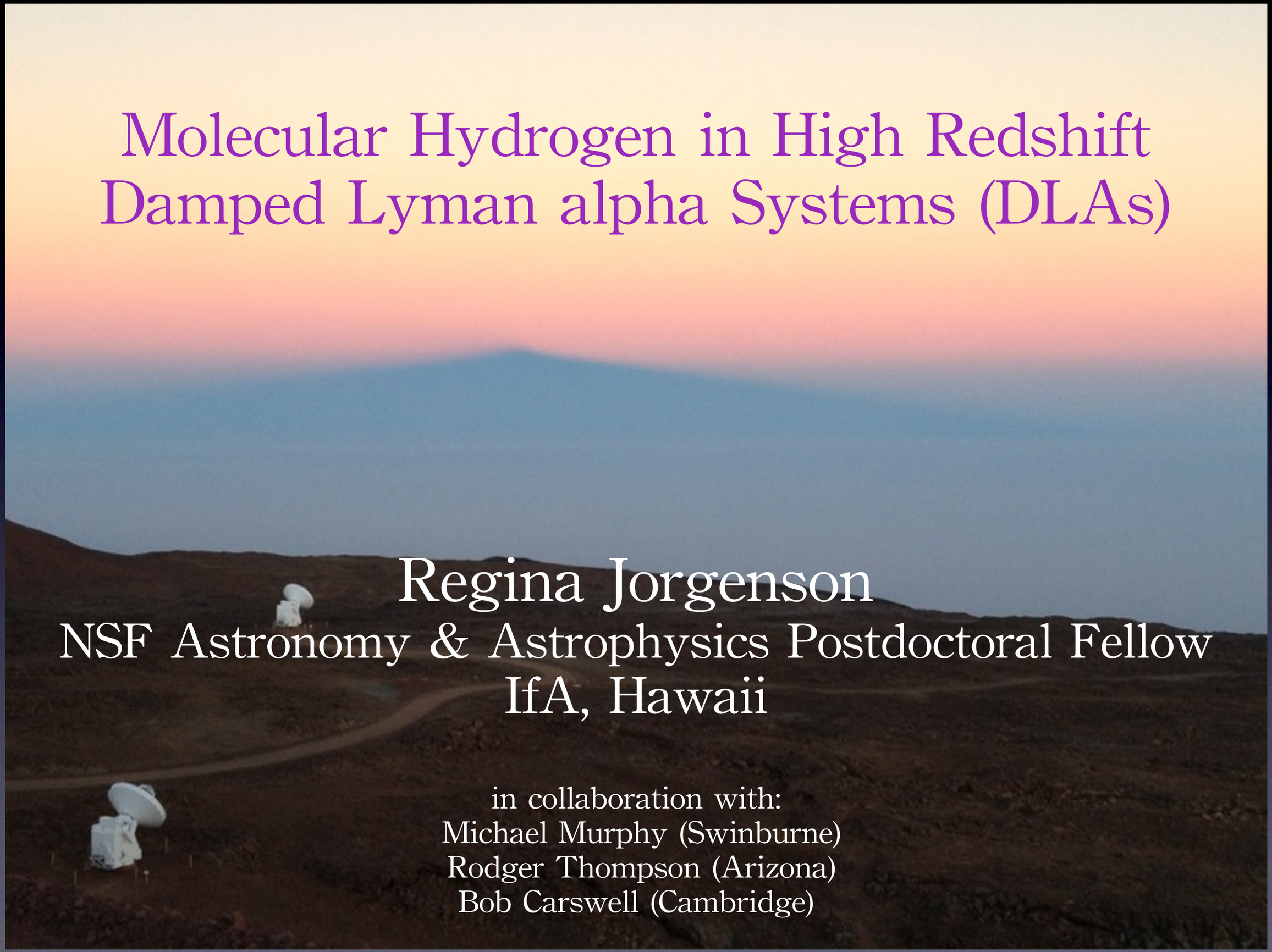
Molecular Hydrogen in High Redshift Damped Lyman alpha Systems (DLAs)



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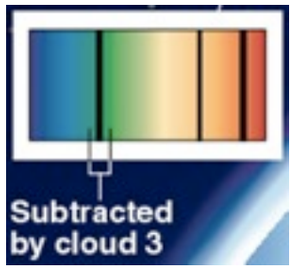
in collaboration with:
Michael Murphy (Swinburne)
Rodger Thompson (Arizona)
Bob Carswell (Cambridge)

