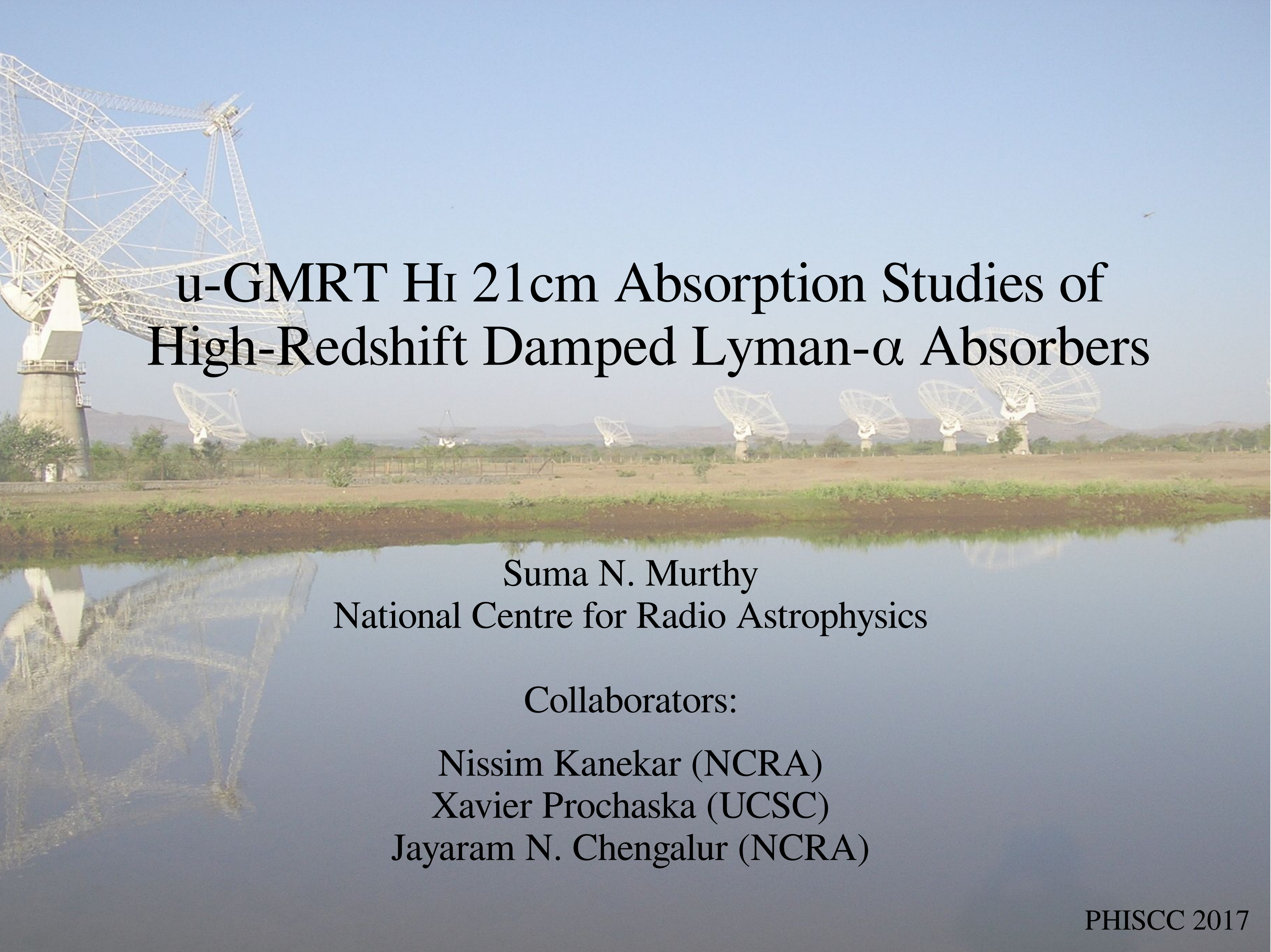

u-GMRT HI 21cm Absorption Studies of High-Redshift Damped Lyman-α Absorbers

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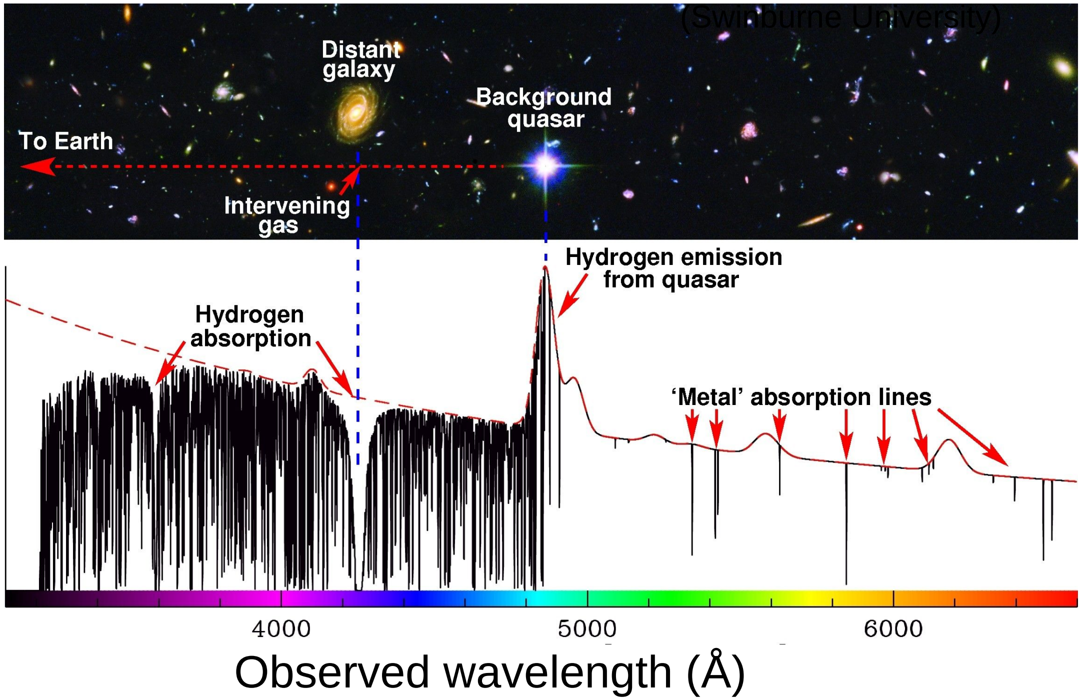
Outline

- Introduction: Damped Lyman-α Absorbers (DLAs).
- HI 21cm absorption studies: The spin temperature.
- Earlier HI 21cm studies of DLAs.
- The upgraded Giant Metrewave Radio Telescope.
- An HI 21cm absorption survey of DLAs.
- The spin temperature of high-redshift DLAs.
- Summary.

Damped Lyman-α Absorbers

(Swinburne University)



- QSO absorbers selected for N(HI) ≥ 2 x 10^{20} cm^{-2}.

  (e.g. Wolfe et al. 2005)

- Absorption-selected ⇒ No luminosity bias.

- Dominate the neutral gas content of the Universe at redshifts > 2.

- Main probe: Optical absorption spectroscopy. Provides abundances, metallicity, dust depletion...

- More than 10,000 DLAs with $z > 2$. Metallicity estimates ~ 300 DLAs.

  (e.g. Noterdaeme et al. 2012, Rafelski et al. 2012)

