Emulating the Impact of Dark Matter Physics and Baryonic Effects on Milky Way–like Galaxies (DREAMS Simulations and ARRAKIHS Mock Images)

Li-Wen Liao (ICE-CSIC; IEEC)

Pablo Fosalba; Jonah Rose; Francisco Villaescusa-Navarro; Paul Torrey; Santi Roca Fabrega; Azadeh Fattahi; ARRAKIHS Mission Collaboration

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Method: Emulating the Impact of Dark Matter Physics and Baryonic Effects on Milky Way–like Galaxies (DREAMS Simulations and ARRAKIHS Mock Images)

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Aimed Variable: Dark Matter Physics and Baryonic Effects on Milky Way–like Galaxies (DREAMS Simulations and ARRAKIHS Mock Images)

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Method: Emulating

Aimed Variable: Dark Matter Physics and Baryonic Effects

Target: Milky Way–like Galaxies

Tools: DREAMS Simulations and ARRAKIHS Mock Images

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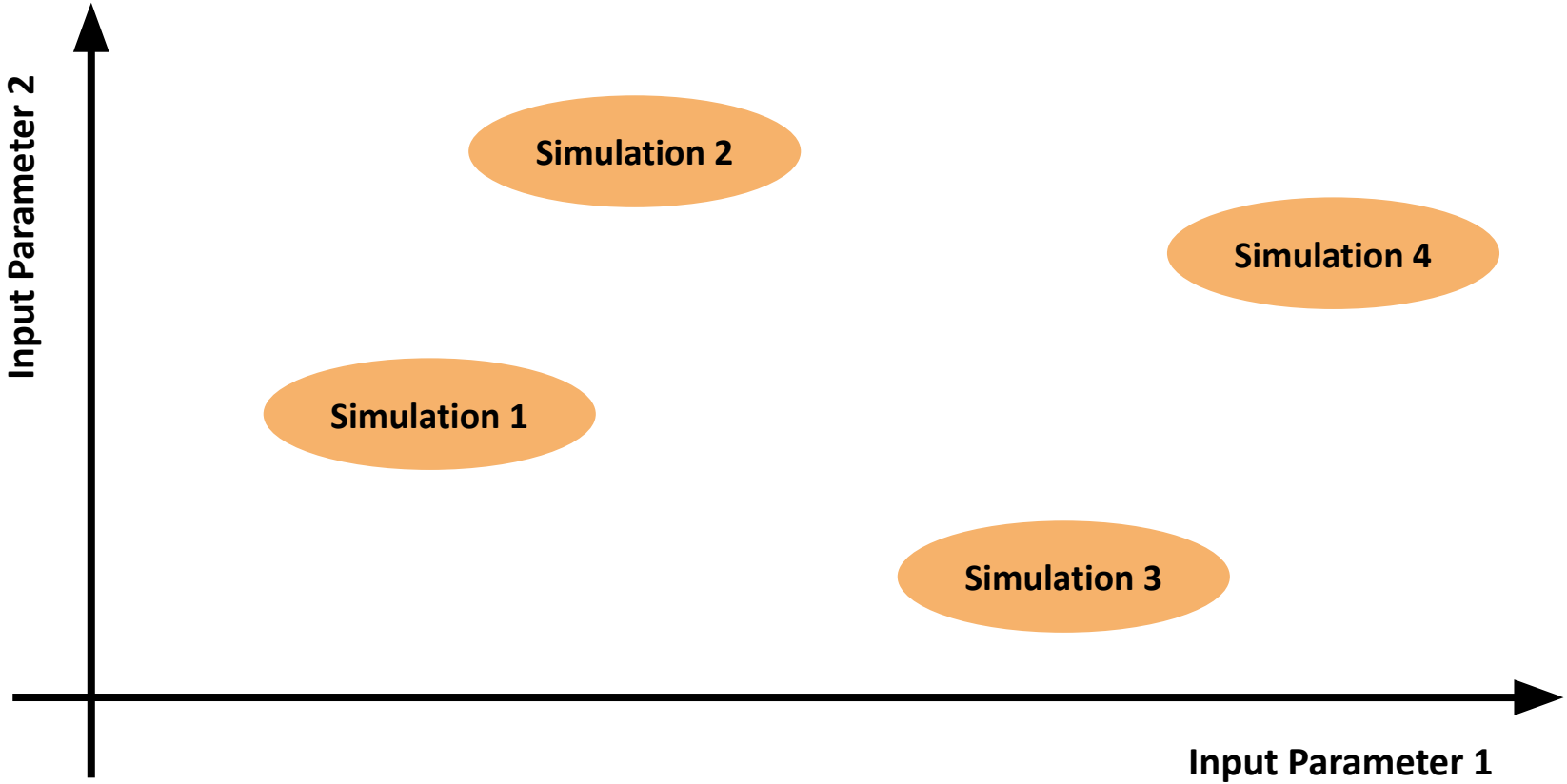
What is Emulator?



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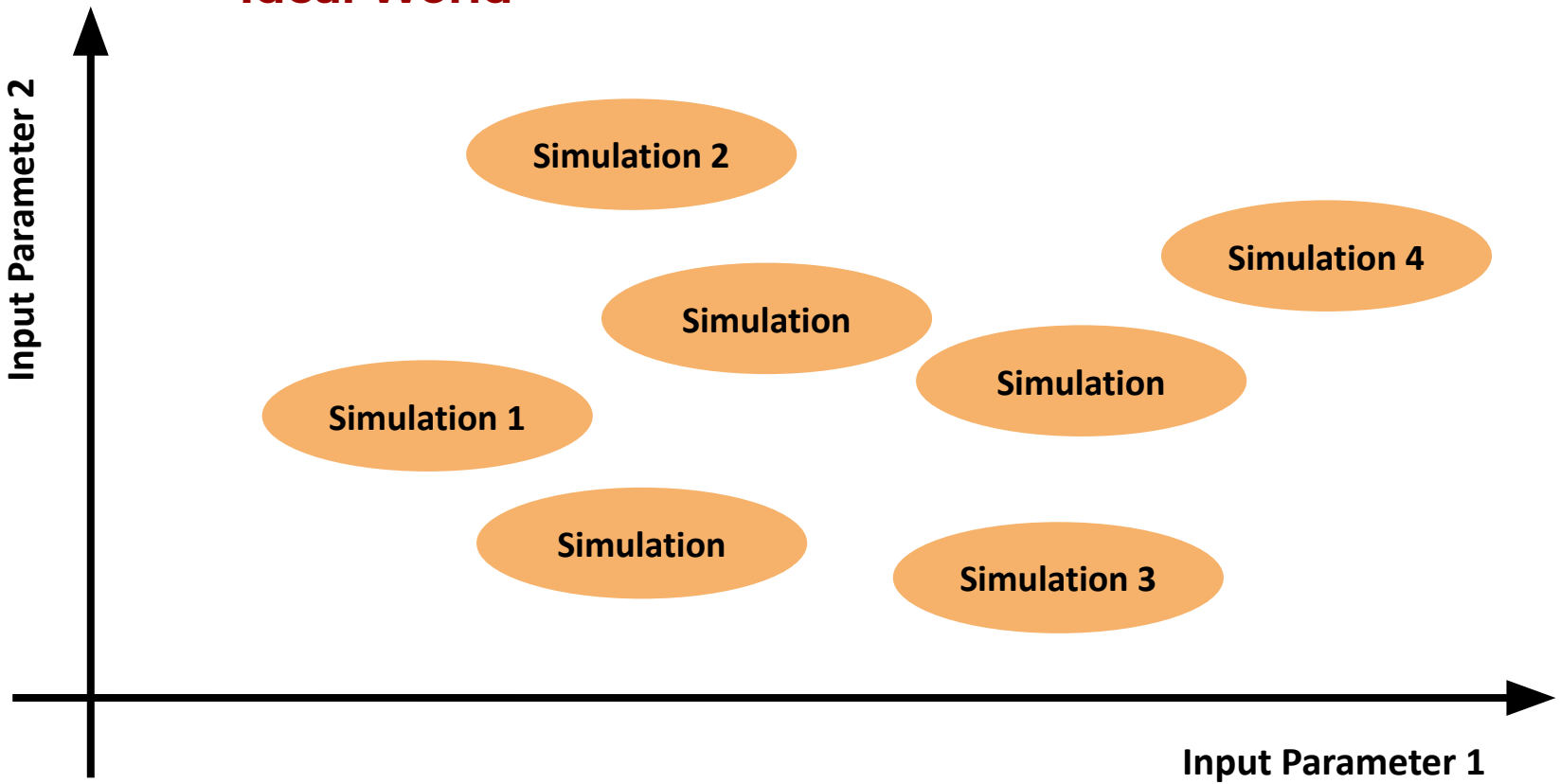
Ideal World



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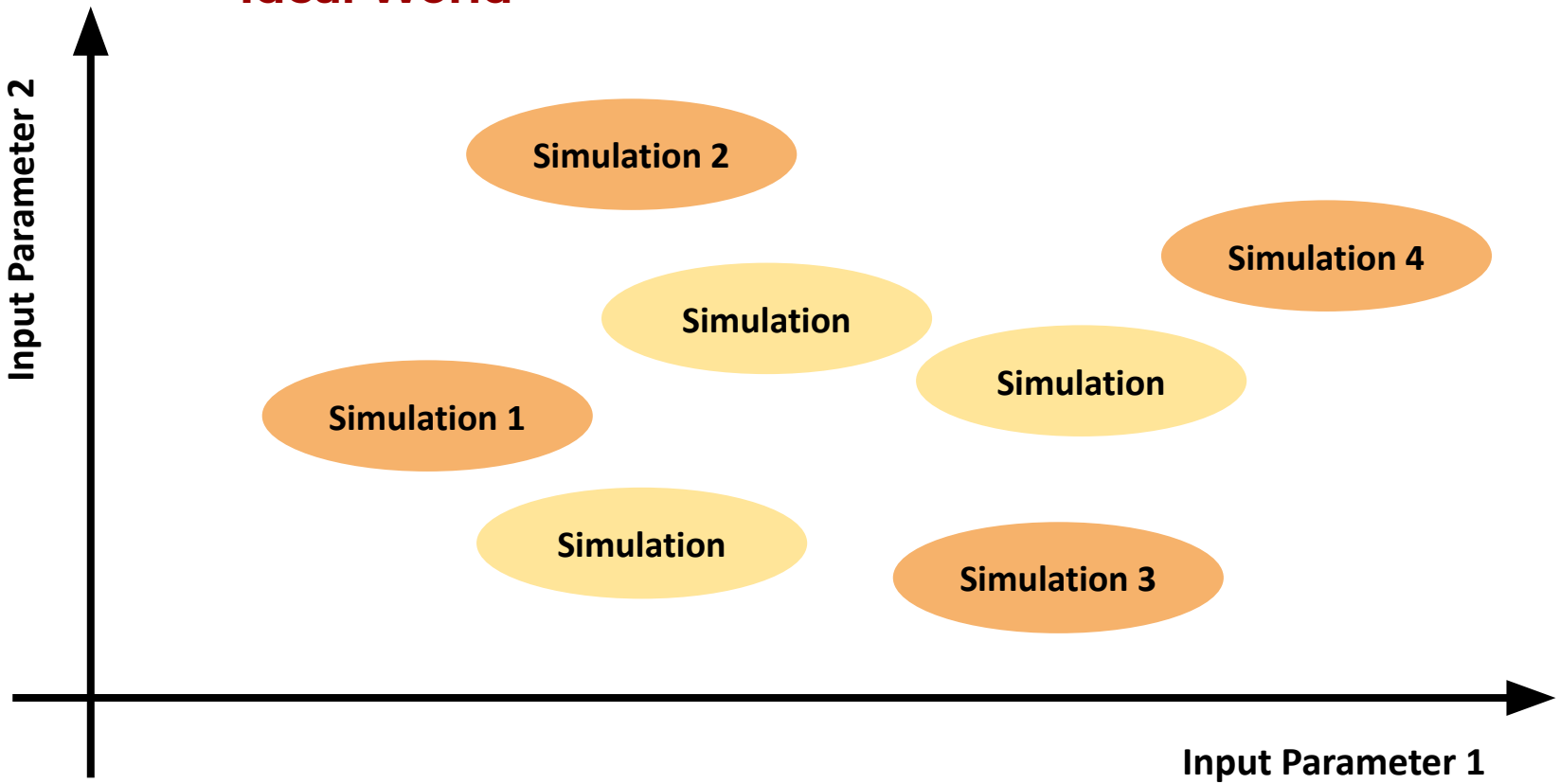

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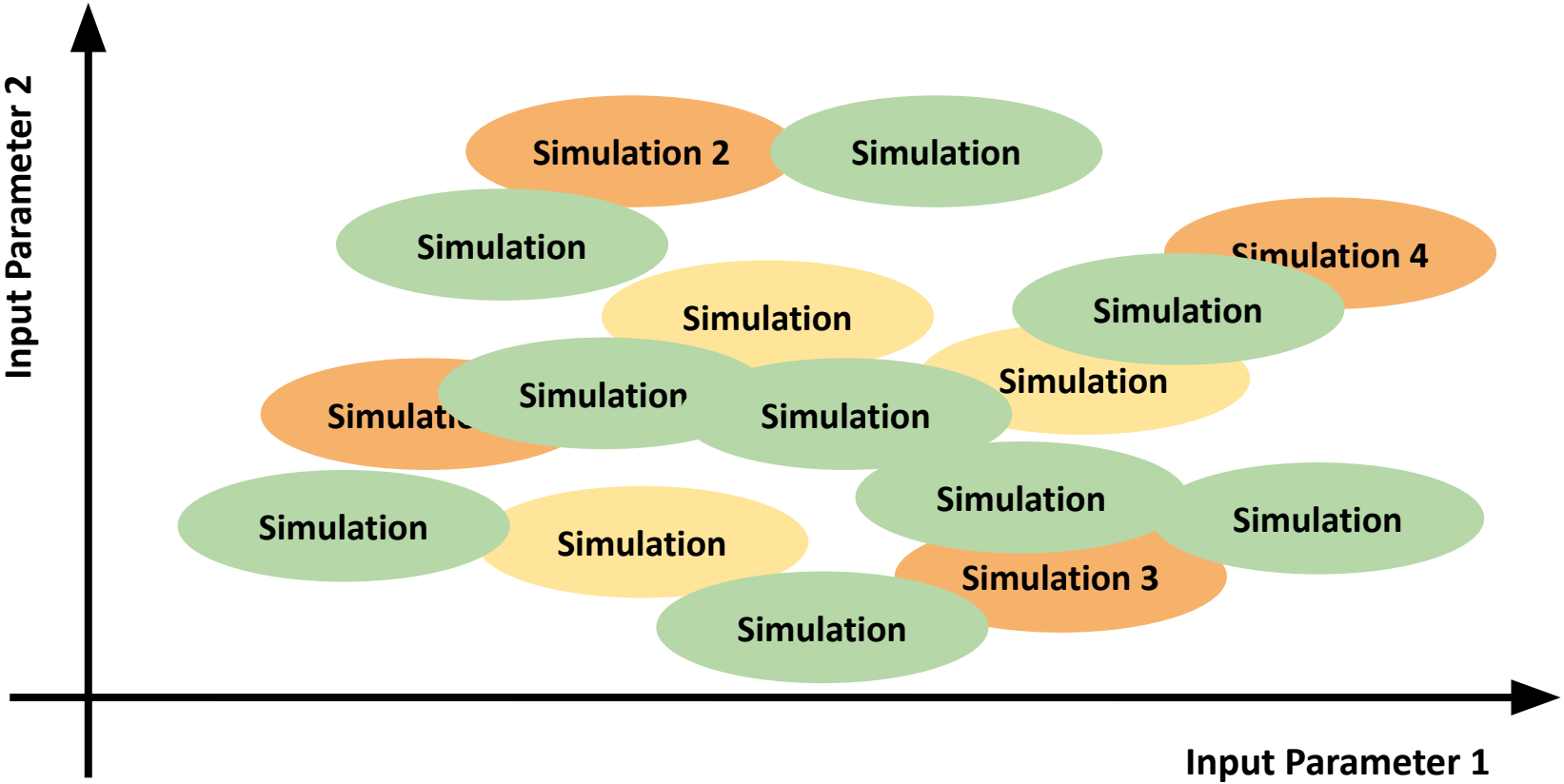

