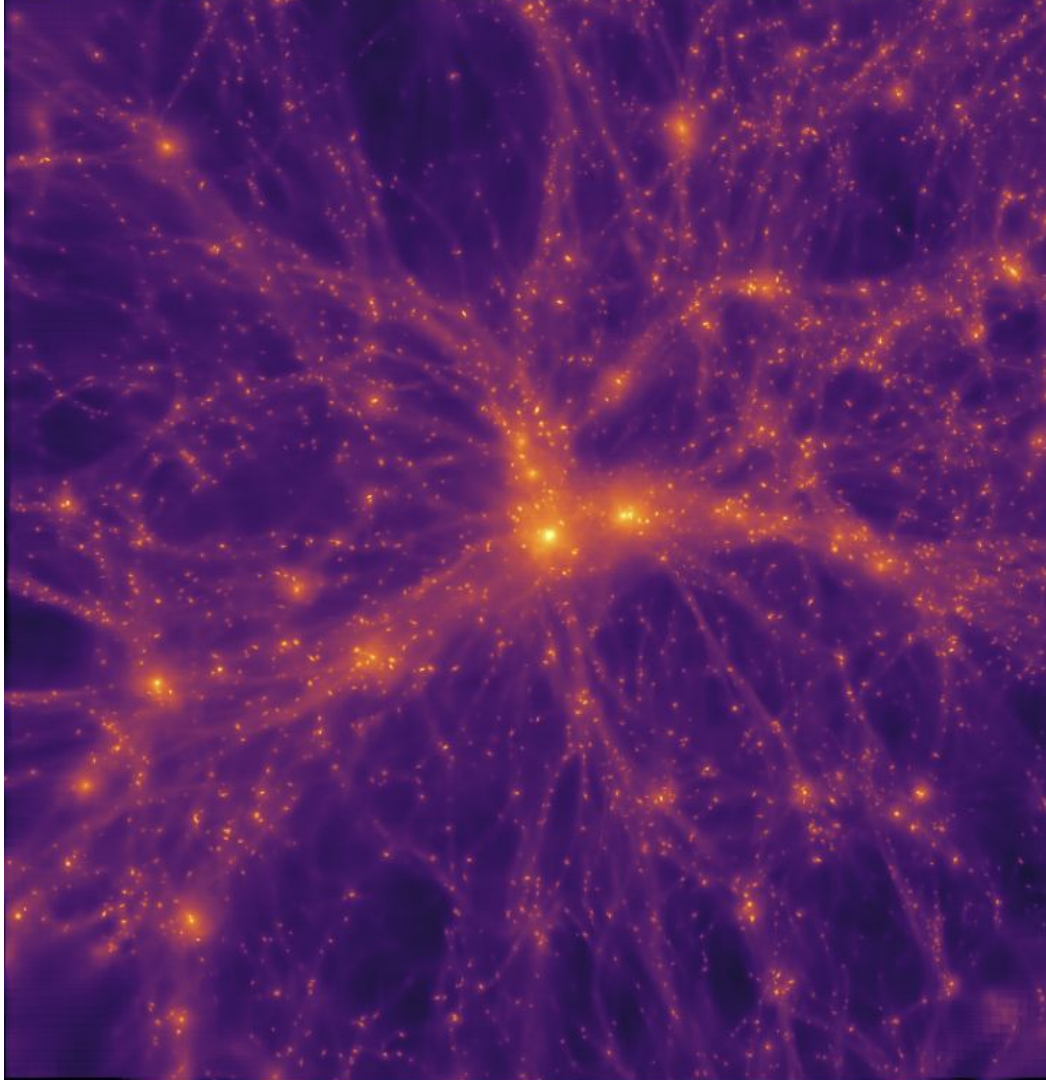
Observatoire de Paris | PSL

The ADELINE suite: Simulations of galaxy clusters in alternative dark energy models

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With **Pier Stefano Corasaniti & Amandine Le Brun**



Colloque national du WG Dark Energy 2026

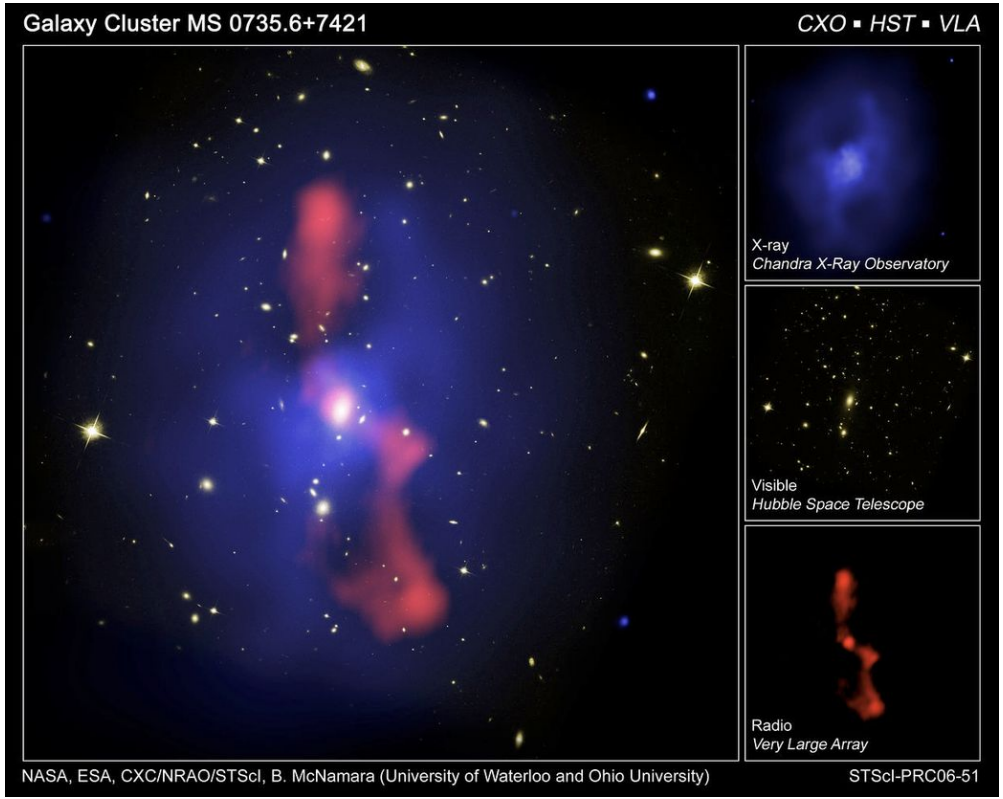
Galaxy clusters

The importance of AGN feedback

Central cluster's galaxy usually host an Active Galaxy Nucleus (AGN)

- **Heating of the surrounding gas**
  Radiations from the accretion disk

- **Injection of momentum**
  Jets, outflows



Galaxy clusters The importance of AGN feedback

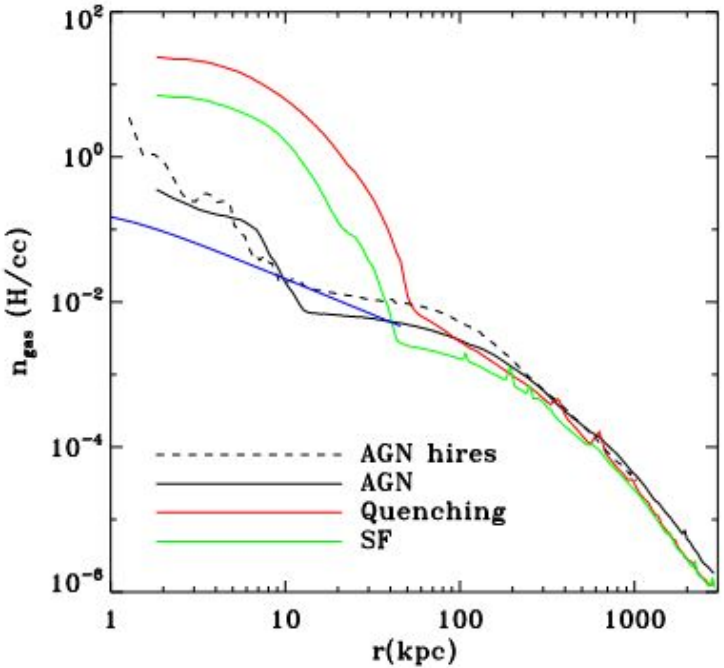
From Simulations:
AGN feedback is mandatory to reproduce realistic galaxy clusters

- **Heating of the surrounding gas**
  Lowers star formation

- **Injection of momentum**
  Lowers star formation
  Expels gas in proto-clusters

AGN feedback diminishes central densities

Teyssier+10



Electron density profile of cluster simulated with an without AGN feedback

Alternative dark energy models (wCDM)

Simplest modification of ΛCDM (of the dark energy part)