- Optical imaging of high-z hosts is difficult: Nature of high-z DLAs unclear.

HI 21cm Absorption Studies

- For a radio loud background quasar, the integrated HI 21cm optical depth and HI column density (from Ly-α absorption / HI 21cm emission) give the spin temperature T_s (the HI 21cm line excitation temperature).

(e.g. Rohlfs & Wilson 2006)

$$N_{HI} = 1.82 \times 10^{18} \times (T_s / f) \times \int \tau \, dV$$

- Single cold cloud: Spin temperature ~ Kinetic temperature.
  Single warm cloud: Spin temperature $\lesssim$ Kinetic temperature.

(e.g. Liszt 2001)

- Multiple phases: Column density weighted harmonic mean of T_s of each phase.

- 50% WNM at 8000 K, 50% CNM at 100 K : $T_s \sim 200$ K.
  90% WNM at 8000 K, 10% CNM at 100 K : $T_s \sim 900$ K.

- 90% of Galactic sightlines: $T_s < 300$ K: Cold gas fraction of ~ 40%.

(e.g. Braun & Walterbos 1992)

- For DLAs, can probe the redshift evolution of T_s, cold gas fraction.

Earlier HI 21cm Studies of DLAs

- First HI 21cm absorption study: $z = 0.692$ DLA towards 3C286.

