CRAZY LITTLE THING CALLED, INTERSTELLAR MAGNETIC FIELD

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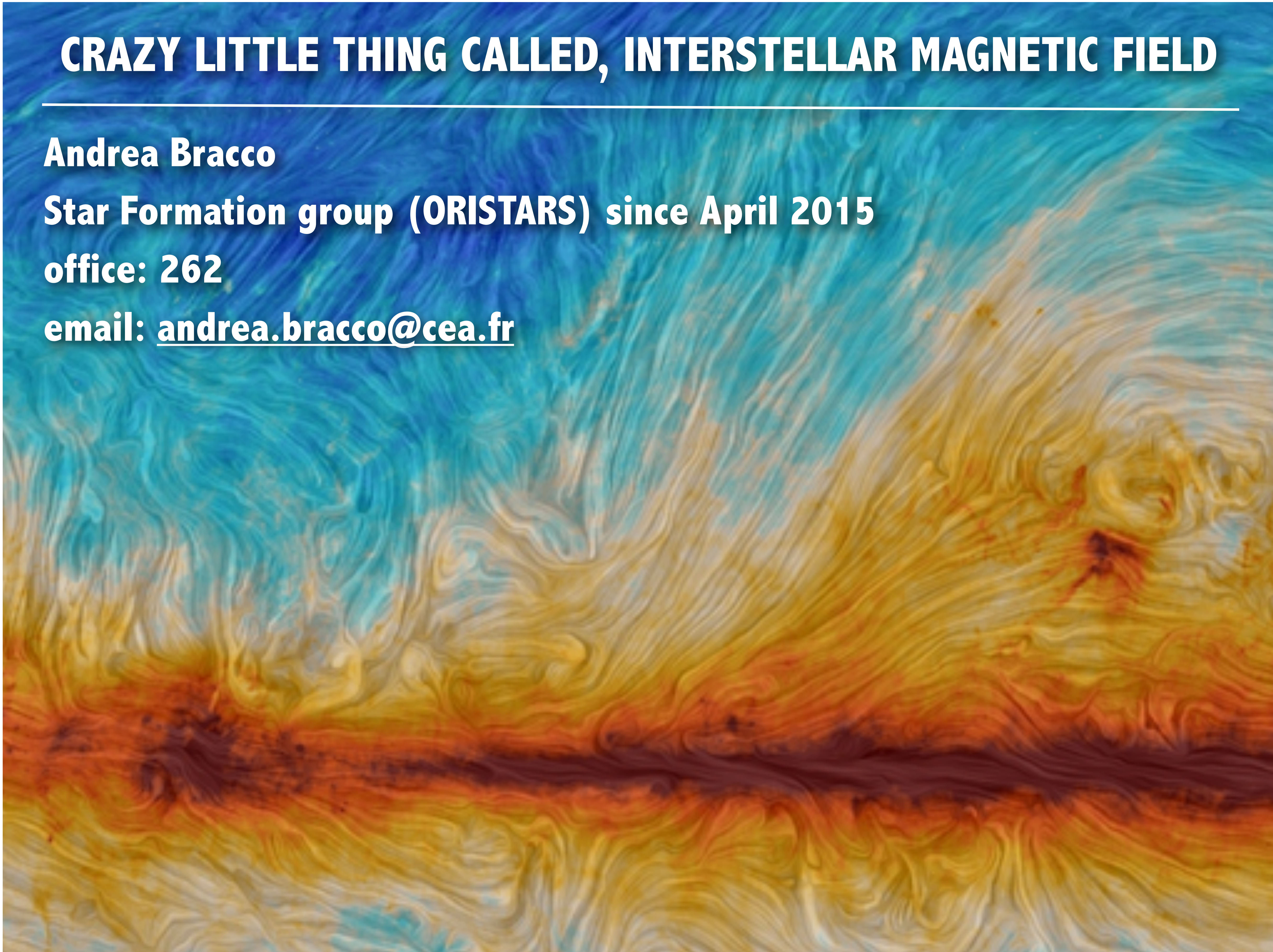
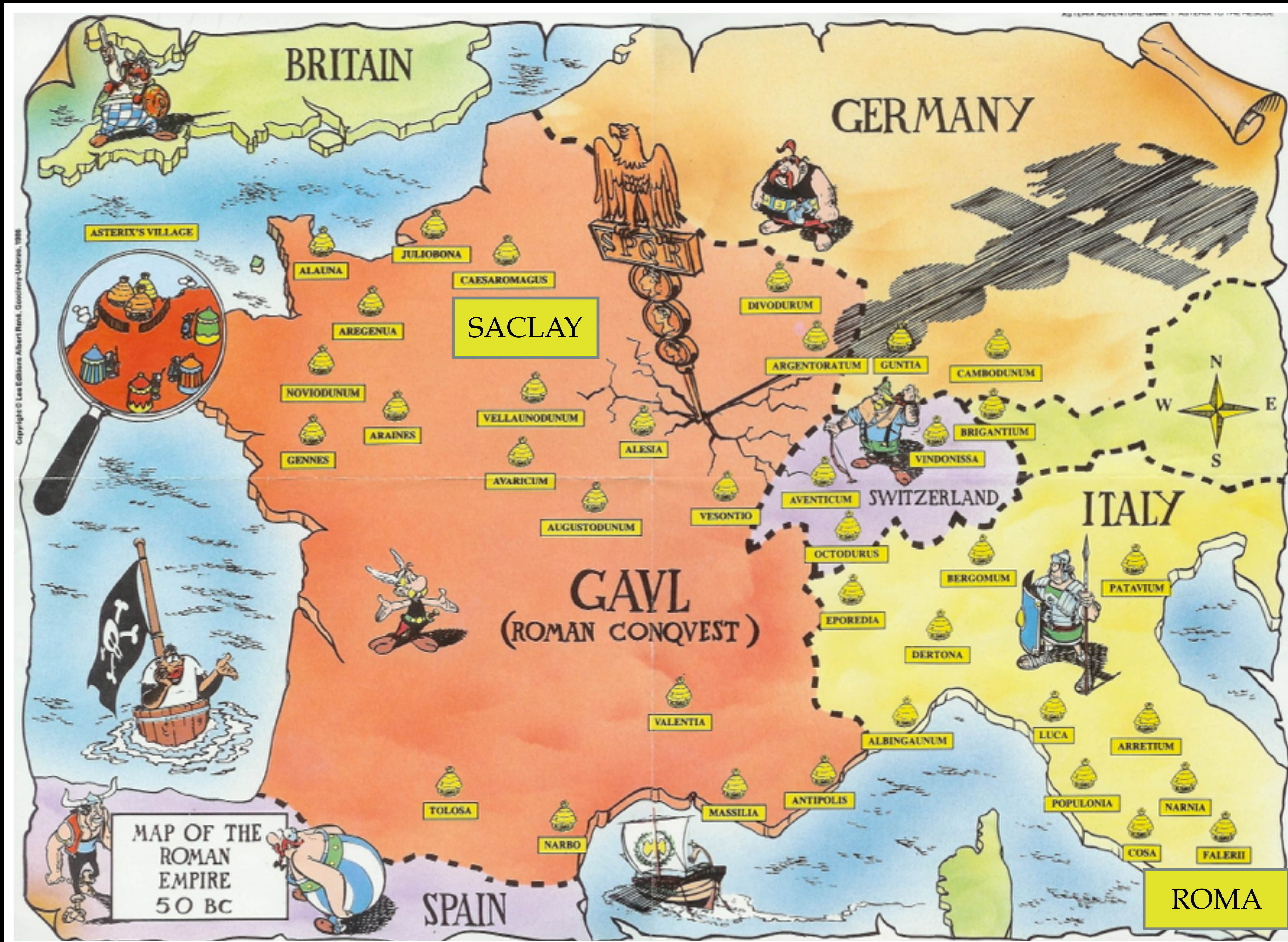


And now for something completely different, about me



And now for something completely different, about me

Undergrad studies (2005-2011): University of Rome "La Sapienza"
Major: Cosmology in the group of Paolo de Bernardis (BOOMERanG)

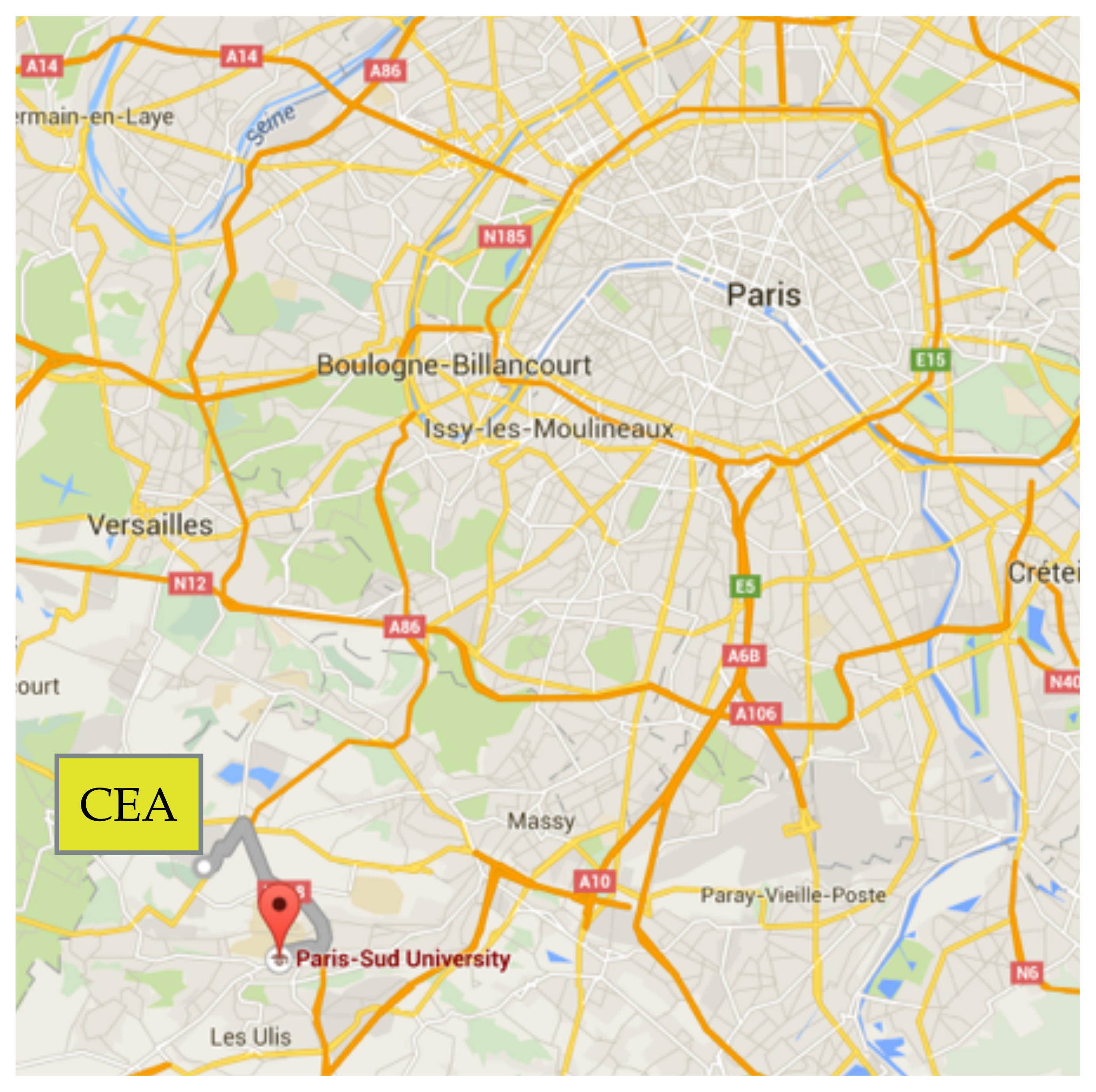
And now for something completely different, about me

<u>Master thesis (2011)</u>:
supervision of Asantha Cooray on Herschel data at
University of California Irvine

Getting closer to the Milky Way and the interstellar medium (ISM):

"Statistical Properties of Galactic Cirrus in the GAMA-9
hour Science Demonstration Phase Field" (Bracco et al. 2011)

And now for something completely different, about me



PhD in Astrophysics at University of Paris-Sud
supervision of Francois Boulanger at Institut d'Astrophysique Spatiale (IAS)
on Planck data for magnetic fields in the ISM:

"Statistical properties of the Galactic magnetic field observed with the Planck satellite"
(Planck int. results. XXXII., Bracco et al. in preparation)

And now for something completely different, about me


(Thanks to Camilla Danielski)
CEA, SACLAY, 3 November 2015

Outline of today

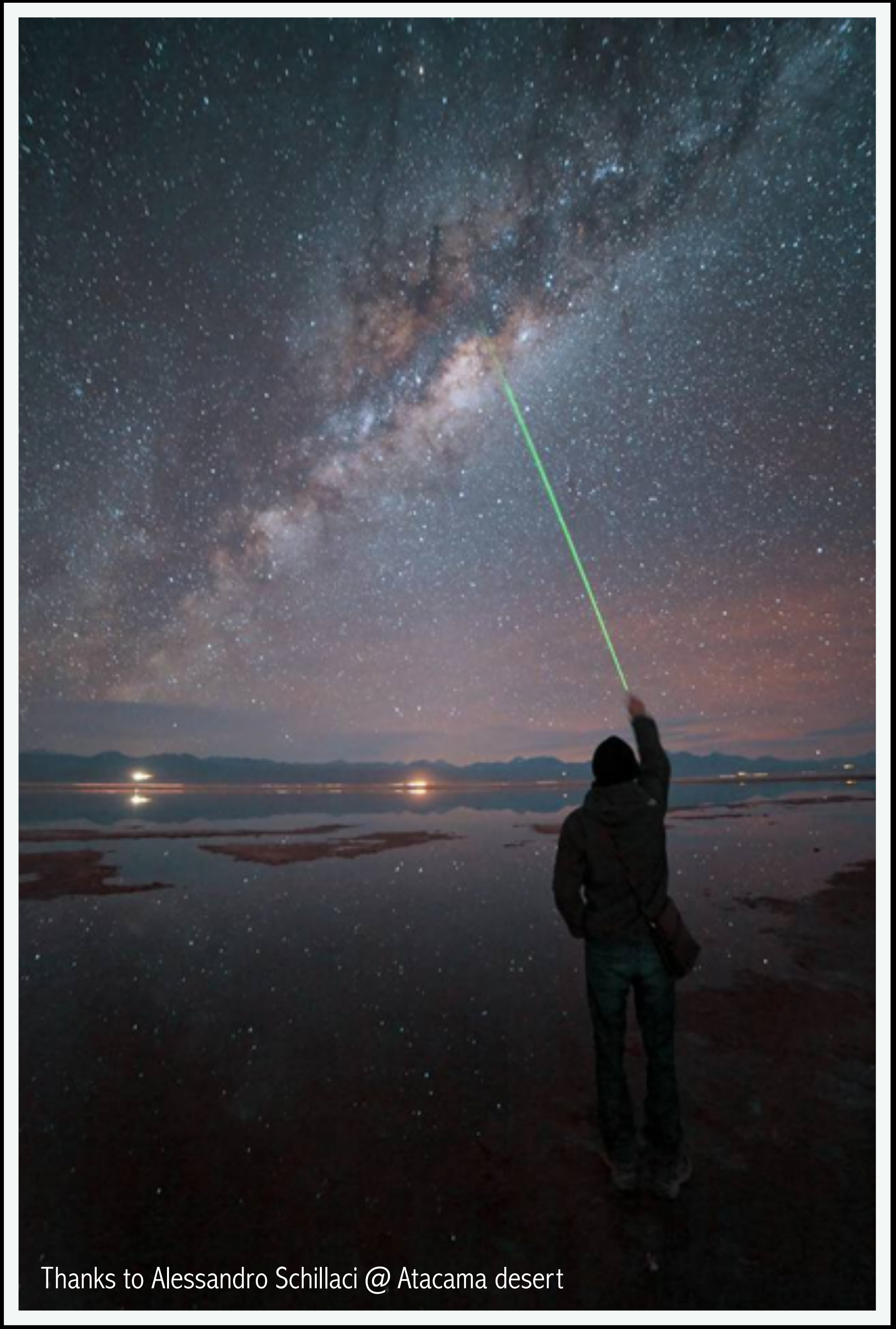
1) Intro.
   - Structure formation in the interstellar medium (ISM)
   - Why do we care of interstellar magnetic fields (MF) ?

