Research Overview and Future Directions Discussion with Prof. Raul Angulo

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February 28, 2025

Introduction

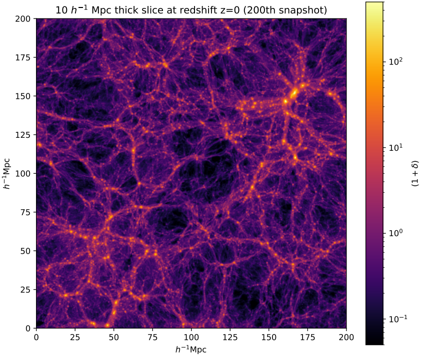
- My research at IUCAA, Pune, with Prof. Aseem Paranjape focus on the interface between cosmology and Astrophysics.
- Primarily I perform and analyse cosmological simulations with and without galactic astrophysics.
- Along with simulations, I do more controlled numerical experiments with a focus on physical modelling which can then be compared with observations.
- Particularly interested in your recent research with FLAMINGO simulations.
- I have several research plans based on my past research that will directly benefit from your expertise and the available simulation data.
- I am also excited with your research and hence open to collaborate in those projects.

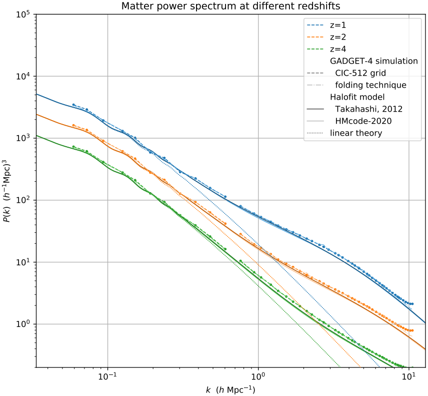
Background

- Completed Master of Science (MS) in Physics in 2019 and 1 year thesis work in theoretical cosmology.
- Joined IUCAA Pune for PhD in August 2019 and did one year gradschool comprehensive training in broader ongoing research in astrophysics.
- Started working with Prof. Aseem in 2020. I did comprehensive exploration with cosmological simulations for 1 year and proposed my thesis work.
- Worked on my thesis "Interplay of galaxy formation and the evolution of dark matter haloes" for 3 years from 2021 to 2024. Awaiting defence in next month.
- As I got another year at IUCAA till July 2025, I continued my research after thesis submission and also developed well-defined long-term research plans.

Exploring large scale structure in cosmological simulations

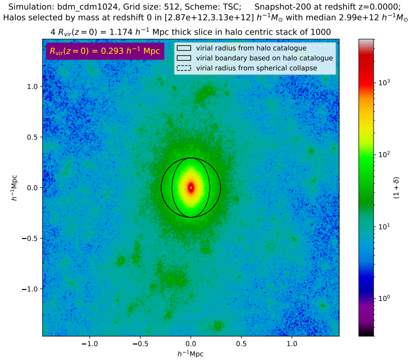
- I started by performing cosmo simulations with GADGET and GADGET based codes.
- Generated transfer function with CAMB and used 2LPT codes to generate initial conditions for cosmo simulations.
- Sample figures from initial exploration with cosmological simulations.

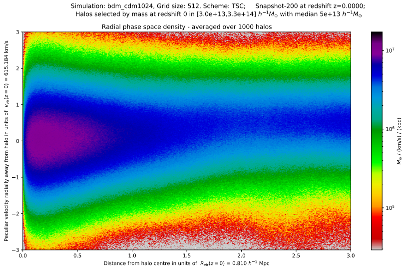




Exploring haloes in galactic and cluster scales

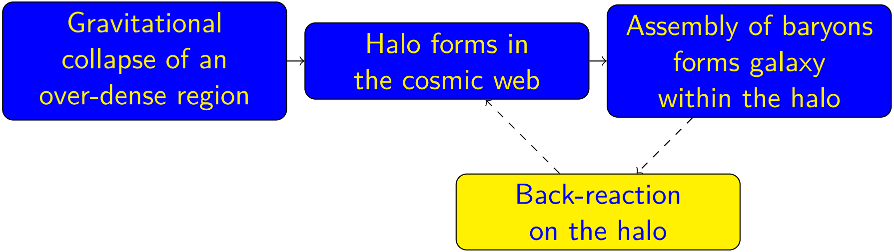
- Found halo substructures with FoF, SUBFIND, ROCKSTAR, VELOCIRAPTOR and built merger trees.
- Sample figures from initial exploration with cosmological simulations.





