Studying dark matter with stellar streams

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Kick-off meeting UNDARK

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EXCELENCIA SEVERO OCHOA

INSTITUTO DE ASTROFISICA DE CANARIAS · IAC

GOBIERNO DE ESPAÑA · MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

Universidad de La Laguna

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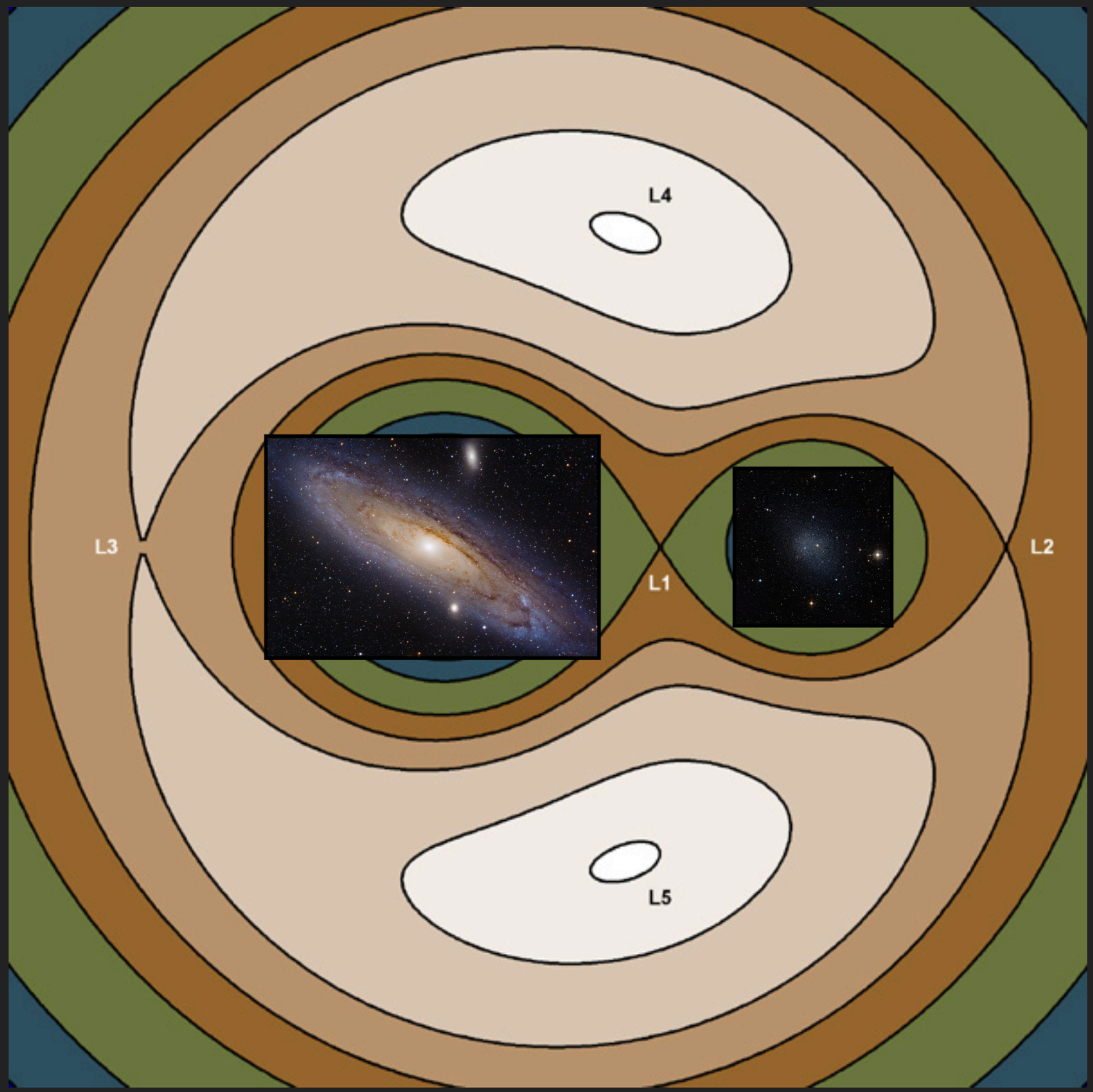
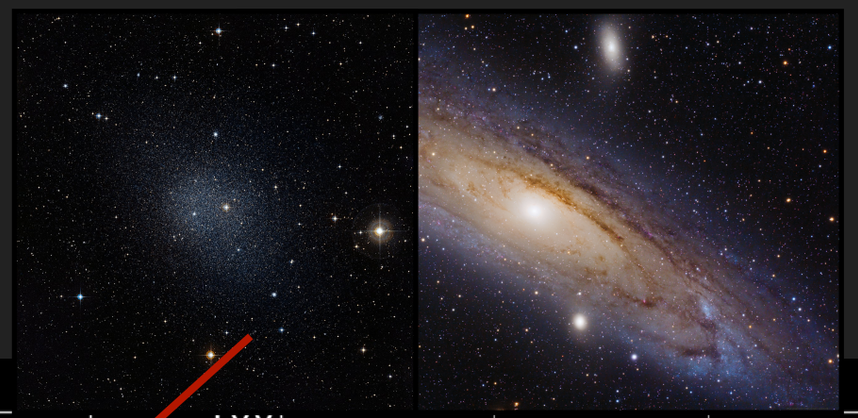
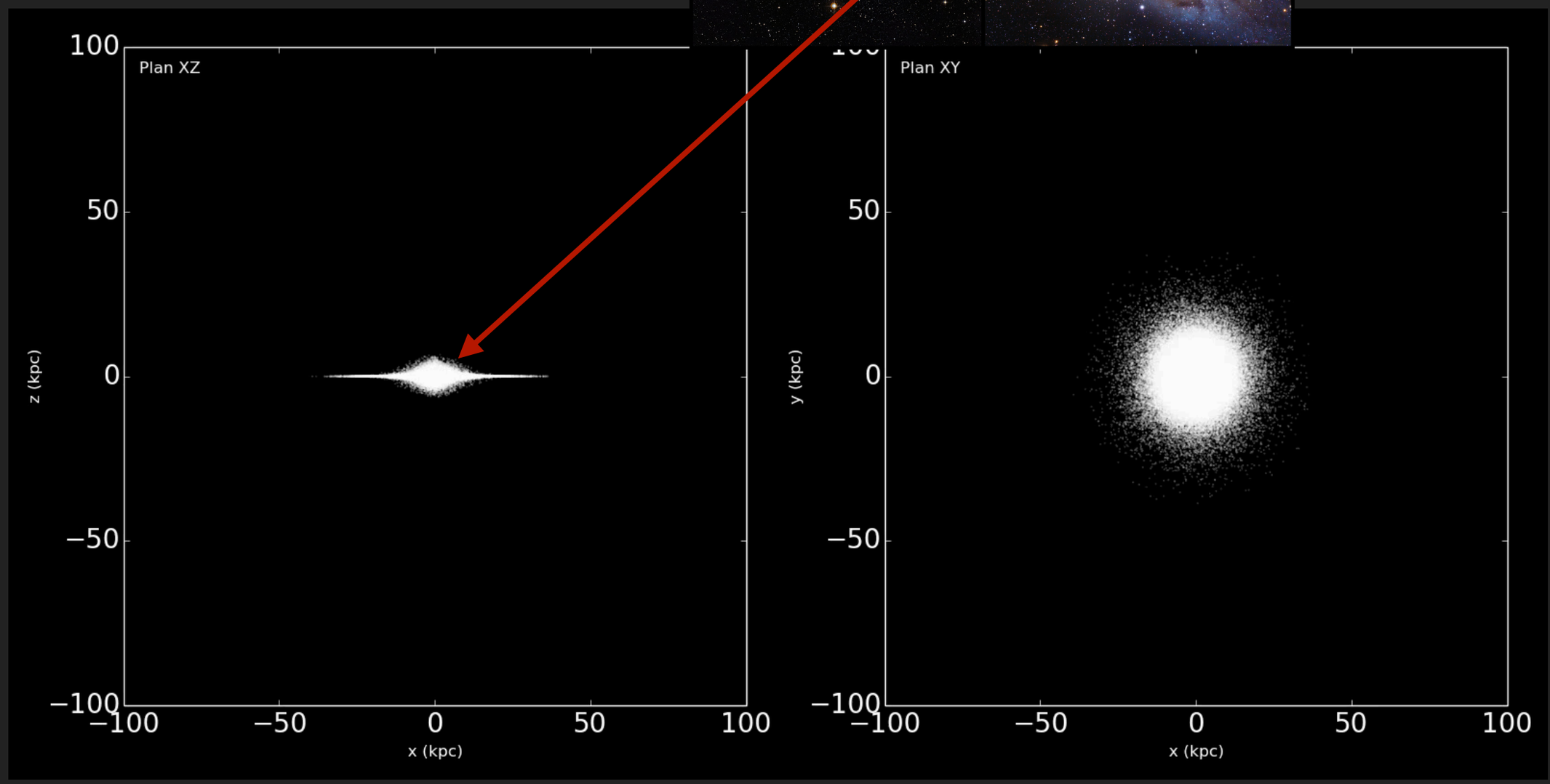
What is a stellar stream?

