Stellar streams embedded in a fermionic dark matter halo

Seventeenth Marcel Grossmann Meeting 2024

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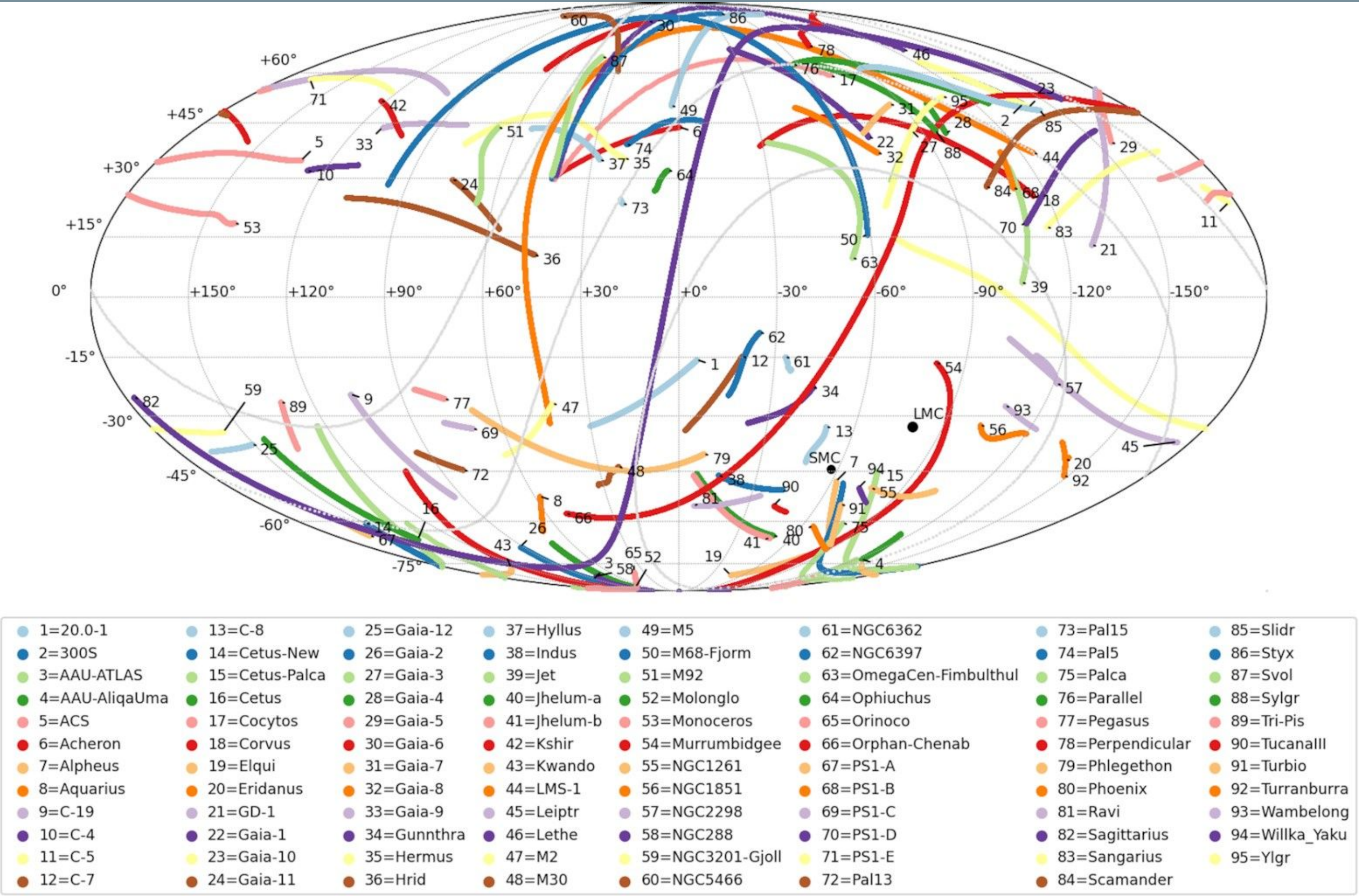
1. Introduction

Stellar streams

Mateu 2023, MNRAS, 520, 4, 5225



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Its leading tail lays in the northern Galactic hemisphere, while the trailing one lays in the southern part of it.

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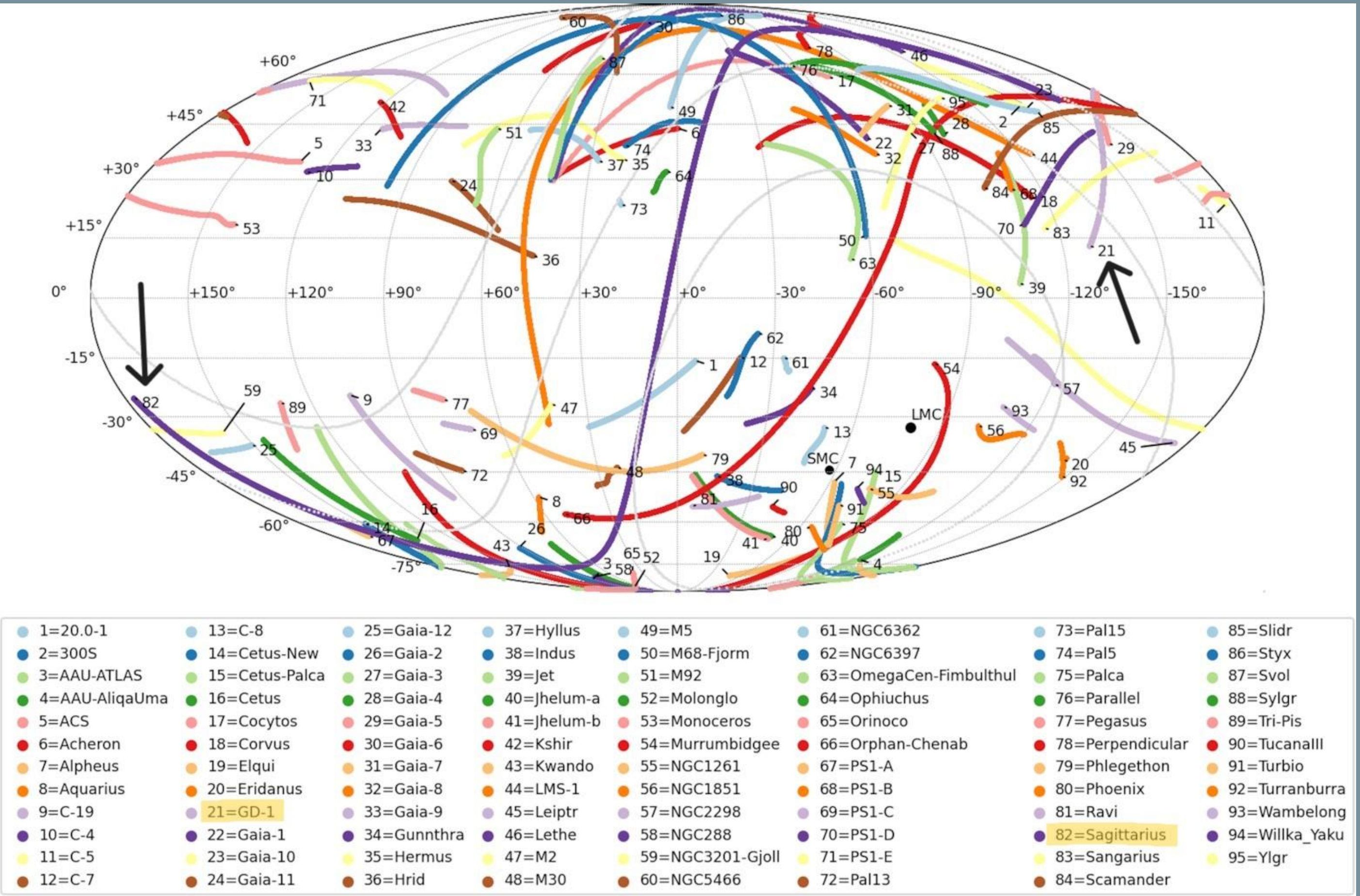

