Deep U-band MeerKAT observations of the COSMOS field

SKACH team

PI: Mirka Dessauges-Zavadsky (UniGE)

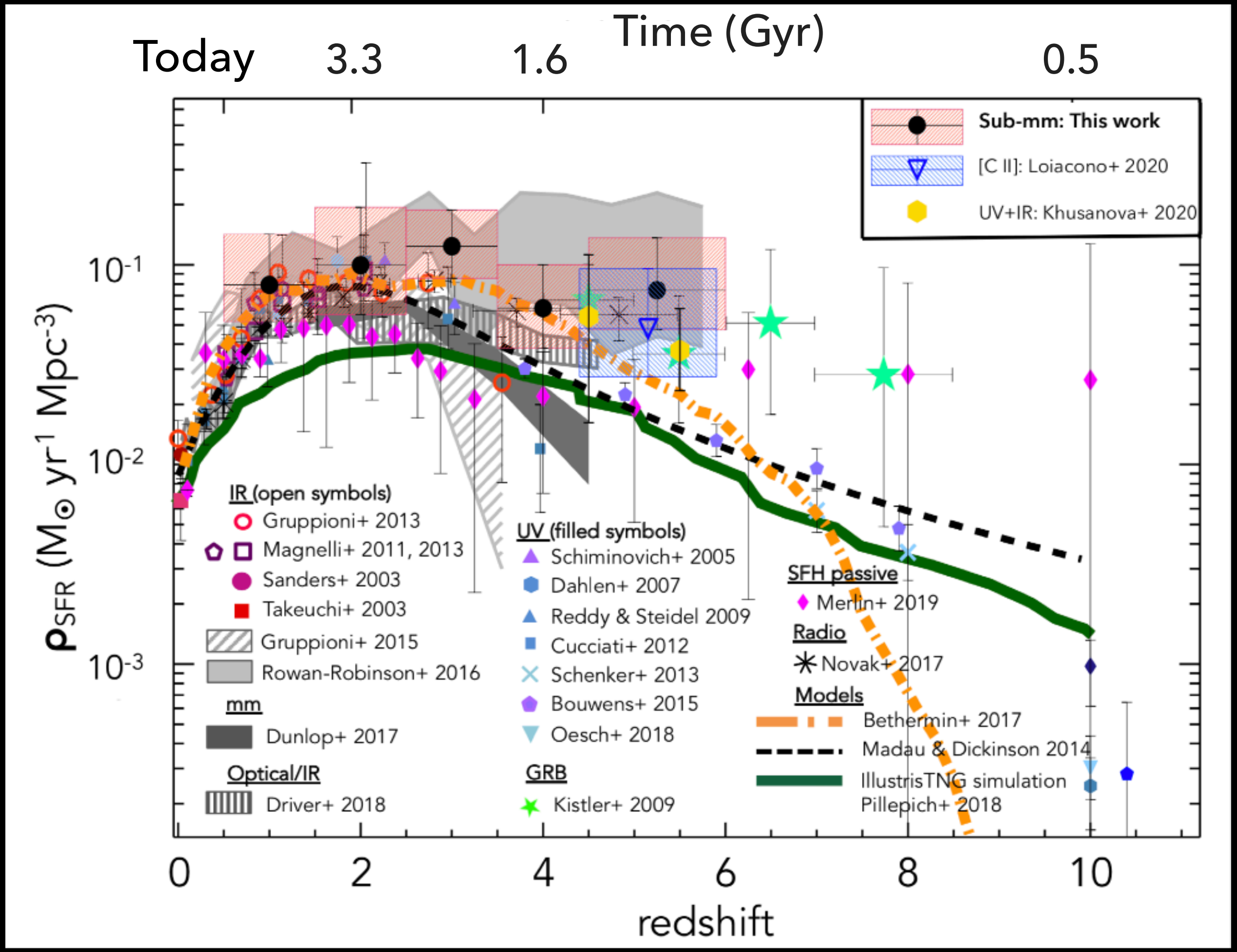
CoIs: Omkar Bait, Daniel Schaerer (UniGE), Mark Sargent (ISSI)

Background

Three fundamental pillars governing galaxy evolution

1 Star formation rate density evolution

High-redshift galaxies experience **a peak in their SFR density at z~2**, which steeply declined since.



