NAM workshop 2025.07.09

Intracluster Light as a Probe for Dark Matter: Exploring SIDM and CDM with C-EAGLE Sim

KIAS KOREA INSTITUTE FOR ADVANCED STUDY

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Self-Interacting Dark Matter

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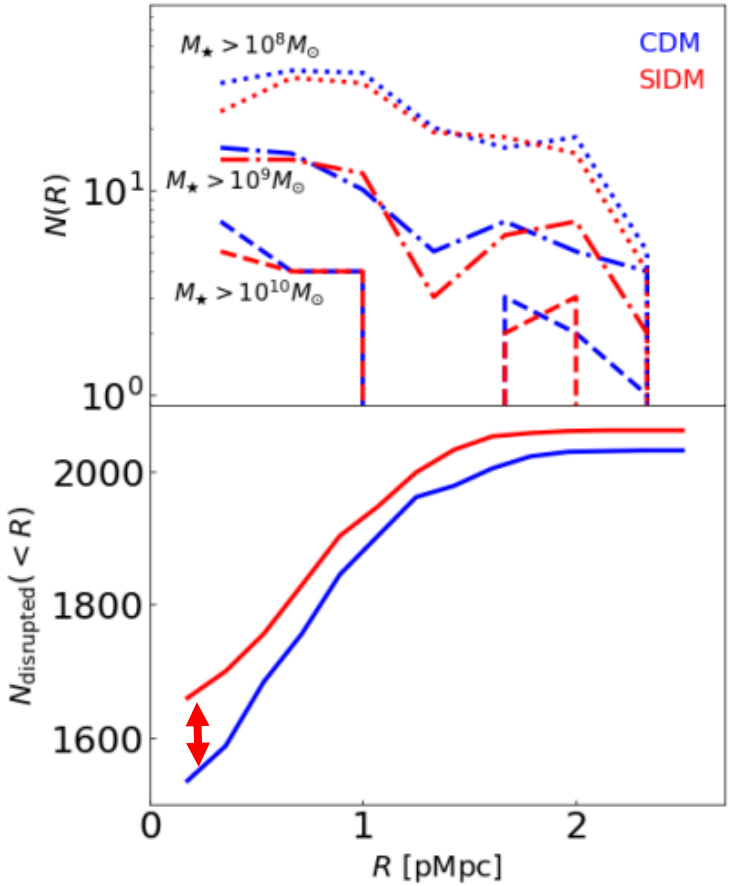
Self-Interacting Dark Matter (SIDM)

- Resolve tensions between simulations and observations on small scales.
- C-EAGLE simulation CDM/SIDM cluster with the same initial condition
- Cross Section

$$\sigma/m = 1 cm^2 g^{-1} \qquad P_{scat} = \frac{(\sigma/m) m_{DM} v \Delta t}{\frac{4\pi}{3} h_{SI}^3}$$

- DM scattered → Additional tidal stripping!
- Different tidal interaction history (~30% different)
  → Different ICL formation?



