Formation and Excitation of the Hydronium Ion in the ISM

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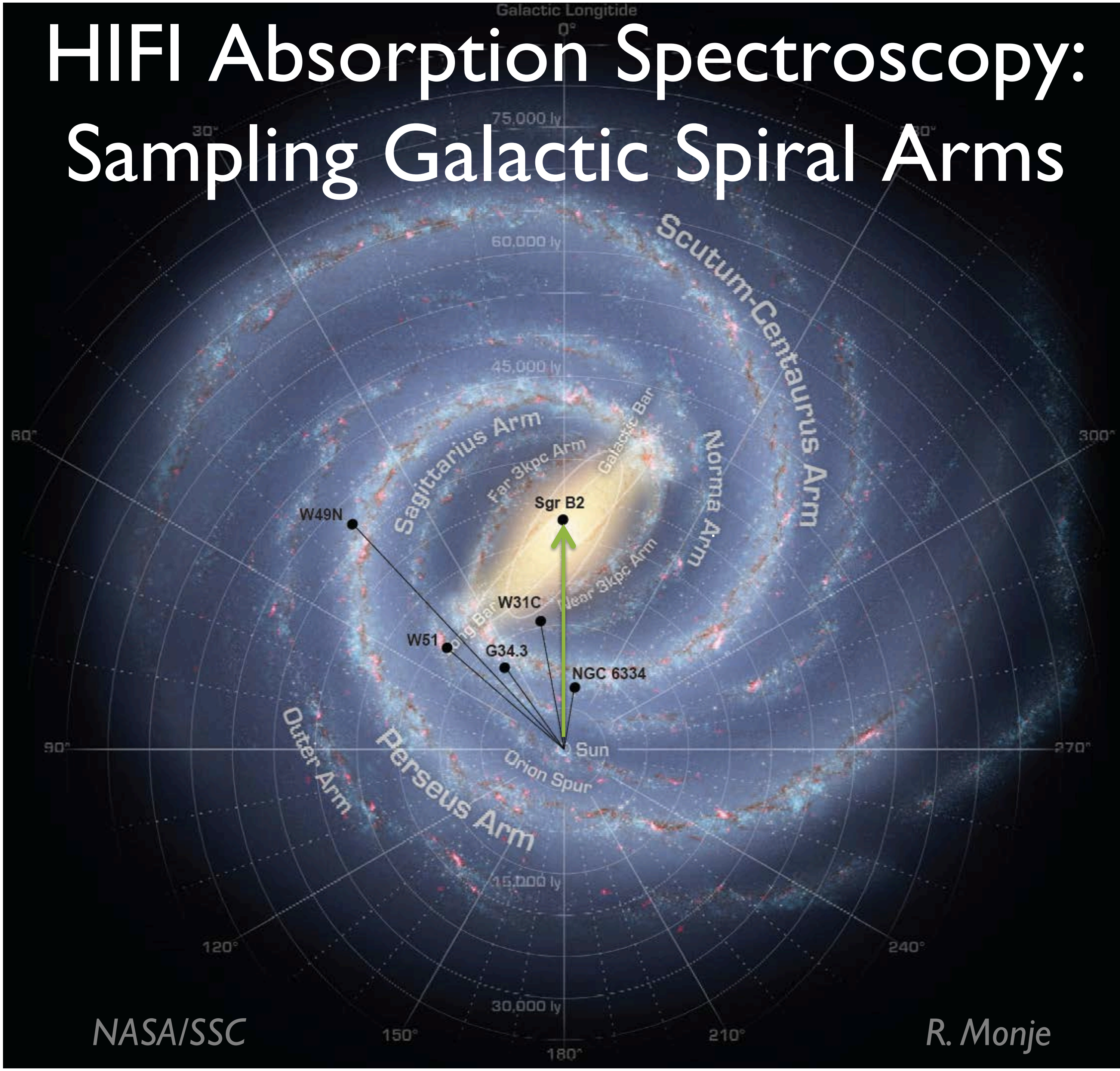
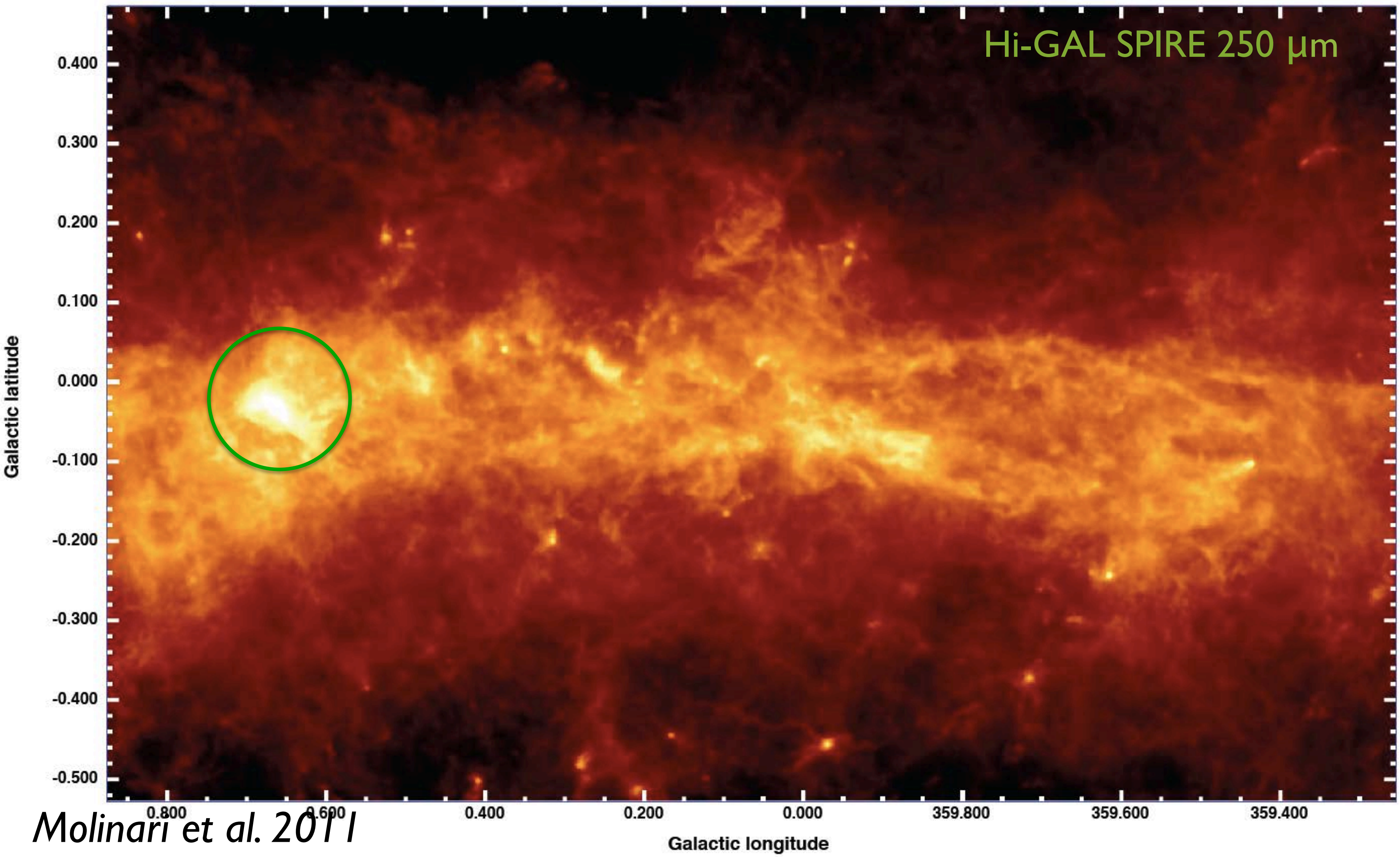
HIFI Absorption Spectroscopy: Sampling Galactic Spiral Arms



