

Title: What's Your Story? Merger tracers in present-day galaxies

Speakers: Lucas Valenzuela

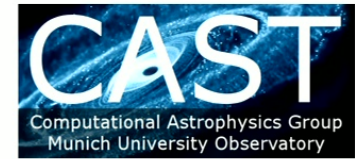
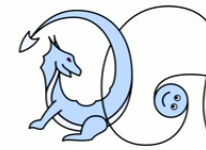
Series: Cosmology & Gravitation

Date: May 21, 2024 - 11:00 AM

URL: <https://pirsa.org/24050088>

Abstract: Present-day galaxies still contain a multitude of clues about their formation histories. But which properties should we best look at and what do they actually reveal about the past? Using cosmological simulations, I will show what insights about a galaxy's formation and merger history can be gained from a diverse set of measurements. For this, I will show how the overall galaxy shapes and tidal features in the outskirts are related to the inner kinematics. These results give us indications about the correlation with the recent merger histories of the galaxies. Finally, I will discuss how early gas-rich mergers can be revealed through the ages of globular cluster populations.

Zoom link



What's Your Story?

Merger tracers in present-day galaxies

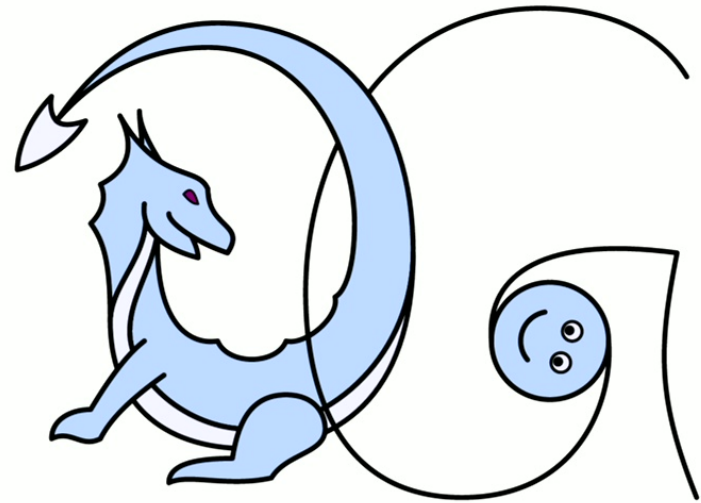
Lucas Valenzuela

Cosmology and Gravitation Seminar – Perimeter Institute

May 21, 2024



Dynamics, environment, and Assembly of Galaxies in Observations and Numerical Simulations



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Lucas Valenzuela – Merger tracers in present-day galaxies

Objective

Understanding Galaxy Formation History

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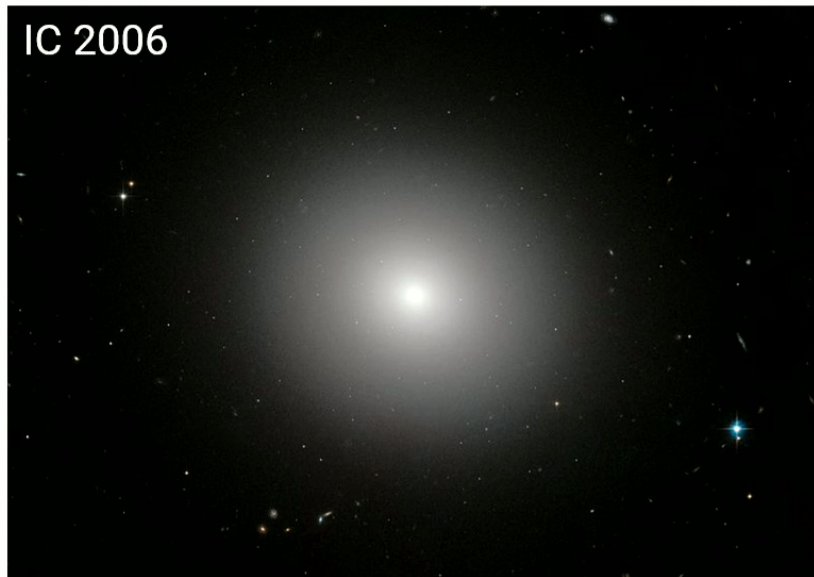
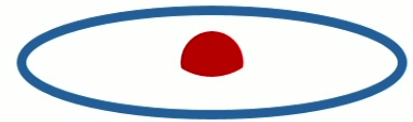
Observational Tools

What do we actually see?

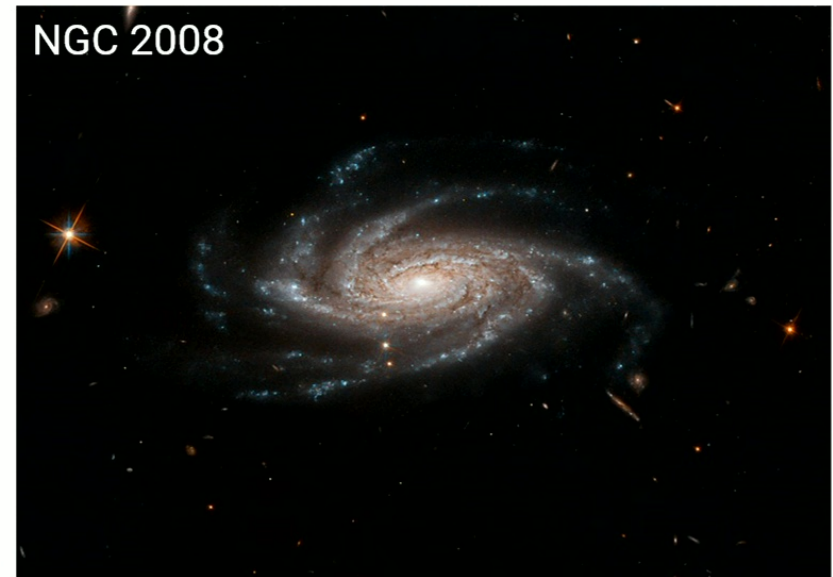
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Photometry



NASA/ESA/Hubble, J. Schmidt, J. Blakeslee



NASA/ESA/Hubble, A. Bellini

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Photometry

Elliptical Galaxies

E0

E3

E6

S0

Sa

Sb

Sc

Spiral Galaxies

SB0

SBa

SBb

SBc

Irr

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Image: Zooniverse

Photometry

Hubble Sequence

Hubble 1926, 1936

Early-Type Galaxies (ETGs)
Elliptical Galaxies

E0

E3

E6

S0

Sa

Sb

Sc

Late-Type Galaxies (LTGs)
Spiral Galaxies

Irr

SB0

SBa

SBb

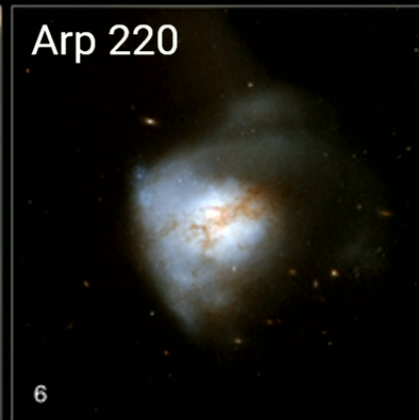
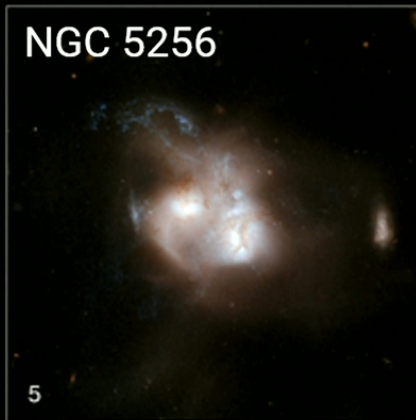
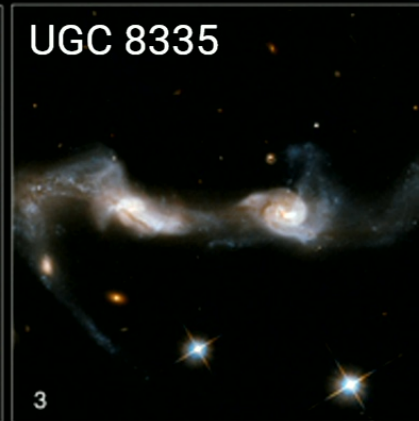
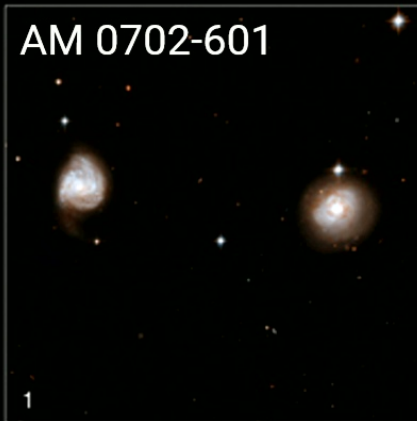
SBc

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Image: Zooniverse

Mergers

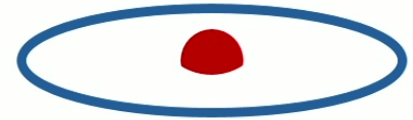


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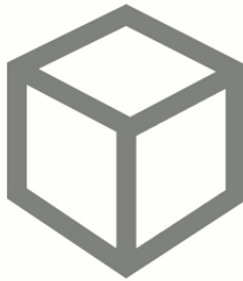
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Image: NASA/ESA/Hubble

Interpretation



Numerical Simulations



Full 3D information



Time evolution captured

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Interpretation

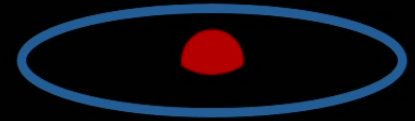


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Lucas Valenzuela – Merger tracers in present-day galaxies

NASA/ESA,
F. Summers, C. Mihos, L. Hernquist

Interpretation

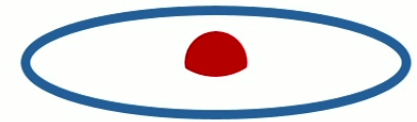


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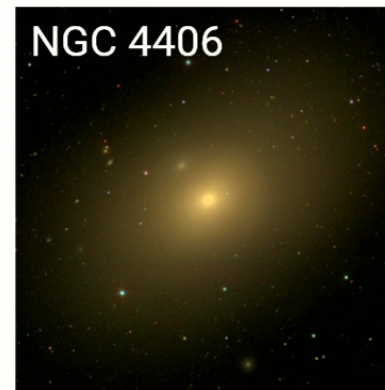
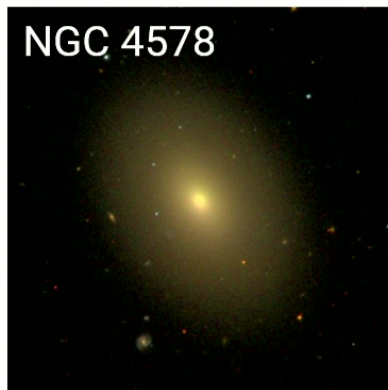
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NASA/ESA,
F. Summers, C. Mihos, L. Hernquist

Elliptical Galaxies



SDSS



SDSS DR14, SciServer



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Observational Tools

2

IFU Measurements

Integral Field Units



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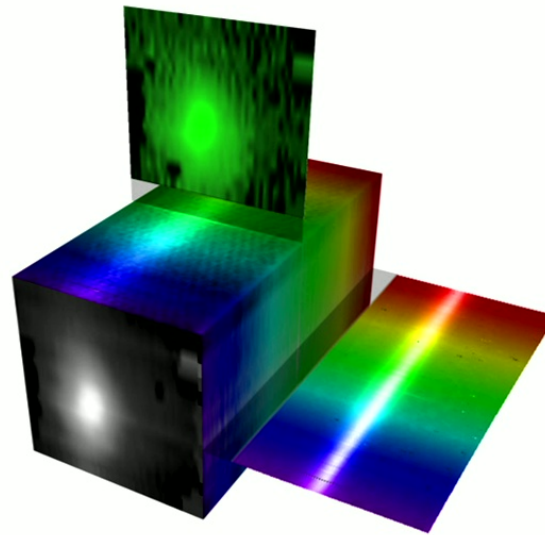
IFU Measurements

SAURON Project

Bacon et al. 2001

ATLAS^{3D} Survey

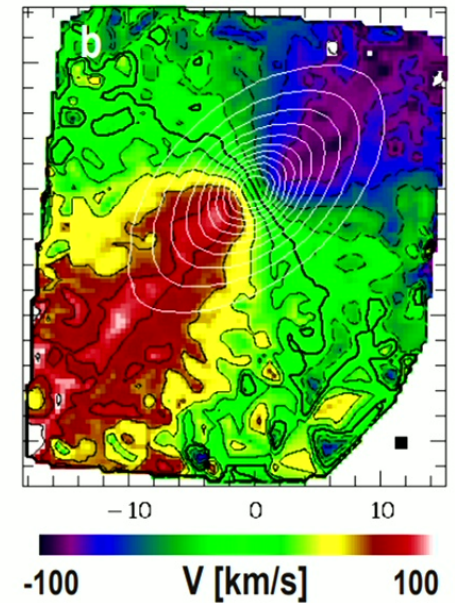
Cappellari et al. 2011



S. Todd, D. Pierce-Price



NGC 3377



Bacon et al. 2001

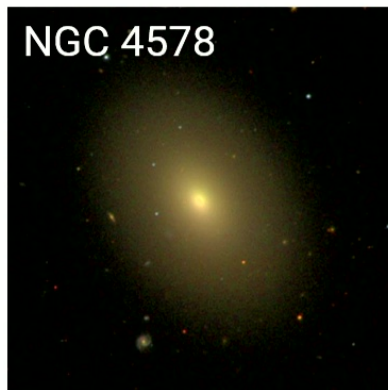
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Elliptical Galaxies



SDSS



SDSS DR14, SciServer

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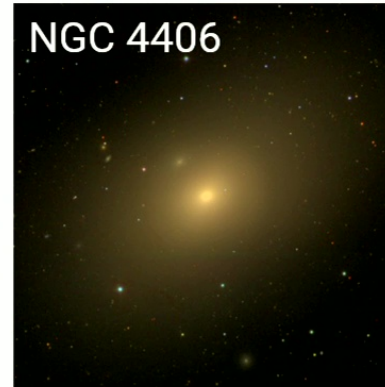
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Elliptical Galaxies

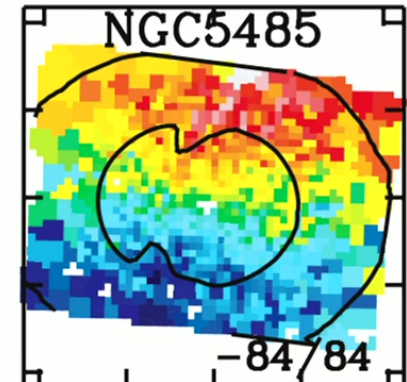
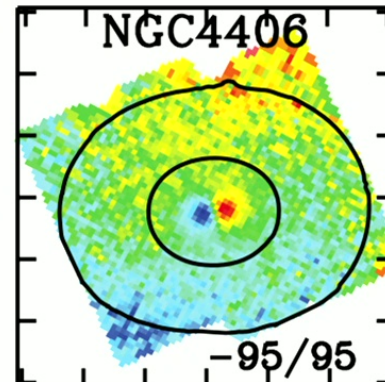
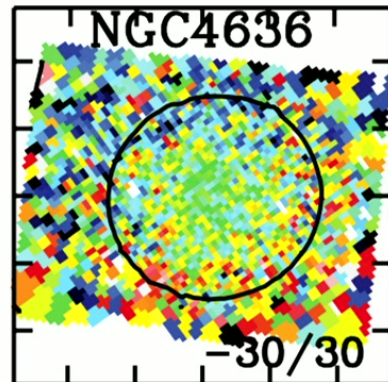
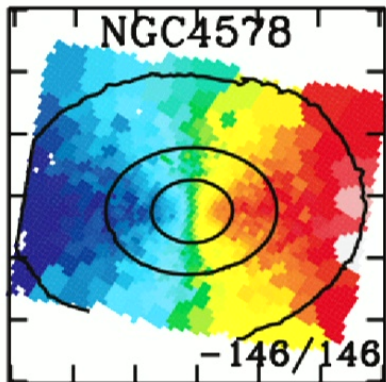


