Gaia eDR3 proper motions energies, angular momenta of Milky Way dwarfs: are they at first infall?

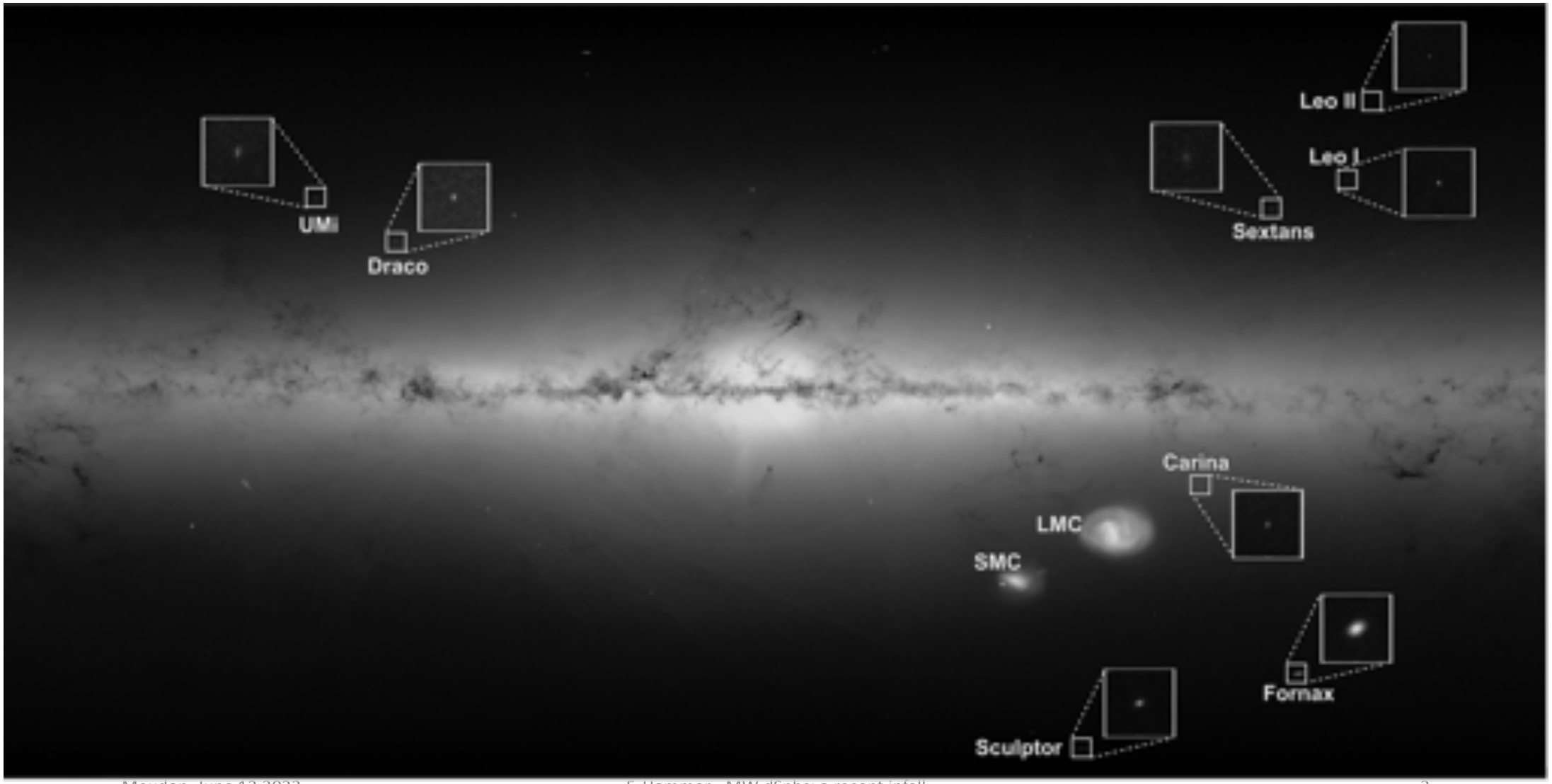
Presented par François Hammer

With: Jianling Wang, Marcel Pawlowski, Yanbin Yang, Piercarlo Bonifacio, Hefan Li, Fréderic Arenou, Carine Babusiaux, and Yongjun Jiao

2 Papers (2021):

I. **Gaia EDR3 Proper Motions of Milky Way Dwarfs. I. 3D Motions and Orbits** **Li et al.** (2021, ApJ, 916, 8)

II. **Gaia EDR3 proper motions of Milky Way dwarfs. II: Velocities, Total Energy and Angular Momentum** **Hammer et al.** (2021, ApJ, 922, 93)


UMi
Draco
Leo II
Leo I
Sextans
Carina
LMC
SMC
Sculptor
Fornax

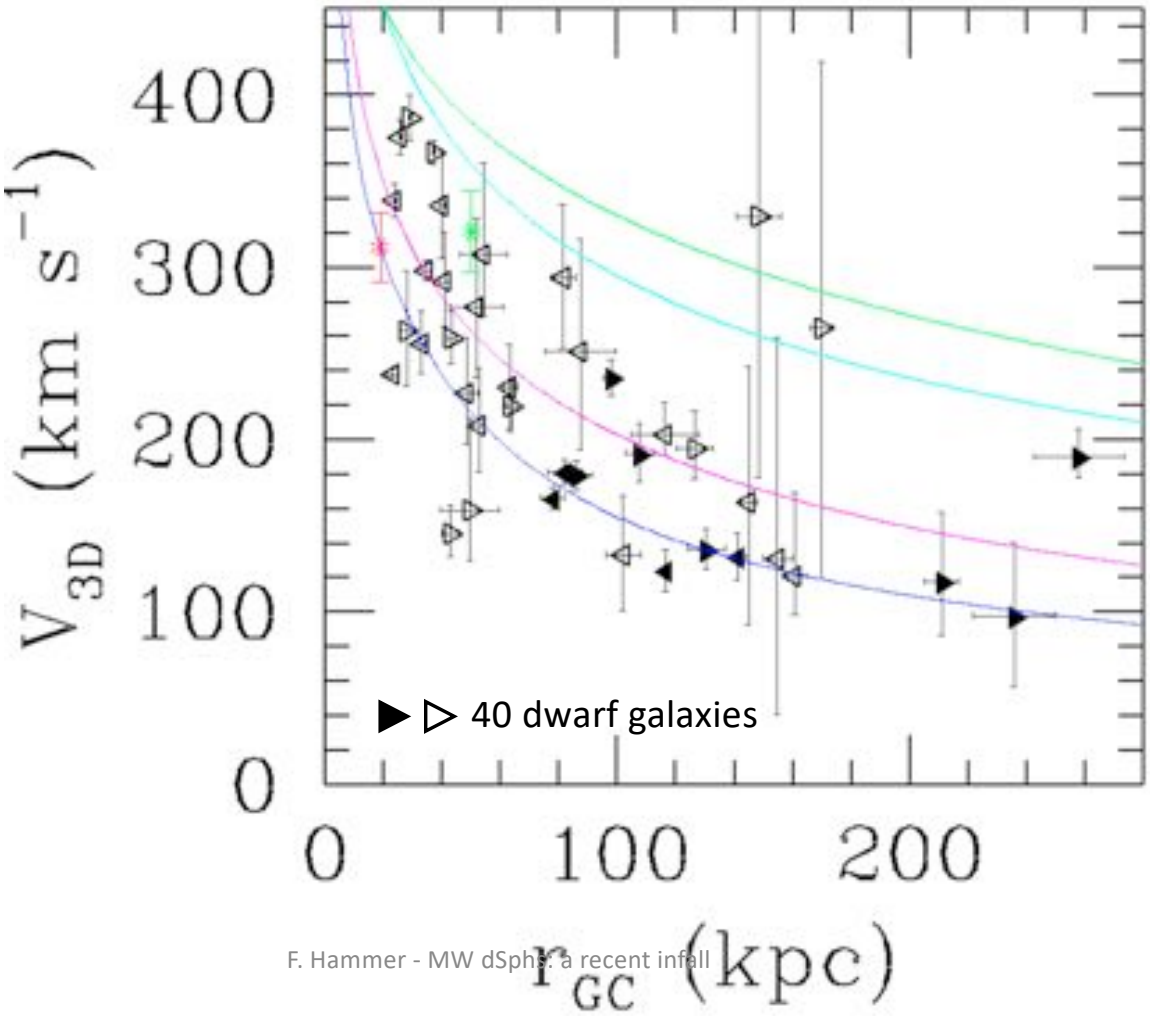
Gaia EDR3: a revolution for Milky Way dwarf orbits

