THE TORSION OF STELLAR STREAMS: THE SHAPE OF GALACTIC GRAVITY SOURCES

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ROTATION CURVE PROBLEM

CYLINDRICAL VS SPHERICAL HALO

TORSION IN STELLAR STREAMS

N-BODY SIMULATIONS OF STELLAR STREAMS

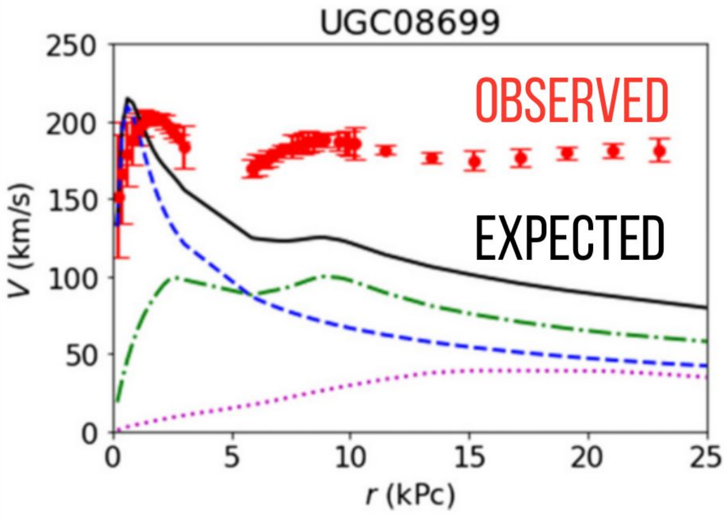
MILKY WAY STREAMS

CONCLUSIONS

ROTATION CURVE PROBLEM

- The problem of galactic rotation is the empirical statement that rotational velocity around the galactic center seems to flatten out for a large fraction of the galaxy population [Rubin, Ford & Thonnard, 1978, ApJ].

- Galactic rotation curves fail to follow Kepler's third law outside of a spherical source.



Expected:

$$\frac{v^2}{r} = \frac{GM}{r^2} \to v = \sqrt{\frac{GM}{r}}$$

Obtained:

$$v \to \text{constant}$$

ROTATION CURVE PROBLEM

- Typical solutions:
  - Modifications of mechanics, such as MOND, solve the issue but run into problems at larger cosmological scales.
  - Modification of the gravity source, usually in the form of a spherical Dark Matter halo envelope [Frenk, White, Efstathiou & Davis 1985, Nature, 317, 595].

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→

IN A 3D COSMOS:

We expect:
$F \propto 1/r^2 \rightarrow v^2 \propto 1/r$

We see:
$v^2 \propto \text{constant} \rightarrow F \propto 1/r$

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We do not live in a 2D cosmos!

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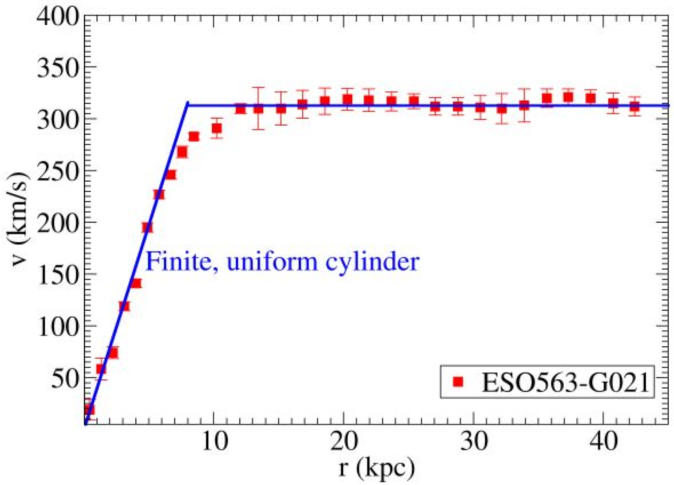
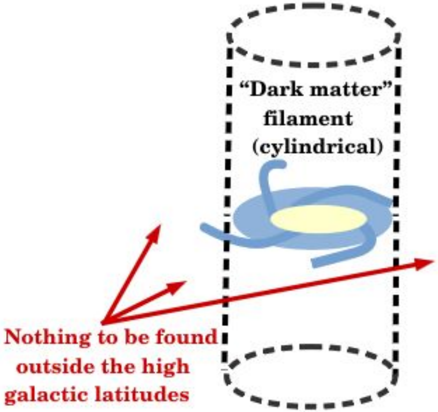
➢ But a **cylindrical matter source** achieves the same dimensional reduction.

