Probing the Local ISM with UV Spectroscopy: Properties, Structure and Possible Causes

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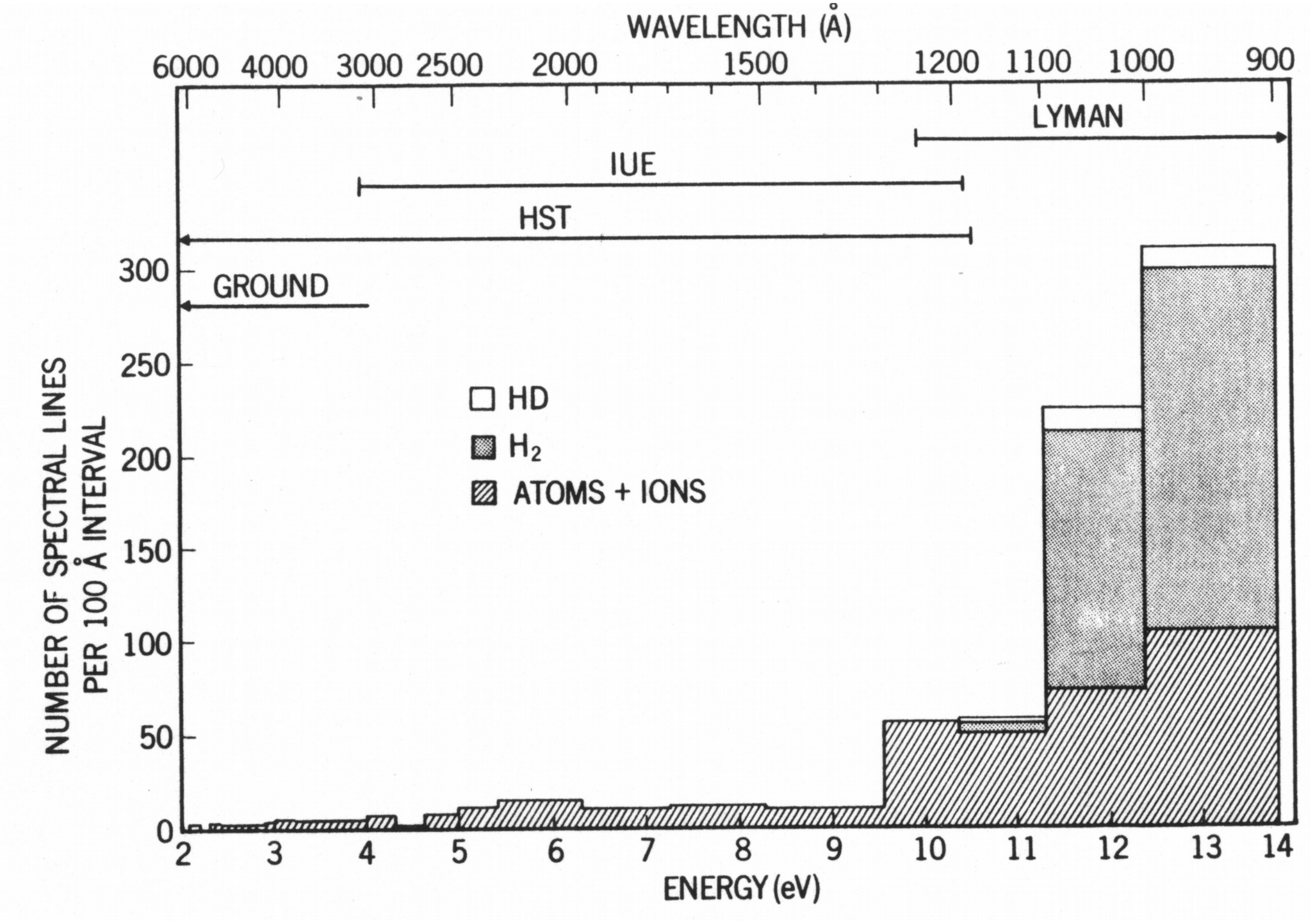
Outline

- Why study the local ISM with UV spectroscopy?
- Measuring the physical properties of the LISM gas-temperature, kinematics, and magnetic fields
- Evidence for structure in the LISM: many warm partially ionized clouds or one cloud?
- Comparing the observed properties of the LISM with theoretical models and simulations
- 4 possible physical causes for structure of the LISM clouds – is there any observational evidence
- What lies between the warm clouds?

The figure that sold FUSE to NASA



Atoms, ions, and molecules with absorption lines suitable for ISM studies

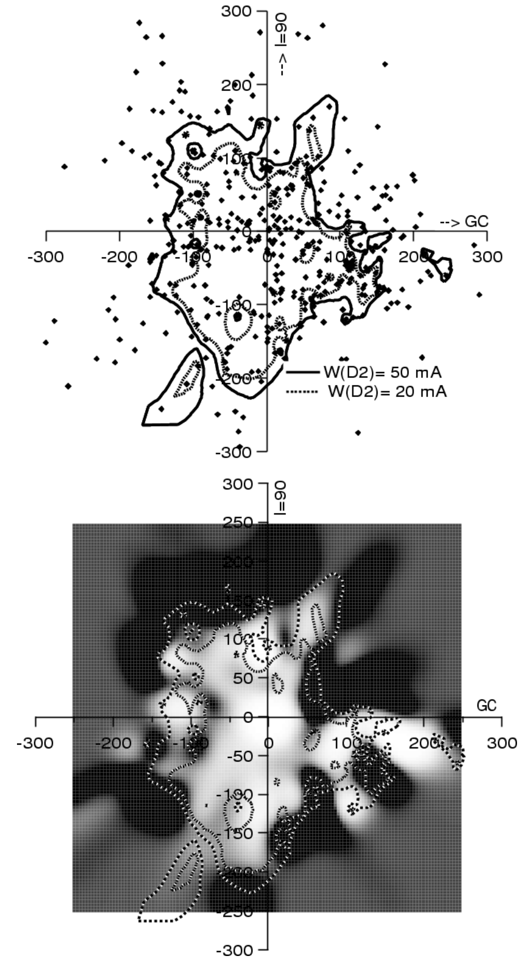
Spectral Range	I	II	III-VI
Optical (300-1000nm)	NaI, AlI, CaI, KI	CaII	
NUV (170-300nm)	NaI, MgI, AlI, SiI	MgII, SiII, FeII	
FUV (120-170nm)	HI, DI, CI, NI, OI, PI, ClI, CO	CII, AlII, SiII, PII, SiII, SII, FeII	CIV, NV, AlIII, SiIII, SiIV, PIII, SiIII
LUV (90-120nm)	HI, NI, ArI, H_2, HD	CII, NII, ClII, ArII	CIII, OVI, NIII, PIV, PV, SIV, SVI, ClIII, ClIV

LISM Science Objectives

- What are the properties of the LISM surrounding the Sun today, in the recent past, and in the future? Is the LISM consistent with the results from Voyager and IBEX?
- What is the distribution of physical properties in the LISM? Are these properties consistent with the classical 3 component ISM? Is there hot gas in the LISM?
- Is the ionization of LISM gas thermal, recombination from past SN explosions, or controlled by stellar EUV?
- Is the structure of LISM gas filamentary?
- How important are magnetic fields in the LISM and what roles do they play?
- Is the LISM a useful role model for understanding the ISM in the Galaxy?

Why understanding the local ISM is important for understanding the Galactic ISM

- Understanding the physical processes in the ISM of our Galaxy is needed before attempting to model other galaxies (i.e., starbursts, low z)
- First understand the physical processes operating in our own back yard where we have the best data and highest angular resolution.
- Figure of the Local Bubble from Lallement et al. (2003) A+A 411, 447.



Relation of the local ISM to the heliosphere

- Physical properties of neutral H gas immediately outside of the heliosphere provide the outer boundary condition for the heliosphere.
- If the surrounding gas were ionized, the structure of the heliosphere would be very different.
- The Sun is moving at 26 km/s in the direction of the edge of the LIC and will leave in 0-4000 yr. The edge is less than 0.1 pc = 20,000 AU upstream.
- Question: Are the properties of the outer heliosphere and inner LISM consistent?
- Question: Are the properties at the edge of the LIC different from deep inside the LIC?

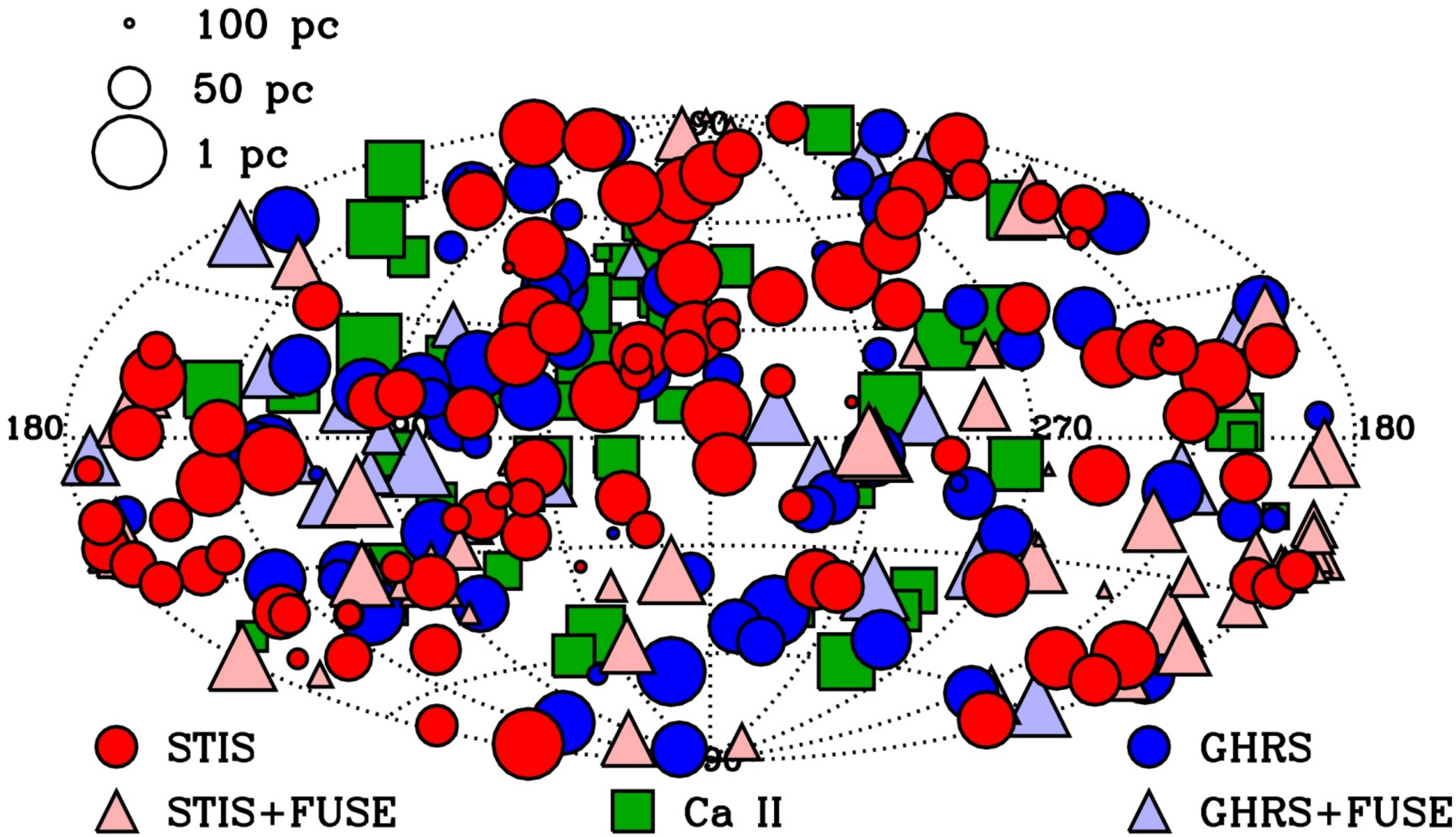
Past and future work of the Redfield-Linsky LISM group

- Redfield & Linsky (ApJ 673, 283 (2008)) – 15-cloud model based on the analysis of high-resolution UV spectra (mostly with HST GHRS + STIS) for 157 sightlines. [RL08]
- Linsky, Rickett, & Redfield (ApJ 675, 413 (2008)) – Quasar radio scintillation screens are located at the edges of nearby LISM clouds.
- Malamut et al. (ApJ 787, 75 (2014)) – an additional 34 sightlines selected through a STIS SNAP observing program.
- Redfield & Linsky. (Apj 822, 125 (2015)) – Morphology of the LISM
- Edelman et al. – properties of the LISM along sightlines to nearby planet-hosting solar-like stars (to be submitted to ApJ)
- Redfield & Linsky (to be submitted to ApJ) – analysis of LISM morphology (continuous or discrete clouds?)

Measuring physical properties of LISM gas – temperature, kinematics, and magnetic fields

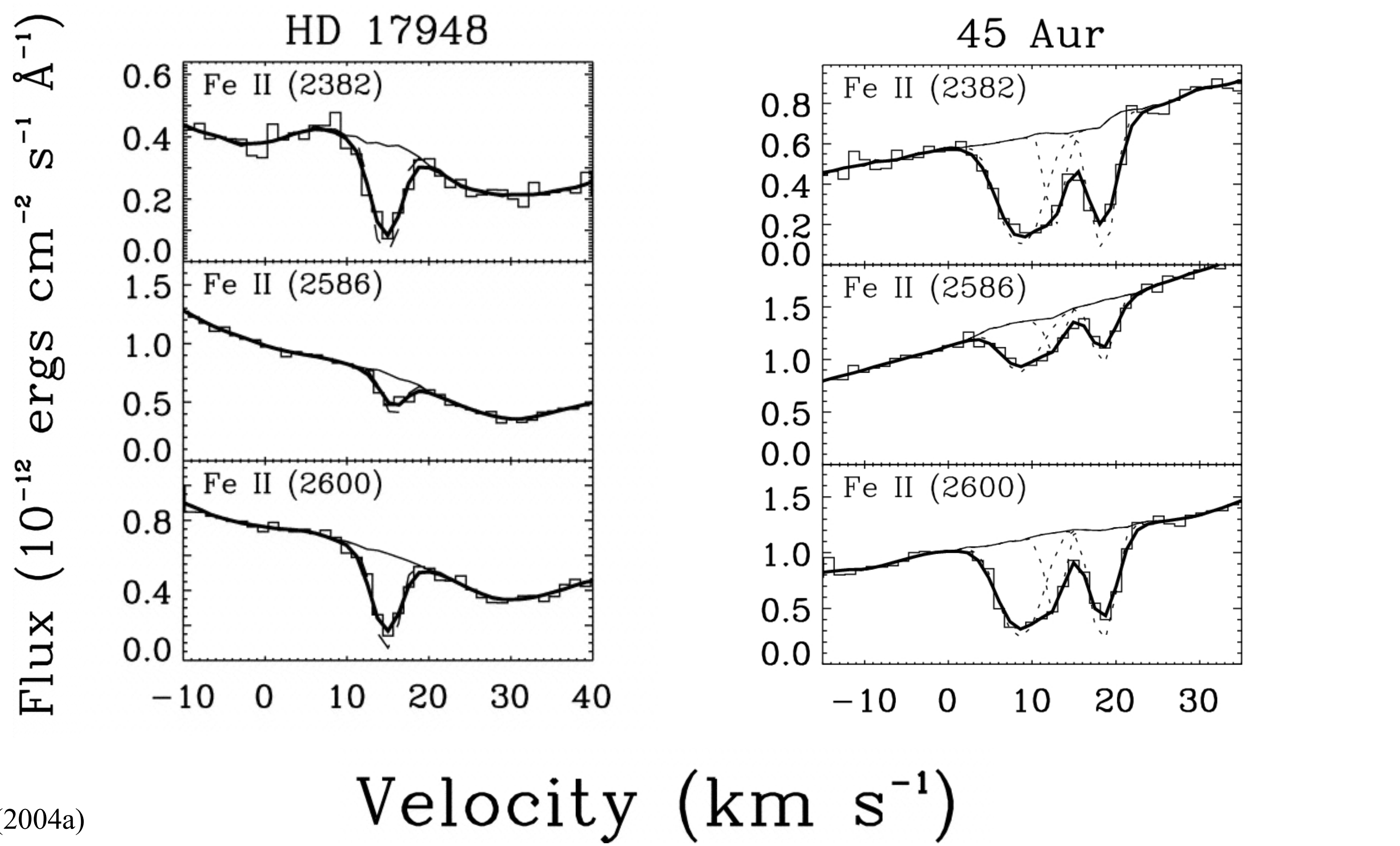
LISM Sample

160 targets within 100 pc observed at high and moderate resolution that contain 270 LISM absorption components (~60% of UV observations taken for other purposes).



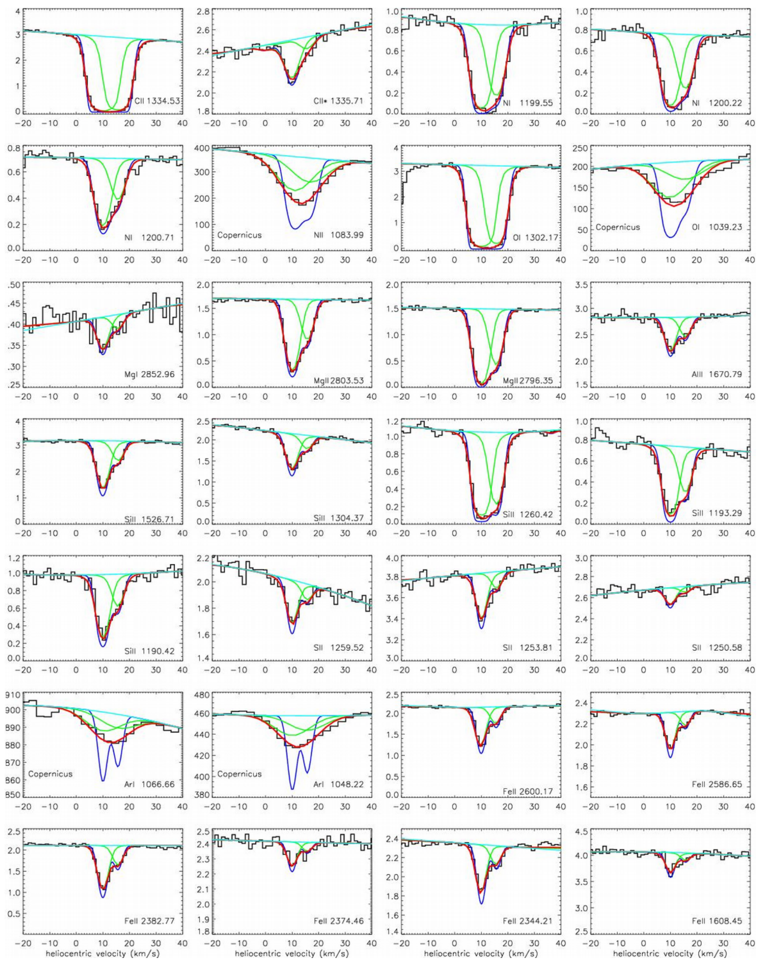
Observational Diagnostics

1 ion, 1 sightline → ***Velocity***, Column Density



Redfield & Linsky (2004a)

High-resolution STIS spectra for the 24 pc LOS to α Leo (Gry & Jenkins 2017)



Observational Diagnostics

1 ion, 1 sightline → ***Velocity***, Column Density

multiple ions, 1 sightline → Temperature, Turbulence, Volume Density, Abundances, Depletion, Ionization Fraction

