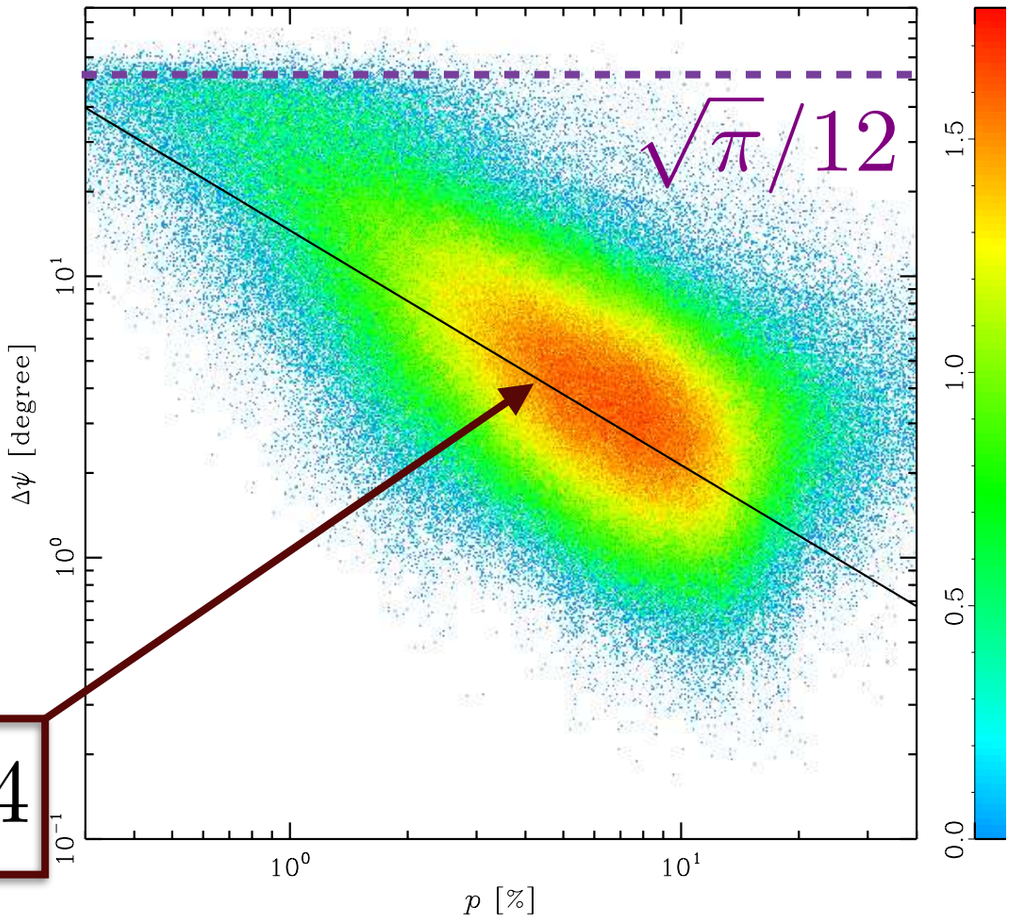
$p < 1\%$

1° resolution
30’ lag

Planck intermediate results. XIX.

Anticorrelation with polarization fraction



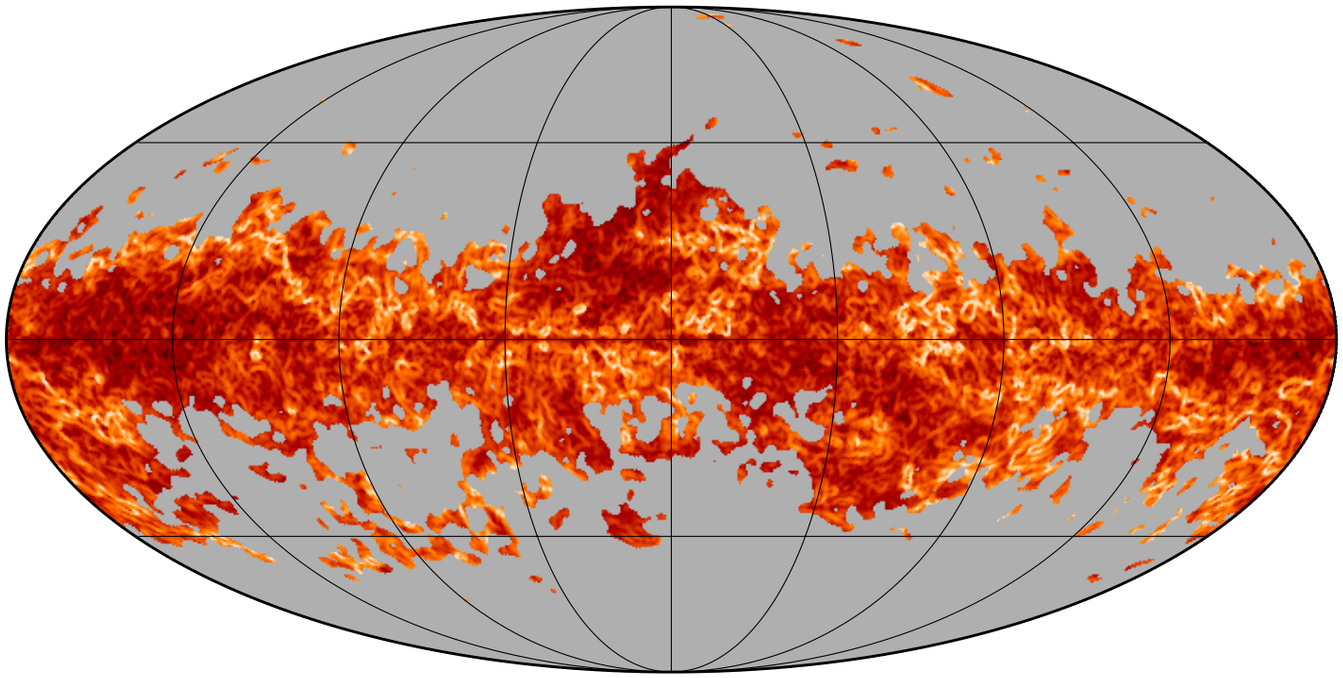


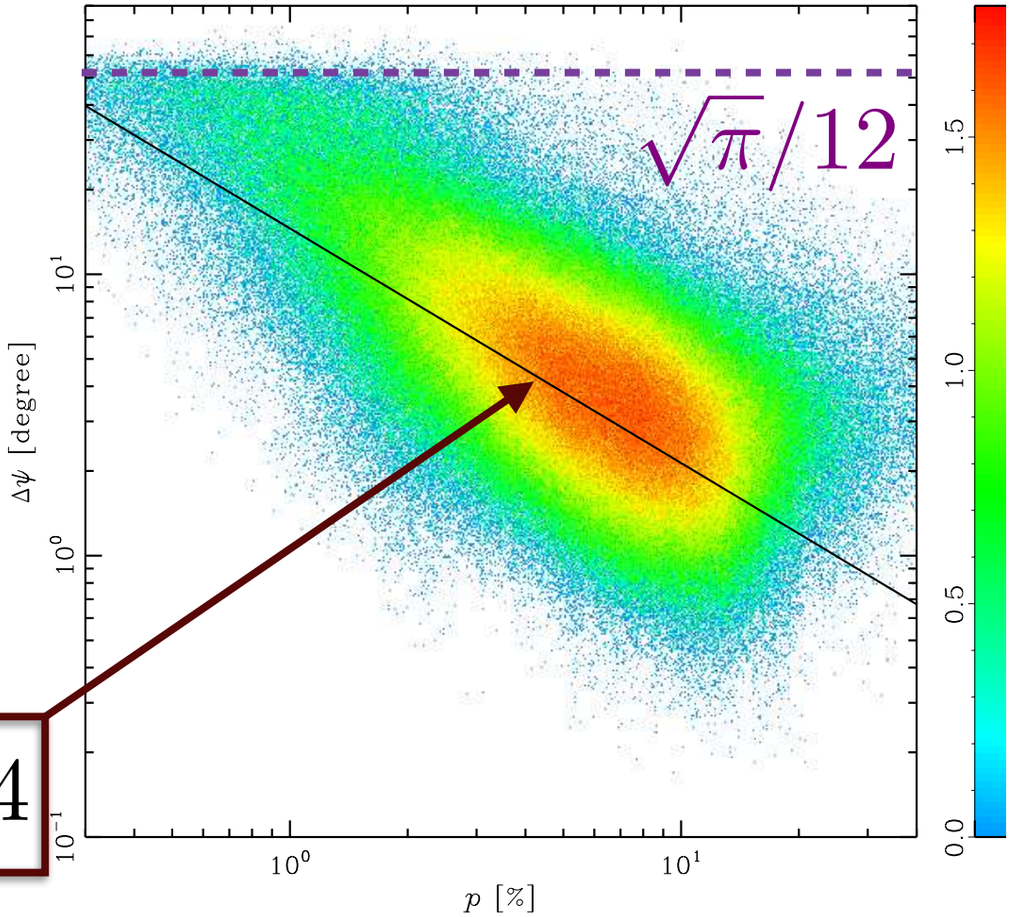
$$\log(\Delta\psi/\,\mathrm{deg}) = -0.834\log p - 0.504$$

- Strong anti-correlation between p and $\Delta\psi$
- Low p where the polarization angle changes abruptly
- Increased lag flattens the anti-correlation

Planck intermediate results. XIX.

Anticorrelation with polarization fraction



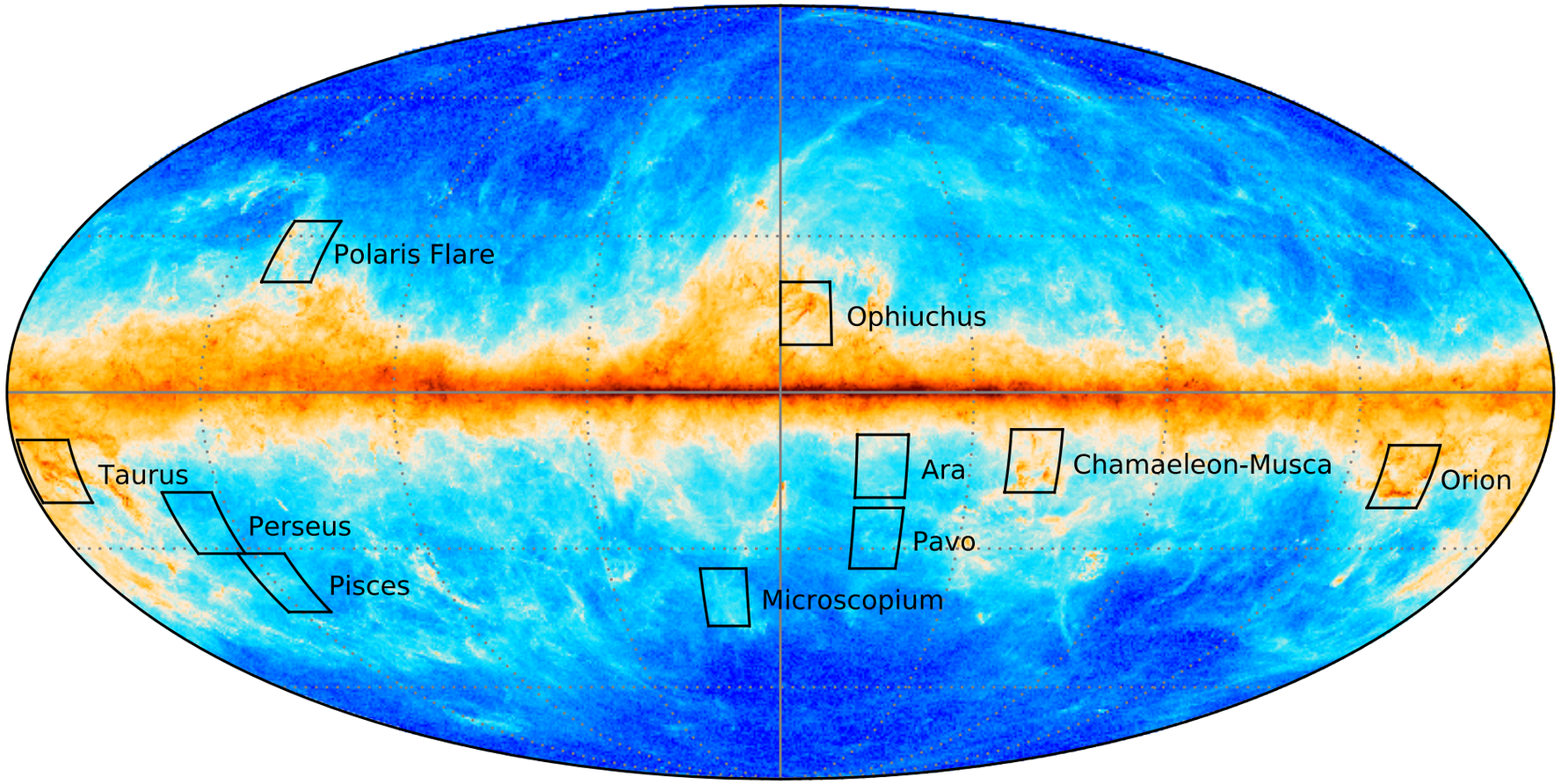


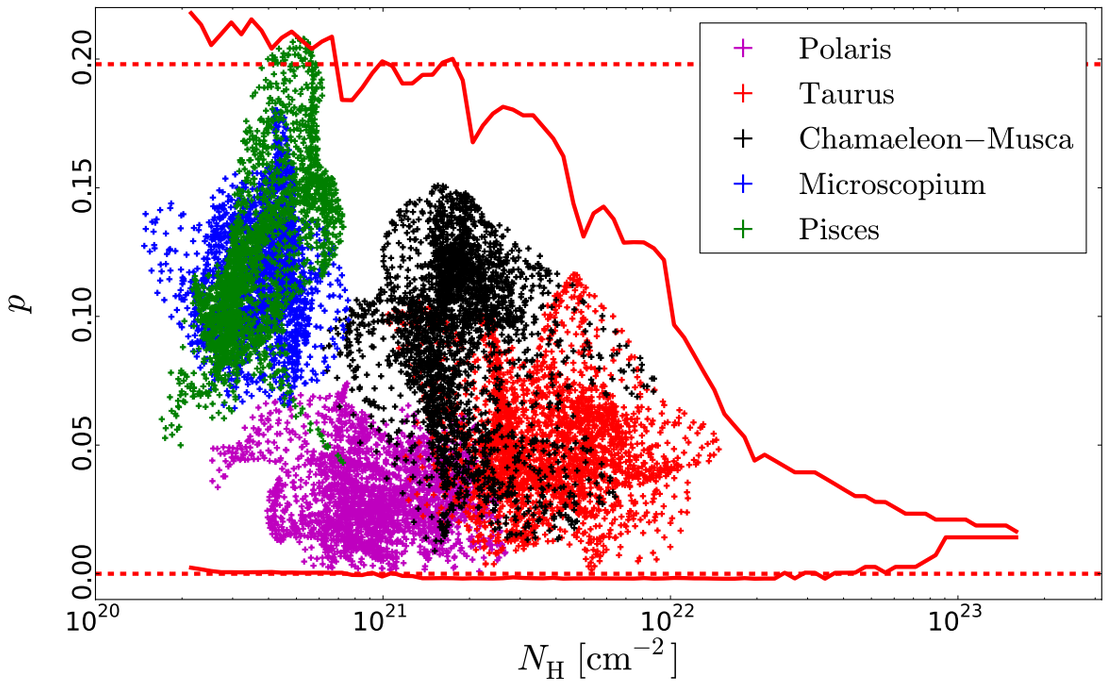
$$\log(\Delta\psi/\,\mathrm{deg}) = -0.834\log p - 0.504$$

