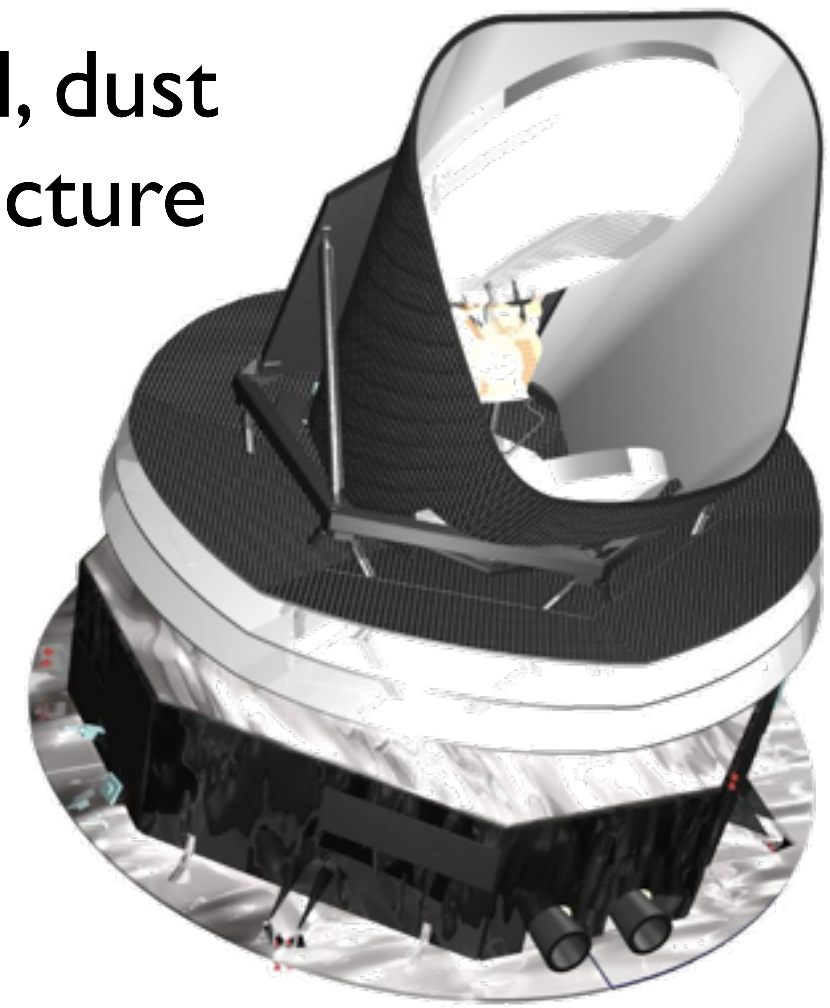
Polarization results from Planck

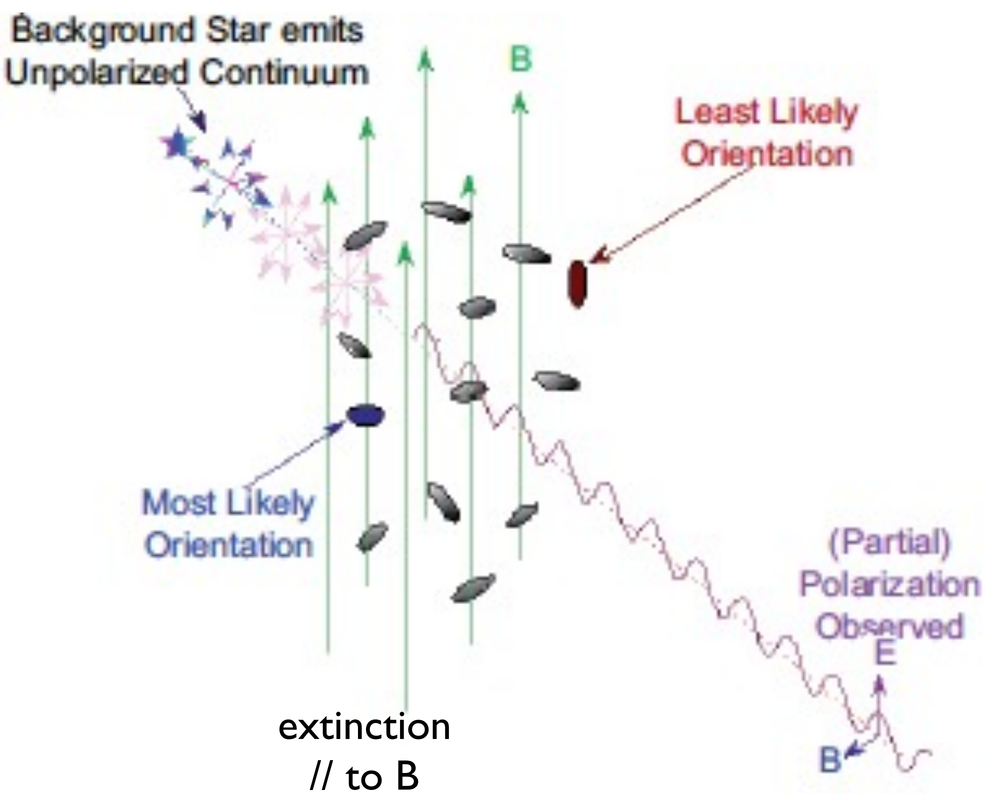
- Methods & data used
- All sky polarization at 353 GHz
- Highest dust polarization regions
- Comparison to starlight polarization
- Spectral variations of polarization fraction
- Spatial variations of polarization fraction
- Connections with large-scale MW B field, dust column density and small-scale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



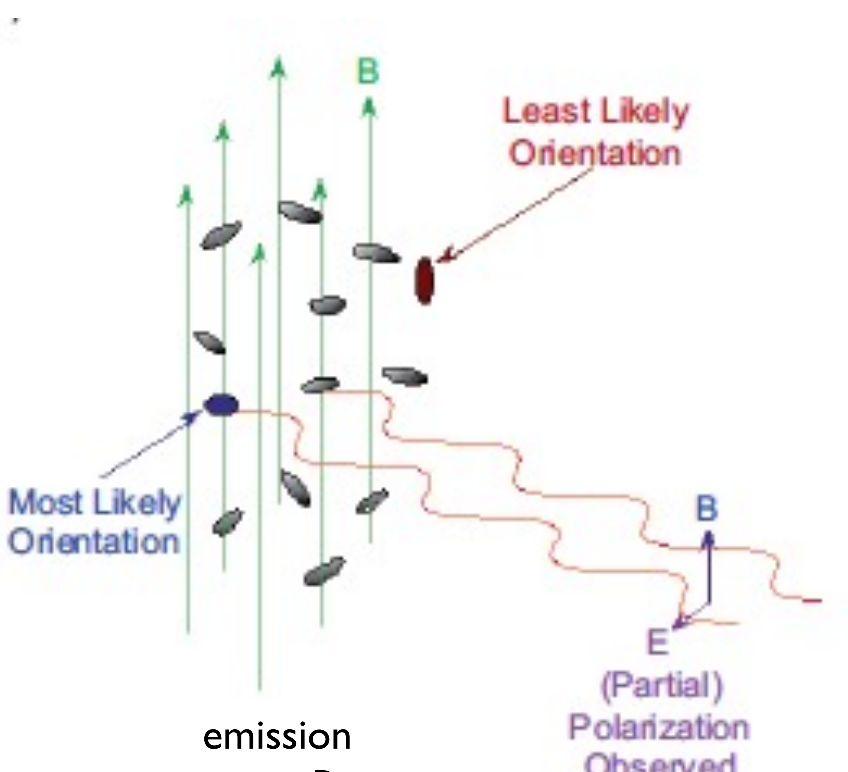
Planck Collaboration.

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

Dust Polarization



extinction
// to B



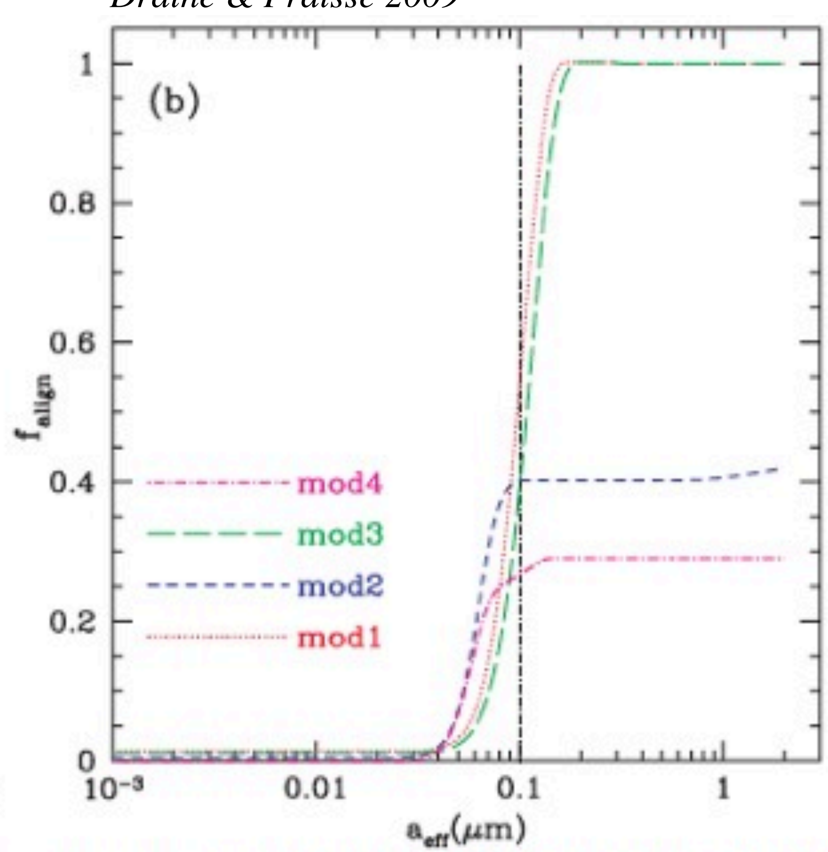
emission
$\perp$ to B

BG:
- Rotating, elongated and align partially on B
- Produce polarized emission & extinction
- Only large grains align

Possible alignment mechanisms:
- Paramagnetic relaxation alignment
- Radiative Alignment Torques (RATs)

Grain disalignment by:
- Gas/grain collisions
- Plasma drag

Draine & Fraisse 2009



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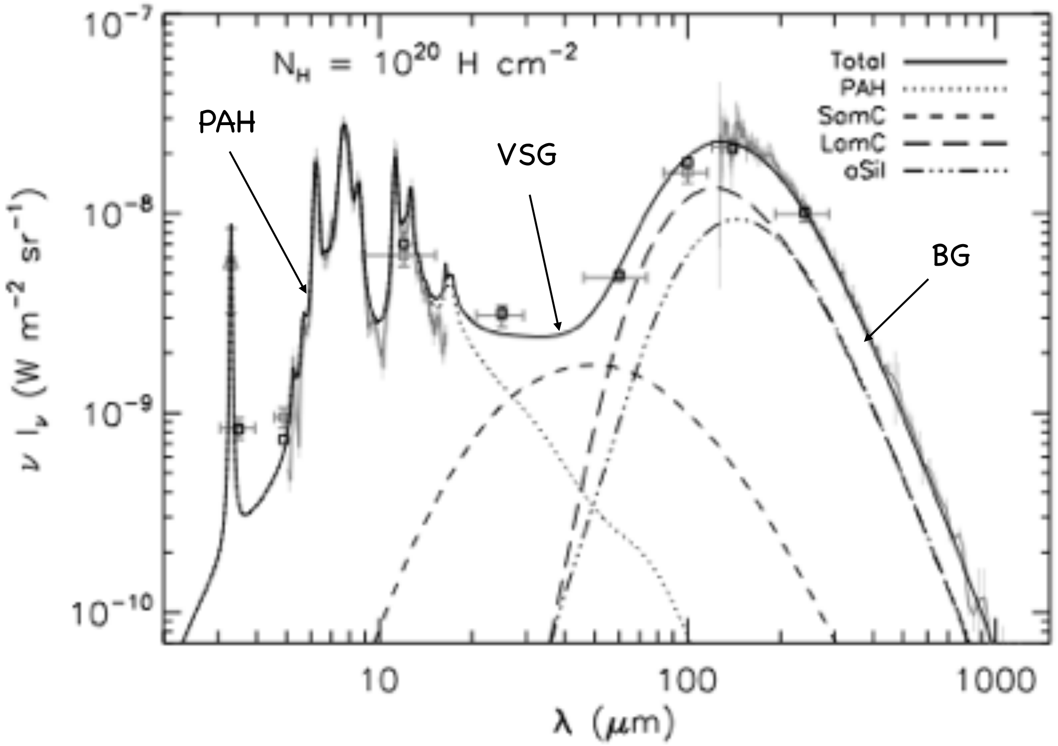
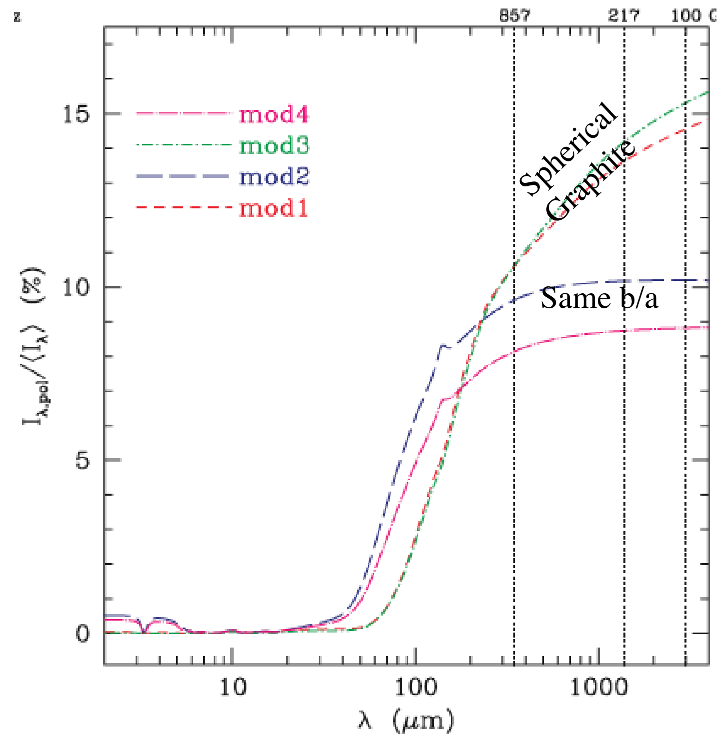
Compiegne et al., (2011)

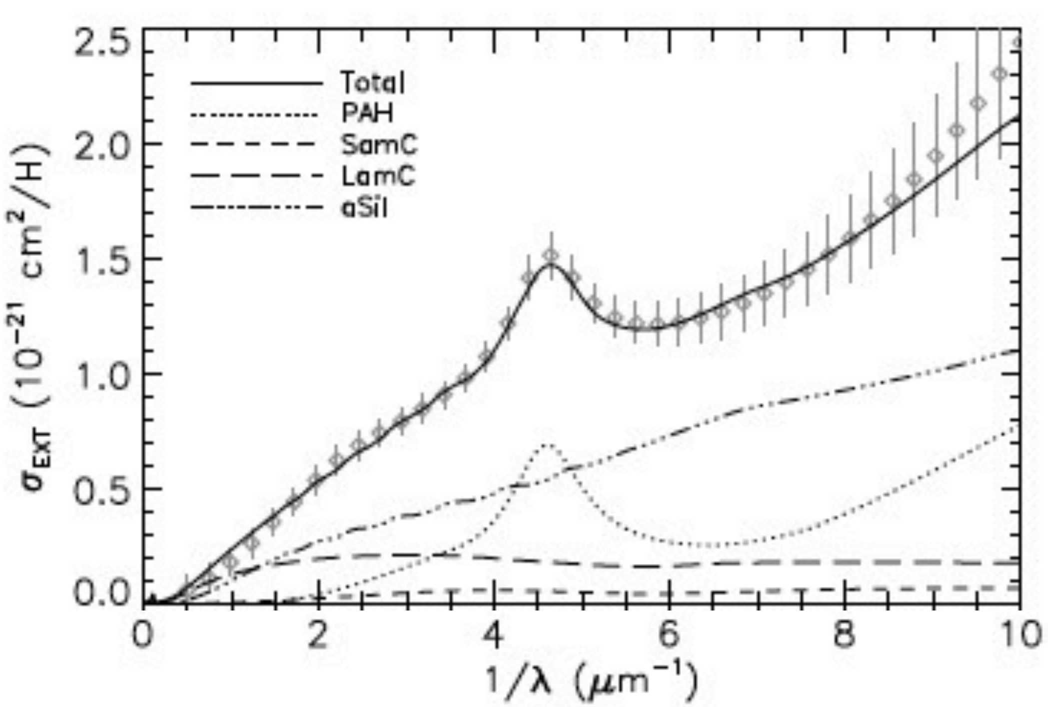


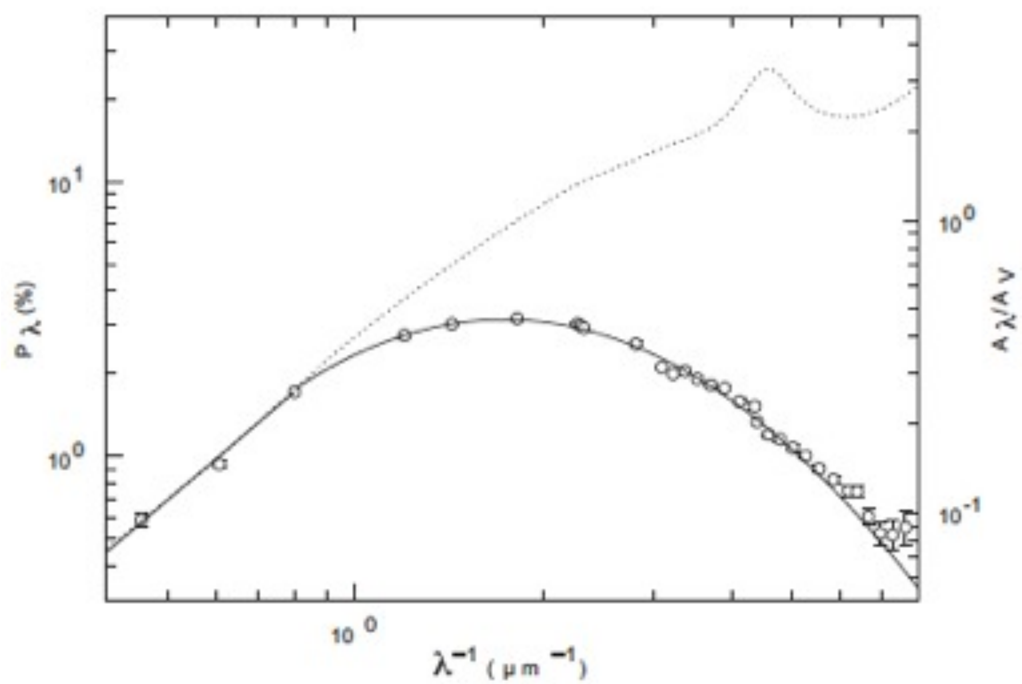
Draine & Fraisse 2009



polarization in emission is predicted ~10-15%

Compiegne et al., (2011)