E. L. Sirks et al. 2022 MNRAS, 511, 4

Galaxy Cluster Components

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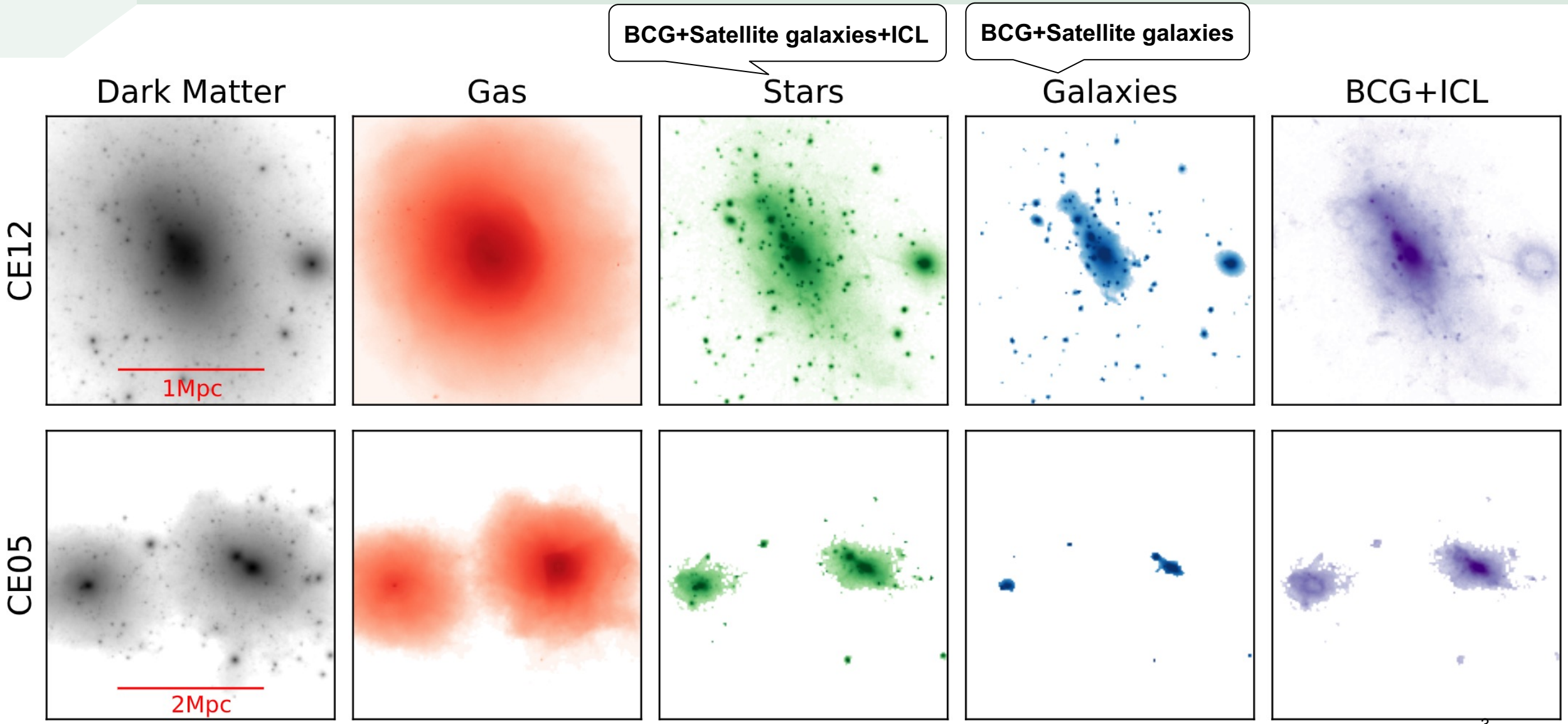

Comparison of Spatial Distribution

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- ***Can you tell how similar those maps are, in a number?***

