The Planck Dust Polarization sky

- Methods & data used
- All sky polarization at 353 GHz
- Highest dust polarization regions
- Spatial variations of polarization fraction
- Connections with large-scale MW B field, dust column density and small-scale B field structure

Planck Collaboration.

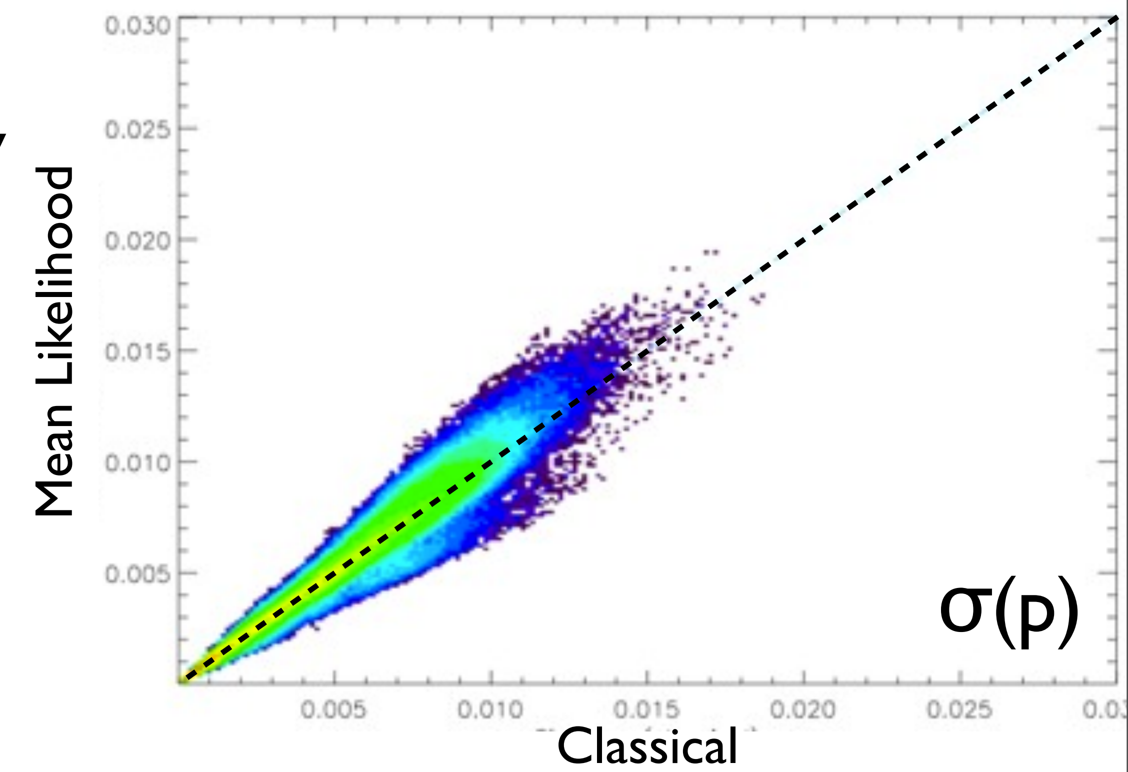
Presented by J.-Ph. Bernard
(IRAP) Toulouse

Data & Methods

- DX9 at 353 GHz
- Dust Band-Pass Mismatch correction using sky coefficients and Planck dust map at 353 GHz
- No CO Band-Pass Mismatch correction

$$p = \frac{\sqrt{Q^2 + U^2}}{I} \qquad \psi = 0.5 \times tg^{-1}(U, Q)$$

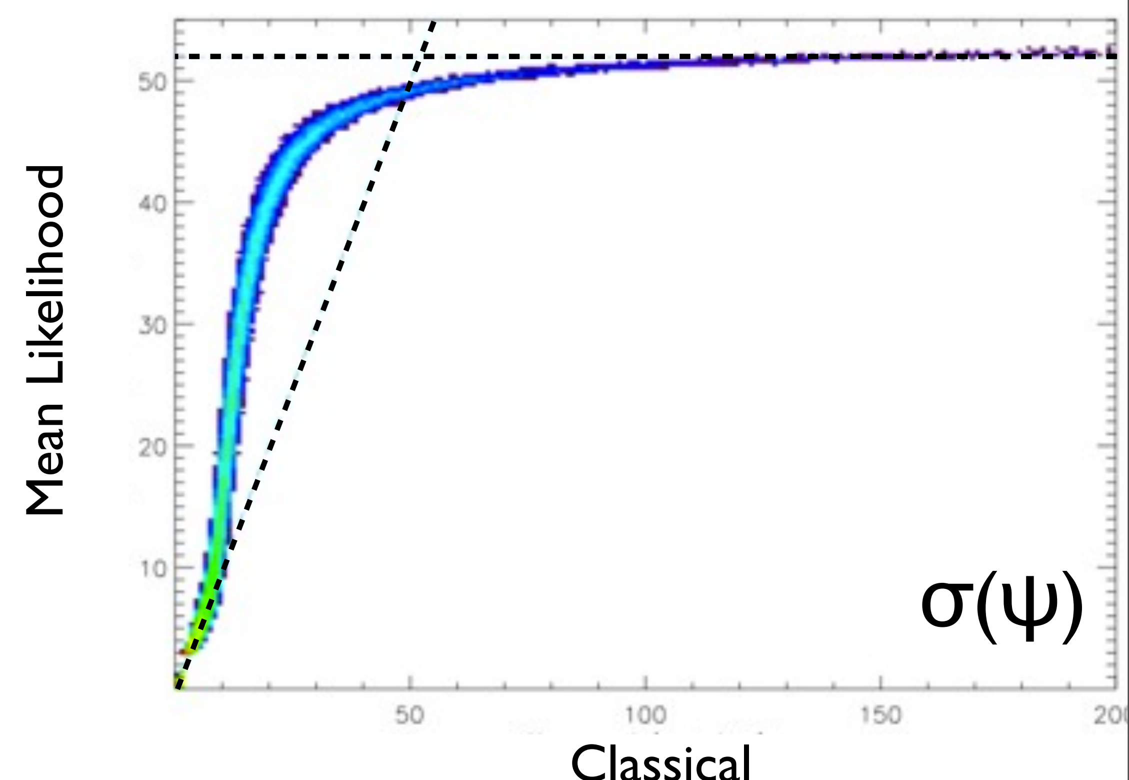
- p is biased in the presence of noise on Q,U



Methods:
- Classical method only valid at high SNR
- Half-ring and Survey correlations

$$p^2_{db} = \frac{\sum_{i>j} Q_i Q_j + U_i U_j}{\sum_{i>j} I_i I_j}$$

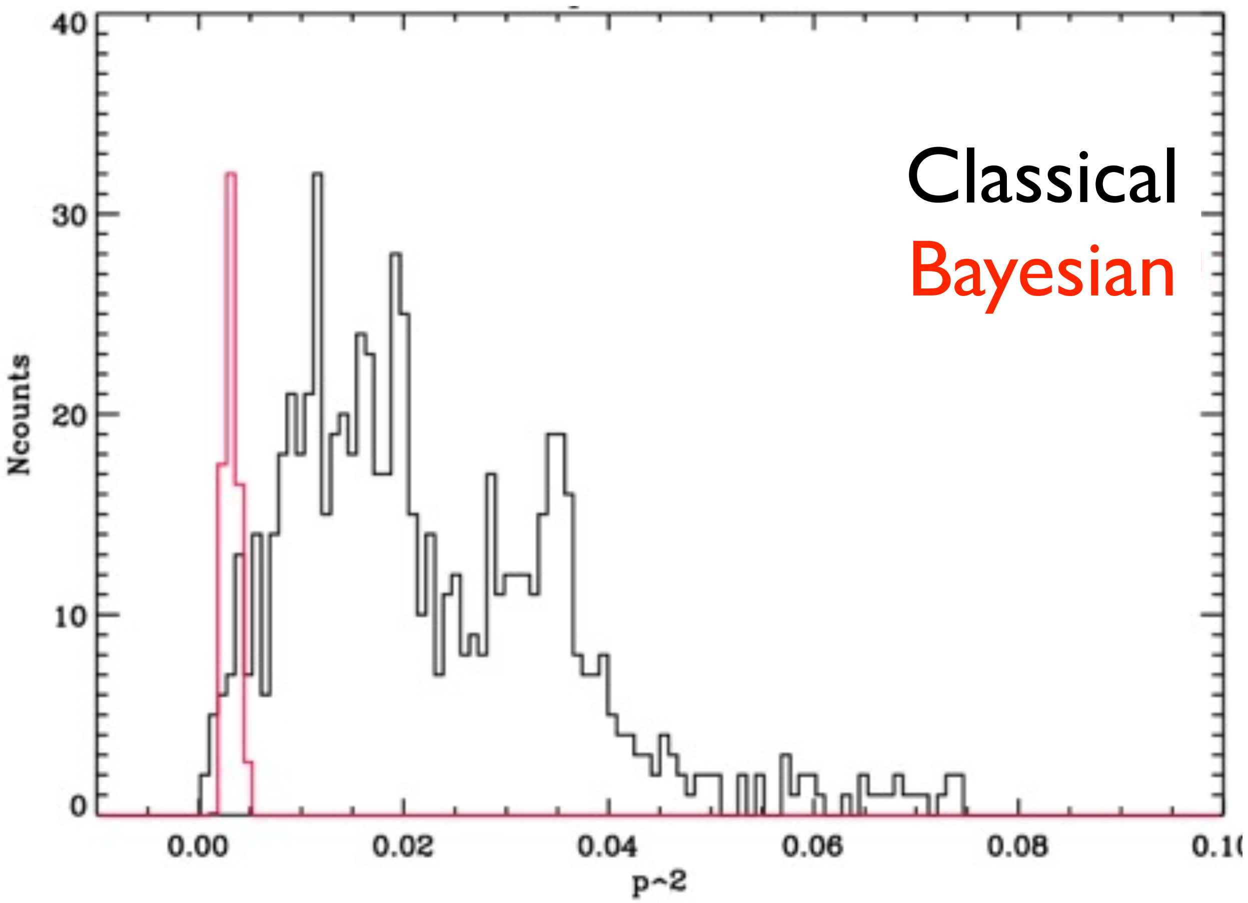
- Monte-Carlo
- Bayesian + mean likelihood using full noise cov. matrix (Quinn 2009, Montier et al. 2013)



