Solving the Mysteries of the Interstellar Medium with High-Resolution Spectroscopy

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Space Astronomy: the UV Window to the Universe

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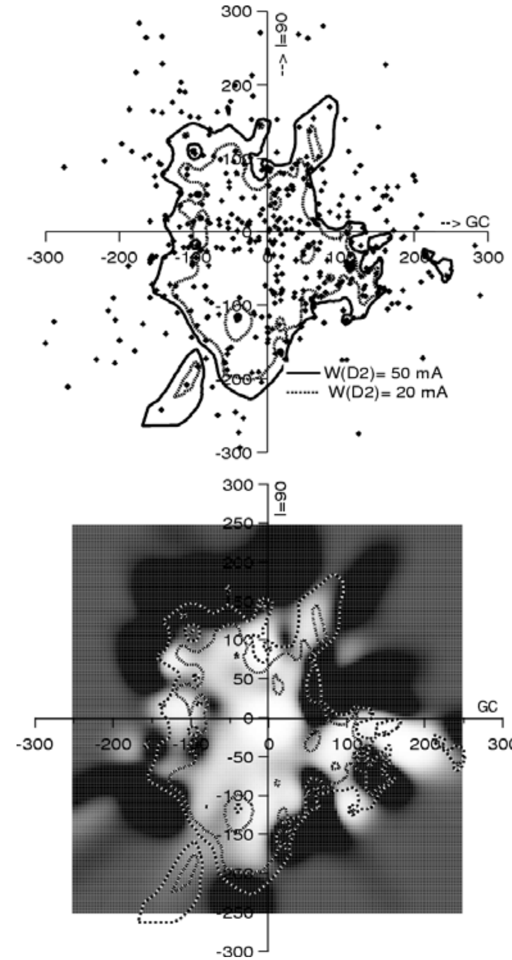
Outline

- Why understanding the Local ISM is critically important
- 10 important unanswered questions concerning the local ISM that can be addressed with UV spectroscopy
- Instrumental requirements for a future UV spectroscopy mission
- Other considerations for future UV spectroscopy missions

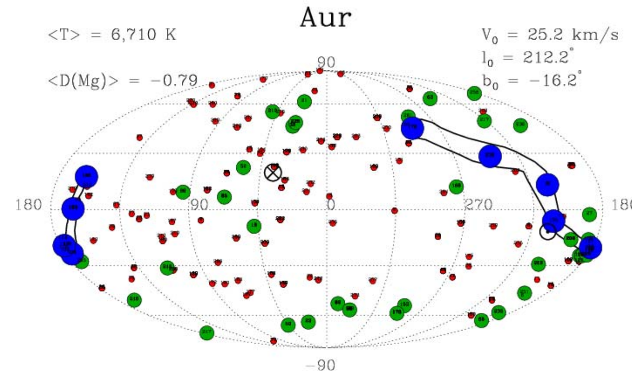
Why understanding the local ISM is critically important

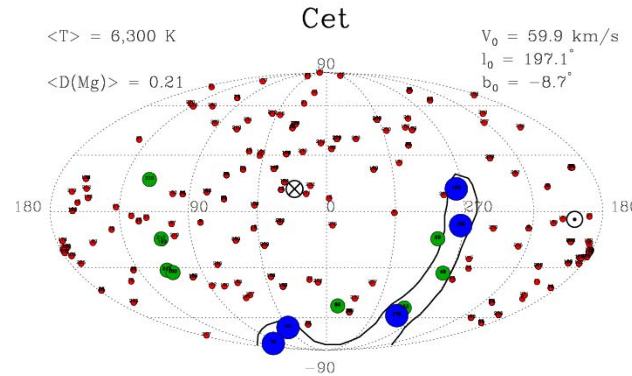
- Understanding the physical processes in the ISM of our Galaxy is needed before attempting to model other Galaxies (i.e., starbursts, low z)
- First understand the physical processes operating in our own back yard where we have the best data and highest angular resolution.
- Figure from Lallement et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



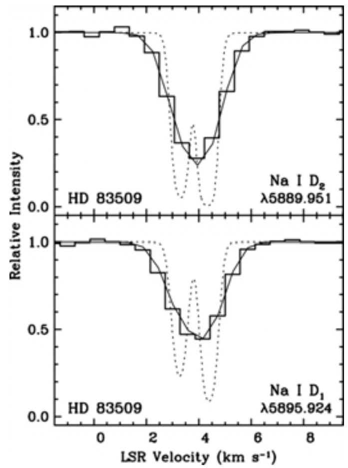
Question #1 What is the structure of warm gas clouds?

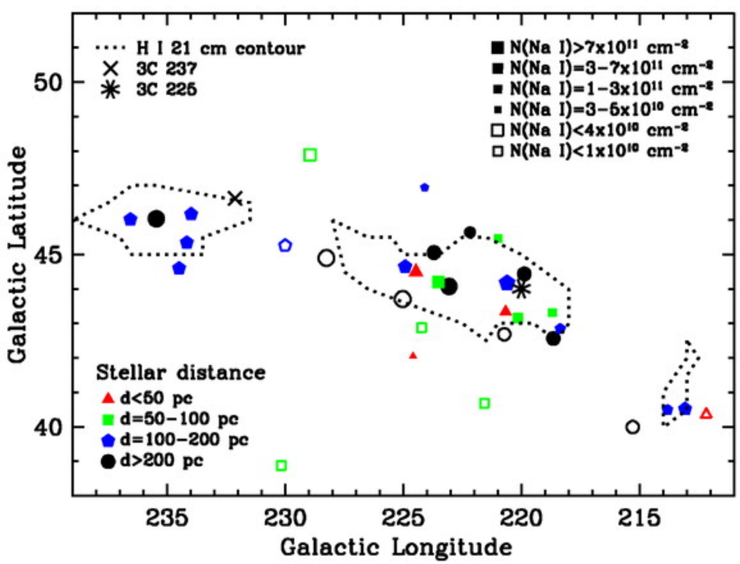
- Are thin filamentary structures typical?
- How realistic is the assumption that the clouds have rigid gas flows?
- Are clouds filled or “swiss cheese”?
- Are outer edges sharp or soft?
- What are the roles played by magnetic fields and cloud-cloud interactions?
- Figures from Redfield et al. (2007) ApJ in press.