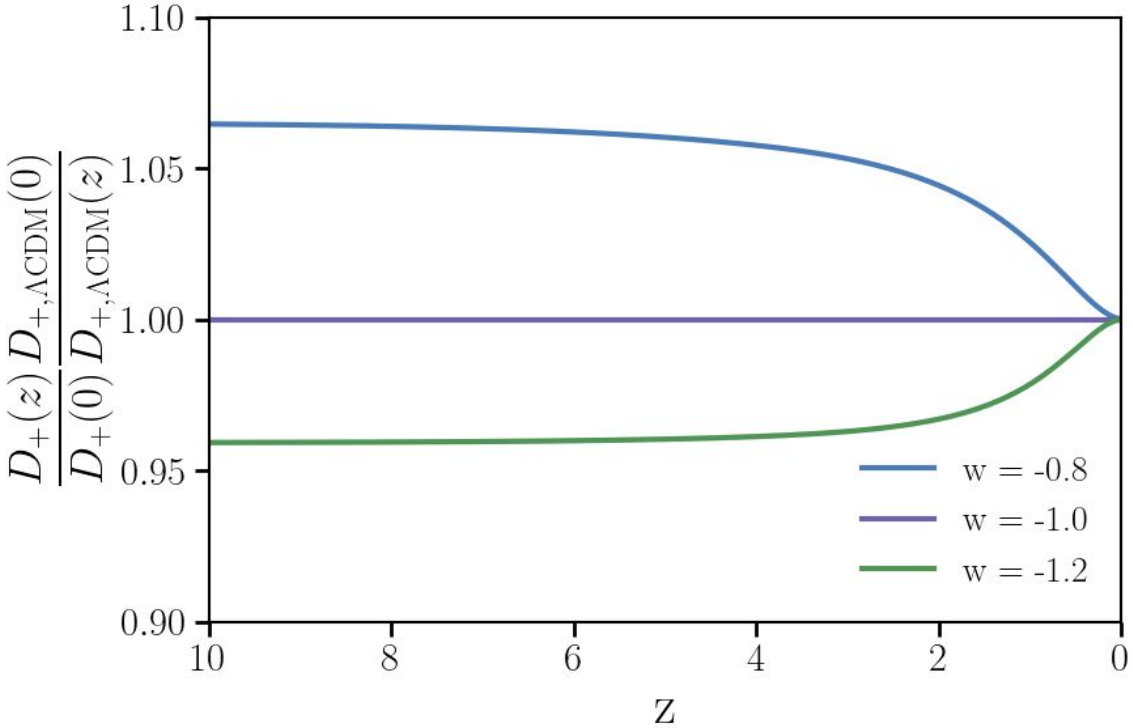
w is the state parameter of dark energy : $p = w\rho c^2$

ΛCDM	wCDM
w = -1	**w ≠ -1**

w > -1 = Quintessence models
w < -1 = Phantom models

Changing w changes the way the Universe expands
and how structures are forming and evolving in it

Alternative dark energy models (wCDM)



Ratio of the growth factors of the wCDM models explored with respect to the ΛCDM one.

Clusters are expected to be **more** / **less** massive in the **quintessence** / **phantom** than in **ΛCDM** at high z

As cosmic evolution goes, **mass differences are damped by the effect of the dark energy**

Motivation

No simulation of galaxy clusters with AGN feedback in alternative cosmology exist yet

But clusters are used for cosmological inference and need to be studied in non ΛCDM context

Problematic

What is the impact of wCDM dark energy models on a realistic population of galaxy clusters ?

The ADELINE suite

Tornatore+26 in prep

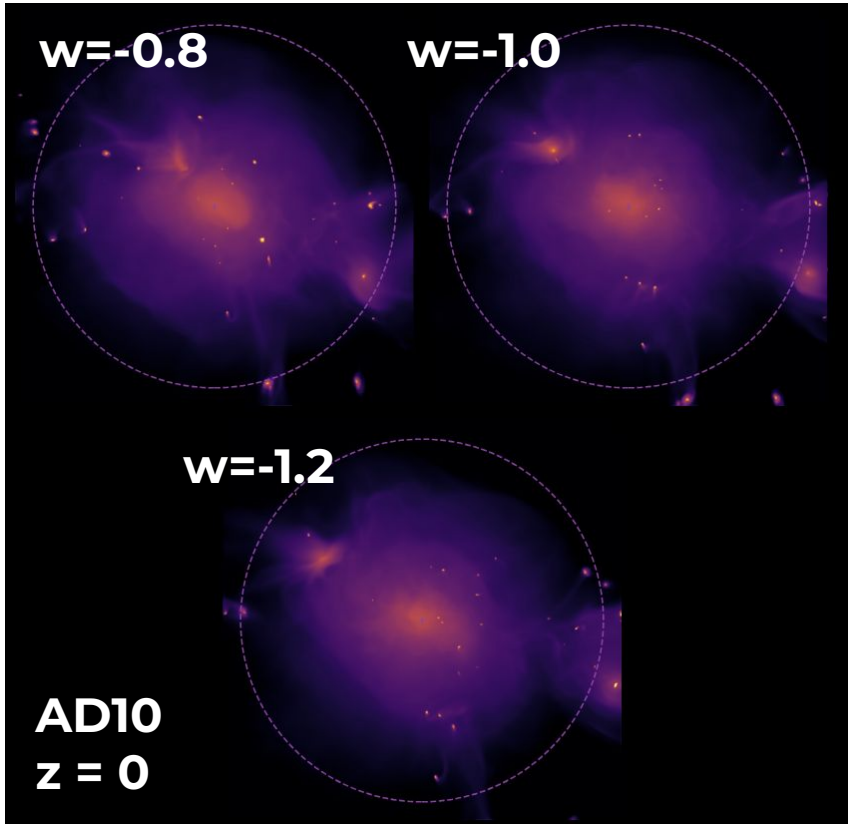
- **9 massive systems**
  re-simulated from a DMO 1.5 Gpcc box

  - 2 wCDM cosmologies per system
  w = -0.8 and **w = -1.2**

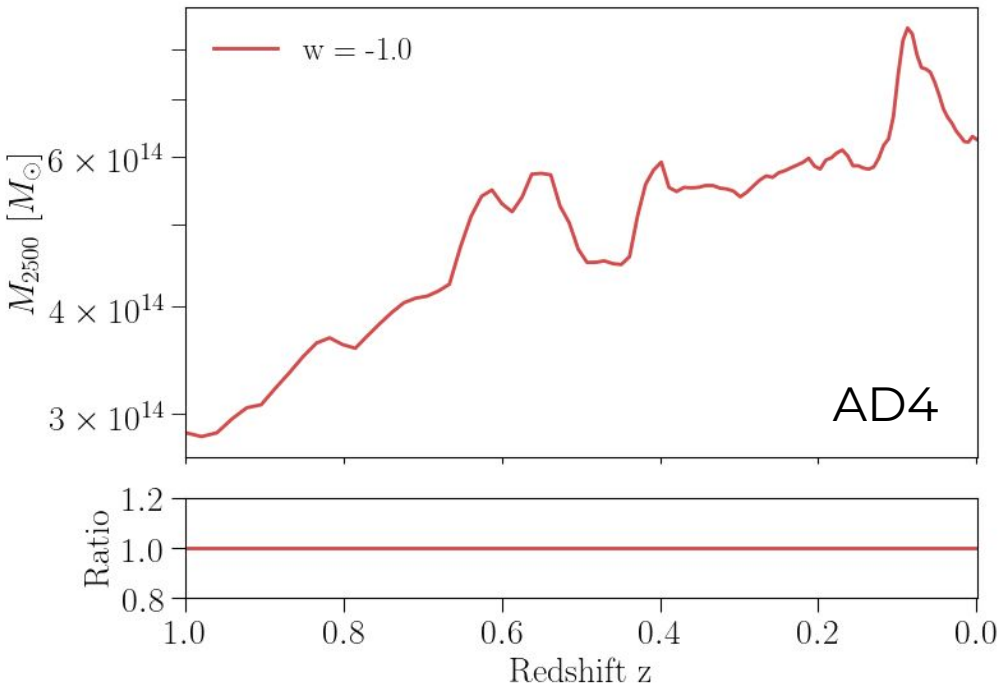
  - 1 ΛCDM cosmology per system
  w = -1.0

- **Resolution:** $\Delta x \approx 0.95\ kpcc$
  $M_{DM} \approx 1.8 \times 10^8 M_\odot$

- **Code:** **RAMSES** (Teyssier+02)
  Horizon-AGN Physics (Dubois+14)
  Bi-modal AGN feedback

