HI 21cm ABSORPTION STUDIES OF DAMPED LYMAN-α SYSTEMS

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- 21cm studies of DLAs towards compact QSOs ⇨ DLA spin temperatures ⇨ Evolution of the temperature of the neutral ISM with redshift.

(e.g. Wolfe & Davis 1979; Wolfe et al. 1985; de Bruyn et al. 1996; Carilli et al. 1996; Briggs et al. 1997; Lane et al. 1998; Chengalur & NK 2000; NK & Chengalur 2003)

- 21cm studies of DLAs towards extended radio sources ⇨ Transverse size & kinematics.

(e.g. Briggs et al. 1989, 2001; NK & Chengalur 2007)

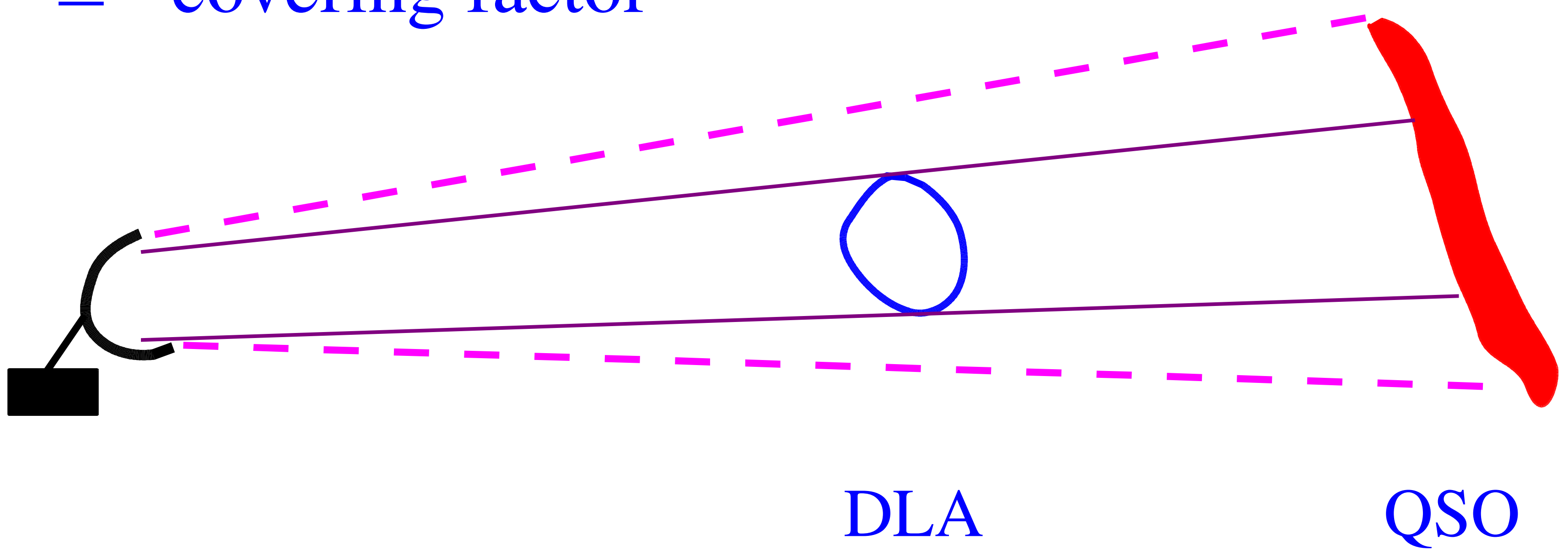
21cm absorption studies

- For DLAs towards radio-loud quasars :

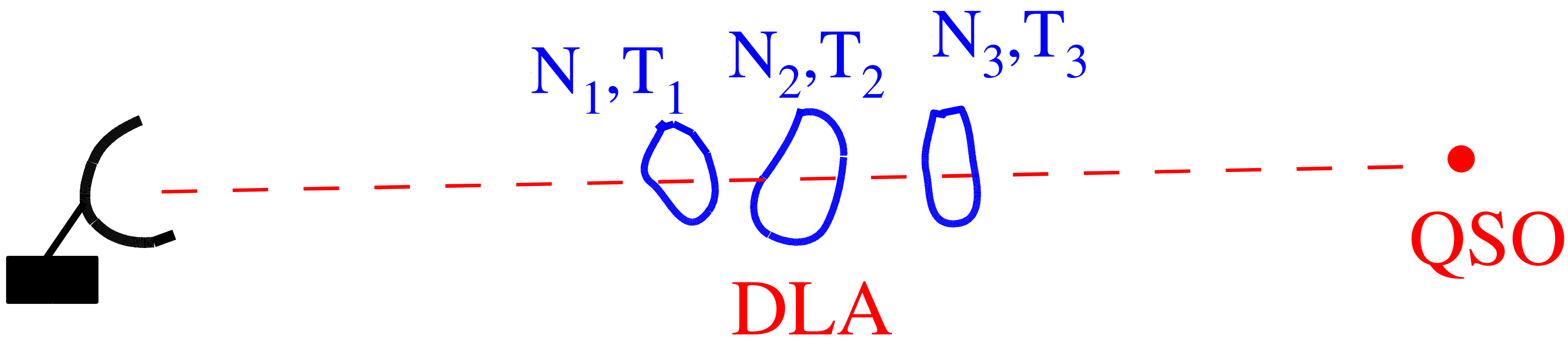
$$N_{HI} = 1.8 \times 10^{18} \times [T_s / f] \times \int \tau_{21} \, dv$$

$T_s \equiv$ 21cm ``spin" temperature; $[n_2/n_1] \propto \exp(-h\nu/kT_s)$

$f \equiv$ covering factor



- For multiple clouds, with $N_{HI} = N_1 + N_2 + N_3 + ...$



$[1/T_S] = [n_1/T_1] + [n_2/T_2] + ...$ $n_i = [N_i / N_{HI}]$

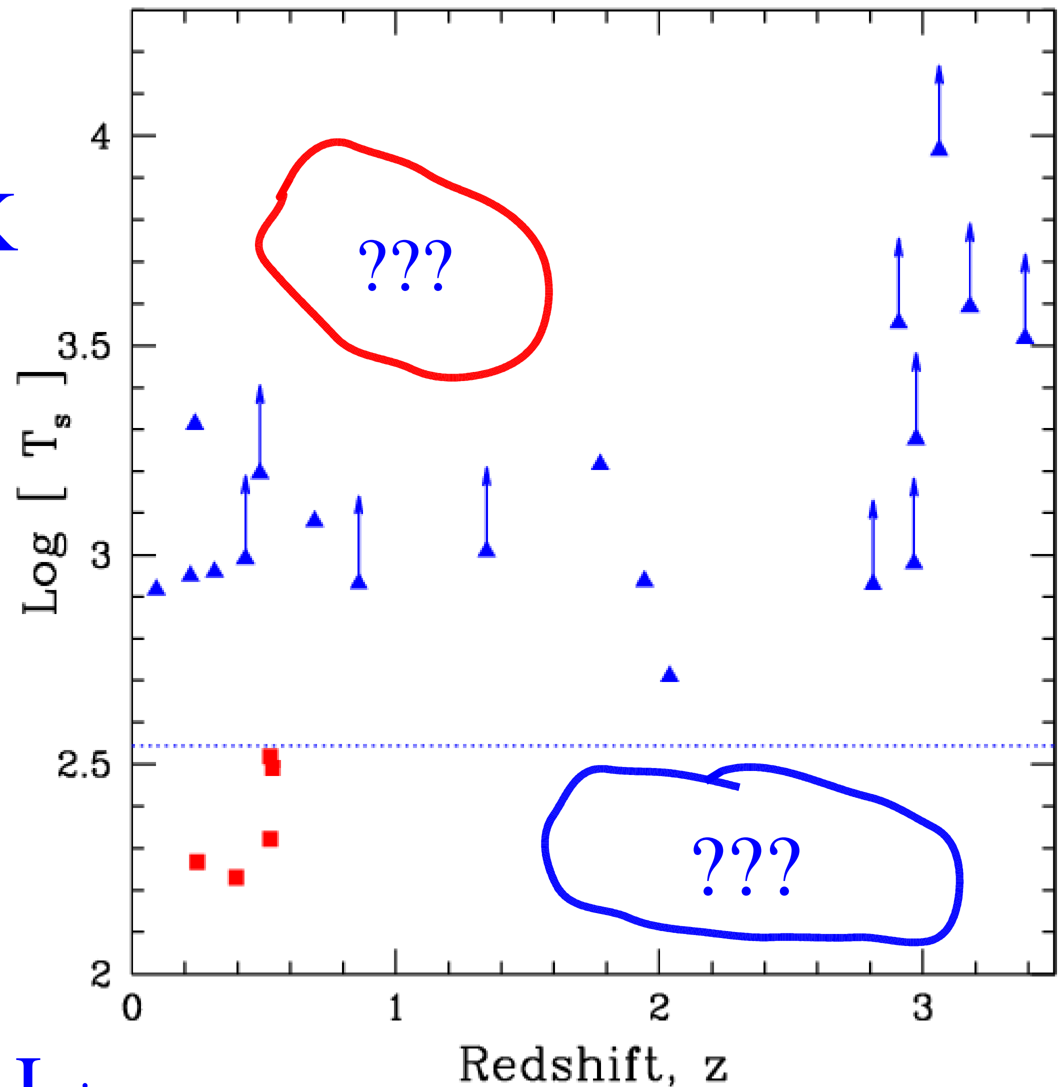
- $T_C \sim 100$ K, $T_W \sim 8000$ K $\Rightarrow$
  - $n_W \sim n_C \sim 0.5 \Rightarrow T_S \sim 200$ K
  - $n_W \sim 0.9$, $n_C \sim 0.1 \Rightarrow T_S \sim 1000$ K

- T_S probes the redshift evolution of the CNM fraction.

(NK & Chengalur 2003)

- T_s (Milky Way) ~ 200 K
- T_s (high-*z* DLAs) ~ 1000 K

⇨ More WNM in DLAs ?



- At low redshifts :

Low T_s DLAs have L ~ L*

High T_s DLAs have L < 0.1 L*

(e.g. le Brun et al. 1997; Rao et al. 2002)

⇨ Two types of DLAs ?

(NK & Chengalur 2001)

High T_s in DLAs ?

- Phase distribution depends on metallicity, pressure

  Higher metallicity, pressure ⇨ more CNM

  (Wolfire et al. 2003)

- Dwarfs ⇨ low pressure, star formation, metallicity

  ⇨ more WNM ⇨ High T_s (NK & Chengalur 2003)

- DLA metallicities < 0.1 Solar at z > 2; [Zn/H] < -1

- Consistent picture if high-z DLAs are small galaxies, with low star formation and low metallicity.

Caveats

- Could high-z DLAs have a very low covering factor ?

  (e.g. Curran et al. 2005)

- N_{HI} from optical line-of-sight used in T_s estimate ?

  (de Bruyn et al. 1995)

- CII* absorption consistent with $N_{CNM} \sim N_{WNM}$.

  (Wolfe et al. 2003)

- No low T_s DLAs detected at high redshifts.

- Few 21cm studies in the redshift desert, $0.7 < z < 1.7$.

- Estimate covering factor at the 21cm frequency ⇨ VLBA 327, 610 MHz imaging of background QSOs

- Significantly increase number of T_s estimates

  WHT + Gemini + VLT survey towards TXS QSOs

  GBT + GMRT + WSRT 21cm searches in DLAs

- Predicted anti-correlation between T_s and metallicity

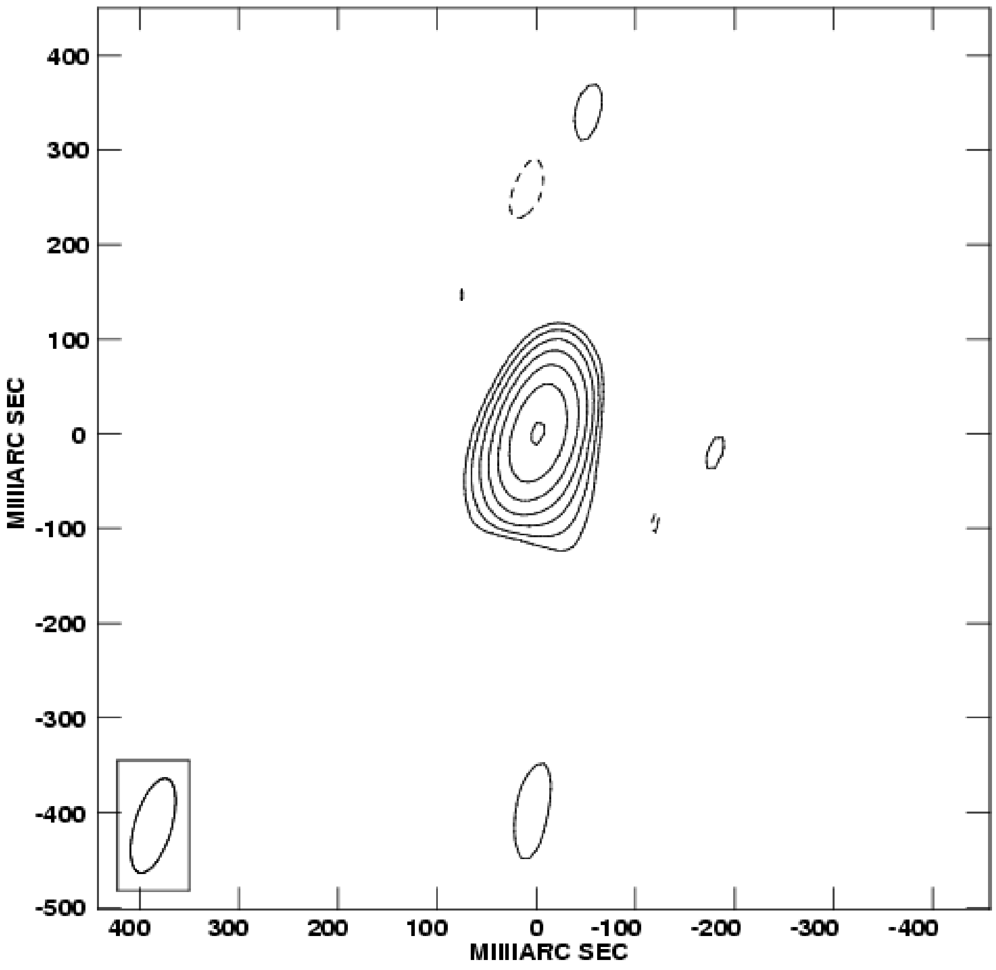
  (NK & Chengalur 2001)