Question #2 How do cold gas clouds survive in an unfriendly environment?

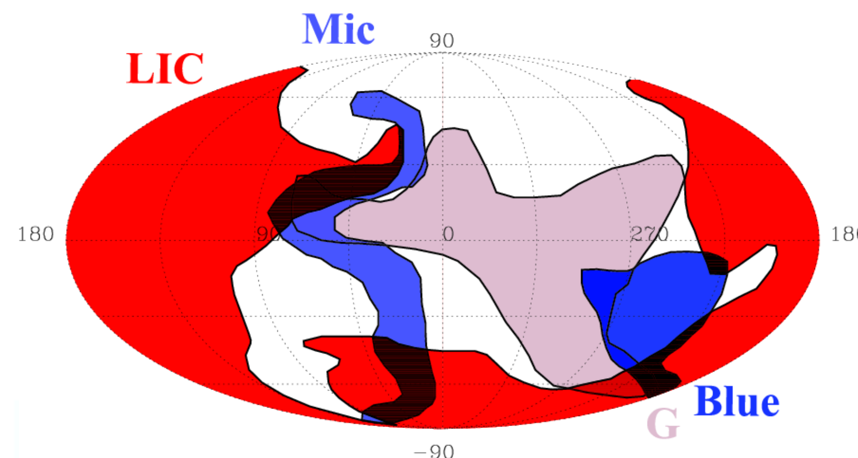


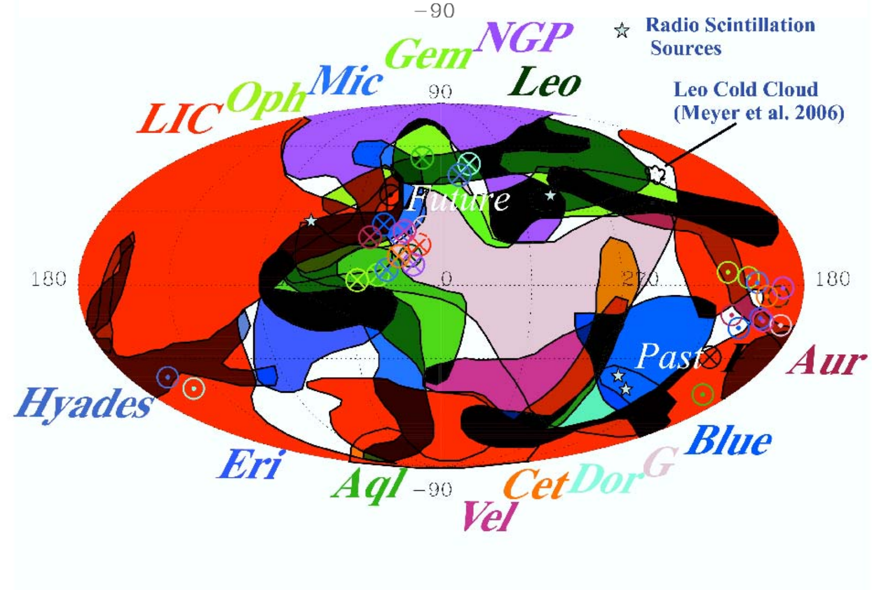


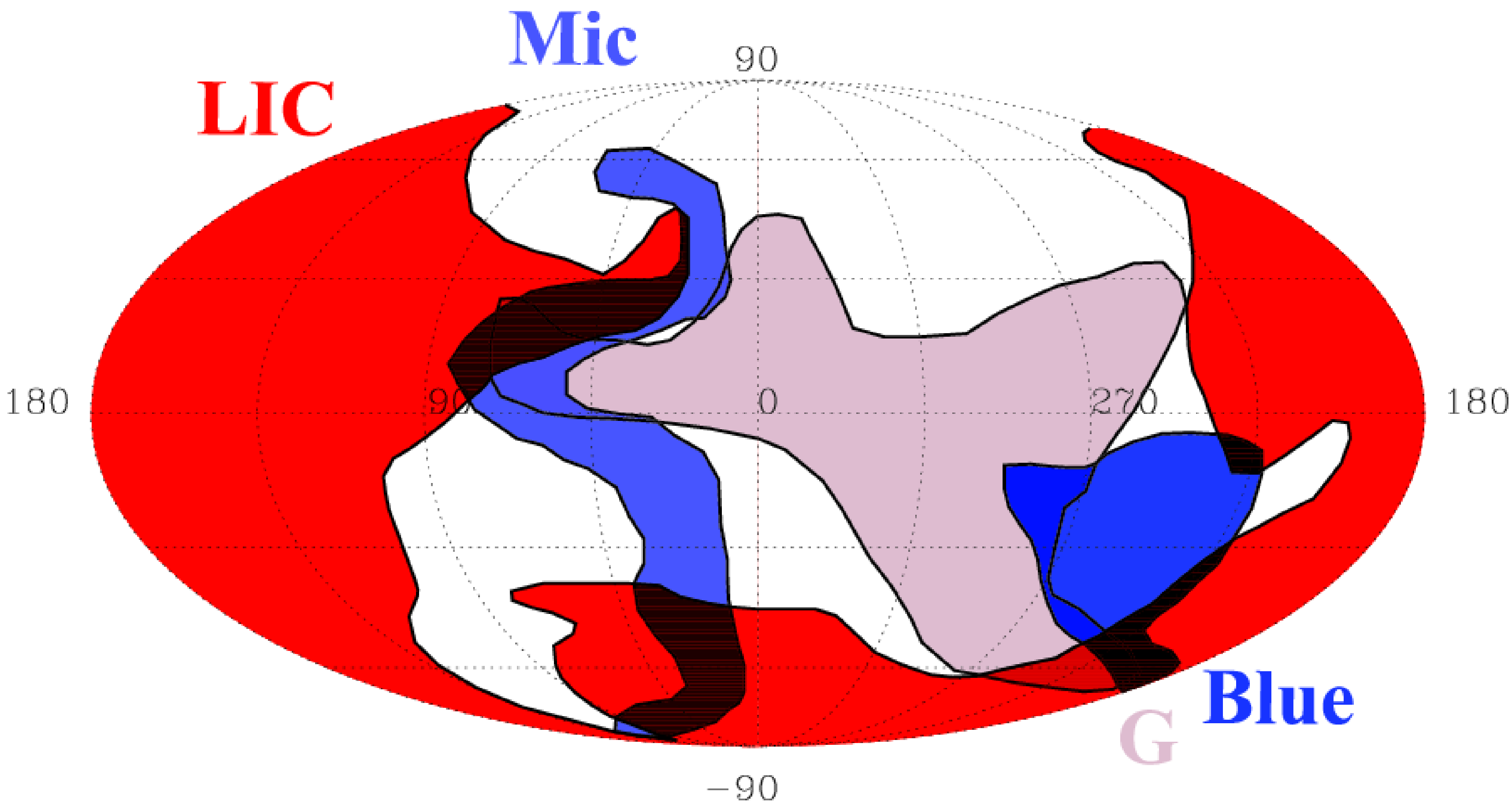
- Cold cloud (T~20 K) inside the Local Bubble (d<41 pc).
- Cold cloud must be shielded from external UV by neutral H (probably in warm clouds).
- Need to identify the warm surrounding gas.
- Figures from Meyer et al. (2006) and Heiles and Troland (2003).