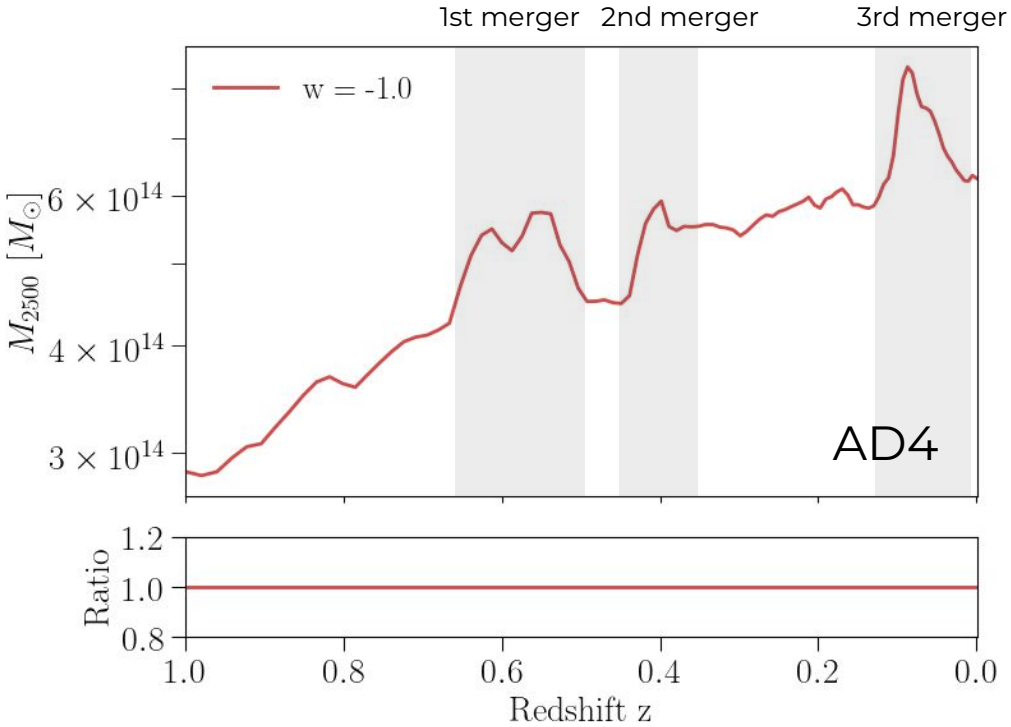


Delayed evolution among cosmologies



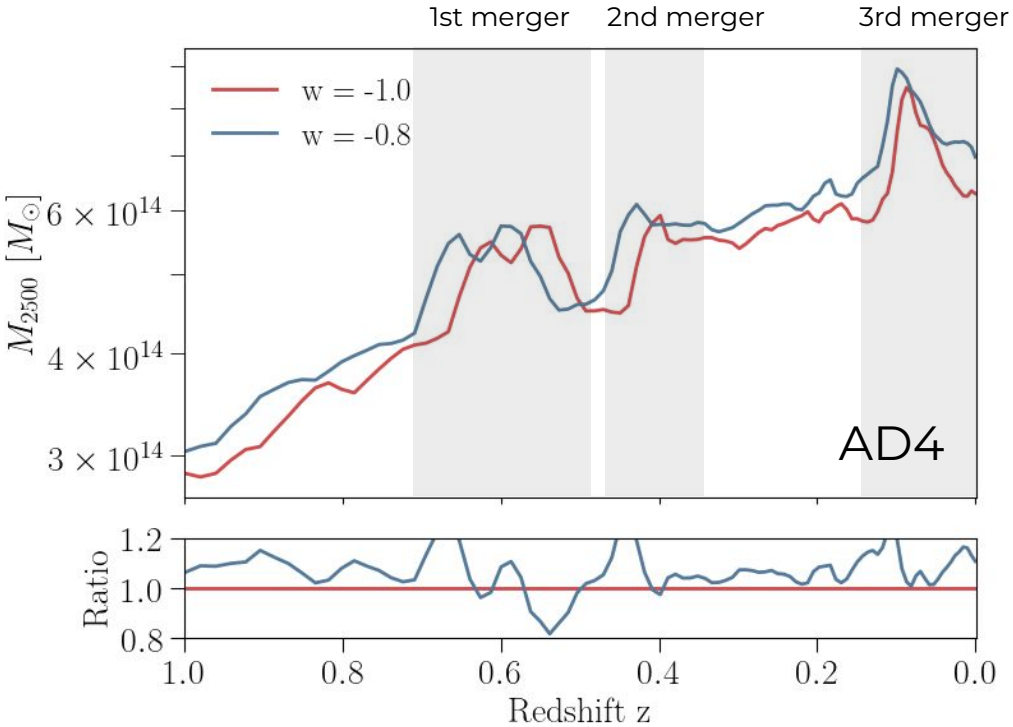
Redshift evolution of M_{2500} for the AD4 cluster

Delayed evolution among cosmologies



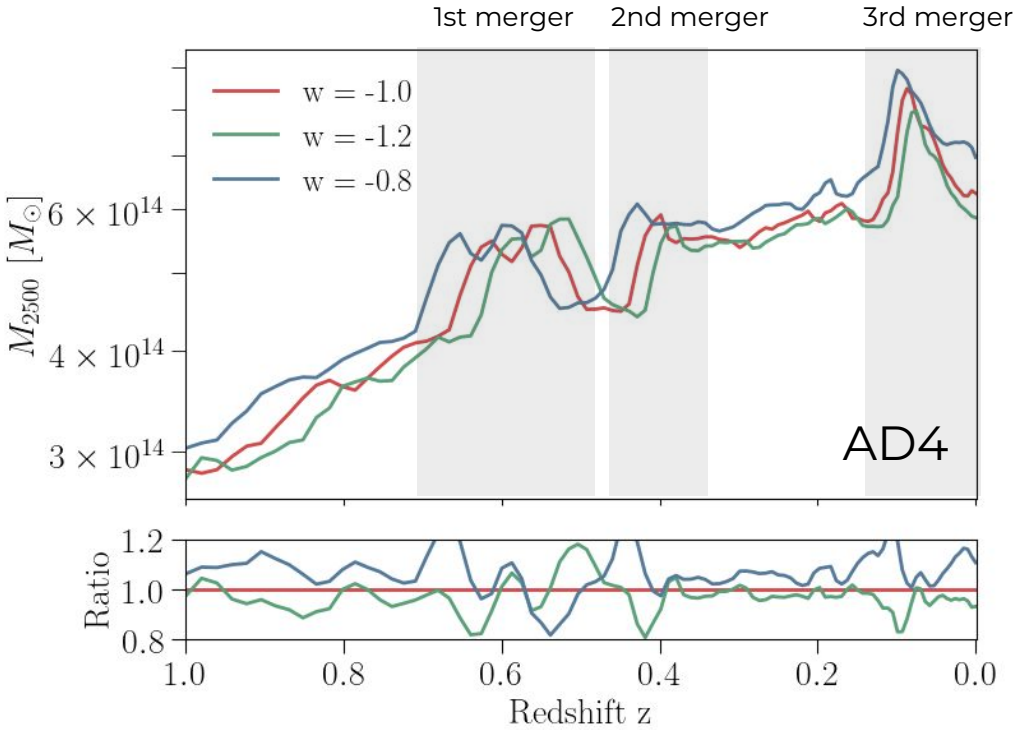
Redshift evolution of M_{2500} for the AD4 cluster

Delayed evolution among cosmologies



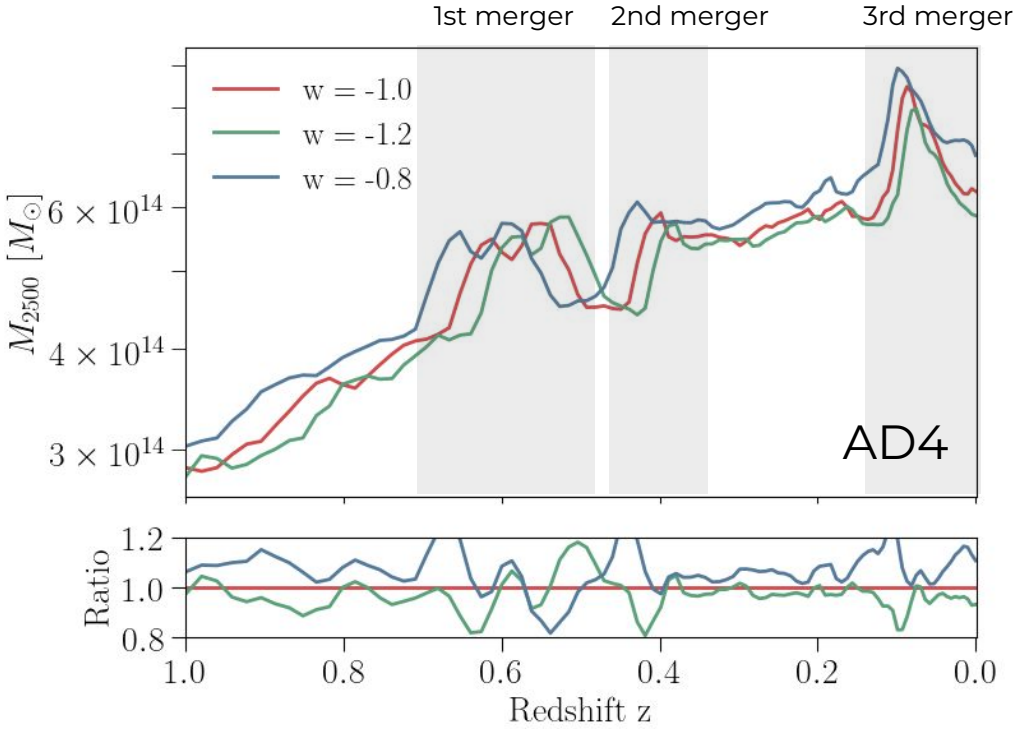
Redshift evolution of M_{2500} for the AD4 cluster

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Redshift evolution of M_{2500} for the AD4 cluster

