Galactic archeology with stellar streams
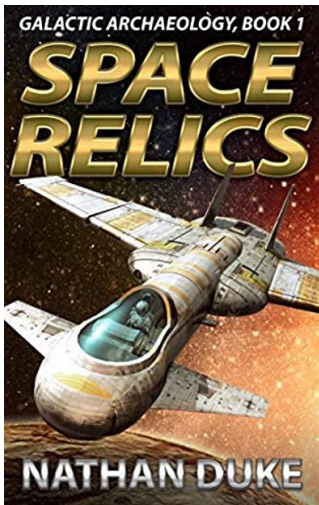
Eugene Vasiliev

Institute of Astronomy

Cambridge, December 2021

Galactic archeology with stellar streams

Galactic archeology

Properties of a star:
- mass
- size
- luminosity
- temperature / colour
- number of planets with intelligent life

Galactic archeology

Properties of a star:
- mass — drawn from a broad distribution ($\sim 0.1 - 100\, M_\odot$)
- size
- luminosity — change with time as the star evolves
- temperature / colour
- number of planets with intelligent life

Galactic archeology

Properties of a star:

▶ mass   – drawn from a broad distribution ($\sim 0.1 - 100\,M_\odot$)

▶ size

▶ luminosity $\Big\}$ change with time as the star evolves

▶ temperature / colour

▶ number of planets with intelligent life

▶ age

▶ chemical composition $\Big\}$ properties of distinct
                                            stellar populations

▶ orbit in the Galaxy

$\Downarrow$

Galactic building blocks

Galaxy formation

. . . is a violent story of mergers, hostile takeovers and destruction

Last major
merger

z = 3.5
(12 Gyr ago)

z = 1.3
(9 Gyr ago)

z = 0.8
(7 Gyr ago)
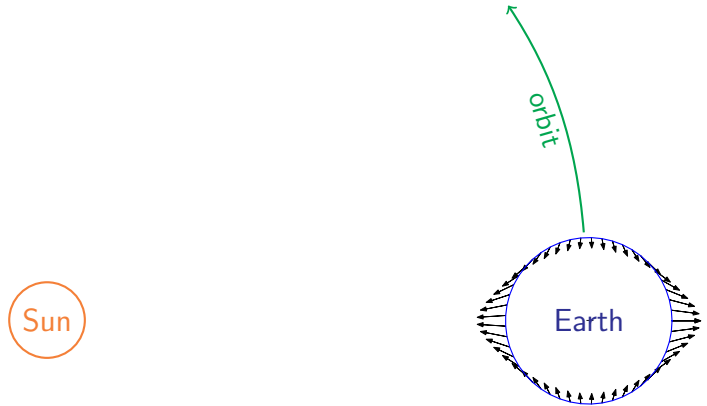
z = 0.2
(2 Gyr ago)
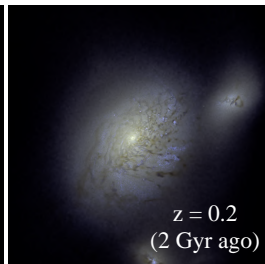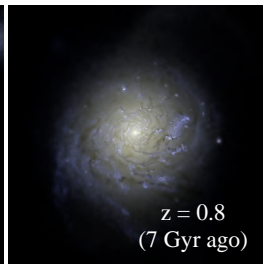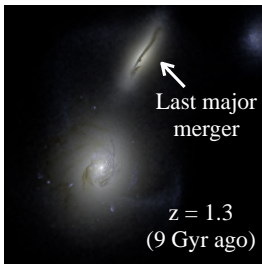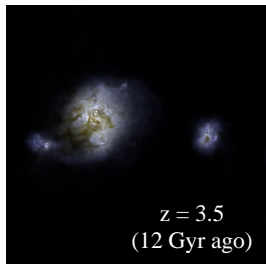
Vintergatan simulation of Milky Way formation

also check out this band: *Wintergatan* →

Tidal forces

Tidal forces, Hill sphere, Lagrange points. . .

Hill sphere:
region around the planet
where its gravity dominates
the gravity of the central star.

Radius of the Hill sphere
(distance from the planet
to Lagrange points L_2, L_3):
$r_{\text{Hill}} \approx r_{\text{orbit}} \left(m_{\text{planet}}/M_{\text{star}}\right)^{1/3}$.

