# SEARCHING FOR ACCRETED STARS IN GAIA DATA : PREDICTIONS FROM N-BODY MODELS


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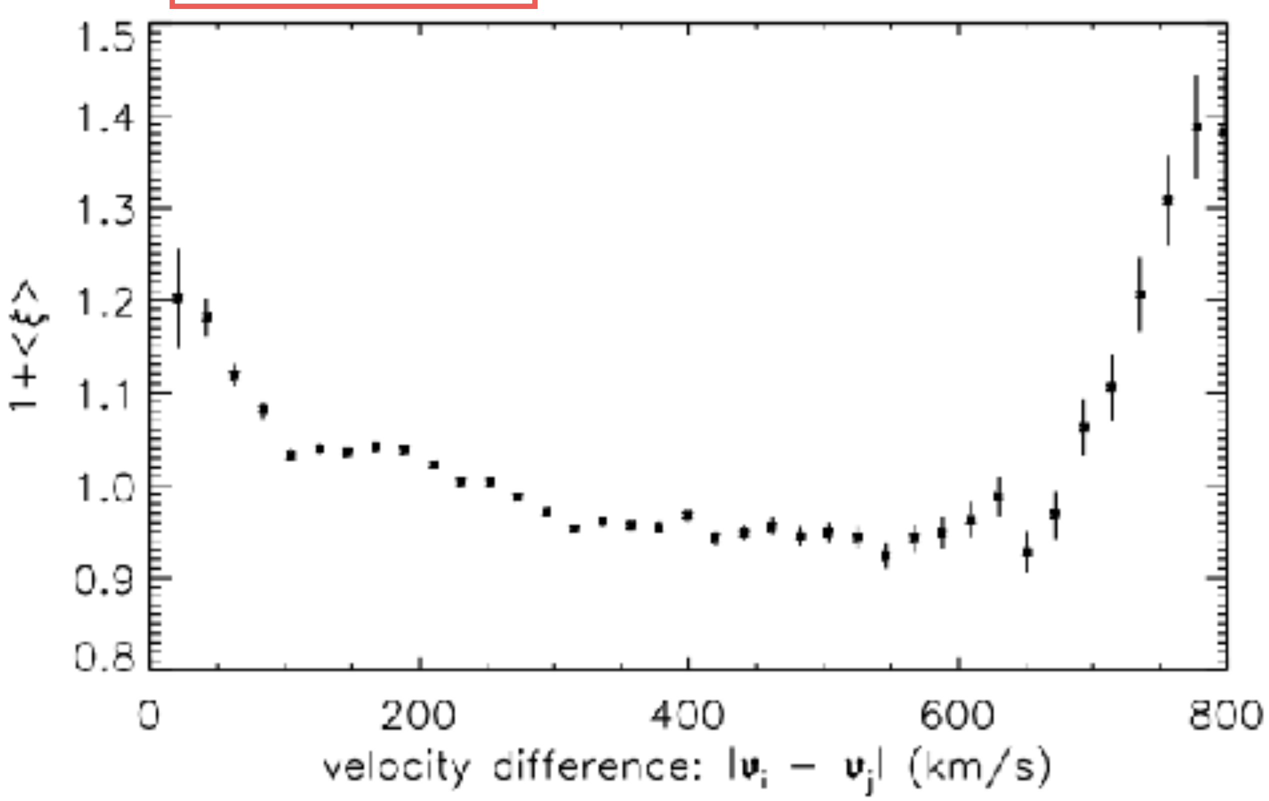
Jean-Baptiste et al, 2017 A&A

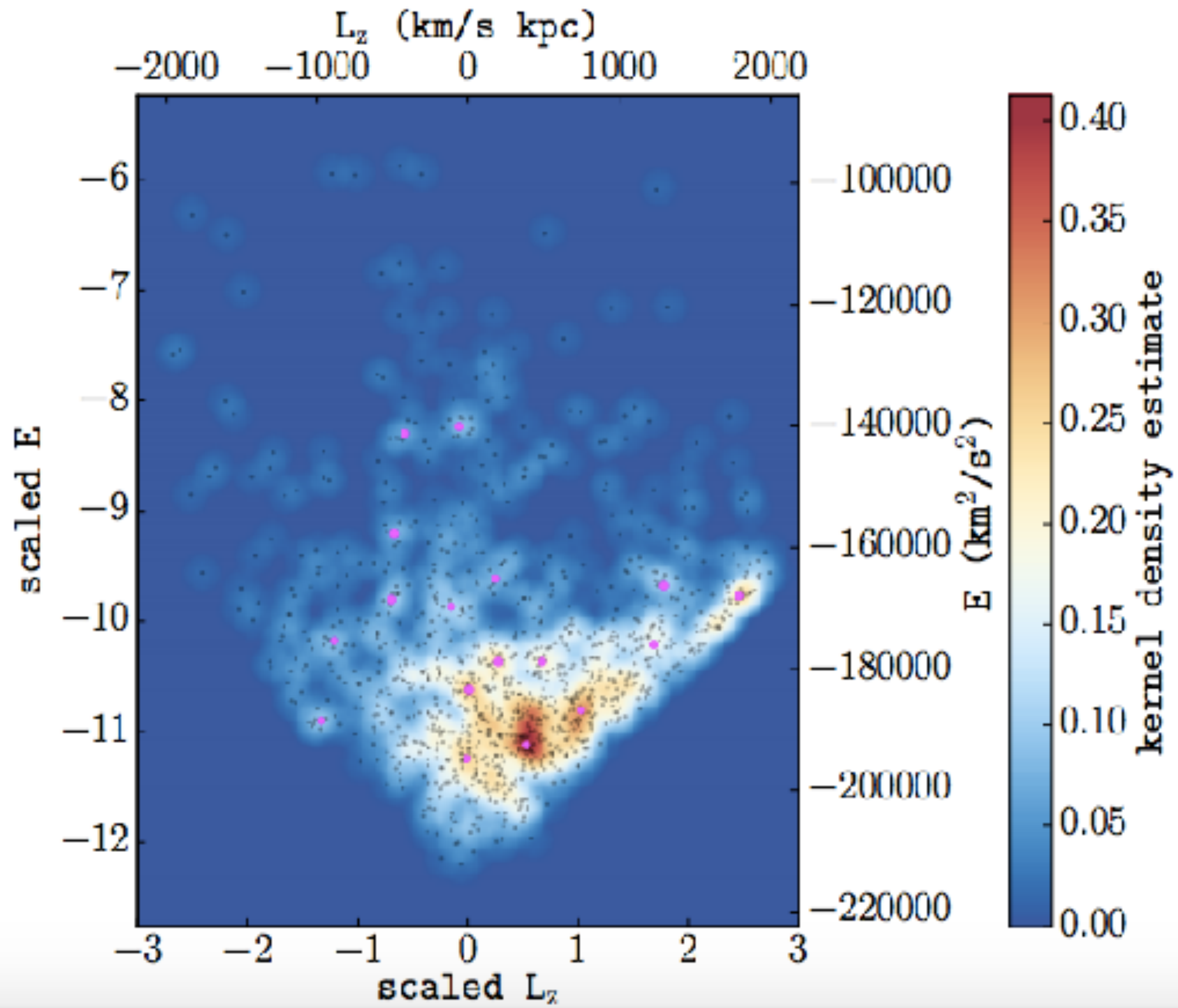
# How do we interpret the signatures found in kinematic spaces with Gaia DR1 ?

Preparing for DR2 and following releases also ..

TGAS + RAVE

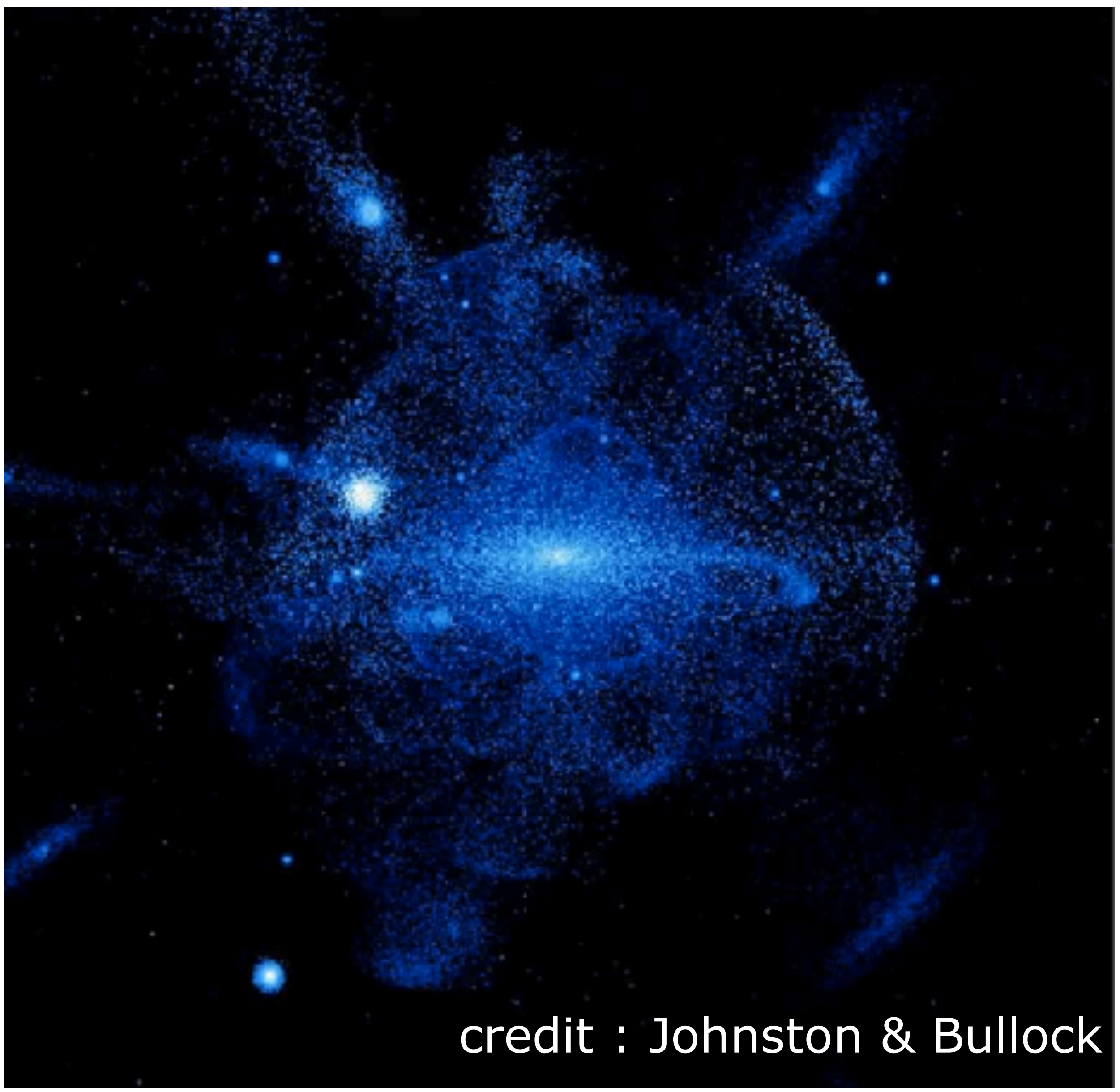



Helmi et al 2017



# WHY KINEMATIC SPACES ?

ΛCDM models predict that a galaxy like the Milky Way should contain hundreds of stellar streams at the solar vicinity, relics of the merging over time of tens of galactic systems, with masses comparable or significantly smaller than our own Galaxy at the time of their accretion



credit : Johnston & Bullock

While we have evidence of ongoing accretions onto the Milky Way, like the Sagittarius galaxy, **how can we recover the remnants of the most ancient accretion events, that now should be fully spatially mixed in the Galaxy ?**

# THE SEARCH IN INTEGRAL-OF-MOTION SPACES

Initial time

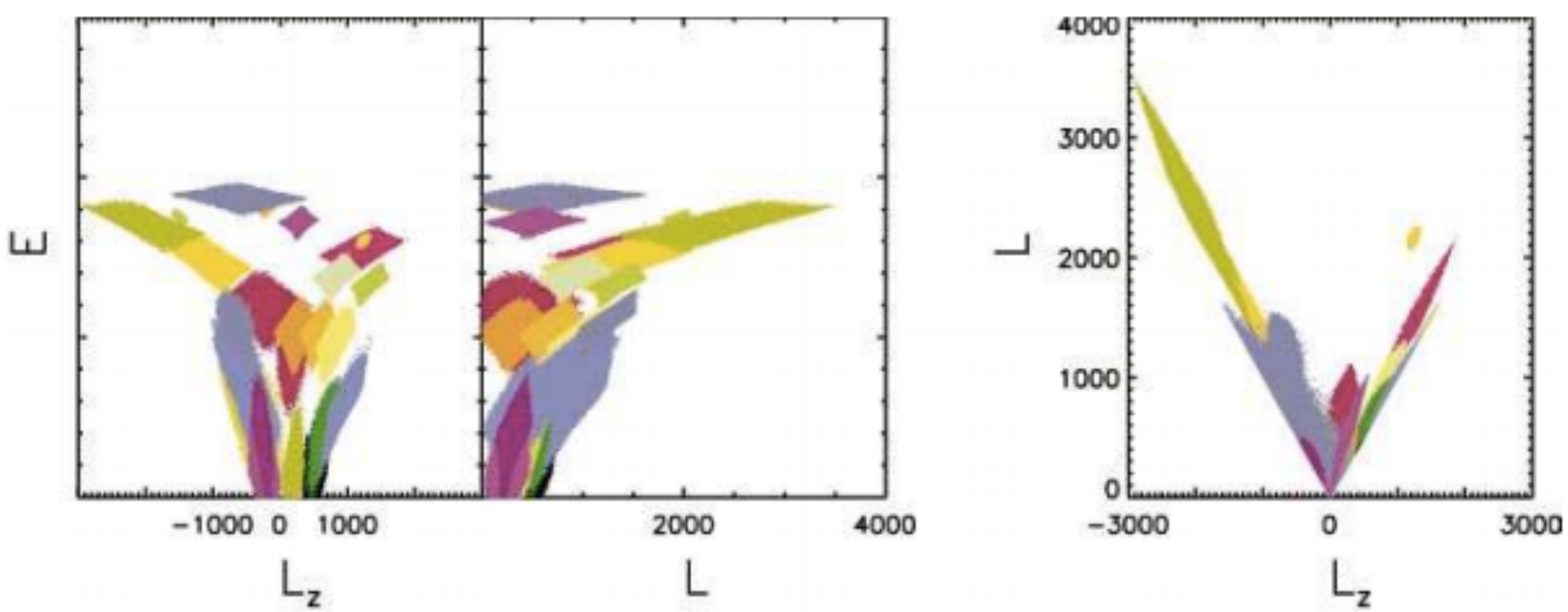
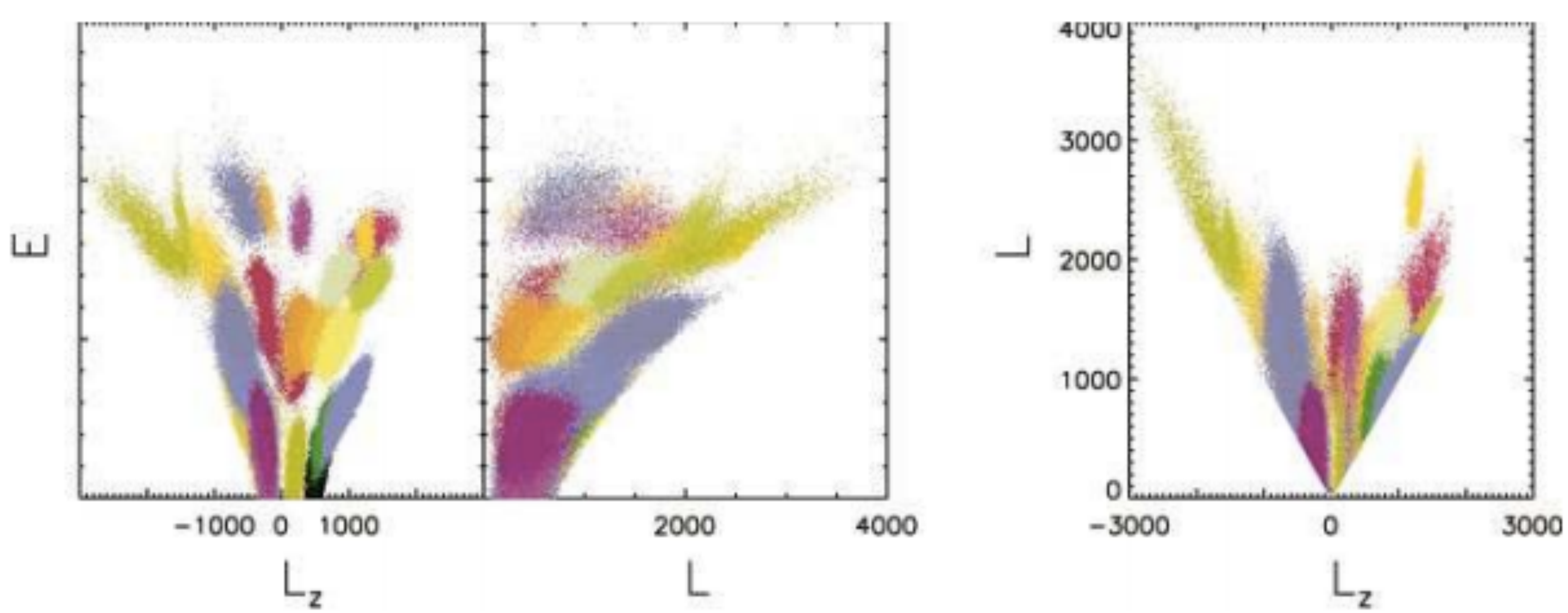



**Figure 3.** Initial distribution of particles in the integrals of motion space. The different colours represent different satellites.

