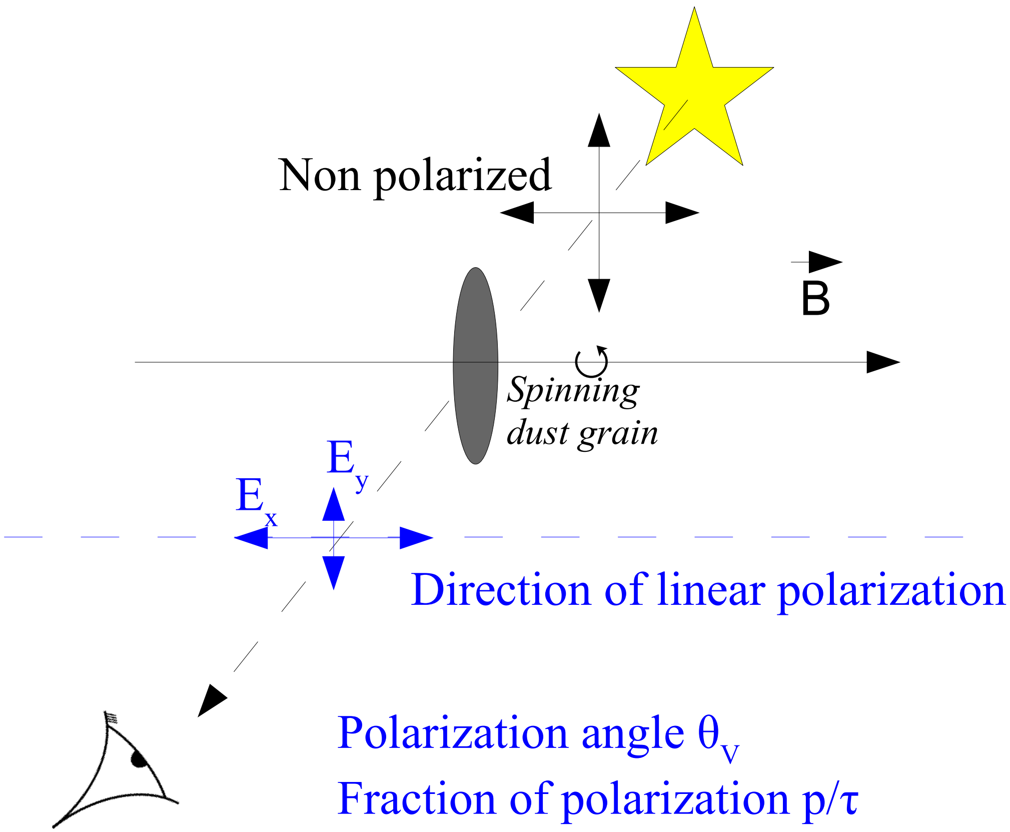
Comparison of dust polarization properties in the submillimeter and visible domains

The Planck Collaboration

Presented by V. Guillet (IAS, Orsay, France)

Polarization by dust is observed in 2 ways

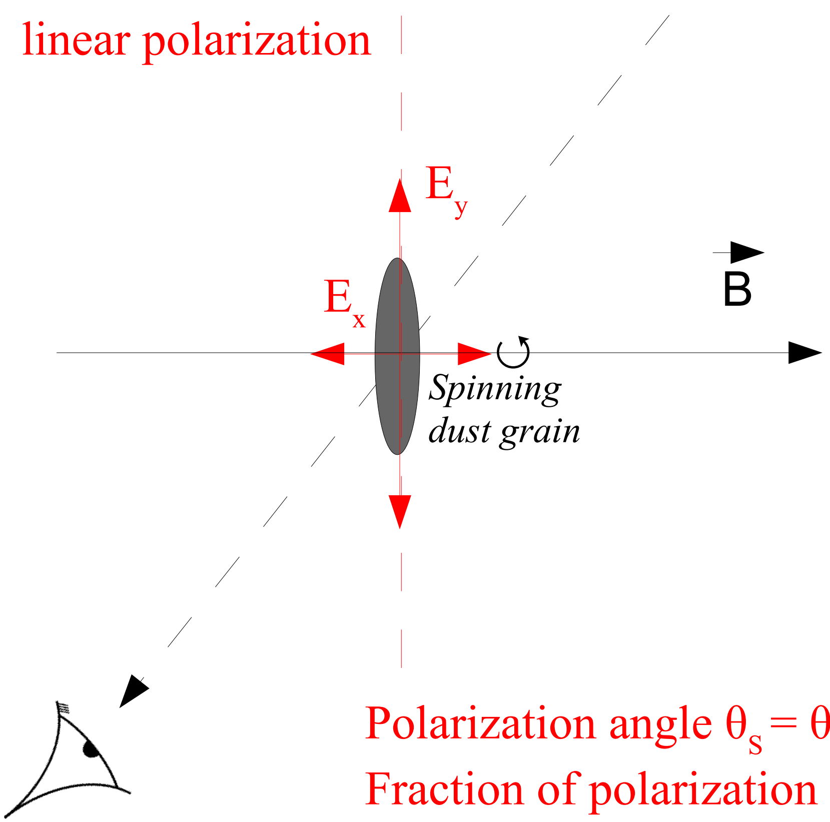
Polarization in the visible (starlight extinction by dust)



Polarization angle θ_V

Fraction of polarization p/τ

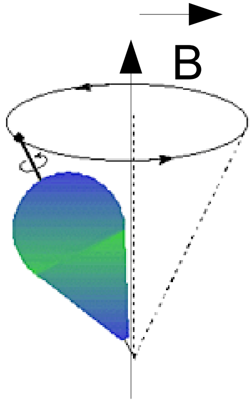
Polarization in the submm (dust emission)