2) Measuring MF in astrophysics.
   - A step forward with Planck

3) An all-sky analysis of the correlation between the MF structure and the distribution of interstellar matter

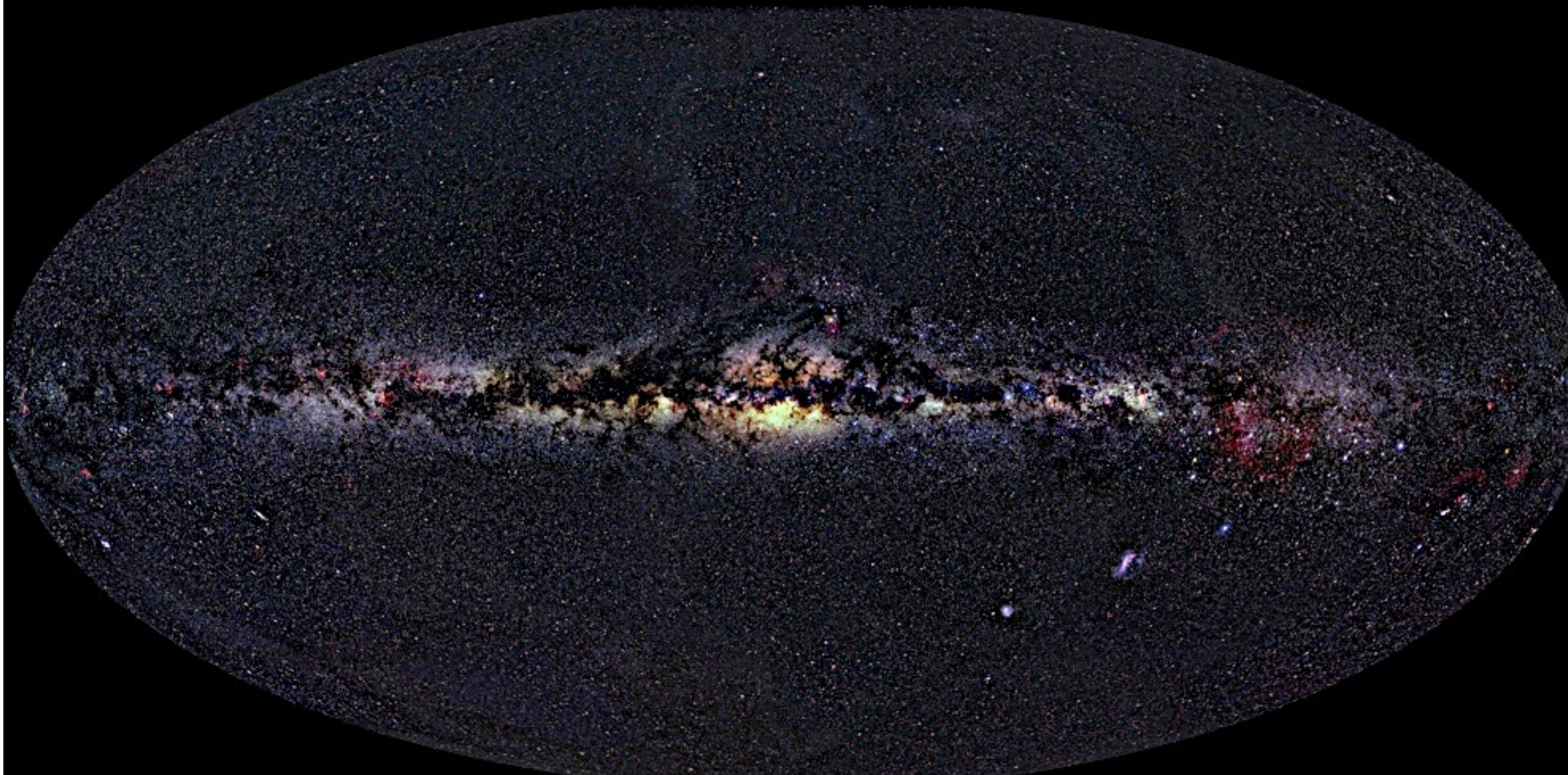
4) Conclusions and perspectives: what am I doing here?

Structure formation in the ISM



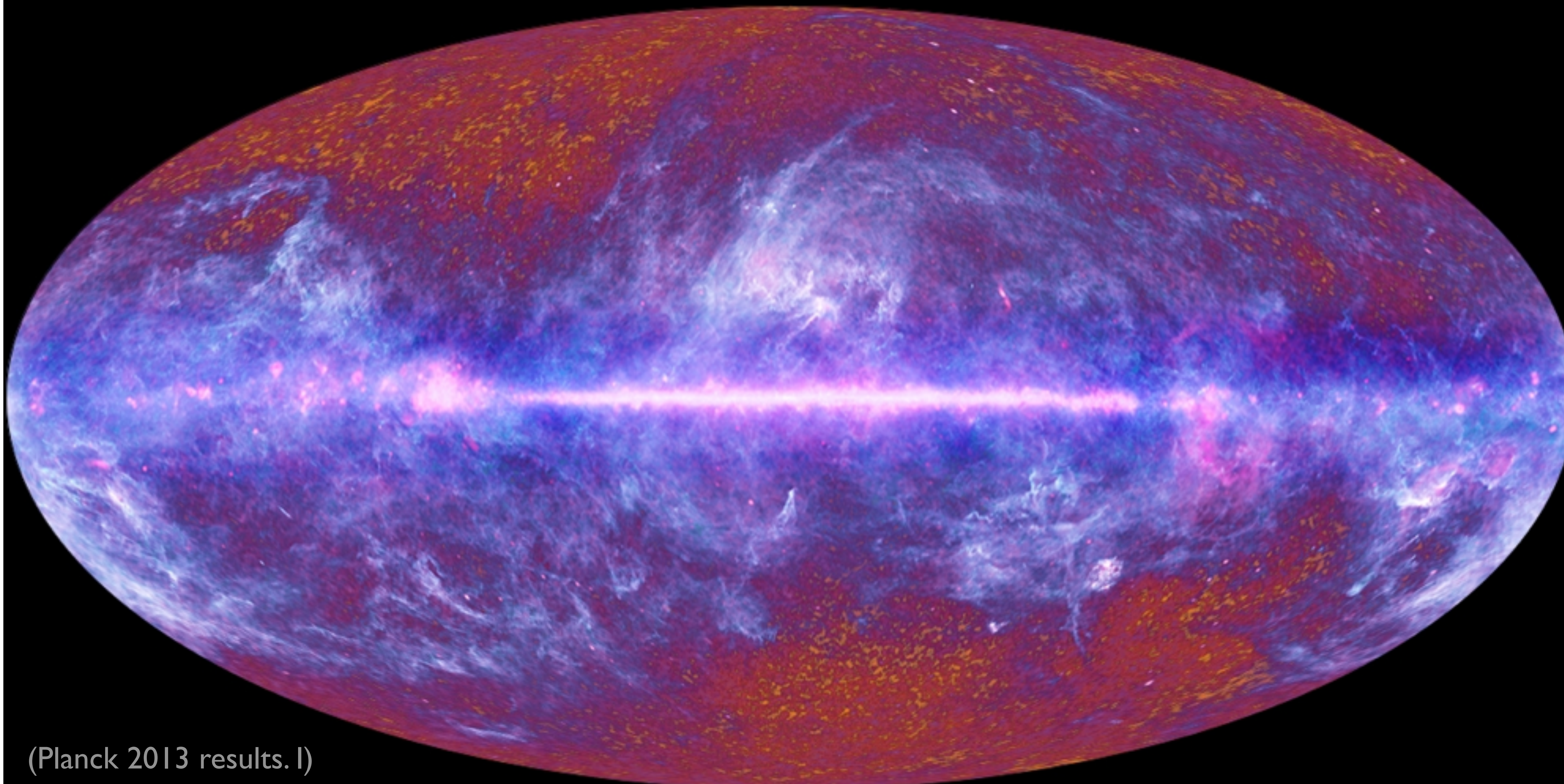
Structure formation in the ISM

in the visible



Structure formation in the ISM

Total intensity of Planck at sub-mm wavelengths

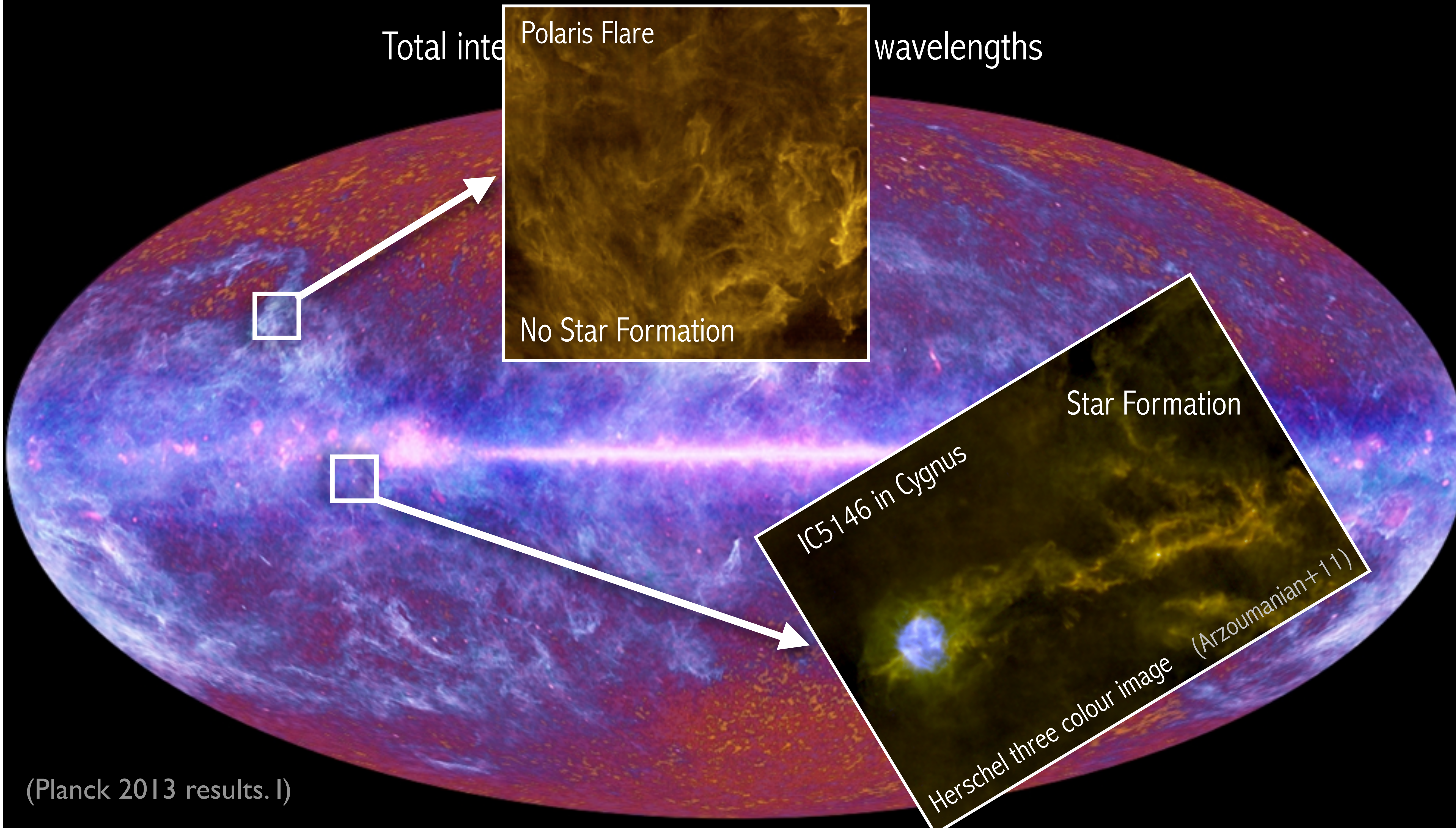


(Planck 2013 results. I)

Neutral gas (~99%)
Dust (~1%)

Structure formation in the ISM

(Men'shchikov+10, Miville-Dechenes+10)



(Planck 2013 results. I)

Neutral gas (~99%)

Dust (~1%)

The dynamics of the ISM

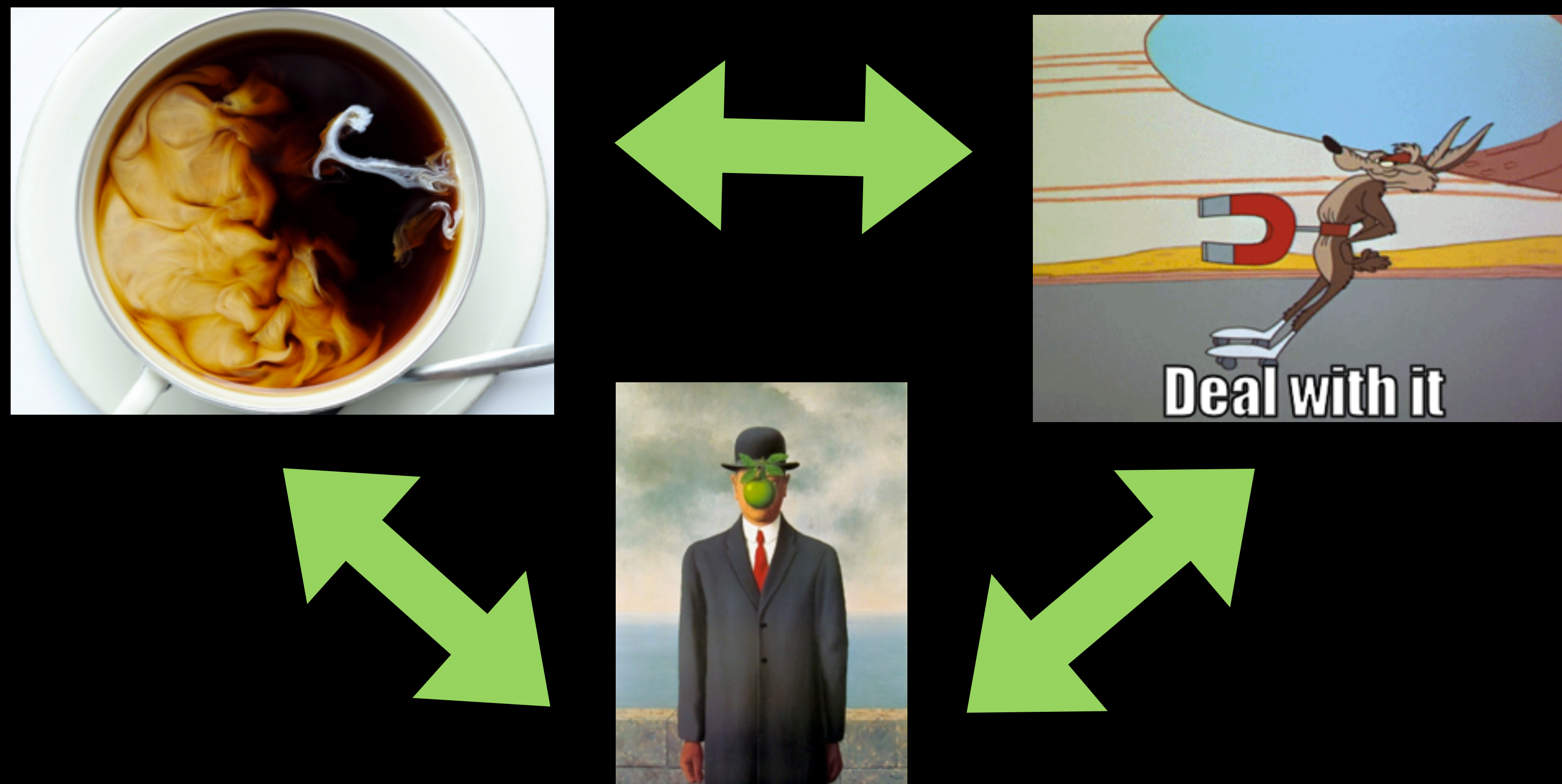
The formation of structures in the ISM depends on the interplay of:

