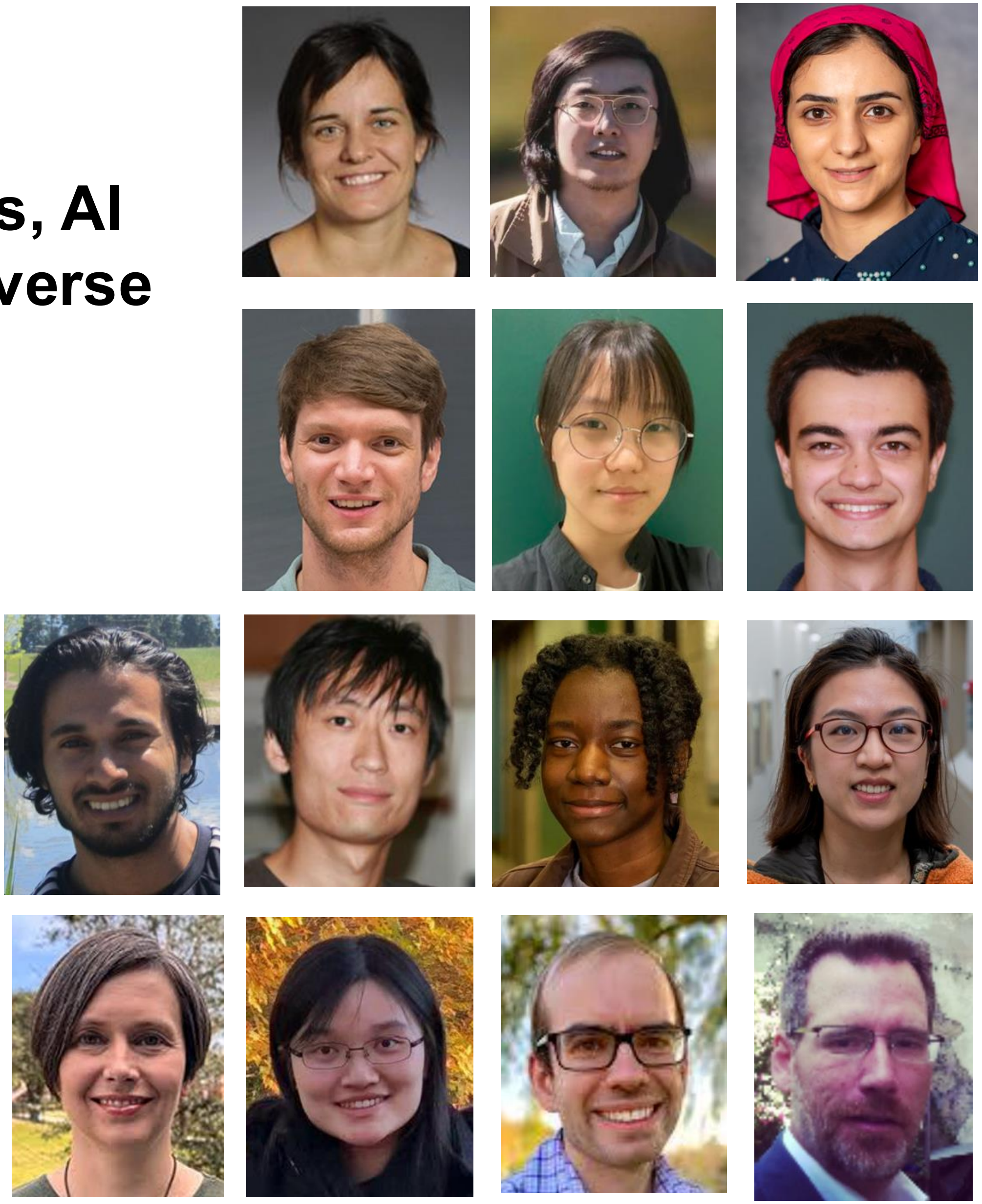
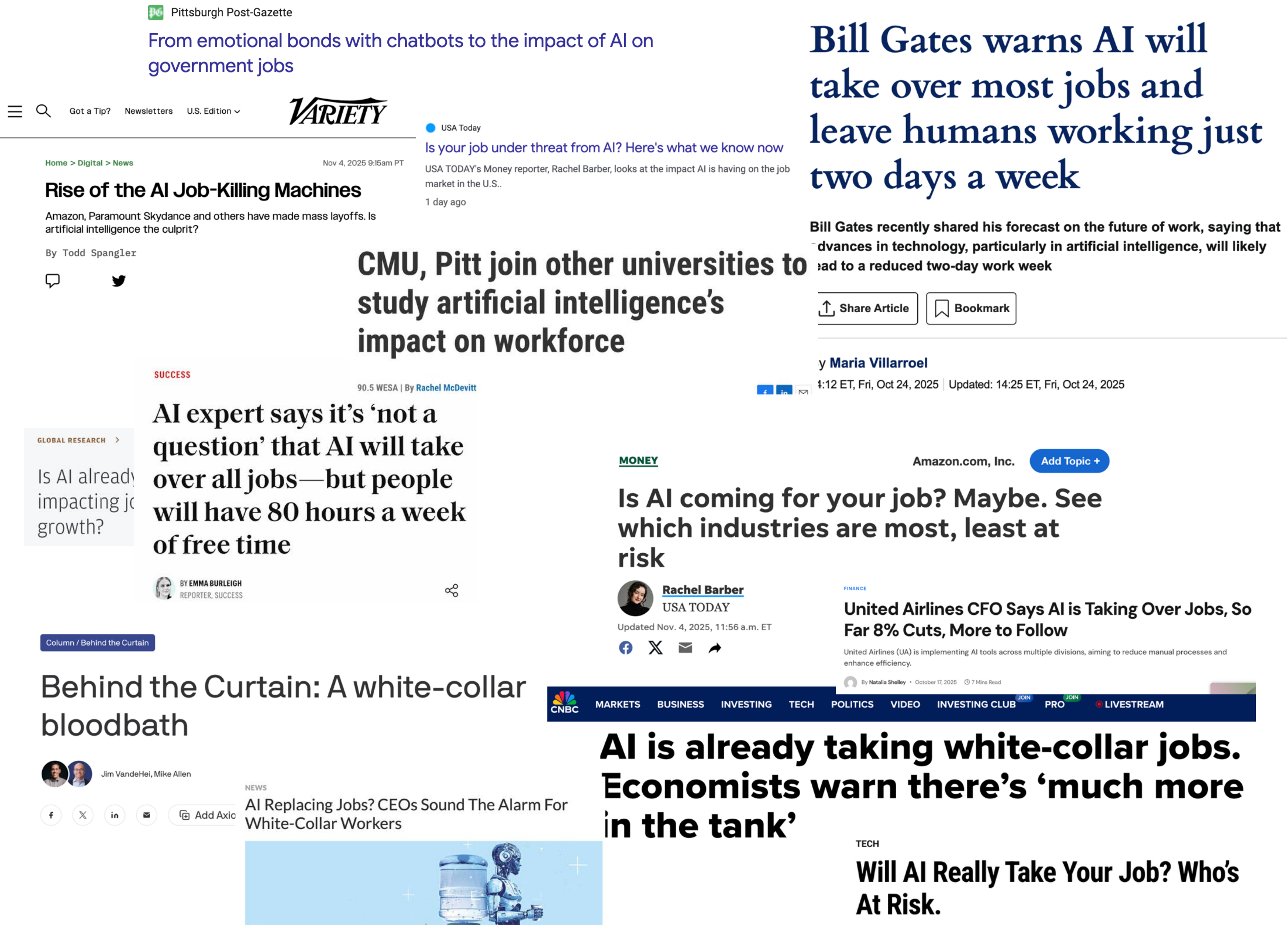
Cosmological simulations, AI and the high redshift Universe

Rupert Croft

Tiziana Di Matteo
Xiaowen Zhang
Fatemeh Hafezianzade
Patrick Lachance
Yihao Zhou
Patrick Shaw
Yu Feng
Ann-Marsha Alexis
Nianyi Chen
Yueying Ni
Simeon Bird
Ben Metcalf
Aklant Bhowmick
Laura Blecha





Pittsburgh Post-Gazette

From emotional bonds with chatbots to the impact of AI on government jobs

Home > Digital > News

Nov 4, 2025 9:15am PT

Rise of the AI Job-Killing Machines

Amazon, Paramount Skydance and others have made mass layoffs. Is artificial intelligence the culprit?

By Todd Spangler

USA Today

Is your job under threat from AI? Here's what we know now

USA TODAY's Money reporter, Rachel Barber, looks at the impact AI is having on the job market in the U.S..

1 day ago

Bill Gates warns AI will take over most jobs and leave humans working just two days a week

Bill Gates recently shared his forecast on the future of work, saying that dvances in technology, particularly in artificial intelligence, will likely ad to a reduced two-day work week

y **Maria Villarroel**

:12 ET, Fri, Oct 24, 2025 | Updated: 14:25 ET, Fri, Oct 24, 2025

CMU, Pitt join other universities to study artificial intelligence's impact on workforce

90.5 WESA | By Rachel McDevitt

SUCCESS

AI expert says it's 'not a question' that AI will take over all jobs—but people will have 80 hours a week of free time

BY EMMA BURLEIGH
REPORTER, SUCCESS

GLOBAL RESEARCH

Is AI already
impacting j
growth?

MONEY

Is AI coming for your job? Maybe. See which industries are most, least at risk

Rachel Barber
USA TODAY

Updated Nov. 4, 2025, 11:56 a.m. ET

FINANCE

United Airlines CFO Says AI is Taking Over Jobs, So Far 8% Cuts, More to Follow

United Airlines (UA) is implementing AI tools across multiple divisions, aiming to reduce manual processes and enhance efficiency.

By Natalia Shelley • October 17, 2025 • 7 Mins Read

Column / Behind the Curtain

Behind the Curtain: A white-collar bloodbath

Jim VandeHei, Mike Allen

AI is already taking white-collar jobs. Economists warn there's 'much more in the tank'

NEWS

AI Replacing Jobs? CEOs Sound The Alarm For White-Collar Workers

TECH

Will AI Really Take Your Job? Who's At Risk.

So what is the future of AI in science? Will it just take our jobs?

Will AI replace astronomers completely?

Astrophysics > Instrumentation and Methods for Astrophysics

[Submitted on 4 Apr 2025]

The AI Cosmologist I: An Agentic System for Automated Data Analysis

Adam Moss

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Moss 2025 arXiv:2504.03424

Computer Science > Artificial Intelligence

[Submitted on 30 Oct 2025]

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Villaescusa-Navarro et. al
arXiv:2510.26887

Will AI replace astronomers completely?


arXiv > astro-ph > arXiv:2504.03424

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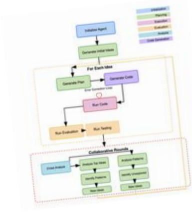
Moss 2025 arXiv:2504.03424

multi-agent systems can



ideate
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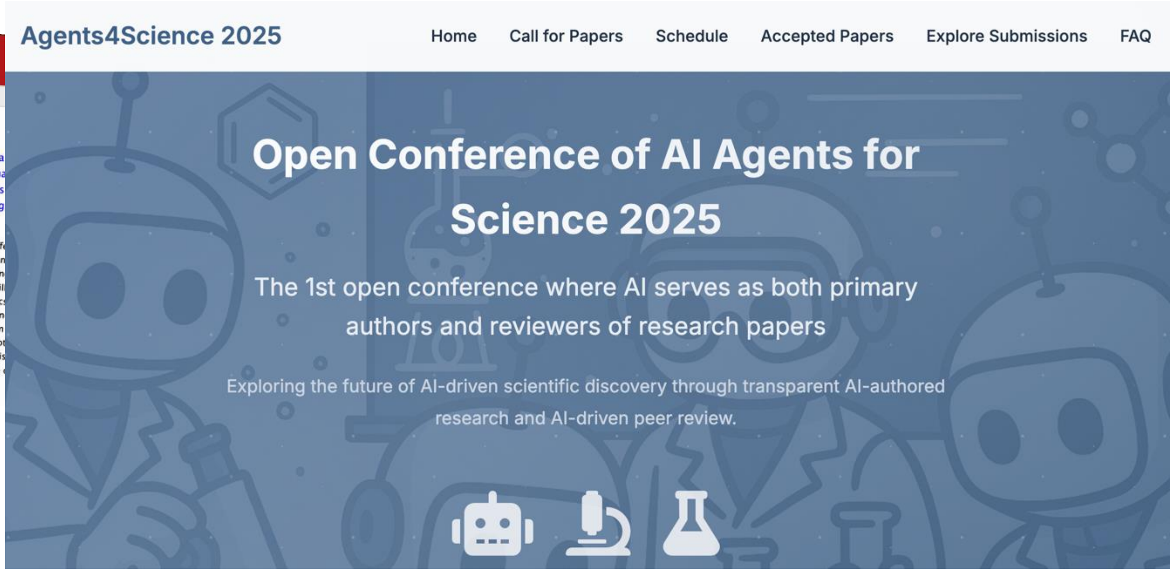
and write

complete journal publications



Open Conference of AI Agents for Science 2025

The 1st open conference where AI serves as both primary authors and reviewers of research papers

Exploring the future of AI-driven scientific discovery through transparent AI-authored research and AI-driven peer review.


arXiv > cs > arXiv:2510.26887

Computer Science > Artificial Intelligence

[Submitted on 30 Oct 2025]

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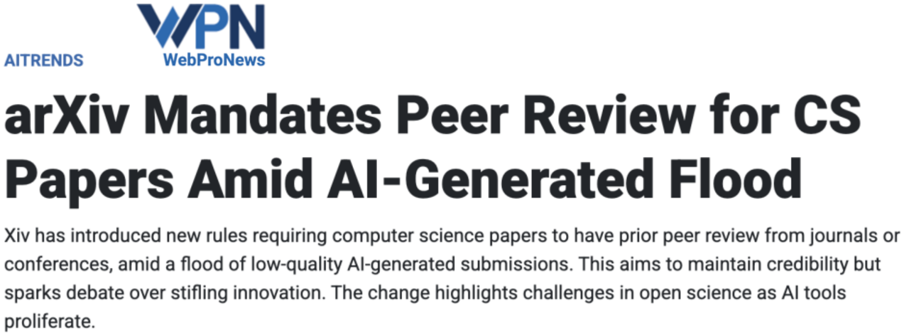
Villaescusa-Navarro et. al
arXiv:2510.26887

AI “slop” is easy to generate:

Rules changed recently
at **arXiv** because of AI slop.

arXiv Changes Rules After Getting Spammed With AI-Generated 'Research' Papers

MATTHEW GAULT · NOV 3, 2025 AT 11:33 AM



AITRENDS

arXiv Mandates Peer Review for CS Papers Amid AI-Generated Flood

Xiv has introduced new rules requiring computer science papers to have prior peer review from journals or conferences, amid a flood of low-quality AI-generated submissions. This aims to maintain credibility but sparks debate over stifling innovation. The change highlights challenges in open science as AI tools proliferate.

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Will AI replace astronomers completely?

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Moss 2025 ar 504.03424

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Computer Scien telligence

[Submitted on 30 O

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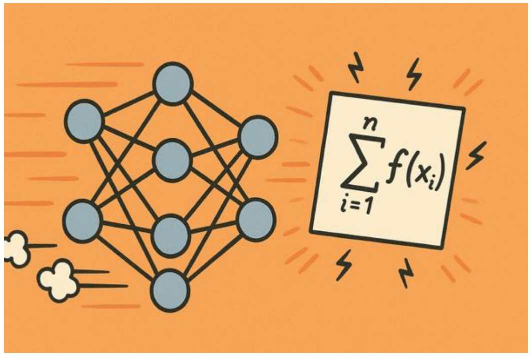
Villaescusa-Navarro et. al
arXiv:2510.26887

or will it assist astronomers… ?

(do boring stuff)



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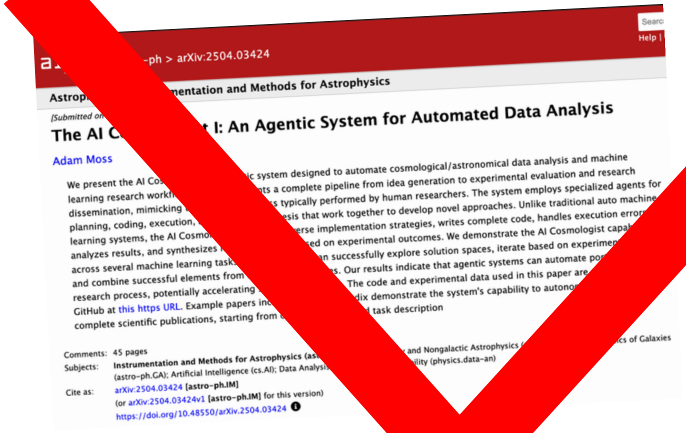
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Help |

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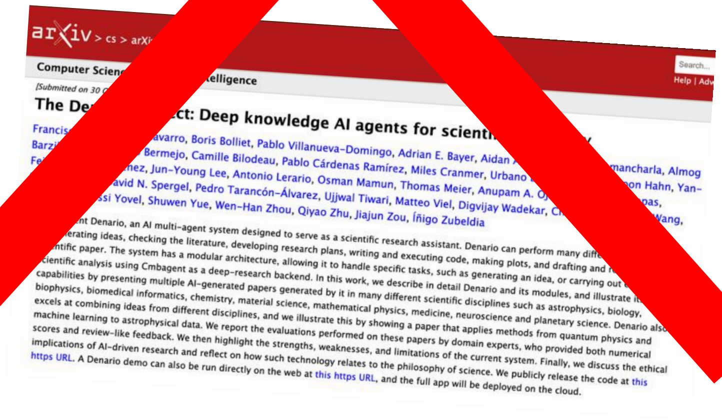
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Computer Scien elligence

[Submitted on 30

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this talk

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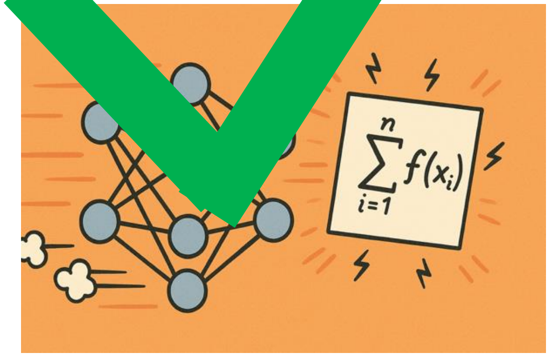
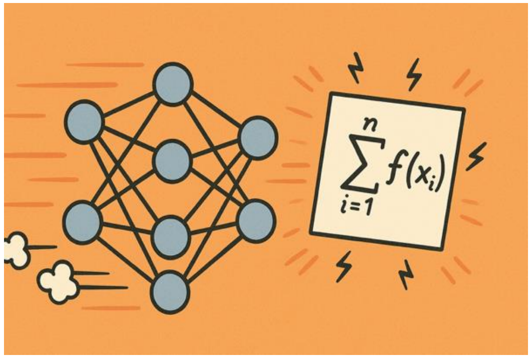


(speed up calculations)



Why do we need AI to speed up calculations?

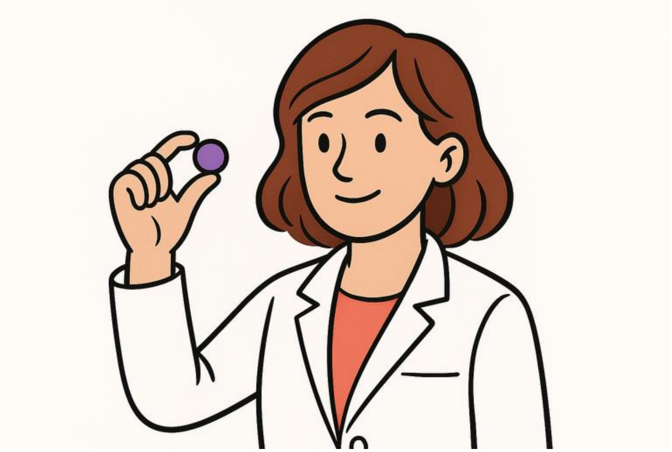
Simulations in astrophysics - e.g., star formation, cosmology are very computationally expensive

e.g., cosmological hydrodynamic simulation `Astrid:` 500 million core-hours!

but want to use them as a tool – e.g., mocks (huge surveys) or for Simulation Based Inference, which requires running large numbers of simulations.

cosmological simulations have a resolution problem:

need large volume



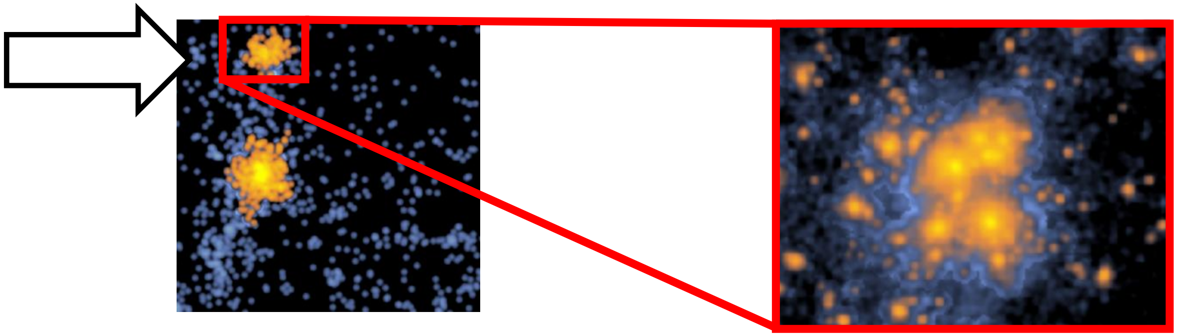
and need high mass resolution (small particles)

this is computationally expensive, but AI offers a way to do things differently:

We have developed **AI super-resolution** (SR) for astrophysics simulations:

hybrid Physics/Neural Network calculations:

(galaxy)



Large scales	Small scales (factor 512 smaller in mass)
N-body + computational hydrodynamics	Neural network (GAN + U-Net)
CPU	GPU

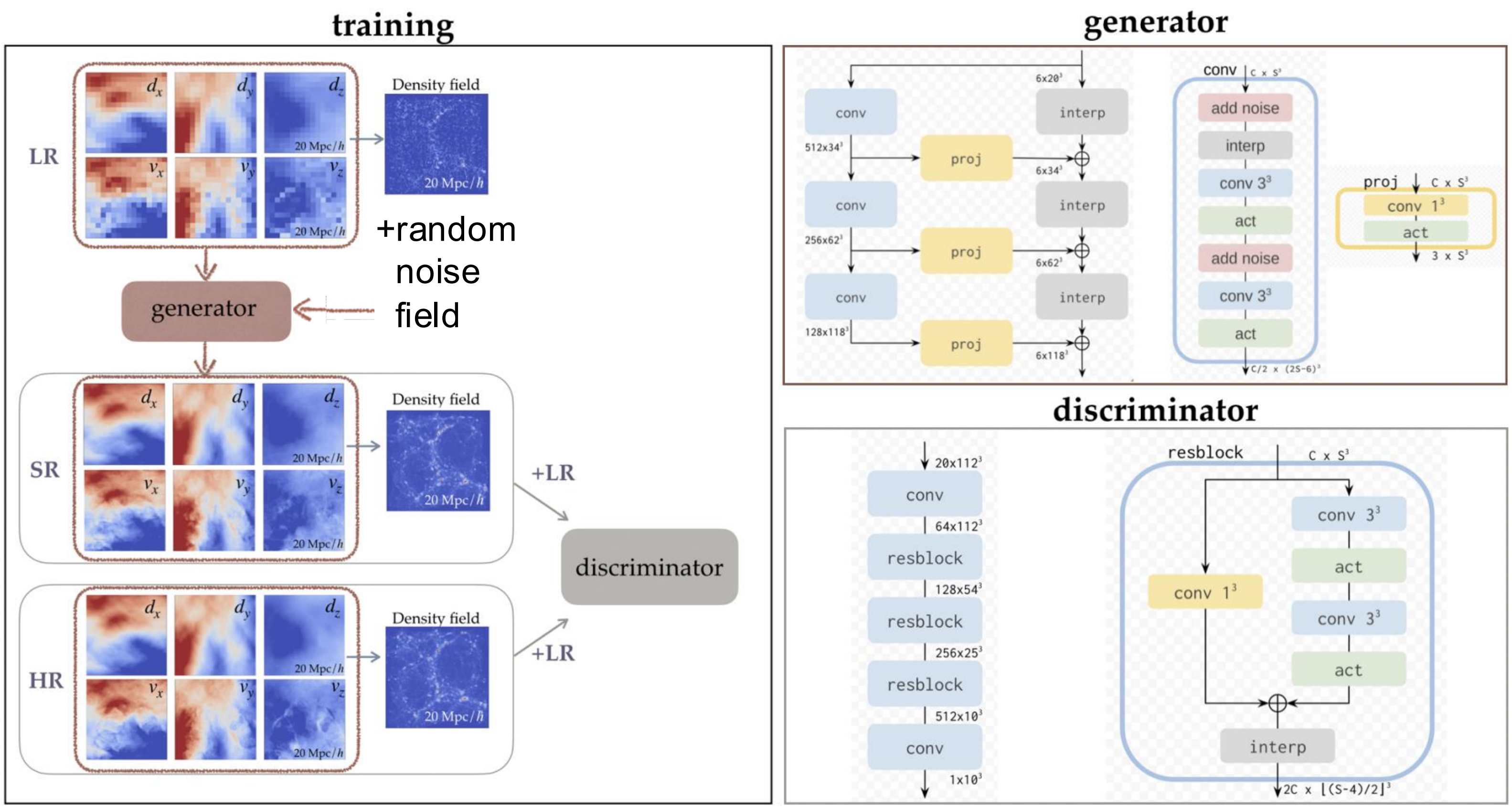
aim to spend roughly equal time on each

Super-resolution training: 7 low res fields + random noise → generator network

LR=low resolution simulation

SR=super-resolution simulation

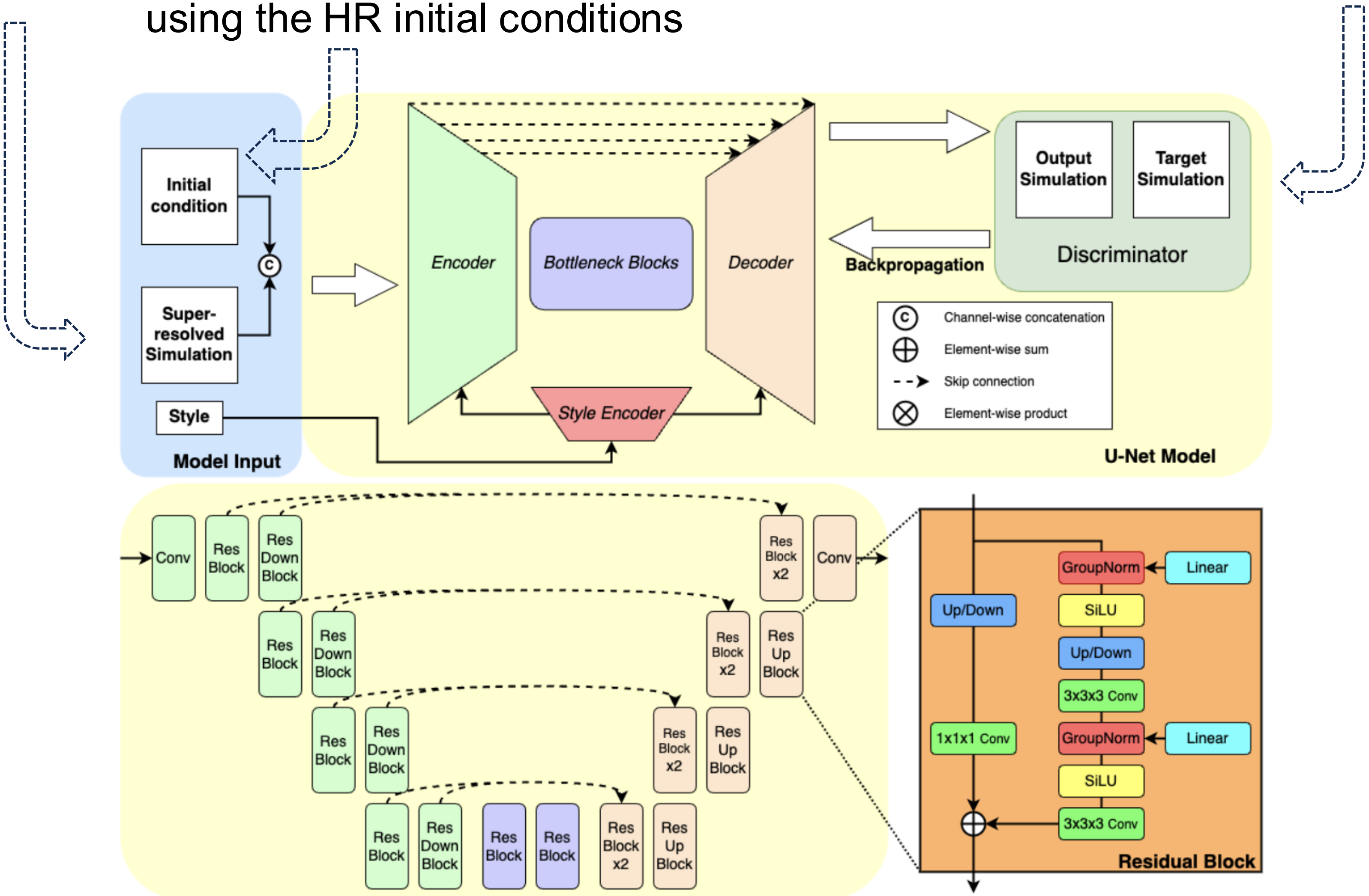
HR=high-resolution simulation



+random noise field

(From Ni et al. , arXiv:2105.01016 - this is for dark matter only)

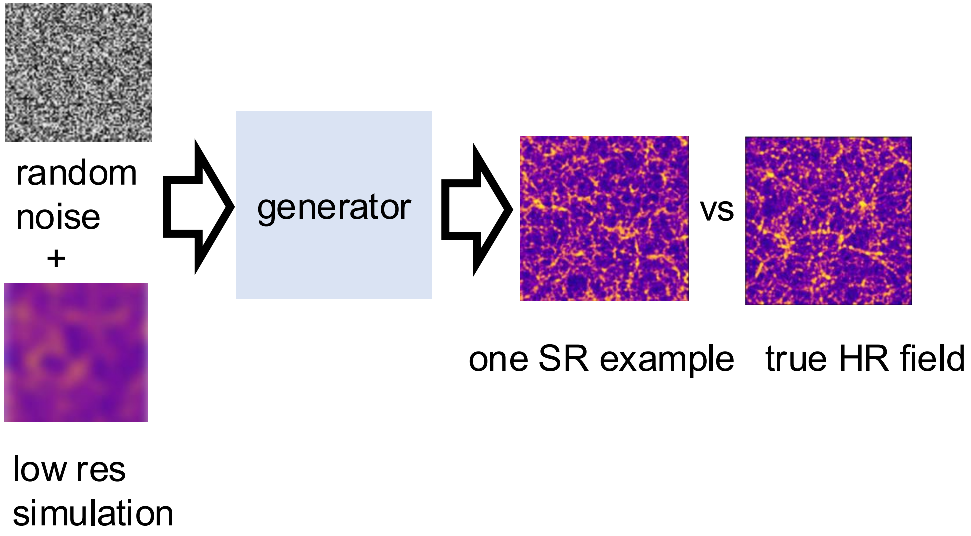
Emulator adds an additional neural network that takes as input an SR simulation (with random small-scale structures) learns how to change it into the target simulation using the HR initial conditions



Zhang+ 2025a

What is the difference between super-resolution **generator** and super-resolution **emulator**?