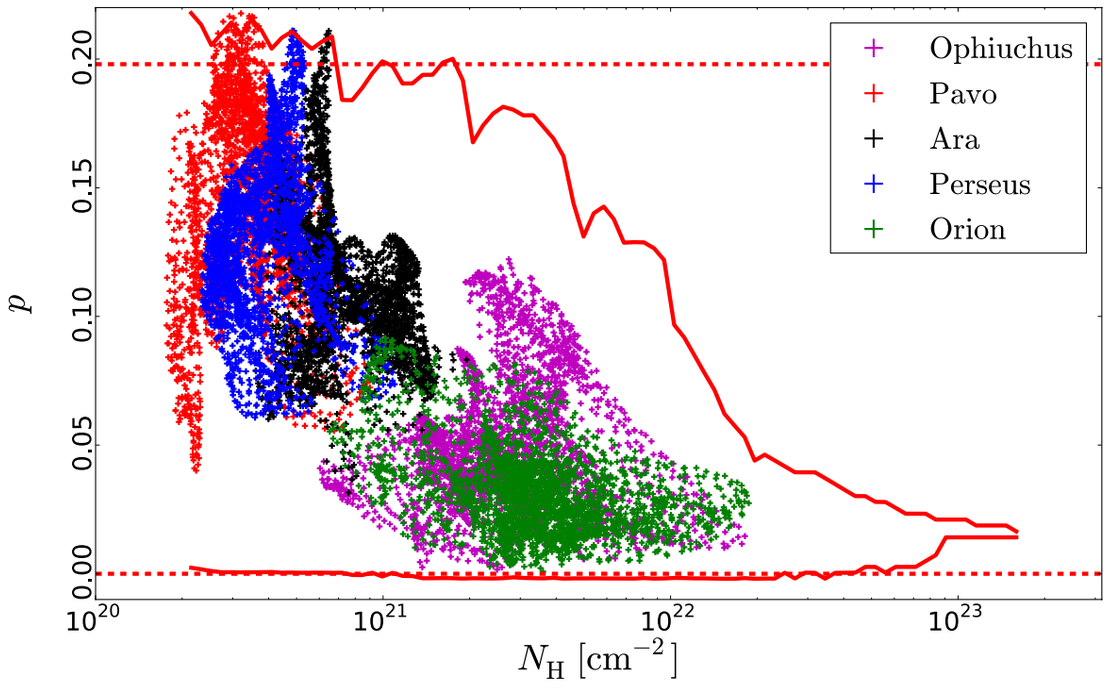
- Strong anti-correlation between p and $\Delta\psi$
- Low p where the polarization angle changes abruptly
- Increased lag flattens the anti-correlation

Planck intermediate results. XIX.

Polarized dust emission in nearby clouds

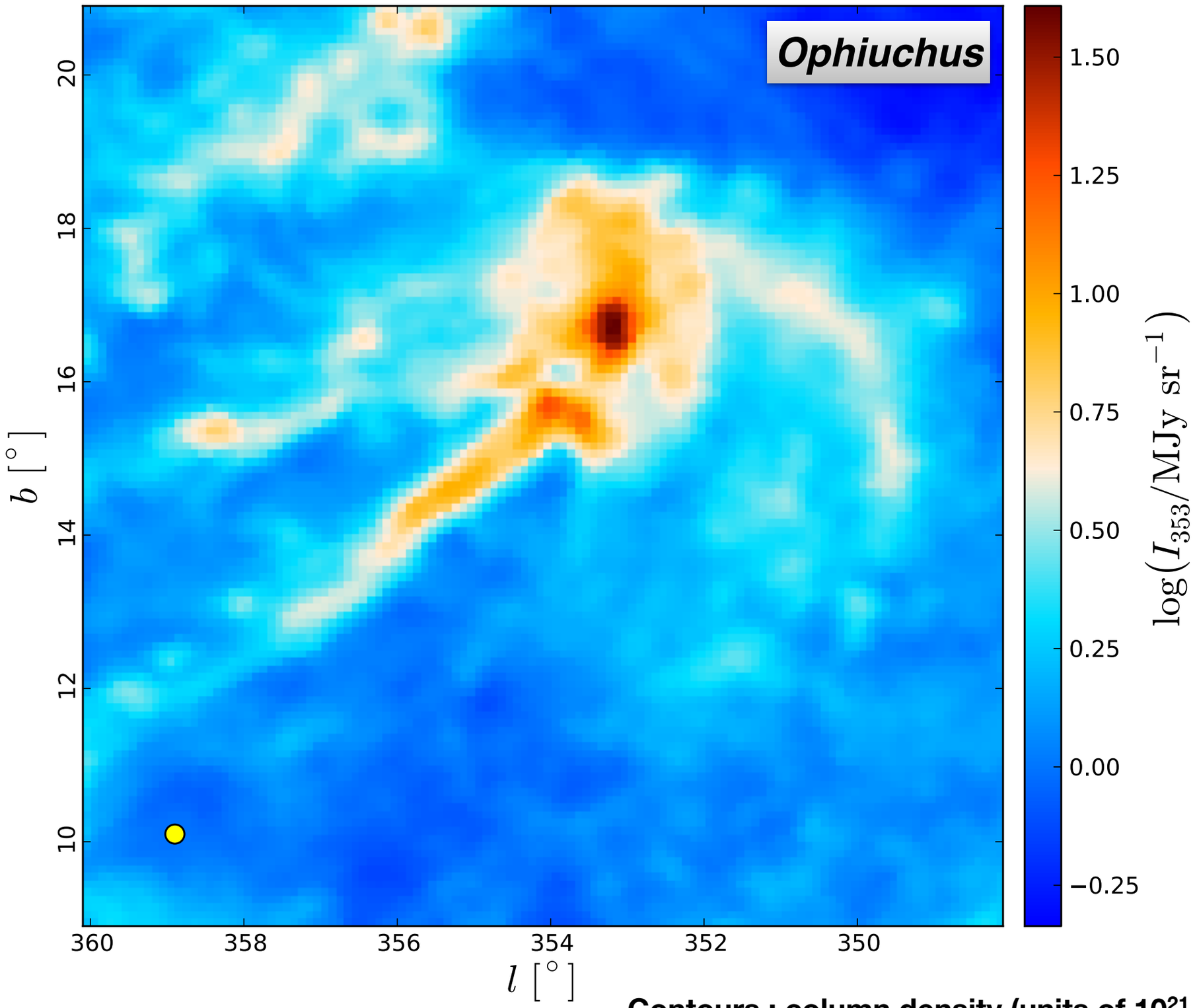






Planck intermediate results. XX.

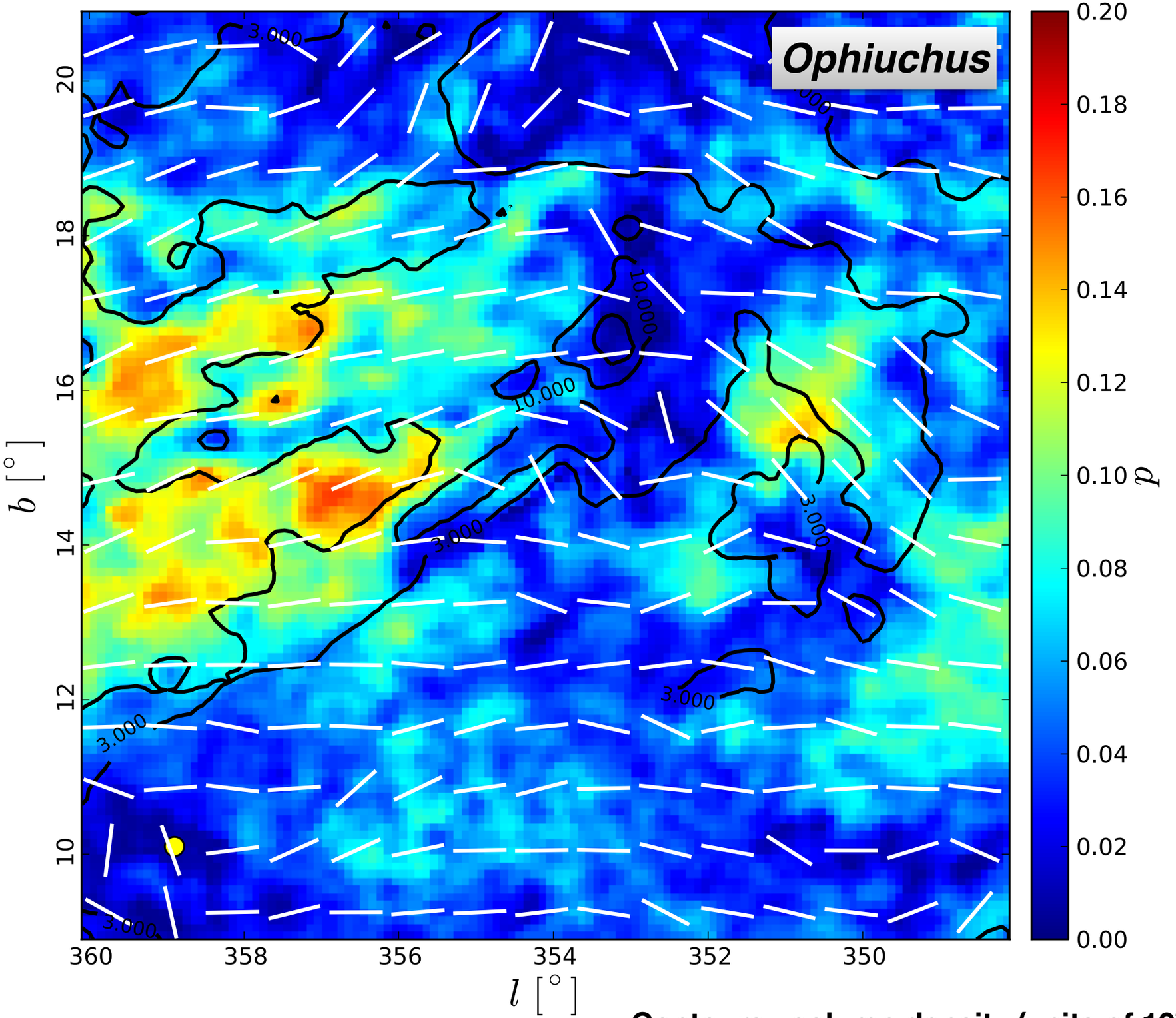
Polarization fraction versus column density



Contours : column density (units of 10^{21} cm^{-2})
Segments : mean orientation of *B* in the plane of the sky

Planck intermediate results. XX.

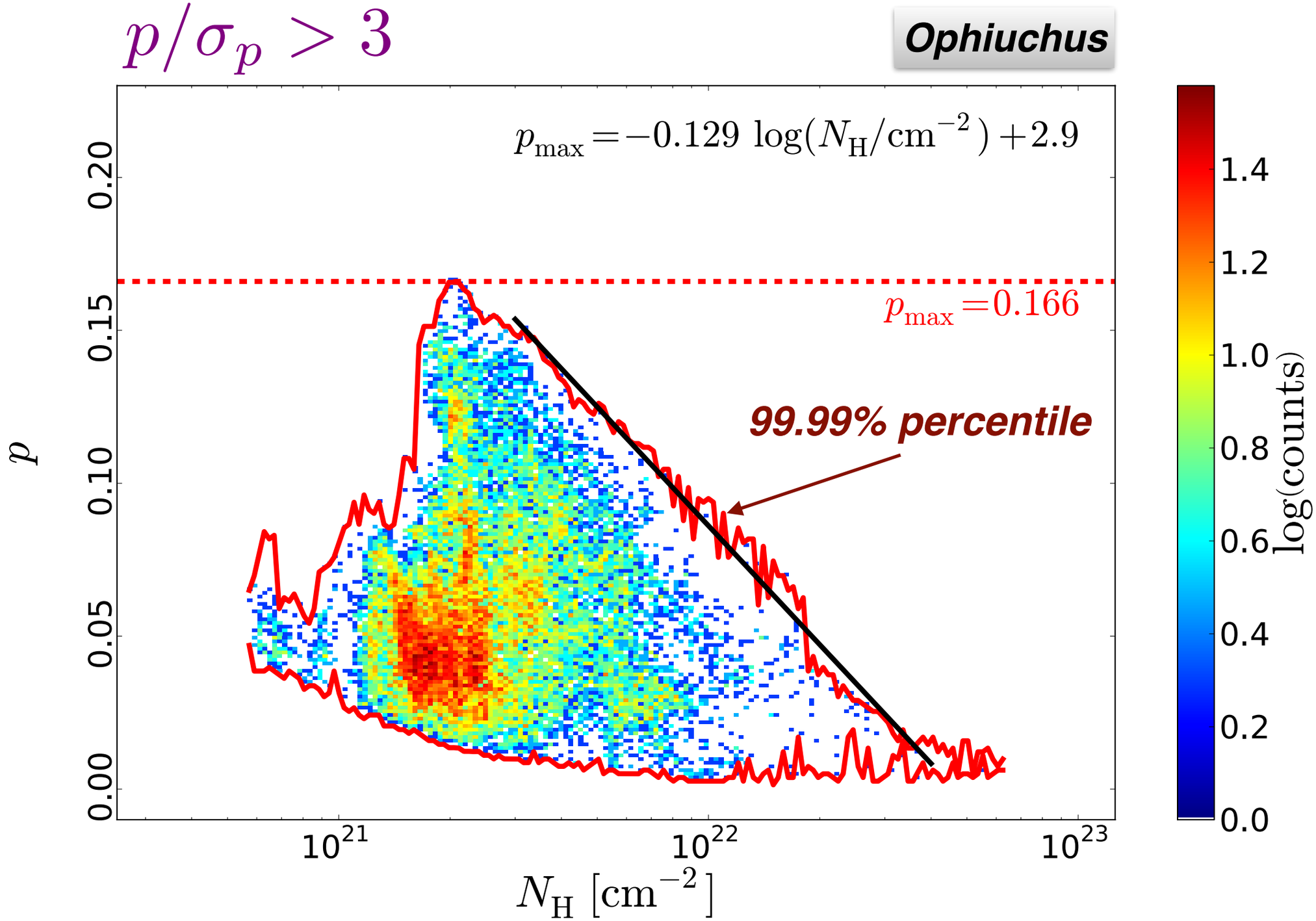
Polarization fraction versus column density



Contours : column density (units of 10^{21} cm^{-2})
Segments : mean orientation of *B* in the plane of the sky

Planck intermediate results. XX.

