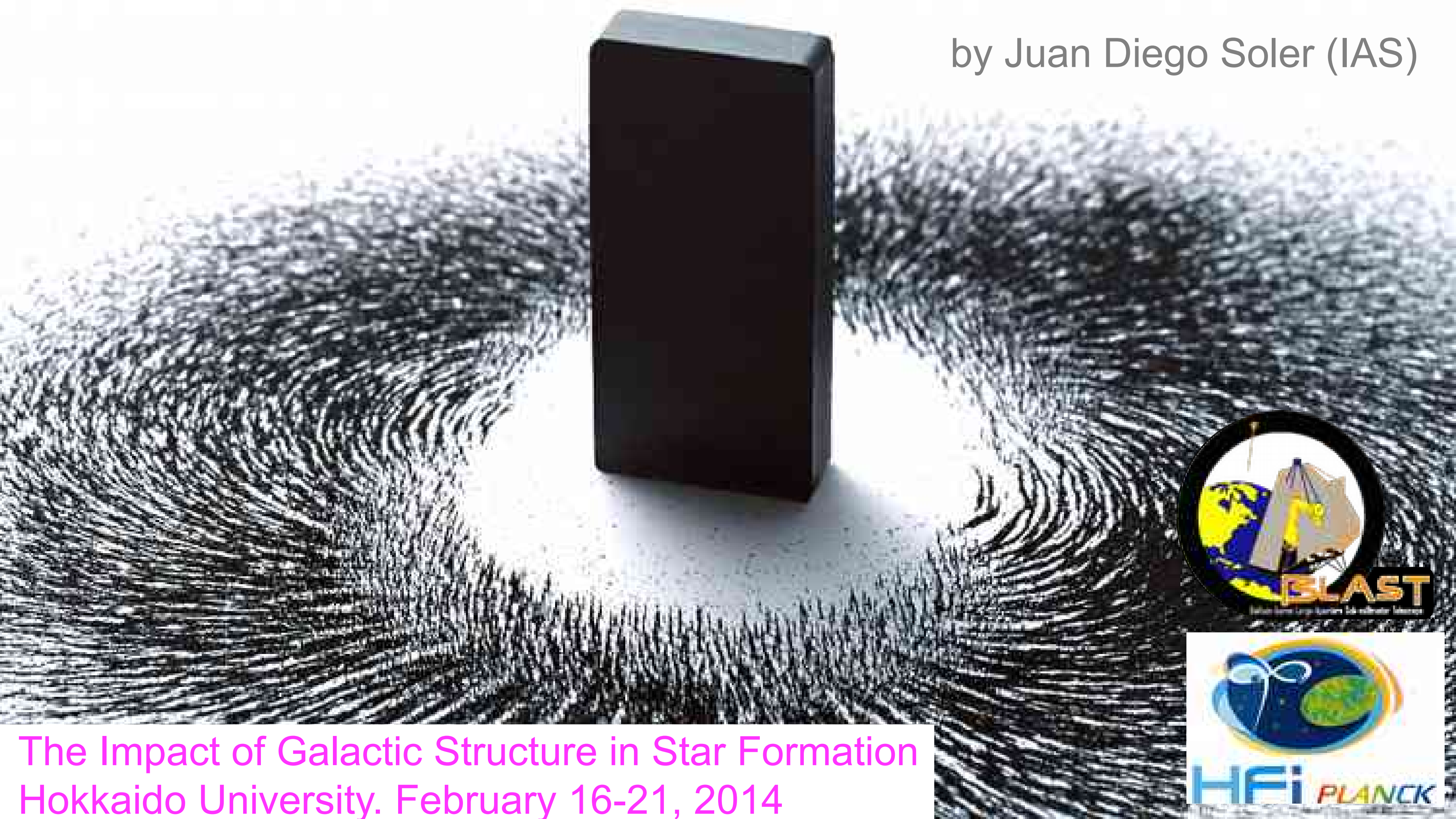
An Imprint of the Magnetization in the ISM Structure

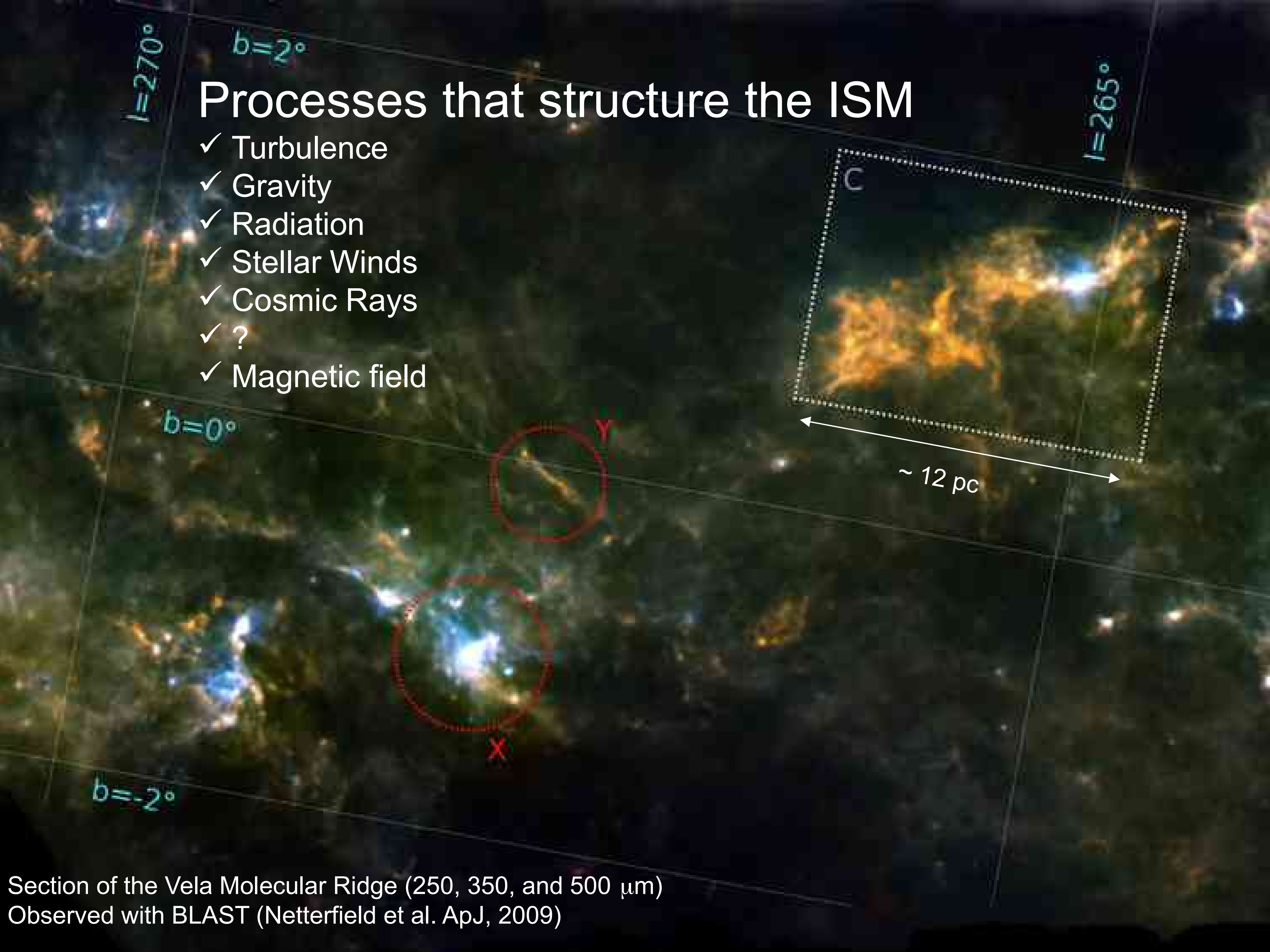
by Juan Diego Soler (IAS)



The Impact of Galactic Structure in Star Formation
Hokkaido University. February 16-21, 2014

Processes that structure the ISM

- ✓ Turbulence
- ✓ Gravity
- ✓ Radiation
- ✓ Stellar Winds
- ✓ Cosmic Rays
- ✓ ?
- ✓ Magnetic field



Section of the Vela Molecular Ridge (250, 350, and 500 μm)
Observed with BLAST (Netterfield et al. ApJ, 2009)

Why?

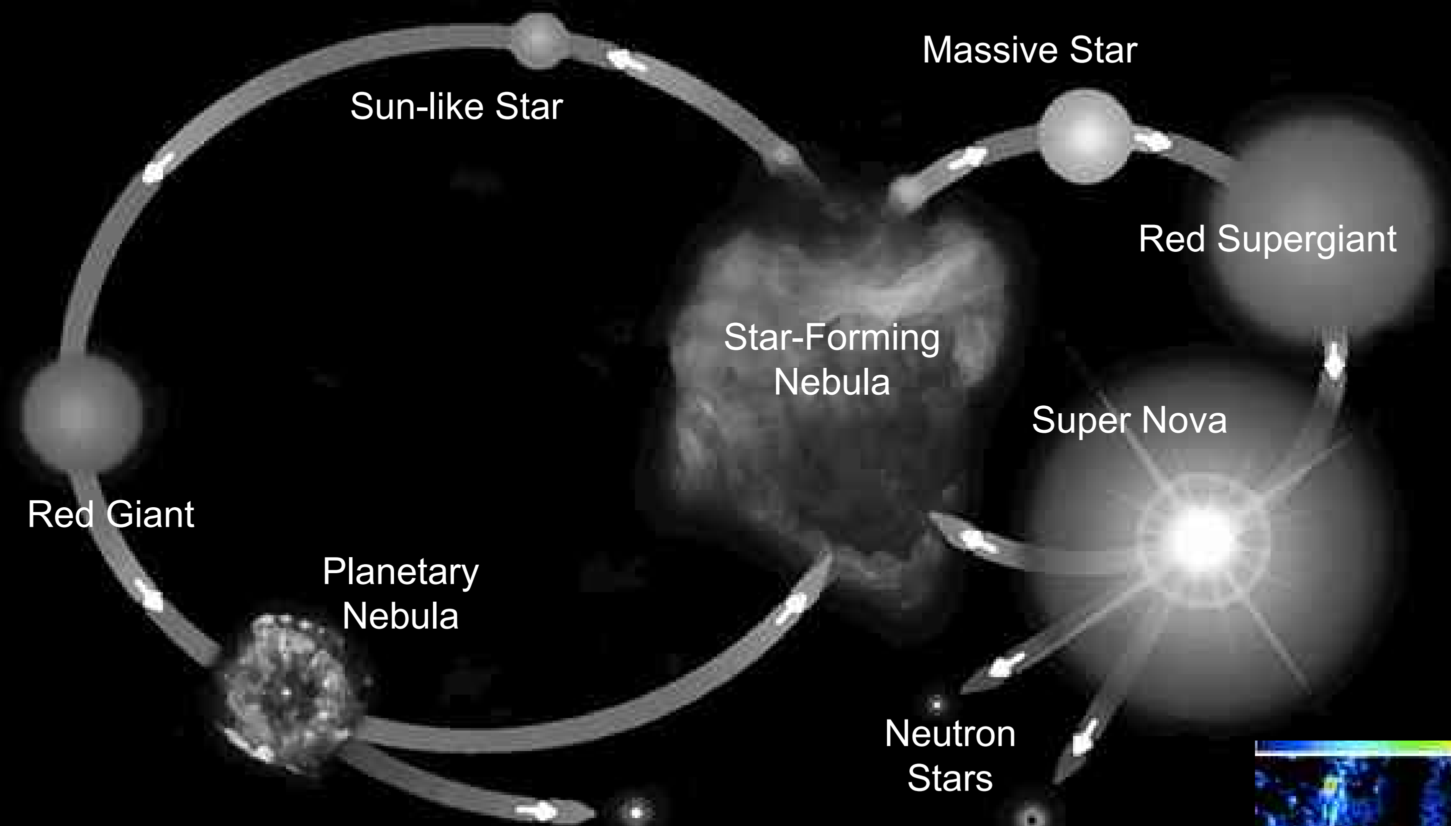
Magnetic fields are hard to measure
and hard to understand…
so most astronomers ignore them.

