MILKY WAY GLOBULAR CLUSTERS IN A COSMOLOGICAL CONTEXT

PRIMILARY RESULTS

IN COLLABORATION WITH
P. DI MATTEO

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Tagging methods in post-treatment:

Simulations: Illustris TNG-50, FIRE, EAGLE, AURIGA, ...

Methods:

- Formation efficiency parameter based on gas and stellar quantities resolved in the simulation *Pfeffer +17, Reina-Campos +22, Grudic +23, Rodriguez +23*
- Identification of the most DM bound particles *Creasey+18*
- DM halo properties *Ramos +20, Park +22, Rodriguez +23, Doppel +23, Chen+23, Chen +24*
- Defining GC candidates as all star particles older than 10 Gyr *Halbesma +20*

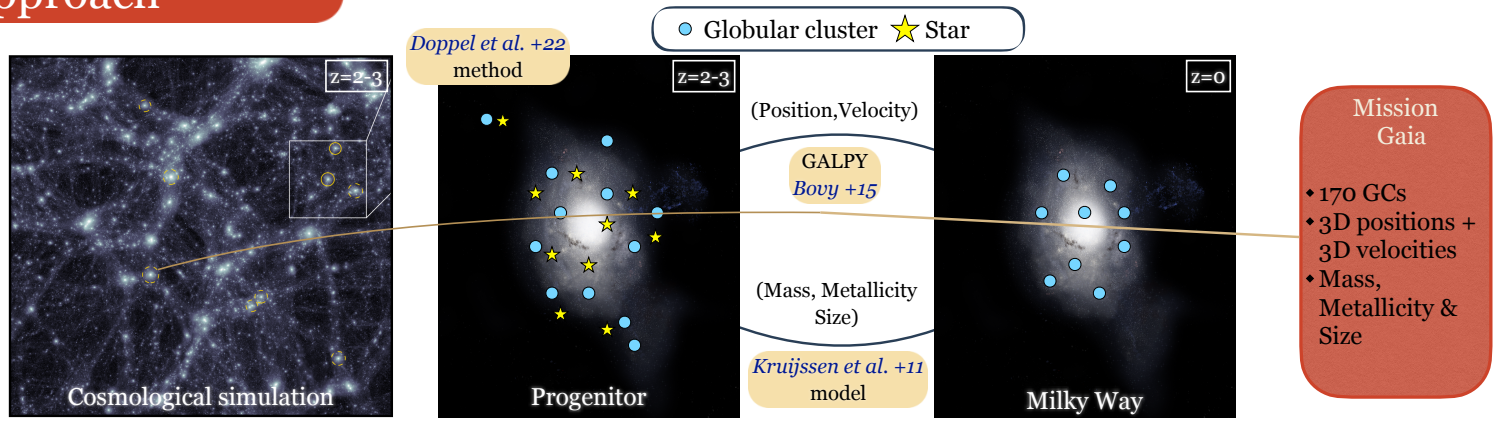
Statistics: 2-8000 galaxies

Doppel +23

Computationally inexpensive with large statistics and several environments

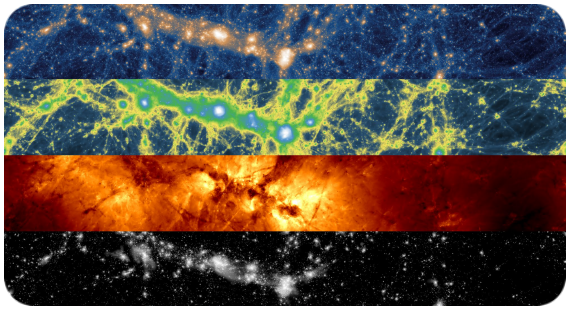
GAIA-CONSTRAINED GC FORMATION AND EVOLUTION MODEL

Our approach



Simulation	Code	Resolution [$10^3 M_\odot$]	#MW-like galaxies	MW environment	Galaxy formation model	Data availability
Illustris TNG-50 (Pillepich et al., 2018)	AREPO	~ 85	198	cosmological box	TNG	P
VINTERGATAN (VTG) (Agertz et al., 2021)	RAMSES	~ 7	1	isolated	VTG	C
HESTIA (Libeskind et al., 2020)	AREPO	~ 200	13	local group	AURIGA	C
ELVIS on FIRE (Garrison-Kimmel et al., 2019)	GIZMO	~ 4	3	local group	FIRE	C

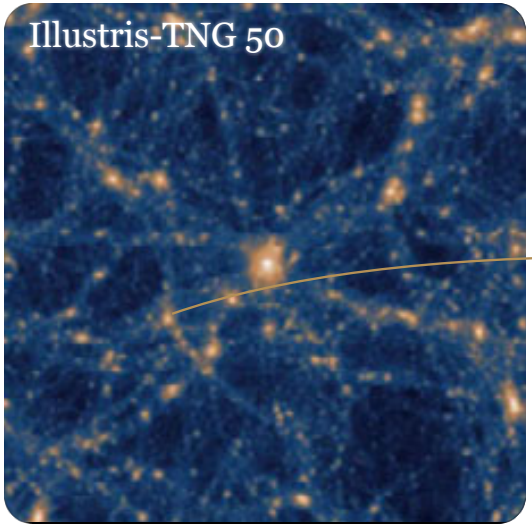
Table 1: *Simulations of MW-like galaxies* (Public (P), Collaboration (C))