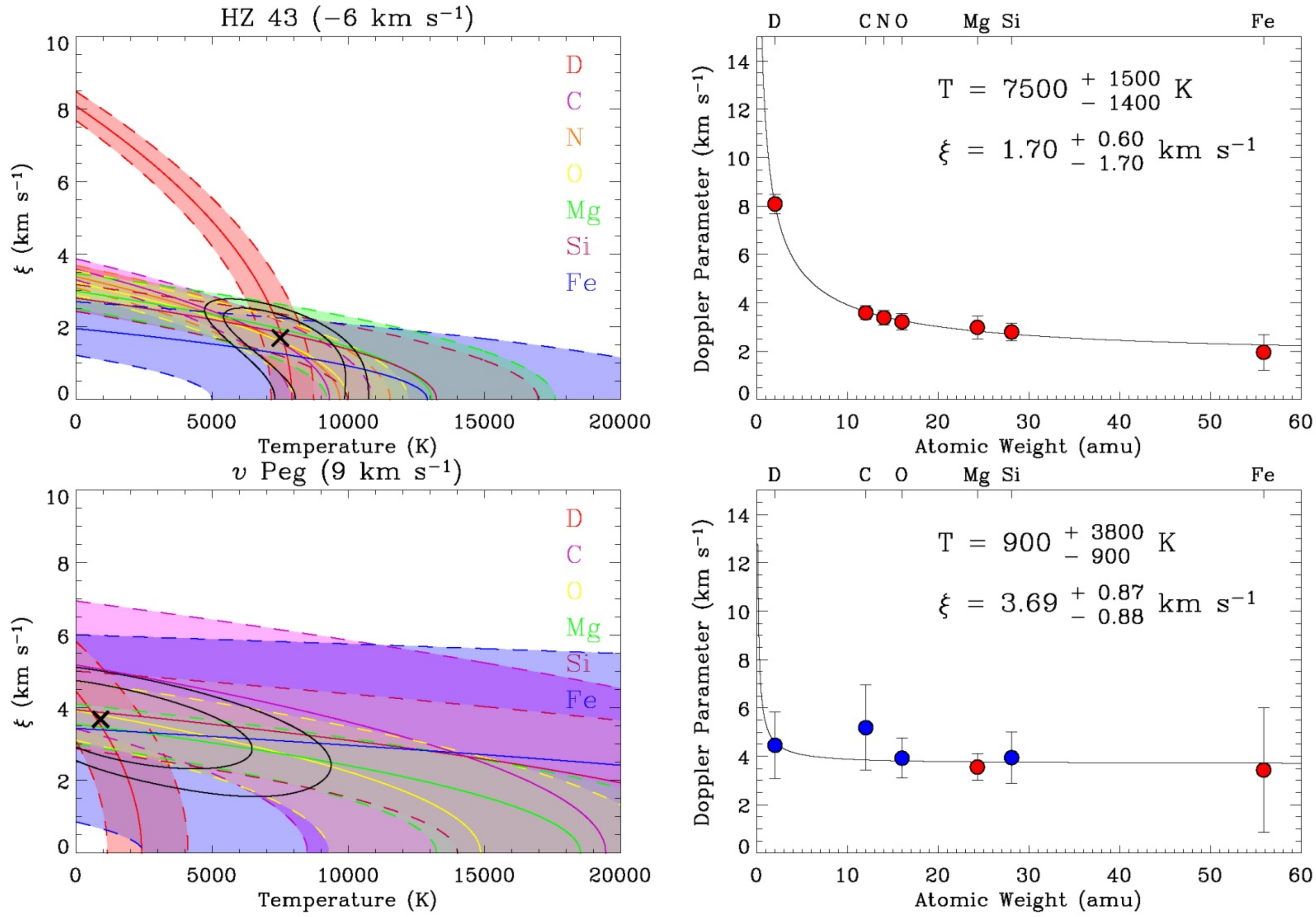
$$b^2 = \frac{2kT}{m} + \xi^2$$

$$D(X) = \log\left(\frac{X}{H}\right) - \log\left(\frac{X}{H}\right)_\odot$$

$$\frac{N_{\mathrm{CII}^*}}{N_{\mathrm{CII}}} = \frac{n_{\mathrm{e}} C_{12}(T)}{A_{21}}$$

Observational Diagnostics

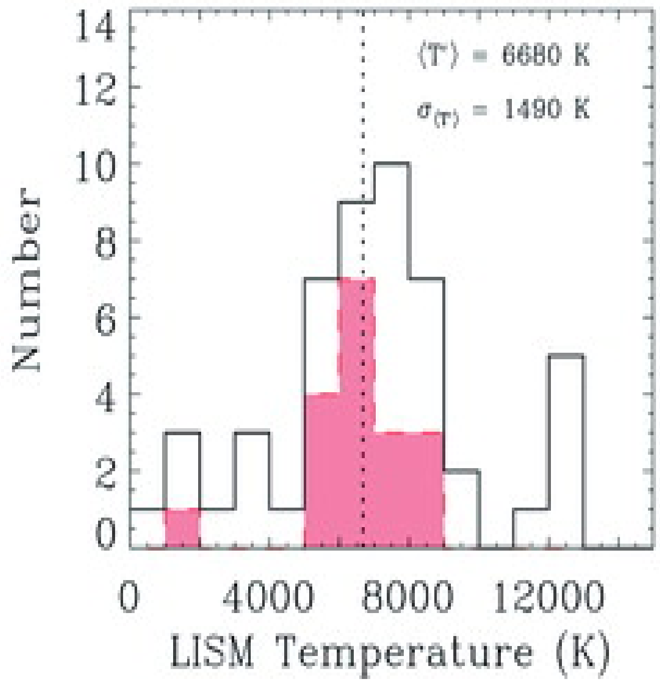
1 ion, 1 sightline →	***Velocity***, Column Density
multiple ions, 1 sightline →	Temperature, Turbulence, Volume Density, Abundances, Depletion, Ionization Fraction
multiple ions, multiple sightlines →	Global Morphology, ***Global Kinematics***, Intercloud Variation
	Origin and Evolution, Interaction of LISM Phases

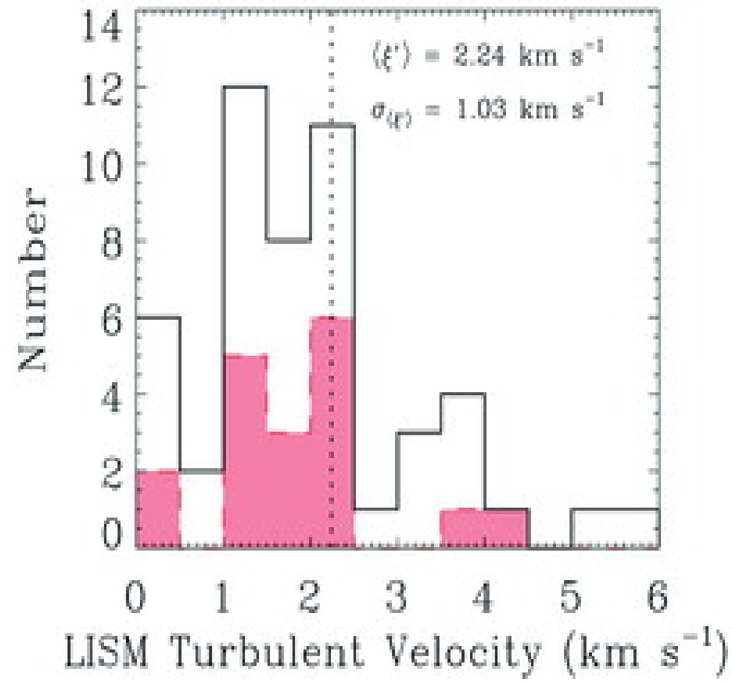


$$b^2 = \frac{2kT}{m} + \xi^2$$

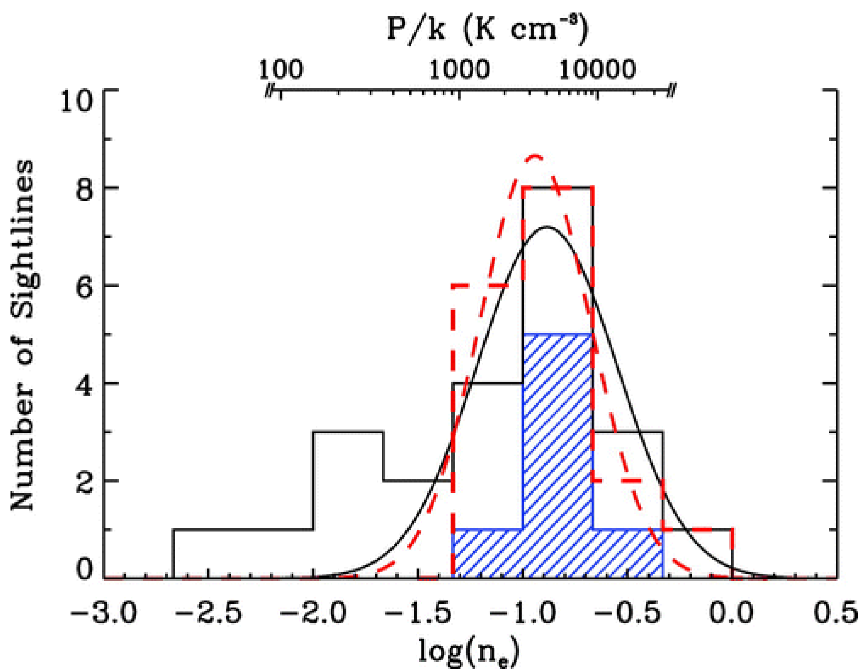
Redfield & Linsky (2004b)

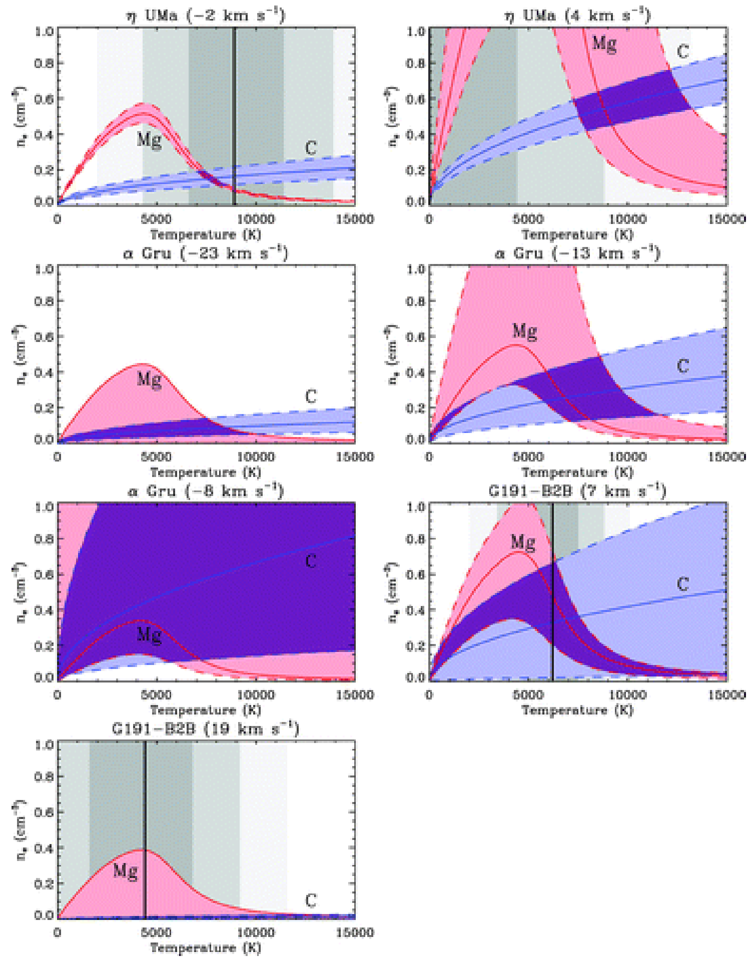
Distributions of temperatures and nonthermal broadening for warm clouds in the Local Bubble with HST spectra (Redfield and Linsky ApJ 613, 1004 (2004))





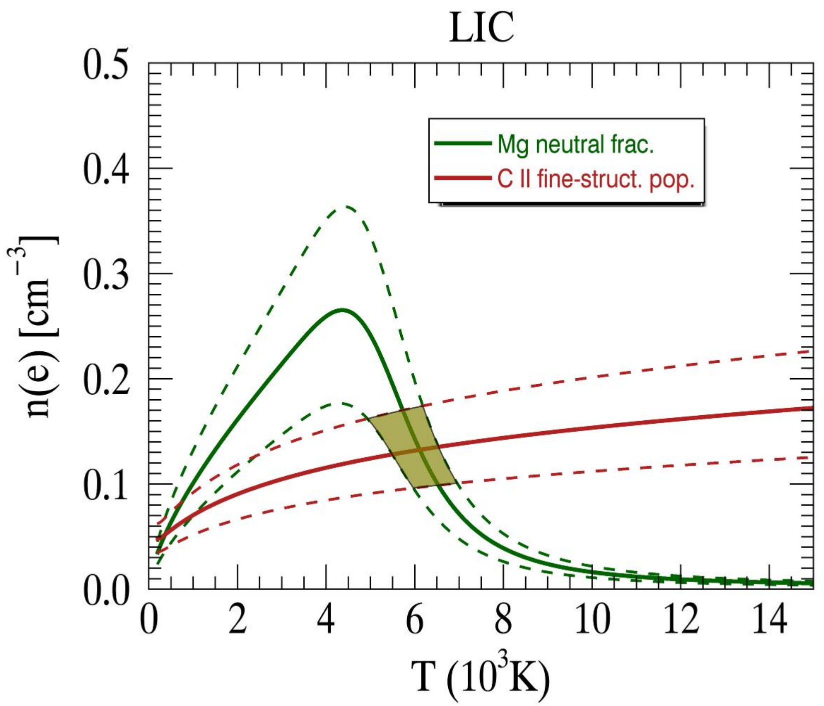
Measuring electron densities from the Mg II/MgI and CII 133.566/133.45 nm fine structure line excitation

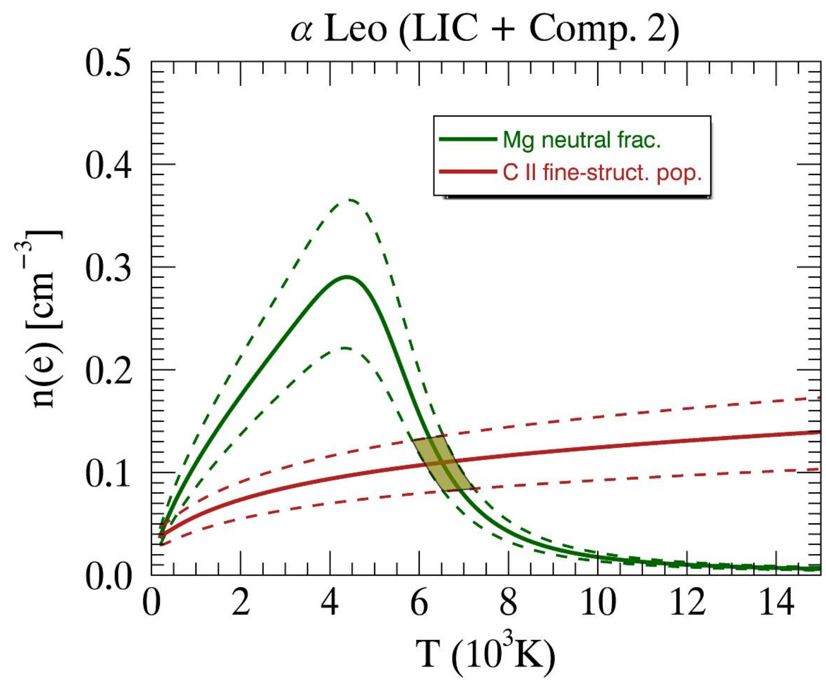




Redfield & Falcon ApJ 683, 207 (2008). Blue hatched is for sightlines through the LIC. Black is for all LOS.

Electron density and temperature measurements using the MgII/MgI and CII fine structure lines (Gry & Jenkins 2017)





T=5,000-7,000
n(e) = 0.095-0.17

T=5,900-7,250
n(e)=0.08-0.135

Comparing temperature measurements inside LISM clouds with gas flowing into the heliosphere

Temperature	Technique	Reference
6200-8800	Line widths (D to FeII) in LIC	Redfield & Linsky (2008)
5900-7250	Line widths and CII excitation to α Leo	Gry & Jenkins (2017)
6990-7530	Reanalysis of the Ulysses He inflow	Wood et al. (2015)
8030-9390	IBEX He flow in heliosphere	Mobius et al (2015)
~7500	IBEX He flow in heliosphere	McComas et al. (2015)

Concerns about the analysis of the IBEX neutral He flow data:

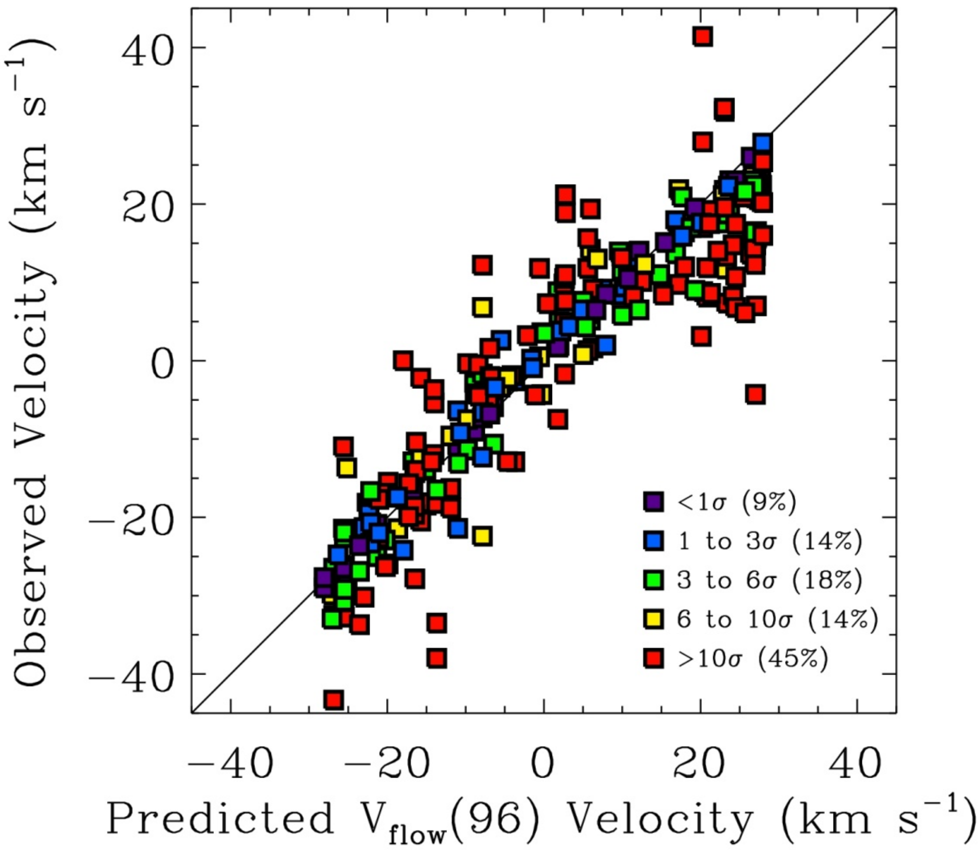
(1) There is evidence for a secondary component (Warm Breeze) with a temperature of about 15,000 K and different inflow direction. Maybe produced by charge exchange in outer heliosphere and thus "local" (Kubiak et al. (2014)).
(2) The flow may have an unmeasured turbulent component or depart from a thermal velocity distribution, leading to T overestimate.

Cloud physical properties

- Temperature range: 3900-9900 K.
- Turbulence: 1.2-3.6 km/s (subsonic)
- Size: roughly 1 pc but many are filamentary
- Ionization in the LIC: H is 80% neutral
- The shape of the LIC may be controlled by EUV radiation from hot stars.
- Magnetic fields: Equipartition ($P_{gas}=P_{mag}$) when B=2.7μG. If B>2.7μG (3-5μG near the Sun), then magnetic fields will control the cloud morphologies.

