The Column Densities of Molecular Gas across Cosmic Time: Bridging Observations and Simulations

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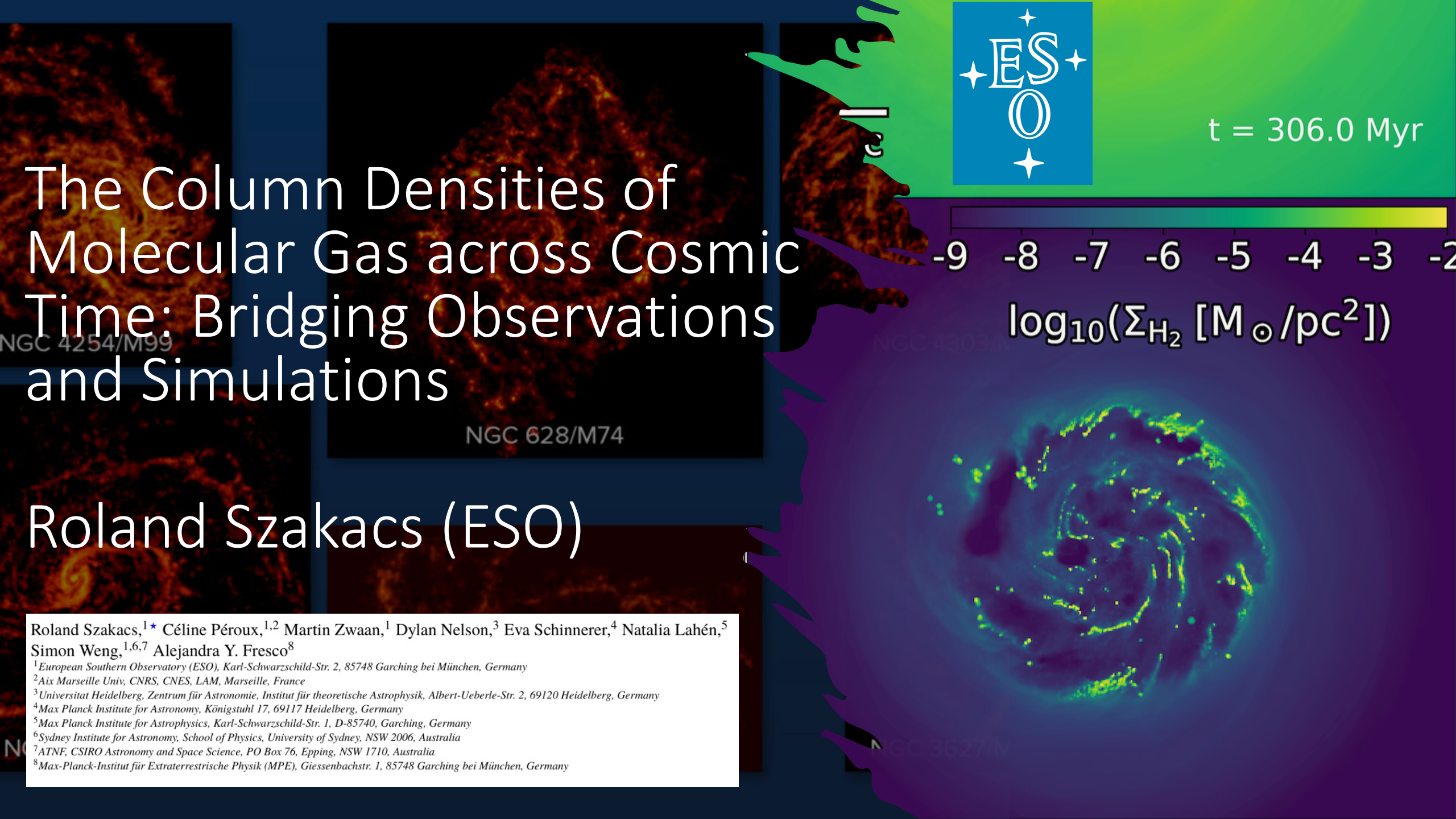
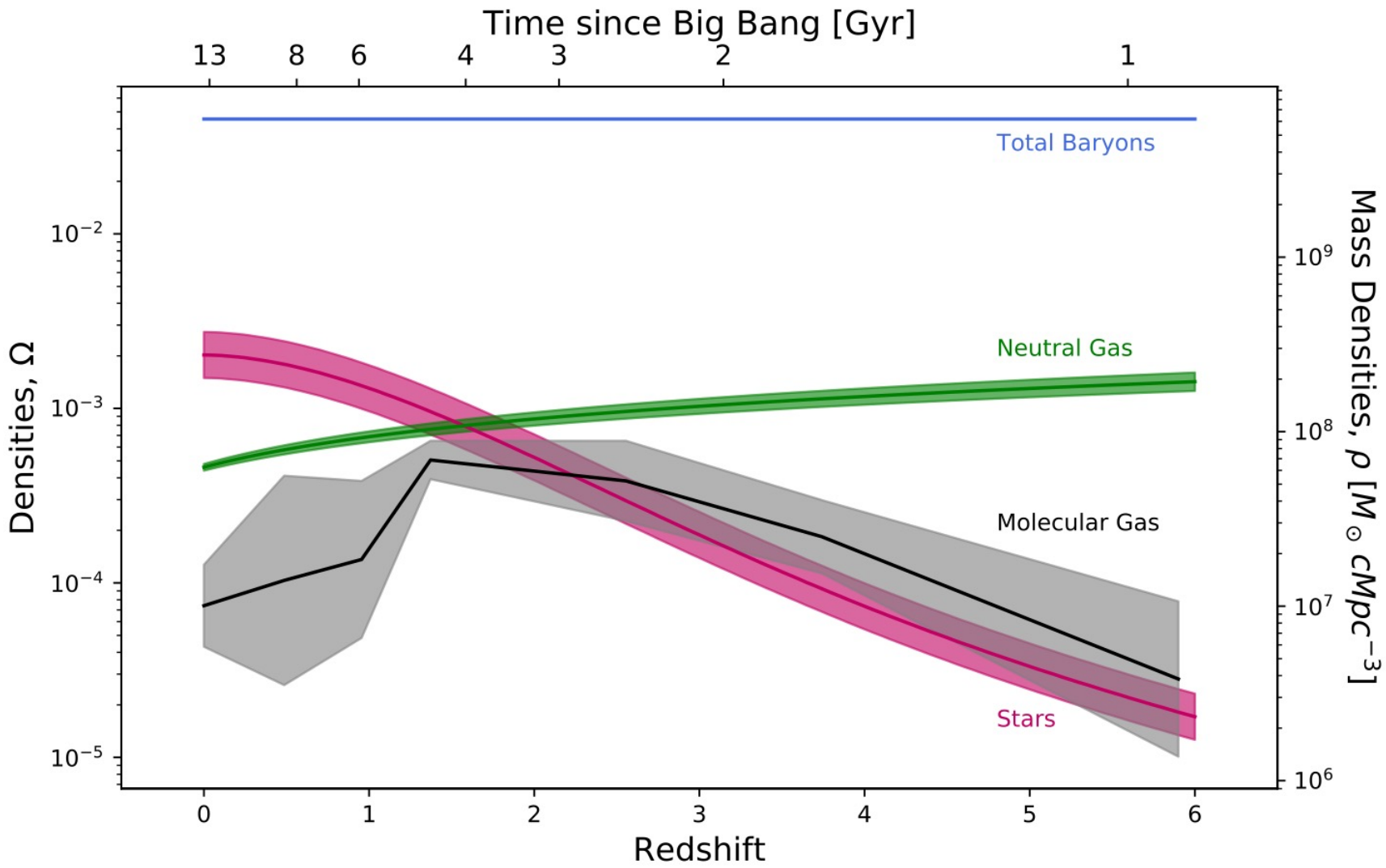