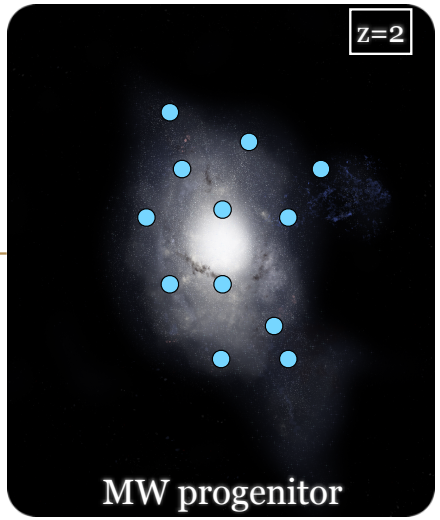


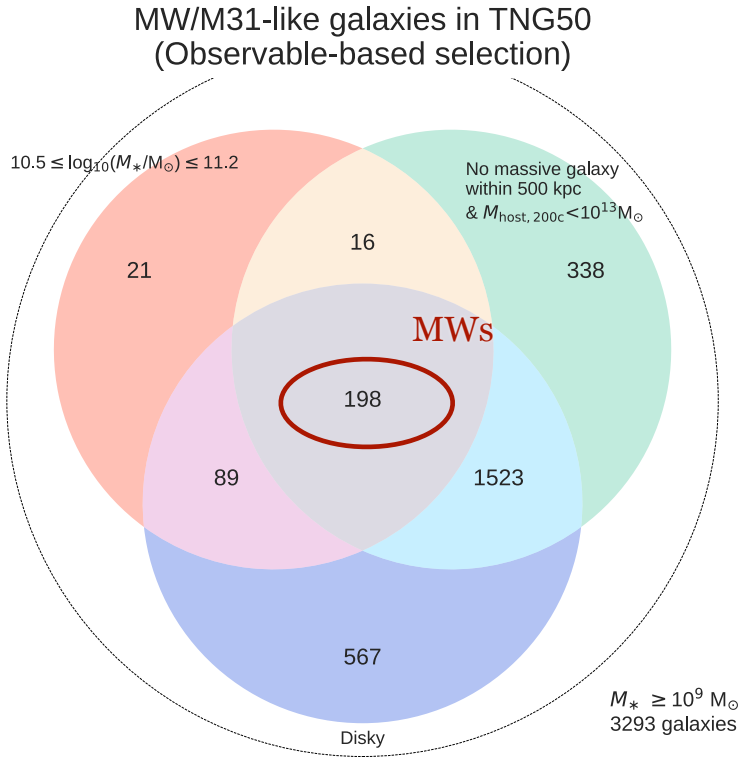
Credits : Illustrious TNG-50

200 MW systems, 40 000 GCs, from redshift z=3 to z=0, 5 physical properties

Ingredients of our approach

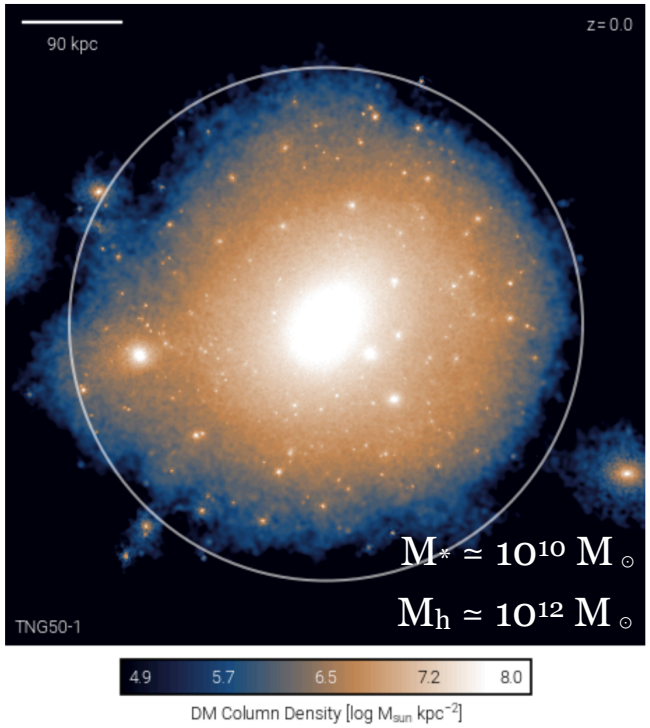


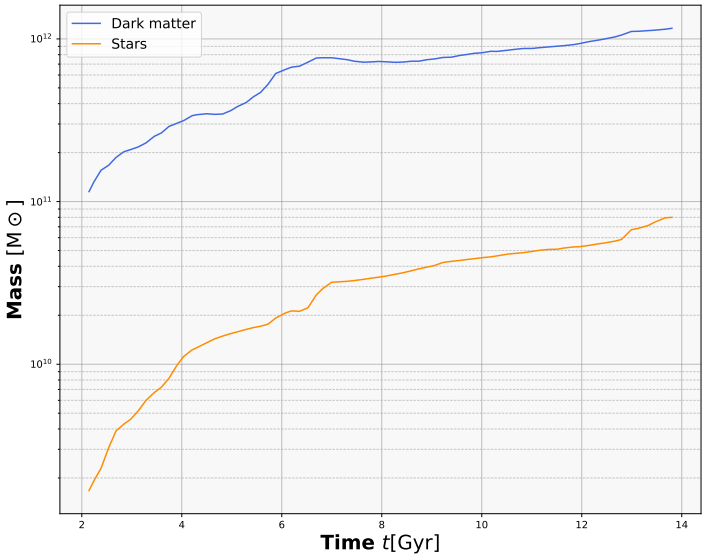


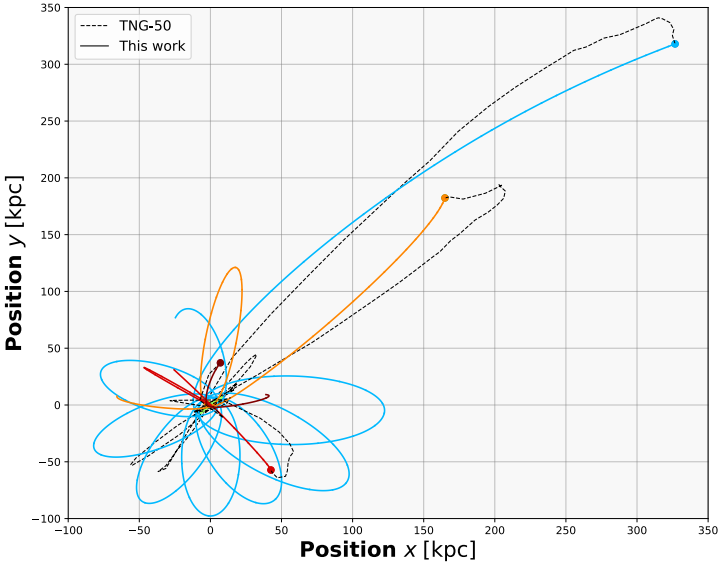


Only for the in-situ GC population

MW and its merging satellites





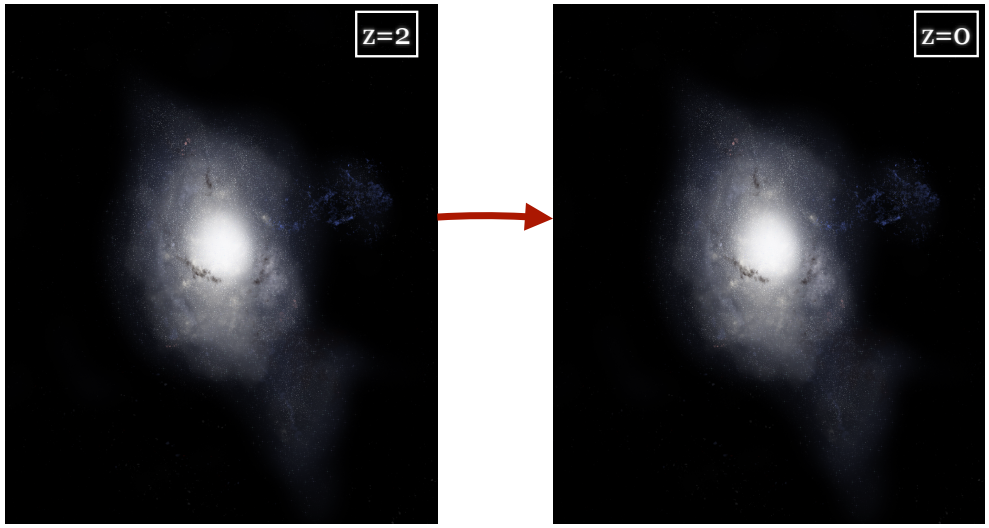


One MW galaxy and 5 merging satellites

TNG50 MW formation and history

- 75 snapshots from TNG-50 (75 different MW potentials)
- All main progenitor of the MW between z=2 and z=0