SR **generator** can produce a field statistically the same as the true field but the SR **emulator** can produce one that is identical to the true field:

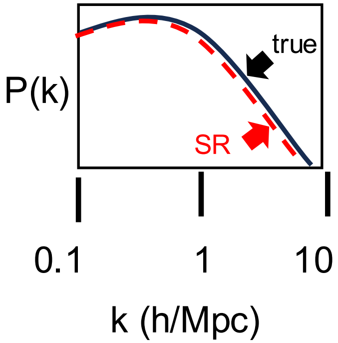


random noise
+
low res simulation

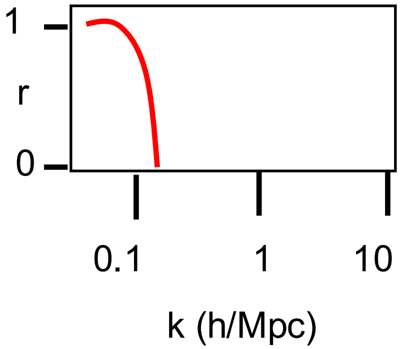
generator

one SR example vs true HR field

Power spectrum

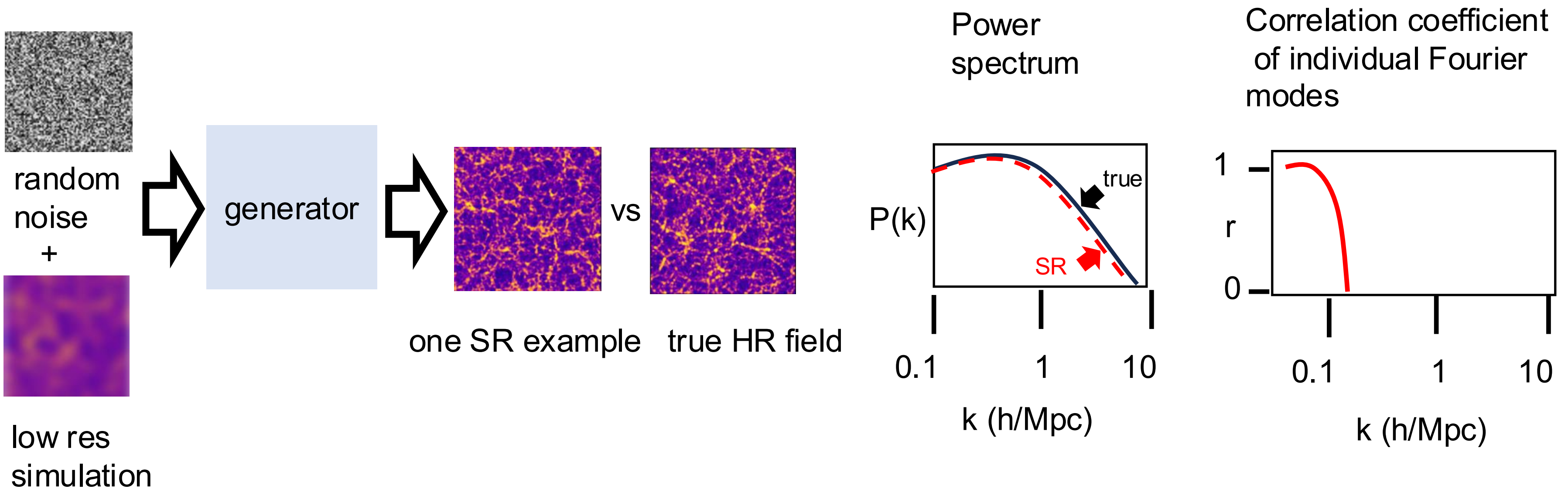


Correlation coefficient of individual Fourier modes



What is the difference between super-resolution **generator** and super-resolution **emulator**?

SR **generator** can produce a field statistically the same as the true field but the SR **emulator** can produce one that is identical to the true field:



random noise

+

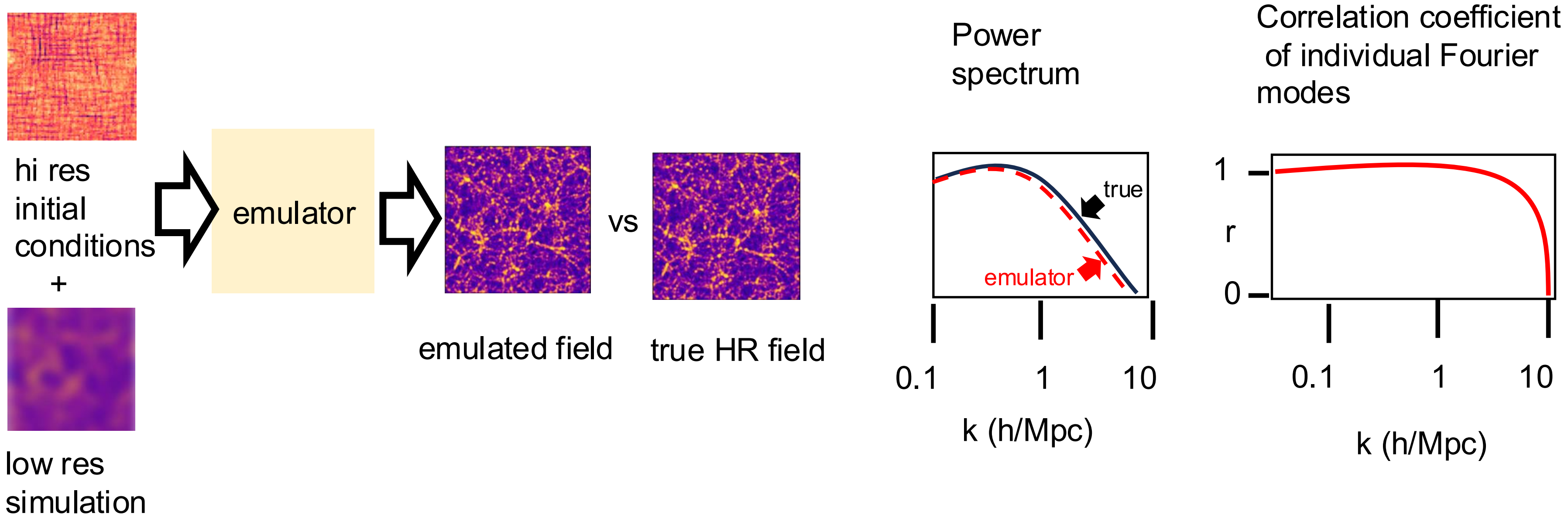
low res simulation

generator

one SR example

vs

true HR field



hi res initial conditions

+

low res simulation

emulator

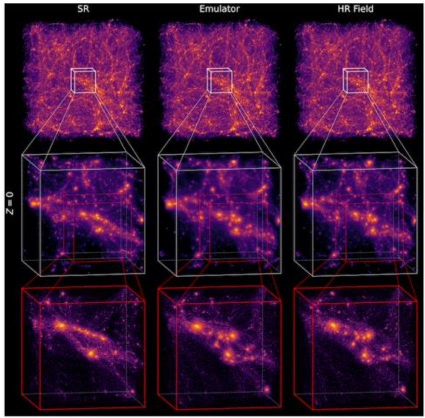
emulated field

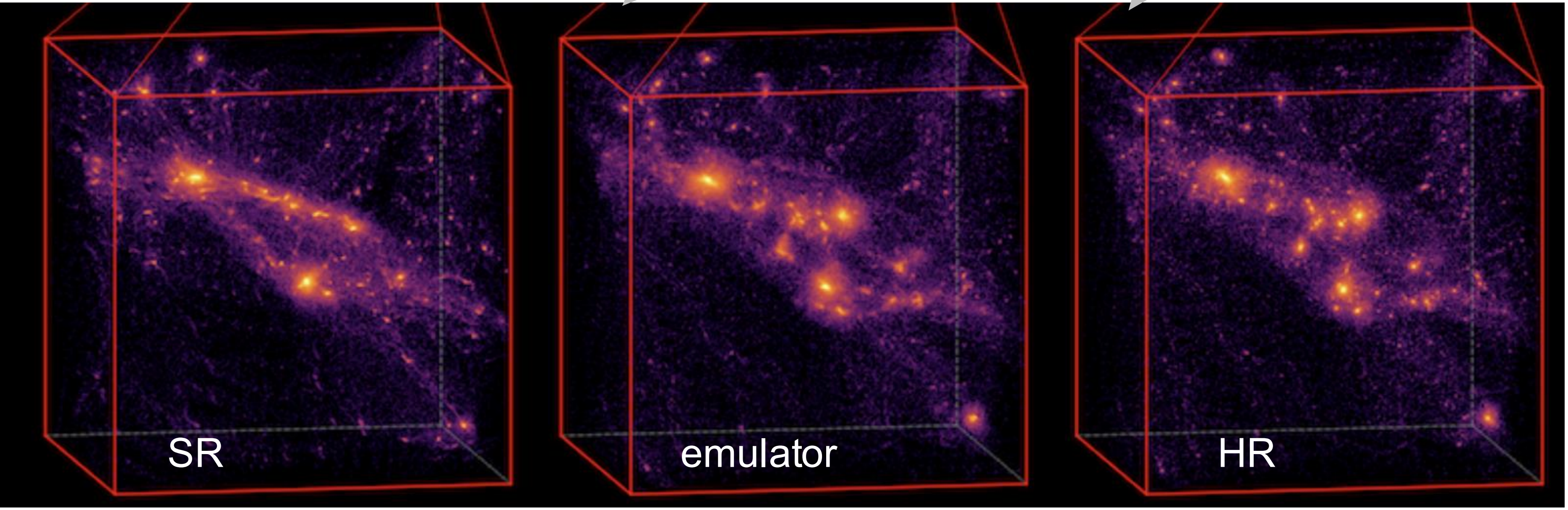
vs

true HR field

Emulator
(Zhang+ 2025)

- emulator is 10,000x faster than HR)
- dark matter only in this work
- emulator output has same format (particles) as full simulation (HR) so can run halo, subhalo finders etc

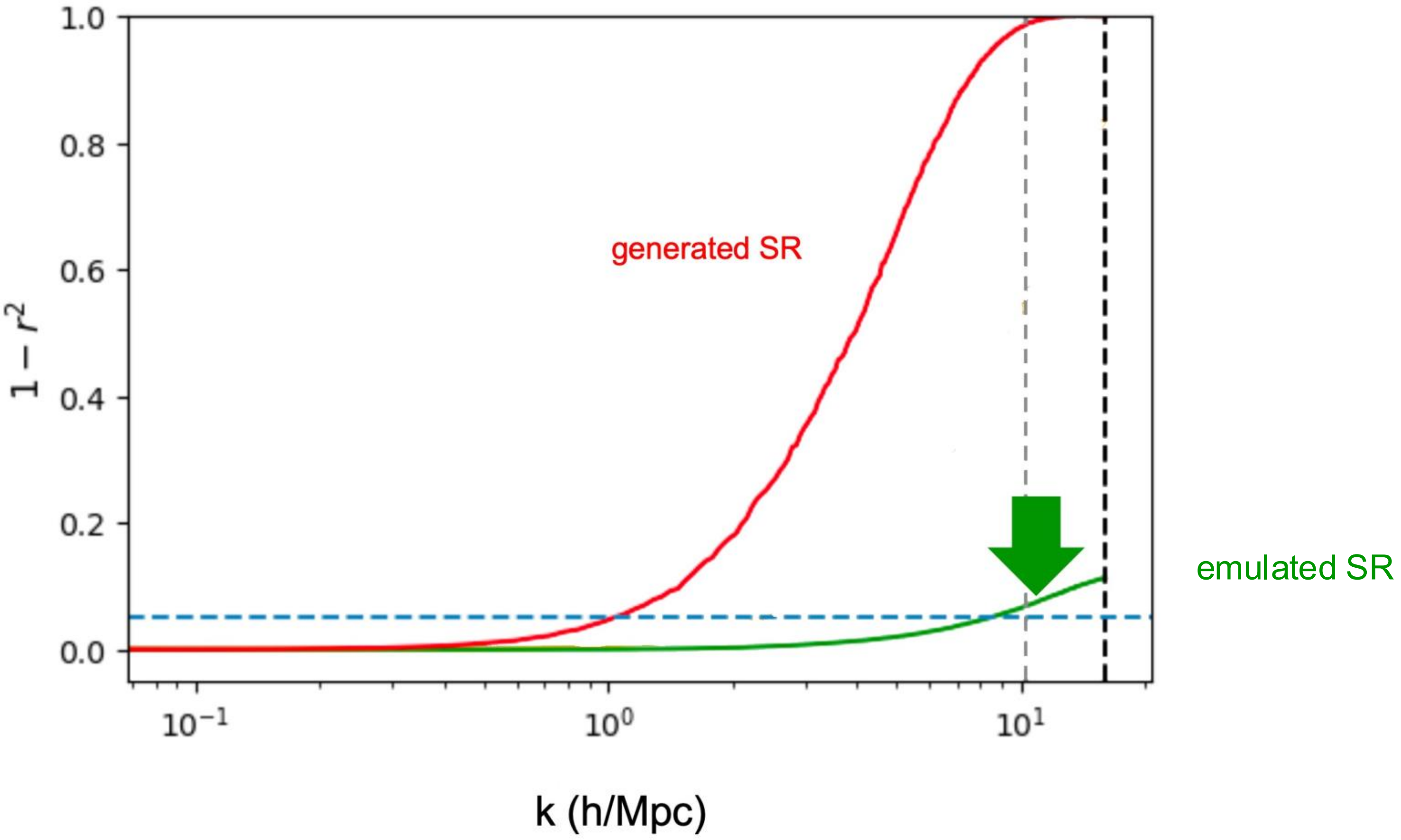




“generator”

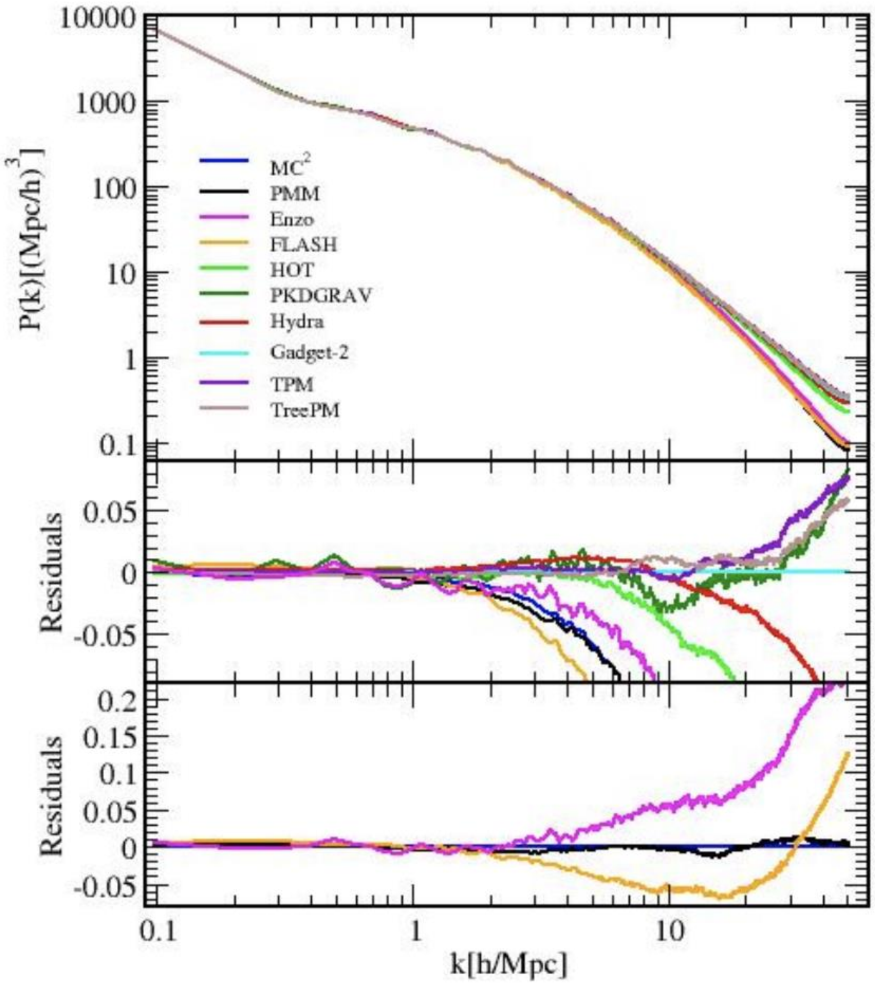
⬅ 10 Mpc/h ➡

Coherence of individual Fourier modes in SR and HR has 5% error at k=10 h/Mpc:

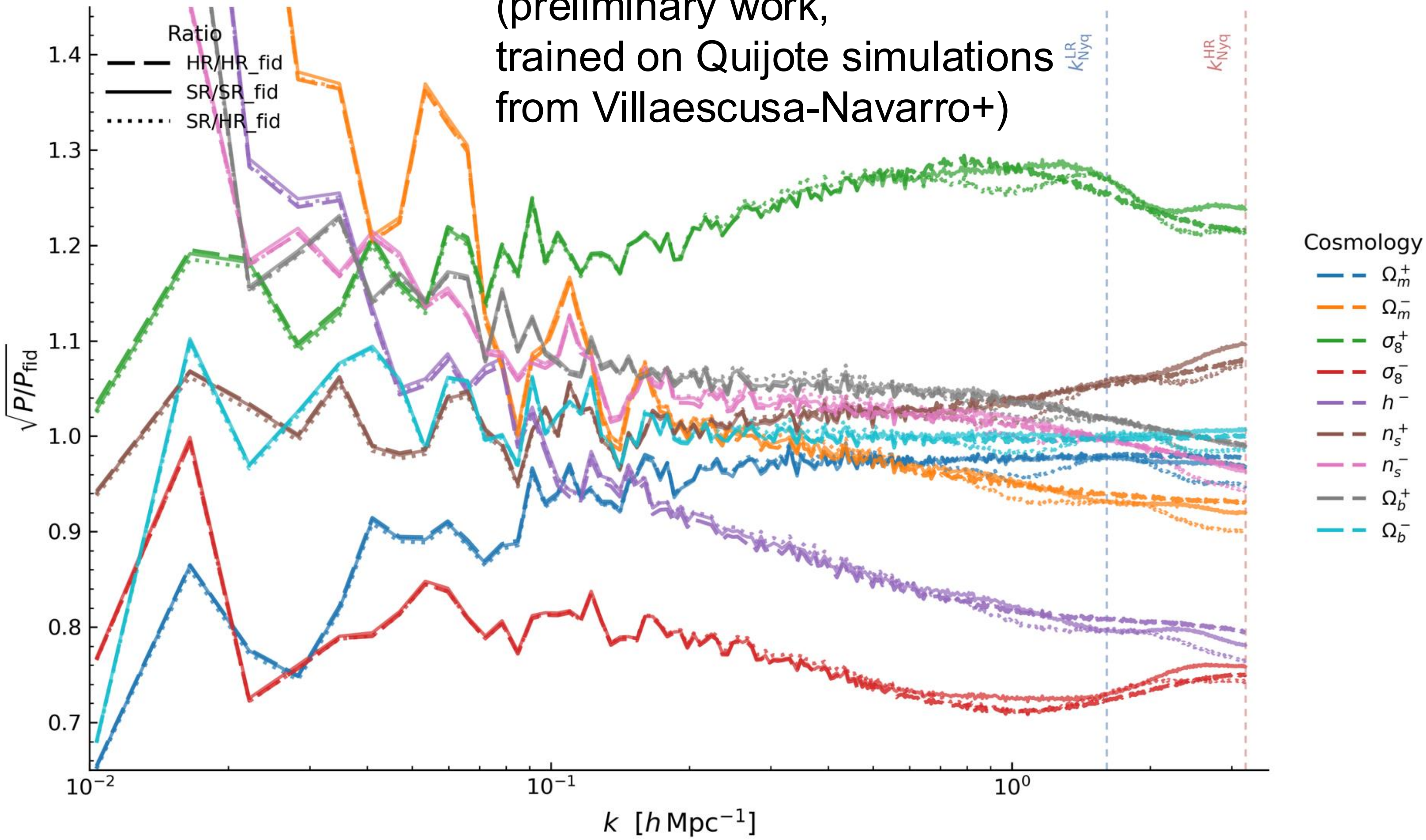


The difference between the emulator and full simulation power spectrum is **as good as the difference between simulation codes:**

power spectrum error in N body code comparison project (Heitmann+ 2008):



Can run different cosmologies with one trained model:



(preliminary work,
trained on Quijote simulations
from Villaescusa-Navarro+)

e.g.

Ω_M=0.4

Ω_M=0.2

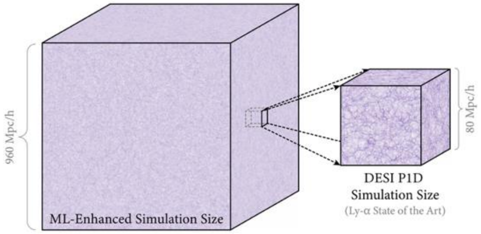
Lines are $P(k)/P_{\text{fiducial }\Lambda\text{CDM}}$ for N-body simulation (solid) and SR (dashed)

Our published work so far is for dark matter (N-body) SR emulation

– what about hydrodynamics?

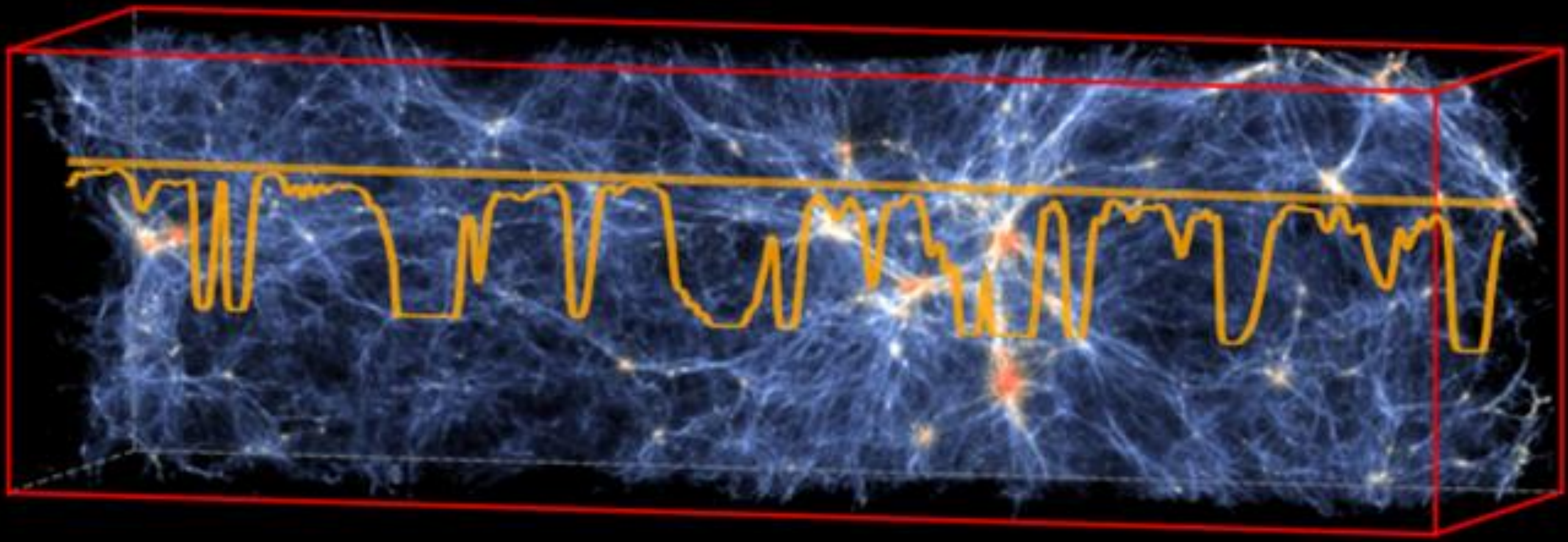
We start with the intergalactic medium – the easiest to simulate.

(see also work at LBNL by Jacobus et al. 2023, 2025



)

The Lyman-alpha forest maps the density field along the line of sight to a quasar :



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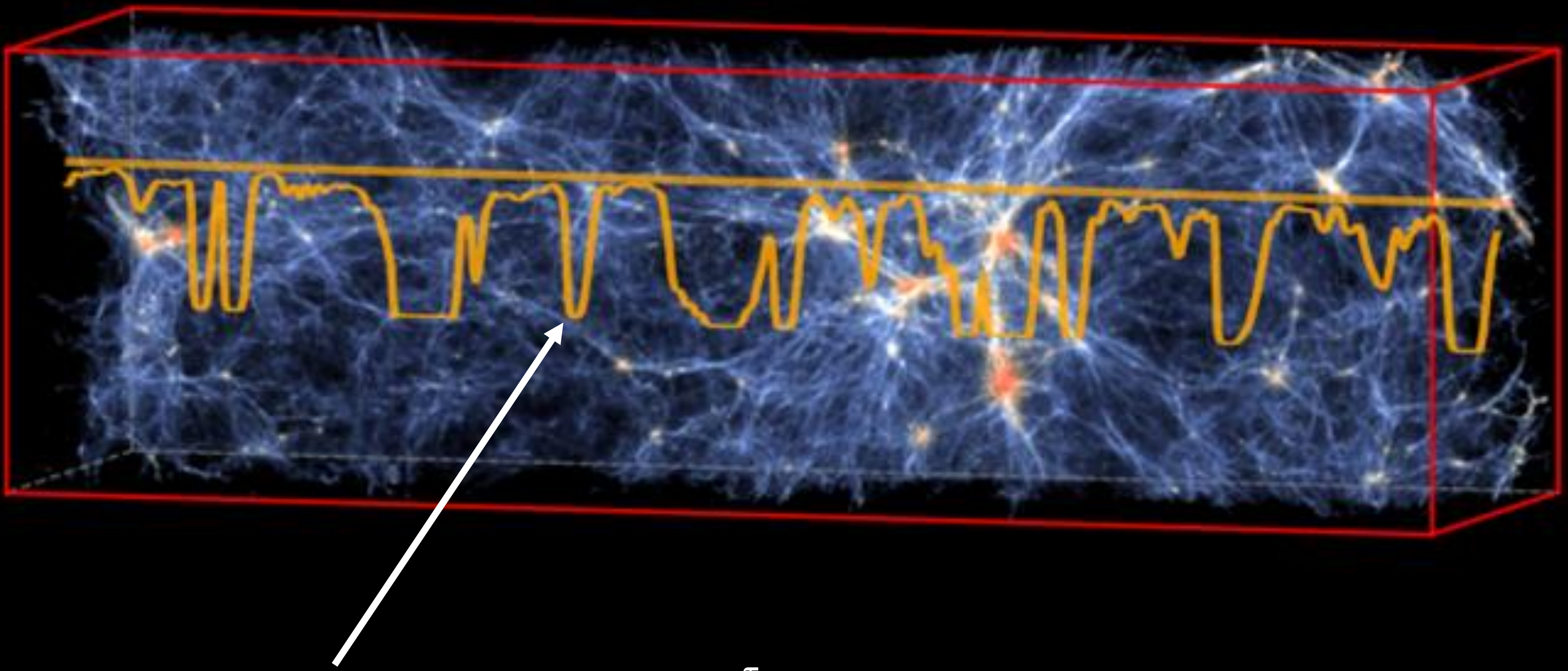
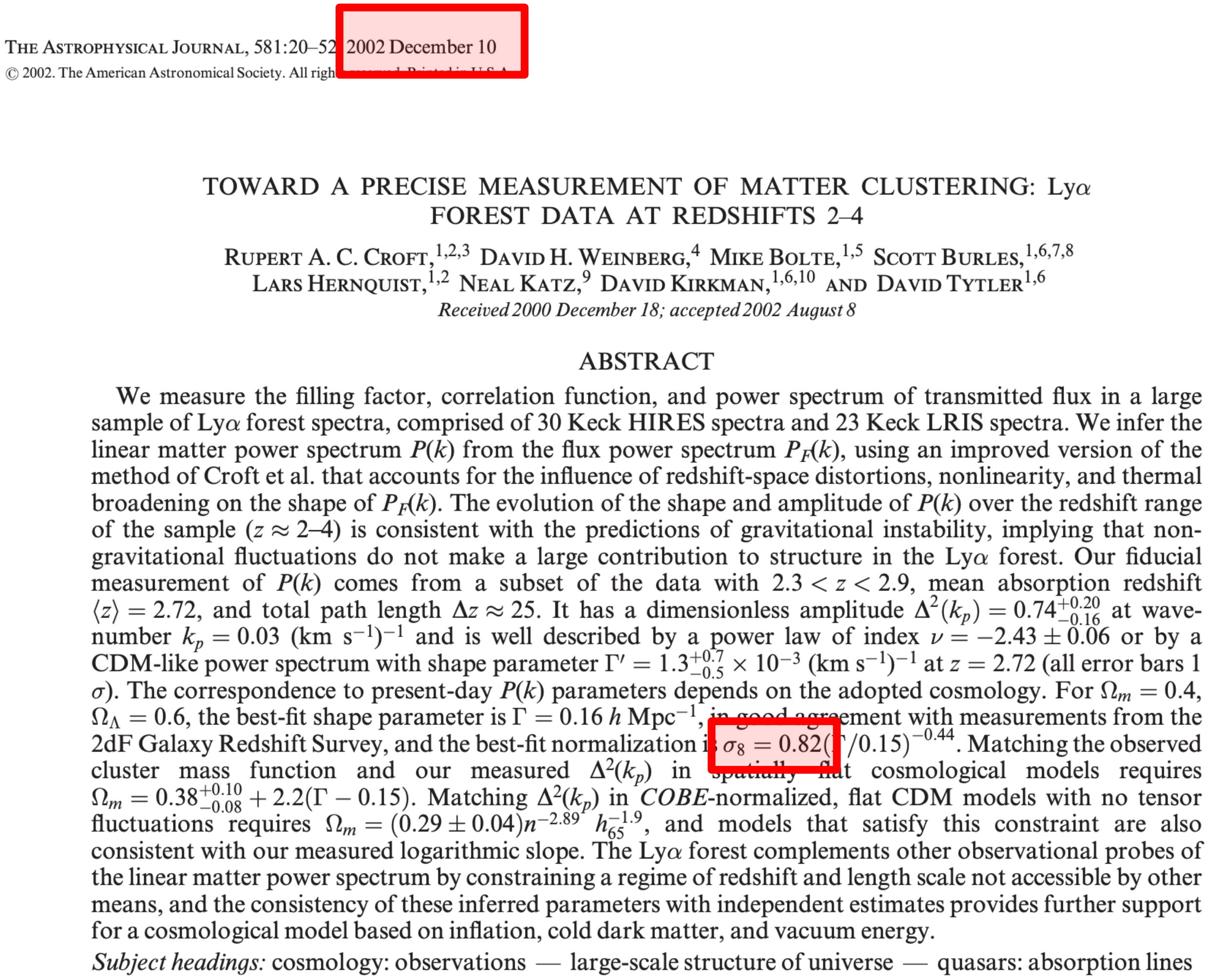


observed flux, F in a spectrum is $F=e^{-\tau}$, where τ n_{HI} (Gunn and Peterson 1965)