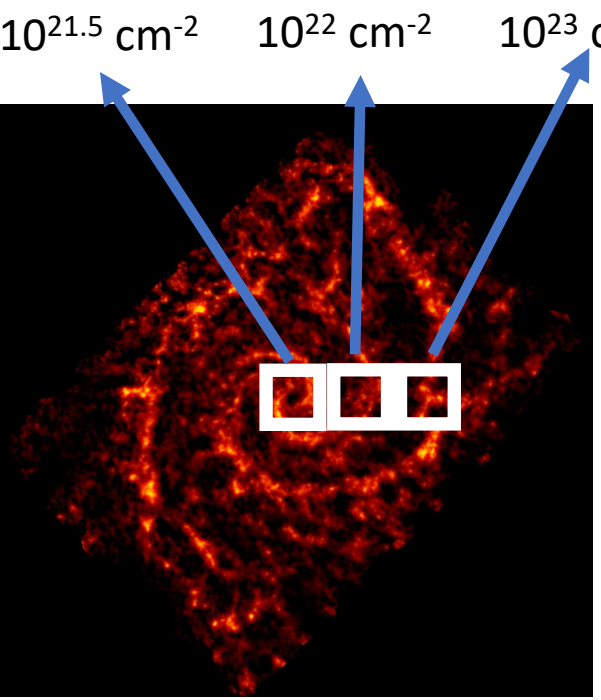
An Evolving Molecular Gas Mass Density Across Cosmic Time



