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International Centre for Radio Astronomy Research

GMRT Observation of H I Gas in the COSMOS field at z~0.37

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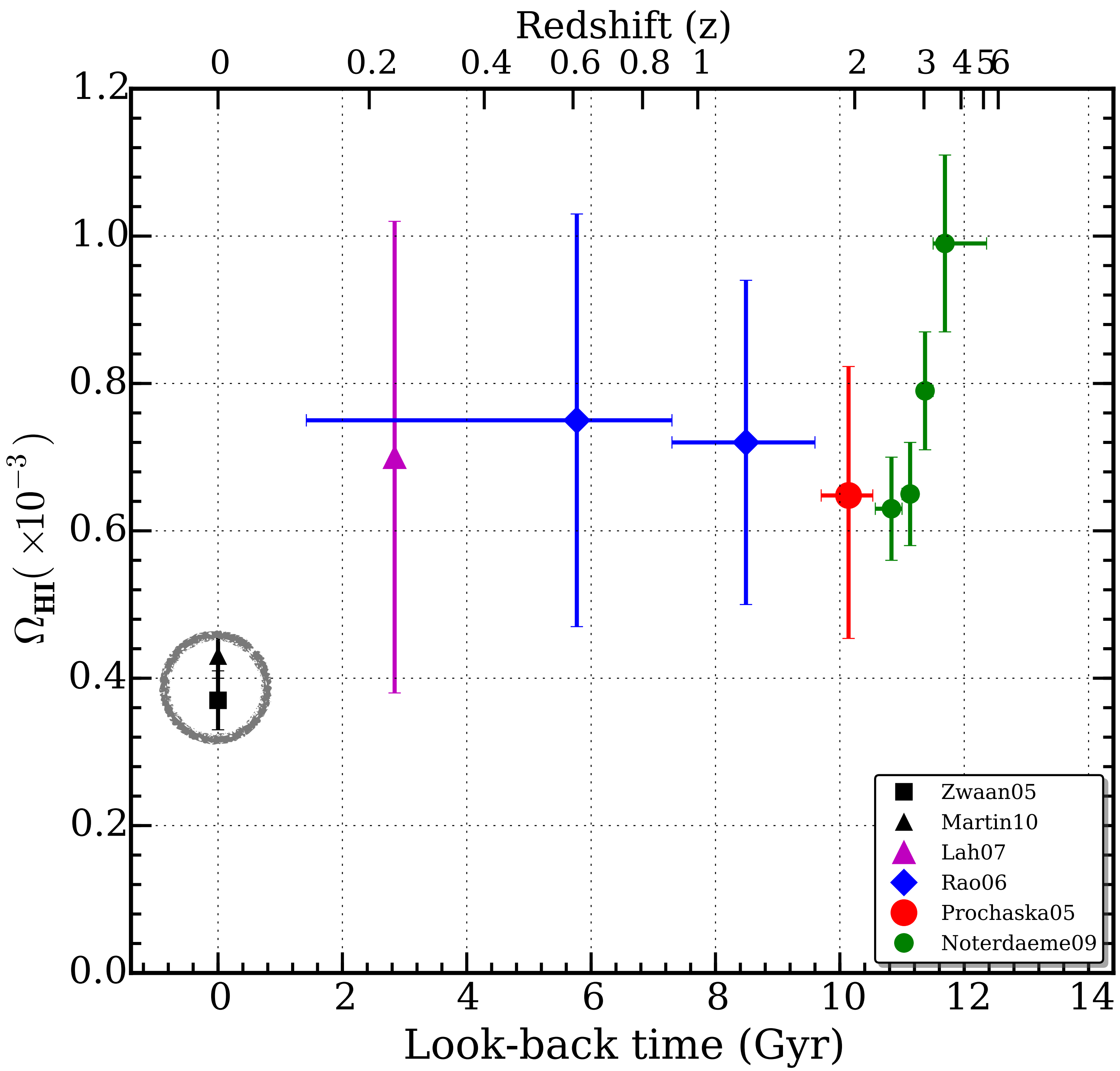
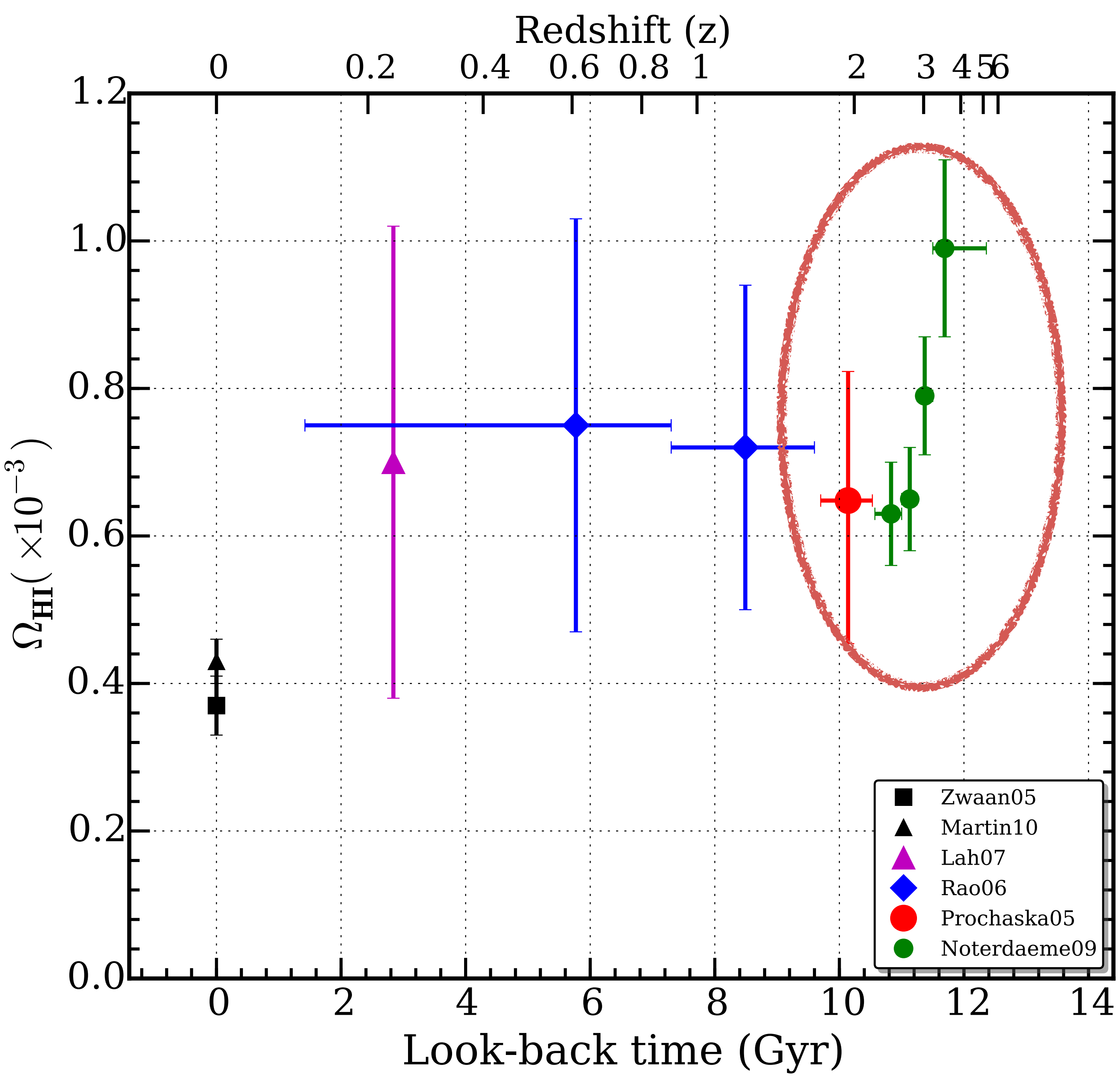
HI gas evolution study



