``ABSORBING'' GALAXIES

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Outline

- Science from radio absorption spectroscopy.
- Where we were: before GMRT and GBT.
- Where we are: Physical conditions in high-z DLAs.
- Where we'd like to be: The EVLA ...

Galaxy Evolution

- 21cm studies of intervening damped Lyman-α systems (DLAs) ⇨ Galaxy sizes, kinematics, spin temperatures.

(e.g. NK & Briggs 2004)

- 21cm studies of ``associated'' gas ⇨ Probes of the AGN environment; fuel for AGN activity ?

(e.g. Morganti et al. 2005)

- CO/OH/... studies ⇨ Conditions in molecular clouds.

(e.g. Wiklind & Combes 1997)

- Zeeman splitting ⇨ Magnetic fields in high-z galaxies.

(Wolfe et al. 2008)

Fundamental Constant Evolution

- 21cm redshifts vs. [Optical / OH / HCO^+] redshifts.

(e.g. Wolfe et al. 1976)

- ``Conjugate'' satellite OH lines.

(Darling 2004; NK et al. 2004)

The situation in early 2002 (pre-GMRT, GBT)

- Three DLAs at $z > 1$ with confirmed 21cm absorption. Few high-z non-detections. Covering factor issues ?

  (e.g. Wolfe et al. 1981, 1985; Carilli et al. 1996)

- Two ``associated'' 21cm absorbers at $z > 1$.

  (Uson et al. 1991; Moore et al. 1998)

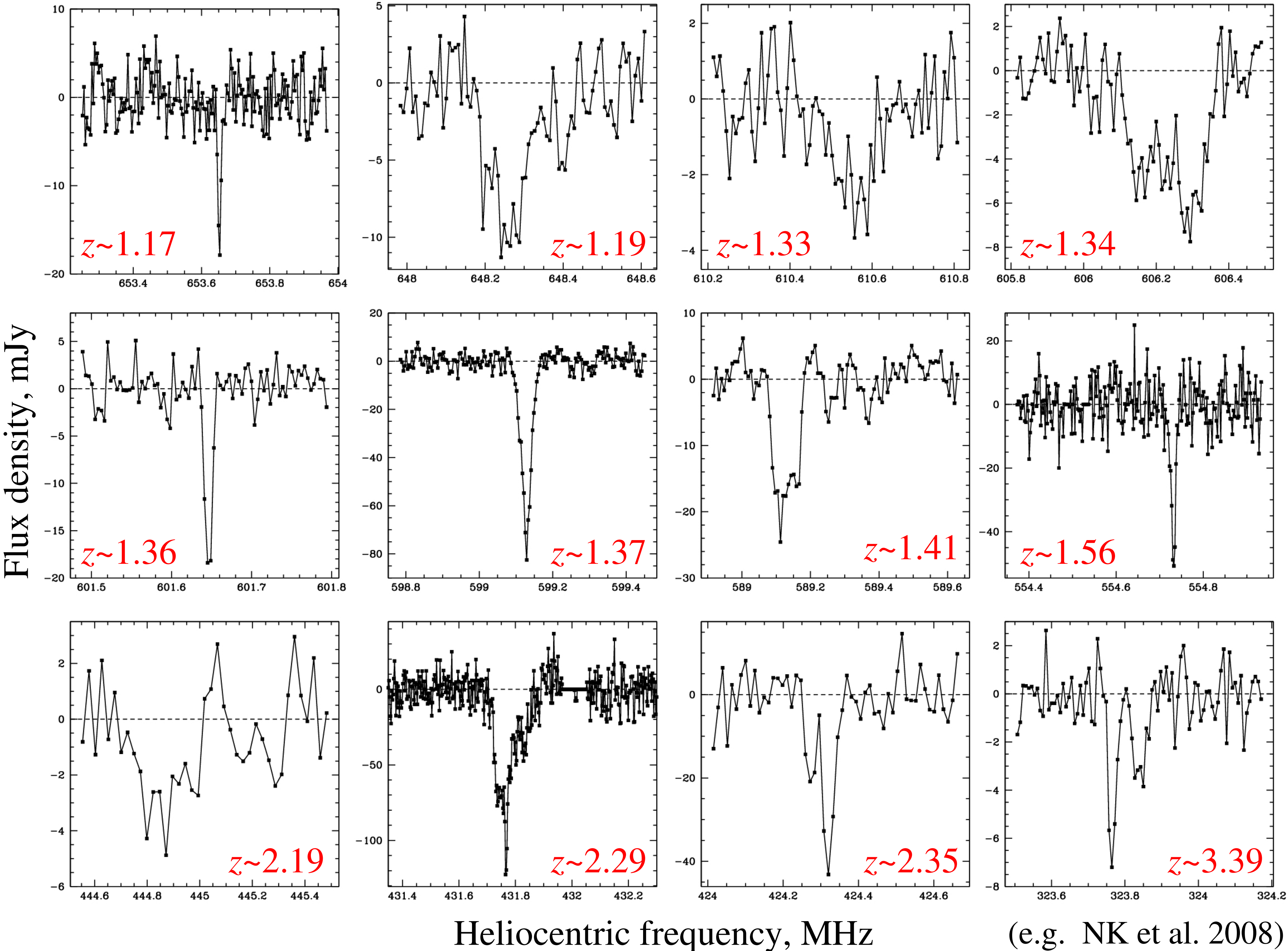
- One redshifted OH 1667 / 1665 absorber at $z > 0.1$.

  (Chengalur et al. 1999)

- No direct 21cm mapping studies, although sizes of two DLAs inferred indirectly. (Briggs et al. 1989, 2001)

- Few studies of changing constants, all with large systematic errors.

  (e.g. Wolfe et al. 1976; Carilli et al. 2000)



(e.g. NK et al. 2008)

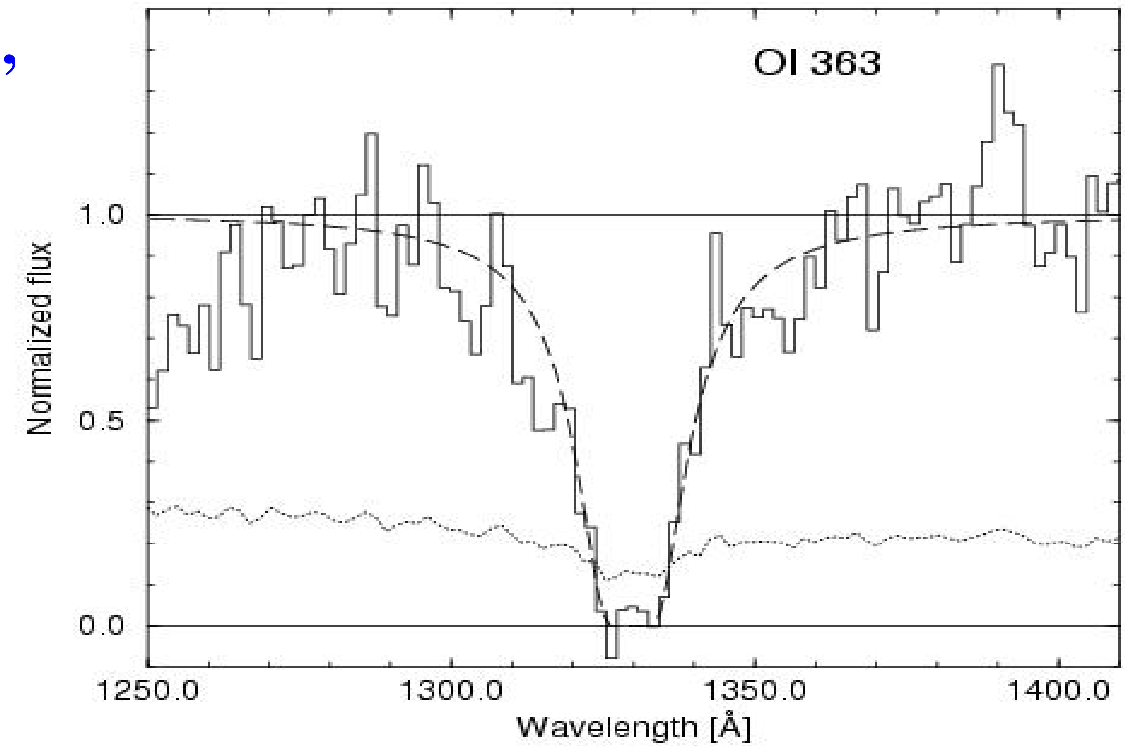
Today

- ~ 20 DLAs at $z > 1$ with detected 21cm absorption; > 20 strong optical depth limits. (York et al. 2007; Gupta et al. 2007; Srianand et al. 2008; NK et al. 2006, 2007, 2008)
- Six redshifted OH 1665/1667 absorbers, all at $z < 1$. (Darling & Giovanelli 2002; NK & Chengalur 2002; NK et al. 2003, 2005)
- Two ``conjugate'' satellite OH systems, at $z < 1$. (Darling 2004; NK et al. 2004, 2005)
- Two DLAs with 21cm mapping studies, at $z \sim 0.4$. (NK & Chengalur 2008)
- OH lines ⇨ Strong constraints on changes in α, μ, g_p. (Darling 2004; NK et al. 2004, 2005, 2008)
- One magnetic field estimate, at $z \sim 0.692$. (Wolfe et al. 2008)

Galaxy Evolution: Damped Lyman-α Systems

(e.g. Wolfe et al. 1986, 2005)

- High HI column density, $N_{HI} \geq 2 \times 10^{20}$ cm^{-2}.
- Absorption-selected ⇨ No luminosity bias.
- ``Normal'' gas-rich galaxies at high z.



- Optically-selected samples ⇨ Dust bias issues ?

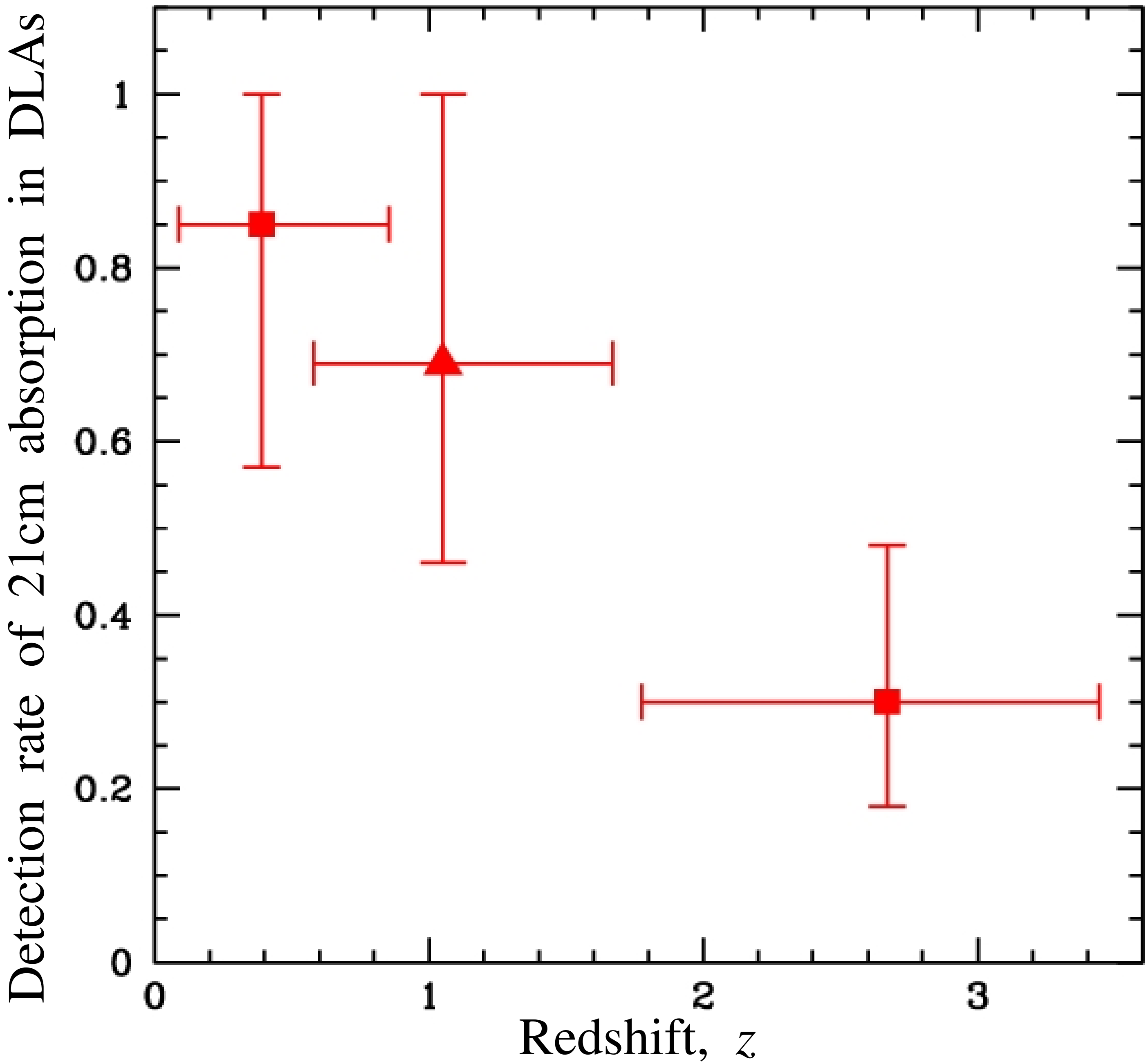
(Ellison et al. 2001; Jorgenson et al. 2006)

