Polarized thermal dust emission as seen by Planck :
A comparison with MHD simulations and lessons from a toy model

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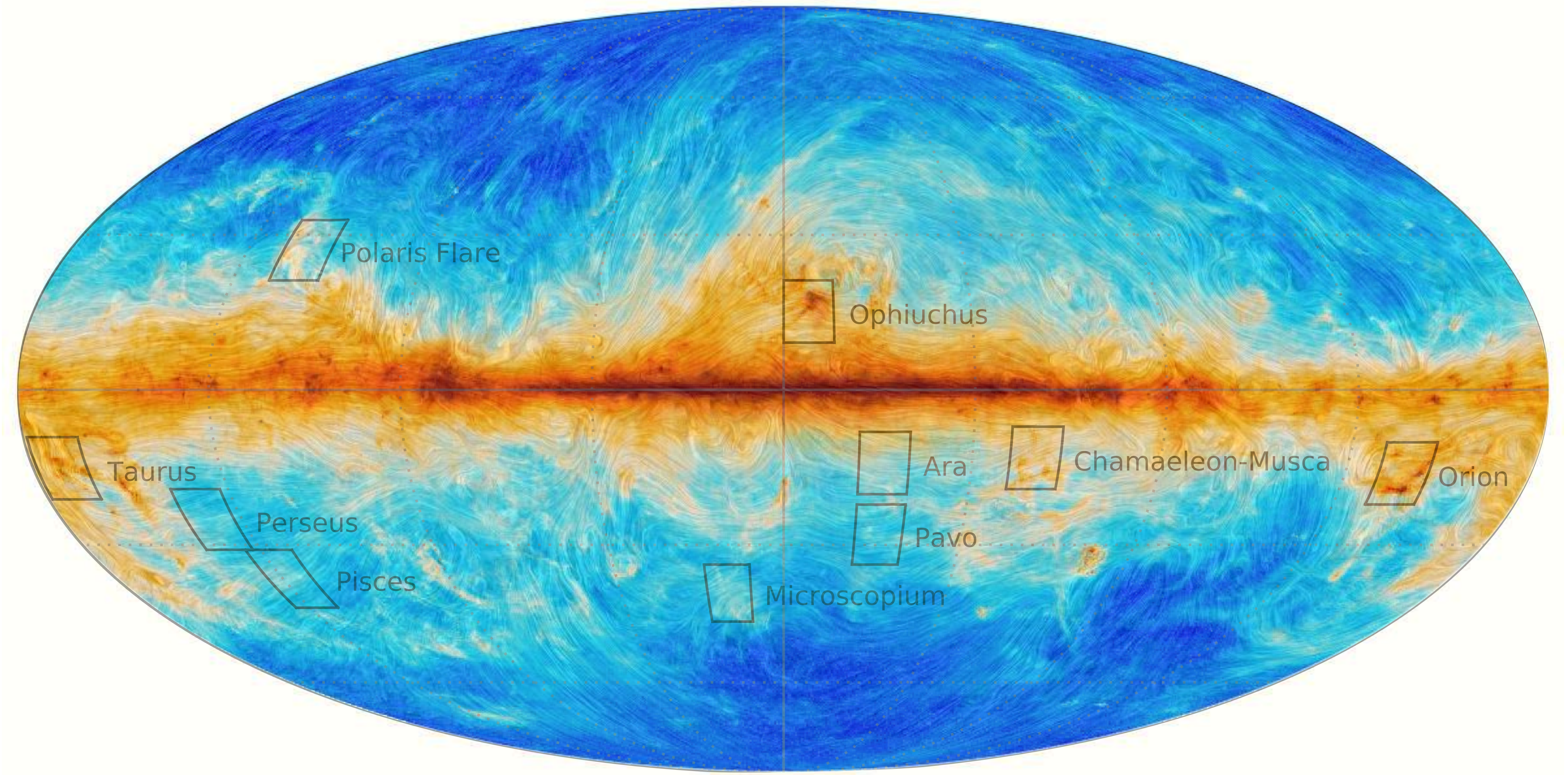
LERMA, Observatoire de Paris, PSL, CNRS, UPMC, ENS Paris

Planck intermediate results. XX.
A&A, 576, 105, 2015



esa

planck

cnes

asi agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

INAF ISTITUTO NAZIONALE DI ASTROFISICA

HFI PLANCK
a look back to the birth of Universe

PLANCK LFI

Science & Technology Facilities Council

CSIC
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IAS orsay

IAP

INAF - IASF BO
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CSA ASC

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

UK SPACE AGENCY

MAX-PLANCK-GESELLSCHAFT

Aalto University

APC

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

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INSTITUTO DE ASTROFISICA DE 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

LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

l'Observatoire de Paris — LERMA

LPSC Grenoble Laboratoire de Physique Subatomique et de Cosmologie

MANCHESTER 1824 The University of Manchester

MilliLab

Max-Planck-Institut für Astrophysik

NUI MAYNOOTH

INAF OSSERVATORIO ASTRONOMICO DI PADOVA

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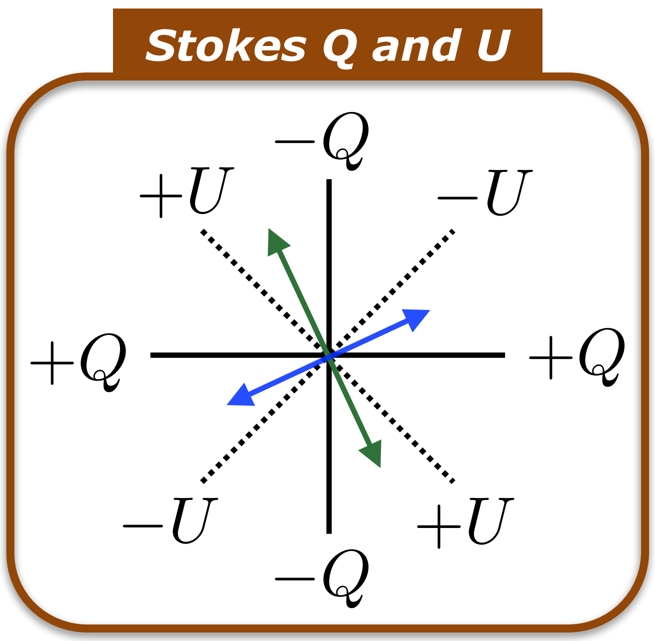
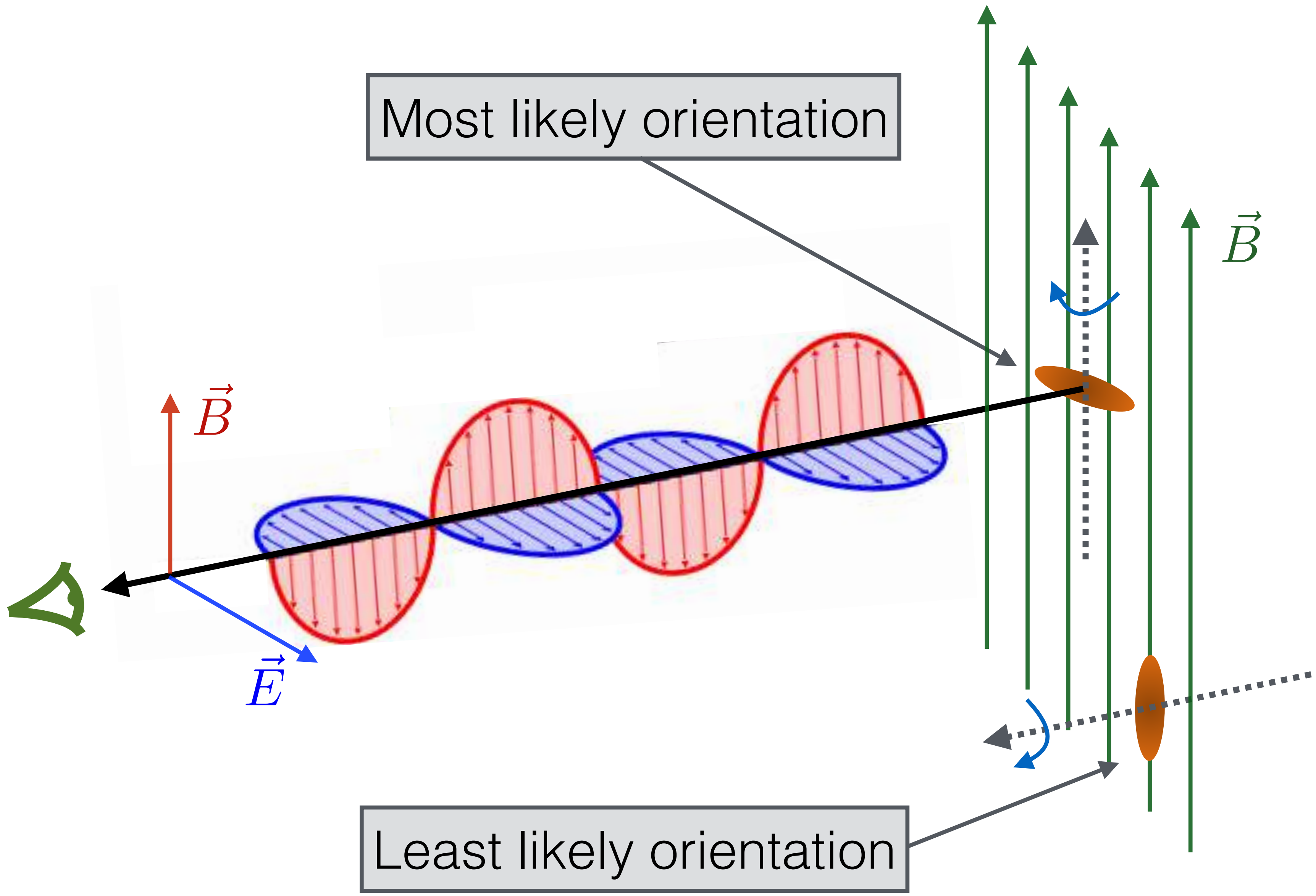
asdc ASI Science Data Center

