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Molecular emission lines from simulations of AGN-driven molecular outflows

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CIERA, Northwestern University

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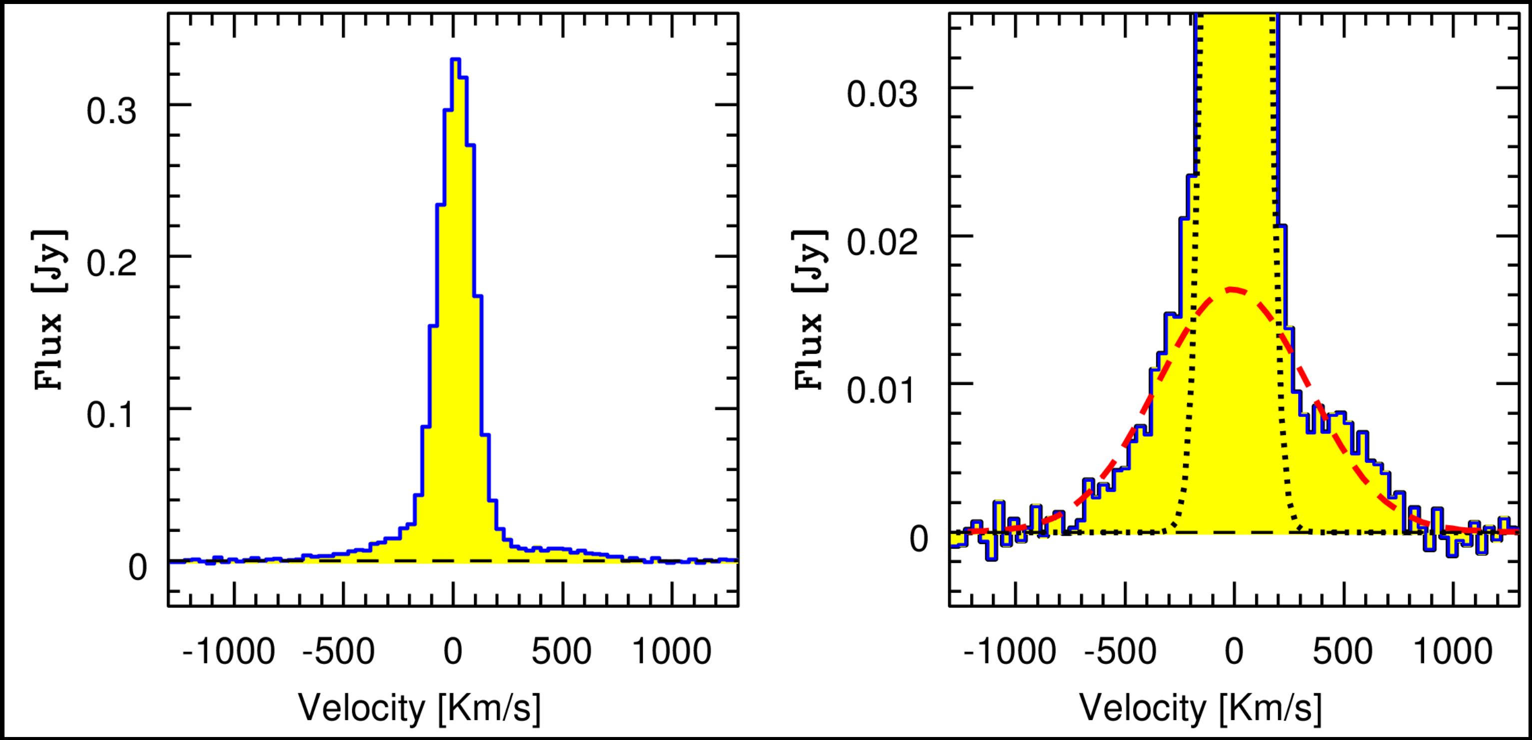
Introduction

Observations of fast molecular outflows

CO 1-0 line in Mrk 231

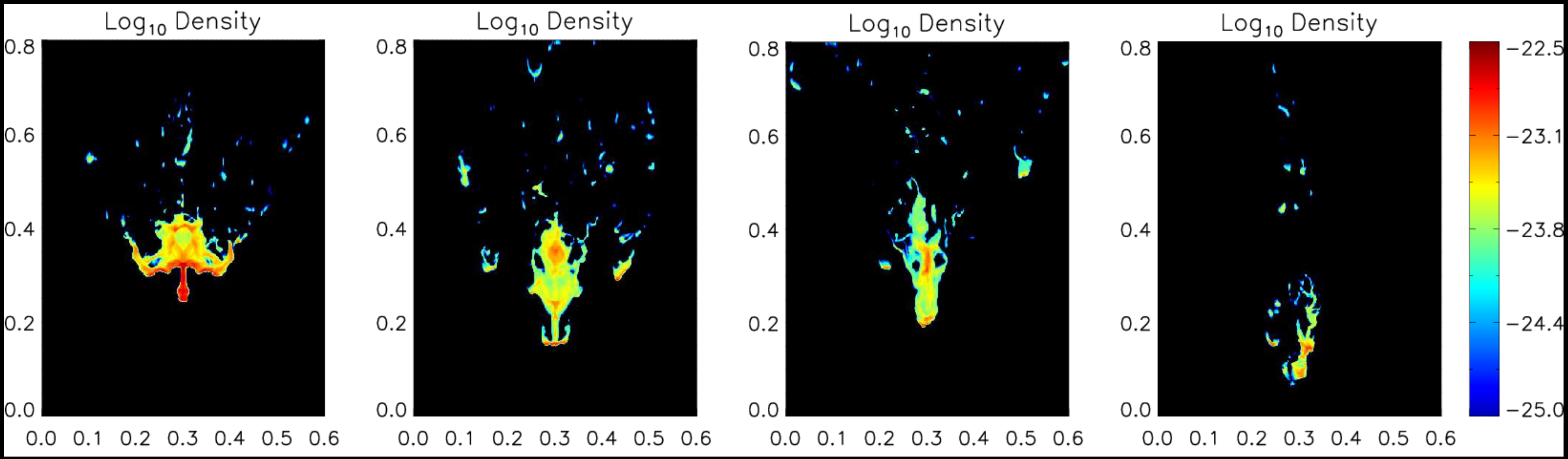


Feruglio et al. (2010)

Introduction

Acceleration of cold clouds

$4.2\ t_{cc}$ $6.0\ t_{cc}$ $8.0\ t_{cc}$ $12.0\ t_{cc}$



Scannapieco & Brüggen (2015)

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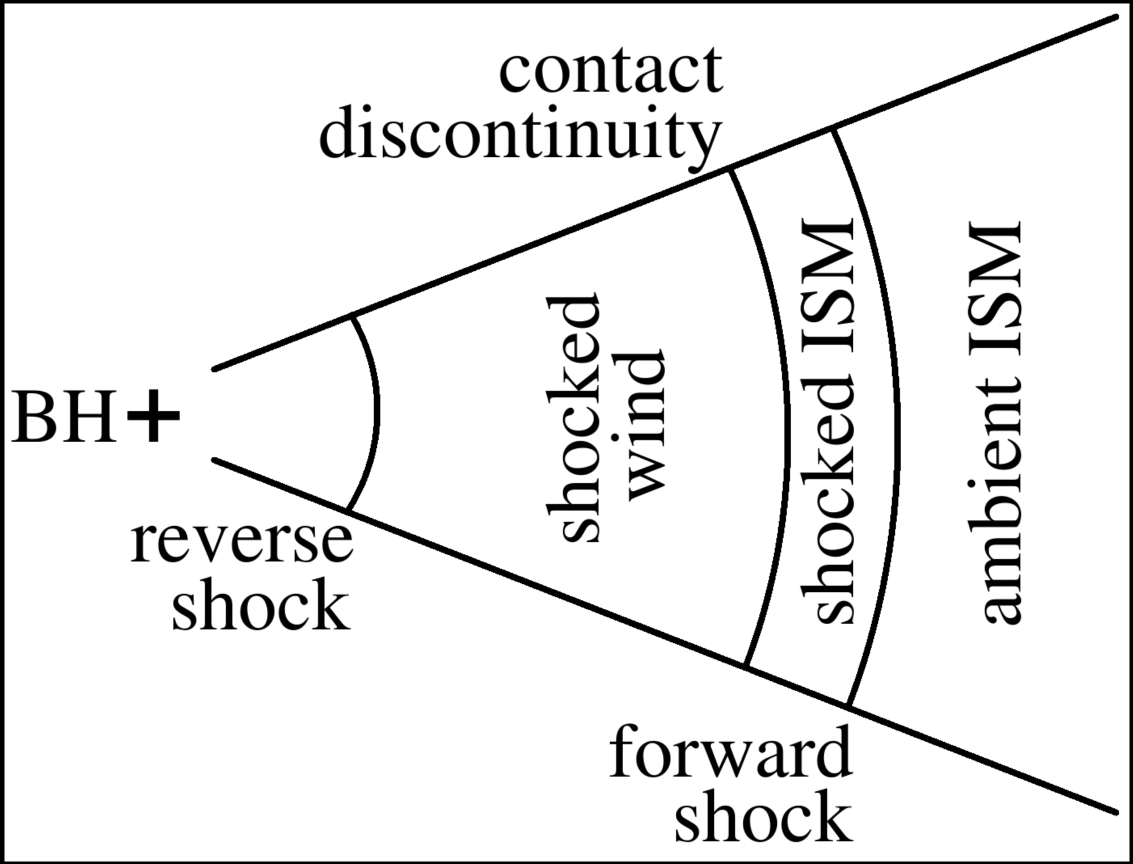
Introduction

In-situ molecule formation

An energy-driven AGN wind



Simulations

- 3D simulations of an isotropic AGN wind.
- 1.6-5.0 kpc box, periodic boundary conditions.
- Inject wind particles, initial $v = 30{,}000 \text{ km s}^{-1}$, $\mathrm{d}P/\mathrm{d}t = L_{\mathrm{AGN}}/c$.

Simulations

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Chemistry

- Evolve time-dependent chemistry of 157 species, including 20 molecules.
- Most importantly: H_2, CO, OH and HCO^+.
- We assume a Milky Way dust-to-metals ratio.