- Low metallicities, < 0.1 solar at $z > 2$.

What galaxies are DLAs at different redshifts ?

Typical mass, kinematics, metallicity, gas temperature ?

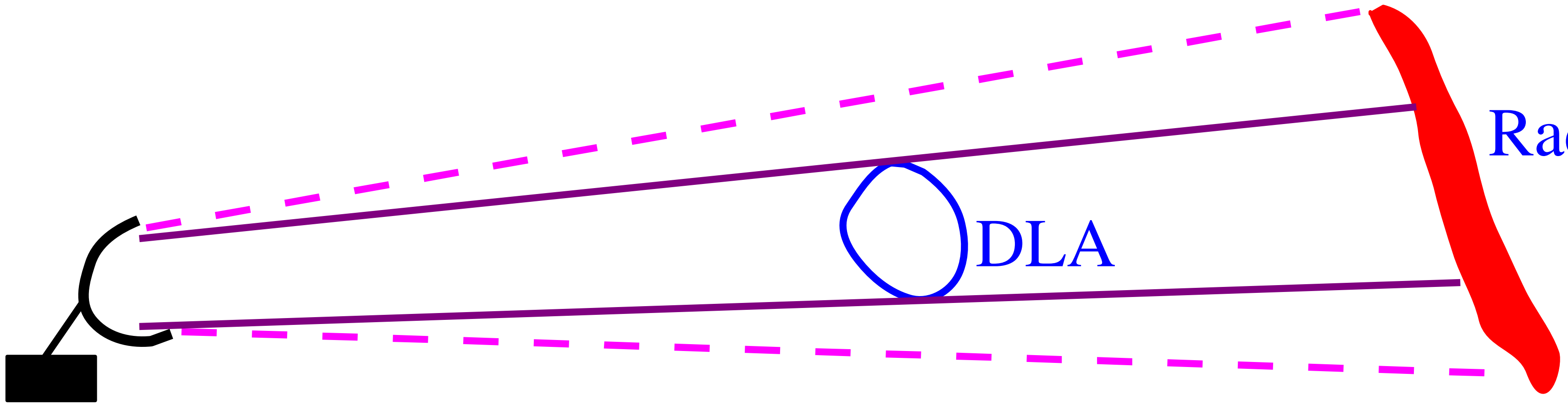
(NK et al. 2008)



- Significant amounts of cold HI in DLAs by $z \sim 1$.

21cm absorption studies: DLA spin temperatures

- For DLAs towards radio-loud quasars :

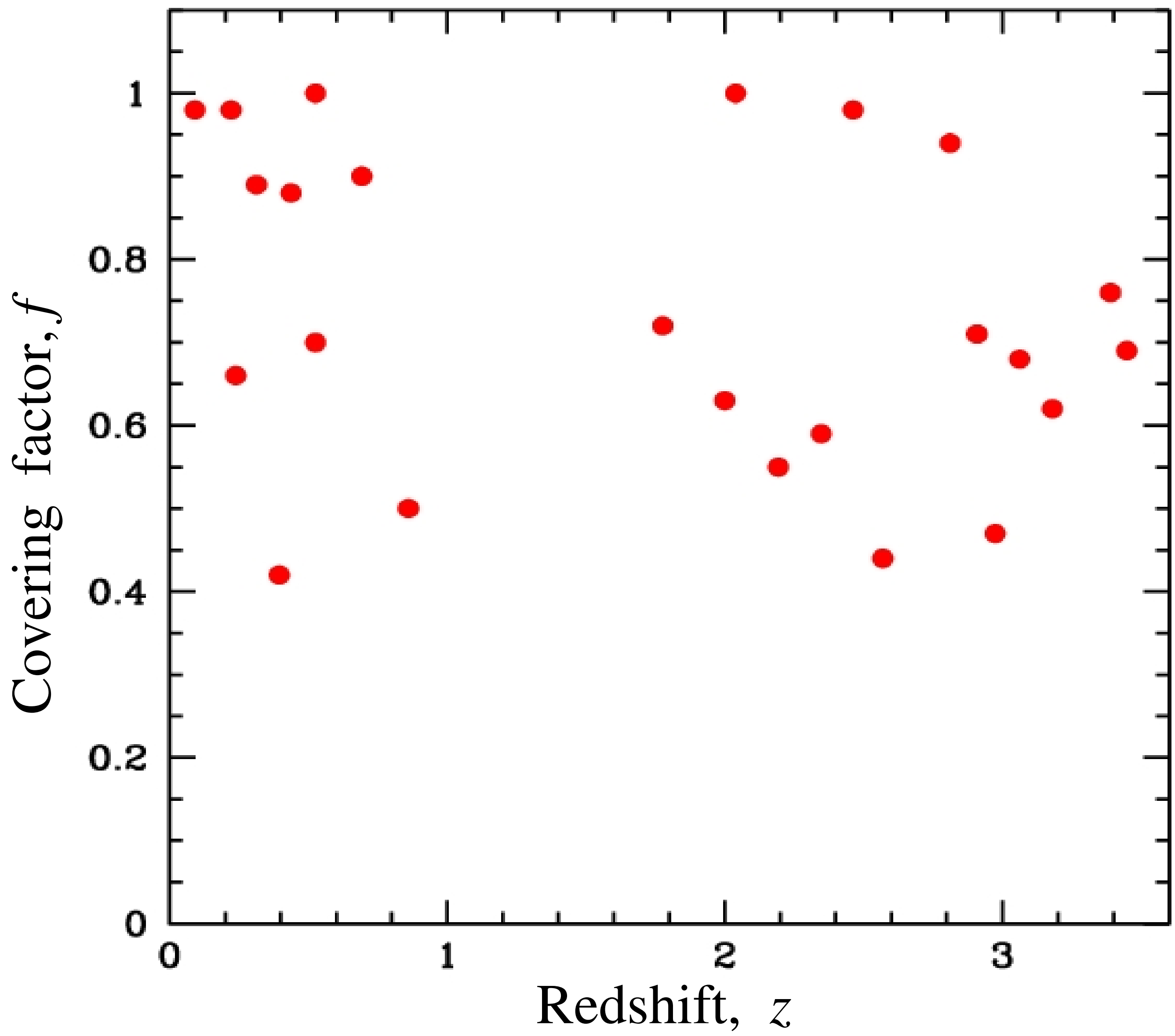


$$\int \tau_{21} dv \propto N_{HI} \times [f / T_s]$$

$T_s \equiv$ 21cm excitation temperature; $f \equiv$ covering factor.

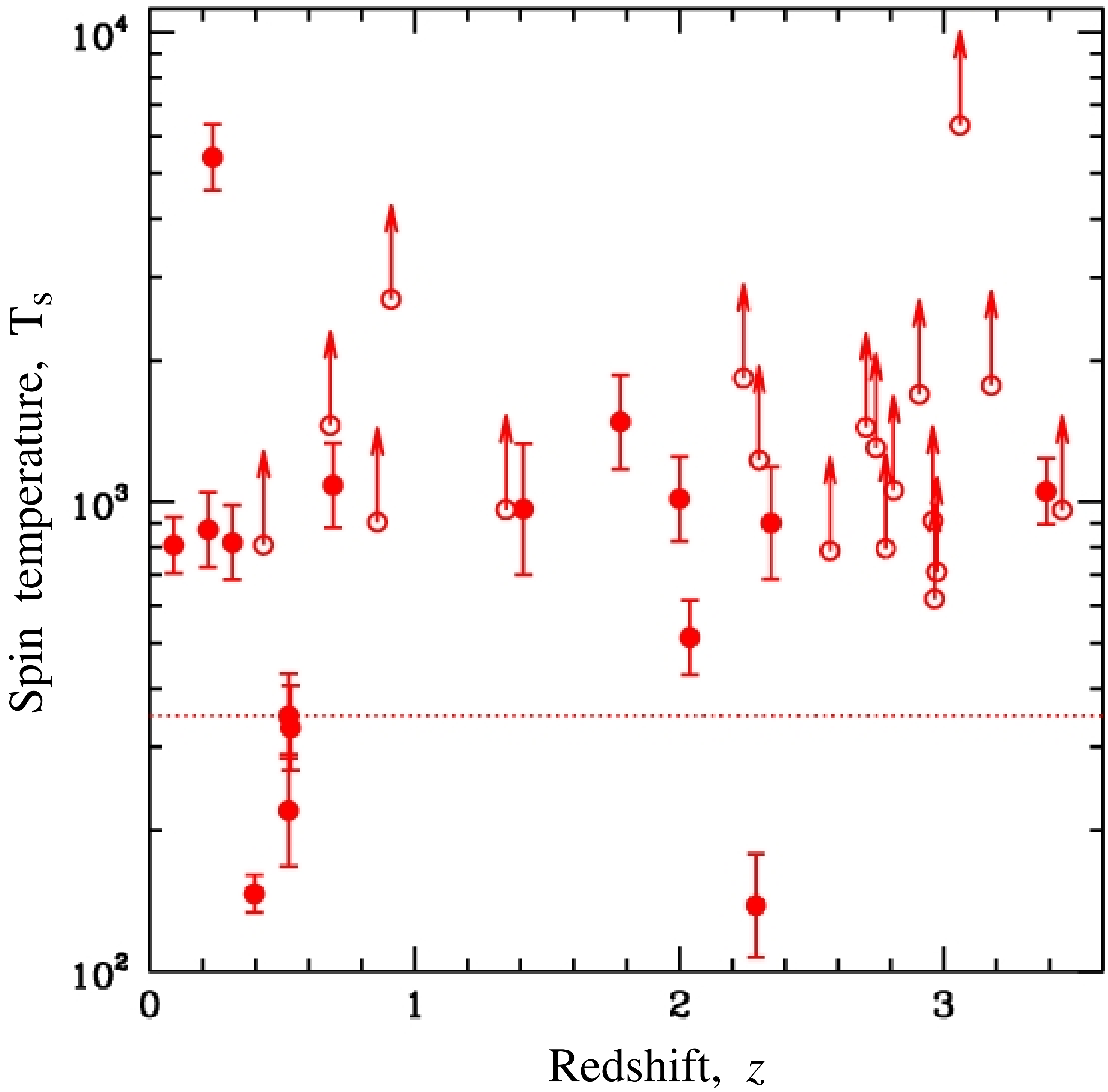
- For DLAs, N_{HI} is measured from the Lyman-α line.
- Low 21cm optical depths ⇨ Low covering factors or high spin temperatures in high-z DLAs.

