FRONTIER
GALACTIC
SURVEY
OPPORTUNITIES

Carl Heiles, U. C. Berkeley

FAST published telescope capabilities:

- > 19 feed multibeam. 1.05-1.45 GHz
- > ZA coverage to 40 degrees
- > HA coverage to +/- 3 hr
- > Continuous frequency coverage 70 MHz to 3 GHz
- > Multiple backends for commensal observing

WHAT THE ISM NEEDS FROM FAST:

1. Repeat the GALFA 21-cm emission line survey, INCLUDING all four OH lines.

2. Repeat the Millennium 21-cm absorption/emission line survey, covering all sources with S ~> 1 Jy.

3. Survey the linear polarization of the Diffuse Galactic Synchrotron radiation from ~100 MHz to ~1500 MHz and perform Faraday synthesis.

GALFA SURVEY

Repeat the Arecibo GALFA survey, which covered the whole 13000 sq deg Arecibo sky with 3.4 arcmin resolutionl.

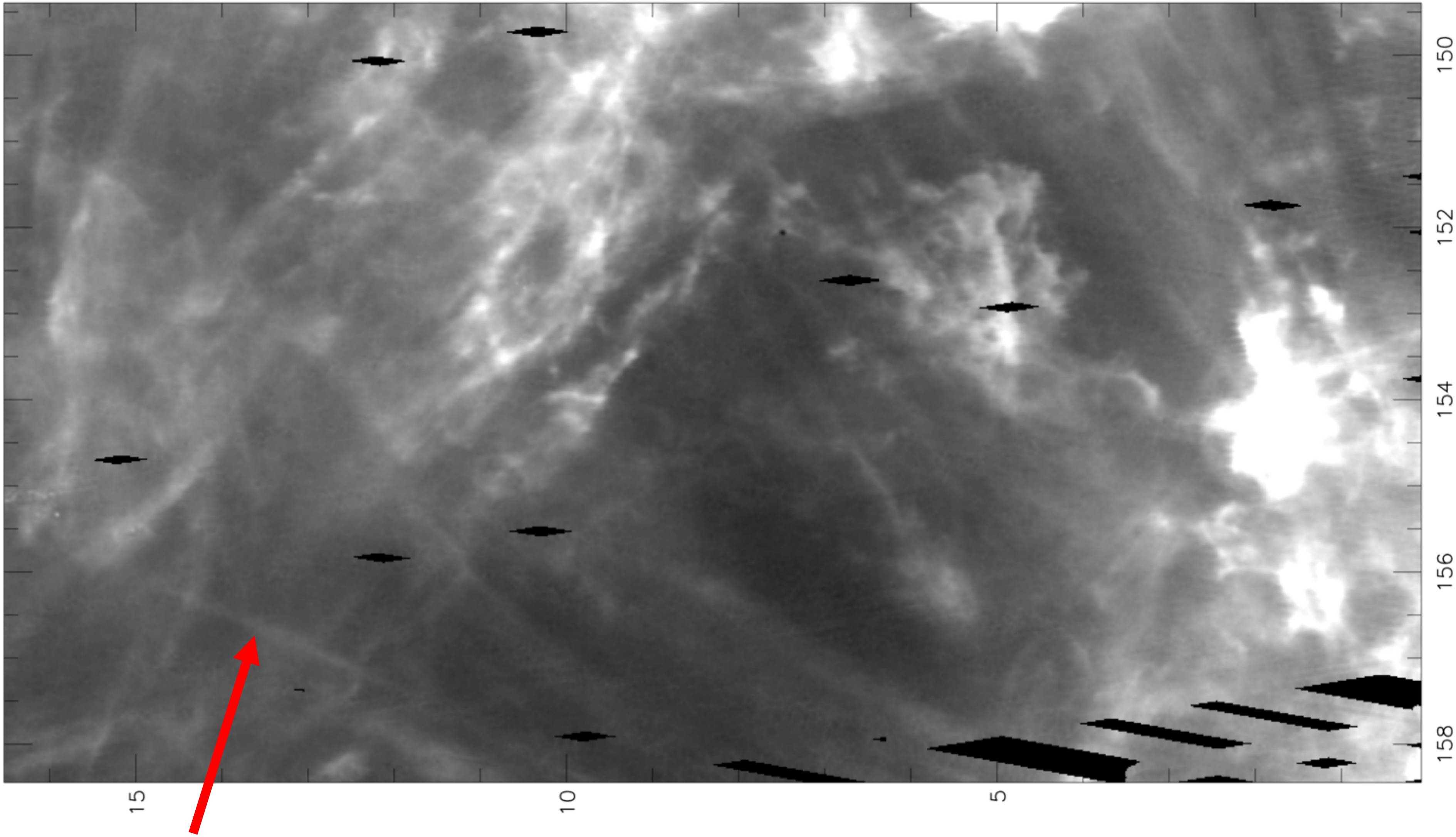
(The Astronomical public has downloaded > 1227 standard GALFA data cubes (8 by 8 deg)). GALFA are unique because:

They have the sensitivity of a single dish

They have the angular resolution of interferometric surveys.

And this probe into new parameter space has discovered NEW STUFF!

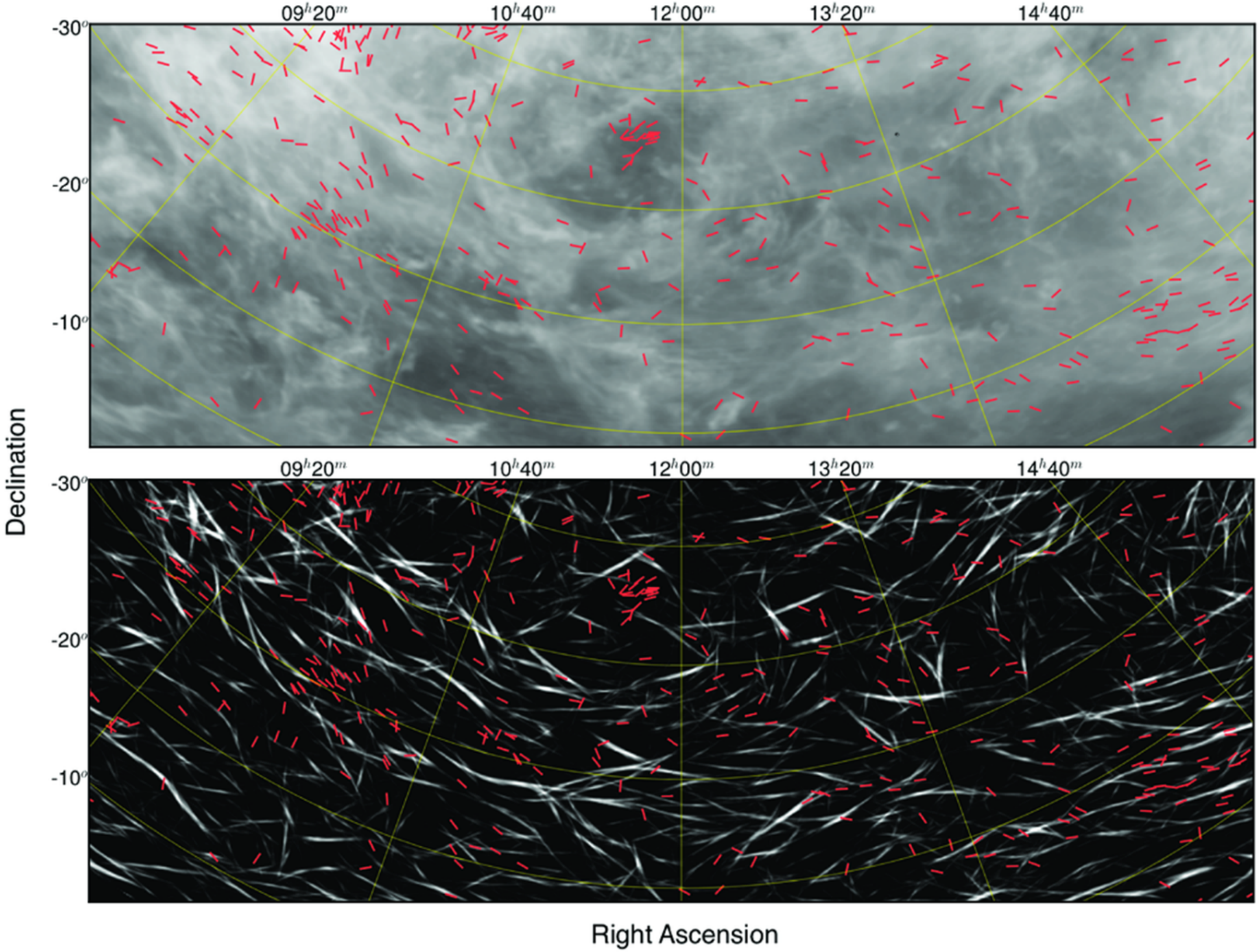
GALFA finds long, straight HI FILAMENTS!



MAGNETIZED HI FIBERS AND THE ROLLING HOUGH TRANSFORM

Clark, S.E.[1,], Peek, J.E.G.[1,2], and Putman, M.E.[1]

Draft version November 26, 2013



The HI Fibers are aligned with the Interstellar Magnetic Field as Revealed by the Polarization of Starlight by Aligned Dust!