THE ASTROPHYSICAL JOURNAL, 581:20–52, 2002 December 10

TOWARD A PRECISE MEASUREMENT OF MATTER CLUSTERING: Lyα FOREST DATA AT REDSHIFTS 2–4

RUPERT A. C. CROFT,[1,2,3] DAVID H. WEINBERG,[4] MIKE BOLTE,[1,5] SCOTT BURLES,[1,6,7,8]
LARS HERNQUIST,[1,2] NEAL KATZ,[9] DAVID KIRKMAN,[1,6,10] AND DAVID TYTLER[1,6]

Received 2000 December 18; accepted 2002 August 8

ABSTRACT

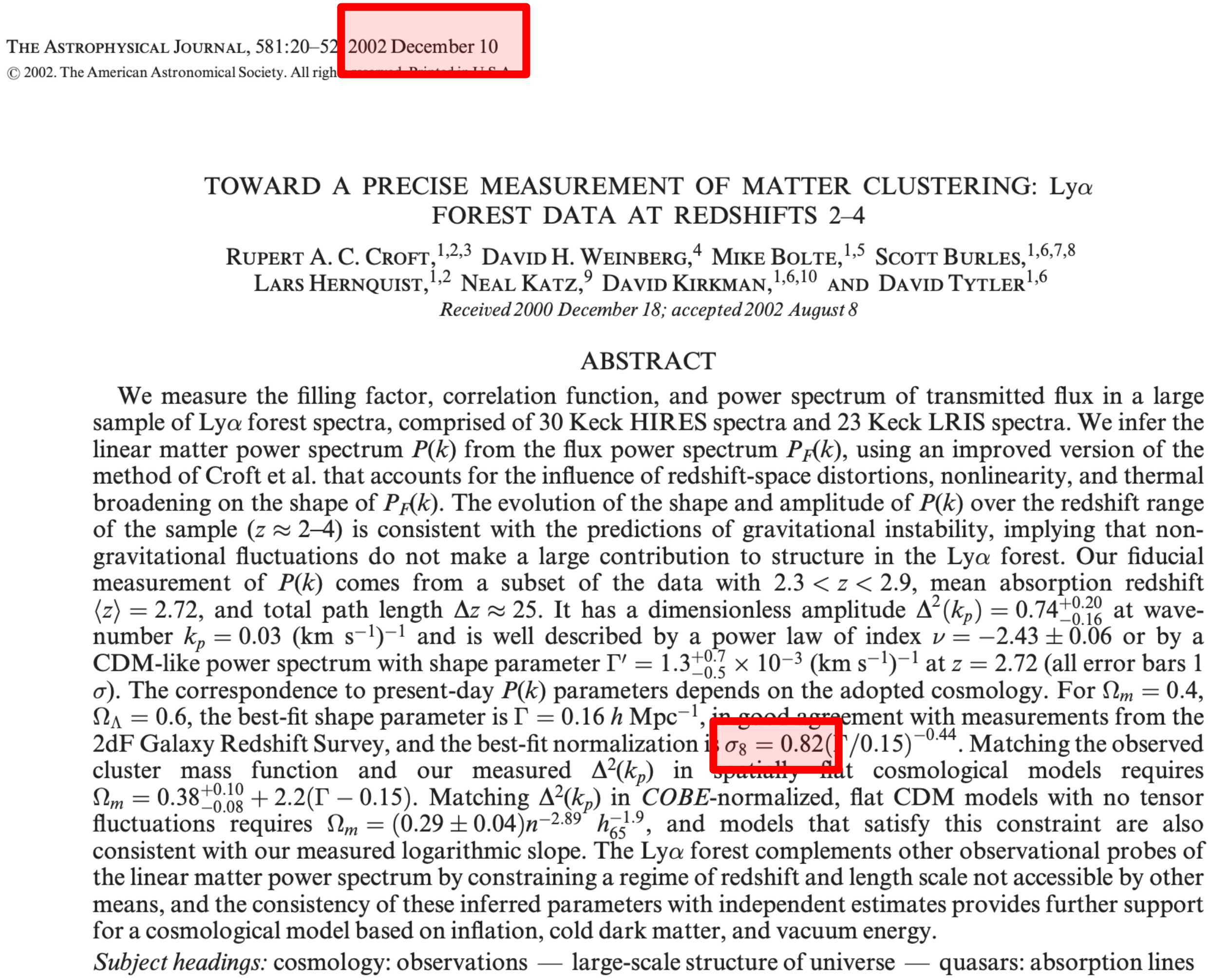
We measure the filling factor, correlation function, and power spectrum of transmitted flux in a large sample of Lyα forest spectra, comprised of 30 Keck HIRES spectra and 23 Keck LRIS spectra. We infer the linear matter power spectrum $P(k)$ from the flux power spectrum $P_F(k)$, using an improved version of the method of Croft et al. that accounts for the influence of redshift-space distortions, nonlinearity, and thermal broadening on the shape of $P_F(k)$. The evolution of the shape and amplitude of $P(k)$ over the redshift range of the sample ($z \approx 2$–4) is consistent with the predictions of gravitational instability, implying that nongravitational fluctuations do not make a large contribution to structure in the Lyα forest. Our fiducial measurement of $P(k)$ comes from a subset of the data with $2.3 < z < 2.9$, mean absorption redshift $\langle z \rangle = 2.72$, and total path length $\Delta z \approx 25$. It has a dimensionless amplitude $\Delta^2(k_p) = 0.74^{+0.20}_{-0.16}$ at wavenumber $k_p = 0.03\ (\mathrm{km\ s^{-1}})^{-1}$ and is well described by a power law of index $\nu = -2.43 \pm 0.06$ or by a CDM-like power spectrum with shape parameter $\Gamma' = 1.3^{+0.7}_{-0.5} \times 10^{-3}\ (\mathrm{km\ s^{-1}})^{-1}$ at $z = 2.72$ (all error bars 1 σ). The correspondence to present-day $P(k)$ parameters depends on the adopted cosmology. For $\Omega_m = 0.4$, $\Omega_\Lambda = 0.6$, the best-fit shape parameter is $\Gamma = 0.16\ h\ \mathrm{Mpc}^{-1}$, in good agreement with measurements from the 2dF Galaxy Redshift Survey, and the best-fit normalization is $\sigma_8 = 0.82(\Gamma/0.15)^{-0.44}$. Matching the observed cluster mass function and our measured $\Delta^2(k_p)$ in spatially flat cosmological models requires $\Omega_m = 0.38^{+0.10}_{-0.08} + 2.2(\Gamma - 0.15)$. Matching $\Delta^2(k_p)$ in *COBE*-normalized, flat CDM models with no tensor fluctuations requires $\Omega_m = (0.29 \pm 0.04)n^{-2.89}\ h_{65}^{-1.9}$, and models that satisfy this constraint are also consistent with our measured logarithmic slope. The Lyα forest complements other observational probes of the linear matter power spectrum by constraining a regime of redshift and length scale not accessible by other means, and the consistency of these inferred parameters with independent estimates provides further support for a cosmological model based on inflation, cold dark matter, and vacuum energy.

Subject headings: cosmology: observations — large-scale structure of universe — quasars: absorption lines

The Lyman-alpha forest has been used as a cosmological tool for since 1998

$\sigma_8 = 0.82 \pm 0.08$

The Lyman-alpha forest has been used as a cosmological tool for since 1998



The Astrophysical Journal, 581:20–52, 2002 December 10

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Rupert A. C. Croft,[1,2,3] David H. Weinberg,[4] Mike Bolte,[1,5] Scott Burles,[1,6,7,8]
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ABSTRACT

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Subject headings: cosmology: observations — large-scale structure of universe — quasars: absorption lines

σ_8=0.82±0.08

compare to:

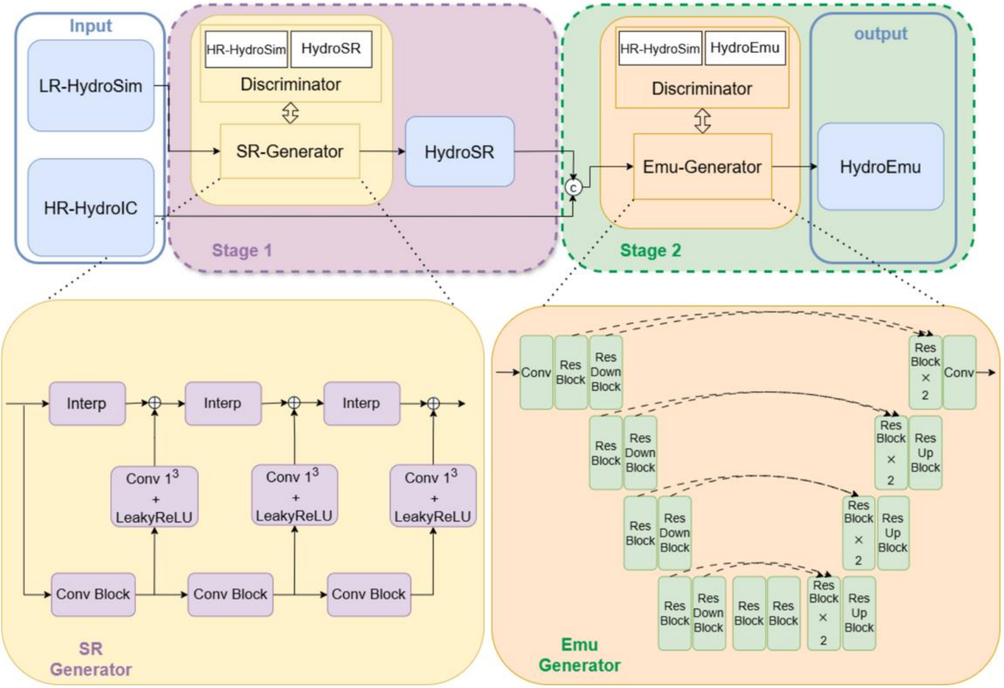
DESI 2024 VII: Cosmological Constraints from the Full-Shape Modeling of Clustering Measurements (Adame et. al 2024)

σ_8=0.8121±0.0053 (includes CMB)

We train our hydrodynamics emulator (HydroEmu) using MP-Gadget SPH simulations :

new input channels:

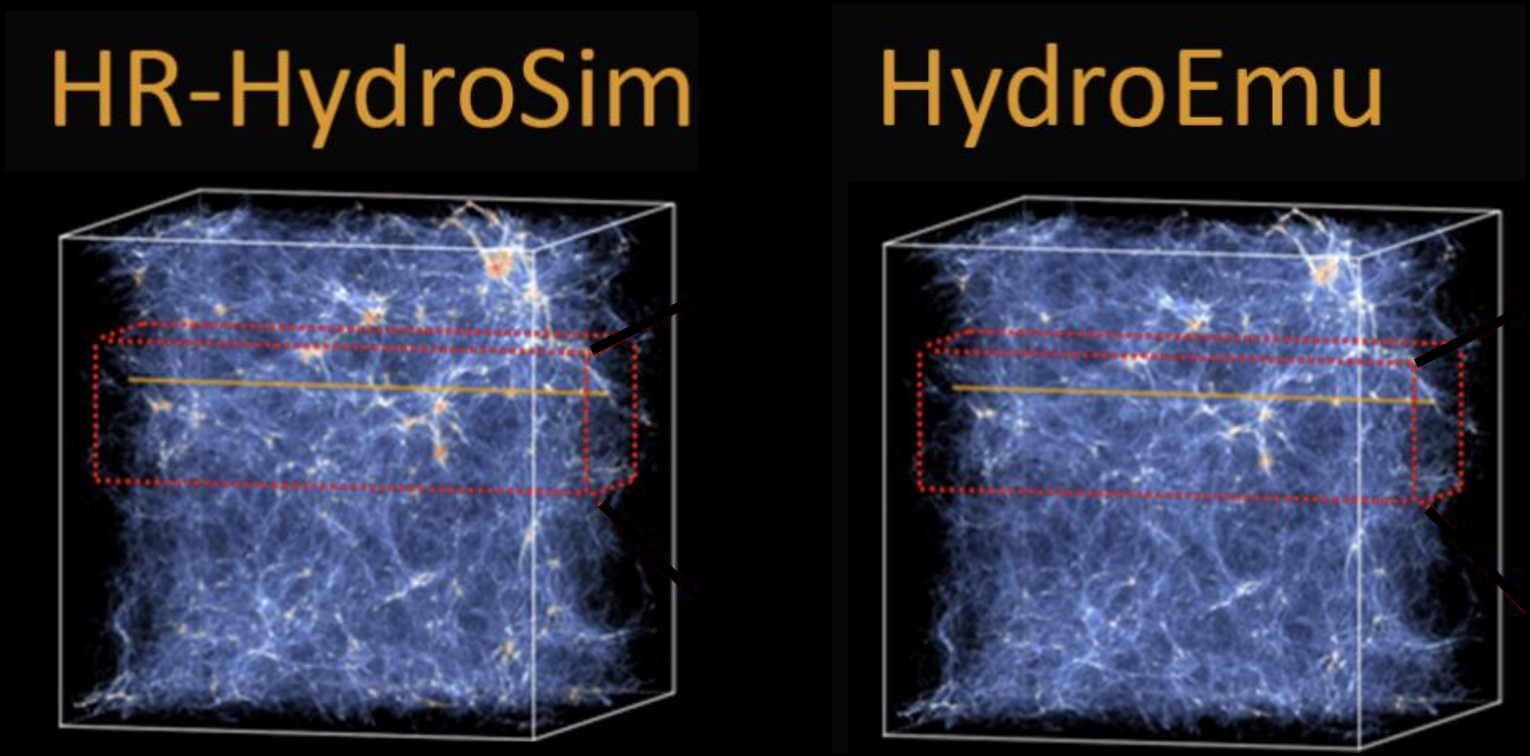
gas properties (displacement, density, velocity, temperature)



emulator output contains gas properties

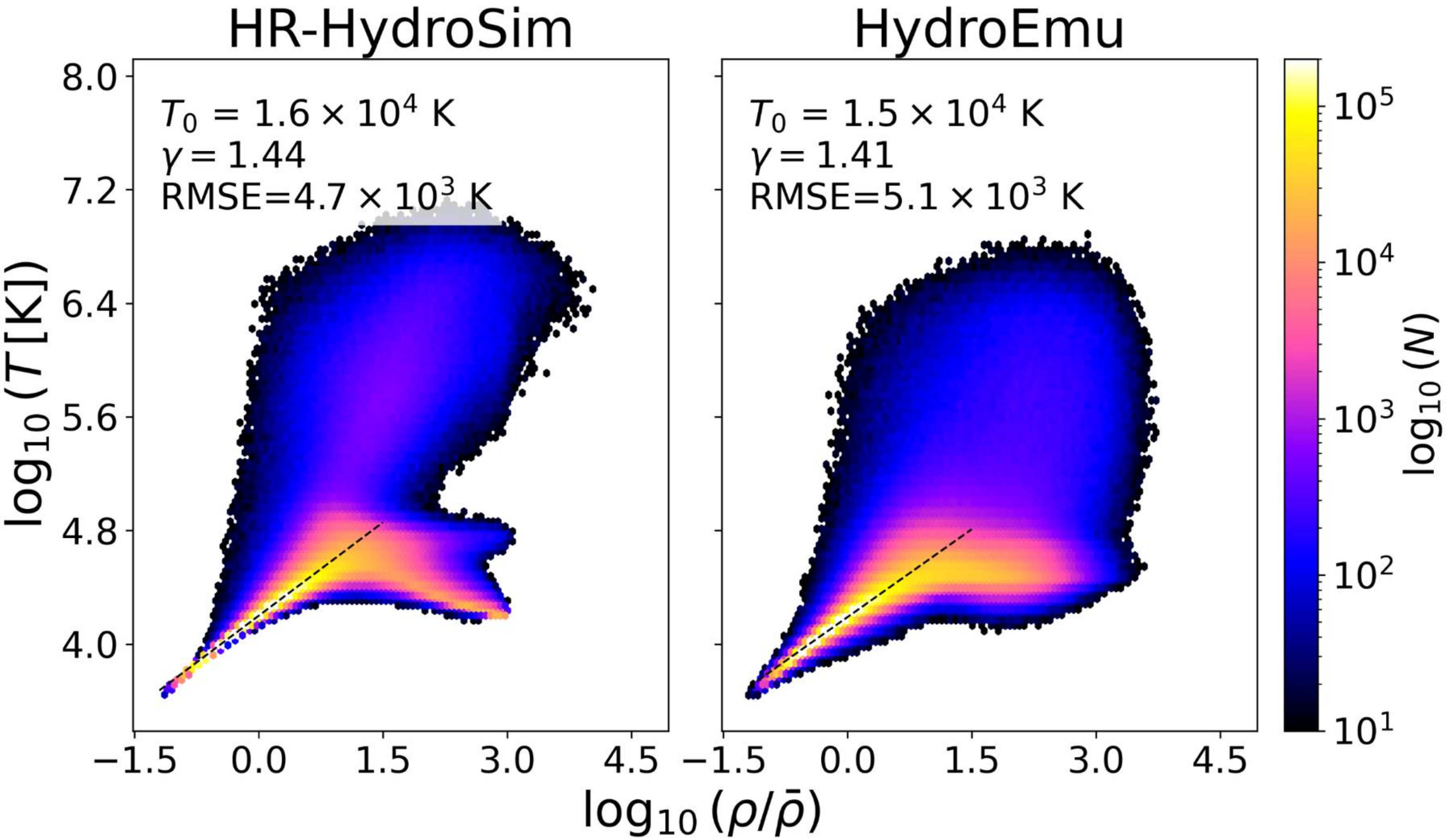
From Hafezianzadeh et al. (arXiv:2507.16189)

The gas distribution in the true SPH simulation and emulator (HydroEmu) is similar :

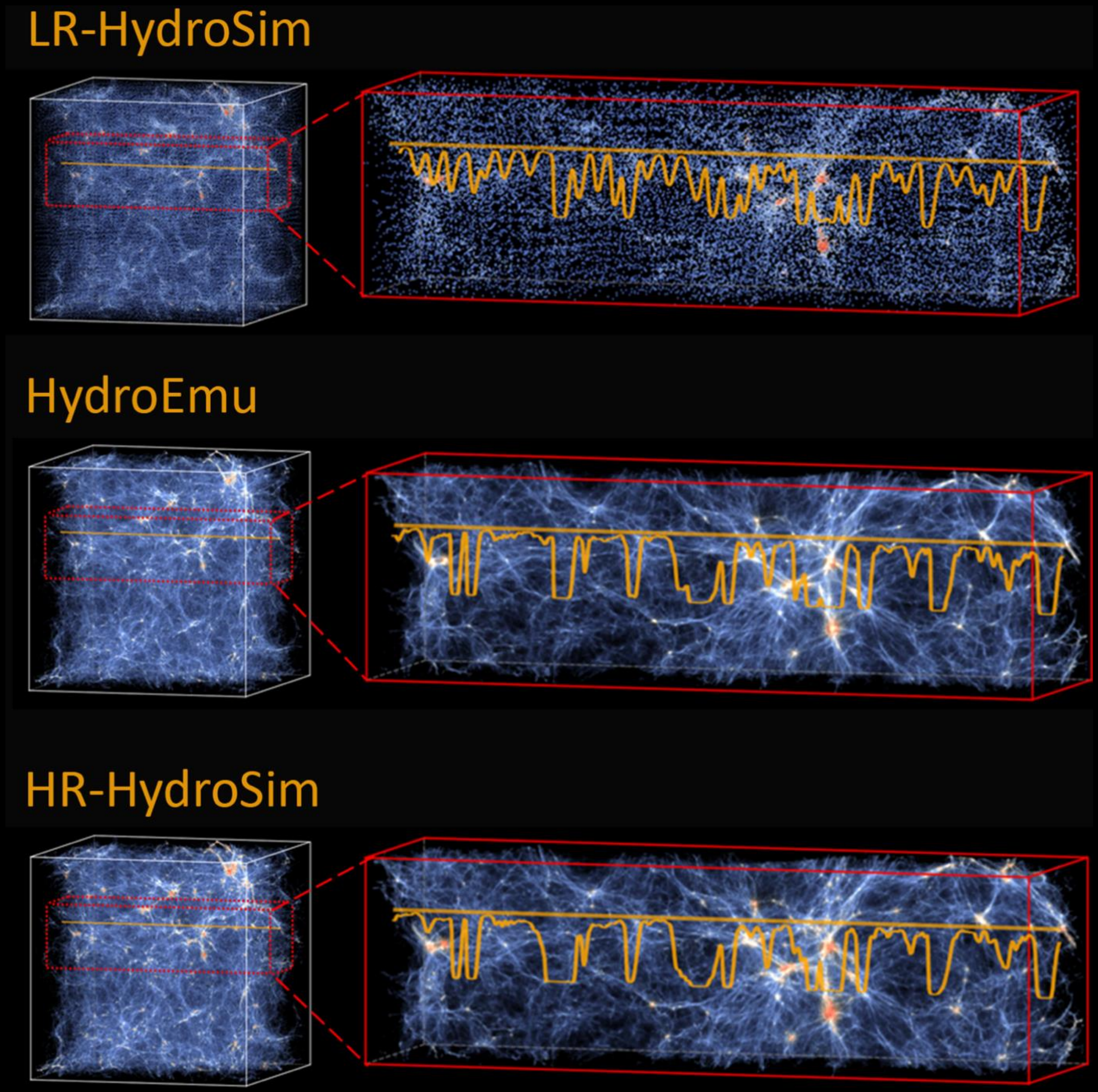


We pick sightlines — for Lyman-alpha spectra

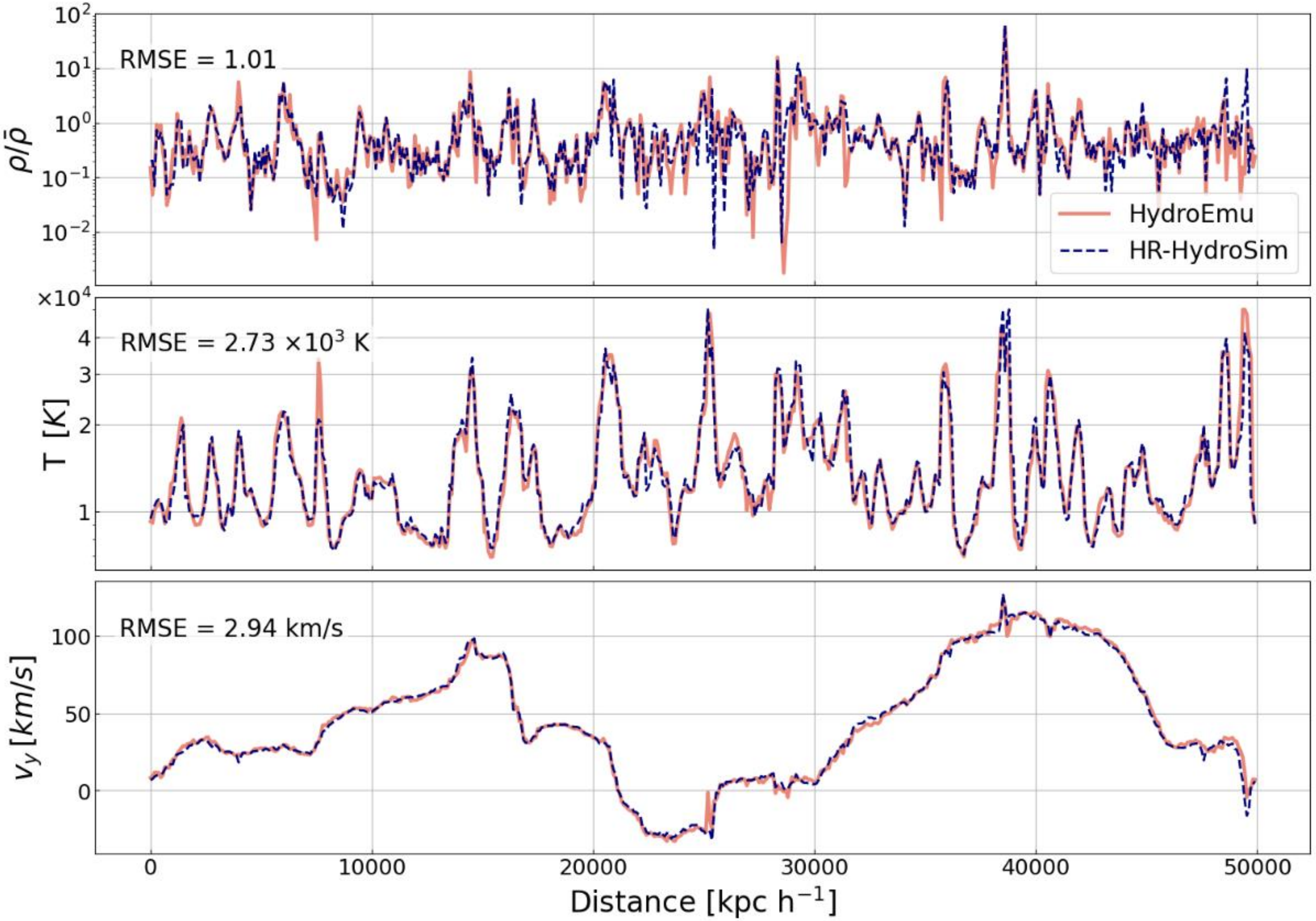
The emulator shows the same power-law temperature-density relation as the true simulation:



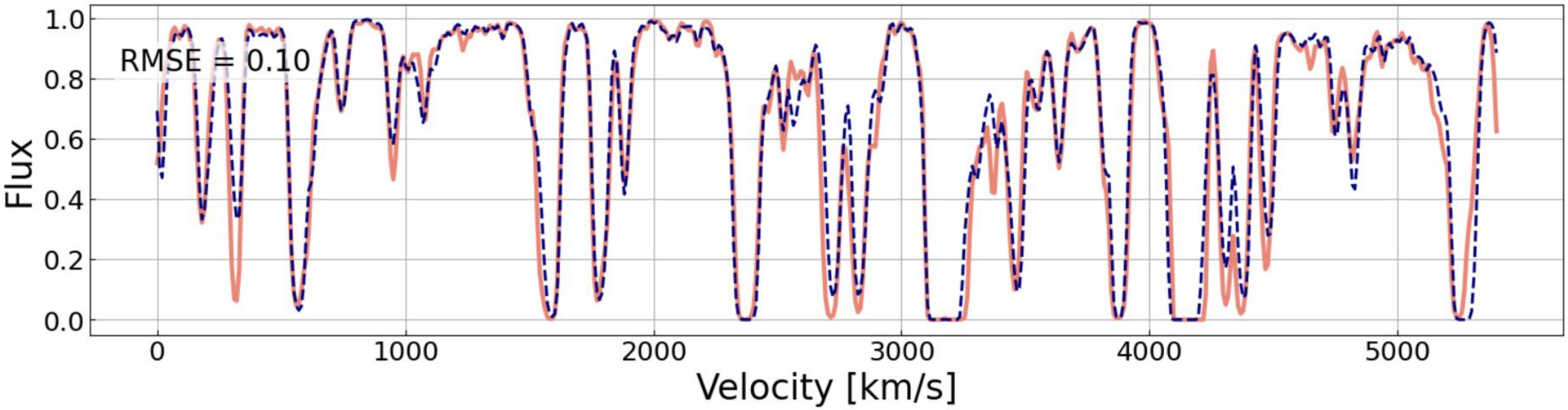
Lyman-alpha spectra from the low-res simulation are no good, but the emulator works well:



The density, temperature and velocity fields of the emulator and true simulation match closely on the 100 kpc gas pressure smoothing scale of the intergalactic medium



Lyman-alpha spectra from the true SPH simulation and the emulator are very close:



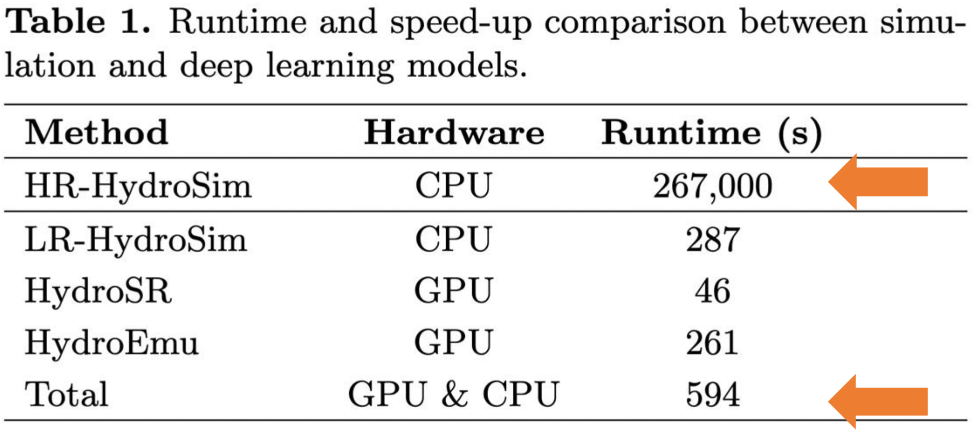


Table 1. Runtime and speed-up comparison between simulation and deep learning models.