Stellar streams



Stellar streams

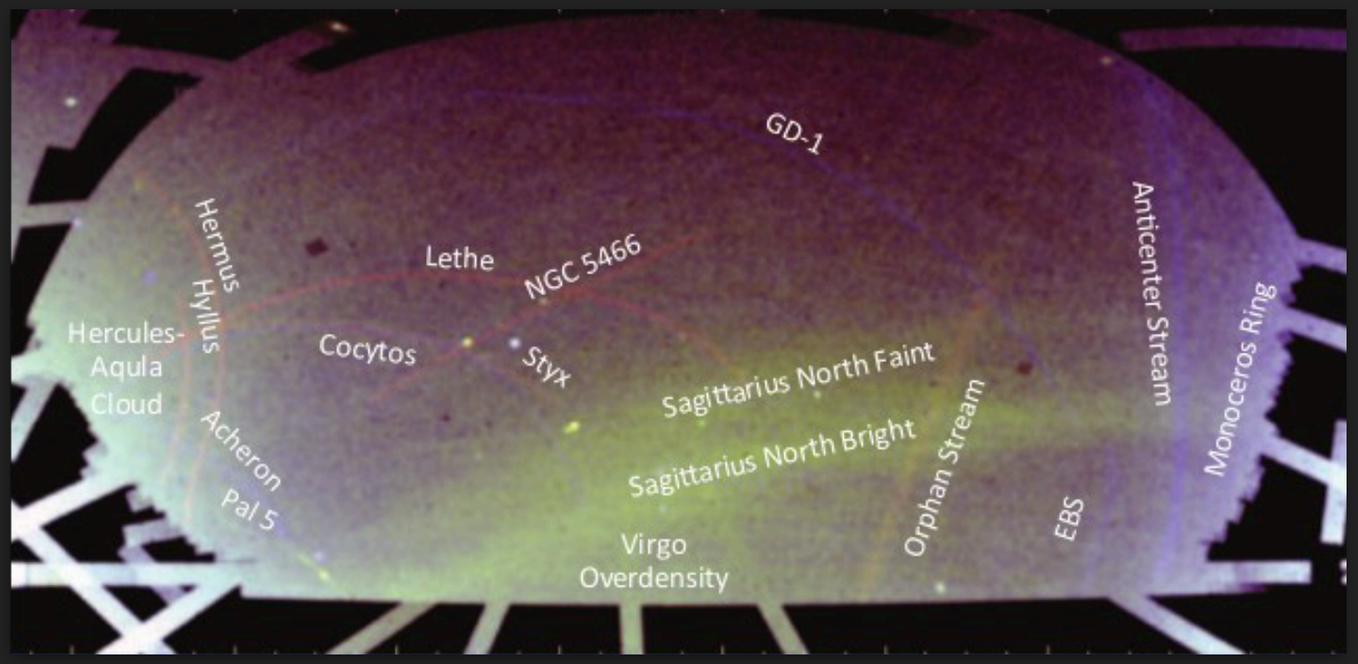




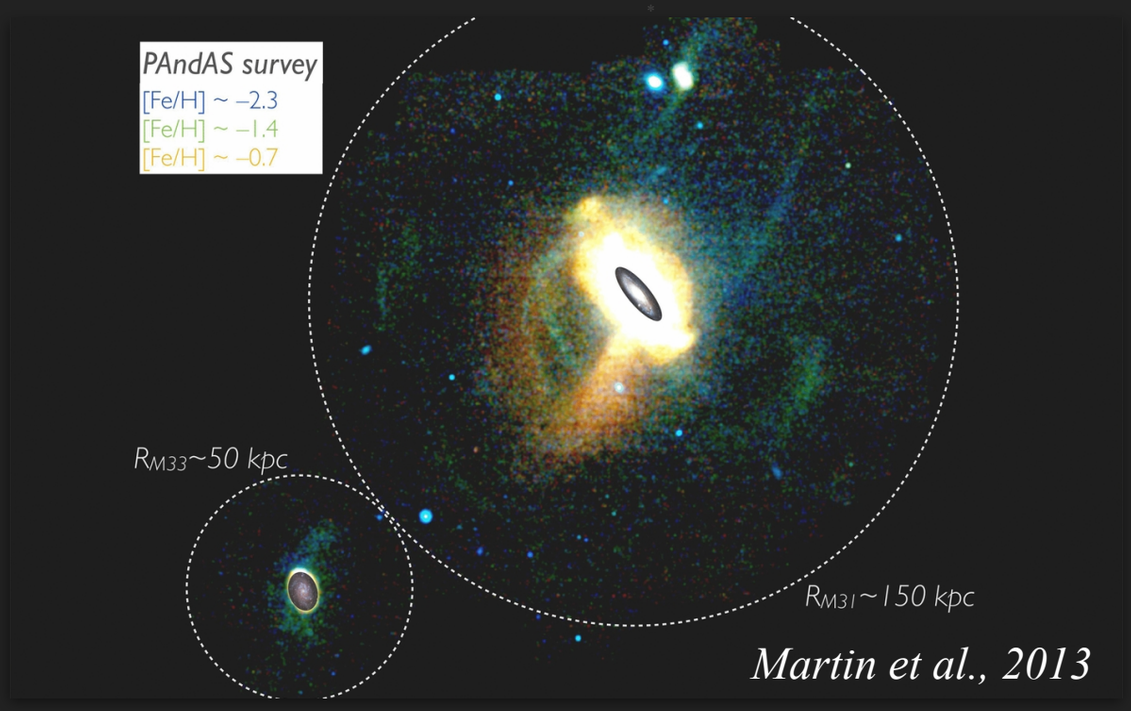
Stellar streams

MW

Grillmair et al., 2016

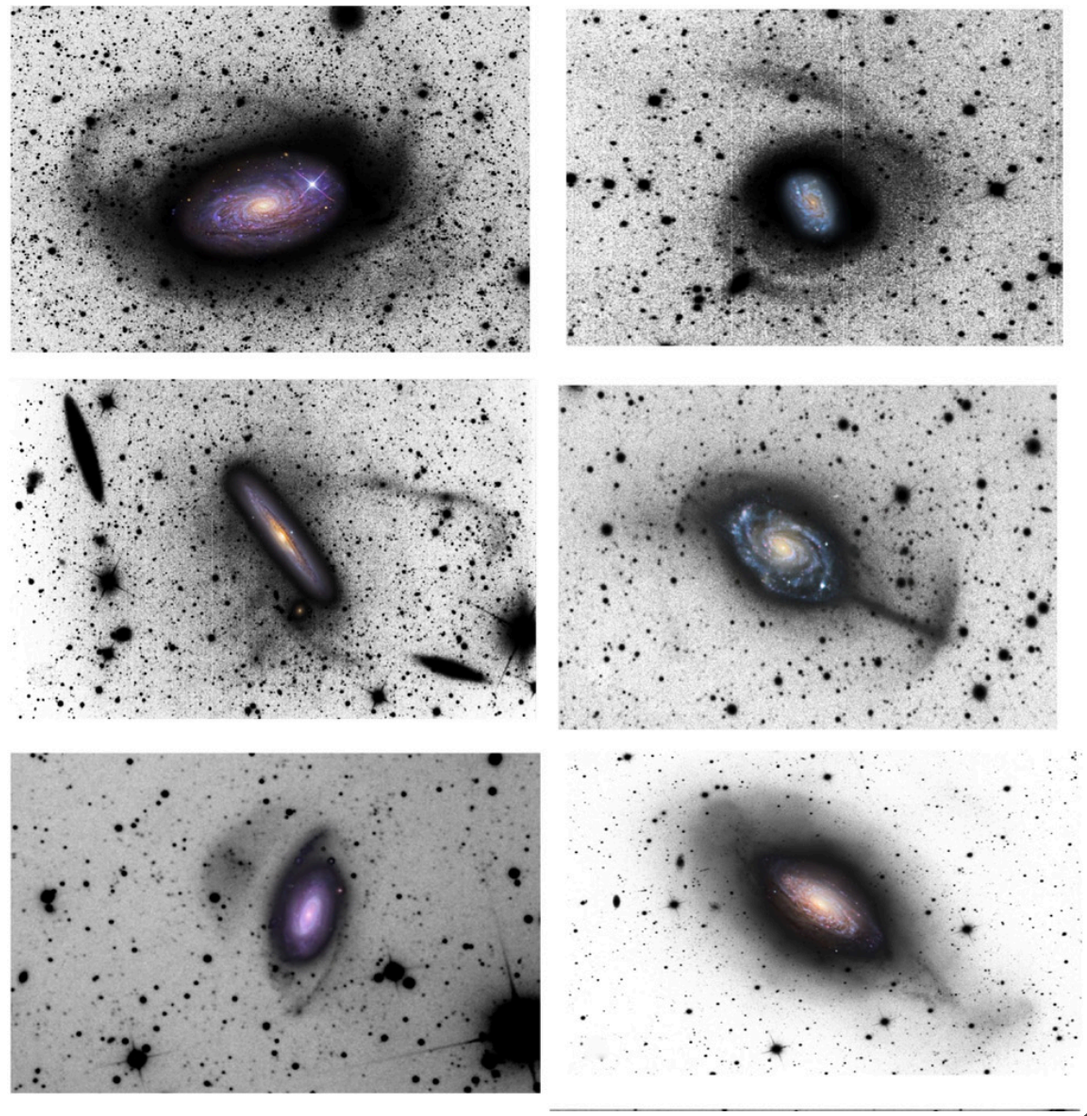


M 31



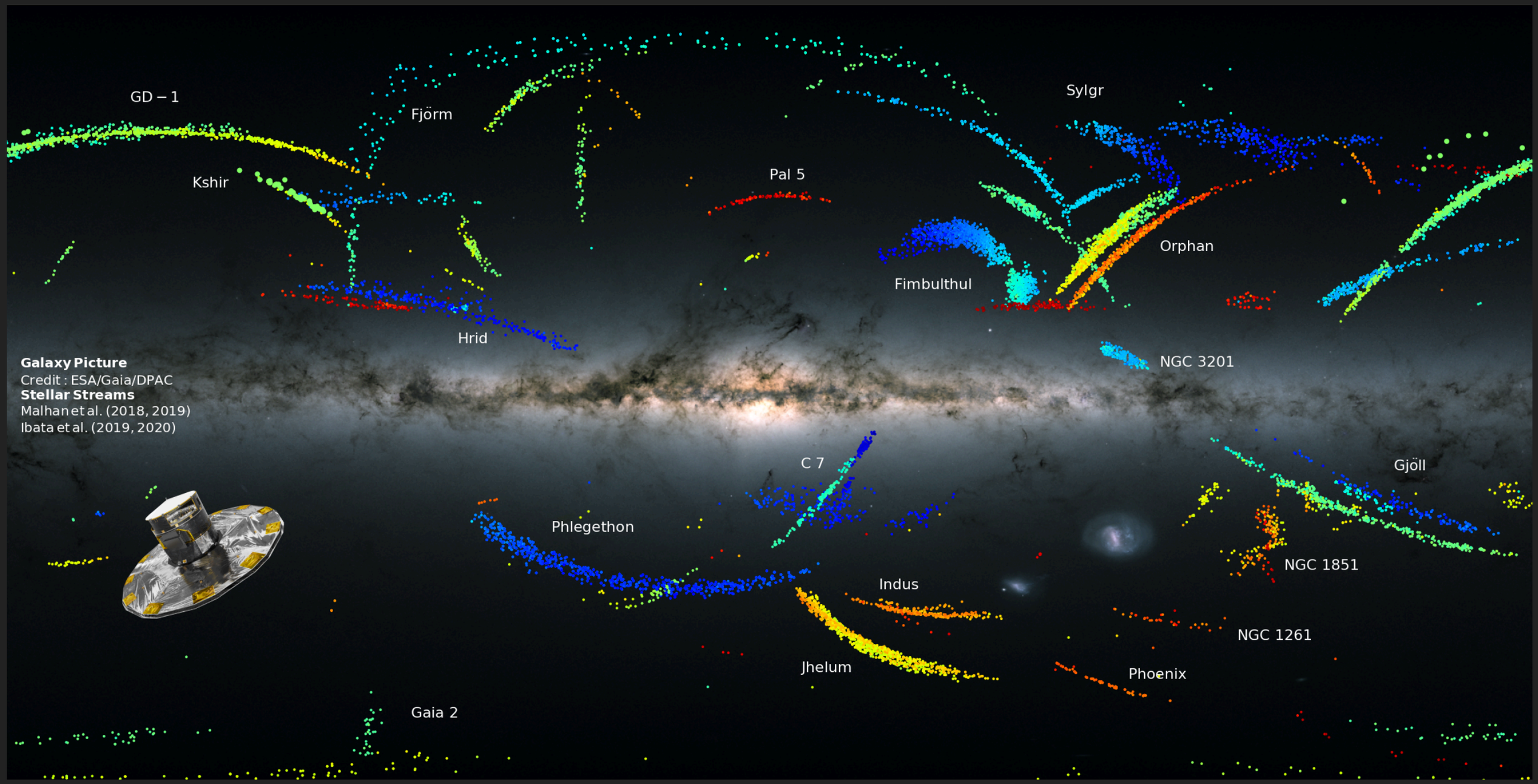
Martin et al., 2013

Other Galaxies



Martínez-Delgado et al., 2010

Stellar streams in the Milky Way



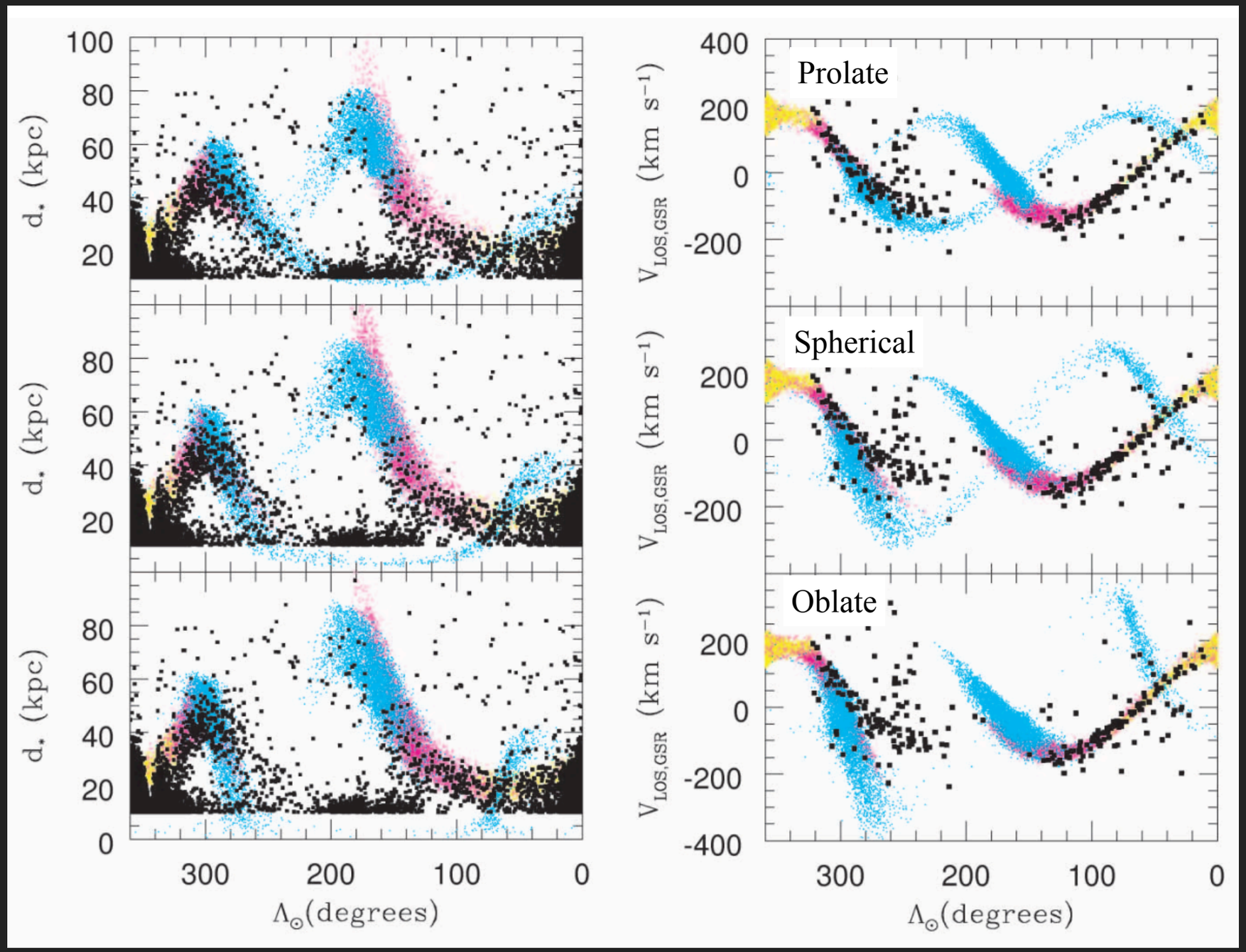
Credit: Khyati Malhan

More than 90 streams know currently around the MW
*(see Mateu 2023, Ibata et al., incl. **GT** 2024)*

What are the stream useful for?

