SLICK Simulations for Line-Intensity Mapping

Karolina Garcia

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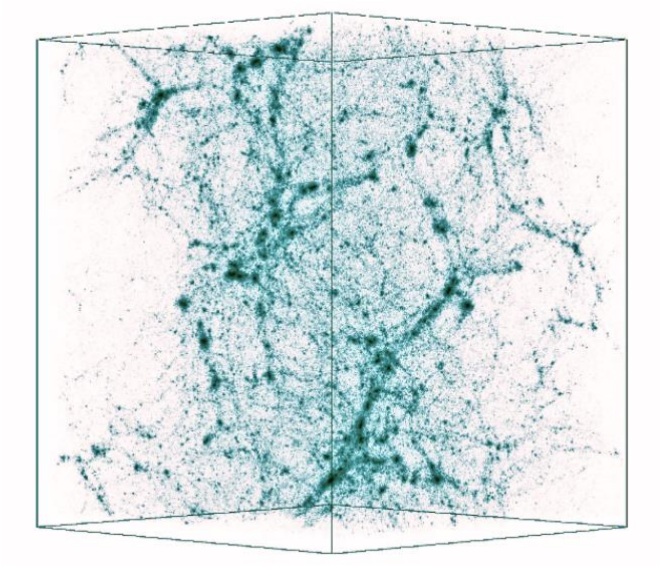
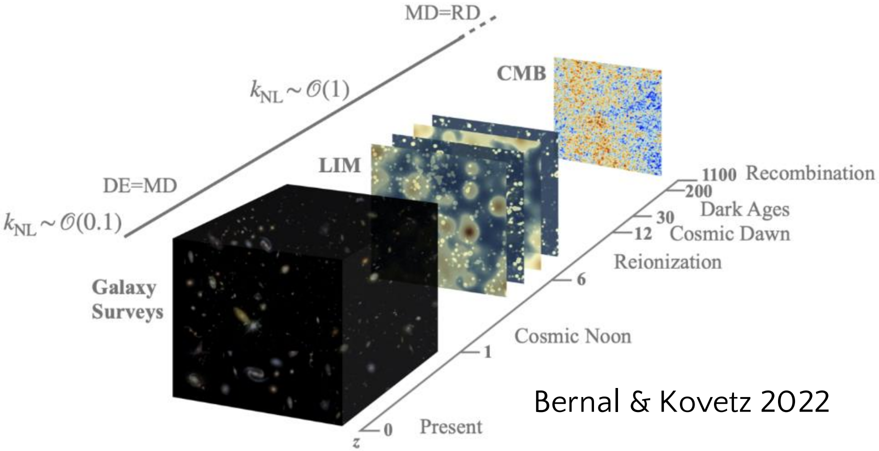
NCSA/University of Illinois

LIM Modeling with Hydrodynamical Simulations





Bernal & Kovetz 2022

Limitations of Cosmological Simulations for LIM

🧊 **Resolution Limits**

Simulations can't resolve individual molecular clouds;

Gas temperature and density are averaged over.

🔬 **Missing Small-Scale Physics**

No direct modeling of ISM chemistry, turbulence, or dust;

Need additional models to predict line emission.

🌌 **Cosmological Volume vs Resolution Trade-off**

Large boxes capture cosmic structure but miss fine gas structure;

Small boxes: more detailed but prone to sample variance.

💫 **Feedback (and other astrophysical) Models**

AGN and SN effects are not "solved from first principles";

Instead, they rely on tunable recipes calibrated to reproduce large-scale galaxy statistics.

✨ **Cosmology Assumption**

Initial conditions and evolution parameters are set.

🎲 **Cosmic Variance**

Usually just one realization of "Universe".

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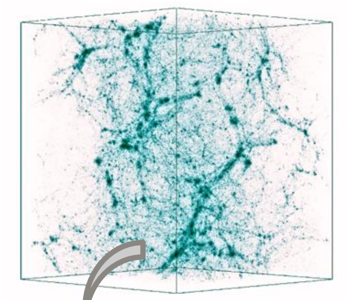
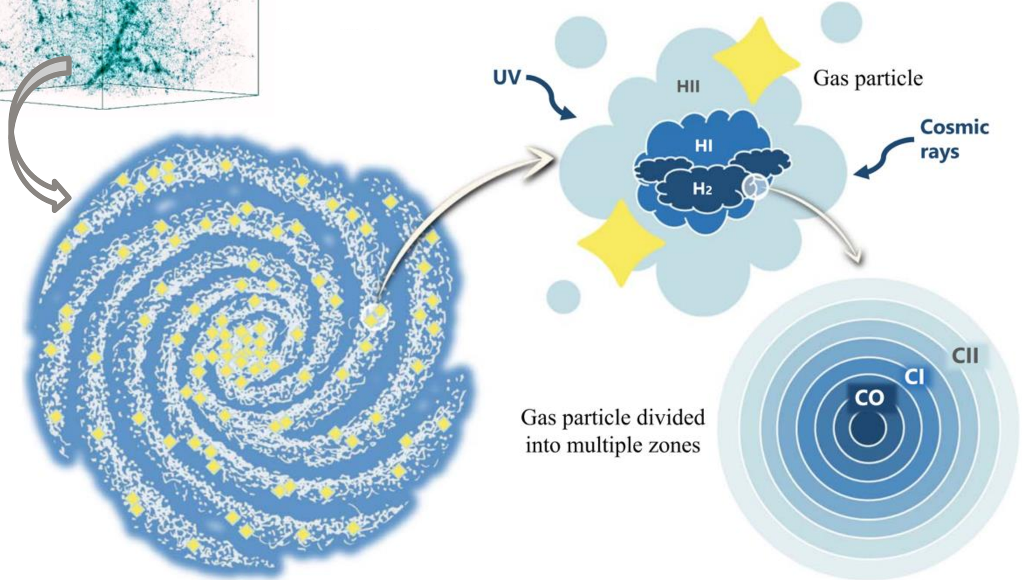
SLICK: Scalable Line Intensity Computation Kit