  (Brown & Roberts 1973)

- Until 2000: Few studies: 3 detections at $z > 2$. Issues: Sensitivity, RFI, redshift coverage.

  (e.g. Wolfe & Davis 1979, Wolfe et al. 1981, 1985)

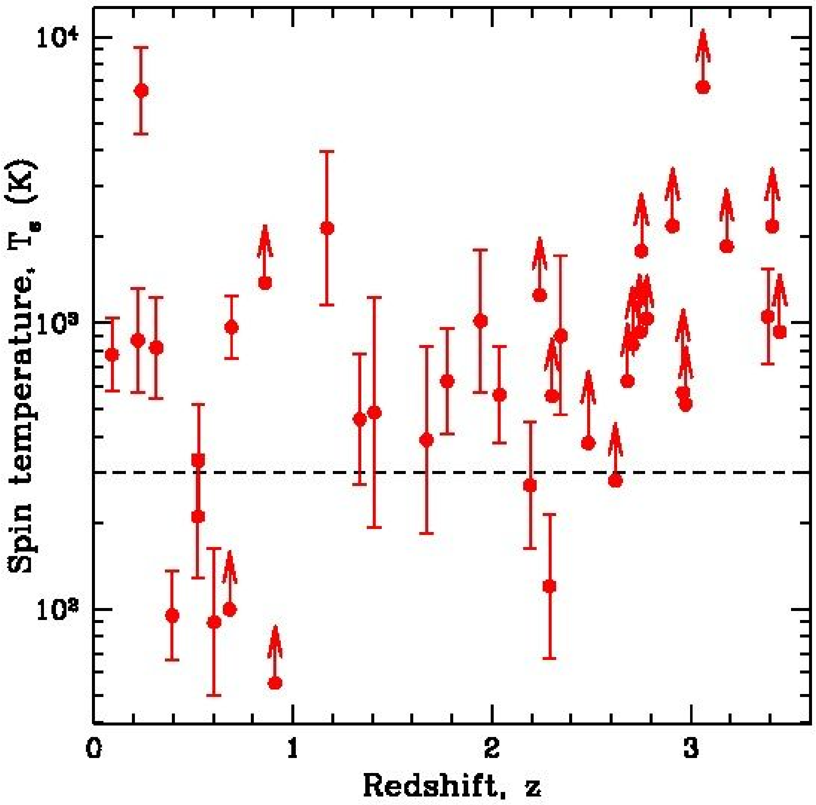
- GMRT/GBT: 20 DLAs, 4 detections at $z > 2$.

  (e.g. York et al. 2007, Kanekar et al. 2006, 2007)

- Redshift evolution: T_s higher at high redshift?

  (Kanekar et al. 2014)

- T_s typically higher in DLAs than in the Milky Way.

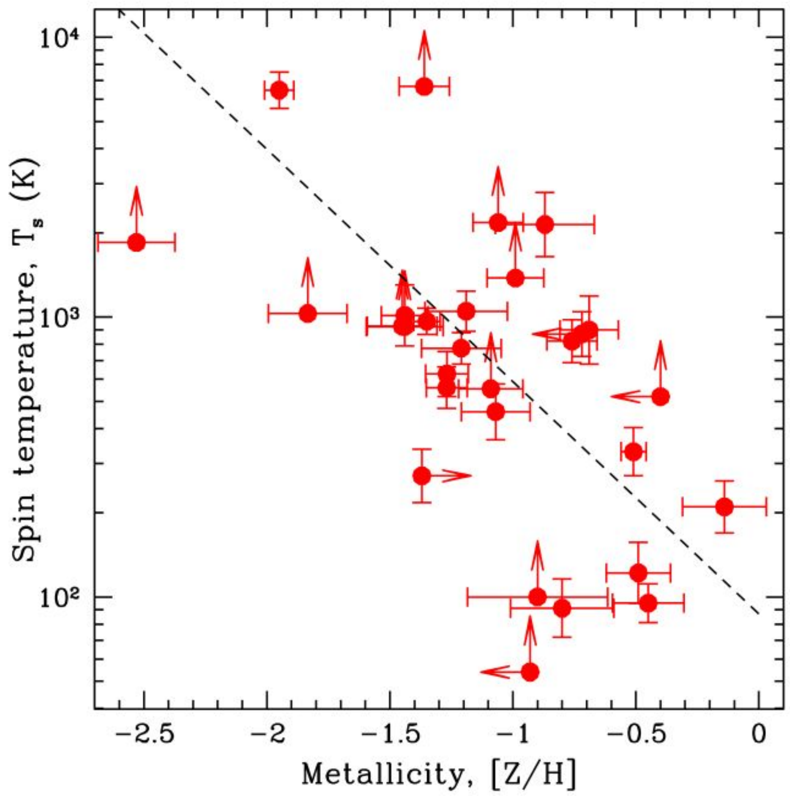


Earlier HI 21cm Studies of DLAs

- Reason for high T_s in high-redshift DLAs : Paucity of metals?