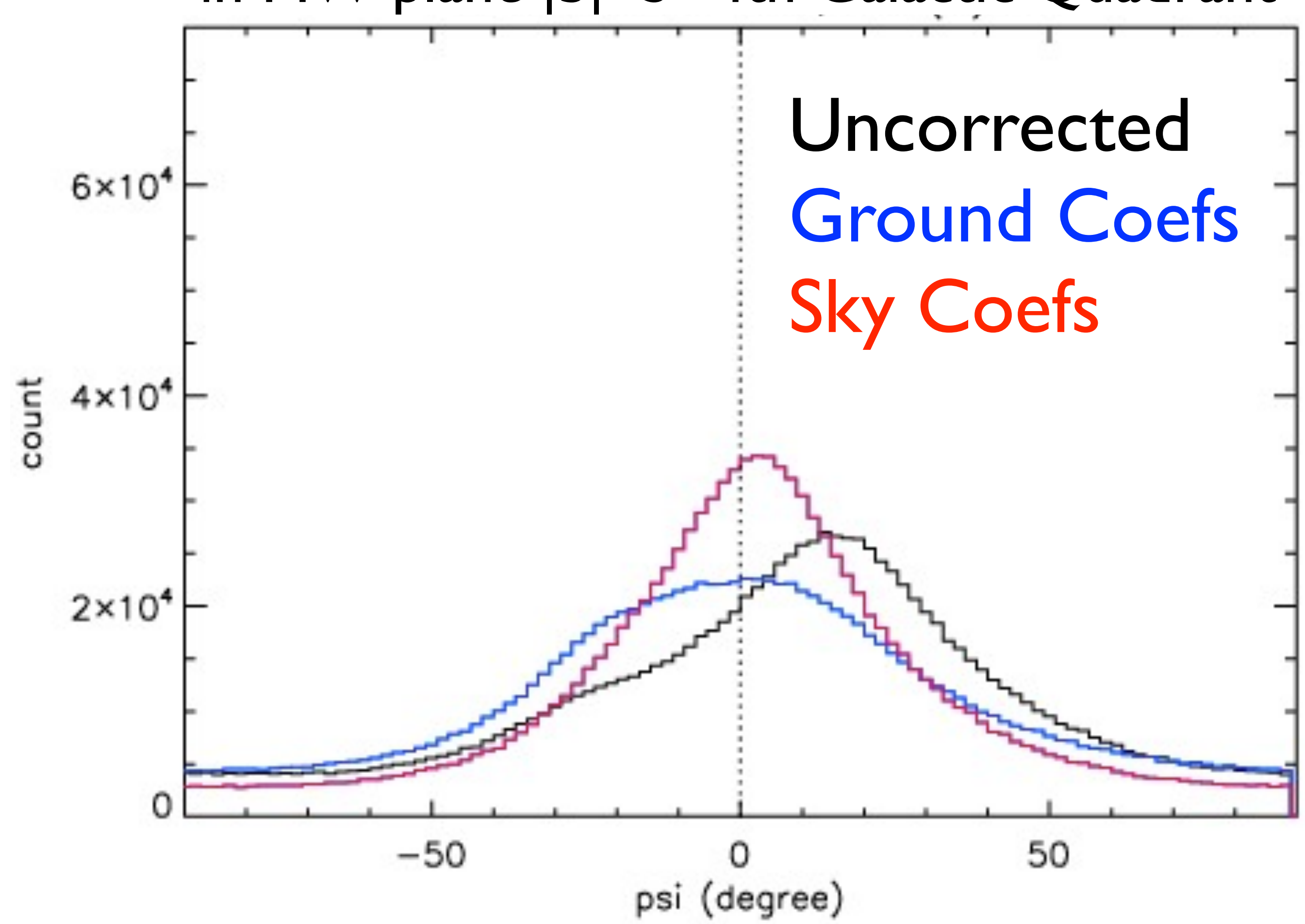
Data Checks

- Apparent polarization consistent with p=0 at high |b| where CIB dominated
- Dust Band-Pass Mismatch correction consistent with psi=0° in MW plane (4 quadrants)

Histogram of p in deep field region where I353<2*CIB



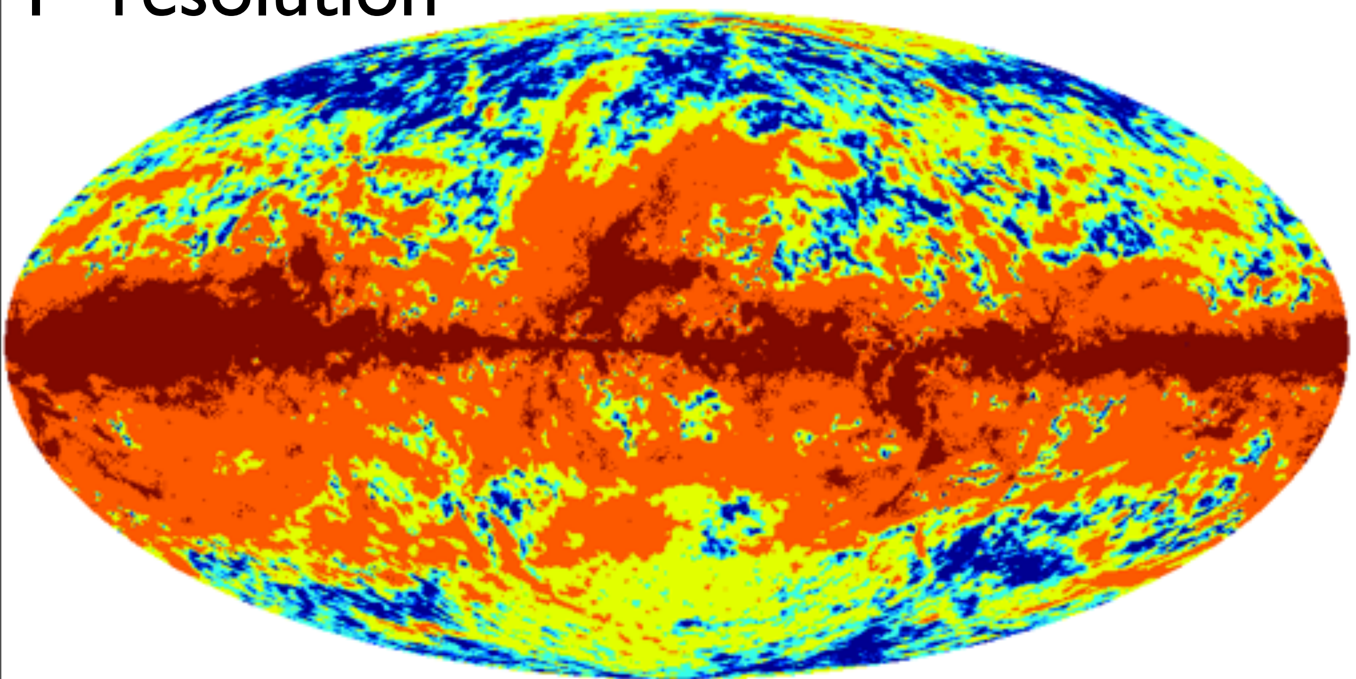
Histogram of polarization angle in MW plane |b|<5° 4th Galactic Quadrant



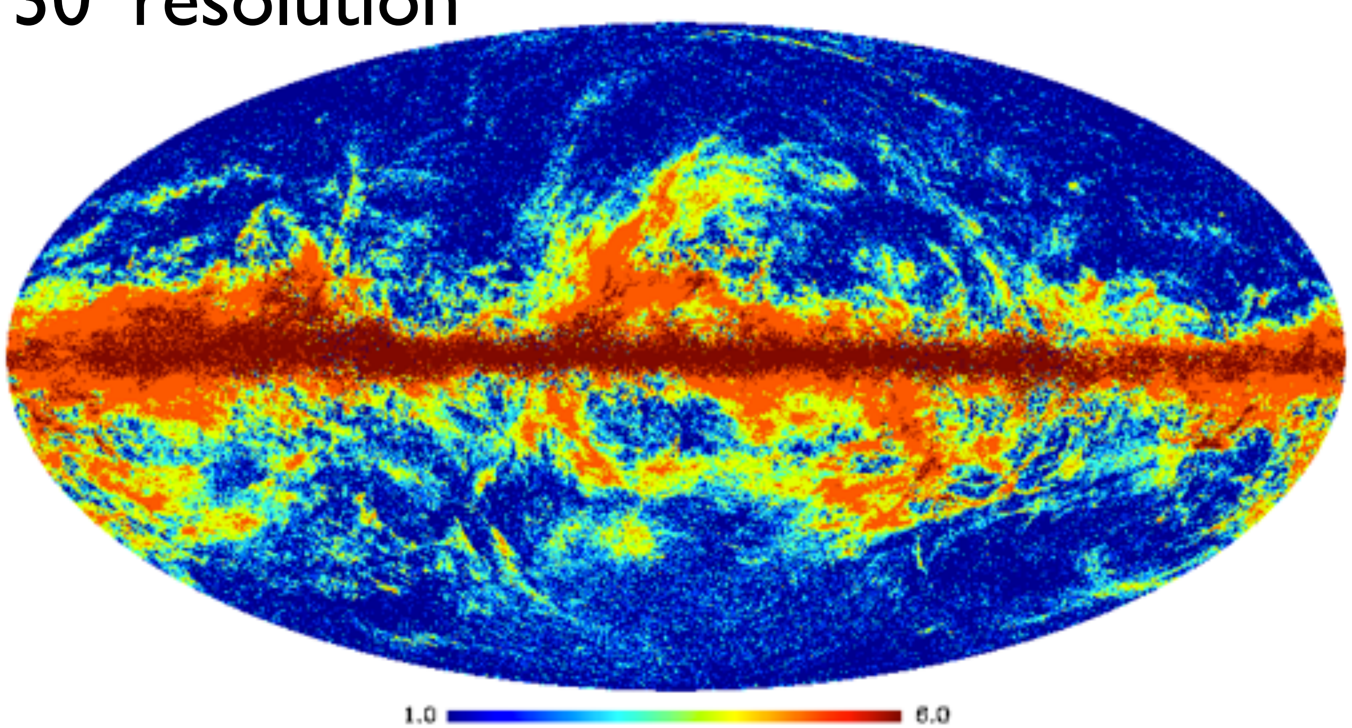
Uncertainties

maps of SNR on p

1° resolution



30' resolution



- Computed from mean likelihood
- Basically reflect Intensity and sky coverage

	1°	30'	15'
SNR>2	93 %	82 %	61 %
SNR>3	89 %	72 %	48 %
SNR>5	77 %	55 %	33 %
SNR>10	53 %	34 %	19 %

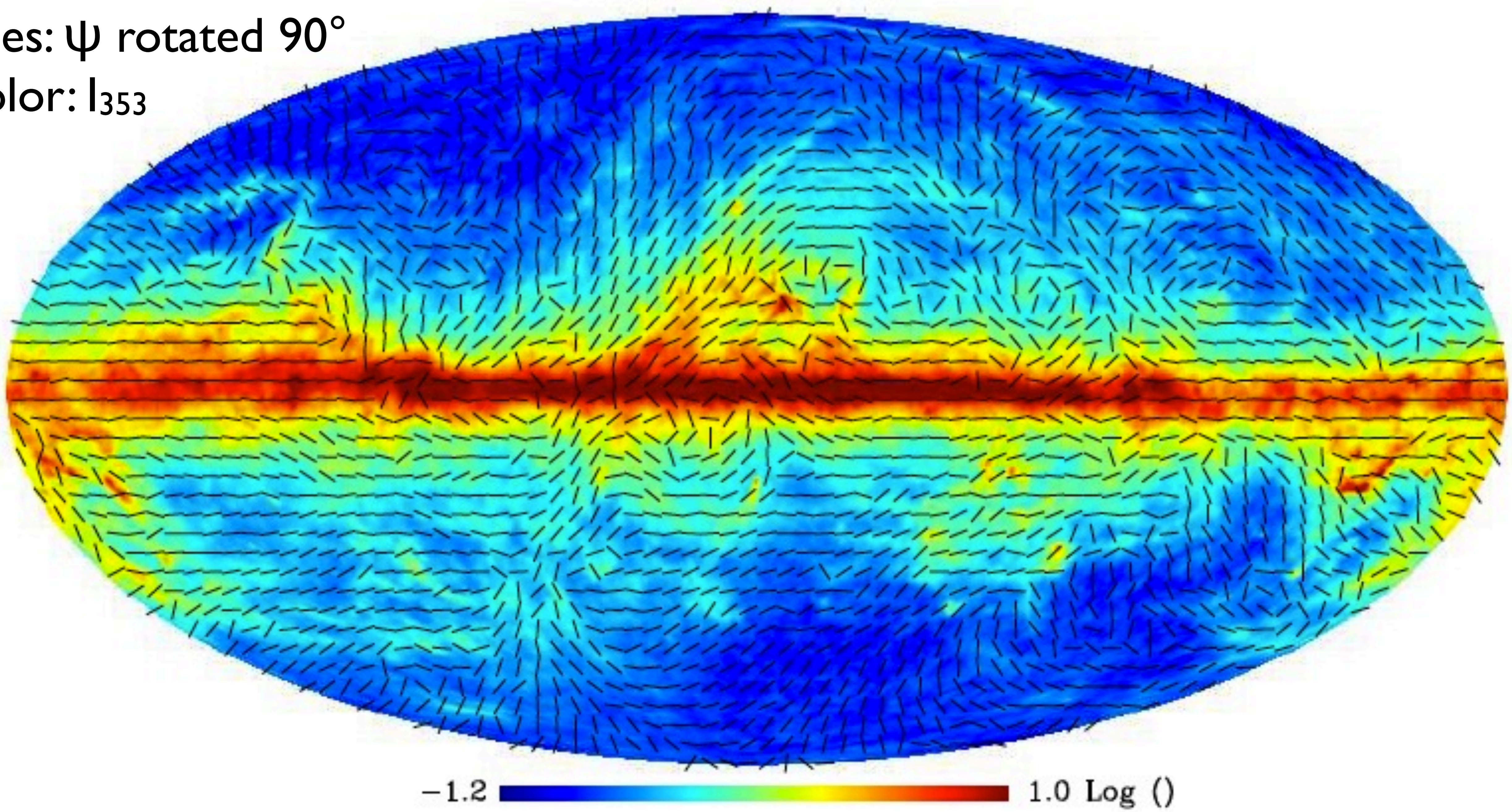
- Work at 1° resolution to lower noise (also 7', 14', 30')
- Smoothed noise cov. matrix using MC simulations