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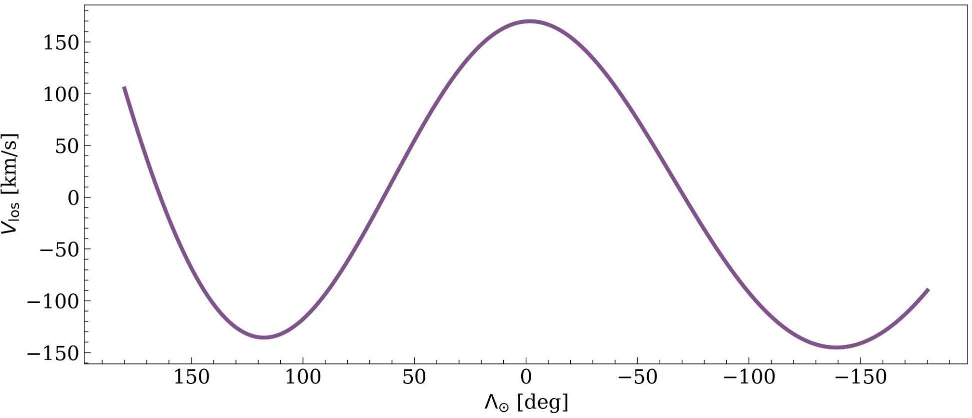
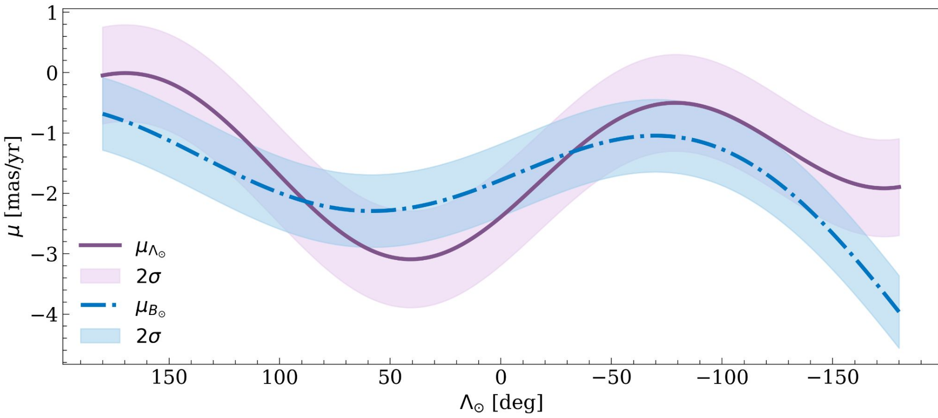
2. Dataset

Sagittarius - Velocity space: Observations from Ibata et al. (2020) ApJL 891 L19, a full 6D map of the Sagittarius stellar stream, reduced from Gaia DR2.





Line of sight velocity

Proper motions

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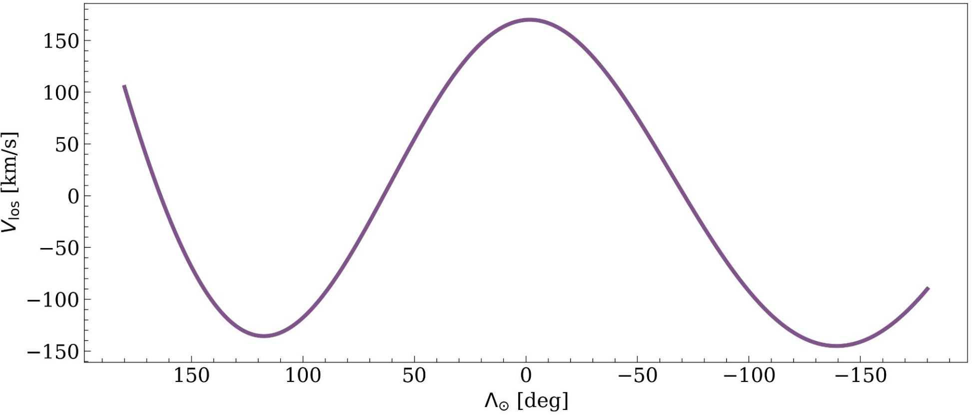

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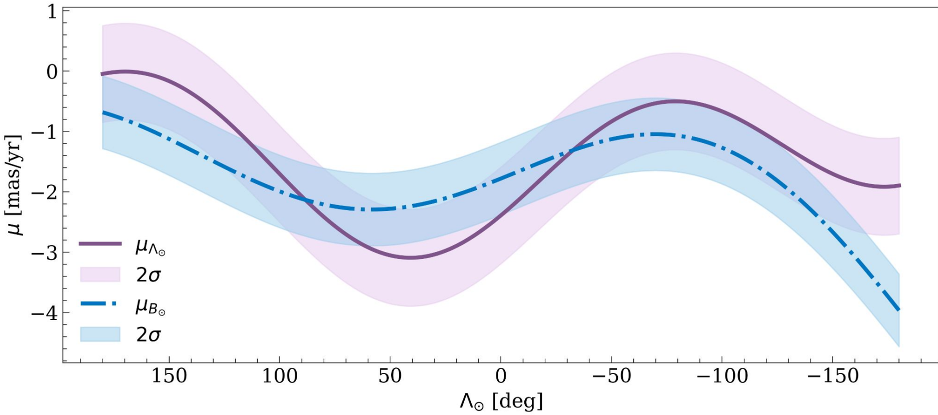

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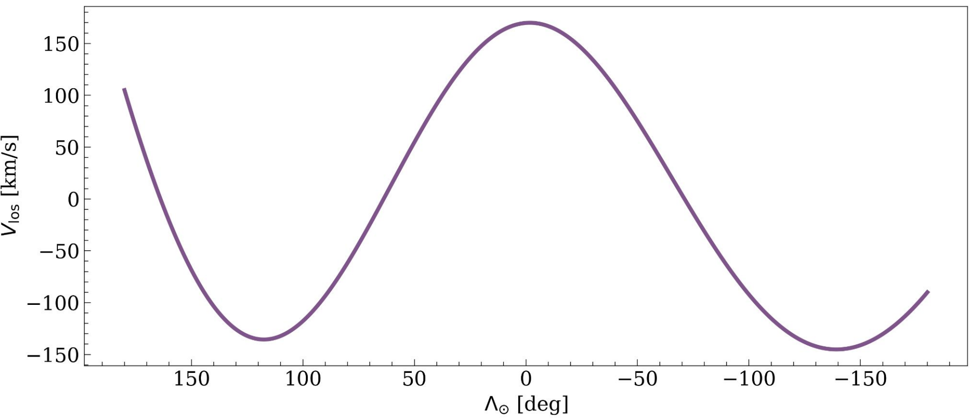