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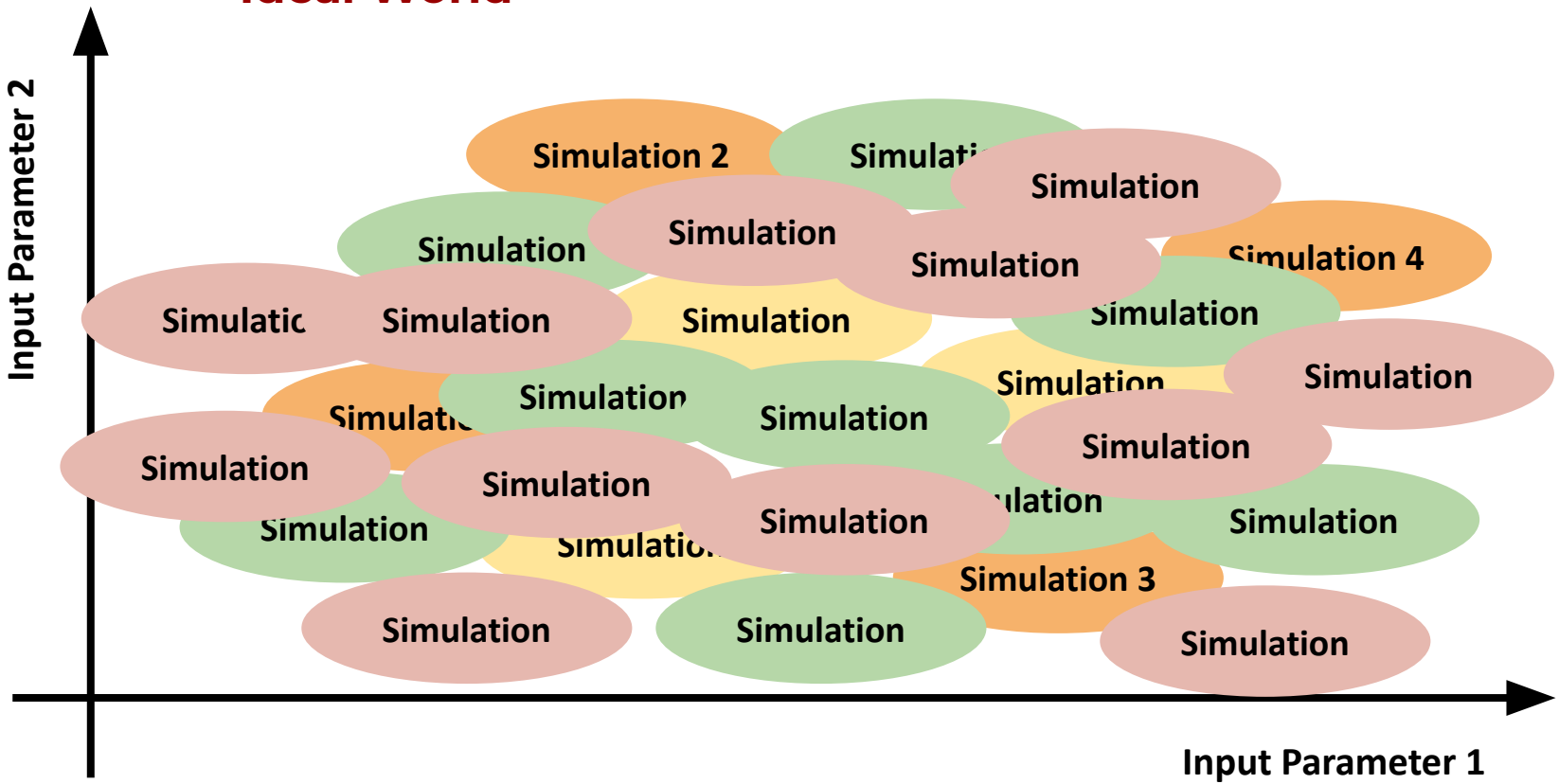

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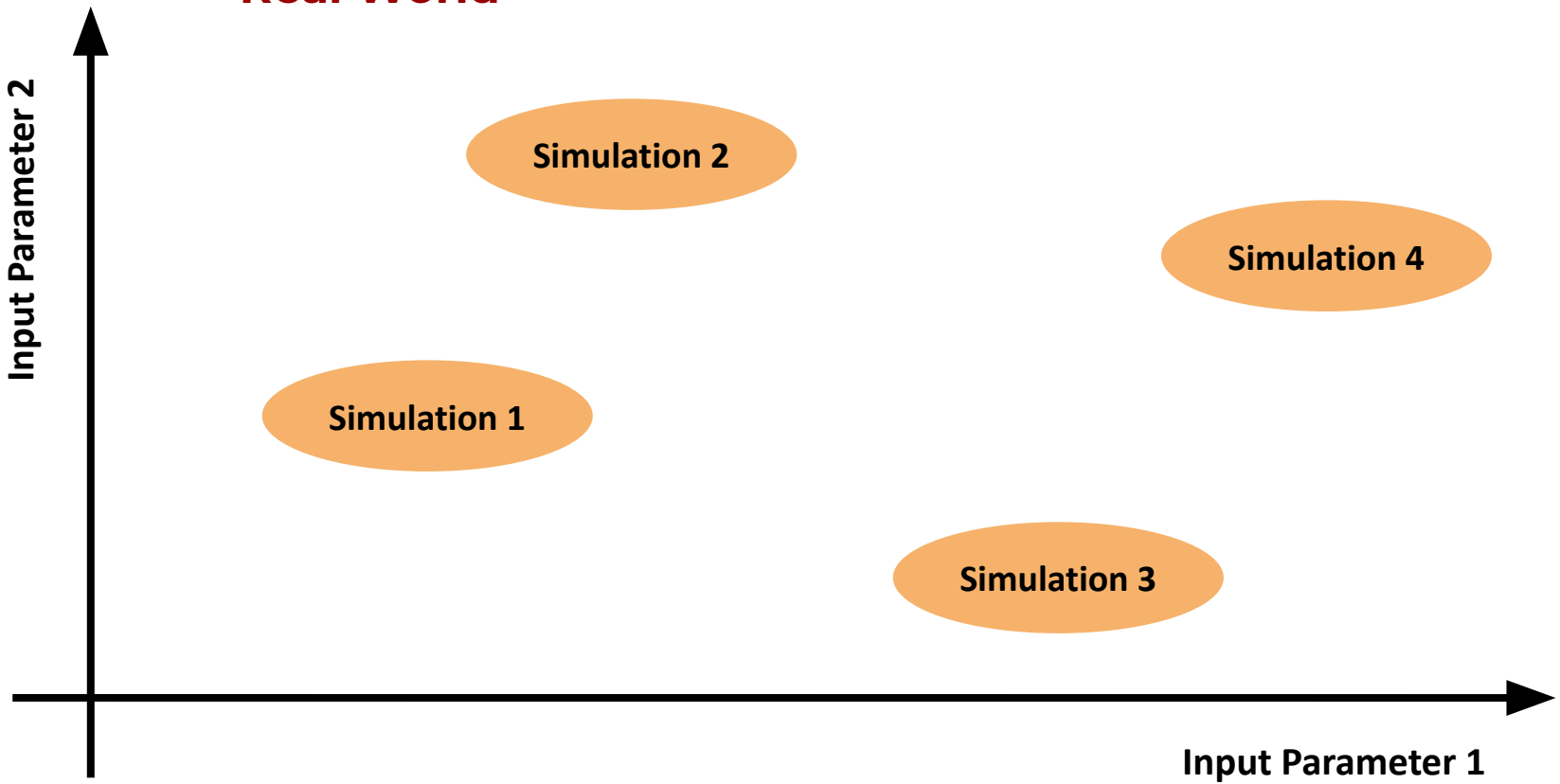

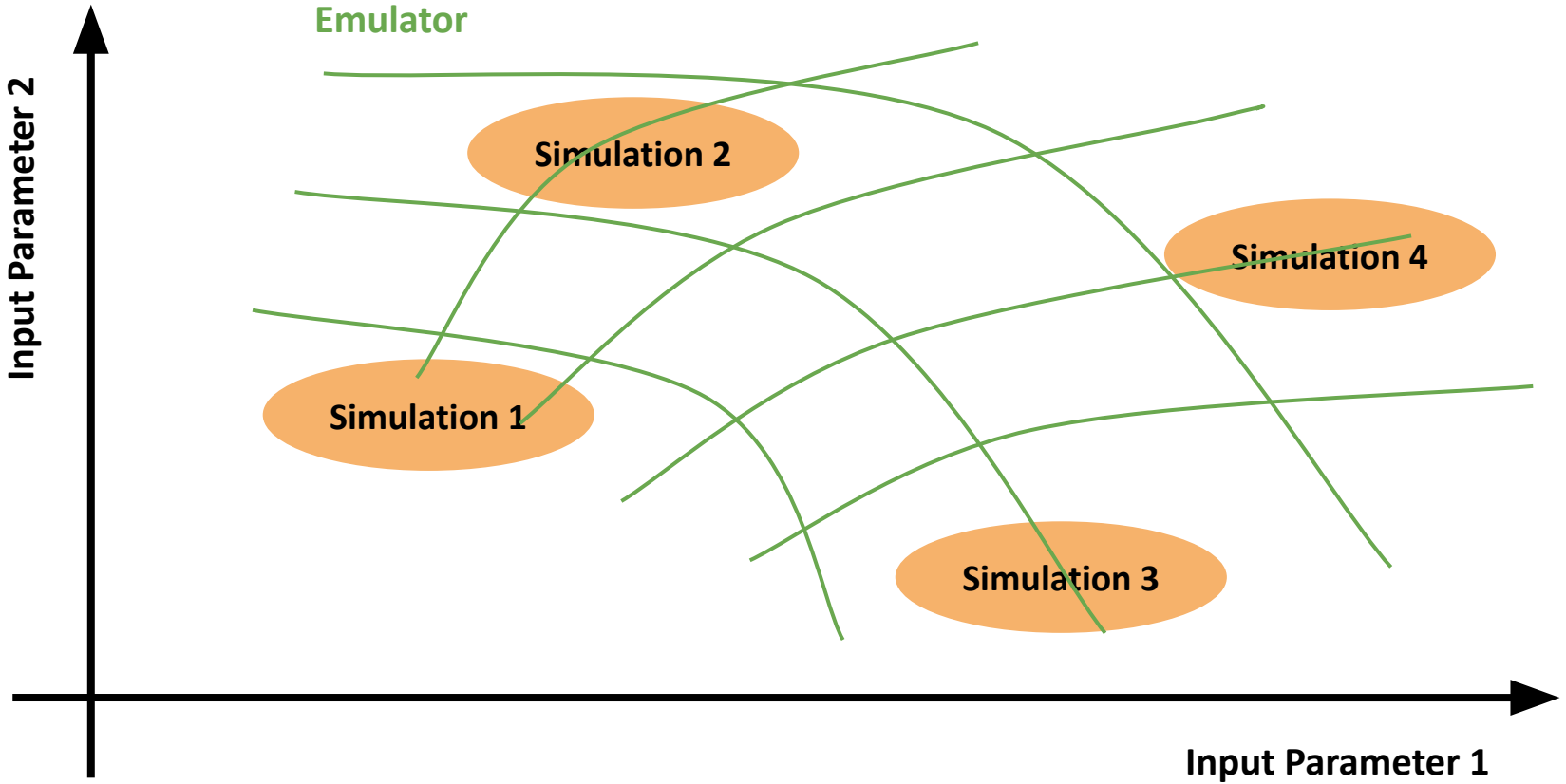

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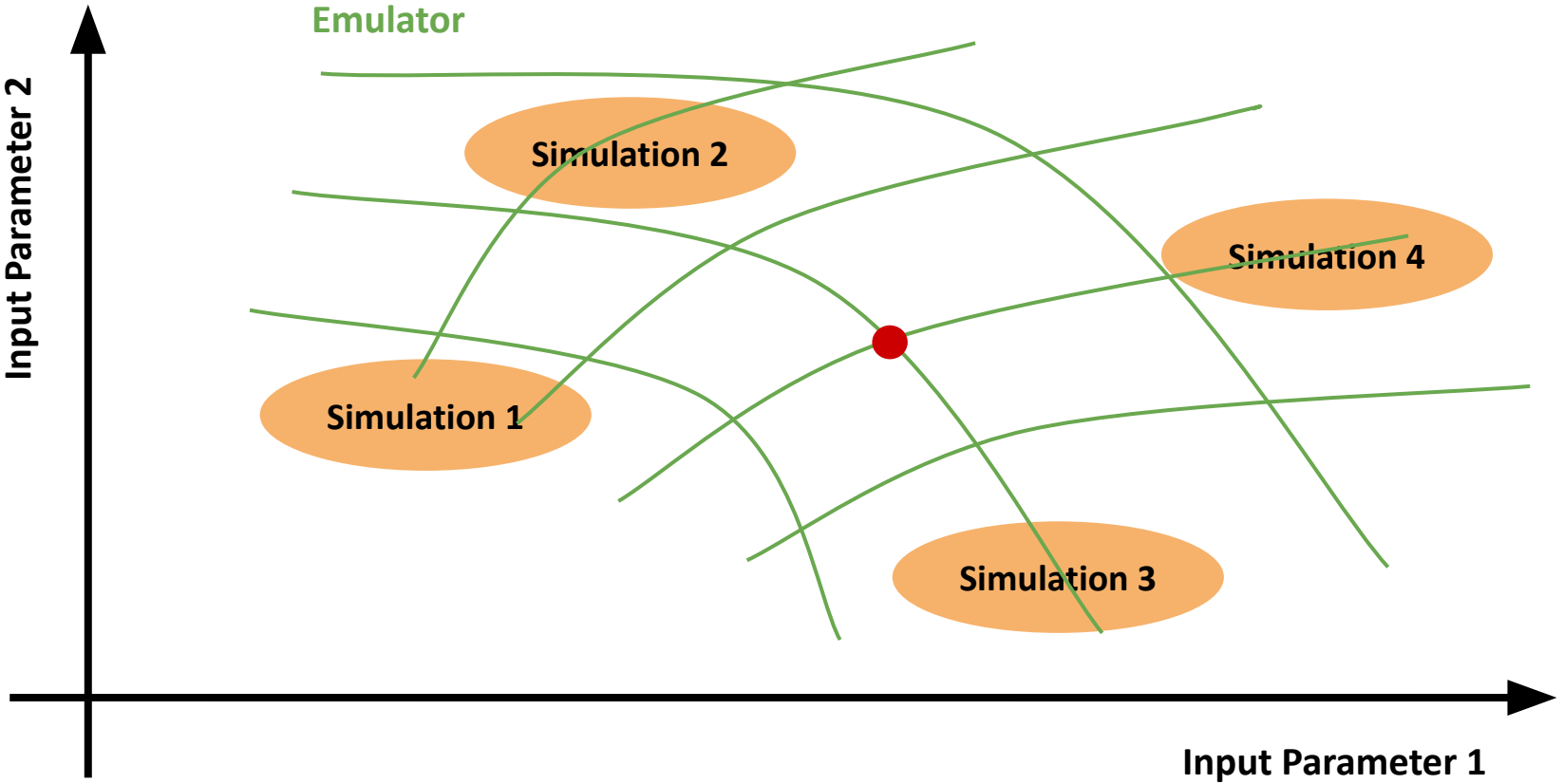

