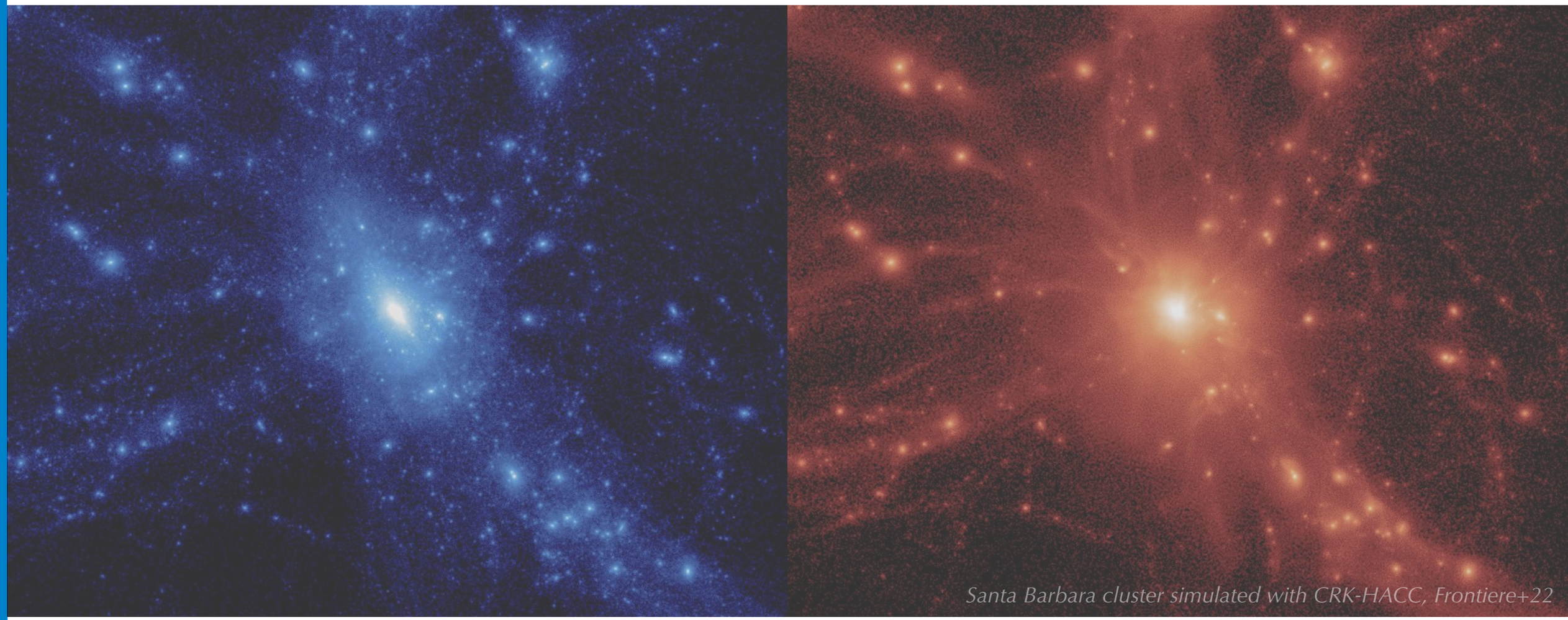

OPTIMIZATION AND QUALITY ASSESSMENT OF BARYON PASTING FOR INTRACLUSTER GAS

Florian Kéruzoré, Argonne National Laboratory
CMB-S4 Summer collaboration meeting, Aug 2023

Kéruzoré et al., arXiv:2306.13807

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

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CONTEXT

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- Clusters = powerful cosmology / astrophysics probe *(see cluster session on Wednesday)*
  - Millimeter-wave: thermal SZ detection *(see F. McCarthy's talk earlier)*
  - Needs simulations to calibrate analyses *(see J. Liu's talk earlier)*
- Argonne produces state of the art simulations w/ HACC *(Habib+16, Frontiere+23)*

Year	Simulation	Code, Algorithm	Supercomputer, Location	Cores [10^3]	N_p [10^{12}]	Box [h^{-1}Gpc]	
2014	Dark Sky (Skillman et al. 2014)	2HOT FMM	Titan USA	20	1.1	8	
2017	TianNu (Emberson et al. 2017)	CUBEP^{3}M PM-PM-PP	Tianhe-2 China	331	2.97	1.2	
2017	Euclid Flagship (Potter et al. 2017)	PKDGRAV3 Tree-FMM	PizDaint Switzerland	4	2.0	3.	
2019	Outer Rim (Heitmann et al. 2019)	HACC Tree-PM	Mira USA	524	1.07	3.0	ANL
2019	Cosmo-π (Cheng et al. 2020)	CUBE PM-PM	π 2.0 China	20	4.39	3.2	
2020	Uchuu (Ishiyama et al. 2021)	GREEM Tree-PM	ATERUI-II Japan	<40	2.0	2.0	
2020	Last Journey (Heitmann et al. 2021)	HACC Tree-PM	Mira USA	524	1.24	3.4	ANL
2021	Far Point (Frontiere et al. 2021)	HACC Tree-PM	Summit USA	?	1.86	1	

Table 1 List of cosmological simulations with a particle number in excess of 1 trillion (10^{12})

Angulo+23

CLUSTER OBSERVABLES IN GRAVITY-ONLY SIMS

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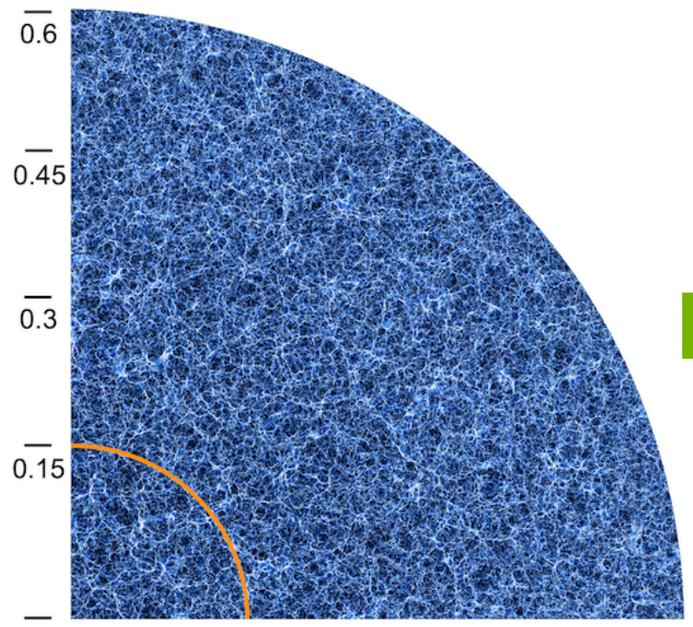
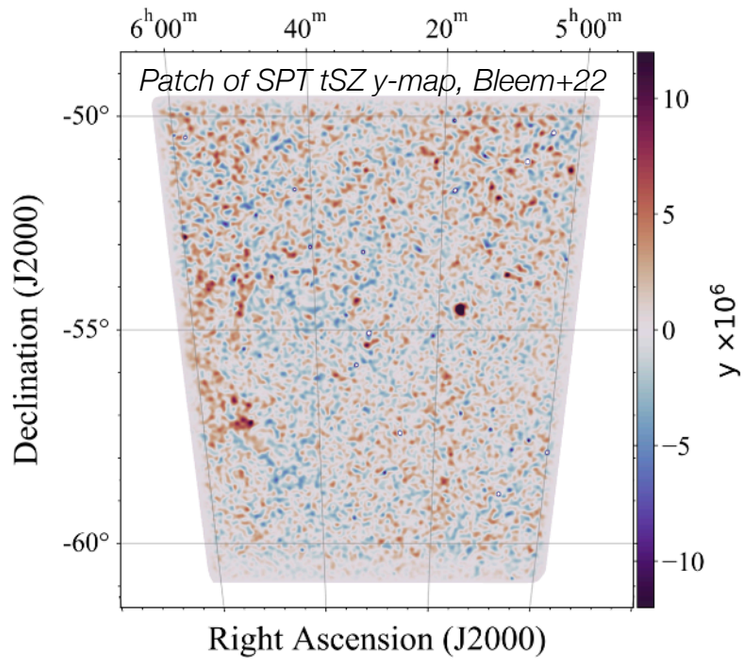
- In particular: **gravity-only (GO)** simulations
  - ☺ **More efficient** than hydro simulations
  - ☹ **No gas** = no SZ