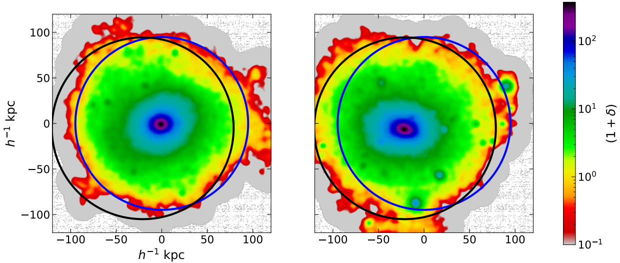
Hydrodynamical simulations with galaxies

- In simulations, the phase-space distribution of dark matter within the haloes have also been found to be significantly different and diverse indicating strong response to galaxies they host.



Dark matter halo response to galaxies

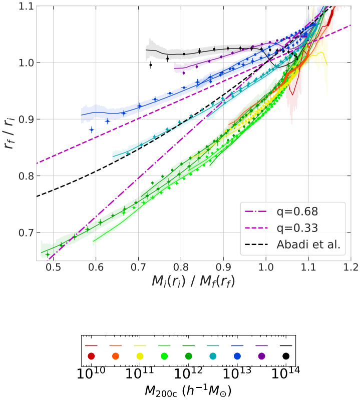
A halo from EAGLE simulation in the presence of galaxy (left image) can be seen more compact, spherical and even their centres shifted.



In particular, the change in the halo-centric distances affects radial mass profiles of haloes that influence key observables such as the rotation curves and radial acceleration relations.

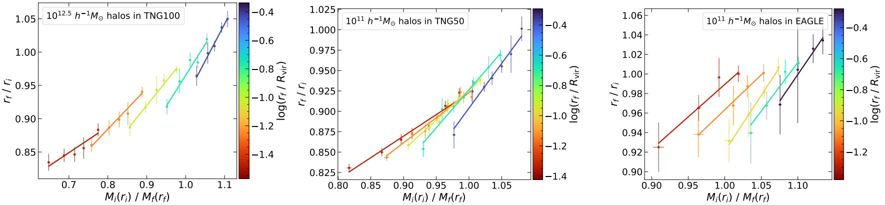
Relaxation response in IllustrisTNG and EAGLE

- Early works modeled this as adiabatic relaxation of dark matter in response to the net change in the gravitational potential due to galaxy formation.
- Quasi-adiabatic relaxation framework focus on modelling the relation between the relaxation ratio r_f/r_i as a function of the mass ratio M_i/M_f.
- We found that the relaxation relation (between r_f/r_i and M_i/M_f) varies widely between haloes of different mass scales in simulations like IllustrisTNG and EAGLE.



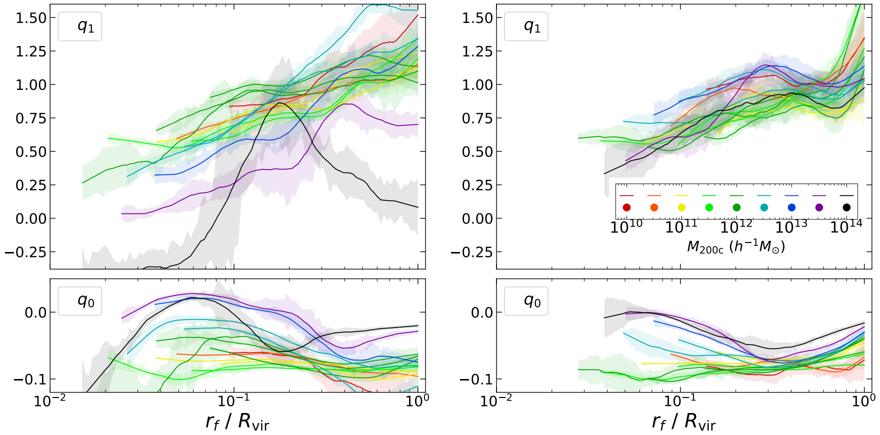
Dependence on halo centric distance

- A simple linear relation can accurately describe the relaxation, provided we assume an additional explicit dependence on the halo-centric distance (indicated by colorbar).



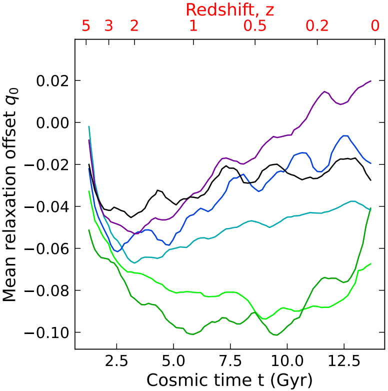
Universal description of Halo Relaxation Response

The radially dependent slope $q_1(r_f)$ and intercept $q_0(r_f)$ of this linear fit, is more universal across a wide range of halo masses up to $10^{13} h^{-1} M_\odot$ at $z = 0$ (left) and up to $10^{14} h^{-1} M_\odot$ at earlier redshift, $z = 1$ (right).



