Ubiquitous Argonium, ArH^+, in the Interstellar Medium

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What is Argonium?

- ArH^+, $^1\Sigma^+$, isoelectronic to HCl

- Formation: $Ar^+ + H_2 \rightarrow ArH^+ + H$
- Destruction (e.g.): $ArH^+ + H_2 \rightarrow Ar + H_3^+$

- Isotopic ratio: ^{36}Ar : ^{38}Ar : ^{40}Ar

	^{36}Ar	^{38}Ar	^{40}Ar
terrestrial:	84.2	15.8	25018.8 (from decay of ^{40}K)
solar/ISM:	~84.6	~15.4	0.025

- $^{36}ArH^+$ toward Crab Nebula SNR:
  $J = 1 – 0$ & $2 – 1$ in emission (w. OH^+ $N = 1 – 0$); SPIRE/*Herschel*
  M. J. Barlow et al., Science 342 (2013) 1343

On the Spectroscopy of ArH^+

- $^{40}ArH^+$; rotational spectroscopy:

  K. B. Laughlin et al., PRL 58 (1987) 996: $J'' = 0$

  J. M. Brown et al., JMSp 128 (1988) 587: $J'' = 1 – 6$

  D. J. Liu et al., JCP 87 (1987) 2442: $J'' = 20 – 24$; $v \leq 4$ (MIR)

- $^{40}ArD^+$; rotational spectroscopy:

  W. C. Bowman et al., JCP 79 (1983) 2093: $J'' = 0$ (+ $^{36}ArD^+$ & $^{38}ArD^+$

  H. Odashima et al., JMSp 195 (1999) 356: $J'' = 2 – 14$

- rovibrational spectroscopy:

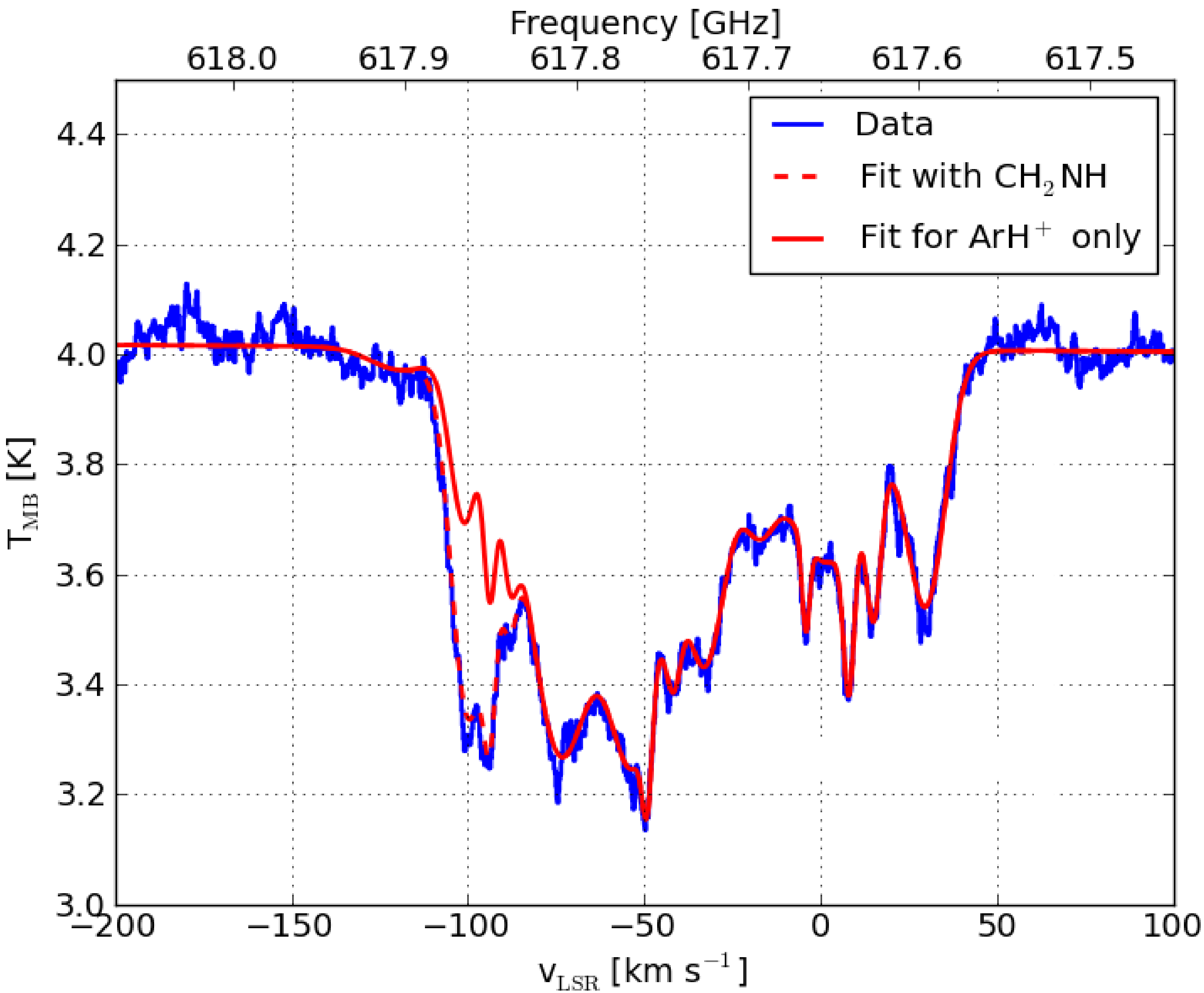
  J. W. Brault & S. P. Davis, Phys. Sript. 25 (1982) 268: $^{40}ArH^+$