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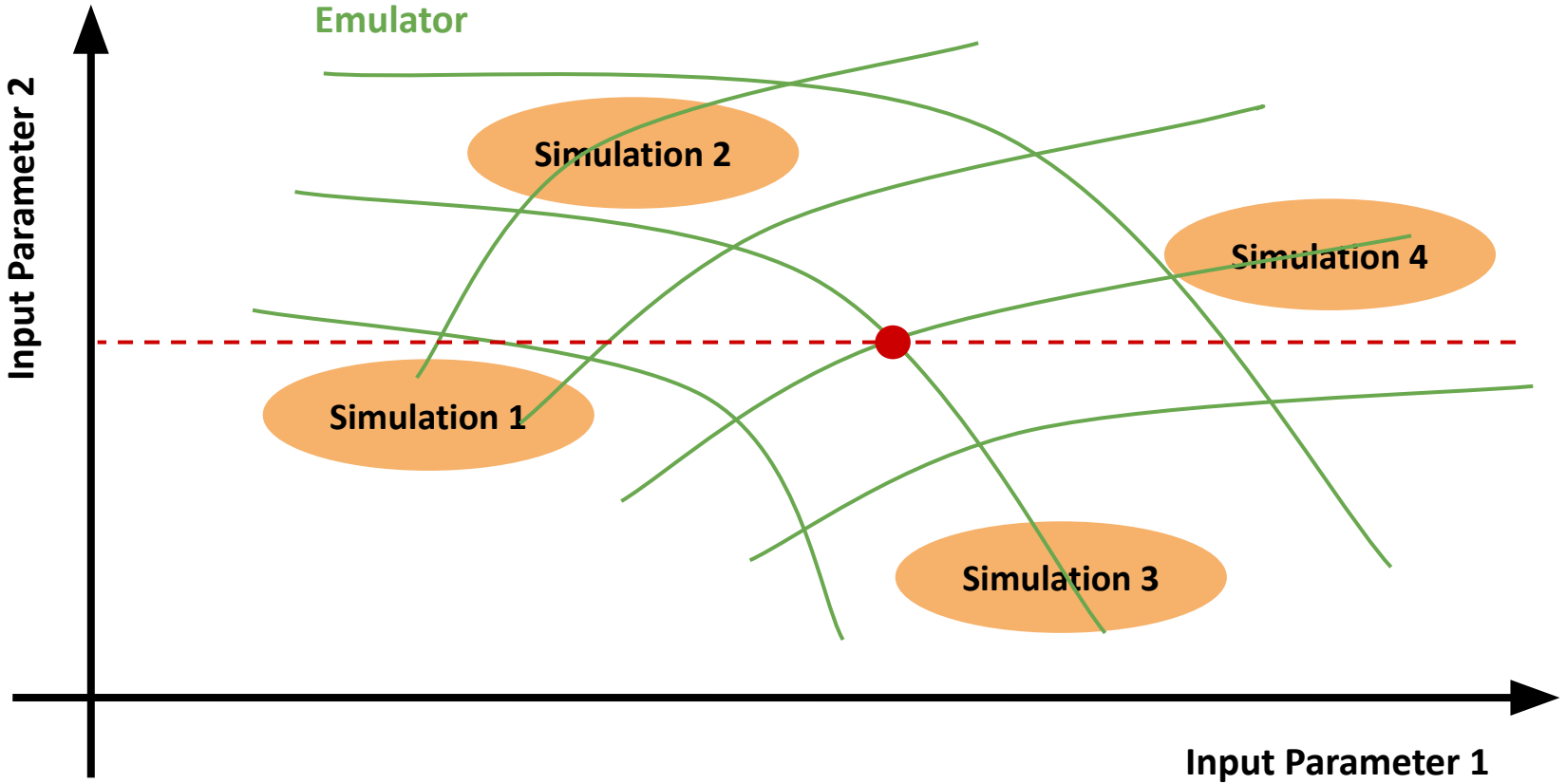

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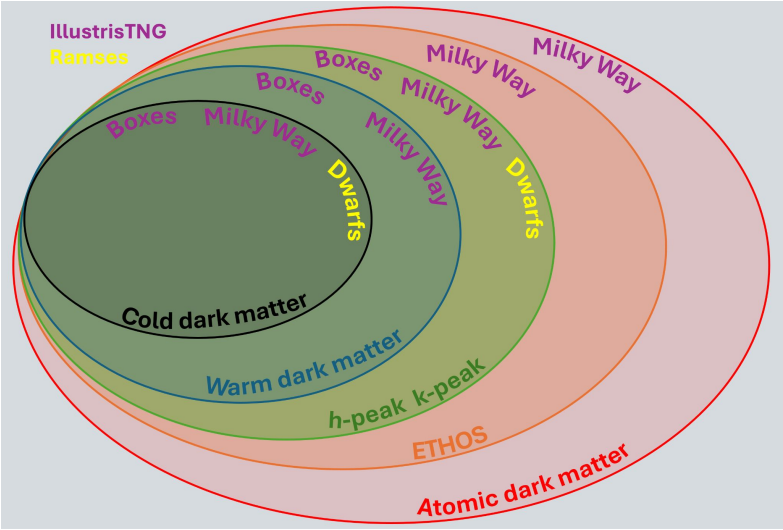
The DREAMs Simulation

- Milky Way zoom-in simulation (WDM)
- Baryon mass resolution 1.9e5 Msun/h
- DM mass resolution 1.2e6 Msun/h
- 1024 simulations with different baryonic physics and WDM
- z=0 snapshots



(Rose et al. 2025)

Input Parameters:

SN1: the specific energy available for generating winds

SN2: parameter related to the galactic winds created by SN feedback

AGN: the fraction of energy that is transferred to the nearby gas

WDM: Implemented warm dark matter mass

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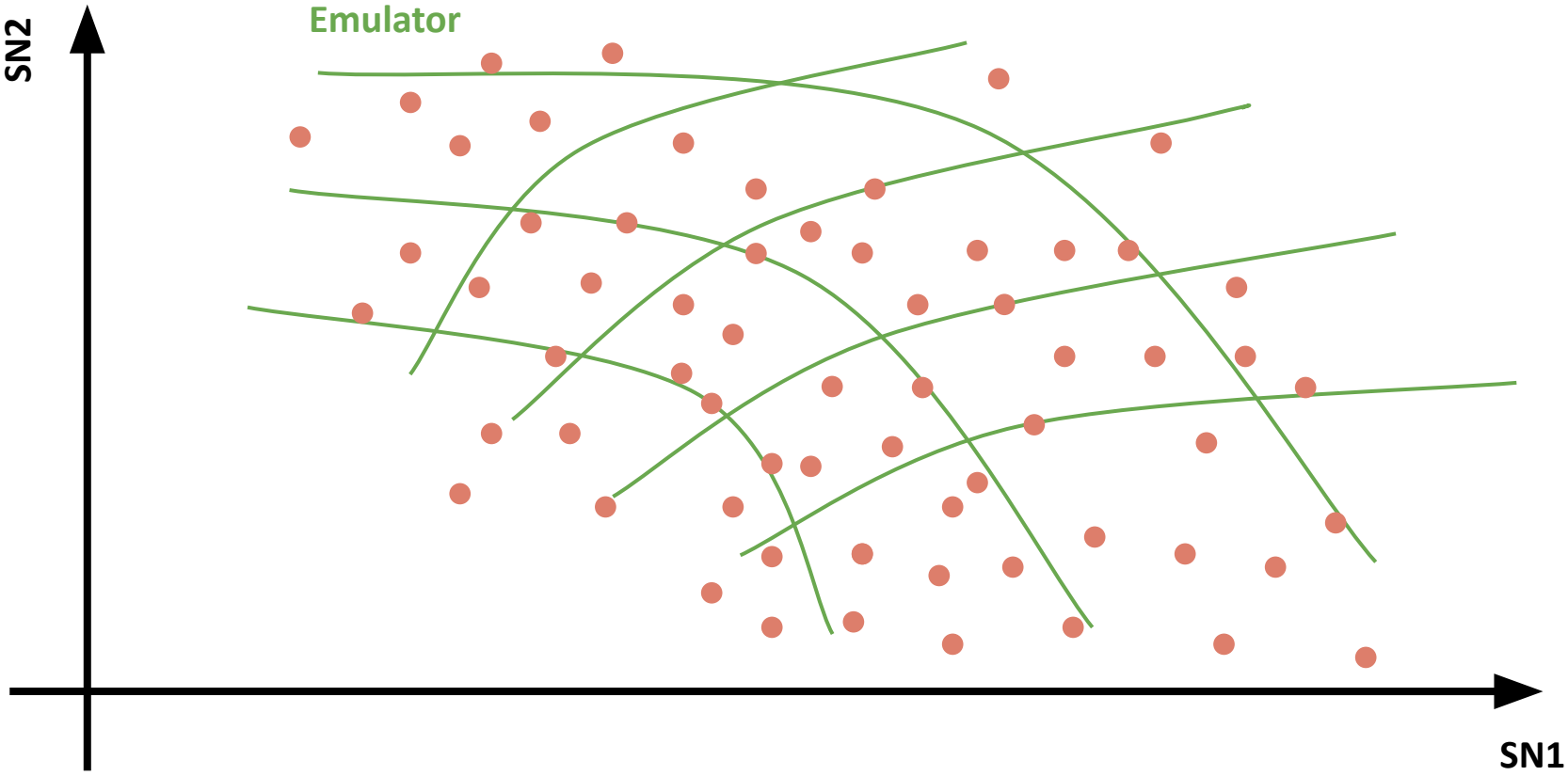

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What we want to Study?

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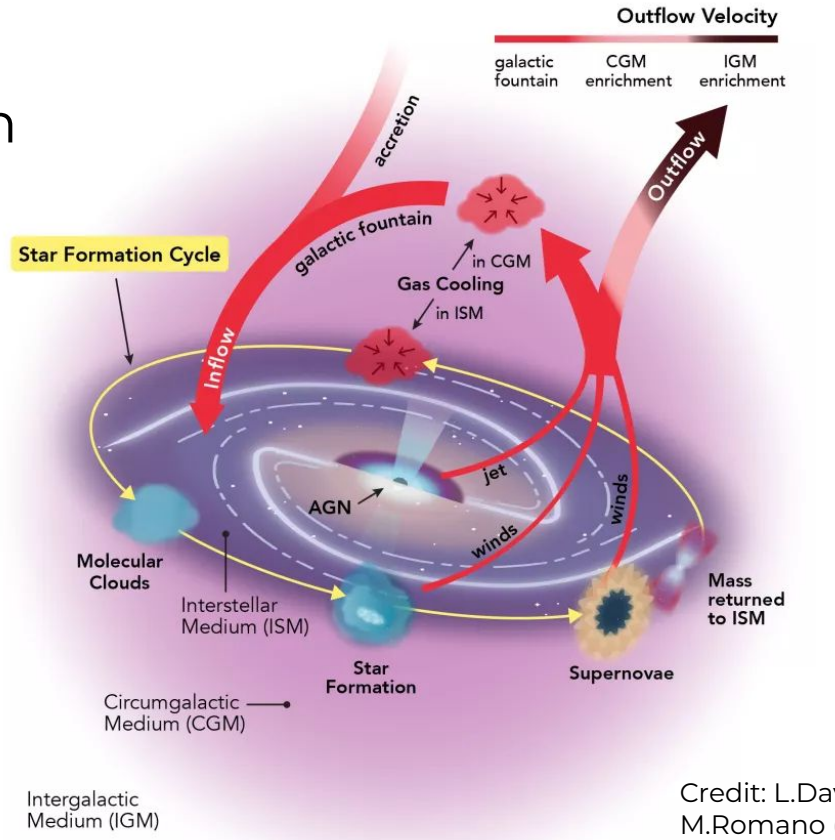
Short Answer: Galaxy Formation



Credit: L.Davies (ICRAR)/ M.Romano (MPIfR)/ M.Saraf (UCL)/ A.Vadolia/ NASA.

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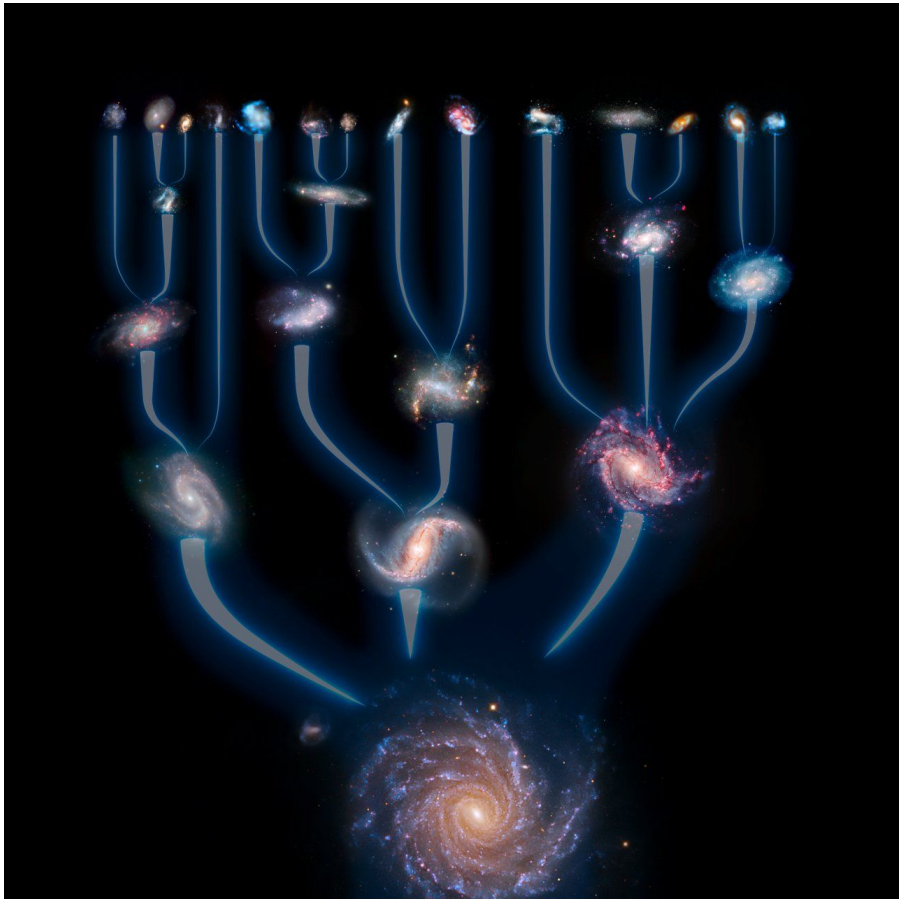

Credit:
ESO/L. Calçada

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Internal:
e.g., How quick the stars are form and dead?

External:
e.g., How many satellites the host galaxy has accreted? Do those accretion event change the structure of the host galaxies?

Supernova

AGN

WDM

Galaxy properties

Stellar mass, Gas mass, star-formation rate, metallicity, and etc.

Distribution of satellites

Number of satellites within Fof groups, Number of satellites within R200, and etc.

Profiles from snapshots

Spherical mass density profiles, age and metallicity profiles.

Profiles from mock images

Surface brightness profile of 4 bands and the corresponding color profiles.