Farpoint GO CDM distribution. Frontiere+22



- **Baryon pasting (BP):** add gas in GO simulations a posteriori
- **This work:**
  - Implement BP pipeline for ANL simulations
  - Optimize model to reproduce cluster gas properties from hydro simulations

DATA

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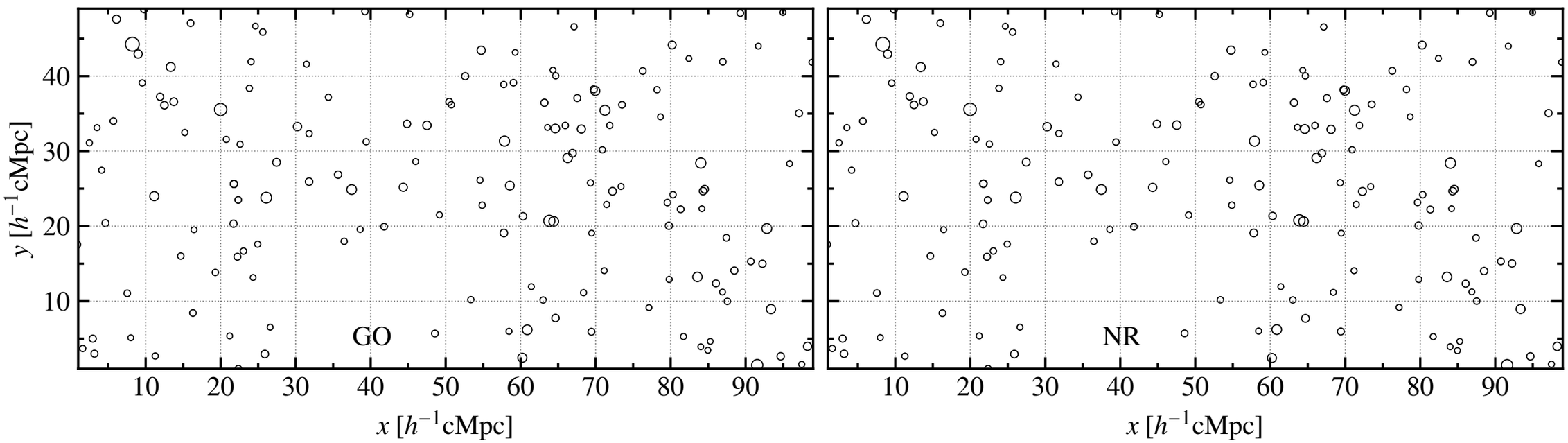
- **Goal:** optimize BP to reproduce hydro simulations gas properties
- **Data: the Borg Cube simulations**
  - Volume = $(800\,h^{-1}\mathrm{cMpc})^3$; particle mass $\lesssim 10^9\,h^{-1}M_\odot$
  - Two simulations with same initial conditions: hydro & GO

    → **True (hydro) gas properties for every GO halo**
  - $z \in \{0, 0.5, 1, 1.5, 2\};\ M_{500} \geqslant 10^{13.5}\,h^{-1}M_\odot$

    → ~40,000 halos

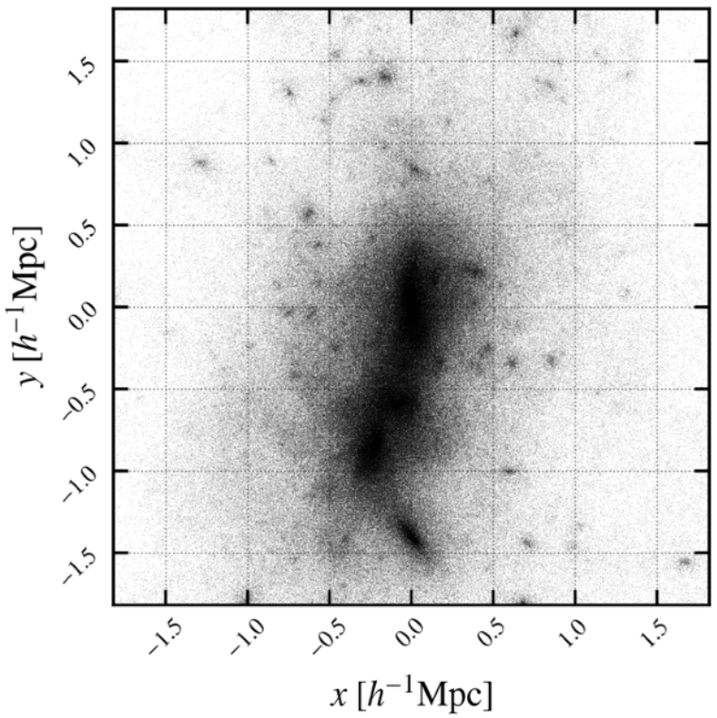
Gravity-only **Hydrodynamic**



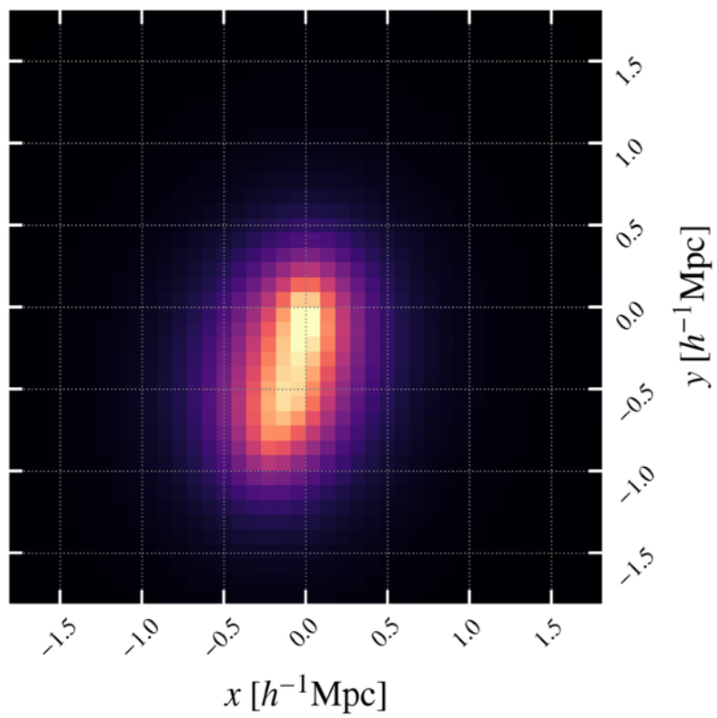
GAS MODEL

- Baryon pasting based on Ostriker+05 3D model
  - On 3D gridded particle distribution — NOT assuming spherical symmetry
  - 2 Model parameters: $(\Gamma, \varepsilon_{\rm DM})$