ROTATION CURVE PROBLEM





Inside:

$$v = \sqrt{2G\lambda}\frac{r}{R}$$

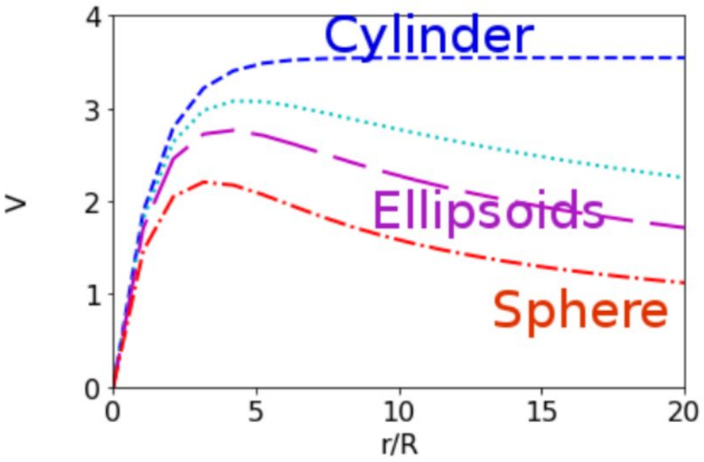
Outside:

$$v = \sqrt{2G\lambda}$$

CYLINDRICAL VS SPHERICAL HALO

- A **spherical** DM distribution has to be fine-tuned to have an isothermal $\rho(r) \propto 1/r^2$ profile to explain the flatness of the rotation curve.
- A **cylindrical** source of linear density λ naturally explains constant rotation curves [Llanes-Estrada 2021, Universe, 7, 346].

Since the rotation curve is measured to a finite r the source does not need to be infinitely cylindrical: it is sufficient that it be prolate (elongated) DM halo [Bariego-Quintana, Llanes-Estrada & Manzanilla Carretero, Physical Review D 2022, 107, 083524].



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Rotation curves cannot distinguish spherical haloes with isothermal profiles from elongated haloes with arbitrary profile.

Out-of-plane observables: Stellar streams

Since the
r the so
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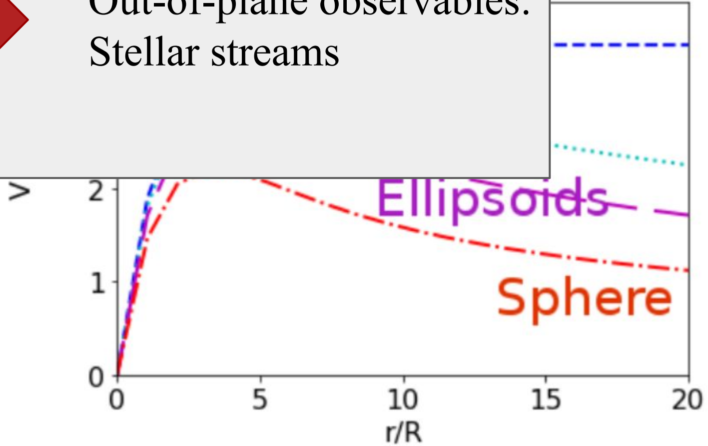

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The torsion of a curve measures how sharply it is twisting out of the osculating plane, it is defined by the velocity and normal acceleration.

