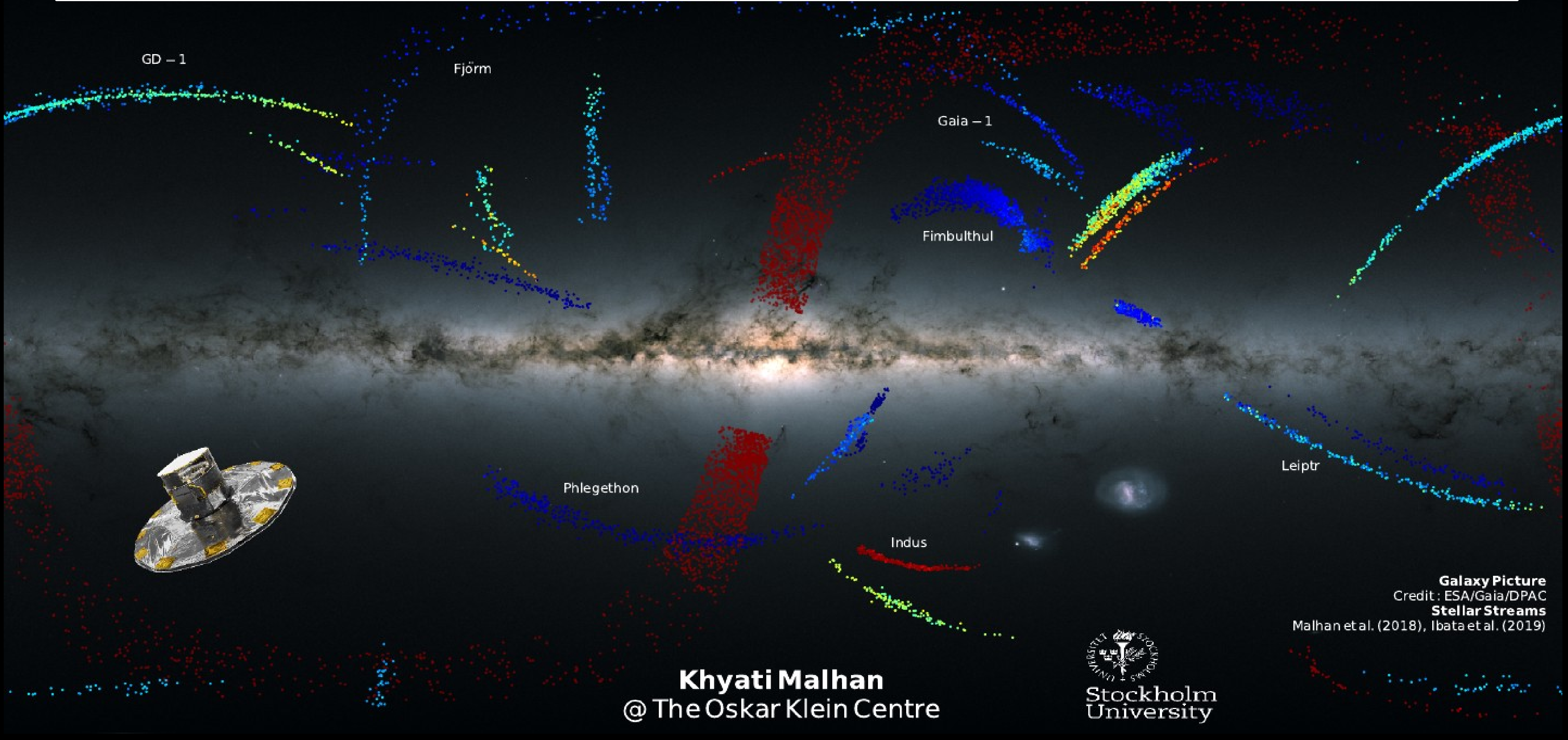
Probing the nature of Dark Matter with Stellar Streams

Some evidence implying DM models beyond CDM (arXiv 2005.12919)



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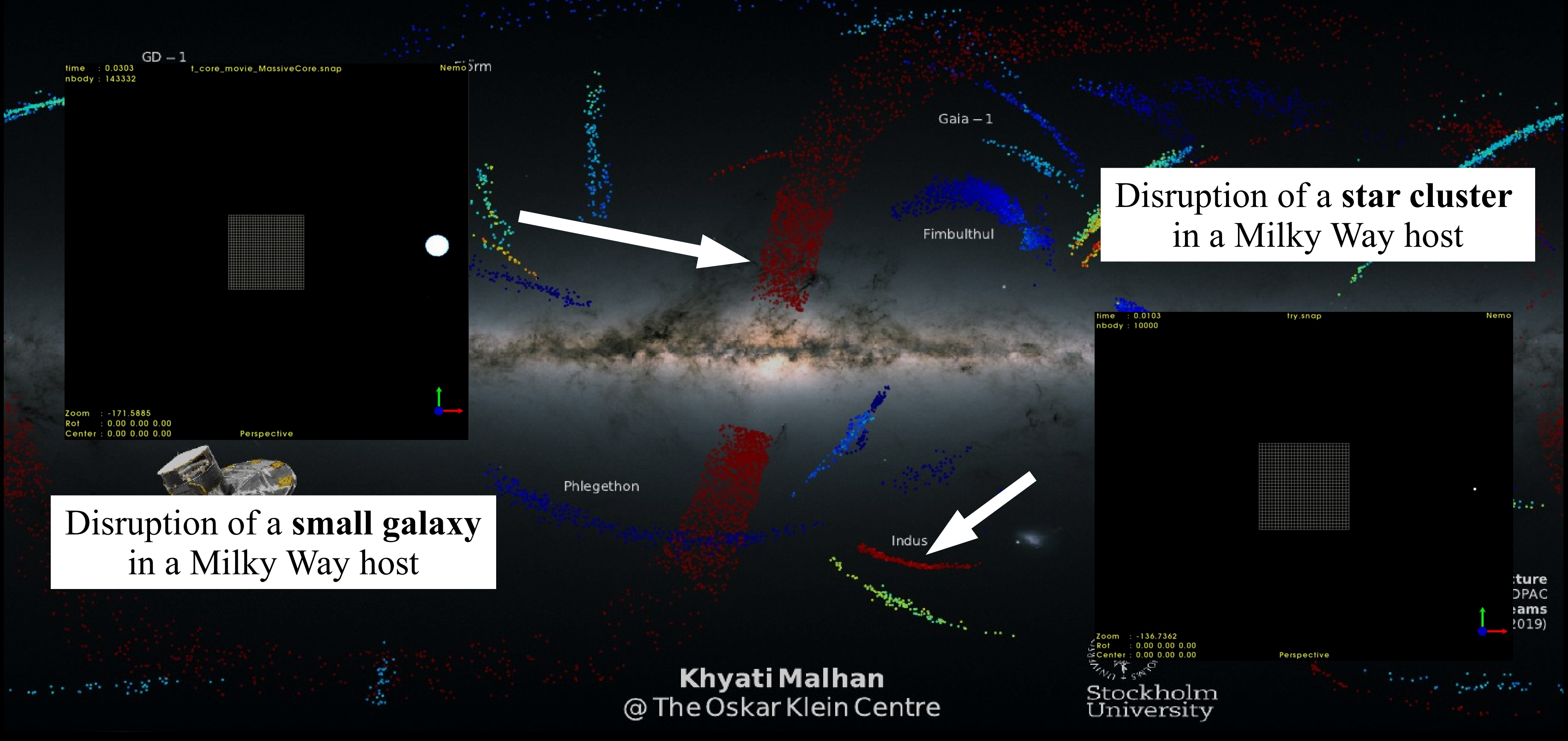
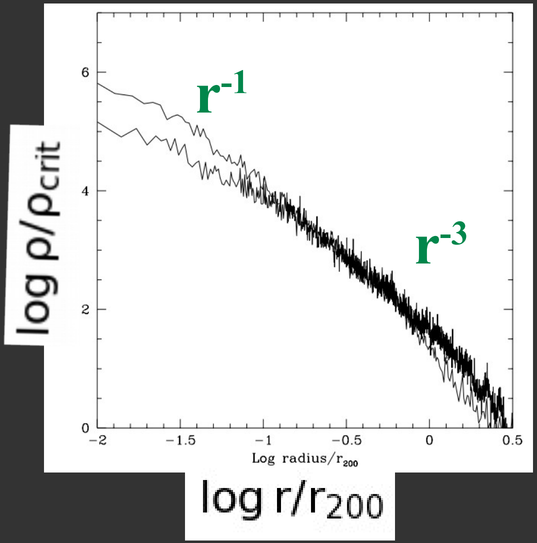


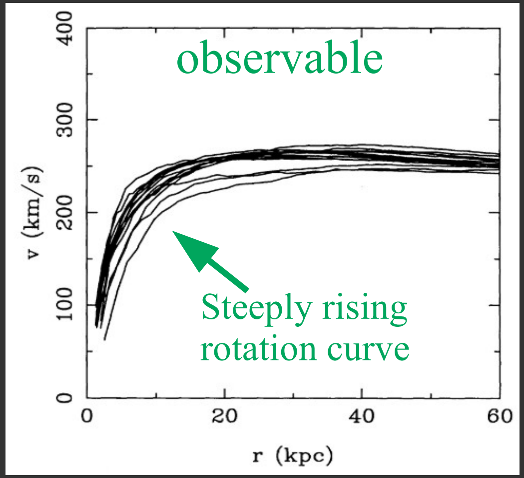
Cusp/core Problem
A challenge to the standard CDM model

CDM simulations
Hypothesis: DM is non-relativistic ("cold"), collisionless, massive.

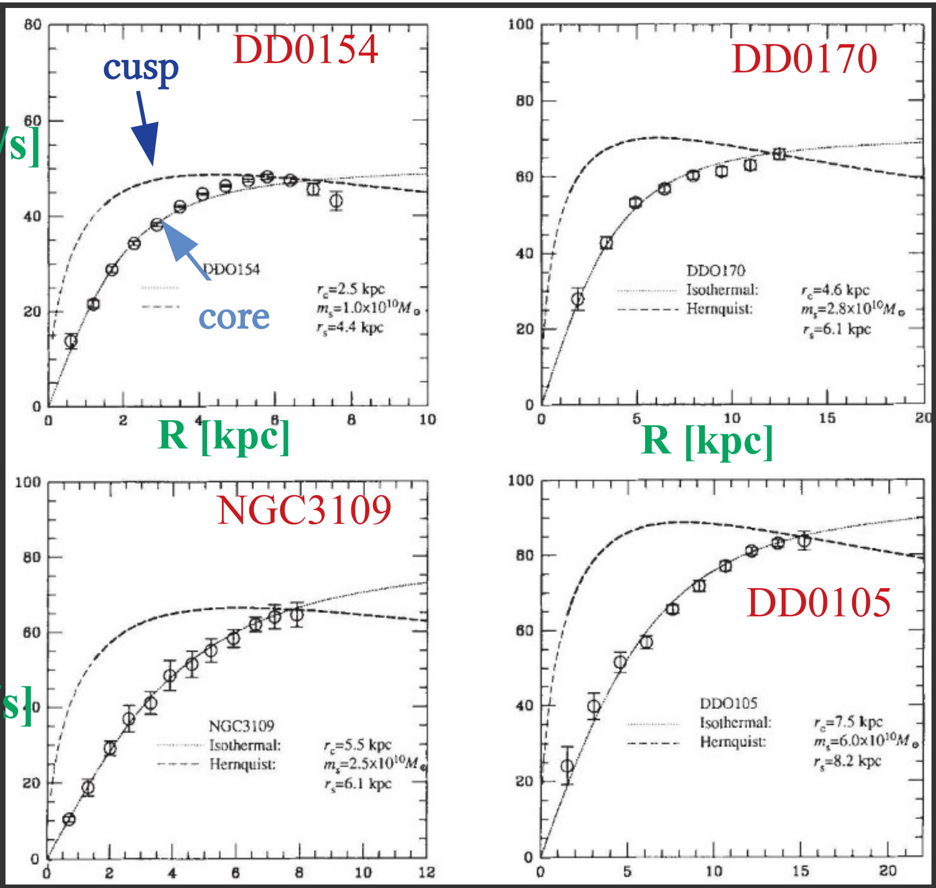
Prediction:
- Dark halos are triaxial (all physical scales)
- **Central density profiles are "universally" cuspy**

$$\rho(r) \propto r^{-\gamma} \text{ (with } \gamma = 1)$$ (NFW profile)





Cusp/core Problem
A challenge to the standard CDM model

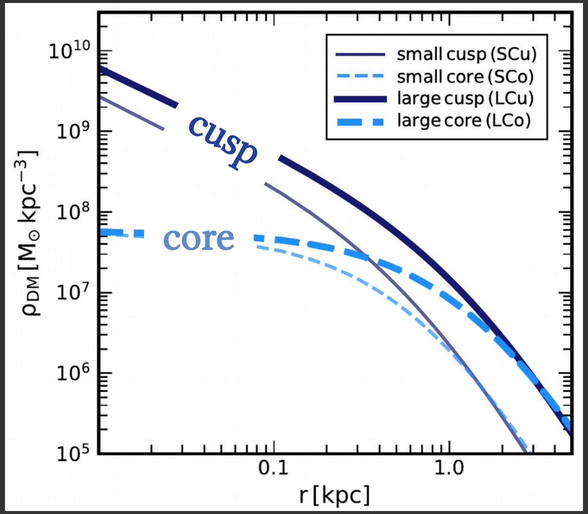


Observations:

DM densities in galaxies ($M \sim 10^9 - 10^{12} M_\odot$) is:

$$\rho(r) \propto r^{0.0}$$

ie., “core” not “cusp”.