Delayed evolution among cosmologies

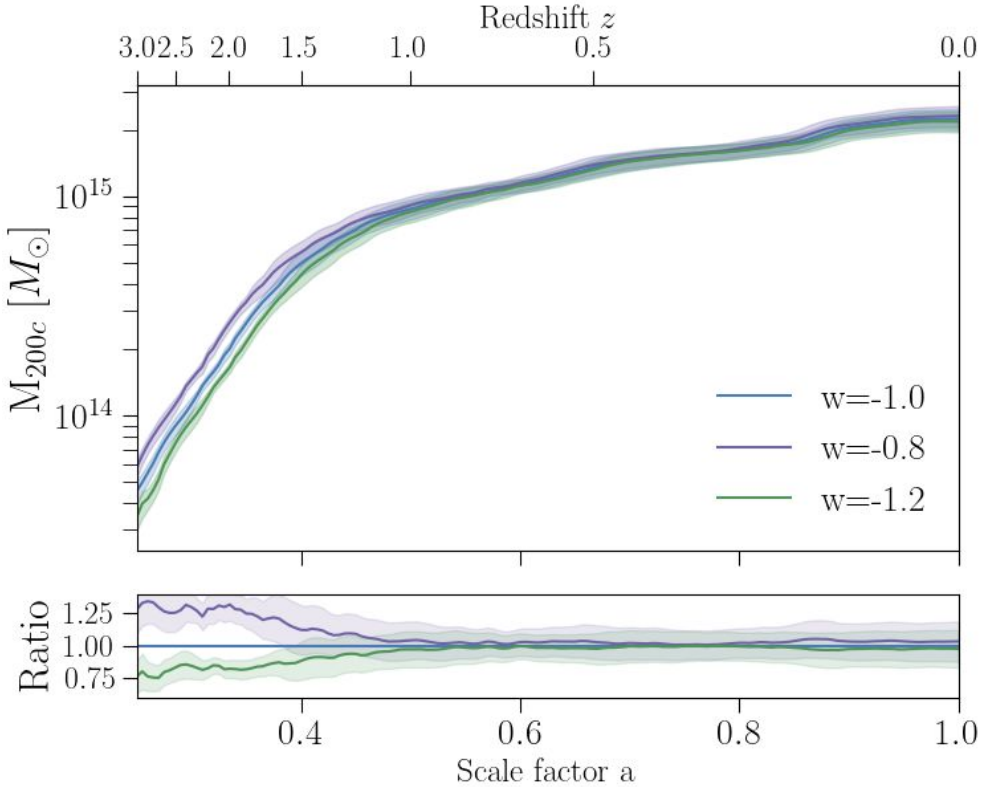


Redshift evolution of M_{2500} for the AD4 cluster

Dynamics is shifted towards higher redshift in the **quintessence** model with respect to the **ΛCDM** model

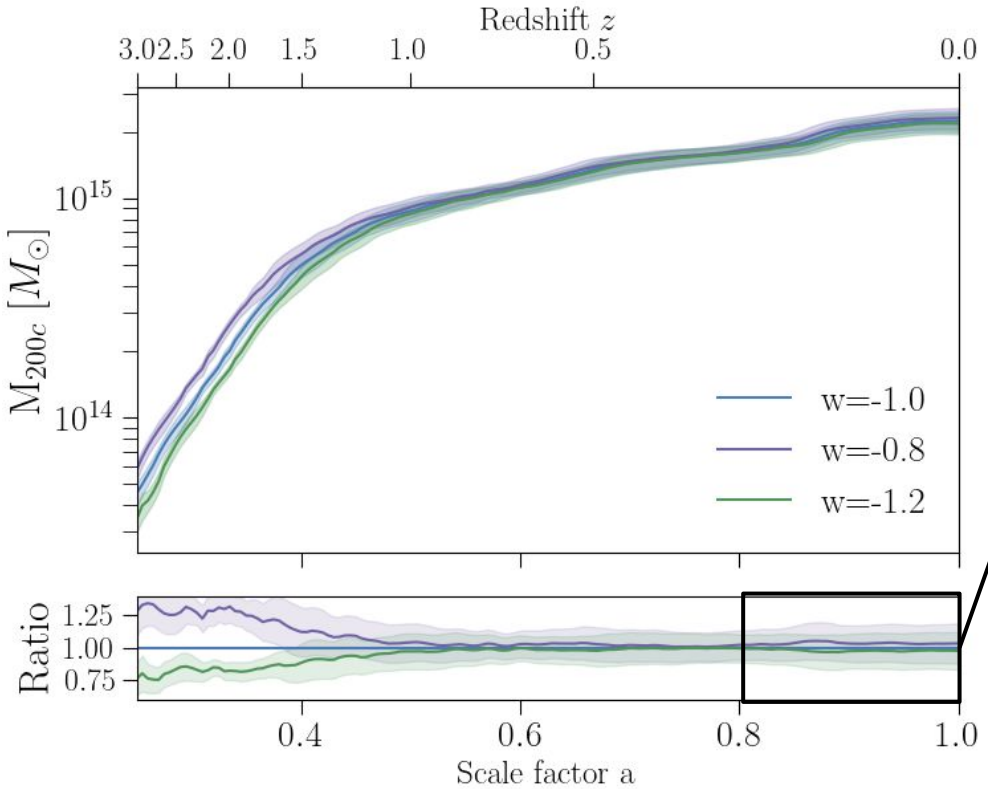
Dynamics is shifted towards lower redshift in the **phantom** model with respect to the **ΛCDM** model

Clusters masses evolution: M_{200c}

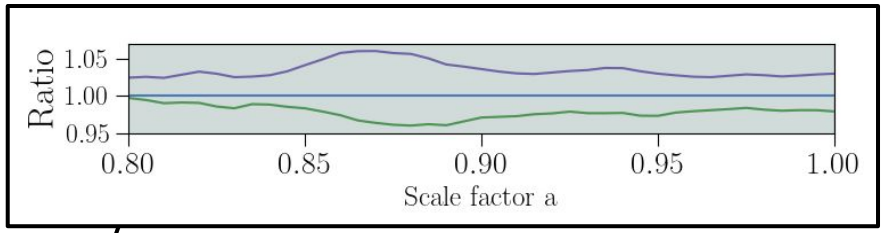


Average evolution of M_{200c} between z=3 and z=0

Clusters masses evolution: M_{200c}



Average evolution of M_{200c} between z=3 and z=0

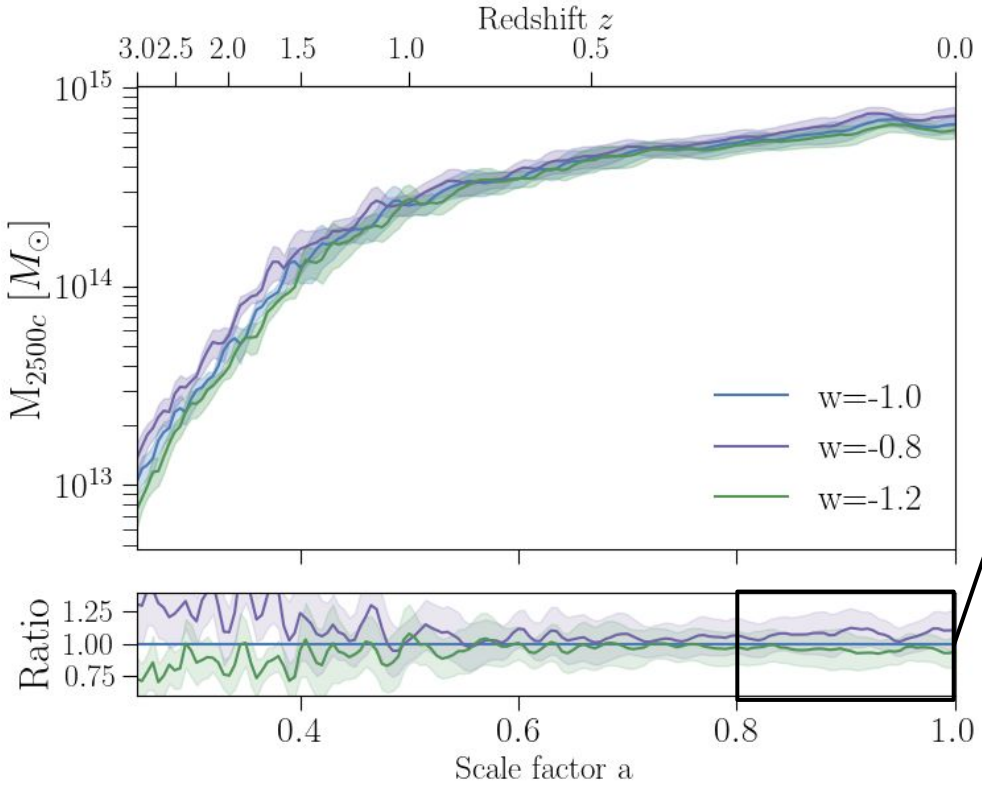


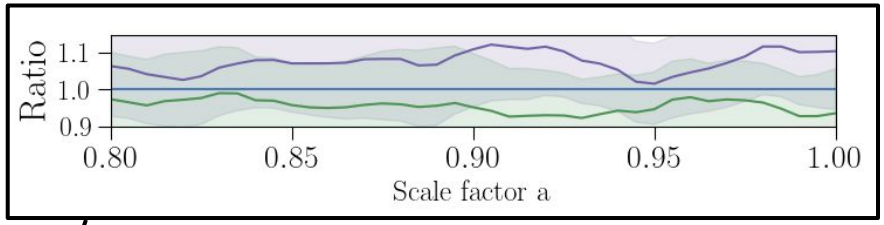
Clusters are **more** / **less** massive in the **quintessence** / **phantom** than in **ΛCDM** at high z