B field direction at 353 GHz, 1° resolution

$\psi = 0.5 \times tg^{-1}(U, Q)$

lines: ψ rotated 90°

color: I_{353}



Field direction consistent with B in MW plane

Field homogeneous over large regions with strong p (e.g. Fan)

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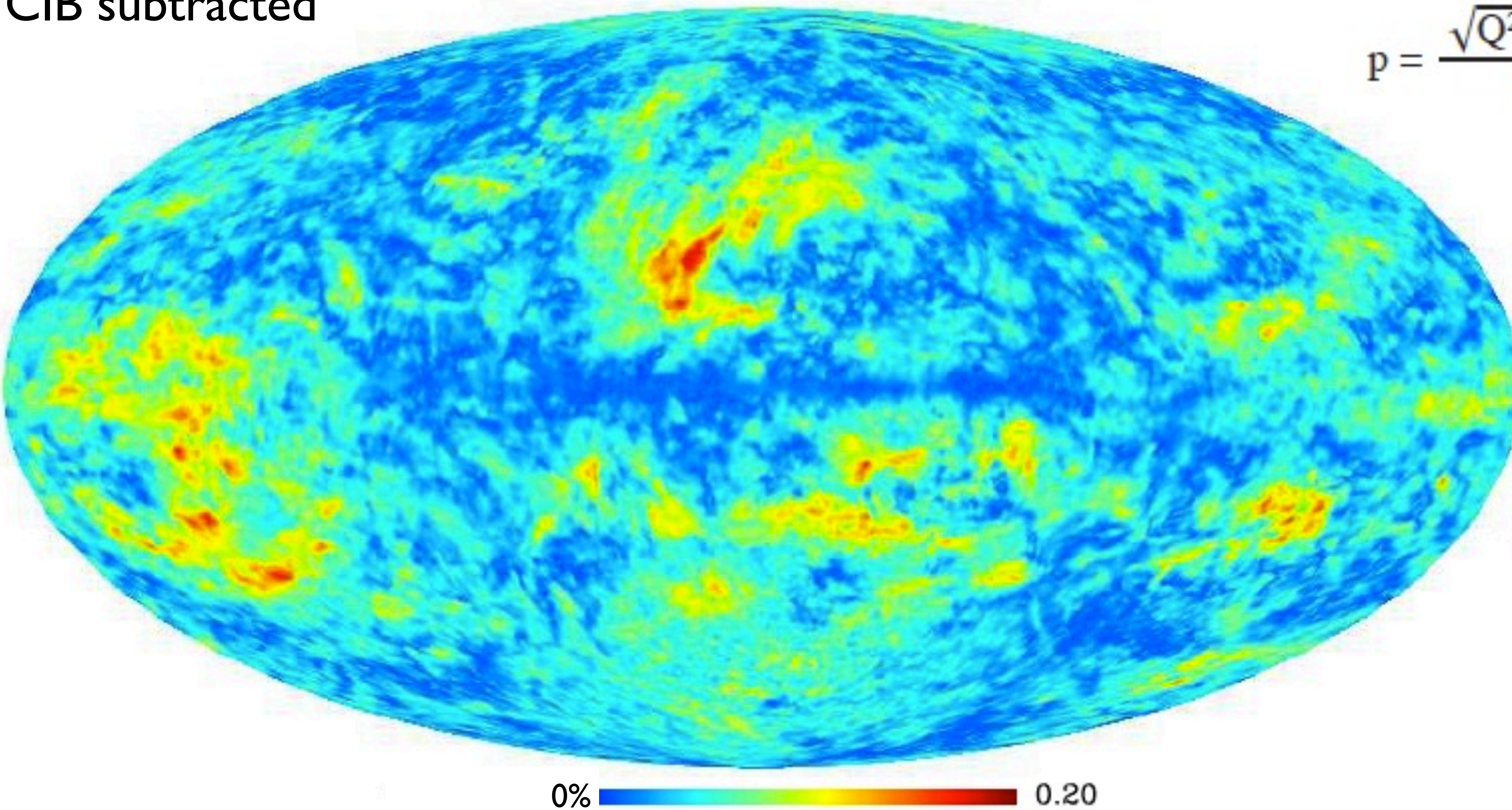
Apparent polarization fraction (p) at 353 GHz, 1° resolution

Not CIB subtracted

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



p ranges from 0 to ~20%

Low p values in inner MW plane. Consistent with unpolarized CIB

Large p values in outer plane and intermediate latitudes

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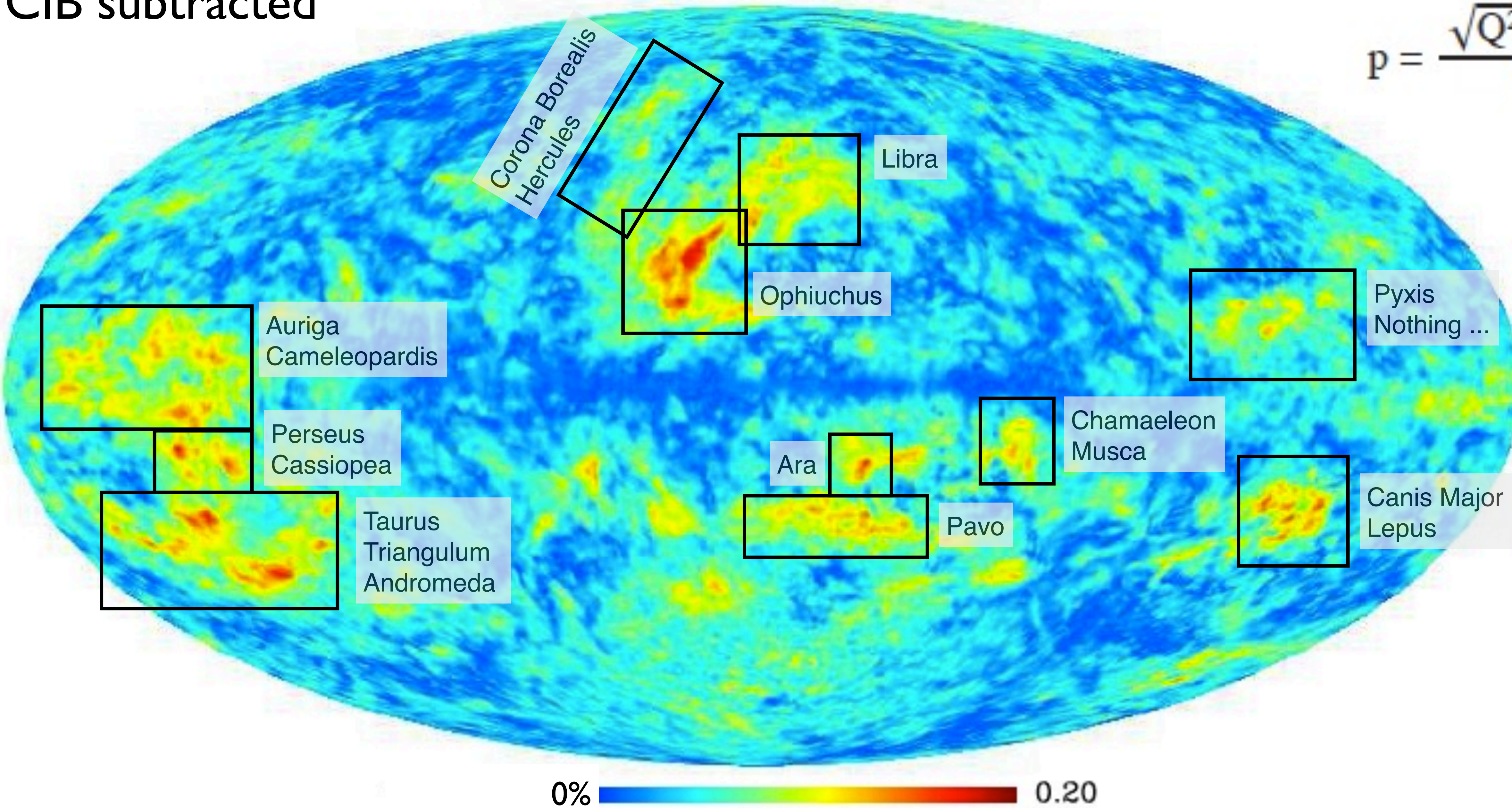

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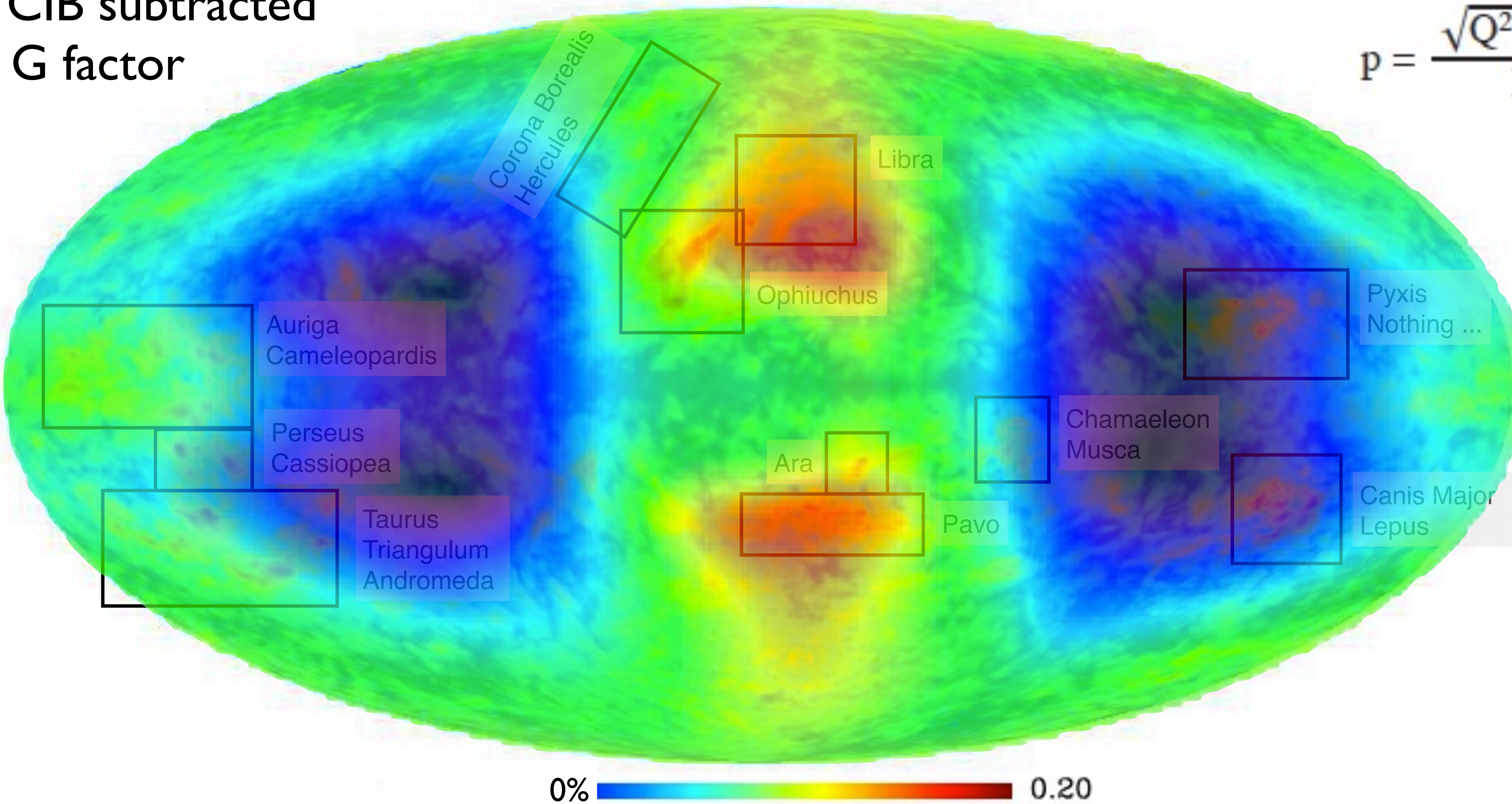
Not CIB subtracted