Moore (1994), Flores & Primack (1994), de Blok & McGaugh (1997), Salucci & Burkert (2000)

Cusp/core Problem
A challenge to the standard CDM model

Alternate DM simulations

Hypothesis:

DM is self-interacting (not collisionless)

Alternate DM models

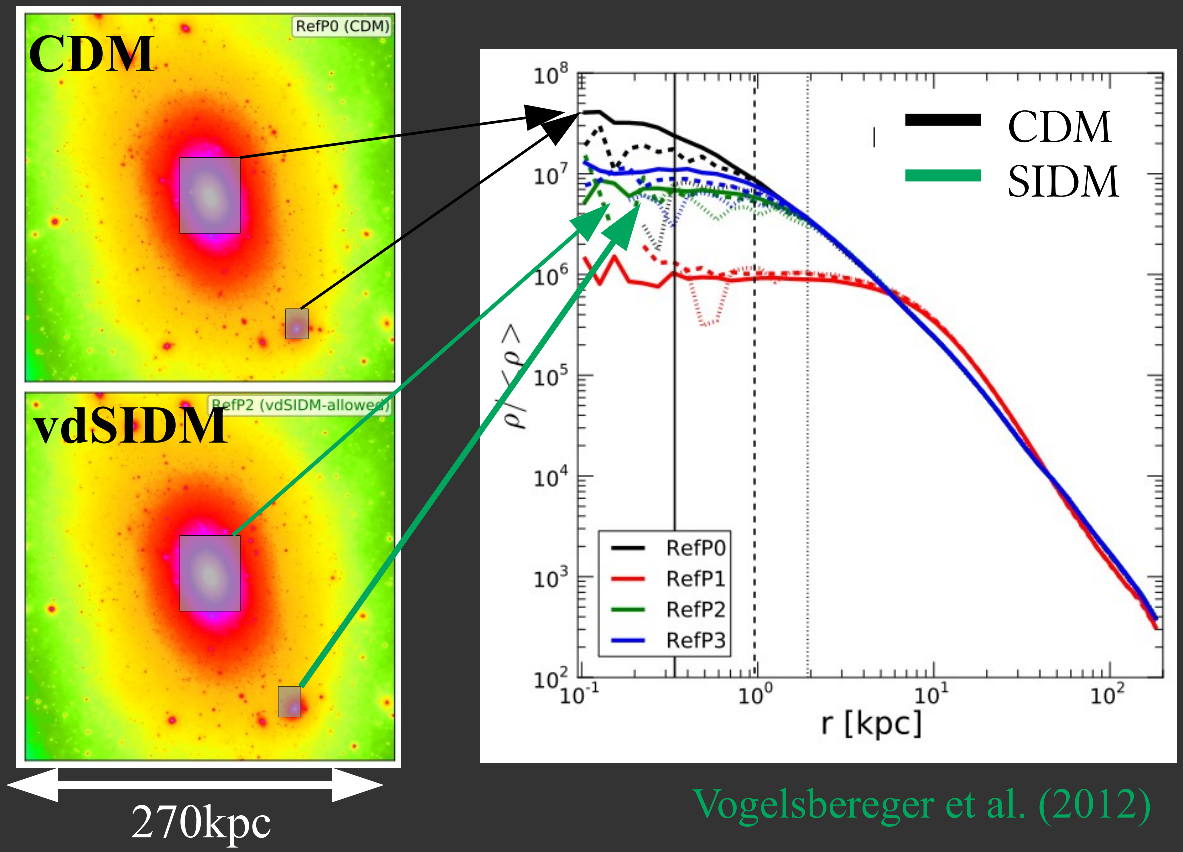
- warm DM (Bond et al. 1980; Boyarsky et al. 2009; Avila-Reese et al. 2001),

ultra-light DM (m_{DM}~10^{-22} ev, Hui et al. 2017).

- super-fluid DM (Berezhiani et al. 2018)
- self-interacting DM (Spergel & Steinhardt 2000, Elbert et al. 2015)

Prediction:

- Density profiles are **centrally-cored** (all physical scales)



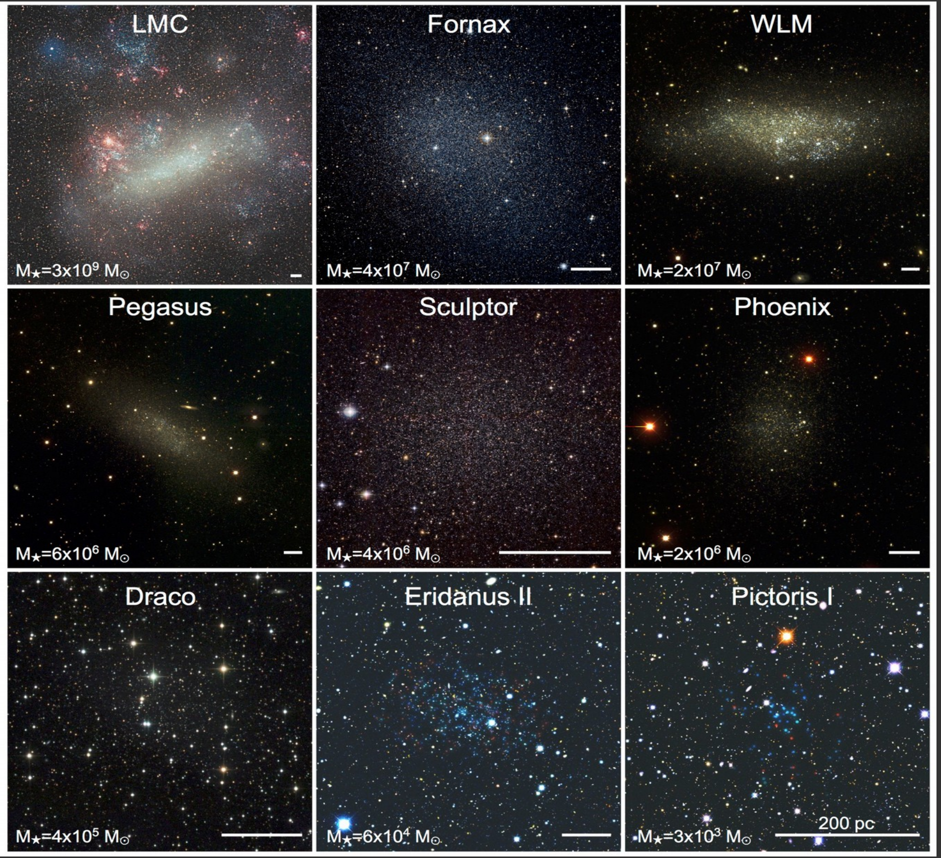
Vogelsbereger et al. (2012)

Oooops!! Baryonic feedback can transform cusps → cores (in massive galaxies)

Galaxy=Baryons (~10%)+Dark Matter (~90%)

Baryonic feedback (fluctuating gravitational potential) is very high in the central regions of galaxies. Sufficient star formation processes can transform central DM density profiles.

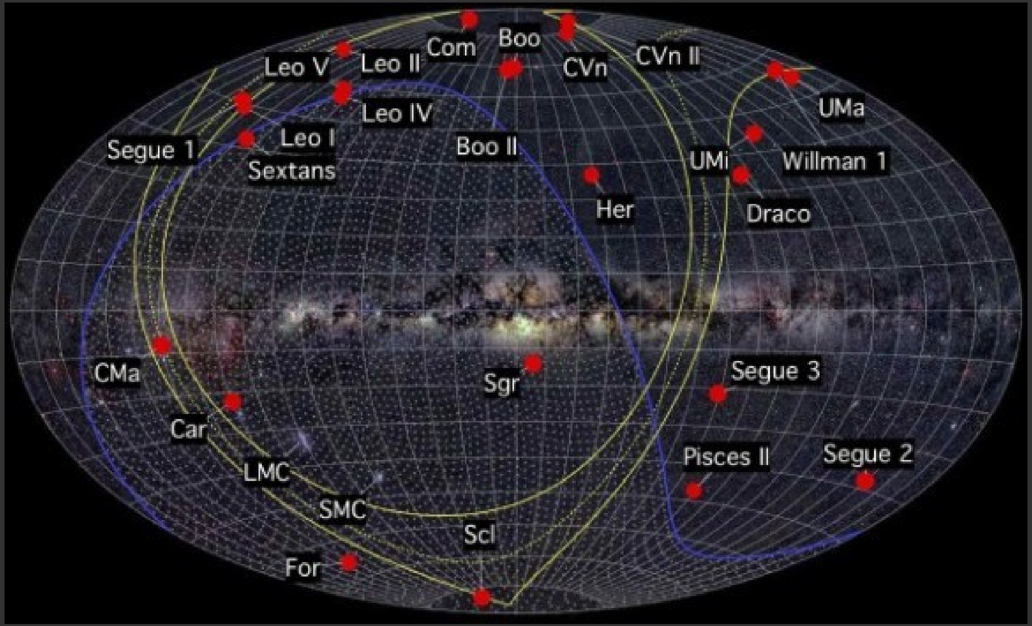
Baryonic feedback can transform cusps to cores in massive galaxies



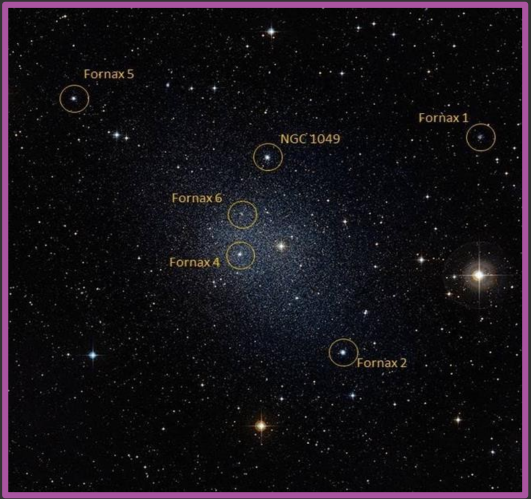
Satellite galaxies of the Local group

But, baryonic feedback is not very effective in low-mass galaxies (e.g., satellite galaxies, M~$10^{8\text{-}9}$ M⊙).

Satellite galaxies must maintain their pristine DM density profiles (whether **cusp** or **core**).