- Searches for 21cm absorption in strong MgII absorbers at $0.7 < z < 1.7$

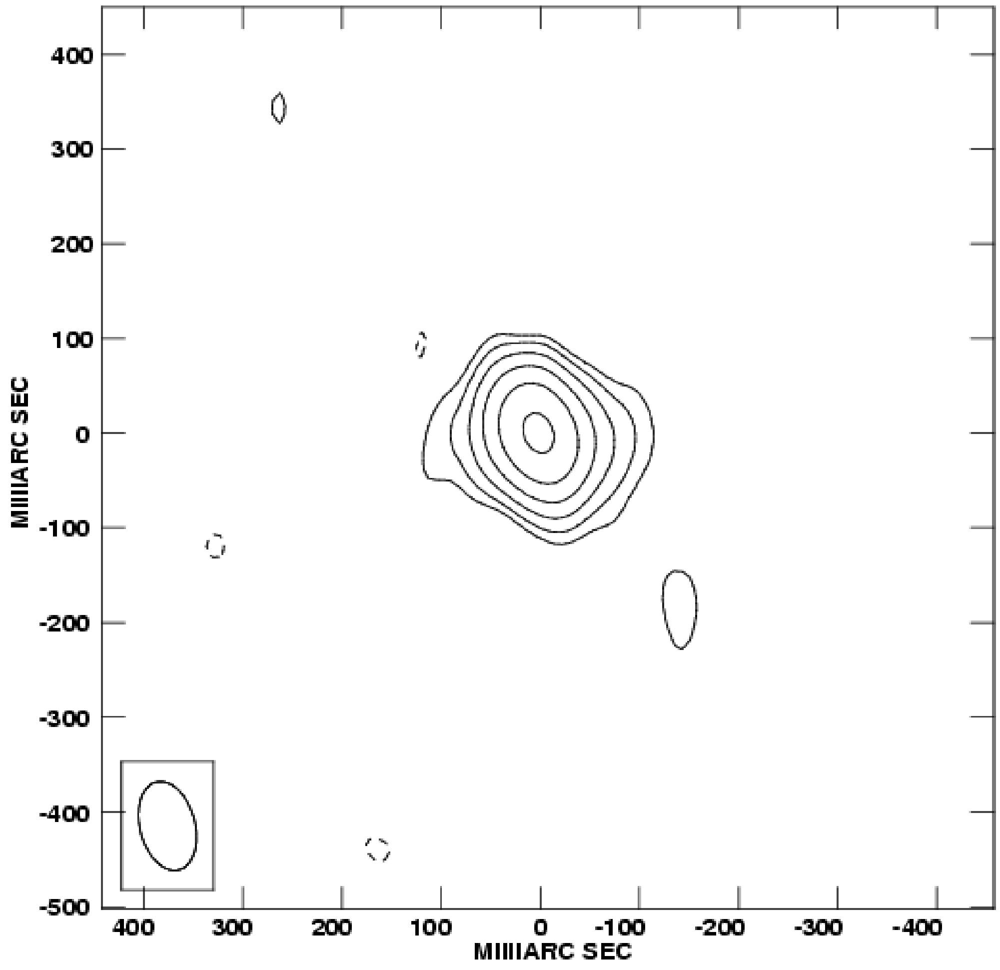
VLBA Imaging ⇨ the covering factor

Observed 17 QSOs at 327, 610 and/or 1420 MHz

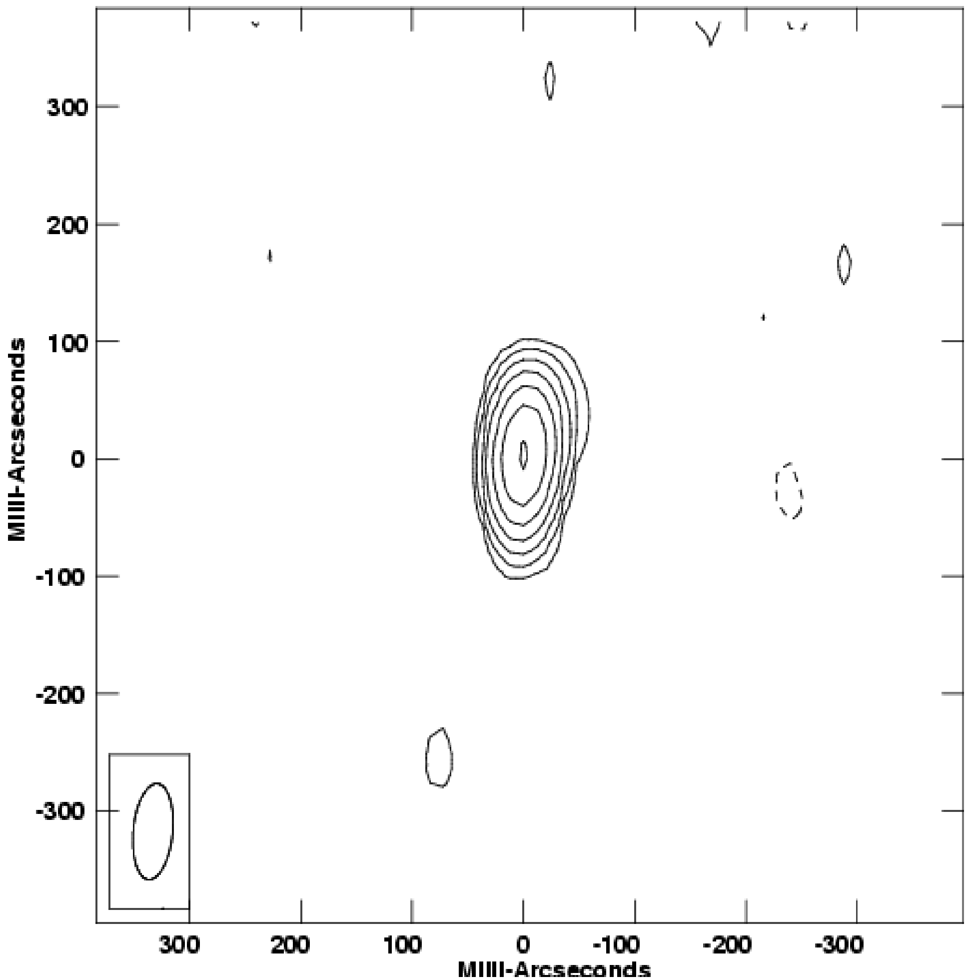
0336-017; z ~ 3.062; f ~ 0.6



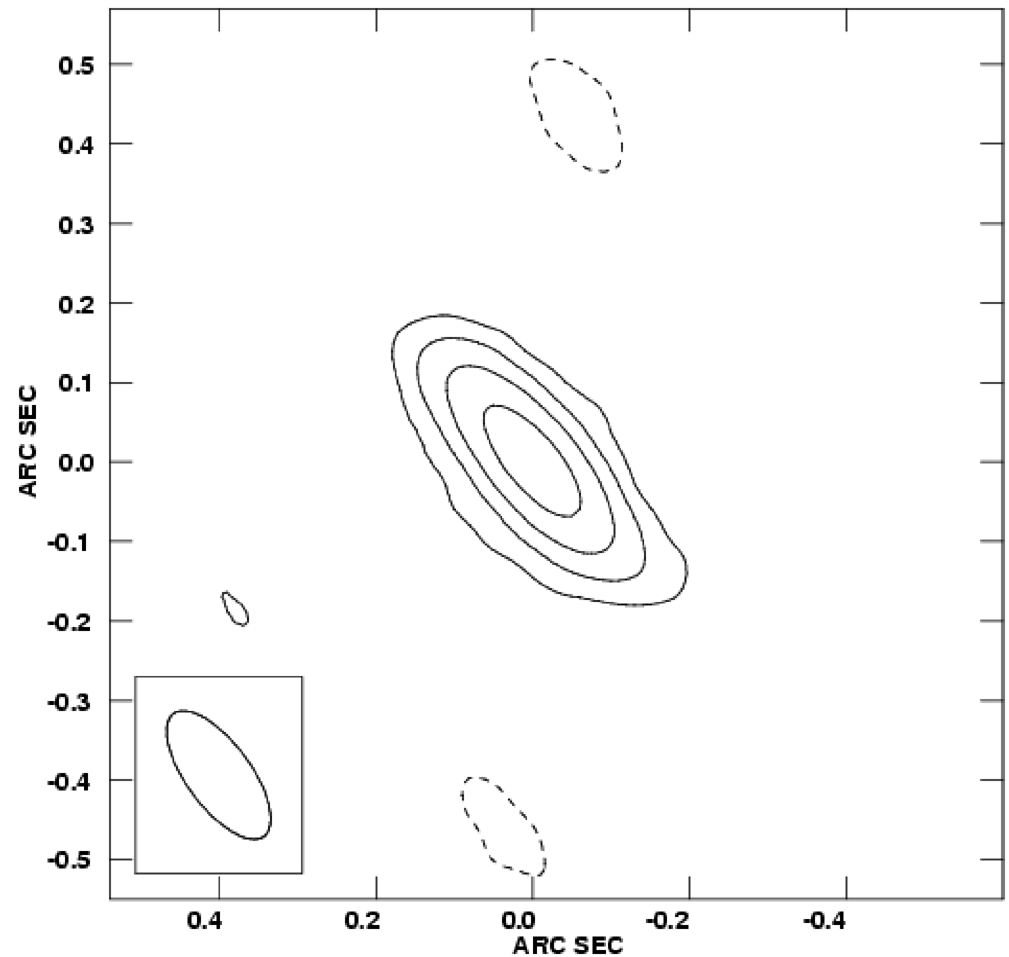
0335-122; z ~ 3.178; f ~ 0.6



0201+113; $z \sim 3.387$; f > 0.7



1418-064; $z \sim 3.449$; f ~ 0.8



Covering factor effects apparently not significant !

(e.g. NK et al. 2007)

21cm absorption searches in DLAs

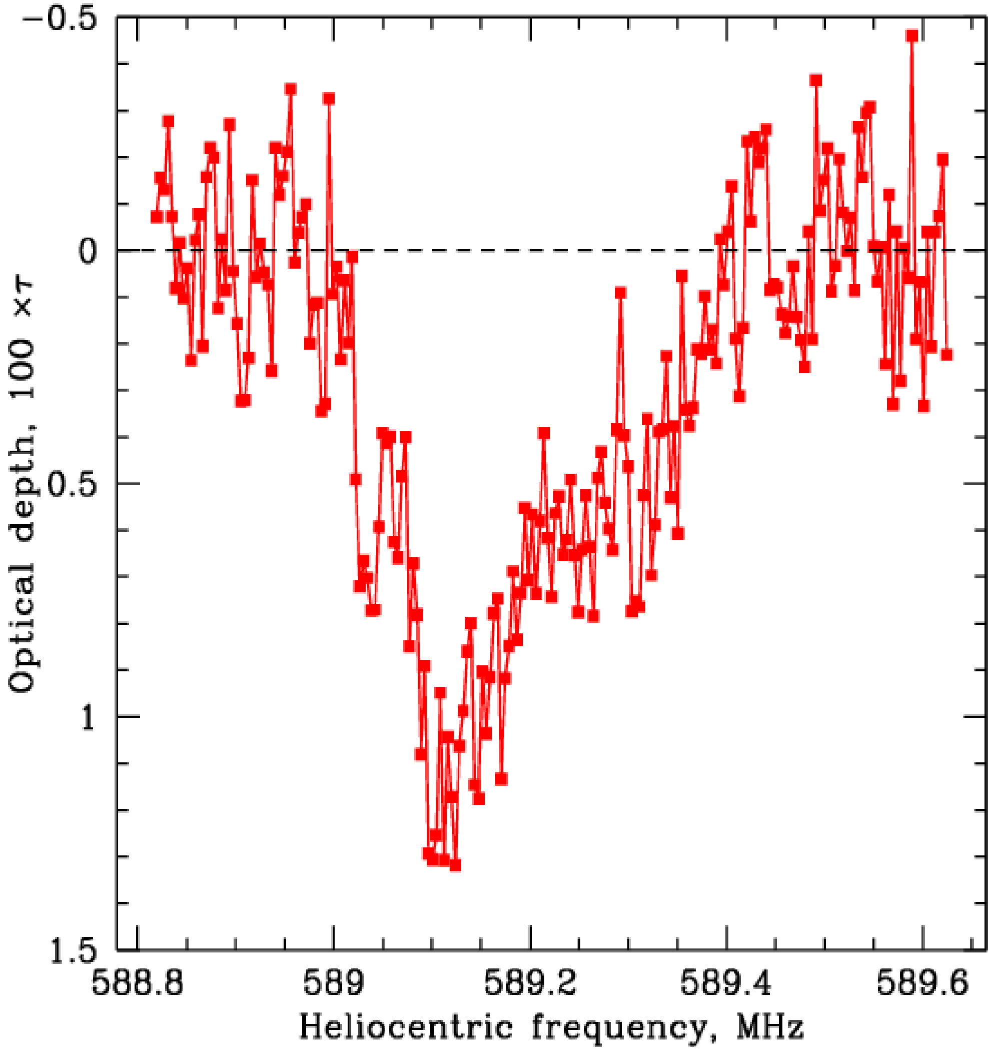
- WHT, VLT & Gemini optical survey of TXS QSOs
  ⇨ 11 new DLAs. Also CORALS & UCSD samples.

- Observed 25 DLAs with GBT, GMRT and WSRT;
  15 presently scheduled.