  J. W. C. Johns, JMSp 106 (1984) 124: $^{40}ArH^+$, $^{40}ArD^+$

  R. R. Filueira & C. E. Blom, JMSp 127 (1988) 279: $^{36}ArH^+$, $^{38}ArH^+$

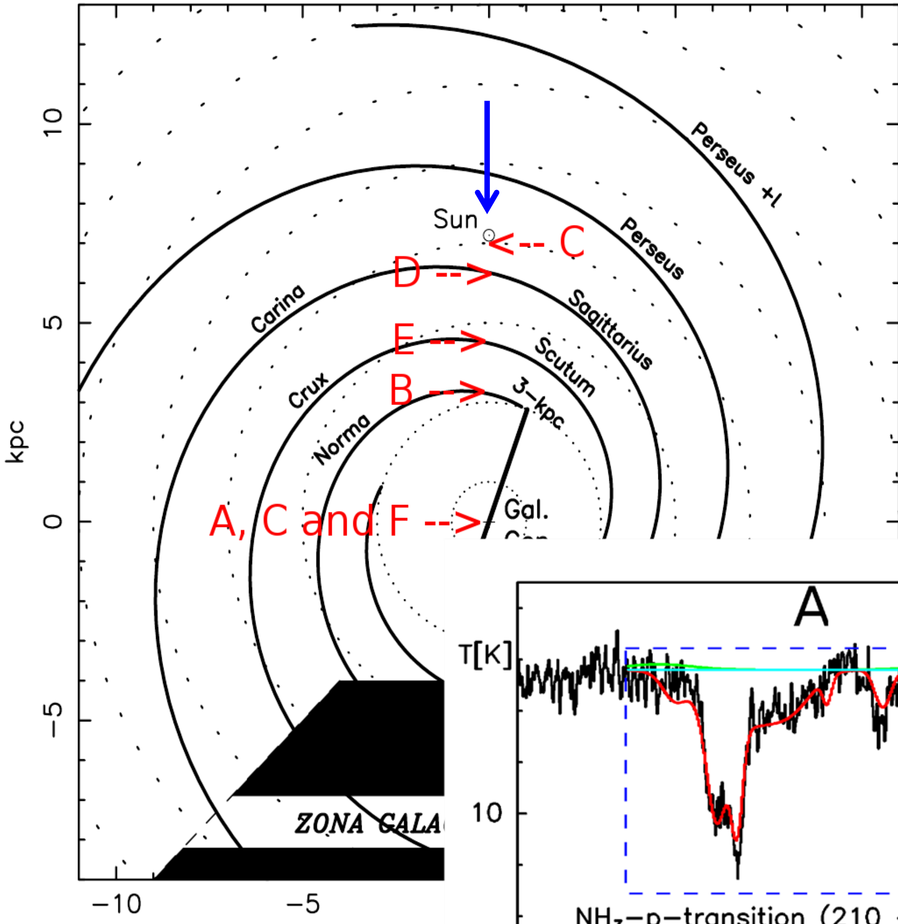
  M. Cueto et al., ApJ 783 (2014) L5: $^{36}ArH^+$, $^{38}ArH^+$

