Galactic Science Overview

10/13/2017

L. Fissel, D. Chuss

Science Traceability Matrix (STM)

		Scientific Measurement Requirements			Instrument		
Science Goals	Science Objectives	Model Parameters	Physical Parameters	Observables	Instrument Functional Requirements	Projected Performance	Mission Functional Requirements (Top Level)
Explore how the universe evolved (magnetic fields)	Connect the small scale fields in SFR to the Galactic magnetic field		Magnetic field maps of molecular clouds	Linear polarization at frequencies > 300GHz over the entire sky	Angular resolution < 1 arcmin		
Explore how the universe evolved (magnetic fields)	Test models of galactic magnetic fields in a statistically significant sample of external galaxies		Magnetic field maps of nearby external galaxies	Linear polarization at frequencies > 300GHz over the entire sky	Angular resolution < 1 arcmin		
Explore how the universe evolved (magnetic fields)	Test models of the magnetic field turbulence in the diffuse ISM		Magnetic field maps of the diffuse ISM	Linear polarization at frequencies > 300GHz over the entire sky	Sensitivity: A_v <0.1(need to convert to Jy/sr)		
Explore how the universe evolved (magnetic fields)	Test grain alignment models, specifically RAT alignment theory.		Polarization spectra	Linear polarization at many frequencies > 300GHz over the entire sky	Combination of number of bands and angular resolution?		

-Part of the final report

-Also being used to determine instrument trades

Sensitivities for the designs under consideration

EPIC, 30K

f (GHz)	FWHM (arcmin)	uK	uK arcmin	Jy/sr	uJy/beam
25	34.1	0.97	33	18.29	112.45
30	28.4	0.79	22.4	21.31	90.9
36	23.7	0.63	15	24.37	72.4
43	19.7	0.46	9.1	25.02	51.36
52	16.4	0.43	7	33.08	47.06
62	13.7	0.36	5	39.07	38.78
75	11.4	0.35	4	52.55	36.11
90	9.5	0.34	3.2	68.29	32.59
107	7.9	0.37	2.9	96.87	31.97
129	6.6	0.41	2.7	138.43	31.89
155	5.5	0.47	2.6	194.19	31.07
186	4.6	0.78	3.6	364.51	40.79
223	3.8	1.39	5.3	674.11	51.48
267	3.2	2.81	9	1259.99	68.23
321	2.7	5.93	16	2119.58	81.72
385	2.2	14.55	32	3472.44	88.88
462	1.8	41.67	75	5308.23	90.96
555	1.5	146.67	220	7565.15	90.02
666	1.3	846.15	1100	12820.87	114.59
799	1.1	9090.91	10000	27444.06	175.62

Small mirror, 4K

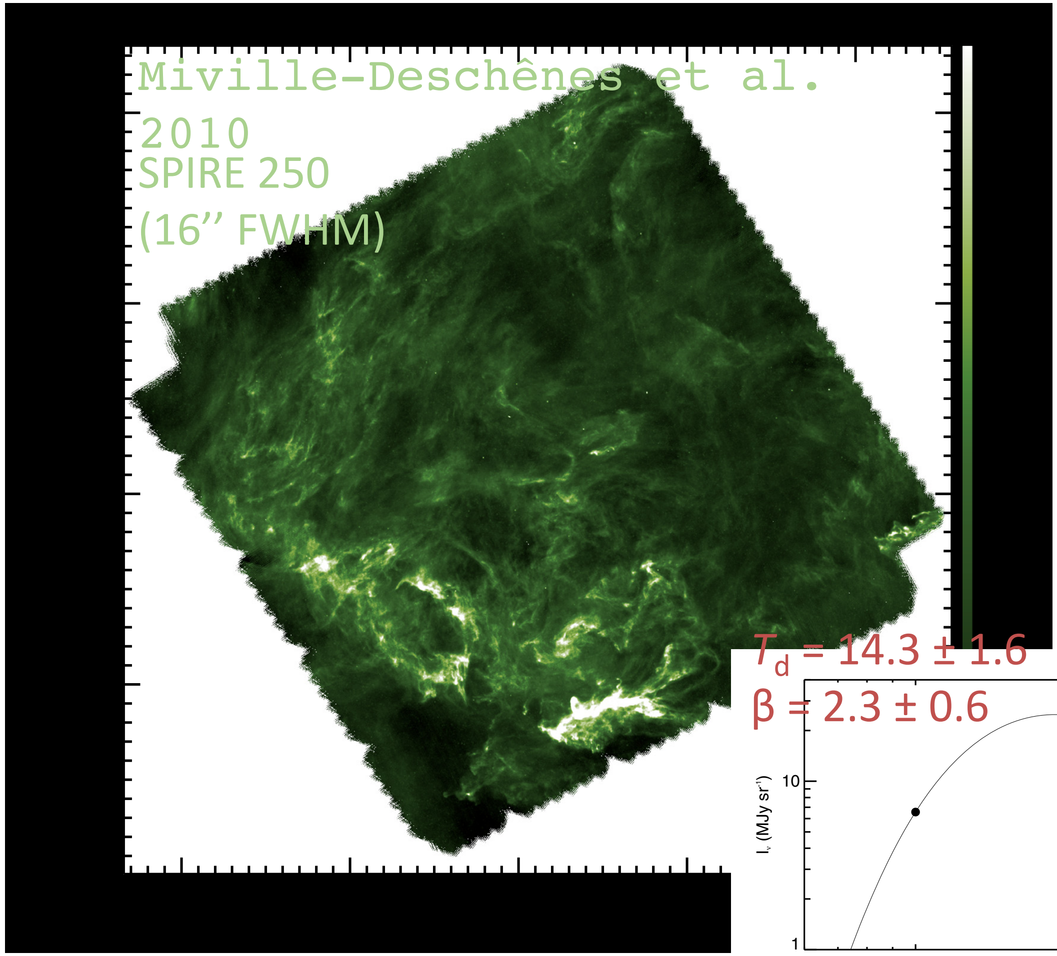
f (GHz)	FHWM (arcmin)	uK	uK arcmin	Jy/sr	uJy/beam
25	95.2	0.14	13.39	2.66	127.46
30	89.2	0.19	16.61	5.03	211.77
36	74.4	0.13	9.8	5.07	148.61
43	76.5	0.18	13.74	9.82	303.69
52	63.6	0.13	8.16	9.87	211.15
62	38.3	0.17	6.33	17.8	137.89
75	31.9	0.17	5.58	25.95	139.61
90	29.9	0.16	4.79	32.26	152.61
108	24.9	0.17	4.31	45.88	150.83
129	25.6	0.17	4.31	56.98	197.13
155	21.3	0.19	4.03	77.44	186.32
186	12.8	0.32	4.06	147.51	128.15
223	10.7	0.48	5.17	234.17	141.27
268	10.0	0.42	4.17	186.04	98.74
321	8.3	0.72	6.02	258.13	95.12
385	8.6	0.8	6.86	191.07	74.11
462	7.1	1.75	12.5	222.7	60
555	4.3	12.71	54.54	657.5	64.06
666	3.6	41.96	150.09	638.77	43.22
799	3.0	159.38	475.06	482.96	22.69

