Cosmic HI Density Evolution

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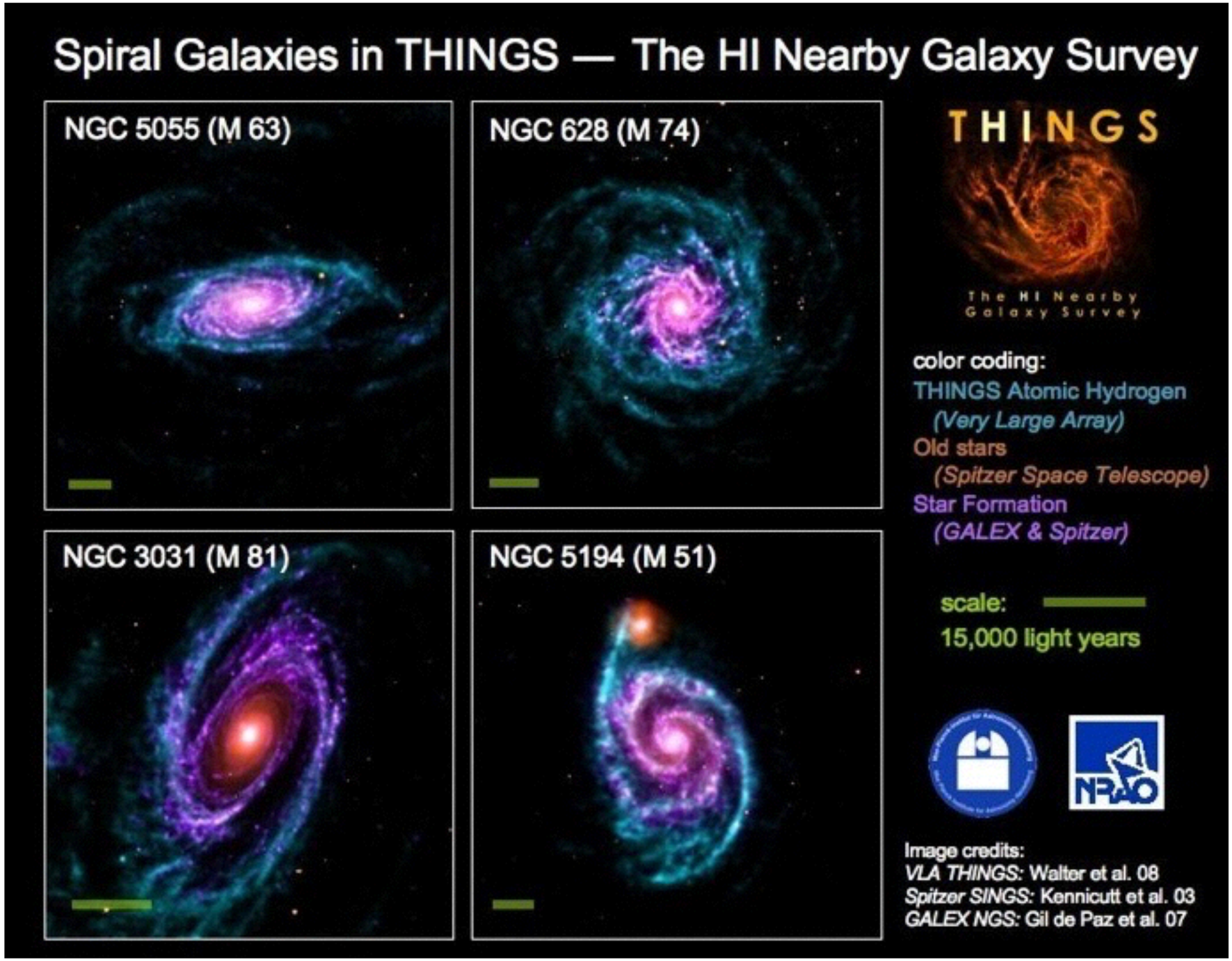
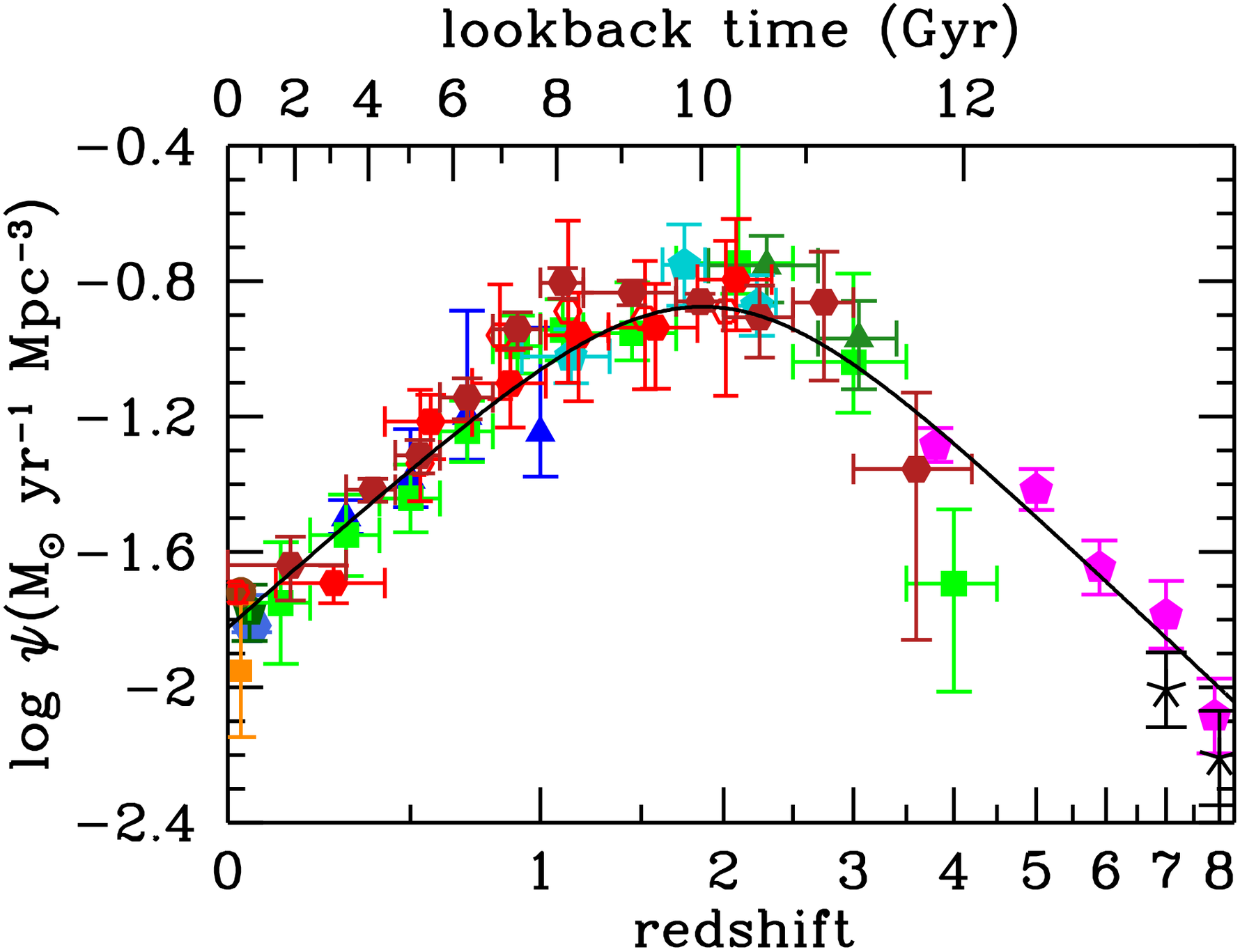
Stellar and Gaseous components

