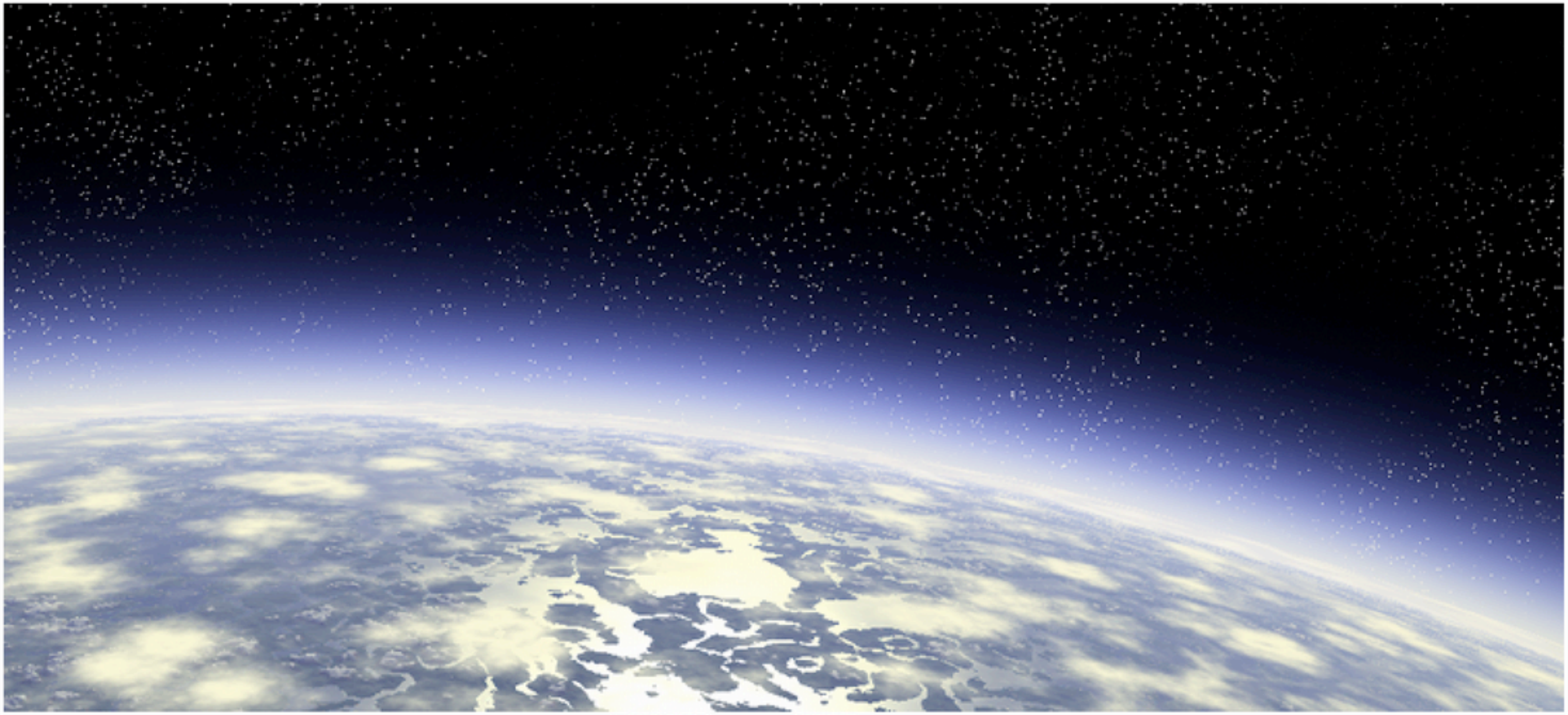
OUR LOCAL MICROCOSMOS

Carl Heiles, UC Berkeley

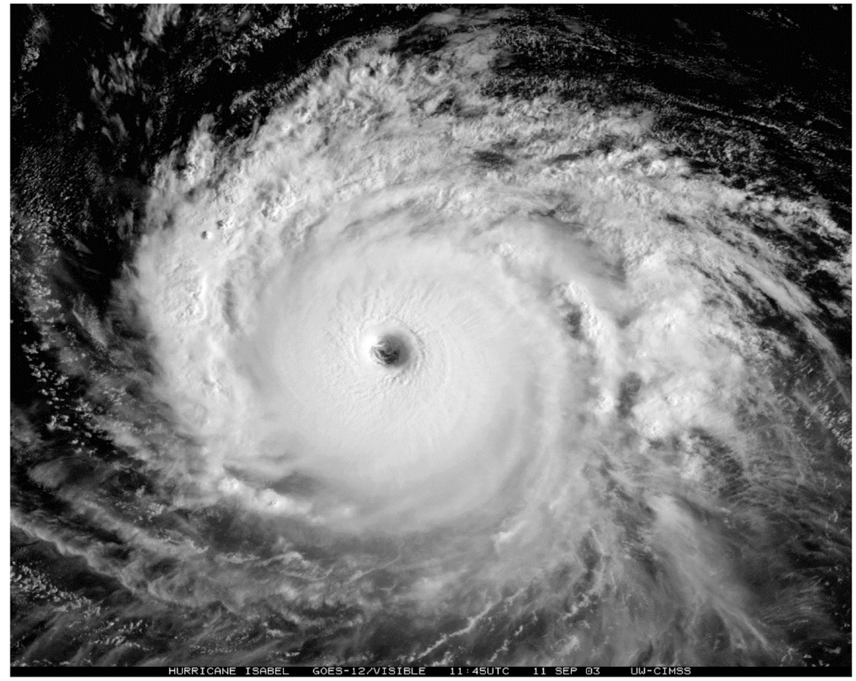
FORCES ON INTERSTELLAR GAS:

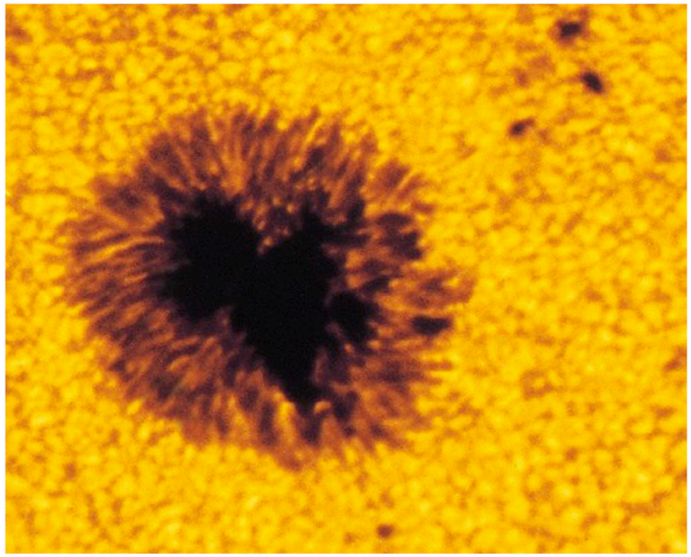
- **Gravity**
- **Pressure**
- **Magnetic Fields**

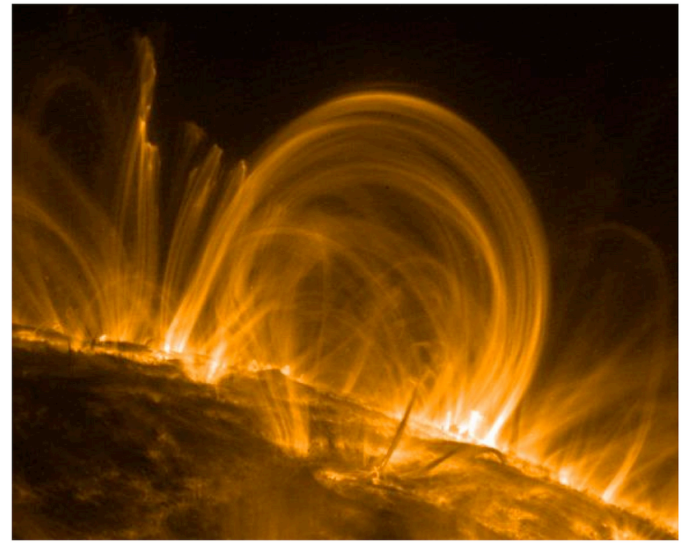


Gravity and Pressure equilibrium... the Earth’s atmosphere, nice and stable!

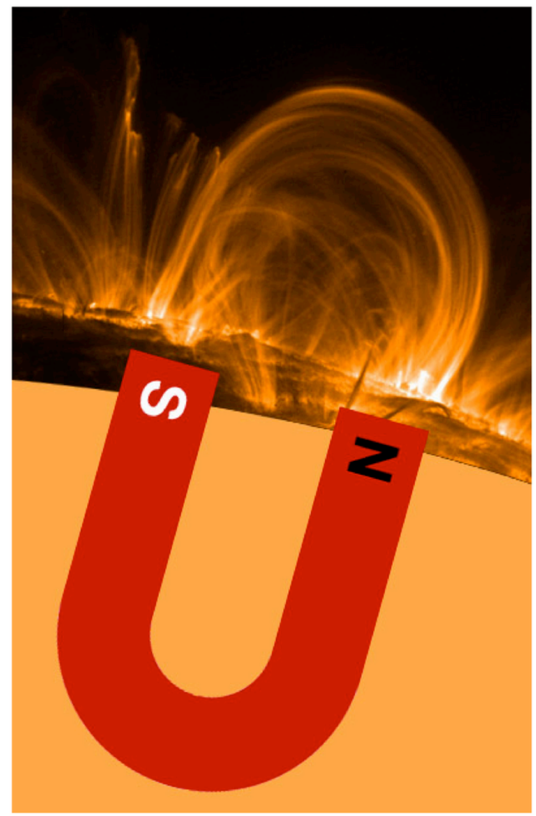
But things aren't ALWAYS nice and stable!





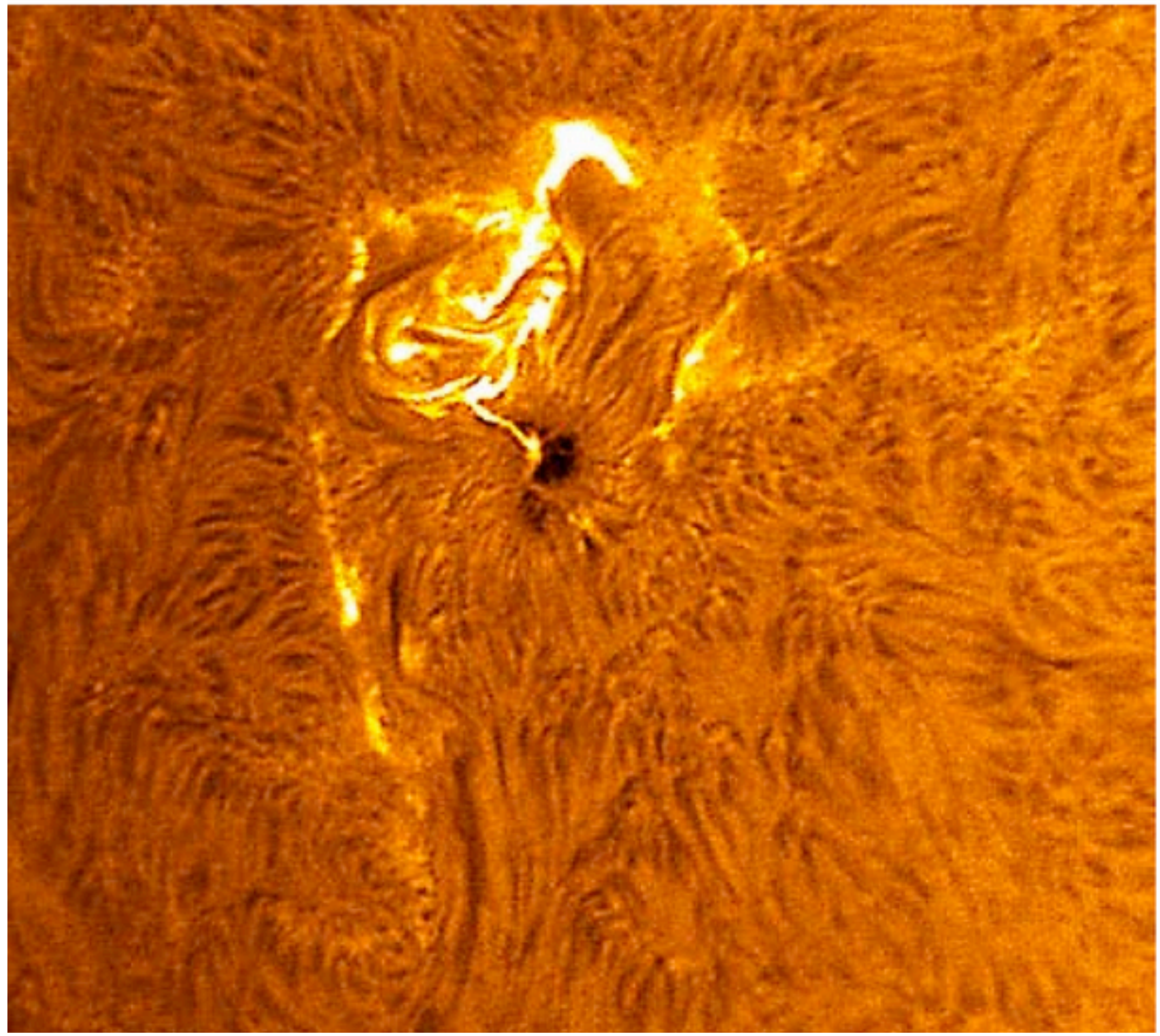


Gravity, Pressure, and Magnetic equilibrium. Solar prominences, sunspots, nice and stable!



SOLAR FLARE – the N and S magnetic poles attract!

NOT so nice and stable!



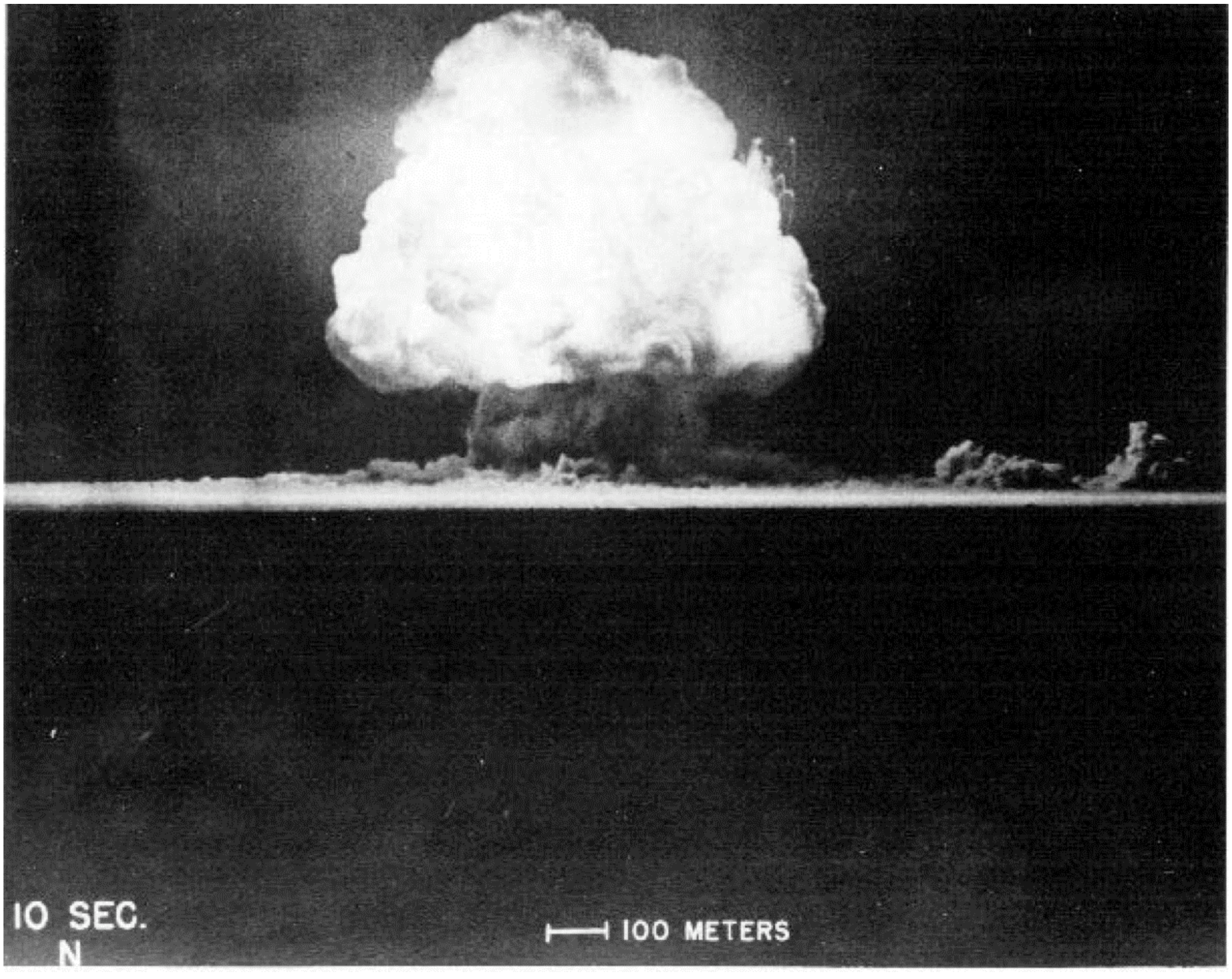
“FLUX FREEZING’’ – the magnetic lines more with the gas. And vice-versa. Nice ordered flows give nice ordered fields; or, if the field is strong, nice ordered fields give nice ordered flows.

But there can be...