Simulations

Parameters

n_H (cm^{-3})	L_{AGN} ($erg\ s^{-1}$)	Z / Z_{sol}
10	10^{46}	1.0
1	10^{46}	1.0
10	10^{45}	1.0
10	10^{46}	0.1

Simulations

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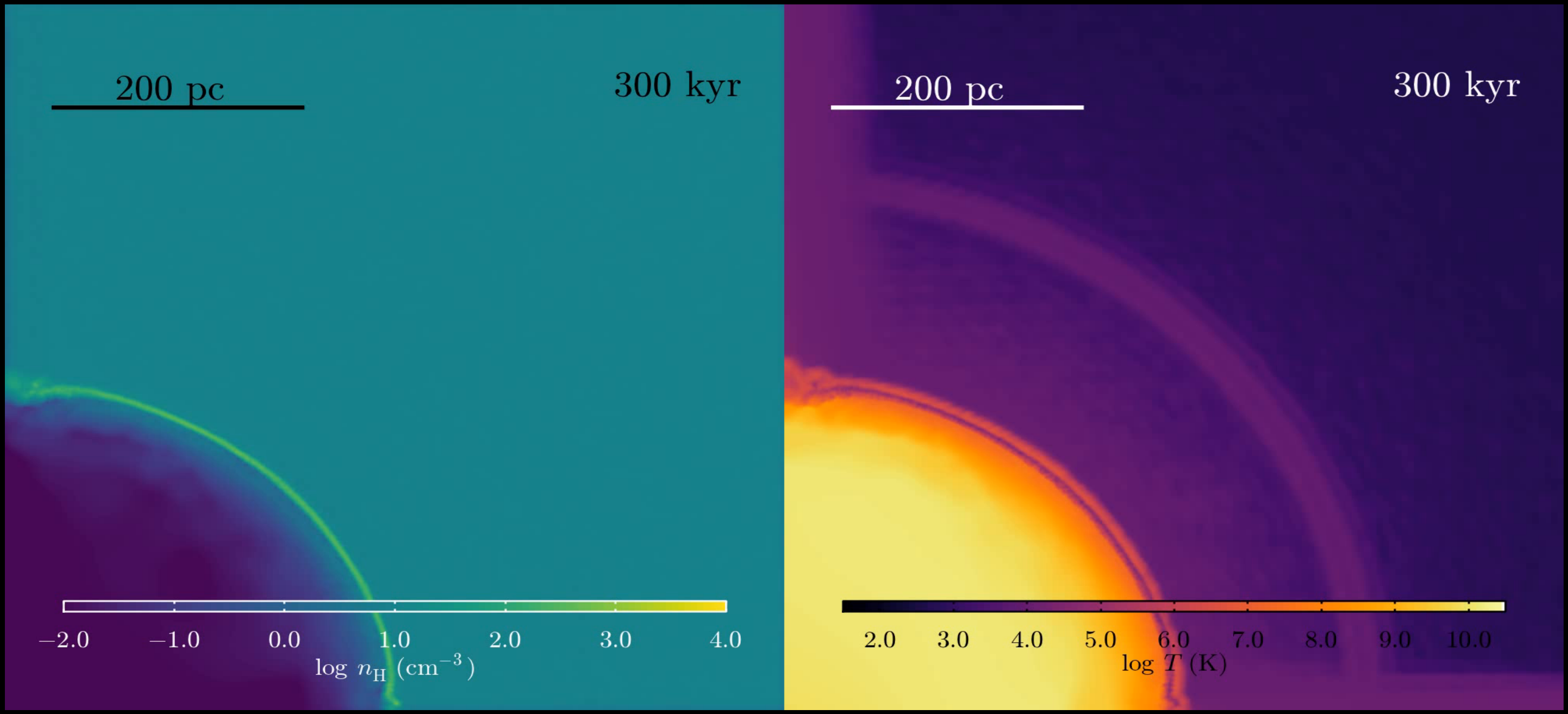
nH10_L45_Z1



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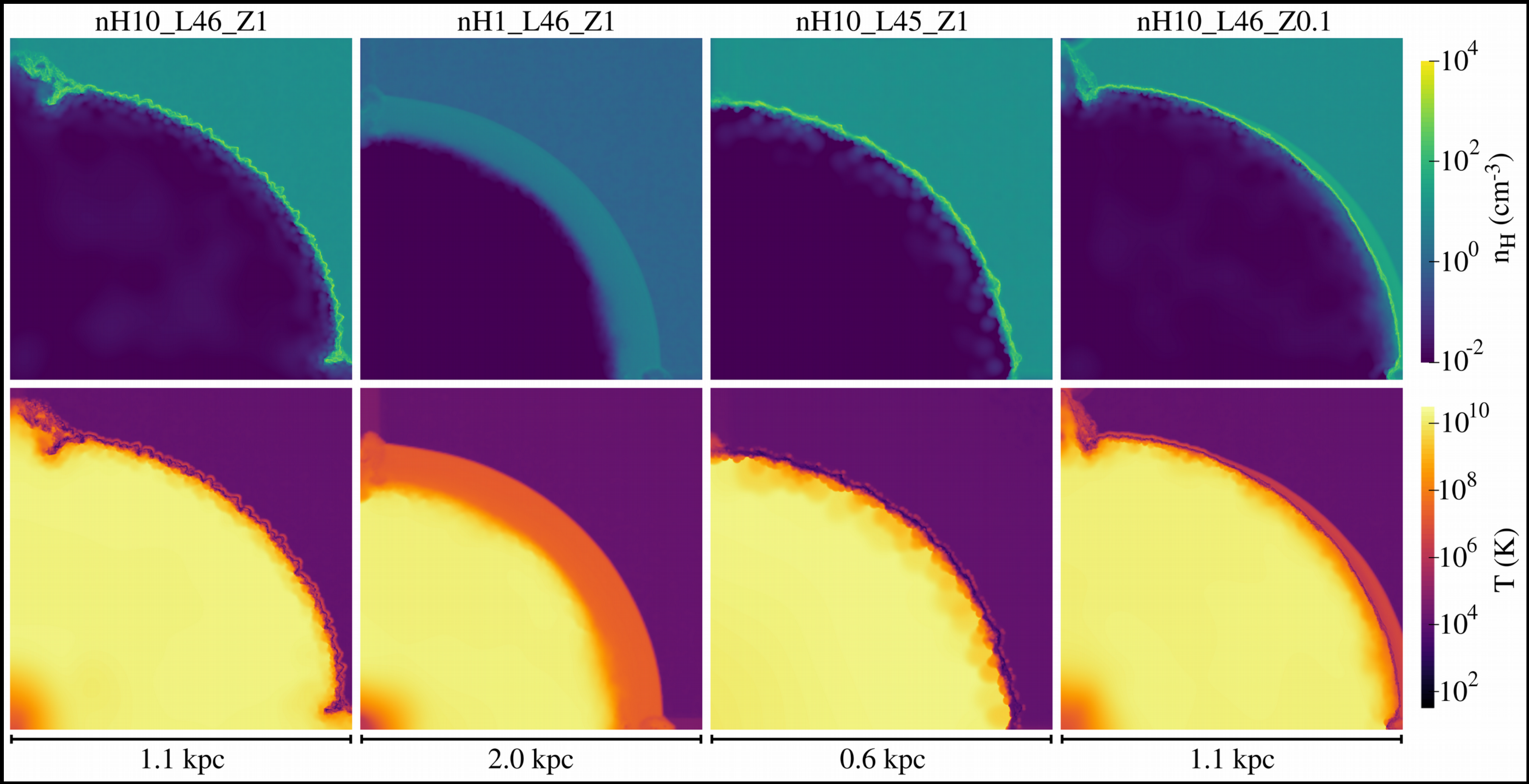
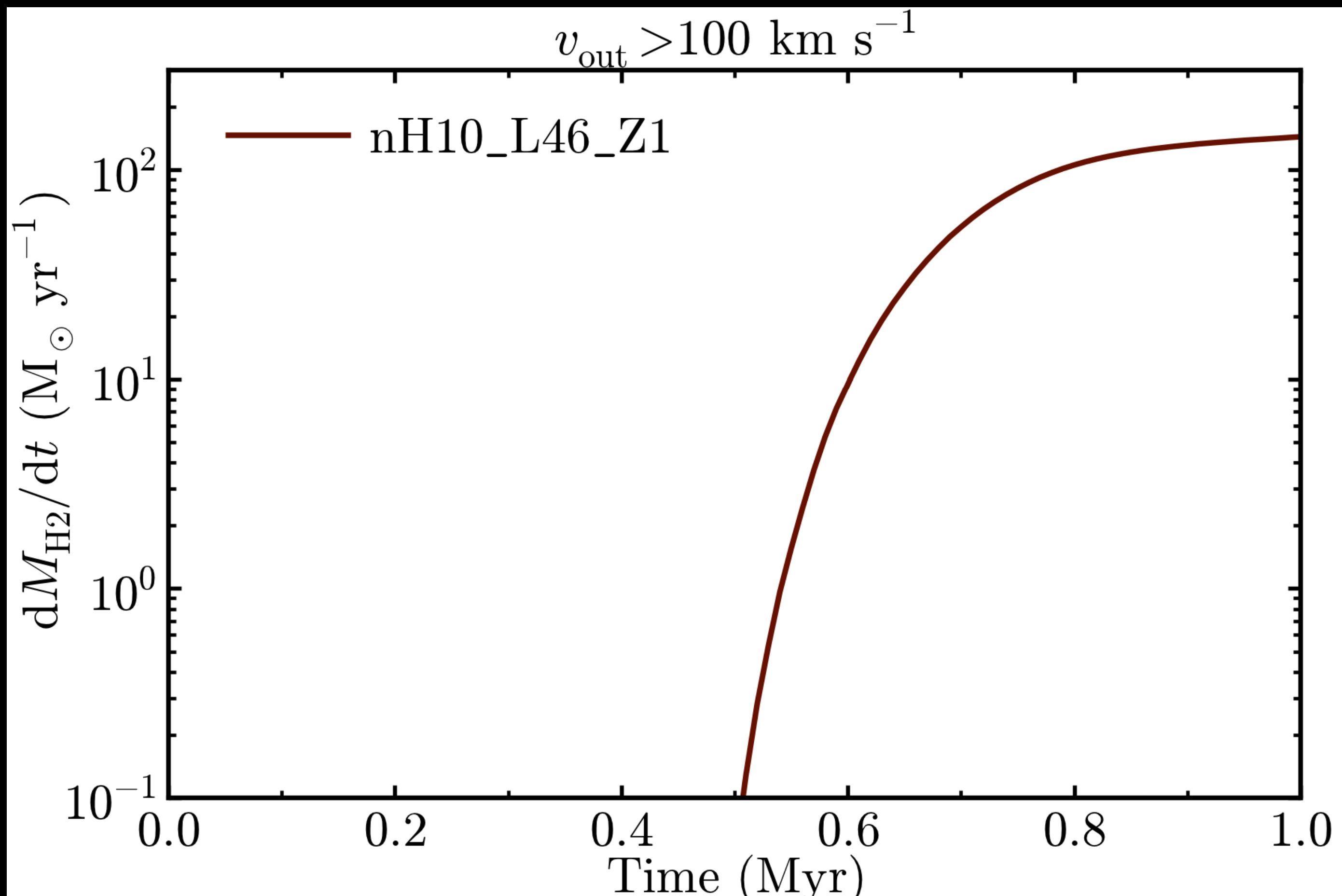
Simulations



Richings & Faucher-Giguère (2018)