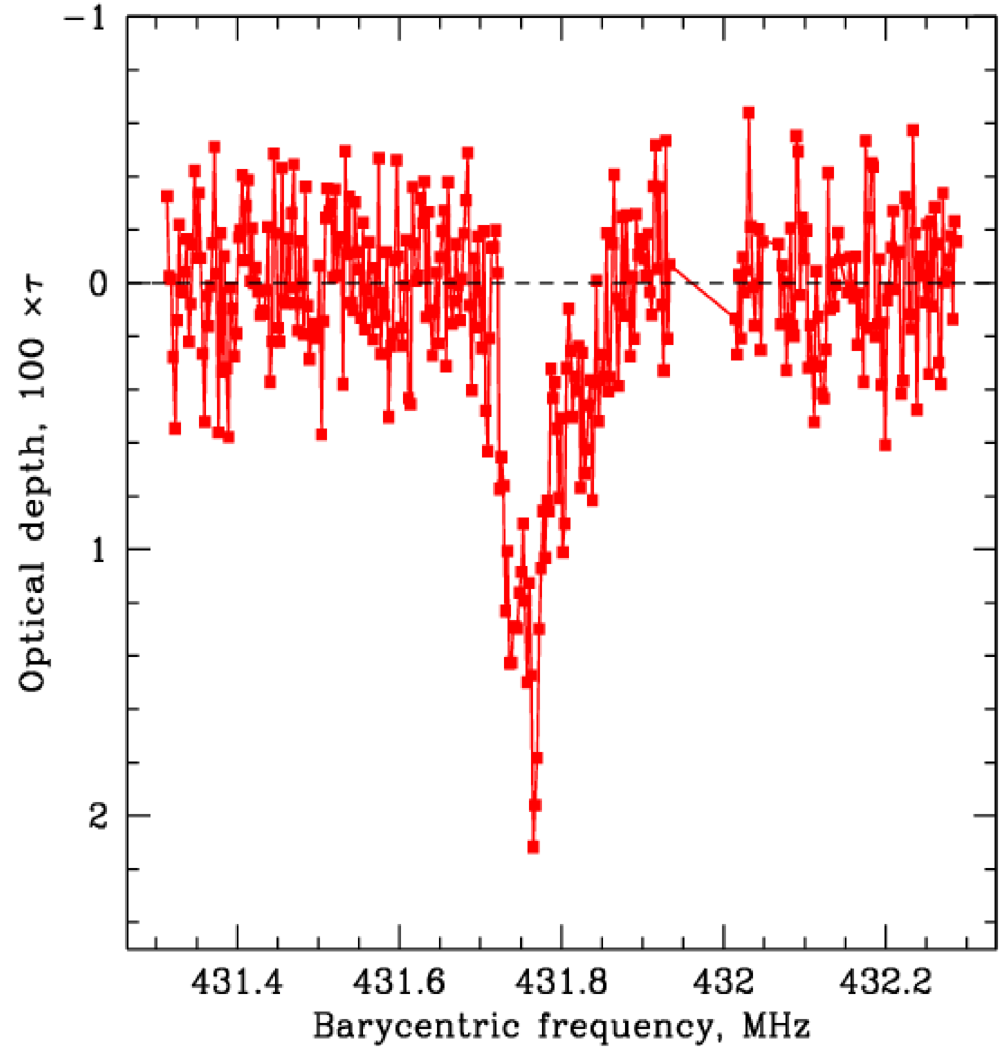
- 4 new detections, towards 2003-025 ($z \sim 1.4106$),
  0311+430 ($z \sim 2.289$), 0438-436 ($z \sim 2.347$) and
  0201+113 ($z \sim 3.387$) (see also Briggs et al. 1997)

- 11 strong lower limits on T_s (> 1000 K)

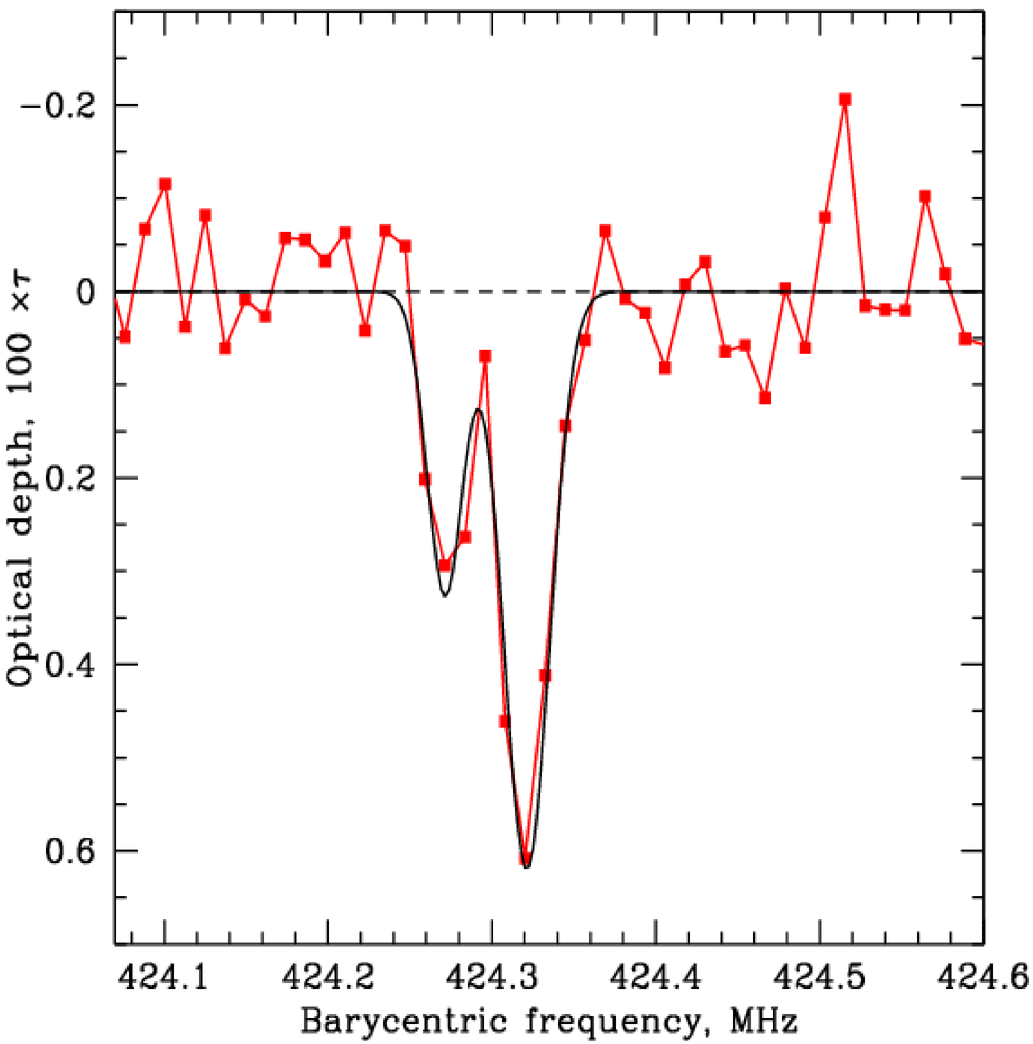
2003-025; z ~ 1.410; GMRT



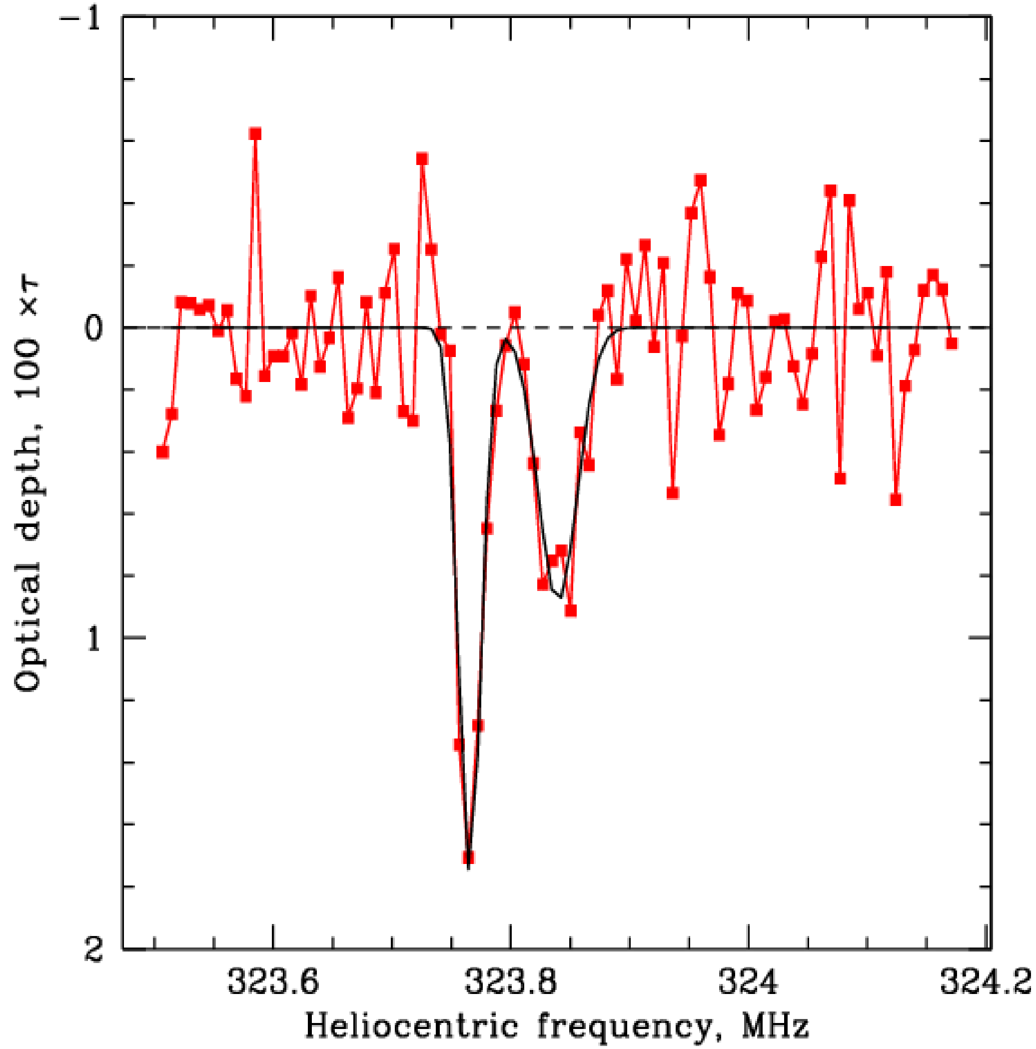
0311+430; z ~ 2.289; GBT



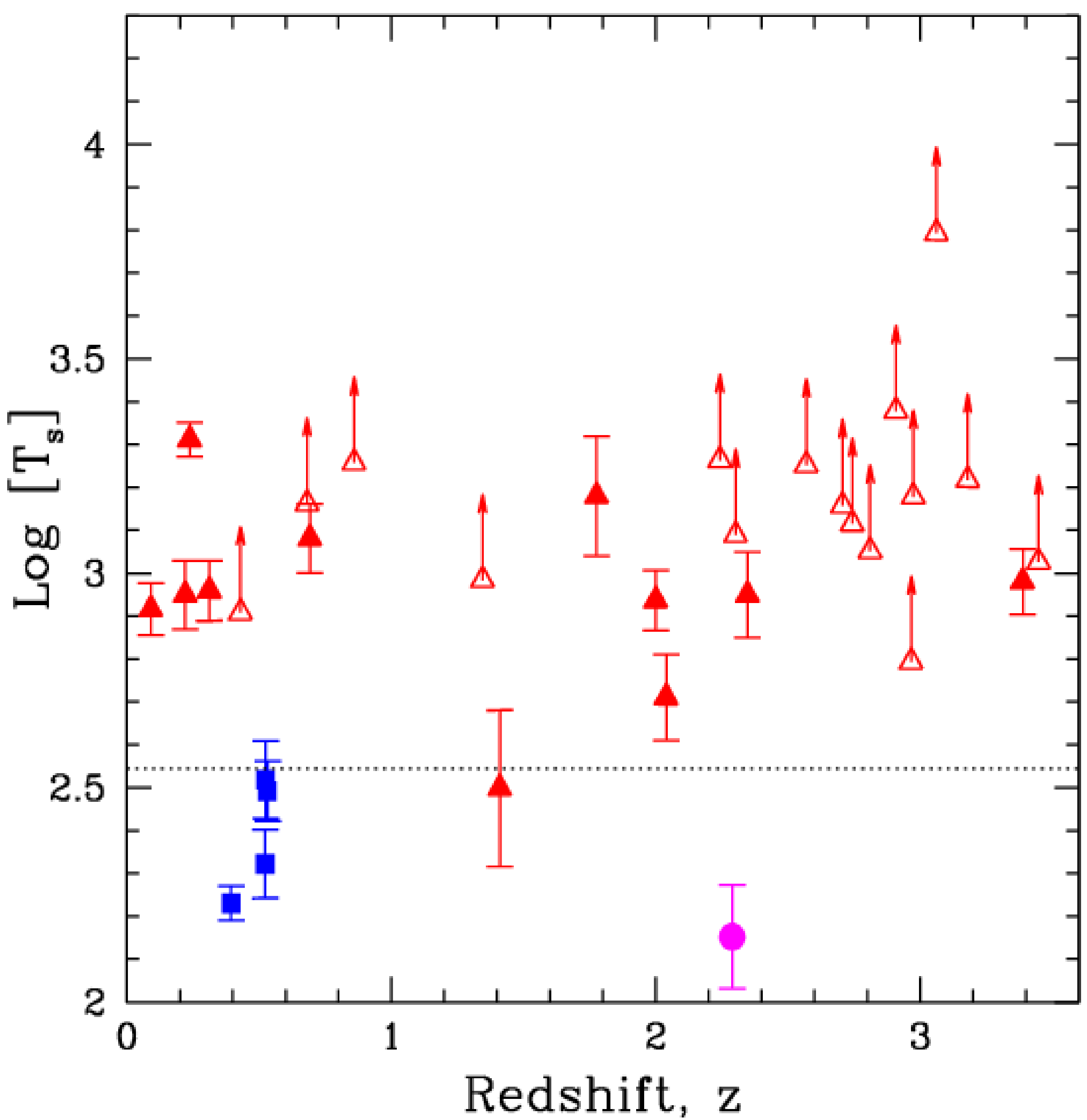
0438-436; z ~ 2.347; GBT



0201+113; z ~ 3.387; GMRT



(NK et al. 2006, 2007)



Log [T_s]
Redshift, z
4
3.5
3
2.5
2
0
1
2
3

21cm absorption searches in DLAs

- 32 T_s estimates ; 18 at $z > 1.5$.

- The $z \sim 2.289$ absorber towards 0311+430 :

  The first low T_S DLA at $z > 0.6$!