Question #3 What happens when interstellar clouds interact?

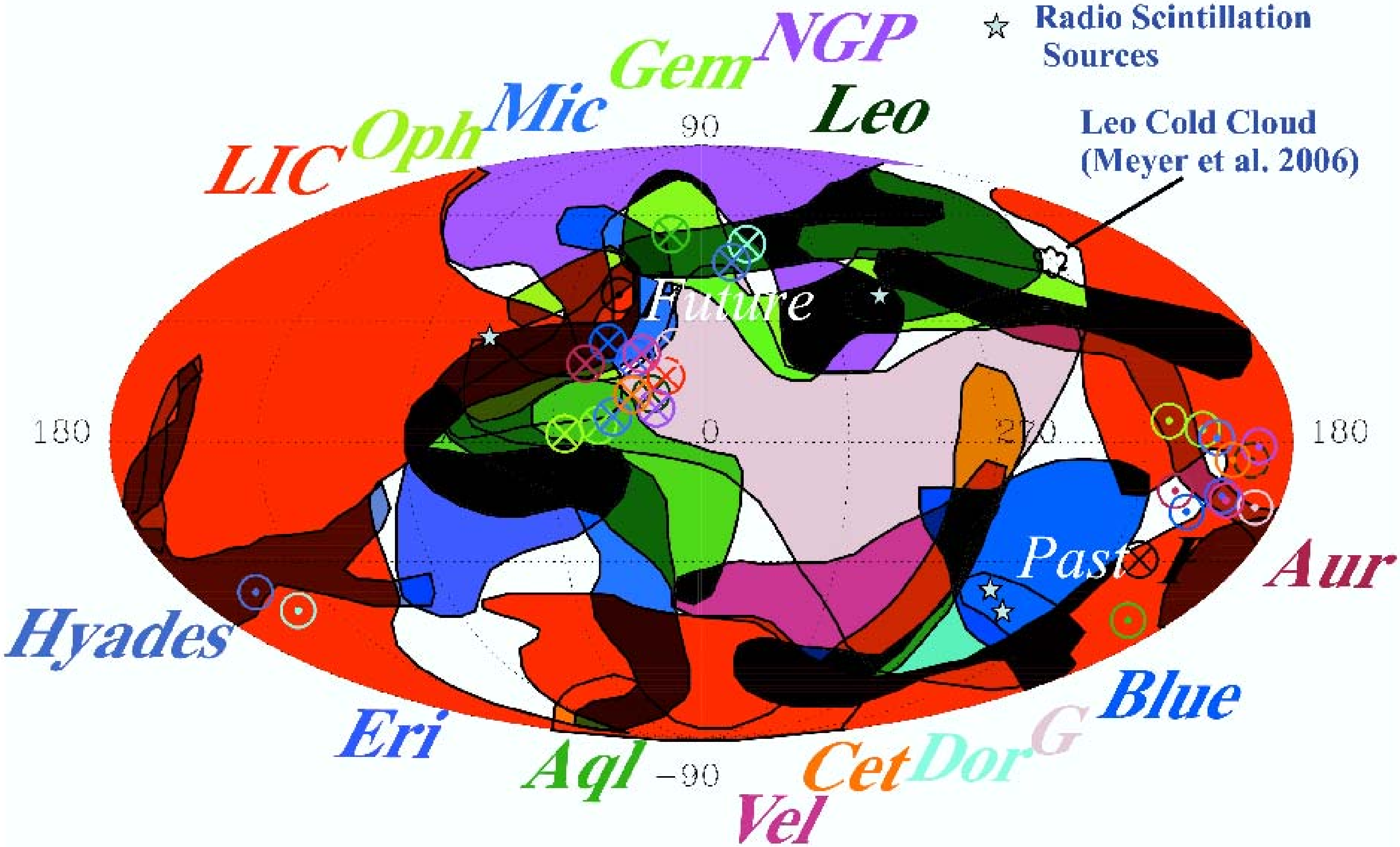
- 15 warm clouds within 15 pc of Sun. Shapes determined by kinematics (velocity vectors) from high-resolution STIS and GHRS data (Redfield & Linsky 2007).
- Mic and Blue clouds may be due to compression.
- Radio scintillation screens where clouds interact?
- Leo cold cloud surrounded by warm gas?
- Relative cloud motions often supersonic (>8 km/s).
- Need more sightlines and T measurements from UV absorption line widths.