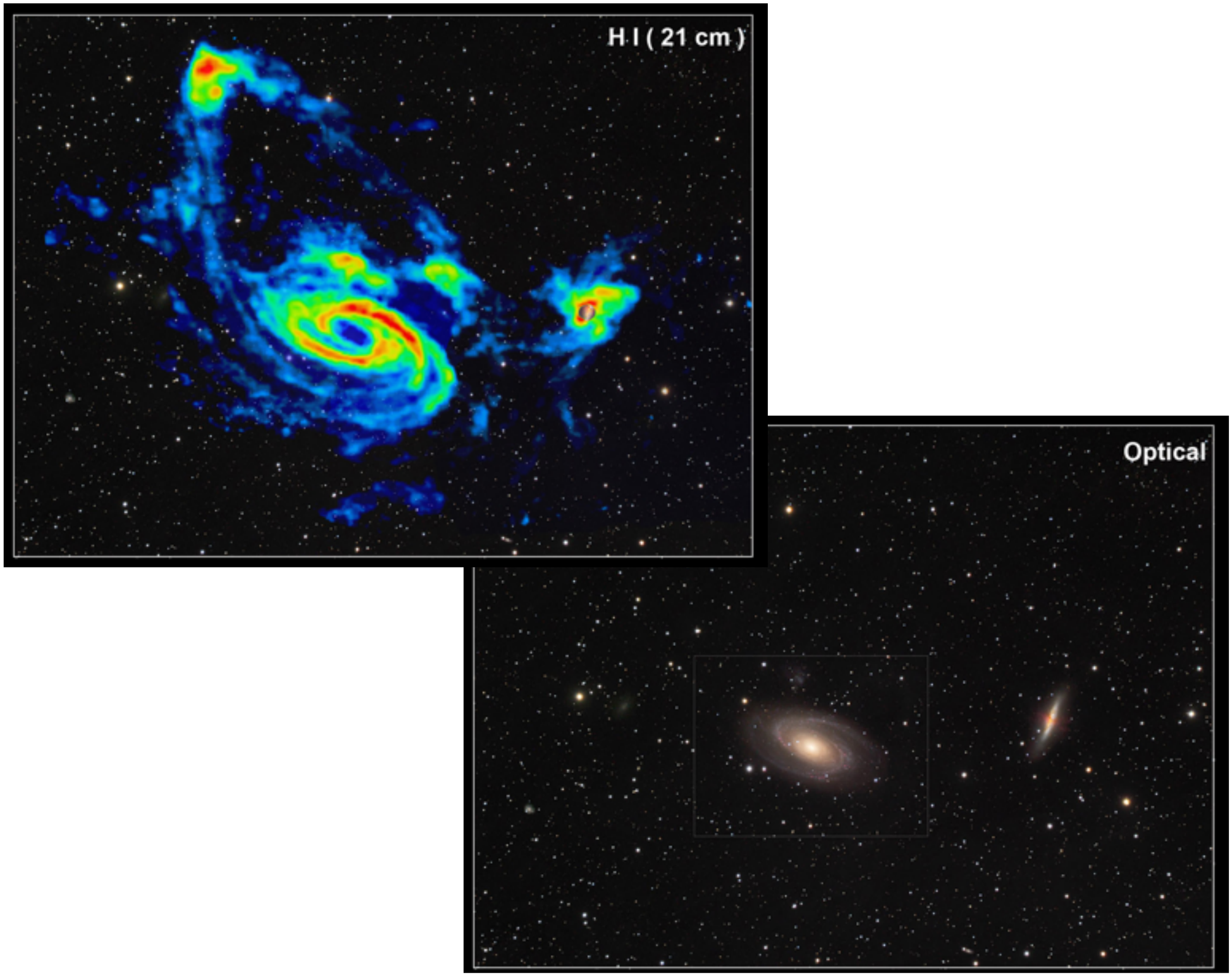


Star formation history

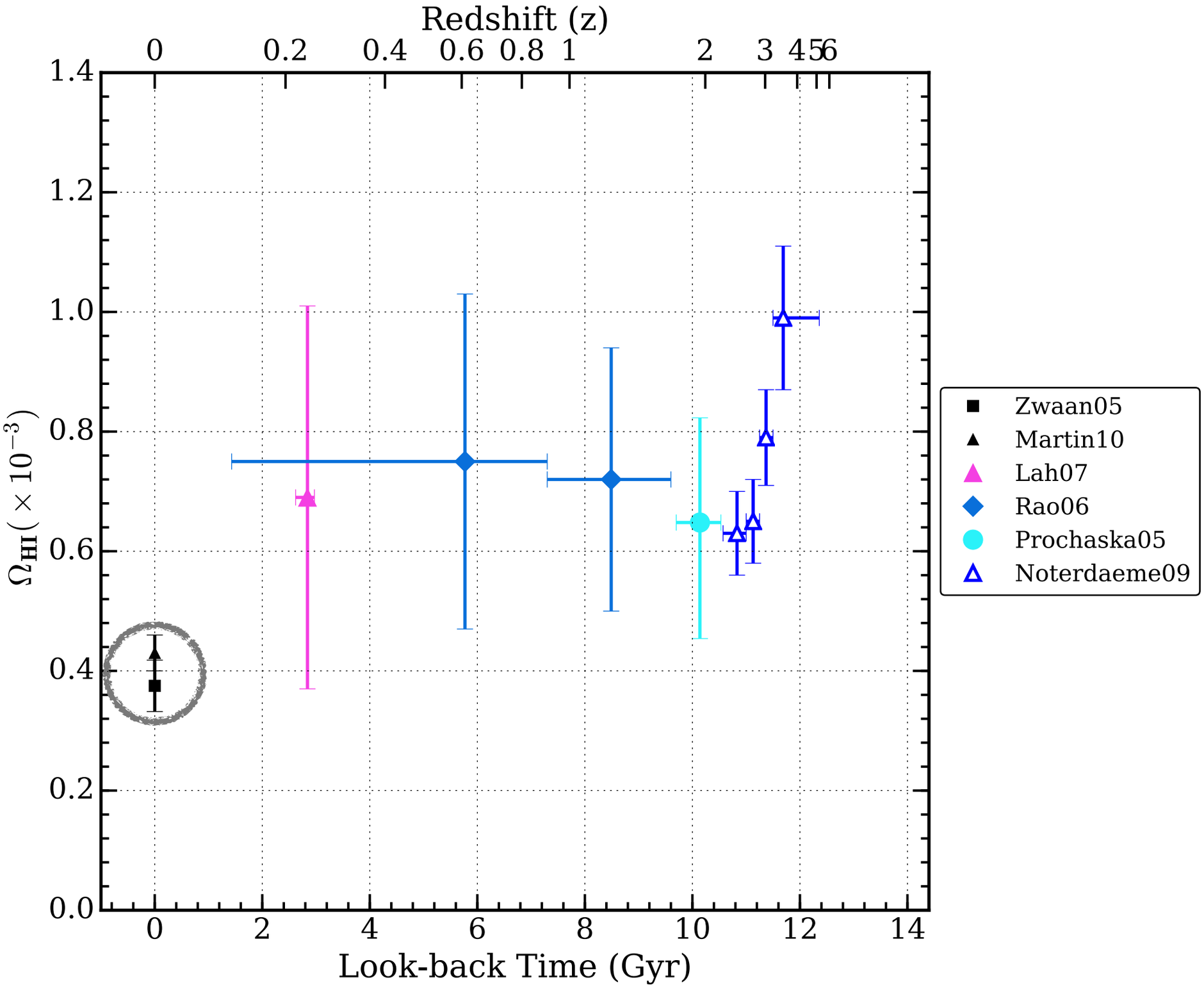


Madau & Dickinson 2014

Cold gas (HI) component



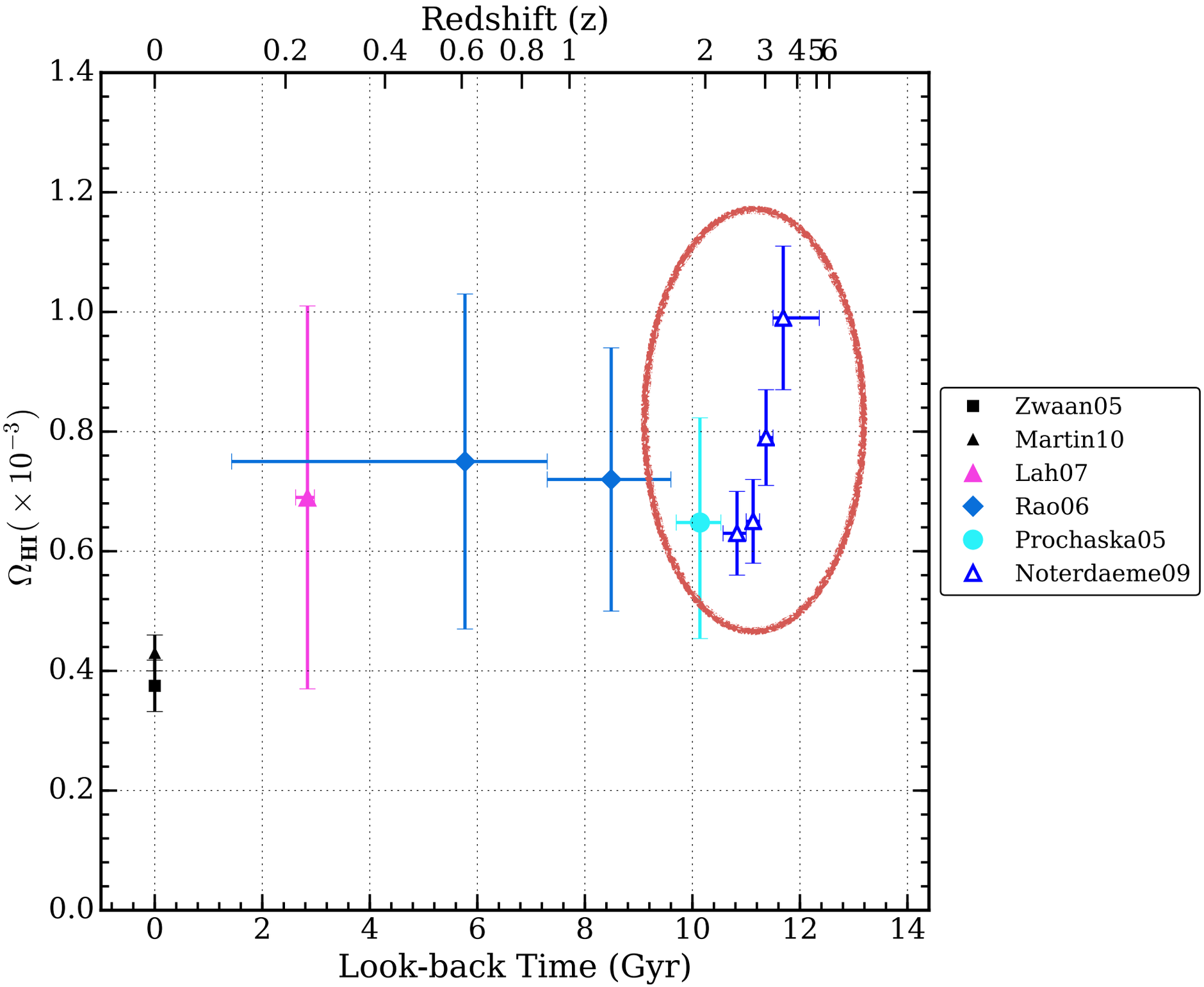
HI gas evolution studies



HI in the local universe

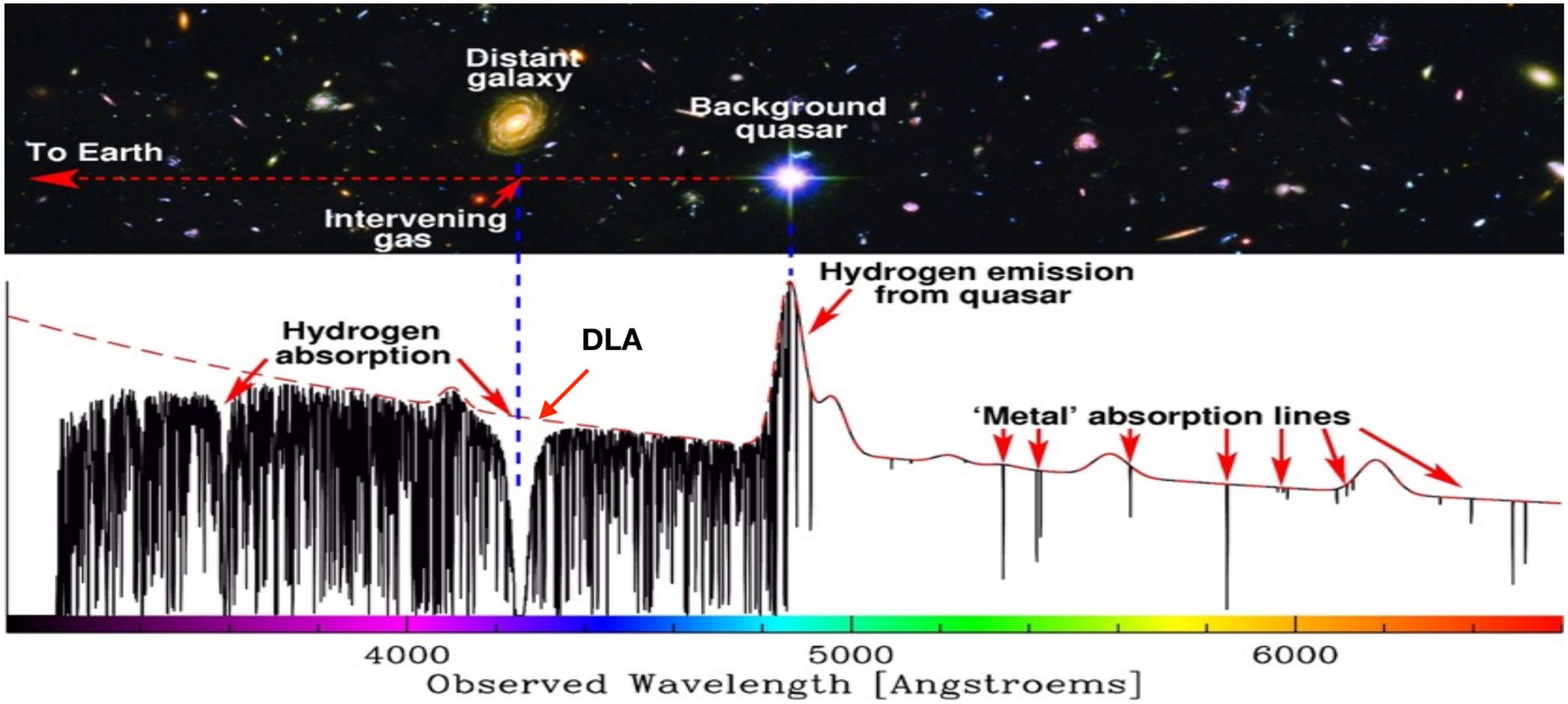
- HI gas quantified from 21-cm blind surveys:
  - **HIPASS:** HI Parkes All Sky Survey (Zwaan et al. 2005)
    survey area 21341 deg^2, 4315 detections, $z < 0.042$
  - **ALFALFA:** Arecibo Legacy Fast ALFA survey (Martin et al. 2010)
    survey area 2799 deg^2, 10119 detection, $z < 0.06$