Peroux & Howk (ARAA, 2020)

The Column Density Distribution Function – f(N)

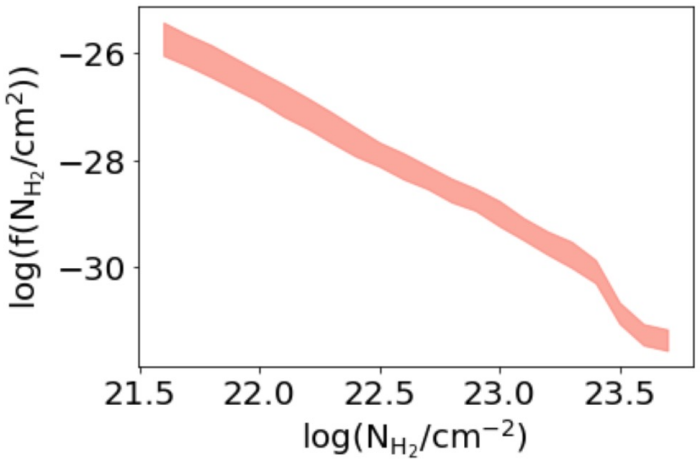
Quantifies the distribution of column densities seen on the sky



ALMA (ESO/NAOJ/NRAO); NRAO/AUI/NSF, B. Saxton≈

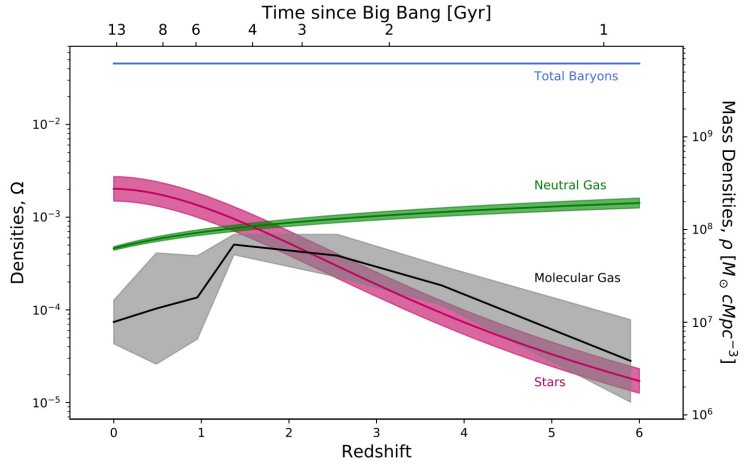
$f(N_{H2})$

Distribution of column densities on the sky at z=x (area / cross section times normalization factors)



Integral

Mass density of molecular gas at z=x

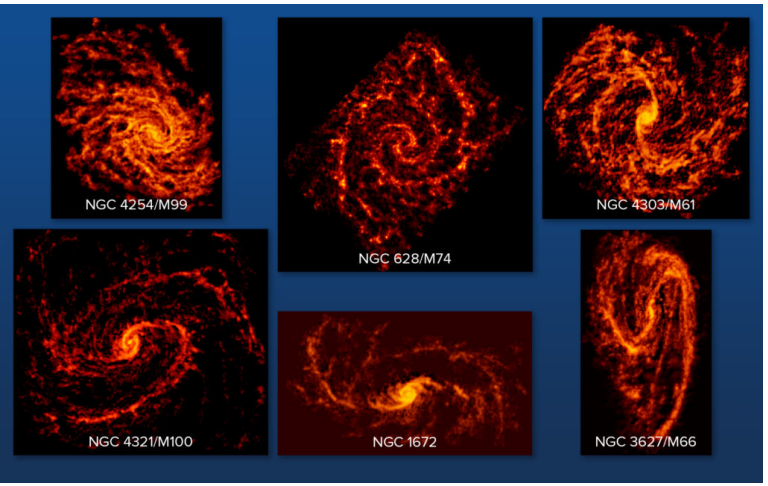


Peroux & Howk (ARAA, 2020)