Polarized thermal dust emission essentials



Polarization orientation
Magnetic field orientation

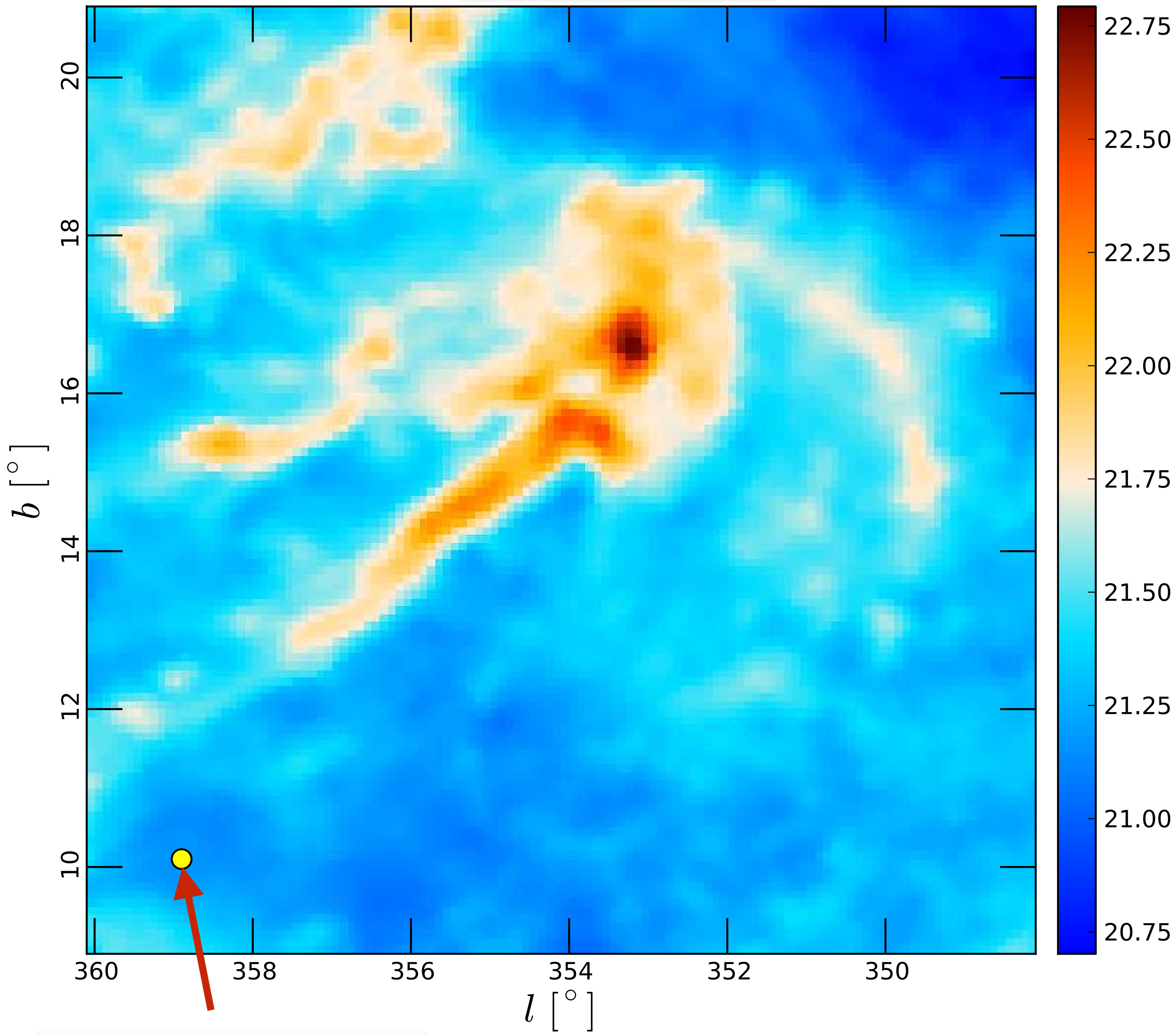


- Grains are aspherical, charged, rotating, and aligned preferentially perpendicularly to the local magnetic field
- Cross sections are proportional to the size, so grains emit more radiation parallel to their long axes
- Polarized thermal emission arises, with an orientation perpendicular to the local magnetic field