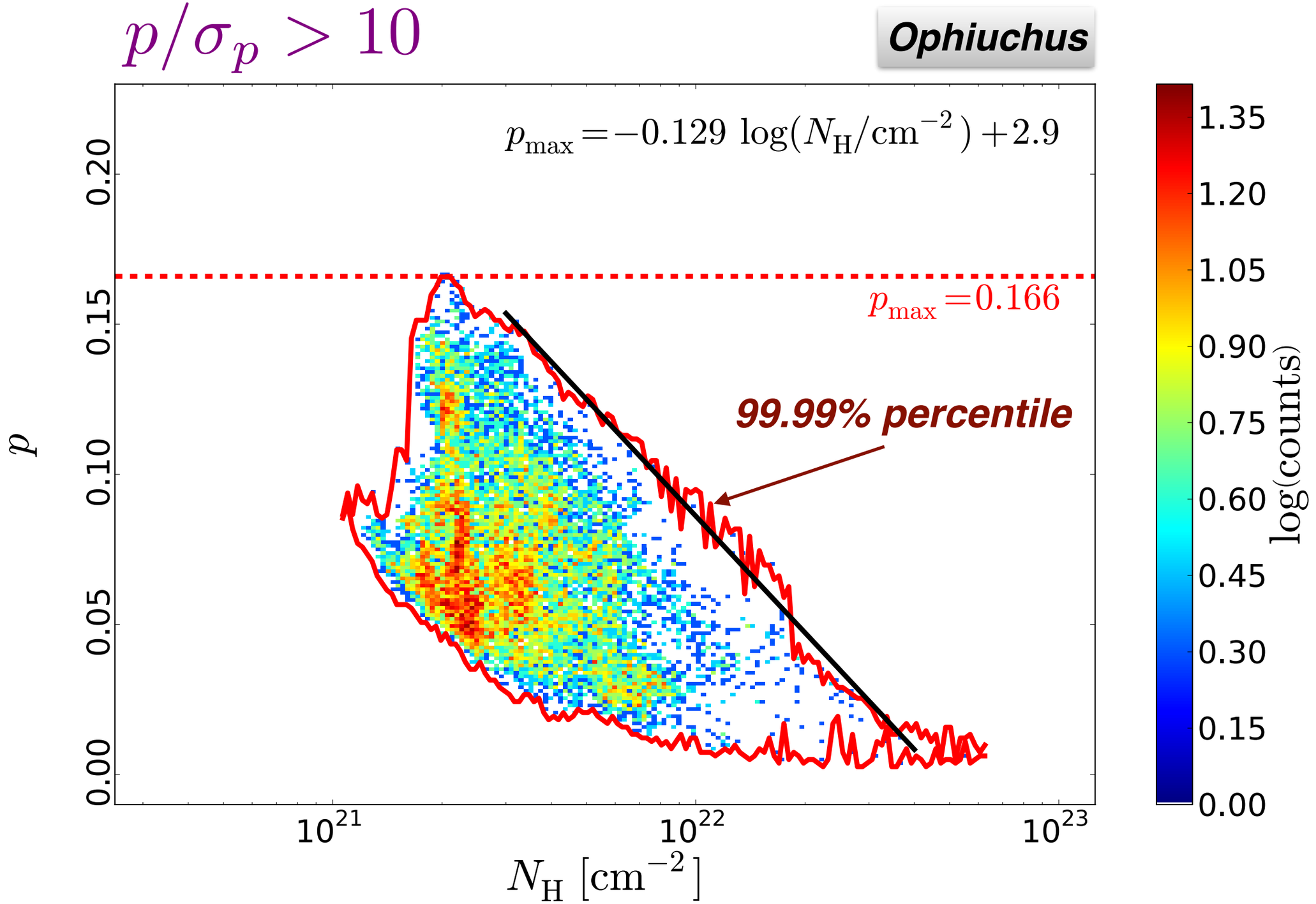
Polarization fraction versus column density



Anti-correlation robust with respect to polarization S/N

Planck intermediate results. XX.

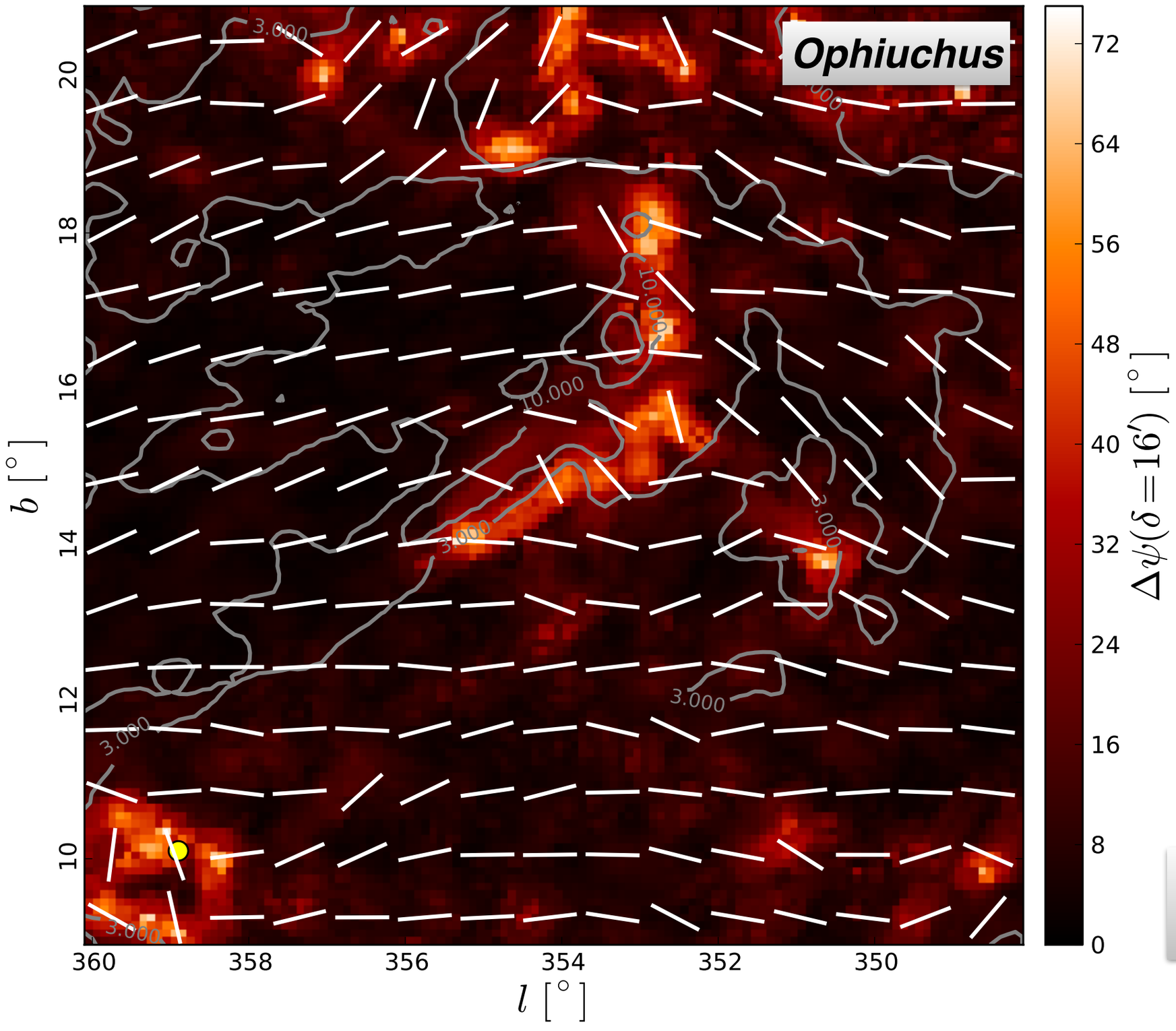
Polarization fraction versus column density



Anti-correlation robust with respect to polarization S/N

Planck intermediate results. XX.

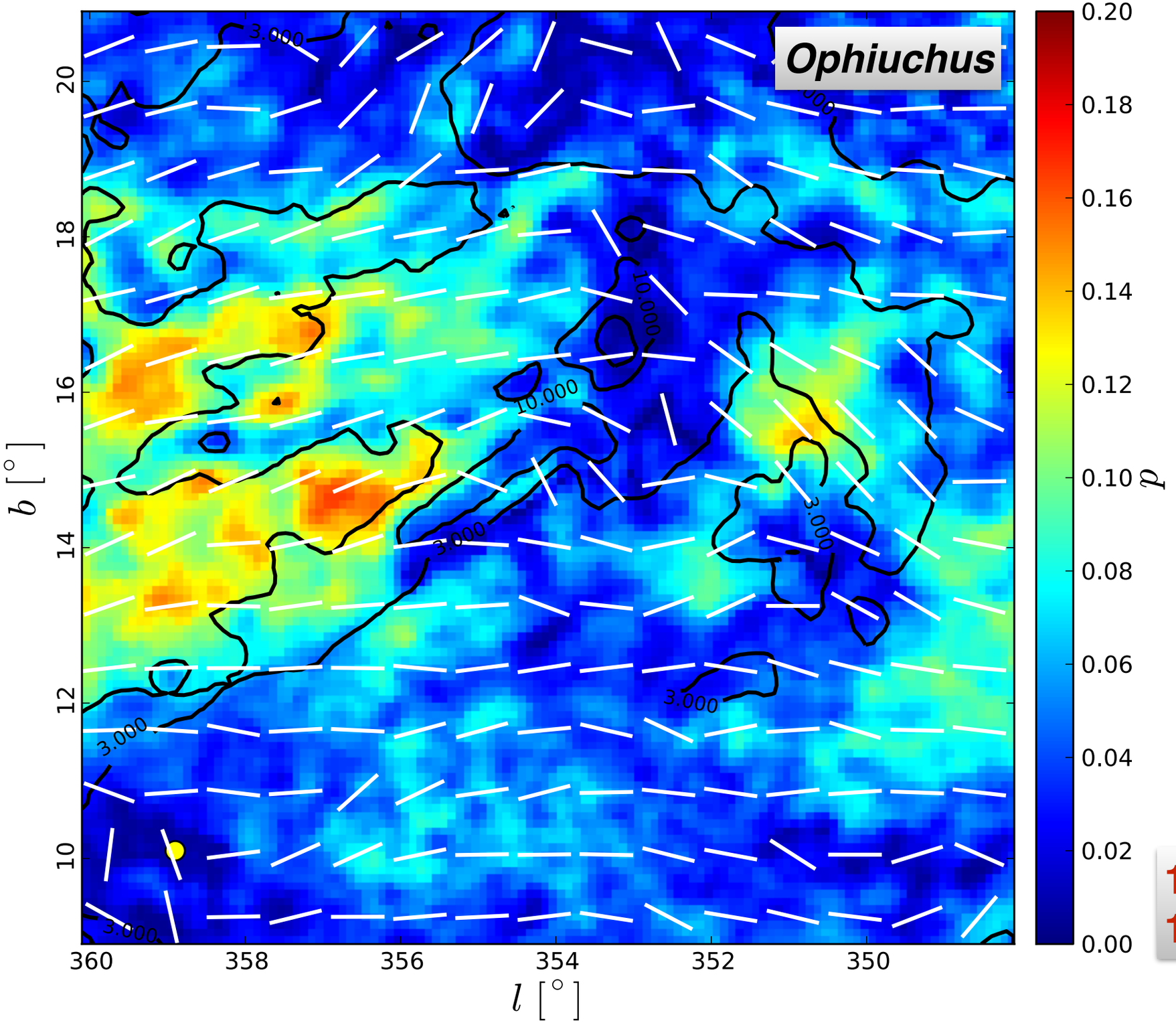
Polarization fraction and angle dispersion



15’ resolution
16’ lag

Planck intermediate results. XX.