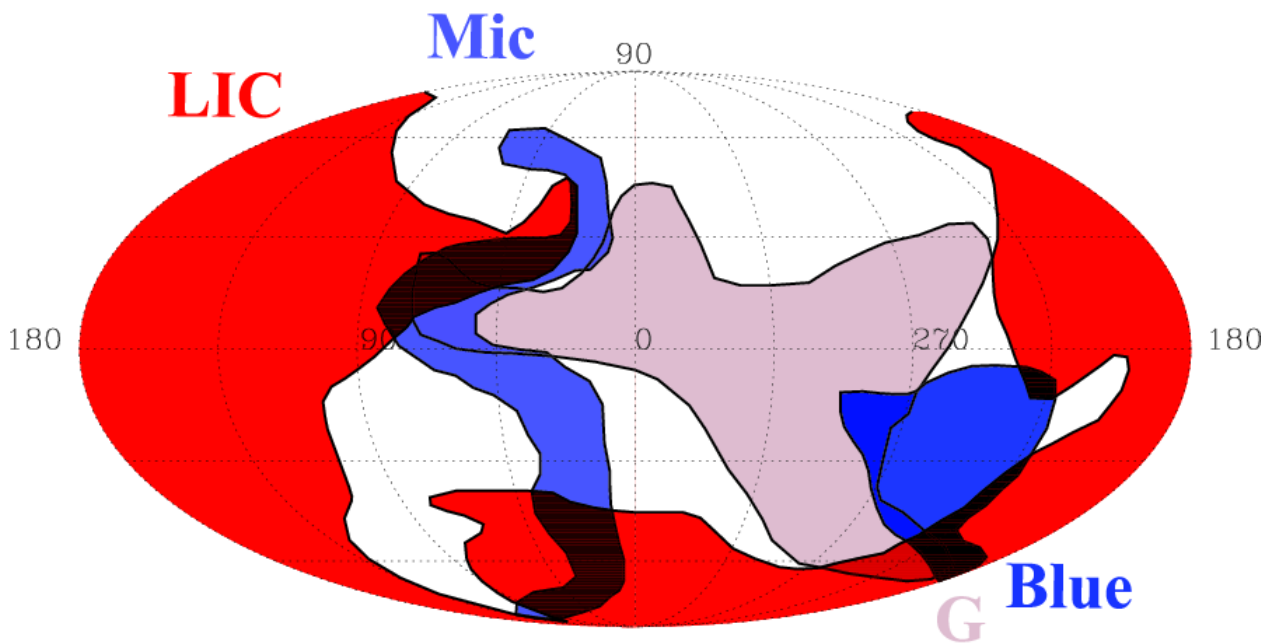
Evidence for structure in the LISM – warm partially ionized discrete clouds

LISM Sample in 2005



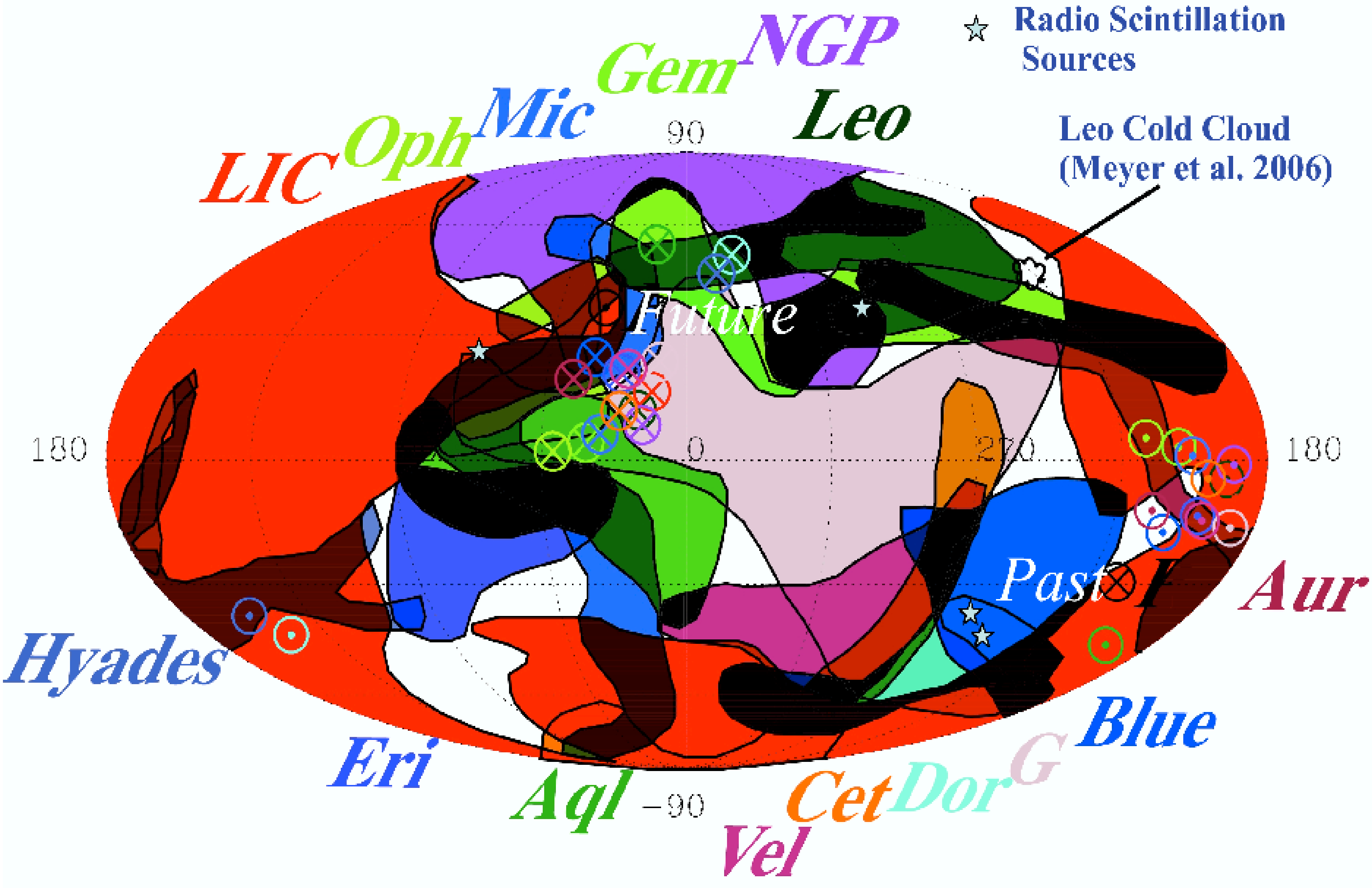
The flow in not homogeneous. Is it a nonrigid medium or discrete clouds?

The mostly neutral gas clouds located closest to the heliosphere: LIC, G(<1.3 pc), Blue (<2.6pc), three clouds (<3.5 pc), two clouds (<5.1 pc)



Each cloud is identified by a velocity vector determined from measured interstellar absorption lines (Redfield & Linsky ApJ 673, 283 (2008)).

The 15 cloud model of Redfield & Linsky (2008)



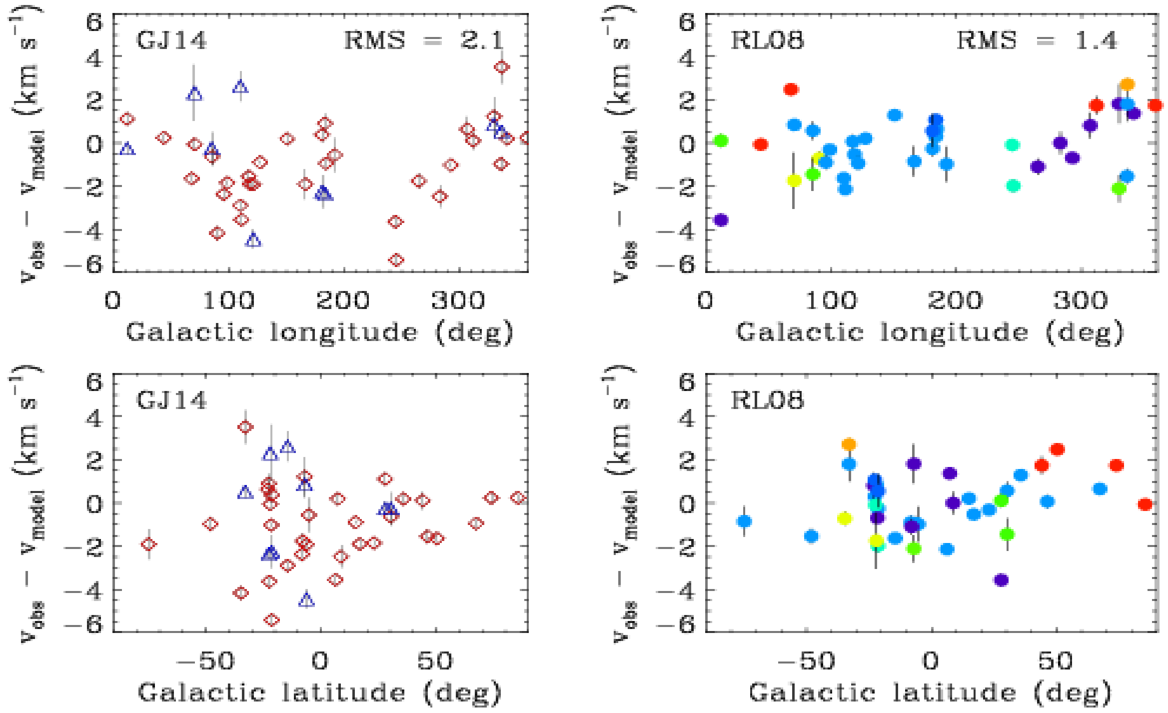
Does the LISM consist of many discrete clouds or one continuous cloud surrounding the Sun?

- Gry and Jenkins (GJ14, A&A 576, A58 (2014)) proposed that the LISM near the Sun is one continuous cloud with nonrigid flows extending out to 9pc rather than many discrete rigid clouds (RL08).
- Flow near the Sun is consistent with the inflow of neutral He measured by Ulysses and IBEX.
- GJ14 model explains why neutral H detected in all lines of sight even to the nearest stars (i.e., no gaps in interstellar HI)
- An unbiased test is to see whether the GJ14 or RL08 models better fit the later SNAP data (Malamut et al. 2014) [M14] with sightlines randomly distributed across the sky.

Reasons for preferring the RL08 multicomponent model rather than the one component CJ14 model

- RL08 model more accurately predicts the radial velocities observed in the SNAP spectra: v(RMS)=1.4 km/s for RL08 vs v(RMS)=2.1 km/s for GJ14.
- RL08 model accurately predicts the radial velocities of all 40 sightlines in the SNAP data set analyzed after the GJ14 paper was published.
- Non-thermal velocities are small compared with velocity component spacing. Little velocity smear seen from changes in flow along line of sight.
- Discrete clouds can be shaped by stellar EUV radiation and strong magnetic fields (both observed).
- Large amplitude radio scintillations seen toward 3 quasars predict scattering screen locations and transverse velocities consistent with the edges of LISM clouds (where clouds may collide).
- But the properties of filler gas between the warm partially ionized clouds in the RL08 model (hot, photo-ionized, recombining) are being discussed. The CJ14 model does not require any filler gas.

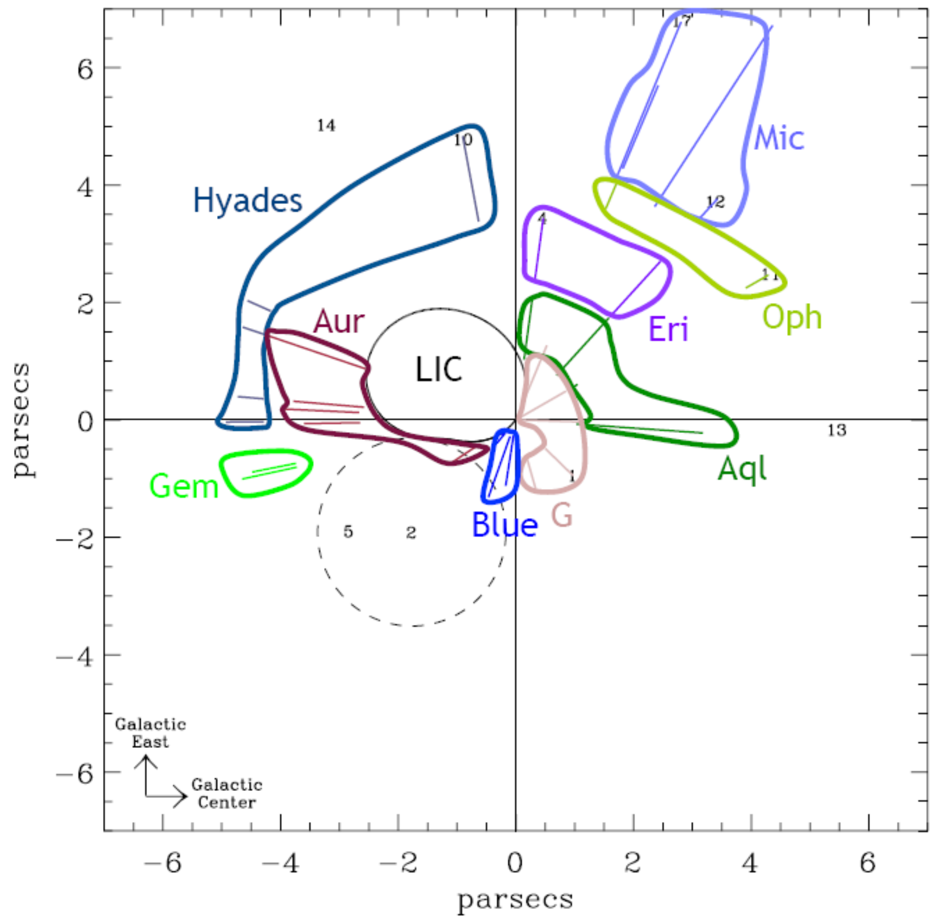
Fits to the SNAP 2014 radial velocities using the GJ14 one-component model (left panels) and the RL08 15-cloud model (right panels)



Assumptions used to visualize the LISM clouds in 3 dimensions

- Input: for each cloud the N(HI) and distance to each star seen behind the cloud. No stars seen in front of clouds.
- Assume: $n(HI)=0.20\ cm^{-3}$ same as LIC.
- Assume: along each LOS that the cloud center is located halfway to the star.
- Compute: thickness of the cloud along each LOS from $\Delta d=N(HI)/n(HI)$ cm.
- Make small changes to insure that clouds do not overlap.
- Require that stars with observed astrospheres are located inside of neutral H clouds.
- Smooth the cloud surfaces.

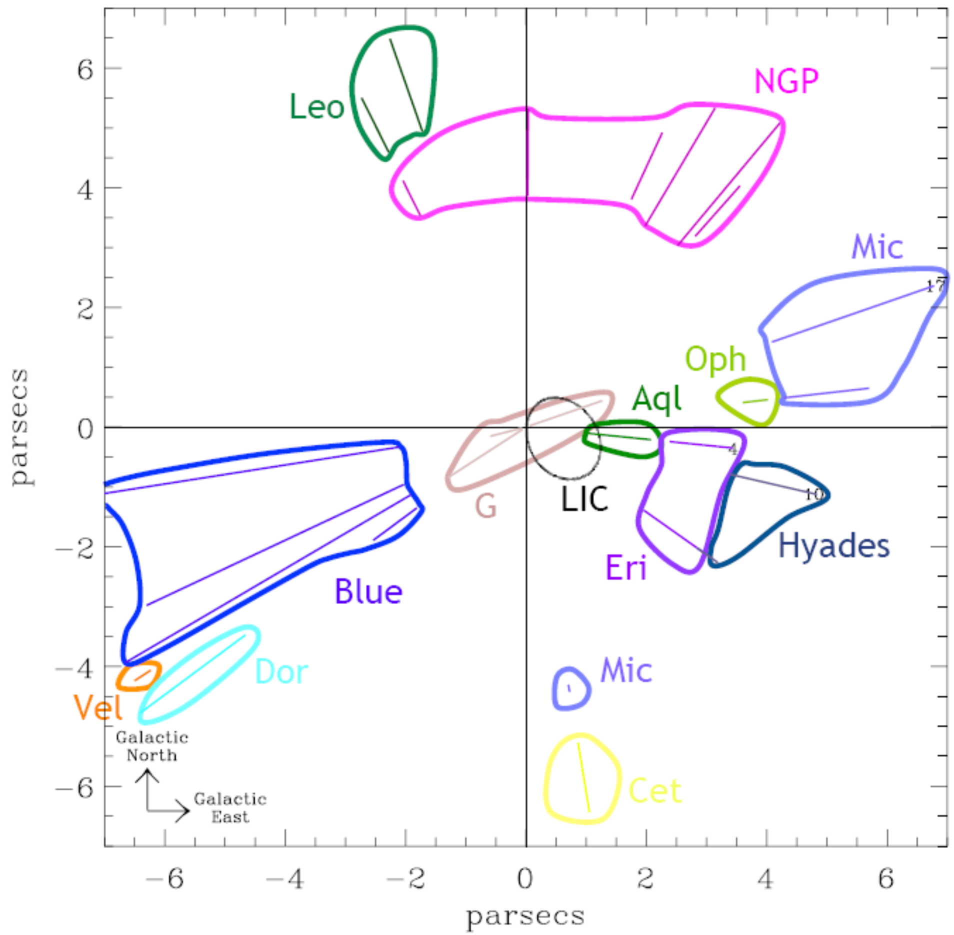
Schematic morphological map of the LISM as viewed from the North Galactic Pole



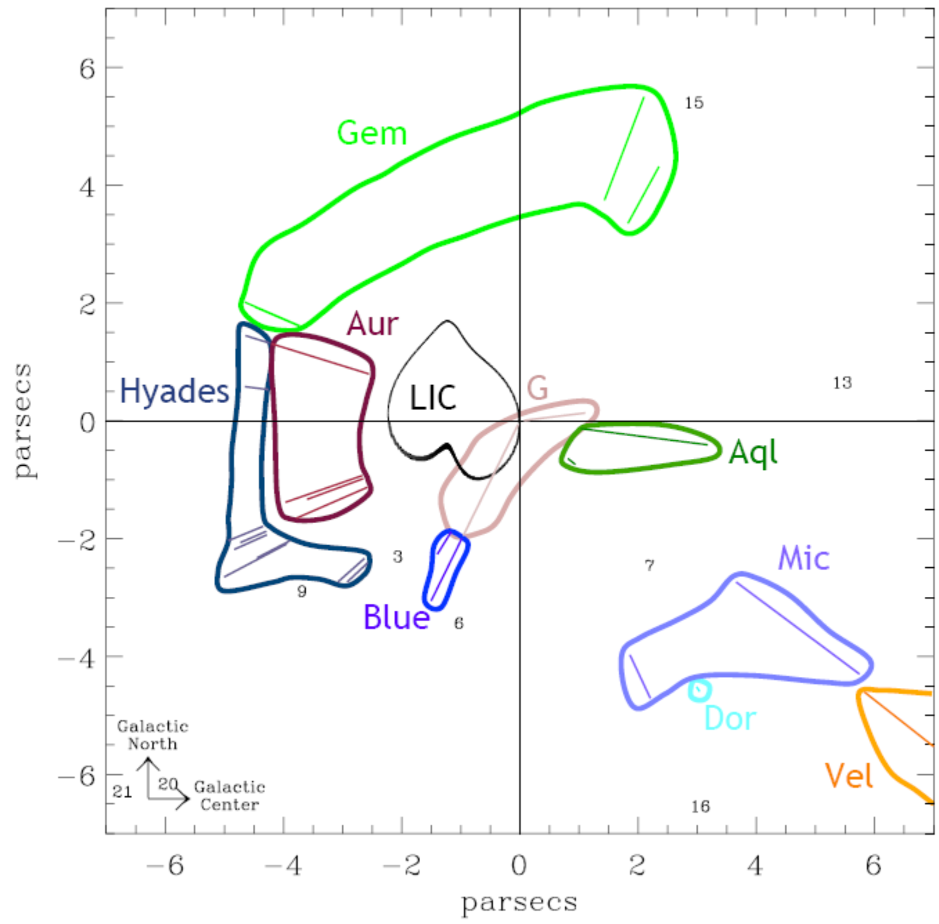
Assuming that n(HI)=1.0 cm^{-3} in Blue cloud and 0.2 in other clouds.

1=α Cen; 2=Sirius B; 4=61 Cyg; 5=Procyon; 10=EV Lac; 11=70 Oph; 12=α Aql; 13=36 Oph; 14=η Cas; 17=Vega. Dashed is the Strömgren sphere of Sirius B.