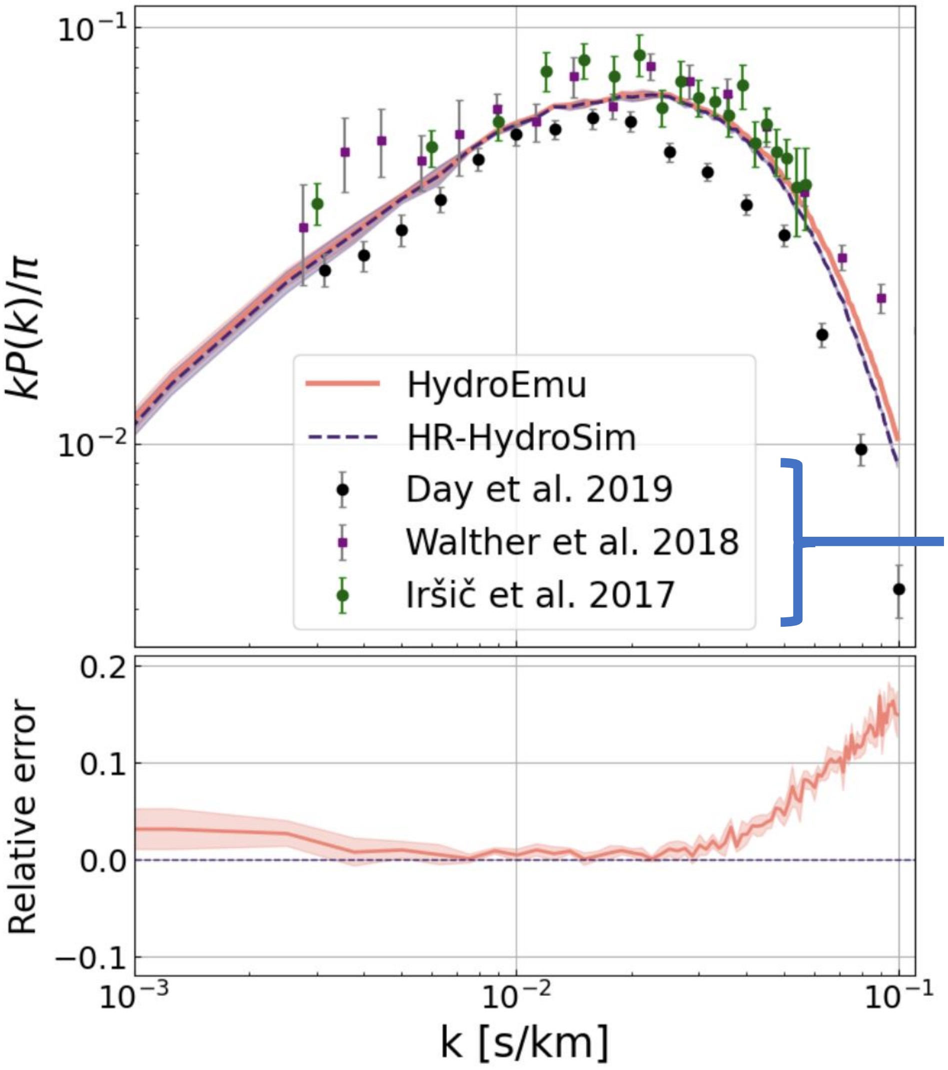
Method	Hardware	Runtime (s)
HR-HydroSim	CPU	267,000
LR-HydroSim	CPU	287
HydroSR	GPU	46
HydroEmu	GPU	261
Total	GPU & CPU	594

Emulator (including LR-HydroSim component) is

450 times faster

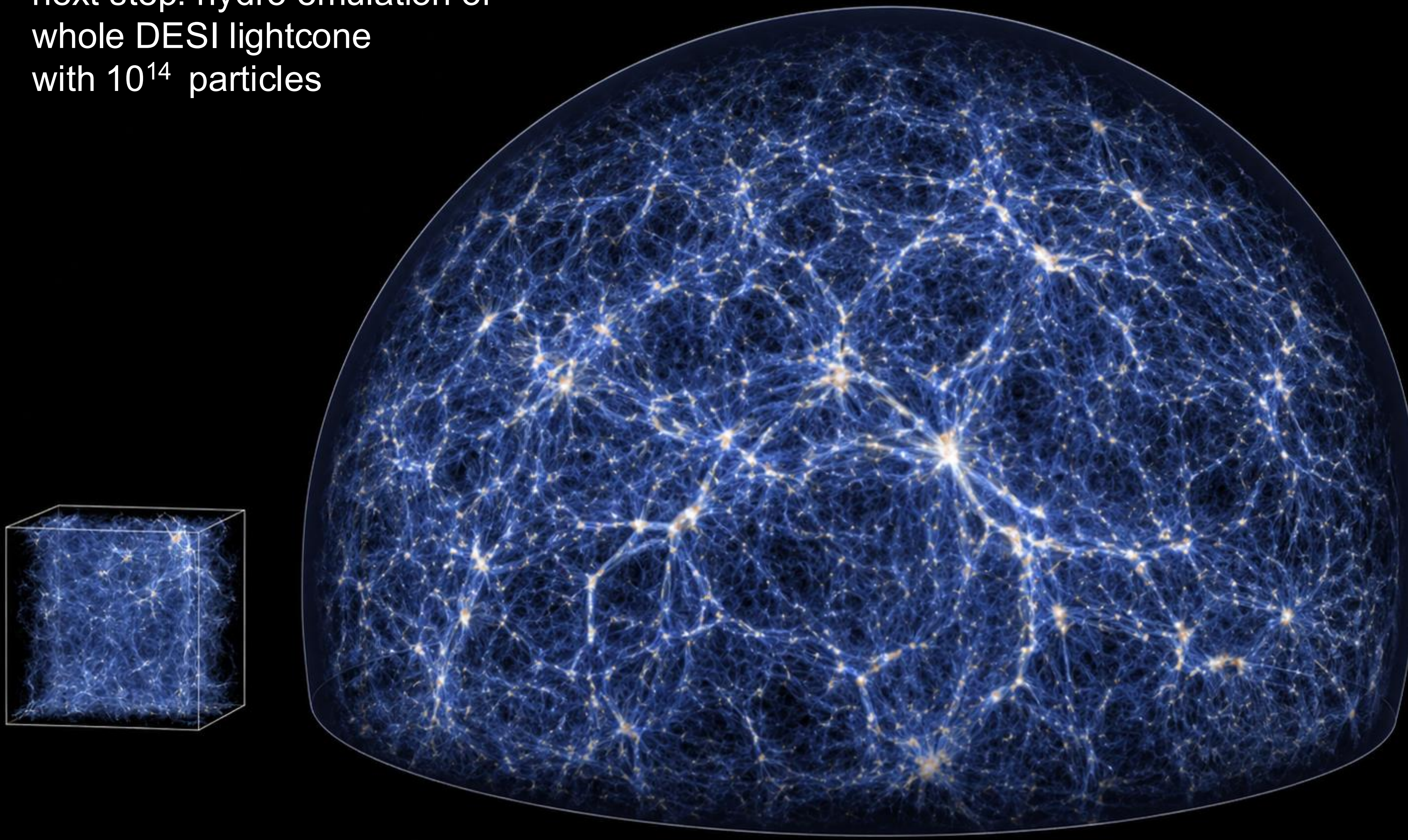
than true HR HydroSim!

The statistics of the flux power spectrum of the emulator and true simulation agree to a few percent on relevant scales:



observational data

next step: hydro emulation of
whole DESI lightcone
with 10^{14} particles



What will the role of AI be in astronomy?

Will AI replace astronomers completely?

arXiv > astro-ph > arXiv:2504.03424

Astrophysics > Instrumentation and Methods for Astrophysics

[Submitted on 4 Apr 2025]

The AI Cosmologist I: An Agentic System for Automated Data Analysis

Adam Moss

We present the AI Cosmologist, an agentic system designed to automate cosmological/astronomical data analysis and machine learning research workflows. This implements a complete pipeline from idea generation to experimental evaluation and research dissemination, mimicking the scientific process typically performed by human researchers. The system employs specialized agents for planning, coding, execution, analysis, and synthesis that work together to develop novel approaches. Unlike traditional auto machine-learning systems, the AI Cosmologist generates diverse implementation strategies, writes complete code, handles execution errors, analyzes results, and synthesizes new approaches based on experimental outcomes. We demonstrate the AI Cosmologist capabilities across several machine learning tasks, showing how it can successfully explore solution spaces, iterate based on experimental results, and combine successful elements from different approaches. Our results indicate that agentic systems can automate portions of the research process, potentially accelerating scientific discovery. The code and experimental data used in this paper are available on GitHub at this https URL. Example papers included in the appendix demonstrate the system's capability to autonomously produce complete scientific publications, starting from only the dataset and task description

Comments: 45 pages
Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); Astrophysics of Galaxies (astro-ph.GA); Artificial Intelligence (cs.AI); Data Analysis, Statistics and Probability (physics.data-an)
Cite as: arXiv:2504.03424 **[astro-ph.IM]**
(or arXiv:2504.03424v1 **[astro-ph.IM]** for this version)
https://doi.org/10.48550/arXiv.2504.03424

Moss 2025 arXiv:2504.03424

arXiv > cs > arXiv:2510.26887

Computer Science > Artificial Intelligence

[Submitted on 30 Oct 2025]

The Denario project: Deep knowledge AI agents for scientific discovery

Francisco Villaescusa-Navarro, Boris Bolliet, Pablo Villanueva-Domingo, Adrian E. Bayer, Aidan Acquah, Chetana Amancharla, Almog Barzilay-Siegal, Pablo Bermejo, Camille Bilodeau, Pablo Cárdenas Ramírez, Miles Cranmer, Urbano L. França, ChangHoon Hahn, Yan-Fei Jiang, Raul Jimenez, Jun-Young Lee, Antonio Lerario, Osman Mamun, Thomas Meier, Anupam A. Ojha, Pavlos Protopapas, Shimanto Roy, David N. Spergel, Pedro Tarancón-Álvarez, Ujjwal Tiwari, Matteo Viel, Digvijay Wadekar, Chi Wang, Bonny Y. Wang, Licong Xu, Yossi Yovel, Shuwen Yue, Wen-Han Zhou, Qiyao Zhu, Jiajun Zou, Íñigo Zubeldia

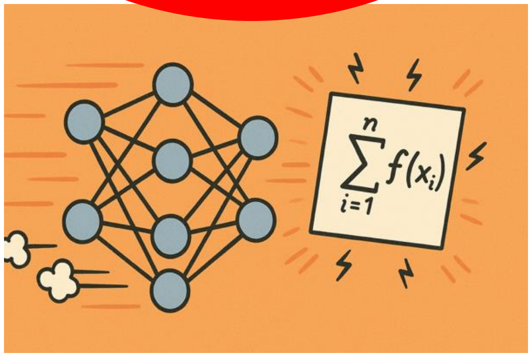
We present Denario, an AI multi-agent system designed to serve as a scientific research assistant. Denario can perform many different tasks, such as generating ideas, checking the literature, developing research plans, writing and executing code, making plots, and drafting and reviewing a scientific paper. The system has a modular architecture, allowing it to handle specific tasks, such as generating an idea, or carrying out end-to-end scientific analysis using Cmbagent as a deep-research backend. In this work, we describe in detail Denario and its modules, and illustrate its capabilities by presenting multiple AI-generated papers generated by it in many different scientific disciplines such as astrophysics, biology, biophysics, biomedical informatics, chemistry, material science, mathematical physics, medicine, neuroscience and planetary science. Denario also excels at combining ideas from different disciplines, and we illustrate this by showing a paper that applies methods from quantum physics and machine learning to astrophysical data. We report the evaluations performed on these papers by domain experts, who provided both numerical scores and review-like feedback. We then highlight the strengths, weaknesses, and limitations of the current system. Finally, we discuss the ethical implications of AI-driven research and reflect on how such technology relates to the philosophy of science. We publicly release the code at this https URL. A Denario demo can also be run directly on the web at this https URL, and the full app will be deployed on the cloud.

Villaescusa-Navarro et. al
arXiv:2510.26887

Now this:

or will it assist astronomers … ?

(do boring stuff)



(speed up calculations)

Cosmological simulations are a useful tool, but what does it take to run them? Imagine that you are a beginning researcher. You want to use simulations to study an astrophysics/cosmology problem but you need to

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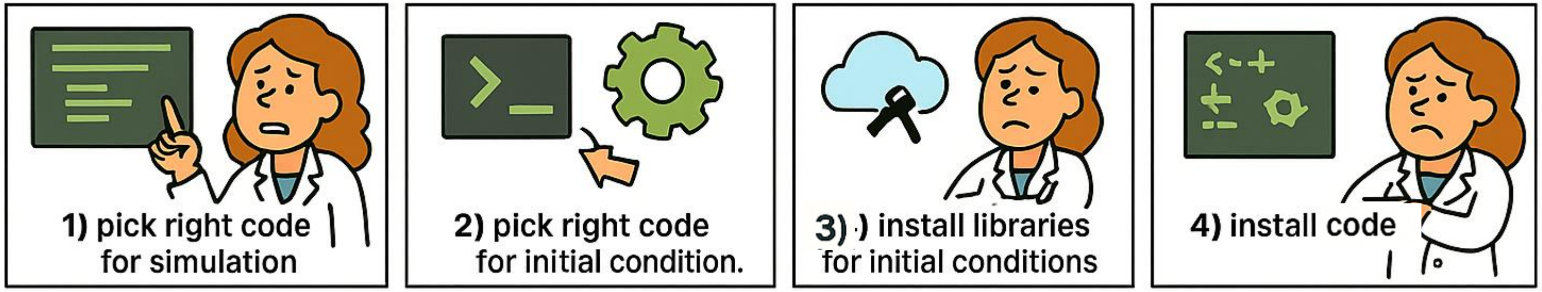

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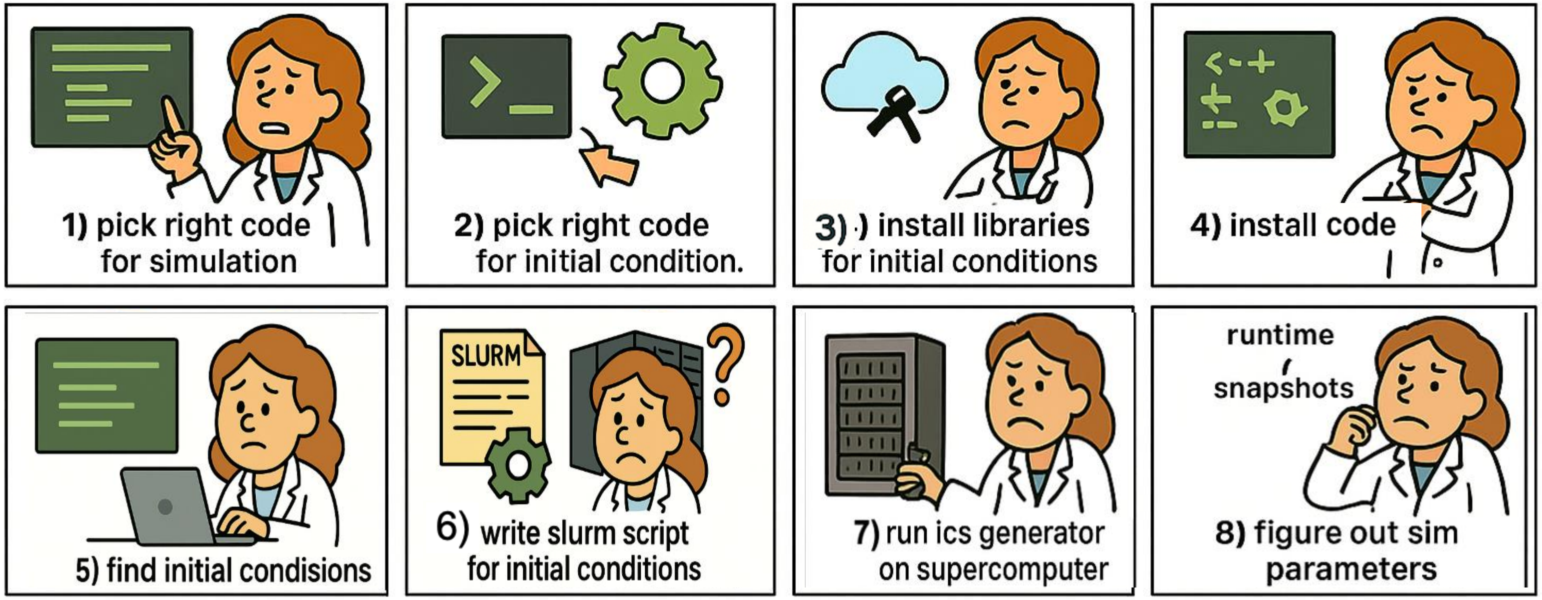

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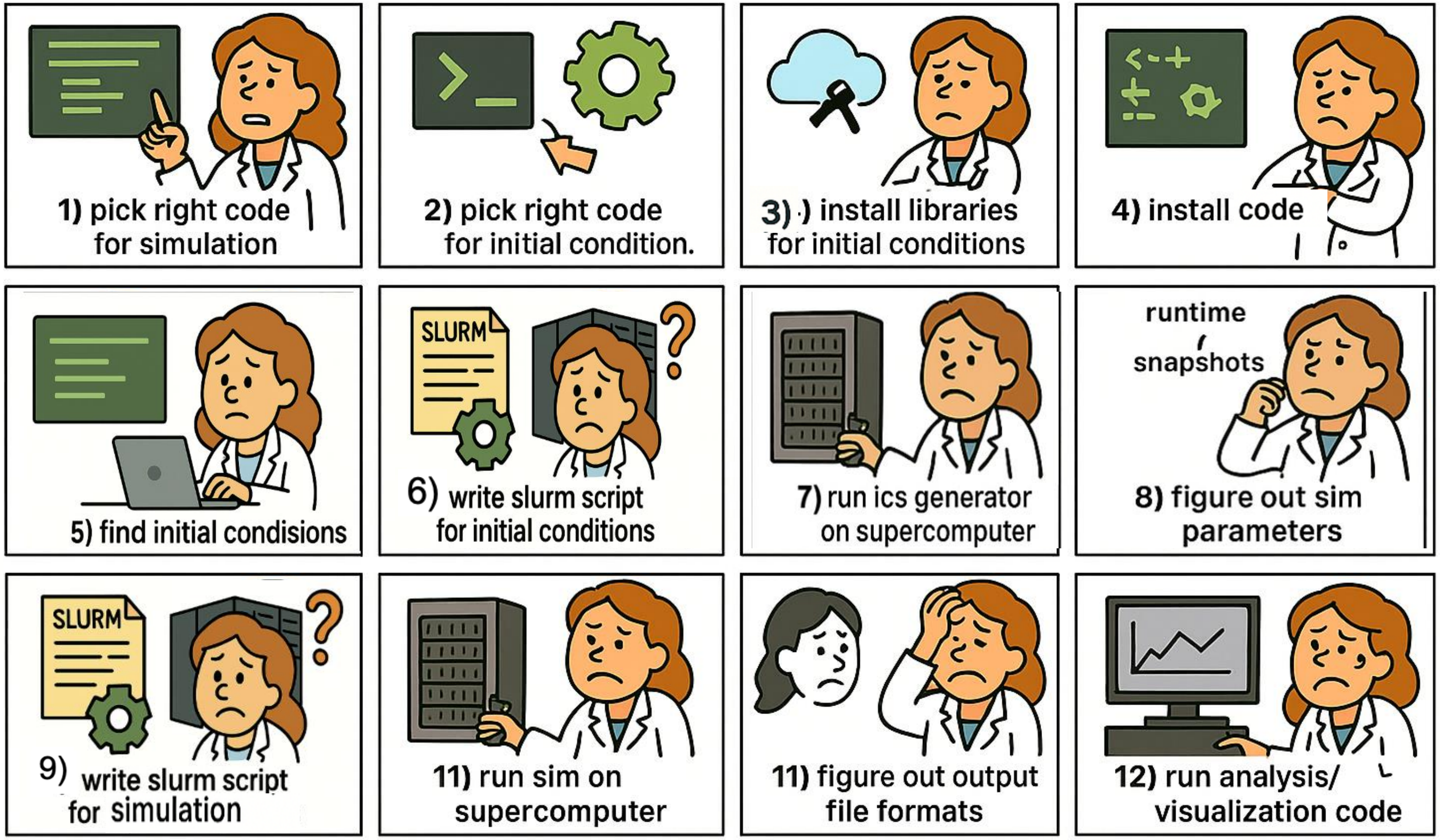
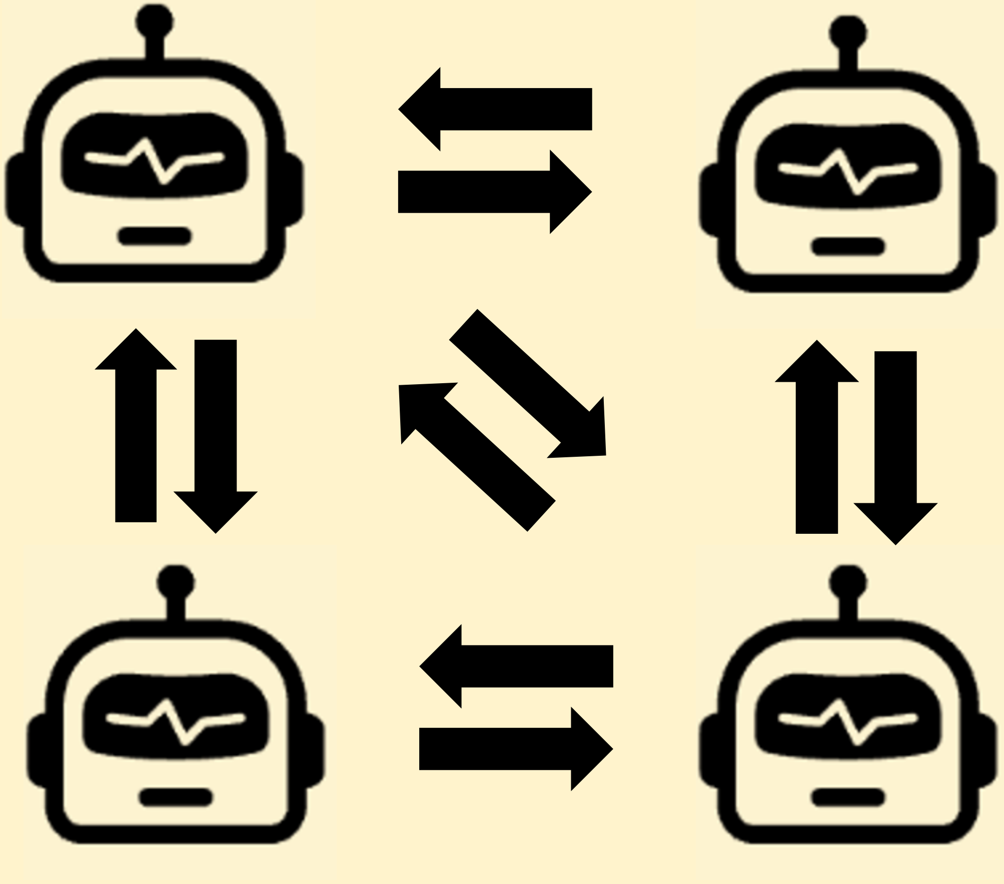


none of this is astrophysics + how long would it take? days, weeks?

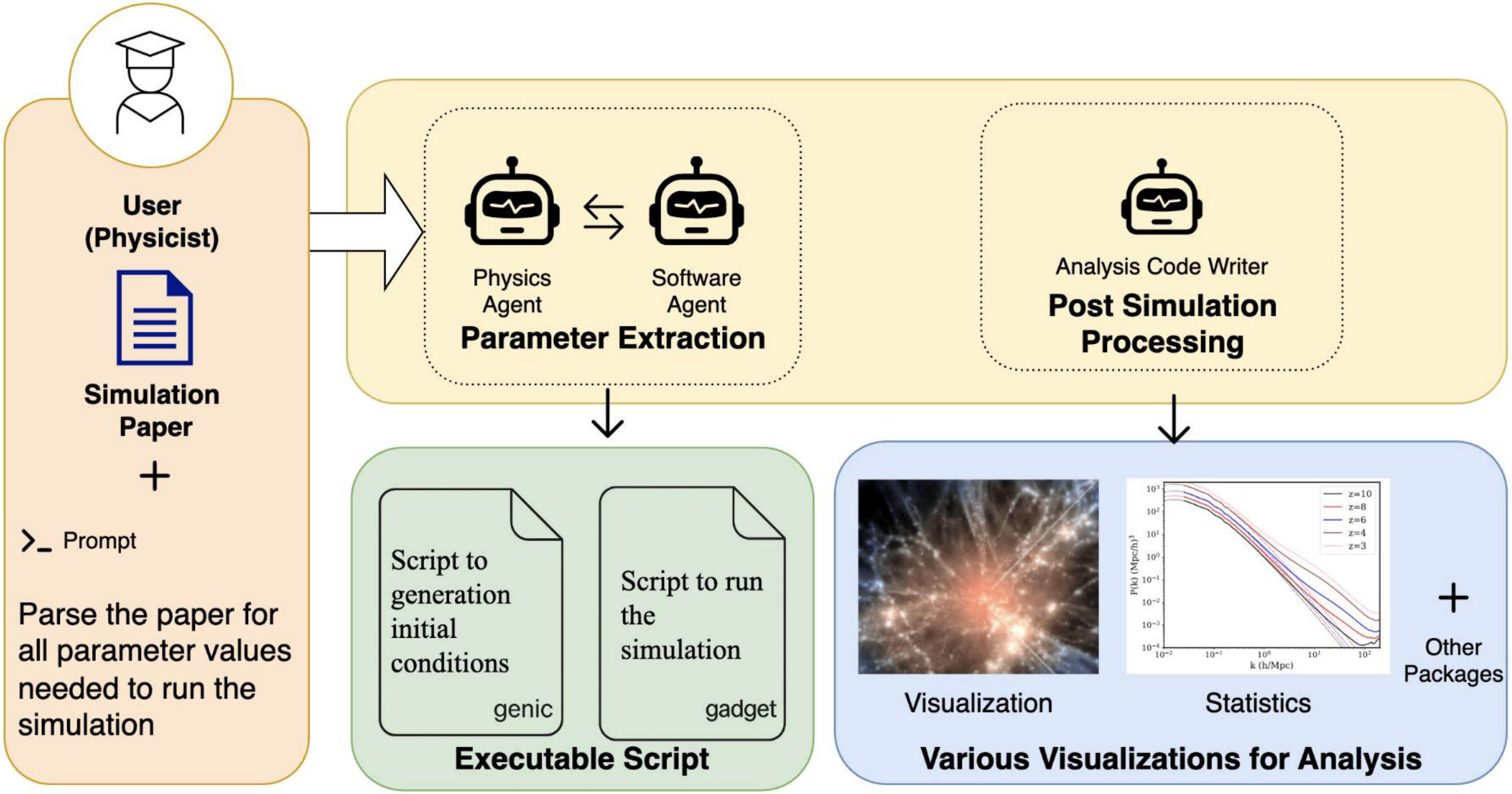
SimAgents



LLM multi-agent system

Zhang et al.
IJCNLP 2025
code and demo vid
at 2507.08958

SimAgents reads code manuals, papers, computing facility documentation…



User (Physicist)