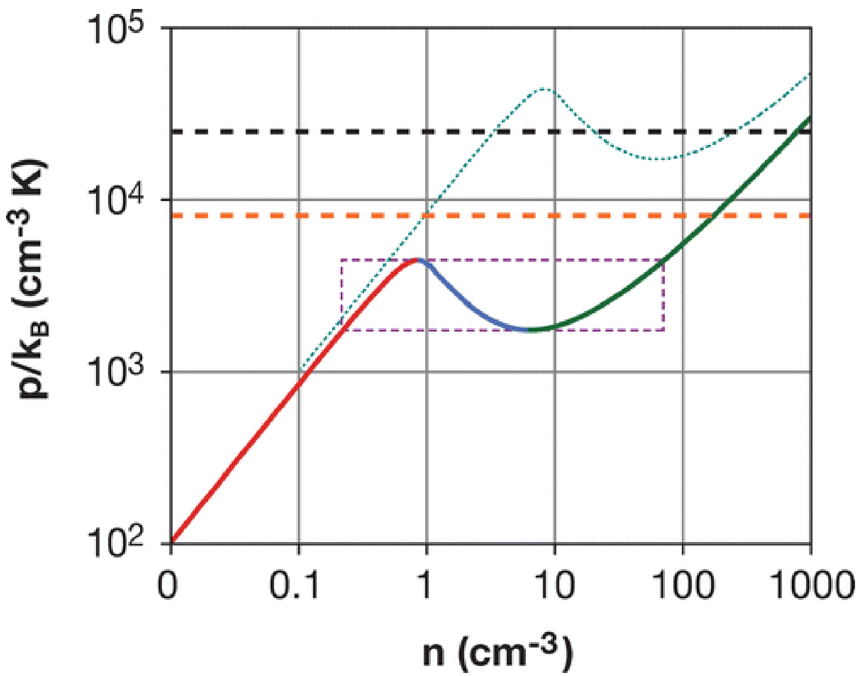


Mic
LIC
90
180
90
0
270
180
−90
G
Blue


Radio Scintillation Sources
LIC
Oph
Mic
Gem
NGP
Leo
Leo Cold Cloud (Meyer et al. 2006)
90
Future
180
0
270
180
Past
Aur
Hyades
Eri
Aql
−90
Vel
Cet
Dor
G
Blue

Question #4 Why is there severe pressure disequilibrium in the ISM?

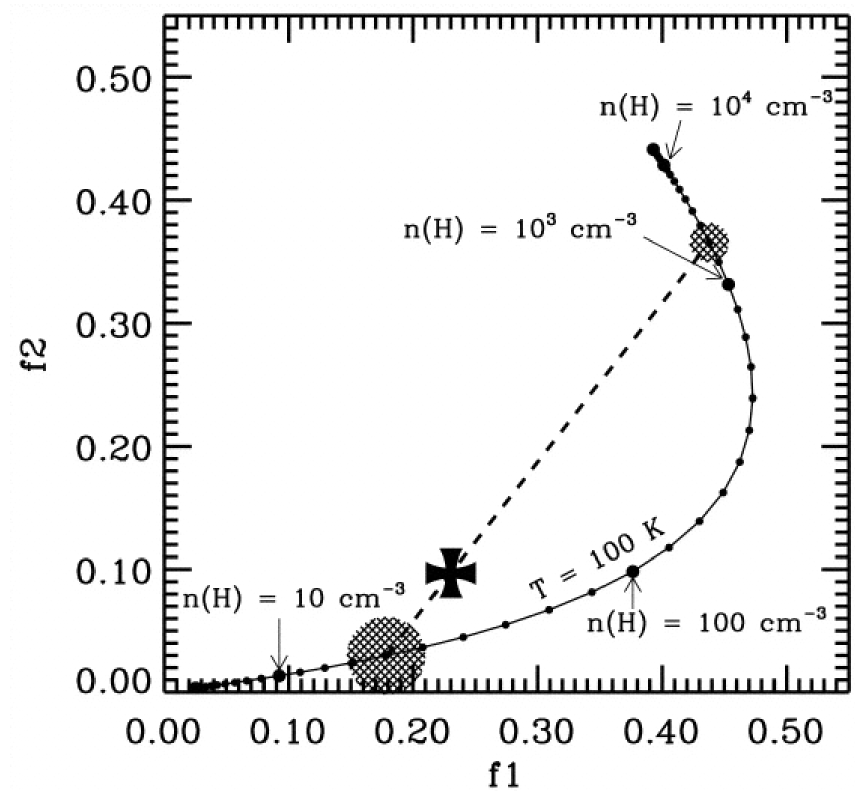
- Theoretical two-phase equilibrium ISM model (Wolfire et al. 2003; Cox 2005).
- Blue dotted curve is 10X higher heating rate.
- Black dashed line is total midplane pressure due to overlying matter.
- Orange dashed line is mean magnetic pressure.
- Nonthermal pressure (dynamic, magnetic, cosmic ray) dominates the thermal pressure. Therefore, a wide range of pressures (1700-20,000 can be compensated by different nonthermal terms.
- Is this the whole story? Dynamic pressures can be measured by high-resolution UV spectroscopy.