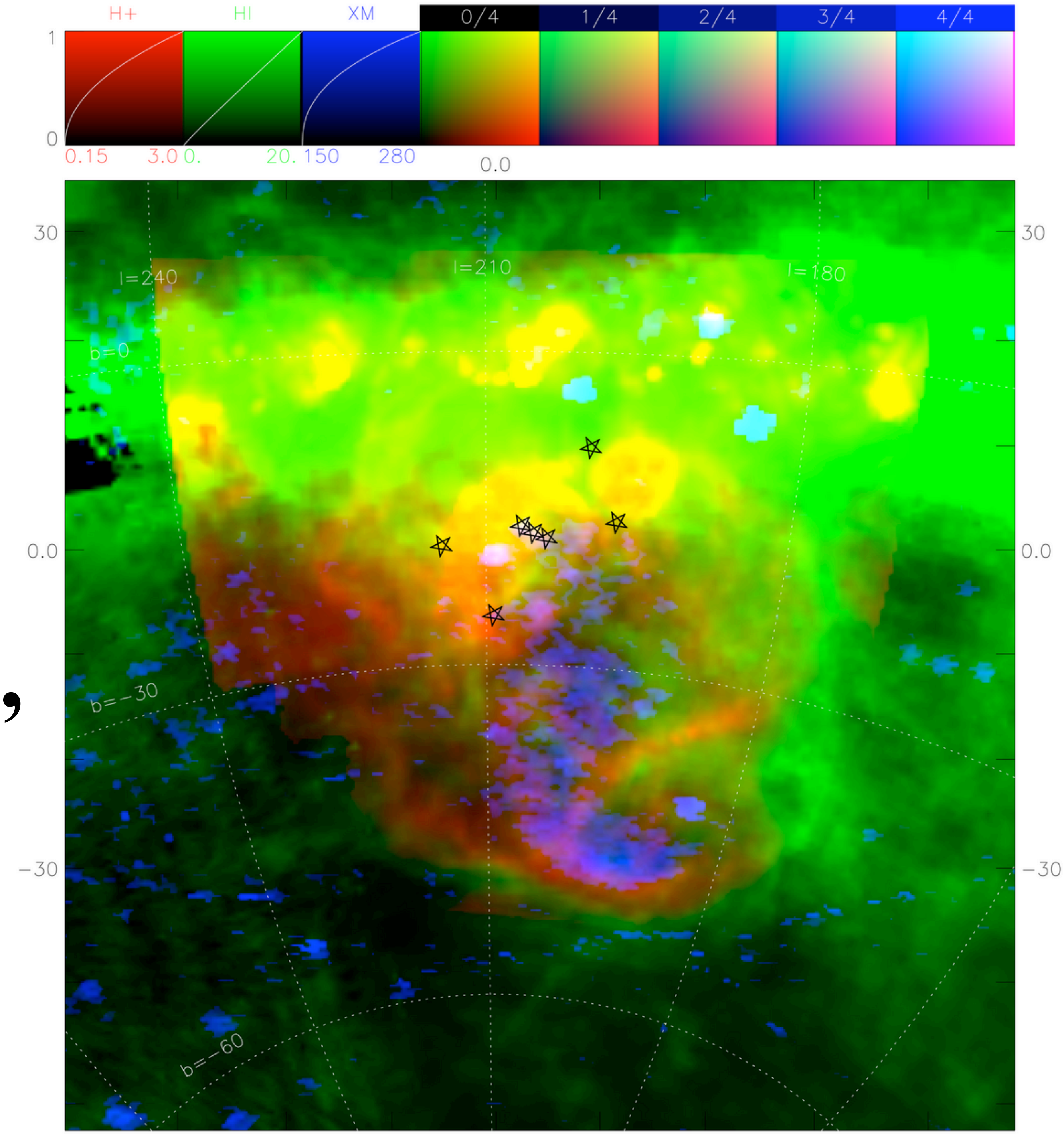
TURBULENCE!!

The interaction of the 3 forces—gravity, pressure, magnetism—produces fascinating and complex phenomenae and is not much understood, in either the terrestrial or astronomical context!

Simple gasdynamics: our own, our first...(LIFE magazine, post-WWII)



Nature's: The "Orion-Eridanus Supershell"



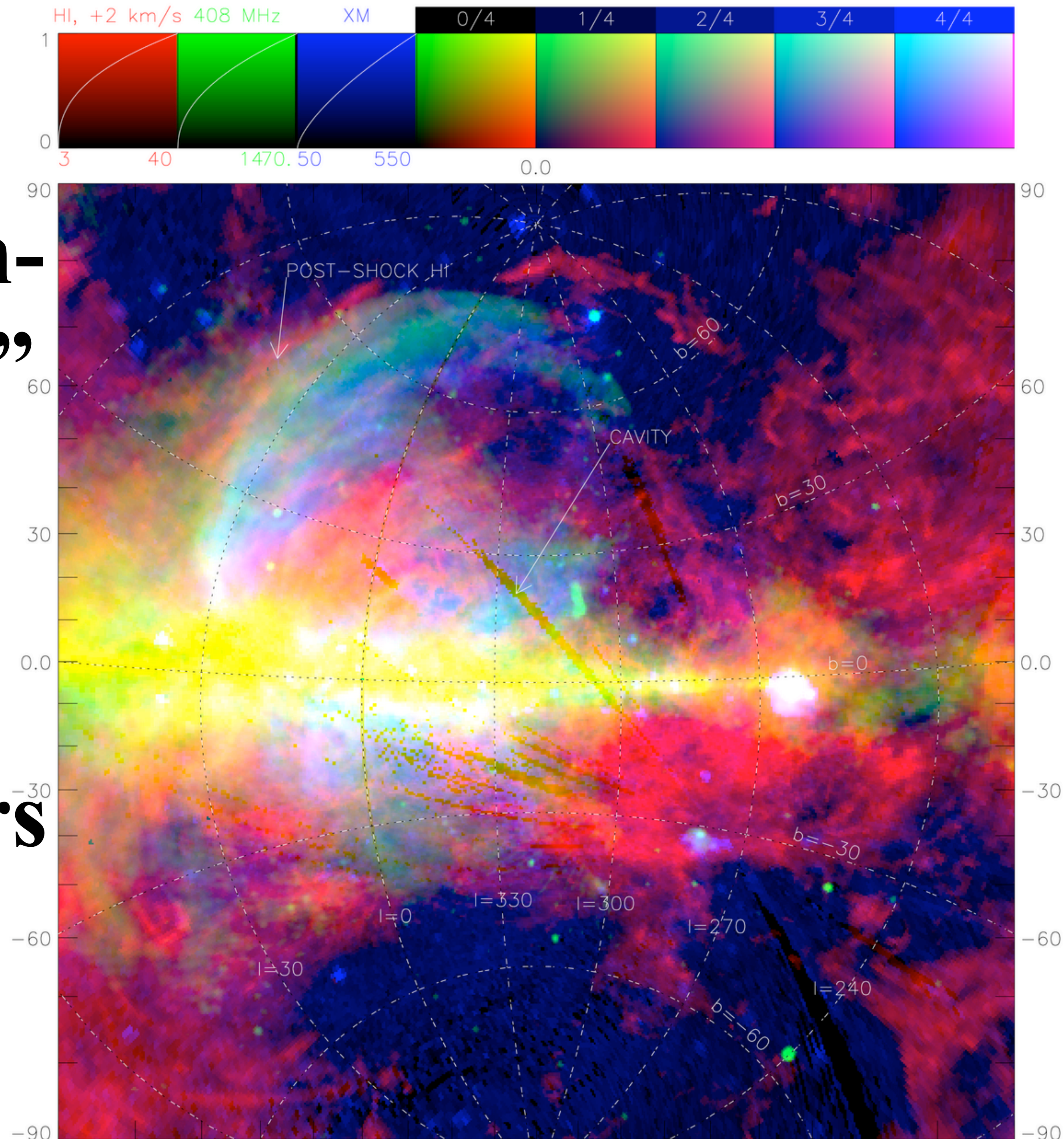
$$\underbrace{Kinetic\ Energy}_{KE} = 1.4 \times \underbrace{Total\ Energy}_{E}$$

$$\underbrace{\underbrace{\frac{4\pi}{3}\rho R^3}_{MASS} v^2}_{KE} = 1.4E$$

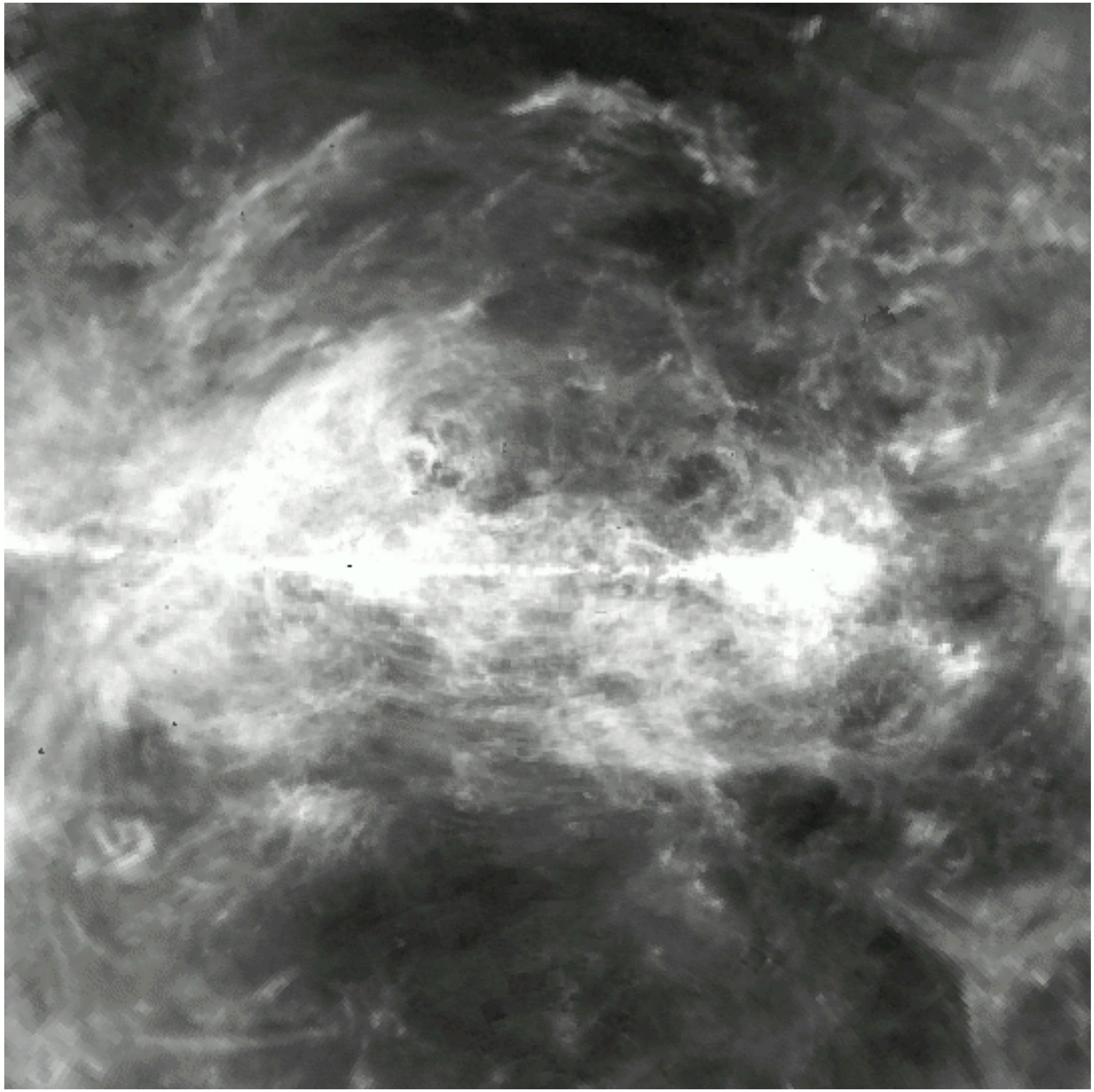
$$R = \left(\frac{2.02E}{\rho}\right)^{1/5} t^{2/5}$$

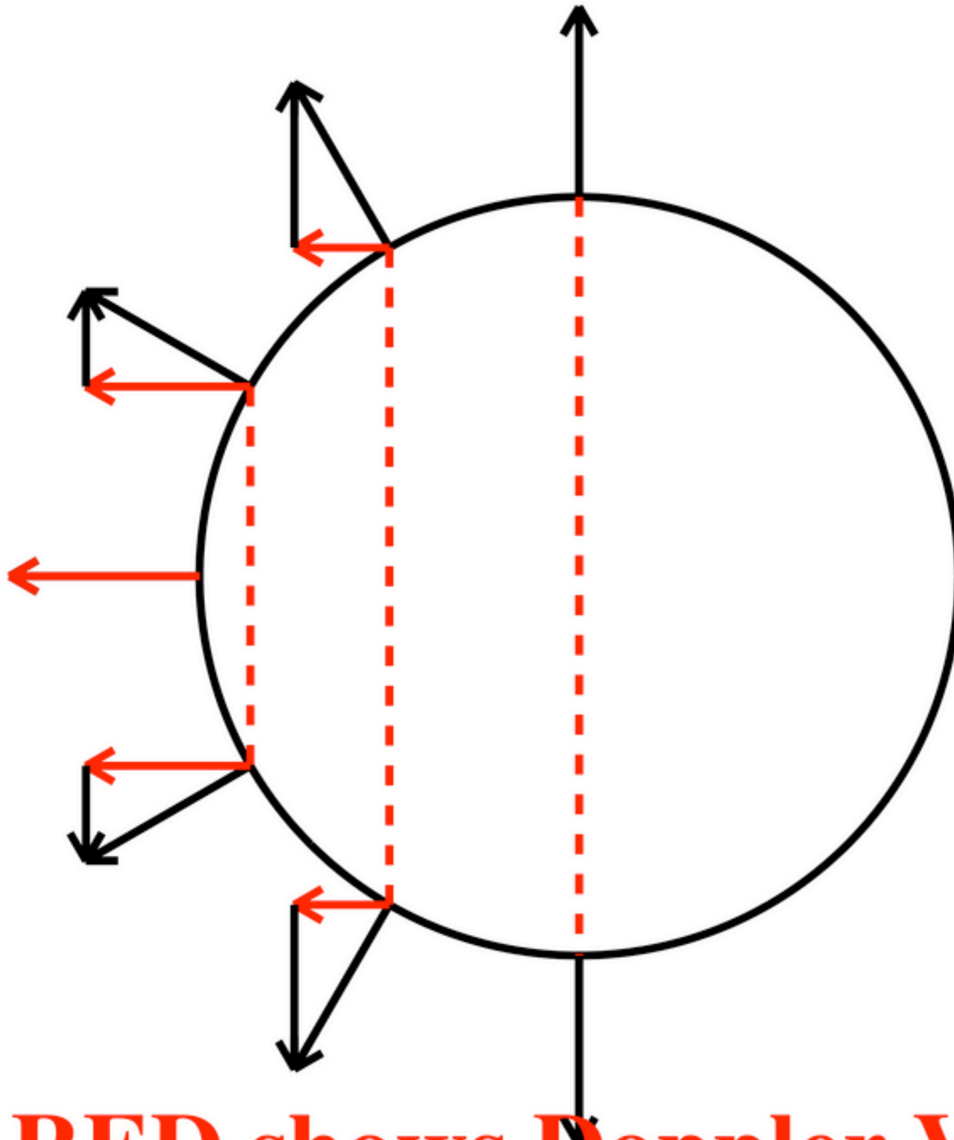
This is the famed <u>Sedov-Taylor</u> solution. Taylor--an Englishman--applied it to the Life Magazine photo (2 slides back) to derive the bomb energy E. He published his result in as a letter to the editor of the *London Times*...