Hydrides

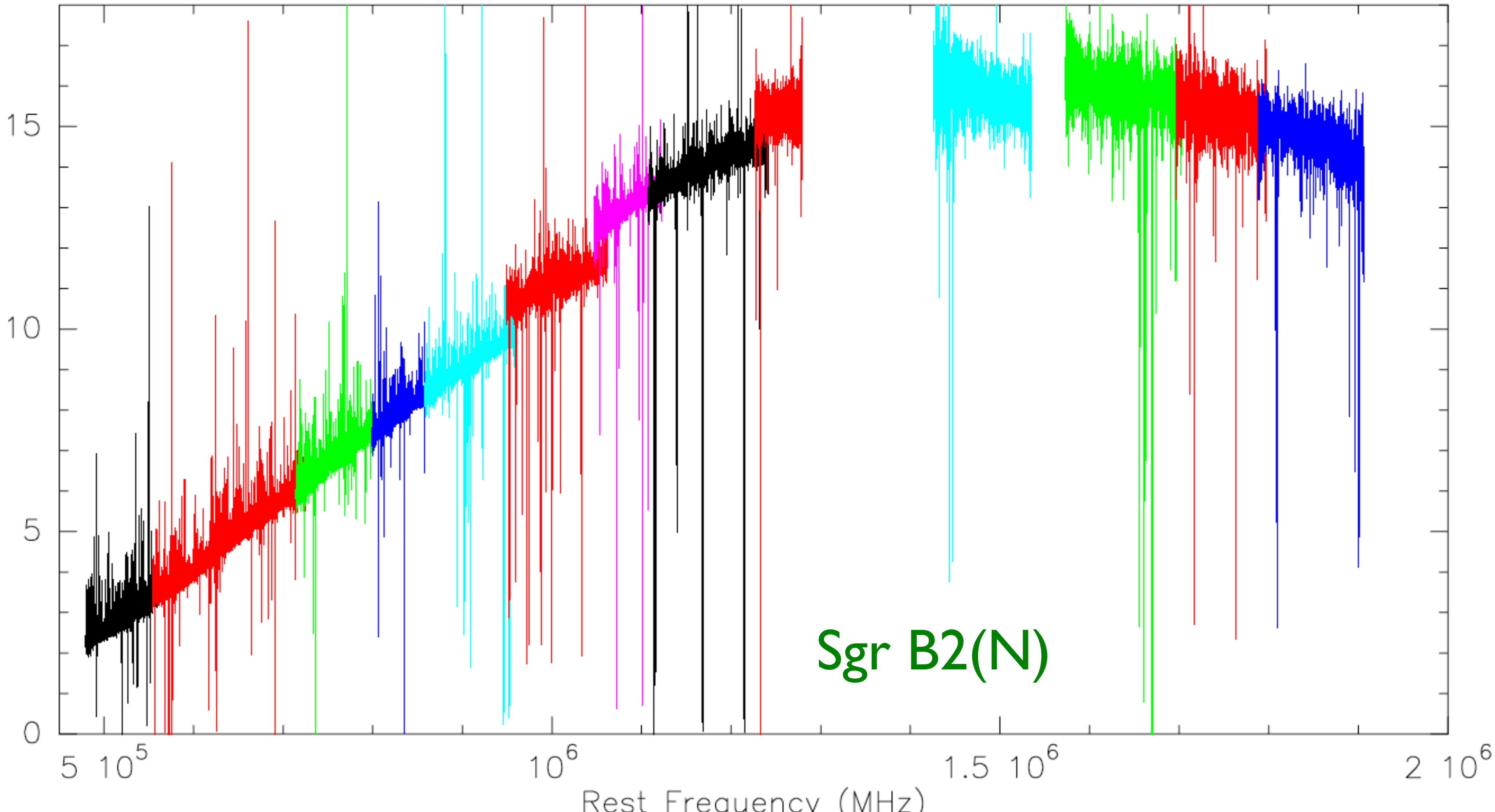
- OH^+
- H_2O^+
- H_3O^+
- H_2O
- HDO
- HF
- CH^+
- CH
- H_2S
- SH^+
- NH
- ND
- NH_2
- NH_3
- HCl
- HCl^+
- H_2Cl^+
- …
- *NH^+*