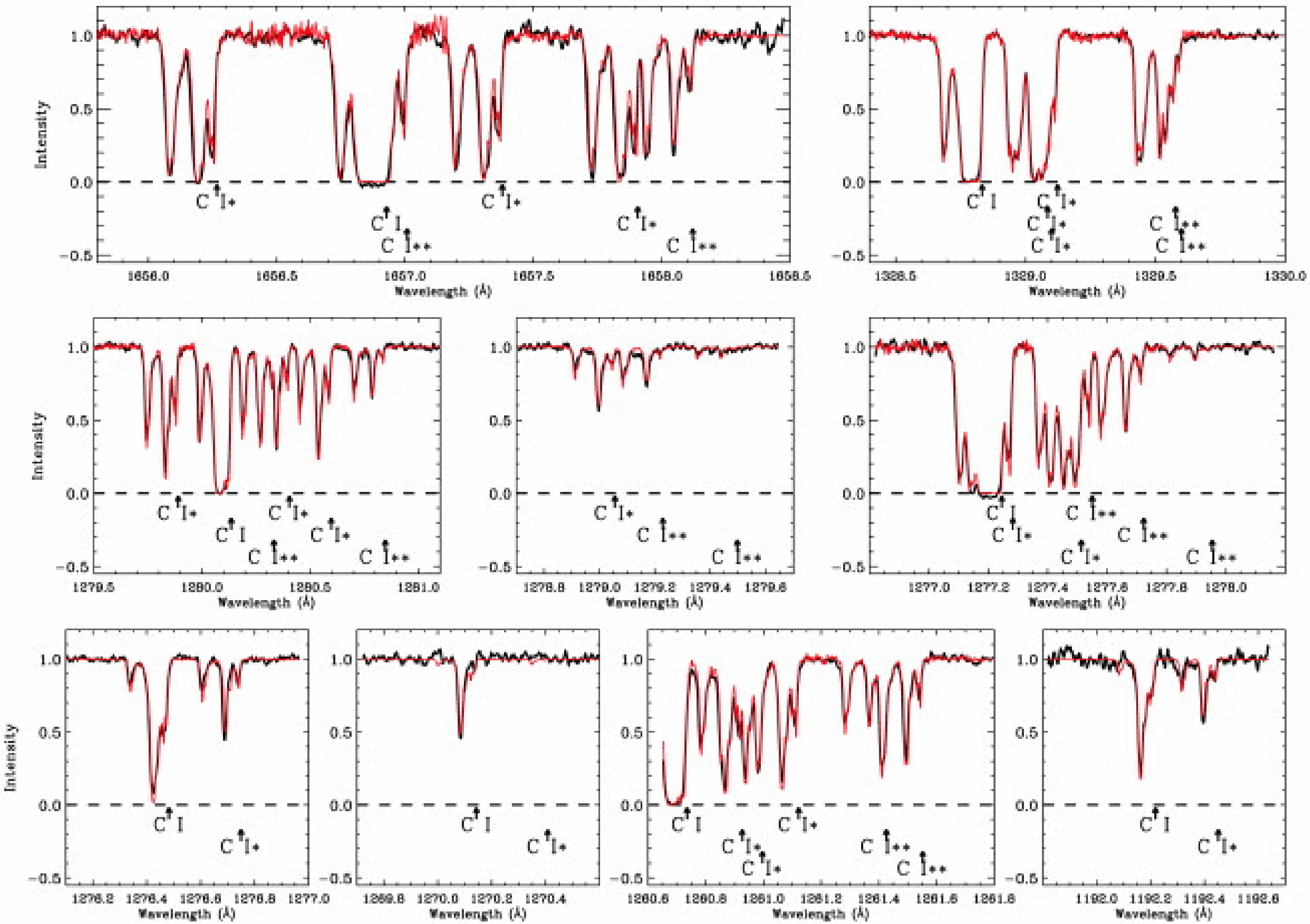
Cox, DP. 2005
Annu. Rev. Astron. Astrophys. 43: 337–85

Measurements of thermal gas pressures

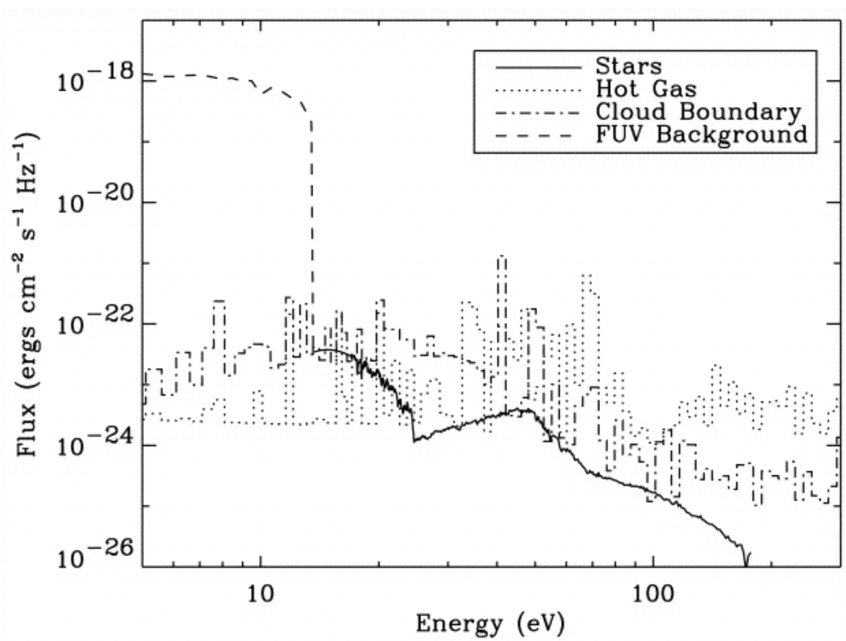
- In LIC, P/k = 2300 from spectral line widths and gas densities.
- Jenkins & Tripp (2001) study of C I fine structure excitation (STIS 1.5 km/s spectra).
- Mean thermal P/k=2240.
- 15% of gas at P/k>5,000
- A very small amount of gas at P/k>100,000. Turbulent compression? Very small sizes (0.01 pc)?