PSM G factor

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



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Low p values in inner MW plane. Consistent with unpolarized CIB

Large p values in outer plane and intermediate latitudes

Large scale variations similar to MW B-field structure

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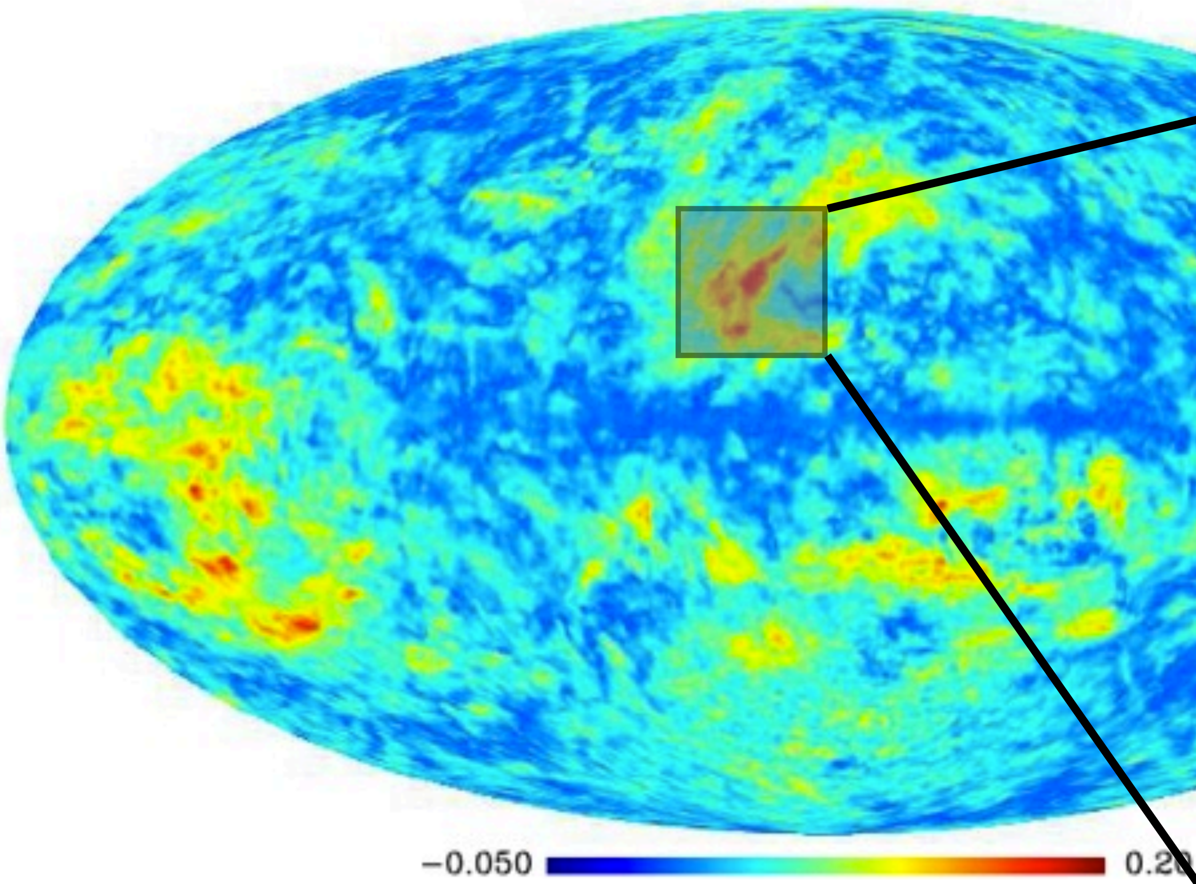
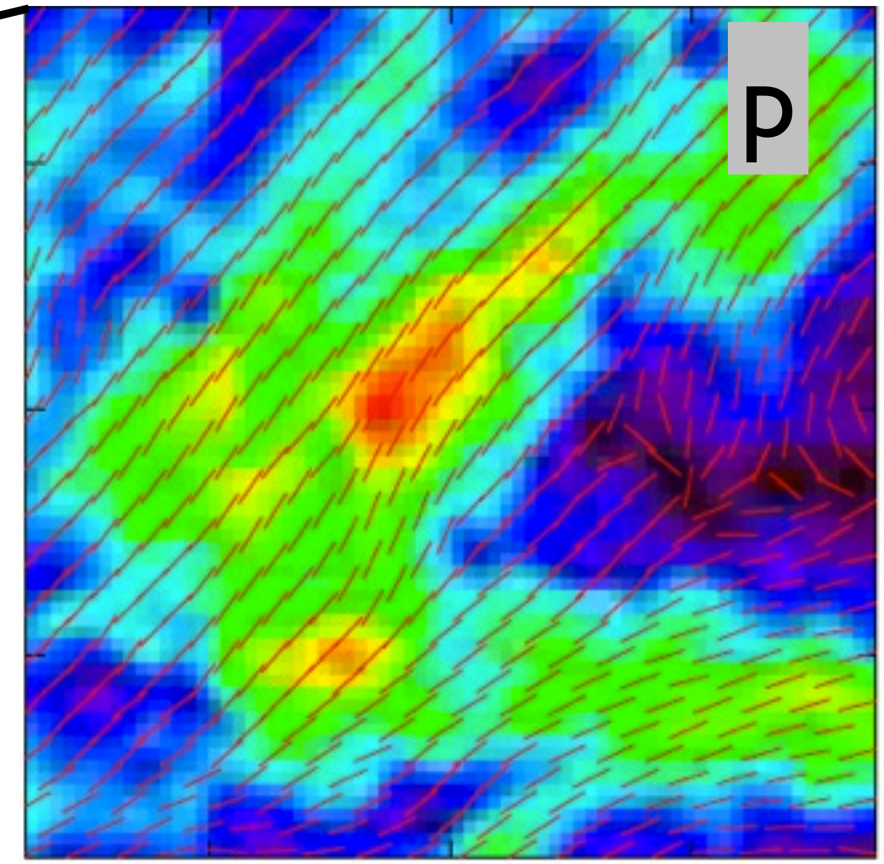
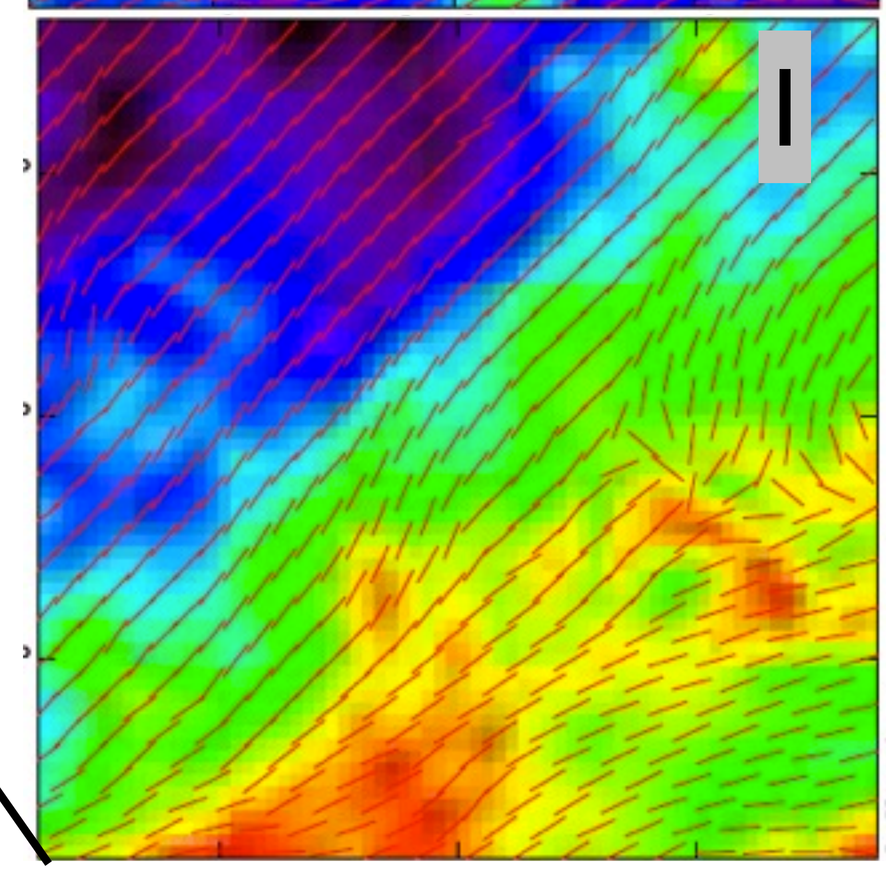
Aquila Rift





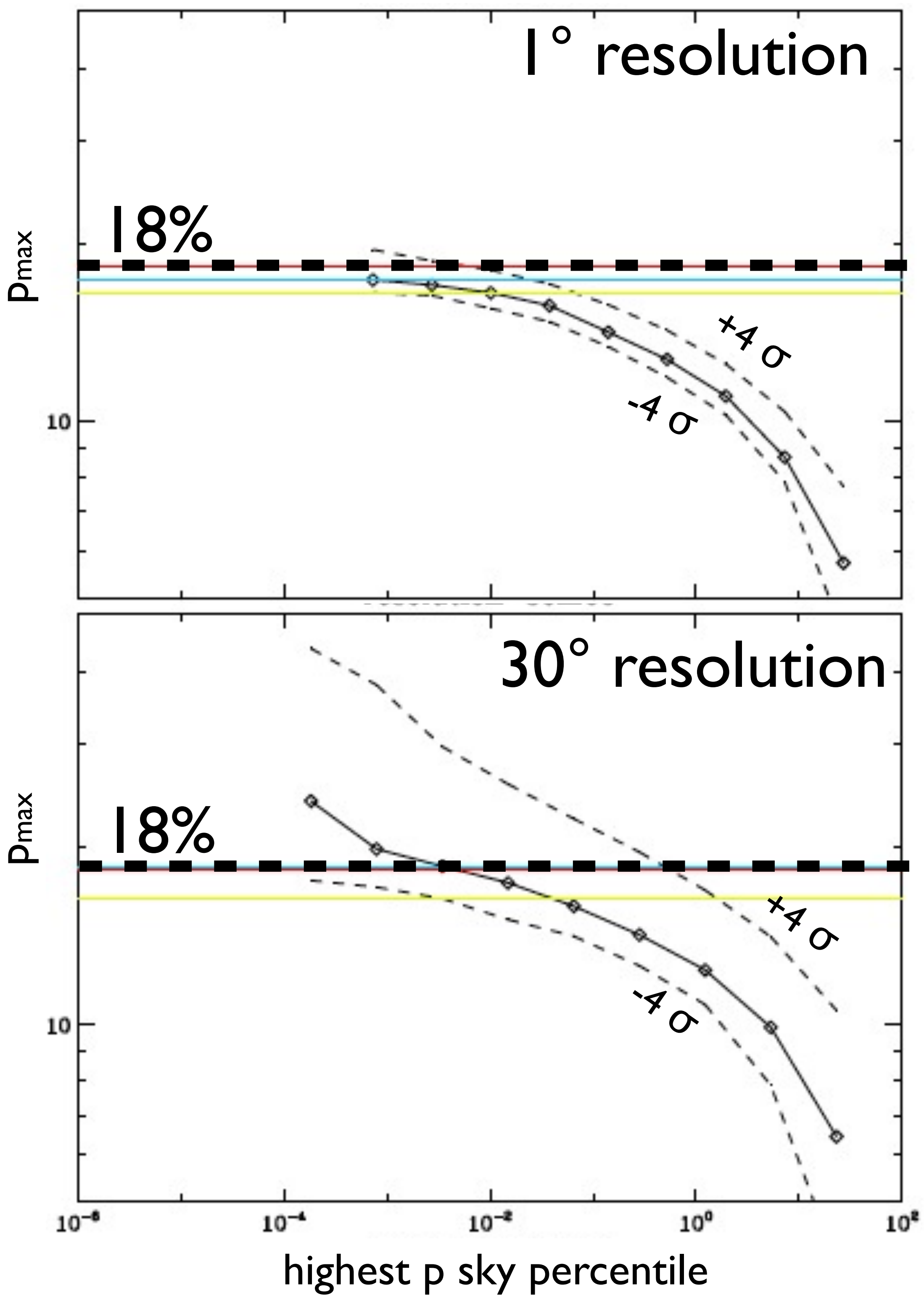


Highly polarized regions:
- found in homogenous field regions
- often at edges of intensity structures

Some of these have little to no intensity counterparts

The sky looks different in polarization !!