HI gas evolution studies

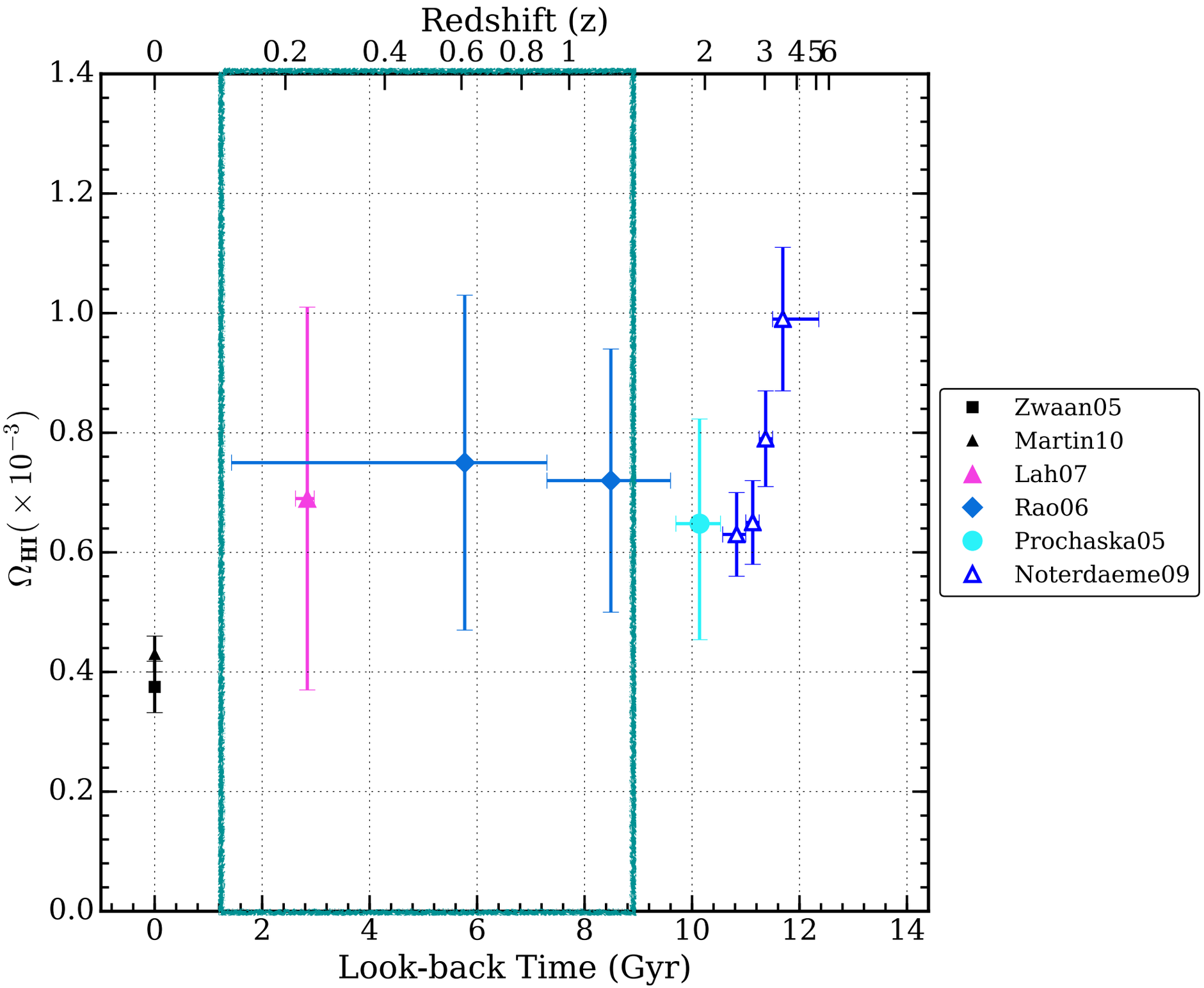


HI gas at high redshifts

- 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).

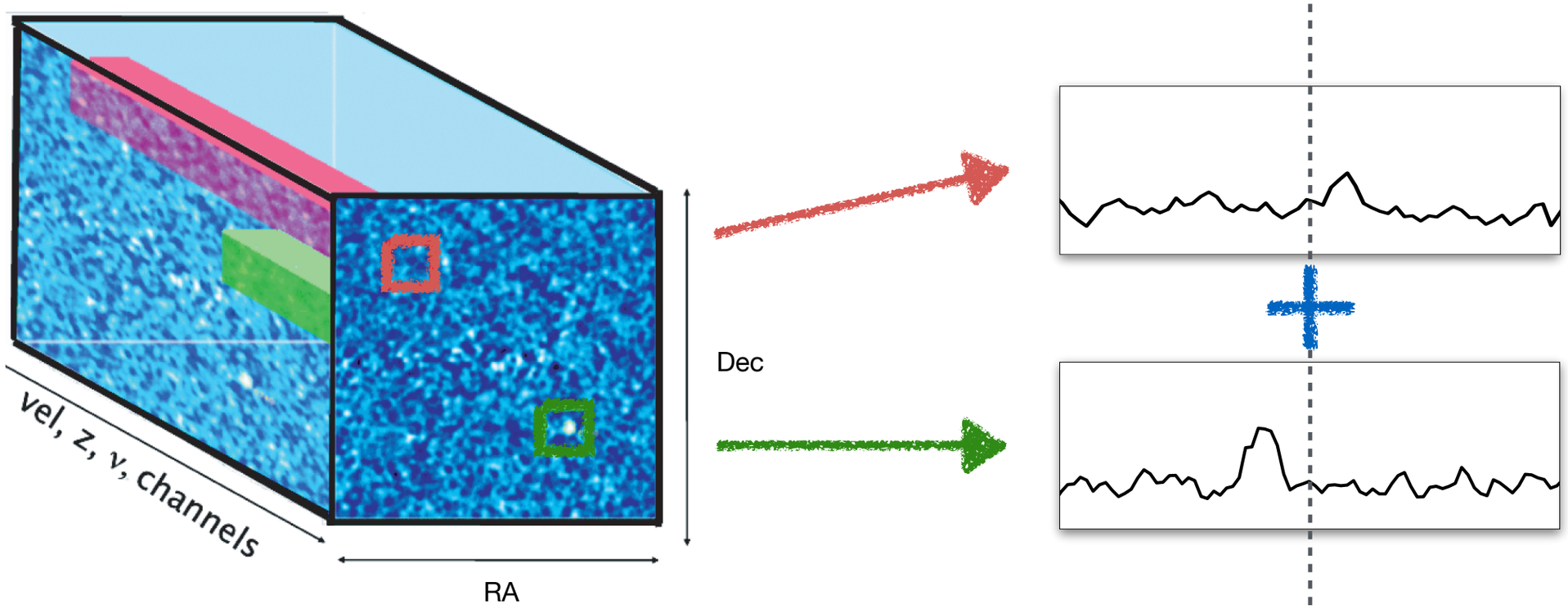


HI gas evolution studies



HI gas between low and high-z

- HI spectral stacking is a powerful tool to study this range.
- 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.