Polarization angle $\theta_S = \theta_V - 90°$

Fraction of polarization P/I

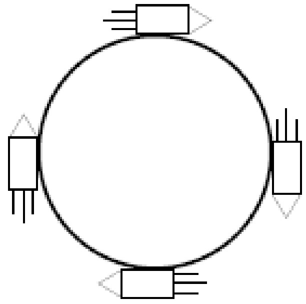
Basic physics of grain alignment



Competition between

- alignment processes : various torques (magnetic, radiative, mechanical)
- disalignment processes : mainly gas collisions

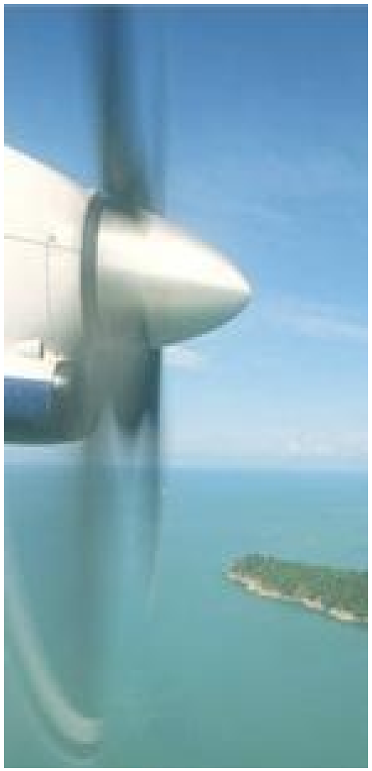
Suprathermal rotation (=> gyroscopic effect)

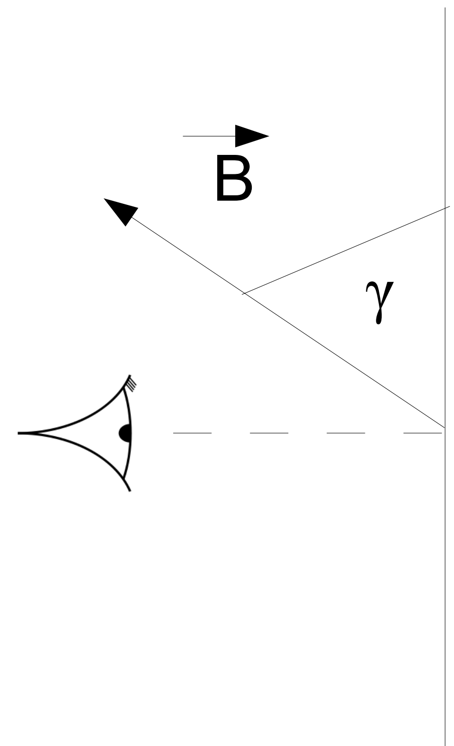


- H_2 formation on the surface of grains drive grain rotation to suprathermal velocities (rocket thrust)
- Radiative torques

  => *Andersson & Potter (2012) for a recent review*

Projection effects of magnetic field orientation





$\vec{B}$

$\vec{B}$ ⊙

P/I and p/τ are maximal

P/I and p/τ = 0

$P/I \propto \cos^2(\gamma)$

Complexity in interpreting the fractional polarization

$$\text{Pol. fraction}(\lambda) = \int_{los} \int_{beam} f\,(\text{dust properties}(\lambda),\ \text{dust elongation } b/a,\ \text{alignment efficiency},\ \text{3D magnetic field})$$

- dust properties(λ), (material, size distribution)
- dust elongation b/a, (shape)
- alignment efficiency (local conditions, size, material)
  - Radiation field (anisotropy, intensity)
  - Gas density
- 3D magnetic field (orientation, structure)

⇨ At the 1st order, models show that dependencies on elongation, alignment, and magnetic field orientation are similar in extinction and in emission. This hypothesis is tested with our data.

⇨ Ratio $R = (P/I)_S \,/\, (p/\tau)_V$ depends primarily on dust optical properties

Existing dust models for the diffuse ISM

Catalogs in extinction : $\tau_V = A_V / 1.086$ is crucial

Polarization catalog : Heiles (2000)

$\Rightarrow$ p_V, σ_p, θ_V $\Rightarrow$ $q_V = p_V \cos(2\theta_V)$ $u_V = - p_V \sin(2\theta_V)$

$\Rightarrow$ low SNR Av : not used

Several extinction catalogs to control systematics in Av

We build independent samples from:

1. Fitzpatrick & Massa (2007) : high quality Av & Rv (147 stars)
2. Andersson & Potter (2007) : Taurus, Musca-Chameleon translucent clouds (54 stars)
3. Valencic et al (2004) : ~ 300 stars
4. Wegner et al (2002,2003) : > 400 stars
5. Our own derived Av from Kharchenko & Roeser (2009) : for the rest of stars not present in the litterature : > 3000 stars

Planck data

Planck Map of submillimeter equivalent to E(B-V)

- $E(B\text{-}V)_S$, to be compared with E(B-V) to the star

Intensity I @ 353GHz

- Average CMB removed, CMB fluctuations model removed (SMICA), Offset removed
- No sensitivity to Zodiacal light removal in our study

Polarization Q & U @ 353GHz

- Sky-Correction for spectral mismatch, CIB not polarized, CMB polarization negligible @ 353GHz
- Polarization position angle $\theta_S = \frac{1}{2} \arctan(-U,Q)$
- Polarization intensity $P = \sqrt{(Q^2+U^2)}$