Simulation Paper

+

>_ Prompt

Parse the paper for all parameter values needed to run the simulation

Physics Agent ⇆ Software Agent

Parameter Extraction

Analysis Code Writer

Post Simulation Processing

Script to generation initial conditions — genic

Script to run the simulation — gadget

Executable Script

Visualization

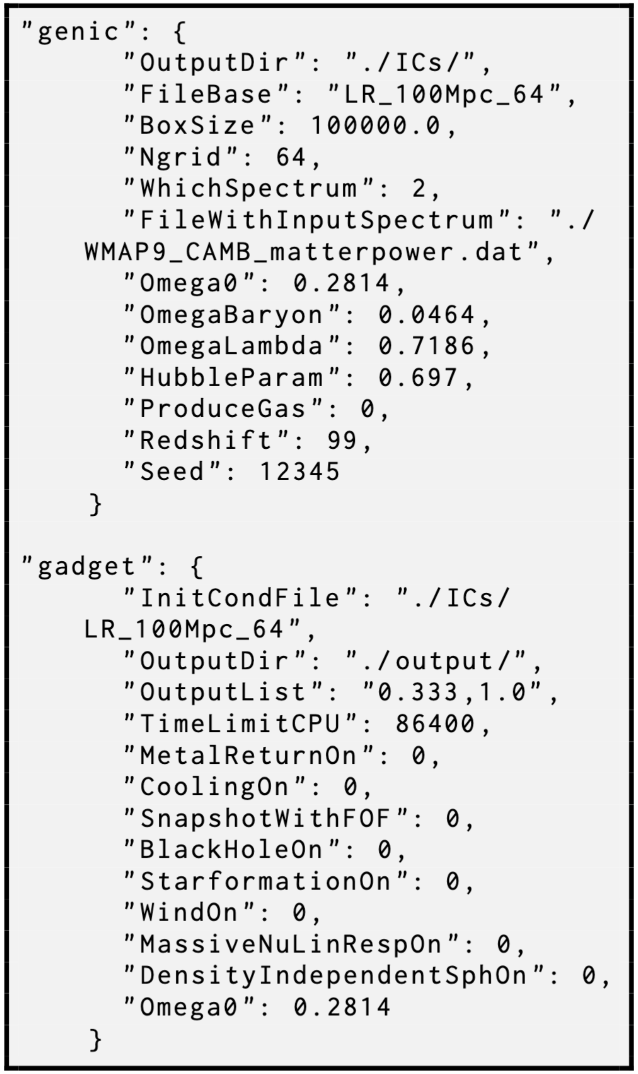
Statistics

+ Other Packages

Various Visualizations for Analysis

built with Microsoft AutoGen framework + OpenAI API

Examples of Gadget parameter files produced by **SimAgents**



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      "OmegaBaryon": 0.0464,
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    }

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      "Omega0": 0.2814
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```

Tests of **SimAgents** against Exchange of Thought and Chain of Thought show many fewer errors:

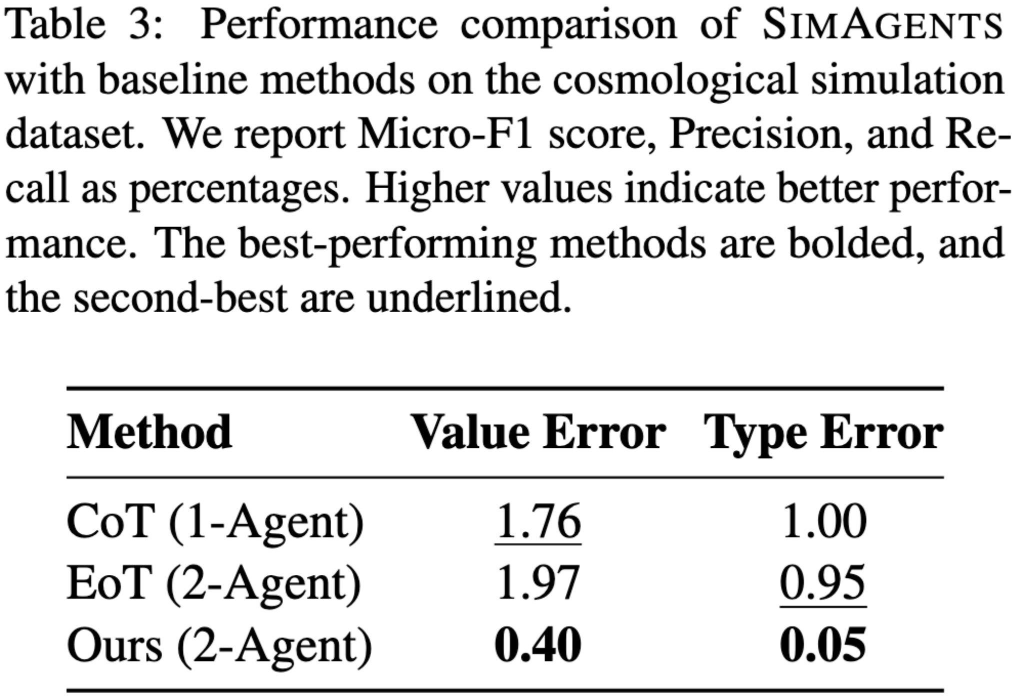
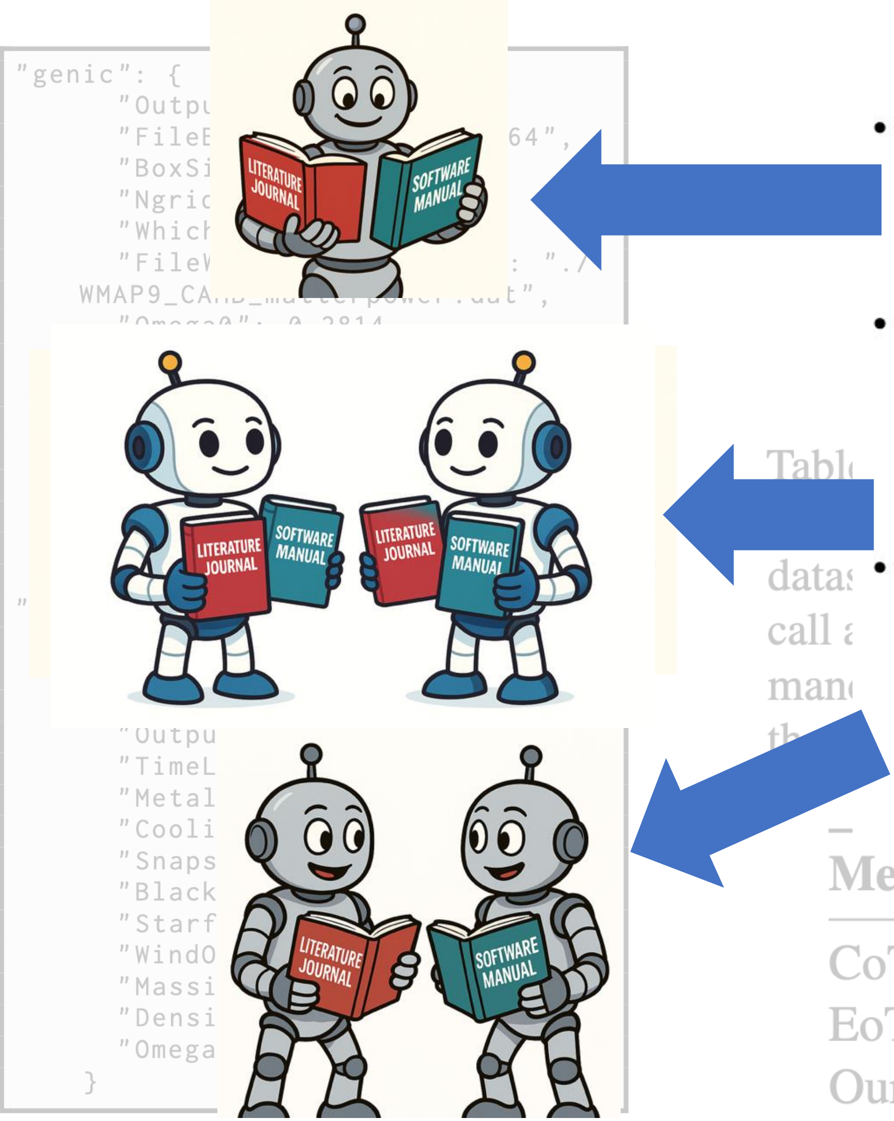


Table 3: Performance comparison of SIMAGENTS with baseline methods on the cosmological simulation dataset. We report Micro-F1 score, Precision, and Recall as percentages. Higher values indicate better performance. The best-performing methods are bolded, and the second-best are underlined.

Method	Value Error	Type Error
CoT (1-Agent)	1.76	1.00
EoT (2-Agent)	1.97	0.95
Ours (2-Agent)	**0.40**	**0.05**

Examples of Gadget parameter files produced by **SimAgents**

Tests of **SimAgents** against Exchange of Thought and Chain of Thought show many fewer errors:



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      "FileE                    64",
      "BoxSi
      "Ngric
      "Which
      "FileV                  : "./
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      "Outpu
      "TimeL
      "Metal
      "Cooli
      "Snaps
      "Black
      "Starf
      "WindO
      "Massi
      "Densi
      "Omega
   }
```
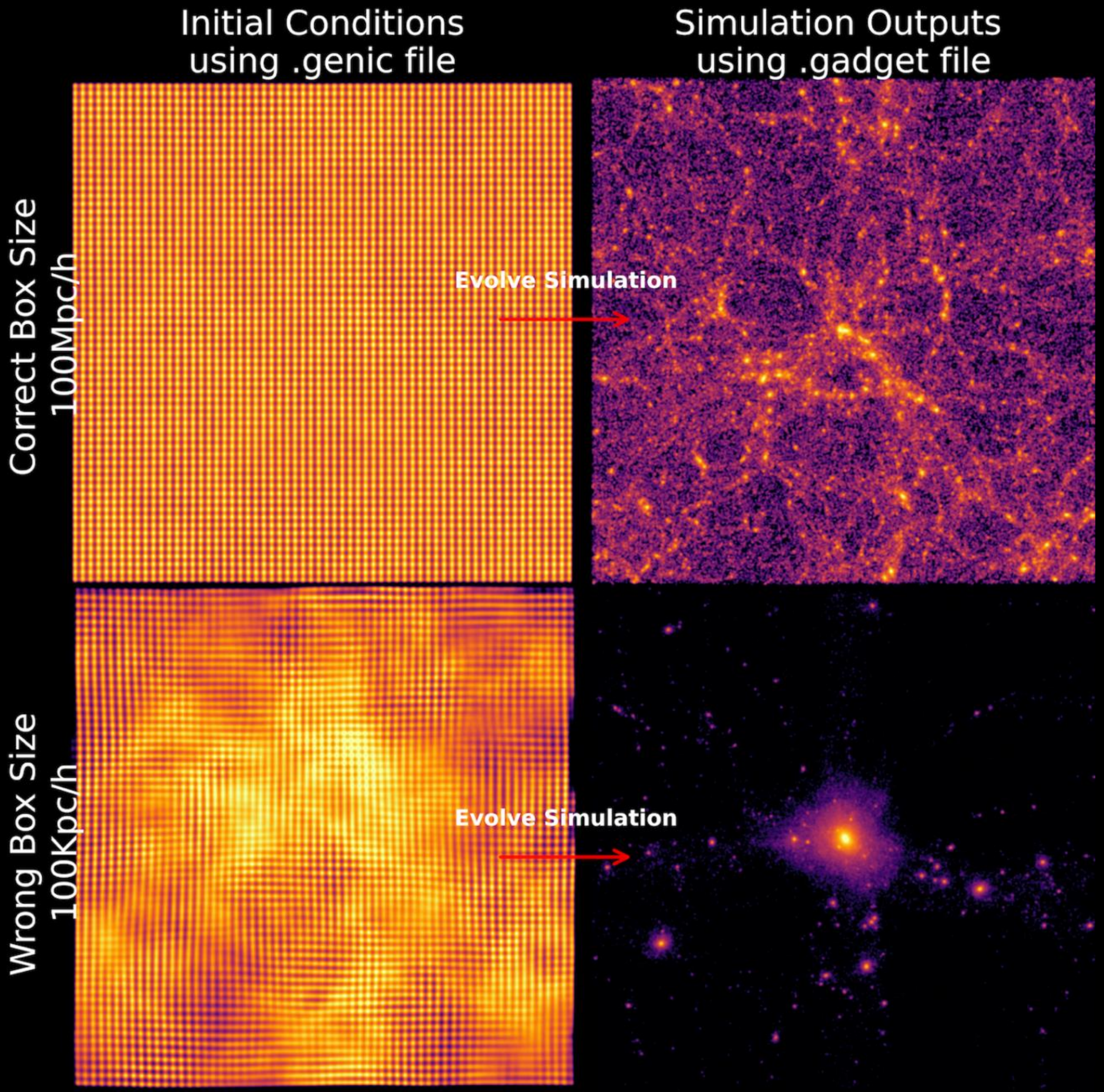
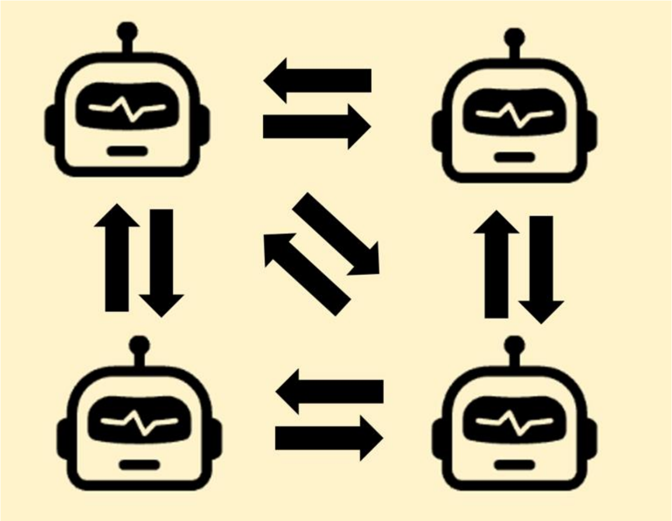

- **Chain-of-thought (CoT)** (Kojima et al., 2022) We implement zero-shot CoT prompting with a single LLM agent. The agent is provided with both the literature and the manual.
- **Exchange-of-thought (EoT)** (Yin et al., 2023) We implement EoT using two agents with the same initialization, and provide them both with the literature and the manual. The agents engage in a discussion with one another.
- SIMAGENTS Our approach employs two task-specific agents: Physics Agent and Software Agent, each with role-specialized profiling. We provide Physics Agent with only the literature and Software Agent with only the manual. The agents engage in a discussion with one another.

Method	**Value Error**	**Type Error**
CoT (1-Agent)	1.76	1.00
EoT (2-Agent)	1.97	0.95
Ours (2-Agent)	**0.40**	**0.05**

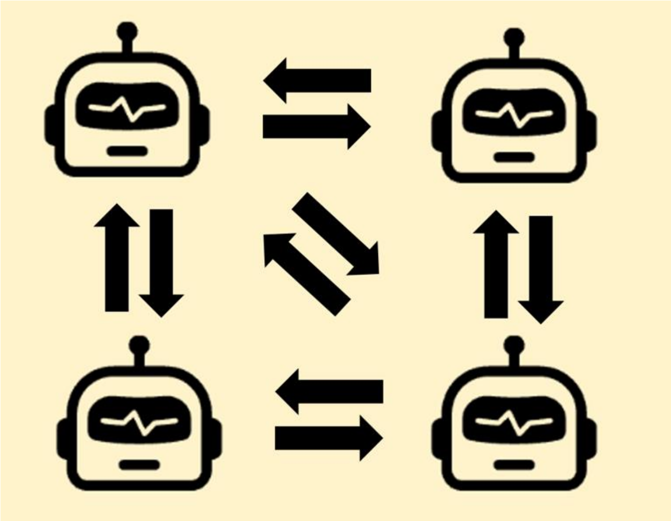
An example of a value error, the effect of getting box size wrong (1 kpc vc 1 Mpc):



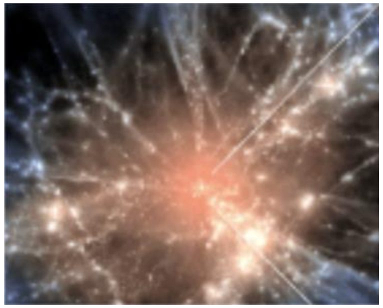
How long does **SimAgents** take to run and analyze a full 512^3 (134 million particle) dark matter emulated simulation)?

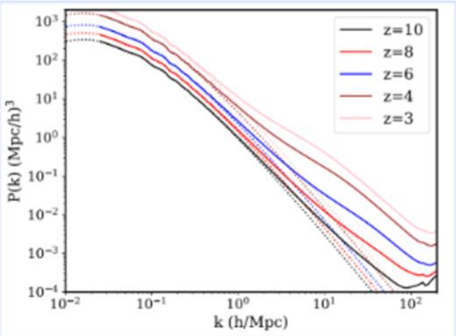


How long does **SimAgent** take to run and analyze a full 512^3 (134 million particle) dark matter emulated simulation)?



~2 minutes

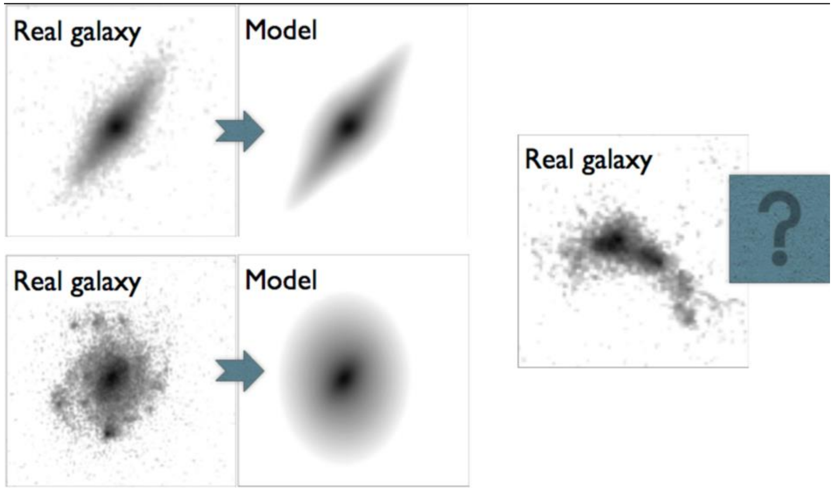




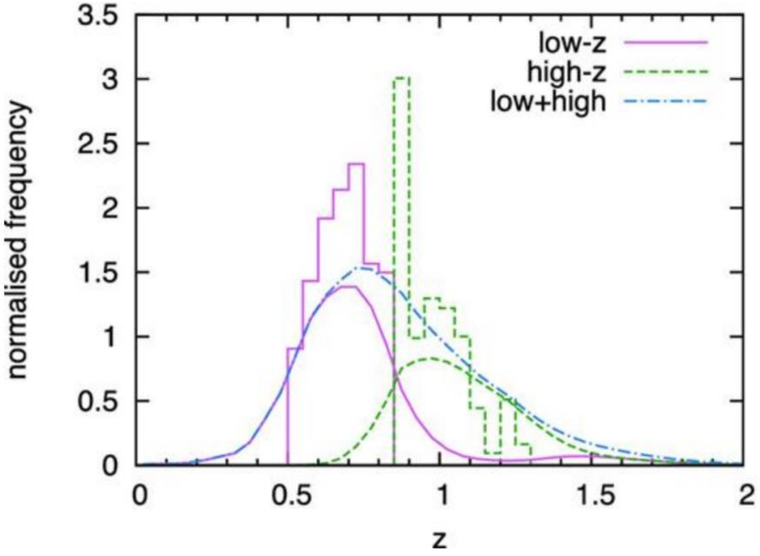
Some Lyman-alpha forest science that can be done with large cosmological hydrodynamic simulations and emulators:

- Lyman-alpha forest lensing
- Quasar proximity effect

Galaxy weak lensing difficulties



(Mandelbaum et al (2013)



(CFHTLens)

shape measurement

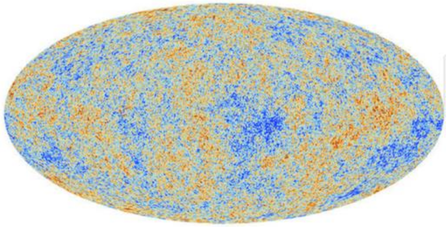
redshift determination

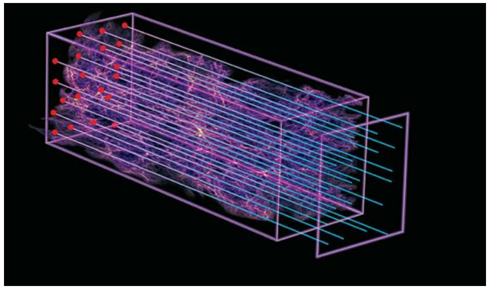
(see e.g. Noah Weaverdyck's DESI lunch seminar yesterday)

CMB lensing

Lya forest lensing

source

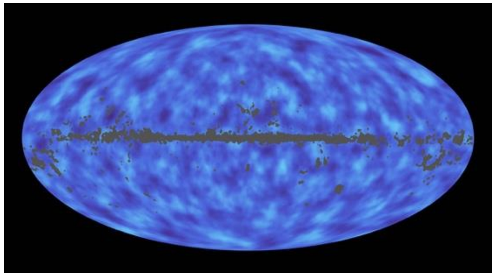




CMB T at $z=1300$

Lya forest at $z=2-3$

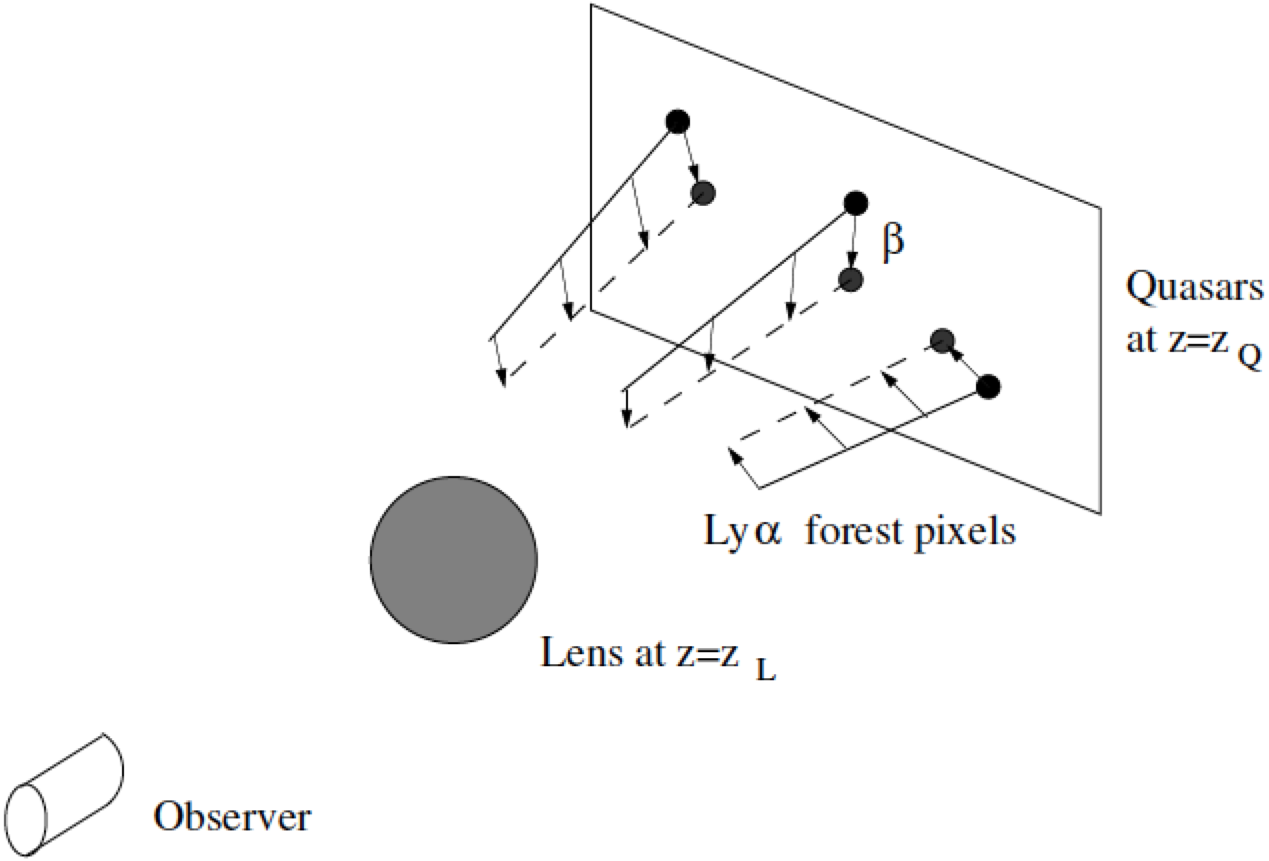
lens

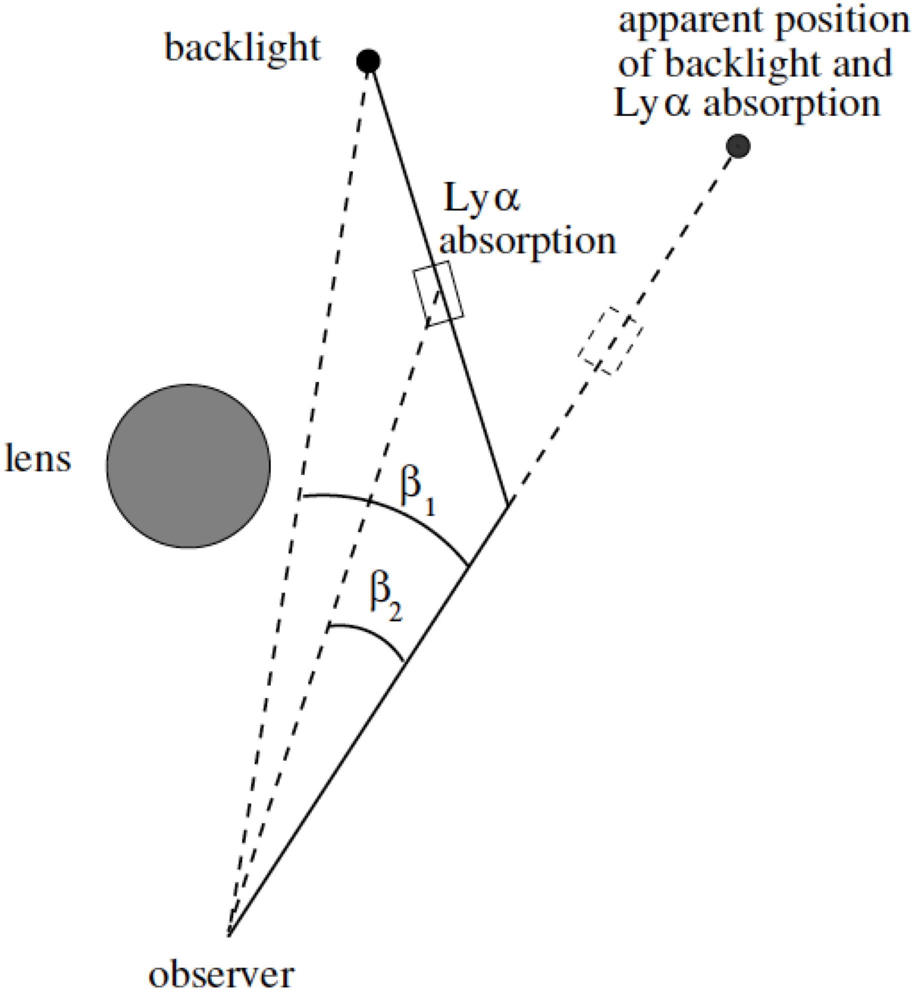


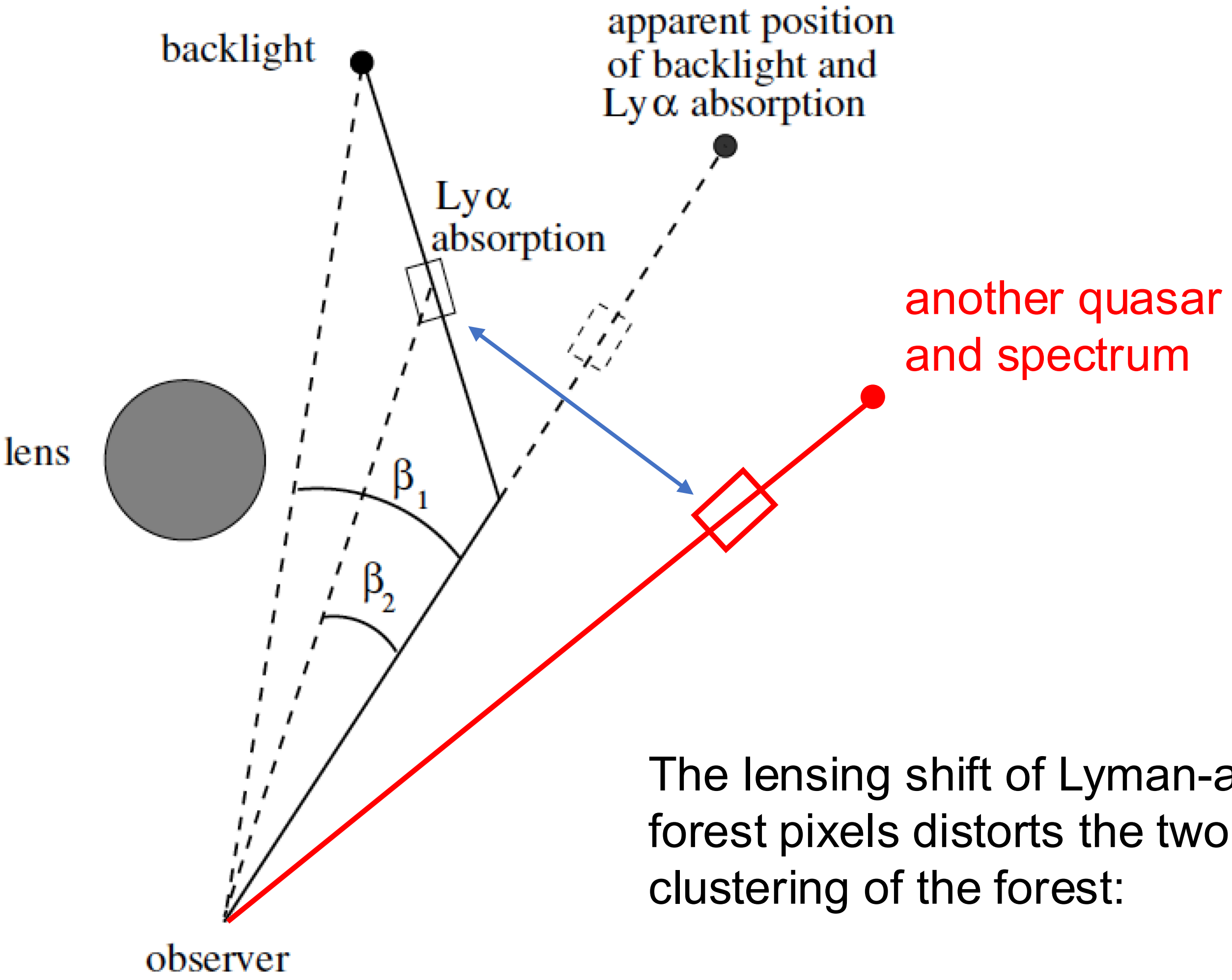
map foreground
mass at $z\sim2.5$

map foreground
mass at $z\sim1$

quasars are deflected, but so are forest pixels



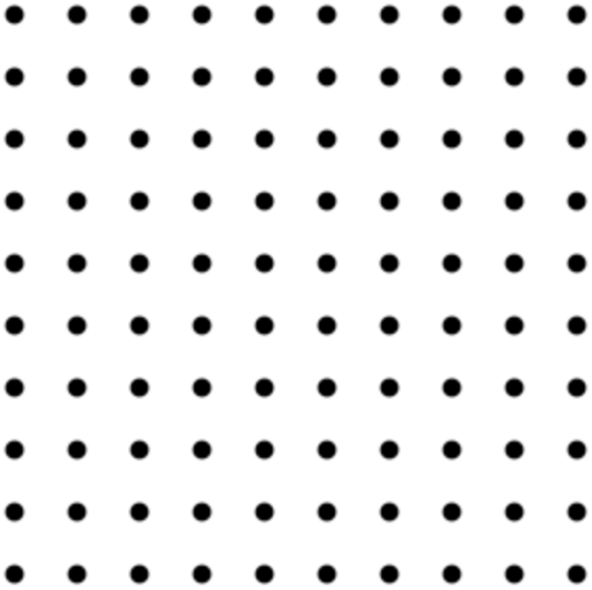

backlight
apparent position
of backlight and
Lyα absorption
Lyα
absorption
lens
β_1
β_2
observer



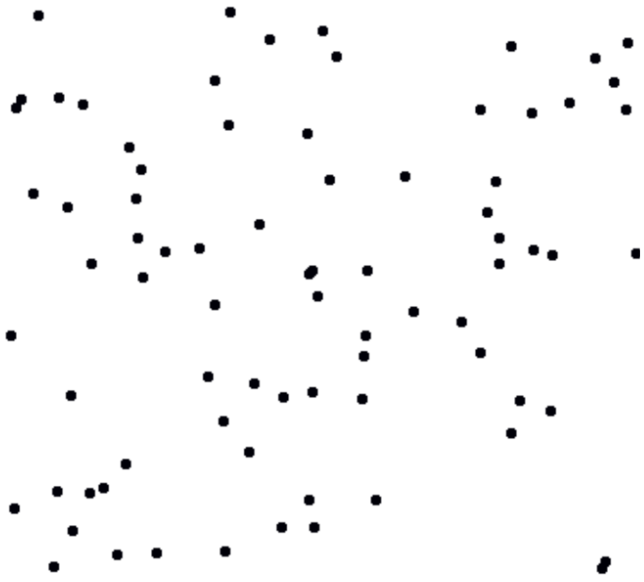
The lensing shift of Lyman-alpha forest pixels distorts the two-point clustering of the forest:

a quadratic estimator (like for CMB lensing) can recover the lensing potential.

Use quadratic estimator as in CMB lensing, but for discrete irregularly spaced sightlines instead of a continuous field.

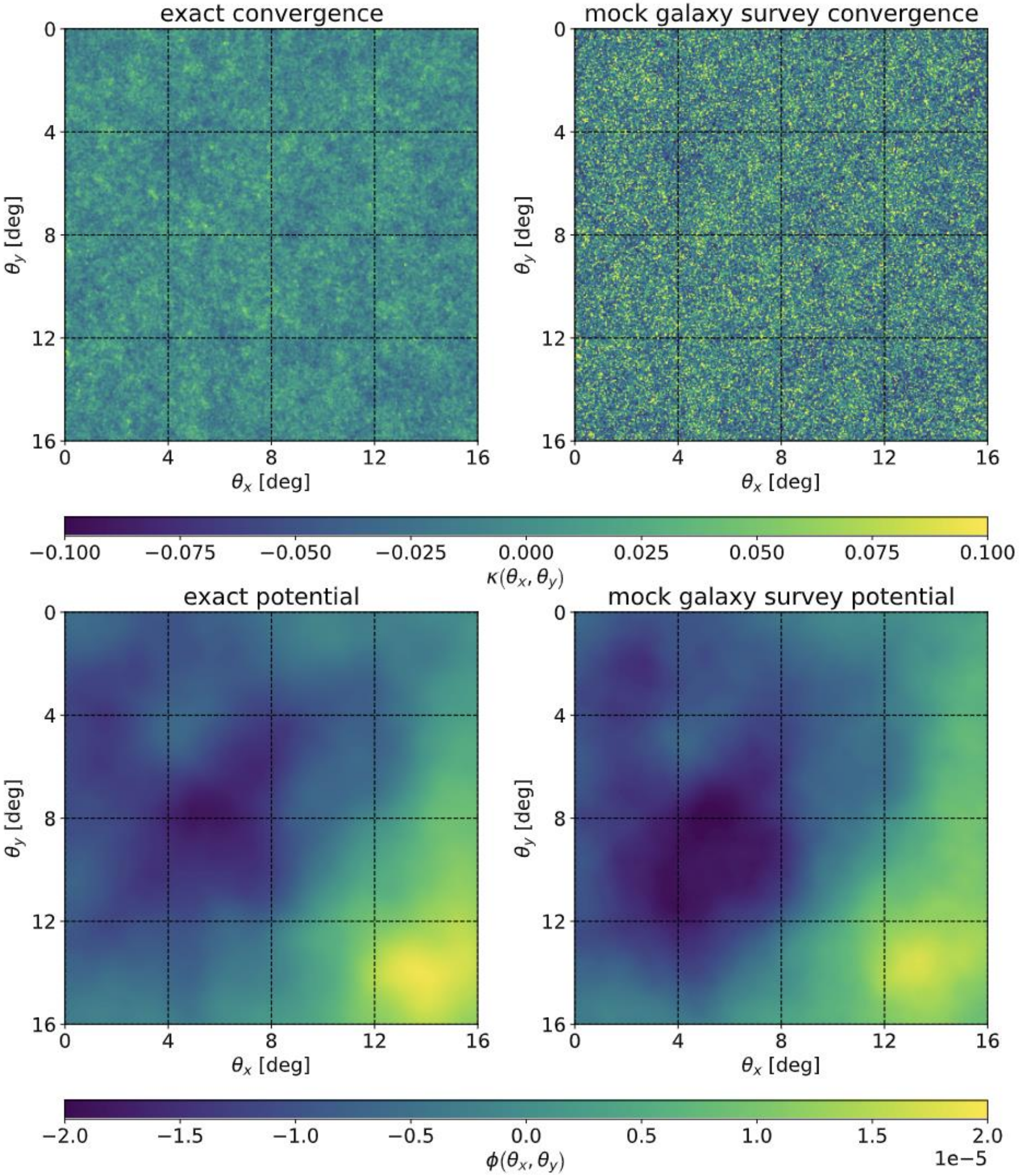


CMB pixels

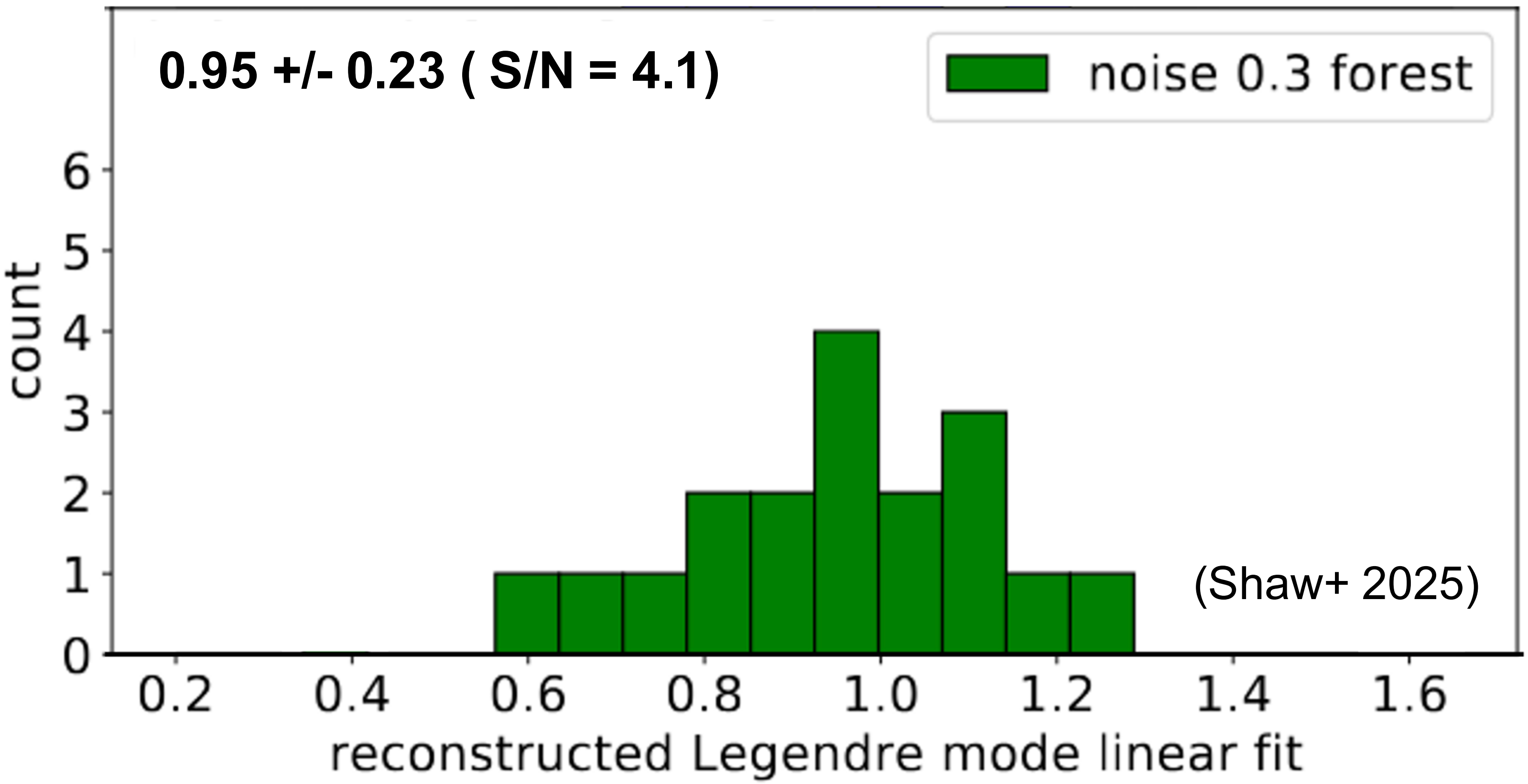


Lya forest quasar positions