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

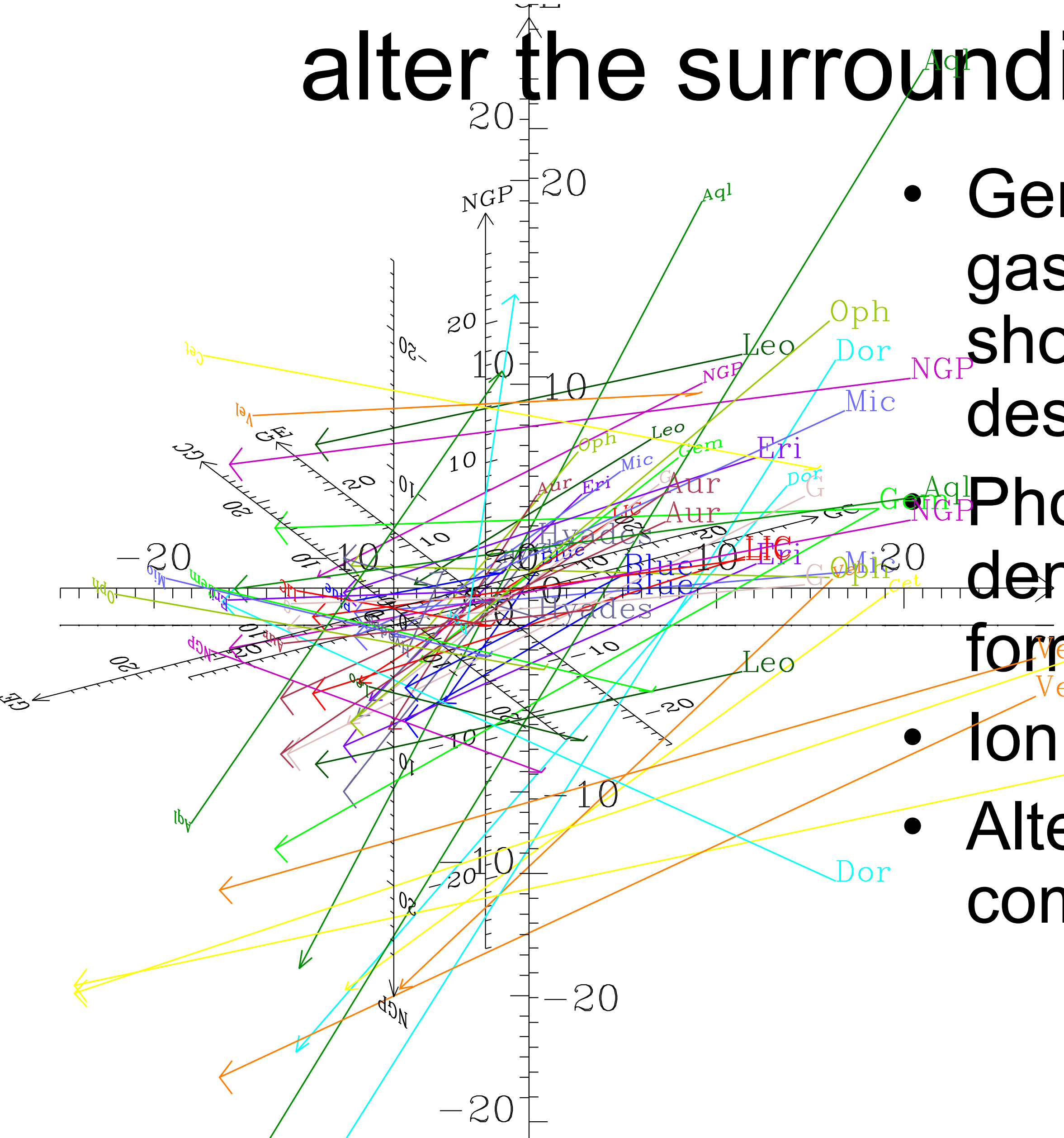


Question #5 Ionization in the ISM: Causes, steady-state or time-dependent?



- Compilation of UV to X-ray radiation field within 5 pc of the Sun (Slavin & Frisch 2002).
- Major sources are ε CMa, WDs, hot gas (?), FUV (?), cloud boundary (??).
- What is emission 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?

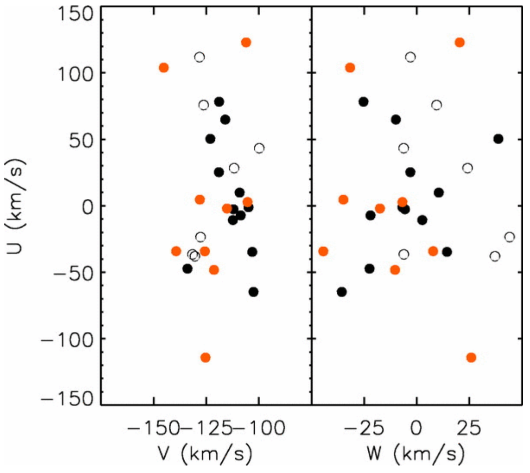
Question #6 How do starbursts alter the surrounding ISM?