Gruppioni/w DZ+20

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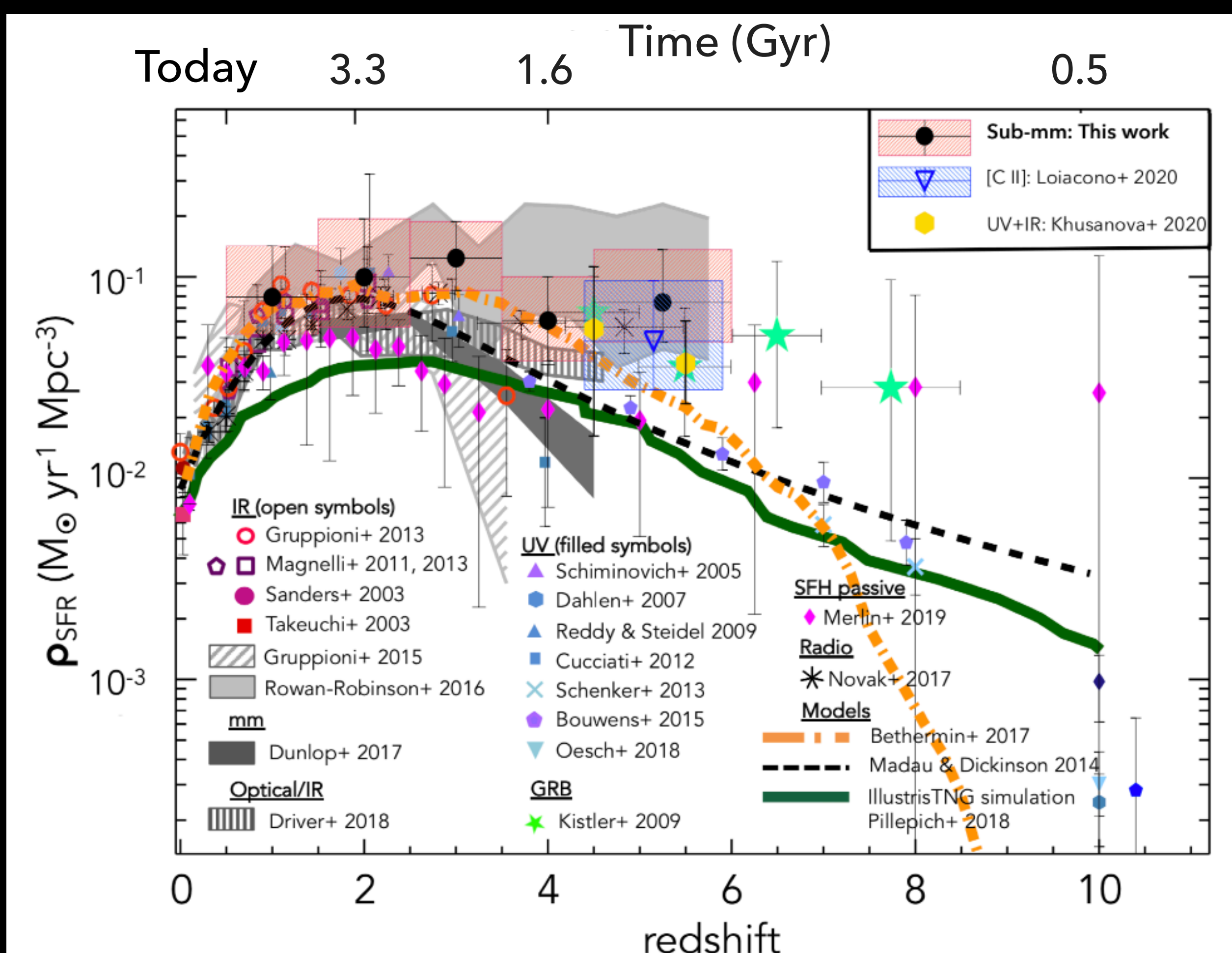
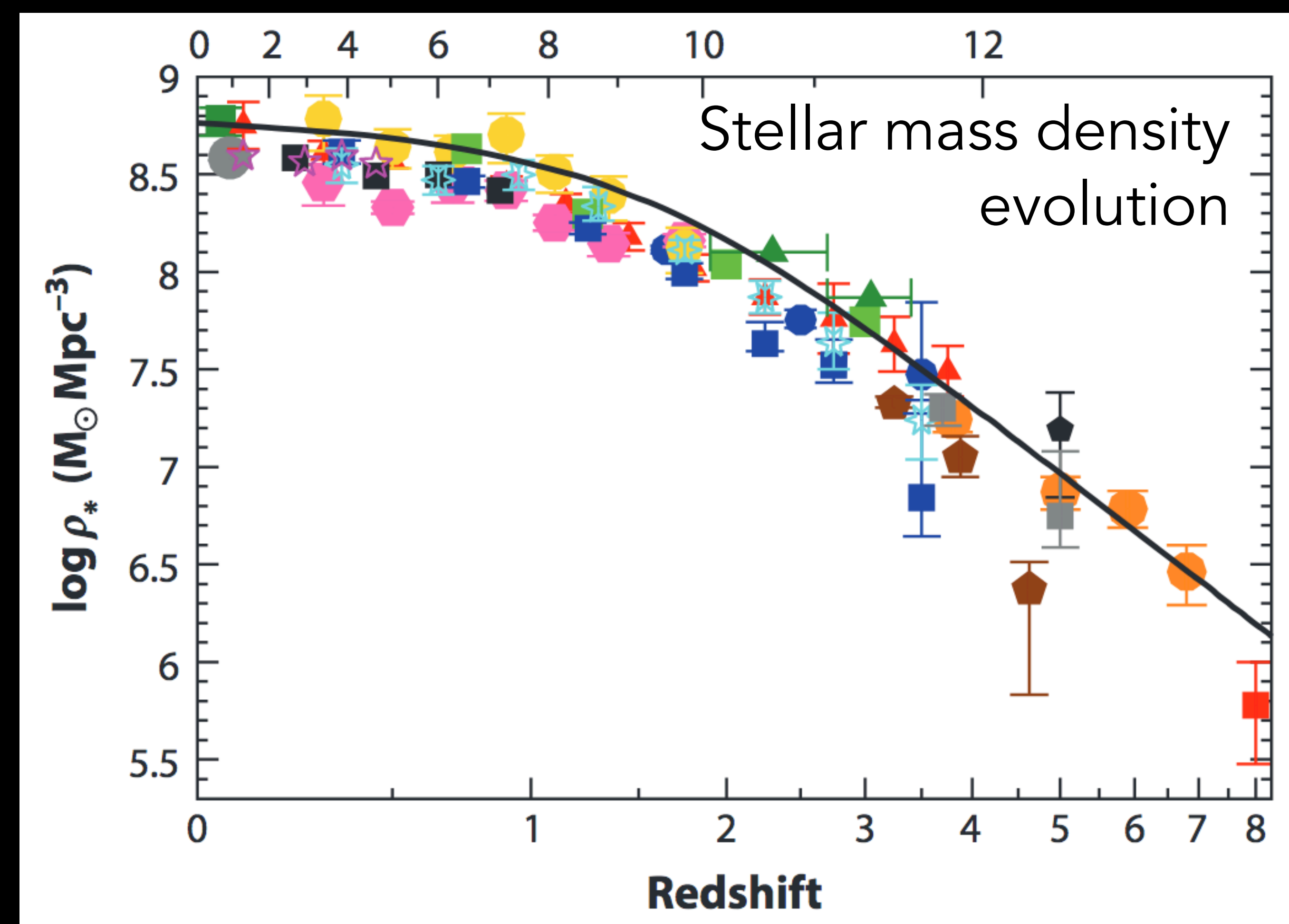
Madau & Dickinson 14





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The integral of the SFR density over cosmic time gives the stellar mass density.

About half of all stellar mass was formed by z~1.

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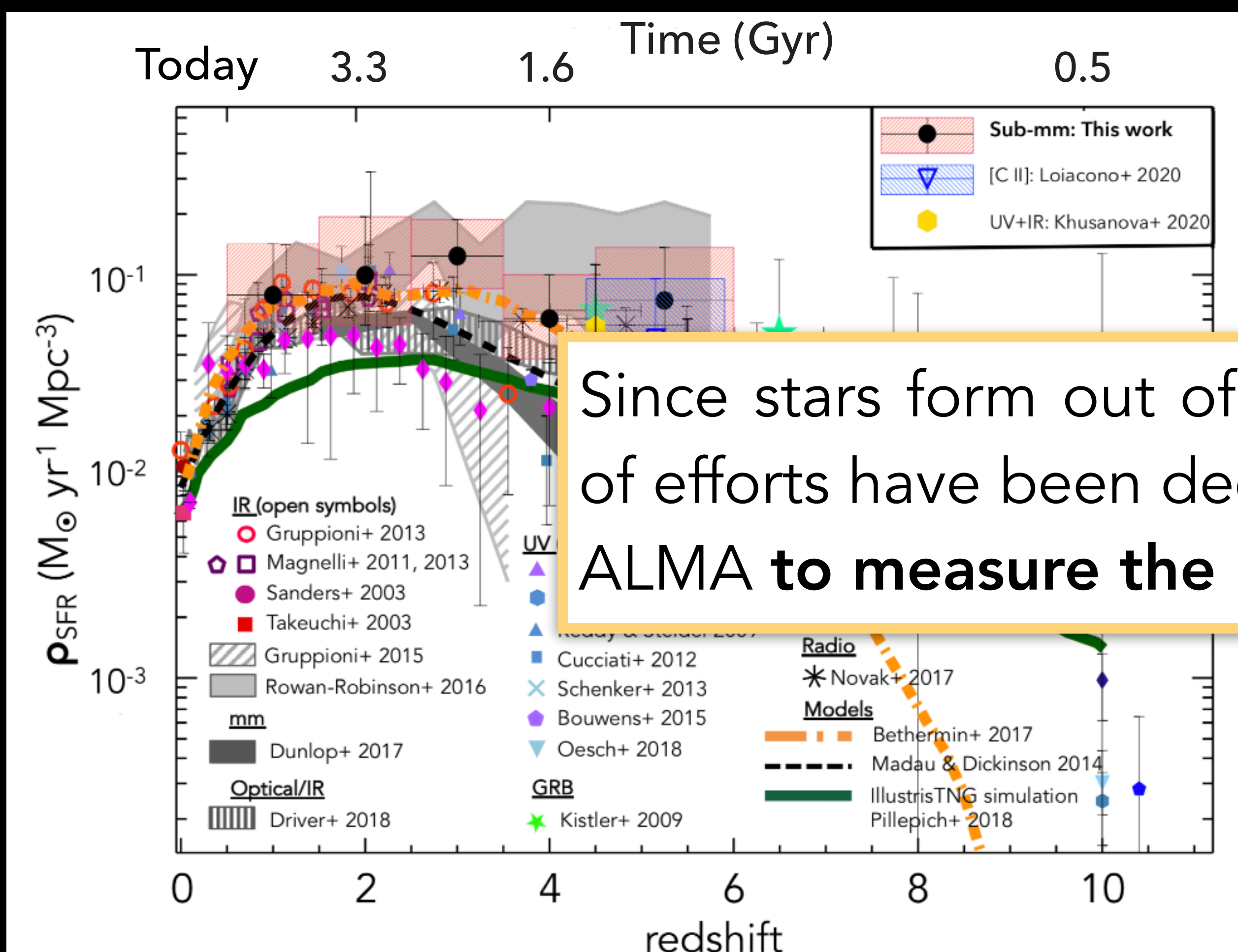