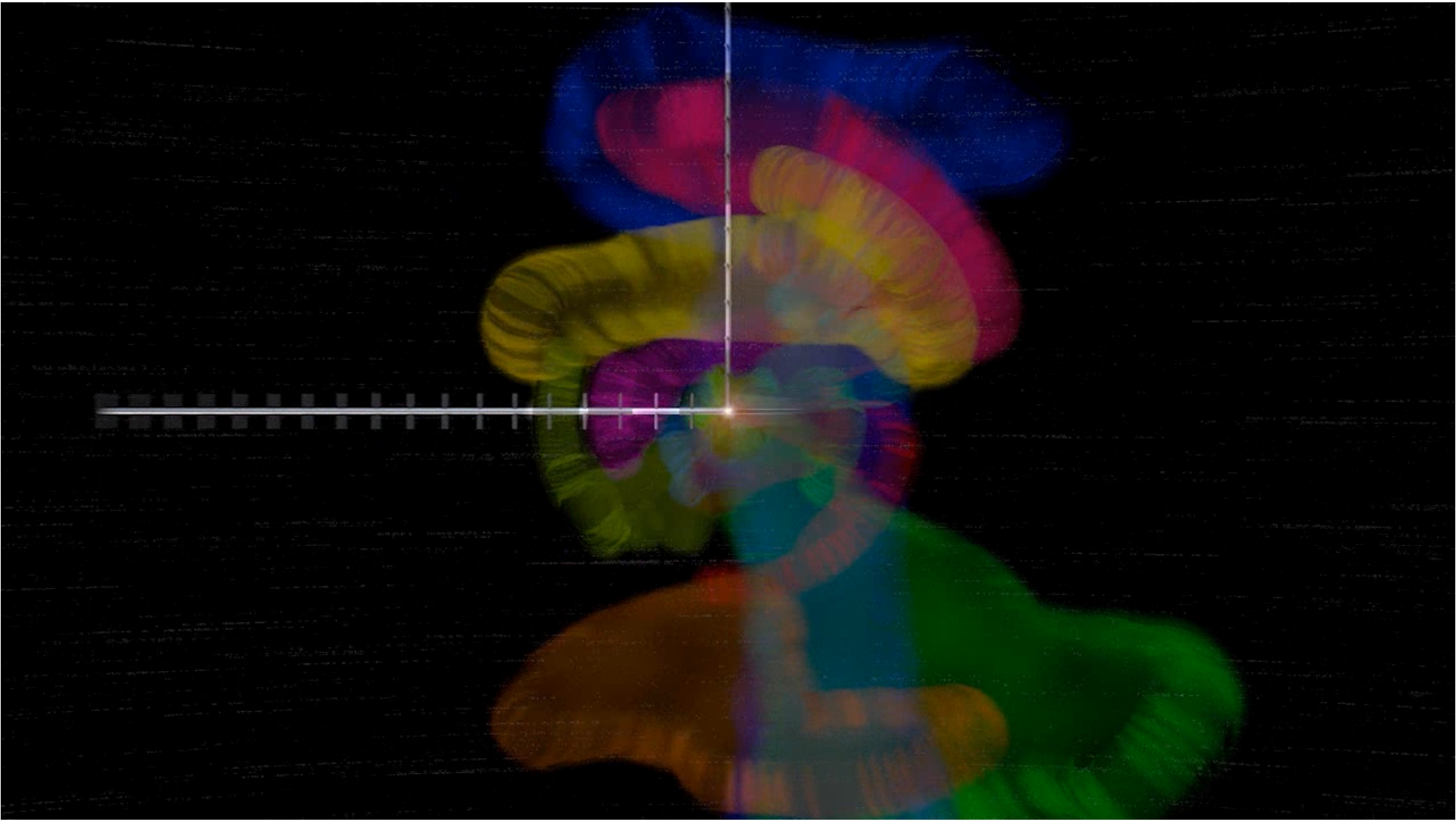
Schematic morphological map of the LISM as viewed from the Galactic Center



Schematic morphological map of the LISM as viewed from Galactic plane l=270°



15 LISM clouds viewed from around the Galactic plane



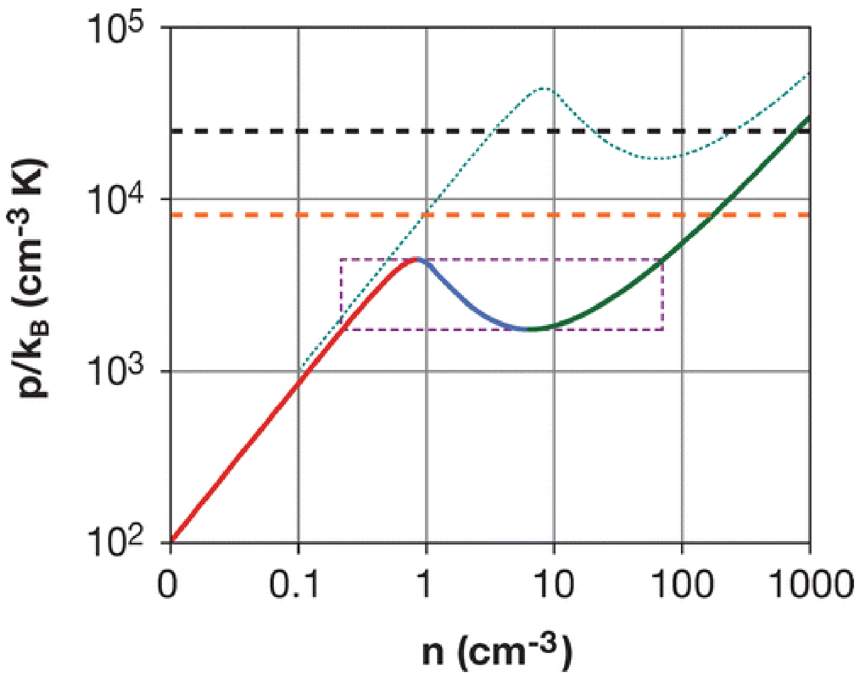
Comparing the observed properties of the LISM with theoretical models and simulations

Classical static theoretical models

- Assume thermal stability (heating=cooling) and pressure equilibrium (no ram pressure or shocks).
- These assumptions predict that the ISM consists of distinct temperature-density phases .
- Two component model of Field et al. (1969): cool dense component ($T<300K$), warm component ($T\sim10^4$ K)
- Three component models of McKee & Ostriker (1977) and Wolfire et al. (1995): hot (10^6 K), warm (8000 K), and cold ($T<200$ K) components. Most of volume is hot ionized gas.
- These models do not take into account hydrodynamics, magnetic forces, ram pressure, supernova explosions, etc.

Is a Thermally Stable ISM in Pressure Equilibrium Theoretically Possible?

- Pressure-density diagram assuming gas pressure equilibrium (Cox 2005). Area in box is thermally unstable (T=200-8000K, 16000-300000K).
- Blue dotted curve is 10X higher heating rate.
- Black dashed line is total midplane pressure due to overlying matter.
- Orange dashed line is mean magnetic pressure.
- Pressure equilibrium in a static ISM is not possible without additional pressure terms (e.g., ram, magnetic, or cosmic ray).



Cox, DP. 2005
Annu. Rev. Astron. Astrophys. 43: 337–85

Including the previously ignored physics: Simulations of de Avillez & Breitschwerdt (A+A 436, 585 (2005))

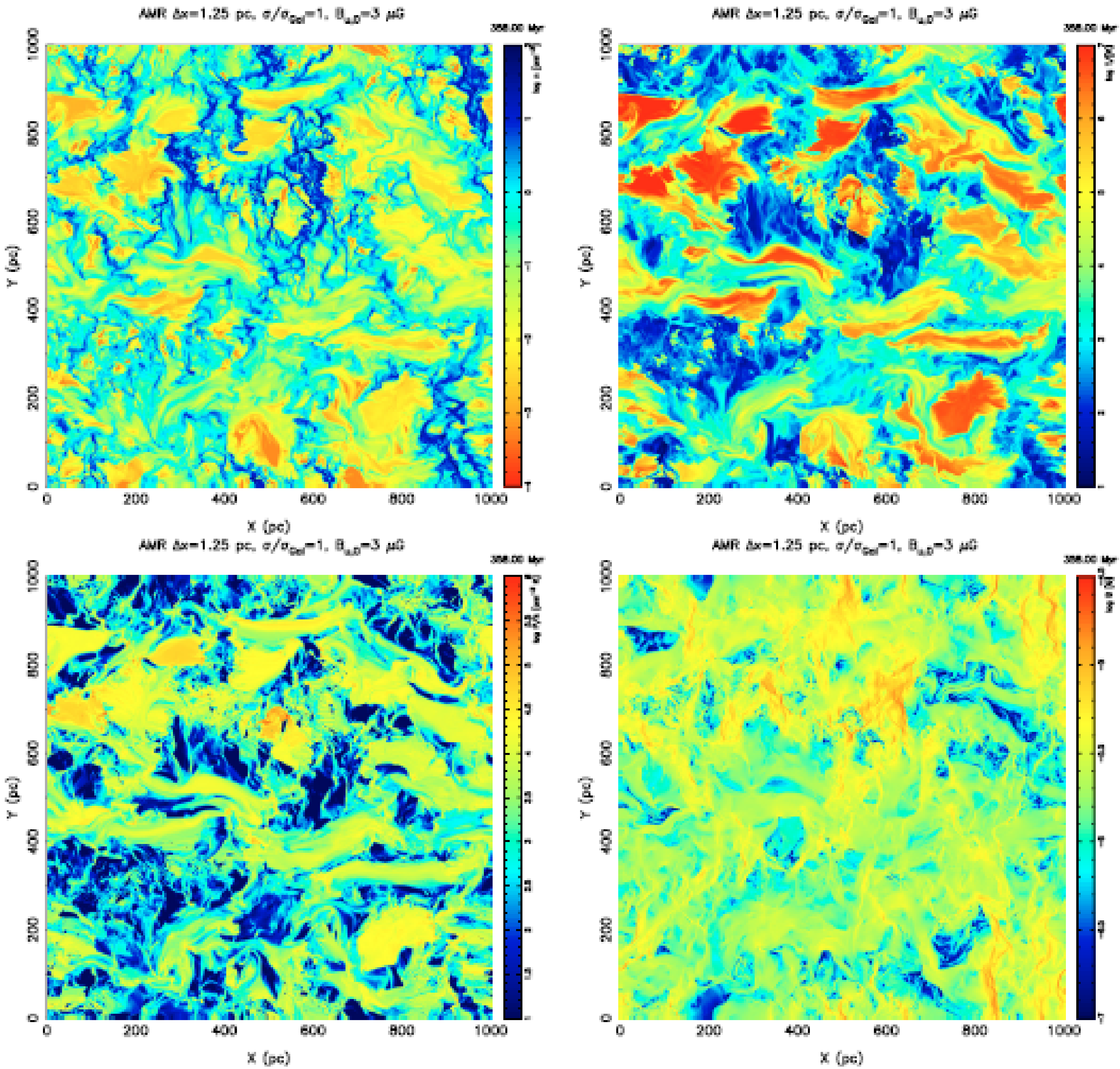
- 3D MHD code with a spatial resolution of 1.25 pc that extends from disk to ±10 kpc in halo.
- Realistic supernova rate (randomly adds heat and kinetic energy to the ISM).
- Assume an initial isotropic B=3μG and let models run for 400 Myr to remove startup values.
- Exchange of matter and energy between disk and halo is driven by SN events that produce expanding bubbles that can rise to the halo (Galactic fountain flows).

Log n

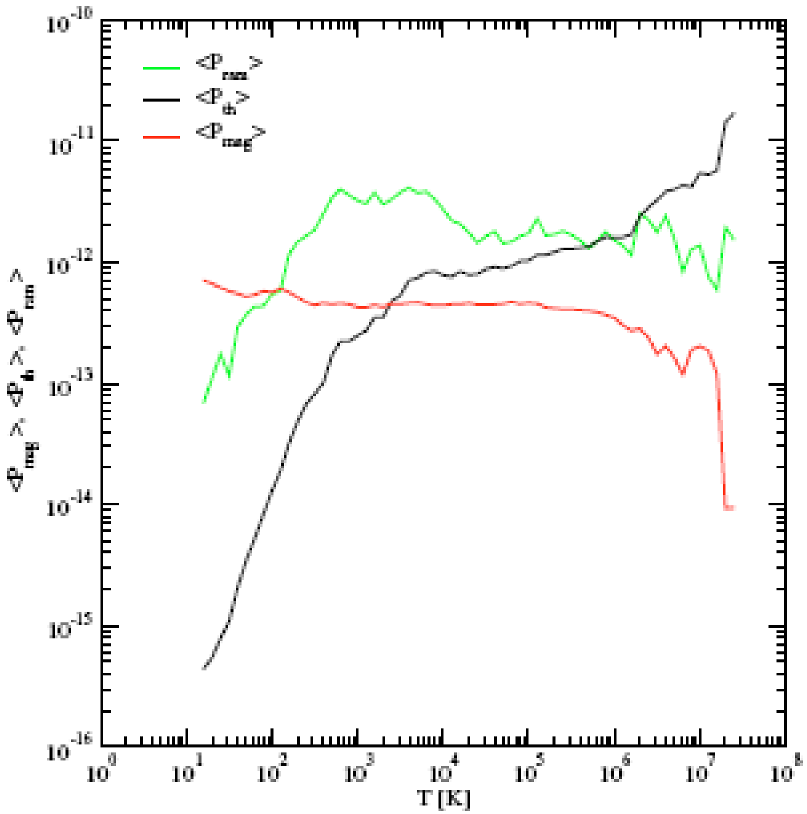
Log T

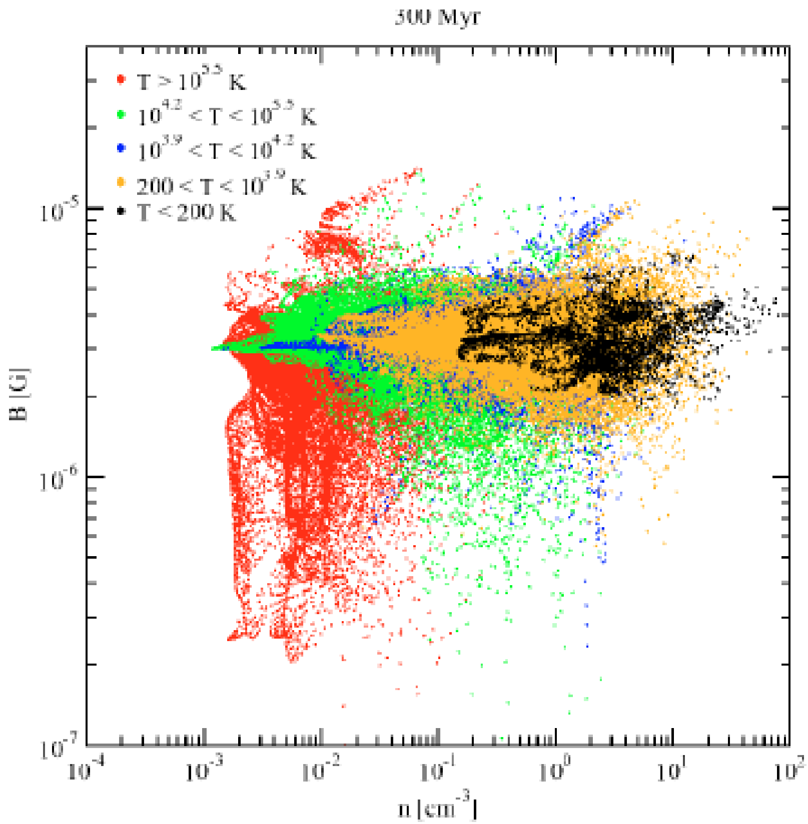
Log P

Log B



P_{mag} dominates at T<200 K, P_{ram} dominates at T=200-10^4 K, P_{th} dominates at T>10^6 K





Important Results of the de Avillez & Breitschwerdt Simulations

- The ISM is highly dynamic: flows are typically supersonic and superalfvenic.
- Gas exists at all temperatures.
- There are no distinct phases unlike the classical models.
- Sheet-like structures are very common for cold and warm gas. These shapes are created by shocks and magnetic fields
- Expansion of SN driven hot gas into the halo is a “pressure release valve”.
- Local magnetic fields are highly variable (0.1-15 μG).
- Can these results be tested by analysis of the LISM clouds?

Table 1. Summary of Cloud Properties

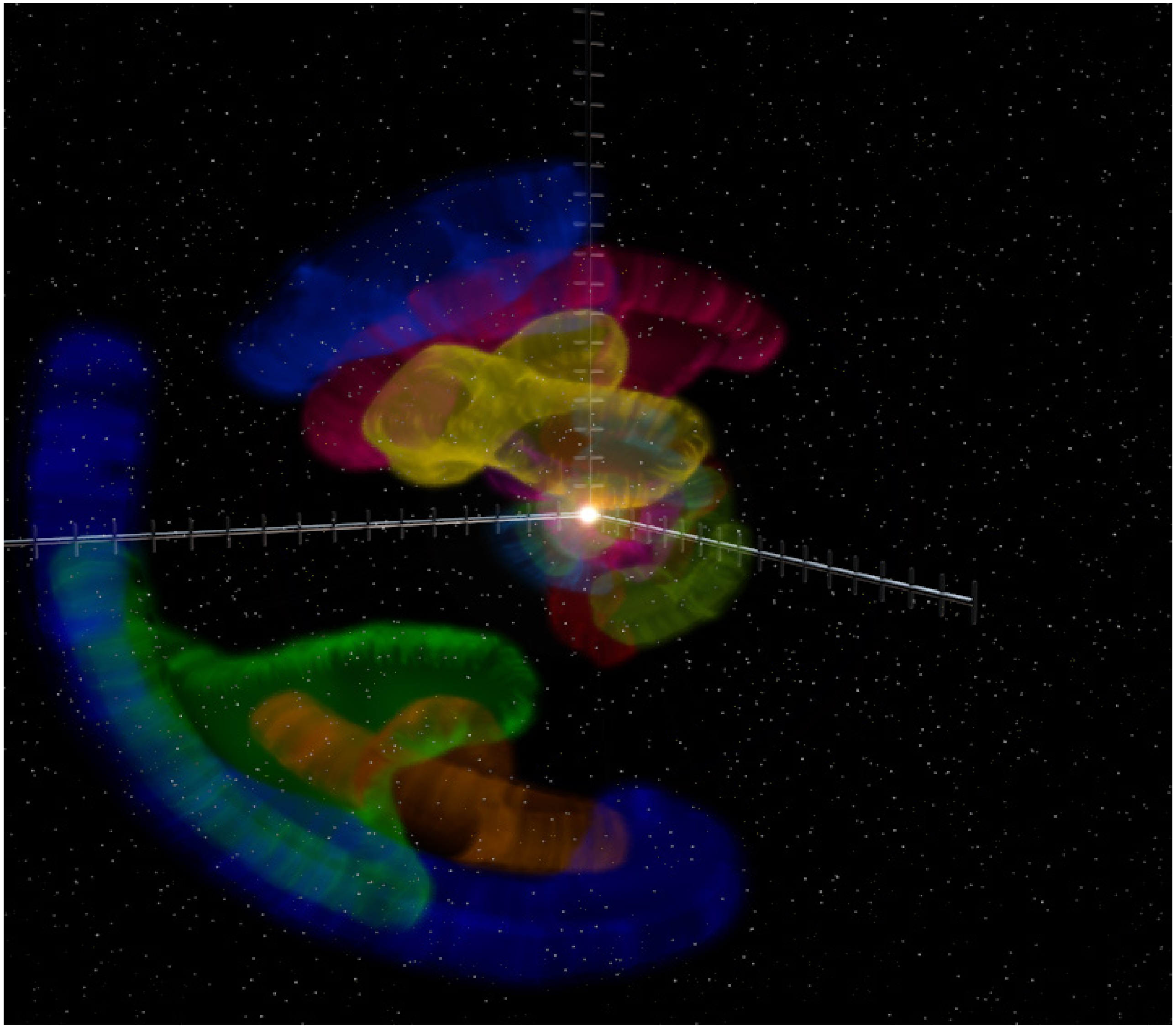
Cloud Name	Number of Stars	Central Coordinates $l(^\circ)$	$b(^\circ)$	Closest Star (pc)	$< T >$ (K)	$< D(Fe) >$
G	21	315	+00	1.3	5500	–0.54
LIC	78	170	−10	2.6	7500	–1.12
Blue	10	250	−30	2.6	3900	–0.84
Eri	8	70	−20	3.5	5300	–0.39
Aql	9	40	−05	3.5	7000	–0.96
Aur	9	210	+10	3.5	6710	
Hyades	14	180	−20	5.0	6200	–0.32
Mic	15	40	+15	5.1	9900	–0.92
Oph	6	45	+25	5.1	1700	
Gem	10	300	+40	6.7	6000	–1.29
NGP	15	5	+75	8.5	8000	–1.04
Leo	7	270	+55	11.1		
Dor	4	270	−50	11.7	7000	–0.80
Vel	6	300	−45	14.9	10600	
Cet	5	290	−40	15.5	6300	

4 possible physical causes of the structure of clouds in the LISM – is there any observational evidence

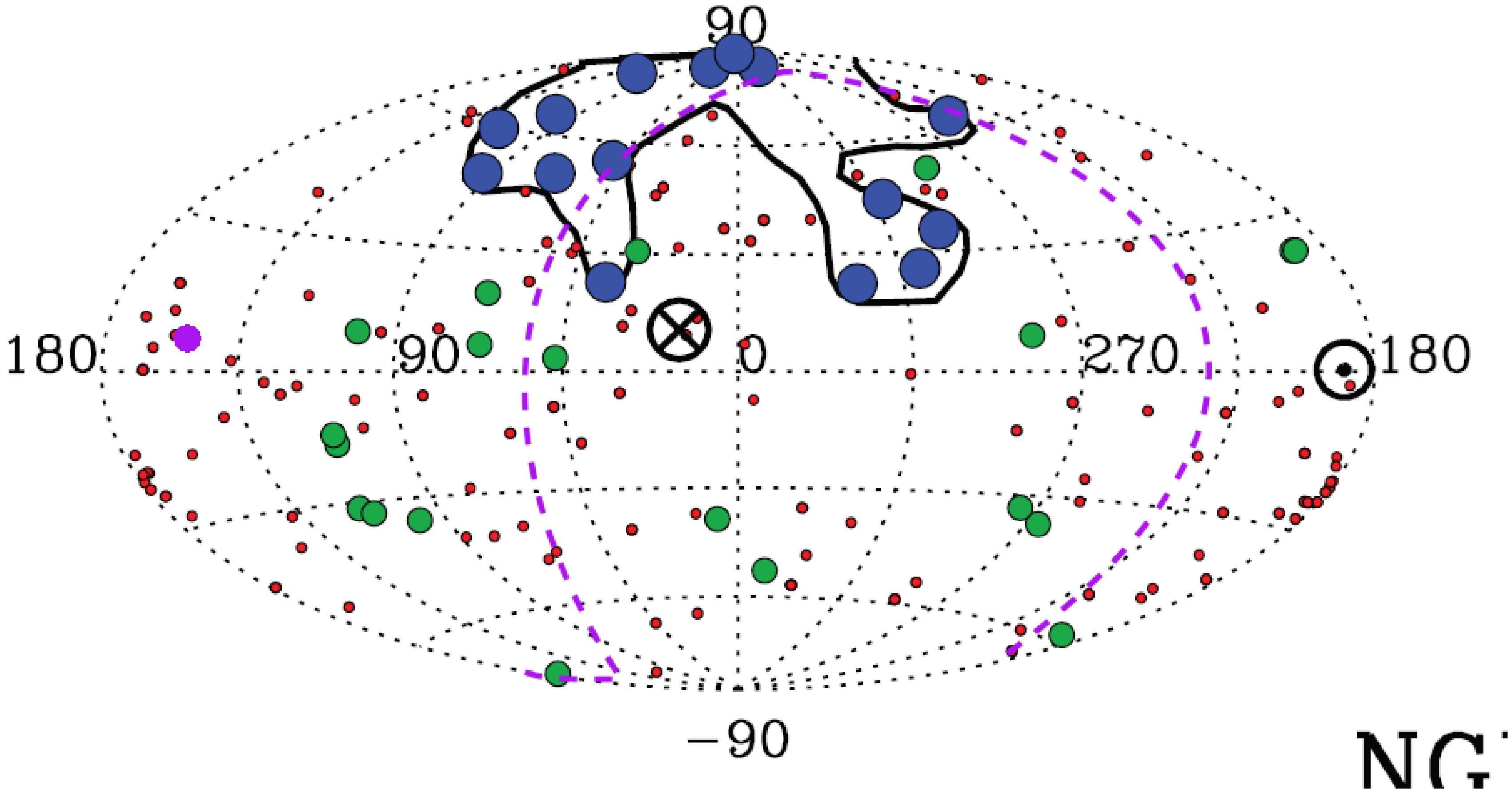
Question #1: Does ram pressure of the ISM flow shape the LISM clouds?