- Error on proper motions divided by a factor 2.5
- 3D velocities, total energies & angular momenta for 30 Milky Way dwarfs instead of 12 !

Gaia EDR3: a revolution for Milky Way dwarf orbits

Do we know if Milky Way dwarfs are bound or not? It depends on the adopted mass for the Milky Way

Here we only consider Milky Way masses and profiles consistent with the Gaia DR2 Milky Way rotation curve (Eilers et al. 2019)



Models from Jiao et al. 2020

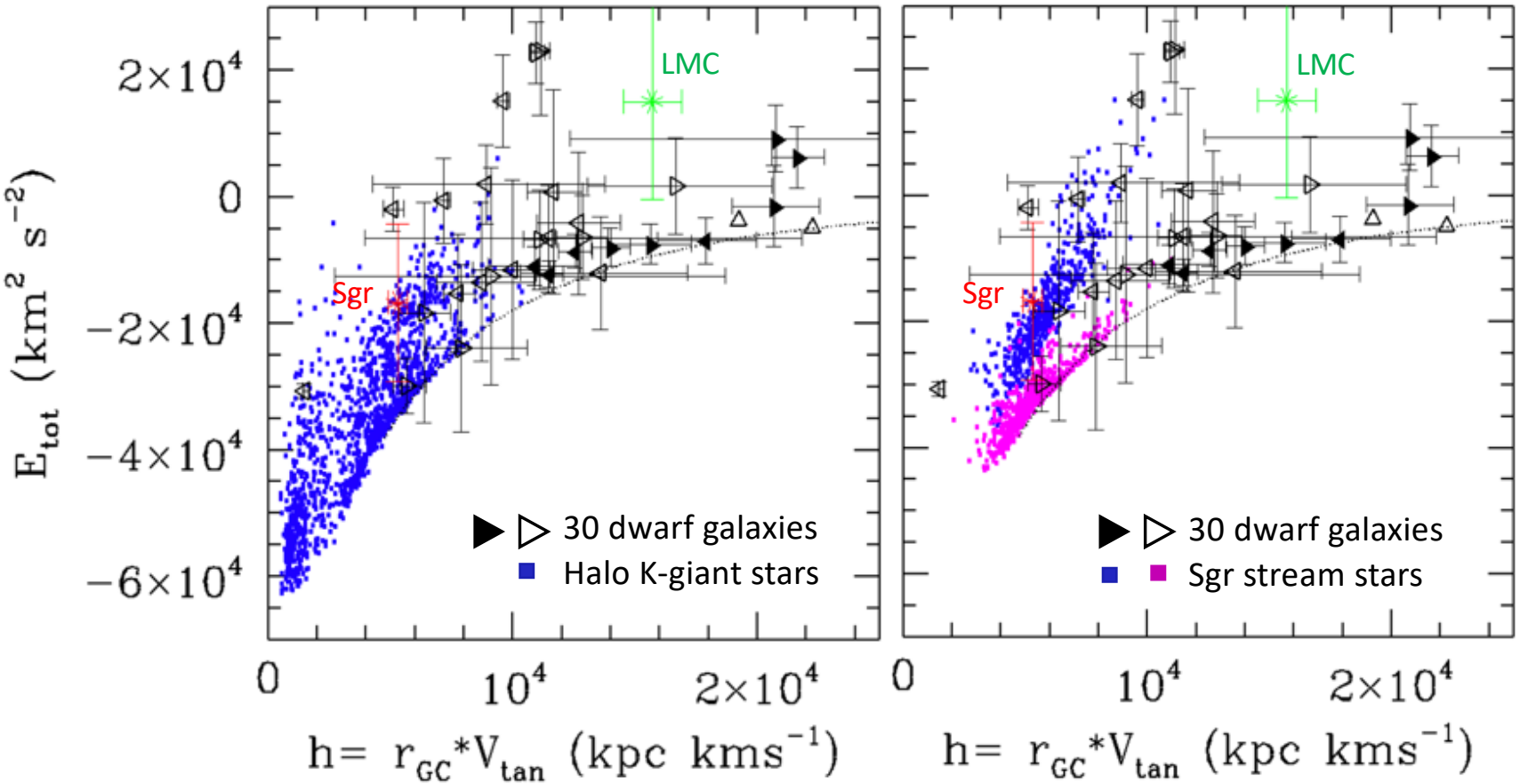
V_{esc}, M_{tot}=14.4 10^{11} M_{sun}

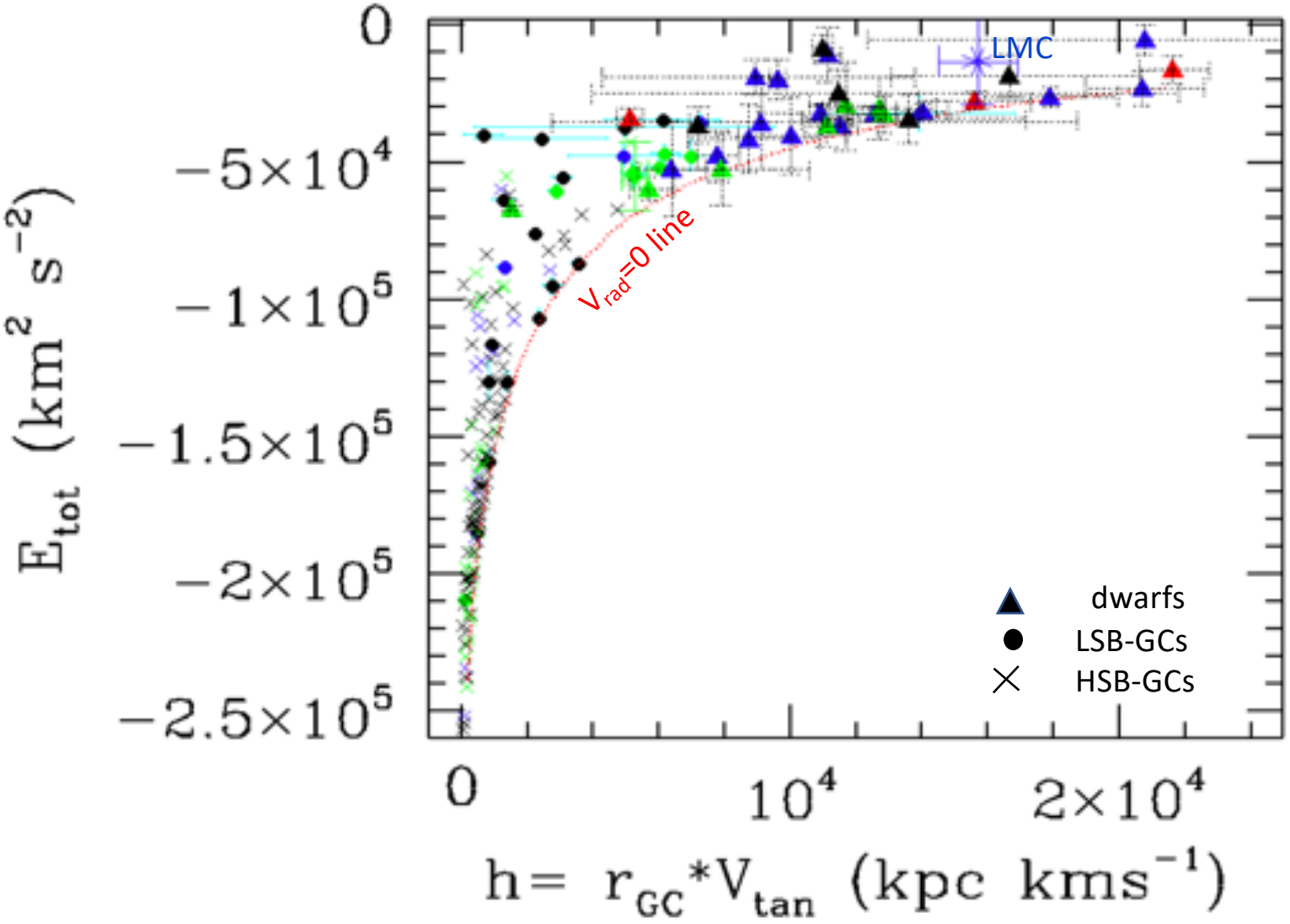
V_{esc}, M_{tot}=8.1 10^{11} M_{sun}

V_{esc}, M_{tot}=5.1 10^{11} M_{sun}

V_{esc}, M_{tot}=2.8 10^{11} M_{sun}