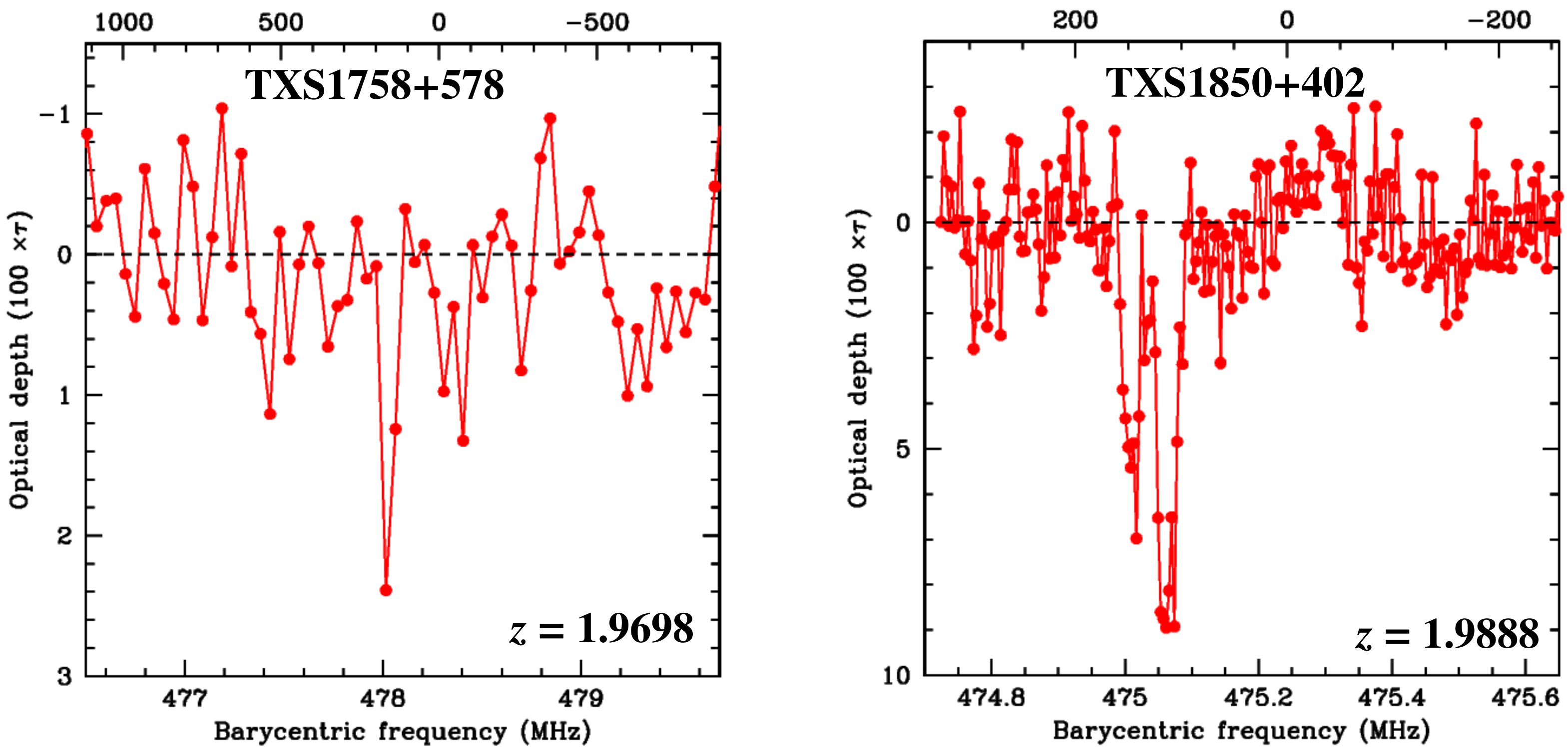
- Low DLA metallicity ⇒ High spin temperature. (Kanekar & Chengalur 2001)

- T_s – metallicity anticorrelation ~ 3.5σ significance. (Kanekar et al. 2009, 2014)



The upgraded Giant Metrewave Radio Telescope

- 250 – 500 MHz receivers: high sensitivity and low RFI.
- 2 new detections in the commissioning phase itself.
- Only 7 detections before this at $z > 1.7$.