Herschel View of the Galactic Center



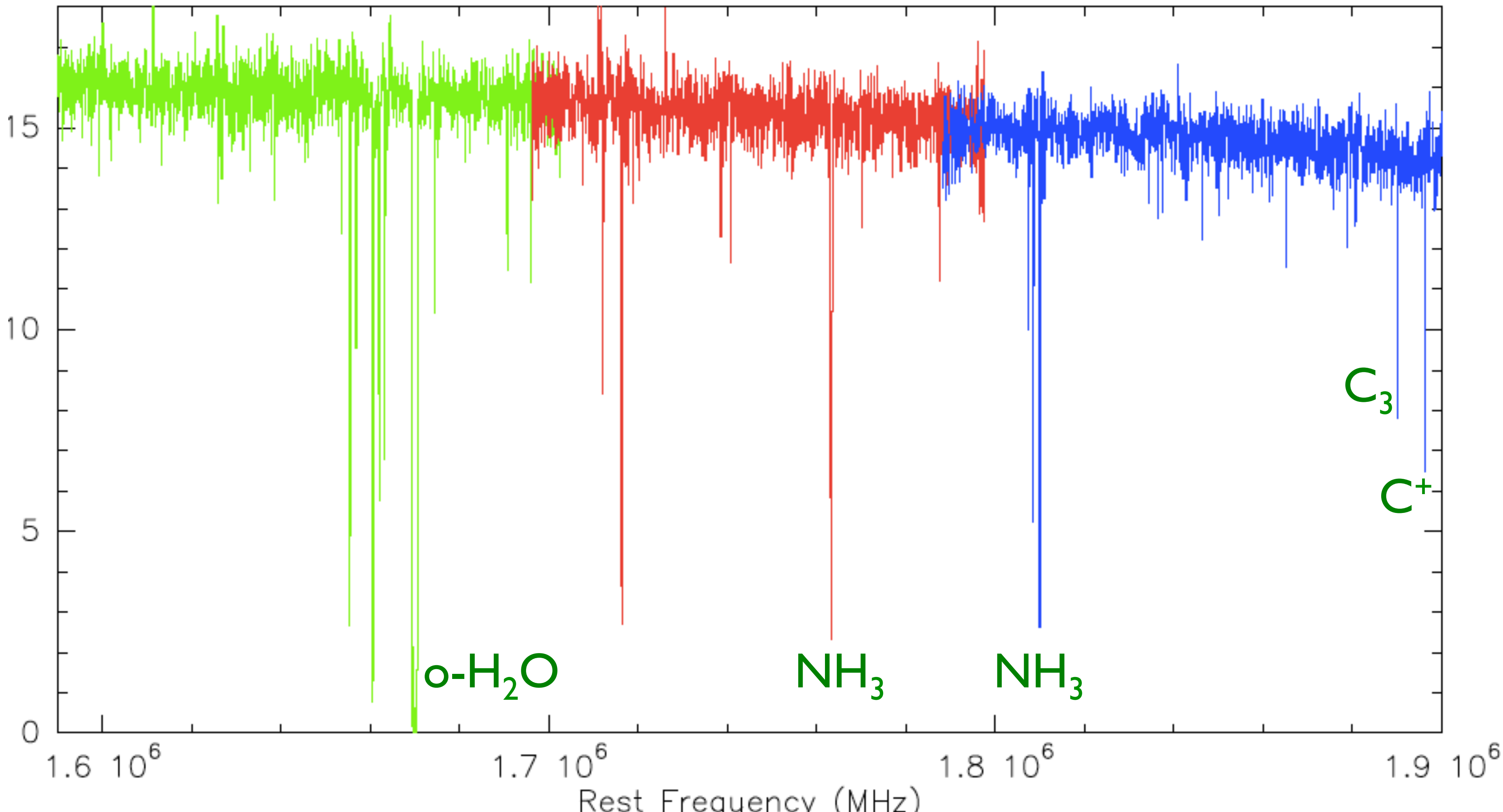
Molinari et al. 2011

HEXOS Sagittarius B2 Program



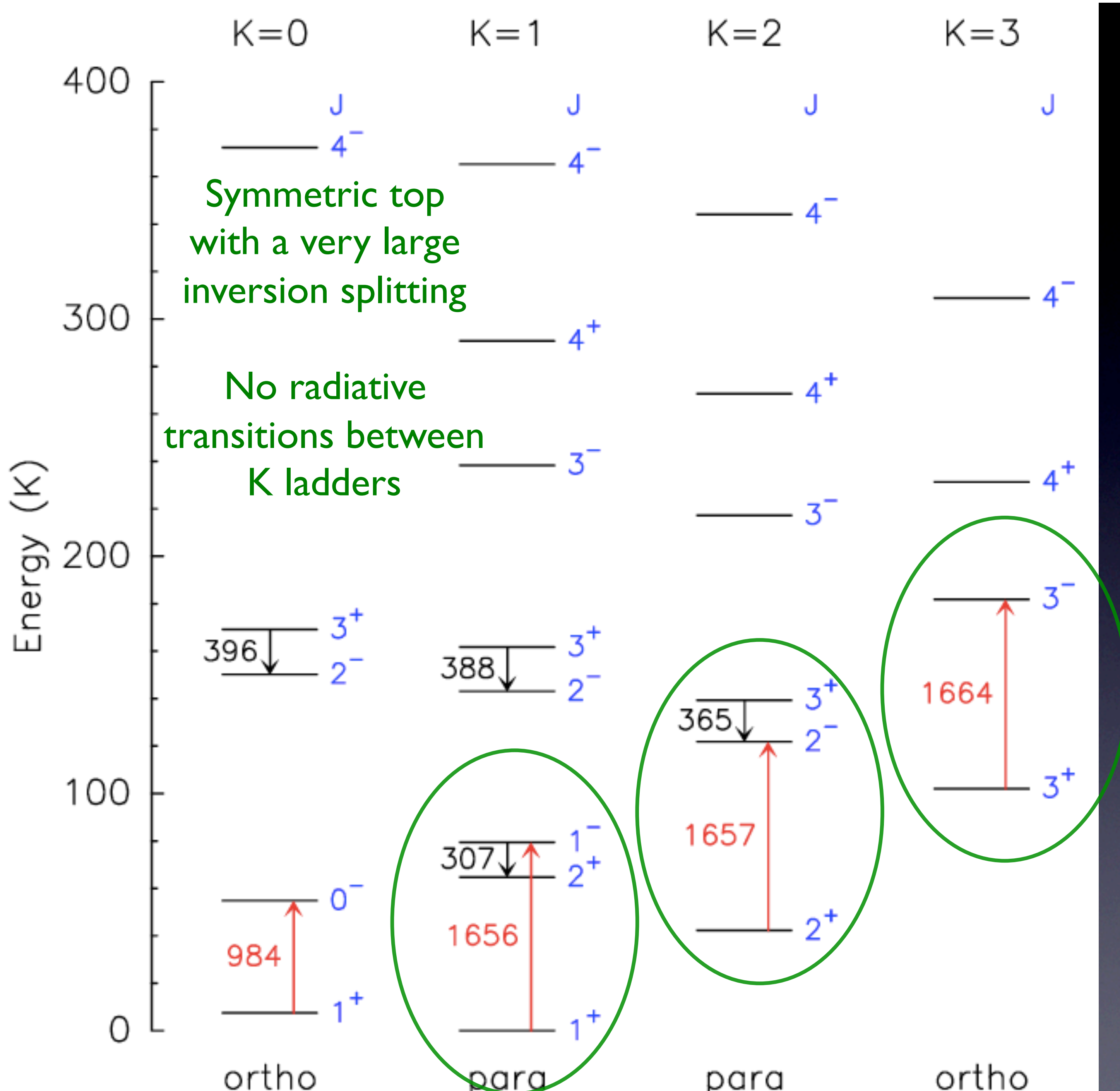
- Complete HIFI scans of Sgr B2(N) and (M); excellent continuum stability

