CORRIENTE ESTELARES

Aquellos ríos de estrellas en la Galaxia y el Universo local

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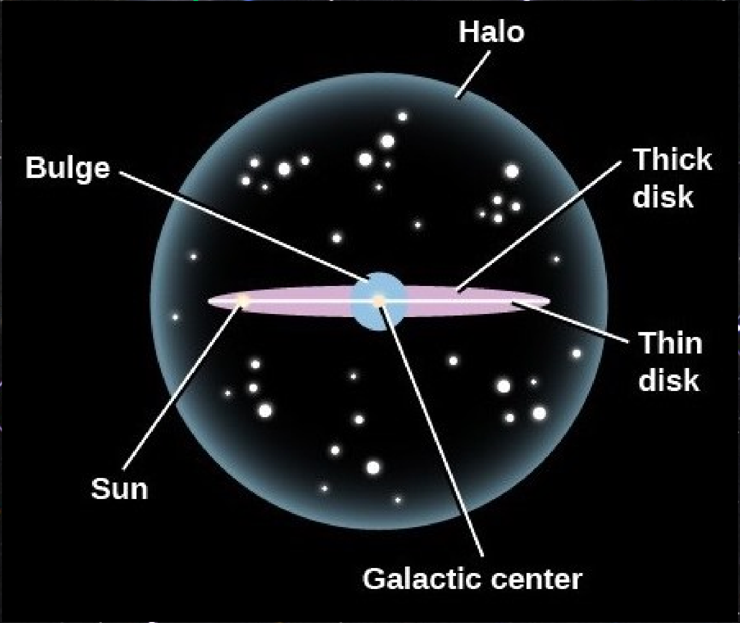
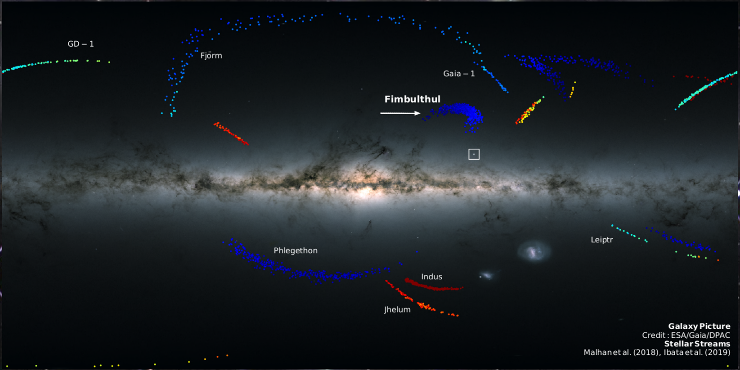
Modelo simplificado de la Galaxia



La Galaxia posee además otras subestructuras



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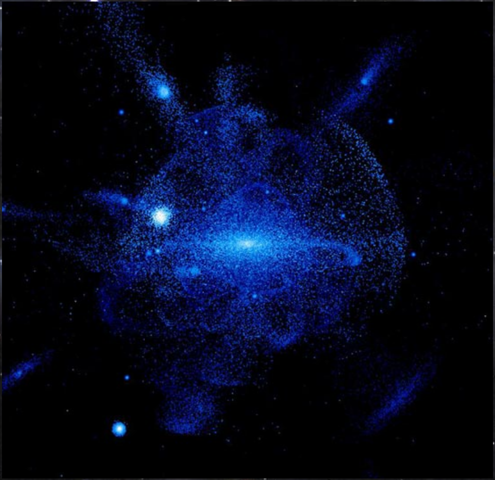


Consistente con un Universo jerárquico formado por sucesivas fusiones de galaxias

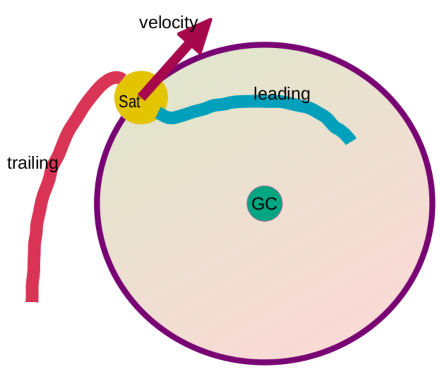
Simulación de corriente estelar

Animación: GlobularClusterStreamInMWwithSubHalos.mp4

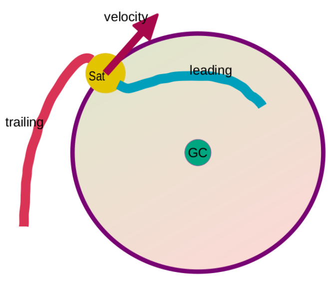
Qué es una corriente estelar?

Es el sistema que se forma cuando un sistema auto-gravitante de estrellas (cúmulo globular o galaxia enana) es desarmada por las fuerzas gravitatorias de marea producidas por la galaxia anfitriona.

Generalmente un par de brazos de marea son formados, uno que va hacia adelante y otro hacia atras del progenitor.