HI in the local universe

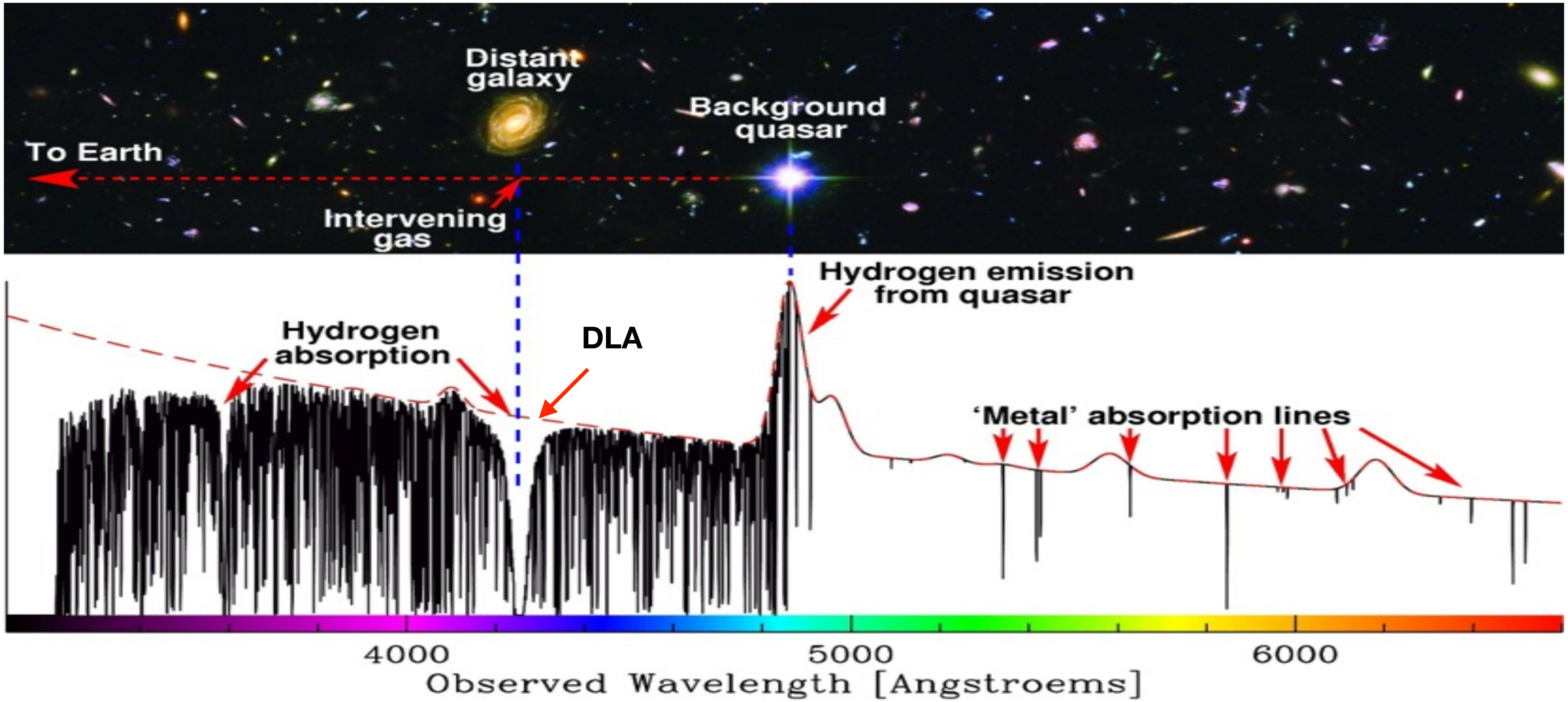
- HI gas quantified from 21-cm blind surveys:
  - **HIPASS:** HI Parkes All Sky Survey (Zwaan et al. 2005)
    survey area 21341 deg^2, 4315 detections, z < 0.042
  - **ALFALFA:** Arecibo Legacy Fast ALFA survey (Martin et al. 2010)
    survey area 2799 deg^2, 10119 detection, z < 0.06

HI gas evolution study



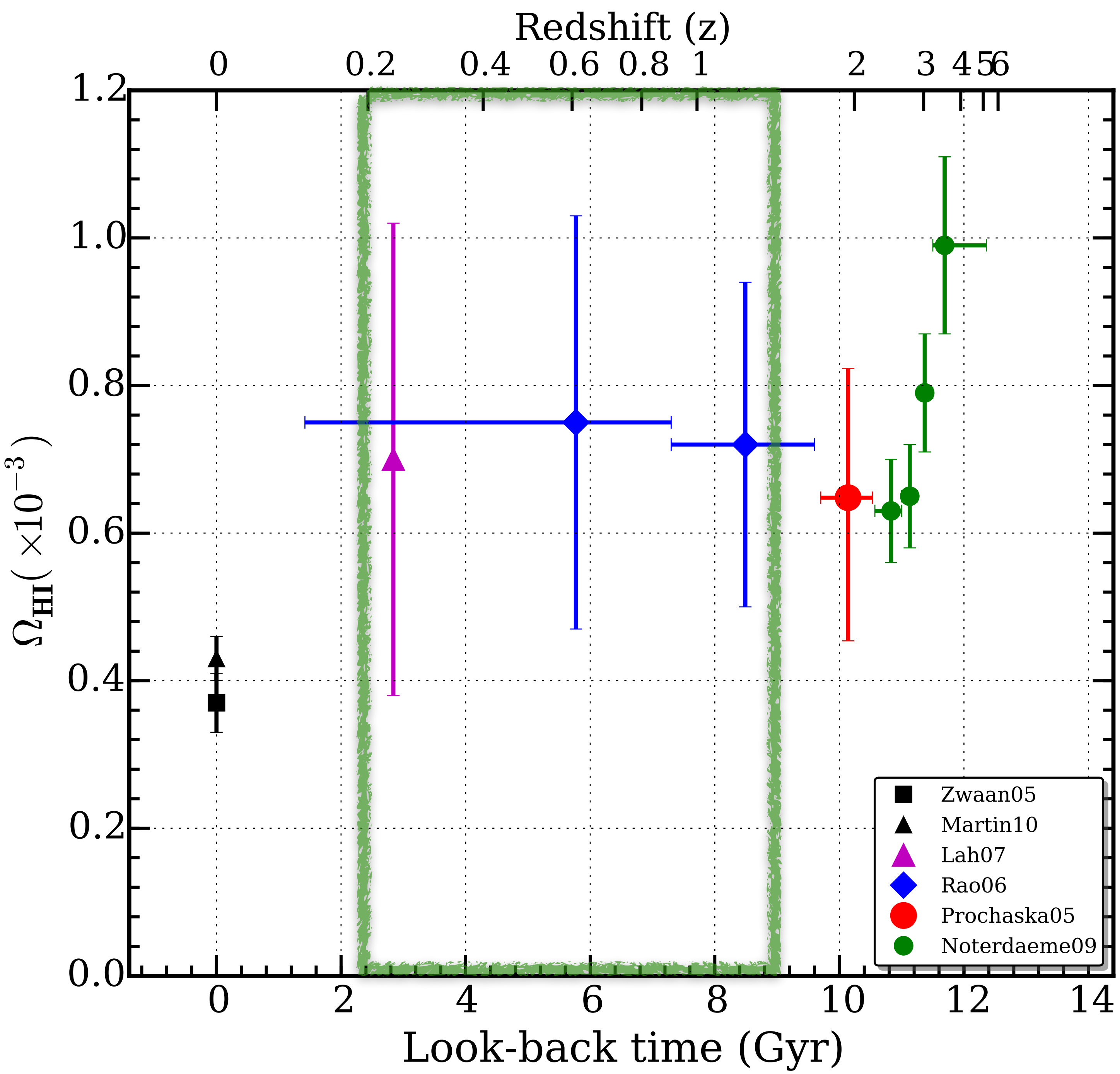
HI gas at high redshifts

- Knowledge of HI gas from 21-cm observations is not available.
- Different techniques for HI measurement at high redshift (z>2): Damped Lyman-α absorption (DLA).