Sagittarius B2(N) HEB Spectrum



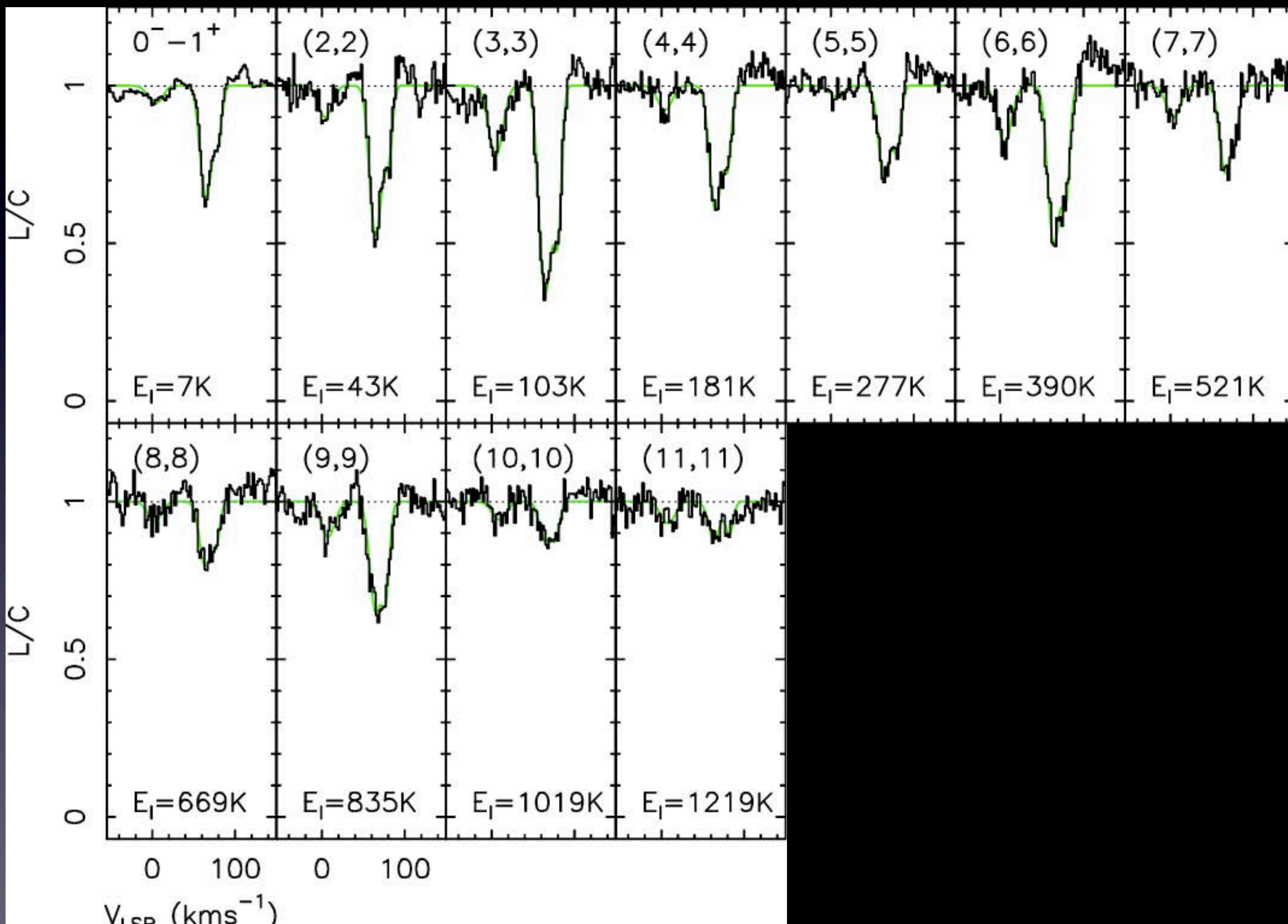
- HEB bands dominated by absorption lines—water isotopologues, low energy ammonia lines, C_3, C^+…