Polarization fraction



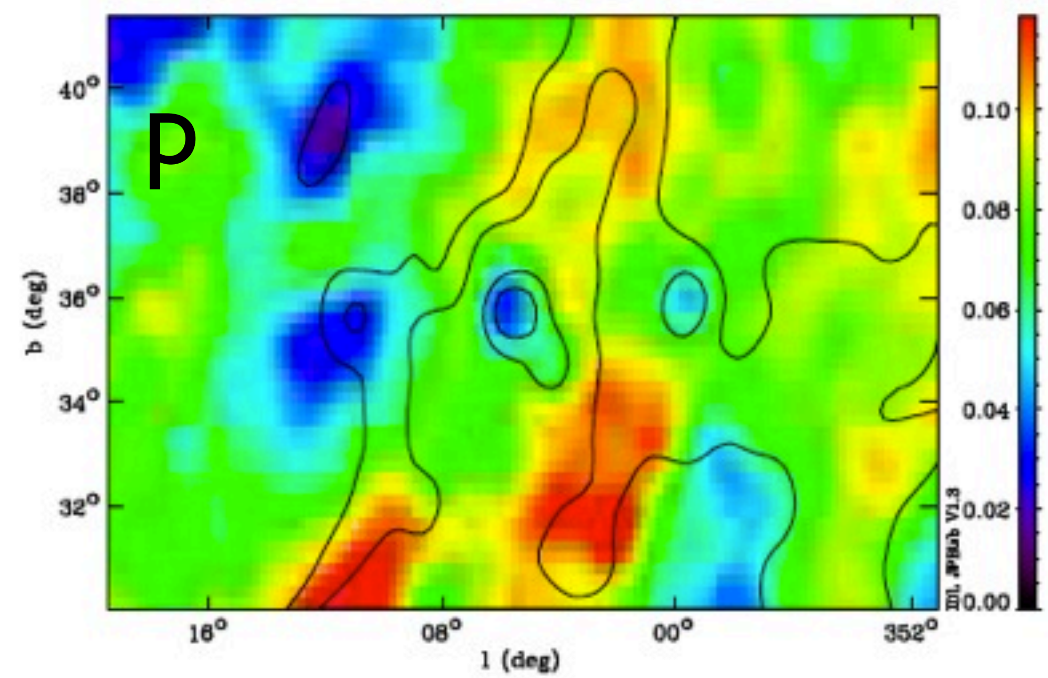
- Maximum dust polarization fraction is an important for dust modeling and component separation
- Planck maps at various resolution indicate pmax>18% at 353 GHz, taking uncertainties (4-σ) into account
- This level is reached in the Aquila rift and other similar regions
- This is only a lower limit
- Consistent with previous results from the Archeops experiment at high latitude.
- Much higher than values previously reported from ground observations

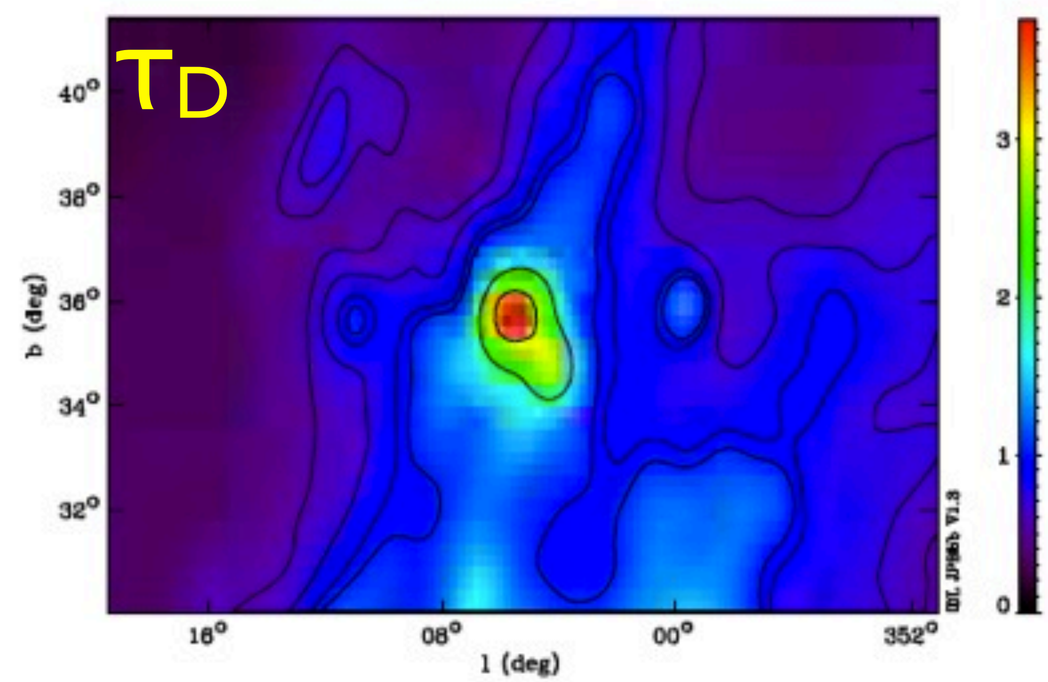
- p shows general decrease with column density
- Consistent with ground observations
- Reasons for this likely to be either:
  - lack of dust alignment in opaque regions
  - B field tangling

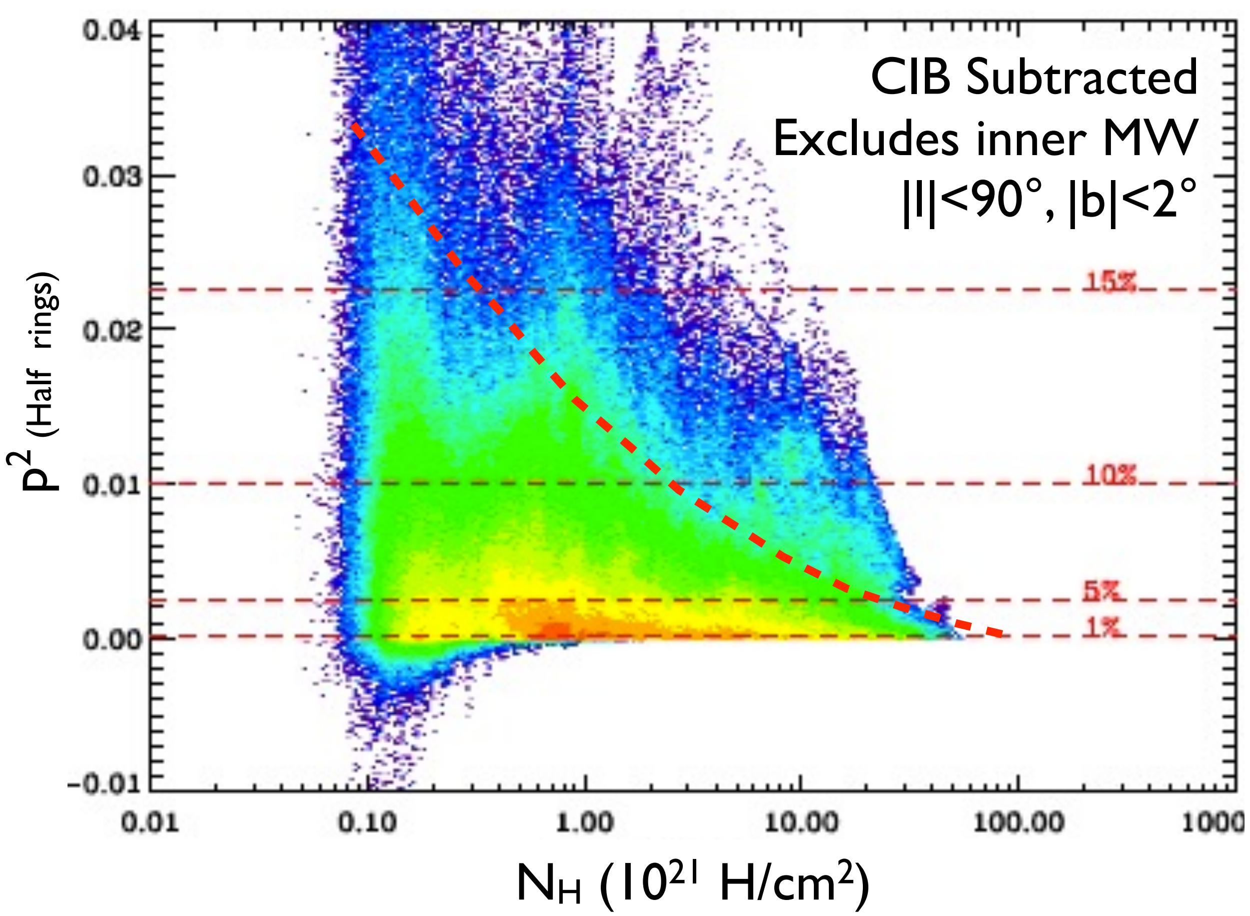
(see poster by Levrier)