- All the merging satellites of the MW between z=2 and z=0

($M_* > 10^7 M_\odot$)



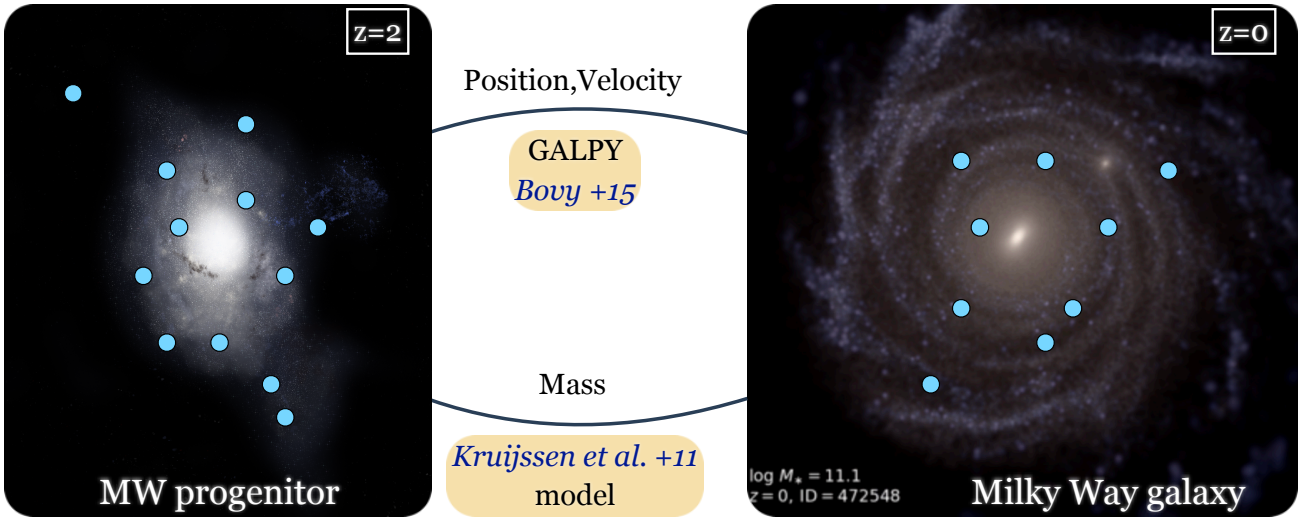
MW Potential
(M_{dm}, r_{dm}, M_*, r_{h*})
at z=2

MW Potential
(M_{dm}, r_{dm}, M_*, r_{h*})
at z=0

Galactic potential = Bulge + DM halo (no disc and no gas component)

GC dynamics

- 200 GCs over 10 Gyr
- 10^6 $M_\odot$ with r_{hm} = 10 pc
- Time resolution: 500 steps per Gyr (2 Myr)
- 0.5 CPU hrs for 200 GCs over 10 Gyr in a MW+environment potential (4 min on my laptop with 8 CPUs)

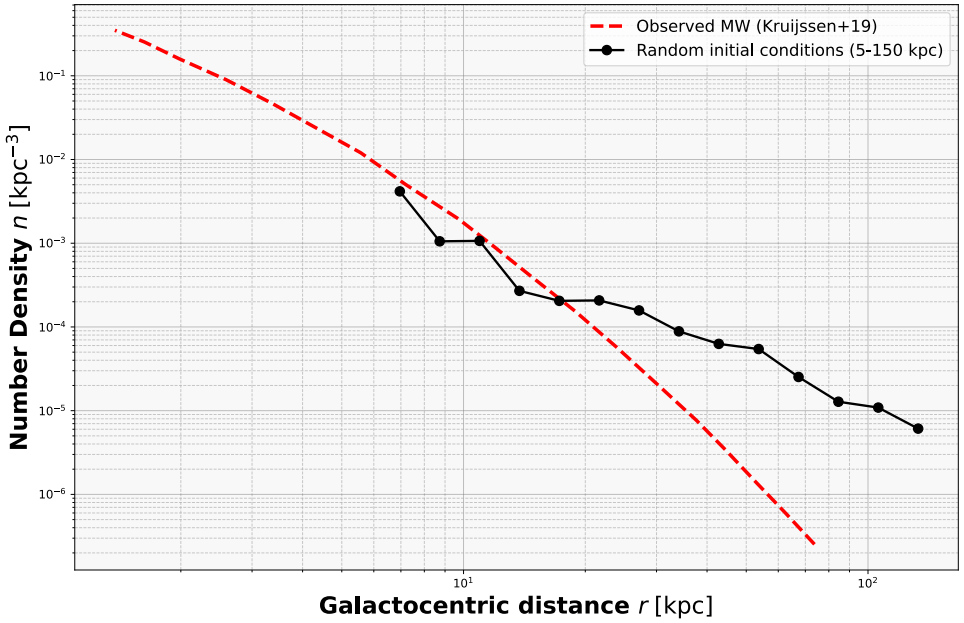


fast and flexible GC model

What are the dynamical perturbers of the in-situ GC population?