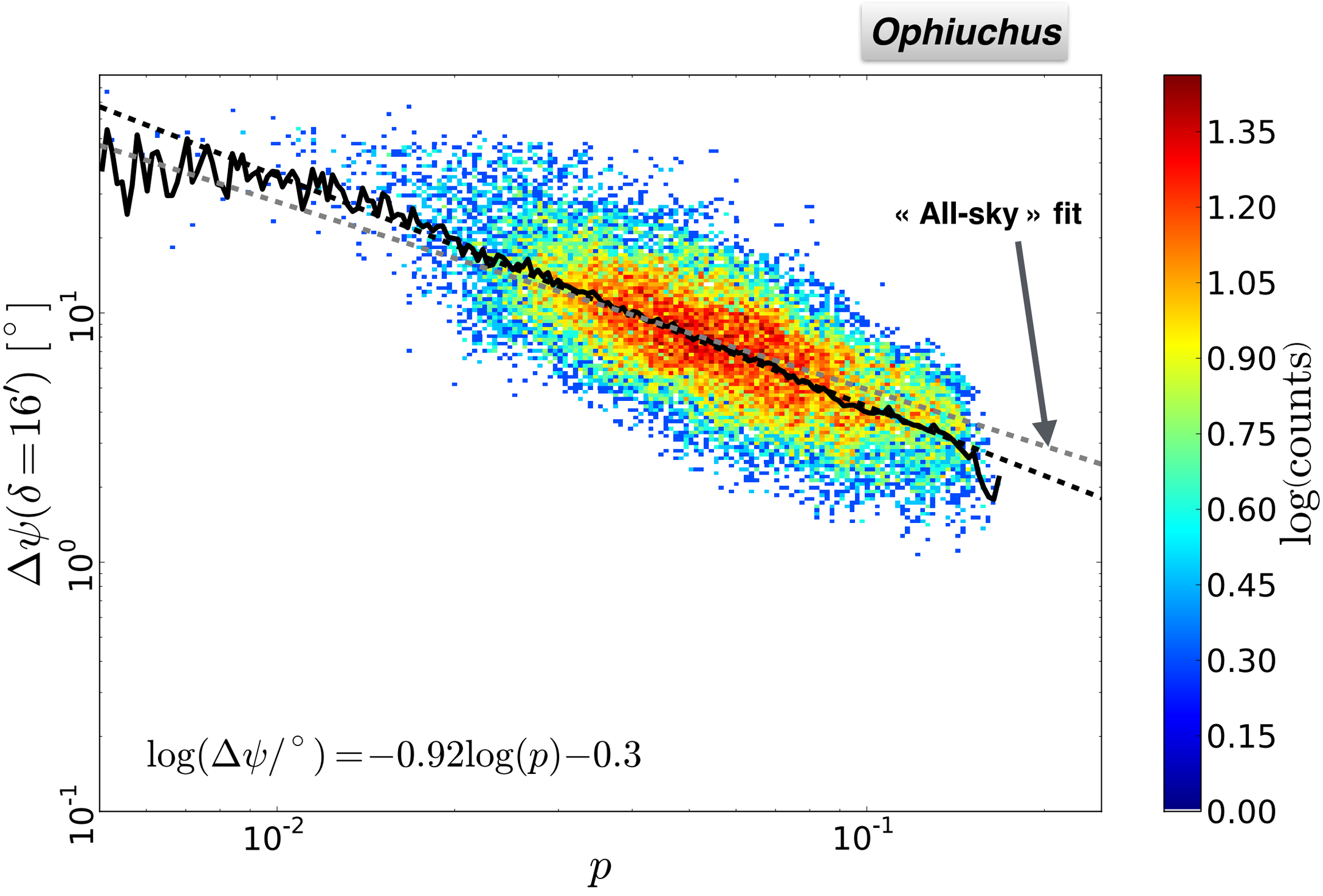
Polarization fraction and angle dispersion



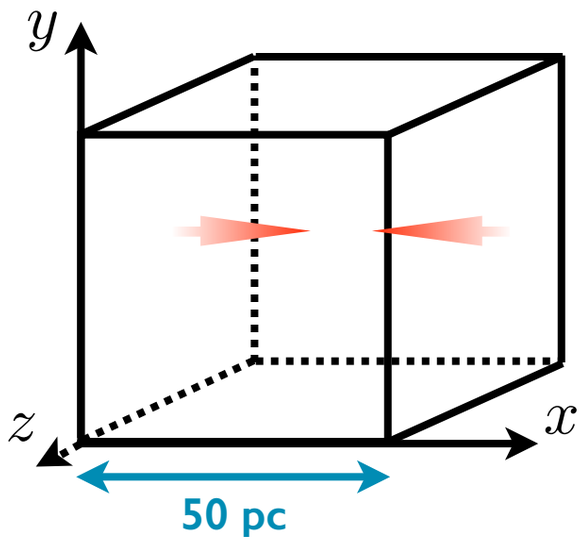
15’ resolution
16’ lag

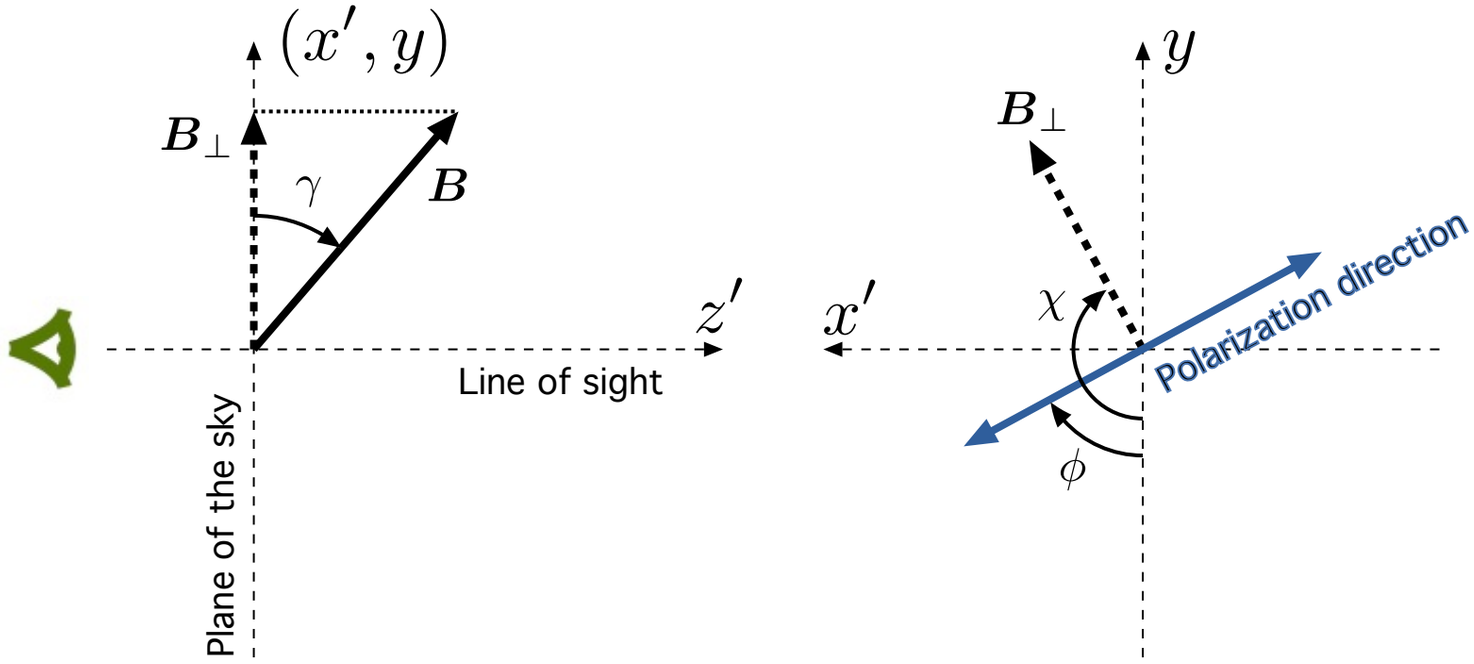
Planck intermediate results. XX.

Polarization fraction and angle dispersion



Simulating polarized thermal dust emission





- 18 pc subset of a 50 pc cube
- Converging flows of magnetized warm gas
- Mean magnetic field along the flows
- Rotation of the cube, placed at 200 pc
- Simulated Stokes maps smoothed at 5’

$$I = \int S_\nu e^{-\tau_\nu} \left[1 - p_0 \left(\cos^2\gamma - \frac{2}{3}\right)\right] \mathrm{d}\tau_\nu$$

$$Q = \int p_0 S_\nu e^{-\tau_\nu} \cos(2\phi) \cos^2\gamma \mathrm{d}\tau_\nu$$

$$U = \int p_0 S_\nu e^{-\tau_\nu} \sin(2\phi) \cos^2\gamma \mathrm{d}\tau_\nu$$

« Intrinsic dust polarization parameter »

$$p_0 = 0.2$$

Opacity at 353 GHz (Planck Collaboration XXXI, 2014)