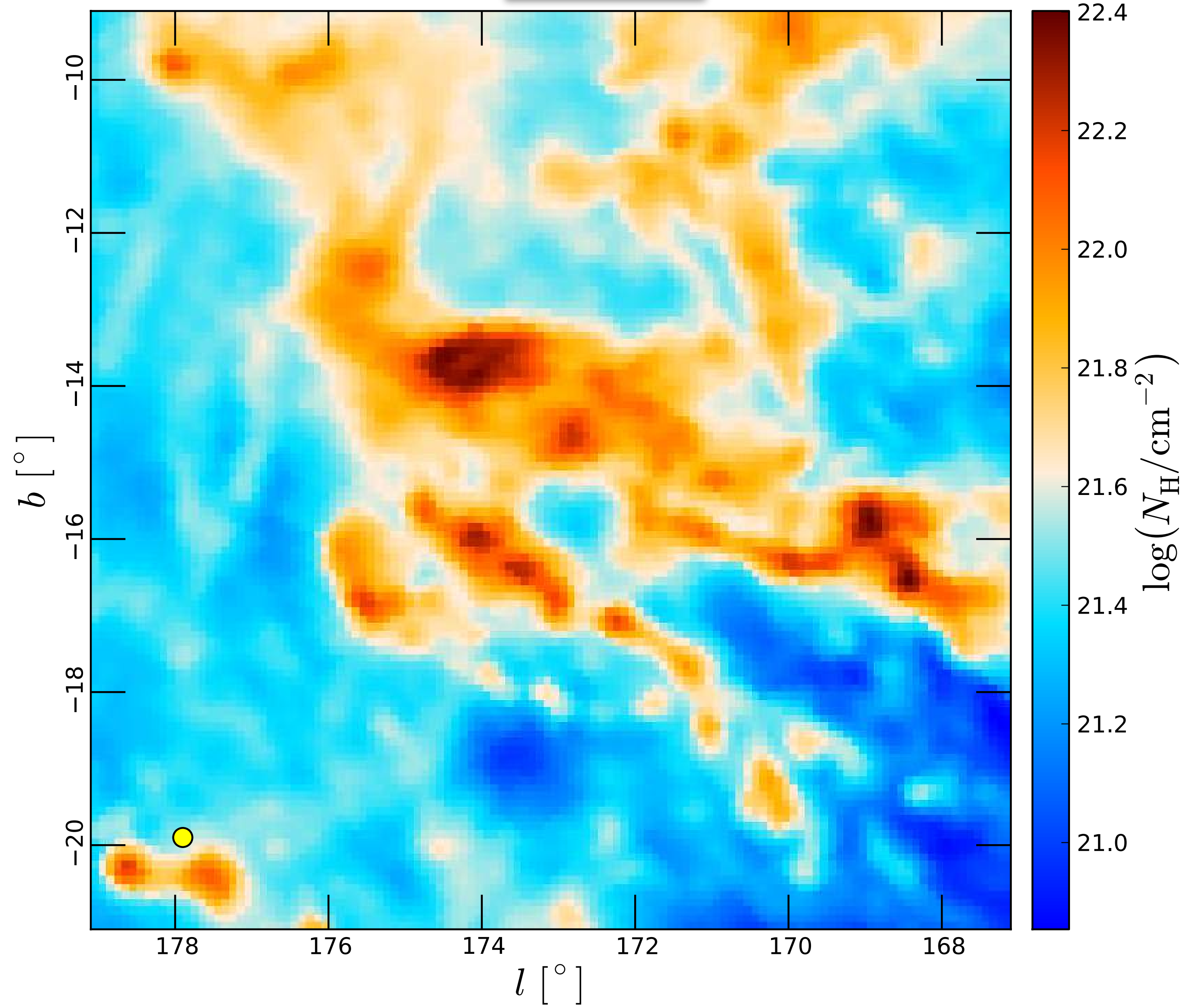
See talk by J.-P. Bernard, this session

Planck maps of nearby molecular clouds

Ophiuchus

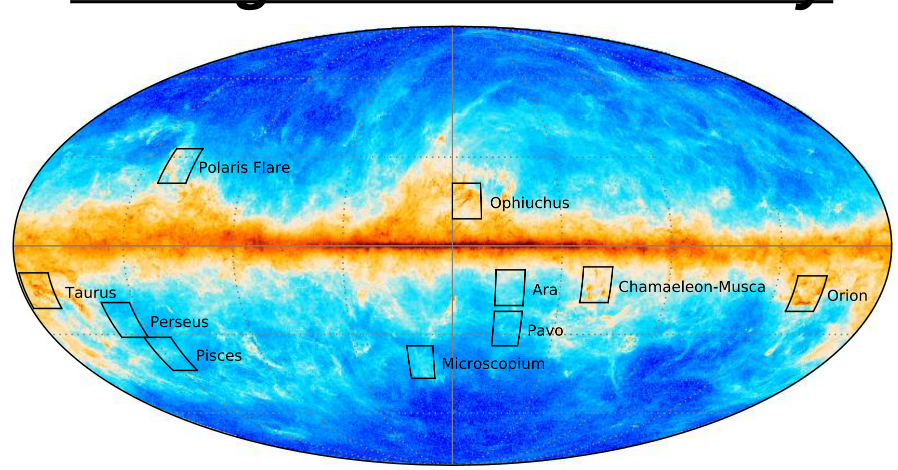


Taurus



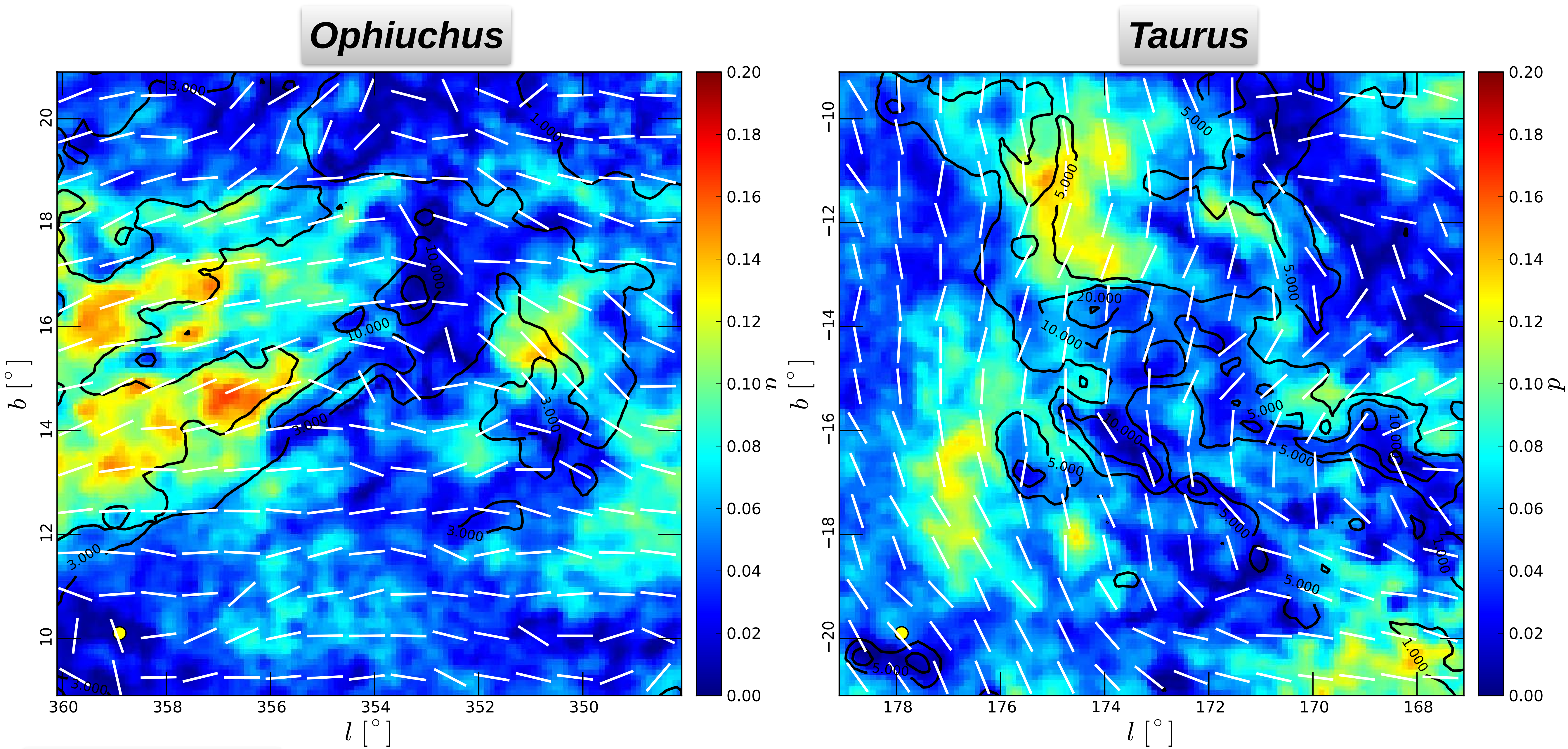
15’ resolution

Total gas column density



Planck 2013 results. XI.
A&A, 571, 11, 2014

Planck maps of nearby molecular clouds



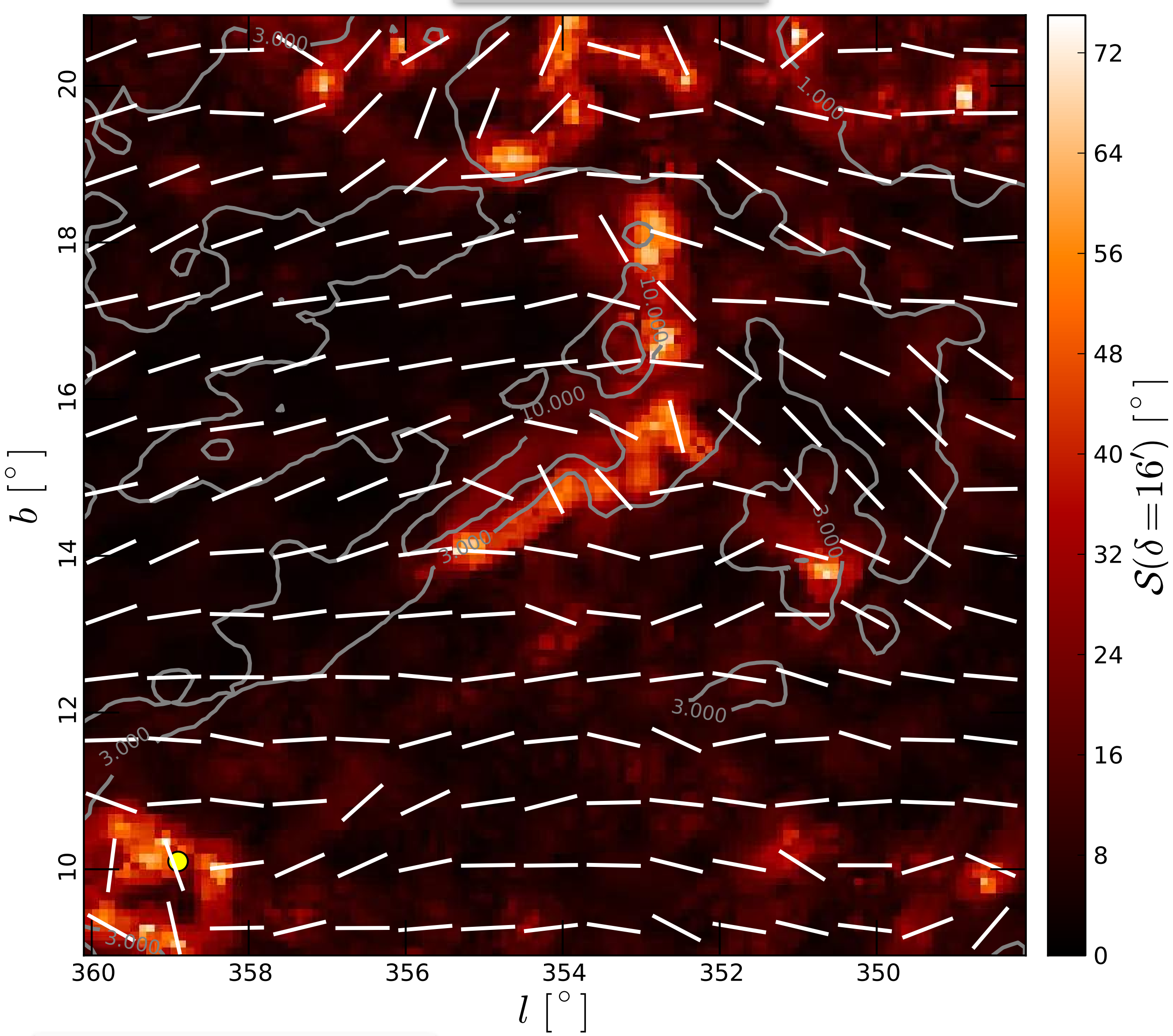
15' resolution

Polarization fraction

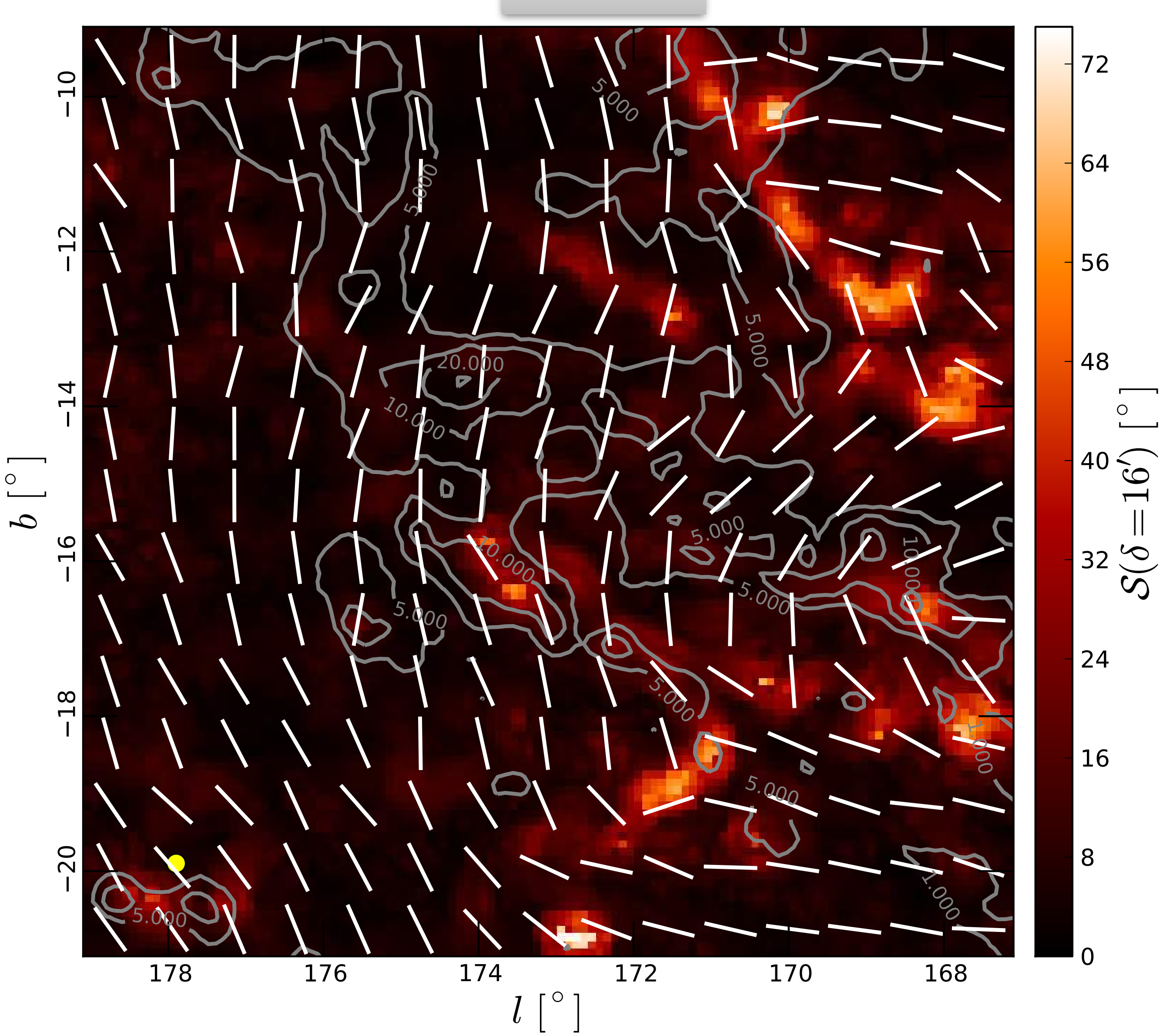
$$p = \frac{\sqrt{Q^2 + U^2}}{I}$$

Planck maps of nearby molecular clouds

Ophiuchus



