# HI 21 cm emission from an Ensemble of Galaxies at an Average Redshift of 1

Chowdhury et al. 2020

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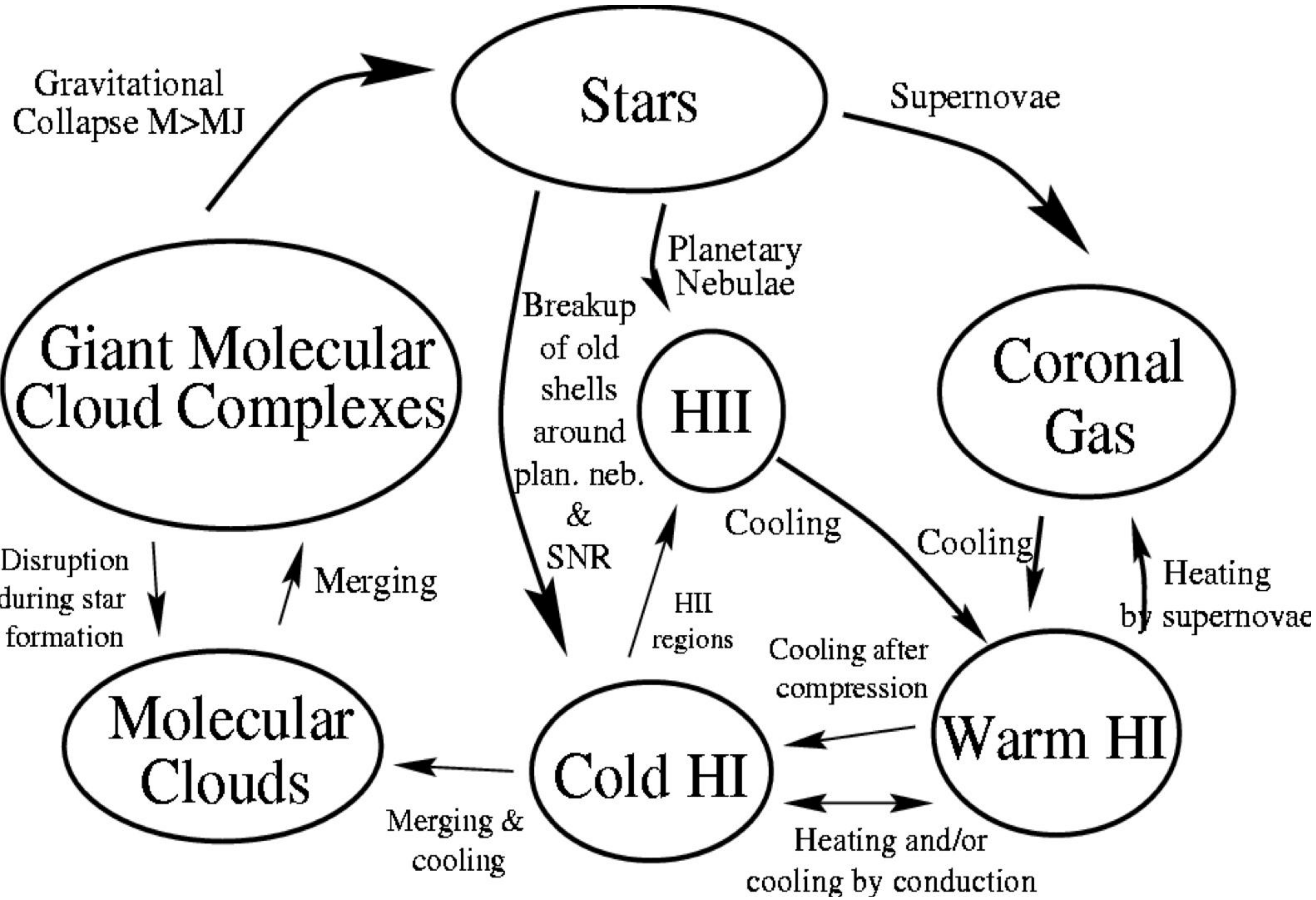
2021.11.19