- Large scatter probably due to field geometry

Example in L134



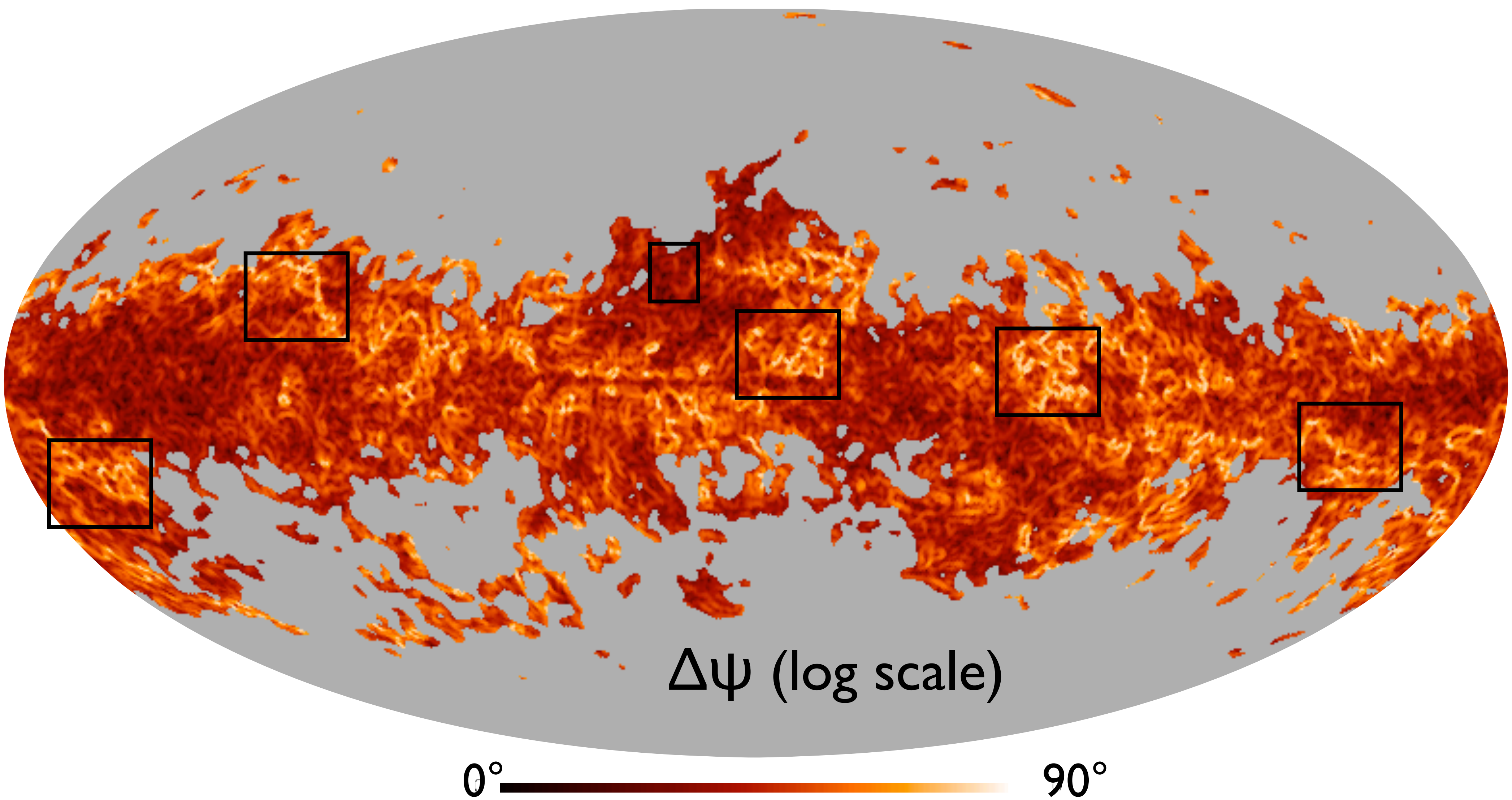


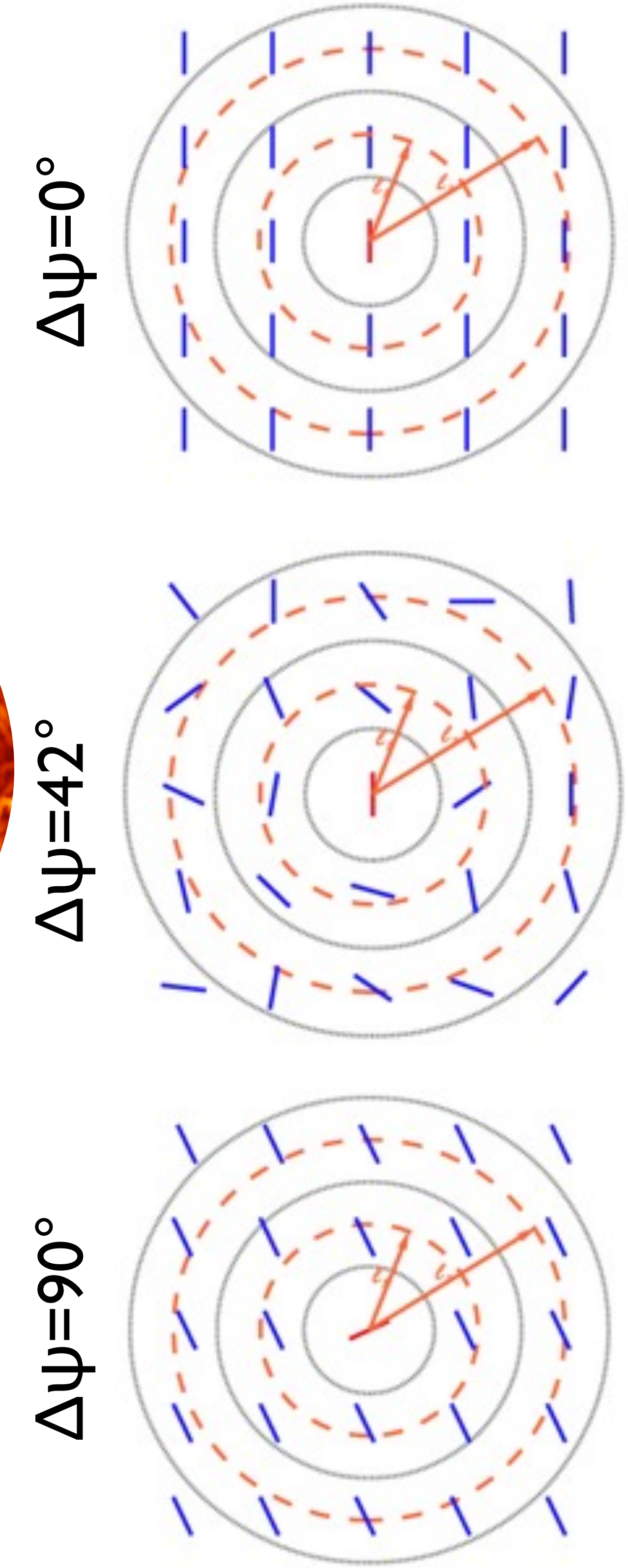


Angular Structure Function

Measure of polarization direction homogeneity at scale ℓ :

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi(\mathbf{r}) - \psi(\mathbf{r}+\mathbf{l}_i)\right]^2$$ (Hildebrand et al. 2009)





- Computed on Full survey on 1° resolution map at ℓ=30'.
- Masked where SN(Δψ)<3 (uncertainties using MC)
- Similar maps for all 5 individual surveys and 2 half-ring surveys
- Spaghetti shaped regions of high polarization rotation

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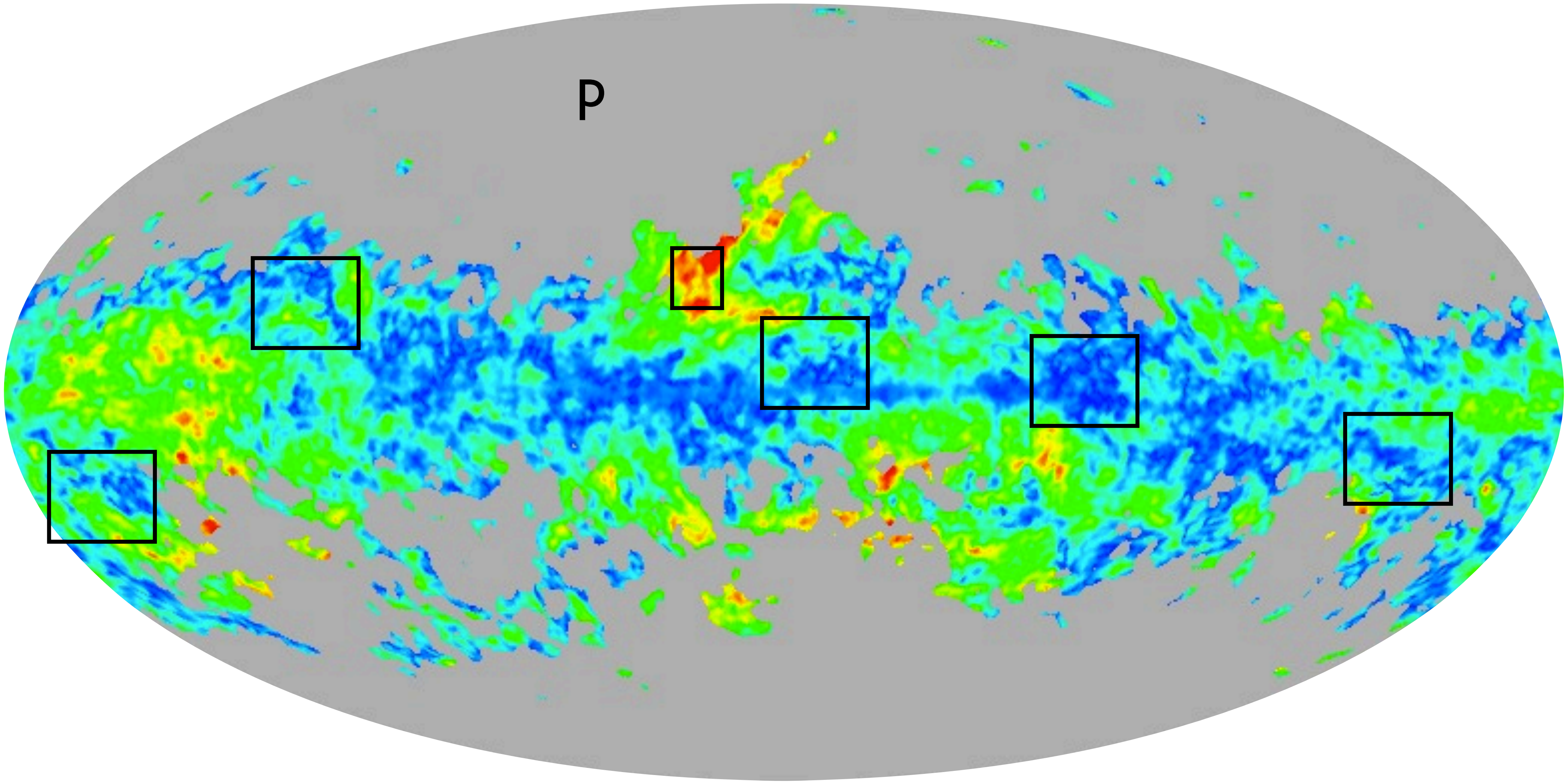
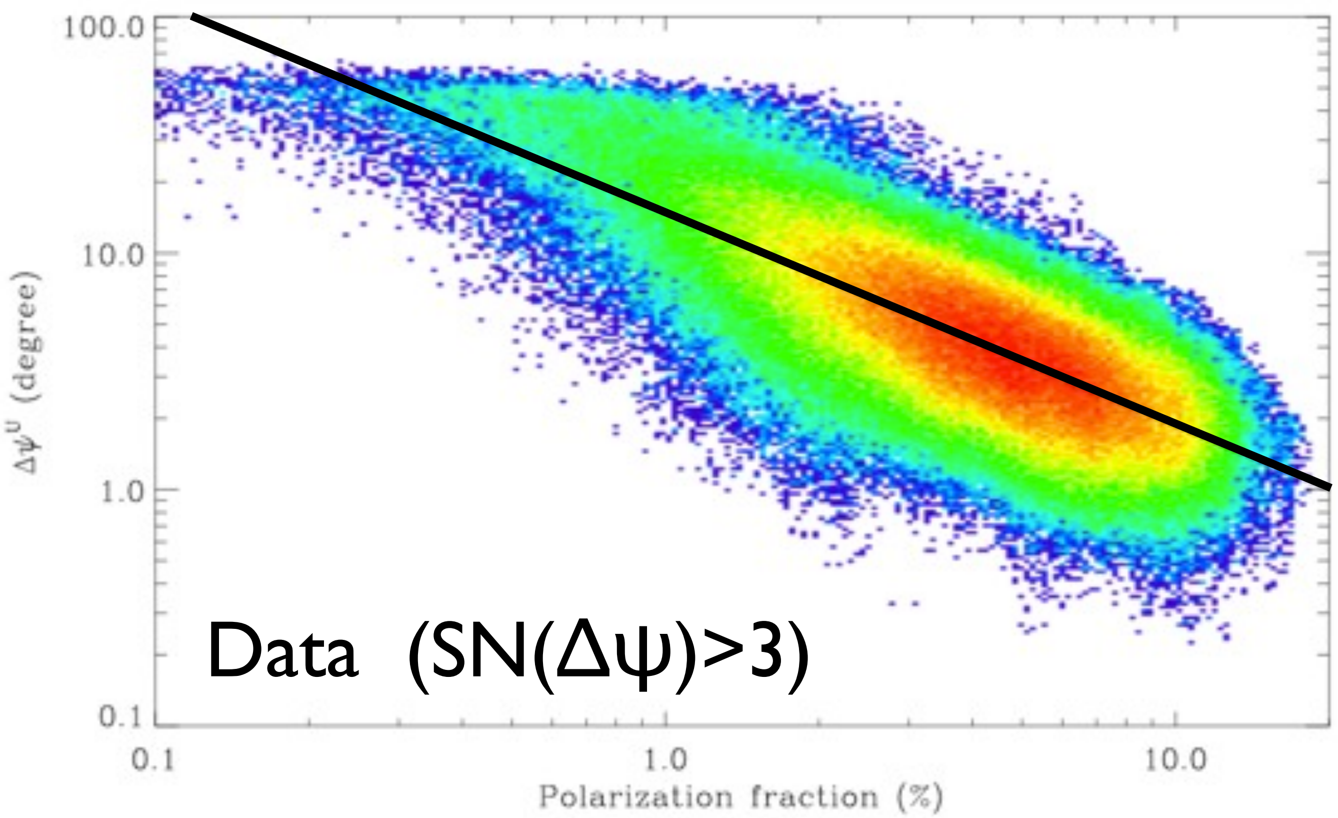
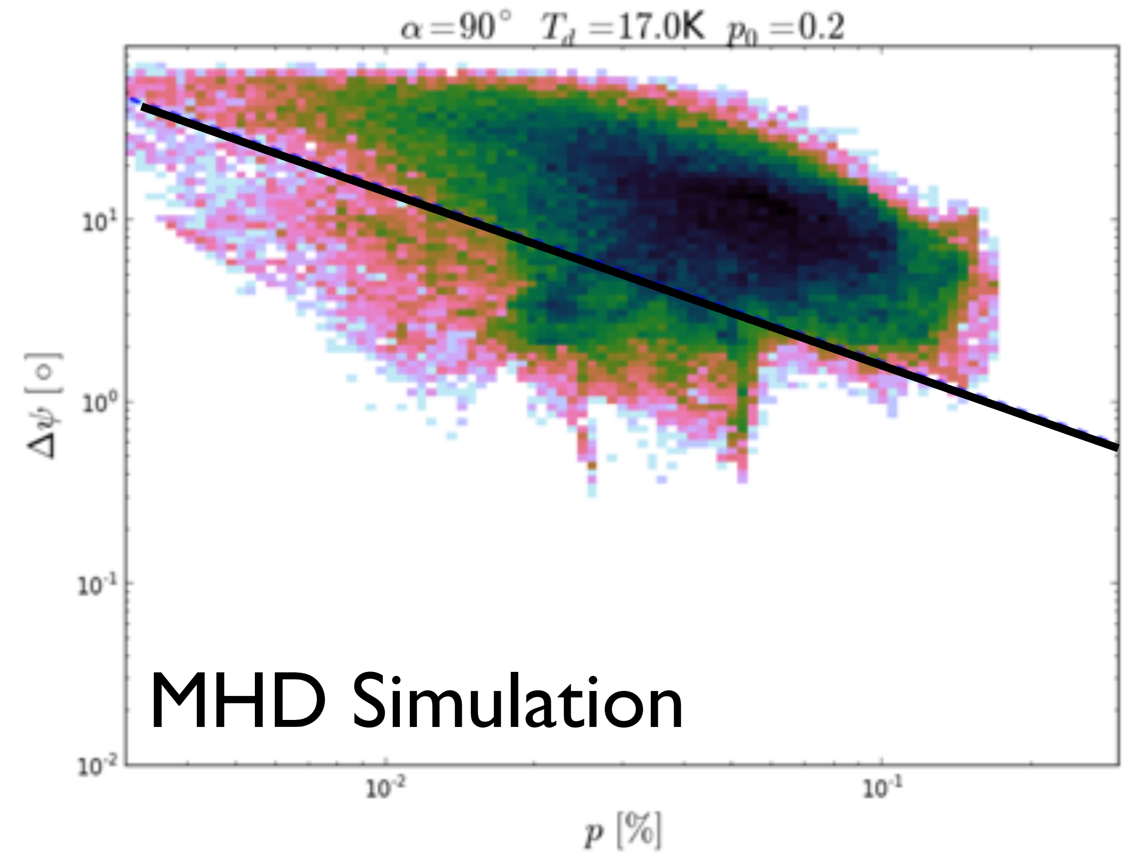