Simulations

H_2 outflow rates



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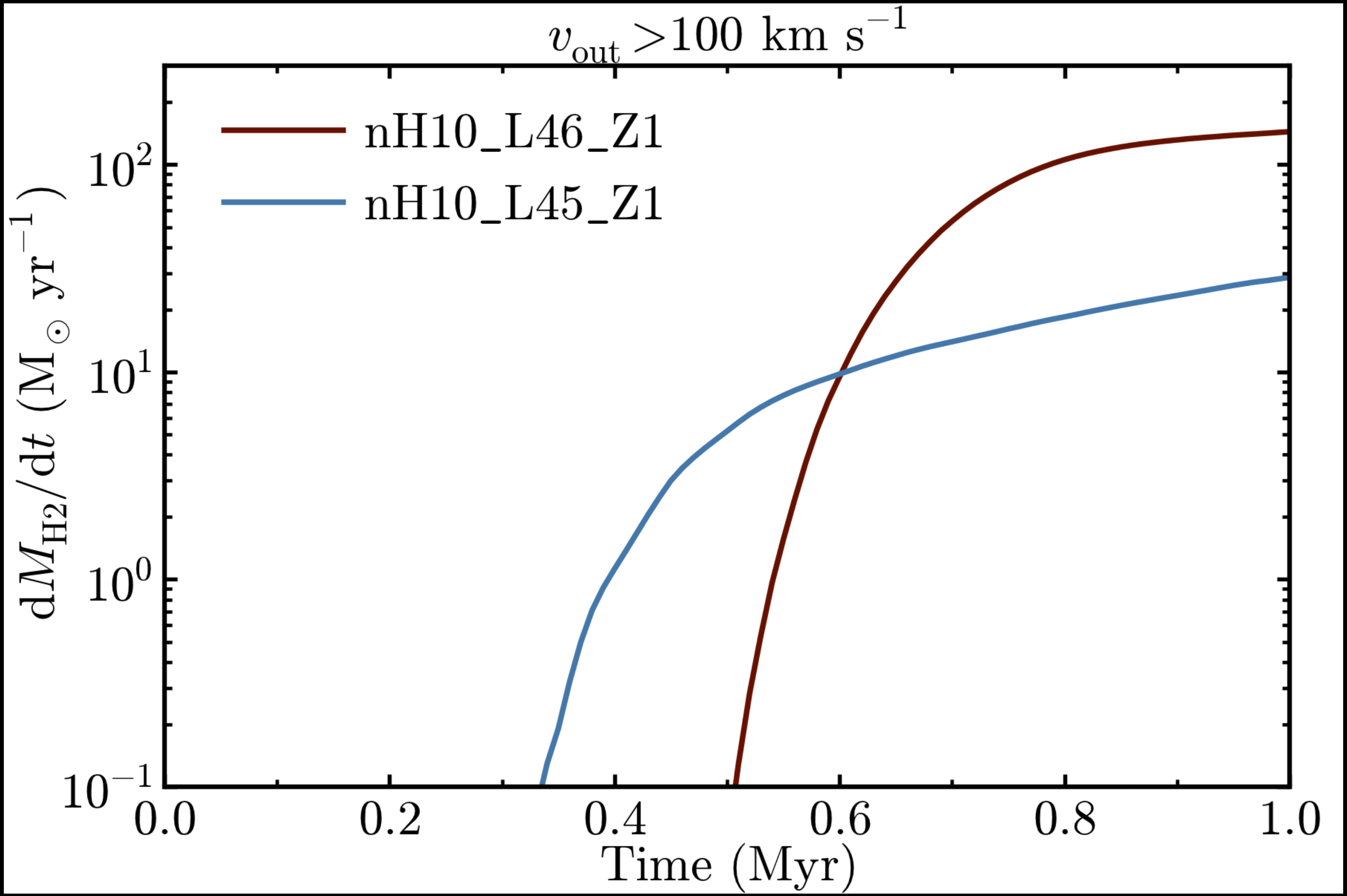

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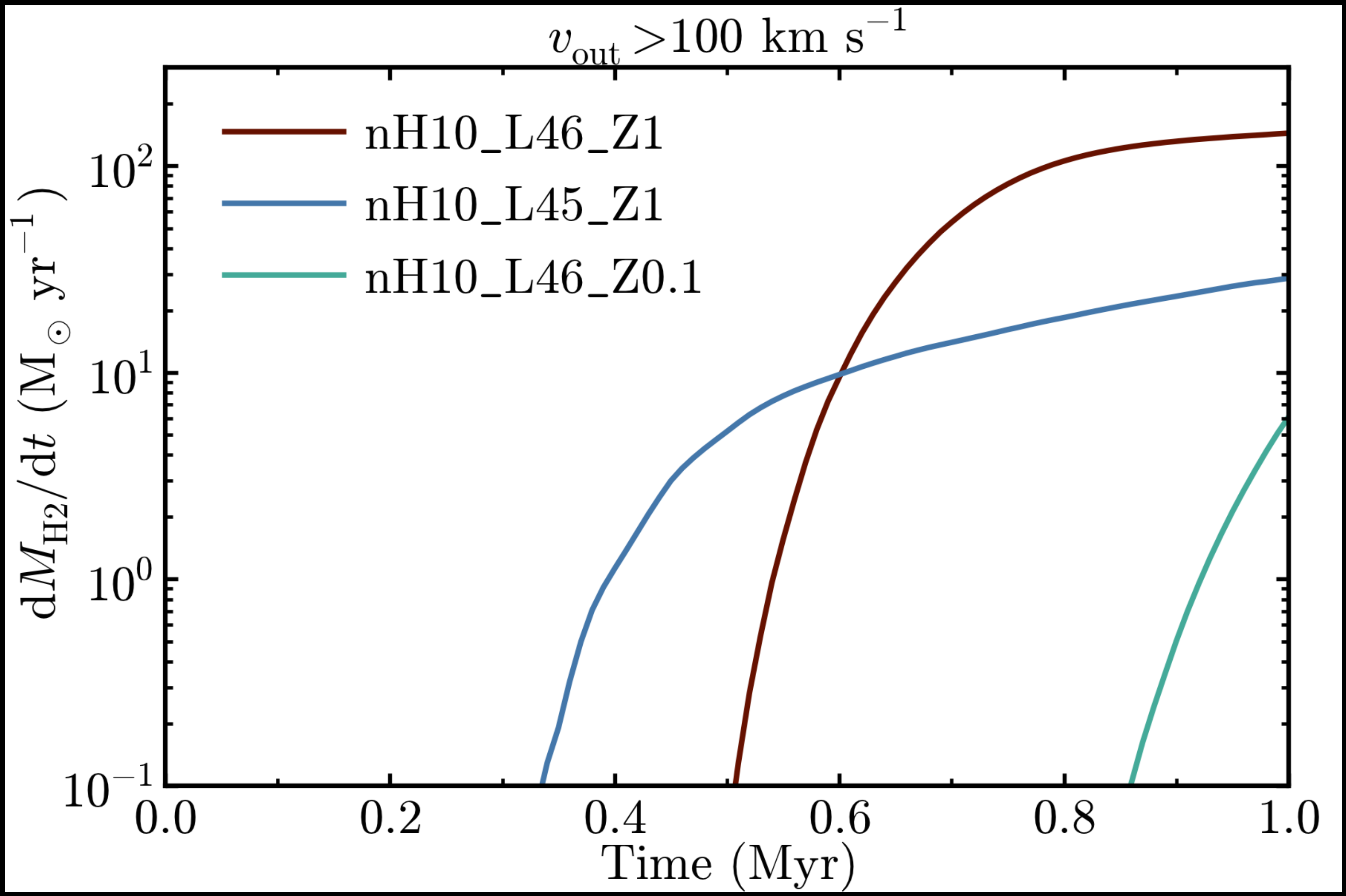

Richings & Faucher-Giguère (2018)

Molecular Emission Lines

- We use the Monte Carlo radiative transfer code RADMC-3D (Dullemond et al. 2012).
- Interpolate particles from the simulations onto an AMR grid, with maximum spatial resolution of 0.07 pc.
- Use non-equilibrium chemical abundances from the simulations.
- CO emission, warm (few hundred K) H_2 emission, and OH absorption.

CO 1-0 line emission

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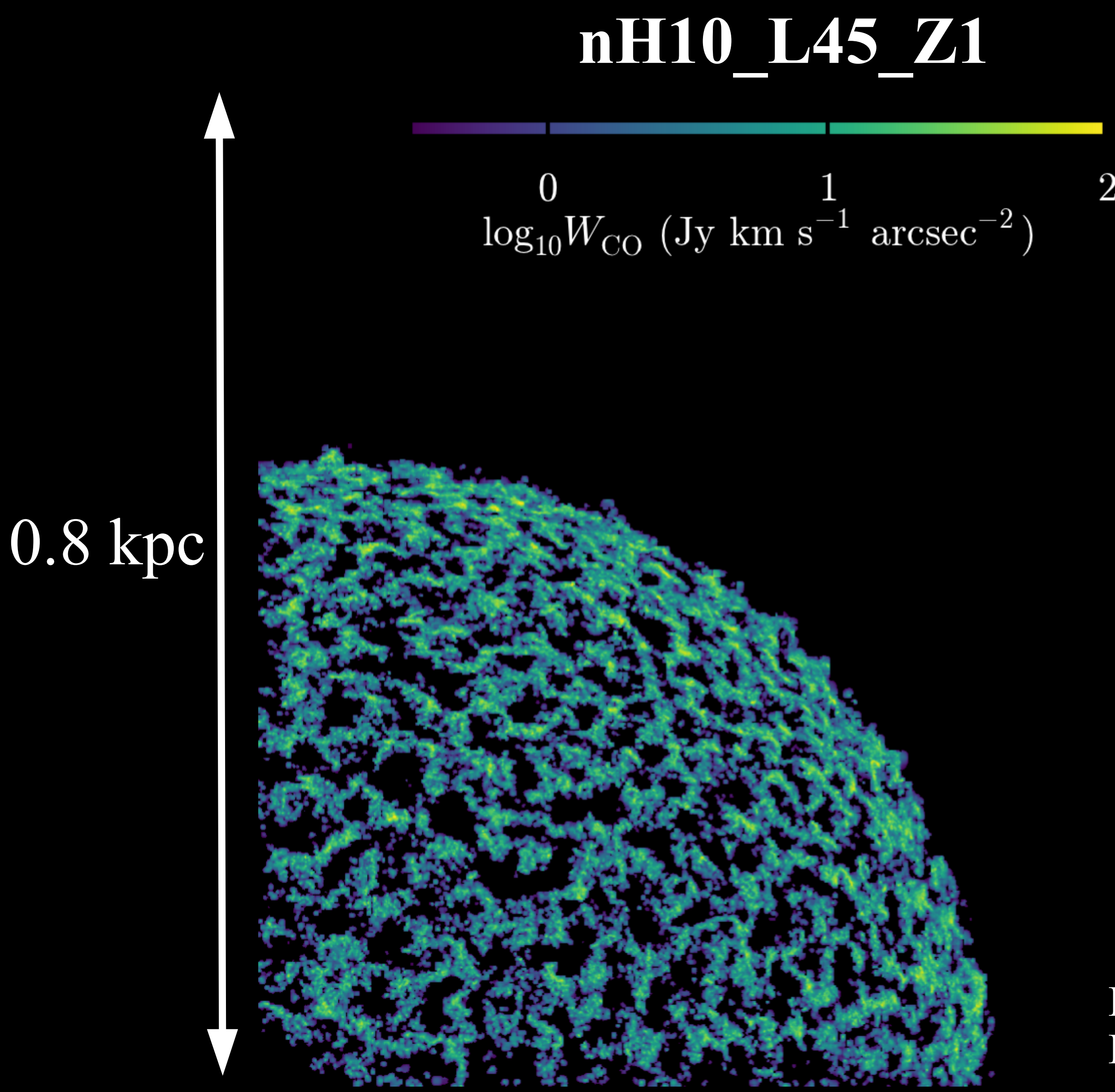

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Comparison with CO-based observations