VLBA @ 327 MHz ⇨ DLA covering factors



⇨ Similar covering factors at all redshifts, $0.4 < f < 1$.

⇨ Covering factor effects are not significant. (NK et al. 2008)



(NK et al. 2008)

High spin temperatures in high-z DLAs ?

- Multi-phase gas: Measured T_S is the harmonic mean of T_S values of different phases, weighted by N_{HI}.

$T_{CNM} \sim 100$ K ⇨ $n_W \sim n_C \sim 0.5$ ⇨ $T_S \sim 200$ K.

$T_{WNM} \sim 8000$ K ⇨ $n_W \sim 0.9$, $n_C \sim 0.1$ ⇨ $T_S \sim 1000$ K.

- Phase distribution depends on metallicity, pressure. Higher metallicity, pressure ⇨ More CNM ⇨ Low T_S.

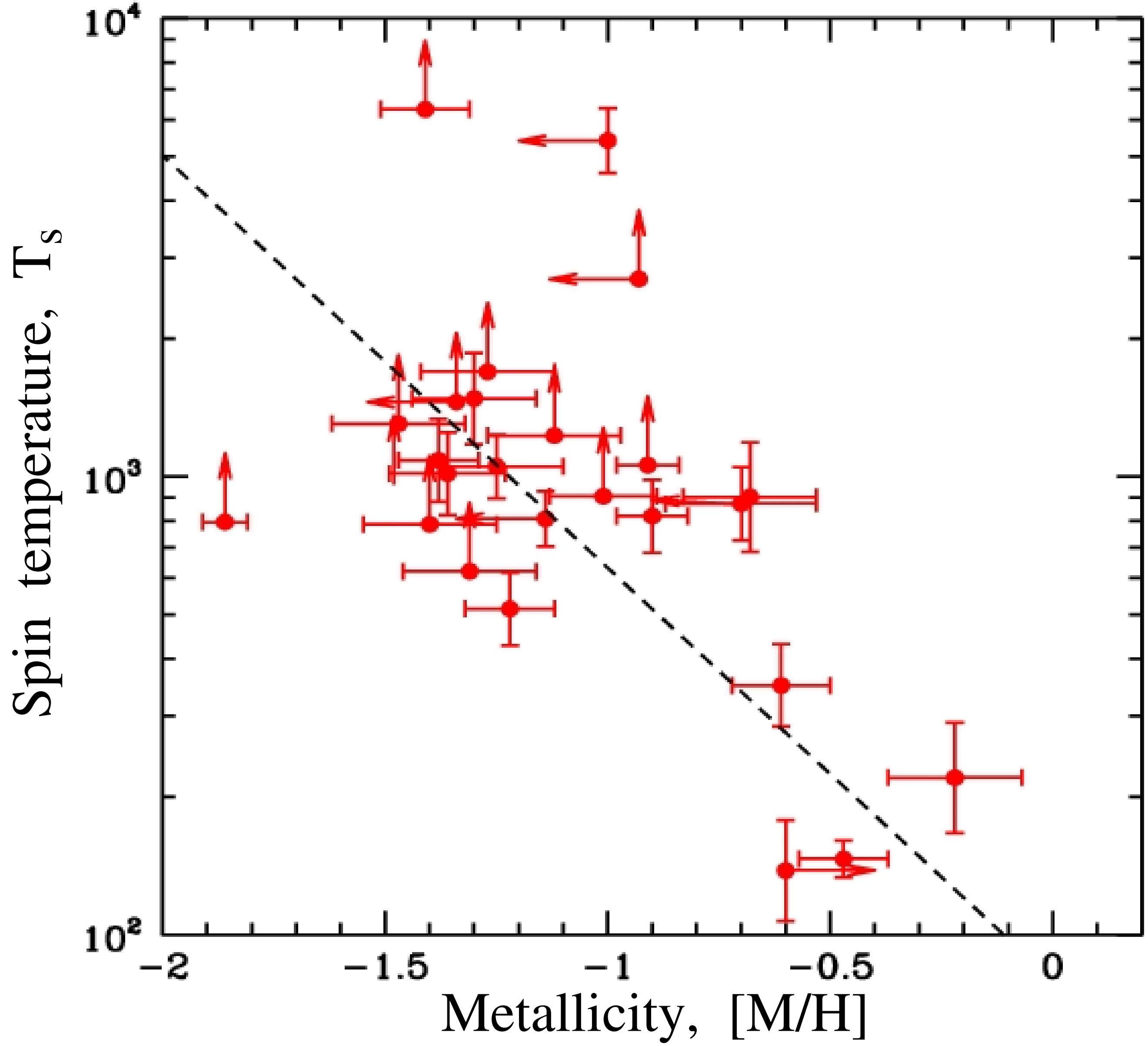
(Wolfire et al. 1995, 2003)

- Dwarfs ⇨ Low pressure, star formation, metallicity. ⇨ More WNM ⇨ High T_S. (Chengalur & NK 2000)

- Expect an anti-correlation between metallicity and T_S.

(NK & Chengalur 2001)

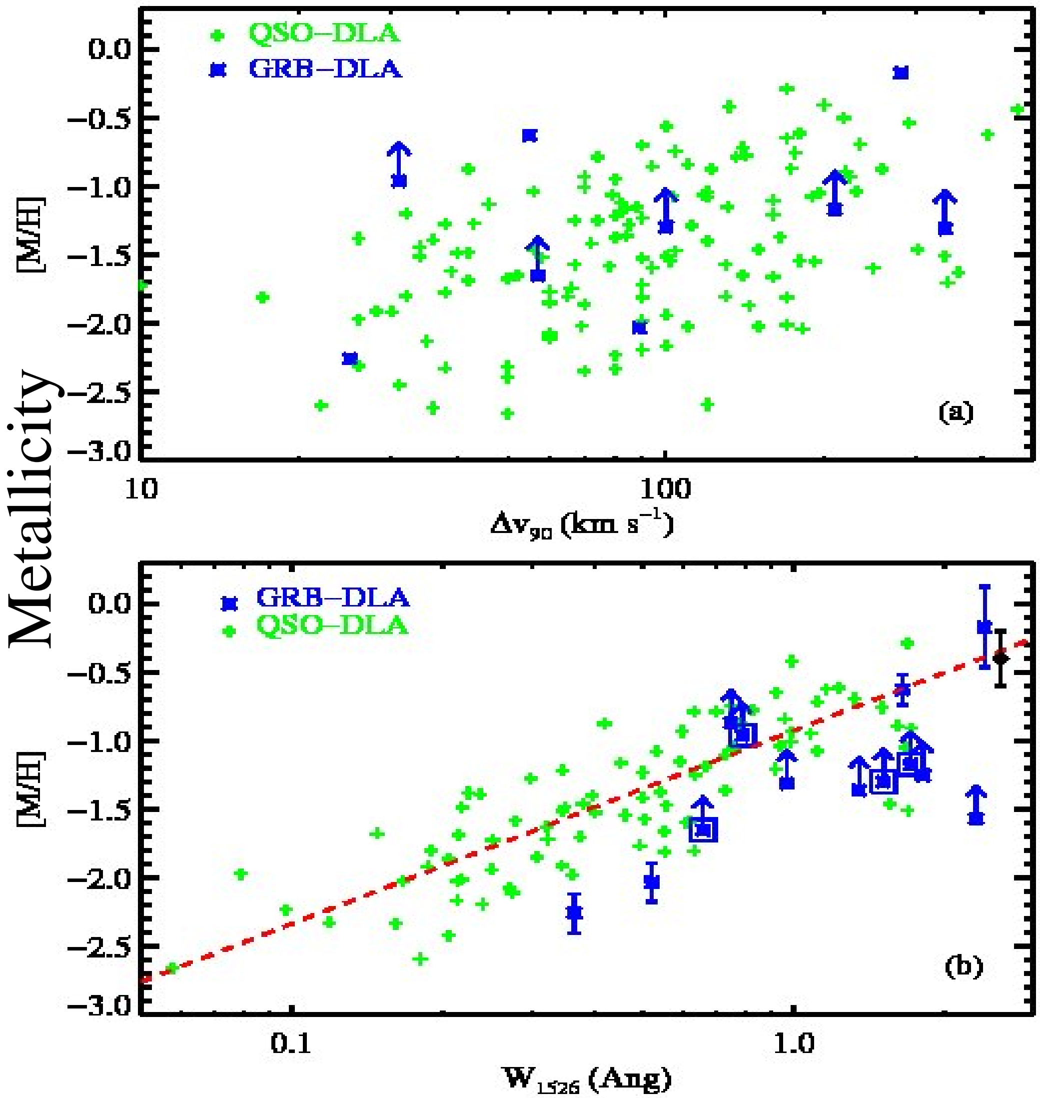
(NK et al. 2008)

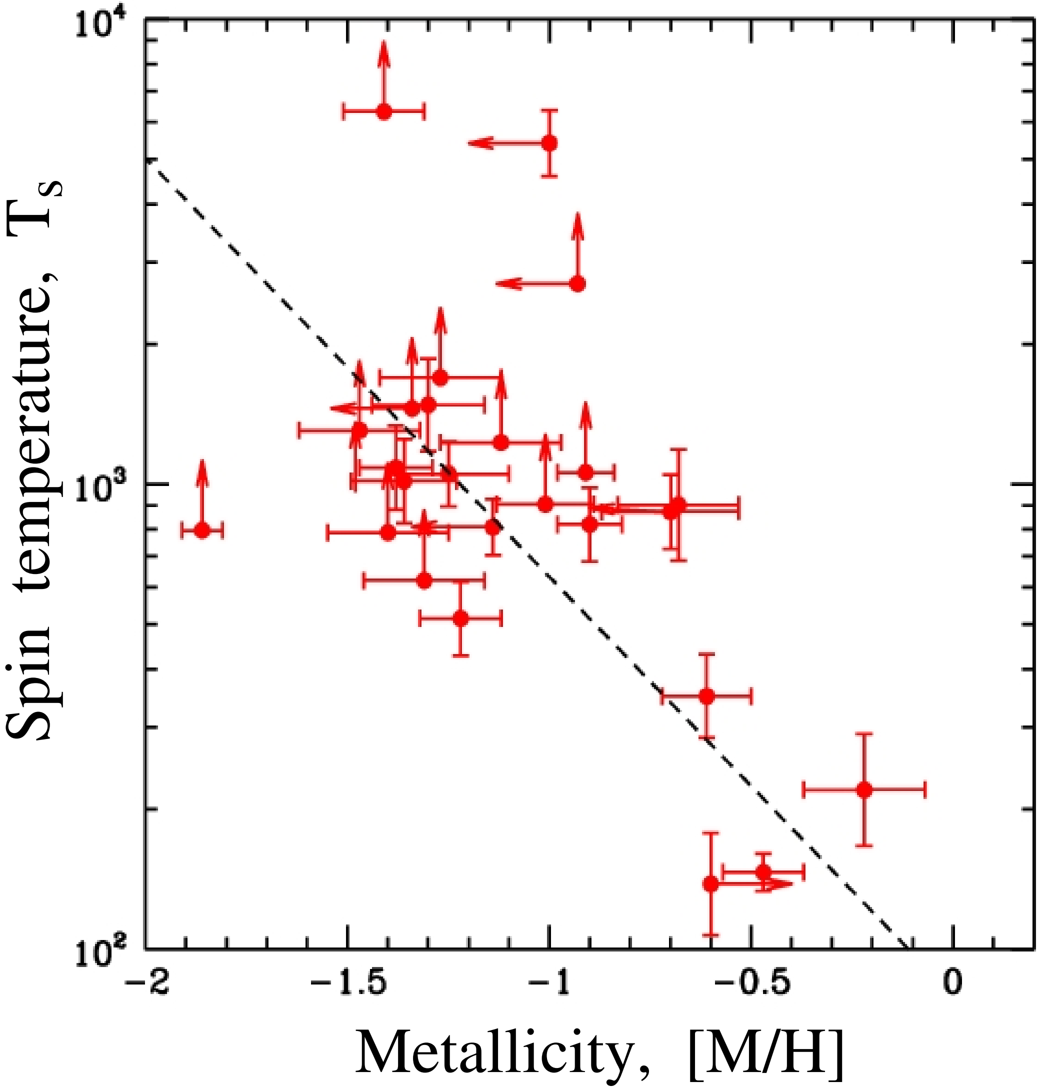


- Anti-correlation between T_S and [M/H] ⇨ High T_S values due to low metallicities, lack of cooling routes.
- Most $z > 2$ DLAs have [M/H] < -1, and thus, high T_S.