GO particle distribution



Baryon pasted tSZ map



- Optimization method:
  - Paste for a grid in parameter space
  - Find best-fit parameters for each redshift by comparing pasted/hydro pressures: $\chi_P = \dfrac{P_{\rm g}^{\rm BP}}{P_{\rm g}^{\rm hydro}} - 1$

RESULTS: Z=0 (N=20,120)

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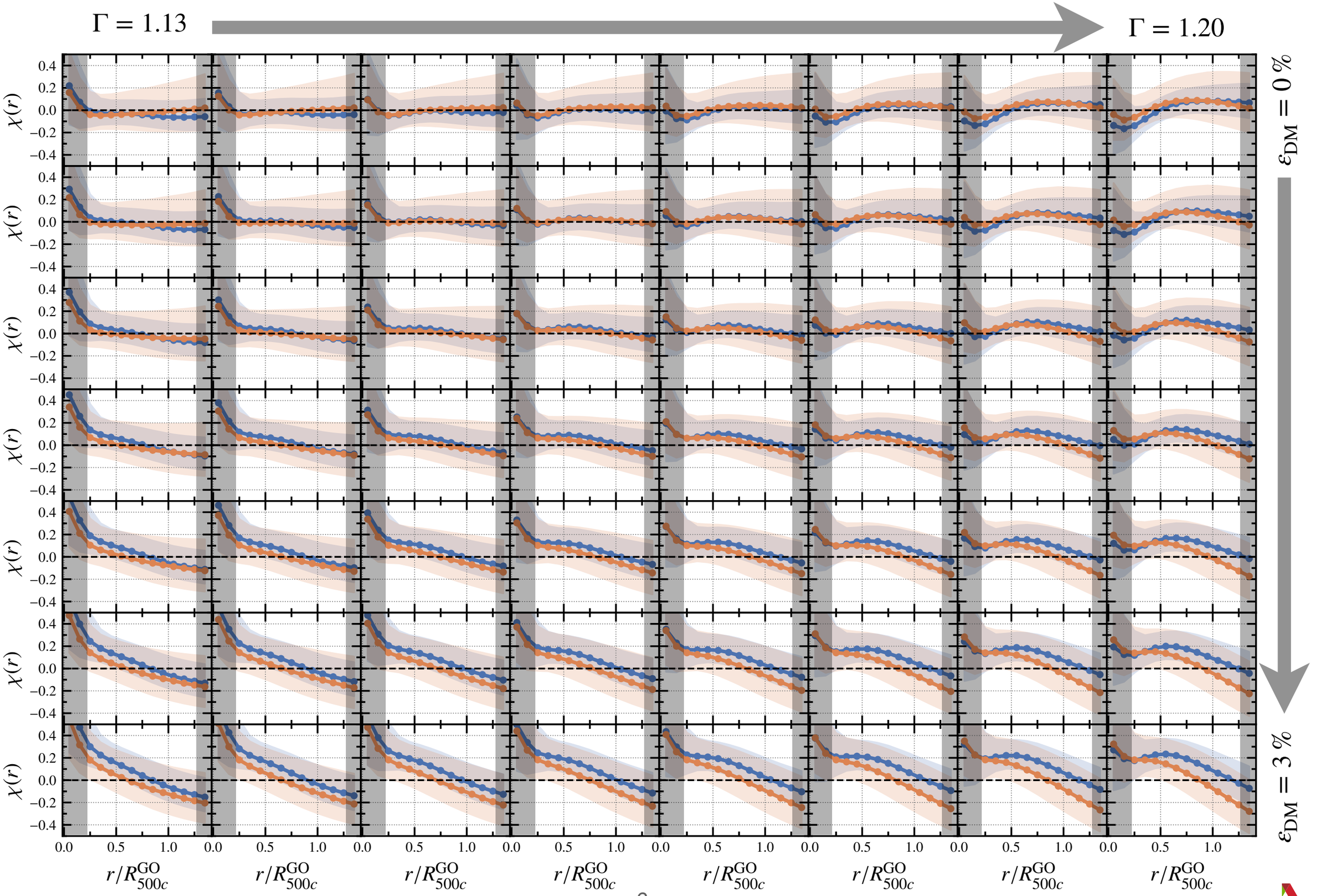
Blue: Density **Orange: Pressure**



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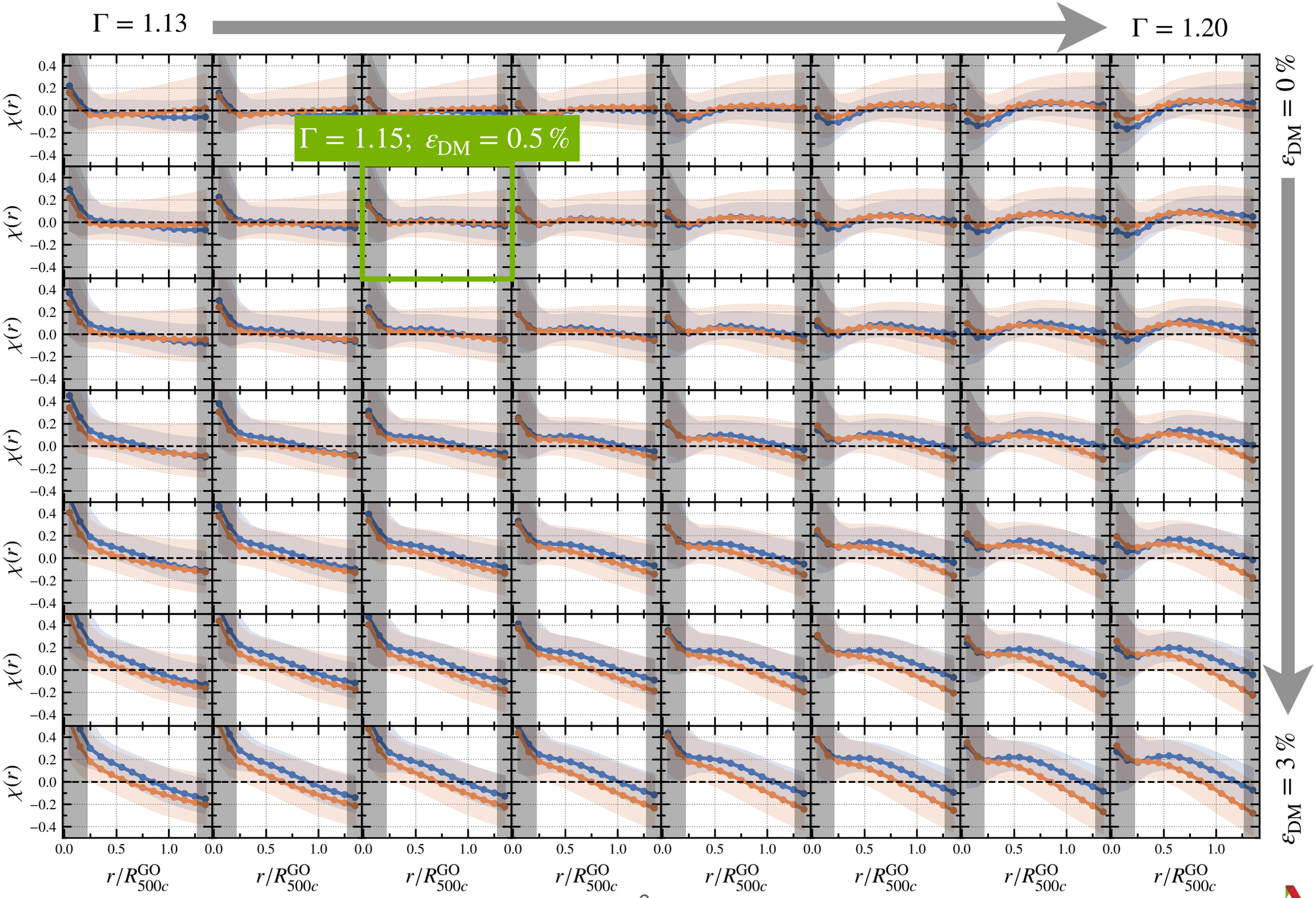