Satellite galaxies hosting Globular cluster(s) in the LOCAL GROUP

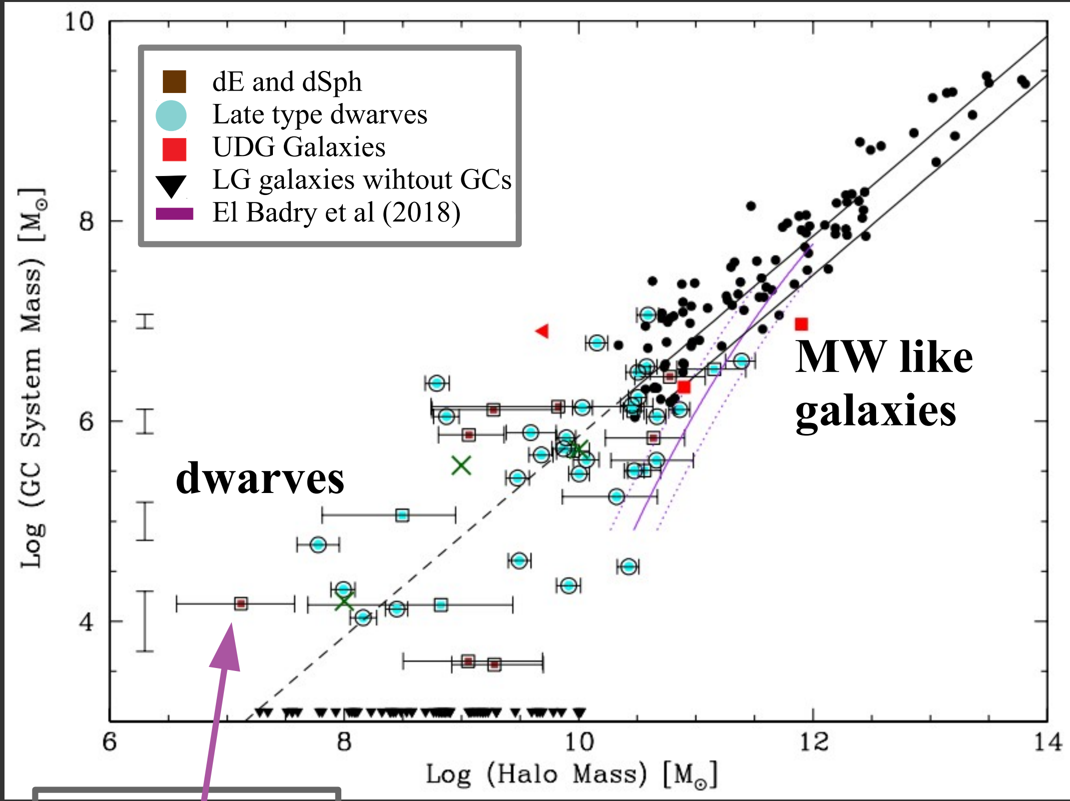


Fornax
- D ~ 140 kpc
- M_{halo}~10^9M⊙
- 5-6 GCs

(Mackey & Gilmore 2003; Greco et al. 2007; Wang et al. 2019)

Eridanus II
- D ~ 410 kpc
- M_{halo}~$10^{8\text{-}9}$M⊙
- 1 GC

(Bechtol et al. 2015; Crnojević et al. 2016)

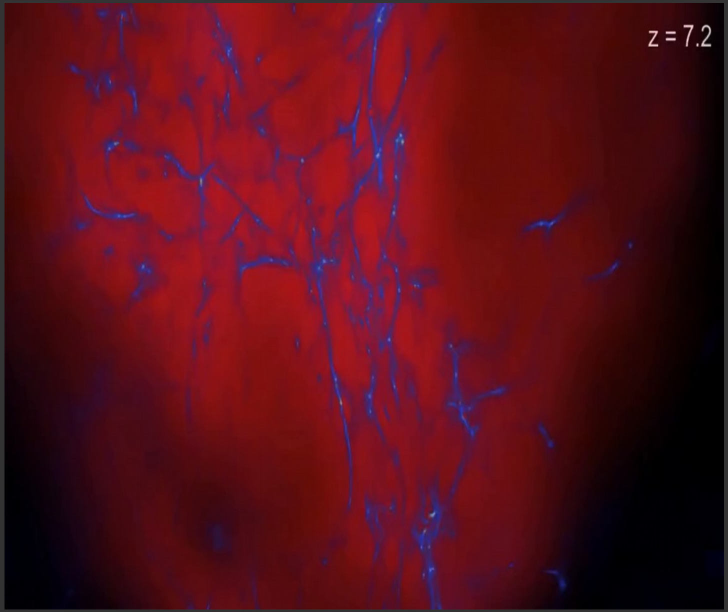


AndXXV
- M_{halo}~10^7M⊙
- 1 GC

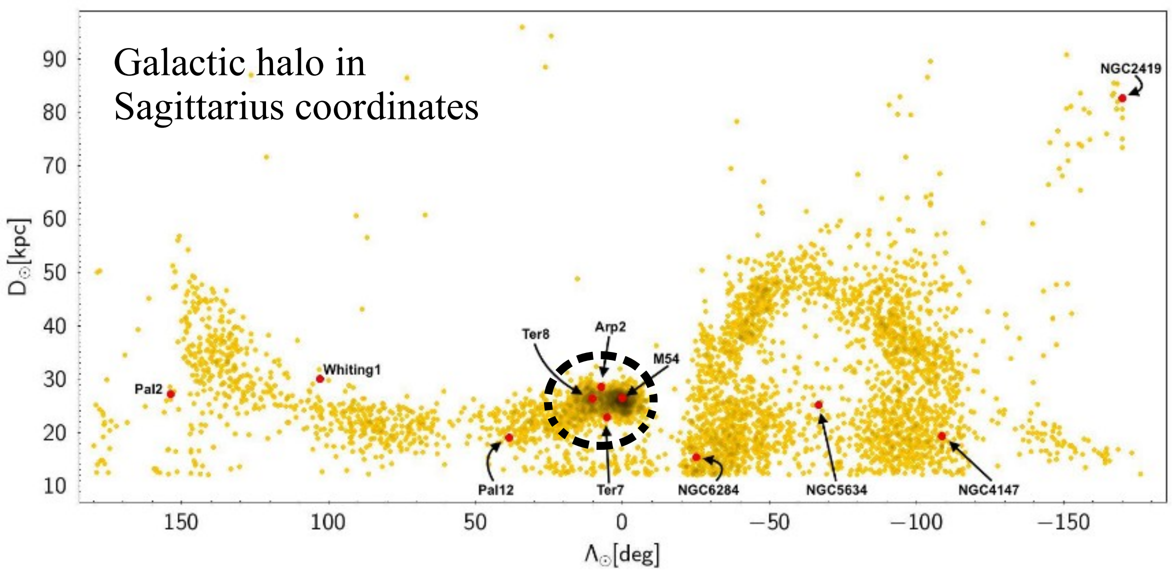
Cusano et al. (2016)

Forbes et al. (2018)

Accreted GC streams: Natural consequence of Hierarchical formation scenario



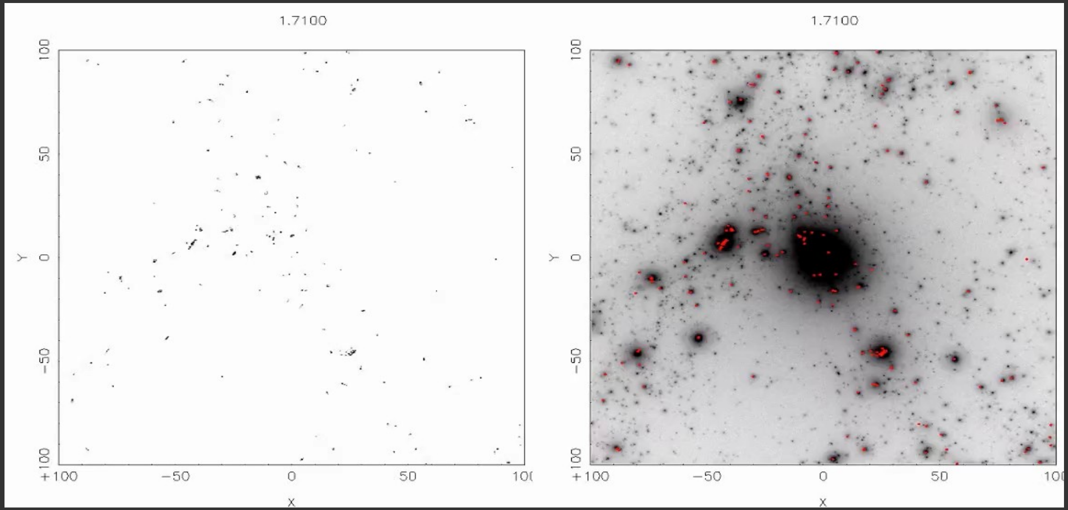
GCs accreting onto a host galaxy
(simulation, Renaud et al. 2017)



GCs associated with the stream of the
accreted Sagittarius galaxy
(Bellazzini et al. 2020)

Accreted GC streams: Natural consequence of Hierarchical formation scenario

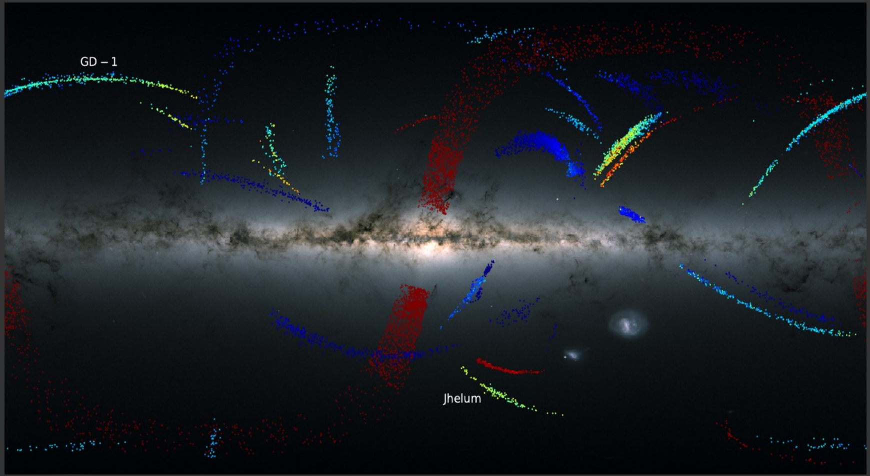
Accreted Globular cluster streams (simulation)