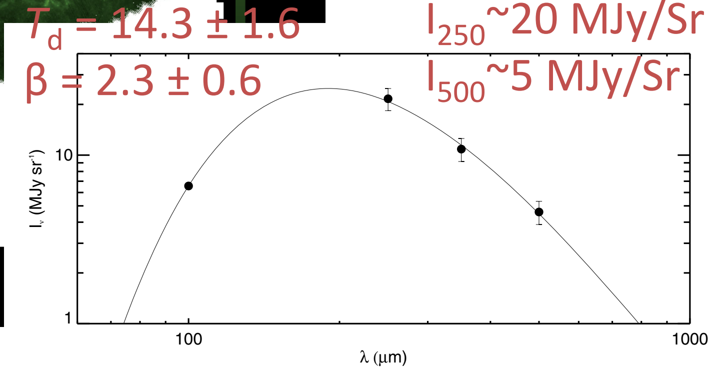
We have also been asked to consider the effects of:

- Resolution Trade-offs:
  - 2x better resolution
  - 2x worse resolution
- Sensitivity Trade-offs:
  - 2x better sensitivity
  - 2x worse sensitivity
  - 4x worse sensitivity
- Frequency Coverage Trade offs:
  - 555 GHz maximum frequency (detector technology changes for f > 600 GHz)

Magnetic Fields in Star Formation Sensitivity Goal: resolve the HI to H_2 transition

High Latitude Cirrus Cloud, distance ~150 pc



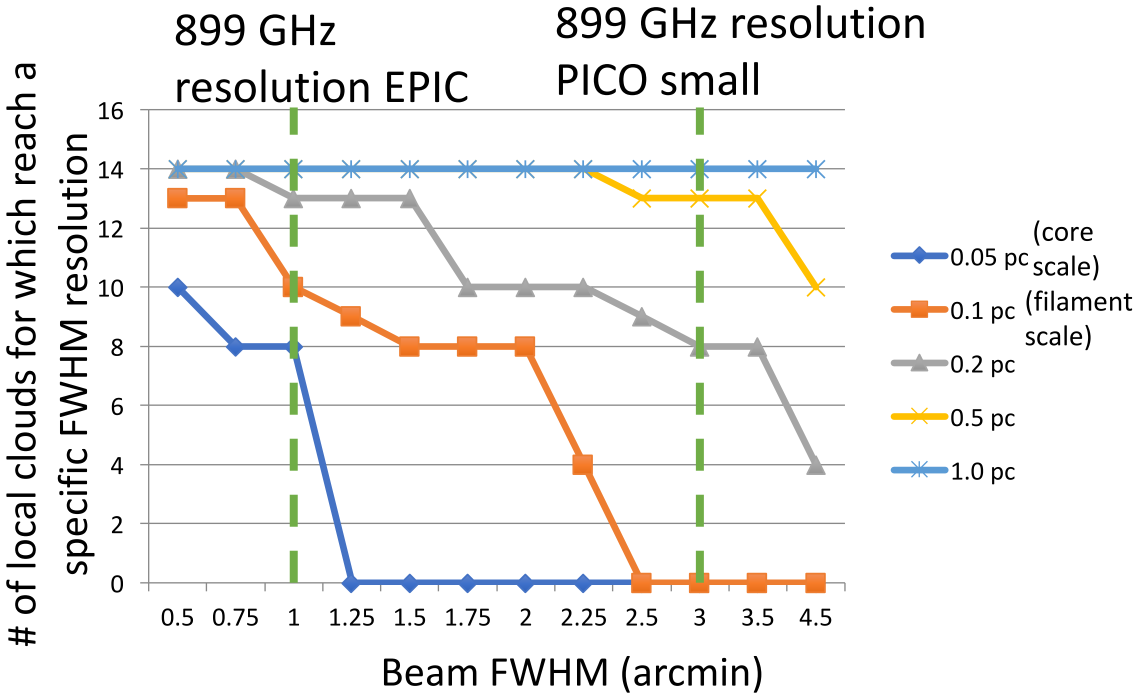


- Base sensitivity estimates on Polaris Flare Cloud
- Intensity of diffuse emission (A_V < 1) at 500 microns: ~5 MJy/Sr.
- To resolve the HI to H2 transition we want a 3-sigma detection of 2% polarized dust.
- Assume T_d = 14.3, β = 2 and scale 5 MJy/Sr to PiCO bands (I_{ref})