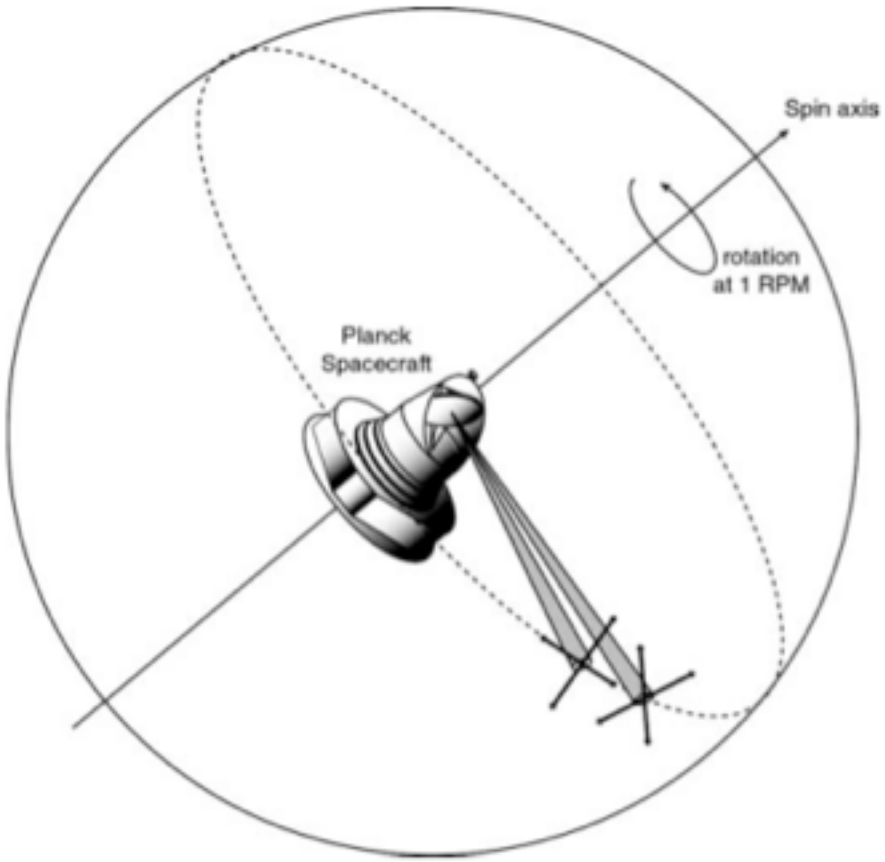


Various possible models lead to different predictions in polarization

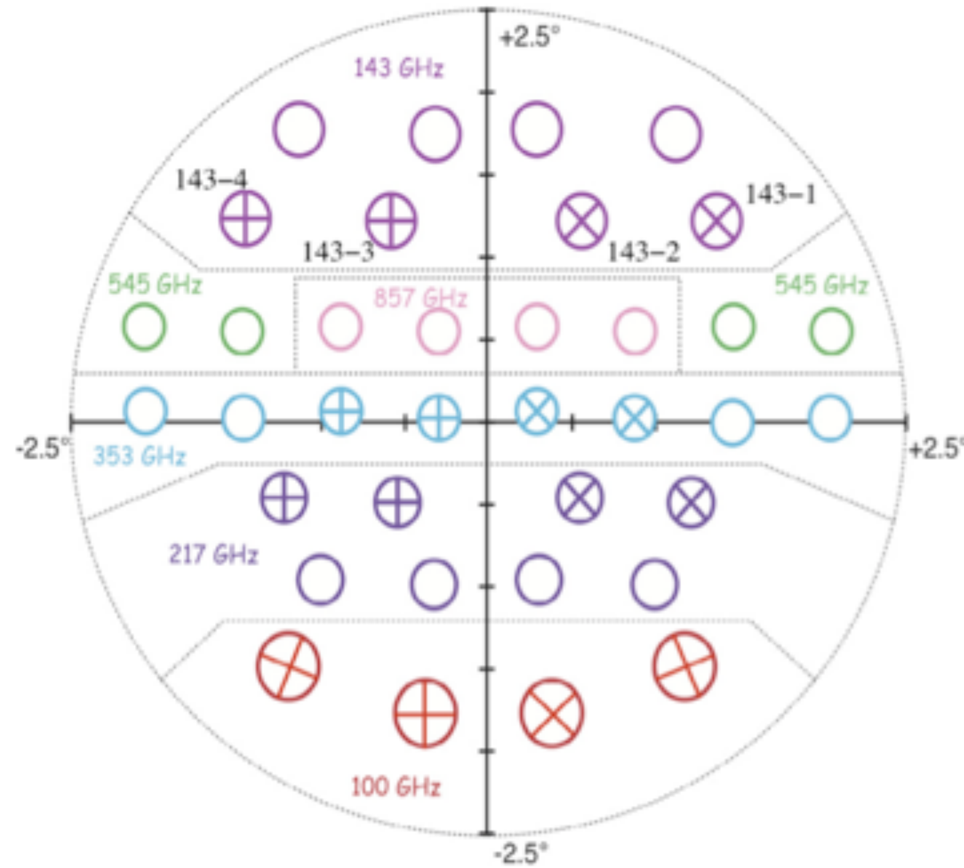
Variations of polarization fraction with frequency will help constrain dust models

From data to Stokes parameters

Planck scanning the sky



Planck/HFI focal plane



Derivation of Stokes parameters (I, Q and U) involves the combination of two pairs of PSB bolometers that observe the same sky positions within a few seconds. The polarizers of the second pair are rotated by 45° with respect to the first pair.

$$s_1 - s_2 = Q\ cos(2\alpha) + U\ sin(2\alpha)$$
$$s_3 - s_4 = Q\ sin(2\alpha) - U\ cos(2\alpha)$$

Multiple scans and multiple surveys provide Q and U measurements with different α orientation. Maps of Q and U and their standard deviations are inferred from the multiple measurements.

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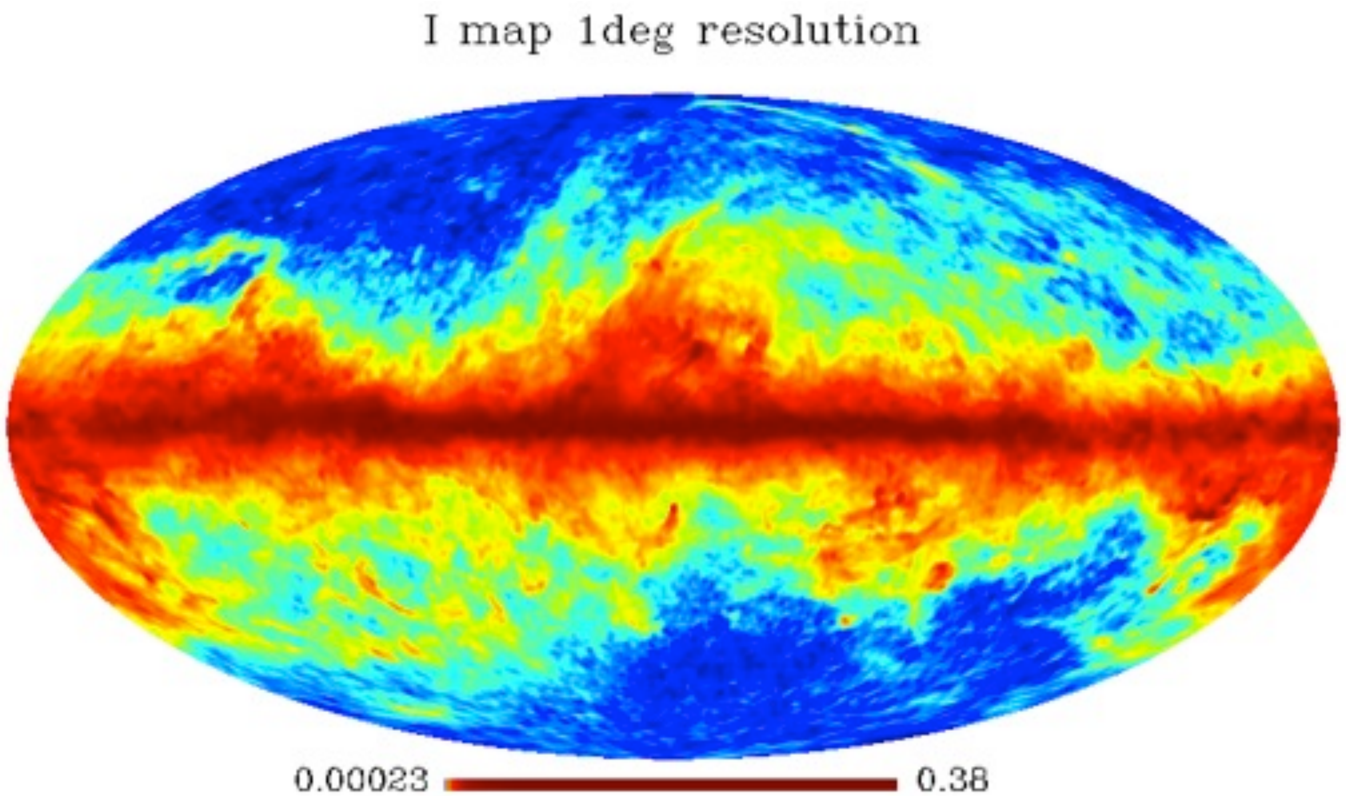
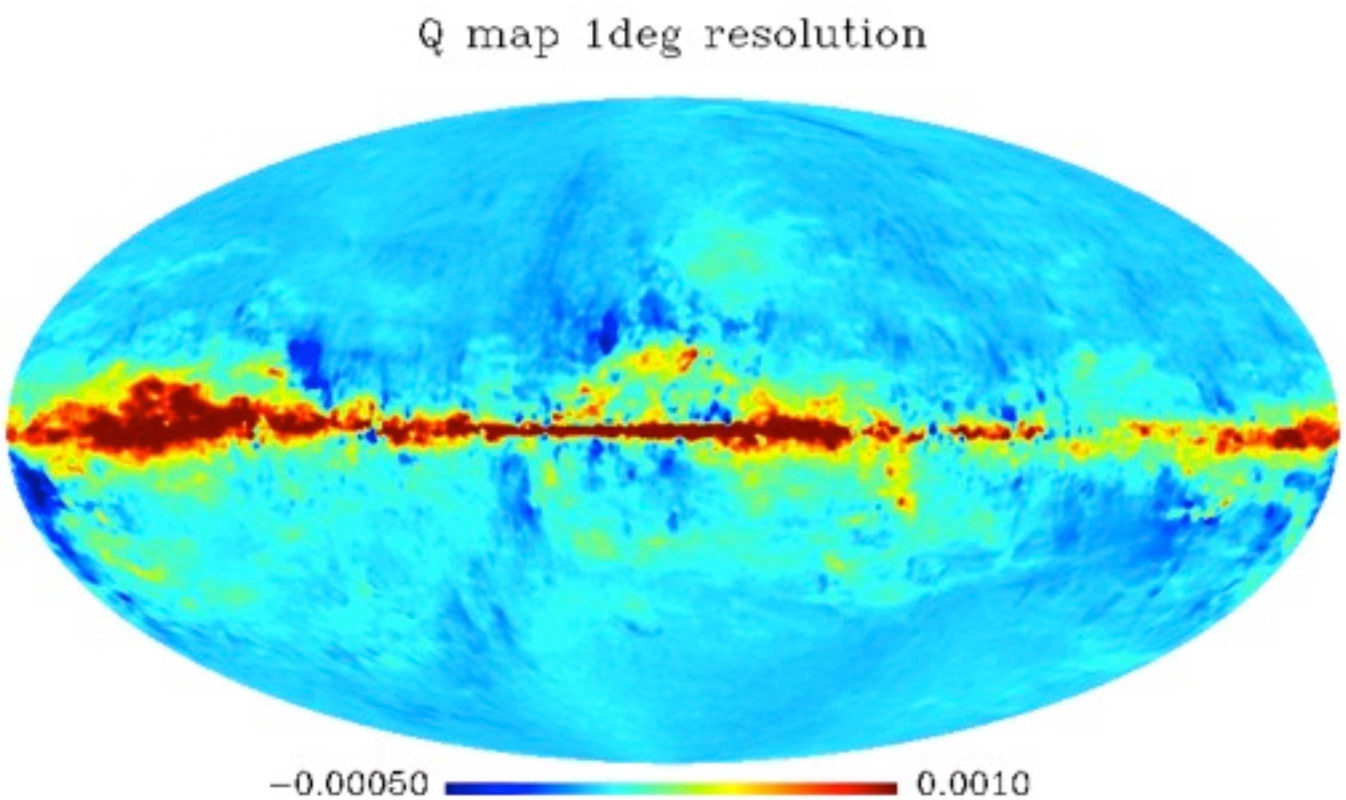
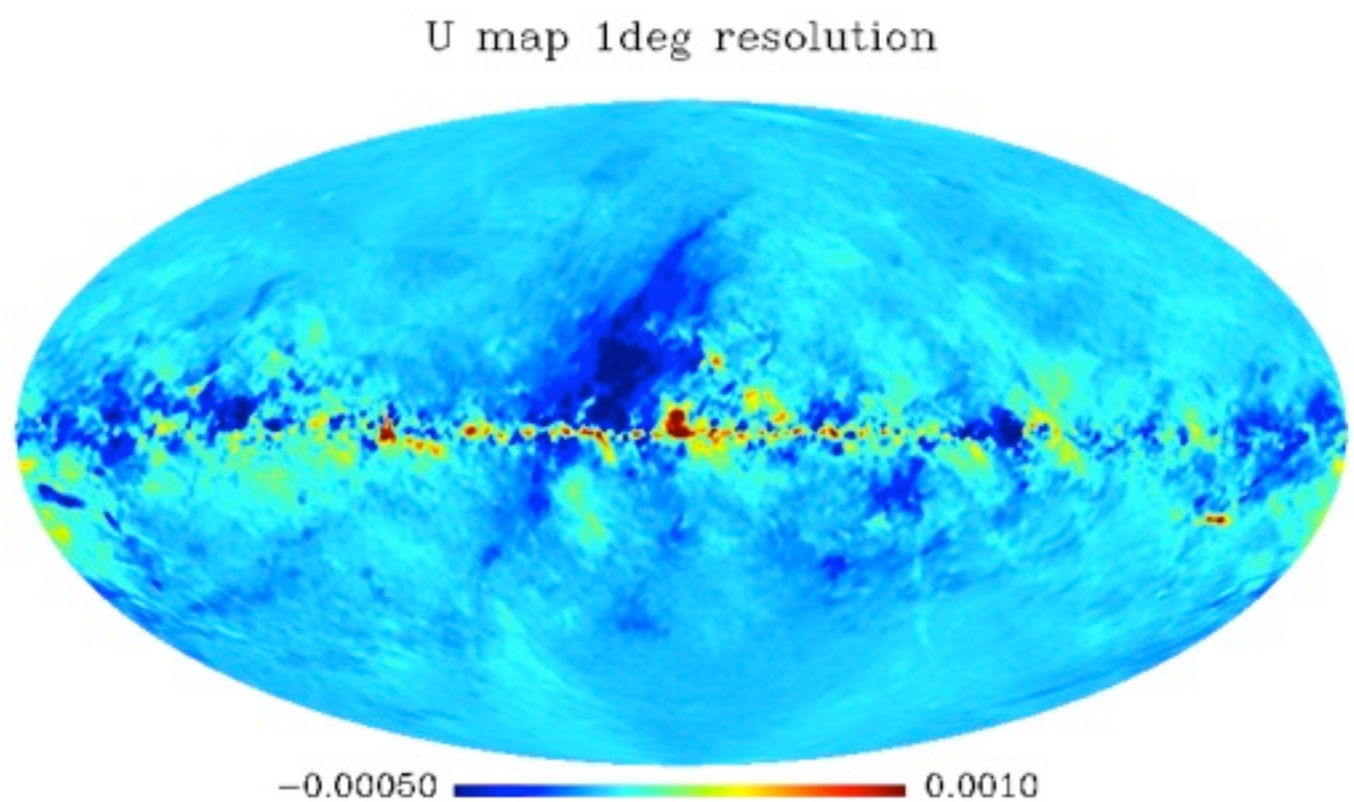
The dust polarization sky at 353 GHz



- First all sky maps of dust polarization.
- The data provides the sensitivity to image the polarization of dust emission over the whole sky
- Complementary to observations of stellar polarization which provide detailed information on smaller angular scales