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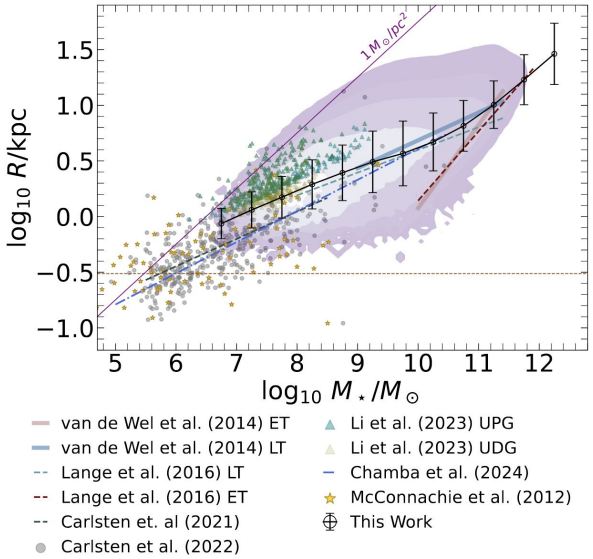
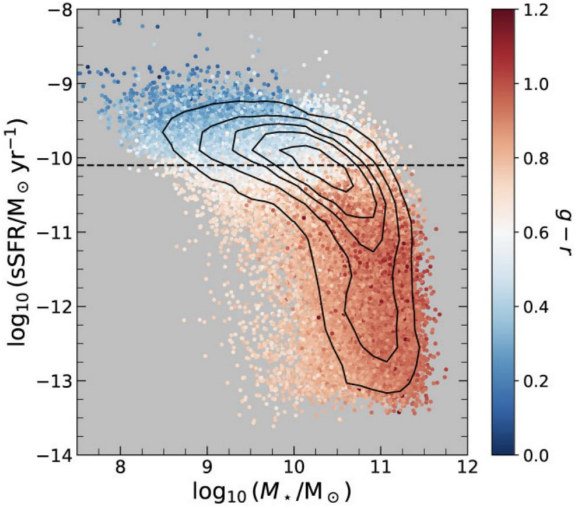
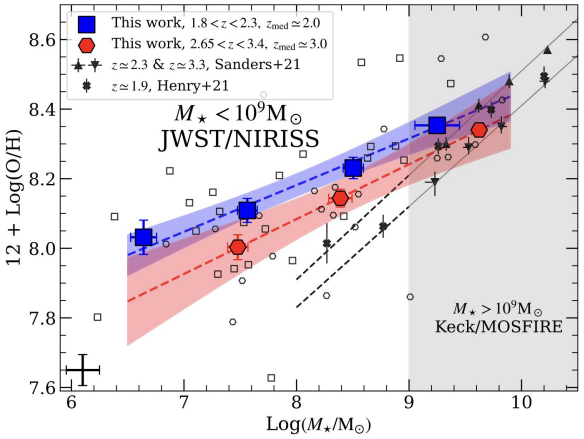
Galaxy properties



Liao & Cooper (2026)



Liao & Cooper (2023)



Li et al. (2023)

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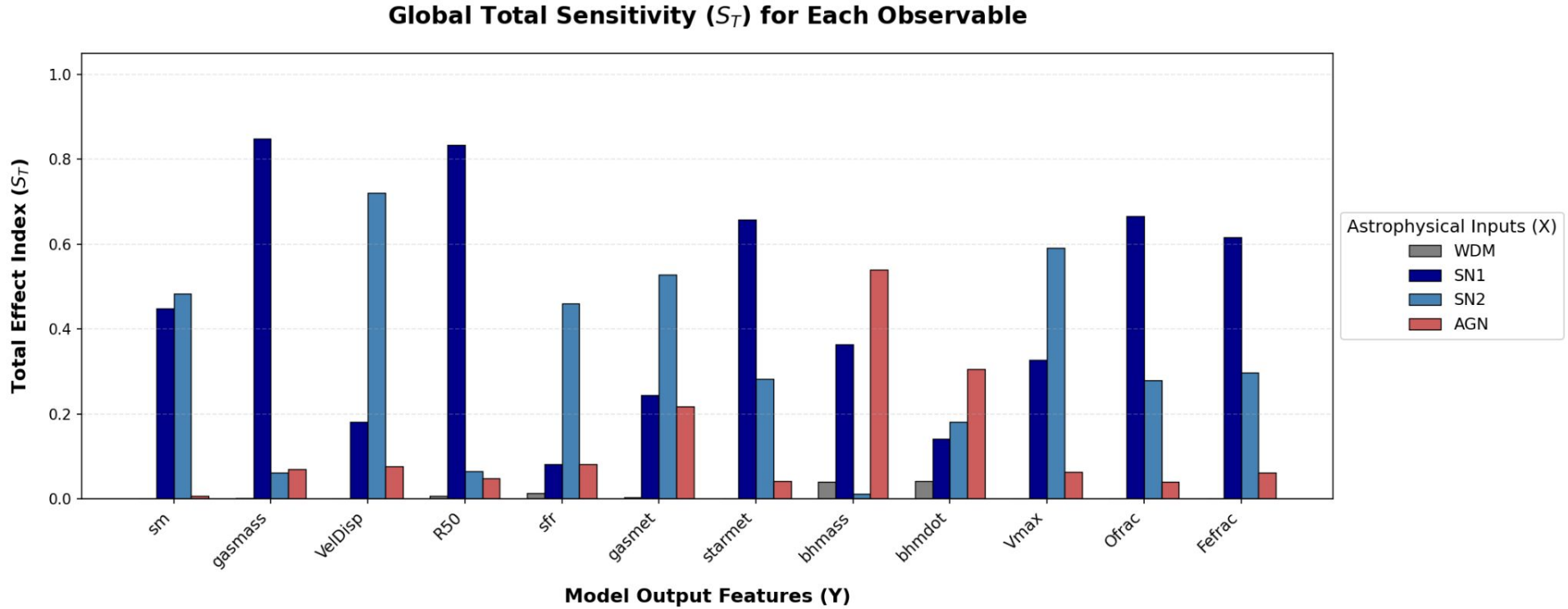
Galaxy Properties: Which input parameters is most related to the aimed parameter



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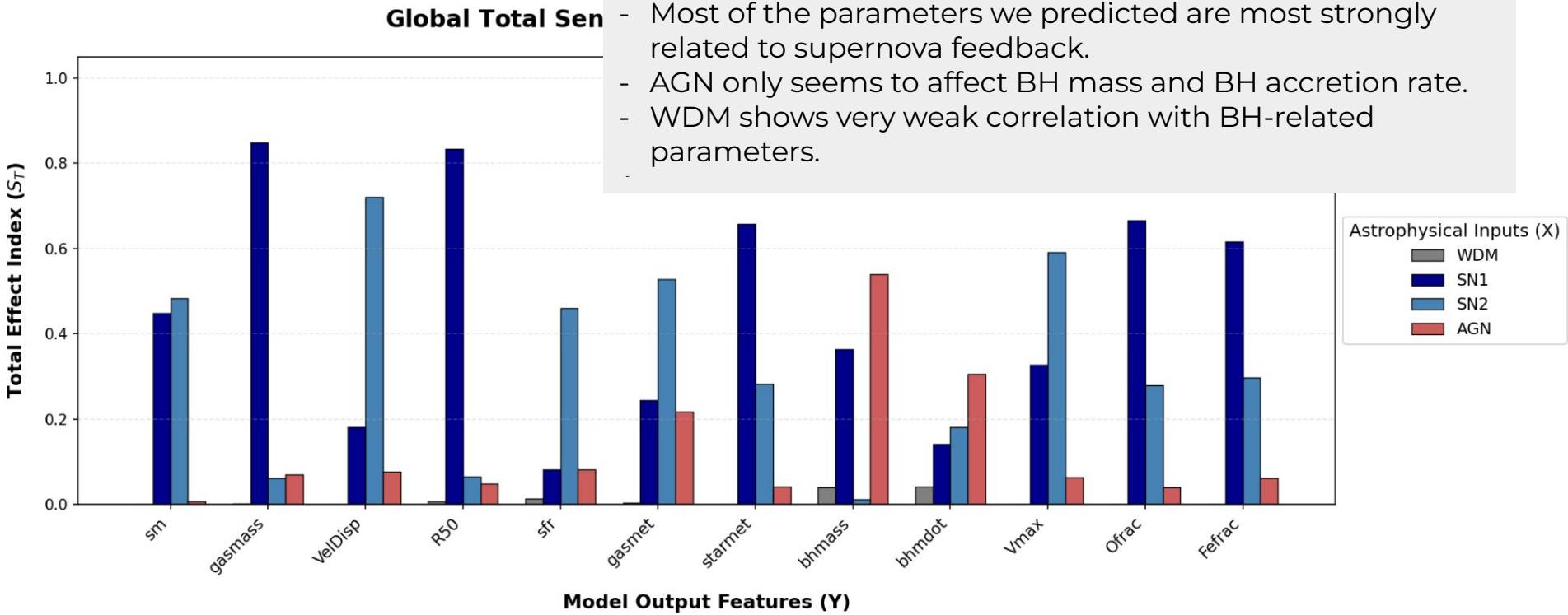
Galaxy Properties: Which input parameters is most related to the aimed parameter

- Most of the parameters we predicted are most strongly related to supernova feedback.
- AGN only seems to affect BH mass and BH accretion rate.
- WDM shows very weak correlation with BH-related parameters.



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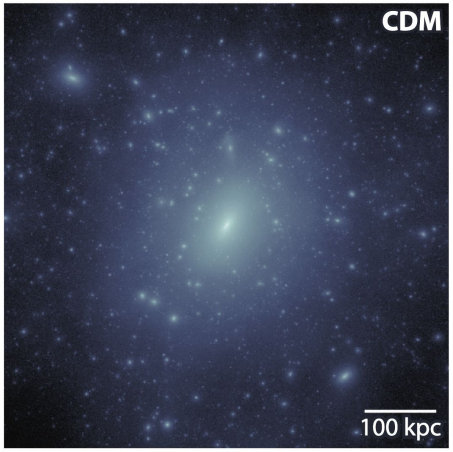
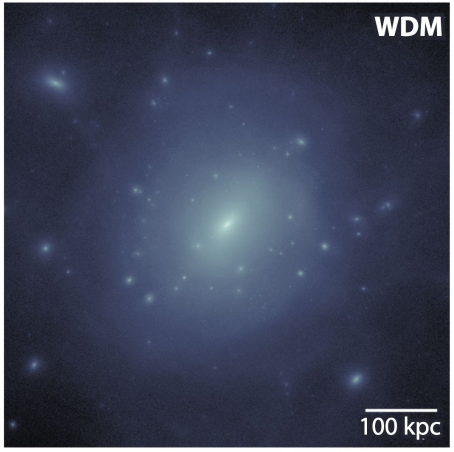
Distribution of Satellites

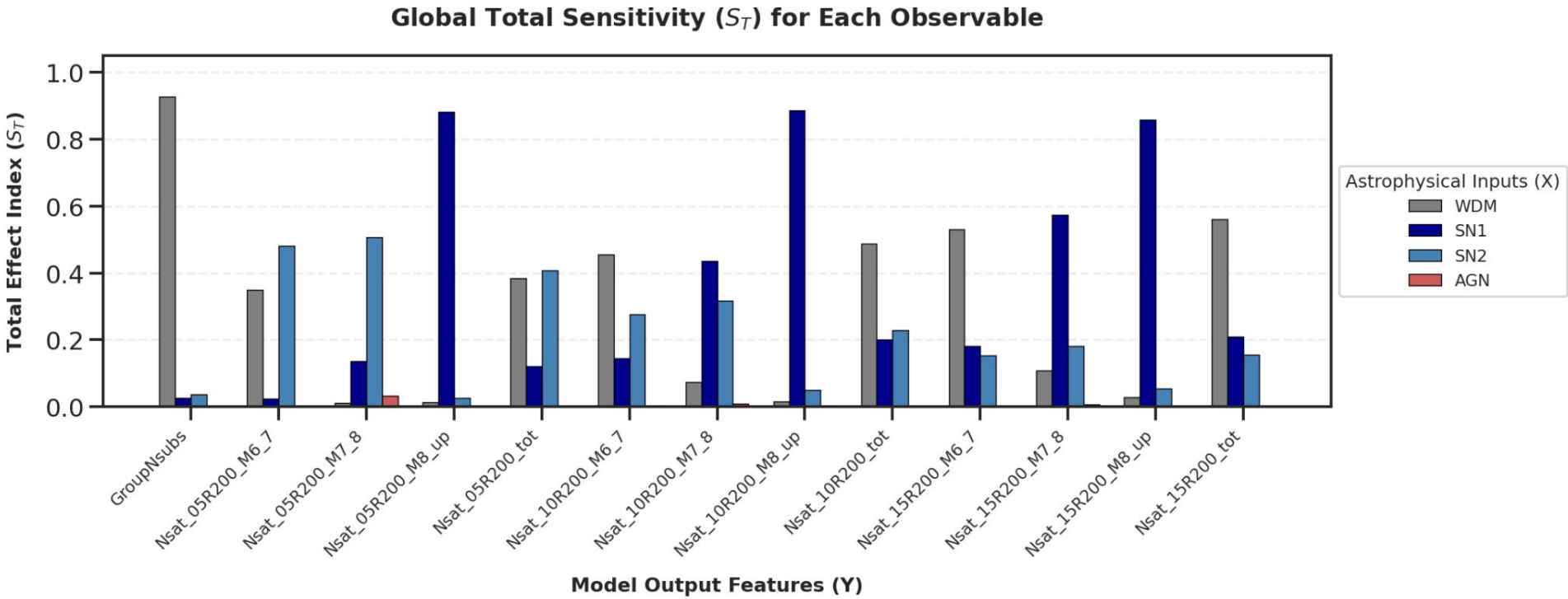
- Number of satellites with the group defined by Fof catalog
- Number of satellites of specific stellar mass range ([6-7], [7-8], and >8) and located within specific R200 (0.5, 1, 1.5 R200)





Bullock & Boylan-Kolchin (2017)

Distribution of satellites



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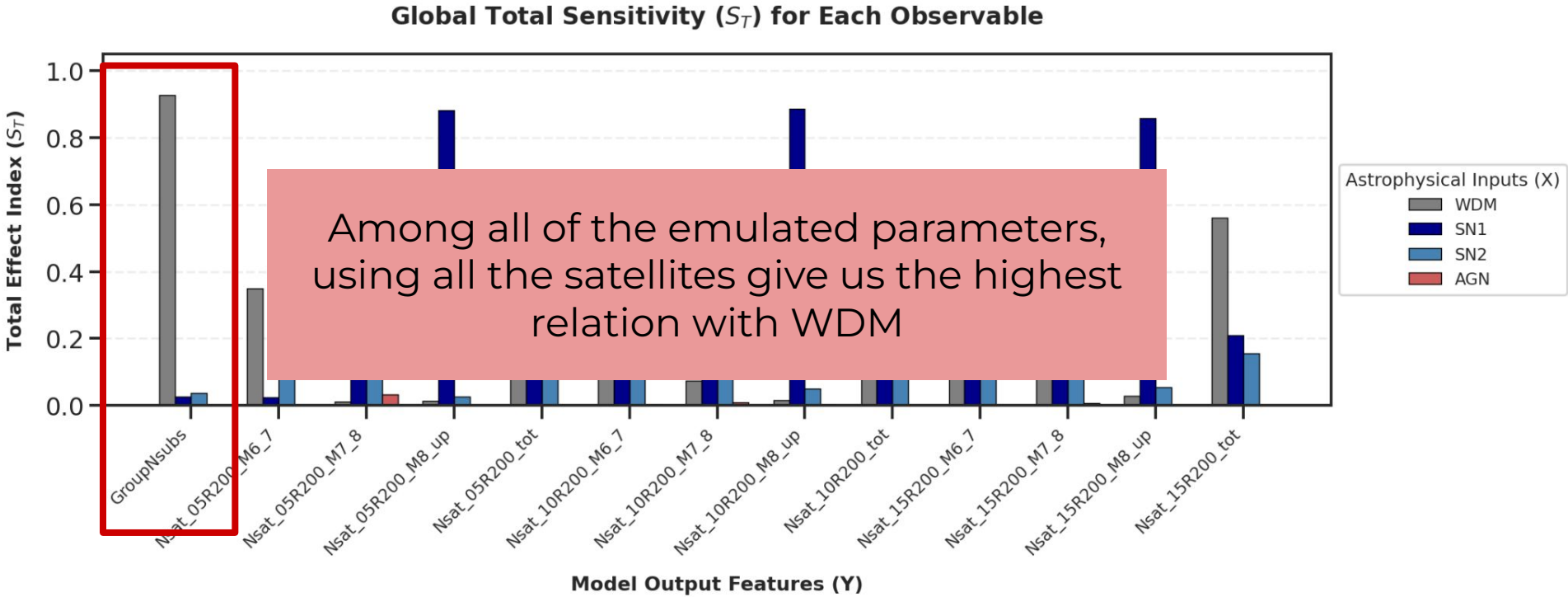
Distribution of satellites



Among all of the emulated parameters, using all the satellites give us the highest relation with WDM