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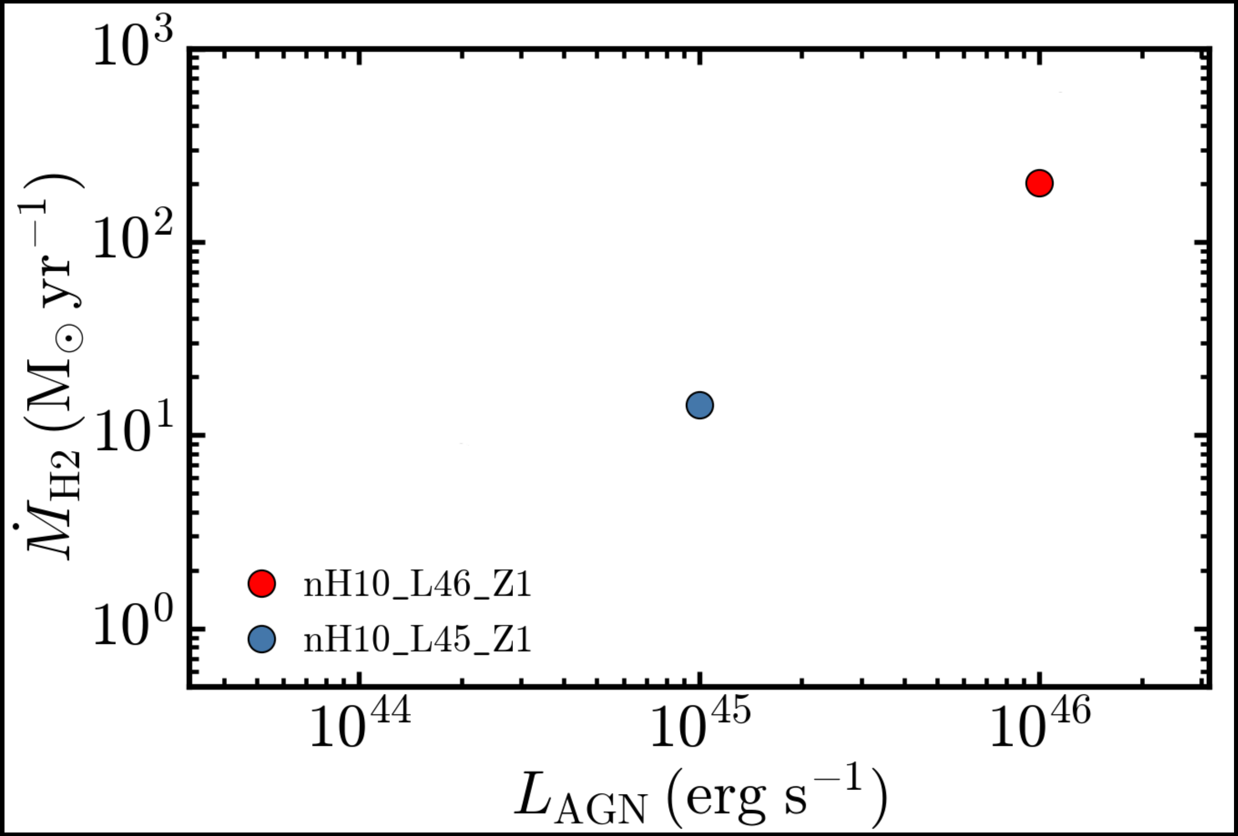

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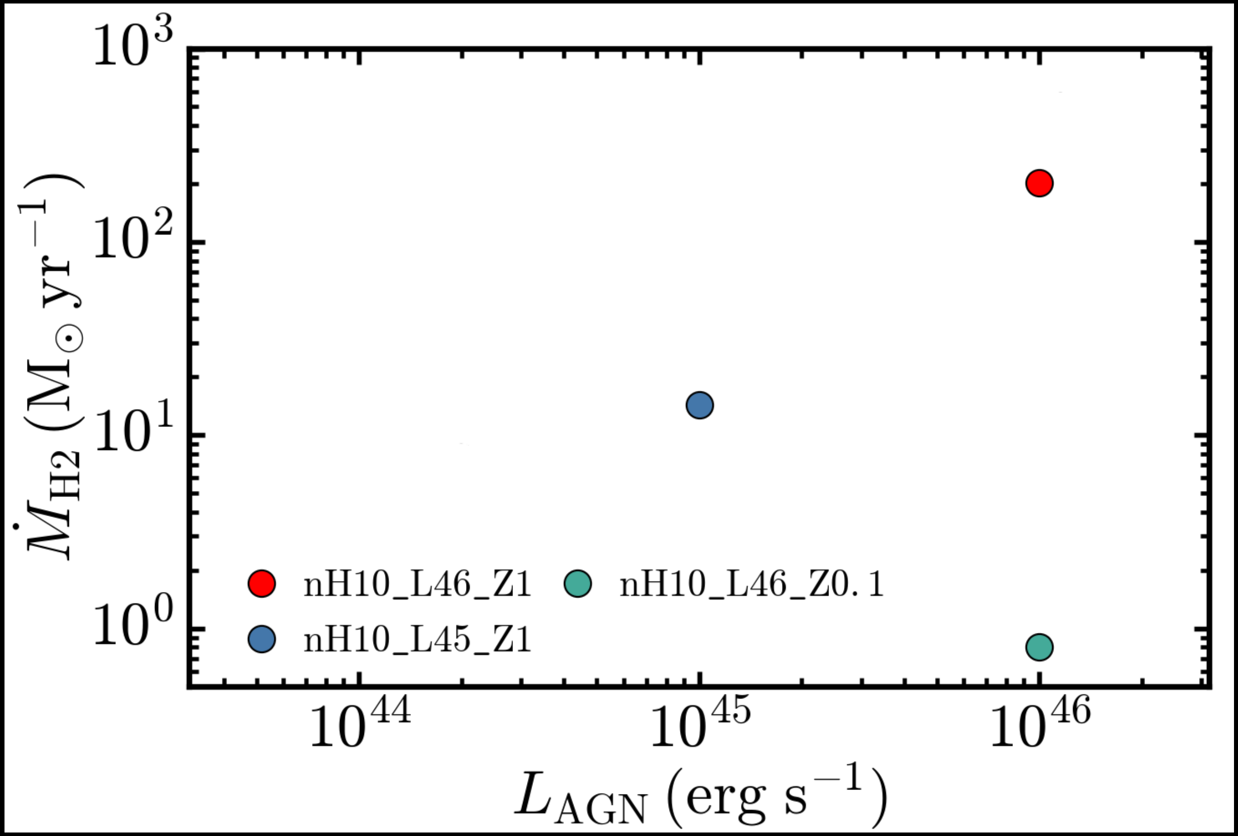

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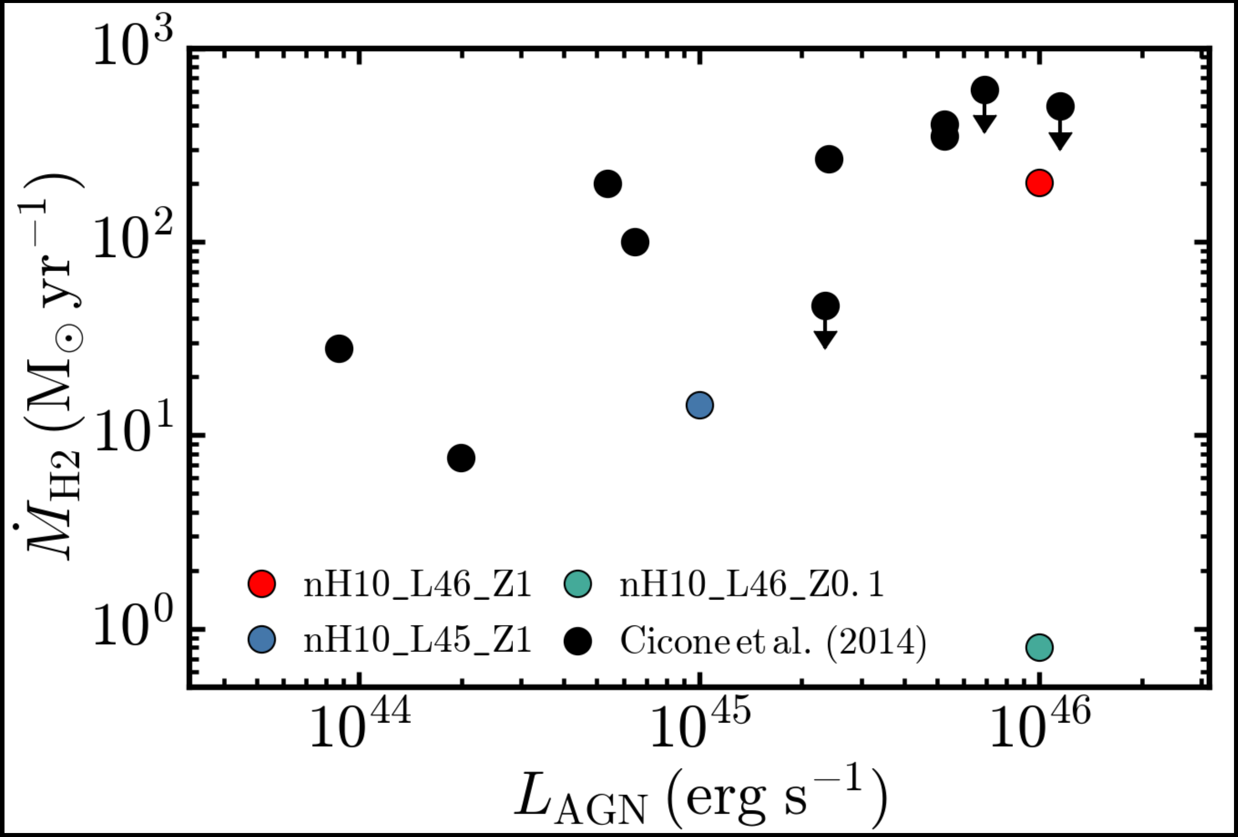

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CO-to-H_2 conversion factors

Simulation	$\alpha_{CO} = M_{H2} / L_{CO}$*		
	(1-0)	(2-1)	(3-2)
nH10_L46_Z1	0.13	0.08	0.06
nH10_L45_Z1	0.15	0.09	0.07
nH10_L46_Z0.1	1.77	0.82	0.80

*Units: M_{sol} (K km s^{-1} pc^2)$^{-1}$

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- Observations typically assume:

$$\alpha_{CO\ (1-0)} = \mathbf{0.8}\ M_{sol}\ (\mathrm{K\ km\ s^{-1}\ pc^{2}})^{-1}.$$