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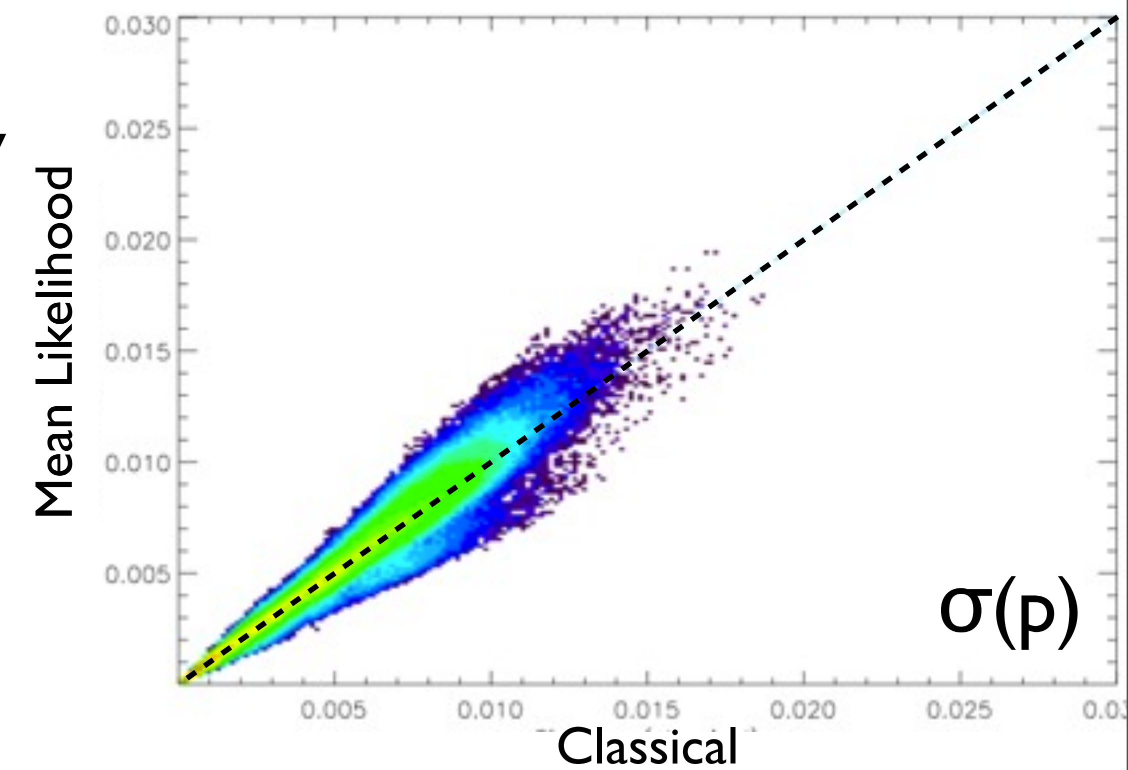
- DX9 at 353 GHz
- Dust Band-Pass Mismatch correction using sky coefficients and Planck dust map at 353 GHz
- No CO Band-Pass Mismatch correction

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

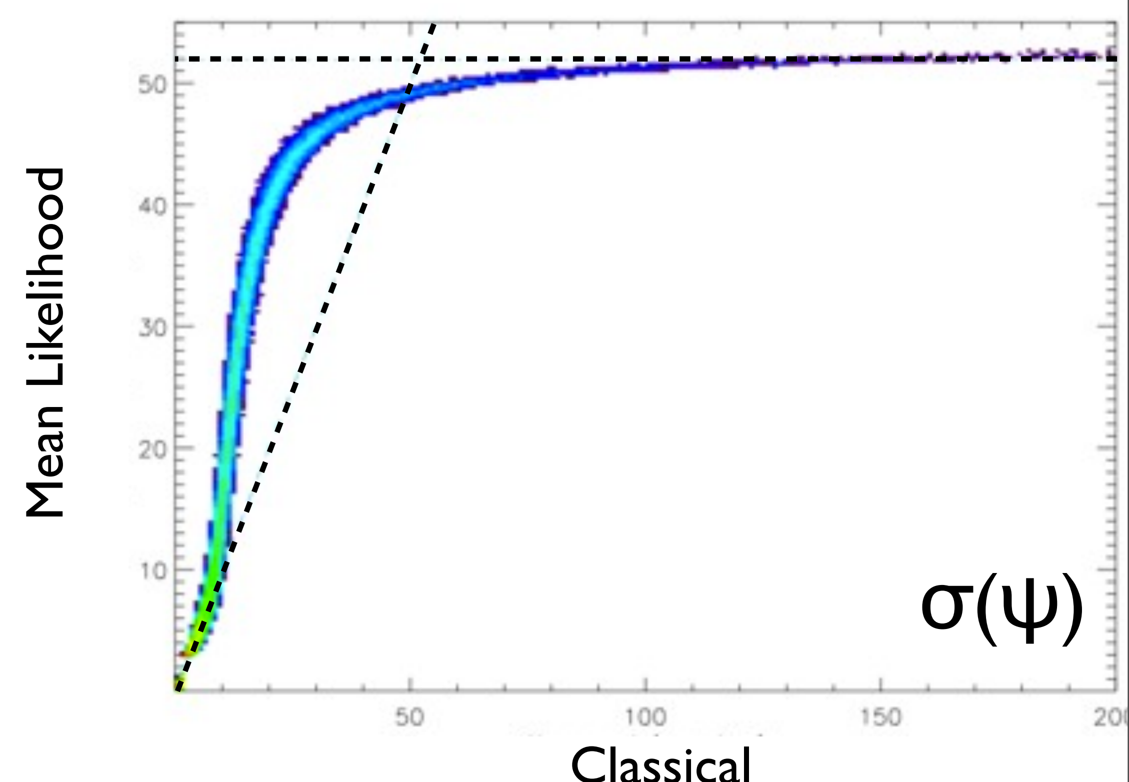
- p is biased in the presence of noise on Q,U



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

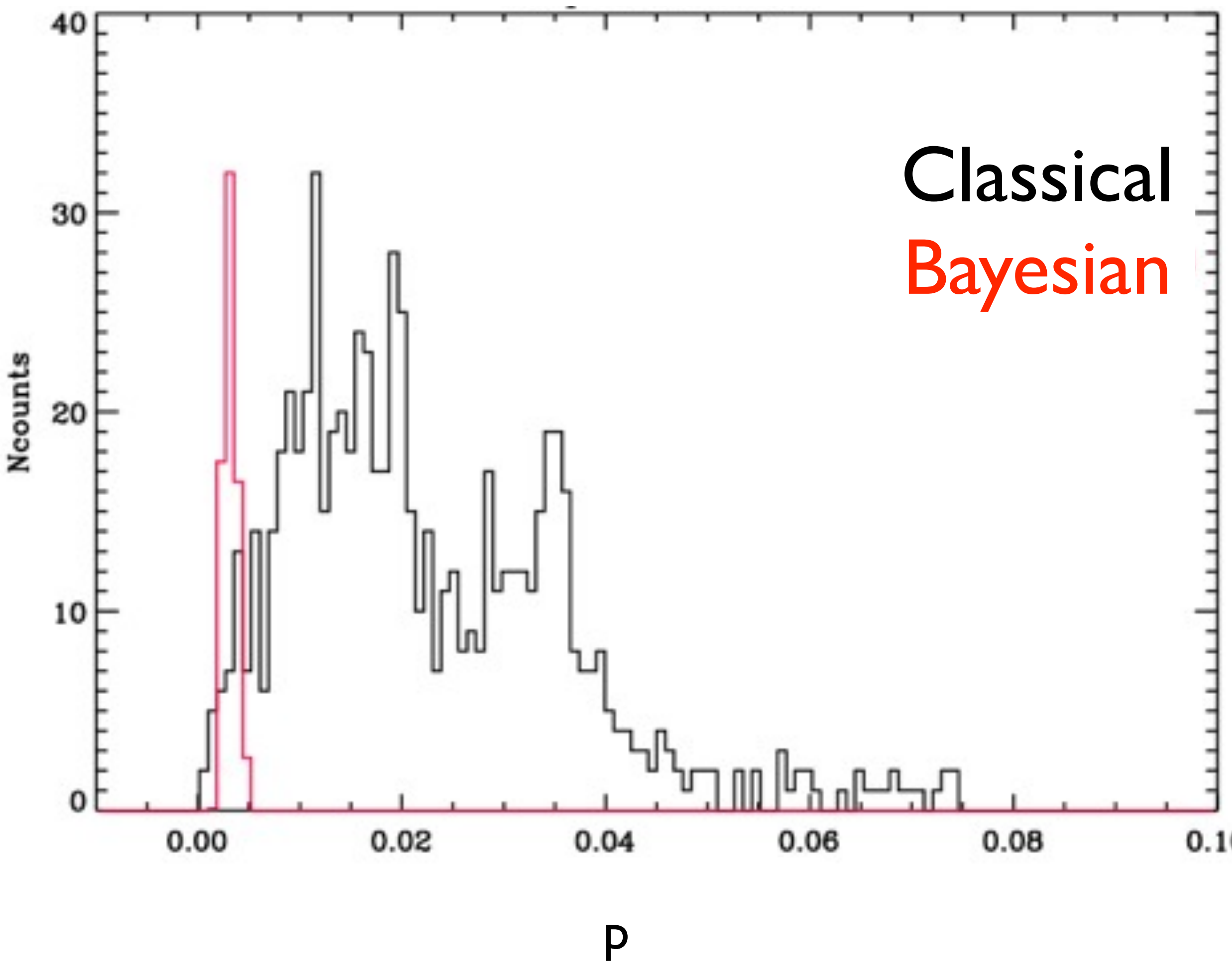
$$p_{db}^2 = \frac{\sum_{i>j} Q_i Q_j + U_i U_j}{\sum_{i>j} I_i I_j}$$

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

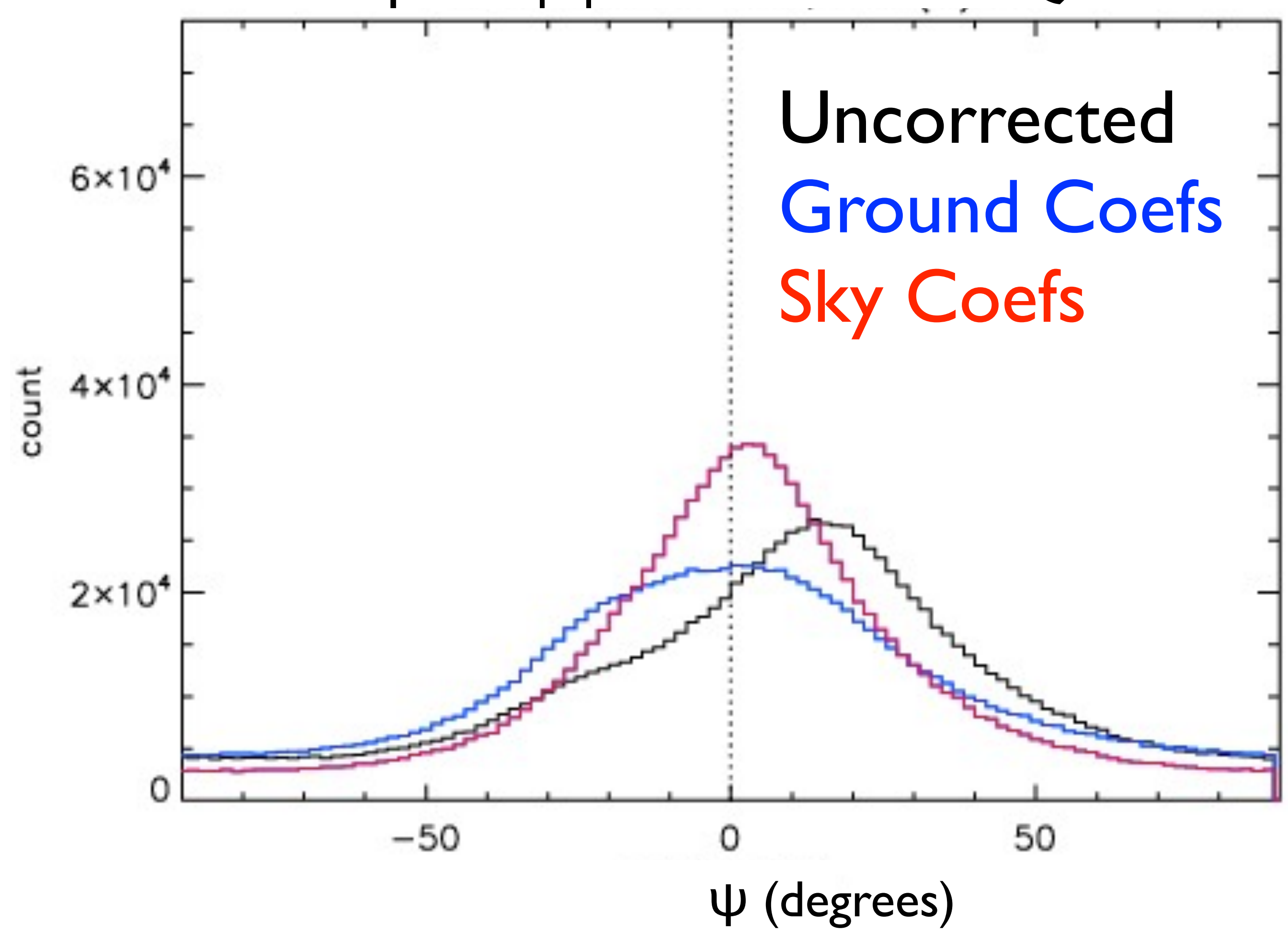


- Apparent polarization consistent with p=0 at high |b| where CIB dominated
- Dust Band-Pass Mismatch correction consistent with psi=0° in MW plane (4 quadrants)