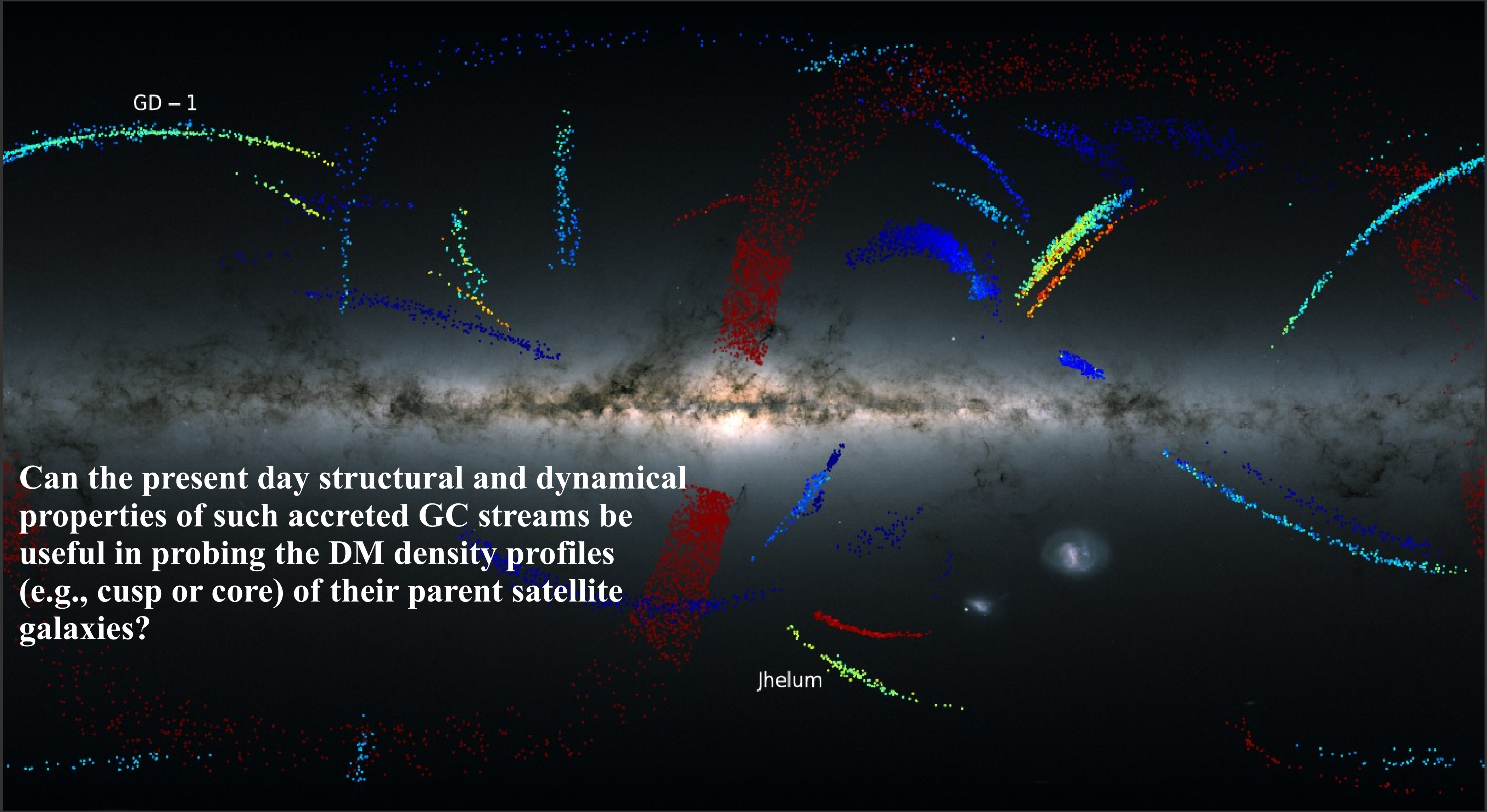


Globular cluster streams

Dark matter

Milky Way streams (observations)



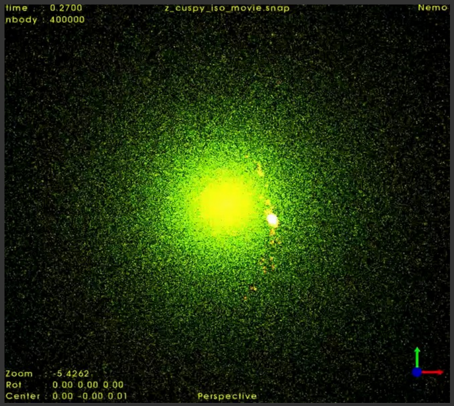


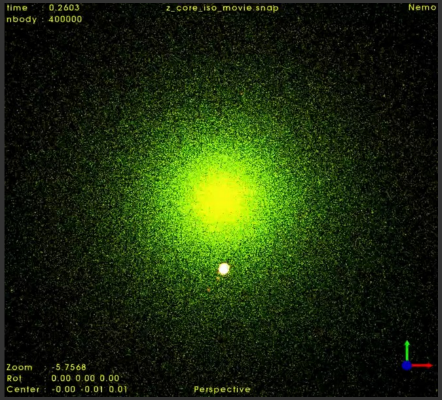
Can the present day structural and dynamical properties of such accreted GC streams be useful in probing the DM density profiles (e.g., cusp or core) of their parent satellite galaxies?

Evolution of Globular cluster inside satellite galaxies (isolated)

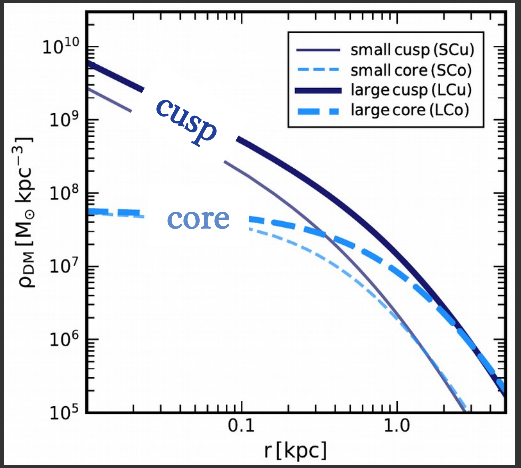
Cuspy satellite
(large dynamical friction)
(large tidal forces)

Cored satellite
(oscillator=>resonances=>No dyn. fric.)
(Compressive forces=>low tidal disruption)

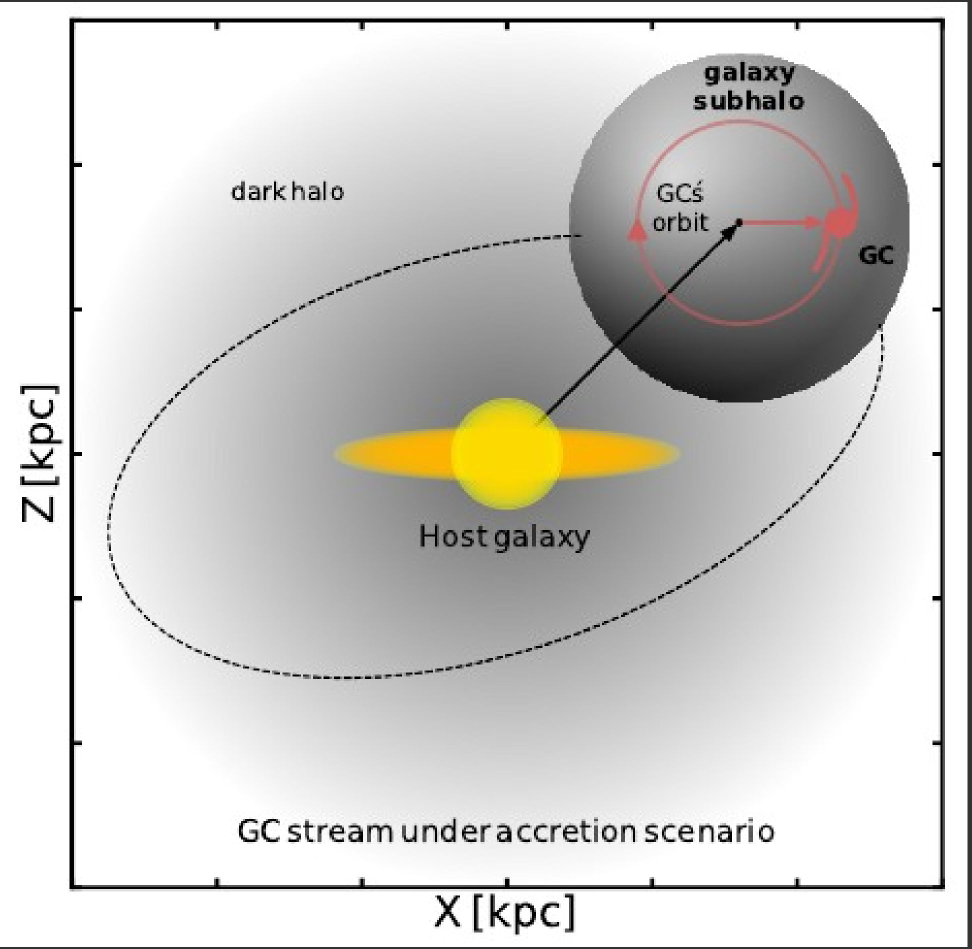




Dynamical evolution of a Globular cluster, orbiting a satellite galaxy, is very sensitive to the underlying DM distribution (cusp/core).

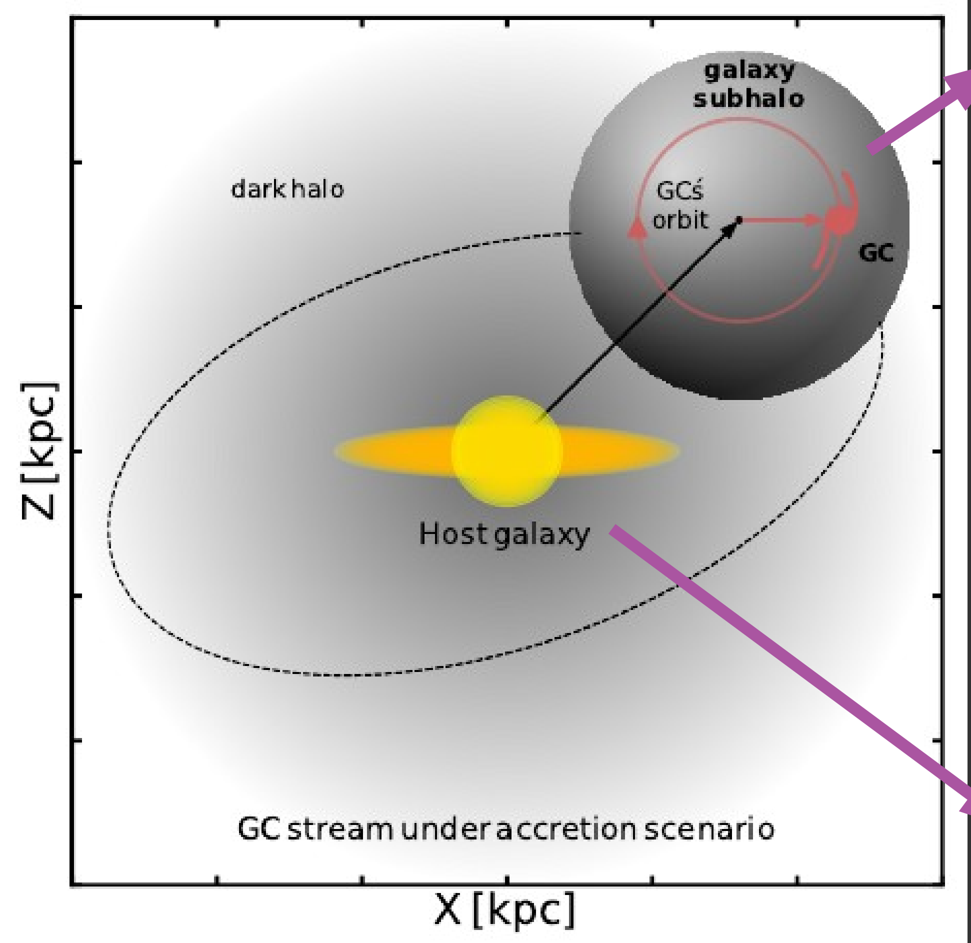


N-body simulations of accreted Globular Cluster streams

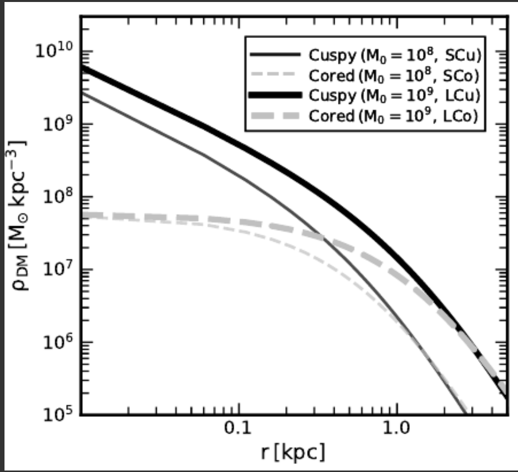


Examine if we get different GC streams in different subhalo (cusp/cored) scenario under the accretion framework!!!