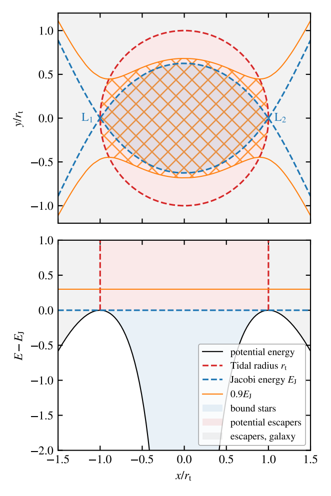


El radio de marea



Para órbitas circulares en un potencial con simetría esférica:

$$r_t \approx \left(\frac{Gm}{\Omega^2 - \frac{\partial^2 \Phi}{\partial R^2}} \right)^{1/3}$$



Arcturus stream

stars in the other old disk population groups (cf. Eggen 1971*c*), the period is probably 80 to 90 days.

III. Kinematics

If we adopt $(U', V')_{\odot}$ with respect to the local standard of rest, of $(+10, -16)$ km/sec (Eggen 1970*a*), the Arcturus group has $V' = -100$ km/sec with respect to that standard. The parameters of the orbits of the group stars, based on the galactic potential field discussed by Eggen, Lynden-Bell, and Sandage (1962) are listed in Table III. The group stars, U' between -20 and -60 km/sec, are now at apogalactium, R_{max} between 10.1 and 10.4 kpc, in orbits with $e = (R_{max} - R_{min})/(R_{max} + R_{min}) = 0.45$.

TABLE III

ORBITAL PARAMETERS FOR STARS WITH $V' = -100$ KM/SEC AND THE LISTED VALUES OF U'

U' (km/sec)	R(Max)	R(Min)	e
	Kpc		
+ 40	10.10	3.87	0.445
+ 20	10.08	3.90	0.44
± 0	10.08	3.90	0.44
− 20	10.08	3.90	0.44
− 40	10.10	3.87	0.445
− 60	10.40	3.84	0.46
− 80	10.90	3.80	0.485
−100	11.10	3.73	0.495

The values of U and Y for the members of the Arturus group are shown as open circles in the (U, Y) plane of Figure 5 where Y is the distance from the sun, in the direction of galactic rotation. The group stars are not only distributed in a

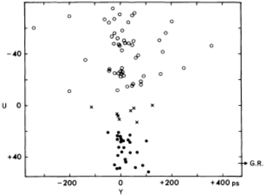
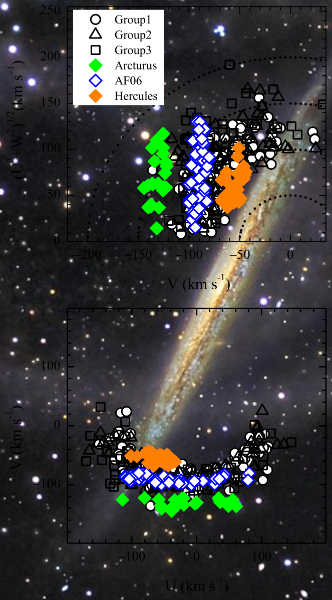


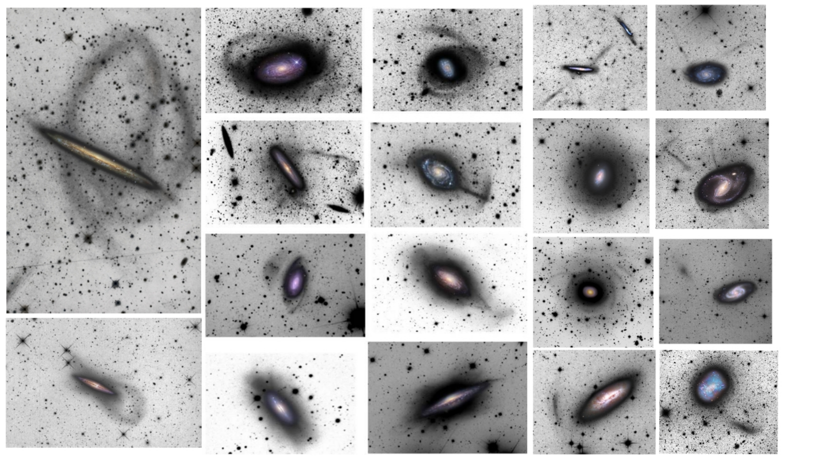
FIG. 5—The correlation between the U vectors of the space motion and Y, the distance from the sun in the direction of galactic rotation, for members of the Arcturus group in Table I (open circles). Stars in Table IV are shown as crosses and the filled circles are members of the η Cephei group.

The η Cephei group members (Eggen 1971*b*) have values of U between $+20$ and $+50$ km/sec and $V(-97$ km/sec) is only about 10 percent less than that for the Arcturus group stars. The U vectors of η Cephei group members are shown as filled circles in Figure 5. The trigonometric parallax of Arcturus is too well established to allow a change from -119 to -97 km/sec and the value of $V = -97$ km/sec for η Cep is based on a trigonometric parallax of 0″071 (weight 52) whereas $V = -116$ km/sec would require a value of 0″027. Although the difference in the V velocity of the two groups is small, it is nevertheless real. The gaps in the distribution of the U velocities in Figure 5 may indicate that either there are two, or perhaps three, groups represented, with $U = +10$ to 0, -15 to -30,