$$\tau_{353}/N_\mathrm{H} = 1.2 \times 10^{-26}\,\mathrm{cm}^{-2}$$

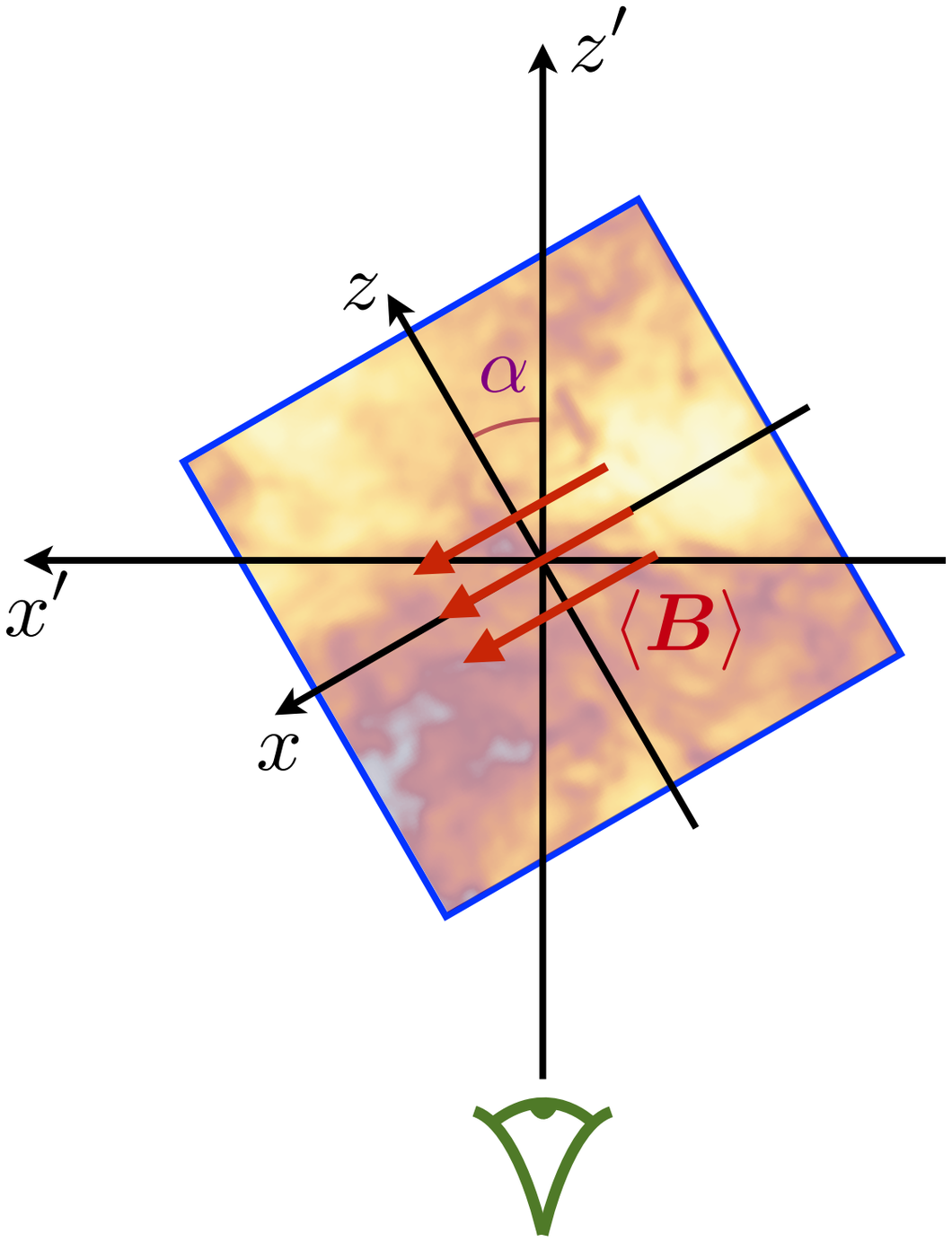
Dust temperature

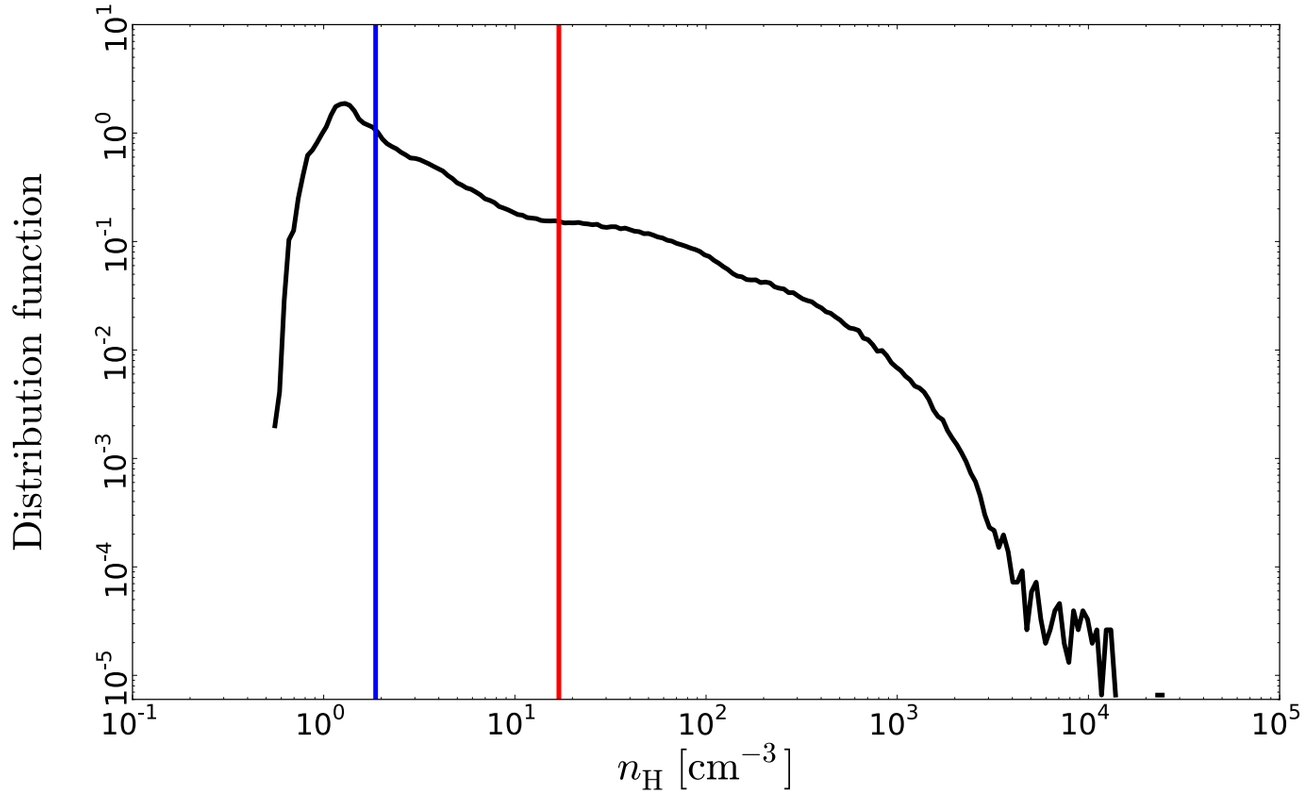
$$T_d = 18\,\mathrm{K}$$

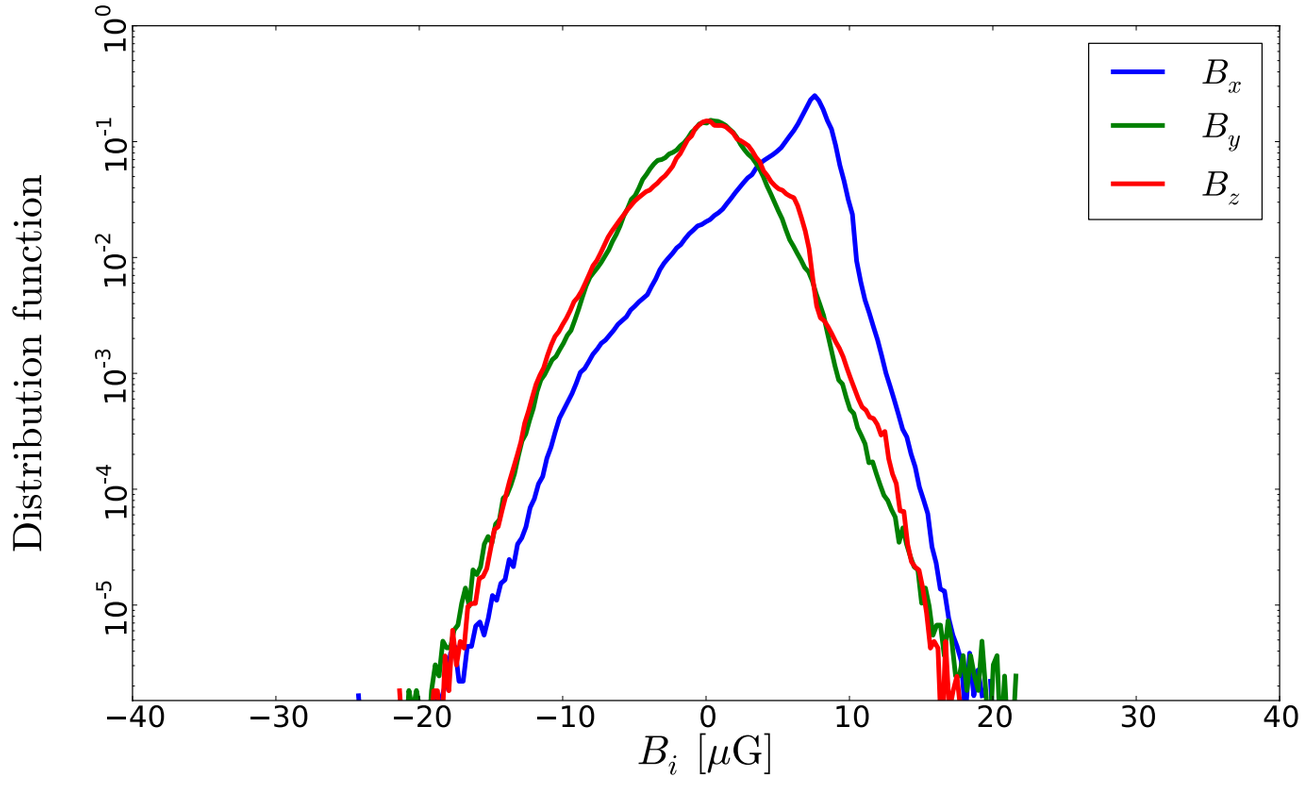
Planck intermediate results. XX.

Following Lee & Draine 85 and others…

Rotating the anisotropic input cubes

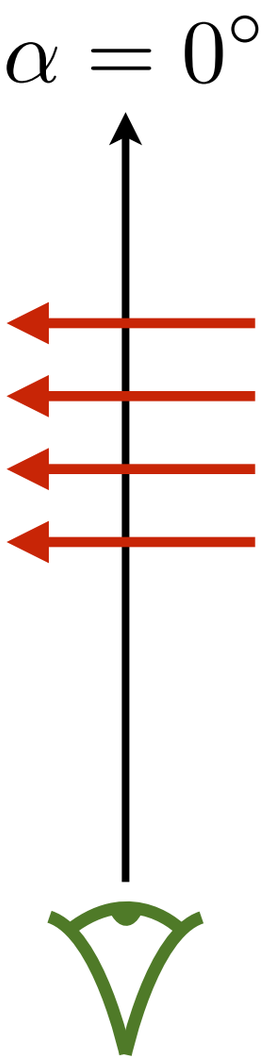


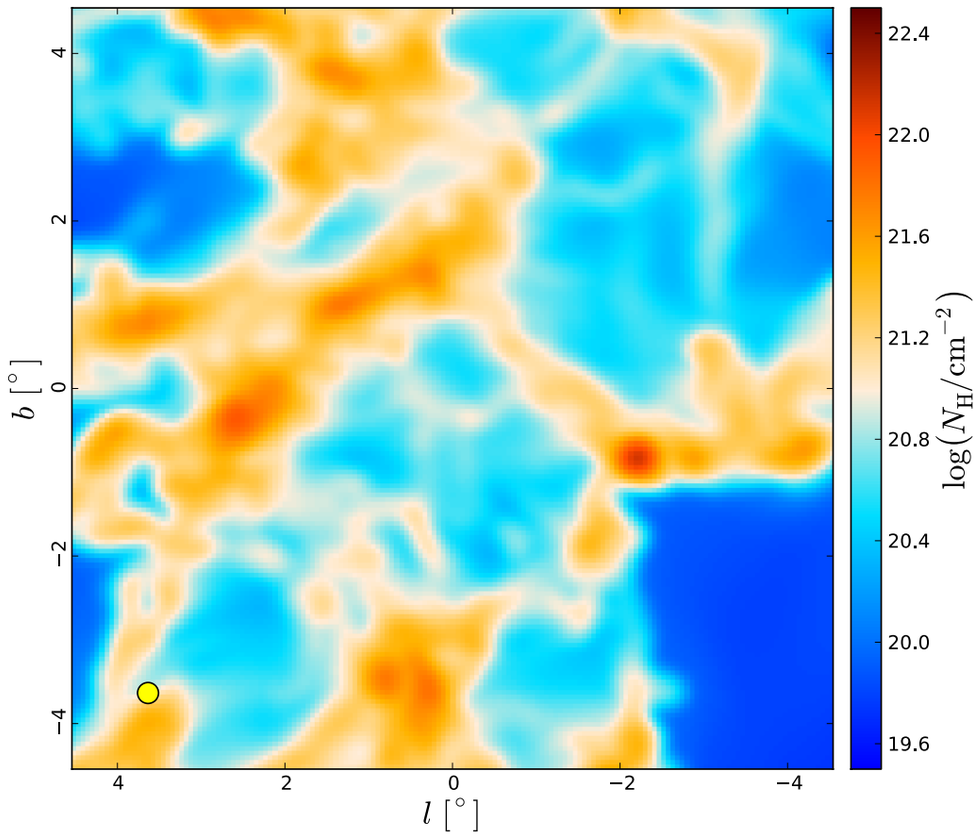


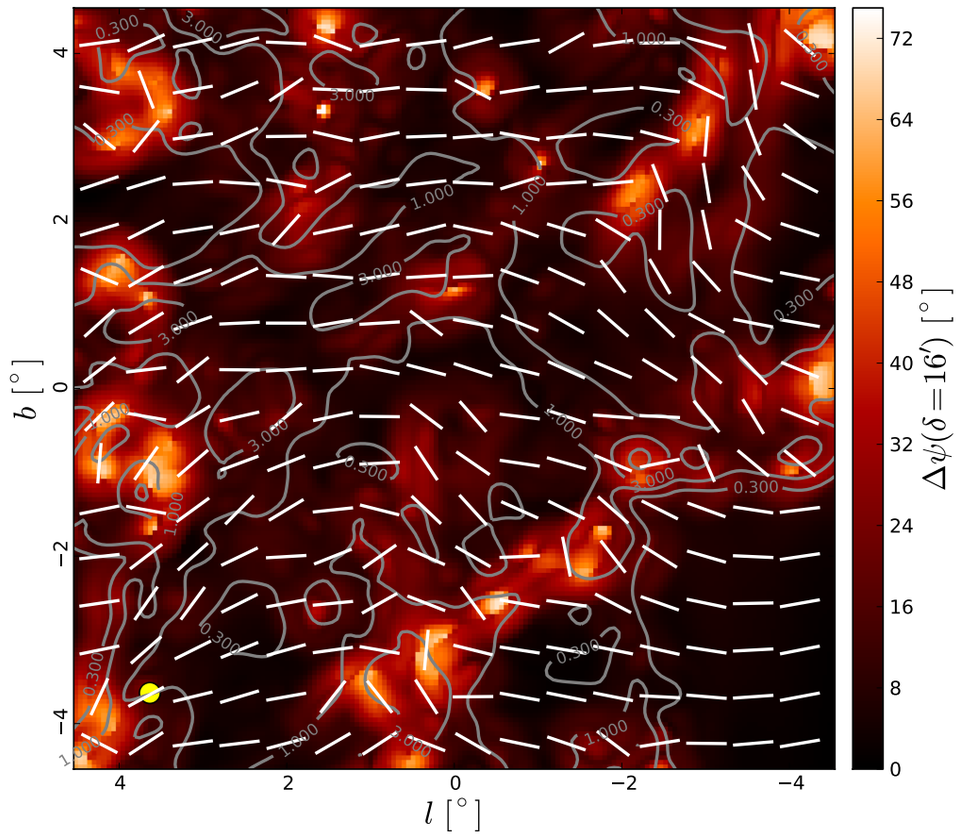


Planck intermediate results. XX.