Freq [GHz]	lamda [microns]	sig_I (EPIC) [MJy/Sr]	sig_I (PICO small) [MJy/Sr]	I_ref [MJy/Sr]	p_min (EPIC) (3-sigma)	p_min (PICOsm) (3-sigma)
107	2803.7	0.00010	0.00005	0.0083	7.0%	3.3%
129	2325.6	0.00014	0.00006	0.0178	4.7%	1.9%
155	1935.5	0.00019	0.00008	0.0373	3.1%	1.2%
186	1612.9	0.00036	0.00015	0.0770	2.8%	1.1%
223	1345.3	0.00067	0.00023	0.1566	2.6%	0.9%
267	1123.6	0.00126	0.00019	0.3117	2.4%	0.4%
321	934.6	0.00212	0.00026	0.6178	2.1%	0.3%
385	779.2	0.00347	0.00019	1.1839	1.8%	0.1%
462	649.4	0.00531	0.00022	2.2035	1.4%	0.1%
555	540.5	0.00757	0.00066	3.9560	1.1%	0.1%
666	450.5	0.01282	0.00064	6.7335	1.1%	0.1%
799	375.5	0.02744	0.00048	10.7565	1.5%	0.0%

Goal #2: Resolve Magnetic Fields in Cores and Filaments in a Large Sample of nearby Molecular Clouds

Assumed Beam FWHM [arcmin]		0.5	1	2	3
Molecular Clouds	distance (pc)	Res [pc]	Res [pc]	Res [pc]	Res [pc]
Taurus	140	0.020	0.041	0.081	0.122
Perseus	300	0.044	0.087	0.175	0.262
Chameleon	160	0.023	0.047	0.093	0.140
Lupus	155	0.023	0.045	0.090	0.135
Ophiuchus	140	0.020	0.041	0.081	0.122
Orion	450	0.065	0.131	0.262	0.393
Aquila	260	0.038	0.076	0.151	0.227
Musca	160	0.023	0.047	0.093	0.140
Pipe	150	0.022	0.044	0.087	0.131
Corona Australis	170	0.025	0.049	0.099	0.148
Cepheus	440	0.064	0.128	0.256	0.384
Coalsack	150	0.022	0.044	0.087	0.131
Vela	700	0.102	0.204	0.407	0.611



	Cores (0.05pc)	Filament Widths (0.1pc)	Cloud Substructure (1pc)
(1 arcmin FWHM) EPIC 30K design	8 nearby MCs	10 nearby MCs	14+ nearby MCs
(3 arcmin FWHM) PICO small design	0 nearby MCs	0 nearby MCs	8 nearby MCs

Goal #3: Resolve cloud field structure in a large sample size of molecular clouds

Use BGPS sample of clouds with well characterized kinematic distances (49%), typical size ~10 pc

Ellsworth-Bowers et al. (2015)

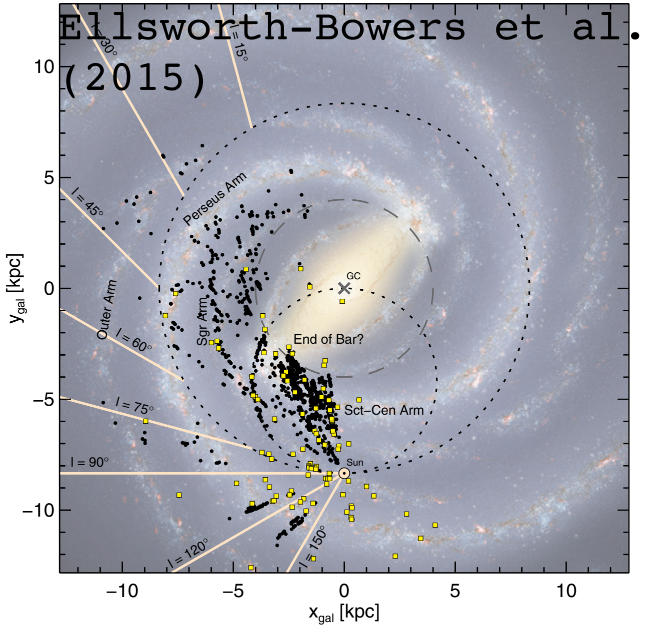
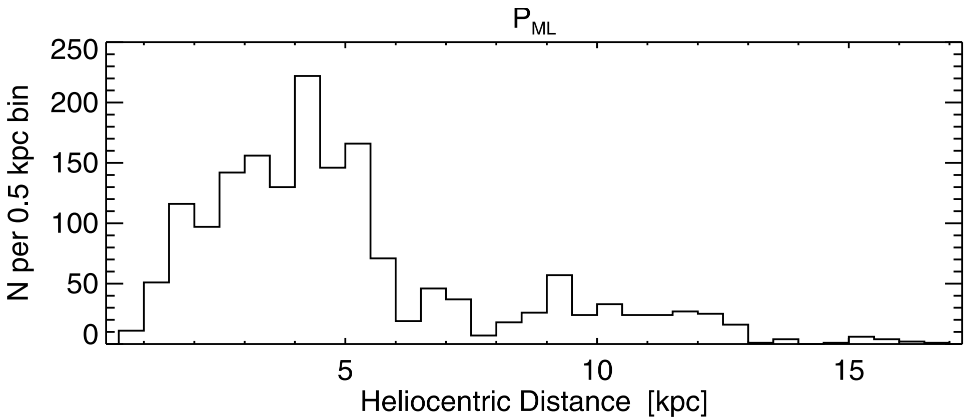