Garcia, Narayanan, Popping, Anirudh, Kaasinen



Input Simulations:

SIMBA, IllustrisTNG, and CAMELS



- Sub-resolution modeling of clouds based on Popping et al. (2019)
- DESPOTIC (radiative transfer code) is run in each cloud zone to compute line emission ([CII], CO, CI, etc).
- Environment-dependent radiation field is used to model UV/CR effects
- Produces cloud-level and galaxy-integrated molecular line luminosities

Garcia et al. 2024

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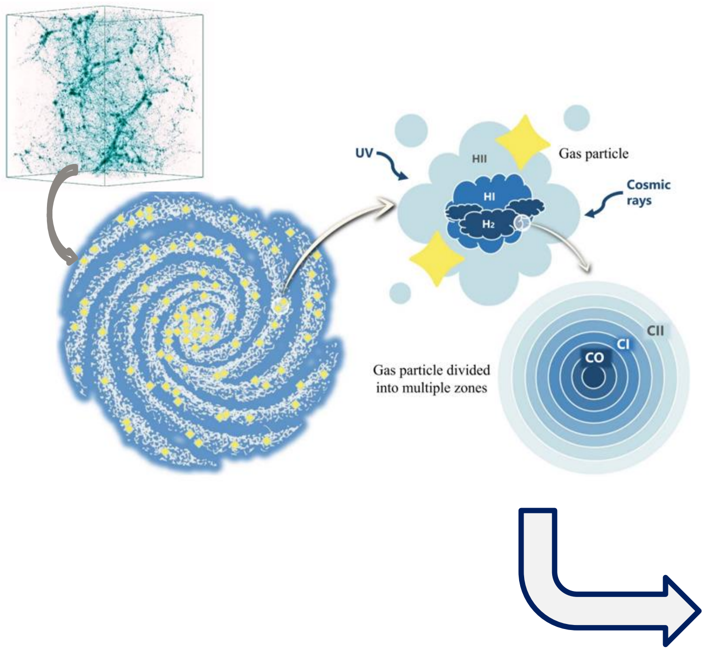
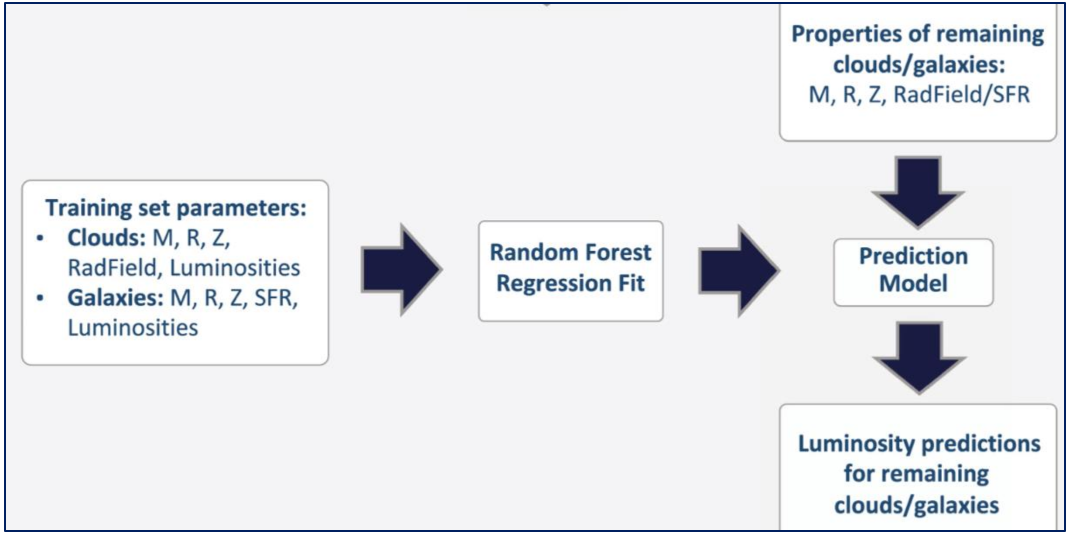
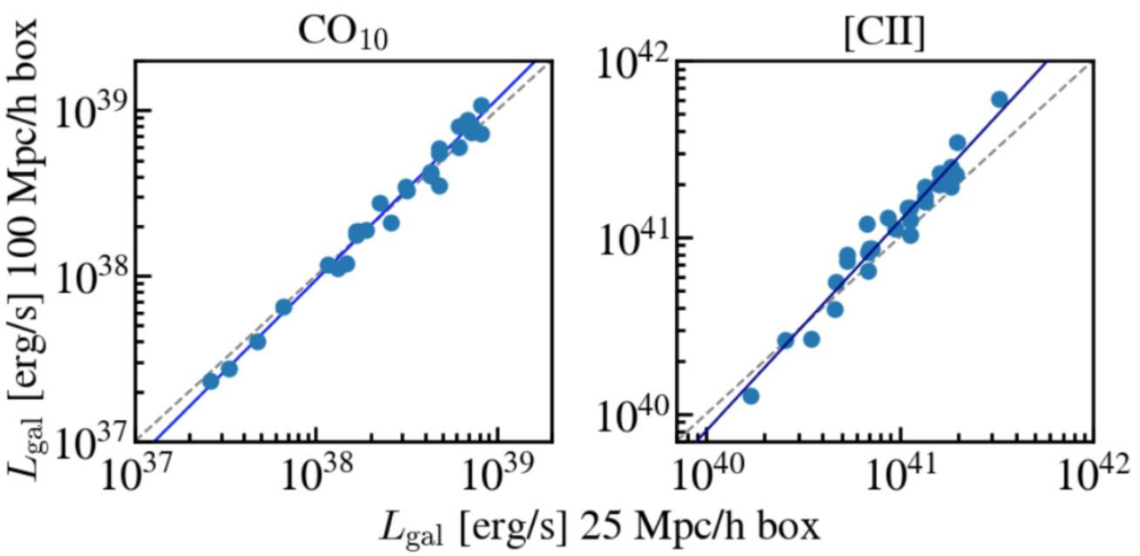