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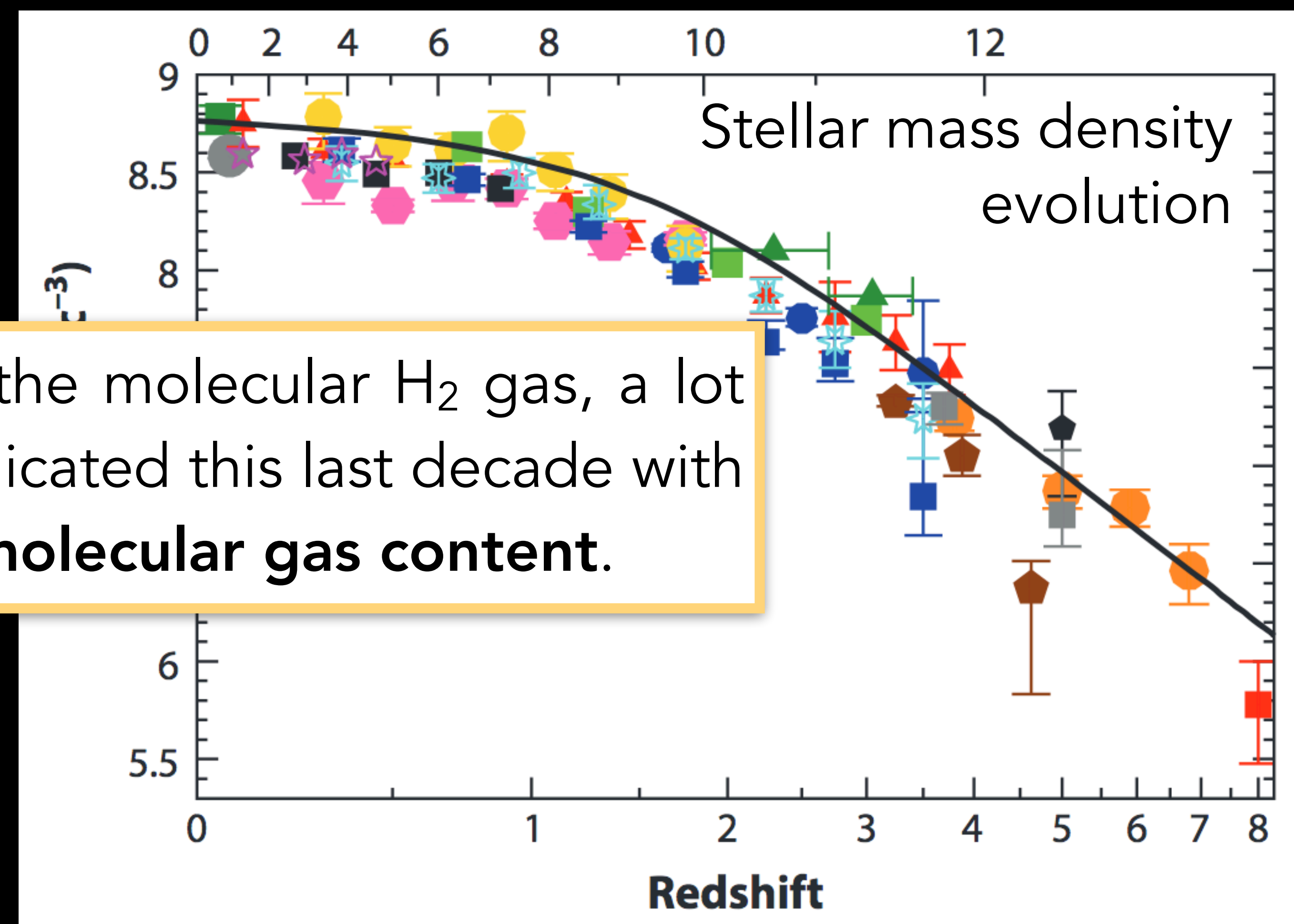

Since stars form out of the molecular H_2 gas, a lot of efforts have been dedicated this last decade with ALMA **to measure the molecular gas content**.

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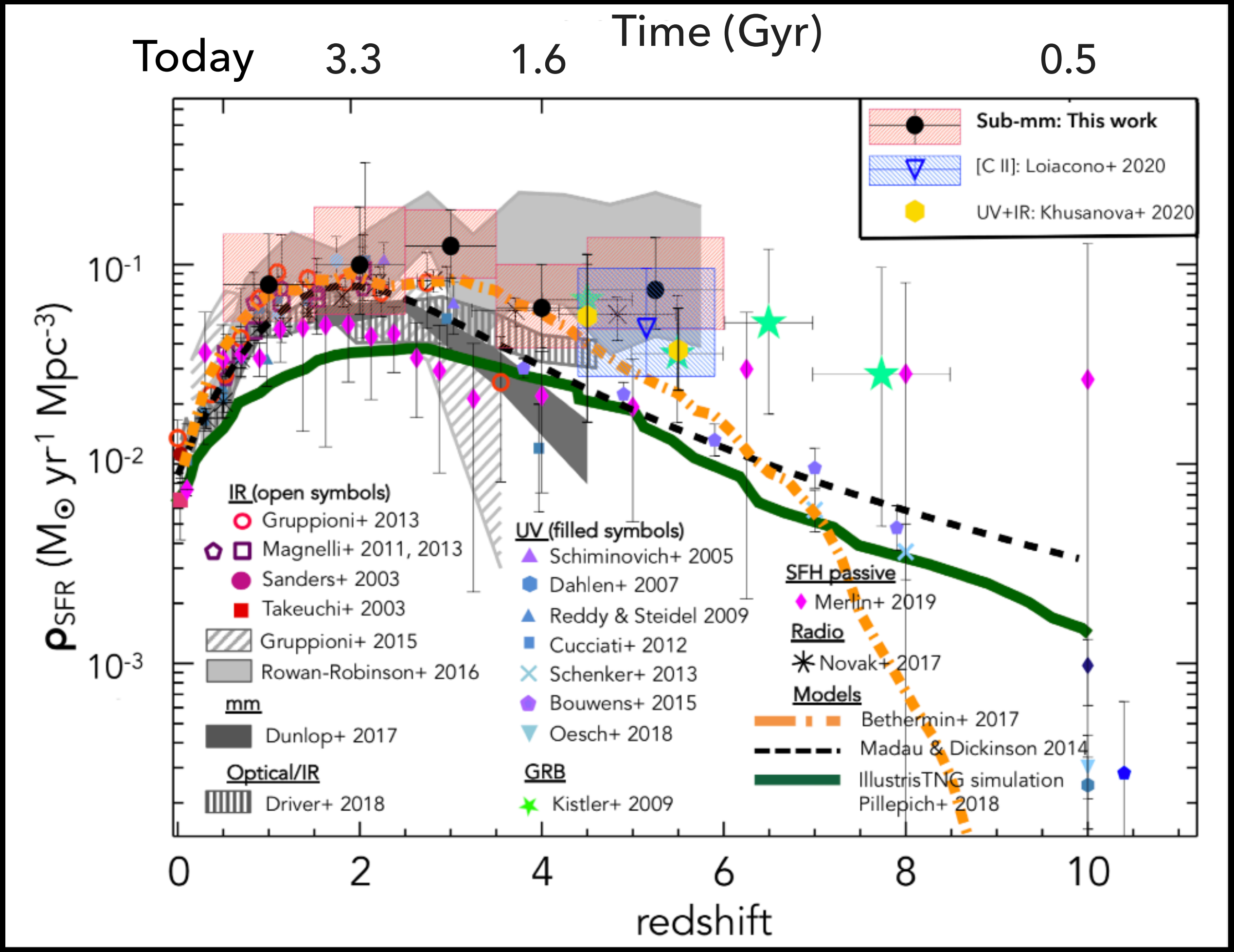