H_3O^+

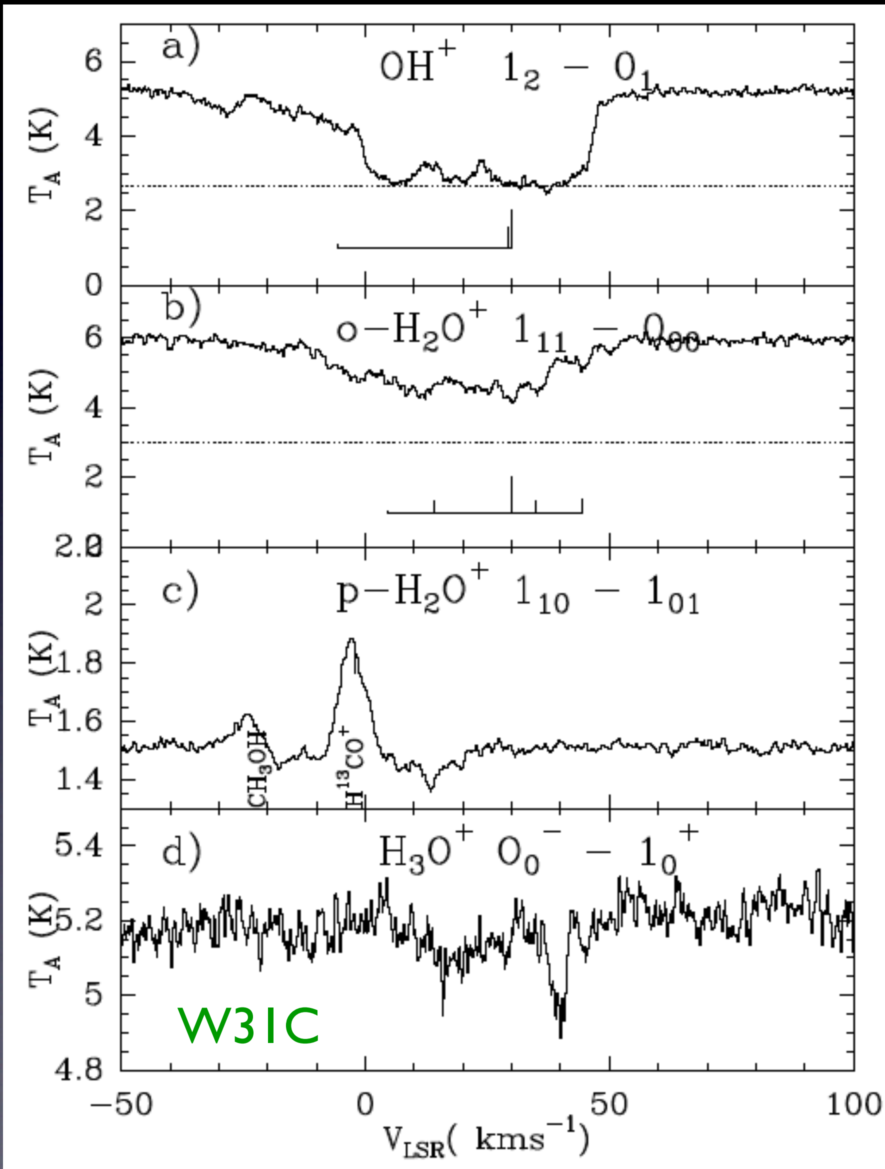


K=0
K=1
K=2
K=3
400
300
200
100
0
Energy (K)
J
4^-
4^+
3^-
3^+
2^-
2^+
1^-
1^+
0^-
396
388
365
307
984
1656
1657
1664
Symmetric top with a very large inversion splitting
No radiative transitions between K ladders
ortho
para
para
ortho

Metastable H_3O^+ in Sgr B2(N)