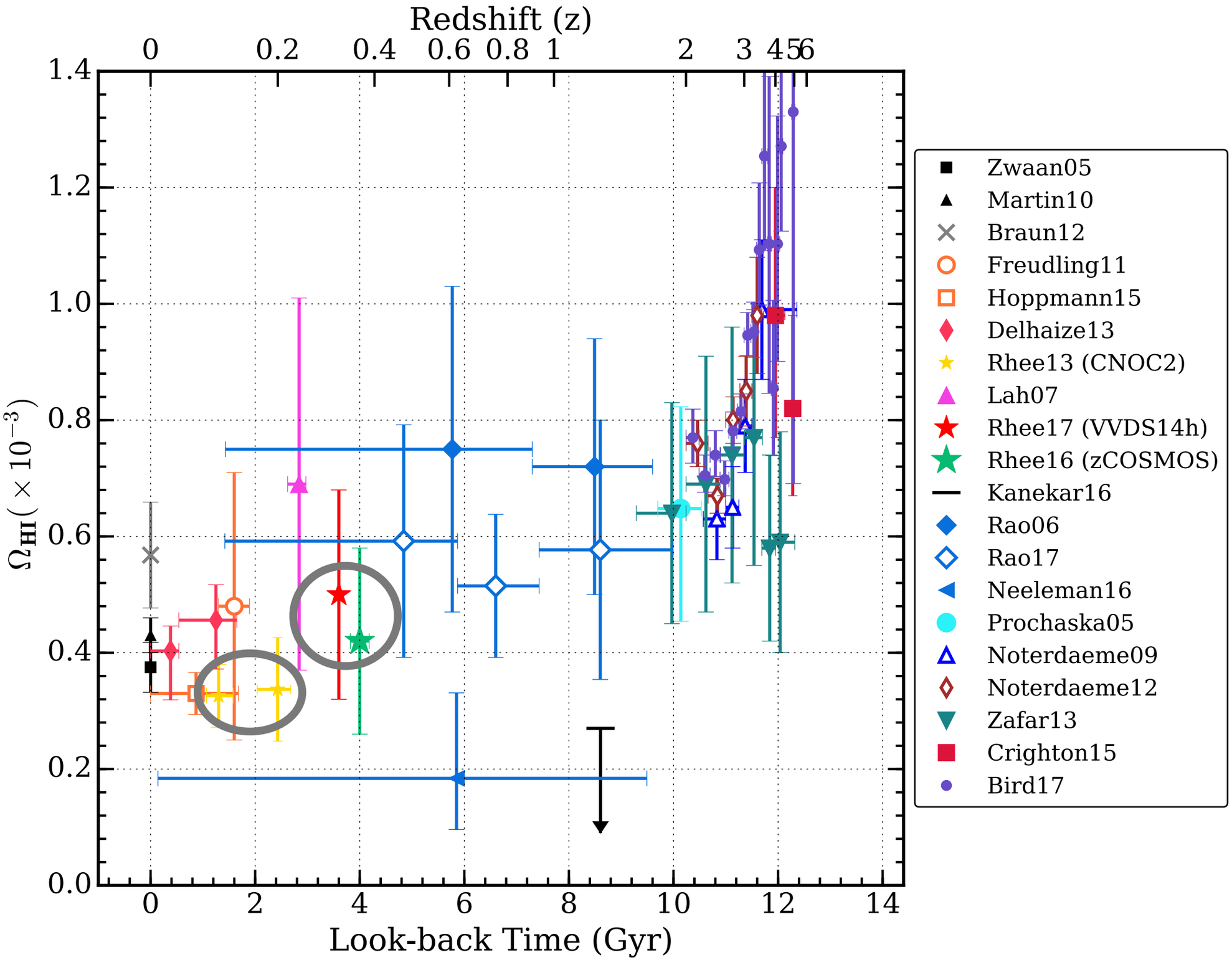
HI Data Cube

HI spectral stacking @ 0.1 < z < 0.4

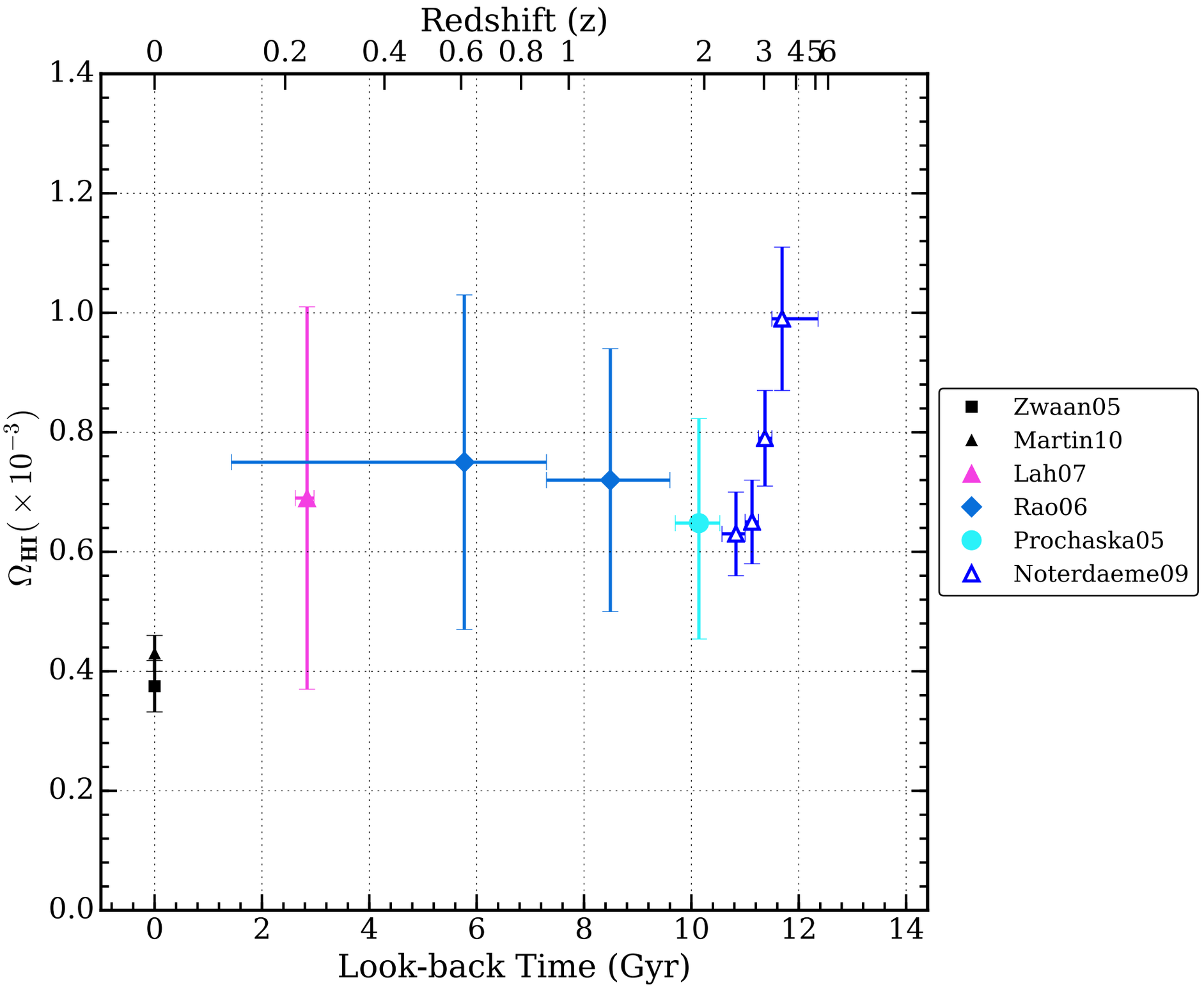
Target Field	Coordinate (RA&Dec)	Redshift (z)	Lookback Time (Gyr)	Observed Frequency (GHz)	Observation Time	Radio Telescope	Number of stacked galaxies
CNOC2	09:23:46.51 +36:57:37.43	0.1, 0.2	1-2.7	1.160-1.321	120 hr	WSRT	55, 96
VVDS 14h	13:58:01.60 +05:04:54.00	0.32	3.6	1.060-1.092	136 hr	GMRT	165
COSMOS	10:00:10.01 +02:19:19.95	0.37	4.0	1.024-1.056	134 hr	GMRT	474