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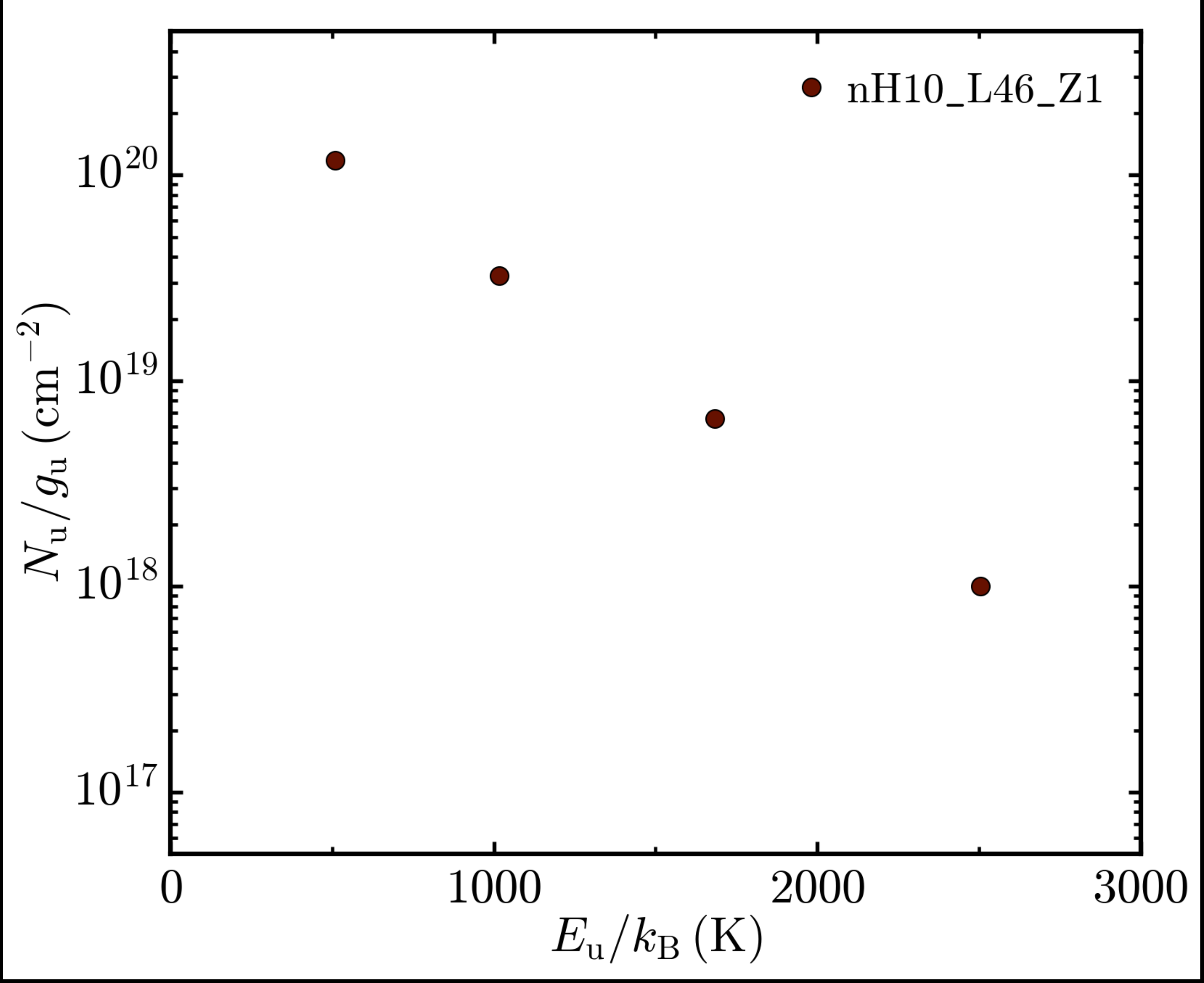
Warm H_2 Emission



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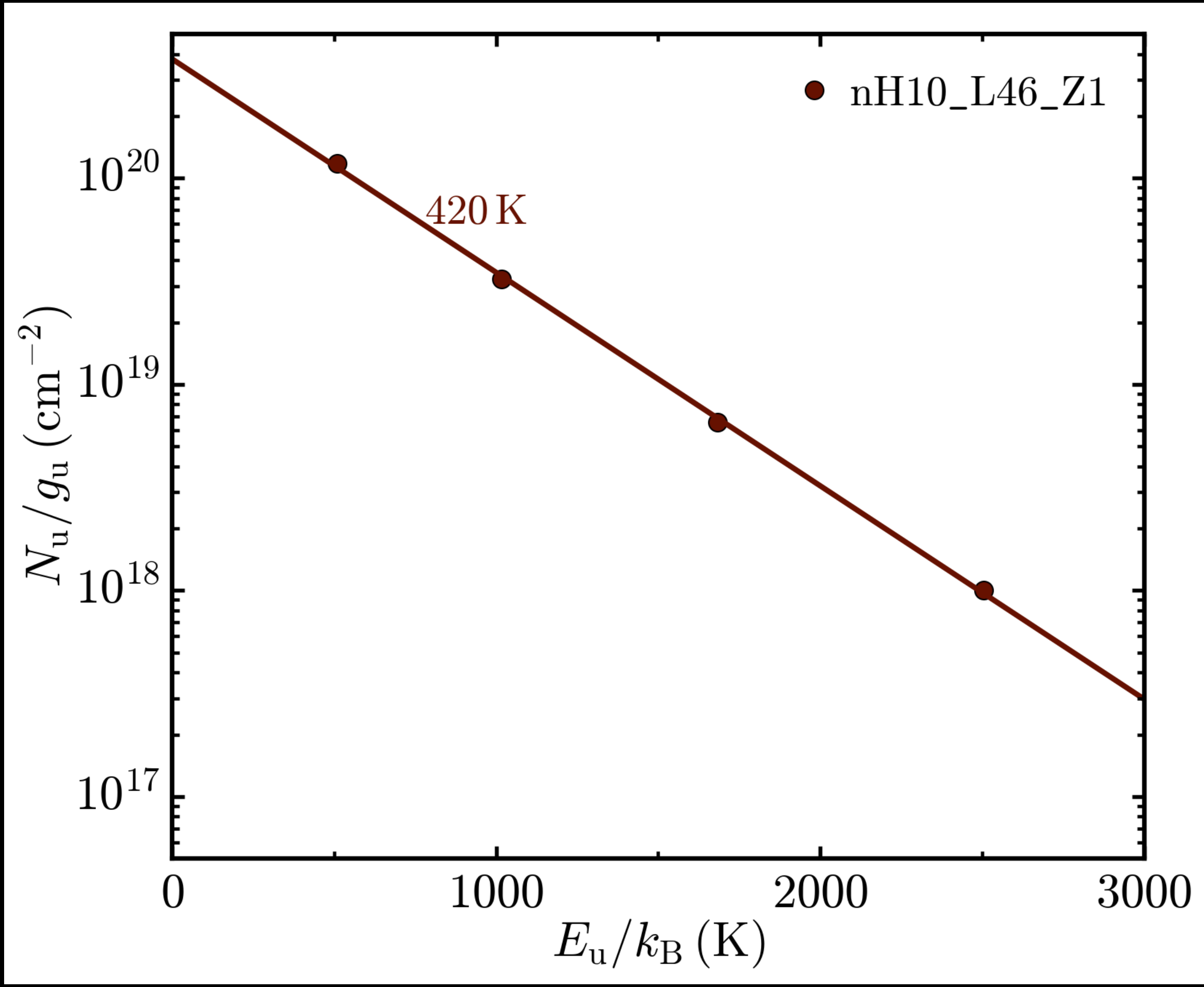

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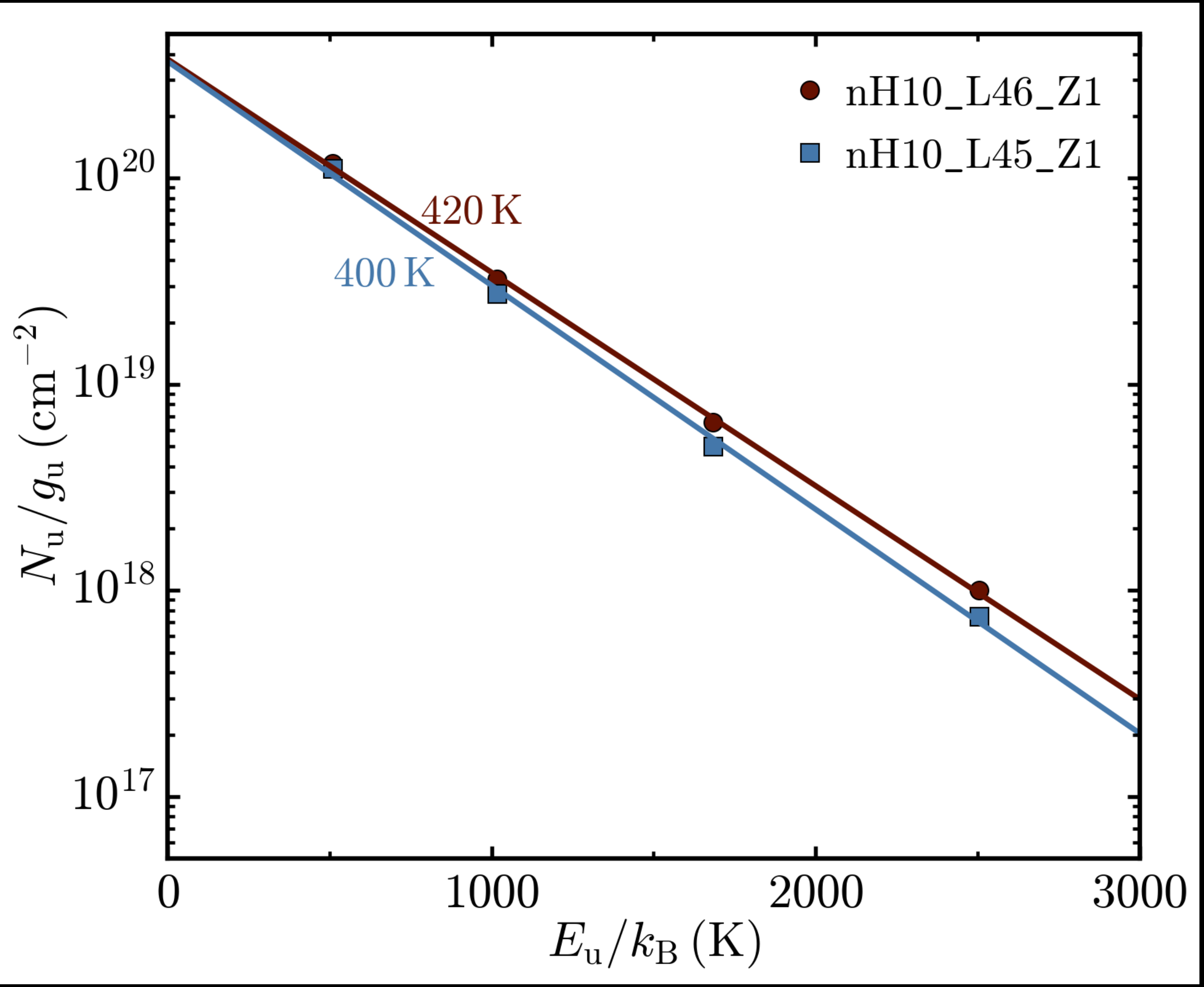