Mass-metallicity relation ? T_S - [M/H] anti-correlation

(Prochaska et al. 2007) (NK et al. 2008)

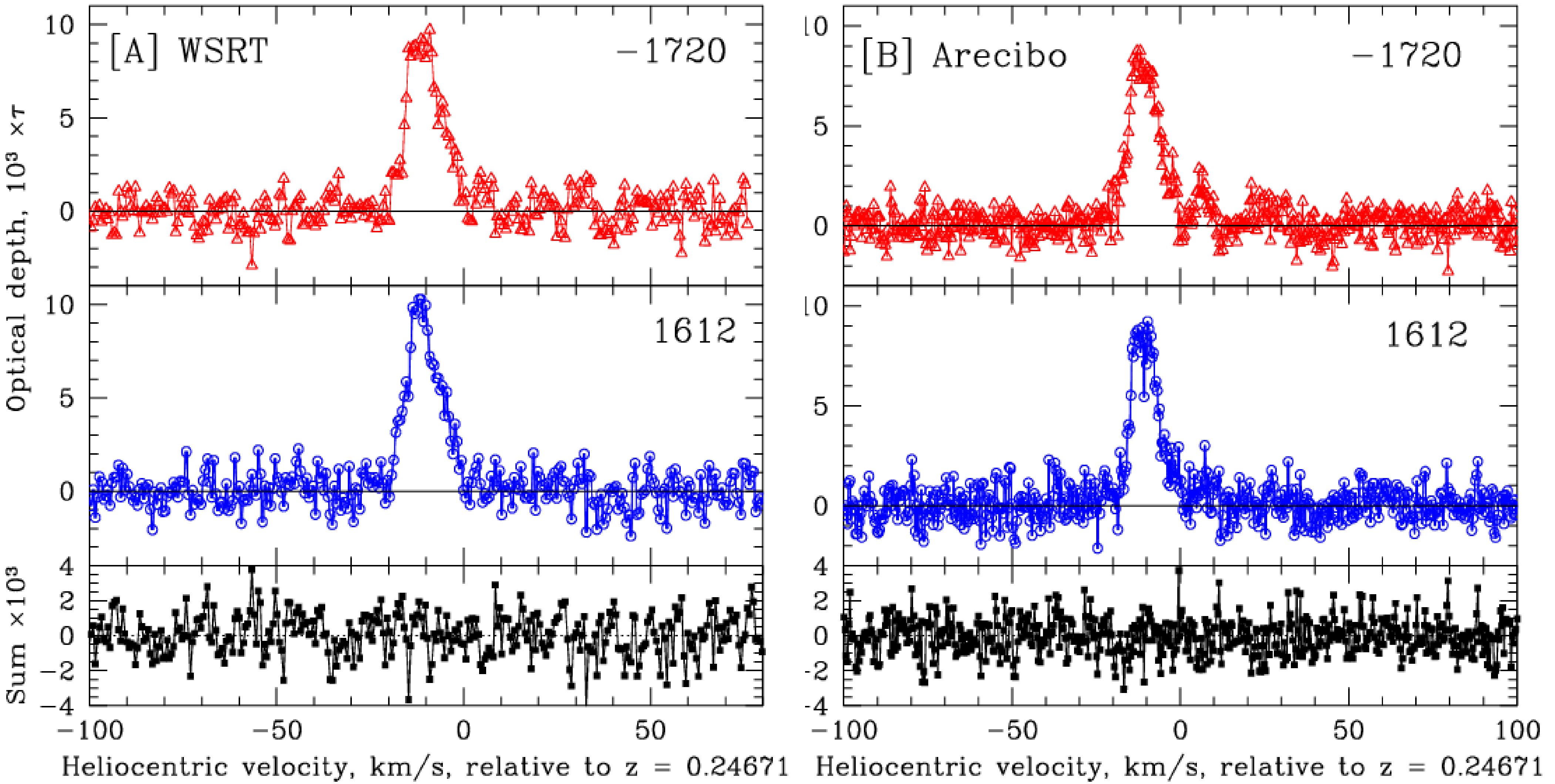




- Consistent picture if high-*z* DLAs are typically small galaxies, with low SFR, metallicity and CNM fraction.

``Conjugate'' OH lines: 1413+135, $z \sim 0.25$ (NK et al. 2008)

WSRT: 58 hours **Arecibo: 40 hours**



- Conservatively :

$[\Delta\alpha/\alpha] < 3 \times 10^{-6}$ (2σ)

$[\Delta\mu/\mu] < 6 \times 10^{-6}$ (2σ)

Open Issues

- Few DLAs at $z < 1.7$ (~ 60 systems).

  Bias in optical DLA samples against dusty galaxies ?

  ``Blind'' 21cm absorption surveys.

- Very few molecular absorbers found so far.

  ⇨ Little known about molecular gas in high-z galaxies.

  ⇨ Few targets to probe evolution in the constants.

  ``Blind'' OH / CO absorption surveys.

- Mapping 21cm absorption in DLAs towards extended radio sources ⇨ Size, kinematics of high-z galaxies.

  Requires 21cm absorber samples towards radio galaxies and high angular resolution (100 - 200 km baselines).

The EVLA

- Uniform frequency coverage, 1 – 50 GHz; 8 GHz bandwidth; fantastic correlator !!!

- Every L-band continuum observation ⇨ Blind 21cm absorption survey at $z < 0.5$; OH at $z < 0.7$; H_2CO at $1.4 < z < 4.1$.

- Every S-band continuum observation ⇨ Blind H_2CO absorption survey at $0.2 < z < 1.4$.
  H_2CO optical depth > 1% for $N(HCO^+) > 10^{12}$ cm^{-2}.
  (Liszt & Lucas 1995)

- Blind 32 – 48 GHz survey ⇨ CO / HCO^+ at $z > 0.85$.

Blind EVLA 32 – 48 GHz survey

- CO, HCO^+: Strong rotational lines, nearby frequencies
  ⇨ One observing frequency covers two redshifts.

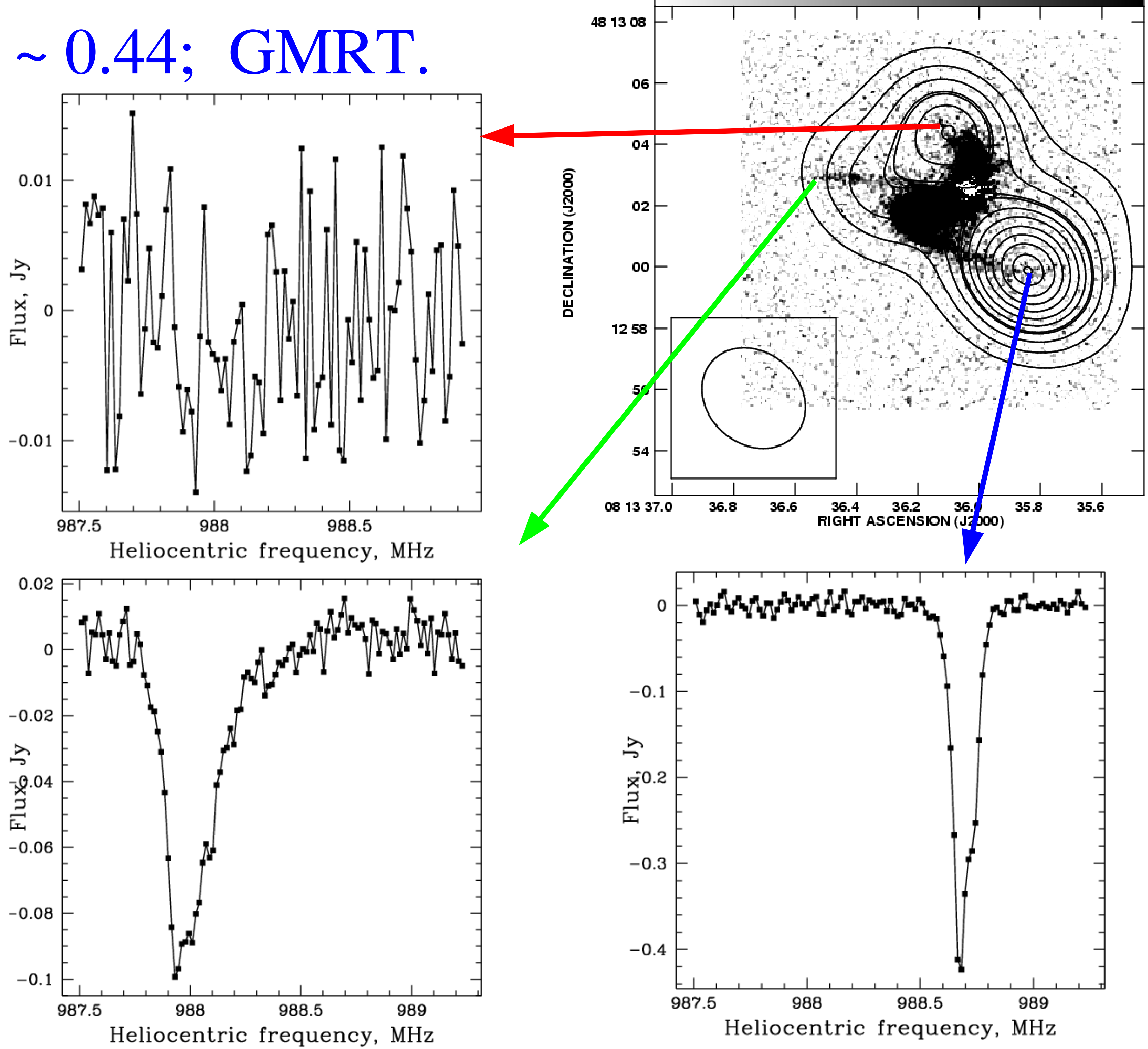
- 32 – 48 GHz ⇨
  HCO^+ 1 – 0 : $0.85 < z < 1.71$
  CO 1 – 0 : $1.40 < z < 2.60$
  HCO^+ 2 – 1 : $2.71 < z < 4.57$

- Blind 32 – 48 GHz survey ⇨ CO / HCO^+ at $z > 0.85$.

- 10m of EVLA@ Q-band ⇨ $N(CO) \sim 5 \times 10^{15}$ cm^{-2}
  against 200 mJy sources.