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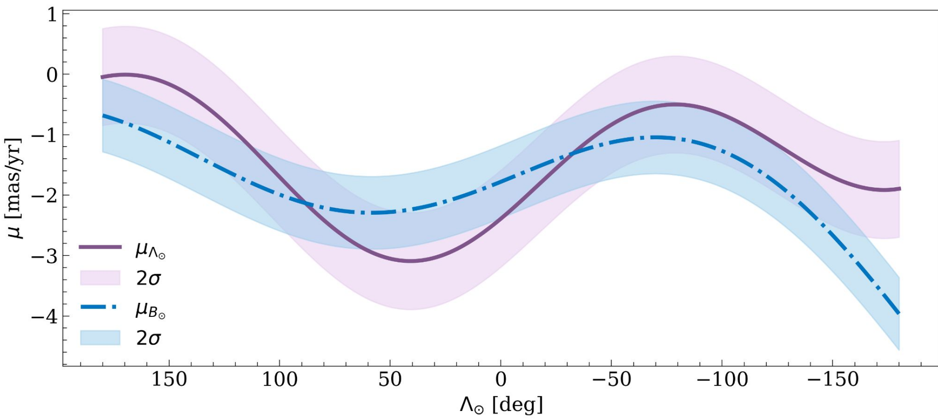

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GD-1 - 5D space: Longitude, latitude, proper motions, and heliocentric radial velocity, parameterized as polynomials as well. Ibata et al. (2020) ApJ 891 161.

3. Modelling methodology

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- Orbit of the progenitor ← Cold streams
- *Spray methods*

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Spray method: IC generator of stars whose orbits are integrated into the joint potential of the satellite and host galaxy. (Gibbons et al. 2014)

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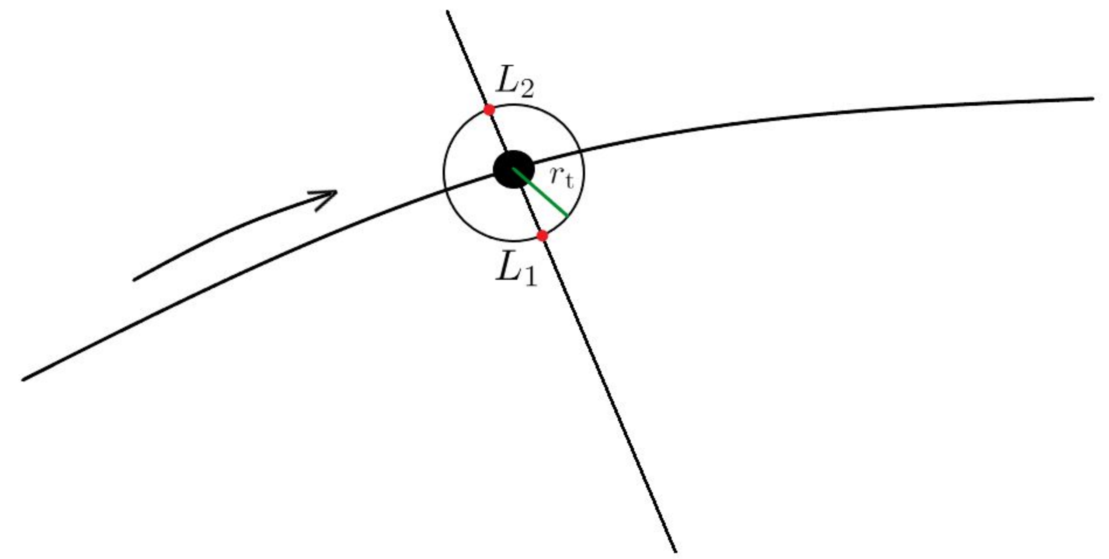
6. Integrate the stars' orbits in the joint potential of the host and satellite.

We modeled the Lagrange points as located at a radial distance r_t, whose model follows the one from Gajda & Łokas (2016).

$$r_t = r\left(\frac{[m(r_t)/M(r)]\lambda(r)}{2\Omega_s/\Omega - 1 + [2 - p(r)]\lambda(r)}\right)^{1/3}$$

$$\lambda(r) = \Omega^2_{\rm circ}/\Omega^2$$

$$p(r) = \frac{d\ \ln M(r)}{d\ \ln r}$$



4. Gravitational potentials

Modeling of the Milky Way (for Sagittarius and GD-1):

- Bulge: Plummer sphere (Pouliasis, E. et al. 2017)
- Thin and thick disks: Miyamoto-Nagai disks (Pouliasis, E. et al. 2017)
- Halo: self-gravitating system of neutral fermions (RAR model, Argüelles et al. 2018)

$$\Phi_{\mathrm{MN}}(R, z) = -\frac{GM}{\sqrt{R^2 + \left(a + \sqrt{z^2 + b^2}\right)^2}}$$

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Modeling of the Sagittarius galaxy:

- Baryons: Plummer sphere
- Halo: RAR model

← The gravitational attraction of the satellite is needed to correctly reproduce the stellar stream (Gibbons et al. 2014).

Enclosed mass

$$\frac{dM(r)}{dr} = 4\pi r^2 \rho(r),$$

Metric potential

$$\frac{d\nu(r)}{dr} = \frac{1}{r}\left[\left(1 - \frac{2GM(r)}{c^2 r}\right)^{-1}\left(\frac{8\pi G}{c^4}P(r)r^2 + 1\right) - 1\right],$$

Cut-off variable

$$W(r) = \frac{1 + \beta_0 W_0 - e^{\nu(r)/2}}{\beta_0},$$

Degeneracy variable

$$\theta(r) = \theta_0 - W_0 + W(r),$$

Temperature variable

$$\beta(r) = e^{-\nu(r)/2}\beta_0.$$

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We defined 2 models for the Sagittarius case:

- RAR 1: Becerra-Vergara, E. A. et al. (2020) (m = 56 keV).
- RAR 3: $W_0 = 2\theta_0$, m = 20 keV.

