PASIPHAE

Polar-Areas Stellar Imaging in Polarization High Accuracy Experiment: Clearing the path to experimental tests of inflation

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The PASIPHAE Collaboration

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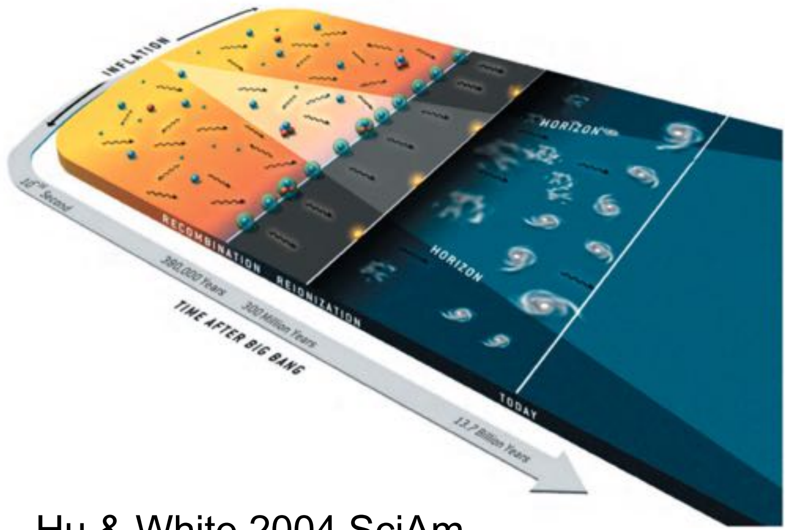
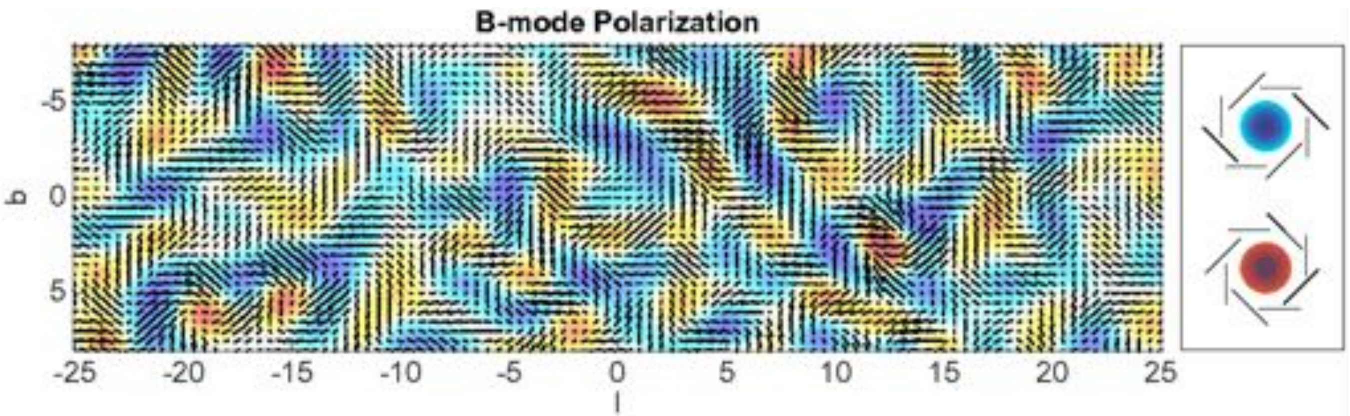
CMB Polarization Probes Inflation



Hu & White 2004 SciAm

Inflation predicts:

Chiral (B-mode) pattern
in polarization of cosmic microwave background



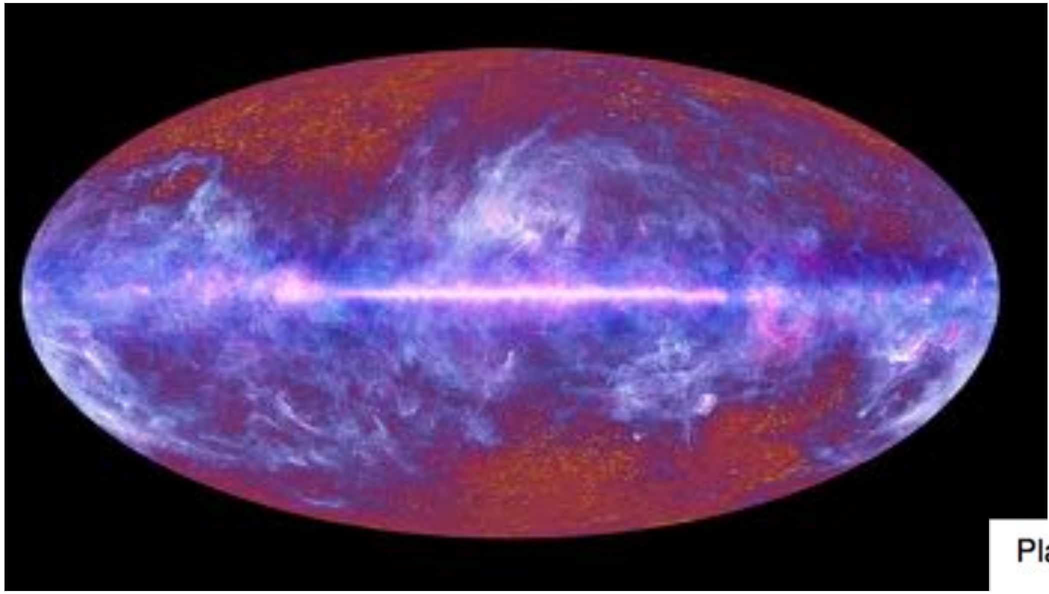
Kamionkowski et al 2016

Worldwide search for B-modes

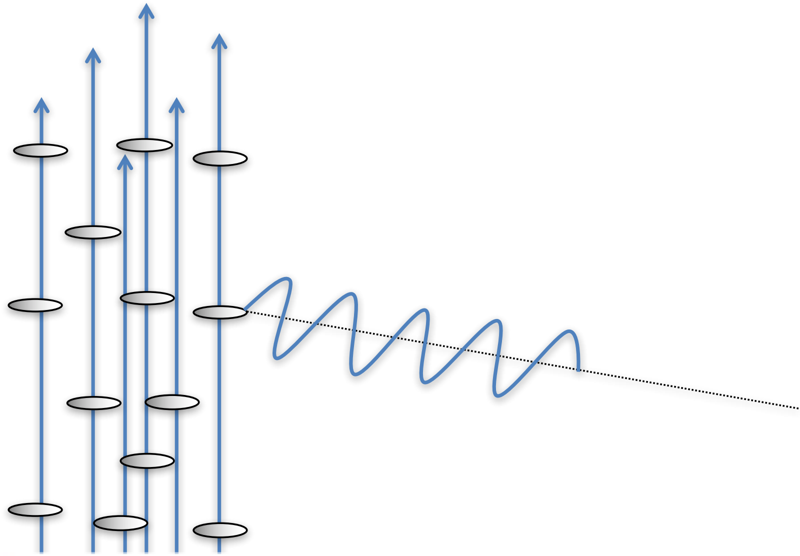
AdvACT, BICEP3, Spider, POLARBEAR-2, CMB-S4, PIPER, LiteBIRD, PRISM, Simons Array…

The Problem

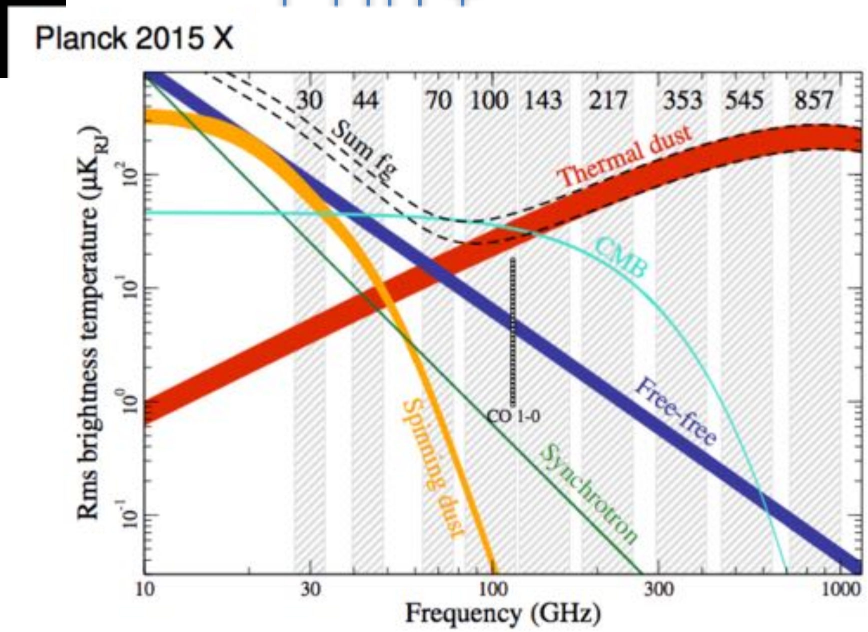
Magnetized Galactic dust also emits polarized microwaves