B. Gaensler

The larger one’s ignorance,
the stronger the magnetic field.

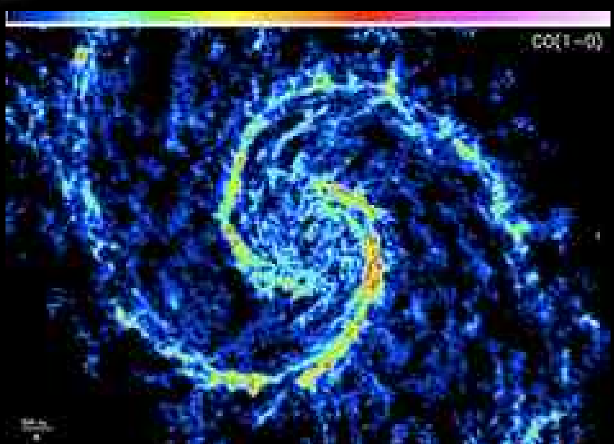
L. Woltjer

The Life Cycle of Stars



NASA Night Sky Network

Schinnerer et al, 2013



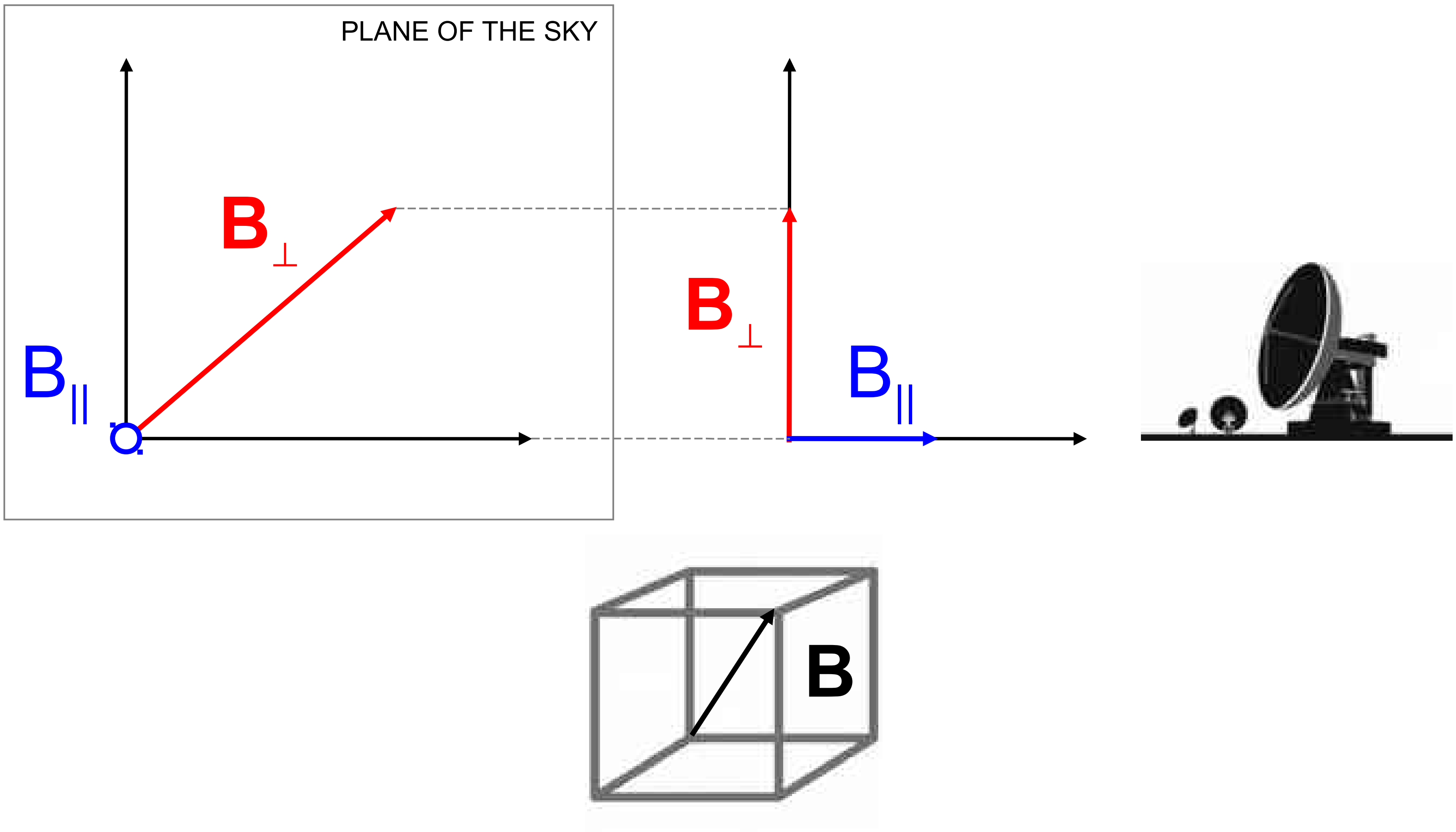
Magnetic fields?
Dust?

You Will Hear About

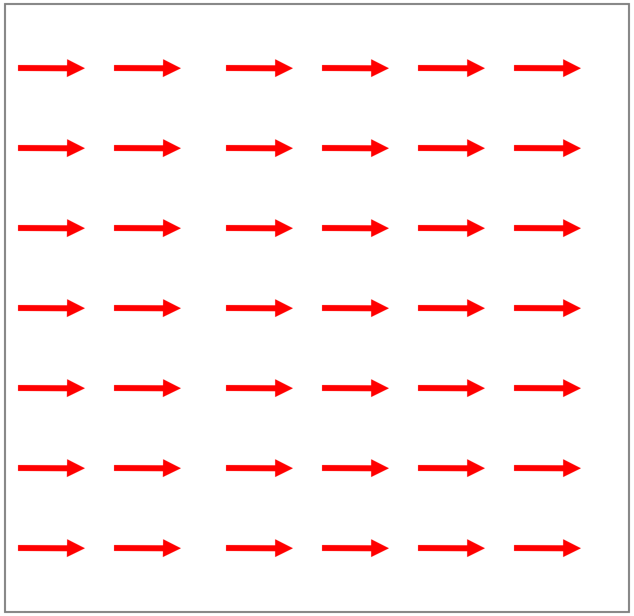
The Study of the Magnetic Field in the Milky Way

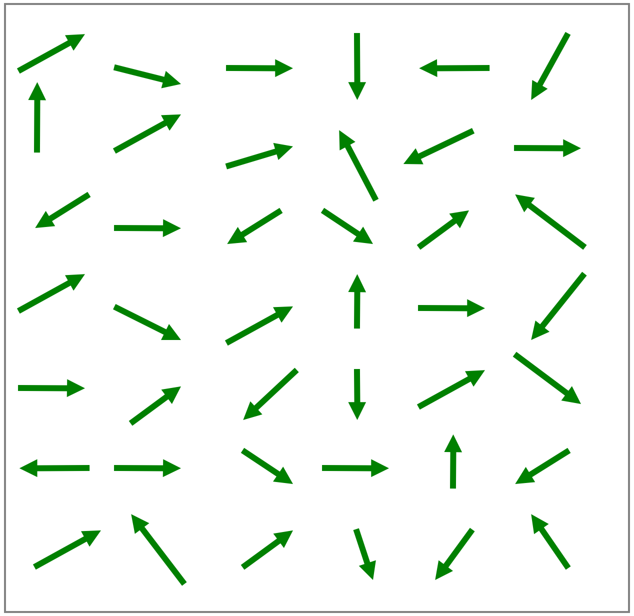
- Observational Techniques
  - Dust Polarized Emission
- Observations
  - Planck
  - BLASTPol
- Analysis Techniques
  - Learning from Simulations

Measuring the Magnetic Field



Measuring the Magnetic Field

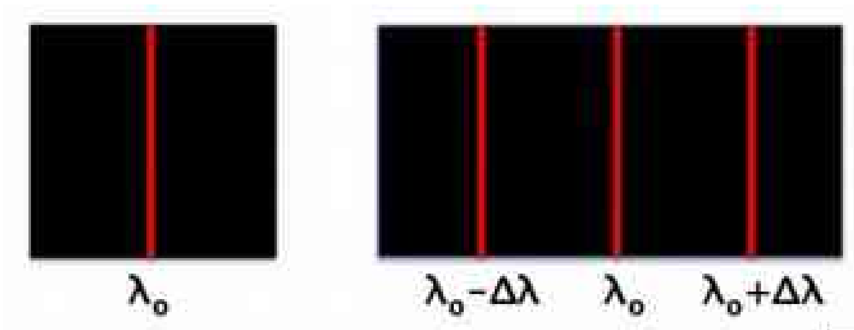




$$\mathbf{B}(r) = \mathbf{B}_o(\mathbf{r}) + \mathbf{B}_t(r)$$

$$\langle \mathbf{B}(r) \rangle = \mathbf{B}_o \qquad \langle \mathbf{B}_t(r) \rangle = 0$$

Zeeman Splitting



Measures $B_{||}$

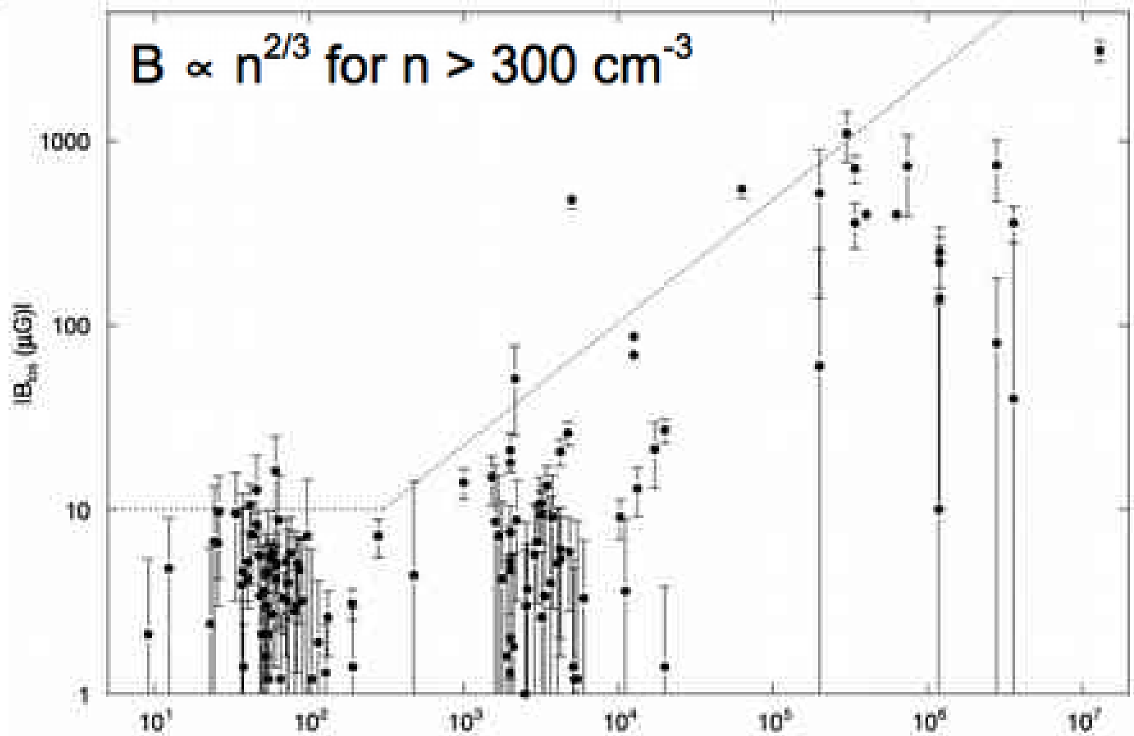
in warm & cool neutral gas

e.g. Singlet (J=1)