ArH^+ toward Sagittarius B2(M) – HIFI Line Survey

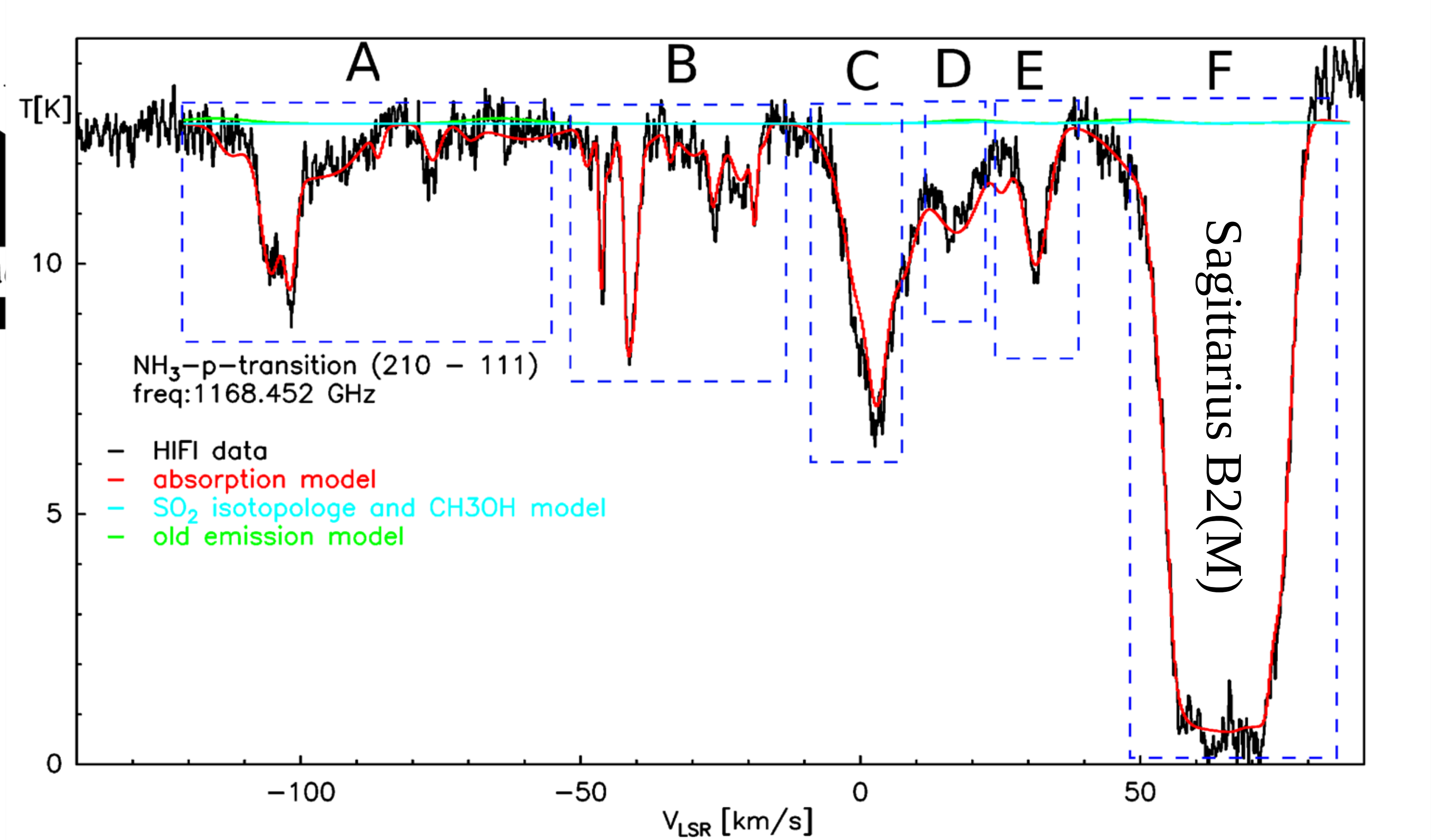


Absorption toward Sgr B2(M)

