By the Light of a Billion Stars: Dark matter and the stellar halo

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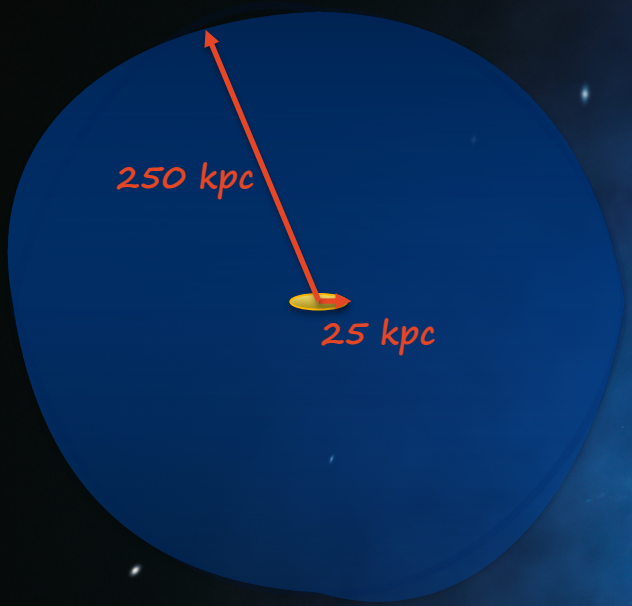


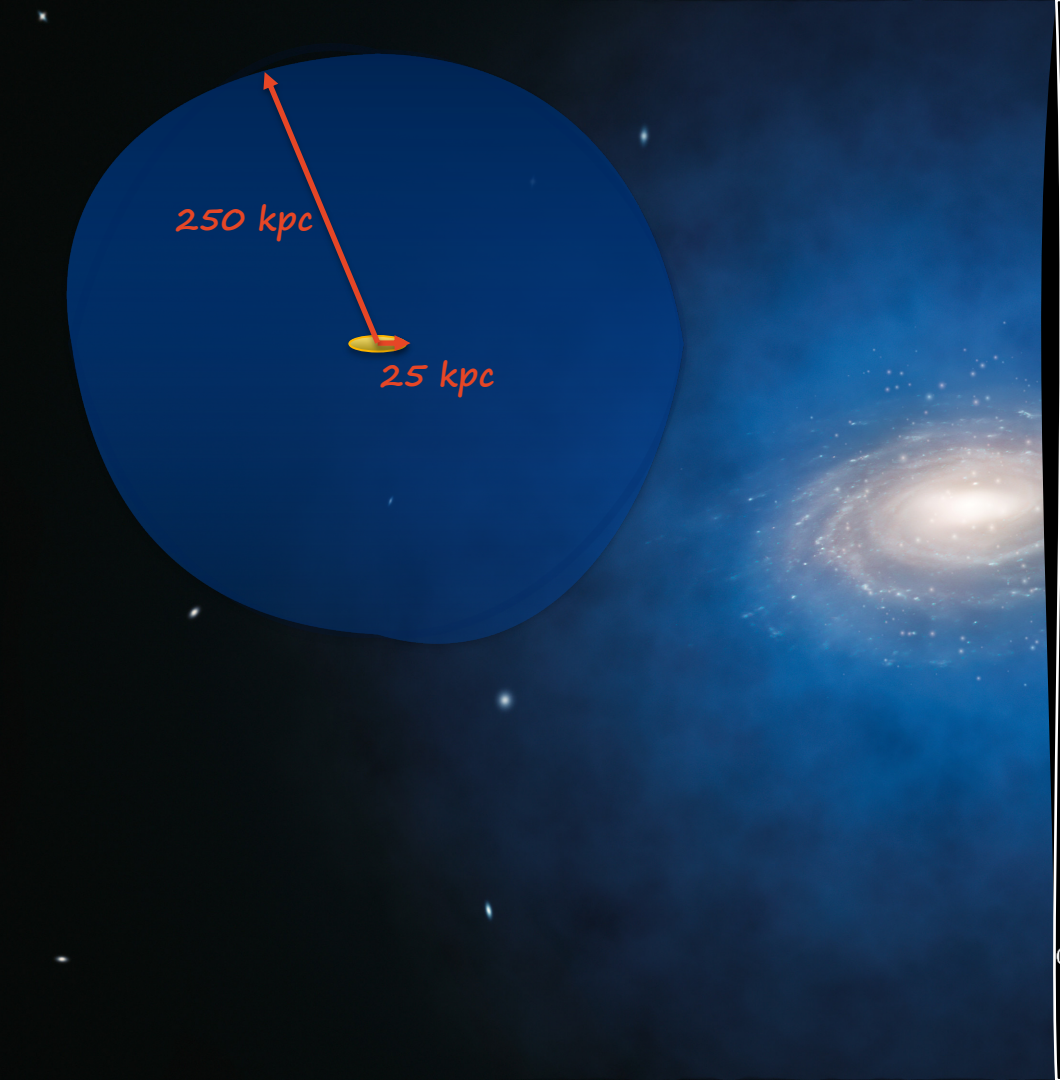
Dark Matter Halo

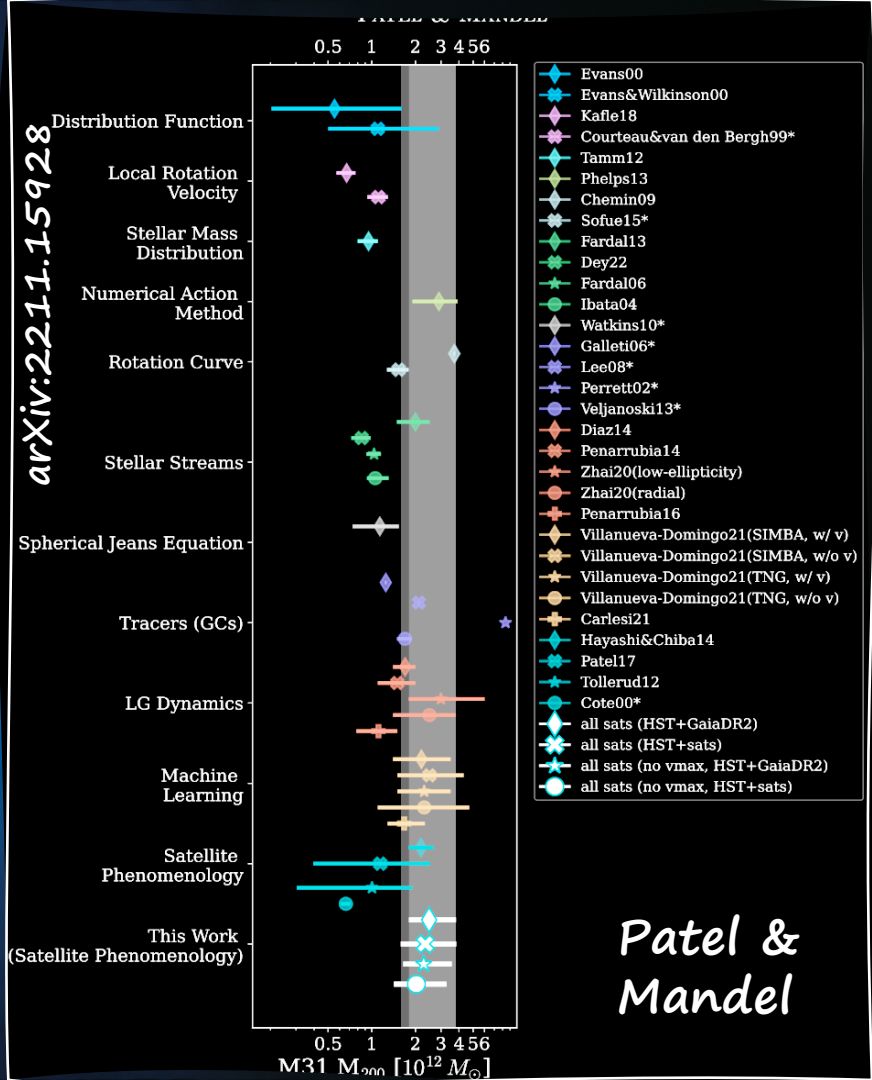
What we don't know:

- How much?
- How far?
- Cusp/core?
- Overall shape?
- Rotation?
- Lumpiness?