RESULTS: Z=1 (N=4,644)

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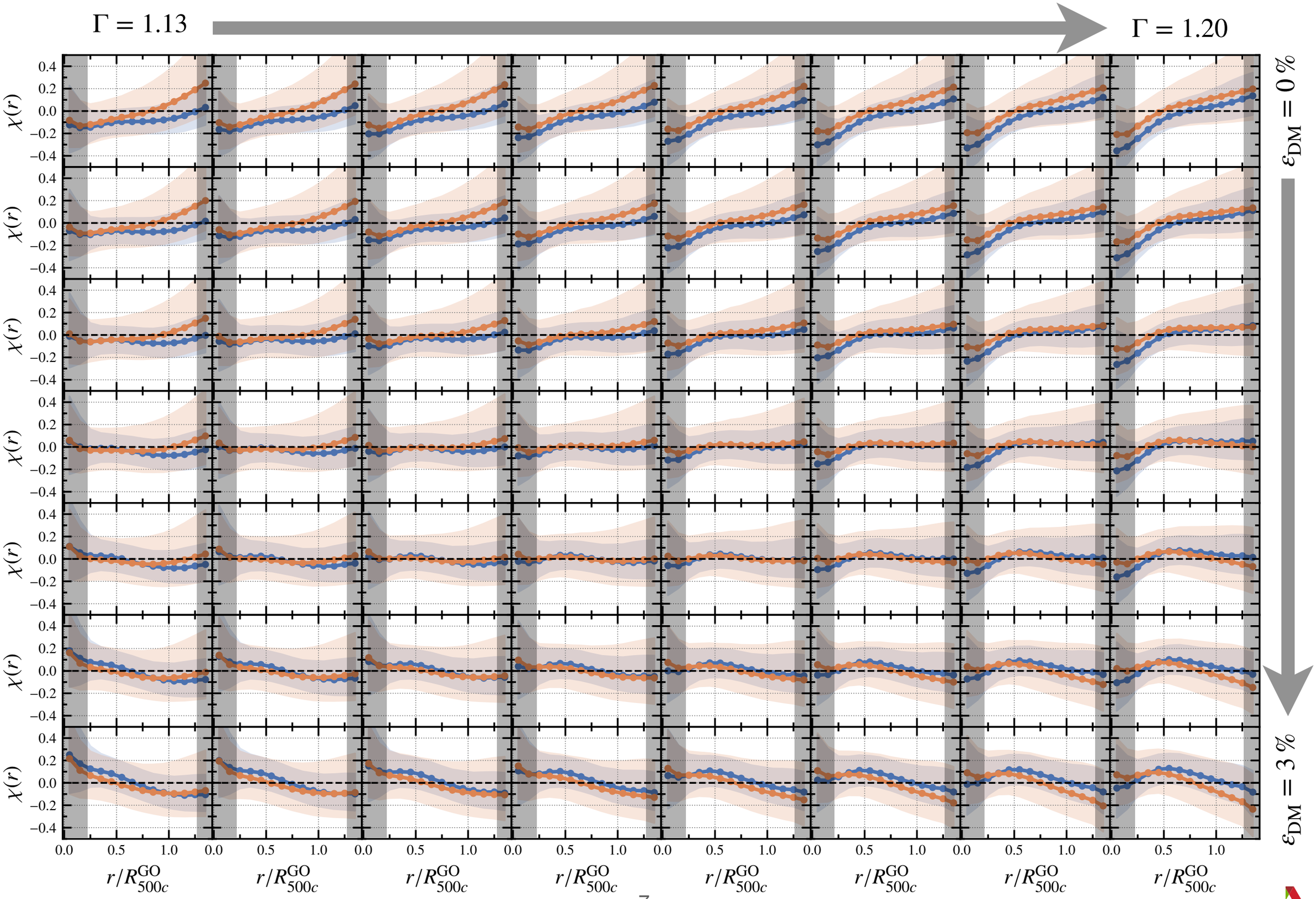
Blue: Density Orange: Pressure



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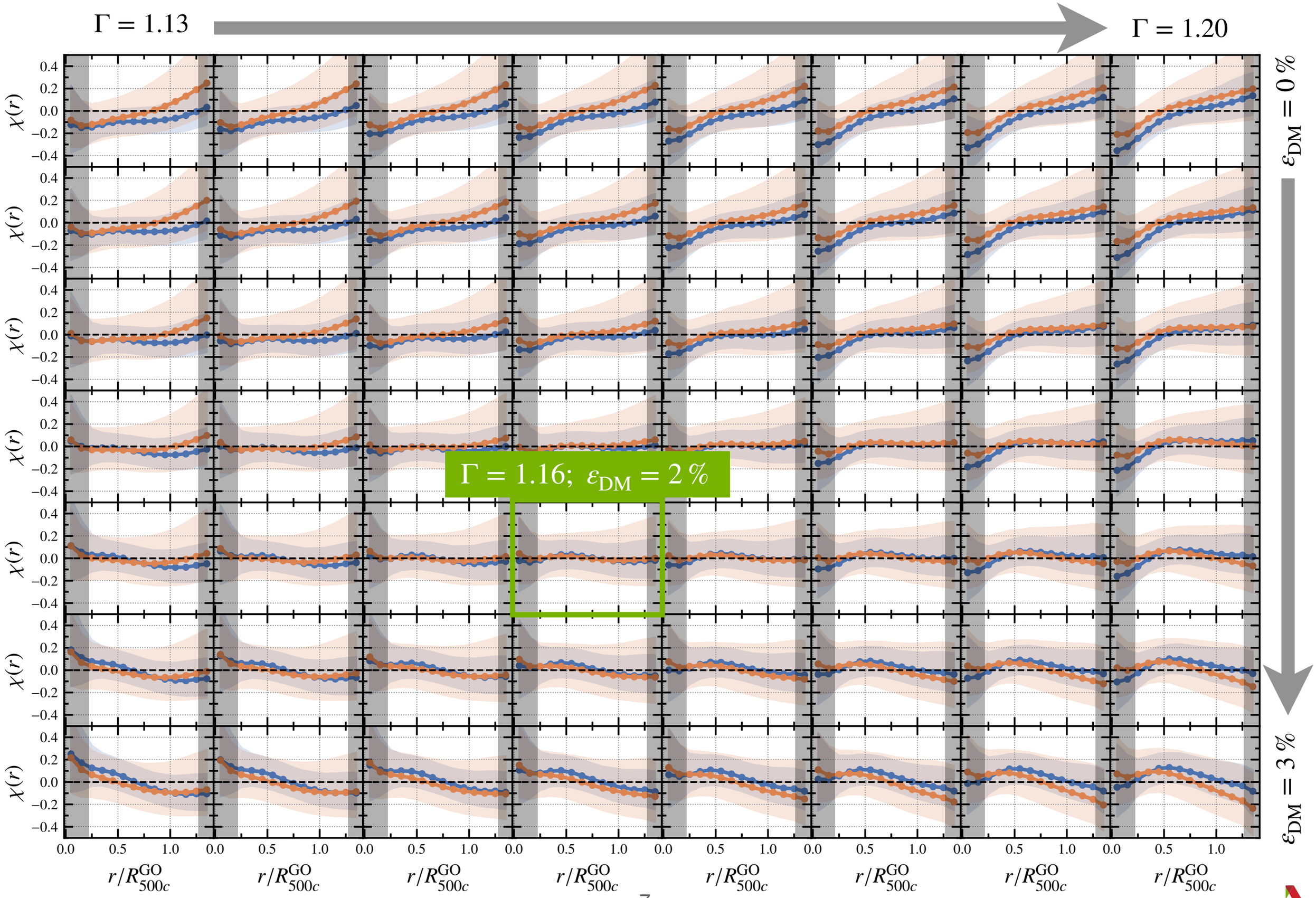
Blue: Density Orange: Pressure