ESA/ LFI & HFI Consortia



CMB dust emission removal:



The Problem

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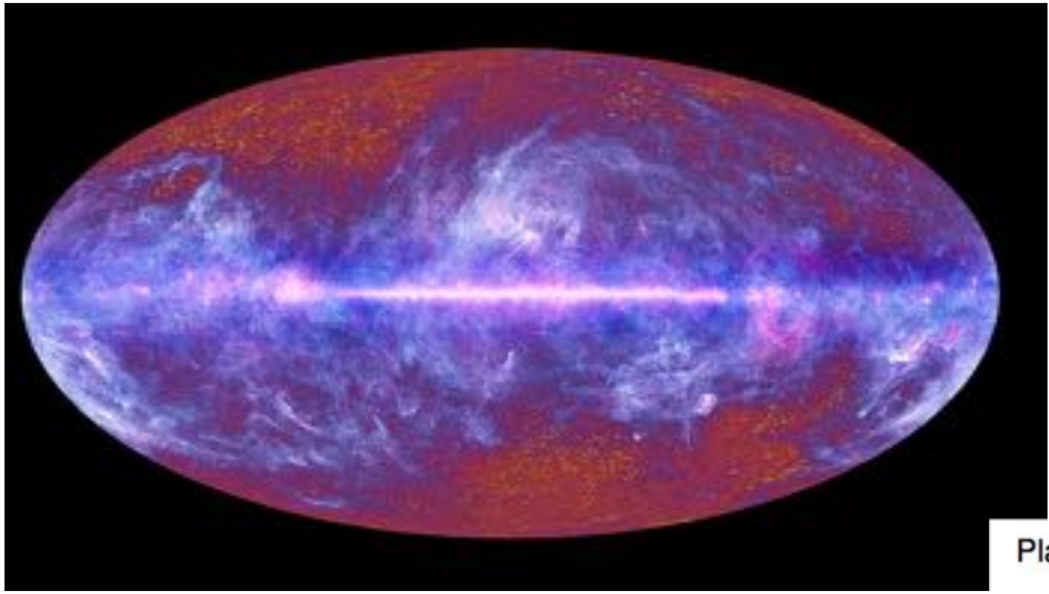

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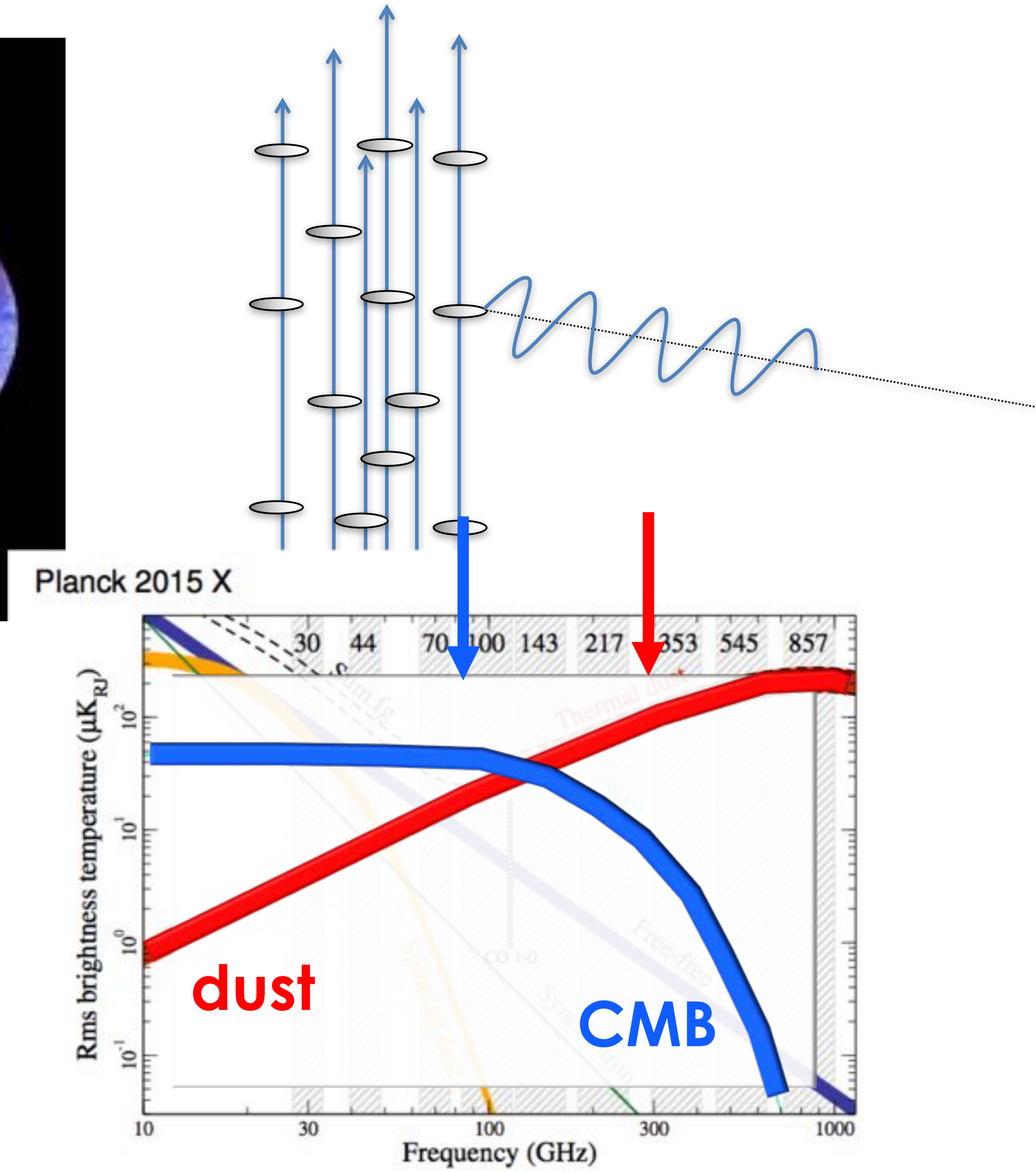
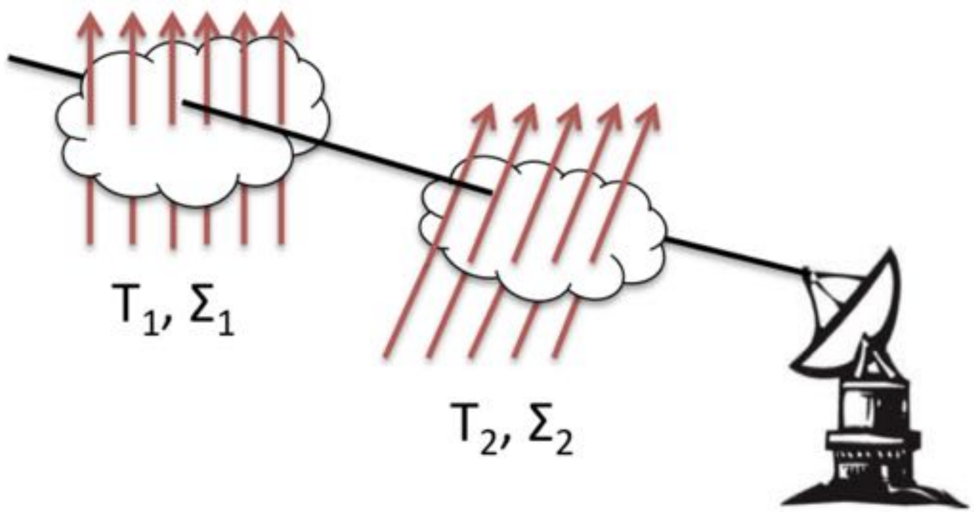


CMB dust emission removal:

- Map at high frequencies (dust dominates)
- Subtract from lower frequencies (CMB dominates)

“Map & Subtract” cannot work with polarization

Polarization ROTATES between frequencies
because of **multiple clouds** and **misaligned B-fields**



