Improving the Determination of Supernova Cosmological Redshifts by Using Galaxy Groups

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Duke Cosmology

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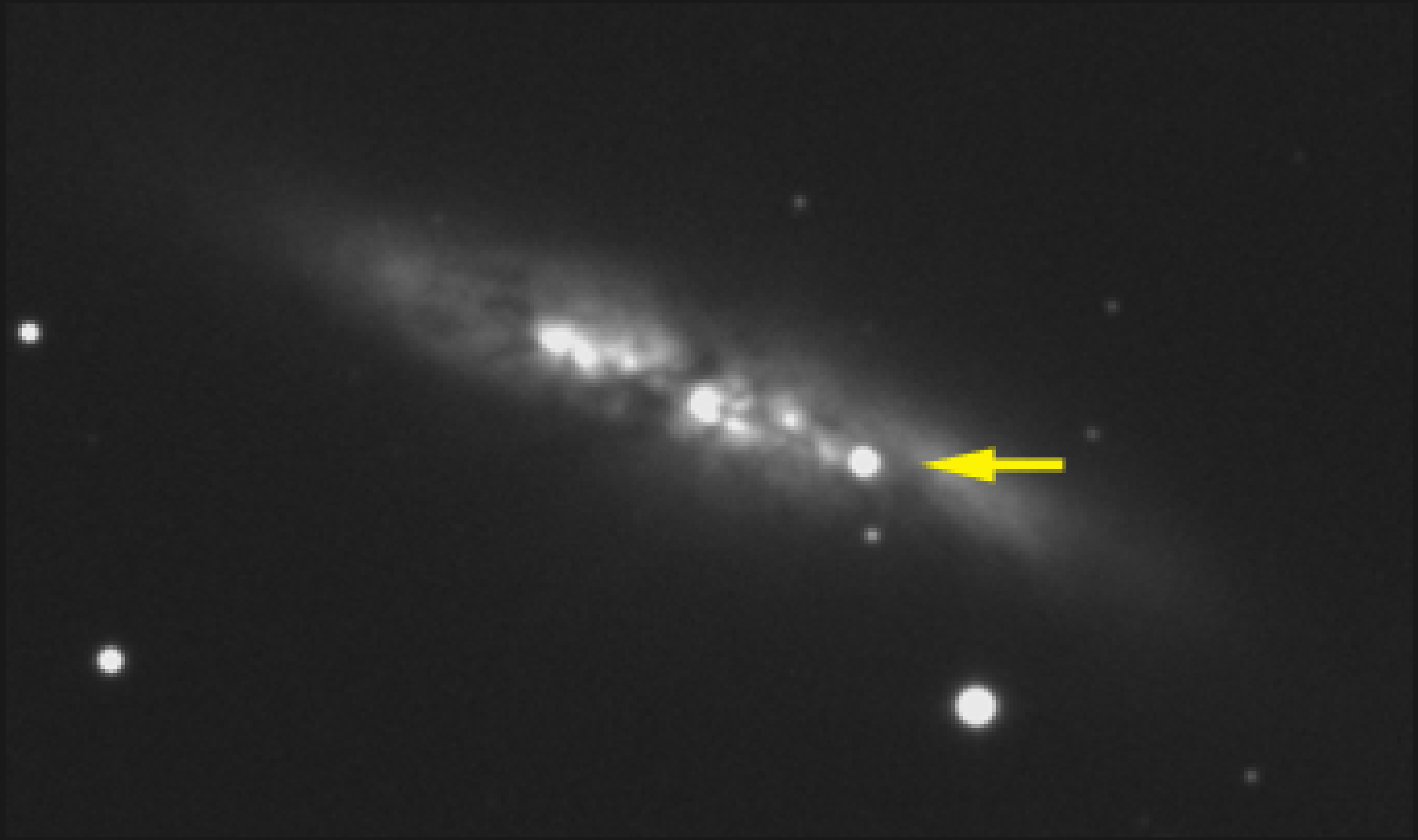
Type Ia Supernovae and Hubble diagram

Type Ia supernovae are exploding white dwarfs!



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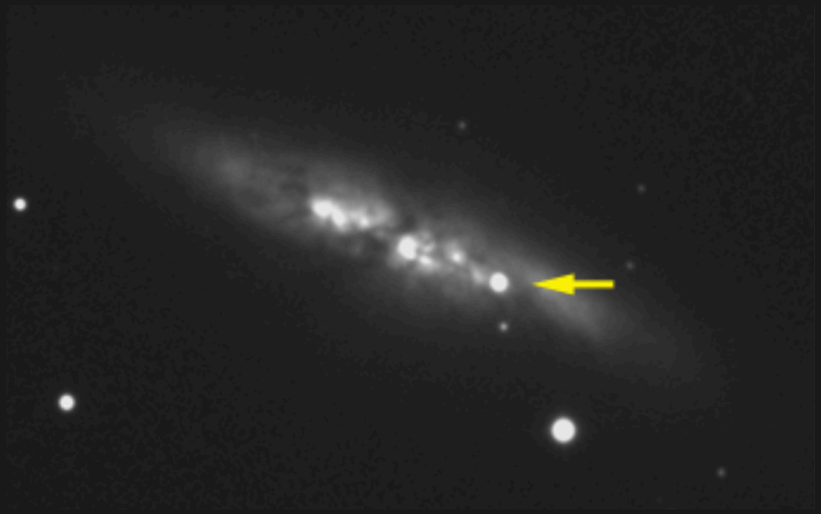

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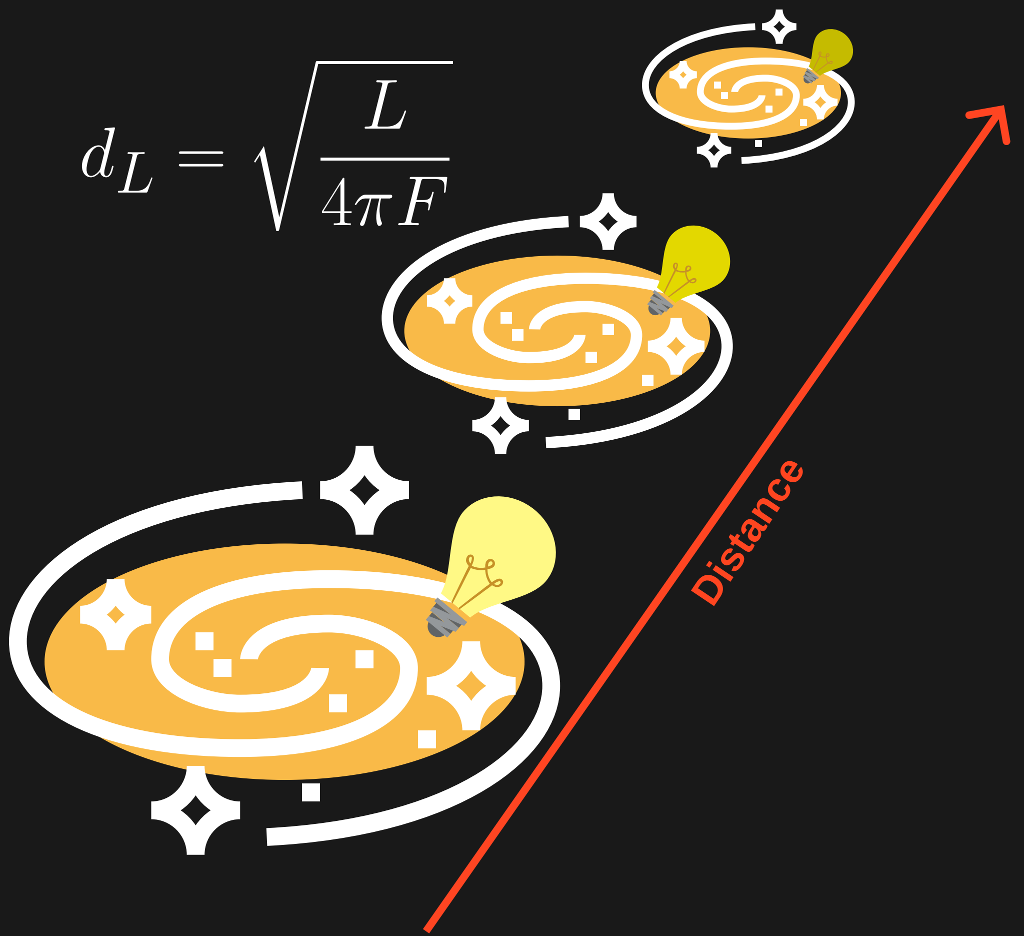
Type Ia Supernovae and Hubble diagram

$$d_L = \sqrt{\frac{L}{4\pi F}}$$



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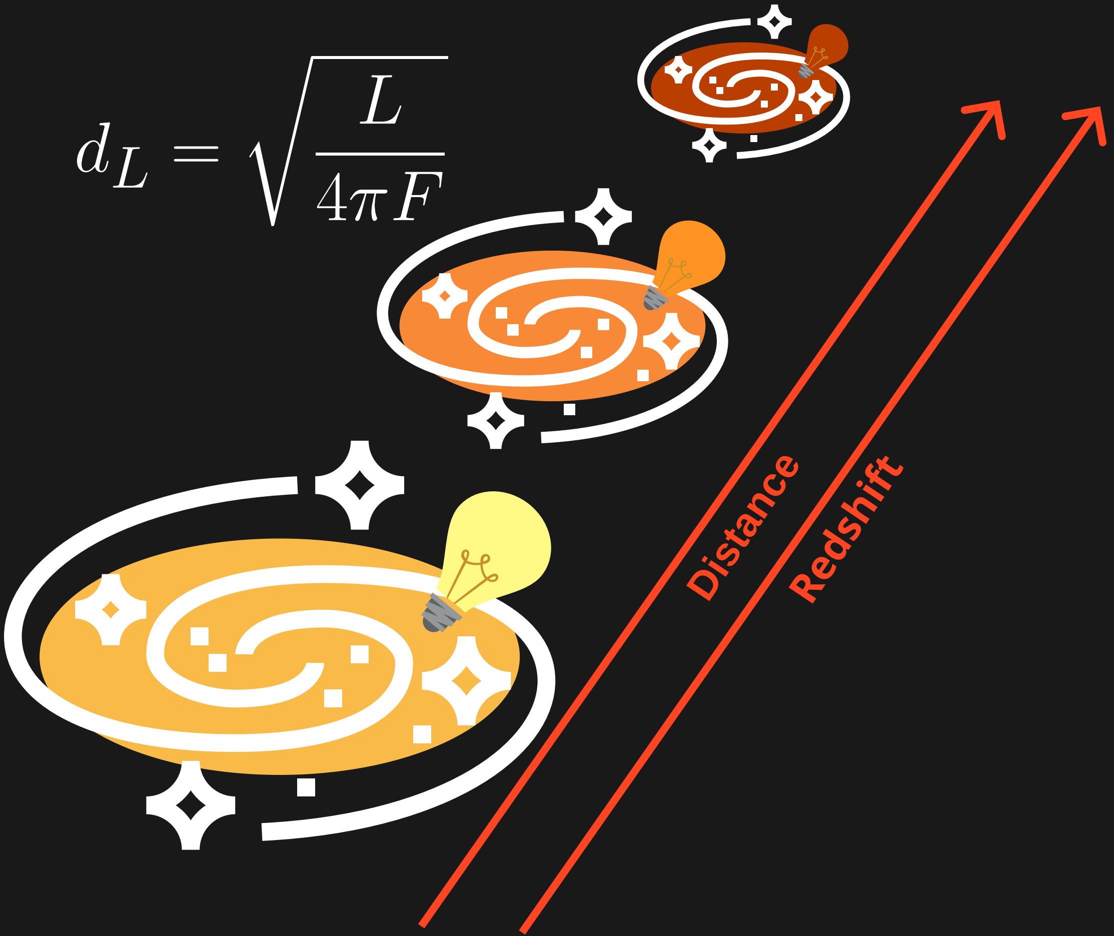