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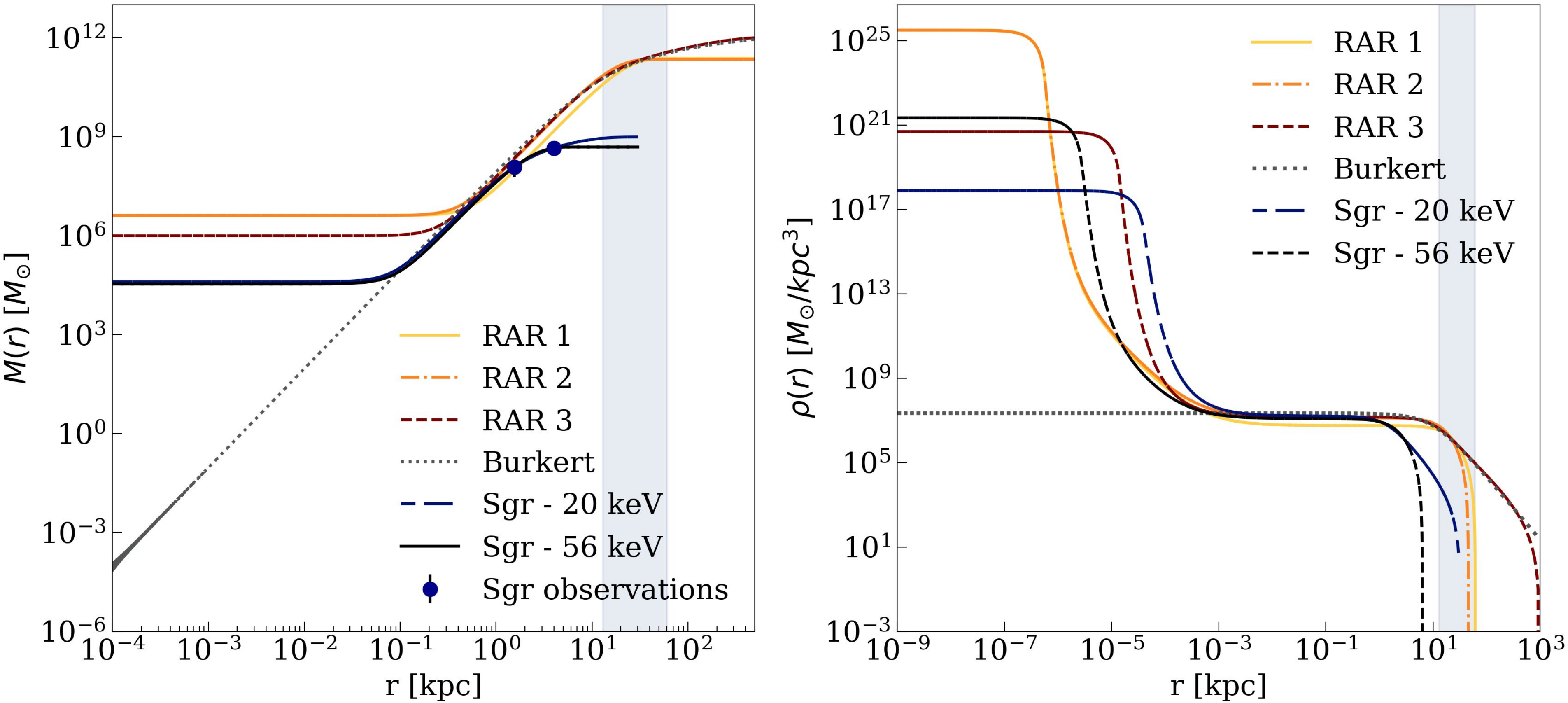
We defined 1 model for the GD-1 case:

- RAR: m = 56 keV.



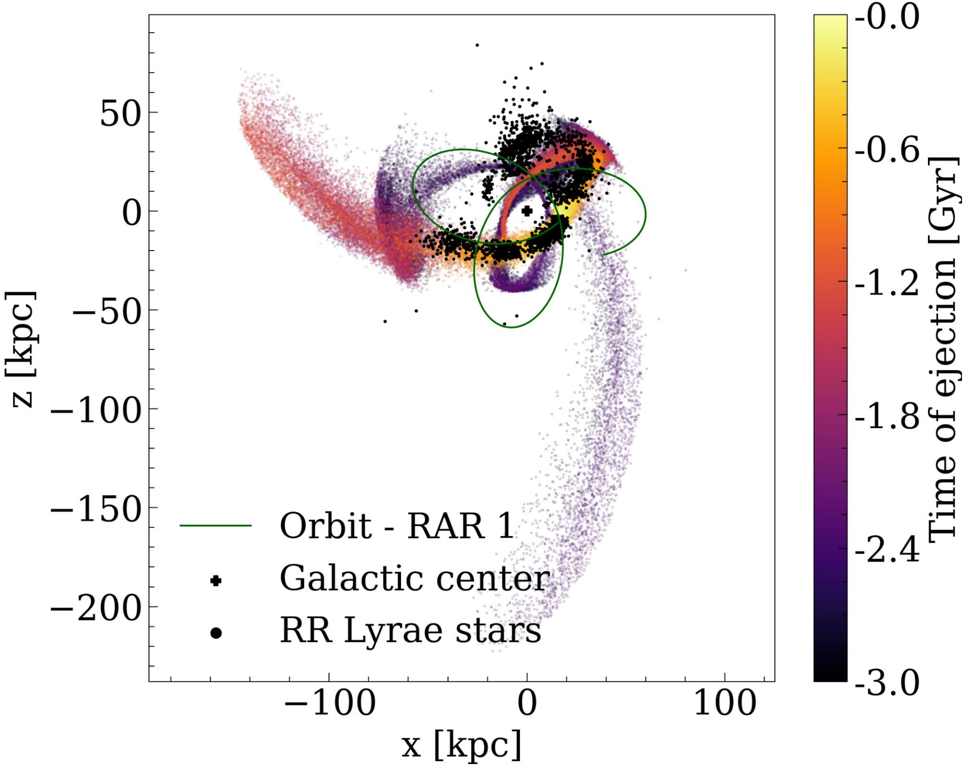
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
$M(r)$ [$M_\odot$]
RAR 1
RAR 2
RAR 3
Burkert
Sgr - 20 keV
Sgr - 56 keV
Sgr observations
10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
r [kpc]
10^{25}
10^{21}
10^{17}
10^{13}
10^{9}
10^{5}
10^{1}
10^{-3}
$\rho(r)$ [$M_\odot/kpc^3$]
RAR 1
RAR 2
RAR 3
Burkert
Sgr - 20 keV
Sgr - 56 keV
10^{-9} 10^{-7} 10^{-5} 10^{-3} 10^{-1} 10^{1} 10^{3}
r [kpc]