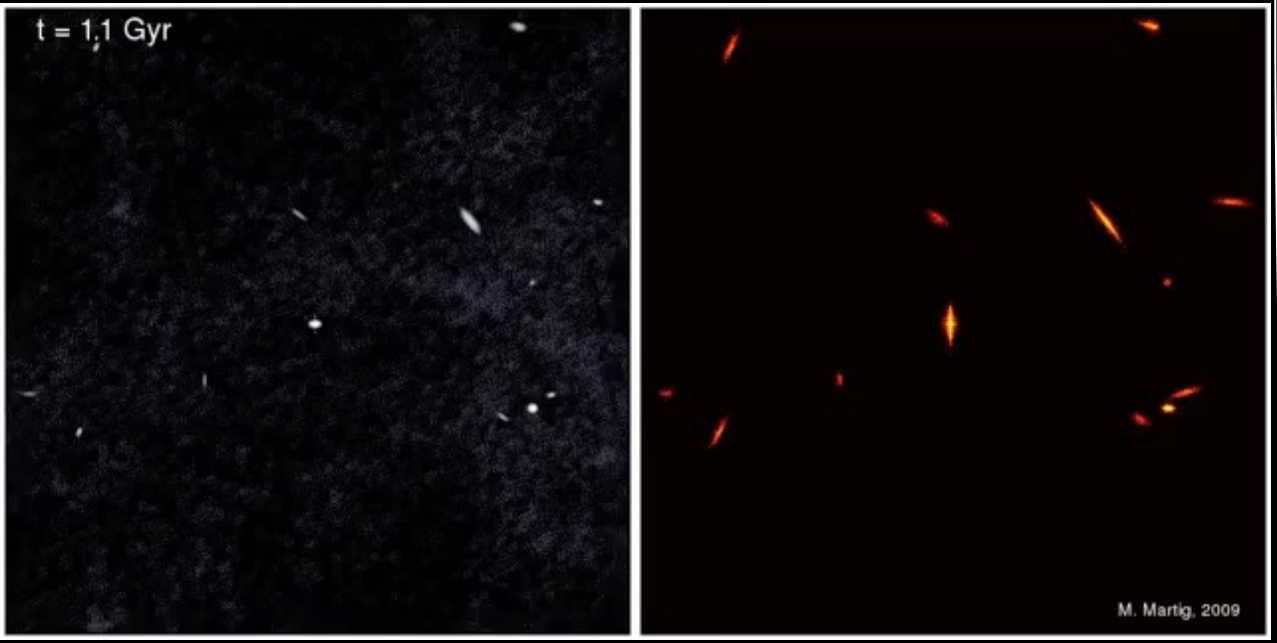
Visible Galaxy

Credit: ESO/L. Calçada

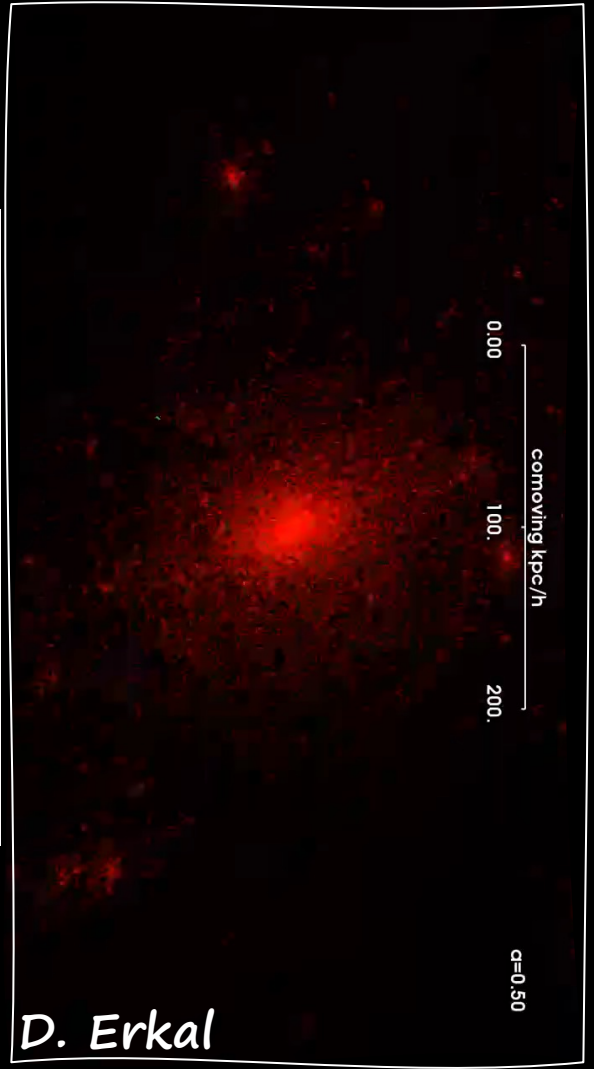

250 kpc
25 kpc


arXiv:2211.15928
0.5 1 2 3 4 5 6
Distribution Function
Local Rotation Velocity
Stellar Mass Distribution
Numerical Action Method
Rotation Curve
Stellar Streams
Spherical Jeans Equation
Tracers (GCs)
LG Dynamics
Machine Learning
Satellite Phenomenology
This Work (Satellite Phenomenology)
Evans00
Evans&Wilkinson00
Kafle18
Courteau&van den Bergh99*
Tamm12
Phelps13
Chemin09
Sofue15*
Fardal13
Dey22
Fardal06
Ibata04
Watkins10*
Galleti06*
Lee08*
Perrett02*
Veljanoski13*
Diaz14
Penarrubia14
Zhai20(low-ellipticity)
Zhai20(radial)
Penarrubia16
Villanueva-Domingo21(SIMBA, w/ v)
Villanueva-Domingo21(SIMBA, w/o v)
Villanueva-Domingo21(TNG, w/ v)
Villanueva-Domingo21(TNG, w/o v)
Carlesi21
Hayashi&Chiba14
Patel17
Tollerud12
Cote00*
all sats (HST+GaiaDR2)
all sats (HST+sats)
all sats (no vmax, HST+GaiaDR2)
all sats (no vmax, HST+sats)
M31 M_{200} [10^{12} $M_\odot$]
Patel & Mandel

Galaxy Formation



Martig (2009)



D. Erkal

The Stellar Halo

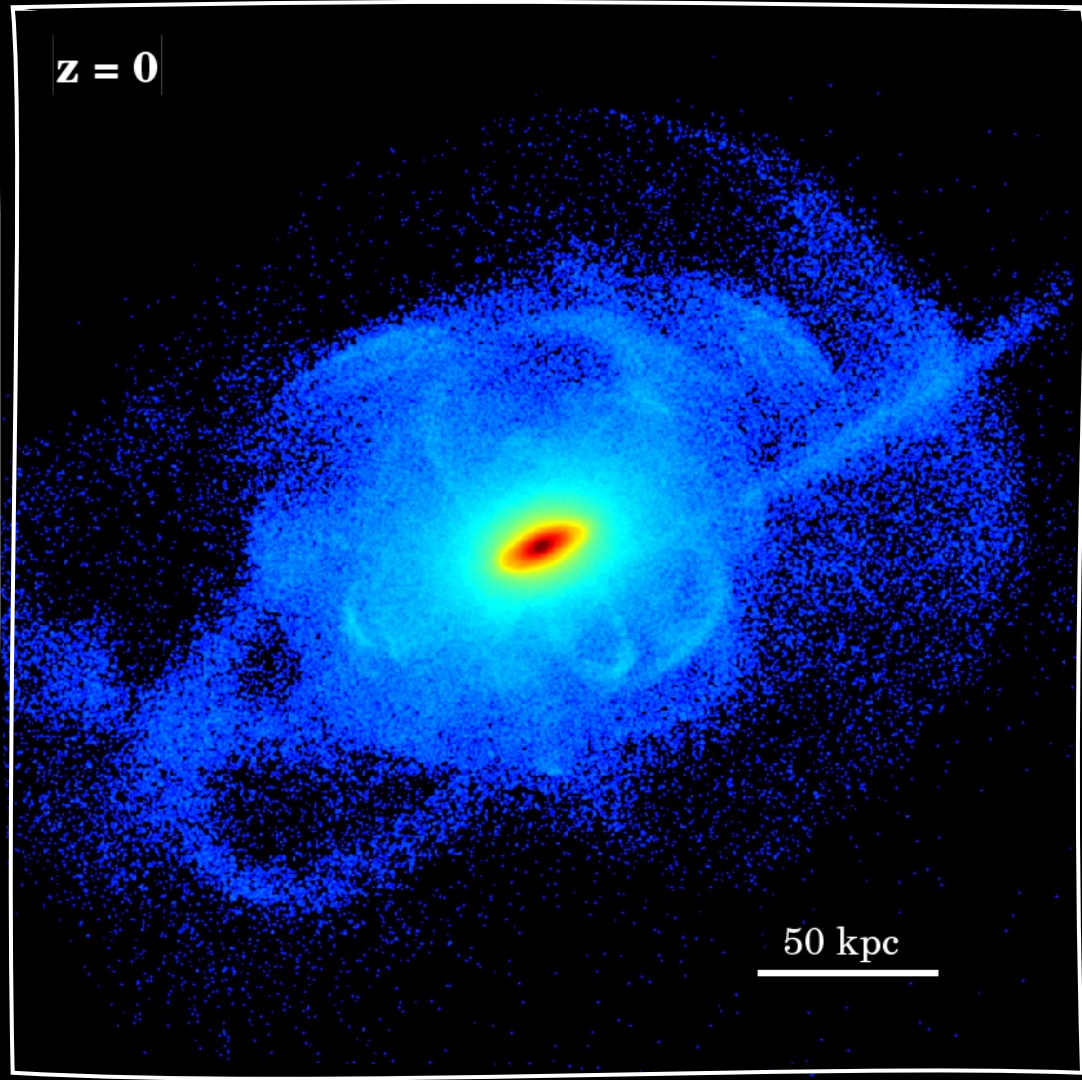
Contains ~% of Galactic light
Extensive (~100s kpc)
Mix of old & young accretions

Smooth(ish) from GES
Streams from recent accretions

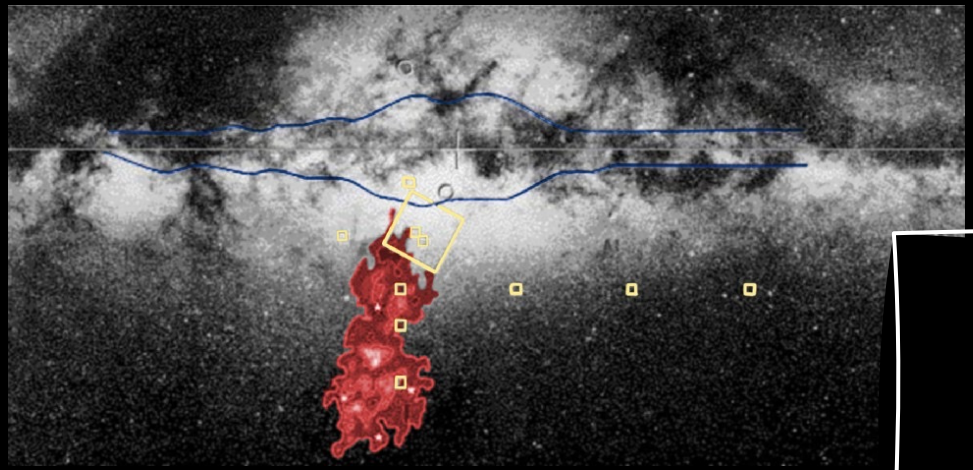
Dynamical probes of DM!

But!

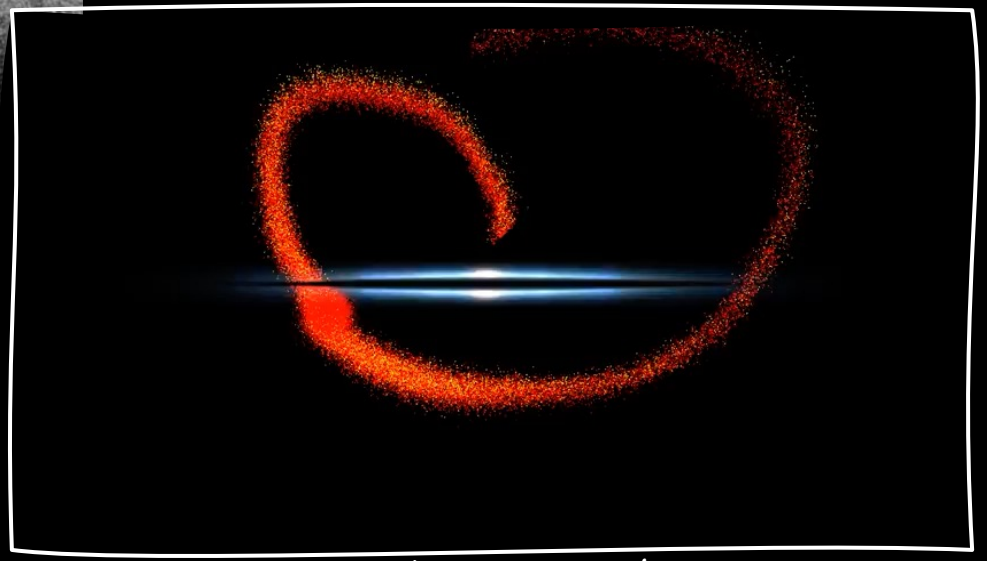
Features are faint
Kinematics are difficult