Using multiple galaxies

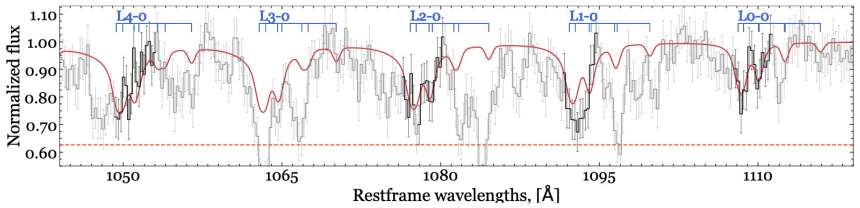
Bridging Observations and Simulations

PHANGS-ALMA Survey
~ 70 local galaxies resolved with ALMA



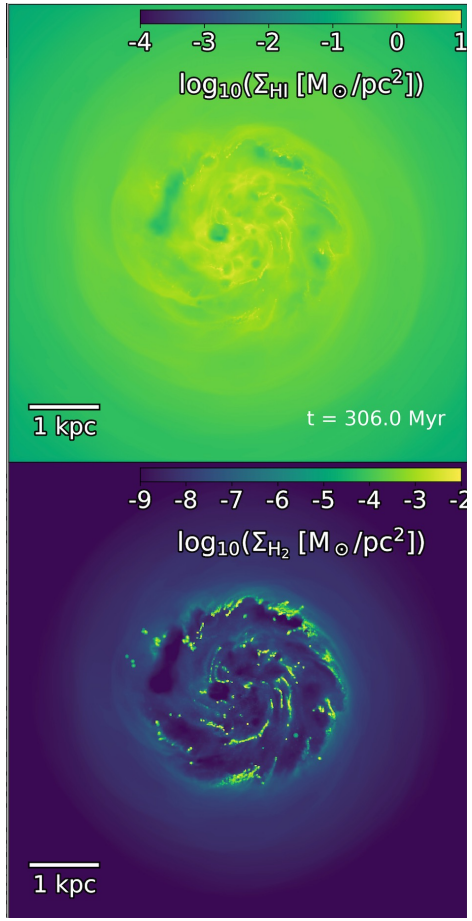
Sun et al. (ApJ, 2020), Leroy et al. (Apj, 2021)

SDSS composite spectra



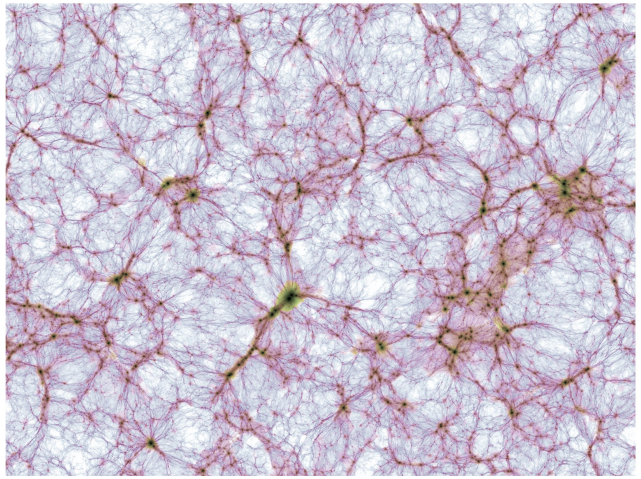
Balashev et al. (MNRAS, 2019)

GRIFFIN Project:
Isolated Dwarf Galaxy Simulation



Lahen et al. (ApJ, 2019, 2020)