- In the de Avillez & Breitschwerdt simulations, P(ram) dominates for T between 200 and 10,000 K.
- Since the solar wind produces tails on comets, the supersonic ionized ISM wind could produce tails or linear structures downstream of neutral clouds.
- Look for linear or tail-like structures 90° away from the upwind flow direction.

LISM as seen from ε CMa (l=155°, b=7°)



NGP (light red cloud) as seen from l=155°, b=7° (upwind flow)

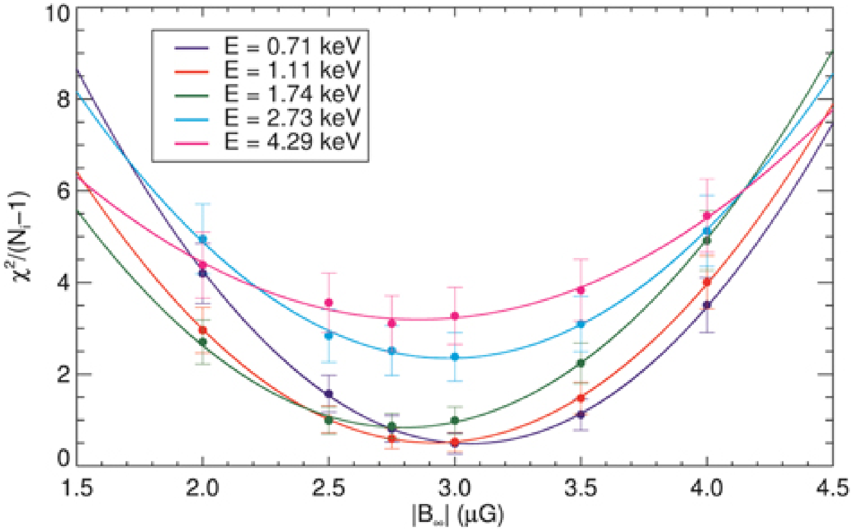


Question #2: Do interstellar magnetic fields shape the LISM clouds?

- LISM clouds are primarily neutral and magnetic fields cannot control the flow of neutral gas.
- However, both charge exchange between the ionized inter-cloud medium and the neutral cloud gas and photoionization could produce ions on cloud surfaces that follow the magnetic field orientation.
- Strong magnetic fields at the cloud surfaces could suppress conductive heating at the cloud boundaries and produce elongated structures along the magnetic field lines.
- Look for structures aligned along the magnetic field.

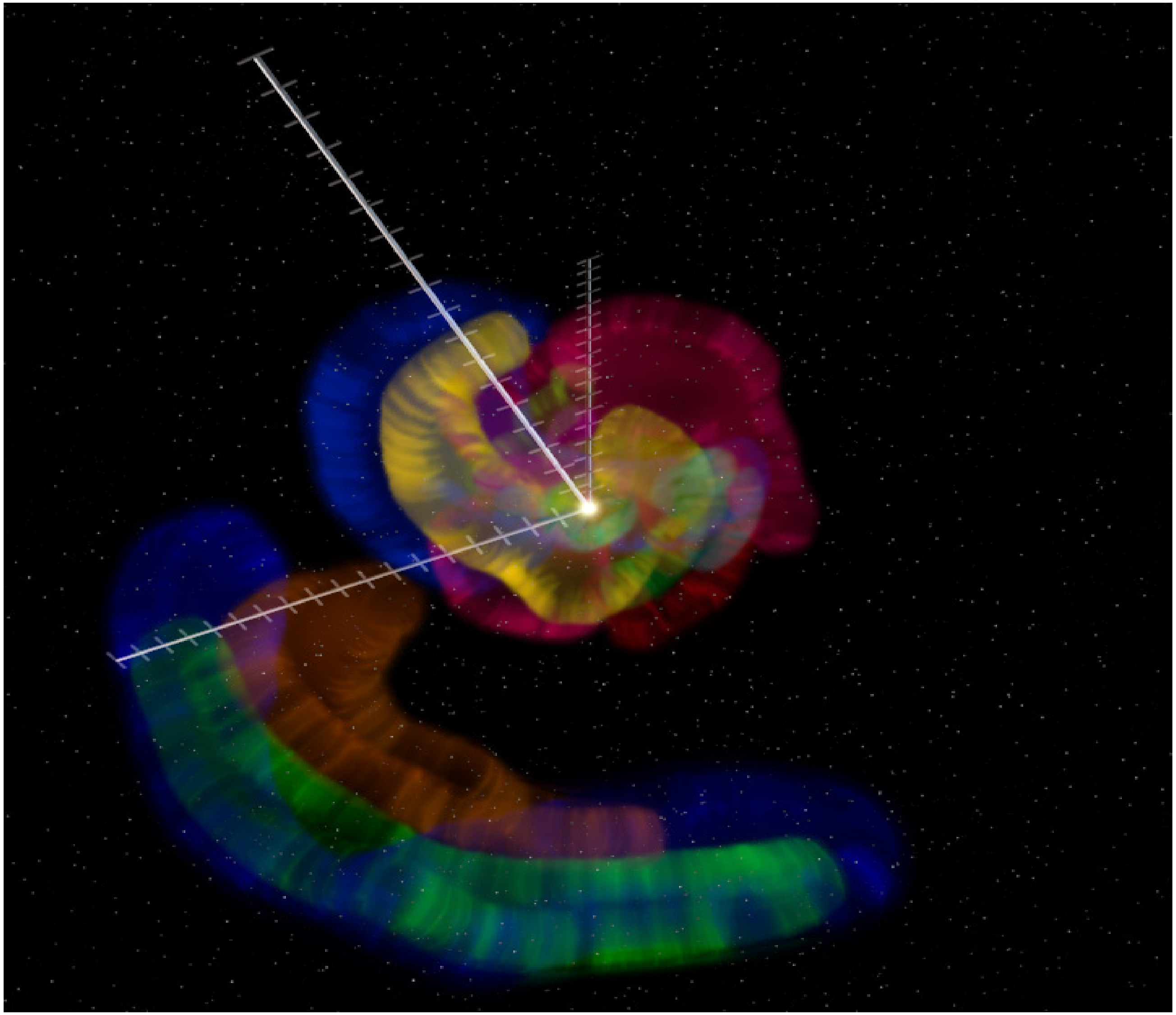
What is the strength and direction of the magnetic field outside of the heliosphere?

- Previous estimates in range B(LISM)=2-4 μG.
- 3D MHD heliosphere models show that B(LISM) is in direction of ENA emission ribbon center with correction for draping.
- Zirnstein et al. (ApJL 818, L18 (2016)) model to fit IBEX ribbon positions at different energies (figure).
- Consistent with V1 data.

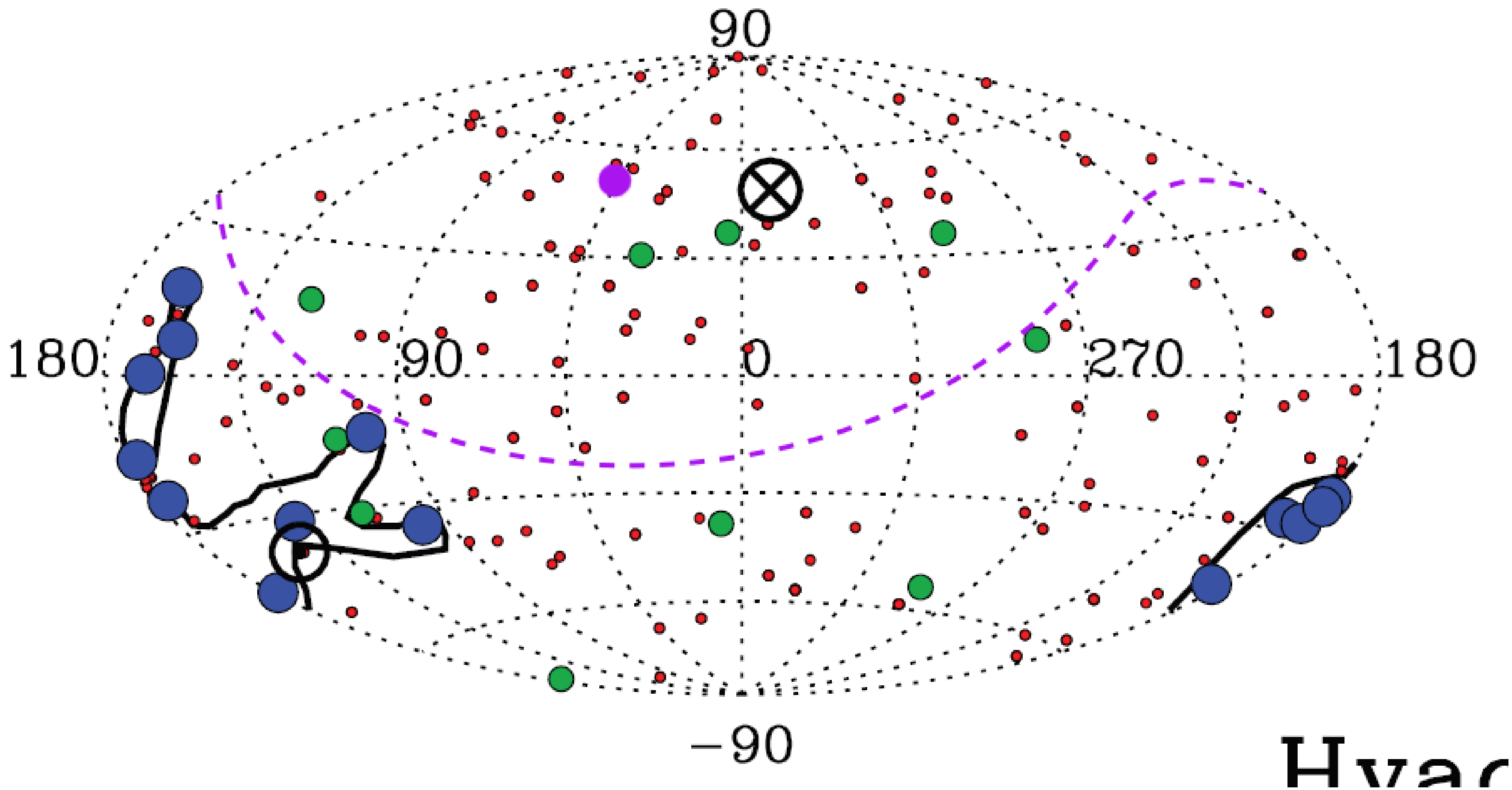


B(LISM)=2.93±0.08 μG
Galactic longitude = 26.0±0.7 degrees
Galactic latitude = 50.1±0.6 degrees
P(mag)/k=$B^2/8\pi$=2480±130
P(th)/k=2050-5030 Frisch et al. (2011)
P(mag)/P(th)=0.5-1.2

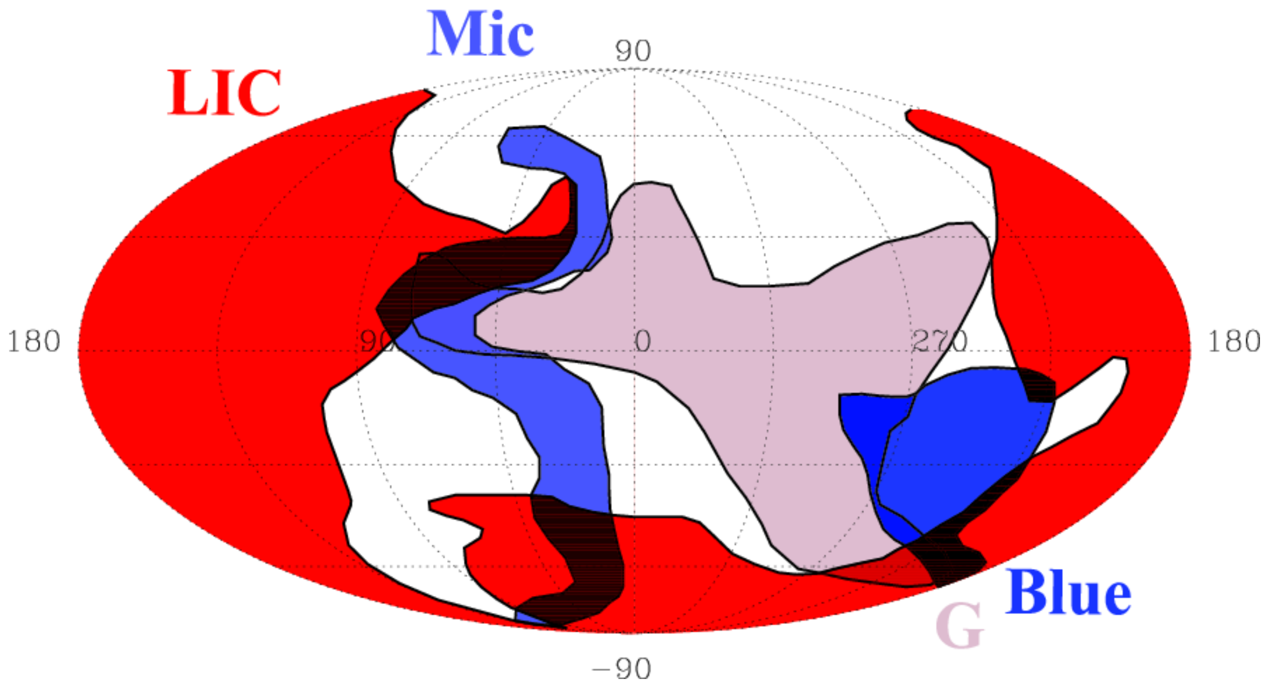
LISM seen from magnetic field direction l=206°, b=-50°



Hyades (light yellow cloud) as seen from l=206°, b=-50° (B(LISM) direction)



Question #3: Could a cloud be shaped by collisions/shock with other clouds or flows?



The G cloud is flowing into the LIC at 5.5 km/s, and Mic is the hottest cloud (T=9900 K). Could intercloud collisions produce the structure of the Mic cloud? But the Mic cloud may be further away than LIC and G.

Question #4: Are the structures of the LISM clouds be determined by the EUV radiation field?

- EUVE measurements of the 70-730 Å radiation from many stars shows that the EUV radiation observed at the Sun is dominated by 2 stars and 3 white dwarfs (Vallerga ApJ 497, 921 (1998)).

* ε CMa (B1.5 II) l=240, b=-11, d=124 pc (largest observed EUV flux) but value outside of the LIC was overestimated because Vallerga (1998) who assumed N(HI)<9x10^17)

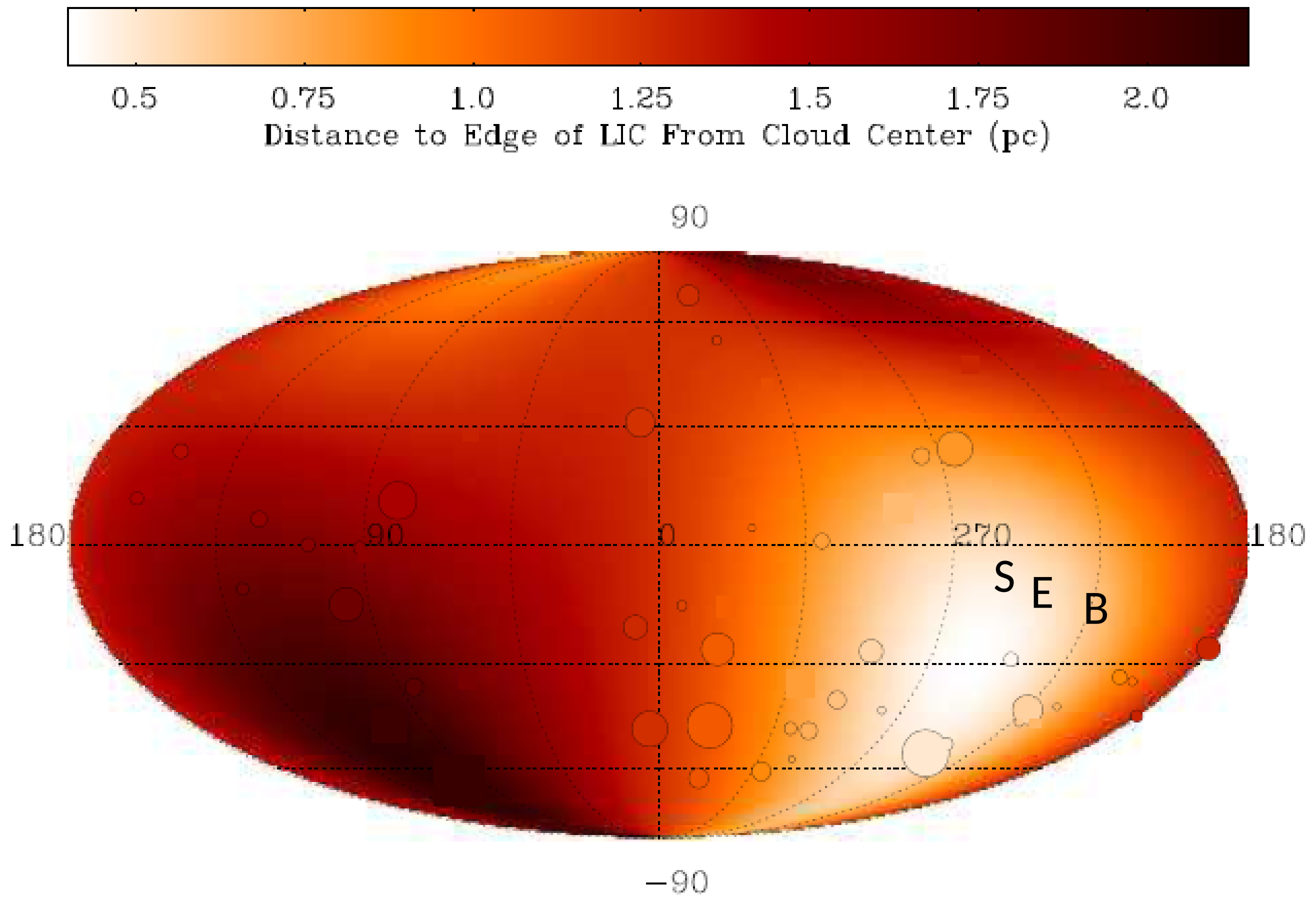
* β CMa (B1 II-III) l=226, b-14, d=151 pc