Sagittarius Dwarf Galaxy

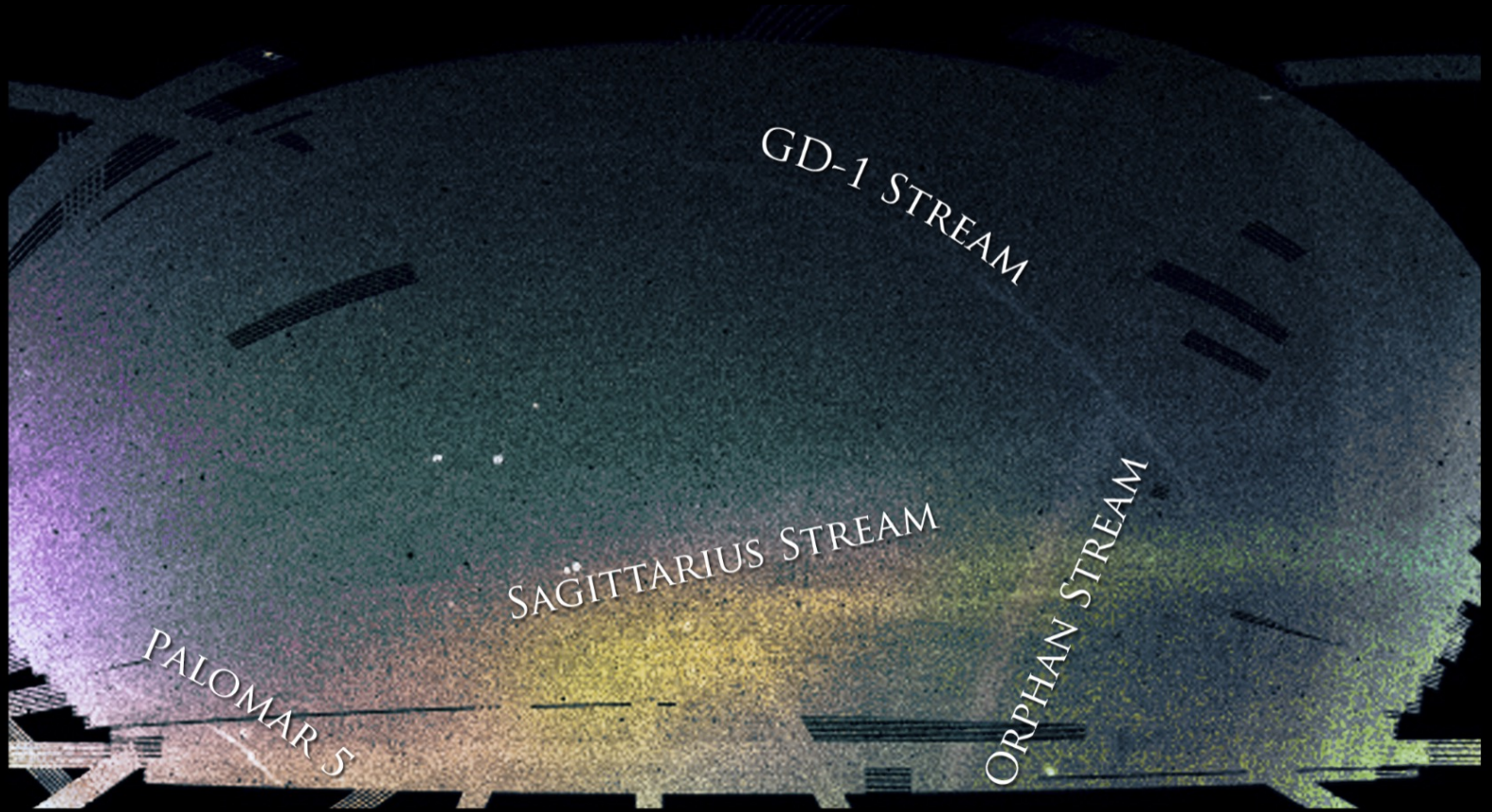


Ibata et al. (1993)