TNG100 (IllustrisTNG Project):
Magnetohydrodynamical cosmological simulation



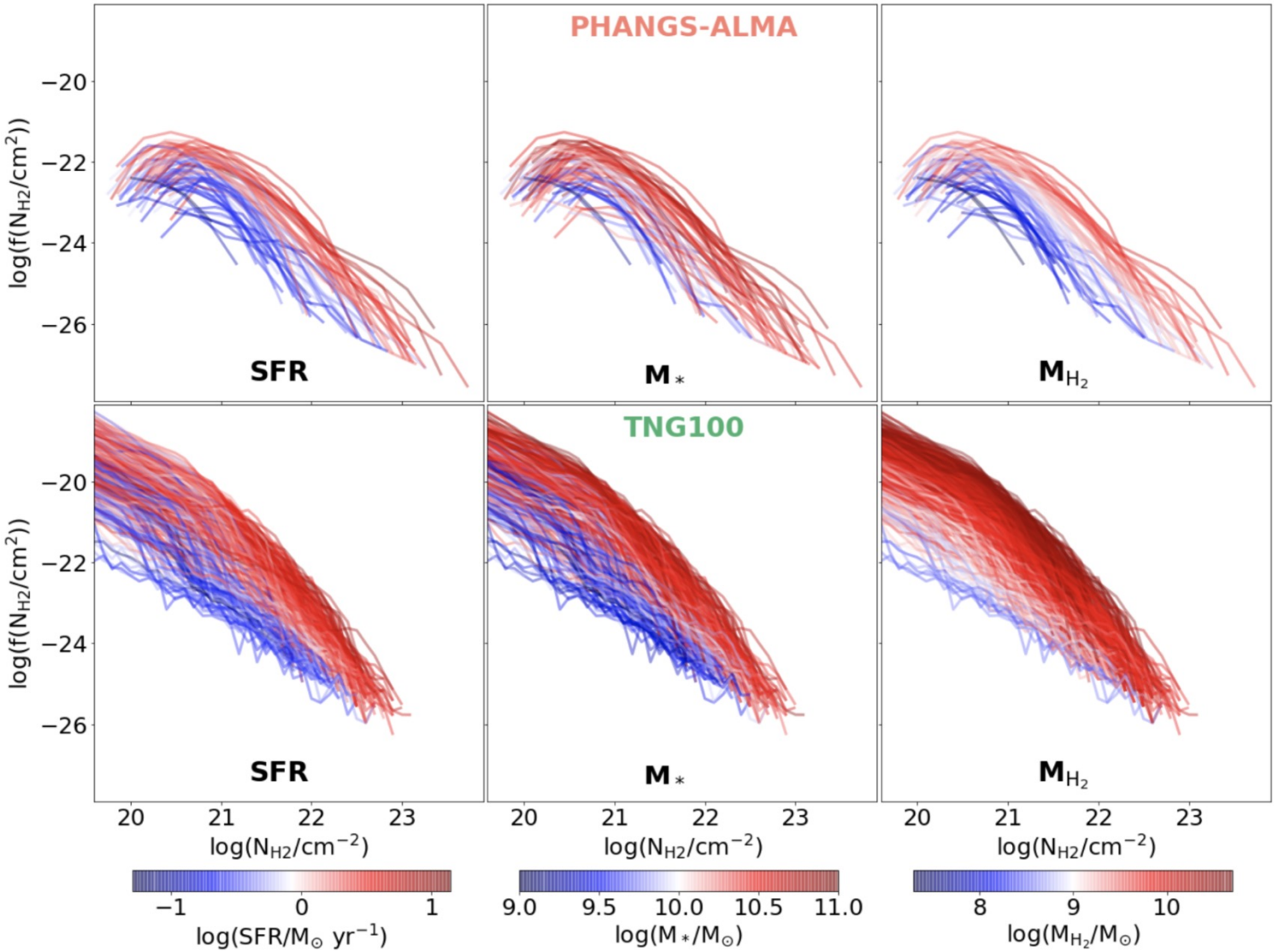
TNG Collaboration

Key Questions

f(NH2) of individual objects	→	Correlated with integrated galaxy properties?
$f(N_{H2})$ derived from simulations and observations	→	How do they compare?
Evolving molecular gas mass density	→	Evolving shape or normalization of $f(N_{H2})$?
Evolving shape or normalization of $f(N_{H2})$	→	Which column densities contribute most to the molecular gas mass density?
$f(N_{H2})$ & $f(N_{HI})$	→	In which regions of galaxies does H_2 dominate over HI?

f(NH2) of individual objects

Correlated with integrated galaxy properties?



Similar shapes of the $f(N_{H2})$ in individual galaxies

Exponential gas distribution in discs

Correlate with SFR, M_* and M_{H2}

Higher SFR, M_* and M_{H2}

Larger Galaxy

Higher column densities & higher normalization

Szakacs et al., MNRAS, in prep

$f(N_{H2})$ derived from simulations and observations

How do they compare?