massive star-forming regions
as background sources



with approximate origins

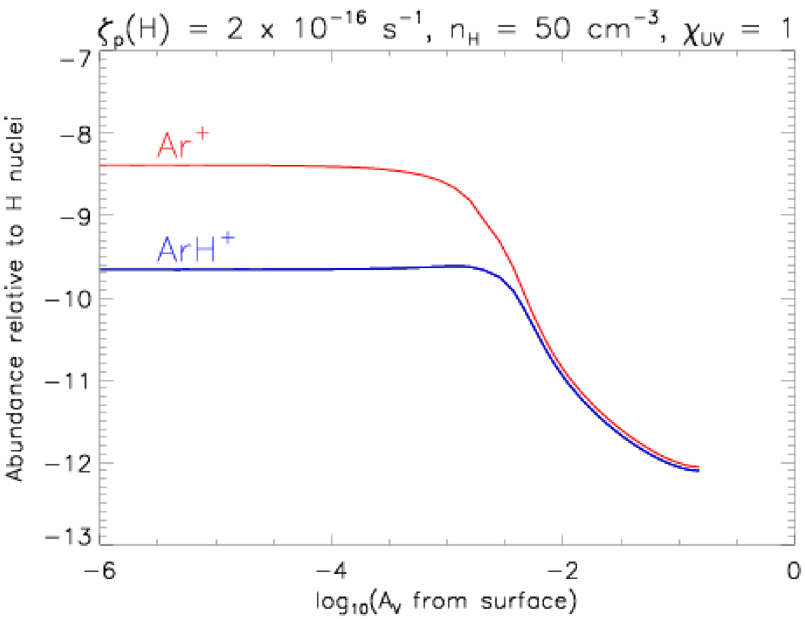


Interstellar Chemistry of ArH^+ I

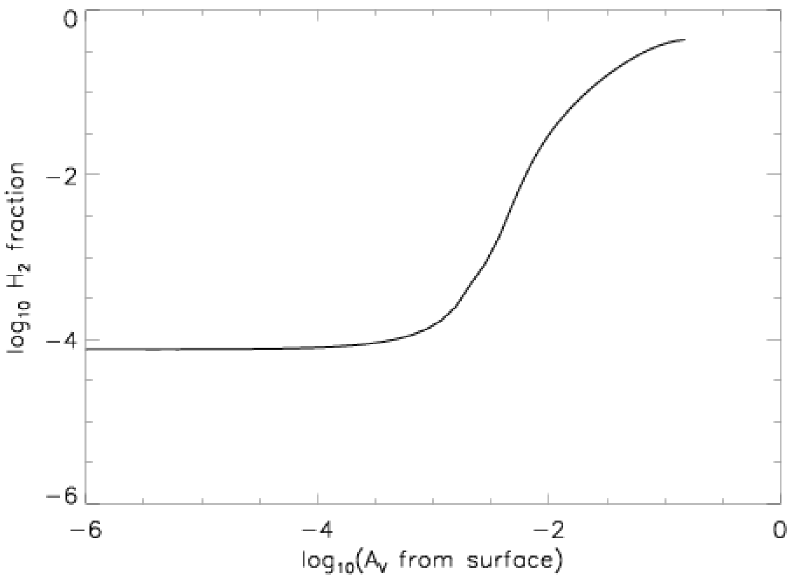
- $Ar^+ + H_2 \rightarrow ArH^+ + H$ exothermic (endo. e.g. for C^+, N^+)
- $Ar^+ + H_2 \rightarrow Ar + H + H^+$ endothermic (exo. e.g. for Ne^+)
- $ArH^+ + H \rightarrow Ar + H_2^+$ endothermic
- $ArH^+ + h\nu$ ineffective (in contrast to HCl)
- $ArH^+ + e^-$ very slow (in contrast to, e.g., NeH^+)
- $ArH^+ + X \rightarrow Ar + HX^+$ exothermic for H_2, O, etc.

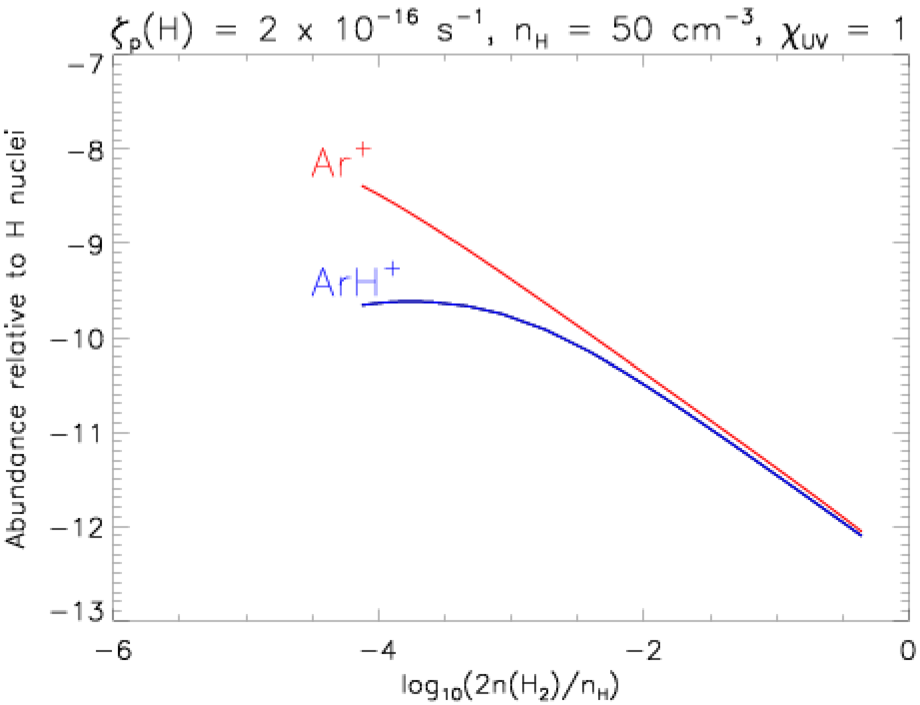
- $IP(\mathrm{Ar}) > IP(\mathrm{H})$; CRI(Ar) >> CRI(H) $\rightarrow$ ArH^+ CRI rate indicator