Gravity	Turbulent motions	Magnetic fields
		

In the diffuse ISM HI observations and Zeeman measurements show: (Heiles & Troland 2005)
(Ionization fraction in the diffuse medium $10^{-3} - 10^{-4}$)

$$E_{\rm grav}(\frac{M^2}{R}) << E_{\rm turb}(M\delta v_{\rm gas}^2) \approx E_{\rm mag}(B^2)$$

Toward dense structures in the ISM



Decoupling B-field and self-gravity is a scale-dependent problem:
ambipolar diffusion (Zweibel 2002), magnetic reconnection (Lazarian & Vishniac 1999),

Dynamical alignment of gas velocity and magnetic field contributes to gather matter along field lines without corresponding increase of magnetic flux (Brandenburg+13)

Study of the relative orientation between the B-field structure and that of matter

(**Dense**: Goodman+90,95; Li+13. **Diffuse**: Clark+14,15)

Crazy magnetic fields

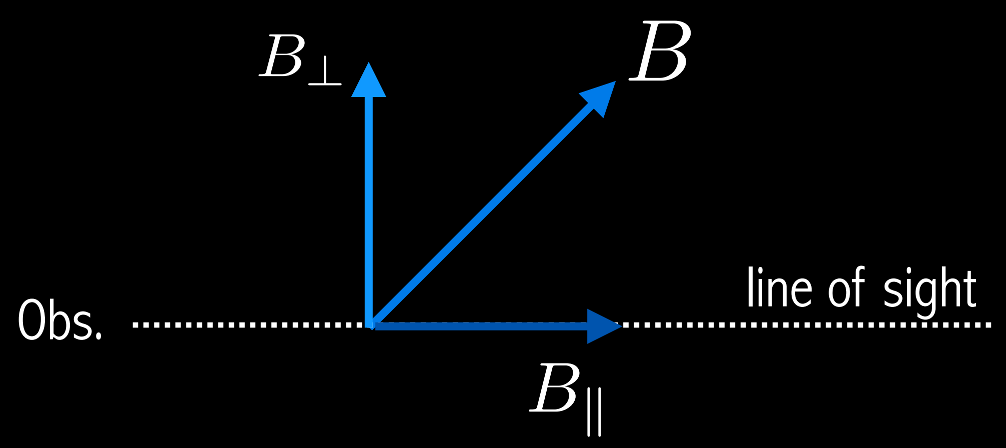
Magnetic fields in the interstellar medium are weak...

	Magnetic field strength [G]
"Seeds" fields in the early Universe	$10^{-30} - 10^{-20}$
Intergalactic gas	$(1 - 10) \times 10^{-9}$
Intracluster gas	$(0.1 - 1) \times 10^{-6}$
Human brain	$(1 - 100) \times 10^{-6}$
Interstellar gas	$< 1 \times 10^{-3}$
Center of the Milky Way	$< 10 \times 10^{-3}$
Earth magnetic field	$\sim 500 \times 10^{-3}$
Refrigerator magnet	~ 50
Magnetic resonance imaging	$(15 - 30) \times 10^3$
Normal star (HD 215441)	34×10^3
White dwarf (PG J1847-0130)	10^6
Strongest pulsed magnetic field (with explosive) in laboratory (VNIIEF, Russia)	28×10^6
Magnetar (SGR 1806-20)	$10^{15} - 10^{16}$

... thus, they are difficult to observe!

Crazy magnetic fields

Observations must rely on the indirect effects of the field interacting with matter



Artistic view of magnetic fields

Panagiotis "Takis" Vassilakis

$B_\perp$

Orientation

Synchrotron polarization (CRs), dust polarization

Strength

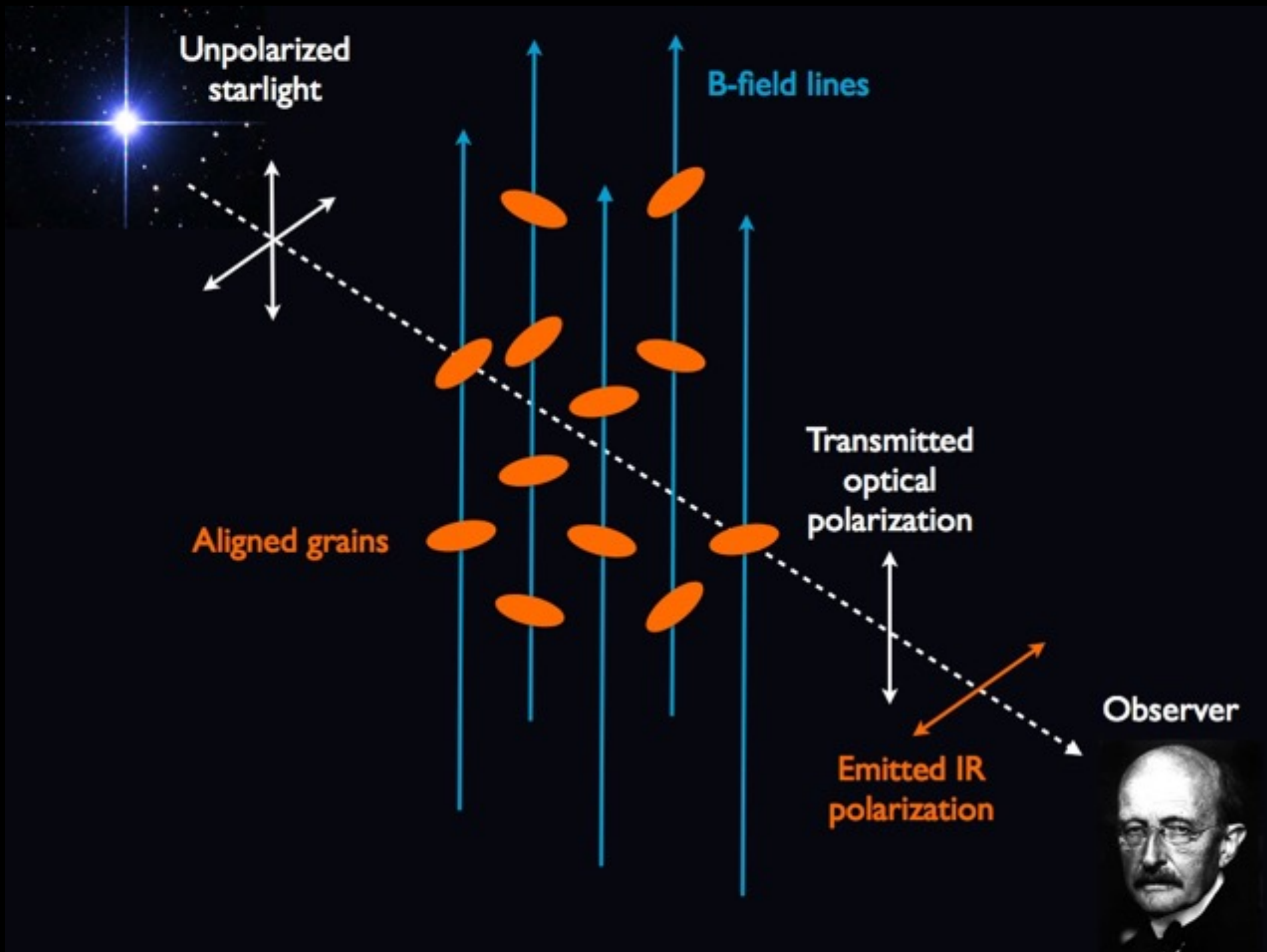
Davis, Chandrasekhar & Fermi method

$B_{||}$

Direction & strength

Zeeman measurements, Faraday rotation

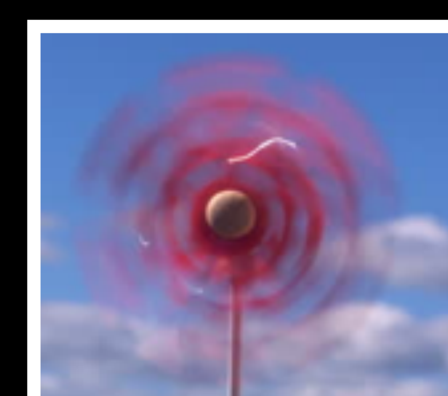
Dust polarization



- Aspherical dust grains rotate at super-thermal velocities and align their axis of maximal inertia with the magnetic field orientation
- Alignment processes are still debated
- We assume that the alignment is ubiquitous and the degree of dust polarization homogeneous.
- In the sub-mm domain we observe linearly polarized light in emission perpendicular to the field lines
- We observe less polarized radiation when the field is along the line of sight

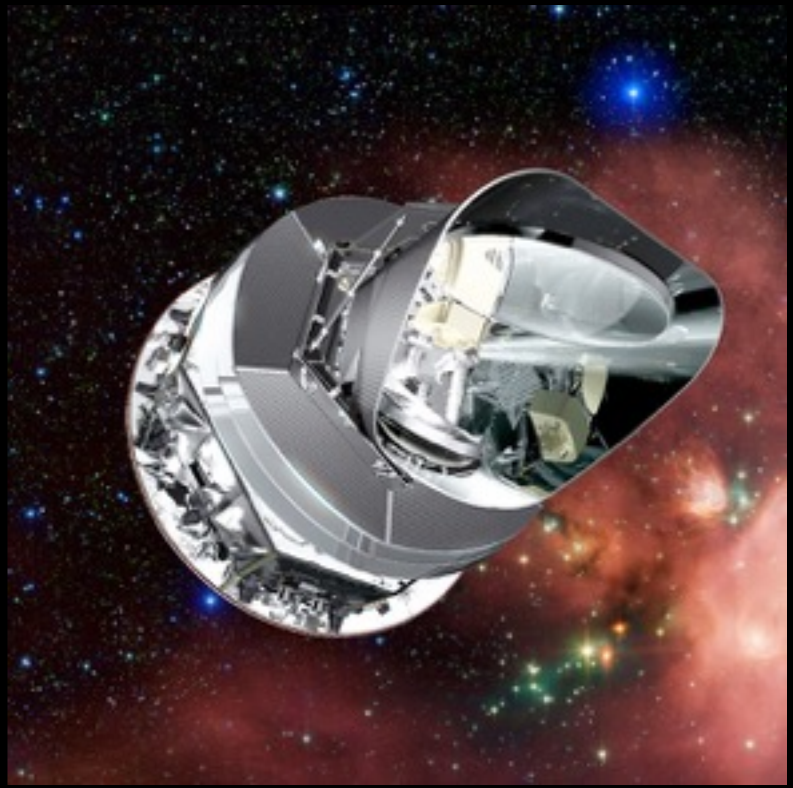
Two observables from the Stokes parameters for linear polarization I, Q, and U:

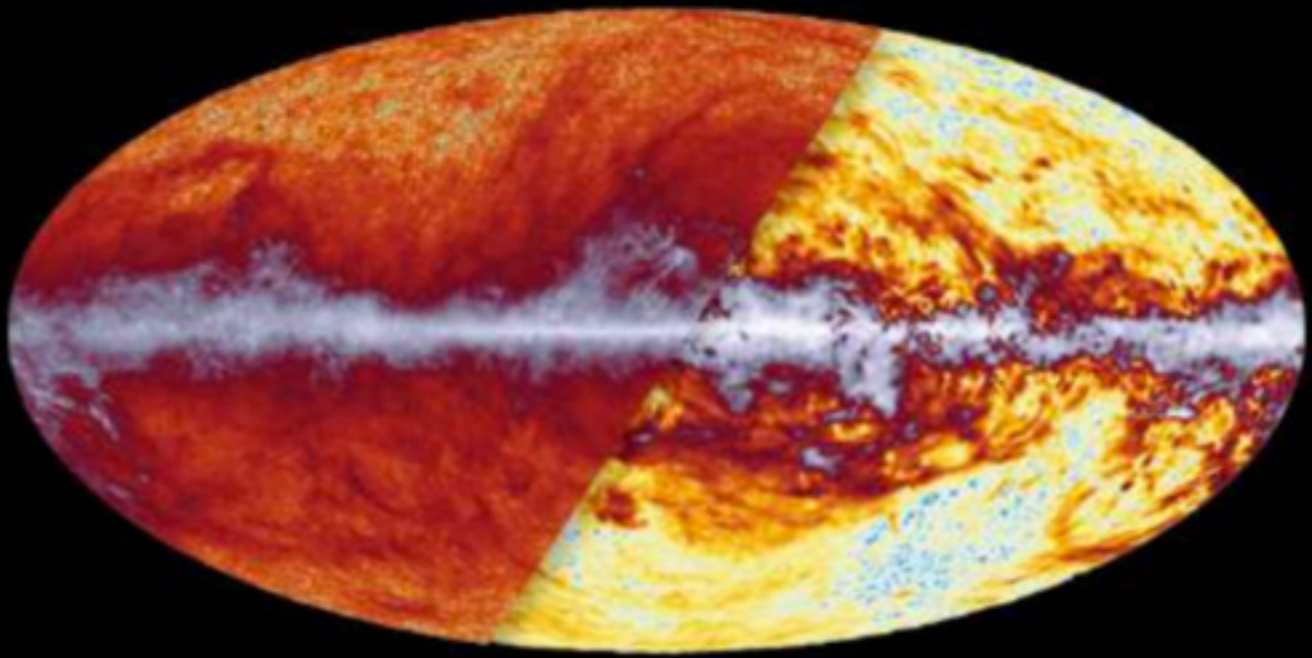
$$p = P/I = \frac{\sqrt{Q^2 + U^2}}{I} \qquad \psi = \frac{1}{2}\tan^{-1}(U/Q)$$



The Planck Mission

- 3rd generation satellite to study CMB anisotropies in intensity and polarization
- Need of studying foregrounds
- High and Low Frequency Instruments: HFI (100-850 GHz) and LFI (30-70 GHz)
- All-sky survey at 9 frequencies. Polarization data for the 7 lowest frequencies (30, 44, 70, 100, 143, 217 and 353 GHz)
- Five HFI full-sky surveys with different scanning strategies. Redundancy is key to identify and correct for systematics
- End of HFI Cryogen in January 2012.