1. Probing the Galactic potential

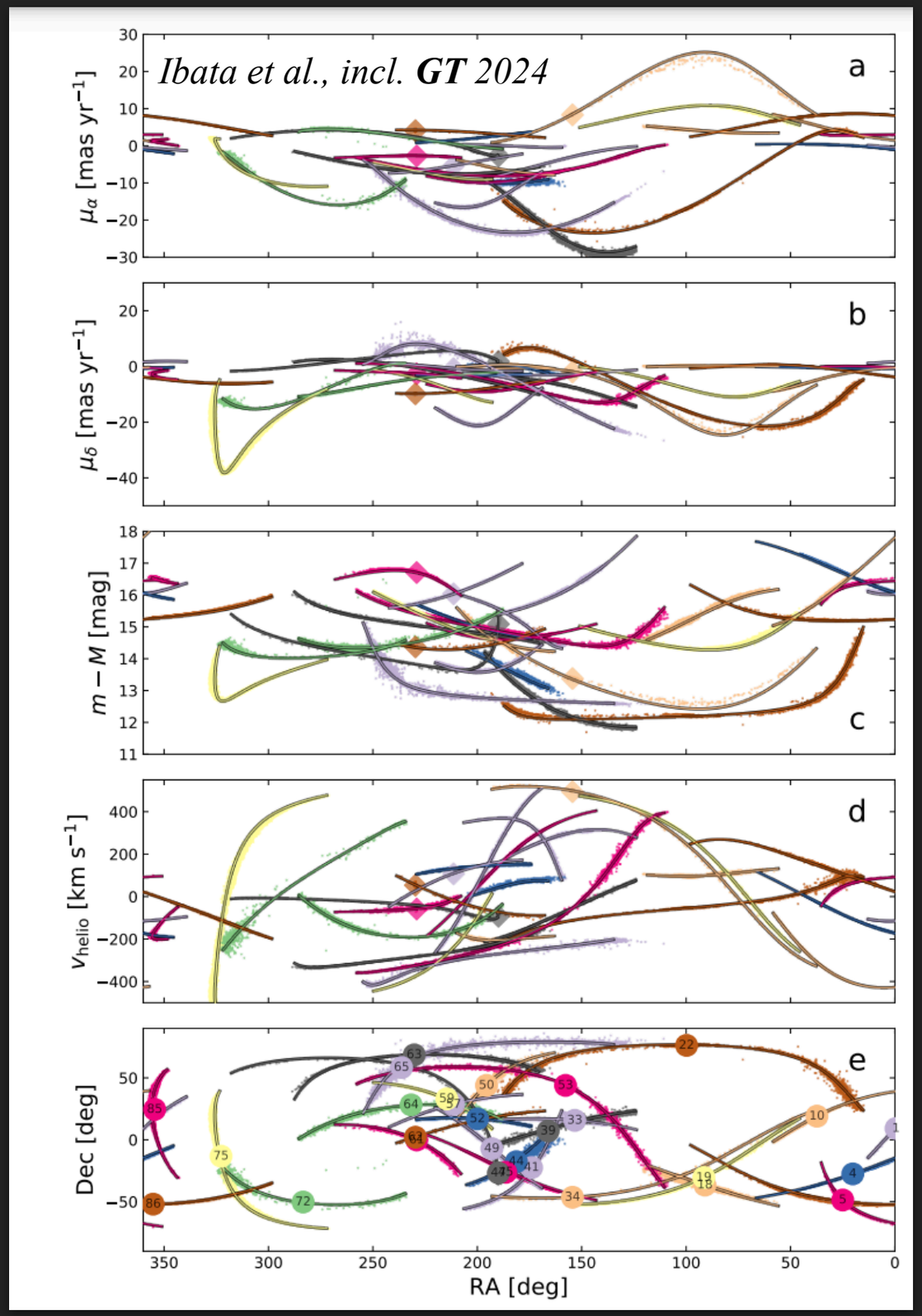
Stellar streams as accelerometers



Law et al., 2005

Global profile and shape of the Galactic potential ⟶ MW Dark Matter profile

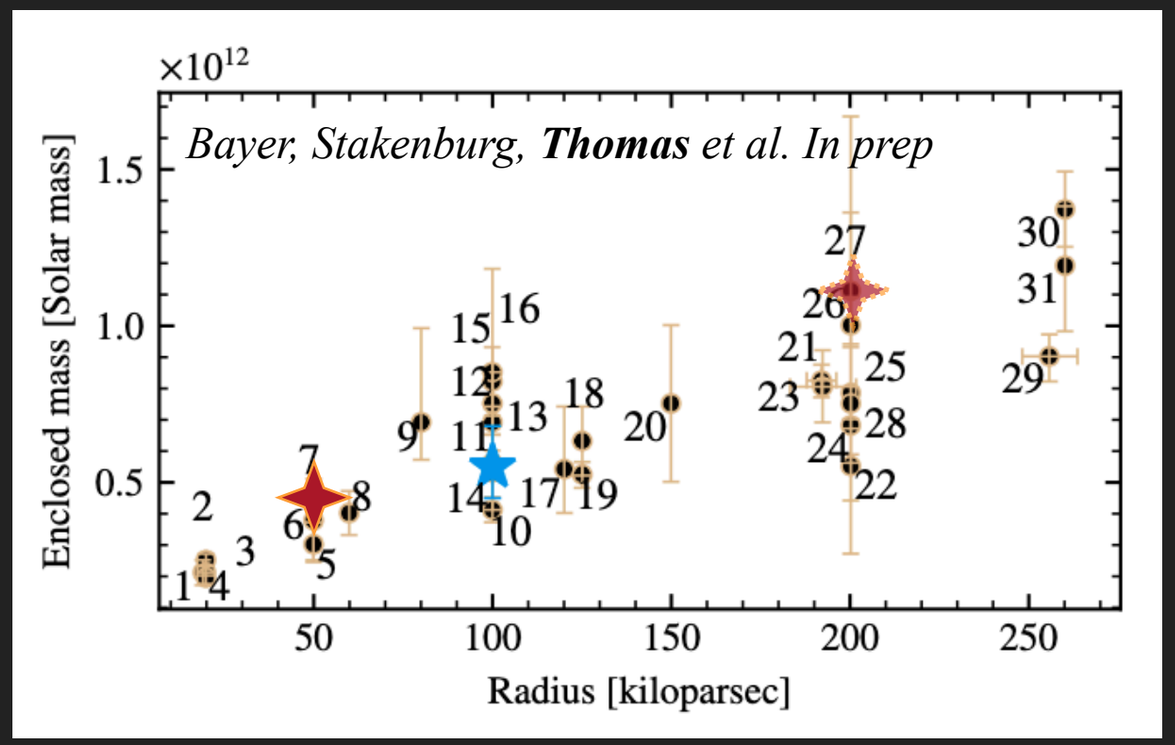
Stellar streams as accelerometers



- **Several streams can be used at once to give better constraints**

- In Ibata et al. 2024:
  - $\mathrm{M_{vir}} = 1.09^{+0.19}_{-0.14} \times 10^{12}\ \mathrm{M_\odot}$
  - $\mathrm{M_{50}} = 0.46 \pm 0.03 \times 10^{12}\ \mathrm{M_\odot}$
  - Flattening of $q = 0.75 \pm 0.03$