Total energy versus angular momentum: comparison with K-giant stars & Sgr stream stars

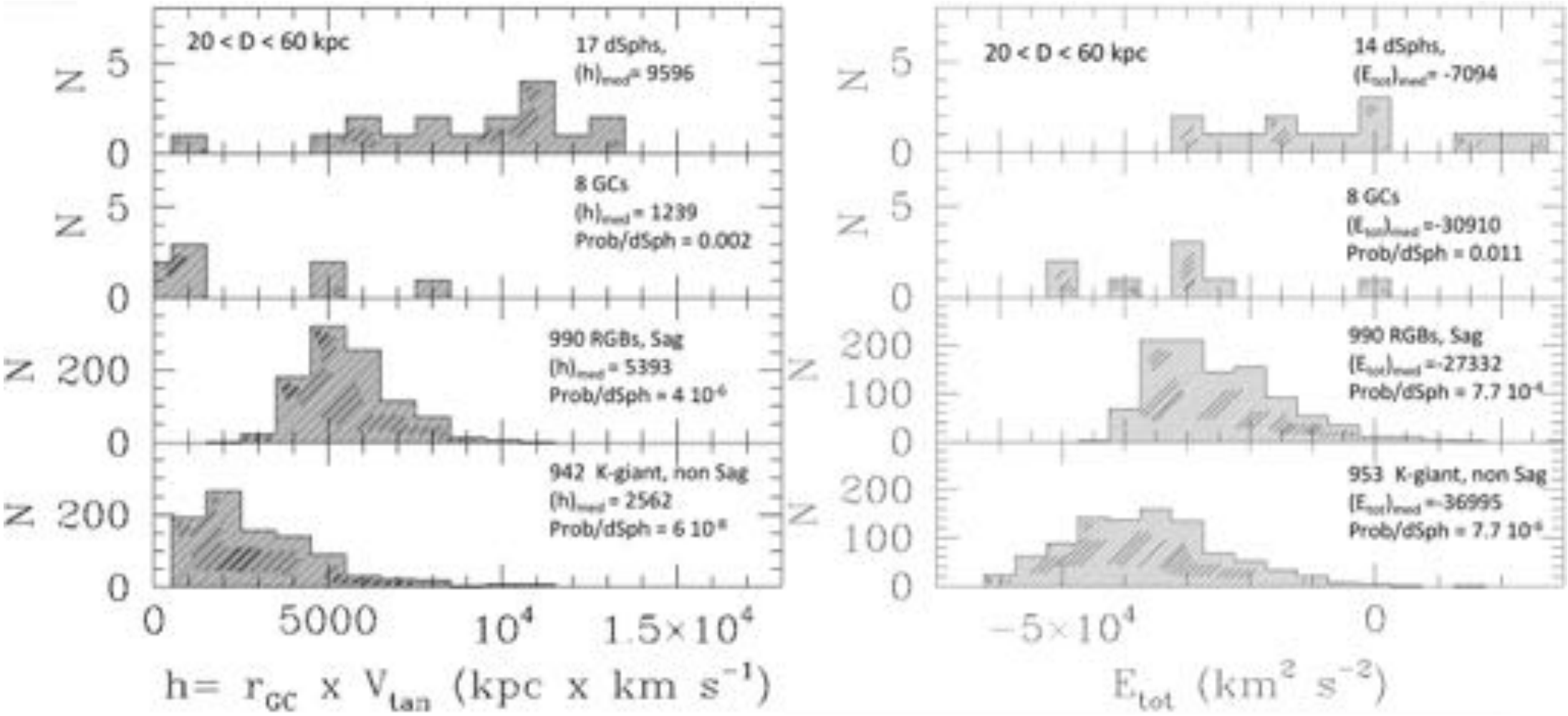




Based on Hammer et al. 2021:

- High energy & angular momentum of dwarfs distinguish them from all other unhabitants of the MW halo
- Highest energy correspond to latest arrival (Boylan-Kolchin et al. 2013)
- Assuming Sgr infall 4-6 Gyr, it is consistent with a recent infall for a large majority of MW dwarfs

Total energy versus angular momentum at ≤ 60 kpc: comparison with K-giant stars & Sgr stream stars



GAIA EDR3 : energies and angular momenta of MW dwarfs are significantly larger than K-giant stars & Sgr stream stars