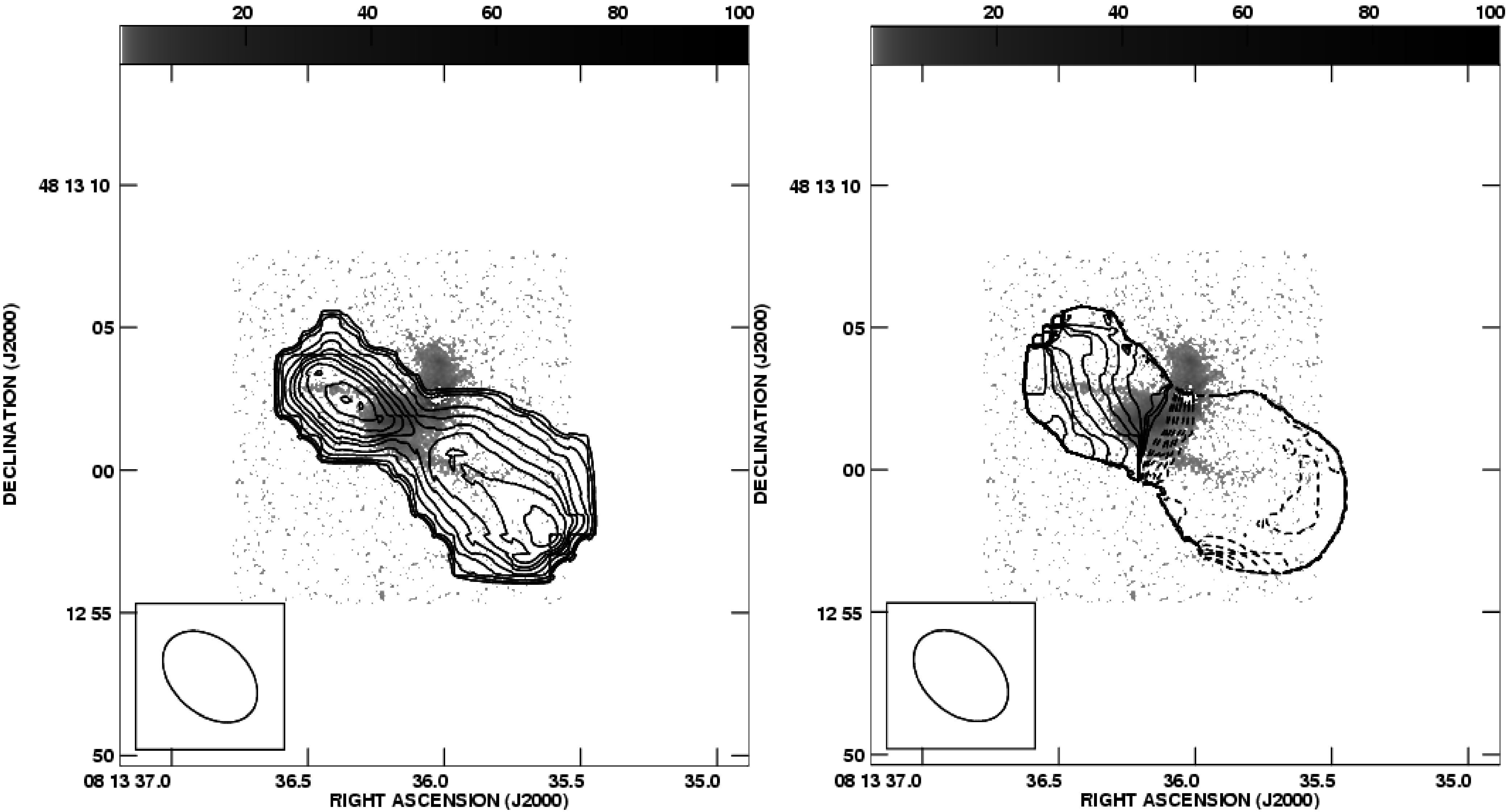
- Total redshift path $\Delta z > 200$ possible in < 100 hours.

3C196; $z \sim 0.44$; GMRT.



Mapping 21cm absorption in high-z DLAs

(NK & Chengalur 2008)



EVLA – II ??? Low frequencies + long baselines.

Summary

- Detection rate of 21cm absorption ~ 80% in $z < 1$ DLAs; detection rate ~ 30% in $z > 2$ DLAs.
- Low 21cm detection rates in high-z DLAs due to low fraction of cold HI and, thus, high spin temperatures. Probably due to low metallicities in high-z DLAs.
- Still very few redshifted radio absorbers (< 25 @ $z > 1$). Effects of dust bias unclear ⇨ Need radio surveys.
- The EVLA ⇨ Large ``blind'' surveys for CO / HCO^+ absorption at $z > 0.85$. 21cm surveys at $z < 0.5$.
- 21cm absorption-mapping studies ⇨ EVLA Phase - II !

Radio vs. Optical

(NK 2008)

- Comparable raw sensitivity, fewer systematics in radio. Relative isotopic abundances not an issue for OH.

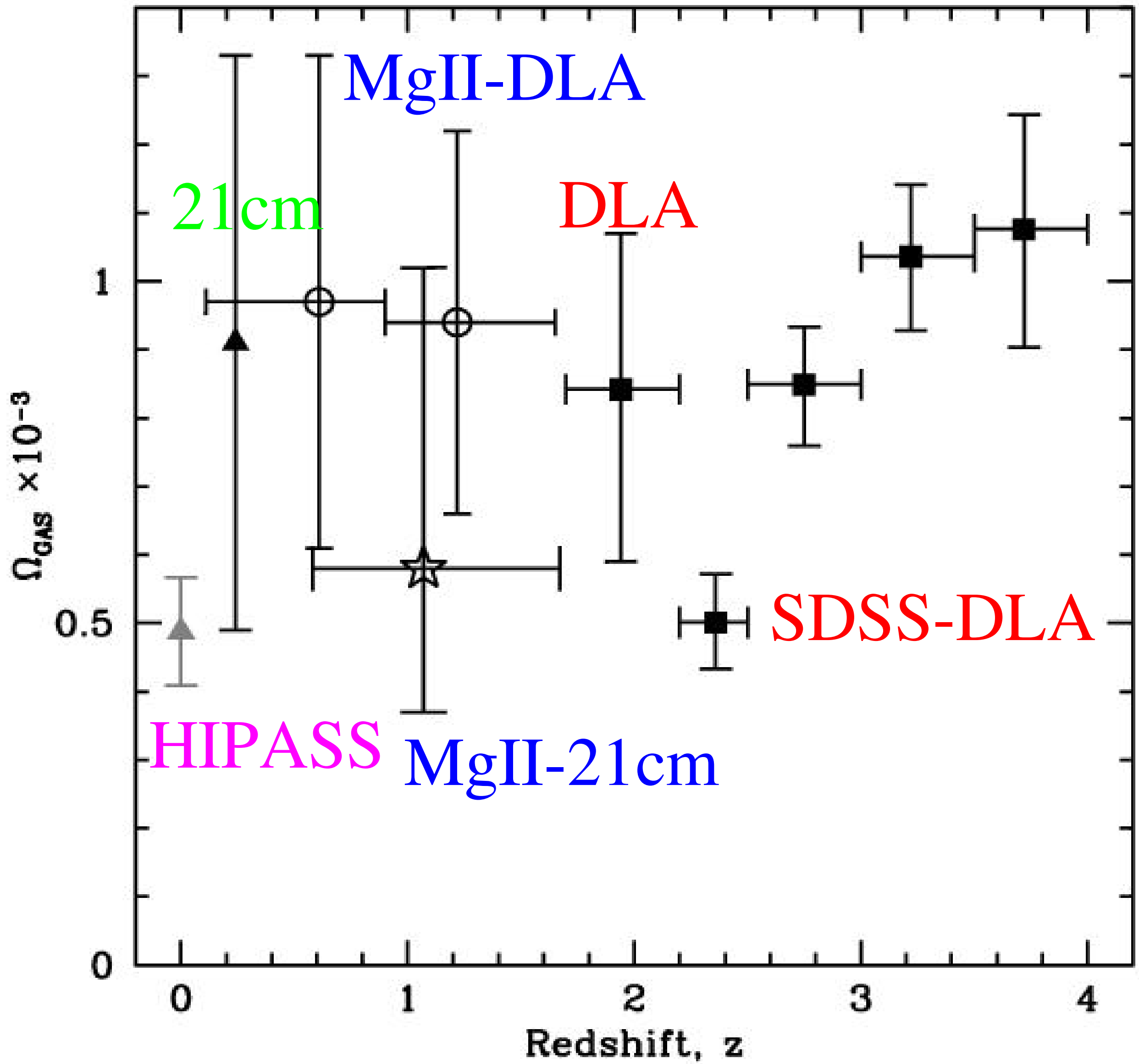
- Far better frequency calibration, spectral resolution in the radio regime. Could change with optical ELTs.

- ``Local'' null results testable in radio, not in optical.

We need more radio absorbers !

- Assuming that the 21cm detection rate in $z \sim 1$ DLAs is the same as that in all DLAs with 21cm searches

$$\Rightarrow \quad \Omega_{GAS}(z \sim 1.07) = 0.58^{+0.44}_{-0.21} \times 10^{-3}$$



(NK et al. 2008)

Today

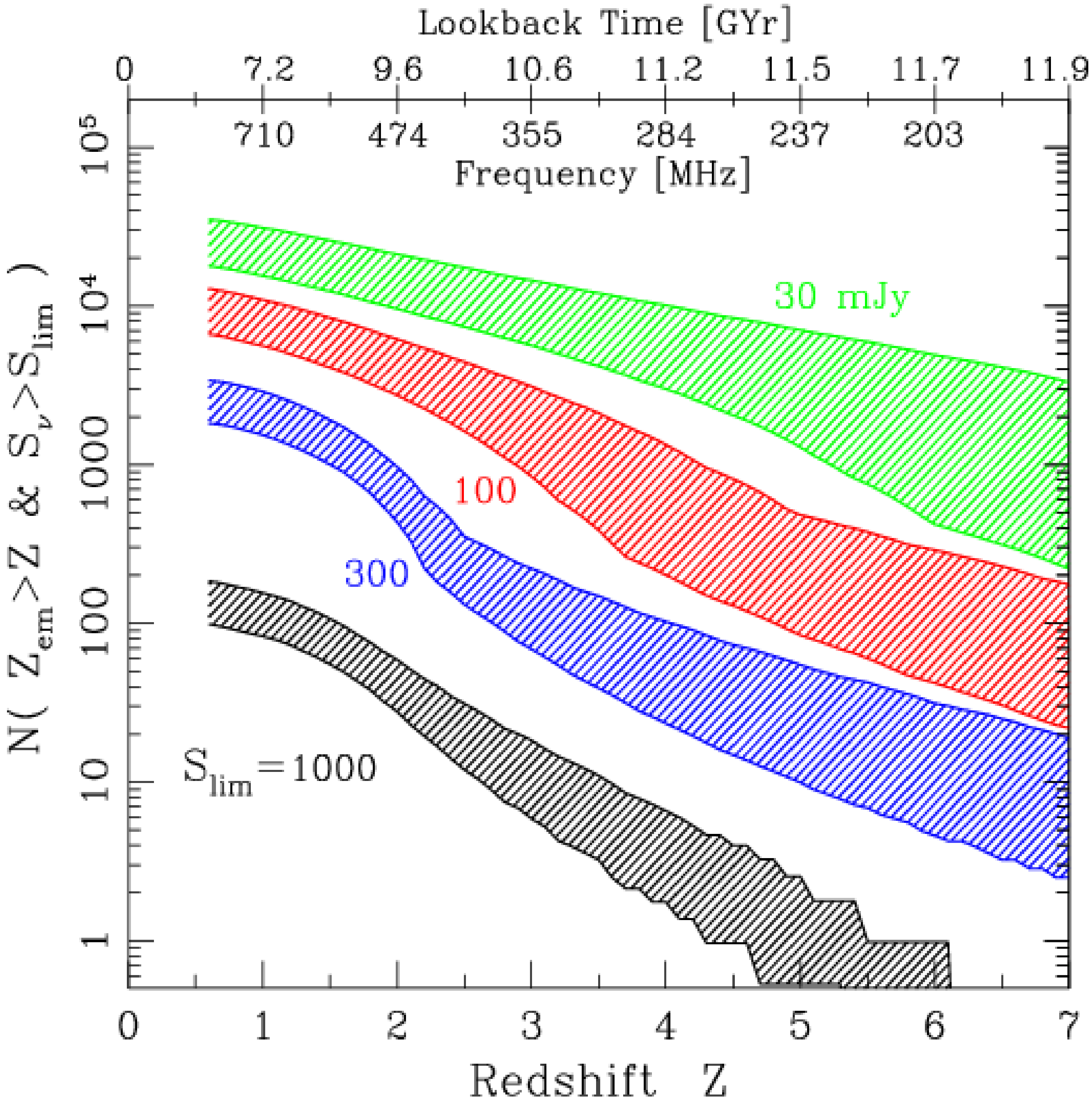
- Blind GBT 21cm absorption survey at $z < 3.5$ ⇨ RFI.
- Blind GBT CO/HCO$^+$ absorption survey at $0.8 < z < 2$.
- Blind Arecibo H_2CO absorption survey at $0.1 < z < 1$.
- Spectral baselines on single dishes ?