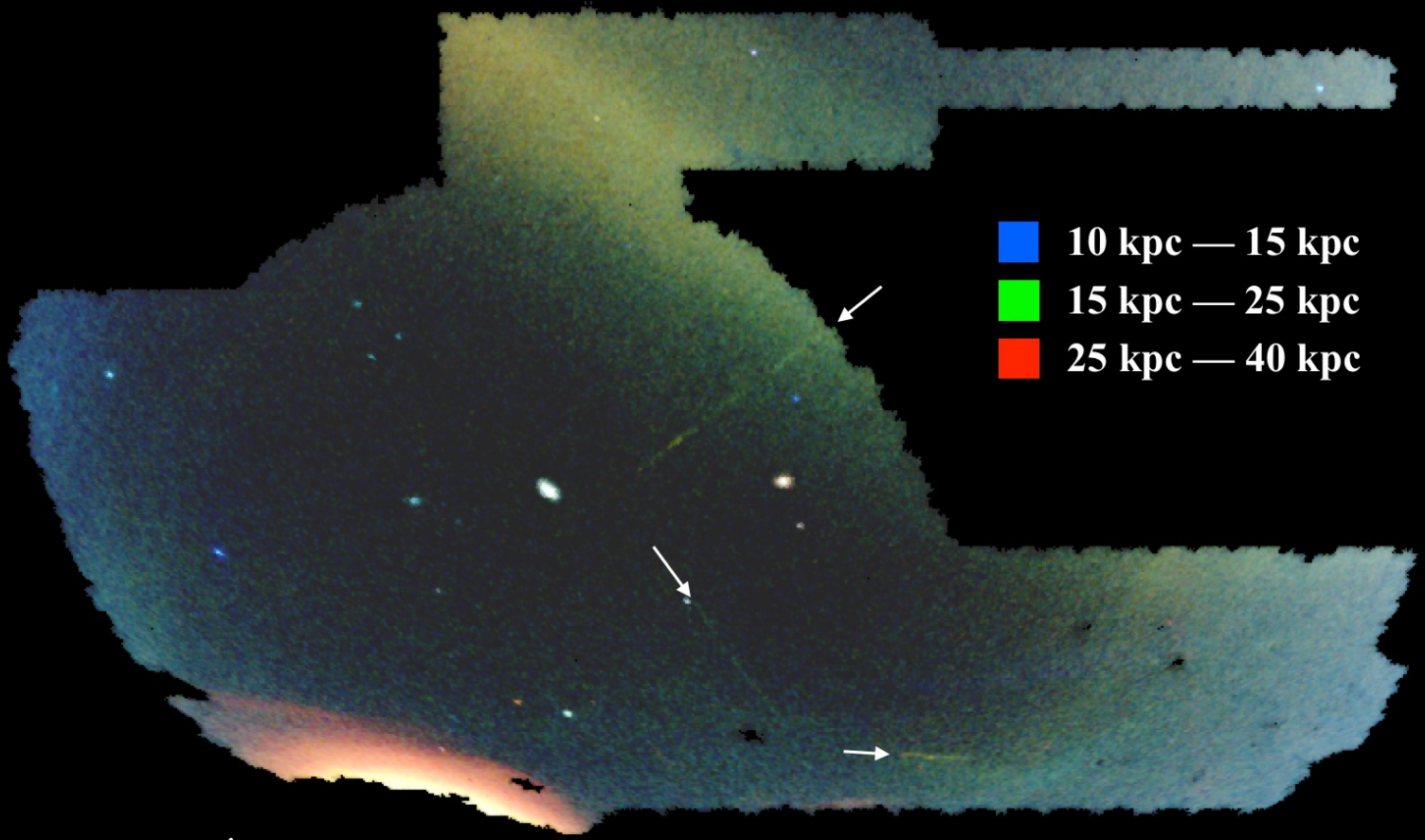
https://youtu.be/tPsKODzs_vQ

Northern Sky



Sloan Digital Sky Survey SDSS DR8 / Bonaca, Giguere, Geha

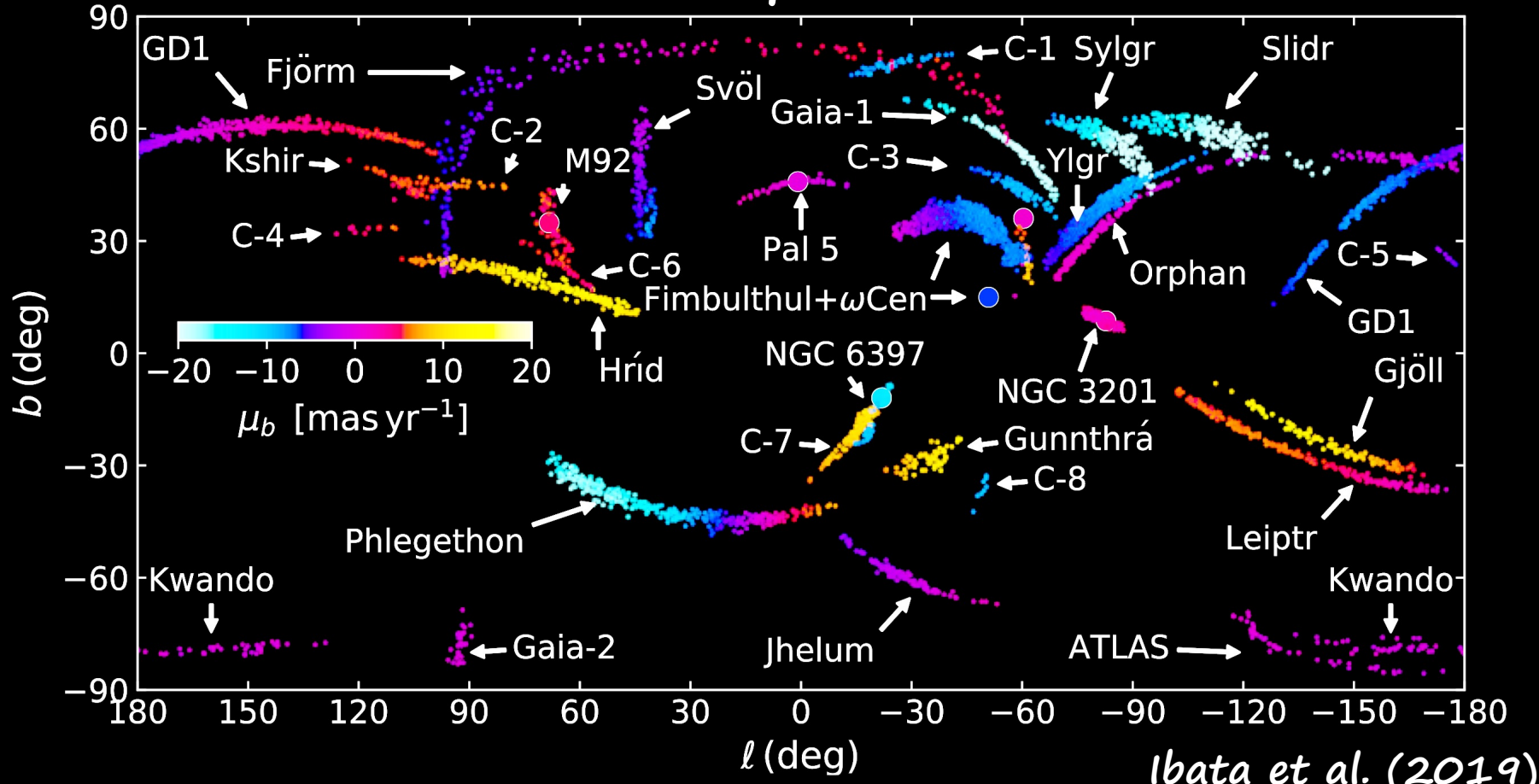
Southern Sky



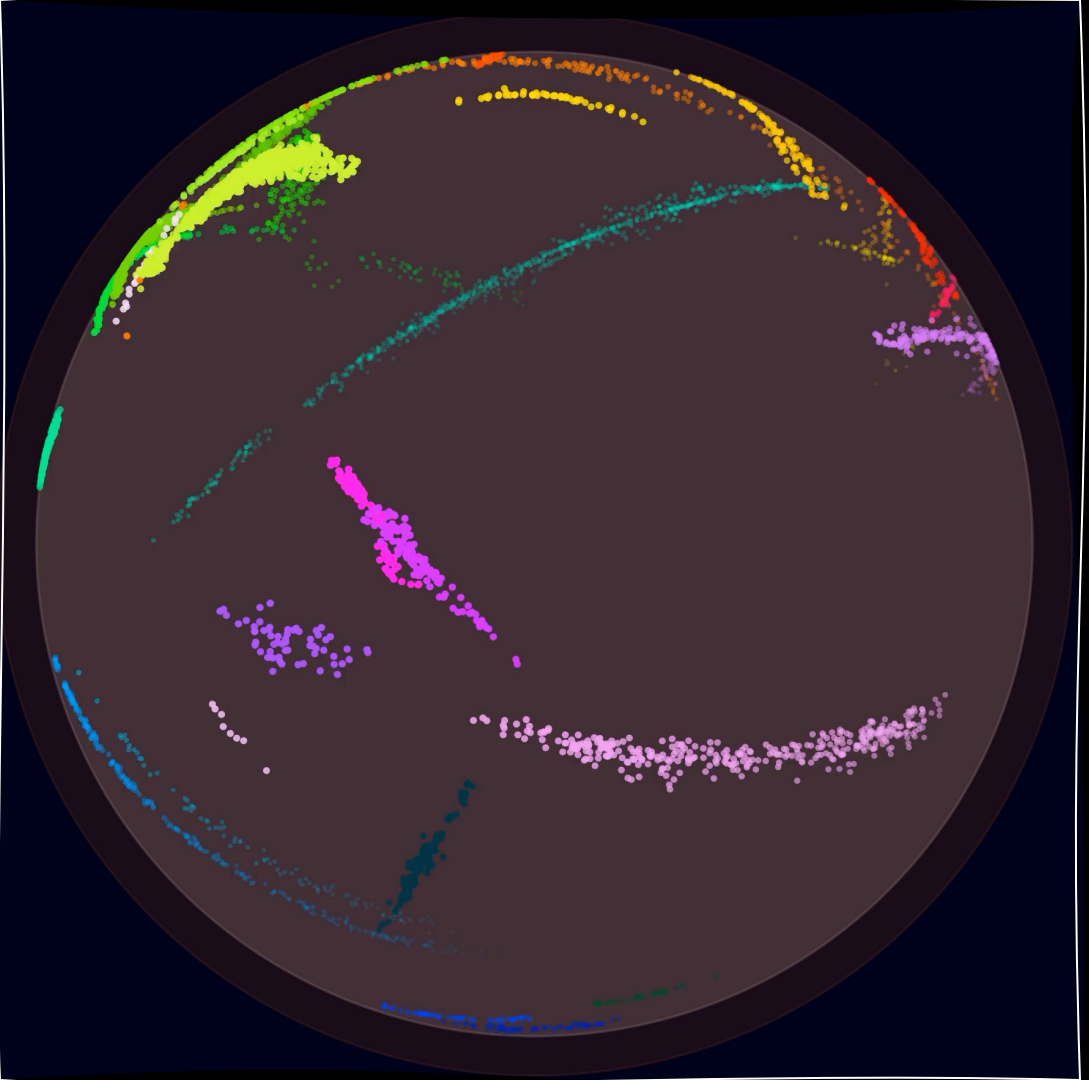
Dark Energy Survey

DES / Shipp, Drlica-Wagner et al. (2018)

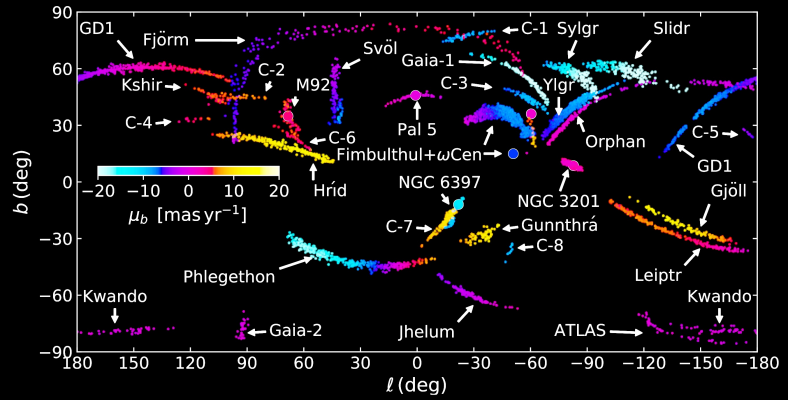
StreamFinder: The power of Gaia



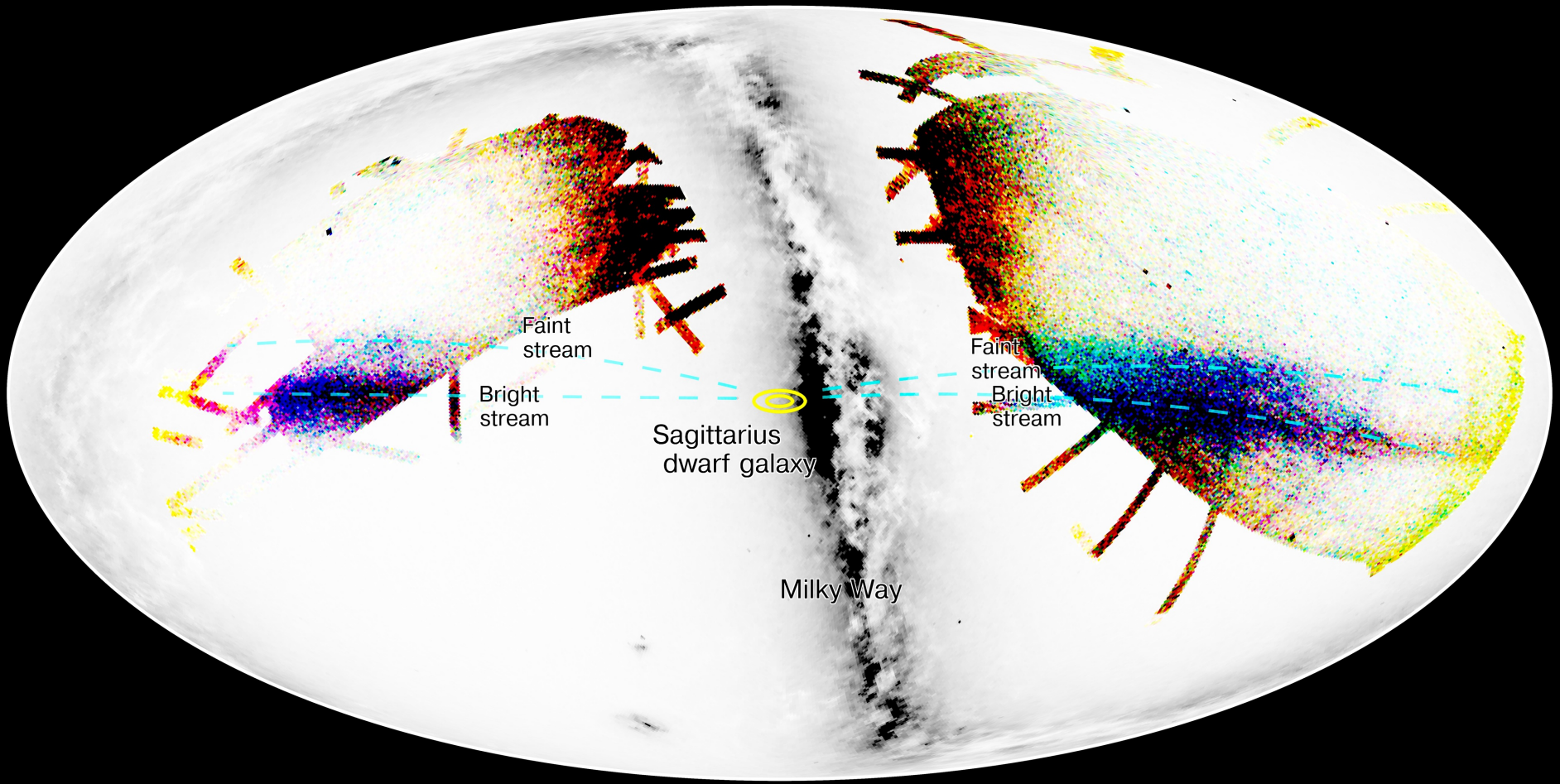
Ibata et al. (2019)



StreamFinder Ibata et al. (2019)



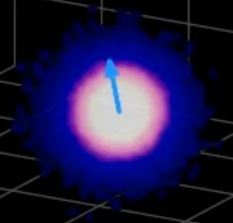
Sagittarius Dwarf Galaxy (Koposov et al. 2012)