WOC method

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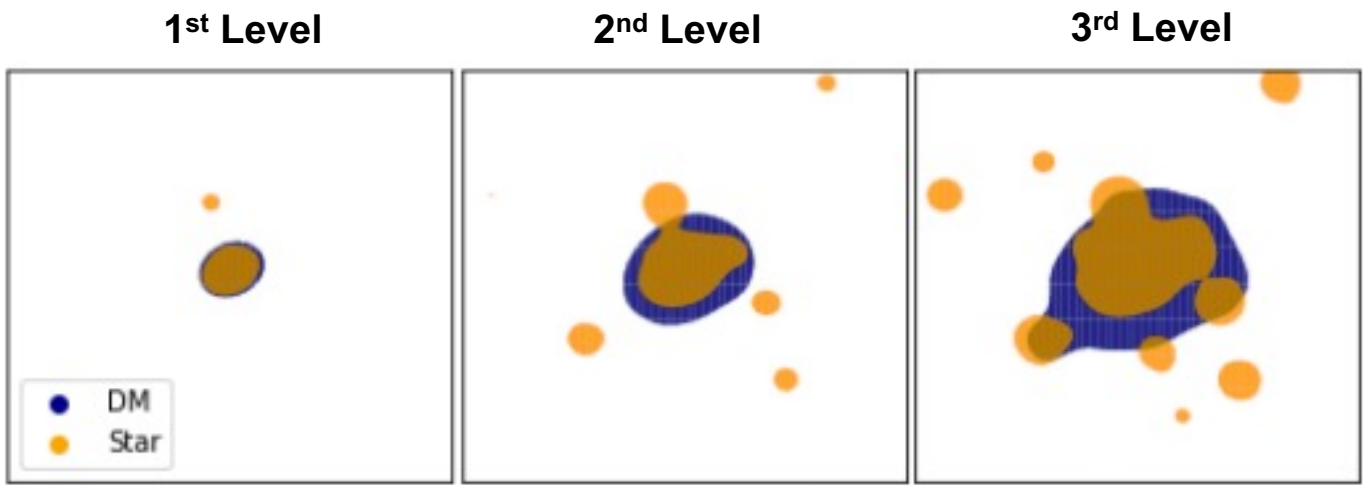
Give Weight to the Overlapping Area



Yoo et al. 2022, ApJS, 261, 28

Weighted Overlap Coefficient

$$\mathrm{WOC}(A,B) = \frac{\sum_{i=1}^{n} f_i\,(w_i + w_{\rho_A,i} + w_{\rho_B,i})}{\sum_{i=1}^{n} (w_i + w_{\rho_A,i} + w_{\rho_B,i})},$$

$$f_i = \mathrm{area}(A_i \bigcap B_i)/\mathrm{area}(A_i)$$

➢ **Give number between 0 and 1**

➢ ***If you want to quantify the similarity of spatial distributions..***

✓ **The WOC method code is available for public use!** https://github.com/csabiu/WOC **pip install pywoc**

WOC Result (CDM vs. SIDM)