Very robust comparison: valid for all Milky Way masses
at ≤ 60 kpc sample of dwarfs is complete

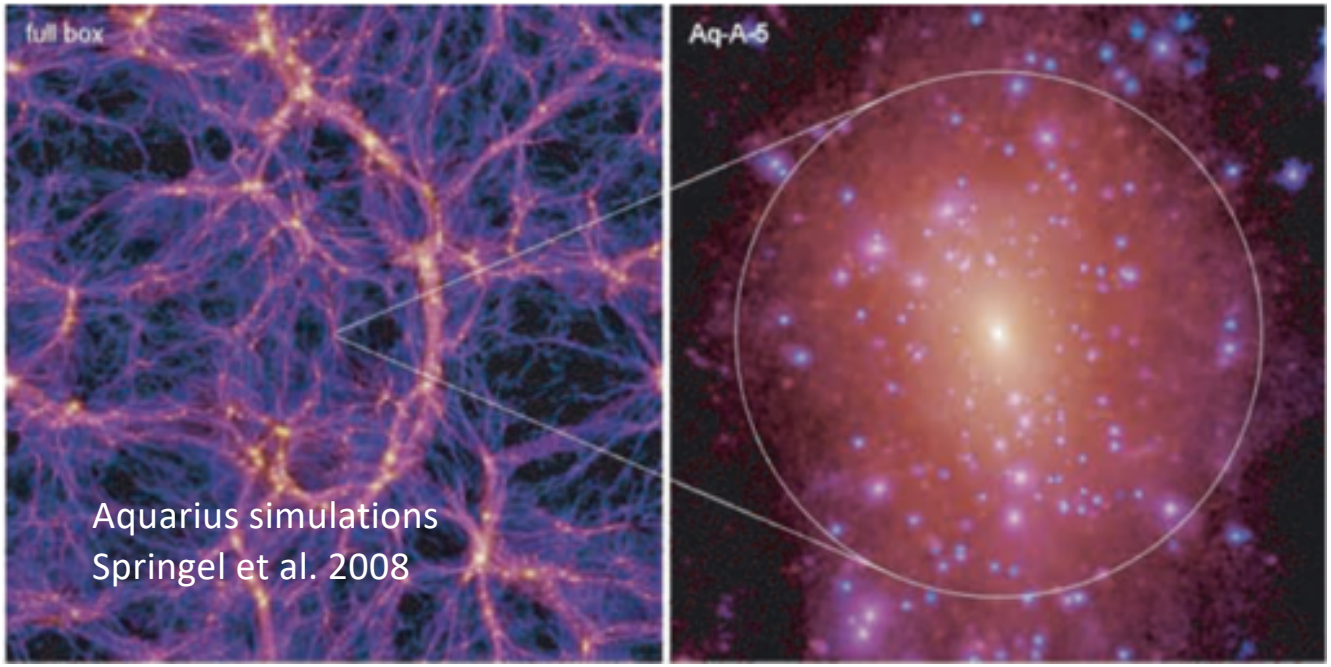
K-giant stars: from the primordial Milky Way or from Gaia-Enceladus (8-10 Gyr ago)

Sgr stream stars: infall 4-6 Gyr ago

Last comers have highest energies & angular momenta (Boylan-Kolchin et al. 2013)

➔ Milky Way dwarfs are coming since ≤ 2 Gyr ago, just the time to make one orbit, i.e., **most Milky Way dwarfs are new comers to the halo! As the LMC!**

Milky Way dwarfs are no more long-lived satellites



Are they consistent with ΛCDM subhalos?

Are Milky Way dwarfs consistent with subhalos?

- Tangential/radial velocities
- Spatial location
- Locations versus pericenters

Are Milky Way dwarfs consistent with subhalos?

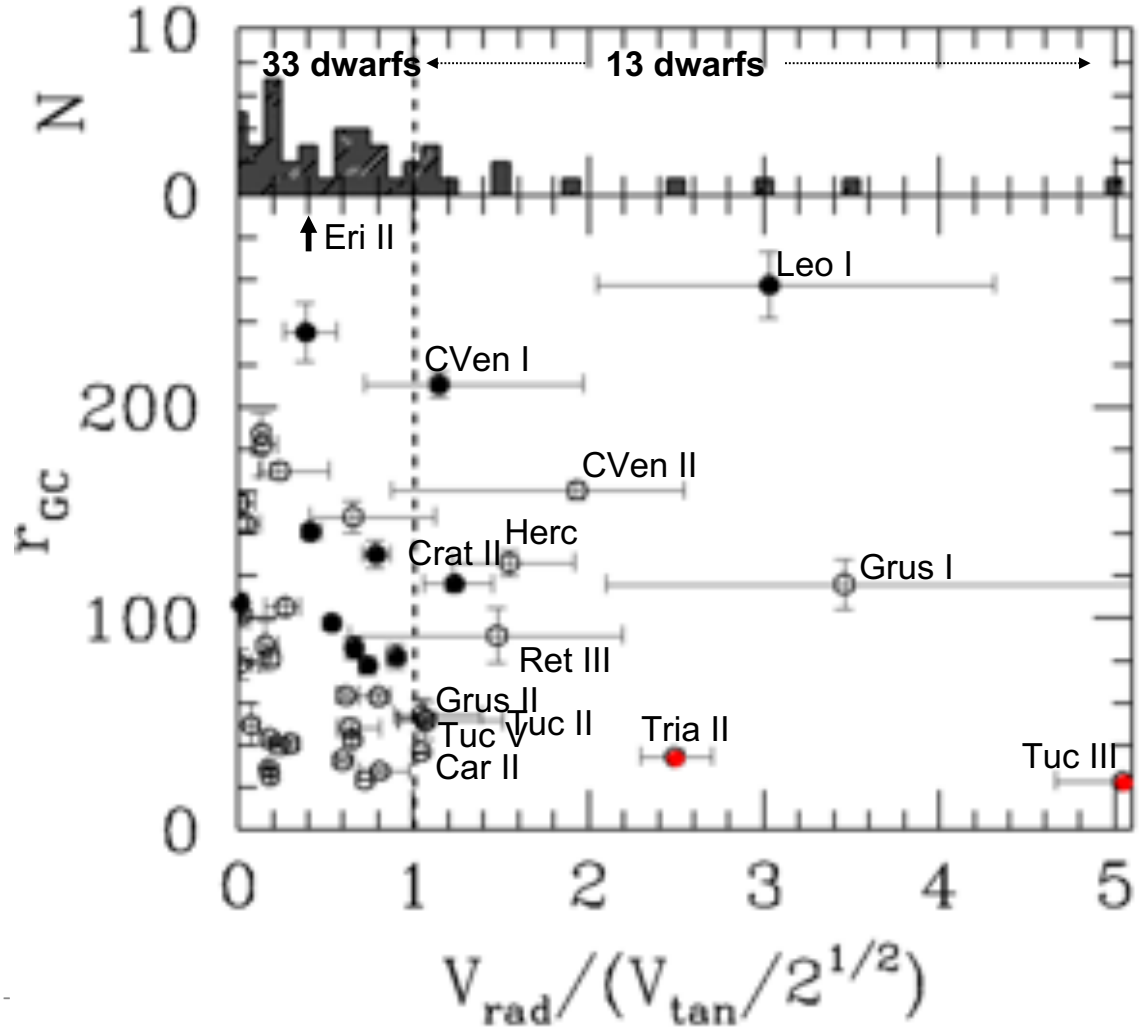
- **Tangential/radial velocities**
- Spatial location
- Locations versus pericenters

Are Milky Way dwarfs consistent with subhalos?