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

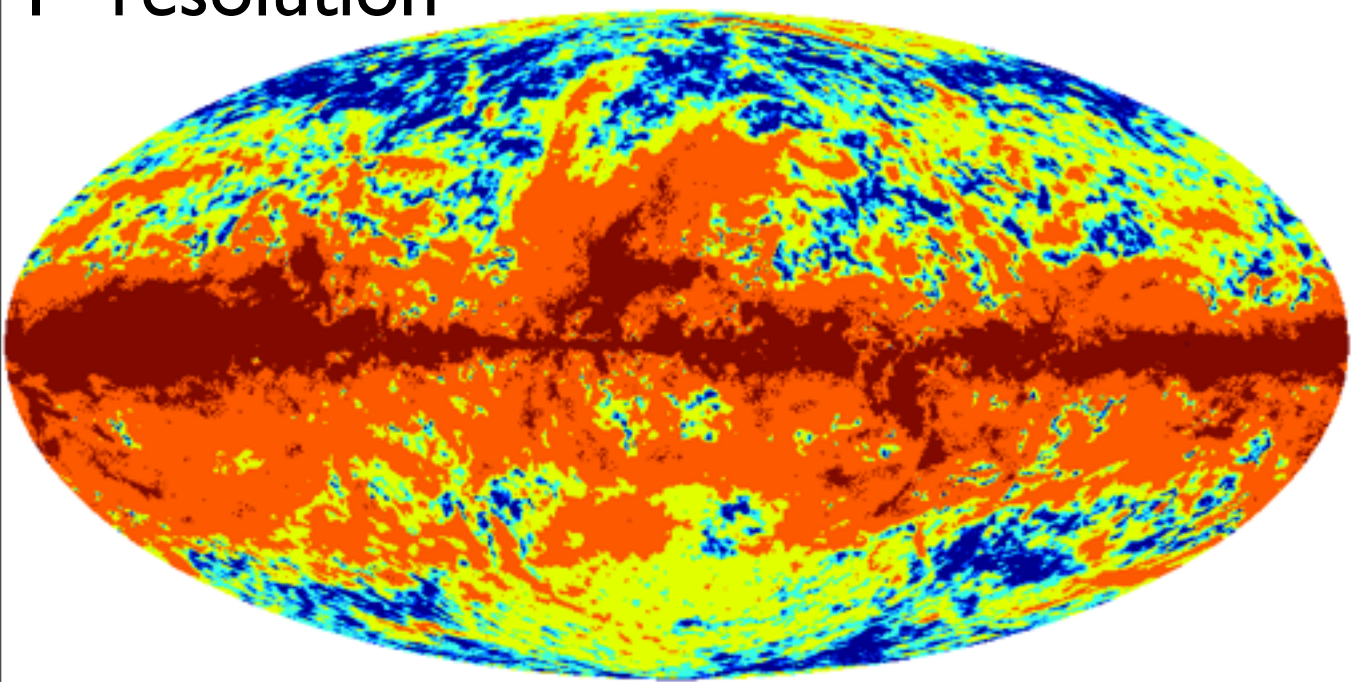


Histogram of polarization angle
in MW plane |b|<5° 4th Galactic Quadrant

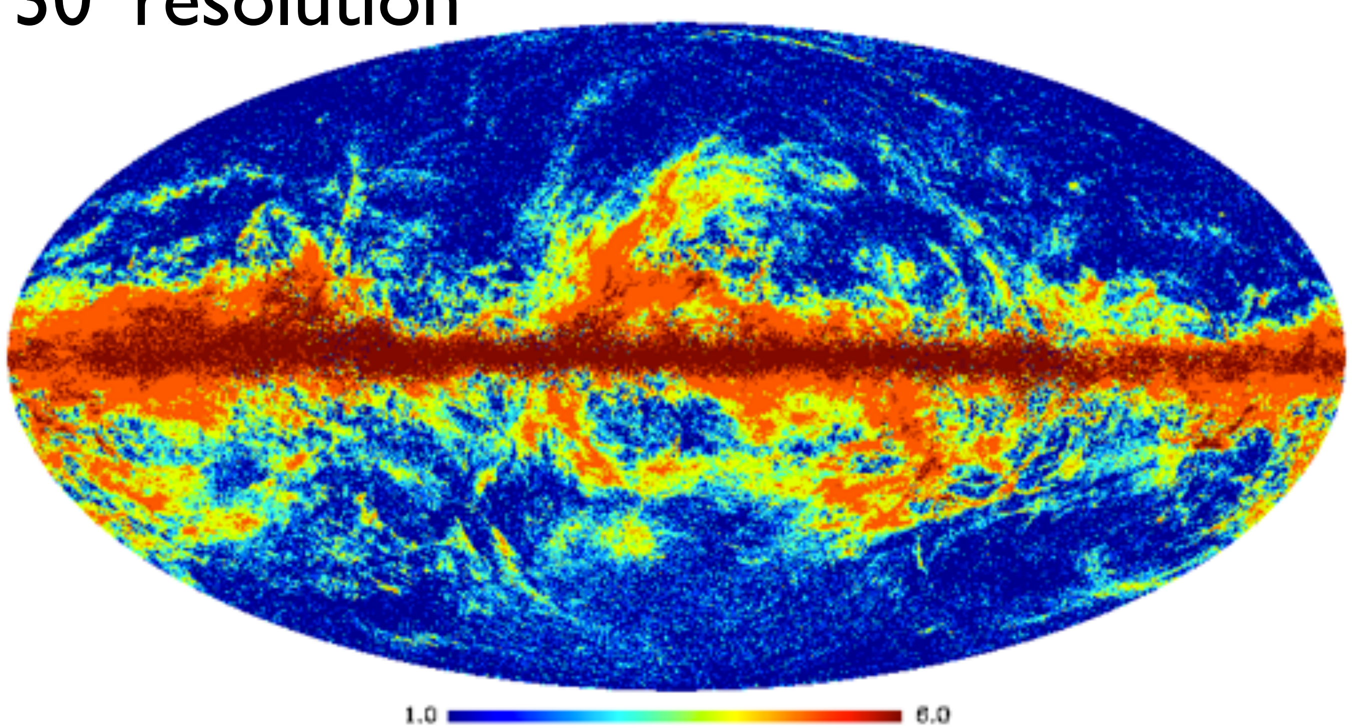


maps of SNR on p

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 %

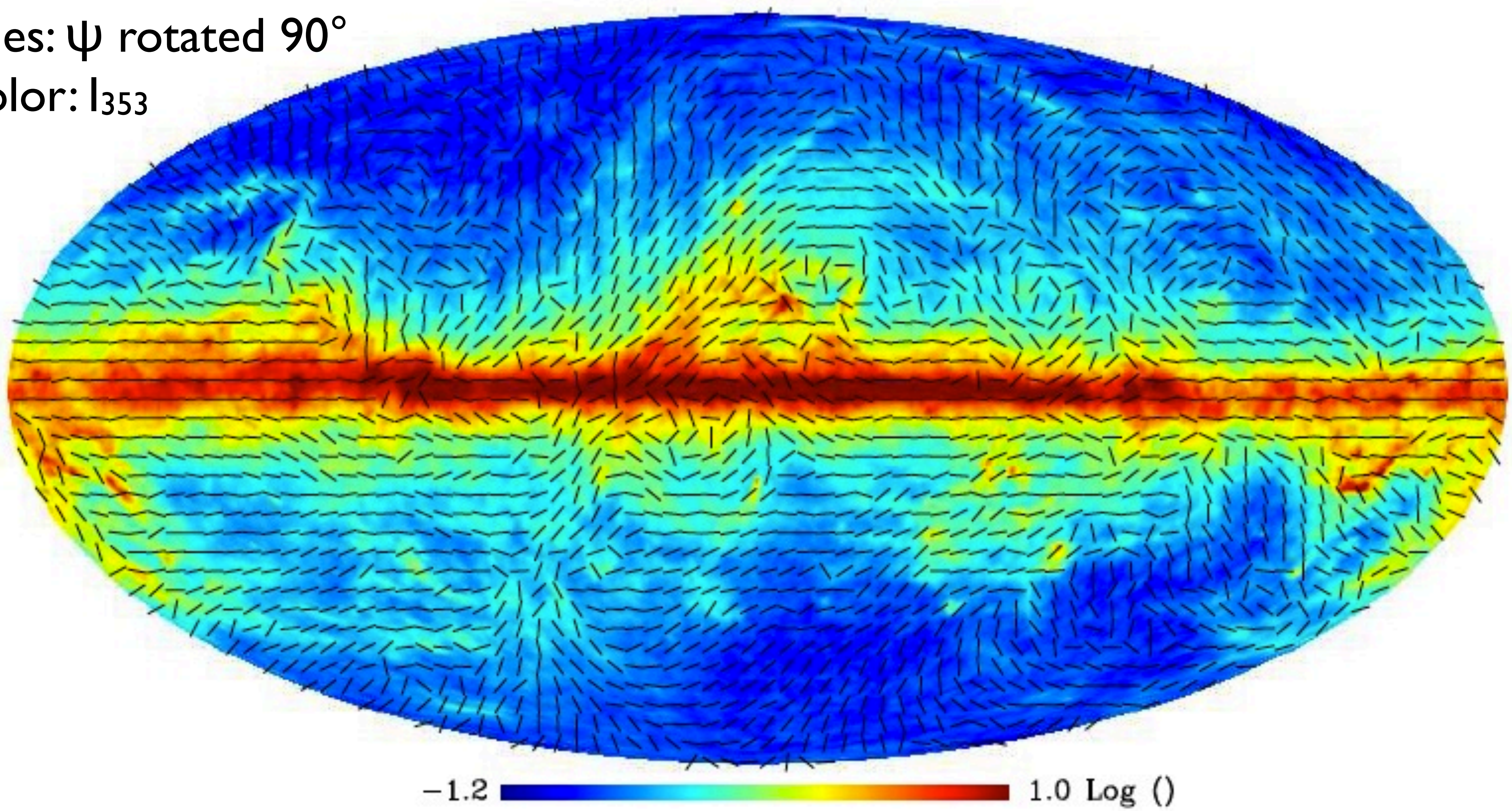
- Work at 1° resolution to lower noise (also 7', 14', 30')
- Smoothed noise cov. matrix using MC simulations

B field direction at 353 GHz, 1° resolution

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

lines: ψ rotated 90°

color: I_{353}



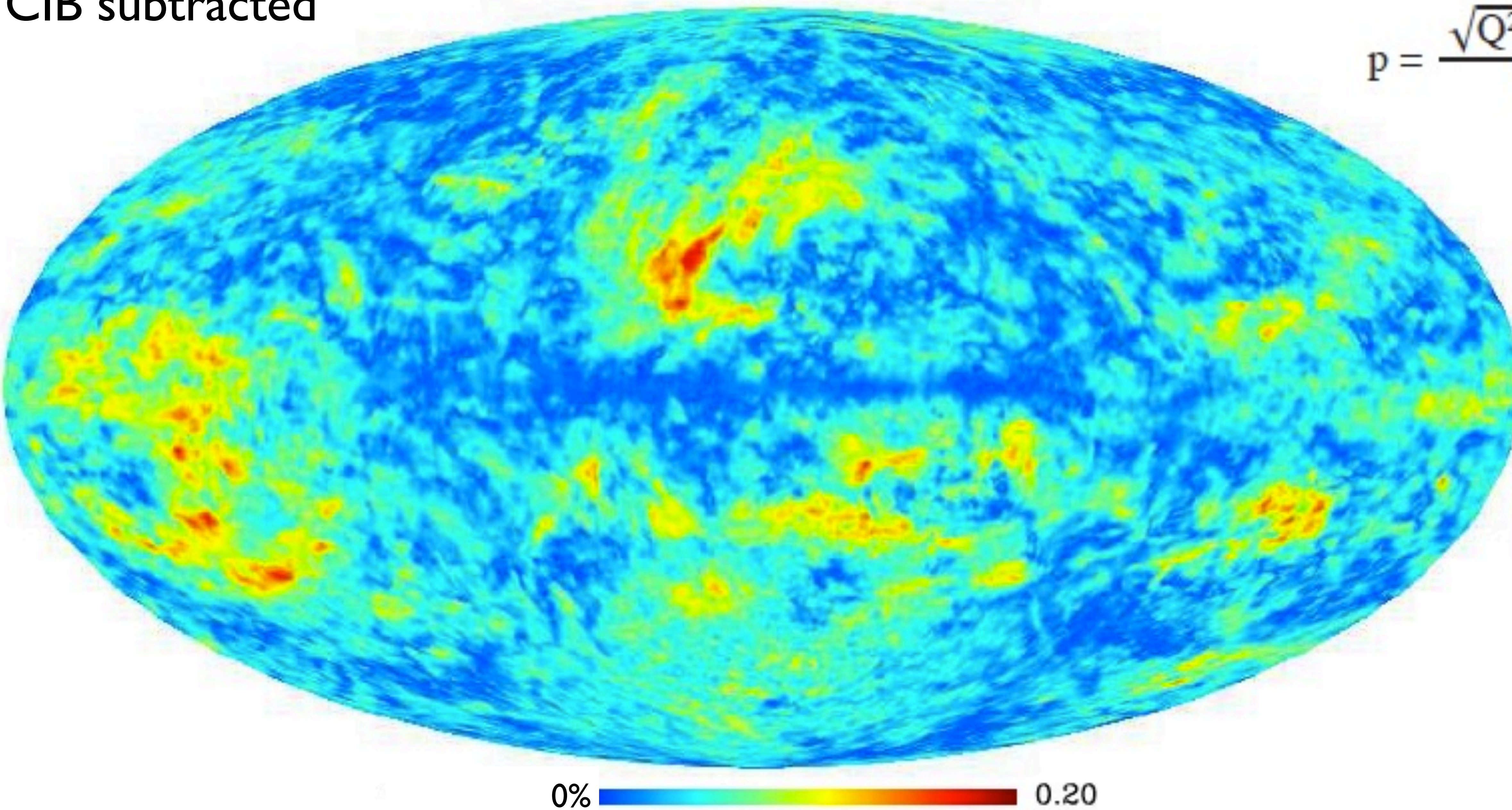
Field direction consistent with B in MW plane

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

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%

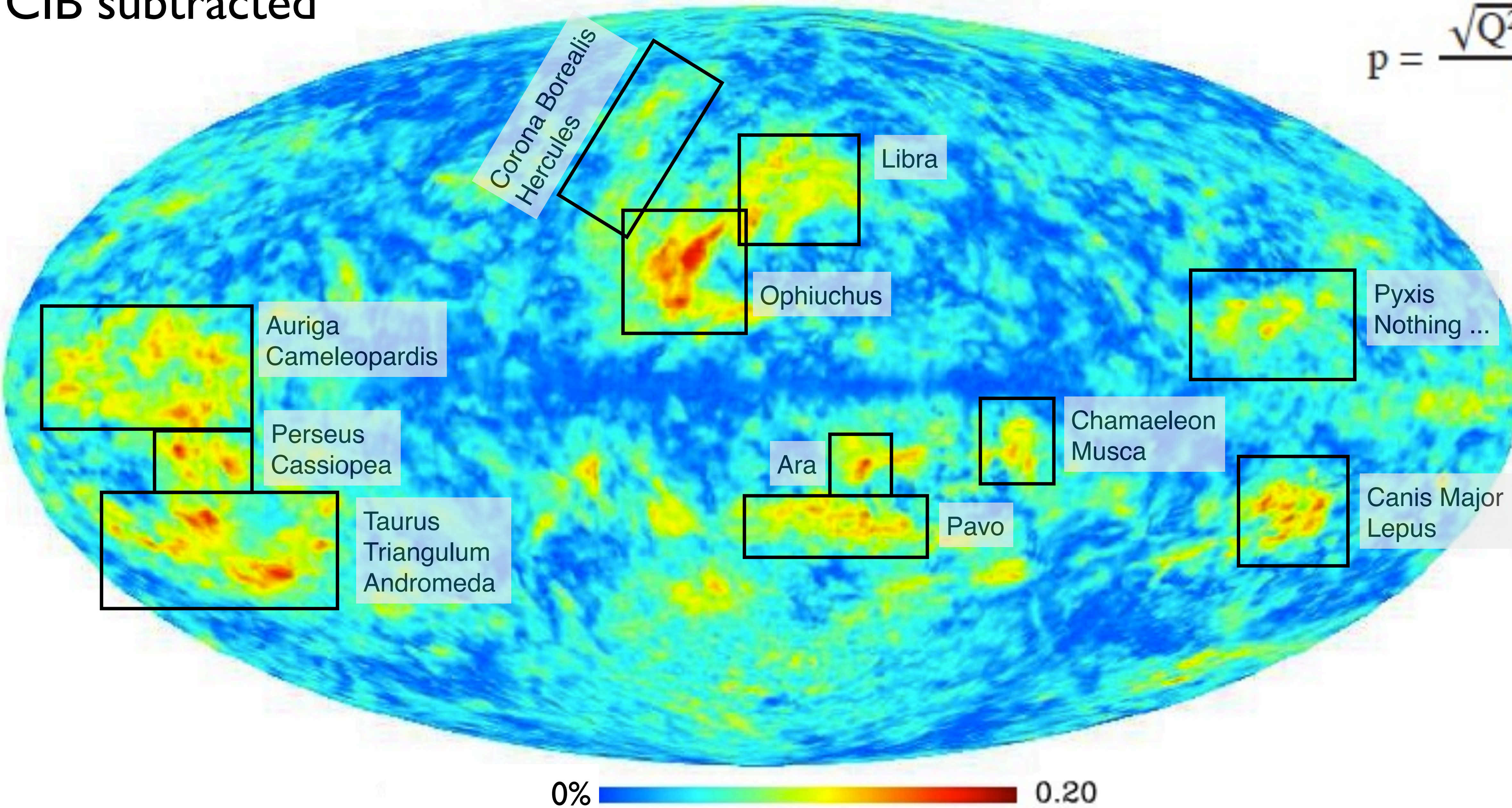
Low p values in inner MW plane

Large p values in outer plane and intermediate latitudes

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

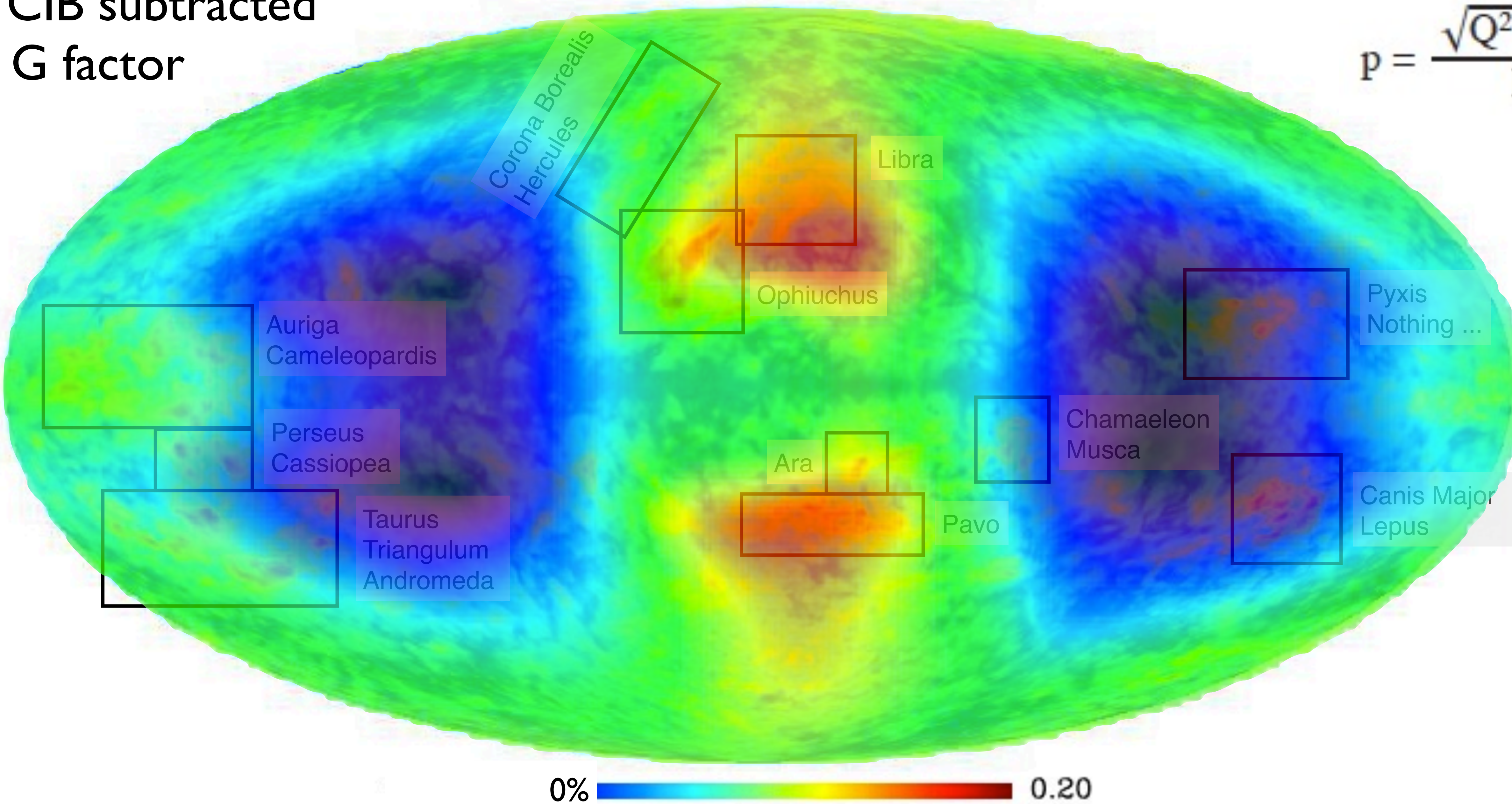
Large p values in outer plane and intermediate latitudes

