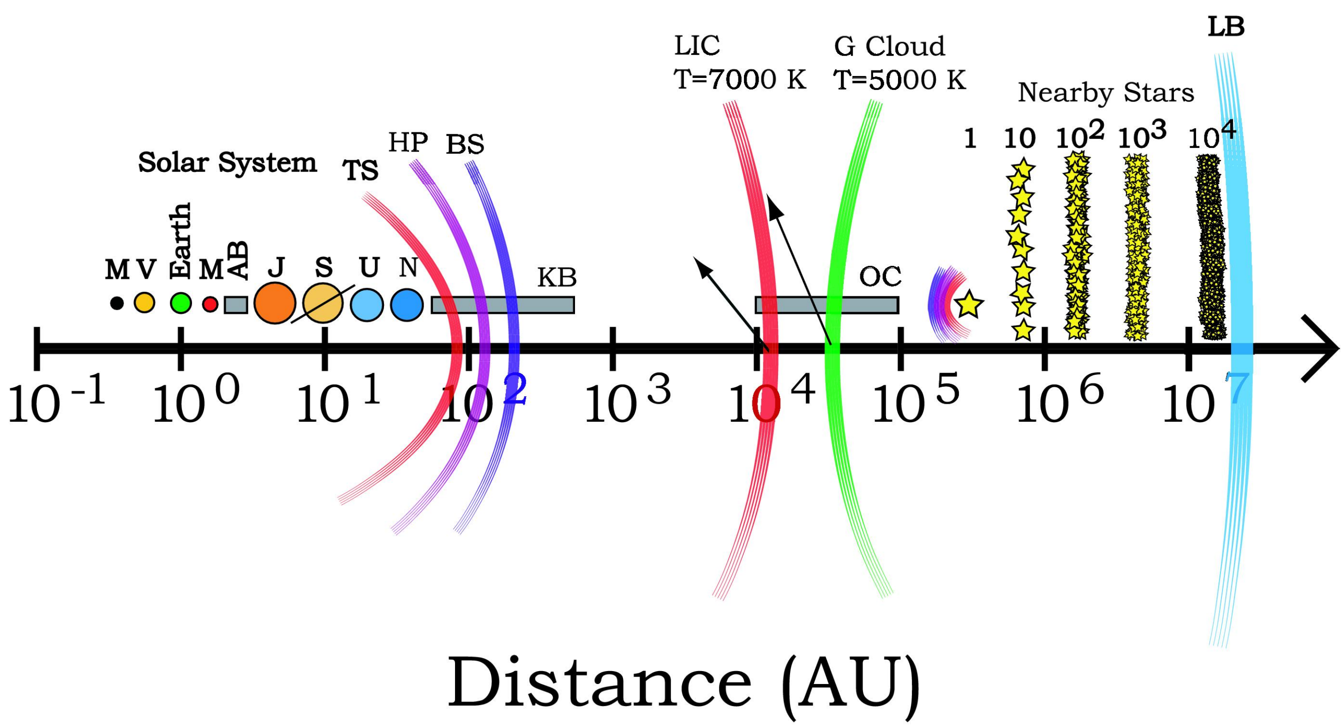
The Interplay of the Local ISM, Cool Star Winds, and Planetary Atmospheres

Seth Redfield
(Wesleyan University)



Adapted from Mewaldt & Liewer (2001)

Outline

Characterizing the Local Interstellar Medium:

ARA&A review: Frisch, Redfield, & Slavin (2011)

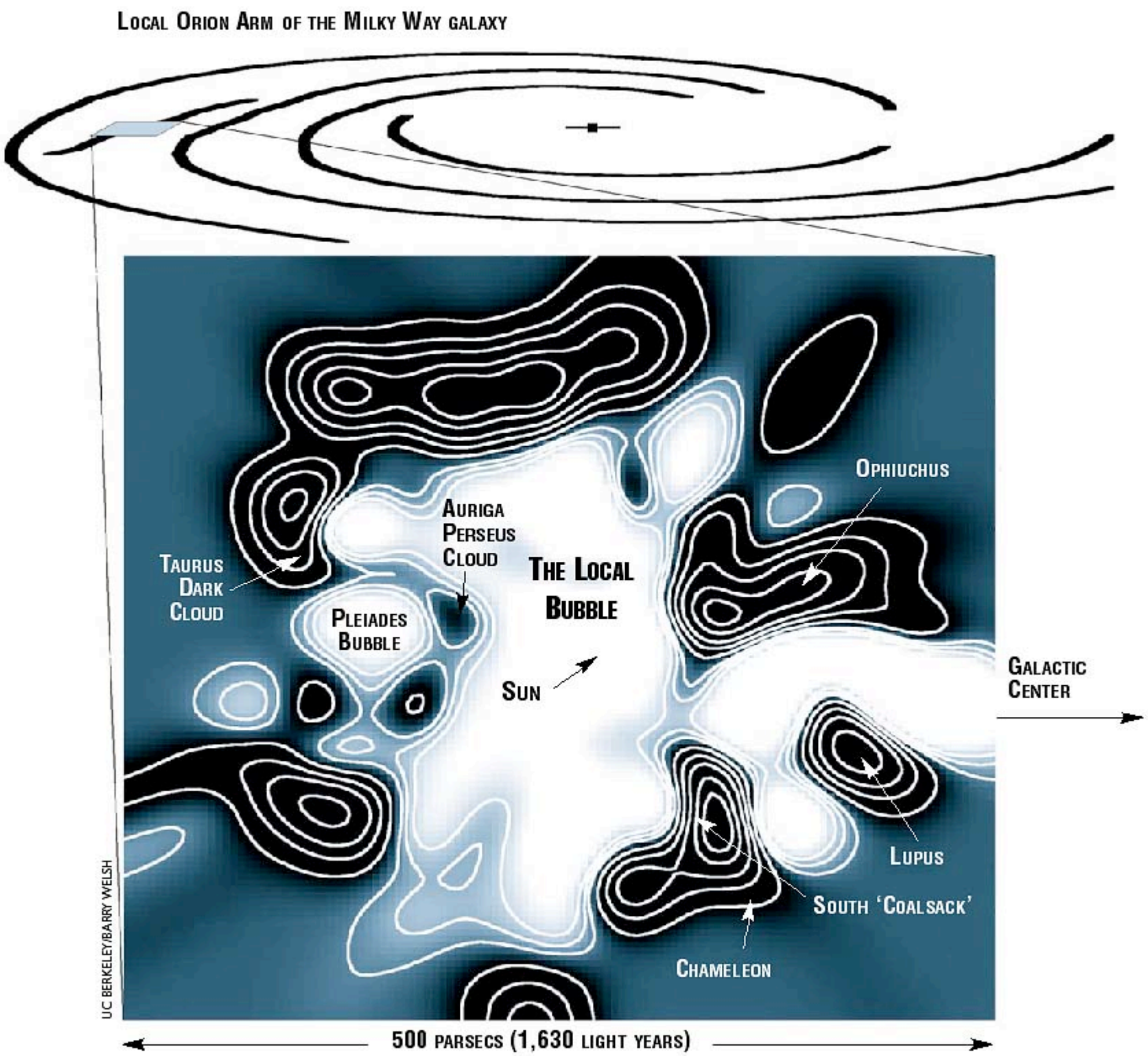
Characterizing Planetary Atmospheres (and Exospheres)

First Hα detection in an exoplanetary atmosphere: Jensen, Redfield, Endl, Cochran, Koesterke, & Barman (2011)

Astrospheres to Estimate Planetary Atmosphere Evolution:

Measuring stellar mass loss rates for exoplanet host stars: 13 orbits for 4 targets in Cycle 19 on *Hubble Space Telescope* (Redfield, Wood, Müller, Linsky, Frisch, Gry, Jensen, Lehner, Knutson, Walkowicz)

Our Galactic Interstellar Community



Lallement, Welsh, et al. (2003)

Local Bubble

R ~ 100 pc; $n_e \sim 10^{-3}$ cm^{-3}; T ~ 10^6 K

Absence of cold material (extinction, NaI spectra)
Soft X-rays (0.25 keV)
Highly ionized absorption and emission lines
(e.g., OVI, OVII, OVIII)

LISM

R ~ 1-10 pc; n ~ 0.2 cm^{-3}; T ~ 7000 K

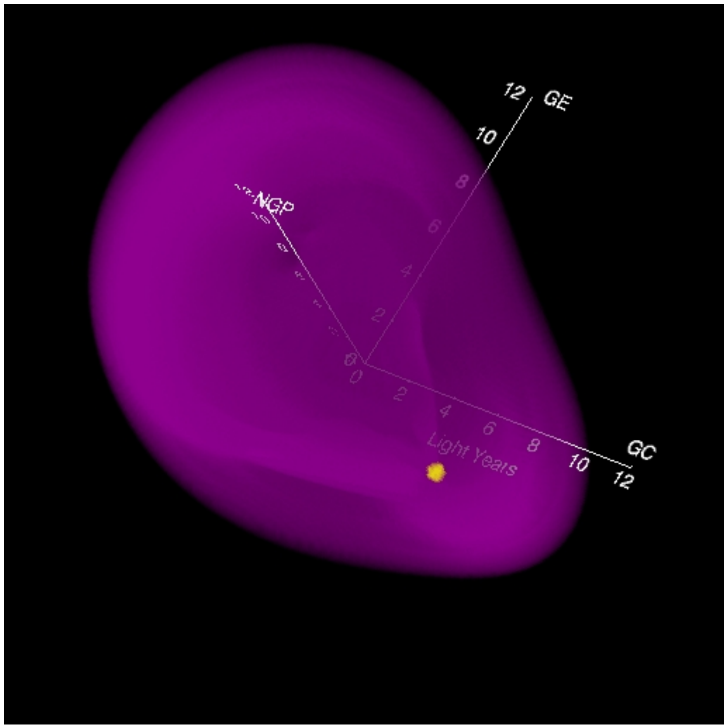
Neutral particles *Ulysses, IBEX* (Möbius et al. 2004)
Backscattered Lyman-α emission
UV/Optical absorption line spectroscopy of neutral and singly ionized elements (e.g., HI, NI, OI, SiII, FeII; Redfield & Linsky 2002, 2004a)

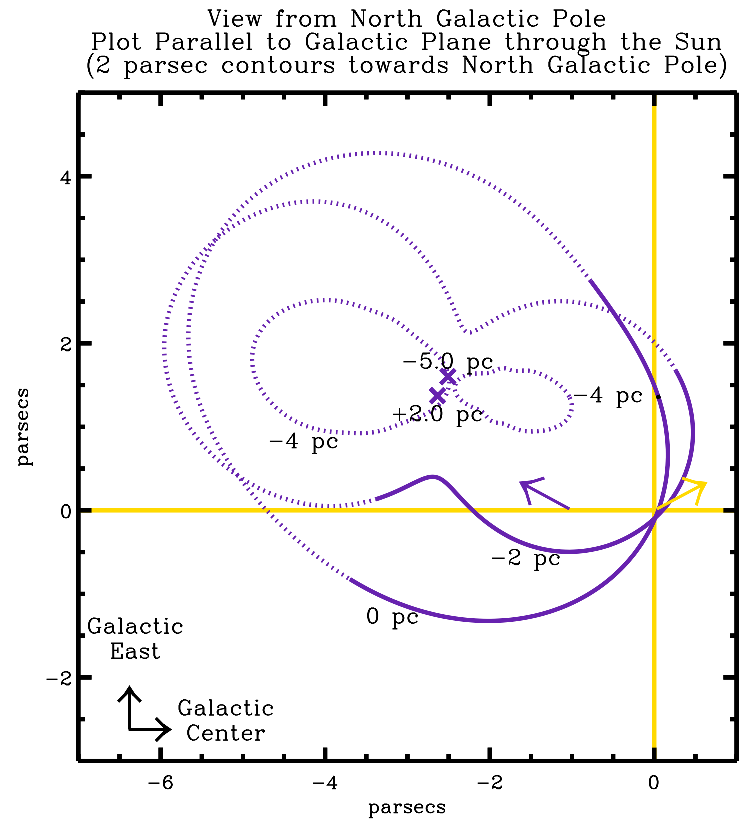
Cold Dense Gas

R~1.4 pc; $n_H \sim 30$ cm^{-3}; T ~ 20 K

Spectroscopy of neutral ions (e.g., NaI)
Leo Cold Cloud (Peek et al. 2011)
Molecules, e.g., H_2, CO