The “North-Polar Spur” (NPS) supershell (some astronomers call it “Loop I”)



The different frames are different Doppler velocities

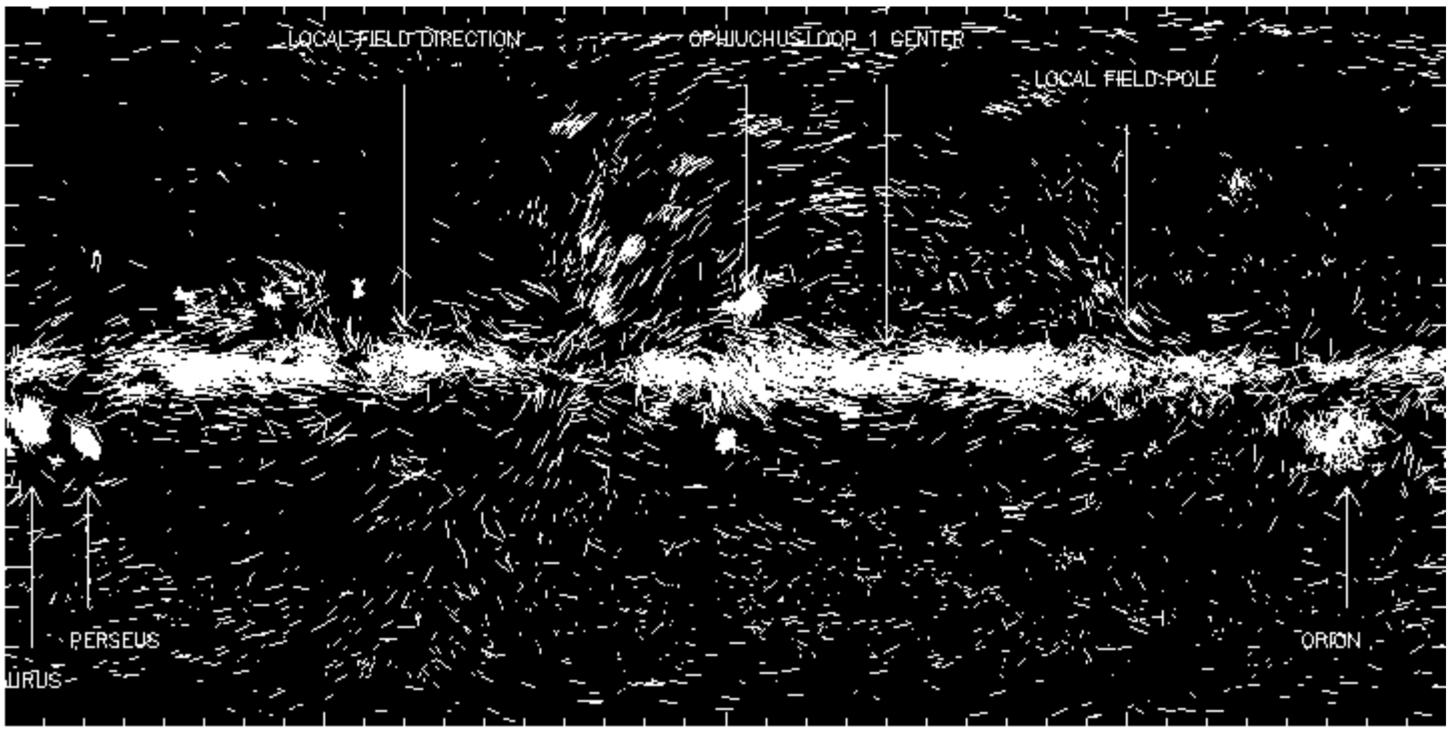


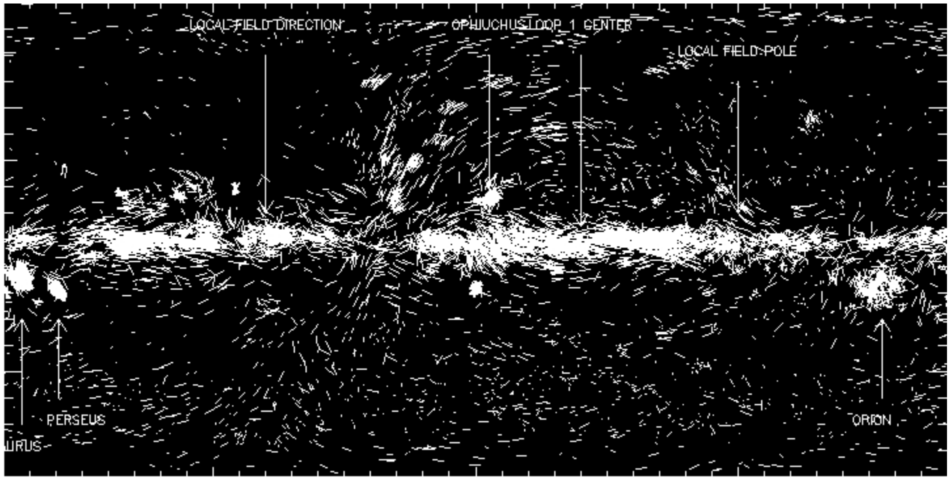


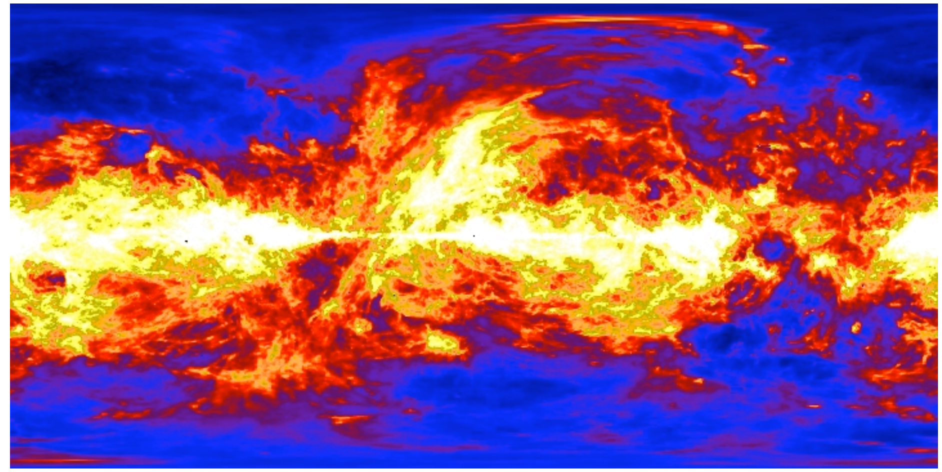
RED shows Doppler Velocity

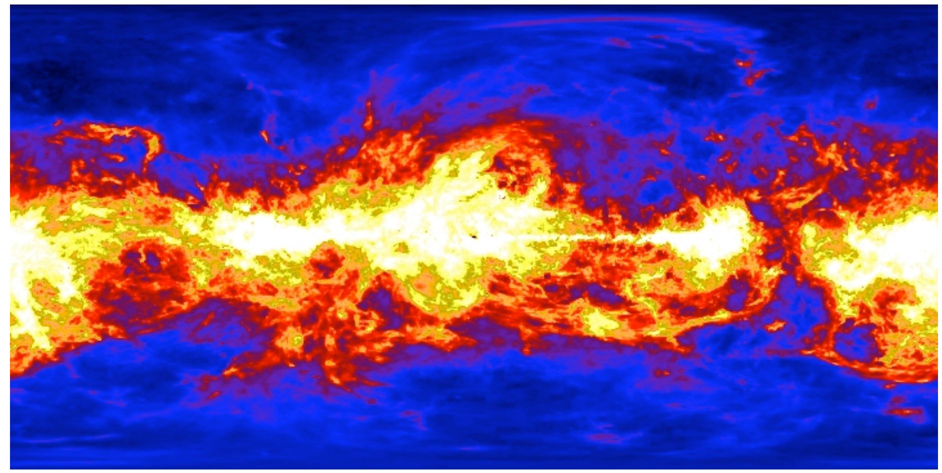
9286 stars

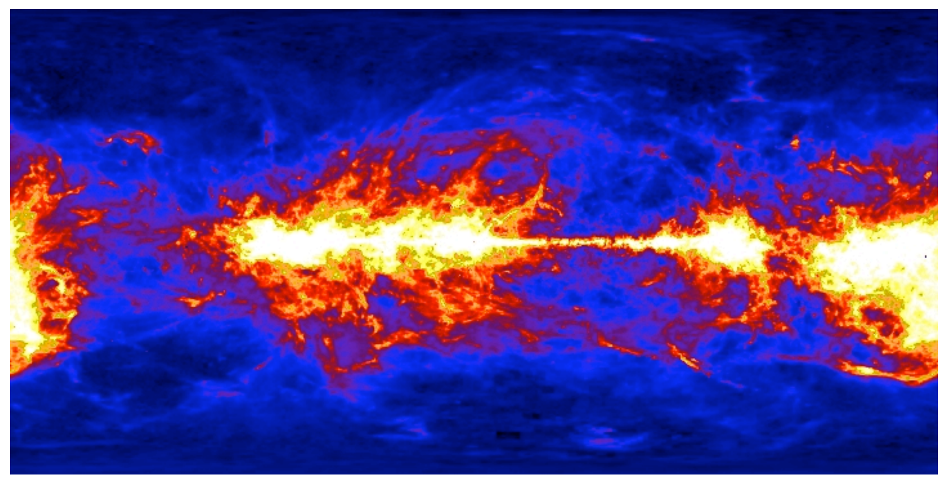
"Iron filings" trace the magnetic field



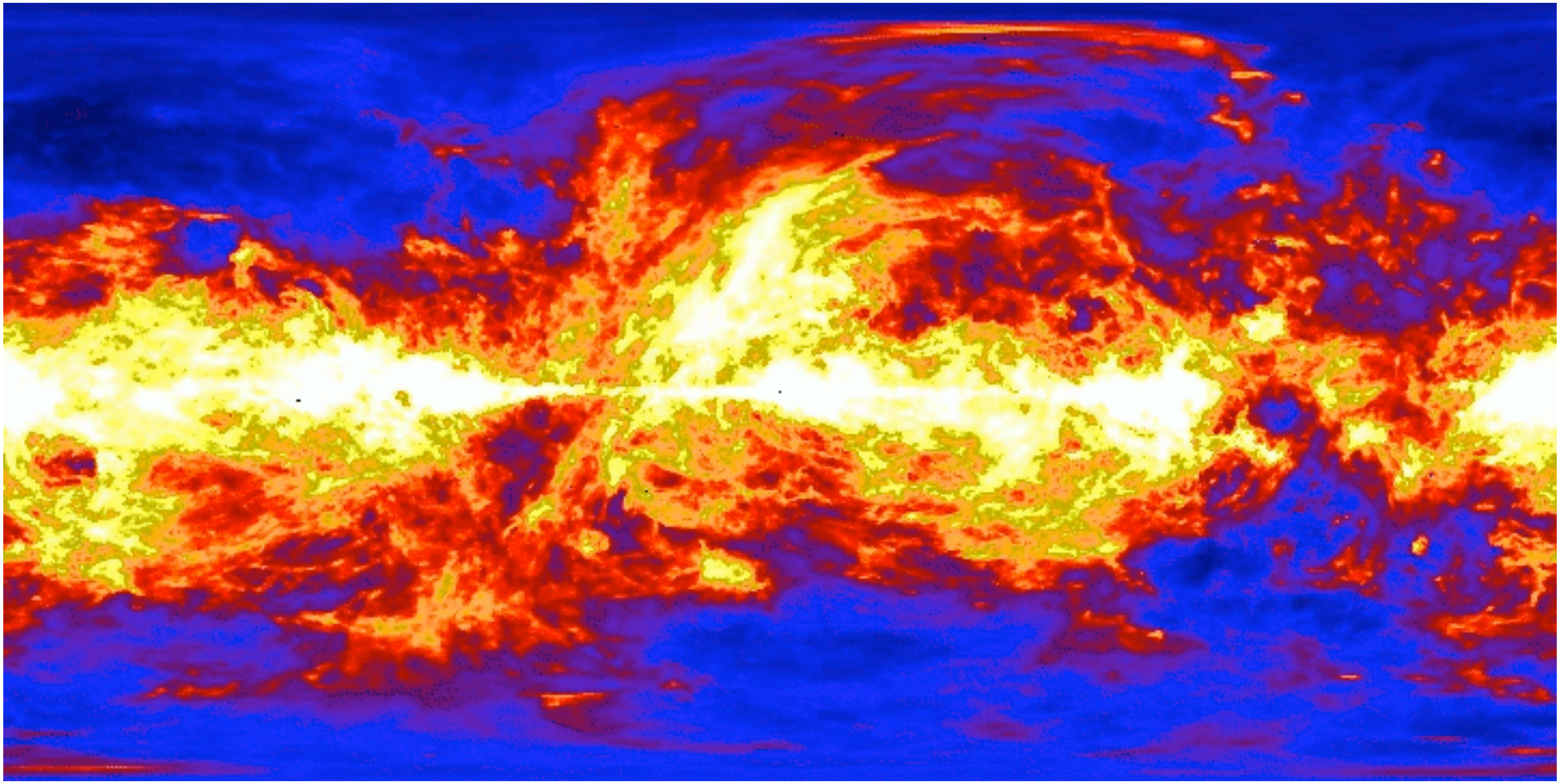






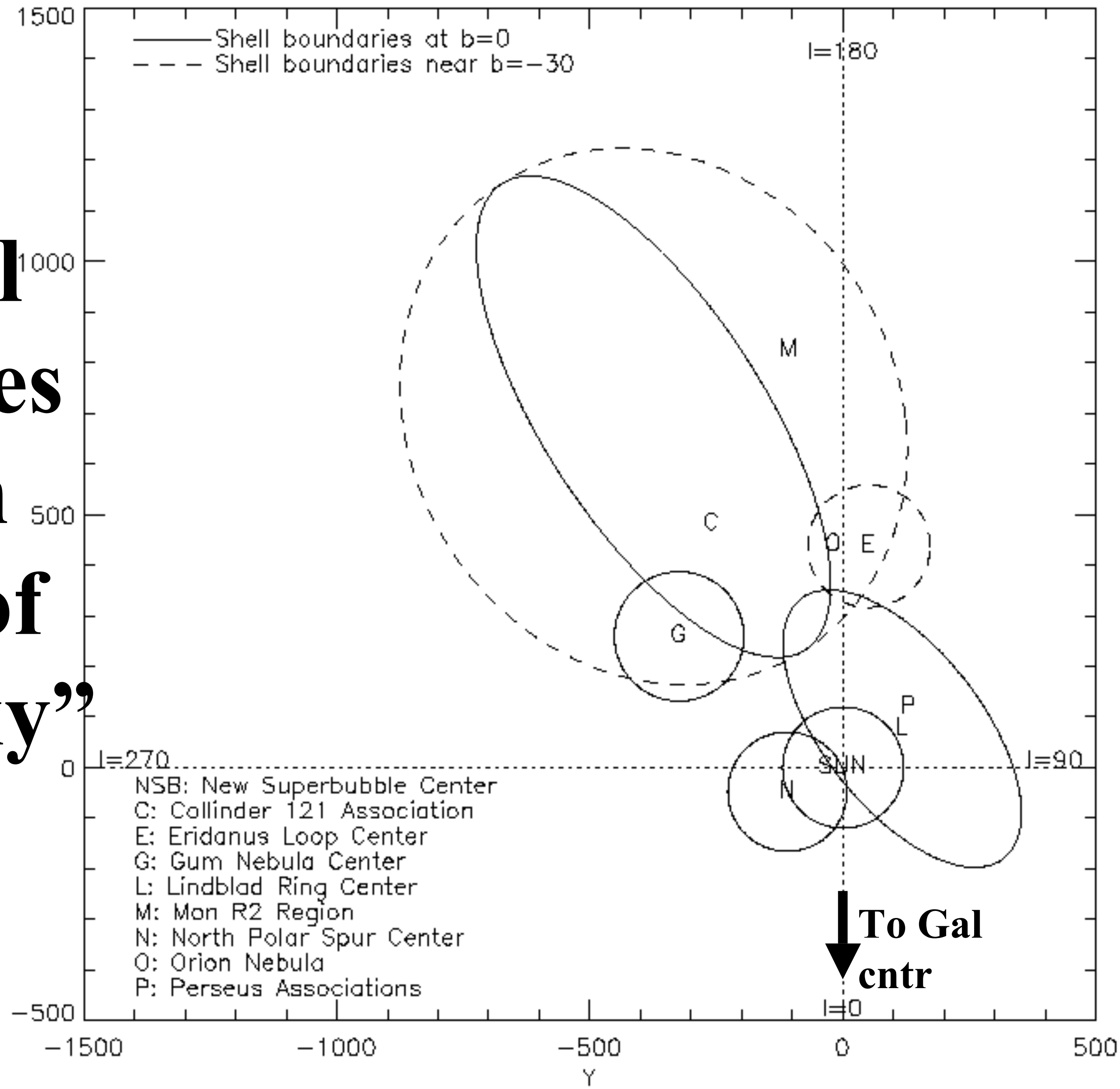


Rectangular projection of the whole sky. colored frames are different Doppler velocities

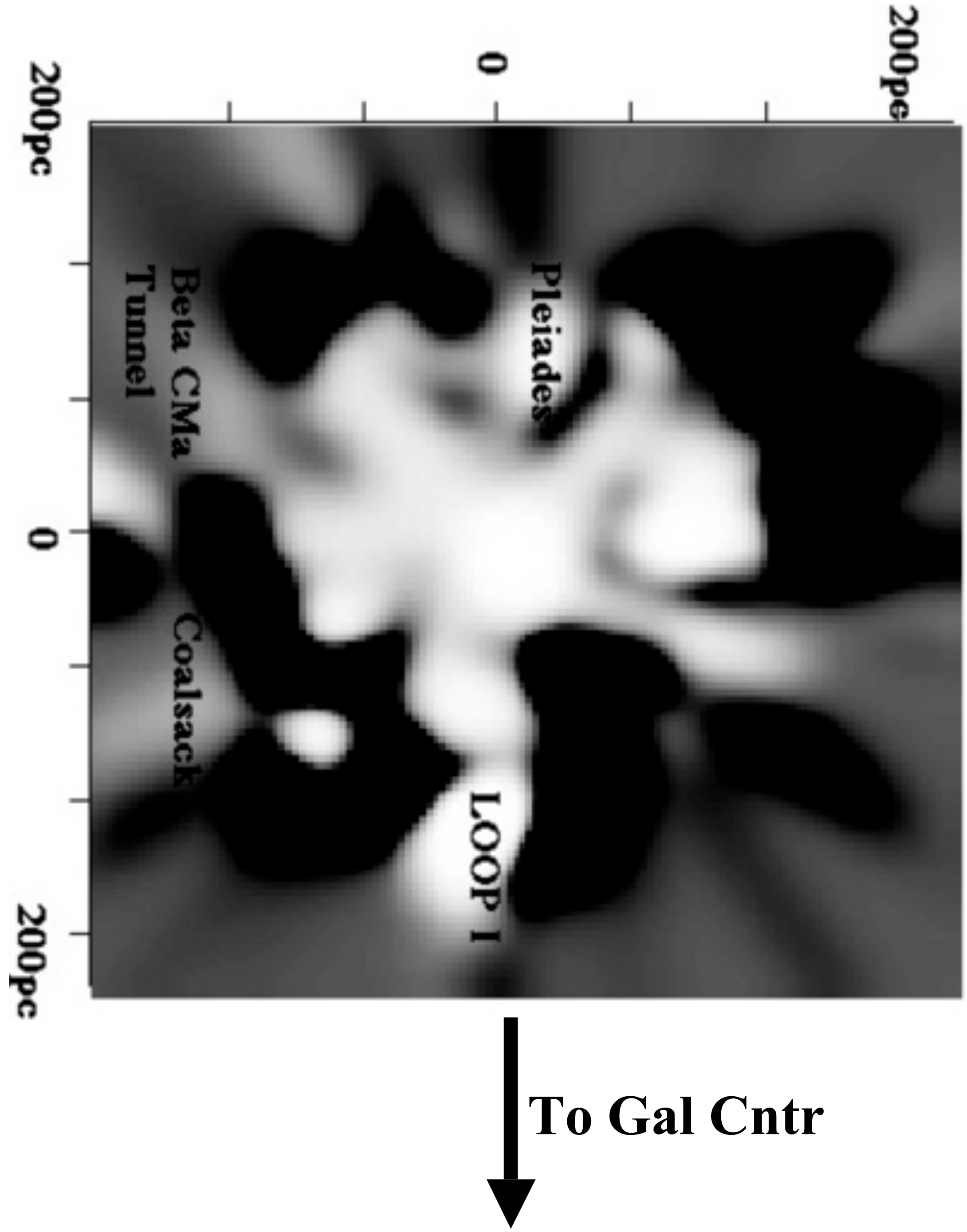


B follows HI morphology!