SDSS DR14, SciServer

SDSS



ATLAS^{3D}



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Krajnović et al. 2011

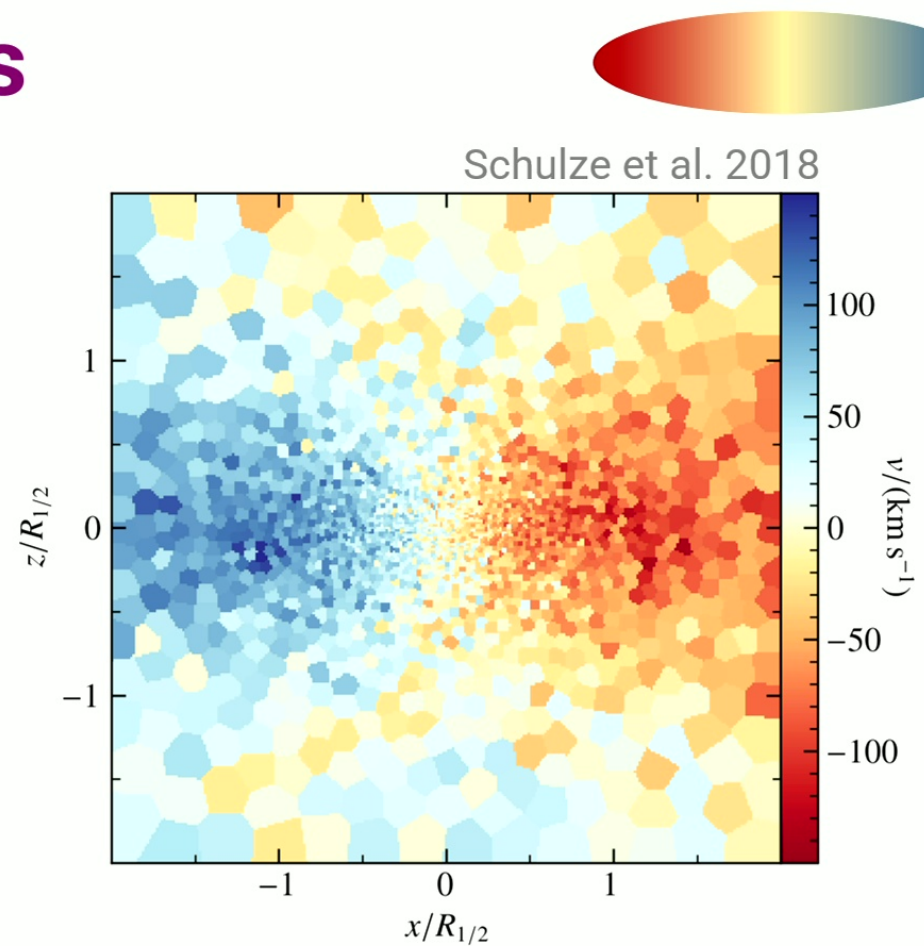
Kinematic Classes

Regular Rotators

Non-Rotators

Distinct Cores

Prolate Rotators



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Kinematic Classes

Regular Rotators

75%

Non-Rotators

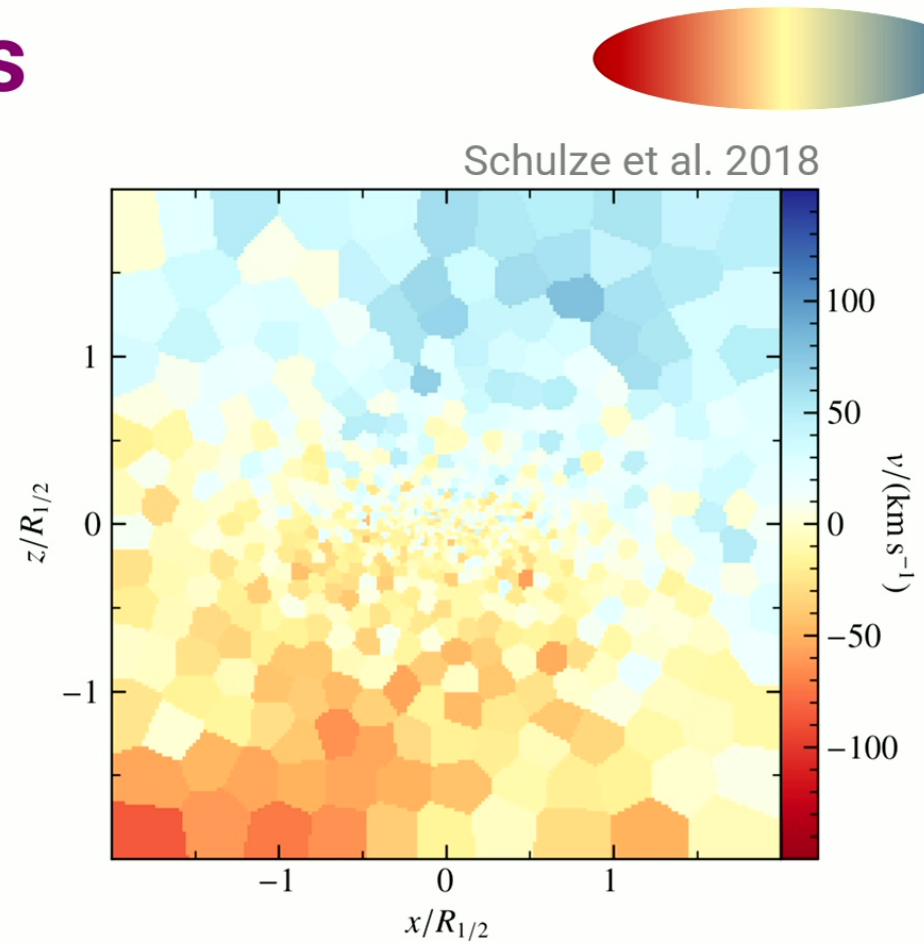
12%

Distinct Cores

5%

Prolate Rotators

2%

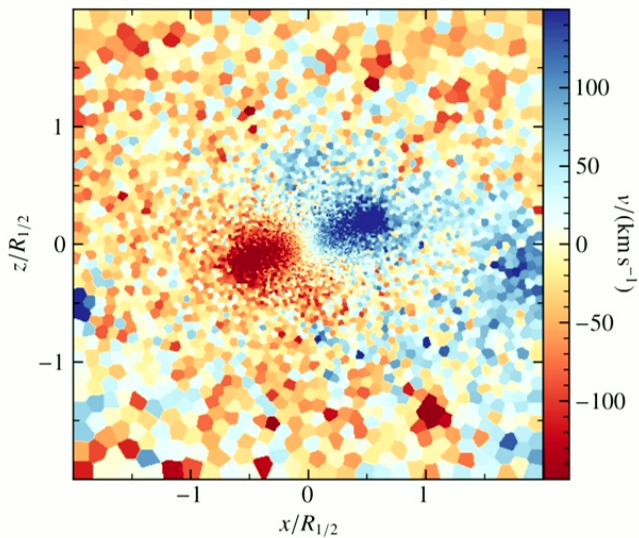


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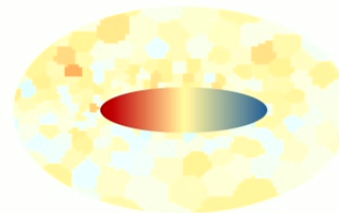
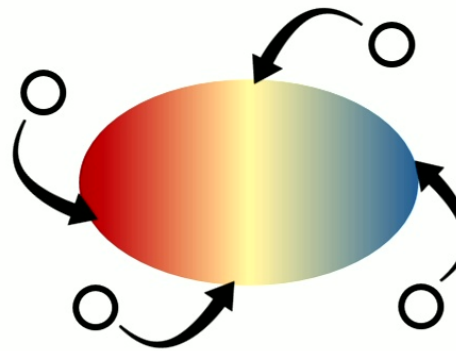
Interpretation

Distinct Cores

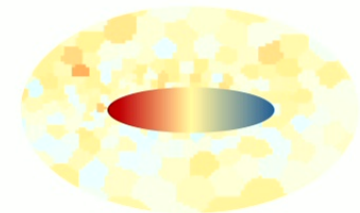
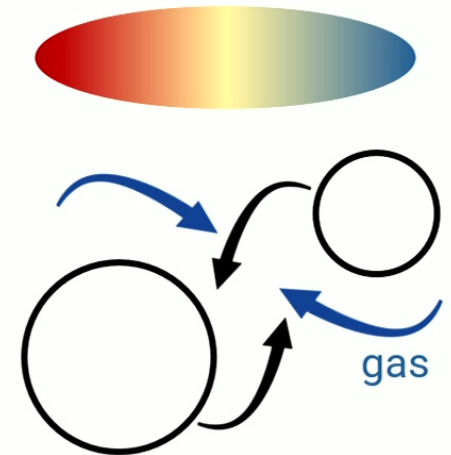


Schulze et al. 2018

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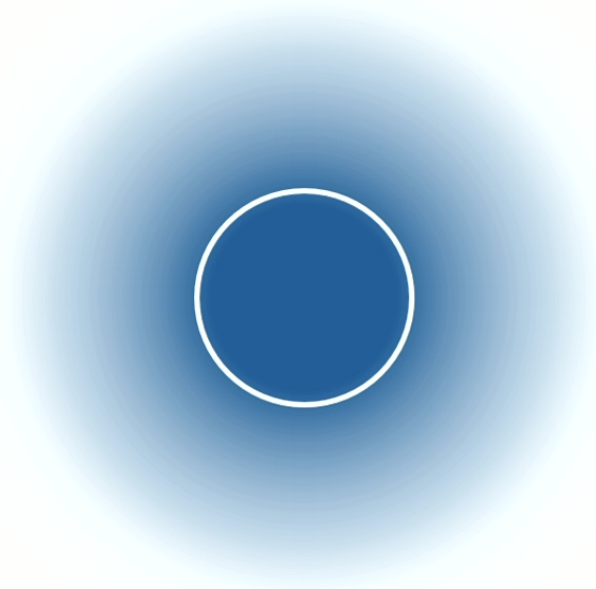
Arnold et al. 2014



Querejeta et al. 2018

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Moving out



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Low Surface Brightness



Sombrero Galaxy



NASA/Hubble

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Low Surface Brightness

Sombrero Galaxy



Matthias Kluge
Wendelstein Observatory

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Ulrich & Valenzuela - Merger traces in the outskirts of galaxies

Low Surface Brightness

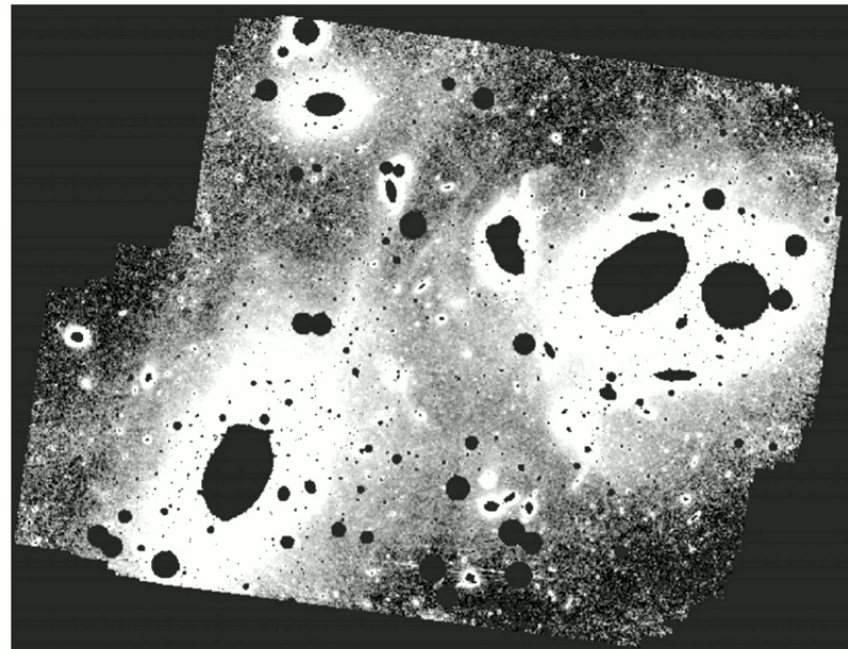


Virgo Cluster

Mihos et al. 2005

MATLAS Survey

Duc et al. 2015



Mihos et al. 2005

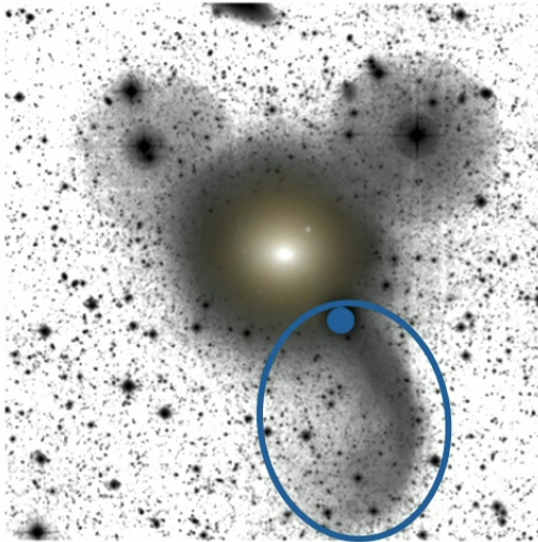
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Tidal Features

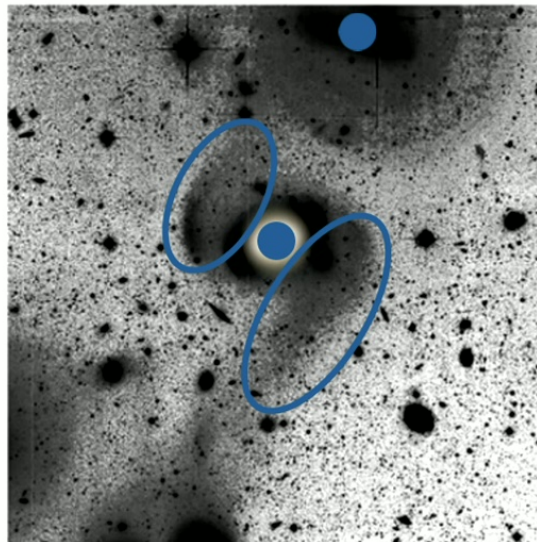


NGC 5576



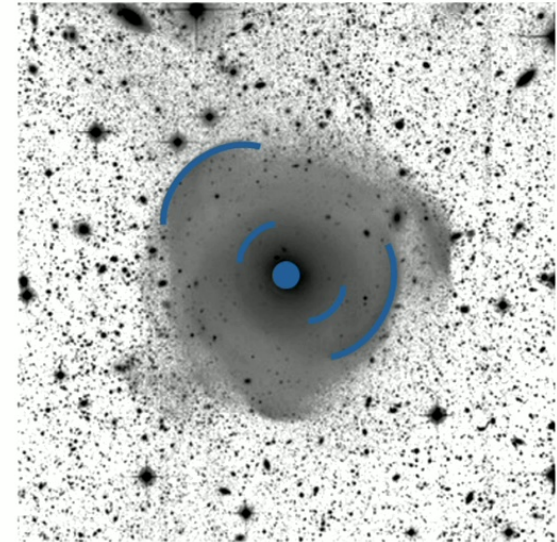
Streams

NGC 4270



Tails

NGC 3619



Shells

MATLAS, Bílek et al. 2020

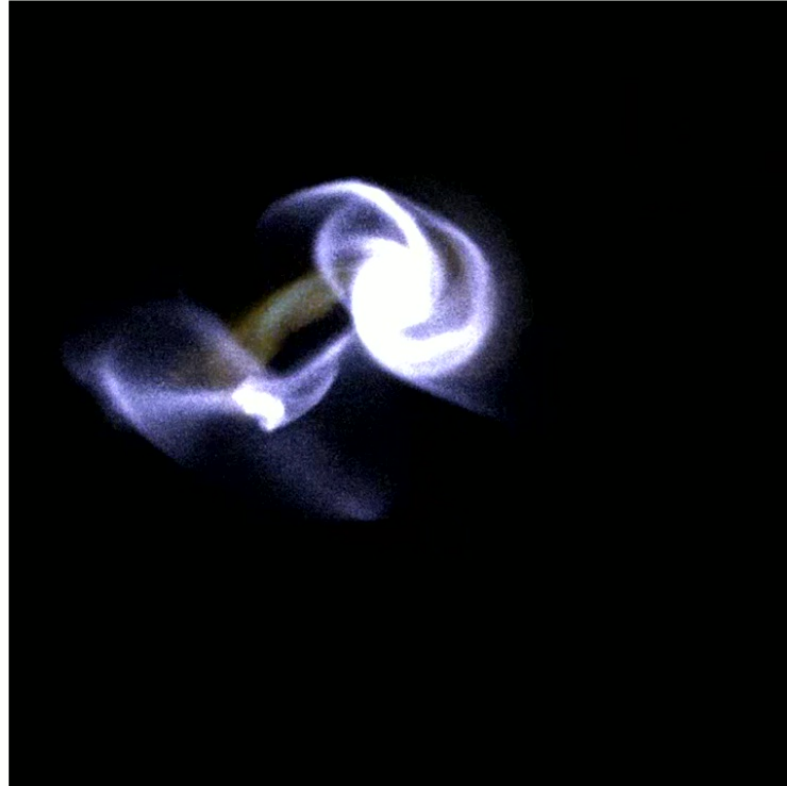
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Interpretation



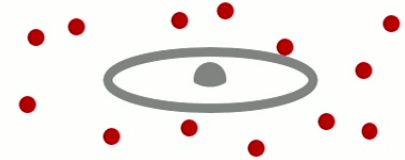
Karademir et al. 2019



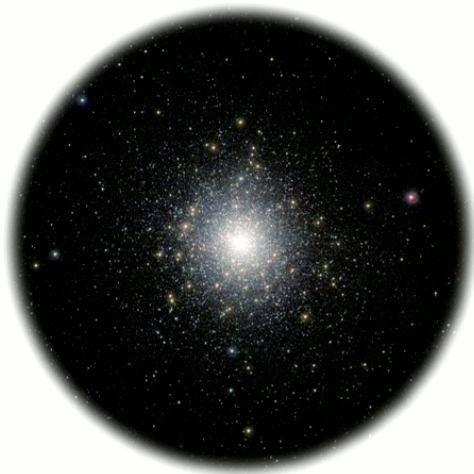
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Globular Clusters



47 Tucanae



ESO, M.-R. Cioni,
VISTA Magellanic Cloud survey



dense star clusters



mostly >10 Gyr old

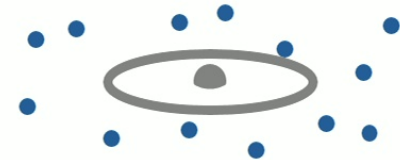


formation details

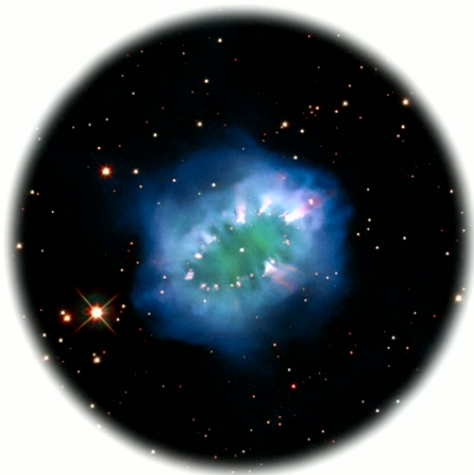
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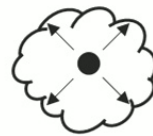
Planetary Nebulae