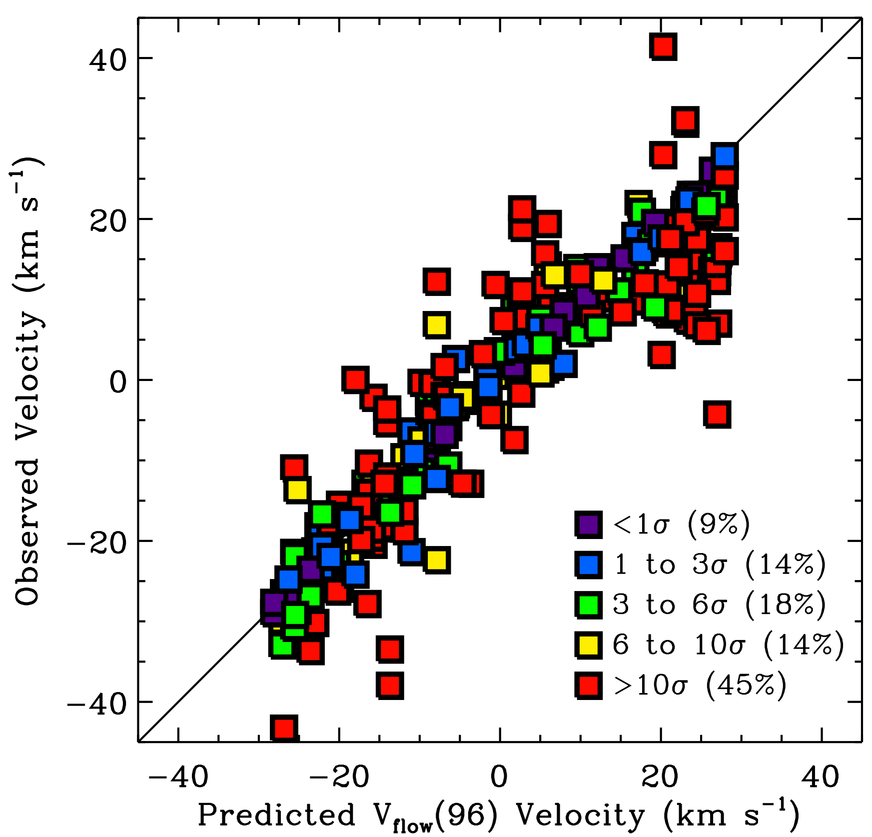
Our Galactic Interstellar Neighborhood



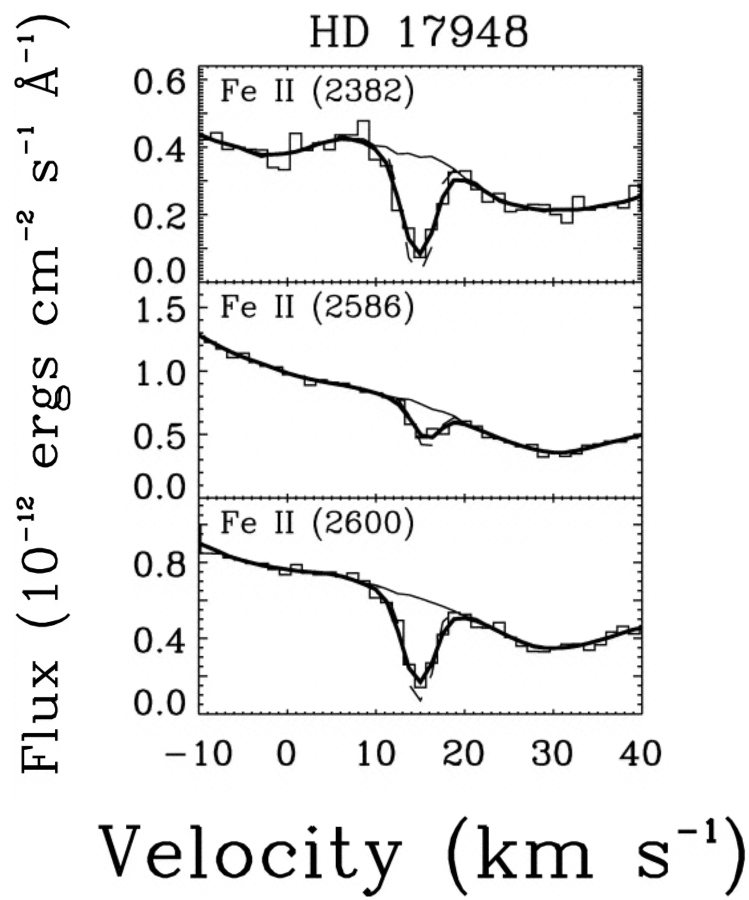


Redfield & Linsky (2000)

Kinematics of the Local ISM

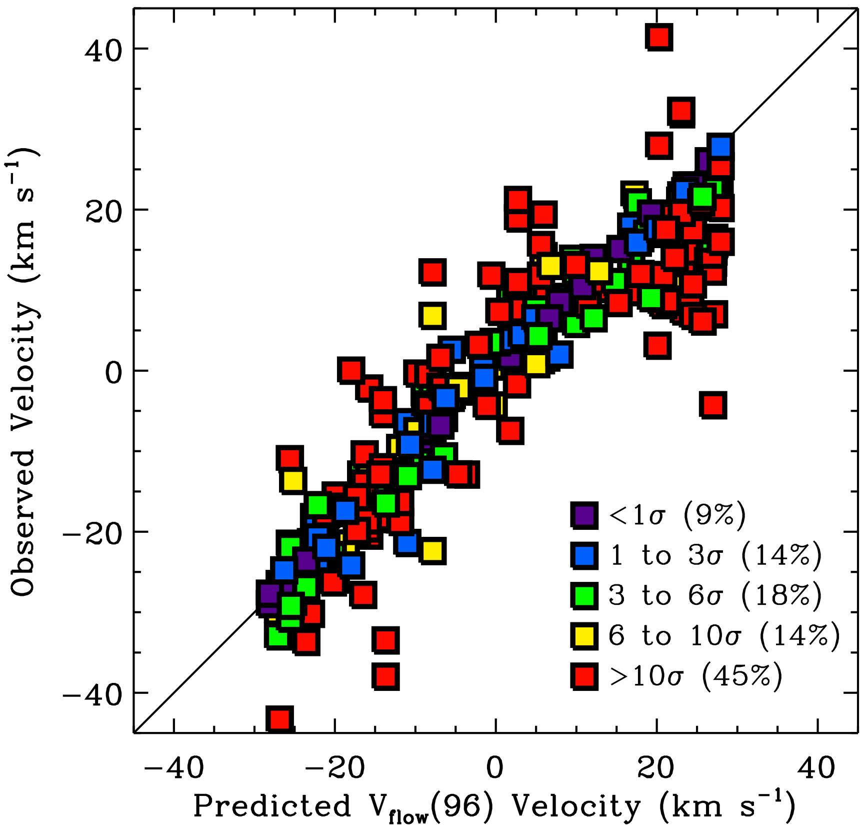


Redfield (2009)

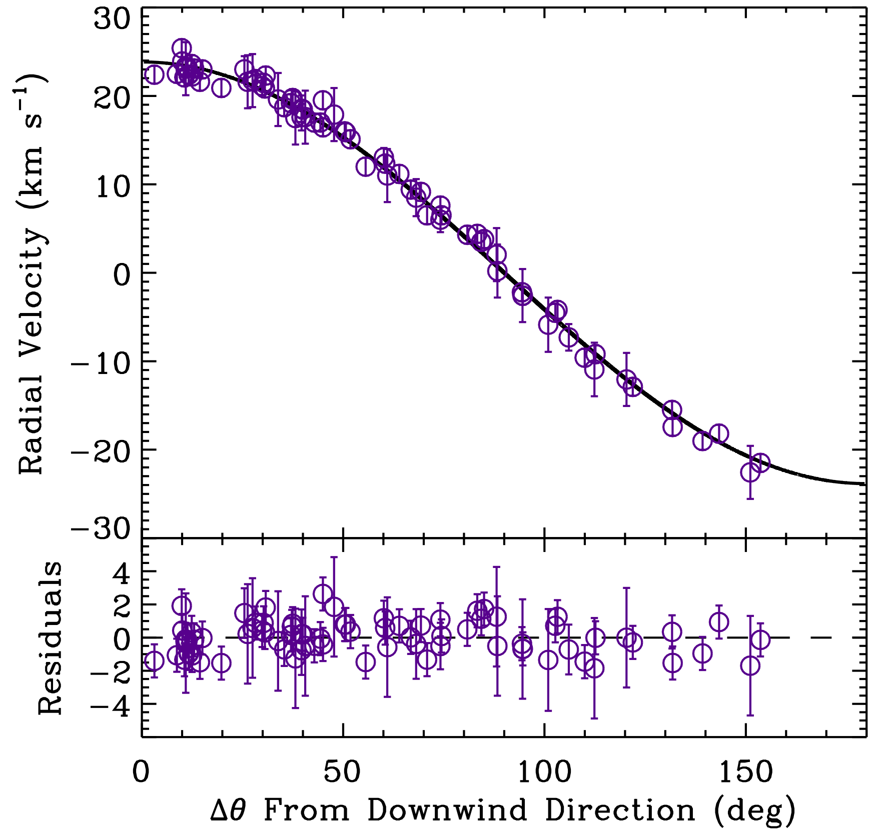


Redfield & Linsky (2004a)