Vasiliev et al. (2021)
The Demise of the Sagittarius Dwarf Galaxy

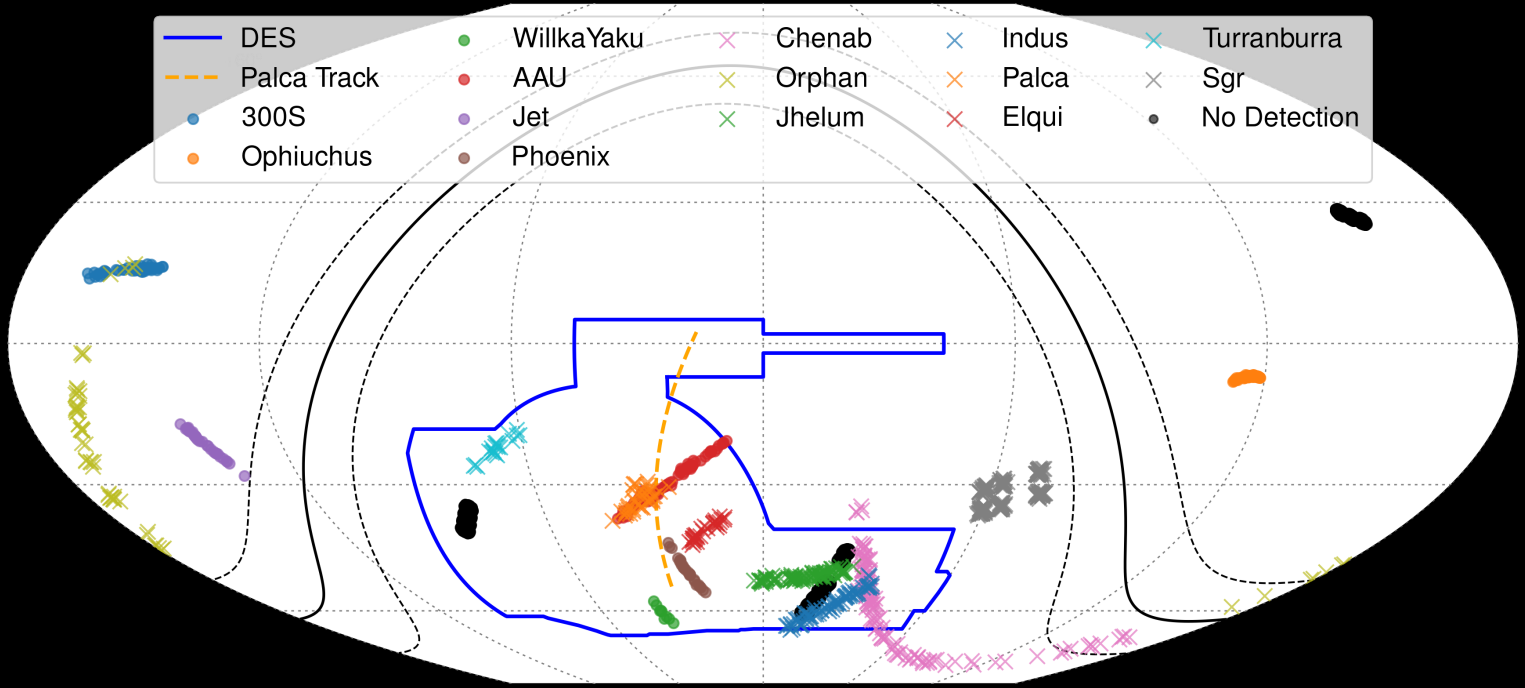
time=-3.00 Gyr

Can't ignore –
- Halo evolution
- Milky Way response
- Large Magellanic Cloud



10 kpc

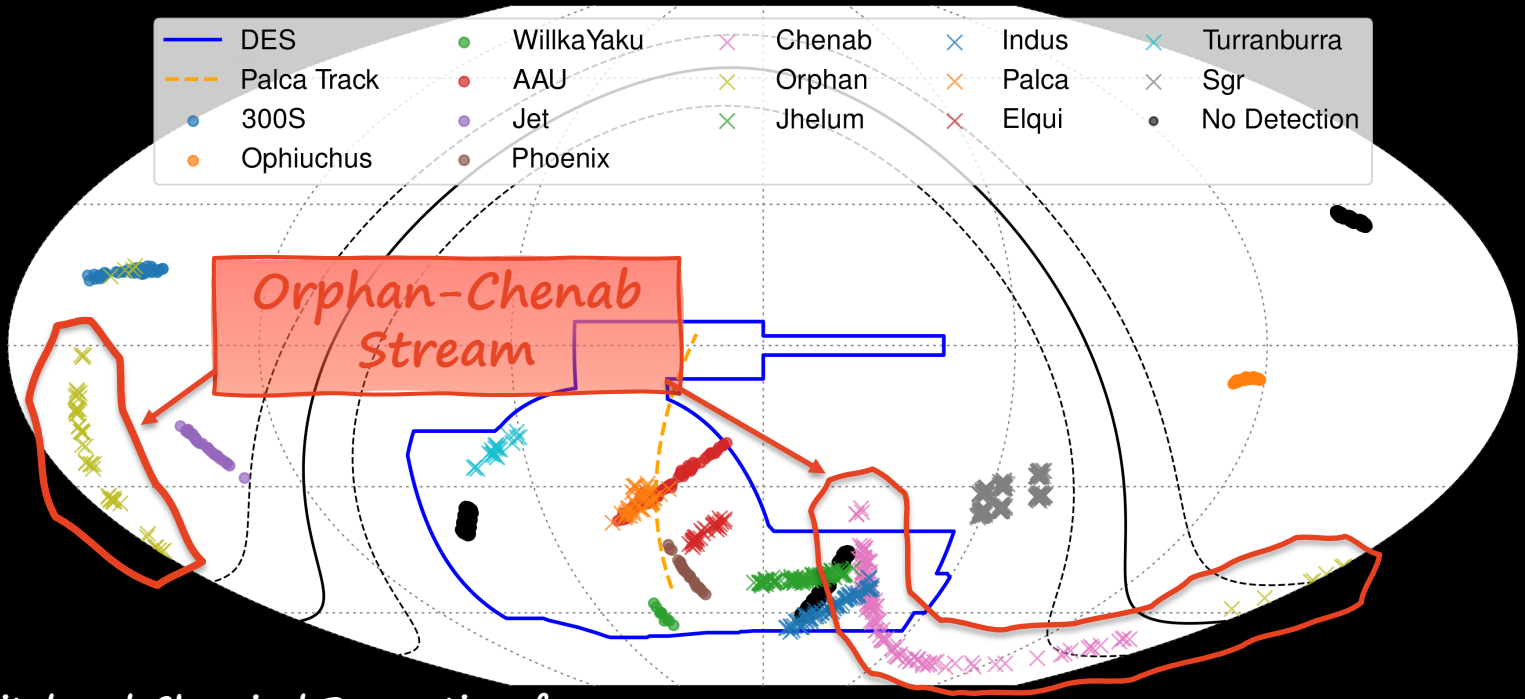
ORBITAL AND CHEMICAL PROPERTIES OF STELLAR STREAMS



S5: The Orbital and Chemical Properties of **One Dozen Stellar Streams**
Li et al. (2022)

12 "progenitor-free" stellar streams at ~10-50 kpc observed in 2018-2020

ORBITAL AND CHEMICAL PROPERTIES OF STELLAR STREAMS



S5: The Orbital and Chemical Properties of **One Dozen Stellar Streams**
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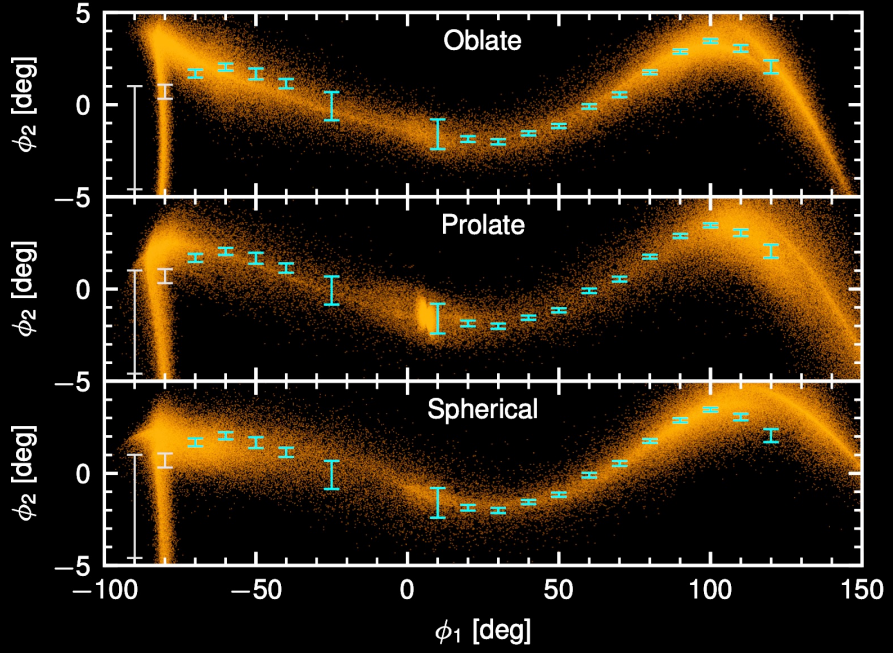
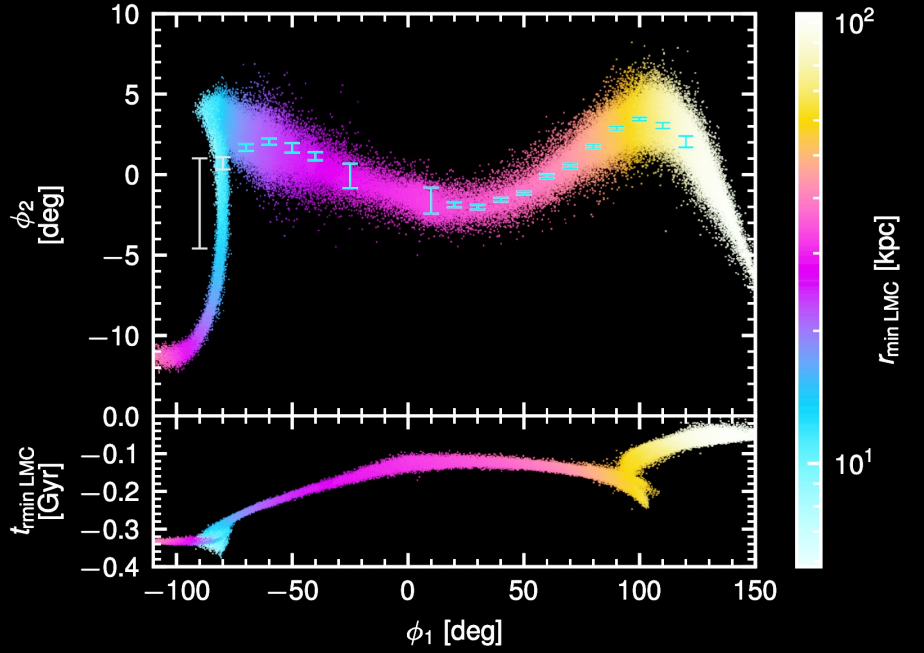
12 "progenitor-free" stellar streams at ~10-50 kpc observed in 2018-2020

S5: THE ORPHAN-CHENAB STREAM IN 6D

Koposov et al. (2022)





$M_{MW}(< 32kpc) = (2.9 \pm 0.1)\times10^{11}\ M_\odot$

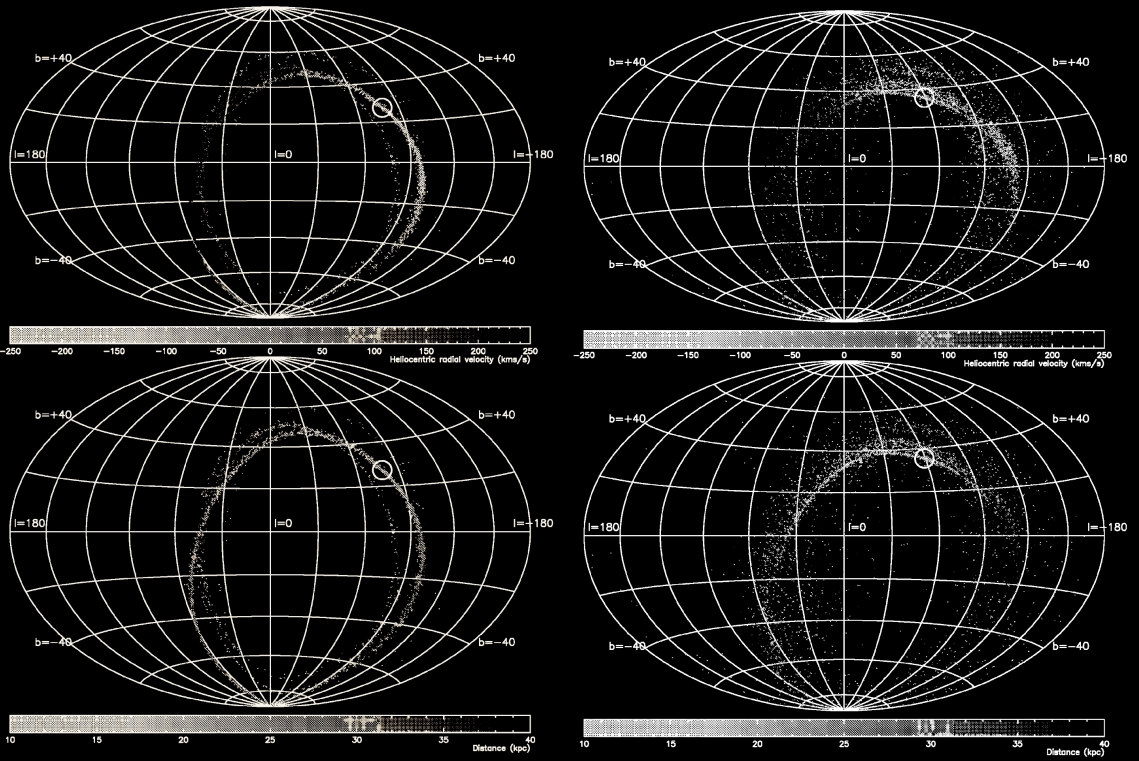
$M_{LMC}(< 33kpc) = (7.0 \pm 0.9)\times10^{10}\ M_\odot$