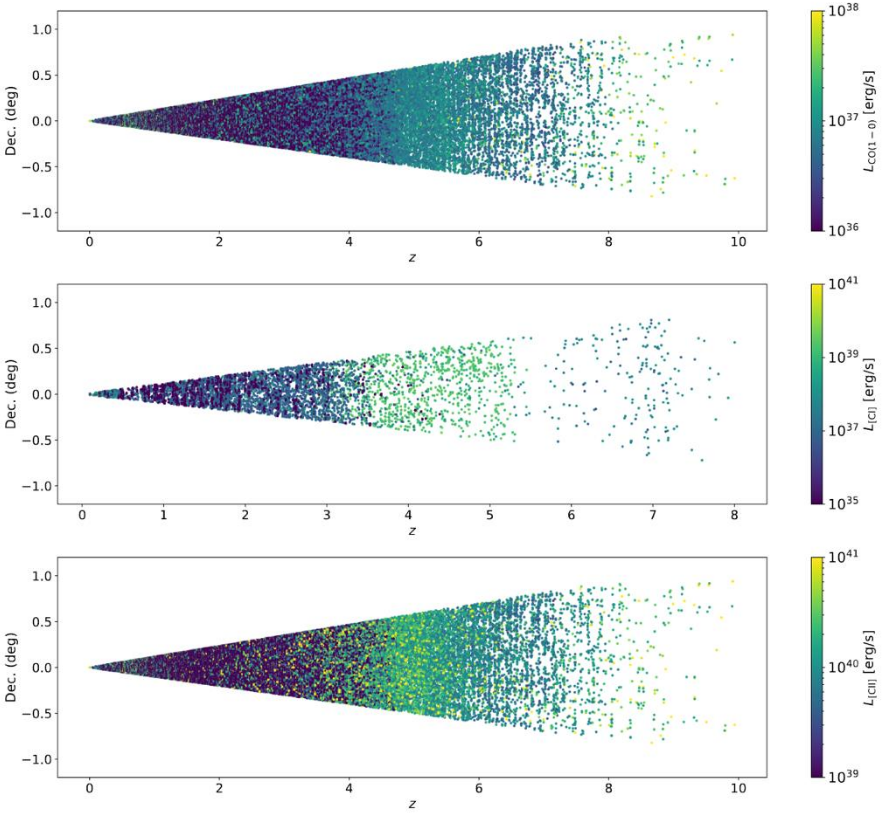
Garcia et al. 2024

Testing *SLICK* on different volumes



Garcia et al. in prep

Molecular Line Luminosities from z=0 to z=10!



Garcia et al. 2024

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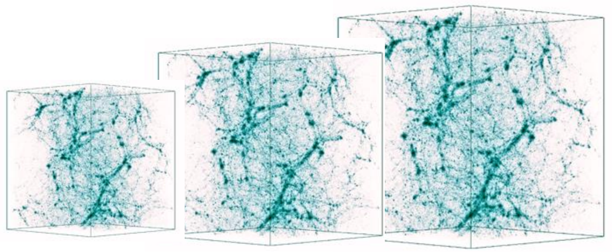
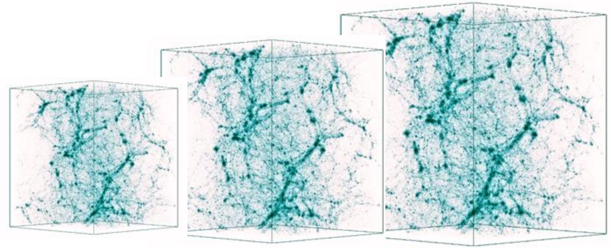
Cosmological Simulations Overview