"The initial clumping in those spaces is maintained to a great extent even after 12 Gyr of evolution."

**Helmi & de Zeeuw 2000**

Final time




see review by Martin Smith, 2016
"Kinematically Detected Halo Streams"

From Gomez et al 2010 :
"With a clustering algorithm, it should be possible recover roughly 50 per cent of all satellites contributing stellar particles to the solar neighbourhood sphere."

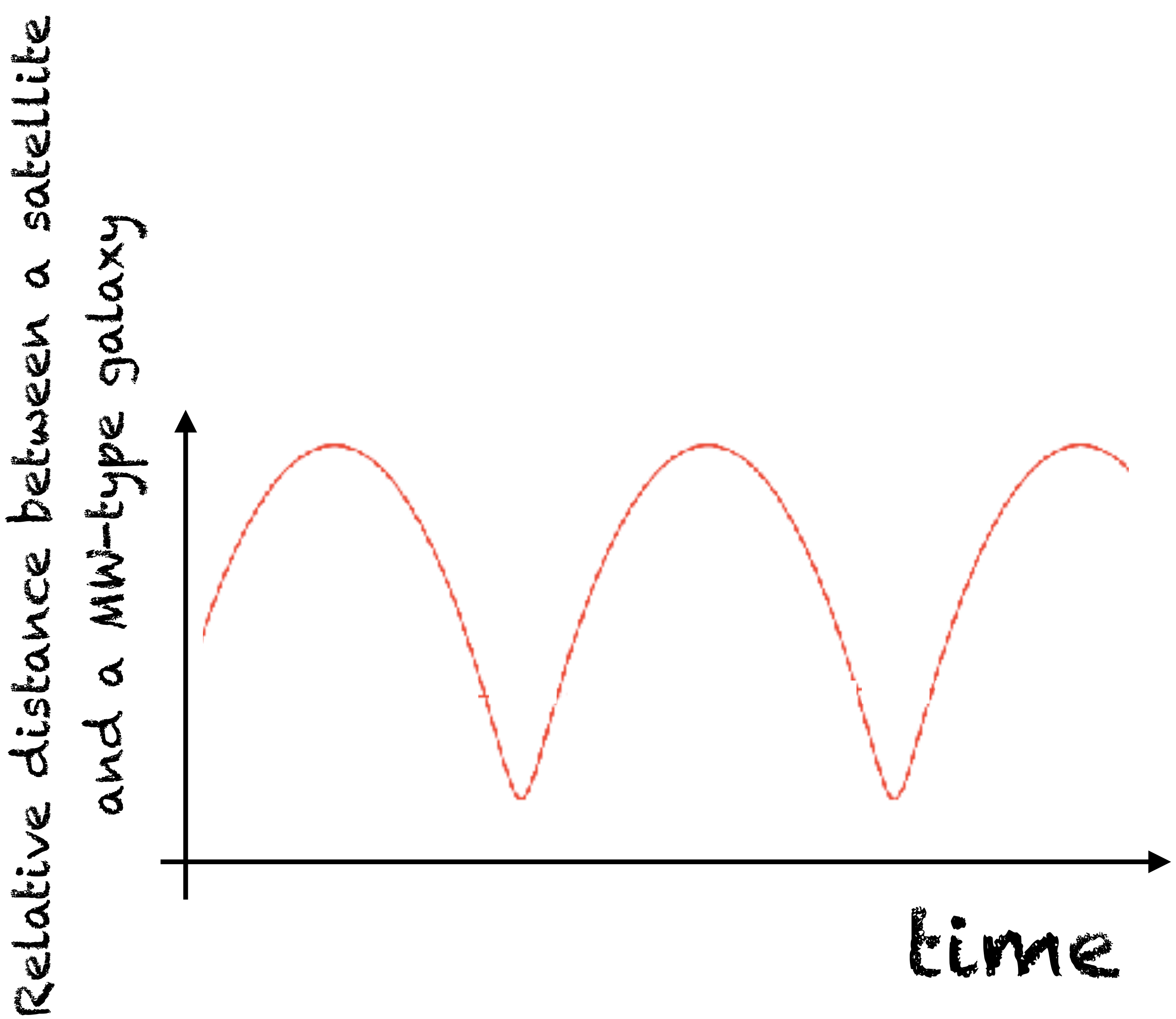
# SOME ASSUMPTIONS IN THE MODELS SO FAR ...

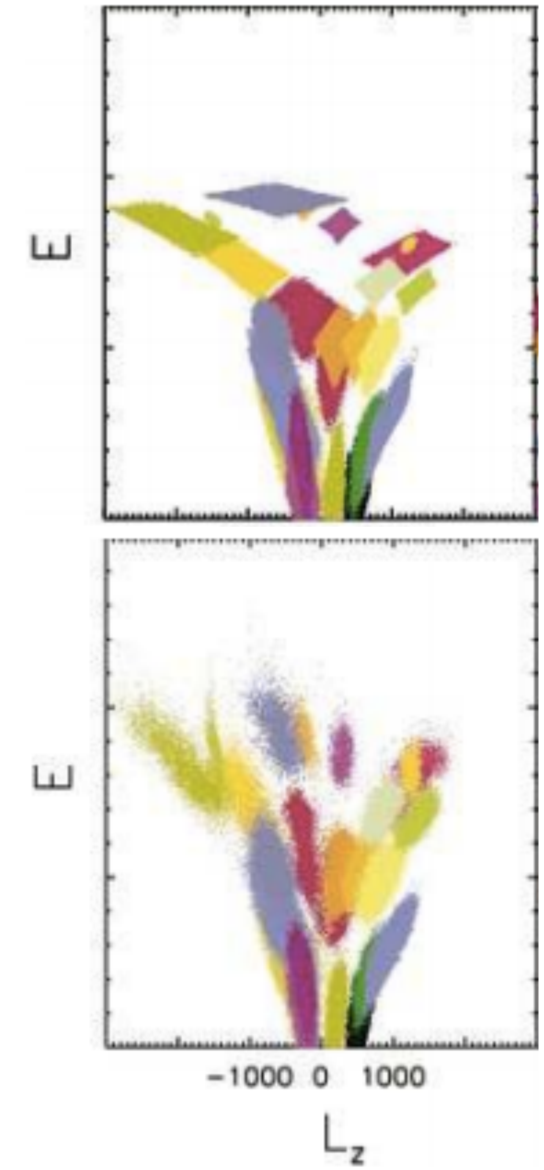
1. In most of the models, dynamical friction exerted on the satellite by the MW-type galaxy is not taken into account.
Energy and angular momentum of the centres of mass of the satellites are thus necessarily conserved,
independently on the mass of the accreted satellite.

2. In-situ stars usually either not taken into account in the modeling and/or analysis, or their distribution is assumed to be smooth both in configuration and velocity spaces.

Both these assumptions are critical

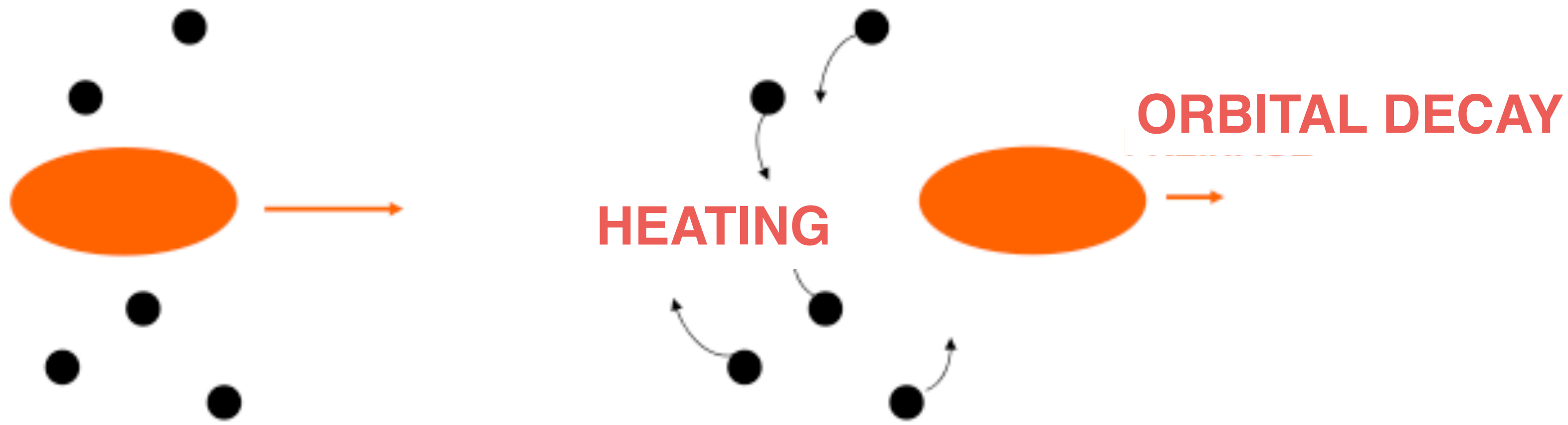
# THE EFFECT OF DYNAMICAL FRICTION



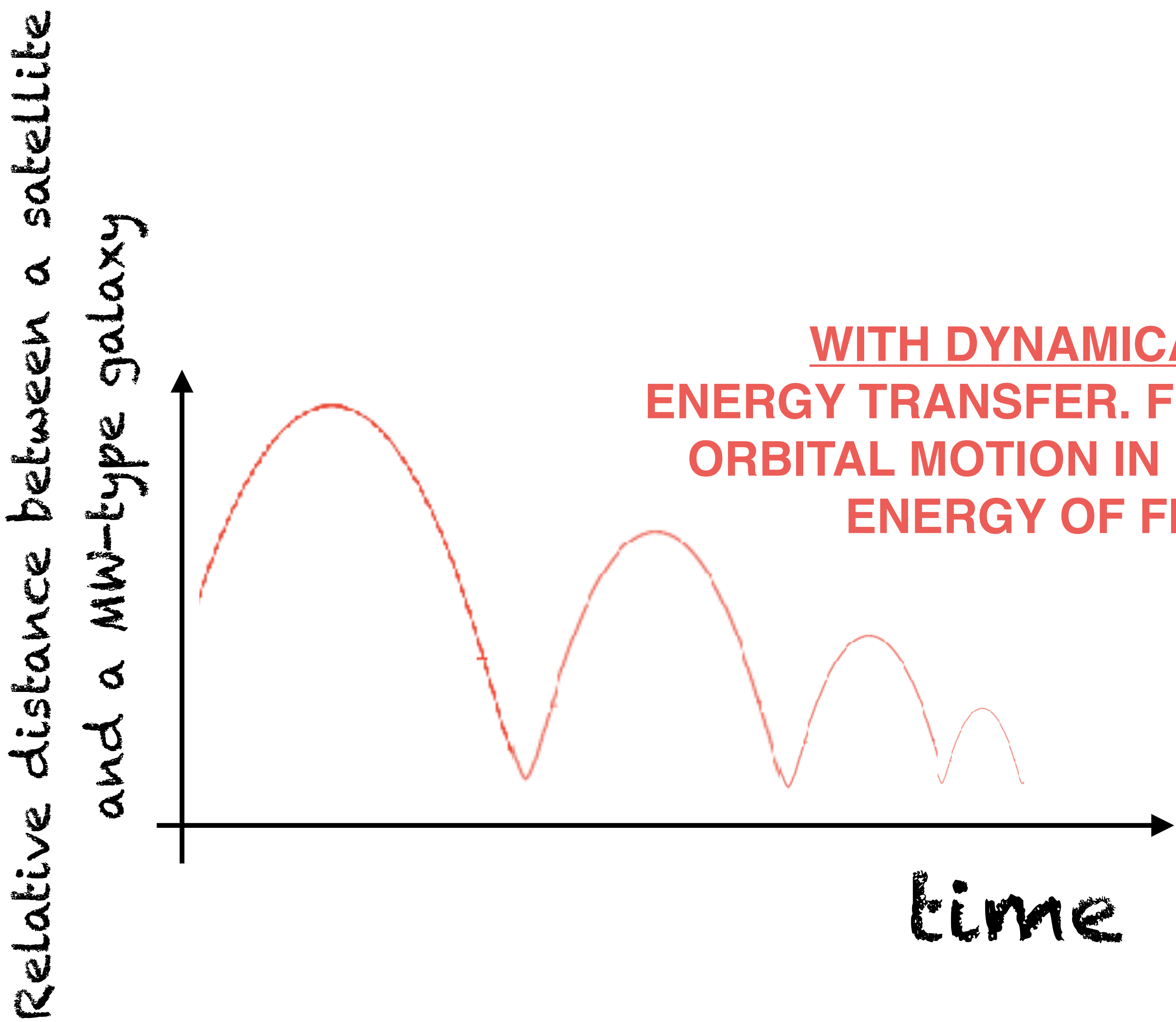




**<u>WITHOUT DYNAMICAL FRICTION :</u>**
**NO ENERGY TRANSFER. THE SATELLITE WILL KEEP OSCILLATING BETWEEN A PERICENTRE AND AN APOCENTRE, AND ITS ORBITAL ENERGY WILL STAY CONSTANT**

# THE EFFECT OF DYNAMICAL FRICTION




**<u>WITH DYNAMICAL FRICTION :</u>**
**ENERGY TRANSFER. FROM THE SATELLITE ORBITAL MOTION IN INTERNAL KINETIC ENERGY OF FIELD STARS.**



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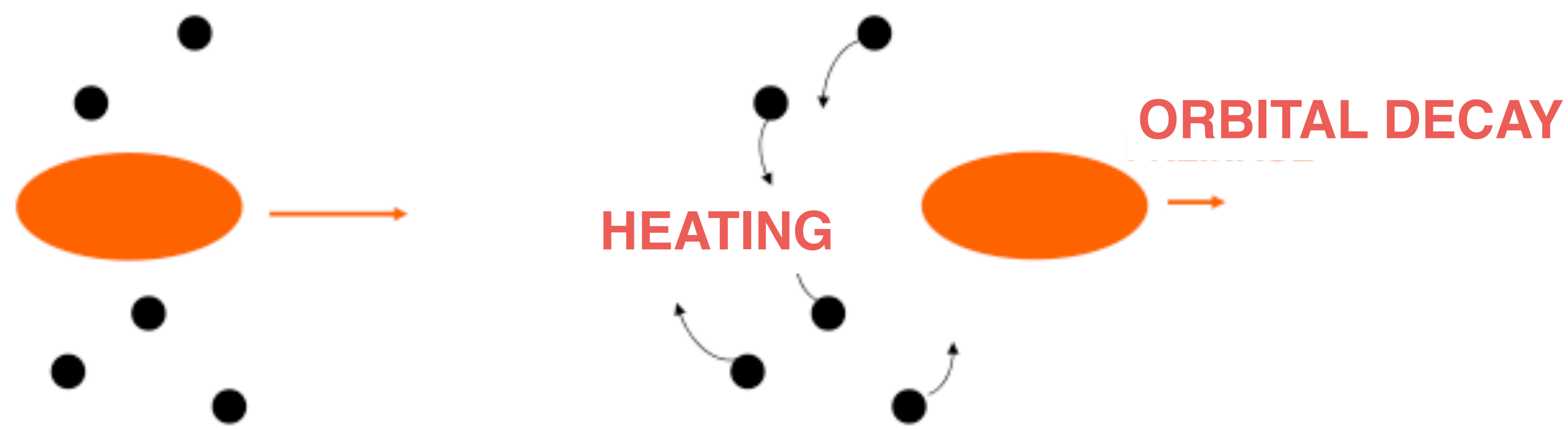