- **Tangential/radial velocities**

As already found by Cautun & Frenk (2017), dwarfs have excessive tangential velocities when compared to subhalos (see also Riley et al. 2019), they estimate to 2-3% the fraction of halos consistent with the observations.

Gaia EDR3: 33/46 dwarfs have excessively large V_{tan}



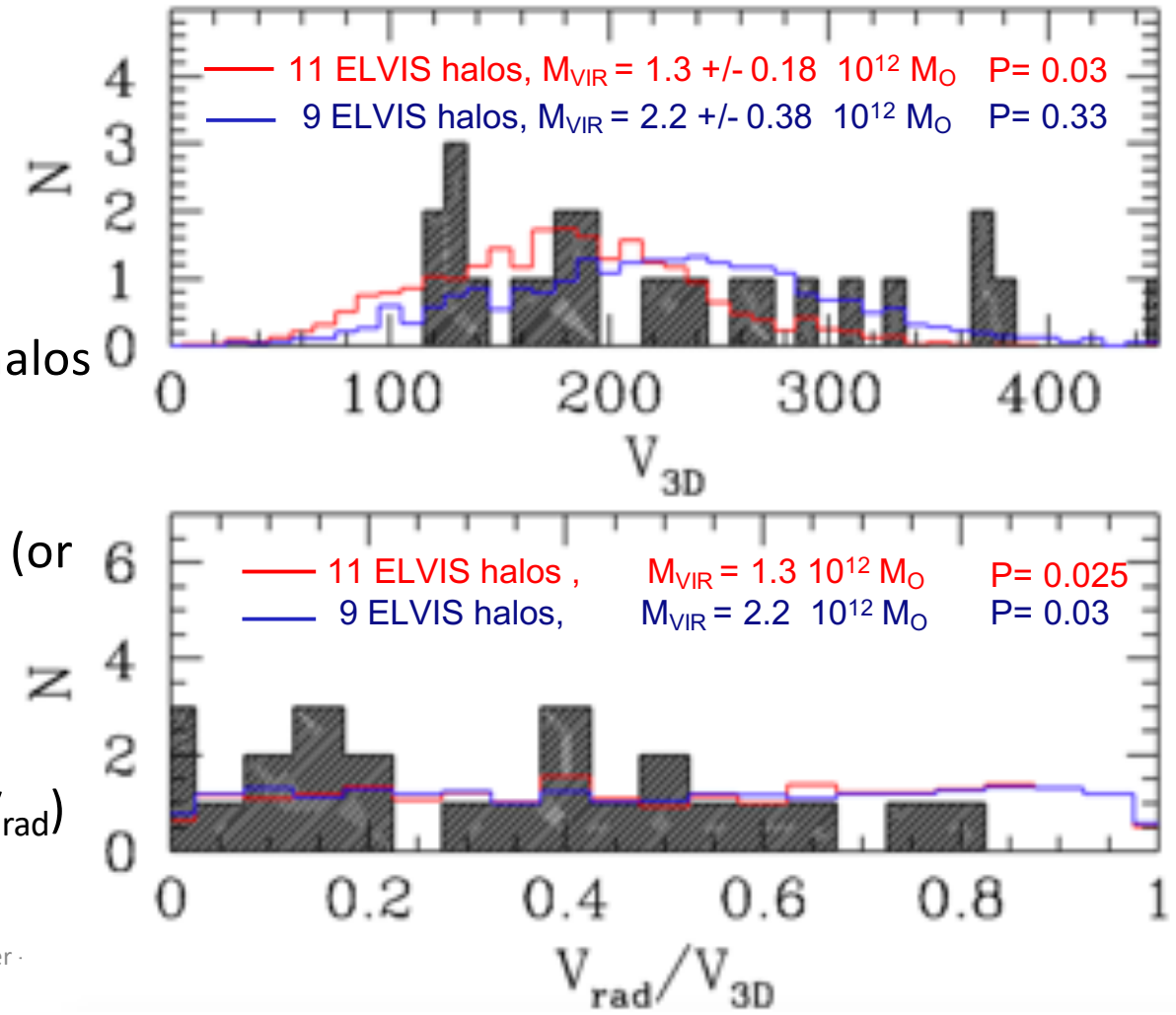
Are Milky Way dwarfs consistent with subhalos?

- **Tangential/radial velocities**

Comparison with ELVIS -host halos and subhalos from Garrison-Kimmel et al. 2014

Only massive host halos fit the 3D velocities (or kinetic energies), but not the rotation curve

Only 3% of host halos have subhalos with tangential velocity excess (or deficiency of V_{rad})



Are Milky Way dwarfs consistent with subhalos?

- **Tangential/radial velocities: 0.03 of occurrence**
- Spatial location
- Locations versus pericenters

Are Milky Way dwarfs consistent with subhalos?

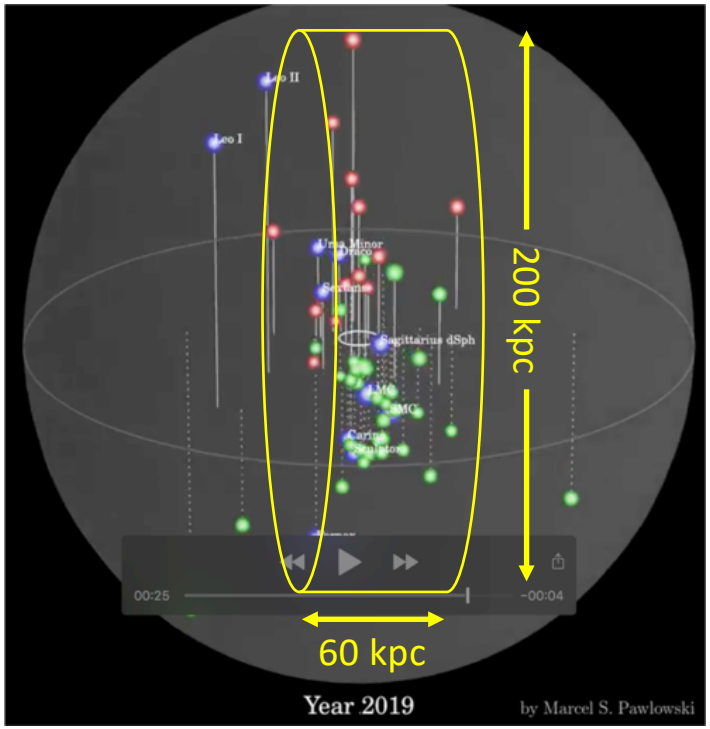
- Tangential/radial velocities: 0.03 of occurrence
- **Spatial location**
- Locations versus pericenters

Are Milky Way dwarfs consistent with subhalos?