Kinematics of the LIC

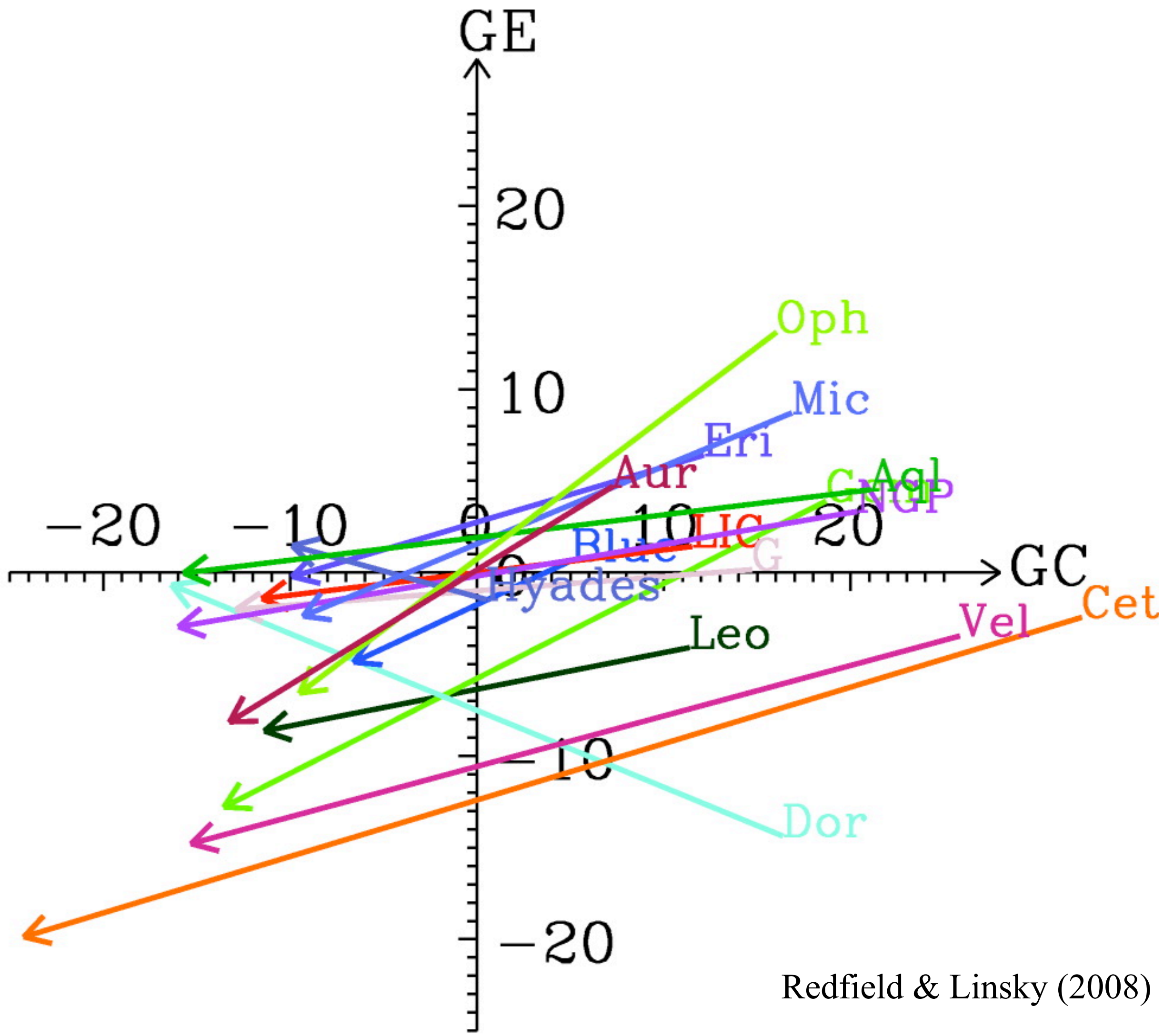


Redfield (2009)



Frisch, Redfield, & Slavin (2011)

Kinematics of the Local ISM



Redfield & Linsky (2008)

Is the Sun inside the LIC?

TABLE 16

LISM Cloud Heliocentric Velocity Vectors

Cloud Name	Number of Sight Lines	V_0 (km s^{-1})	l_0 (deg)	b_0 (deg)	χ^2_ν
LIC	79	23.84 ± 0.90	187.0 ± 3.4	−13.5 ± 3.3	2.2
G	21	29.6 ± 1.1	184.5 ± 1.9	−20.6 ± 3.6	1.3
Blue	10	13.89 ± 0.89	205.5 ± 4.3	−21.7 ± 8.3	2.4
Aql	9	58.6 ± 1.3	187.0 ± 1.5	−50.8 ± 1.0	2.6
Eri	8	24.1 ± 1.2	196.7 ± 2.1	−17.7 ± 2.6	0.3
Aur	9	25.22 ± 0.81	212.0 ± 2.4	−16.4 ± 3.6	2.1
Hyades	14	14.69 ± 0.81	164.2 ± 9.4	−42.8 ± 6.1	1.3
Mic	15	28.45 ± 0.95	203.0 ± 3.4	−03.3 ± 2.3	0.5
Oph	6	32.25 ± 0.49	217.7 ± 3.1	+00.8 ± 1.8	3.9
Gem	10	36.3 ± 1.1	207.2 ± 1.6	−01.2 ± 1.3	1.7
NGP	15	37.0 ± 1.4	189.8 ± 1.7	−05.4 ± 1.1	3.8
Leo	7	23.5 ± 1.6	191.3 ± 2.8	−08.9 ± 1.8	1.5
Dor	4	52.94 ± 0.88	157.3 ± 1.5	−47.93 ± 0.63	0.8
Vel	7	45.2 ± 1.8	195.4 ± 1.1	−19.1 ± 1.0	0.8
Cet	5	60.0 ± 2.0	197.11 ± 0.56	−08.72 ± 0.50	8.9
LIC[a]	9	25.7 ± 0.5	186.1	−16.4	...
LIC[b]	16	26 ± 1	186 ± 3	−16 ± 3	...
LIC[c]	63	24.20 ± 1.05	187.0 ± 3.1	−13.5 ± 3.0	2.1
G[a]	...	29.4	185.5	−20.5	...
Helio[d]	...	26.24 ± 0.45	183.4 ± 0.4	−15.9 ± 0.4	...
(LIC+G)/2[e]	...	26.74 ± 0.71	185.7 ± 3.4	−16.95 ± 3.6	...

[a] Lallement & Bertin (1992).

[b] Lallement et al. (1995).

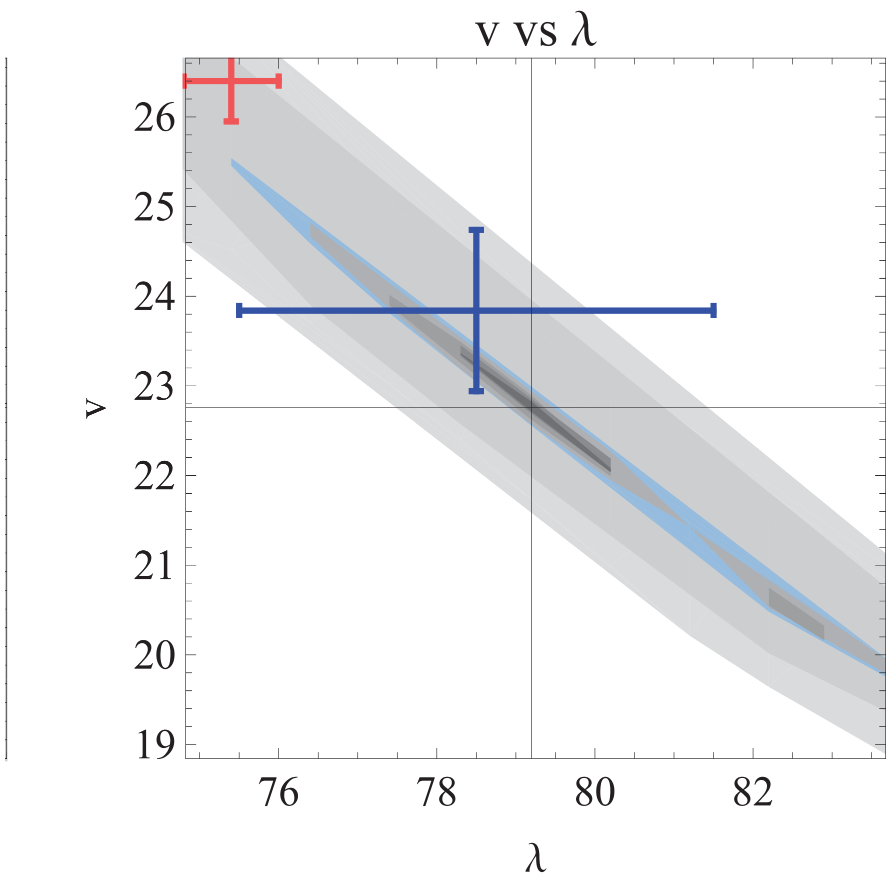
[c] LIC flow vector deleting the 16 lines of sight near the decelerated leading edge of the LIC in the direction of the Hyades Cloud.

[d] Flow vector for interstellar helium gas in the heliosphere. Temperature is 6303 ± 390 K (Möbius et al. 2004). See temperatures for individual dynamical clouds in Table 18.

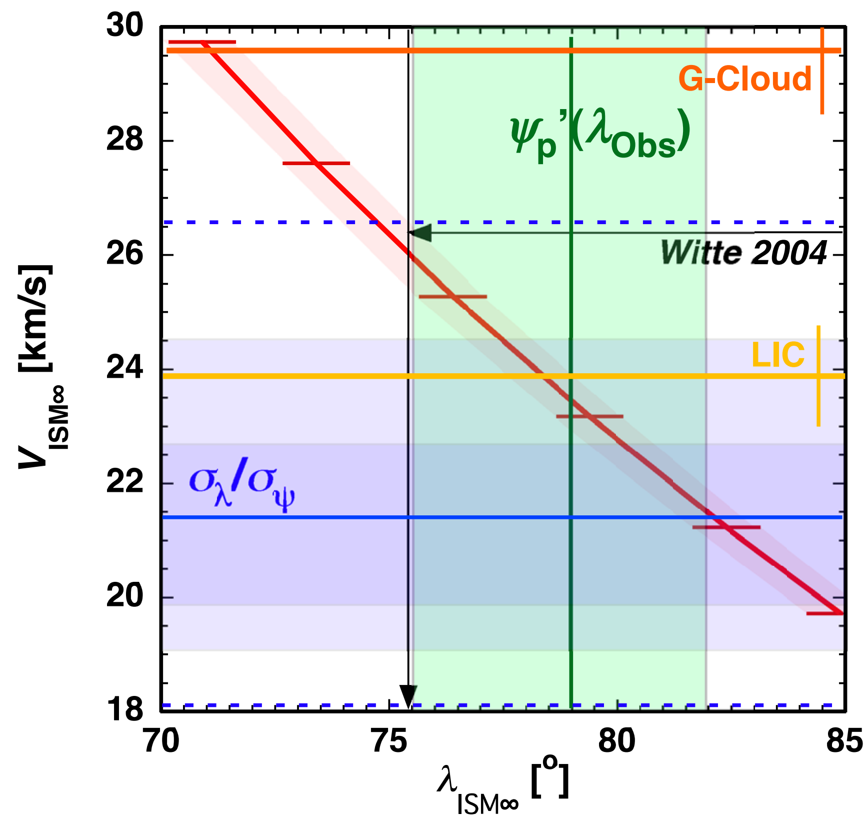
[e] Average of the LIC and G vectors. Average temperature of the LIC and G Cloud is 6500 ± 680 K. The in situ "Helio" measurement is closer to the average LIC and G temperature than either cloud individually; see Table 18.