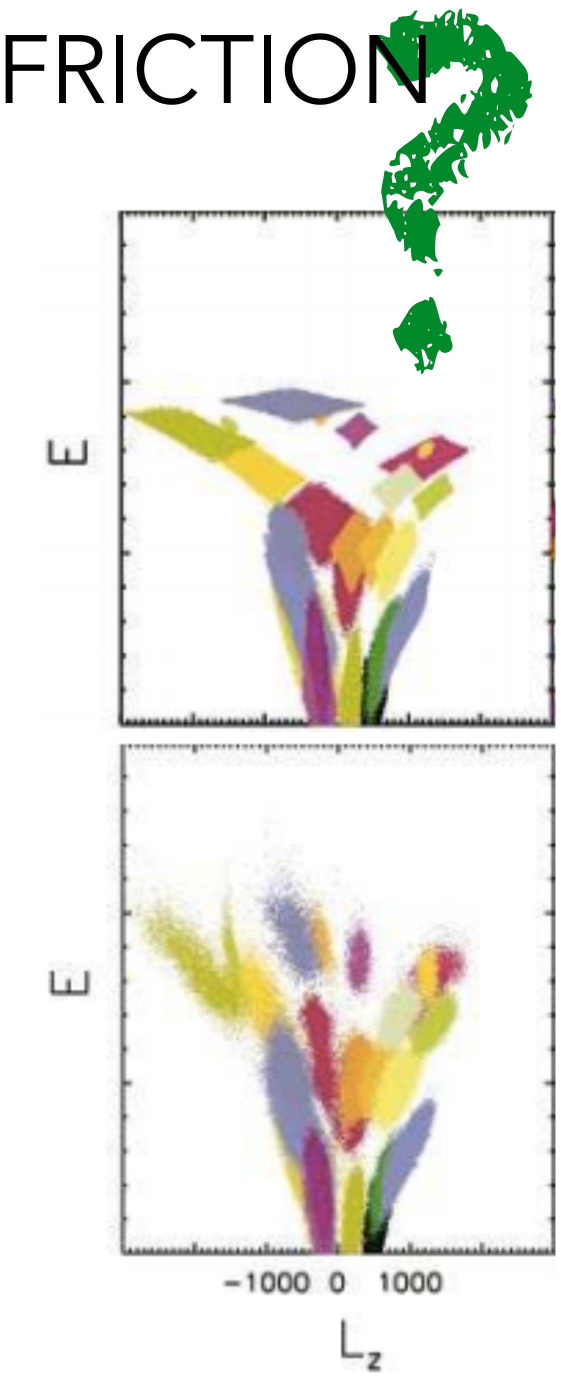


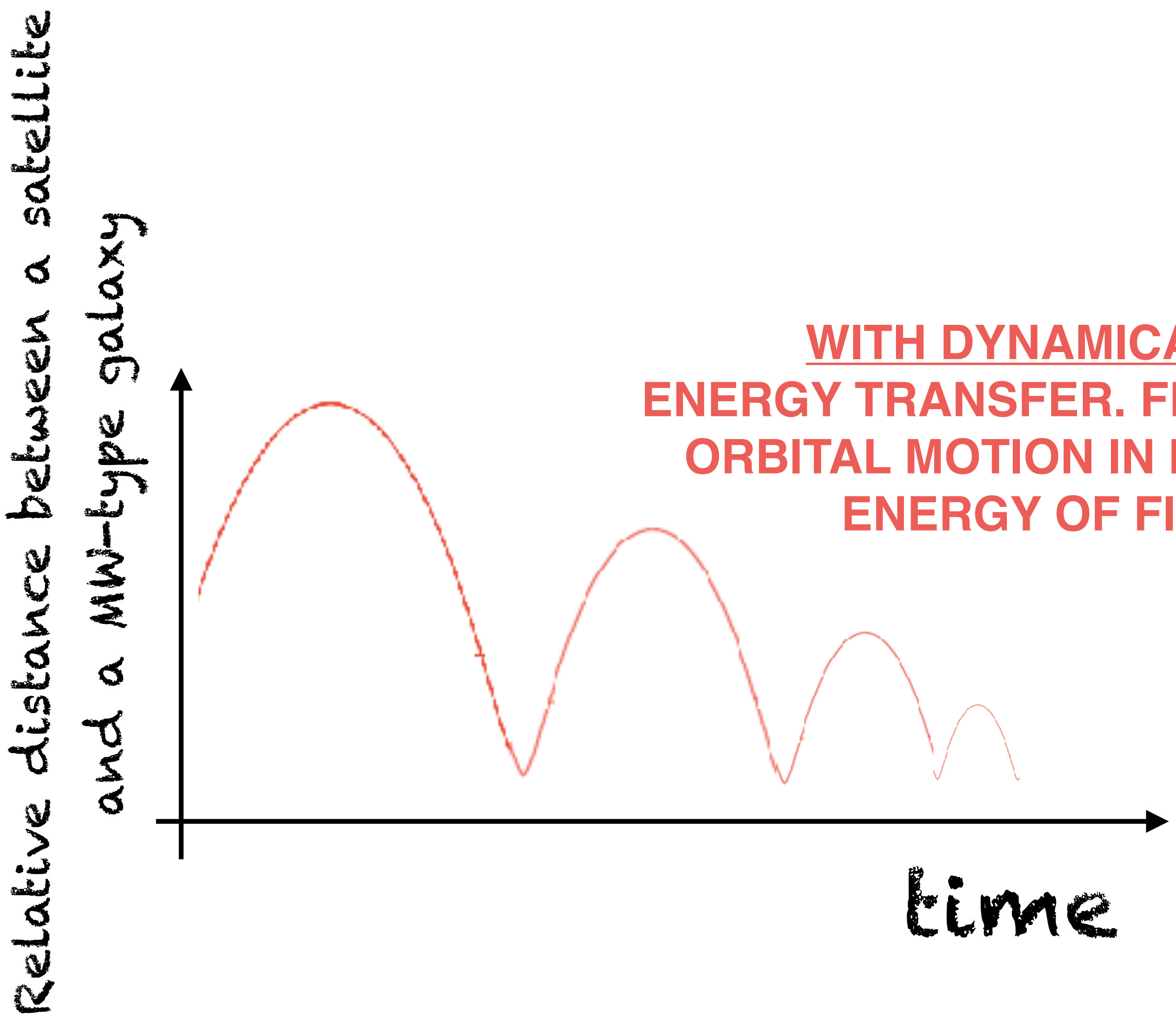


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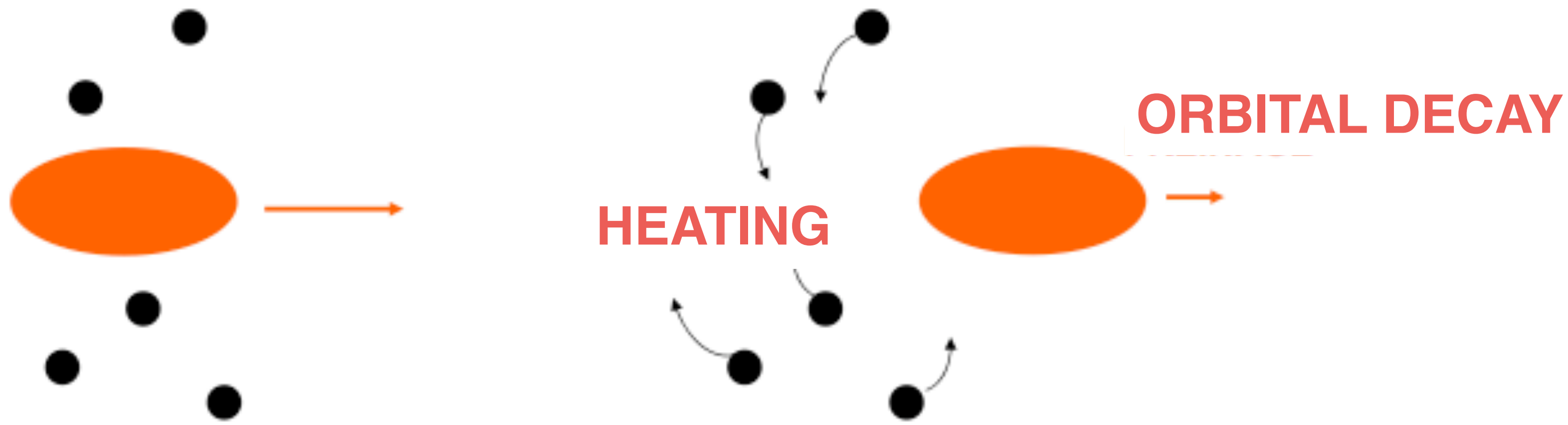


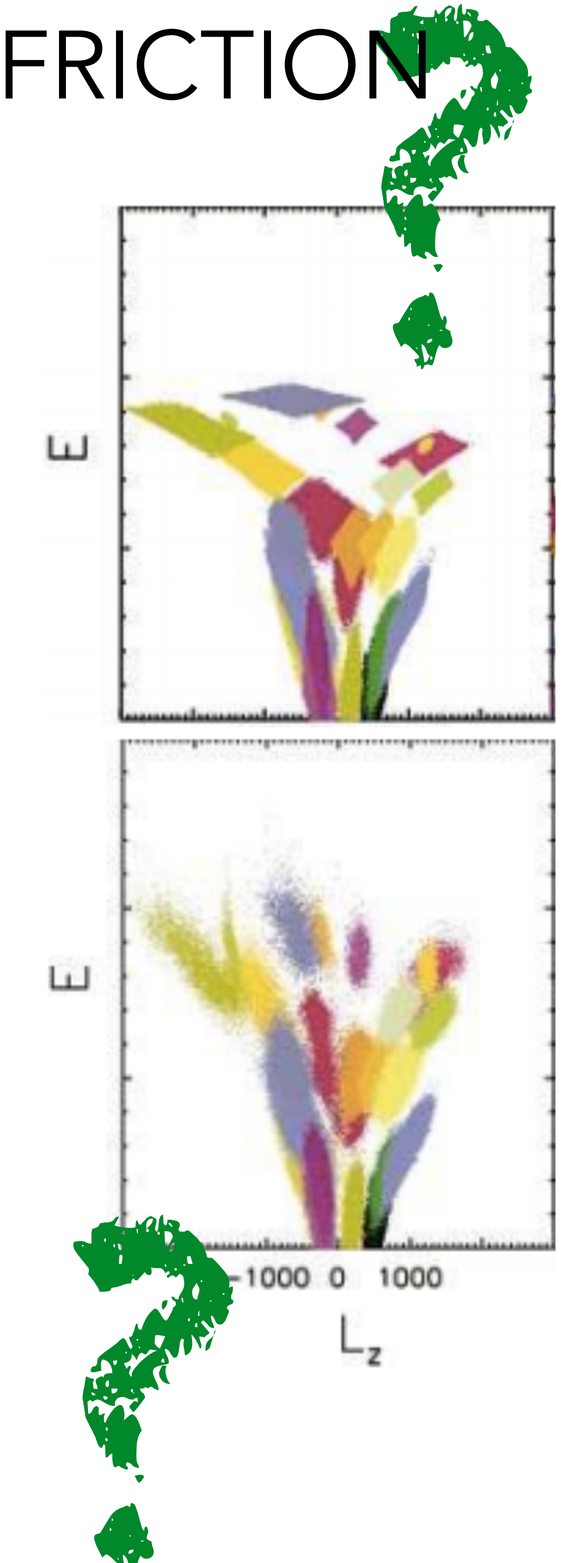


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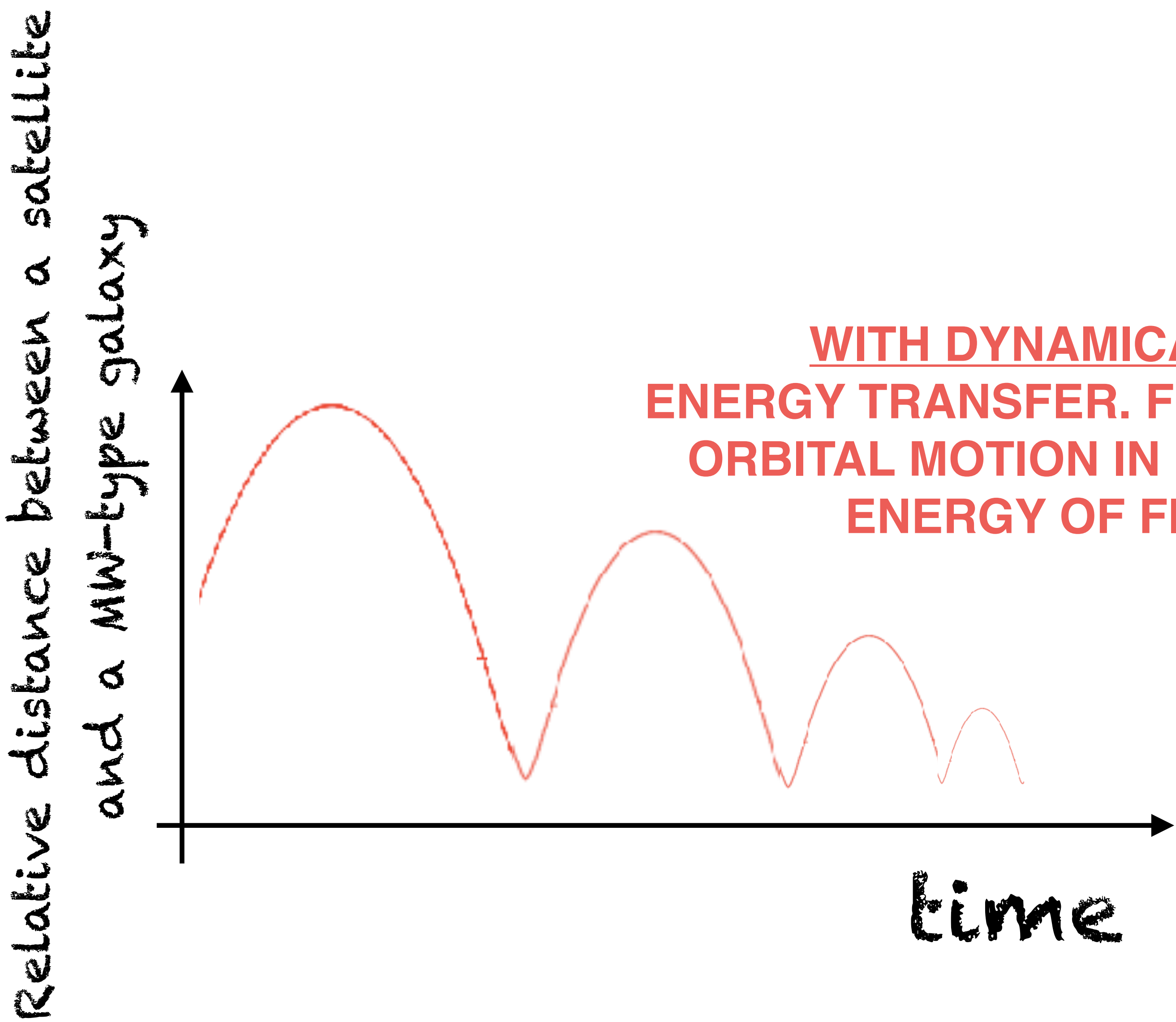



Also : how do in-situ stars redistribute in those spaces ?

# SOME WORDS ON THE SIMULATIONS

In all simulations,
**the MW type galaxy is modeled with 25 000 100 particles** :
20M in stars redistributed in a disc, 5M in dark matter.
A population of 100 thick disc globular clusters, modeled as point masses, is also added.

**Each satellite has a mass which is 1/10 of the mass of the MW-type galaxy** (Read et al 2008, Deason et al 2016, and references in those papers), and its own population of 10 globular clusters.

**We run three simulations, where the MW-type galaxy accretes respectively 1, 2 or 4 satellites over a time interval of 5 Gyr.**

Some additional simulations have been run to study the accretion of less massive satellites (mass ratio 1:100).