$R_{LMC}(DM) \approx 53\ kpc$

Dark Matter Substructures

Smooth DM

Lumpy DM



Ibata et al. (2001)

Smooth vs Lumpy ->

CDM vs WDM

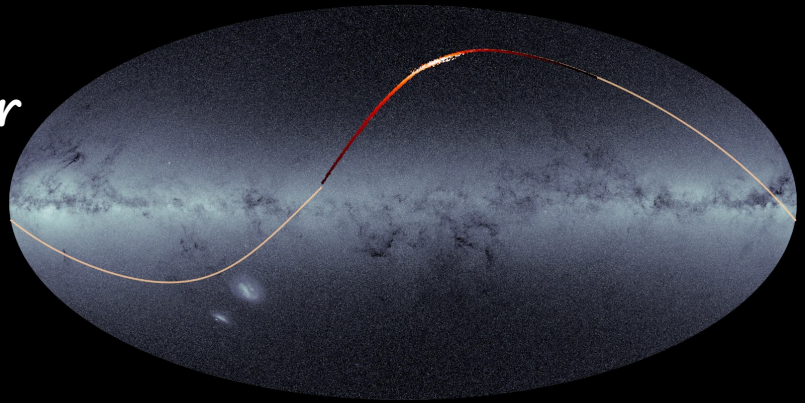
Need cold streams ->

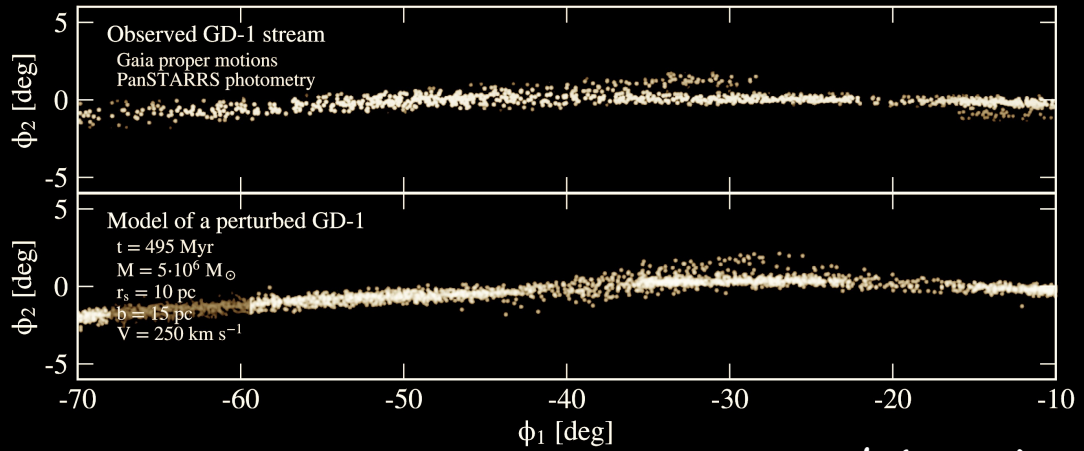
Globular clusters

These present us with numerous observational challenges!

Dark Matter Substructures

Globular Cluster GD-1





Bonaca et al. (2019)

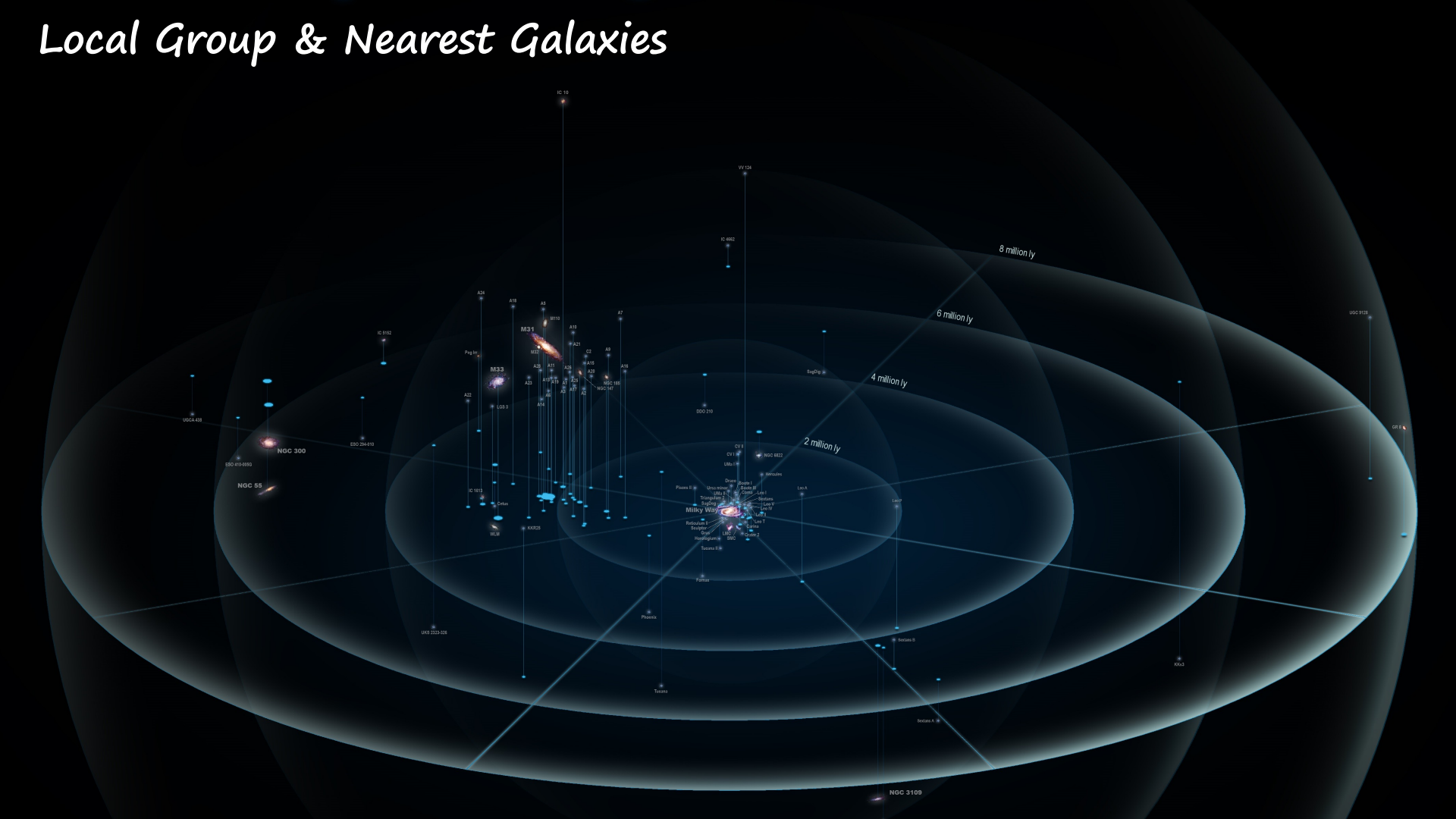
GD-1 has an extensive tidal stream

Appears to have been perturbed by a five million solar mass "something"

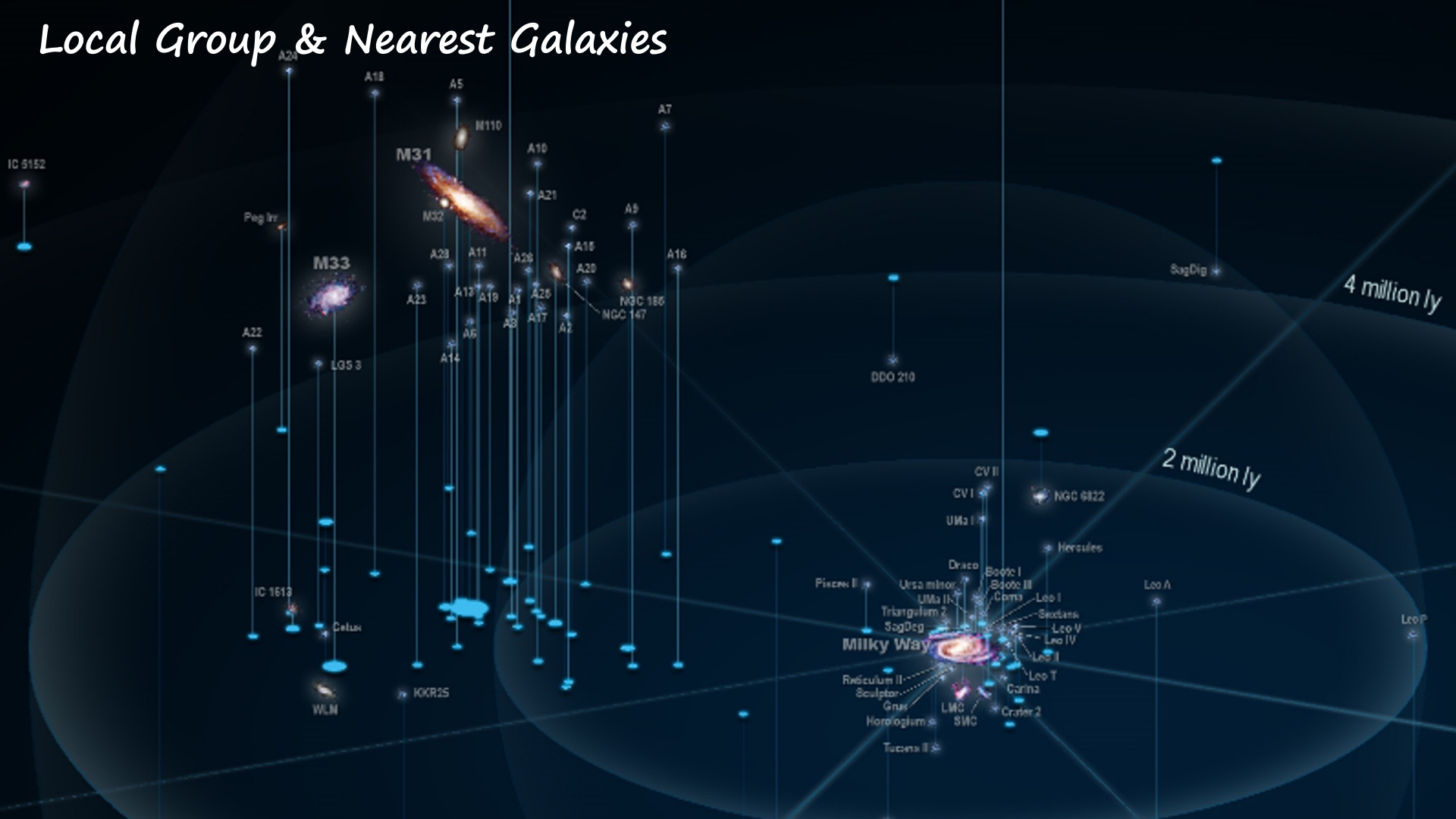
Need to analyze multiple streams to deduce power spectrum

But have to worry about orbital "resonances"!