As cosmic evolution goes, **mass differences are damped by the effect of dark energy**

But small non linear differences persist at low redshift

Clusters masses evolution: M_{2500c}

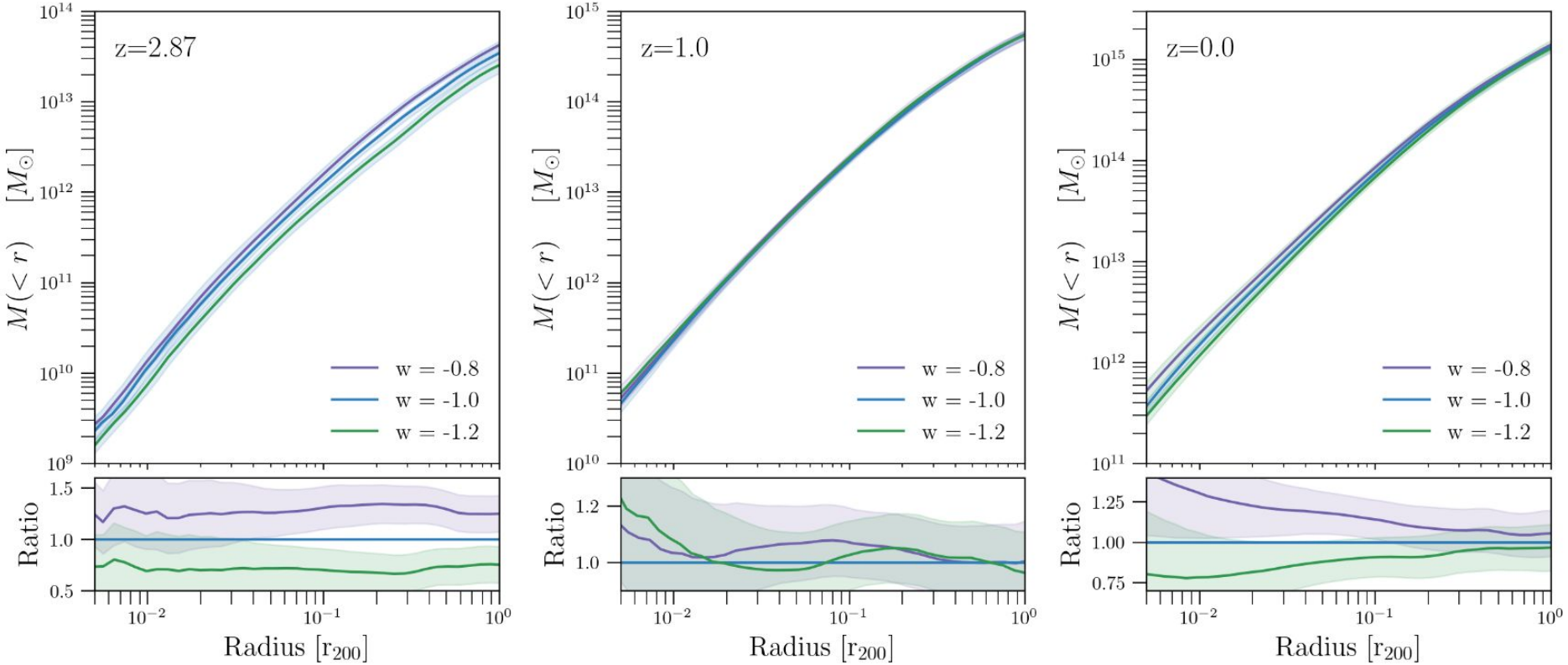




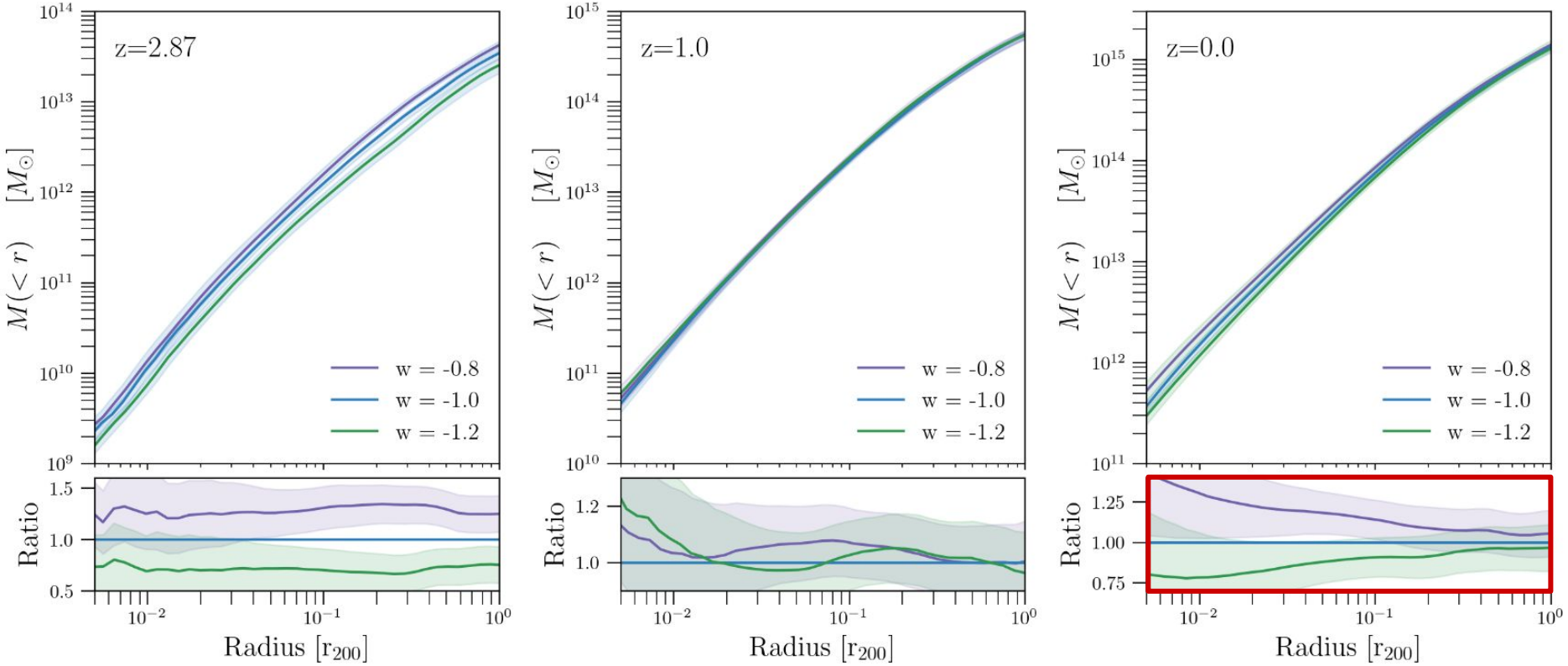
Signature of DE modelling is stronger in the core than in the outskirts at low z
=
change of halo concentration