I, Q and U smoothed at 7' (FWHM of the smooth = 5') to increase SNR

Comparing polarization fractions in emission and extinction

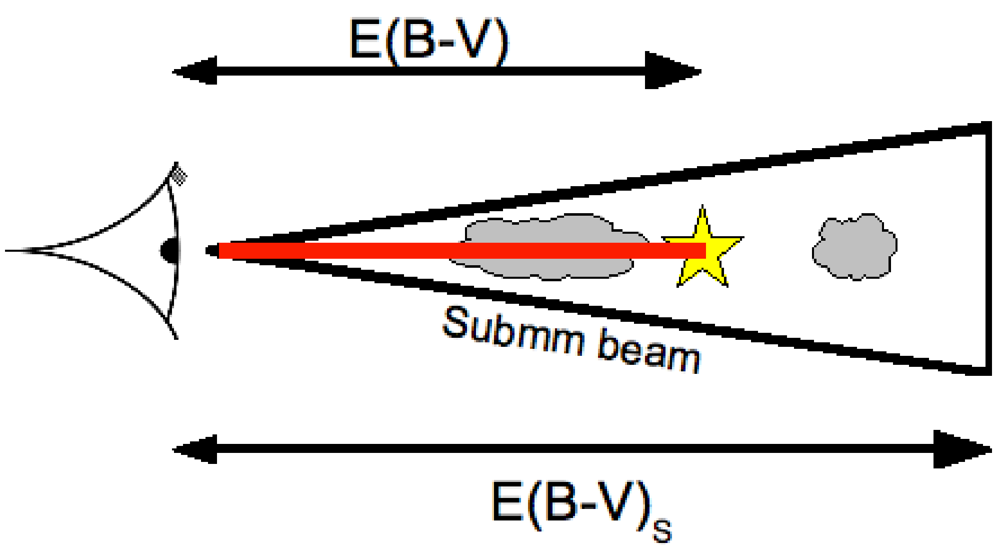
Extinction @ Vband : p/τ | Emission @ 353GHz : P/I

Large grains

dependency on the column density is removed

Pencil beam measurement *vs* Large beam integrated measurement

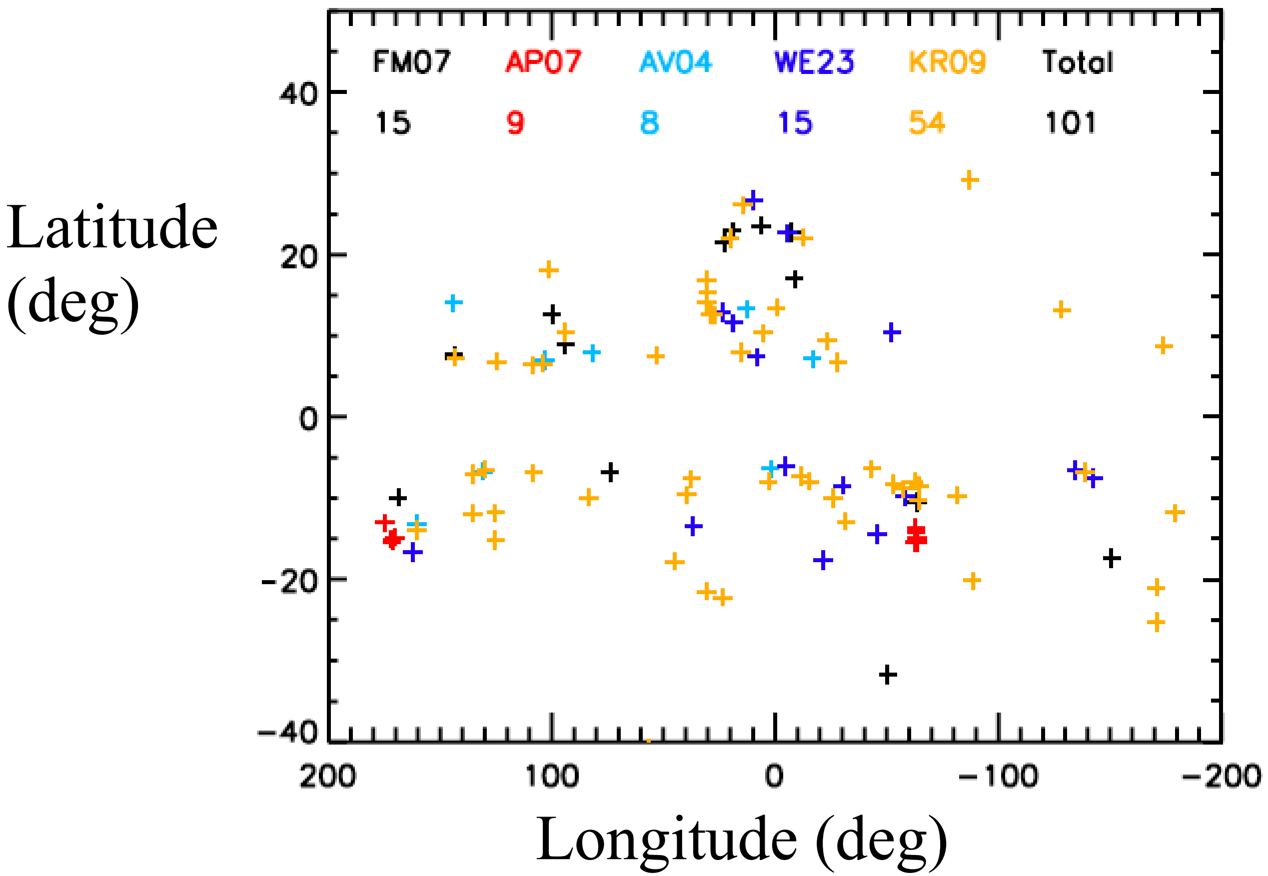
Foreground to the star *vs* Total line of sight emission



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

4 selection criteria

1. SNR > 3 for p, E(B-V) (visible), P, and I (submm)
2. |b| > 6 deg : high-latitude stars with less depolarizing background