$$\lambda_{1,2} = \lambda_0 \pm \frac{e}{4\pi m_e c^2} \lambda^2 g B$$

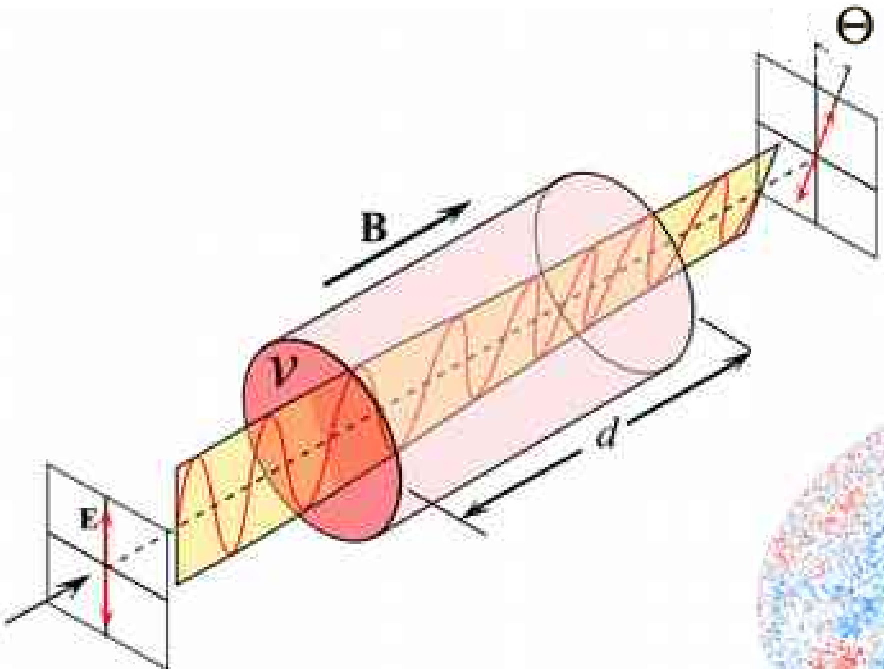
HI	1420 MHz
OH(1-0)	1665(7) MHz
CN(1-0)	113.144 GHz