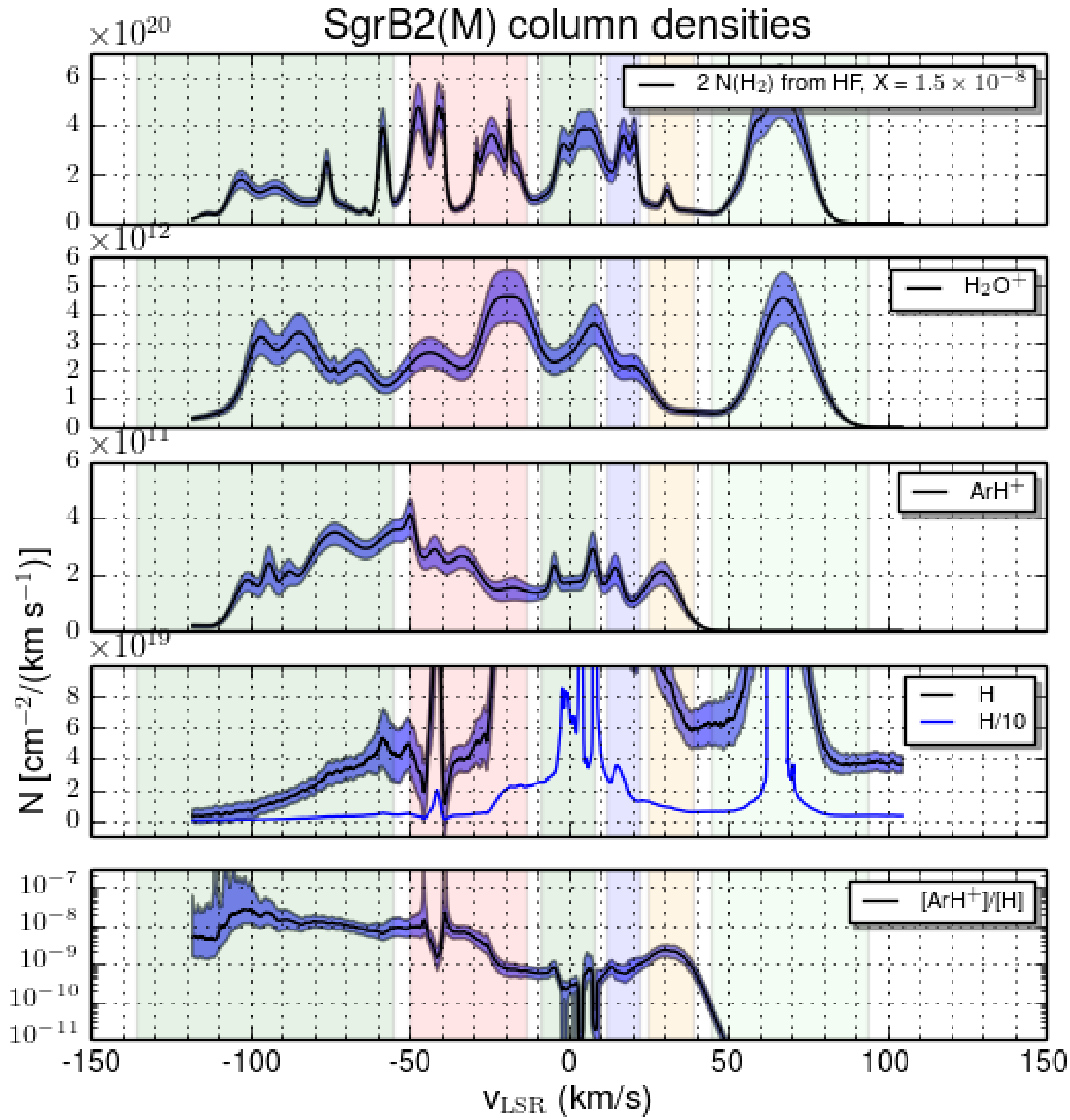
Interstellar Chemistry of ArH^+ II



- Highest ArH^+ fraction: $n(H_2)/n(H) \approx 10^{-3} - 10^{-4}$

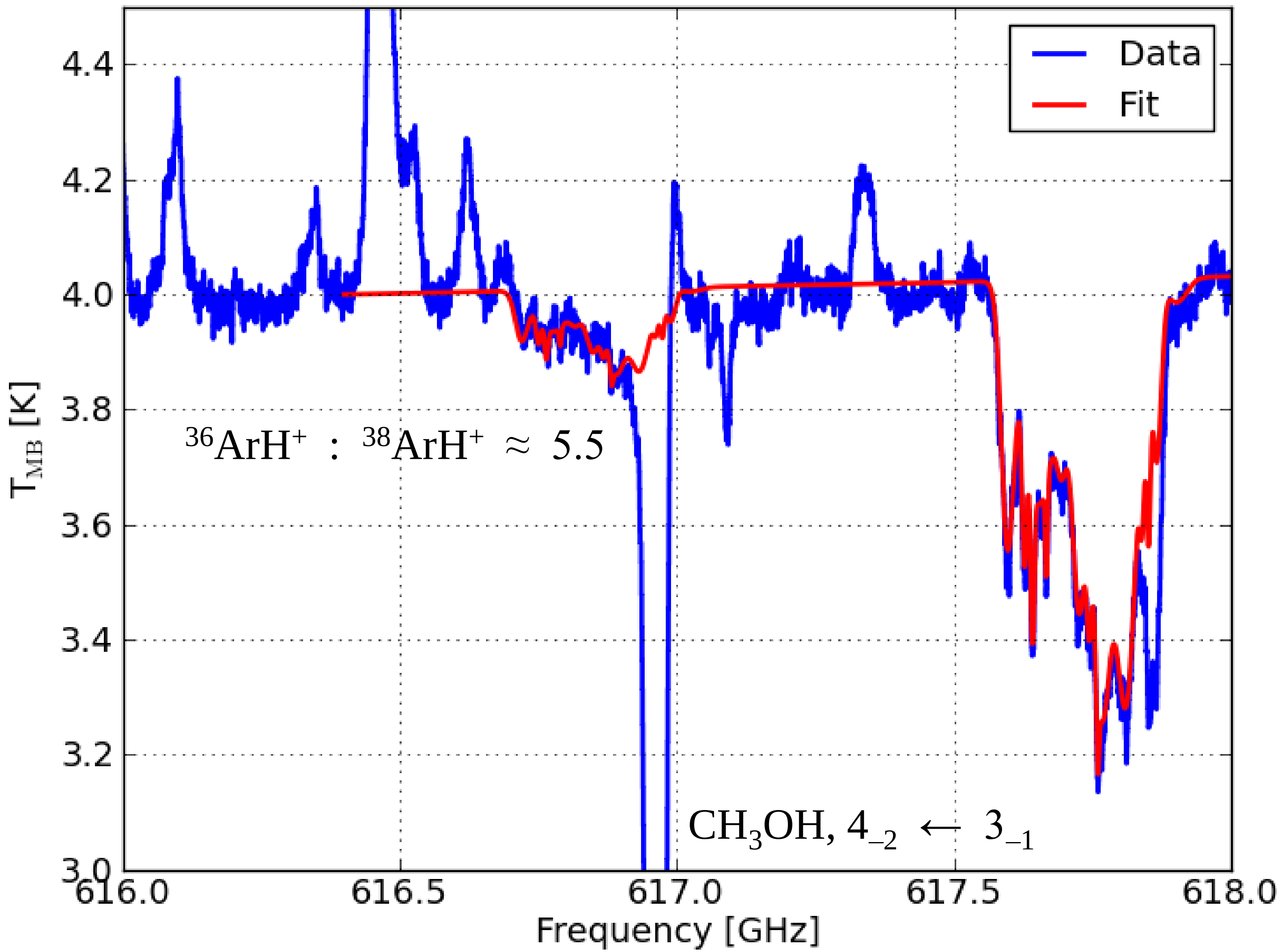