- **Spatial location**

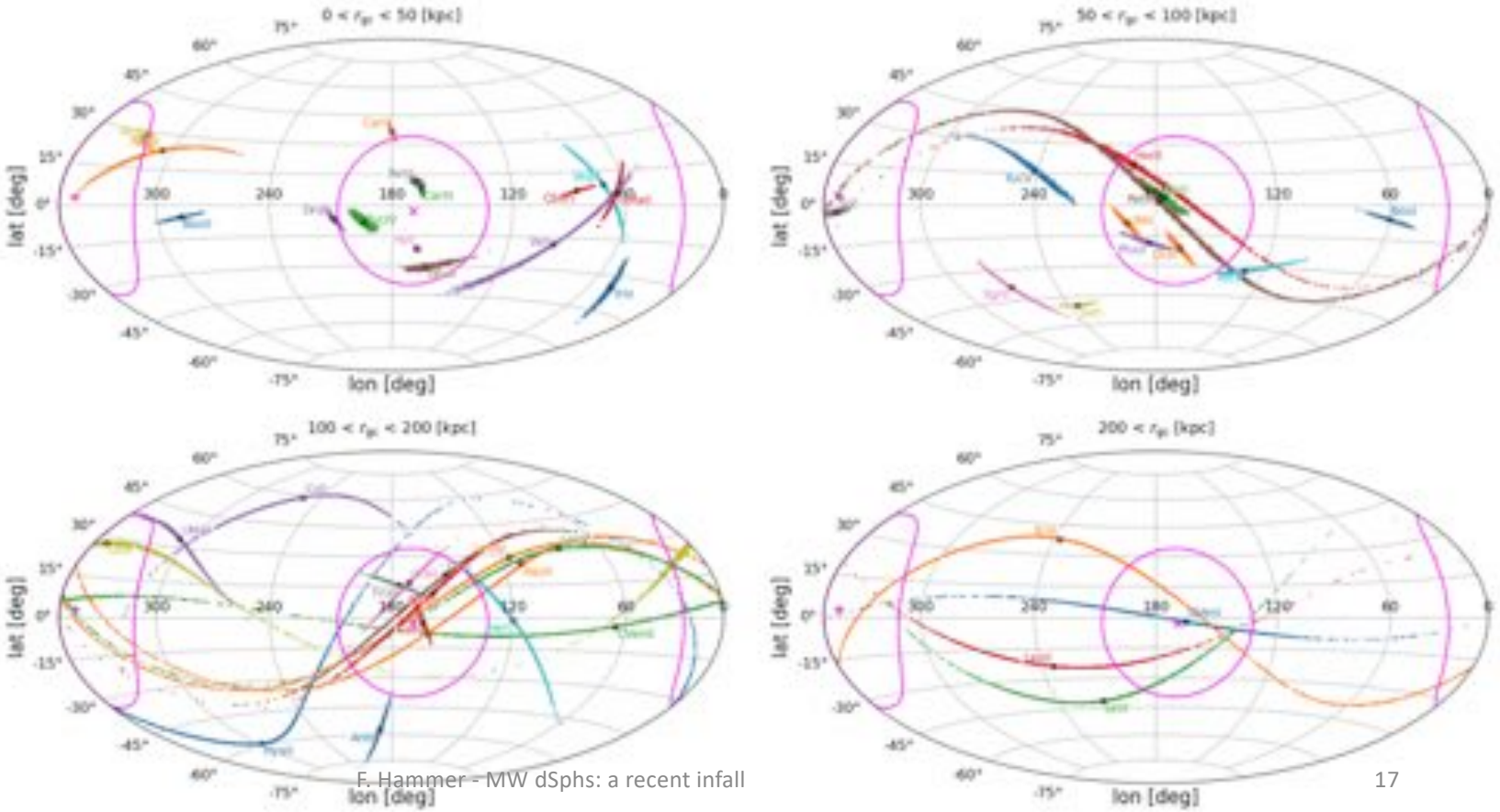
Many Milky Way dwarfs lie and move into the Vast Polar Structure (200x60 kpc^2), still not consistent with LCDM halo/subhalos (Pawlowski et al. 2014-2021)

Comparison with simulated subhaloes: P < 0.005 (Pawlowski 2018, and others)



Are Milky Way dwarfs consistent with subhalos?

- **Spatial location: Gaia EDR3 confirms that 50 to 66% of dwarfs lie and move in the VPOS**



Li et al. (2021)

Are Milky Way dwarfs consistent with subhalos?

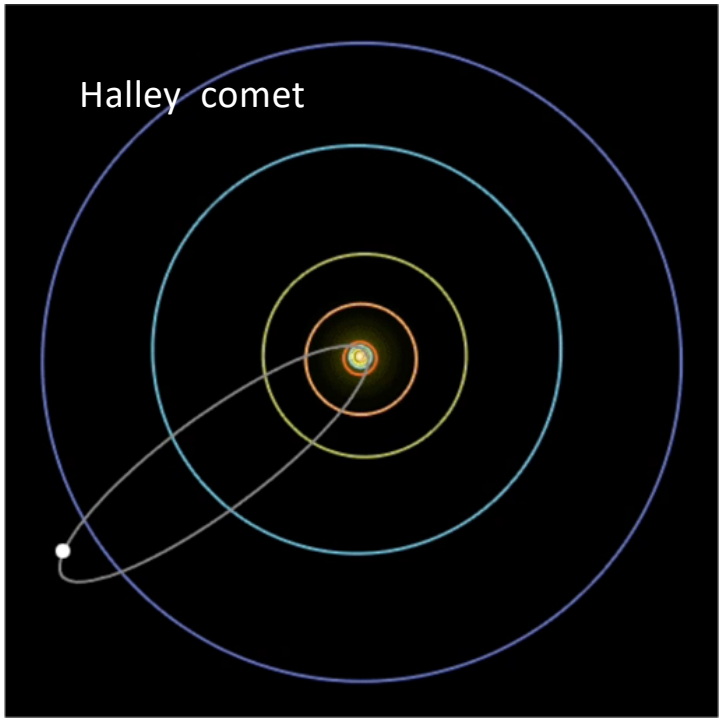
- Tangential/radial velocities: 0.03 of occurrence
- **Spatial location: < 0.005 of occurrence**
- Locations versus pericenters