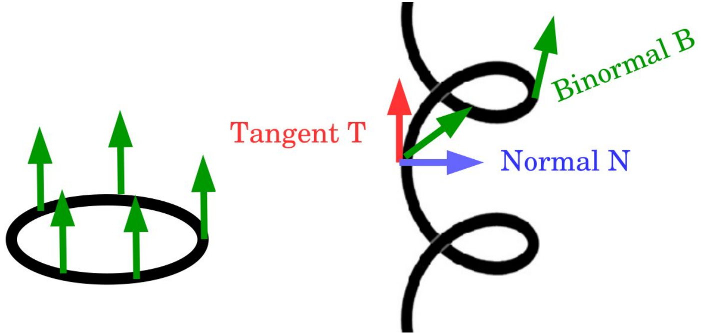
$$\mathbf{T} = \frac{d\mathbf{r}}{ds}$$

$$\mathbf{N} = \frac{d\mathbf{T}}{ds}$$

$$\mathbf{B} = \mathbf{T} \times \mathbf{N}$$

$$\tau = -\frac{d\mathbf{B}}{ds} \cdot \mathbf{N} = \frac{(\mathbf{r}' \times \mathbf{r}'') \cdot \mathbf{r}'''}{|\mathbf{r}' \times \mathbf{r}''|^2}$$

Illustrated by the Frenet-Serret trihedron:



SPHERICAL SOURCE τ=0

CYLINDER SOURCE τ=ct

$$\tau = \frac{1}{\rho} \frac{v_z v_\varphi}{v_\varphi^2 + v_z^2}$$

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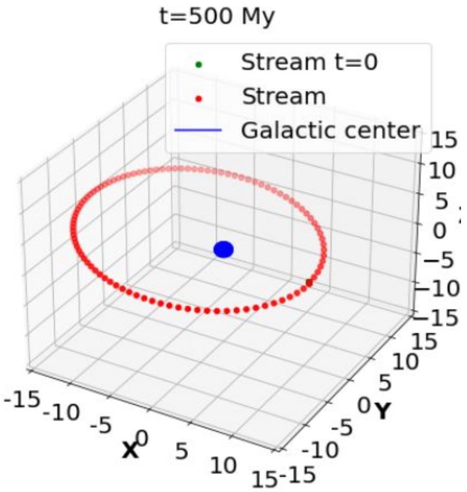
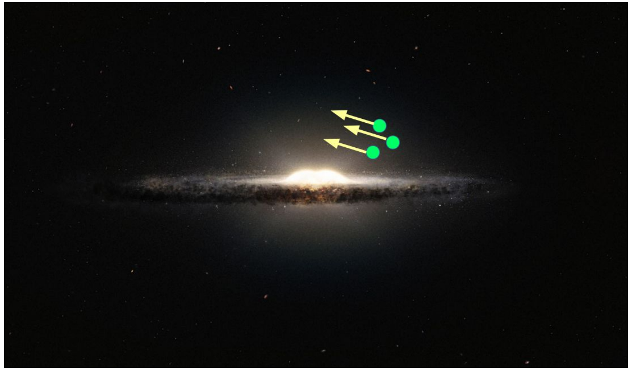
A test body moving in a central field has null torsion τ=0.



A cluster made of test bodies moving around a galaxy would lose dust grains forming a kind of contrail, its shape through space would be a planar curve.



Tidal distortion of a cluster around a galaxy

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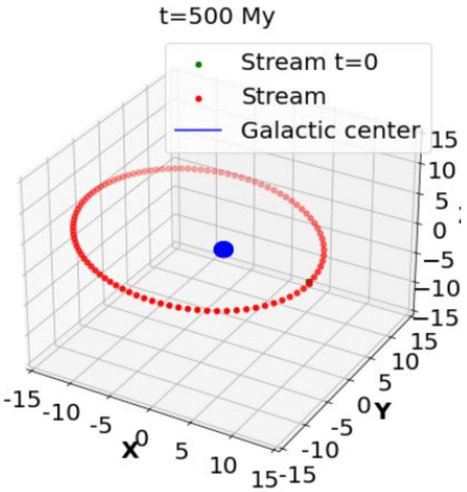
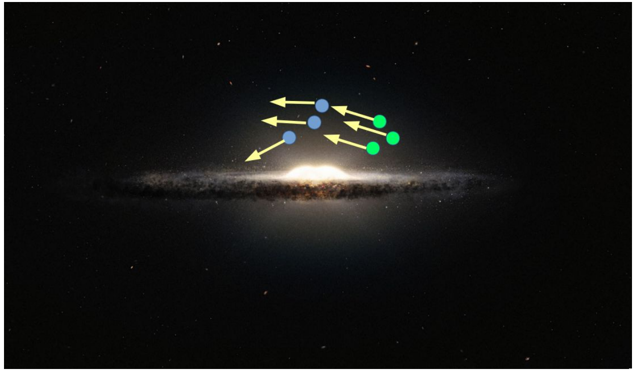


A cluster made of test bodies moving around a galaxy would lose dust grains forming a kind of contrail, its shape through space would be a planar curve.