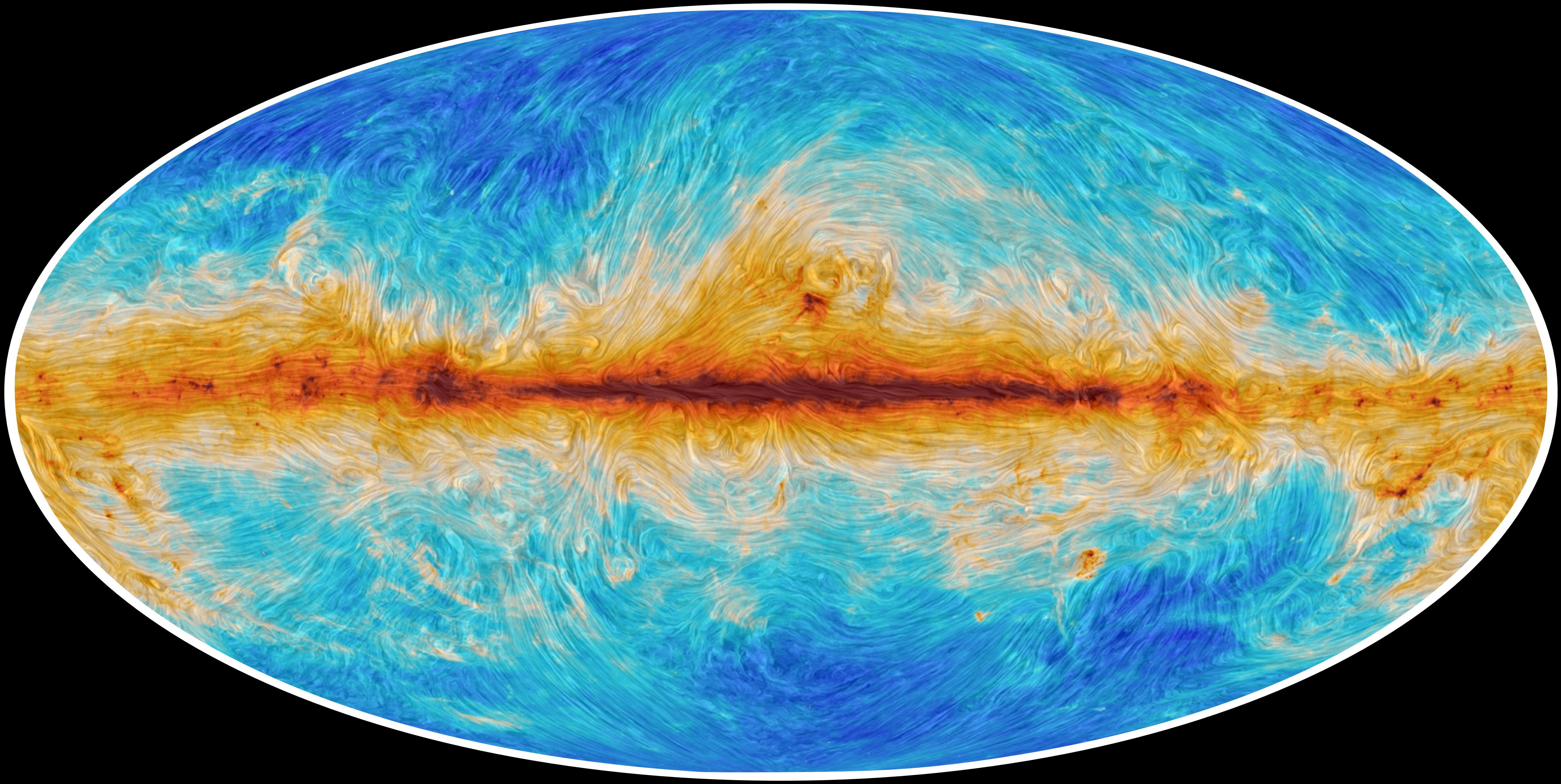




353 GHz $(850\,\mu\mathrm{m})$

The ISM structure in polarization from dust grains

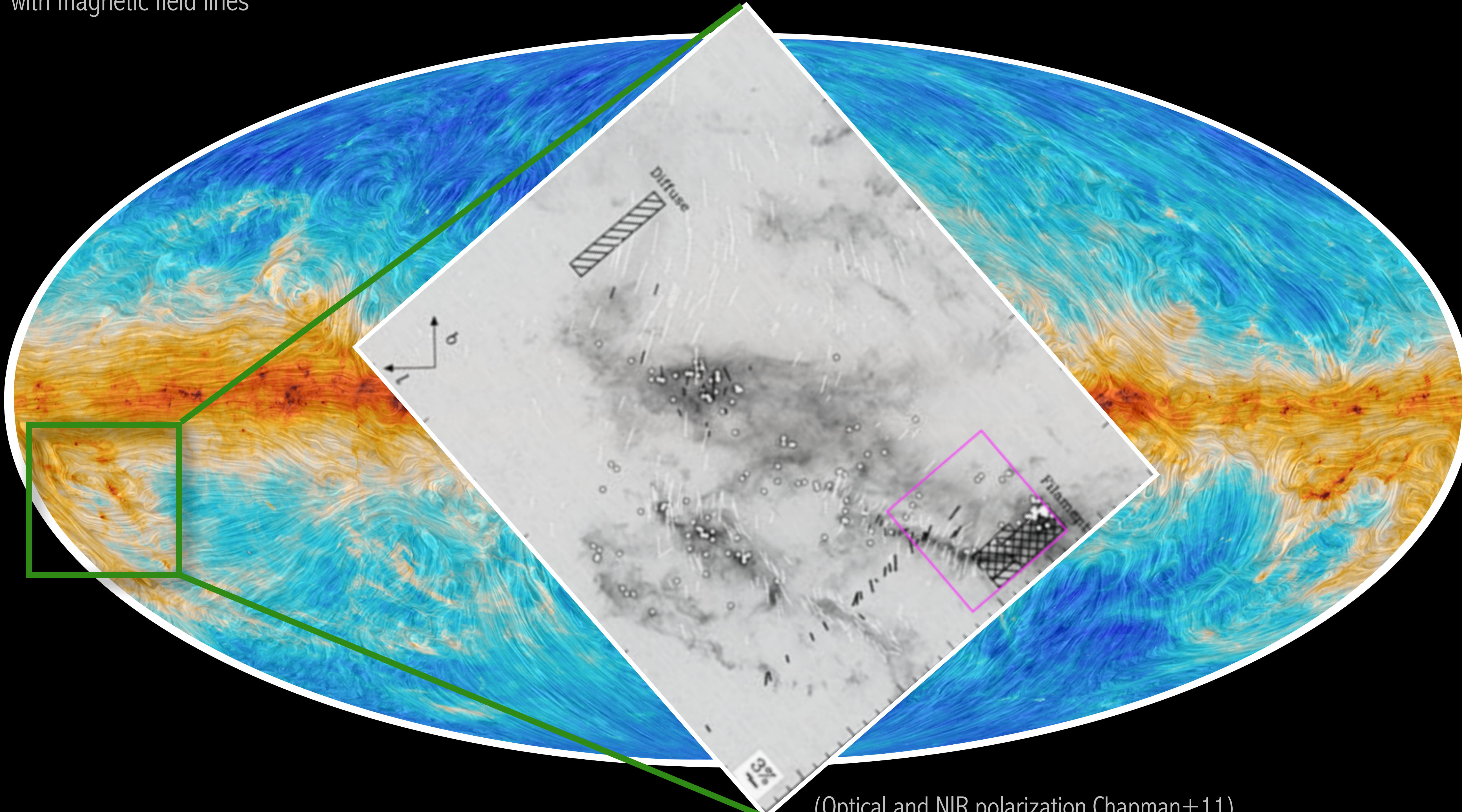
Galactic emission at 353 GHz (Planck 2013 results. I)
with magnetic field lines



Now we have the whole sky: unprecedented statistics!

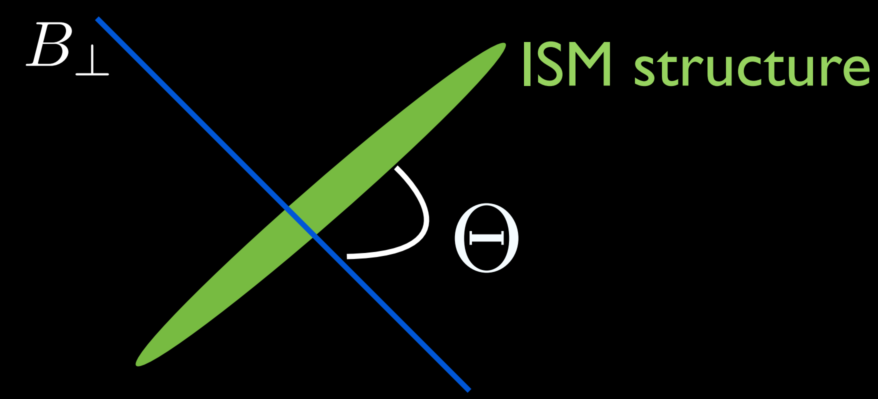
The ISM structure in polarization from dust grains

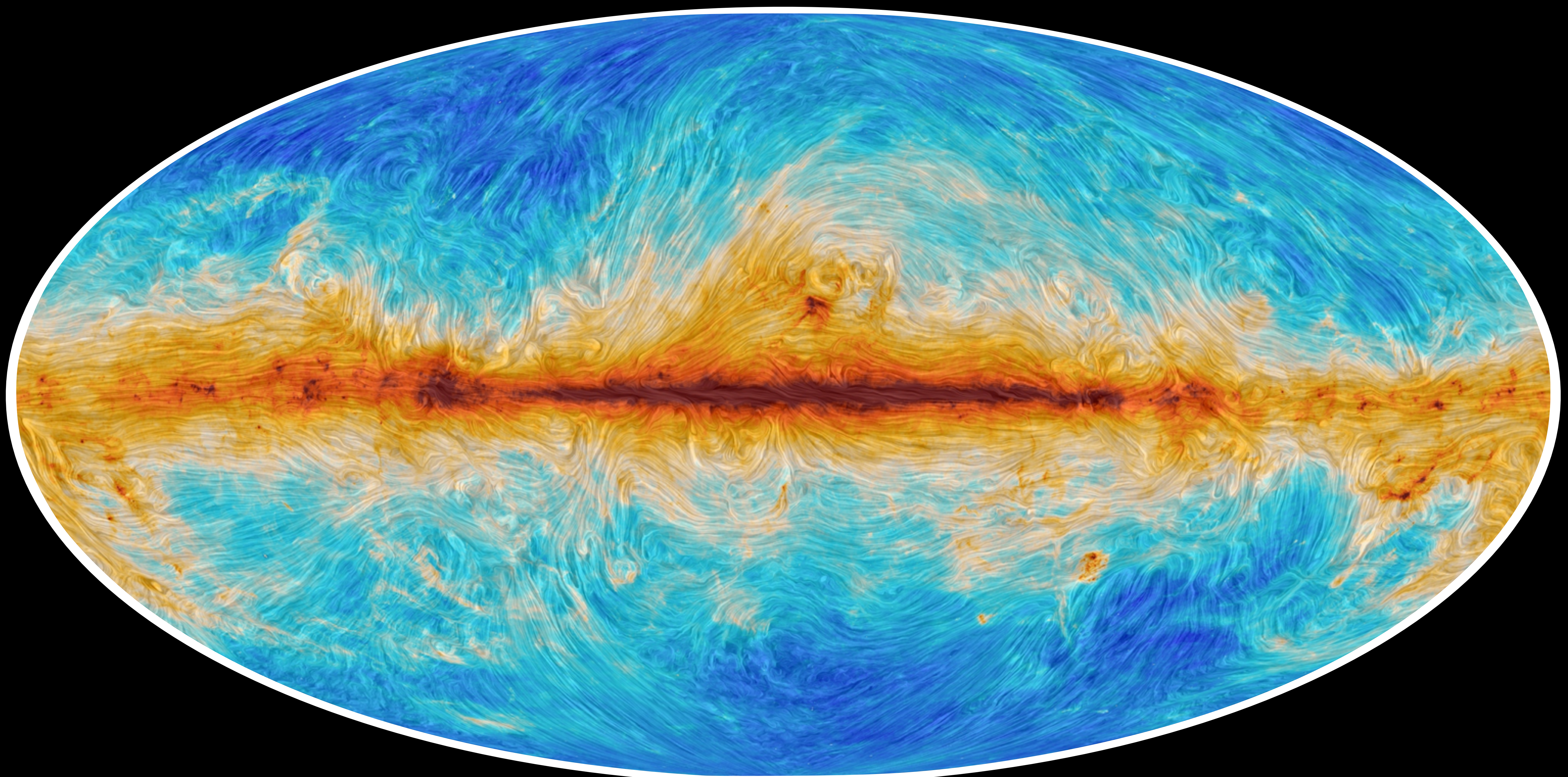
Galactic emission at 353 GHz (Planck 2013 results. I)
with magnetic field lines



(Optical and NIR polarization,Chapman+11)

Histogram of relative orientation (HRO) (Planck int. results XXXII)





Selection of PIXELS!