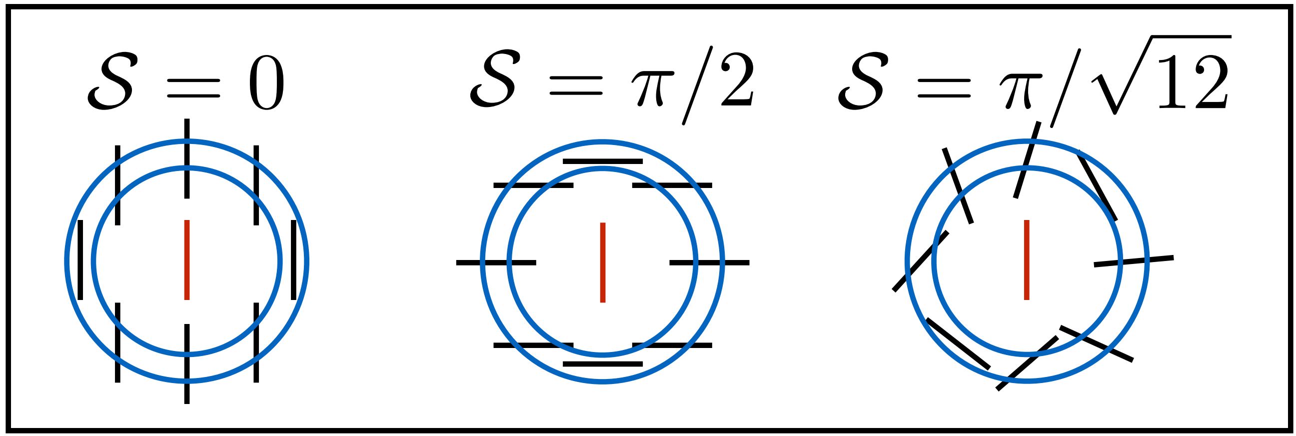
Taurus



15’ resolution
16’ lag

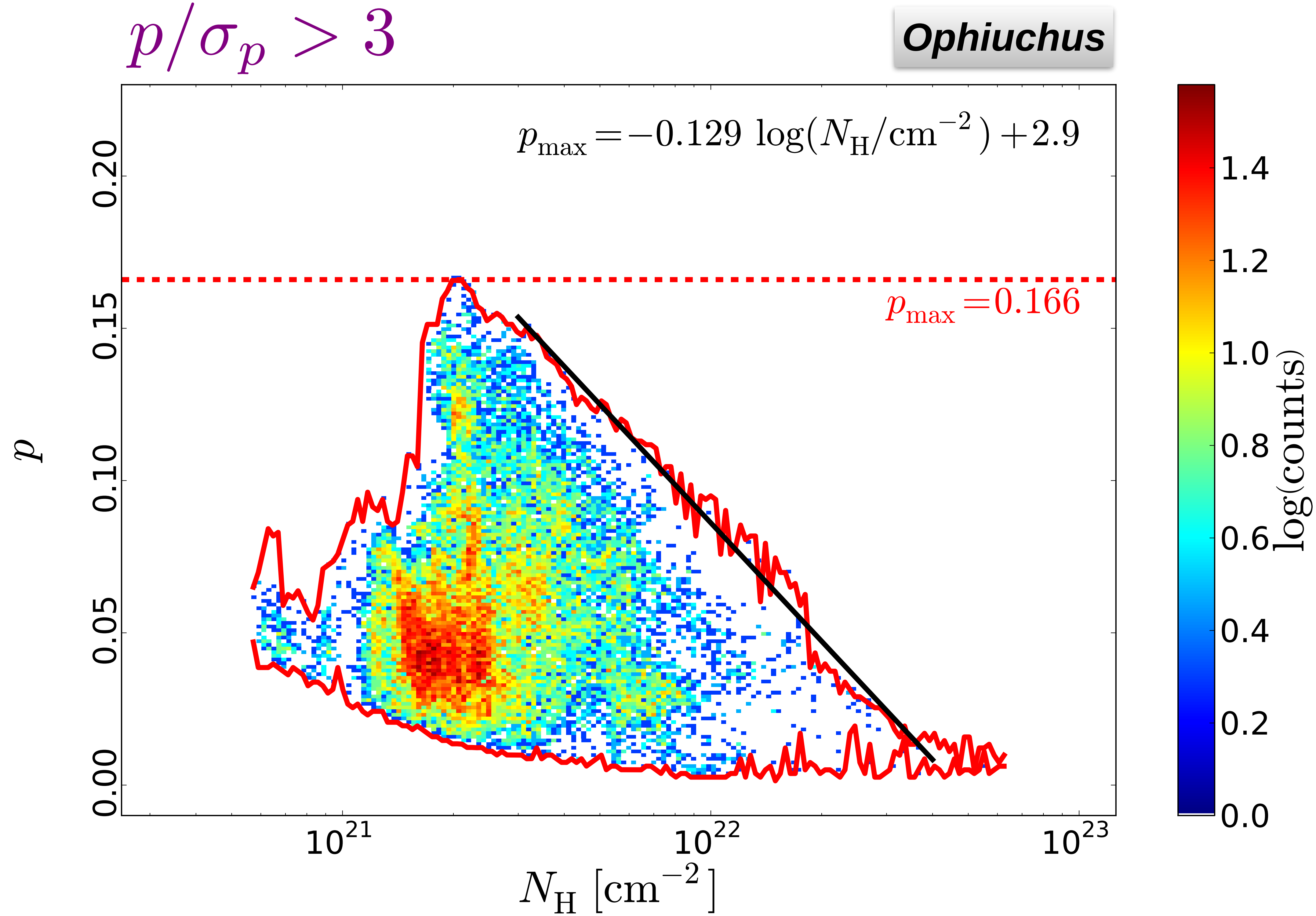
Polarization angle dispersion function

$$\mathcal{S}(\boldsymbol{r}, \delta) = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[\psi(\boldsymbol{r} + \boldsymbol{\delta}_i) - \psi(\boldsymbol{r})\right]^2}$$



Correlations in Planck polarization maps

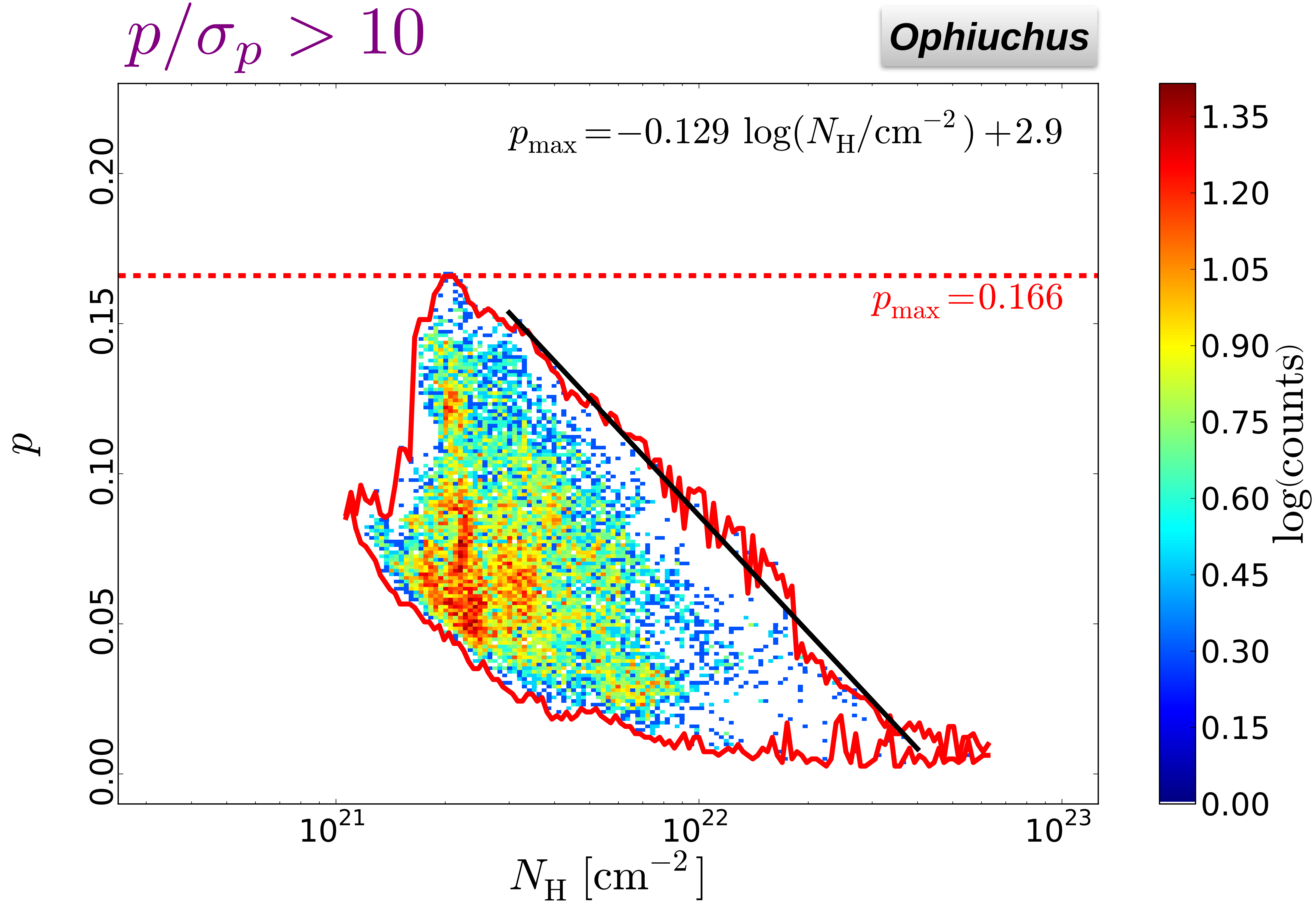
$p/\sigma_p > 3$



Anti-correlation robust with respect to polarization S/N

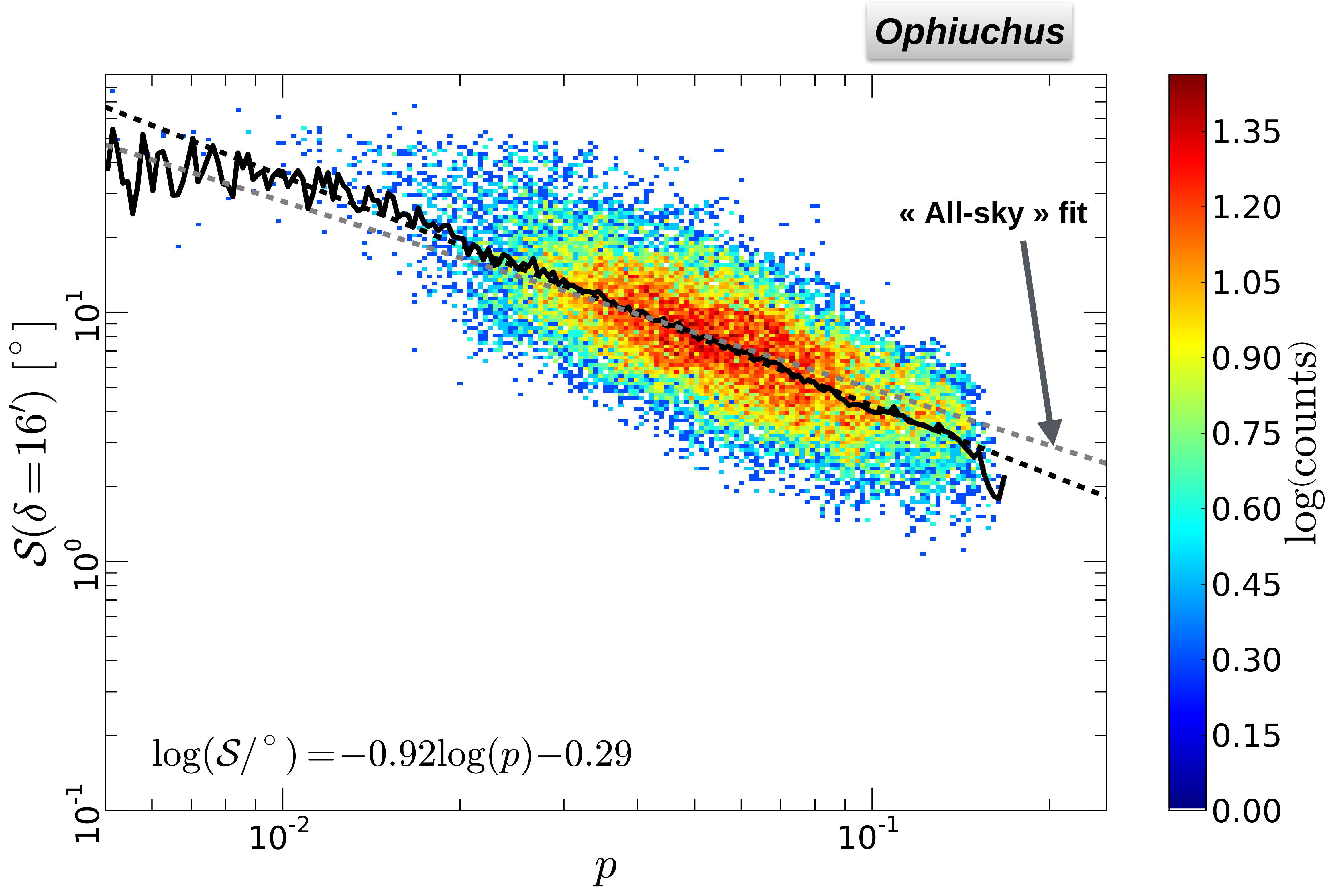
Correlations in Planck polarization maps