- SIMBA



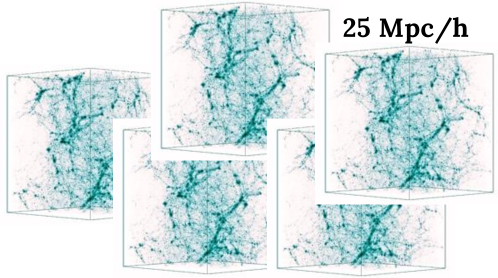
25 Mpc/h 50 Mpc/h 100 Mpc/h

- IllustrisTNG



25 Mpc/h 75 Mpc/h 225 Mpc/h

- CAMELS



25 Mpc/h

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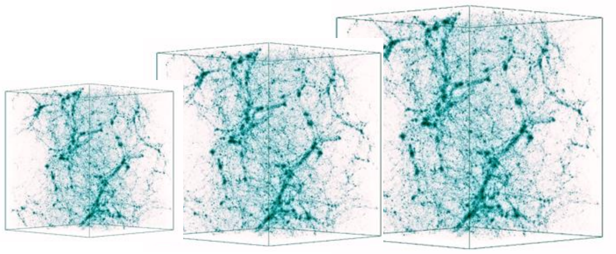

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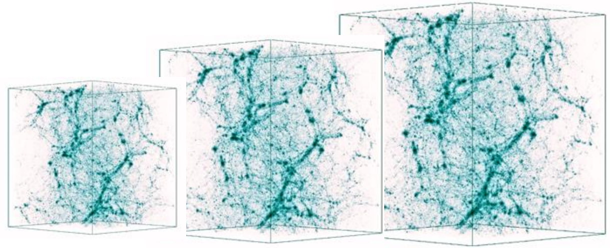

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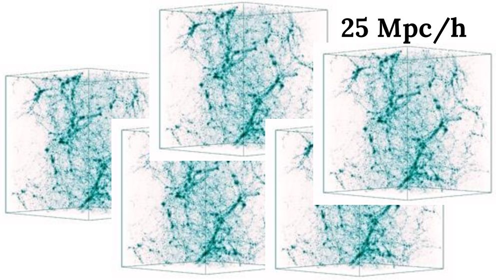


Sets that I'm using:

First set: Extreme combinations of AGN + SN

Second set: Varies one parameter at a time

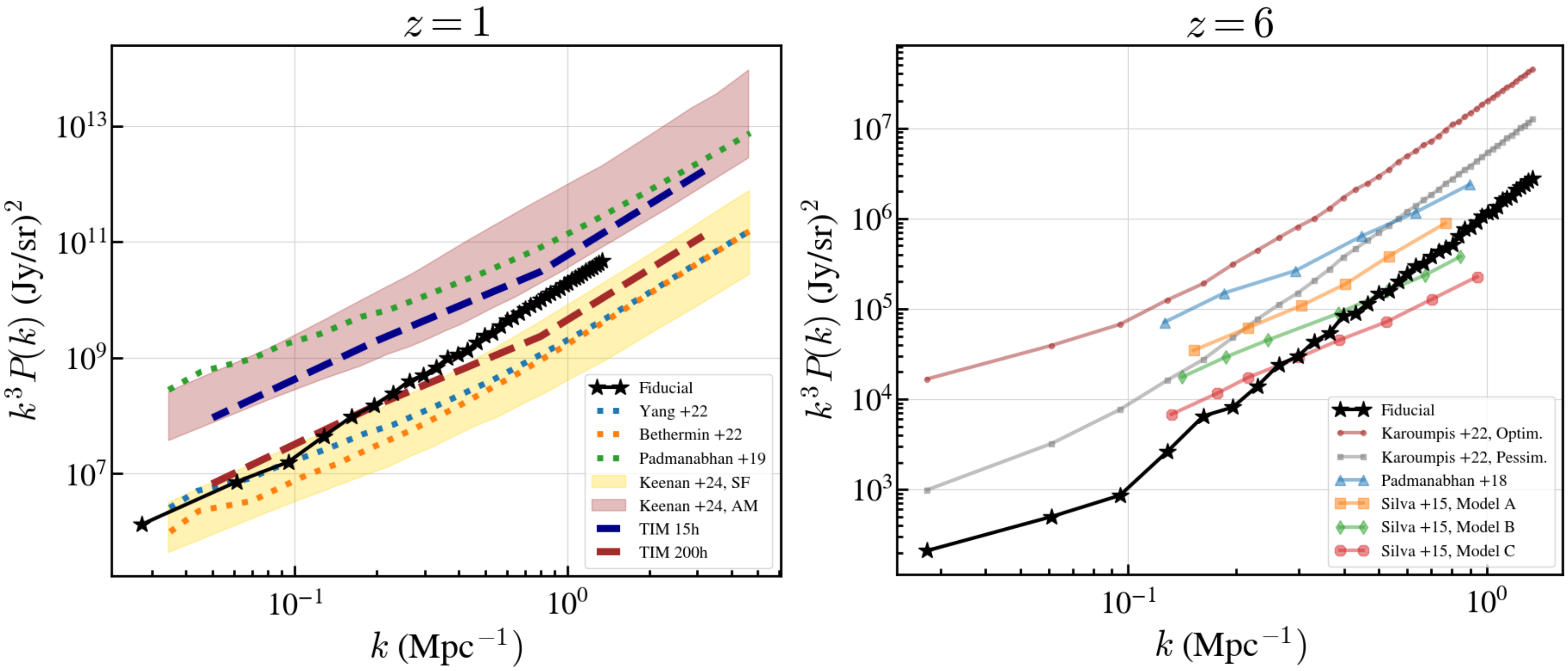
Third set: Same physics, different realizations → cosmic variance