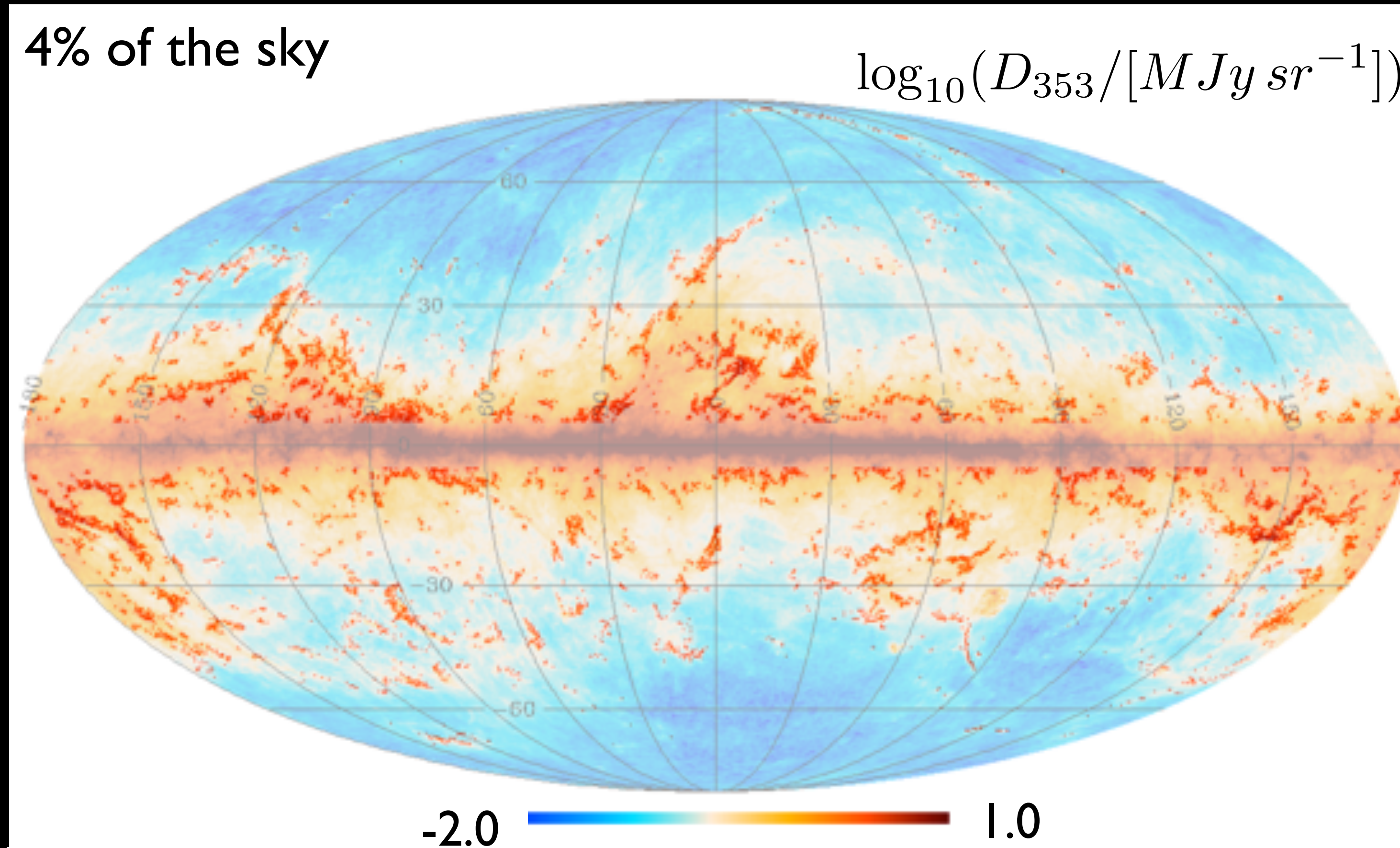
- Galactic plane (|b|<5˚)
- Hessian matrix analysis of the curvature of D_{353}

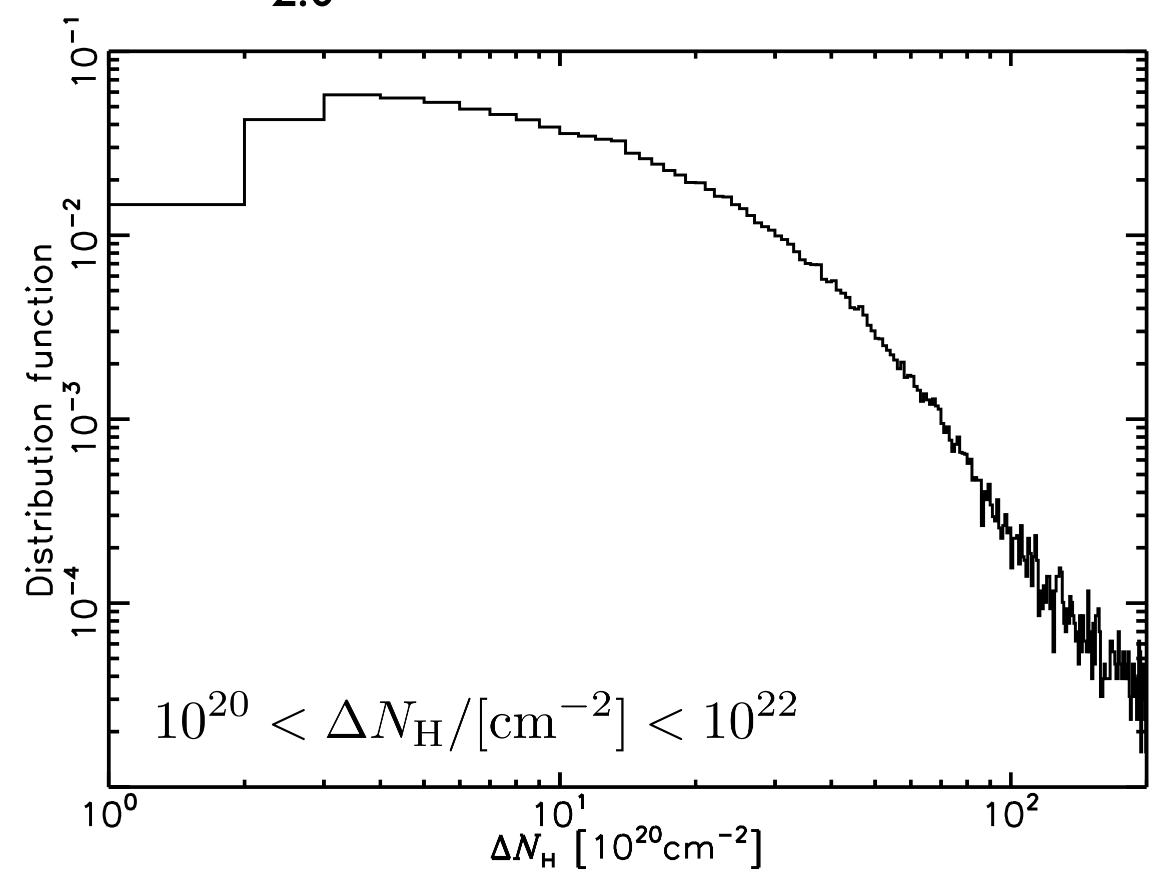
The filamentary structures are the regions of minimum negative eigenvalues

The Hessian analysis provides also the position angle :

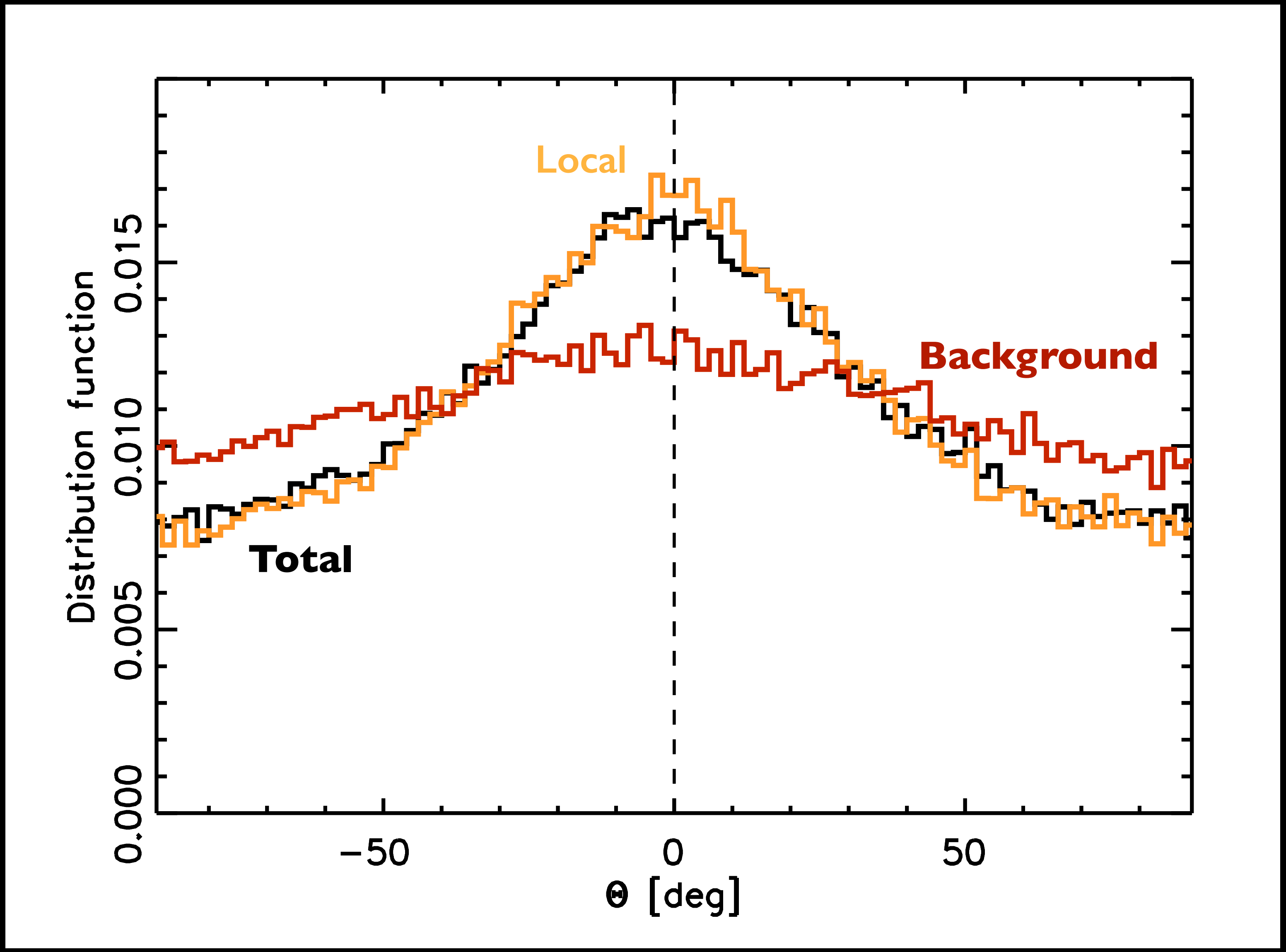
$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{H_{xy}+H_{yx}}{H_{xx}-H_{yy}}\right)$$

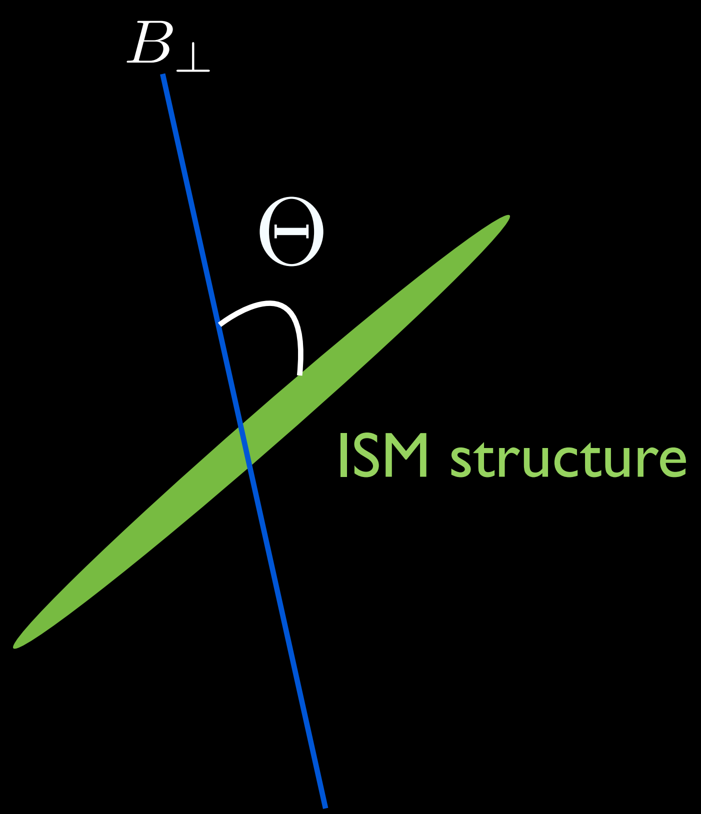
- S/N > 3 in polarization fraction (uncertainty on $\sigma_\psi < 10°$)
- Threshold in intensity contrast with respect to the local background
- On the crest $<n_H> \approx 300\,\mathrm{cm}^{-3}$ which is Cold Neutral Medium (HI)