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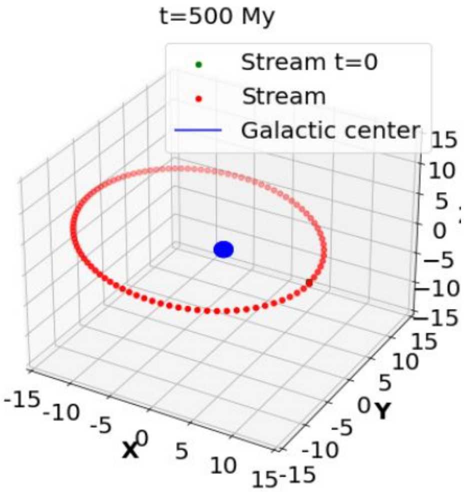
A test body moving in a central field has null torsion $\tau=0$.



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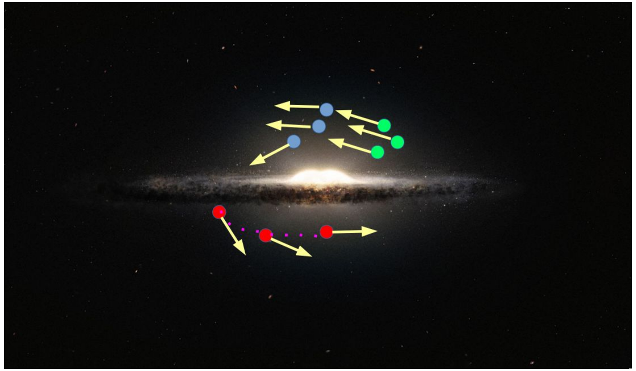

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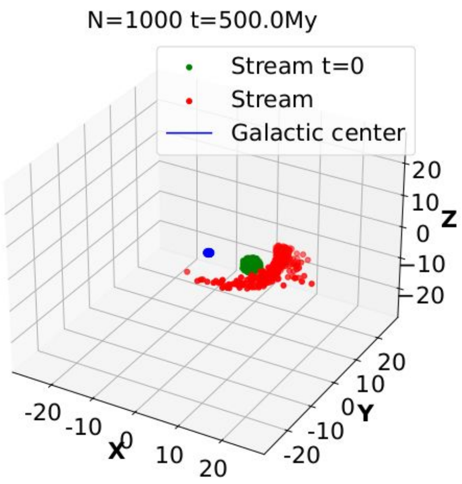

Stellar streams are the result of the tidal stretching of a globular cluster or dwarf galaxy [Noreña, Muñoz-Cuartas, Quiroga, & Libeskind, N. 2019, Rev. Mexicana Astron. Astrofis., 55, 273].

Stars at different heights can deviate the orbit from a planar curve. That the effect is negligible.

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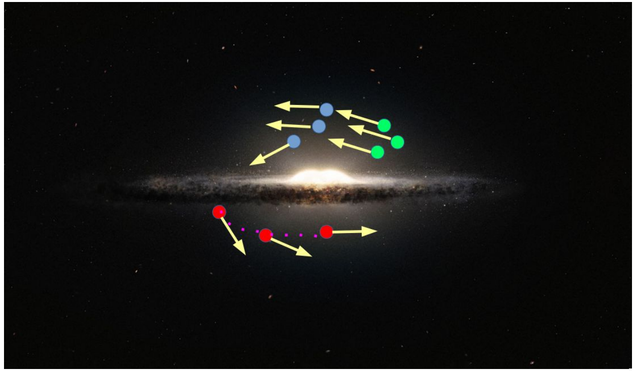