# Outline

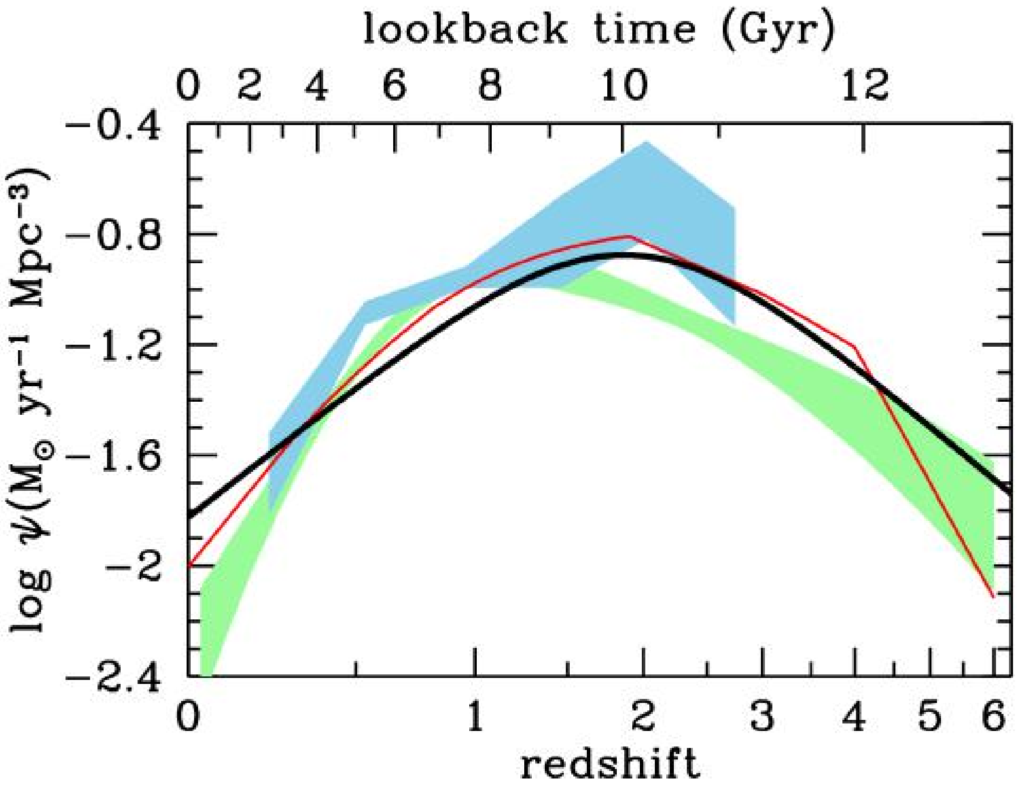
- Background
- Observation & Data sample
- Method & main results
- Summary