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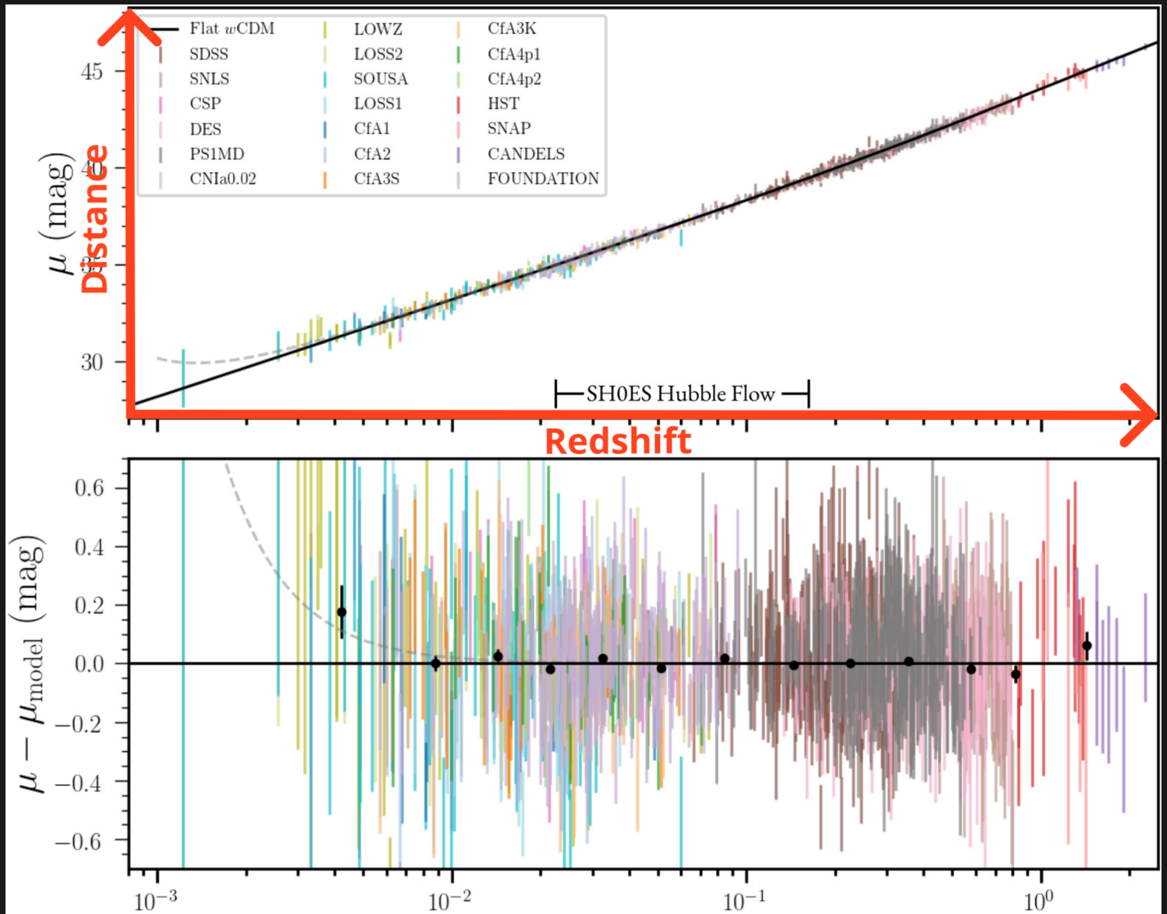
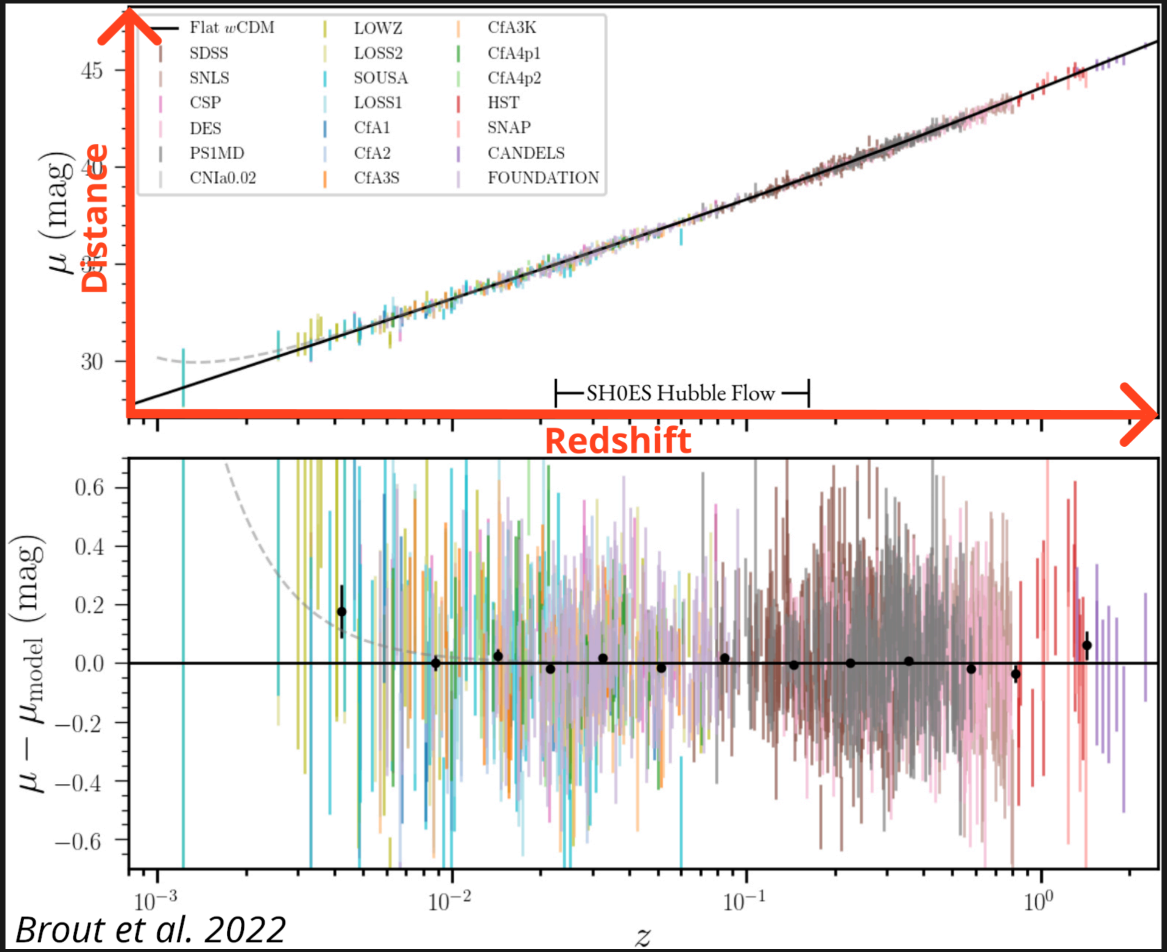


Brout et al. 2022

Type Ia Supernovae and Hubble diagram

Distance modulus:

$$\mu = 5\log\left(d_L/10\ \mathrm{pc}\right) = m - M$$



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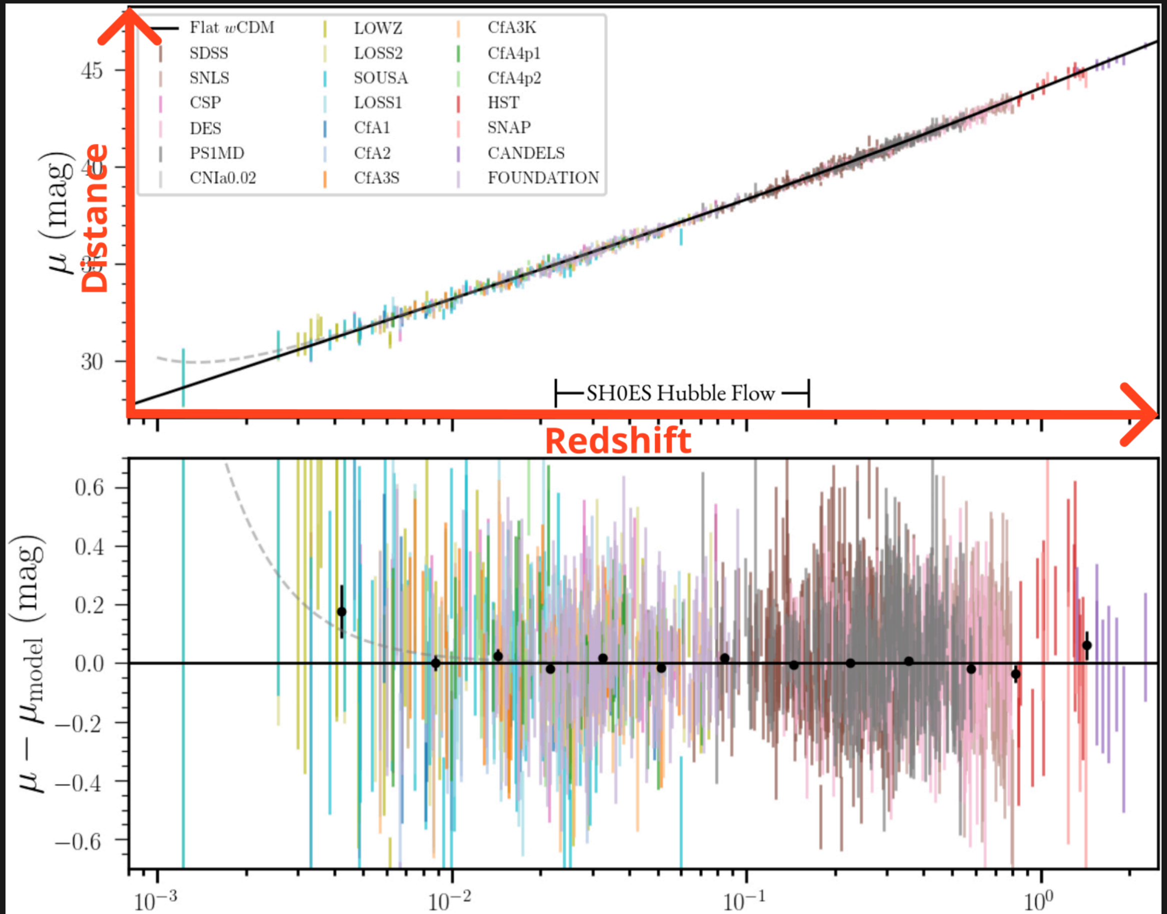

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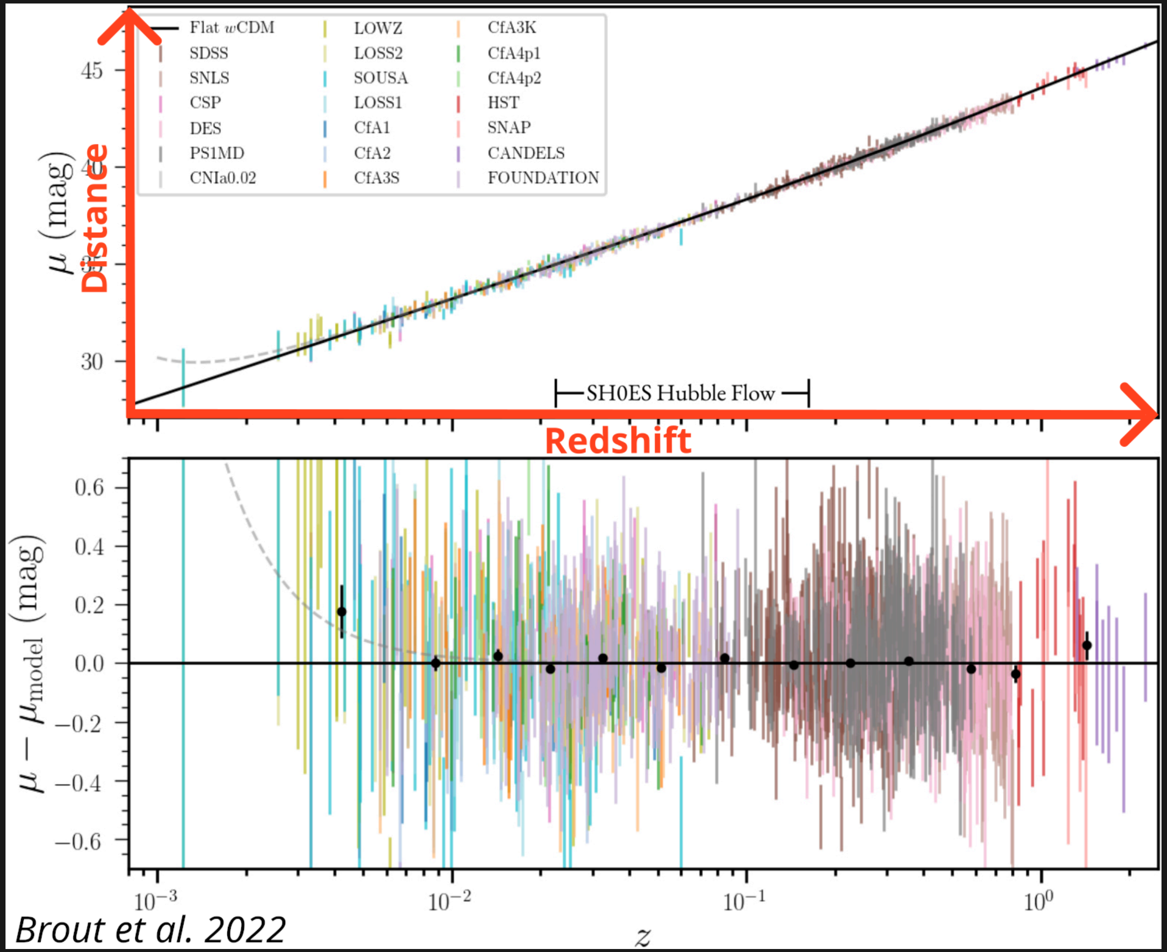