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

Not CIB subtracted

PSM G factor

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

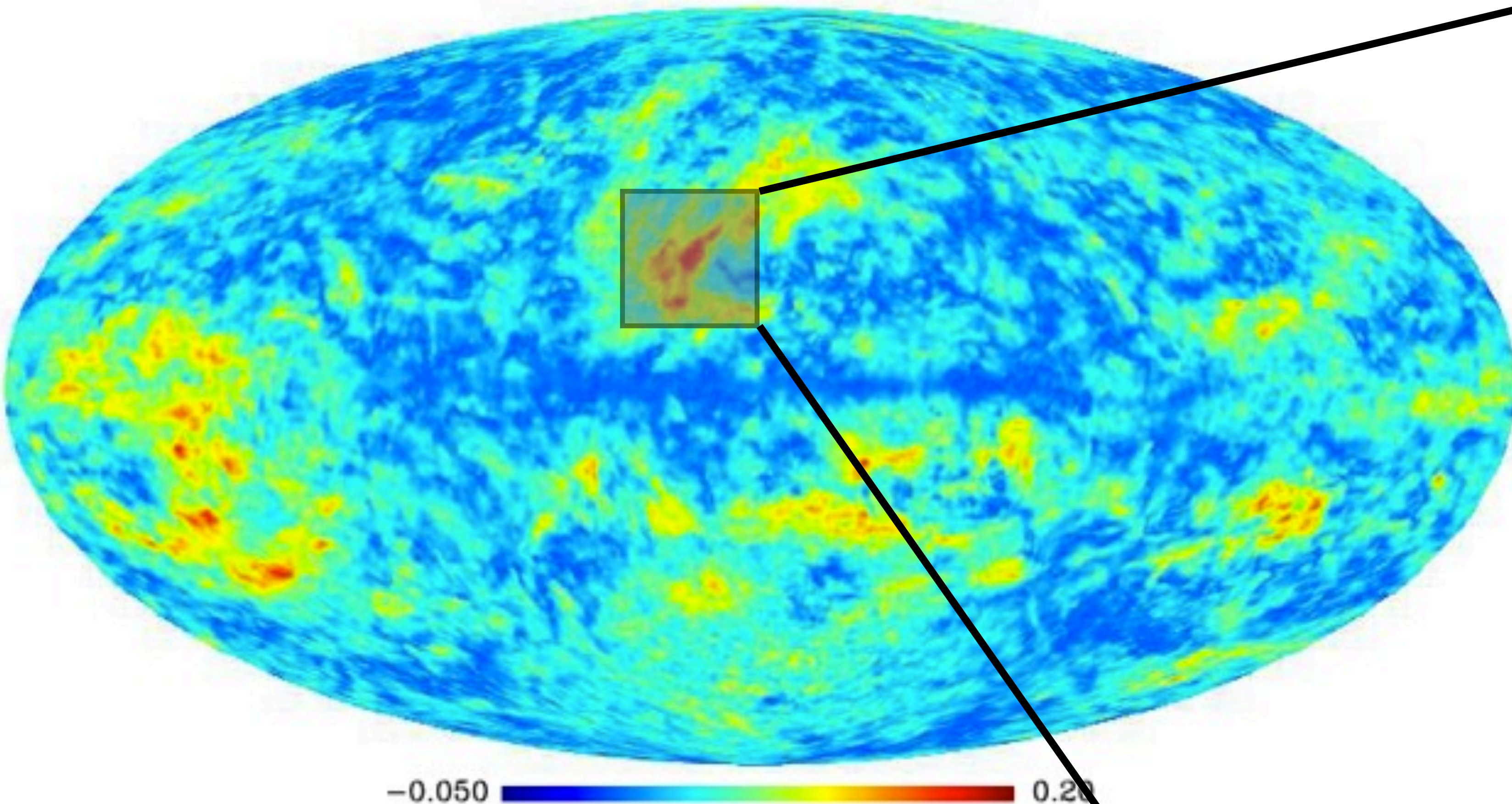


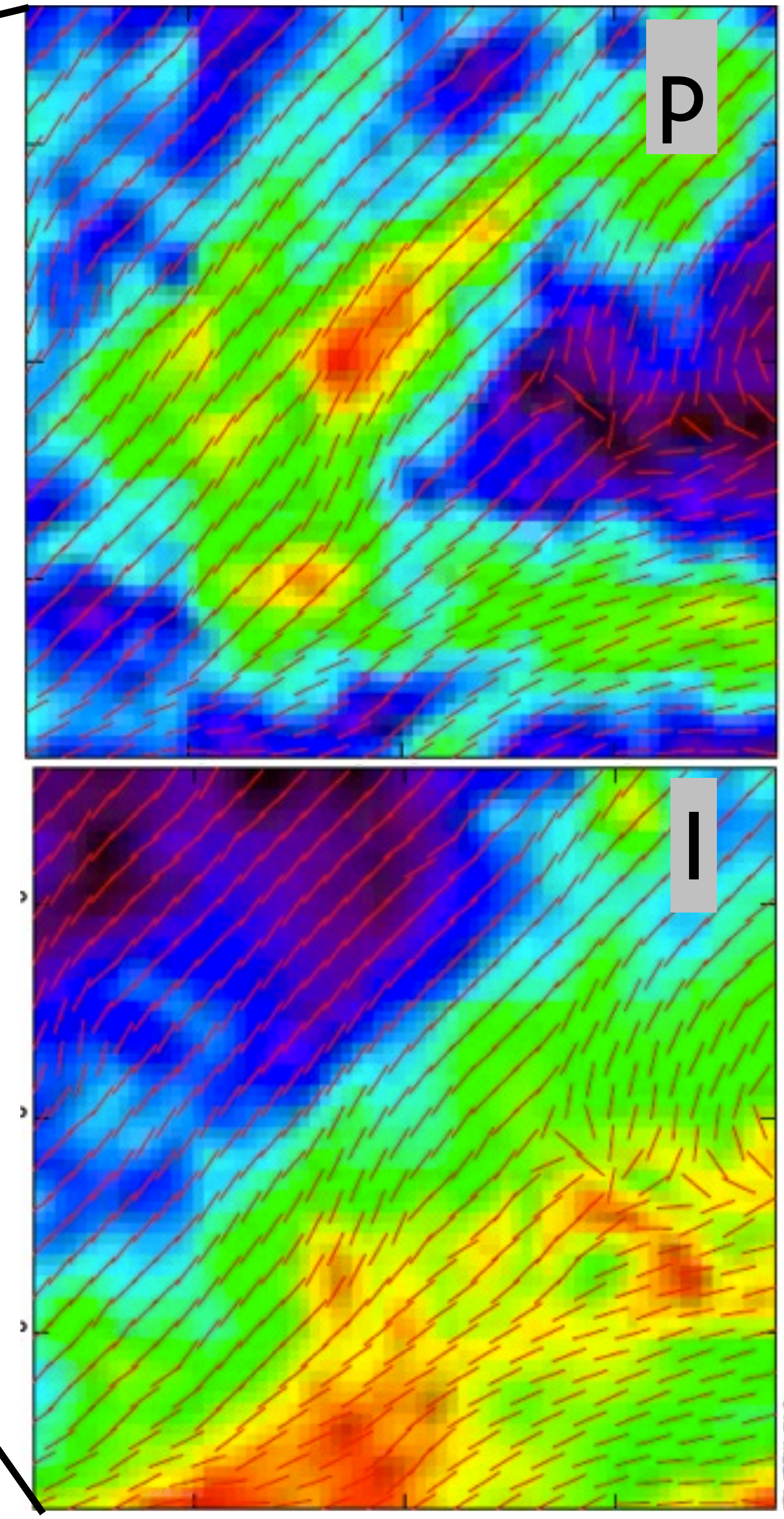
p ranges from 0 to ~20%

Low p values in inner MW plane

Large p values in outer plane and intermediate latitudes

Large scale variations similar to MW B-field structure

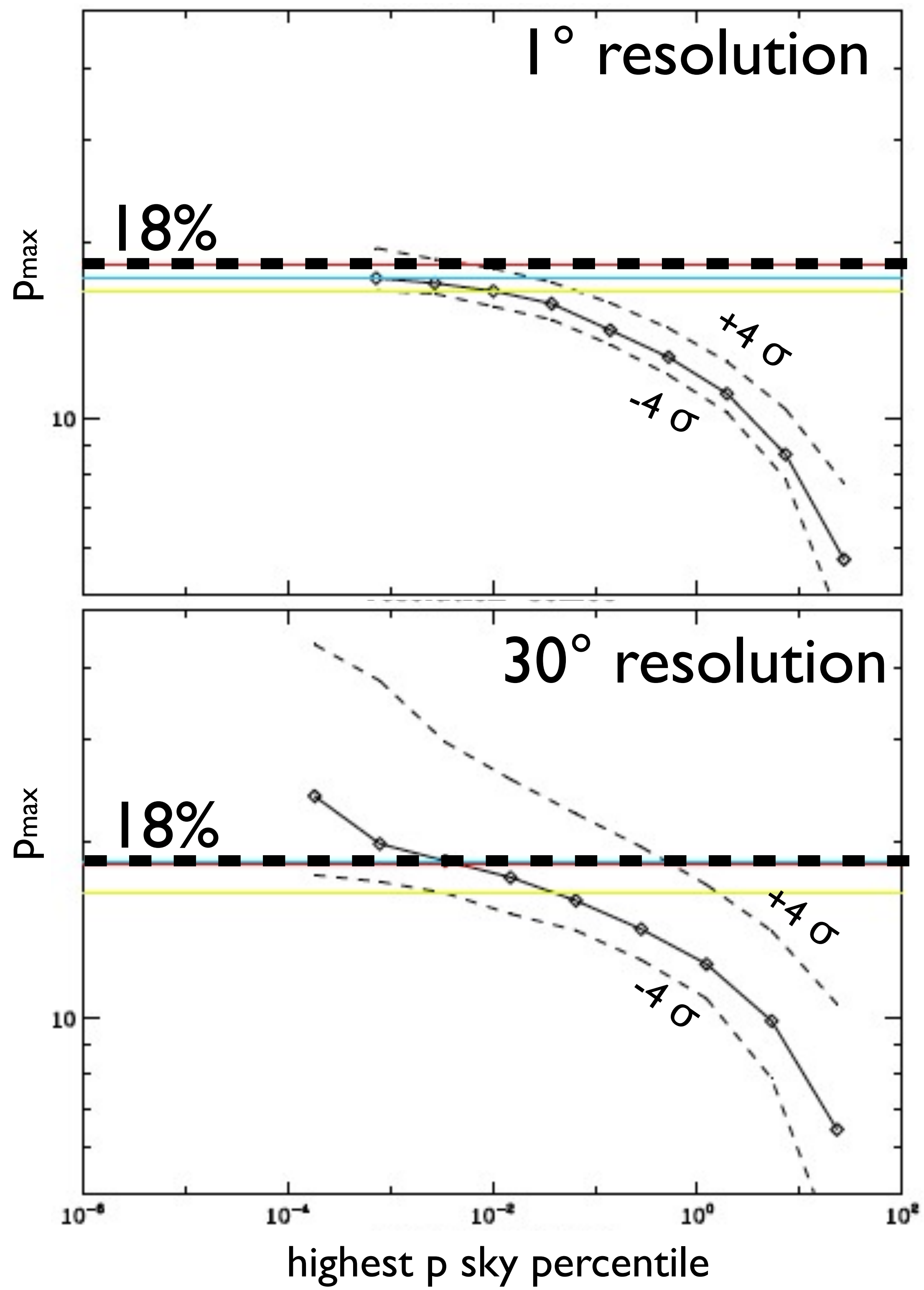




Highly polarized regions:
- found in homogenous field regions
- often at edges of intensity structures

Some of these have little to no intensity counterparts

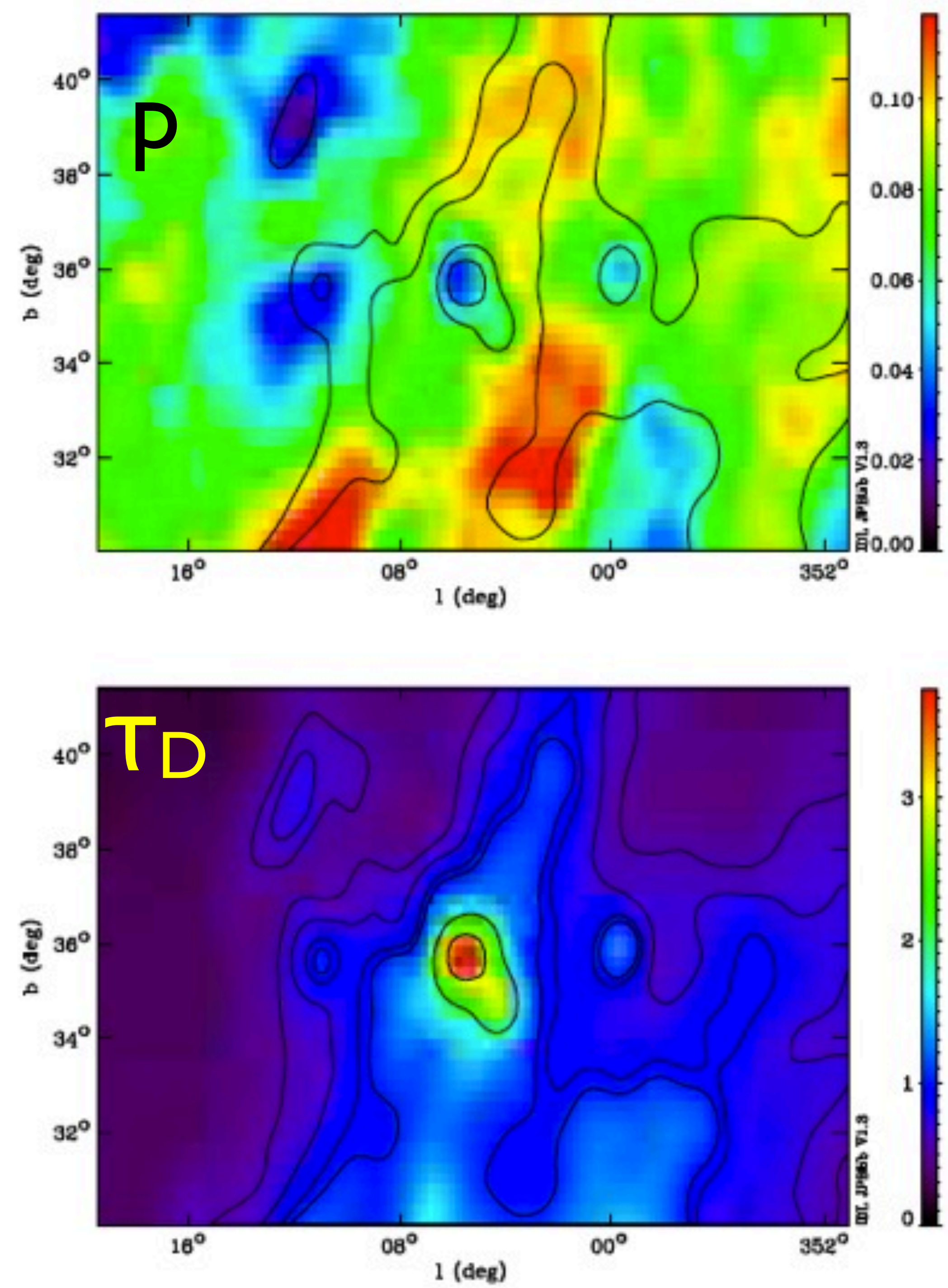
The sky looks different in polarization !!

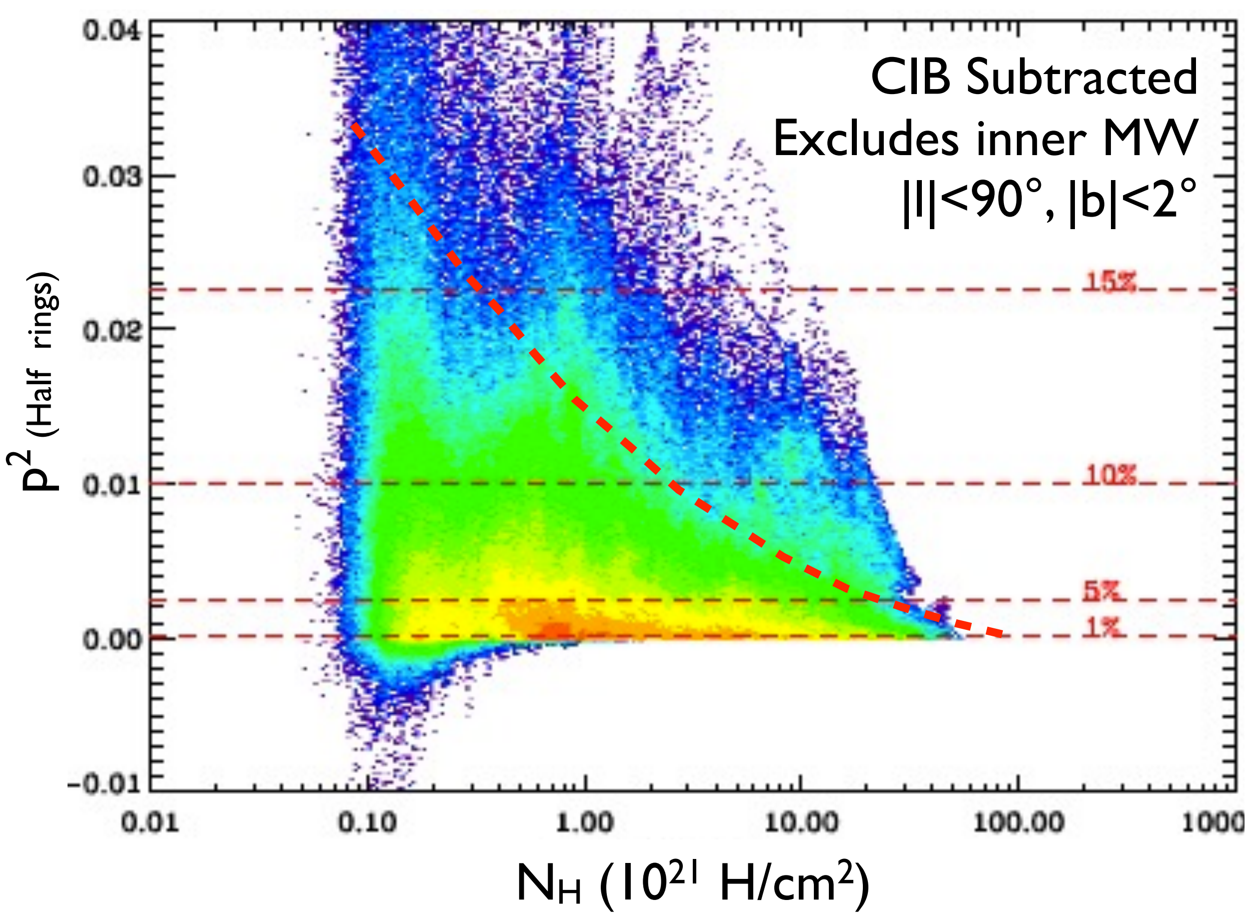


- Maximum dust polarization fraction is an important for dust modeling and component separation
- Planck maps at various resolution indicate pmax>18% at 353 GHz, taking uncertainties (4-σ) into account
- This level is reached in the Aquila rift and other similar regions
- This is only a lower limit
- 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
- Large scatter probably due to field geometry

Example in L134





Comparing polarization fractions in emission and extinction

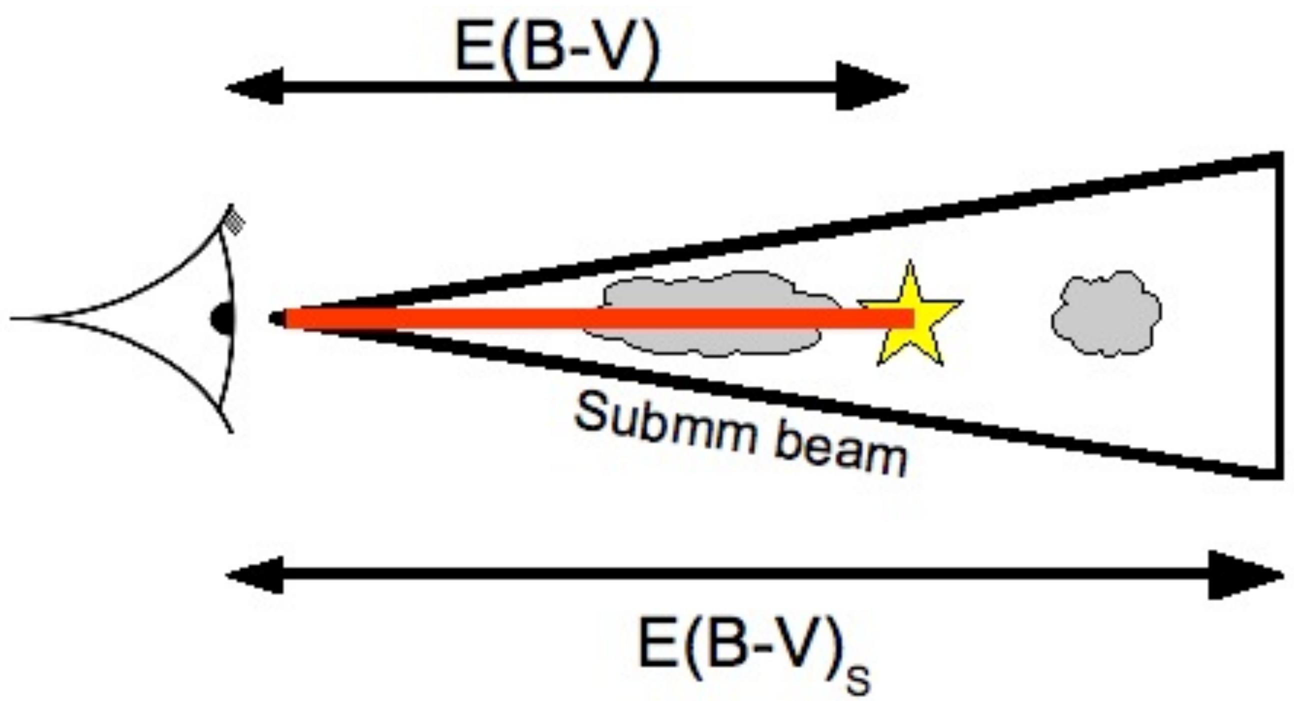
Extinction @ Vband : p/τ | Emission @ 353GHz : P/I