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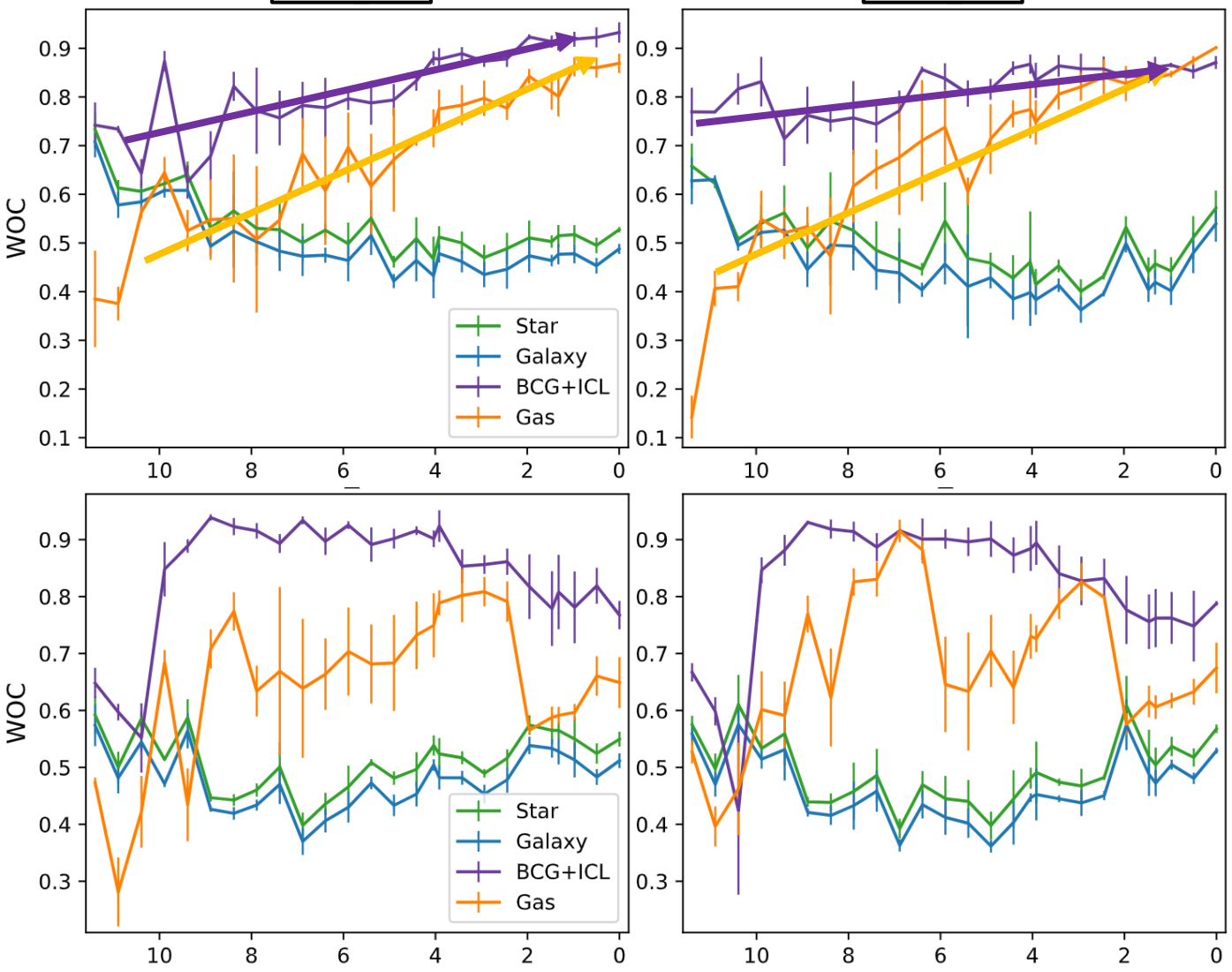
CDM | **SIDM**