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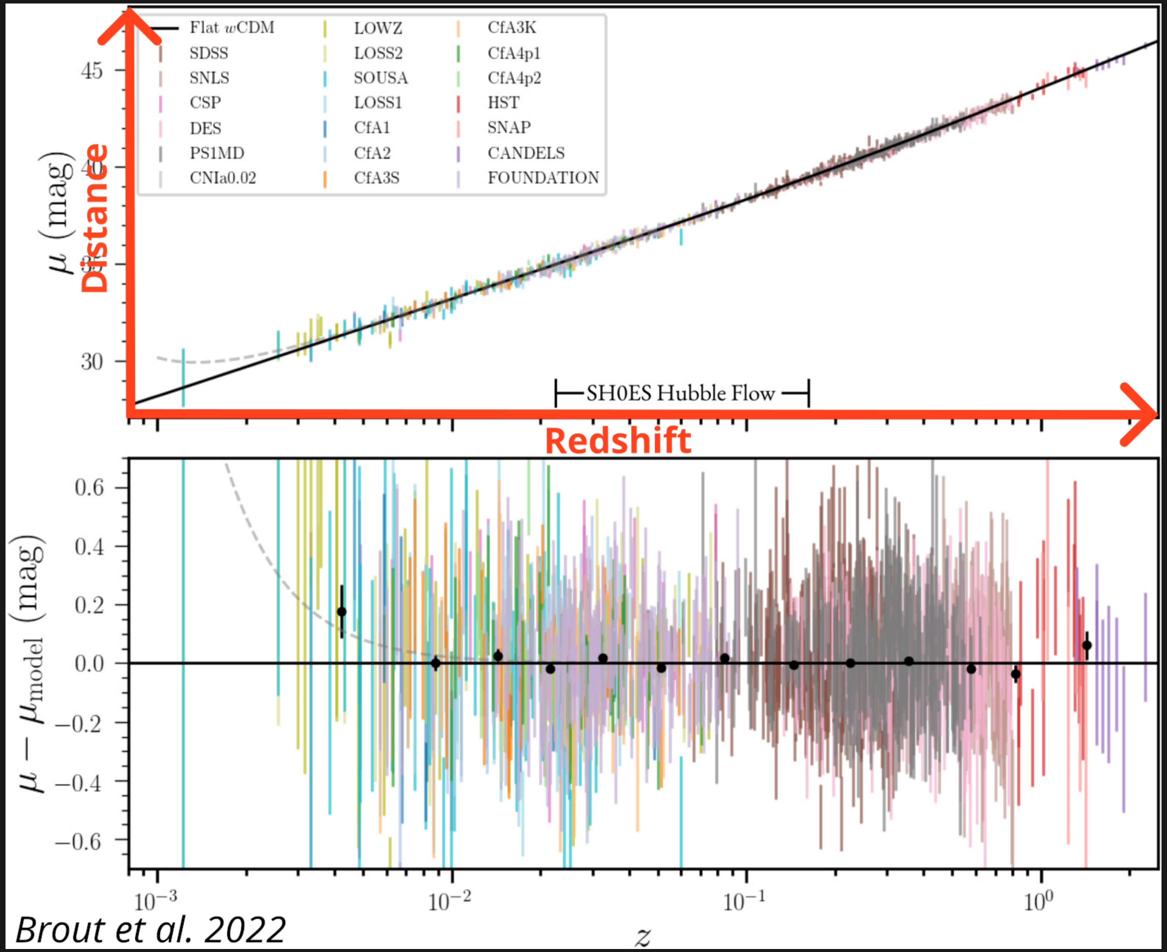

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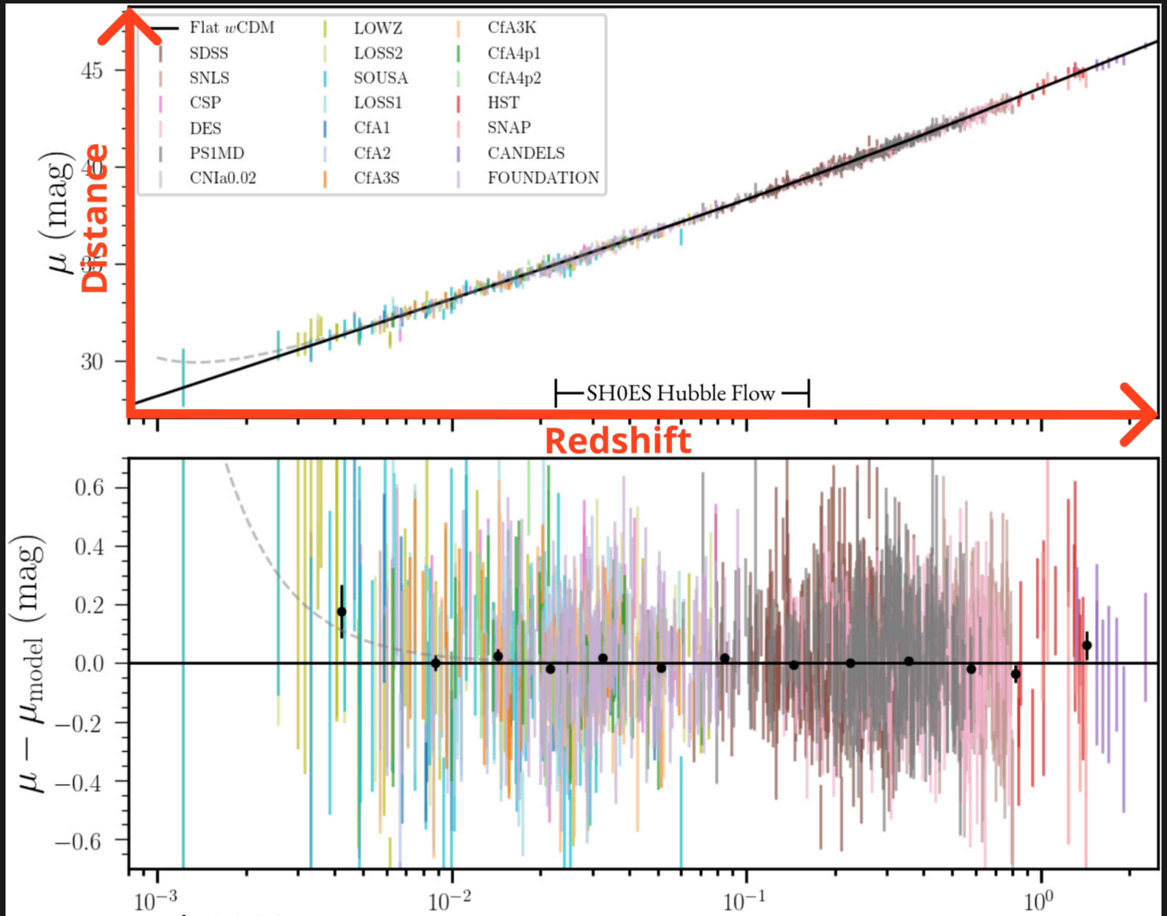

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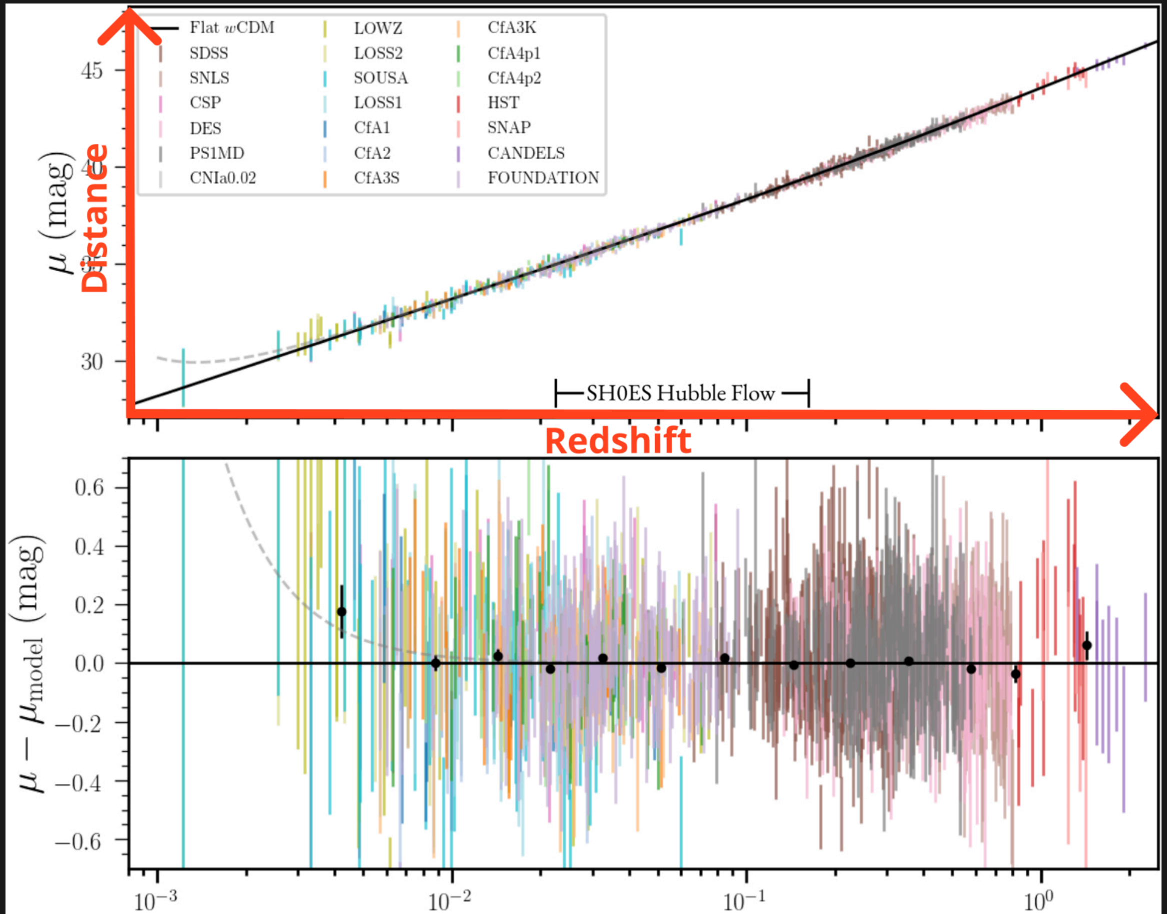

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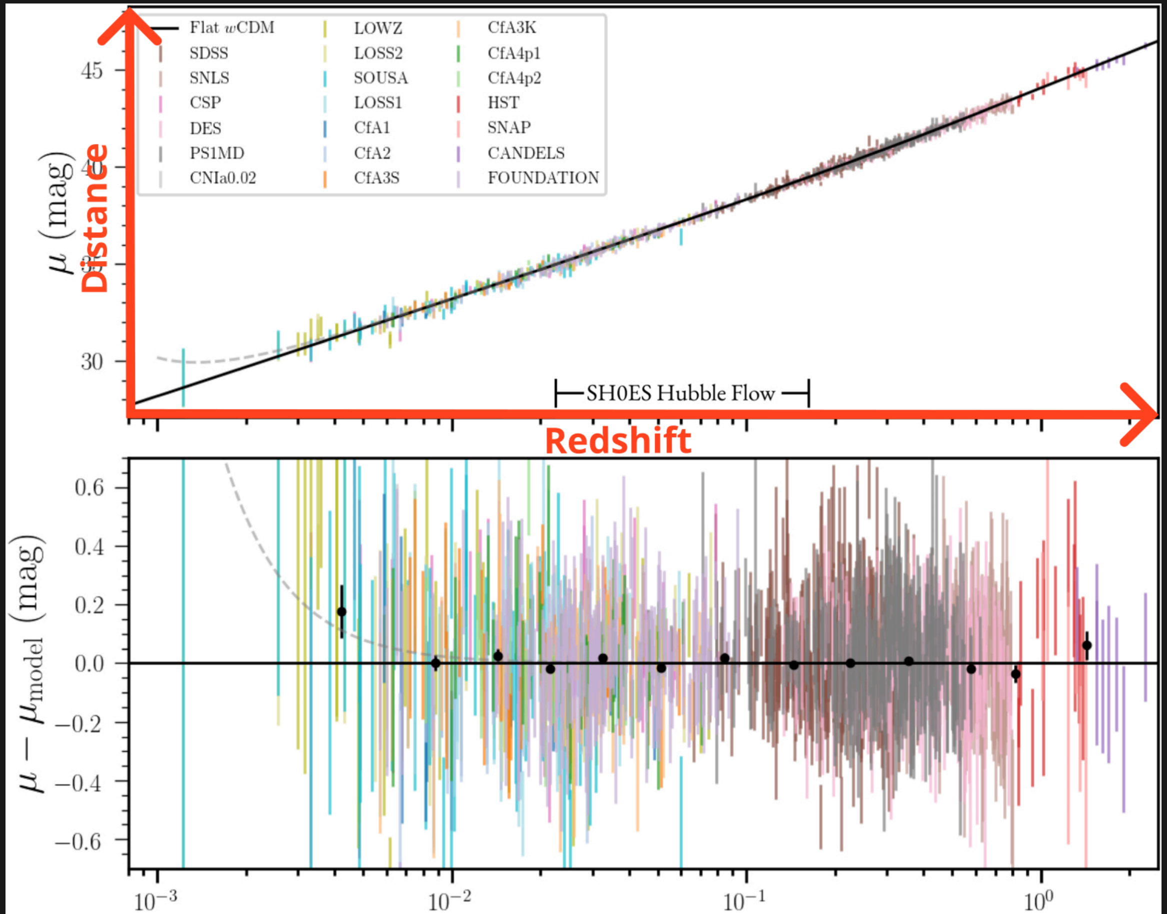
Cosmological and nuisance parameters are estimated by minimizing $\chi^2 = \sum_i \frac{\Delta\mu_i^2}{\sigma_i^2}$

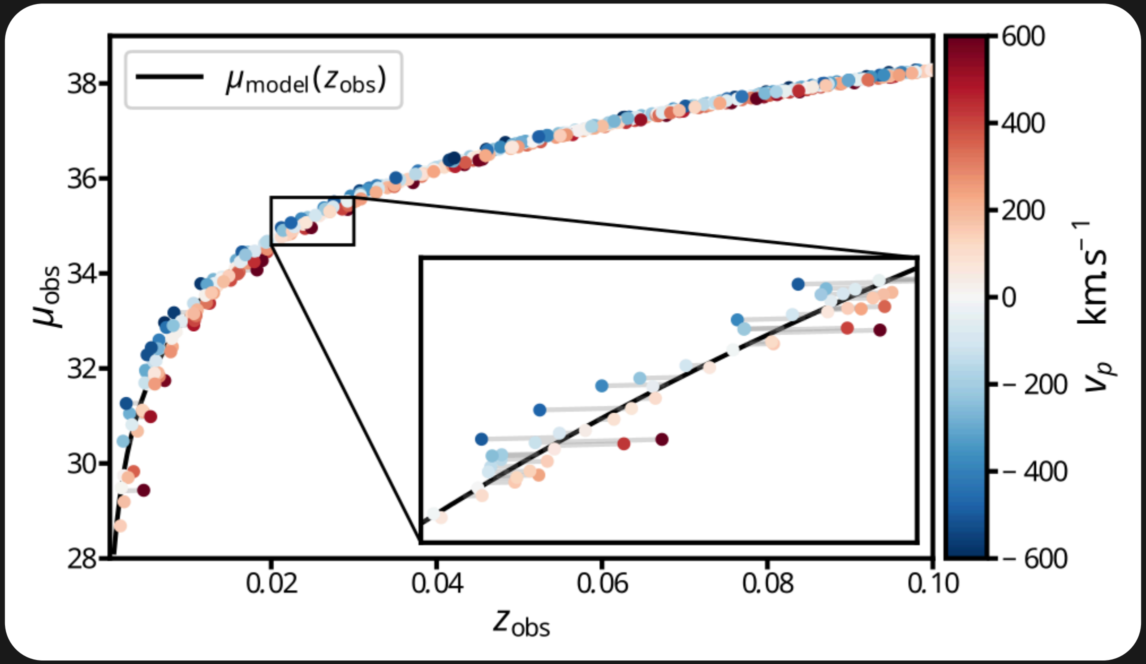


Brout et al. 2022

What is the impact of PVs on the Hubble diagram?