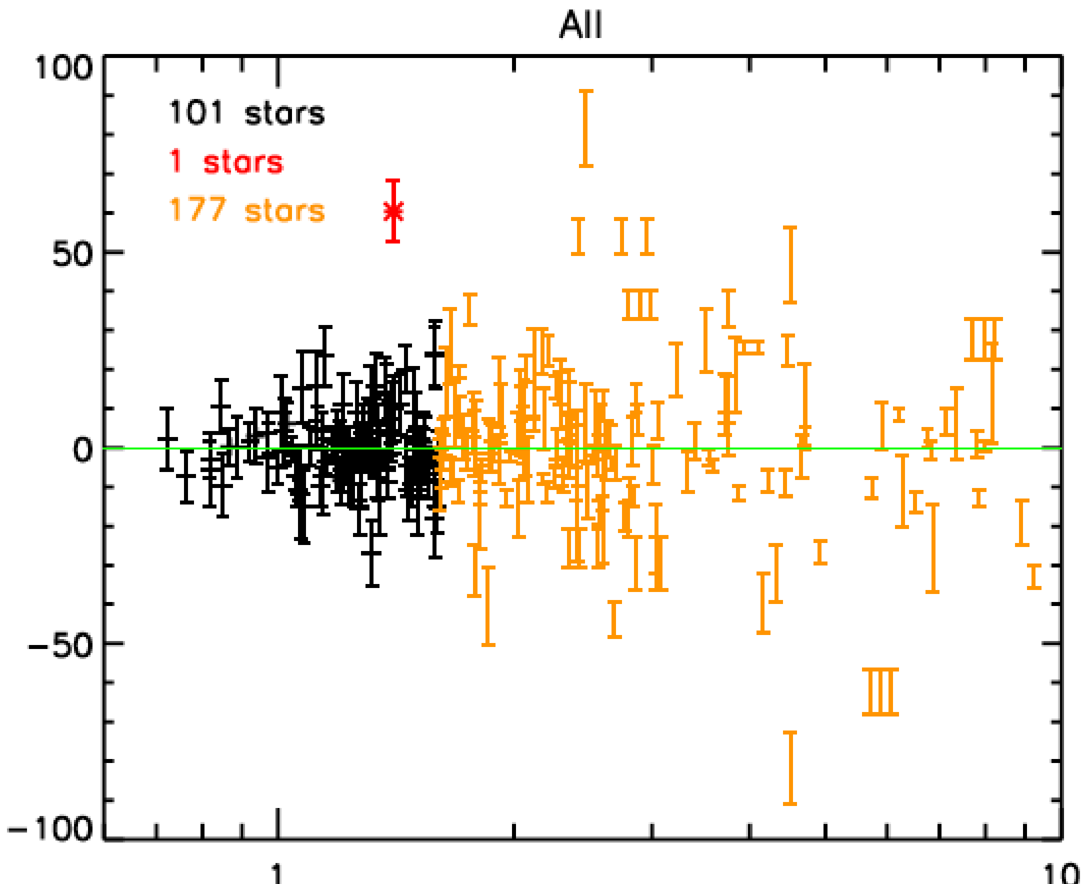
Legend indicates
the extinction catalog

All polarization data
is from Heiles (2000)
except for
Andersson & Potter (2007)

4 selection criteria

3. Agreement in column densities : $0.7 < E(B-V)_S / E(B-V) < 1.6$

Upper limit is our main systematics on $R = \frac{(P/I)_{353GHz}}{(p/\tau)_V}$

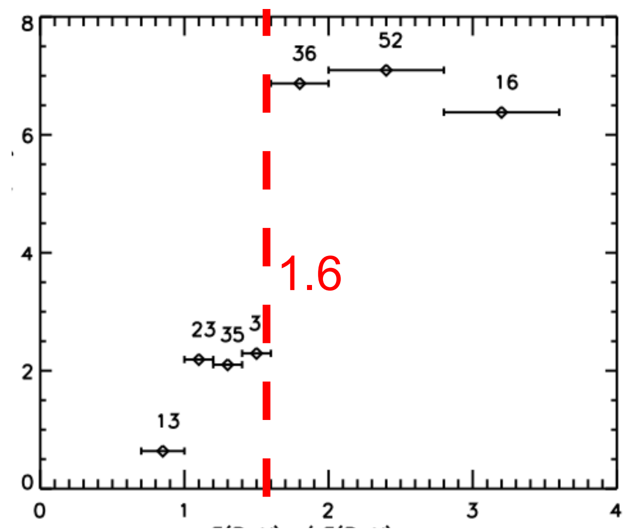


$\Delta\theta = \theta_V - \theta_S - 90°$

$E(B-V)_S / E(B-V)$

Reduced chi2 of difference in angles

$$\chi 2_r(\Delta\theta) = \frac{1}{N}\sum_{i=1}^{N}\left(\Delta\theta/\sigma_{\Delta\theta}\right)^2$$