Dynamical perturbers:

- Evolved MW potential
- Dynamical friction
- Mass loss
- Satellite galaxies



Observed from Gaia DR3

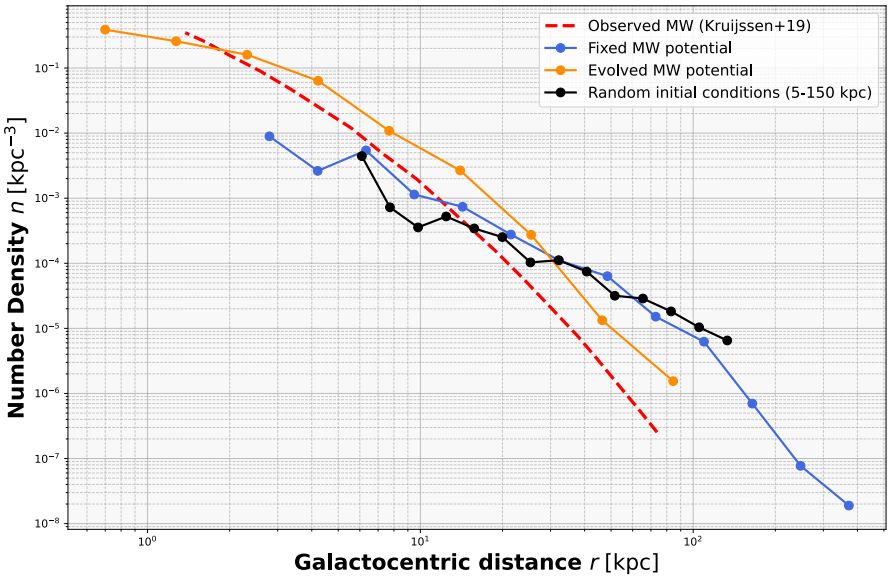
Random initial conditions

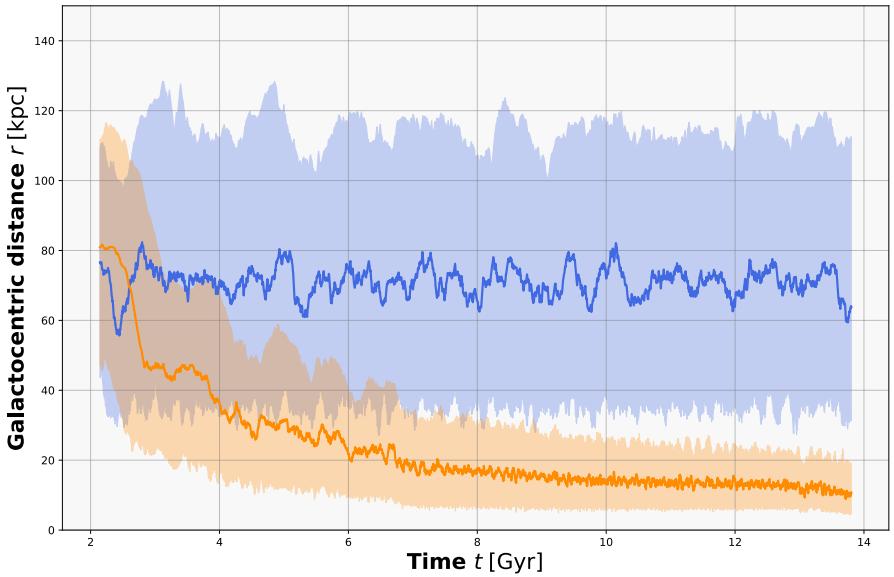
The most important perturber is the **evolved MW potential**