Rhee+2013, 2016, 2017

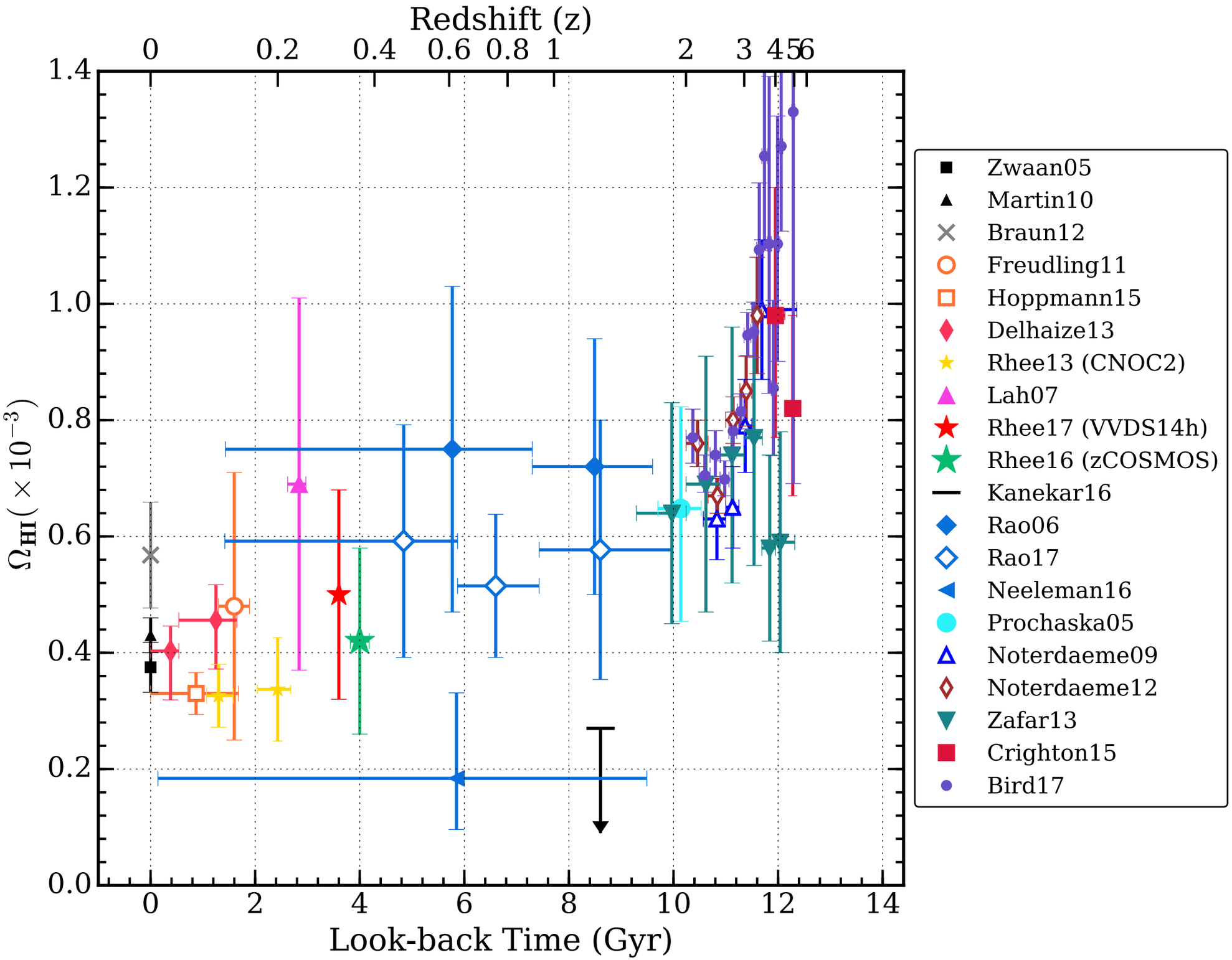
HI gas evolution over cosmic time



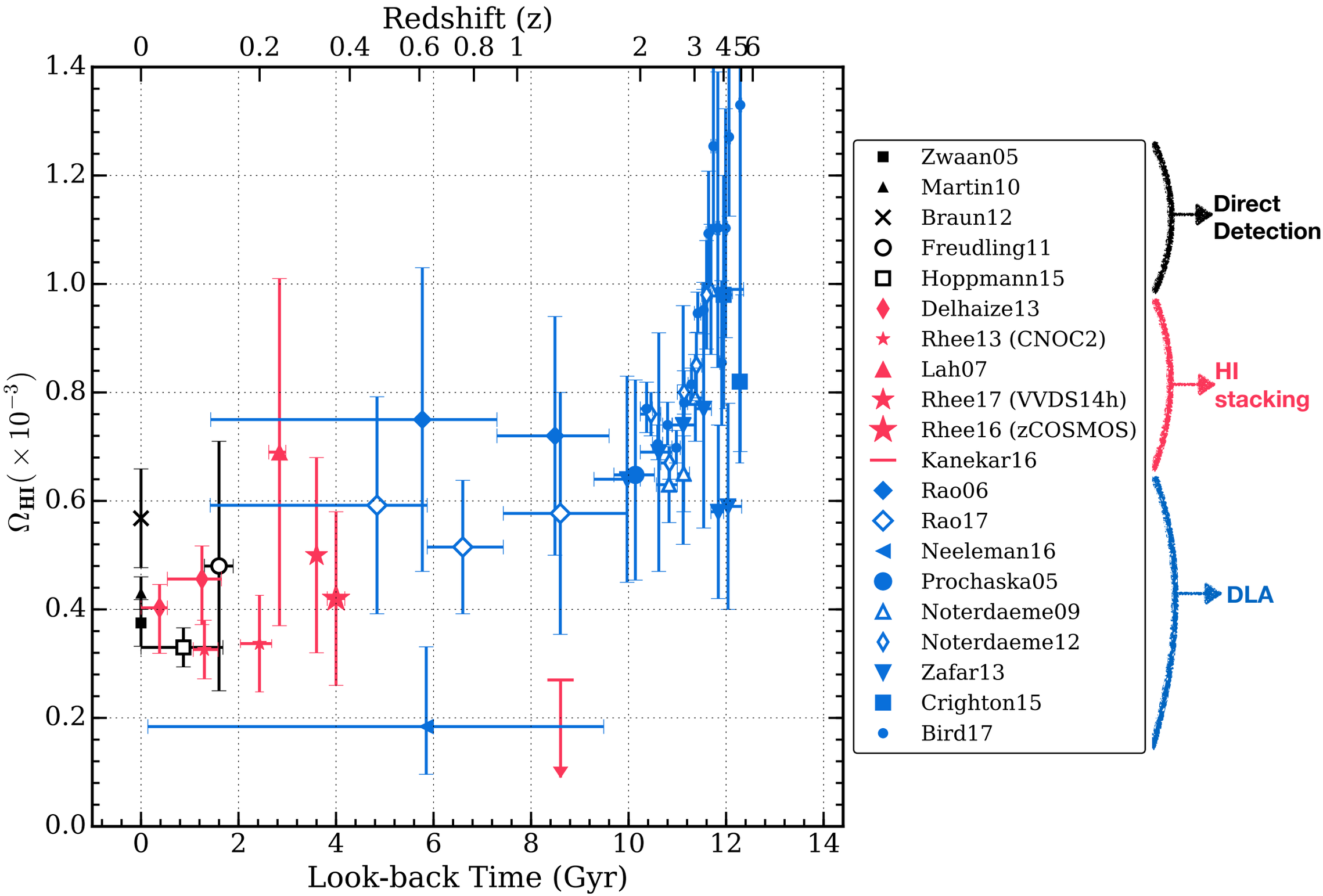
HI gas evolution plot (7 years ago)