N-body simulations of accreted Globular Cluster streams

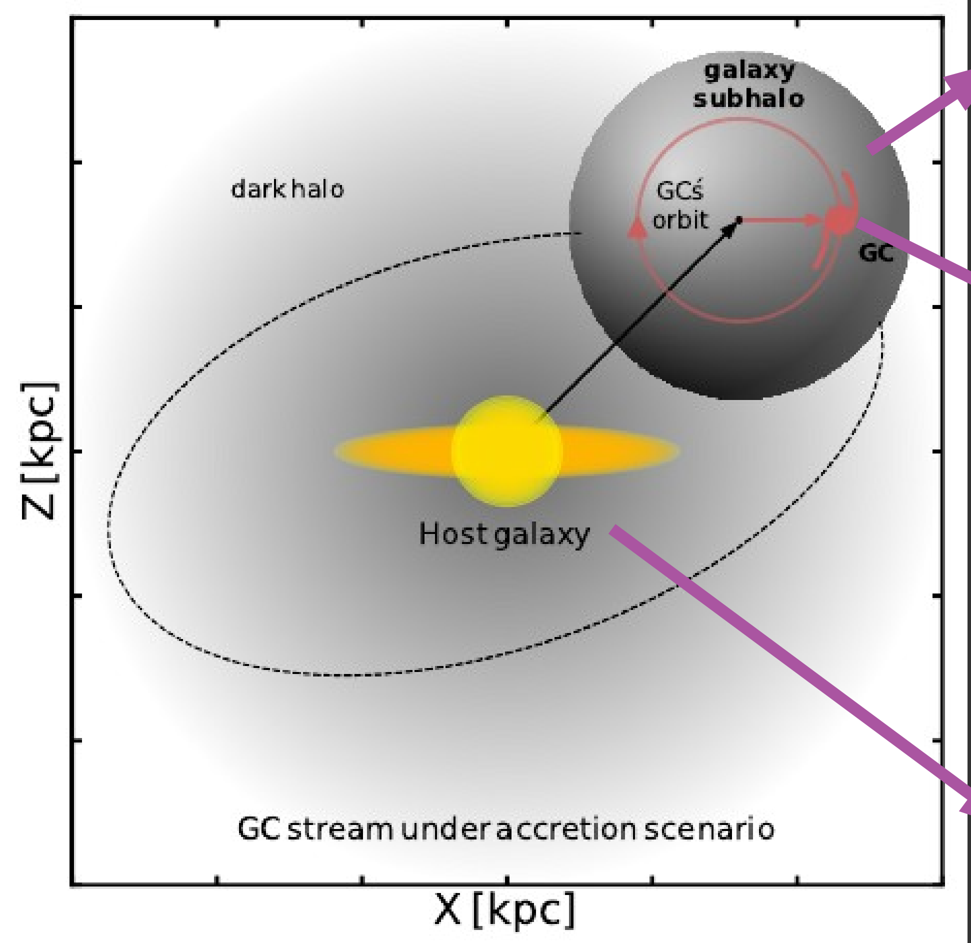


Four **subhalo models**:
- Cuspy (10^8M⊙ and 10^9M⊙)
- Cored (10^8M⊙ and 10^9M⊙)



Host galaxy (static potential)
thin disk, a thick disk, interstellar medium, bulge and DM halo (Dehnen & Binney 1998)

N-body simulations of accreted Globular Cluster streams



Four **subhalo models**:
- Cuspy ($10^8 M_\odot$ and $10^9 M_\odot$)
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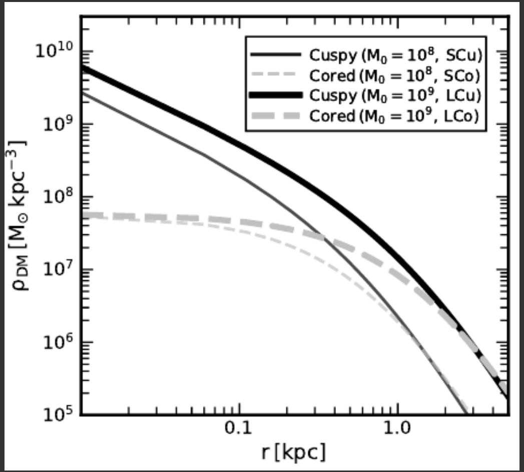
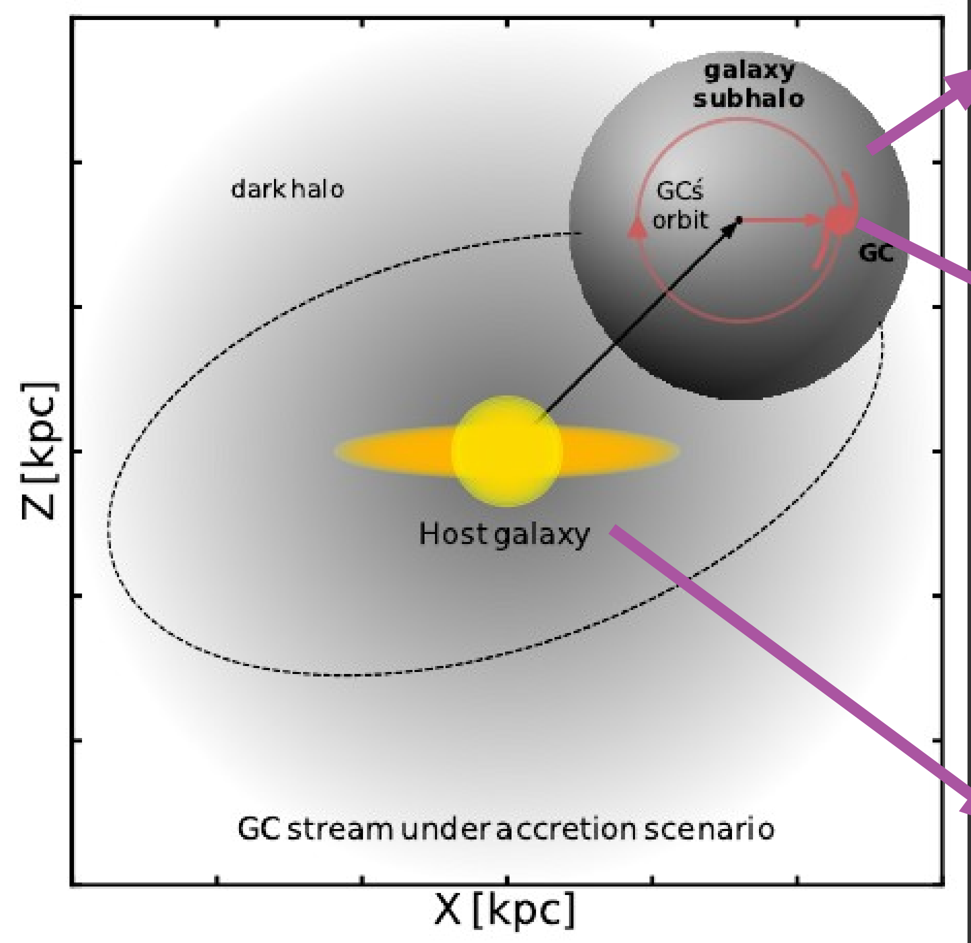


Cluster
- M=5 x $10^4 M_\odot$

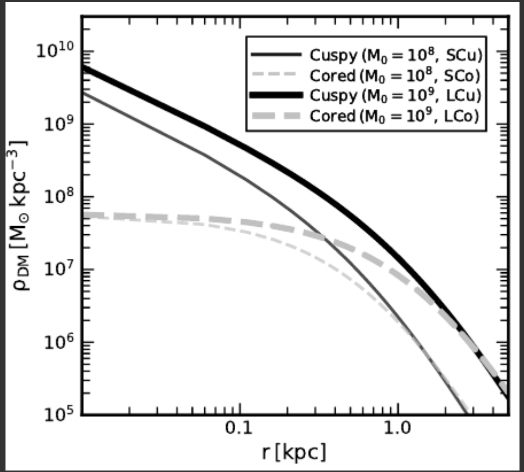
Host galaxy (static potential)
thin disk, a thick disk, interstellar medium, bulge and DM halo (Dehnen & Binney 1998)

N-body simulations of accreted Globular Cluster streams



Four **subhalo models**:

- Cuspy (10^8M⊙ and 10^9M⊙)
- Cored (10^8M⊙ and 10^9M⊙)



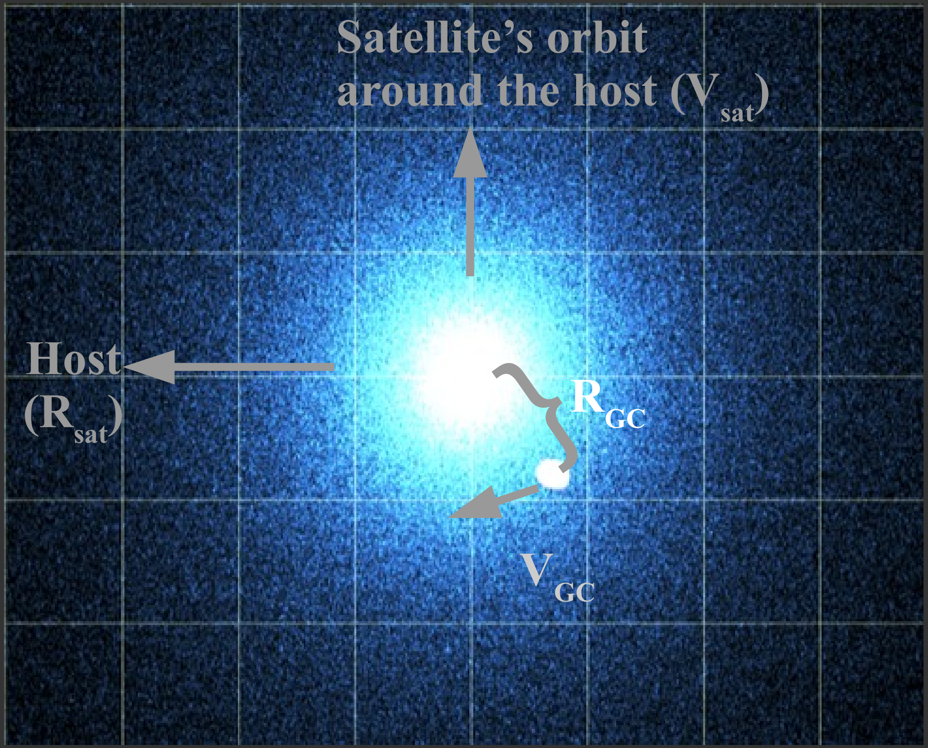
Cluster

- M=5 x 10^4 M⊙

In total we run >100 N-body simulations

Host galaxy (static potential)
thin disk, a thick disk, interstellar medium, bulge and DM halo (Dehnen & Binney 1998)