$$\Delta\nu_{\mathrm{Zeeman}} > \Delta\nu_{\mathrm{Doppler}}$$



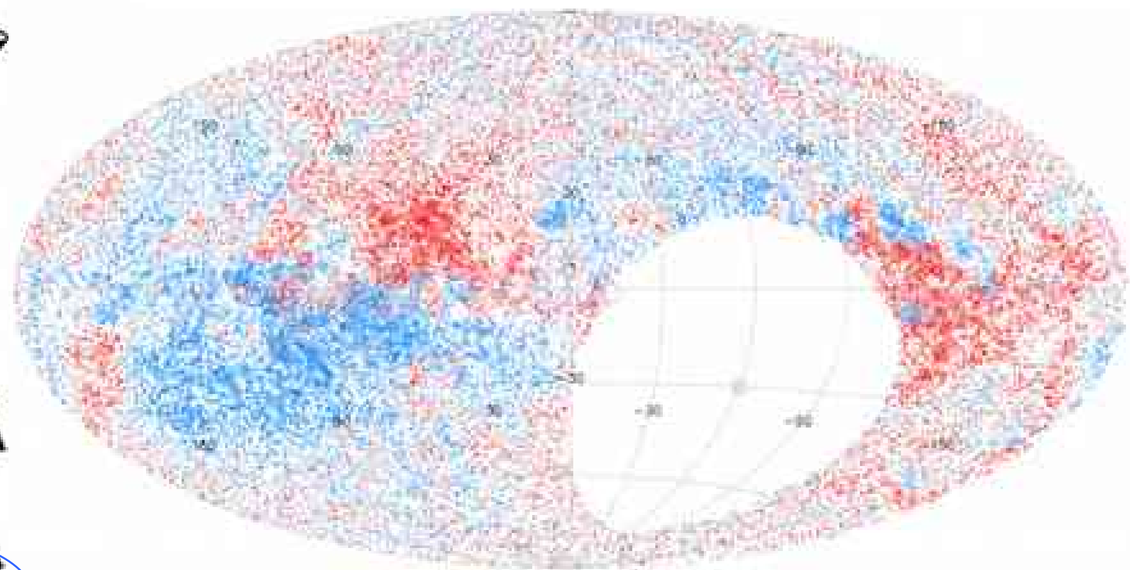
Crutcher et al, 2009

Faraday Rotation



Measures $B_{||}$

in warm ionized medium

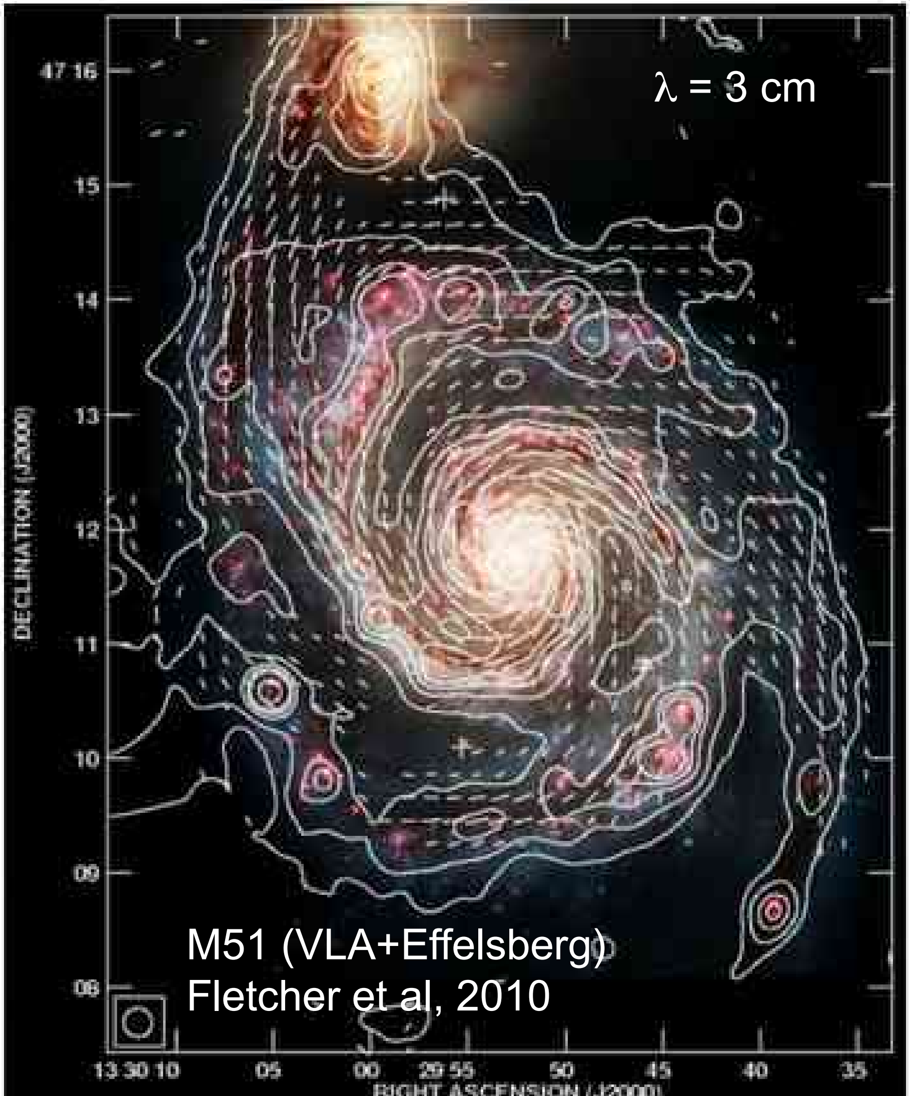


$$\Theta = \Theta_0 + \mathrm{RM}\ \lambda$$

$$\mathrm{RM} = K \int n_e \vec{B} \cdot d\vec{l}$$

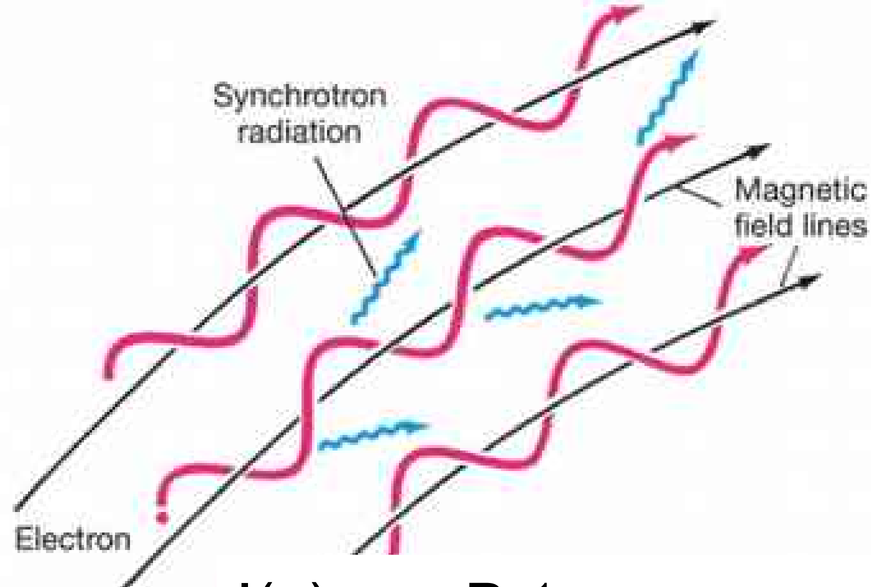
37,543 RM
Taylor et al, 2009

Synchrotron Emission



Measures $B_\perp$

in relativistic electrons

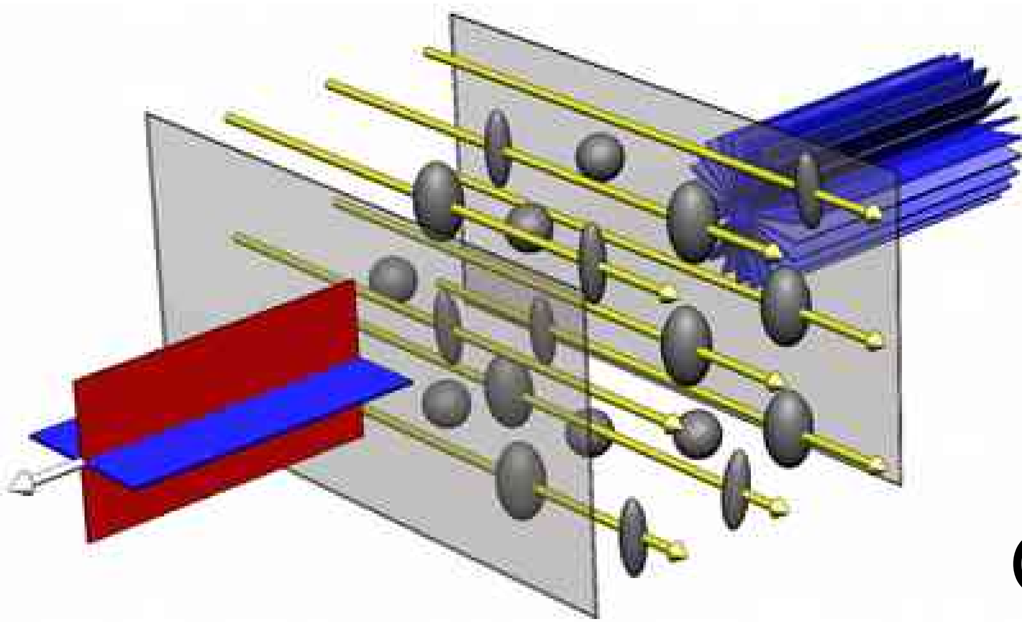


$I(\nu) \propto n_e B_\perp^{1+\alpha} \nu^\alpha$

0.5 $\mathit{atan}(U,Q) \perp B_\perp$

Π related to $n(\varepsilon)$

Dust Polarized Emission



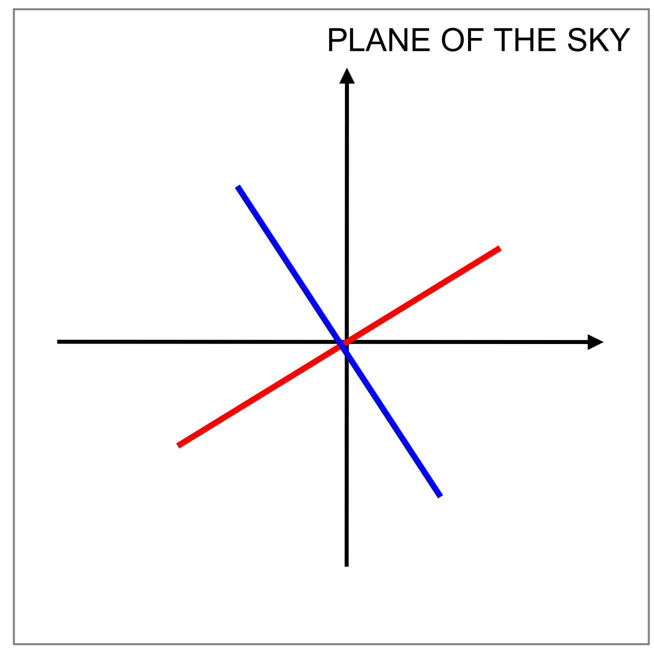
Measures $B_\perp$

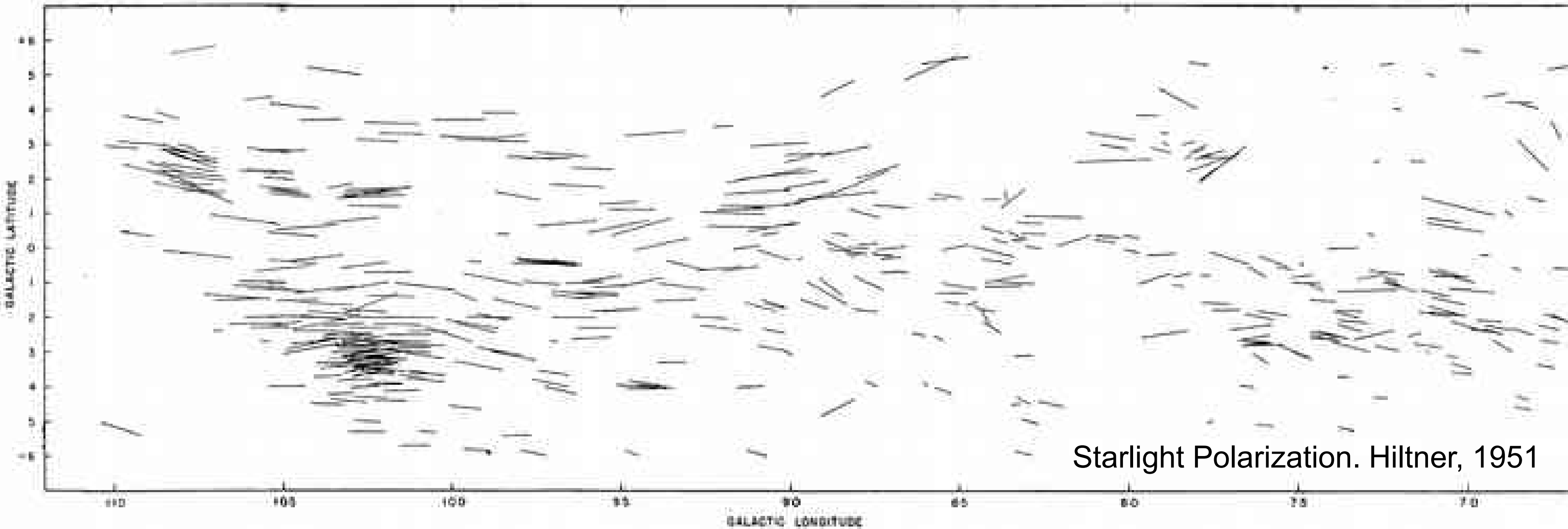
in dust clouds

$I(\nu)$

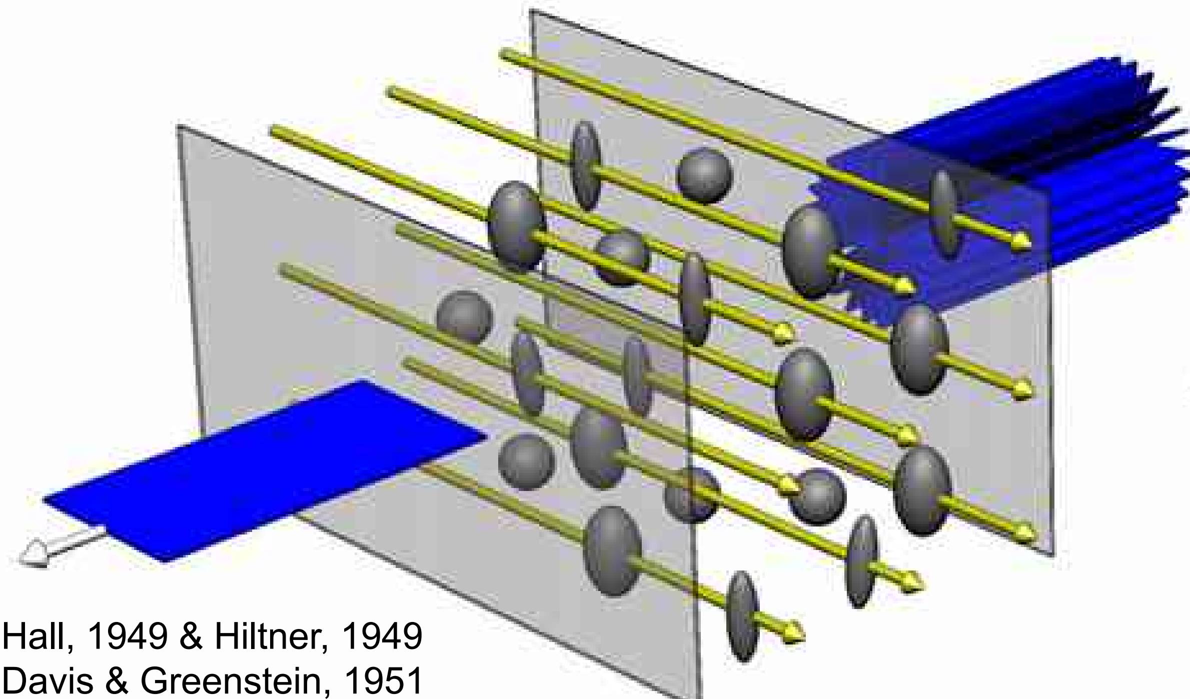
$Q(\nu)$

$U(\nu)$





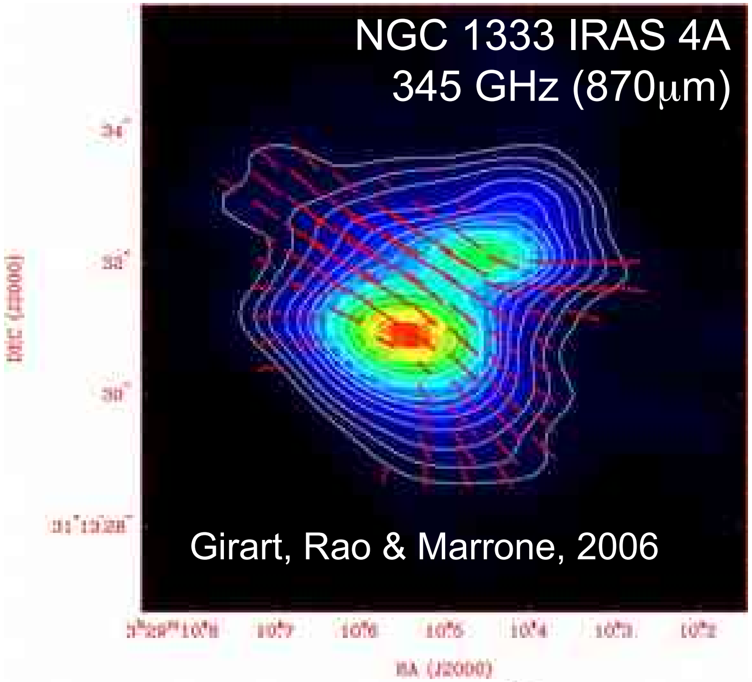
Starlight Polarization. Hiltner, 1951

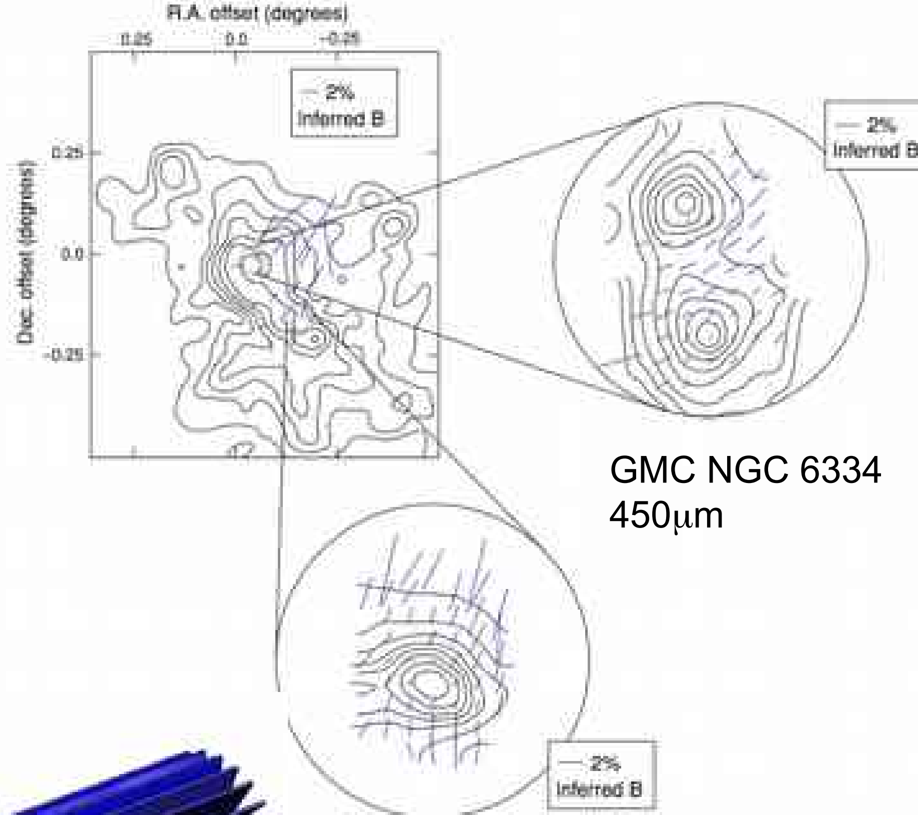


Hall, 1949 & Hiltner, 1949
Davis & Greenstein, 1951

$$B_\perp = (4\pi\rho)^{1/2}\frac{\Delta V}{\Delta\phi}$$

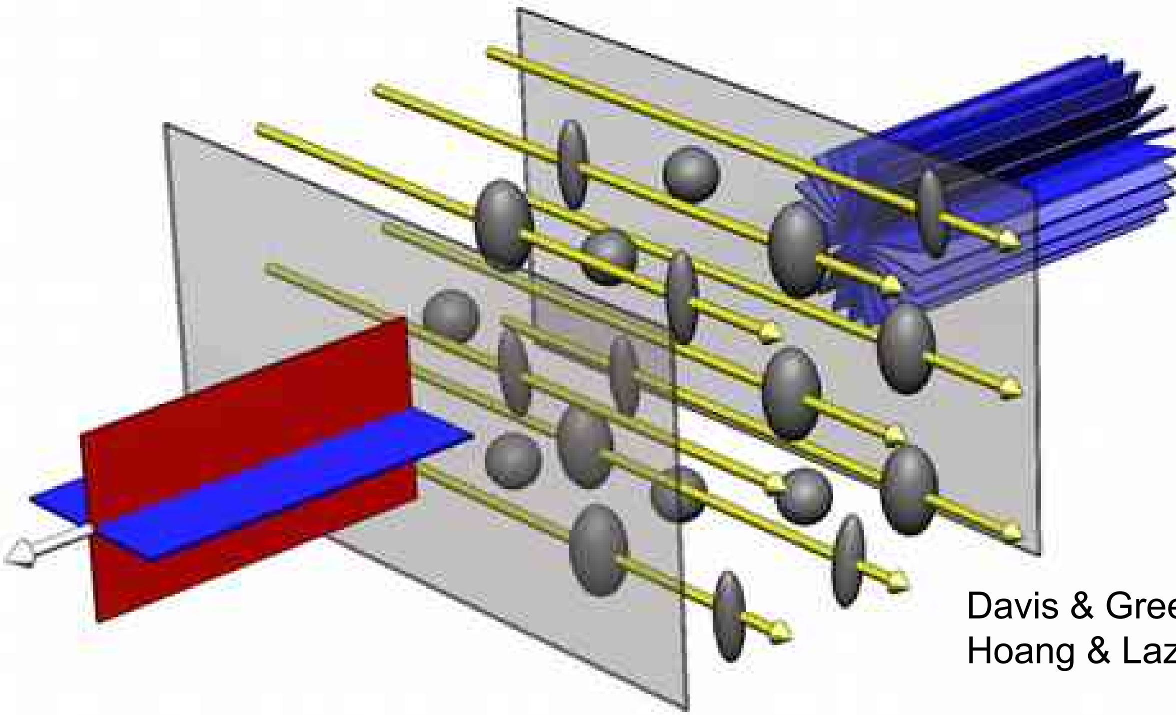
Chandrasekhar & Fermi, 1953





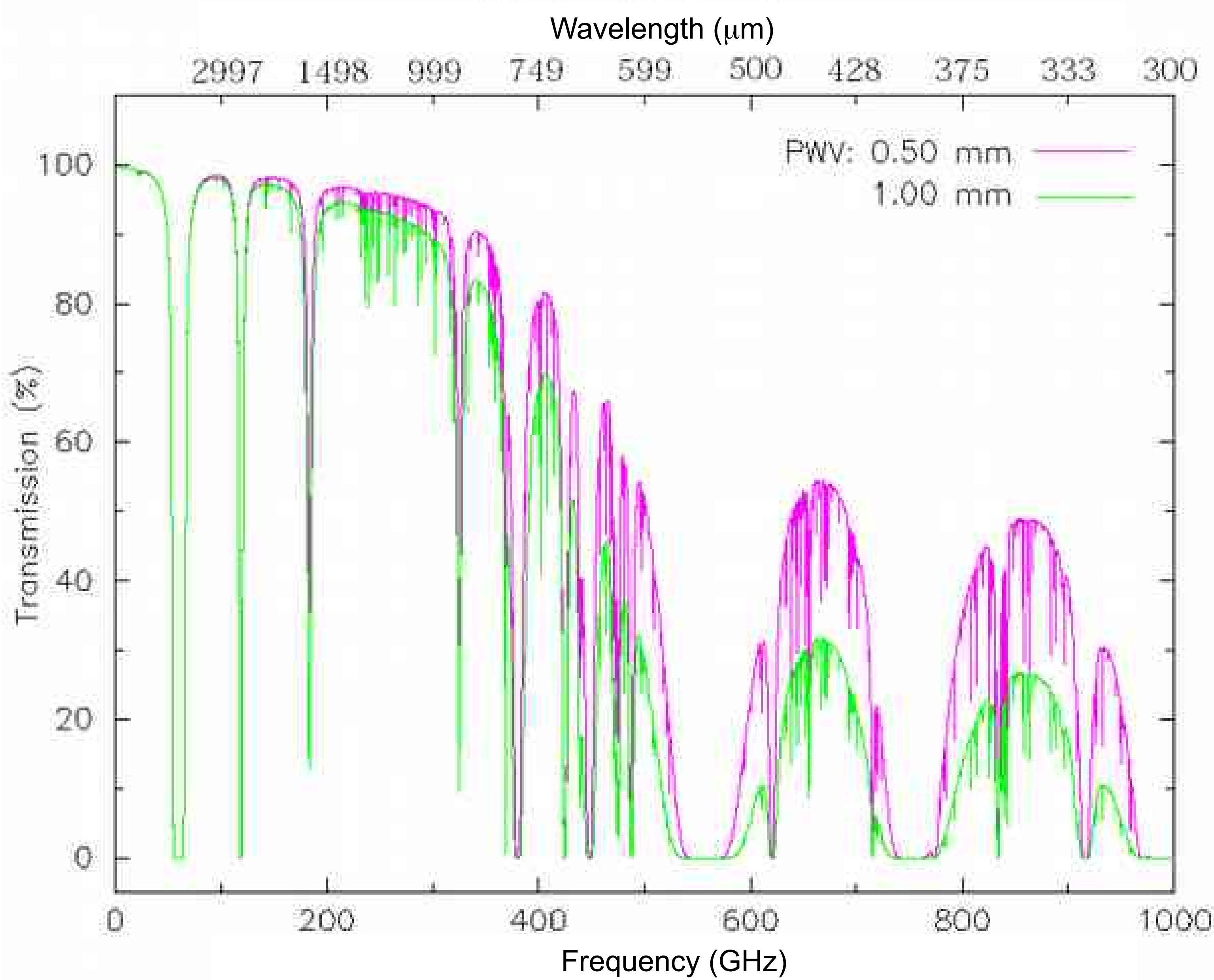
GMC NGC 6334
450μm

Novak, Dotson & Li, 2009



Davis & Greenstein, 1951
Hoang & Lazarian, 2008