# Background

**Life Cycle of ISM (dominated by H)**

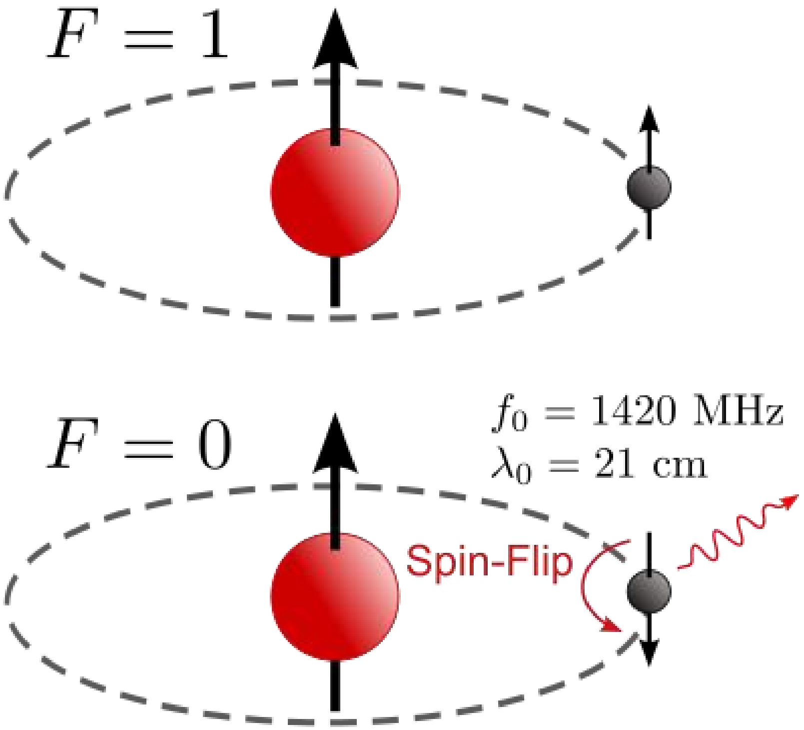



**Cosmic star formation history**




Madau, P. & Dickinson, M. 2014

# Background




**HI 21cm emission**

**Current study:**

detect individual galaxy: z_max=0.376 (Fern´andez et al. 2016).
stacking: non-detection with z>1 (Kanekar et al. 2016).
intensity mapping

**Further imporvement:**

next generation of radio telescopes (e.g. SKA)

# Observation & Data sample

- New telescope:The upgraded Giant Metre-Wave Radio Telescope in India
- New Band: 550-850 MHz
- Accurate redshift: v≈55 km/s from the DEEP2 Galaxy Redshift Survey(Keck II Telescope)
- Large galaxy samples: 7653 blue, star-forming galaxies with z = 0.74~1.45
- observing time: 90 hours

# The average HI mass of star-forming galaxies

- Stacking the HI 21cm emission
- spatial resolution: 60kpc
- signal: 4.5 σ
- luminosity density:

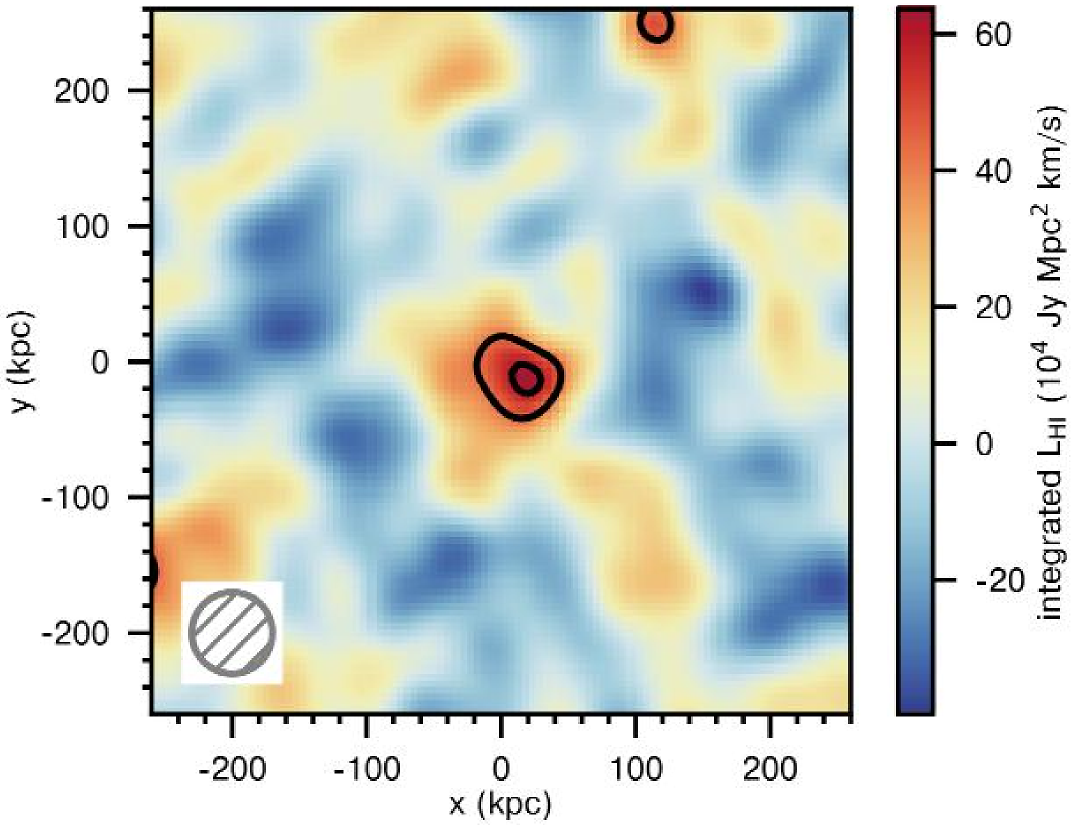
$L_{HI} = (6.37 \pm 1.42) \times 10^5 \, \mathrm{JyMpc^2kms^{-1}}$