$\chi 2_r$

$E(B-V)_S / E(B-V)$

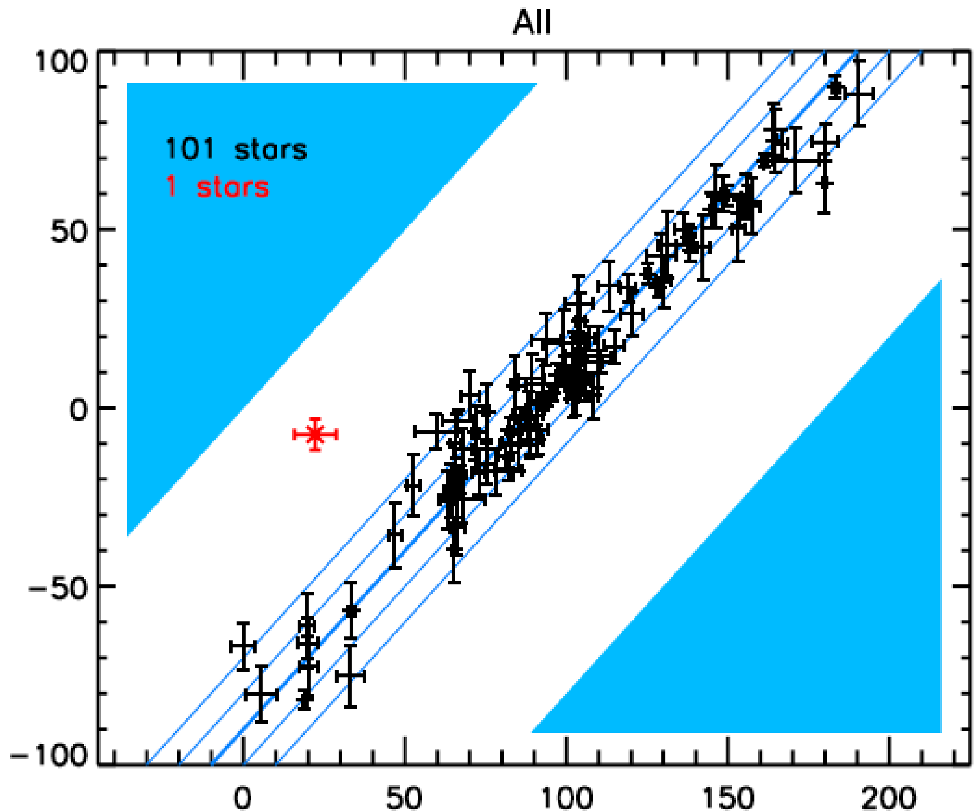
Dynamics in angles for our selected stars

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)