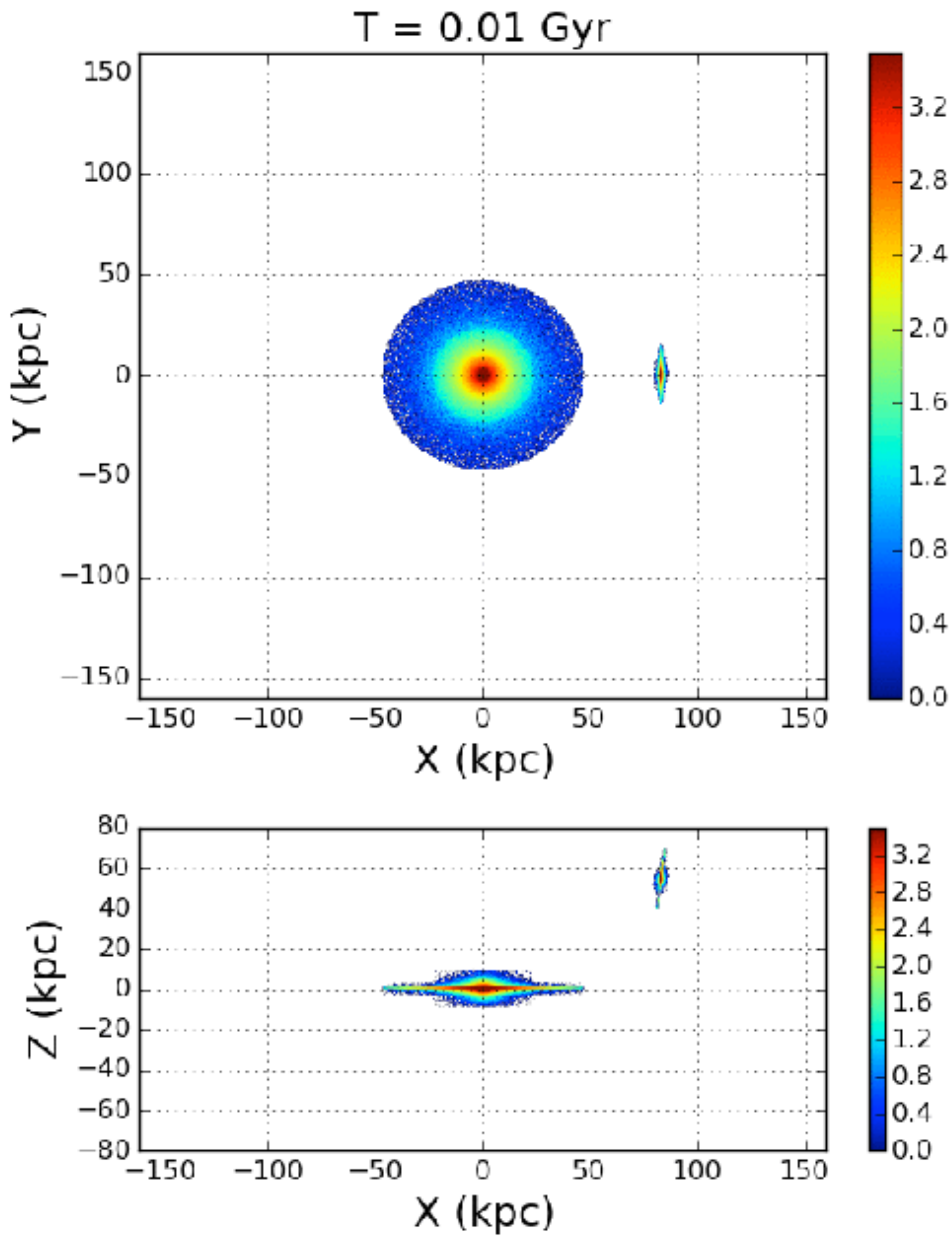
# SOME NOMENCLATURE

**In-situ stars :** stars that are in the disc of the MW-type galaxy before the accretion event(s).

**Accreted stars :** stars deposited in the MW-type galaxy from one or several satellite galaxies

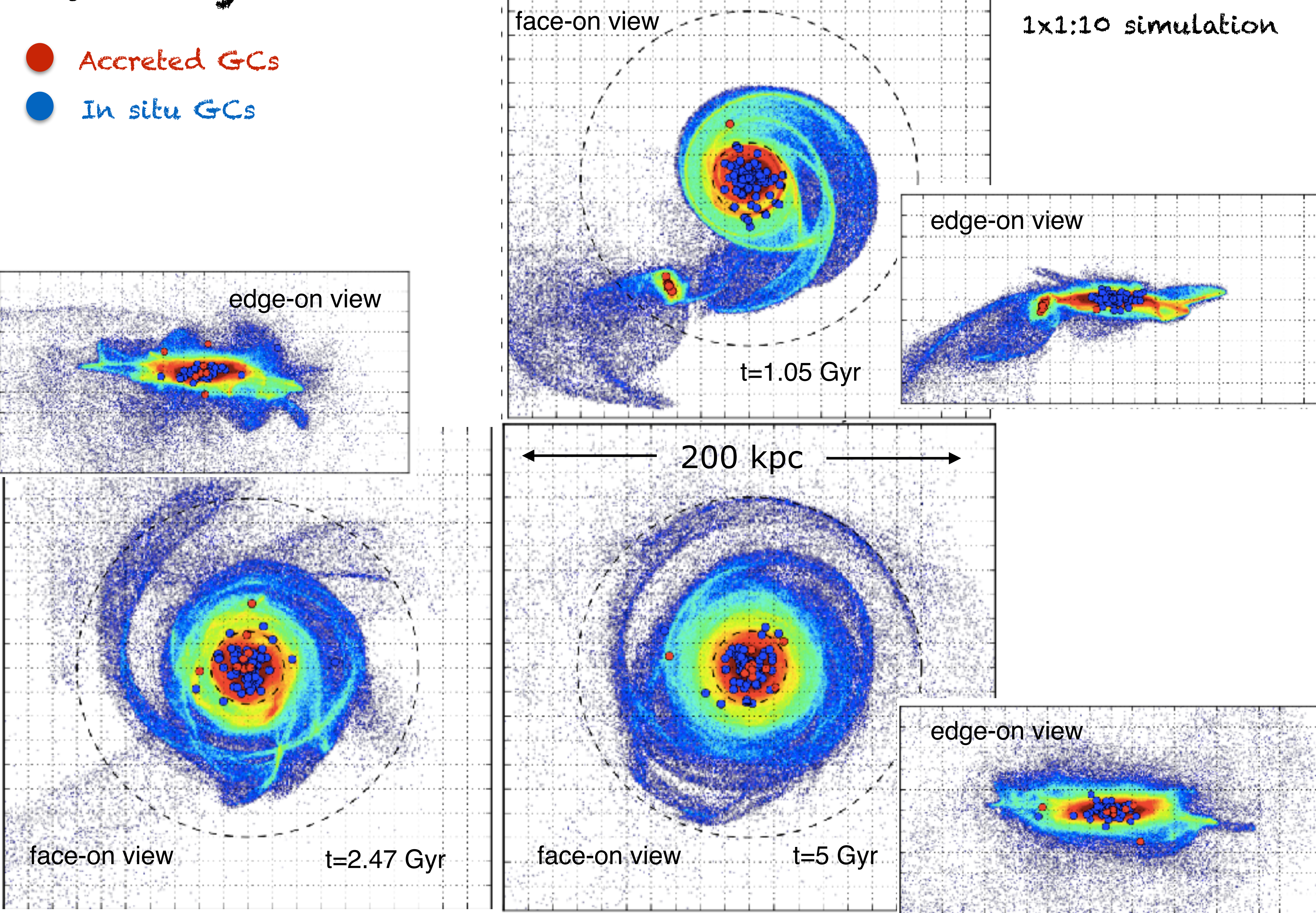
**Halo.** In these simulations initially. there is no stellar halo. The stellar halo forms naturally, as a result of the interaction(s), through two channels :

1. heating of the pre-existing MW-disc
2. deposit of accreted material




Credit : I. Jean-Baptiste, PhD Thesis

# A gallery of accretions



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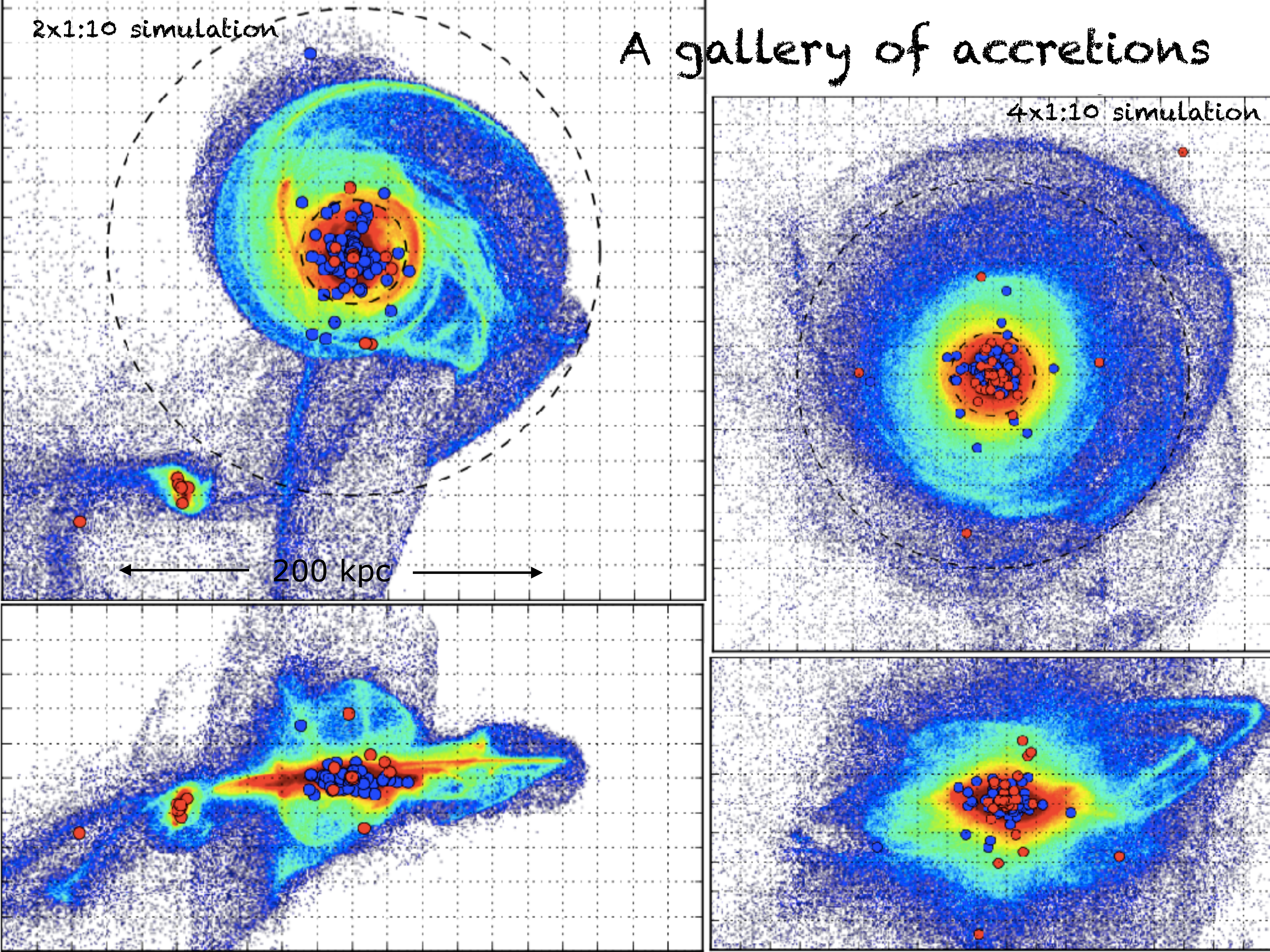
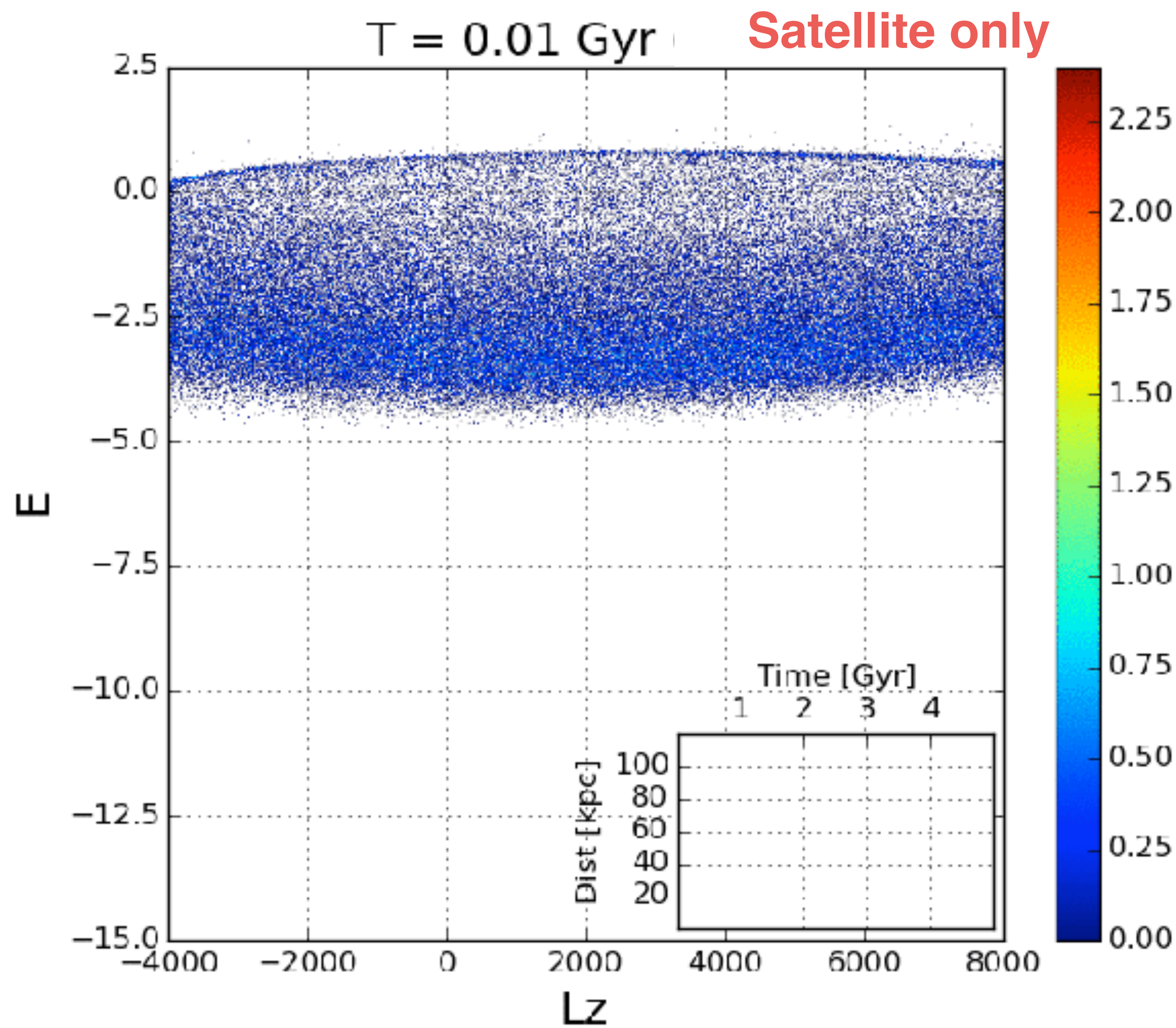


# ON THE COHERENCE OF ACCRETED STRUCTURES IN THE E-LZ SPACE

If dynamical friction has time to act on the satellite before it becomes a gravitational unbound set of stars, ***satellite stars loose their coherence in the E – Lz space***:

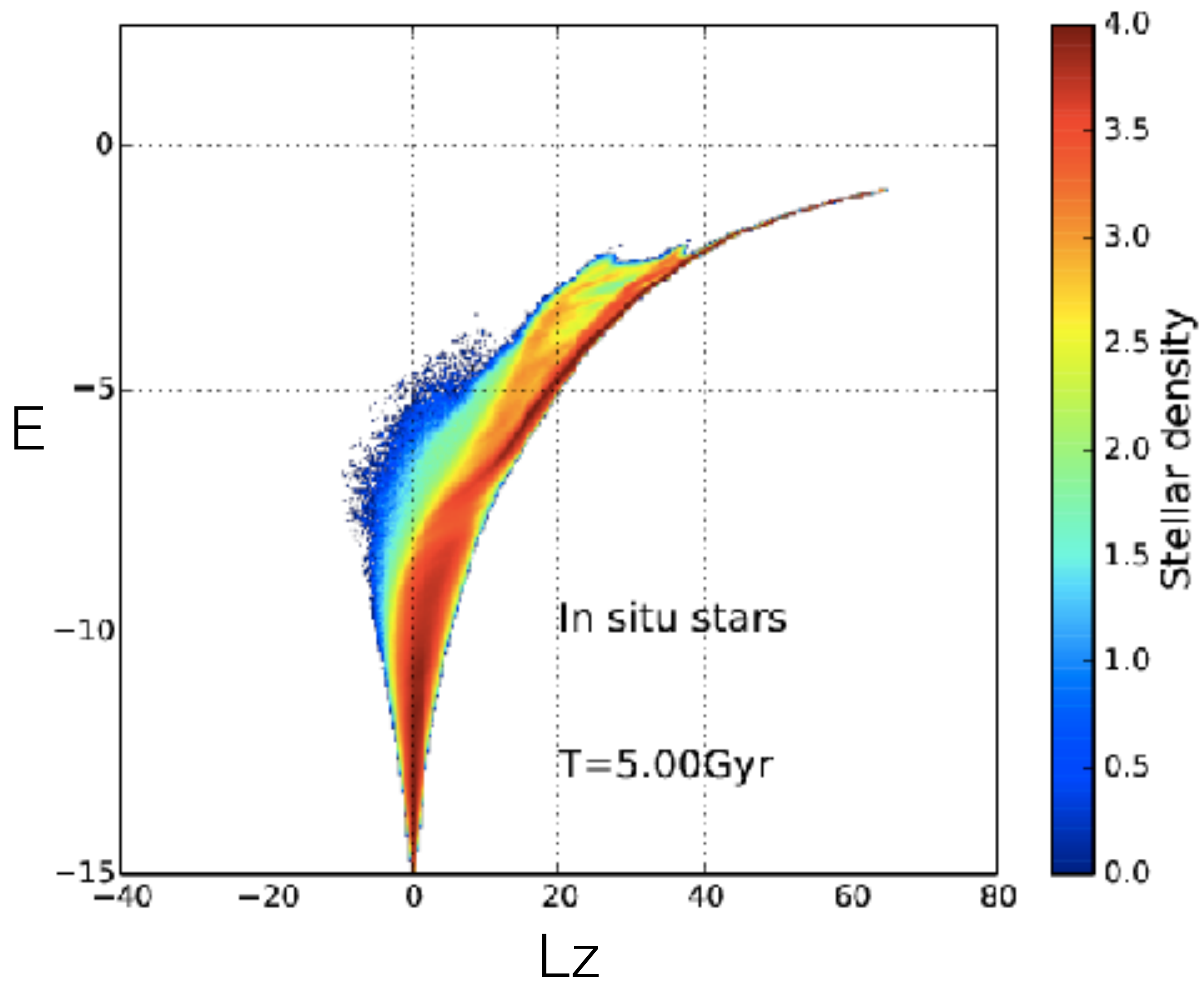
a satellite gives rise to several clumps, whose number and density depend on the number of passages the satellite experienced around the main galaxy, and on the mass loss it experienced at each passage.