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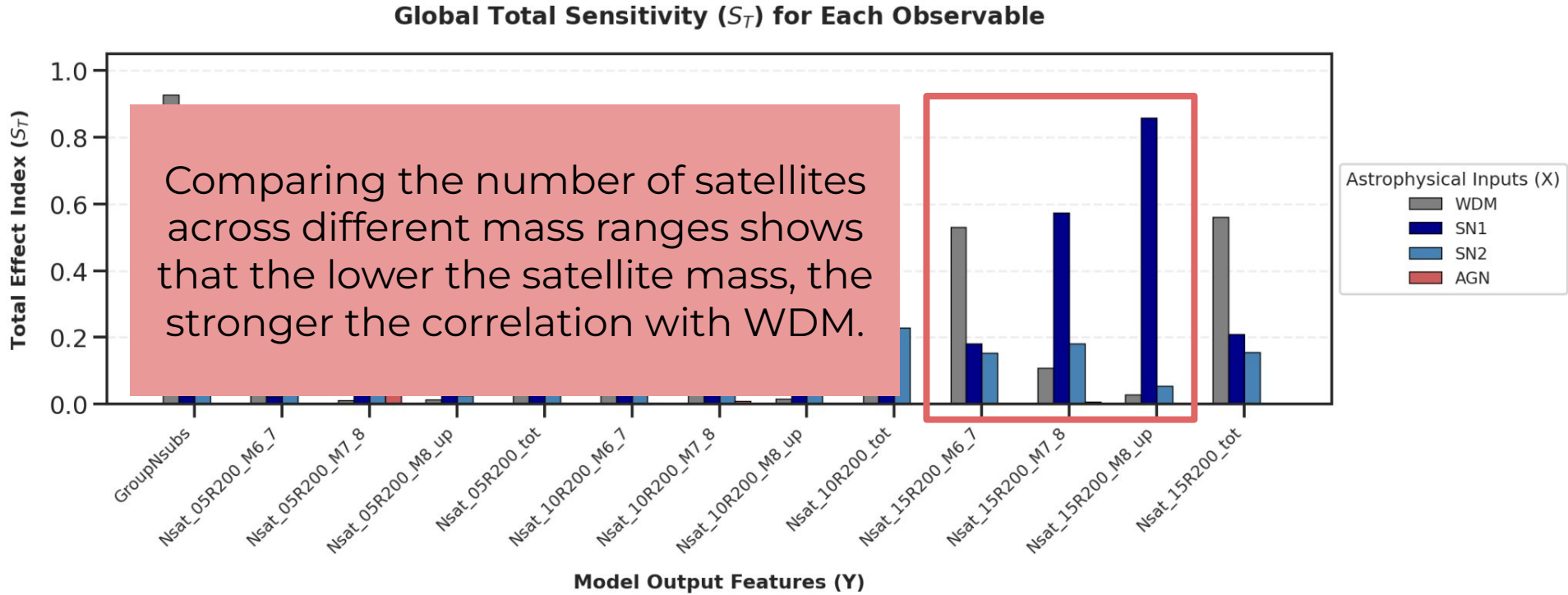
Distribution of satellites



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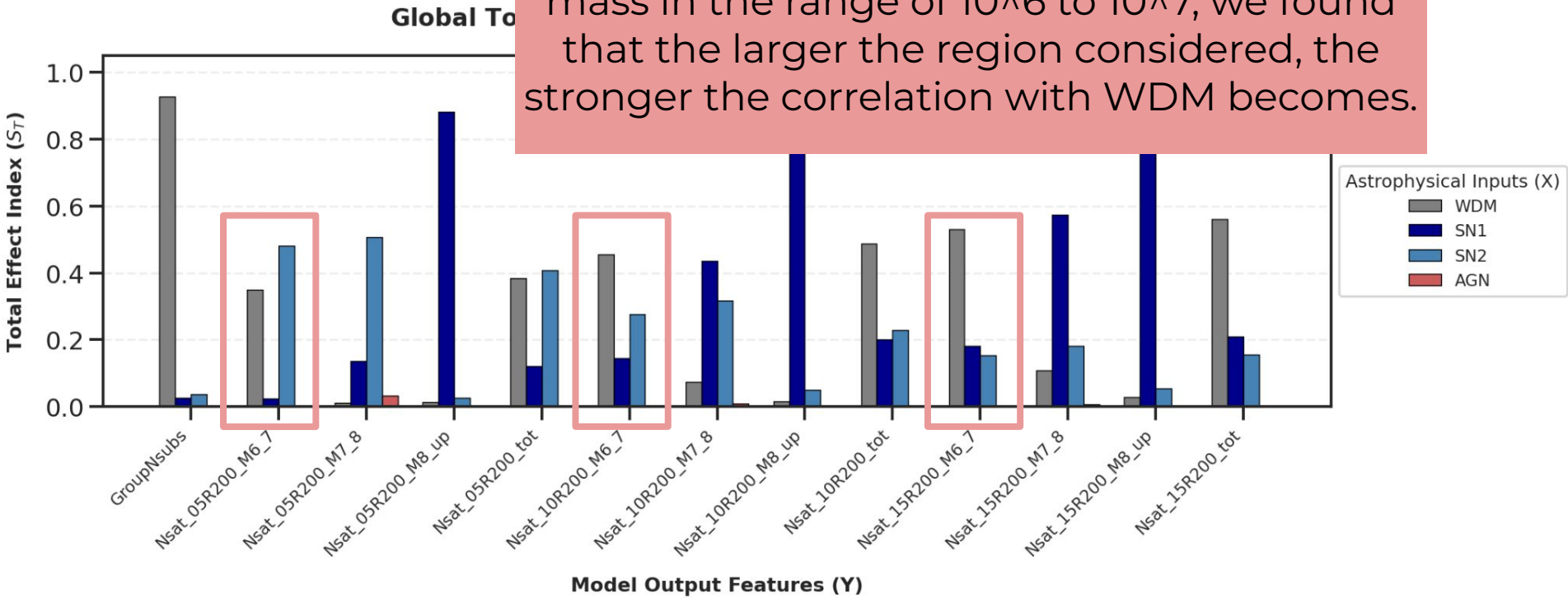
Distribution of satellite

Looking at the number of satellites with mass in the range of 10^6 to 10^7, we found that the larger the region considered, the stronger the correlation with WDM becomes.



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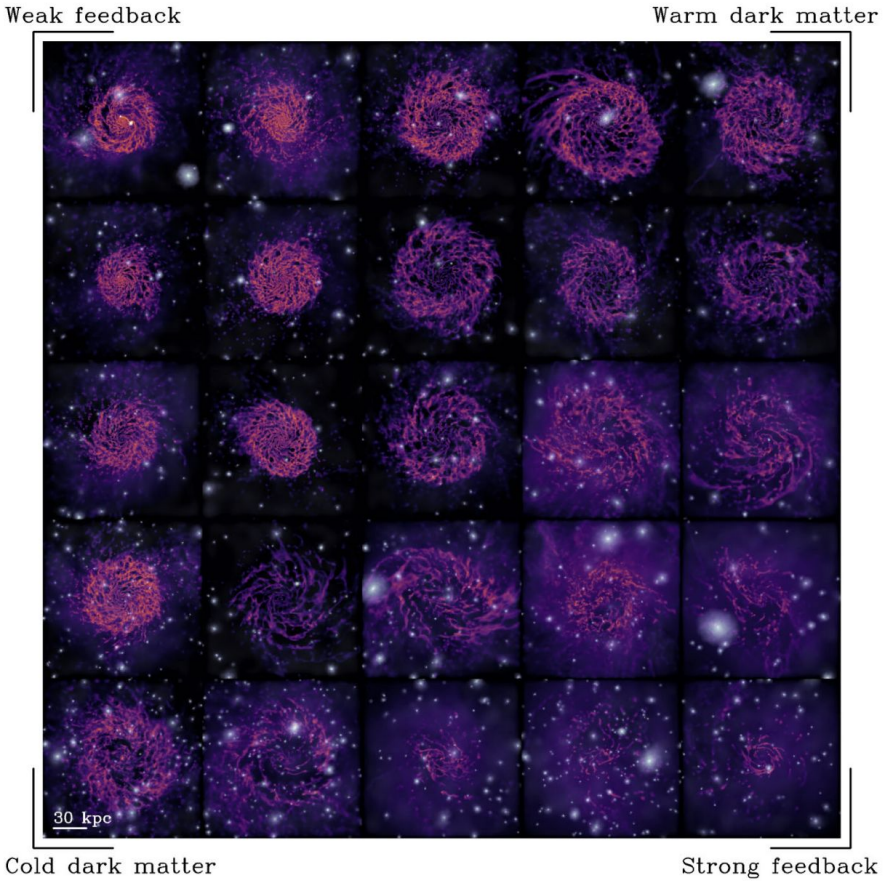
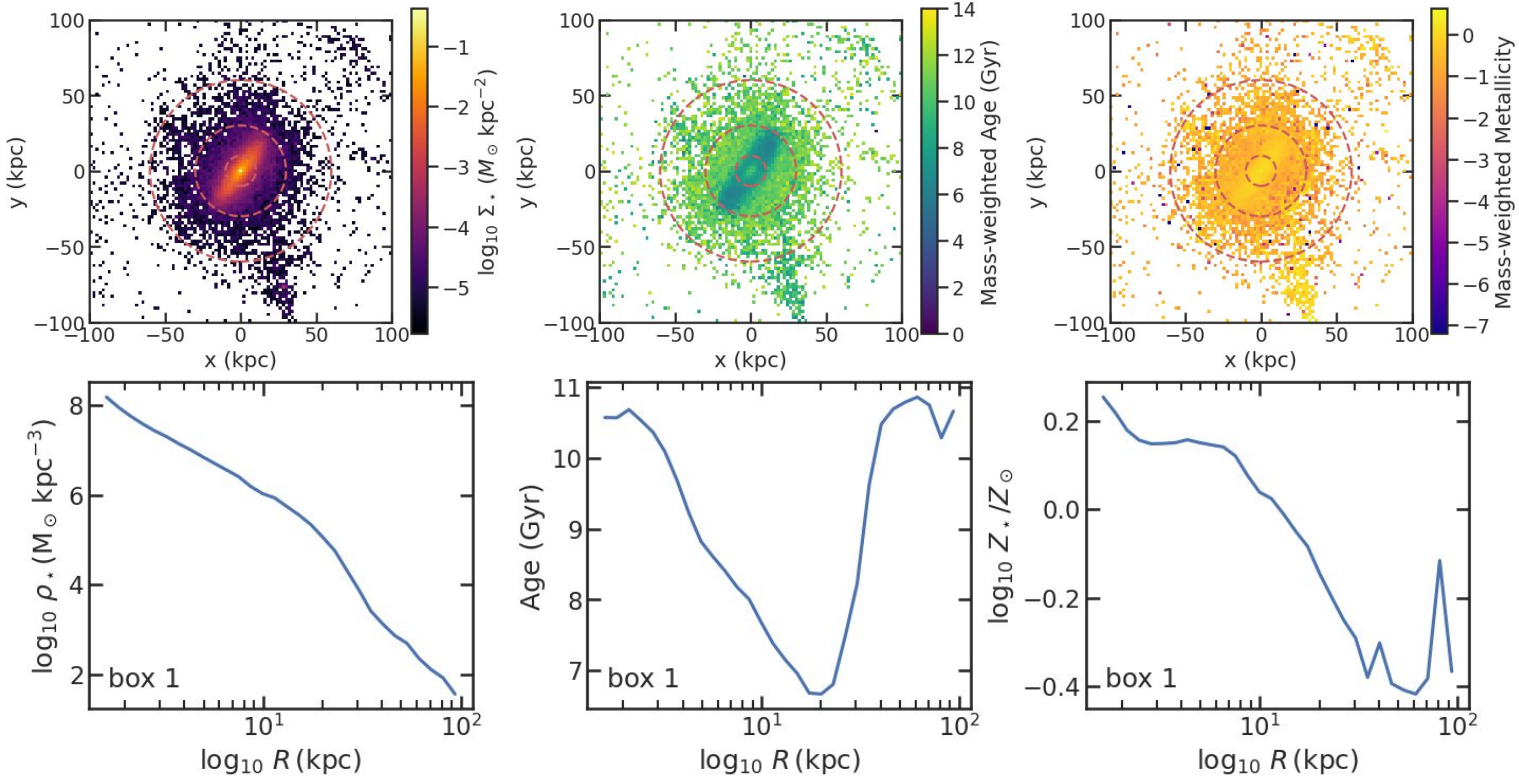
3D profiles



ARTEMIS Simulation
Brown et al. (2024)

3D profiles



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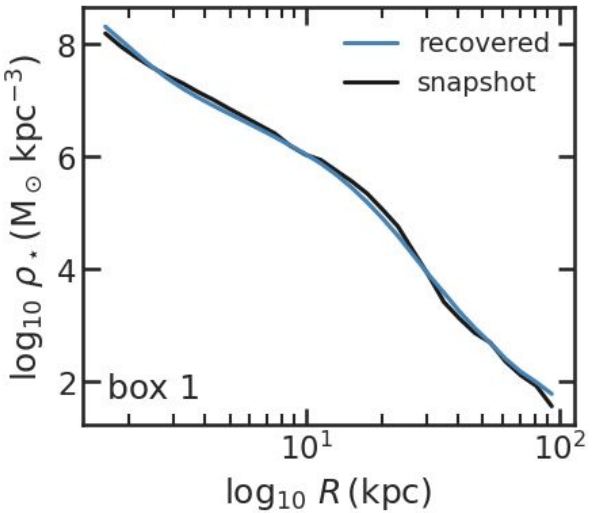
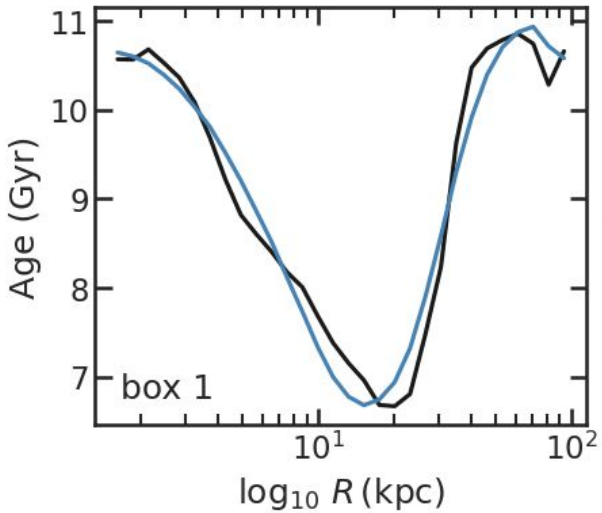
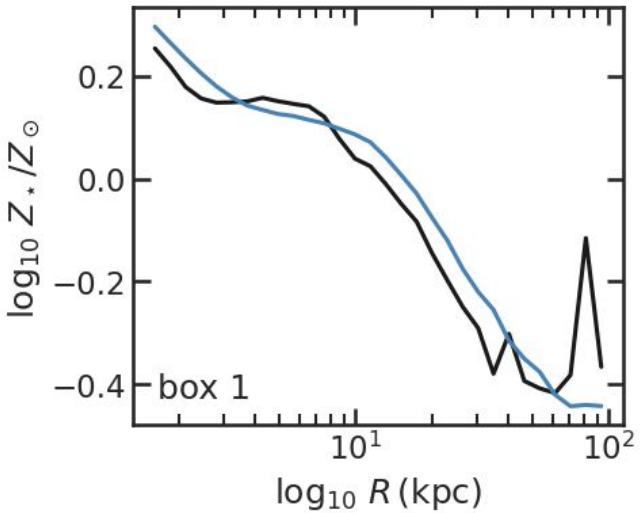
Profiles from snapshots: PCA Analysis