Post-2011: ASKAP, EVLA, GMRT !!!

- EVLA: High sensitivity, excellent frequency coverage.
  - ⇨ Blind 34 – 48, 1 – 2 GHz absorption surveys.
  - ⇨ CO/HCO^+ at $z > 0.8$, H_2CO at $1.4 < z < 3.8$.
- ASKAP: Large field of view, very little RFI.
  - ⇨ 21cm absorption surveys at $0 < z < 1$.
- GMRT ⇨ Blind 300–500 MHz survey: $1.8 < z < 3.7$.

  Needs new correlator and expanded P-band coverage.

- ASKAP RMS ~ 1.1 mJy/Bm/18 kHz in 12 hours.
- $T_s < 300$ K, against ~ 100 mJy sources.
- ~100 $z > 1$ sources per 30 sq. deg.

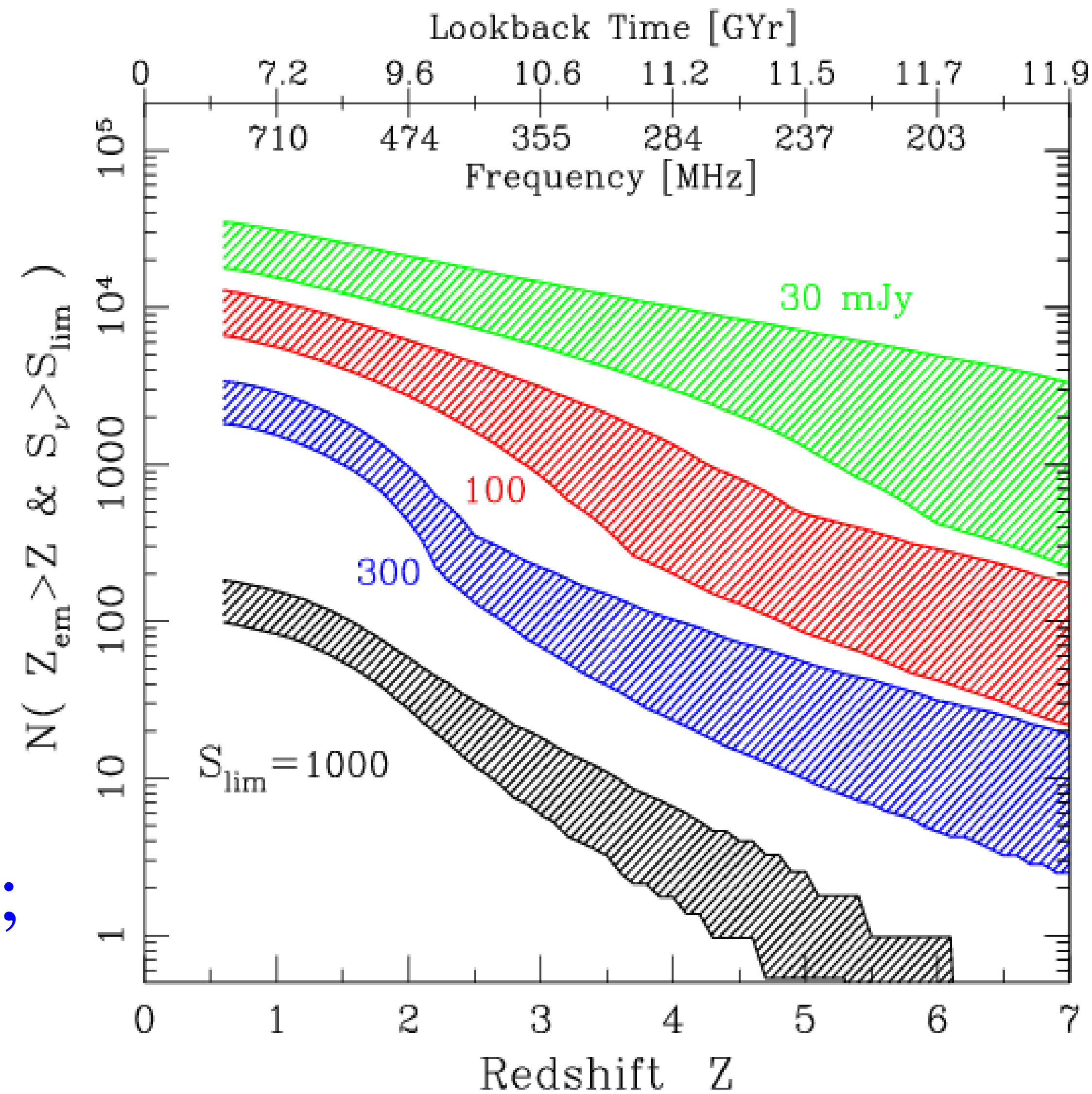


- Would need ~ 2500 hours to detect > 150 absorbers at $0.5 < z < 1$.

(Johnston et al. 2007; NK & Briggs 2004)

The distant future: The Square Kilometre Array

- @500 MHz ($z \sim 2$) ⇨ 5000 K DLAs towards 20 mJy sources (12h, 5σ).
- @200 MHz ($z \sim 6$) ⇨ 5000 K DLAs towards 100 mJy sources (12h, 5σ).
- *few* $\times 10^2$ targets at $z \sim 6$; 2×10^4 targets at $z \sim 2$.

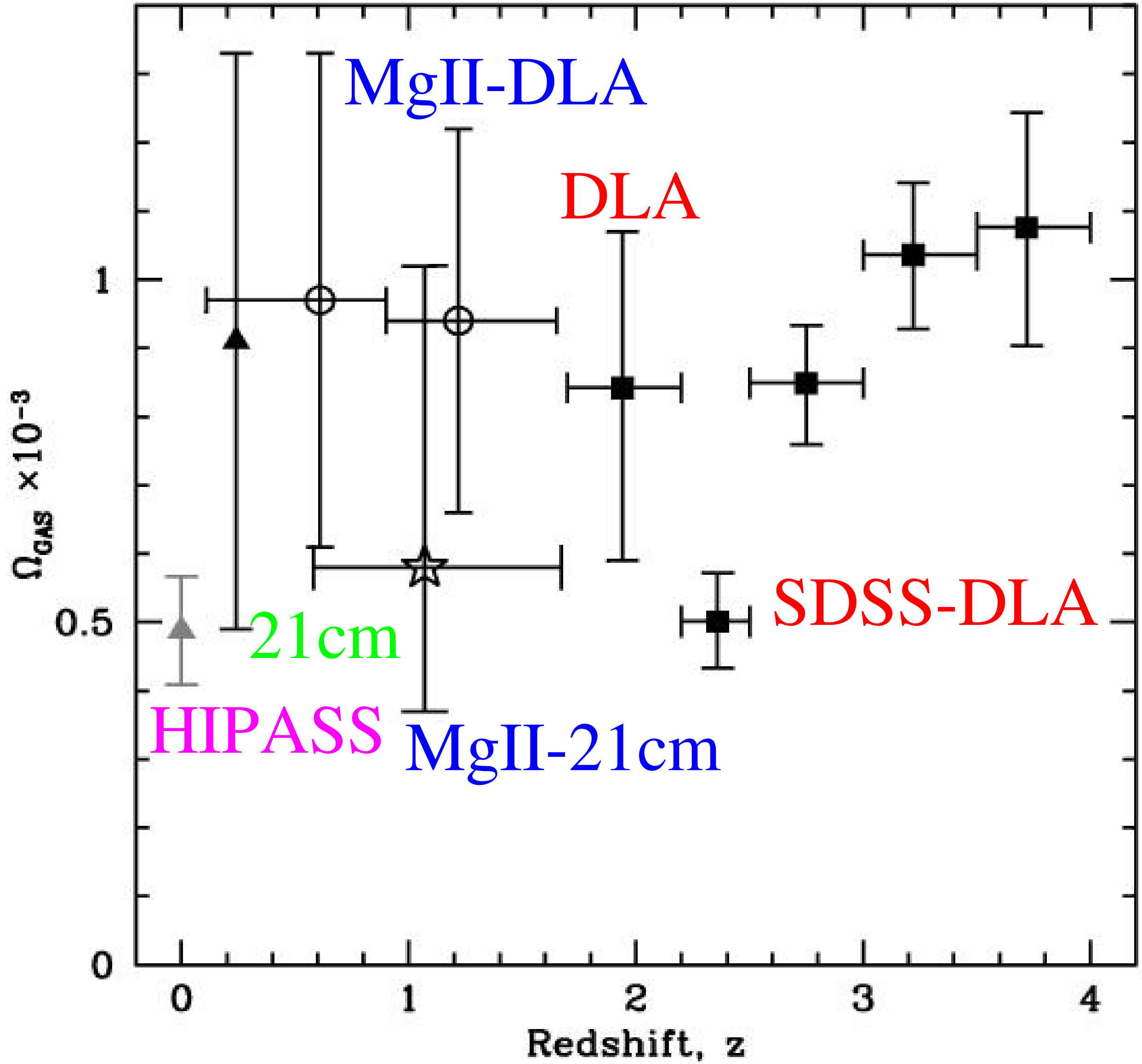


- SKA resolution < 1 kpc ⇨ 21cm mapping at $z < 6$!