Credit : I. Jean-Baptiste, PhD Thesis

# IN-SITU STARS IN THE E-Lz space

Galaxy evolved isolated

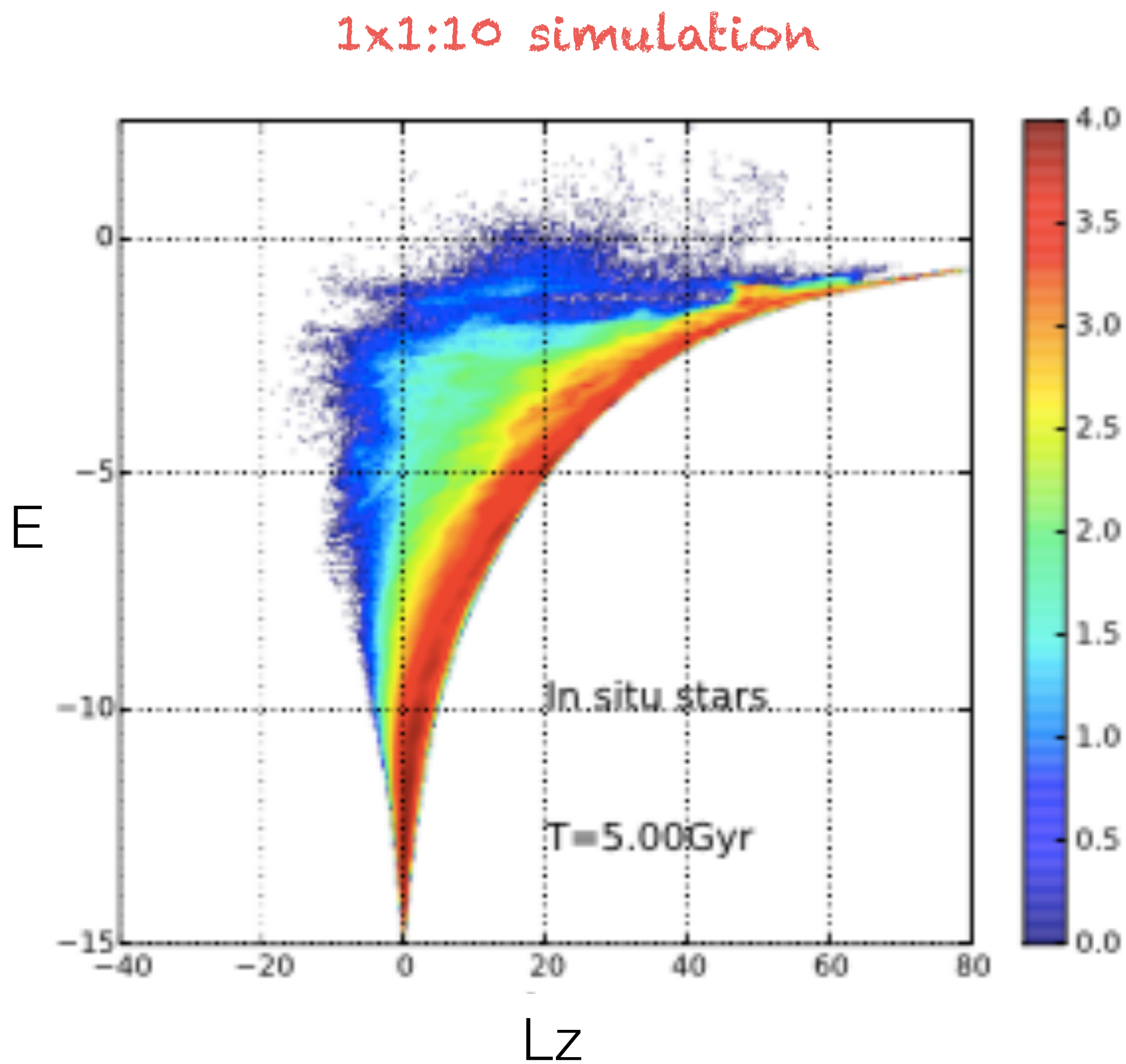



**Heating of the stellar disc.**
The higher the number of accreted satellites (and thus the larger the accreted mass),

the broader the distribution of in-situ stars in $E - Lz$ space is.

Jean-Baptiste et al, 2017 A&A

# IN-SITU STARS IN THE E-Lz space

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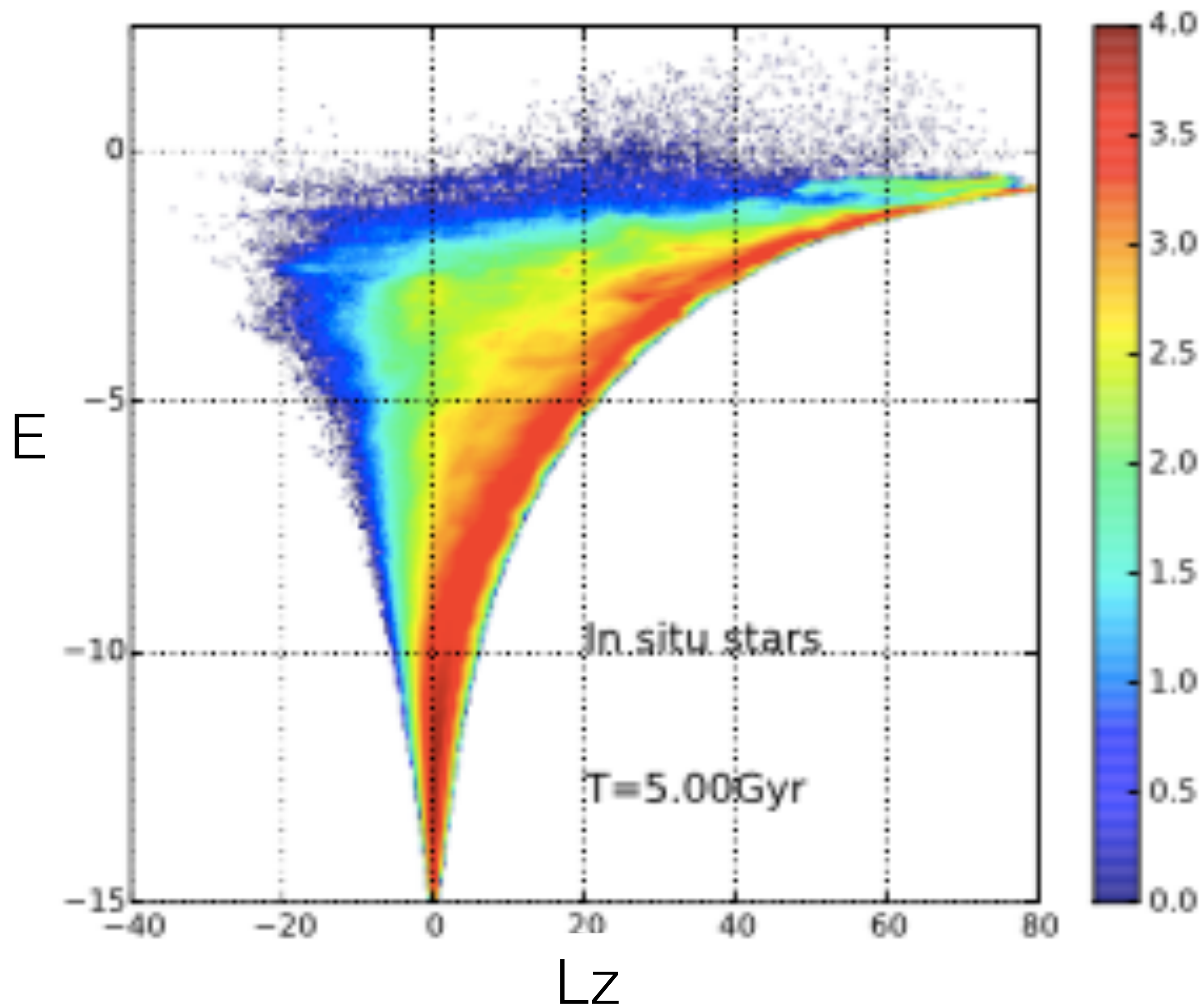
# IN-SITU STARS IN THE E-Lz space

2x1:10 simulation

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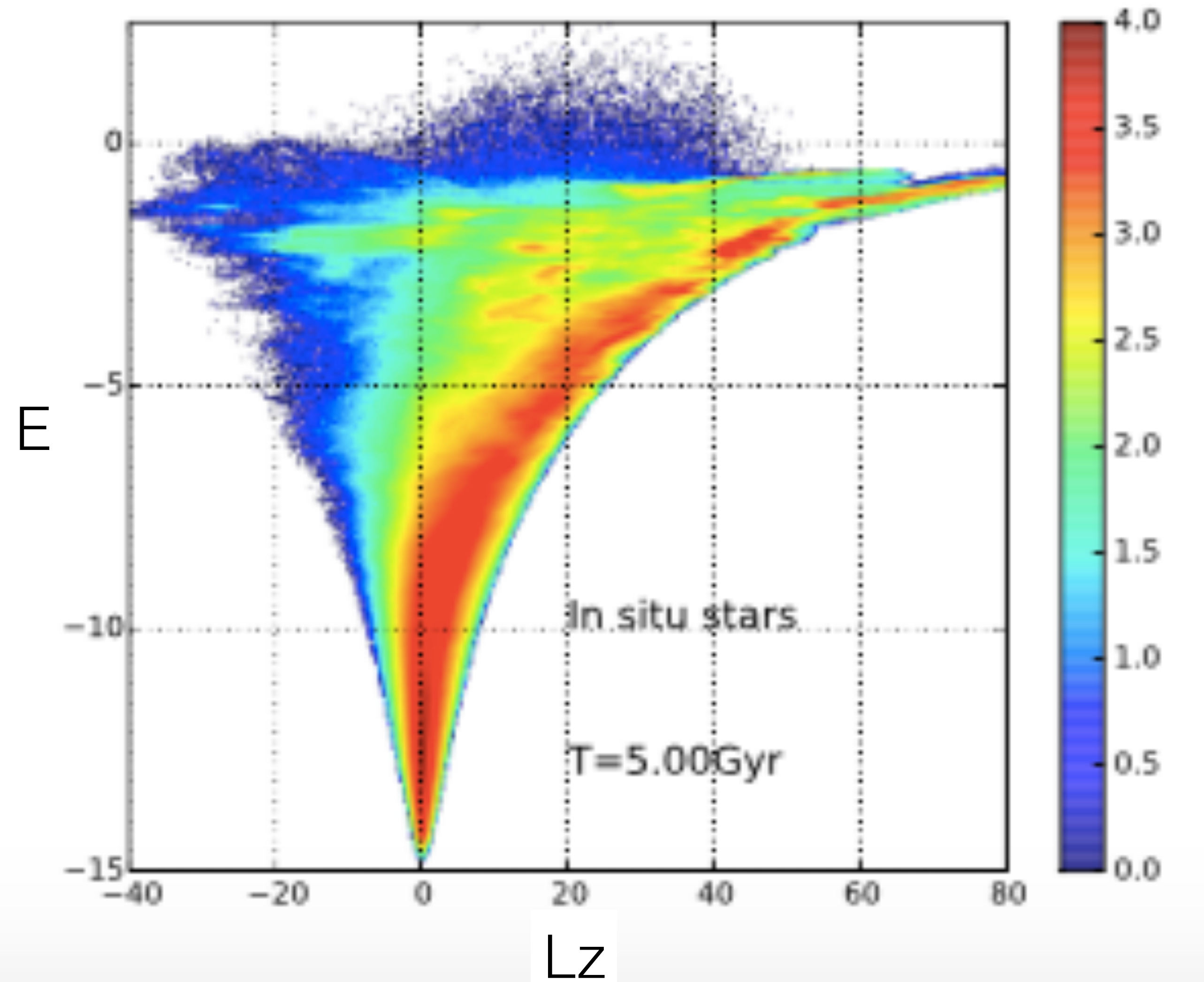
# IN-SITU STARS IN THE E-Lz space

4x1:10 simulation




**Heating of the stellar disc.**
The higher the number of accreted satellites (and thus the larger the accreted mass),

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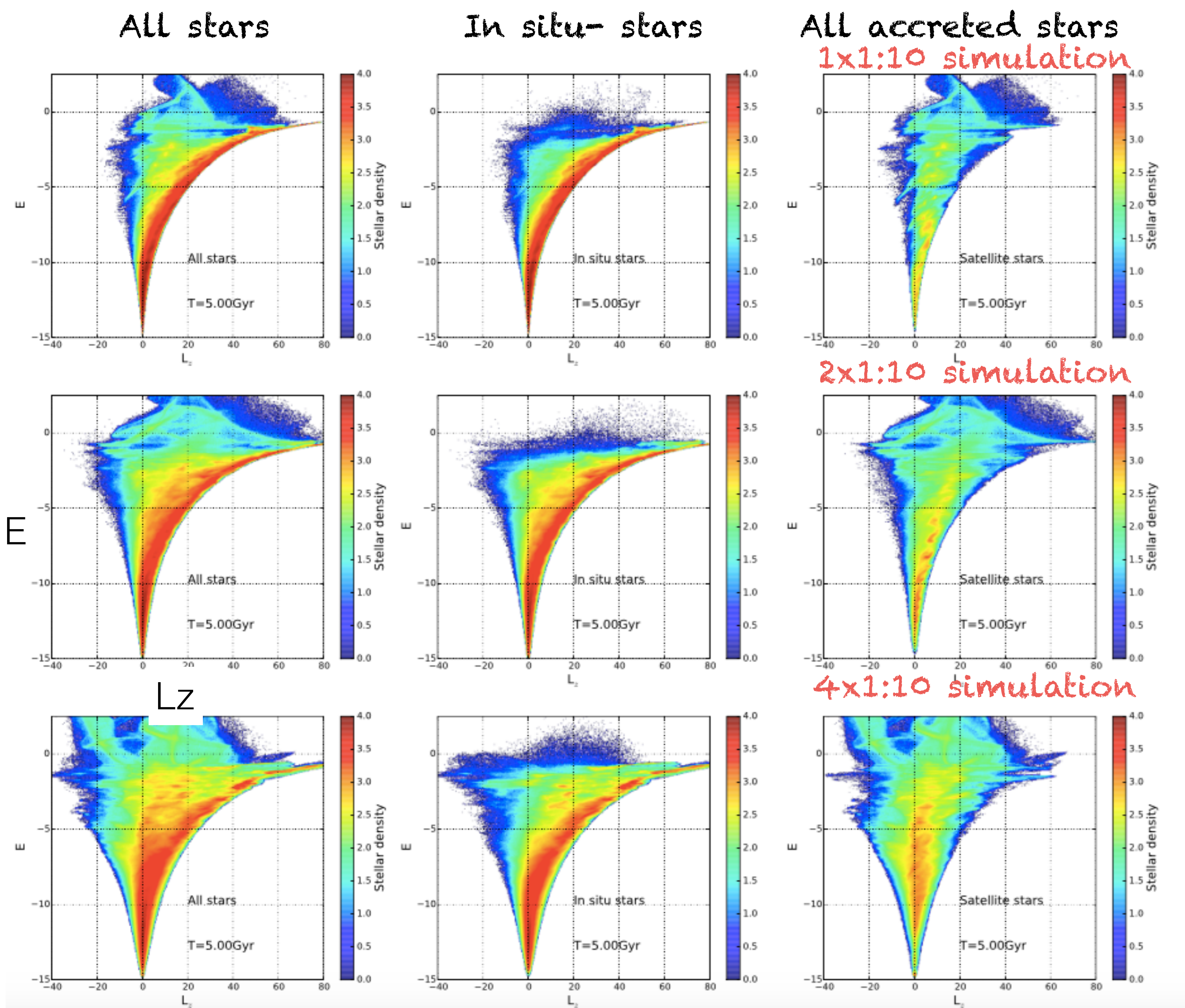
# IN-SITU & ACCRETED STARS IN THE E-Lz space