PVs add scatter to the Hubble diagram!

$$1 + z_{\rm obs} = (1 + z_{\rm cos})(1 + z_p);\; z_p \simeq v_p/c$$



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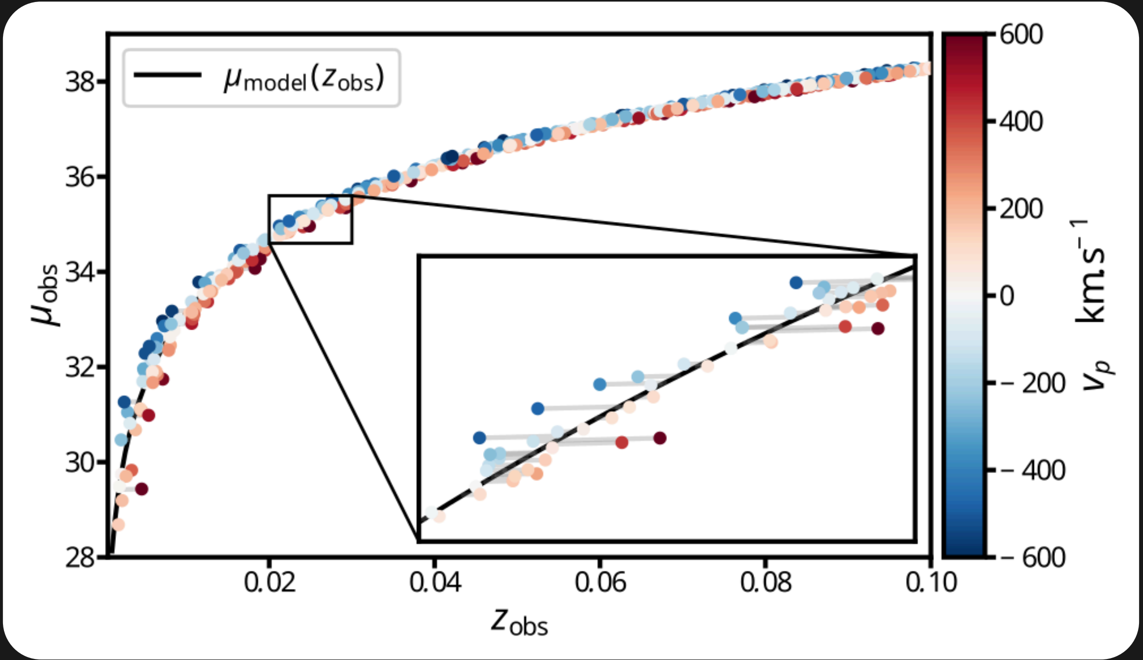

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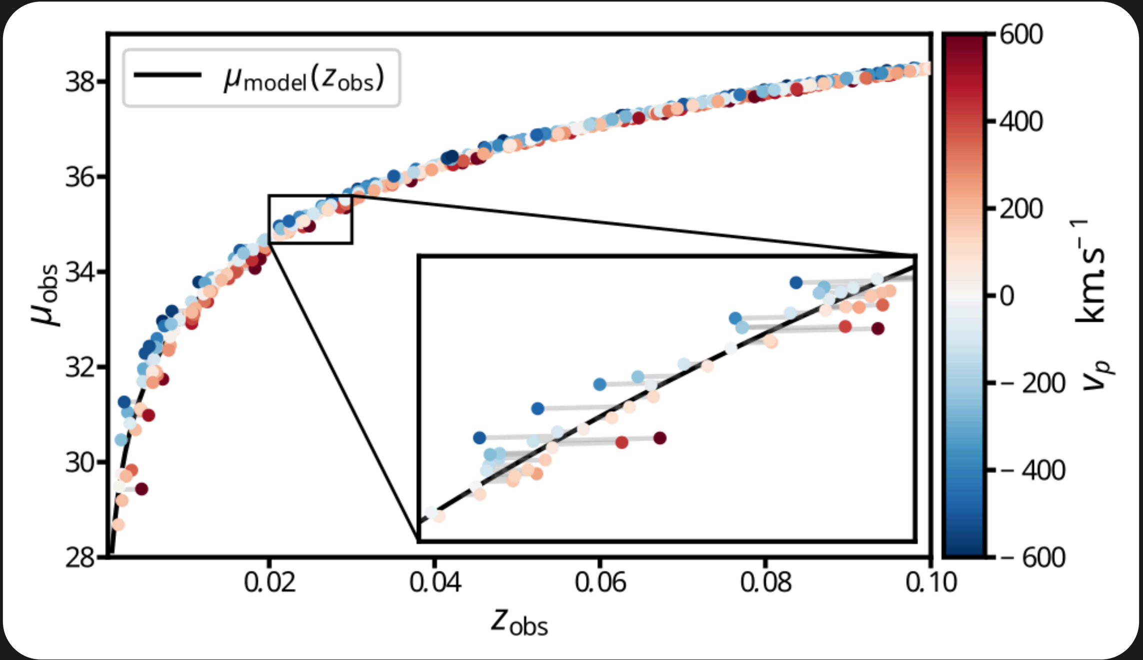
This noise is correlated on large scales and can impact cosmology (*Davis et al. 2011*, *Peterson et al. 2022*, *Carreres et al. 2024*)



Correcting PVs at different scales

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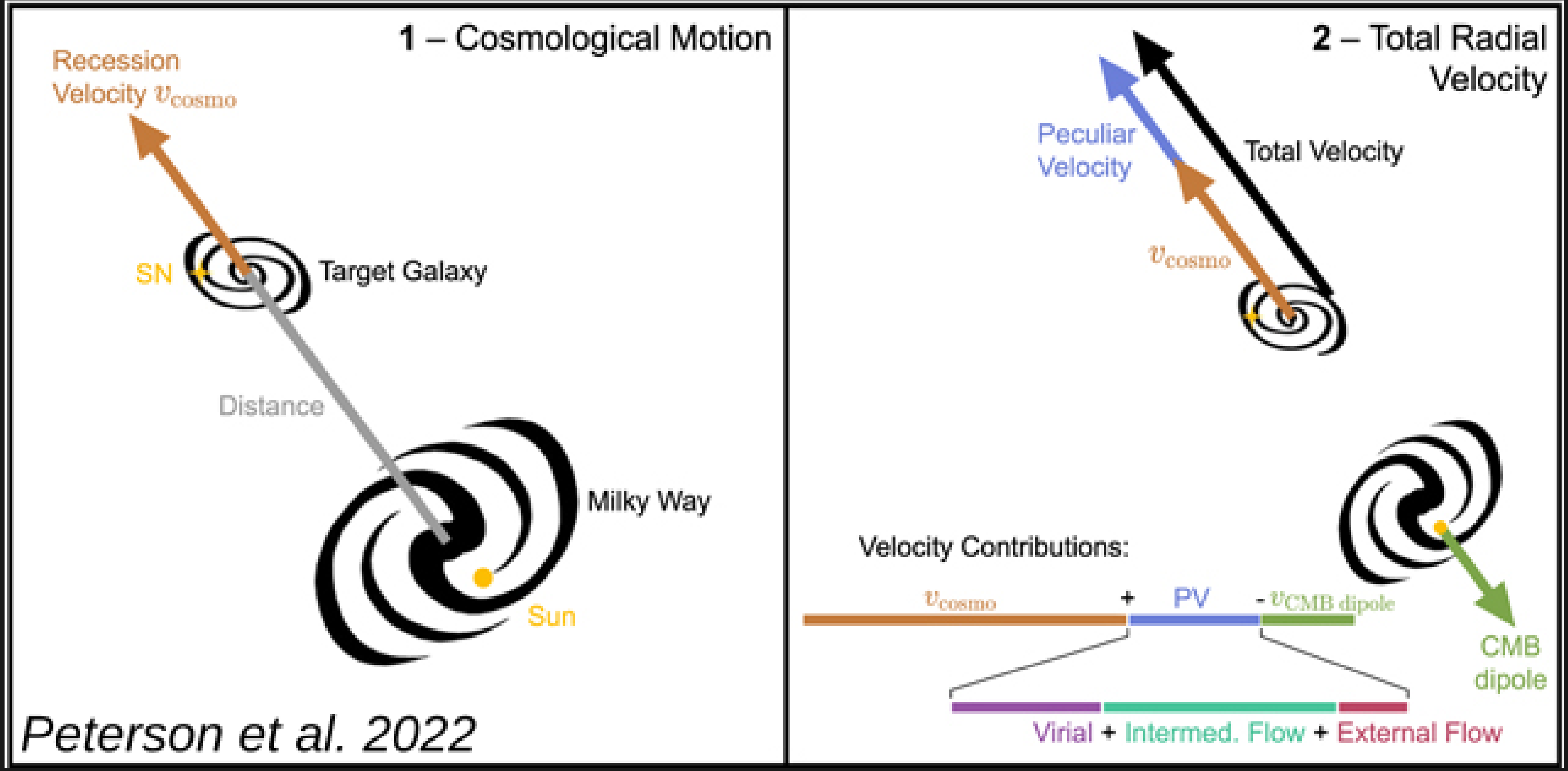

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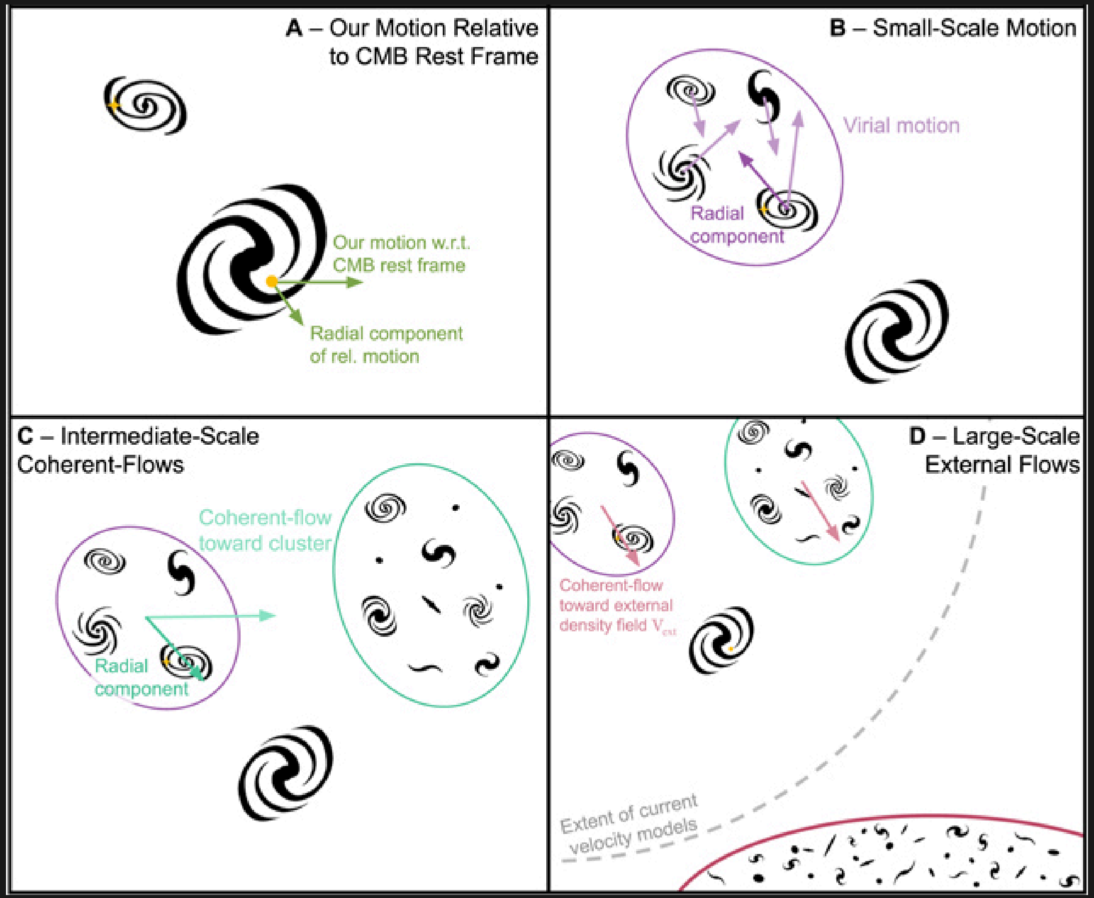