Necklace Nebula



NASA/ESA/Hubble, K. Noll



late stellar evolution phase



1–8 $M_{\odot}$ initial mass

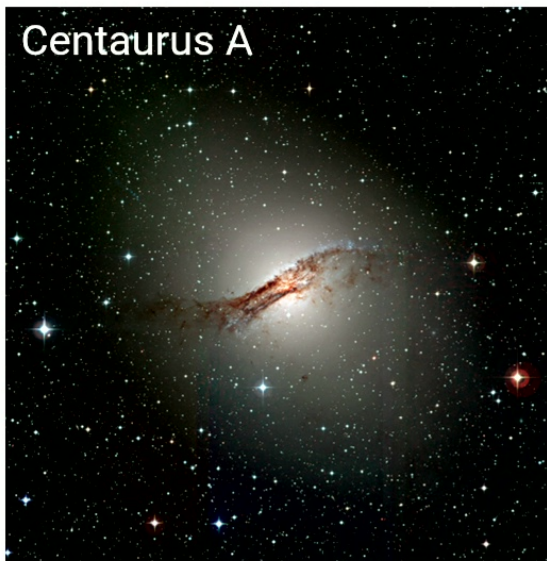
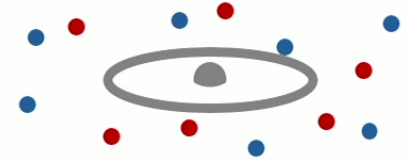


O[III] luminosity function

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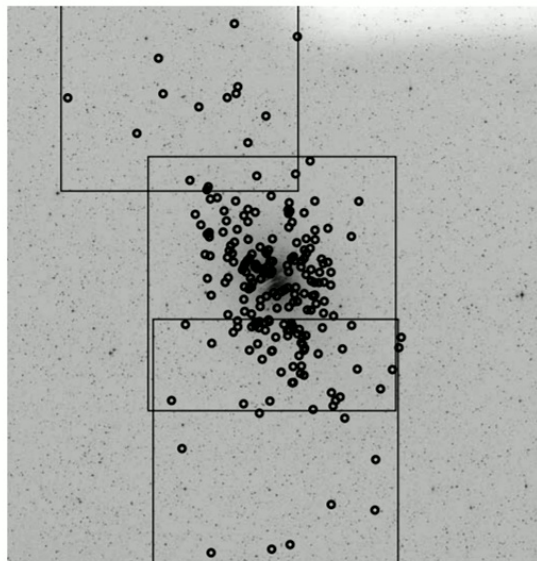
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Tracer Populations



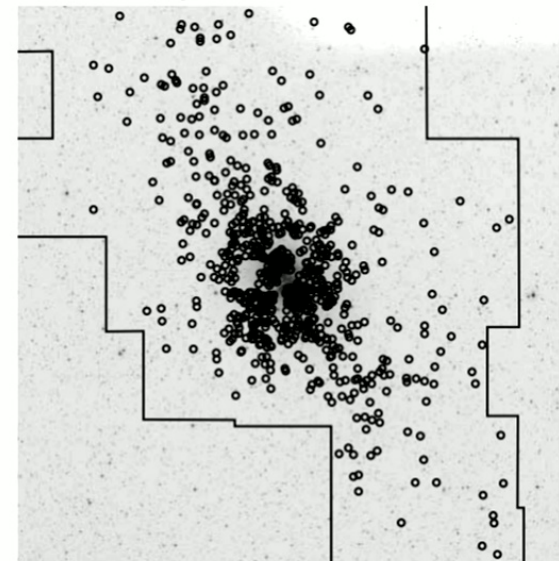
ESO, 1999

Globular Clusters



DSS, Peng et al. 2004a

Planetary Nebulae

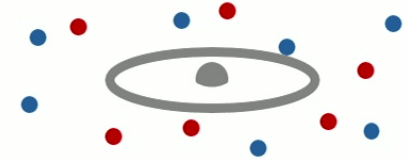


DSS, Peng et al. 2004b

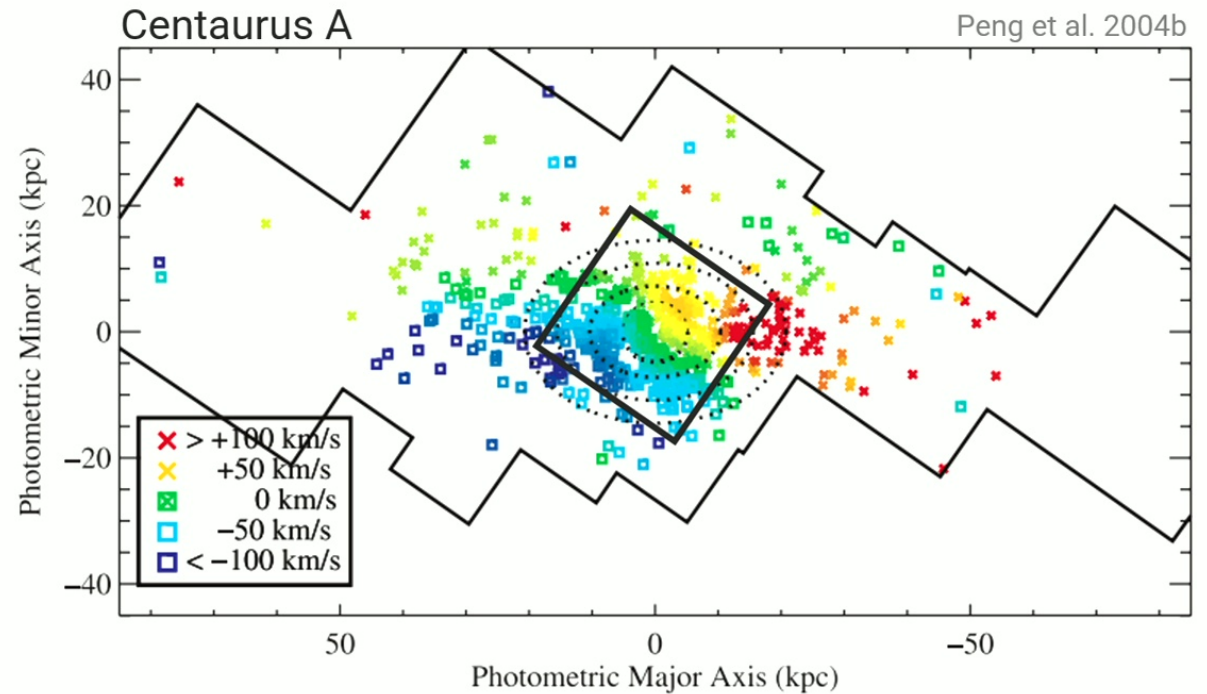
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Tracer Populations



Planetary Nebulae Velocity Map



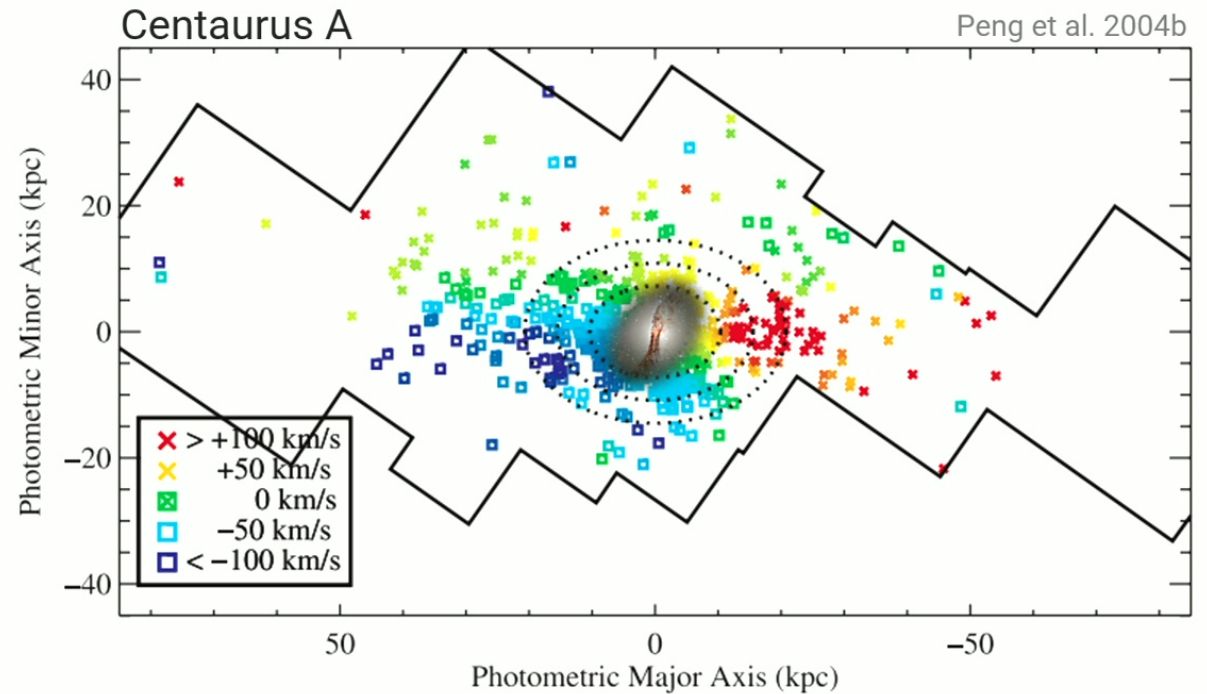
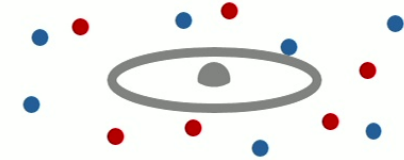
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Interpretation

Inner Kinematics vs. Halo Shape

Veršič et al. 2024



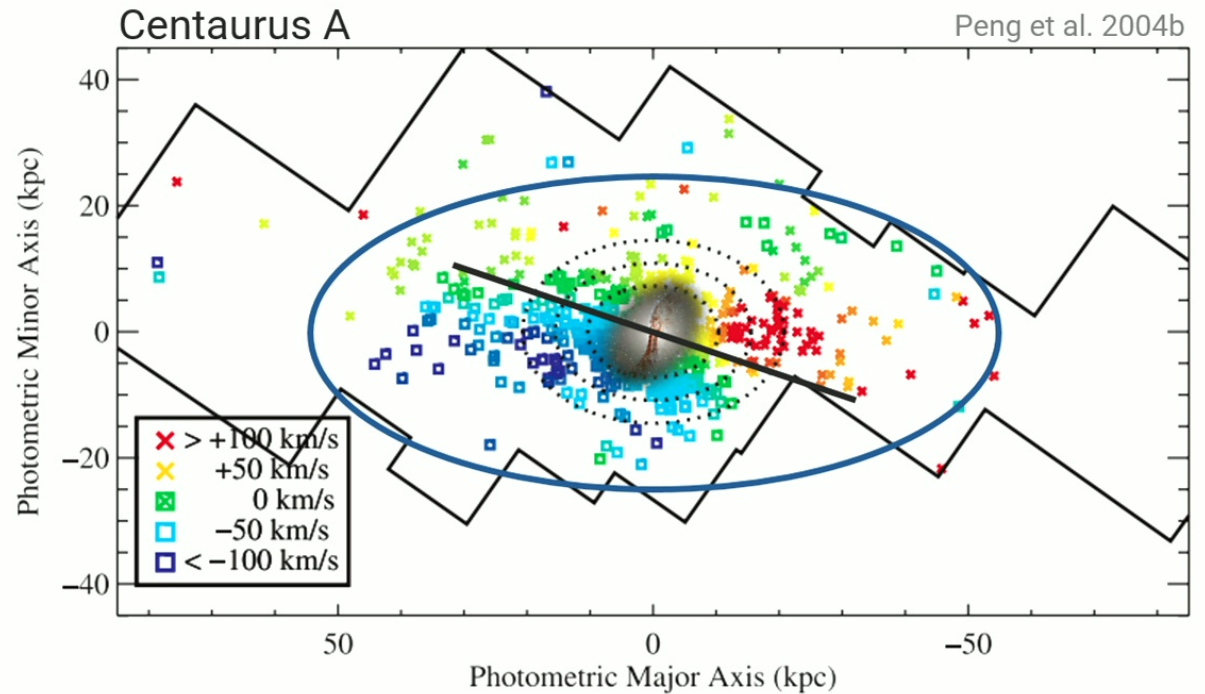
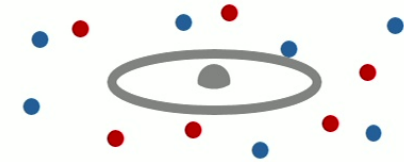
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Interpretation

Inner Kinematics vs. Halo Shape

Veršič et al. 2024



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Shapes

A geometrical description of galaxies

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Shapes

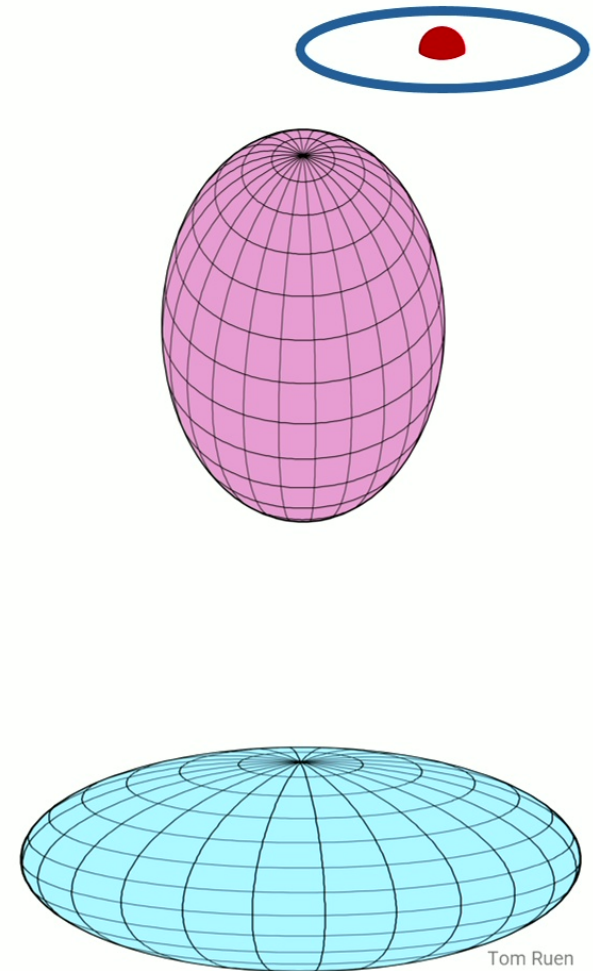
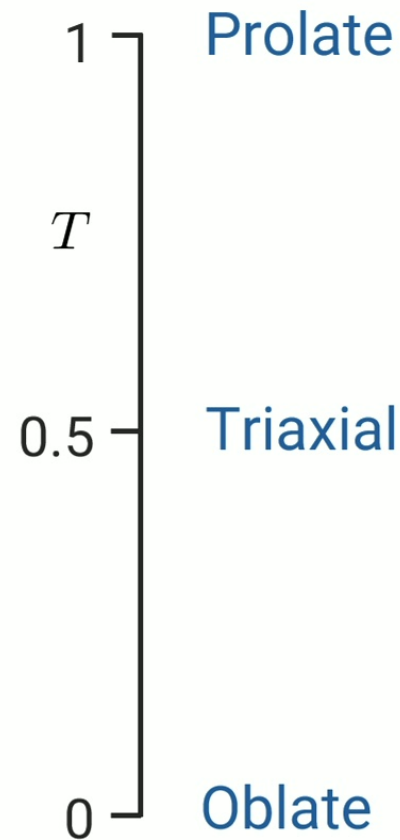
Ellipsoidal fitting