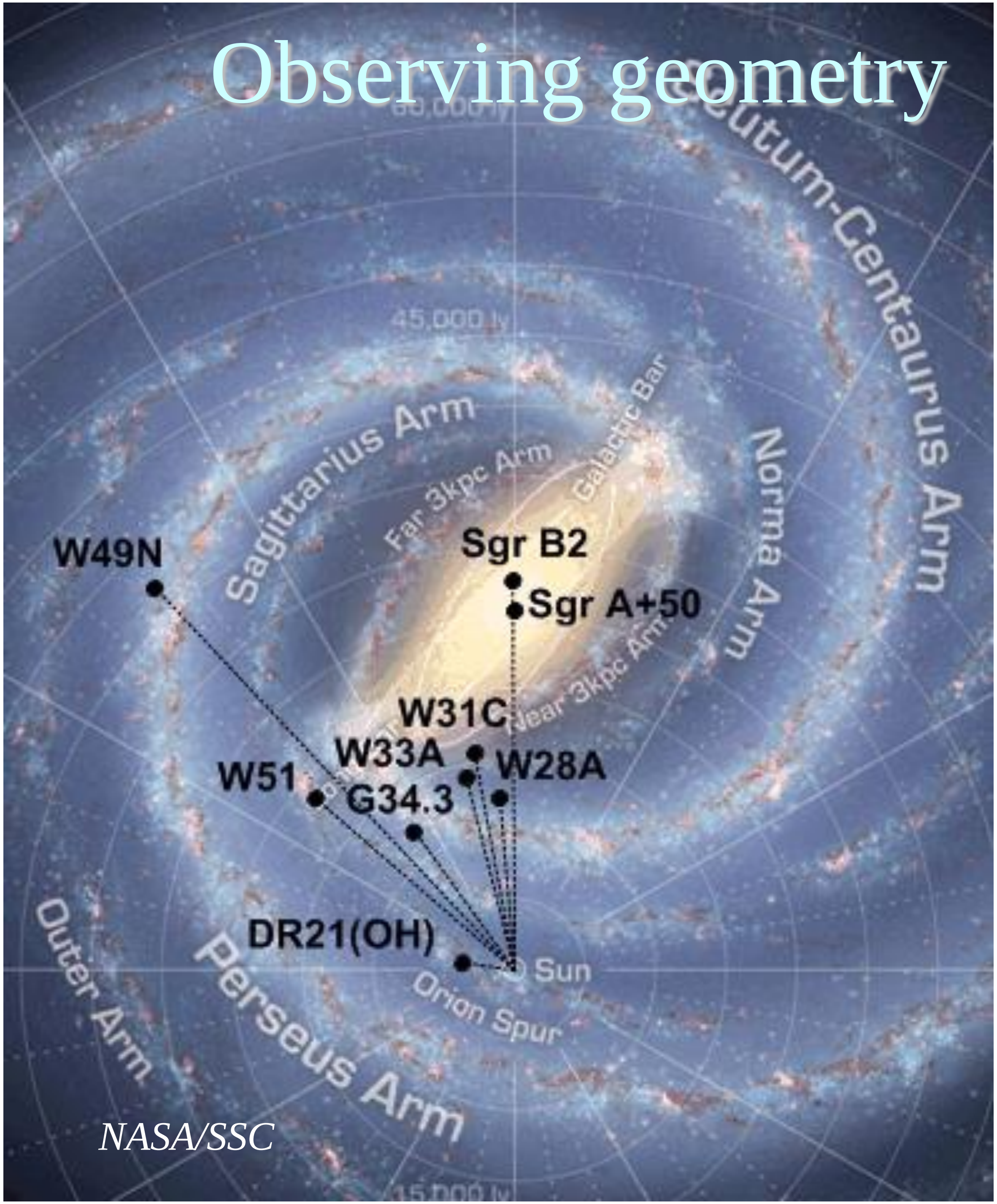


SgrB2(M) column densities
×10^20
2 N(H2) from HF, X = 1.5 × 10^-8
×10^12
H2O+
×10^11
ArH+
×10^19
H
H/10
[ArH+]/[H]
N [cm^-2/(km s^-1)]
vLSR (km/s)
-150
-100
-50
0
50
100
150