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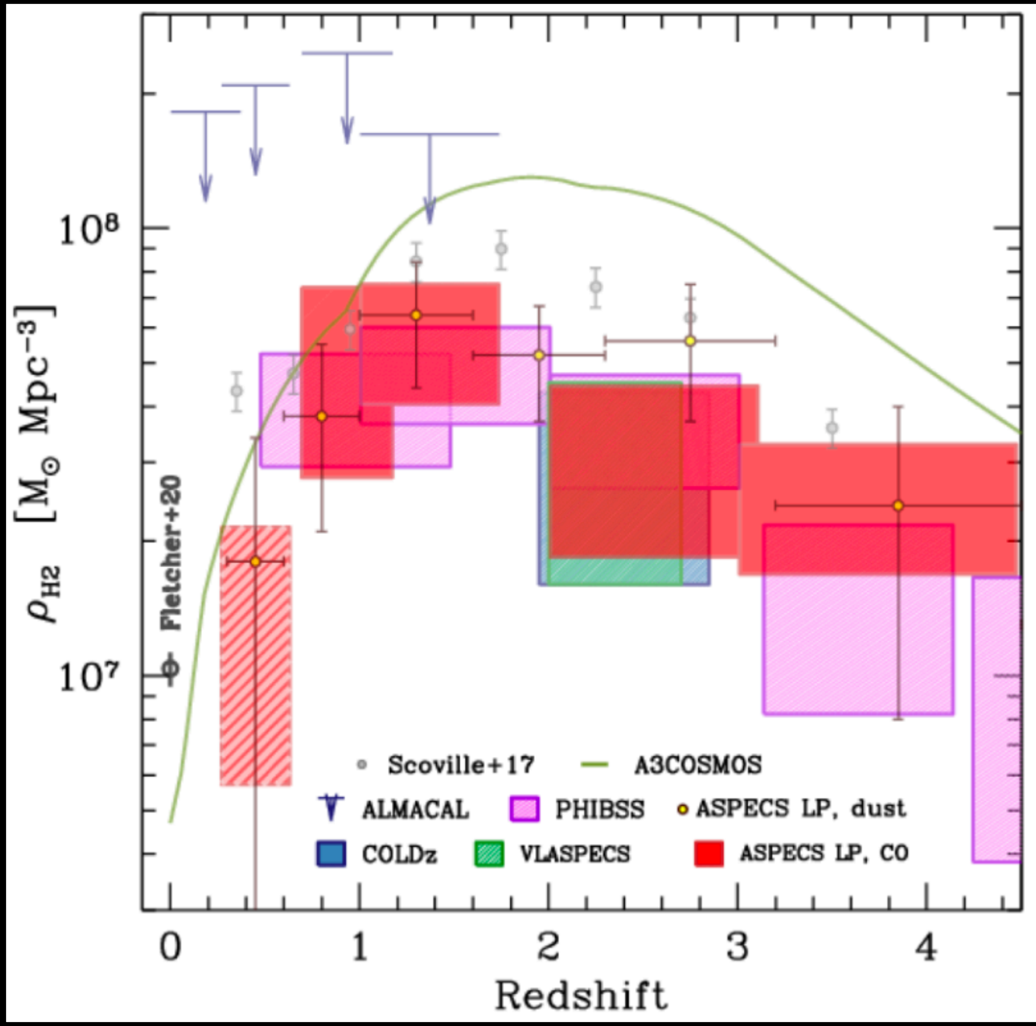
② Molecular H_2 mass density evolution

There is now a growing observational evidence that **the H2 mass density follows the SFR density evolution** as expected.



Decarli+19,20; Aravena/w DZ+24

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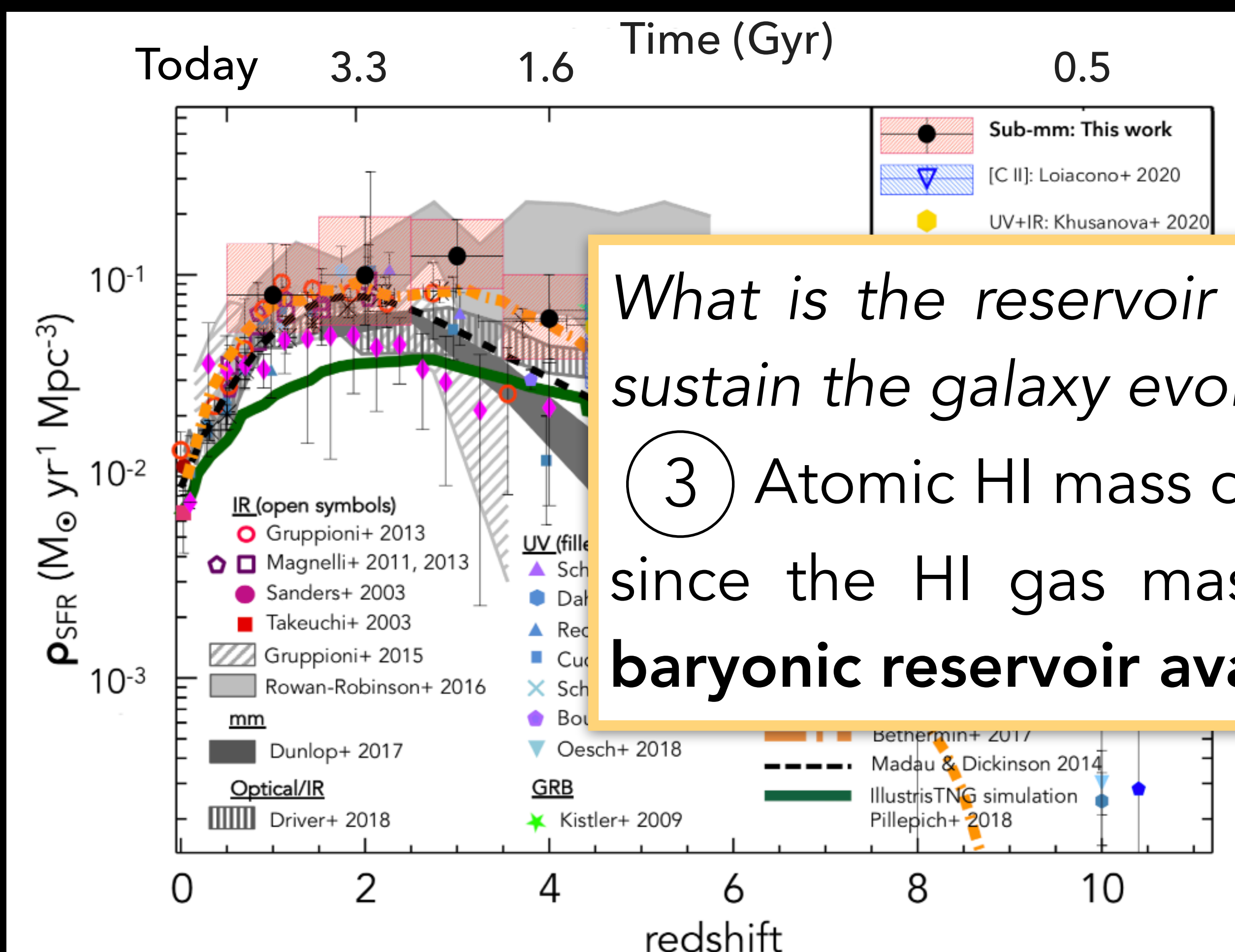