Arcturus stream

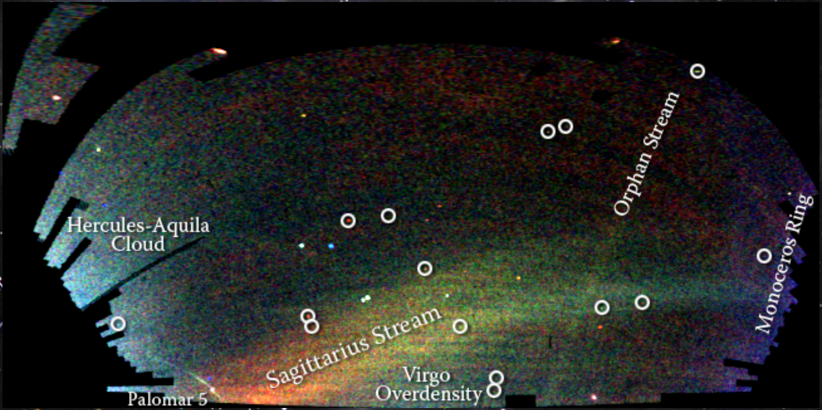


Stellar streams in the Local Universe



Martínez-Delgado D. et al. 2018

Stellar streams in the Milky Way (Origins)

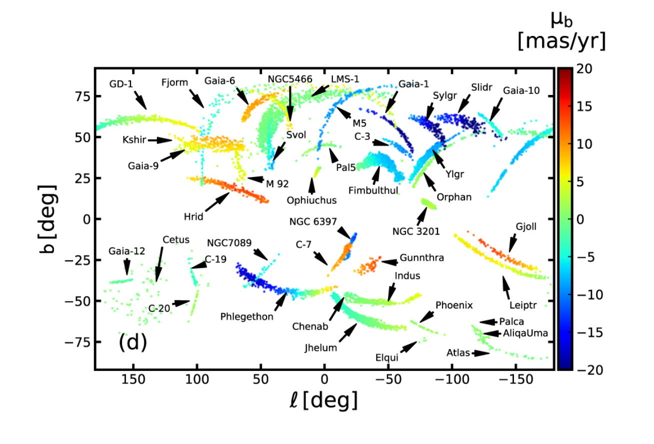


Belokurov V. et al. 2006

Stellar streams in the Galaxy

Atlas of the Milky Way Mergers (Malhan et al. 2022)

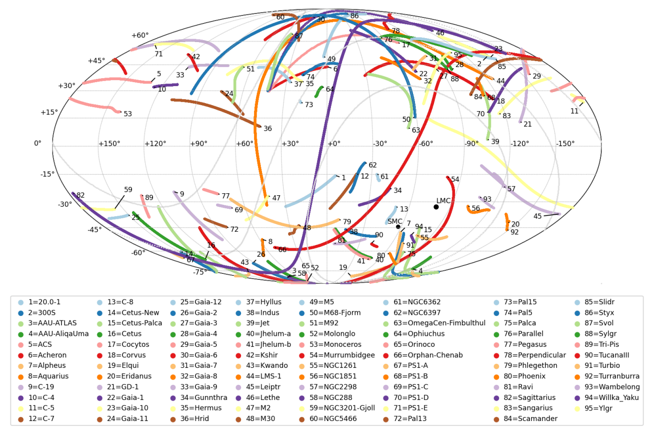
41 stellar streams comprising 9192 Gaia EDR3 stars



Stellar streams in the Galaxy

Galstreams Python Package (Cecilia Mateu 2022)

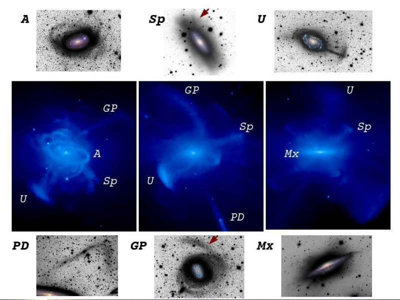
95 stellar stream 5D/6D tracks available in Galstreams



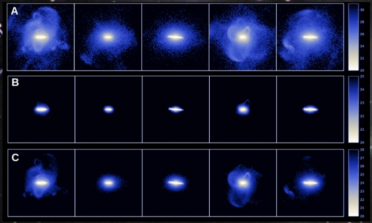
Stellar streams in the Computer

Tidal features:

- Great circles
- Plumes
- Shells
- Umbrellas
- Spikes
- Giant clouds



Martinez-Delgado D. et al. 2010, Johnston et al. 2008



Martinez-Delgado D. 2018

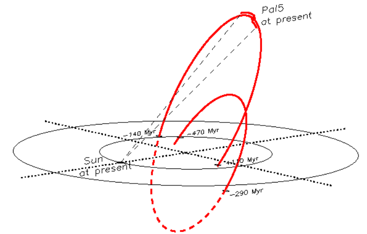
Expected streams around a Milky Way–like galaxy for different surface brightness detection limits (mag/arcsec^2):

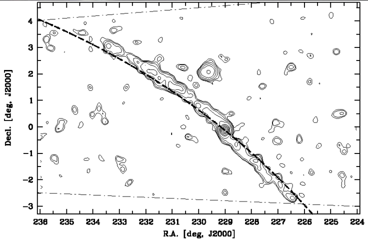
- $\mu_{\mathrm{A}} = 31$
- $\mu_{\mathrm{B}} = 25$
- $\mu_{\mathrm{C}} = 28$

Palomar 5 stream

(Odenkirchen 2000+)