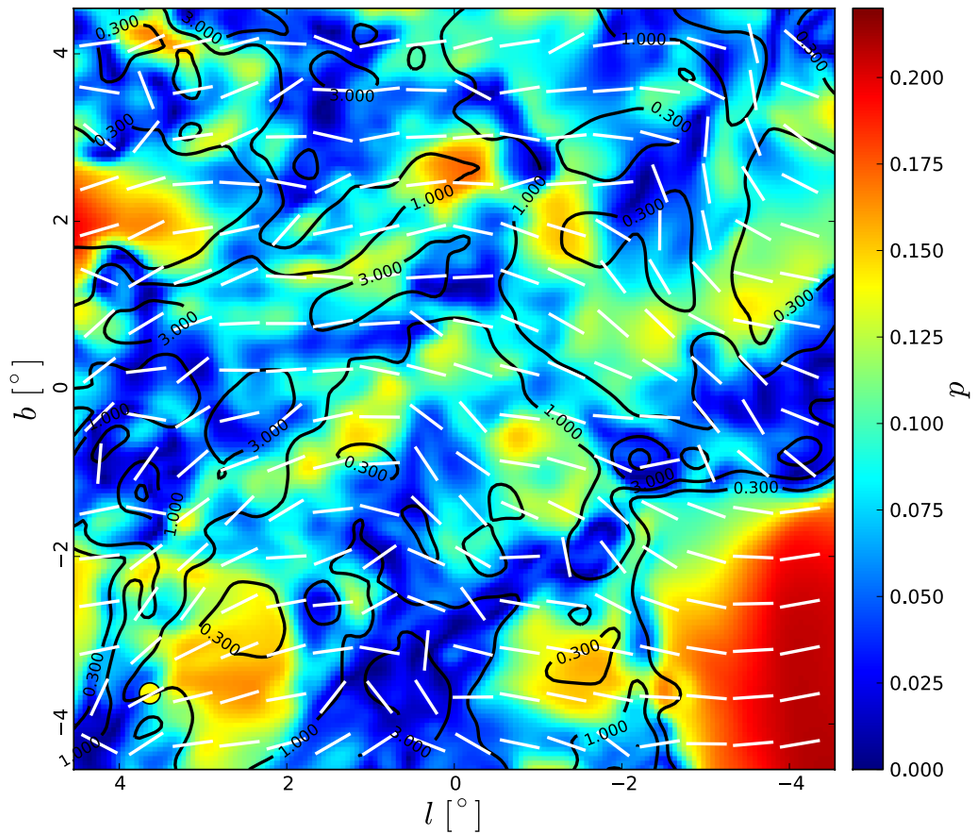
Simulated polarization maps





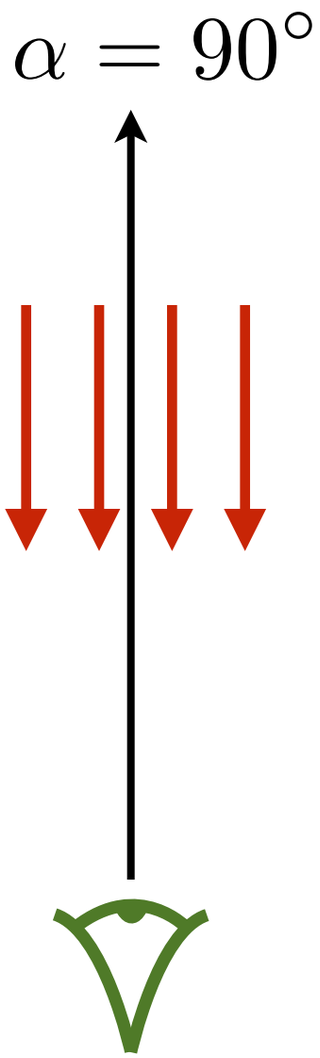


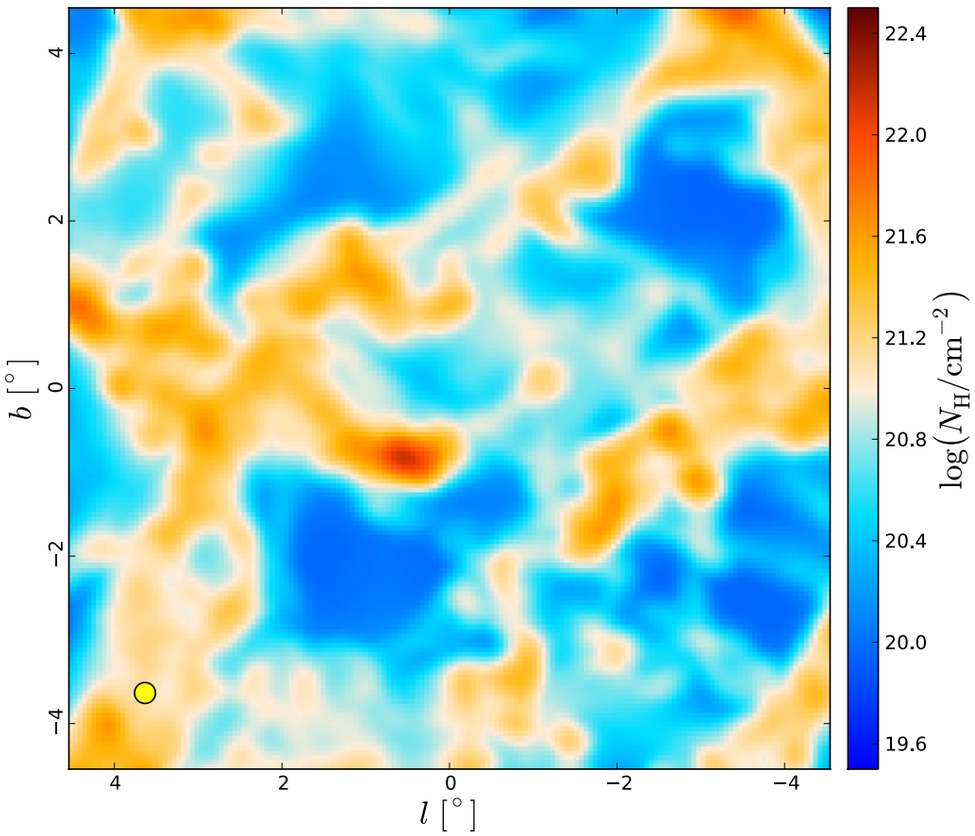
Anti-correlation p and $N_{\rm H}$
Anti-correlation p and $\Delta\psi$

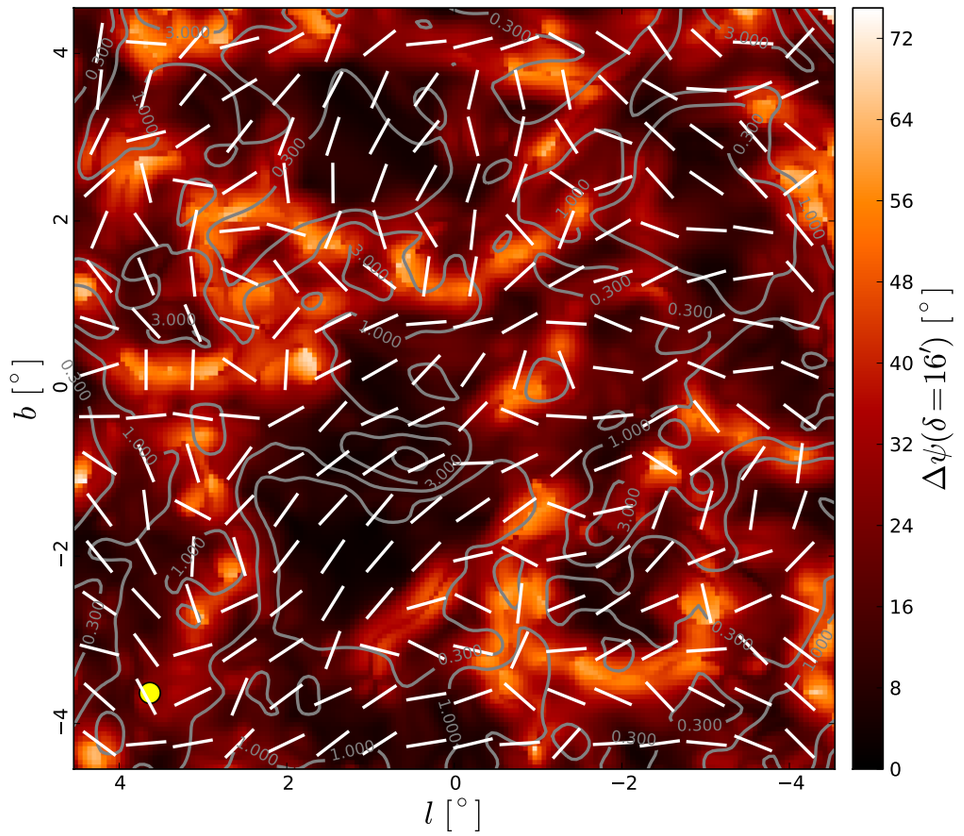


Planck intermediate results. XX.

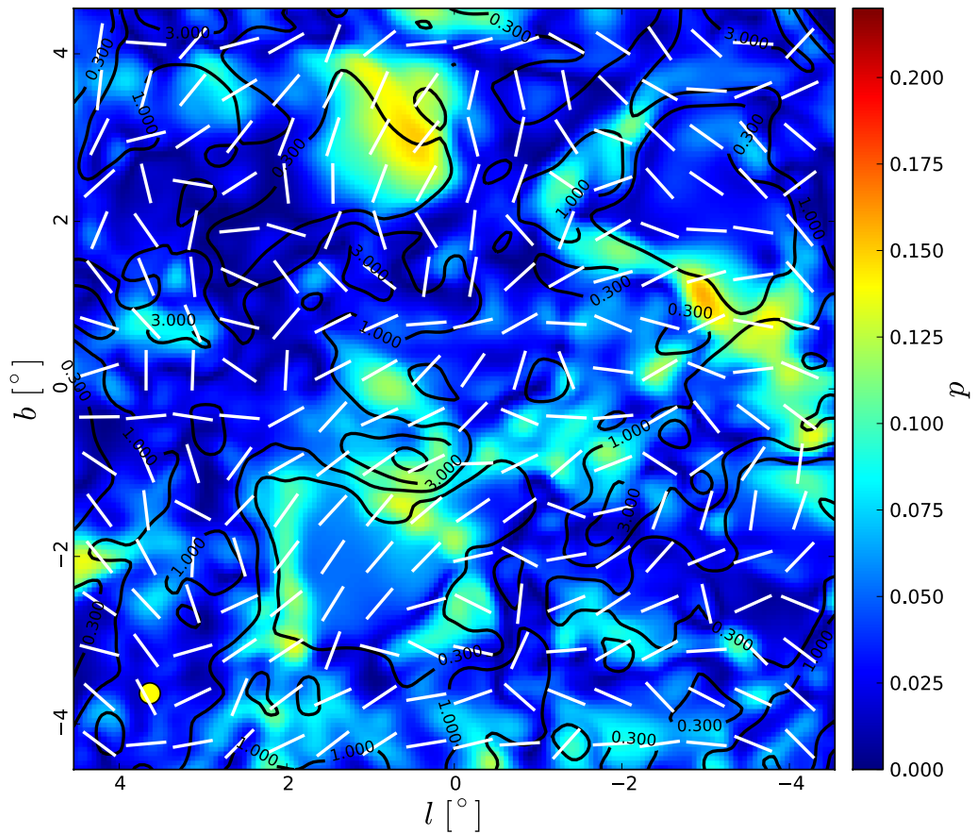
Simulated polarization maps





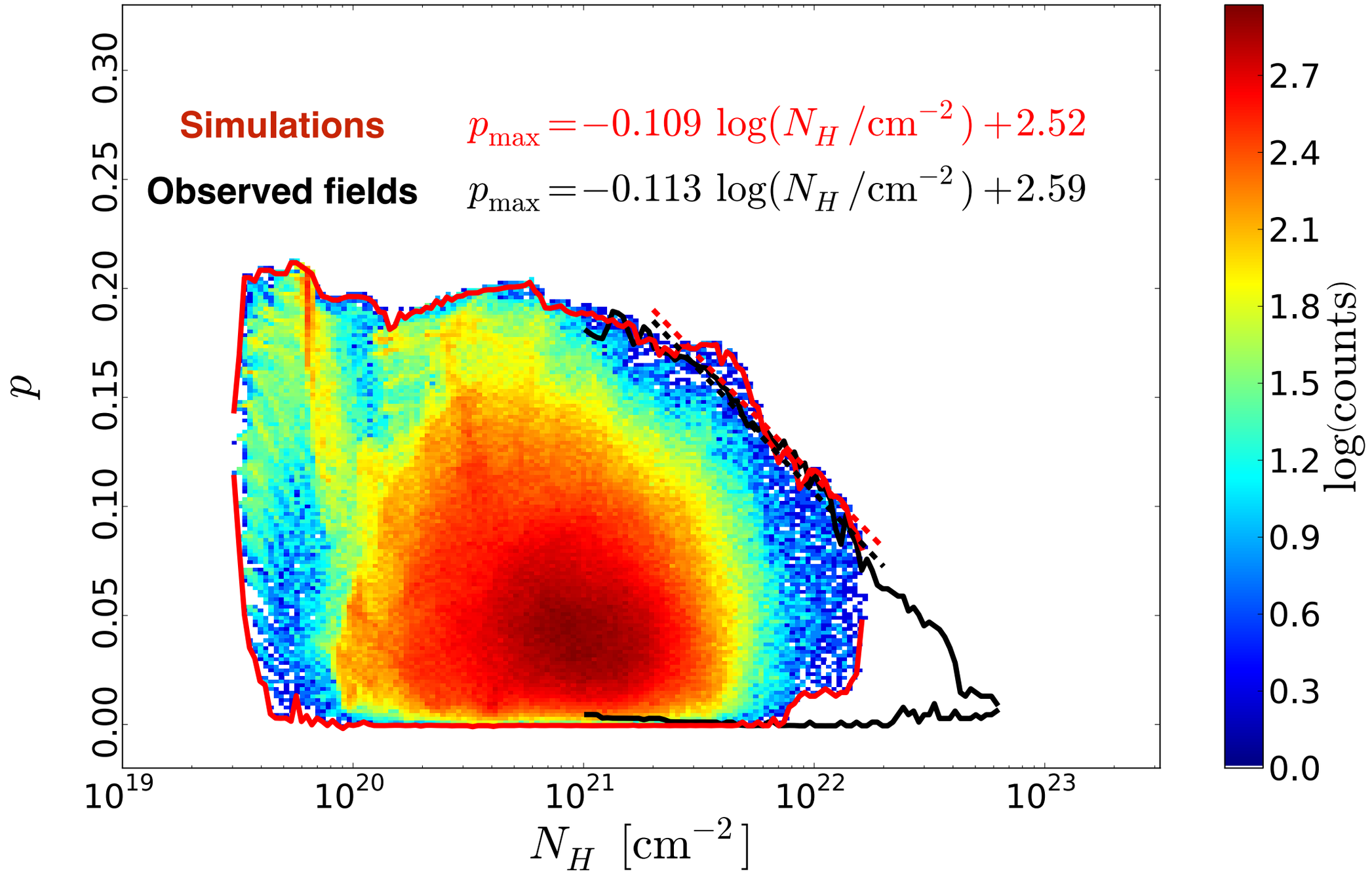


Anti-correlation p and $N_{\rm H}$
Anti-correlation p and $\Delta\psi$
Overall lower polarization fractions



Planck intermediate results. XX.

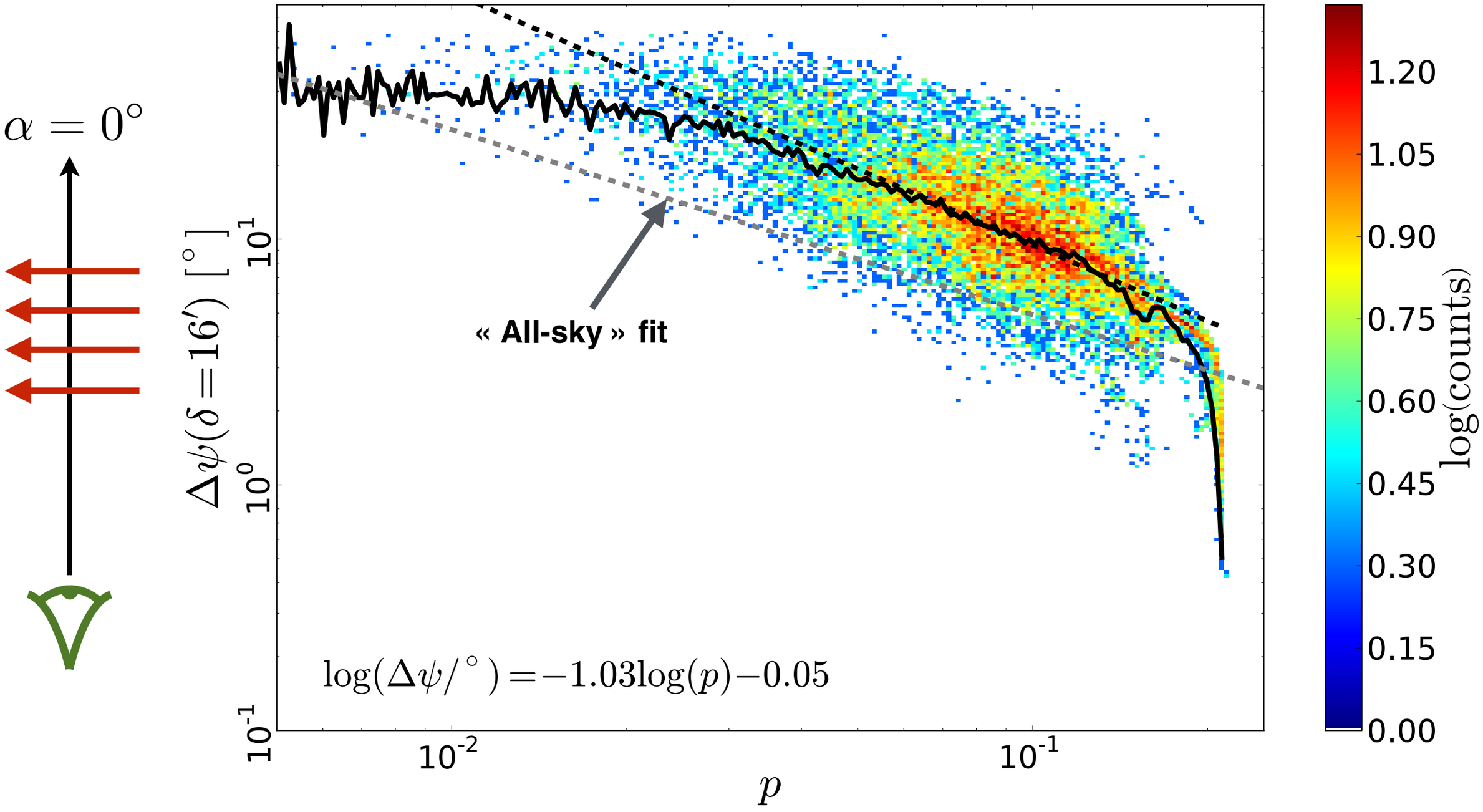
Polarization fraction versus column density



Simulations reproduce very well the decrease of p_{max} with N_H in the range 10^{21} to 2×10^{22} cm^{-2}

Planck intermediate results. XX.