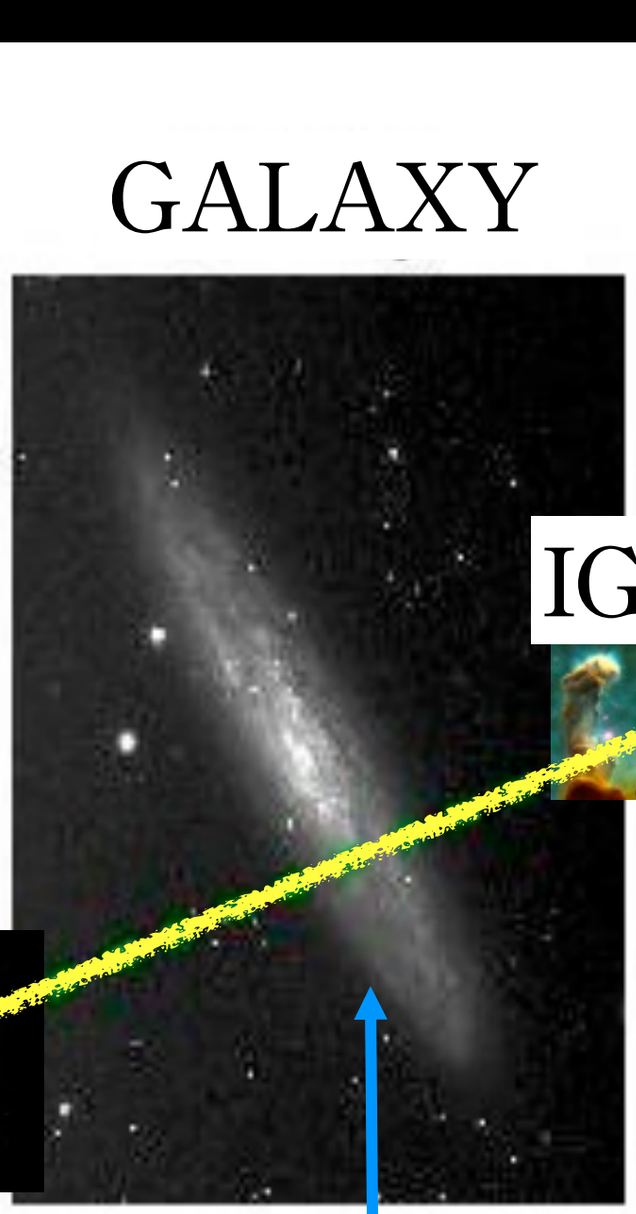
GALAXY

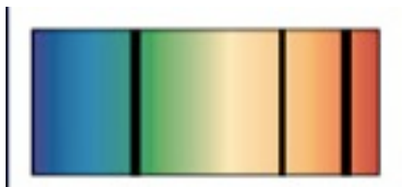
QUASAR



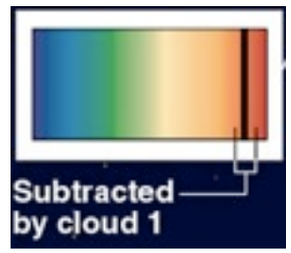
IGM

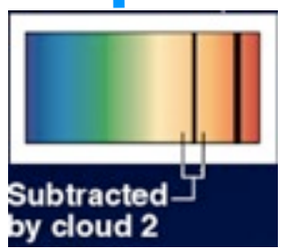
IGM



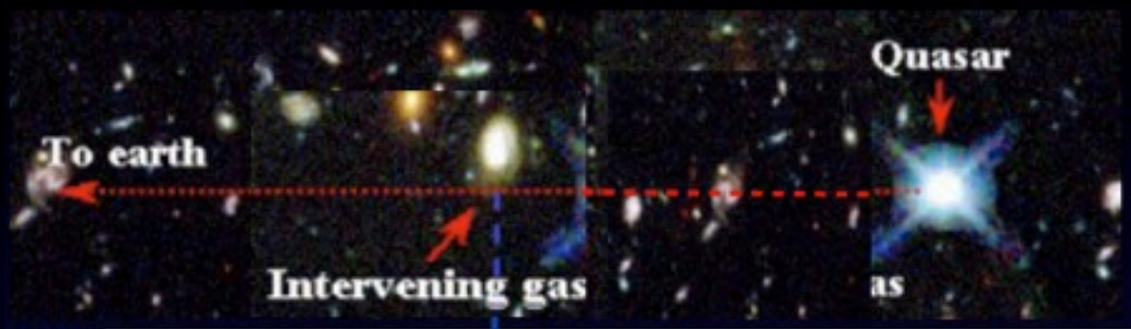


Final absorption
spectrum

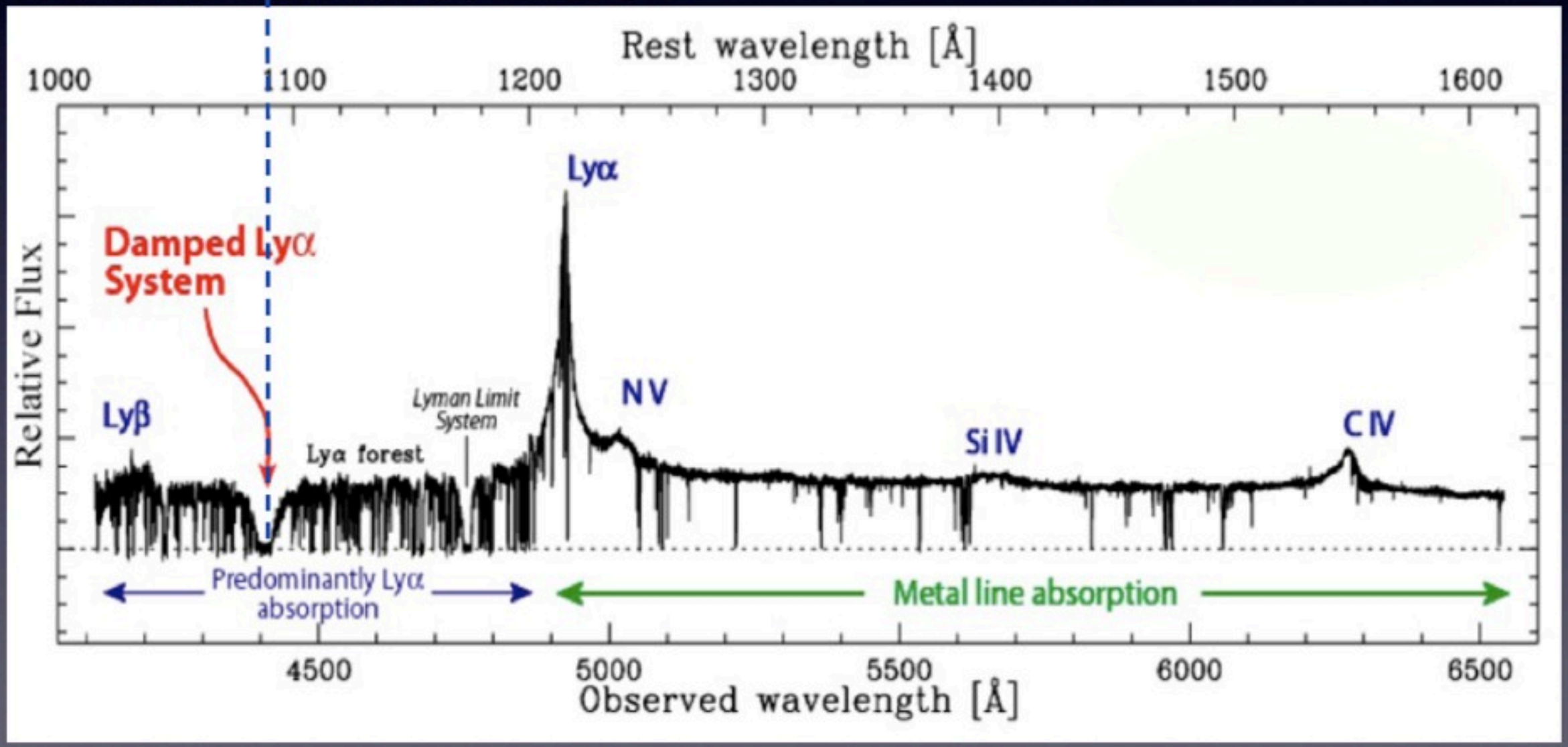




Typical Quasar Spectrum



~1 in 3 quasars contains a DLA



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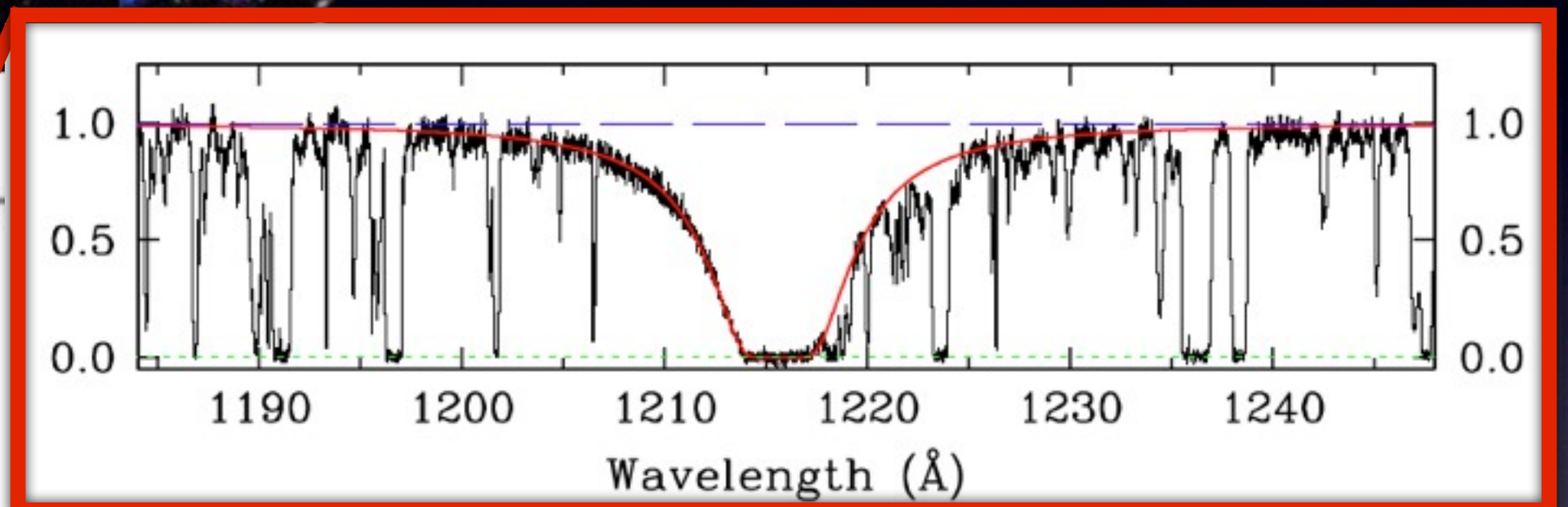

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DLA Basics

- Damped Lyman alpha Systems (DLAs) are quasar absorption line systems with:
  - $N(HI) \geq 2 \times 10^{20}$ cm^{-2}
    - Gas is primarily neutral
    - Crucial for star formation

DLA Basics

- Detected from $z \sim [0,5]$ and known to dominate the neutral gas content of the U over this redshift range.
  - >1000 DLAs found in SDSS
- Identified as absorption systems ⇨ no luminosity bias
  - Only probe of normal (not high mass/luminosity) galaxies at high redshift
- Gas content of DLAs at $z\sim[3,4]$ is approximately equal to the amount of matter in stars today
  - DLAs serve as important neutral gas reservoirs for star formation

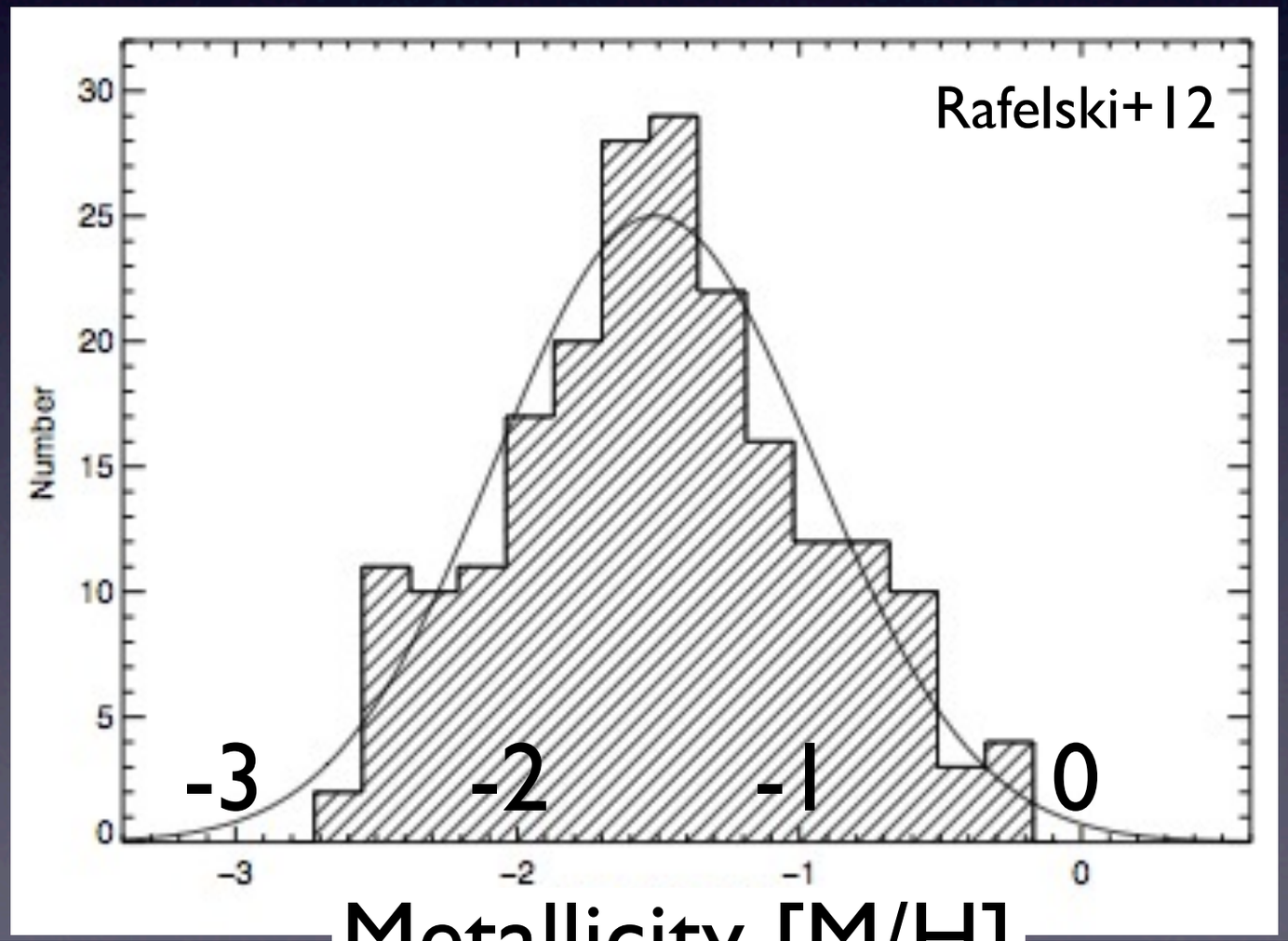
Question

- Is this neutral gas turning into stars?

Evidence for star formation in DLAs?

1) DLA metallicities are generally [M/H] > −2.6 and typically 1/30th of solar

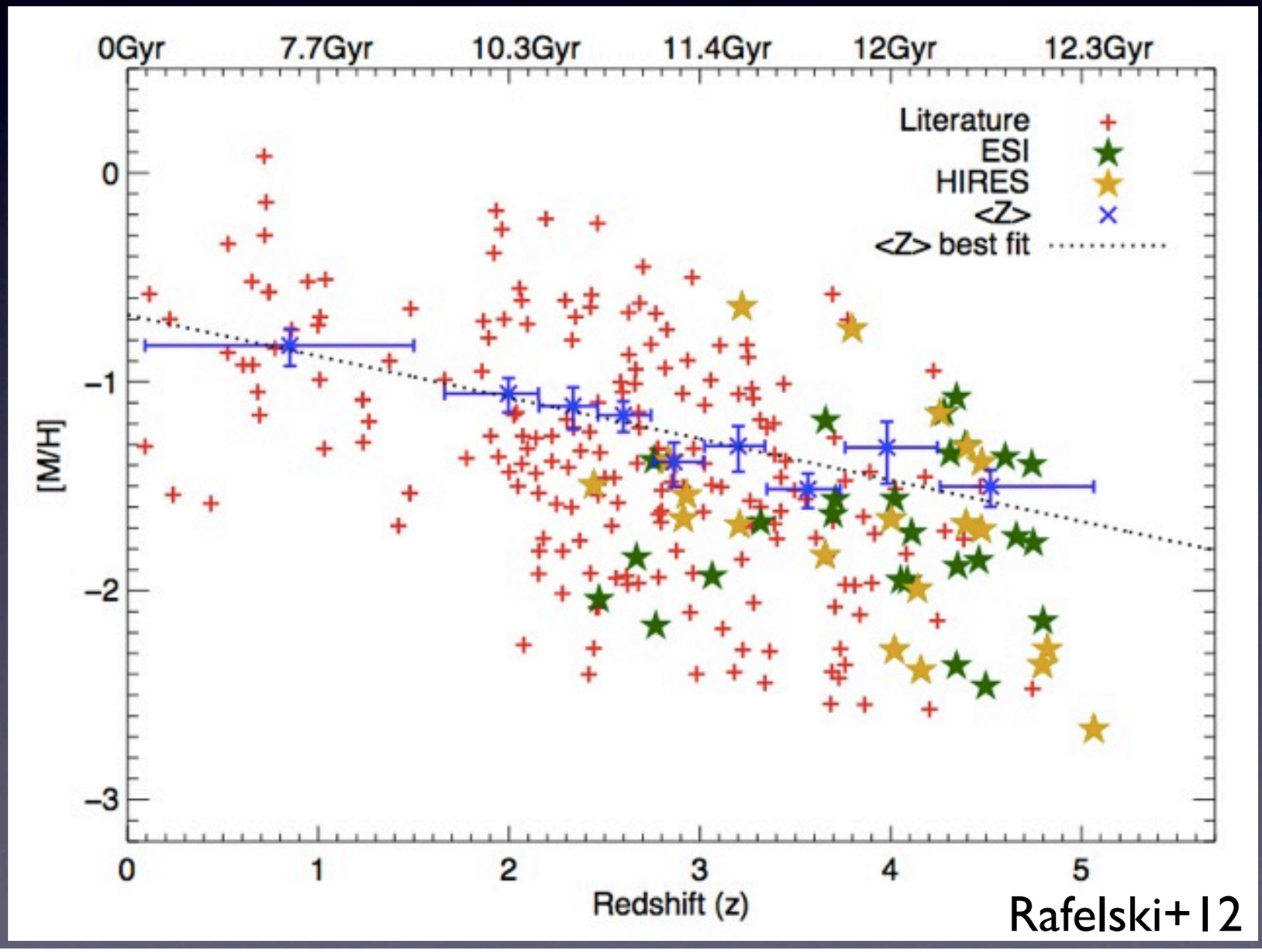
- well above the IGM -- implies either in situ star formation or enrichment from previous generations of stars



Evidence for star formation in DLAs?

2) Metallicity evolves with cosmic time

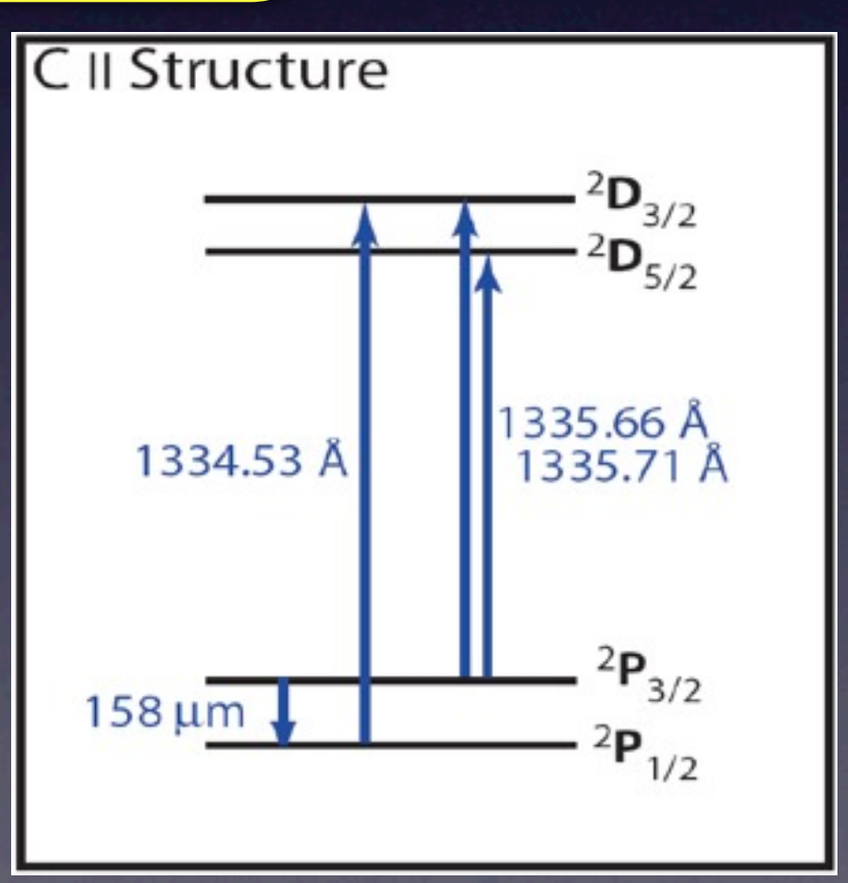
(Prochaska+03, Rafelski+12)