Local Group & Nearest Galaxies

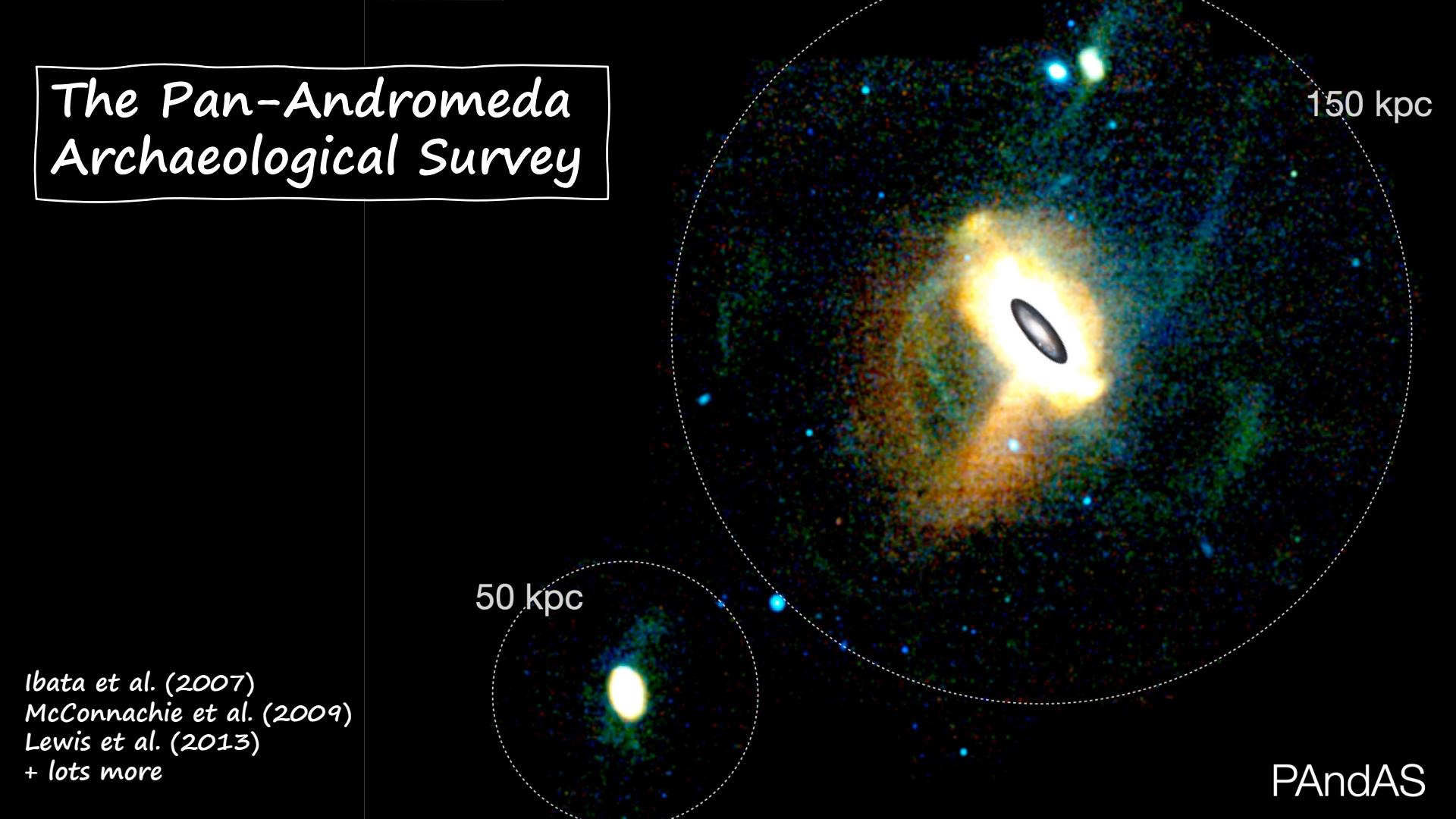


Local Group & Nearest Galaxies

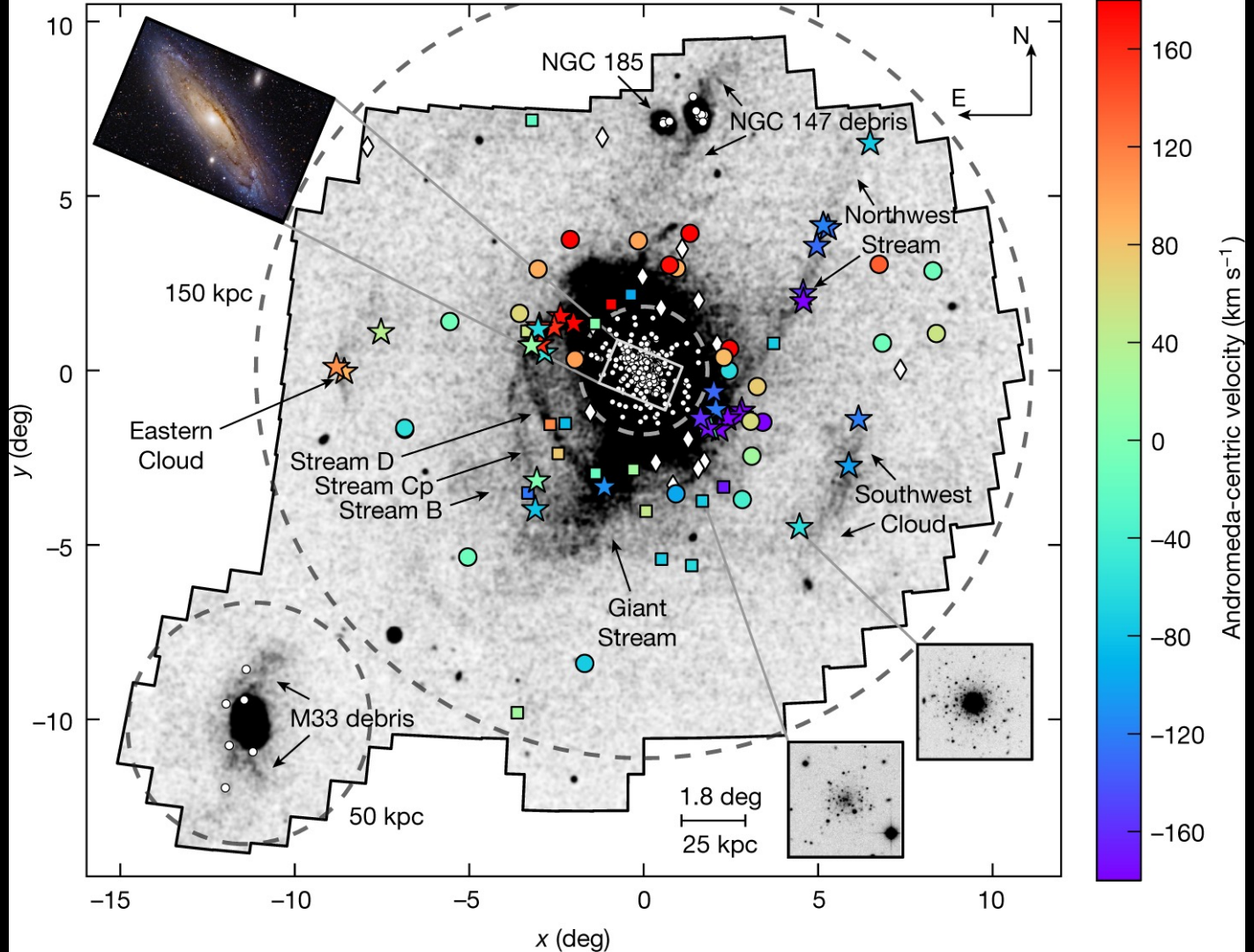



tombh @ imagur.com

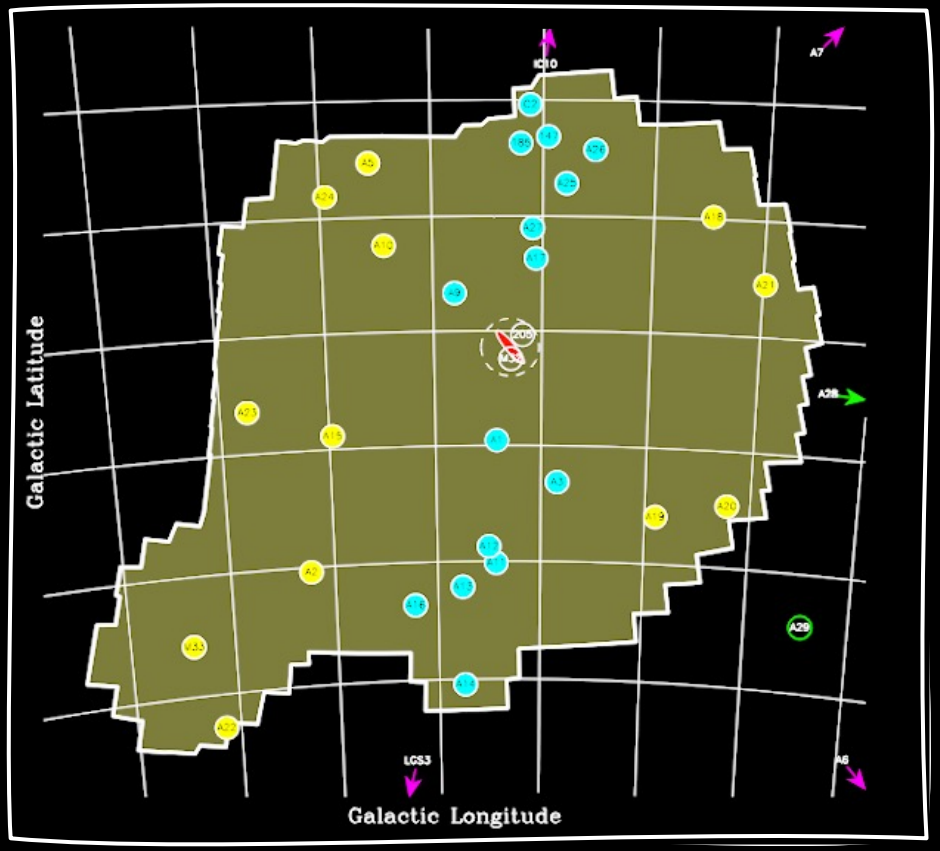
The Pan-Andromeda Archaeological Survey



Ibata et al. (2007)
McConnachie et al. (2009)
Lewis et al. (2013)
+ lots more


NGC 185
NGC 147 debris
N
E
Northwest
Stream
150 kpc
Eastern
Cloud
Stream D
Stream Cp
Stream B
Southwest
Cloud
Giant
Stream
M33 debris
50 kpc
1.8 deg
25 kpc
10
5
0
−5
−10
−15
−10
−5
0
5
10
y (deg)
x (deg)
160
120
80
40
0
−40
−80
−120
−160
Andromeda-centric velocity (km s−1)