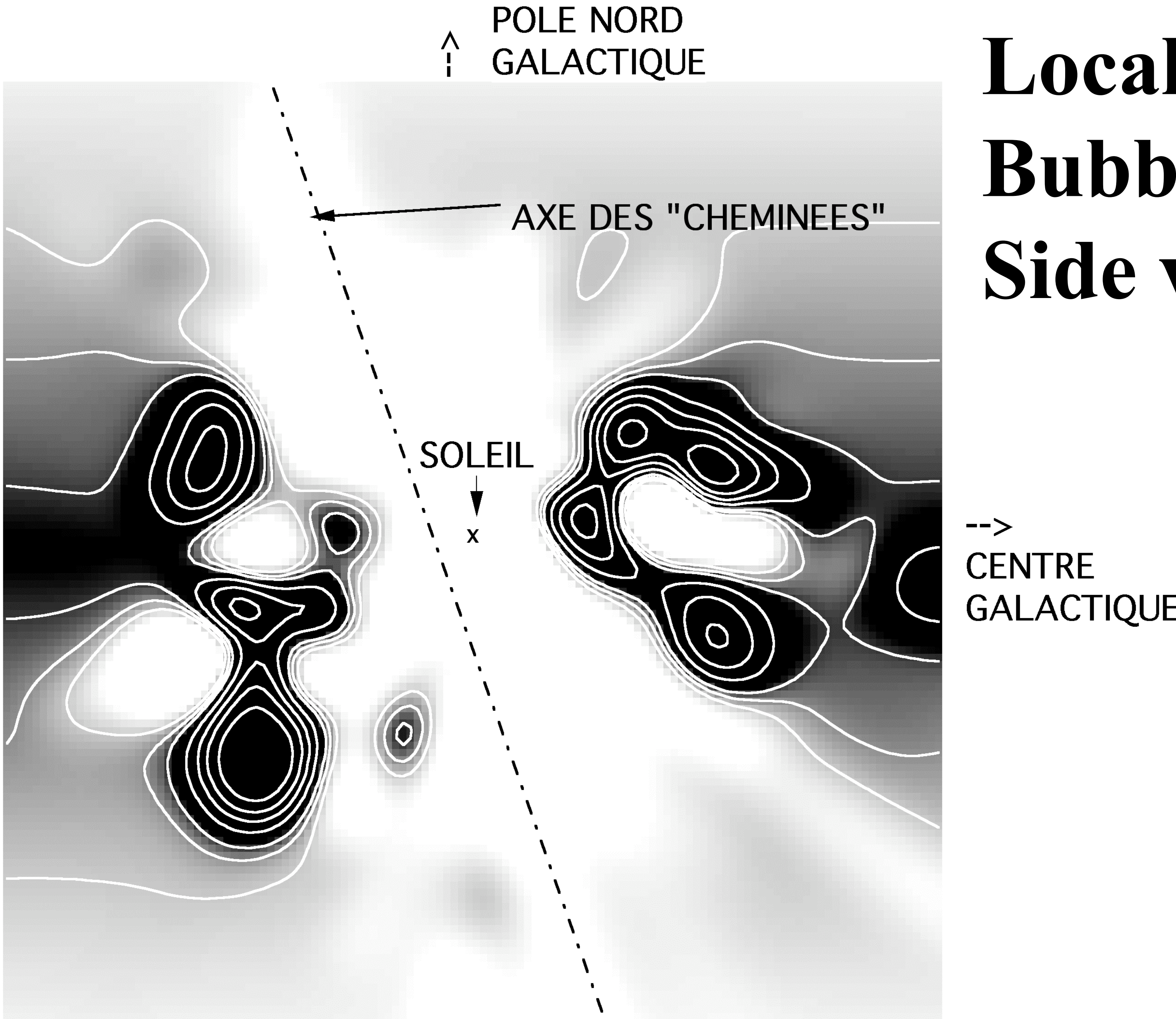
Local supershell boundaries seen from the "top of the Galaxy"



Top view of our "Local Bubble". Well-defined boundaries formed from the inside's swept-up gas.



Local Bubble: Side view



Let’s explore the CONTENTS of the Local Bubble--it is, after all, our

LOCAL MICROCOSMOS !

From the early days of the first X-ray rockets, we deduced that the Local Bubble is full of HOT GAS (about a million degrees Kelvin). We know from its X-ray emission. We see X-ray emission between us and opaque neutral gas structures.

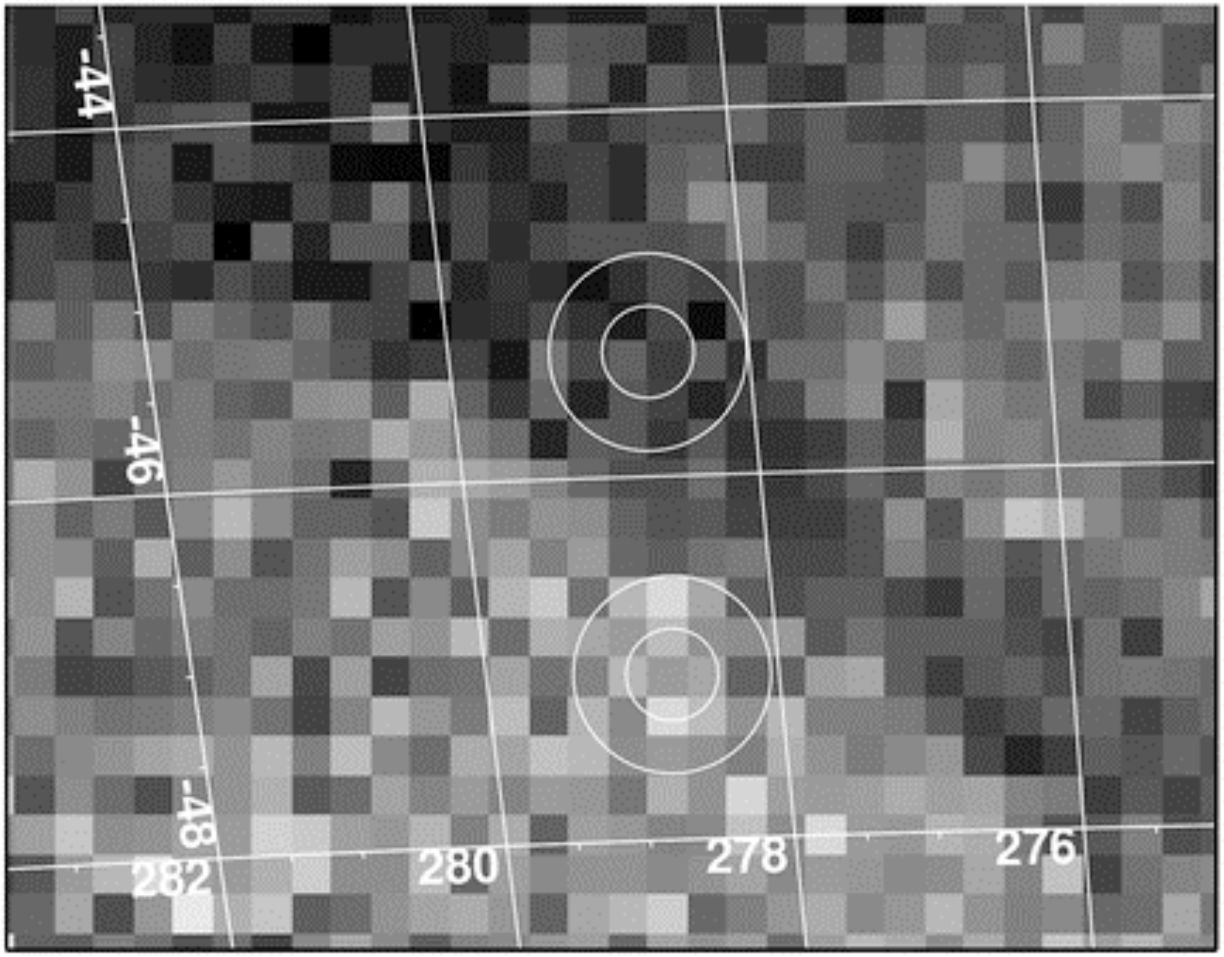


FIG. 1.— *ROSAT* All-Sky Survey R1+R2 image centered on $l = 279°$, $b = -46°$, showing the absorbing filament used for our observations (data from Snowden et al. 1997). The circles show our on-filament (upper) and off-filament (lower) pointing directions. The smaller circles (radius $= 14'$) show the approximate areas from which our *XMM-Newton* spectra were extracted, while the larger circles (radius $= 30'$) show the areas from which our *ROSAT* spectra were extracted.

OVII and OVIII line emission in the diffuse soft X-ray background: heliospheric and galactic contributions

D.Koutroumpa[1], F.Acero[2], R.Lallement[1], J.Ballet[2], and V.Kharchenko[3]

[1] UMR 7620, IPSL/Service dAéronomie, CNRS, Université Pierre et Marie Curie, Université Versailles-Saint-Quentin, Verrières-le-Buisson, France
[2] UMR 7158, DSM/DAPNIA/SAp, CEA Saclay, 91191 Gif-sur-Yvette, France
[3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

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ABSTRACT

Aims. We study the 0.57 keV (O VII triplet) and 0.65 keV (O VIII) diffuse emission generated by charge transfer collisions between solar wind (SW) oxygen ions and interstellar H and He neutral atoms in the inner Heliosphere. These lines which dominate the 0.3-1.0 keV energy interval are also produced by hot gas in the galactic halo (GH) and possibly the Local Interstellar Bubble (LB).
Methods. We developed a time-dependent model of the Solar Wind Charge-Exchange (SWCX) X-ray emission, based on the localization of the Solar Wind Parker spiral at each instant. We include input SW conditions affecting three selected fields, as well as shadowing targets observed with XMM-Newton, Chandra and Suzaku satellites and calculate X-ray emission in the oxygen lines O VII and O VIII in order to determine the SWCX contamination and the residual emission to attribute to the galactic soft X-ray background. We obtain ground level intensities and/or simulated lightcurves for each target and compare to X-ray data from the three instruments mentioned.
Results. The local 3/4 keV emission (due essentially to O VII and O VIII) detected in front of shadowing clouds is found to be entirely explained by the CX heliospheric emission. No emission from the LB is needed at these energies. The observed and modeled range of the foreground oxygen emission is 0.3-4.6 LU (Line Units = photons cm^{-2} s^{-1} sr^{-1}) for OVII and 0.02-2.1 LU for OVIII depending on directions and conditions.
Using the model predictions we subtract the heliospheric contribution to the measured emission and derive the halo contribution. We also correct for an error in the preliminary analysis of the Hubble Deep Field North (HDFN). We find intensities of $4.9^{+1.29}_{-1.04}$ LU, $6.25^{+0.63}_{-0.98}$ LU, $11.15^{+2.36}_{-1.41}$ LU for OVII and $1.41^{+0.60}_{-0.49}$ LU, $1.62^{+0.35}_{-0.49}$ LU, $1.97^{+1.11}_{-0.71}$ LU for OVIII towards the Marano Field, the Hubble Deep Field-North, and the Lockman Hole respectively.

You probably couldn’t read that. Or if you could it probably didn’t register. They are saying...

¡¡¡THERE’S NO HOT GAS IN THE LOCAL BUBBLE!!!

This is HERESY!! Generations of astronomers have grown up with X-ray shadowing data implying that the Local Bubble is full of hot gas—not from the Sun's heliosphere.

¡SUCH IS SCIENTIFIC PROGRESS!

Eventually, the truth wins out.

More contents: Possibly highly overpressured, tiny (astronomically speaking) ionized blobs.

SIZE: 20000 km (a few Earth diams!)

DENSITY: 1 to 100 electrons per cc

OVERPRESSURE: factor 1 to 100.

DISTANCE: a few parsecs (600000 AU

Australia Telescope Compact Array ←

Very Large Array (New Mexico) →

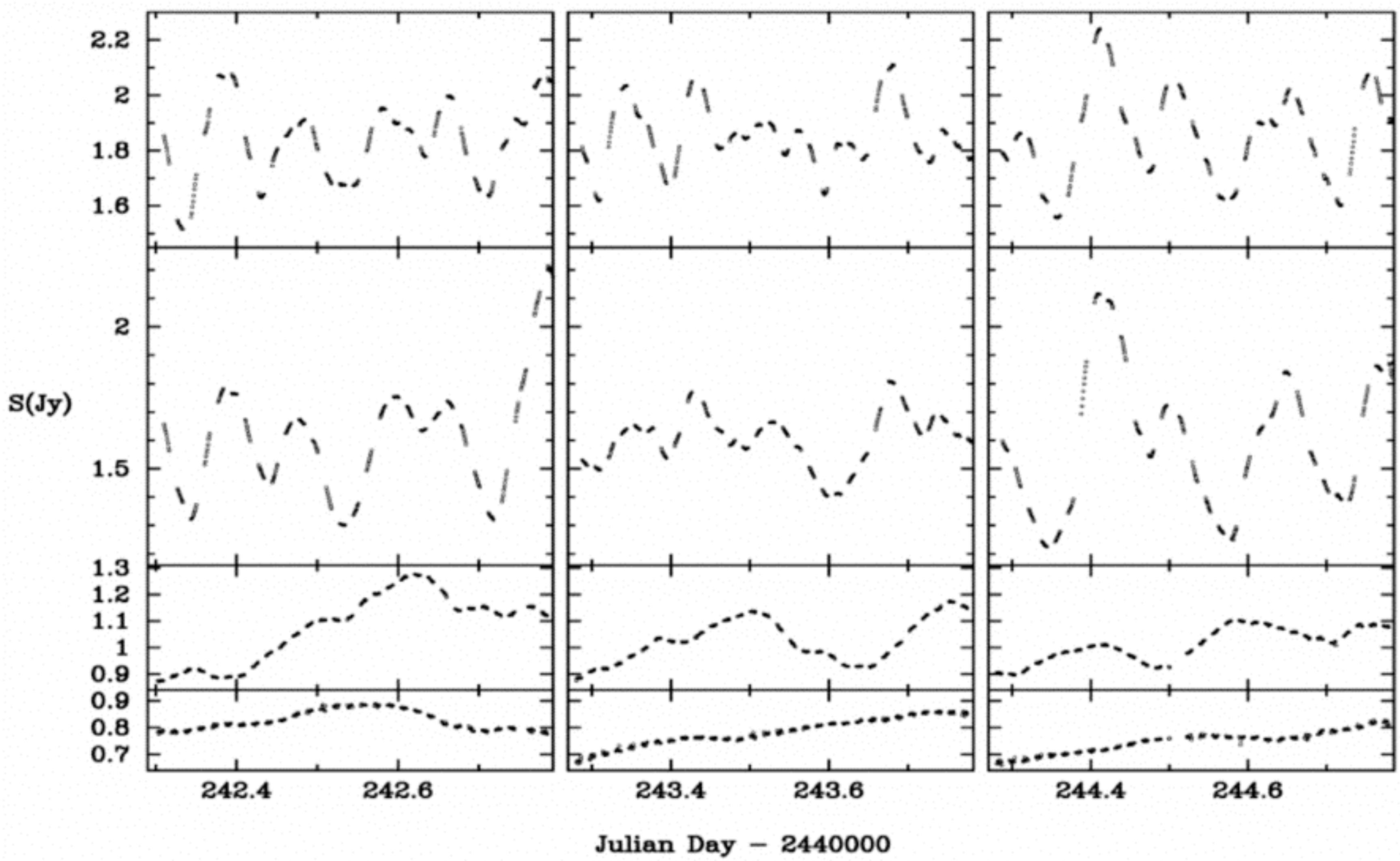
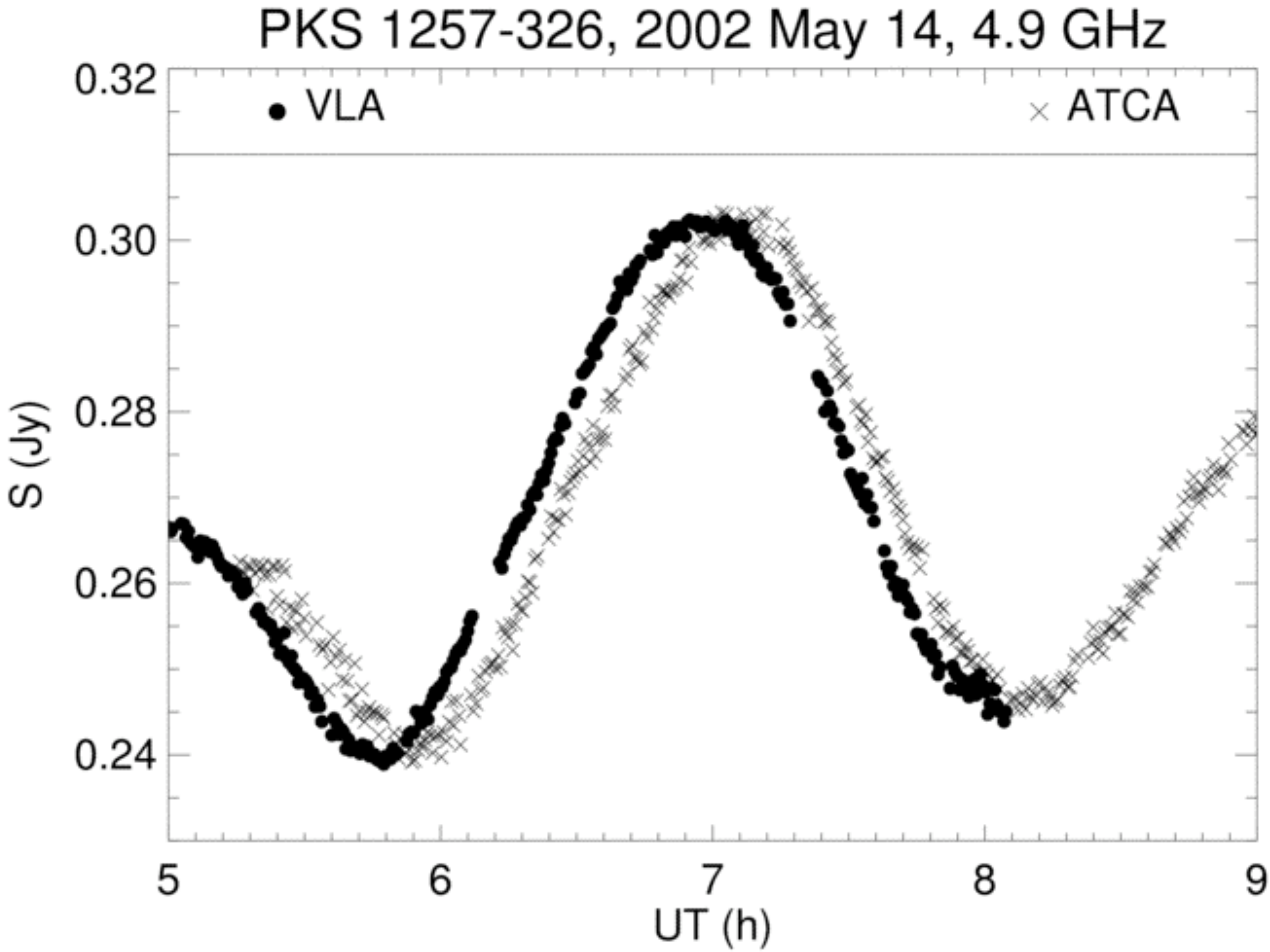