(Kanekar 2014)

HI 21cm Absorption Survey of DLAs

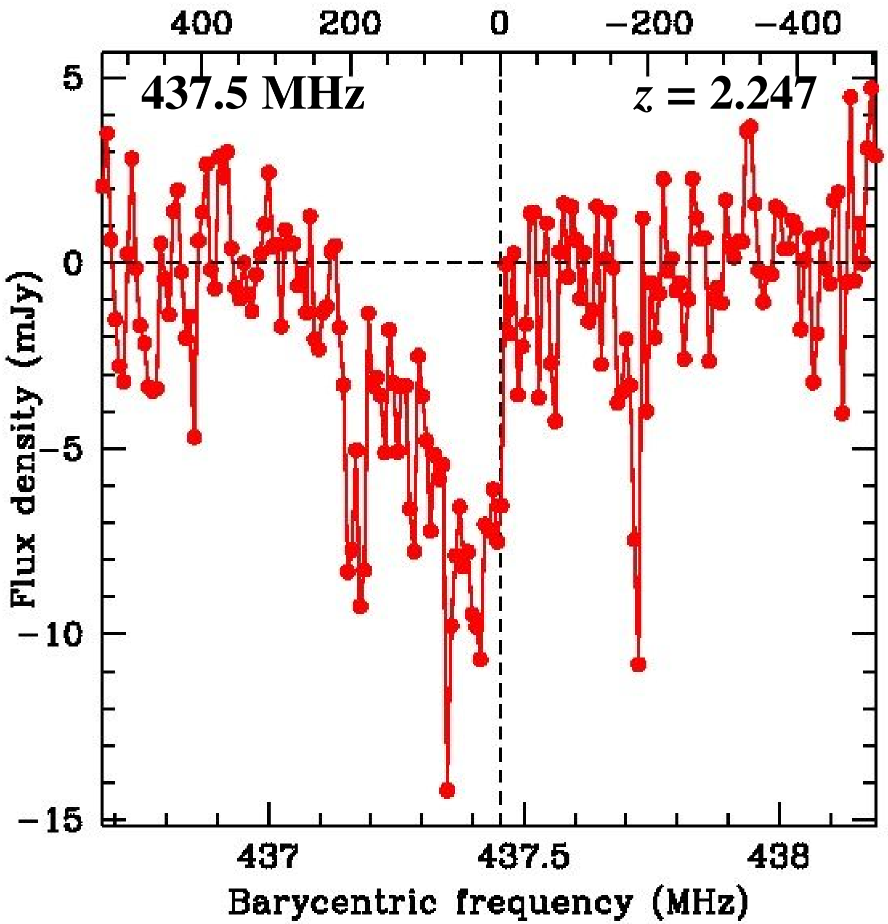
- Sample from the Sloan Digital Sky Survey : DLAs towards radio loud quasars with 1.4 GHz flux density > 100 mJy.
  (e.g. Prochaska et al. 2005, Notredaeme et al. 2012)
- 56 DLAs with z ~ 1.9 – 3.6: line frequencies ~ 310 – 490 MHz.
- Aims:
  - Increase number of T_s estimates in high-z DLAs; test for T_s evolution.
  - Increase the number of HI 21cm absorbers at high redshift.
  - Probe the dependence of T_s on metallicity, dust depletion.
  - Redshift evolution of HI 21cm detection rate $\Rightarrow$ Cold gas fraction.