Atmospheric Transmission: Mauna Kea



CSO Atmospheric Transmission Interactive Plotter esa

planck

cnes

agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

Science & Technology
Facilities Council

CSIC

National Research Council of Italy

CSA ASC

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

UK SPACE
AGENCY

HFI PLANCK

PLANCK LFI

IAS orsay

IAP

INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA

A''

ioa

KICC

UNIVERSITY OF CAMBRIDGE

CARDIFF UNIVERSITY

irfu

cea

CESR

CITA-ICAT

IN2P3

ipac

HELSINKI INSTITUTE OF PHYSICS

Imperial College
London

Università degli Studi di Milano

NÉEL Institut

IPAG

ISDC

JPL

LAL

LPSC

MilliLab

SAPIENZA

Rutherford Appleton Laboratory

UBC

UC

UCSB

SISSA

US

esa

UNIVERSITÉ DE GENÈVE

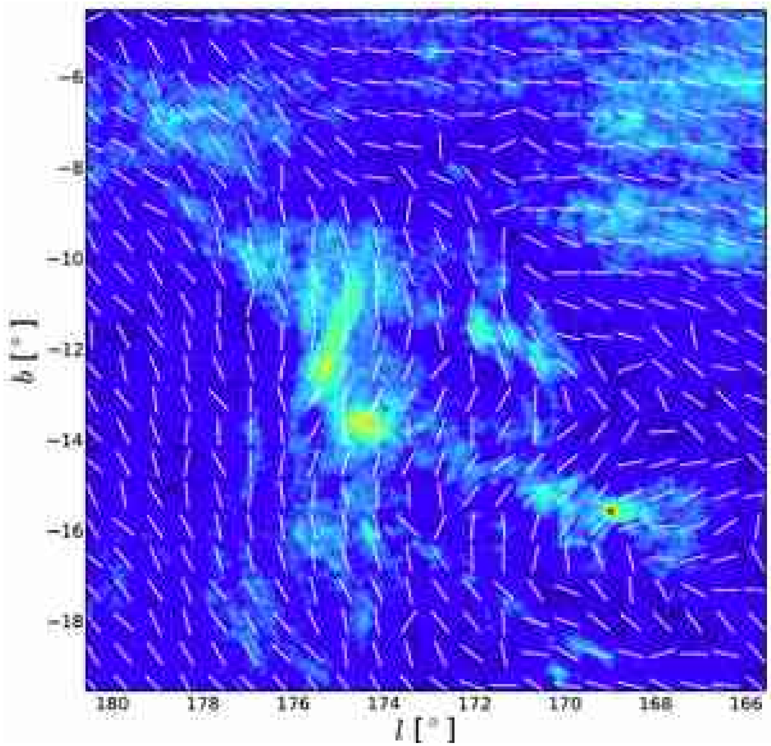
UNIVERSITY OF TORONTO

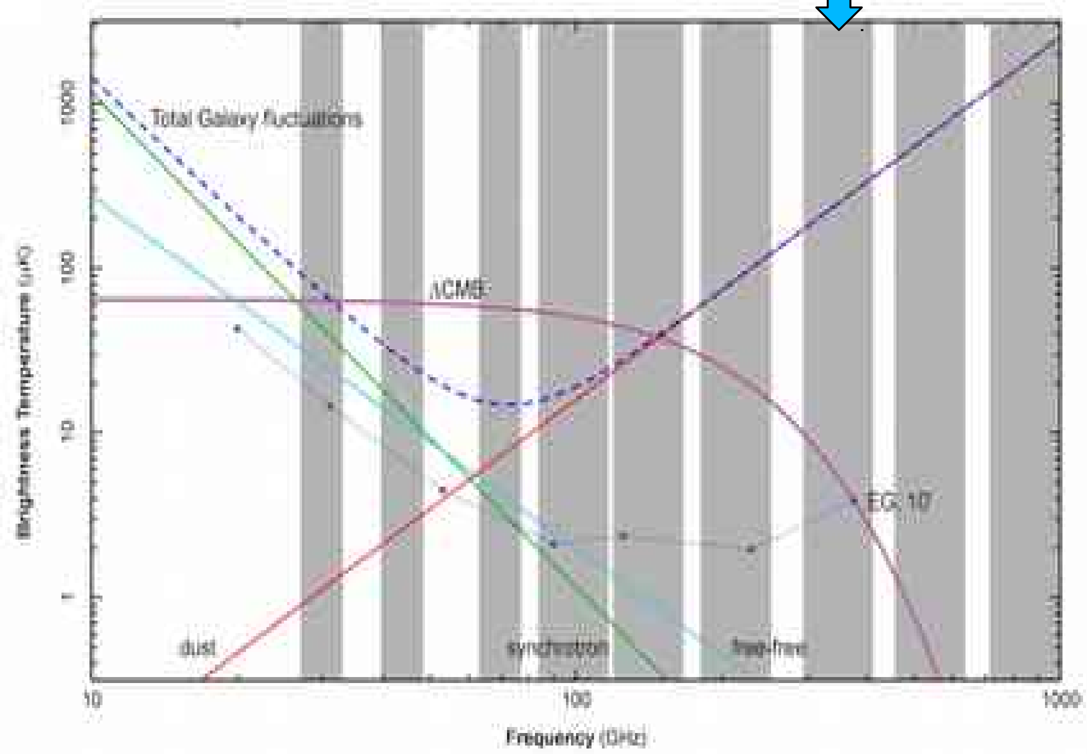
UNIVERSITÉ DE PARIS-SUD XI

ISM dust emission with Planck

Taurus Region

353 GHz
(850 μm)





Polarized Intensity at 353 GHz and
Polarization Orientation

Planck 2013 results. I. Overview of products and scientific results

ISM dust emission with Planck

Polarization Fraction at 1° resolution

Unpublished map.Please visit:
http://www.rssd.esa.int/index.php?project=planck

First Dust Polarization Maps Over the Whole Sky!