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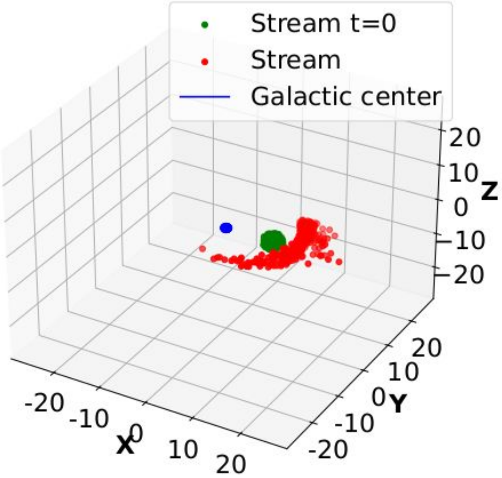
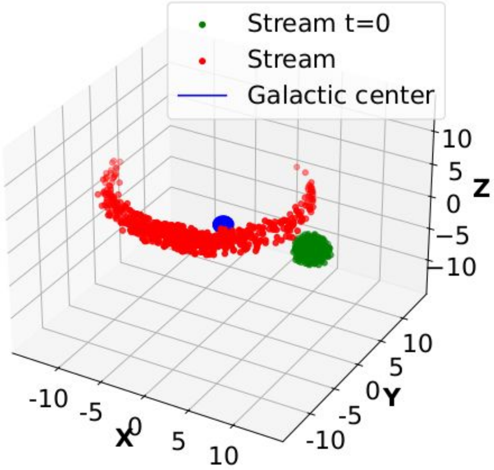
Sphere t=500 My



Cylinder t=500 My



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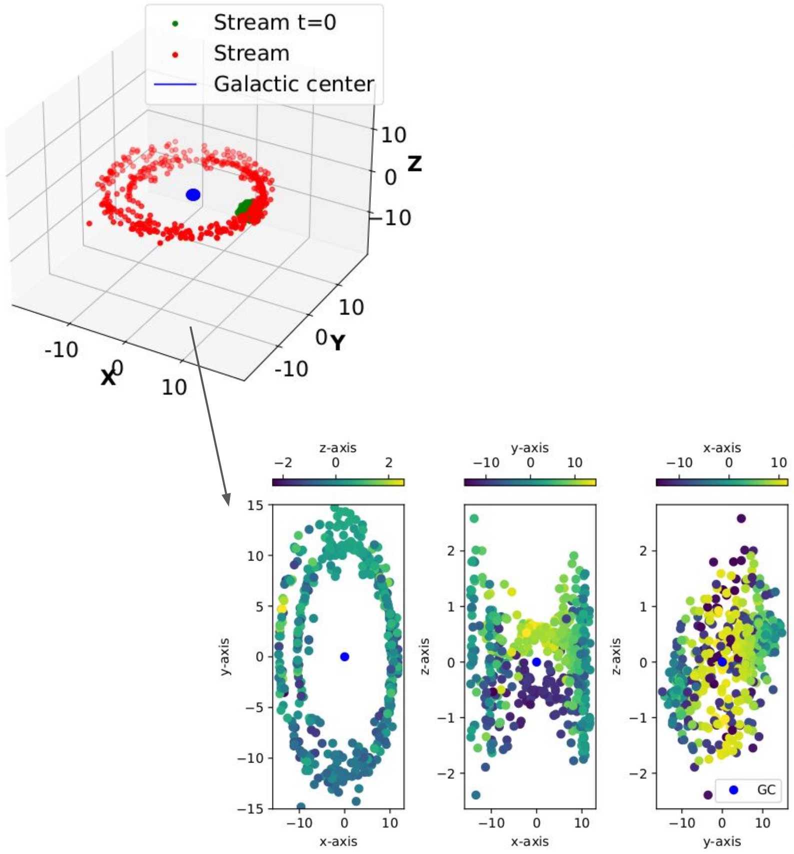
Sphere t=1 Gy