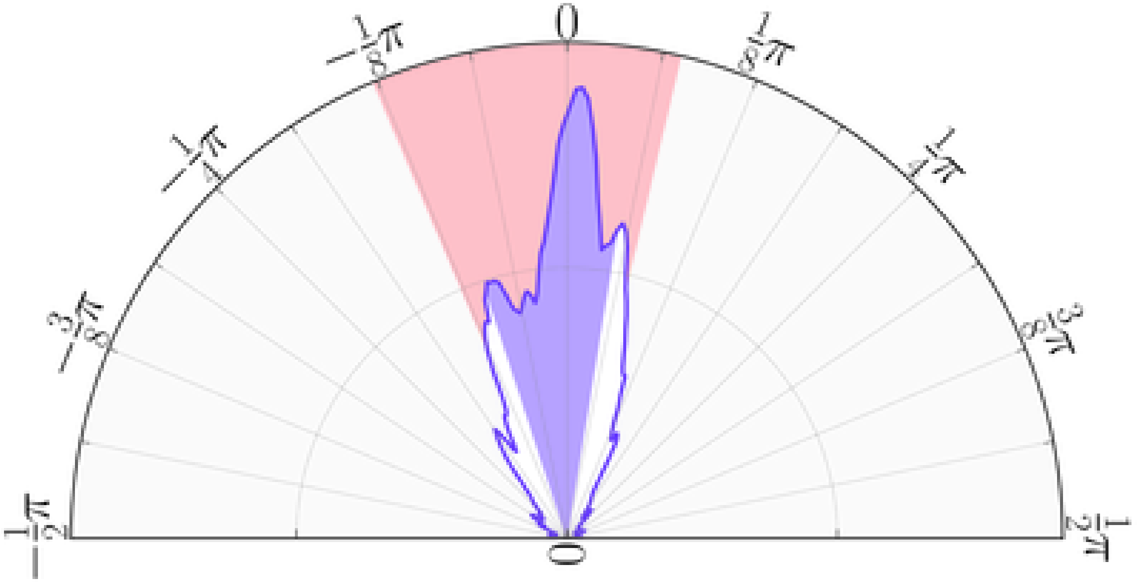
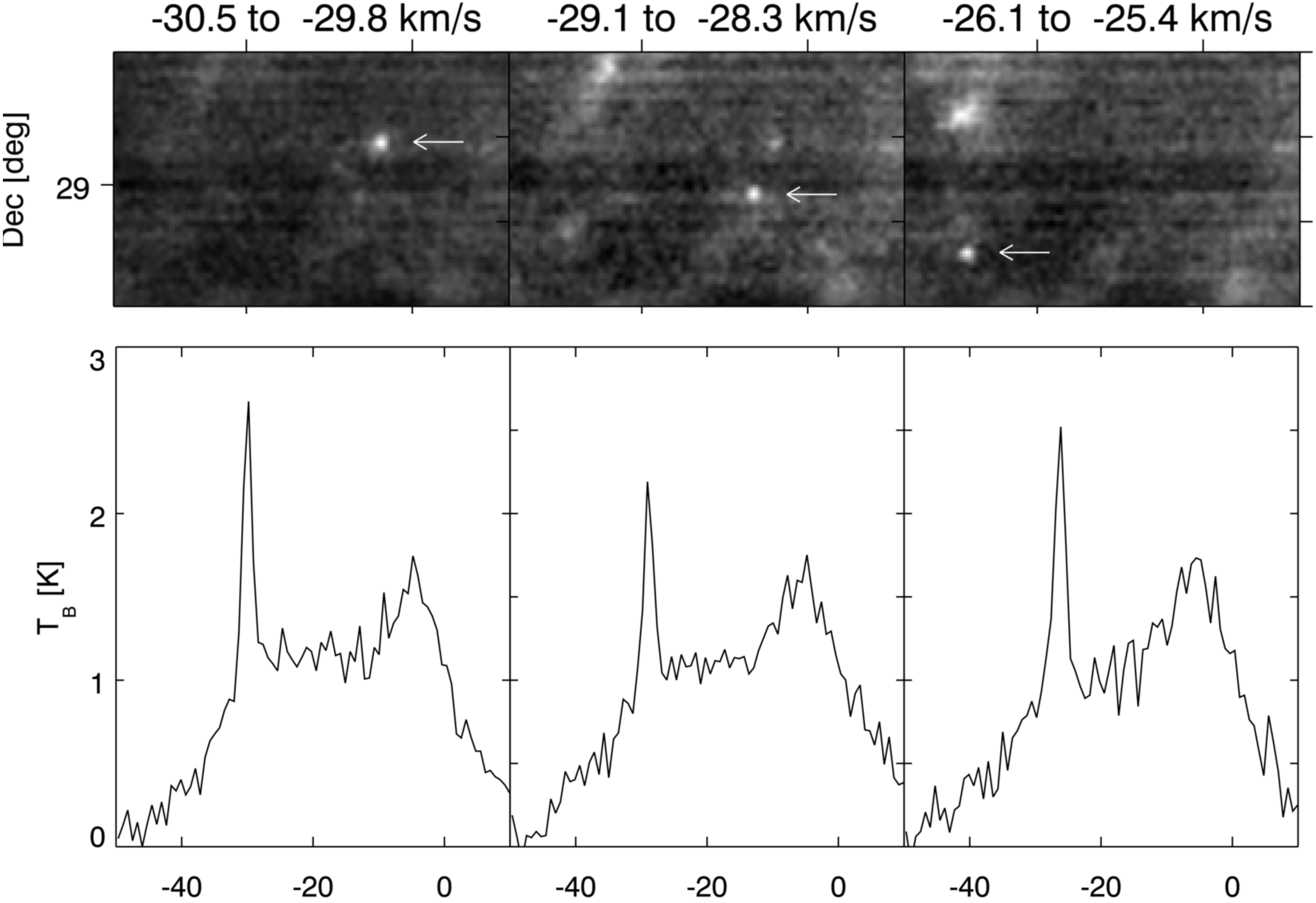
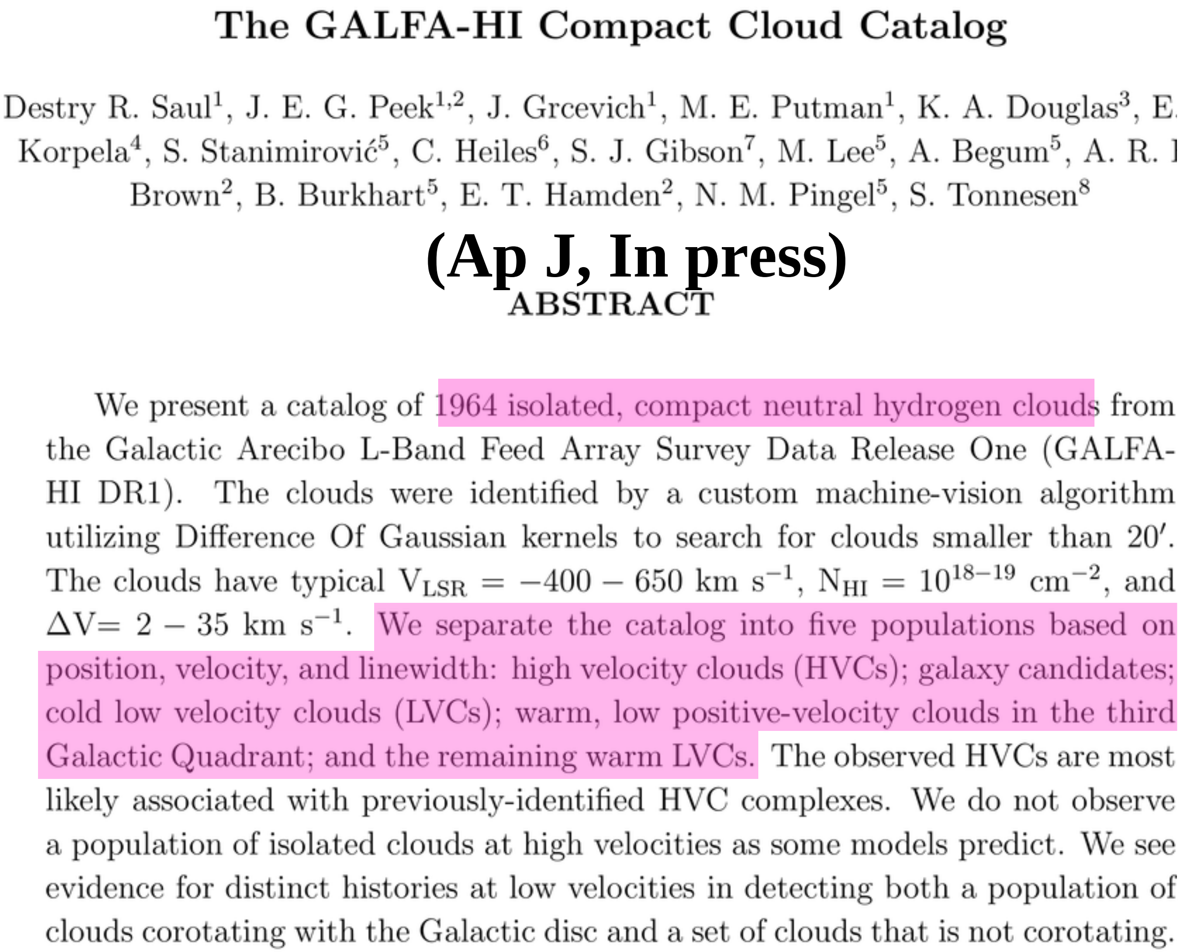


FIG. 3.— Integrated RHT output $R_\star(\theta)$ (see §3) for all stars in the GALFA-HI field (purple line). Normalization is arbitrary. The velocity range is -7.0 km s^{-1} to -1.1 km s^{-1}. RHT was run with $D_W = 100'$, $D_K = 10'$, and Z = 70%. The RHT output is sampled in regions of radius 0.5° around each star. IQR($R_\star(\theta)$) is 27° (purple shading). IQR($\langle\theta_{RHT}\rangle$) is 37° (red shading).

GALFA FINDS HI BLOBS





The GALFA-HI Compact Cloud Catalog

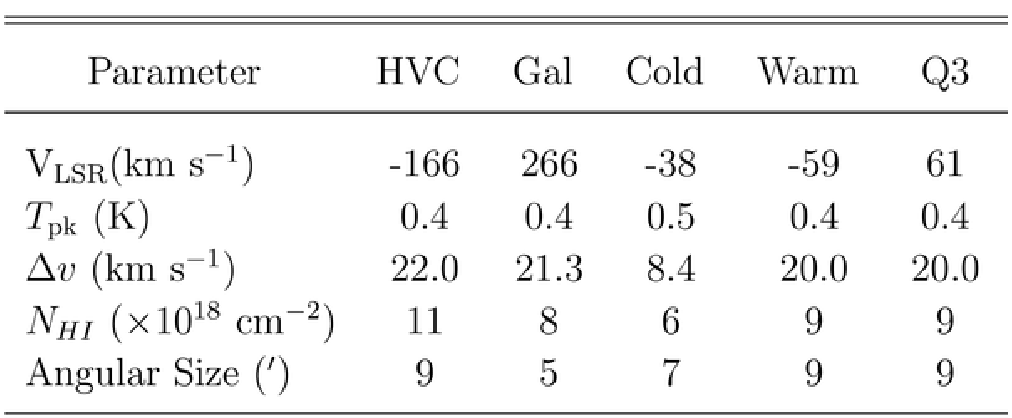
Destry R. Saul[1], J. E. G. Peek[1,2], J. Grcevich[1], M. E. Putman[1], K. A. Douglas[3], E.
Korpela[4], S. Stanimirović[5], C. Heiles[6], S. J. Gibson[7], M. Lee[5], A. Begum[5], A. R.
Brown[2], B. Burkhart[5], E. T. Hamden[2], N. M. Pingel[5], S. Tonnesen[8]

(Ap J, In press)

ABSTRACT

We present a catalog of 1964 isolated, compact neutral hydrogen clouds from the Galactic Arecibo L-Band Feed Array Survey Data Release One (GALFA-HI DR1). The clouds were identified by a custom machine-vision algorithm utilizing Difference Of Gaussian kernels to search for clouds smaller than $20'$. The clouds have typical $V_{LSR} = -400 - 650$ km s^{-1}, $N_{HI} = 10^{18-19}$ cm^{-2}, and $\Delta V = 2 - 35$ km s^{-1}. We separate the catalog into five populations based on position, velocity, and linewidth: high velocity clouds (HVCs); galaxy candidates; cold low velocity clouds (LVCs); warm, low positive-velocity clouds in the third Galactic Quadrant; and the remaining warm LVCs. The observed HVCs are most likely associated with previously-identified HVC complexes. We do not observe a population of isolated clouds at high velocities as some models predict. We see evidence for distinct histories at low velocities in detecting both a population of clouds corotating with the Galactic disc and a set of clouds that is not corotating.

Table 2. Median Properties of Cloud



Parameter	HVC	Gal	Cold	Warm	Q3
V_{LSR}(km s^{-1})	-166	266	-38	-59	61
T_{pk} (K)	0.4	0.4	0.5	0.4	0.4
Δv (km s^{-1})	22.0	21.3	8.4	20.0	20.0
N_{HI} ($\times 10^{18}$ cm^{-2})	11	8	6	9	9
Angular Size ($'$)	9	5	7	9	9

Both small and weak!