$p/\sigma_p > 10$



Anti-correlation robust with respect to polarization S/N

Correlations in Planck polarization maps



Planck intermediate results. XIX.
A&A, 576, 104, 2015

Building simulated polarized emission maps

- 18 pc subset of a 50 pc MHD simulation cube
- Converging flows of magnetized warm gas
- Mean magnetic field along the flows
- Rotation of the cube, placed at 100 pc
- Simulated Stokes maps smoothed at 15'

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

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

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

« Intrinsic dust polarization parameter »

$$p_0 = 0.2$$

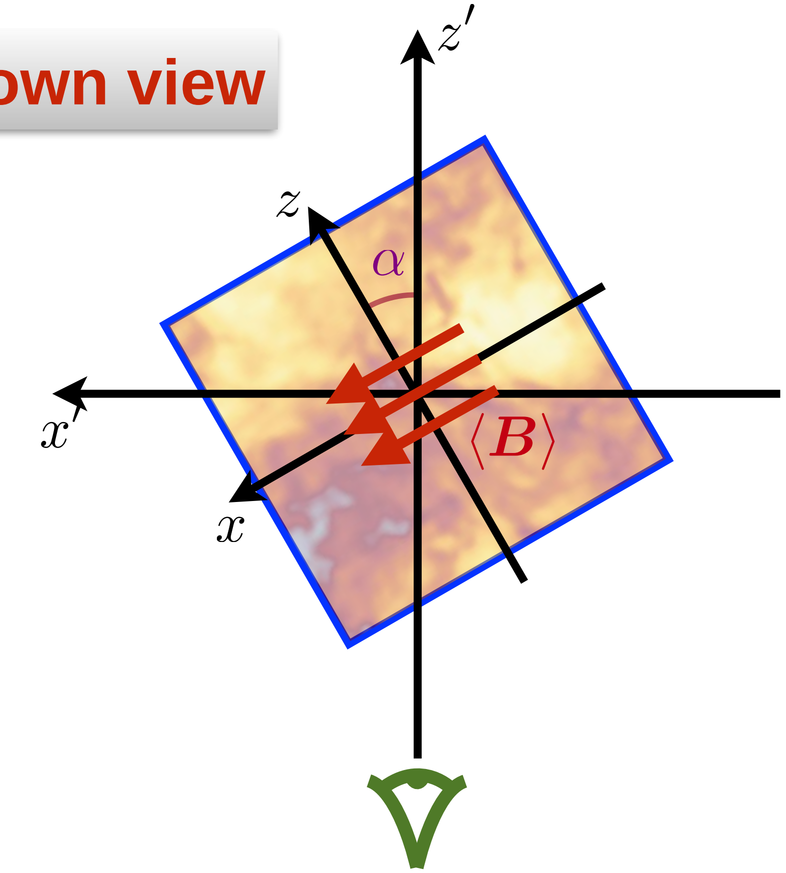
Opacity at 353 GHz (Planck Collaboration XXXI, 2014)

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

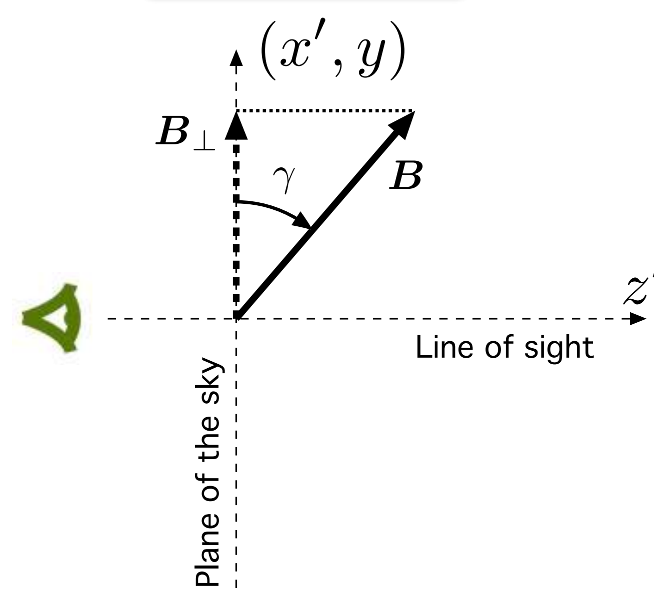
Dust temperature

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

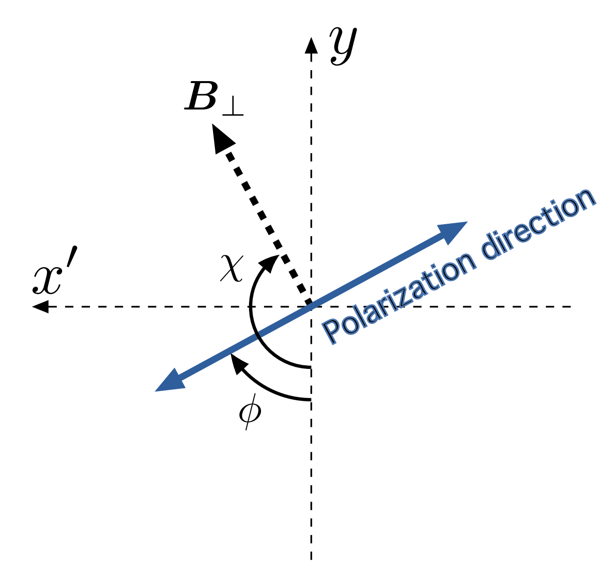
Top-down view



Side view



Line-of-sight view



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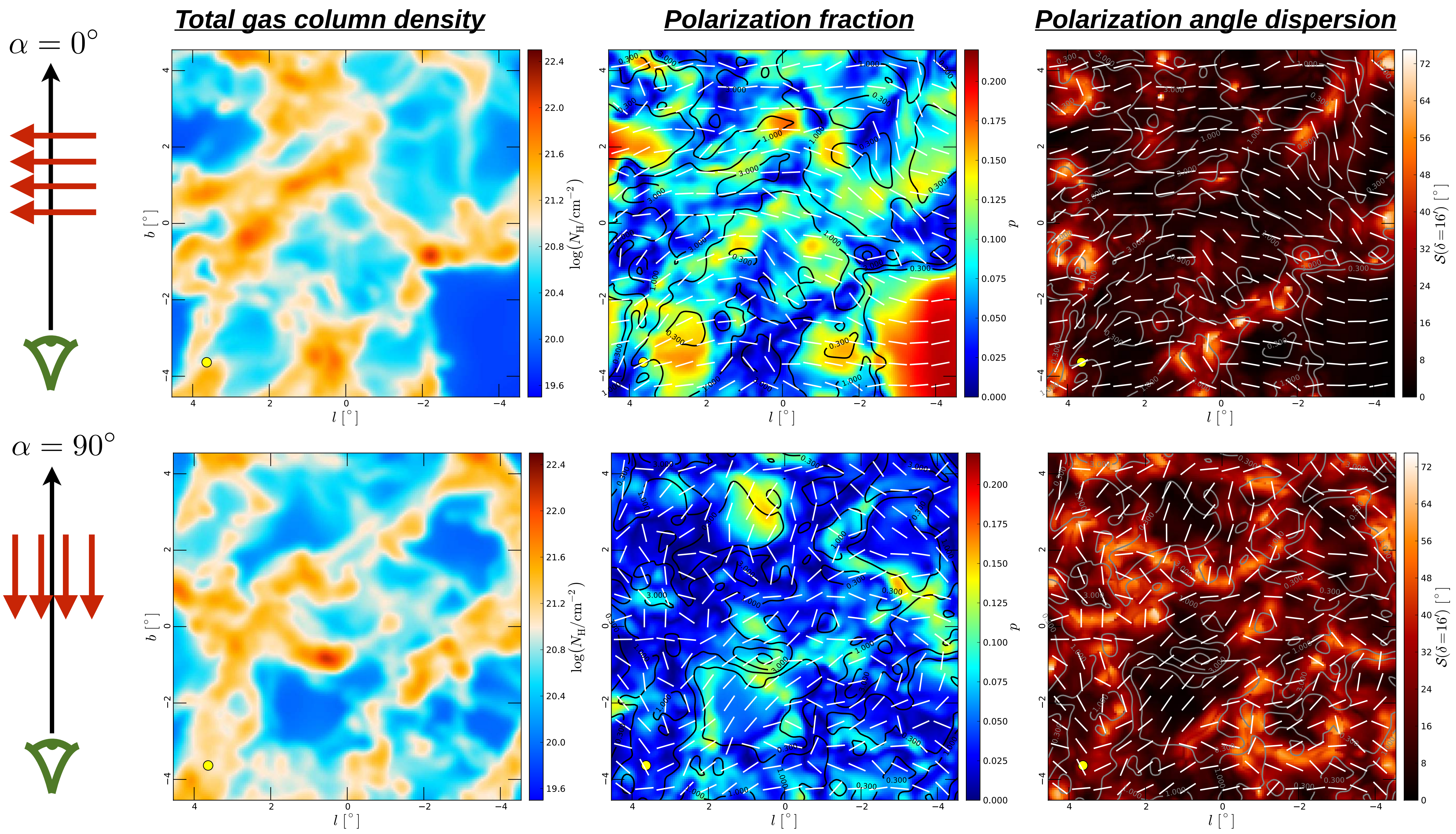
Following Lee & Draine 85 and others…