  Also has a high metallicity, [Si/H] > -0.4

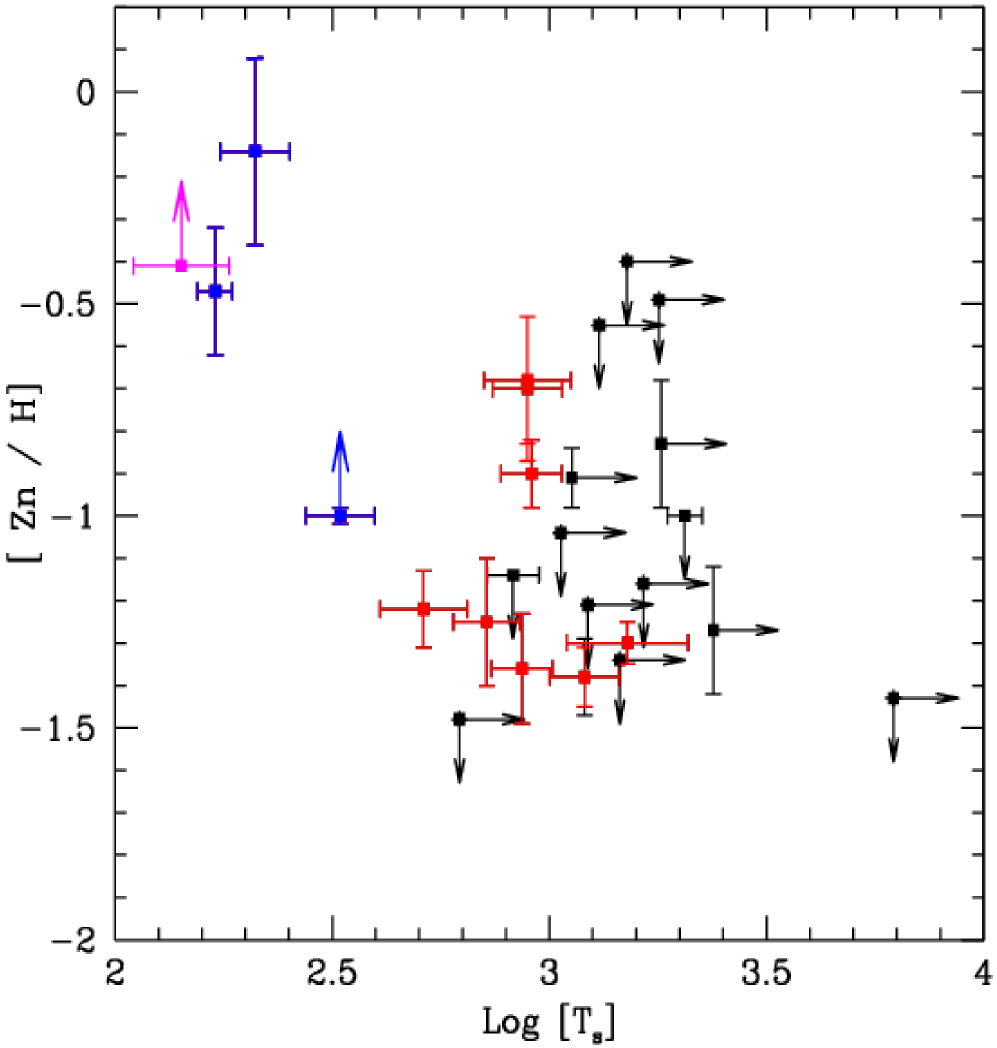
- 17 of 18 DLAs at $z > 1.5$ have high T_s (> 1000 K)

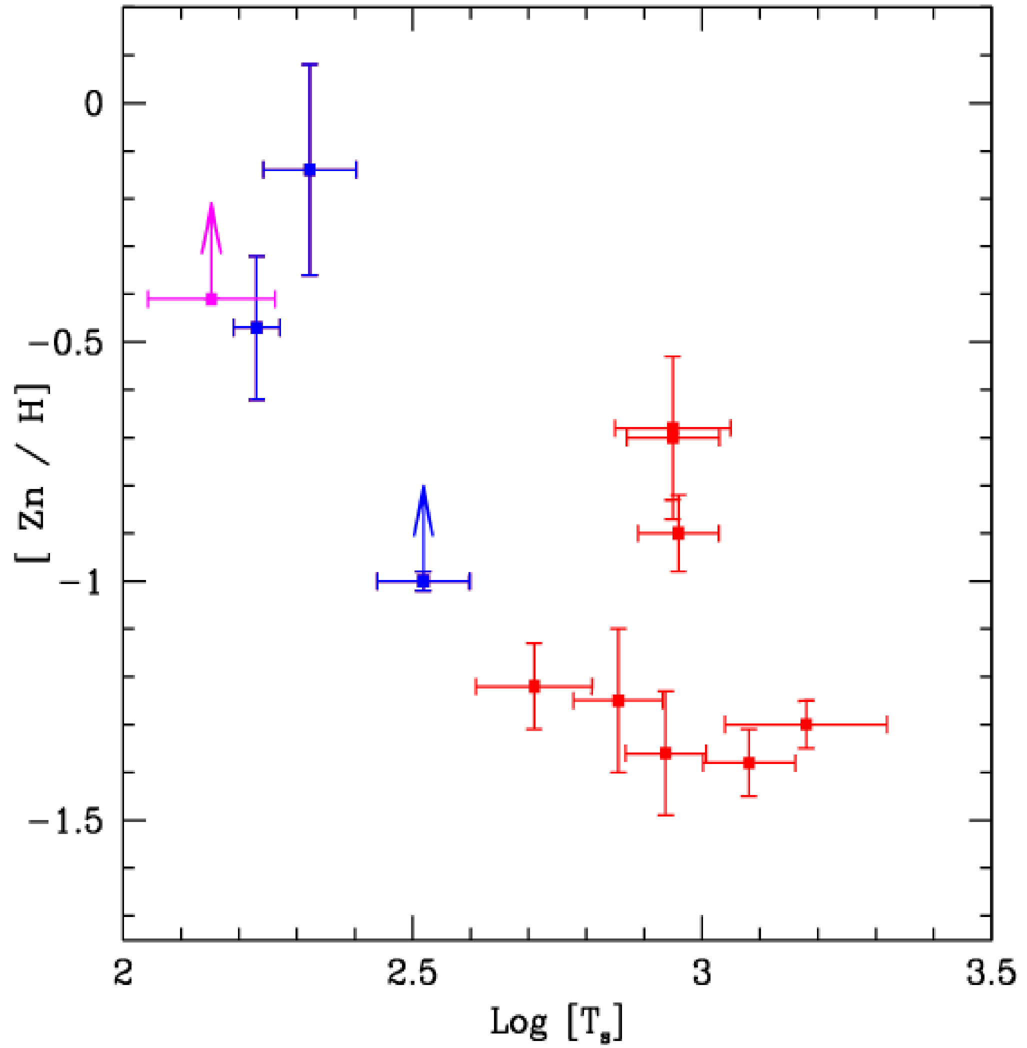
  5 of 14 DLAs at $z < 1.5$ have low T_s (< 300 K)

- 25 DLAs have estimates of T_s and metallicity [Zn/H],

  10 at $z < 1$ and 15 at $z > 1.7$.

Metallicity v/s Spin temperature





Kendall–τ test ⇨ 3.5σ anti-correlation !

All known effects can only worsen the correlation.

Mapping 21cm absorption in high-z DLAs

- 21cm emission maps ⇨ HI mass, size, regular v/s disturbed kinematics, dynamical mass.

- ~ 360 SKA hours needed to detect M^*_{HI} at $z \sim 2.5$!

- 21cm absorption maps ⇨ Kinematics and spatial extent of gas against extended radio structure.

Optical-depth-weighted velocity field.

Lower limit to HI mass, assuming $T_S \sim 100$ K.

Lower limit to transverse size.

Model velocity field ⇨ Derive dynamical mass.

Mapping 21cm absorption in high-z DLAs

- Limited by poor spatial resolution at 21cm frequency

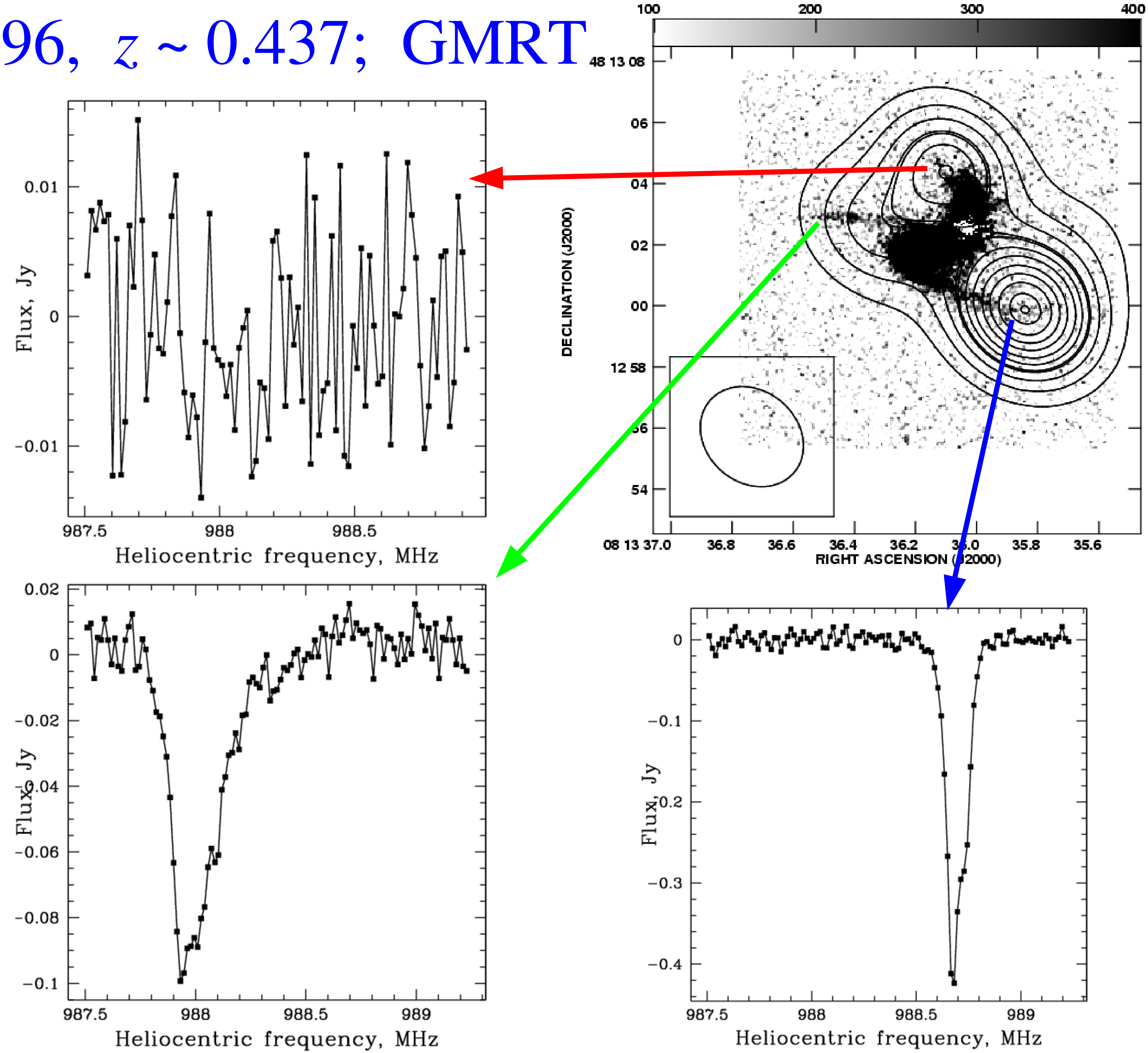
- $z \sim 2.04$ DLA towards 0458-020 ⇨ Match between single-dish and VLBI profiles gives size > 8 kpc.

(Briggs et al. 1989)

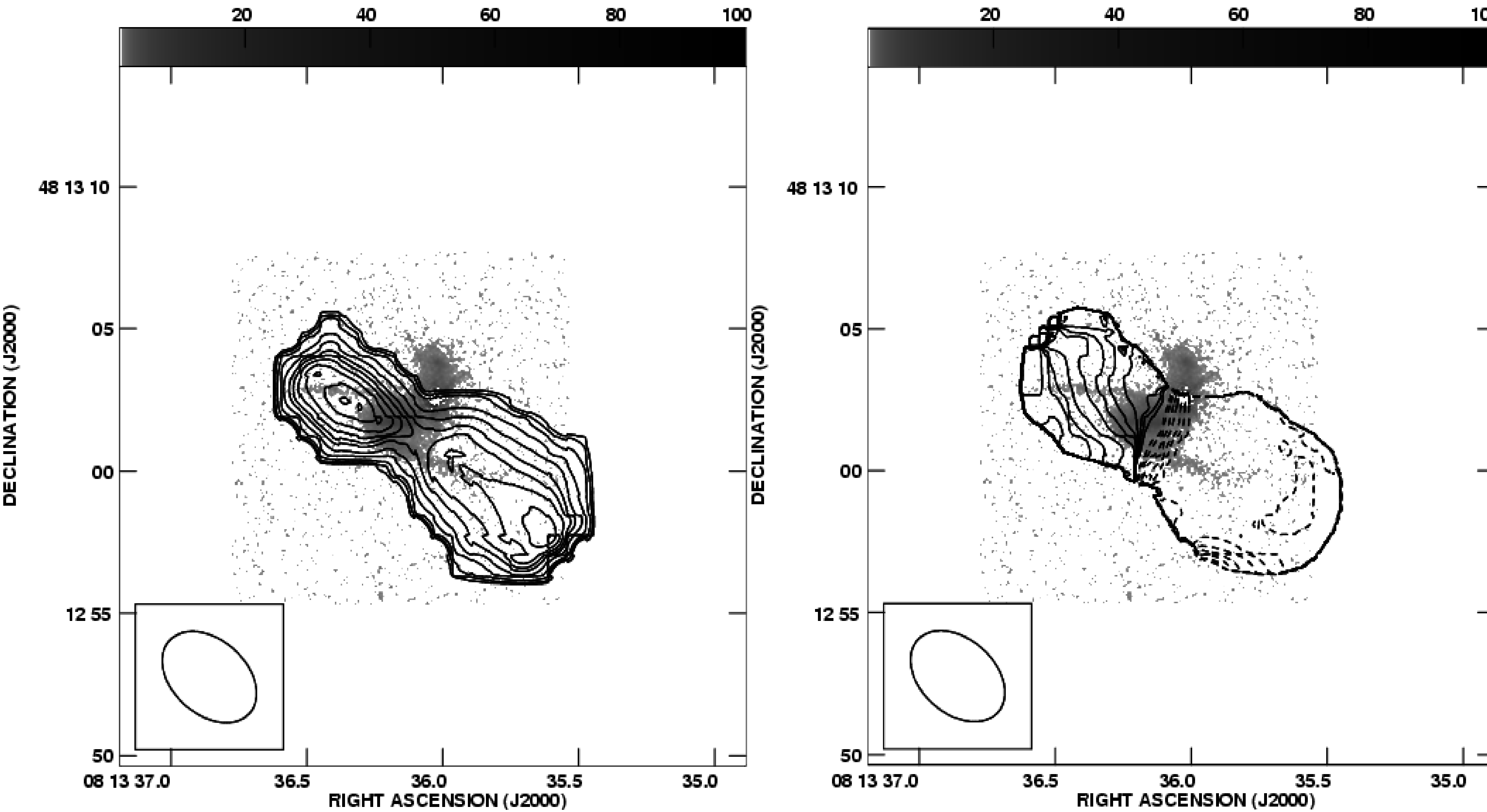
- $z \sim 0.437$ DLA towards 3C196 ⇨ Source unresolved but shift in peak centroid as a function of frequency allows absorption location to be determined !