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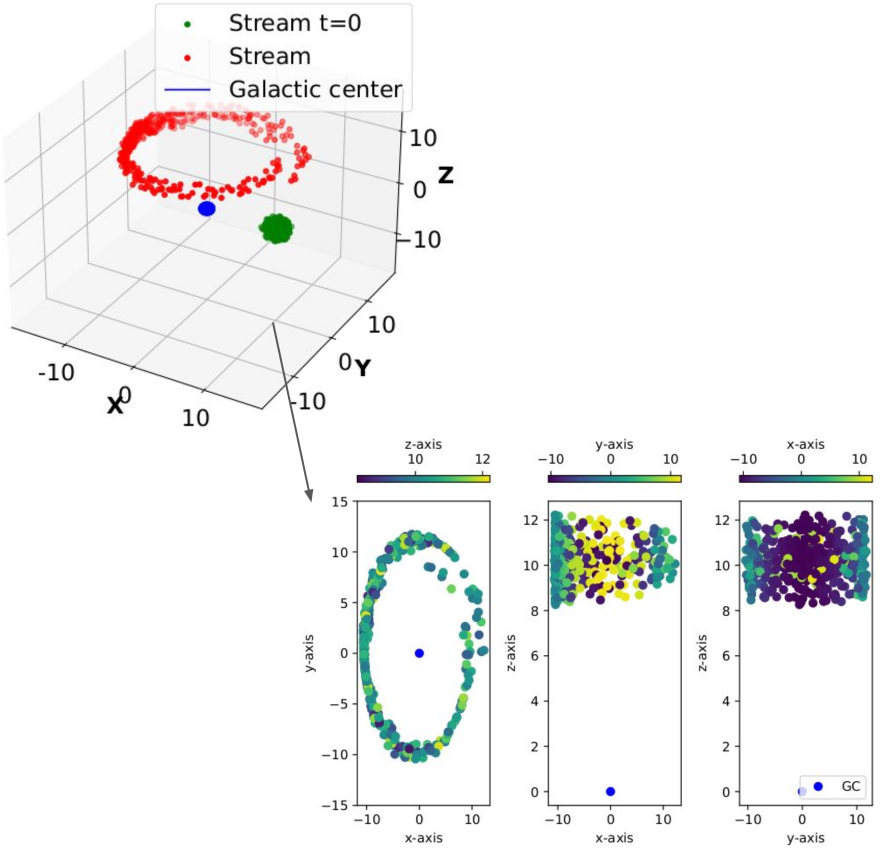

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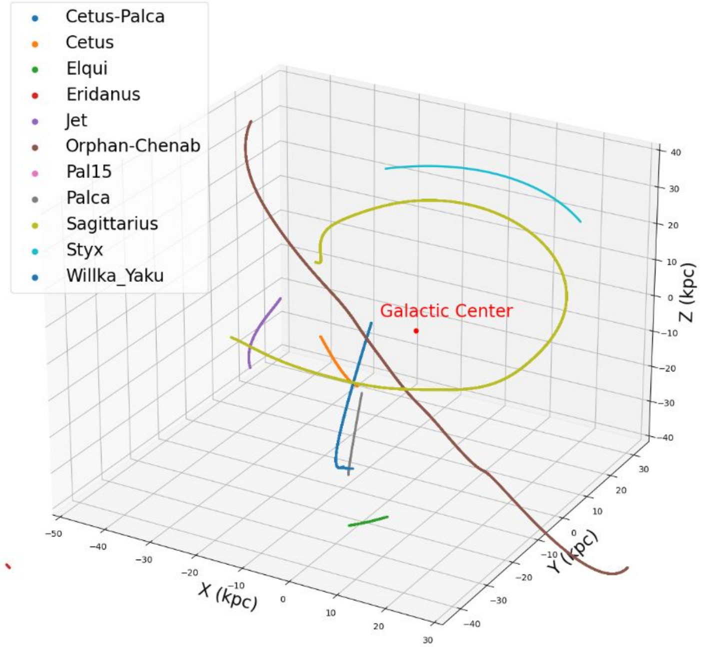
We select as relevant streams at distances d>30 kPc from the galactic center, so that the internal structure of the galaxy produces the minimum possible alteration in the stream [Mateu. 2023, Monthly Notices of the Royal Astronomical Society,520, 5225].