HI gas between low and high-z

- 0.2 < z < 1.5 less explored regime by observations



HI gas between low and high-z

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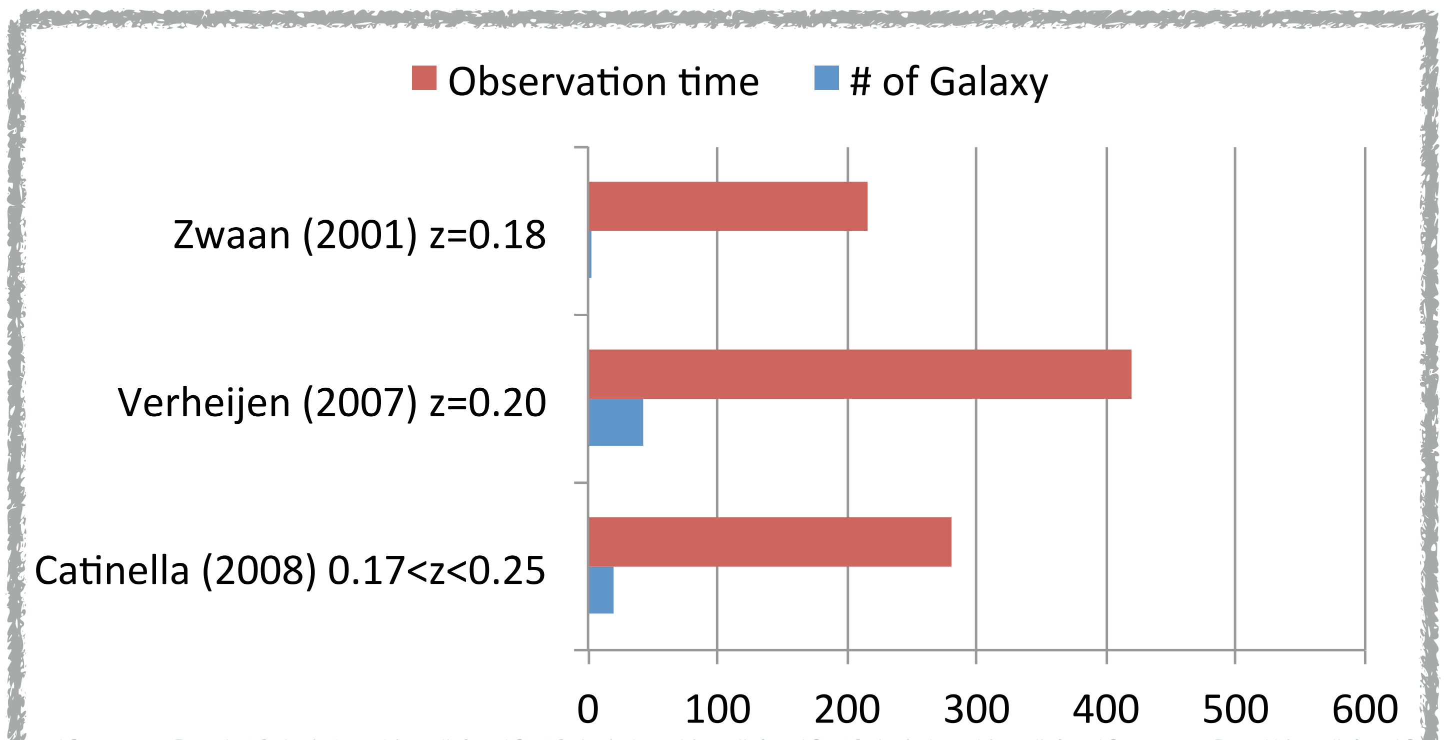
- Both techniques (21-cm and DLA) not practically available in the redshift range:
  - Existing radio observing facilities are not sensitive enough to detect weak 21cm signal



HI gas between low and high-z

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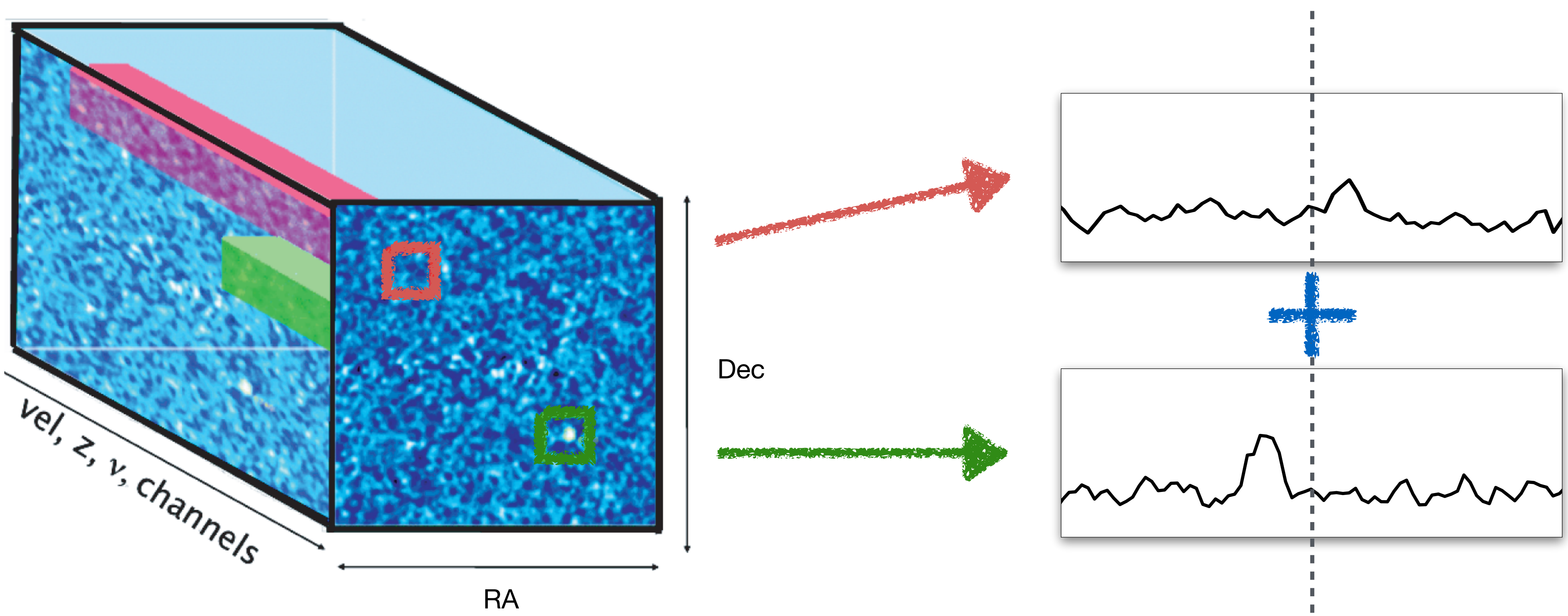
- Both techniques (21-cm and DLA) not practically available in the redshift range:
  - Existing radio observing facilities are not sensitive enough to detect weak 21cm signal
  - Lyman-α line can be observed in UV wavelength and incidence of DLA is low.