Observations & Data Analysis

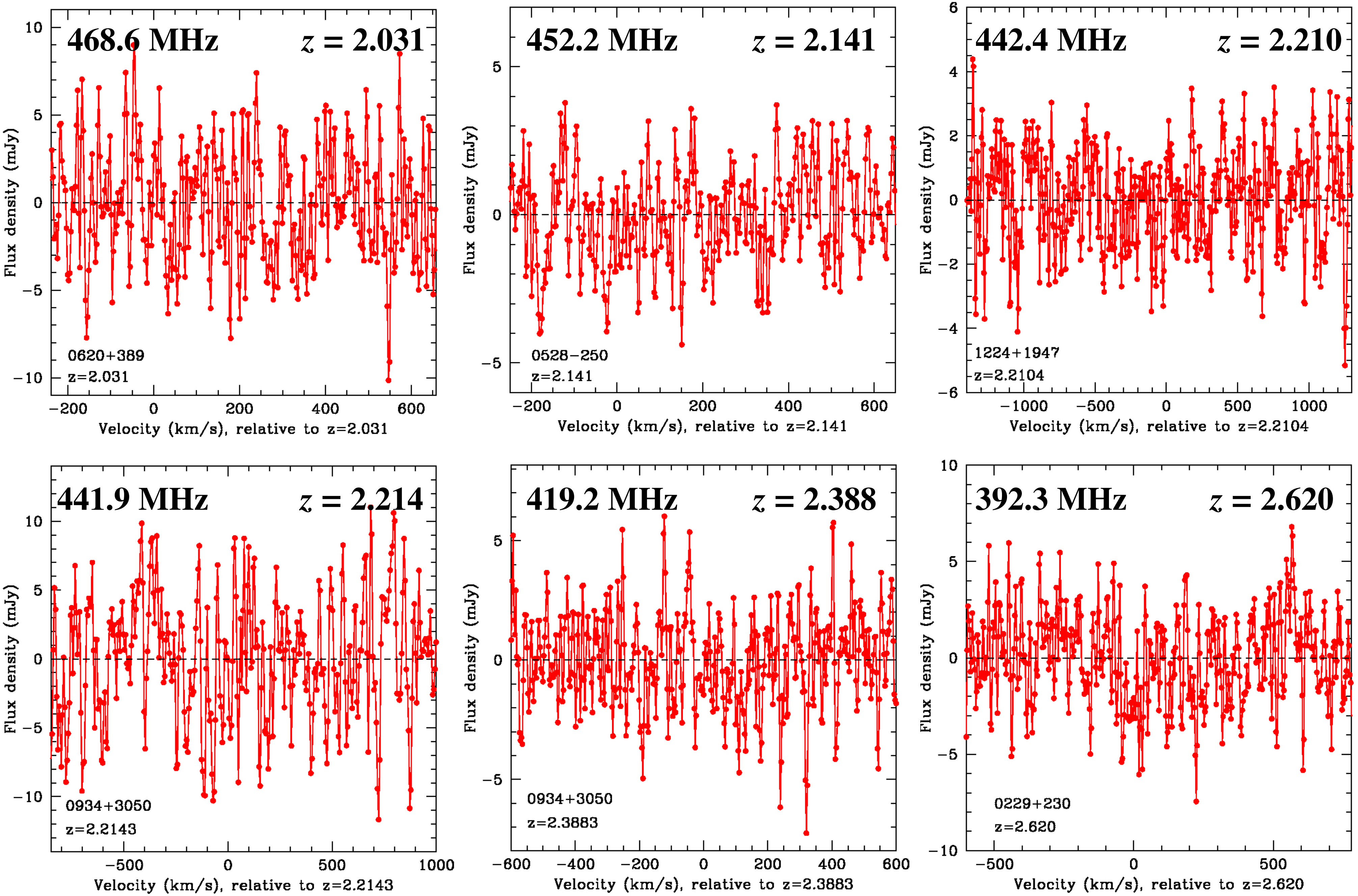
- Observations during the GMRT upgrade: ~ 15 – 20 antennas available.
- Observing time: 1 – 2 hours on source.
- Bandwidth: 2 – 4 MHz; 512 channels; 4 – 8 kHz spectral resolution.
- Standard data analysis approach using AIPS.
- 20 – 30% of data lost due to RFI. 100% loss in 2 systems (MUOS).
- Typical continuum RMS noise: 0.1 – 0.2 mJy per beam.
- Typical spectral RMS noise: 2 – 5 mJy per 15 km/s channel.
- Integrated optical depth limit (3σ): 0.1 – 0.5 km/s per 15 km/s channel.
- 30 systems analysed so far. 1 detection of HI 21cm absorption.

HI 21cm Absorption Spectra: Lone Detection

- Proximate DLA at $z = 2.247$ towards 0827+3525.
- Very high velocity width ~ 400 km/s.
- Not included in our spin temperature sample due to proximity of the AGN.