(Briggs et al. 2001)

3C196, $z \sim 0.437$; GMRT

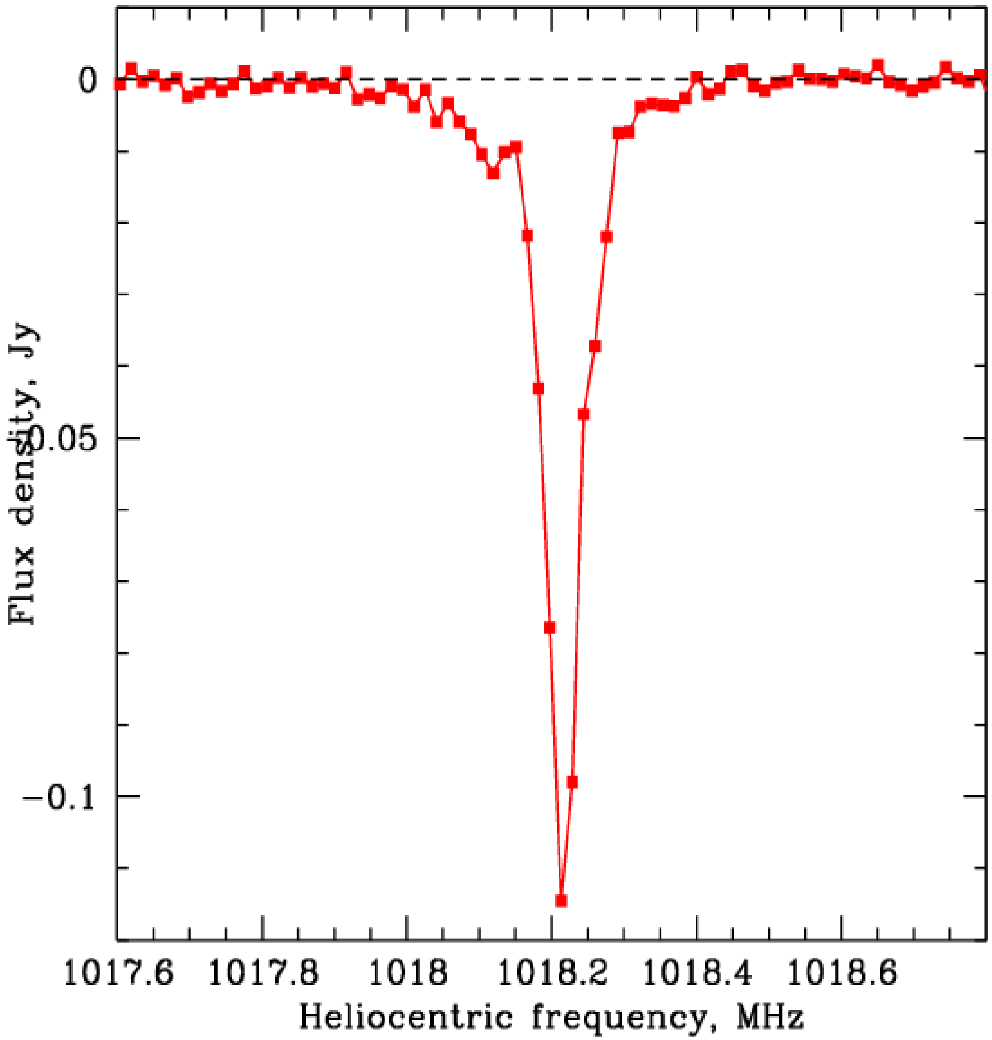


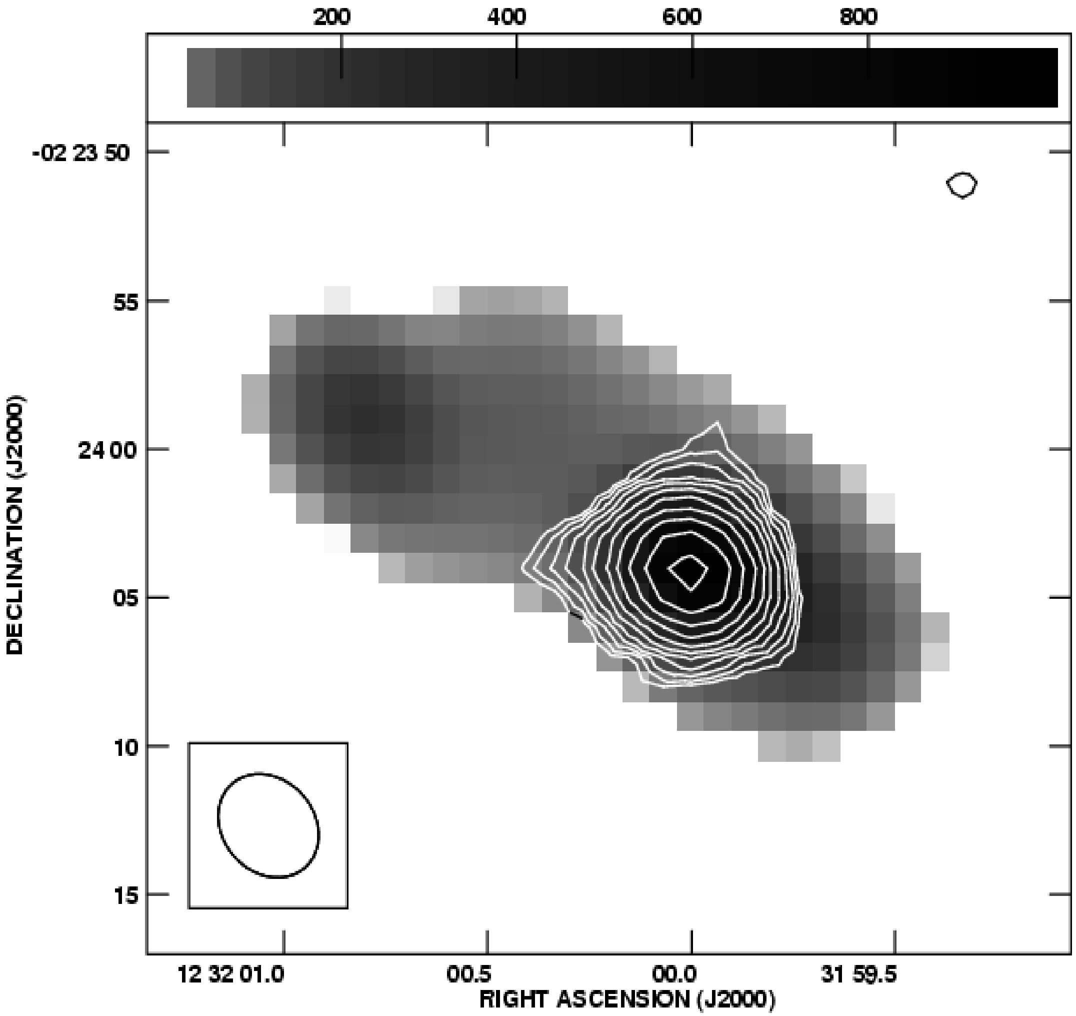
3C196; z ~ 0.437; GMRT



(NK & Chengalur 2007;
see also Briggs et al. 2001)

1229-021; $z \sim 0.395$; GMRT





(NK & Chengalur 2007;
see also Lane & Briggs 2000)

Moving to higher redshifts ?

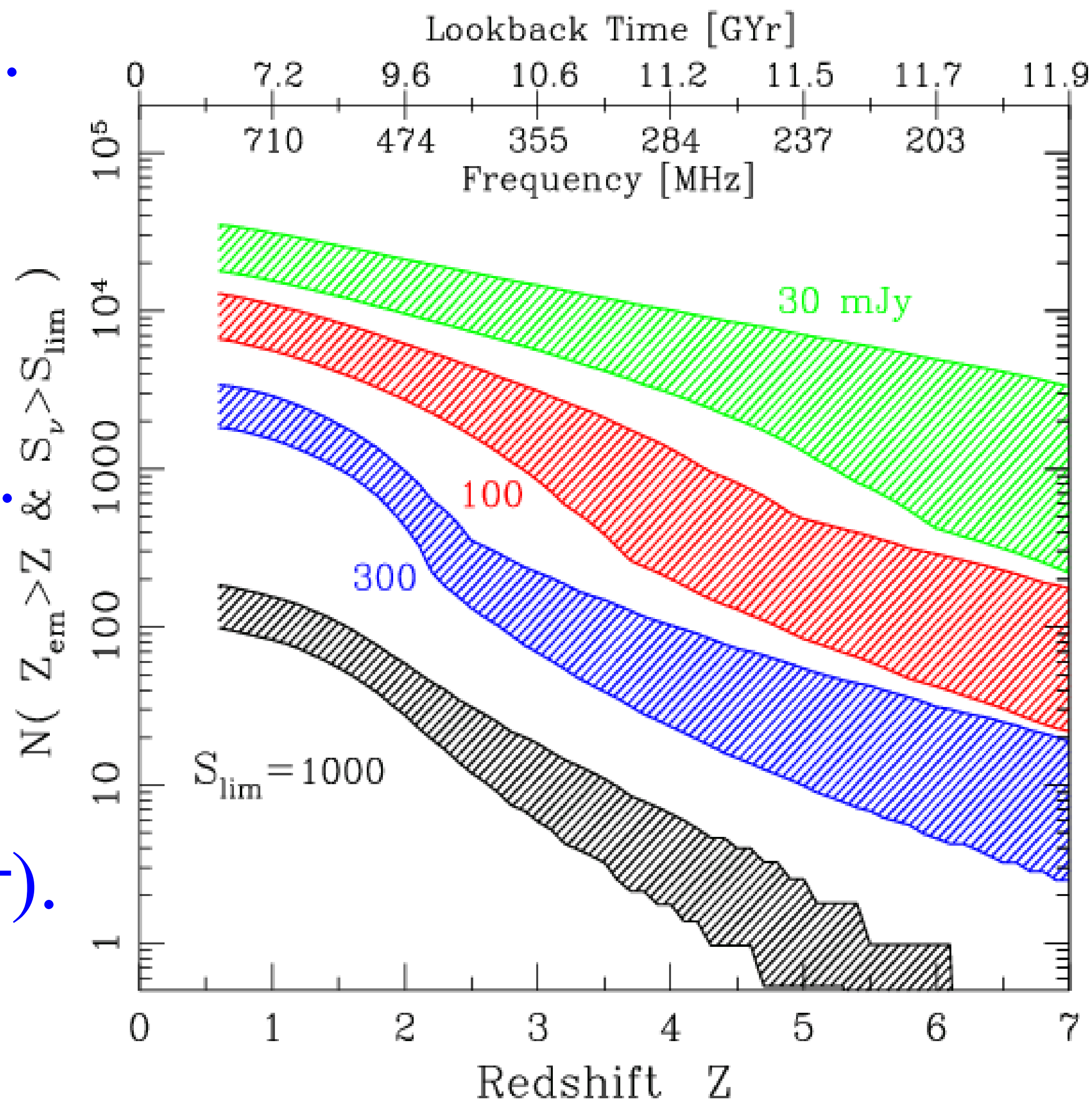
- Connected-element interferometers : Poor resolution e.g. 25 kpc at z ~ 1.4 with the GMRT

- VLBI : Excessively high resolution; resolves out source structure on scales > 0.5 kpc

- Need both good U-V coverage out to ~ 200 km baselines and good sensitivity ⇨ The SKA

"Car salesman" viewpoint

- SKA resolution ~ 500 pc.
- @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 $z \sim 2$.



(NK & Briggs 2004)

(See Carilli et al. 2000 for 21cm forest)

“Cassandra” perspective

- Two 21cm detections at $z \sim 3.39$ (~ 324 MHz);
  Spectral dynamic range < 1000 per ~ 10 km/s.

(Uson et al. 1991; NK et al. 2007)

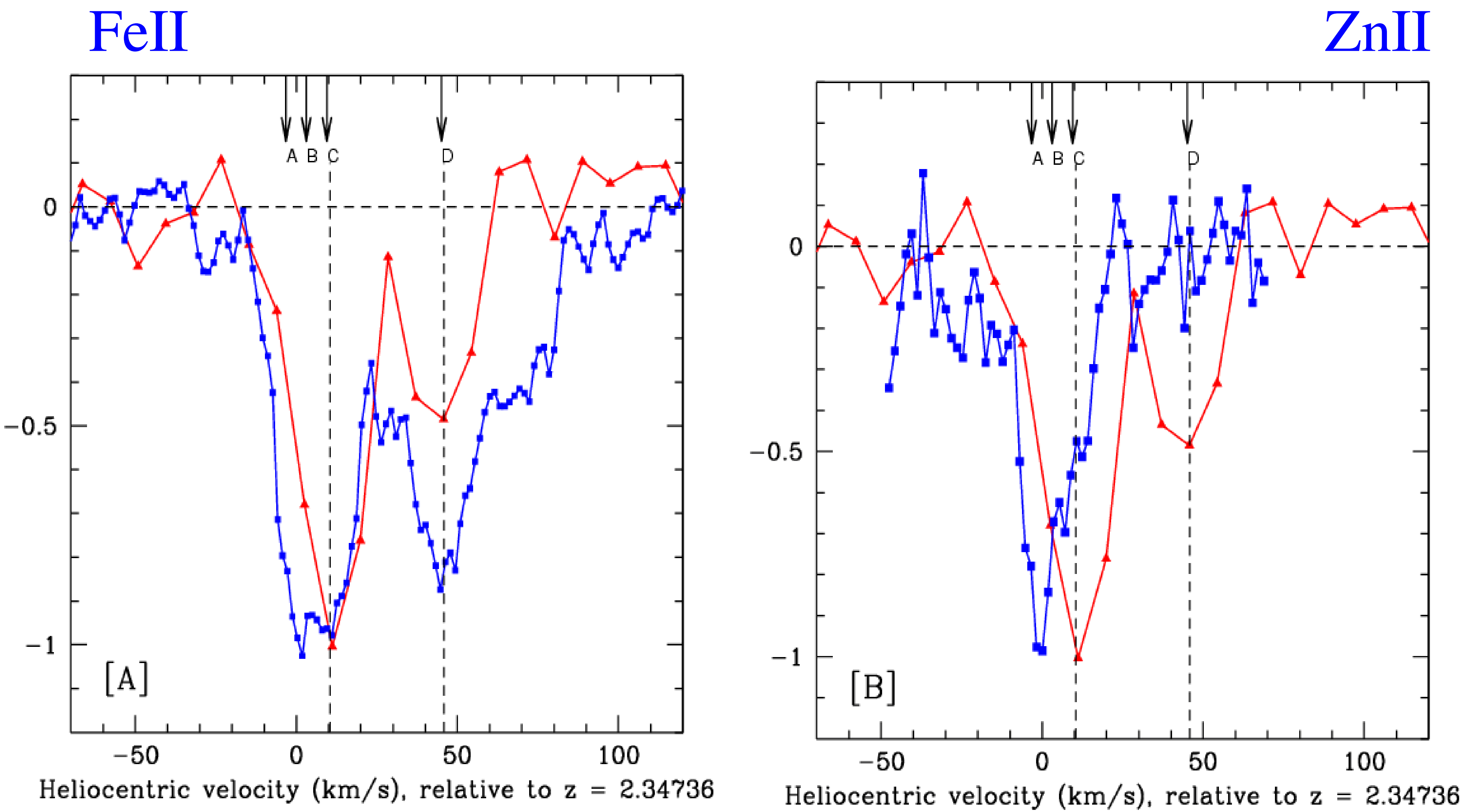
- Multiple iso-planatic patches inside the primary beam ?
- Deconvolution of bright sources (e.g. in sidelobes) ?
- Multi-frequency synthesis ?
- RFI ?
- Here comes the Sun : solar maximum coming up.