$^{38}ArH^+$ and $^{36}ArH^+$ in Sgr B2(M)



Observing geometry



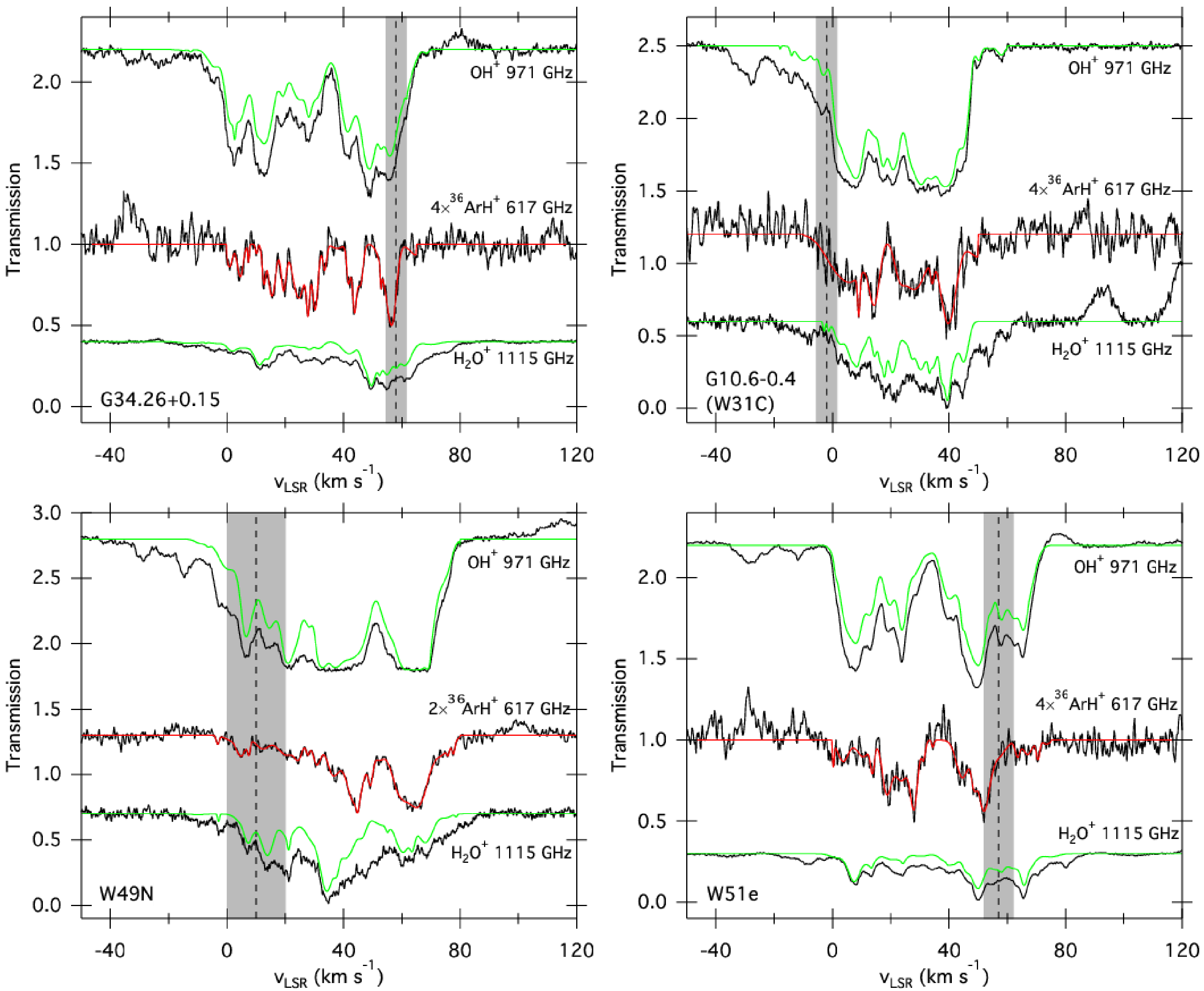
NASA/SSC

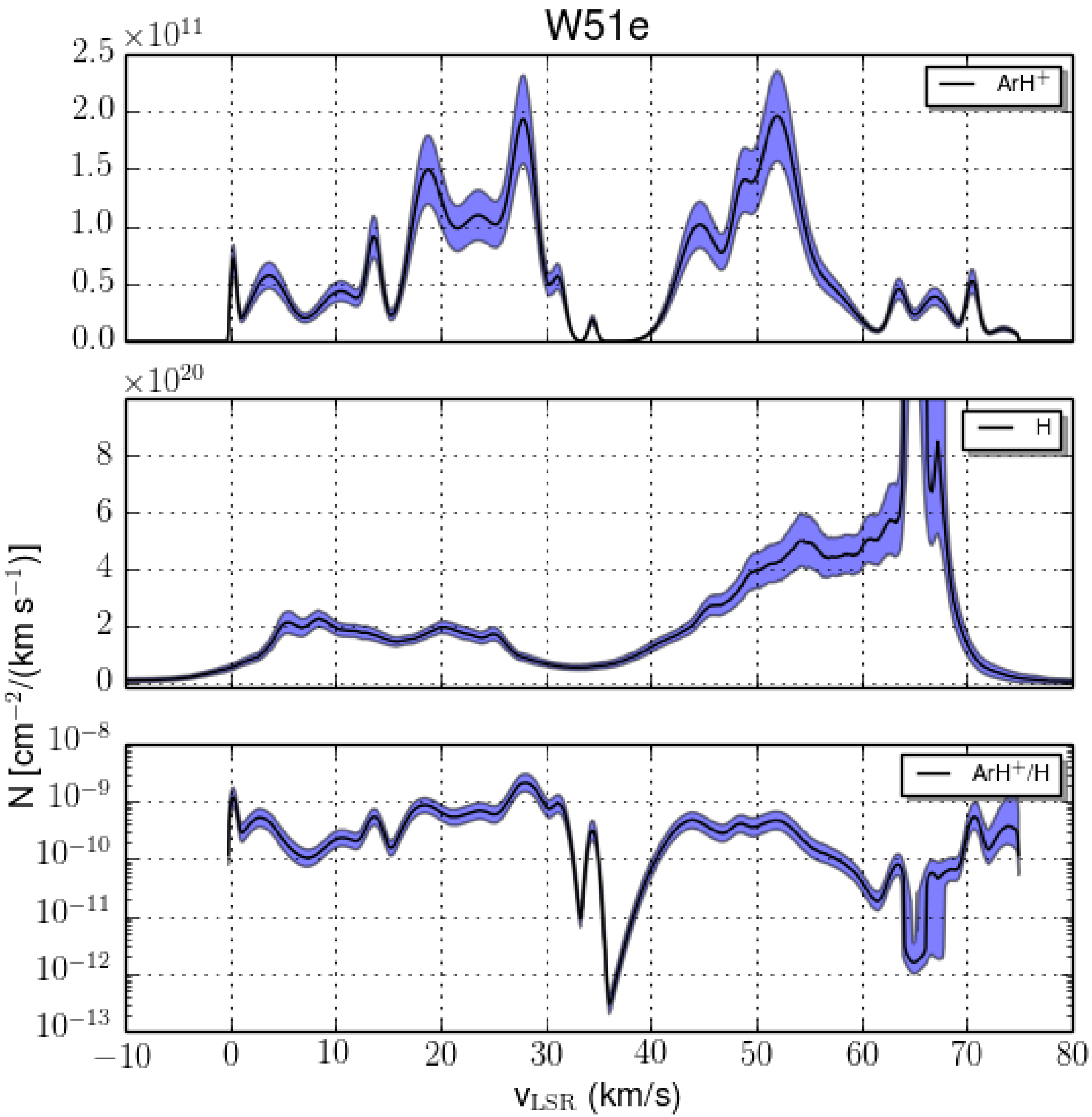
PRISMAS

Massive star forming regions as background sources for absorption spectroscopy

– different molecular clouds along the sightlines

ArH^+ in PRISMAS Sources




W51e
×10^11
2.5
2.0
1.5
1.0
0.5
0.0
ArH+
×10^20
8
6
4
2
0
H
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
ArH+/H
N [cm^-2/(km s^-1)]
−10
0
10
20
30
40
50
60
70
80
vLSR (km/s)

Conclusion

- ArH^+ is a very good tracer of the very atomic diffuse ISM much better than atomic H (which also resides in much denser gas) is the molecule that avoids molecular clouds

- even better with OH^+ and H_2O^+ tracing gas with $n(H_2)/n(H) \sim 0.1$

- ArH^+ is a good probe into cosmic ray ionization rate instead of or together with OH^+, H_2O^+, or H_3^+

- see also: Schilke et al., *Astron. Astrophys.* **566** (2014) A29.

Outlook

- **Observability with ALMA:**
  – very difficult for galactic sources; proximity to H_2O, $5_{32} – 4_{41}$ (620.7 GHz)
  cycle 2: B. Swinyard et al.: $^{36}Ar/^{38}Ar$ ratio in ArH^+ toward Crab Nebula
  – better for extragalactic sources
  cycle 2: H. S. P. Müller et al.: search for $^{36}ArH^+$ and $^{38}ArH^+$ at moderate redshift

- Better with the **S**tratospheric **O**bservatory **F**or **I**nfrared **A**stronomy:
  – option for a receiver on the **G**erman **RE**ceiver **A**t **T**erahertz frequencies
  around H_2O lines at 567, 621, ... 1113 GHz