RESULTS: Z=2 (N=260)

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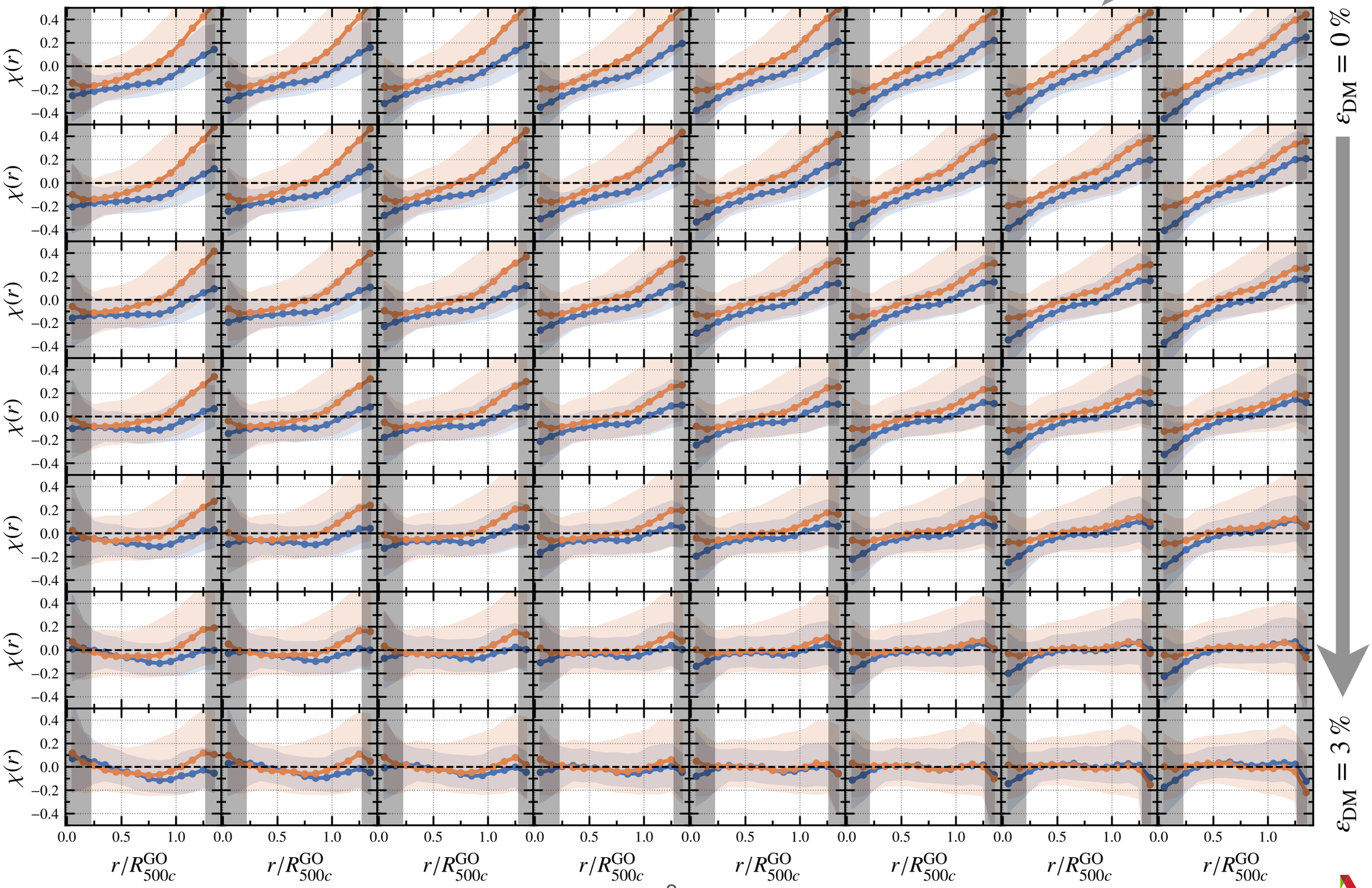
Blue: Density **Orange: Pressure**

$\Gamma = 1.13$ → $\Gamma = 1.20$



RESULTS: Z=2 (N=260)