  + constraint on thin and thick disc scale length & height



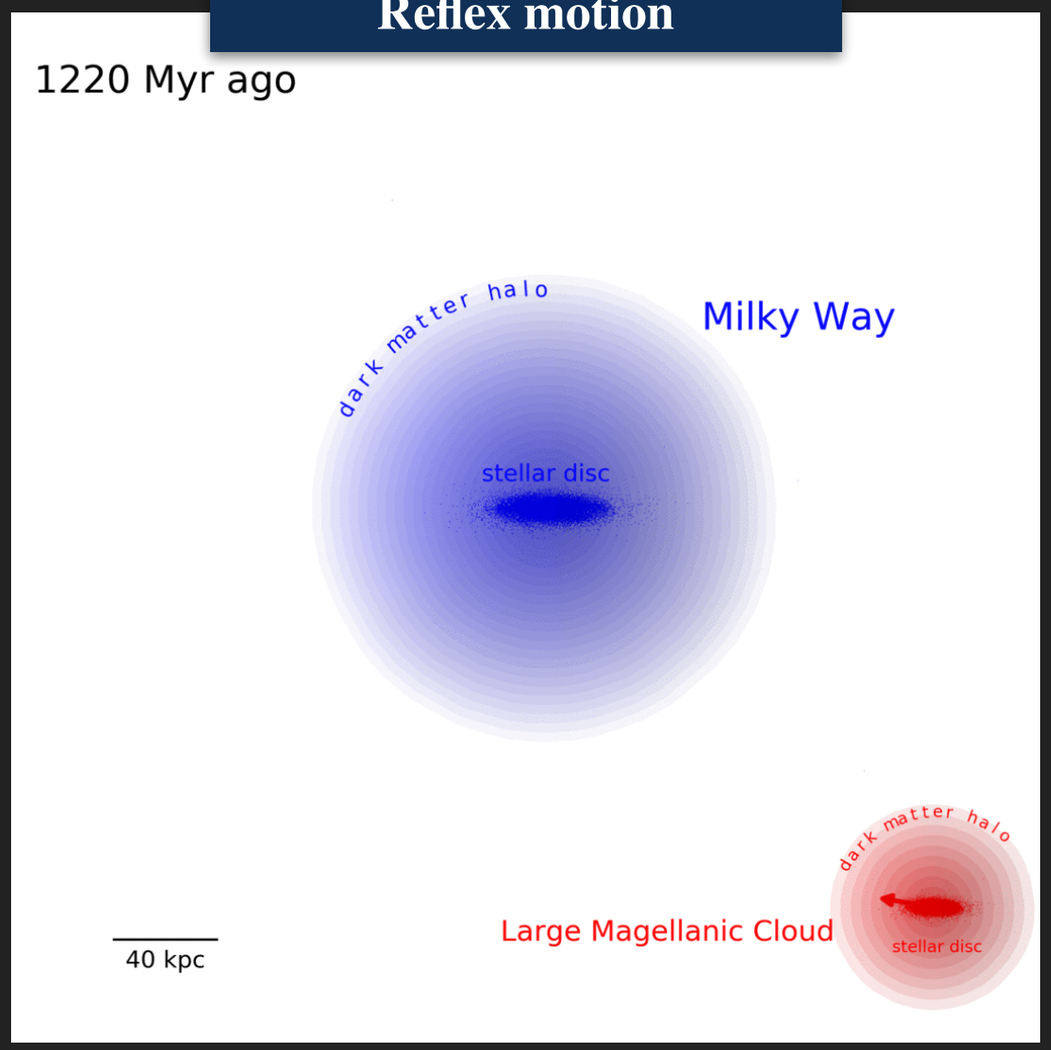
What are the stream useful for?

2. Detect and quantify large scale perturbations

The Milky Way is not in Equilibrium

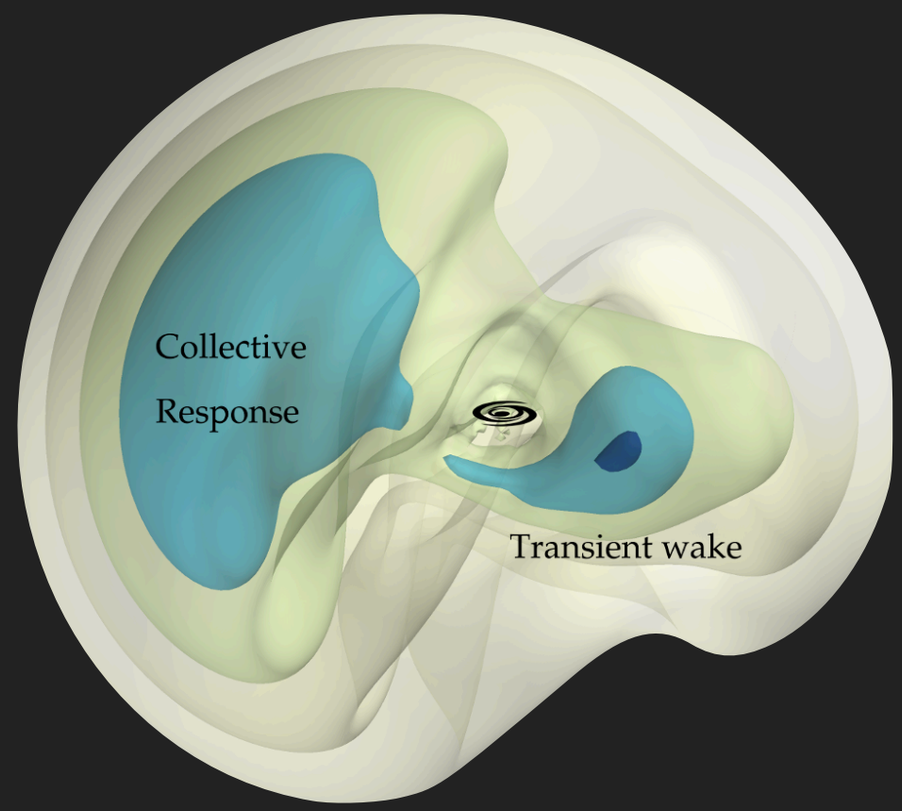
The **infall of the LMC** perturbs the gravitational potential of the MW:

Reflex motion



Credit: Mike Petersen

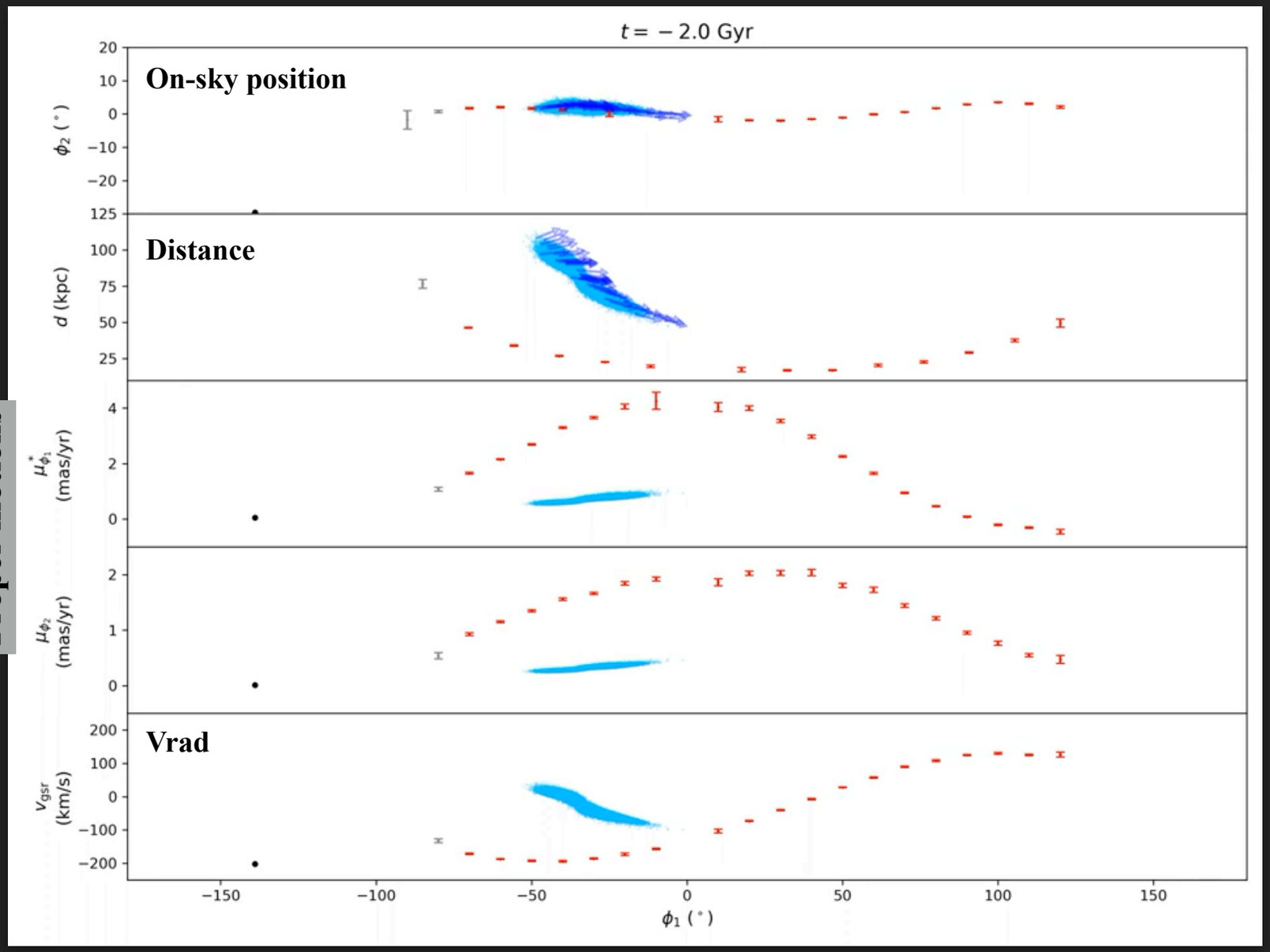
Dark matter wake

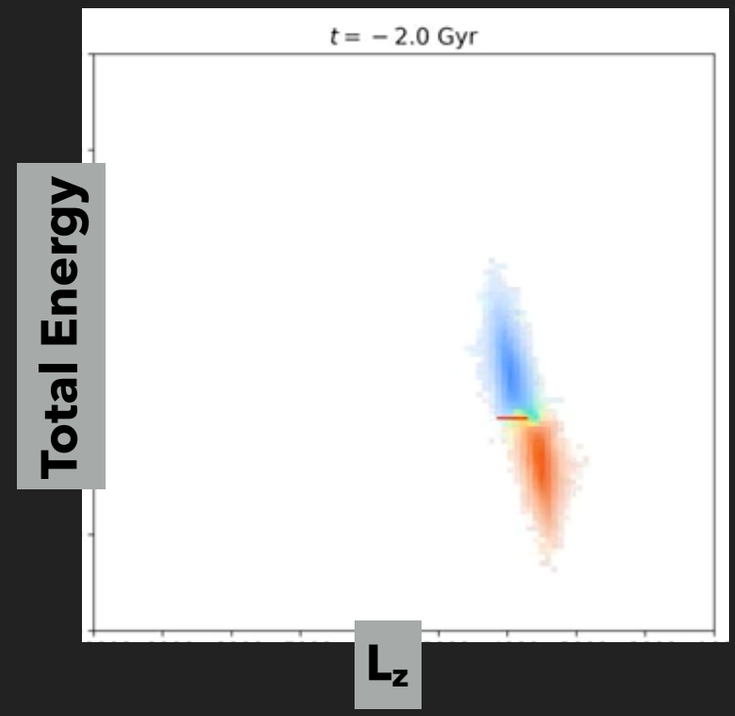


Credit: Nicolas Garavito-Camargo

Stellar streams to quantify perturbation

- Stellar streams are very useful tools to probe several dynamical effects and perturbations:
  - **The infall of the LMC** *(ex. Orphan-Chenab, Sagittarius)*