Magnetic Field Direction at 1° resolution

Unpublished map.Please visit:
http://www.rssd.esa.int/index.php?project=planck

Planck 2014. PIP 75. In preparation.

BLASTPol

Univ. of Pennsylvania: Mark Devlin (PI), Elio Angile, Jeff Klein, Nicholas Galintzki

Brown University: Greg Tucker, Andrei Korotkov

Northwestern University: Tristan Matthews, Giles Novak

Univ. of Toronto: Steve Benton, Laura Fissel, Natalie Gandilo, Barth Netterfield, Jamil Sharif, Juan D. Soler (now at IAS, Orsay)

JPL: Jamie Bock

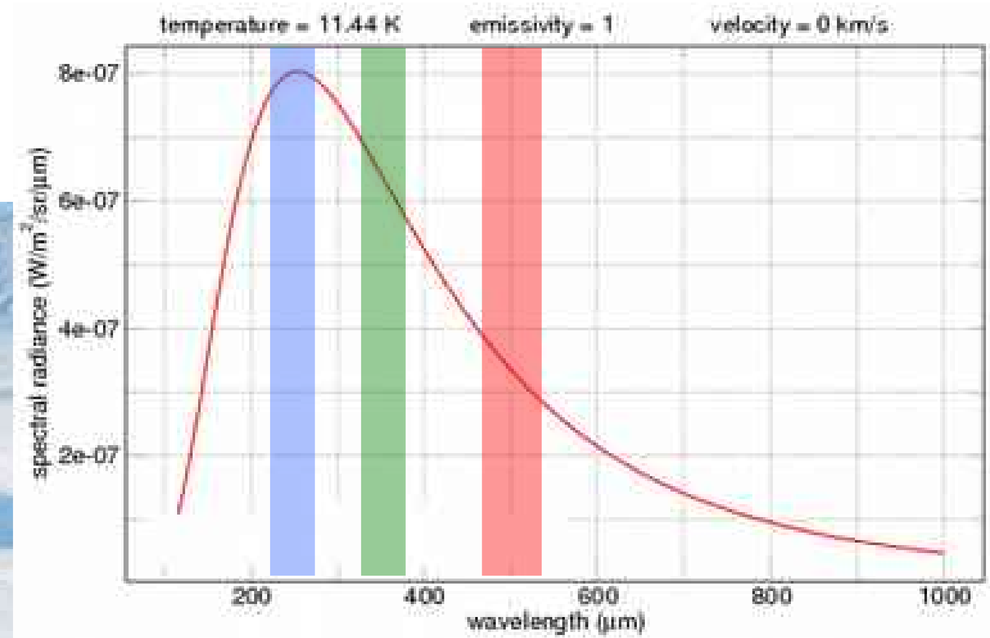
UCL: Giorgio Savini

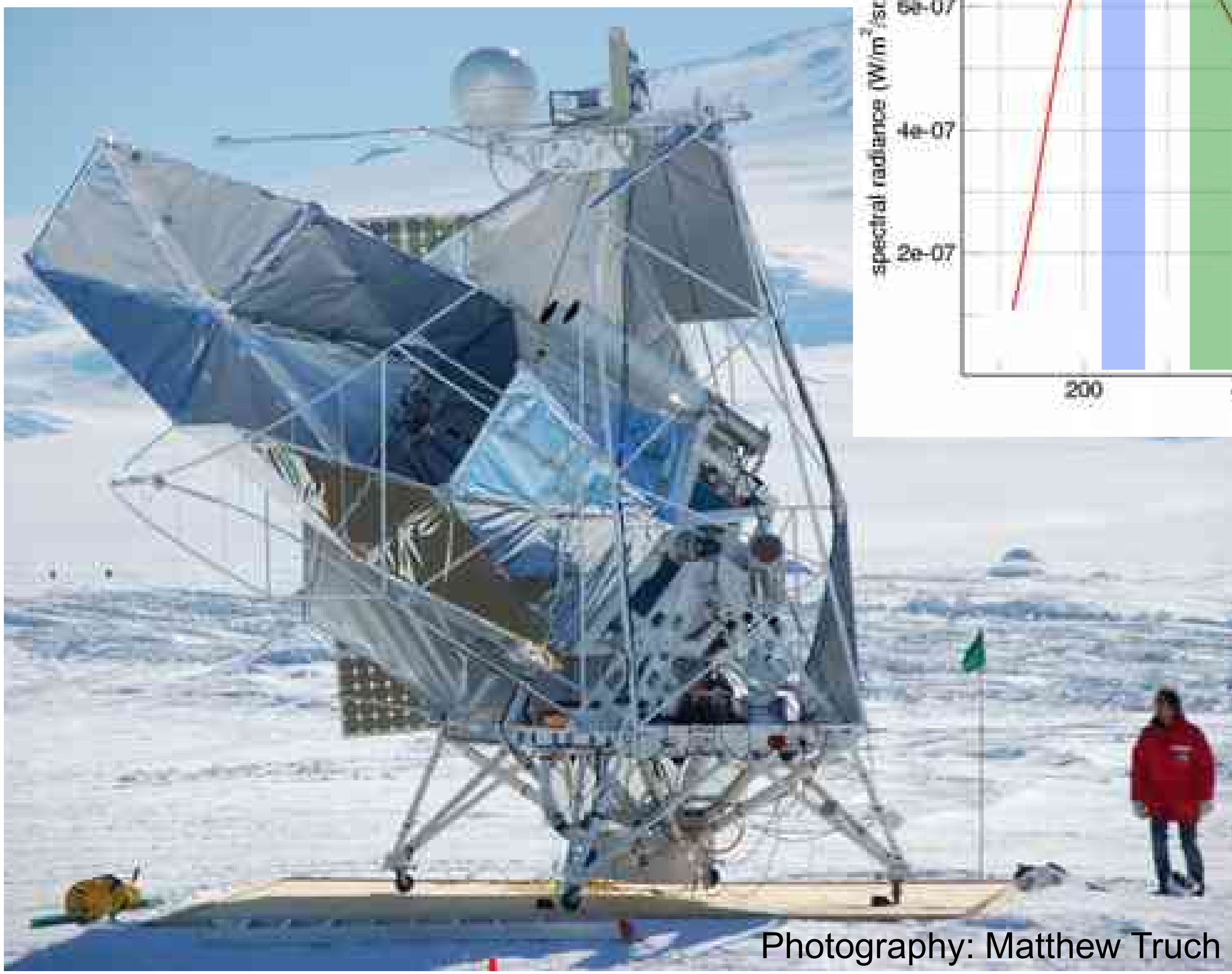
Cardiff University: Peter Ade, Lorenzo Moncelsi, David Nutter, Enzo Pascale, Carole Tucker, Derek Ward-Thompson

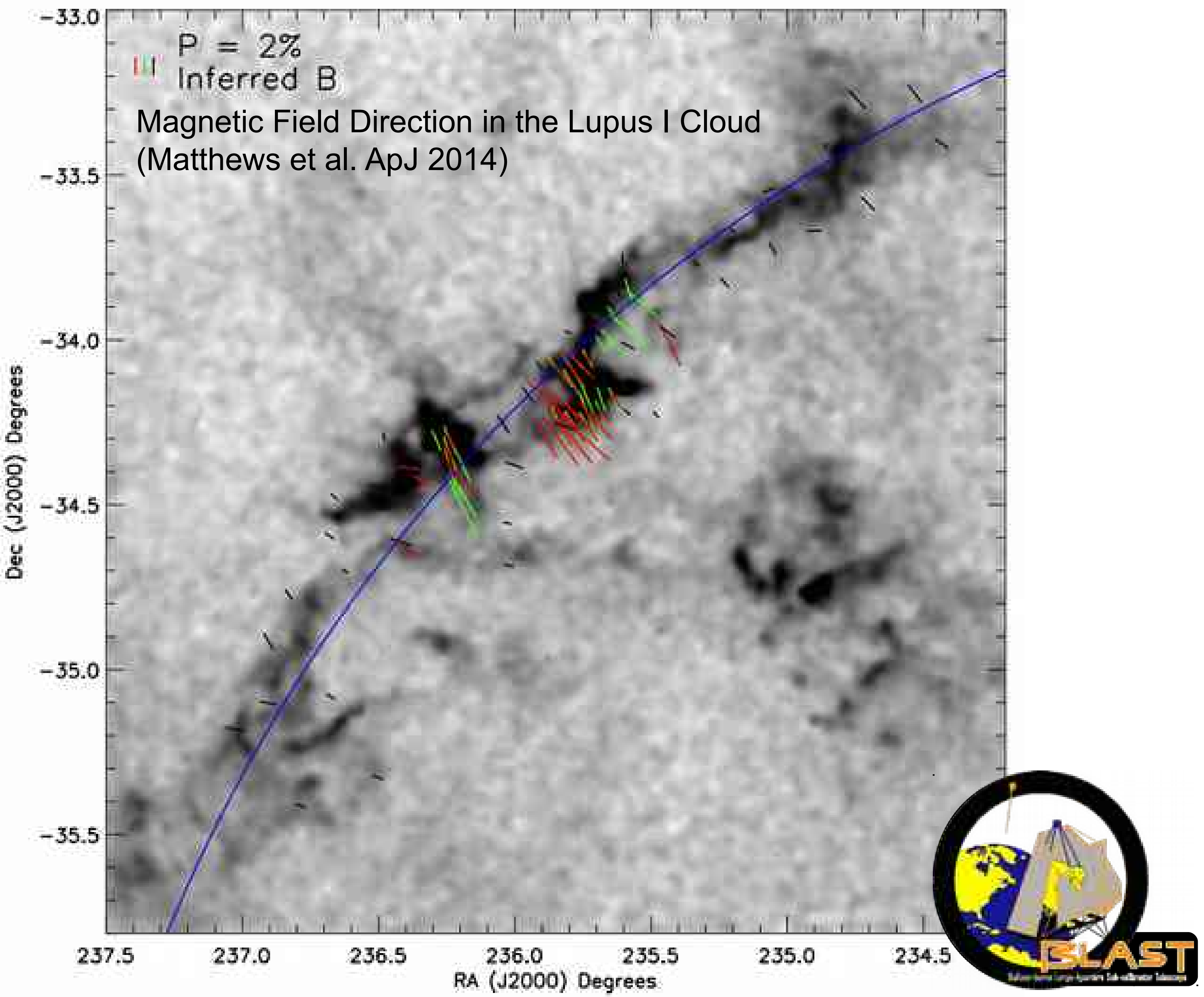
Nagoya University: Yasuo Fukui, Tengo Tachihara

Photography: Tristan Matthews

ISM dust emission with BLASTPol




Photography: Matthew Truch


P = 2%
Inferred B
Magnetic Field Direction in the Lupus I Cloud
(Matthews et al. ApJ 2014)
−33.0
−33.5
−34.0
−34.5
−35.0
−35.5
Dec (J2000) Degrees
237.5
237.0
236.5
236.0
235.5
235.0
234.5
RA (J2000) Degrees
BLAST