Simulated polarized thermal dust emission maps

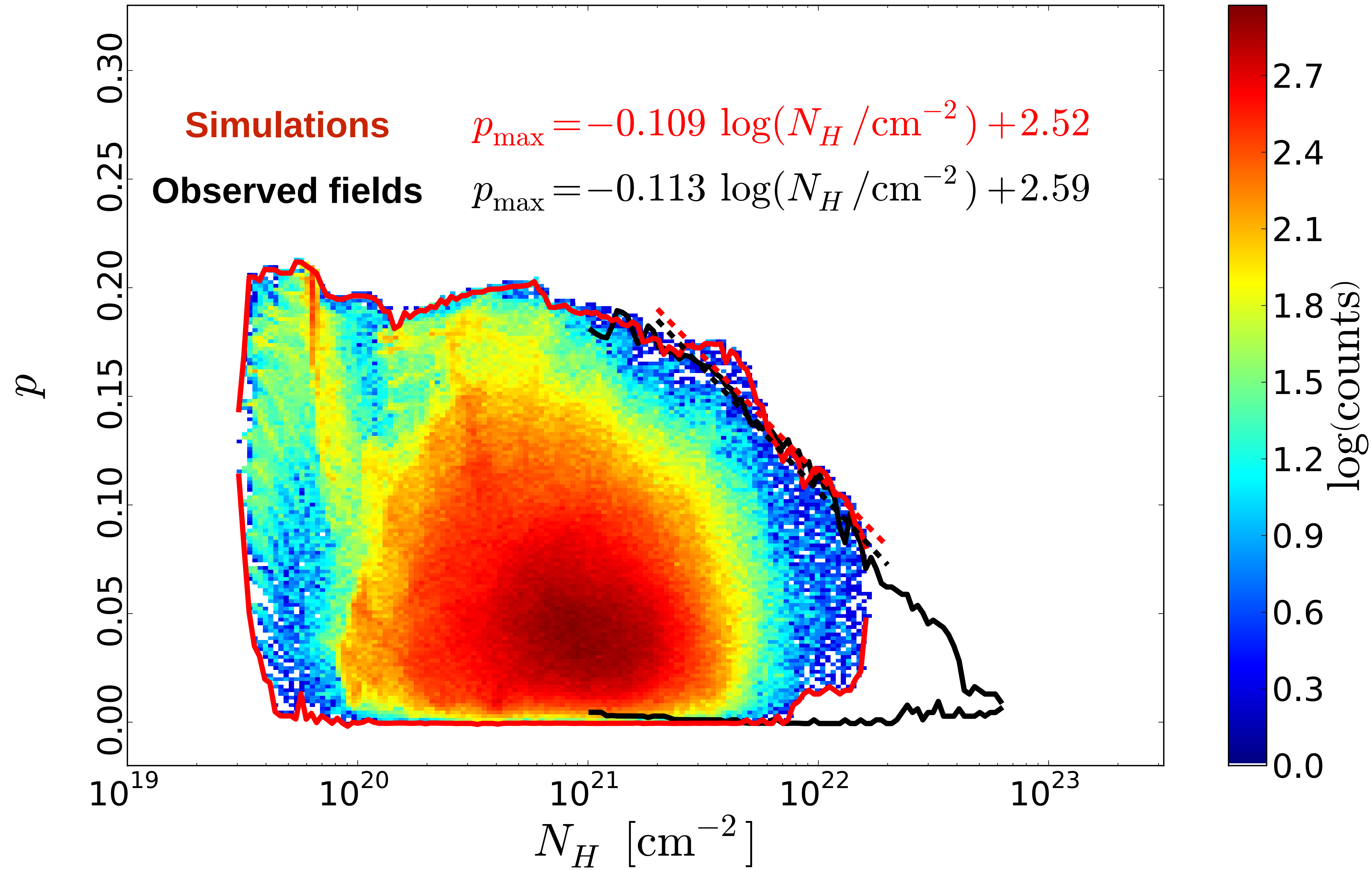


Anti-correlation p and N_{H}

Anti-correlation p and $\mathcal{S}$

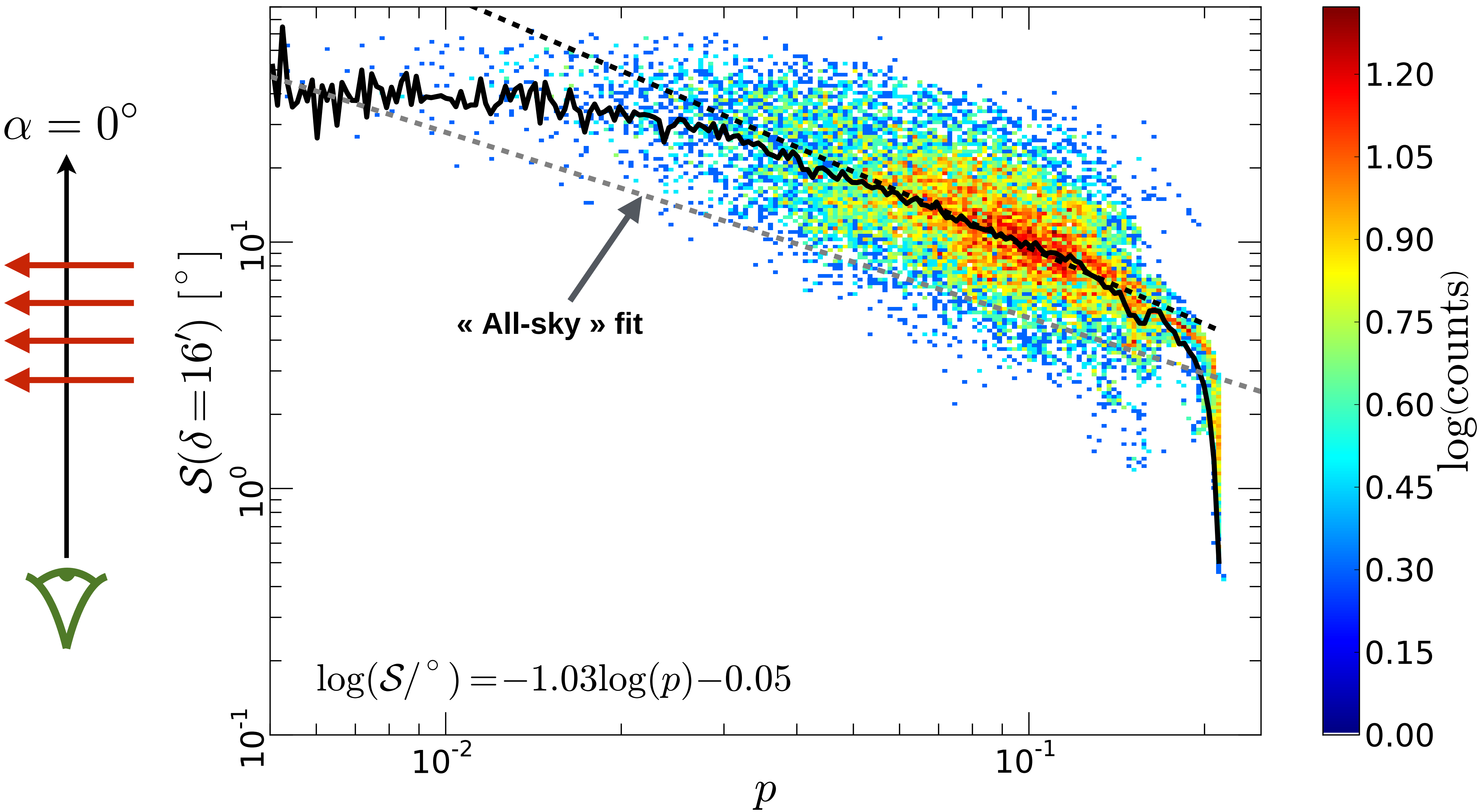
Lower polarization fractions when along the mean field

Simulations vs. Observations



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

Simulations vs. Observations



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

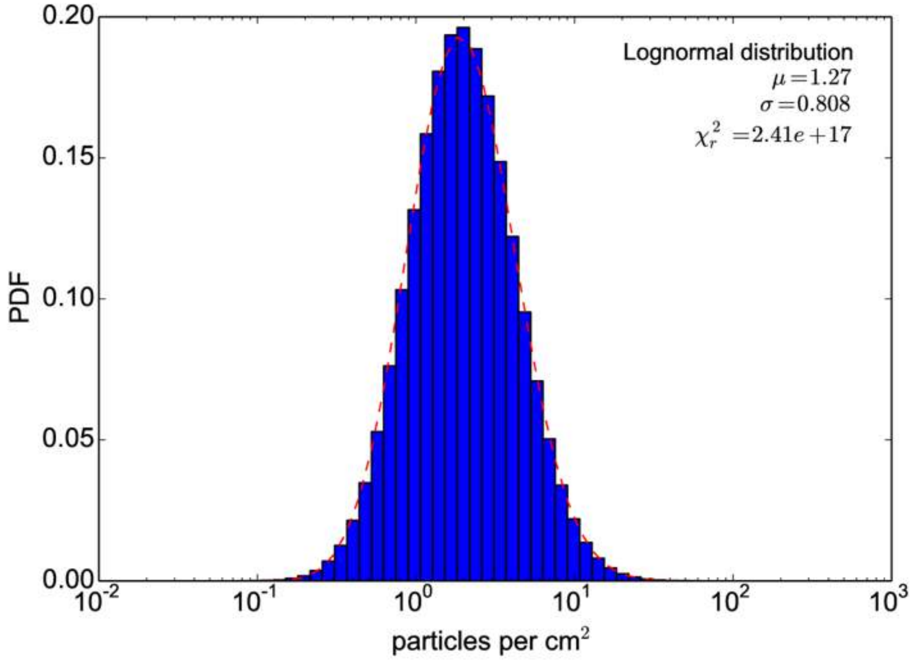
Building toy models of the turbulent ISM