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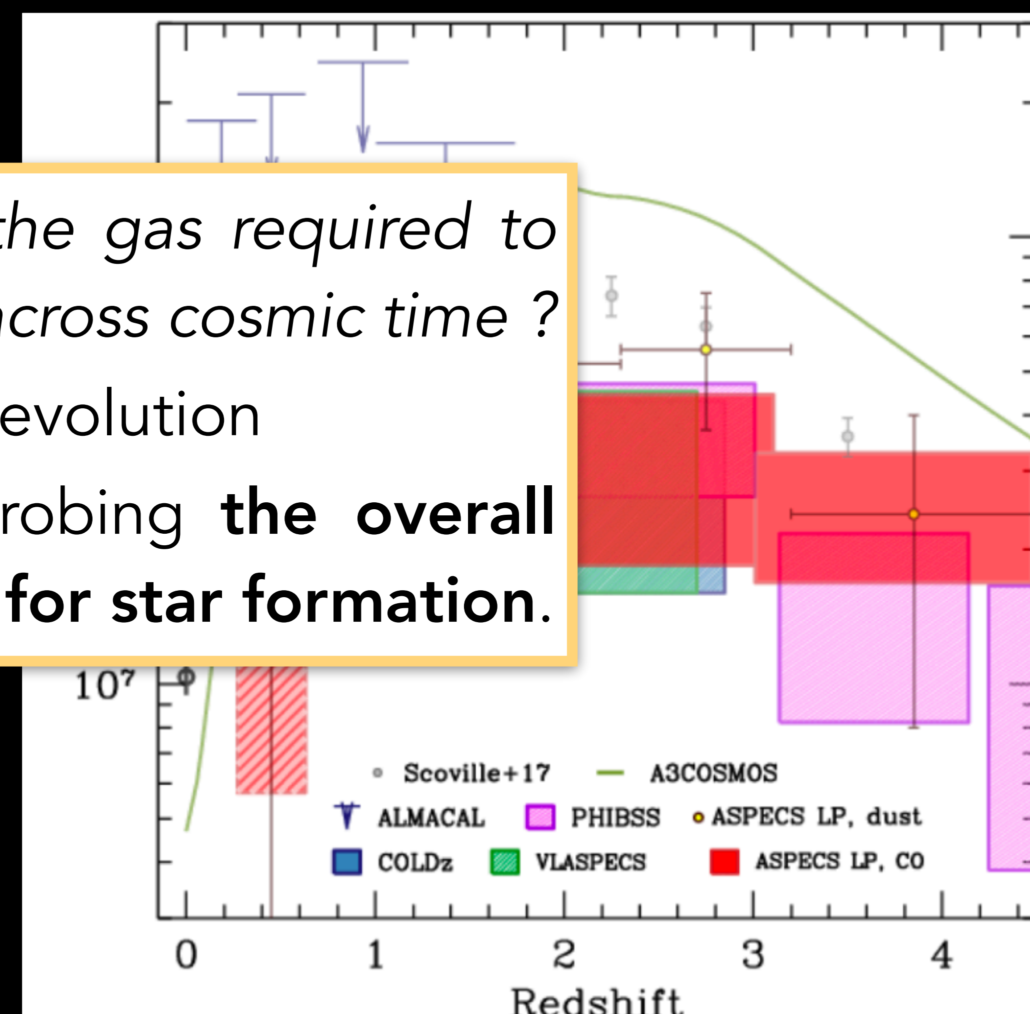


Decarli+19,20; Aravena/w DZ+24

What is the reservoir of all the gas required to sustain the galaxy evolution across cosmic time ?

③ Atomic HI mass density evolution

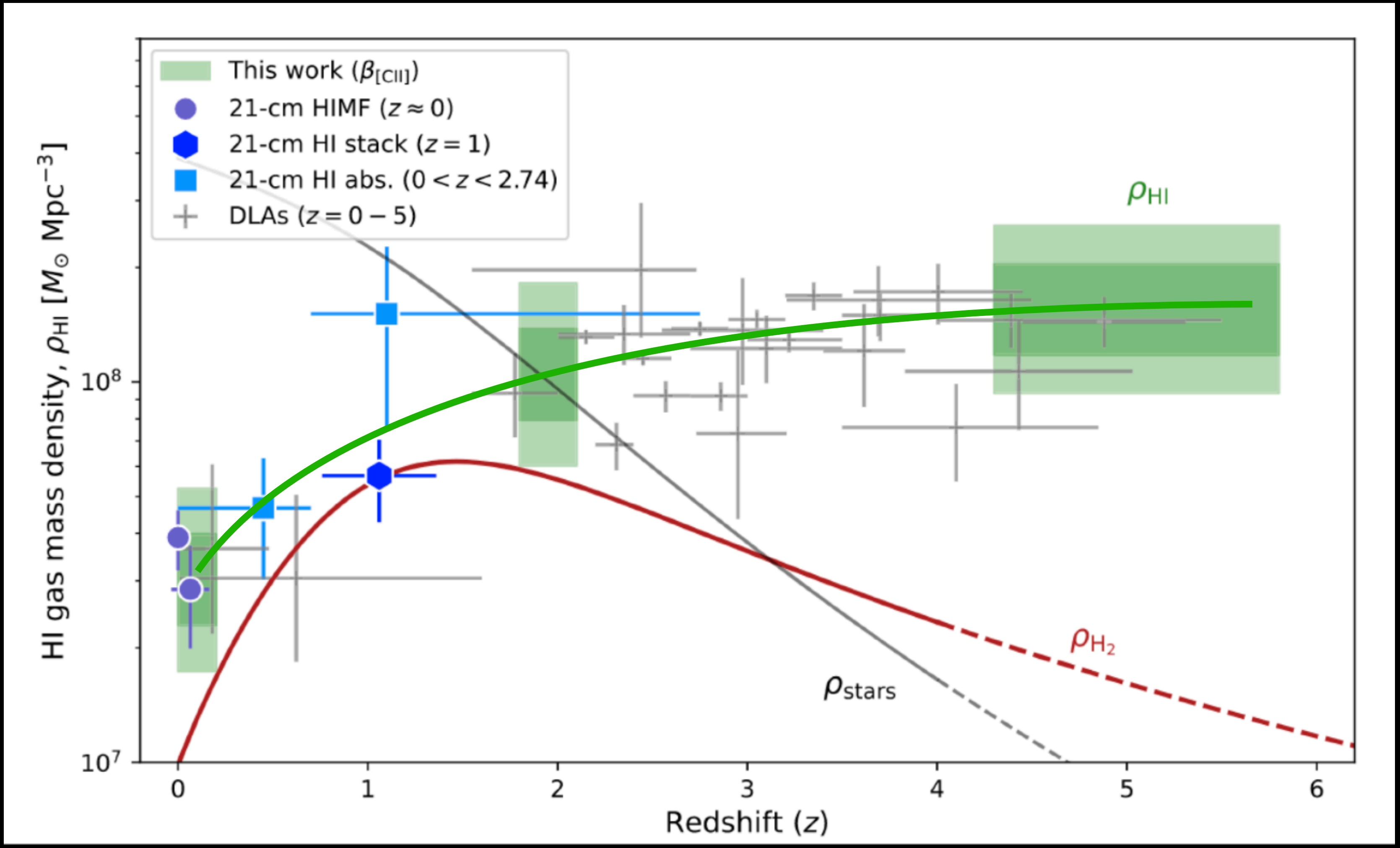
since the HI gas mass is probing **the overall baryonic reservoir available for star formation**.

Context between 2020-2024

Sampling the HI neutral gas content across cosmic time

- Until 2020 only **estimates of HI column densities measured in absorption** (through the damped Lyman-alpha line) along lines-of-sight of luminous quasars and gamma-ray bursts **are available at z>0.4**.

  From the extrapolation of the measured HI column densities to **the cosmic HI mass density**, *Walter+20 and Heintz+21,22* found:



Heintz+21

The HI density dominates over the H_2 density from z~6 to z~2, and the HI and H_2 densities reach comparable values near cosmic noon (z~1–2).