(The Beatles 1965)

Summary

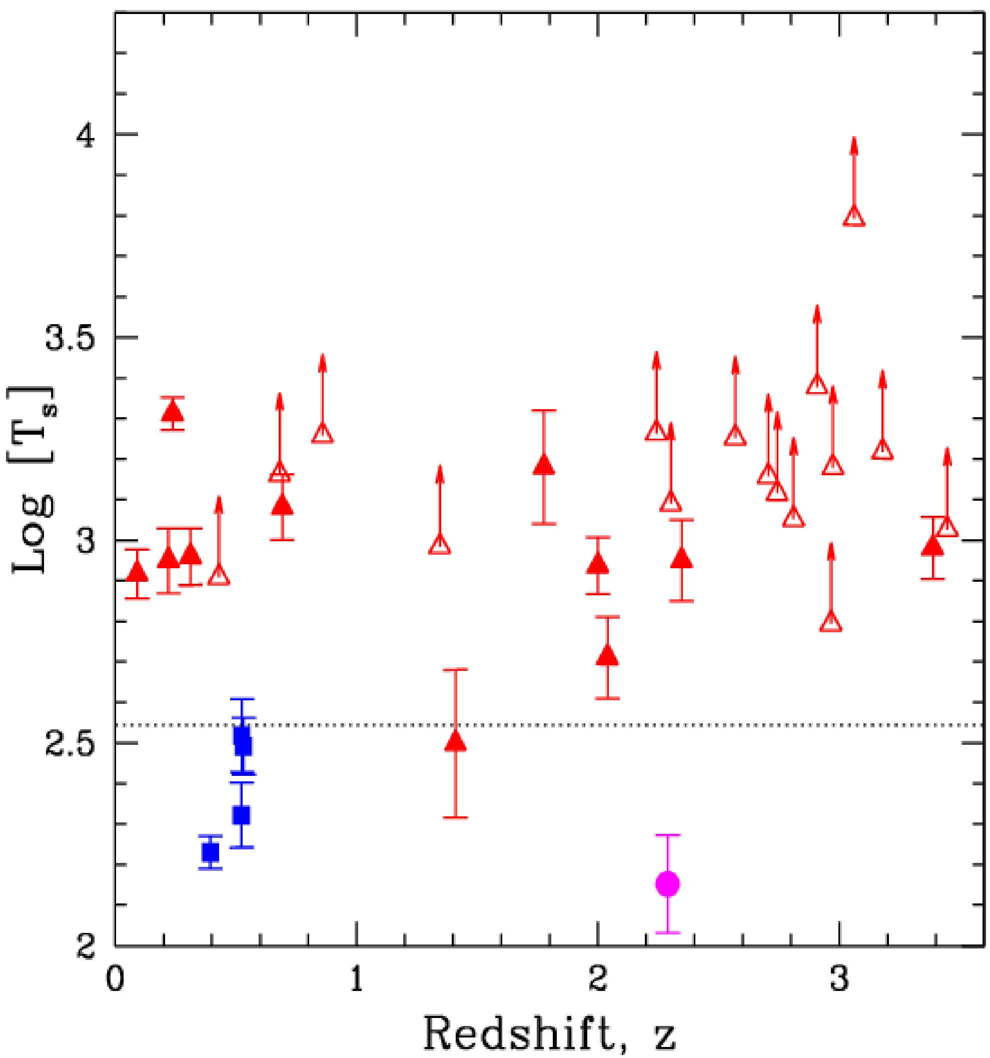
- 32 T_S estimates; 17 of 18 high-z DLAs have high T_S. First $z > 0.6$ low T_S DLA discovered.
- Covering factor not a significant issue.
- 3.5σ anti-correlation between T_S and [Zn/H]
  ⇨ High T_S appears due to higher WNM fraction.
- Ten new 21cm absorbers in the redshift desert.
- Extended 21cm absorption detected in 2 $z \sim 0.4$ DLAs.
- Still a long way to go !

0438-436; z ~ 2.347

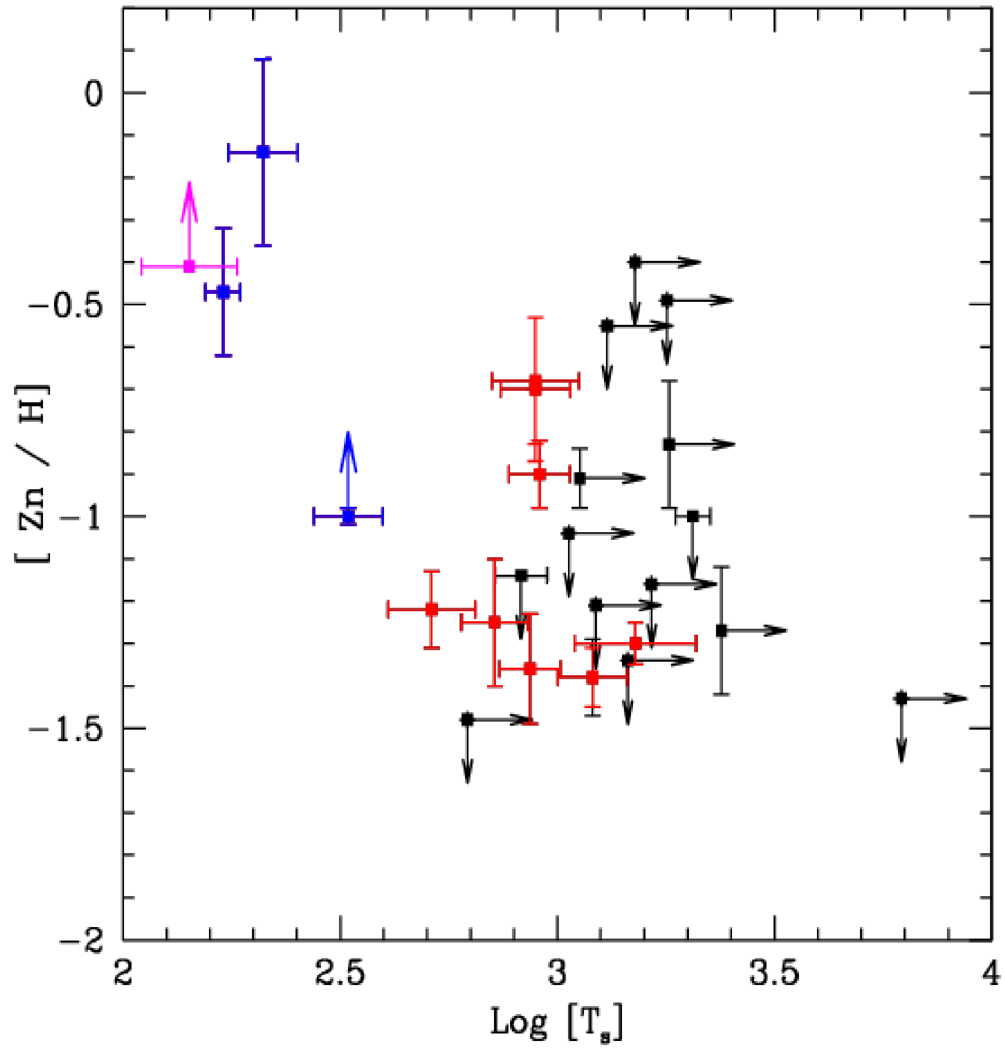


(NK et al. 2006)