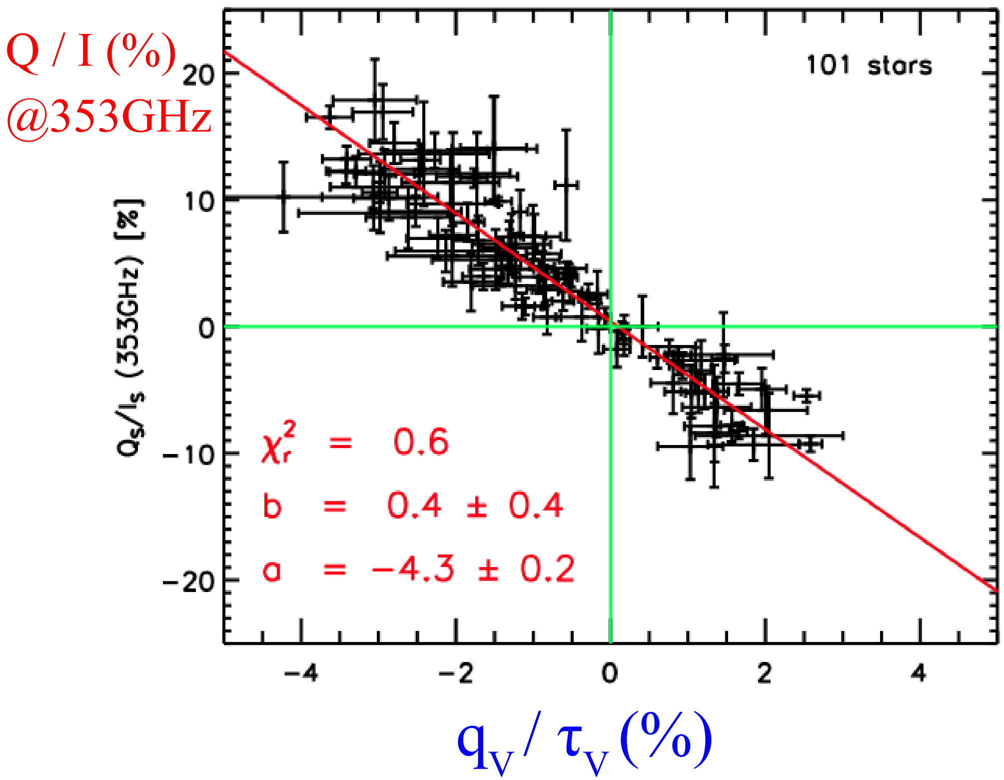
θ_S

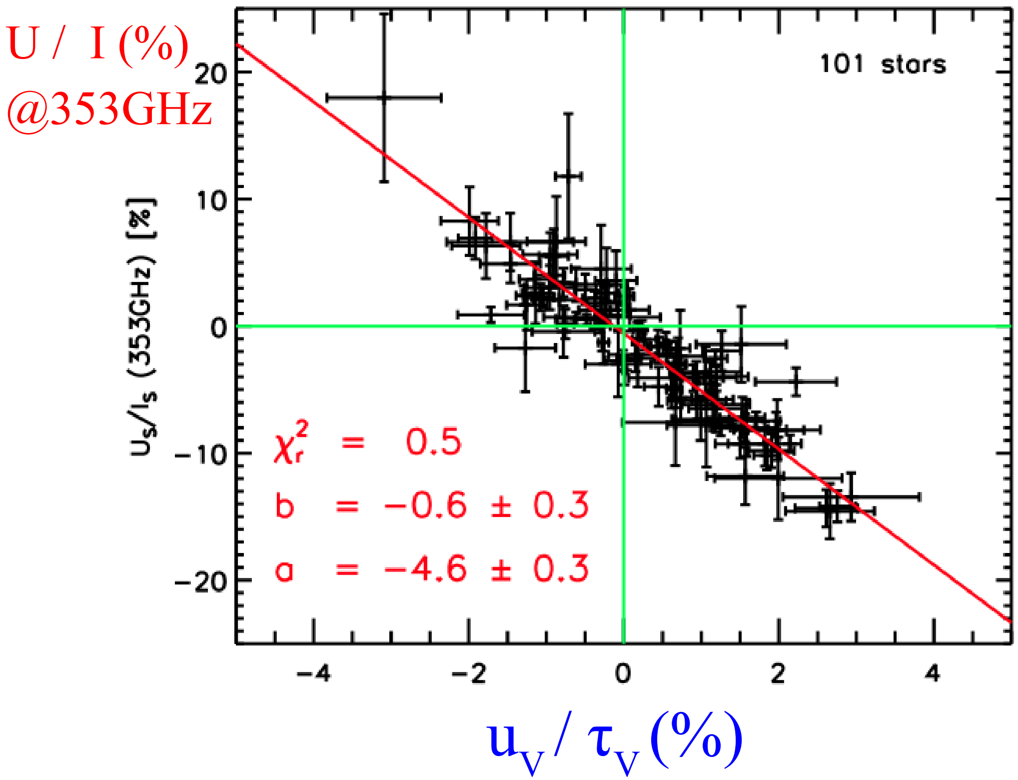


Polarization Angle in the visible (deg) θ_V

Correlation study of $R = \frac{(P/I)_{353\mathrm{GHz}}}{(p/\tau)_V}$

- $P = \sqrt{(Q^2+U^2)}$ and p_V are biased by noise (.e.g Simmons & Stewart 1985), not Q and U.
- Q/I correlates with q_V/τ, and U/I with u_V/τ when polarization angles agree
- Slope is -R (orthogonality in angles is responsible for the – sign) :
- Fit with systematics added to error bars (2% in P/I, 0.5 in p/τ)

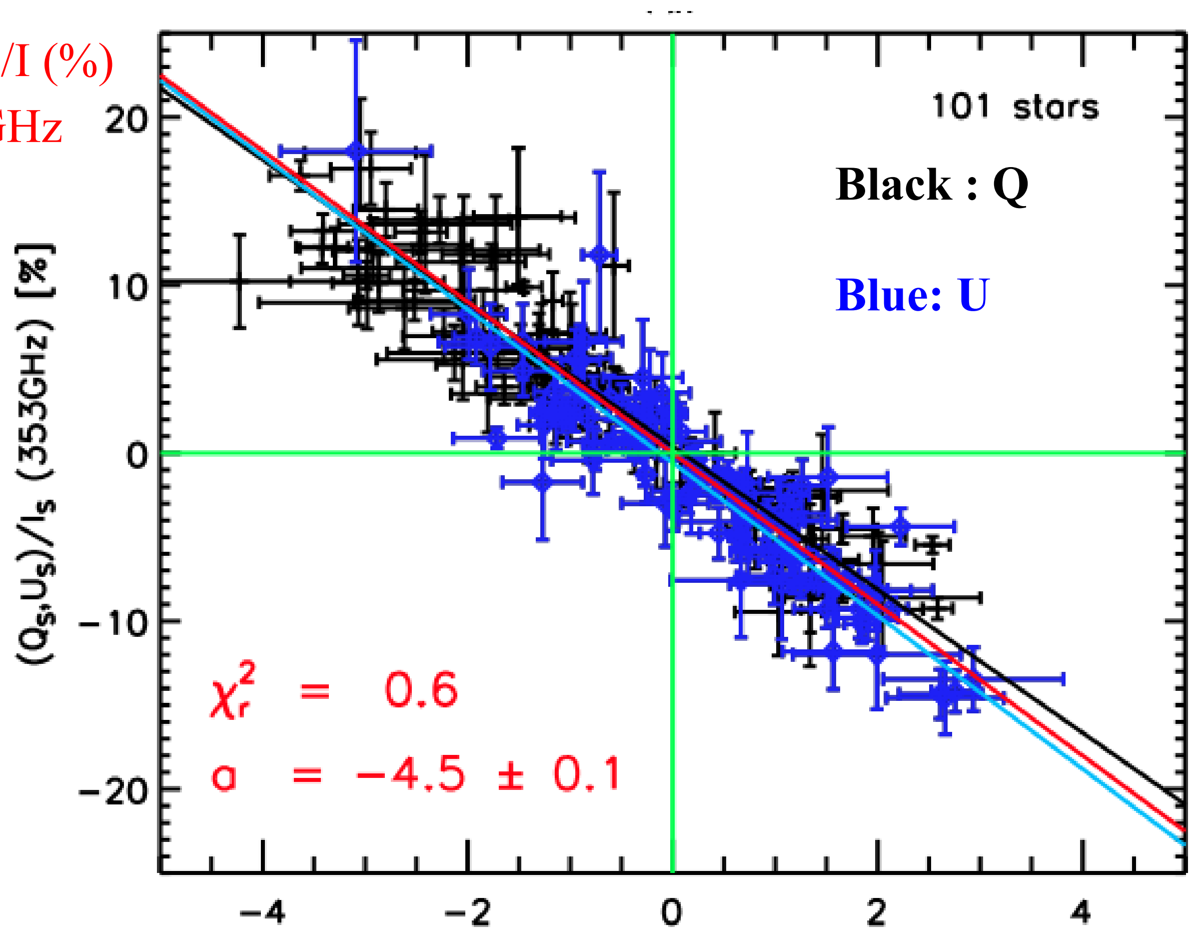




Correlation study of $R = \frac{(P/I)_{353\mathrm{GHz}}}{(p/\tau)_V}$

Join fit of Q/I = f (q/τ) and U/I = f (u/τ) forced through the origin

(Q,U)/I (%)
353 GHz



$(q_V, u_V) / \tau_V$ (%)