- Next generation of radio telescopes can reach this redshift range: strong drive to initiate SKA and SKA pathfinders projects
- New techniques emerged to overcome the limitation before the future telescopes: **HI spectral stacking and HI intensity mapping technique**

HI spectral stacking technique

- Using known optical data (RA, Dec and Redshift), HI spectra are extracted from a 3D radio map.
- Co-add the spectra to obtain average HI spectrum.



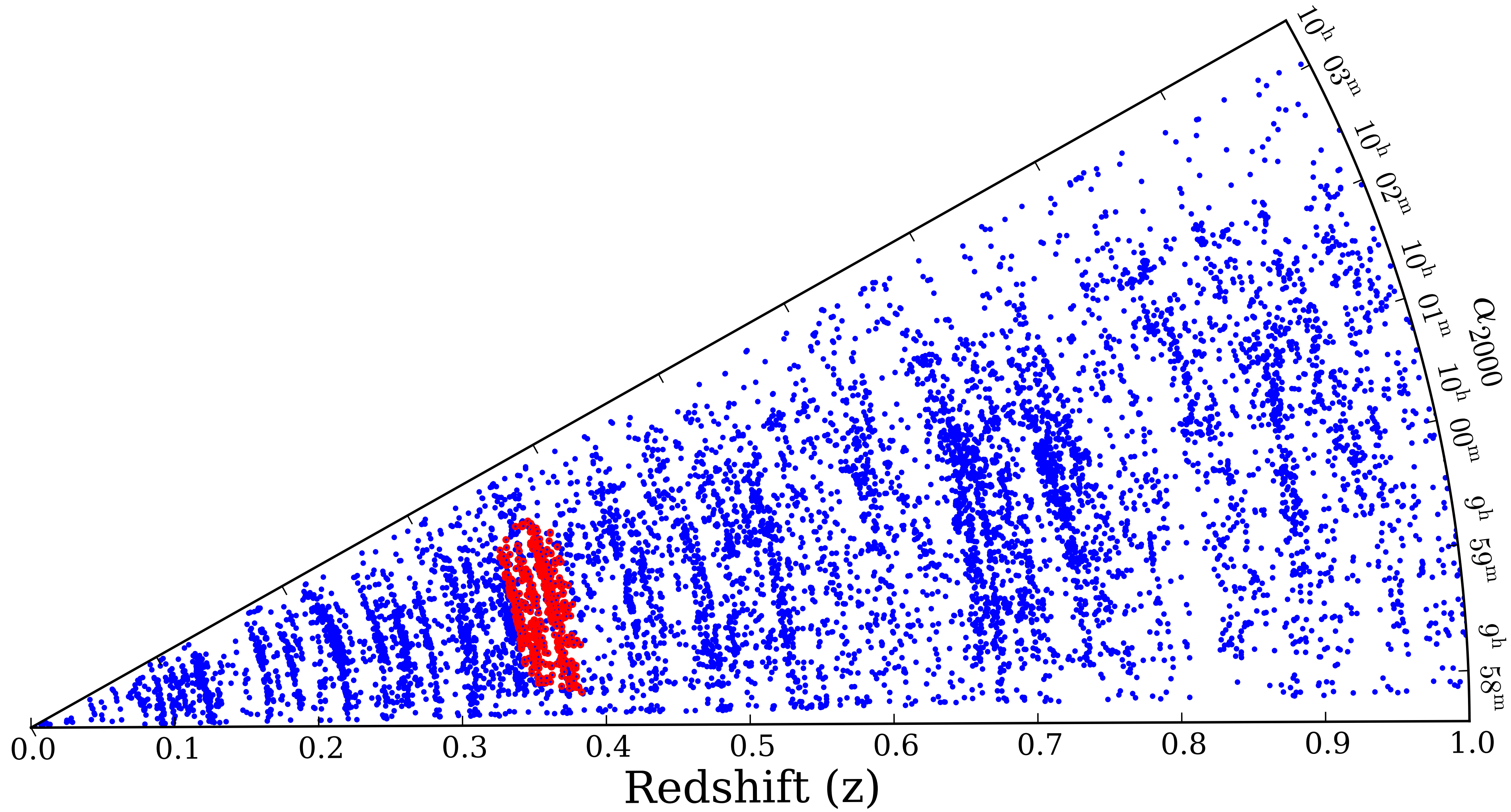
Radio Data Cube

Target Fields for HI stacking

Target Field	Redshift (z)	Lookback time (Gyr)	Obs. Time (Radio)	Radio Telescope	# of stacked galaxies	FoV (deg)
CNOC2 0920+37	0.1, 0.2	1~2.7 Gyr	120 hr	WSRT	59, 96	1.0
VVDS14h	0.32	3.6 Gyr	136 hr	GMRT	165	0.98
zCOSMOS	**0.37**	**4.0 Gyr**	**134 hr**	**GMRT**	**474**	**0.95**

zCOSMOS Field at z~0.37

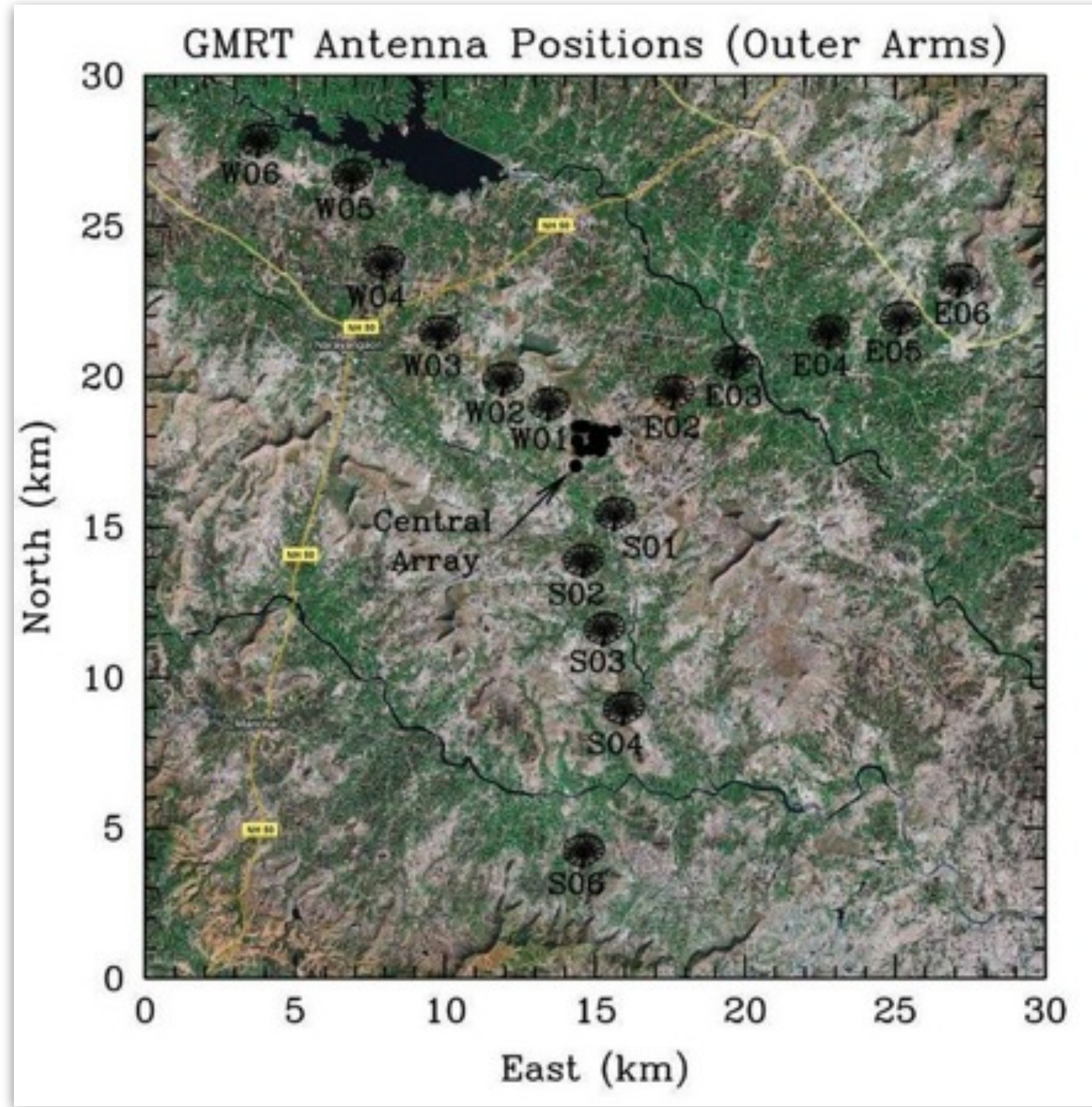
- A large optical redshift survey on 1.7 deg^2 COSMOS field.
- zCOSMOS-bright 10 k catalogue used.
- Redshift uncertainty ~110 km s^{-1}
- 474 reliable redshifts available for our analysis