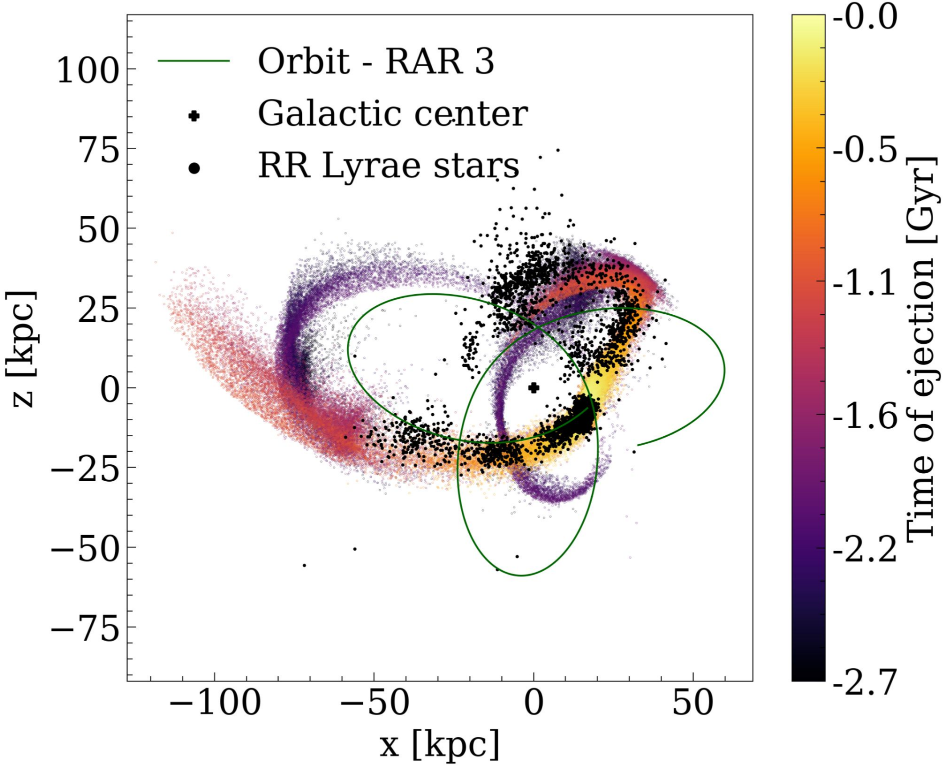
5. Results

We will see just the RAR 1 and RAR 3 results.