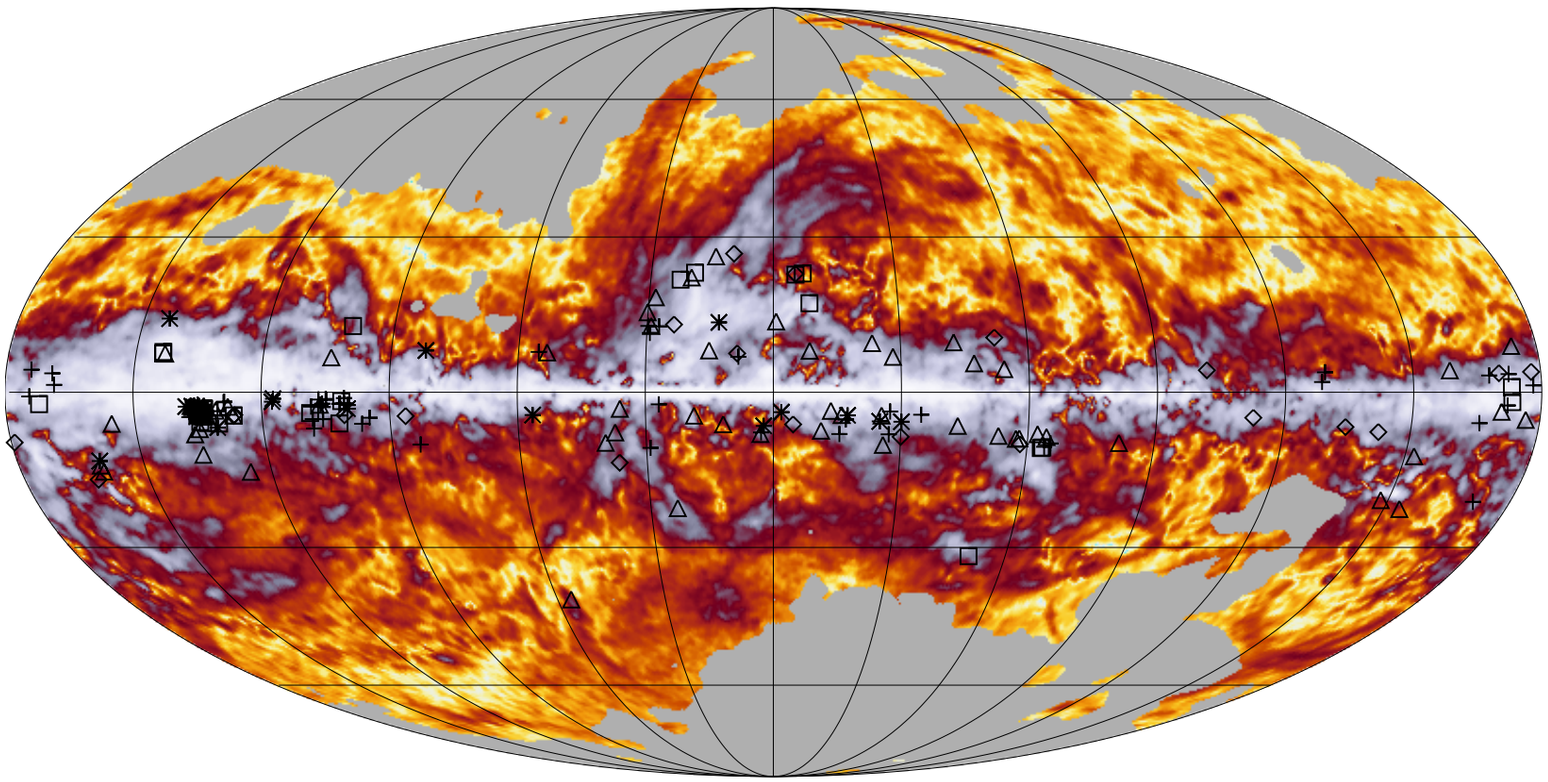
Polarization fraction and angle dispersion



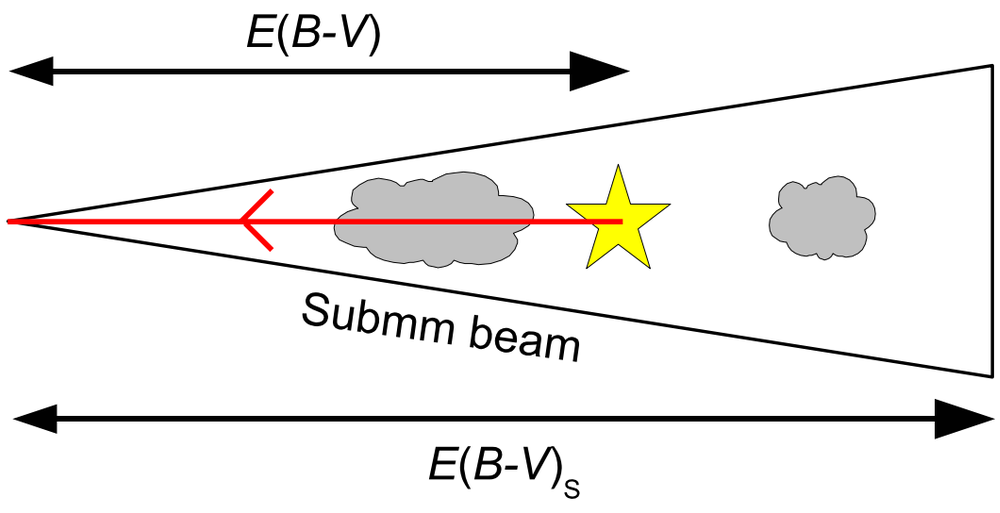
Global trend is reproduced, but simulations tend to have too high an angular dispersion

Planck intermediate results. XX.

Comparison with polarization in extinction

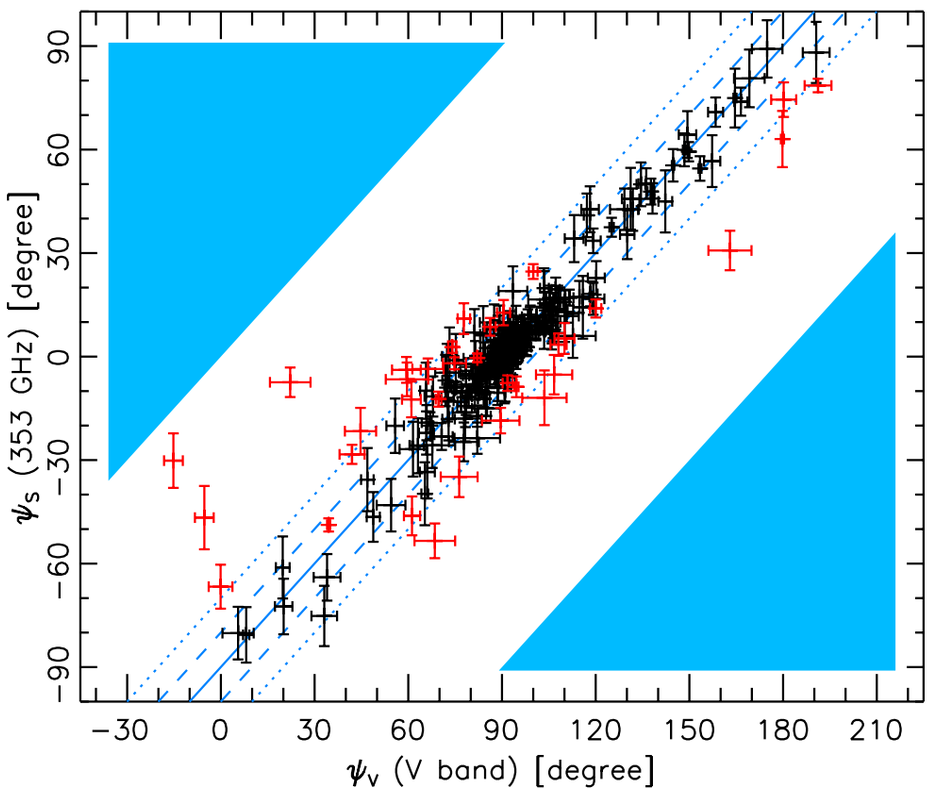


Selection of 215 stars with optical polarization measurements with consistent polarization angles and column densities

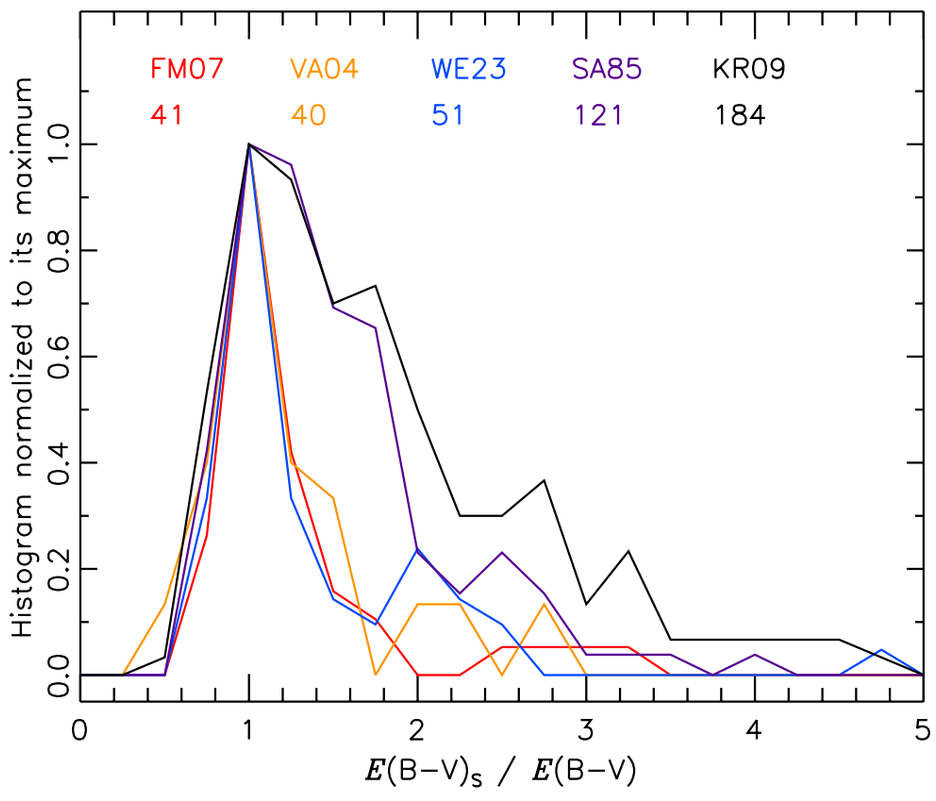


Planck intermediate results. XXI.