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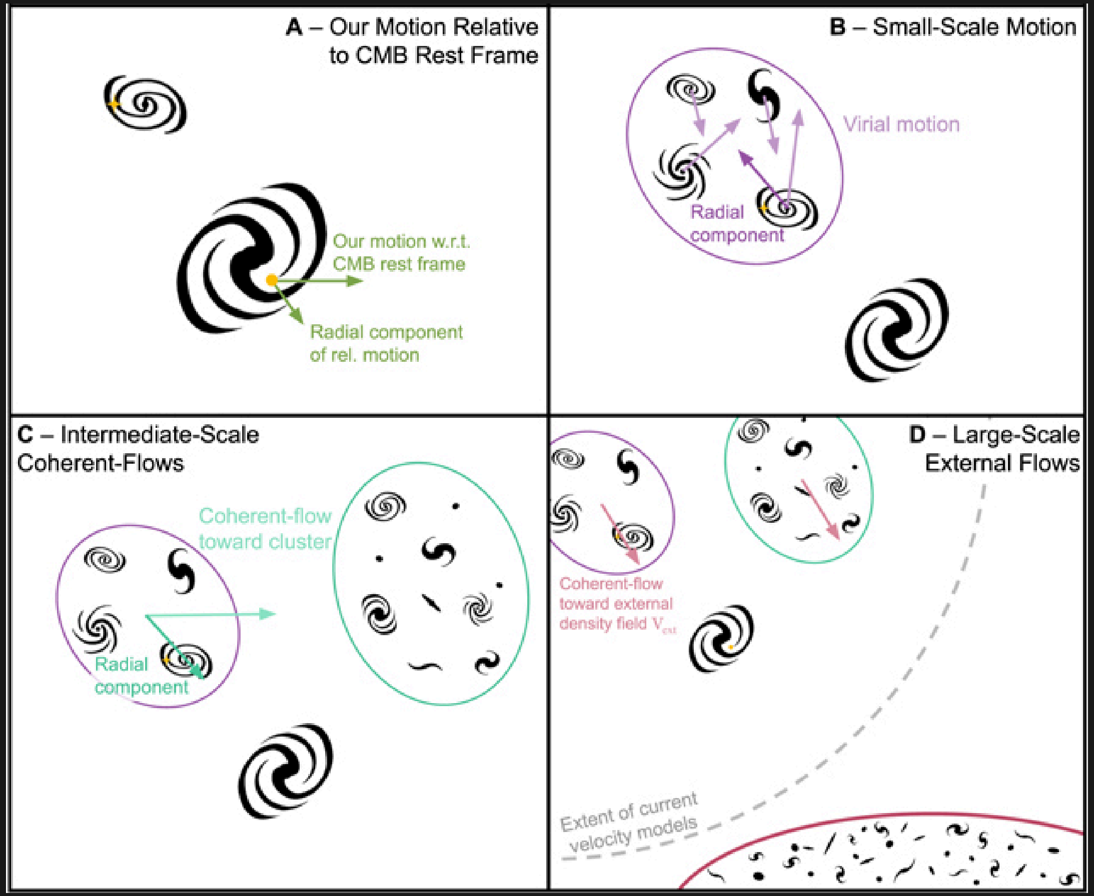

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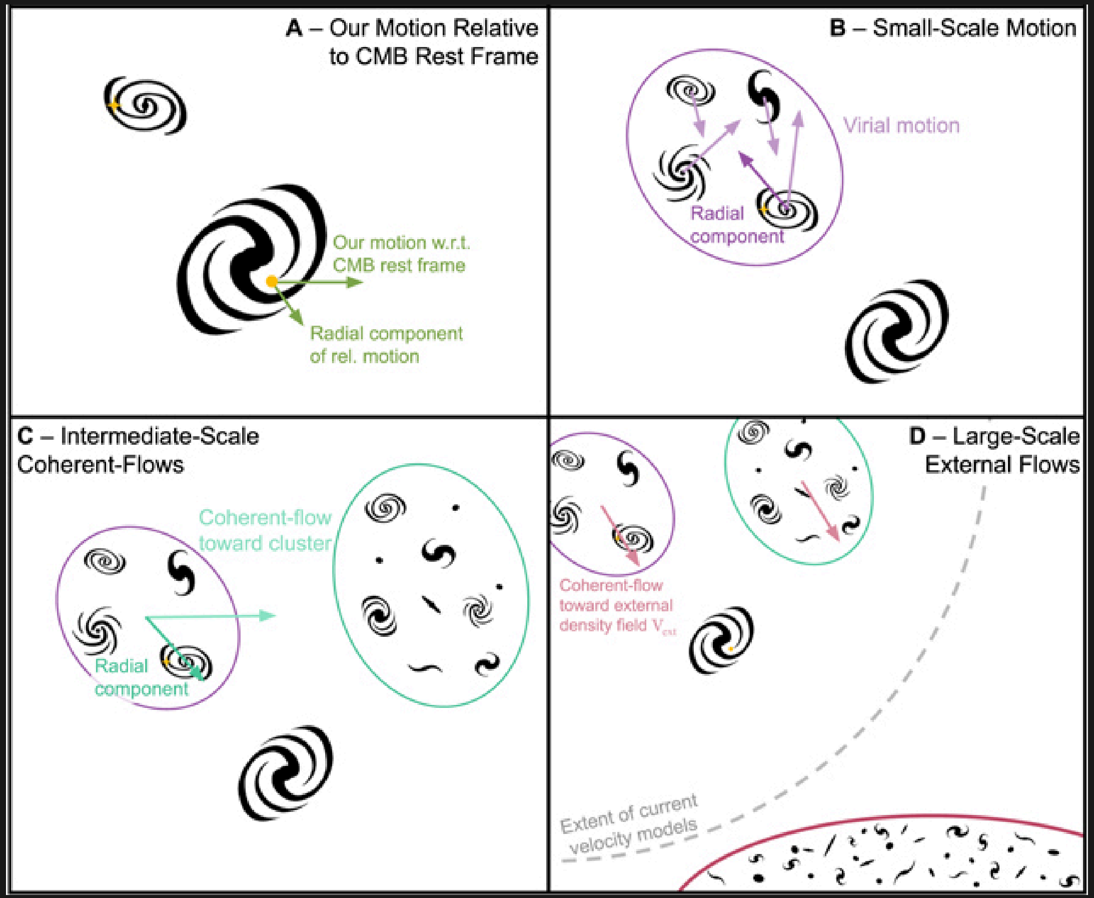

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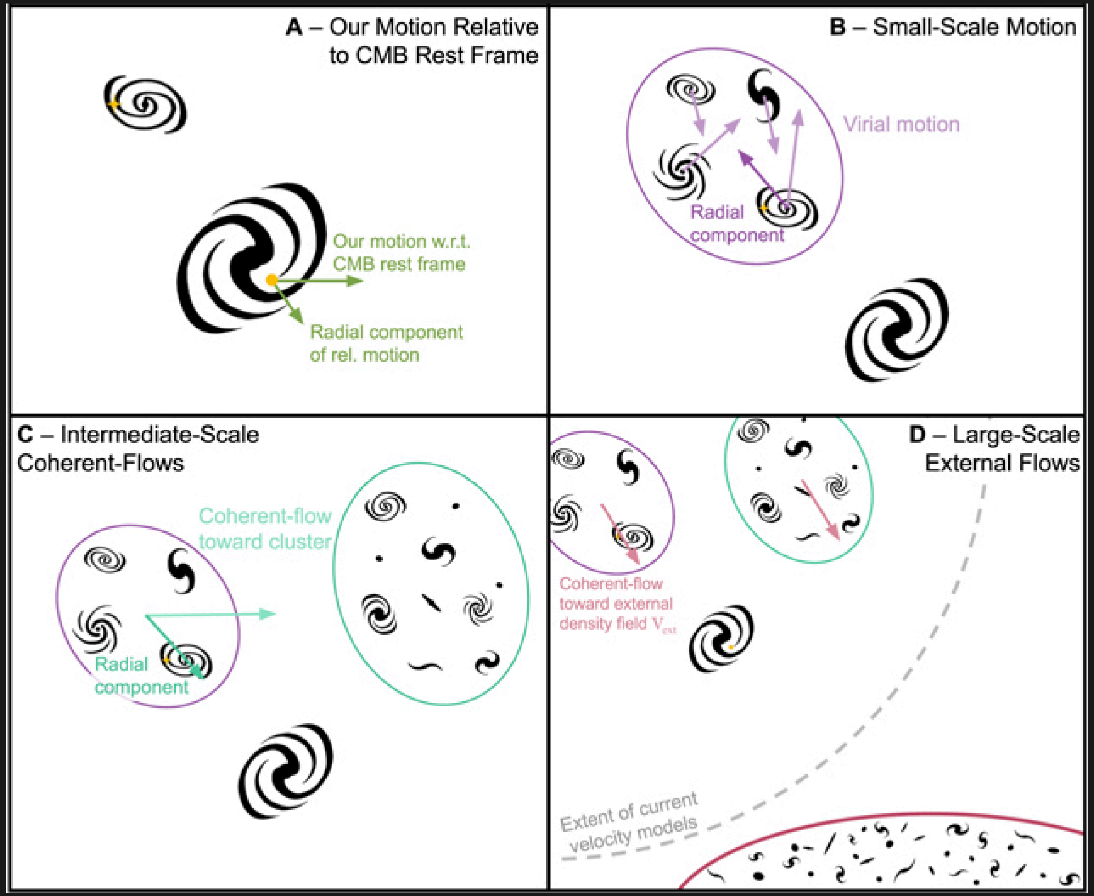

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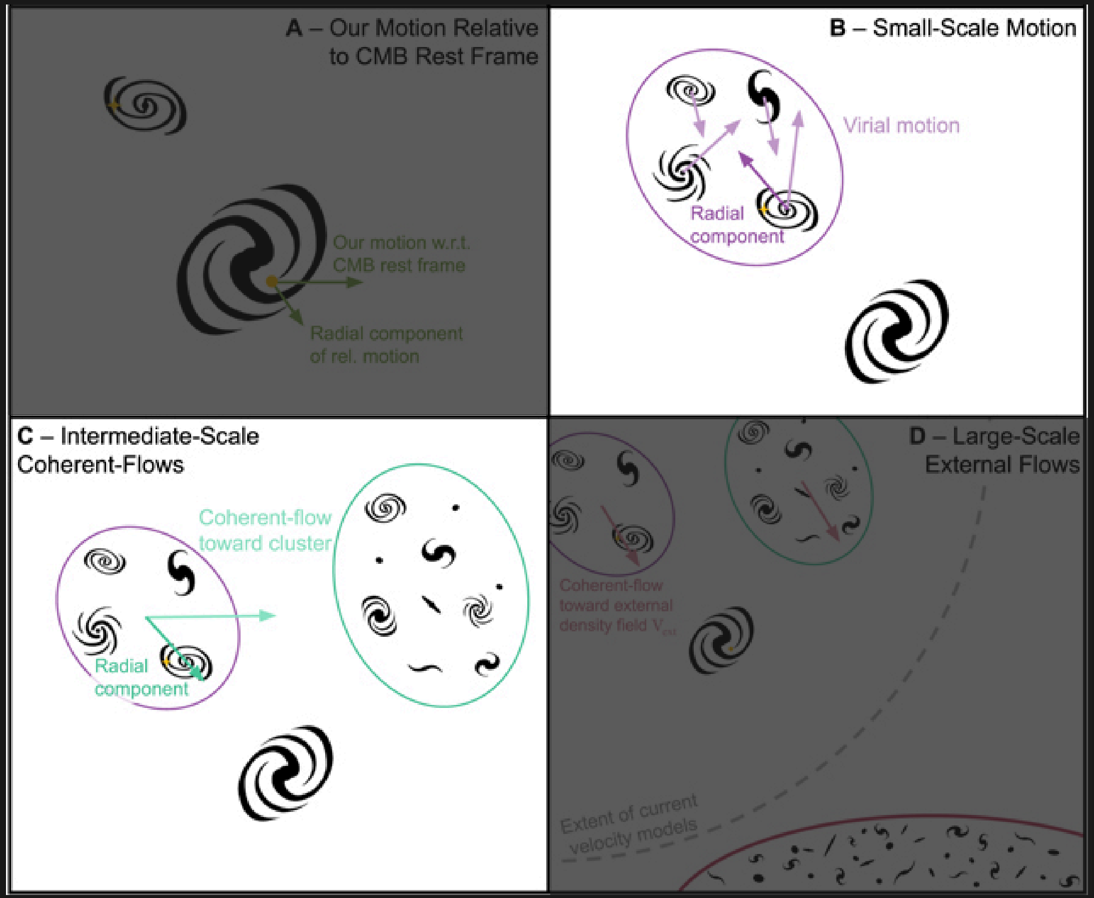