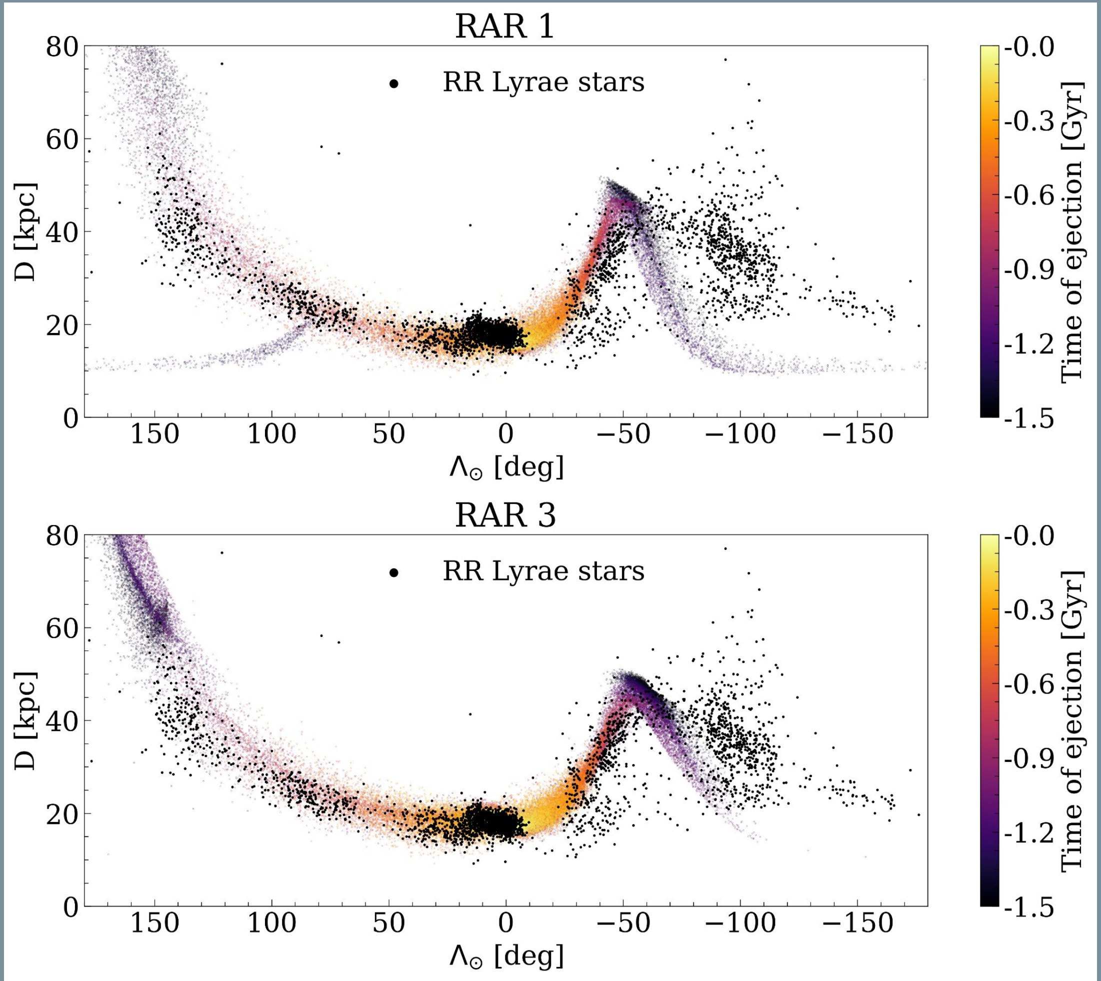
Sagittarius

XZ plane



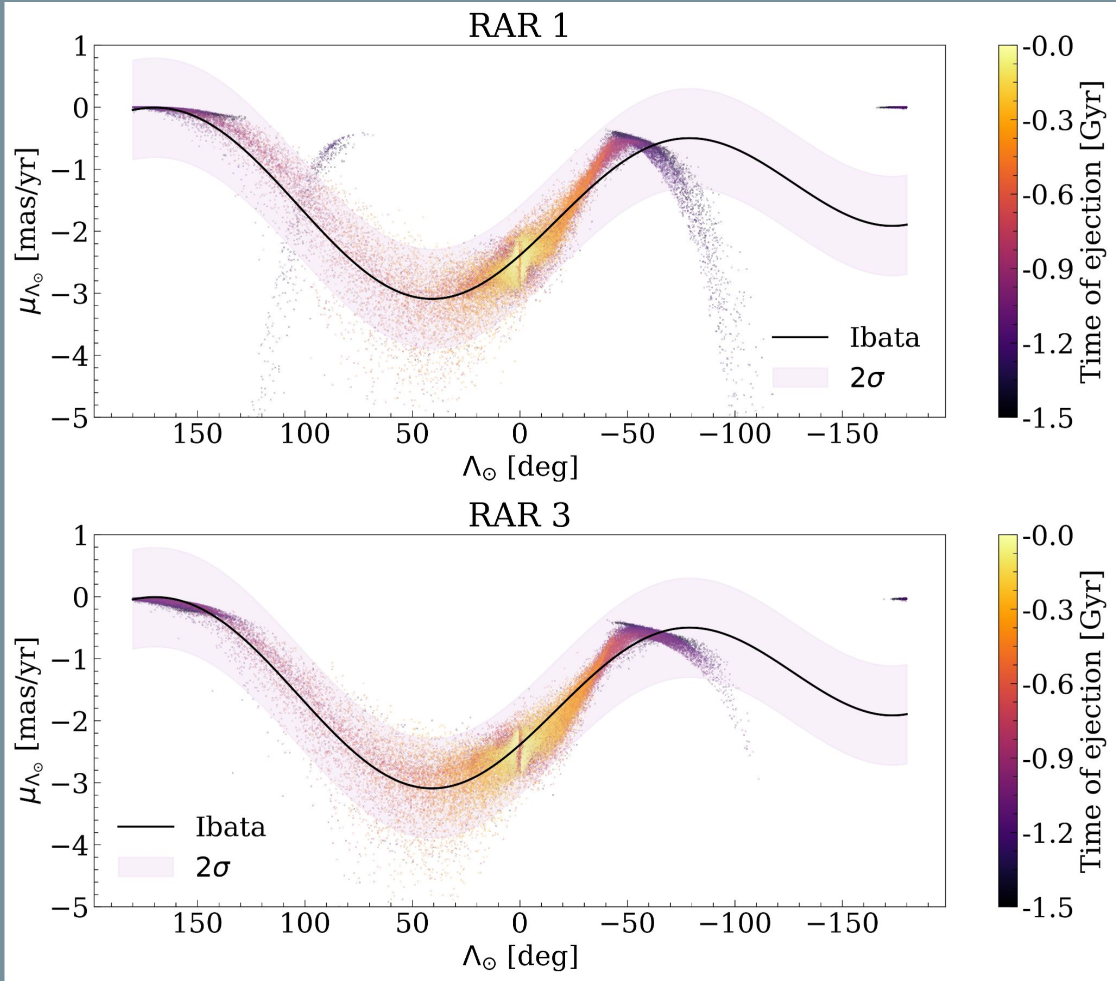


Galactocentric distance vs. Λ Sagittarius



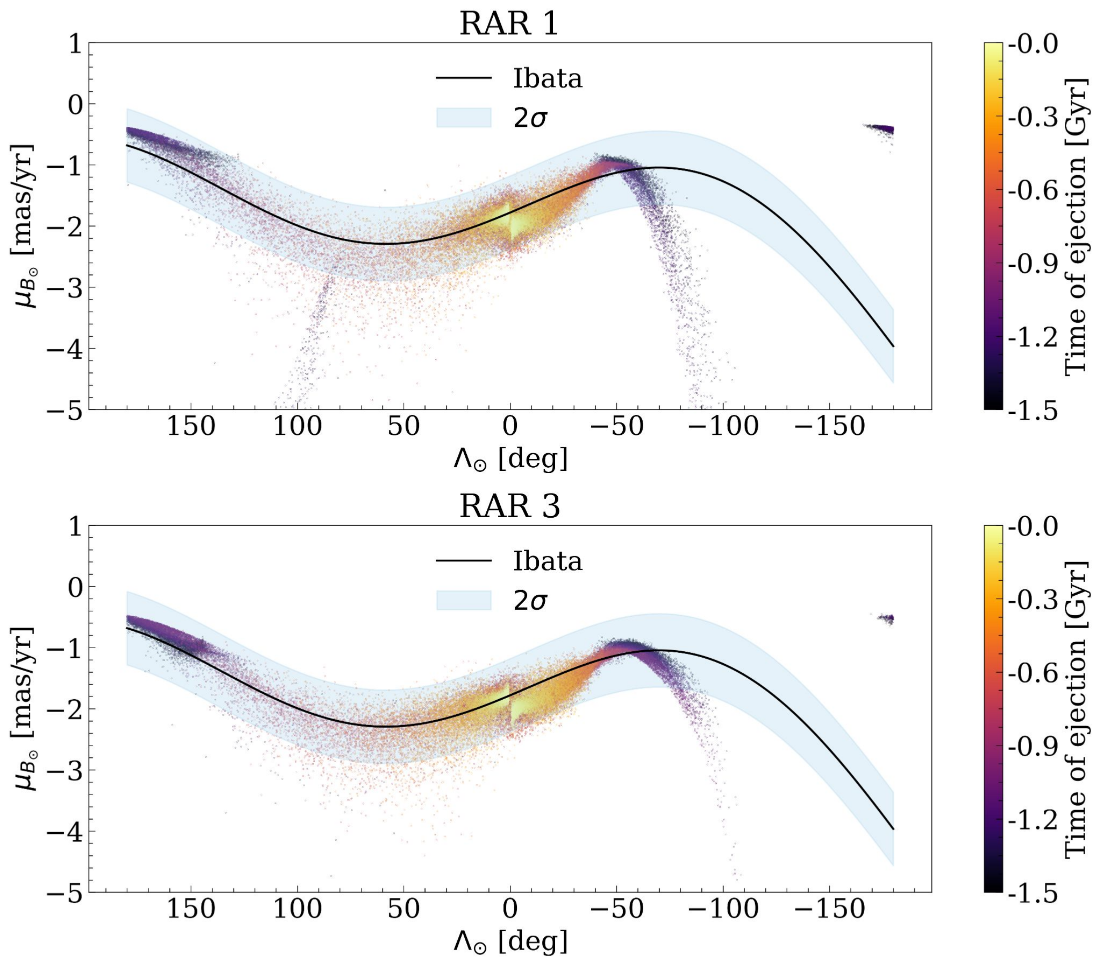
Proper motion Λ vs. Λ

Sagittarius

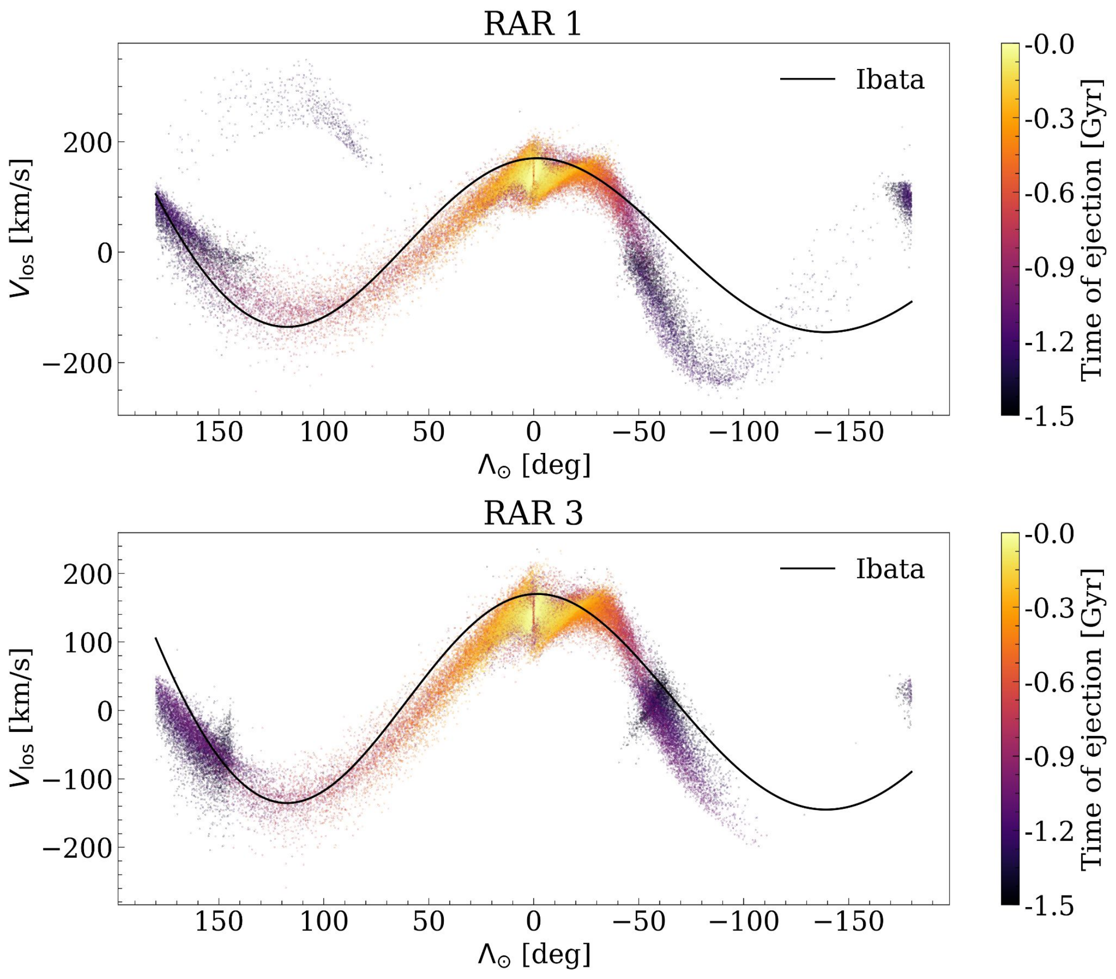


Proper motion B vs. Λ

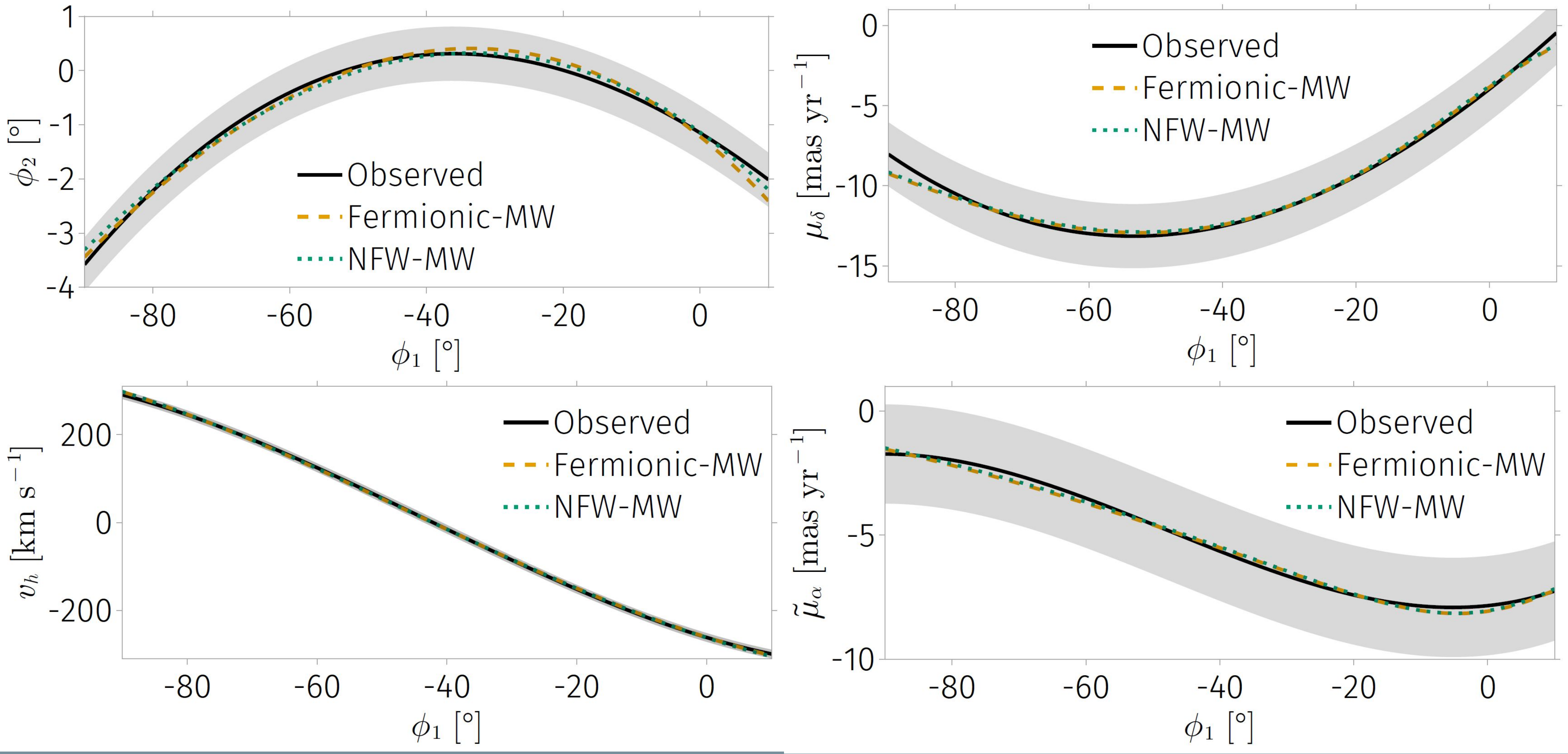
Sagittarius



Line of sight velocity vs. Λ   Sagittarius



Stream fits in observable space GD-1



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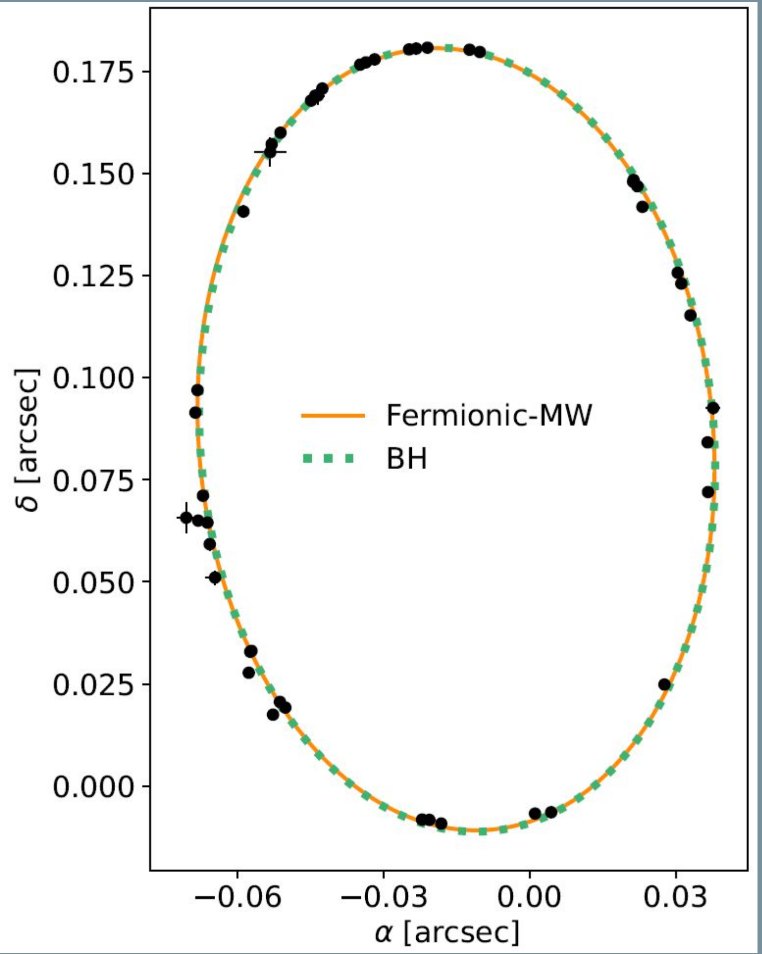
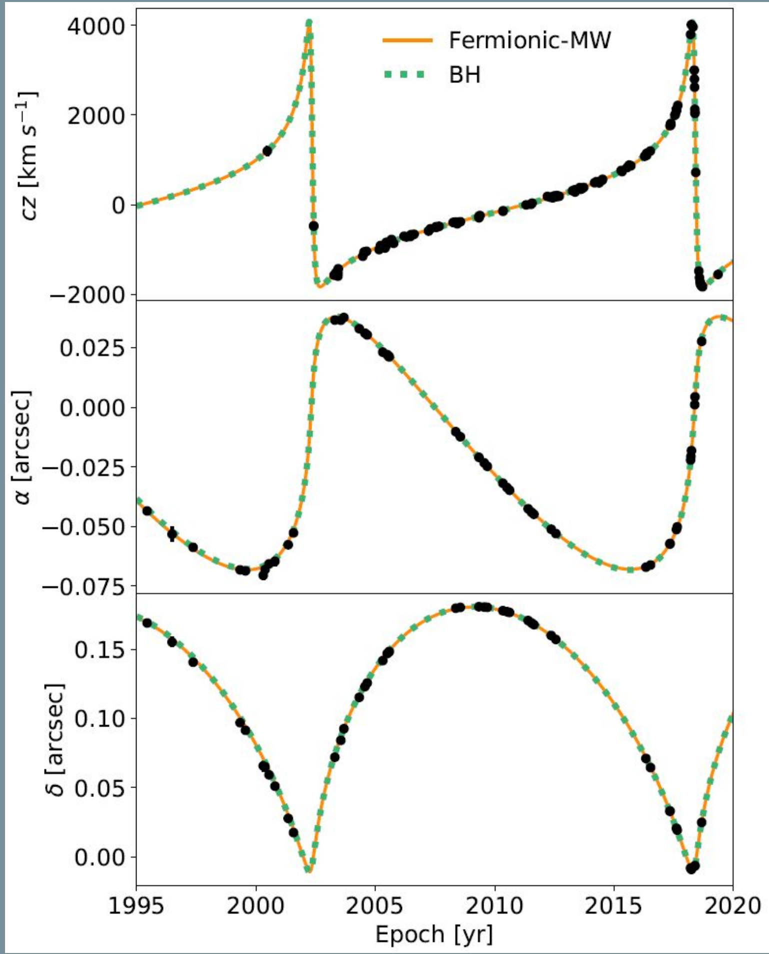