Why?

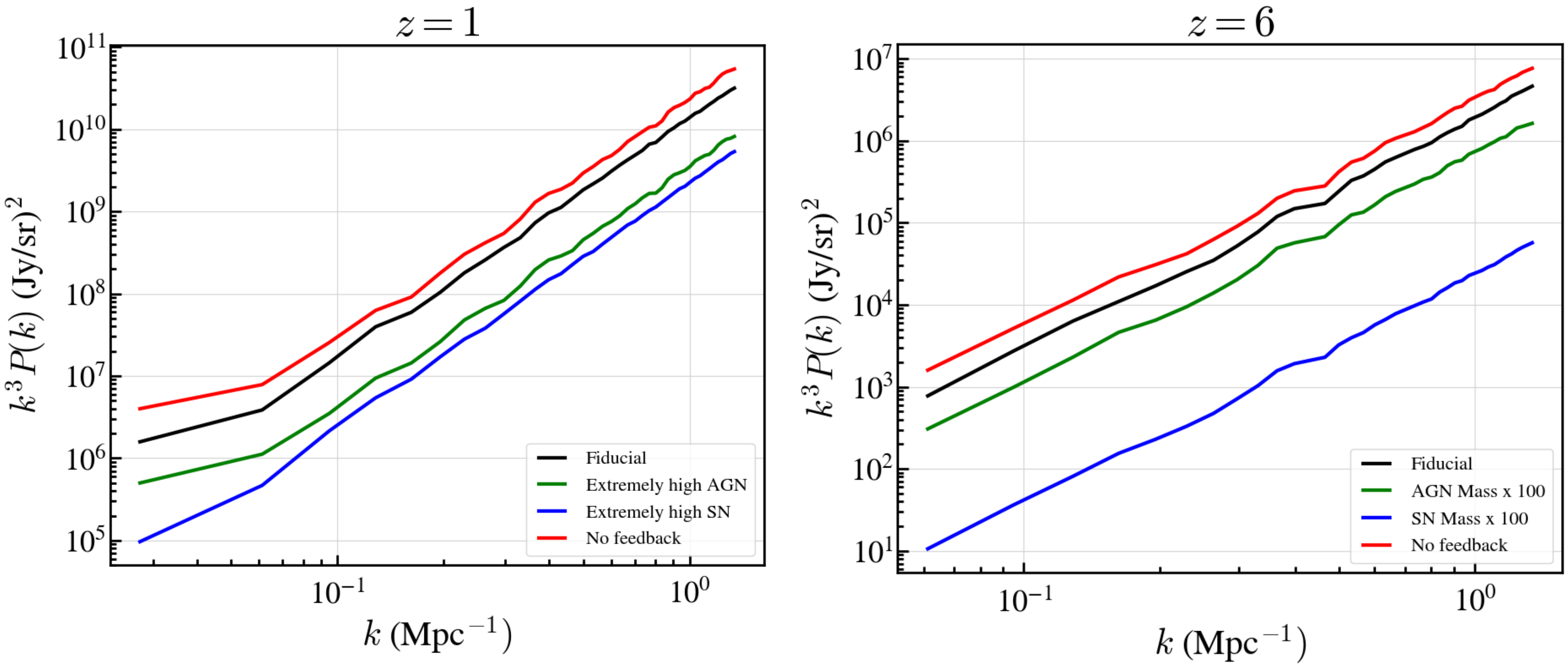
Identifies which parameters matter most

Helps marginalize over uncertainty in modeling

SLICK + CAMELS
Fiducial [CII] Power Spectrum



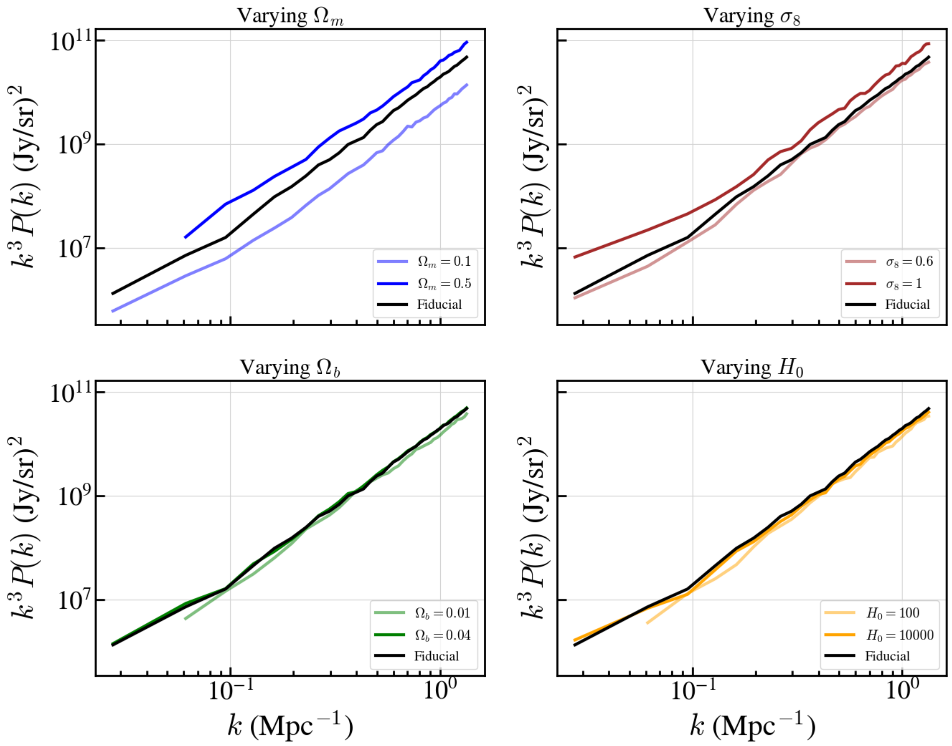
[CII] Power Spectrum for Extreme SN/AGN Models