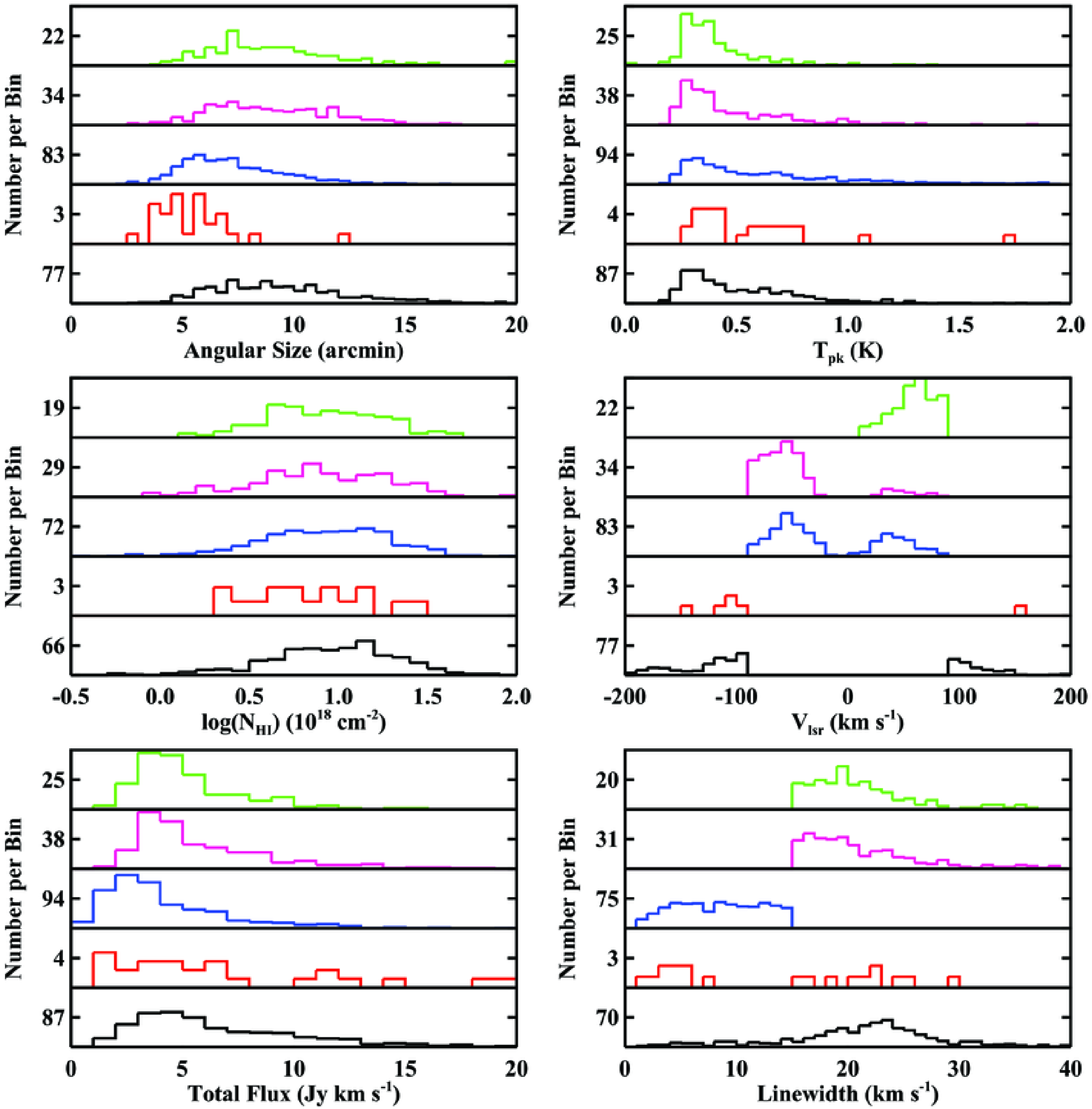
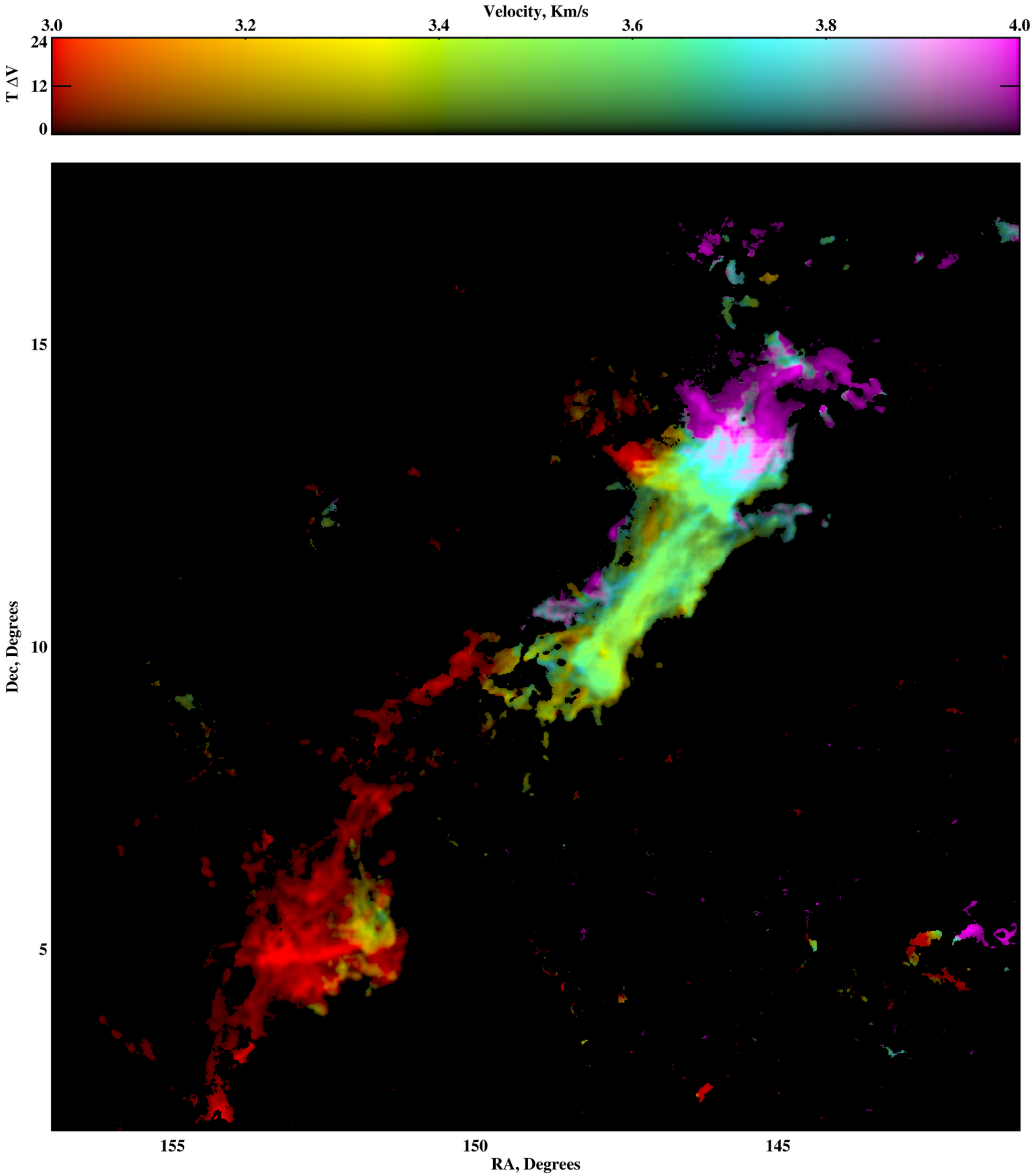


Figure 9. Distributions of angular size, peak brightness temperatures ($T_{\rm pk}$), column density, LSR velocity, total flux, and line width for all cataloged clouds, separated by population—HVCs (black, lower pane), galaxy candidate (red, second pane), cold LVCs (blue, center pane), warm LVCs (pink, fourth pane), and warm Q3 LVCs (green, upper pane). To aid in comparing the different populations, each histogram is scaled so that the fractional number of clouds per bin is consistent for each plot. The y-axis values are the mid-values for each histogram in number of clouds.

(A color version of this figure is available in the online journal.)

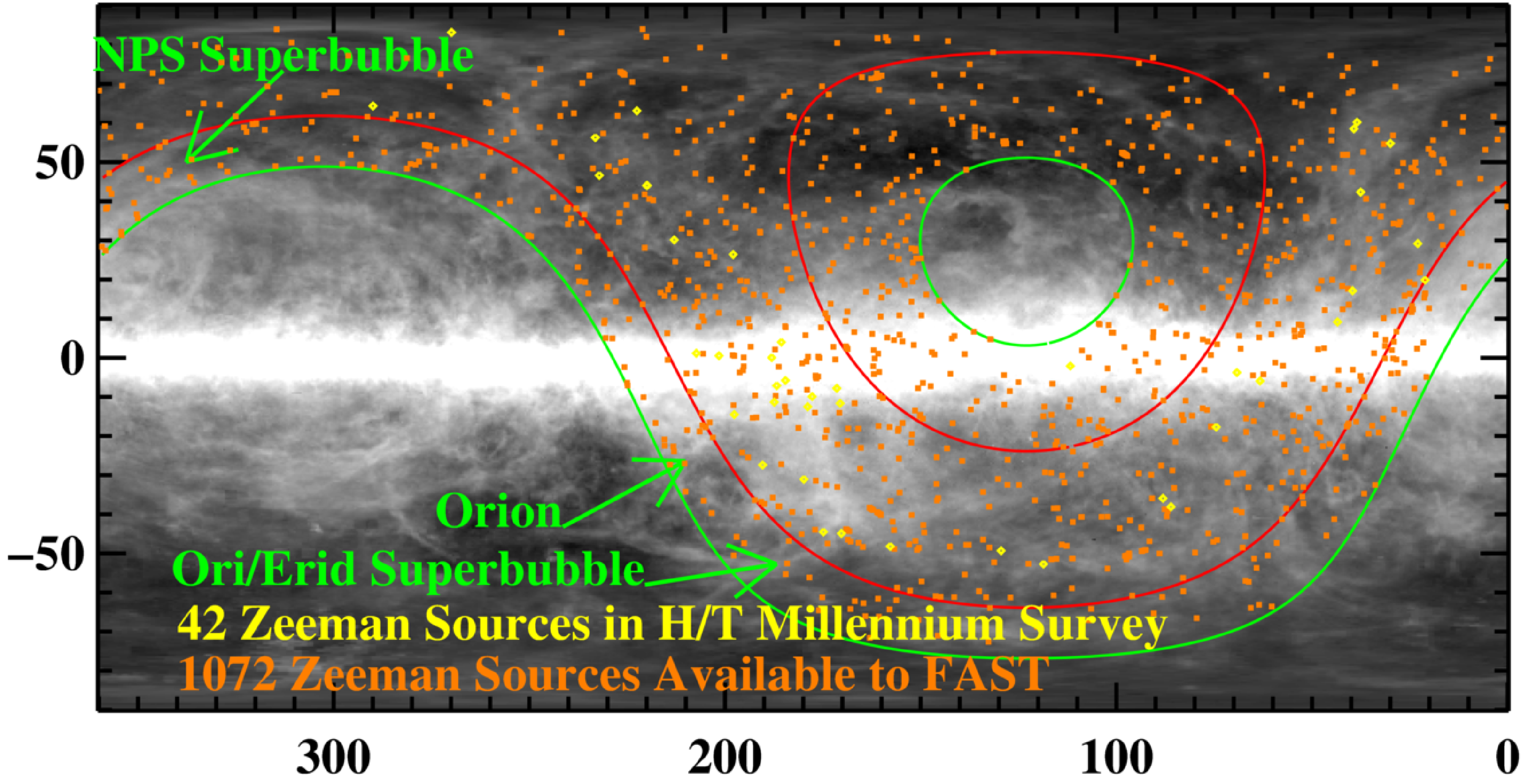
Arecibo (GALFA) map of the Knapp ultrathin sheet (aka the 'Local Leo Cold Cloud', or LLCC.