Metallicity v/s T_S

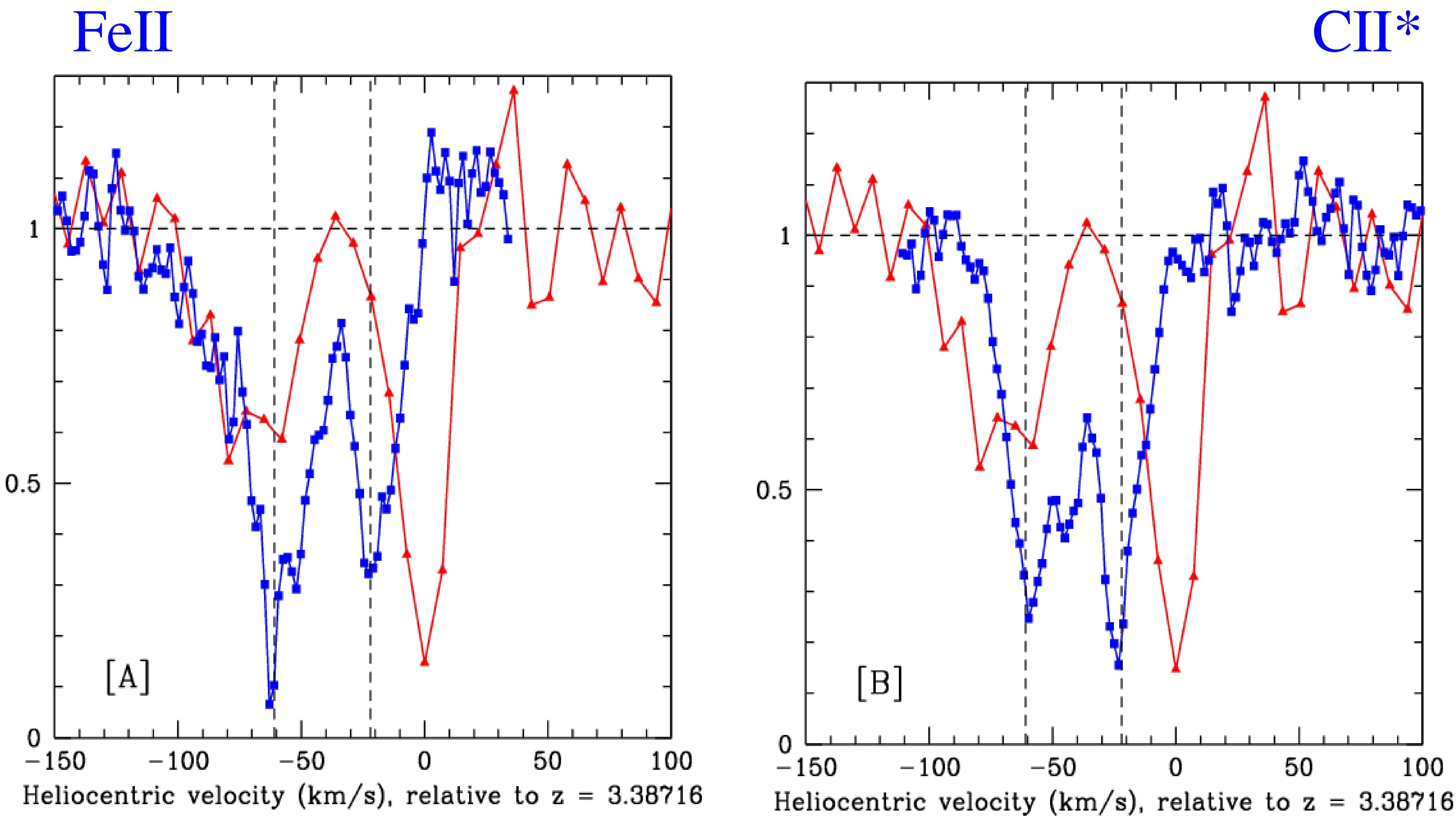


T_S v/s redshift, z

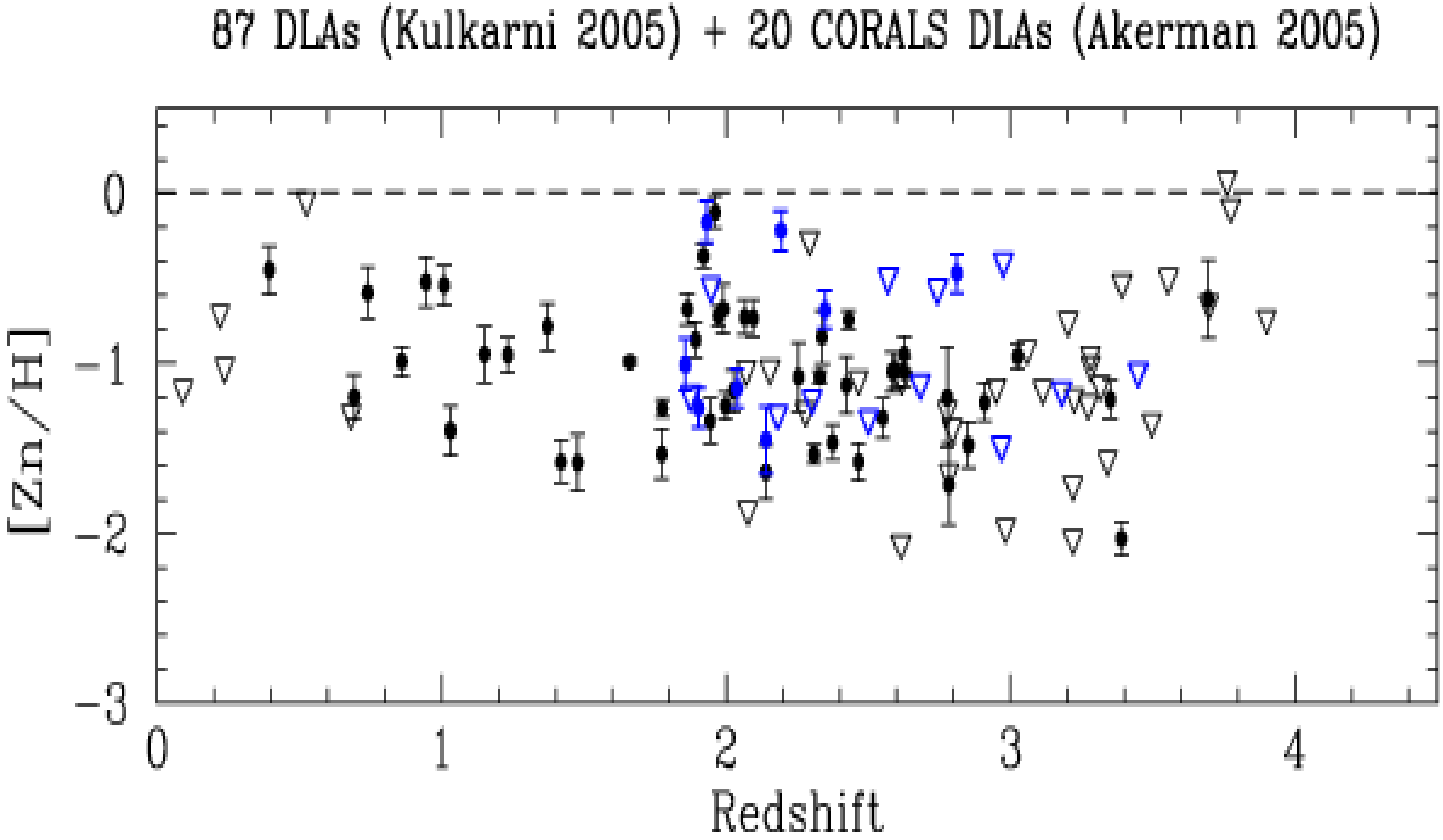


(NK et al. 2007)

0201+113; z ~ 3.387



(NK et al. 2007)



(Akerman et al. 2005)

21cm ABSORPTION IN MgII SYSTEMS

- Very few DLAs in the redshift desert, $0.7 < z < 1.7$
- Strong MgII absorption (EW > 0.5) ⇨ High N_{HI}

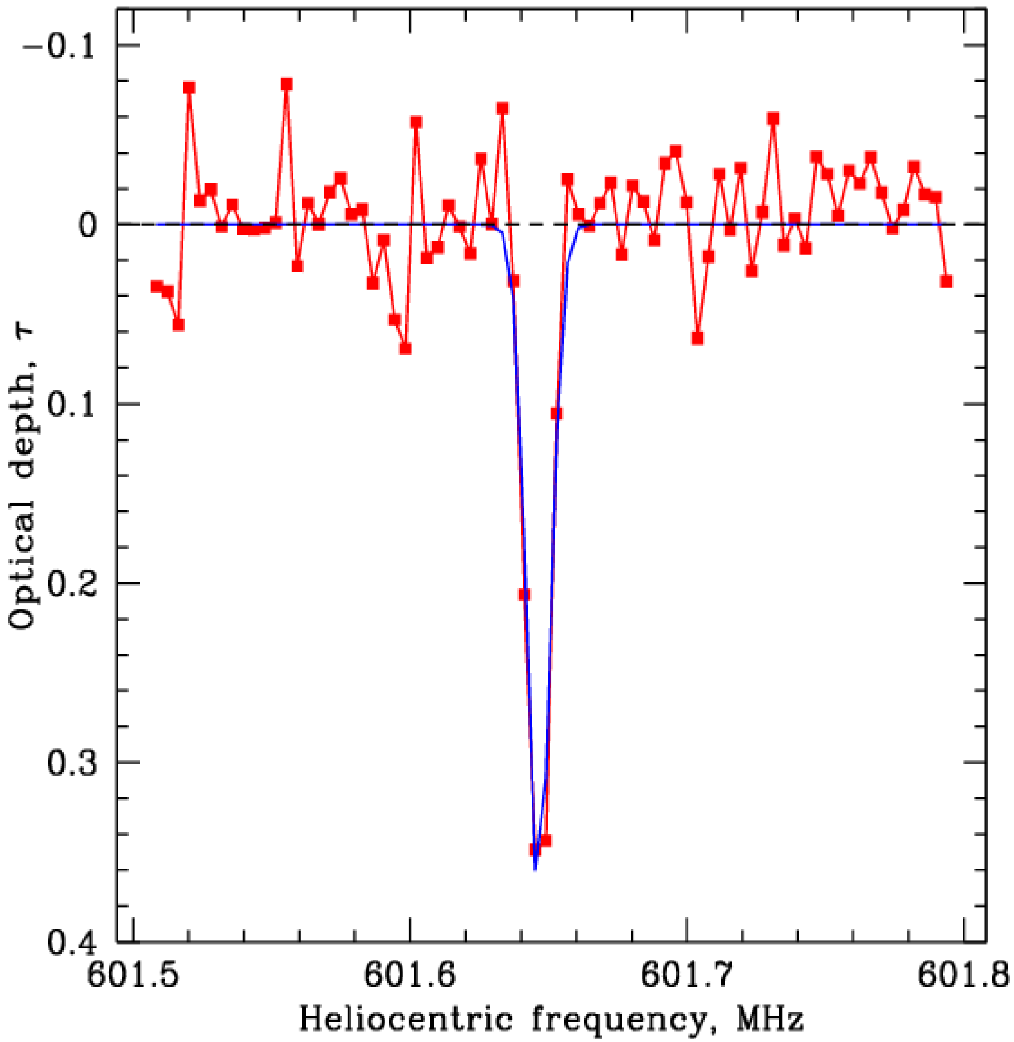
(Rao & Turnshek 2000; Rao et al. 2005)

- SDSS ⇨ Large MgII samples ; $0.5 < z < 2.1$
- 35 MgII systems observed with GBT & GMRT :

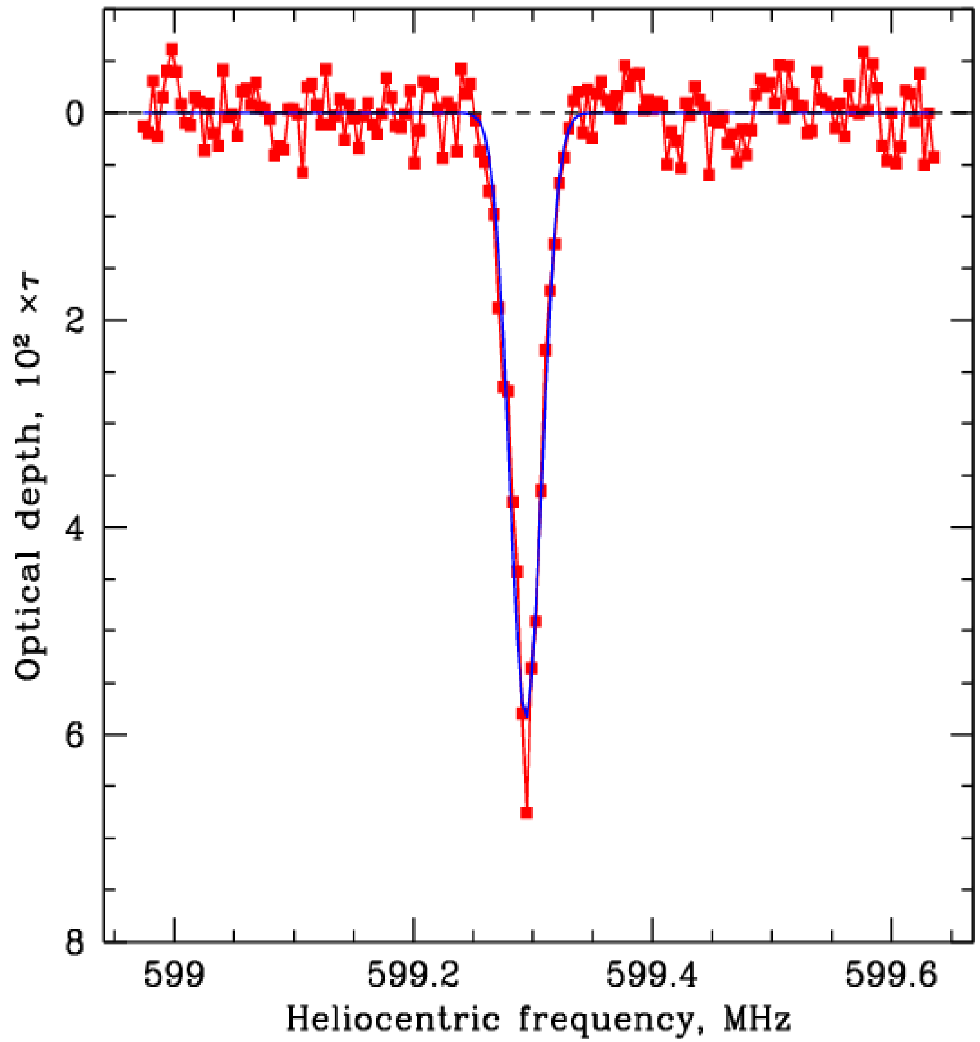
  Four detections at $1.361 < z < 1.561$;

  Three candidates at $z \sim 1.001, 1.068, 1.672$.

2340-005; z ~ 1.361; GMRT



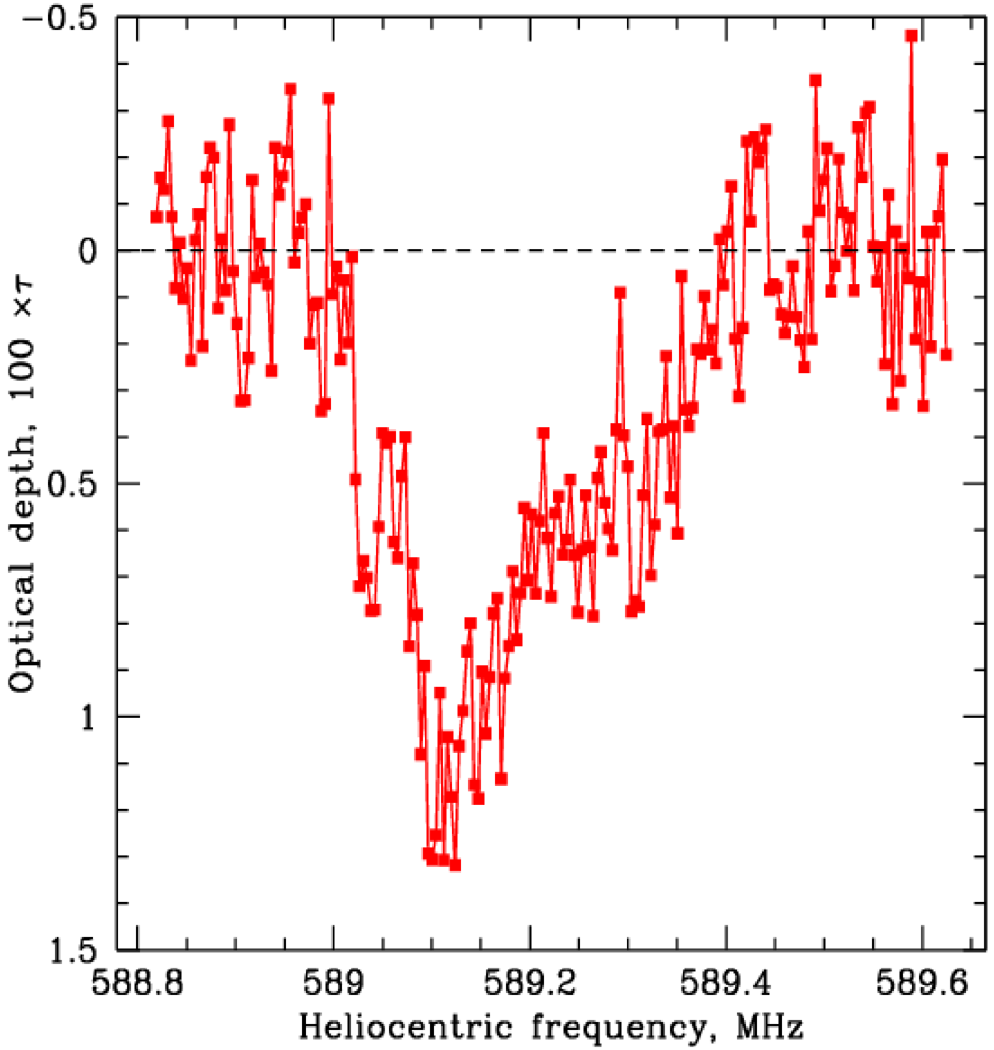
0105-008; z ~ 1.371; GMRT



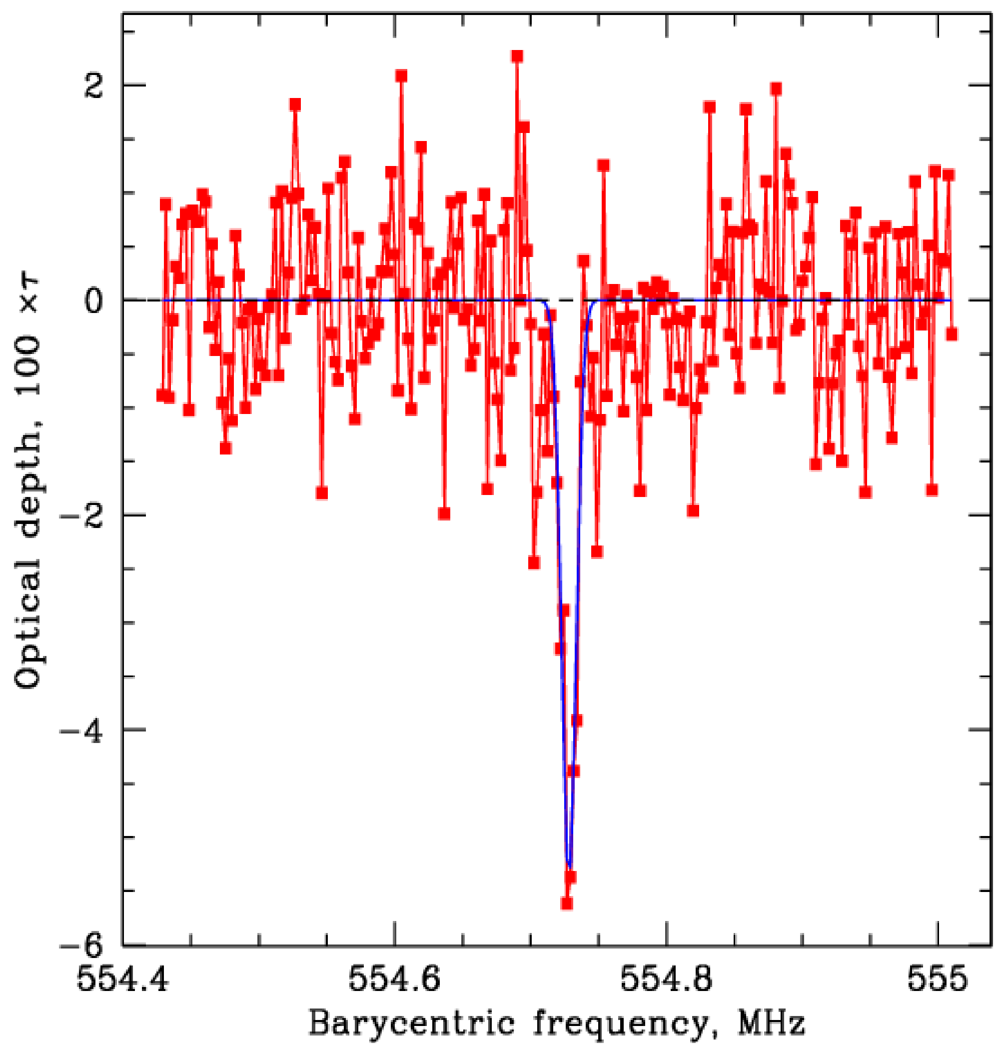
(NK et al. 2007;

see also Gupta et al. 2006)