* G191-B2B (WD) l=156, b=07, d=59 pc

* HZ 43 (WD) l=54, b=84, d=39 pc

* Feige 24 (WD) l=166, b=-50, d=74 pc

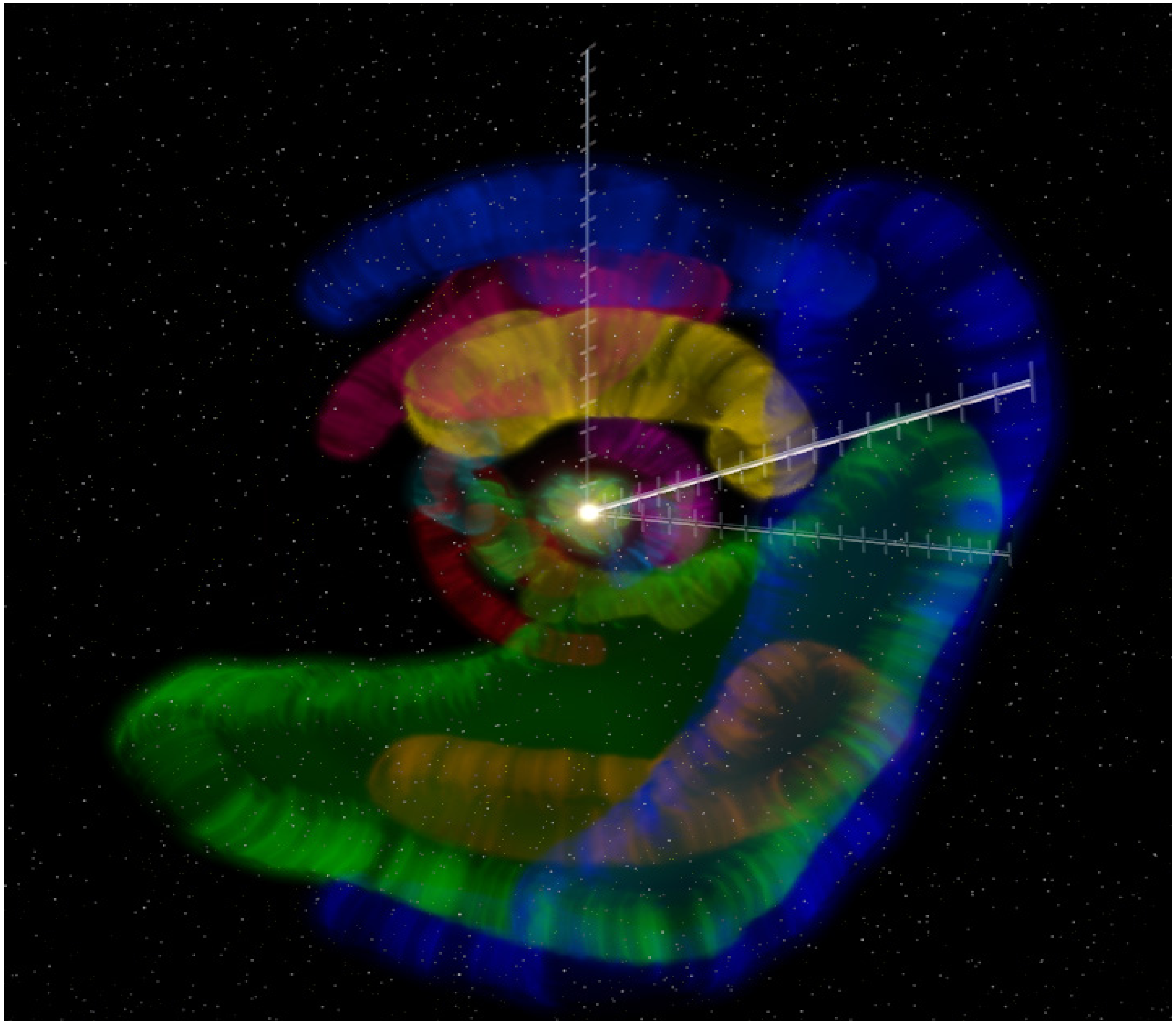
Morphology of the Local Interstellar Cloud as seen from cloud center



S=Sirius B
E=ε CMa
B=β CMa

ε CMa (B2 Iab, d=124 pc) is the brightest EUV source observed by EUVE.

LISM as seen from ε CMa (l=59°, b=11°)



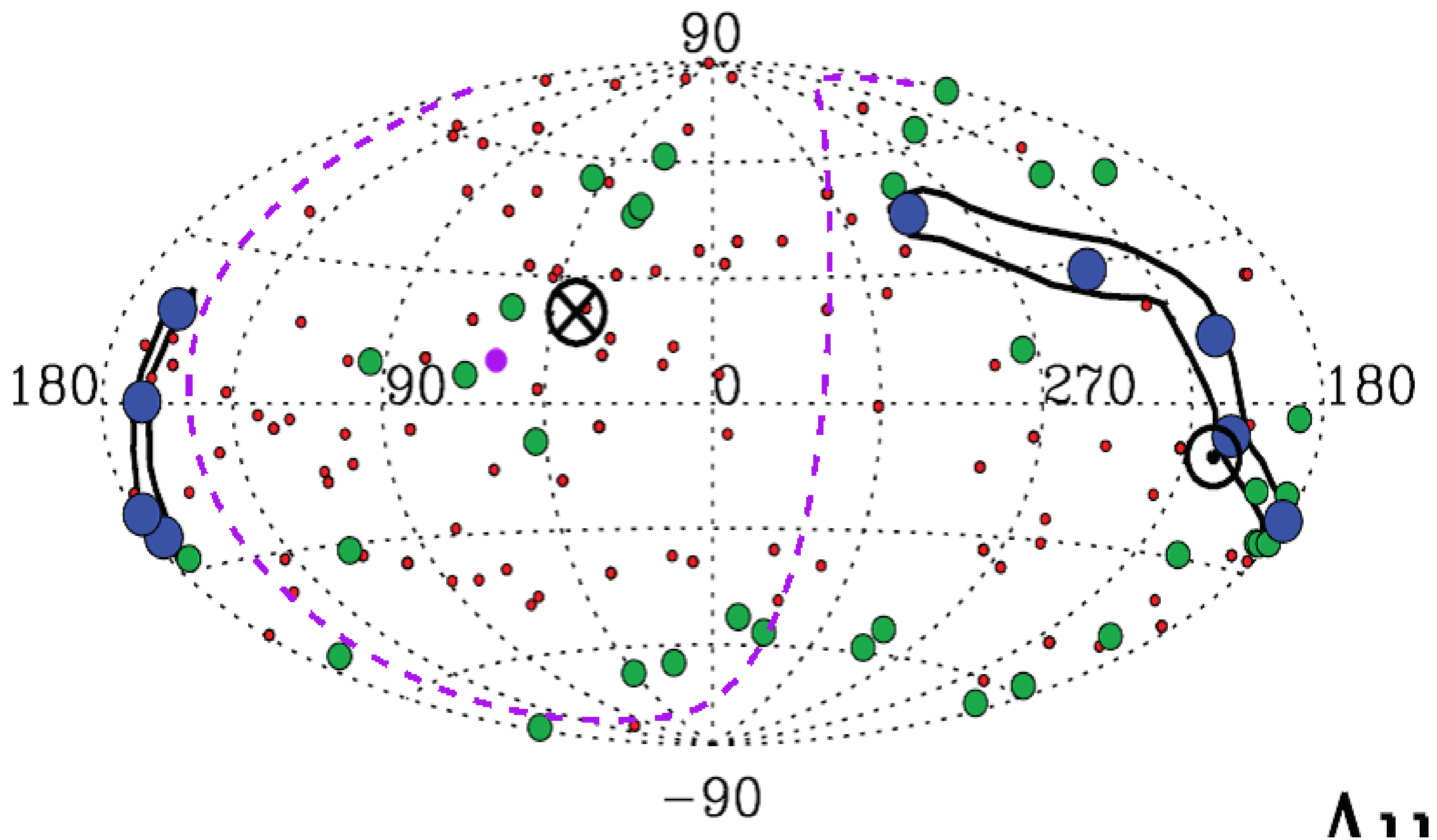
Penetration depth of EUV photons from ε CMa

- ε CMa is the brightest source of EUV photons with an integrated flux = 320±20 ph/cm²/s at Earth (Vallerga & Welsh 1995).
- 1/e of photoionizing photons will be absorbed at distance 1/n(H)σ = 1/(0.2)(10^{-17} cm)=0.2pc.
- Essentially all of the photons will be absorbed within 0.6pc consistent with the hole in the LIC (mean radius of the LIC is about 1.5 pc.).
- EUVE found that there is an interstellar tunnel of highly ionized gas between ε CMa and the LIC (Welsh et al. 1998).

How might EUV radiation from a distant source shape a neutral cloud?

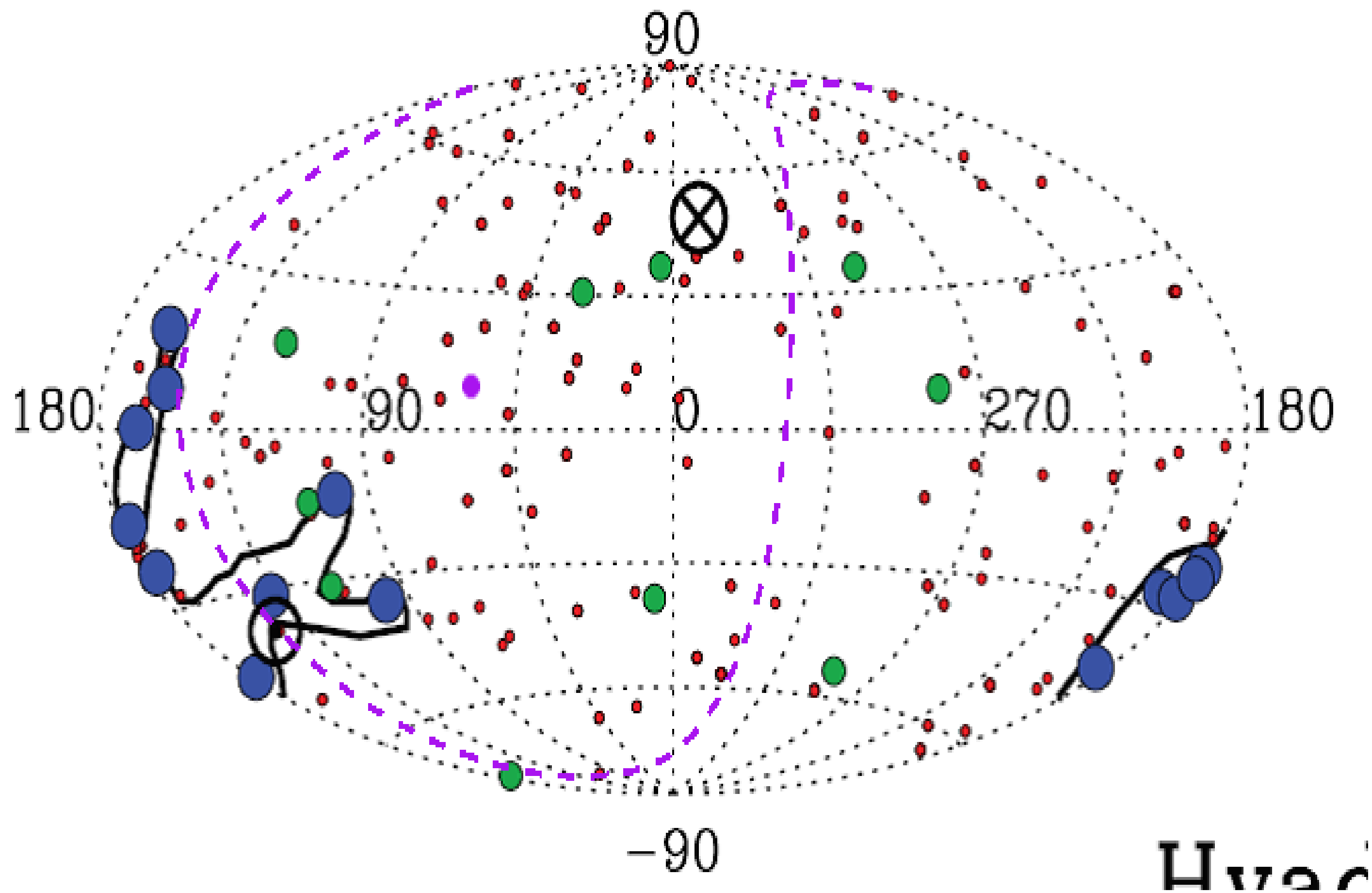
- For n(HI)=0.2 cm^{-3}, the 1/e penetration depth of EUV photons is about 0.2 pc.
- This will change the shape of clouds into more flattened structures perpendicular to the LOS from ε CMa.
- So, look for long thin structures aligned 90° from the line of sight from ε CMa.

Aur cloud and dashed line 90° from ε CMa

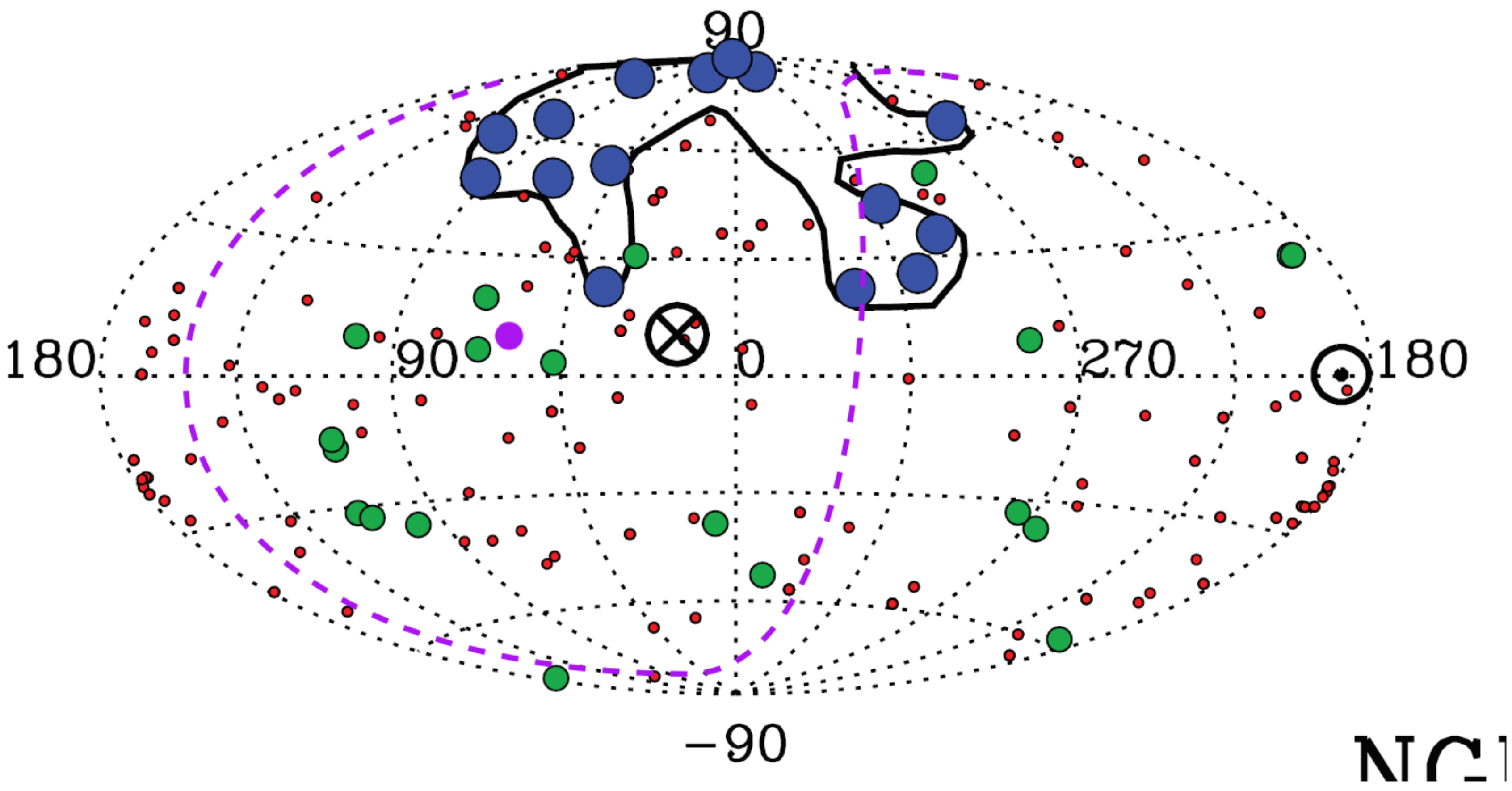


Note that projection effects will broaden the 90° contours.

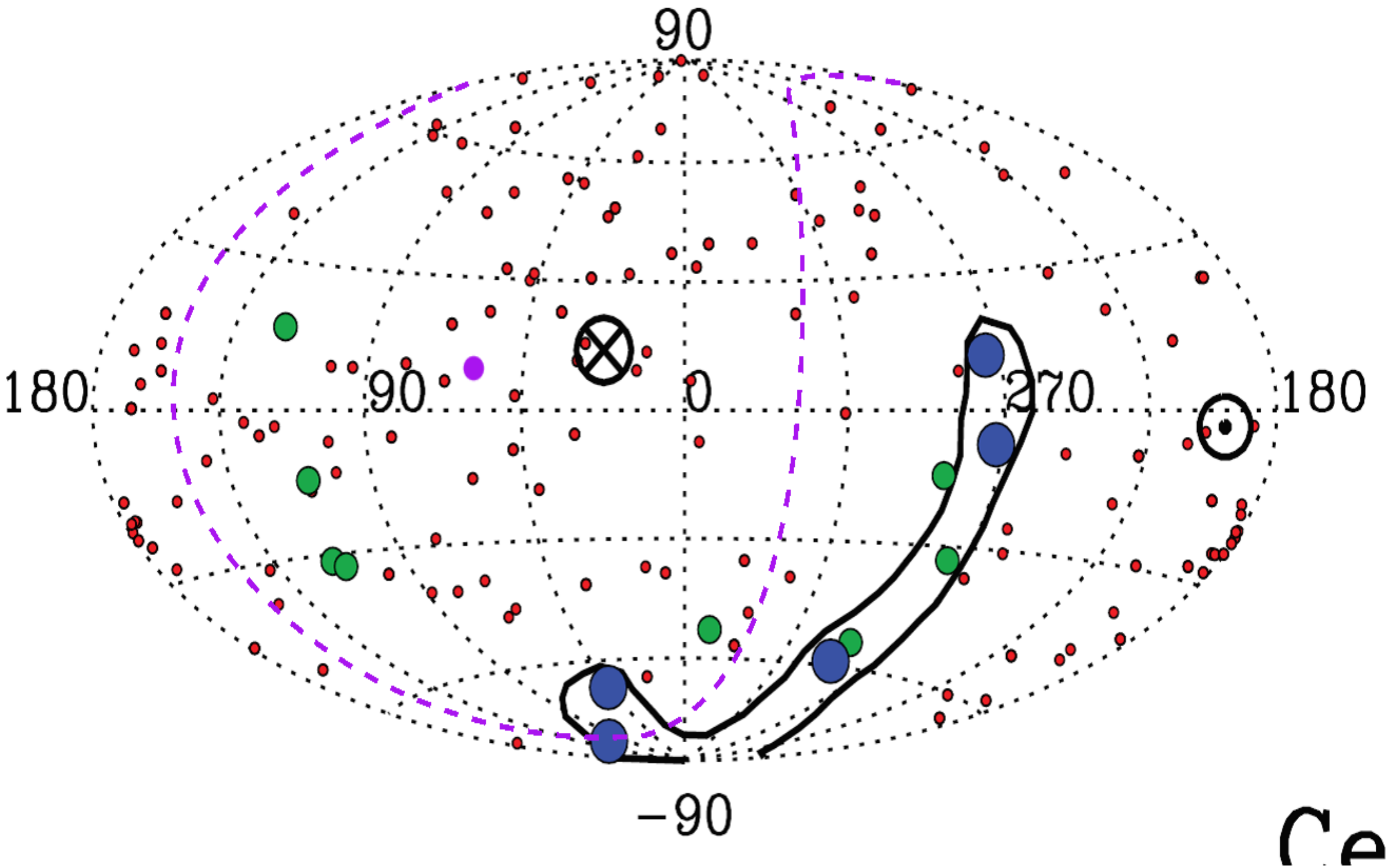
Hyades cloud and dashed line 90° from ε CMa