Axis lengths

$$a \geq b \geq c$$

Triaxiality

$$T = \frac{a^2 - b^2}{a^2 - c^2}$$

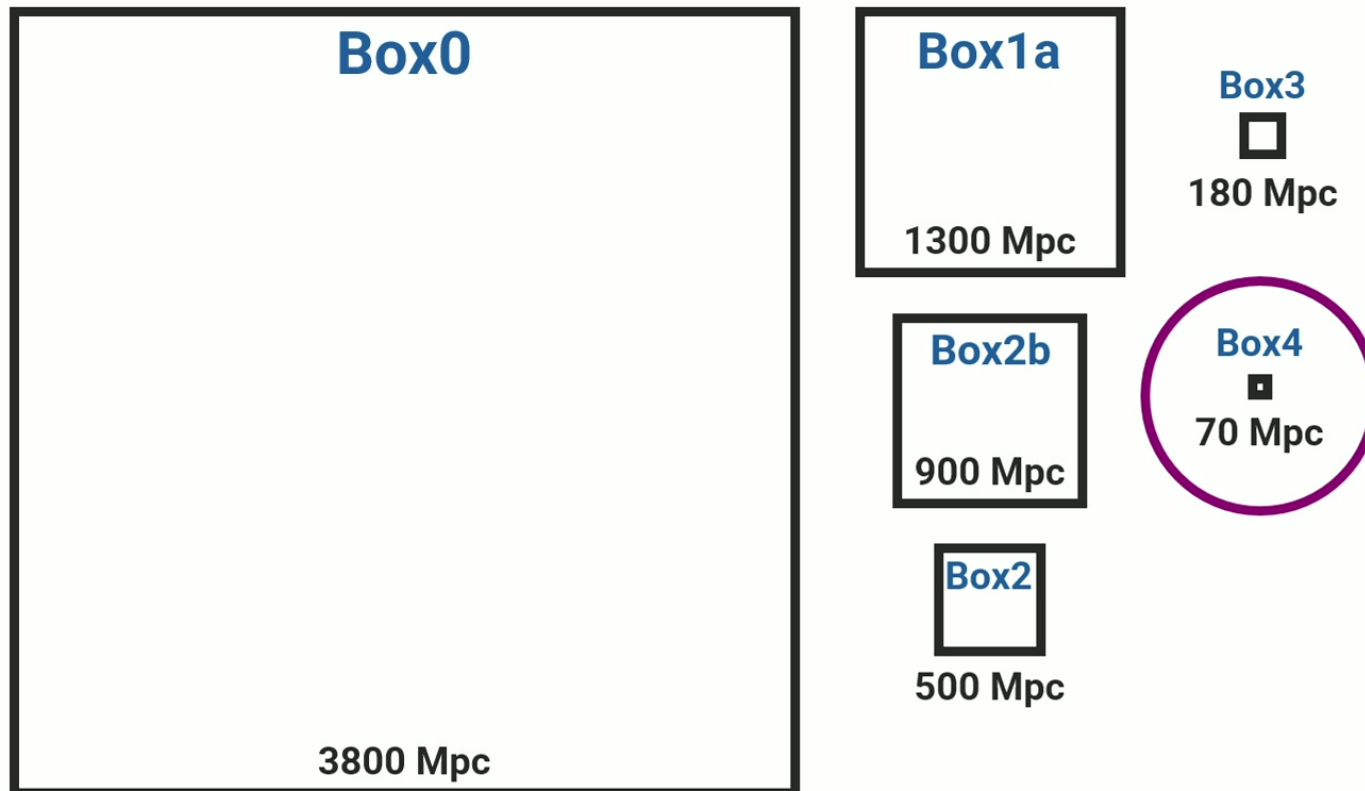


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Magneticum Pathfinder

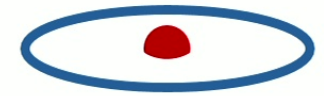
www.magneticum.org



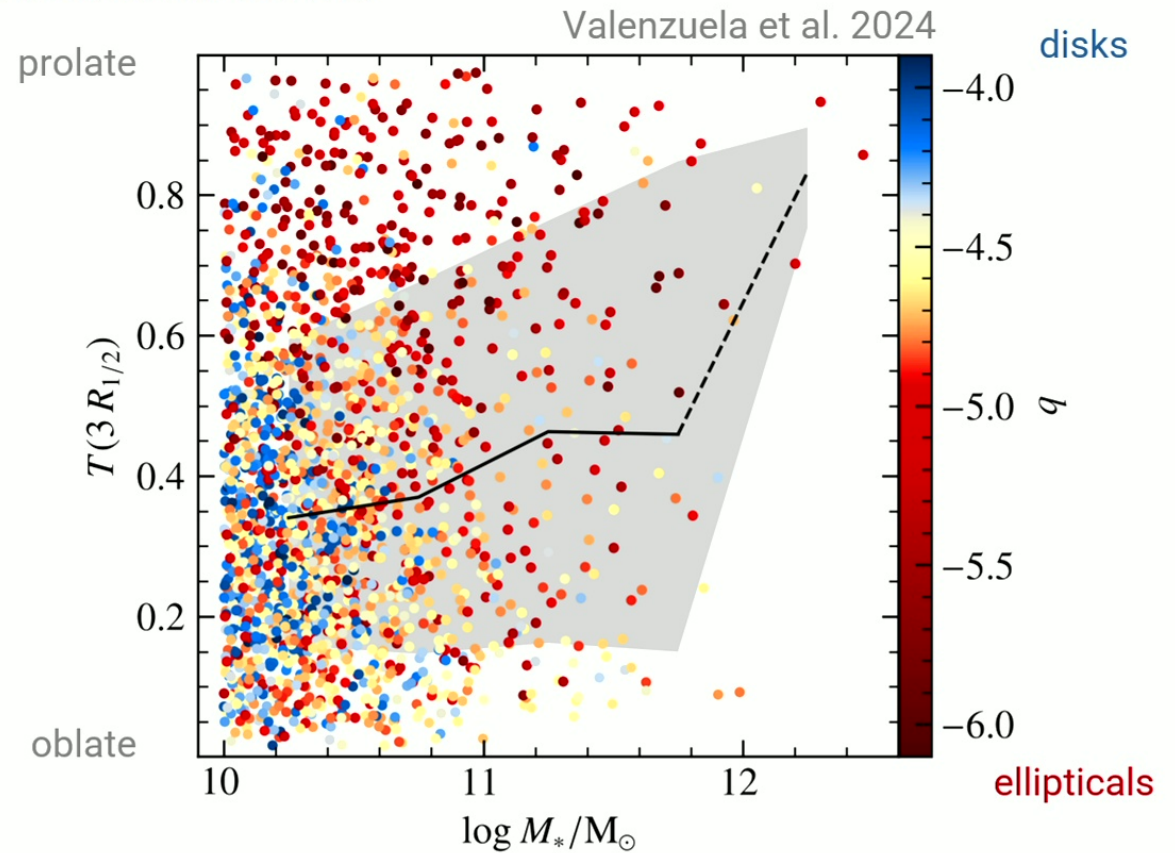
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General Shape Relations



Stellar Mass

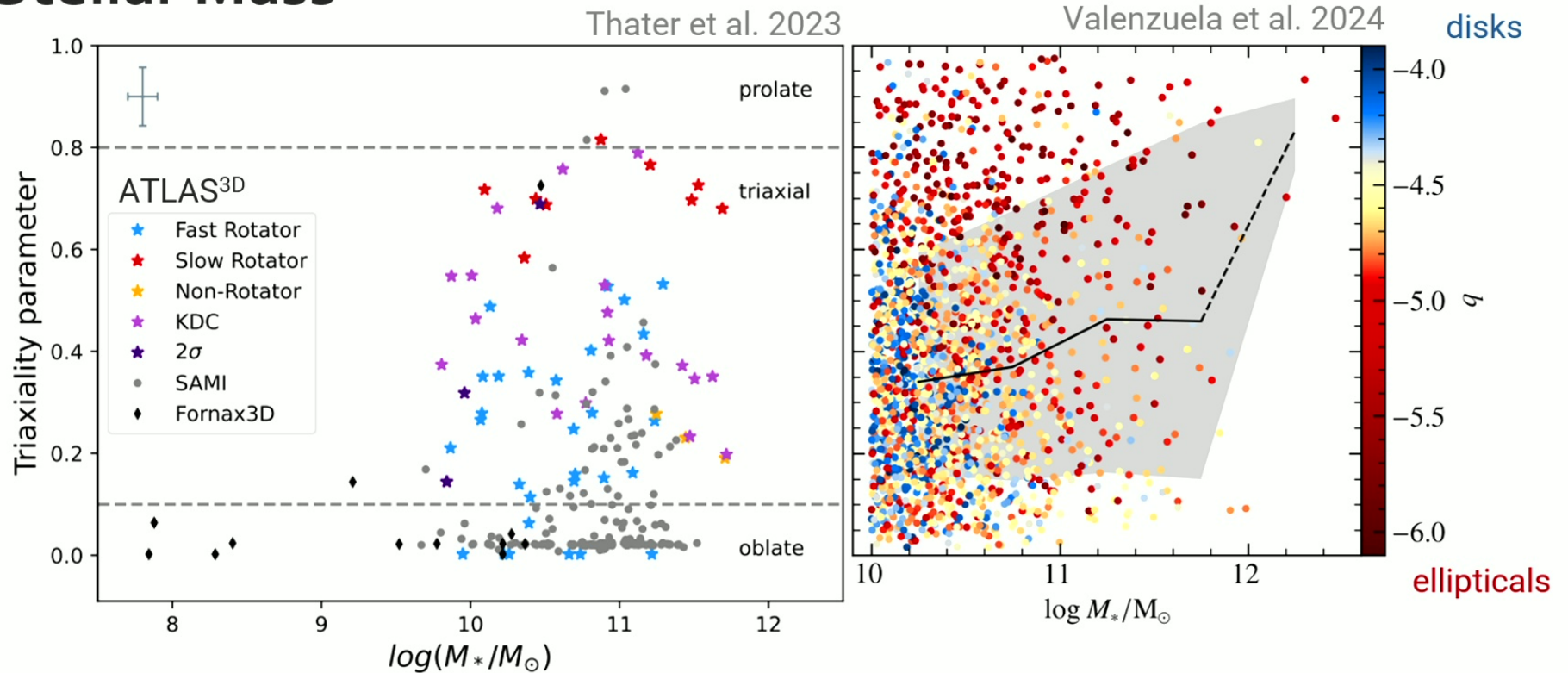
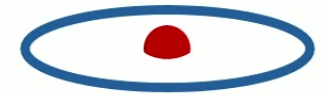


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General Shape Relations

Stellar Mass

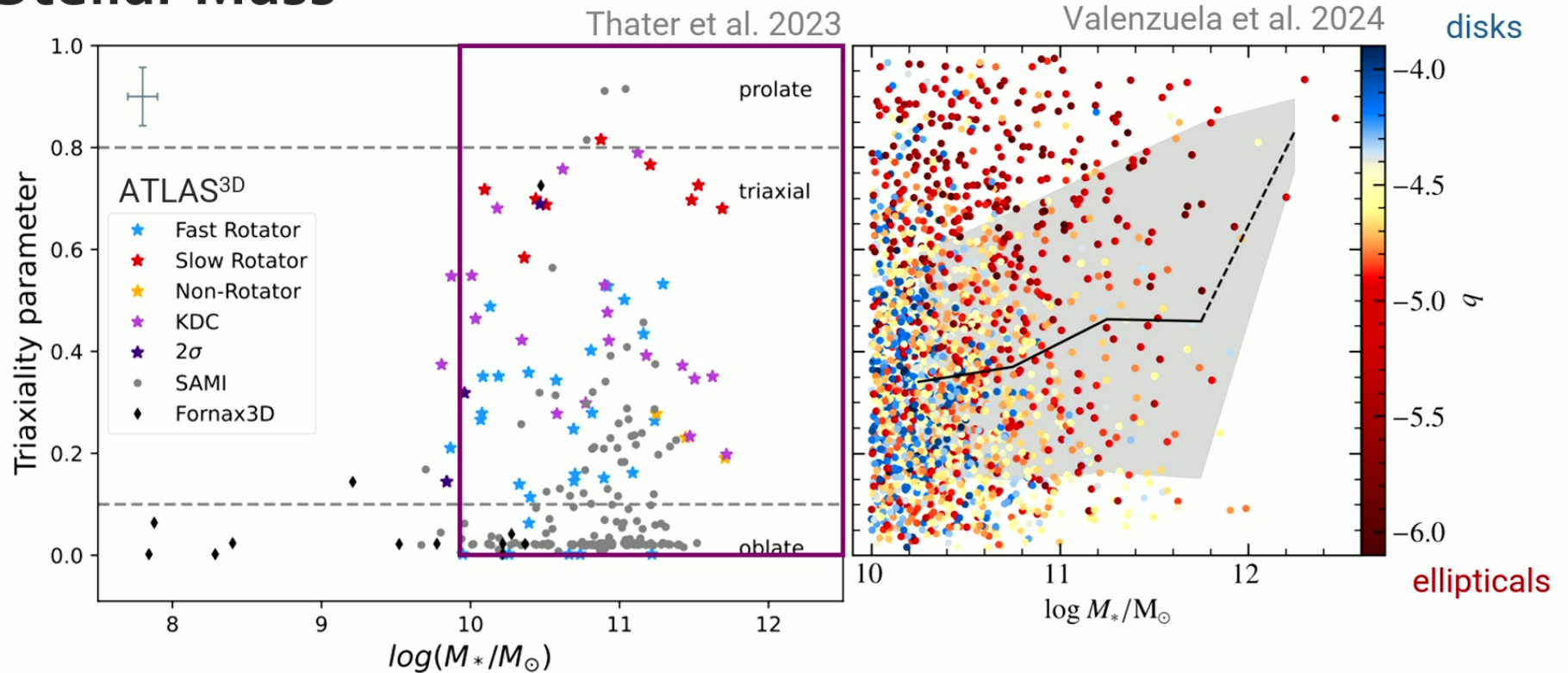
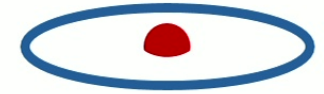


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General Shape Relations

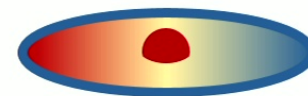
Stellar Mass



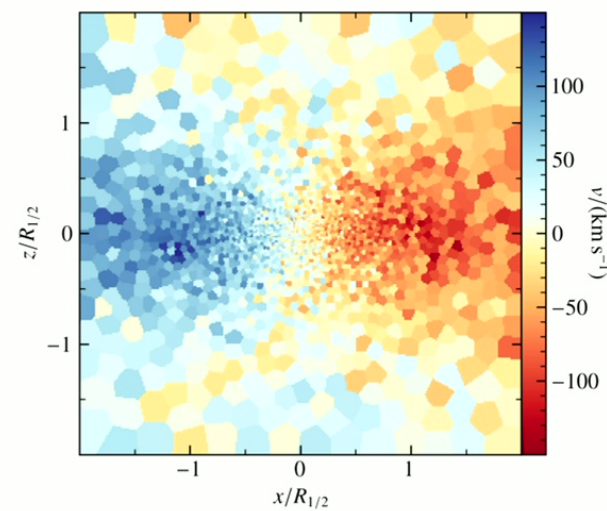
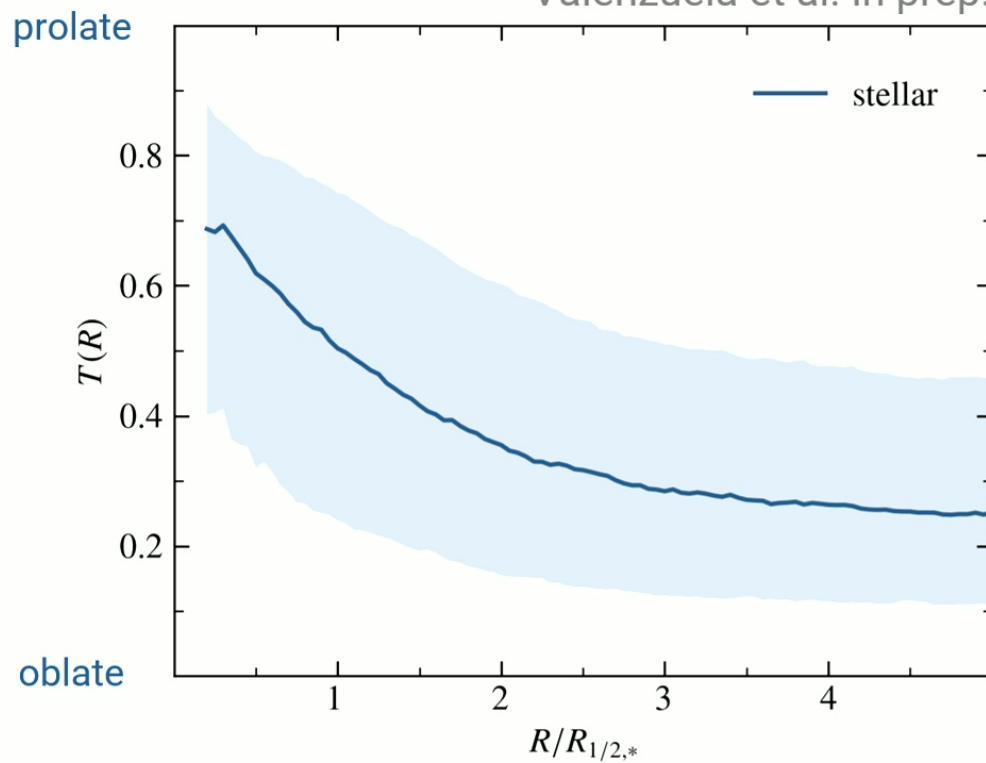
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Regular Rotators



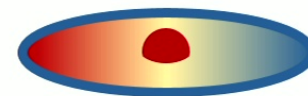
Valenzuela et al. in prep.



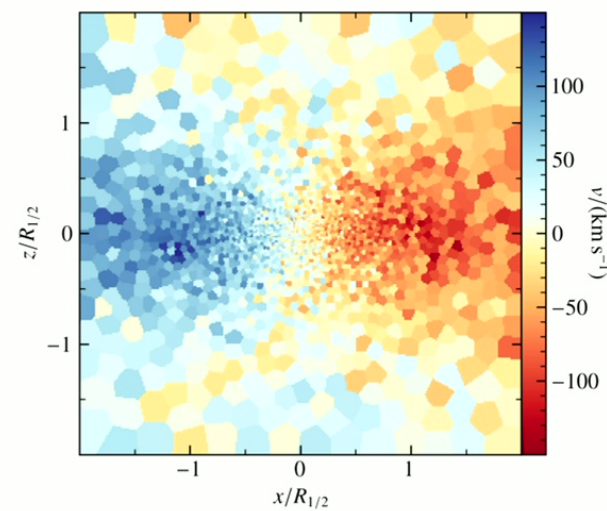
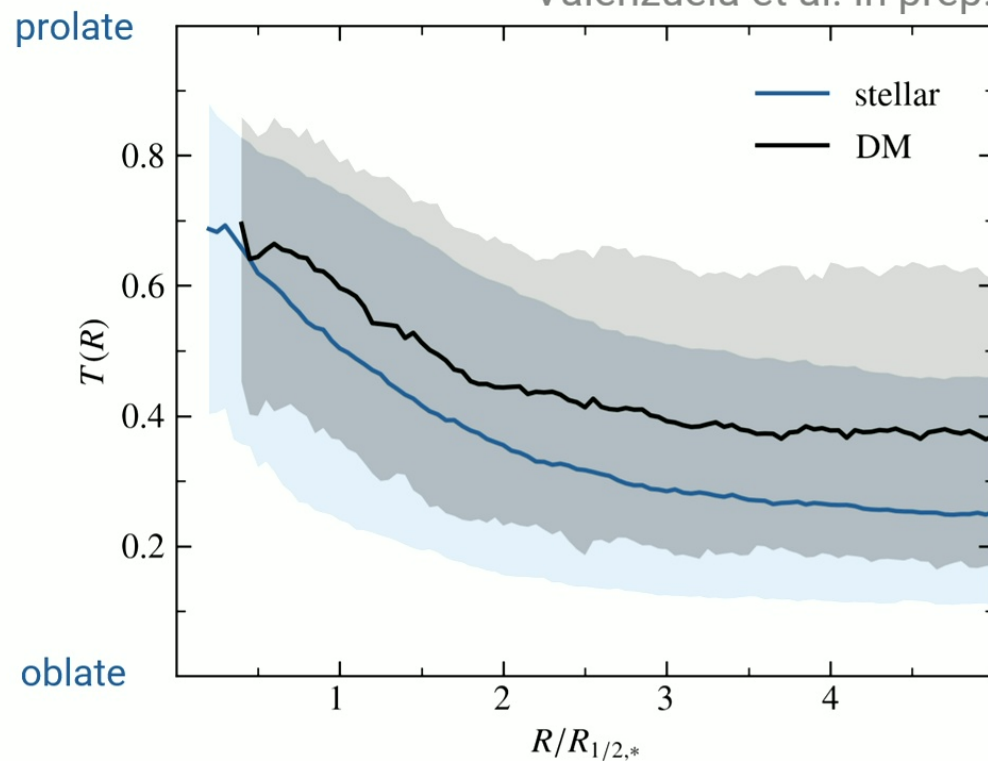
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Regular Rotators



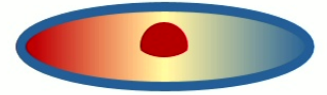
Valenzuela et al. in prep.