Matter Vs Magnetic field



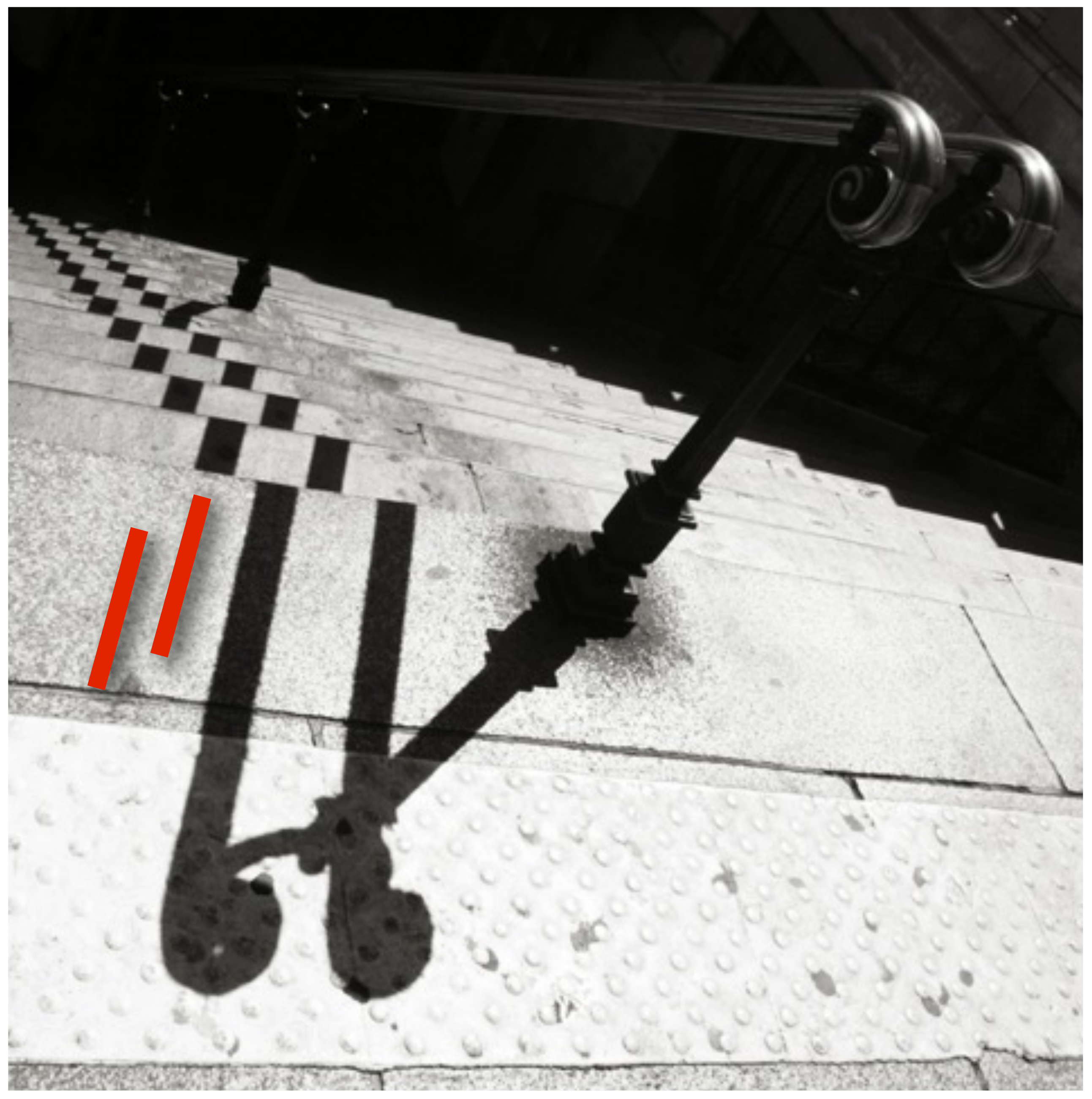


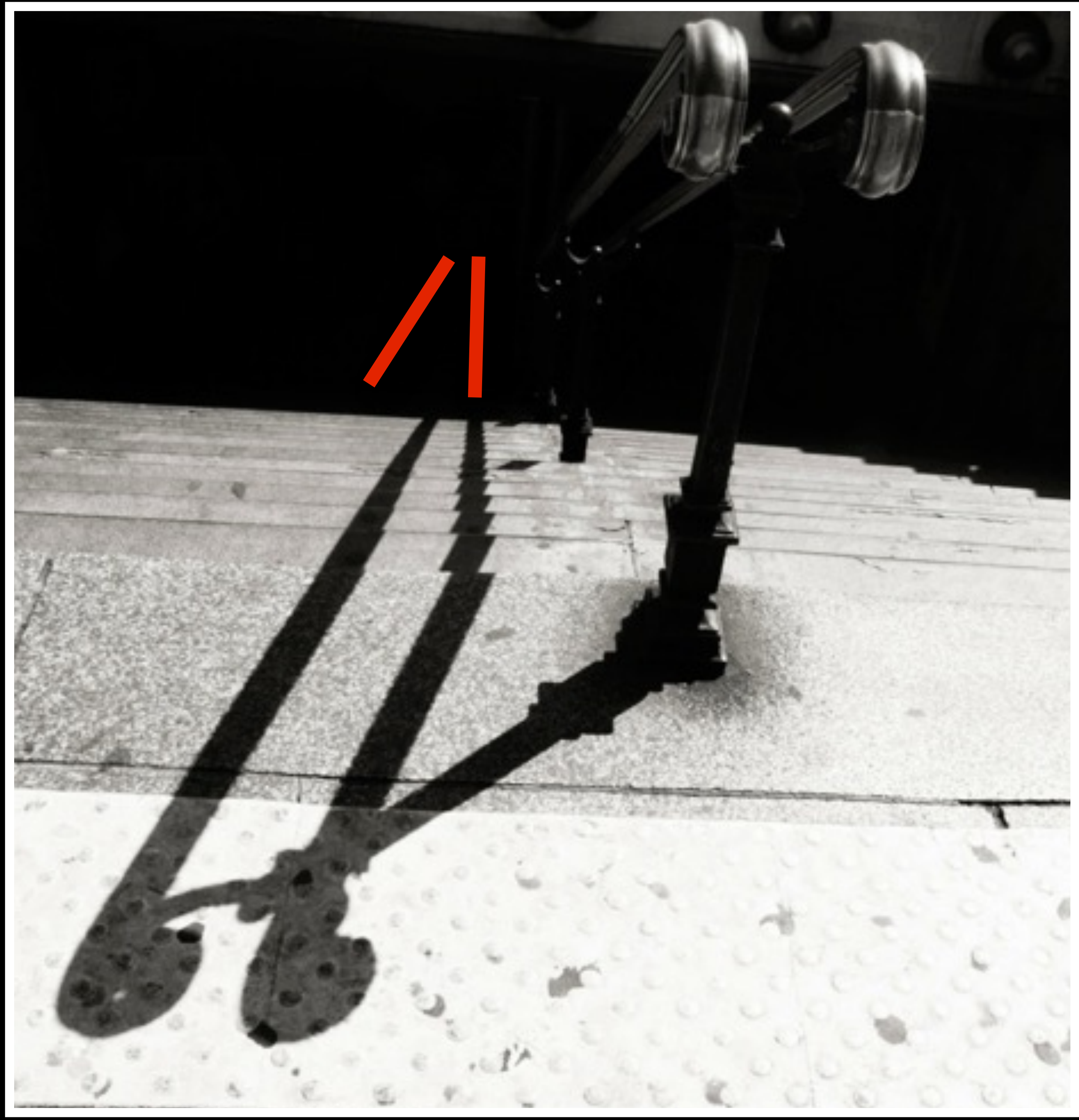
The structures tend to be aligned with the local magnetic field

Projection effects (3D to 2D) are crucial for the interpretation of the shape of the distribution!

Matter Vs Magnetic field

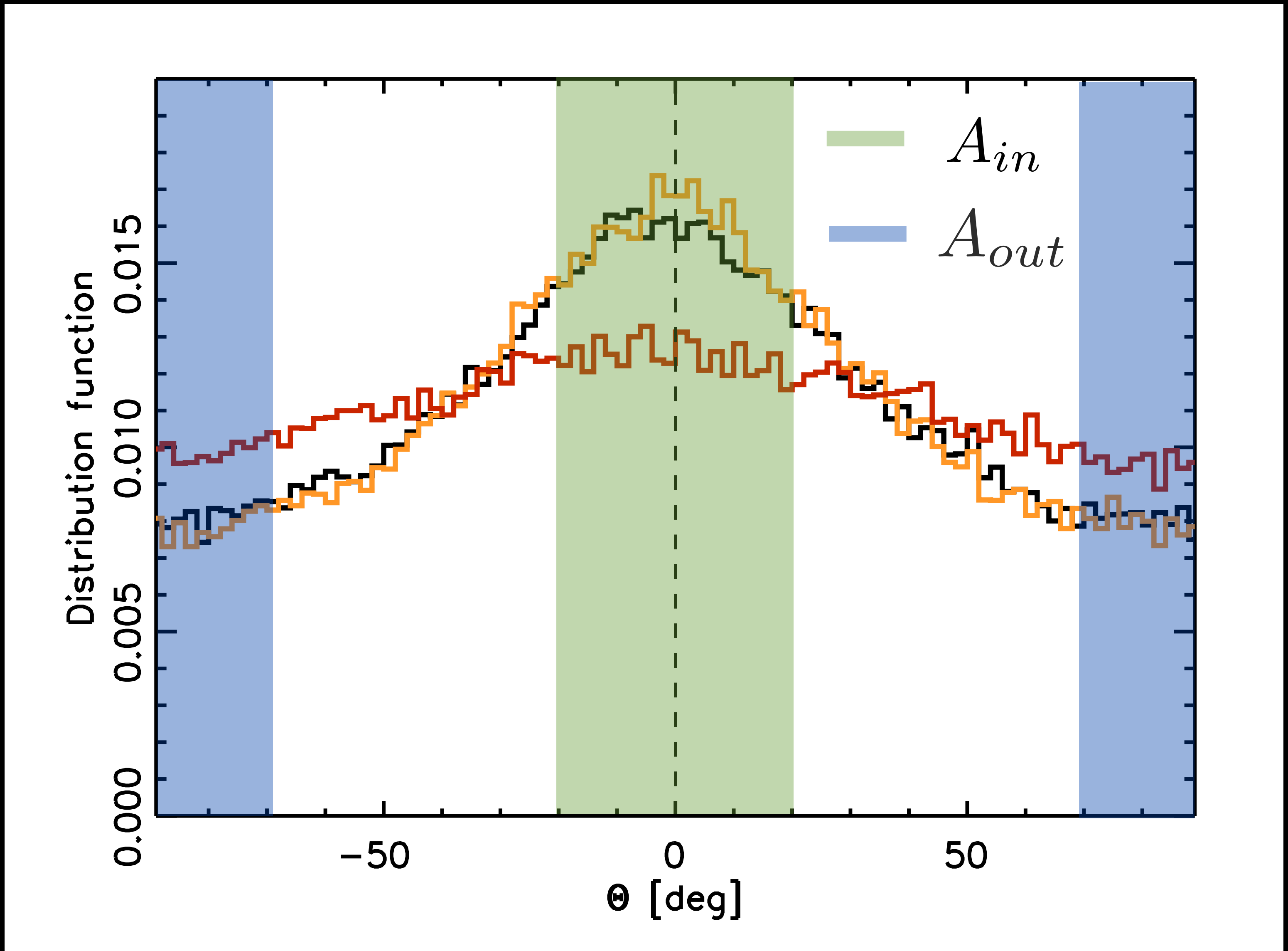
Projection effects (3D to 2D) are crucial for the interpretation of the shape of the distribution!





Degree of alignment

$$\xi = \frac{A_{in} - A_{out}}{A_{in} + A_{out}}$$

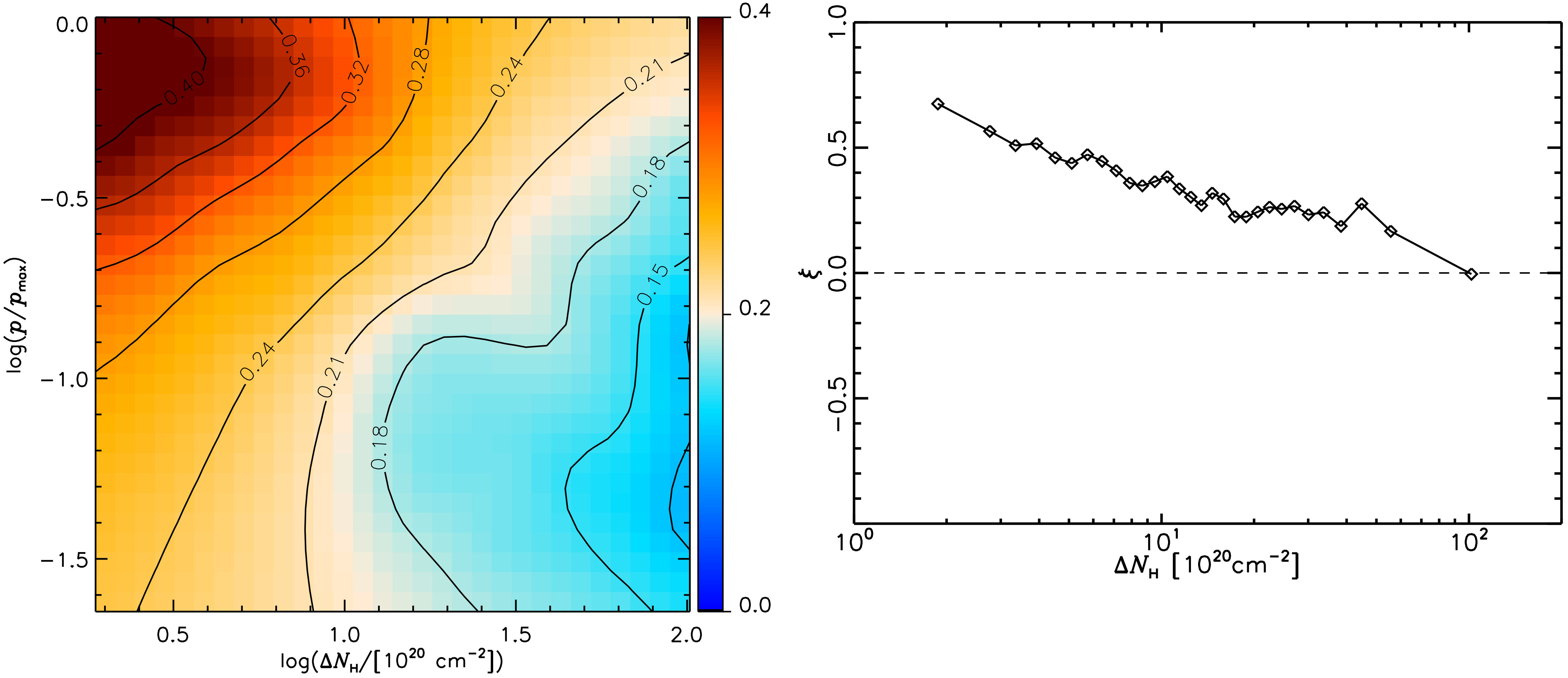


the degree of alignment is :

equal to 1 in case of perfect alignment
equal to -1 in case of perfect perpendicularity

Degree of alignment Vs N_H

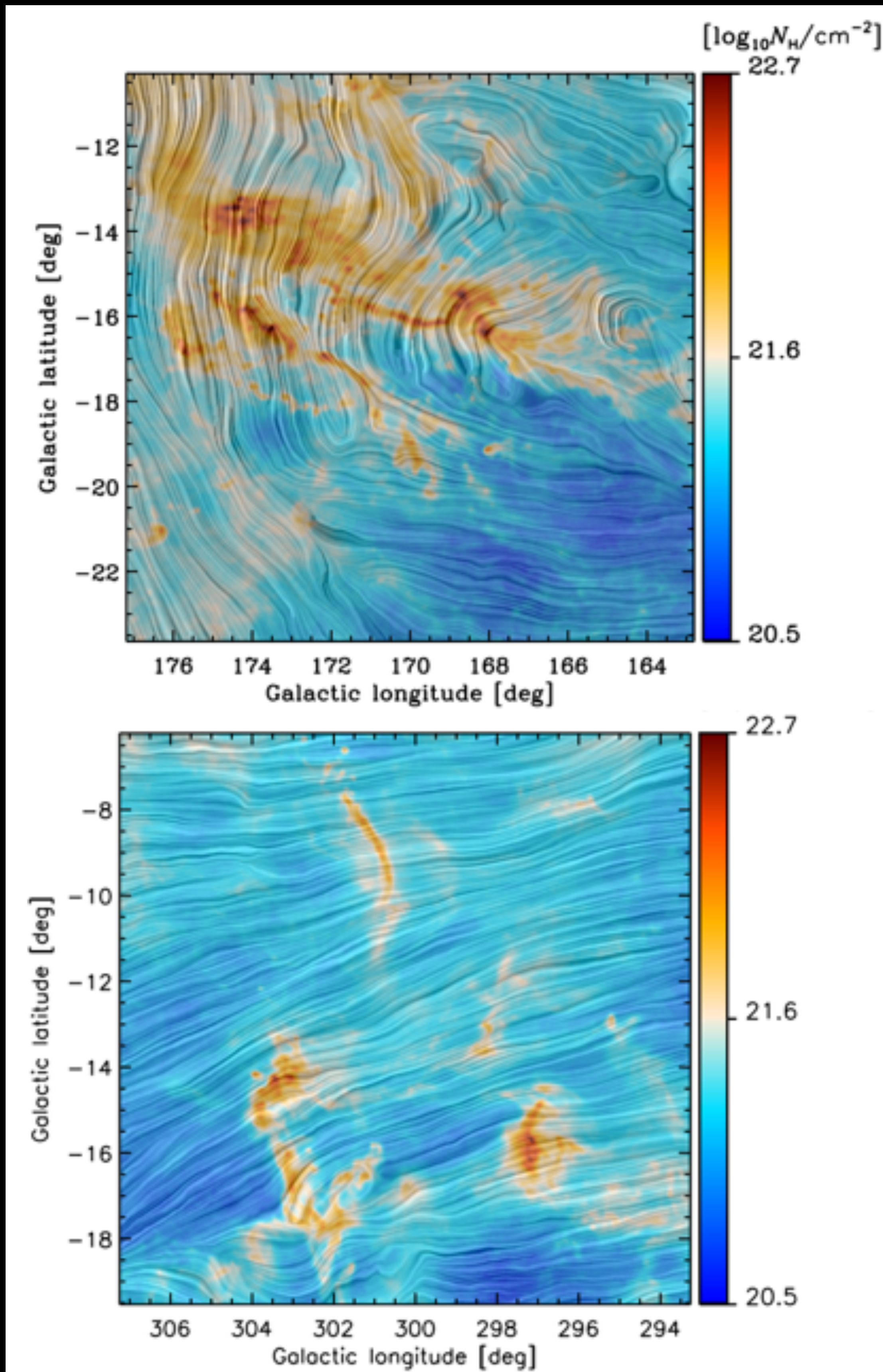
We use the same number of elements within each bin of column density and p