Giant Metrewave Radio Telescope

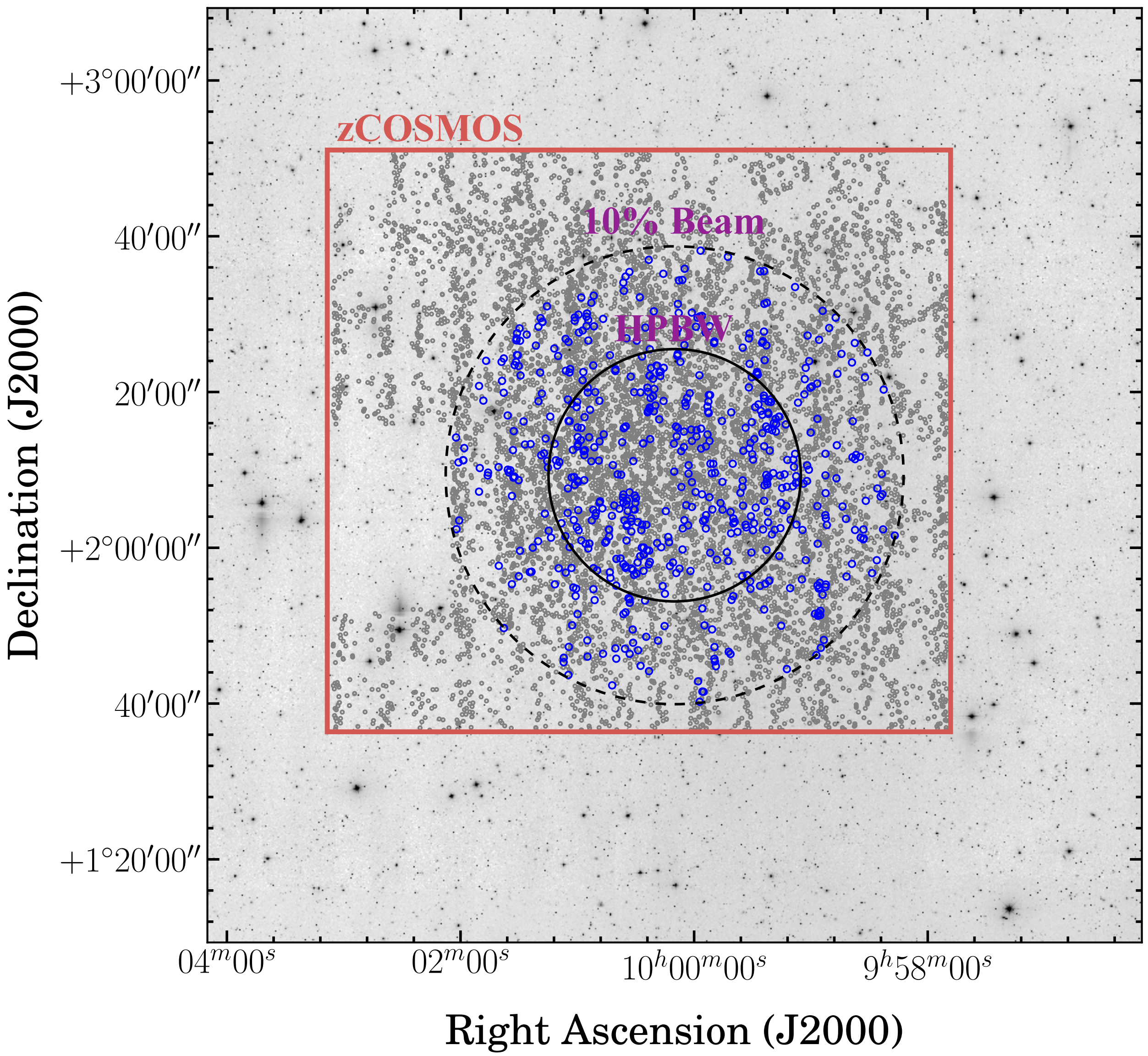
- One of sensitive telescopes to survey atomic hydrogen gas out to z~0.4 before SKA and its pathfinders.
- Array of 30 dishes of 45m ea. (14 central antennas, 16 outer antennas)
- Baseline range: 100m ~ 25km
- Frequency coverage:

  L band 1000~1450 MHz



Radio observation (GMRT)