Recovered profile using only first five principal components







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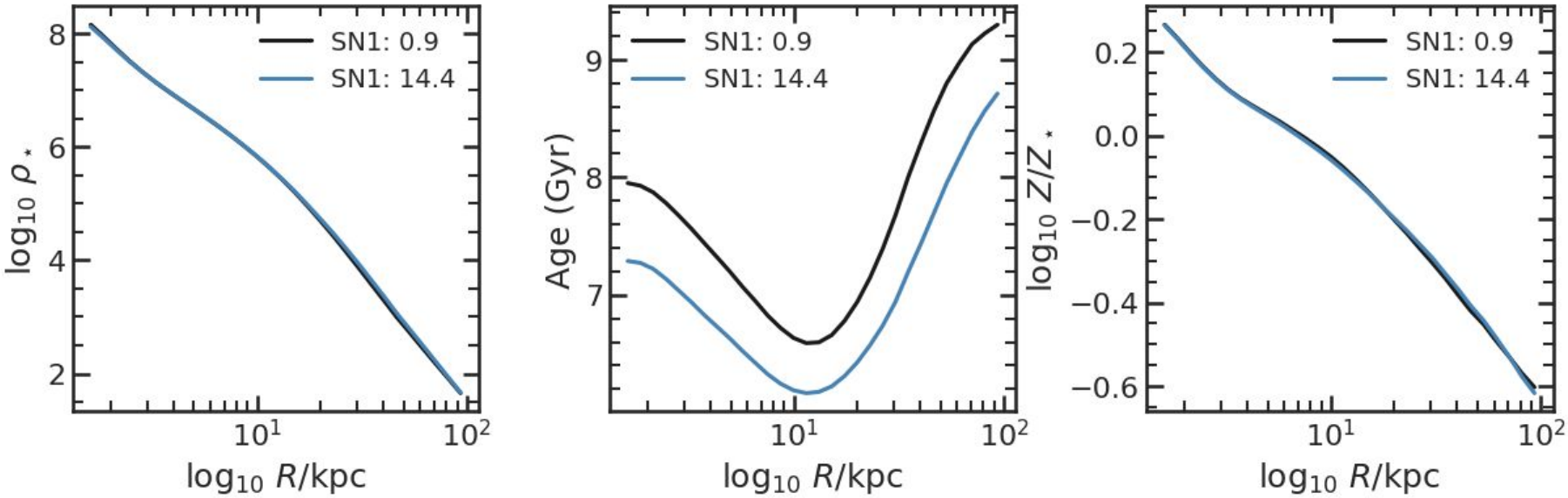
Profiles from snapshots: S

SN1: **Age** inner+outer



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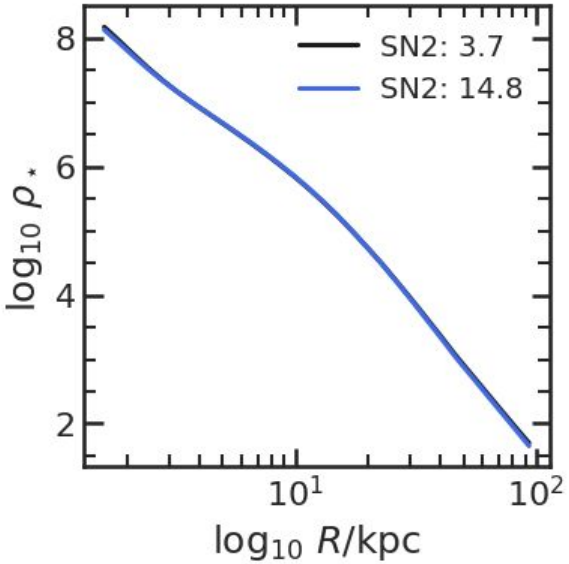
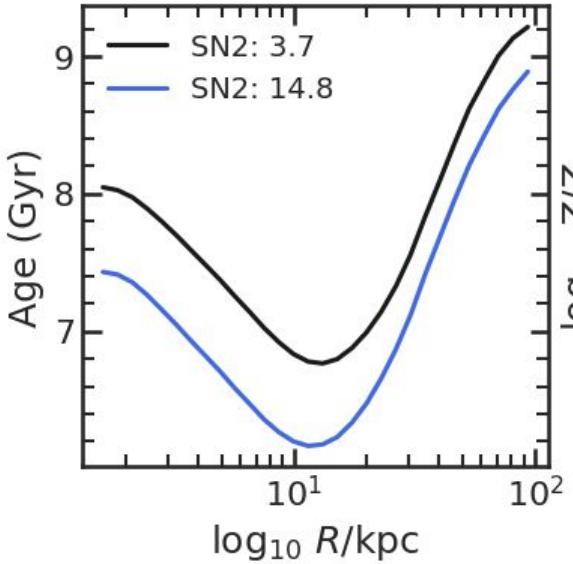
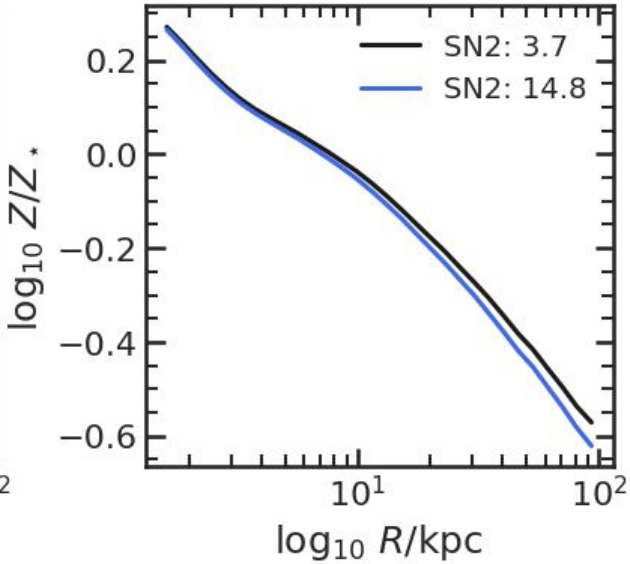
Profiles from snapshots: S

SN1: **Age** inner+outer
SN2: **Age** inner (more) + outer; **Metallicity** outer







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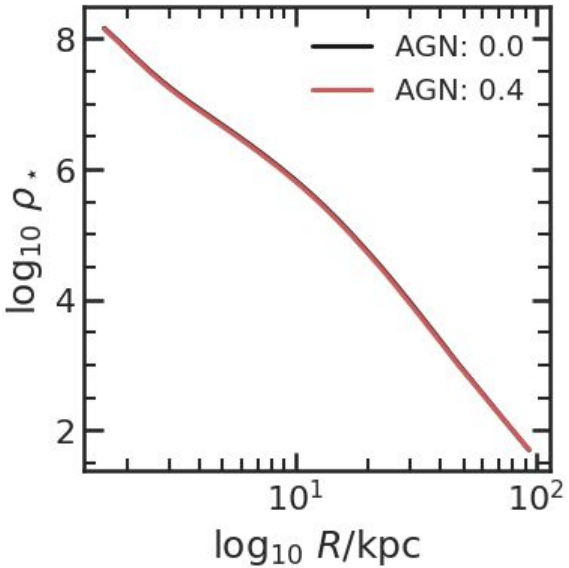
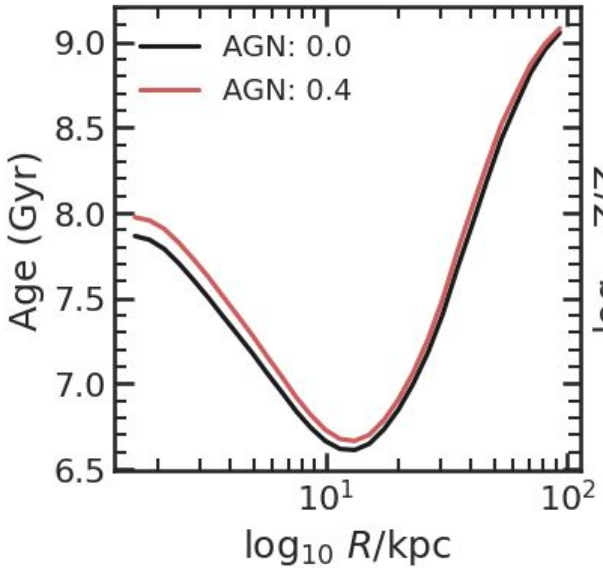
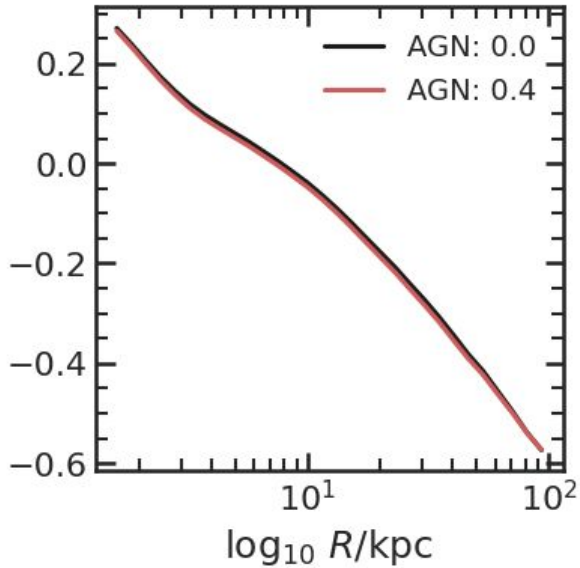
Profiles from snapshots: A

SN1: **Age** inner+outer
SN2: **Age** inner (more) + outer; **Metallicity** outer
AGN: **Age** inner (more); **Metallicity** very slightly







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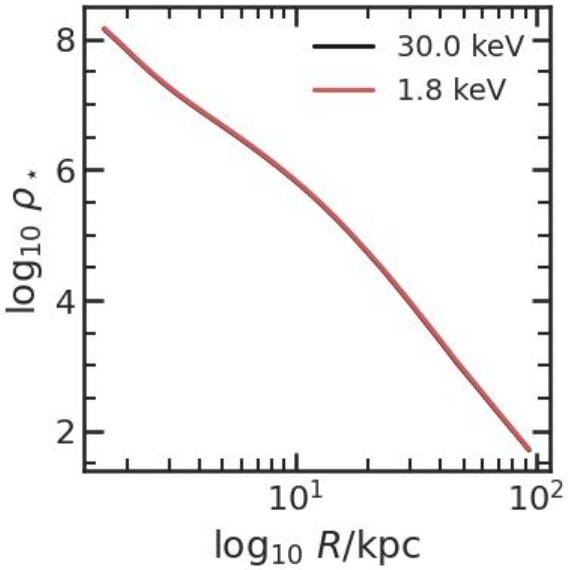
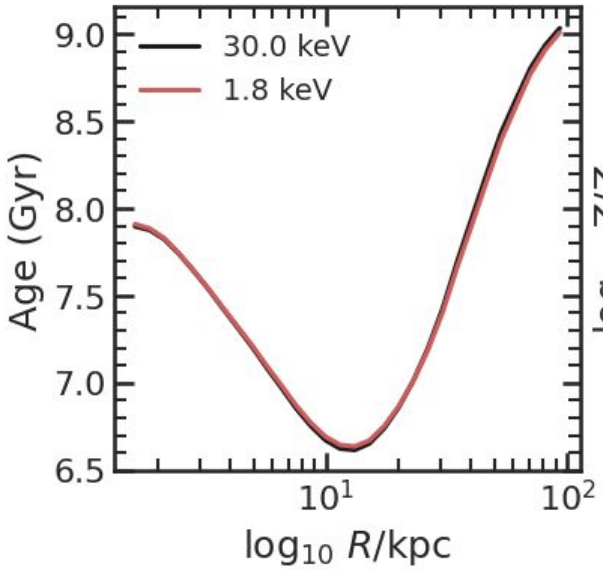
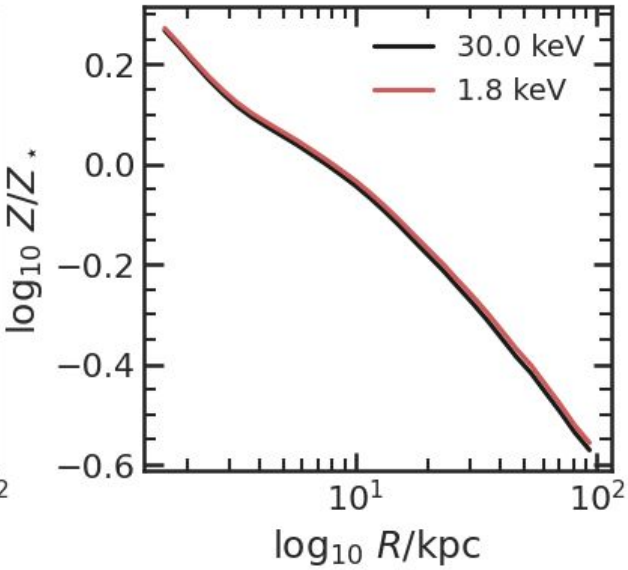
Profiles from snapshots: V

SN1: **Age** inner+outer
SN2: **Age** inner (more) + outer; **Metallicity** outer
AGN: **Age** inner (more); **Metallicity** very slightly
WDM: **Age**? **Metallicity**? outer very slightly







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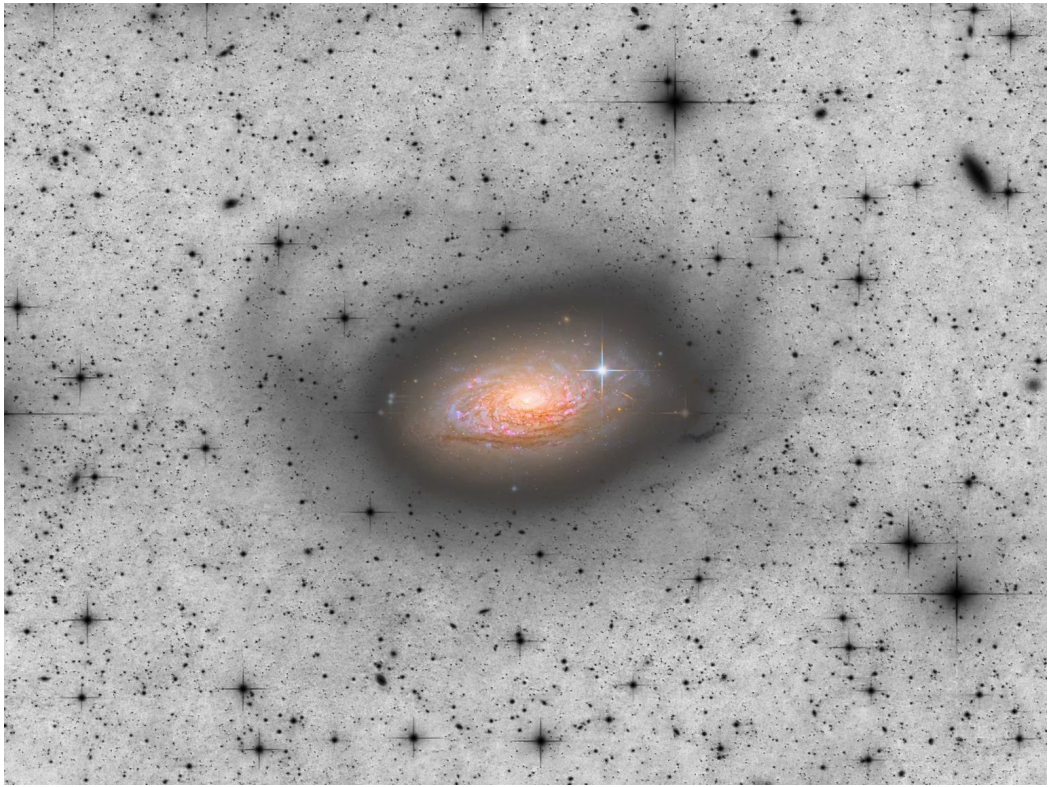
Profiles from mock images