Redfield & Linsky (2008)

Is the Sun inside the LIC? Yes

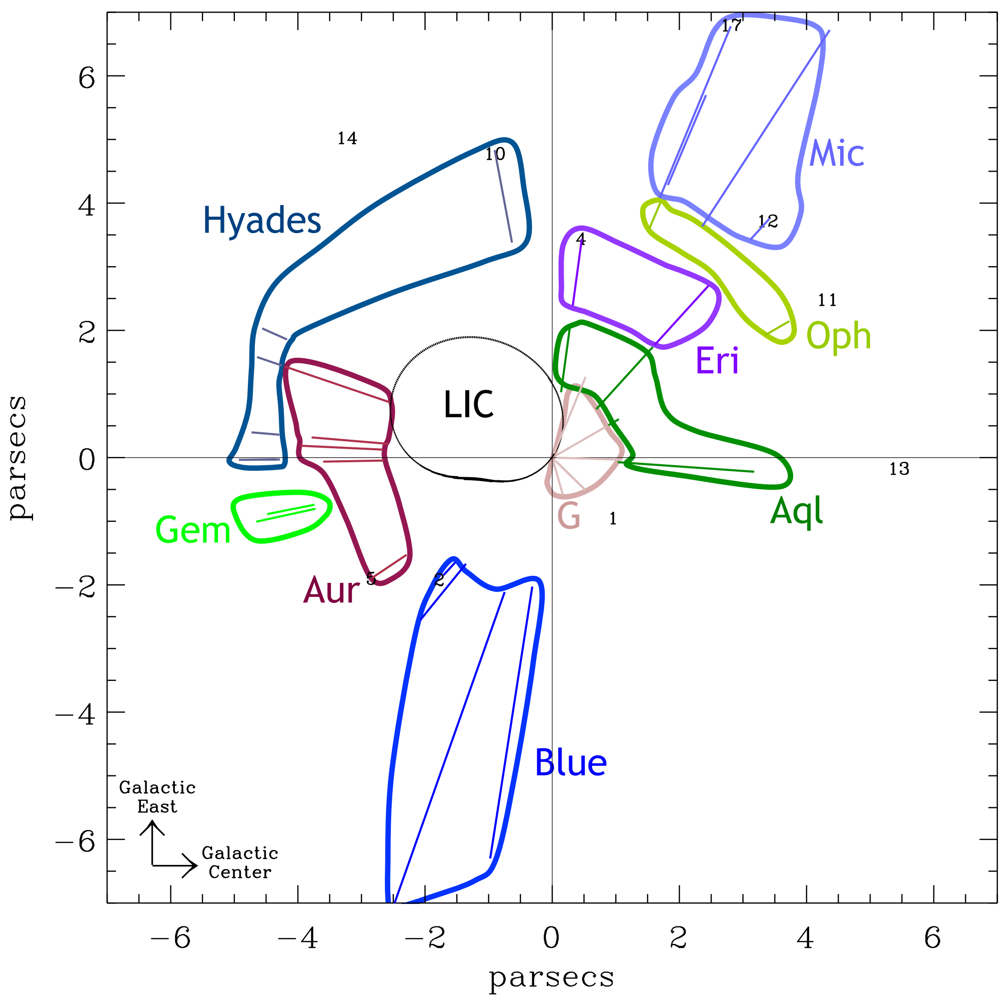


Bzowski et al. (2011)



Möbius et al. (2011)

Global LISM Morphology



Redfield & Linsky (2011)

Outline

Characterizing the Local Interstellar Medium:

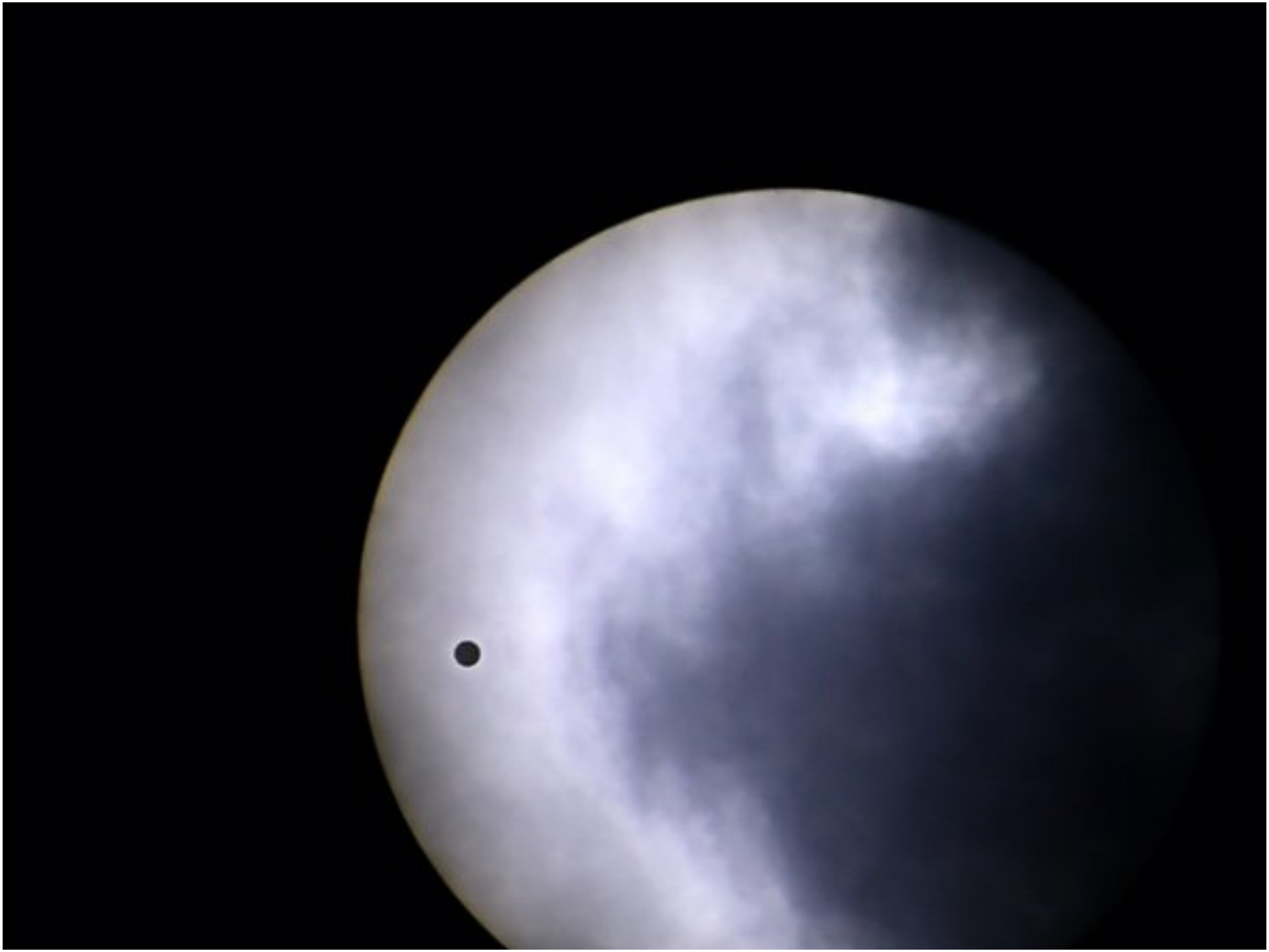
ARA&A review: Frisch, Redfield, & Slavin (2011)

Characterizing Planetary Atmospheres (and Exospheres)

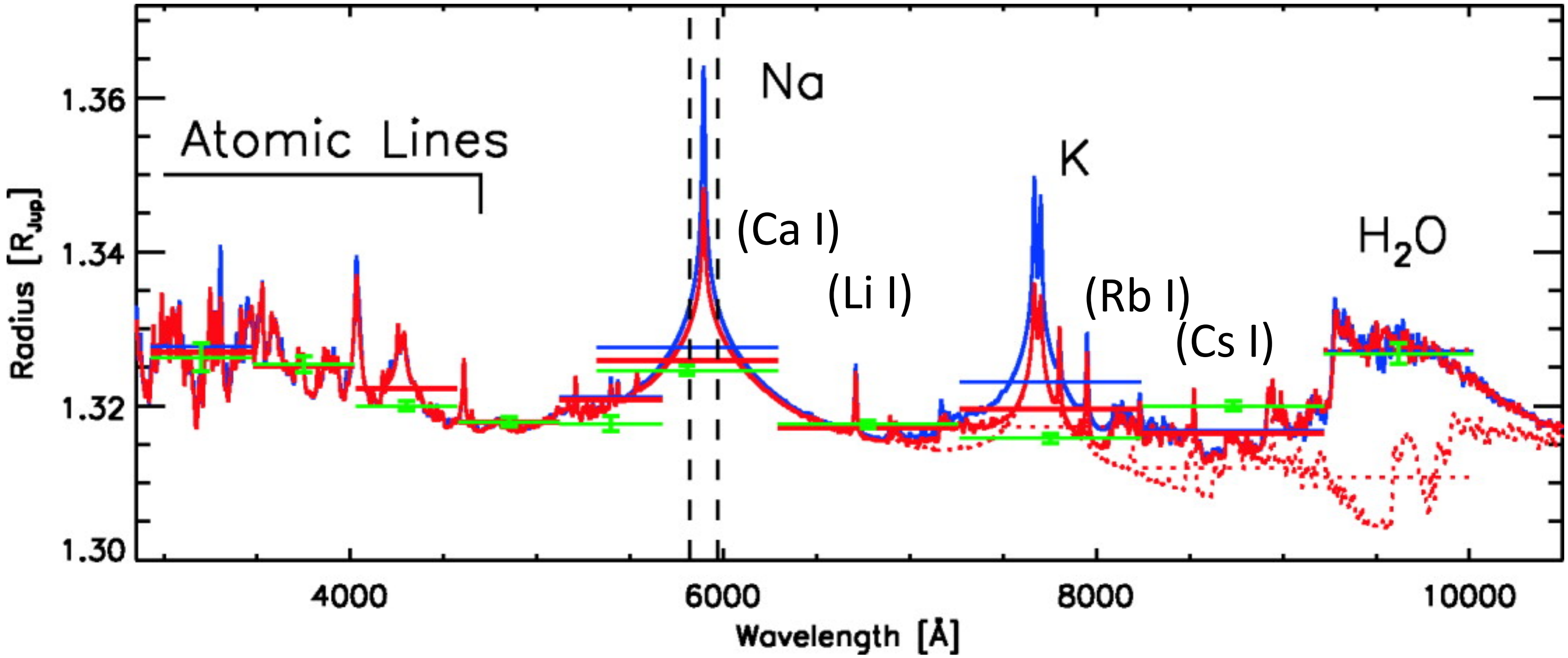
First Hα detection in an exoplanetary atmosphere: Jensen, Redfield, Endl, Cochran, Koesterke, & Barman (2011)

Astrospheres to Estimate Planetary Atmosphere Evolution:

Measuring stellar mass loss rates for exoplanet host stars: 13 orbits for 4 targets in Cycle 19 on *Hubble Space Telescope* (Redfield, Wood, Müller, Linsky, Frisch, Gry, Jensen, Lehner, Knutson, Walkowicz)