A stellar stream that probes the halo and the bar





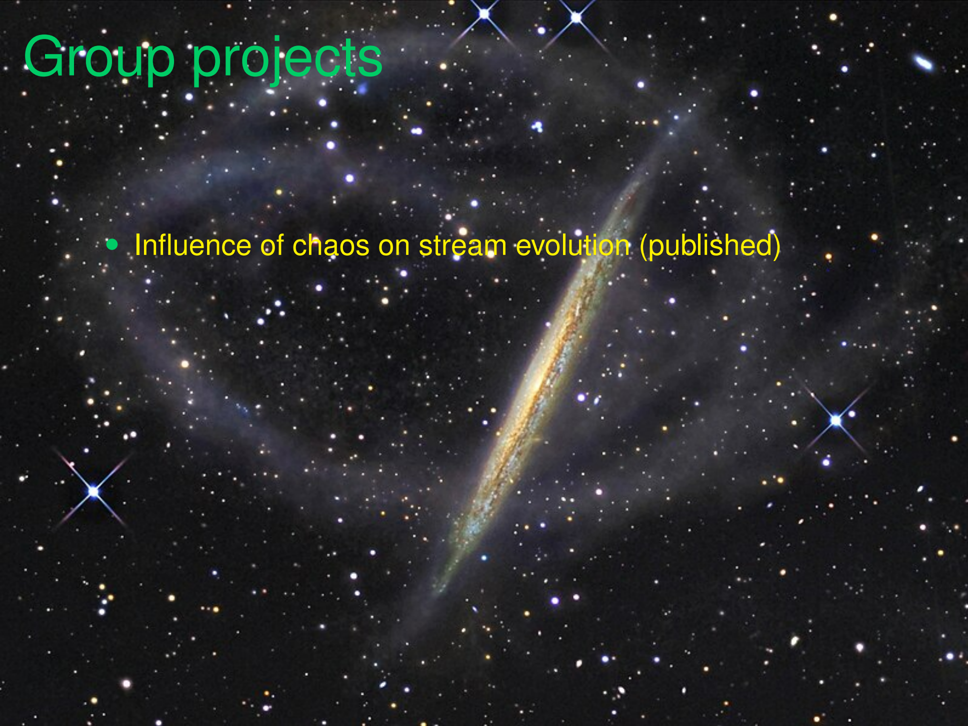
$d_{CG} \approx 16$ kpc

$d_{\odot} \approx 20$ kpc

length $\approx 20^\circ$ / 7 kpc

width ≈ 120 pc

Group projects



- Influence of chaos on stream evolution (published)

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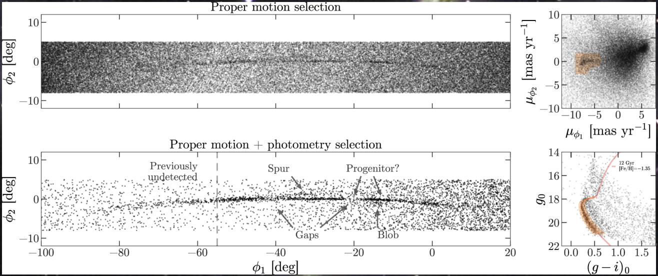
- Applications of fermionic DM code to other astrophysical phenomenae (to be submitted)

The GD-1 stellar stream

(Grillmair & Dionatos 2006)

A cold stream traveling through the halo, shown in self coordinates ϕ_1, ϕ_2

(Price-Whelan & Bonaca 2018)



$d_\odot \approx$ 10 kpc

length $\approx 100^\circ$ / 10 kpc

width $\approx 12^\circ$ / 30 pc

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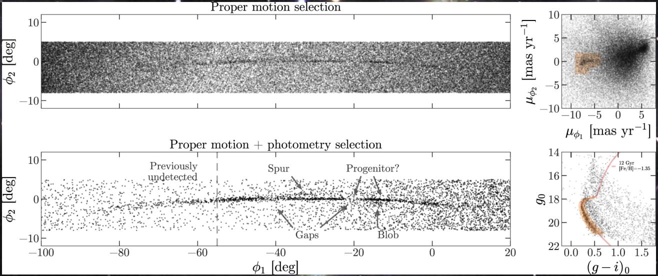


to study a

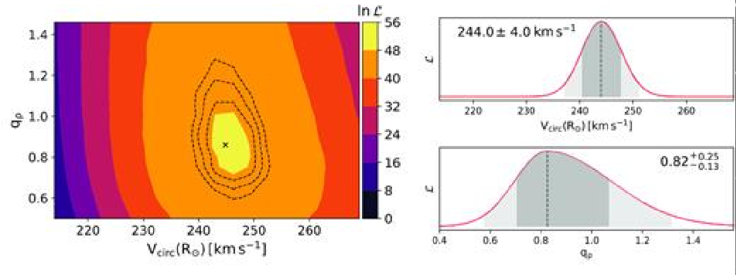
System of Self-Gravitating Fermions

that satisfy a

Maximum Entropy Production Principle (the RFK/RAR model)

Previus motivations

GD-1 fit to MWPotential2014 with axisymmetric NFW (Malhan et al. 2019).