M31
Credit: Bart Delsaert

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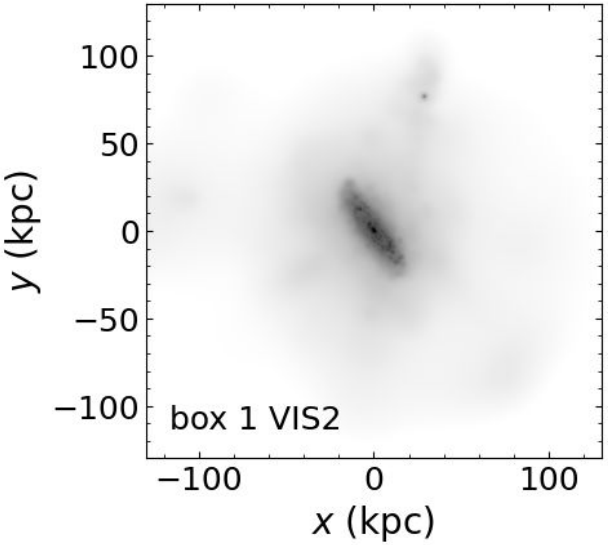
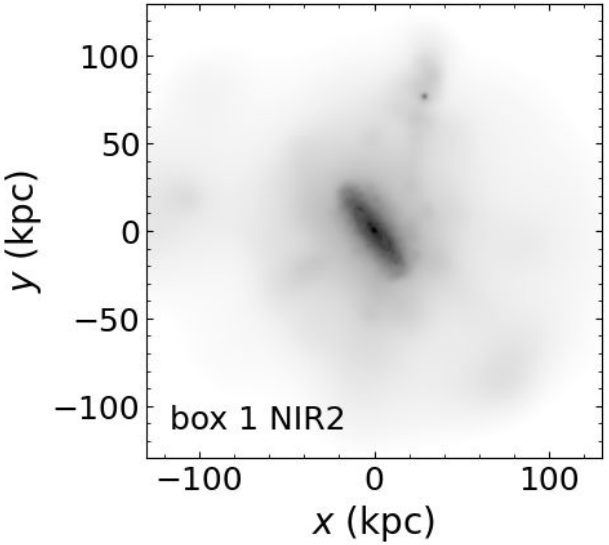
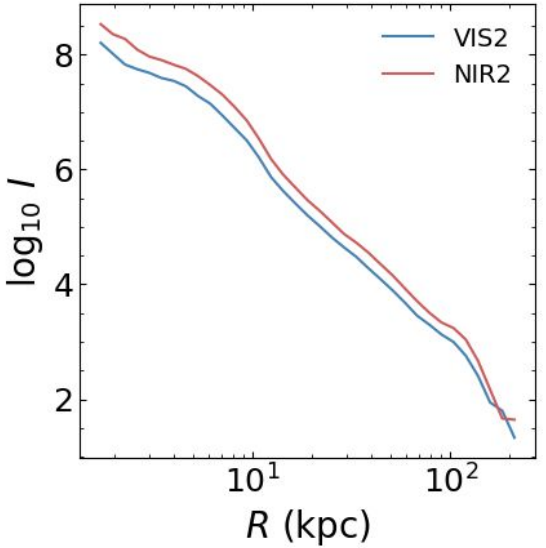
Profiles from mock images

- We use PnBody to create the mock images with Arrakihs bands: VIS1, VIS2, NIR1, and NIR2
- We measured the surface brightness profiles using circular apertures







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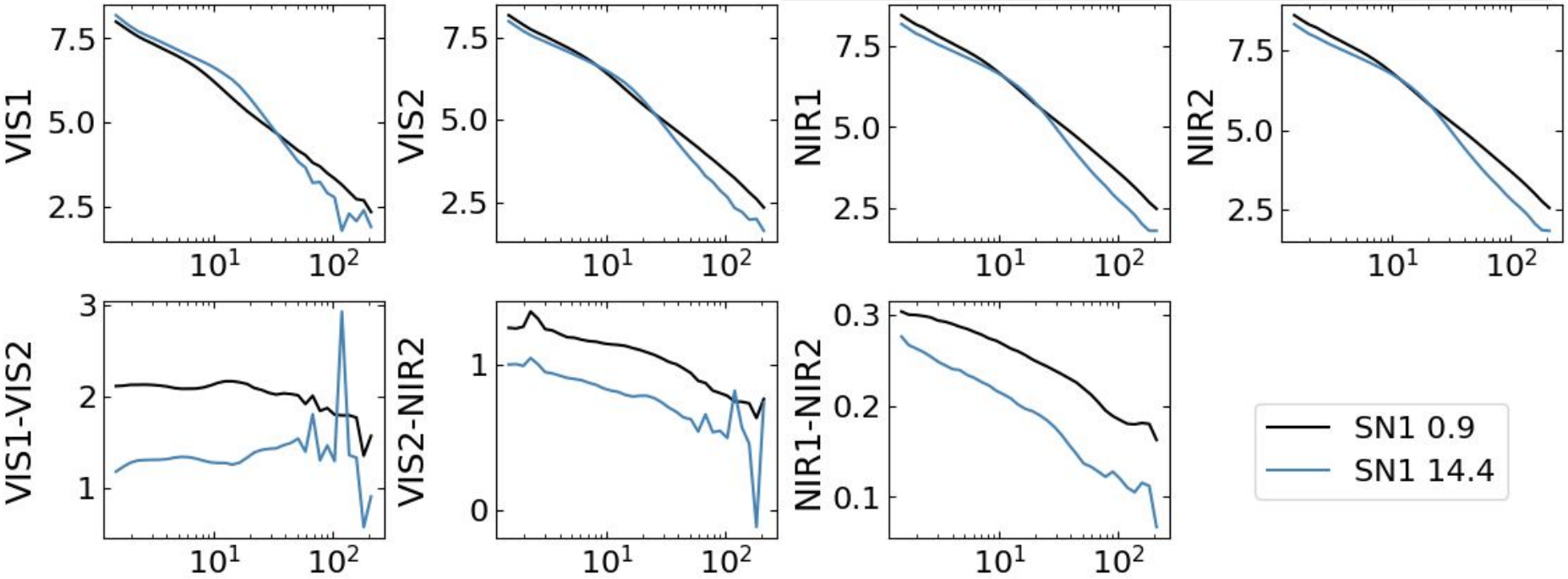
Profiles from mock images: SN1

SN1: Brightness (outer); Color (inner+outer)



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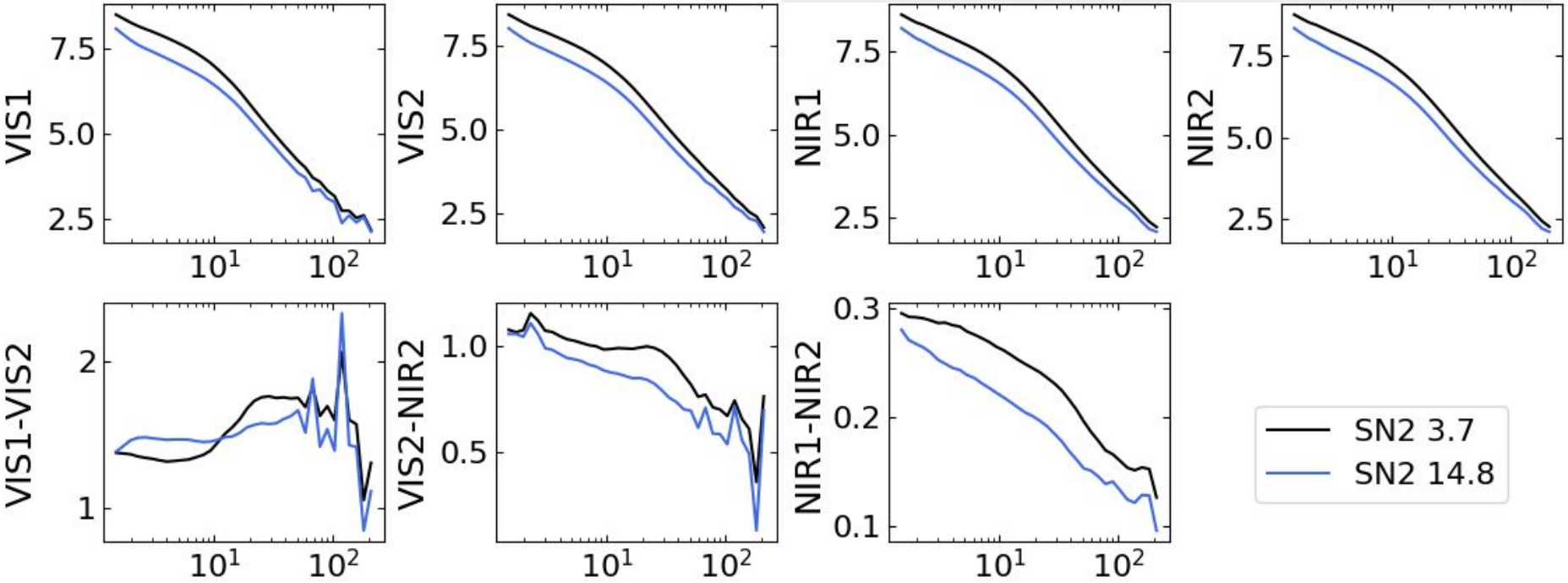
Profiles from mock images: SN2

SN1: Brightness (outer); Color (inner+outer)
SN2: Brightness (inner); Color (inner+outer)



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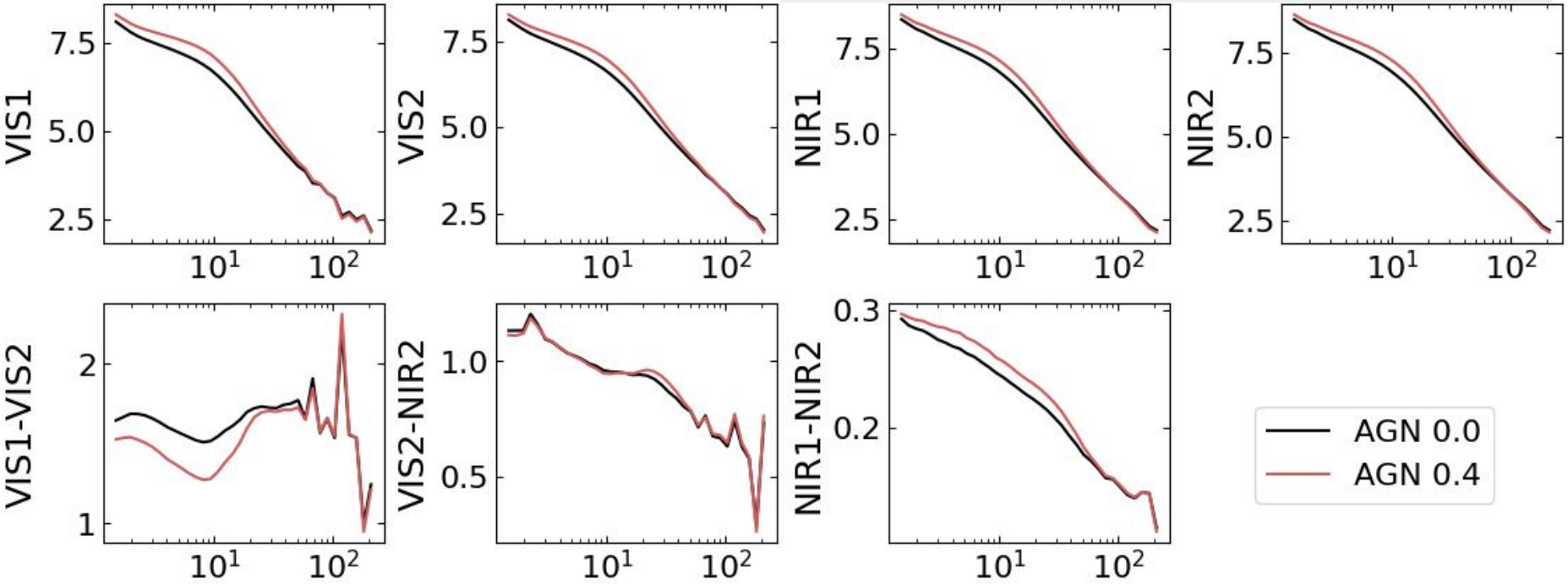
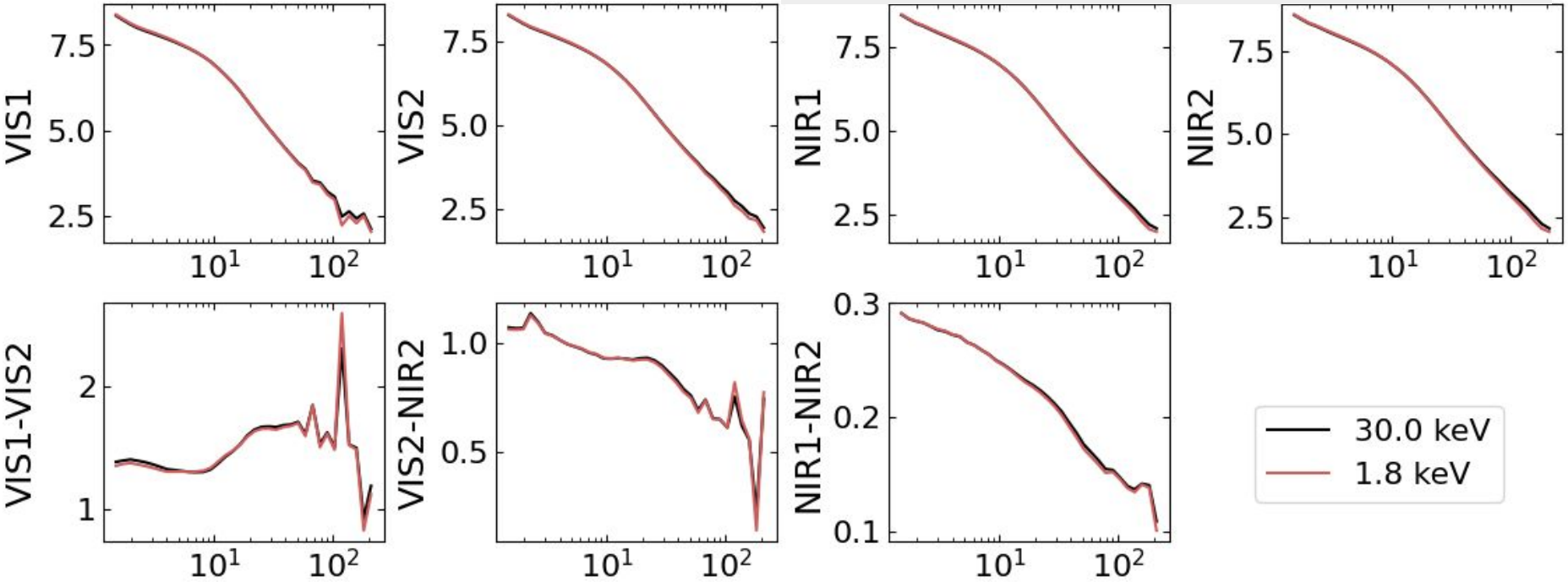
Profiles from mock images: AGN

SN1: Brightness (outer); Color (inner+outer)
SN2: Brightness (inner); Color (inner+outer)
AGN: Brightness (inner); Color (inner)



Profiles from mock images: WDM

SN1: Brightness (outer); Color (inner+outer)
SN2: Brightness (inner); Color (inner+outer)
AGN: Brightness (inner); Color (inner)
WDM: Brightness? (outer very slightly)



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Summary

Galaxy properties
Stellar mass, Gas mass, star-formation rate, metallicity, and etc.

Distribution of satellites
Number of satellites within Fof groups, Number of satellites within R200, and etc.

Profiles from snapshots
Spherical mass density profiles, age and metallicity profiles.

Profiles from mock images
Surface brightness profile of 4 bands and the corresponding color profiles.