Fixed versus evolved MW potential

Fixed MW potential

Evolved MW potential



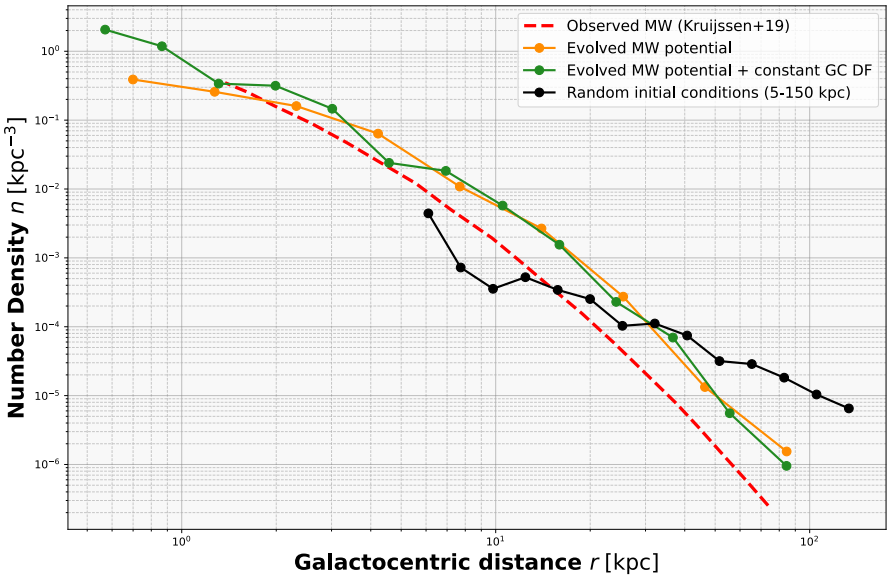


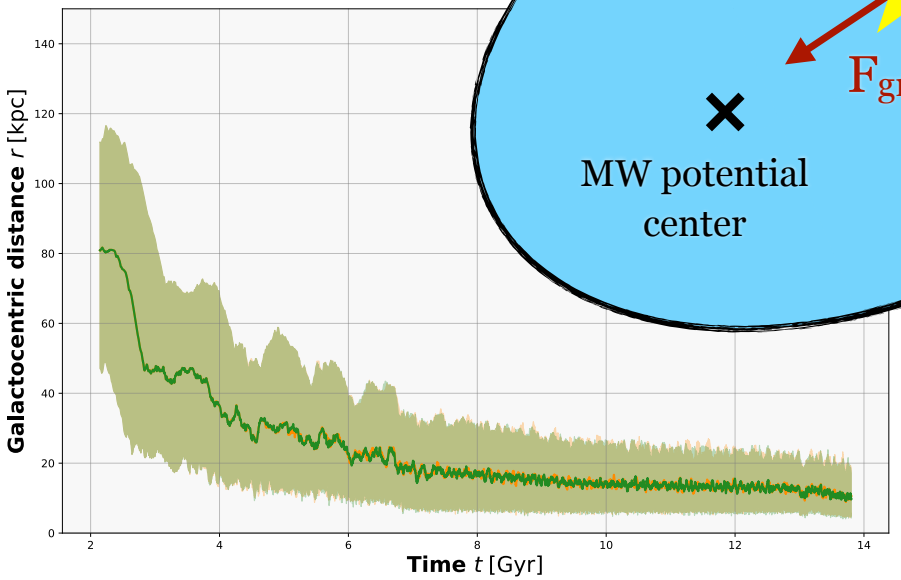
Dynamical friction efficiency?

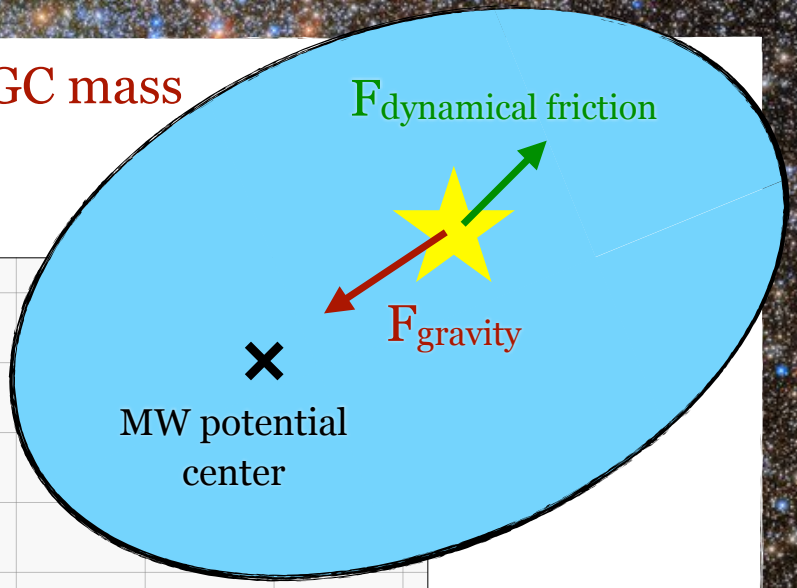
DF ∝ MW potential, GC mass

Evolved MW potential

Evolved MW potential + **constant dynamical friction on GCs**







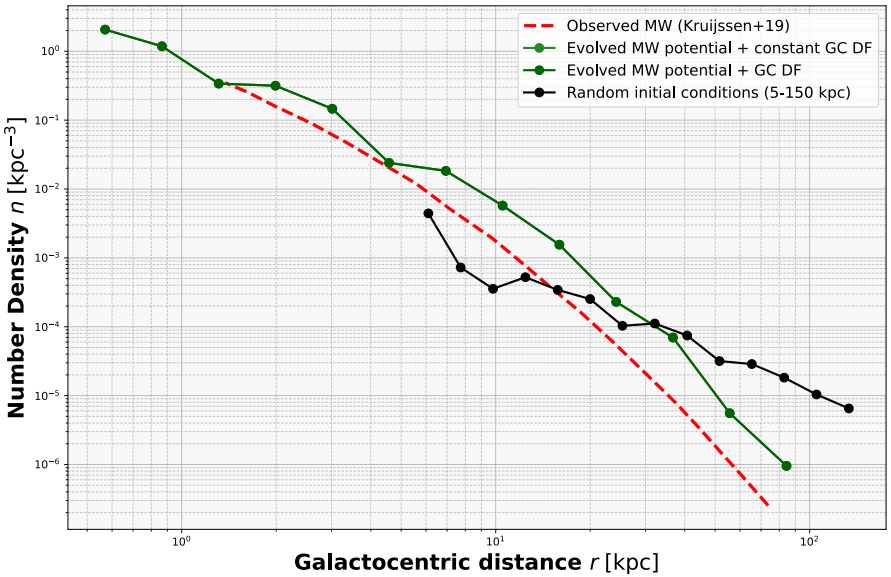
DF ∝ GC mass/MW mass << 1

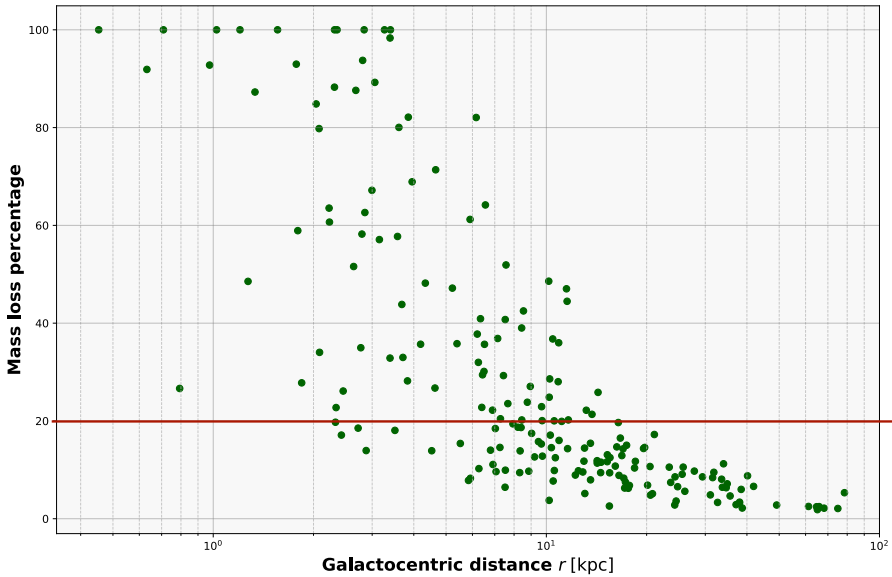
Mass loss efficiency?