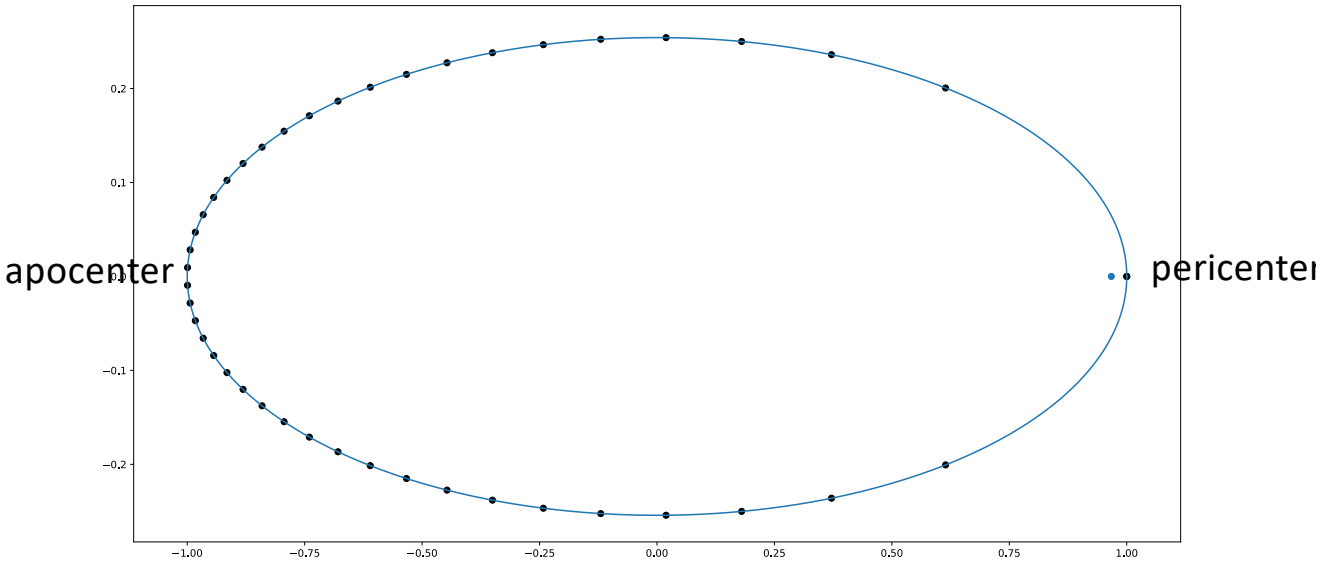
Are Milky Way dwarfs consistent with subhalos?

- Tangential/radial velocities: 0.03 of occurrence
- Spatial location: < 0.005 of occurrence
- **Locations versus pericenters**

Are Milky Way dwarfs consistent with subhalos?

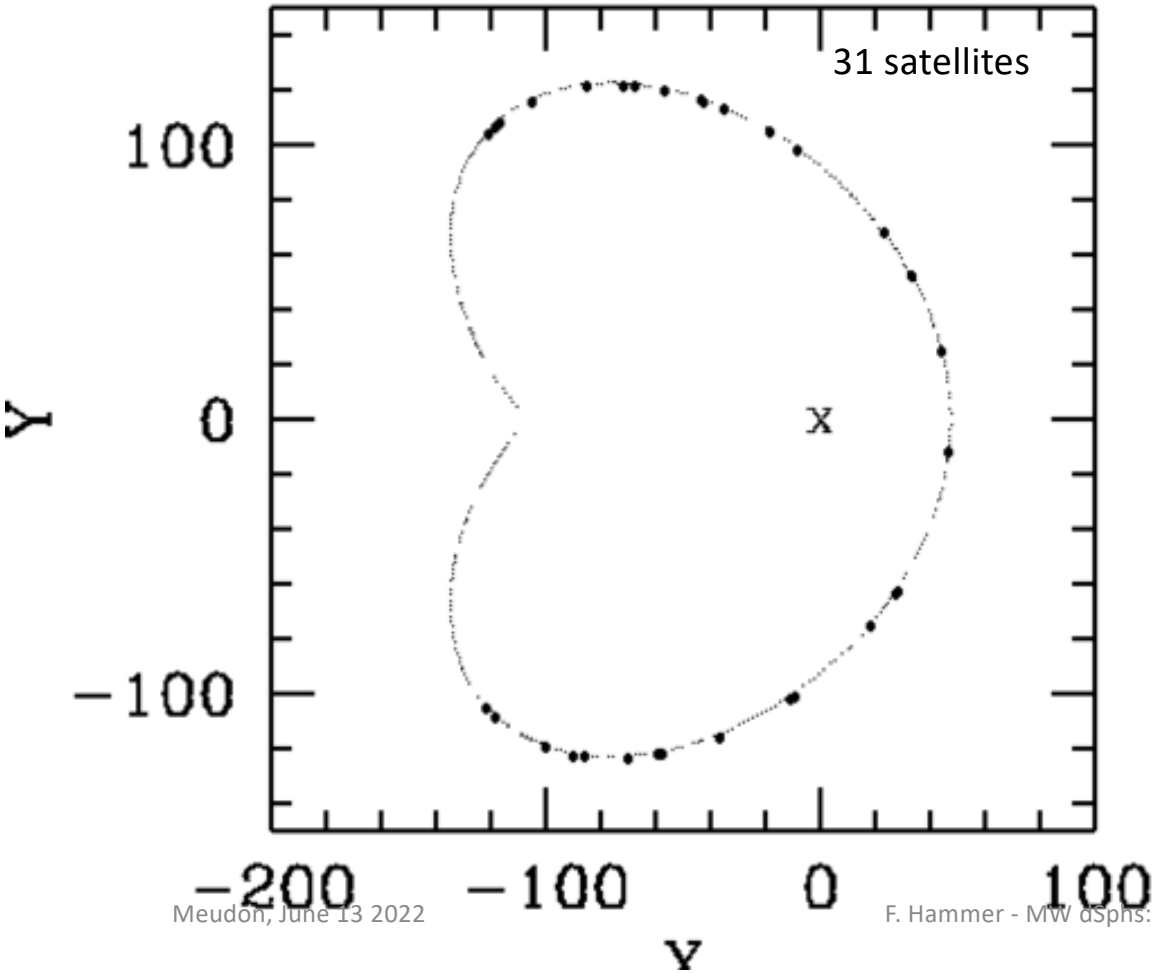
- **Locations versus pericenters: expectations for satellite orbits**