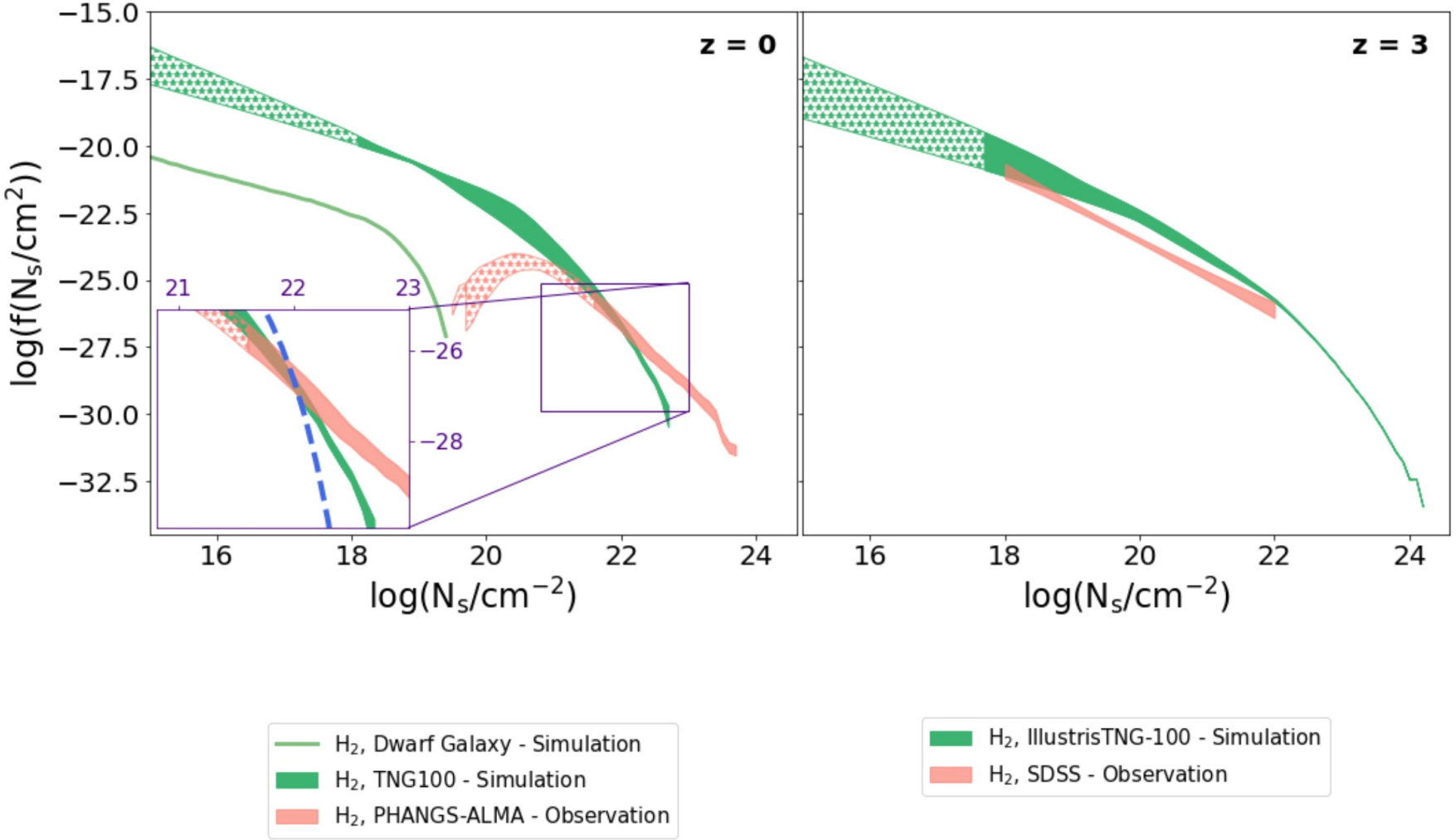
TNG-100 broadly reproduces $f(N_{H2})$ of observations