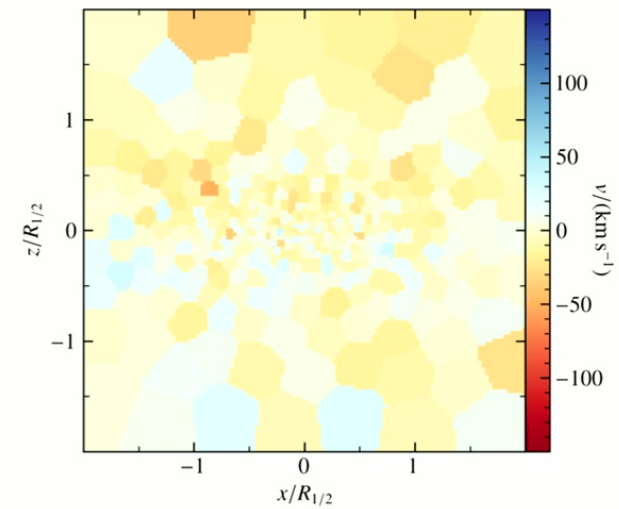
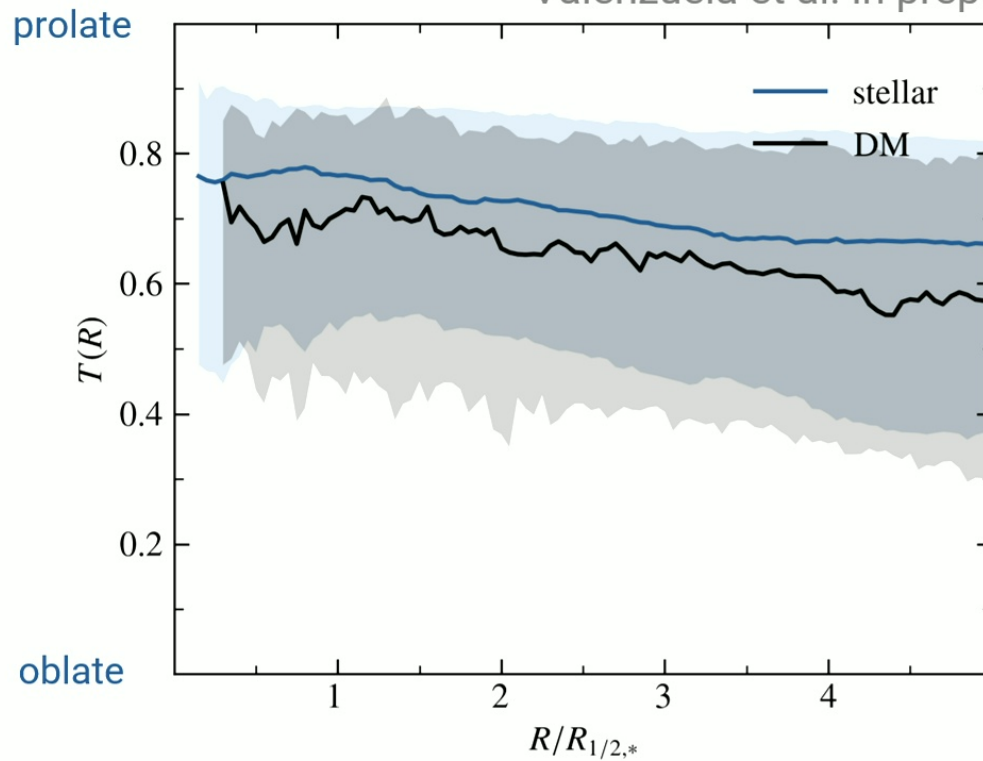
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Non-Rotators



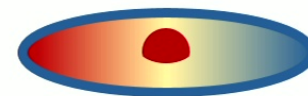
Valenzuela et al. in prep.



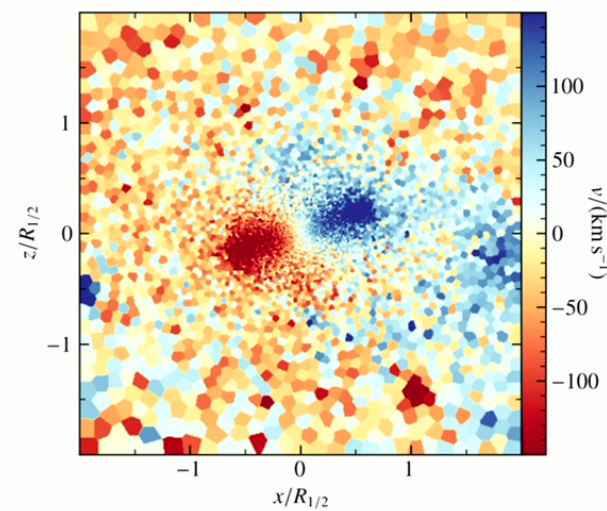
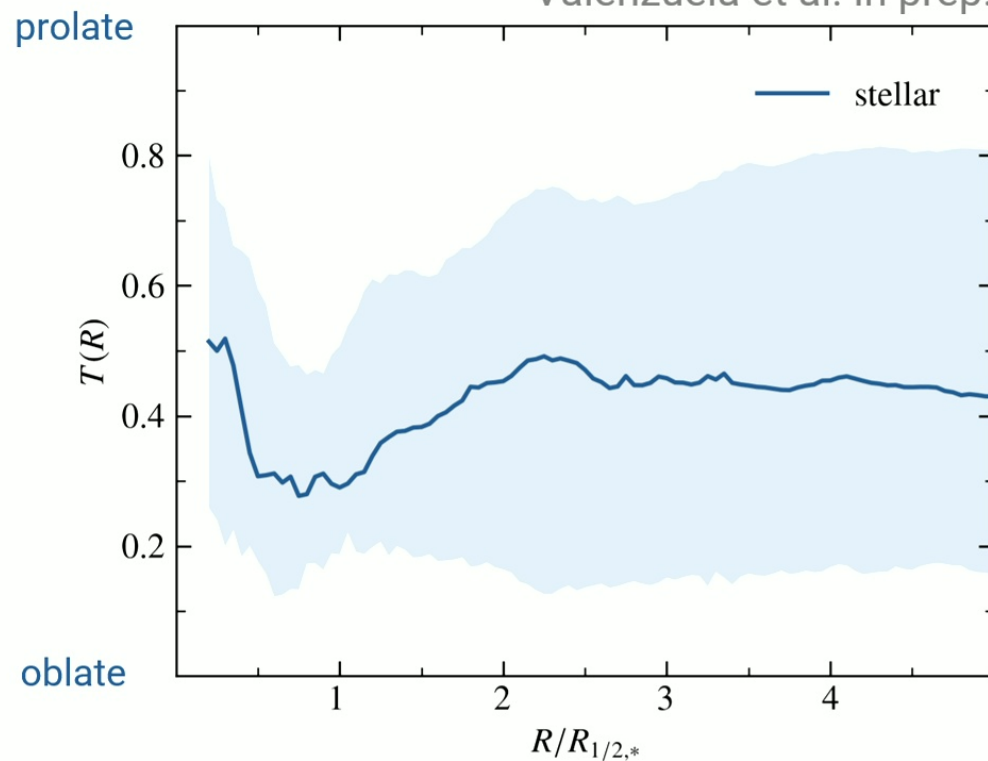
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Lucas Valenzuela – Merger tracers in present-day galaxies

Distinct Cores



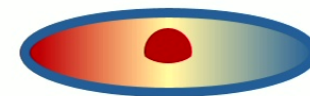
Valenzuela et al. in prep.



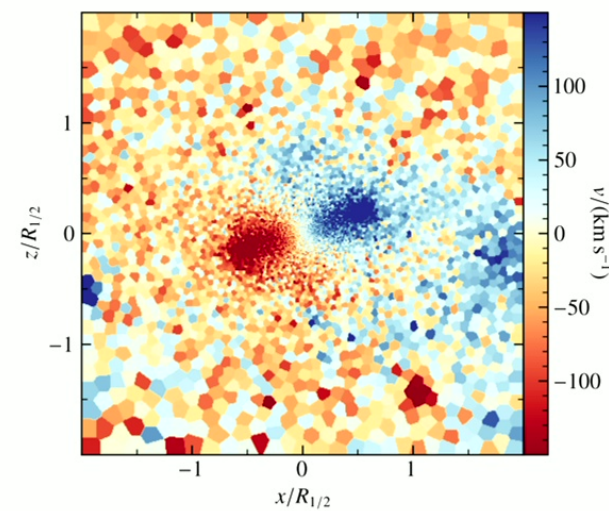
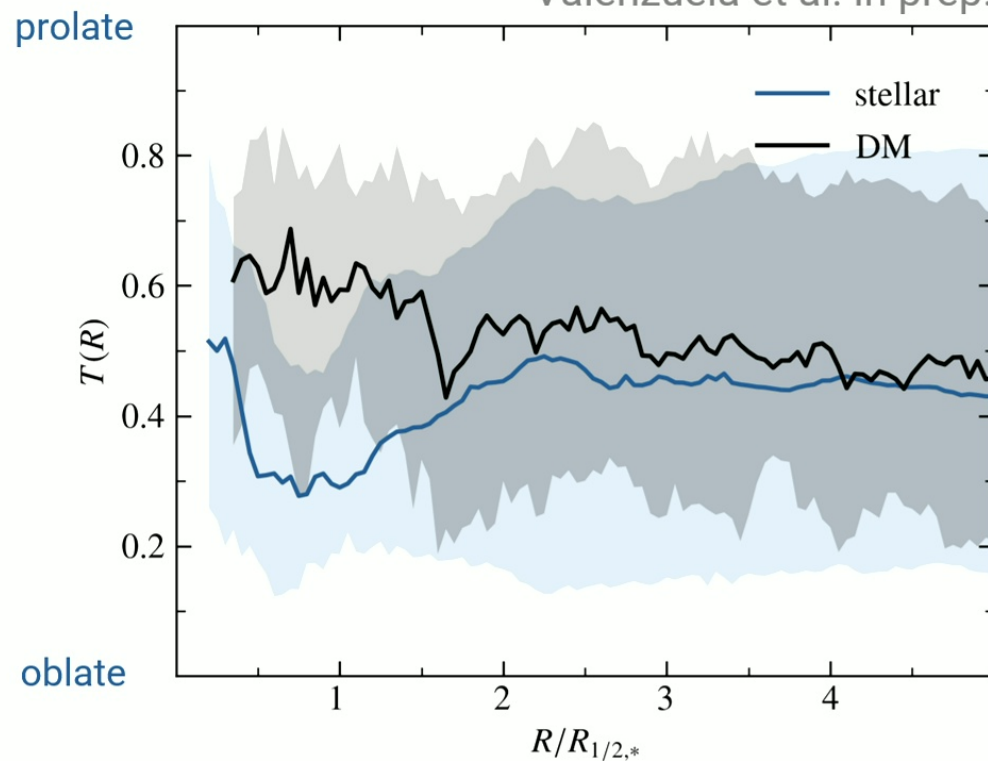
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Distinct Cores



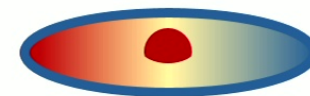
Valenzuela et al. in prep.



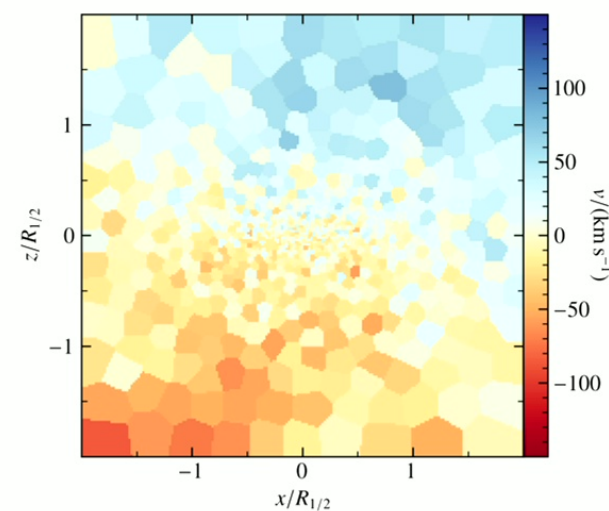
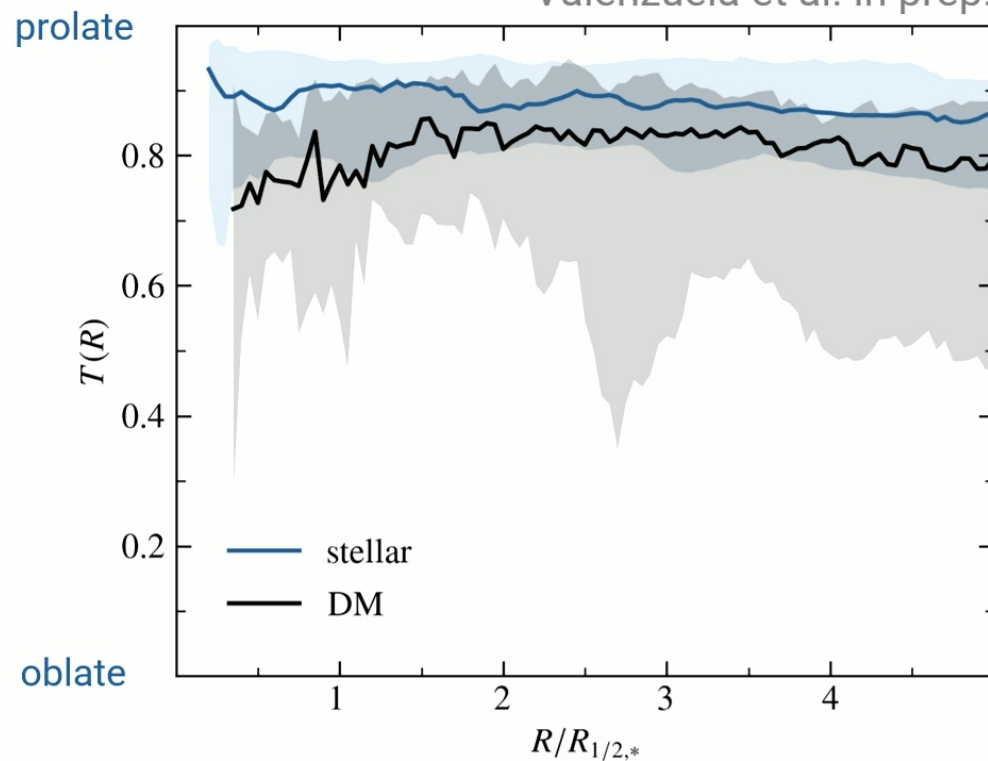
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Lucas Valenzuela – Merger tracers in present-day galaxies

Prolate Rotators



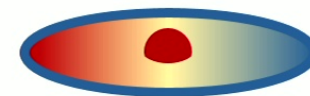
Valenzuela et al. in prep.