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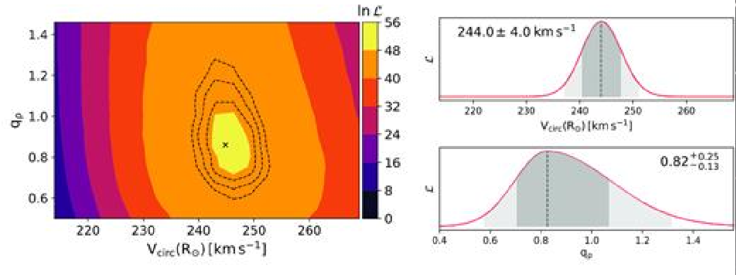

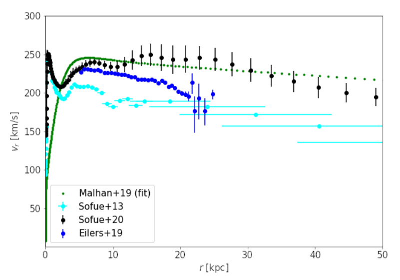

RFK model for MW relies on rotation curves. Rotation curves depend on the assumption on V_{LSR}.

Streams probe the acceleration field.

The relativistic fermionic King model

We solve Einstein equations for a gas of fermions at finite T in hydrostatic equilibrium (i.e. T.O.V), in spherical symmetry Argüelles, Krut, Rueda, Ruffini (2018).

$$\frac{d\nu}{d\zeta} = \frac{1}{2}\left[e^{z} + e^{2\zeta}\frac{P(r)}{\rho_{rel}c^2}\right]\left[1 - e^{z}\right]^{-1} \tag{1}$$

$$\frac{dz}{d\zeta} = -1 + e^{(2\zeta - z)}\frac{\rho(r)}{\rho_{rel}} \tag{2}$$

$$\zeta = \ln(r/R),\ z = \ln\left(\frac{M(r)}{M}\frac{R}{r}\right)$$

$$\rho(r) = \frac{4\rho_{\rm rel}}{\sqrt{\pi}}\int_1^{\infty} \epsilon^2[\epsilon^2 - 1]^{1/2} f(r,\epsilon)d\epsilon \tag{3}$$

$$P(r) = \frac{4\rho_{\rm rel}c^2}{3\sqrt{\pi}}\int_1^{\infty} [\epsilon^2 - 1]^{3/2} f(r,\epsilon)d\epsilon \tag{4}$$

The RFK model

Maximum Entropy production Priniciple: Chavanis, MNRAS (1998)

$$f(r,\epsilon) = \begin{cases} \dfrac{1-e^{[\epsilon-\epsilon_c(r)]/\beta(r)}}{1+e^{[\epsilon-\alpha(r)]/\beta(r)}} & \epsilon \le \epsilon_c(r) \\ 0 \quad \epsilon > \epsilon_c(r) \end{cases} \tag{5}$$

Klein, Tolman and energy conservation equations imply:

$$\alpha(r) = \alpha_0 e^{-(\nu-\nu_0)}, \qquad \beta(r) = \beta_0 e^{-(\nu-\nu_0)}, \qquad \epsilon_c(r) = \epsilon_0 e^{-(\nu-\nu_0)}. \tag{6}$$

4 RFK parameters:

$m, \quad \beta_0 = kT_0/mc^2,$

$\theta_0 = (\alpha_0 - 1)/\beta_0, \quad W_0 = (\epsilon_{c0} - 1)/\beta_0$

A single objective

- Fit the fermionic model according to a few observables (next slide).

- To begin with we have the following full stream model:
  - Stream(17) = Potential(12) + Orbit_IC(5).

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- But there is some a priori knowledge:
  - Fits to the orbits of Sagittarius A*-stars imply $m_f \geq 56$ keV & Core Mass $\approx 3.5 \times 10^6 M_\odot$ (Becerra-Vergara+21).
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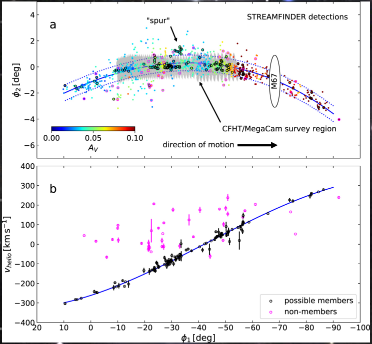
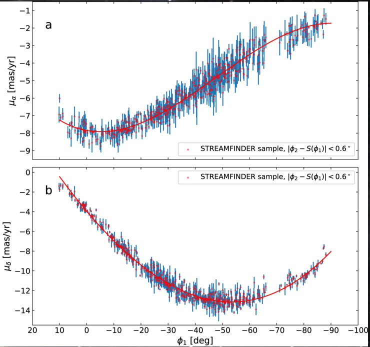
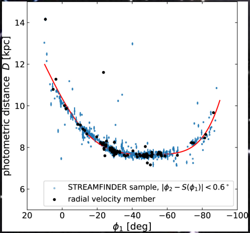
- Then we are left with:
  - Stream(8) = RFK(θ_0, W_0, β_0) + Orbit_IC(5)

GD-1 Observables

(Ibata+20)







- STREAMFINDER (Gaia DR2): 811 candidate members.