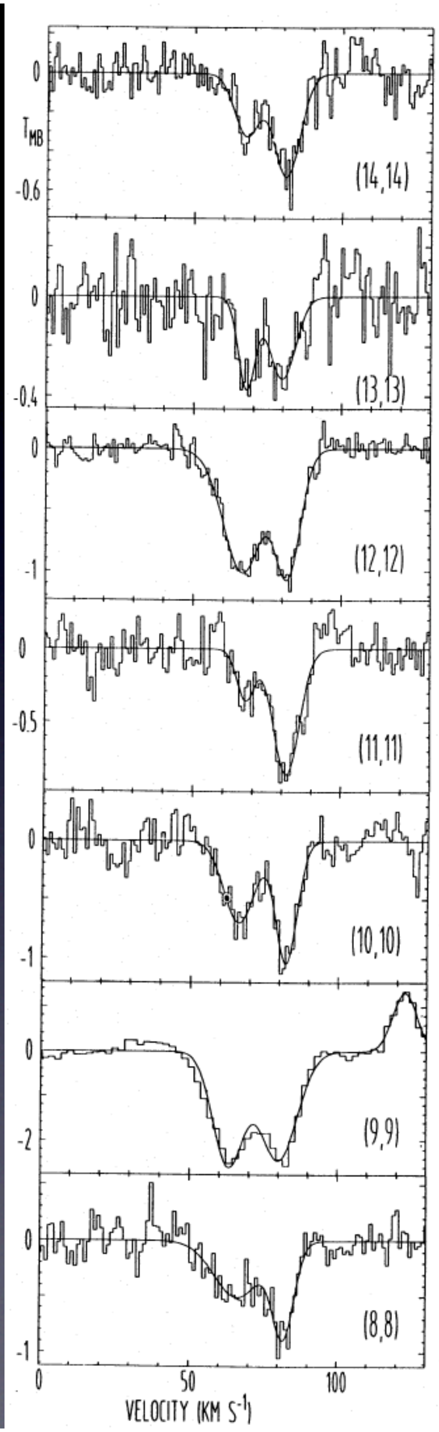


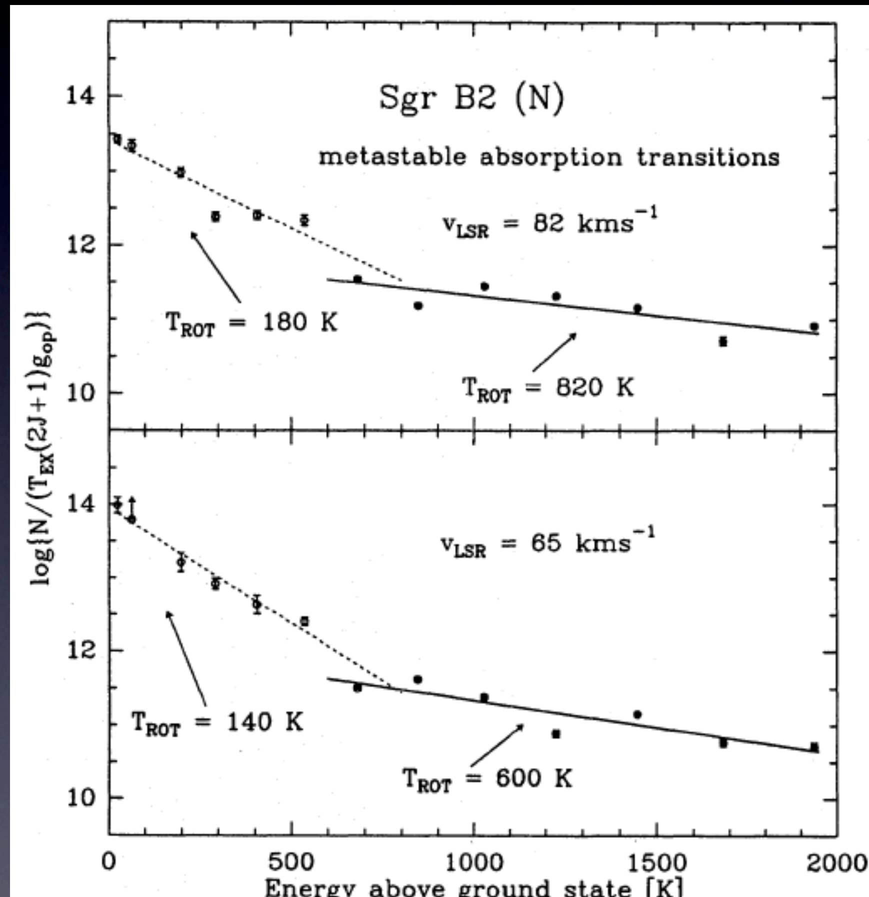
Herschel/HIFI: OH^+, H_2O^+, H_3O^+



- PRISMAS: W31C (Gerin et al. 2010) W49N (Neufeld et al. 2010)
- Strong OH^+ and H_2O^+ absorption, but only weak H_3O^+
- Observations probe primarily diffuse gas
- If the ratio of electron density to H_2 is sufficiently high, the pipeline leading from O^+ to OH^+ to H_2O^+ to H_3O^+ can be "leaky"
- In dense gas the H^+ abundance and T are too low to to produce O^+ by charge transfer; dominant source of OH^+ is reaction of $H_3{}^+$ with O
- Conversion from OH^+ to H_3O^+ proceeds with high efficiency
- Nevertheless, H_3O^+ not detected in Orion KL (Gupta et al. 2010)
- *What is special about Sagittarius B2?*

Ammonia Inversion Lines in Sgr B2





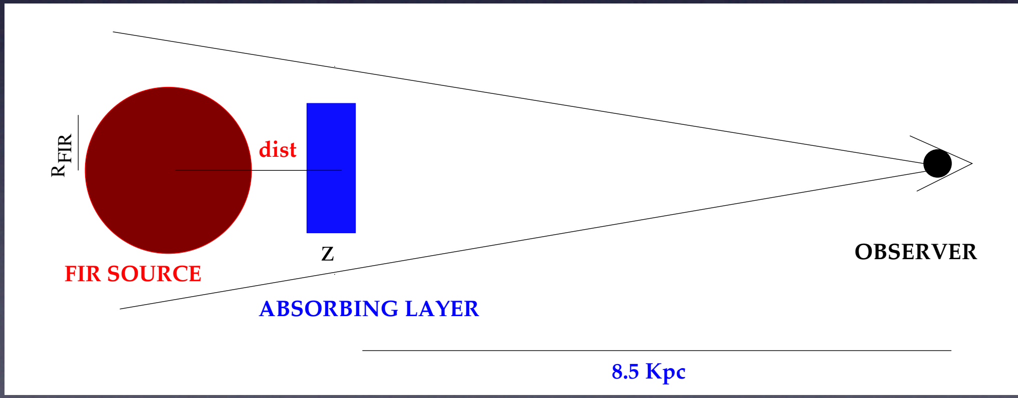
Hüttemeister et al. (1995)

Shocked Gas Layer toward Sgr B2

- Earlier evidence of hot gas in the Galactic center from ground-based observations of the ammonia inversion lines (H ttemeister et al. 1995; Flower et al. 1995)
- ISO LWS observations of 21 ammonia lines, both ortho and para, metastable and non-metastable (Ceccarelli et al. 2002)

- Absorbing gas layer: temperature (700±100) K, density < 10^4 cm^{-3}, NH_3 column density $(3\pm1)\times10^{16}$ cm^{-2}, H_2 column density 3×10^{22} cm^{-2}

    - Interpreted as a layer of *shocked gas* between us and Sgr B2



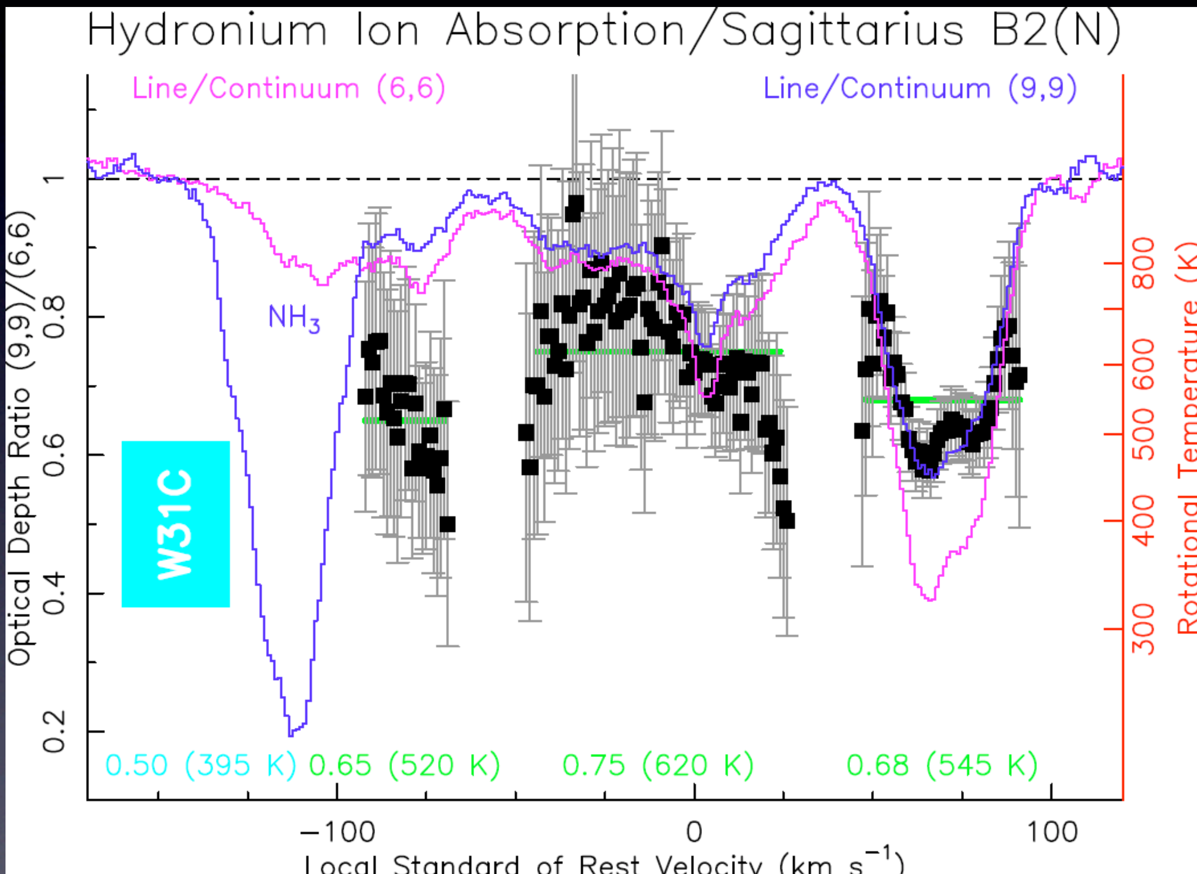
- Size ~30", but the 60 kms^{-1} component seen toward both Sgr B2(M) and (N)
    - Why is the velocity of the shocked layer the same as the dense cores?