We make mock DESI surveys: mock DESI galaxy surveys – to compare to reconstructed potential from lensing from mock DESI Lya surveys



From 20 mock DESI surveys we find that a S/N~4 detection is likely from DESI:



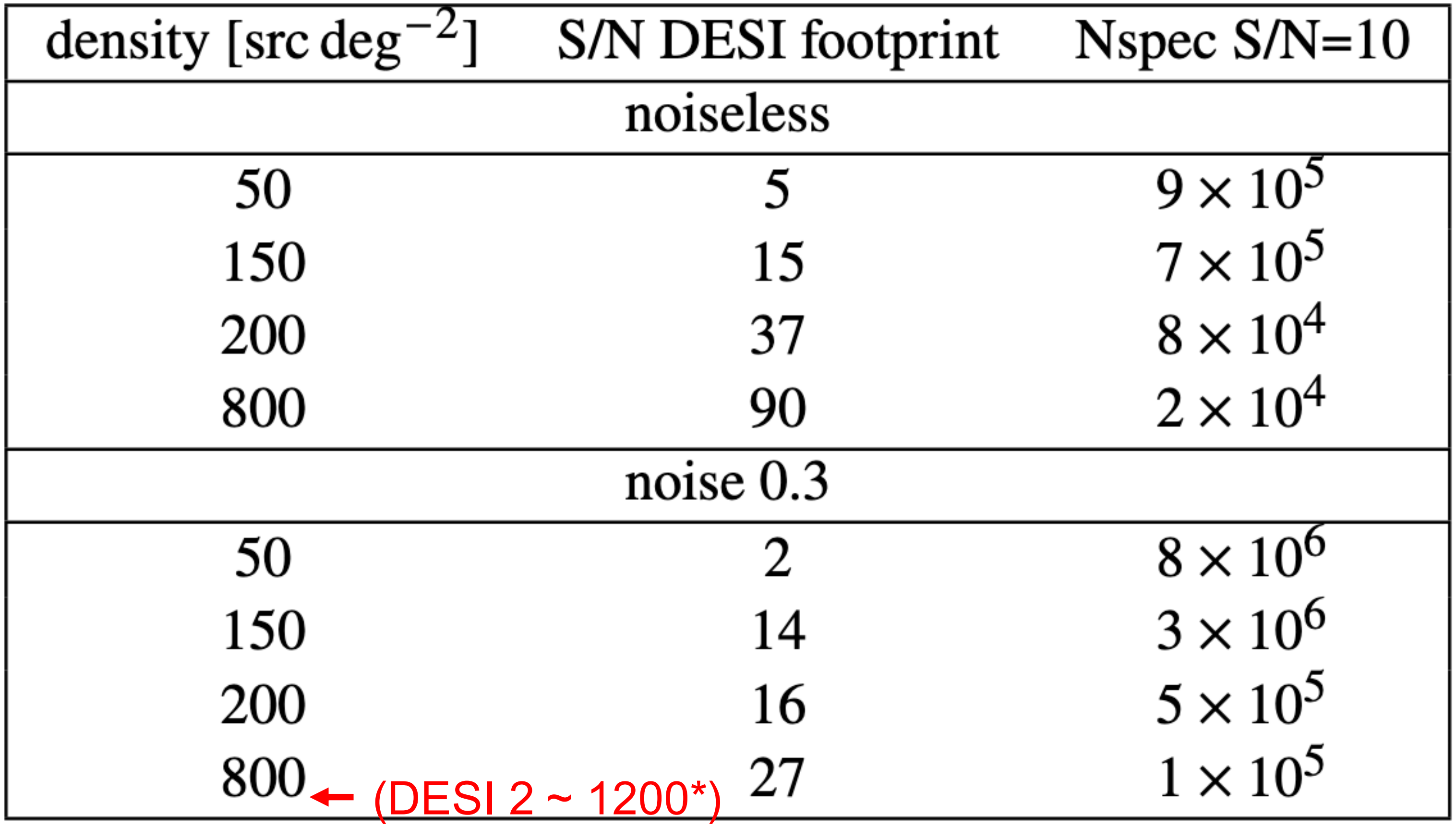
0.95 +/- 0.23 (S/N = 4.1)

(Shaw+ 2025)

Why is it so difficult to measure Lyα weak lensing?

- Unlike CMB, no oscillatory features so lensing doesn't dramatically shift correlation function
- DESI forest is very noisy

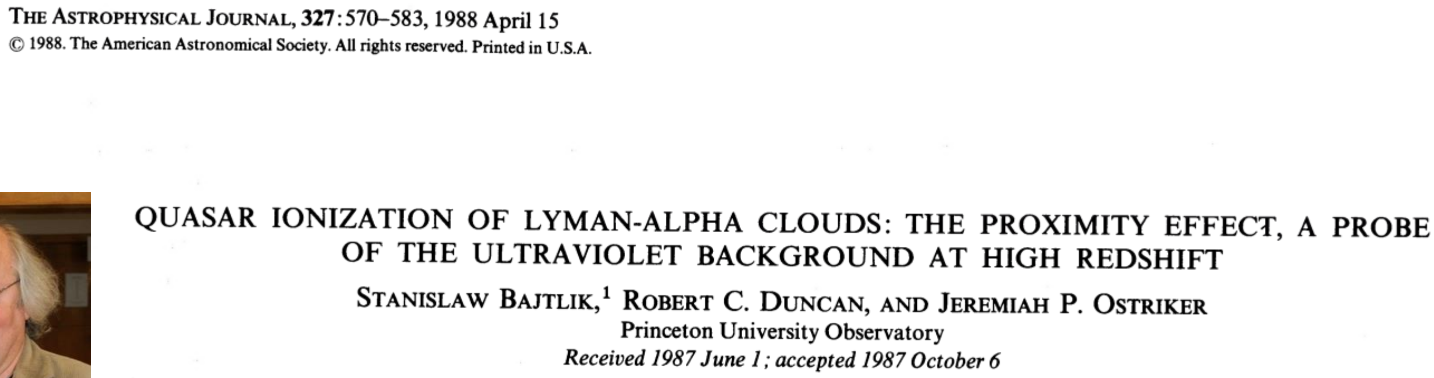
Beyond DESI surveys such as DESI 2 could measure
Lyα lensing with a S/N > 10:



density [src deg^{-2}]	S/N DESI footprint	Nspec S/N=10
	noiseless	
50	5	9×10^5
150	15	7×10^5
200	37	8×10^4
800	90	2×10^4
	noise 0.3	
50	2	8×10^6
150	14	3×10^6
200	16	5×10^5
800 ← (DESI 2 ~ 1200*)	27	1×10^5

* QSO + ELG + LBG $1.6 < z < 4.0$

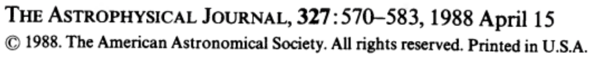
Now we turn to the interaction between quasar radiation and the Lyman-alpha forest: the quasar proximity effect.



THE ASTROPHYSICAL JOURNAL, **327**:570–583, 1988 April 15

QUASAR IONIZATION OF LYMAN-ALPHA CLOUDS: THE PROXIMITY EFFECT, A PROBE OF THE ULTRAVIOLET BACKGROUND AT HIGH REDSHIFT

STANISLAW BAJTLIK,[1] ROBERT C. DUNCAN, AND JEREMIAH P. OSTRIKER
Princeton University Observatory
Received 1987 June 1; accepted 1987 October 6



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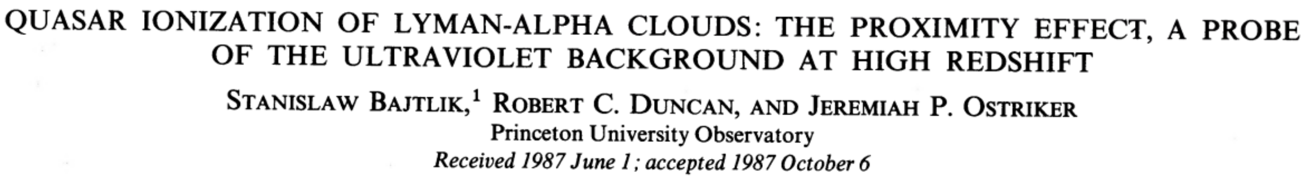

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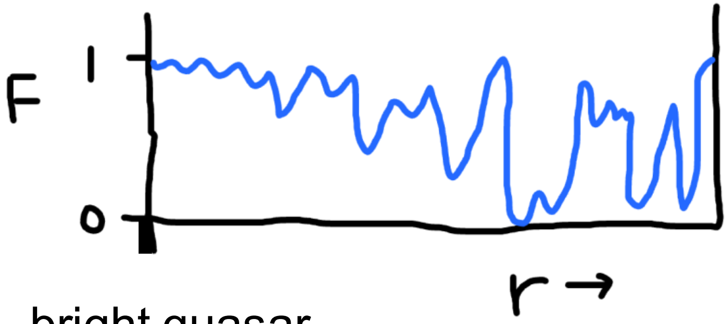
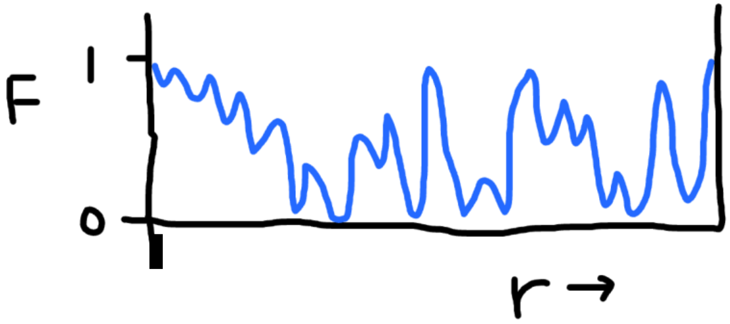
Effect on forest:



bright quasar



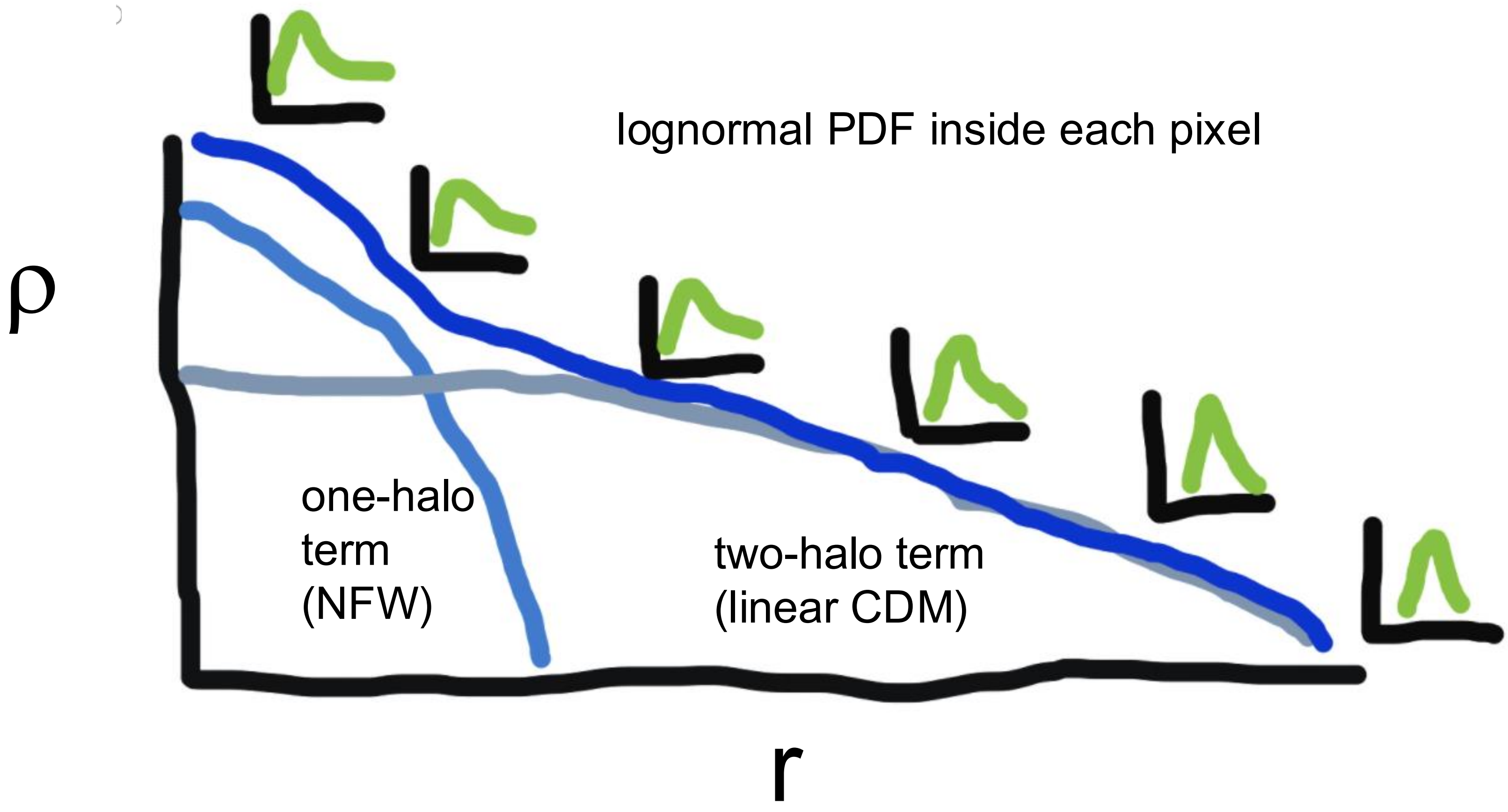
faint quasar

- Published measurements from largest samples are for ~30 quasars (e.g., Scott et al. 2017)

- No one has measured proximity effect from large (e.g., SDSS or DESI) surveys

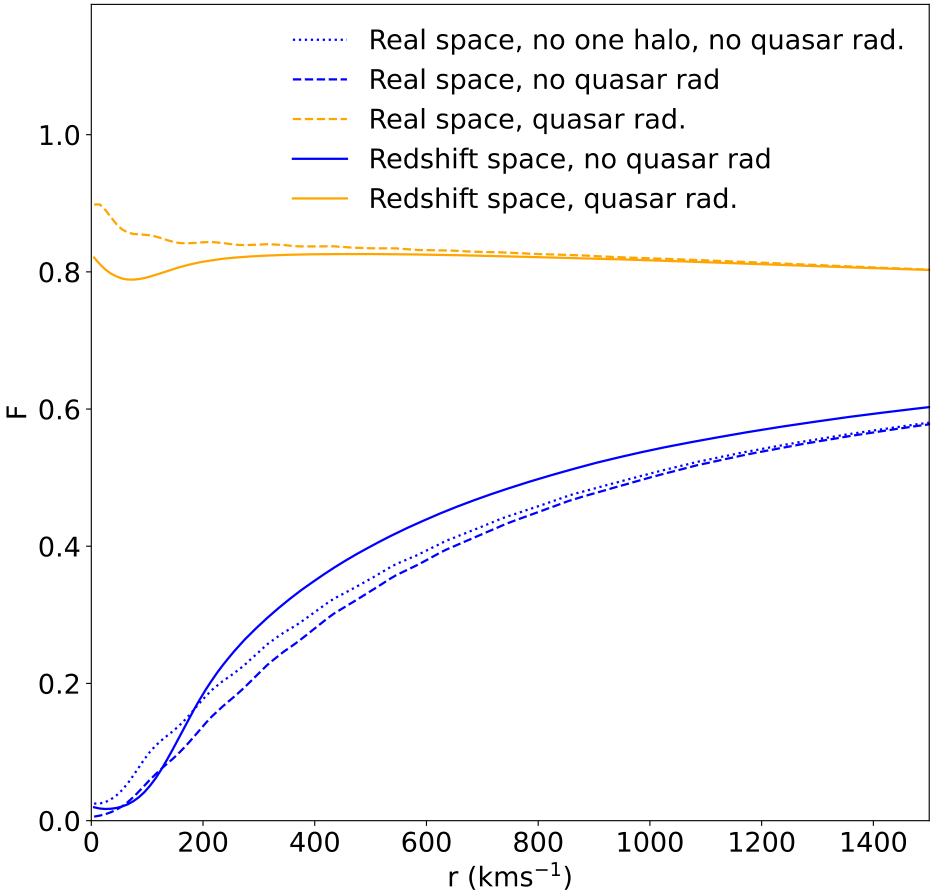
- How could we do that and why?

A halo model of the quasar proximity effect

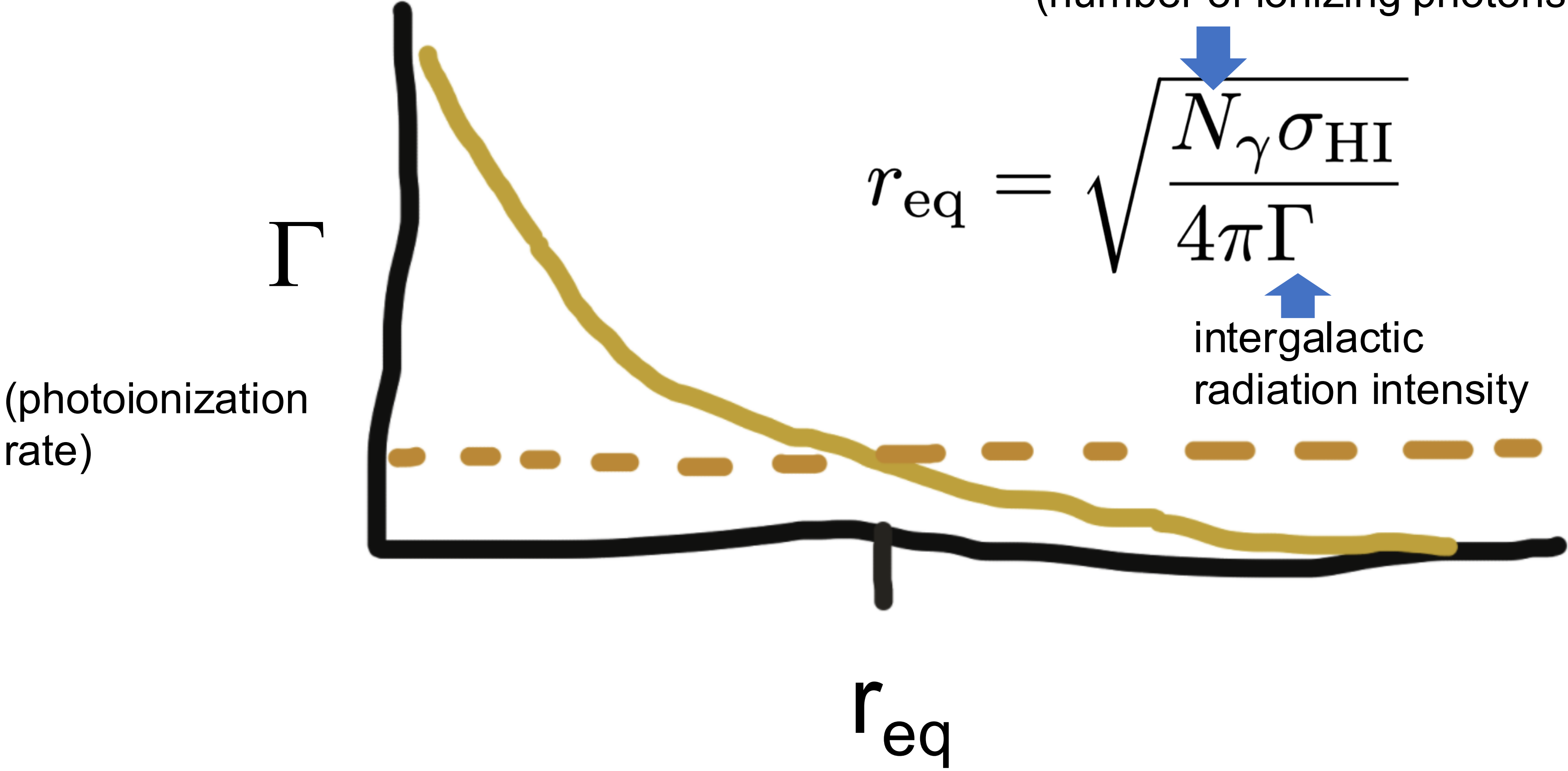


(+thermal broadening + redshift distortions + quasar radiation field)

The halo model predicts the average profile of Lya-forest flux near quasars:



We parametrize quasar luminosity by r_{eq}
(radius where quasar radiation=intergalactic background)



quasar luminosity
(number of ionizing photons)

$$r_{\mathrm{eq}} = \sqrt{\frac{N_\gamma \sigma_{\mathrm{HI}}}{4\pi\Gamma}}$$

intergalactic
radiation intensity

If we know the quasar luminosity (observed), we get the value of Γ

(This is the intergalactic radiation intensity at the position of the quasar.)

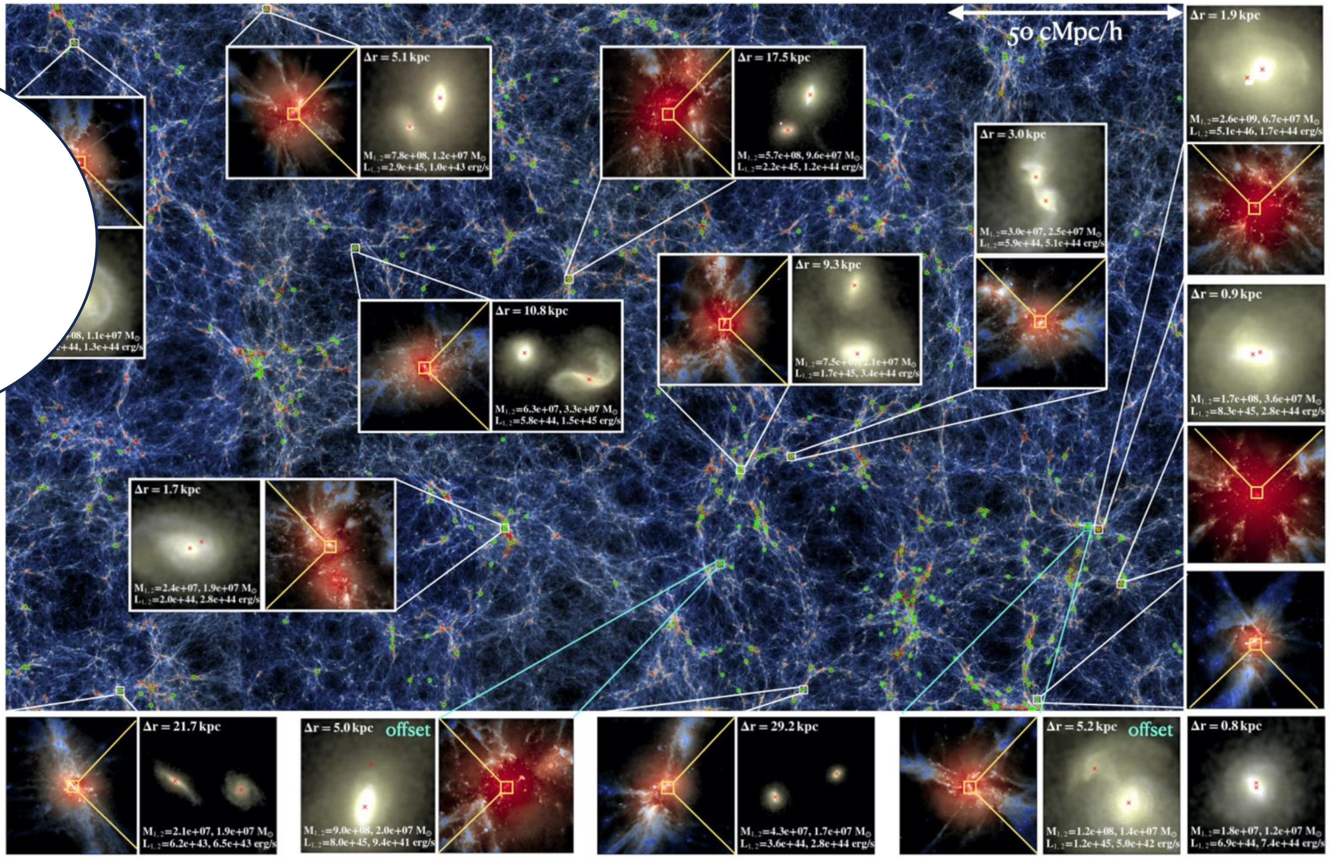
Let’s try this out on simulated quasars...

We use the **Astrid** simulation:

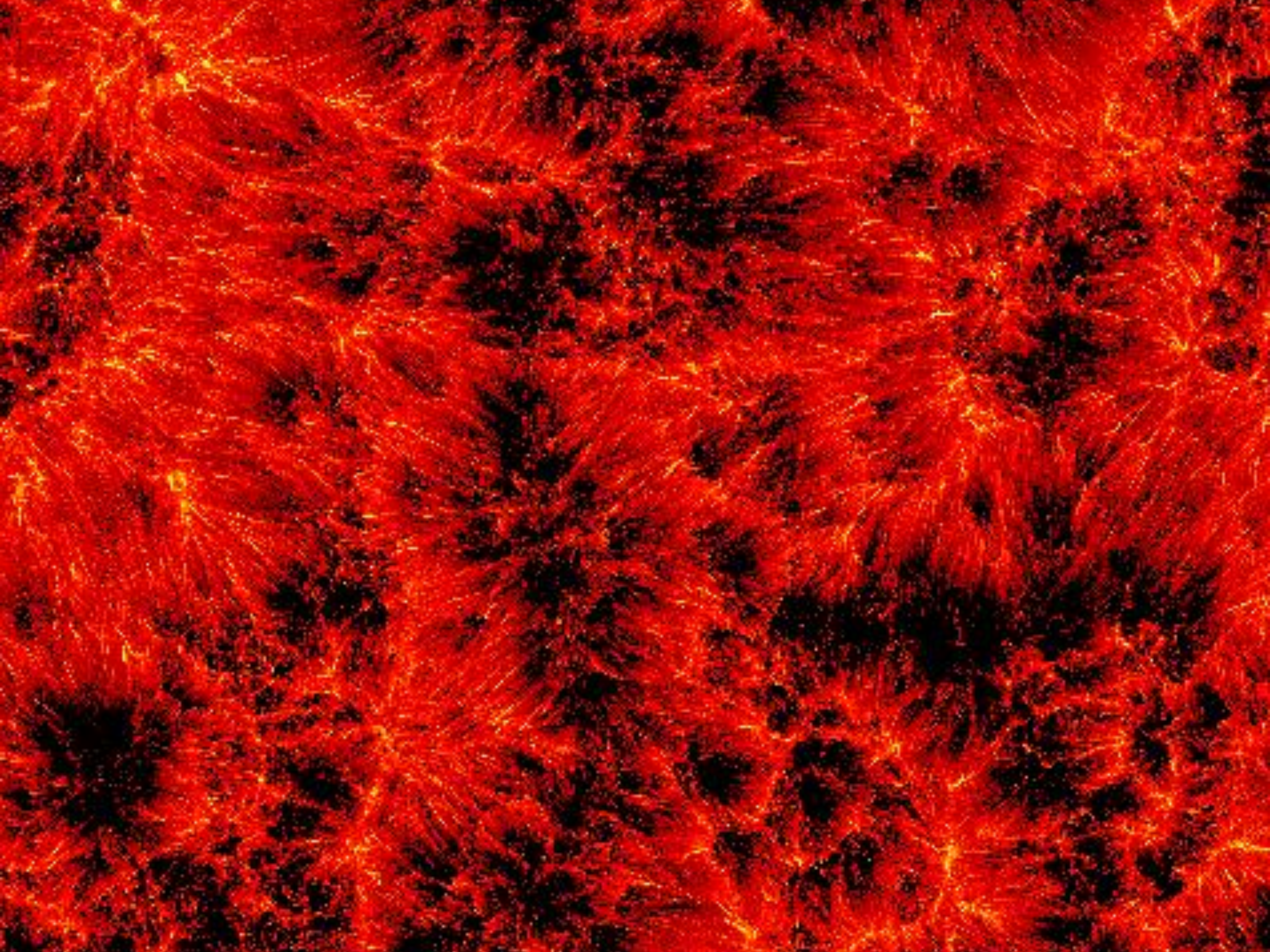
250 Mpc/h volume   2x5500^3 part.   2x10^6 M$_{sun}$/h gas part. mass   MP-Gadget SPH

It reached z=0.0 a few months ago after 4 years of running!
(but we focus on z-3 for this project)

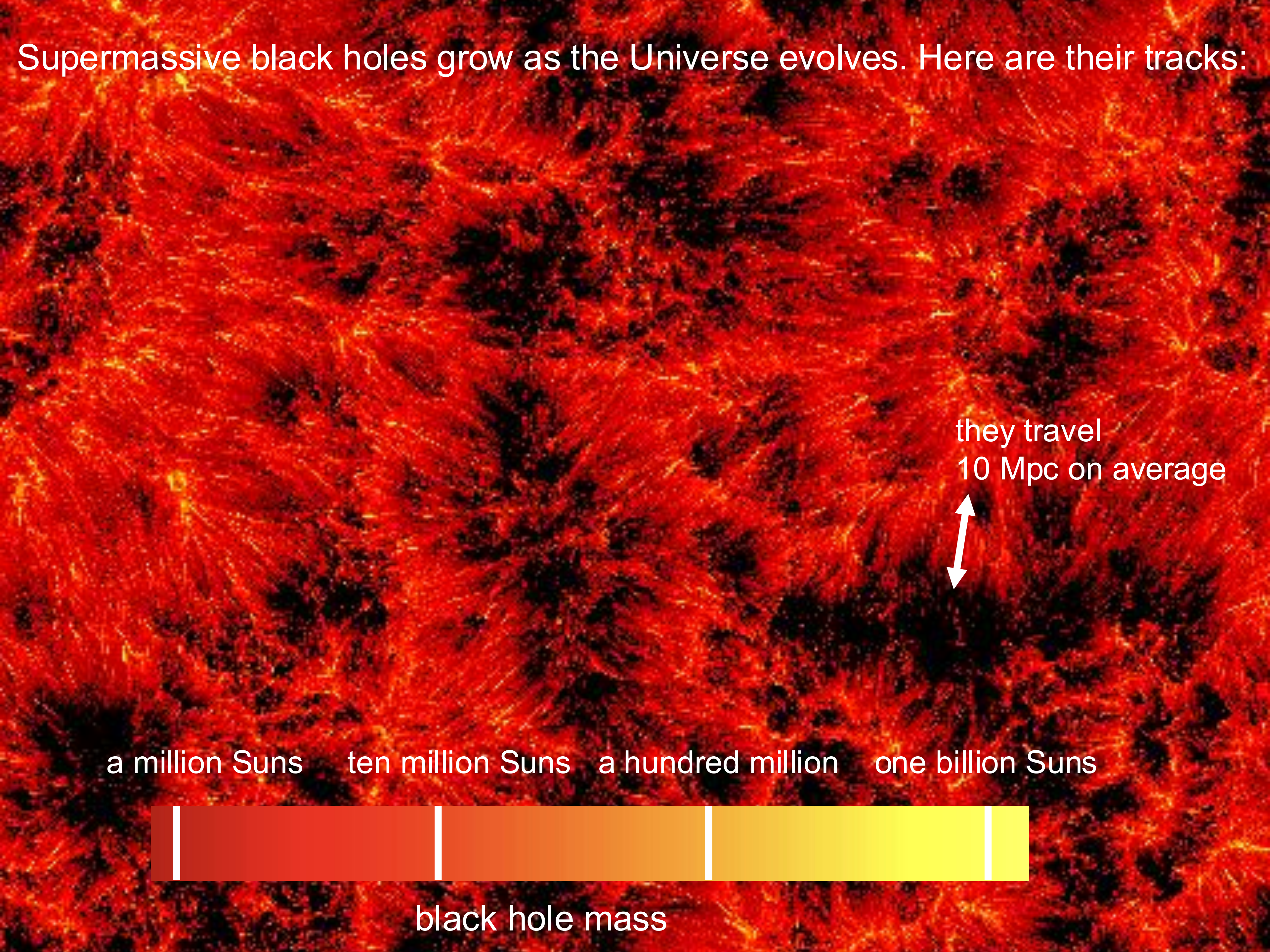
some
dual-AGN
at z=0.5
in **Astrid:**



Data is public : https://astrid.psc.edu/



Supermassive black holes grow as the Universe evolves. Here are their tracks:



they travel
10 Mpc on average

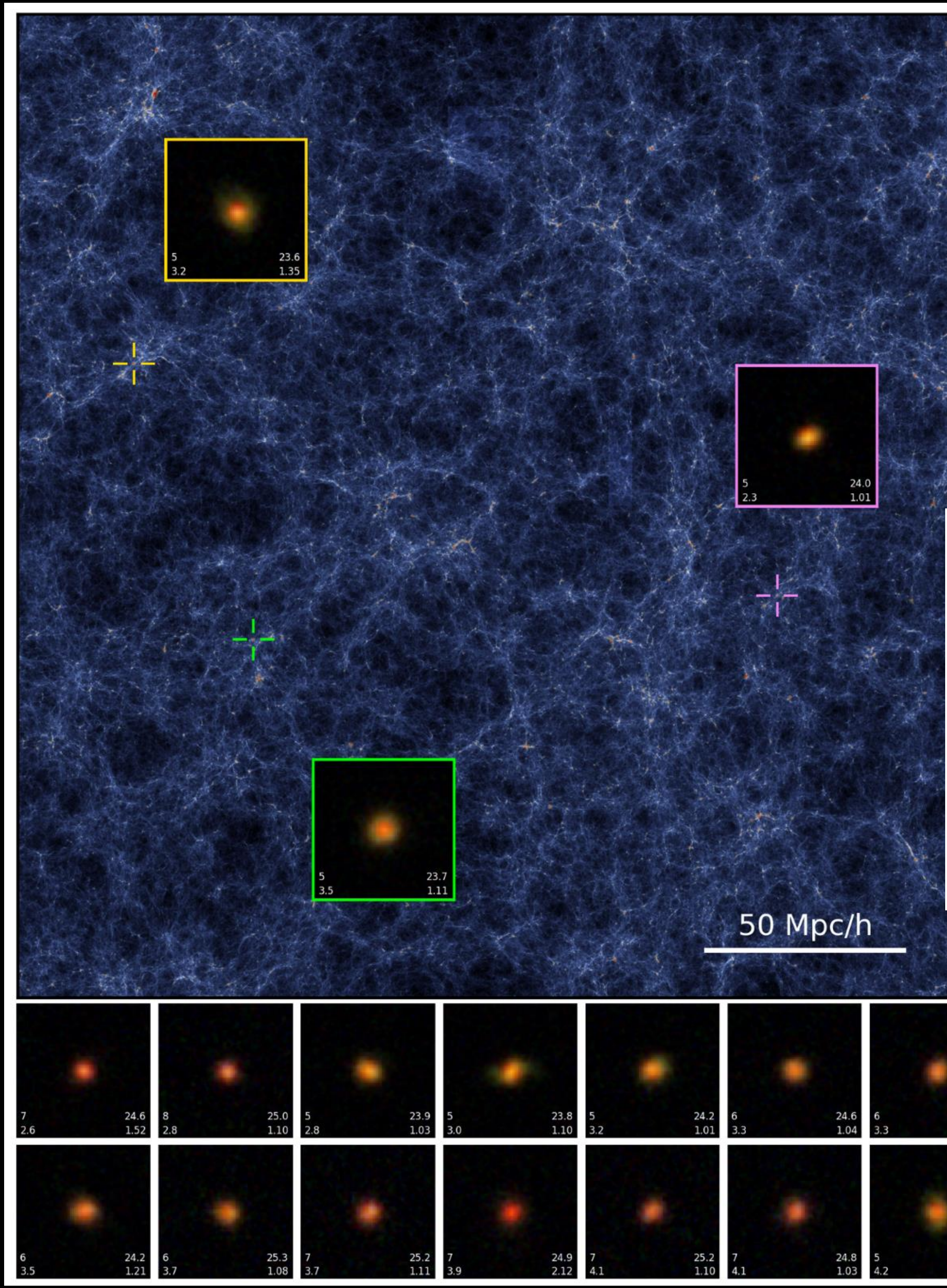
a million Suns

ten million Suns

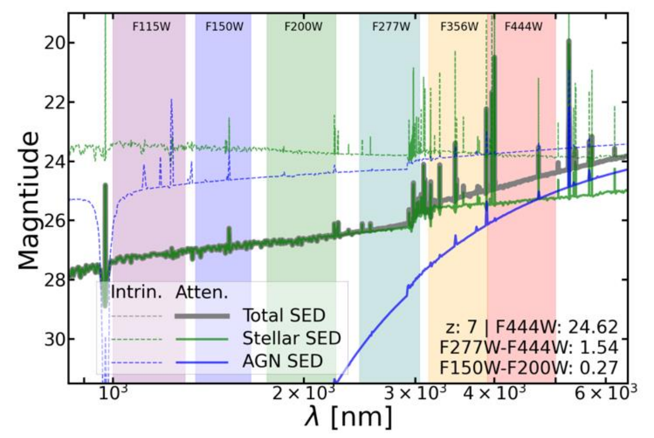
a hundred million

one billion Suns

black hole mass

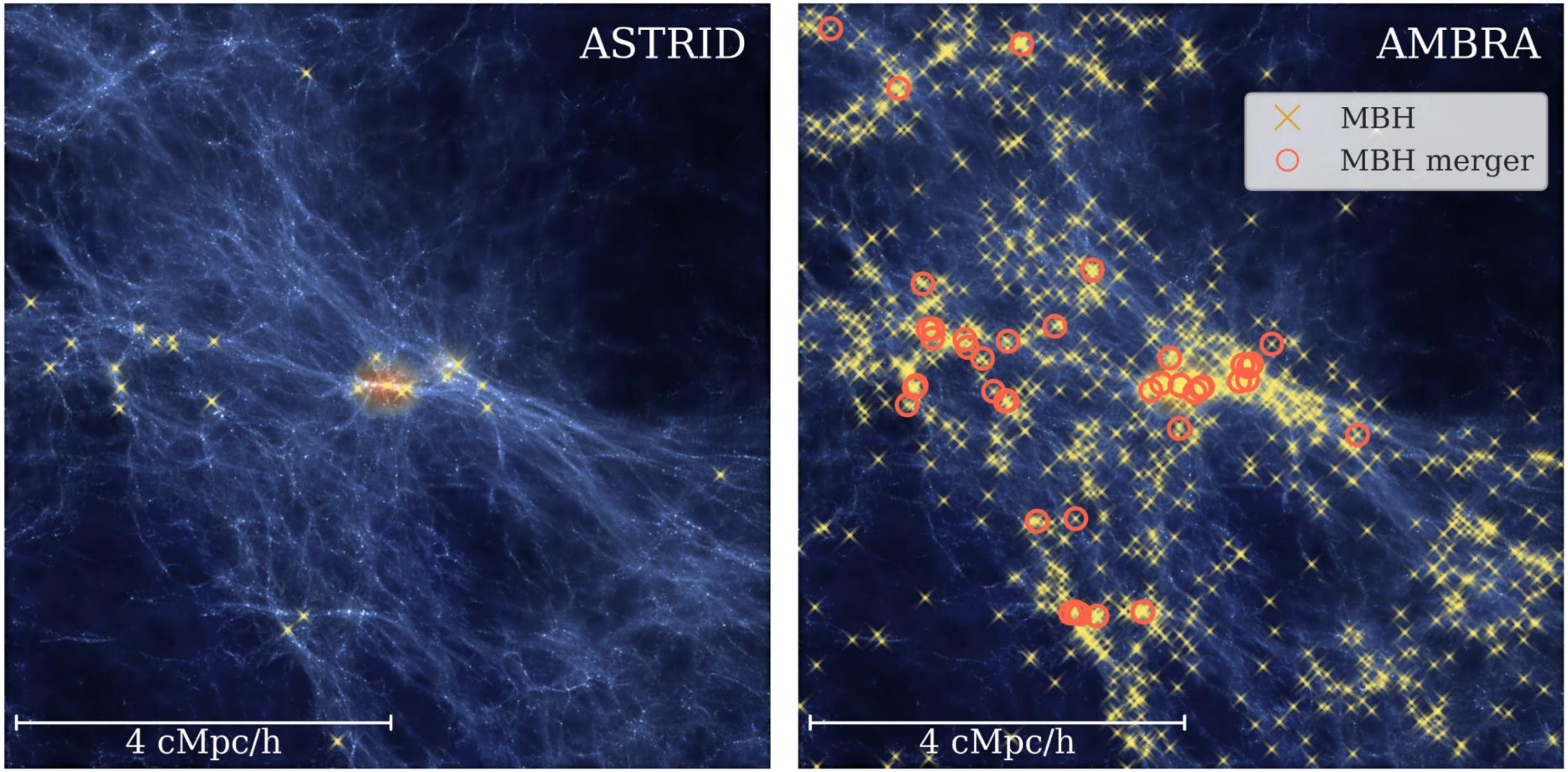