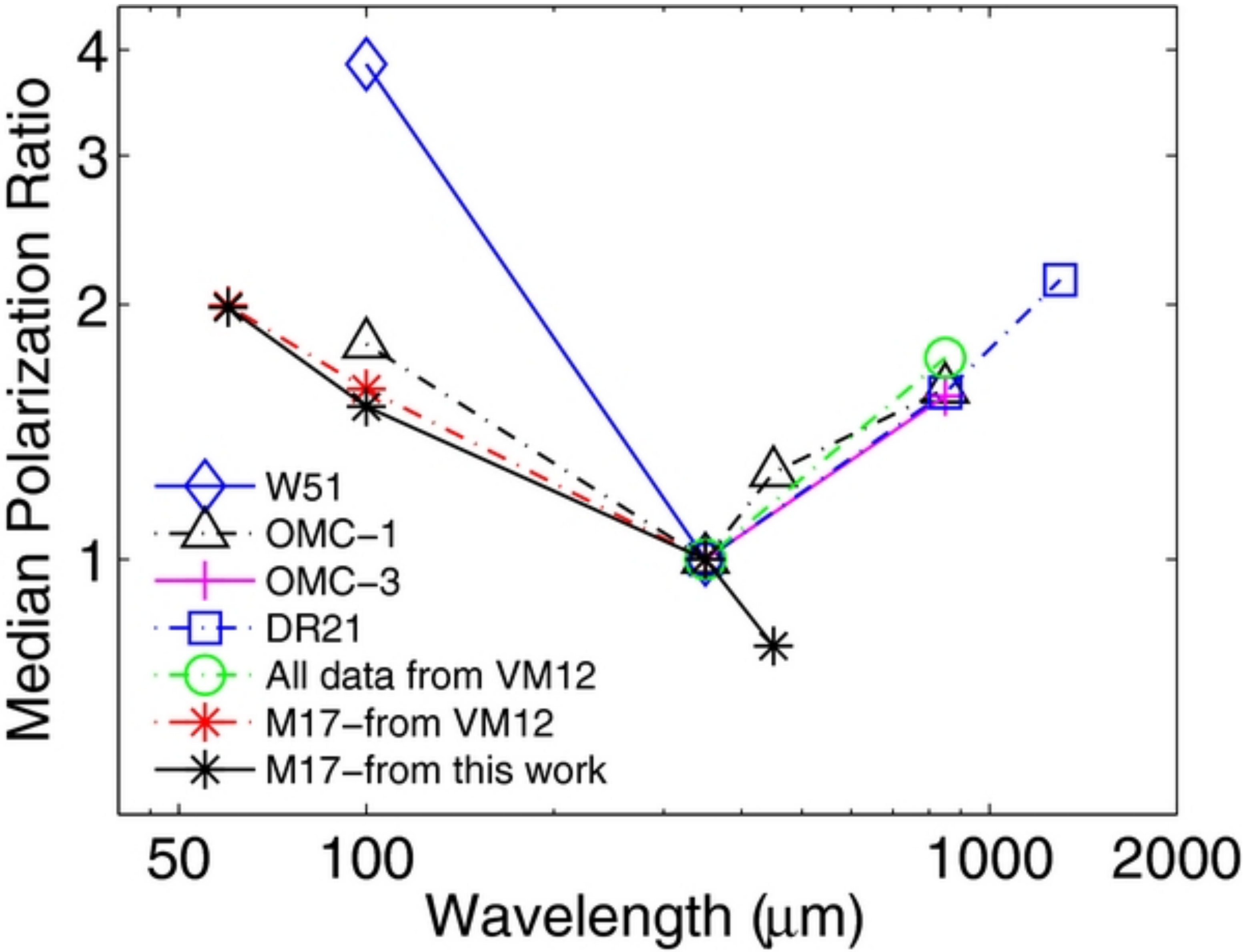
Figure 15. Face-on view of the Milky Way for sources with well-constrained distance estimates (black circles), plotted atop an artist's rendering of the Milky Way (R. Hurt: NASA/JPL-Caltech/SSC) viewed from the north Galactic pole. Yellow squares mark the locations of masers with trigonometric parallaxes (Reid et al. 2014, Table 1). The image has been scaled to match the R_0 used for calculating kinematic distances. The outer dotted circle marks the solar circle, and the inner dotted circle the tangent point as a function of longitude. The dashed circle at $R_{gal} = 4$ kpc outlines the region influenced by the long Galactic bar where the assumed flat rotation curve breaks down (Benjamin et al. 2005; Reid et al. 2014). Various suggested Galactic features are labeled. For clarity, distance error bars are not shown.