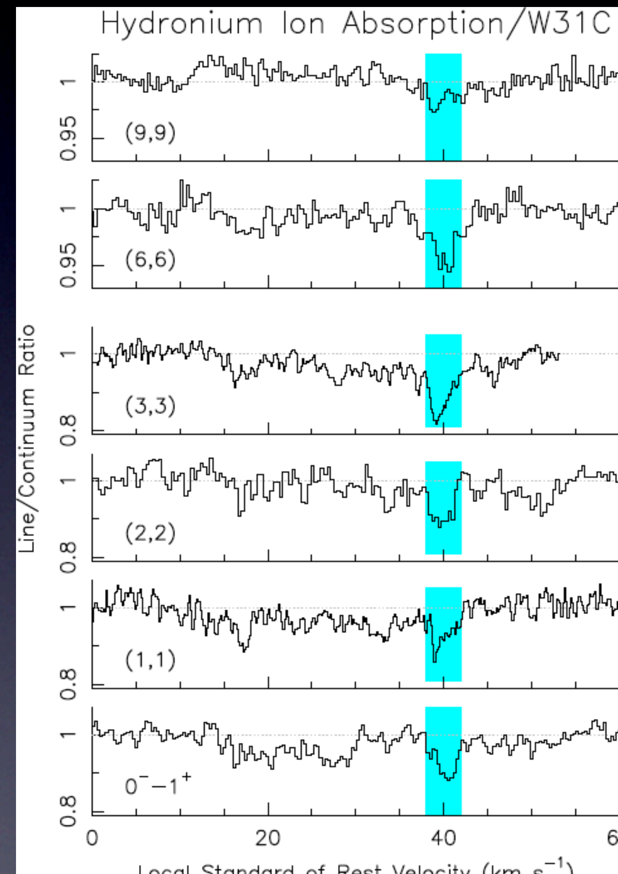
Galactic Center Chandra Composite

Energy: Red (1-3 keV); Green (3-5 keV); Blue (5-8 keV)

- Strong 6.4 keV Fe line and hard X-ray emission: Sgr B2 illuminated by an X-ray flash originating from the GC black hole (Sunyayev et al. 1993; Koyama et al. 1996)
  - X-ray emission now fading quickly (~8 yr timescale; Terrier et al. 2010)