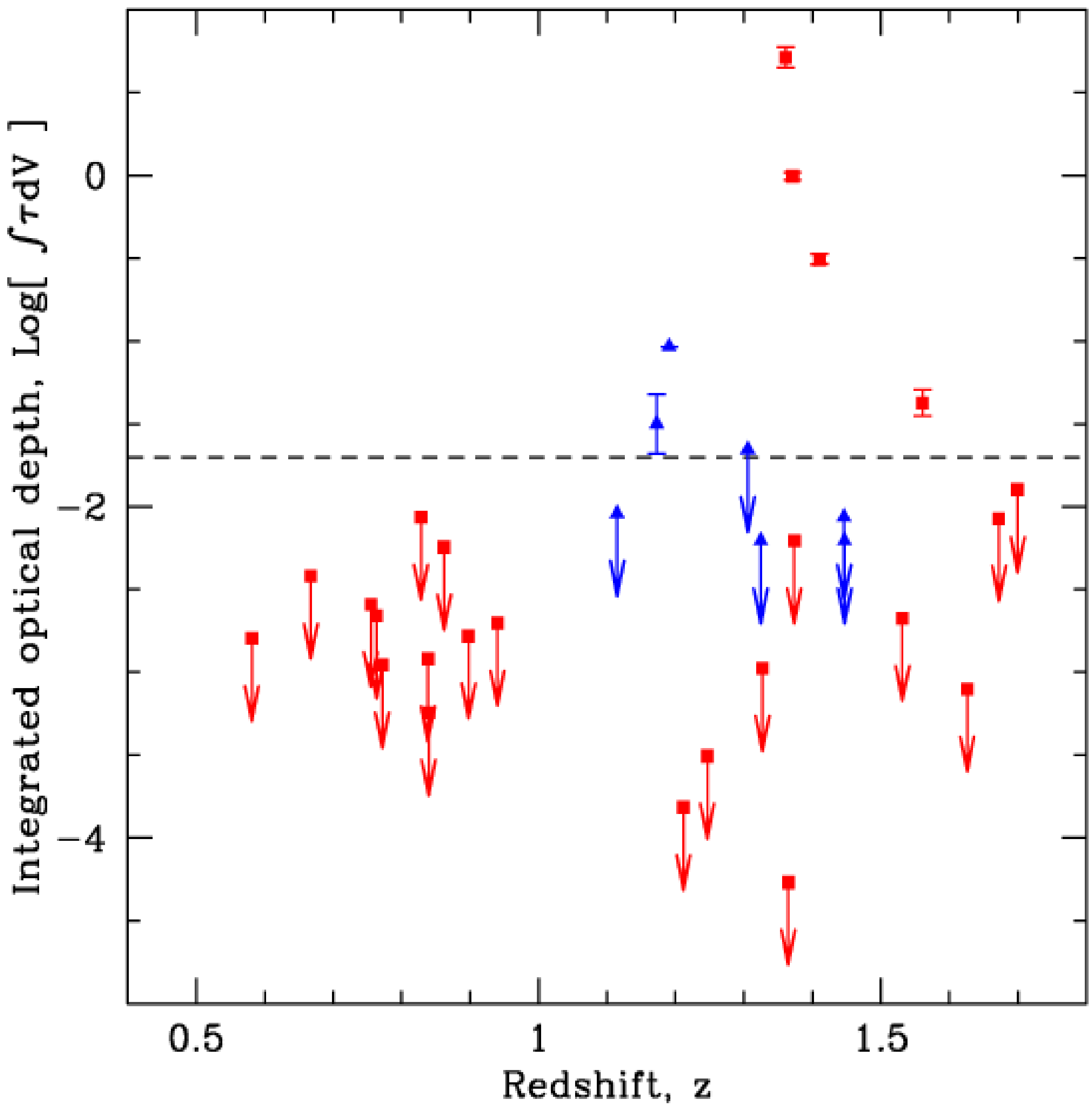
2003-025; z ~ 1.410; GMRT



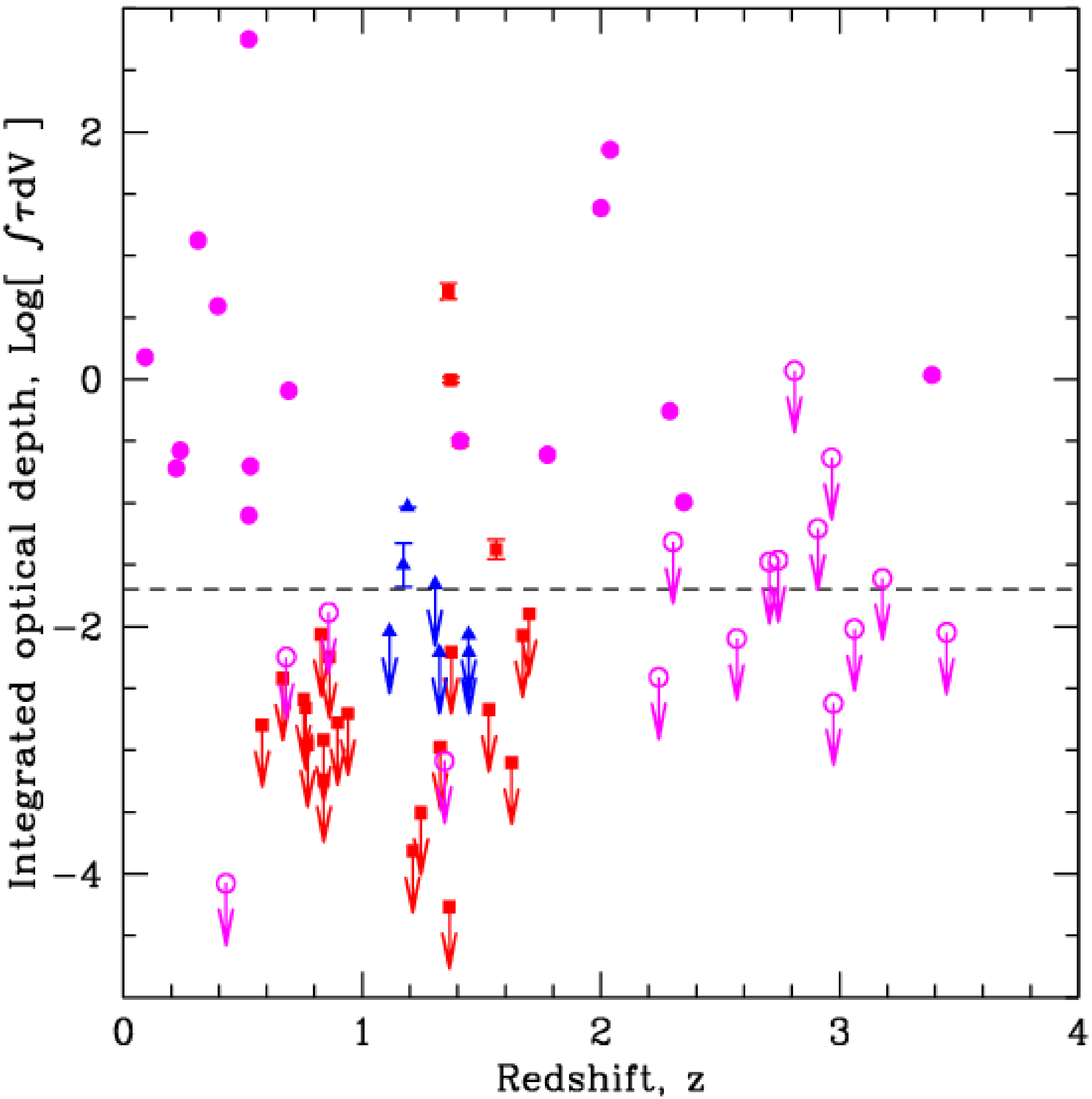
0458-020; z ~ 1.561; GBT



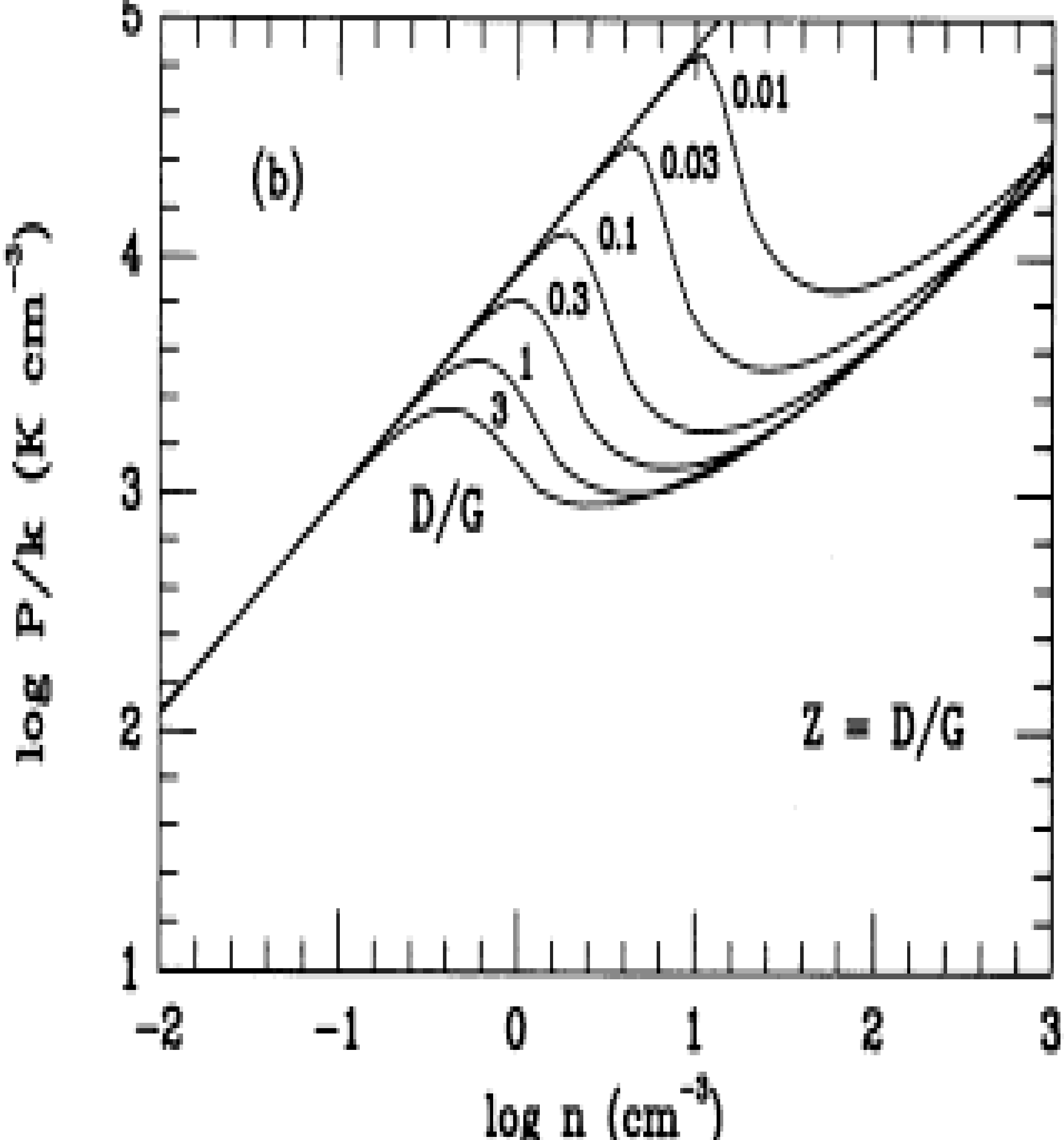
(NK et al. 2007)



(Gupta et al. 2006
NK et al. 2007)



(Gupta et al. 2006;
NK et al. 2007)



(Wolfire et al. 1995)

DAMPED LYMAN-α SYSTEMS (DLAs)

- HIGH HI COLUMN DENSITY, $N_{HI} > 2 \times 10^{20}$ cm^{-2}
- Ω_{HI} (z ~ 3) ≈ Ω_{STARS} (z ~ 0) ; ``NORMAL'' GALAXIES
- NATURE OF DLAs, PHYSICAL CONDITIONS ???

  LARGE DISKS v/s SMALL MERGING SYSTEMS ?

  TEMPERATURE, METALLICITY, etc ?
- LYMAN-α AT 1216 A ⇨ MOST DLAs AT z > 2 (> 1000 !)
- GOOD METALLICITIES AT z > 2; IMAGES AT z < 0.7