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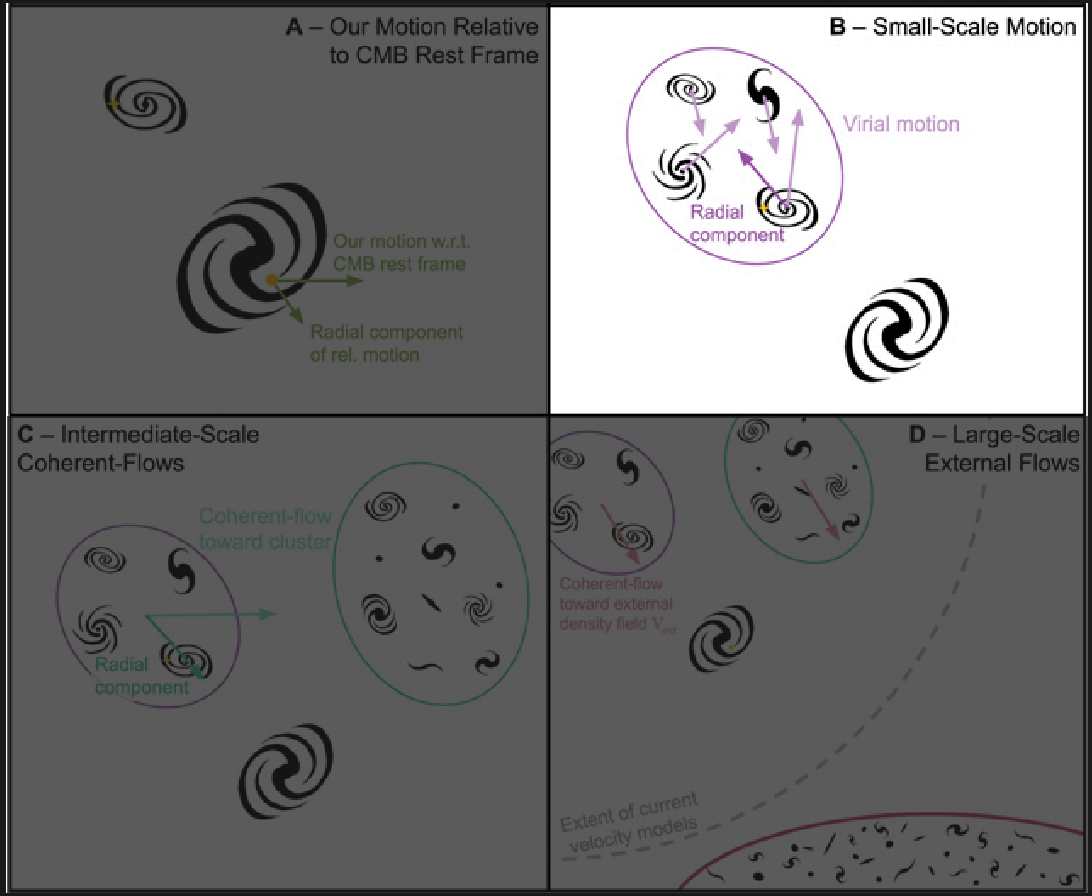
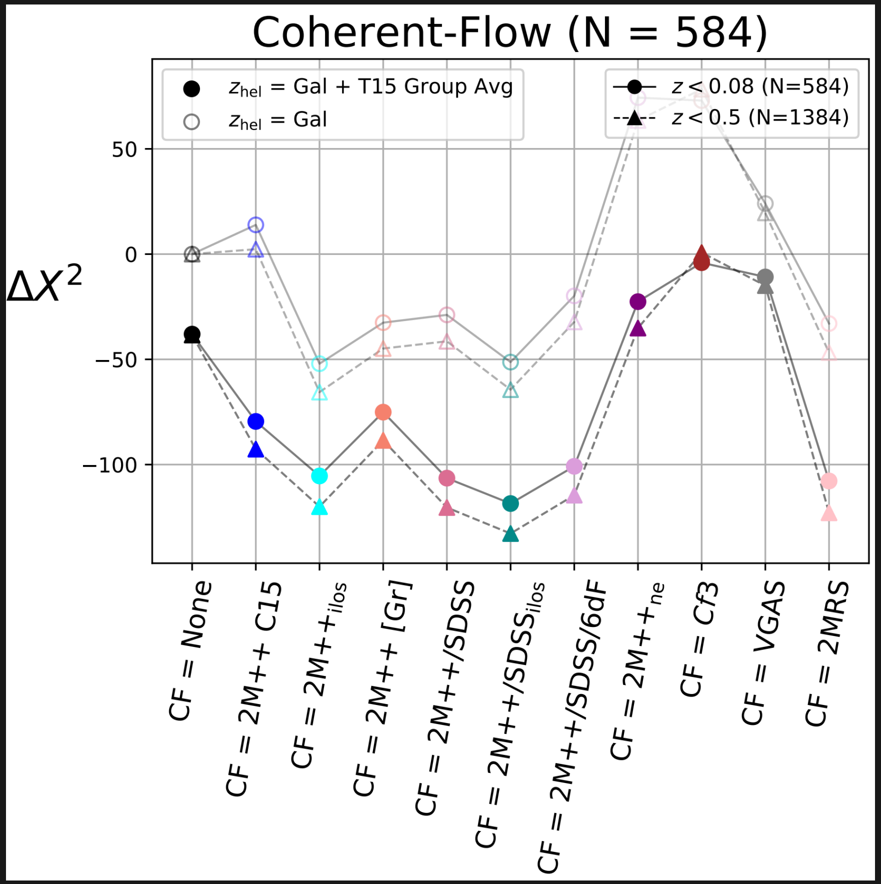


Correcting PVs at different scales

Group-averaged redshifts of $\sim 30\%$ of the SN Ia sample (identified in *Tully et al. 2015*) already results in an improvement in terms of the χ^2 of the Pantheon+ Hubble diagram !



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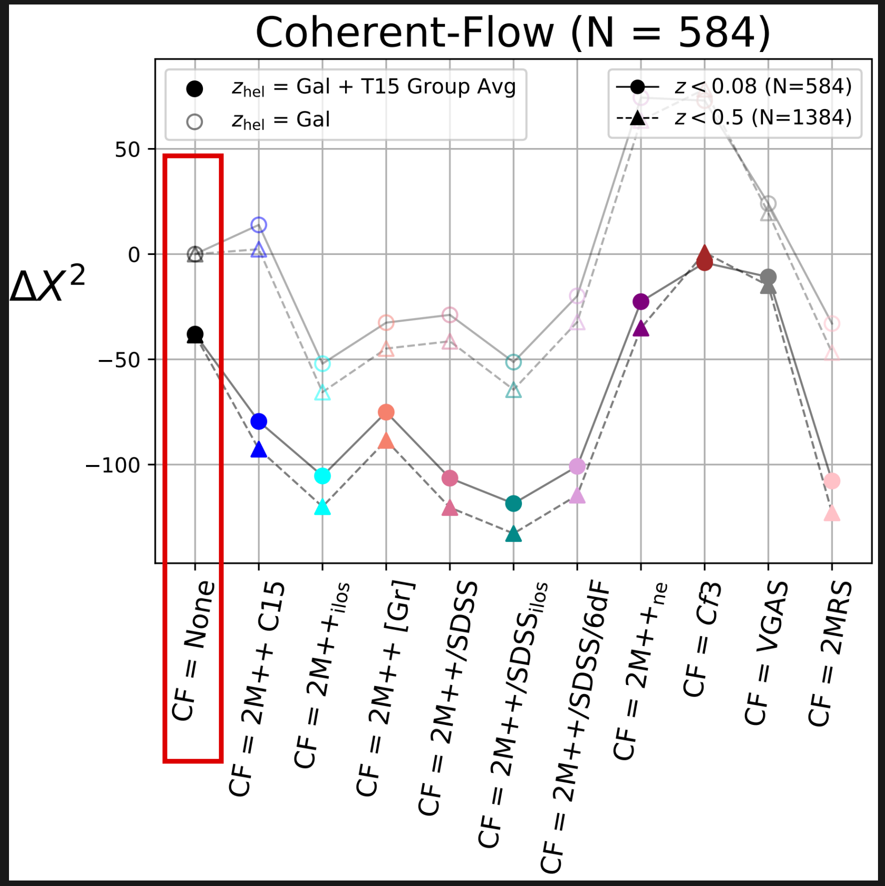

Galaxy groups in Pantheon+ data

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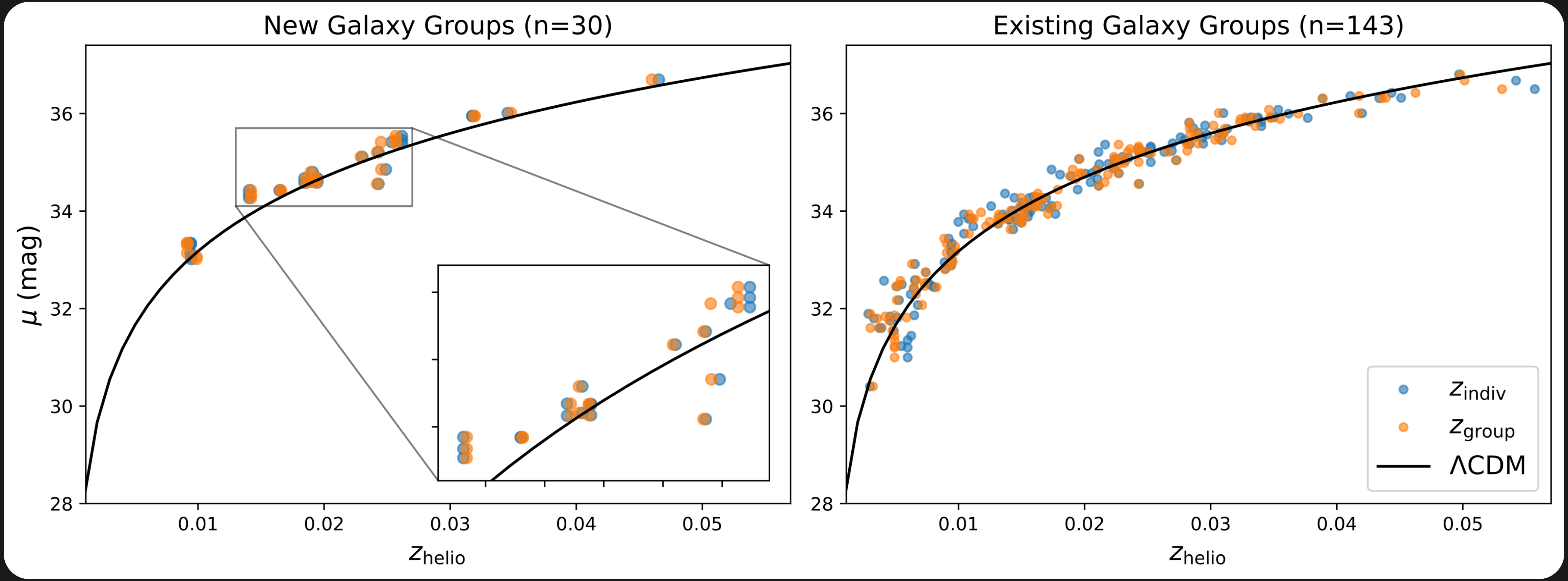