- Aim is to look at magnetic field structure and large scale turbulence as a function of cloud age, mass, SF history, turbulent line widths, etc…



We can resolve 1pc out to:
1' resolution -> 3.4 kpc (700 BGPS sources)
2' resolution -> 1.7 kpc (180 BGPS sources)
3' resolution -> 1.4 kpc (60 BGPS sources)

Polarization Spectrum



Zeng et al. 2013

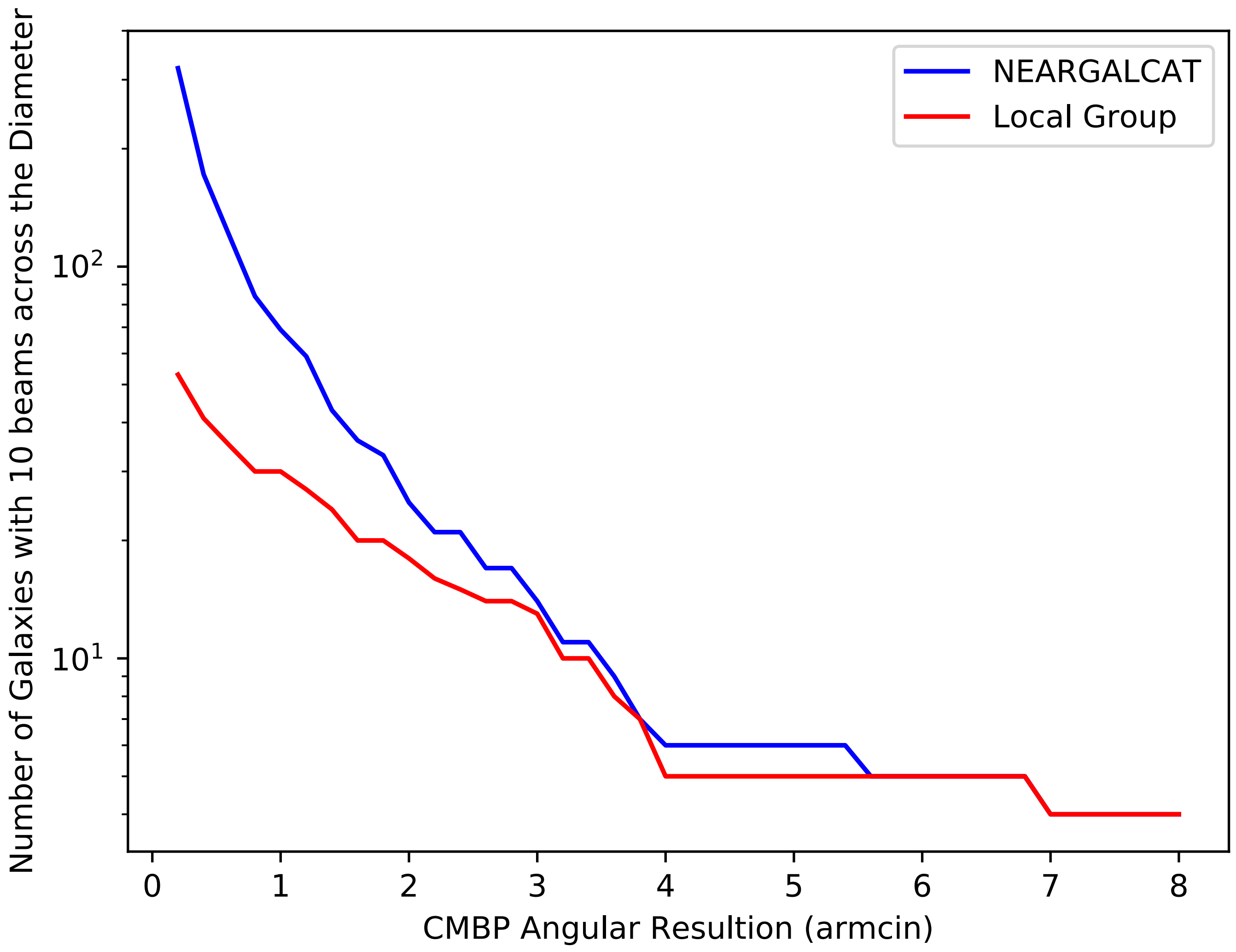
EPIC vs. PICO Small Trade offs: Molecular Cloud Studies

	Nearby Clouds Studies	Distant Cloud Studies	Polarization Spectrum
Sensitivity	Both EPIC and PICO Small designs achieve required sensitivity	same as NCS	PICO small has better sensitivity should get better measurements of the spectrum in the cloud envelopes.
Resolution	EPIC can resolve field structure in cores and filaments, PICO small cannot	EPIC: can study the magnetic field structure in detail for a few thousand MCs PICO small: can study the field structure for a few hundred clouds	PICO small can't study the polarization spectrum of cores and filaments.

EPIC Magnetic Fields in Star Formation Trade-offs

	Nearby Clouds Studies	Distant Cloud Studies	Polarization Spectrum
2x better sensitivity	could better resolve turbulence in A_V<<1	same as NCS	N/A
2x worse sensitivity	probably require beam smoothing to study B-fields in cloud envelopes	same as NCS	N/A
4x worse sensitivity	definitely require beam smoothing to study B-fields in cloud envelopes	same as NCS	N/A
2x worse resolution (2')	Can't resolve core (0.05 pc) scales for any nearby clouds	Observe 500 clouds at 1pc resolution, instead of 2500	Can't study polarization spectrum of starless cores.
2x better resolution (0.5')	Resolve core (0.05 pc) scales for Perseus, Aquilla	Many more clouds	Detailed studies polarization spectrum/efficiency of starless cores.
max 555 GHz band	Can't resolve core (0.05 pc) scales for any nearby clouds	Observe 2,000 clouds at 1pc resolution, instead of 2500	Farther from polarization spectrum minimum at ~350 microns