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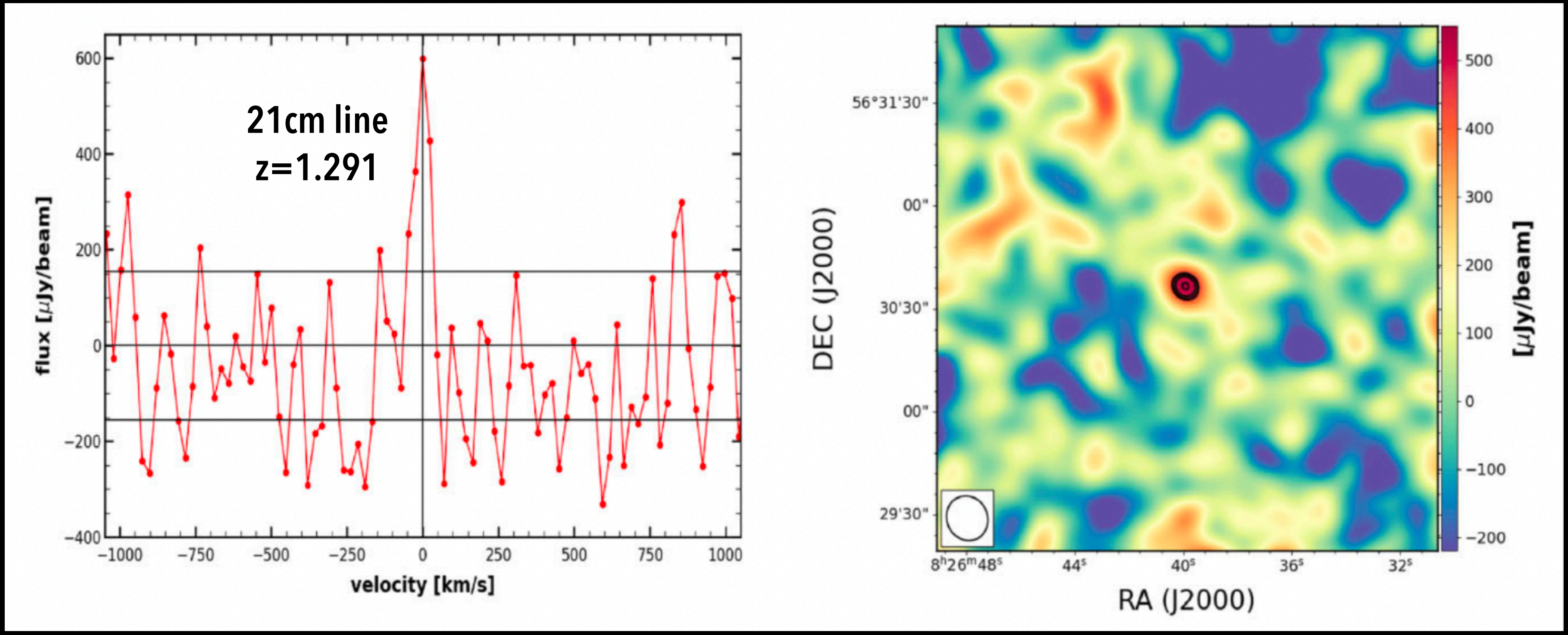
- **HI mass measurements of individual galaxies *via the 21cm emission line*** are still **very challenging at z>0** with current radio facilities because of the line faintness.

—long-term detection record at z=0.376 *(Fernandez+16)*
—debatable detection in a strongly lensed galaxy at z=1.291 *(Chakraborty&Roy23)*



Chakraborty & Roy 23

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- **HI mass measurements of individual galaxies *via the 21cm emission line*** are still **very challenging at z>0** with current radio facilities because of the line faintness.
- Recently, independent teams developed **stacking techniques of the HI 21cm signal of thousands of galaxies** to measure the HI mass based on 2 main surveys.

MIGHTEE-HI survey with MeerKAT

Field : COSMOS
galaxies : 9'023
Redshift range : **0.23<z<0.49** / <z>=0.37
Integration time : 16 h
Frequency range (L-band) : 950-1050 MHz
References : Maddox+21; Heywood+22,24
HI stacking : Sinigaglia+22,24

CATz1 survey with GMRT

Field : DEEP2
galaxies : 11'419
Redshift range : **0.74<z<1.45** / <z>=1.01
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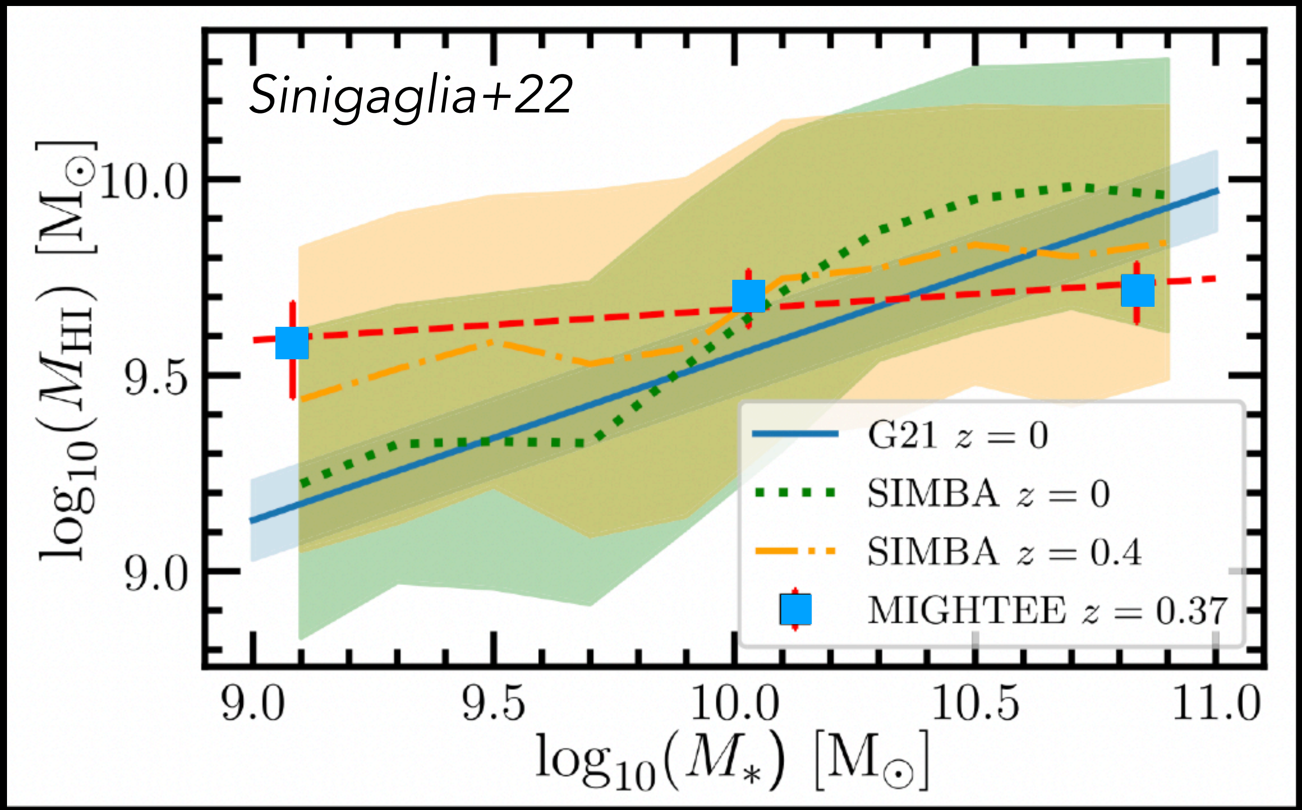
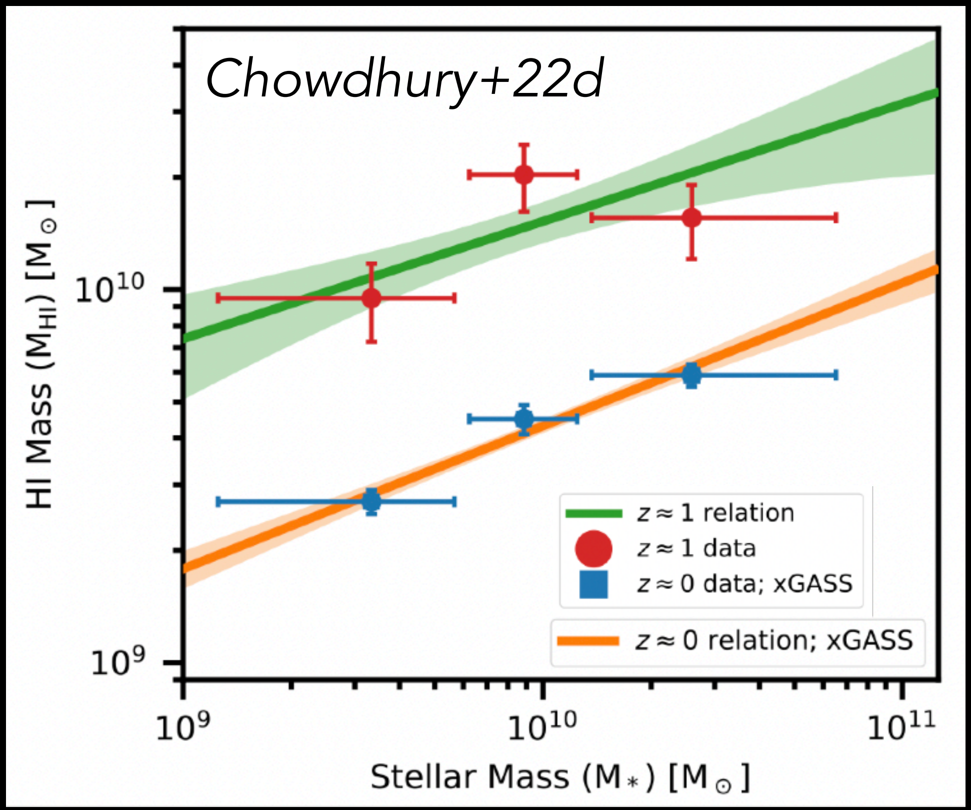
Latest results on HI mass at z>0