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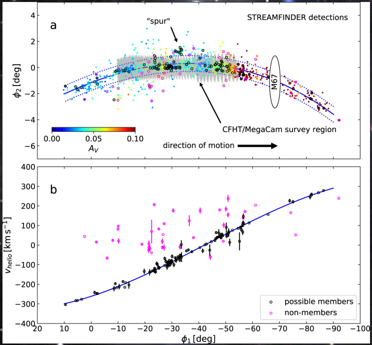

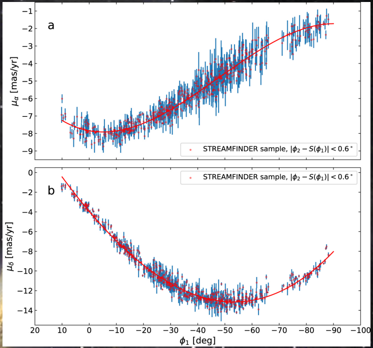

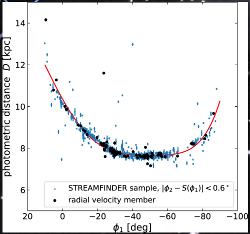

- STREAMFINDER (Gaia DR2): 811 candidate members.
- Cross correlation with spectroscopy: 156 stars in RV sample.

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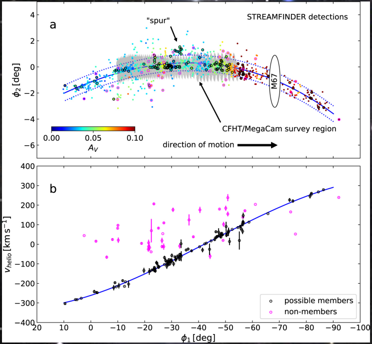

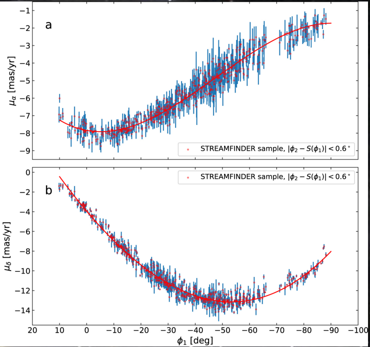

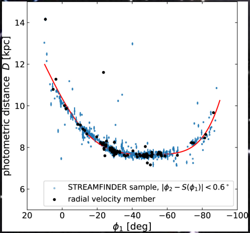

- STREAMFINDER (Gaia DR2): 811 candidate members.
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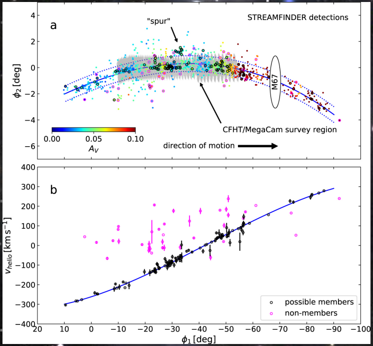
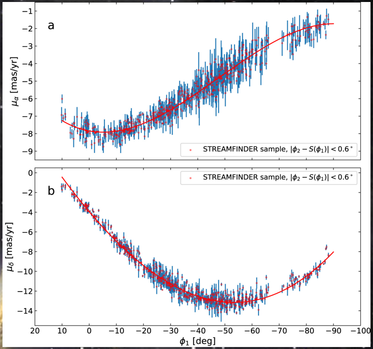
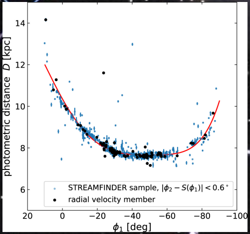
- Velocity fit: 117 RV member stars.

GD-1 Observables

(Ibata+20)







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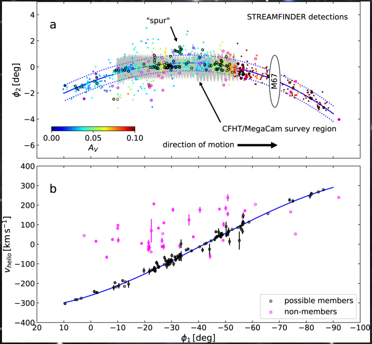

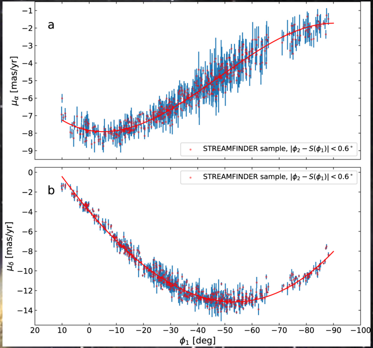

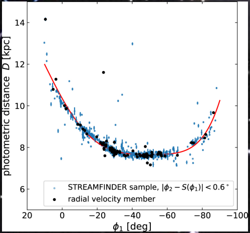

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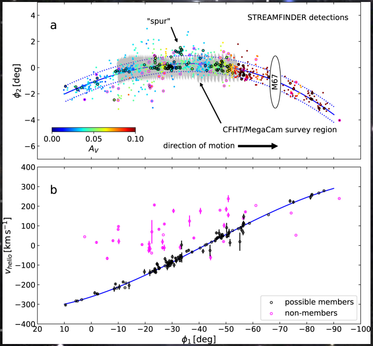
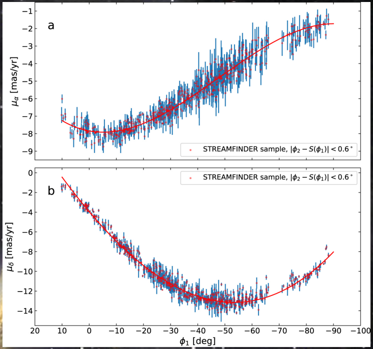
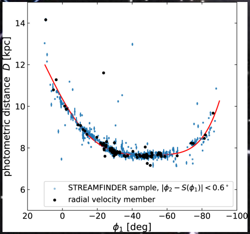
- Cross correlation with spectroscopy: 156 stars in RV sample.
- Velocity fit: 117 RV member stars.
- Sky coords fit (with 117 RV members): $\phi_2 = S(\phi_1)$.
- Final selection ($|\phi_2 - S(\phi_1)| < 0.6^\circ$ & not RV outlier): 603 Gaia stars.