At z=0 TNG100:
higher slope than PHANGS-ALMA
similar normalization

At z=3 TNG100:
higher normalization than SDSS
similar slope

Simulated dwarf galaxy shows similar slopes as TNG100

Contribution by this type of dwarf galaxy negligible



Szakacs et al., MNRAS, in prep

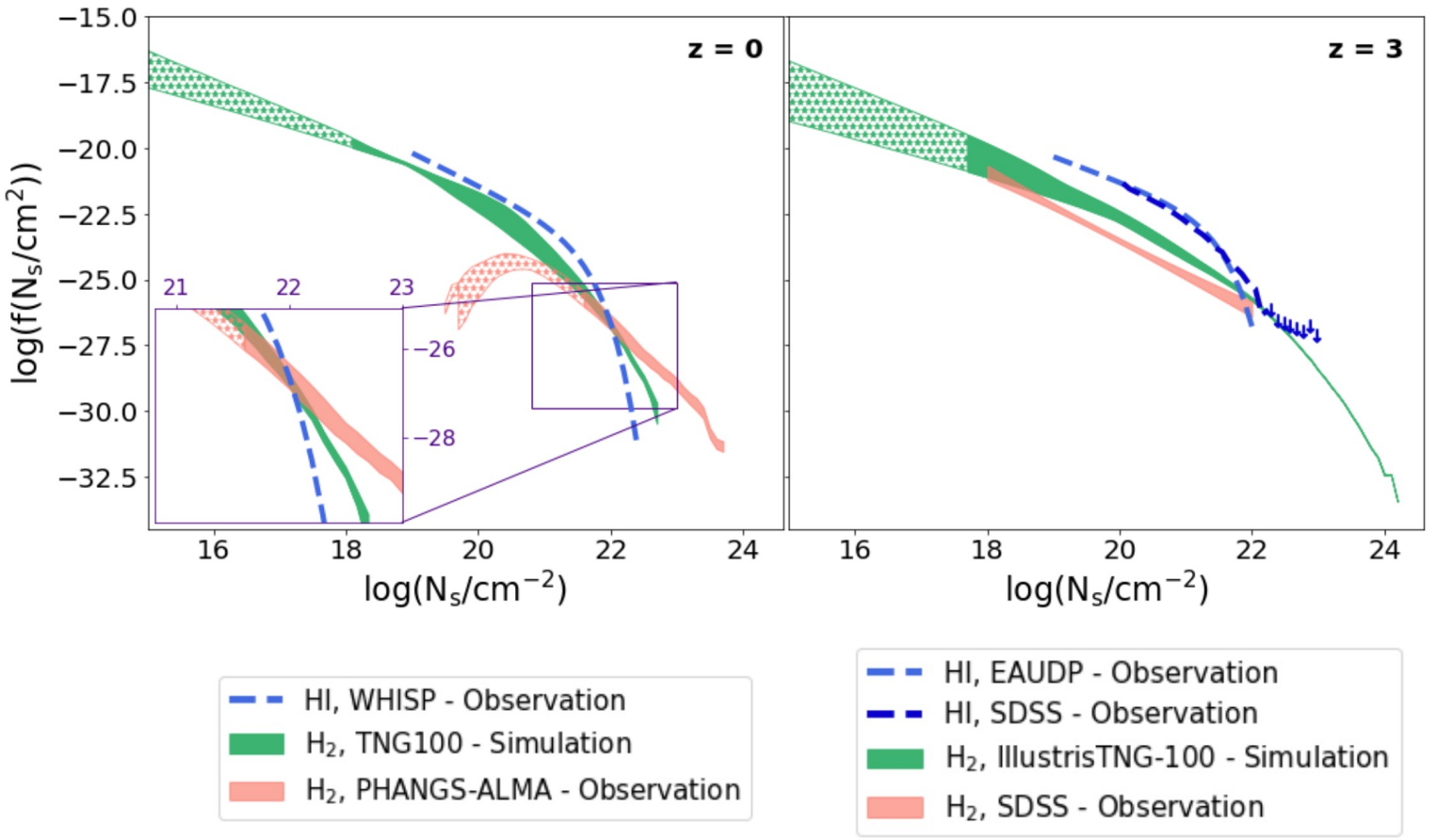
Evolving molecular gas mass density → Evolving shape or normalization of $f(N_{H2})$?