- average HI mass:

$M_{HI} = 1.87 \times 10^4 L_{HI}$
$= (1.19 \pm 0.26) \times 10^{10} M_{\odot}$

- HI mass in Milky Way:

$M_{HI} \sim 8 \times 10^9 M_{\odot}$ (Kalberla et al. 2009)



# The mean stellar mass of the galaxies

- $M_* = 9.4 \times 10^9 M_\odot$
- The relation between the (U - B) color and the ratio of the stellar mass to the B-band luminosity:

  For z=0: $\log M/L_B(z=0) = -0.942 + 1.737(B - V_{\rm Vega}),$

  Calibrate using stellar masses estimated from the DEEP2 sample:

$$M_* = L_{B,\rm Vega} \times M/L_B(z=0) \times C_K(U-B, z),$$

$$\log C_K(U-B, z) = -0.0244 - 0.398\, z + 0.105\, (U - B_{\rm Vega}).$$

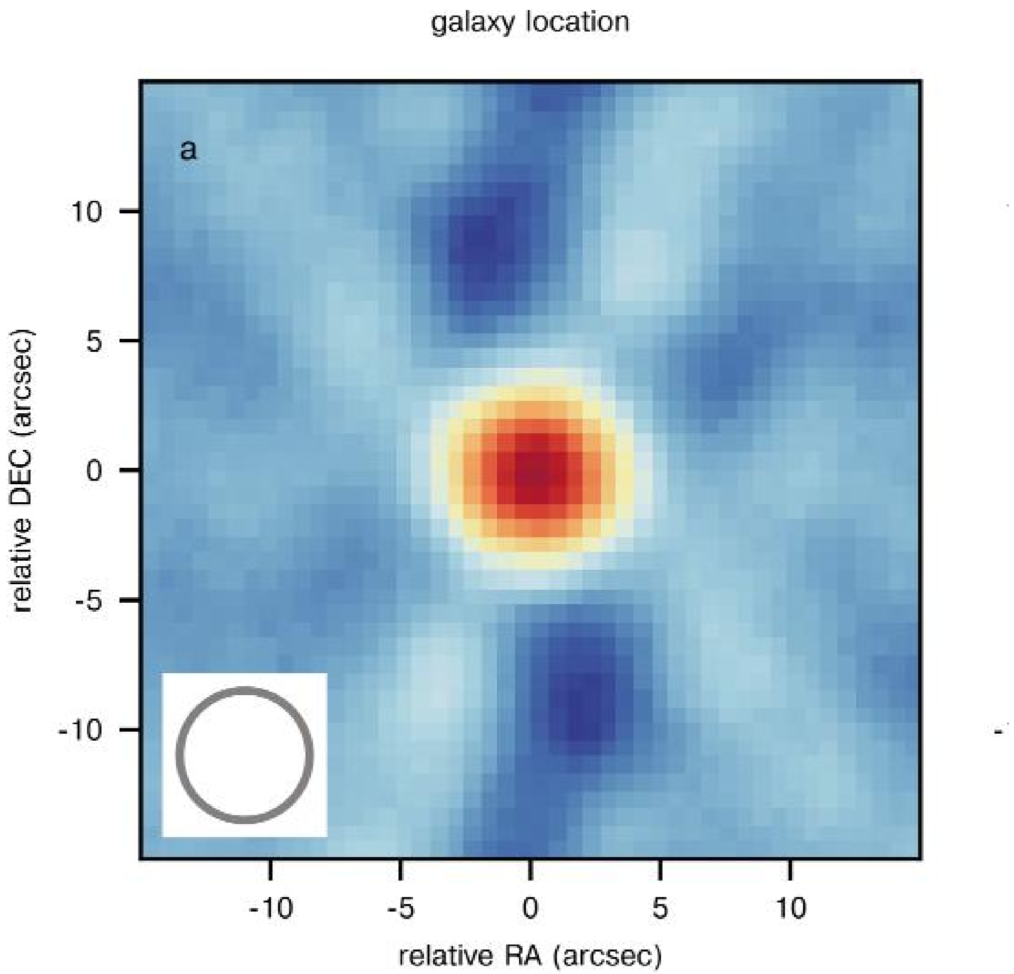
- The ratio of average $M_{HI}$ to average $M_*$