GD-1 Observables

(Ibata+20)







- STREAMFINDER (Gaia DR2): 811 candidate members.
- Cross correlation with spectroscopy: 156 stars in RV sample.
- Velocity fit: 117 RV member stars.
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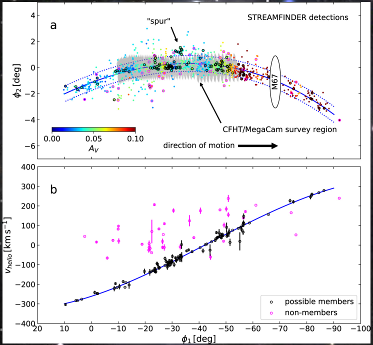
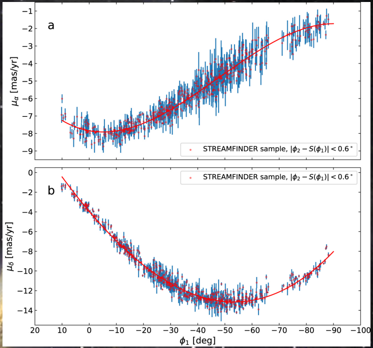
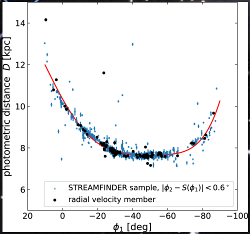
GD-1 Observables

(Ibata+20)







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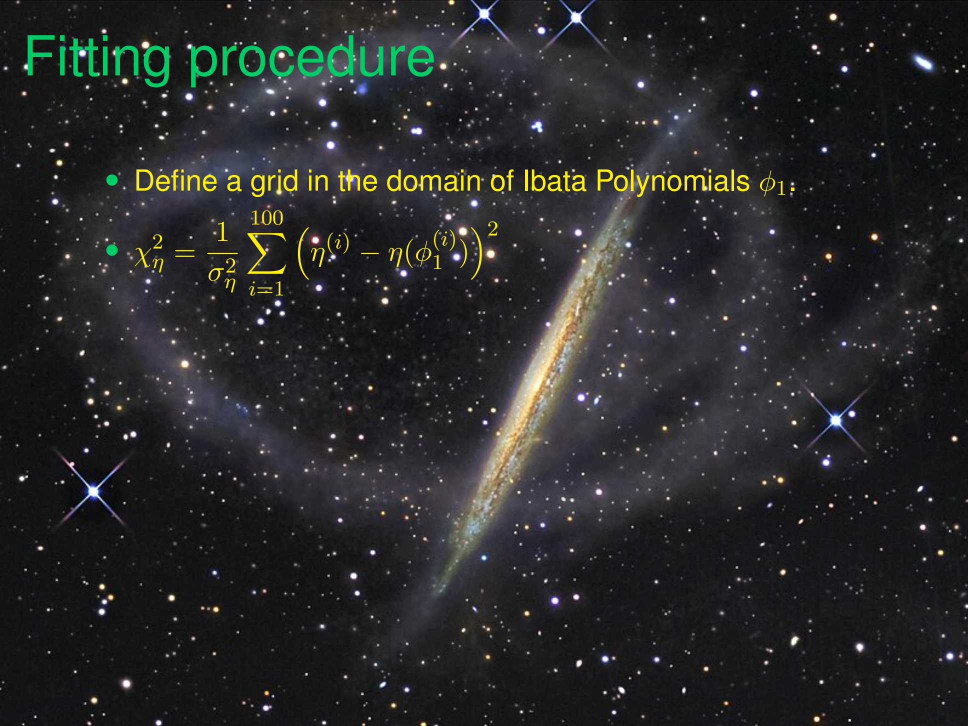

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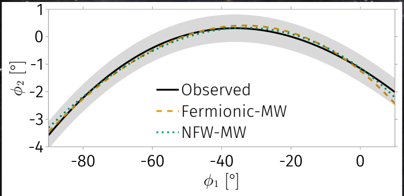
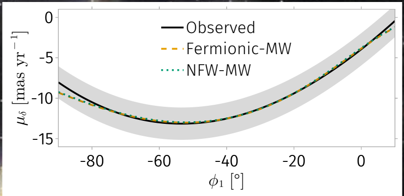
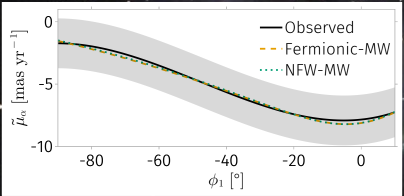
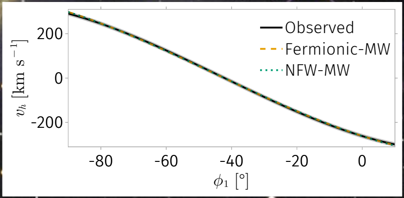
Result of the fitting: stream features