Basic properties of the LLCC:

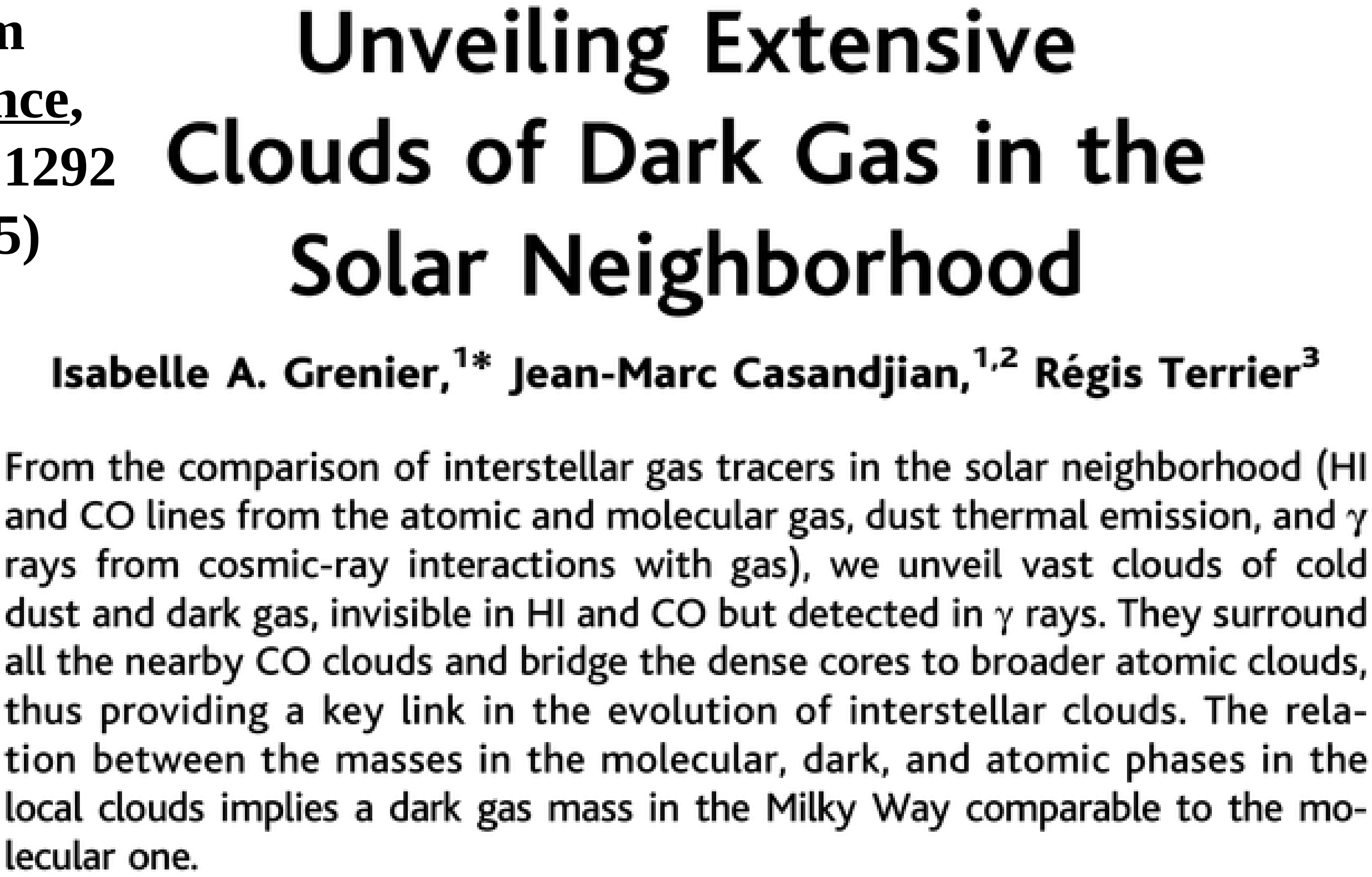
1. **Distance between 8 and 20 pc**
2. **Temperature ~ 18 K**
3. **Pressure ~ 60000 cm^{-3} K (Meyer et al 2012)**
4. **Overpressured by > 10 wrt local ISM WIM clouds (Redfield/Linsky)**
5. **Paper-thin. Aspect ratio ~ 1000:1**
6. **Most emission profiles are double-peaked and indicate (but not infallibly) two components approaching at ~ 0.7 km/s**

HI and OH emission/absorption against continuum sources is very important in telling us physical conditions in the diffuse ISM. The Heiles/Troland Arecibo Millennium Survey is an important example---but we need a much bigger sample to firm up our conclusions! For example, in our Millennium survey, the number of actual Zeeman-splitting detections is…pitifully small.


NPS Superbubble
Orion
Ori/Erid Superbubble
42 Zeeman Sources in H/T Millennium Survey
1072 Zeeman Sources Available to FAST
50
0
−50
300
200
100
0

Illuminating “Dark Gas” (Translucent gas) with OH…

From Science, 307, 1292 (2005)



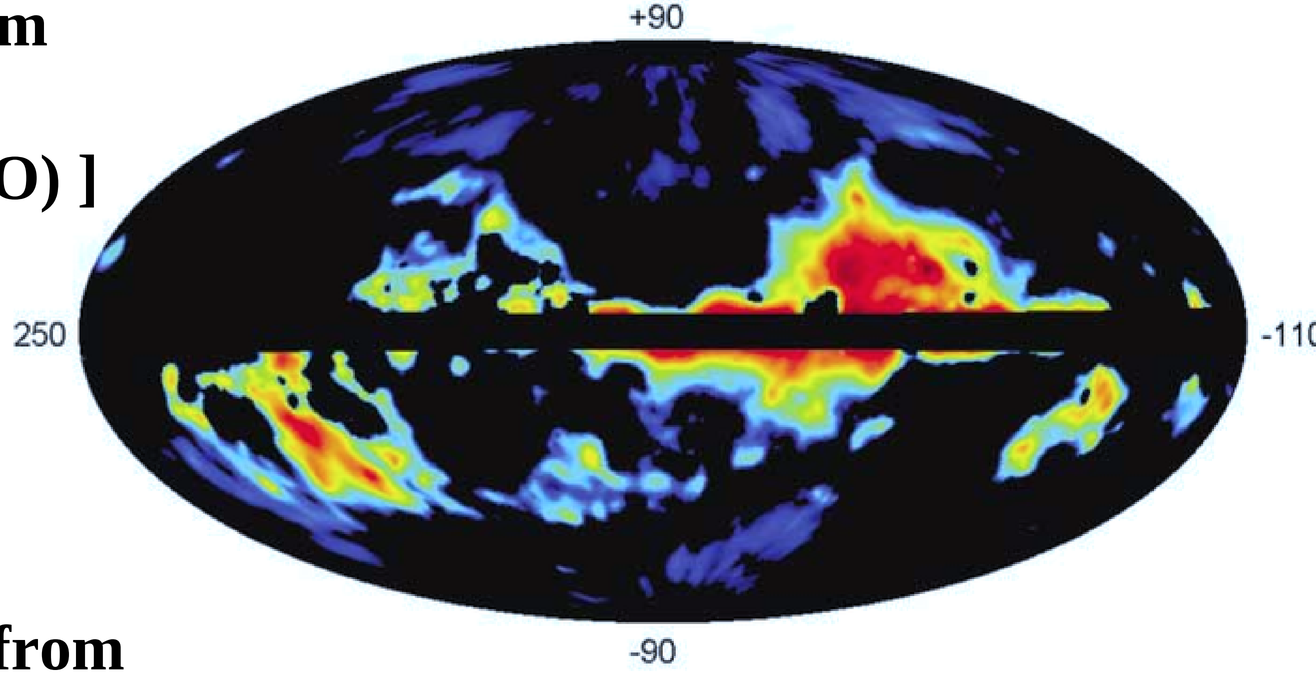
Unveiling Extensive Clouds of Dark Gas in the Solar Neighborhood

Isabelle A. Grenier,[1*] Jean-Marc Casandjian,[1,2] Régis Terrier[3]

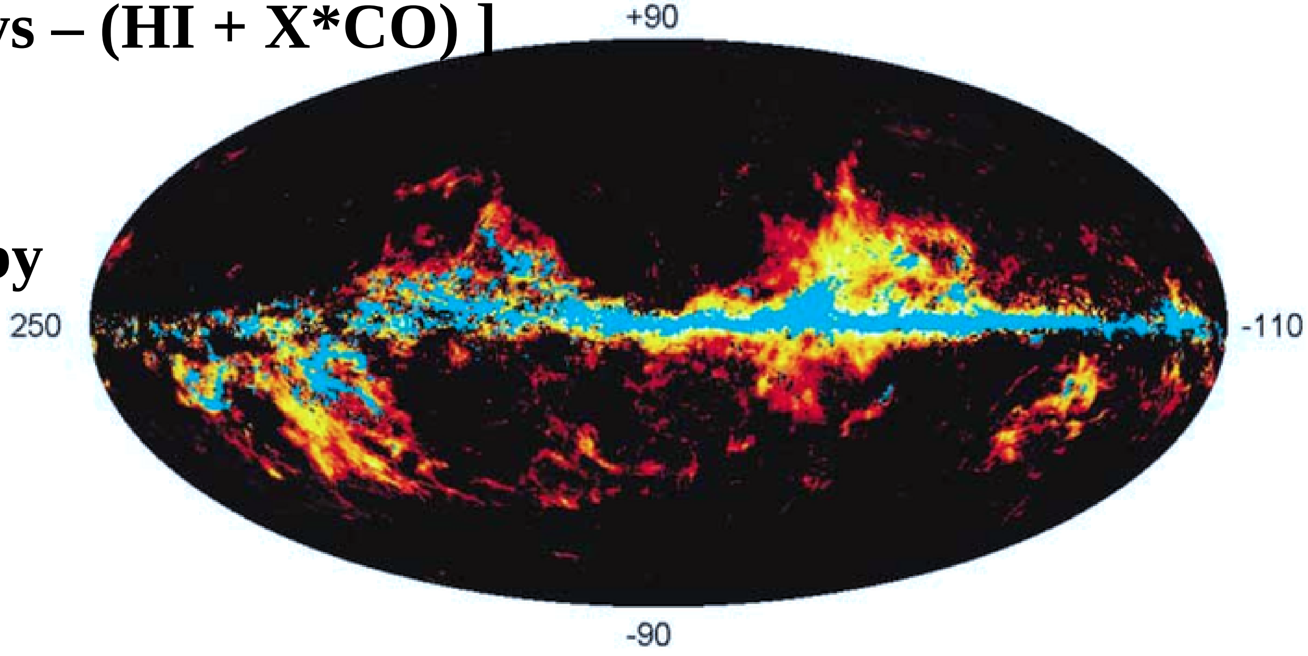
From the comparison of interstellar gas tracers in the solar neighborhood (HI and CO lines from the atomic and molecular gas, dust thermal emission, and γ rays from cosmic-ray interactions with gas), we unveil vast clouds of cold dust and dark gas, invisible in HI and CO but detected in γ rays. They surround all the nearby CO clouds and bridge the dense cores to broader atomic clouds, thus providing a key link in the evolution of interstellar clouds. The relation between the masses in the molecular, dark, and atomic phases in the local clouds implies a dark gas mass in the Milky Way comparable to the molecular one.