R ~ 4.5 ± 0.1 ± 0.5

Random error : 0.1
(from the fitting method)

Systematic error : 0.5
(mainly from the upper limit on $E(B\text{-}V)_S/E(B\text{-}V)$: [1.2 – 3])

What the models predict (Draine & Fraisse 2009, Martin 2007)

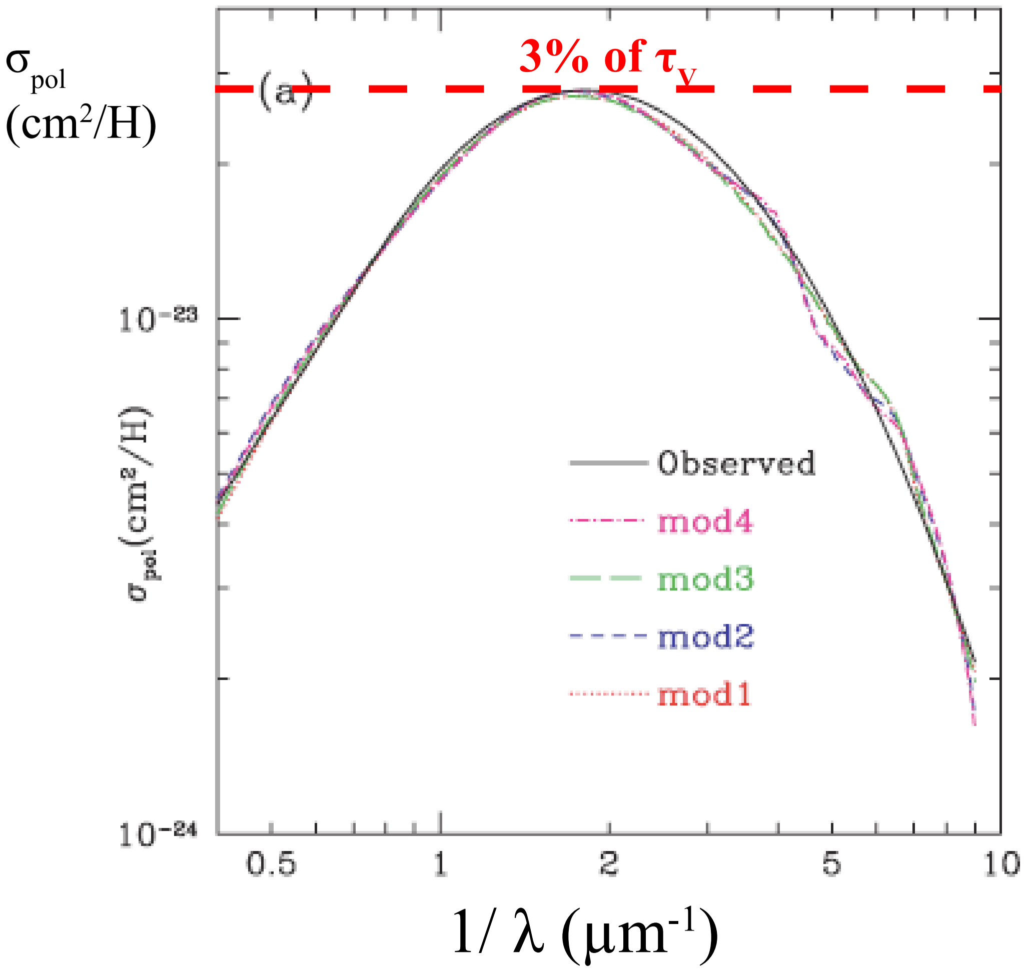
Constraints from the visible

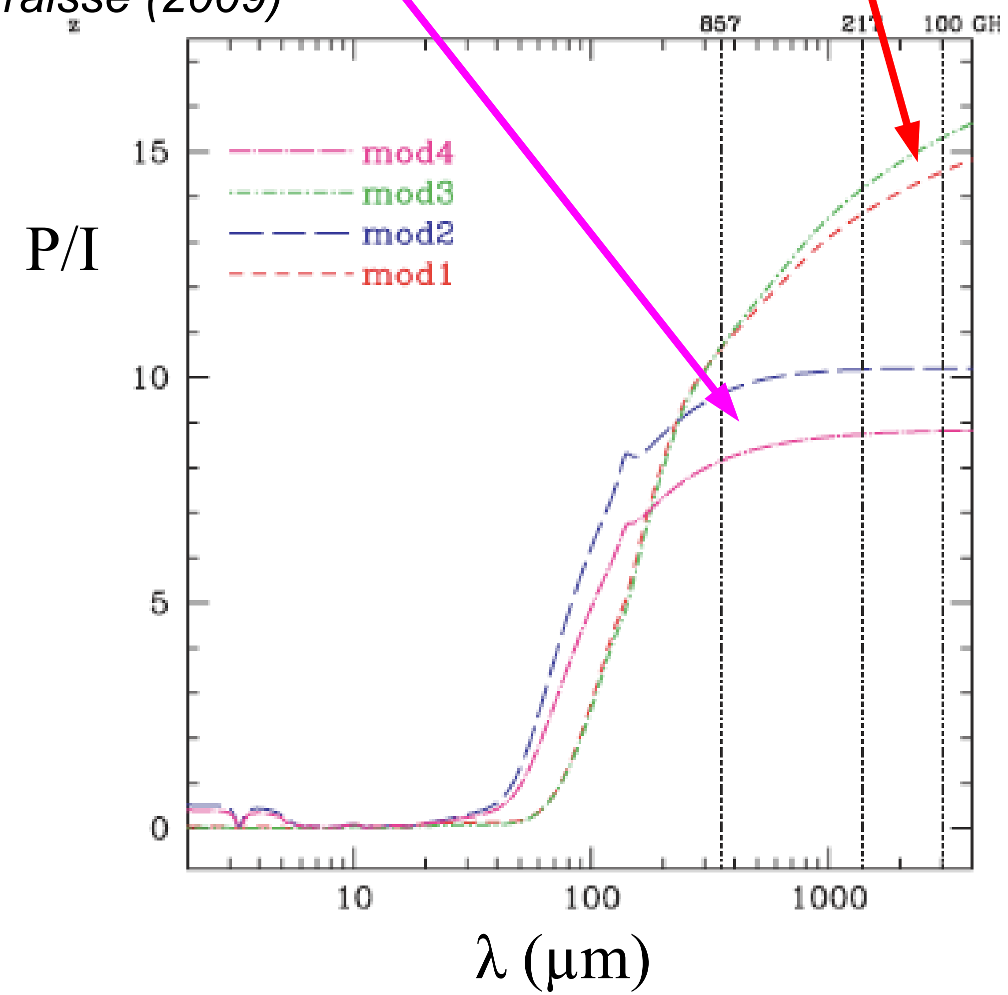
$(p/\tau)_{max} = 3\%$

$(P / I)_{max} \sim 13\%$ (graphite not aligned)

$\sim 9\%$ (graphite aligned)

Draine & Fraisse (2009)