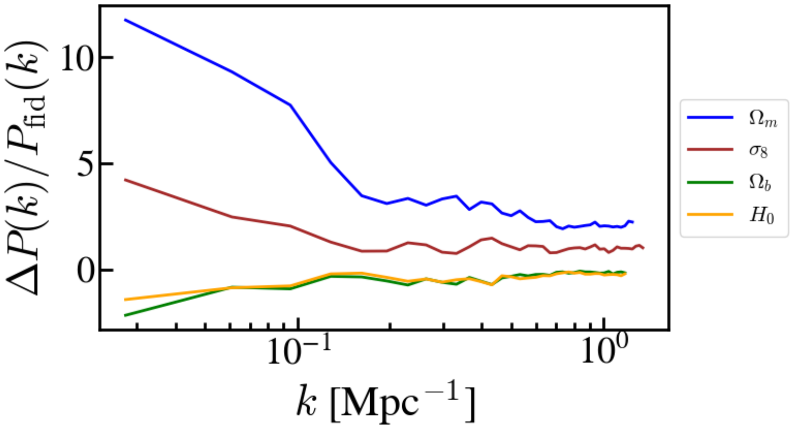


PRELIMINARY

[CII] Power Spectrum for Varying Cosmological Parameters

CAMELS SIMBA 25 Mpc/h, z = 1





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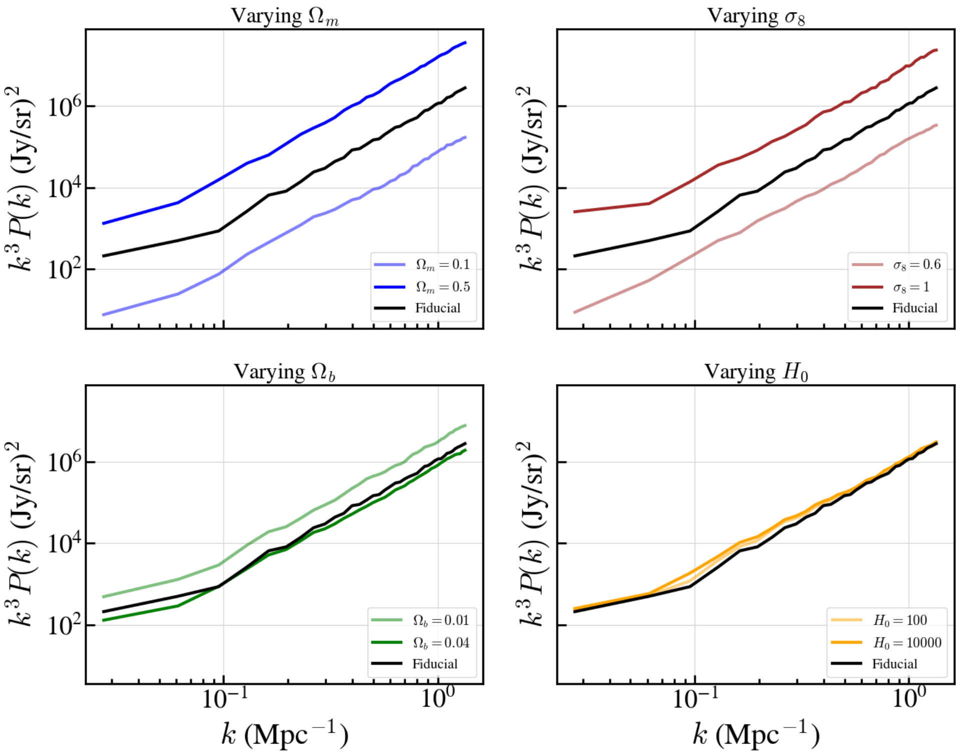
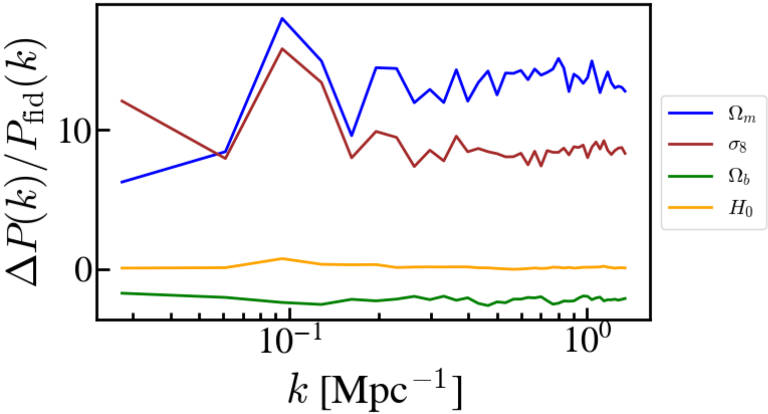
CAMELS SIMBA 25 Mpc/h, z = 6