Fig. 1.— Rapid variations observed in PKS 0405−385 over three days in June 1996, from Kedziora-Chudczer et al. (1997). The observed frequencies are, from top to bottom, 8.6, 4.8, 2.4 and 1.4 GHz.



PKS 1257-326, 2002 May 14, 4.9 GHz
VLA
ATCA
S (Jy)
0.32
0.30
0.28
0.26
0.24
5
6
7
8
9
UT (h)

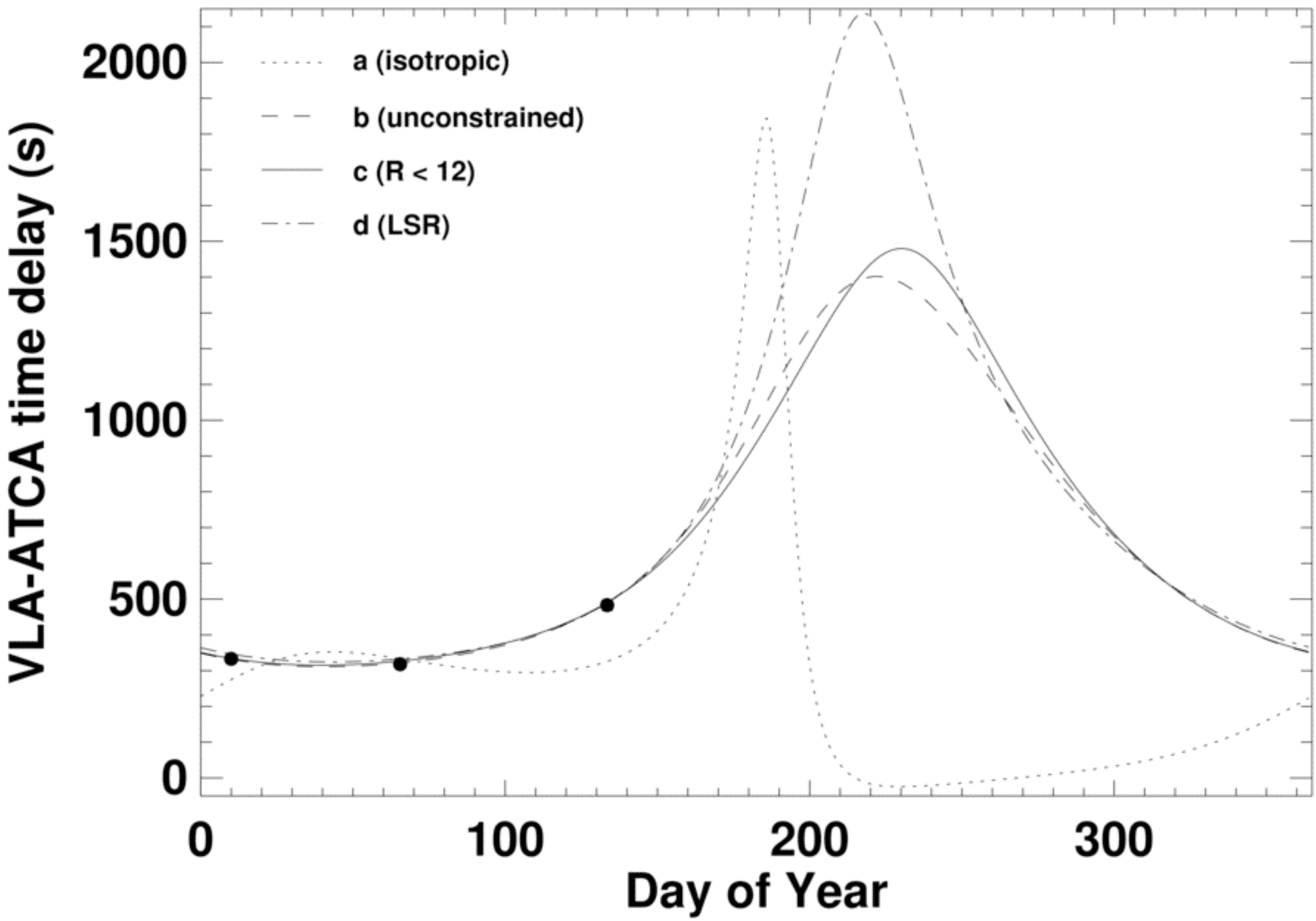
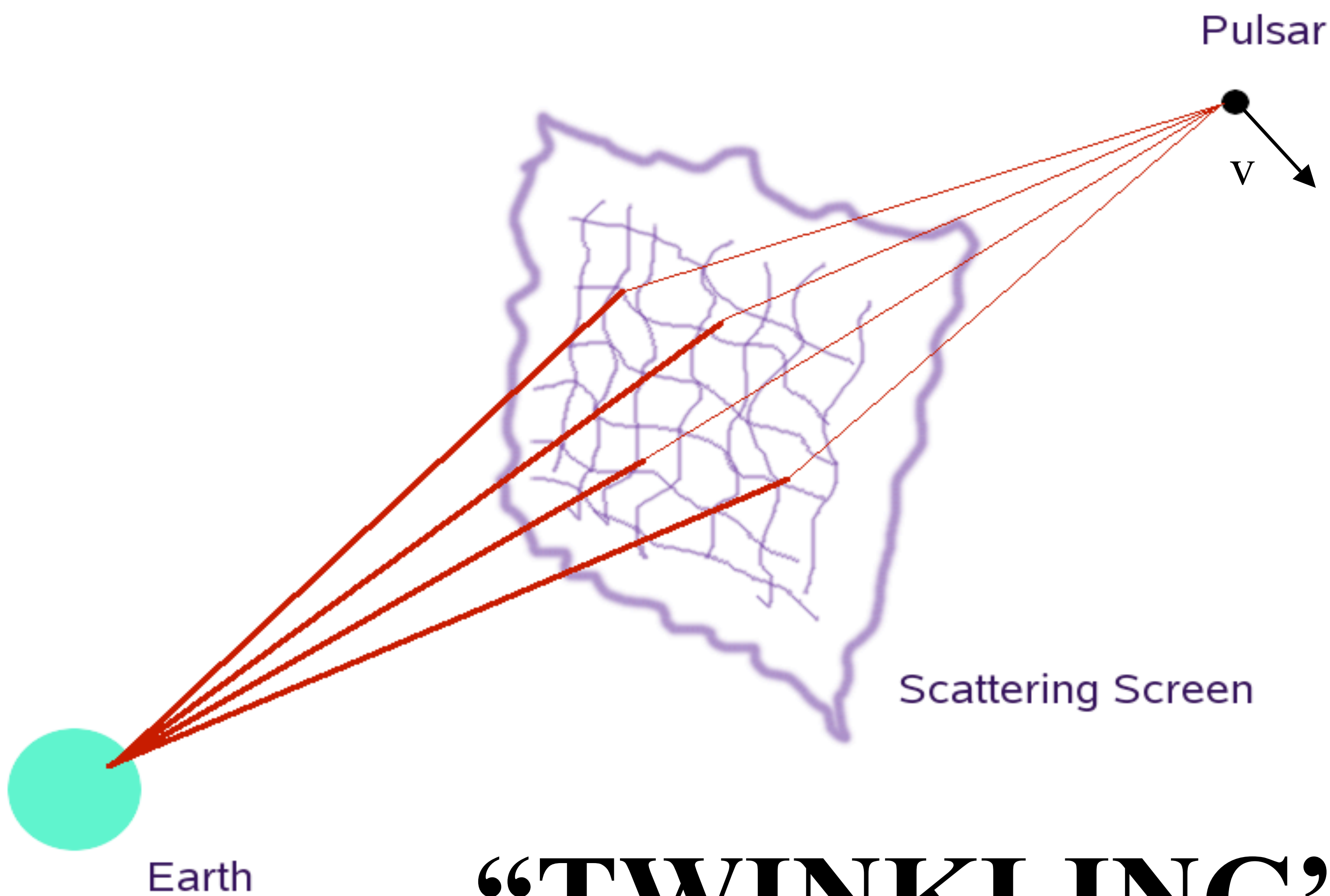


Fig. 4.— Variation of time delay as a function of day of year for the solutions shown in Table 2. Points near DOY 10, 67 and 134 show the measured time delays.

Scintillation geometry



"TWINKLING"

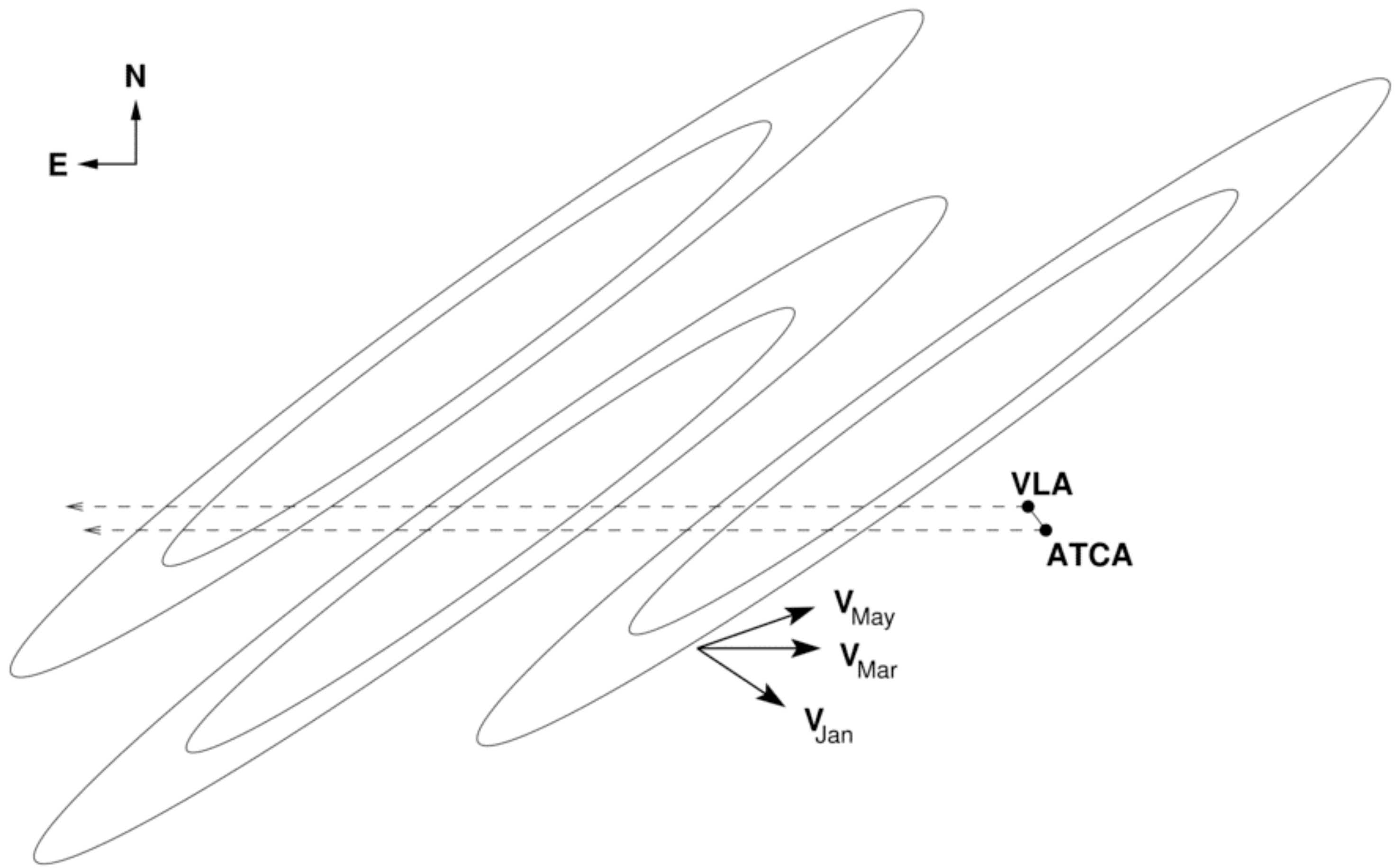


Fig. 3.— Sketch illustrating the geometry of the time delay model (not to scale, but the illustrated anisotropy, angles and velocities shown are approximately consistent with our preferred solution). The ellipses represent contours of constant intensity in the scintillation pattern, assumed to be "frozen-in" over a timescale of at least several minutes. Arrows indicate the direction of the velocity $\mathbf{v}$ at which the scintillation pattern passes over the telescopes for each observed epoch. The straight dashed lines show the cut through the scintillation pattern observed at each telescope for the direction of $\mathbf{v}_{\rm Mar}$ shown.

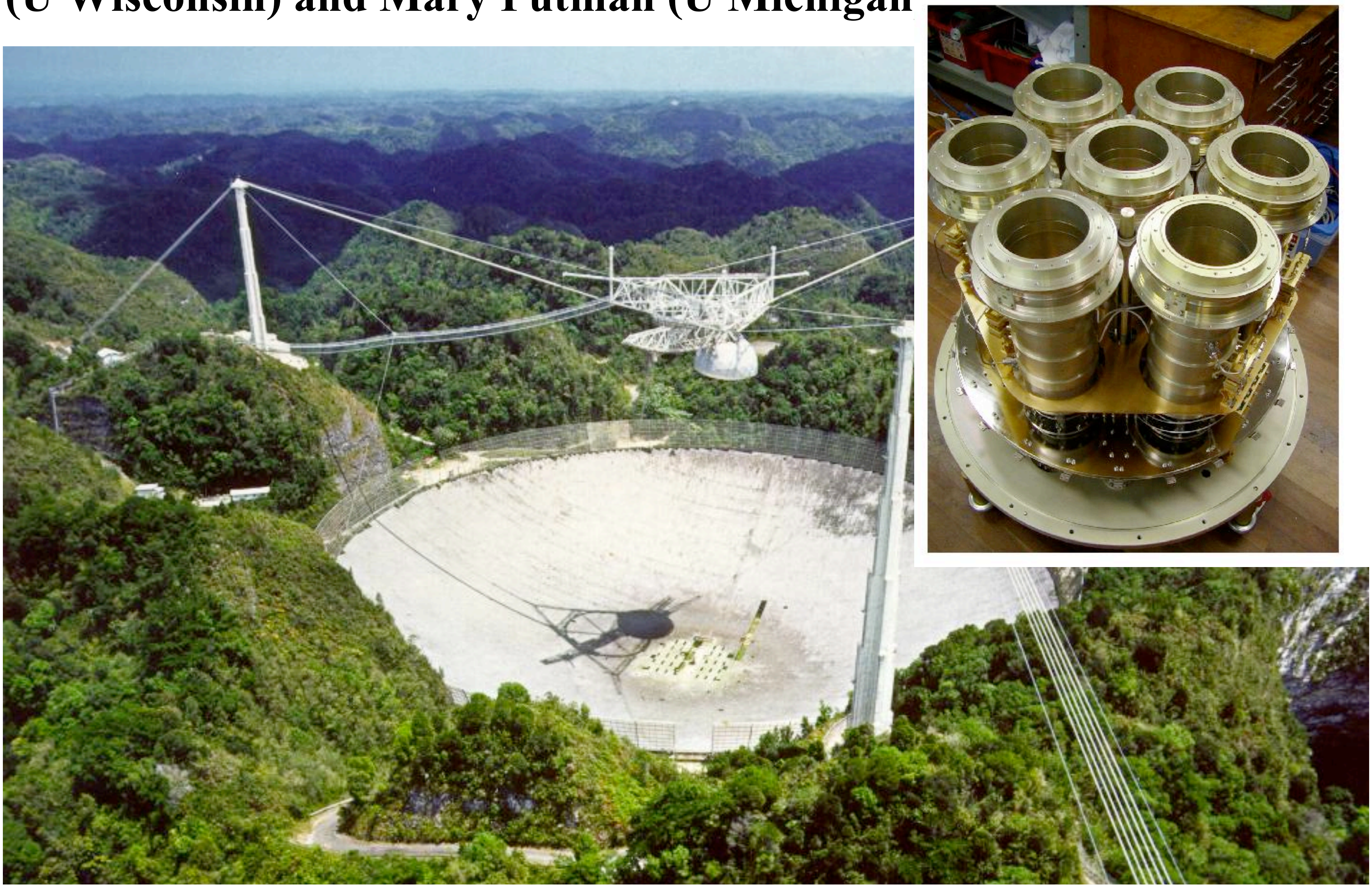
More Local Bubble content: a “paper-thin” cloud.