The mass of Dark Gas is comparable to that of H_2 as revealed by CO! In the Solar vicinity, HI and H_2 have comparable mass, so Dark Gas increases the total gas mass by 50%!

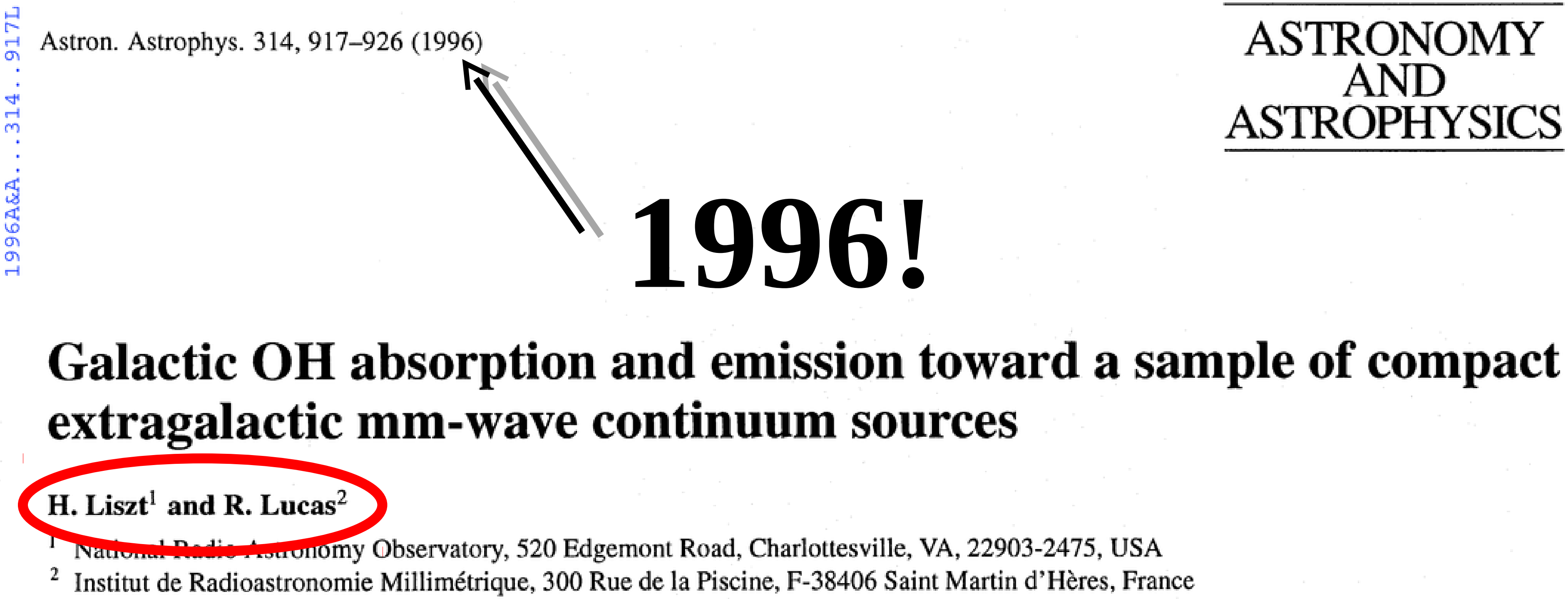
Top is Dark Gas from IRAS:
[IRAS – (HI + X*CO)]



Bottom is Dark Gas from
[EGRET gamma rays – (HI + X*CO)]



(Recall that gamma rays are produced by [CR/H-nuclei] interaction)



1996A&A...314..917L

Astron. Astrophys. 314, 917–926 (1996)

ASTRONOMY
AND
ASTROPHYSICS

1996!

Galactic OH absorption and emission toward a sample of compact extragalactic mm-wave continuum sources

H. Liszt[1] and R. Lucas[2]

[1] National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA, 22903-2475, USA
[2] Institut de Radioastronomie Millimétrique, 300 Rue de la Piscine, F-38406 Saint Martin d'Hères, France

This classic, but underappreciated, work pioneered the way towards Dark Gas.

1996A&A...314..917L

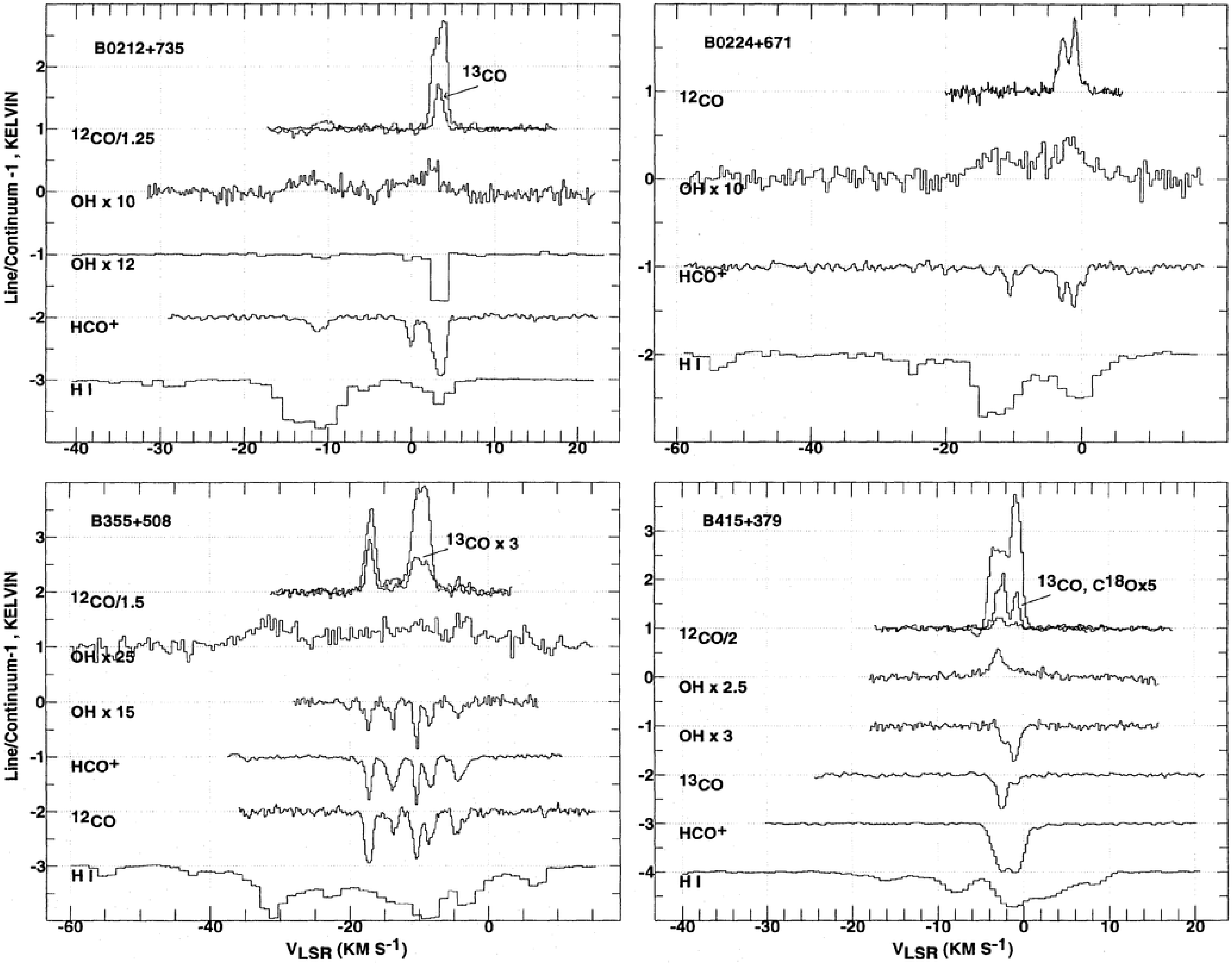


Fig. 2. H I, HCO$^+$, OH, and CO absorption and emission profiles toward and around four compact extragalactic mm-wave continuum sources. The OH emission spectra are averaged over four positions 20′ displaced from the continuum (see Sect. 2a for a description of the observing). Note the components of OH emission which are matched in H I but not in the other profiles.

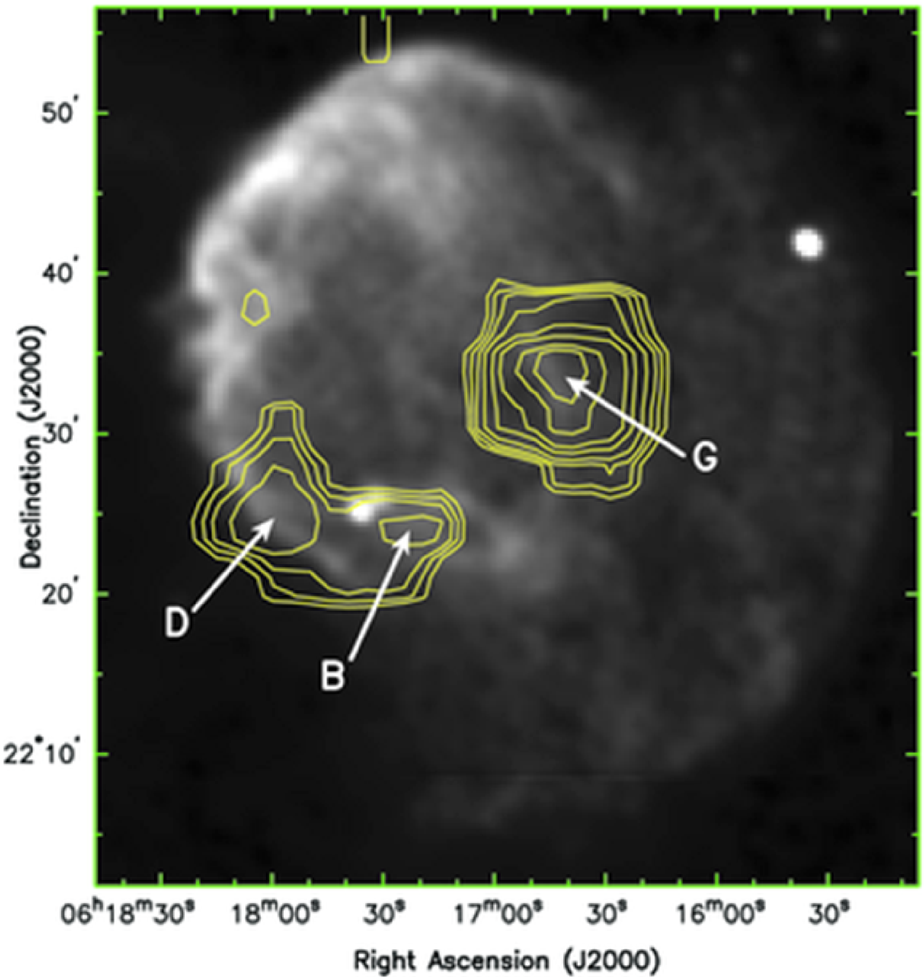
Dark Gas studies continue “apace”.
In 2012, work by