HI 21cm Absorption Spectra: Non-Detections



Redshift Evolution of Spin Temperature

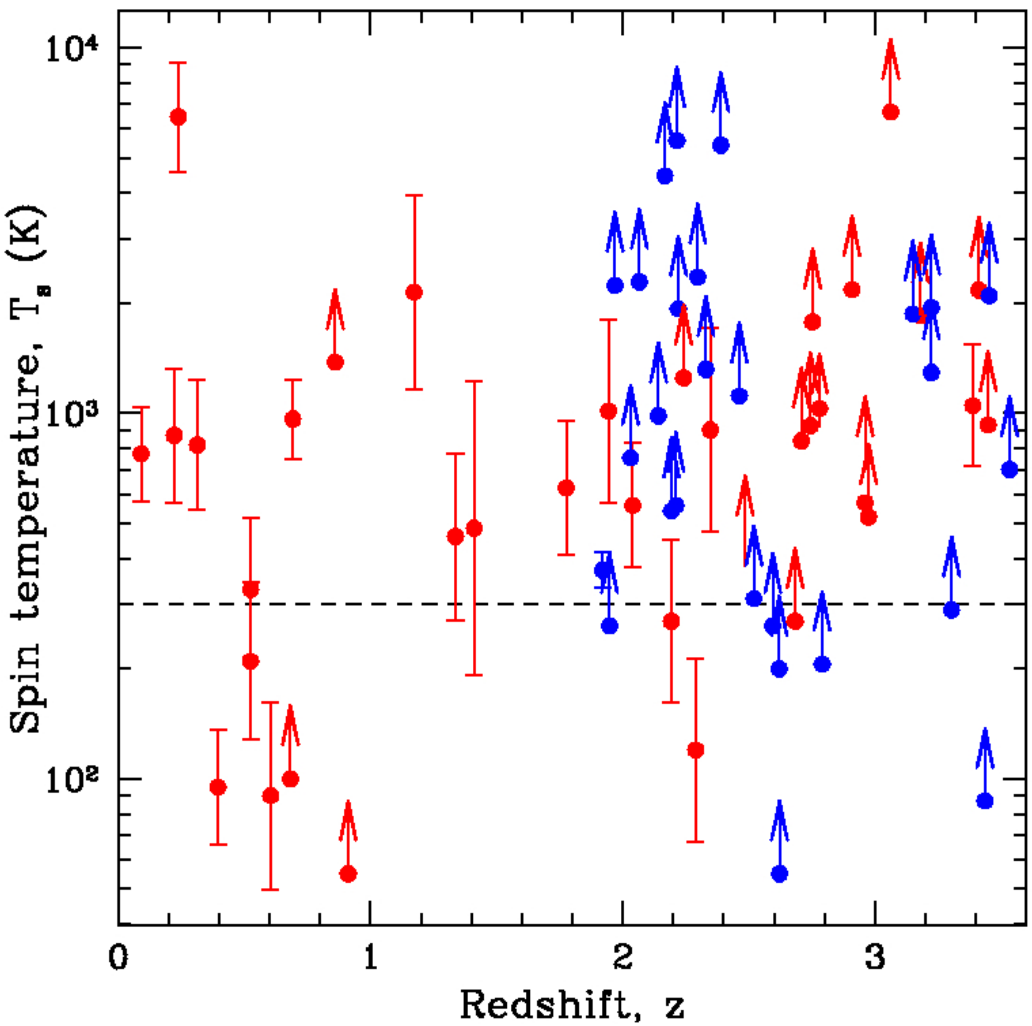
- One T_s estimate from the earlier u-GMRT observations.
(Kanekar 2014)

- 26 non-detections ⇒ Lower limits on the spin temperature.

- We have already doubled the number of T_s estimates at $z > 2$.