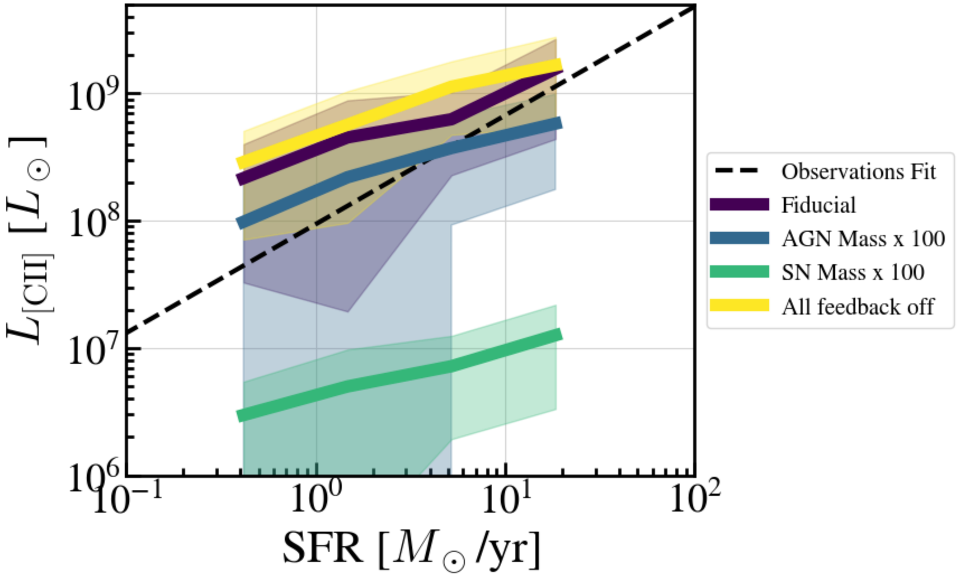




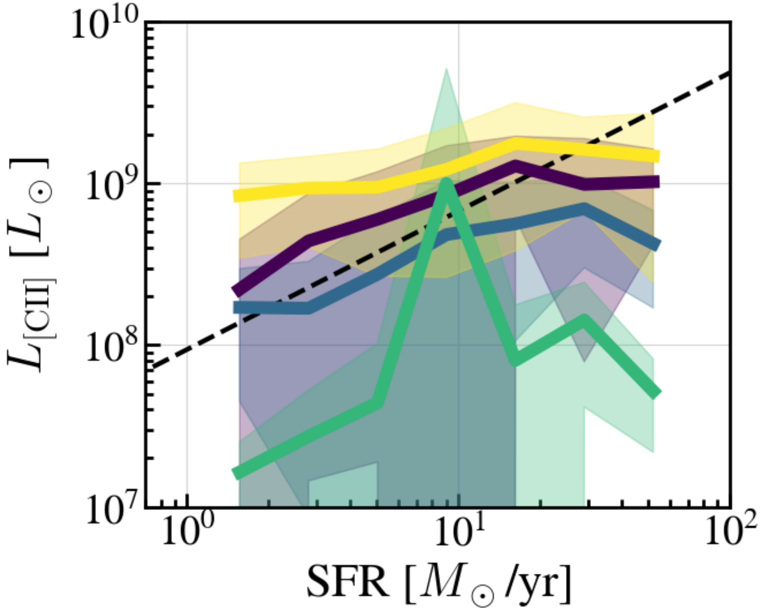
PRELIMINARY

[CII] x SFR for Extreme SN/AGN Models

z = 1



z = 6



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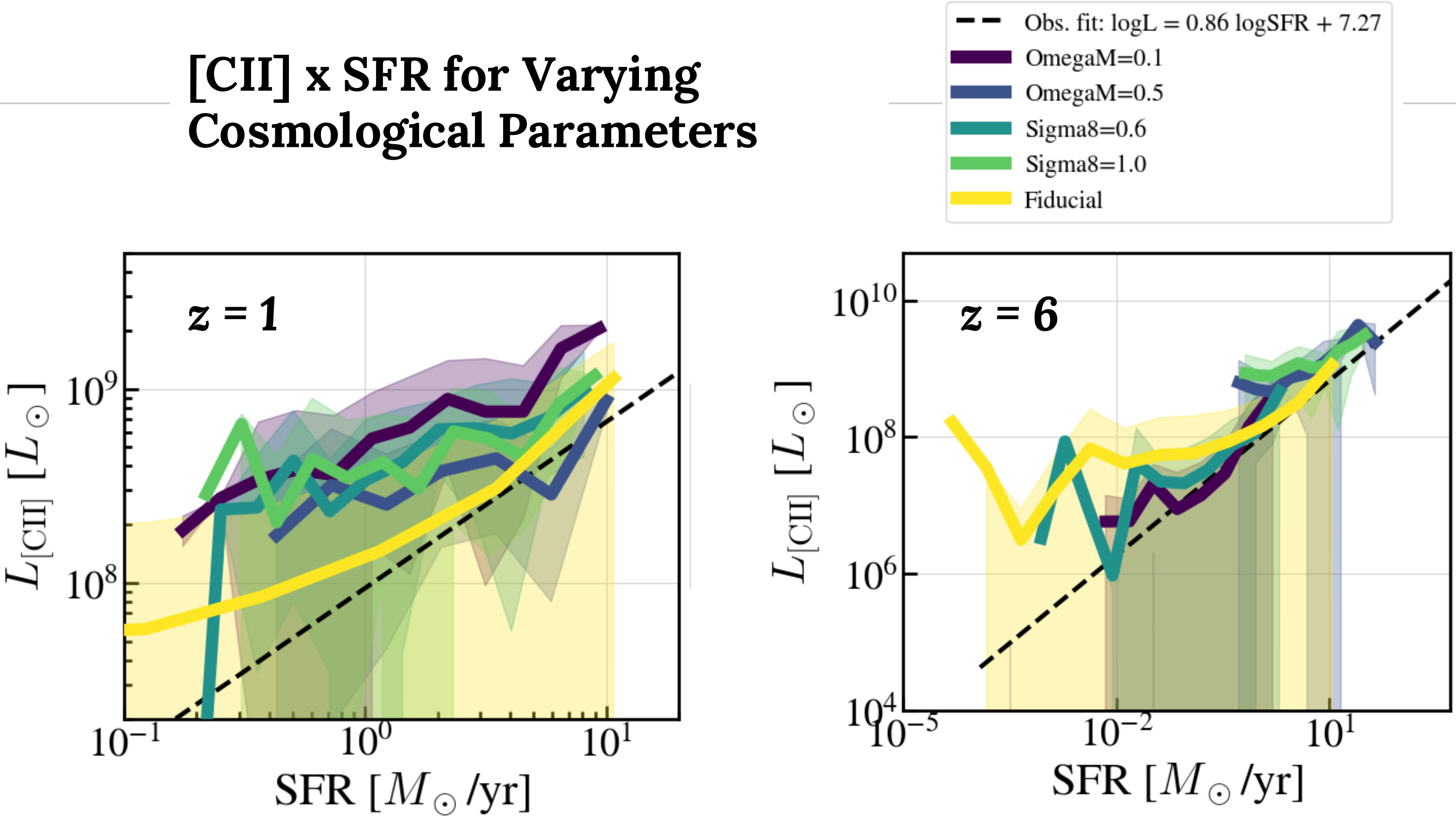

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🔄 Feedback (and other astrophysical) Models

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Instead, they rely on tunable recipes calibrated to reproduce large-scale galaxy statistics.

→ Solution: Explore how much these assumptions affect LIM predictions

✨ Cosmology Assumption

Initial conditions and evolution parameters are set.

→ Solution: Test the sensitivity of LIM to varying cosmological parameters

🎲 Cosmic Variance

Usually just one realization of "Universe".

→ Solution: Evaluate the impact of cosmic variance on LIM observables

Other amazing *SLICK* projects

Anirudh Ravishankar (IISER/MPIA), Gergo Popping (ESO),
Melanie Kaasinen (ANU), Desika Narayanan (UF)
→ Resolved CO transitions in galaxies
→ Accepted to A&A

Dariannette Valentin Martínez (UF),
Desika Narayanan (UF)
→ Dark-CO studies

Pallavi Patil, Andreea Petric, Kate Rowlands
(Johns Hopkins University/STScI)
→ Impact of AGNs on molecular line luminosities

Conclusions

- Cosmological hydrodynamic simulations are powerful tools for LIM studies, but modeling the complex physics of galaxy formation, especially at small scales, is challenging.

- *SLICK* addresses this by combining PDR-based modeling of the ISM with machine learning, offering both physical interpretability and computational efficiency.

- By integrating with the CAMELS simulation suite, *SLICK* enables us to explore how changes in astrophysical and cosmological parameters affect predicted line luminosities.

- Feedback processes and other astrophysical/cosmological assumptions can significantly impact LIM observables. *SLICK* helps us quantify these effects and develop strategies to marginalize over theoretical uncertainties.