For the Earth–Sun system,
$r_{\text{Hill}} \simeq 1.5 \times 10^6$ km
$= 1\%$ of the Earth's orbit radius
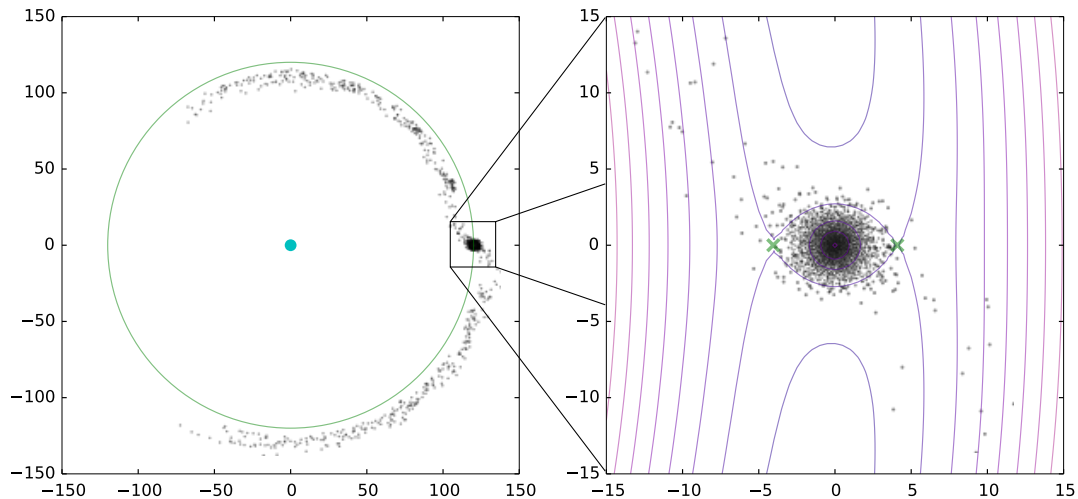$= 4\times$ the distance to the Moon.
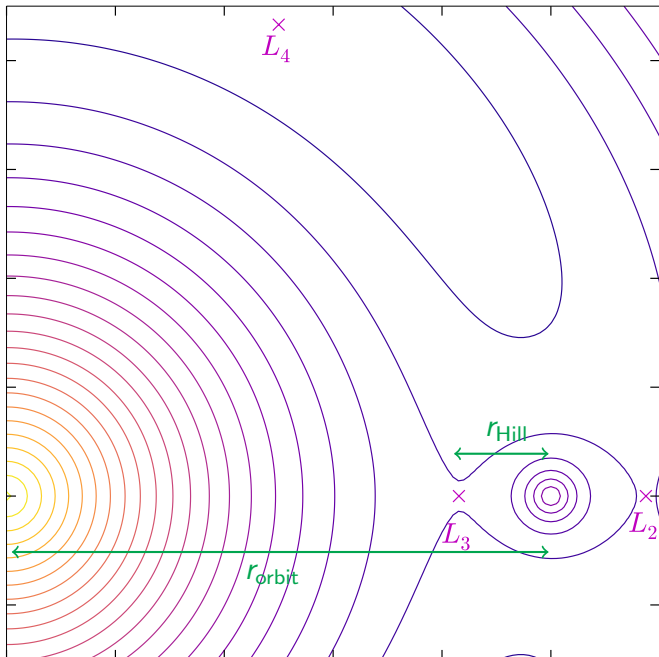
Tidal forces, Hill sphere, Lagrange points. . .

Replace the Sun by the Galaxy and the planet by a star cluster (or a satellite galaxy): any stars outside the Hill sphere of the satellite will be tidally stripped.
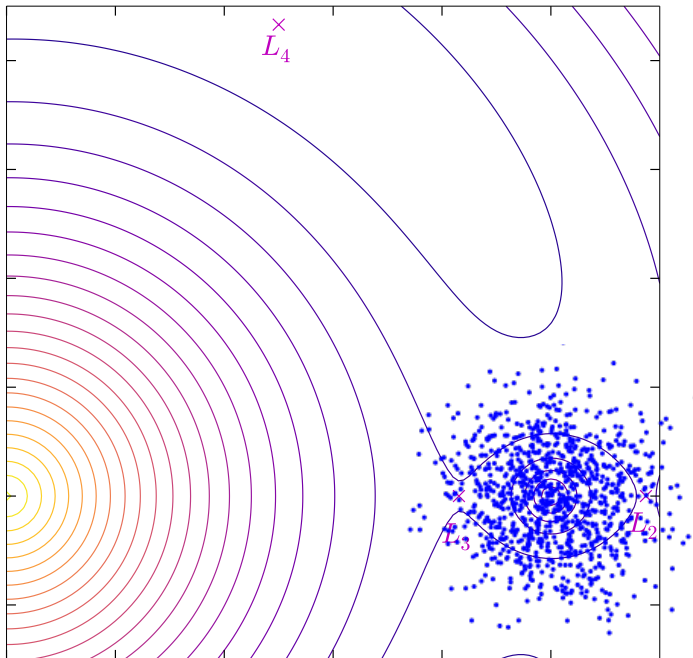
Formation of tidal tails
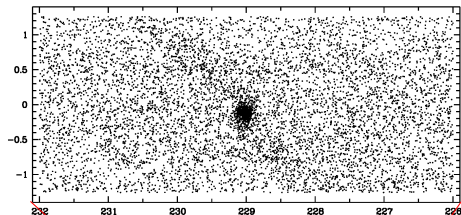
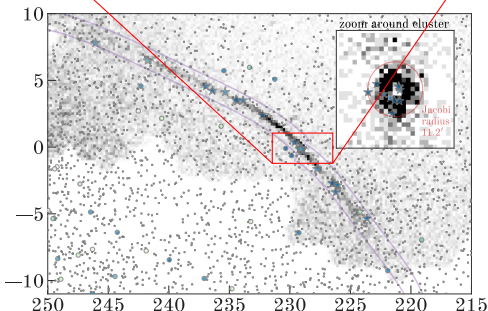# Shells and streams in external galaxies