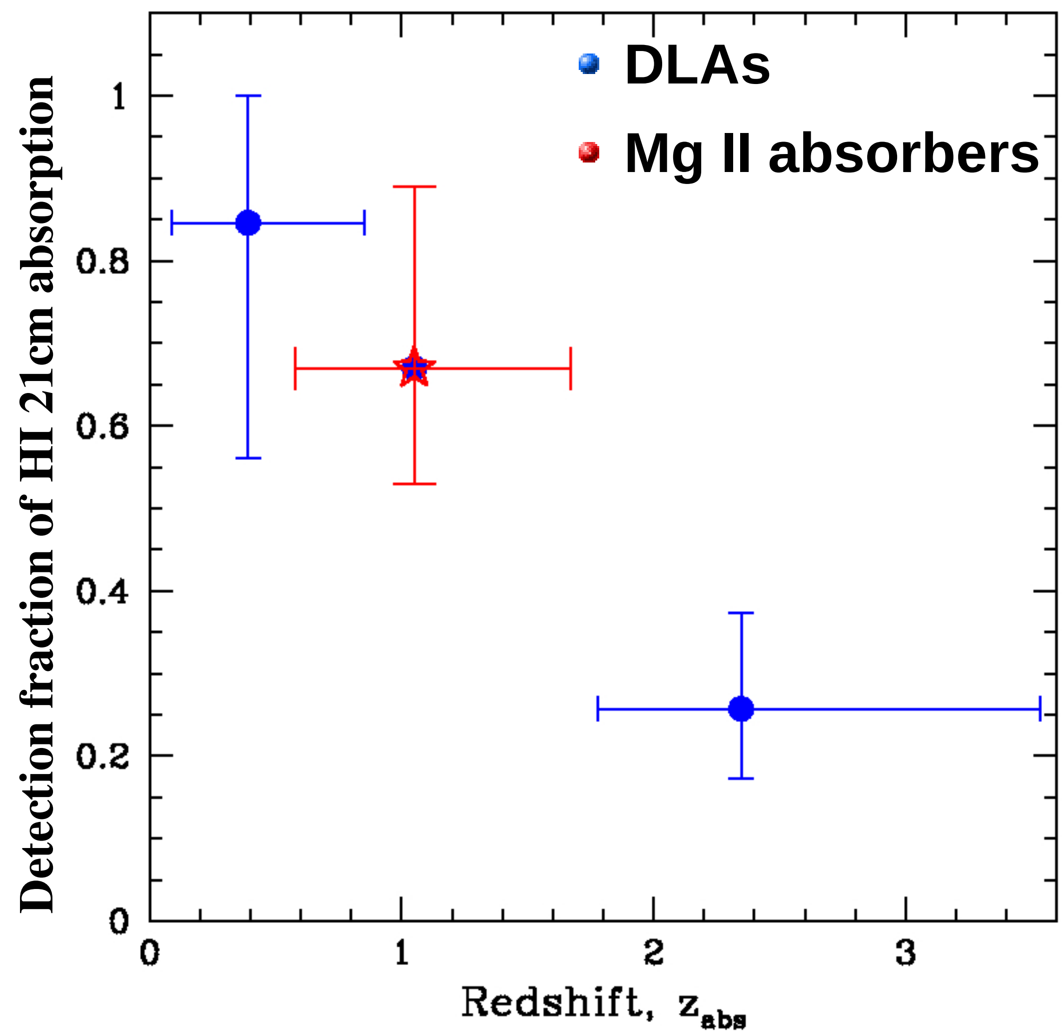
- Lack of absorption detections and high inferred spin temperatures supports the hypothesis that high-redshift DLAs have high spin temperatures.

- VLBA 327 MHz observations under way to estimate covering factors of the new DLAs.



Redshift evolution of HI 21cm Detection Rate

- High cold gas fraction ⇒ High detection rate.
- Tentative evidence for a change in the detection rate of HI 21cm absorption at $z < 1.7$ and $z > 1.7$.
- Suggests that cold gas is building up in galaxies at $z < 2$.
- Errors governed by Poisson statistics: Larger sample needed for confirmation.
- GMRT data on 26 more systems to be analysed.



Summary

- H I 21cm absorption studies of DLAs towards radio-loud quasars ⇒ Spin temperature of DLAs.
- u-GMRT 250-500 MHz receivers have opened a new window onto the conditions in DLAs through H I 21cm absorption studies.
- Aims: Increase T_s estimates and H I 21cm absorption detections at $z > 2$, probe the metallicity – spin temperature relationship, determine the detection rate of H I 21cm absorption.
- Sample: 56 DLAs with $z \sim 1.9 - 3.6$. Analysis complete for 30 DLAs.
- Already doubled the number of spin temperature estimates at $z > 2$.
- 1 detection, 26 non-detections, 18 systems with $T_s > 500$ K.
- T_s higher in high-z DLAs and significantly higher than in the Milky Way. Despite high sensitivity, remains difficult to detect high-z H I 21cm absorption.
- H I 21cm absorption detection rate increases with decreasing redshift. Low detection rate at $z > 2$ ⇒ Larger cold gas fraction in galaxies at $z < 2$.