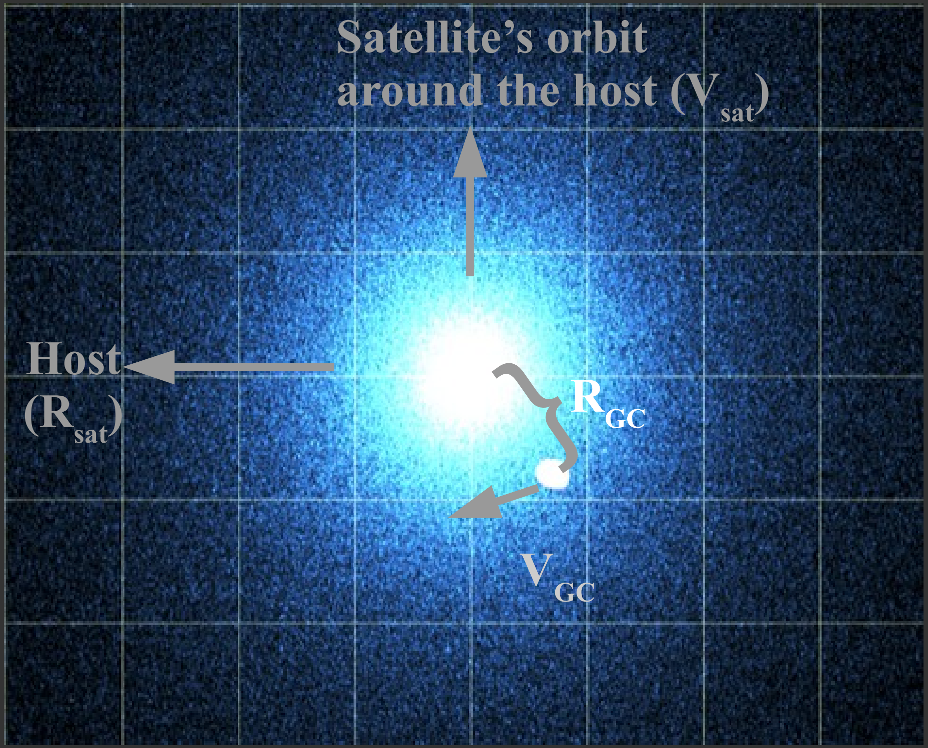
N-body simulations of accreted Globular Cluster streams



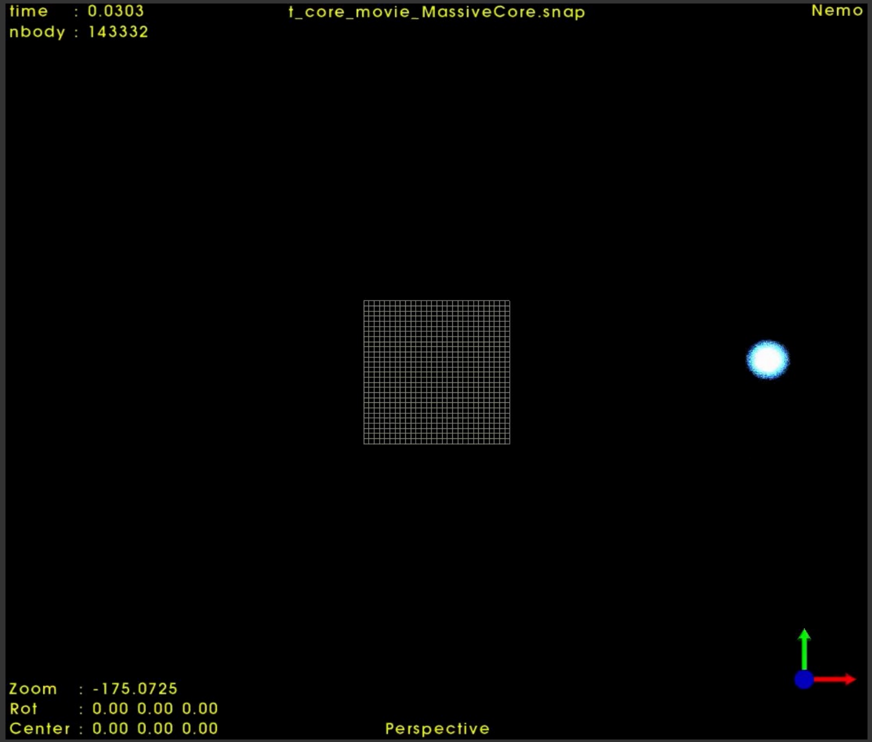
GC inside parent satellite (subhalo)

Initialisation, COM frame

N-body simulations of accreted Globular Cluster streams



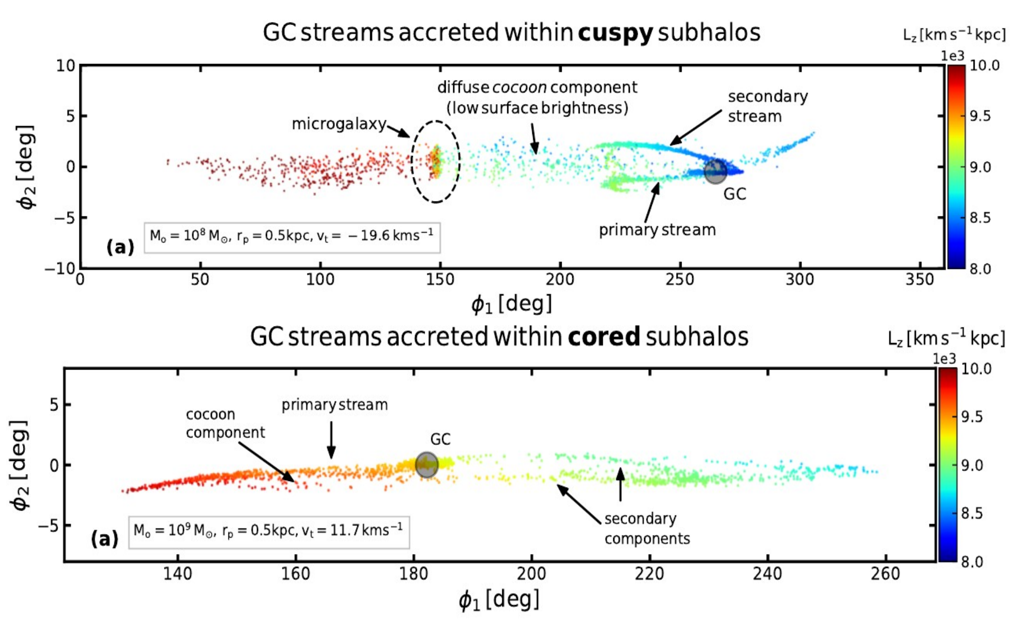
GC inside parent satellite (subhalo)
Initialisation, COM frame

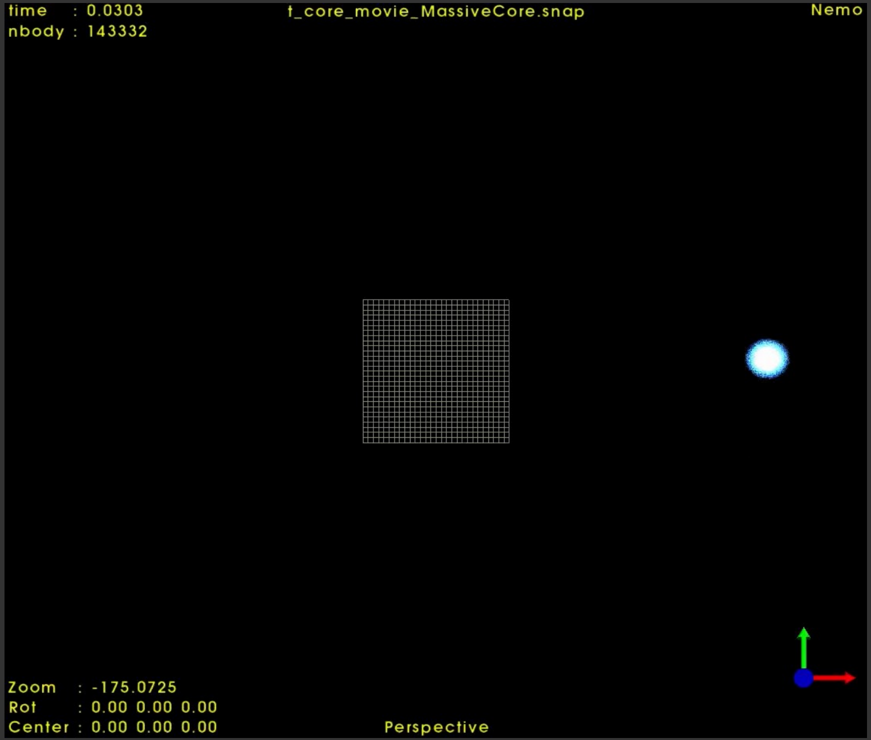


Evolution of **GC**+**Satellite** inside the Milky Way like host

Morphologies of Stellar streams

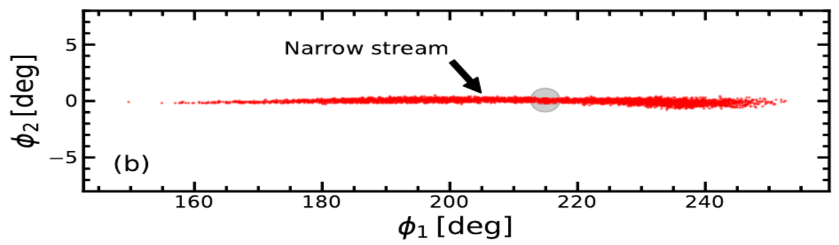
Accreted GC streams are complex structures (cocoon, neighbouring structures)



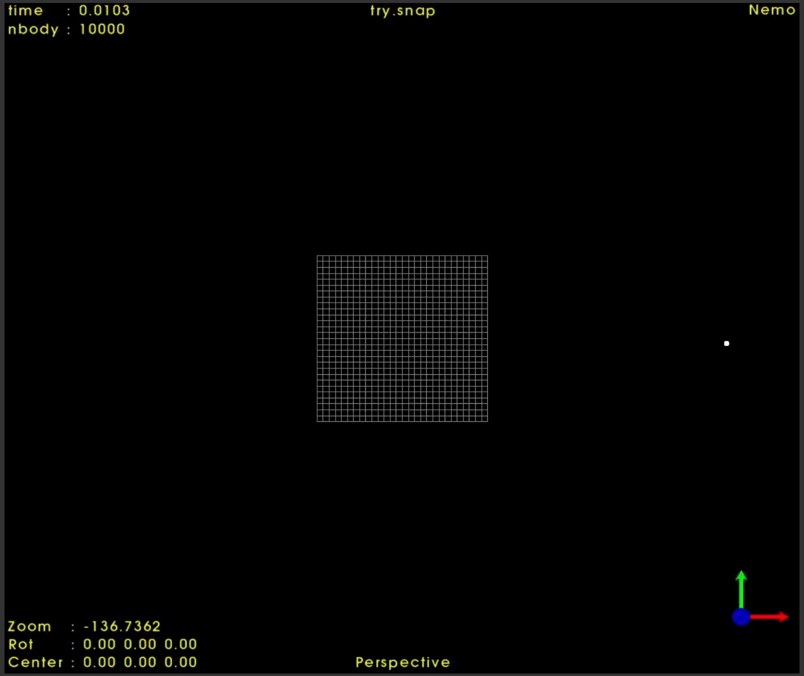


Evolution of GC+Satellite inside the Milky Way like host

Morphologies of Stellar streams



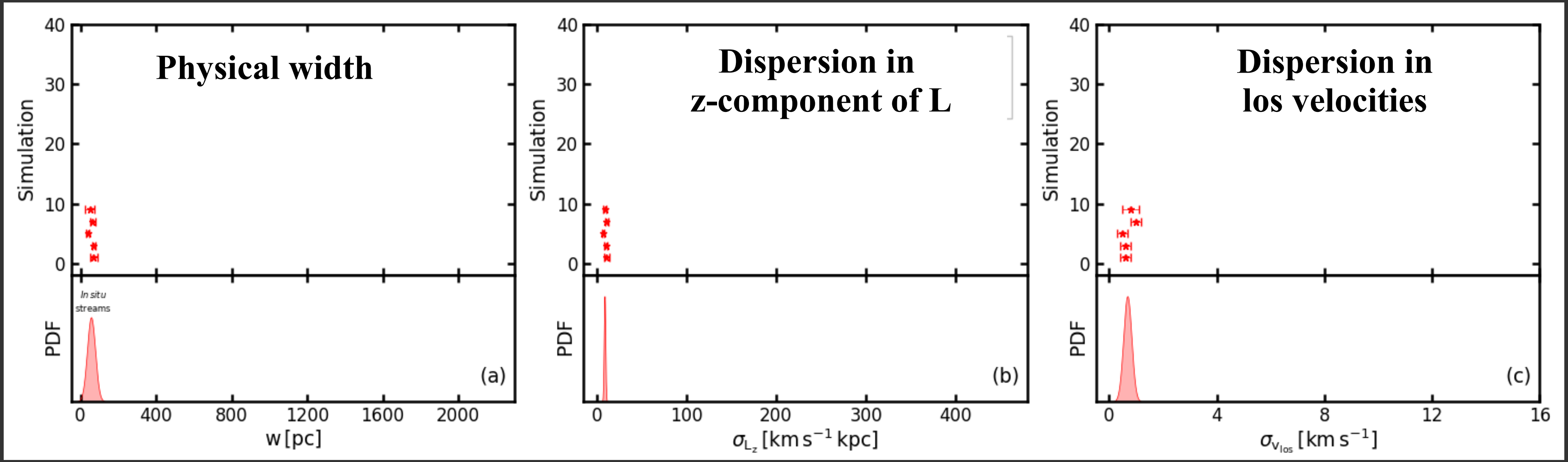
Tidal disruption of simple
(in situ) GC forms simple, narrow,
dynamically cold streams