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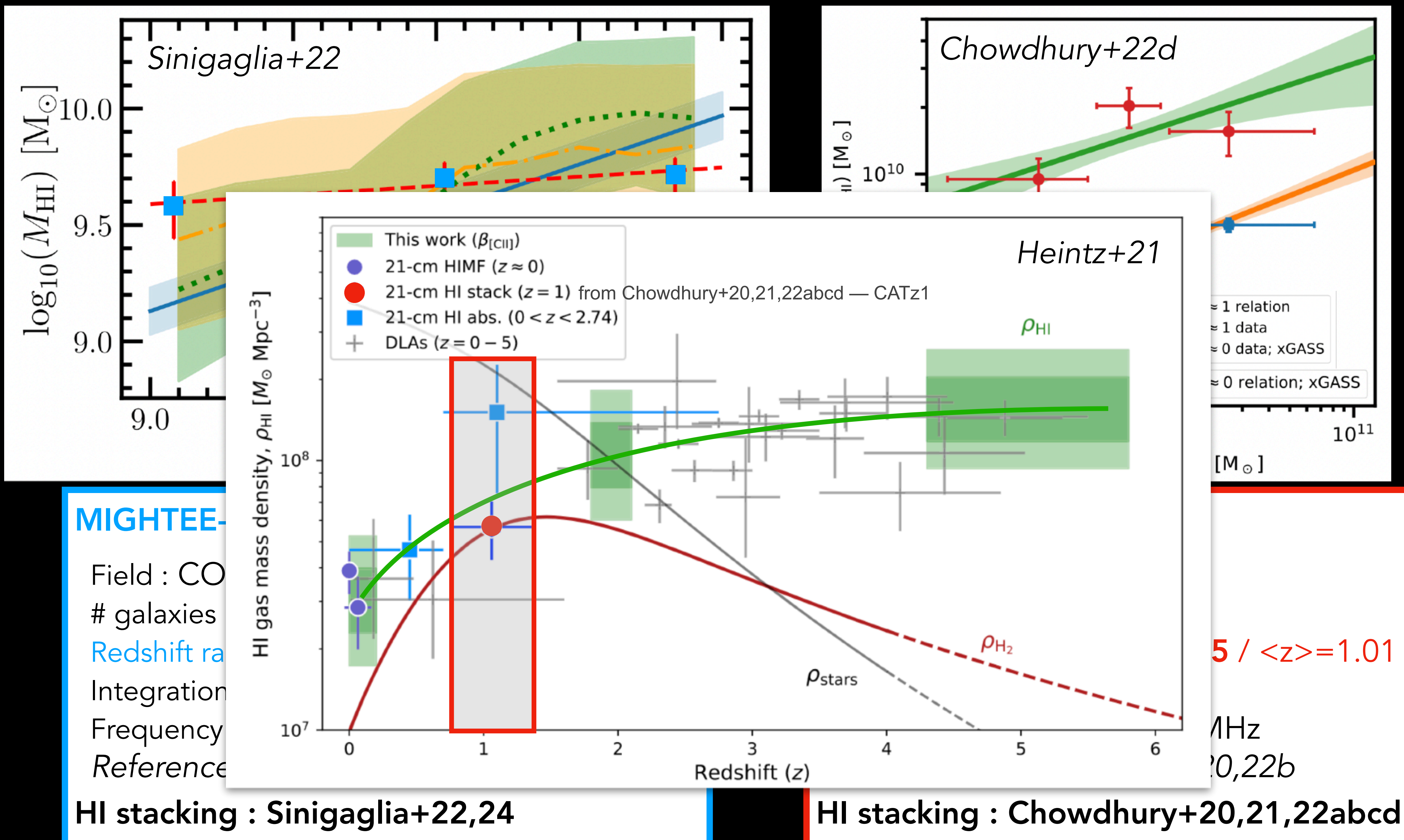
The 2 surveys show:
—an HI mass increase as a function of the stellar mass for galaxies at a given z
—an overall HI mass increase as a function of z

Latest results on HI mass at z>0

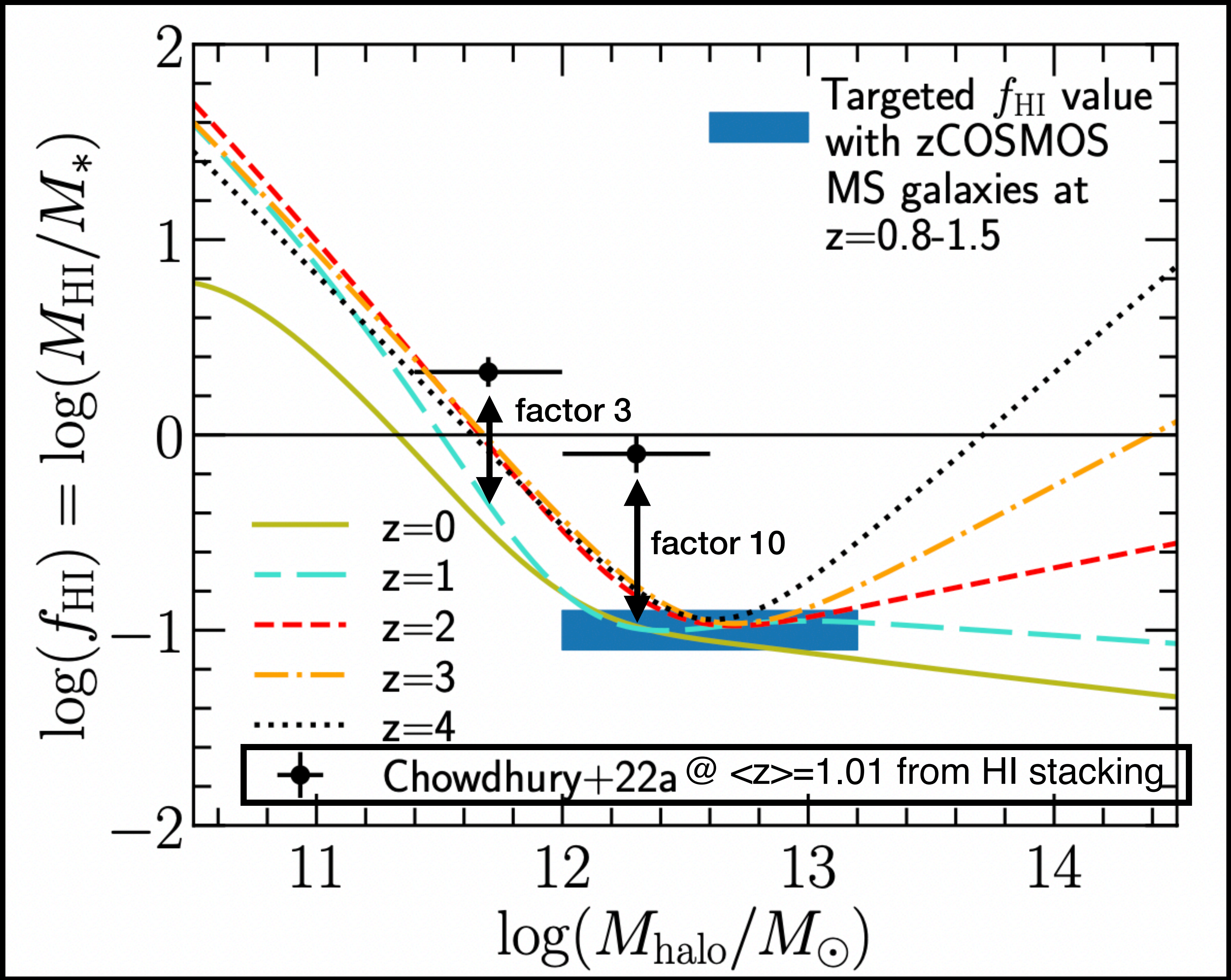


—a cosmic HI density agreement with the HI density derived from HI absorption and with the H_2 density at z~1