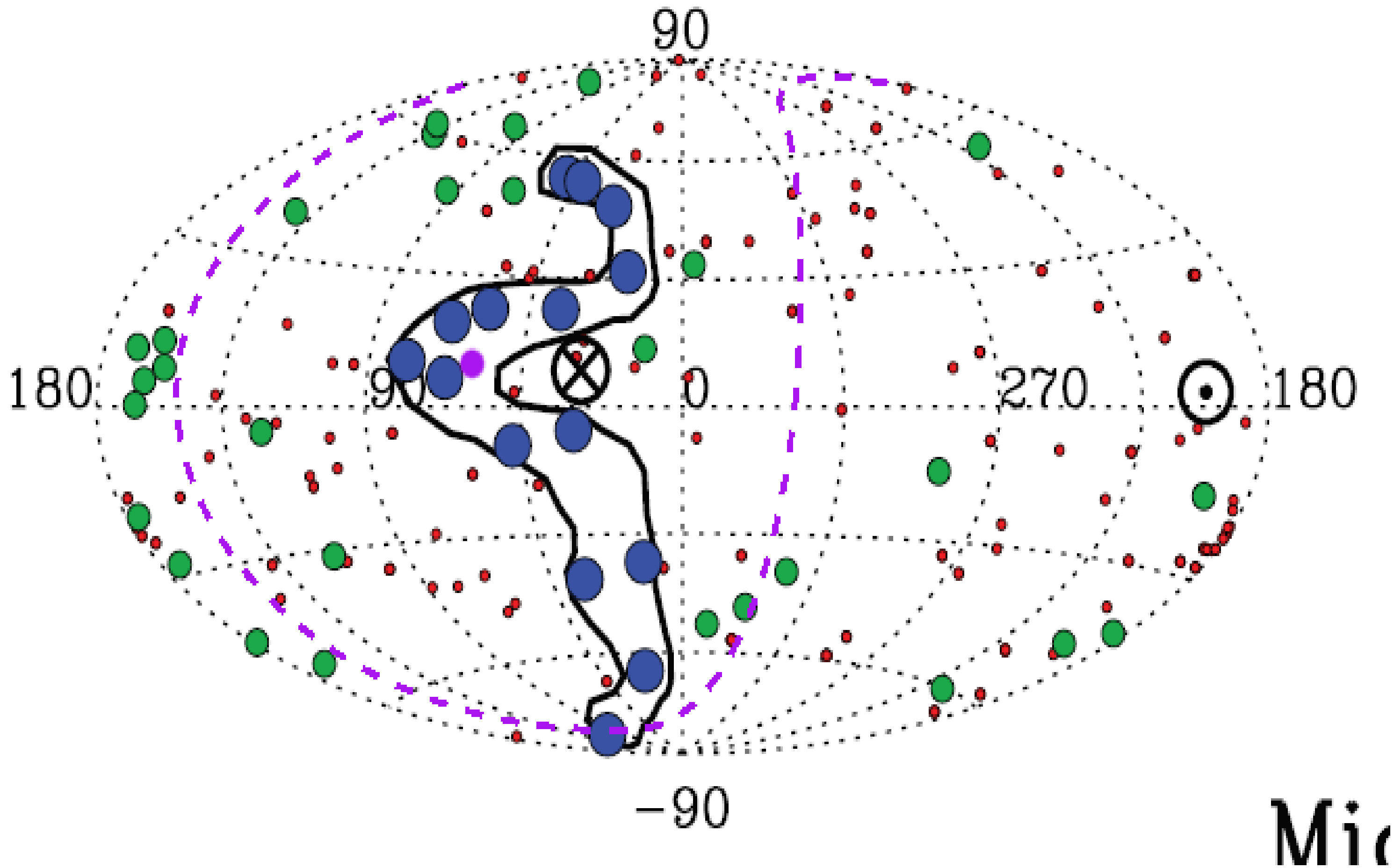
NGP cloud and dashed line 90° from ε CMa



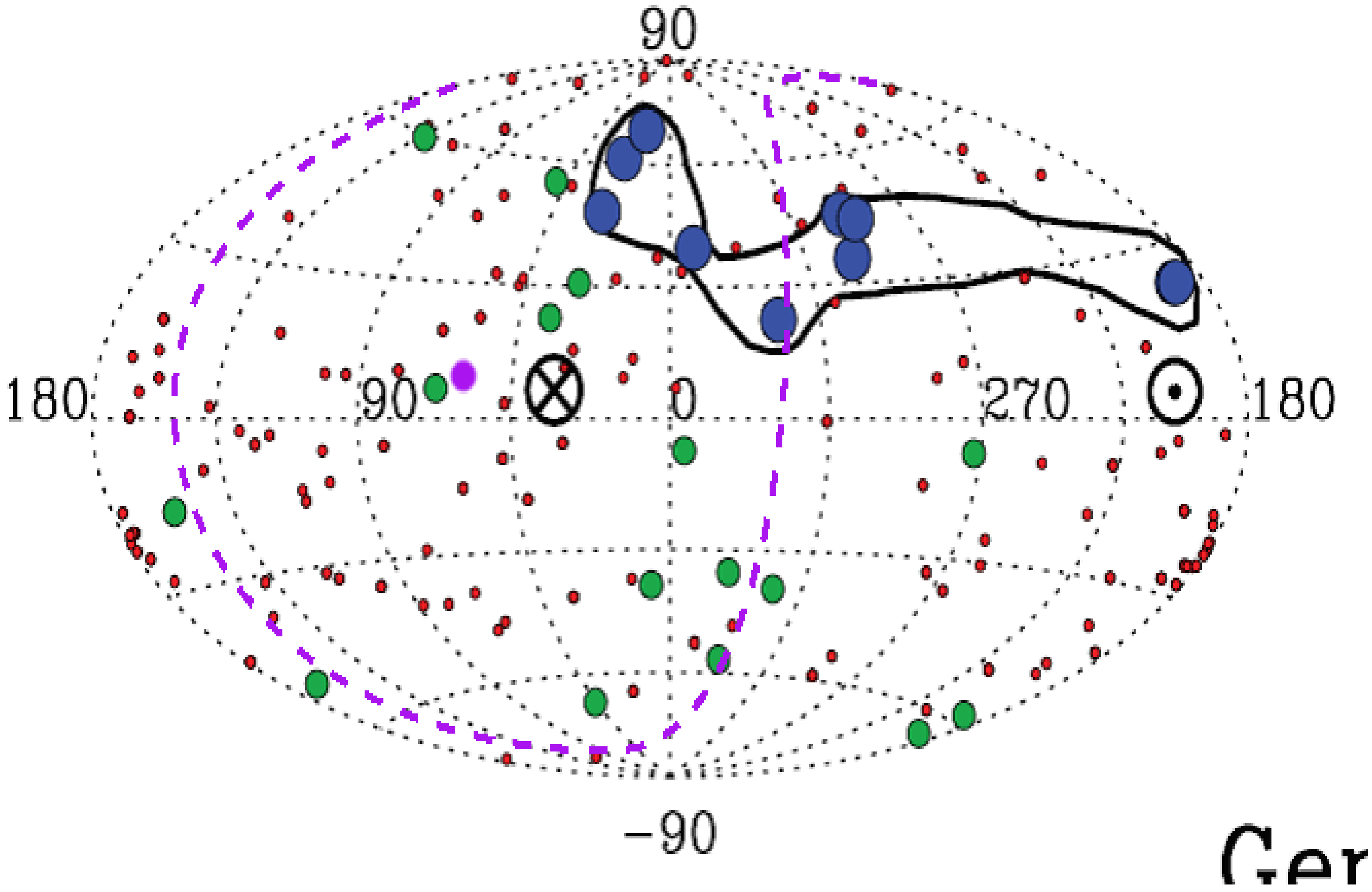
Cet cloud and dashed line 90° from ε CMa



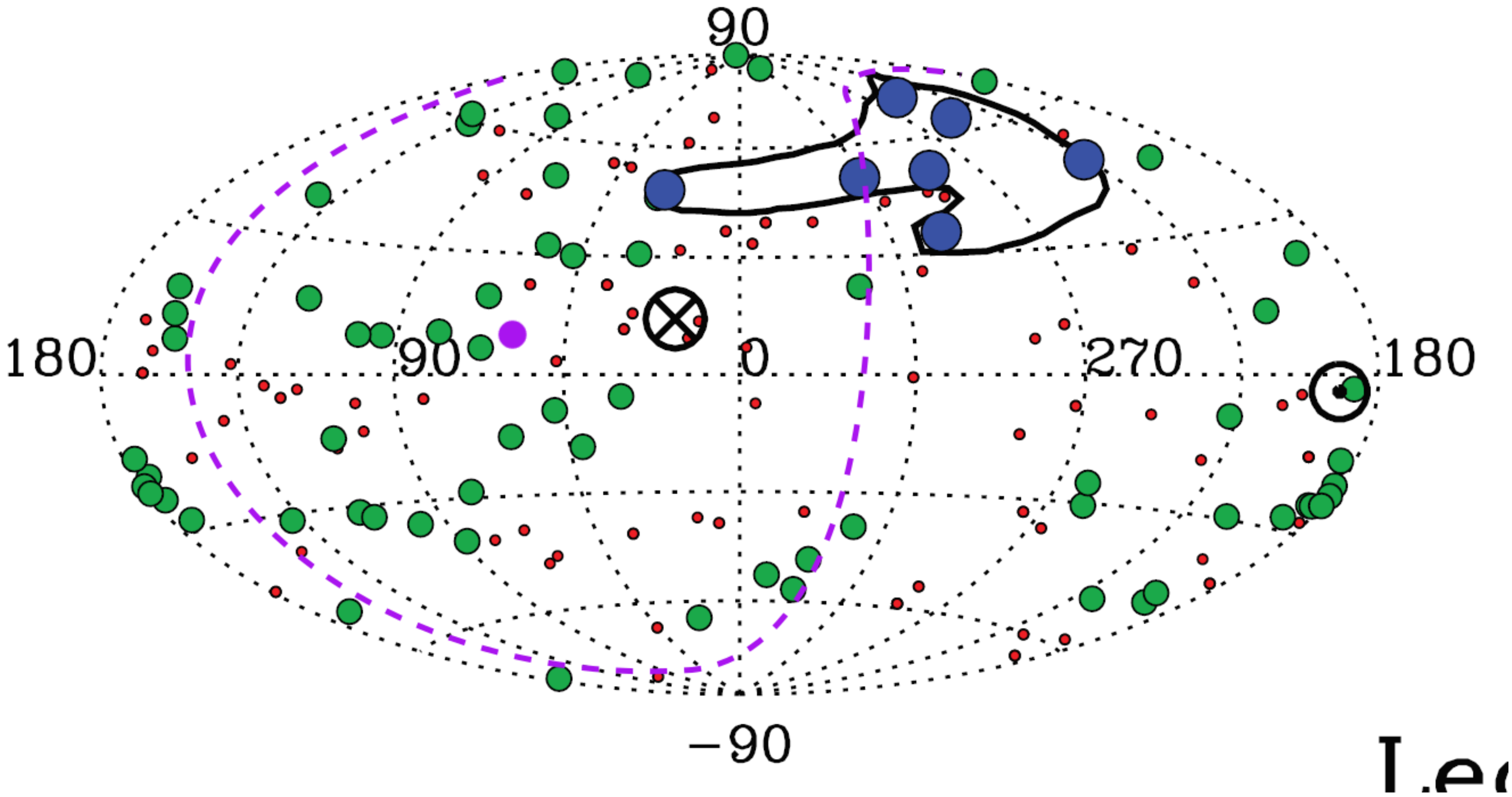
Mic cloud and dashed line 90° from ε CMa



Gem cloud and dashed line 90° from ε CMa



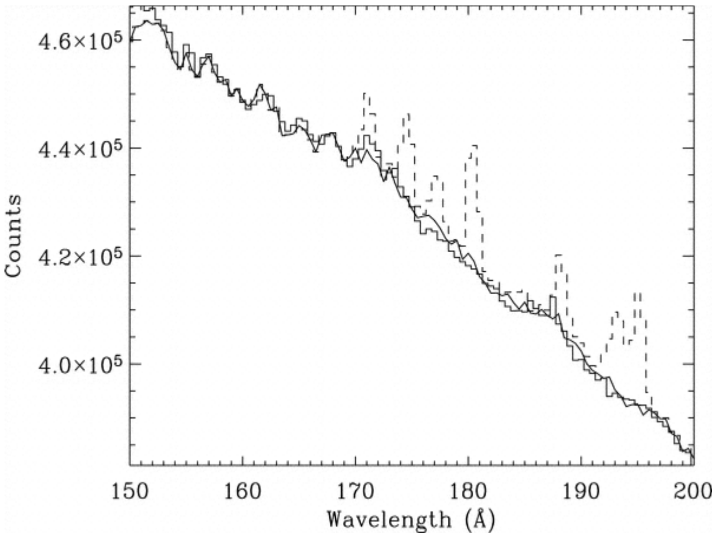
Leo cloud and dashed line 90° from ε CMa

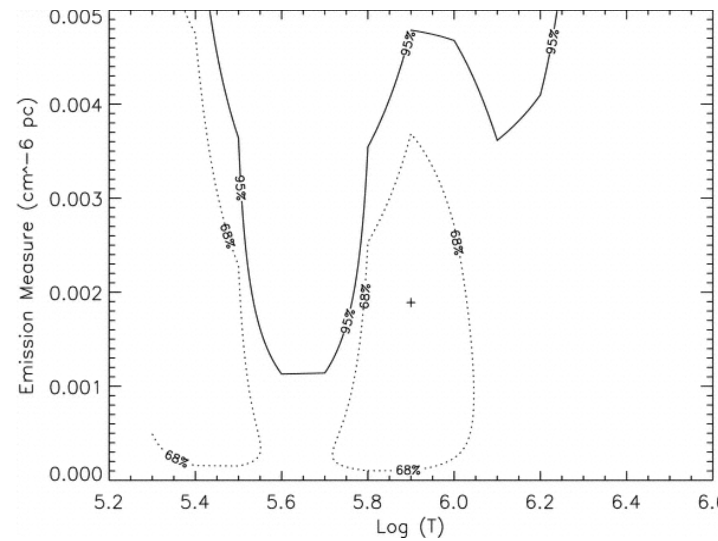


What fills the space between the warm partially-ionized gas clouds?

- Must be ionized and low density, but is the gas thermal (hot) or nonthermal (highly ionized and recombining following a shock or photoionized by EUV photons.).
- Most of the diffuse soft X-ray emission is produced by charge-exchange between solar wind ions and interstellar H (Snowden, Koutroumpa). Possible evidence for hot gas nearby.
- Filler gas could be ionized and warm (T~20,000 K) (Welsh+Shelton 2009).
- Filler gas could be Strömgren sphere gas (T~10,000 K) ionized by hot stars and WDs (Tat&Terzian 1999).
- Warm partially ionized cloud gas could be Strömgren sphere shells (recombining gas). Thickness ≈ $1/[n_H\sigma]$ ≈ 0.2 pc.

Is there any hot gas in the Local Bubble or is the gas recombining, or is Fe depleted?





- Observation with the Cosmic Hot Interstellar Plasma Spectrometer (CHIPS) satellite (Hurwitz et al. ApJ 623, 911 (2005)).
- Diffuse emission upper limit of the Fe IX 171Å line (formed at log T = 5.4-6.4). EM<0.001 cm^{-6}pc at logT=5.6.
- Emission measure (~n_e^2 x length) upper limit depends on T and Fe depletion and assumption of collisional ionization equilibrium.
- Significant foreground component (large in daylight) not removed!

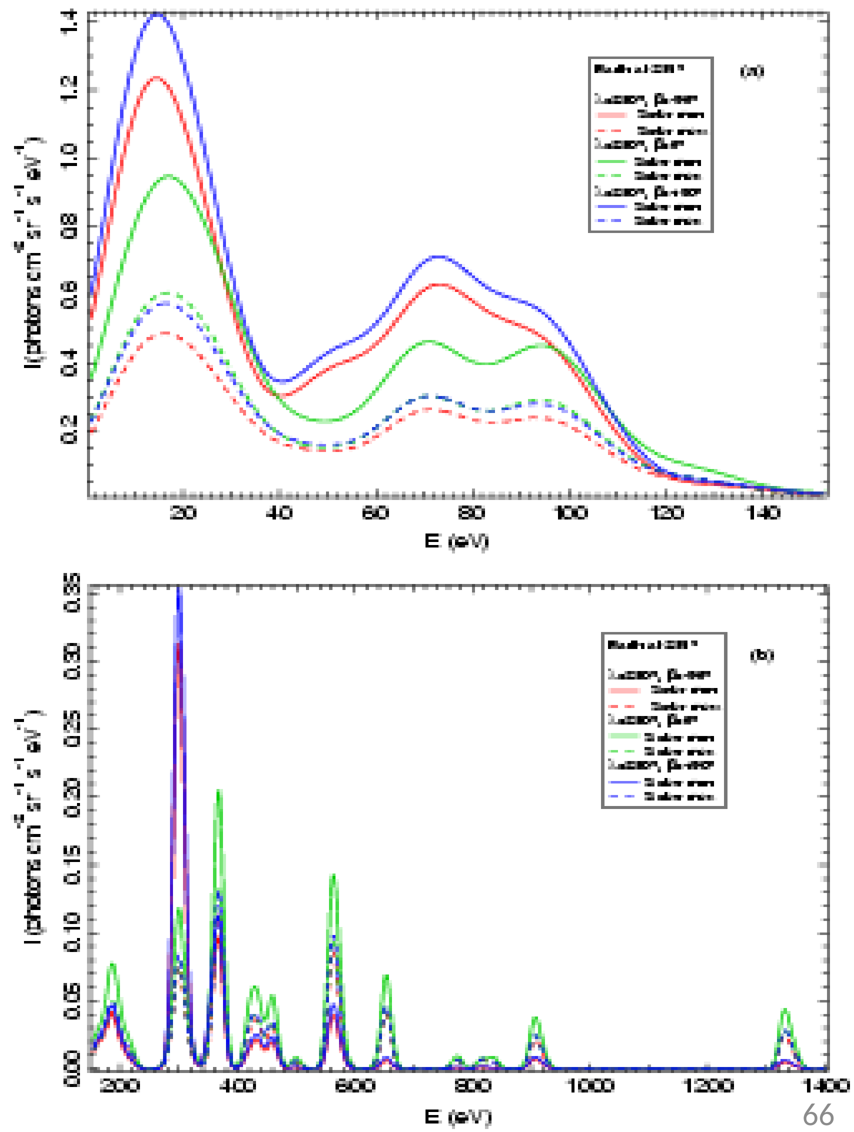
Conclusions

- UV spectroscopy is the essential tool for LISM studies.
- The measured temperatures and kinematics of LISM warm gas are consistent with measurements of gas flowing into the heliosphere.
- A cluster of discrete partially ionized clouds with distinct kinematics is a better description of the LISM than one cloud with velocity structure.
- The heliosphere is located close to the edge of a partially ionized warm cloud. Expect inhomogeneity and time variability.
- We have created a draft 3D model of the warm partially ionized clouds in the LISM (within about 7 pc of the Sun).
- We find no strong evidence that magnetic fields or interstellar flows (ram pressure) or collisions shape the cloud structures. Contrary to de Avillez & Breitschwerdt (2005) simulation.
- 3 or more clouds are consistent with EUV radiation from ε CMa shaping the cloud morphology.
- The filler gas is ionized – Stromgren sphere or out of equilibrium.

Thank you for your interest in this continuing program.