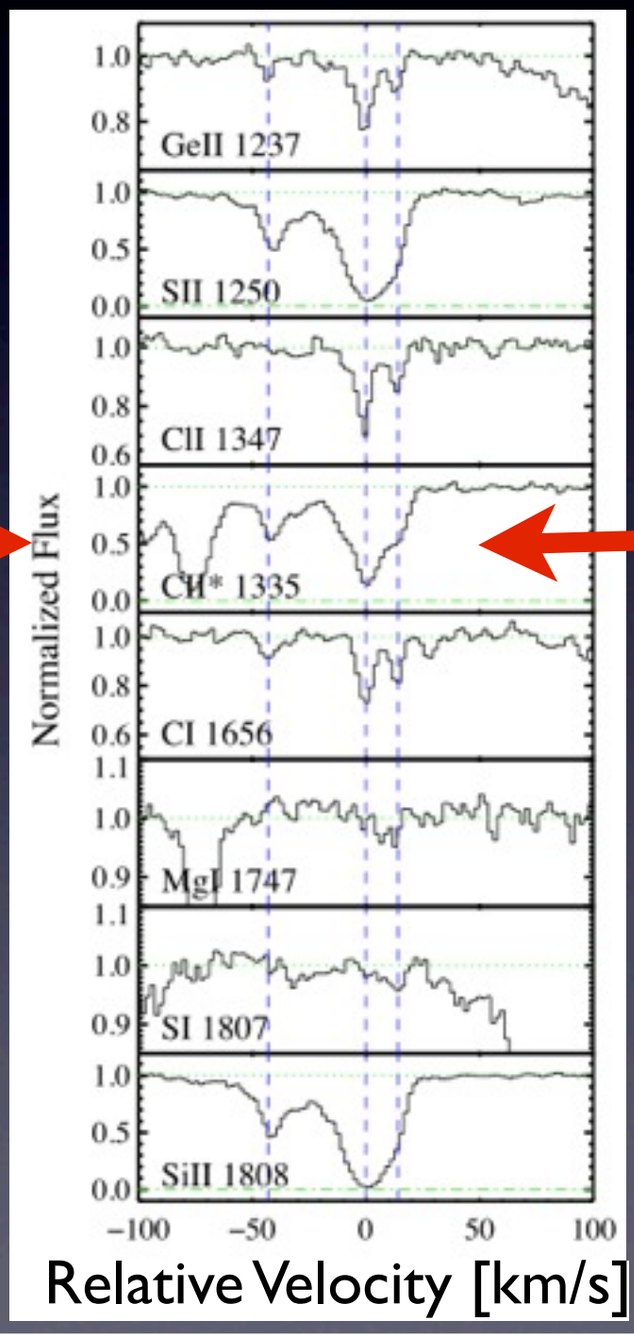
Evidence for star formation in DLAs?

3) CII* absorption implies star formation

No budget for special effects so please imagine Alberto's cartoon/animation of FUV photons to 159 micron emission graphic here



(Wolfe+03)

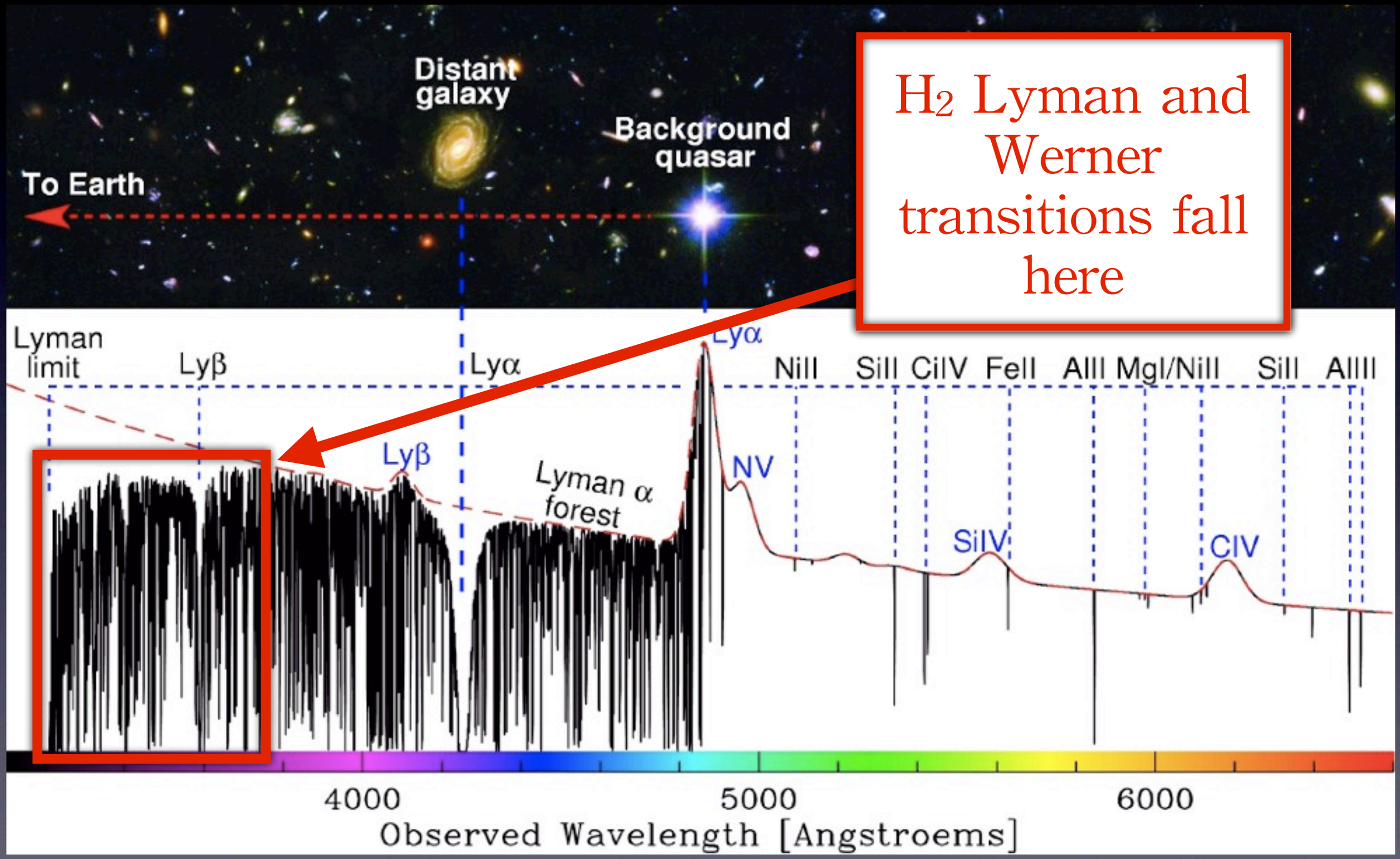


Key Question

- So there is evidence of star formation in DLAs, but where and how is the gas actually turning into stars?

- Star formation requires/traces molecular hydrogen (H_2) so...

Where to look for H_2 in DLAs?



H_2 Lyman and Werner transitions fall here

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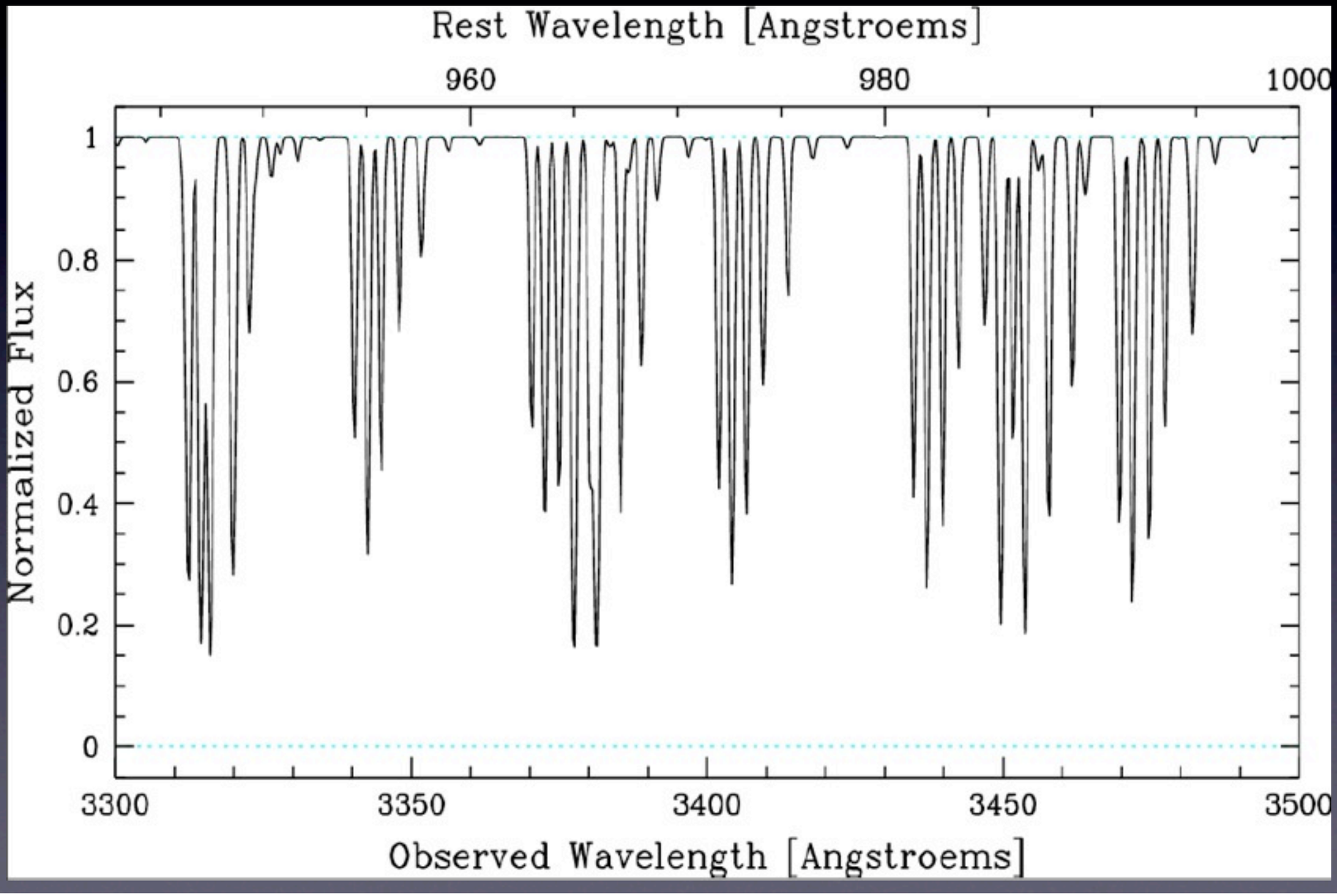
Synthetic H_2 spectrum



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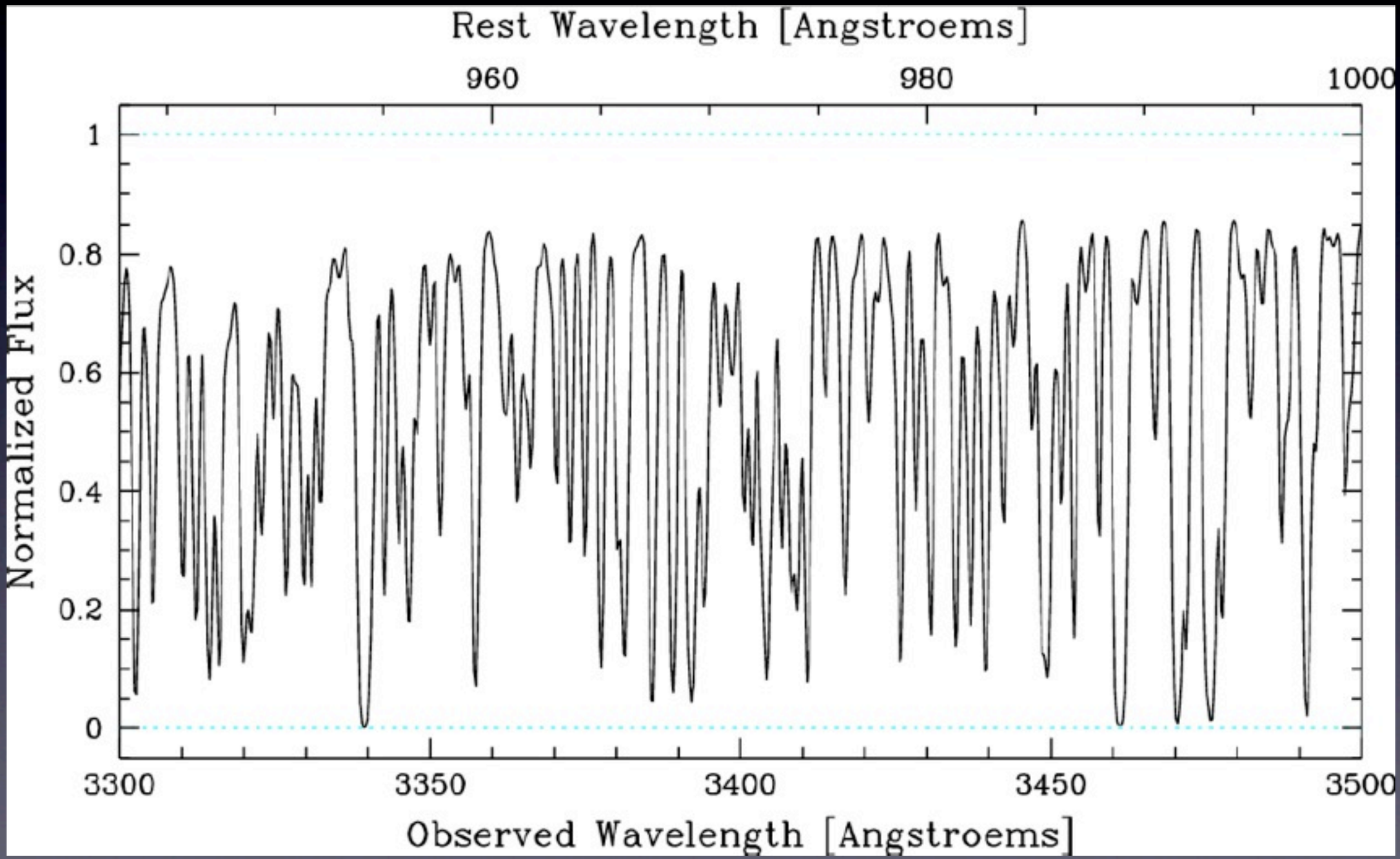
Synthetic H_2 + forest spectrum