External Galaxies

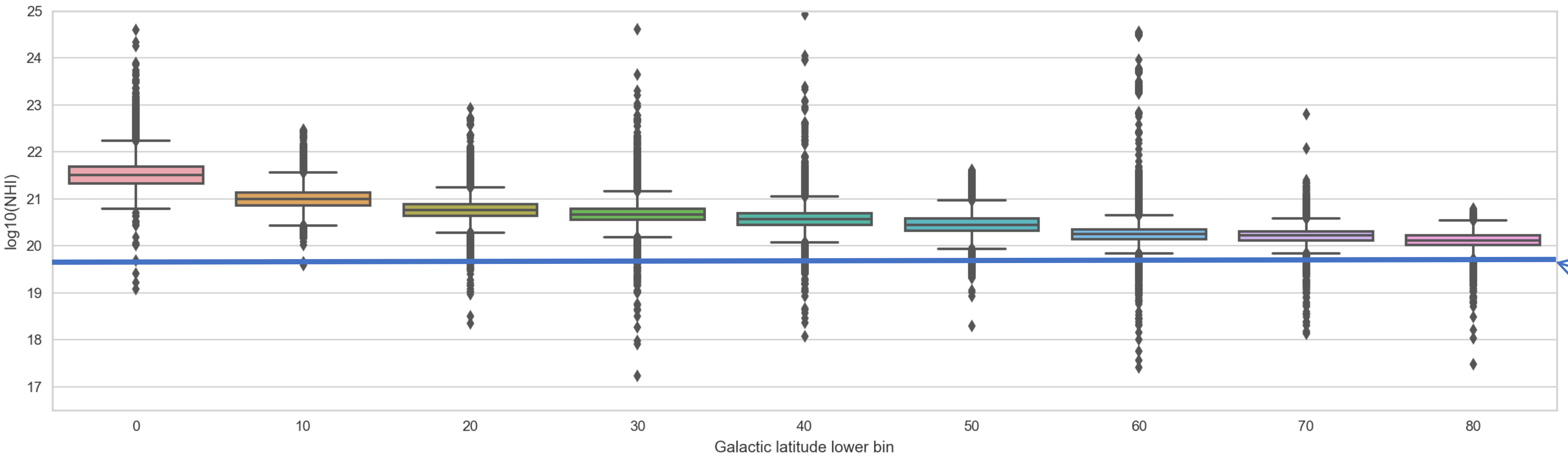


Studies of Magnetic Fields in the Diffuse ISM

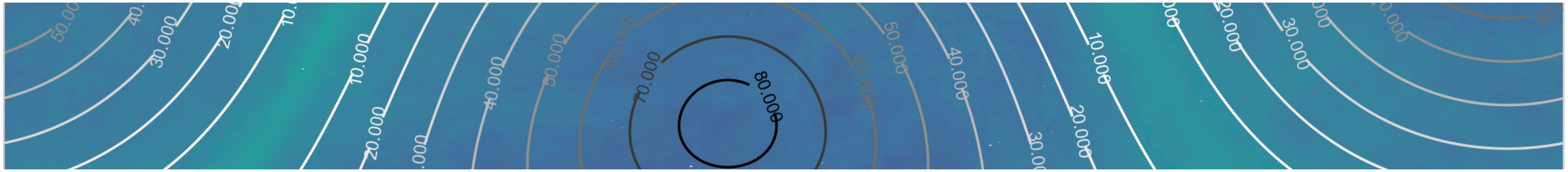
- Goal characterize the magnetic field strength and magnetized turbulence power spectrum for the diffuse ISM.
- Sensitivity Goal: Detect polarized emission from diffuse dust at all Galactic latitudes.
- Resolution Goal:
  - At least match the resolution of GALFA-HI survey (4’)
  - Want to resolve scales <0.1 pc for the nearest diffuse clouds (100pc). This corresponds to angular resolution FWHM < 3.4’

GALFA-HI Column Density Statistics

Susan Clark



Minimum Column Density Target
$N_H=5x10^{19}$ cm^{-2}



Top: box-and-whisker plots of NHI binned in 10 degrees in Galactic latitude (first bin is 0-10 deg, and so forth)
Bottom: all-sky column density image with latitude bin contours overlaid

Data are from GALFA-HI DR2, just accepted and soon-to-be-public.
Column density map is integrated over -90 to +90 km/s
Stray radiation corrected by comparison with LAB
FWHM=4’, sensitivity ~100 mK for a 1 km/s channel, velocity resolution 0.18 km/s

Polarized Dust Properties from Planck:

High-latitude dust typically higher polarization levels (green) than the all-sky dust emission (black)

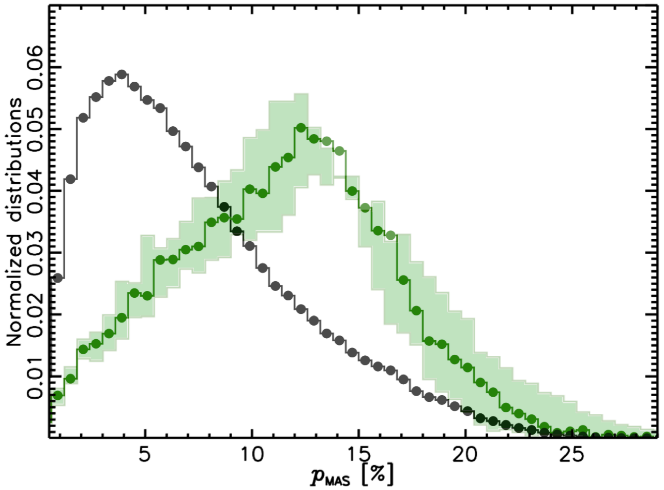


Fig. 3. Normalized distributions of the polarization fraction from the p_{MAS} debiased estimator (see text). The black distribution shows p_{MAS} over the whole sky. The green distribution shows p_{MAS} at $b < -60°$. The green-shaded area represents the 1σ error on p_{MAS} at high latitude.