There are “Little Red Dots” in Astrid as well as quasars.



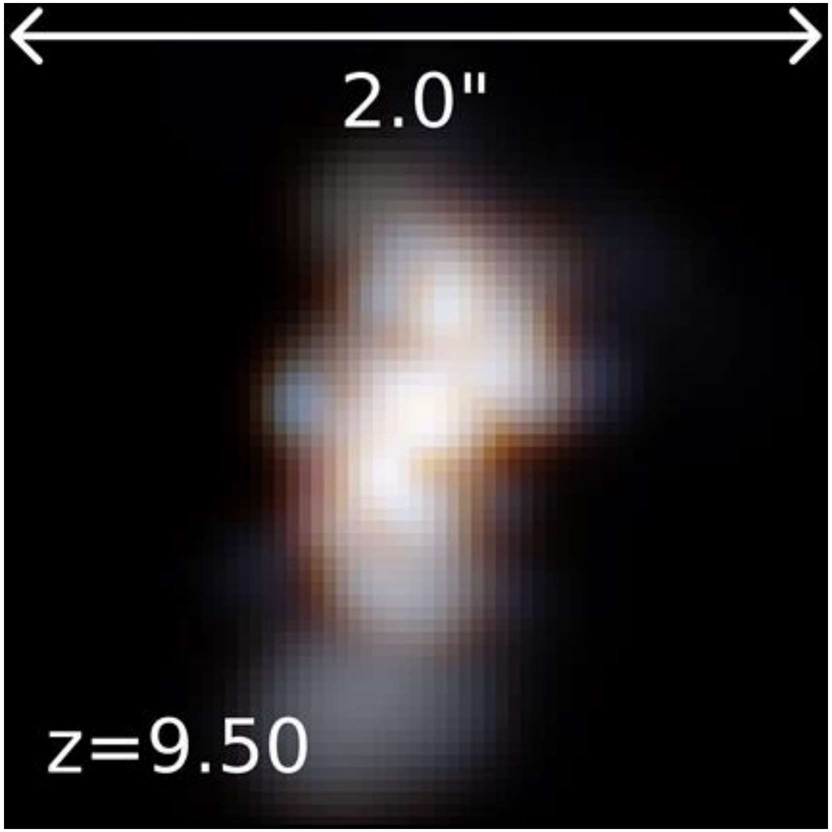
(Lachance et al. 2026)

The black hole seeding prescription matters: we have also run a new simulation (AMBRA) to z=5 with a different prescription



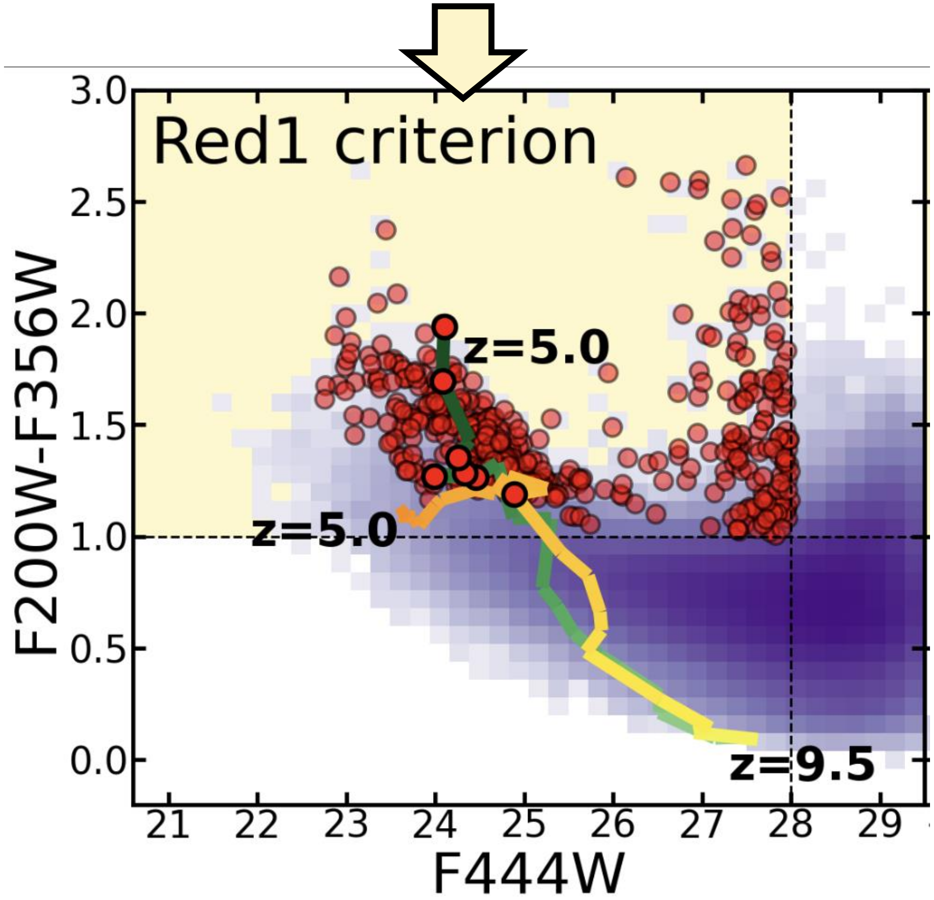
AMBRA modifies the ASTRID simulation, eliminating the halo-mass threshold for seeding and allowing seeds in all resolvable halos where active star formation and low-metallicity gas occur.

Many galaxies in AMBRA and (to a lesser extent Astrid) have LRD phases

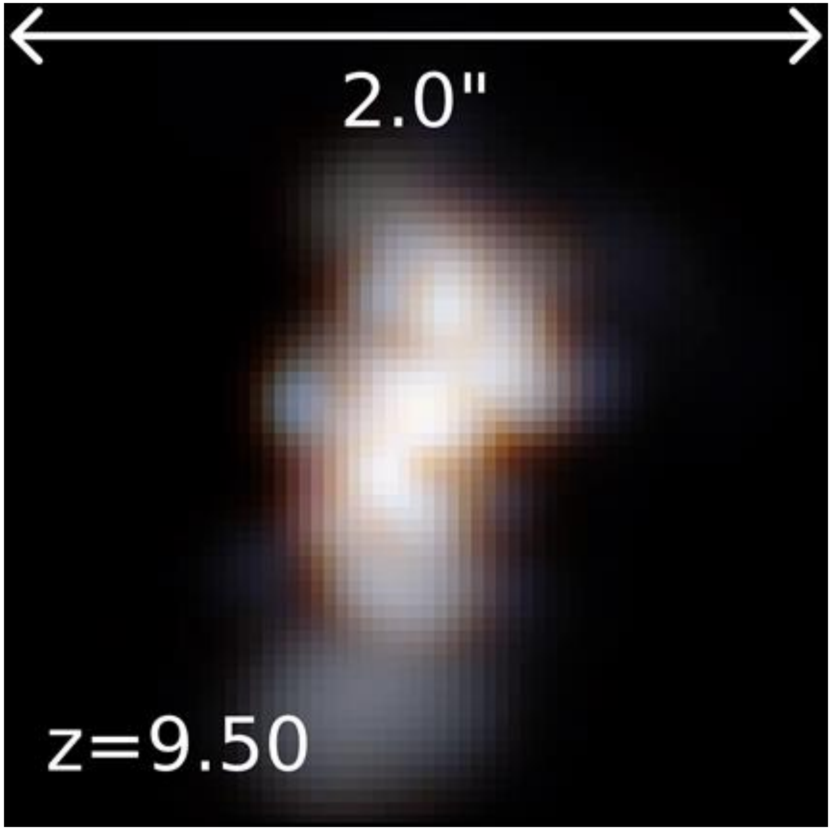


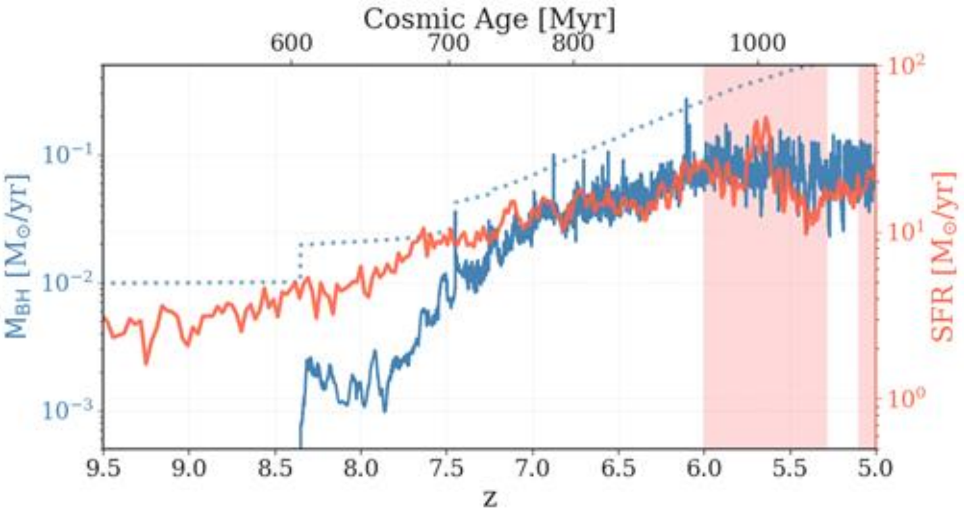
simulated JWST image

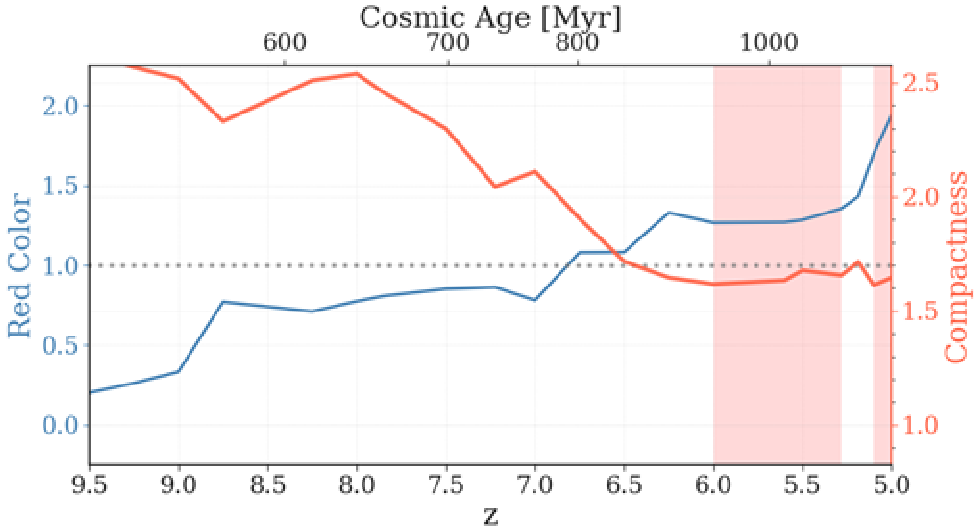
An LRD color-magnitude criterion



LRD phases happen when star formation is quenched, black hole is gas enshrouded, and galaxy is isolated



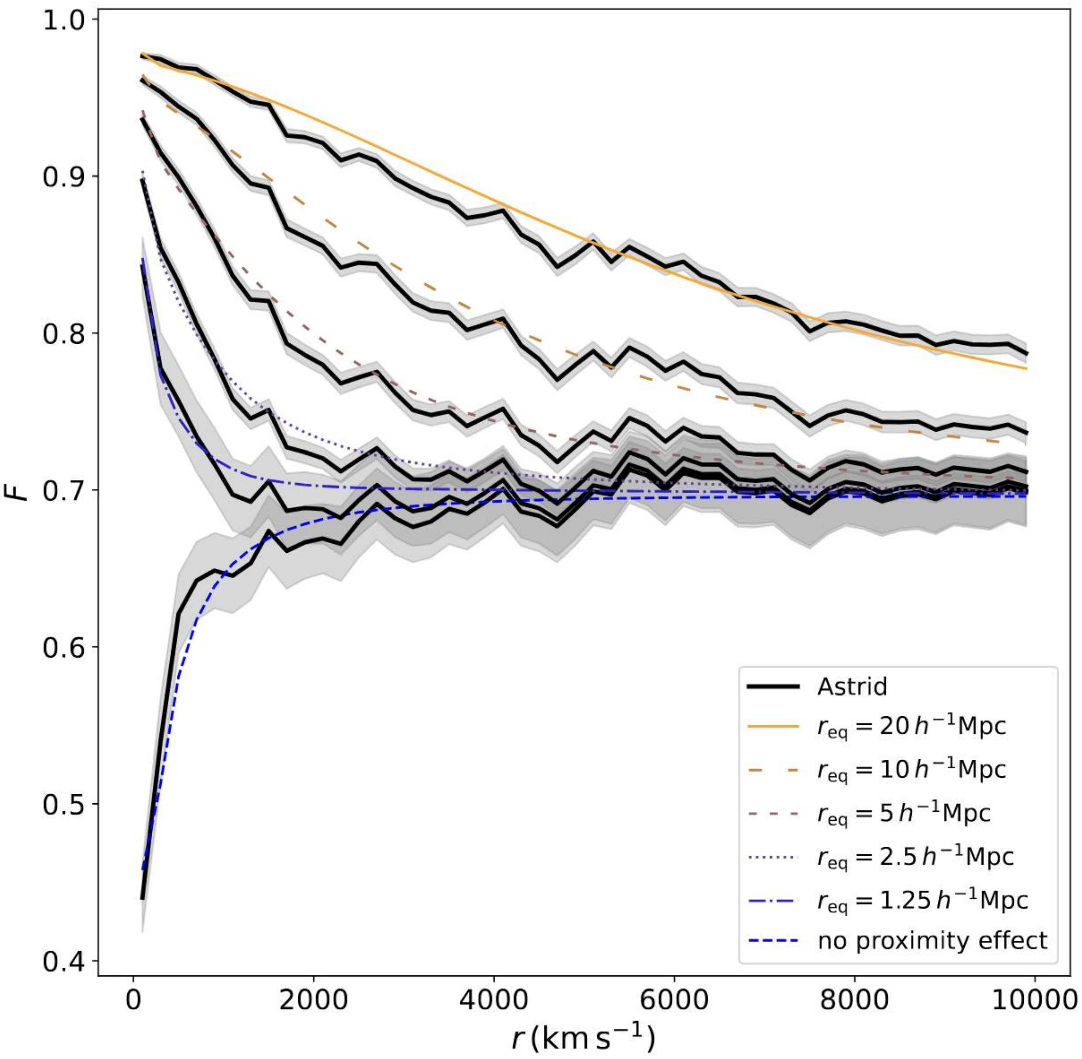




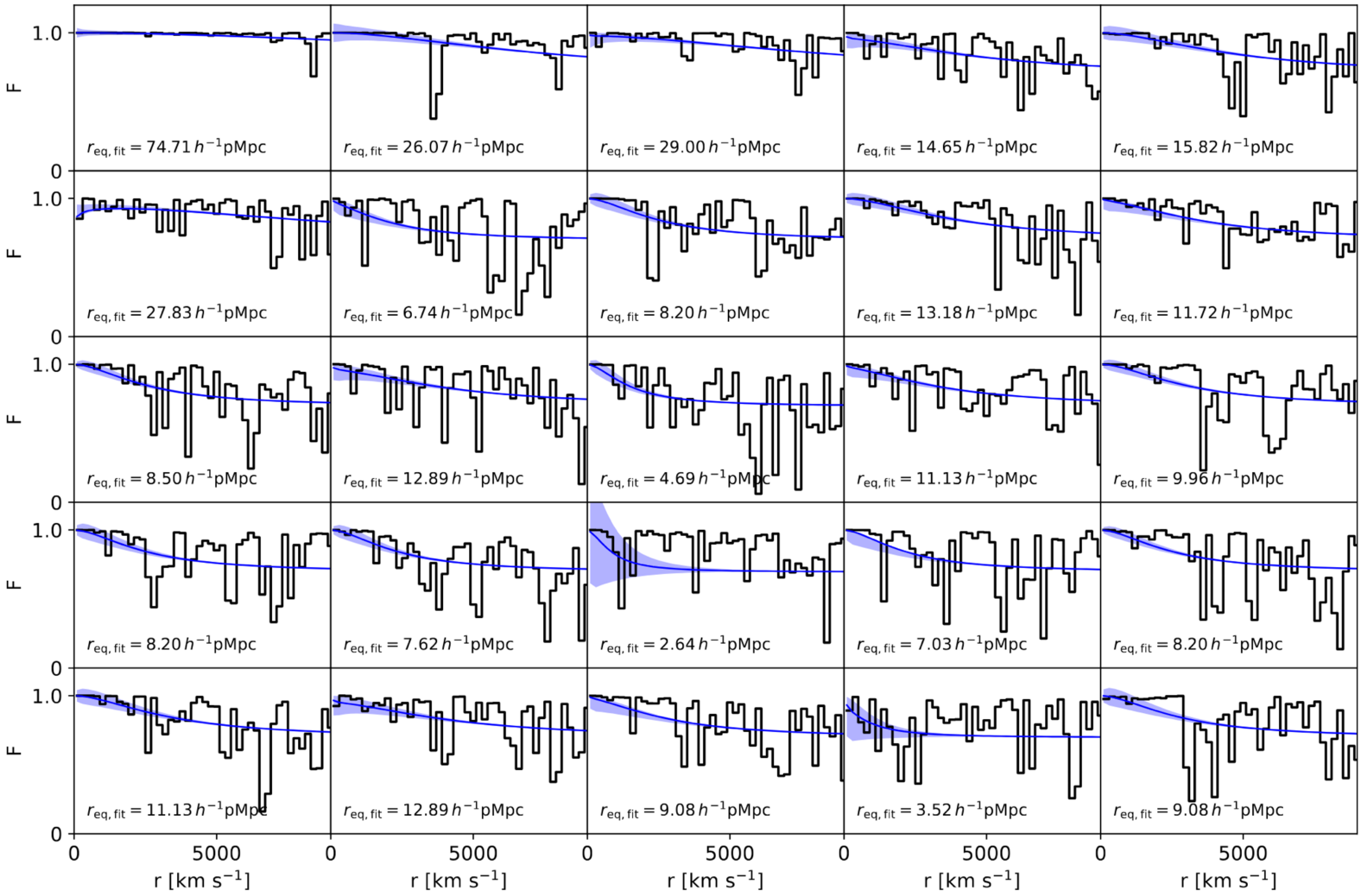
back to quasars and the proximity effect:

testing halo model vs simulation data

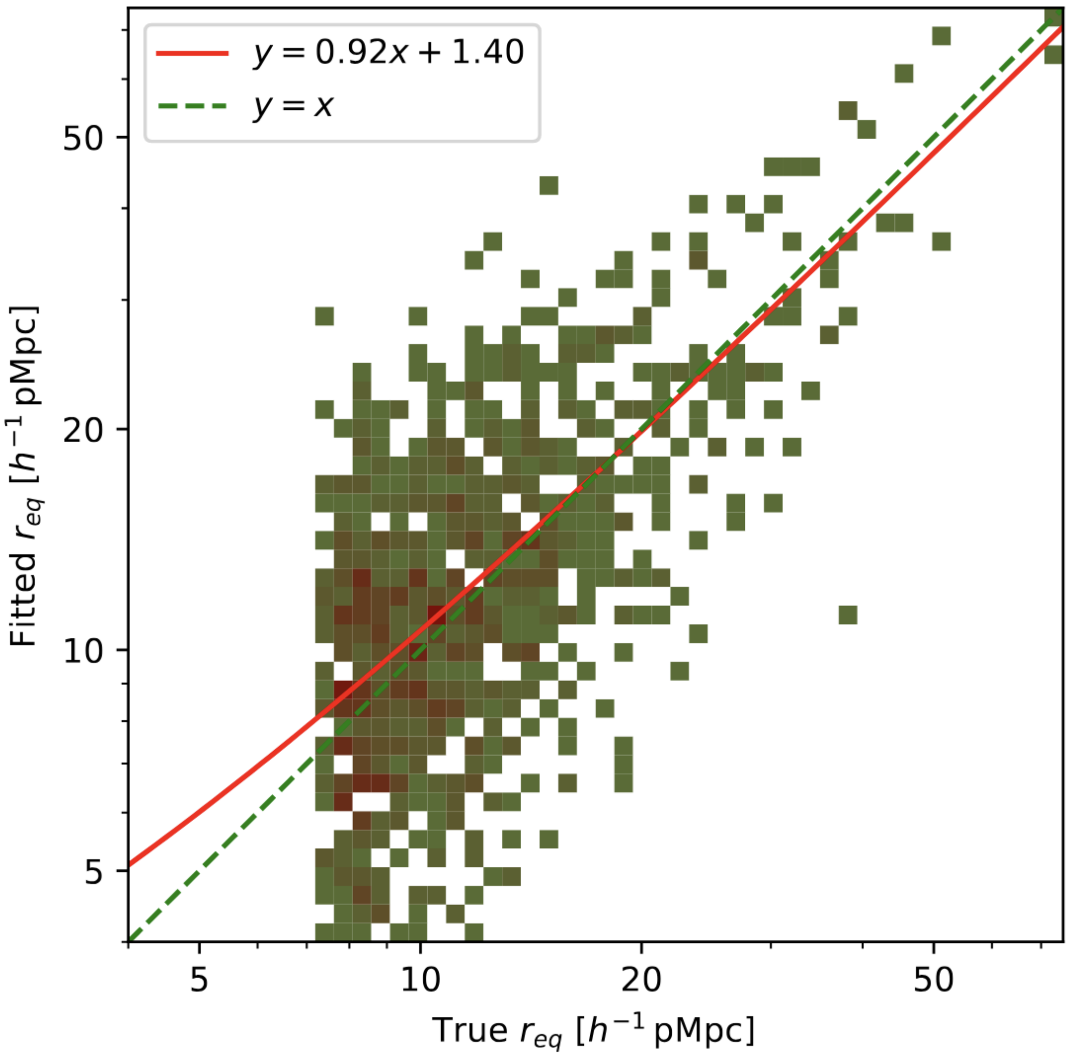
The halo model mean Lya forest profiles match the Astrid simulation quasar results:



That was the mean profiles – the profiles for individual quasars are much noisier:

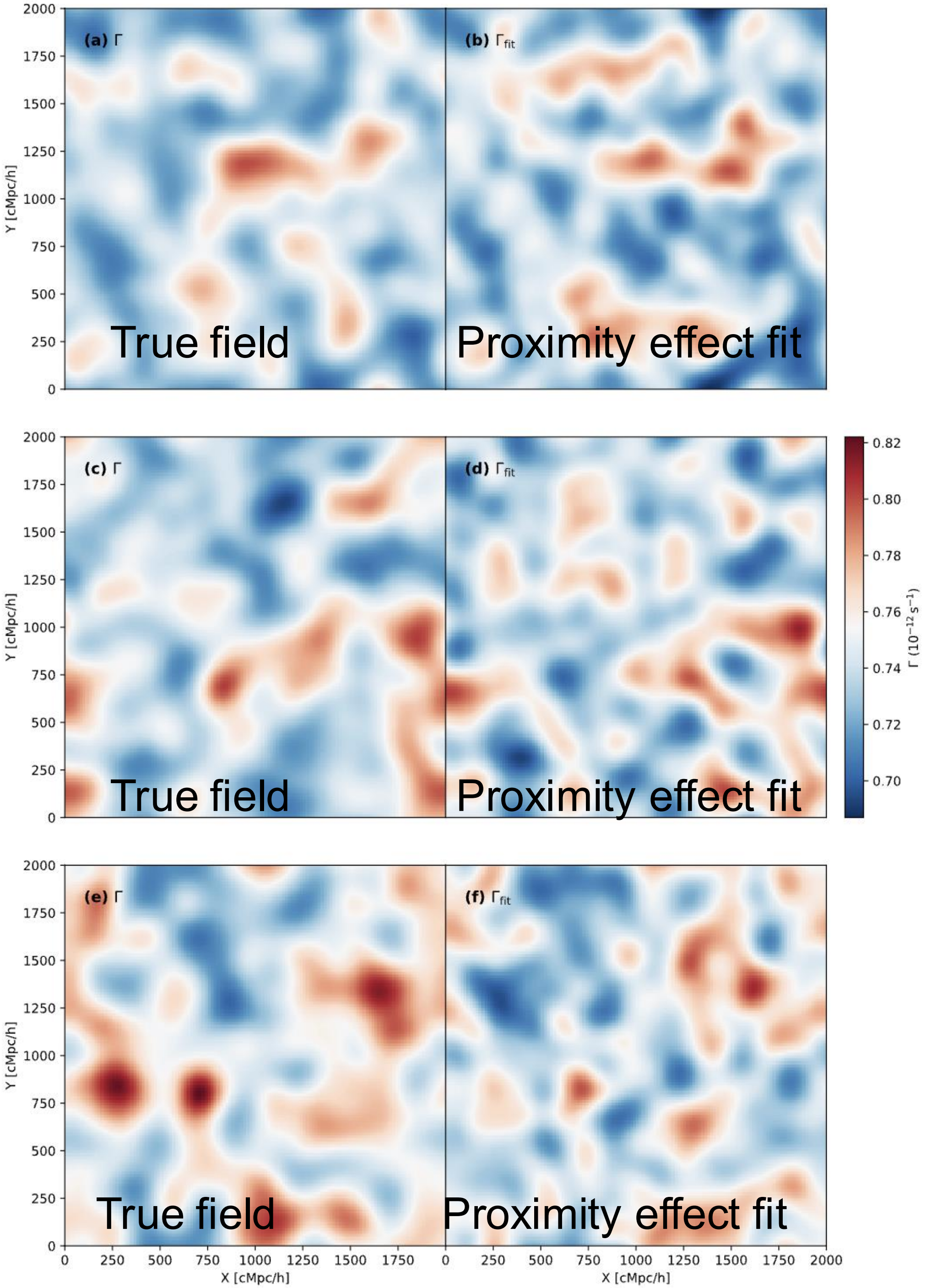


With an individual quasar spectrum we can measure r_{eq} and hence the radiation intensity at that point with 20-50% accuracy:

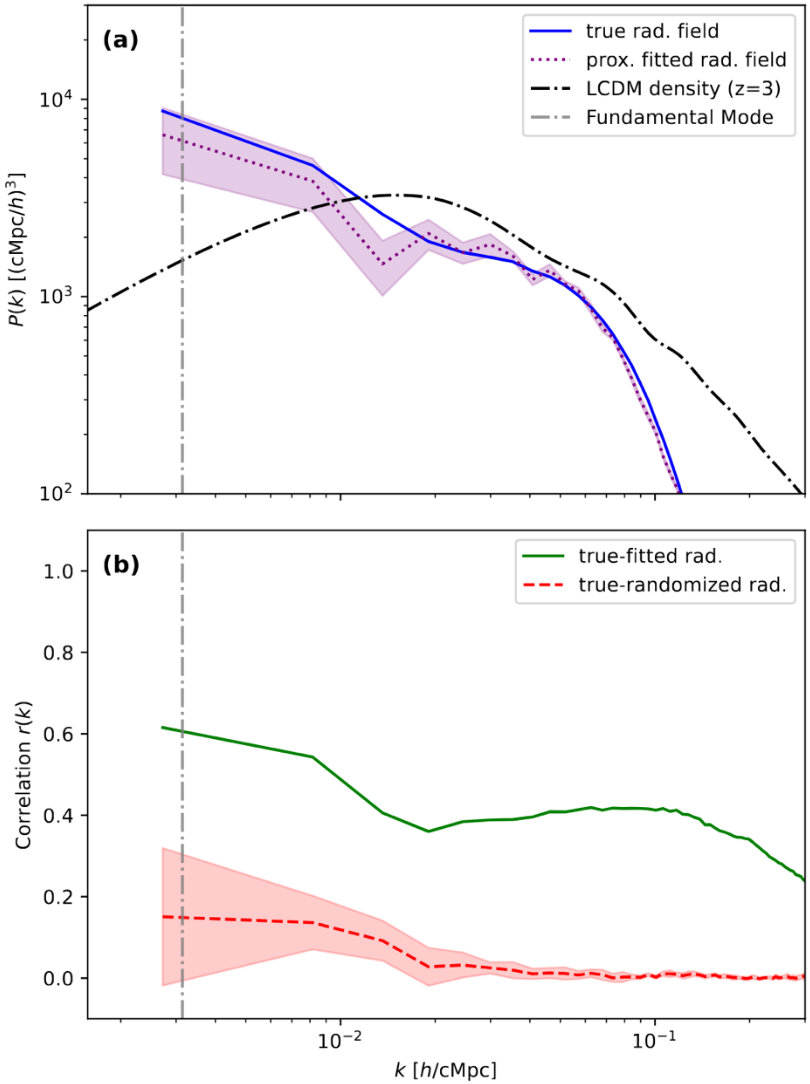


Three slices through the intergalactic radiation field in a simulation:

we can measure structure in the radiation field on 100-1000 Mpc scales.

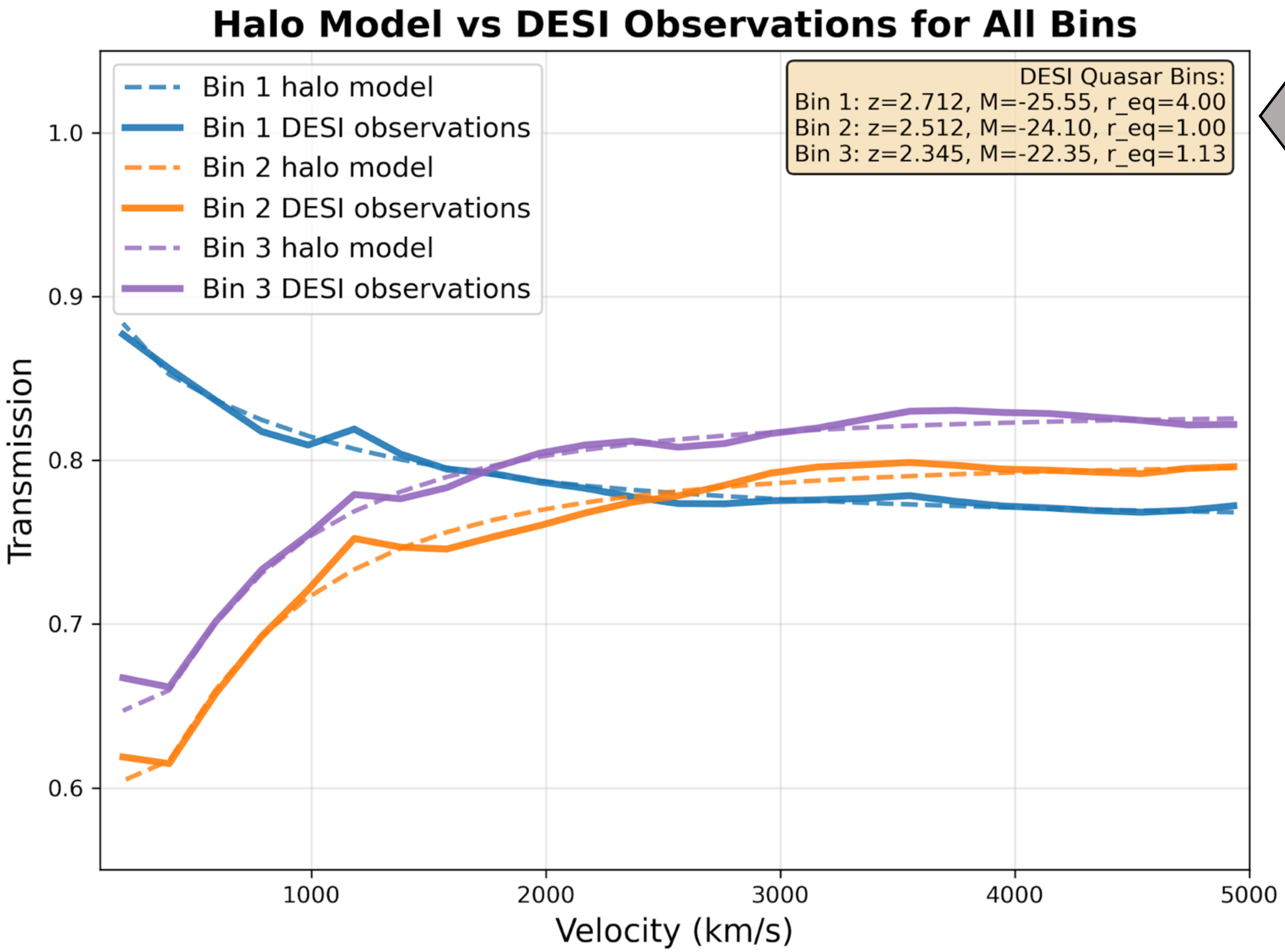


We could measure the power spectrum of the intergalactic radiation field on 100-1000 Mpc scales : a new tool for cosmology.



Work in progress- first measurements from DESI DR1 observations vs halo model:

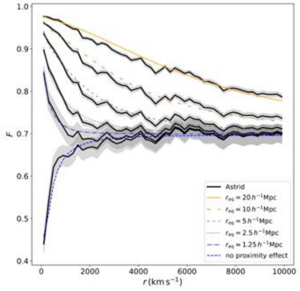
F



3 luminosity bins

15,000 quasars in total

(like simulation results:)

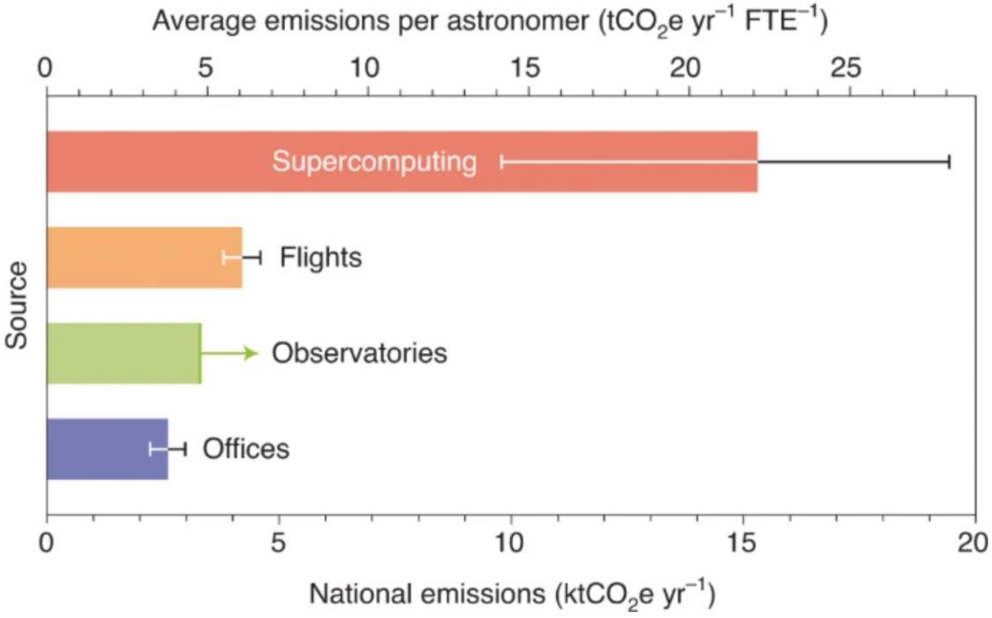


Shaw et al. (in prep)

Back to AI for one last point...

Astrophysics simulations already use enormous amounts of energy: AI could make this worse.

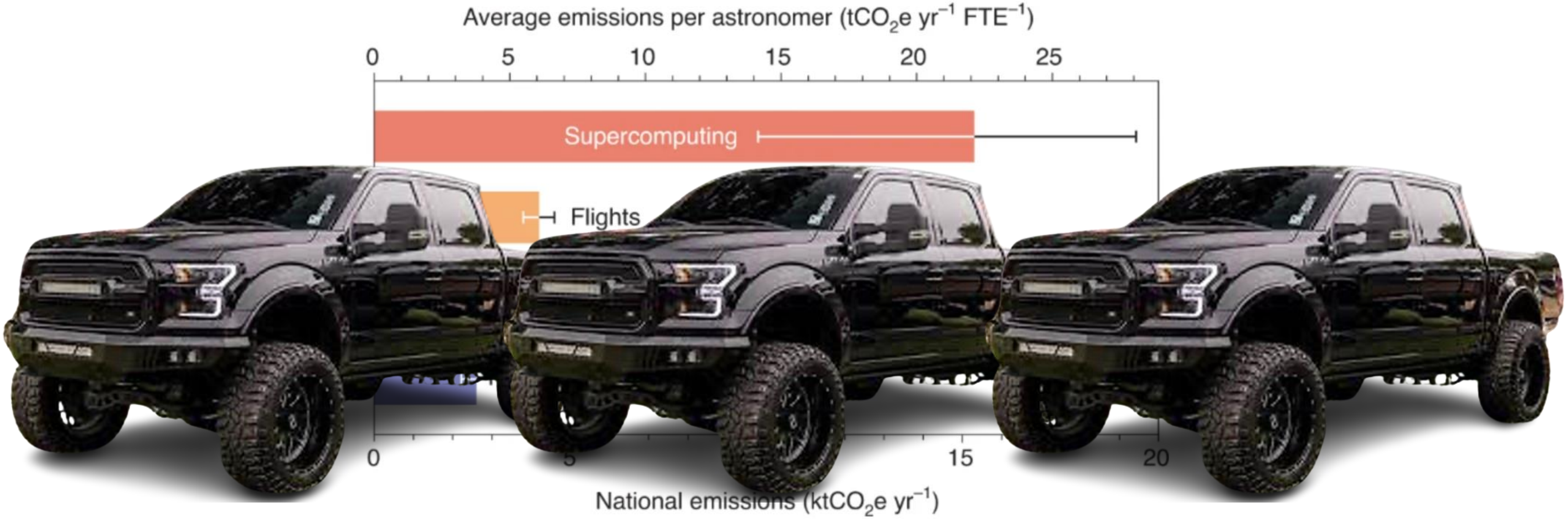
Greenhouse gases associated with astronomy:



Stevens et al. 2020 (for Australian astronomers) : 400 million core hours for 700 researchers

Astrophysics simulations already use enormous amounts of energy: DL could make this worse.

Greenhouse gases associated with astronomy:



Supercomputing use per average astronomer equivalent to driving three Ford F150s

Or LBNL equivalent: each astronomer driving their own Berkeley Shuttle:

There is room to improve: AlphaGo uses 50,000x more energy than Lee Sedol, World Go Champion

power
consumption:

10^6 watts

power
consumption:

20 watts

Conclusions

- Next steps for AI super-resolution emulator: star formation, black holes
- Mock catalogs of full sky surveys with Lyα resolution could be made using AI super-resolution techniques (10^{14} particle hydrodynamics)
- DESI should lead to a ~4σ first detection of Lyα weak lensing and DESI 2 will do much better in the future
- DESI will map out the intergalactic radiation field with proximity effect
- We should try to develop AI that will help us do our jobs, not replace us!