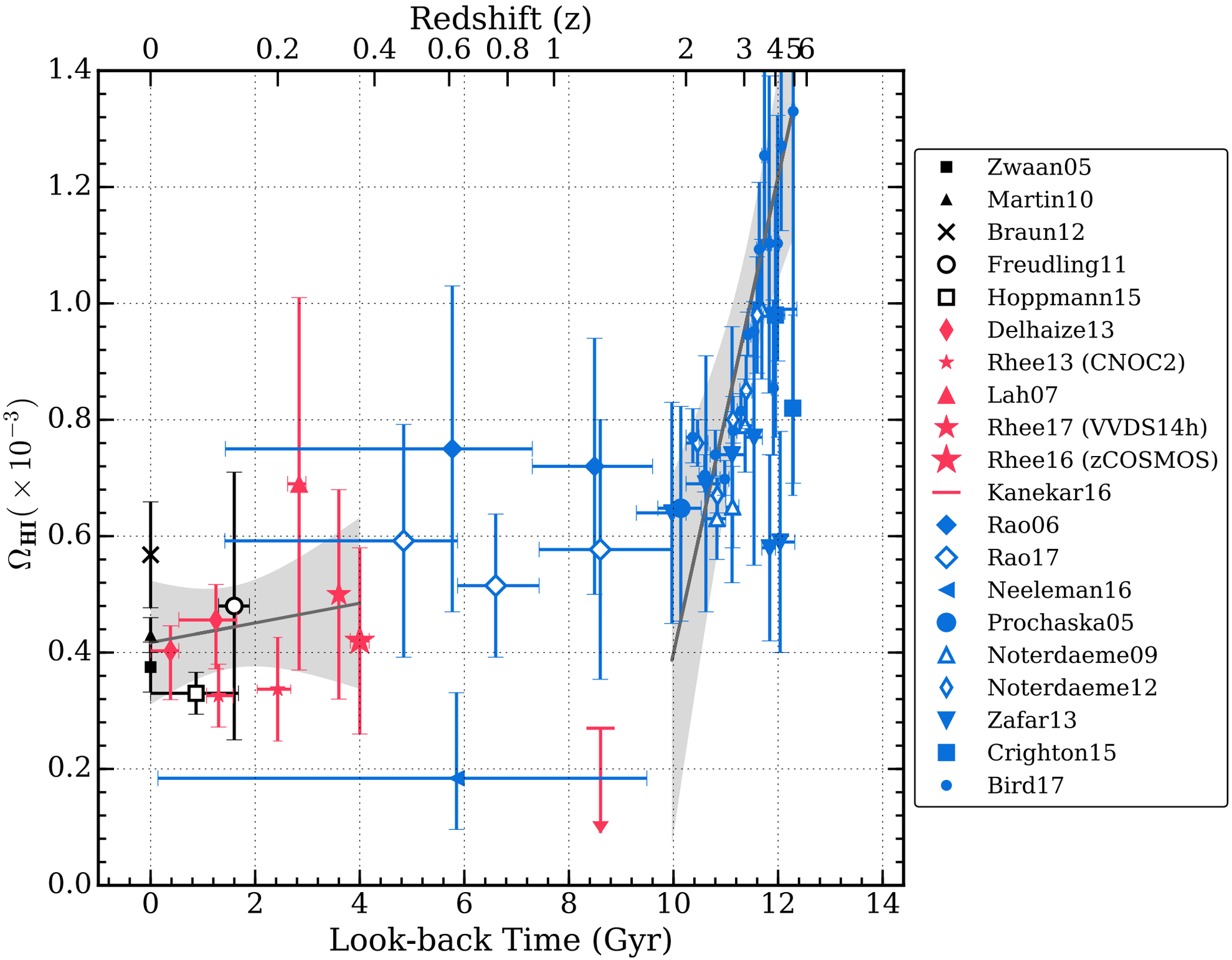
HI gas evolution over cosmic time



HI gas evolution over cosmic time



HI gas evolution over cosmic time



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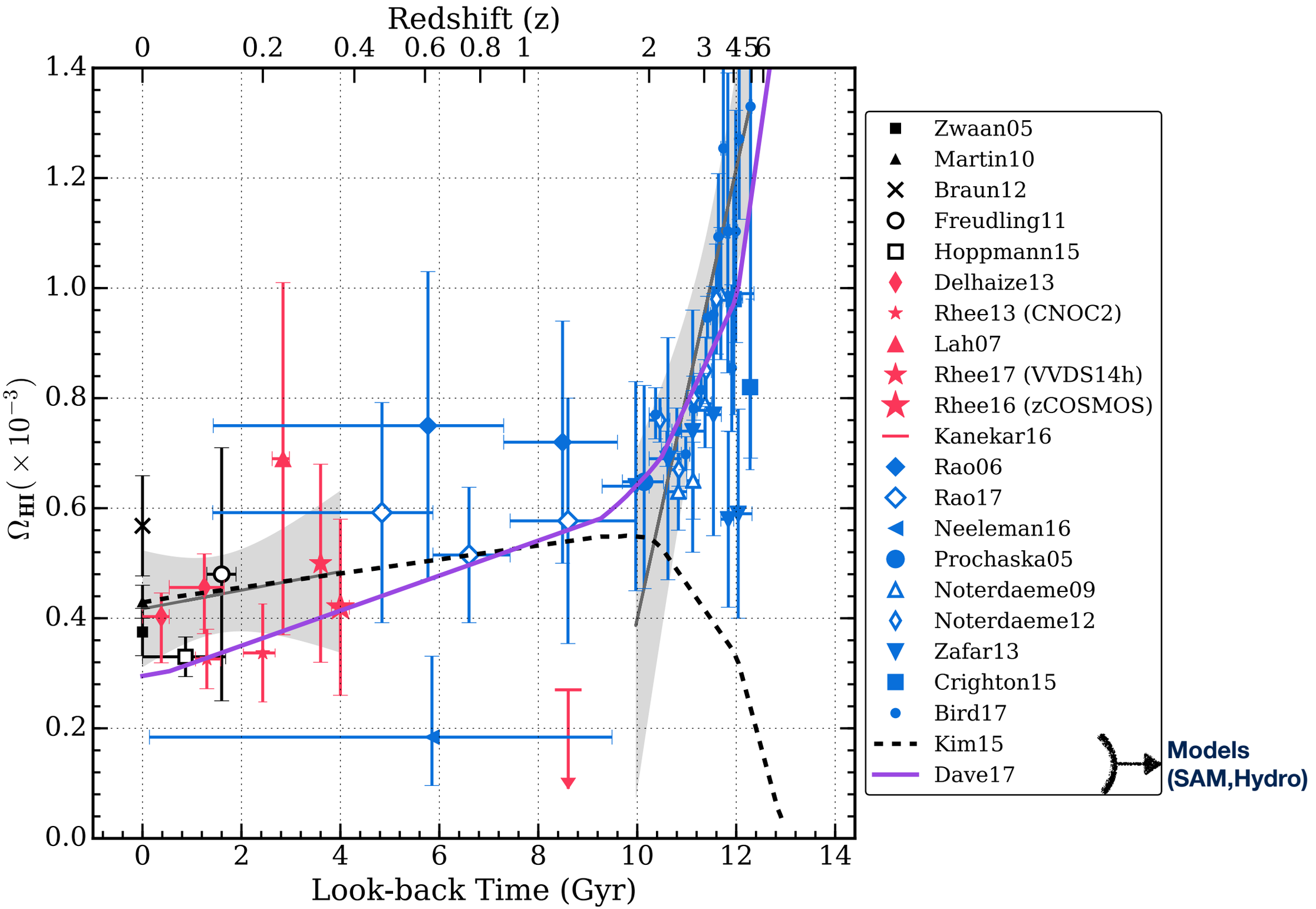