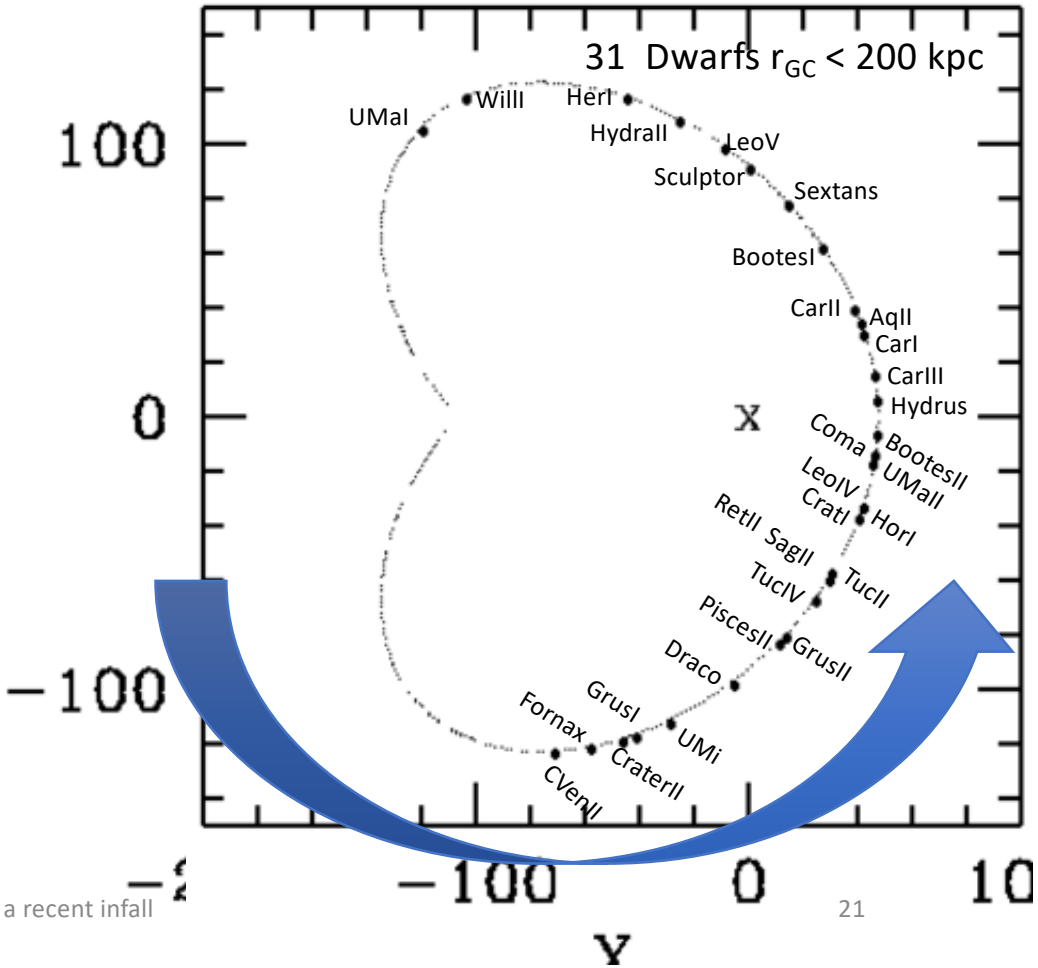




Are Milky Way dwarfs consistent with subhalos?

- **Locations versus pericenters: expectations for satellite orbits**



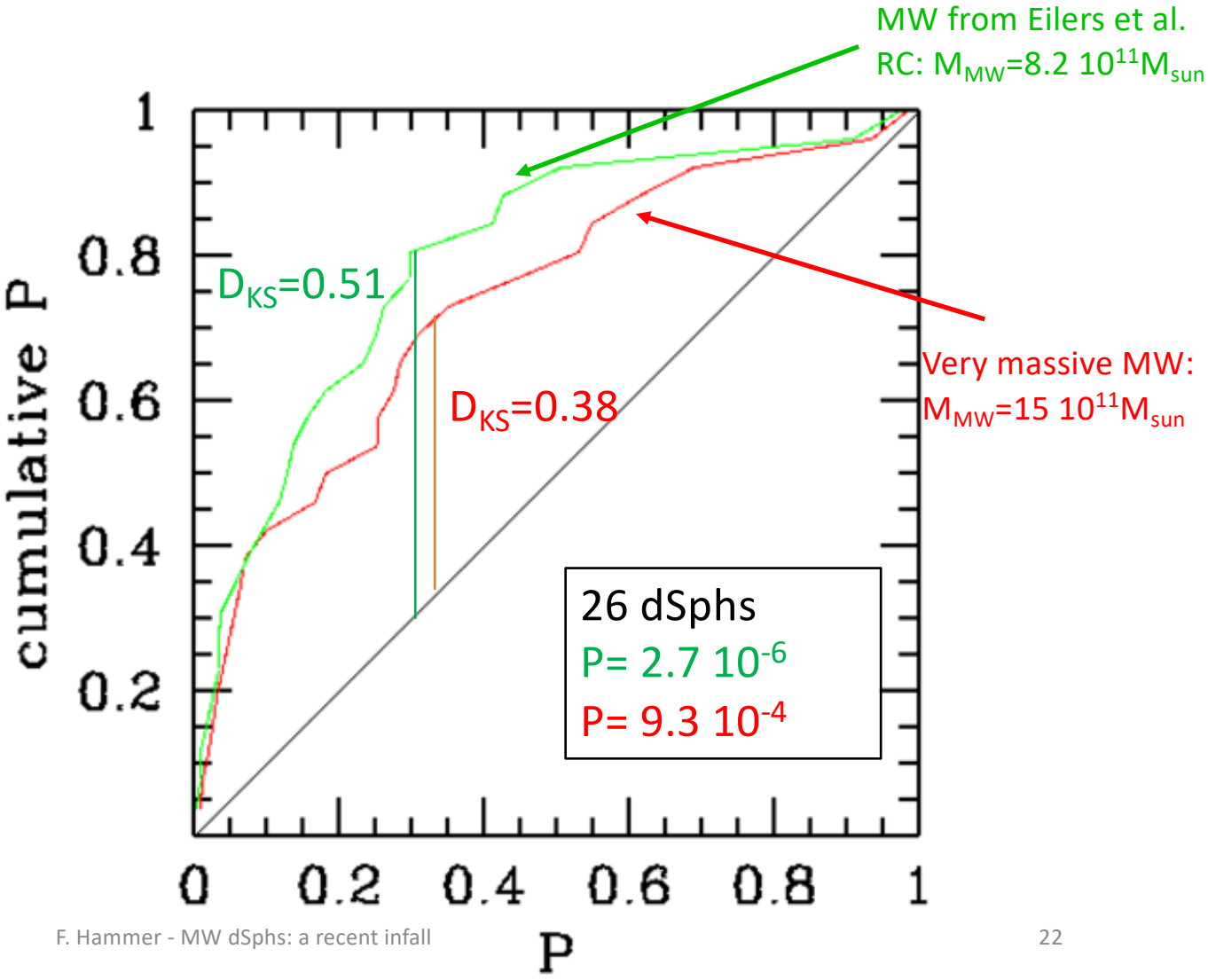


- **Locations versus pericenters: expectations for satellite orbits**

There could be incompletness in the dwarf inventory affecting especially those at r_{GC} > 100-200 kpc (Drlica-Wagner et al. 2020).

That is why here (Li et al. 2021) we have selected a complete sample of **26 dSphs kept in a complete sample at 90 kpc.**

Dwarfs are too close to their pericenters even if the Milky Way is very massive!!



Are Milky Way dwarfs consistent with subhalos?

- Tangential/radial velocities: 0.03 of occurrence
- Spatial location: < 0.005 of occurrence
- **Locations versus pericenters: < 0.001 of occurrence**

Are Milky Way dwarfs consistent with subhalos?

- Tangential/radial velocities: 0.03 of occurrence
- Spatial location: < 0.005 of occurrence
- **Locations versus pericenters: < 0.001 of occurrence**
- **AND MILKY WAY DWARFS ARE MOSTLY AT FIRST PASSAGE**

Conclusion:
due to their excessive energies and angular momenta, Milky Way dwarfs are late comers into the halo

They are also more anisotropic in space & velocity than subhalos

- Combined rate of occurrence for Milky Way dwarfs to behave as subhalos is rather low: **P << 10^{-3} or ~ 10^{-6} depending on how spatial & velocity anisotropy are dependent one from each other**

➔ **One has to study how they arrived, how they loose their gas, why their velocity dispersions are large, and what is their matter content**