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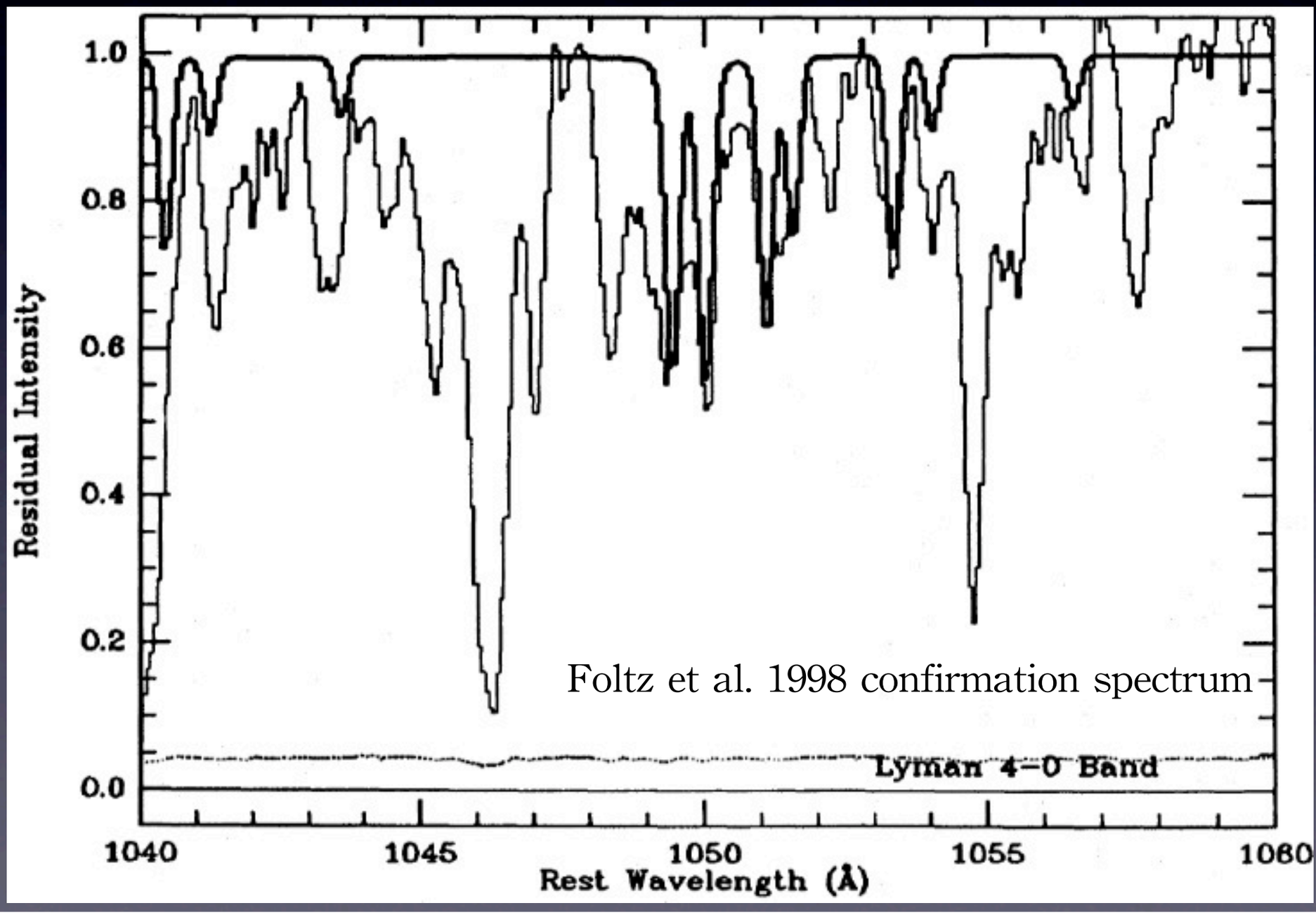
First H_2 detection in a DLA

Levshakov & Varshalovich (1985)



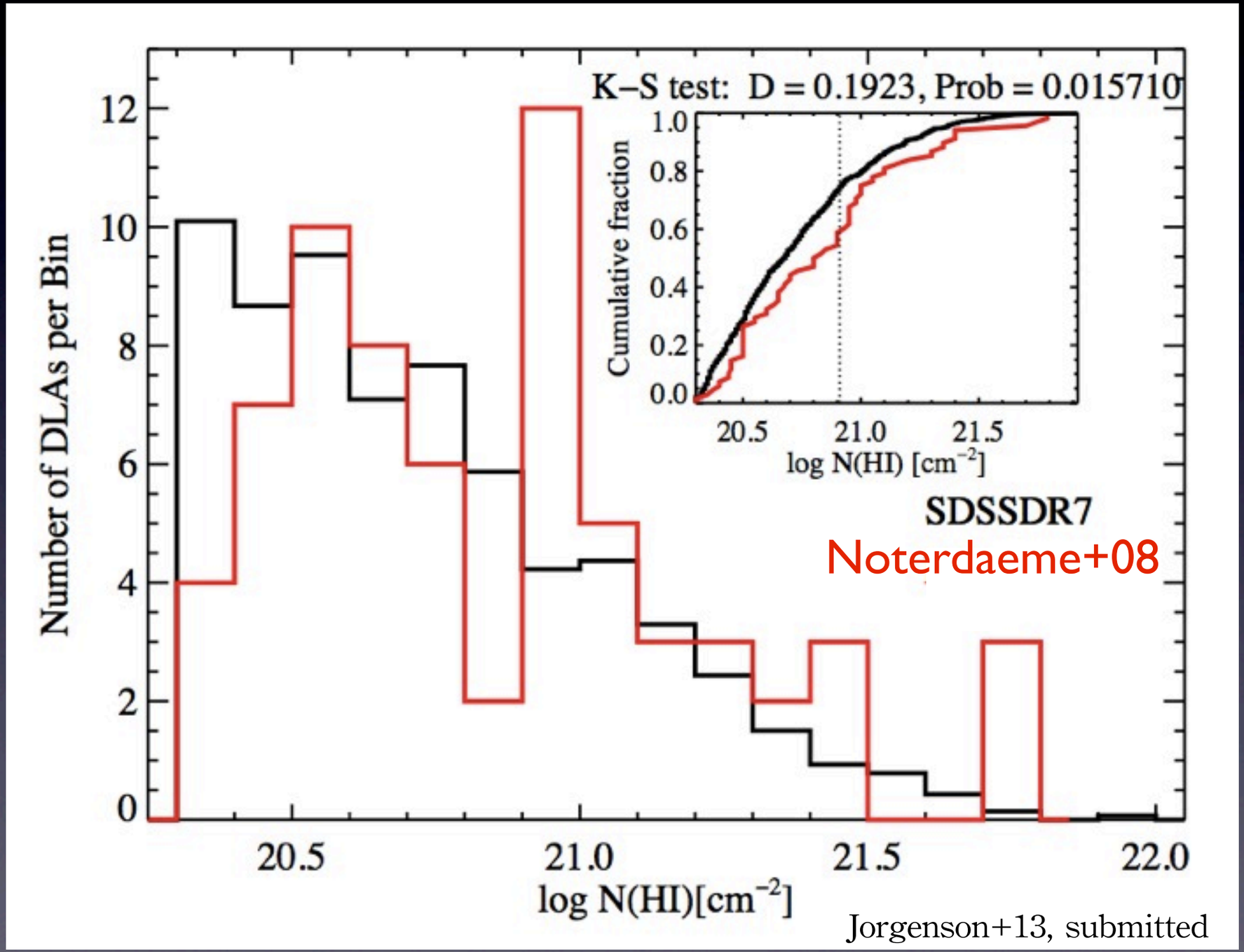
Foltz et al. 1998 confirmation spectrum

Surveys for H_2 in DLAs

- 2003: Ledoux et al.
  - 33 mainly archival VLT/UVES spectra
    - 13 – 20% detection rate
- 2008: Noterdaeme et al. (N08)
  - 77 mainly archival spetra
    - 10 – 18% detection rate
    - molecular fractions of log f = –1 to –6

- But, strong biases exist!
  - Bright quasars selected for high resolution spectroscopy
  - strong metal-absorption selection in archive
  - mainly high N(HI) systems targetted

Biases in previous surveys



The Magellan Uniform DLA Survey: the first large, blind and uniform DLA survey

- ~100 $z \geq 2.2$ DLAs
  - $i \leq 19.0$ mag
    - $\delta \leq 15^{\circ}$
- Magellan/MagE spectrograph is ideal for this
  - R~4000 (~ 71 km/s)
  - Very UV sensitive