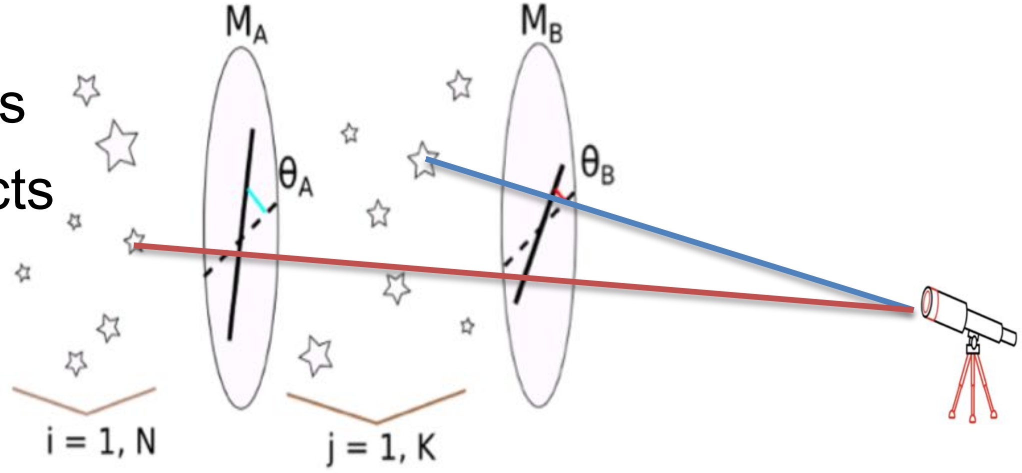
Tassis & Pavlidou 2015

Consensus: frequency decorrelation ***most unconstrained effect*** for current & upcoming B-mode experiment foreground subtraction

Planck Collaboration L 2017, Poh & Dodelson 2017, Hensley & Bull 2017, Puglisi et al 2017, Martizez-Solaeche et al. 2017, Planck Collaboration XXX 2016, Planck 2018 results. XI.

The Solution: 3D Magnetic Tomography

- Use stars of **known distances** as lamp posts
- Measure **stellar polarization**
  - ✓ get B direction in different clouds
  - ✓ measure and model out 3D effects

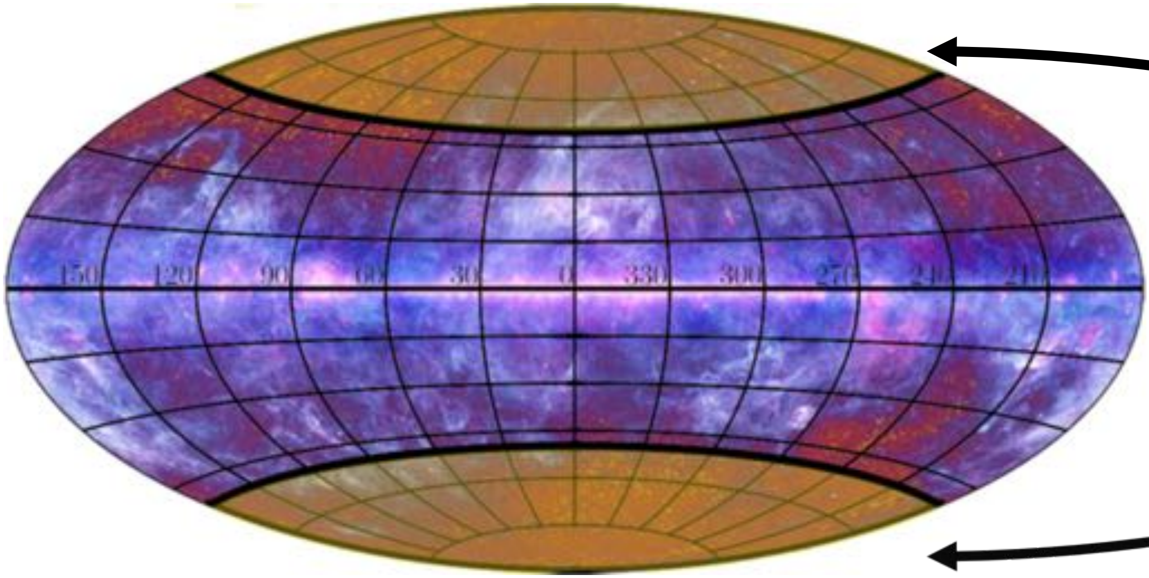


Possible for the first time

PASIPHAE

esa
gaia

PASIPHAE optopolarimetric survey

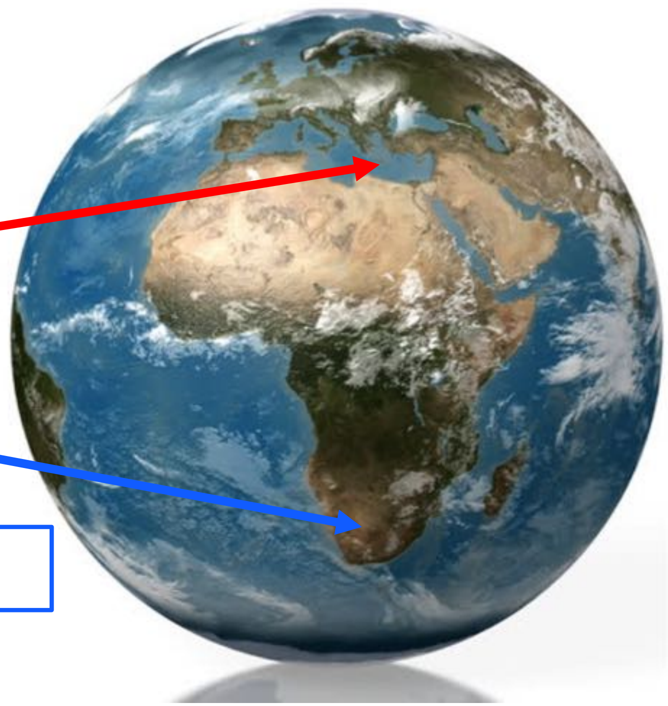


PASIPHAE survey area

Skinakas Observatory, Crete, Greece

PASIPHAE survey sites

SAAO, Sutherland, South Africa



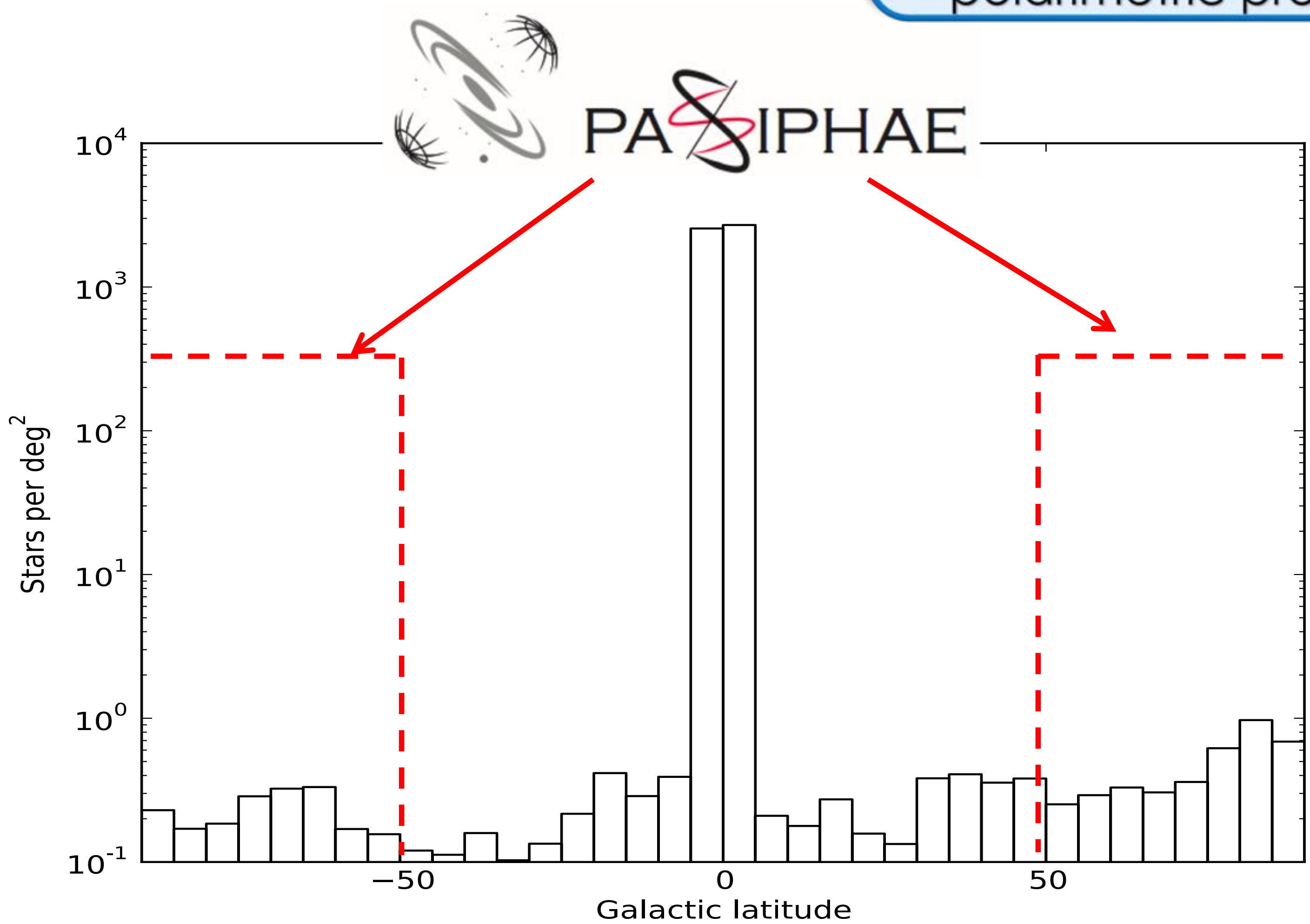
The PASIPHAE survey:

- Will observe all stars with Rmag ≤ 16.5
- Will deliver mean polarization down to 0.1% at 3σ for 0.25 deg^2 pixels
- Survey rate: 8 deg^2/night (Skinakas 1.3m) -- 7 deg^2 /night (SAAO1.0 m) assuming 70% efficiency
- 7,500 deg^2 in 5 yr

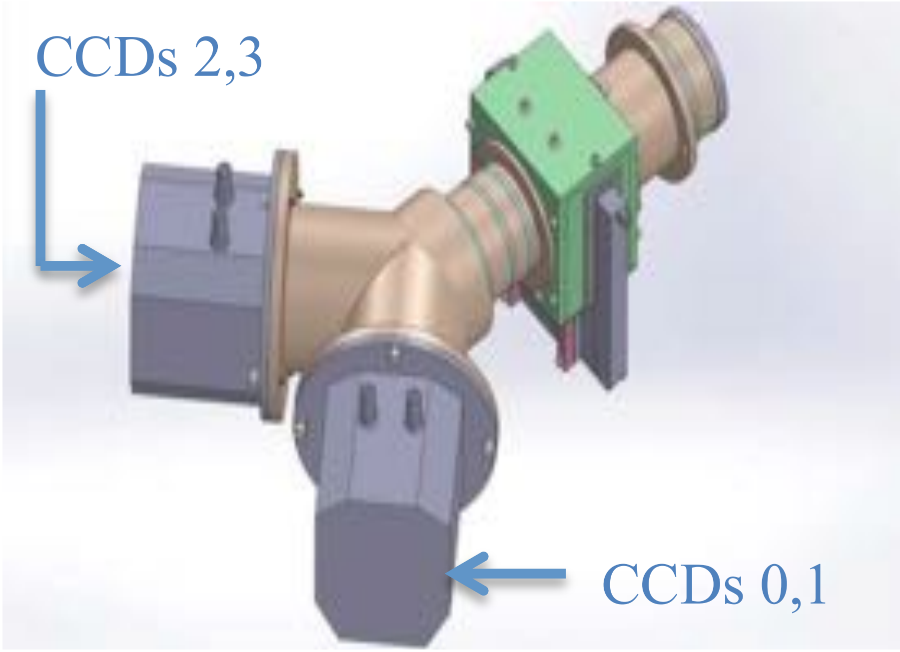
PASIPHAE optopolarimetric survey

Measure polarization of **several million stars**

Major Leap:
x1000 improvement
in # of stars with measured polarimetric properties



WALOP: the PASIPHAE polarimeter

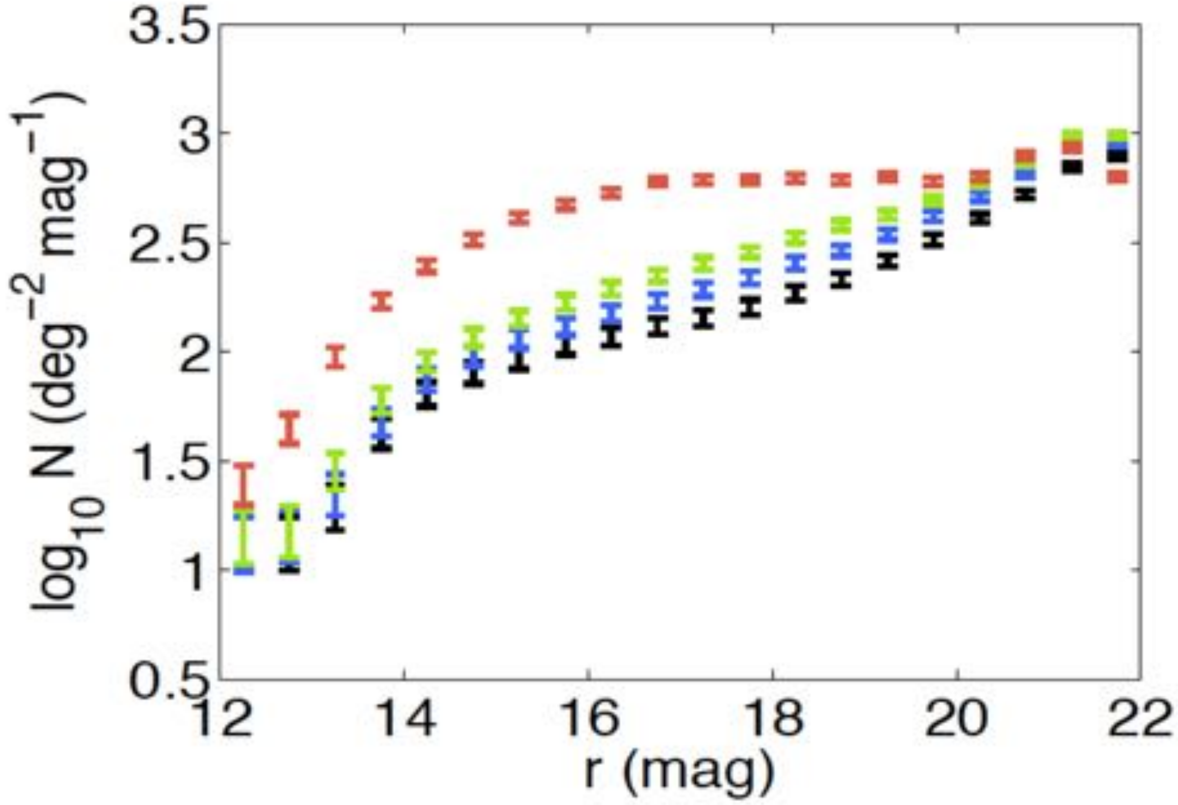


Wide Area Linear Optical Polarimeter (WALOP)

- **Innovative** and **well-tested technology** of RoboPol
- Implements low-systematics design **in a wide field**
- Commissioning in 2019