Transmission Model

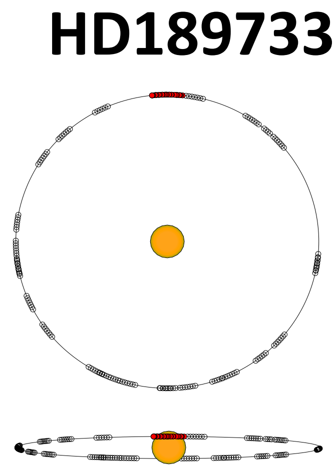


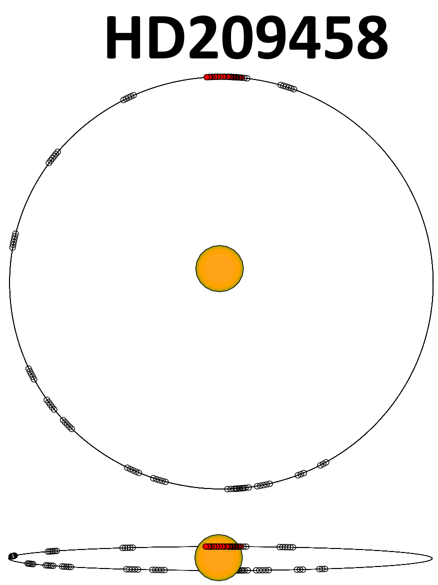
(Barman 2007)

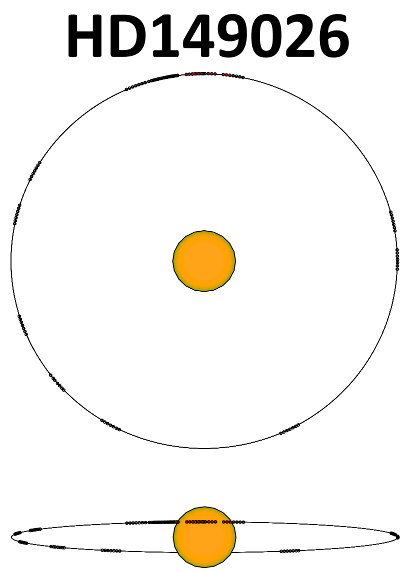
- Early models (Seager & Sasselov 2000, Brown 2001, Hubbard et al. 2001)
- Most gases in molecular form except He and alkali metals
- Strongest features are narrow lines of NaI and KI
- Volatile elements (e.g., Mg, Ca, Ti) have condensed into grains

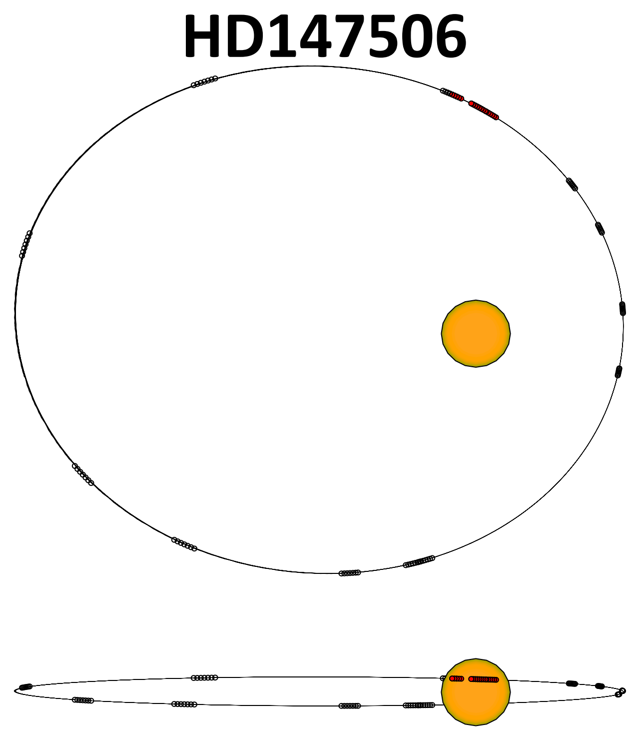
Observations

- 9.2m Hobby-Eberly Telescope (HET)
- High Resolution Spectrograph (R ~ 60,000)
- Observations taken between 2006 and 2010
- Queue-based scheduling allowed for multiple transits and random collection of out-of-transit observations
- Substantial optical coverage (5000-9000 Å)
- 6-11 transits observed along with 2.5-5x number of out-of-transit visits

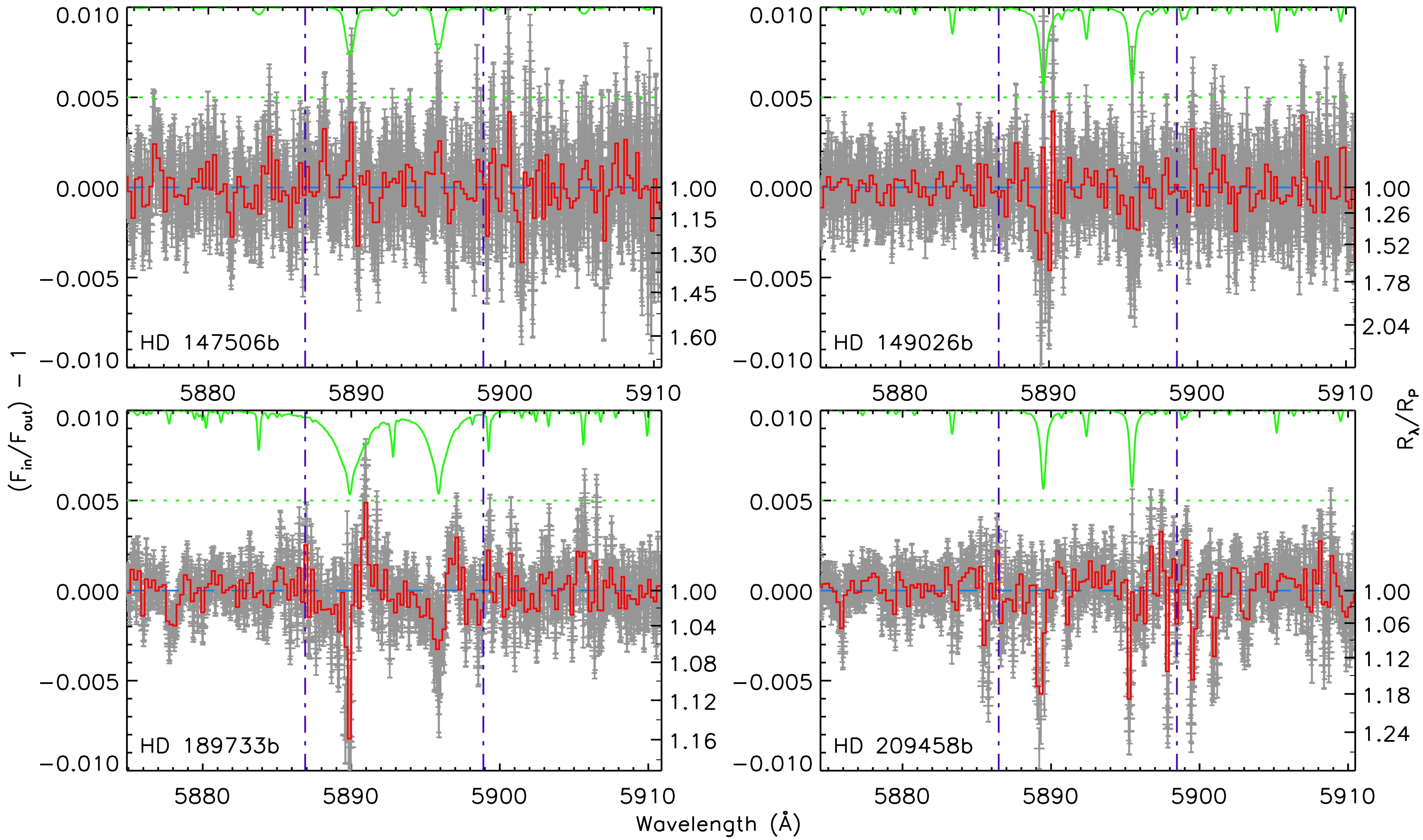






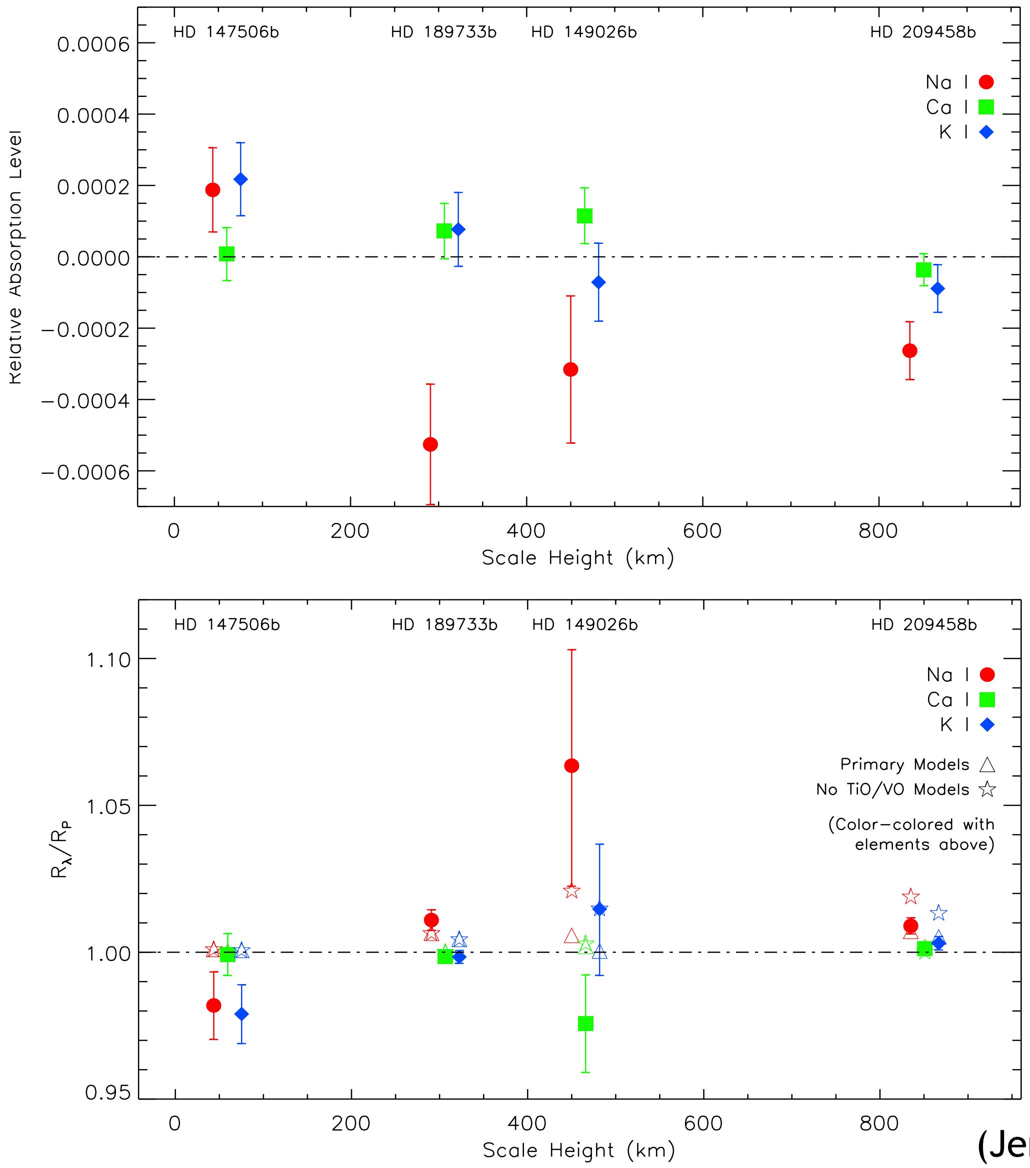


NaI Transmission Spectra



(Jensen et al. 2011)