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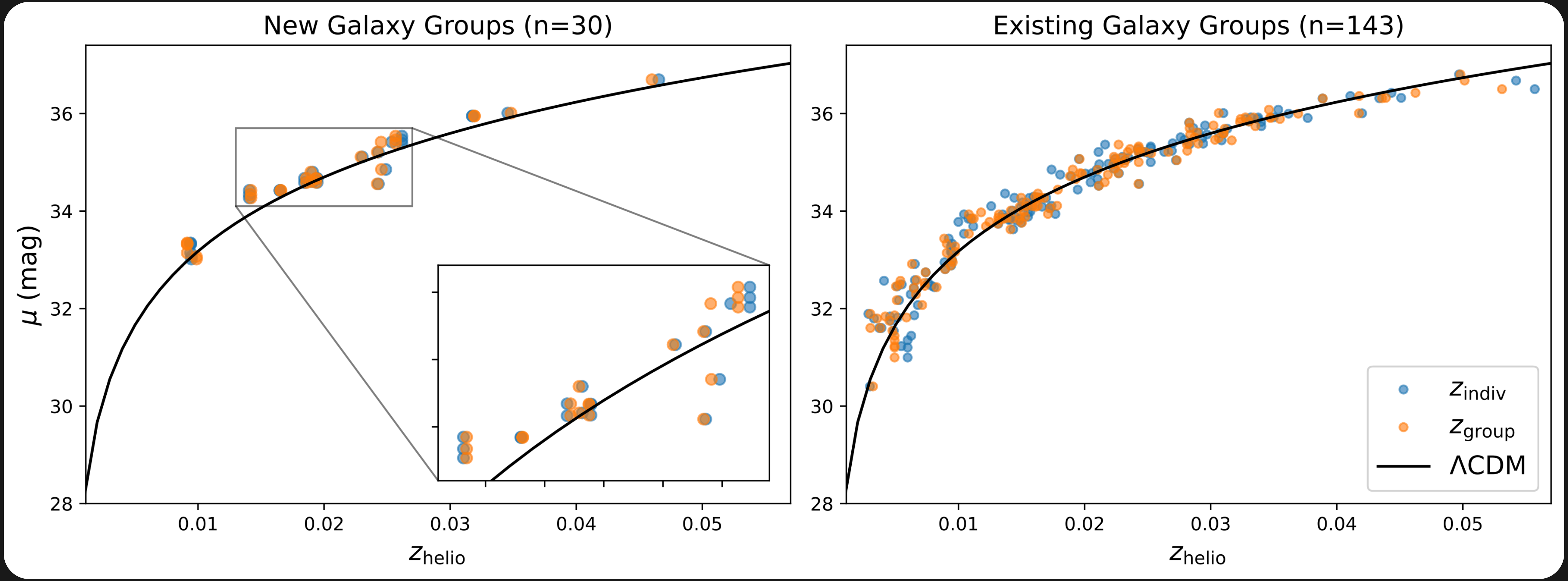
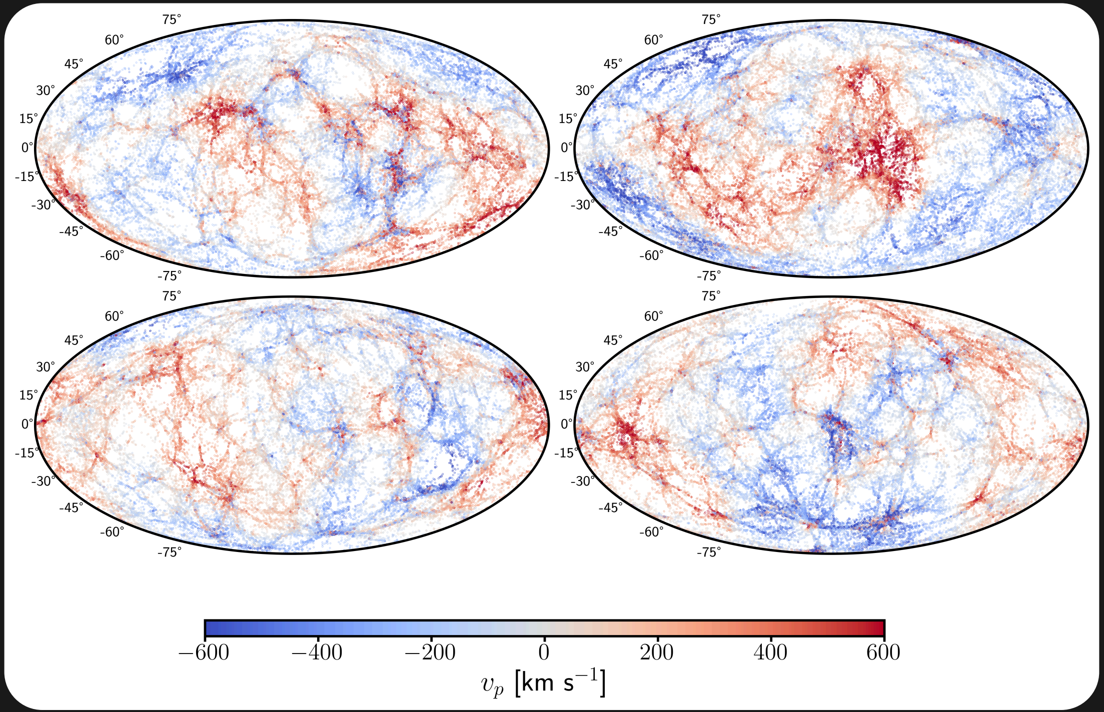
Groups are found using the modified FoF algorithm used in *Lambert et al. 2020* and we defined them for $N_{\rm gal} \geq 2$



Galaxy groups and SN Ia hosts in the Uchuu simulations

Uchuu UniverseMachine N-body simulation (*Ishiyama et al.* 2021, *Aung et al. 2023*):



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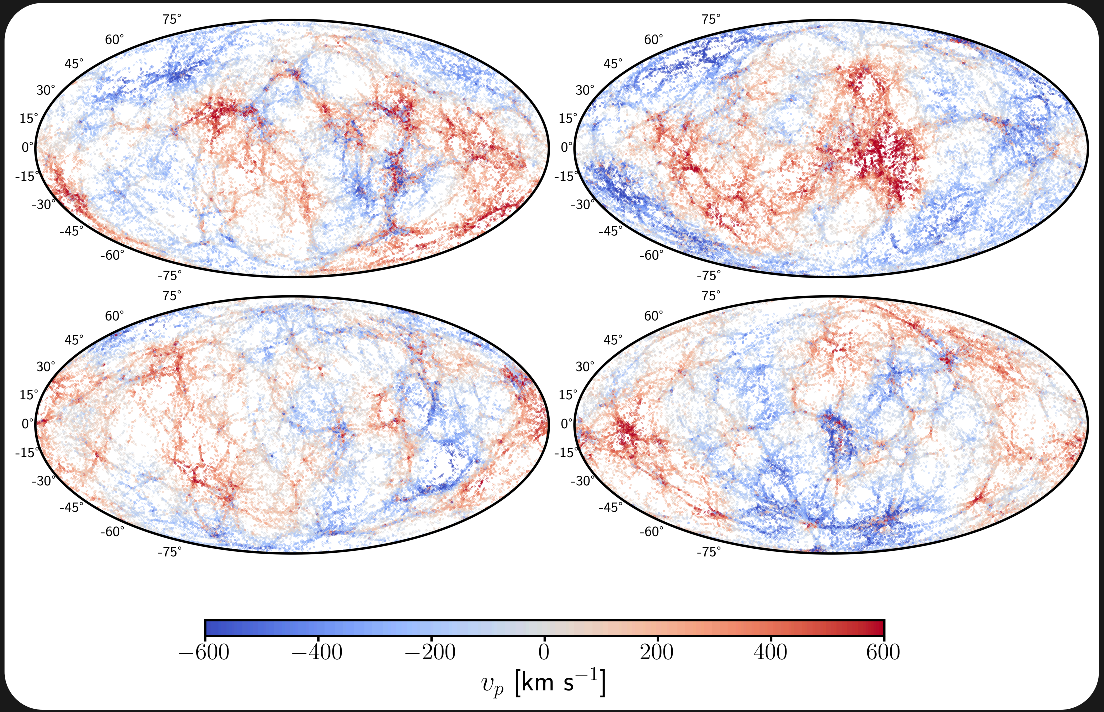

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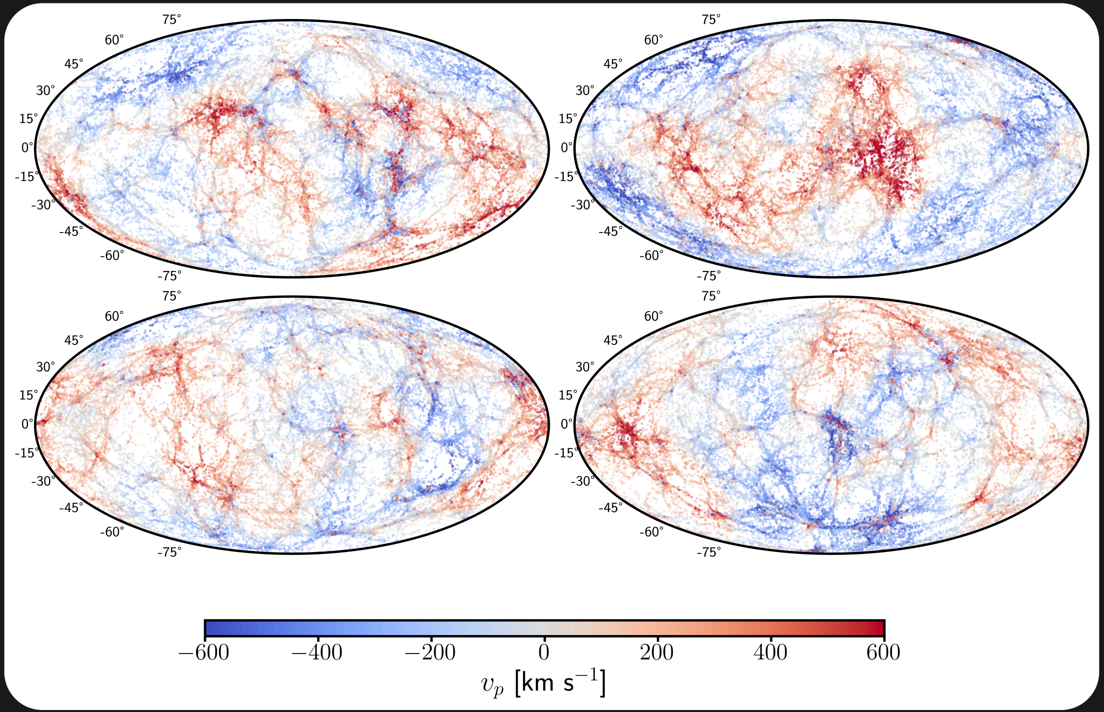

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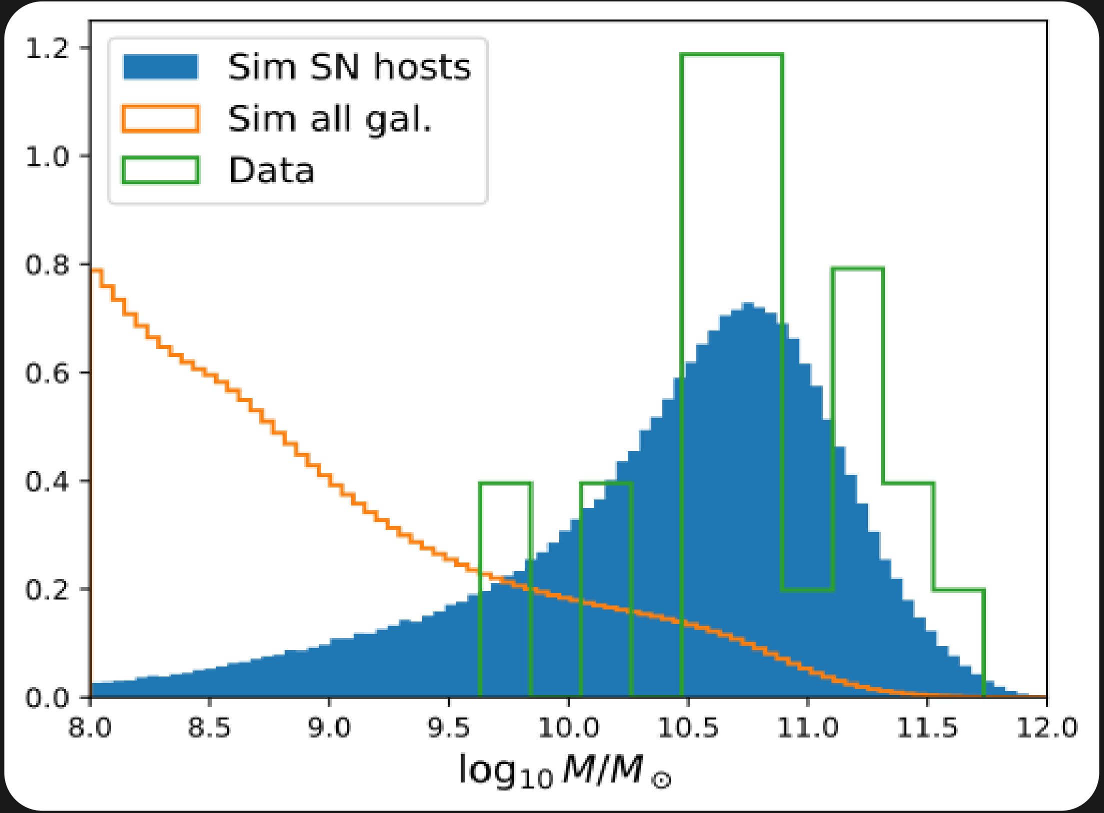
- We draw 500 000 galaxies as SN Ia hosts following *Wiseman et al. 2021* mass distribution



Results: Proportion of SN Ia hosts in galaxy groups

From our data we found that $> 90\%$ of SN Ia host galaxies are in groups and 73% from the simulation.