Average evolution of M_{200c} between z=3 and z=0

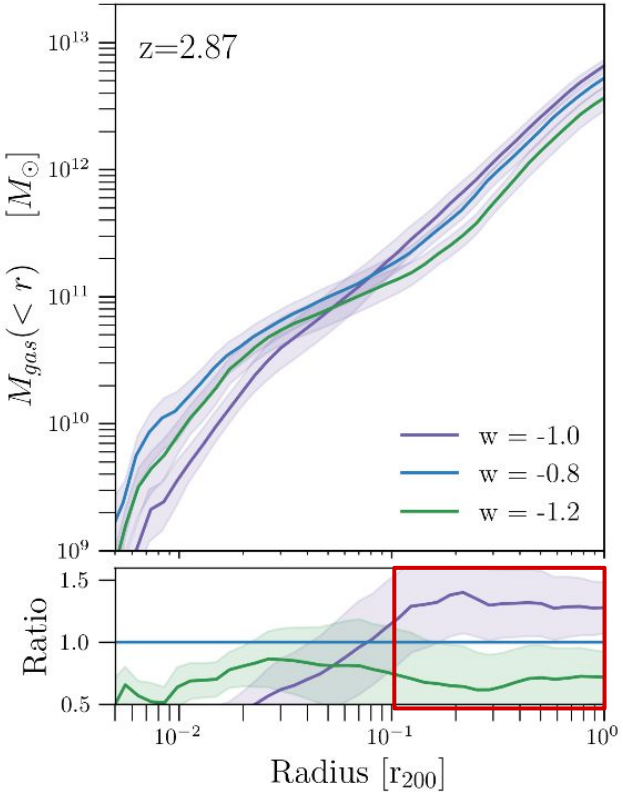
Dark matter mass profiles evolution



Dark matter mass profiles evolution

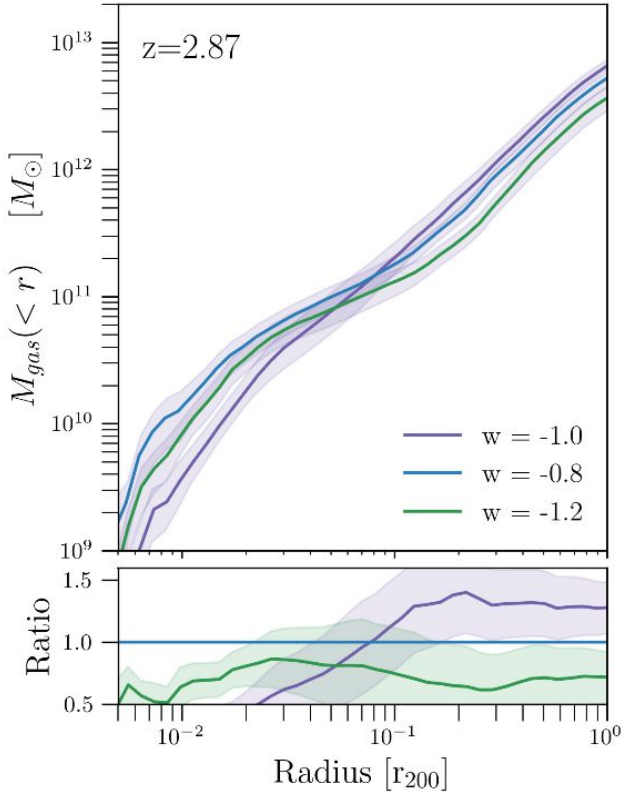


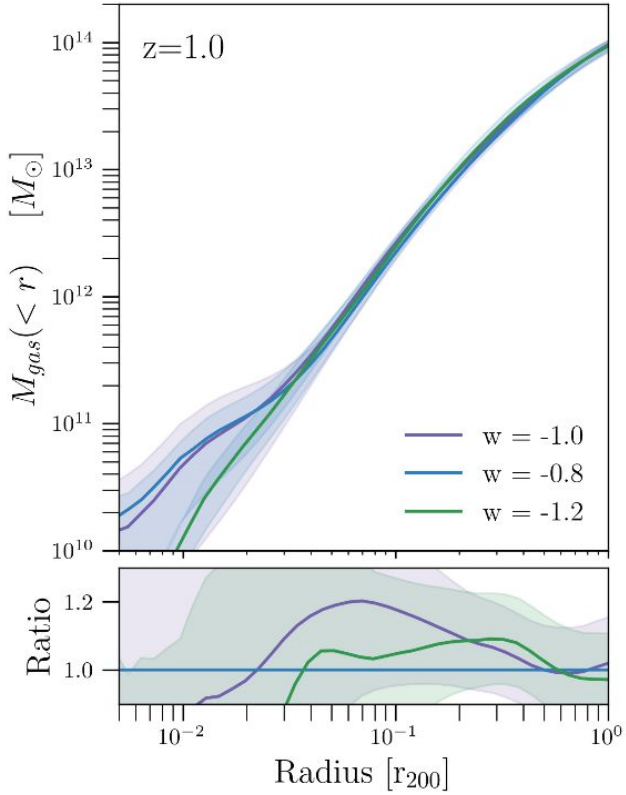
Gas mass profiles evolution

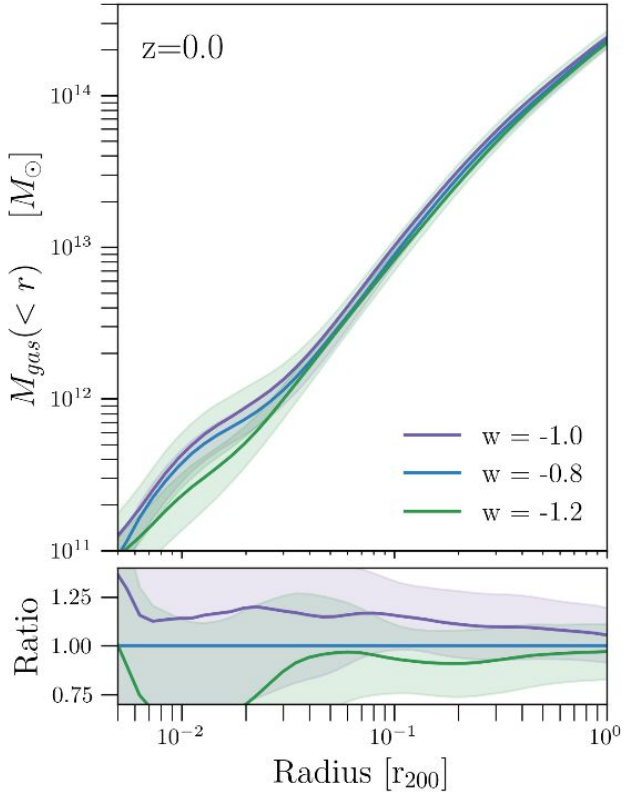


At high z, cosmological information appears in the outskirt but is lost in the inner region

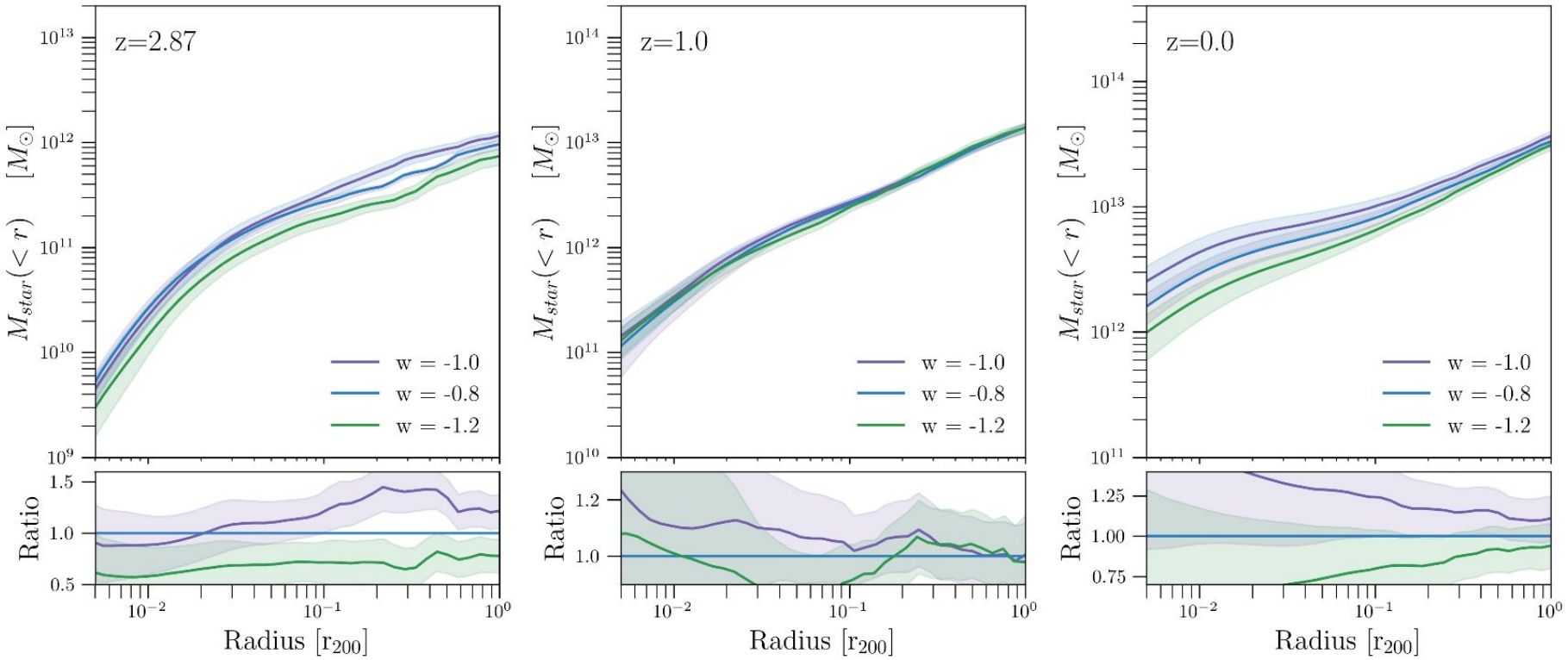
Gas mass profiles evolution







Star mass profiles evolution



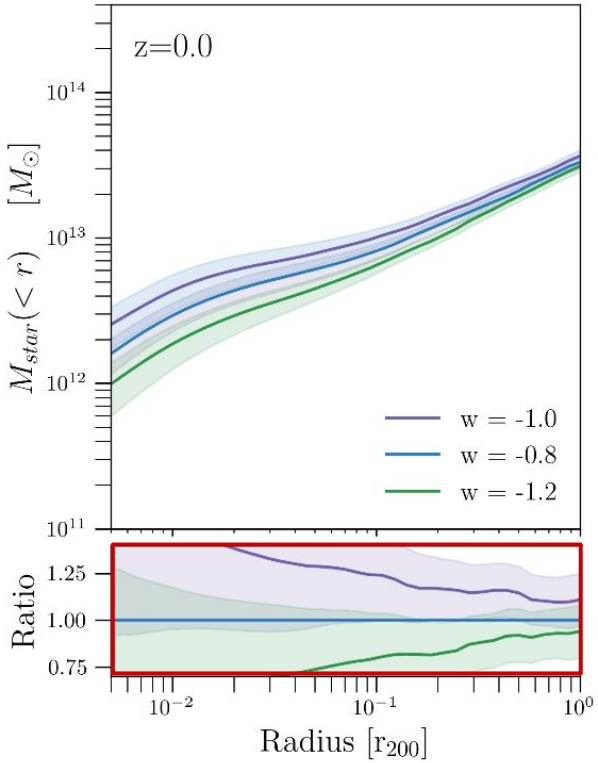
Star mass profiles evolution: a nice example of degeneracy