THICKNESS: 4000 AU

SIZE: 100 X thickness

Distance: about 20 parsecs

The Arecibo telescope and the ALFA feed array. Fast HI mapping! Berkeley student Josh Goldston Peek, Profs Snezana Stanimirovic (U Wisconsin) and Mary Putman (U Michigan



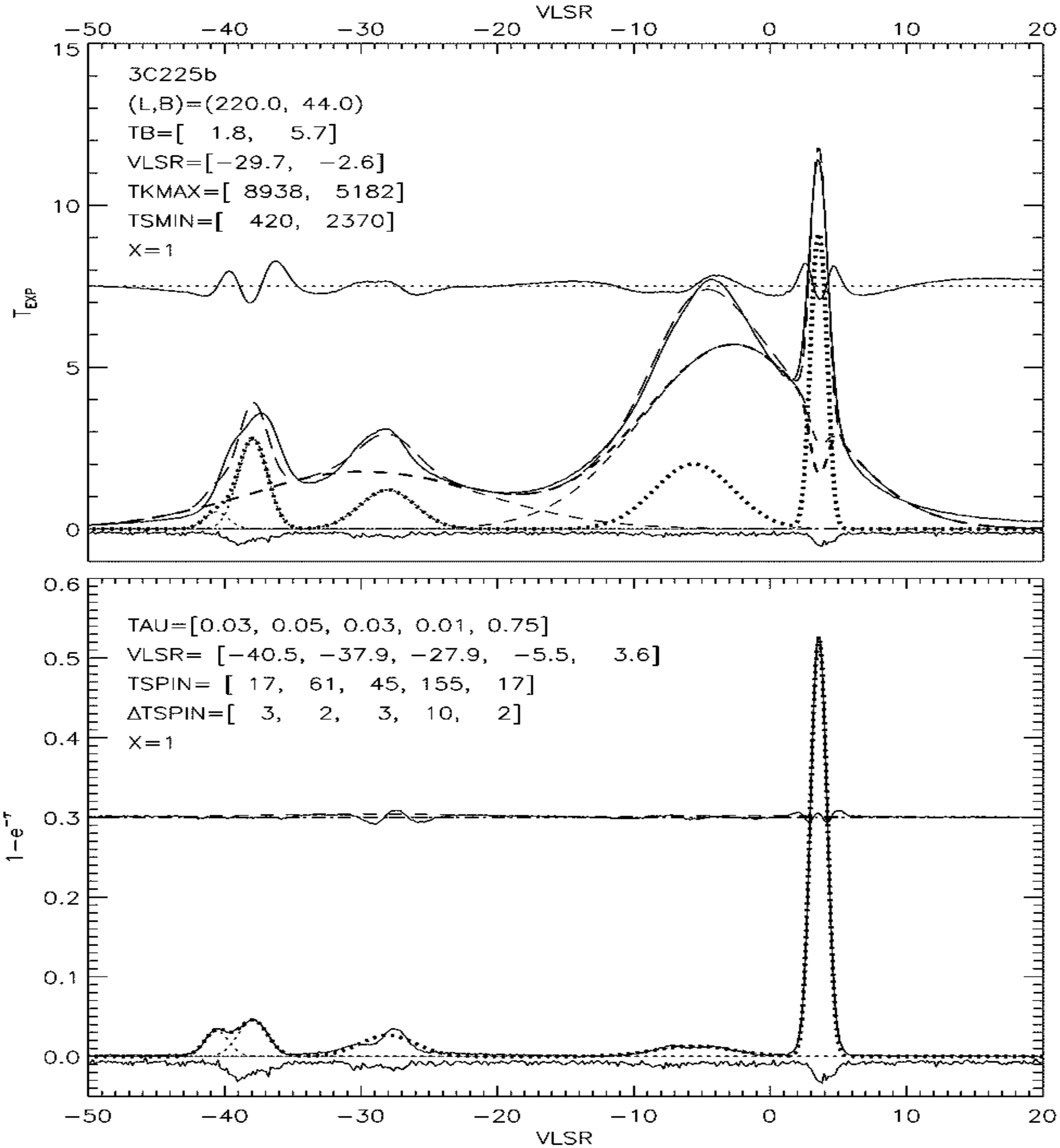
Here's our Millennium-survey friend 3C225b, showing prominent HI absorption.

We measure the temperature (17 K); we use ISM pressure (4000 cm^{-3} K) to get volume density.

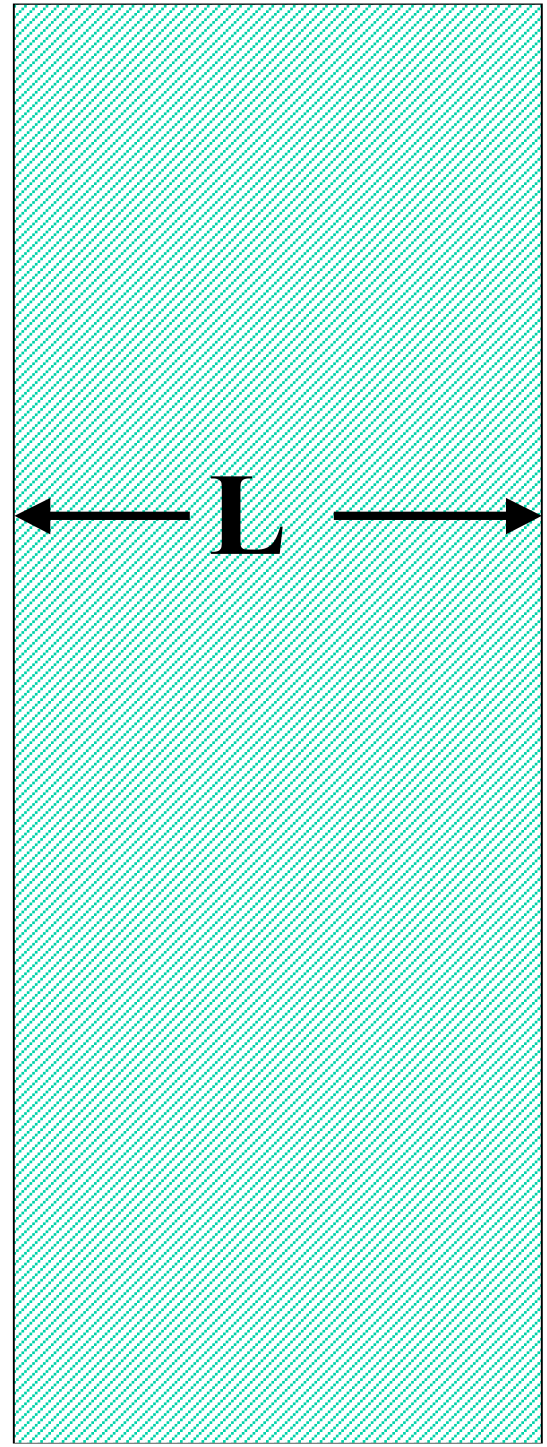
N(HI) ~ 10^{19} cm^{-2}
n(HI) ~ 200 cm^{-3}

N(HI)=n(HI) * L

WHAT'S L????

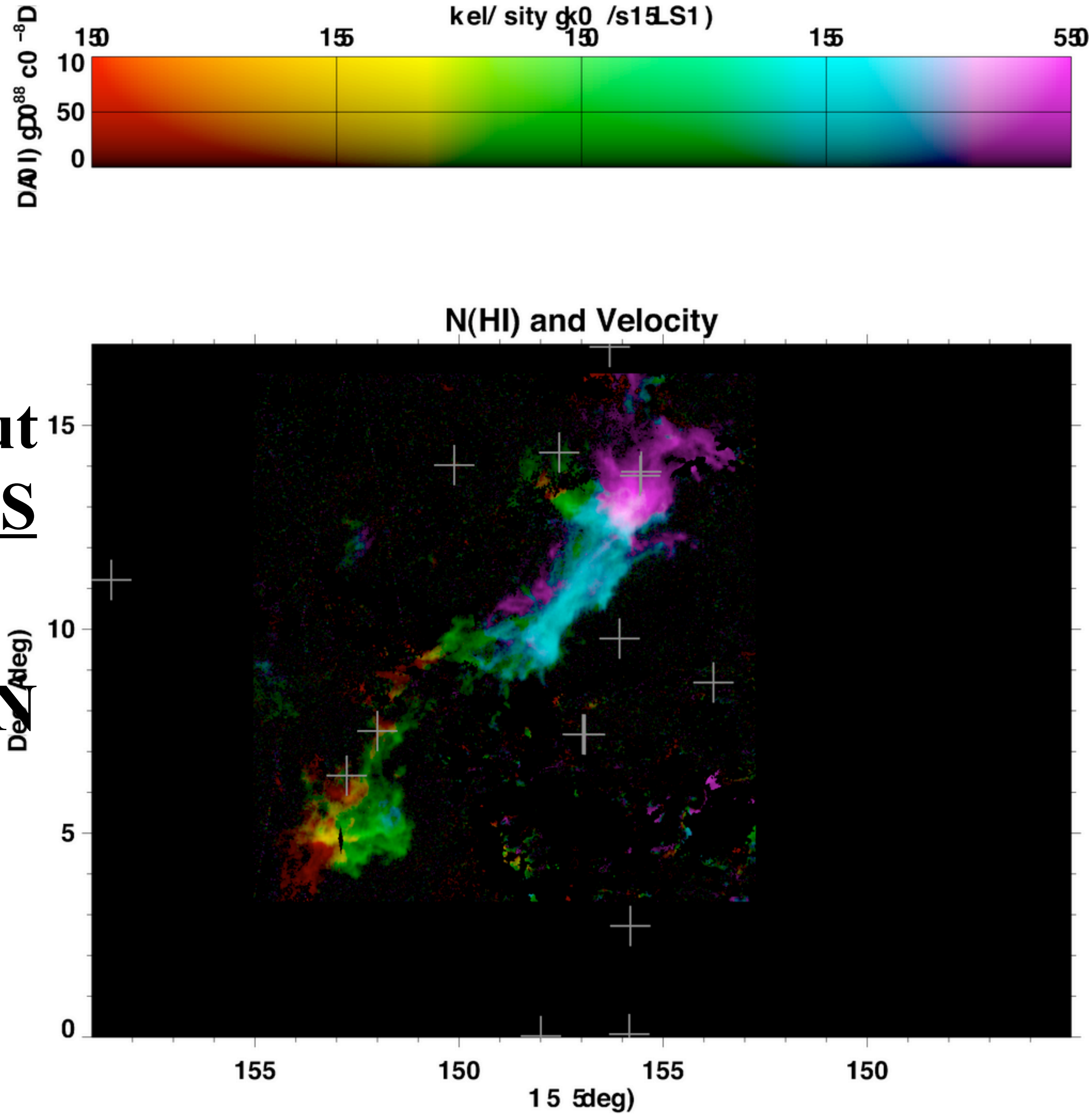


L is the thickness of the cloud along the line of sight. It's small: 0.02 parsecs. If this cloud were spherical, it would occupy an angle of 30 arcsec or so—tiny!



Arecibo (GALFA) map. It occupies an angle of about 10 <u>DEGREES</u>

So it's an ULTRATHIN SHEET, like a piece of paper.



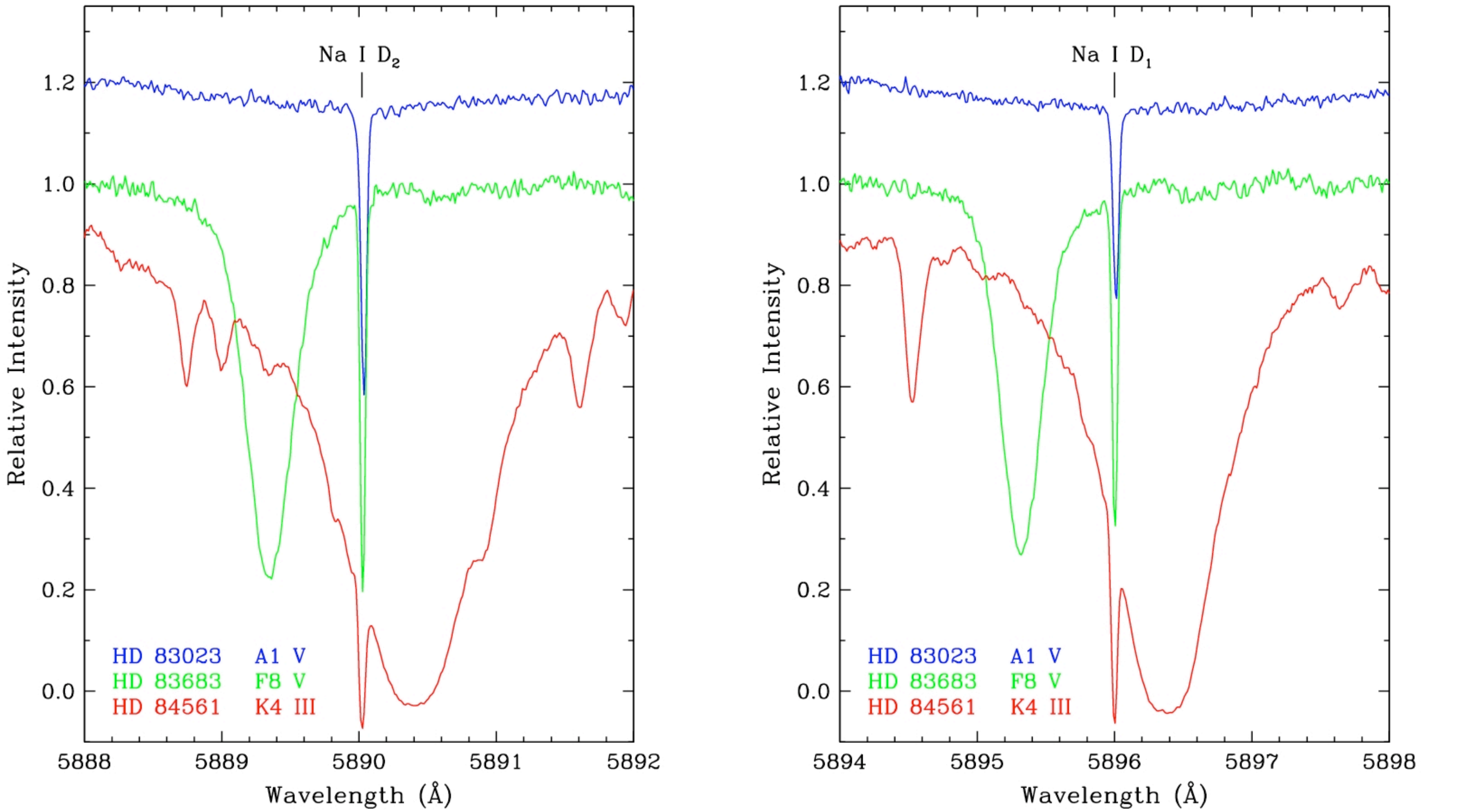
Kitt Peak 2.1m

high spectral resolution!

Keck 10m.

BIG, but lower resolution.

Interstellar Na I Absorption in 3C 225 Region



Recent high-resolution (1.3 km/s) observations with the KPNO Coude Feed have revealed interstellar Na I toward a number of nearby stars in the 3C 225 region.

The Na I lines are strong & narrow - easily detected toward even late-type stars!