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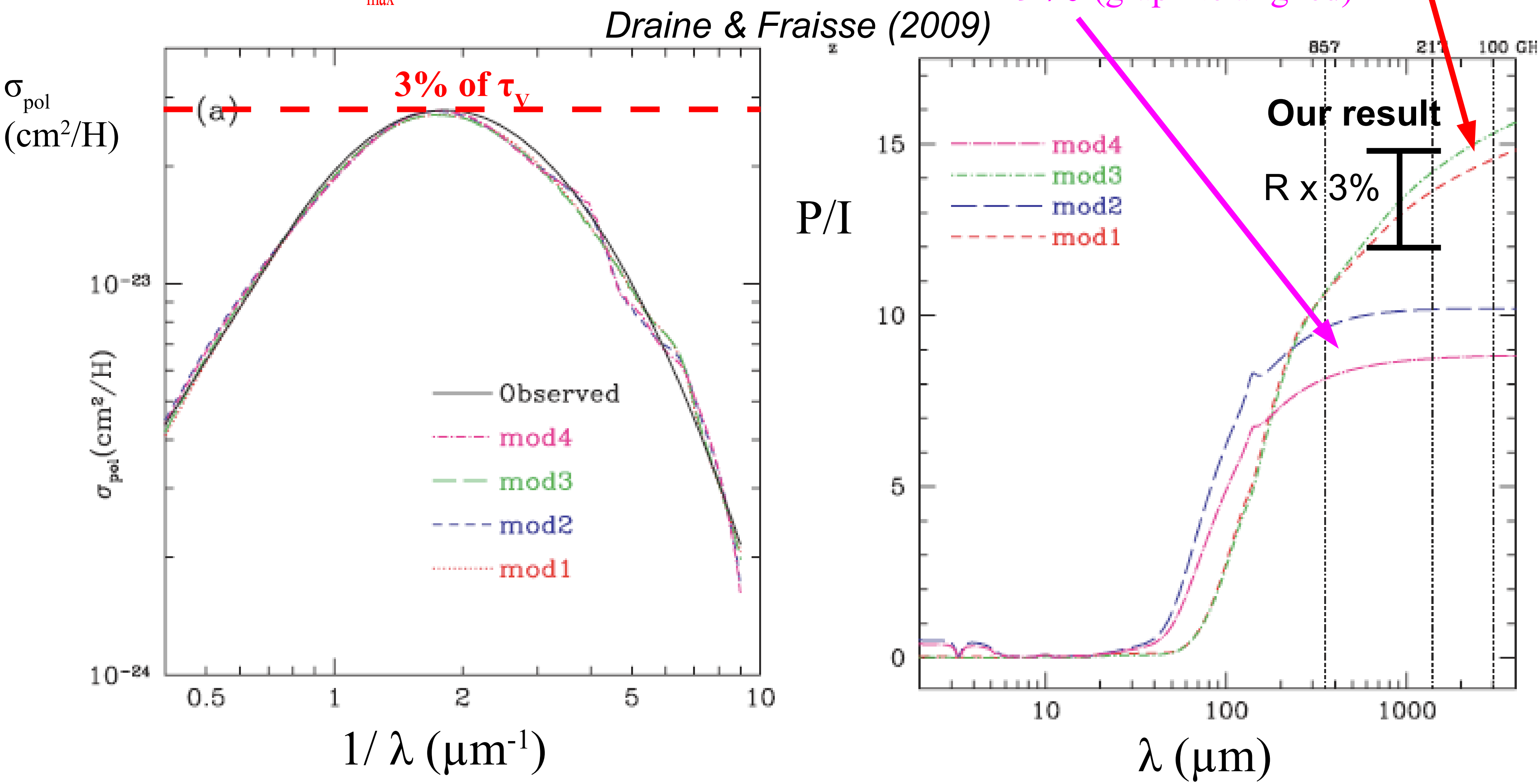

Conclusions

- We find a uniform polarization ratio in the diffuse ISM

$$R=\frac{(P/I)_{353\mathrm{GHz}}}{(p/\tau)_V}=4.5\pm0.1(random)\pm0.5(systematic)$$

- Globally consistent with existing dust models, with « tensions »
- Constraint to be completed with the spectral dependency of P/I : see Tuhin Ghosh's Poster.

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.