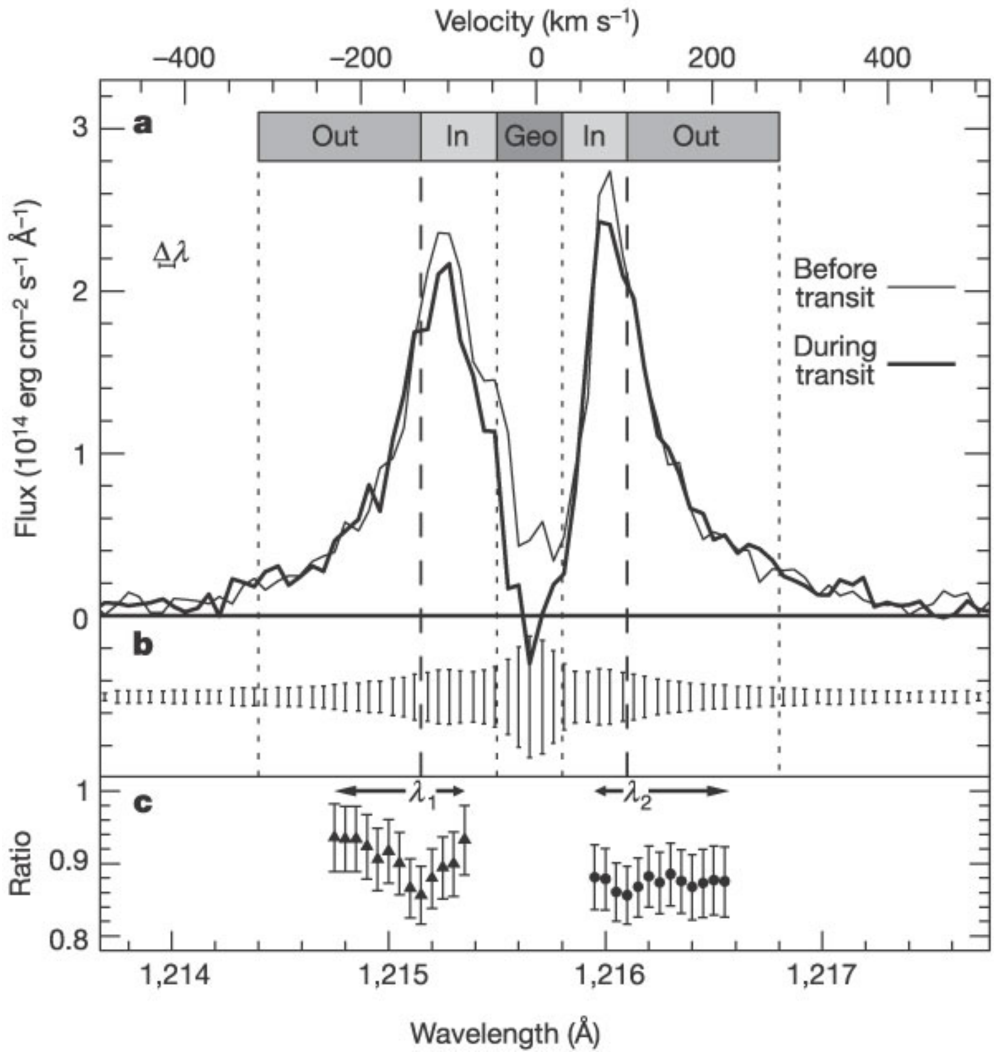
Na and K Results



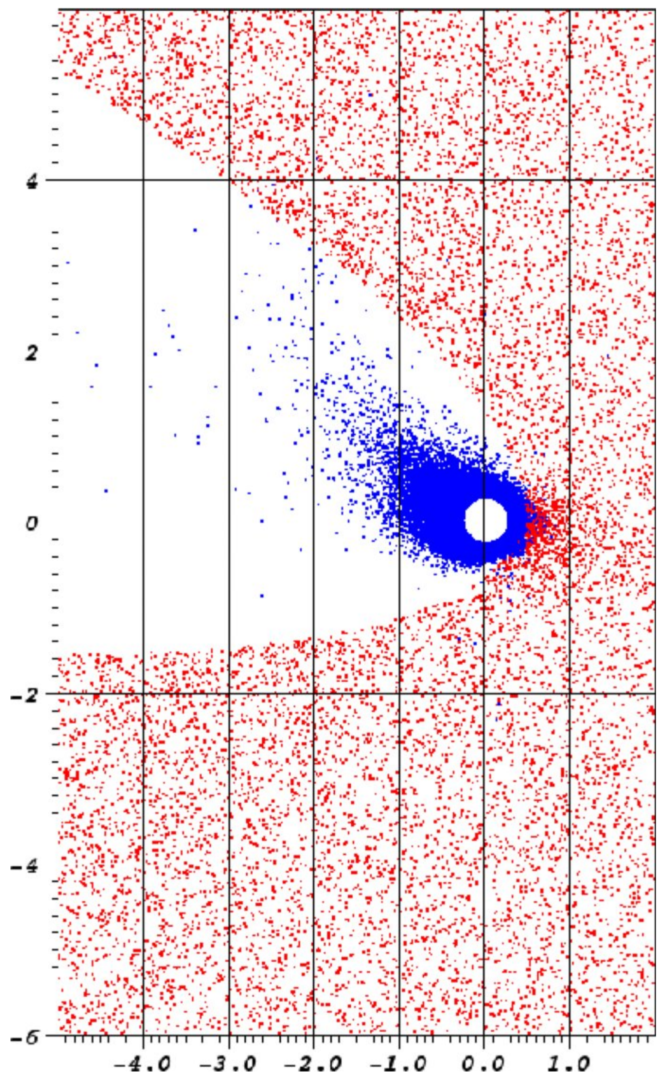
- New reduction and analysis pipeline reproduce HD189733b NaI detection (Redfield et al. 2008; Huitson et al. 2011)
- Confirm HD209458b NaI detection (Charbonneau et al. 2002; Snellen et al. 2008)
- Low significance absorption for HD149026b, but seen in both NaI lines
- No KI absorption detected for any of our targets (see Sing et al. 2010; Colón et al. 2010)

(Jensen et al. 2011)

HD209458b: Active Atmospheric Loss

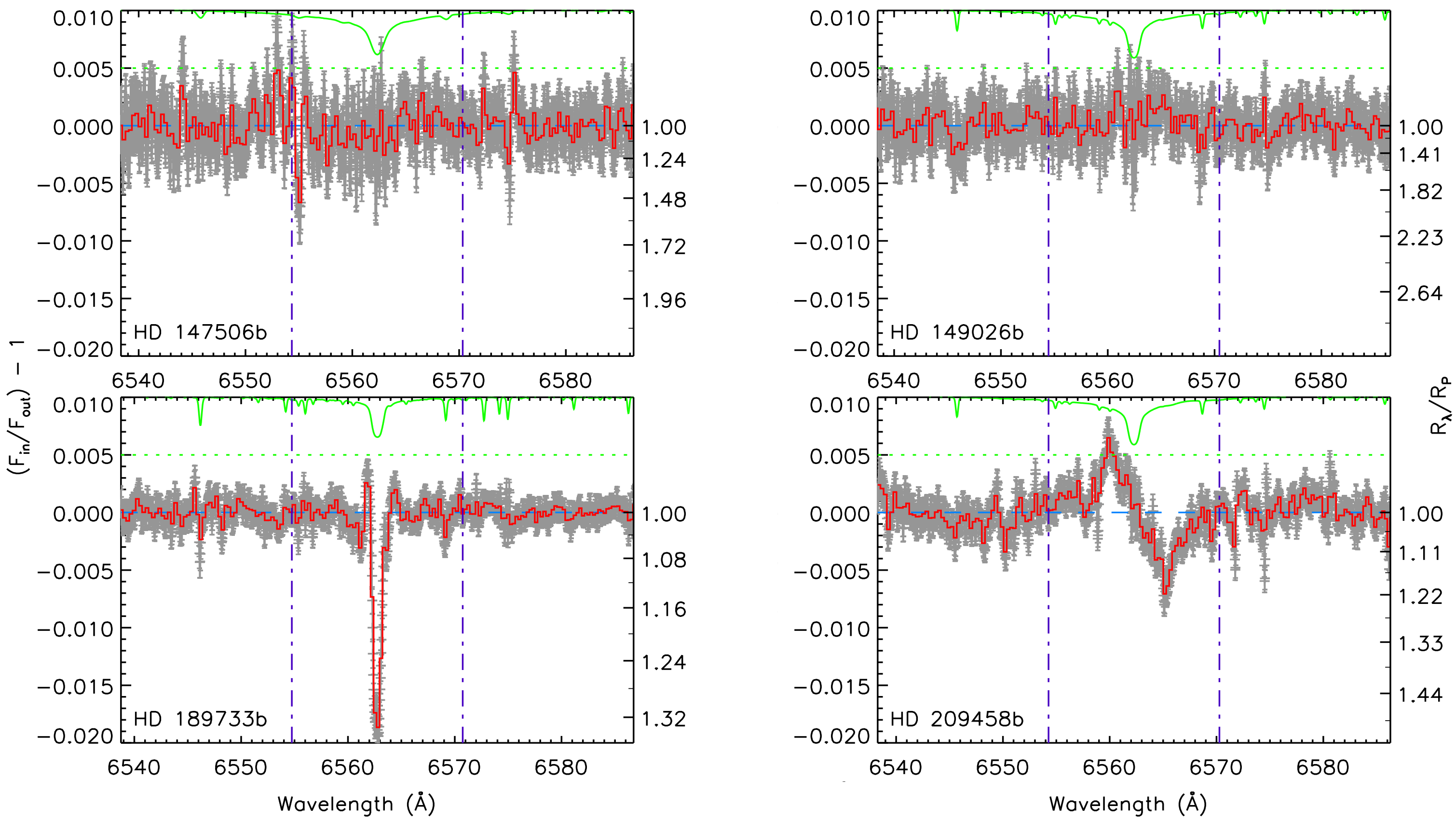


Vidal-Madjar et al. (2003)



Ekenbäck et al. (2010)

Hα Transmission Spectra



(Jensen et al. in prep)

- Strong absorption in HD189733b correlated with transit (1.55% across absorption feature ±25 km/s or ~1.1 Å)
- Chromospheric variability detected for HD189733 (Fares et al. 2010; Lecavieler des Etangs et al. 2010); in-transit absorption significant at 4.6σ
- Symmetric feature seen in HD209458b correlated with phases near transit

Outline

Characterizing the Local Interstellar Medium:

ARA&A review: Frisch, Redfield, & Slavin (2011)

Characterizing Planetary Atmospheres (and Exospheres)

First Hα detection in an exoplanetary atmosphere: Jensen, Redfield, Endl, Cochran, Koesterke, & Barman (2011)