Large grains

dependency on the column density is removed

Pencil beam measurement *vs* Large beam integrated measurement

Foreground to the star *vs* Total line of sight emission



➪ **Select lines of sight with little background**

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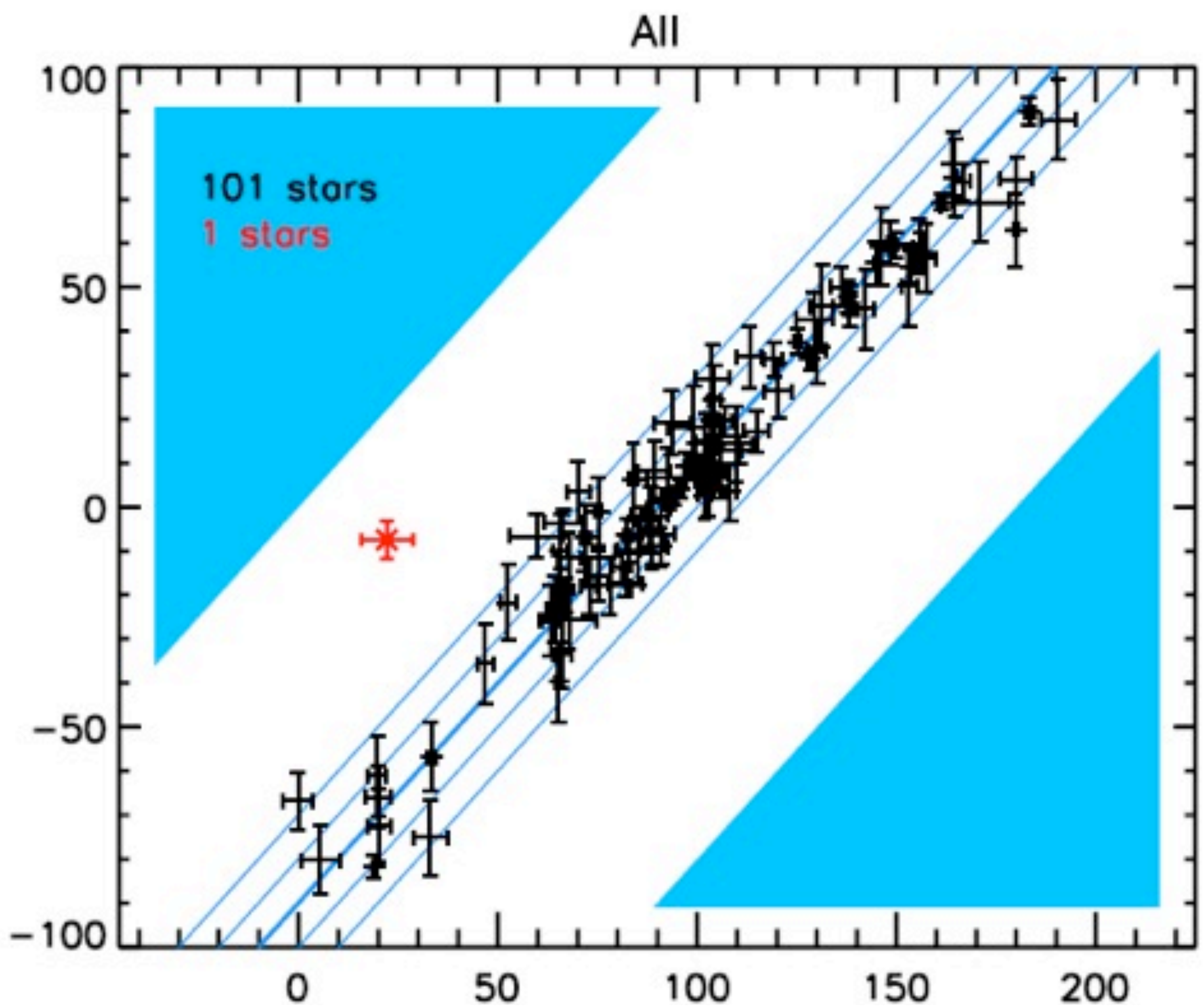
Dynamics in angles for our selected stars

4. Agreement in polarization angles : | θ_s - θ_V | < systematic + noise

We take : systematics = 20° (compromise between nb of stars selected and accuracy of selection). Not crucial (same polarization ratio with systematics = 10° or 5°).

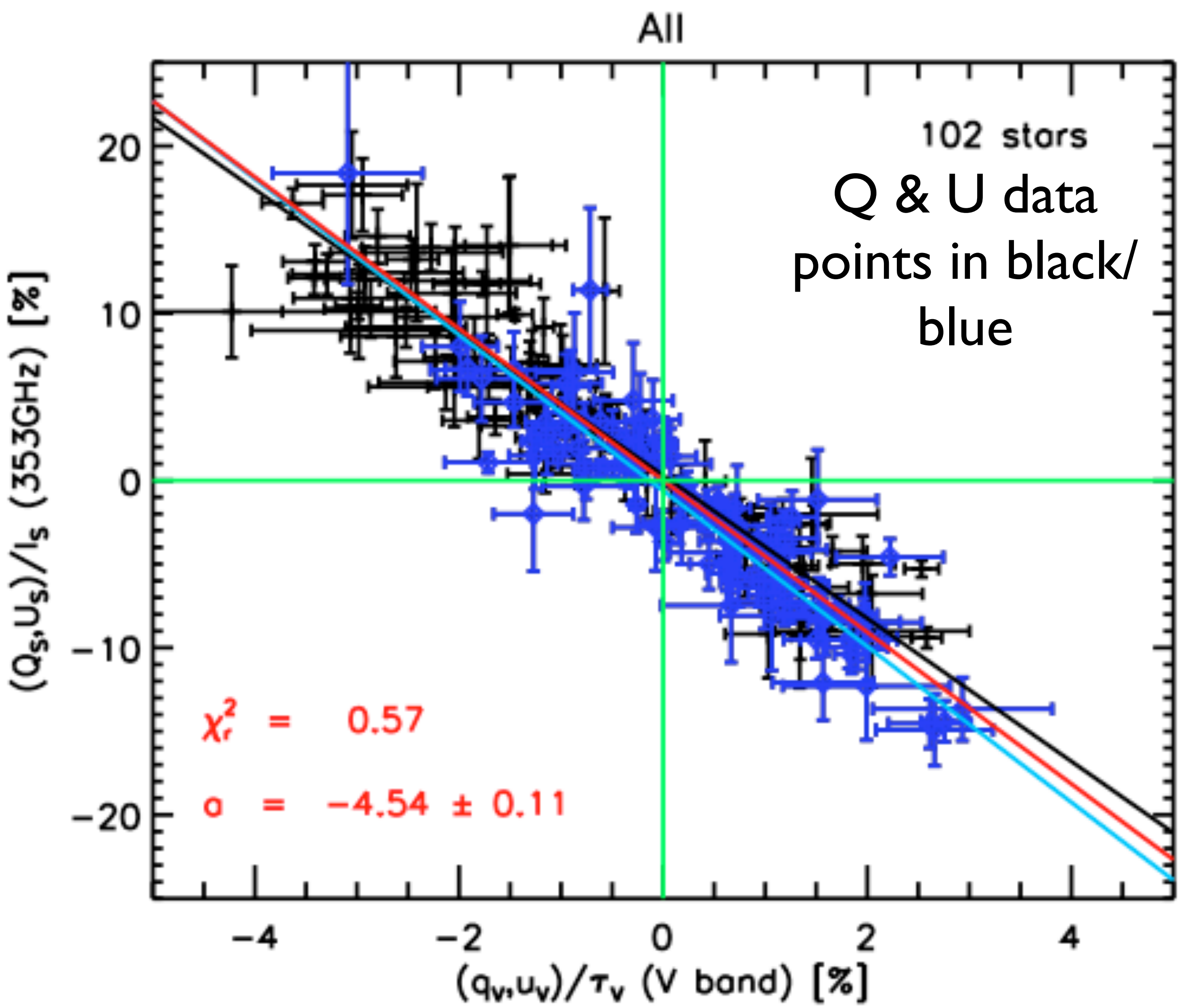
Polarization angle @ 353GHz (deg)

θ_S



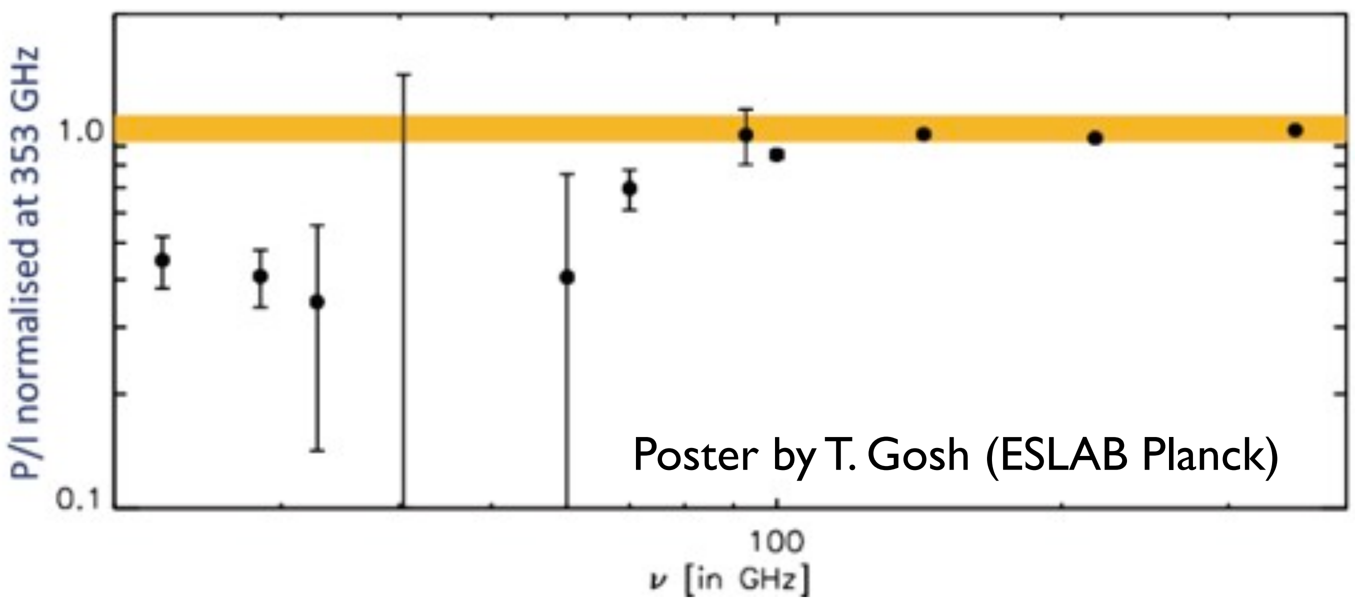
Polarization Angle in the visible (deg) θ_V

Comparison with stellar polarization data

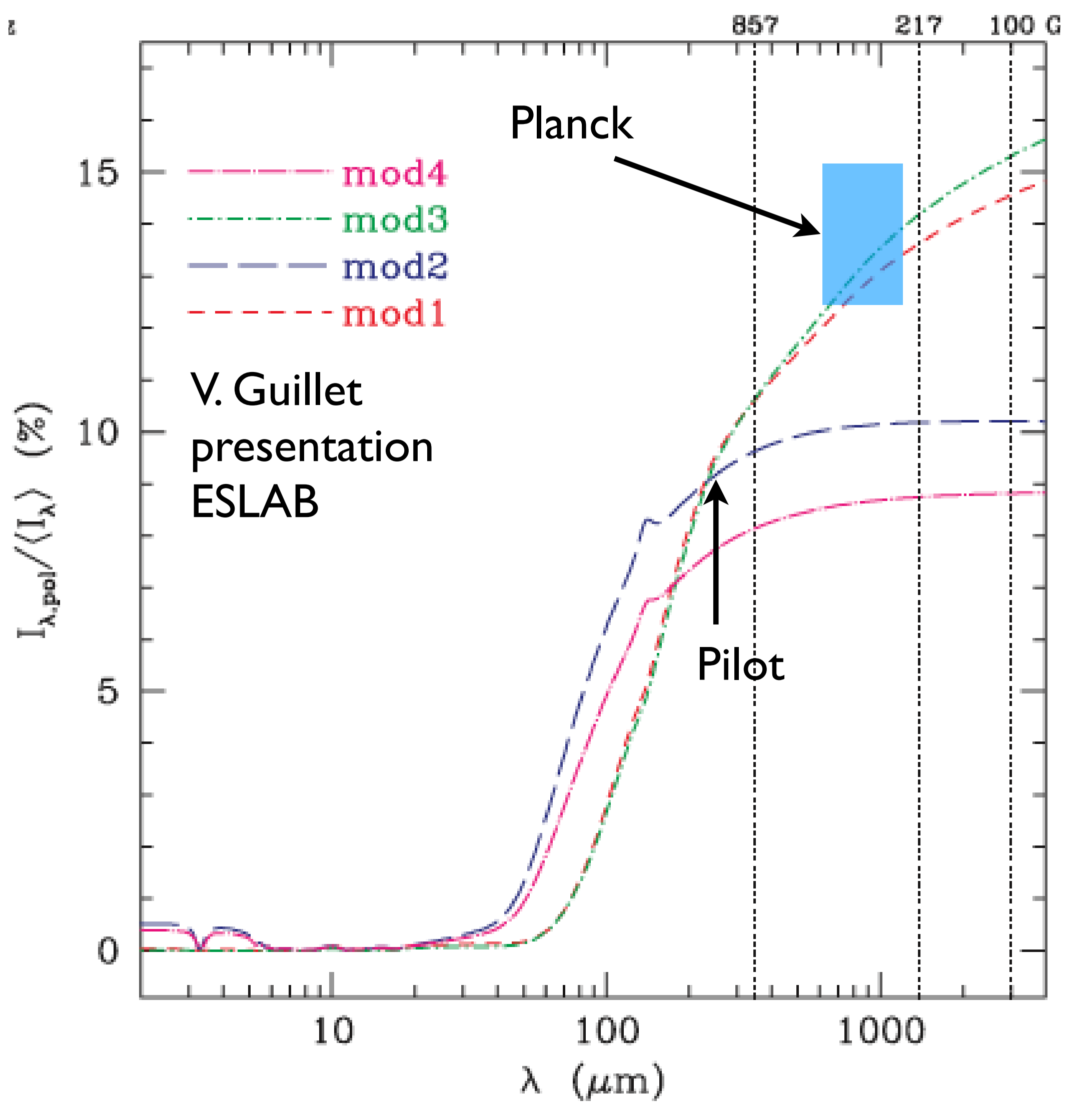


- Data comparison allows us to measure the Polarization ratio R= $p_{353GHz}/(P_{ext}/\tau_{ext})_V$ that only depends on dust polarization properties
- The measured value, 4.5±0.5, is within the range that may be accounted for by the Draine & Fraisse models with no alignment of carbon grains (Models 1 & 3)
- For p_{353GHz} of 18%, $(P_{ext}/\tau_{ext})_V$ = 4±0.5%, a value higher than that used to normalize the model.

Planck Results: polarization frequency dependence ?