Great Plane of Satellites in Andromeda



Half dwarf population in plane

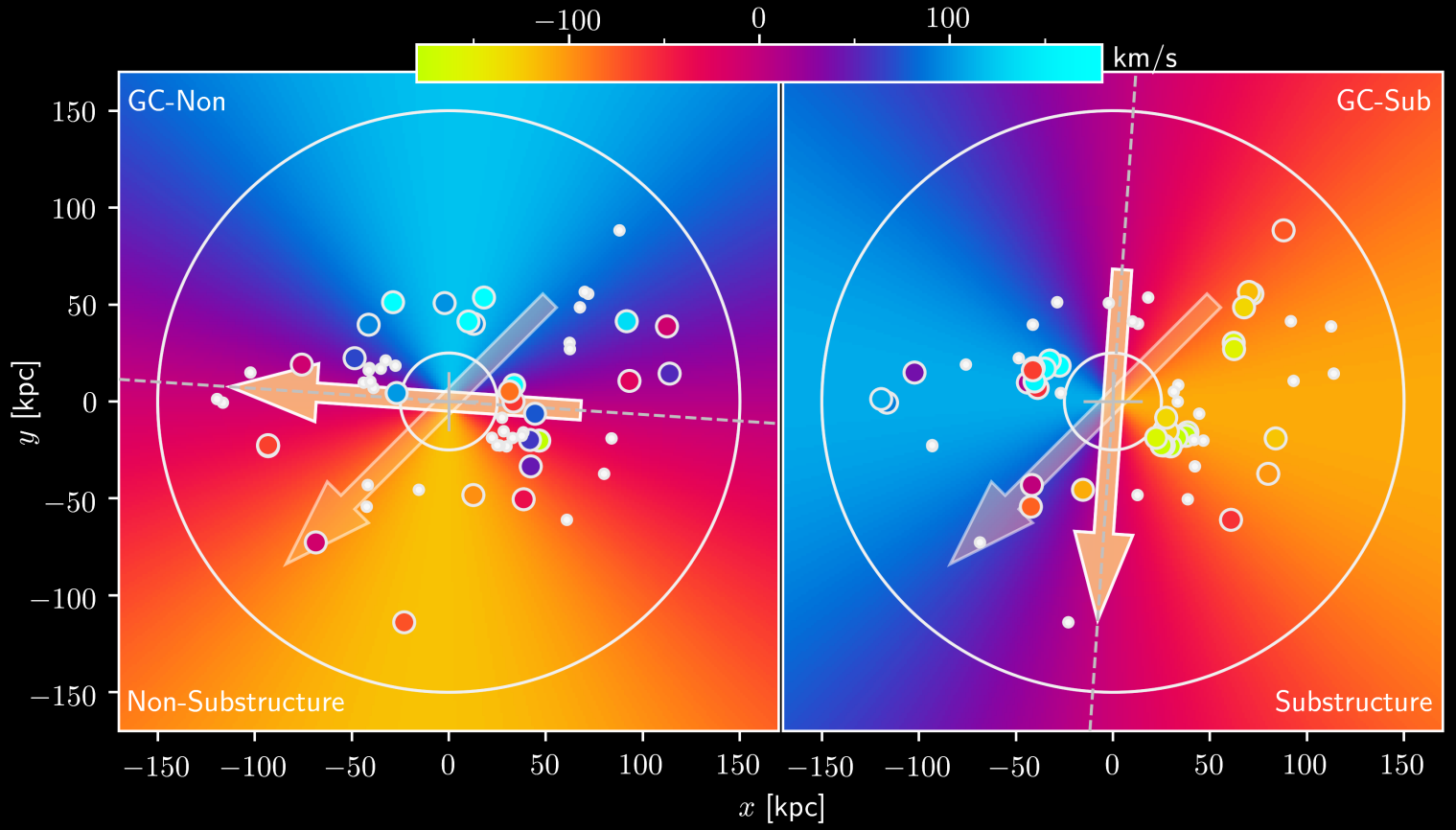
Very narrow & coherent
Very sensitive to halo shape
Very sensitive to clumpiness

A challenge to DM?

Preferred accretion directions?

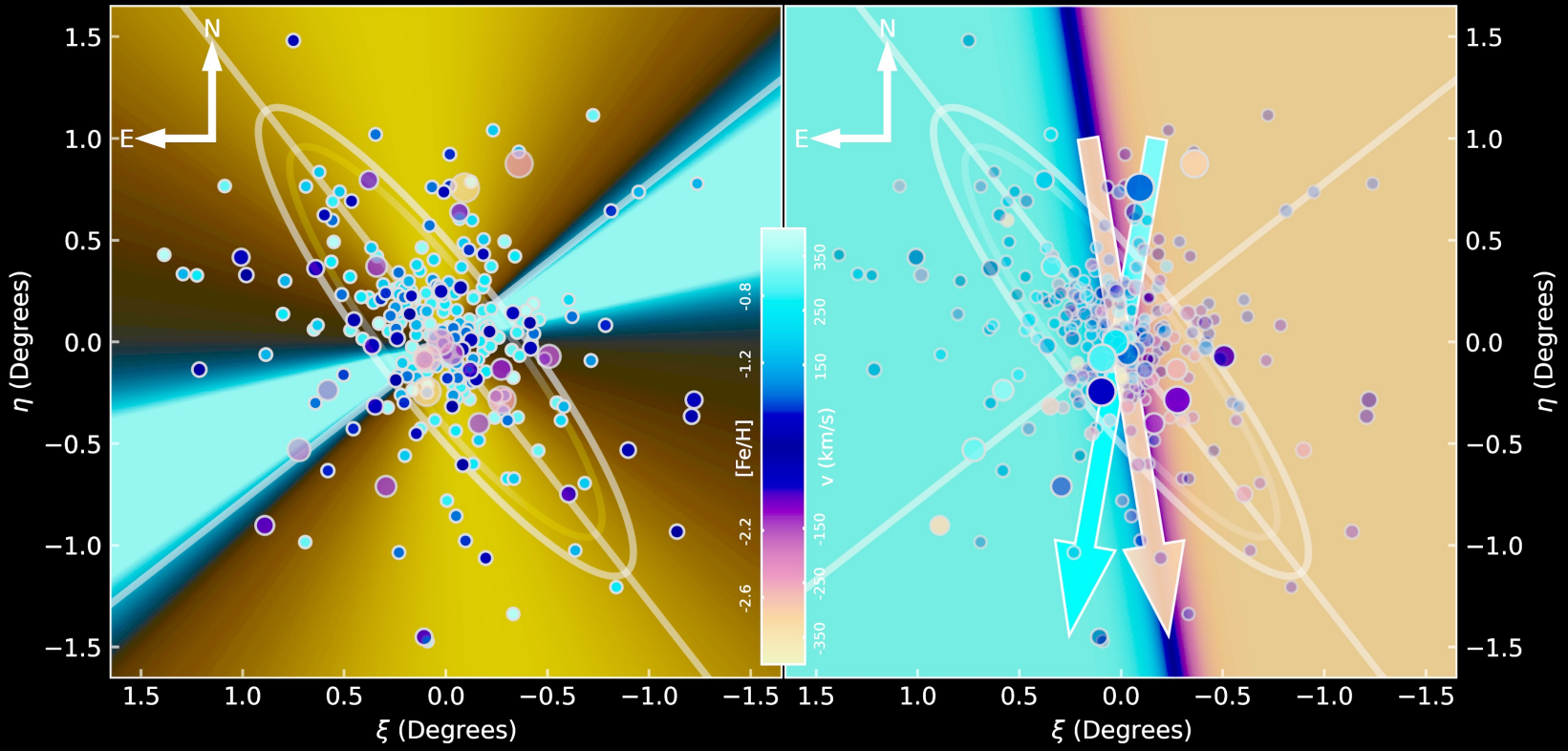
Ibata et al. (2013)
Conn et al. (2013)

Two orthogonal accretion events seen in Globular Clusters

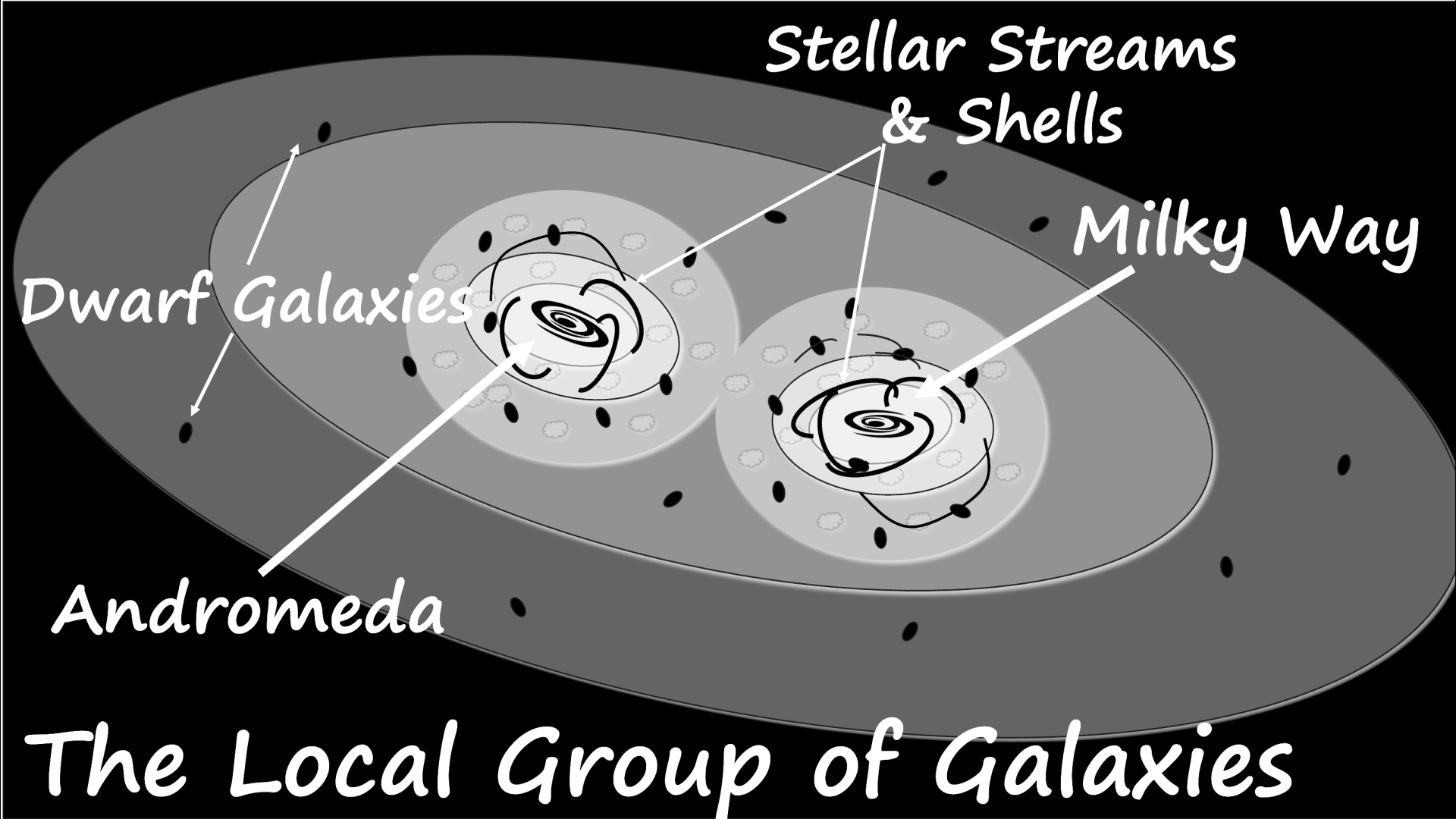


Mackey et al. (2018)

Accretion Signatures in the Inner Halo Globular Clusters



Lewis et al. (2023)



The Local Group of Galaxies

Conclusions:

- Halos are sparse but populated by streams and shells
- Dynamical modelling has the promise of revealing DM
- Dynamics are complicated by
  - Halo evolution
  - Halo response
  - Galaxy-galaxy interactions
  - Unrelaxed dynamics
  - Evolution of the Local Group
  - Preferred accretion directions

We will need to take a "global" approach if we are to reveal the dark matter properties of the Local Group!