CE12 Relaxed

CE05 Merging



BCG+ICL > **Gas** > **All Stars** > **Galaxies**

BCG+ICL trace DM from high-z
Gas improves & catches up

Cf) WOC Evolution in HR5

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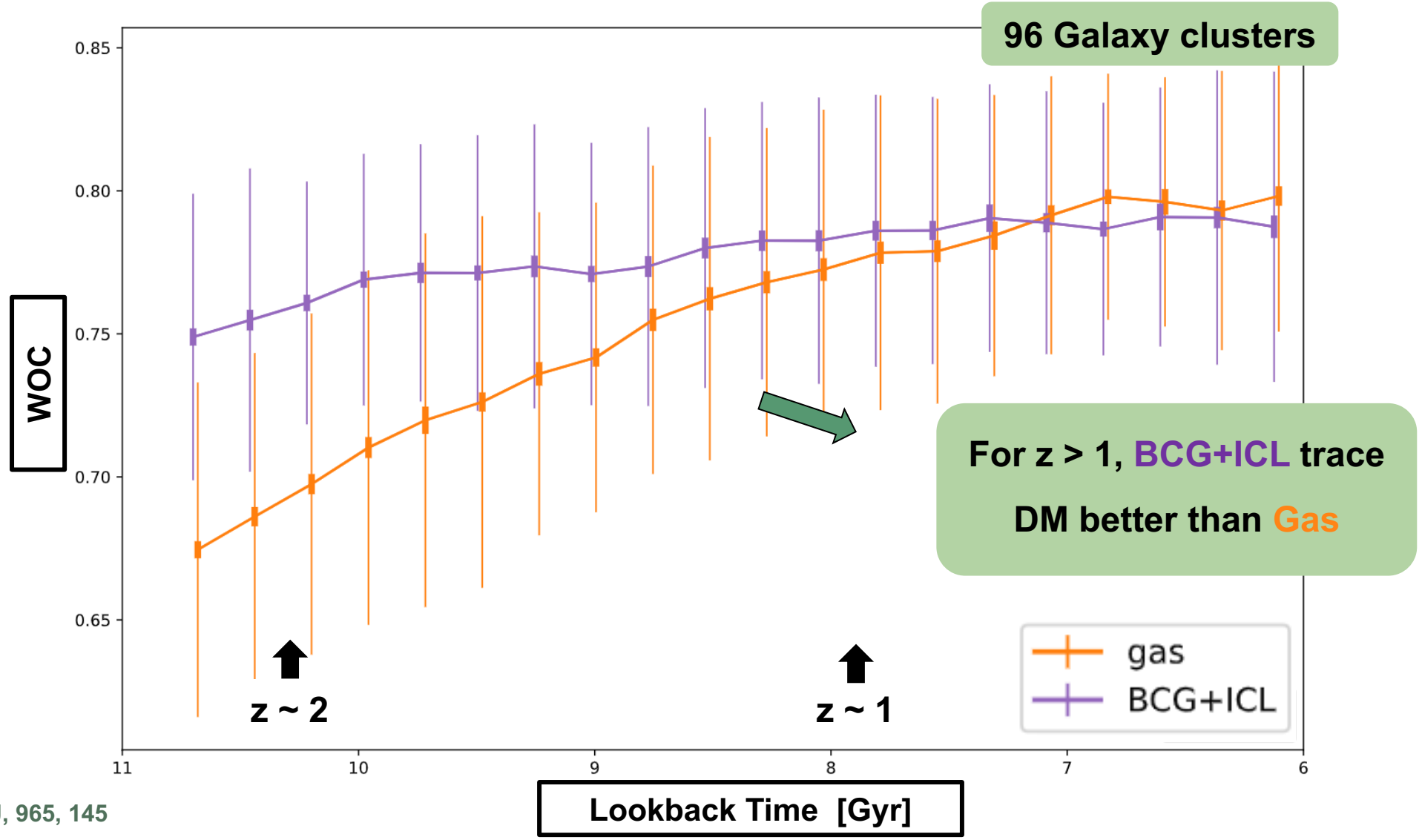

Yoo et al. 2024, ApJ, 965, 145

WOC Result (CDM vs. SIDM)