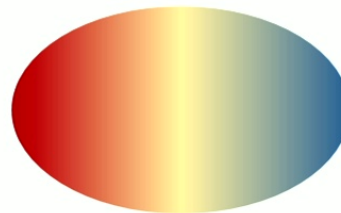
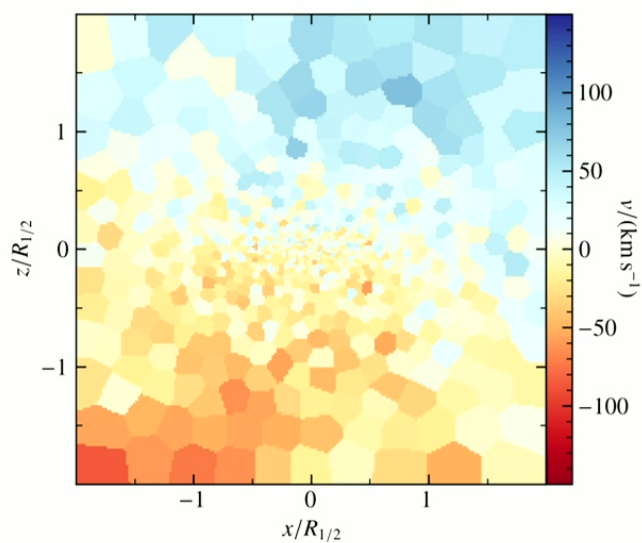
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Lucas Valenzuela – Merger tracers in present-day galaxies

Interpretation



Prolate Rotators



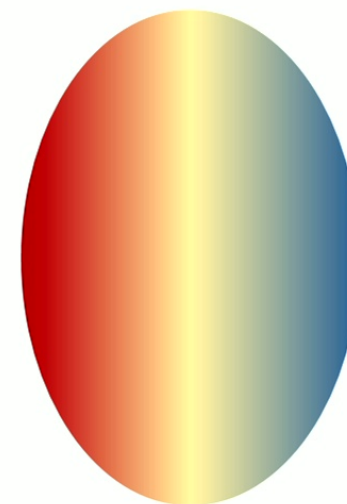
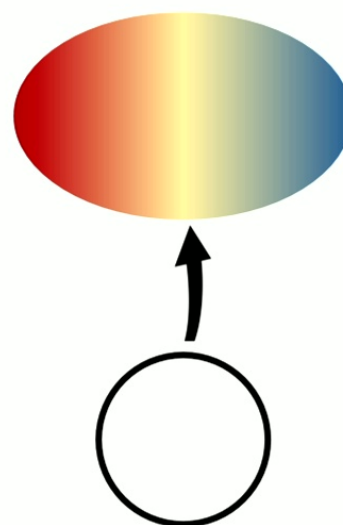
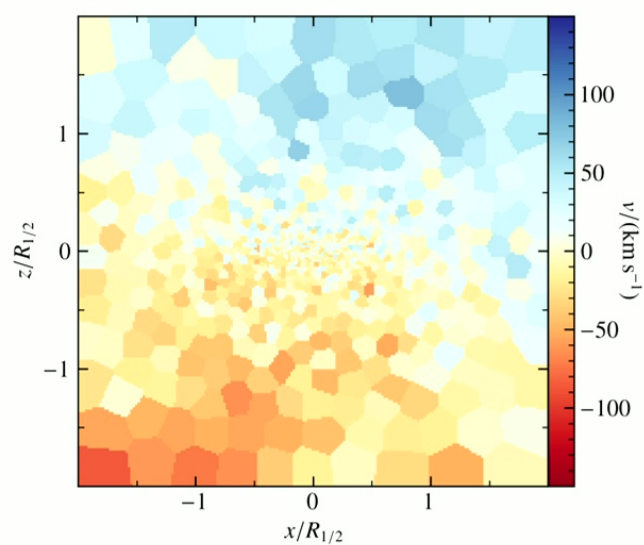
Hegde et al. 2022

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Interpretation

Prolate Rotators



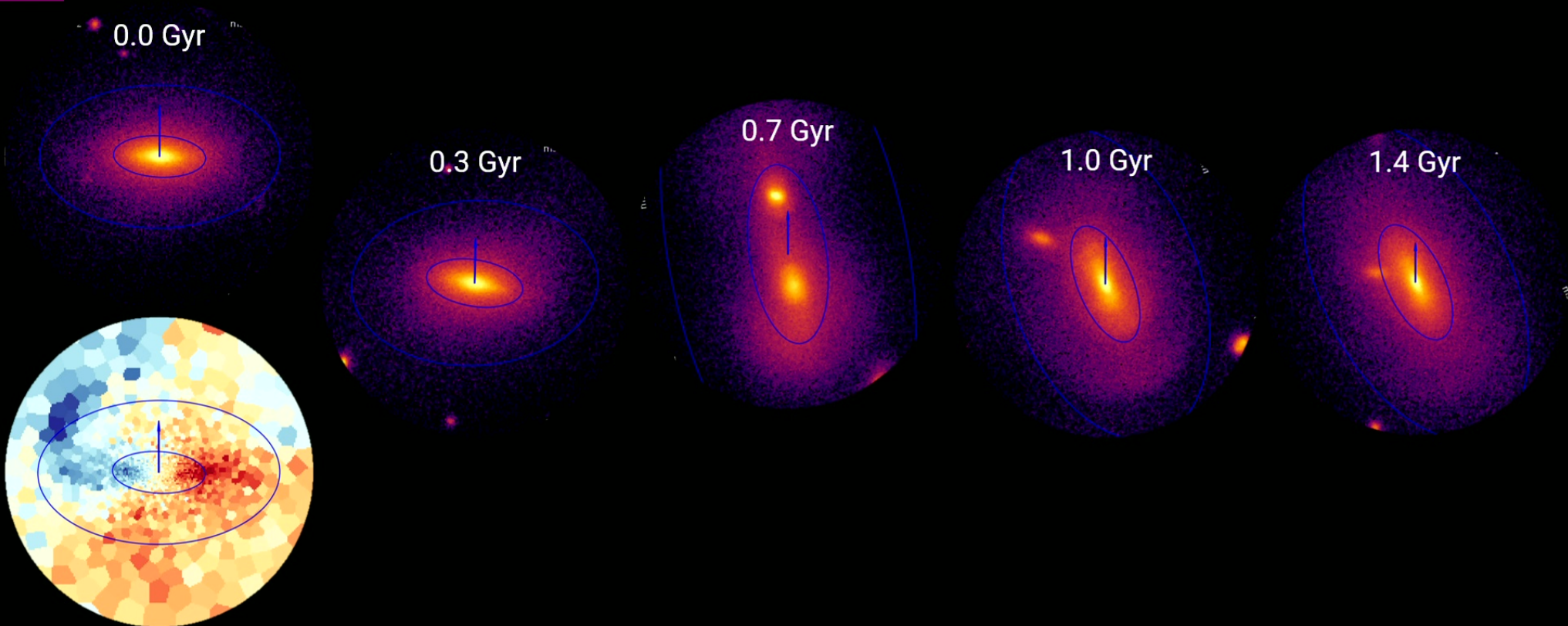
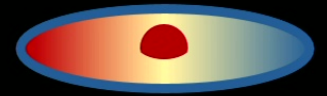
Hegde et al. 2022

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Case Study

Johannes Stoiber

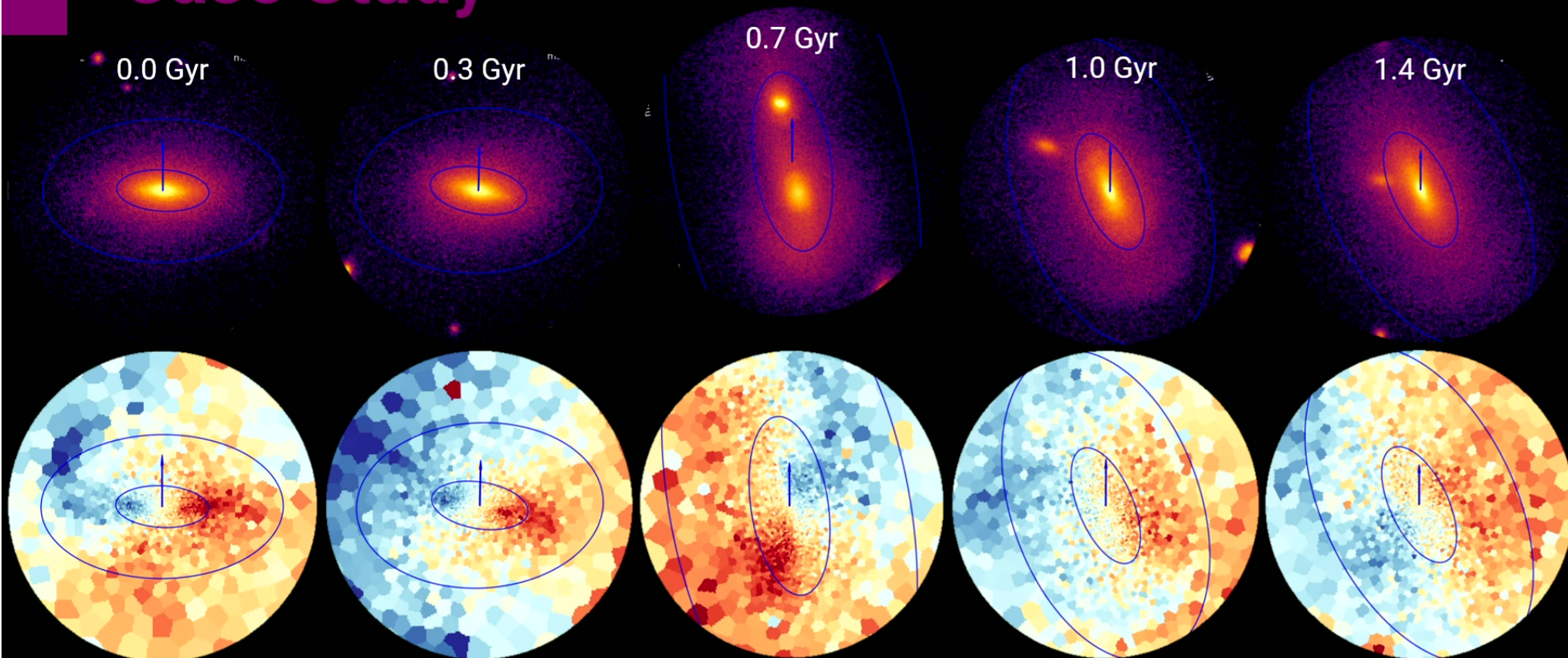
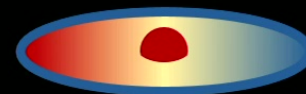


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Case Study

Johannes Stoiber



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Tracing Dry Mergers

Using tidal features

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Tidal Features – Classification



Observations

MATLAS

Bílek et al. 2020

Simulations

Magneticum Box4

Valenzuela & Remus 2022

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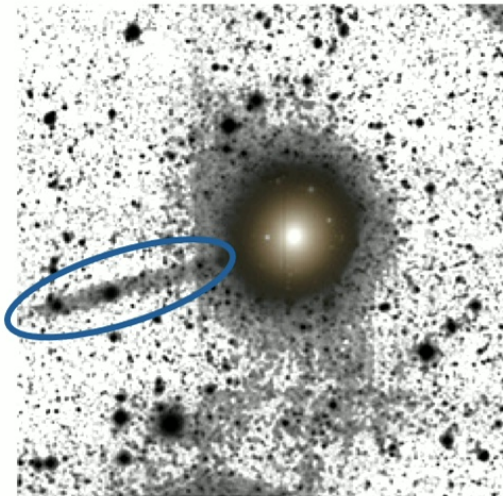
Lucas Valenzuela – Merger tracers in present-day galaxies

Tidal Features – Classification



Observations

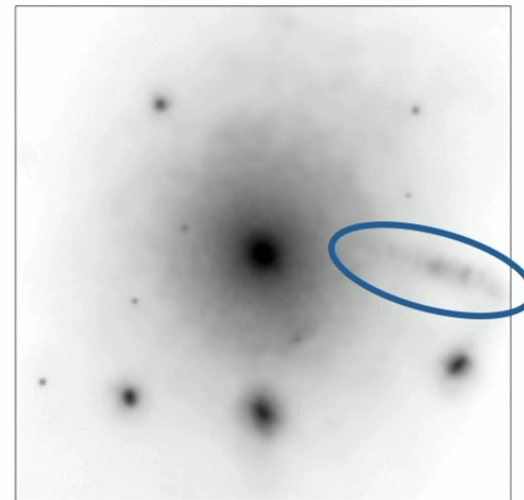
MATLAS



Bílek et al. 2020

Simulations

Magneticum Box4



Valenzuela & Remus 2022

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Lucas Valenzuela – Merger tracers in present-day galaxies

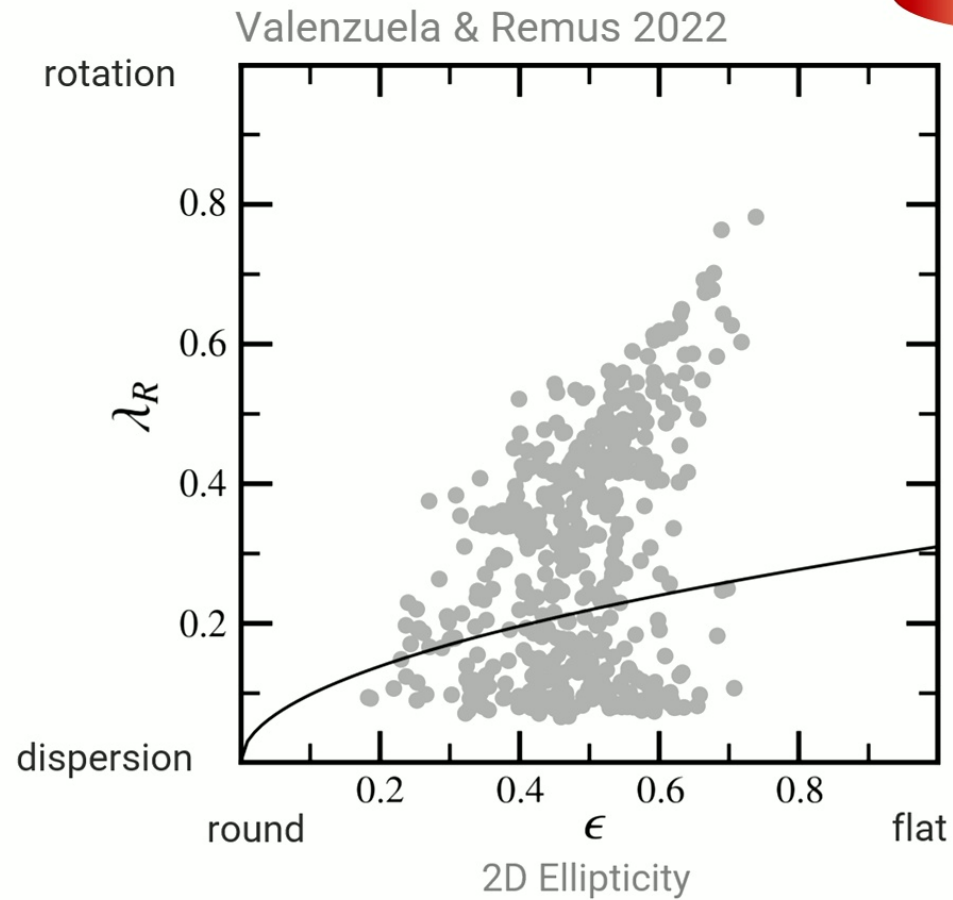
Kinematics

Kinematic Parameter



λ_R -parameter
rotation vs.
dispersion

Emsellem et al. 2007, 2011



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Kinematics

Valenzuela & Remus 2022

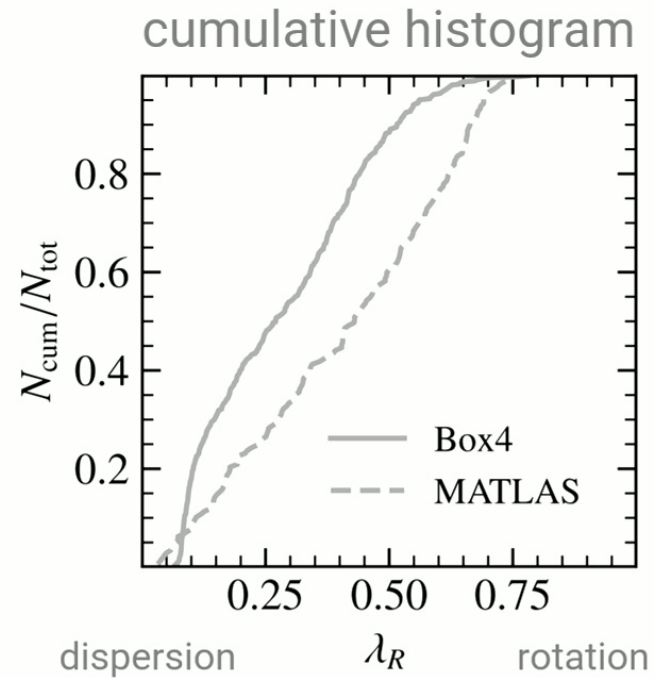


Kinematic Parameter



λ_R -parameter
rotation vs.
dispersion

Emsellem et al. 2007, 2011



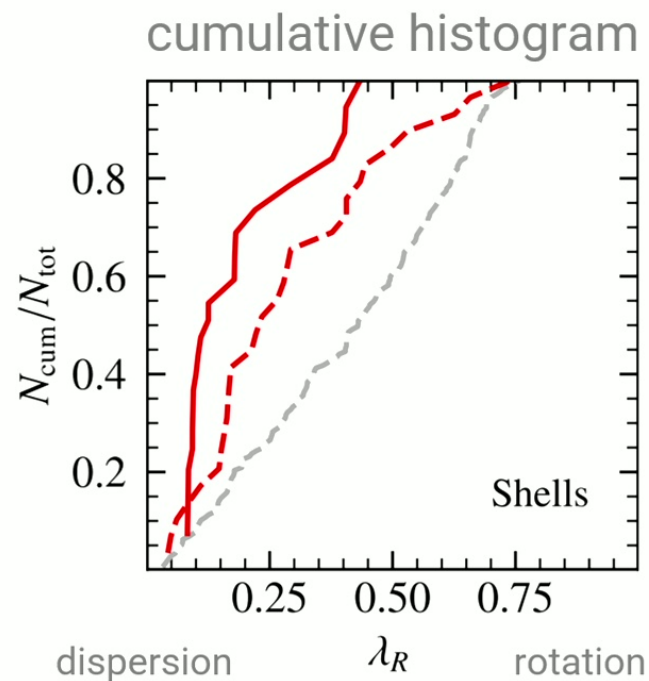
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Tidal Features & Inner Kinematics