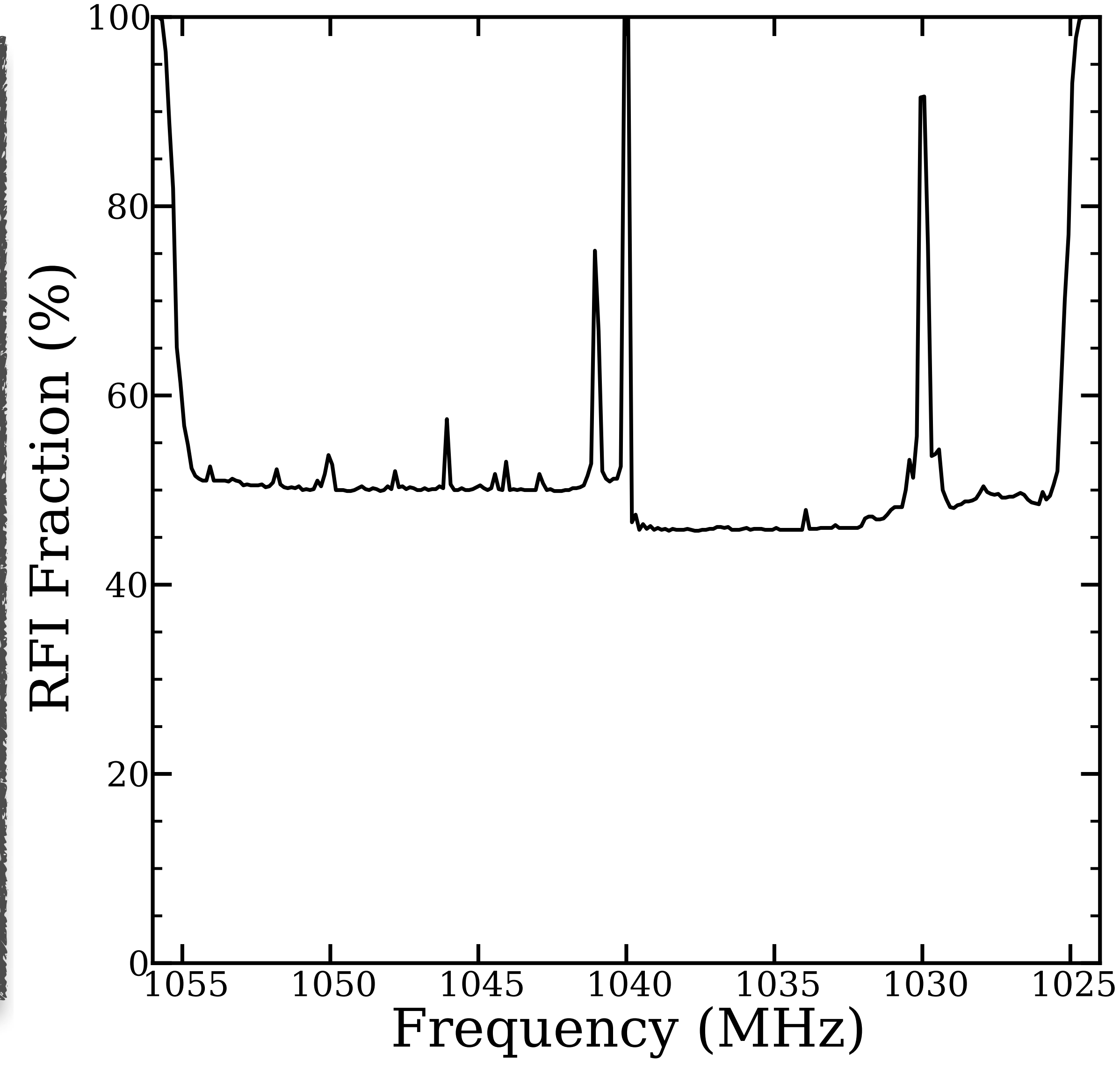
- A total observing time:
  134 hr for 20 days in 2008 & 2009
  (115 hr on-source time)
- Bandwidth of 32 MHz, split into two 16 MHz sidebands (each 128 channels).
- Frequency range:
  1056 MHz to 1024 MHz
  ($0.345 < z < 0.387$)
- Channel width of 0.125 MHz
  (~36.3 km s^{-1} at $z = 0.37$)
- Synthesized beam of 3.6″×2.4″



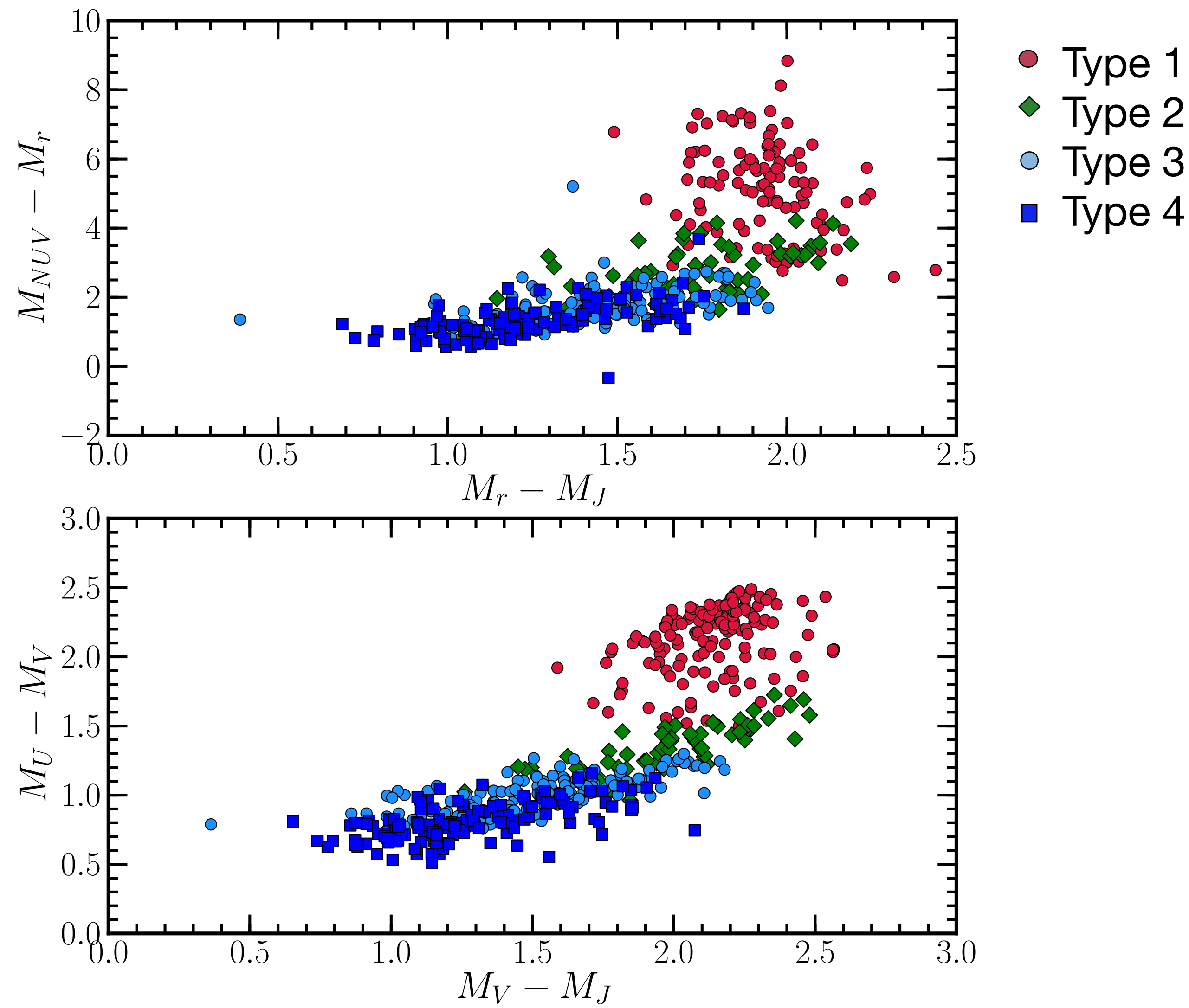
Data Reduction

Data Reduction

- Automated flagging software "flagcal" used before data reduction.
- CASA pipeline developed for GMRT data reduction.
- Following standard radio data reduction procedures: flagging, calibration, and imaging.