Dust polarization fraction seems frequency independent over Planck range (!)
(J. Aumont, T. Gosh presentation ESLAB)



Most likely indicates that a single grain component dominates emission and polarization

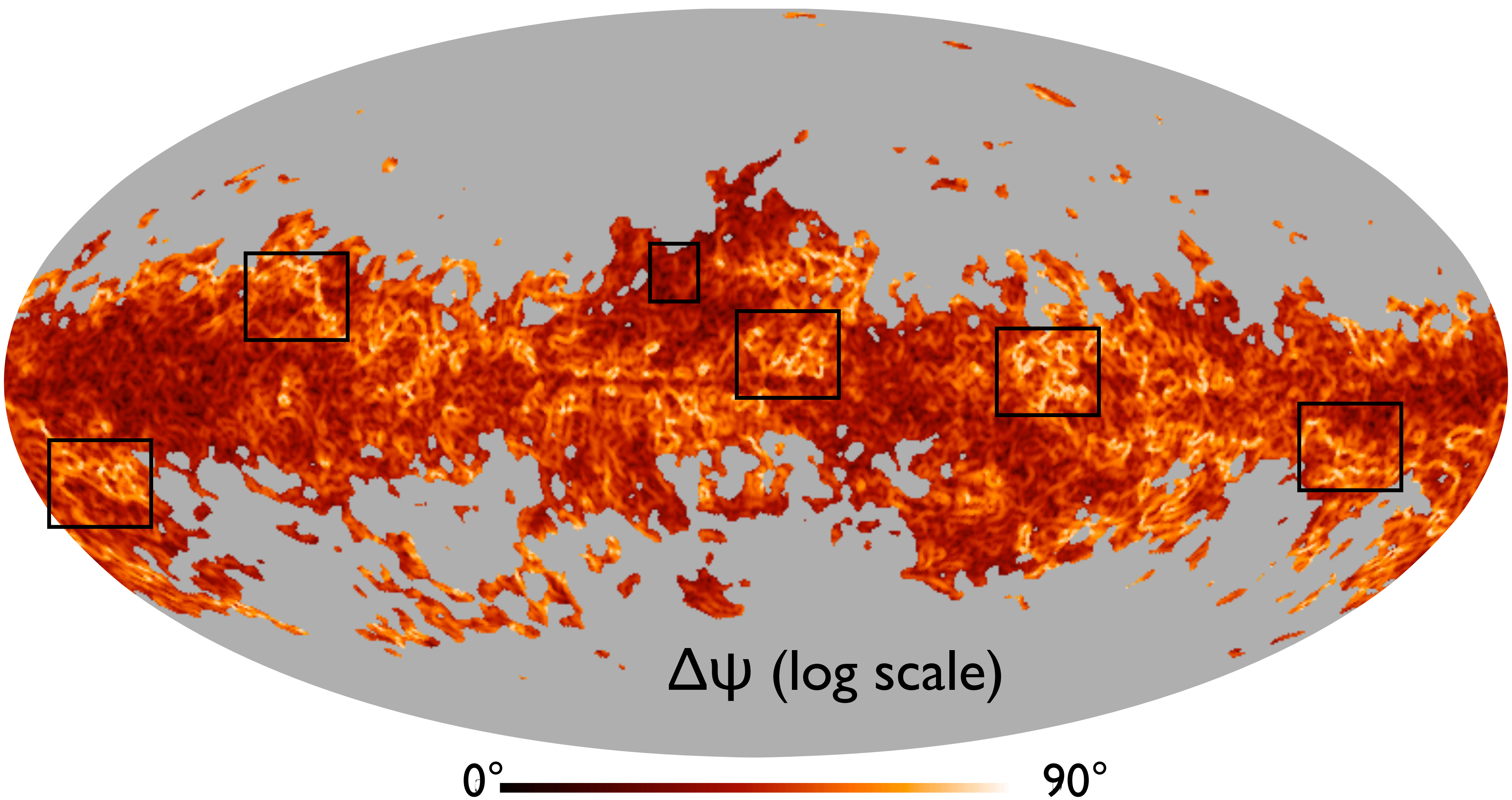
Large ratio of submm/visible polarization : $(p_{353GHz})/(p/\tau)_{Vis}$ =4.5
(V. Guillet presentation ESLAB)

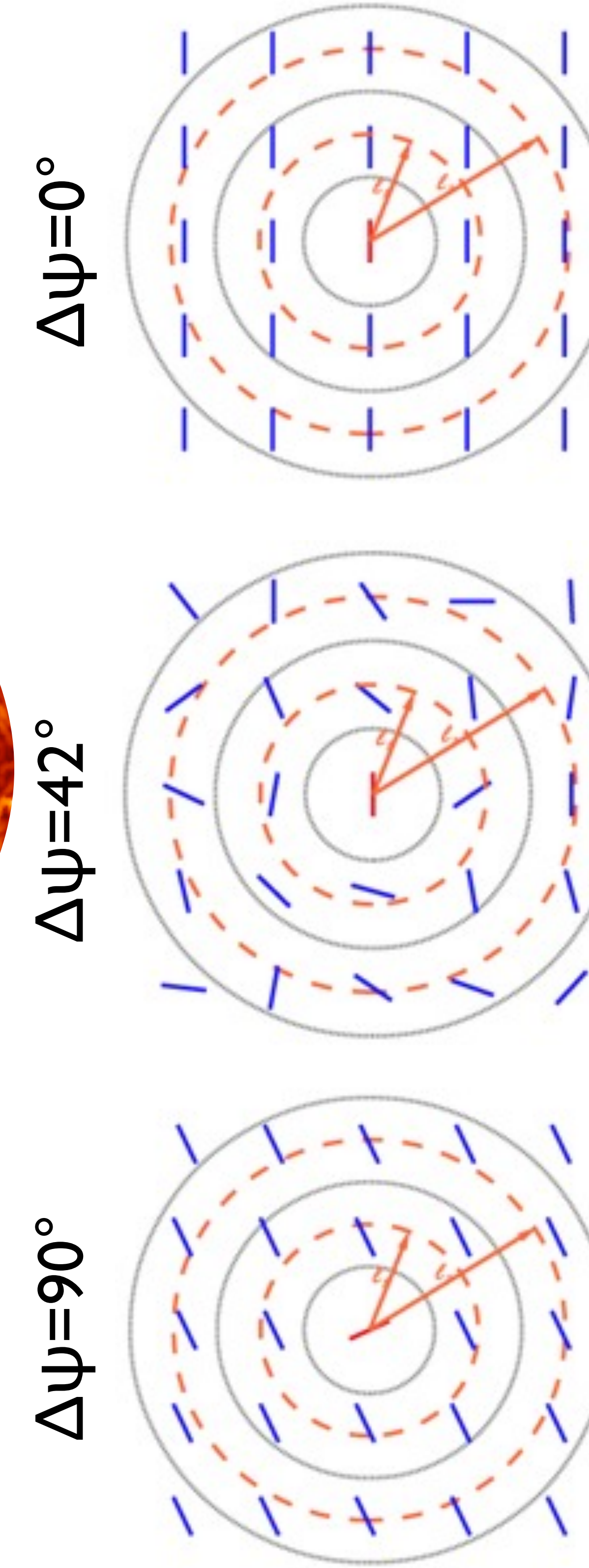
Combination difficult to explain with current dust models

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

Angular Structure Function

Measure of polarization direction homogeneity at scale ℓ :

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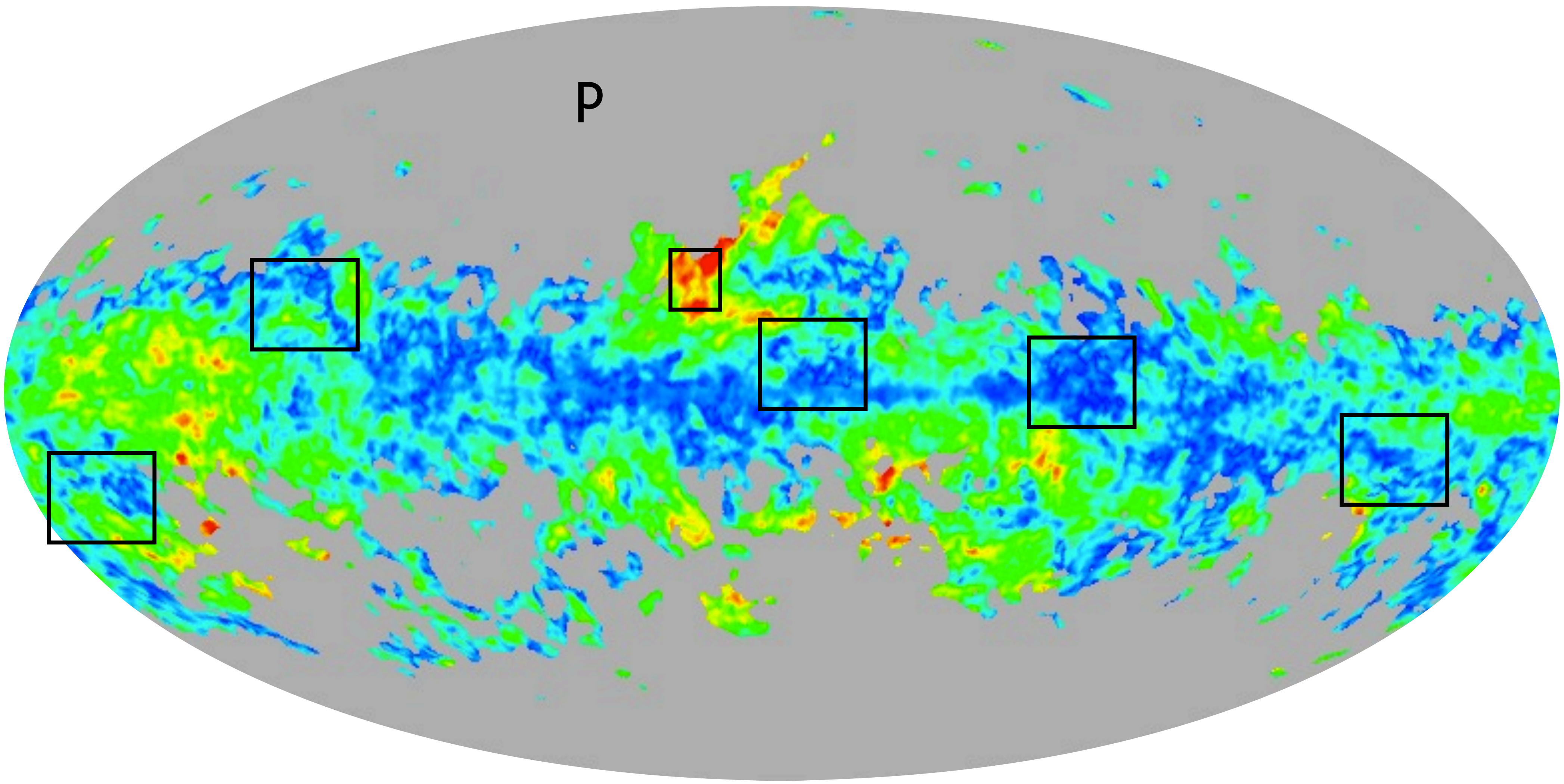
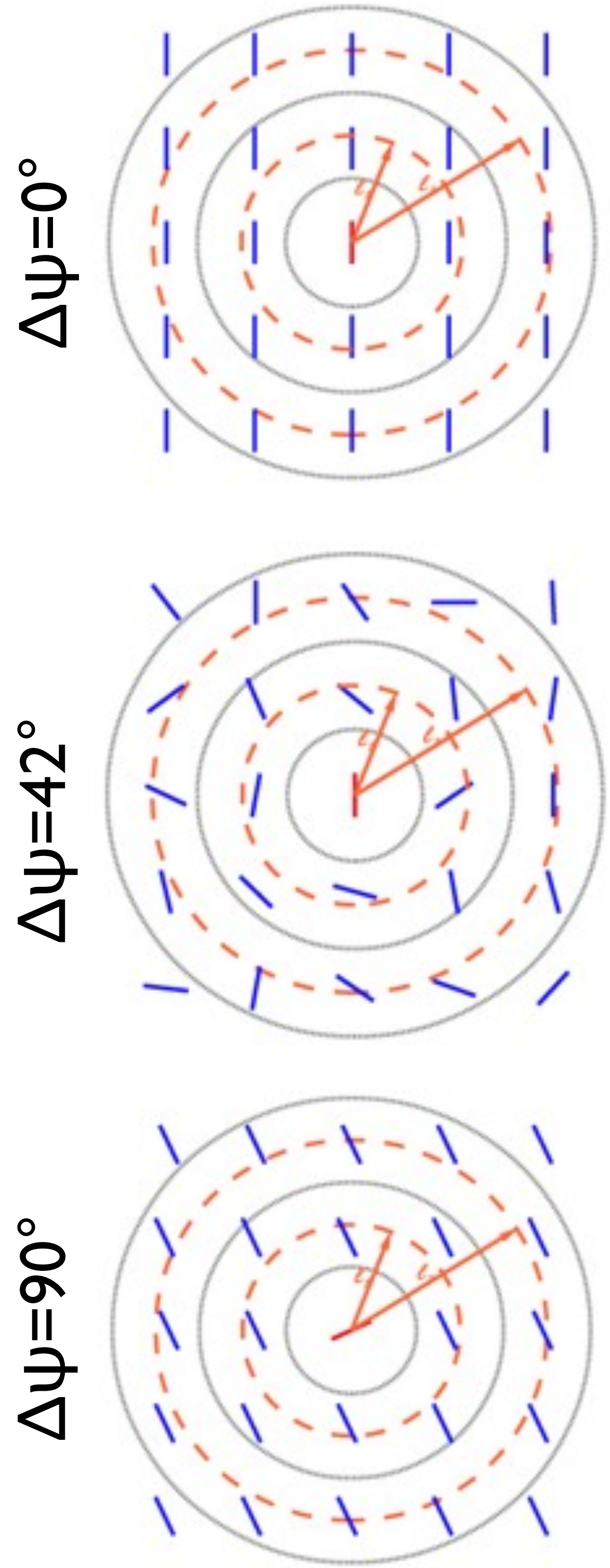
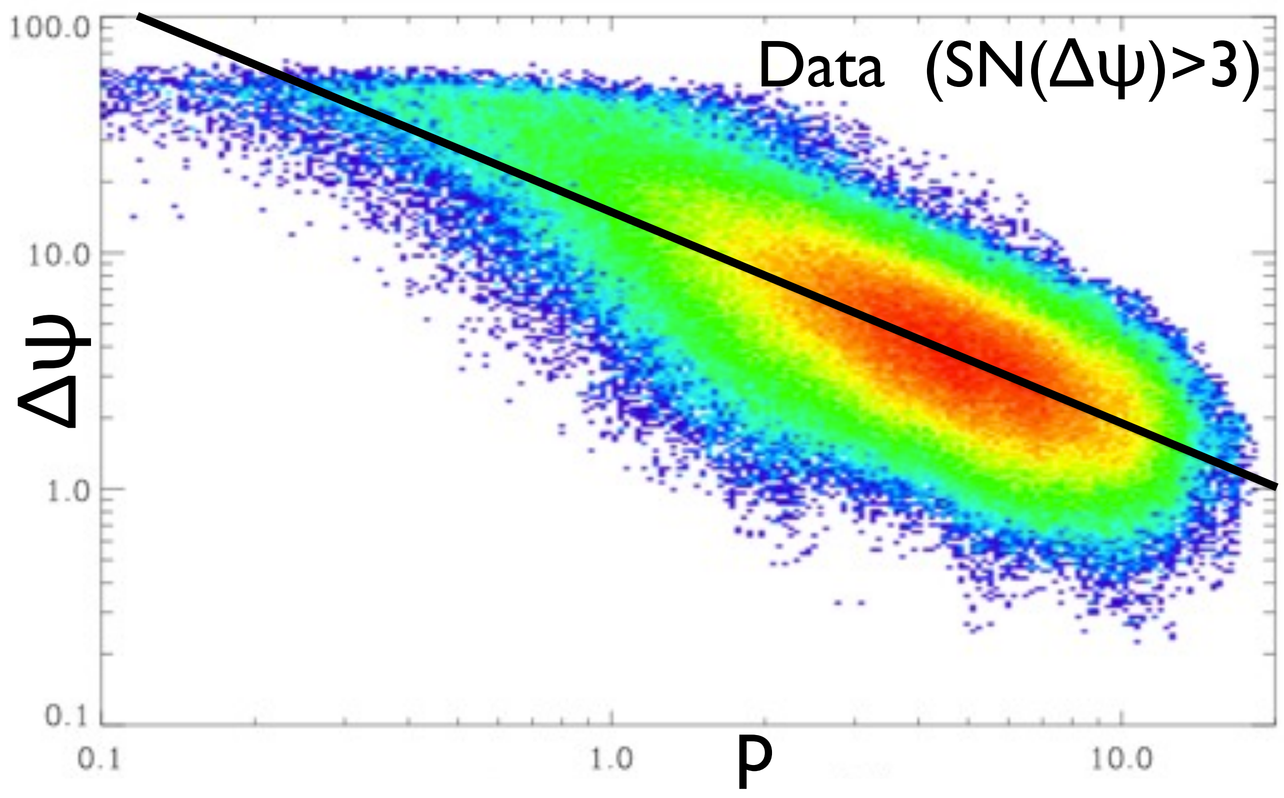
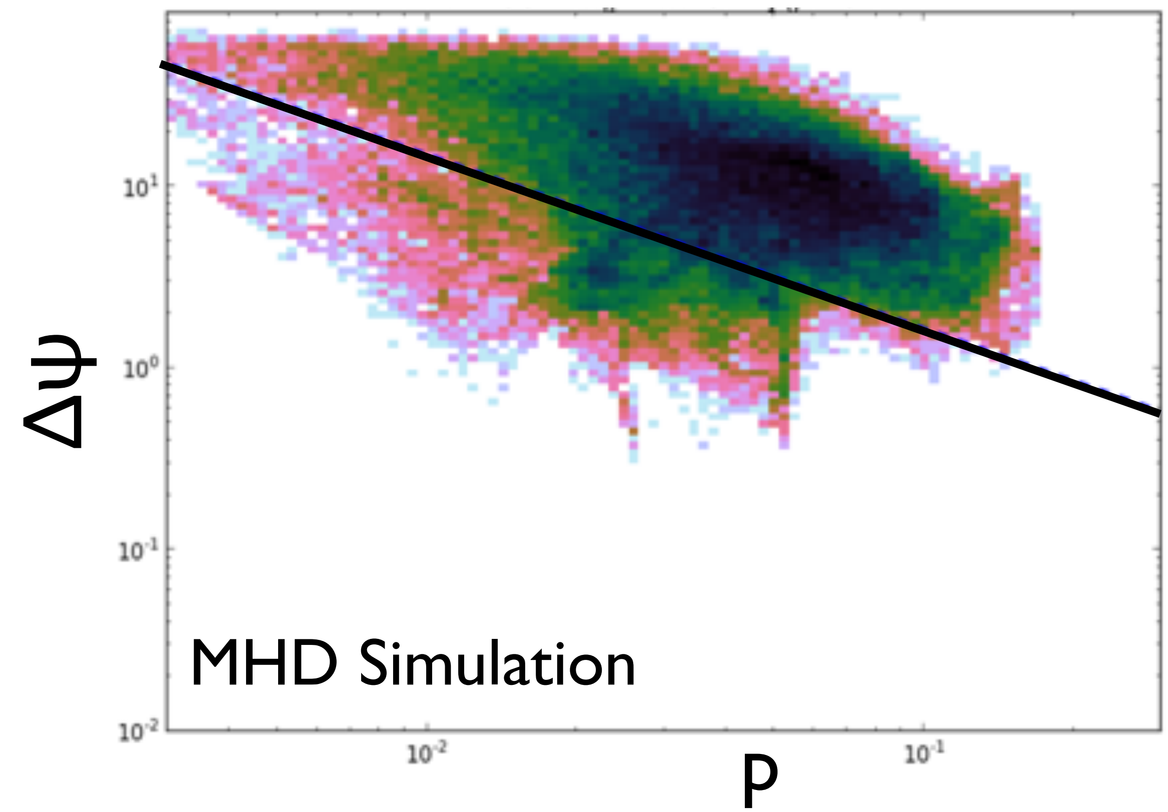