Feasibility: Stellar Density

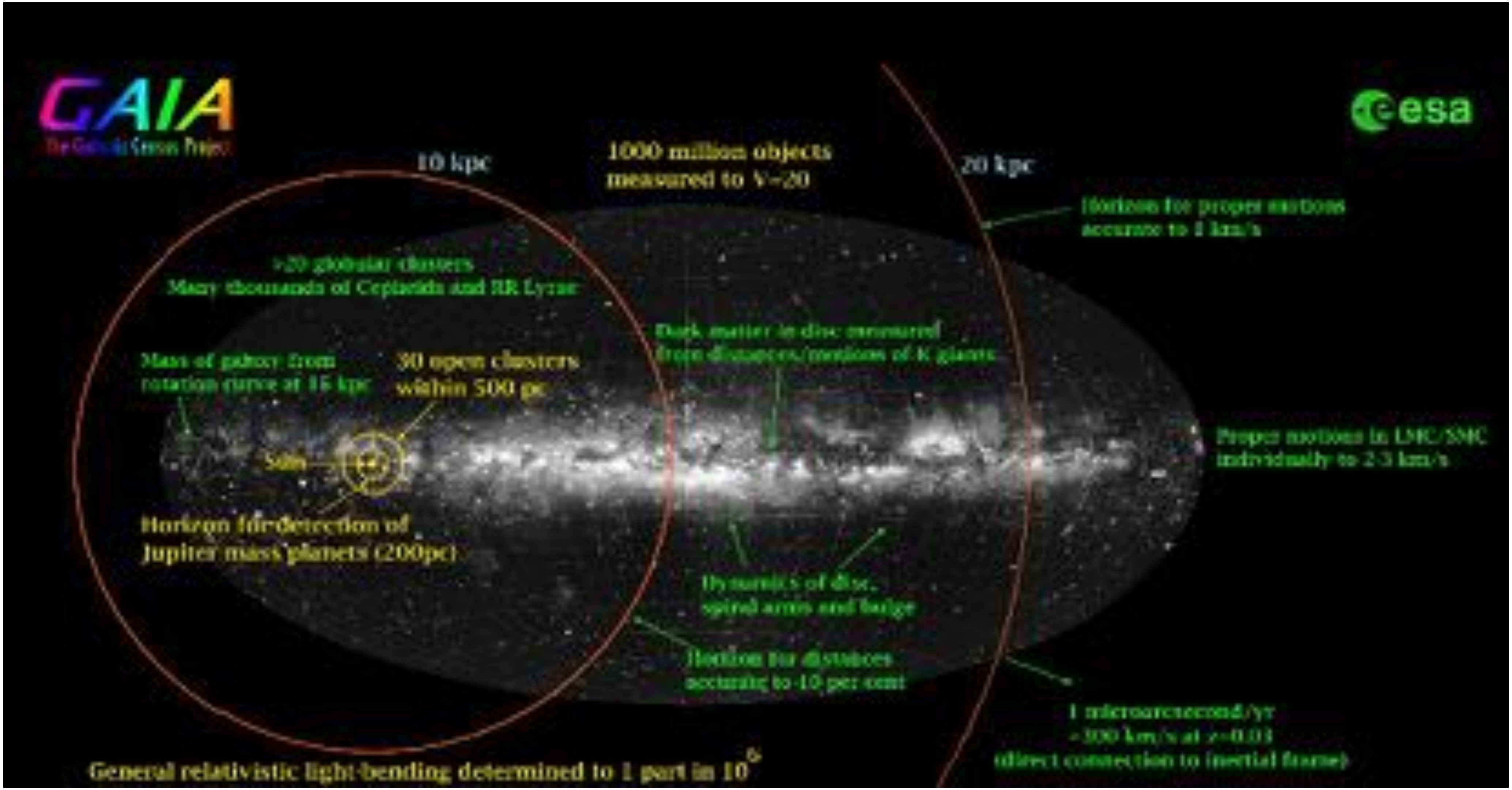
At least 360 stars of R_{mag} < 16.5 at the Galactic pole