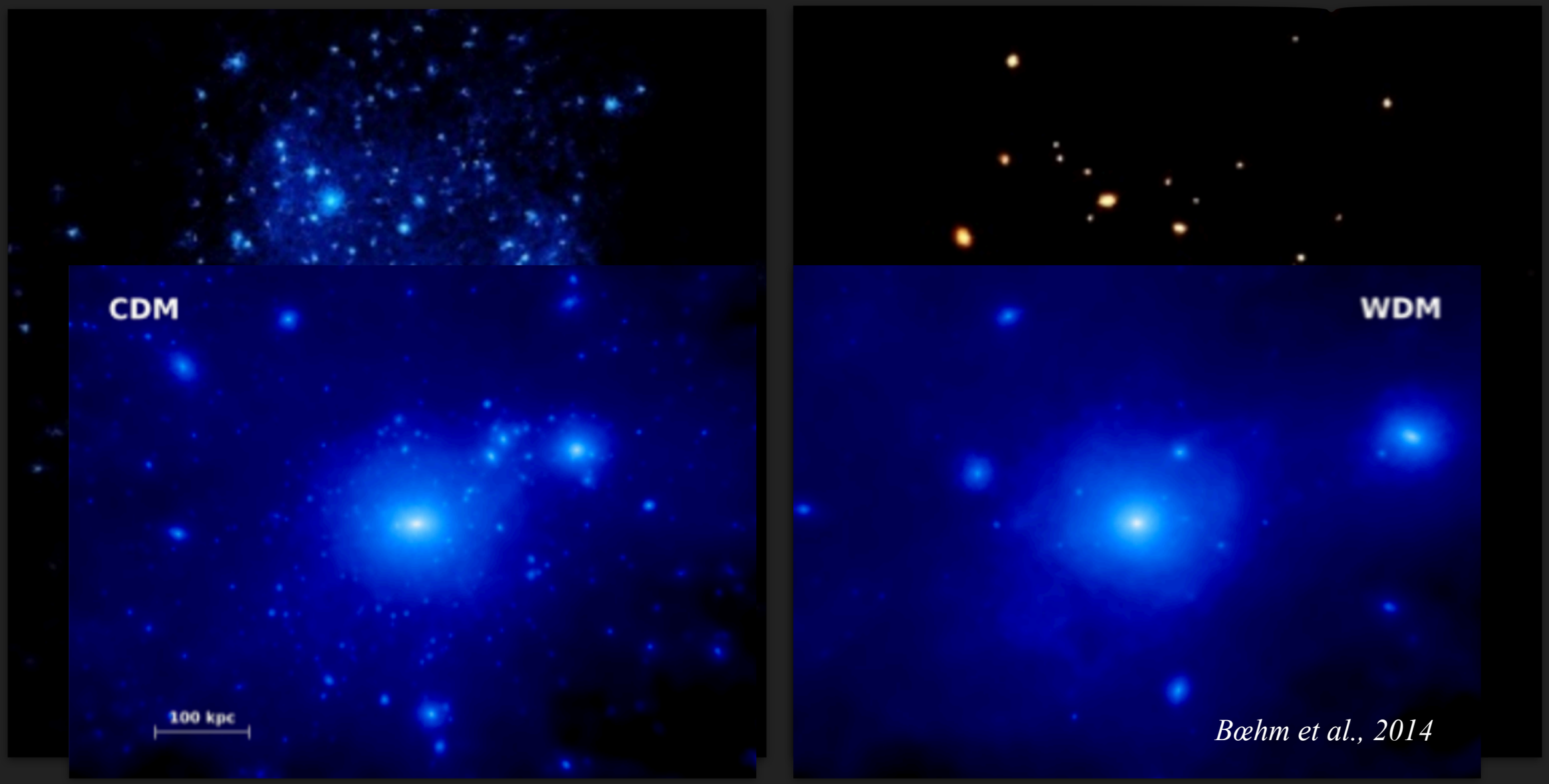
Credit: Denis Erkal

Erkal et al. 2019, Koposov et al. 2019, 2023, Lilleegen et al. 2023

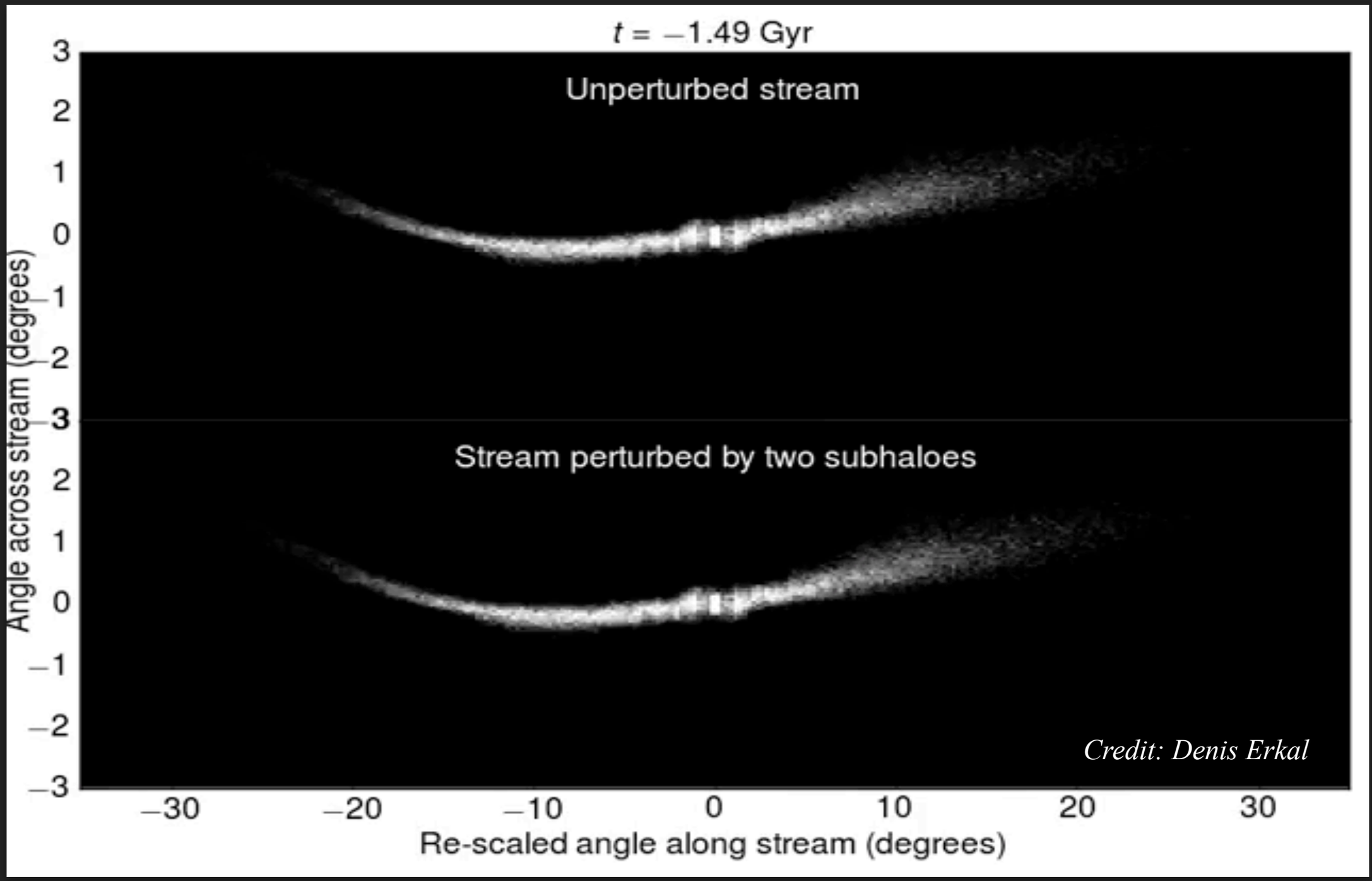
What are the stream useful for?

3. Detect DM subhaloes

Stellar streams as DM subhaloes detector



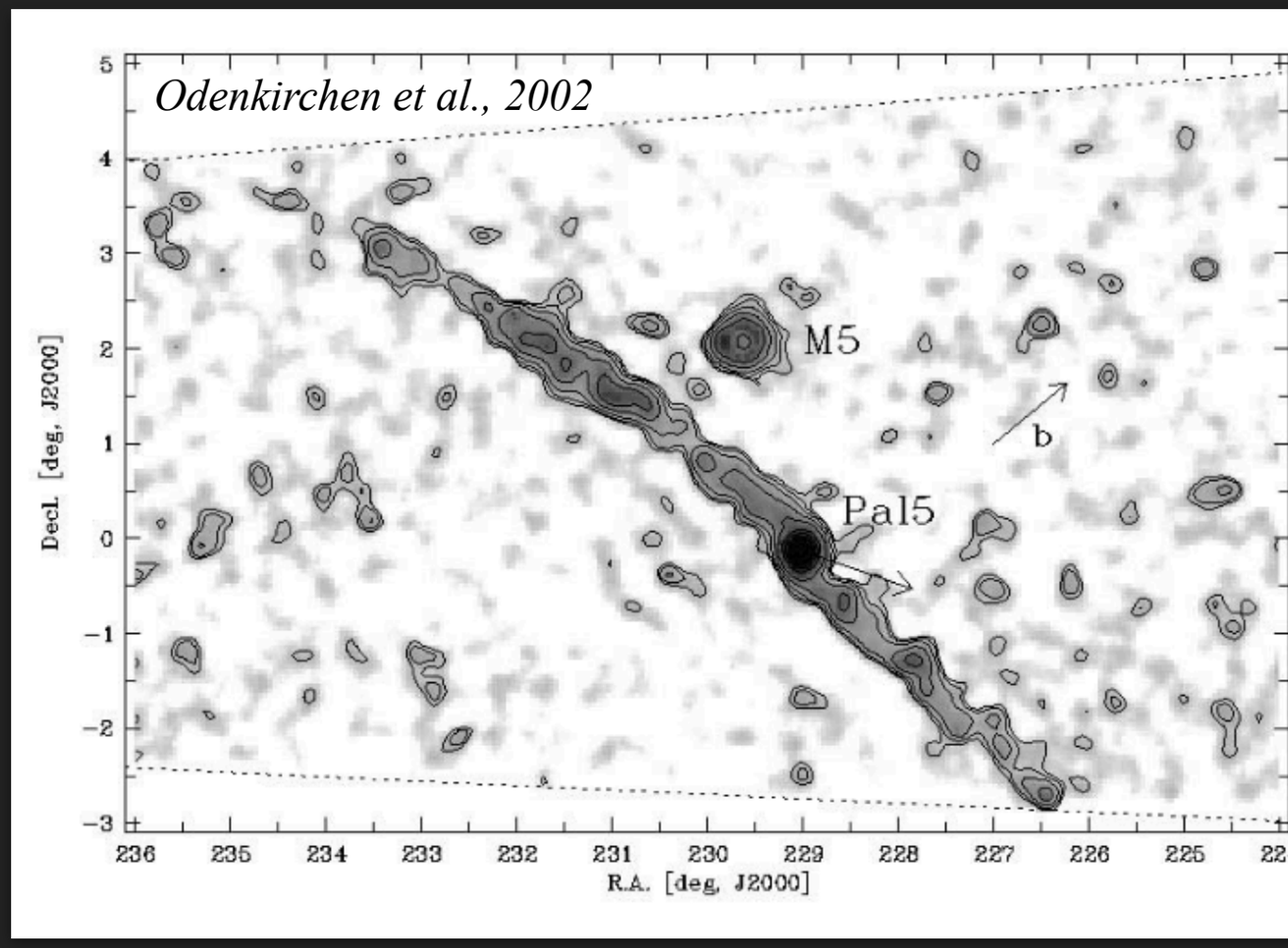
Stellar streams as DM subhaloes detector