Strong low redshift differences in the star distribution

Consequence of degeneracy between AGN feedback and DE modeling

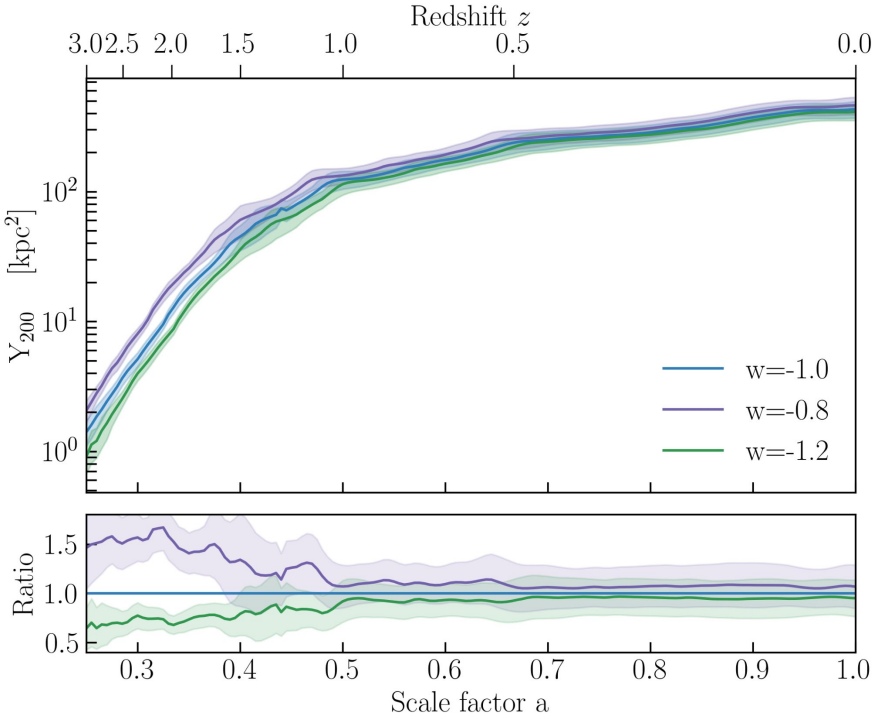
When AGN feedback struggles at regulating cooling flows, SFR explodes

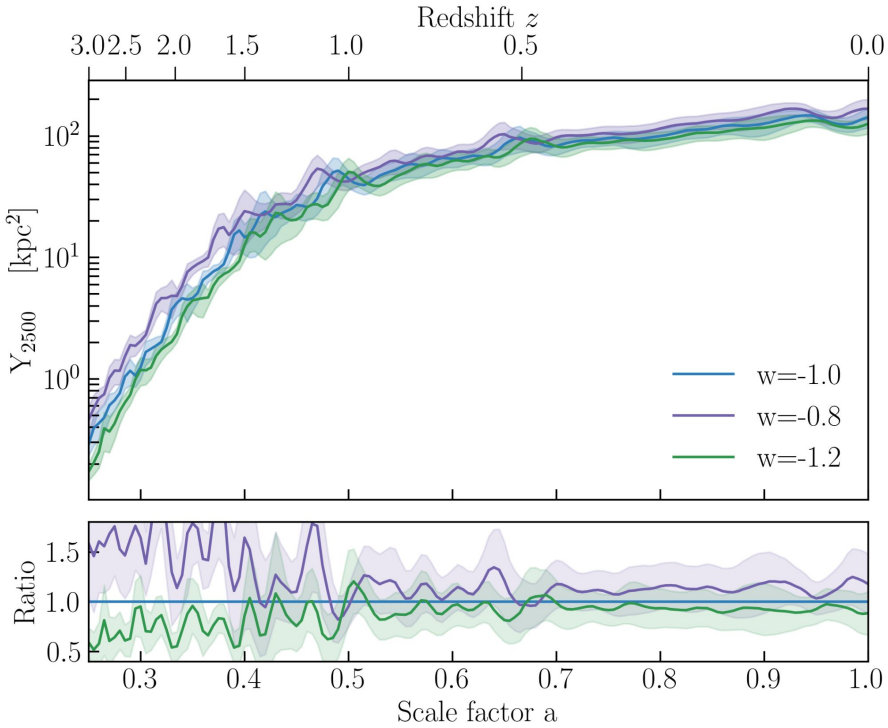
Coupling between SFR and DE modeling



Compton-Y parameter evolution

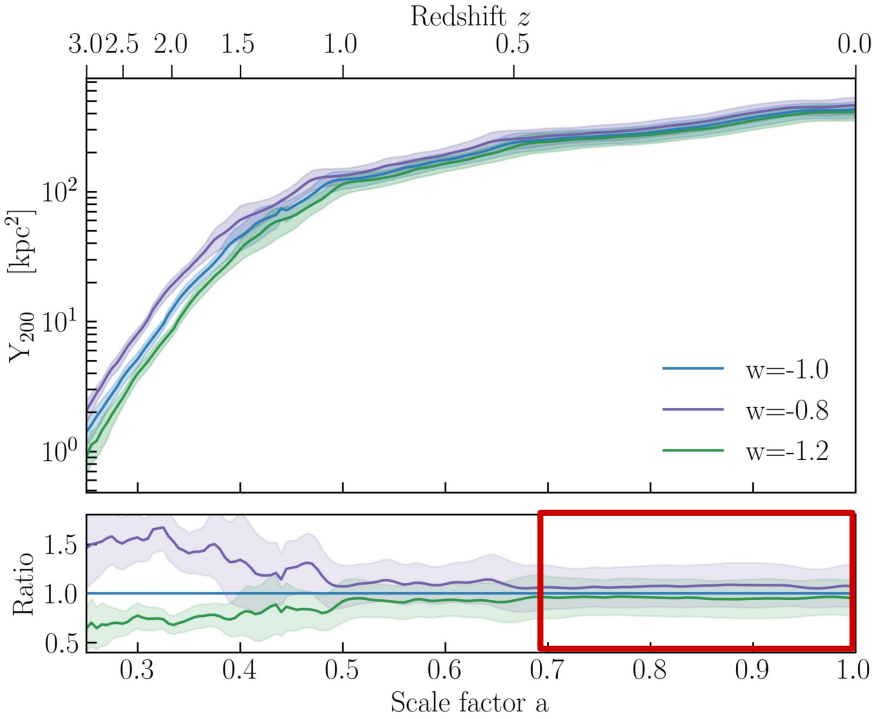
$$Y_{500} = \int_{|\mathbf{x}|<R_{500}} \sigma_T \frac{kT}{m_e c^2} n_e \, \mathrm{d}^3 x$$