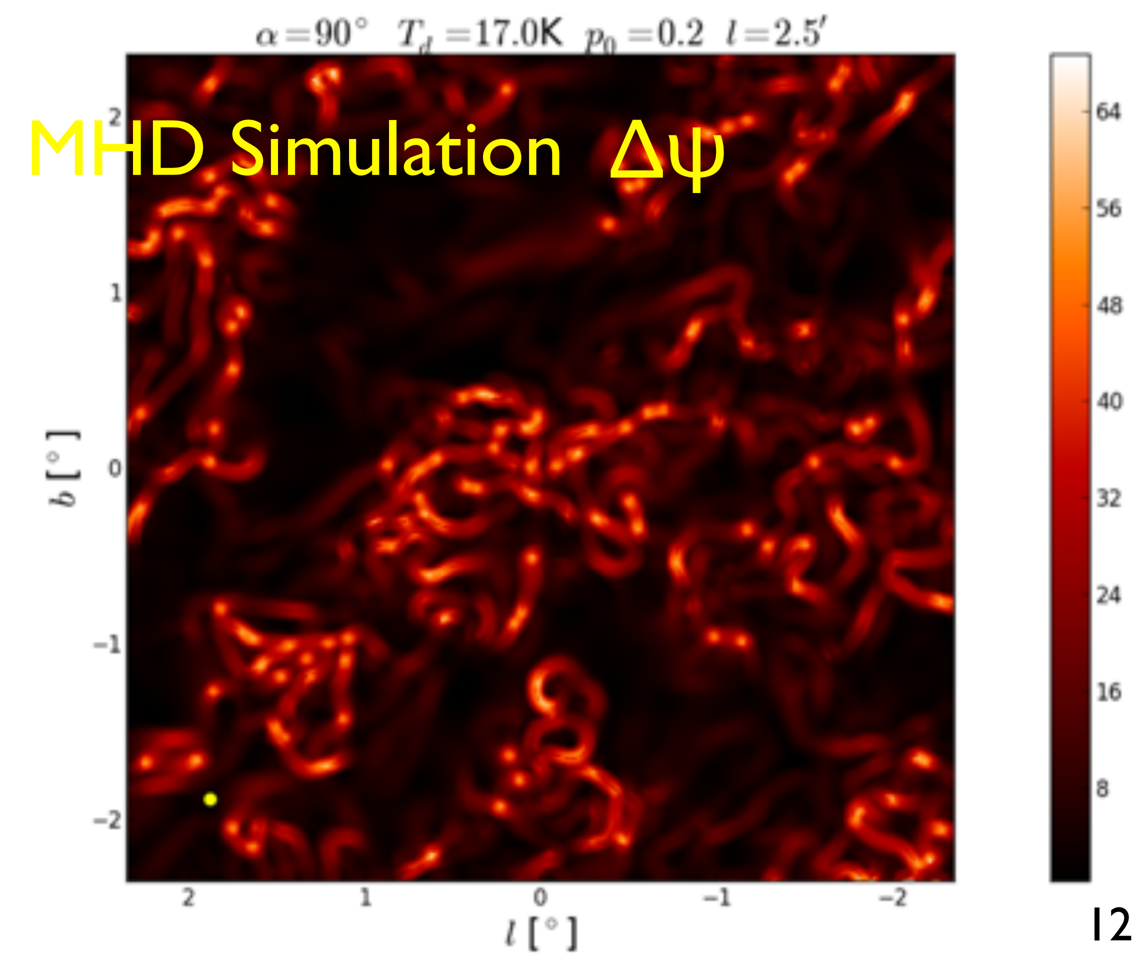
- $\Delta\psi$ anticorrelates with p
- High $\Delta\psi$ correspond to depolarization regions
- No clear correspondence with intensity filaments

Angular Structure Function





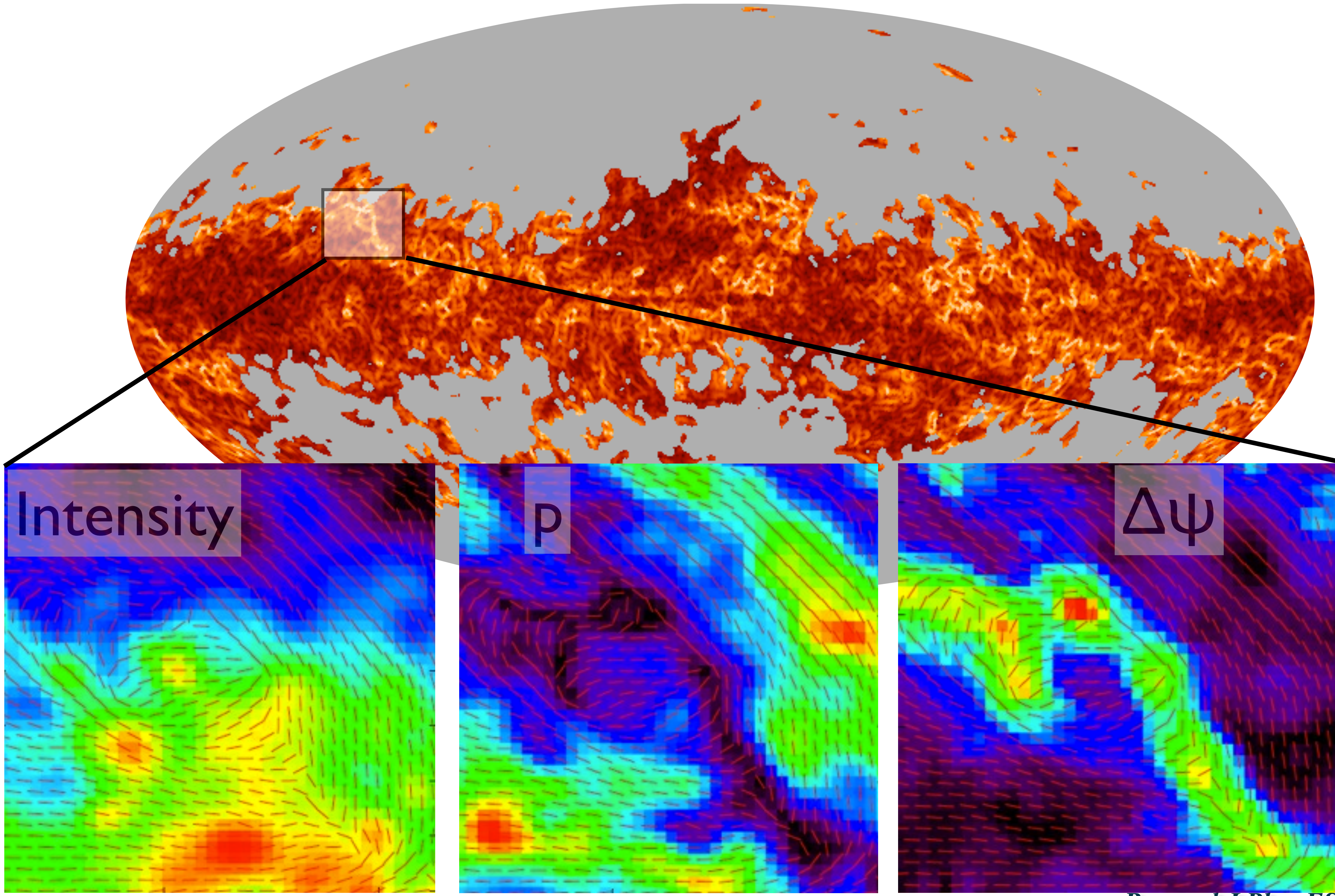
- Δψ increases with scale ℓ
- Δψ anticorrelates with p
- Similar behaviour observed in MHD simulations (see Poster by Levrier)
- MHD Δψ shows similar spaghetti structure
- Difference in absolute Δψ level can be due to fraction of diffuse emission in MHD cube