DF ∝ MW potential, GC mass

Evolved MW potential + constant DF on GCs

Evolved MW potential + DF on GCs + GC mass loss





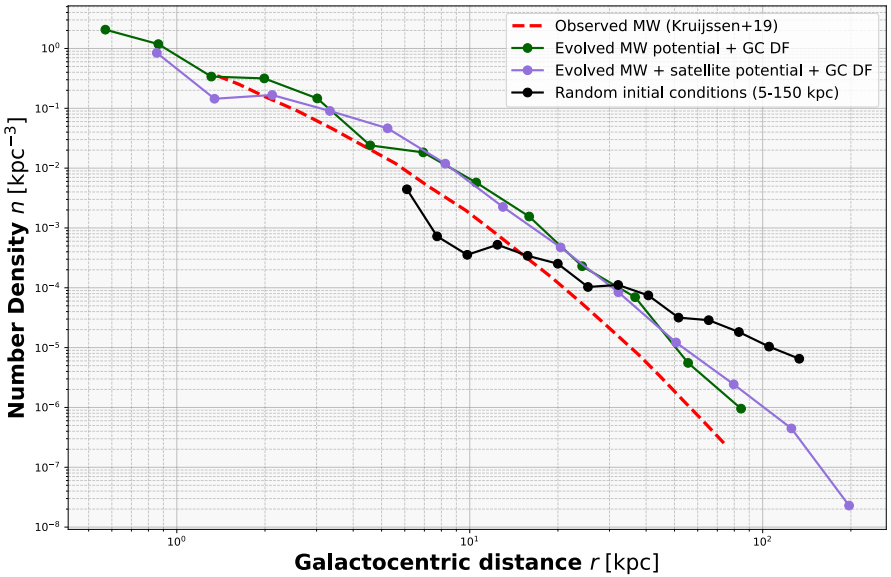
60%

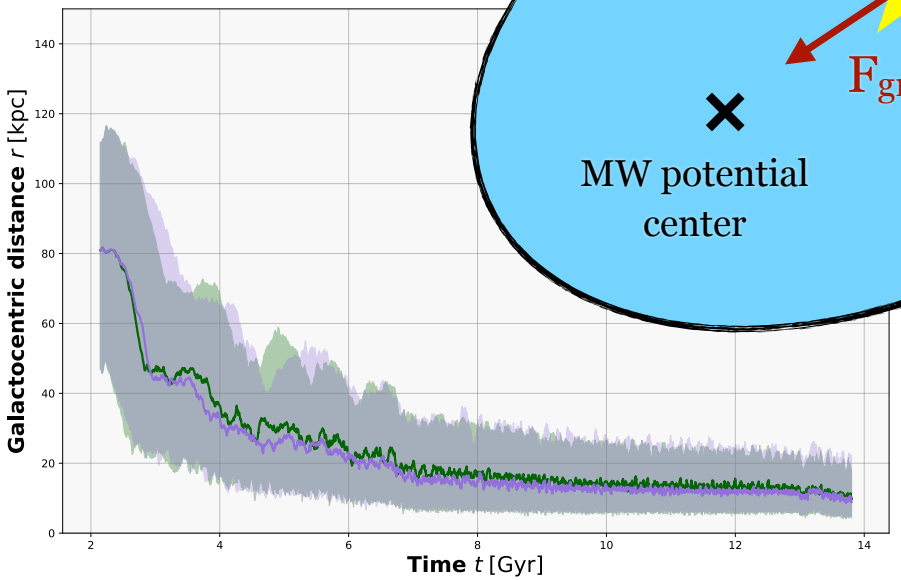
DF ∝ GC mass/MW mass << 1

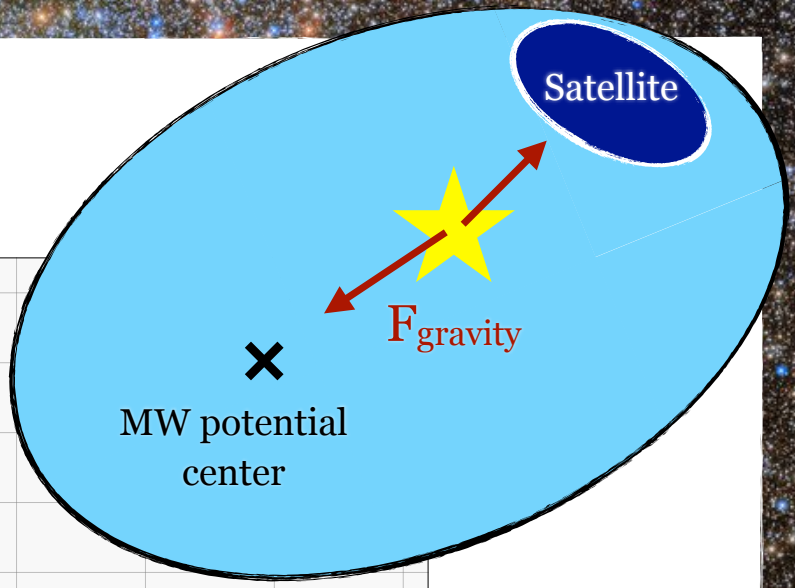
Merging satellites have a impact or not?