Black b = 90^0
Blue b = 75^0
Green b = 65^0
Red $20^0 < b < 30^0$

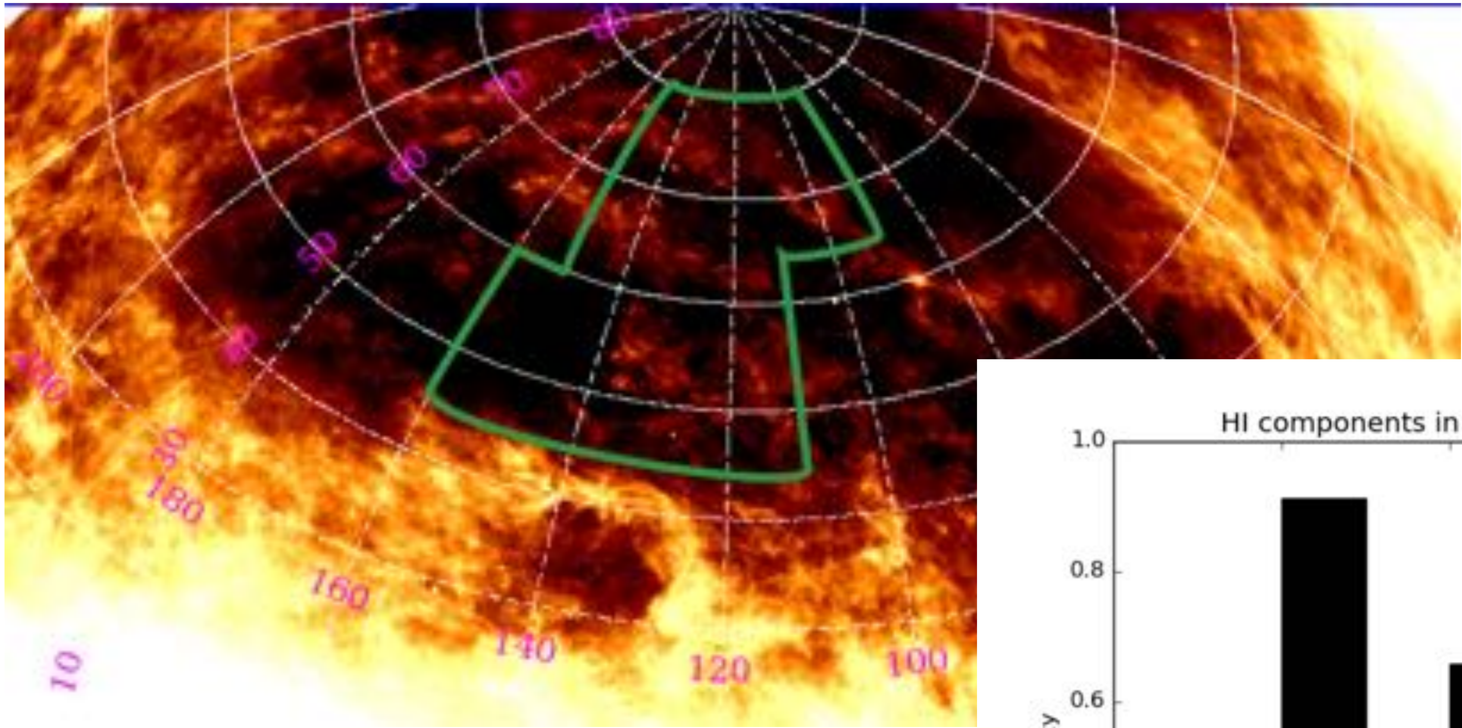
Gao 2011 from SDSS DR7

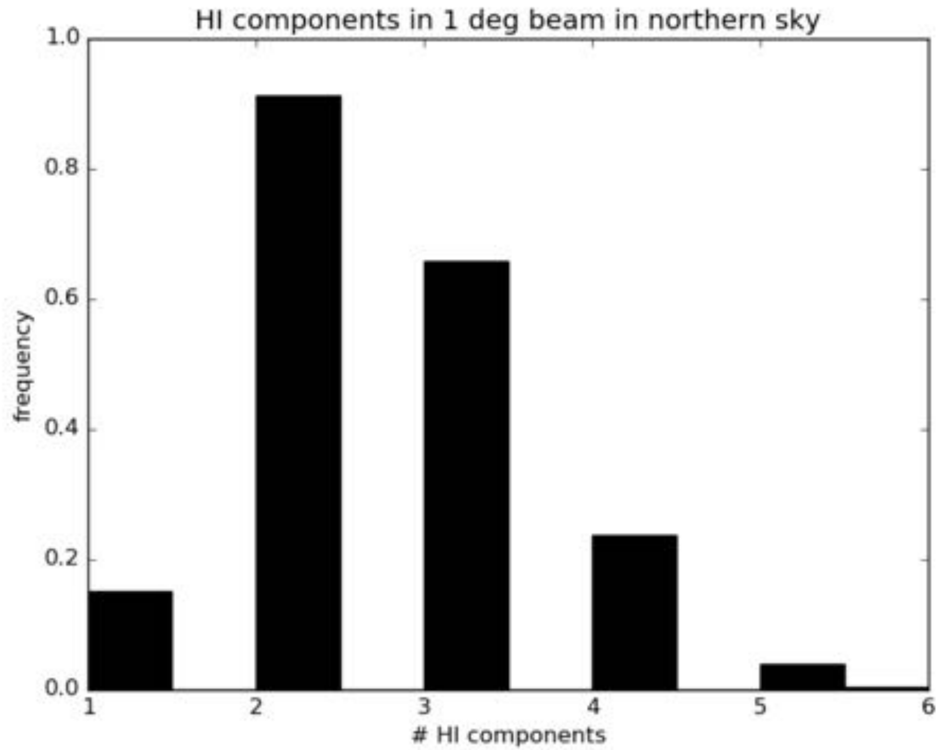
Feasibility: Distances



Feasibility: # of clouds along the los

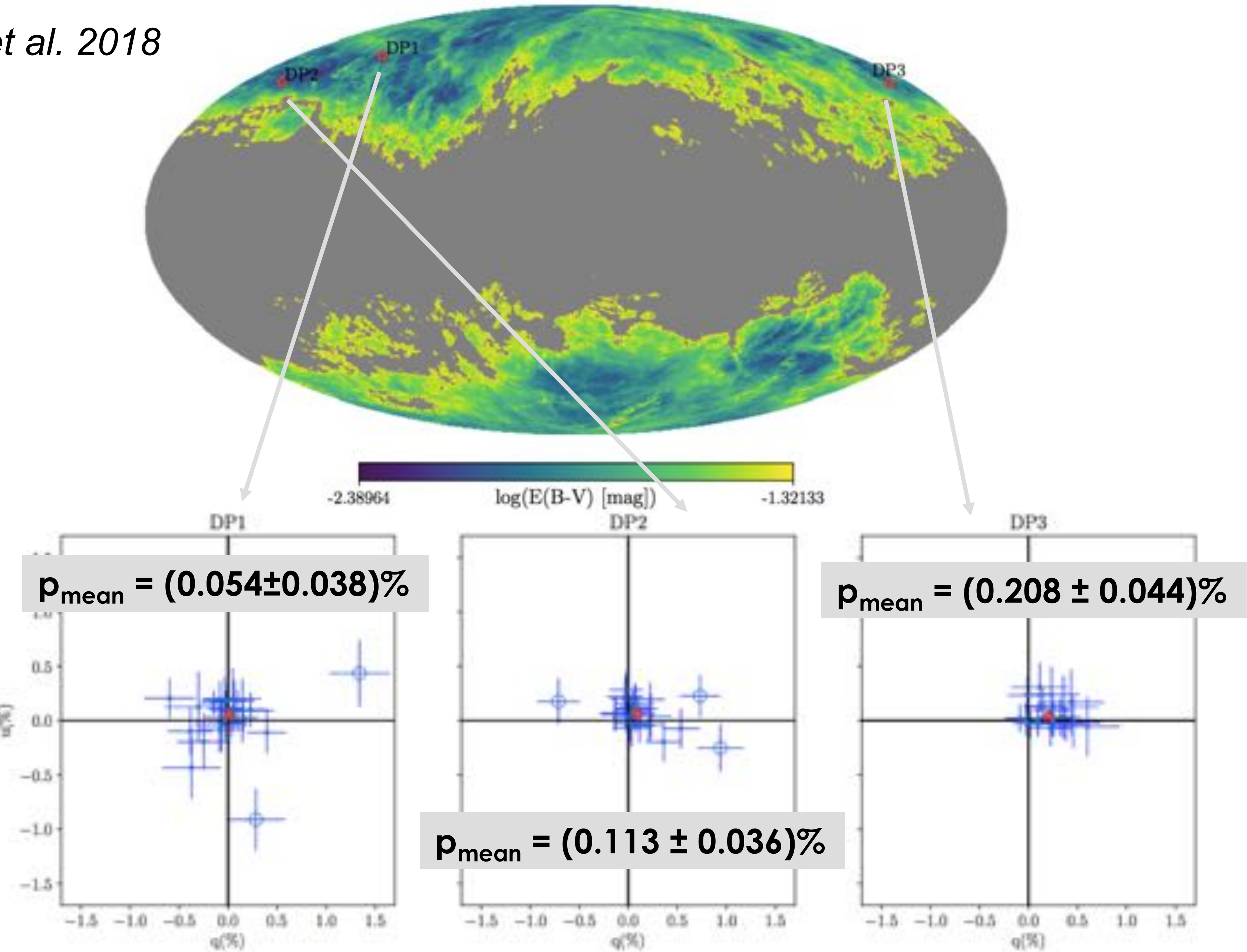
HI data from the Effelsberg-Bonn HI survey