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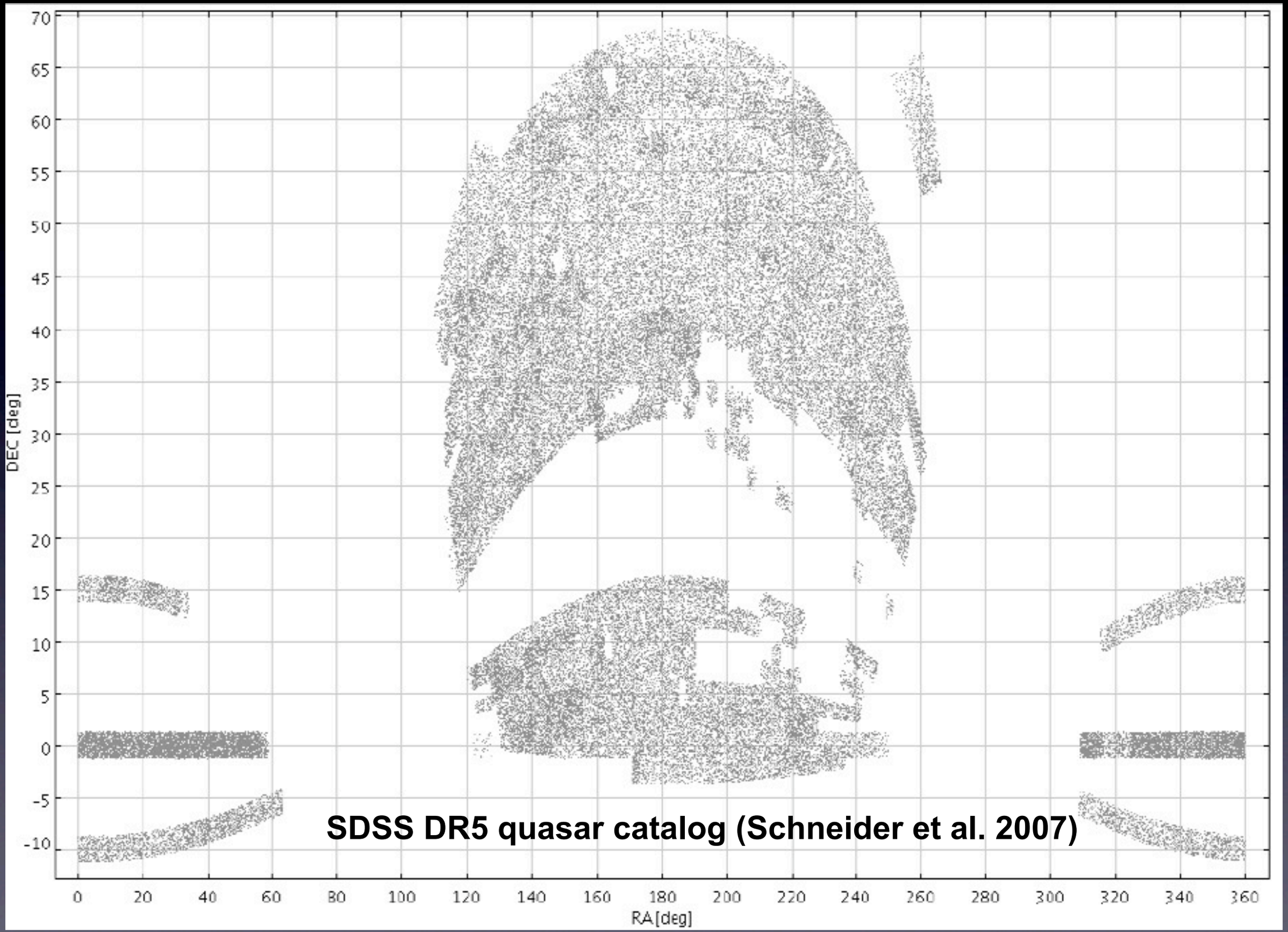
DEC [deg]
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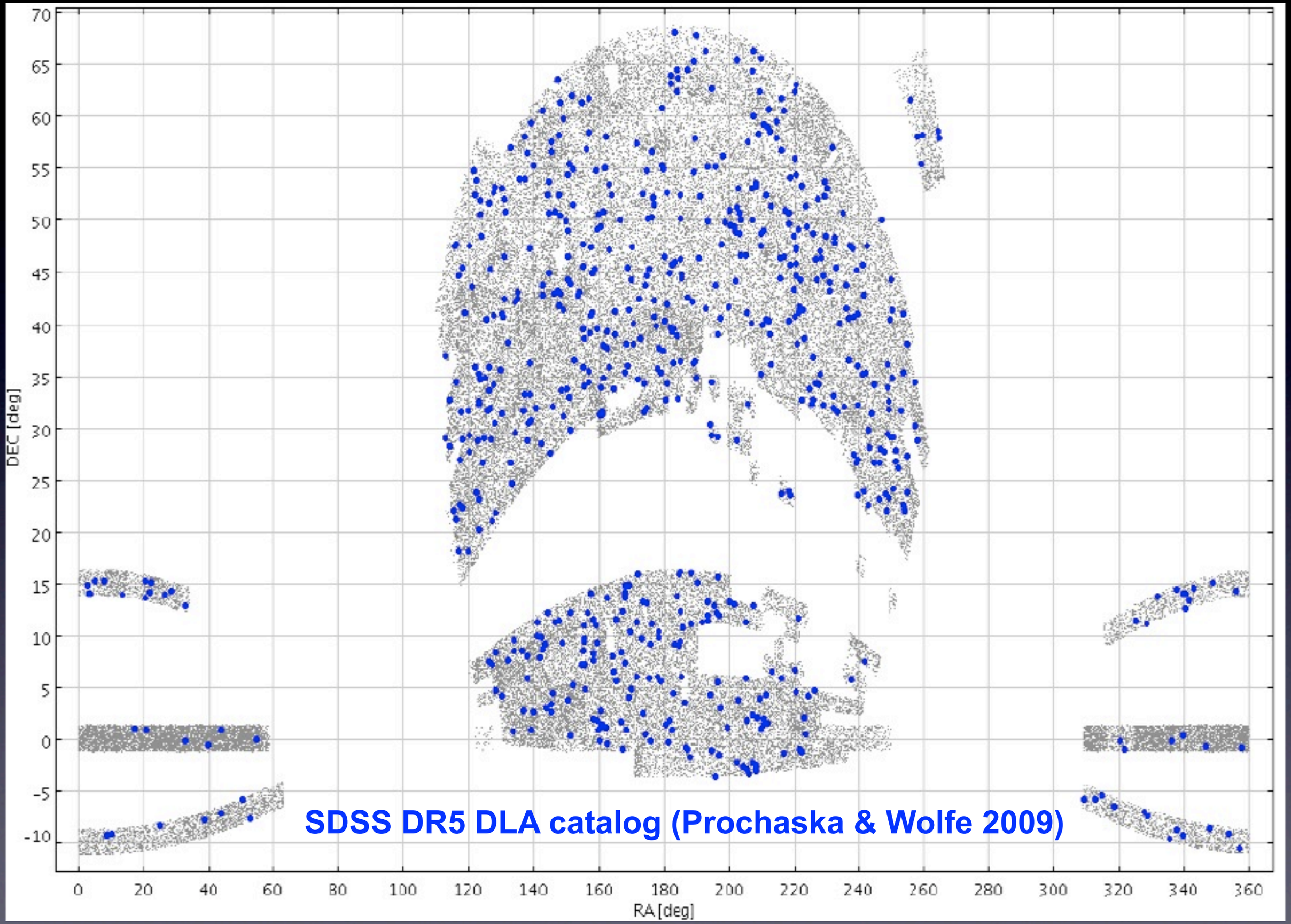
SDSS DR5 quasar catalog (Schneider et al. 2007)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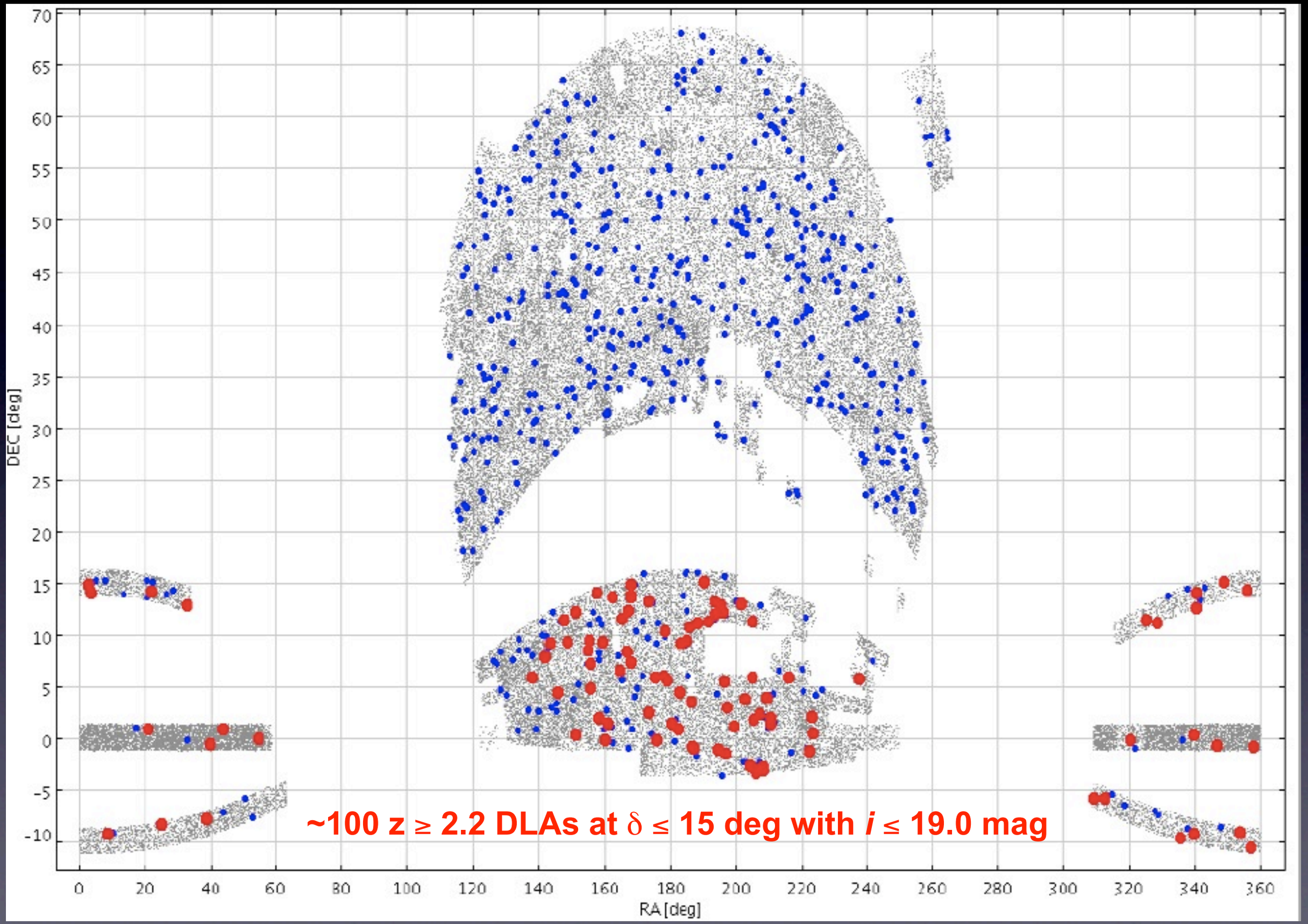
SDSS DR5 DLA catalog (Prochaska & Wolfe 2009)



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Magellan Uniform DLA Survey Results

- 86 DLAs with searchable H_2 spectra
- Main Result: Only 1 (previously known) H_2 absorber found!
  - detection rate ~ 1%
    - Naive expectation = ~15 H_2 -bearing DLAs
      - 12/68 (18%) H_2 -bearing DLAs from Noterdaeme+08
    - Expected ~9 strong H_2 -bearing DLAs
      - 8/12 (~60%) of the N08 H_2 detections are above the general MagE H_2 sensitivity limit ($N(H_2) \geq 10^{18}\,cm^{-2}$)
      - Given that we only detect 1, this is a 3σ deviation from the expected result.

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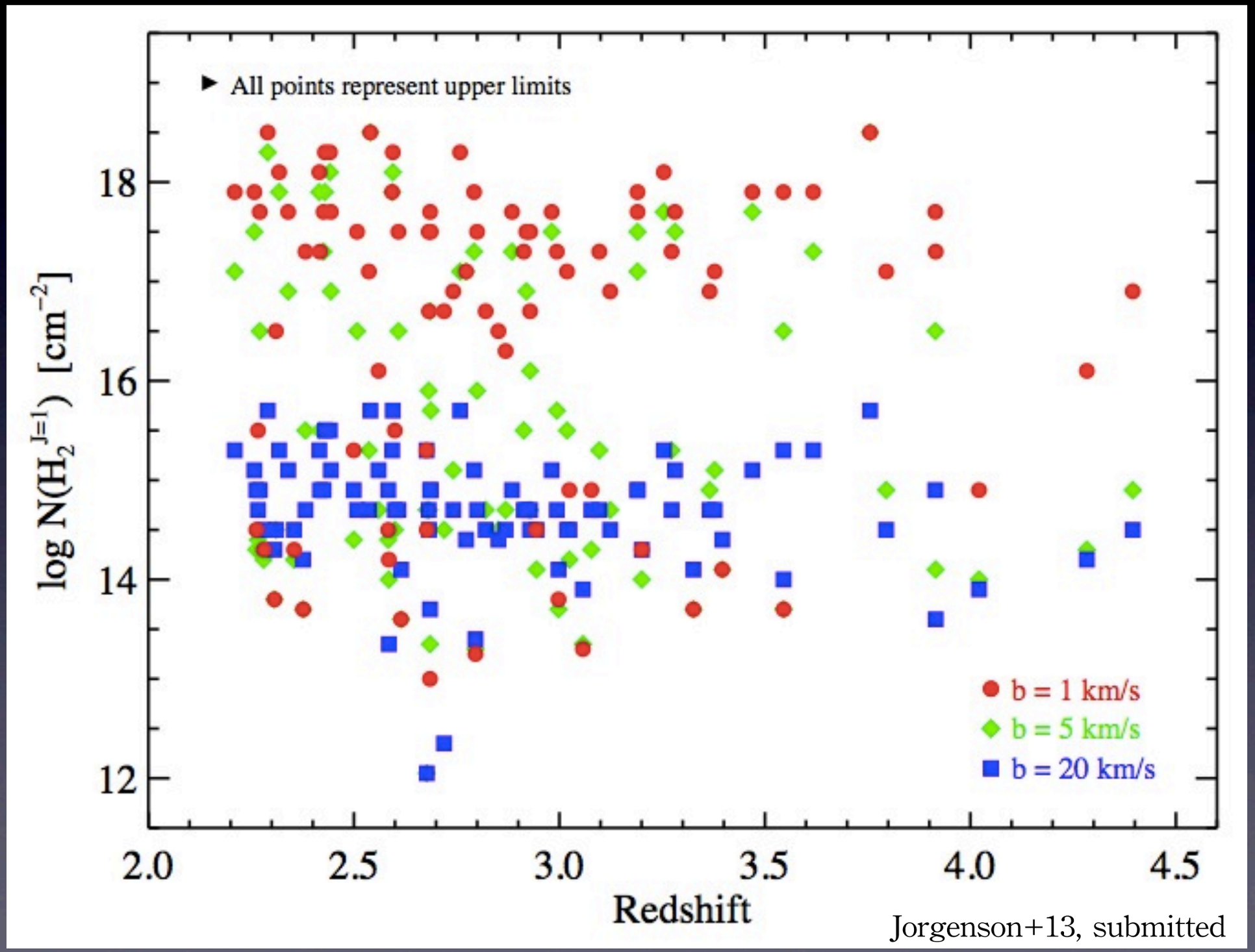
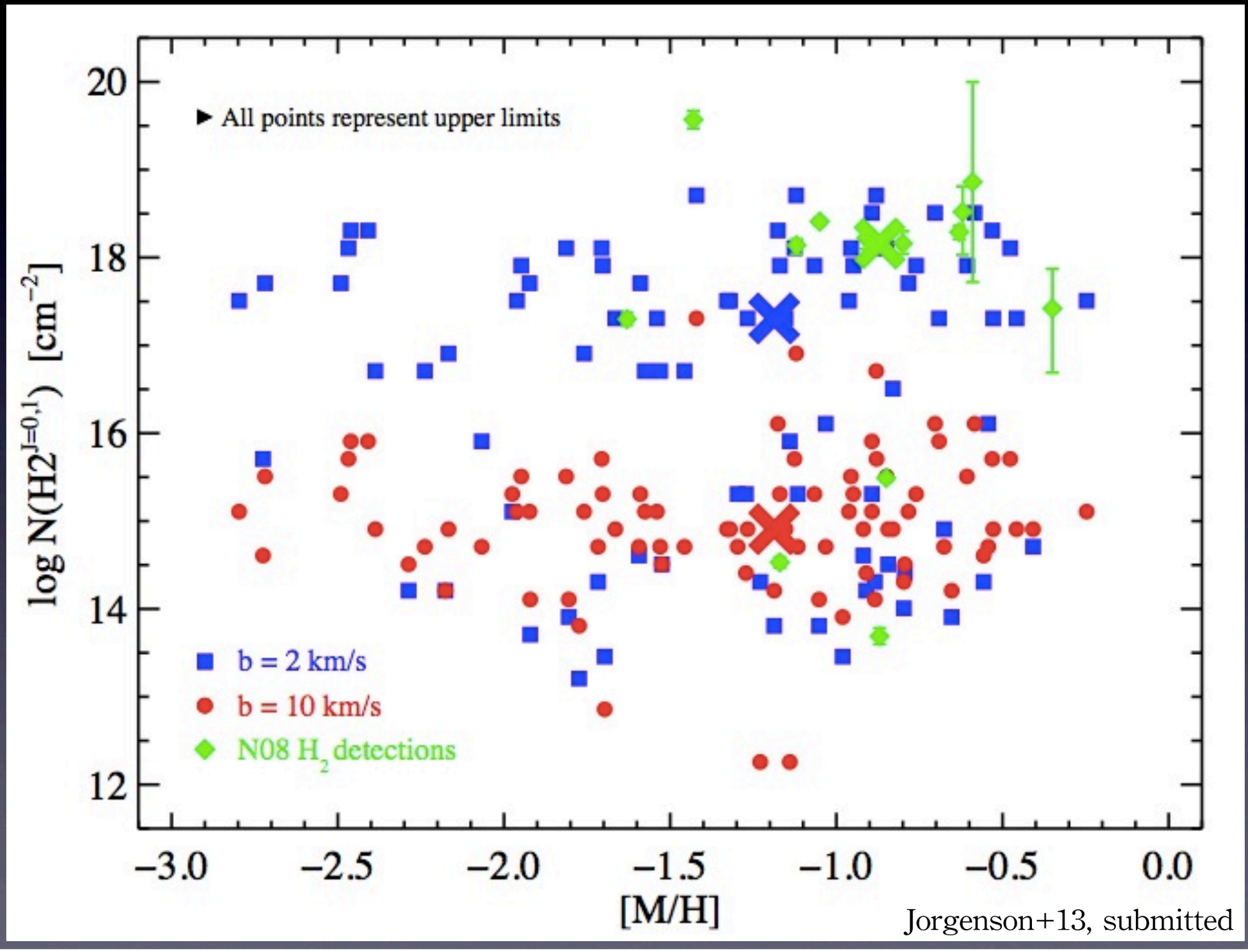
H_2 upper limits depend on assumed Doppler parameter (b)