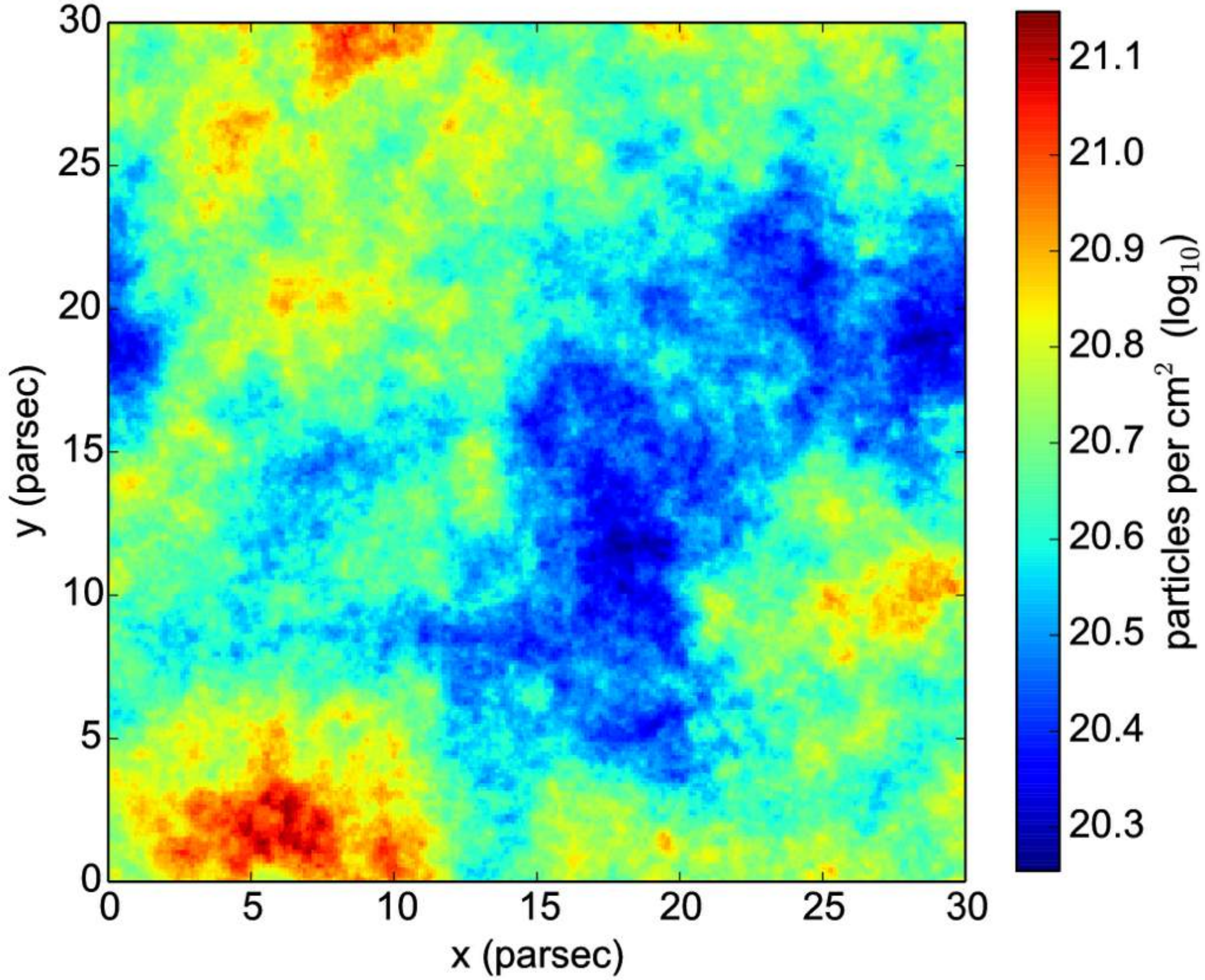
We wish to constrain the statistical properties of the interstellar B field

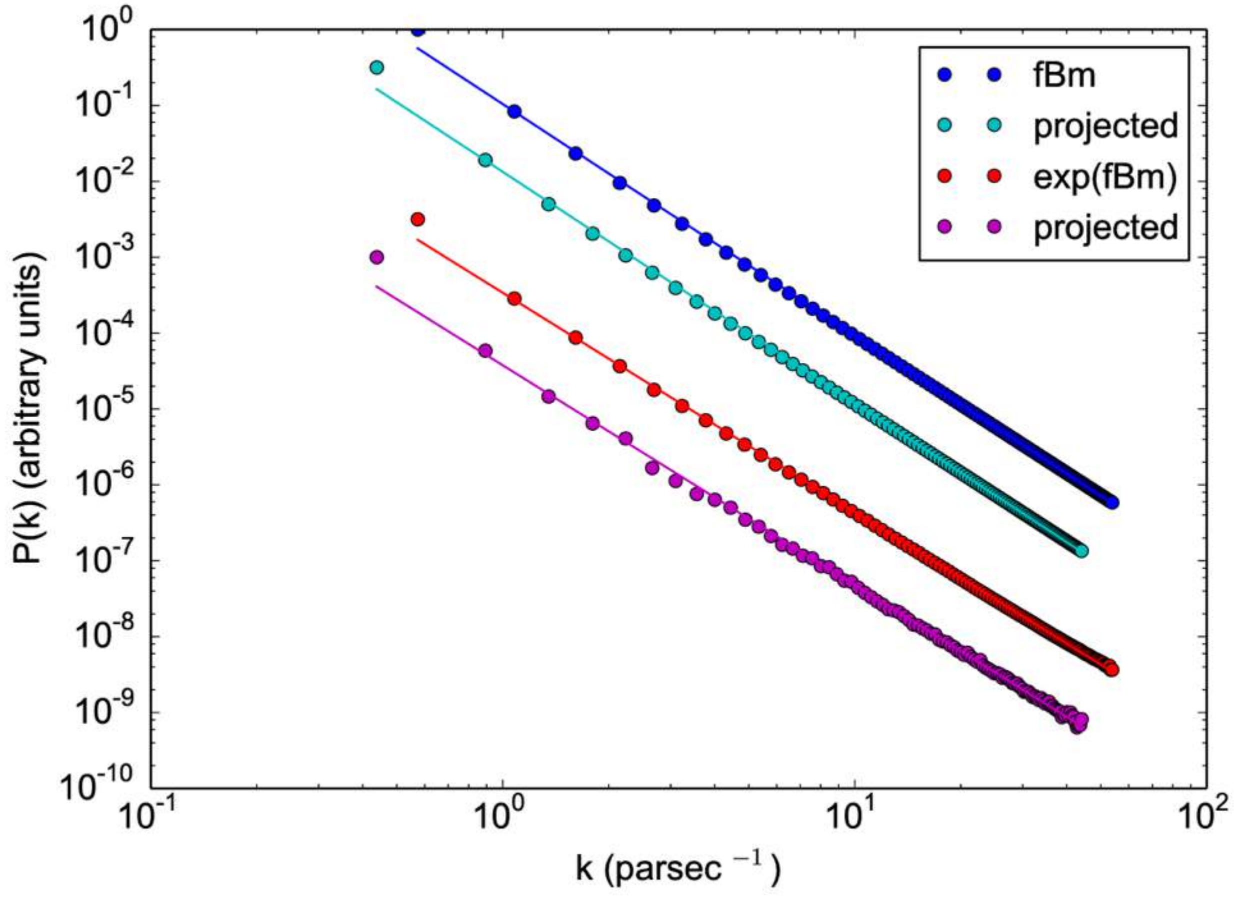
Dust density : exponentiated fractional Brownian motion field (fBm)

$$n_{\mathrm{d}} = n_0 \exp\left(\frac{X}{X_r}\right)$$

- Power-law power spectrum with index β_n
- Log-normal distribution
- Possibly large fluctuations $\frac{\sigma_n}{n_{\mathrm{d}}} > 0.3$







Building toy models of the turbulent ISM

Magnetic field from fBm vector potential components

Input Fourier phase map

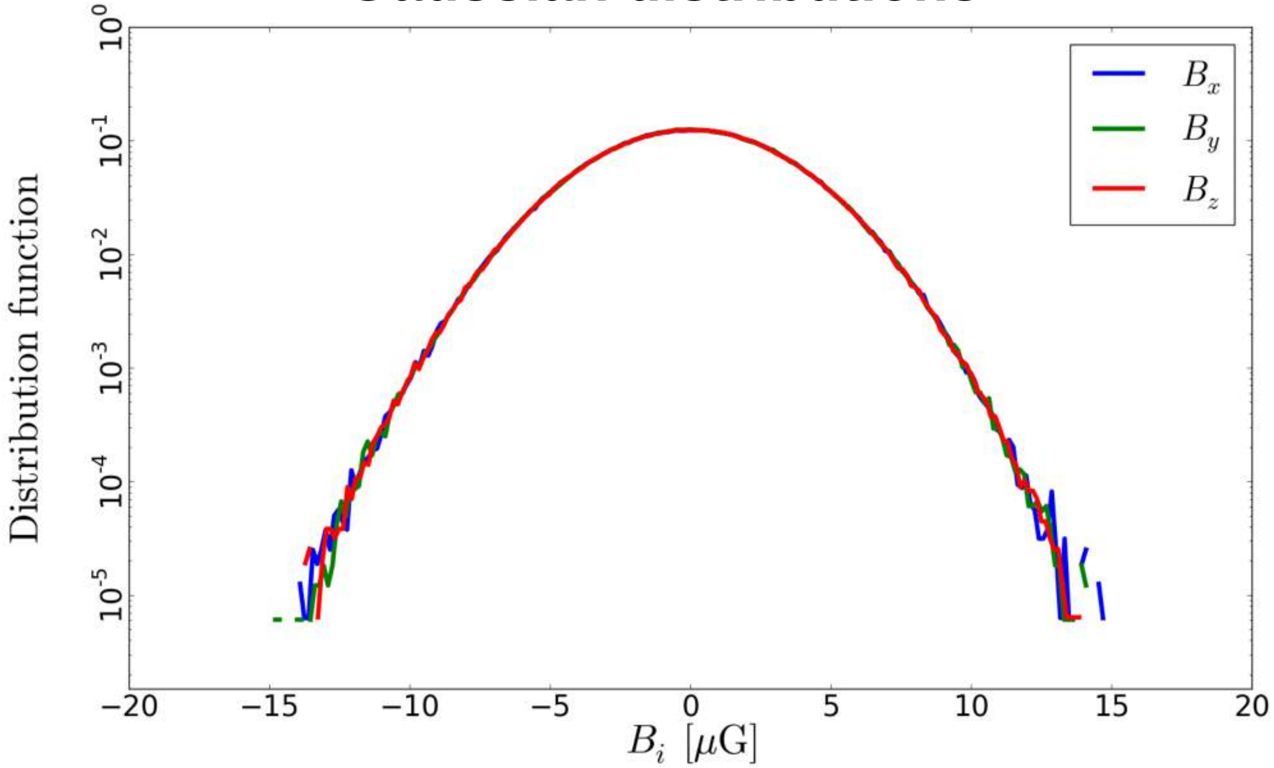
$$\widetilde{B_\lambda}(\boldsymbol{k}) = \epsilon_{\lambda\mu\nu} i k_\mu \mathcal{F}_0 |\boldsymbol{k}|^{-\beta_A/2} \exp\left[i\phi_{A_\nu}(\boldsymbol{k})\right]$$