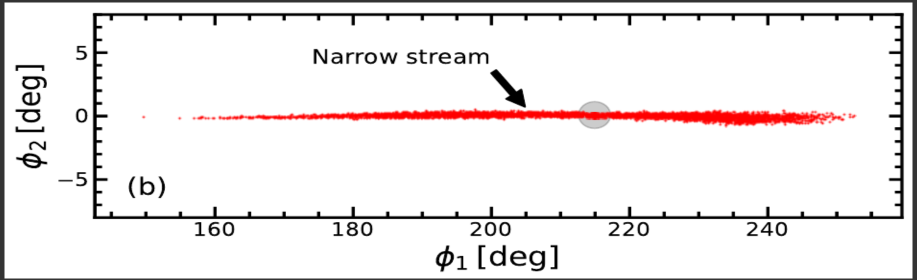


N-body simulation of a
simple (*in situ*) GC stream
(Dehnen et al. 2004, Sanders & Binney 2013)

Physical properties of Streams in different scenarios

Each point represents a GC stream





w < 90 pc

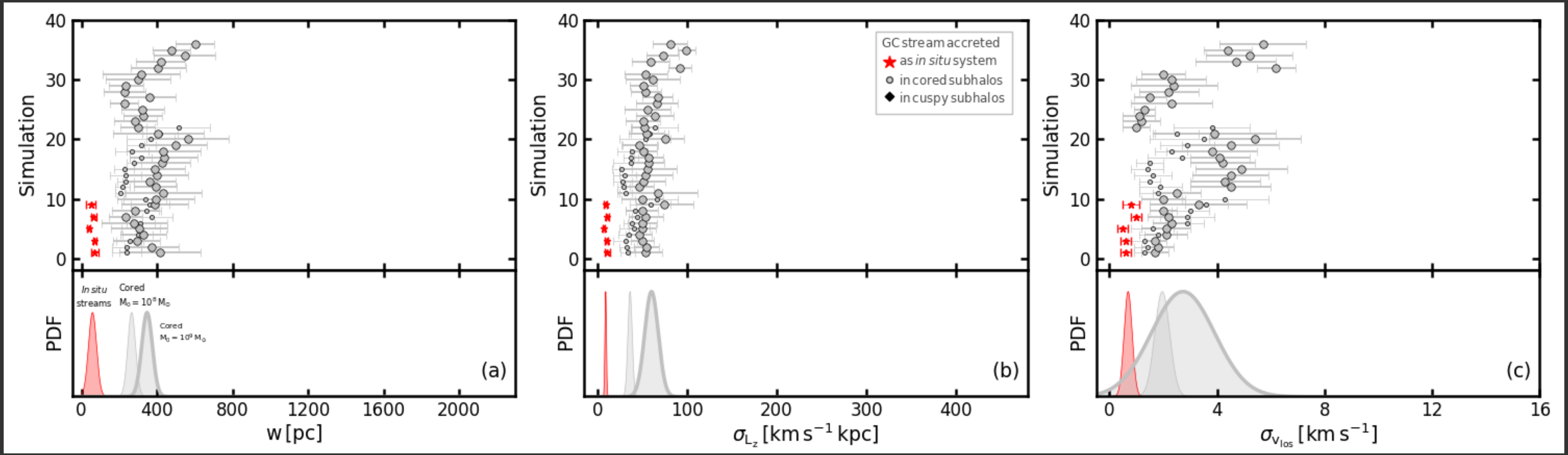
σ_{Lz}<15 kms kpc^{-1}

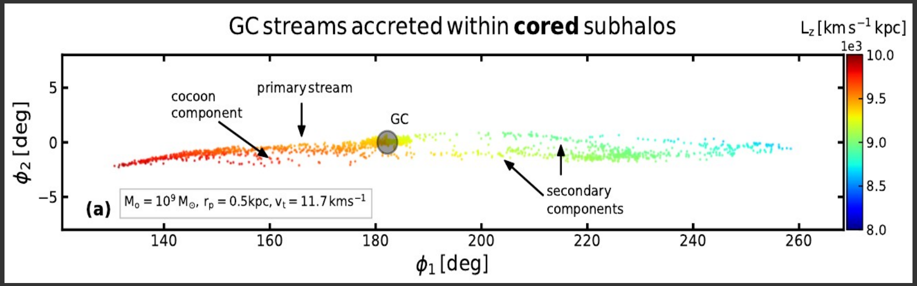
σ_{vlos}<~1 kms^{-1}

Tidal disruption of **simple GCs** forms narrow and dynamically cold streams

Physical properties of Streams in different scenarios

Each point represents a GC stream





w ~ 90-500 pc

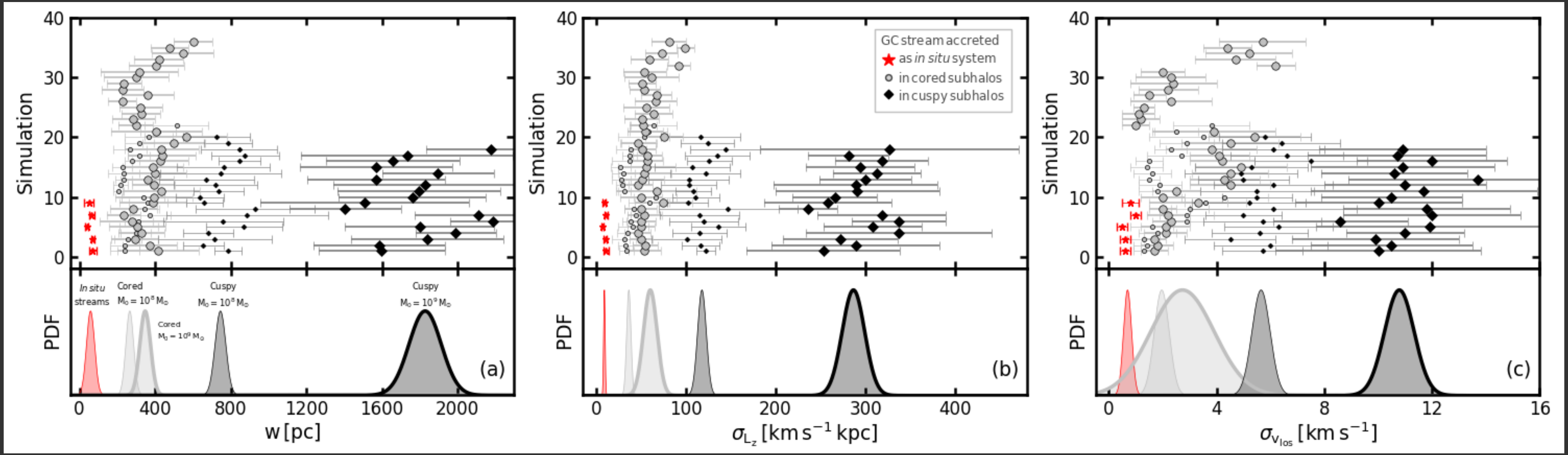
σ_{Lz}~15-95 kms kpc^{-1}

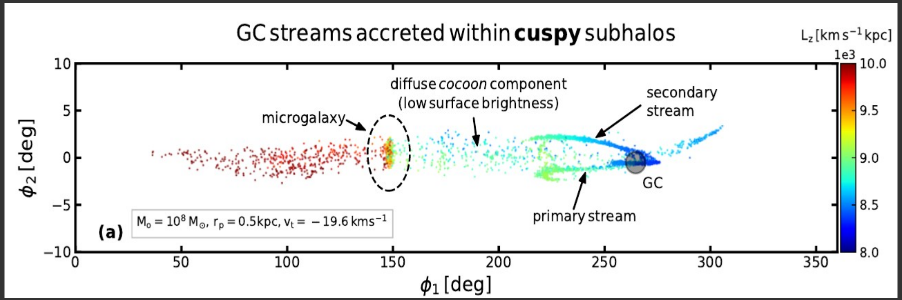
σ_{vlos}<4 kms^{-1}

Tidal disruption of **GCs** evolved in **cored subhalos** forms streams that are broader and hotter