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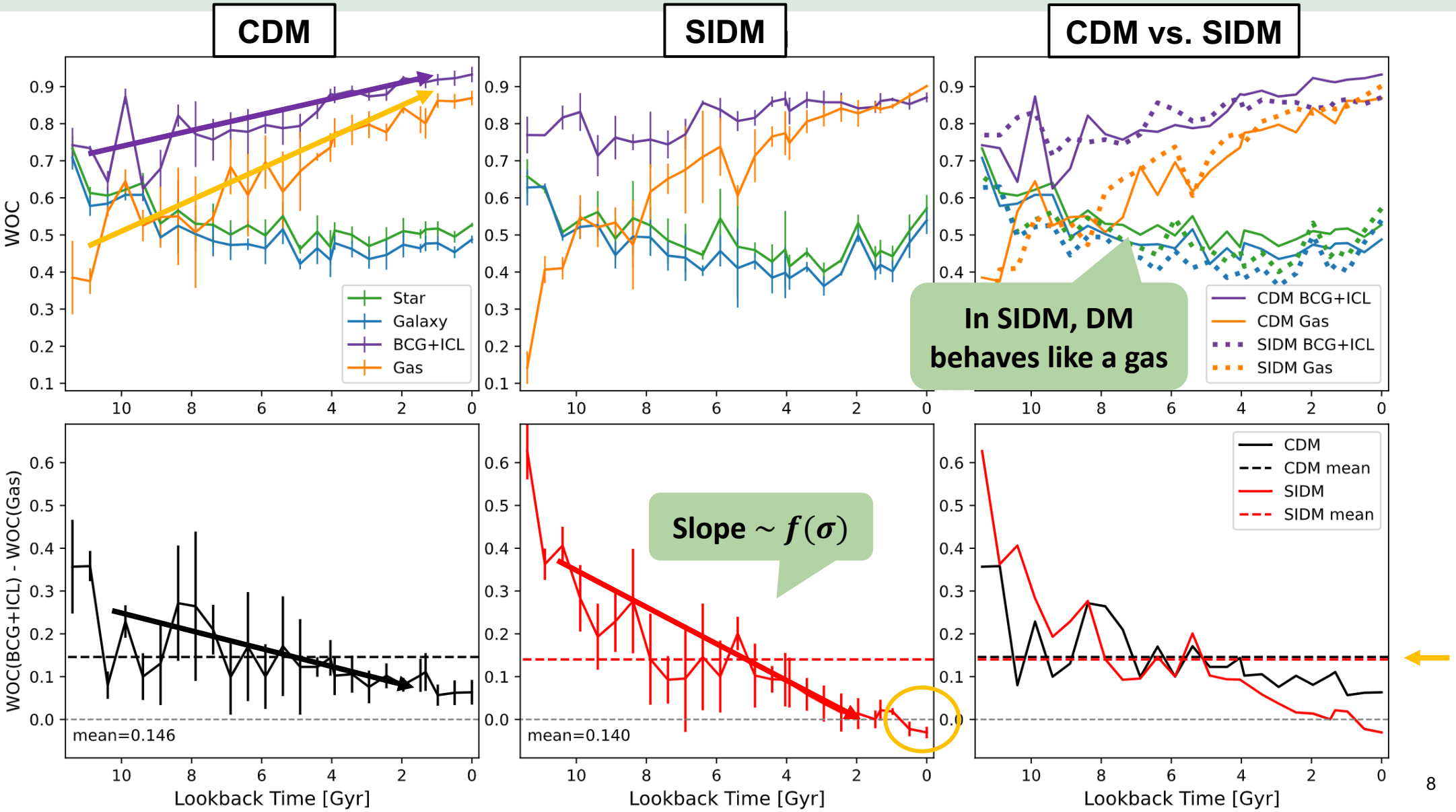
CE12 Relaxed



WOC Result (CDM vs. SIDM)