ISM dust emission with BLASTPol

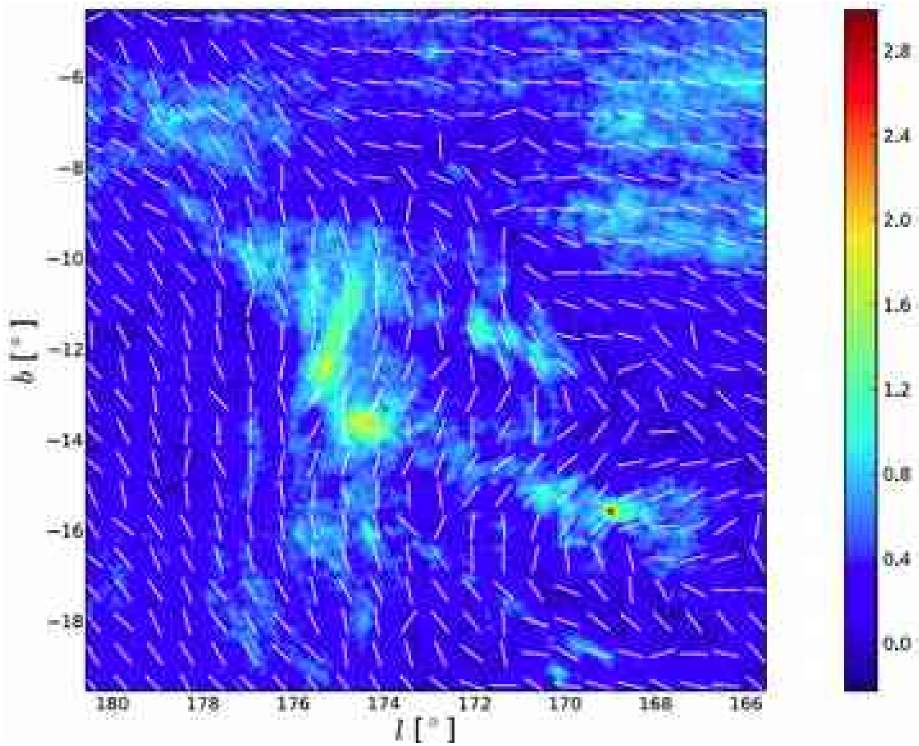
Magnetic Field Direction in the Carina Nebula

250 μm
350 μm
500 μm

Unpublished Map
Please visit: http://blastexperiment.info

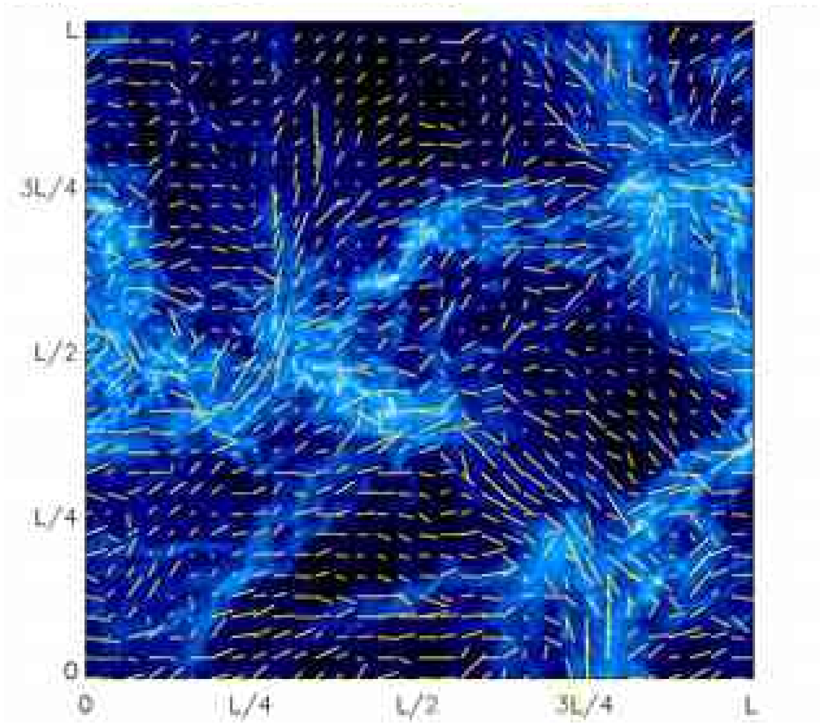
Learning About the Magnetic Field

Molecular Cloud Observation



Polarized Intensity at 353 GHz and
Polarization Orientation

Molecular Cloud Simulation

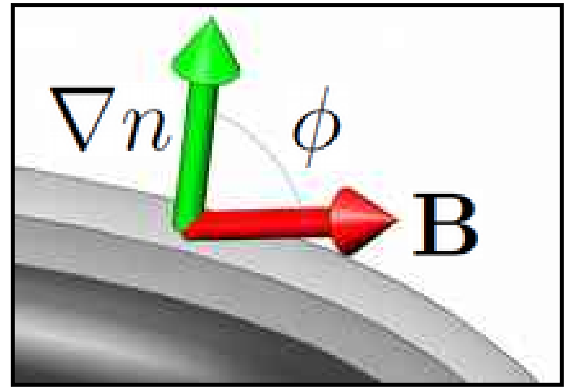


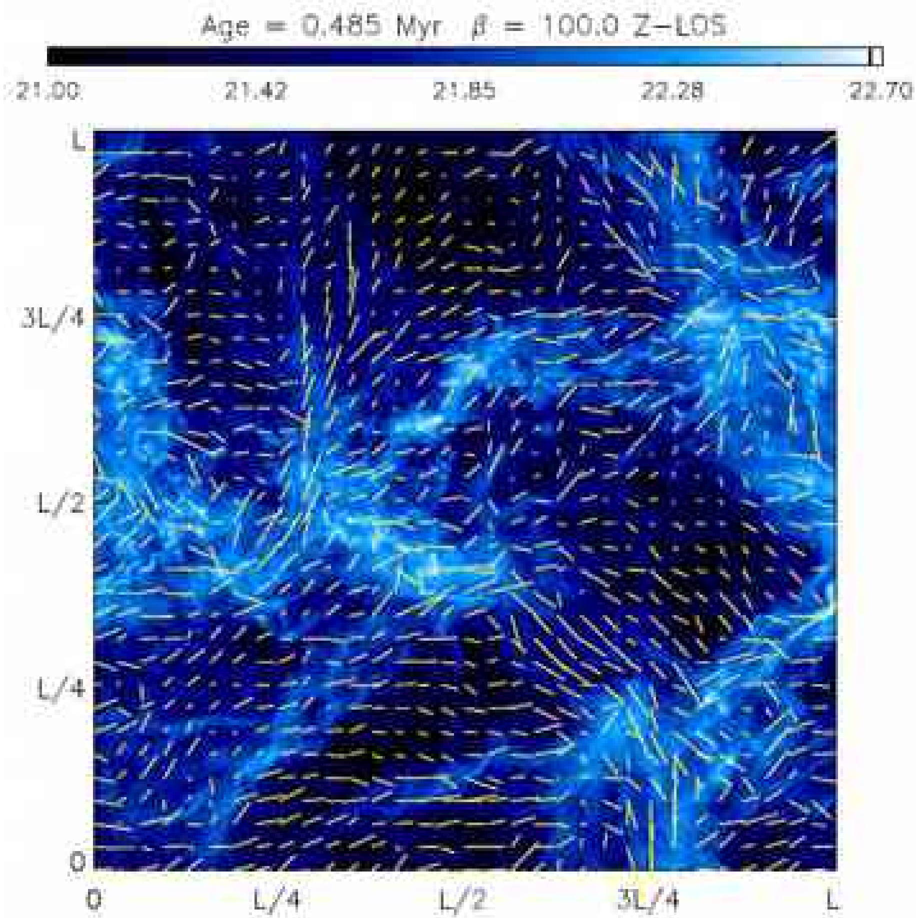
Intensity and
Polarization Orientation

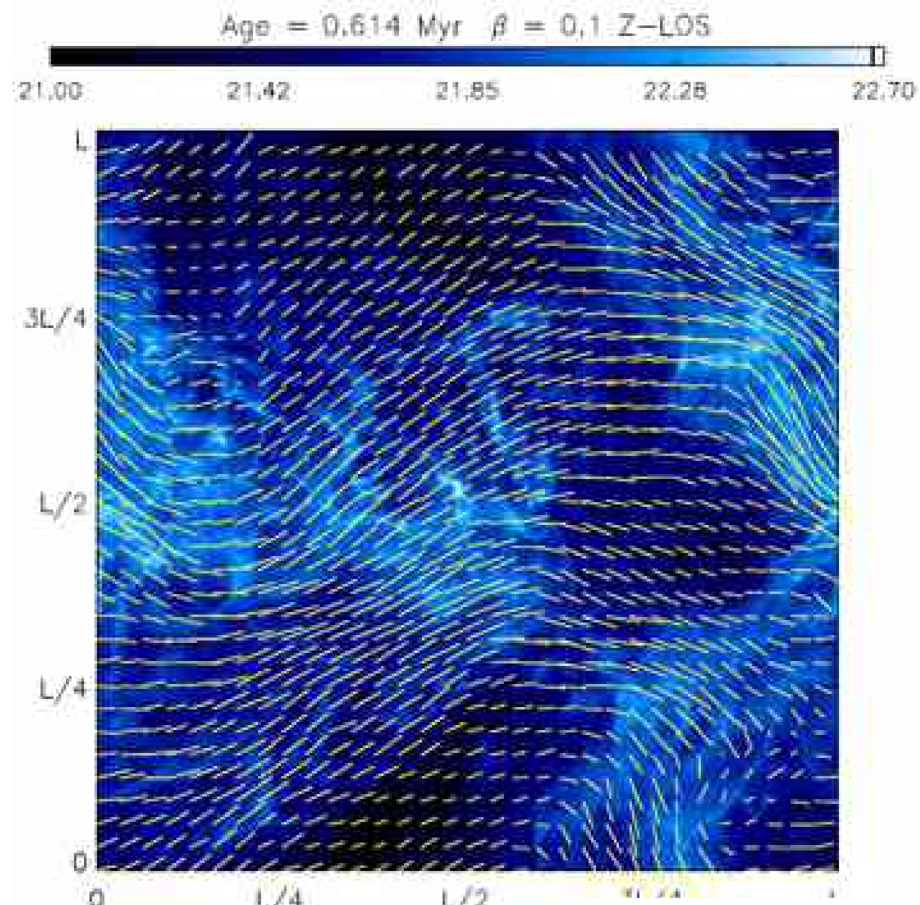
Planck 2013 results. I. Overview of products and
scientific results