Gaps in streams

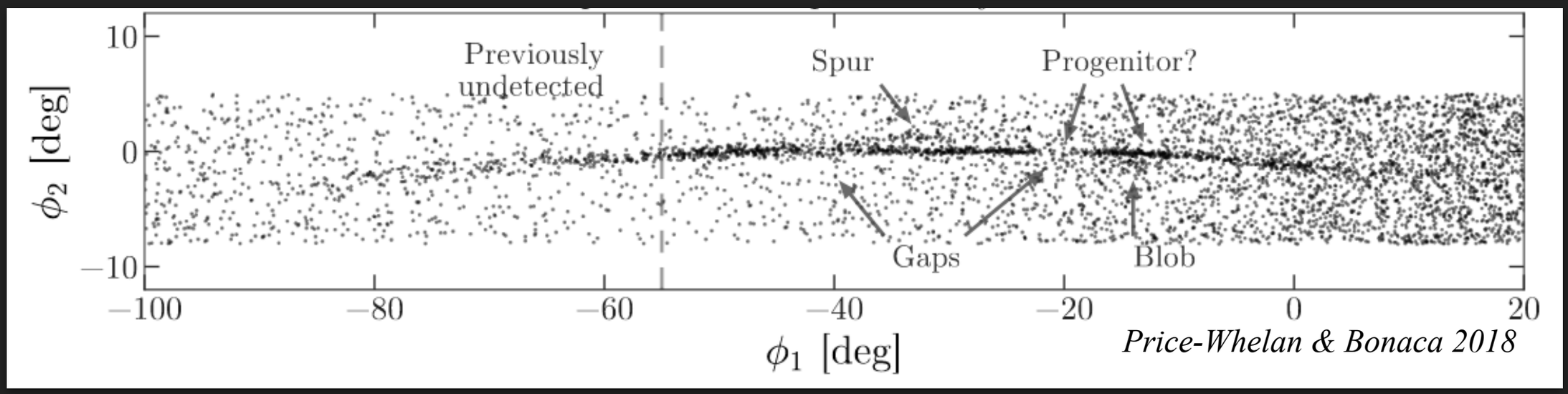
Pal 5

***Carlberg et al. 2012*:**
5 gaps at 99% confidence in Pal 5



Price-Whelan & Bonaca 2018:
2 gaps in GD-1

GD-1



Gaps in streams

- But… other effects can create gaps in streams:

1. External perturbers:

- Galactic Bar
  Hattori+2016, Pearson+2017, Banik & Bovy 2019
- Spiral arms
  Banik & Bovy 2019
- GMC
  Amorisco+2016, Banik & Bovy 2019
- LMC/Sgr/Other objects
  *de Boer et al. 2020, Li et al. 2021, Shipp et al. 2021, Malhan et al. 2021, Foote+(incl. **GT**) sub.*

2. Internal perturbations:

- Epicycle motion
  *Küpper +2008, 2010, 2012, Mastrobuono-Battisti+2013, **Thomas**+2016, Sanders+2016, Ibata, **GT**+2020, Jerabkova+2021*
- Progenitor dissolution
  Webb & Bovy, 2018
- Stellar mass black holes?
  Gieles+2021

3. Observational artefacts

- Photometric uncertainties
  *Ibata+(inc. **GT**)2016, **Thomas**+2016*
- Survey's inhomogeneities
  Thomas+2016
  *Ibata, **Thomas**+2020*
- Scanning laws
  *Ibata, **Thomas**+2020*

Gaps in streams

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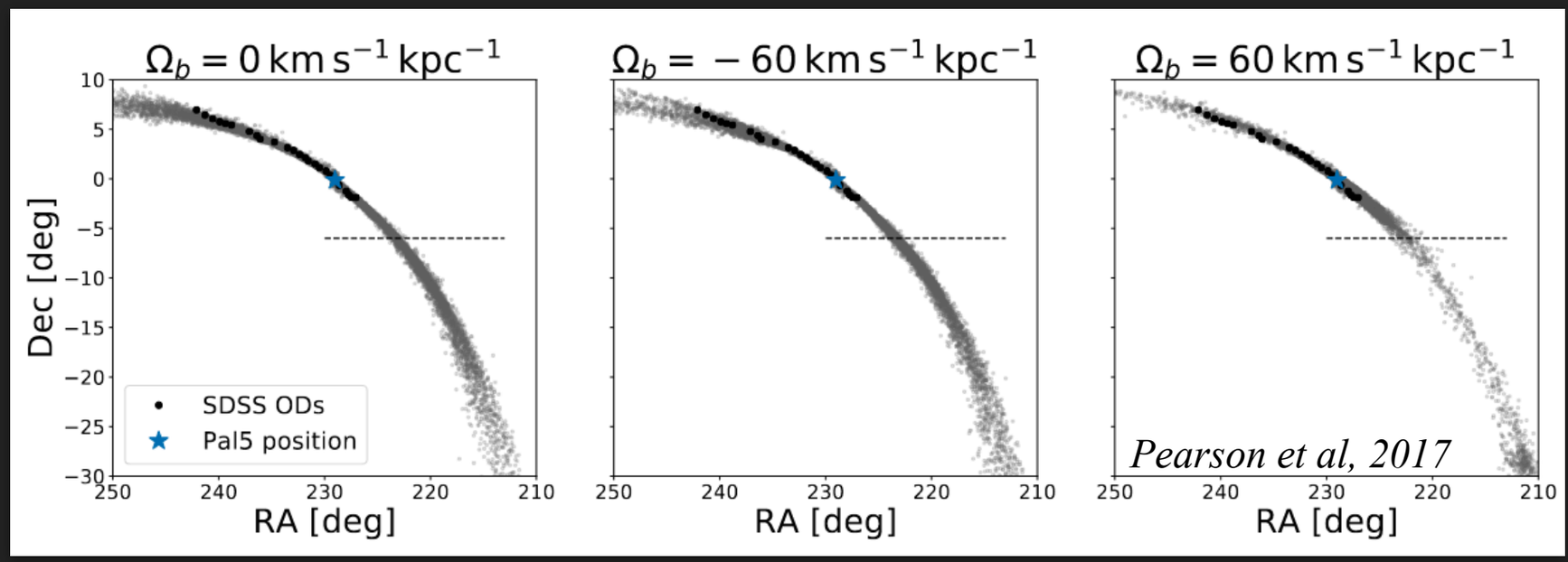

Gaps in streams

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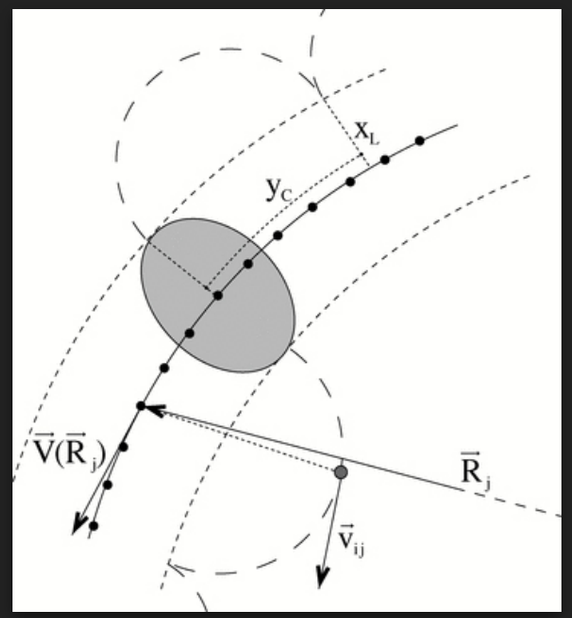
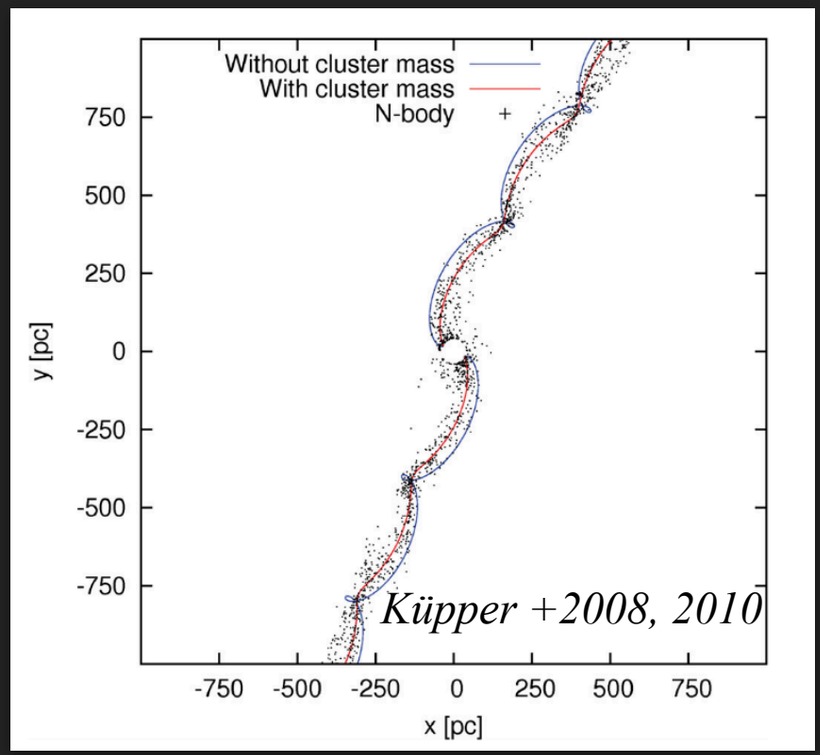
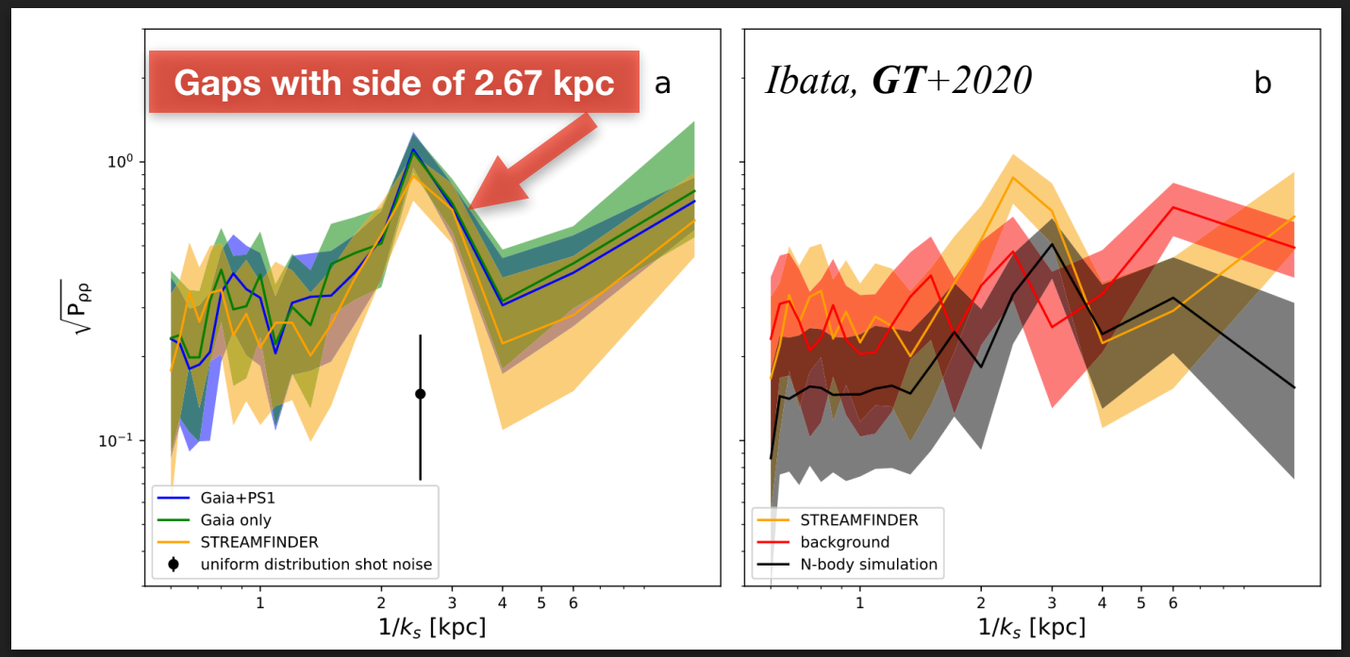