Angular Structure Function

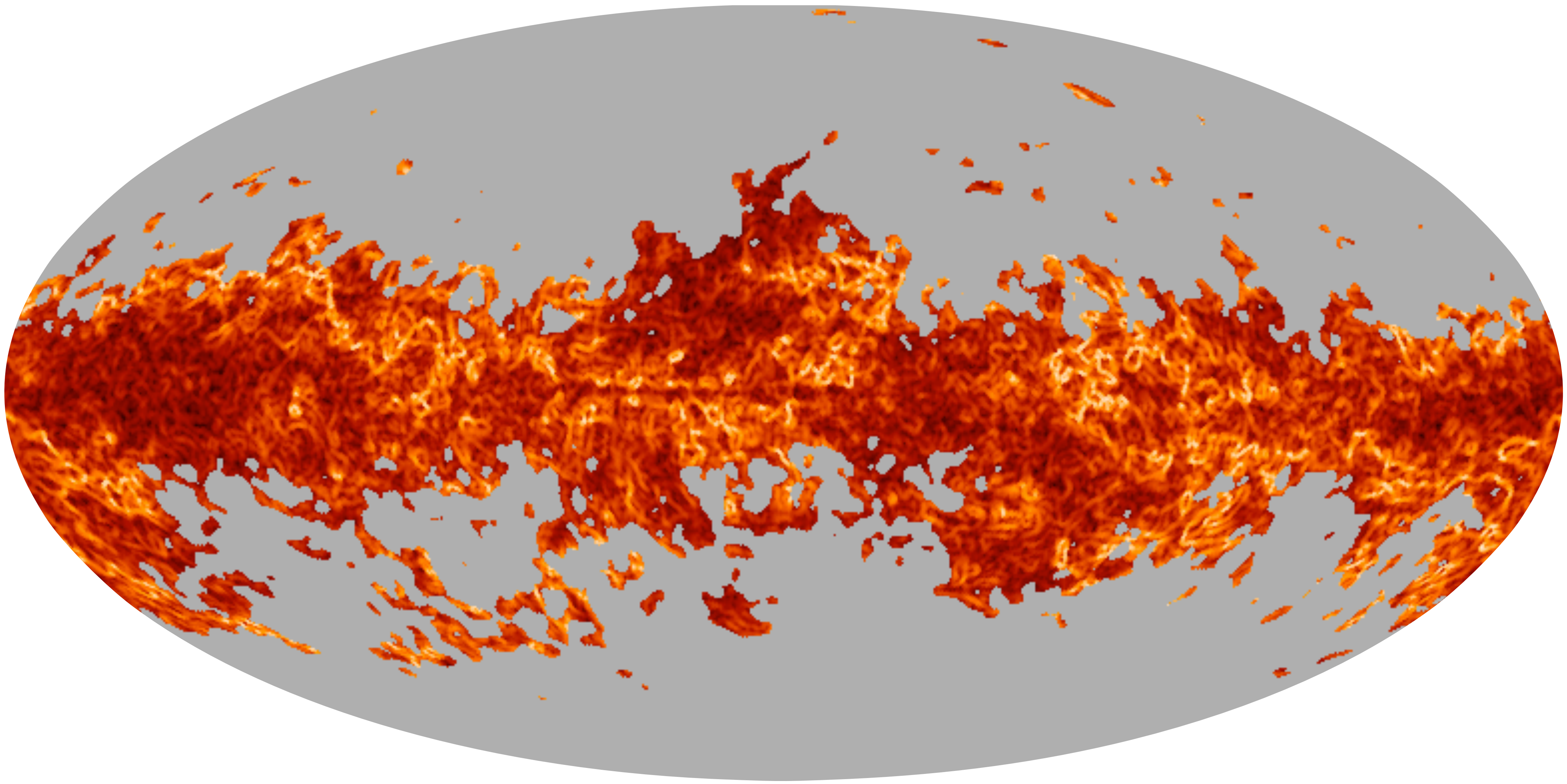
Those structures avec very large: most likely nearby

They delineate the edges of regions with homogenous field of different directions



Angular Structure Function

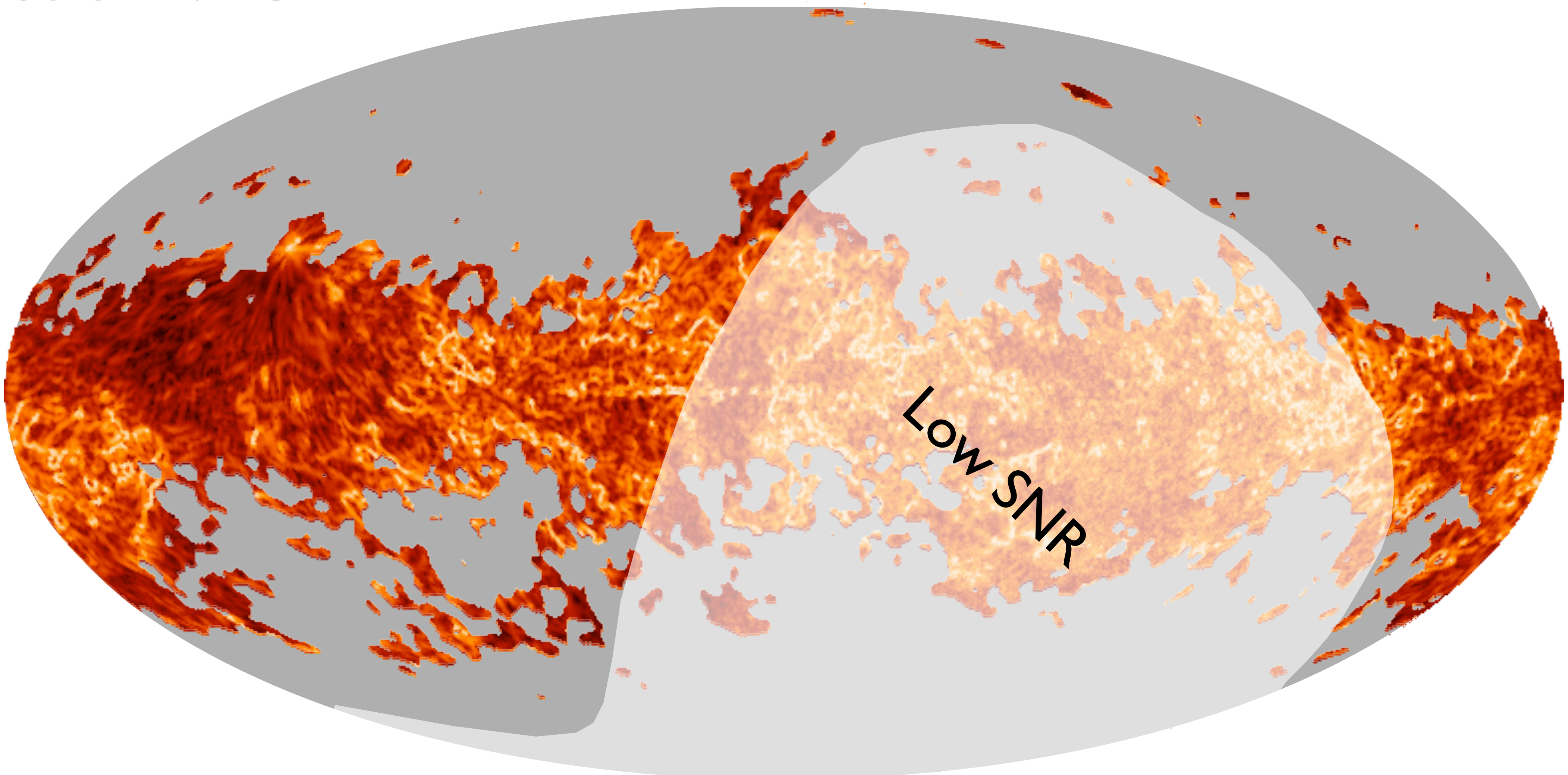
$\Delta\psi$ Dust 353 GHz



Synchrotron data (Reich 82, Reich & Reich 86) shows similar structures
These structures also correspond to low p (depolarization canals)
Those are likely due to Faraday rotation (not present at 353 GHz)
The structures in the dust and synchrotron $\Delta\psi$ do not match

Angular Structure Function

Δψ Synchrotron 1.4 GHz



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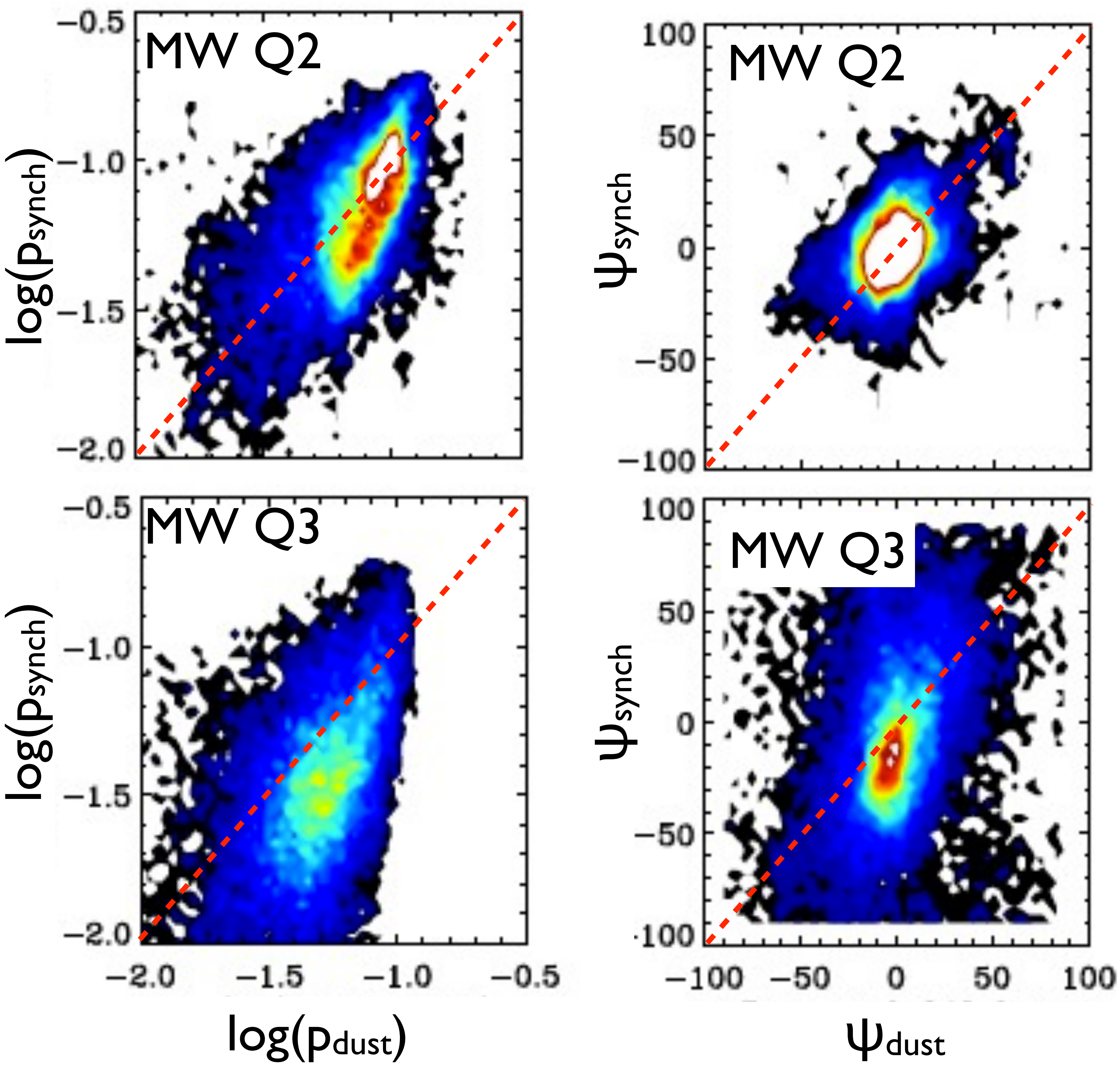
Dust vs Synchrotron



here :
synch=WMAP 23 GHz
dust=Planck 353 GHz

- Correlation between dust and Synchrotron is rather poor (p and ψ)
- Synchrotron and dust may not trace the same part of LOS and field rotates between the two

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Conclusions

- Polarization fraction is surprisingly high: p_{max} is > 18%
(large dust alignment efficiency or b/a)

p variations caused by:
- variations of overall galactic B field (large scale)
- dust column density (small scale)
- B field geometry ($\Delta\psi$, B angle w.r.t LOS)

$\Delta\psi$:
- Shows filamentary structure
- Anticorrelates with p
- Similar structure and behavior in MHD simulation
- Similar to Synchrotron $\Delta\psi$ (Faraday rotation dominated), but not located in same regions
- Origin currently unclear

- Dust-Synchrotron correlation is poor indicating they sample different parts of LOS with varying B

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

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