— Box4
--- MATLAS

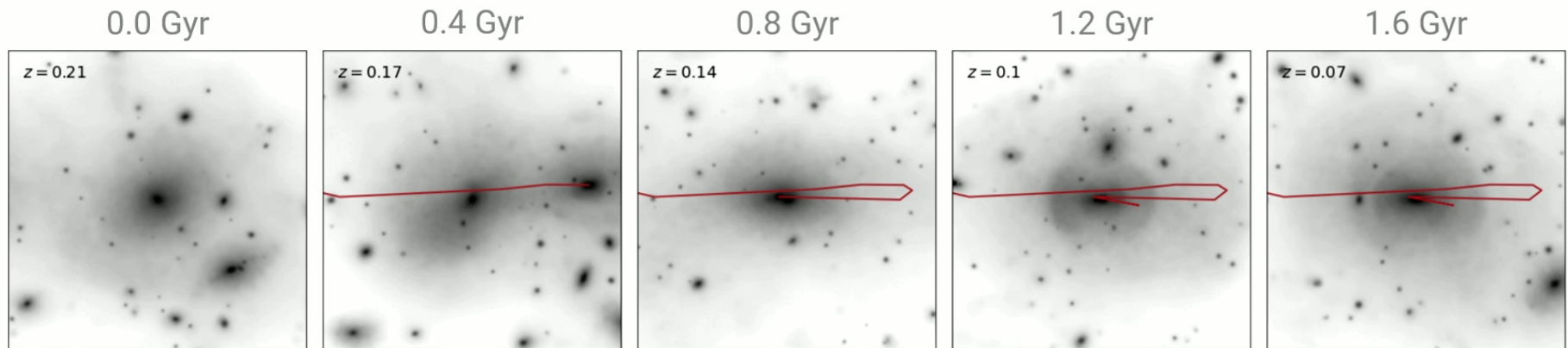


Valenzuela & Remus 2022

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Shells & Slow Rotation

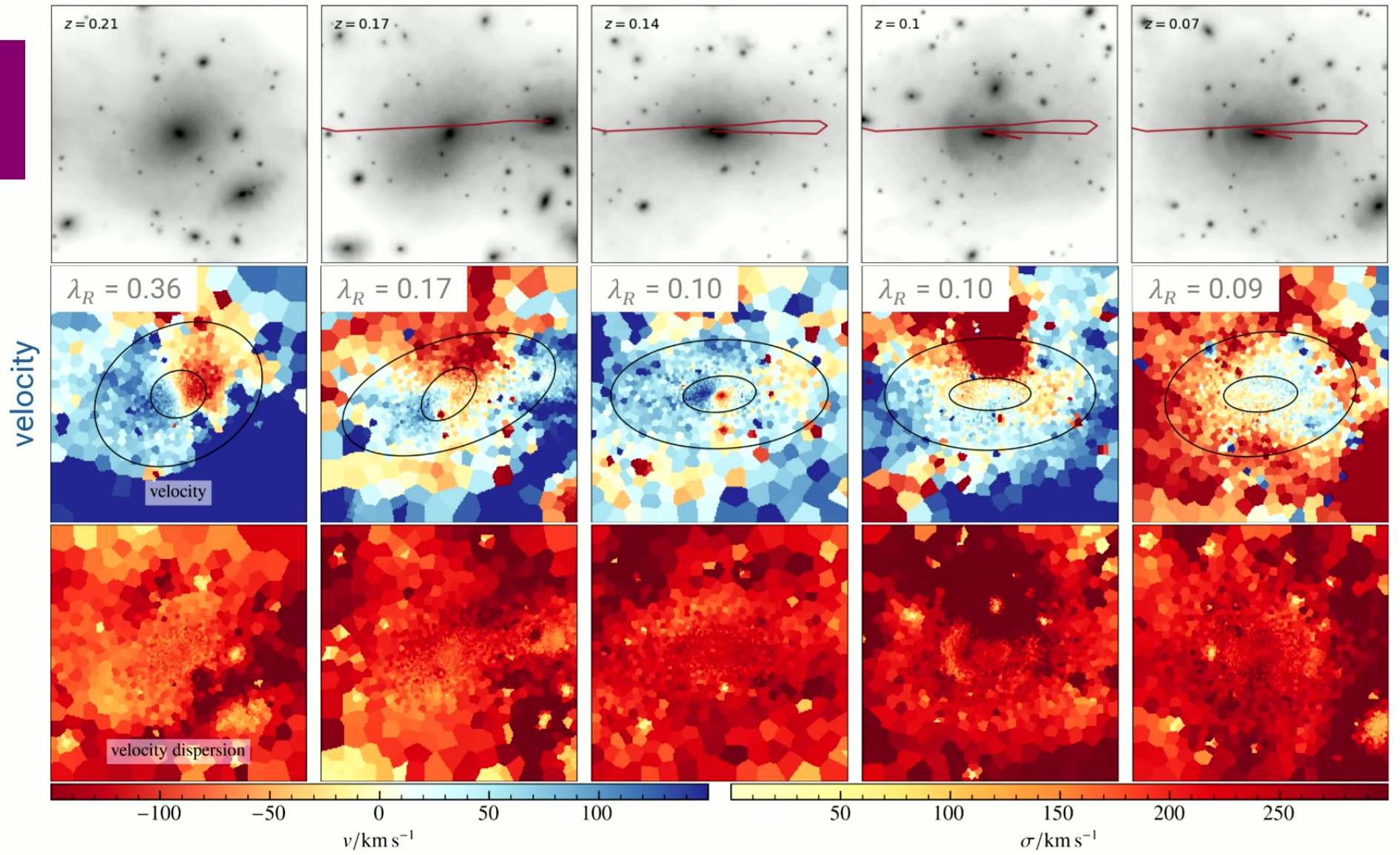


Valenzuela & Remus 2022

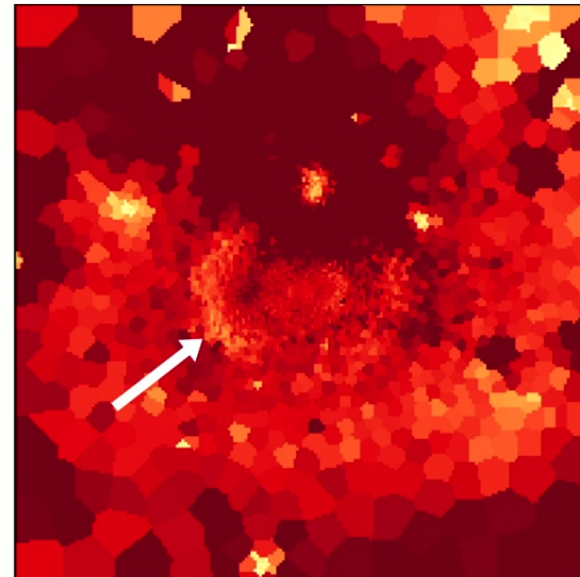
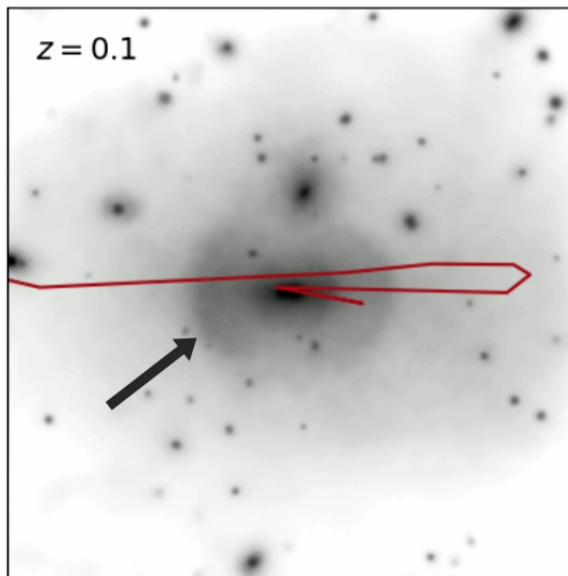
see also Pop+18

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Shells & Velocity Dispersion

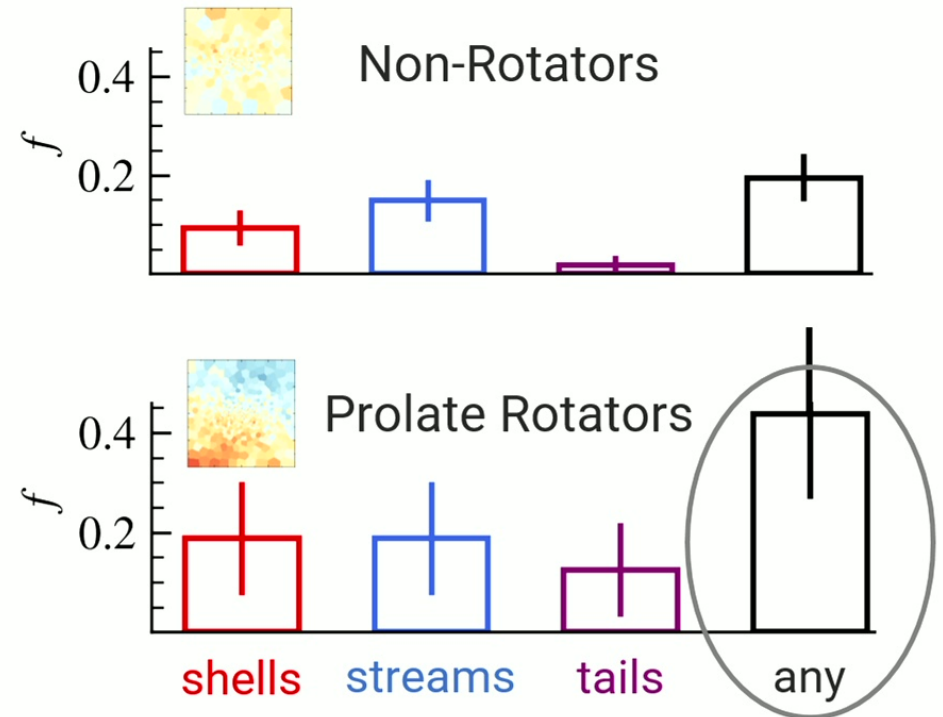
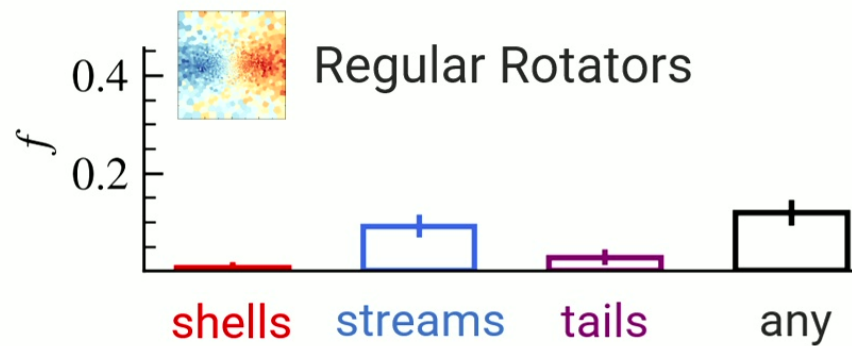


Valenzuela & Remus 2022

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Tidal Feature Statistics

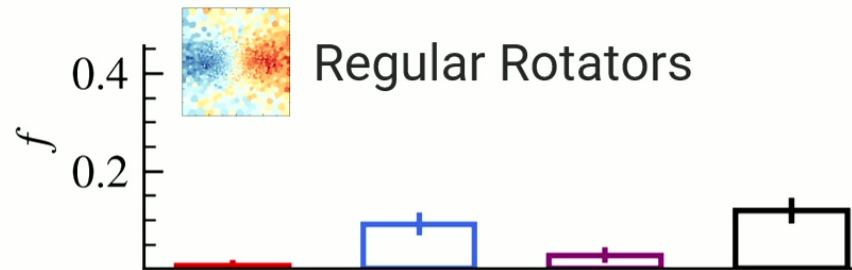


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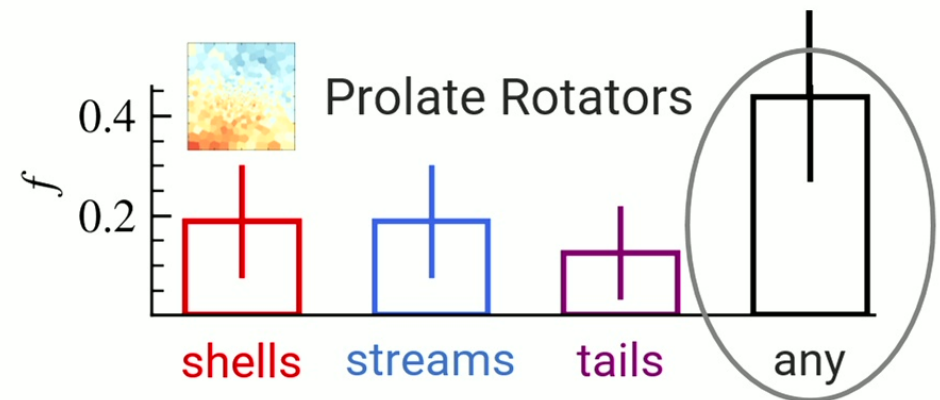
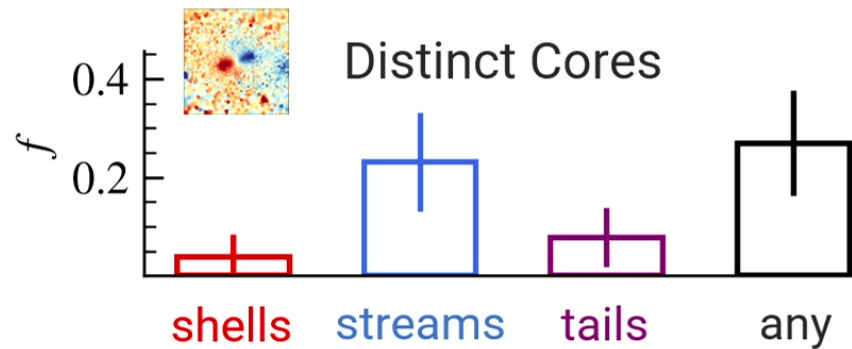
Valenzuela & Remus 2022

Tidal Feature Statistics



From simulations:
recent mergers & interactions

Ebrov et al. 2021

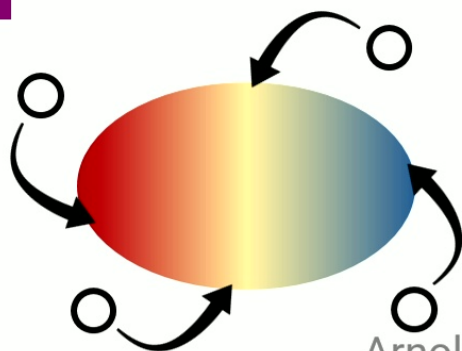


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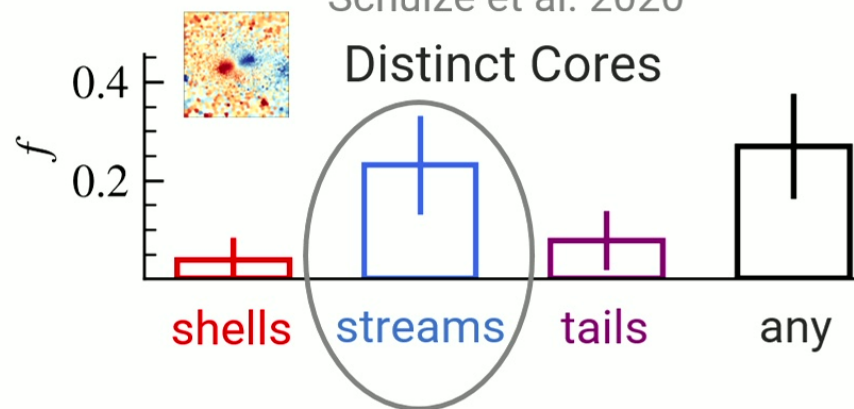
Lucas Valenzuela – Merger tracers in present-day galaxies