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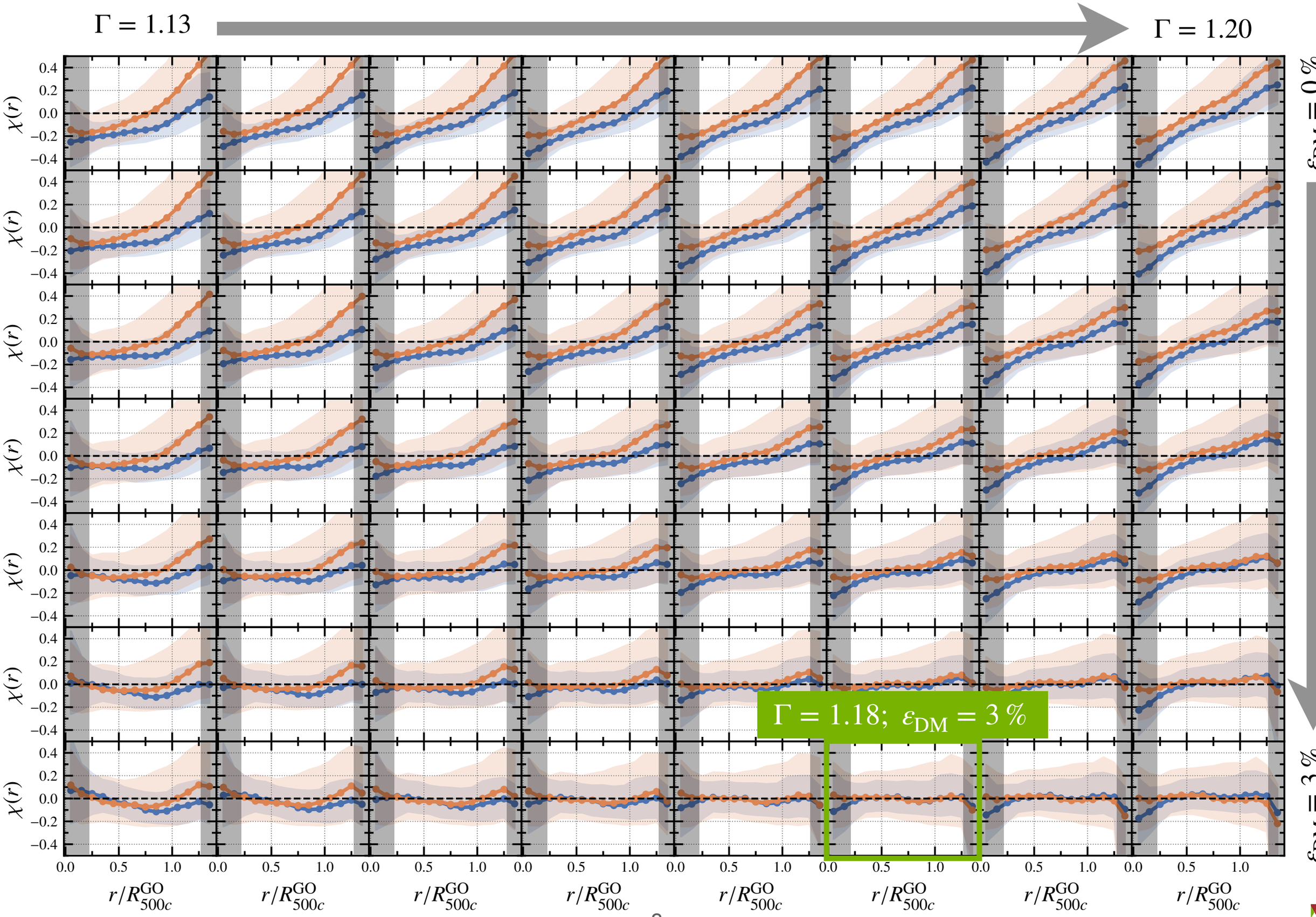
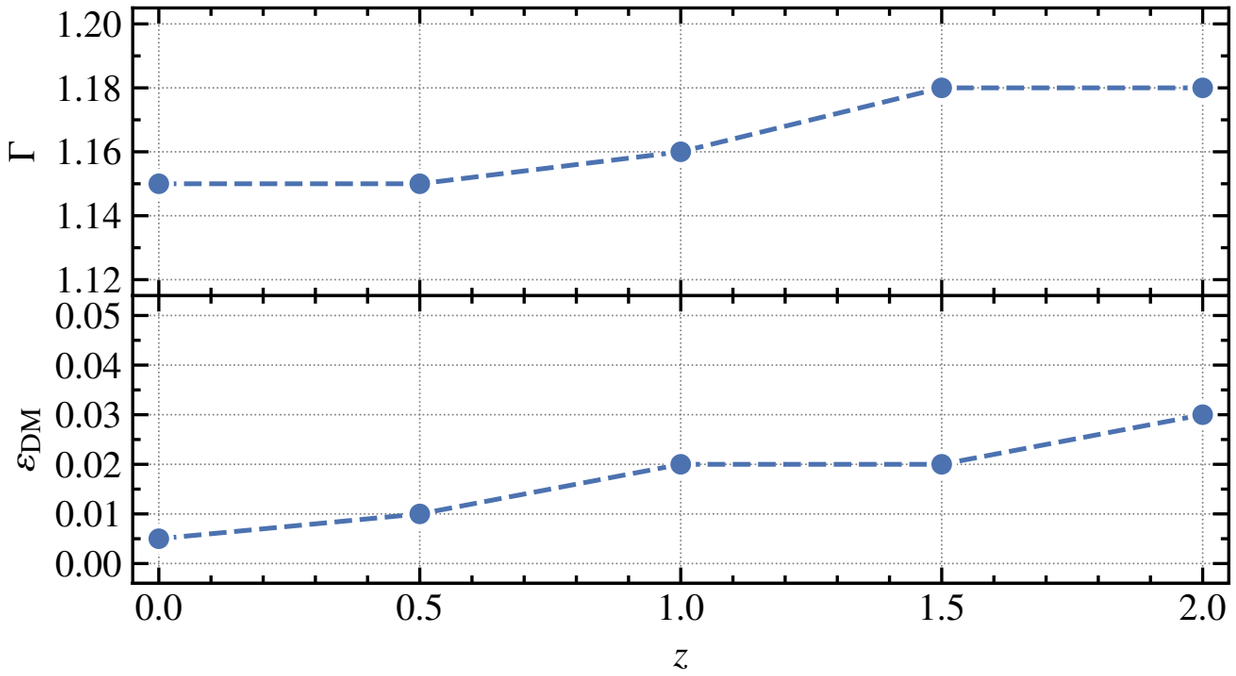


OPTIMIZATION: PARAMS = F(Z)