Relaxation Dynamics

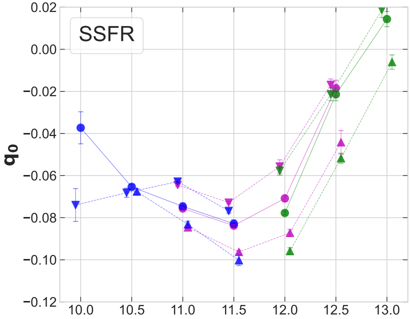
- Focusing on the intercept offset q_0, which describes the amount of relaxation $r_f/r_i - 1$ for dark matter shells with no net change in the total enclosed mass $M_i/M_f = 1$.
- It starts at zero, becomes more negative initially, but then slowly revert back to zero.



Connection with star formation rate?

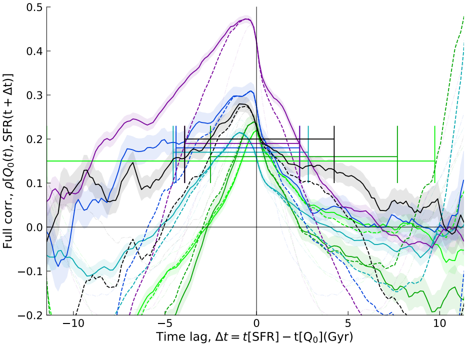
Astrophysical connection

- An excess of relaxation relation quantified by q_0 today was found to be more negative among haloes hosting galaxies with higher specific star formation rate (SSFR).
- This higher excess relaxation might be related to larger amount of recent feedback output.



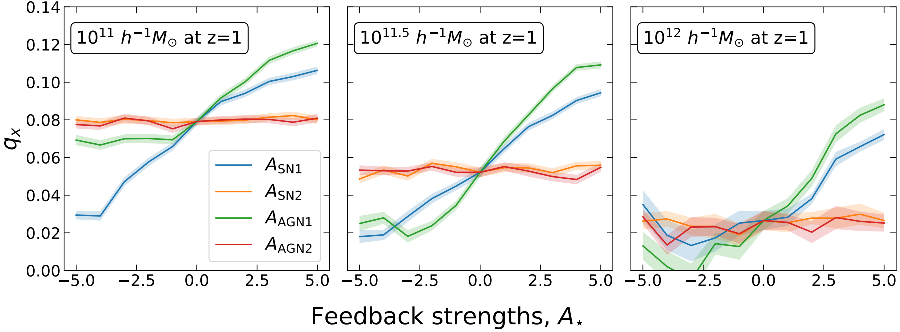
Temporal Connection with Astrophysics

- Relaxation response parameter is more strongly correlated to SFR and feedback at earlier times usually.
- And this response time lag is progressively larger as we go towards the outer halo.



Role of Astrophysical Feedback

We found that the relaxation response parameter (q_x shown), indeed strongly depends on the overall feedback flux from the galaxies, but not the burstiness in CAMELS simulations.



Future plans

- Use analytical tools and semi-analytical experiments to build an entirely physical and accurate model of relaxation.
- Develop galaxy forming cosmological simulations and perform simulations to answer specific questions regarding the dark matter halo relaxation response.
- Use direct probe of feedback to understand the role of AGN and other feedback on the relaxation dynamics.
- Identify gas properties such as metallicity that keeps record of evolutionary history of gas in galaxy allowing accurate modelling of dark matter in haloes and large-scale structure.
- Interested to collaborate in several of your current works especially in exploring the effect of galaxy on the large scale gas distribution.

List of Publications

- Premvijay Velmani, Aseem Paranjape, 2023, "The quasi-adiabatic relaxation of haloes in the IllustrisTNG and EAGLE cosmological simulations", *Published in MNRAS*.
- Premvijay Velmani, Aseem Paranjape, 2024,"Dynamics of the response of dark matter halo to galaxy evolution in IllustrisTNG", submitted to JCAP, *Published in JCAP*.
- Premvijay Velmani, Aseem Paranjape, 2024,"Role of astrophysical modeling on dark matter halo relaxation response at redshifts $z = 0$ and $z = 1$", *submitted response to editor in JCAP*.
- Premvijay Velmani, Aseem Paranjape, 2024, "A self-similar model of galaxy formation and dark halo relaxation", *Published in JCAP*.
- Sujatha Ramakrishnan, Premvijay Velmani, 2022, "Properties beyond mass for unresolved haloes across redshift and cosmology using correlations with local halo environment.", *published in MNRAS*.

Summary

- Extensive experience in performing and analysing cosmological simulations with astrophysics.
- Primary research involves understanding baryonic astrophysical impacts on dark matter halo structure and evolution giving me the expertise to immediately join with in your research projects.
- I also have clear long-term research plans that strongly align with your expertise and benefit from the available resources.
- Looking forward to collaborate in exploring galaxies, haloes and large-scale structure through cosmological simulations.
- Excited to discuss potential research ideas with you.

Thanks for your interest!