**Significant overlap of accreted and in situ stars**

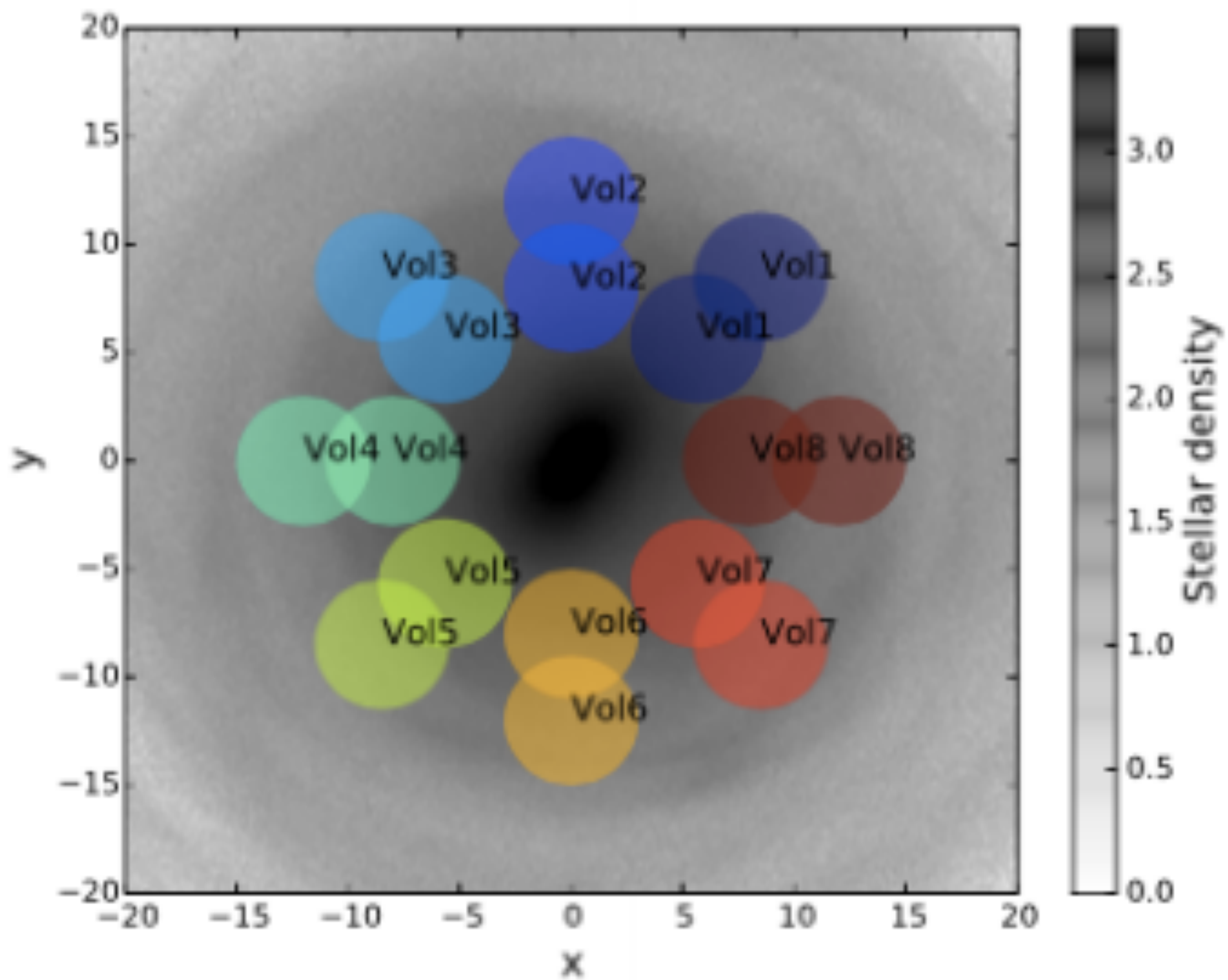
at the point that the space becomes hardly decipherable

**Lumpiness also in the in situ population**

Jean-Baptiste et al, 2017 A&A

# IN-SITU & ACCRETED STARS IN THE E-Lz space

Solar vicinity volumes



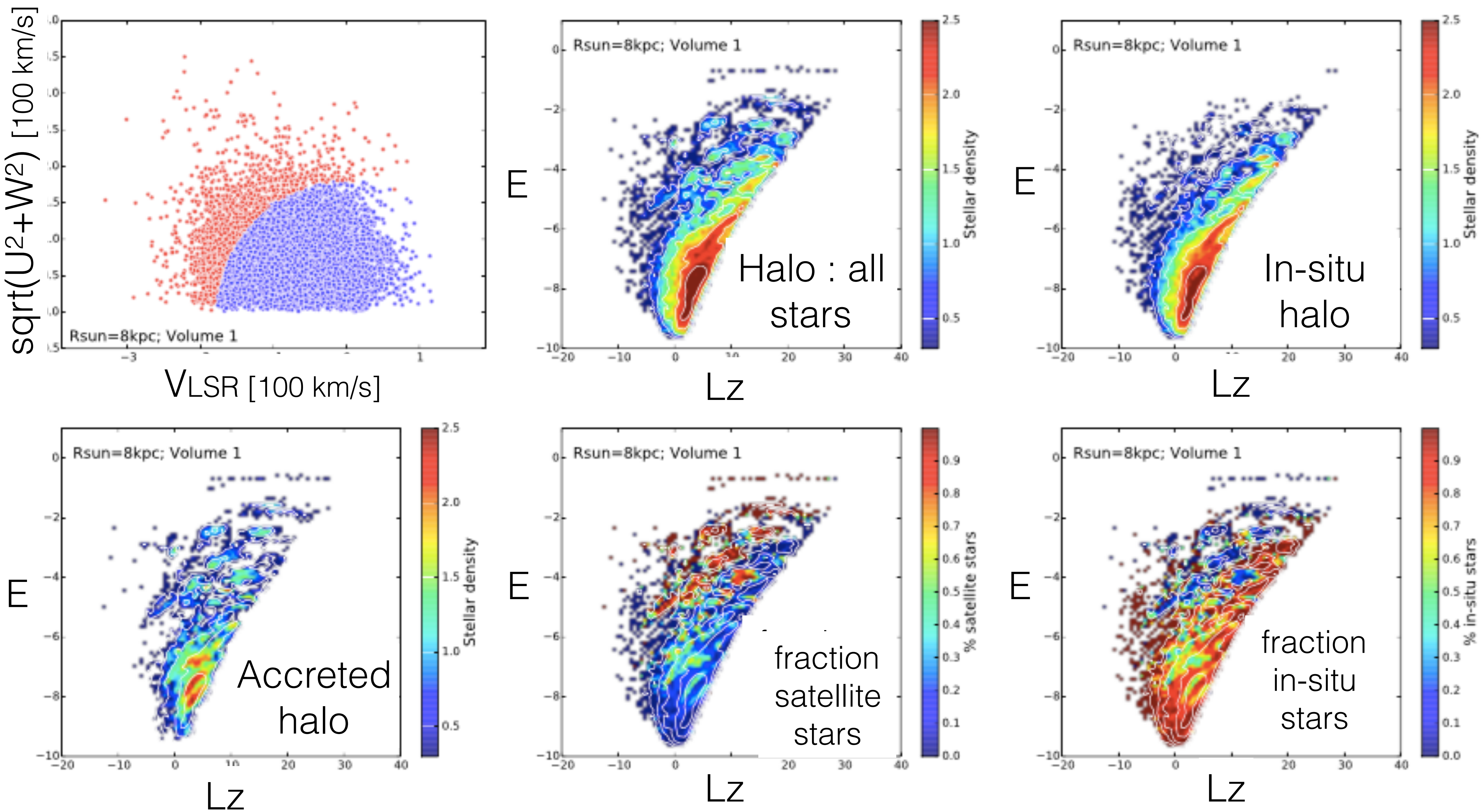

Each spherical volume has a radius of 3 kpc. Volume are located at 8 kpc and 12 kpc from the galaxy centre and are homogeneously distributed in azimuth.

The grey map in foreground is simply used to indicate the location of the volumes, for one of the simulations analyzed

# IN-SITU & ACCRETED STARS IN THE E-Lz space

Halo stars in a 3 kpc volume around the Sun

**1x(1:10) merger**

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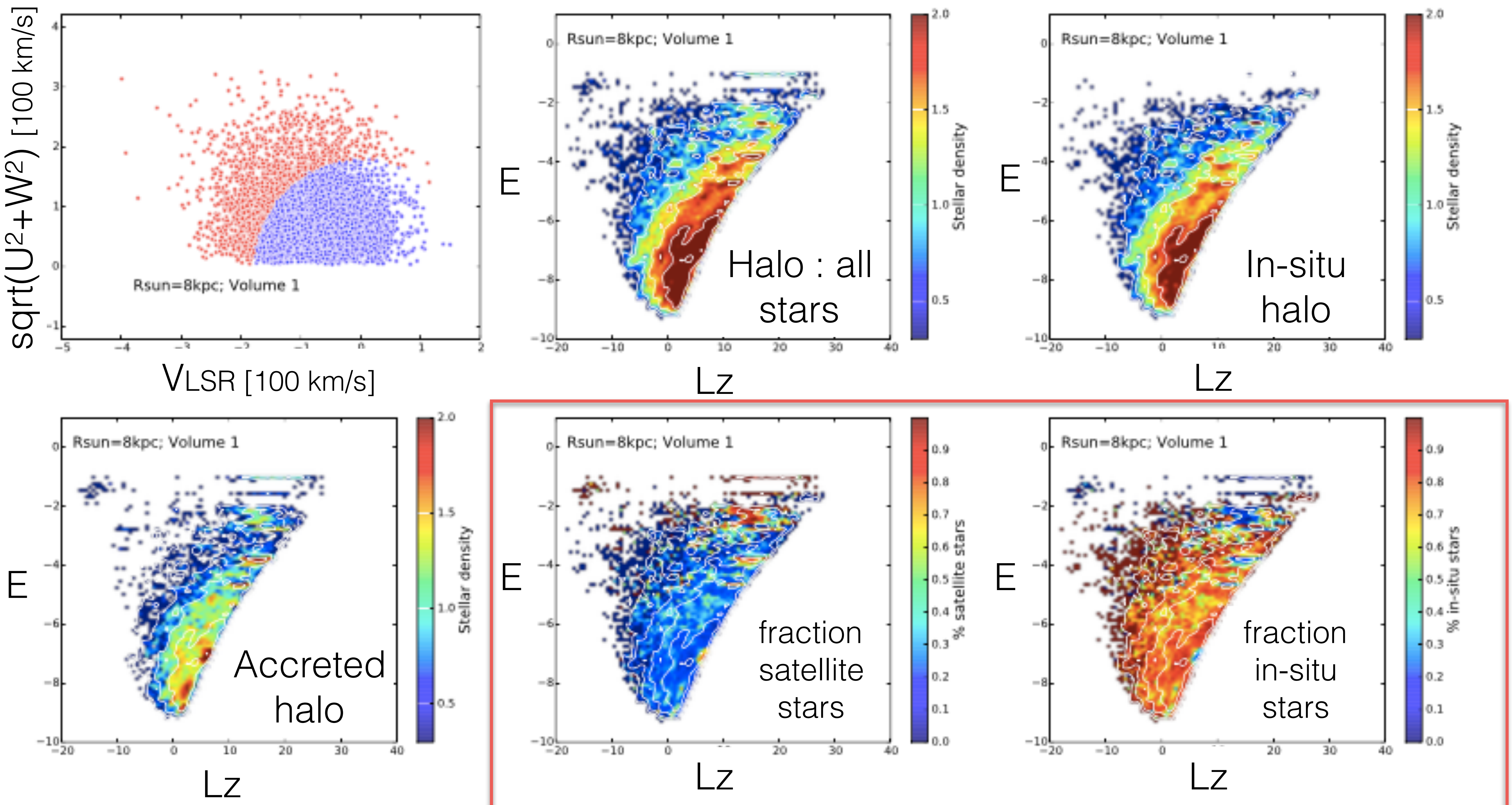
# IN-SITU & ACCRETED STARS IN THE E-Lz space

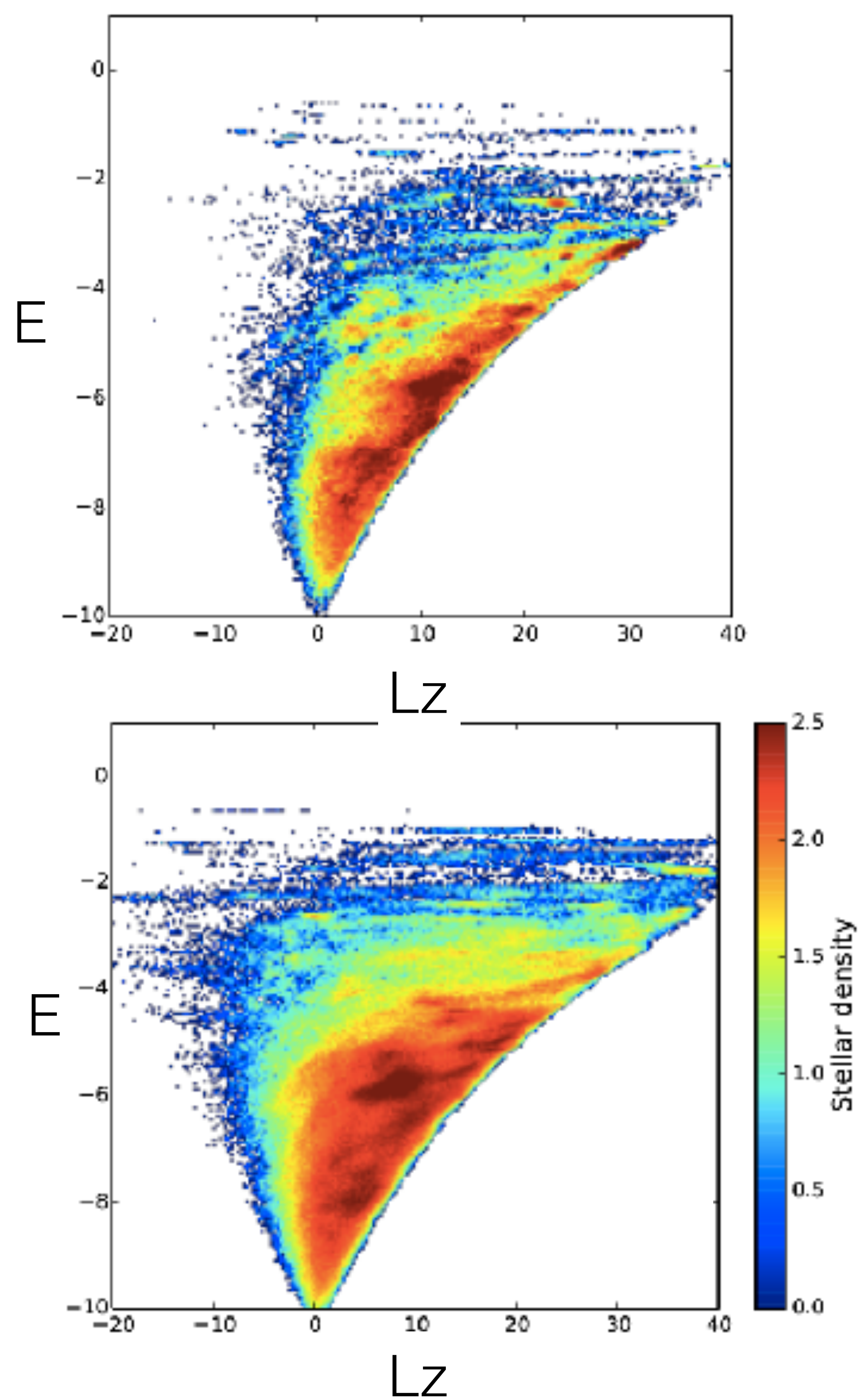
Halo stars in a 3 kpc volume around the Sun

**2x(1:10) merger**



# IN-SITU & ACCRETED STARS IN THE E-Lz space

A 10 kpc volume around the Sun



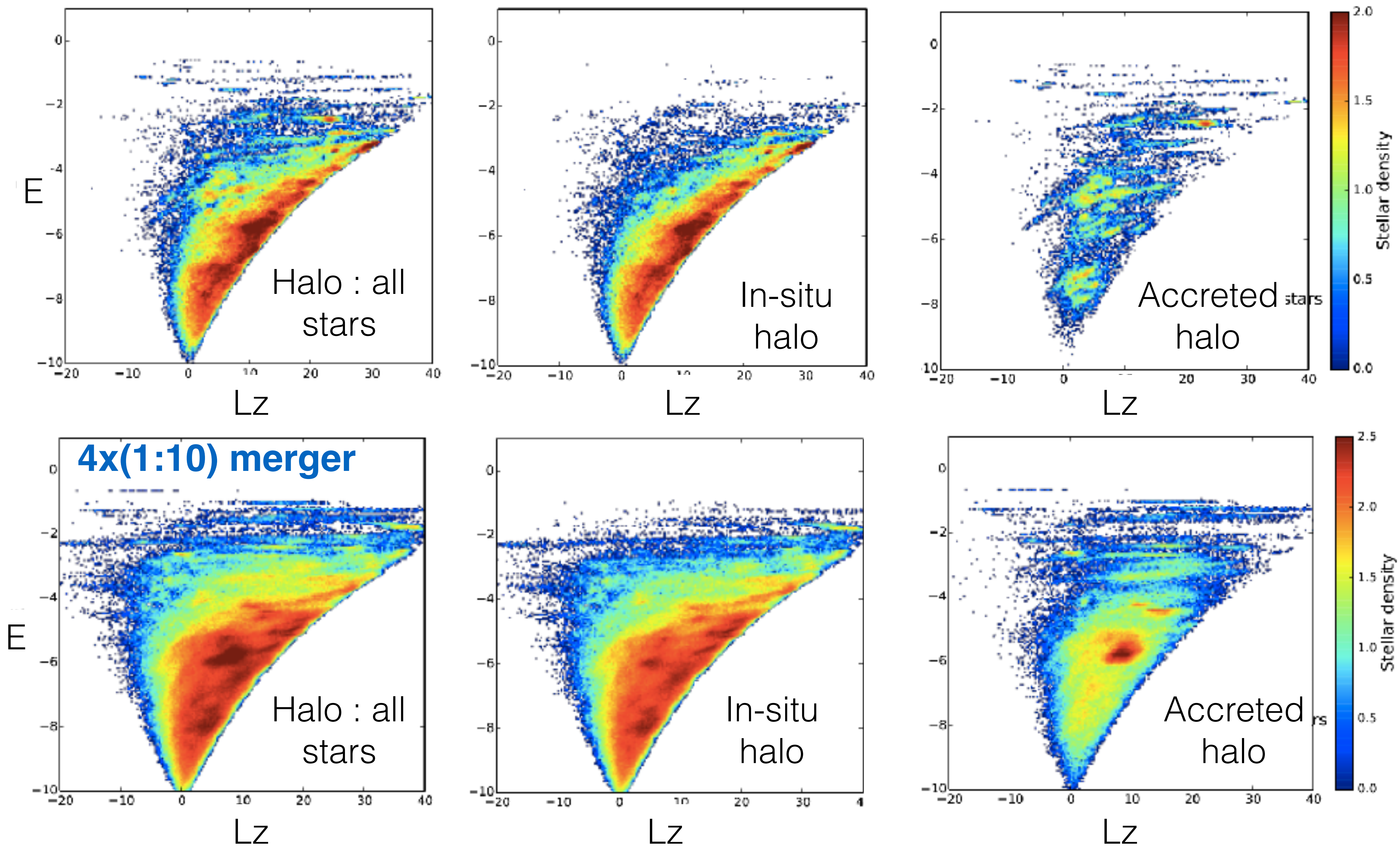

Where are the accreted stars in these plots ?
From how many satellites ? Which masses ?
Where are the in-situ stars ?