Jorgenson+13, submitted

Magellan sample < $N(H_2)$ upper limit> for conservative b=2 km/s is 0.85 dex less than N08



Jorgenson+13, submitted

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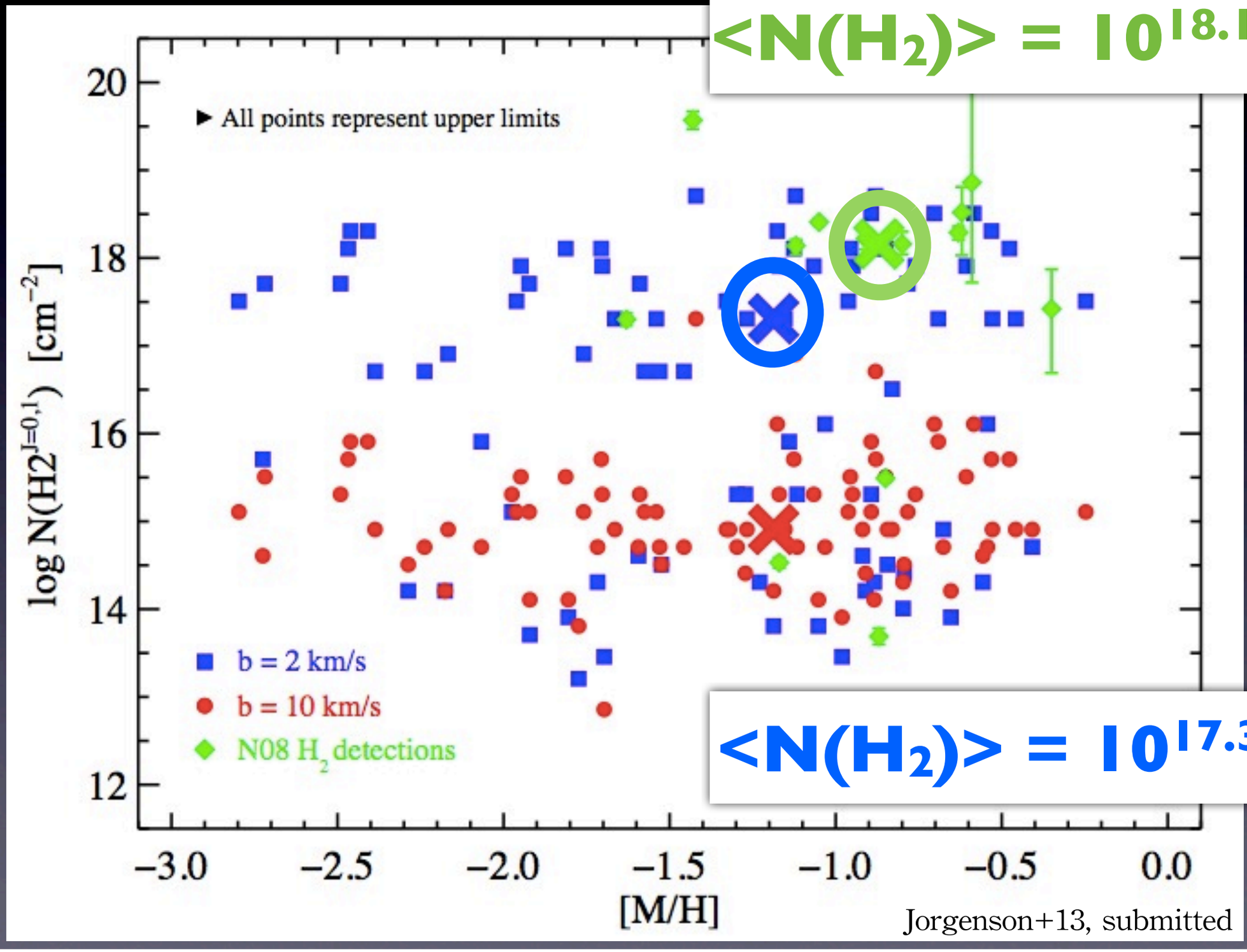
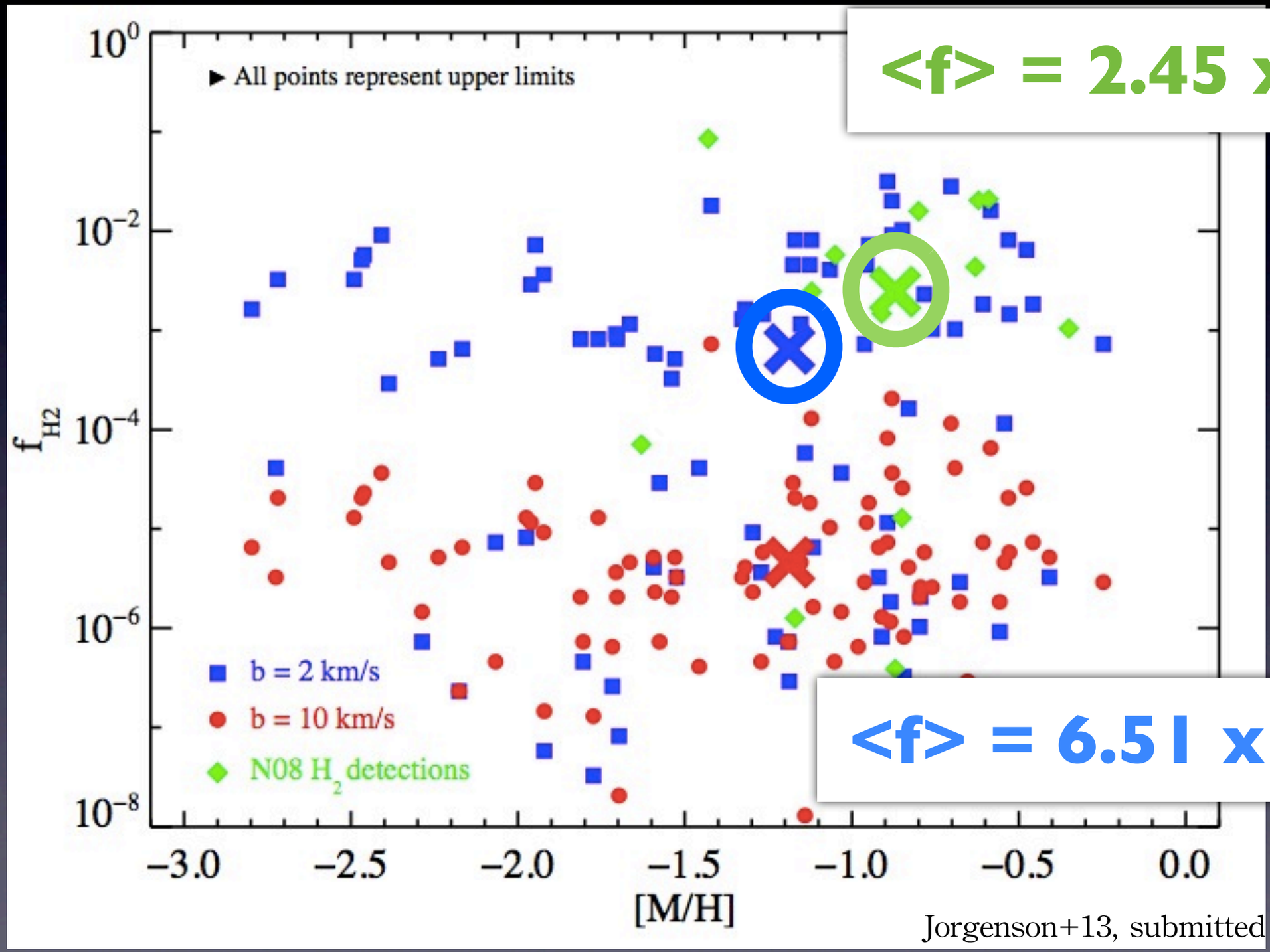
$\langle N(H_2) \rangle = 10^{18.16} cm^{-2}$



$\langle N(H_2) \rangle = 10^{17.3} cm^{-2}$

Jorgenson+13, submitted

Similar result for molecular fraction, $f \equiv 2N(H_2) / [2N(H_2) + N(HI)]$ ~3.7 times less