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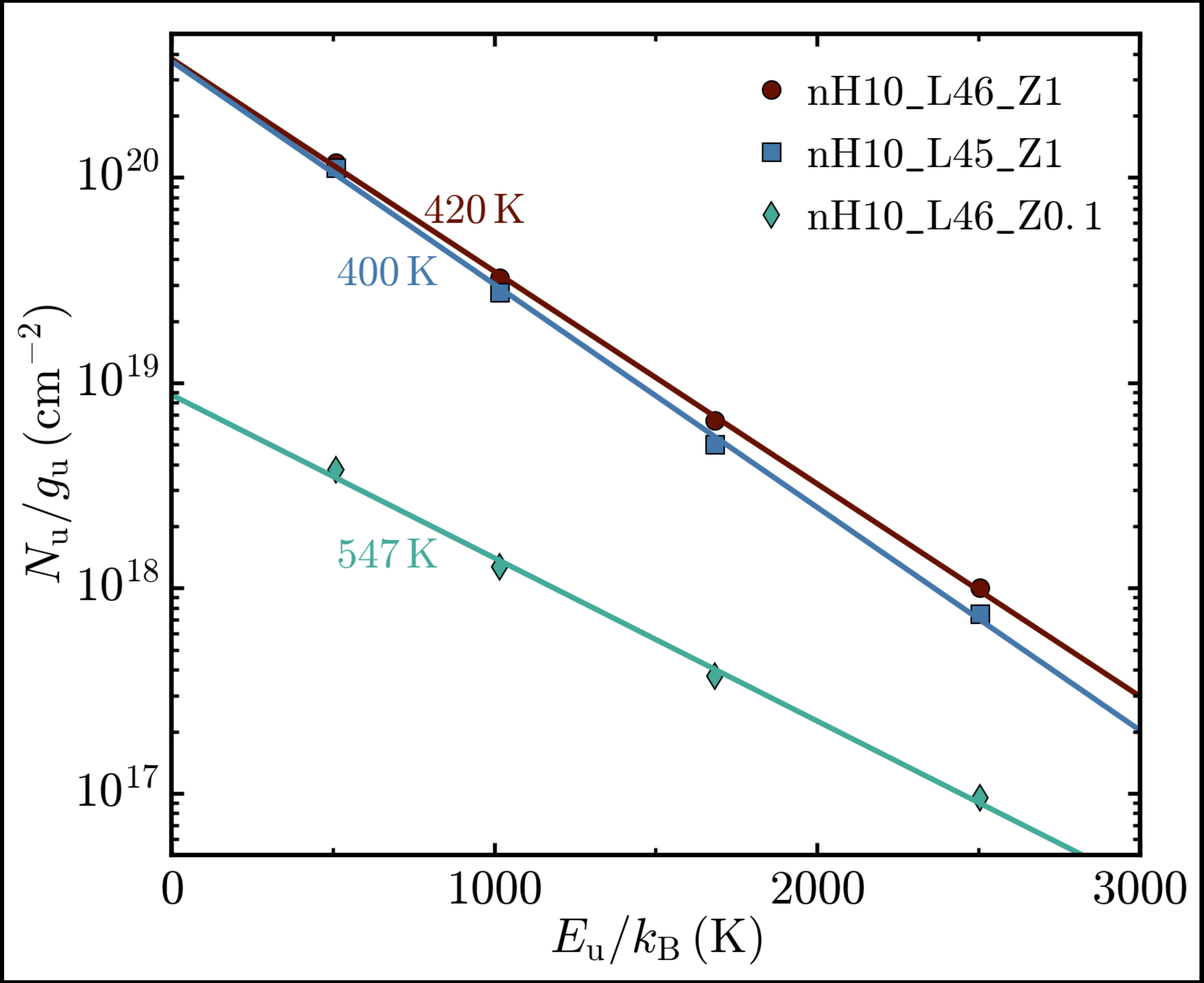

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Warm H_2 Emission

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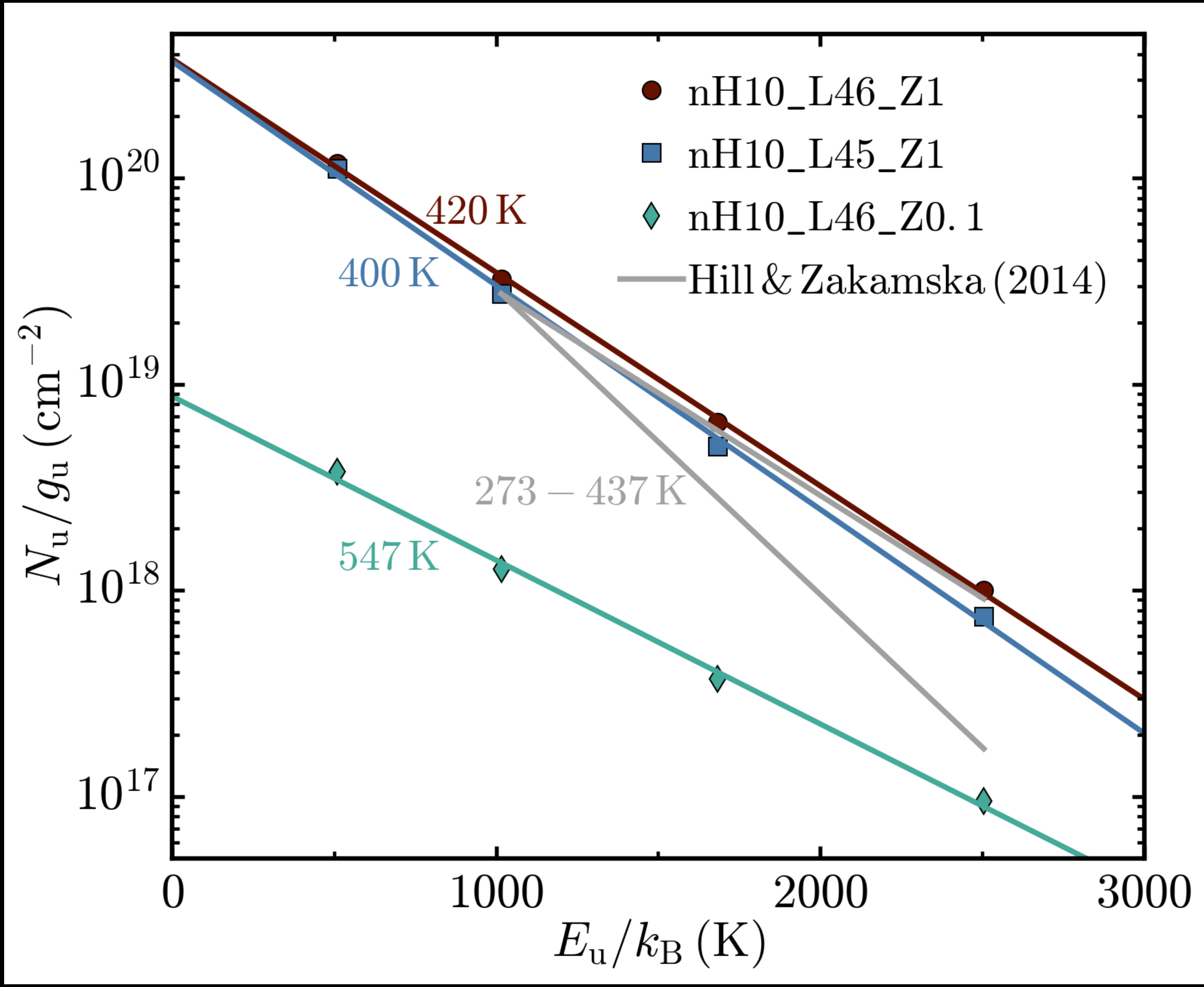

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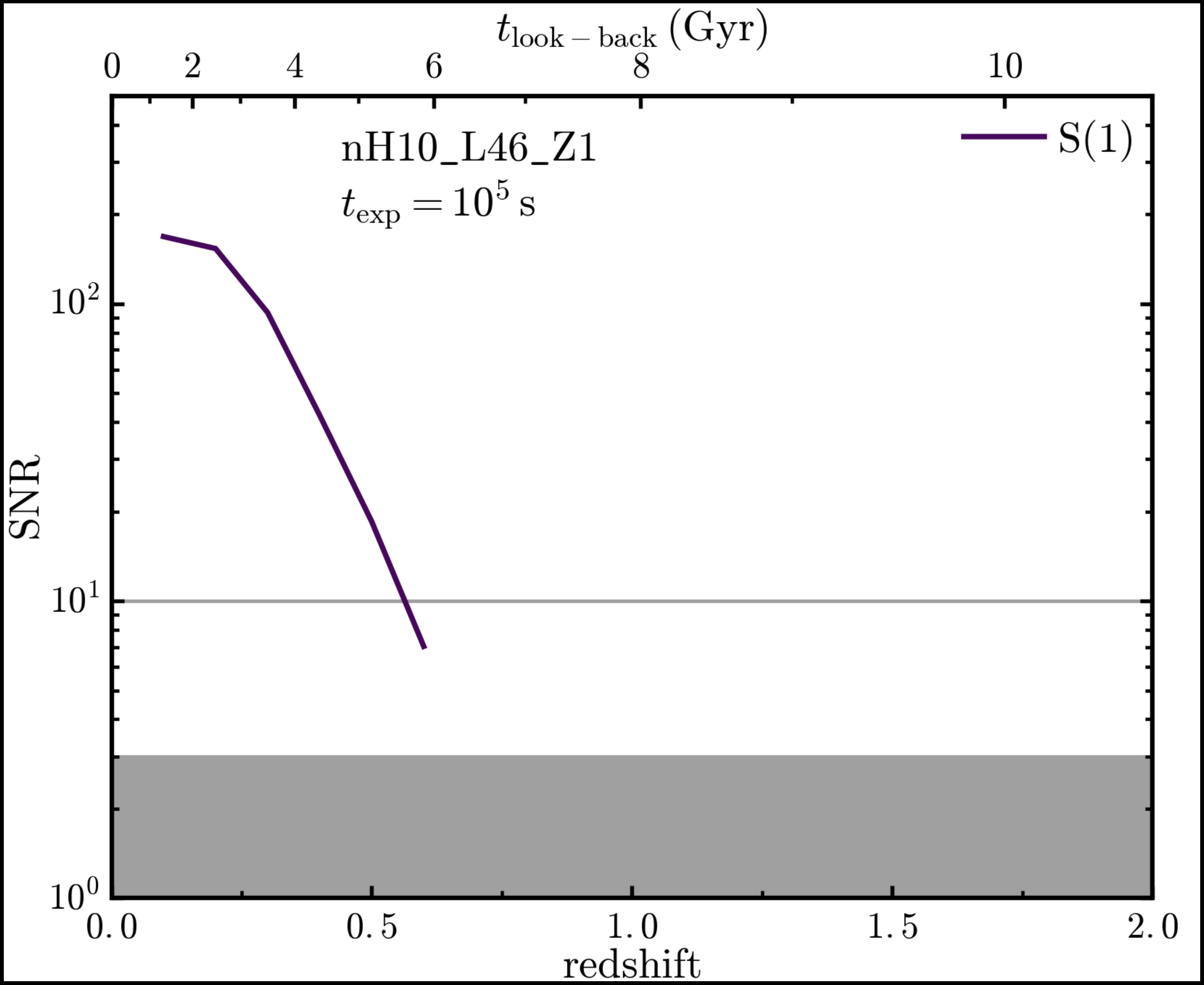
Warm H_2 Emission