GD-1



Gaps in streams

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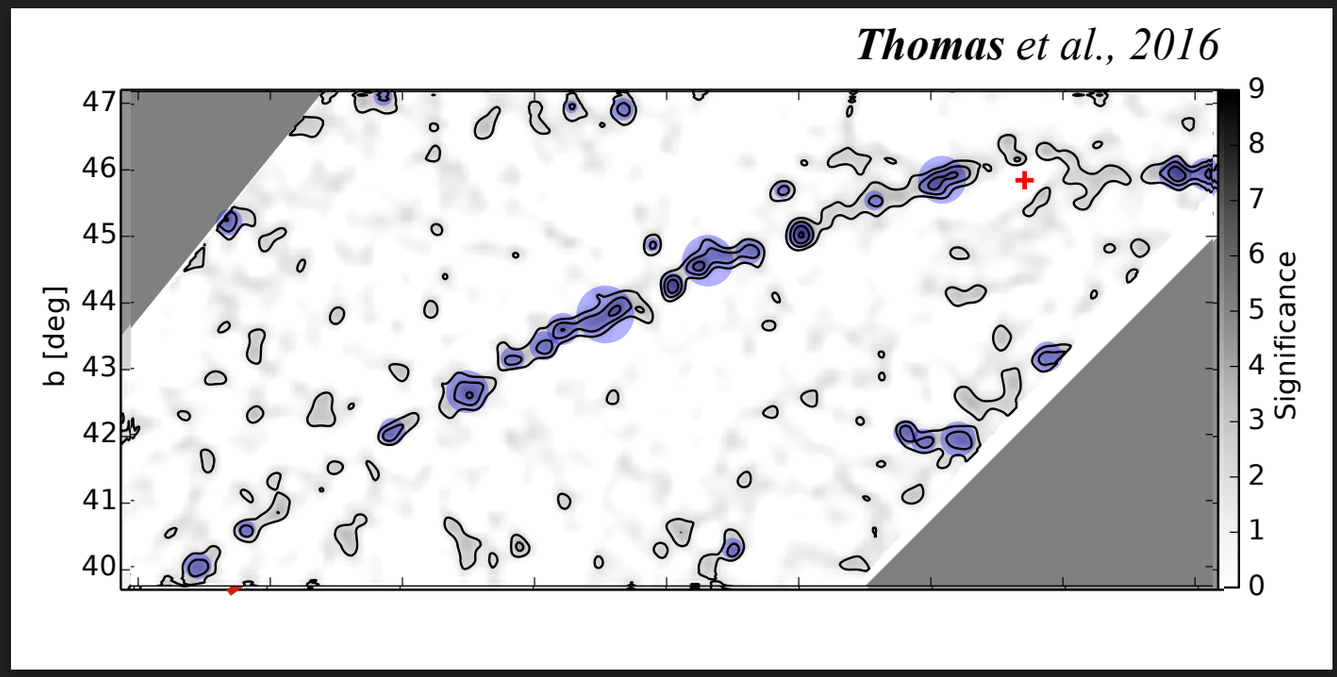

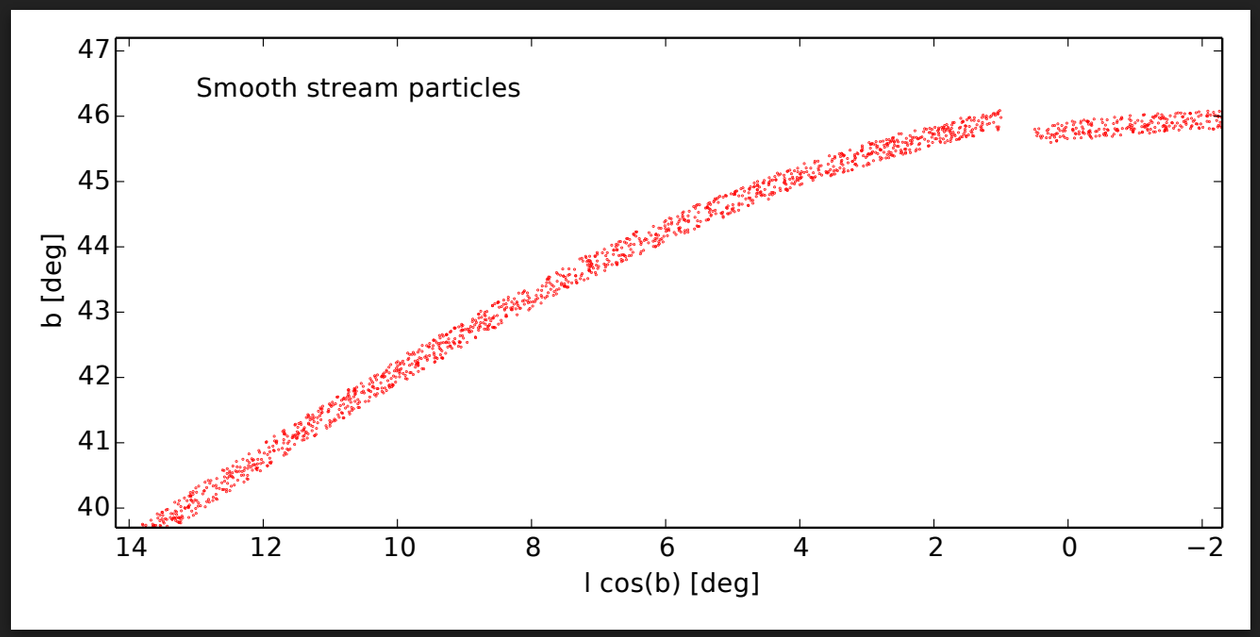

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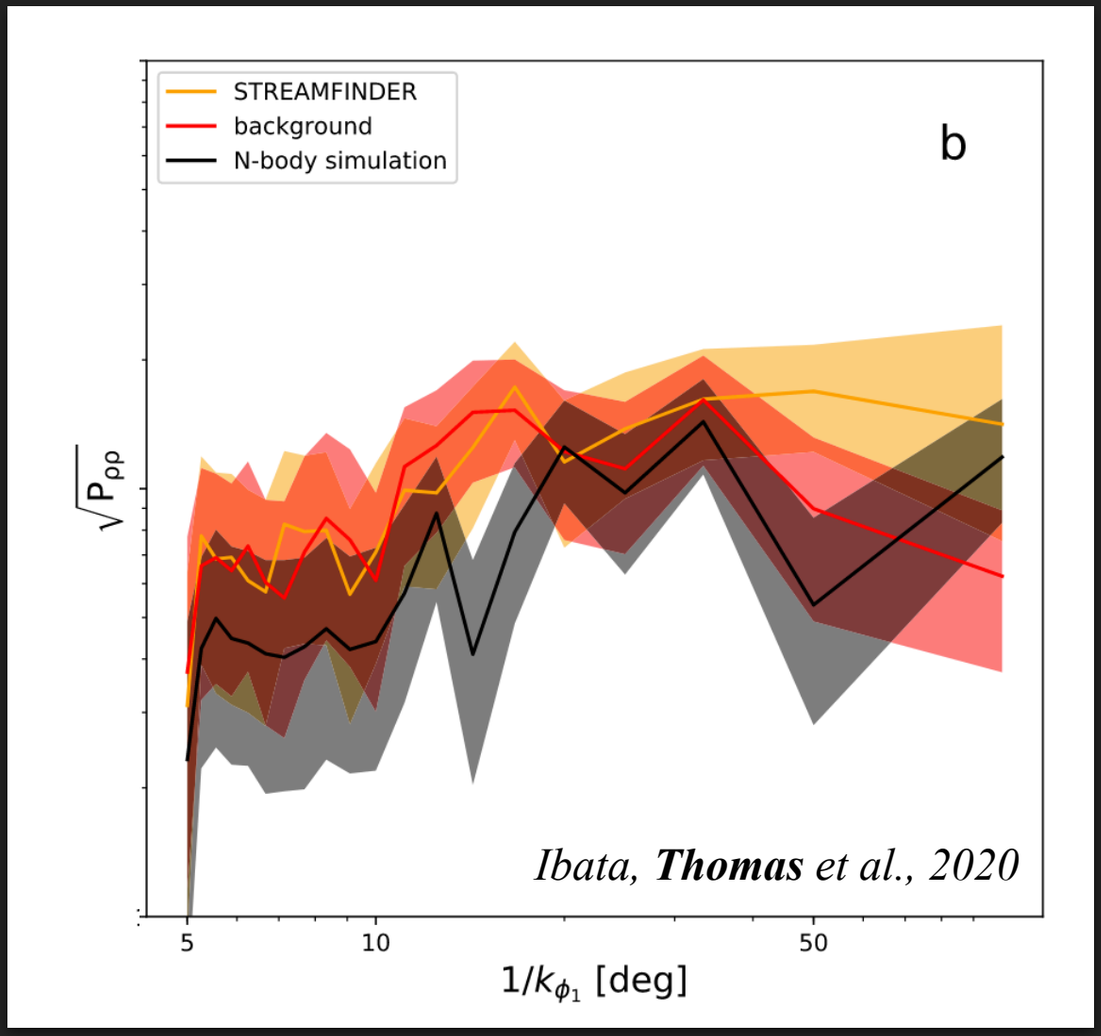
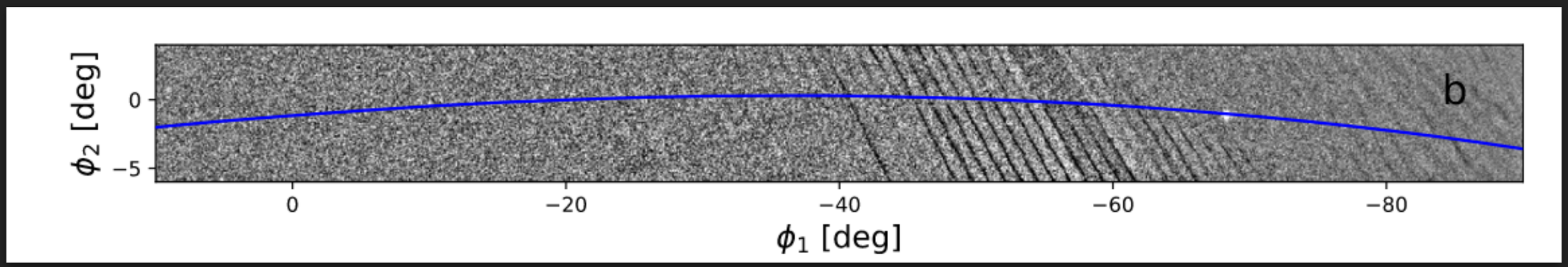