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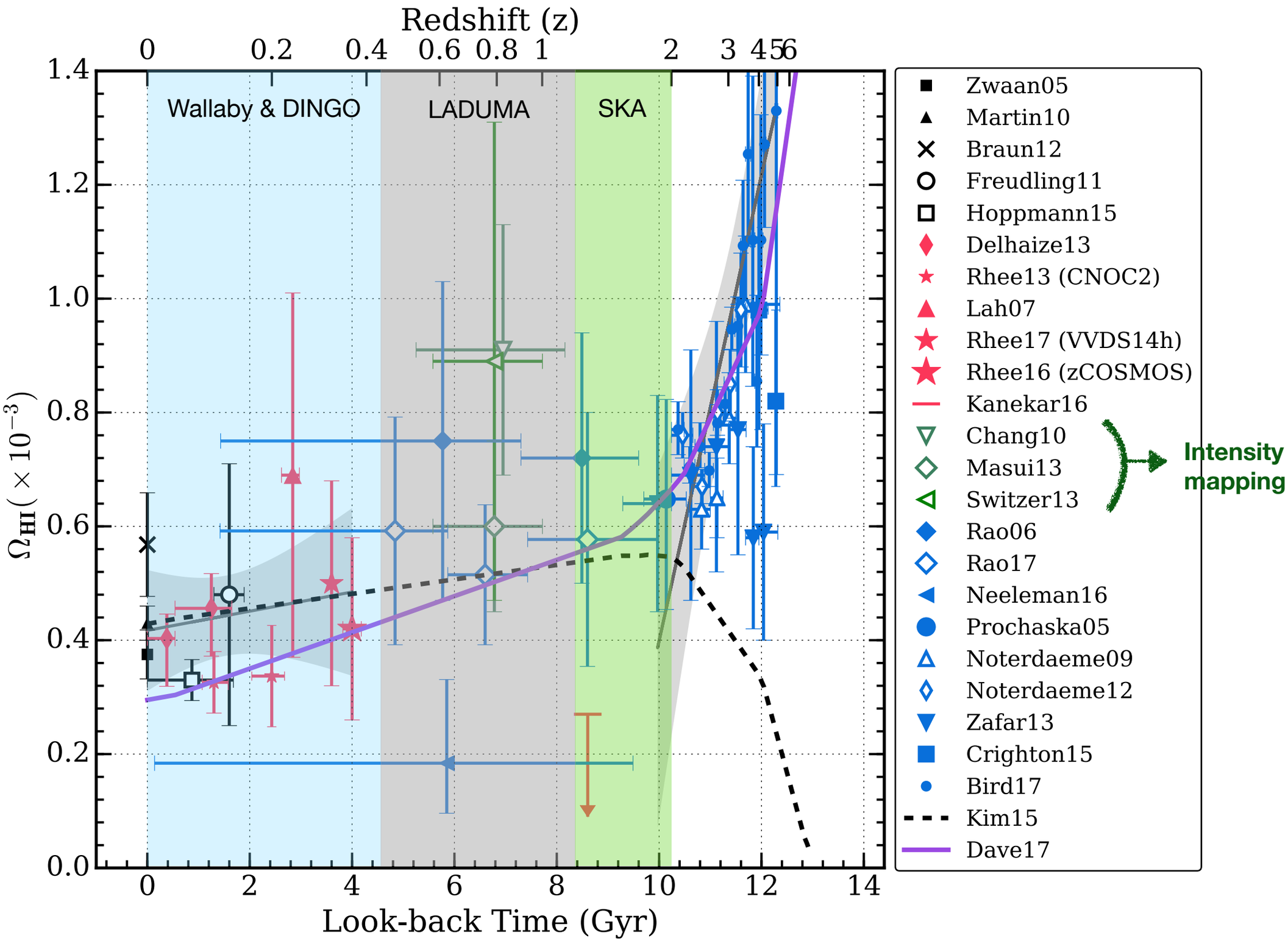
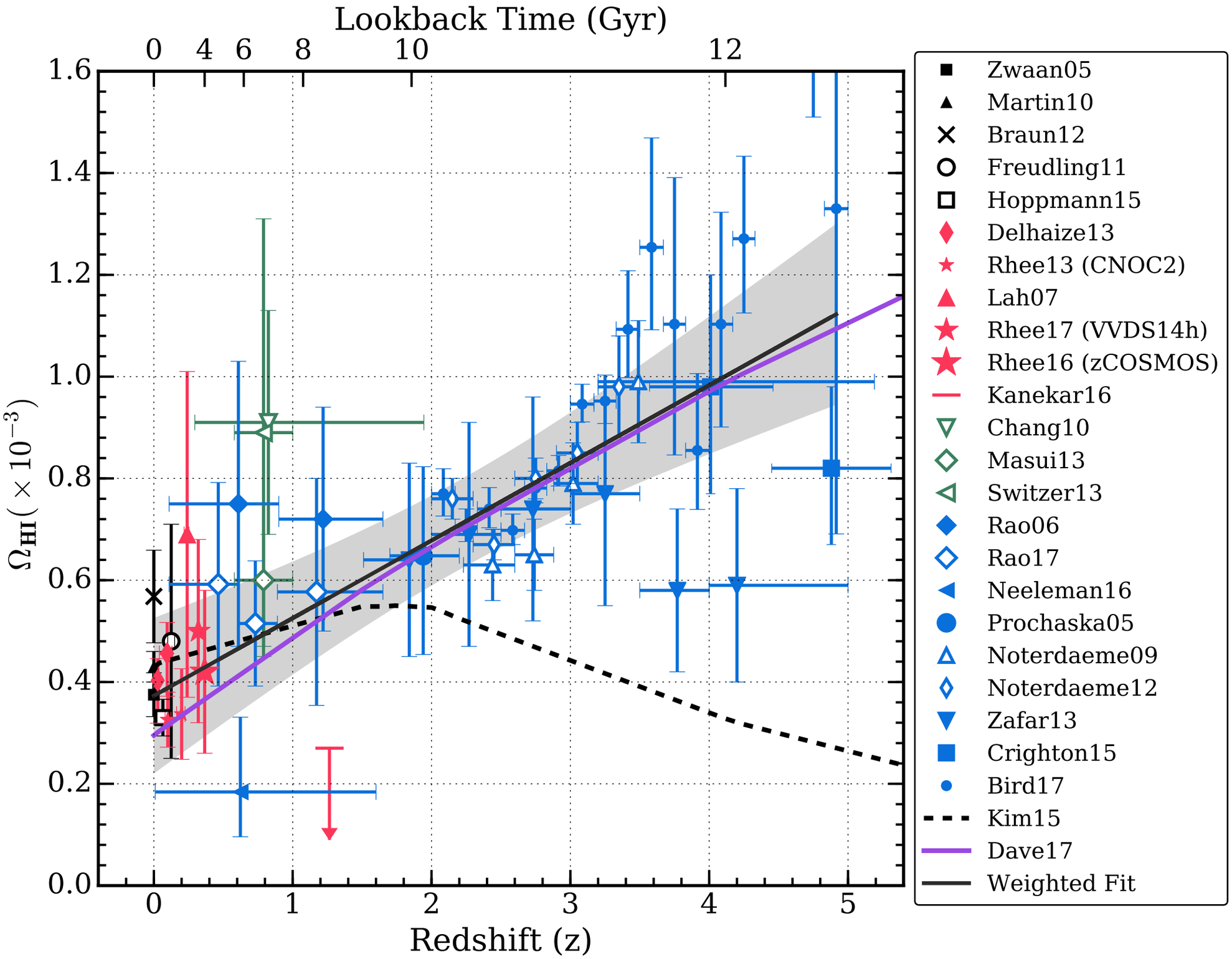


HI gas evolution with redshift



Summary

- HI gas evolution is **no longer** poorly constrained.
- HI spectral stacking and intensity mapping are very useful for future HI surveys to push their limit still further.
- Intermediate redshift ($0.5 < z < 2.0$) is crucial to understand the whole picture of HI gas evolution.
- Next generation HI surveys (e.g. Wallaby, DINGO, FLASH, CHILES, LADUMA) will explore this redshift interval **SOON**.