Evolved MW potential + DF on GCs + GC mass loss

Evolved MW potential + **satellite potential**s + DF on GCs + GC mass loss







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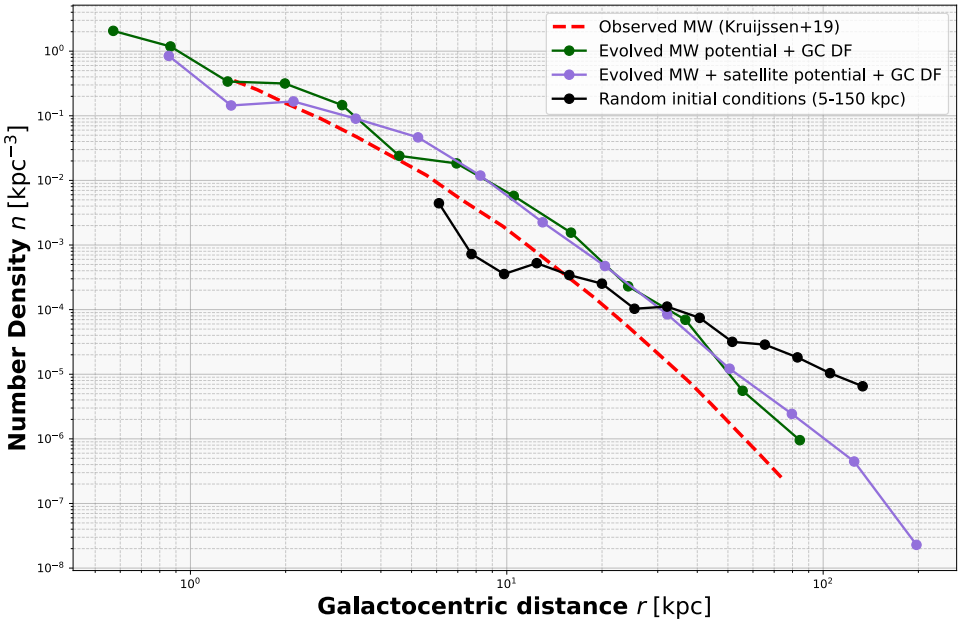


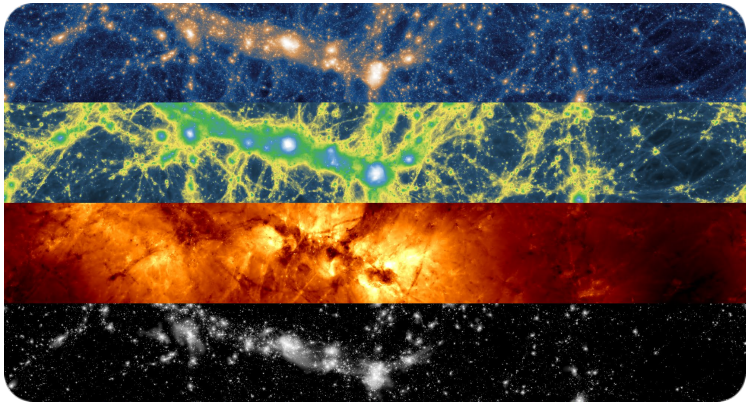
Observed from Gaia DR3

Random initial conditions

Evolved MW potential
+ **satellite potentials**
+ DF on GCs
+ GC mass loss

The most important perturber is the **evolved full MW potential**

- Incorporating dark satellites
- Incorporating disk components
- Adding tagging methods
- Simulating the GC dynamics for 198 MW galaxies
- Constraining with Gaia data
- Non spherical potential?



Credits : Illustrious TNG-50

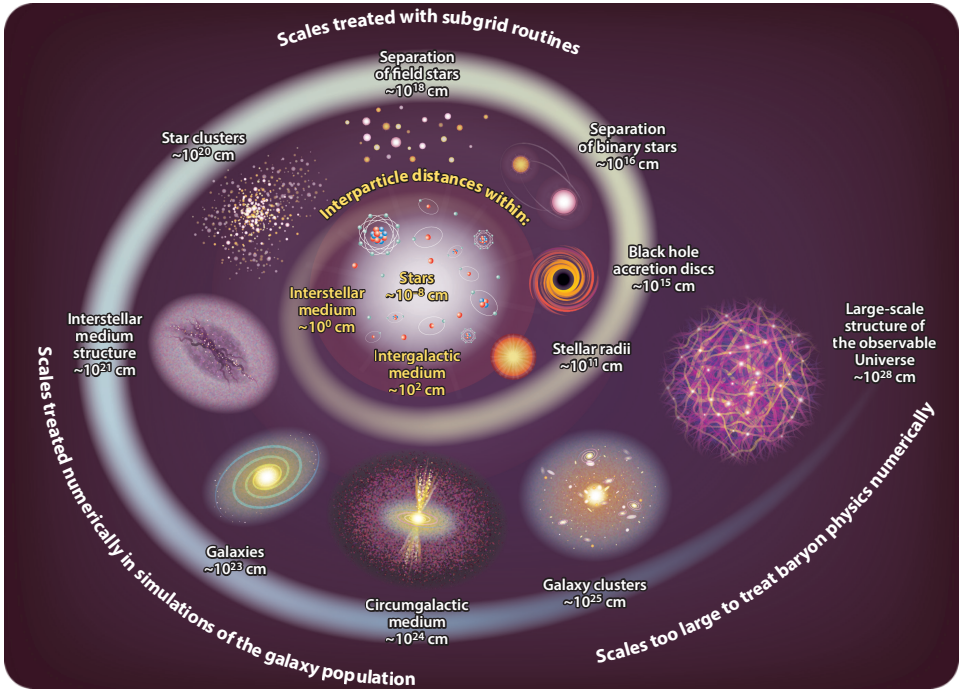
Comments and suggestions are welcome

GAIA-CONSTRAINED GC FORMATION AND EVOLUTION MODEL

	Previous models for MW	Our approach
Simulations:	unique	Several simulations
Number of MW galaxies:	2 - 50	200
Tagging time:	GC tagged at different redshift	GC tagged at z=2 and then follow their dynamics
Tagging method:	unique	Several methods
Dynamical friction:	no or analytically	yes
Mass loss:	no or analytically	yes
Observational constraints:	No or mass, metallicity, distribution	Gaia and Apogee
References:	*Halbesma +20, Doppel +23, Chen +24*	*Boldrini & Di Matteo, 2025, in prep*