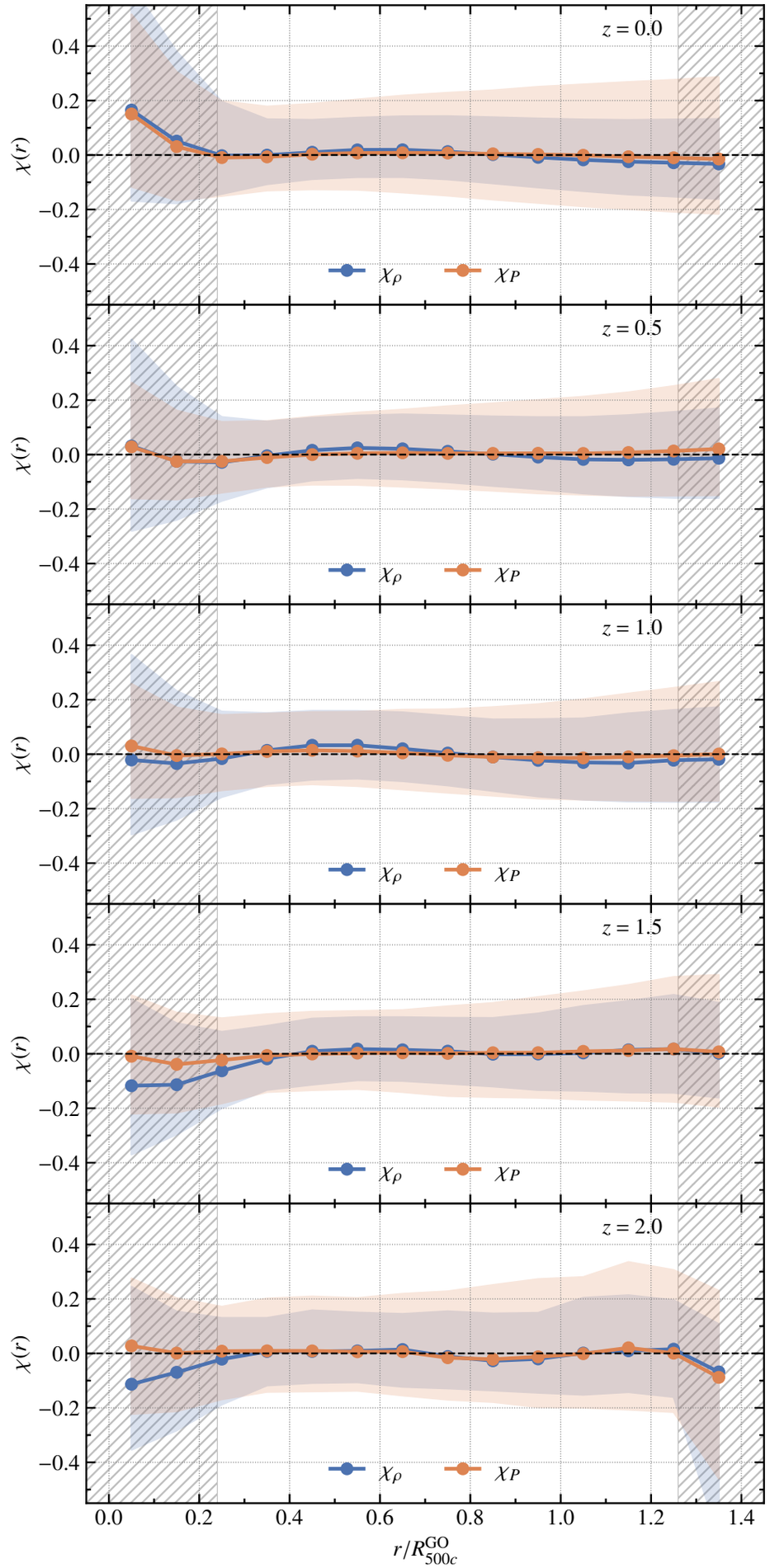


→ **Measured redshift trend in** $(\Gamma, \varepsilon_{\mathrm{DM}})$**:**

- $\Gamma(z = 0) = 1.15 \quad \rightarrow \quad \Gamma(z = 2) = 1.18$
- $\varepsilon_{\mathrm{DM}}(z = 0) = 0.5\,\% \quad \rightarrow \quad \varepsilon_{\mathrm{DM}}(z = 2) = 3\,\%$

QA: GAS PROFILES RECONSTRUCTION

- **Agreement between density and pressure:**
  - For the best parameters at each z
  - Focusing on $r \in [0.25, 1.25]\, R_{500c}$
- **Accuracy:**
  - $< 2\,\%$ difference on pressure
  - $< 3\,\%$ difference on density
- **Scatter:**
  - $\sim 20\,\%$ on pressure
  - $\sim 15\,\%$ on density



QA: $Y_{500}|M_{500}$ SCALING RELATION RECONSTRUCTION

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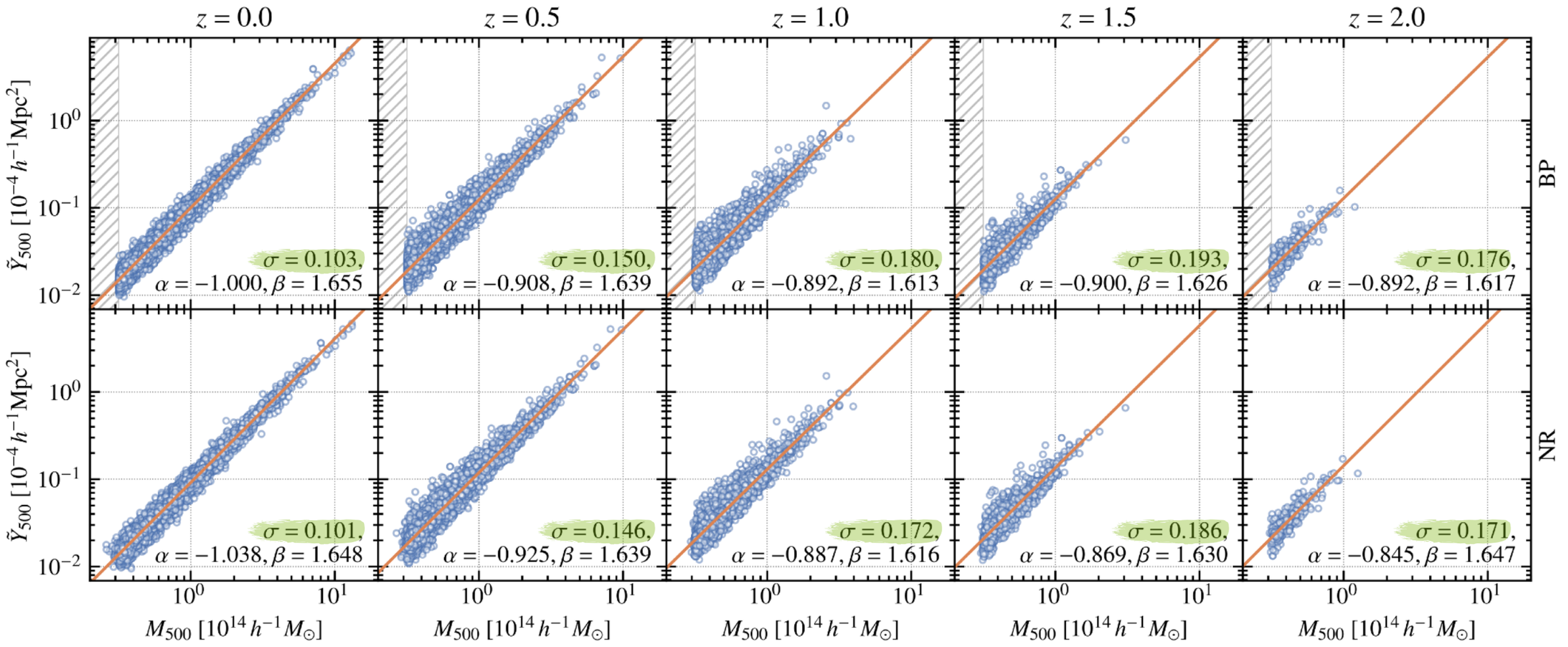
$$E^{-2/3}(z)\frac{D_{\rm A}^2\, Y_{500}}{10^{-4}\ h^{-1}{\rm Mpc}^2} = 10^{\alpha}\left[\frac{M_{500}}{3\times10^{14}\ h^{-1}{\rm M}_{\odot}}\right]^{\beta} + \mathcal{N}(0,\sigma^2)$$

- Compare YIM from BP (top) vs hydro (bottom):
  - Similar reconstructed parameters
  - Extra scatter due to baryon pasting: $< 5\,\%$ of hydro scatter