Galaxy Classification



- Galaxies classified by a SED template fitting code (LE PHARE Ilbert at al. (2006))
- 4 galaxy types are defined:

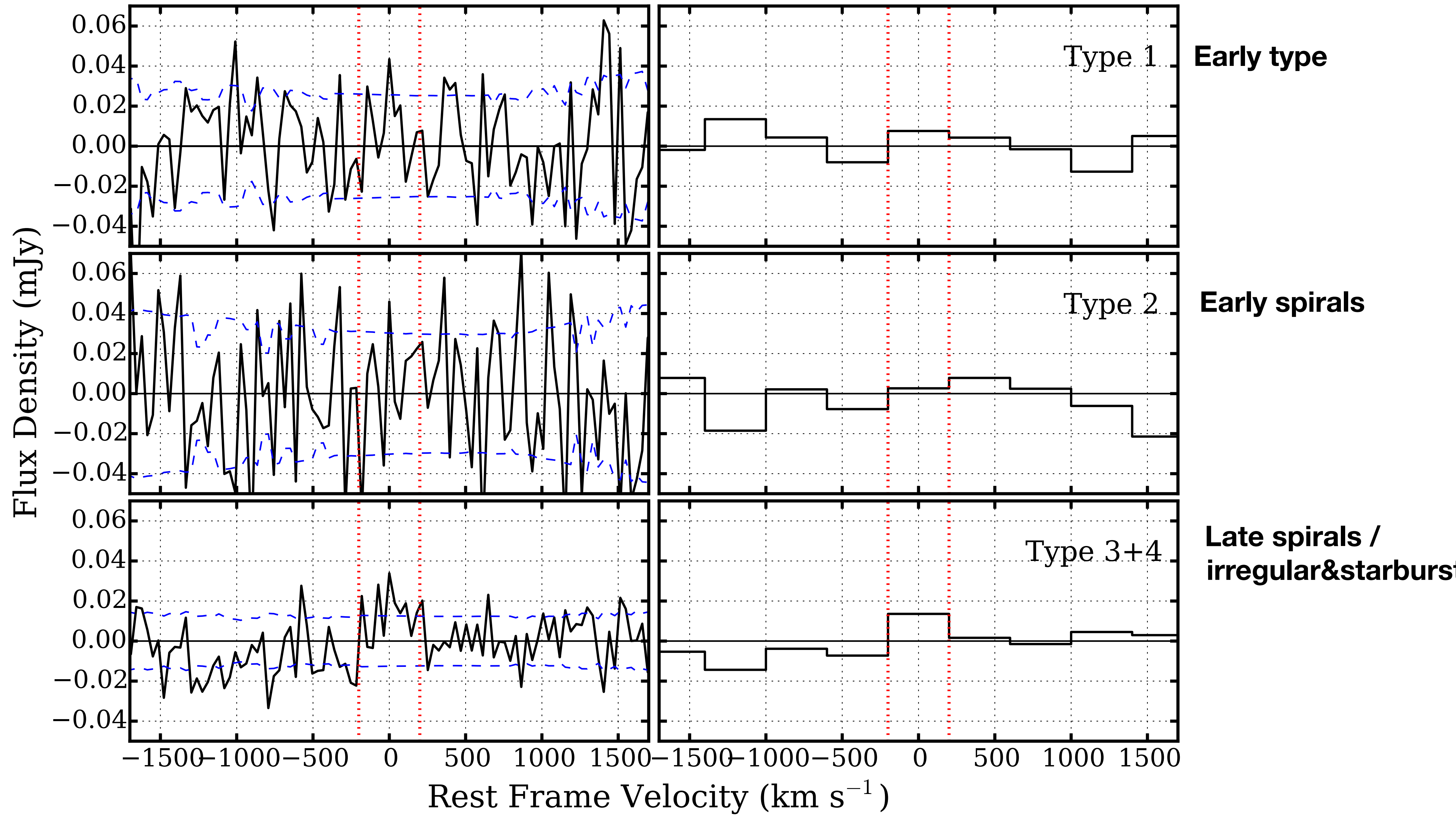
Type 1 for early types (E/S0)

Type 2 for early spirals(Sa, Sb)

Type 3 for late spirals (Sc, Sd)

Type 4 for irregular and starburts

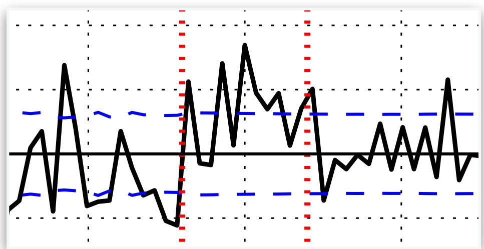
Stacked HI spectra



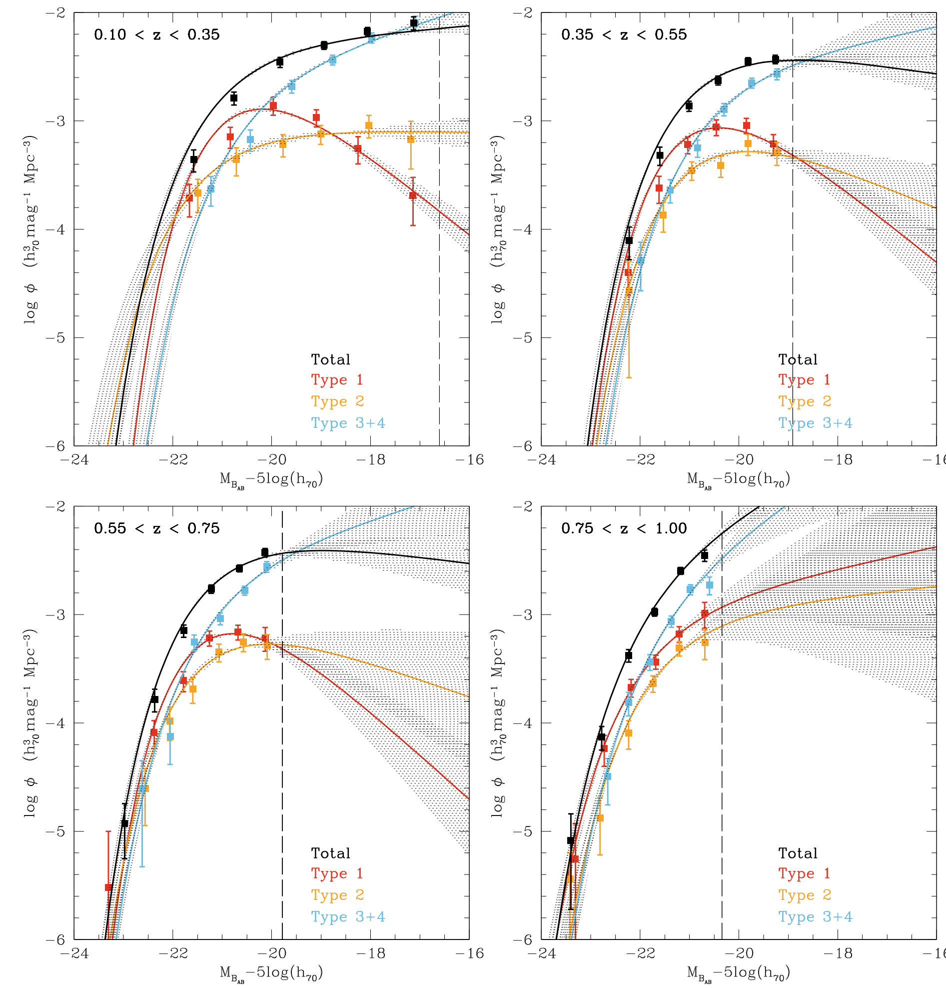
$$\frac{M_{\mathrm{HI}}}{\mathrm{M}_\odot} = \frac{236}{(1+z)} \left(\frac{D_L}{\mathrm{Mpc}}\right)^2 \left(\frac{\int S_V\, dV}{\mathrm{mJy\,km\,s^{-1}}}\right)$$