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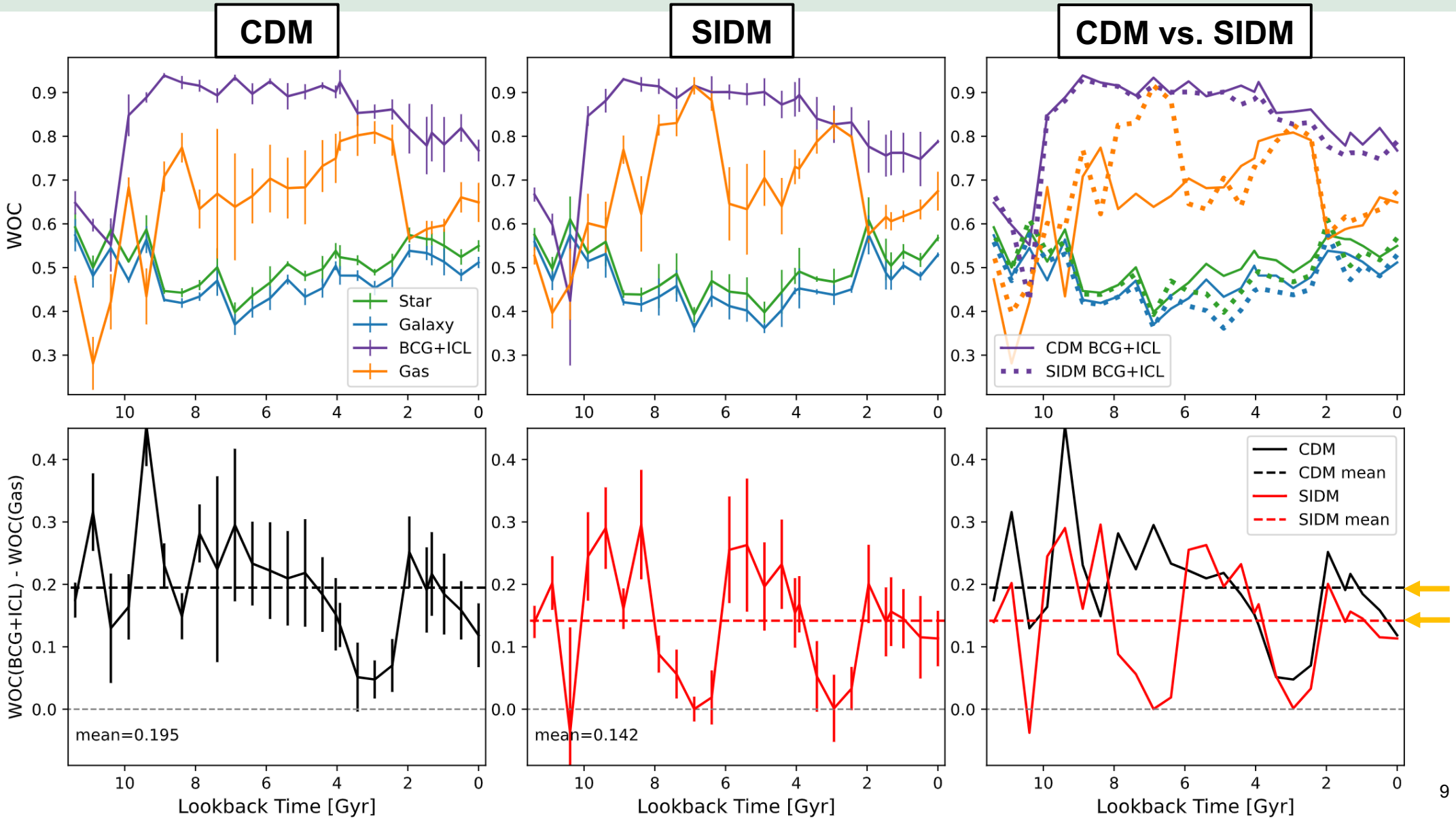
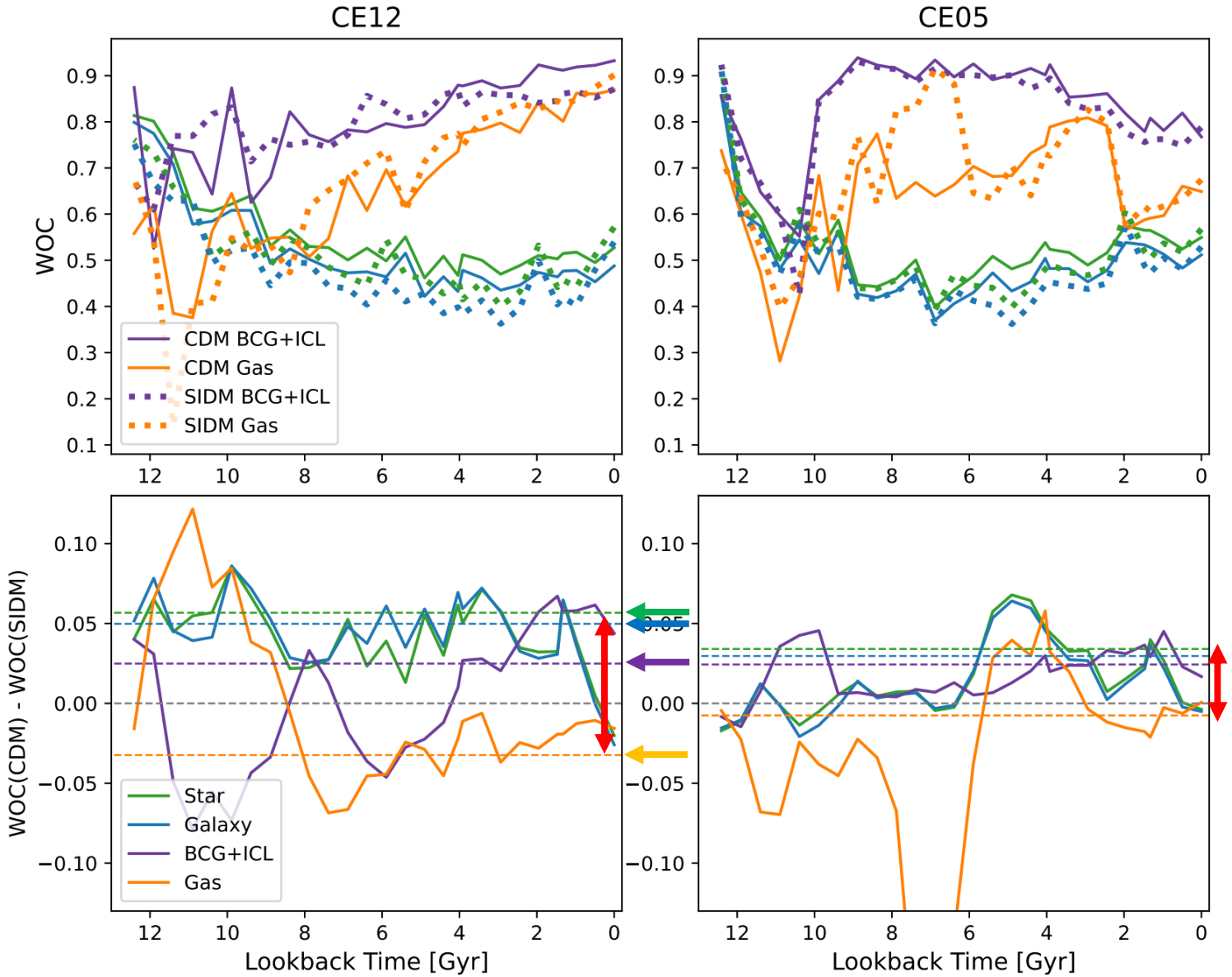
CE05 Merging