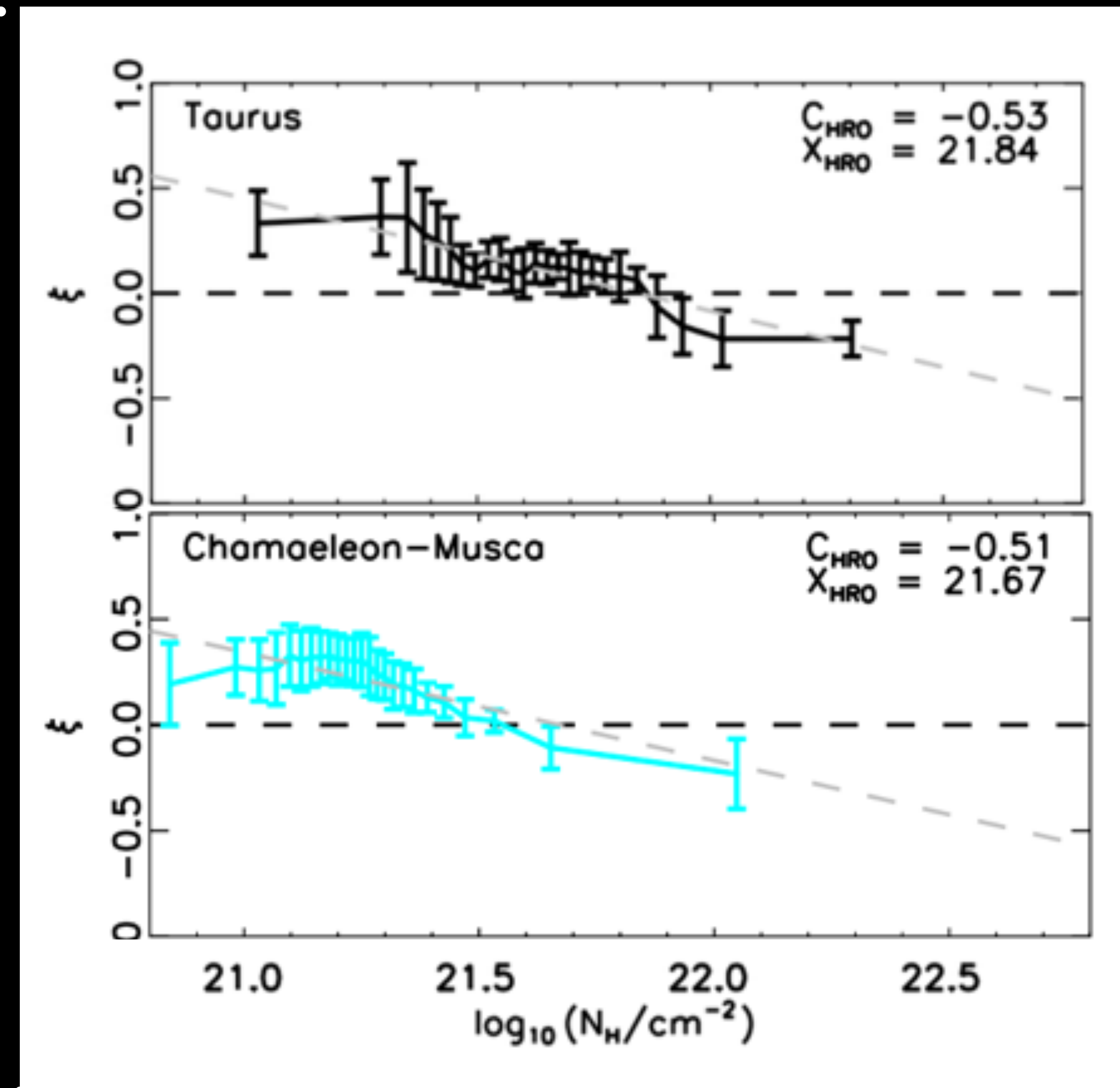


The degree of alignment larger for low column densities and high polarization fraction

What is happening at high column density?

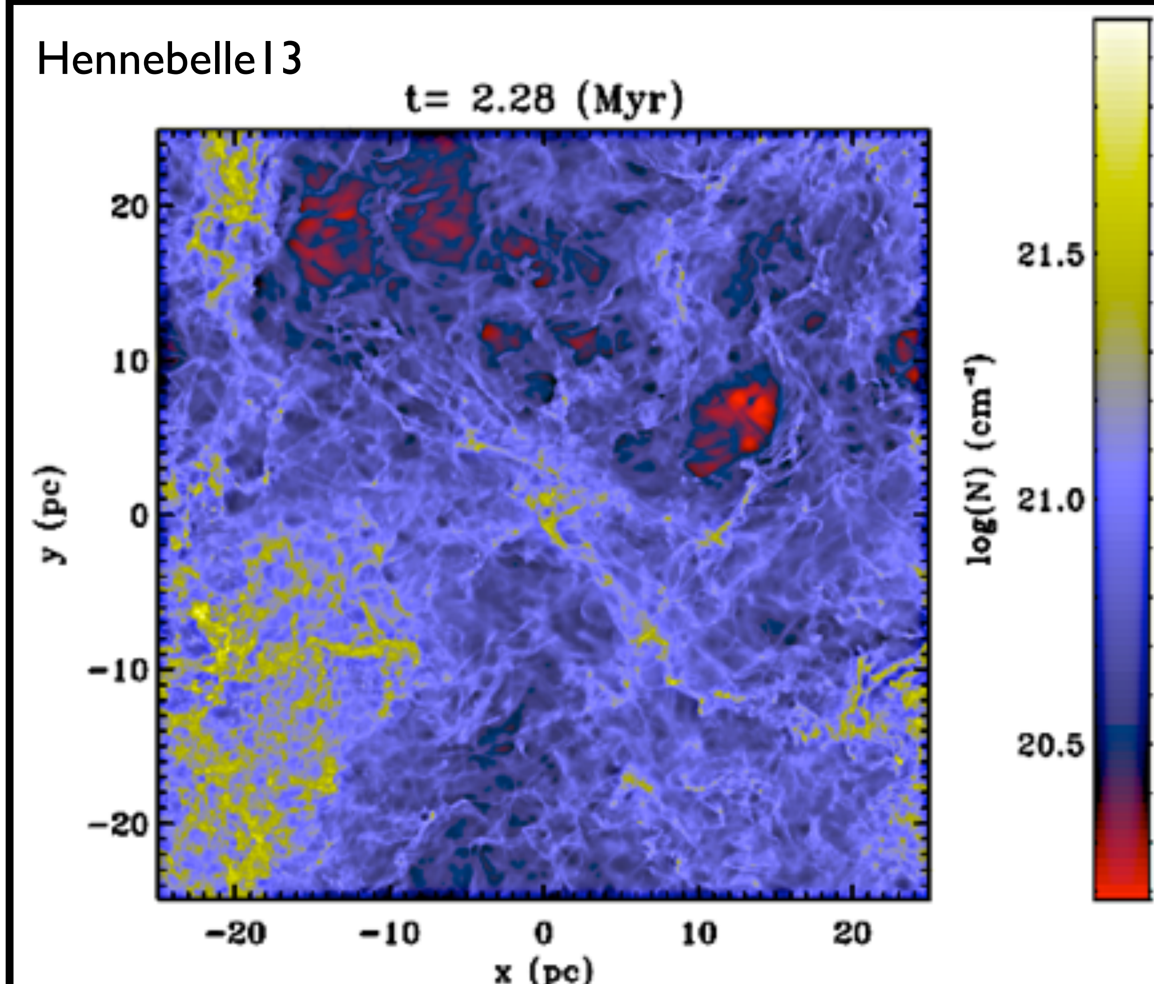
Degree of alignment in molecular clouds (Planck int. results XXXV)

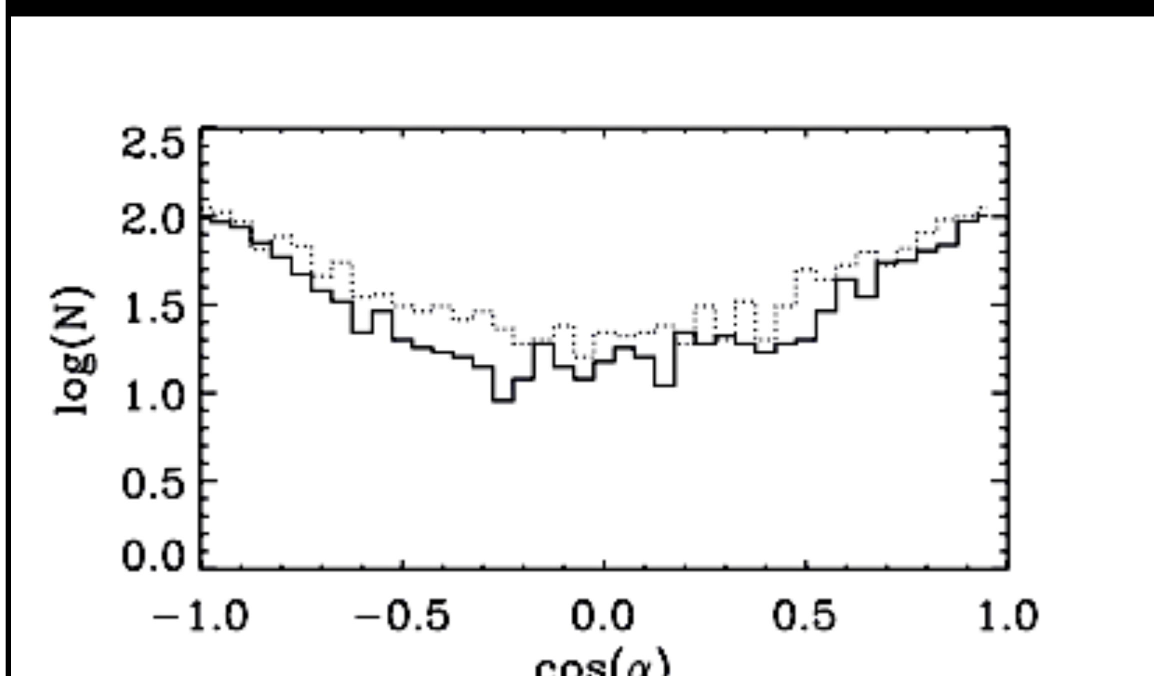




In molecular clouds, we observe structures of matter perpendicular to the orientation of the magnetic field

Numerical simulations: Diffuse ISM





Strain Vs main axis of the filaments

Useful experiments, although important limitations: physical processes, spatial scales, numerical resolution

- MHD simulation
- Two-phase medium
- Decaying turbulence (super-sonic and trans-Alfvenic)

$$E_{grav} << E_{turb} \approx E_{mag}$$

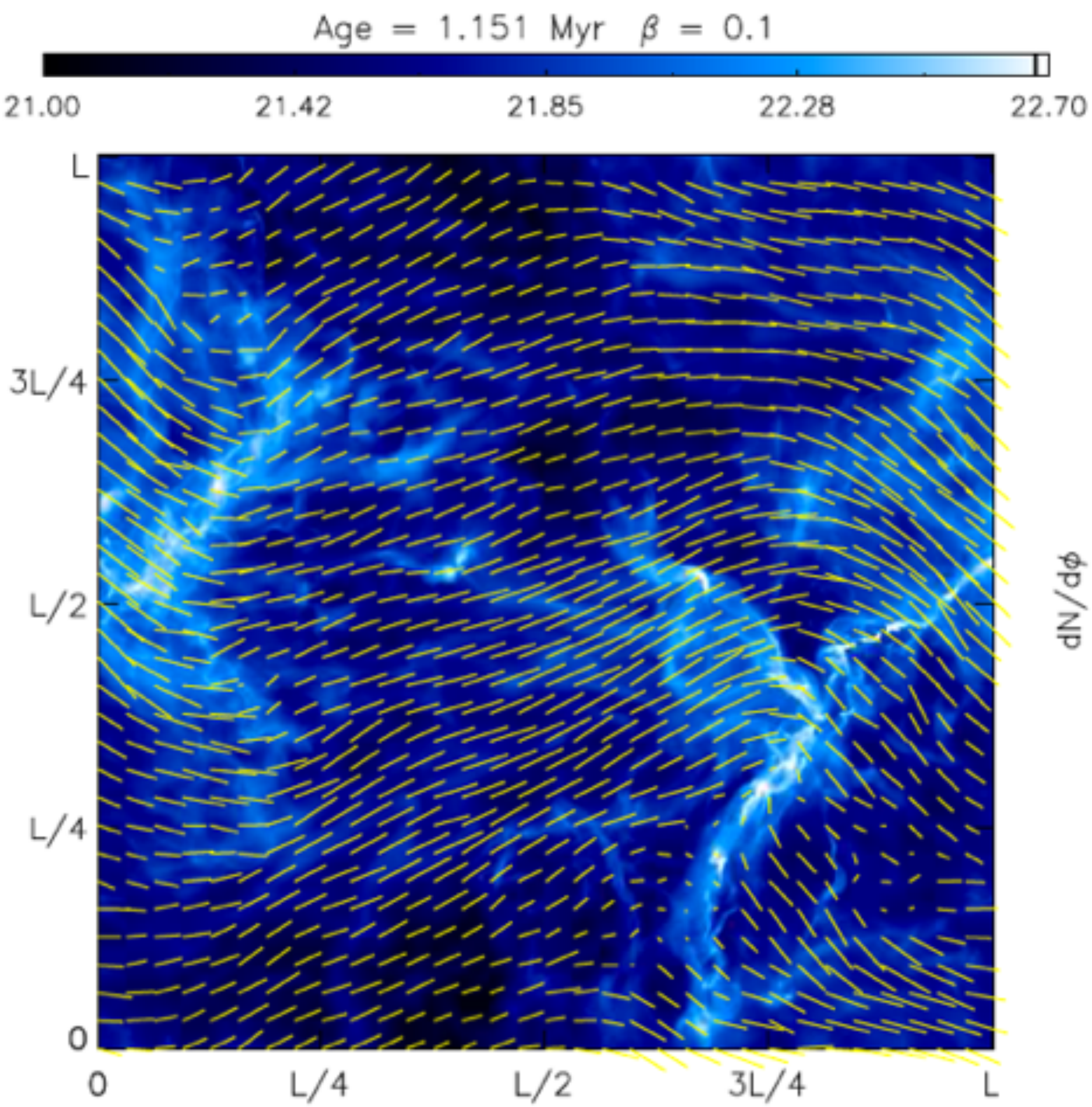
- Filamentary structures result mainly from stretch induced by turbulence in the diffuse ISM
- This can account for the preferred alignment between B-field and matter