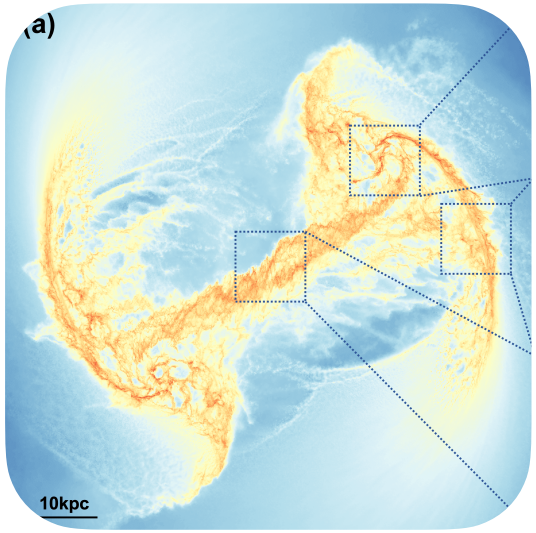
Crain+23

- Spatial resolution ~ sub-pc
- Mass resolution ~ 1 $M_\odot$
- **Cosmological context:**
  large range of space (pc - Mpc) and time-scales (Myr - Gyr)



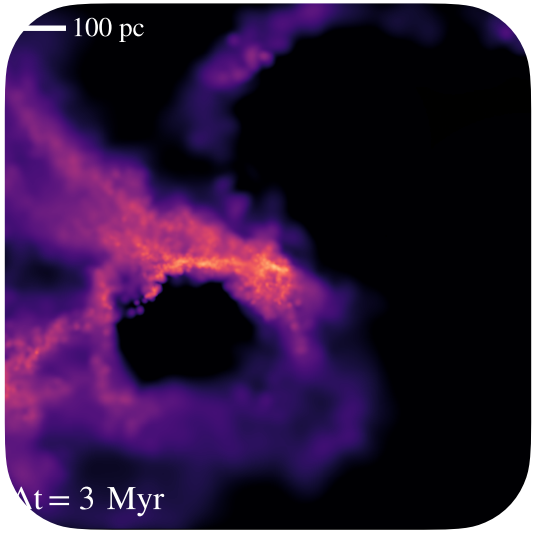
Resolution requirements make this presently impossible to do in direct calculations that track the formation of individual stars

Li +22



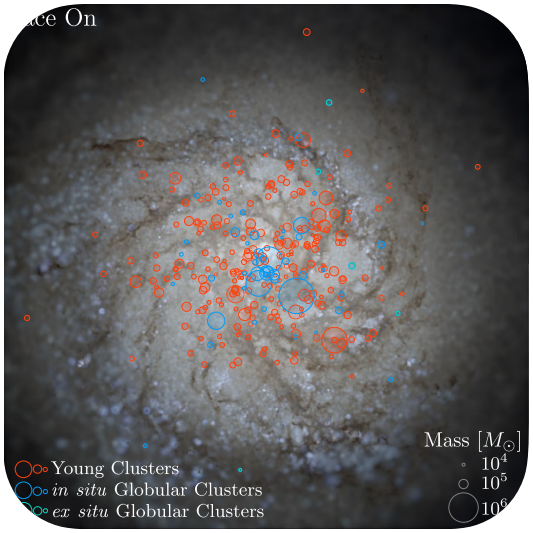
IDEALIZED GALAXY SIMULATIONS

Sameie +22



HIGH-RESOLUTION COSMOLOGICAL SIMULATIONS

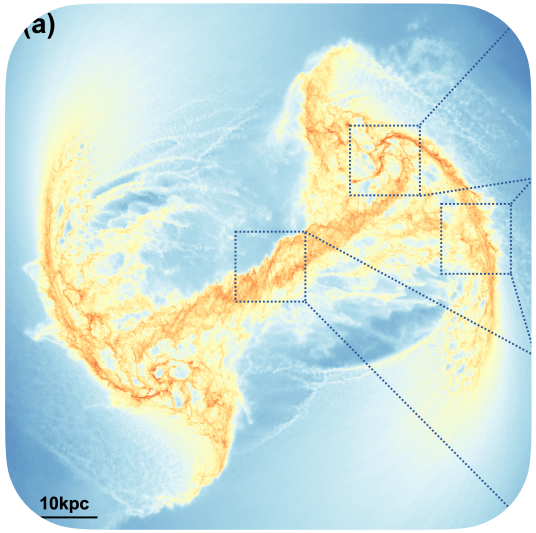
Rodriguez +23



COSMOLOGICAL SIMULATIONS
+
POST-PROCESSING MODELS

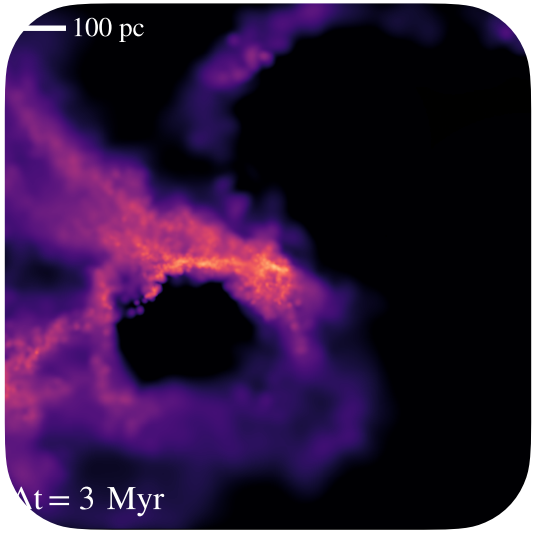
Reviews: Beasley +20, Renaud +19

Li +22



IDEALIZED
GALAXY
SIMULATIONS

Sameie +22



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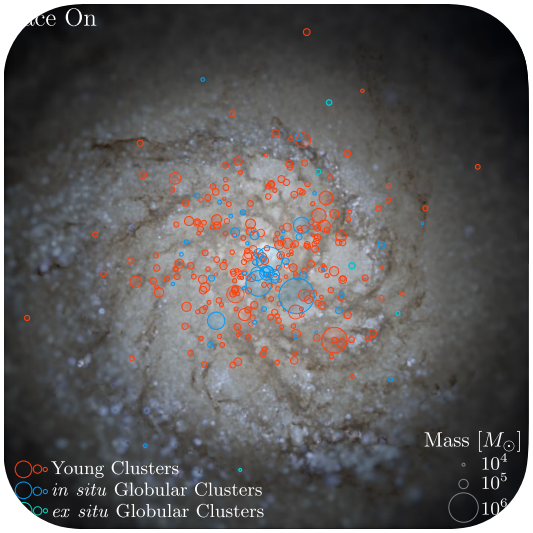

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