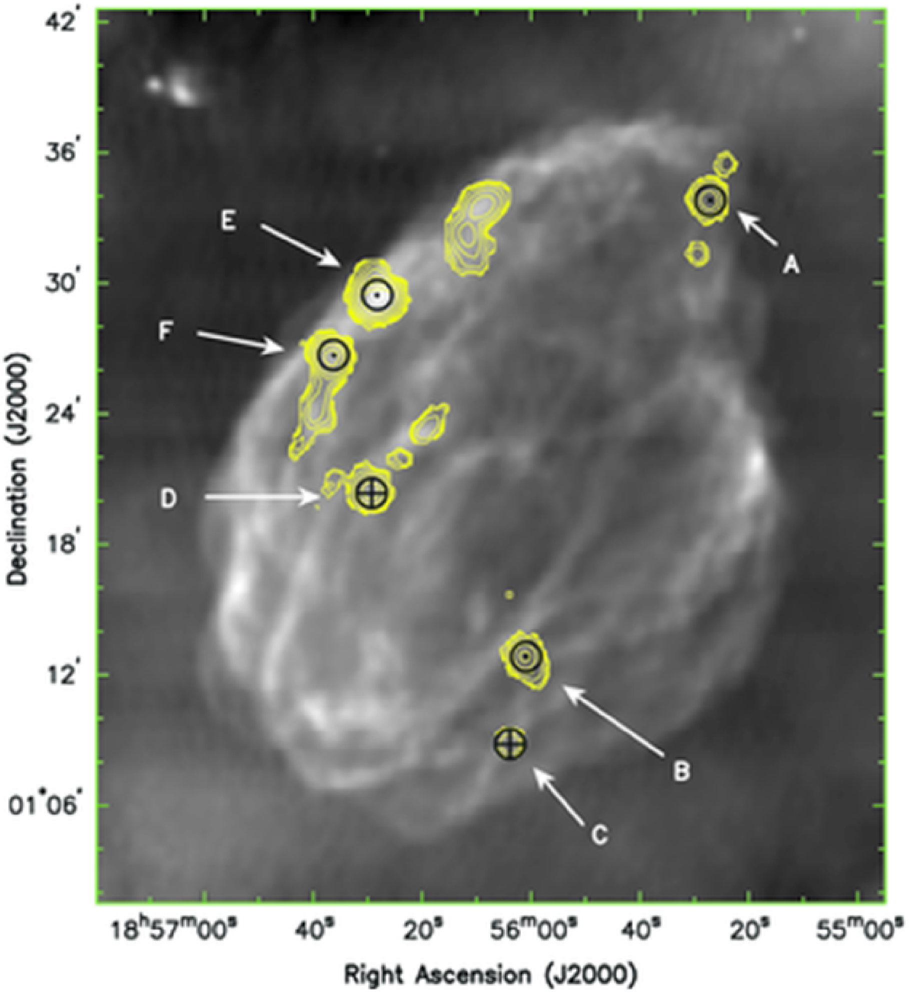
- **> Cotton, Magnani et al (2012)**
- **> Allen (2012)**

shows that the Dark Gas is
<u>ubiquitous!</u>

Extended OH(1720 MHz) maser emission from supernova remnants

J. W. Hewitt[1], F. Yusef-Zadeh[1], M. Wardle[2] and D. A. Roberts[1]





FARADAY ROTATION

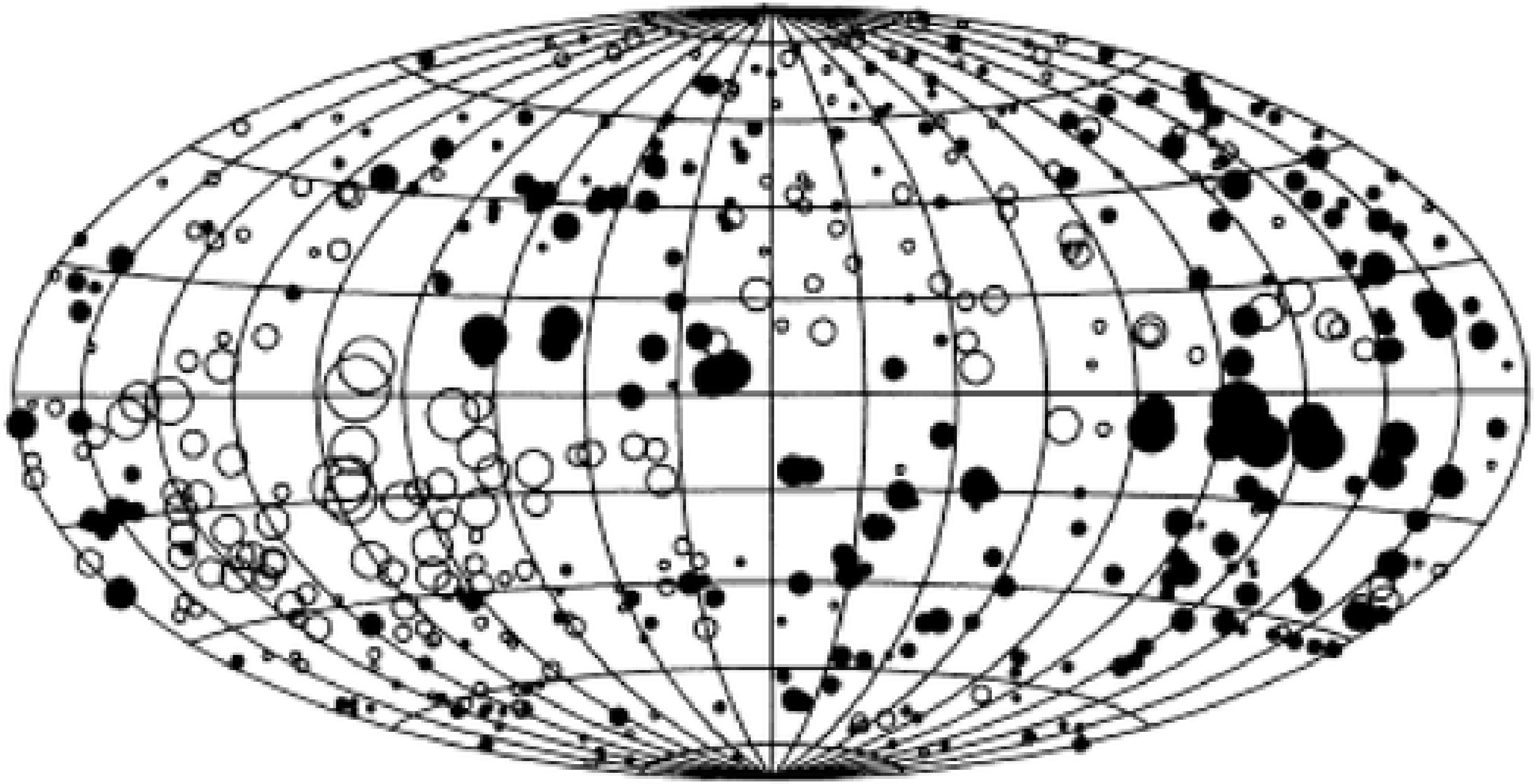
The Faraday Rotation Measure (RM) is

$$\mathrm{RM} = 0.81 \int n_e B_{los}\, ds \quad \mathrm{rad\ m^{-2}}$$

It is the easiest magnetic field tracer to measure---by far.

First, let's consider the Galactic Faraday Rotation of EXTRAGALACTIC SOURCES (usually, Galactic RMs dominate those that are intrinsic to the source itself).

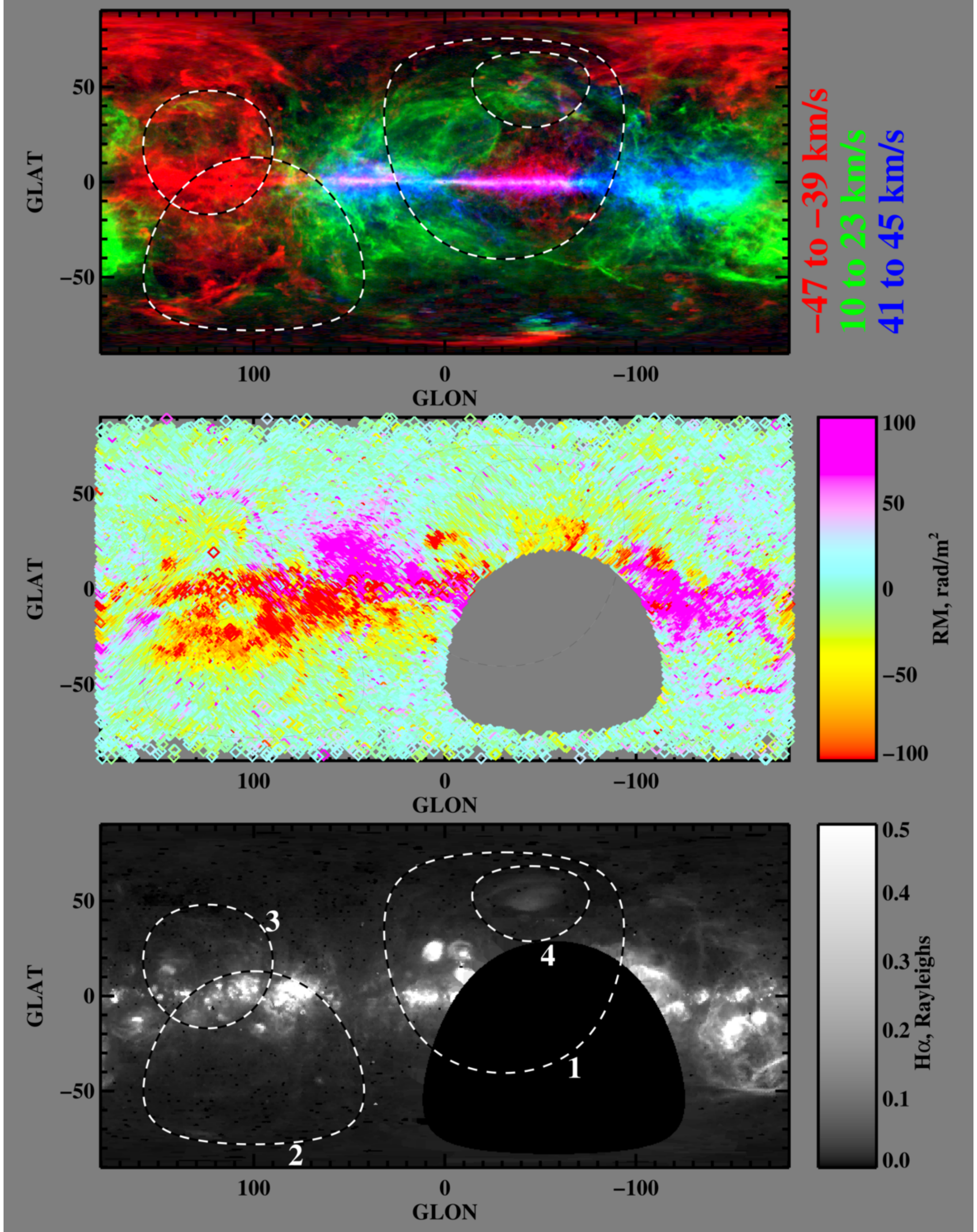
Taylor, Stil, Sumsrum (2009) derived 'best guess' RMs for all 37,543 NVSS sources. Most of these RMs are correct. They allow a detailed mapping of RM on the sky. This is a MAJOR ADVANCE. To understand this, we first look at the RM distribution given by Oren & Wolfe (1995)—for 499 sources…