Interpretation: Molecular clouds

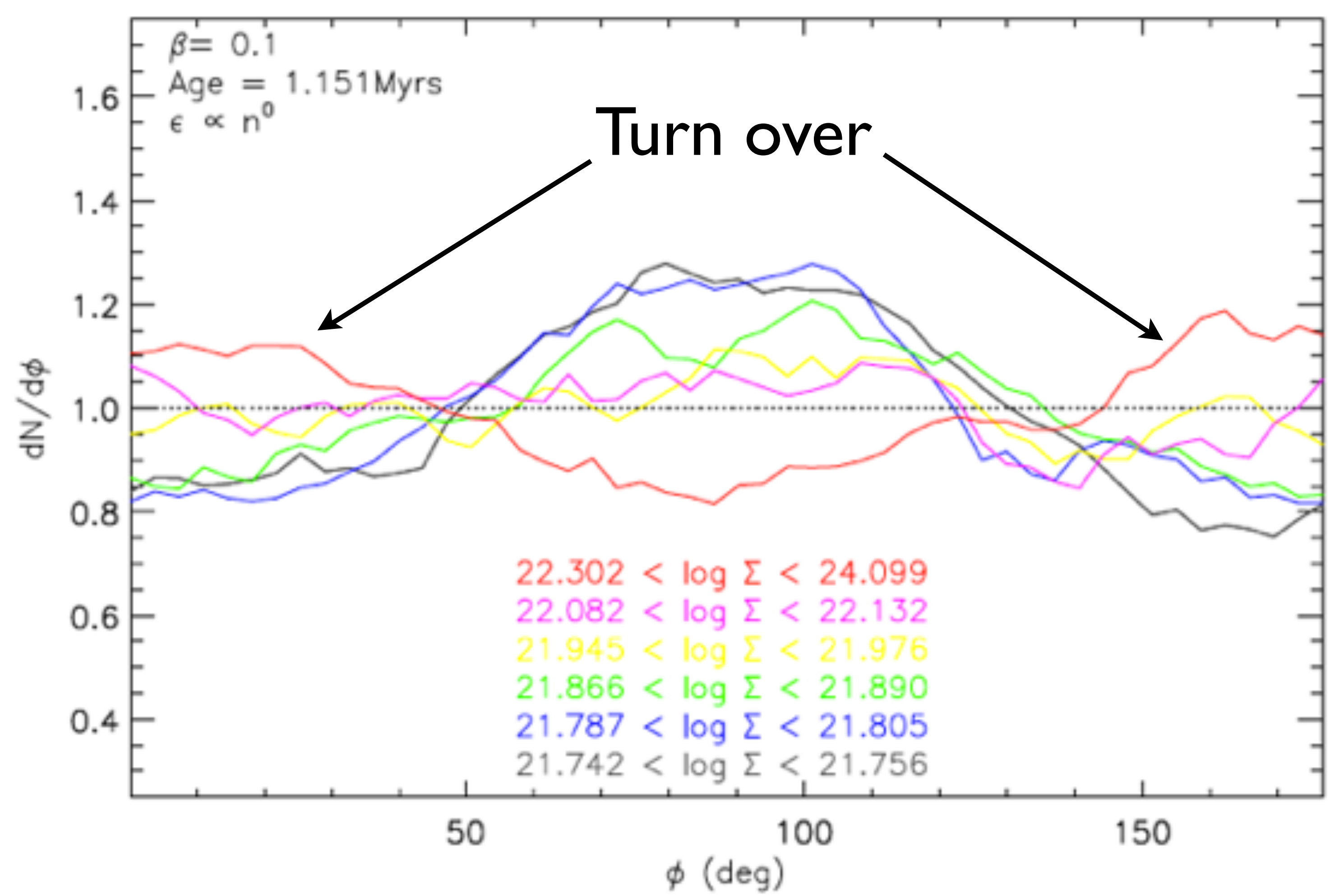
Soler+13 (similar initial conditions of Taurus, including gravity, decaying turbulence, isothermal)

$$E_{grav} \approx E_{turb} < E_{mag}$$

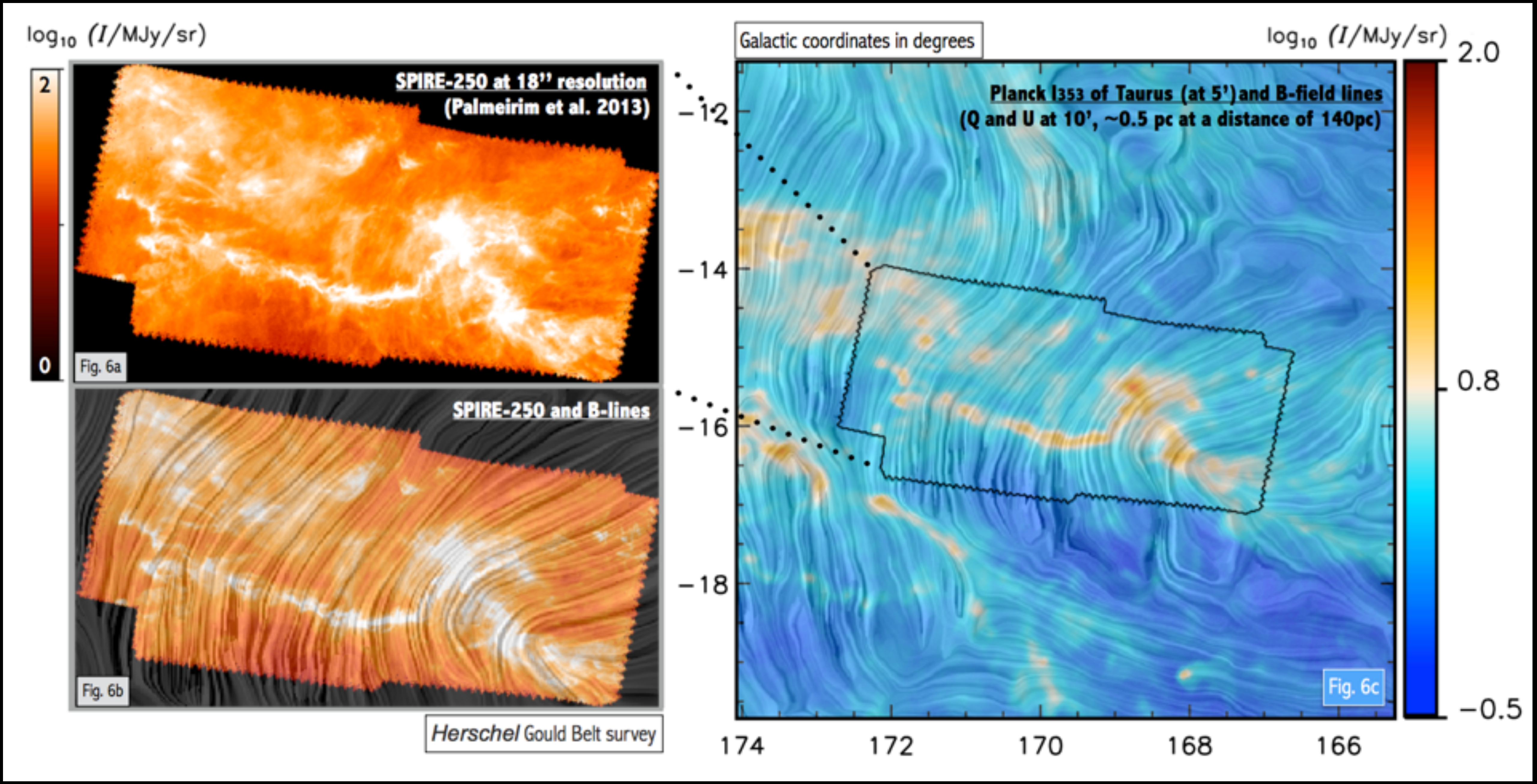
Strong initial magnetic field case



Binning in column density



What next?



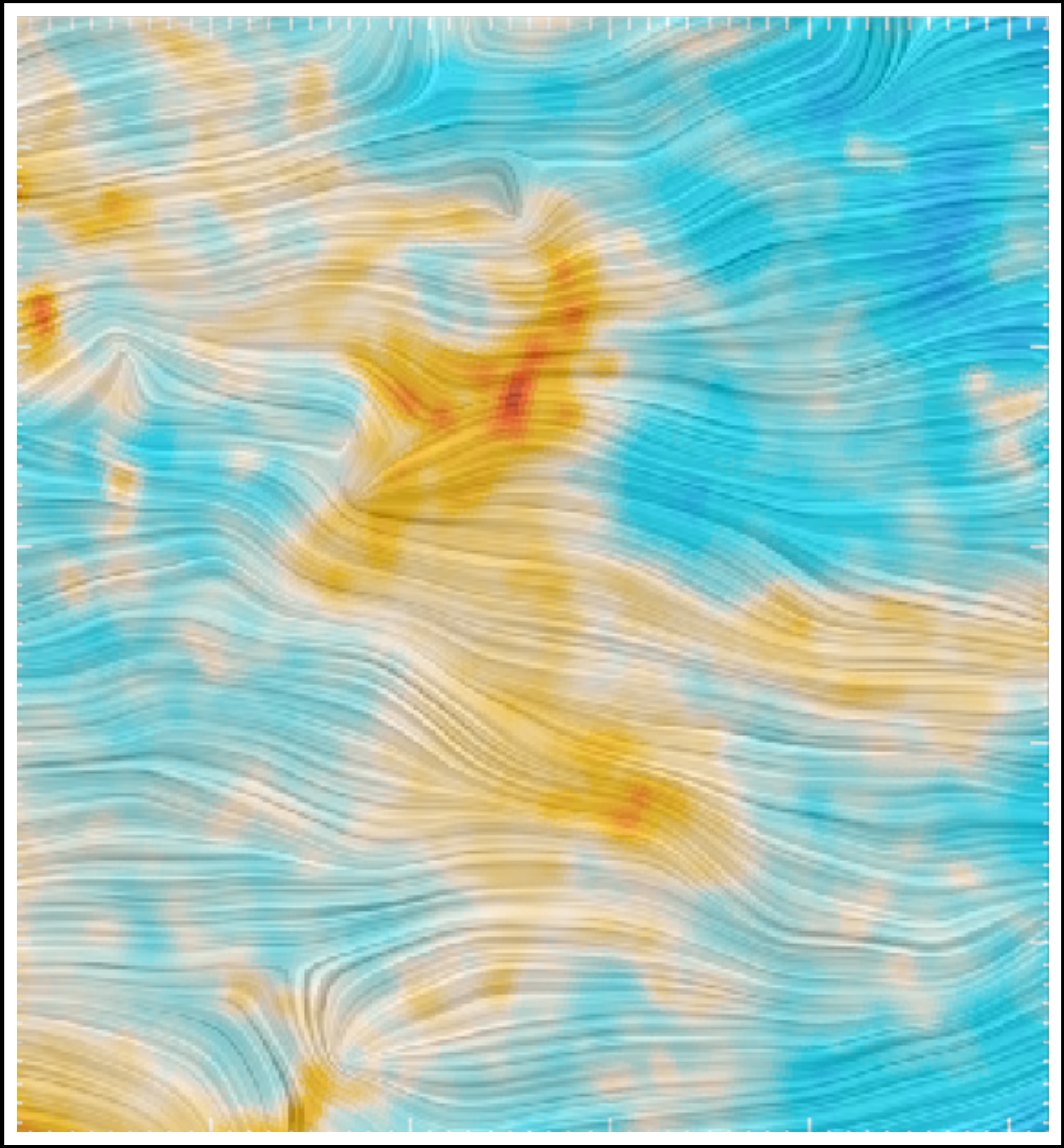
We observe sub-structure in molecular clouds at submm wavelengths and in velocity (Palmeirim+13, Hacar+13)

It will be crucial to probe the B-field structure at higher resolution and investigate the role of the magnetic field in the evolution of matter structure toward the formation of supercritical filaments, which undergo gravitational collapse (i.e. NIKA2 camera at IRAM-30m…soon!)

Where do we start?

PRELIMINARY

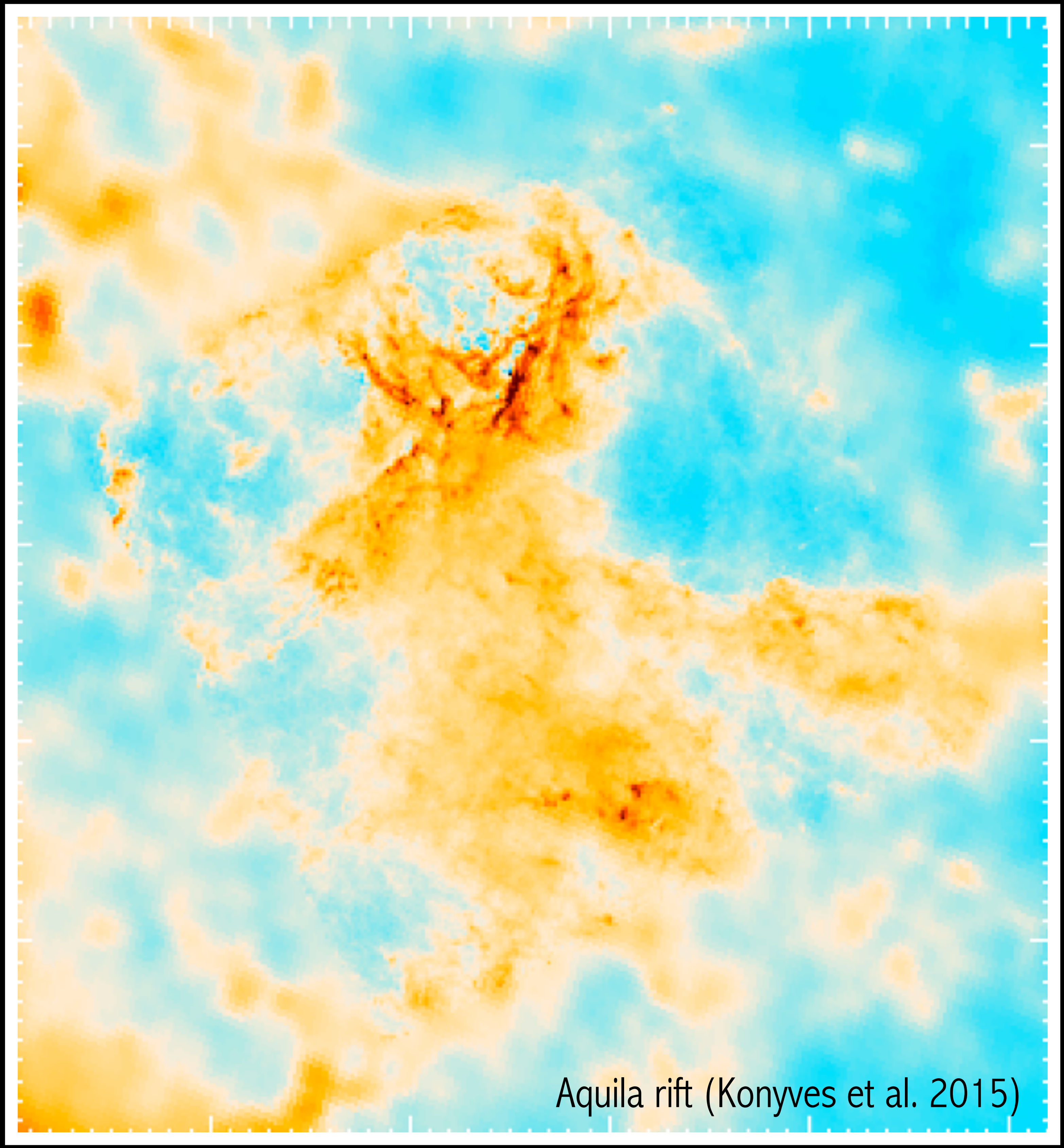
Planck column density at 5’



Where do we start?

PRELIMINARY

Planck column density at 5’ & Herschel column density at 36’’



Conclusions

The structures of matter are preferentially aligned with the magnetic field projected on the plane of the sky: the alignment is the strongest for the lowest column densities and the highest polarization fractions

In molecular clouds we observe structures at high column density perpendicular to the magnetic field orientation

Our results support a scenario of formation of structures in the ISM where **turbulence organizes matter parallel to the magnetic field in the diffuse medium** - supported by numerical MHD simulations of diffuse two-phase ISM in Hennebelle13 -

while the **gas self-gravity produces perpendicular structures in the densest and magnetically dominated regions** - supported by numerical MHD isothermal simulations in Soler+13

For further information check the following papers and page:

Planck intermediate results. XXXII
Planck intermediate results. XXXIII
Planck intermediate results. XXXV

www.planckandthemagneticfield.info

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