Higher molecular gas densities at higher redshifts

Slope below $N_{H2} \sim 10^{20}$ cm^{-2} does not evolve in TNG100

More drastic changes at higher column densities (not constrained by observations)

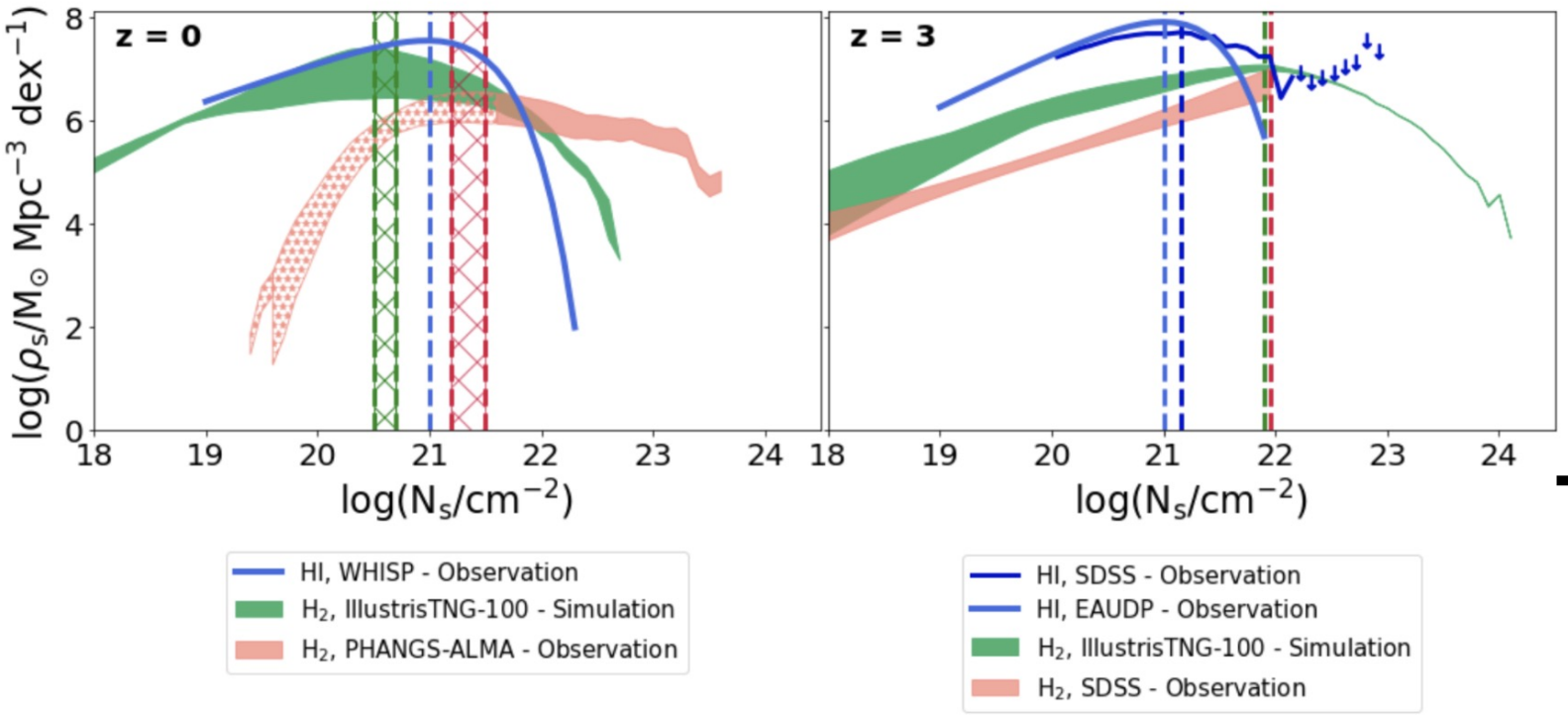
HI shows little to no evolution



Szakacs et al., MNRAS, in prep

If evolving shape or normalization of $f(N_{H2})$

Which column densities contribute most to the molecular gas mass density?



HI

H_2

HI highest mass density contribution at ~ 10^{21} cm^{-2} at z=0 and z=3

H_2 highest mass contribution shifts!

In line with higher SFR density at z=3 and evolving molecular mass density

HI dominates below ~ 10^{22} cm^{-2}

Clouds turn molecular above

HI important contributor to cold gas mass at both z=0 and z=3!

Szakacs et al., MNRAS, in prep

Summary

f(NH2) of individual objects	→	Corellated with SFR, M_* and M_{H2}
$f(N_{H2})$ derived from simulations and observations	→	Simulations are broadly reproducing observations
Evolving molecular gas mass density	→	$f(N_{H2})$ evolves at column densities above 10^{20} cm^{-2}
Evolving shape or normalization of $f(N_{H2})$	→	Column density contributing most to H_2 mass density higher at z=3 than for z=0
$f(N_{H2})$ & $f(N_{HI})$	→	HI important contributor to the cold gas mass at both z=0 and z=3

Questions?

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