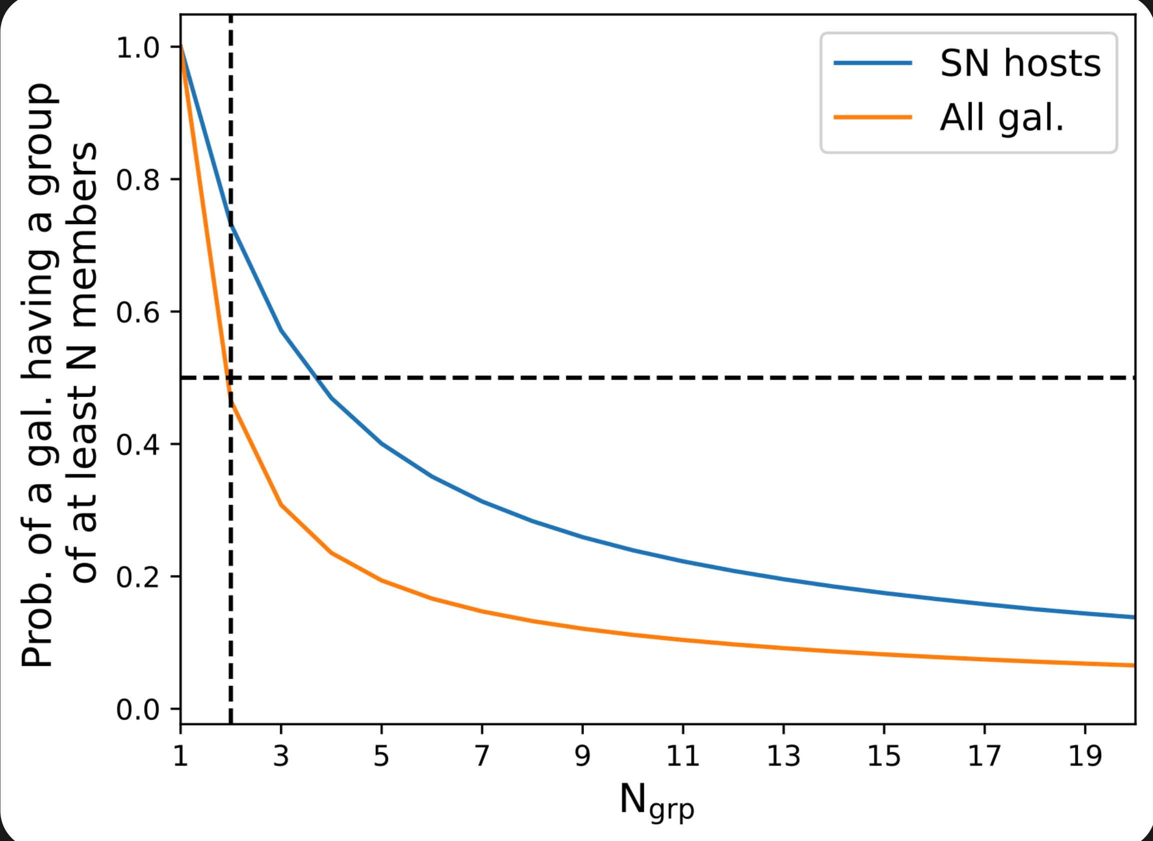
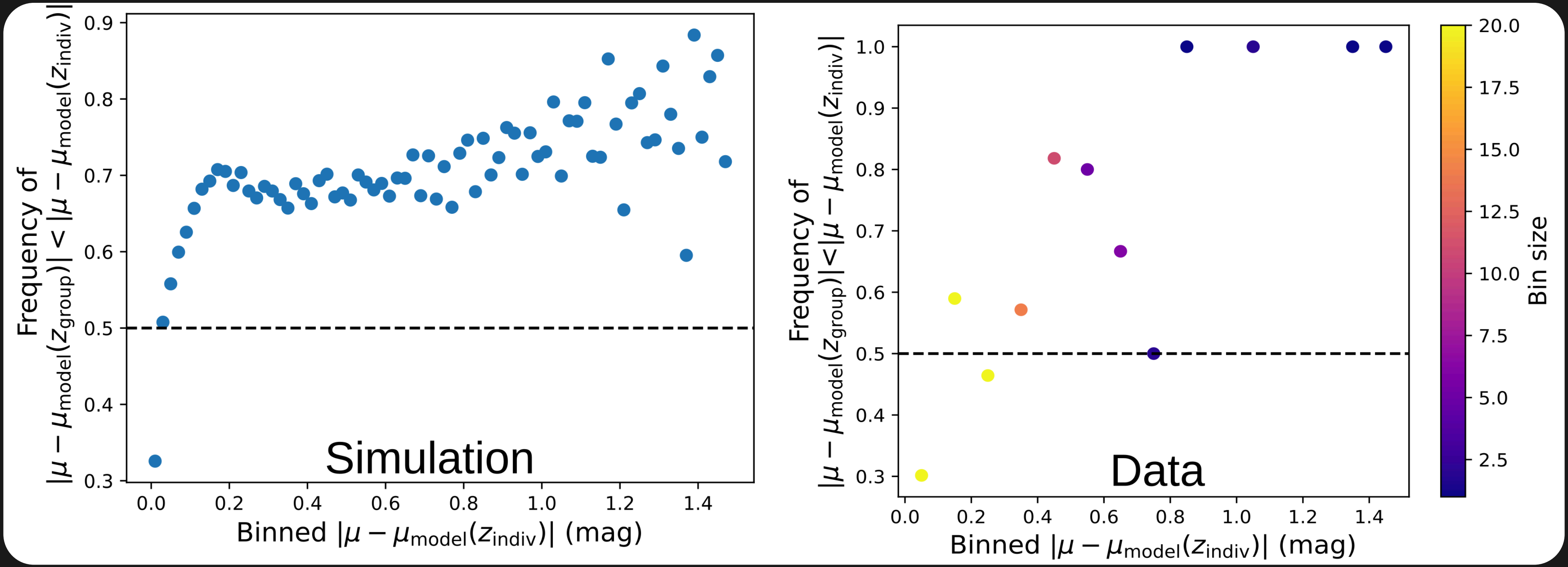


Table 2. Percent of galaxies found to be in groups for different works

Work	% in groups	Notes
Crook et al. (2007) (data)	73%	All gal., 2MRS (Huchra et al. 2005a)
Tully (2015) (data)	58%	All gal., 2MRS (Huchra et al. 2012)
Peterson et al. (2022) (data)	30%	SN hosts, Pantheon+
This work (sims)	47%	All gal., Uchuu simulations
This work (sims)	73%	SN hosts, Uchuu simulations
This work (data)	91%	Targeted SN hosts on the AAT

Results: Improvements on Hubble residuals

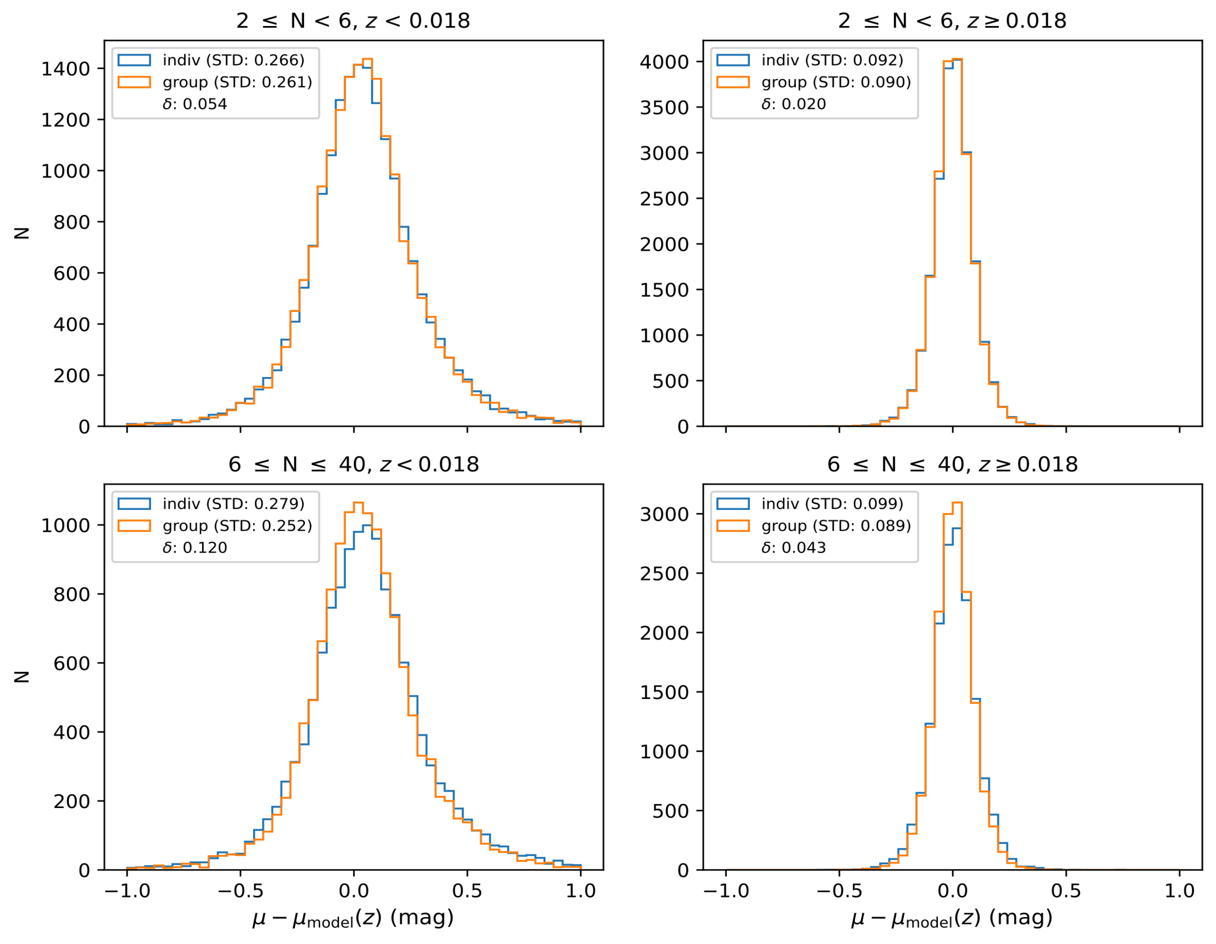
Group-averaged redshifts can lead to large improvements of the Hubble diagram residuals



Results: Improvements on Hubble residuals

We quantified the improvement in HD residuals scatters using $\delta = \sqrt{\mathrm{STD}^2_{\mathrm{indiv.}} - \mathrm{STD}^2_{\mathrm{grp}}}$

Simulations: maximum improvement of $\delta \sim 0.120$ mag for larger group ($N > 6$) at lower redshift ($z < 0.018$)



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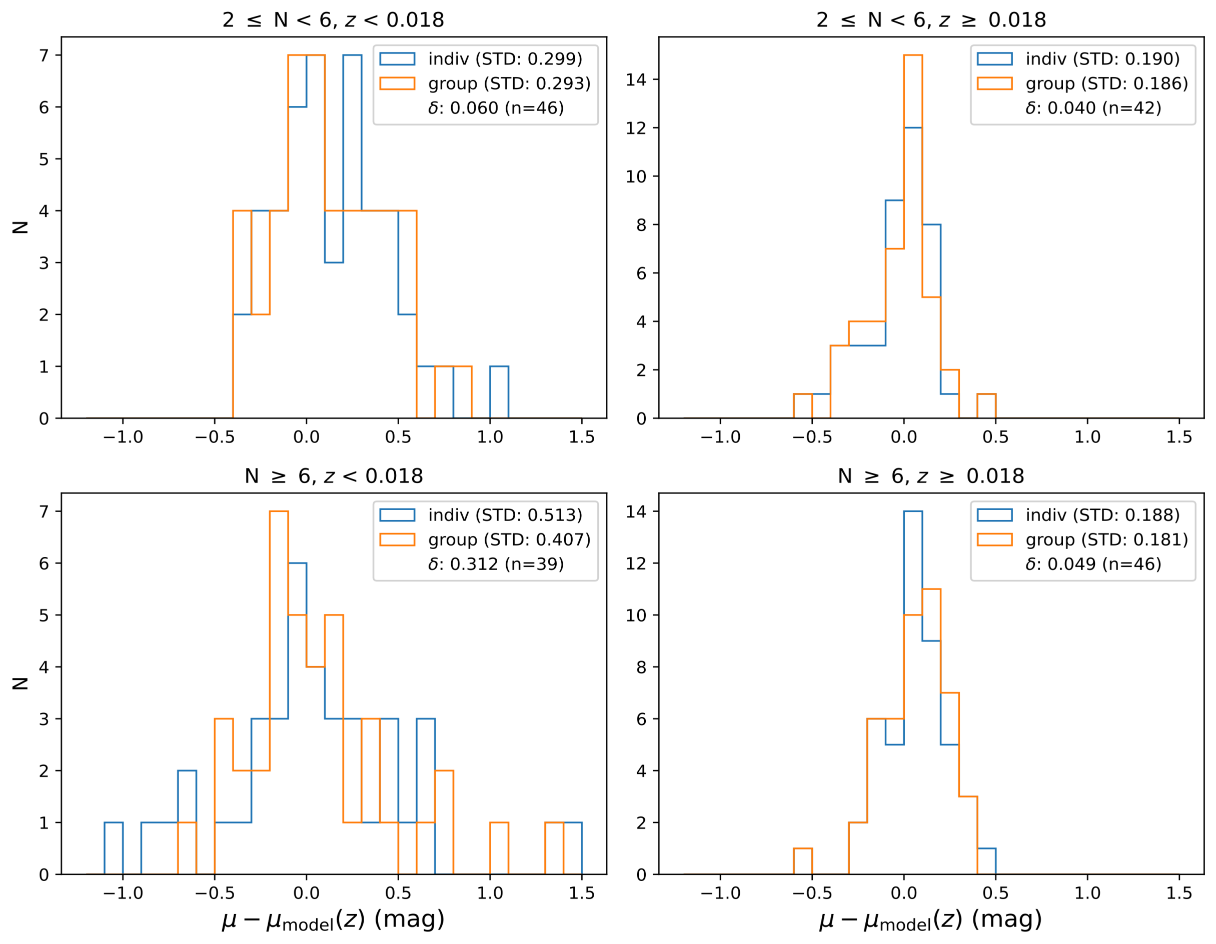
We quantified the improvement in HD residuals scatters using $\delta = \sqrt{\mathrm{STD}^2_{\mathrm{indiv.}} - \mathrm{STD}^2_{\mathrm{grp}}}$

Data: maximum improvement of $\delta \sim 0.312$ mag for the same bin



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- Largest improvements come from large groups ($N > 6$) at low redshift ($z < 0.018$)

Group-averaged redshifts will be usefull to increase statistical power of low-z SN Ia sample in the incoming new generation of surveys such as the Rubin-LSST

Thanks for your attention !