Input spectral index

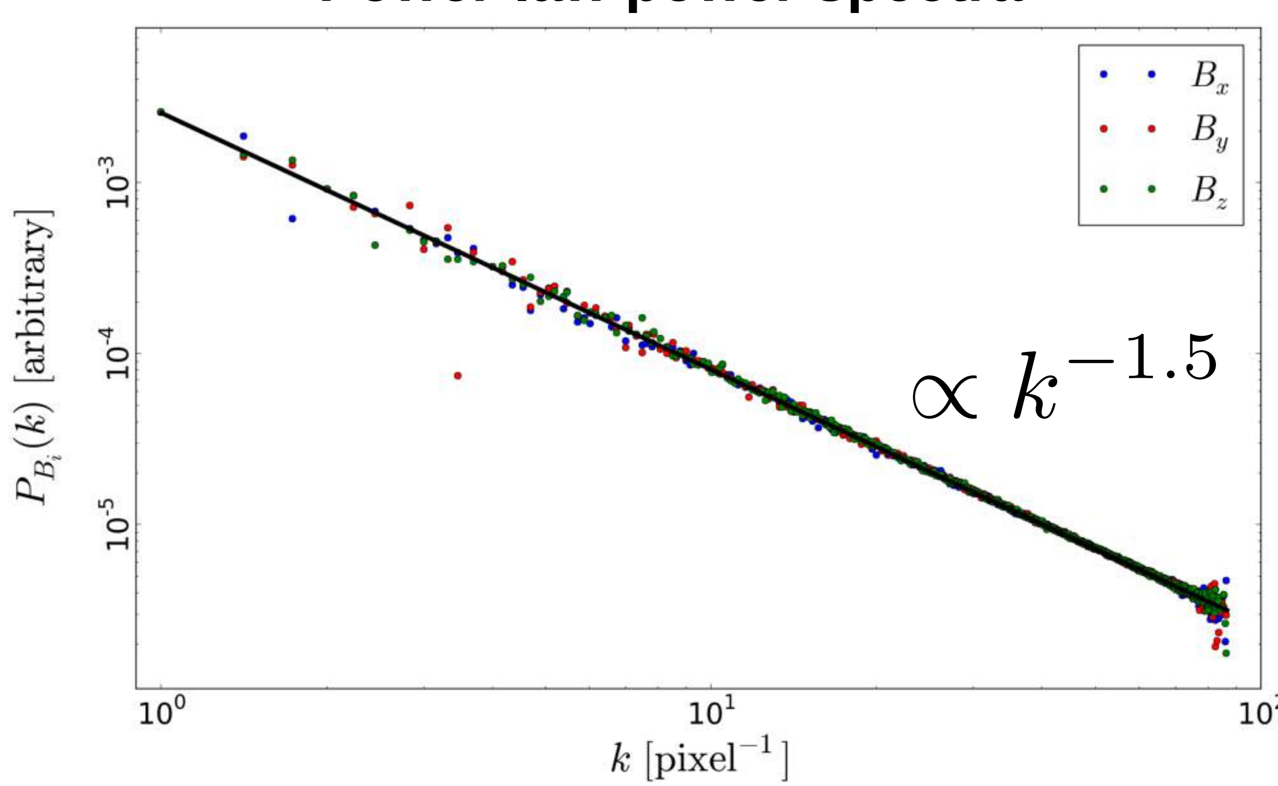
Component of the B field in Fourier space

- Power-law power spectrum with index $\beta_B = \beta_A - 2$
- Divergence-free by construction
- Gaussian distribution with zero mean
- Possibility to add a large-scale uniform field

Gaussian distributions



Power-law power spectra

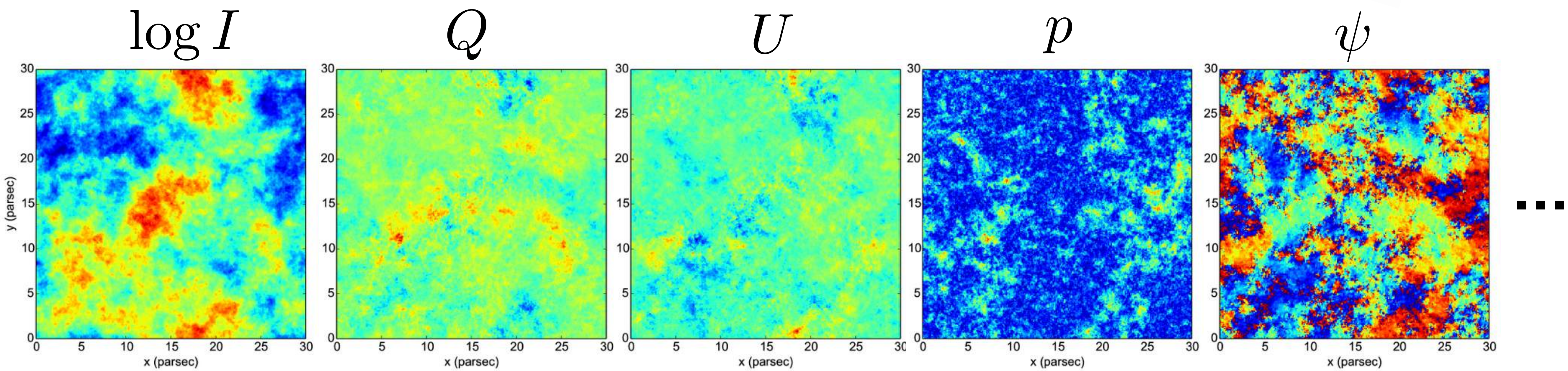


Physical parameters and observables

Physical parameters of the input cubes

- **Spectral indices**
- **Fluctuation ratios**
- **Depth**

$$\beta_n,\ \beta_B,\ \frac{\sigma_n}{\langle n_\mathrm{d}\rangle},\ \frac{\sigma_B}{\langle B\rangle},\ d$$

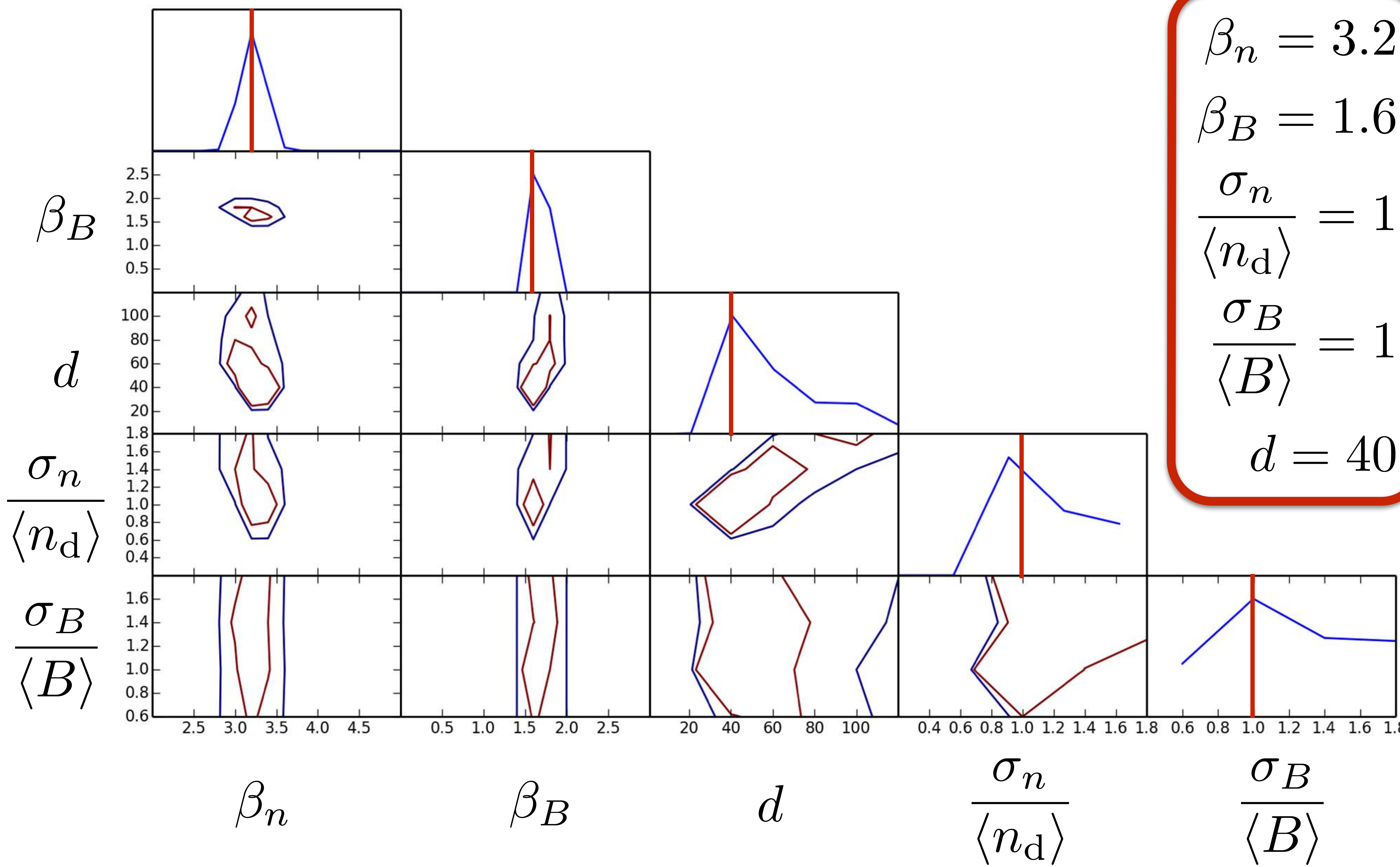


Observables derived from simulated Stokes maps

- **Spectral indices of** $I,\ Q,\ U,\ P$
- **Fluctuation ratios of** $I,\ P$
- **Position of PDF maximum of** $\mathcal{S},\ p,\ |\nabla P|/P$
- **Correlation** $\mathcal{S}$ vs. p
- **Correlation** $\mathcal{S}$ vs. $|\nabla P|/P$

Validating the method

A least-square analysis validates the method on simulated maps



$$\beta_n = 3.2$$
$$\beta_B = 1.6$$
$$\frac{\sigma_n}{\langle n_d \rangle} = 1$$
$$\frac{\sigma_B}{\langle B \rangle} = 1$$
$$d = 40$$

Conclusions

Decrease of p_{max} with N_H well reproduced by simulations

Anticorrelation between polarization fraction and angle dispersion underlines the role of the magnetic field

Development of a promising method to recover statistical properties of the interstellar B field