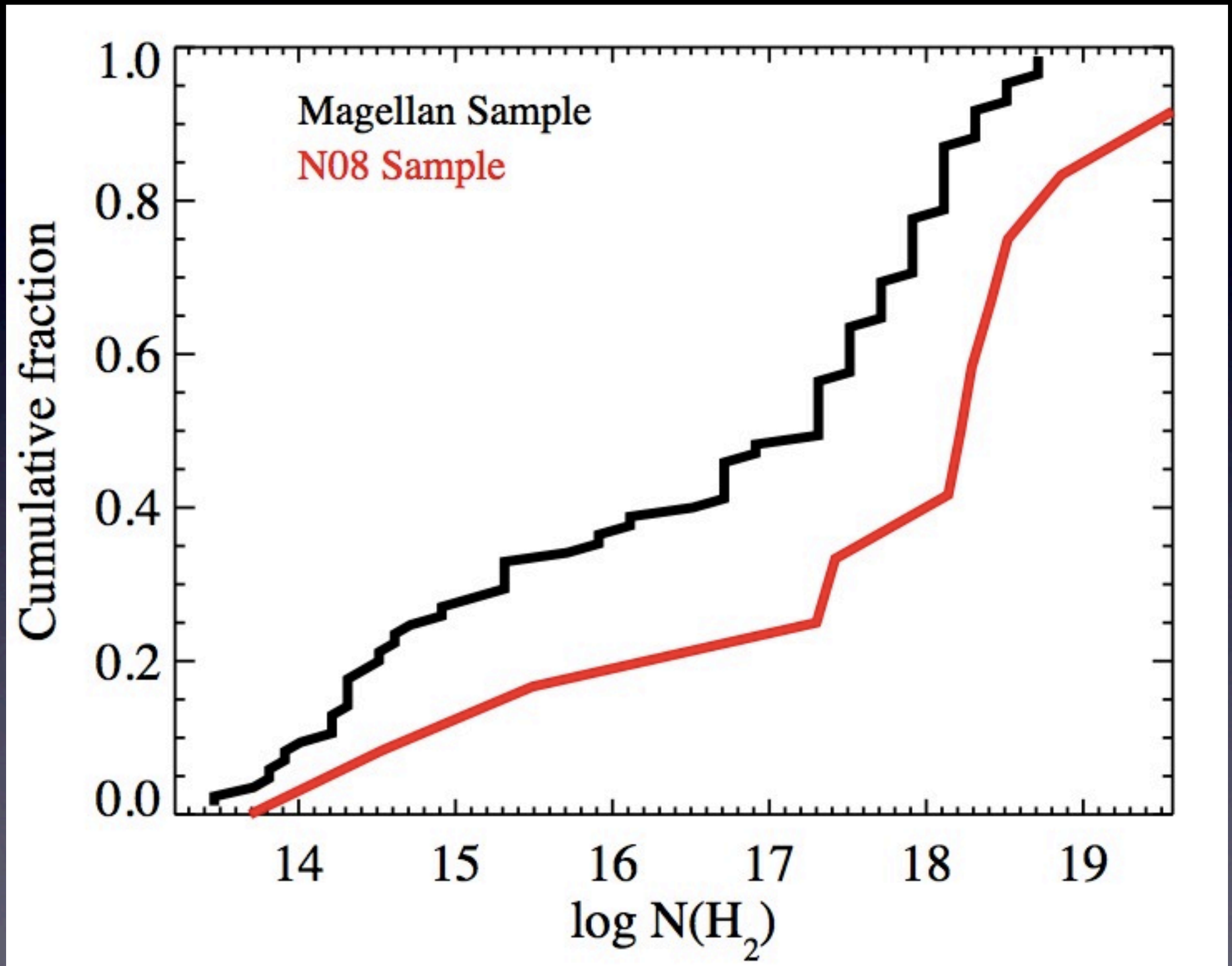


<f> = 2.45 x 10⁻³

<f> = 6.51 x 10⁻⁴

Jorgenson+13, submitted

Cumulative Distribution confirms result



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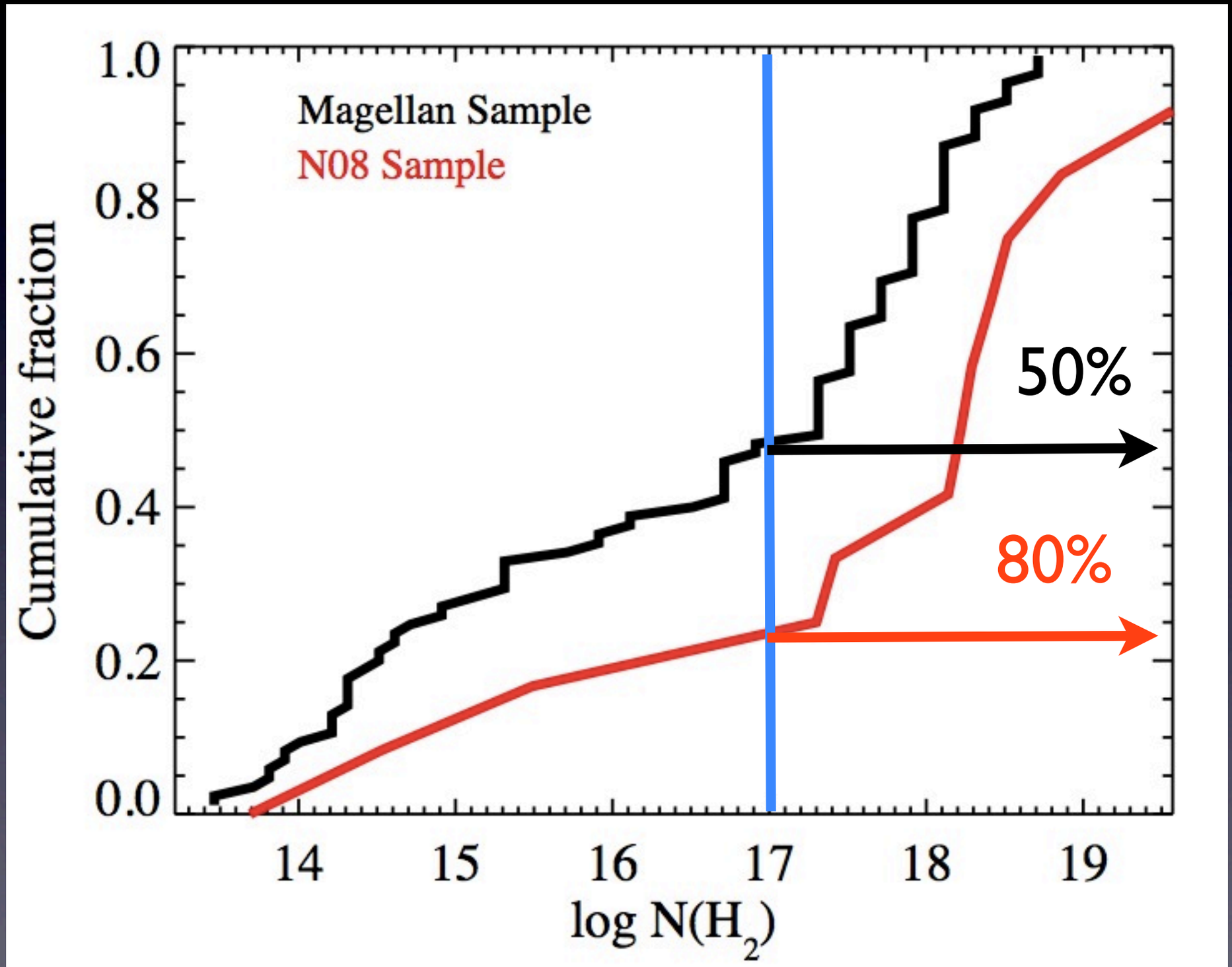
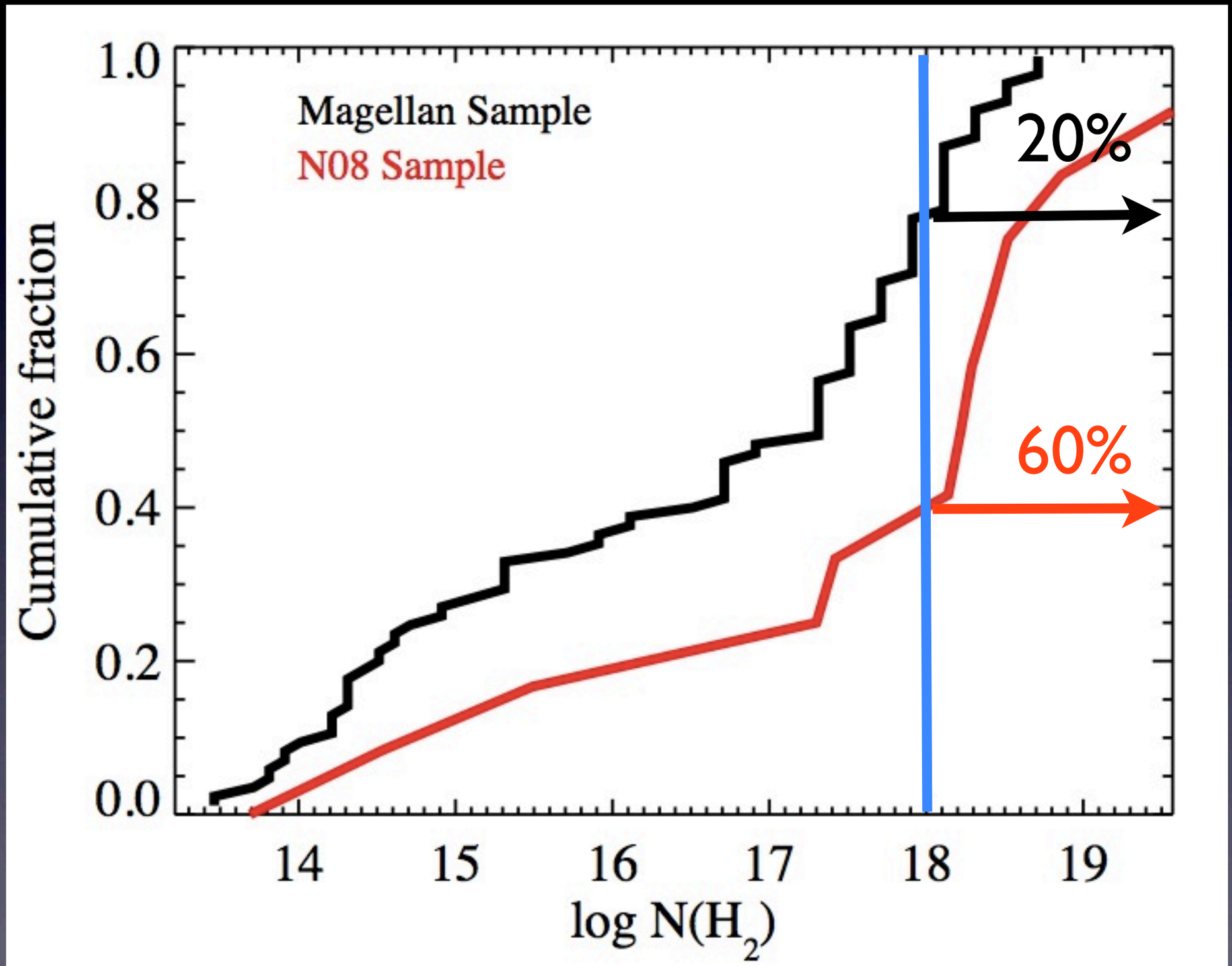
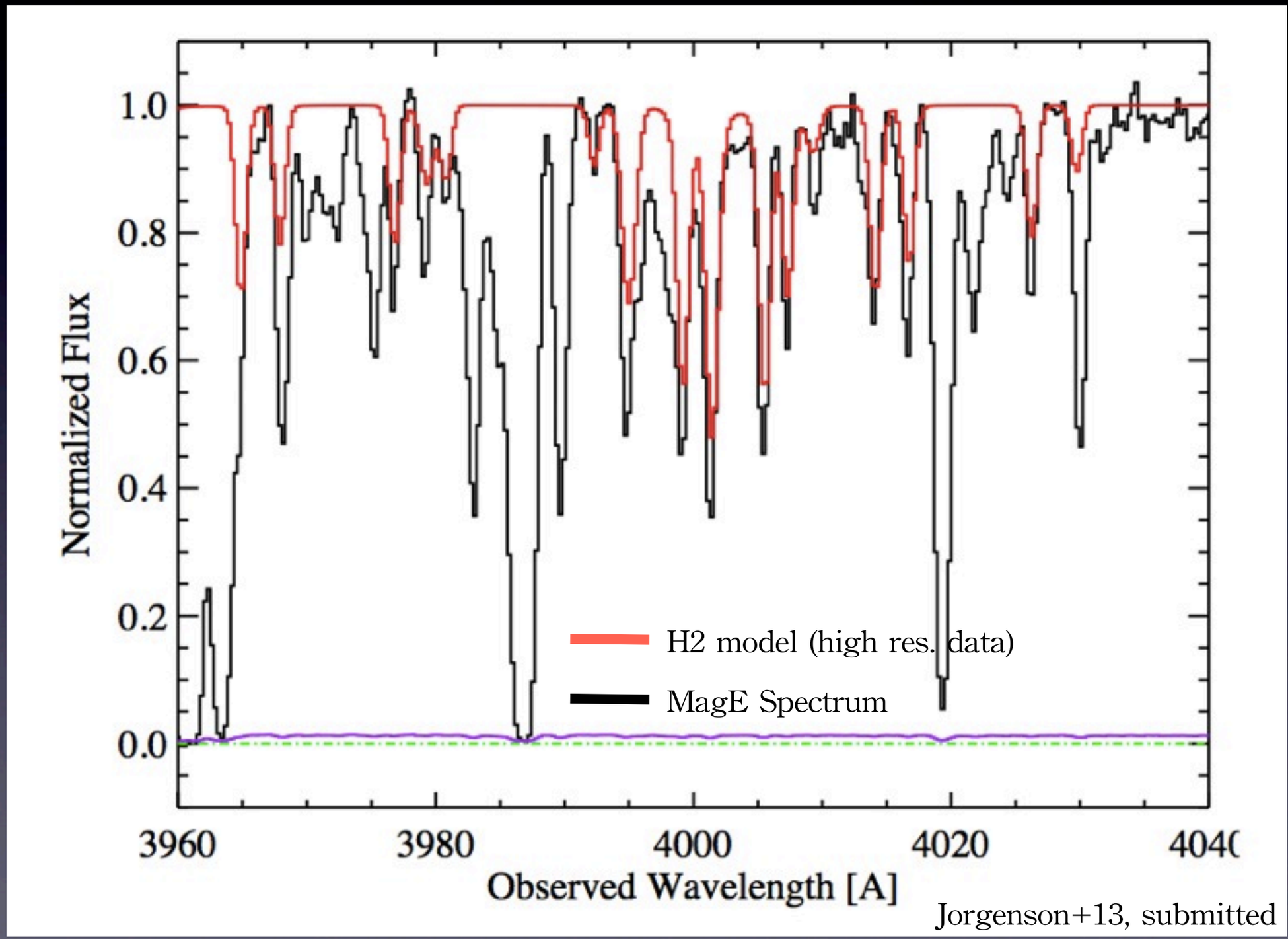


Cumulative Distribution confirms result



Did we detect known H_2? (yes!)