A COLD NEARBY CLOUD INSIDE THE LOCAL BUBBLE

DAVID M. MEYER[1] AND J. T. LAUROESCH[2]
Department of Physics and Astronomy, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208;
davemeyer@northwestern.edu, jtl@elvis.astro.northwestern.edu
AND
CARL HEILES, J. E. G. PEEK, AND KYLE ENGELHORN
Department of Astronomy, University of California at Berkeley, 601 Campbell Hall, Berkeley, CA 94720-3411;
heiles@astro.berkeley.edu, goldston@astro.berkeley.edu, kengelho@ugastro.berkeley.edu
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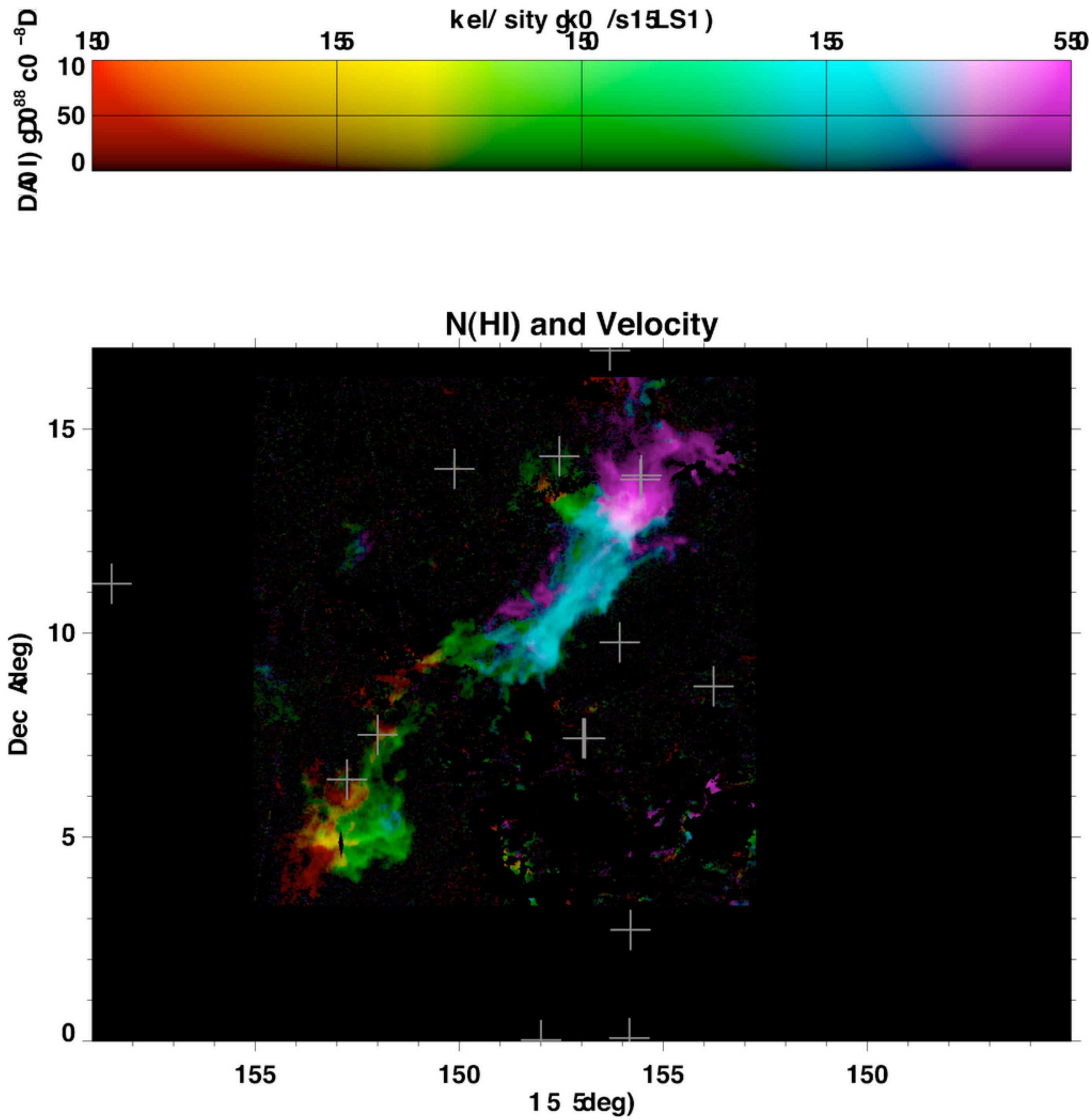
ABSTRACT

The high-latitude Galactic H I cloud toward the extragalactic radio source 3C 225 is characterized by very narrow 21 cm emission and absorption indicative of a very low H I spin temperature of about 20 K. Through high-resolution optical spectroscopy, we report the detection of strong, very narrow Na I absorption corresponding to this cloud toward a number of nearby stars. Assuming that the turbulent H I and Na I motions are similar, we derive a cloud temperature of 20^{+6}_{-8} K (in complete agreement with the 21 cm results) and a line-of-sight turbulent velocity of 0.37 ± 0.08 km s^{-1} from a comparison of the H I and Na I absorption line widths. We also place a firm upper limit of 45 pc on the distance of the cloud, which situates it well inside the Local Bubble in this direction and makes it the nearest known cold diffuse cloud discovered to date.

and...new Keck observations show LOWER limit of 11.3 pc.
Aspect ratio ≈ 1000:1, like a sheet of paper!

This ultrathin sheet lies within the “Local Bubble”!

Arecibo (GALFA) map of the ultrathin sheet.



The edges show rapid variations in velocity and width; the central portions show much slower variations.

The velocity fluctuations at the edges are ~0.5 km/s. For a thickness of 0.02 pc, the timescale for disruption is…

Disruption time = (L / v) = 35000 years.

This cloud does not exist in a vacuum. In what kind of medium is it embedded?

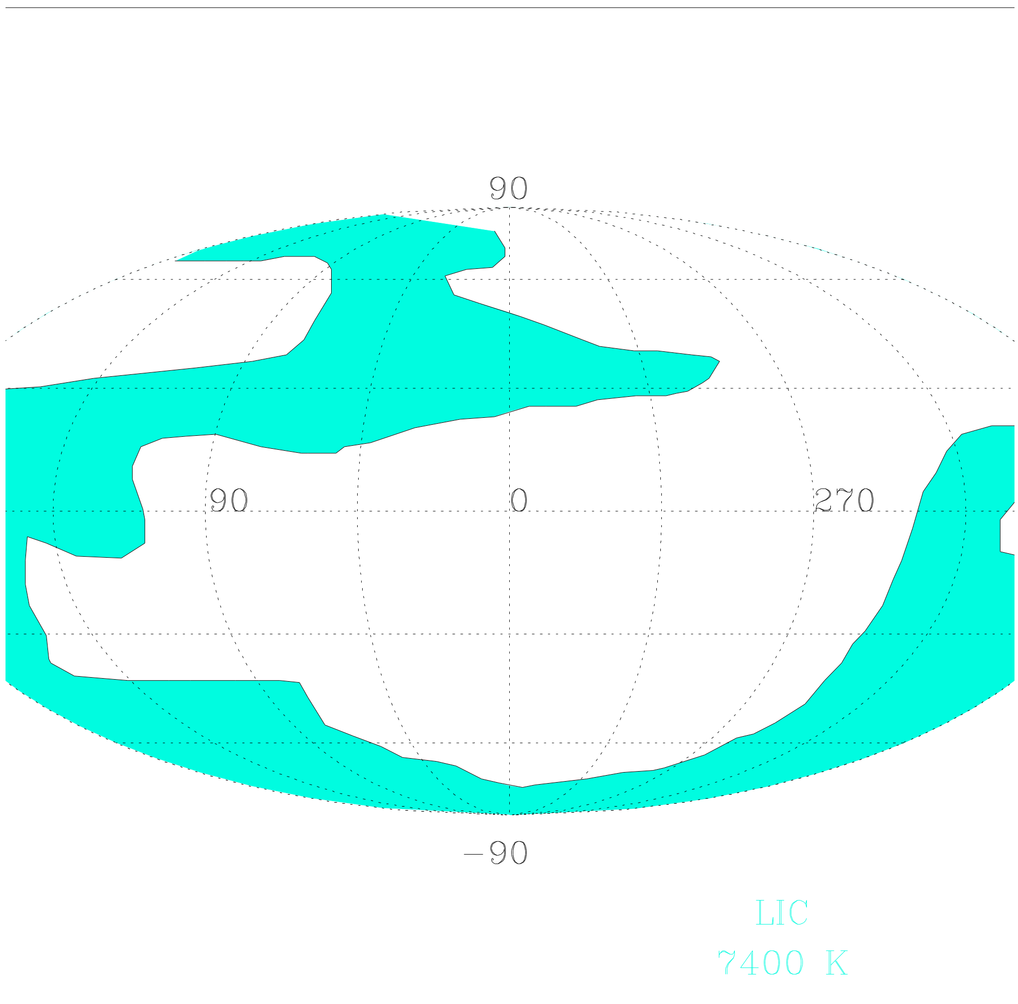
Is the cloud evaporating into its surroundings, or are the surroundings condensing onto the cloud? Are we seeing ablation? Shredding?

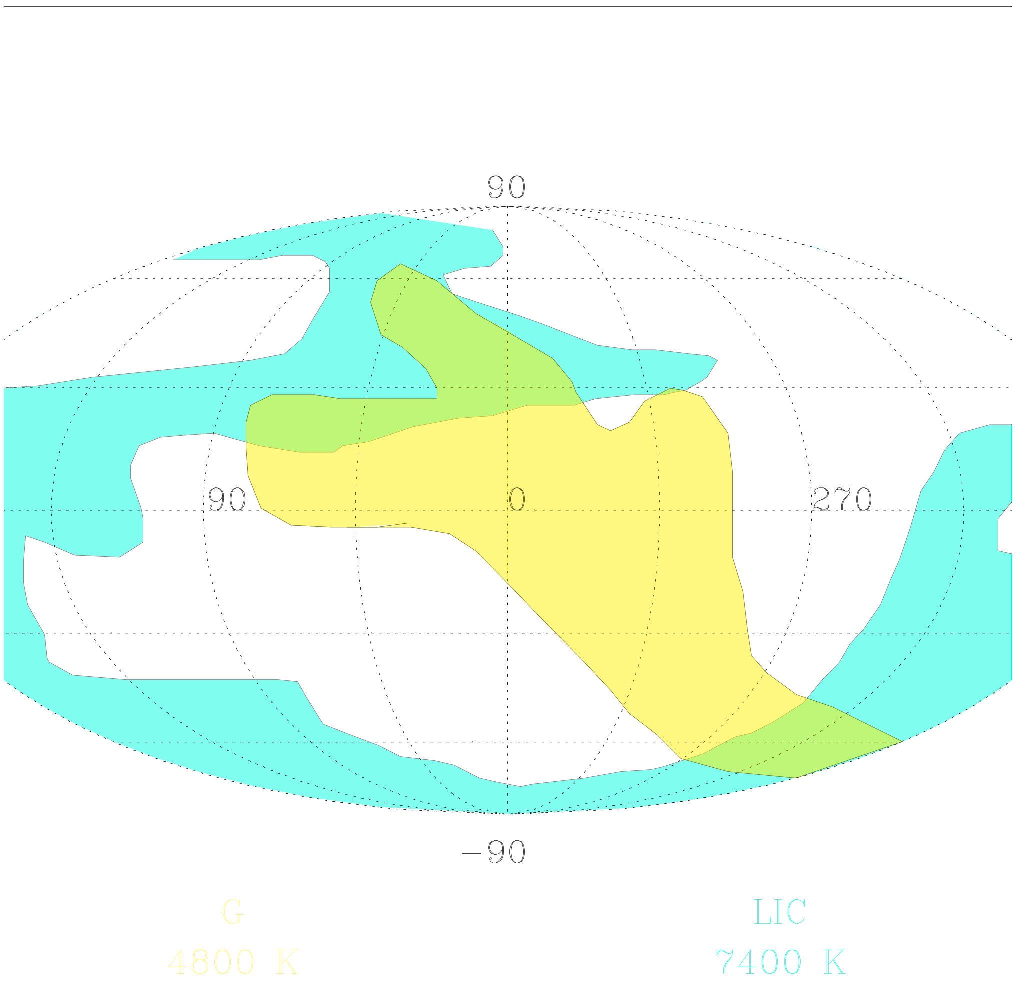
The velocity/width fluctuations are dynamics. Does the dynamics arise from motion through the surroundings? Or thermal processes like evaporation/condensation? Are they affected by magnetic field?

YET MORE CONTENTS OF THE LOCAL BUBBLE:

Warm (about 10000 K—a lot less than a million K!) clouds, mainly atomic, partially ionized.

Mapped from their absorption lines against dozens of nearby stars (Redfield and Linsky 2007).


90
90
0
270
−90
LIC
7400 K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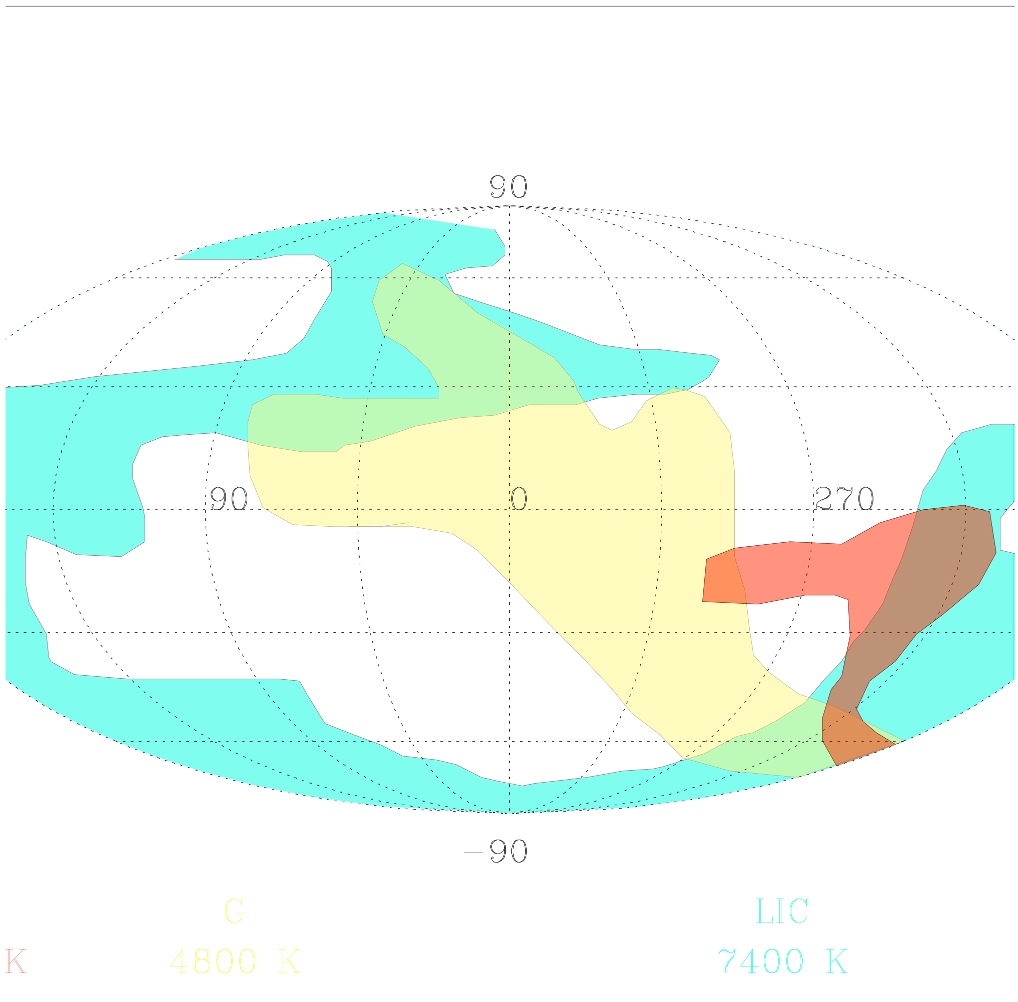
0
270
−90
G
4800 K
LIC
7400 K