Planck Int XLIV

Use Planck measurements of I/N_H to calculate target map depth levels

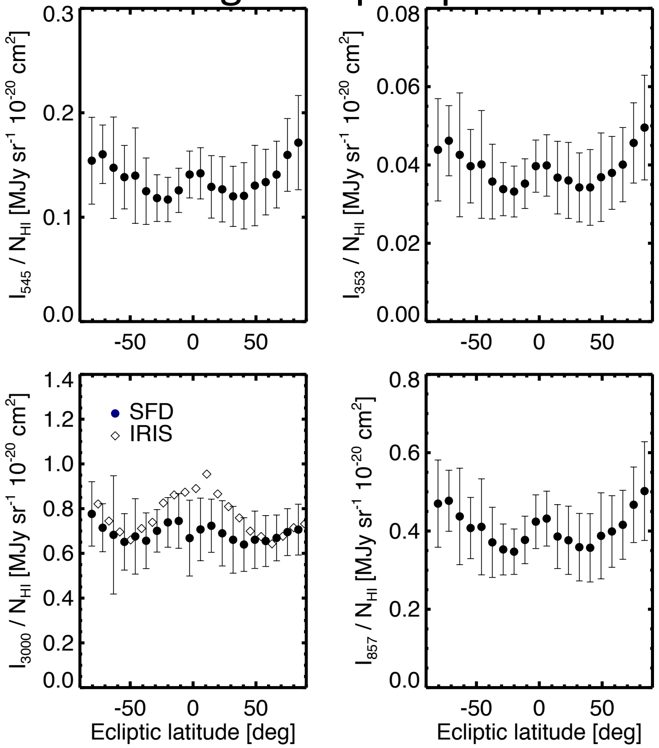


Fig. A.1. Dust emissivity $I_\nu/N_{\mathrm{H\,I}}$ as a function of ecliptic latitude for 3000 GHz (*lower left*), 857 GHz (*lower right*), 545 GHz (*upper left*) and 353 GHz (*upper right*). Each point gives the average and standard deviation (error bar) of all pixels in the corresponding bin in ecliptic latitude (IRIS error bars omitted for clarity). These plots were obtained using data smoothed to 1° and selecting pixels with $N_{\mathrm{H\,I}} < 3 \times 10^{20}$ cm^{-2}.

Planck Int XI

Use Planck diffuse dust model by Meisner & Finkbeiner (2015) to interpolate I to the EPIC/PICO frequency bands.

$$I_\nu \propto 8570 \left(\frac{\nu}{GHz}\right)^{1.63} B_\nu(9.75K) + 1.49 \left(\frac{\nu}{GHz}\right)^{2.82} B_\nu(15.7K)$$

Sensitivity Limits for high latitude (b>60 deg) for EPIC vs PICO small

How polarized would the dust emission need to be for a >3 sigma detection of $N_H = 5 \times 10^{19}$ cm^{-2}?

EPIC design, 30 K smoothed to 10 arcmin FWHM

Freq [GHz]	lamda [microns]	Resolution (arcmin)	sigma_I [MJy/Sr]	I_ref [MJy/Sr]	p_min 3-sigma
107	2803.7	10	0.00010	0.0004	118%
129	2325.6	10	0.00014	0.0007	74%
155	1935.5	10	0.00019	0.0014	46%
186	1612.9	10	0.00036	0.0026	39%
223	1345.3	10	0.00067	0.0048	32%
267	1123.6	10	0.00126	0.0089	27%
321	934.6	10	0.00212	0.0164	21%
385	779.2	10	0.00347	0.0299	15%
462	649.4	10	0.00531	0.0539	11%
555	540.5	10	0.00757	0.0958	7%
666	450.5	10	0.01282	0.1655	6%
799	375.5	10	0.02744	0.2757	7%

PICO small 4K, full resolution

f (GHz)	lamda [microns]	resolution [arcmin]	sigma_I MJy/sr	I_ref [MJy/Sr]	p_min 3-sigma
108	2777.8	24.9	0.00005	0.0004	68.3%
129	2325.6	25.6	0.00006	0.0007	46.0%
155	1935.5	21.3	0.00008	0.0014	33.3%
186	1612.9	12.8	0.00015	0.0026	34.0%
223	1345.3	10.7	0.00023	0.0048	29.1%
268	1119.4	10.0	0.00019	0.0090	12.4%
321	934.6	8.3	0.00026	0.0164	9.4%
385	779.2	8.6	0.00019	0.0299	3.8%
462	649.4	7.1	0.00022	0.0539	2.5%
555	540.5	4.3	0.00066	0.0958	4.1%
666	450.5	3.6	0.00064	0.1655	2.3%
799	375.5	3.0	0.00048	0.2757	1.0%

Diffuse ISM- polarization spectrum

Meisner & Finkbeiner (ApJ, 798,88, 2015) give the emission as

$$I_\nu \propto 8570\left(\frac{\nu}{GHz}\right)^{1.63} B_\nu(9.75K) + 1.49\left(\frac{\nu}{GHz}\right)^{2.82} B_\nu(15.7K)$$