Best fit parameters for 56 keV: $\theta_0 = 36.07$, $W_0 = 63.41$, $\beta_0 = 1.26 \times 10^{-5}$









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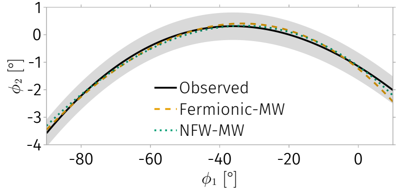

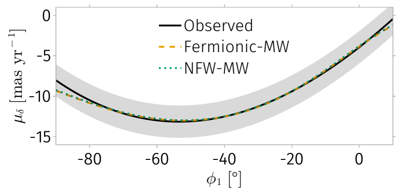

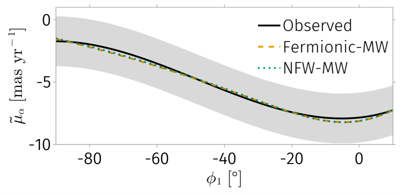

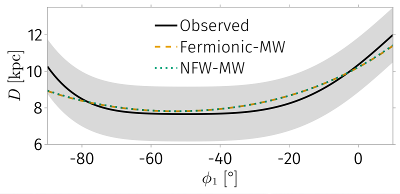

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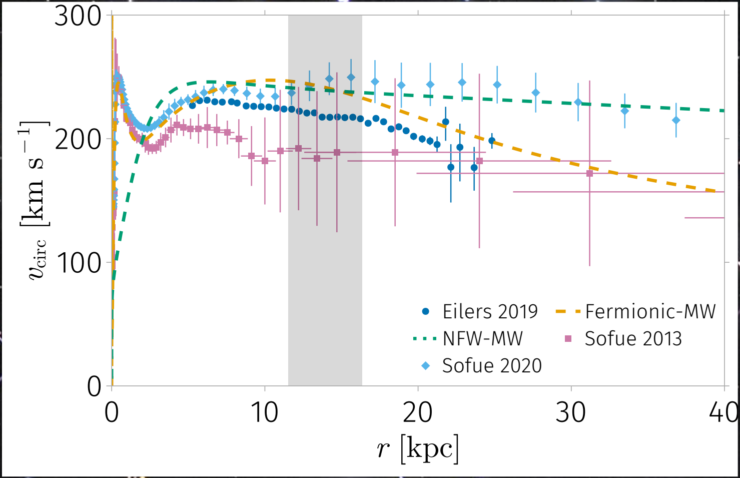

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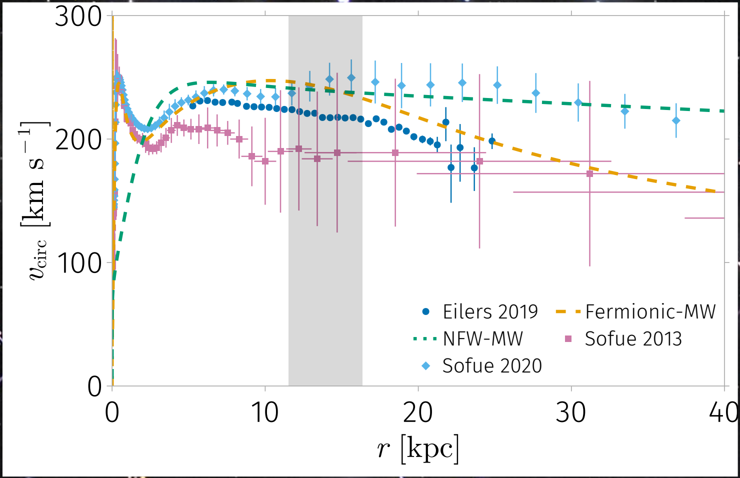
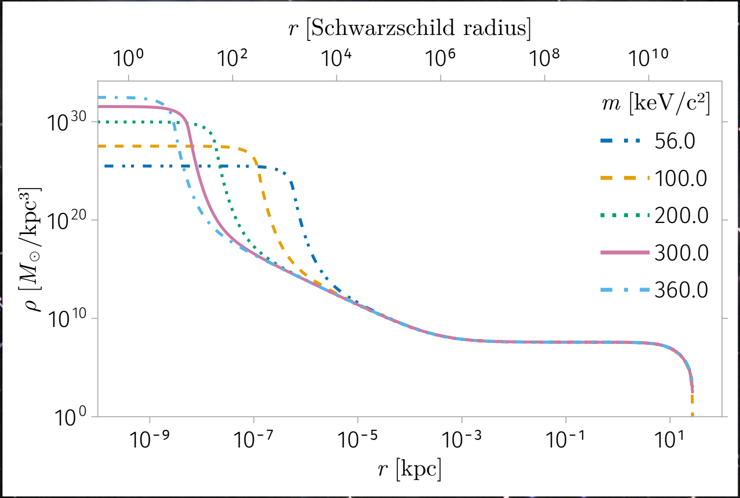


Important halo features:

Radius = 28 kpc

Mass = $1.4 \times 10^{11}\ M_\odot$

Going to higher fermion masses to allow more compact cores



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- Stellar streams are good tracers of the acceleration field.

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¡Muchas gracias!

Facultad de Ciencias Astronómicas y Geofísicas
UNIVERSIDAD NACIONAL DE LA PLATA

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