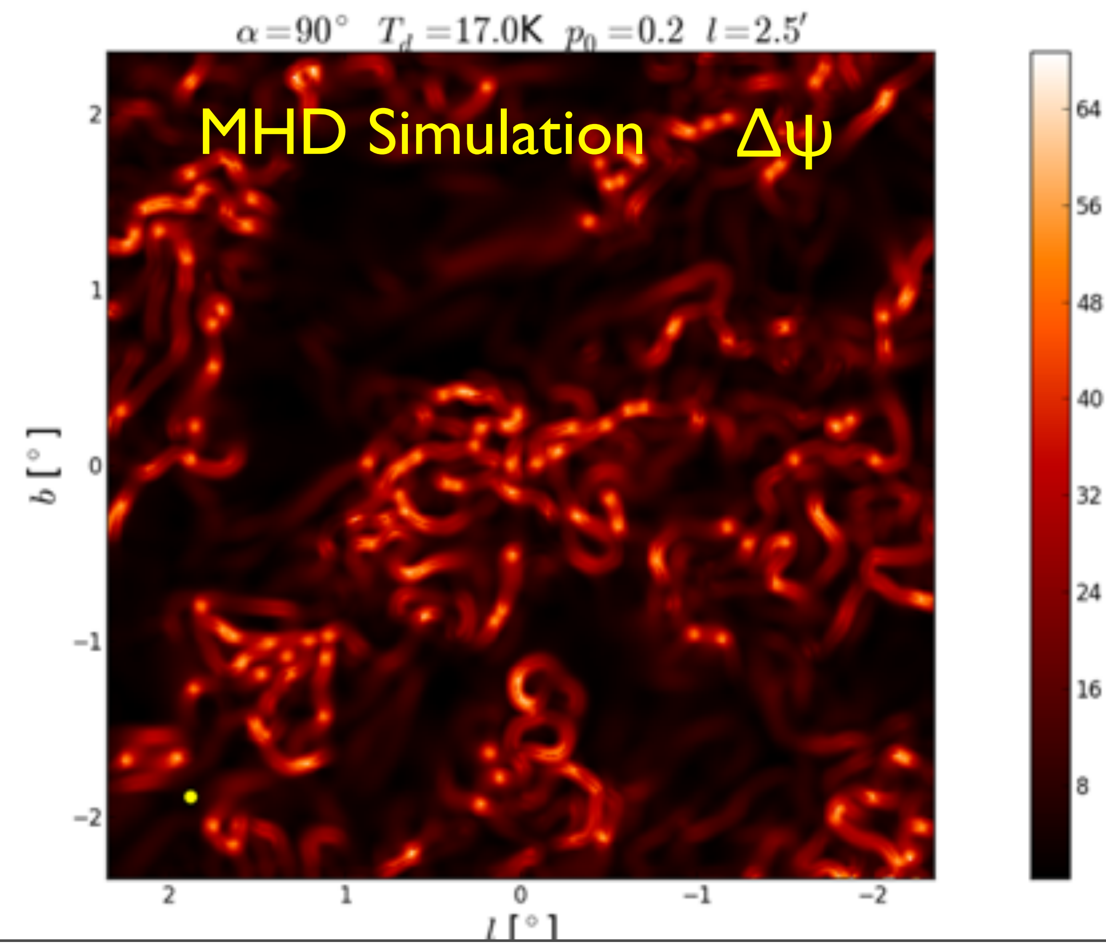


Angular Structure Function





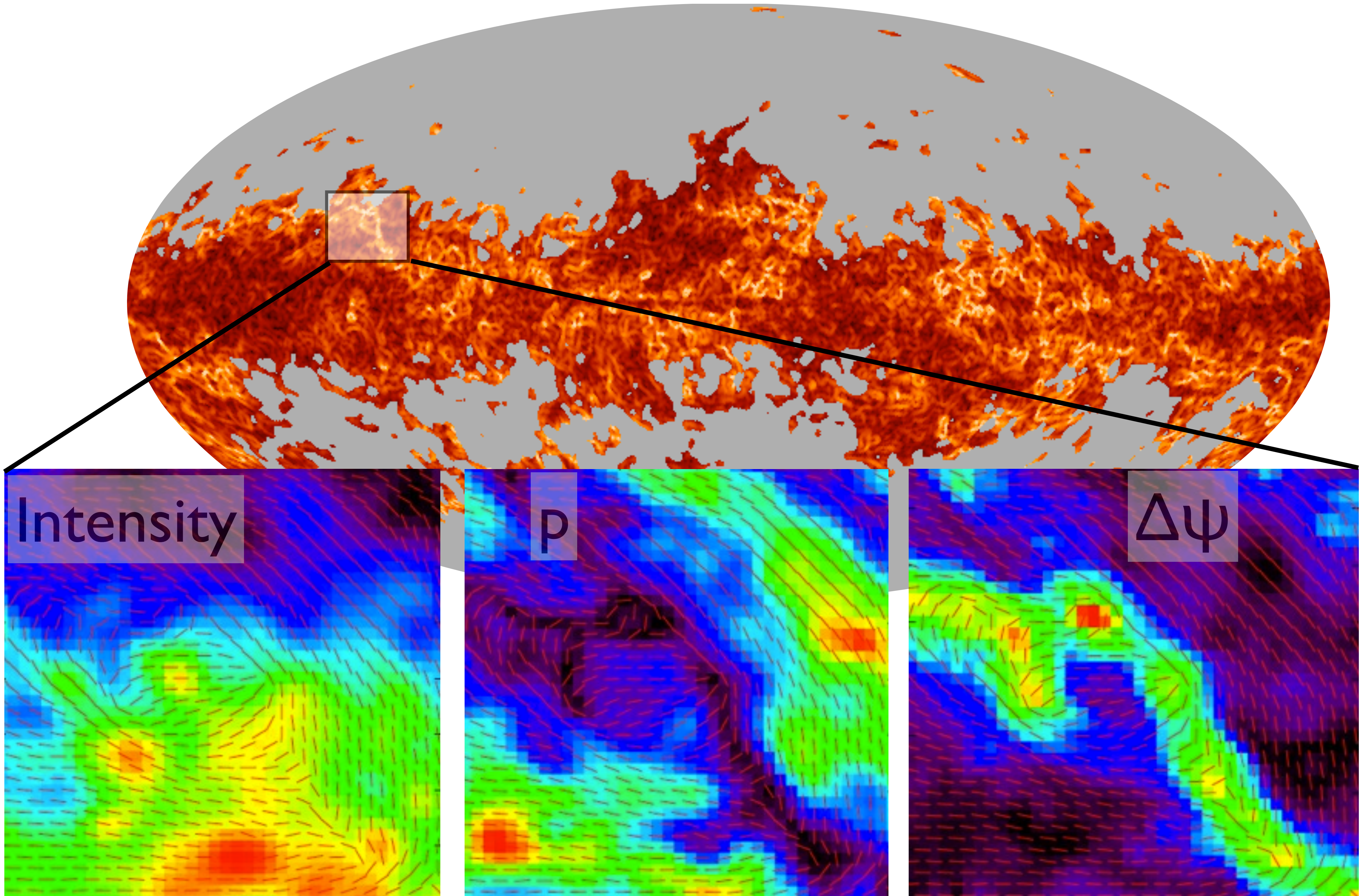
- Δψ increases with scale ℓ
- Δψ anticorrelates with p
- No clear correspondence with intensity filaments
- Similar behaviour observed in MHD simulations (see Poster by Levrier)
- MHD Δψ shows similar spaghetti structure
- Difference in absolute Δψ level can be due to fraction of diffuse emission in MHD cube



Angular Structure Function

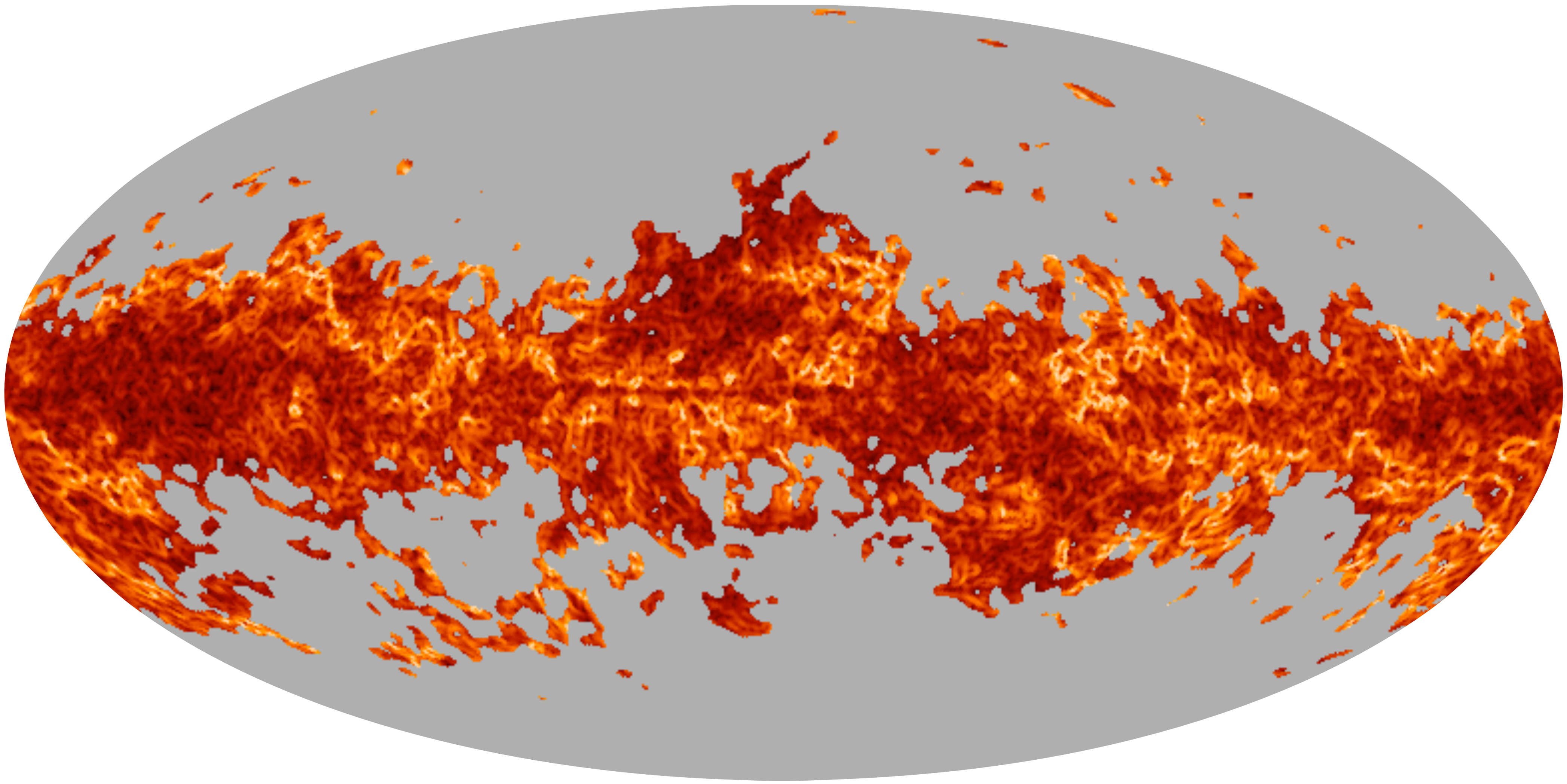
Those structures avec very large: most likely nearby

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



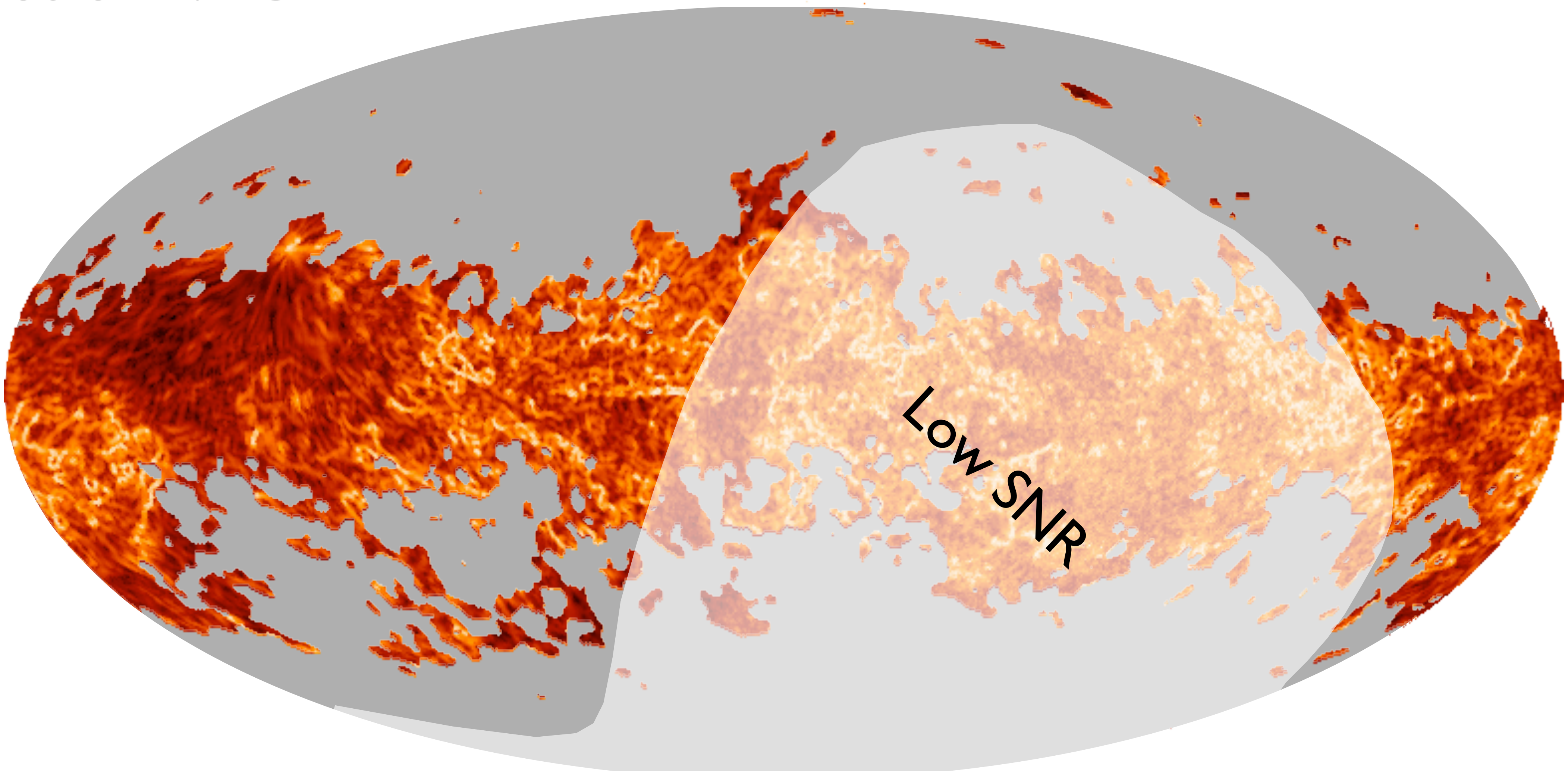
Angular Structure Function

Δψ 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 Δψ do not match

Δψ Synchrotron 1.4 GHz



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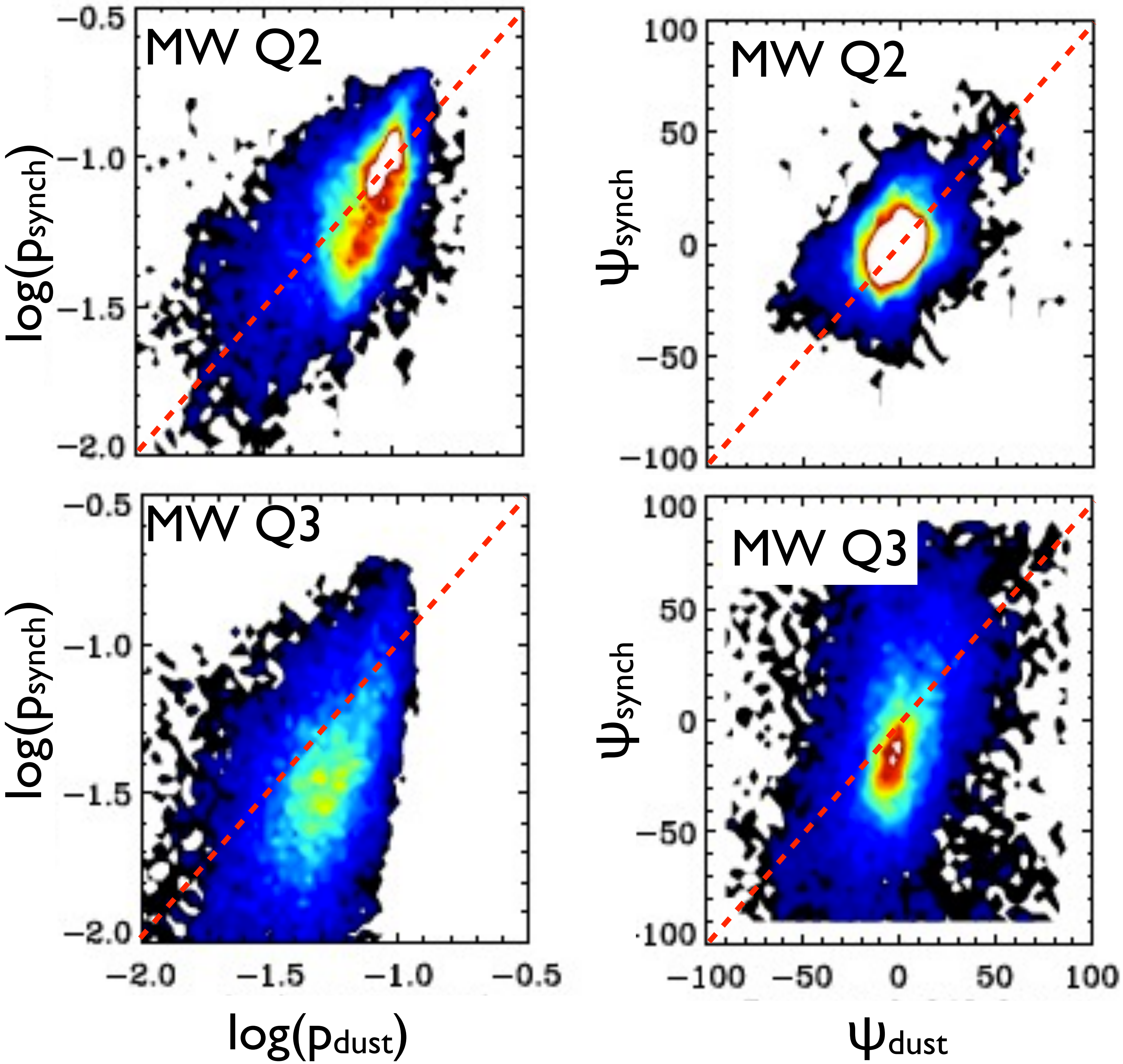
- These structures also correspond to low p (depolarization canals)
- Those are likely due to Faraday rotation (not present at 353 GHz)
- The structures in the dust and synchrotron Δψ do not match

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

- Polarization fraction is surprisingly high: p_{max} is > 18%
- p ratio submm/vis is surprisingly high: $R= p_{353GHz}/(P_{ext}/\tau_{ext})_V = 4.5 \pm 0.5$

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.