WOC(CDM) vs. WOC(SIDM)



- Collisionless component; CDM > SIDM, whereas Gas; SIDM > CDM
- Relaxed case shows bigger difference between CDM/SIDM
- Sensitivity on the DM model; Star > Galaxy > BCG+ICL ~ Gas

Summary

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(1) Except high-z regime, DM is traced in the following order of accuracy: **BCG+ICL> gas> all stars> galaxies**.

(2) The DM-tracing performance **improves over time for BCG+ICL and gas**.

(3) For CE12 (the more relaxed case), **BCG+ICL consistently performs well, even at high-z**.

Gas performs poorly at high-z but improves over time and eventually becomes comparable to BCG+ICL.

(4) In the **SIDM** case, **gas distribution resembles DM more closely compared to CDM**.

In CDM, DM is collisionless and more similar to BCG+ICL,

whereas in SIDM, DM has slight viscosity and behaves like a gas

Future Work

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Constraining DM Model

If we simulate more CDM/ SIDM relaxed/ unrelaxed galaxy clusters and confirm this result,

And observe galaxy clusters measuring WOC (DM, Gas) and WOC (DM, BCG+ICL),

If in relaxed galaxy clusters at z=0,

WOC (DM, Gas) > WOC (DM, BCG+ICL) ⇒ Our universe is SIDM

WOC (DM, Gas) < WOC (DM, BCG+ICL) ⇒ Our universe is CDM or $\sigma/m < 1 cm^2 g^{-1}$

Thank You!

Jaewon Yoo ▪ ICL ▪ Galaxy Cluster

Yoo et al. 2021, MNRAS, 508, 2

Yoo et al. 2022, ApJS, 261, 28

Yoo et al. 2024, ApJ, 965, 145

Yoo et al. 2025, ApJ, in press (arXiv:2506.16280)

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