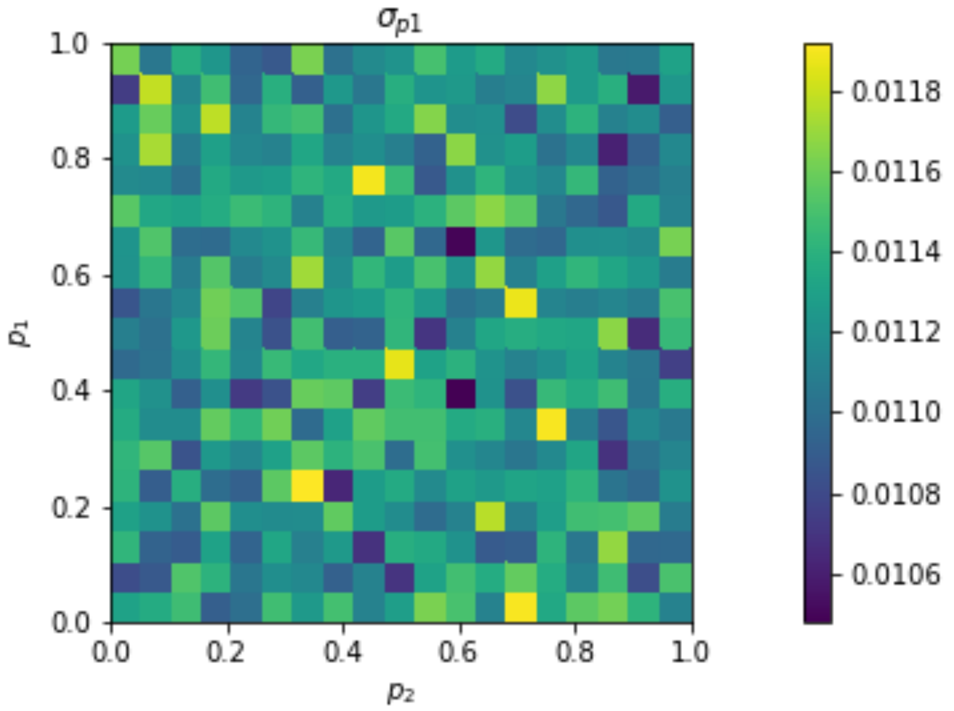
The polarization measured is presumably due to alignment in the cold (p1) and warm (p2) dust components

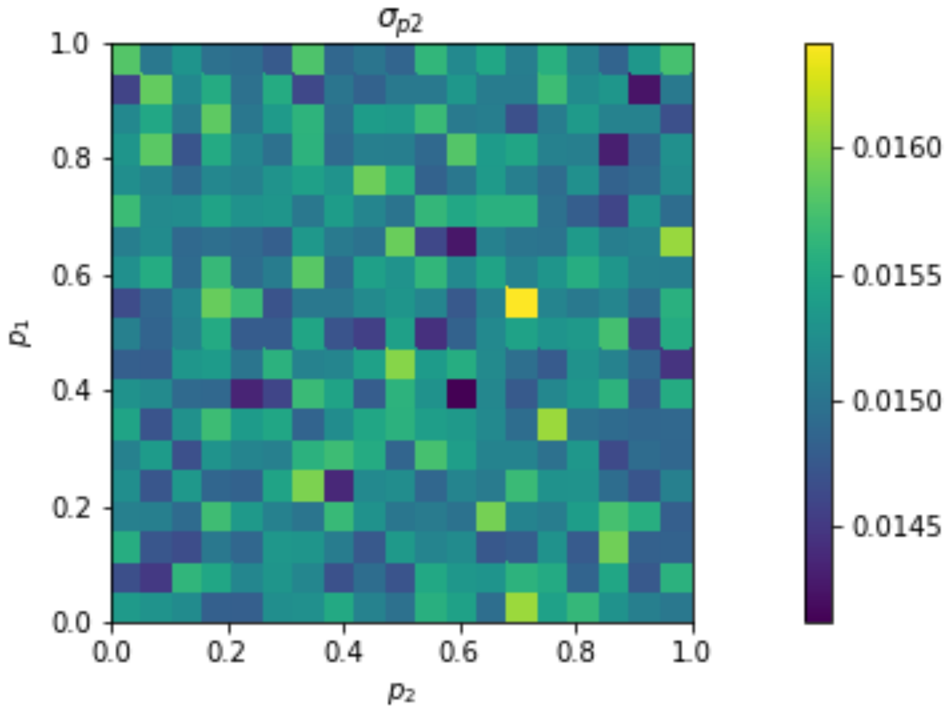
$$p = \frac{p_1 \times 8570\left(\frac{\nu}{GHz}\right)^{1.63} B_\nu(9.75K) + p_2 \times 1.49\left(\frac{\nu}{GHz}\right)^{2.82} B_\nu(15.7K)}{8570\left(\frac{\nu}{GHz}\right)^{1.63} B_\nu(9.75K) + 1.49\left(\frac{\nu}{GHz}\right)^{2.82} B_\nu(15.7K)}$$

The goal would be to determine p1 and p2 from measurements of the polarization spectrum.

Simulations

- Simulate an ensemble of observations given sensitivities in each band. Fit for p1, p2 in each case and report mean standard deviations for each parameter. Take as target 0.5 MJy/sr diffuse flux.





Each point is simulated 1000 times and the standard deviation is plotted.

0.5 MJy sr Intensity- sensitivity over an area 3 arcmin wide

	30 K mission, all channels	30 K mission, no 799 GHz	4 K mission, all channels	4 K mission, no 799 GHz
Sigma_p1	0.23	0.25	0.0075	0.011
Sigma_p2	0.4	0.5	0.0075	0.015

EPIC vs. PICO Small Trade offs: Diffuse ISM Studies

	Nearby Clouds Studies
Sensitivity	EPIC design would require smoothing to reach required sensitivity limits for b> 60 deg dust.
Resolution	EPIC would have better resolution for molecular cloud observations, but would require smoothing to 10 arcmins for highest latitude dust. PICO would be able to use full resolution over almost all the sky.