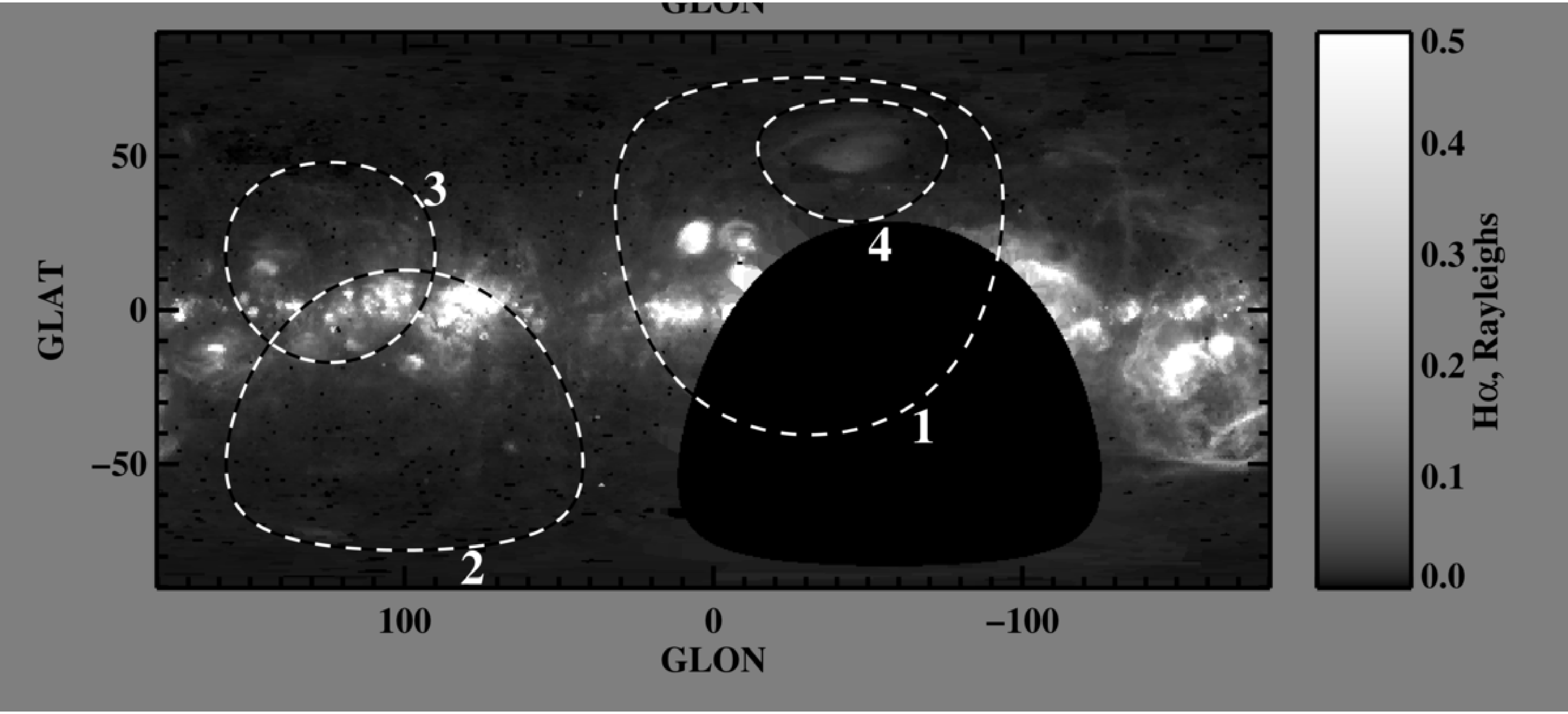


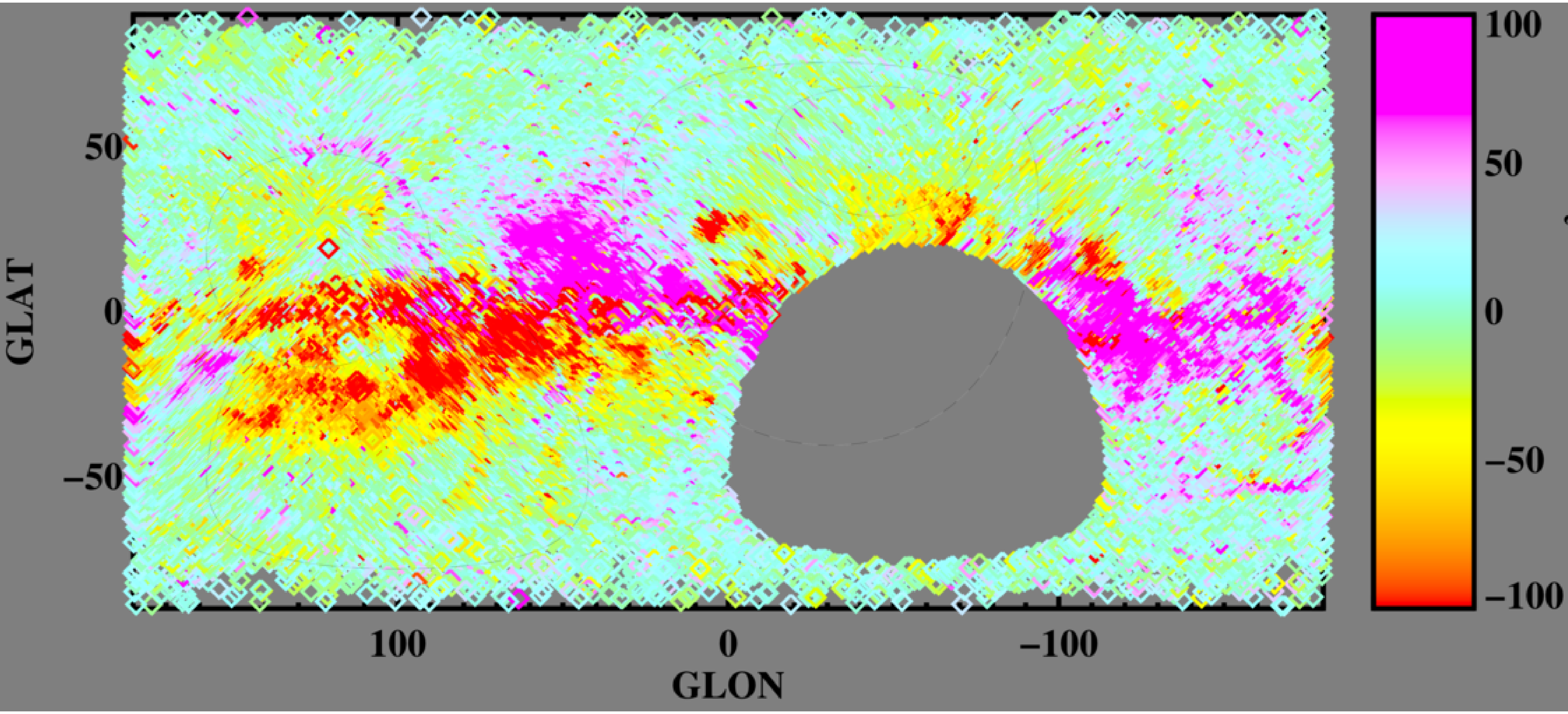
HI: 21-cm line (LAB)

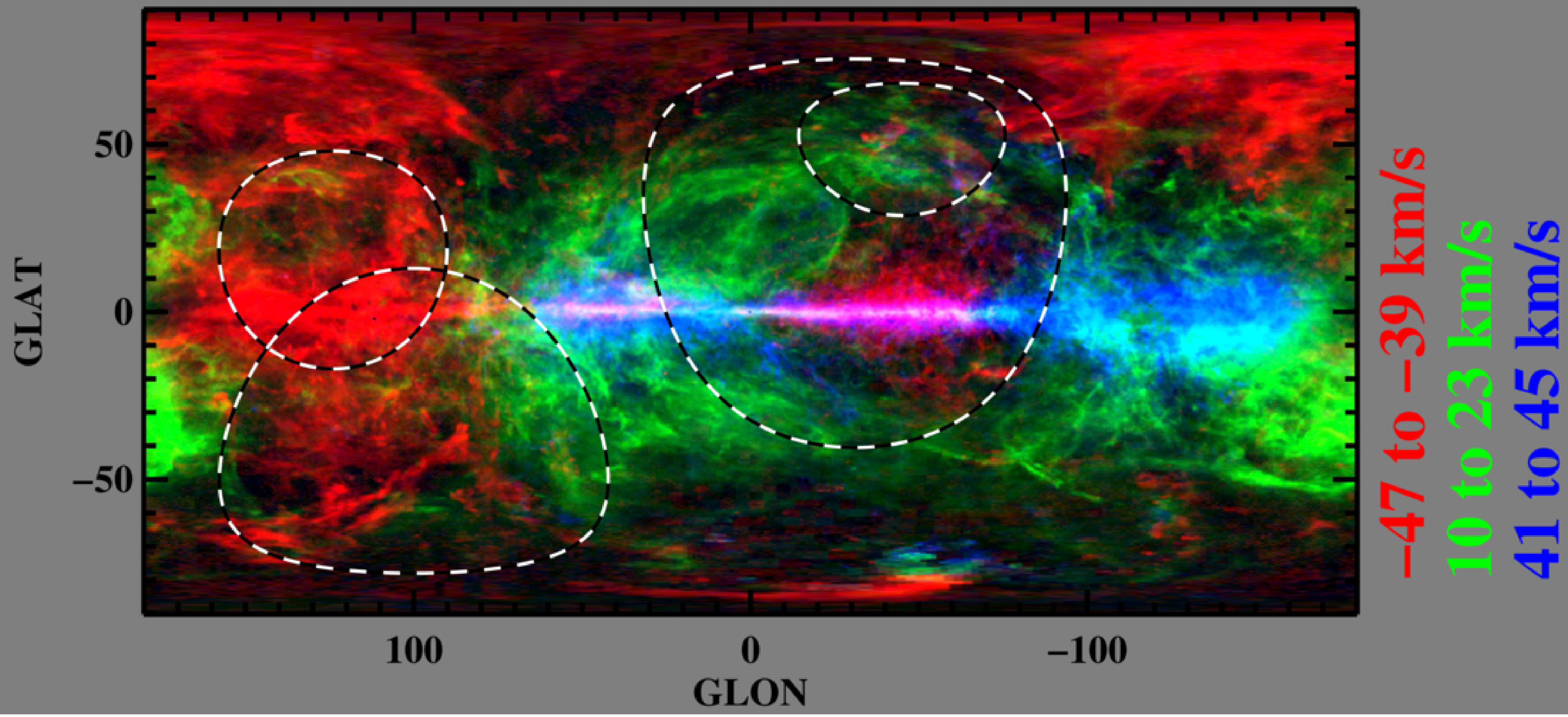
Faraday RMs **(Taylor, Stil, Sumsrum 2009)**