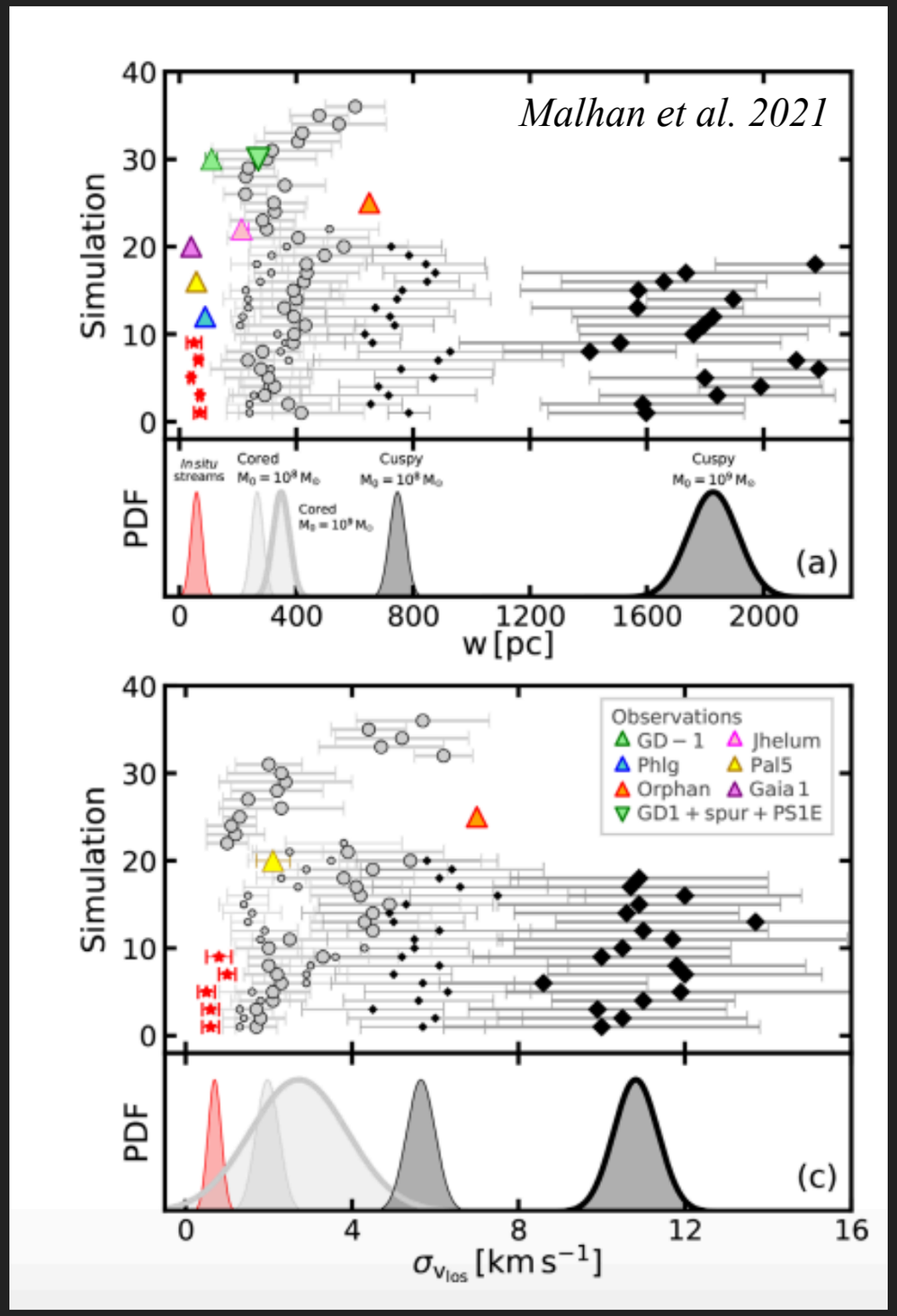


What are the stream useful for?

4. Probing the inner profile of a dark matter halo

Cusp/core with streams

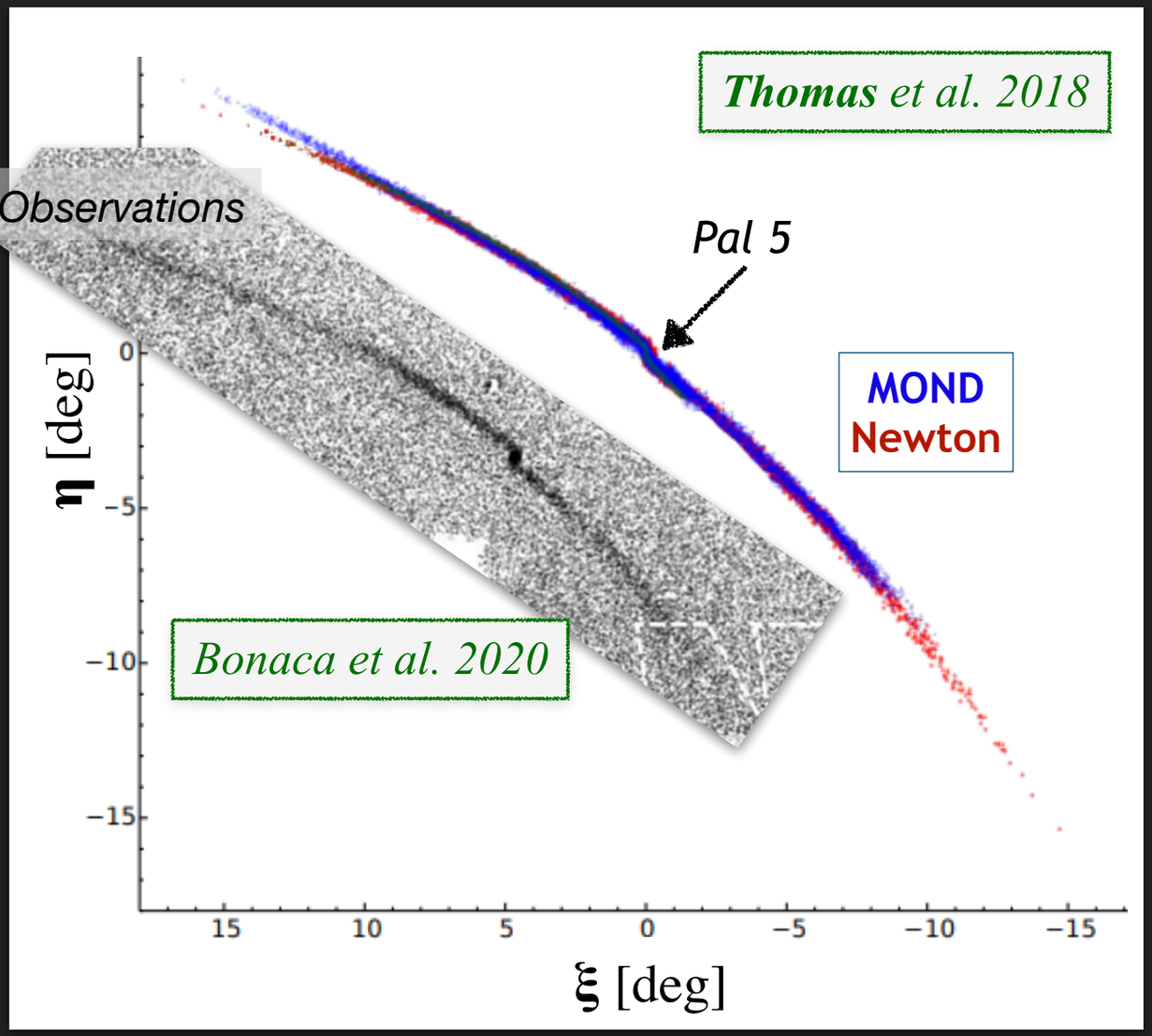
- **Globular cluster streams** can also be used to study the **cusp/core** problem:
    - In a clumpy halo:
        + wide
        + velocity dispersion
        (+ broken)
    - In core halo:
        - narrower
        - velocity dispersion
        (- broken)



What are the stream useful for?

5. Test alternative DM theory

Test alternative DM theory

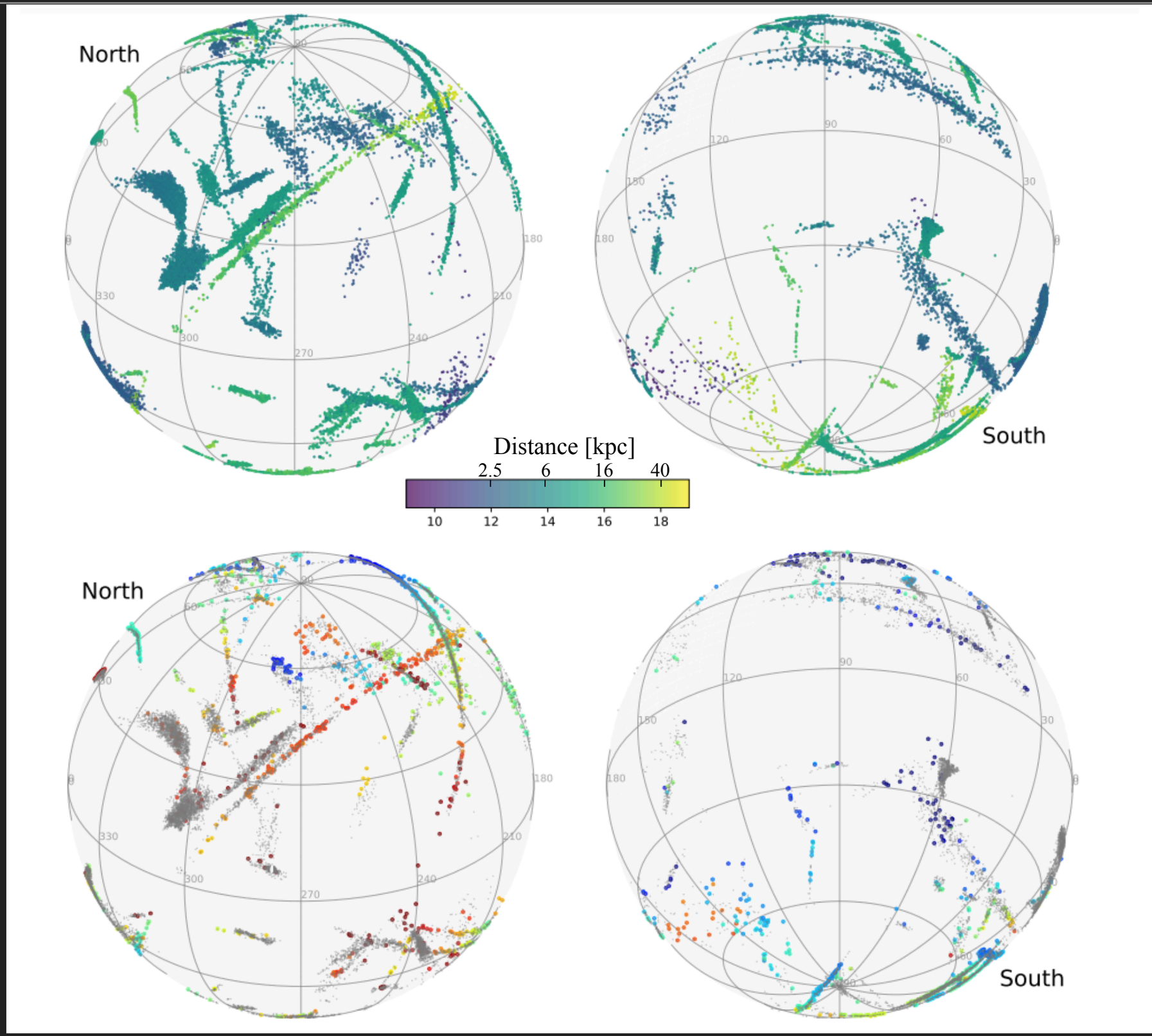


- **In Newtonian theory:** streams tend to be symmetric

- **In MOND:** stream can be asymmetric (due to EFE)

Streams @ IAC

Streams @ IAC



Ibata et al., incl. ***GT*** *2024*

Stars with spectra

Streams @ IAC

- **Spectroscopic follow-up:**

➡ Line-of-sight velocity

- ➡ Gravitational potential
- ➡ Gravitational perturbation(s)
- ➡ Dark matter sub-haloes
- ➡ Test alternative gravity

- **Deep multi-wavelength photometry**

- ➡ Discover more streams (larger distances, in other galaxies)
- ➡ Study density variation

Conclusions

- Stellar streams are very good tools to study indirectly dark matter @ astrophysical scale:

…(But also needed for direct measurement)

1. Probing the Galactic potential
2. Detect and quantify large scale perturbations
3. Detect DM subhaloes
4. Probing the inner profile of a dark matter halo
5. Test alternative DM theory

- Require precise multi-domain measurements
- **Need to understand other astrophysical effects to study DM with streams**

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