(NK & Briggs 2004)

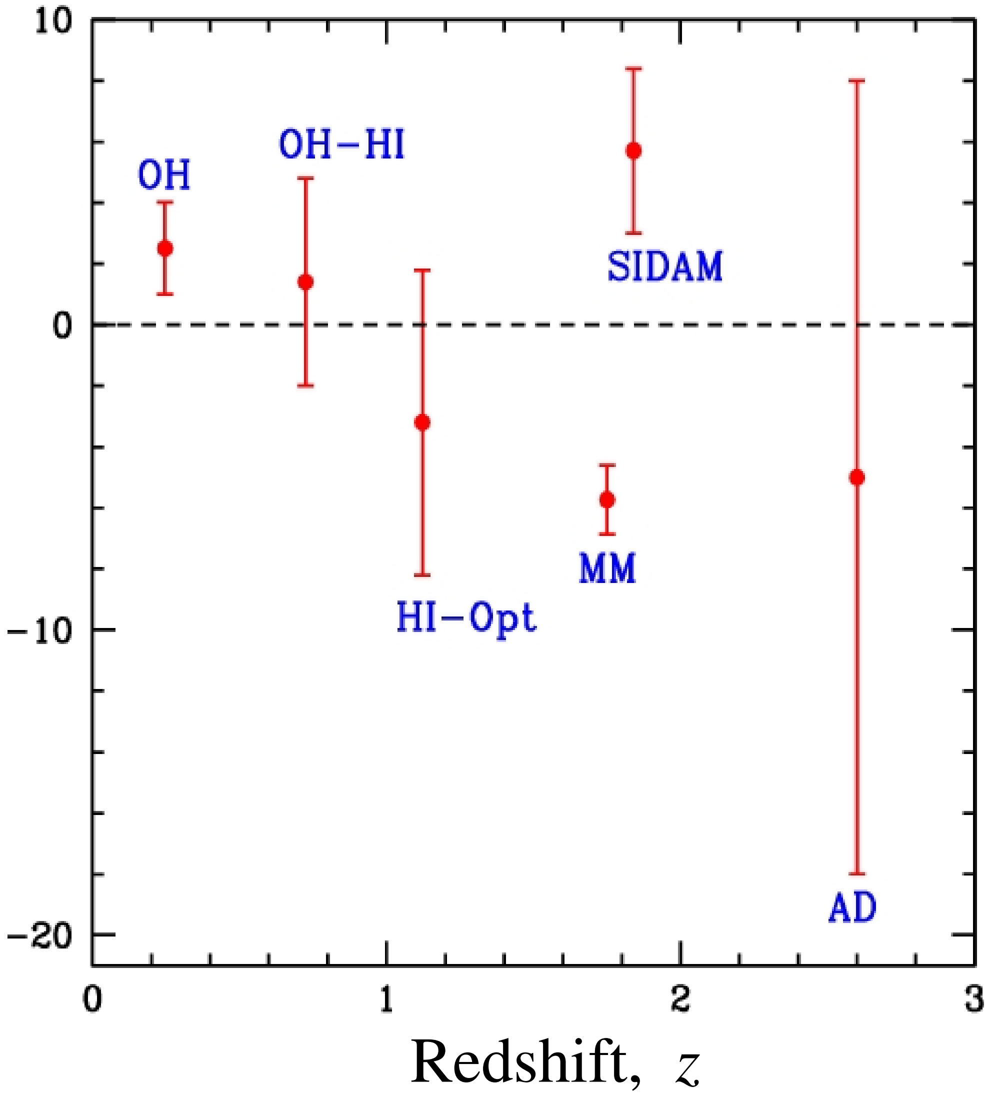
- Assuming that the 21cm detection rate in $z \sim 1$ DLAs is the same as that in all DLAs with 21cm searches

$$\Rightarrow \quad \Omega_{GAS}(z \sim 1.07) = 0.58^{+0.44}_{-0.21} \times 10^{-3}$$

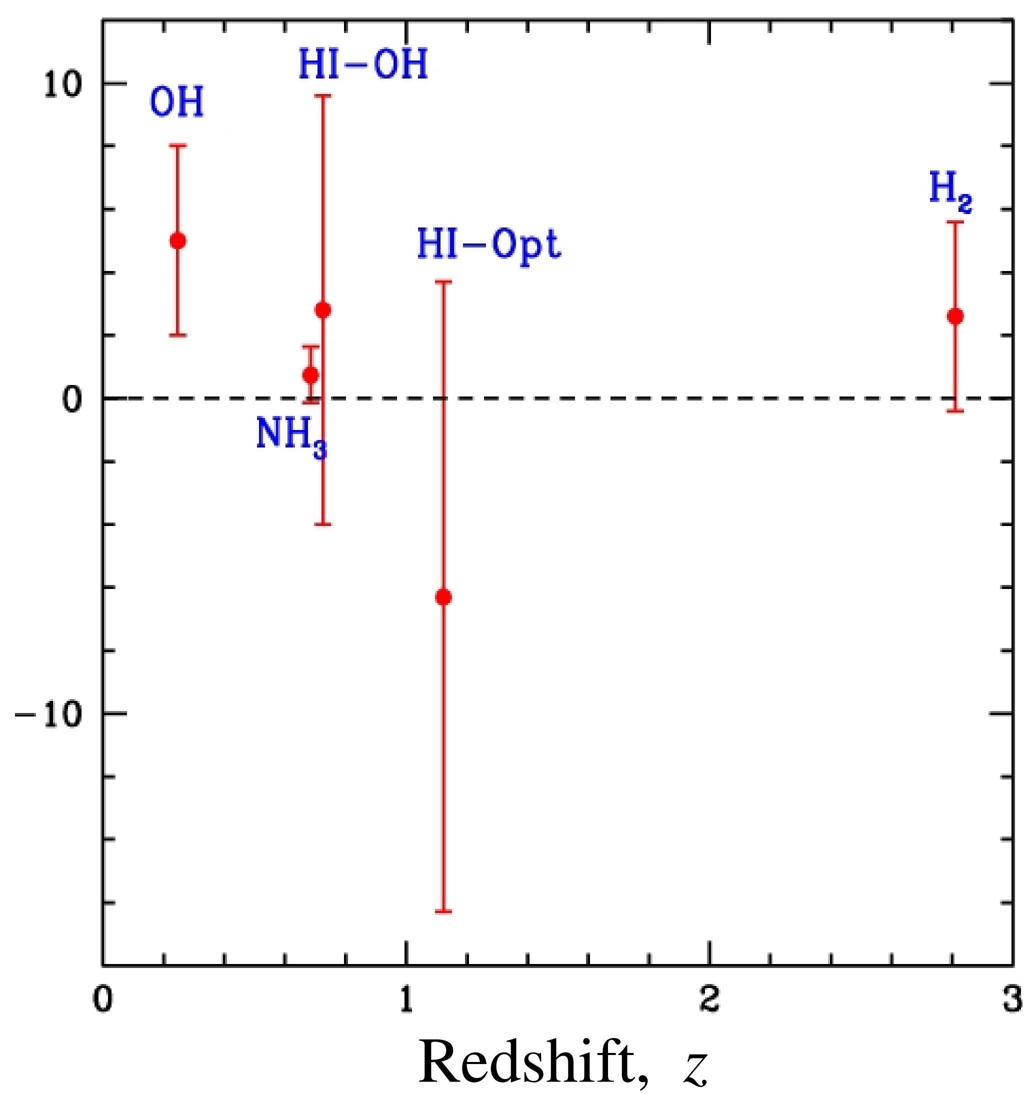


(NK et al. 2008)

$[\Delta\alpha/\alpha] \times 10^{-6}$



$[\Delta\mu/\mu] \times 10^{-6}$



(NK 2008)

Conjugate satellite OH lines

- Quantum mechanical selection rules ⇨ 1720 emission, 1612 absorption or vice-versa, ***with the same shape !***

(Elitzur 1976; van Langevelde et al. 1995)

- Lines arise in the same gas ⇨ No velocity offsets !

Excellent to probe changes in μ α, g_p !

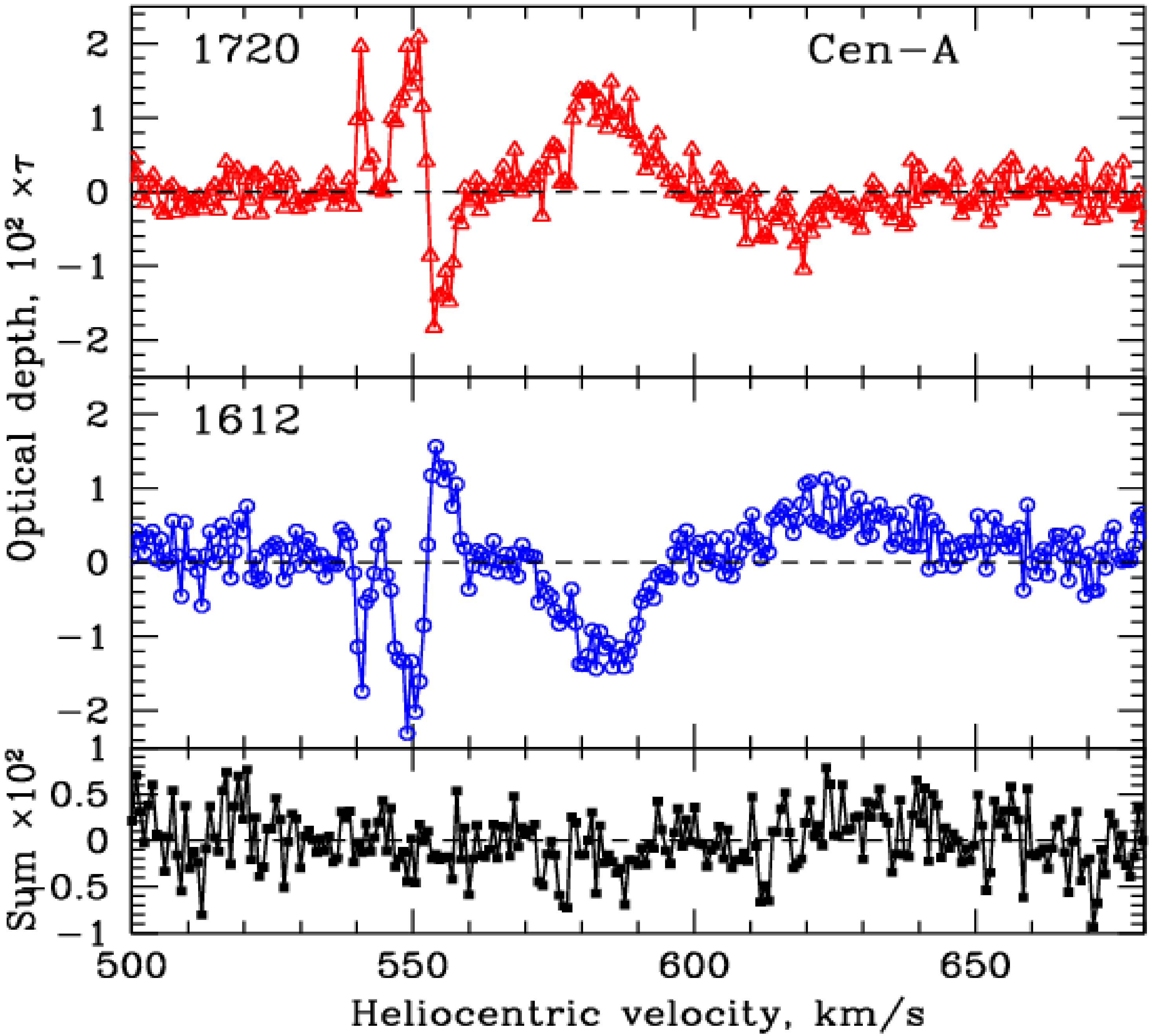
(NK et al. 2004)

- Probes changes from a single space-time location !