NB : Those shown on the left are ideal cases : no error on radial velocities, proper motions and parallaxes has been assumed, gravitational potential exactly known

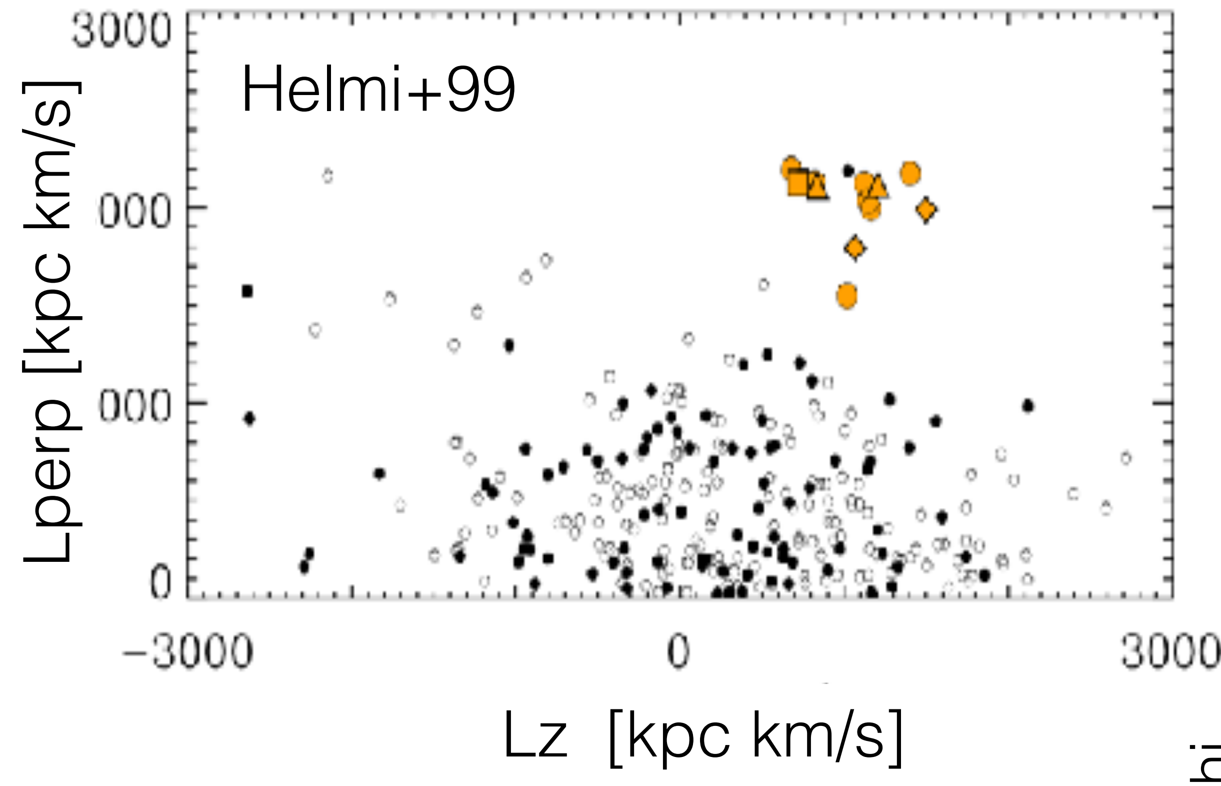
# IN-SITU & ACCRETED STARS IN THE E-Lz space