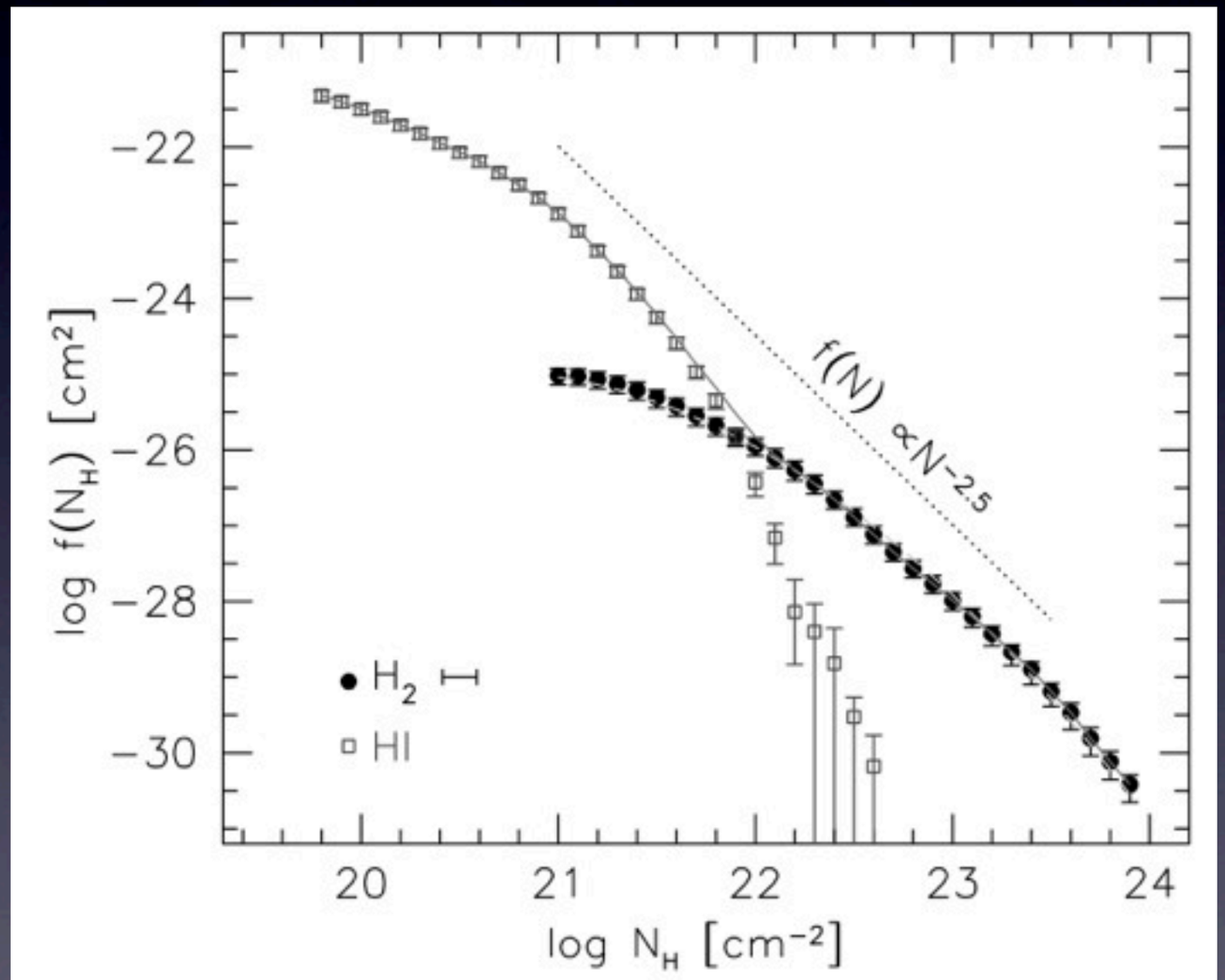
Jorgenson+13, submitted

Local Comparisons

- H_2 detected in most sightlines through MW (Wakker+06)
- H_2 detected in >50% of Magellanic cloud sightlines (Shull+00, Welty+12)
- Average H_2 fractions are typically 10% for MW and 1% for Magellanic Clouds (Tumlinson+02, Welty+12)

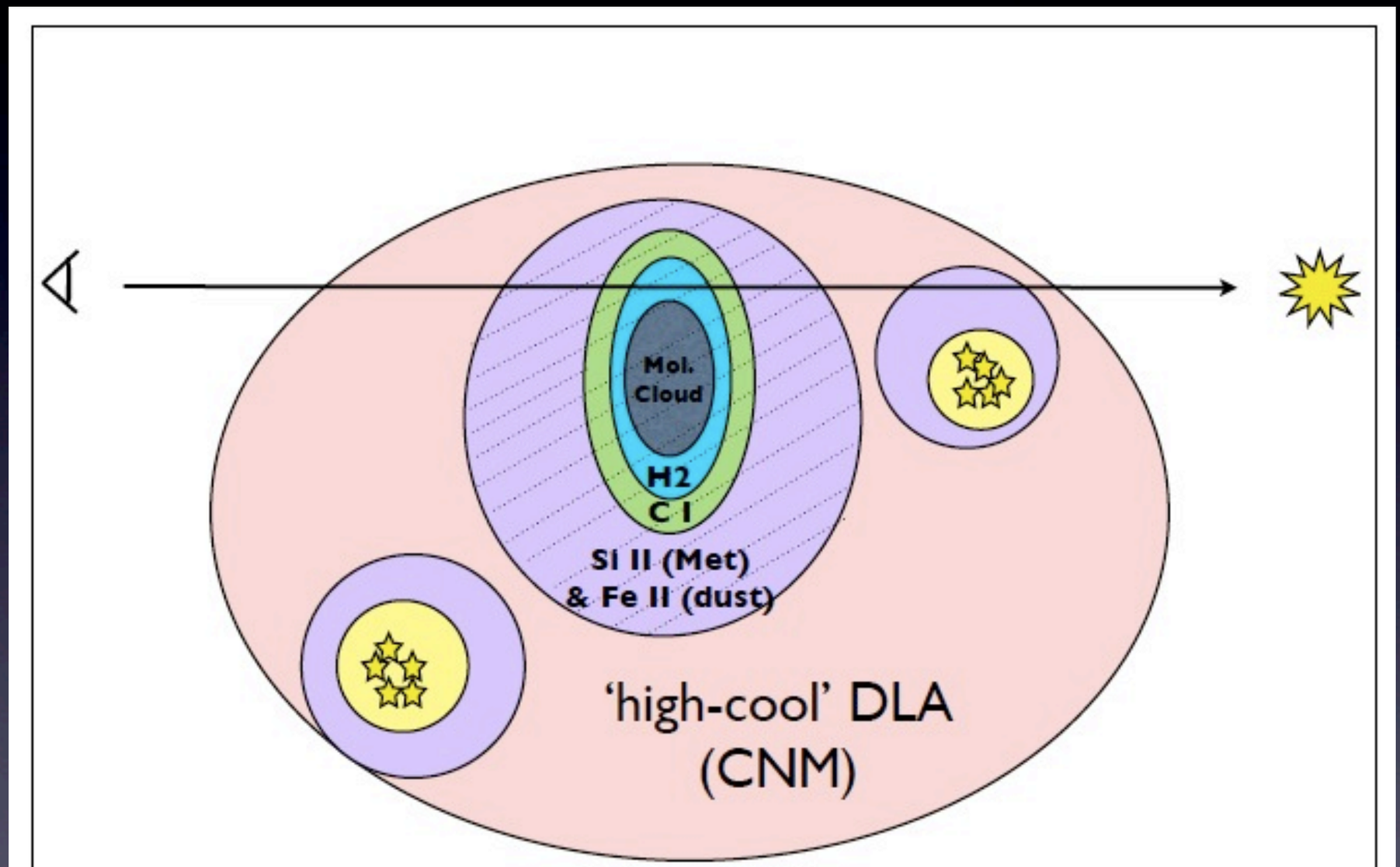
Where is the H_2 in DLAs?

- Zwaan & Prochaska, 2006
  - used CO maps of local galaxies
    - 97% of the H_2 mass is in systems with $N(H_2) > 10^{21} cm^{-2}$
  - Much of it may be in much higher column density systems that also have small impact parameters, small covering factors and high dust content



Zwaan&Prochaska 2006

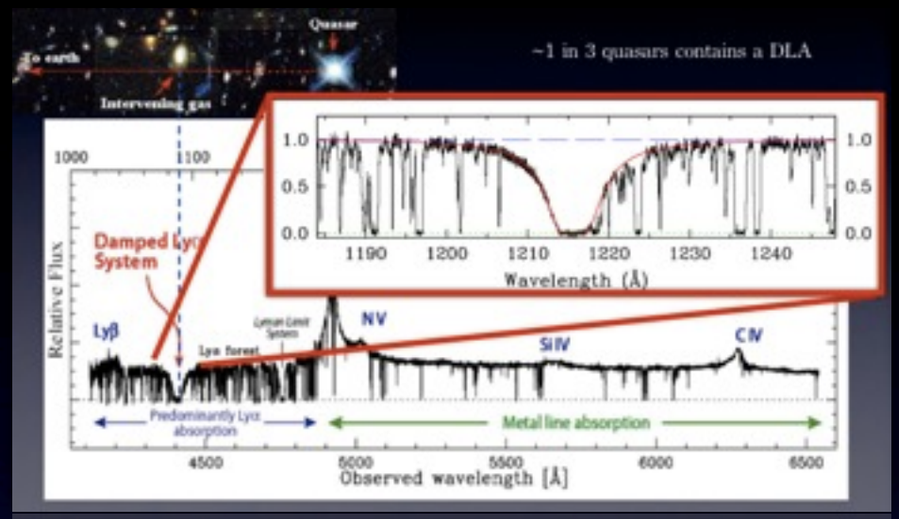
DLA cartoon model

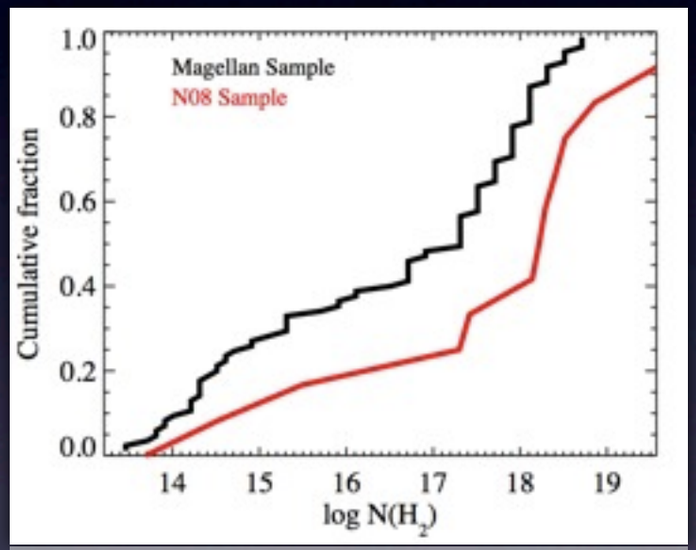


Jorgenson, in prep

Summary

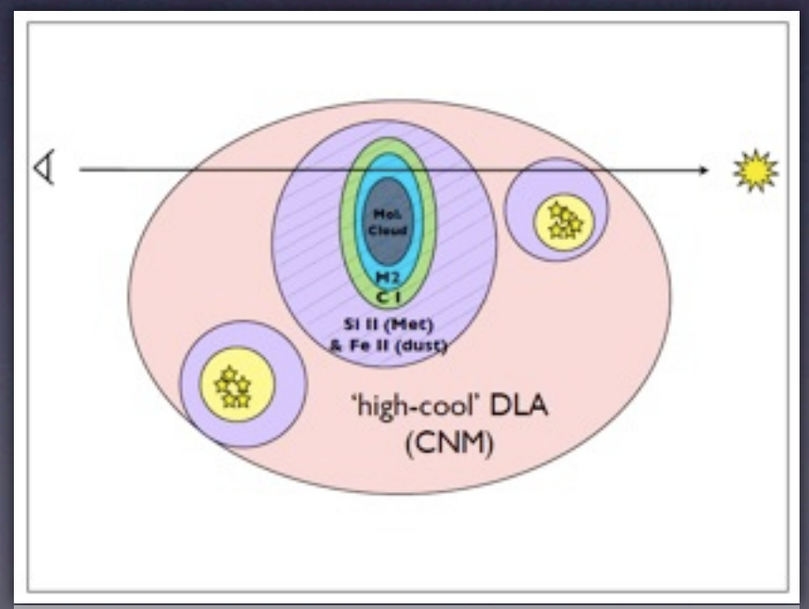
At high redshifts DLAs serve as important neutral gas reservoirs for star formation





H_2 content (covering factor and fraction) in DLAs less than expected from previous (biased) samples, more likely ~1 – 5%

H_2 most likely confined to cold, dense `clouds' with small covering factor, likely associated with PDR-type regions



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