Could the soft X-ray background be foreground? (Koutroumpa et al. A+A 460, 289 (2006))

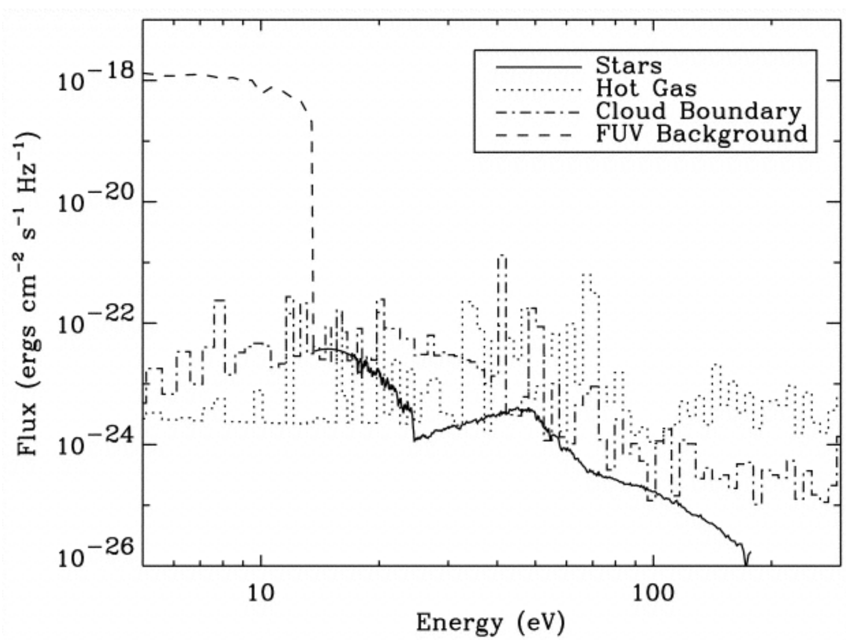
- Calculation of EUV/soft X-ray emission from charge transfer between solar wind heavy ions and interstellar neutral atoms.
- Solid lines are: N ecliptic pole, South ecliptic pole, equitorial antisolar. Solid: solar min. Dashed: solar max.
- Important emission ions: C VI, O VII, O VIII, Ne IX, and Mg XI.
- A large fraction of the EUV and soft X-ray background is heliospheric foreground.
- Earlier studies by Cravens and Lallement with similar conclusion.
- Welsh & Shelton (2009) argue that most of the LB is filled with highly-ionized warm gas.



Possible hot gas models

- If n_e = 0.1 cm^{-3} like in warm clouds, then EM_{LB}= 1 $cm^{-6}pc$ (>1000 times too large).
- If gas pressure equilibrium P/k=2280 Kcm^{-3}, and log T=6.0, then EM_{LB}=0.001 (5 times too small).
- If gas pressure equilibrium and logT as low as 5.6, then EM_{LB}=0.001 (but does not account for significant foreground emission).
- Some semi-hot gas could fill most of volume of the Local Bubble (but not seen in O VI).
- But, there are other pressure terms and the LB could be far from any equilibrium.

Question #5 Ionization in the local ISM: Where is it from and is the ionization in equilibrium with the gas?



- Compilation of UV to X-ray radiation field within 5 pc of the Sun (Slavin & Frisch 2002).
- Major sources are ε CMa, WDs, LB hot gas (?), FUV (?), warm cloud boundary (??).
- What is the amount of ionizing radiation from evaporative boundaries of warm clouds? (O VI, C IV)?
- What are gas and dust phase abundances of C, N, O, etc.?
- Is the ionization of important species in equilibrium with the radiation field or a recombining plasma following a SN event?

Table 8. Hot White Dwarfs and their Strömgren Sphere Radii

WD	l	b	d(pc)	R(7,500K)	R(10,000K)	R(15,000K)	R(20,000K)	R($n_e = 0.03$)
Sirius B	227.2	–9.9	2.64	1.29	1.56	2.04	2.48	4.12
Sirius A+B	227.2	–9.9	2.64	1.59	1.93	2.51	3.05	5.08
40 Eri B	200.8	–38.0	5.04	0.37	0.44	0.58	0.70	1.17
GJ3753	123.3	+62.0	14.1	0.75	0.91	1.18	1.44	2.39
GJ433.1	284.9	+27.7	14.8	0.72	0.88	1.14	1.39	2.31
UZ Sex	245.3	+46.3	18.2	0.52	0.63	0.82	0.99	1.65
GD 50	188.9	–40.1	29.	1.55	1.88	2.47	2.99	4.11[a]
G191-B2B	155.9	+7.1	59.	6.75	8.18	10.72	12.98	17.86[a]
HZ 43	54.1	+84.2	68.	3.88	4.70	6.16	7.47	10.27[a]
Feige 24	166.0	–50.3	74.	7.88	9.55	12.51	15.16	20.85[a]
ϵ CMa	239.8	–11.3	124.	26.2	31.7	41.5	50.3	69.2[a]
β CMa	226.1	–14.3	151.	10.4	12.6	16.5	20.0	27.5[a]
n_e				0.172	0.129	0.0860	0.0645	0.03
$(n_e/0.03)^{-2/3}$				0.313	0.379	0.495	0.601	1.00
$(n_e/0.04)^{-2/3}$				0.378	0.458	0.600	0.727	1.00

[a] R($n_e = 0.04$).

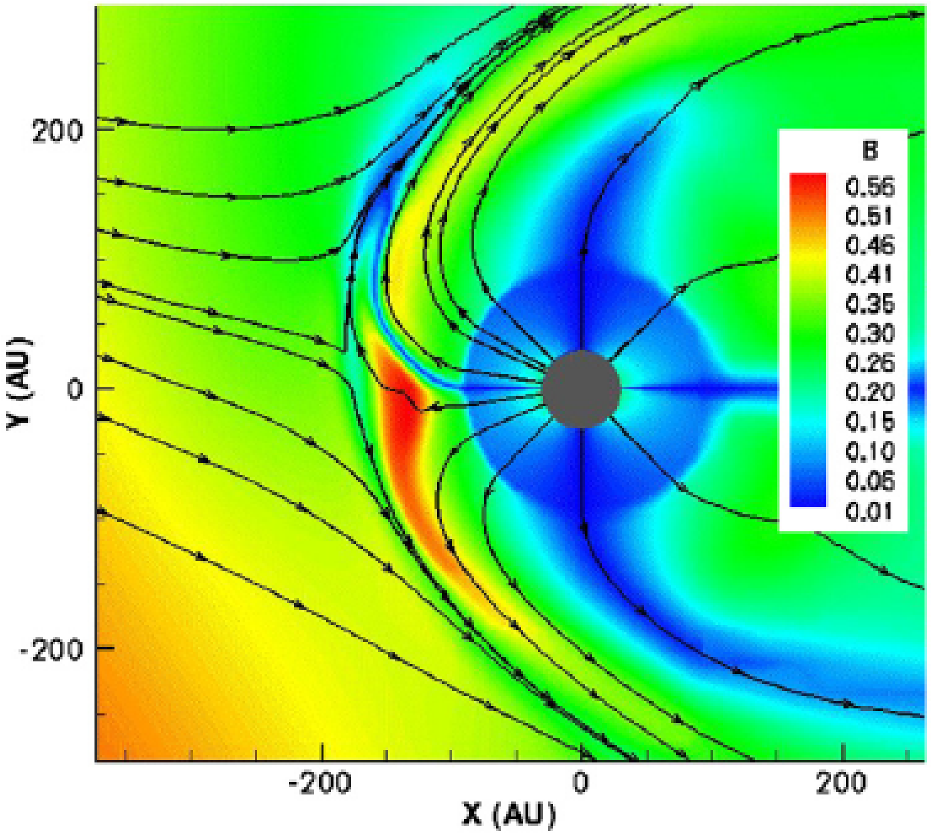
Strömgren sphere radius: $R^3=(3/4\pi n_i n_e \alpha)dN_i/dt$

Possible hot gas models

- If n_e = 0.1 cm^{-3} like in warm clouds, then EM_{LB}= 1 cm^{-6}pc (>1000 times too large).
- If gas pressure equilibrium P/k=2280 Kcm^{-3}, and log T=6.0, then EM_{LB}=0.001 (5 times too small).
- If gas pressure equilibrium and logT as low as 5.6, then EM_{LB}=0.001 (but does not account for significant foreground emission).
- Some semi-hot gas could fill most of volume of the Local Bubble (but not seen in O VI).
- But, there are other pressure terms and the LB could be far from any equilibrium.

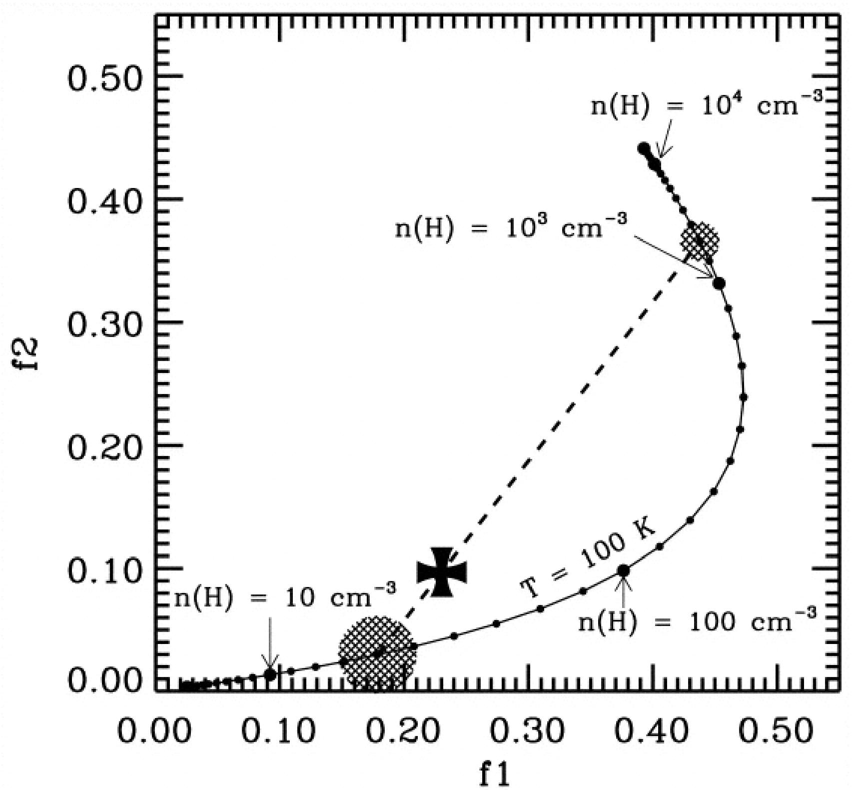
What is the strength of the magnetic field just outside of the heliosphere?

- MHD simulations of the flow and B fields in the heliopause and local ISM.
- Consistent with the Voyager 1 and 2 measurements.
- Swisdak et al. (ApJ 710, 1769 (2010) model.
- B=3.7-5.5μG=0.35-5.5nT (Merav Ophir).
- $P_{mag}/k=B^2/8\pi=3900\text{-}8700$

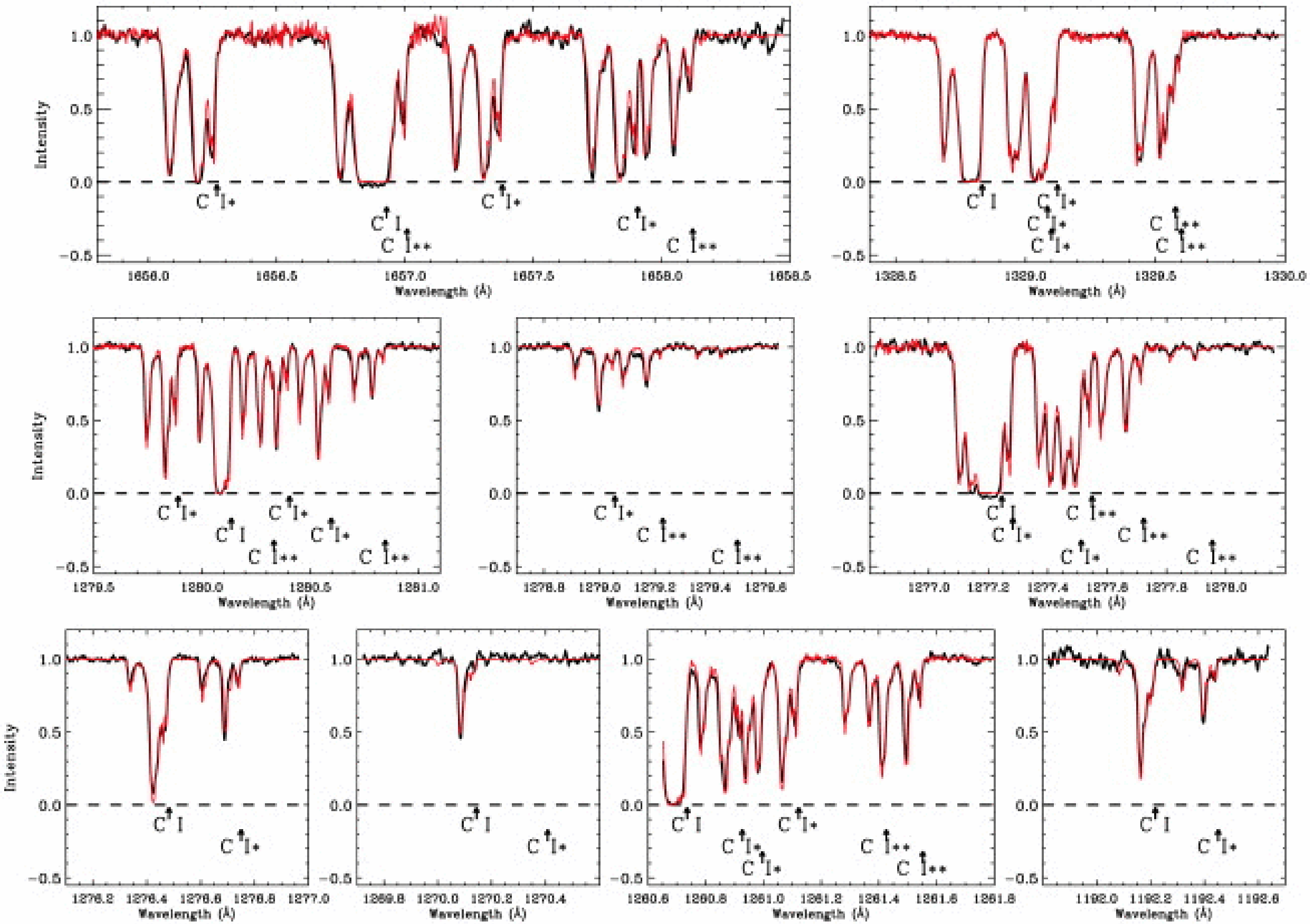


Measurements of thermal gas pressures

- In LIC, P/k = 2300 from spectral line widths and gas densities.
- Jenkins & Tripp (2001) study of C I fine structure excitation (STIS 1.5 km/s spectra).
- Mean thermal P/k=2240.
- 15% of gas at P/k>5,000
- A very small amount of gas at P/k>100,000. Turbulent compression? Very small sizes (0.01 pc)?



C I fine structure line spectra obtained by Jenkins & Tripp (2001) with STIS at 1.5 km/s resolution



What are the Properties of the Local Interstellar Cloud (LIC)? Is this a Typical Warm Cloud?

- From Slavin & Frisch (A&A 491, 53 (2008)).
- $n(H^0)$=0.19-0.20 cm^{-3}
- n(e)=0.07±0.01 cm^{-3} (Photoionization from ε CMa, other stars, and photoevaporation at warm cloud boundaries for harder photons)
- T≈6300±340 K (inflowing He I gas)
- Fractional H ionization ~0.2
- Heat sources: photoelectrons from ionization of H I and He I
- Cooling: [C II] 157.6μm, [S II] 6731Å, other lines
- P_{th}/k=2100 cm^{-3}K, $P_{th}=P_{mag}$ at B~2.7μG
- Inflow velocity 26.3 km/s from Sco-Cen Association
- LIC assumed to be in ionization, thermal, and dynamic equilibrium in this model but probably not in equilibrium.

LIC with dashed line 90° from ε CMa

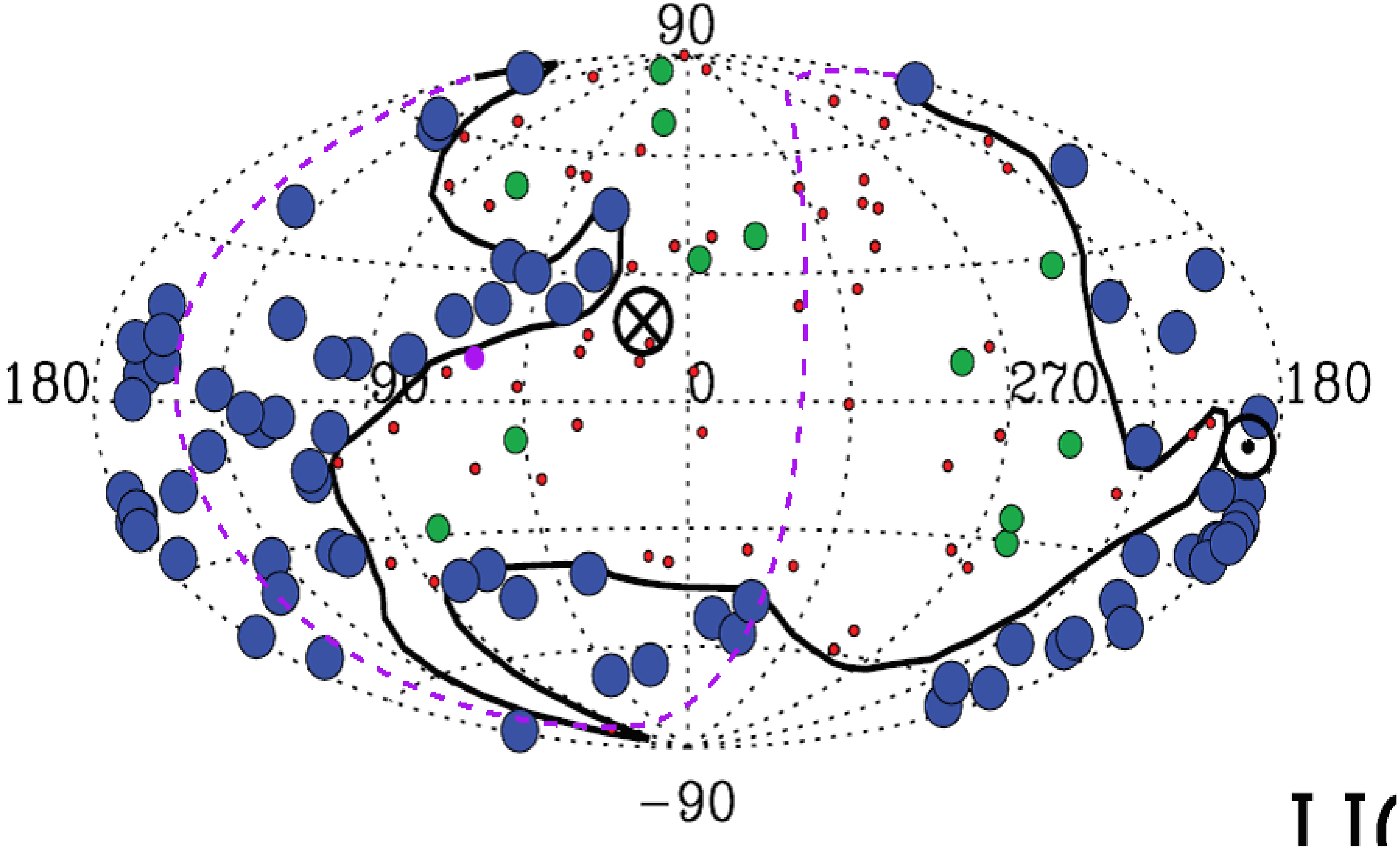


Table 1. Summary of the average values of volume filling factors, mass fractions and root mean square velocities of the disk gas at the different thermal regimes for the HD and MHD runs.

T [K]	$\langle f_{\rm v}\rangle^a$ [%] HD	$\langle f_{\rm v}\rangle^a$ [%] MHD	$\langle f_{\rm M}\rangle^b$ [%] HD	$\langle f_{\rm M}\rangle^b$ [%] MHD	$\langle v_{\rm rms}\rangle^c$ HD	$\langle v_{\rm rms}\rangle^c$ MHD
<200 K	5	6	44.2	39.9	7	10
$200-10^{3.9}$	46	29	49.0	43.7	15	15
$10^{3.9}-10^{4.2}$	10	11	4.4	8.5	25	21
$10^{4.2}-10^{5.5}$	22	33	2.0	7.4	39	28
$>10^{5.5}$	17	21	0.3	0.5	70	55

[a] Occupation fraction.
[b] Mass fraction.
[c] Root mean square velocity in units of km s^{-1}.

Comparison of parameters for the LIC (Slavin & Frisch 2008) vs LIC (Redfield & Linsky 2008, Falcon & Redfield 2008)) vs α Leo line of sight (Gry & Jenkins (2017)

Parameter	LIC (S&F)	LIC (R&L)	α Leo (LIC +)
Temperature	≈6300	6200-8800	5900-7250
Electron density	0.06-0.08	0.08-0.16	0.08-0.135
Neutral H density	0.19-0.20		0.10-0.28
Pressure			1580-3460
H Ionization fraction	≈0.2		0.27-0.42