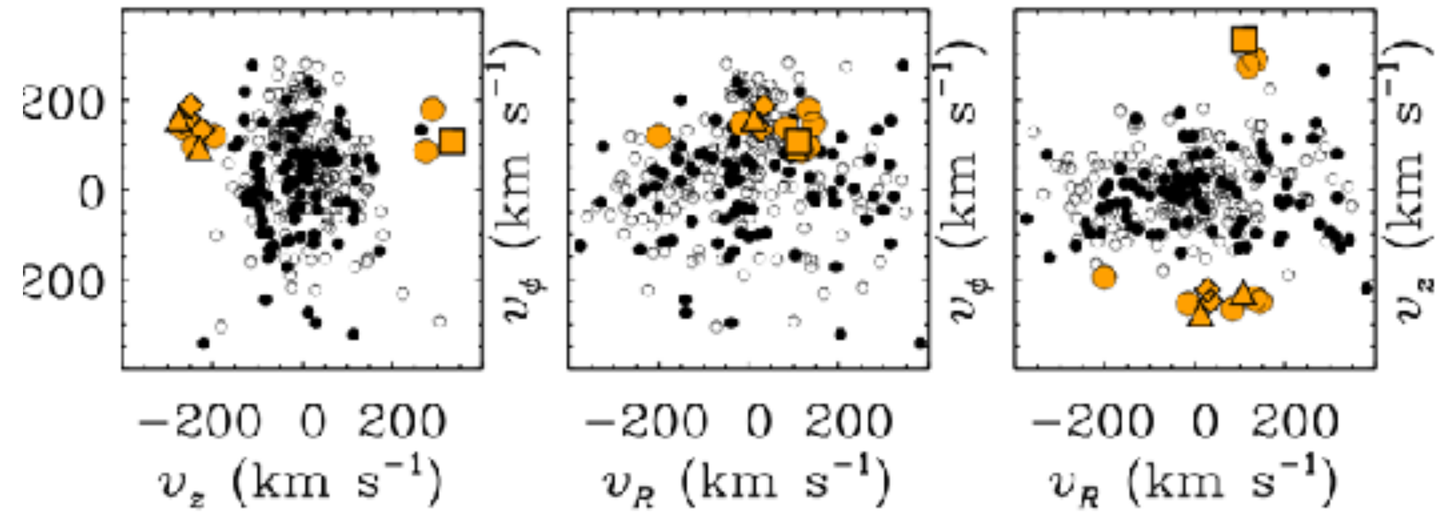
A 10 kpc volume around the Sun

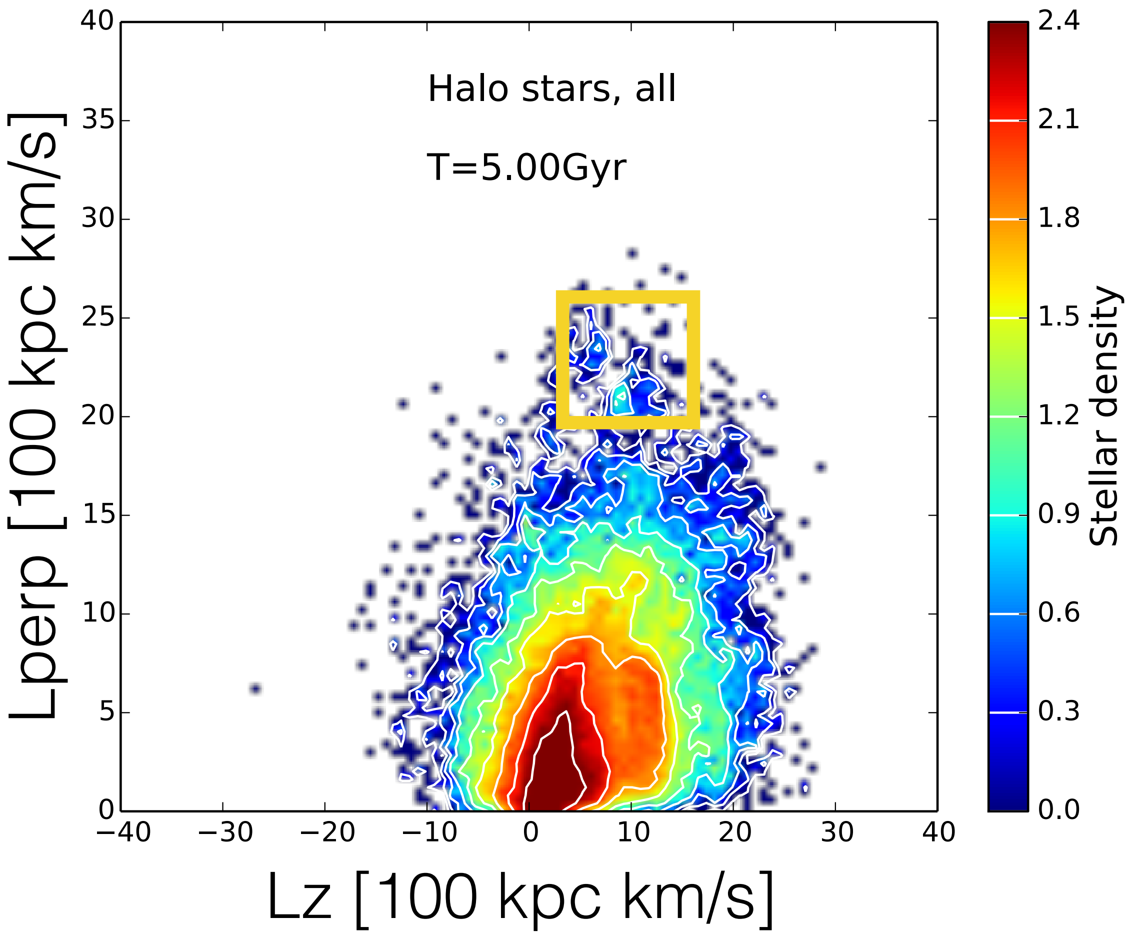
**2x(1:10) merger**

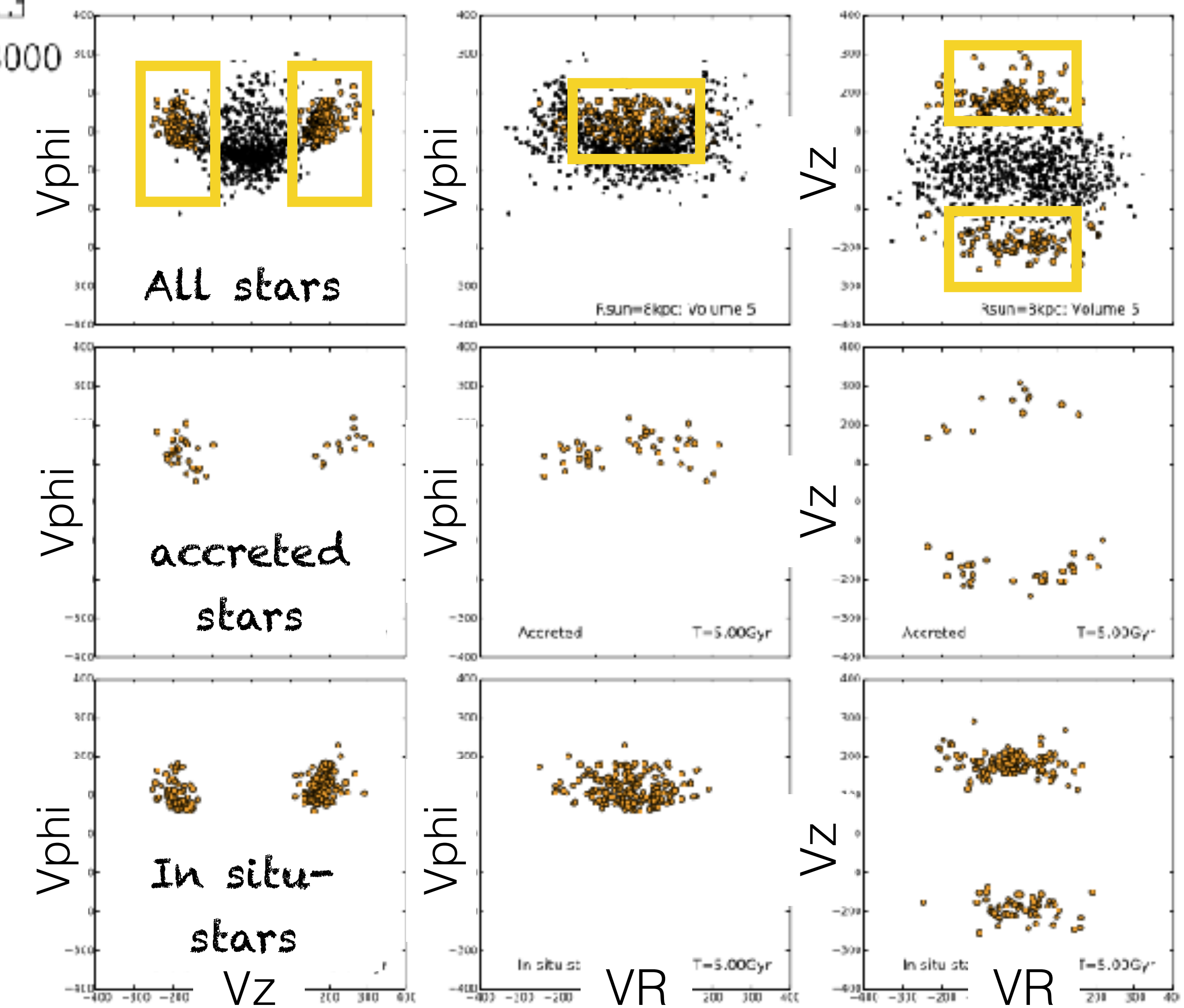


# IN-SITU & ACCRETED STARS IN ANGULAR MOMENTA space

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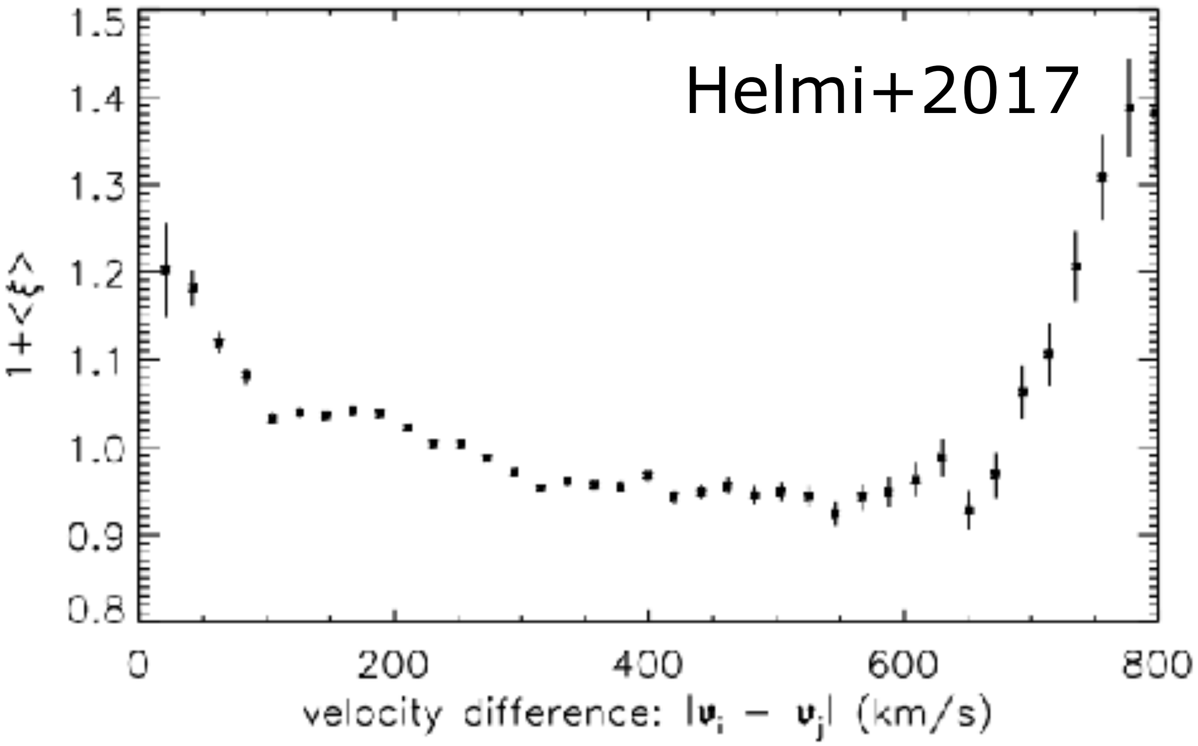
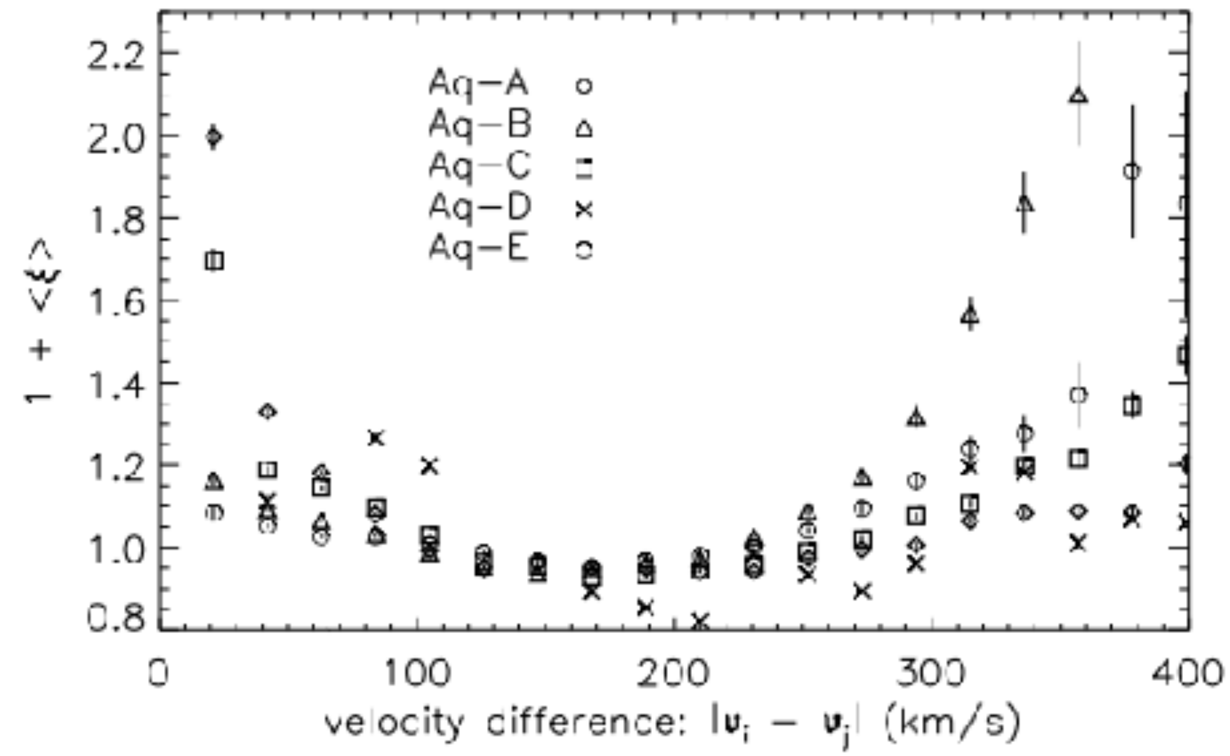
# VELOCITY CORRELATION FUNCTION

TGAS + RAVE



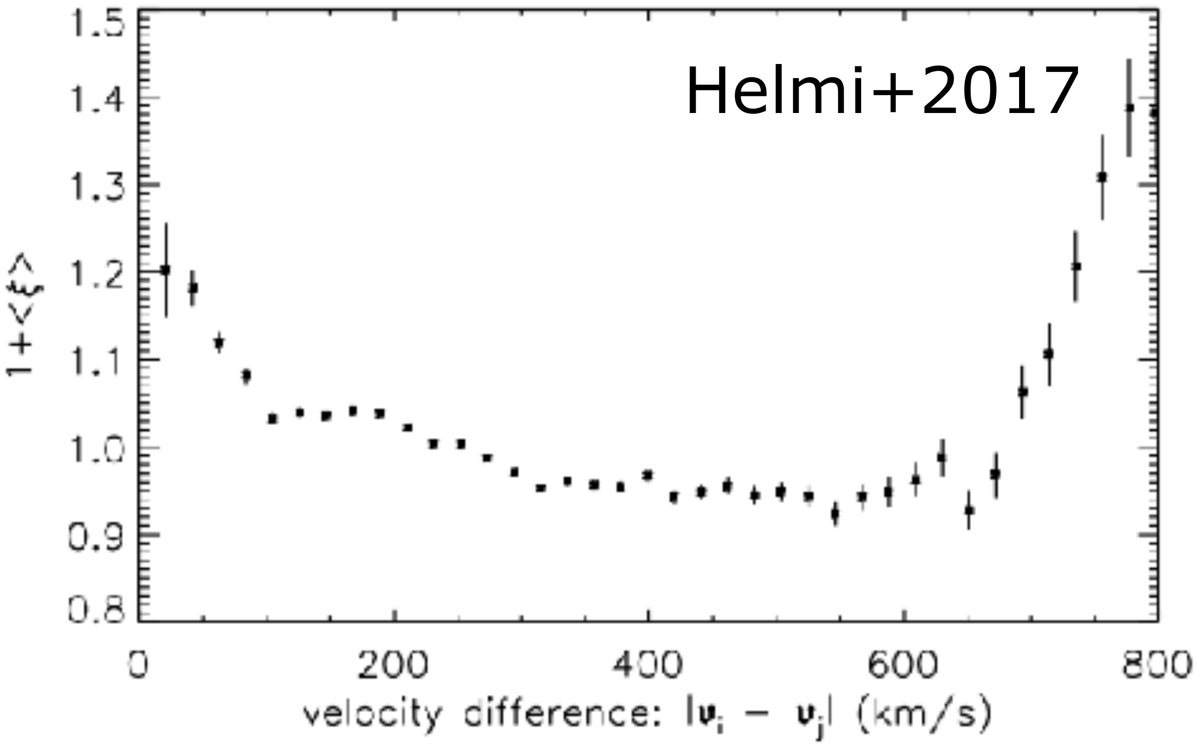

Cosmological simulations



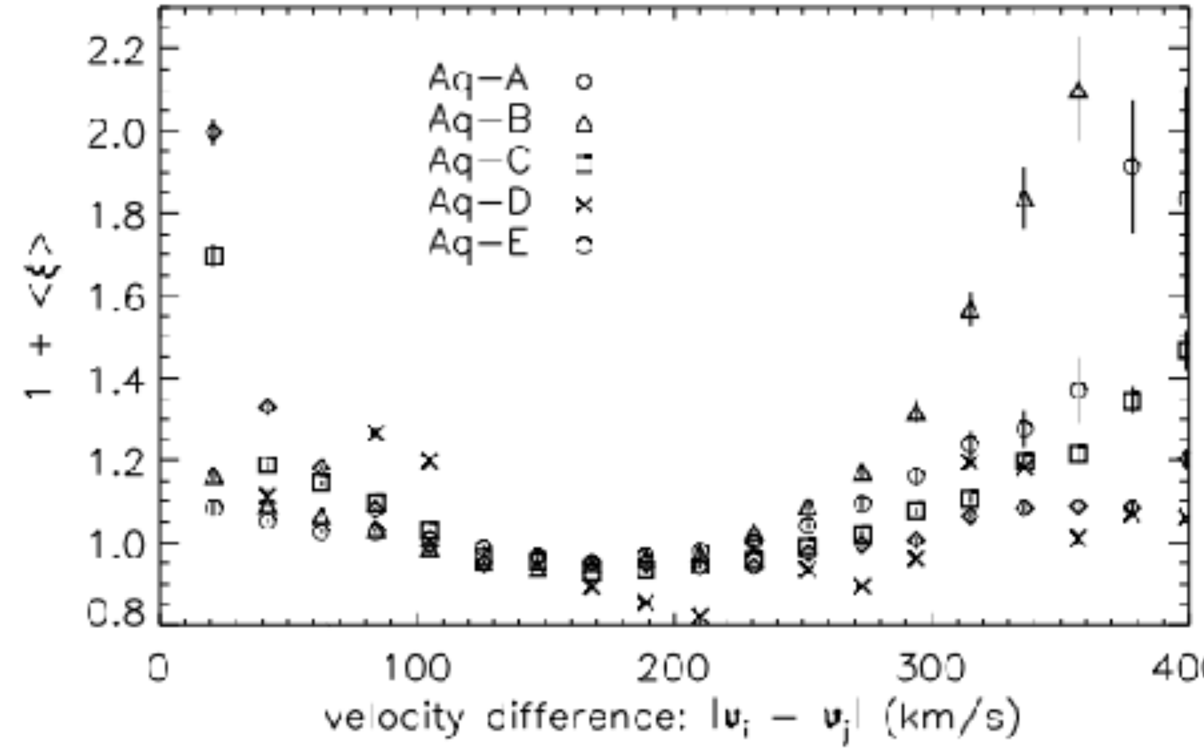

<u>Compatible with a stellar halo solely built via accretions</u>

# VELOCITY CORRELATION FUNCTION

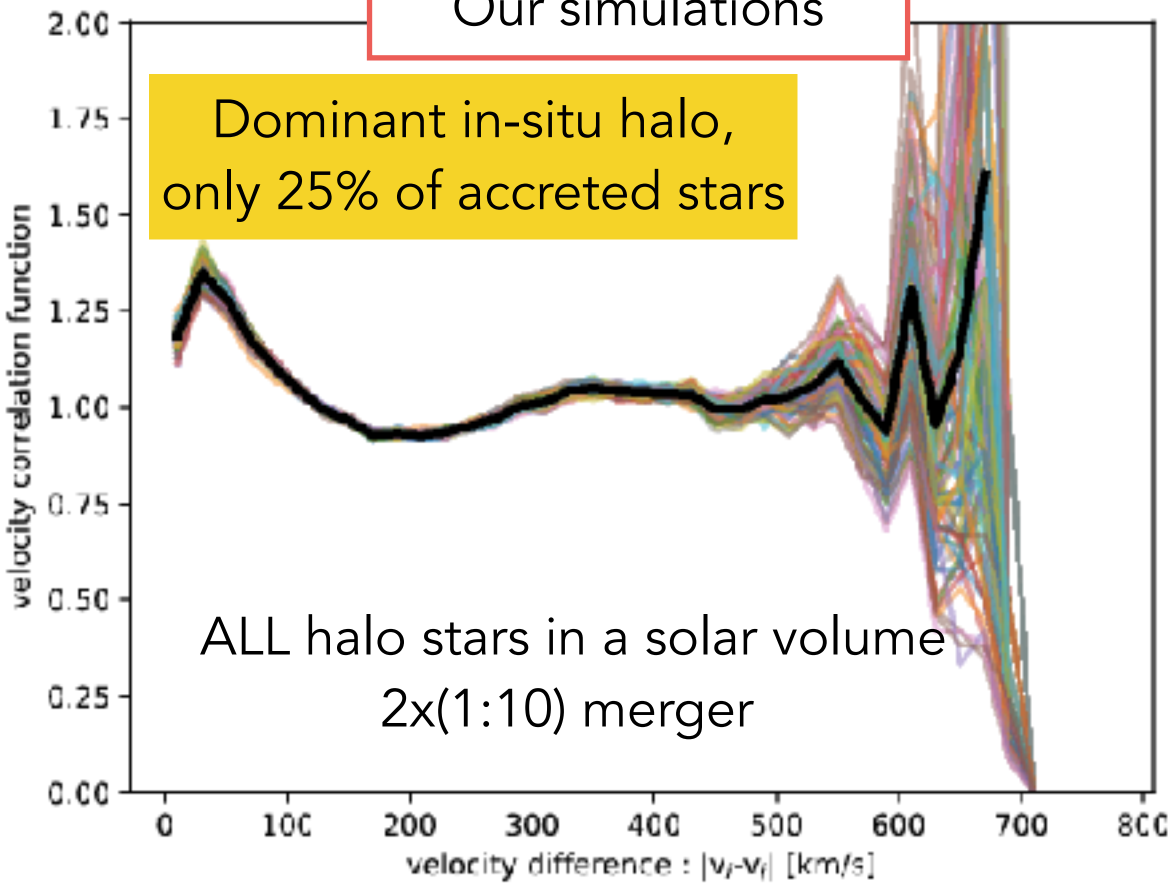
TGAS + RAVE




Cosmological simulations :
stellar halos built solely via accretions




Our simulations

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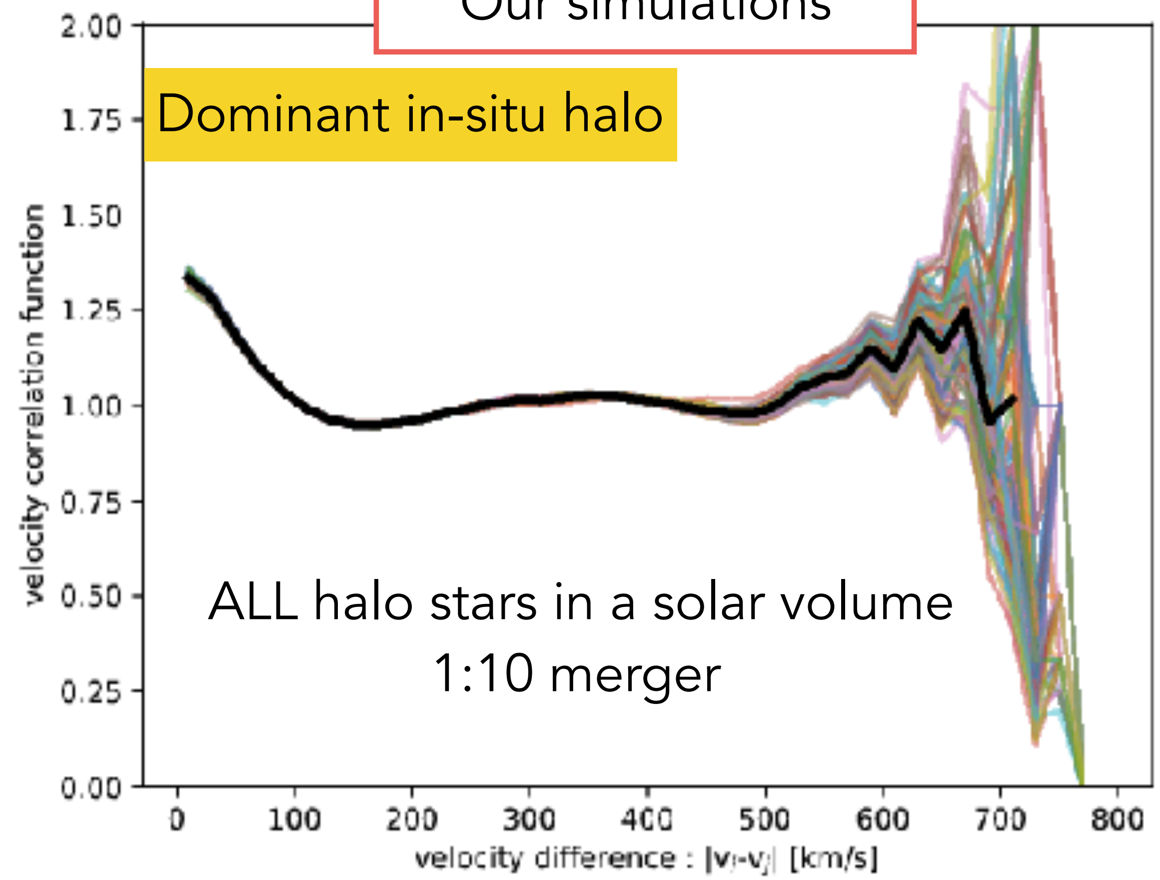

# CONCLUSIONS

1. A clump in integrals-of-motion and/or kinematic spaces does not necessarily have an extragalactic origin. In-situ stars, heated by mergers, have a clumpy distribution as well

2. Satellites which experience dynamical friction do not retain memory of their initial conditions in integrals of motion spaces

3. In all kinematic spaces analyzed so far (E-Lz, Lz-Lperp, Rapo-Rperi) accreted and -in situ stars overlap

4. **The level of substructures found in the solar neighborhood with Gaia DR1** (velocity correlation function) is **compatible** with a stellar halo built solely via accretions (see Helmi+2017), but **also with a stellar halo mostly made of in-situ stars.**

5. Points 1, 2, 3 and 4 suggest that the search for accreted streams in kinematic spaces is highly degenerate.

7. We **crucially need chemistry (and ages)** to robustly establish the accreted/in-situ nature of stars in the Galaxy, and derive the formation history of the halo