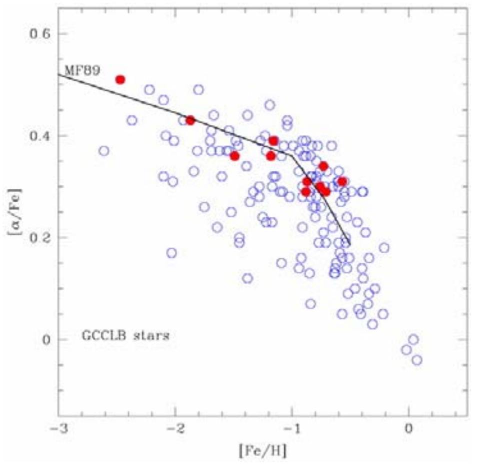


- Generate high speed gas flows producing shocks, heating, grain destruction.
- Photoevaporate dense clouds→star formation, EGGs.
- Ionize the gas.
- Alter chemical composition.

Question #7 Is there alien material in the local ISM?

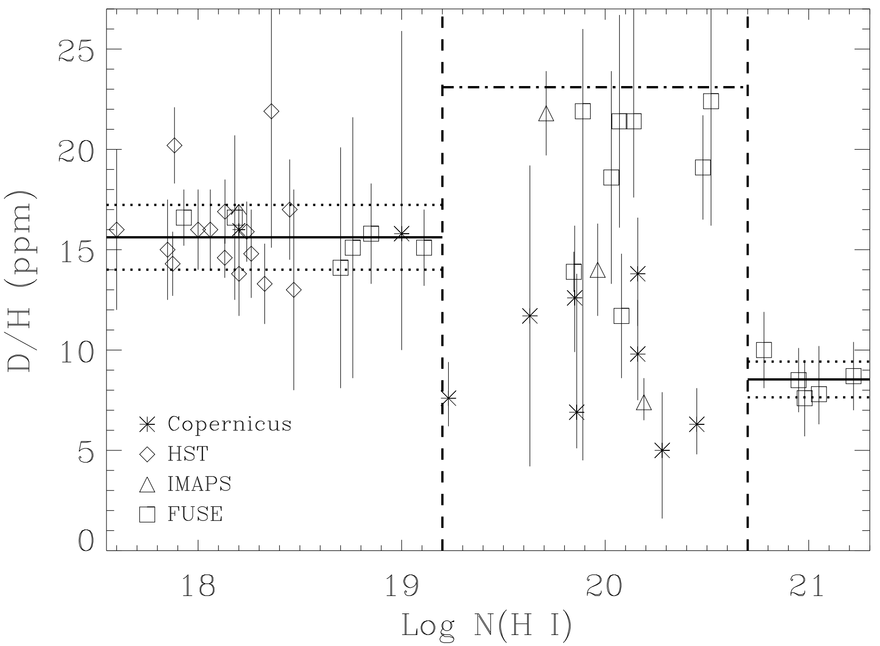
- The Arcturus moving group likely originated from debris of a shredded satellite galaxy (Navarro et al. 2004).
- Kinematic basis: move 100 km/s more slowly than LSR about Galactic center.
- Abundance anomaly
- Close stars: Arcturus (11.2 pc) and HD 199288 (21.6 pc).



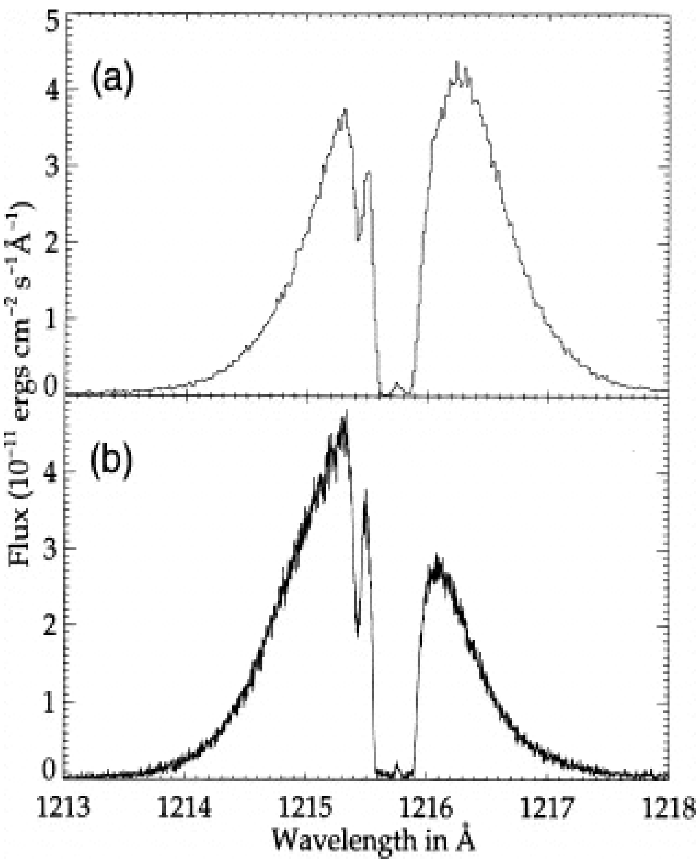


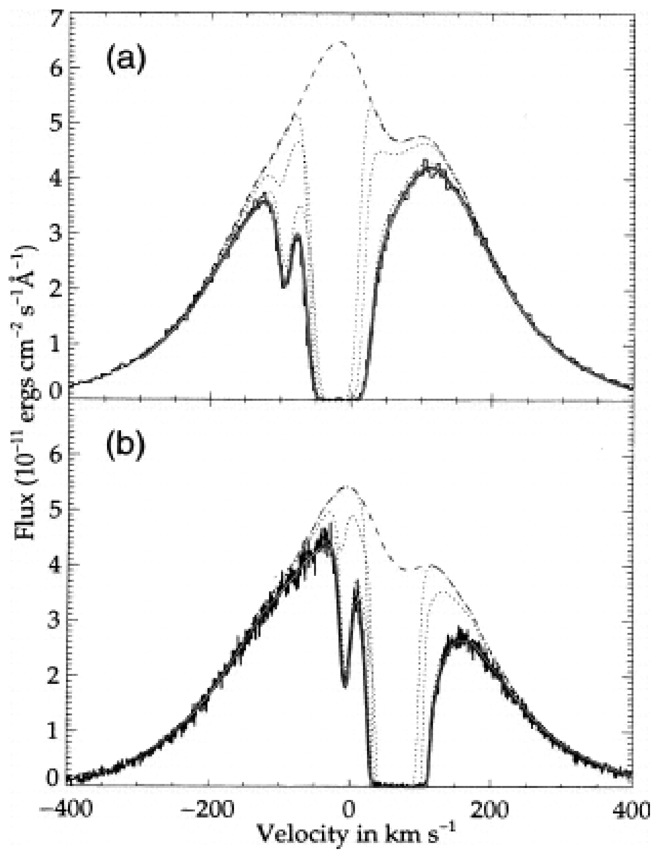
Evidence for near primordial gas falling into the Galaxy