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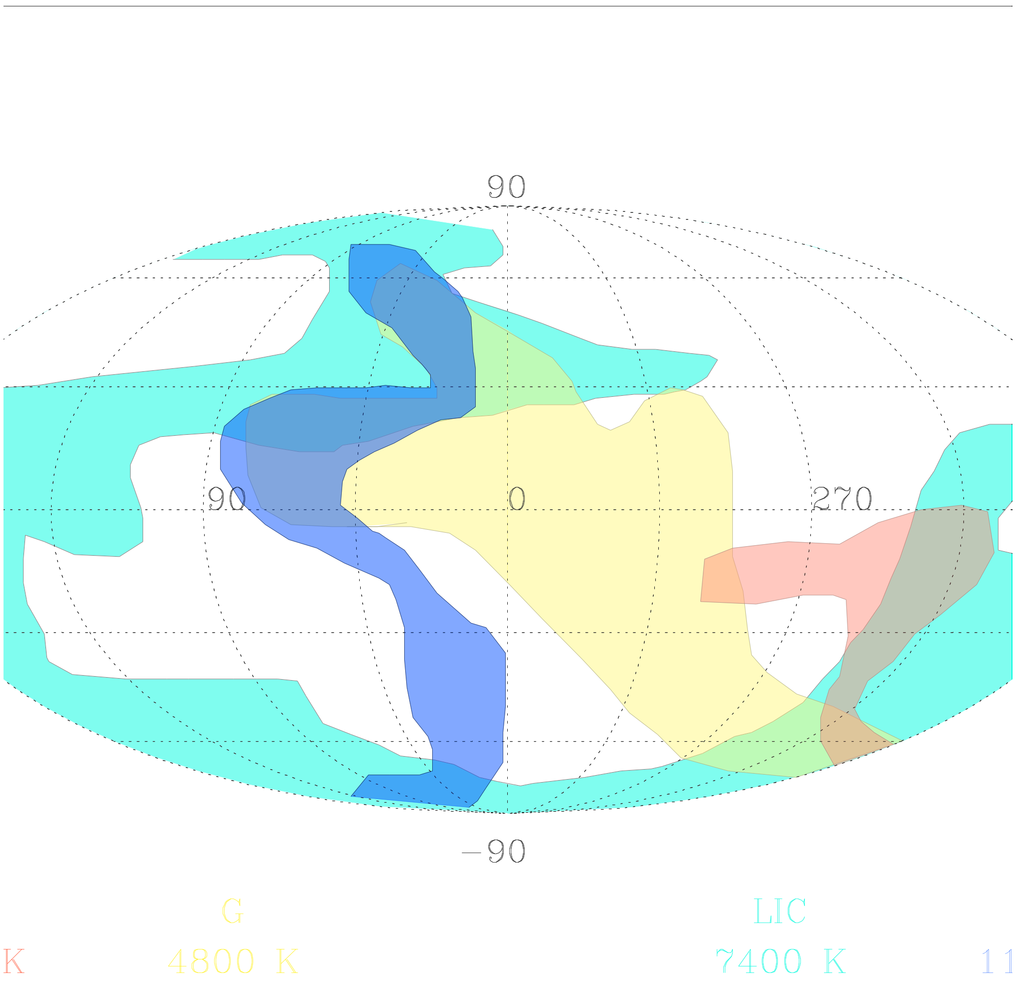
G
4800 K
LIC
7400 K
K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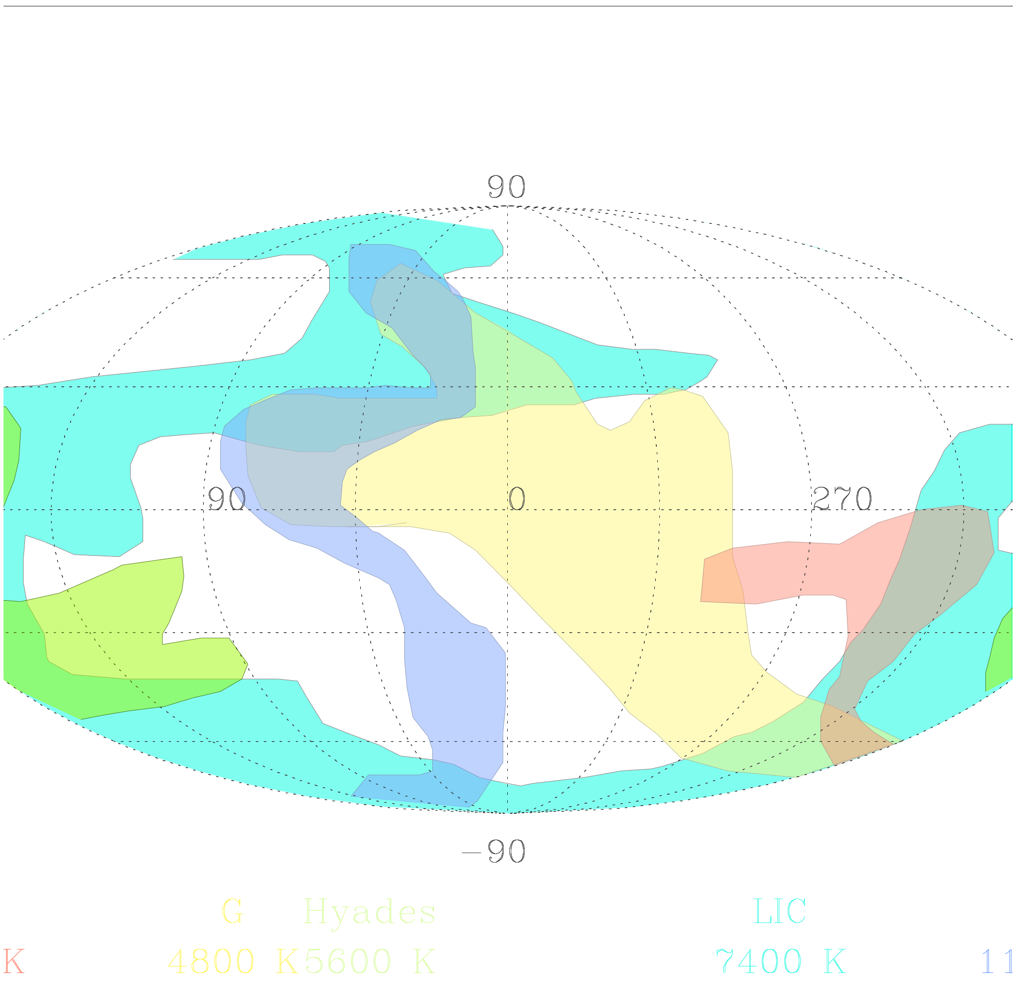
LIC
7400 K
K
11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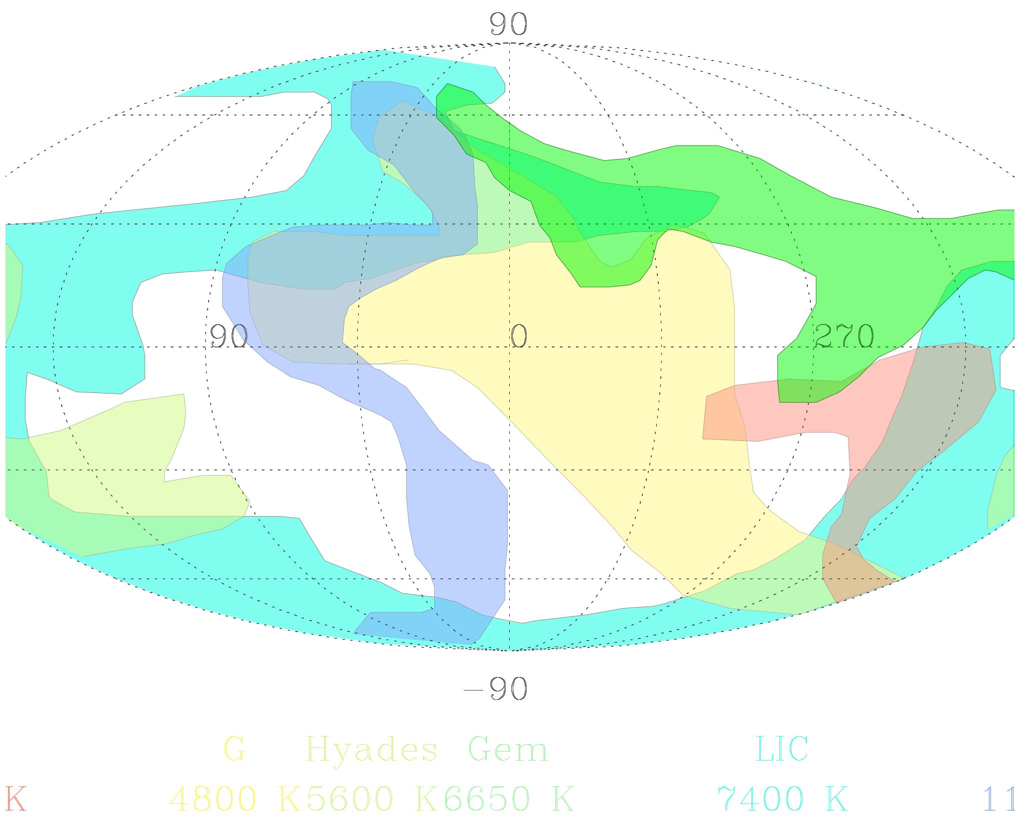
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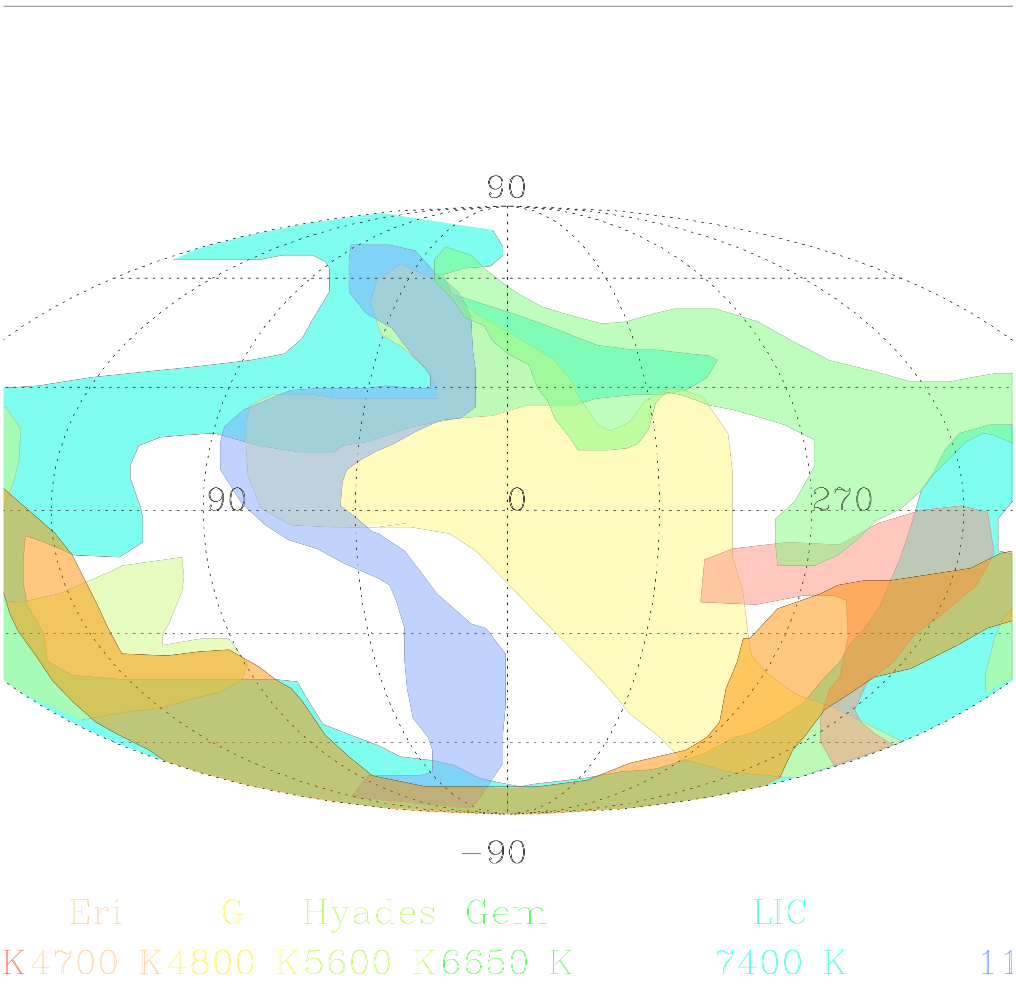
−90
G Hyades Gem
LIC
K
4800 K5600 K6650 K
7400 K
11



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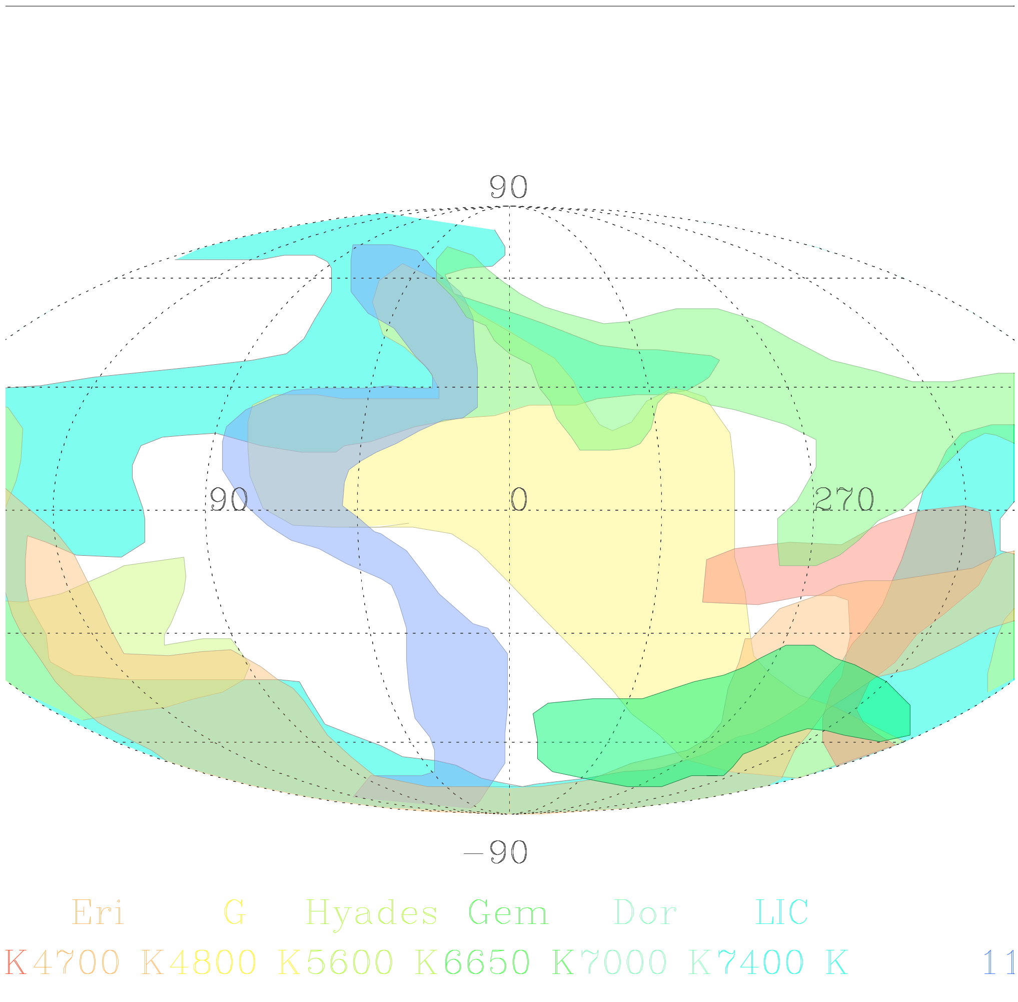
LIC
K4700 K4800 K5600 K6650 K
7400 K
11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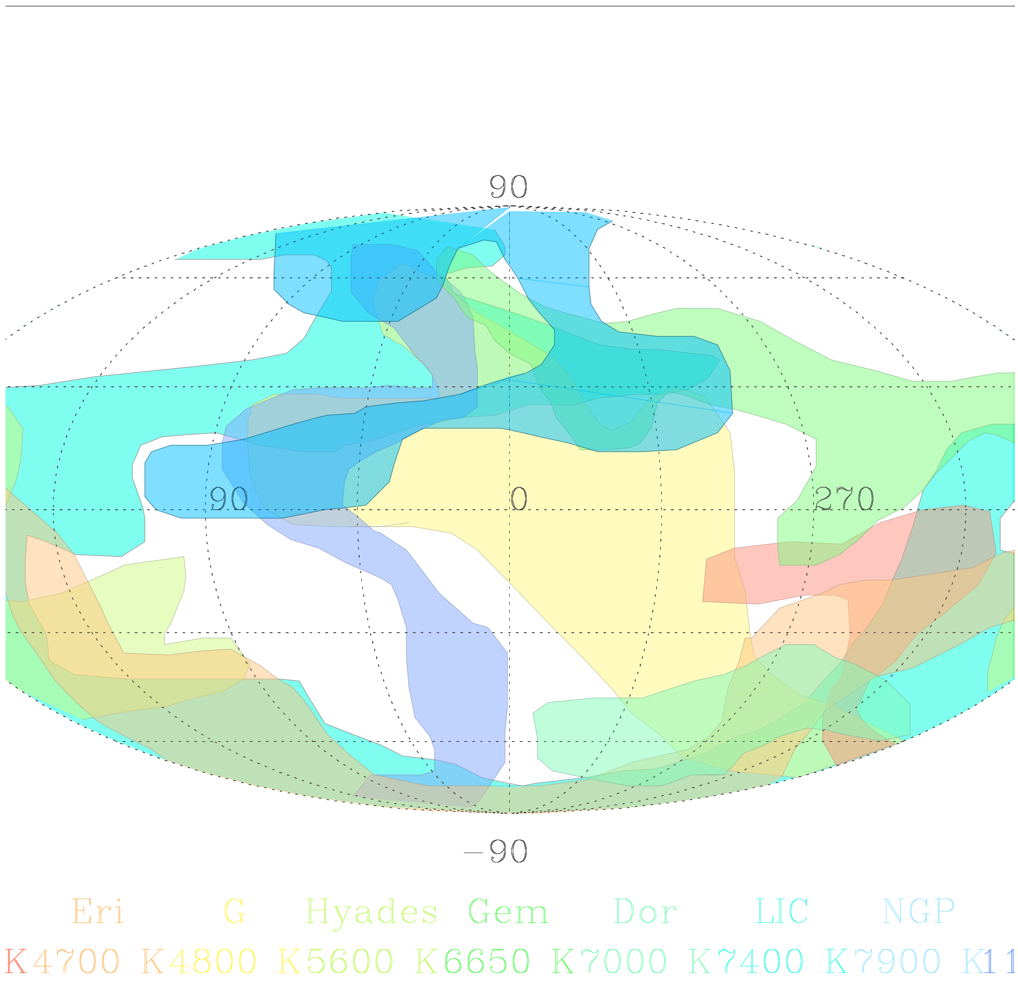

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G
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LIC
NGP
K4700
K4800
K5600
K6650
K7000
K7400
K7900
K11

Table 13. Summary of Cloud Properties

Cloud Name	Number Stars	Central Coordinates $l(^\circ)$	$b(^\circ)$	Closest Star (pc)	$< T >$ (K)	Number Stars	<D(Fe)>	Number Stars	<D(Mg)>	Number Stars
G	18	0	+10	1.3	4,800	4	–0.53	4	–0.33	4
LIC	37	180	+00	2.6	7,400	12	–1.16	9	–0.96	11
Blue	4	240	–30	2.6	3,000	2	–0.95	1	–0.77	1
Mic	13	40	+15	5.1	11,300	4	–0.90	2	–0.41	4
Hyades	12	180	–20	9.2	5,600	4	–1.04	3	–0.95	4
Gem	8	300	+40	10.3	6,650	2	–1.29	1	–1.19	2
Leo	9	0	+60	11.1	–	–	–	–	–	–
Eri	8	180	–15	11.7	4,700	2	–0.43	2	–0.02	2
Dor	4	270	–50	11.7	7,000	1	–0.80	1	–0.65	1
NGP	12	10	+45	14.3	7,900	4	–1.10	4	–0.95	3

There is some suspicion that our

(1) Earth-size scintillation-producing turbulence

(2) paper-thin sheet

are related to <u>intersecting boundaries</u> of these warm clouds.

Our Local Microcosmos:

- **7 nearby superbubbles, including Ori-Eri and the NPS**

- **Local Bubble clearly defined by its dense walls. Also by X-rays?**

- **Interstellar twinkling, VLA/ATCA: Earth-size spicules a few parsecs away**

- **Paper-thin cloud ~20 parsecs away**

- **9 Warm clouds close to sun, related to above?**

Basic message of science:

WE ARE NOT UNIQUE

WE ARE NOT THE CENTER OF THE UNIVERSE

so

¡¡ALL THESE STRUCTURES MUST BE COMMON!!