JWST Predictions



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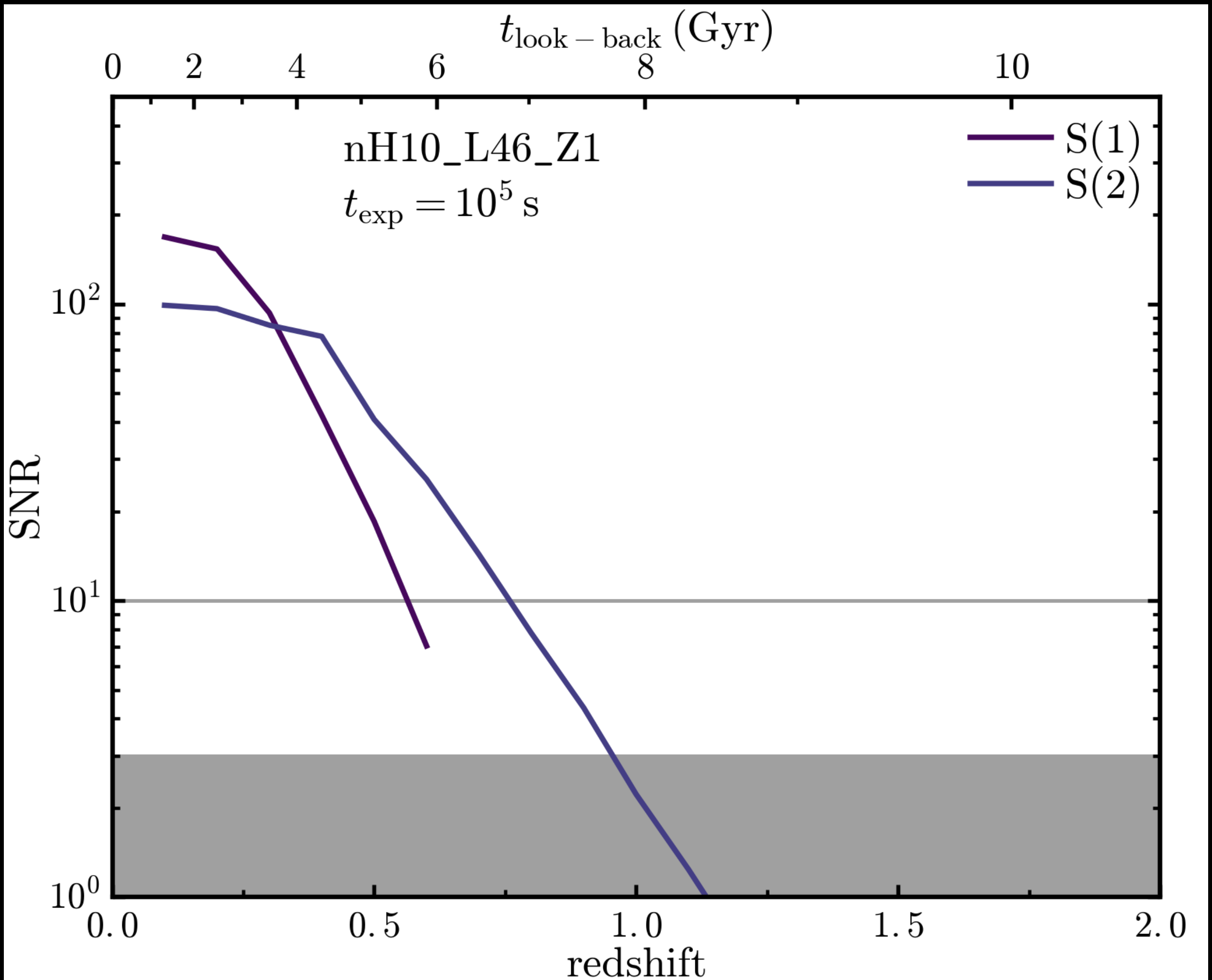
Warm H_2 Emission
JWST Predictions



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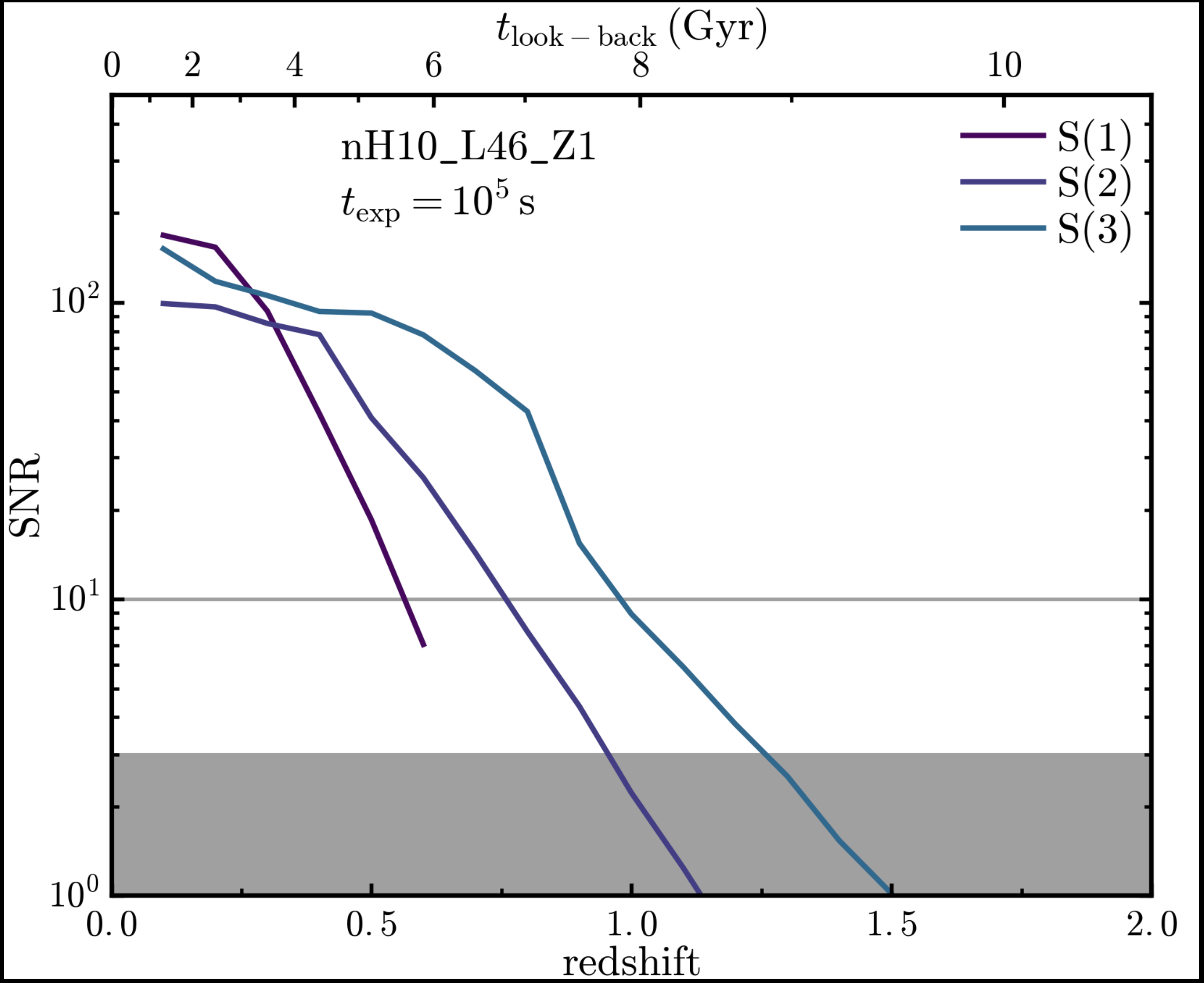

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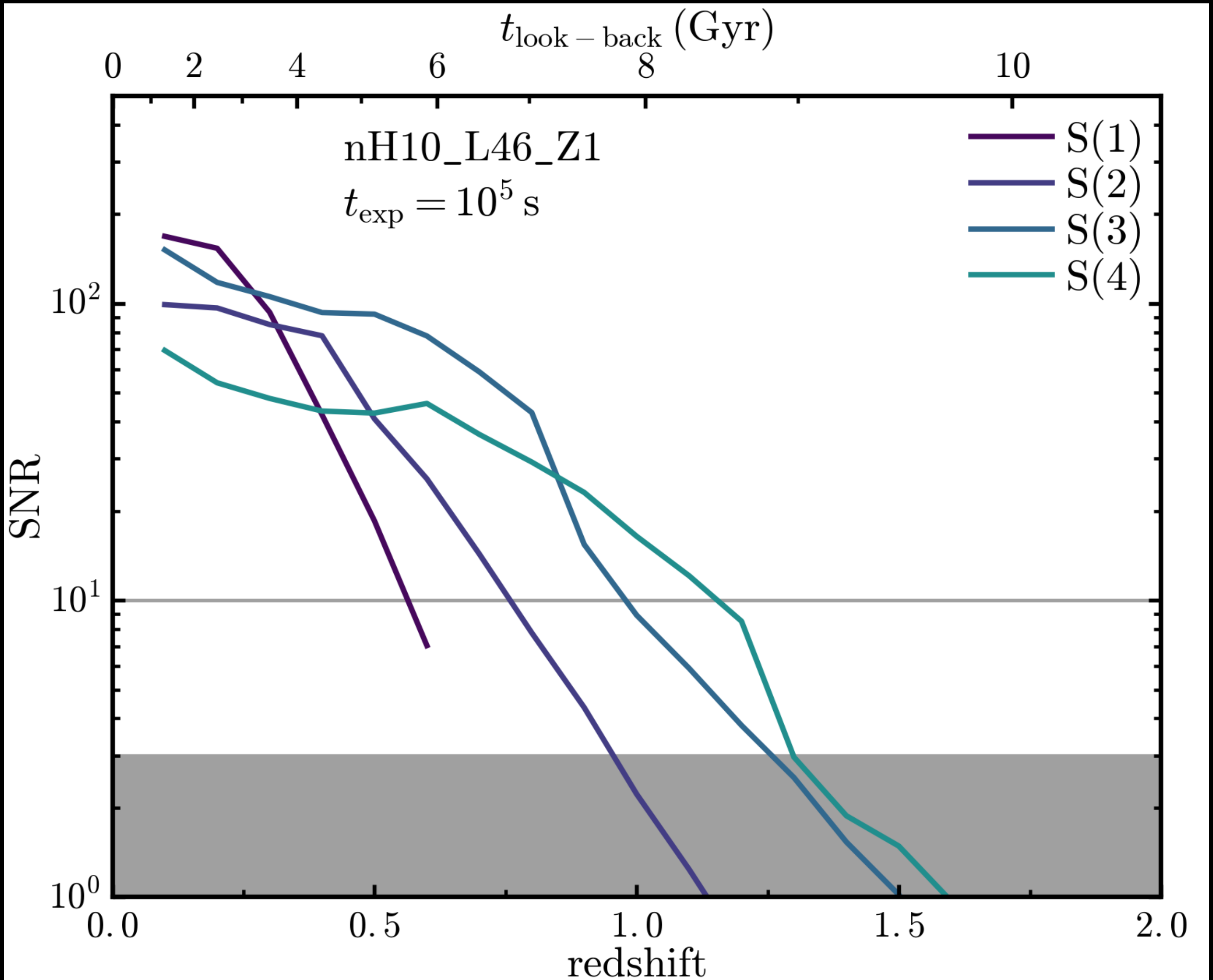