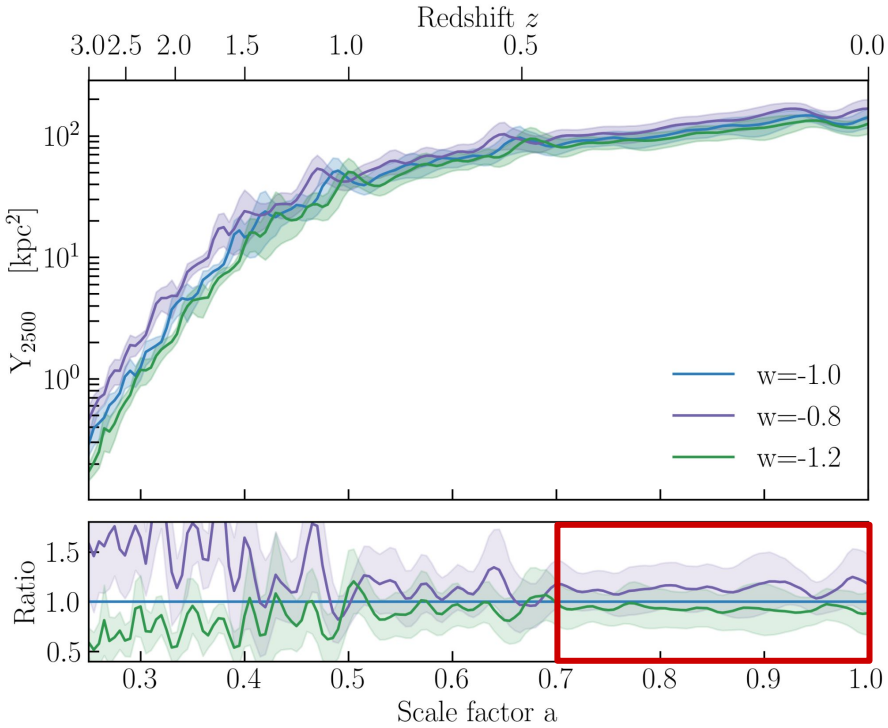




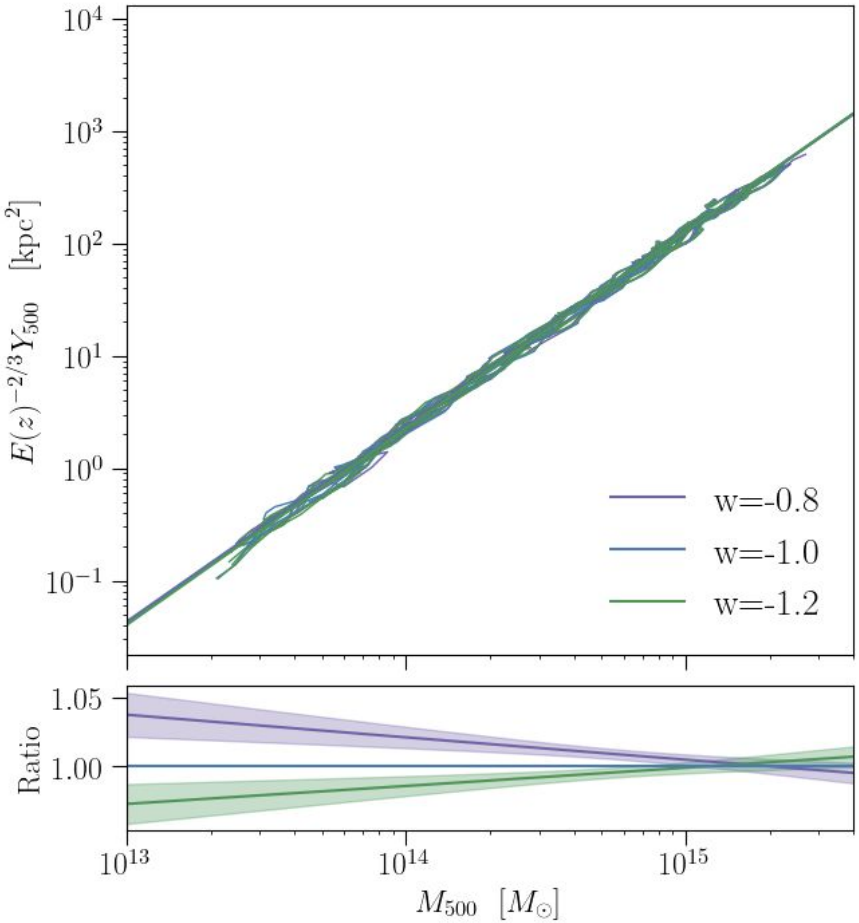
Compton-Y parameter evolution

$$Y_{500} = \int_{|\mathbf{x}|<R_{500}} \sigma_T \frac{kT}{m_e c^2} n_e \, \mathrm{d}^3 x$$





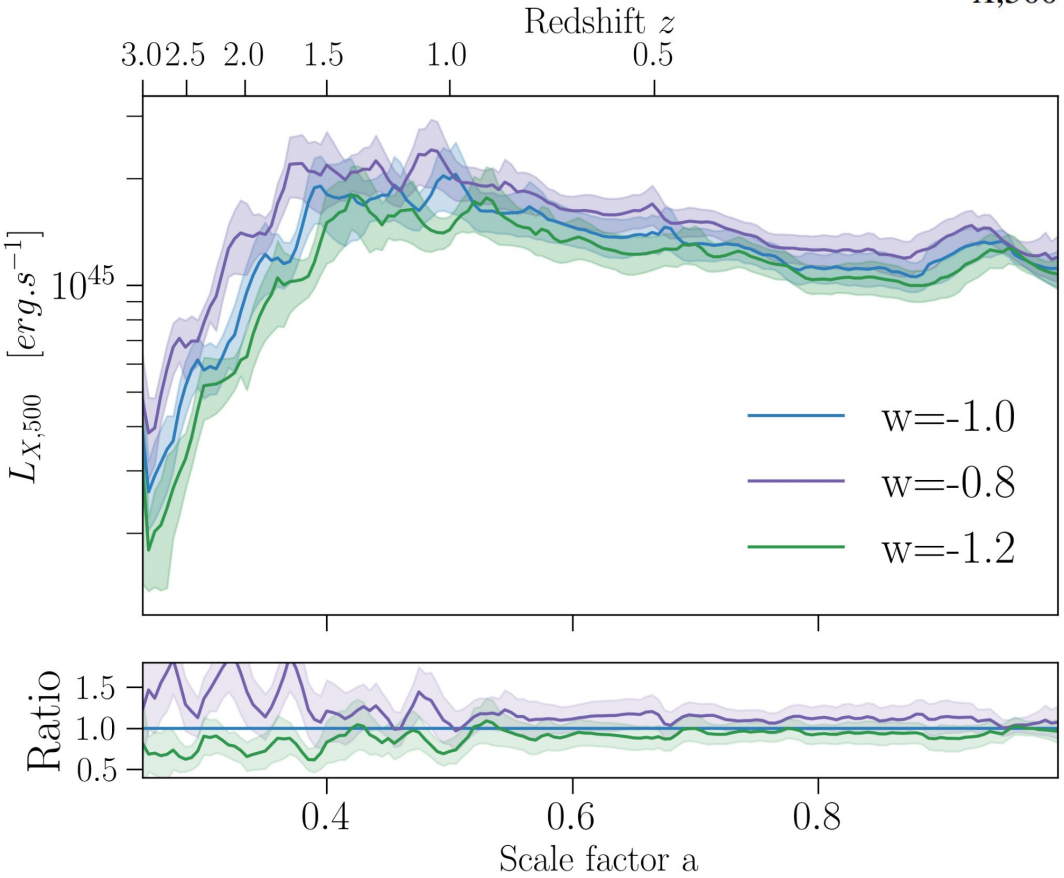
Evolution along the M_{500} - Y_{500} scaling relation



We found a weak but **significative dependance of M_{500} - Y_{500} in the w parameter**

X-rays luminosity evolution

$$L_{X,500} = \int_{0.15 r_{500} < |\boldsymbol{x}| < r_{500}} kT\,\epsilon(T,Z) n_e n_H \, \mathrm{d}^3\mathrm{x}$$



What is next: The SWANLAKE suite

Extension of the ADELINE suite:

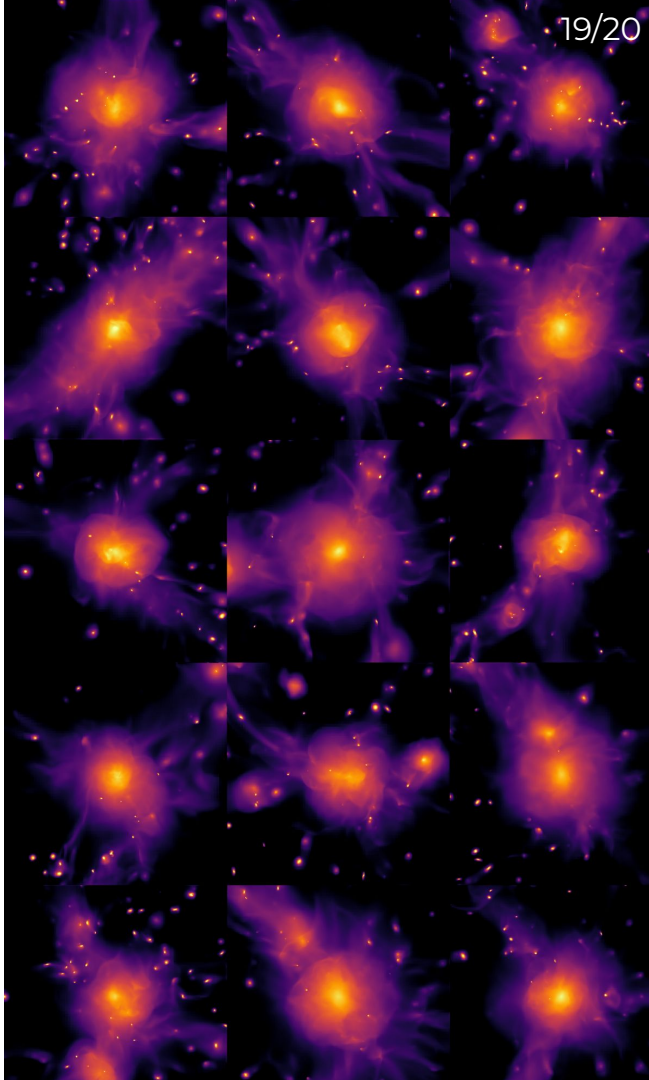
- **70 systems** with masses in $[8 \times 10^{14} - 3 \times 10^{15}]\ M_\odot$
  $\Delta x \approx 3.8\ kpcc\,, \quad M_{DM} \approx 1.44 \times 10^9 M_\odot$

- **3 realistic wCDM models**
  within 2σ of Planck18+BAO+CMB_lensing+Pantheon constraints

- **2 AGN feedback models**

¼ of the suite is already done

11 Mh allocation for 2026/27



Conclusion THEADELINESUITE

First simulations of galaxy clusters with AGN feedback in alternative cosmology

Dark energy signatures are important at high redshift and are damped at low redshift

Non-linear imprints persist up to z=0, especially in thermodynamic properties

If you are interested in using the ADELINE data don't hesitate !