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Summary

Galaxy properties

Distribution of satellites

Profiles from snapshots

Profiles from mock images

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Application and prospects for future low-surface brightness observations (e.g., ARRAKIHS)

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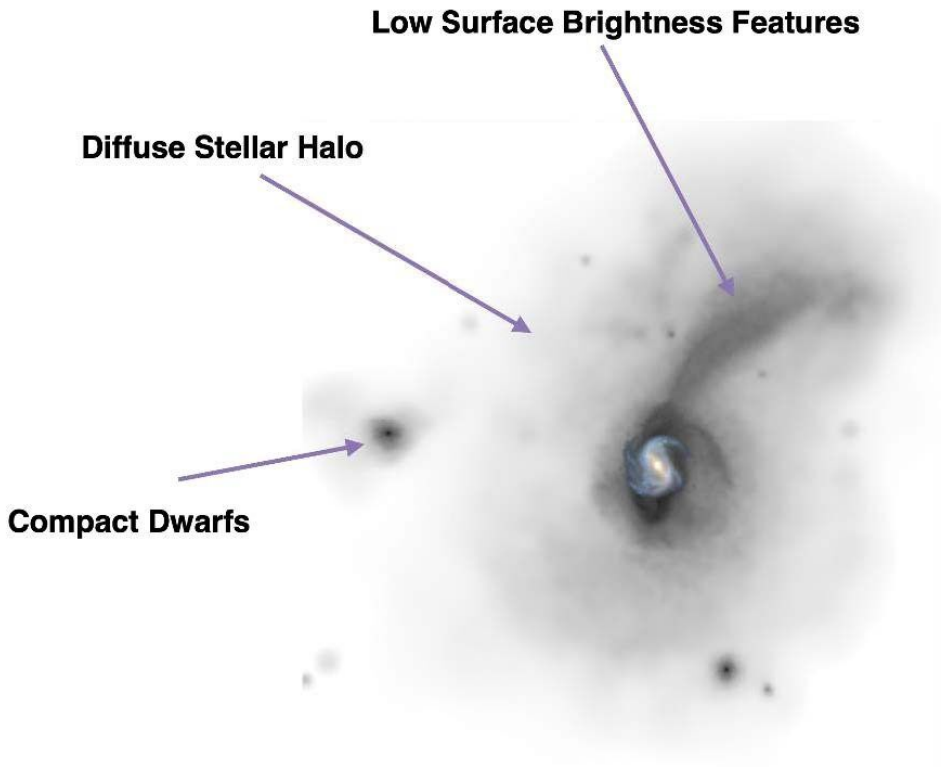

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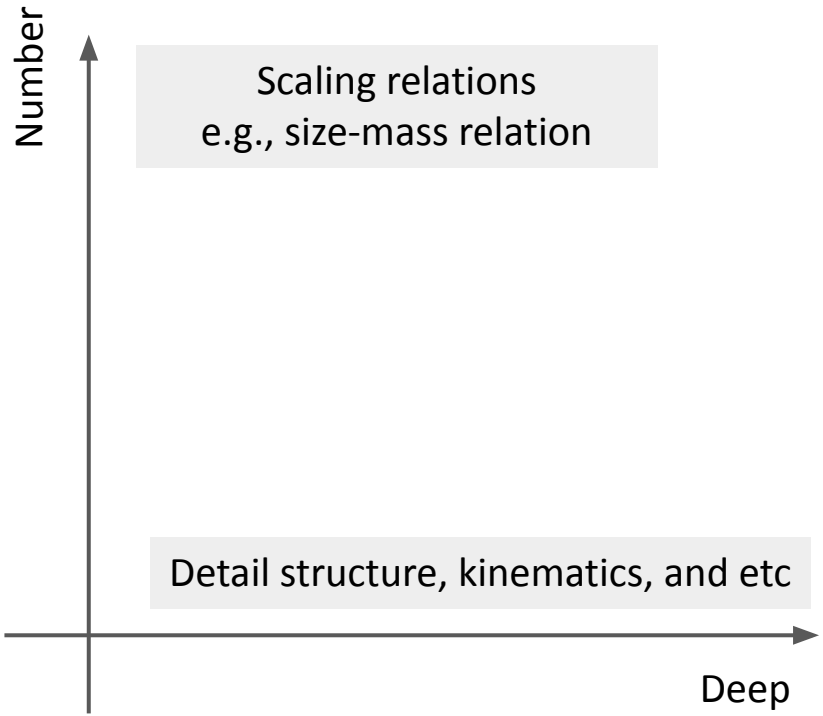
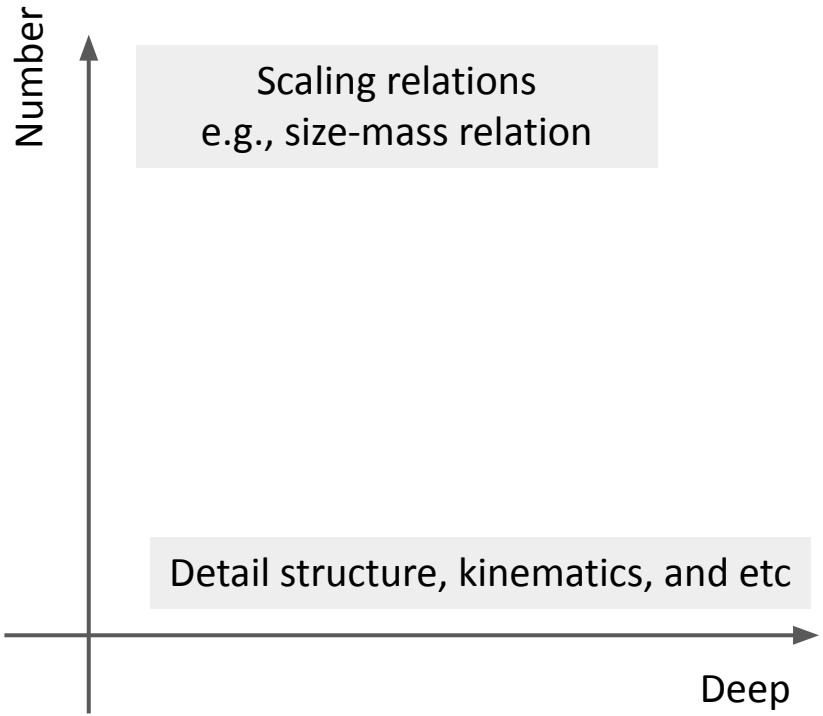
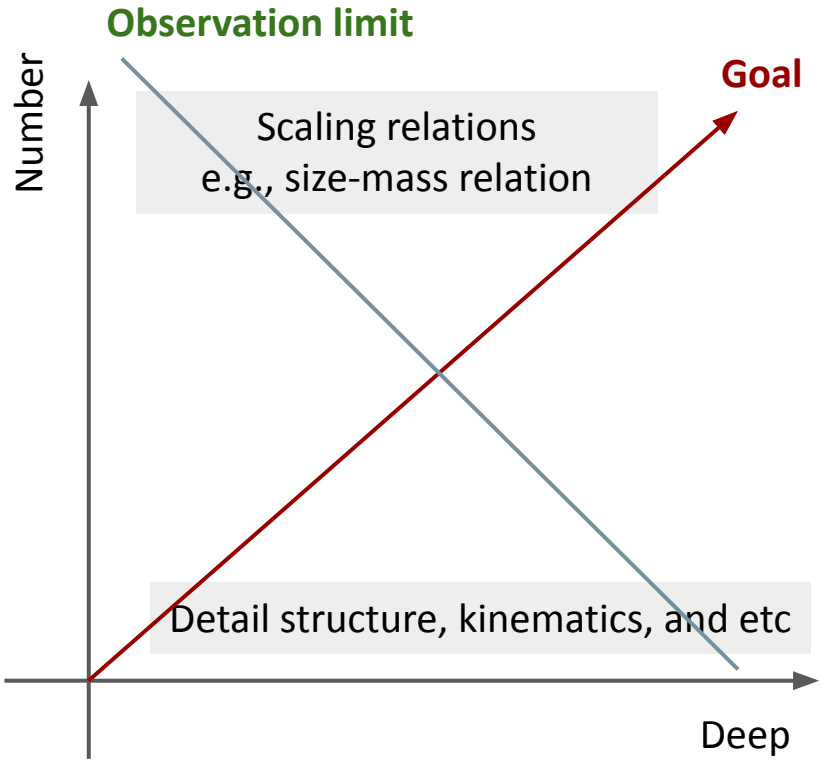

Number
Scaling relations
e.g., size-mass relation
Detail structure, kinematics, and etc
Deep



The benefit of going deep

- Faint structures: low-surface brightness structures, stellar streams, and stellar haloes
- Fainter galaxies: dwarf galaxies
- Higher Redshift



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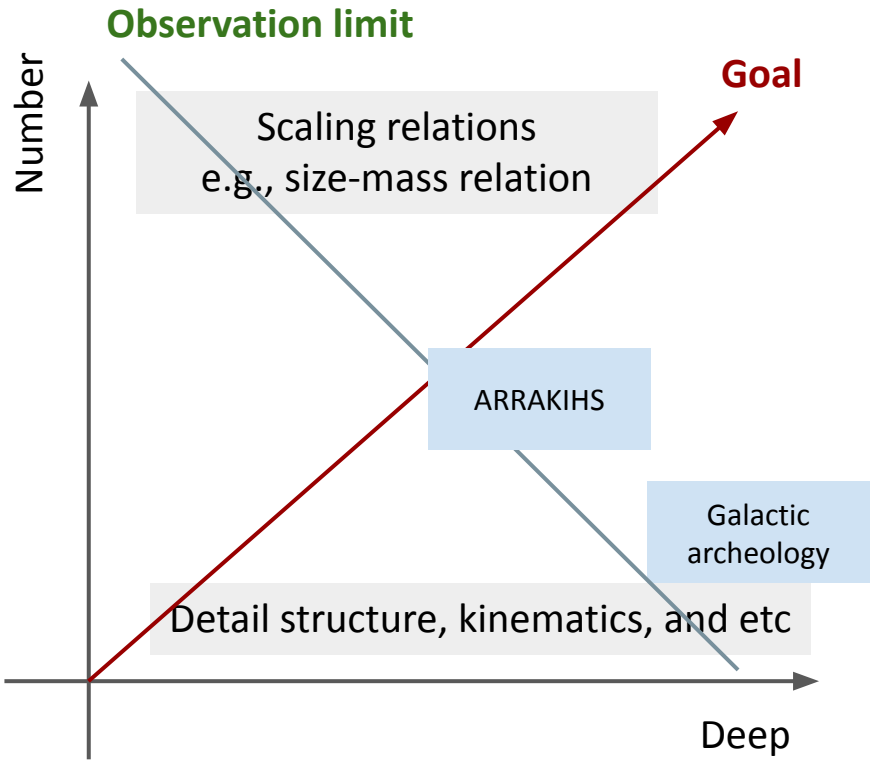

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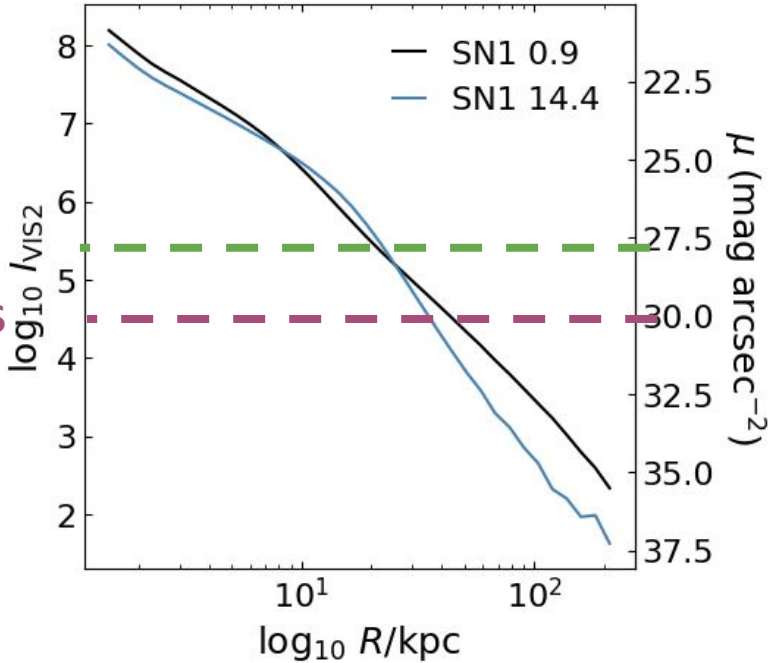

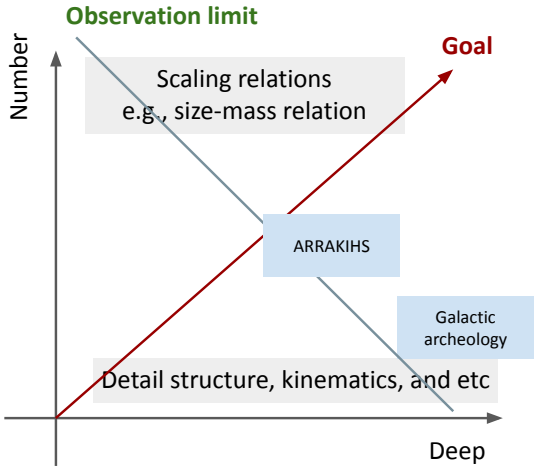

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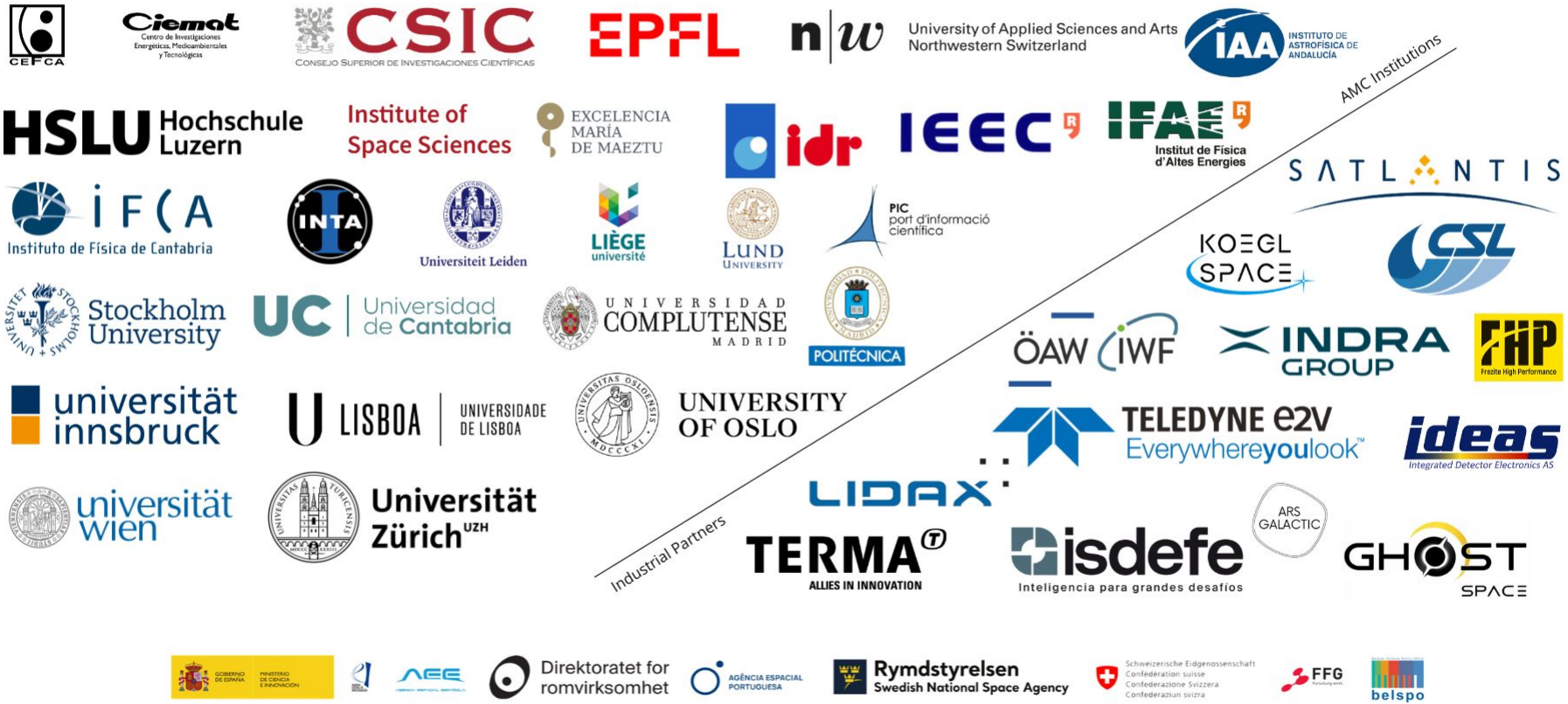
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