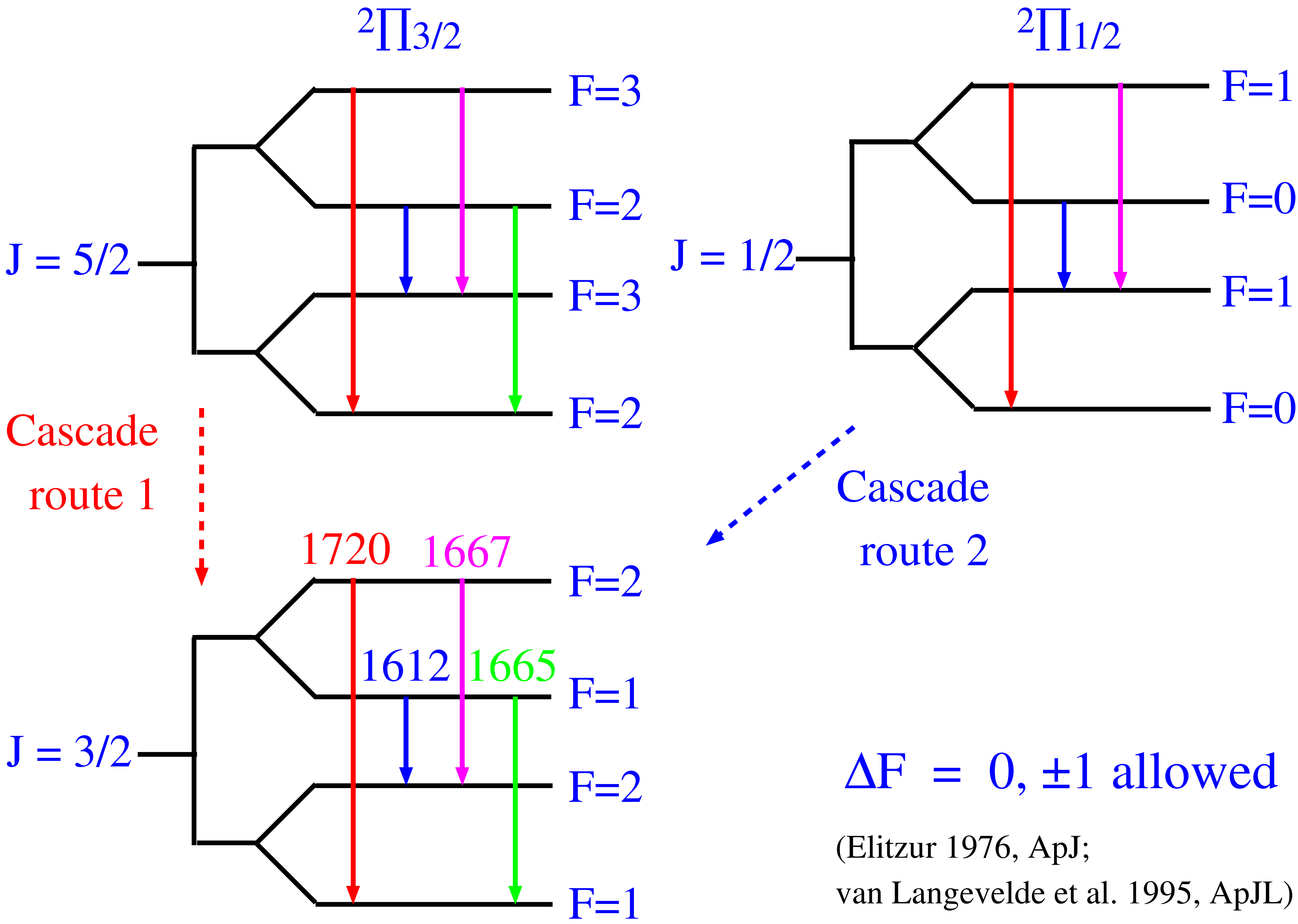
- Inherent test of the applicability of the technique !

- 2 conjugate satellite systems known, at $z < 1$; Requires high N_{OH}, $> 10^{15}$ cm^{-2} (Darling 2004; NK et al. 2004,2005)

``Conjugate'' satellite OH lines in Cen. A

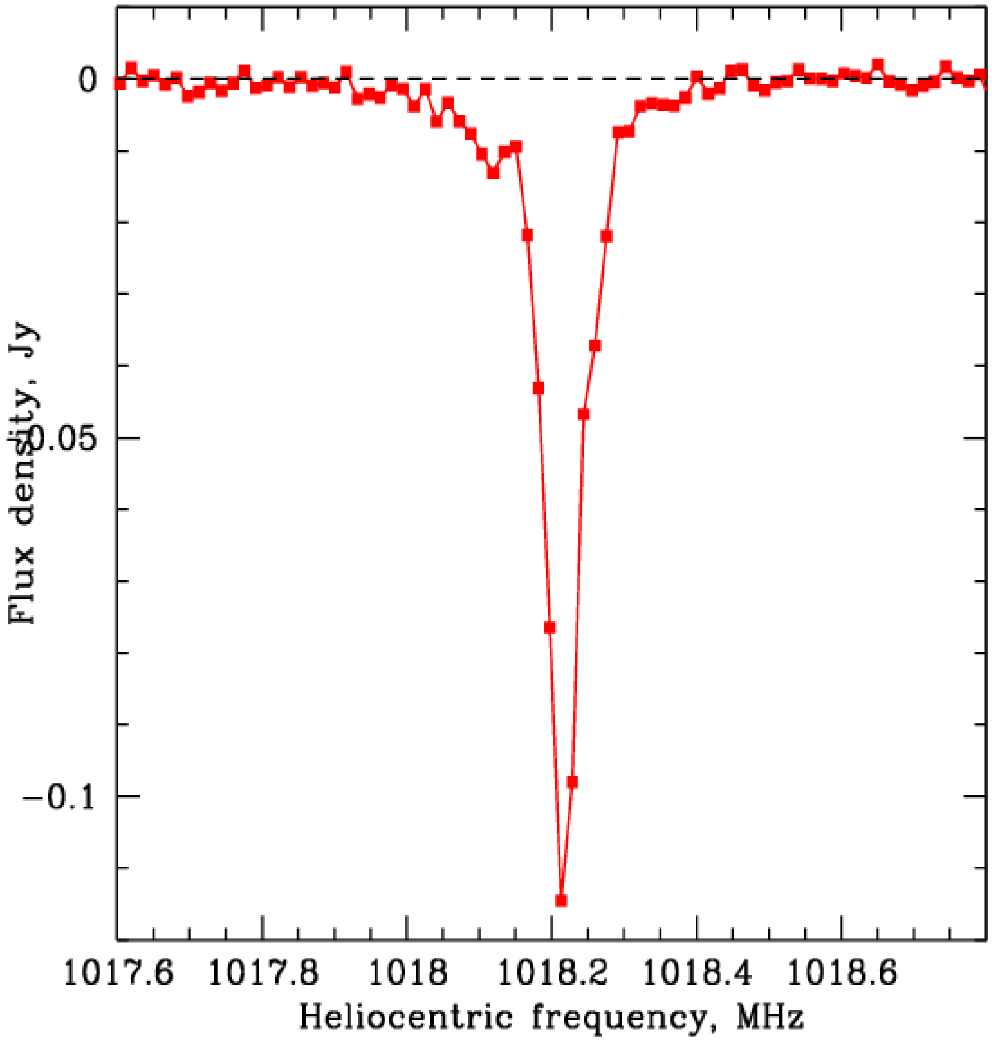


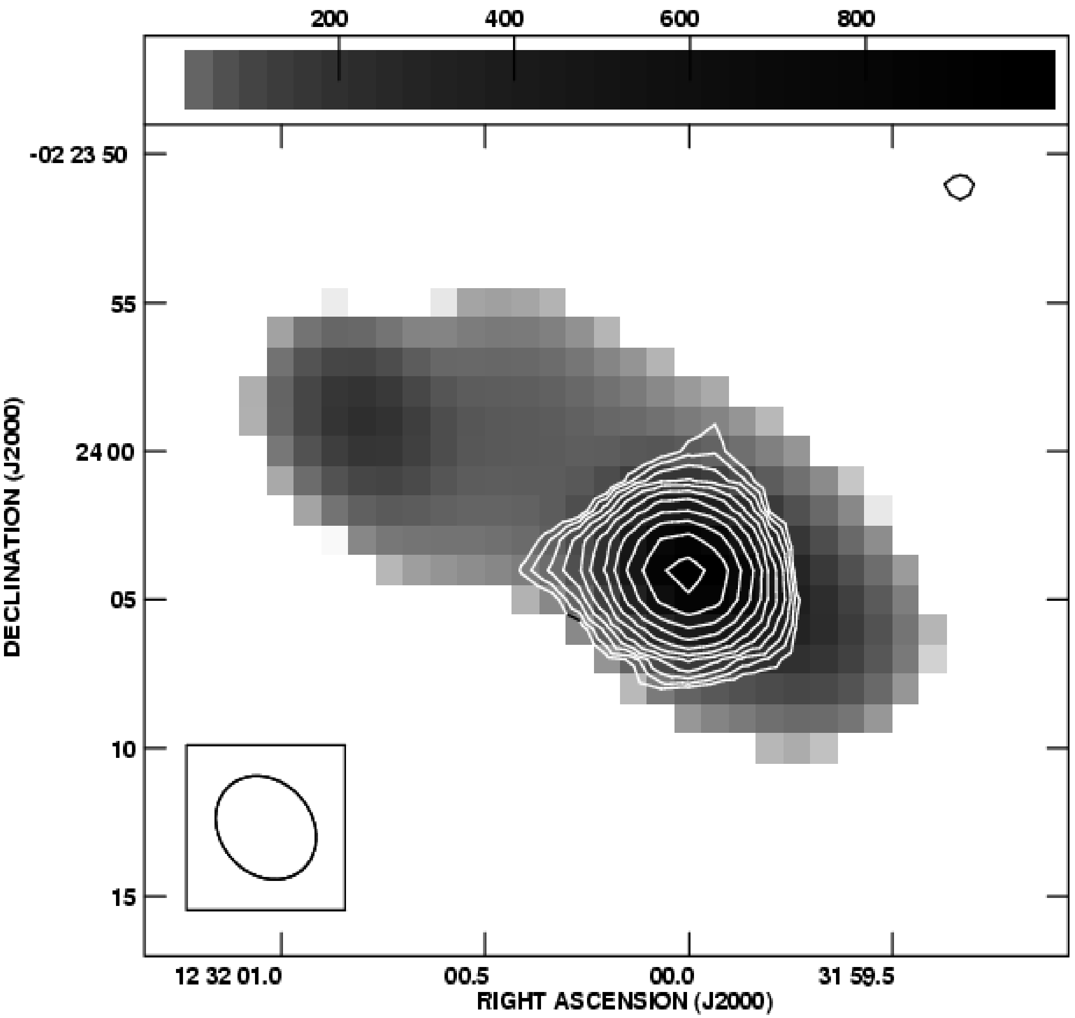
(van Langevelde et al. 1995)



$^2\Pi_{3/2}$
$^2\Pi_{1/2}$
J = 5/2
F=3
F=2
F=3
F=2
J = 1/2
F=1
F=0
F=1
F=0
Cascade
route 1
Cascade
route 2
1720
1667
1612
1665
J = 3/2
F=2
F=1
F=2
F=1
ΔF = 0, ±1 allowed
(Elitzur 1976, ApJ;
van Langevelde et al. 1995, ApJL)

z ~ 0.395 DLA towards 1229-021 (GMRT)





(NK & Chengalur 2008)

Spectroscopic Techniques

- Alkali doublets ⇨ $[\Delta\alpha/\alpha] < 2.6 \times 10^{-5}$ $(z \sim 2.6)$

  (Murphy et al. 2001)

- Many-multiplet ⇨ $[\Delta\alpha/\alpha] = (-5.7 \pm 1.1) \times 10^{-6}$ $(z \sim 1.8)$

  (Murphy et al. 2004)

- H_2 lines ⇨ $[\Delta\mu/\mu] < 6 \times 10^{-6}$ $(z \sim 3)$

  (King et al. 2008)

- HI-21cm vs. Optical ⇨ Changes in $[g_p \, \mu \, \alpha^2]$

  HI-21cm vs. HCO^+ ⇨ Changes in $[g_p \, \alpha^2]$

  (e.g. Wolfe et al. 1976)

- HI-21cm vs. OH-1667 ⇨ Changes in $[g_p \, \mu^{1.5} \, \alpha^{3.1}]$

  Conjugate ``Satellite'' OH ⇨ Changes in $[g_p \, \mu^{1.9} \, \alpha^{3.7}]$

  (Chengalur & NK 2003)