Starformat Simulation.
Soler, Hennebelle et al. ApJ, 2013

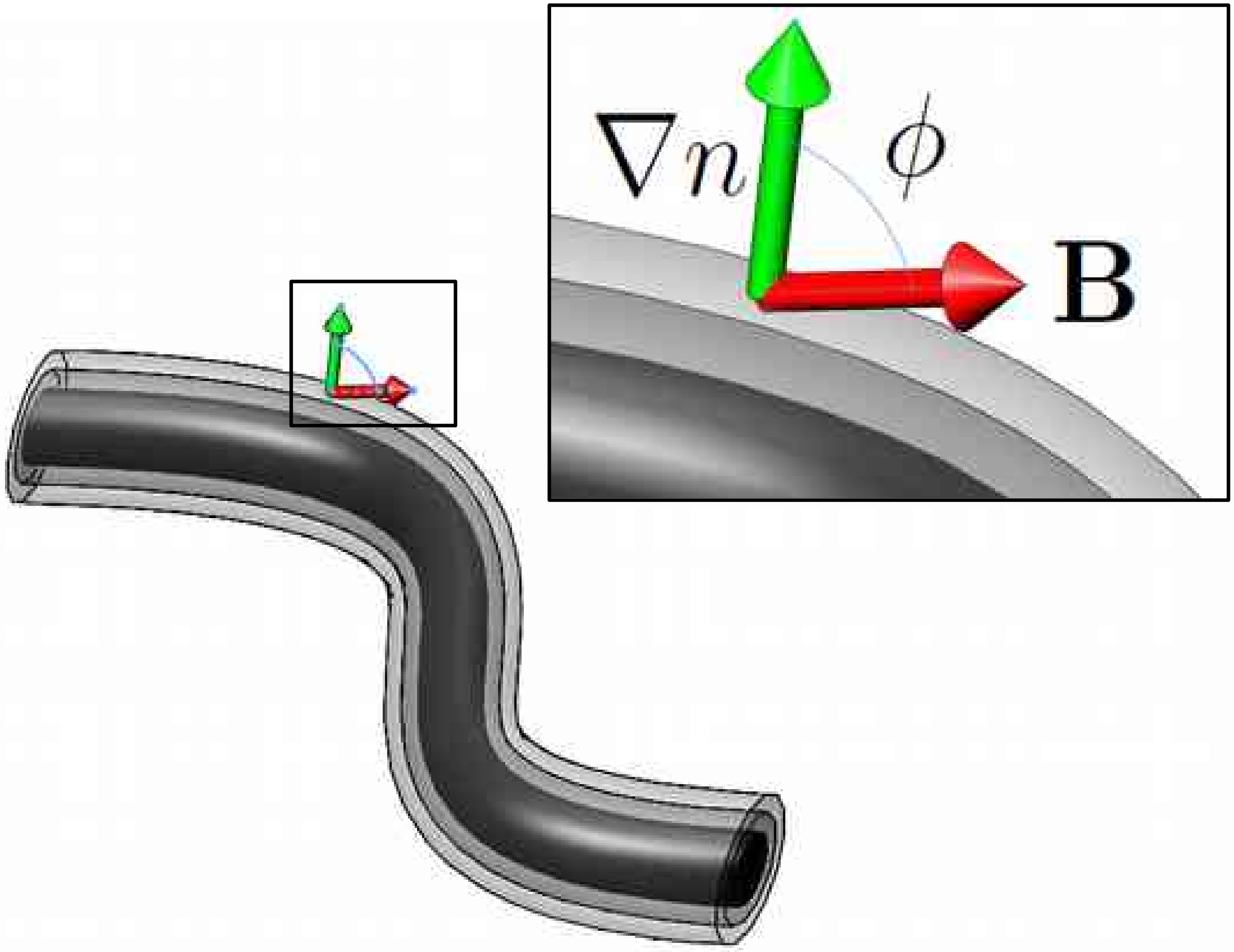
Histogram of Relative Orientations





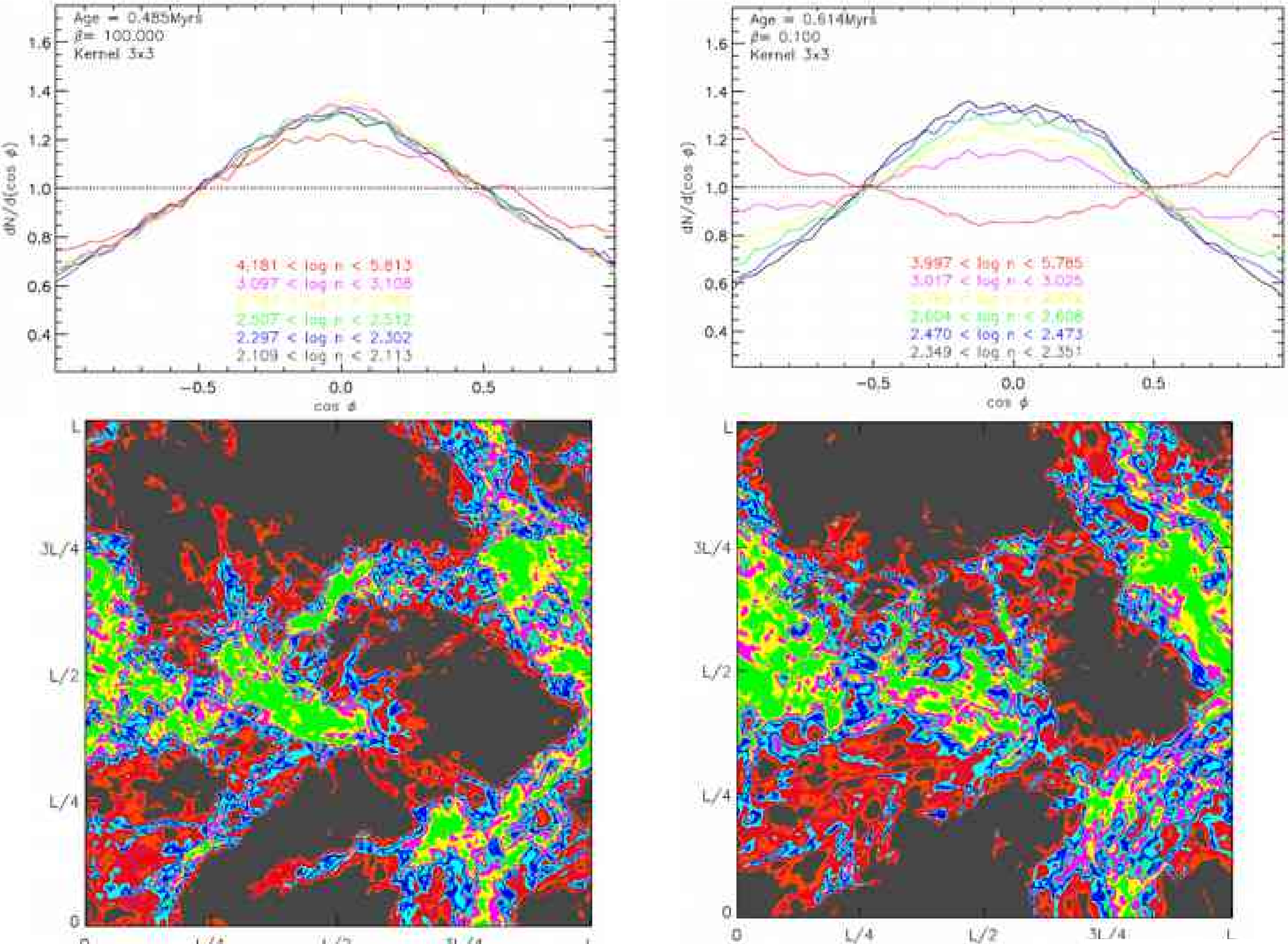


Soler et al. ApJ, 2013

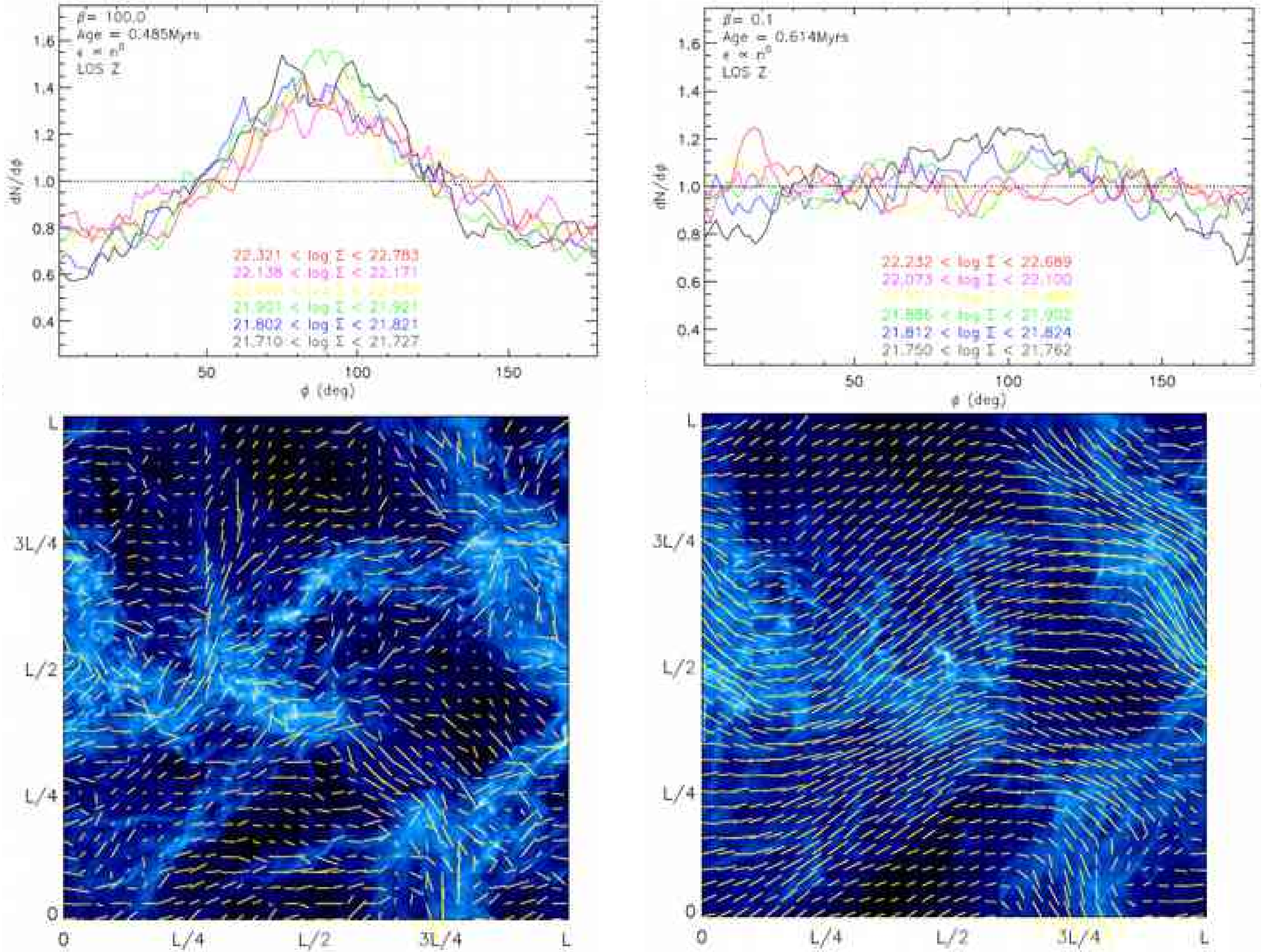


$$\phi = \arctan\left(\frac{\mathbf{B} \times \nabla n}{\mathbf{B} \cdot \nabla n}\right)$$

Soler et al. ApJ, 2013



Soler et al, 2013


β= 100.0
Age = 0.485Myrs
ε ∝ n^0
LOS Z
dN/dφ
φ (deg)
22.321 < log Σ < 22.783
22.138 < log Σ < 22.171
21.901 < log Σ < 21.921
21.802 < log Σ < 21.821
21.710 < log Σ < 21.727
β= 0.1
Age = 0.614Myrs
ε ∝ n^0
LOS Z
dN/dφ
φ (deg)
22.232 < log Σ < 22.689
22.073 < log Σ < 22.100
21.886 < log Σ < 21.902
21.812 < log Σ < 21.824
21.750 < log Σ < 21.762
0
L/4
L/2
3L/4
L

Summary

Probing the Magnetic Field Morphology with dust emission

Submm polarization ⊥ to B_{POS} in source

New Observations of Multiple Scales

All-sky to individual clouds Planck

Individual clouds to cores BLASTPol

Statistical Analysis of Relative Orientation

Imprint of Magnetic Fields in the ISM structure in observations and simulations