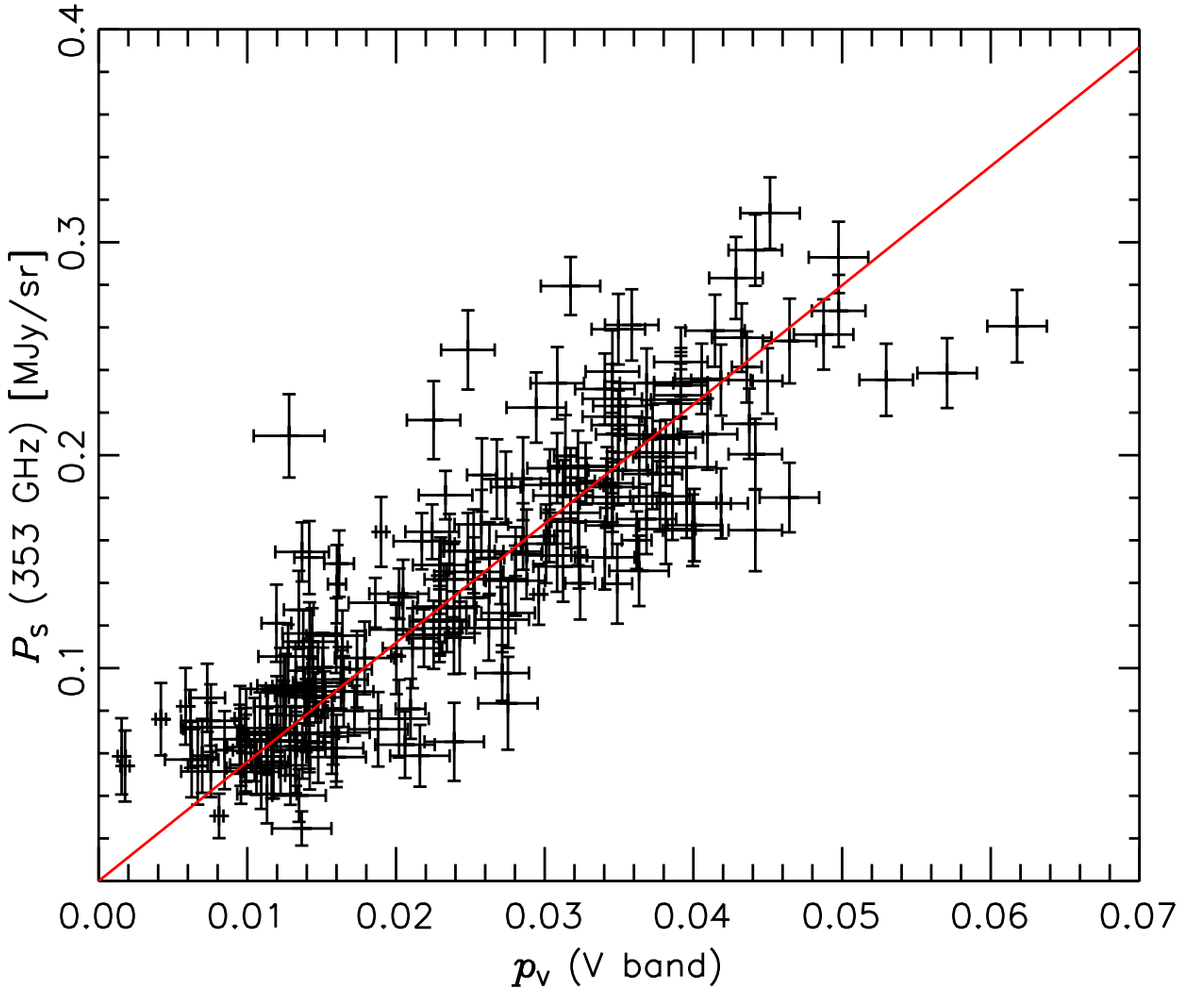
Selection on angle consistency

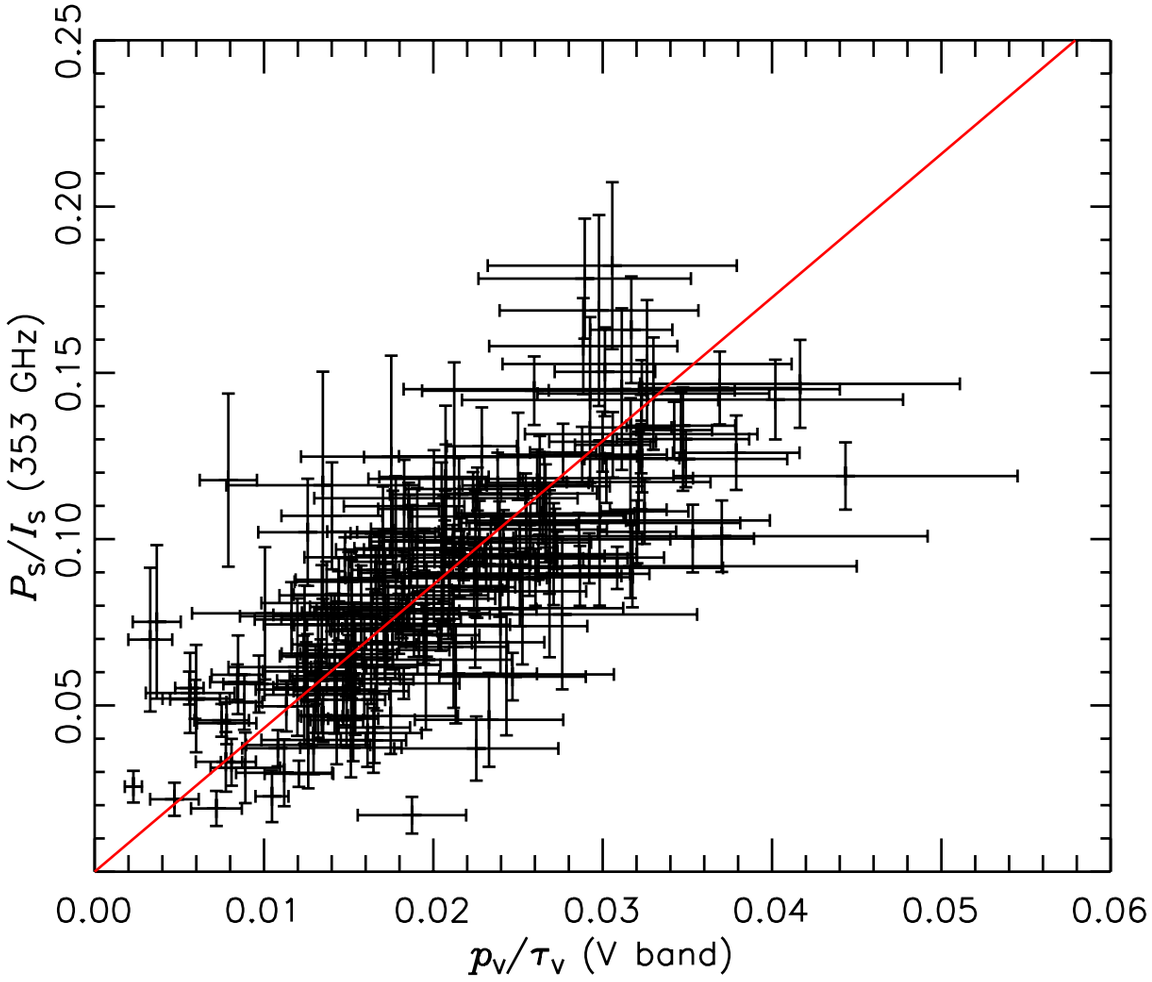


Selection on reddening ratio



Comparison with polarization in extinction





$$R_{S/V} = \frac{P_S/I_S}{p_V/\tau_V} = 4.3 \pm 0.2 \pm 0.4$$

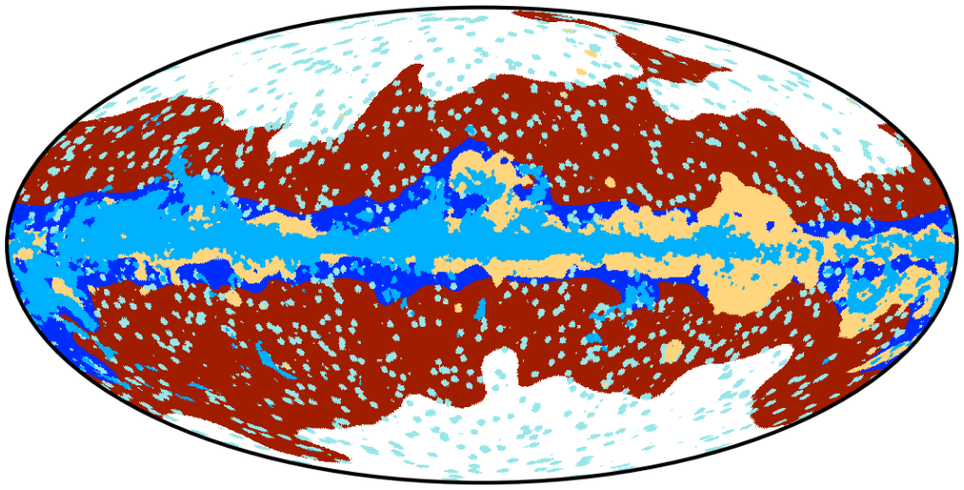
- **Reasonably compatible with current dust models**
- **Not very discriminating**

$$R_{P/p} = \frac{P_S}{p_V} = 5.6 \pm 0.2 \pm 0.4\,\mathrm{MJy\,sr^{-1}}$$

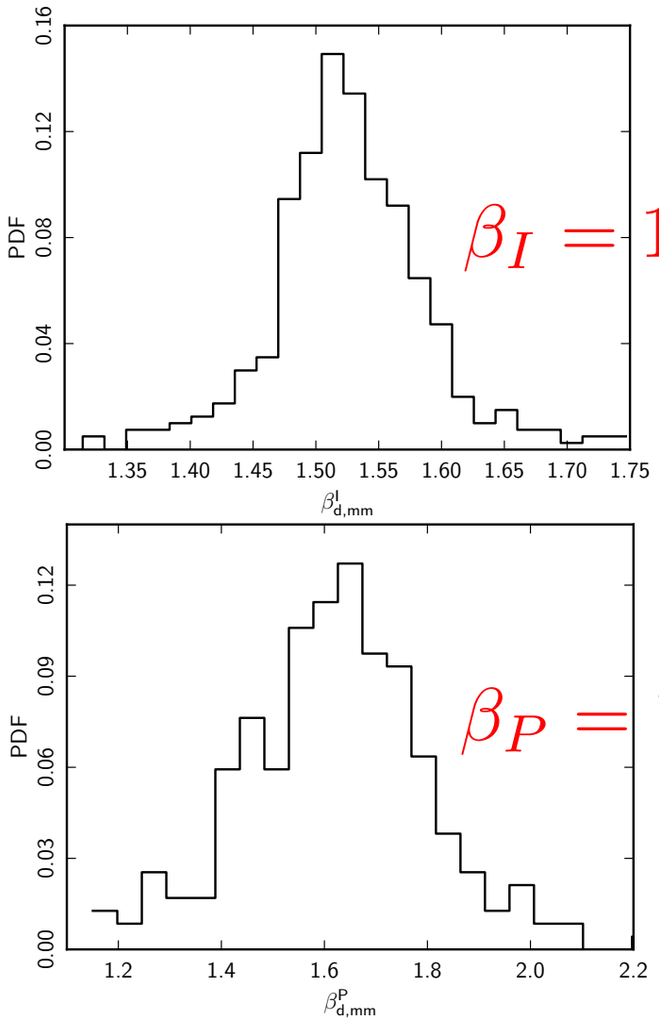
- **Much more discriminating diagnostic**
- **Current dust models predict a value lower by a factor 2.5**

Planck intermediate results. XXI.

Frequency dependence

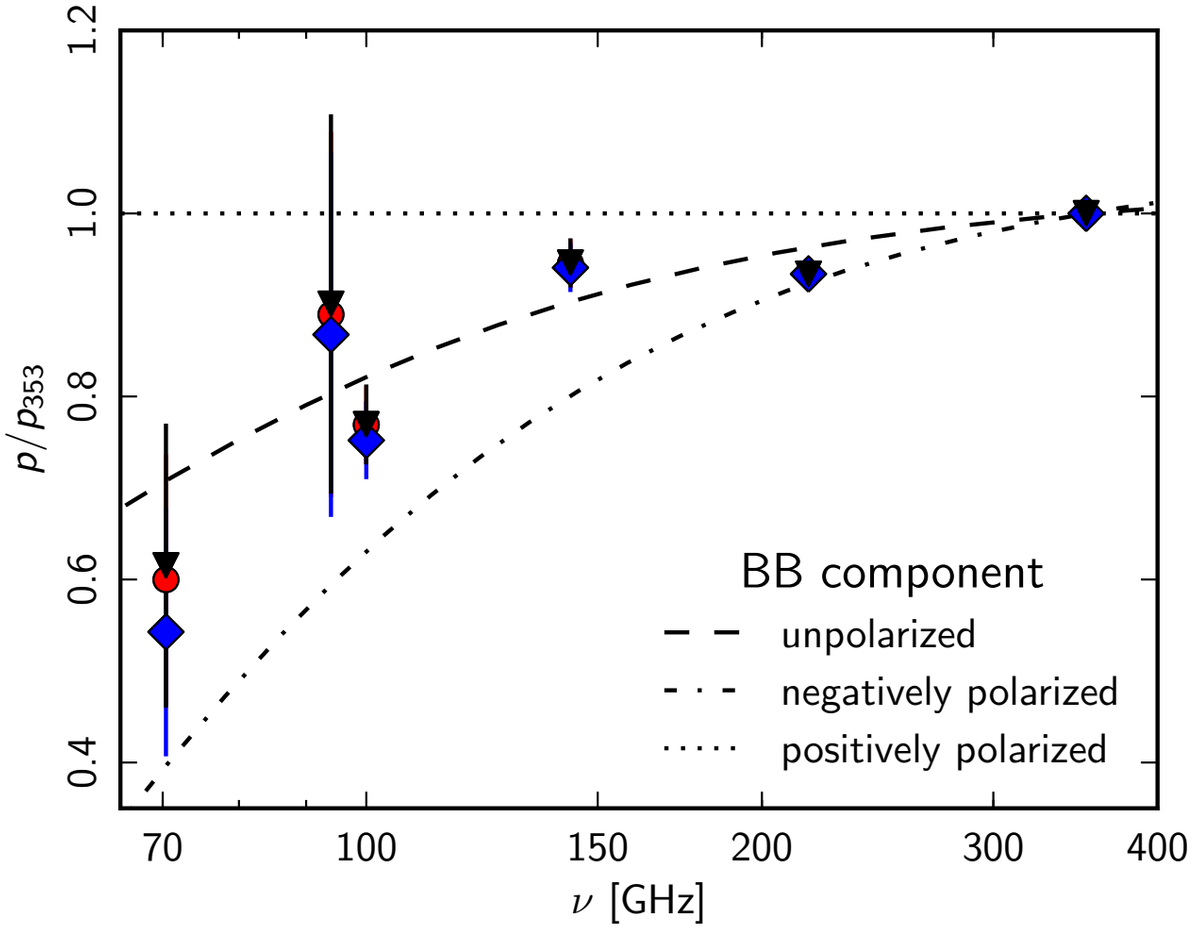


- 353 GHz maps of Stokes I, Q, U used as dust emission templates
- Cross-correlation with Stokes I, Q, U maps from 23 GHz (WMAP) to 353 GHz at intermediate latitudes
- Determination of 100-353 GHz spectral indices in total intensity and polarization over 10° radius patches



$$\beta_I = 1.52 \pm 0.02$$

$$\beta_P = 1.63 \pm 0.03$$



Decrease of polarization fraction by about 30% from 353 GHz to 70 GHz : Constraints on dust models

Planck intermediate results. XXII.

Conclusions

Take home messages

- **Intrinsic polarization fraction of dust > 20%**
- **Decrease of p with N_H well reproduced by simulations**
- **Anticorrelation between polarization fraction and angle dispersion underlines the role of the magnetic field**
- **Comparison with polarization in extinction and frequency dependence are constraints for necessary future dust models**
- **Data to be released in the fall**

What remains to be done…

- **High latitude diffuse sky, including the BICEP2 field**
- **High column-density lines of sight (cold cores)**