$$\langle M_{HI} \rangle / \langle M_* \rangle = 1.26 \pm 0.28$$

- The ratio of average $M_{HI}$ to average $M_*$ in local universe ~ 40% (Catinella, B. et al. 2018)

# The average star-formation rate of the galaxies

- stacking the rest-frame 1.4 GHz continuum
- detection: 29σ significance
- luminocity density: $L_{1.4GHz} = (2.09 \pm 0.07) \times 10^{22} WHz^{-1}$
- average star-formation rate: $SR = (3.7 \pm 1.1) \times 10^{-22} L_{1.4GHz}$ $= 7.72 \pm 0.27 (M_{\odot}/yr)$



# HI depletion time

main-sequence galaxy at z=1.03:

- $t_{dep,HI} = \frac{M_{HI}}{SFR} = (1.54 \pm 0.35)$ Gyr
- $t_{dep,H_2} = \frac{M_{H2}}{SFR} \approx 0.7$ Gyr (Tacconi, L. J. et al. 2013)
- the atomic gas need to be replenished via gas accretion after 1-2 Gyr
- similar to the timescale of SFR decline steeply

For local universe:

- $t_{dep,HI} (\approx 7.8 Gyr) > t_{dep,H_2} (\approx 1$ Gyr)
- sustain its present SFR without the need for fresh gas accretion