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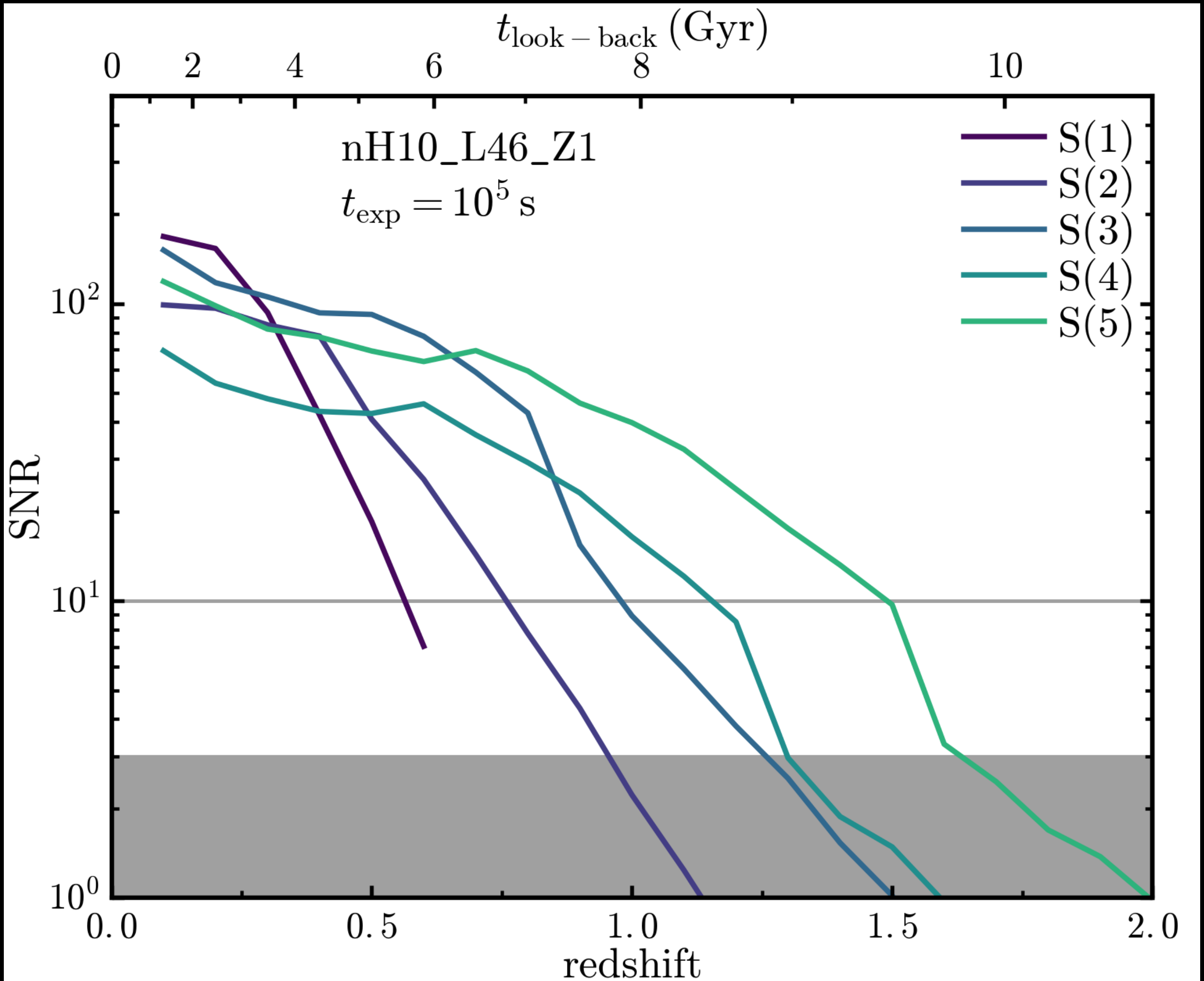

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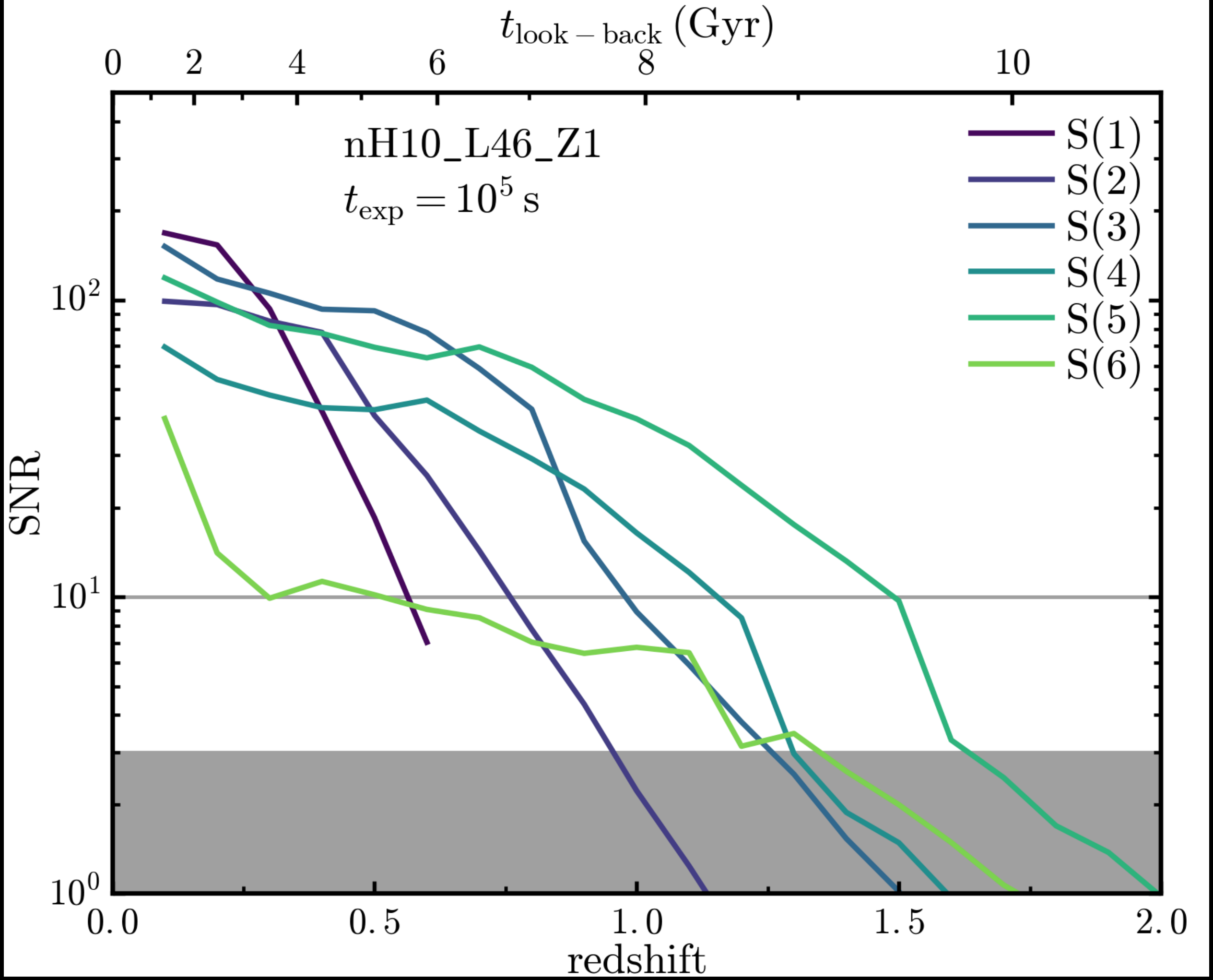

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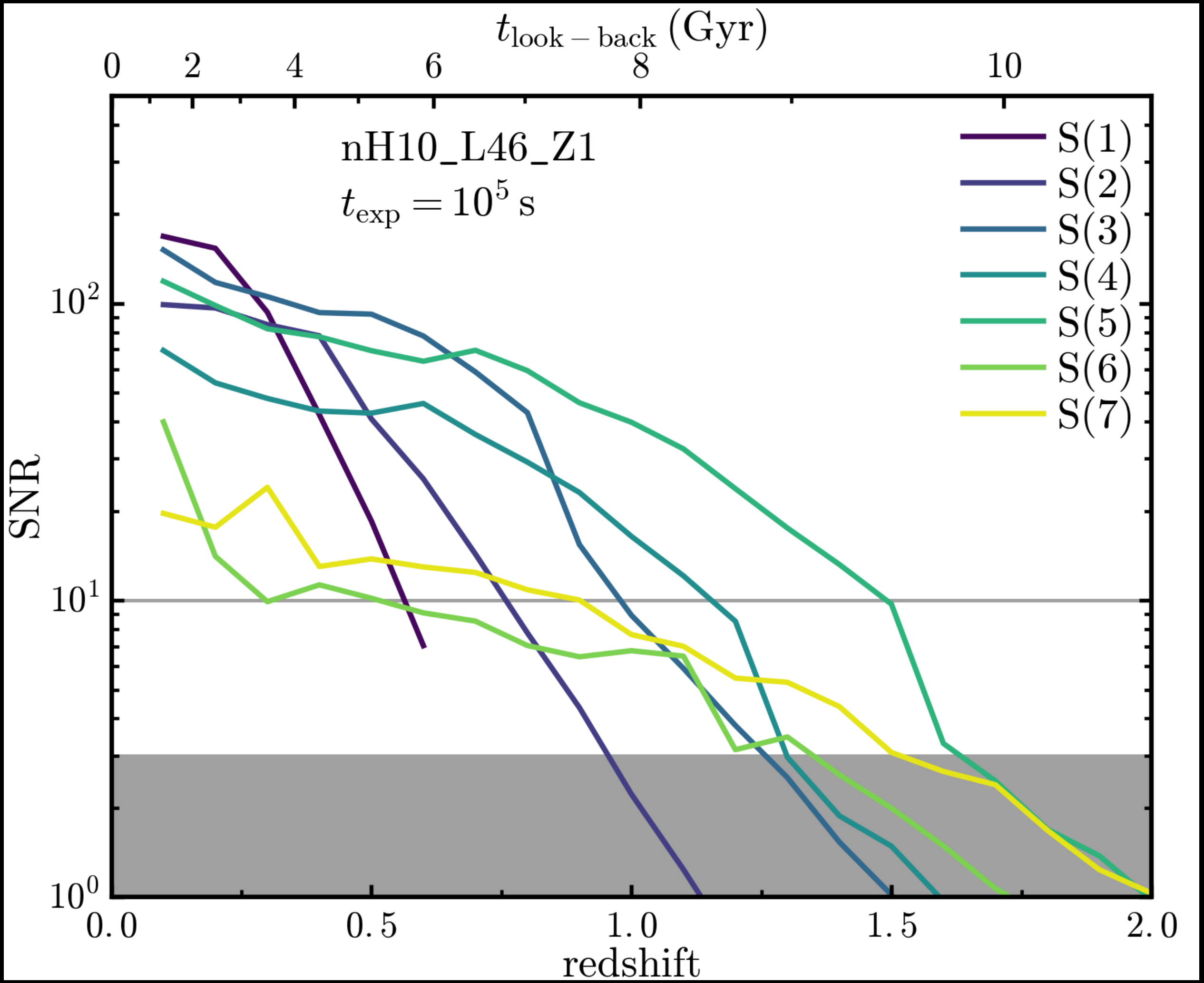

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Summary

- Molecular outflow rates up to $140\ M_{sol}\ yr^{-1}$ formed within the AGN wind after 1 Myr.
- CO to H_2 conversion factor at solar metallicity: $\alpha_{CO\ (1\text{-}0)} = 0.13\ M_{sol}\ (K\ km\ s^{-1}\ pc^2)^{-1}$.
- Strong warm H_2 emission, with T_{exc} ~400 K at solar metallicity.
- Warm H_2 emission observable by JWST out to redshift 1.6 at an SNR of 3 (redshift 1.5 at an SNR of 10).