H+: H-alpha line (WHAM)




GLON
50
0
−50
GLAT
100
0
−100
GLON
1
2
3
4
0.5
0.4
0.3
0.2
0.1
0.0
Hα, Rayleighs


GLAT
50
0
−50
100
0
−100
GLON
100
50
0
−50
−100
RM, rad/m^2


50
0
−50
GLAT
100
0
−100
GLON
−47 to −39 km/s
10 to 23 km/s
41 to 45 km/s

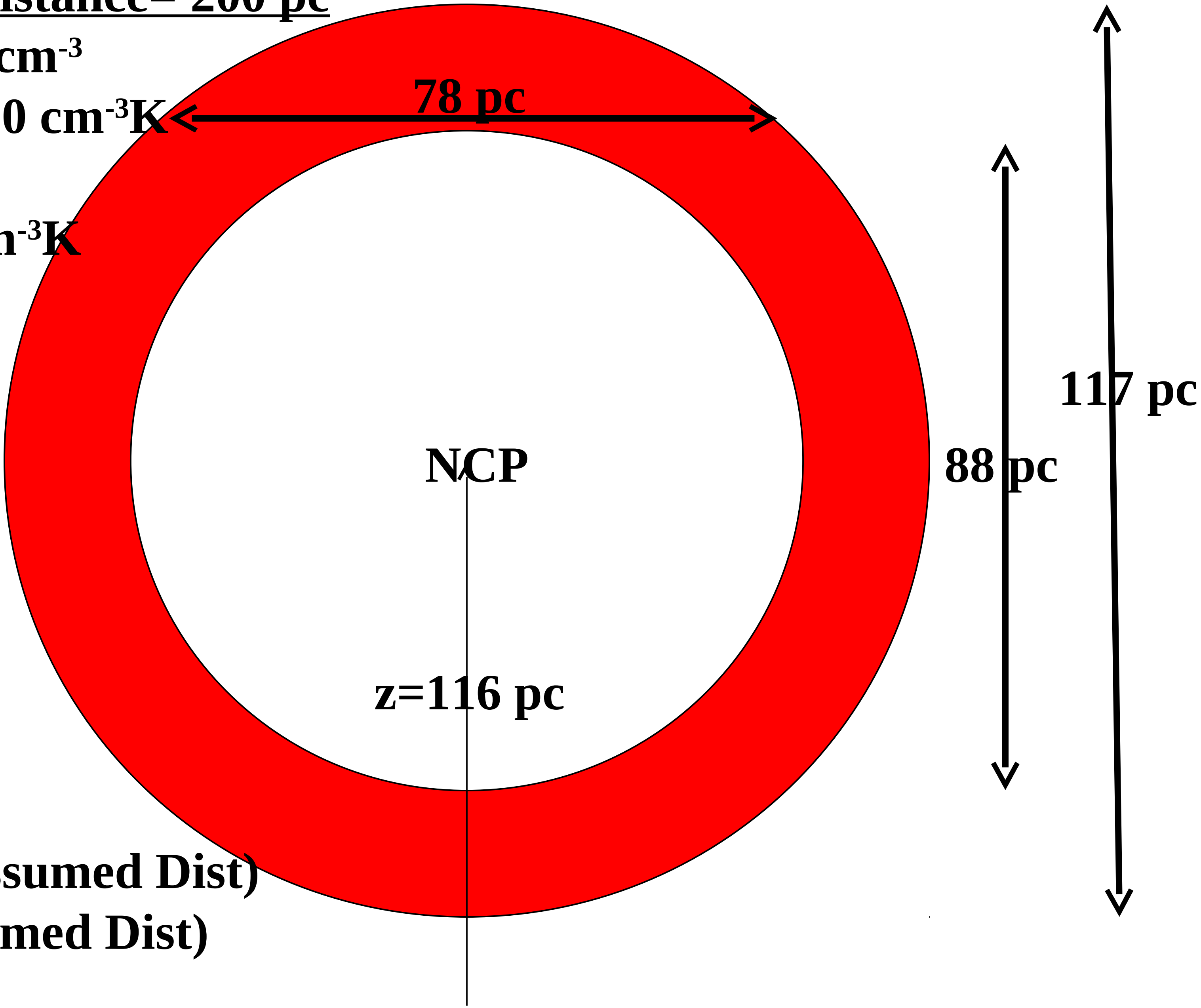
Assumed Distance= 200 pc

$n(e) = 0.10\ cm^{-3}$

$2n(e)T=1650\ cm^{-3}K$

$B=7.6\ \mu G$

$P=16400\ cm^{-3}K$



$n(e) \sim (1/\text{Assumed Dist})$

$B \sim (1/\text{Assumed Dist})$

Now, let’s consider the Diffuse Galactic Synchrotron Polarization

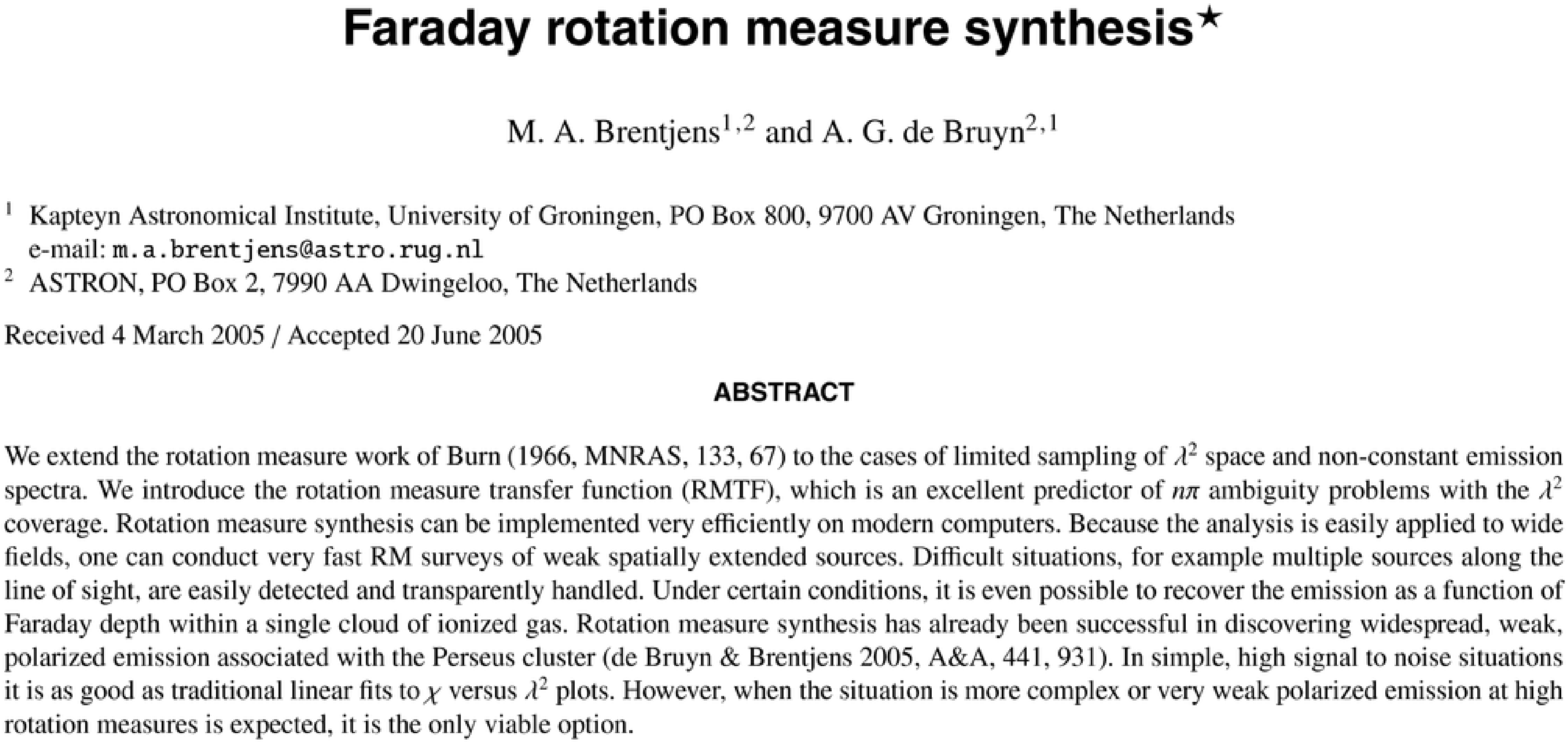
> We can map the polarization and Faraday Rotation

> But these maps are tricky:

-You need to consider the ‘Faraday Depth’.

- Interferometric maps are spatially filtered, providing only the small scales. Stokes parameters, polarization position angle, and polarized intensity suffer severe distortions without the “zero-spacing” data.

- Single dishes miss the small scales.



Faraday rotation measure synthesis★

M. A. Brentjens[1,2] and A. G. de Bruyn[2,1]

[1] Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands
e-mail: `m.a.brentjens@astro.rug.nl`
[2] ASTRON, PO Box 2, 7990 AA Dwingeloo, The Netherlands

Received 4 March 2005 / Accepted 20 June 2005

ABSTRACT

We extend the rotation measure work of Burn (1966, MNRAS, 133, 67) to the cases of limited sampling of λ^2 space and non-constant emission spectra. We introduce the rotation measure transfer function (RMTF), which is an excellent predictor of $n\pi$ ambiguity problems with the λ^2 coverage. Rotation measure synthesis can be implemented very efficiently on modern computers. Because the analysis is easily applied to wide fields, one can conduct very fast RM surveys of weak spatially extended sources. Difficult situations, for example multiple sources along the line of sight, are easily detected and transparently handled. Under certain conditions, it is even possible to recover the emission as a function of Faraday depth within a single cloud of ionized gas. Rotation measure synthesis has already been successful in discovering widespread, weak, polarized emission associated with the Perseus cluster (de Bruyn & Brentjens 2005, A&A, 441, 931). In simple, high signal to noise situations it is as good as traditional linear fits to χ versus λ^2 plots. However, when the situation is more complex or very weak polarized emission at high rotation measures is expected, it is the only viable option.

When you map an area like this, you don’t get a map of polarized emission; rather, you get a <u>data cube</u>, in which the polarized emissivity is a function of (α, δ, φ).

The application, and in particular the <u>interpretation</u>, of F(φ) spectra derived from Faraday Rotation Synthesis is in its infancy.

Applying Faraday Rotation Synthesis requires good coverage and sampling in frequency space---just as applying standard Aperture Synthesis requires good (uv) coverage. The Galaxy has RMs ranging up to a few hundred (sometimes more). One needs to cover roughly 100 MHz to 1500 MHz…or more.

WHAT THE ISM NEEDS FROM FAST:

Repeat the GALFA 21-cm emission line survey, INCLUDING all four OH lines.

Repeat the Millennium 21-cm absorption/emission line survey, covering all sources with S ~> 1 Jy.

Survey the linear polarization of the Diffuse Galactic Synchrotron radiation from ~100 MHz to ~1500 MHz and perform Faraday synthesis.

FIN

Fin