Cosmic HI density ($\Omega_{\rm HI}$)

Stacked HI spectra

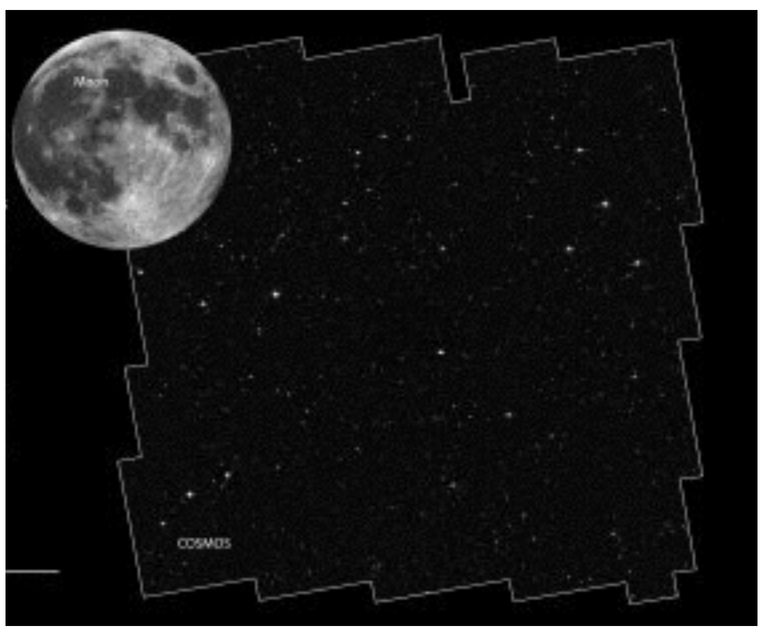


Luminosity Function



$$\rho_{\rm H\,I} = \frac{\sum M_{\rm H\,I}}{\sum L_B} \times \rho_{L_B(z)}$$

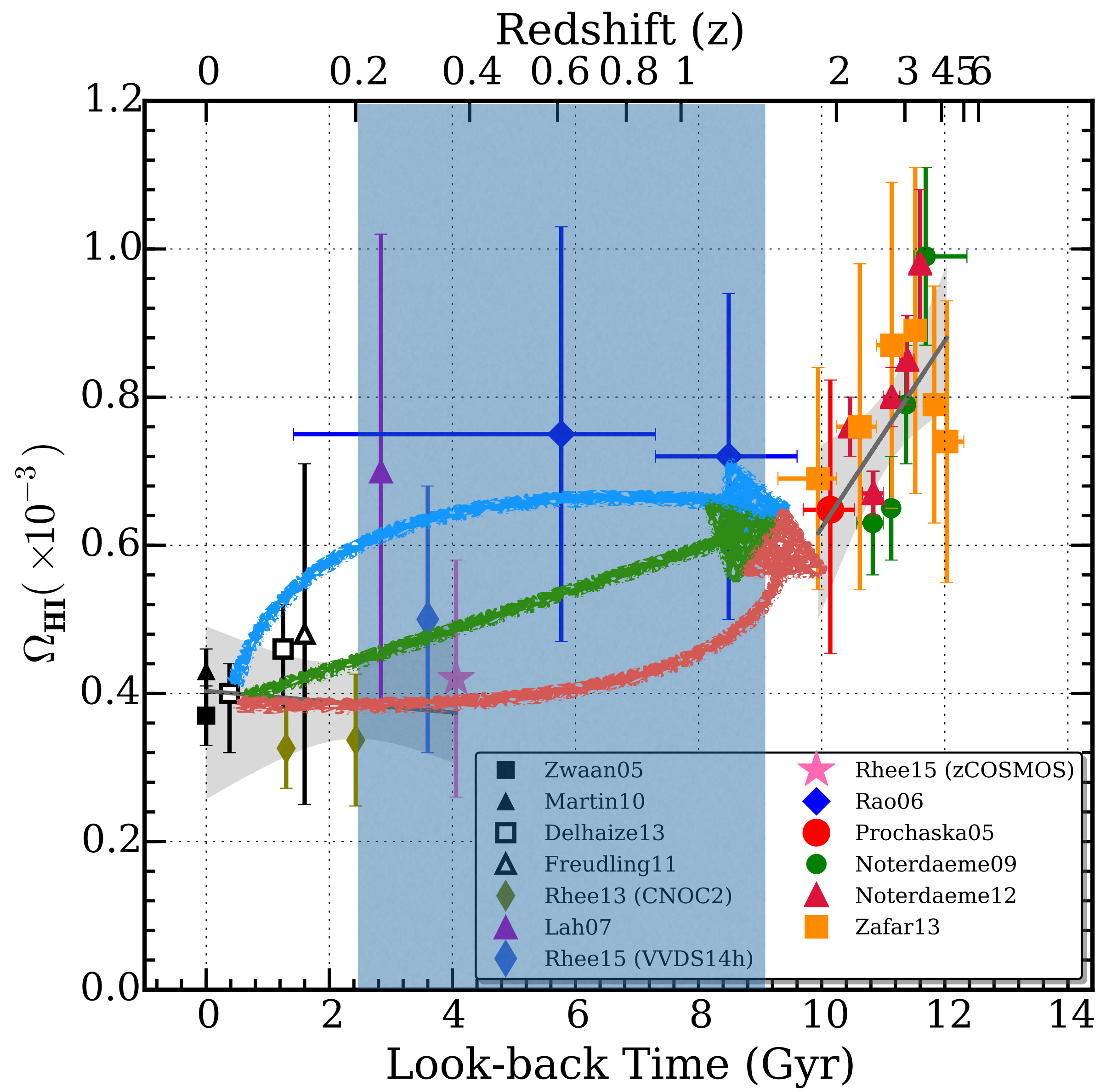
$$\Omega_{\rm H\,I} = \frac{\rho_{\rm H\,I}}{\rho_{\rm crit}}, \quad \rho_{\rm crit} = \frac{3H_0^2}{8\pi G},$$



Luminosity

Sample	$N_{\rm gal}$	$\langle M_{\rm H\,I}\rangle$	$\langle L_B\rangle$	$\langle M_{\rm H\,I}\rangle/\langle L_B\rangle$	ρ_{L_B}	$\rho_{\rm H\,I}$
Type 1	95	2.20 ± 2.60	17.76 ± 0.04	0.12 ± 0.15	5.11 ± 0.65	0.56 ± 0.67
Type 2	58	1.50 ± 2.74	21.33 ± 0.05	0.07 ± 0.13	2.69 ± 0.65	0.21 ± 0.38
Type 3+4	321	3.83 ± 1.20	10.07 ± 0.01	0.38 ± 0.12	8.12 ± 2.15	4.86 ± 1.99
All			$\Omega_{\rm H\,I}$= (0.42 ± 0.16) × 10^{-3}			

Cosmic HI gas evolution



- The highest-redshift measurement of $\Omega_{\rm HI}$ ever made with the HI spectral stacking technique.
- All 21-cm measurements of $\Omega_{\rm HI}$ are consistent.
- The H I 21-cm emission measurements to date show no evidence for significant evolution of H I gas abundance over the last 4 Gyr.

Summary

- The global HI gas abundance does not change significantly over the last 4 Gyr ($z < 0.4$)
- This research successfully demonstrates the viability of HI stacking technique at the intermediate redshift range ($z < 0.4$) using current radio telescopes.
- HI stacking is promising to give more scientific outcomes to future HI deep surveys such as CHILES, DINGO and LADUMA, pushing their limit still further.

Thank you for your attention !