# The cosmological HI mass density

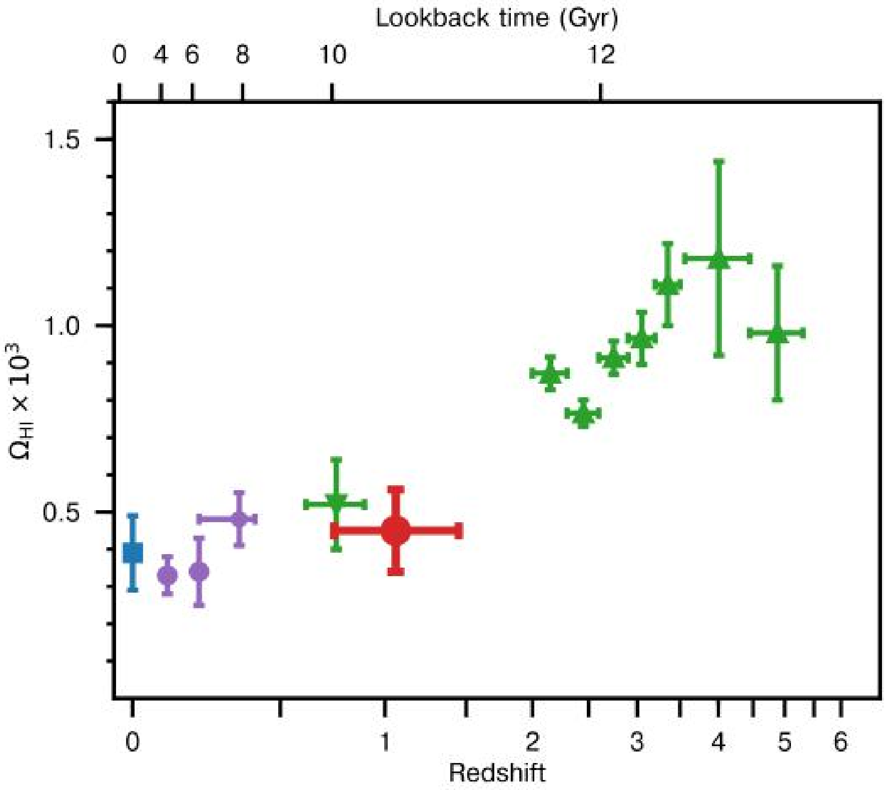
The comoving HI mass density:

$$\rho_{\rm HI} = \int_{-\infty}^{-20} {\rm M_{HI}(M_B)}.\phi({\rm M_B})\,{\rm dM_B} = (3.15 \pm 0.79) \times 10^7\,{\rm M_\odot\,cMpc^{-3}}.$$

- $M_B$:B-band magnitude
- $\phi(M_B)$:the B-band luminosity function of blue galaxies,obtained from the DEEP2 survey (Willmer et al.2006)
- a relation between $M_{HI}$ and $M_B$:

$$\log[M_{HI}(M_B)] = K - \beta M_B$$

$$K = 2.88 \pm 0.11 \text{ and } \beta = 0.34 \pm 0.01$$




The cosmological HI mass density:

$$\Omega_{\rm HI,bright}(z) = \rho_{\rm HI,bright}(z)/\rho_{\rm crit,0} = (2.31 \pm 0.58) \times 10^{-4}$$

$$\Omega_{\rm HI}(z) = \rho_{\rm HI}(z)/\rho_{\rm crit,0} = (4.5 \pm 1.1) \times 10^{-4}$$

# Summary

- The first detection of the stacked HI 21 cm emission signal at z ≈ 1
- The explanations of the decline in the cosmic SFR at redshifts below 1:

    insufficient infall atomic gas

✓ short depletion timescale

✓ the slow evolution of HI mass density

| | |
|---|---|
| Number of Galaxies | $7,653$ |
| Redshift range | $0.74 - 1.45$ |
| Mean redshift, $\langle z \rangle$ | $1.03$ |
| Mean stellar mass, $\langle M_* \rangle$ | $9.4 \times 10^9\ M_\odot$ |
| Mean HI Mass, $\langle M_{HI} \rangle$ | $(1.19 \pm 0.26) \times 10^{10}\ M_\odot$ |
| $\langle M_{HI} \rangle / \langle M_* \rangle$ | $1.26 \pm 0.28$ |
| Radio-derived SFR | $7.72 \pm 0.27\ M_\odot/yr$ |
| HI depletion timescale, $\langle t_{dep,HI} \rangle$ | $1.54 \pm 0.35$ Gyr |
| $\Omega_{HI,Bright}$ at $\langle z \rangle = 1.06$ | $(2.31 \pm 0.58) \times 10^{-4}$ |
| Total $\Omega_{HI}$ at $\langle z \rangle = 1.06$ | $(4.5 \pm 1.1) \times 10^{-4}$ |

# Question

- The tension between the evolution of the ratio of average HI mass to average stellar mass and the non-evolution of HI mass density?
- Why there is a bar in the stacking continuum figure?
- How to approve the senario: the quenching of star-formation activity at $z < 1$ is likely to arise due to insufficient gas infall?