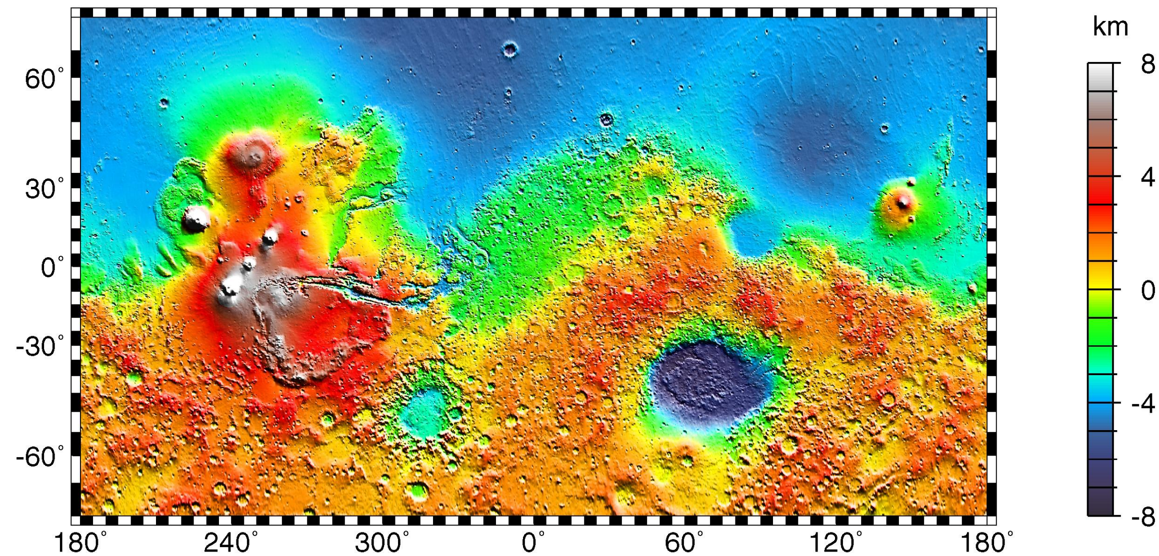
Astrospheres to Estimate Planetary Atmosphere Evolution:

Measuring stellar mass loss rates for exoplanet host stars: 13 orbits for 4 targets in Cycle 19 on *Hubble Space Telescope* (Redfield, Wood, Müller, Linsky, Frisch, Gry, Jensen, Lehner, Knutson, Walkowicz)

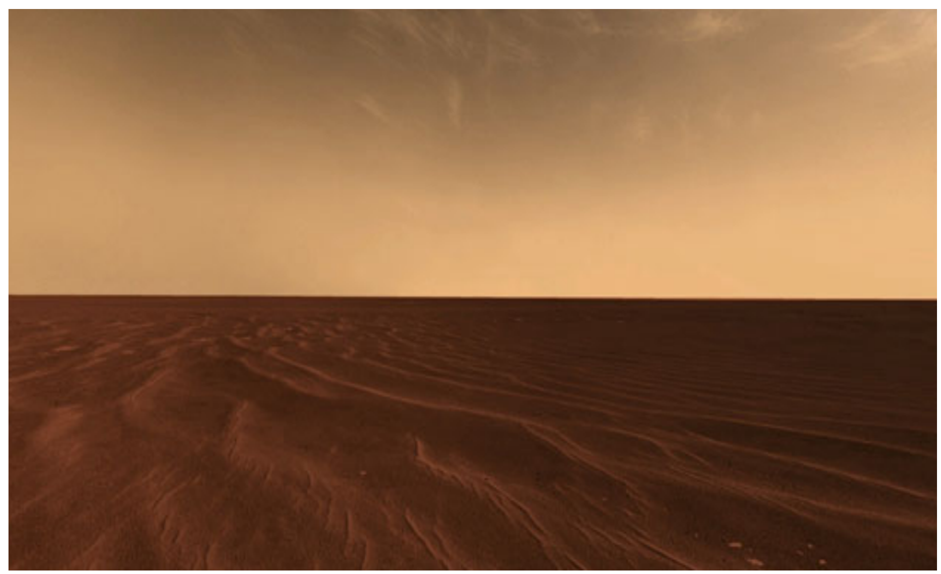
Mars and Habitability

Wet Past

(Mars Global Surveyor 2000)

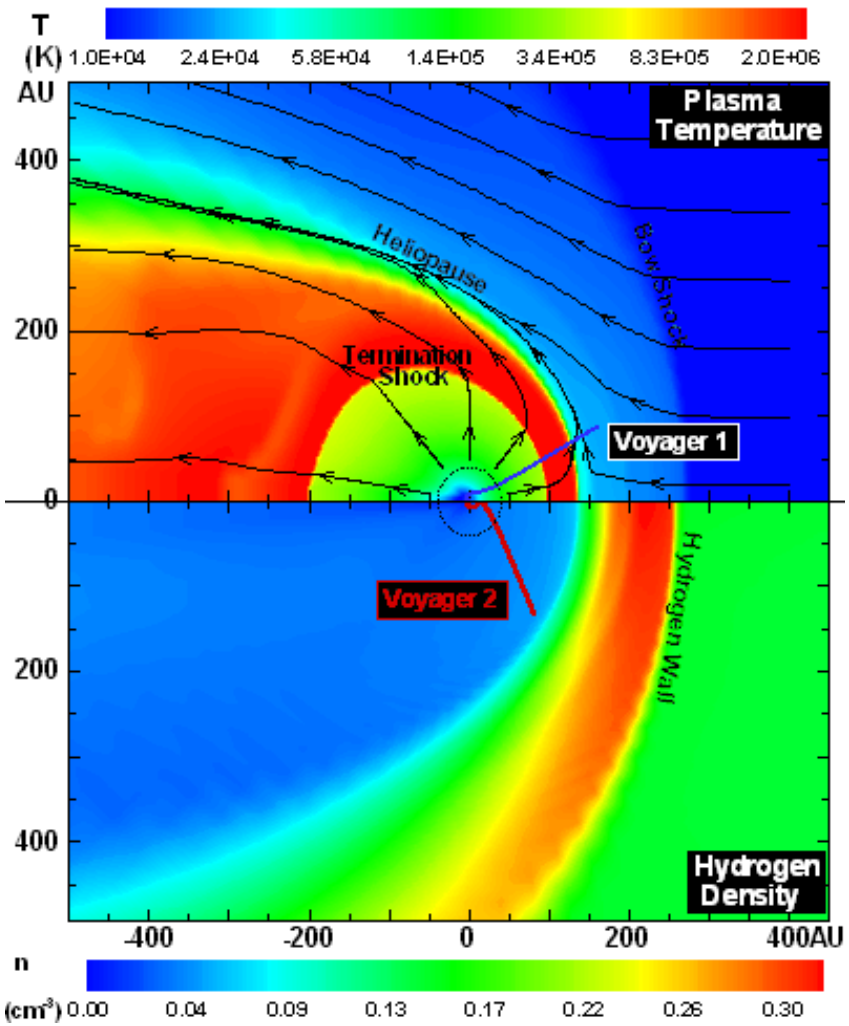


Dry Present



(Opportunity 2006)

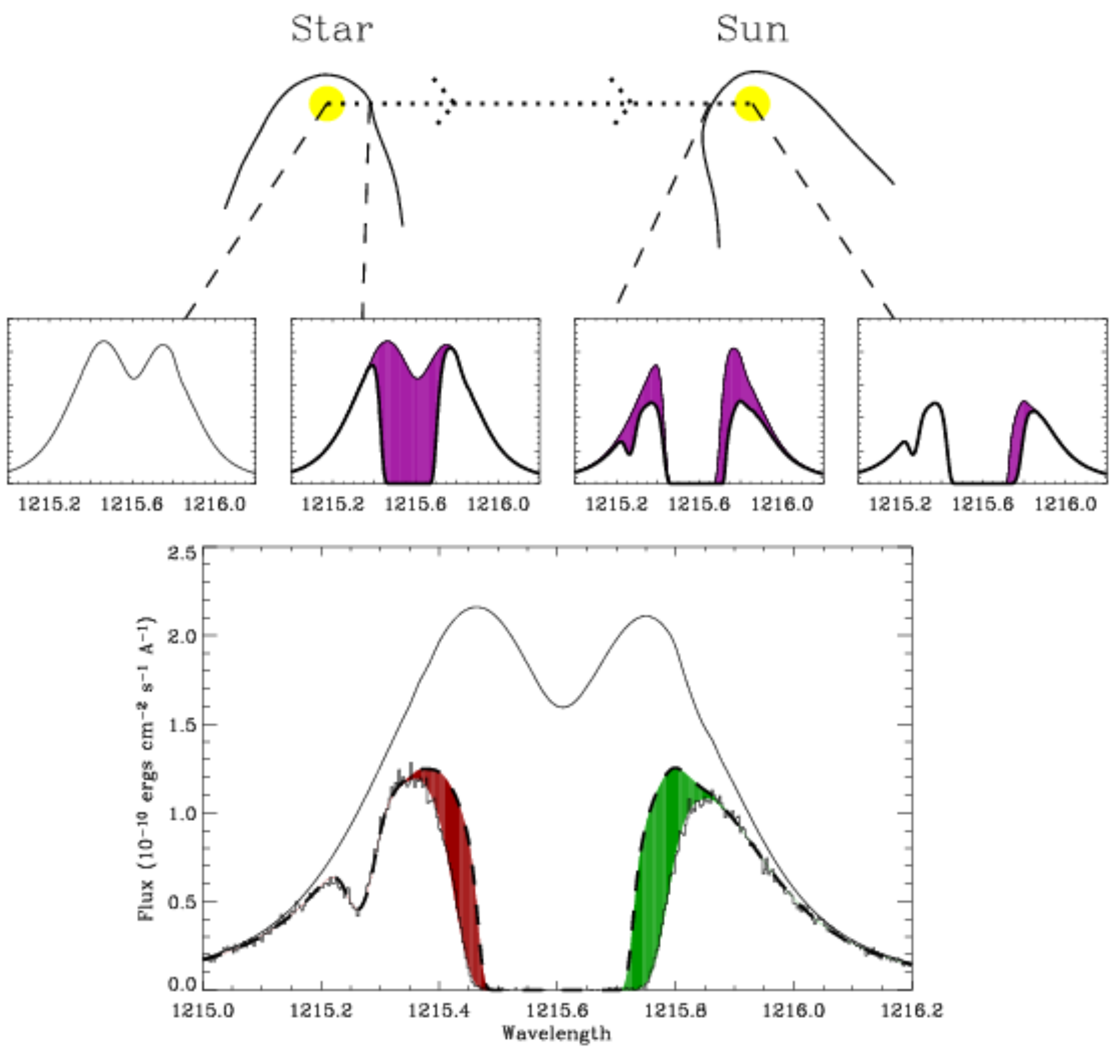
The Hydrogen Wall



Müller (2004)