FIRST LOOK AT TSZ THUMBNAILS

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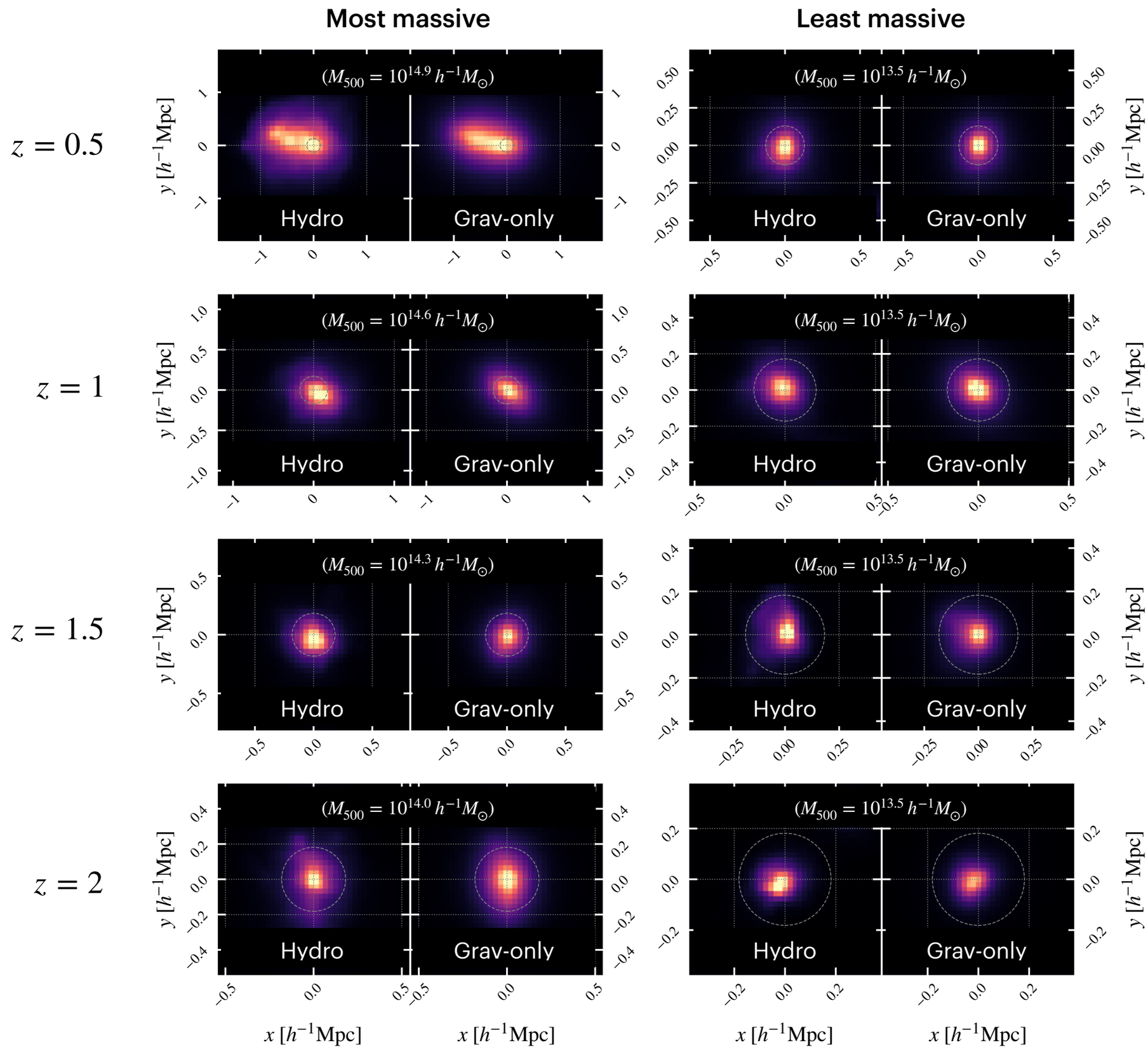

(Circle = 1′)

CONCLUSIONS, NEXT STEPS

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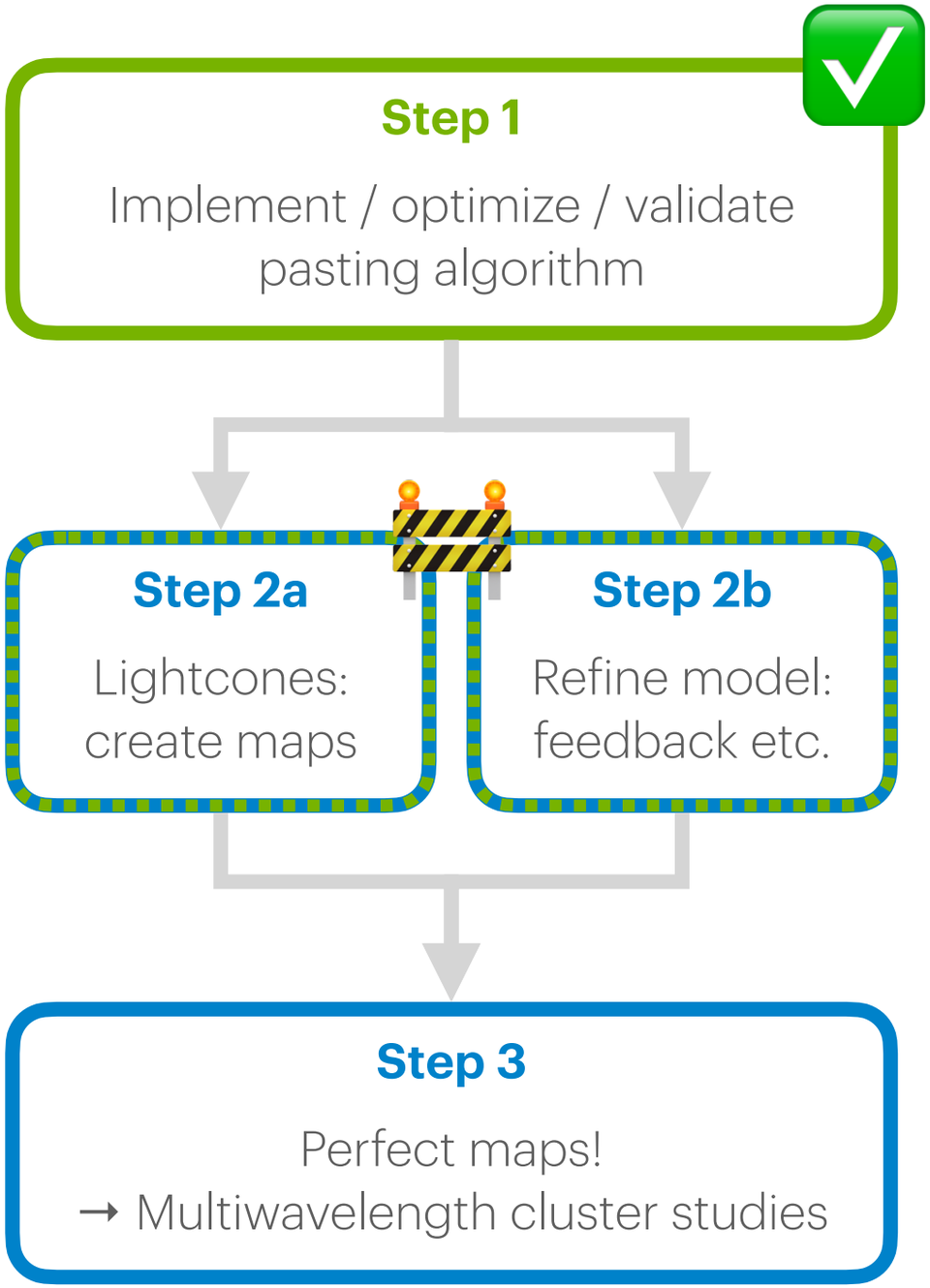

- Validation / optimization of baryon pasting on hydro sims:
  - Few-% bias, ~20% scatter on gas pressure
  - Small excess scatter on YIM scaling relation
  - → First paper out! arXiv:2306.13807
- Baryon pasted maps from ANL simulations on the way!
  - Potential for cross studies: ANL sims come with optical observables, lensing maps, …
  - Next steps:
    - Refine model (feedback / star formation) + Validate on observations
    - Maps