Latest results on HI mass at z>0

In tension with the cosmological halo mass model…

- Predicting the evolution of the HI fraction (f_{HI}) with halo mass over z=0–4 that is **a factor of ~3–10 smaller than f_{HI} at <z>=1.01 measured from HI stacking**.



Padmanabhan & Loeb 20

Cosmological data-driven halo mass model (*Padmanabhan+17; Padmanabhan & Loeb 20*)

built on the compilation of 21cm HI measurements at z~0, line intensity mapping, and DLAs ⊕ the stellar–halo mass relation from Behroozi+19.

MeerKAT observing program

Goal — Obtain a consensus in our understanding of the baryonic cycle between observations and model predictions.

Need of an <u>independent</u> 21 cm HI mass measurement at z~1 !

 # with another telescope/in another field

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ALMA detections (A^3COSMOS) : 74
Redshift range : **0.8<z<1.5** / <z>=1
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Redshift range : **0.4<z<0.8** / <z>=0.6
Integration time : 110 h (89 h on-source)
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Why the COSMOS field :

—Most extensive multi-wavelength coverage providing robust stellar mass and star formation measurements.

—Largest compilation of 20K galaxies with spectroscopic redshifts.

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2–3x deeper than MIGHTEE-HI and CATz1.

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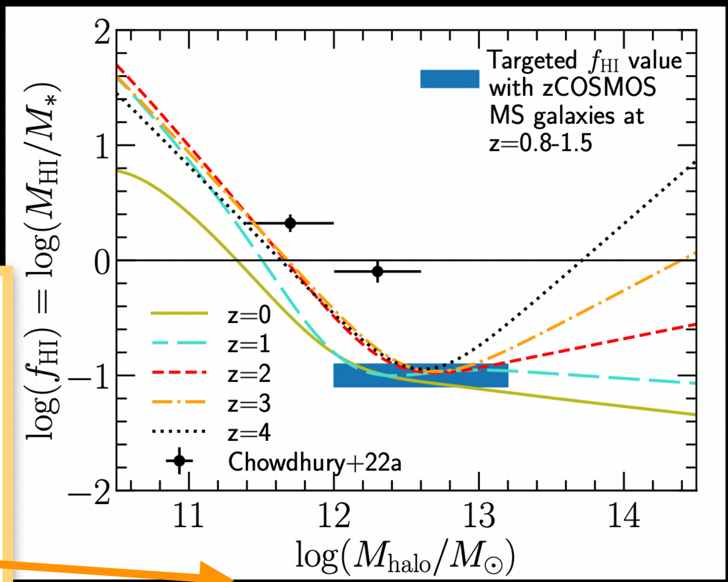

I. Should be able to detect **the model-predicted f_{HI}** by stacking 2’514 galaxies.

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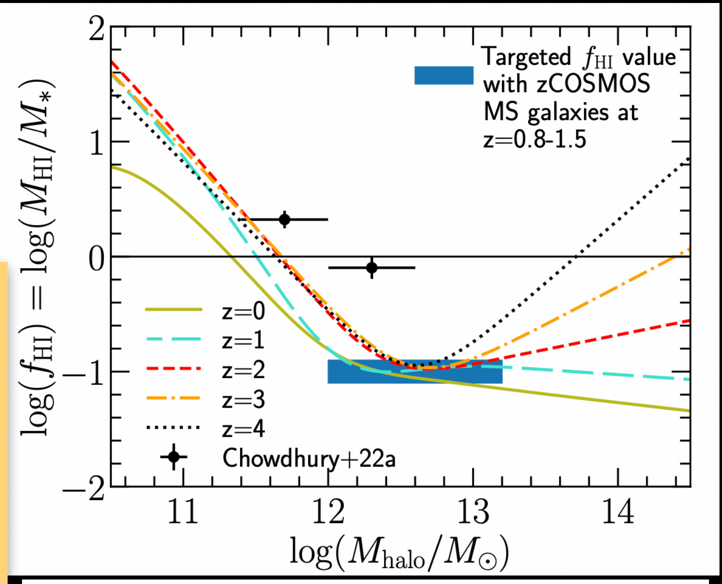

I. Should be able to detect **the model-predicted f_{HI}** by stacking 2'514 galaxies.

II. Should be able **to detect HI from the stack of 74 ALMA-detected galaxies** and *<u>get the first complete HI + H2 census for the same galaxy sample</u>* in case the CATz1 GMRT HI detection at z=1 is correct.

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III. Should be able **to detect HI at <z>=0.6 by stacking 6’000 galaxies** yielding *<u>the first observational constraint of the HI mass evolution</u>* from low z (MIGHTEE-HI) to cosmic noon (Uband COSMOS-HI) in the same field.

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IV. Possible HI detections of **individual most gas-rich galaxies** at 0.4<z<1.5.

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IV. Possible HI detections in **individual most gas-rich galaxies** at $0.4<z<1.5$.

V. Expected **radio continuum detections for ~10K individual galaxies** allowing to trace *<u>the 800 MHz continuum luminosity function evolution</u>*.

MeerKAT observing program

Current status of the observations

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—Thermal RMS noise of 1.2 uJy/beam in the continuum (confusion noise of 3.1 uJy/beam)

2–3x deeper than **MIGHTEE-HI** and **CATz1**.

- Proposal ***submitted*** for the MeerKAT Open Call in May 2023.
- Proposal ***accepted*** in August 2023.
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110 hours of observing time sub-divided in 21 Observing Blocks (OBs) [32K channels]:

1 OB : **10 TB** with *full polarisation*
[tar.gz file] **3.5 TB** with *2-components polarisation*

OB format : CASA Measurement Set of **5 TB**

21 OBs (105 TB untar/zip) to be downloaded from SARAO via wget (no other solution) !!!!

In progress since December 2024…

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Next steps...

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1. **Finalise the data download :**
   60% of data imported so far at UniGE
2. **Calibrate the uncalibrated visibilities** (amplitude, phase, flux) for the HI line :
   —What storage needed for 105 TB ?
   Will the data expand by a factor of ~3 ?
   —What compute resources needed for 5 TB MS files ?
   —Doable with CASA ?
   —Need of another software with a specific MeerKAT data reduction pipeline ?
   —RFI subtraction needed ?
   —Other difficulties to face ?
3. **HI spectral line imaging** (data cubes)
4. **HI line stacking** over redshift bins and stellar mass bins
5. **Continuum calibration + imaging**
6. **Continuum-detected source extraction** and assembly of deep U-band catalogs

MeerKAT observing program

Conclusions

This MeerKAT program offers a nice opportunity for the SKACH community to play with and face problems that will be of the same nature, and even of higher complexity when the SKA high-frequency array will be fully deployed, given the even larger amount of data to store/reduce/image/analyse.

The bright future of SKA lies in the 21 cm HI emission line that will be accessible for individual galaxies up to z=1.5.

Any help and expertise to share are warmly welcome!