Valenzuela & Remus 2022

Tidal Feature Statistics

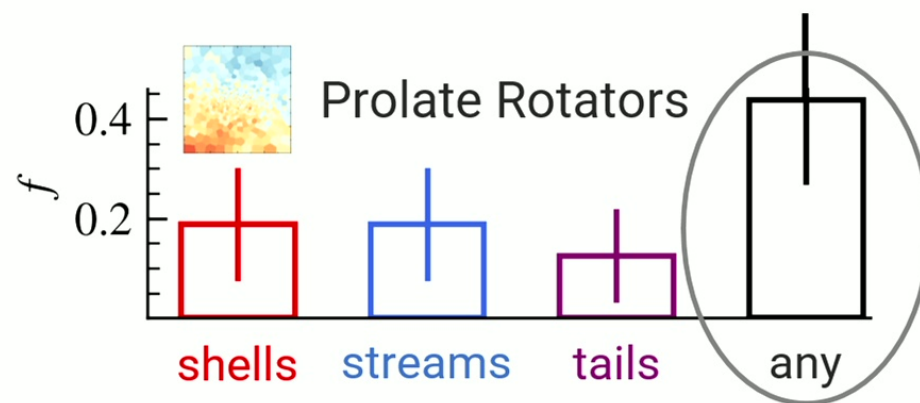


Arnold et al. 2014
Schulze et al. 2020



From simulations:
recent mergers & interactions

Ebrov et al. 2021

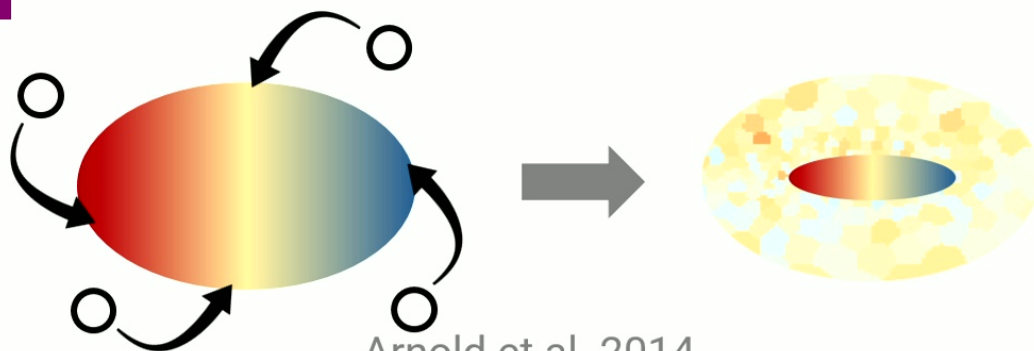


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Valenzuela & Remus 2022

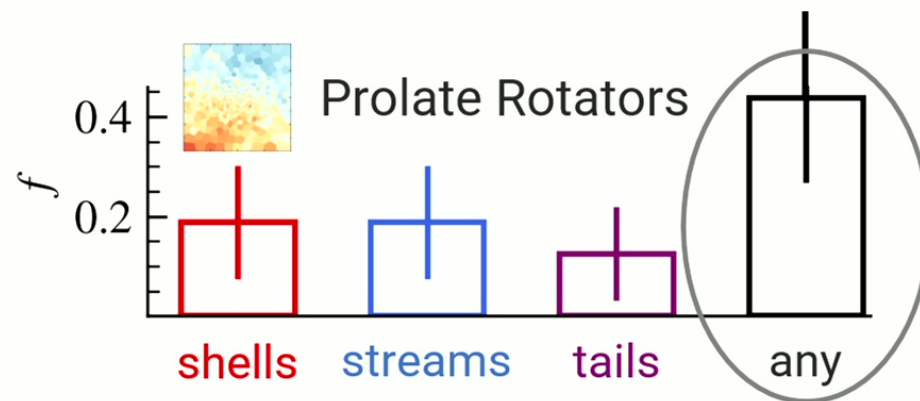
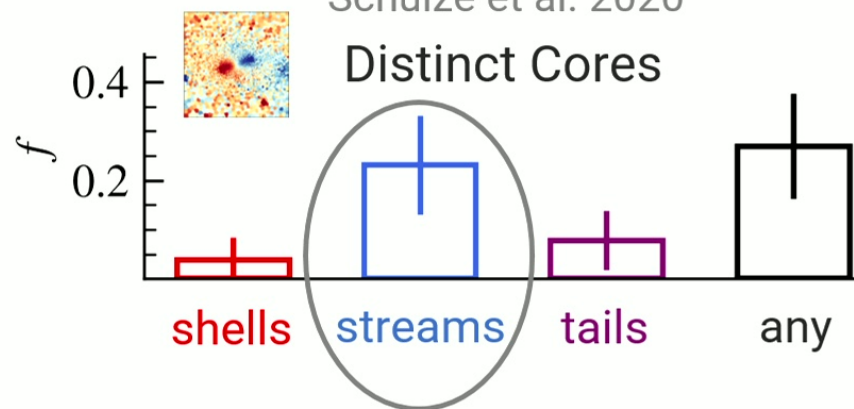
Tidal Feature Statistics



Arnold et al. 2014
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From simulations:
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Valenzuela & Remus 2022

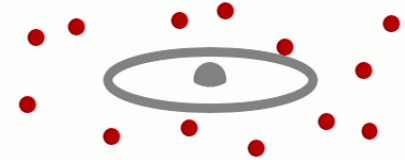
Tracing Wet Mergers

Using globular clusters

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Globular Cluster Model



Empirical Modeling

In a Cosmological Simulation

123

GC number



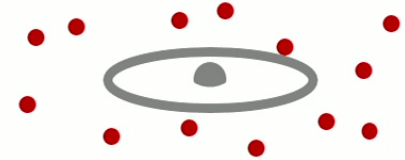
GC formation time

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Valenzuela et al. 2021

Formation Pathways



1st Pathway

2nd Pathway

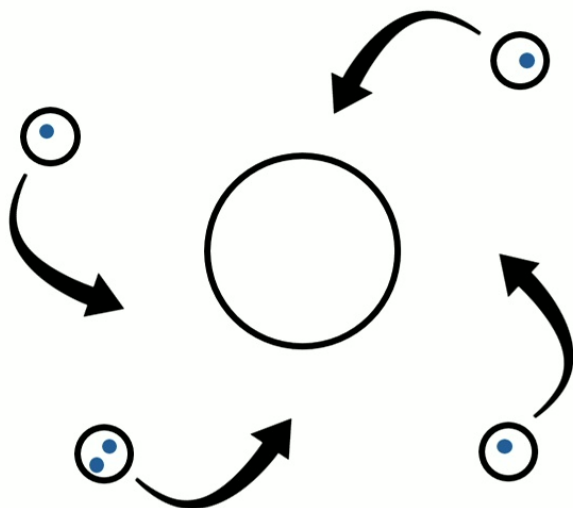
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Valenzuela et al. 2021

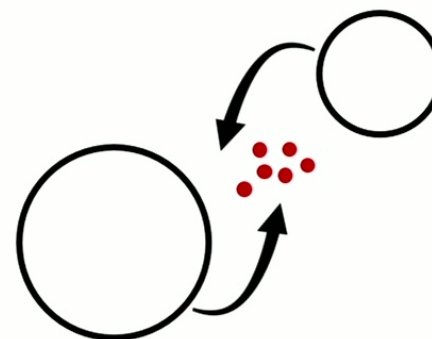
Formation Pathways

1st Pathway



Côté et al. 1998

2nd Pathway



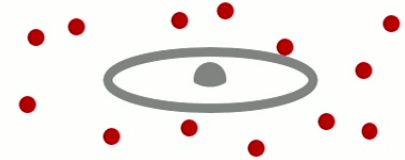
Ashman & Zepf 1992

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Valenzuela et al. 2021

Prediction



Major Merger



Sufficient Gas



Peak in the
GC age distribution

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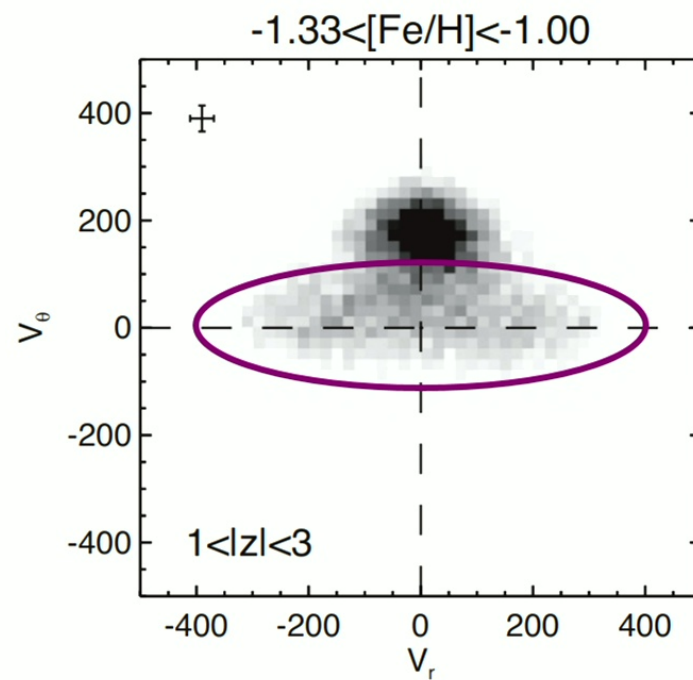
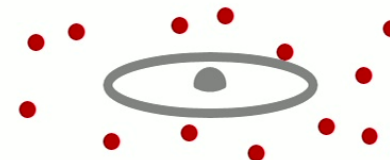
Lucas Valenzuela – Merger tracers in present-day galaxies

Milky Way Assembly

Gaia Sausage/Enceladus

Last gas-rich major merger
8–11 Gyr ago

Belokurov et al. 2018
Helmi et al. 2018

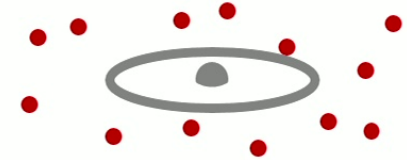


Belokurov et al. 2018

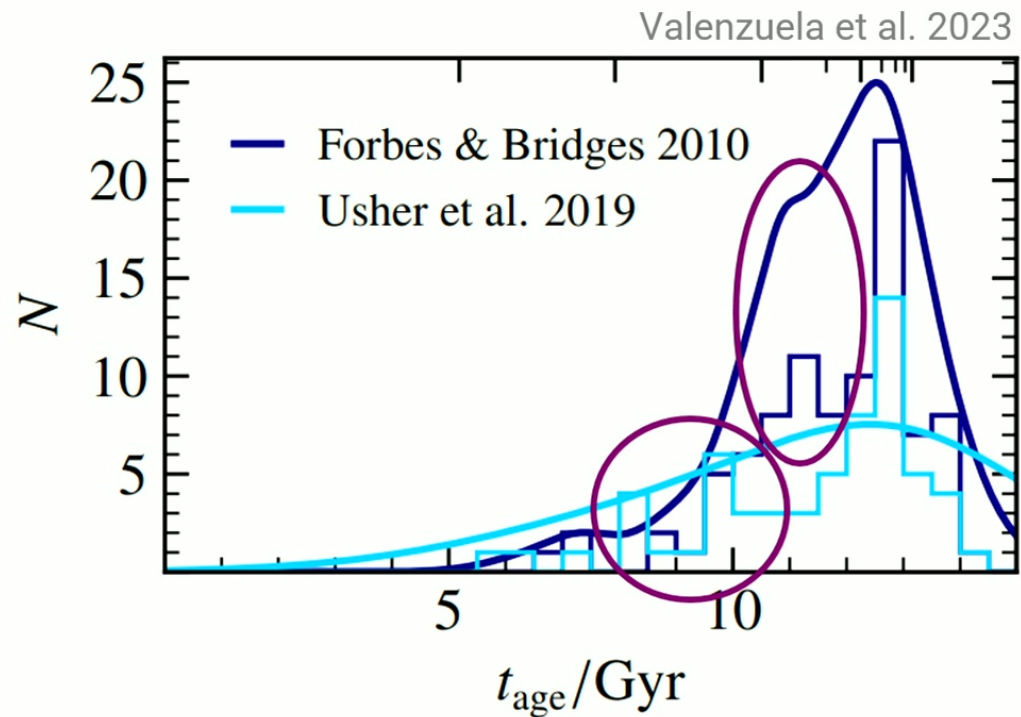
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Milky Way Globular Clusters



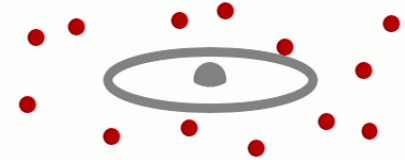
GC Age Distribution



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Milky Way Globular Clusters



Milky Way in-situ

Gaia Sausage/Enceladus

Helmi Streams

Sequoia

Sagittarius

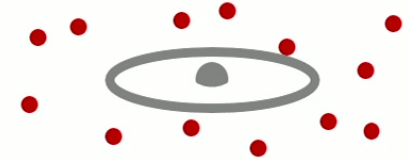
High-Energy

Low-Energy

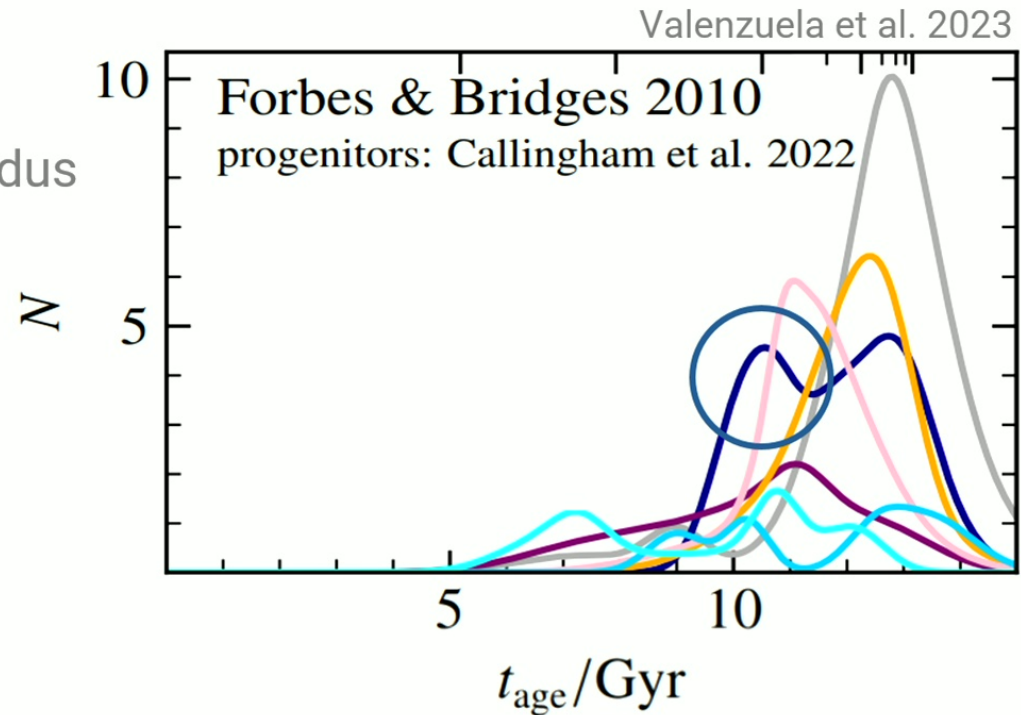
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Milky Way Globular Clusters



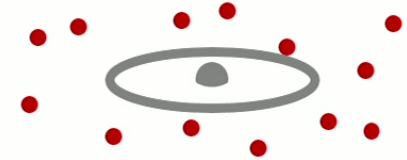
- Milky Way in-situ
- Gaia Sausage/Enceladus
- Helmi Streams
- Sequoia
- Sagittarius
- High-Energy
- Low-Energy



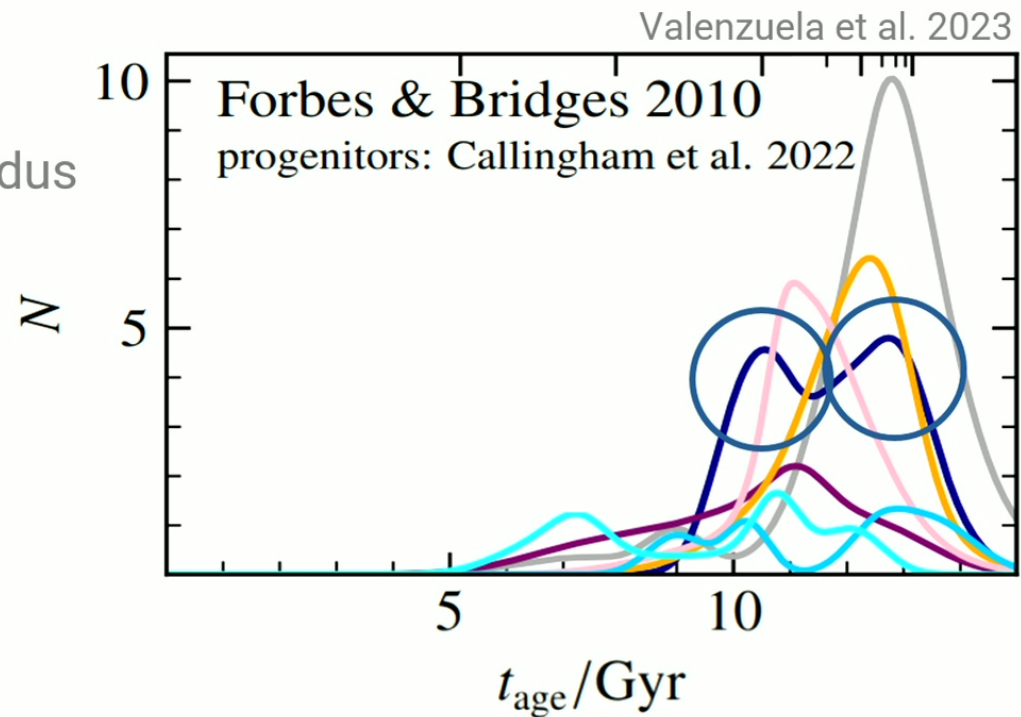
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Milky Way Globular Clusters



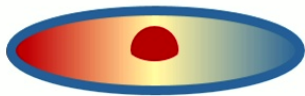
- Milky Way in-situ
- Gaia Sausage/Enceladus
- Helmi Streams
- Sequoia
- Sagittarius
- High-Energy
- Low-Energy



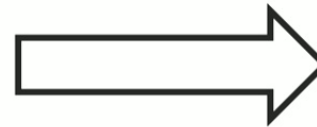
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Galaxy Formation History



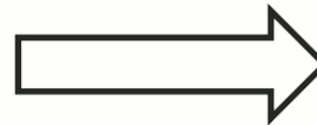
Prolate Shape
Prolate Rotator



**Merger along
Minor Axis**



Shells
Slow Rotator

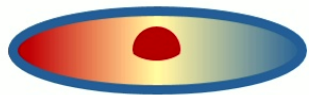


**Recent Radial
Major Merger**

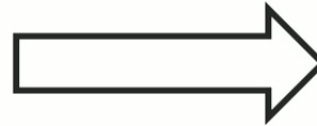
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Galaxy Formation History



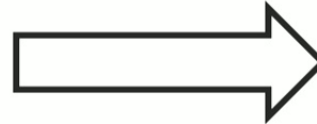
Prolate Shape
Prolate Rotator



**Merger along
Minor Axis**



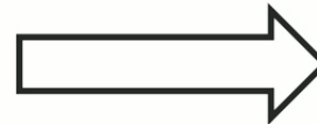
Shells
Slow Rotator



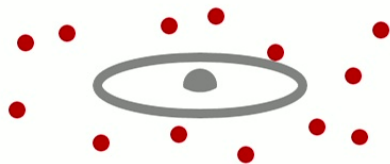
**Recent Radial
Major Merger**



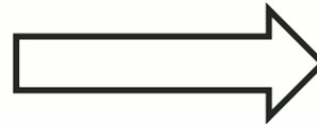
Streams
Distinct Core



**Circular
Minor Mergers**



GCs
Age Distribution



**Gas-Rich
Major Merger**

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