Physical properties of Streams in different scenarios

Each point represents a GC stream



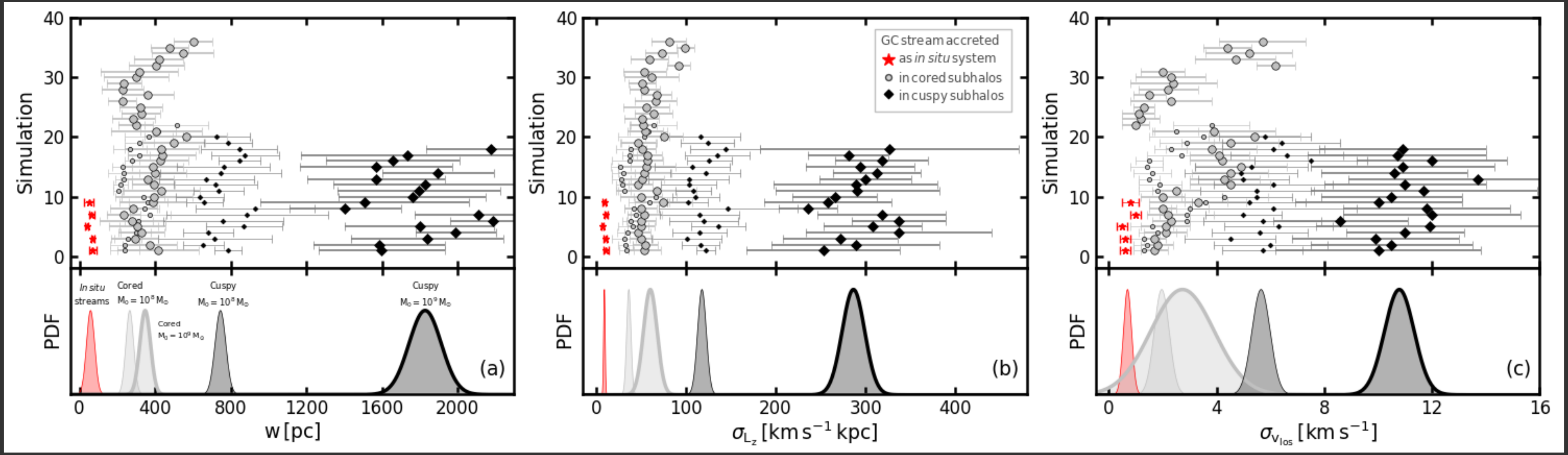


$w > 650$ pc
$\sigma_{L_z} > 95$ kms kpc^{-1}
$\sigma_{v_{los}} > 4$ kms^{-1}

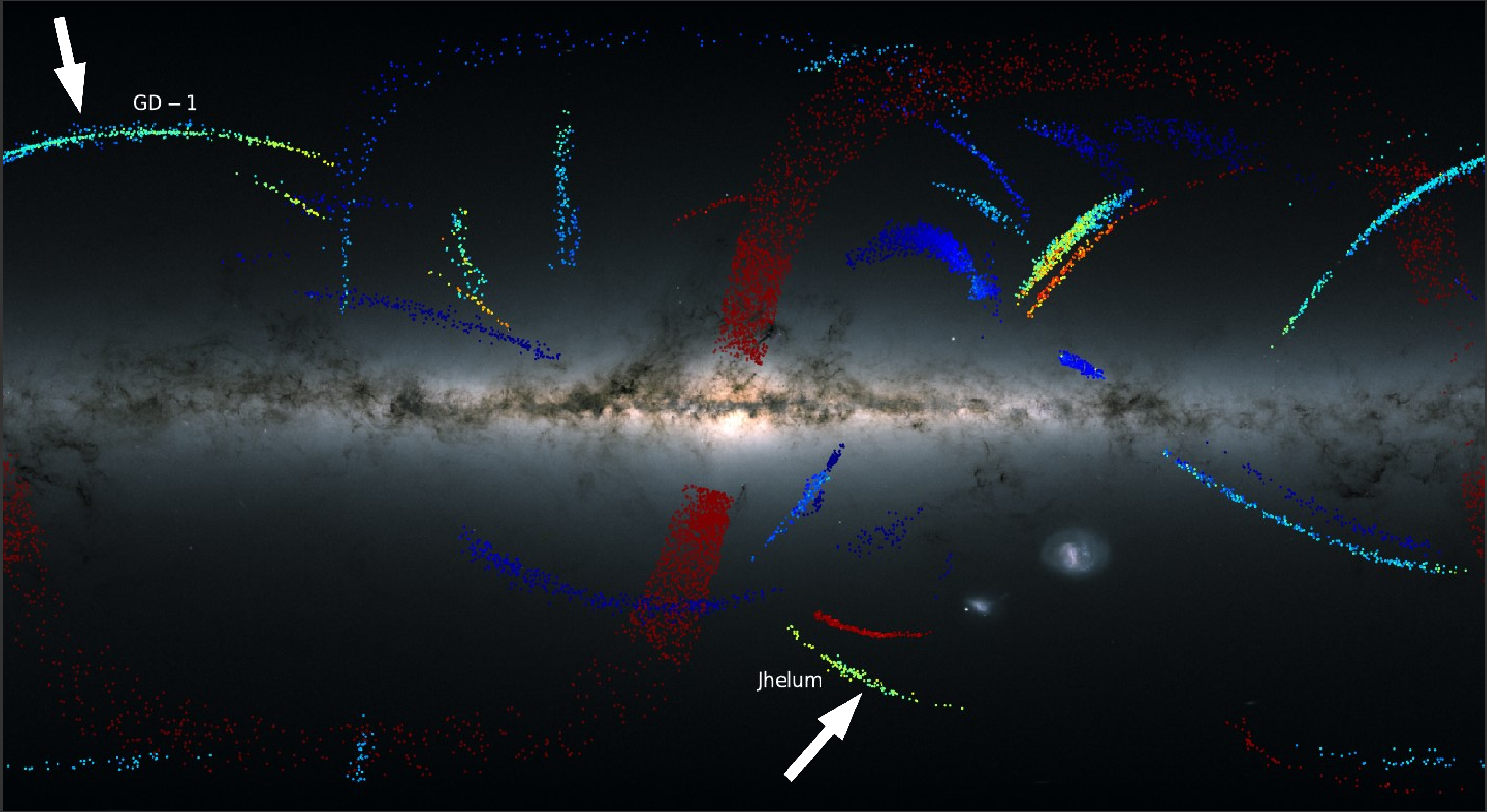
Tidal disruption of **<u>GCs</u>**
evolved in **<u>cuspy subhalos</u>**
forms streams that are
very broad and dynamically hot

Probing dark matter with accreted GC streams

Each point represents a GC stream

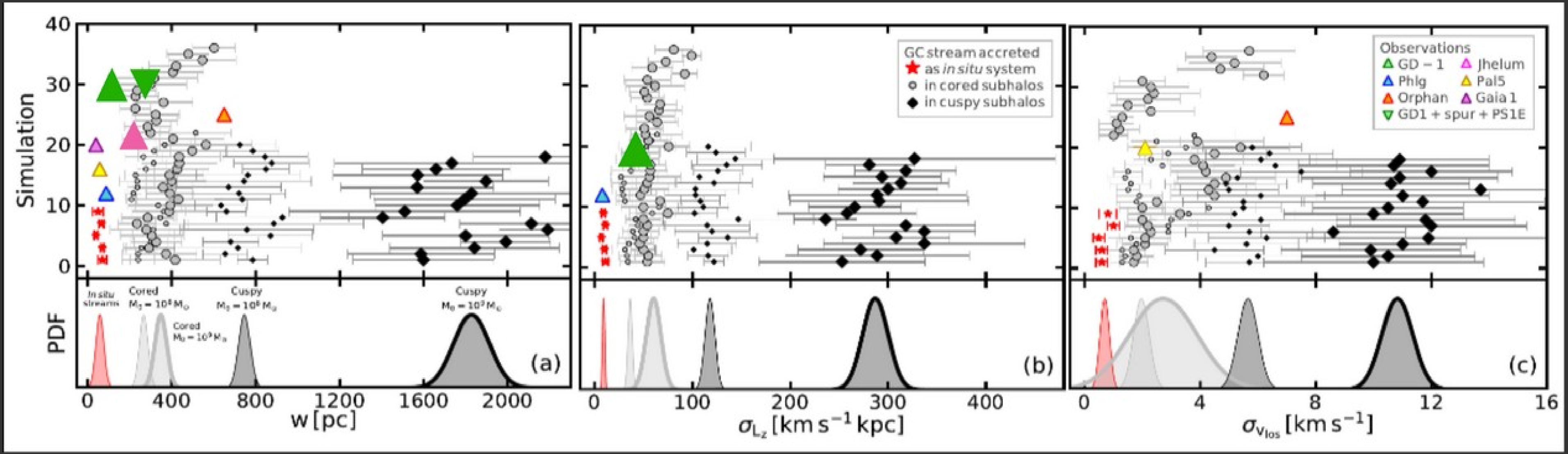


RESULT 1: The measurable physical properties of accreted GC streams (w, σ_{Lz}, σ_{vlos}) are sensitive to the central DM density profiles of the parent satellite, and can be used to directly probe the cusp/core scenarios.


GD – 1
Jhelum

Probing dark matter with accreted GC streams (arXiv 2005.12919)

Each point represents a GC stream



RESULT 2: A first comparison of Milky Way streams **GD-1** and **Jhelum** (likely of accreted GC origin) with the simulations favours scenario where parent satellite galaxies of these streams possessed **cored** DM density profiles (M_{halo}~$10^{8\text{-}9}$ M⊙).

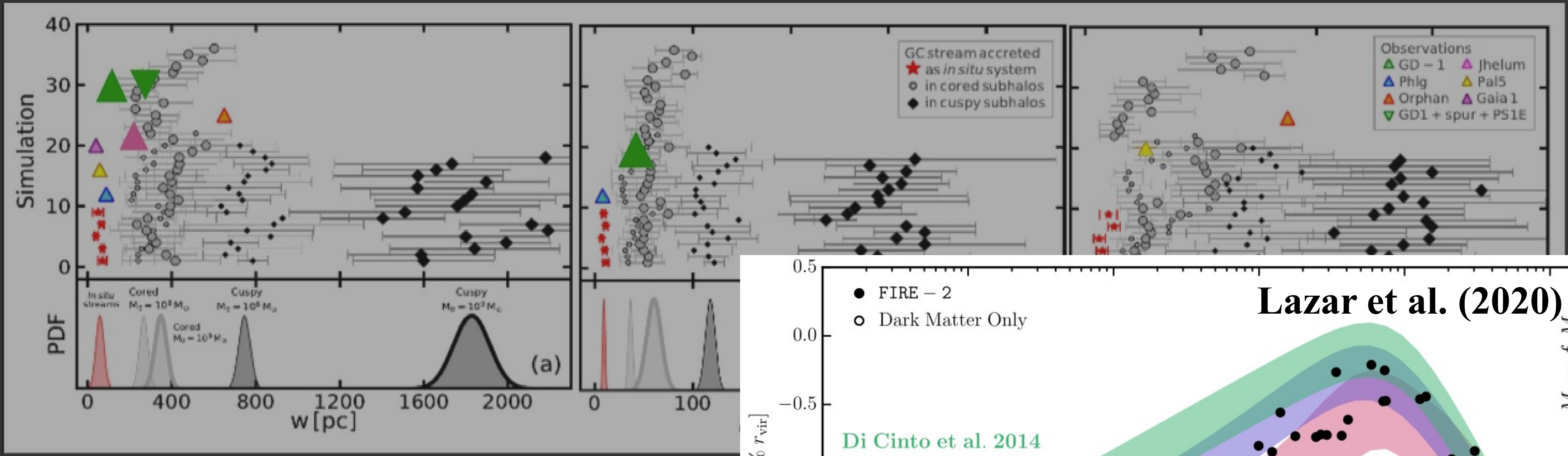
~~Take~~ Stay home messages (arXiv 2005.12919)

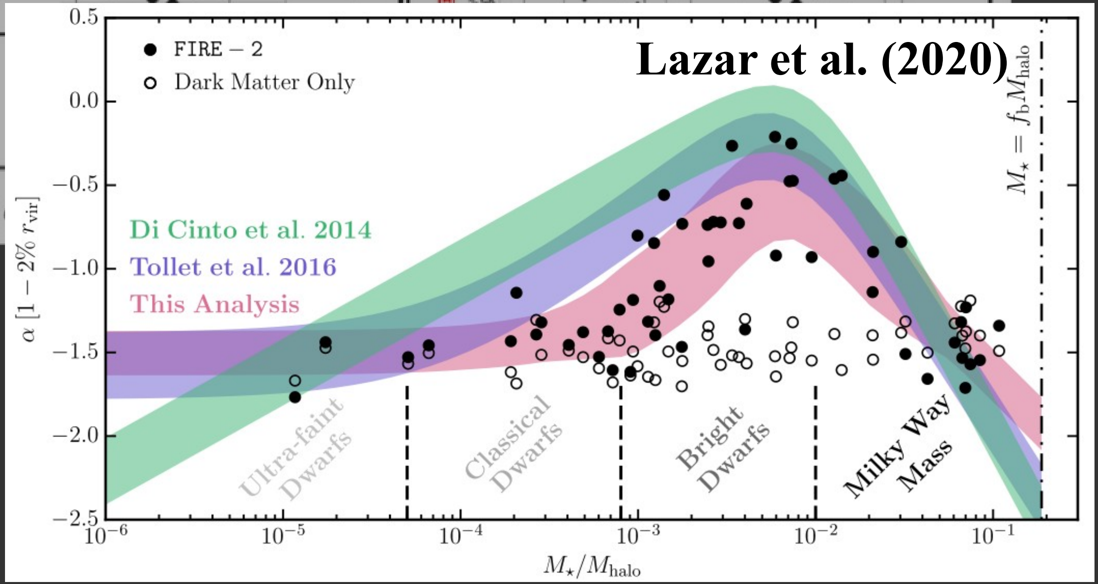
1. Accreted GC streams are extremely sensitive to the inner DM density profiles (e.g., cusp or core) of their parent satellite galaxies, and therefore provide a new way to probe the nature of DM.

2. A first comparison of Milky Way streams **GD-1** and **Jhelum** with the simulations favours scenario where parent satellite galaxies of these streams possessed **cored** DM density profiles. This measurement at some level implies DM models beyond CDM (e.g. SIDM, etc).

Probing dark matter with accreted GC streams

Each point represents a GC stream





If the analysis of stellar populations of these stellar streams indicate that their parent galaxies were ultra faint/classical dwarfs with DM masses ∼ < 10^{10} M⊙ (and M_*/Mhalo ∼ < 10^{-3}), then we are driven to consider physics beyond CDM.