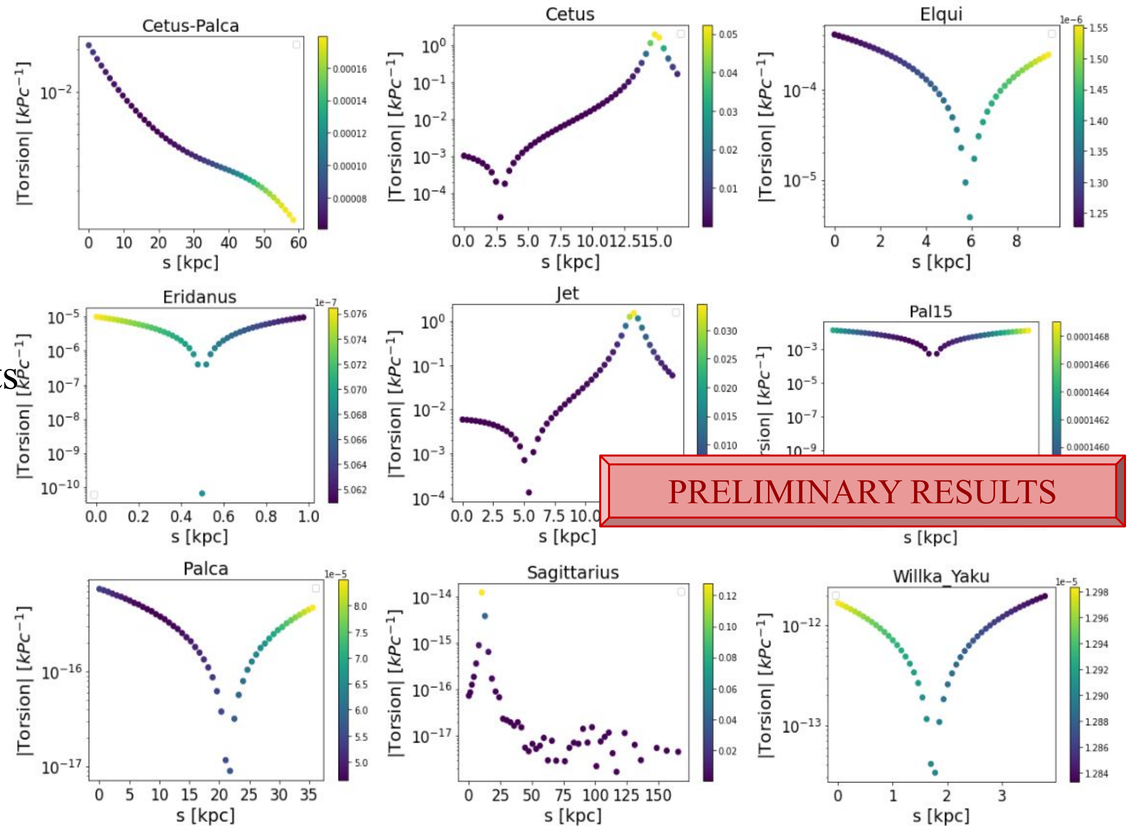
Torsion (as curvature) has dimensions of inverse length, we would expect stellar streams to perhaps show an inverse relation with respect to their distance from the galactic center.

$$\tau = \frac{(\mathbf{r}' \times \mathbf{r}'') \cdot \mathbf{r}'''}{|\mathbf{r}' \times \mathbf{r}''|^2} \Rightarrow [\tau] = L^{-1}$$

THE MILKY WAY STREAMS

In a galaxy such as the Milky Way the torsion of galactic streams should have a characteristic scale of 1 / (10 kPc).

Our selection of streams at 30 kpc or more means that we would consider values of the torsion of order 0.03 in units of inverse kPc to be sizeable and very different from zero.



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Key ideas:

- This is a first exploratory study.
- Proposal for a new observable: Torsion, $\boldsymbol{\tau}$
- We do not favor one or another interpretation of the DM halo shape in view of current data.

Future approaches:

- Calculate the torsion of N-Body simulations to compare to Milky Way streams

THANK YOU!