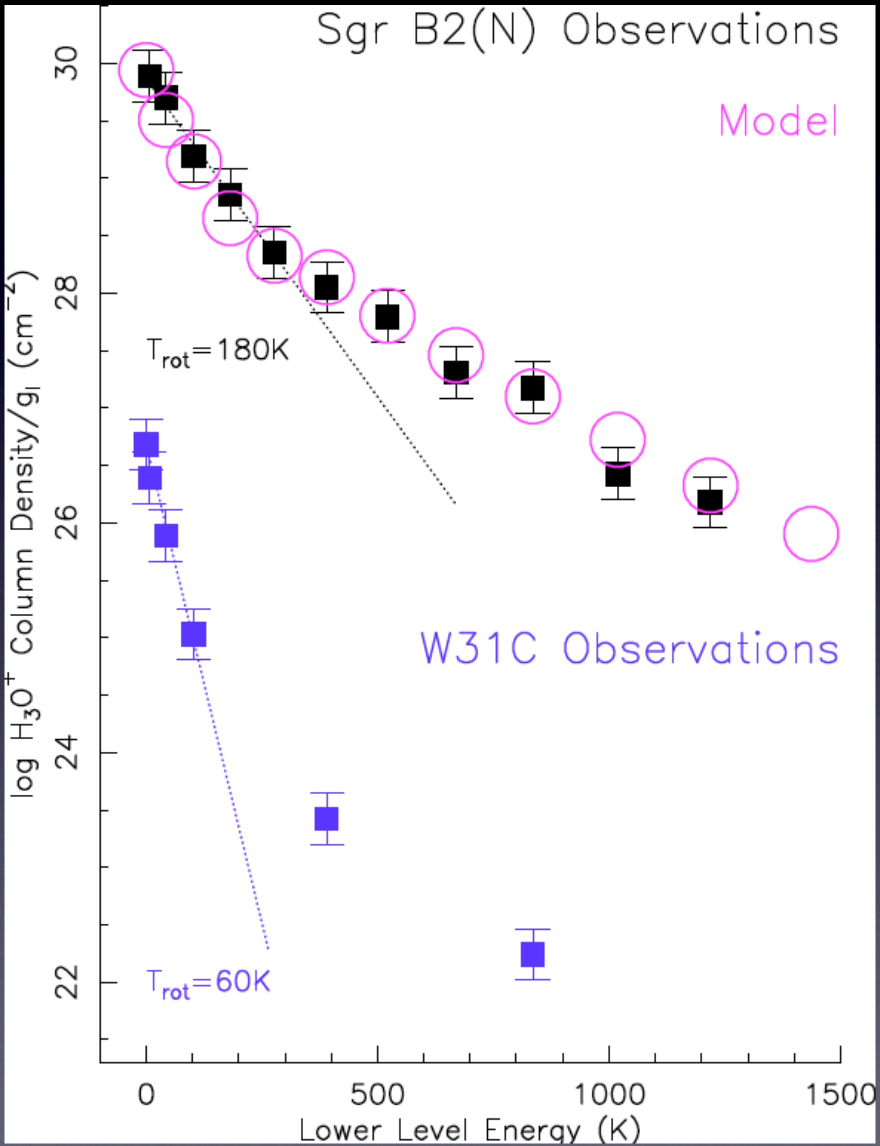
New "Must Do" Observations





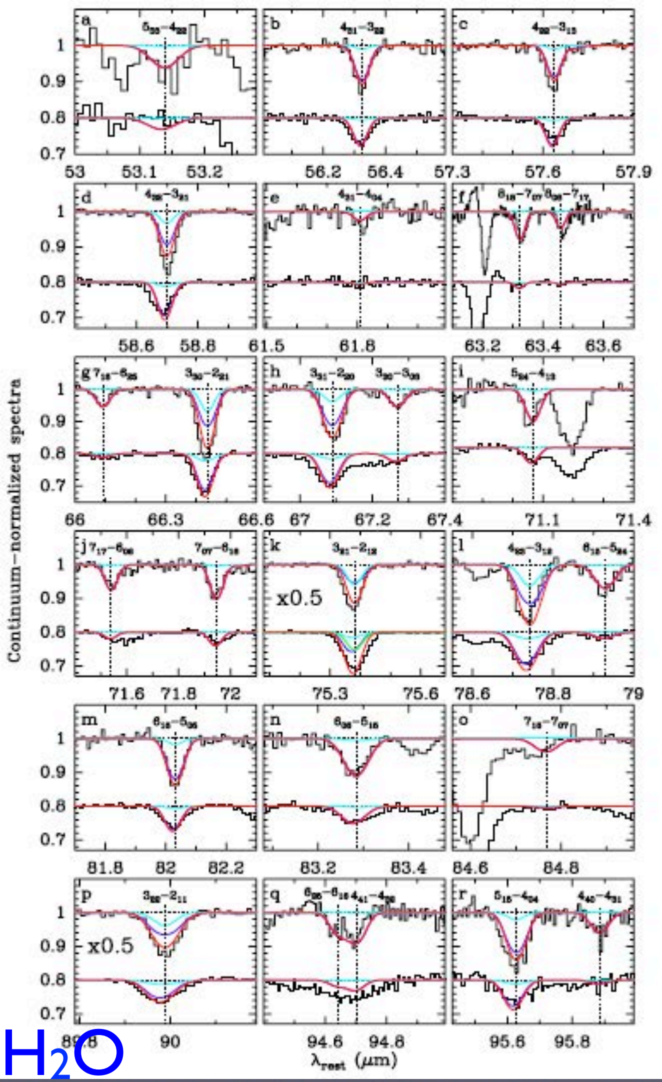
- Hot H_3O^+ not limited to the GC environment, but also seen toward W31C

Formation Pumping

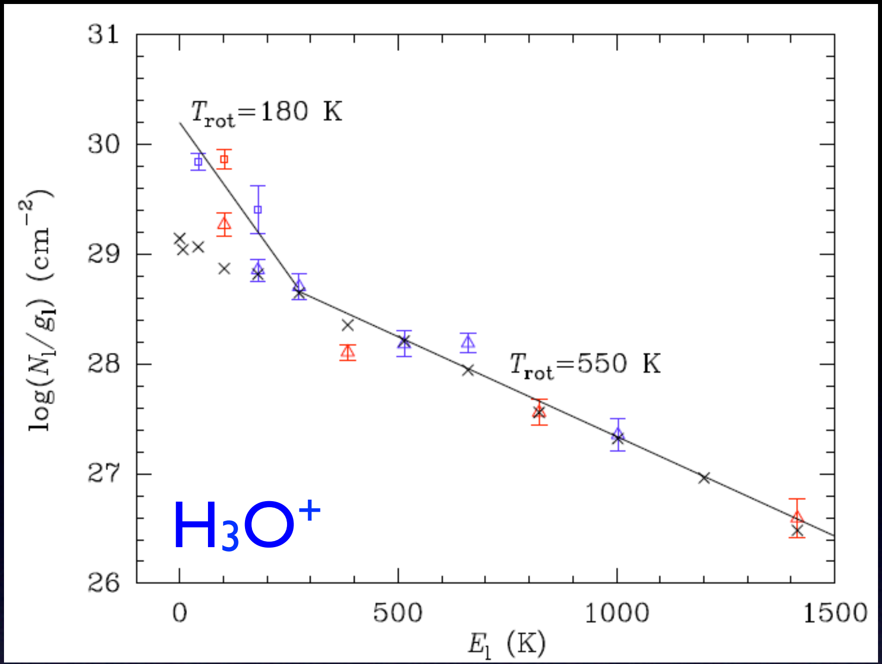


- Cosmic/X-ray + $H_2 \rightarrow H_3^+$ (widespread in the Galactic Center region)
  $H_3^+ + O \rightarrow OH^+ + H_2$
  $OH^+ + H_2 \rightarrow H_2O^+ + H$
  $H_2O^+ + H_2 \rightarrow H_3O^+ + H +$ 1.69 eV
- Also
  $H_3^+ + H_2O \rightarrow H_3O^+ + H_2 +$ 2.81 eV
- Collisional relaxation time has to be long compared to recombination/reformation of H_3O^+ molecules to maintain the population
- Can the hot ammonia also be explained by formation pumping? (More stable, long lived—more time to relax through collisions?)

PACS NGC4418 and Arp 220



E. Gonzalez-Alfonso



- Nuclear regions have high water abundances ~10^{-5}
- Chemistry typical of evolved hot cores, where grain mantle evaporation has occurred
- OH/H_2O~0.5 indicates effects of X-rays or CRs
- H_3O^+ rotational temperature ~500K in Arp 220, similar to Sagittarius B2
- Lines arise in a relatively low density (>10^4 cm^{-3}) interclump medium with a very high ionization rate (>10^{-13} s^{-1})

Summary

- Unbiased HIFI spectral line surveys are the key for investigations of the chemical complexity of ISM sources (new species, e.g., H_2O^+, OH^+, H_2Cl^+, HCl^+, O_2, …)
- H_3O^+ targeted in PRISMAS and shown to be weak on sightlines in the Galactic disk
- Strong H_3O^+ absorption from metastable levels up to 1200 K toward Sagittarius B2 came in as a surprise
- Formation pumping in X-ray irradiated gas is an attractive explanation
- Deep observations of W31C indicate that the same mechanism also operates in less extreme environments
- Under some conditions, rotational temperatures derived from observations of symmetric top molecules cannot be interpreted as kinetic temperature of the medium