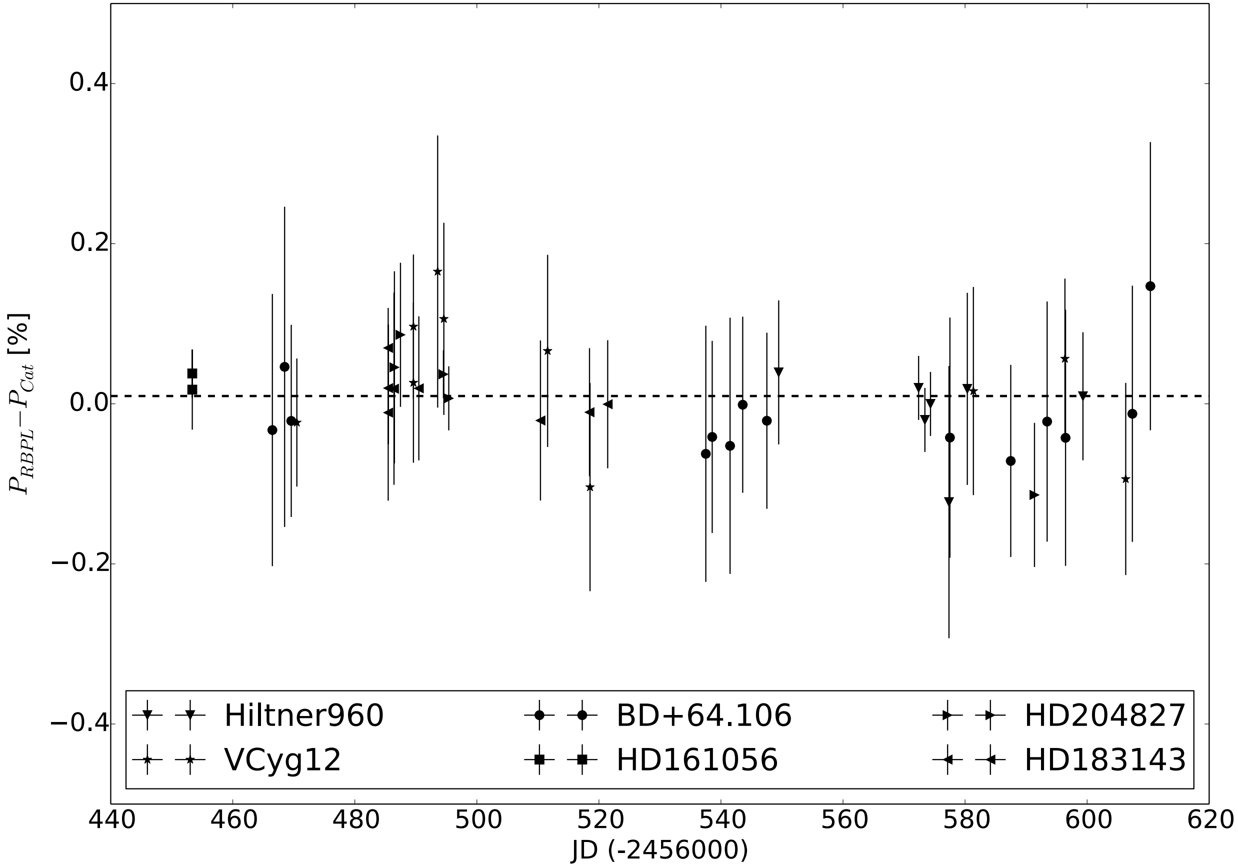


Feasibility: Degree of Polarization

Skalidis et al. 2018



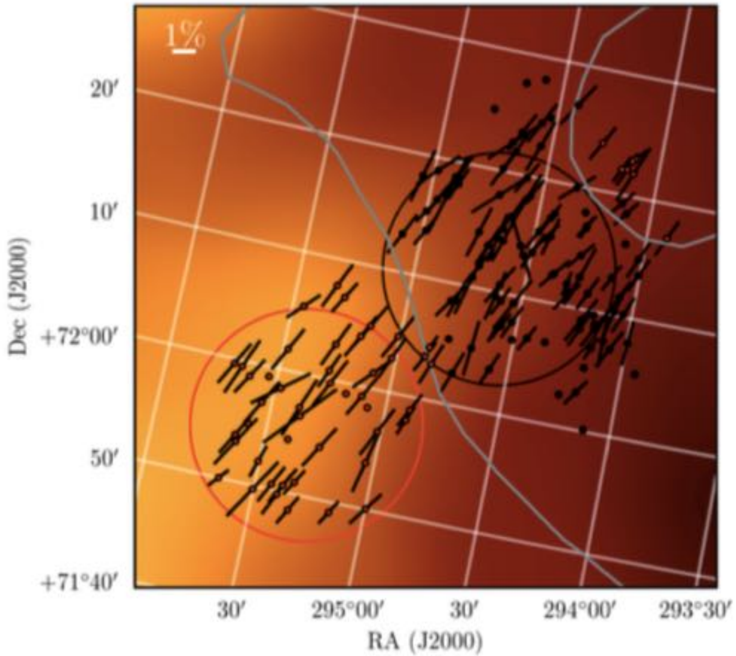
Feasibility: Polarization Systematics



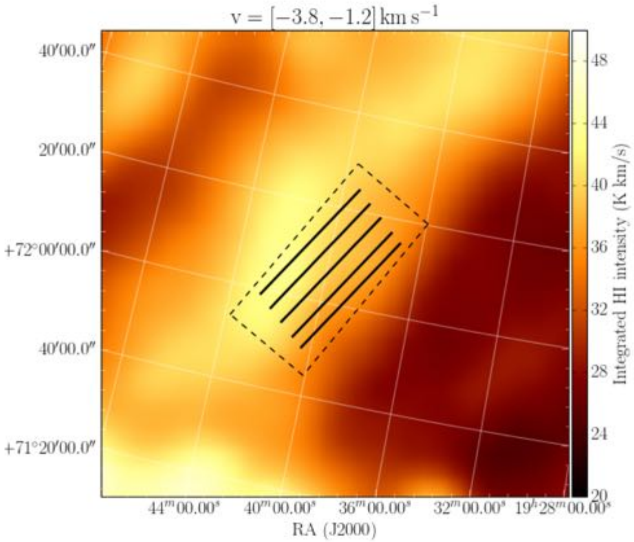
RoboPol standards program

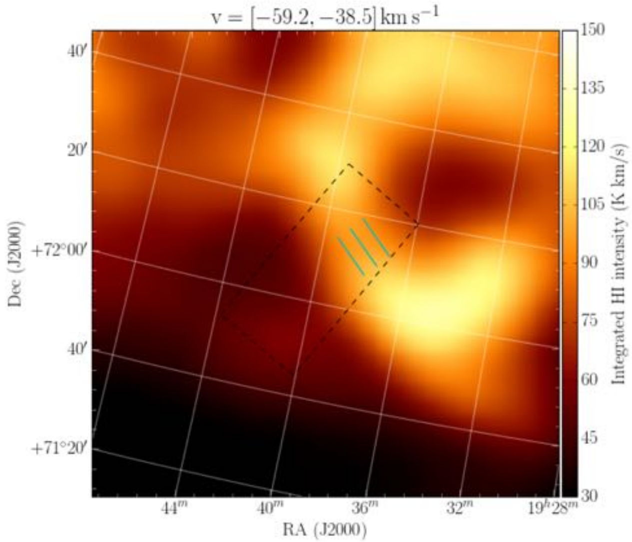
Feasibility: Tomography

Panopoulou et al. 2018 in prep.



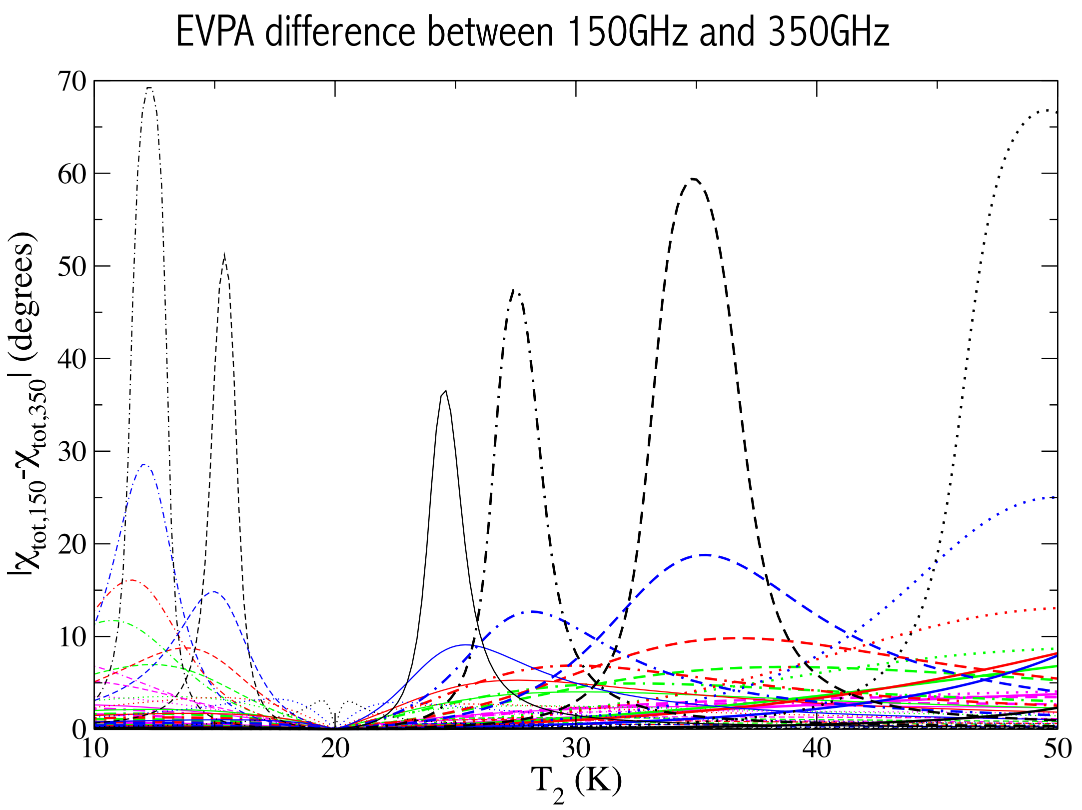
robopol





Improving CMB foreground subtraction 1

- **0th-order approach**
  - ✓ 3-D effects important only when B-fields in different clouds along LOS are ***misaligned*** (by >60 deg)
  - ✓ Pixels with such misaligned clouds can be identified and **masked out** (as with point sources)
  - ✓ PASIPHAE+Gaia data *alone* can produce such a mask.



Tassis & Pavlidou 2015

Misalignment:

Improving CMB foreground subtraction 2

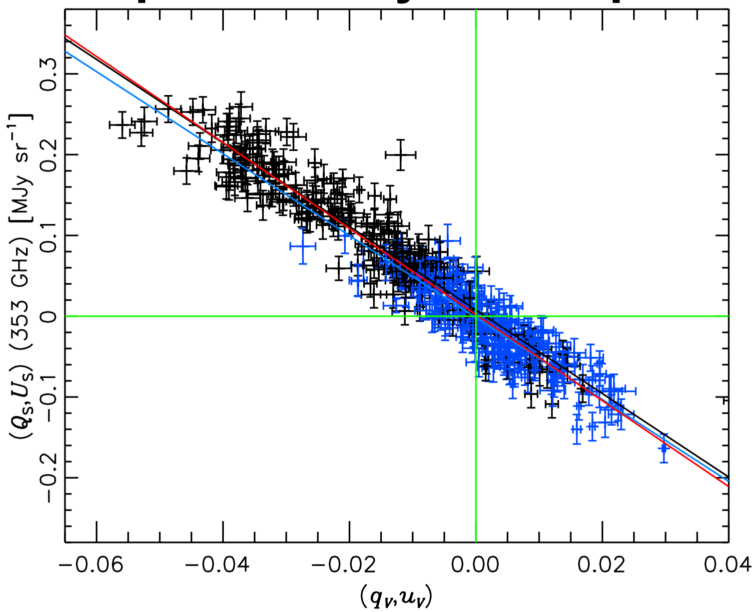
- **1st-order approach**
  - ✓ Now: modified-black-body model is fitted in **each pixel** (using e.g. Planck data)
  - ✓ With PASIPHAE: fit one modified-black-body model for **each cloud**, using: B-field direction from PASIPHAE/Gaia + Planck data (T) + cloud edges, column density from all-sky HI surveys
  - ✓ Approach is both **more accurate** and **computationally less expensive**

Is polarization due to absorption predictive of emission polarization?