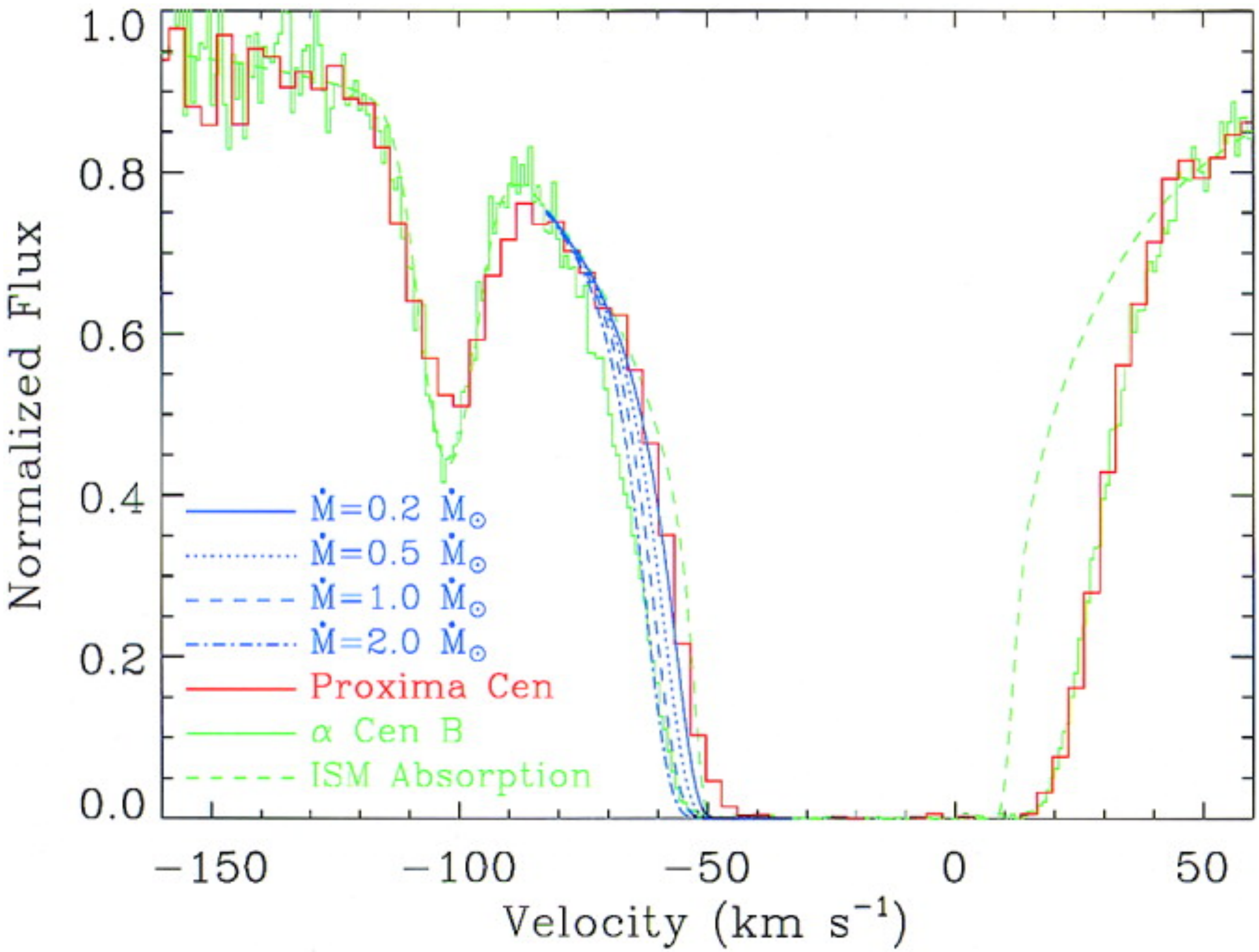
Most neutrals stream into Solar System unperturbed, except neutral hydrogen, which due to charge exchange reactions, is heated and ***decelerated*** forming "Hydrogen Wall" (log N_H (cm^{-2}) ~ 14.5).

Detection of Astrospheres



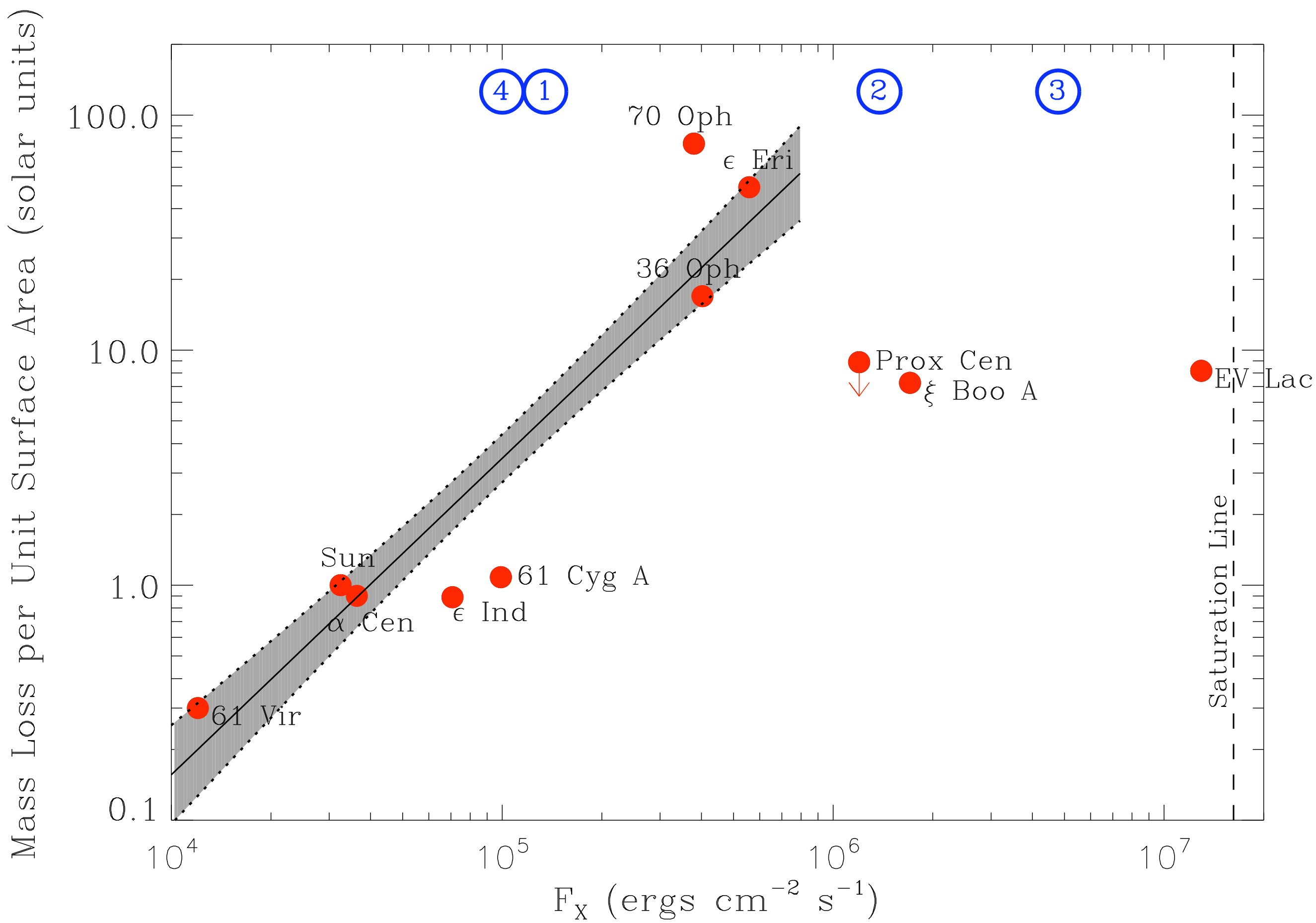
Wood, Redfield, & Linsky (2003)

Sensitive to solar-like Mass Loss



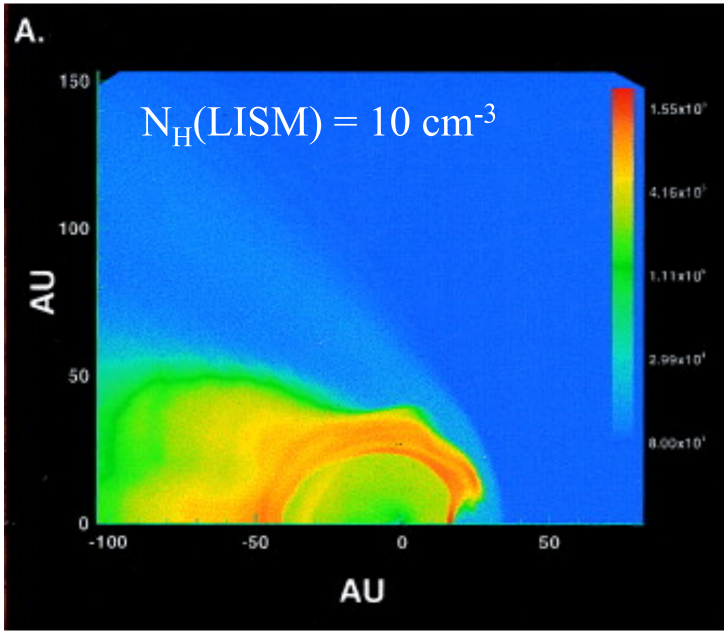
Wood et al. (2001)

Mass Loss as a Function of Age

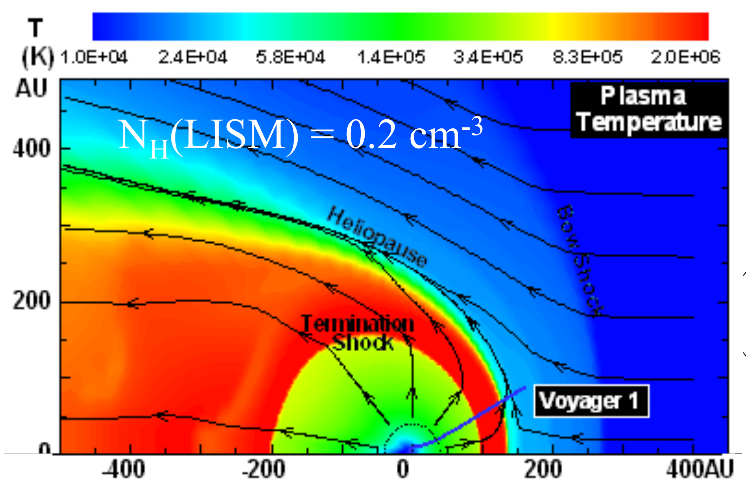


Wood et al. (2005)

Must Understand Local ISM



Zank & Frisch (1999)



Müller (2004)

How large of a density increase is needed to significantly alter the structure of the heliosphere?

Increase the density of the surrounding LISM by only a factor of 50 (n_H from 0.2 to 10 cm^{-3}) and the termination shock shrinks from 100 AU to 10 AU.

Mass Loss and Planetary Atmospheres

Half of all known exoplanets are within 50 pc: These will be the most extensively observed systems

Astrospheres are detectable toward nearby stars: Need to be able to characterize the local interstellar environment

Mass Loss Varies with Activity: A saturation level appears at the highest activity levels.

Activity Varies with Age: Consistent with a high solar mass loss at the time of loss of Martian atmosphere (solar wind sputtering; Lammer et al. 2003)

Outline

Characterizing the Local Interstellar Medium:

ARA&A review: Frisch, Redfield, & Slavin (2011)

Characterizing Planetary Atmospheres (and Exospheres)

First Hα detection in an exoplanetary atmosphere: Jensen, Redfield, Endl, Cochran, Koesterke, & Barman (2011)

Astrospheres to Estimate Planetary Atmosphere Evolution:

Measuring stellar mass loss rates for exoplanet host stars: 13 orbits for 4 targets in Cycle 19 on *Hubble Space Telescope* (Redfield, Wood, Müller, Linsky, Frisch, Gry, Jensen, Lehner, Knutson, Walkowicz)