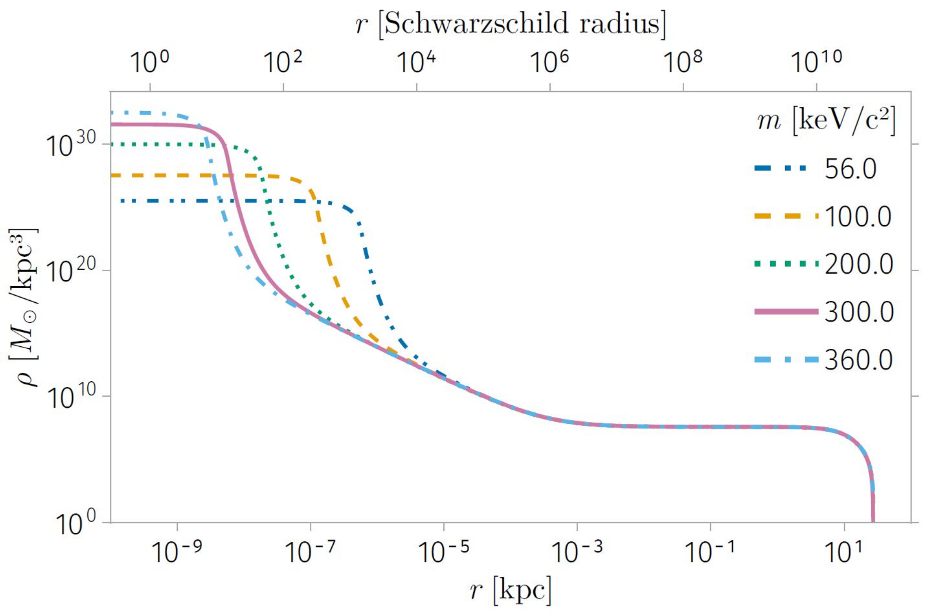
Modeled and observed projected orbit in the sky

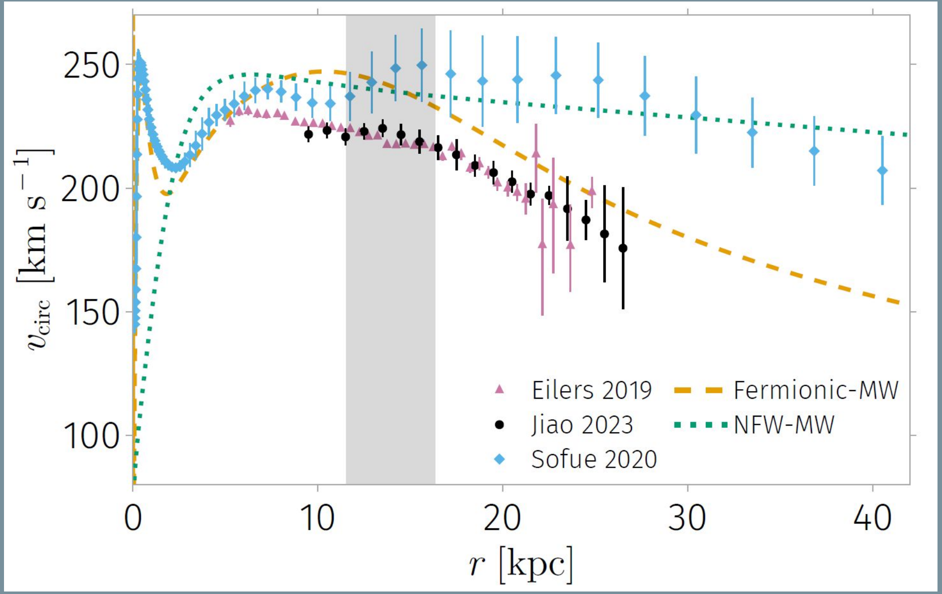
Redshift z, right ascension α, and declination δ as a function of time epoch



GD-1

Density profiles for different DM masses. They simultaneously fit the GD-1 stream and the DM core





Circular rotation curves for RAR and NFW, both fitting GD-1, contrasted against observables

NFW: Malhan & Ibata (2019)

6. Conclusions

Sagittarius

- The RAR 3 model seems to achieve better results than the RAR 1 but neither of them can't fit the entire leading tail in the velocity space.

- It is well known that it is not possible to fit the Sgr stellar stream under a spherical symmetric dark matter halo (Helmi 2004; Johnston et al. 2005; Law & Majewski 2010).

Large Magellanic Cloud

there is a way out

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GD-1

- The fermionic core-halo distribution allows to fit *simultaneously* the GD-1 stellar stream at ~ 10 kpc scale and the orbit of the S2 star at ~ 1 mpc scale.
- The total mass and virial radius of the Galaxy agree very well with estimations derived from Gaia DR3.