- Peak D/H ≥ 23 ppm (Linsky et al. 2006).
- Primordial D/H≈27 ppm (WMAP, QSOs).
- GCC models predict more destruction of D.
- Evidence for inflow of near-primordial gas into the Galaxy.
- Requires high-resolution spectroscopy in UV and FUV with small slit to remove geocoronal Lyman line emission.



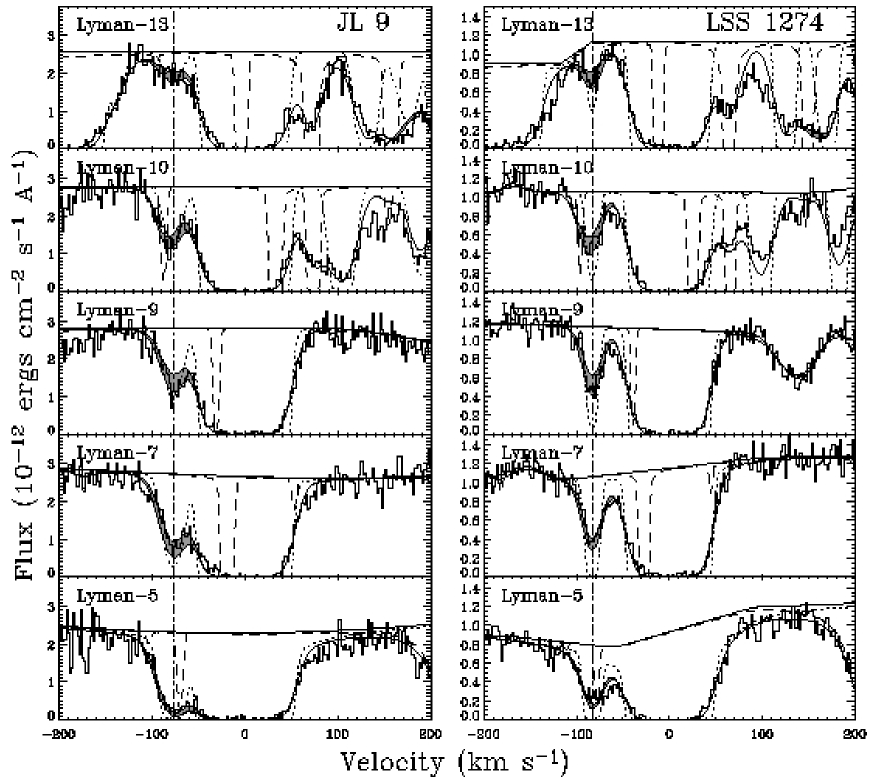
Lyman-α profiles of HR 1099 at phases 0.24 and 0.85 (radial velocity separation 113 km/s) at resolutions 3.5 and 15 km/s





FUSE $(D/H)_{gas}$ measurements toward JL 9 and LSS 1274

- Wood et al. (ApJ 609, 838, 2004).
- JL 9 (sdO at 590 ± 160 pc and log N(HI) = 20.78) $(D/H)_{gas}$ = 10 ± 1.0 ppm.
- LSS 1274 (sdO at 580 ± 100 pc and log N(HI) = 20.98) $(D/H)_{gas}$ = 7.6 ± 1.8 ppm.



Other ISM science questions requiring UV/FUV spectroscopy

- (8) How hot is the Local Bubble gas and why is it hot? (Need spectroscopic diagnostics to separate thermal emission from charge-exchange processes.)
- (9) What are the important physical processes at cloud interfaces? (Thermal conduction, evaporation, MHD interactions, etc.)
- (10) What are the causes and scales of turbulence in the ISM? (Kolmogorov turbulent spectrum on all scales?, how produced?, how maintained?)

Instrumental requirements for a future UV spectroscopy mission

Science Objectives	Res. (km/s)	S/N	Wavelengths
Structure of warm clouds	3	50	UV, FUV
Cold gas clouds	1	50	UV, FUV
Cloud interactions	3	30	UV, FUV
Pressure disequilibrium	1	50	UV, FUV
Ionization processes	3	30	UV, FUV
Effects of starbursts	3	30	UV, FUV
Alien matter in the ISM	3	30	UV
How hot is the LB?	10	30	UV, FUV
Cloud interfaces	3	30	UV, FUV
Turbulence	1	50	UV

Other considerations for a future UV spectroscopy mission

- High S/N must requires low fixed pattern noise and low background.
- An accurate wavelength scale requires an onboard spectral line lamp and excellent thermal stability.
- Many programs require the full 912-3000 Å spectral range but could be acieved in separate bands on the same spacecraft.
- Small and large apertures are needed for different programs.
- Need sufficient observing time to complete major programs (many sightlines and targets).
- With increasing spectral resolution more programs become feasible. 3 km/s resolution is highly desirable. This requires excellent stable optics.
- HEO or beyond is highly desirable. Smaller aperture in HEO better and cheaper than larger aperture in LEO.