YES!

emission, absorption Q,U are tightly correlated

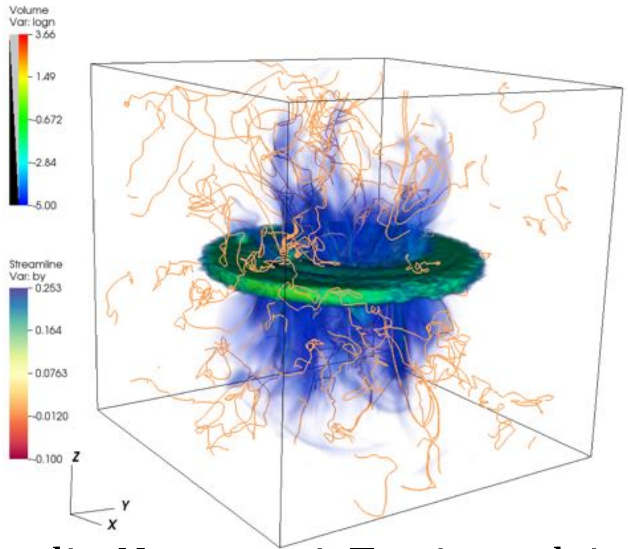
3-d effects can account for most of scatter



Planck Intermediate results XXI (2015)

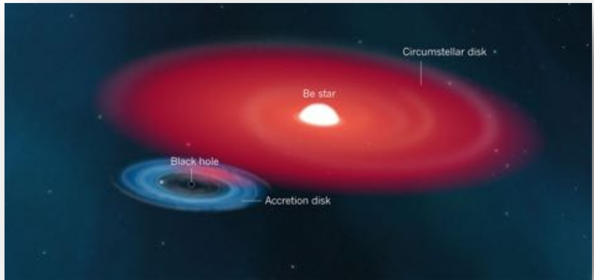
Wider Impact

- **3-D Tomographic Map of Galactic B-field:**
  - ✓ **What is the origin of Galactic B-field?**
  - ✓ **Is the B-field dynamically important in interstellar clouds?**
  - ✓ **Where are ultra-high-energy cosmic rays coming from?**

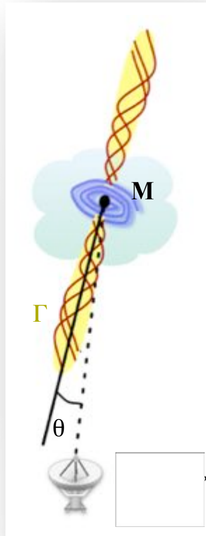


credit: Ntormousi, Tassis et al. in pre

- **Polarimetric Database PUBLICLY AVAILABLE**
  - ✓ **Stellar Astrophysics**
  - ✓ **High-energy astrophysics**



credit: McSwain 2014

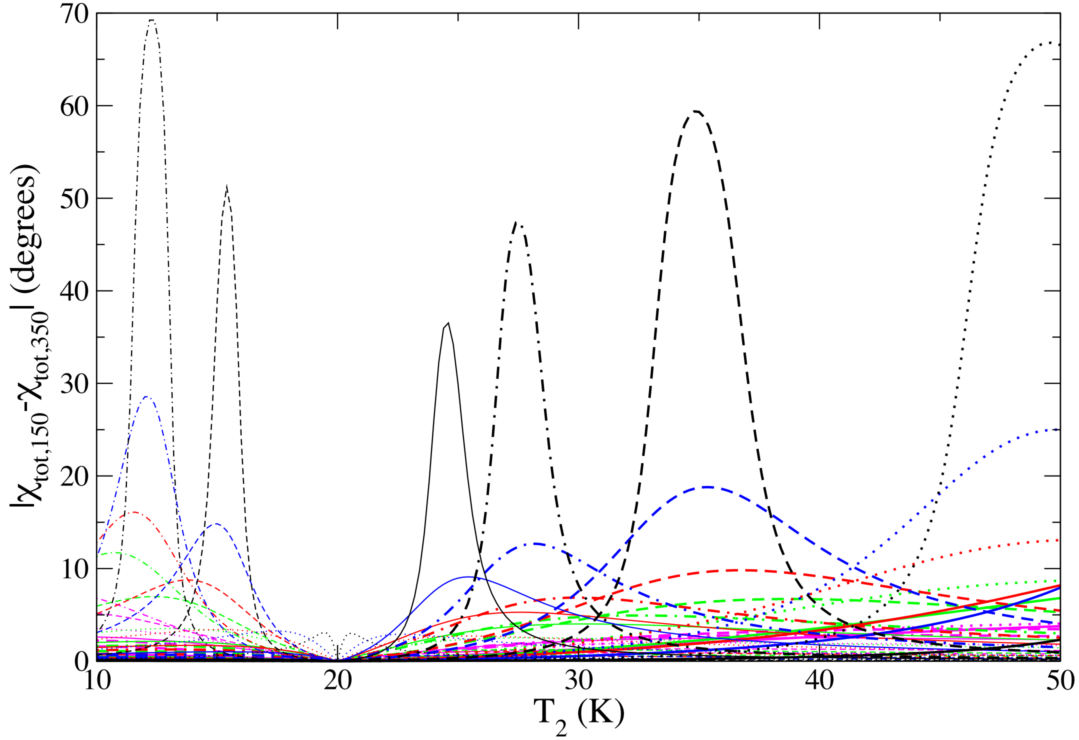


credit: Pavidou 2015

Thank you

http://pasiphae.science

Cloud Temperature Gradient



Component	T_{BG} (K)	1 σ	3 σ	ϵ_{160}	1 σ	3 σ
Local	17.4	16.3–18.8	14.3–22.6	3.0	1.9–4.9	0.60–12.5
HVC	10.7	9.9–11.6	7.7–13.6	36.0	16.8–83.7	3.8–1442.8
IVC1	14.6	13.6–15.8	11.8–19.4	13.2	7.0–24.1	1.6–79.6
IVC2	19.4	17.1–23.1	14.1–107.4	1.5	0.5–3.6	0.003–15.5

NOTES.—The big grain temperature (T_{BG}) and dust emissivity at 160 μm ($\epsilon_{160} = \tau_{160}/N_{H\,I}$, given in units of 10^{-25} cm^2 per H atom) and their corresponding 1 σ and 3 σ ranges for each H I component are given. The values for the local ISM deduced from the *COBE* data (Boulanger et al. 1996) are T_{BG} = 17.5 K and $\epsilon_{160} = 2.4 \times 10^{-25}$ cm^2.

THE ASTROPHYSICAL JOURNAL, 631:L57–L60, 2005 September 20

THE FIRST DETECTION OF DUST EMISSION IN A HIGH-VELOCITY CLOUD

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ABSTRACT

By comparing sensitive *Spitzer Space Telescope* infrared observations with Green Bank Telescope 21 cm observations, we are able to report the first detection of dust emission in Complex C, the largest high-velocity cloud in the sky. The dust in the region of Complex C studied here has a colder temperature ($T = 10.7^{+0.9}_{-0.8}$ K; 1 σ) than the local interstellar medium (T = 17.5 K), in accordance with its great distance from the Galactic plane. Based on the metallicity measurements and assuming diffuse Galactic interstellar medium dust properties and a dust-to-metals ratio, this detection could imply gas column densities more than 5 times higher than observed in H I. We suggest that the dust emission detected here comes from small molecular clumps, spatially correlated with the H I but with a low surface filling factor. Our findings imply that the mass of high-velocity clouds would be much larger than inferred from H I observations and that most of the gas falling on the Milky Way would be in cold and dense clumps rather than in a diffuse phase.

Subject headings: dust, extinction — Galaxy: halo — ISM: clouds

Online material: color figures

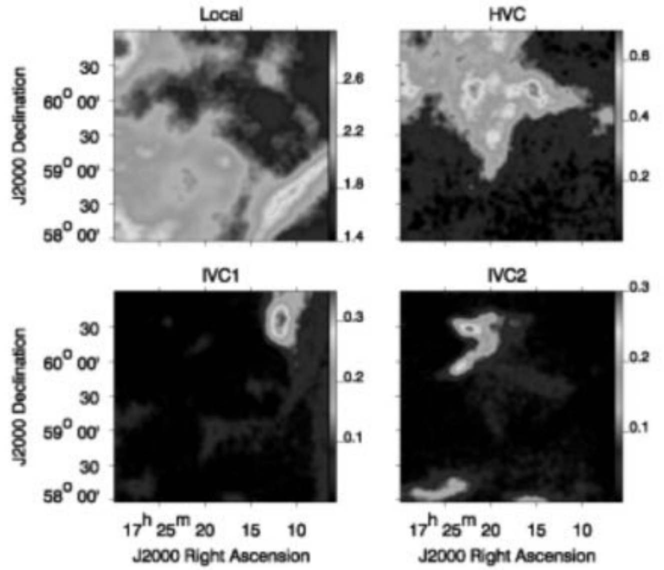

FIG. 3.—H I column density of the four H I components (local, HVC, IVC1, and IVC2). All maps are in units of 10^{20} cm^{-2}. An opacity correction was applied to convert the 21 cm integrated emission to H I column density (see text for details). [*See the electronic edition of the Journal for a color version of this figure.*]