NGC 5907 [credit: J.Gabany]

NGC 474 [credit: P.-A.Duc, J.-C.Cuillandre]
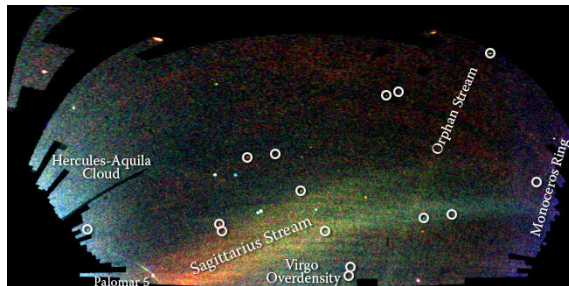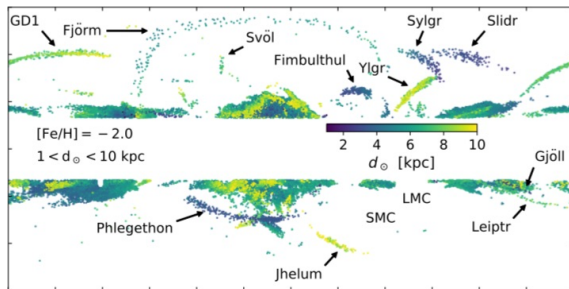
Streams in the Milky Way

Globular cluster Palomar 5

... in 2001 [Odenkirchen et al.]

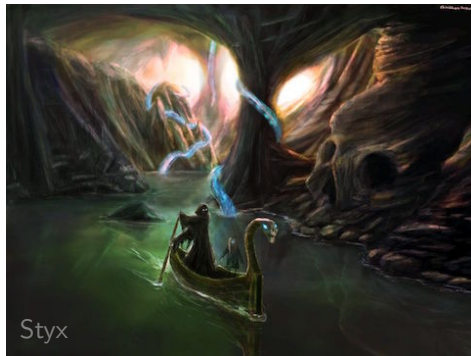field of streams in SDSS survey [Belokurov et al. 2006]

... in 2019 [Price-Whelan et al.]

streams discovered after *Gaia* DR2 [Ibata et al. 2018]

Streams in the Milky Way

Nix

Styx

Stream name
Ylgr
Sylgr
Fjörm
Fimbulthul
Phlegethon
Styx
Kwando
Murrumbidgee
Chenab
Indus
Jhelum
Nix
Aliqa Uma
Willka Yaku
Turranburra
Orinoco
Wambelong
...
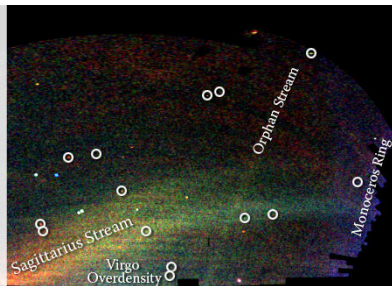
few halo streams in SDSS survey [Belokurov et al. 2006]

streams discovered after *Gaia* DR2 [Ibata et al. 2018]

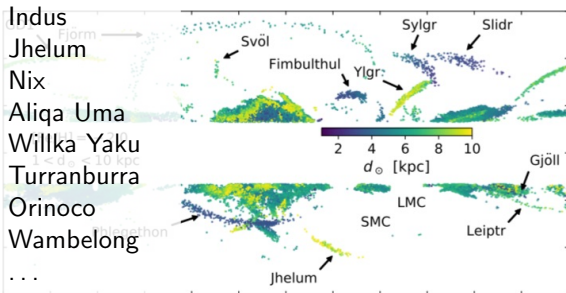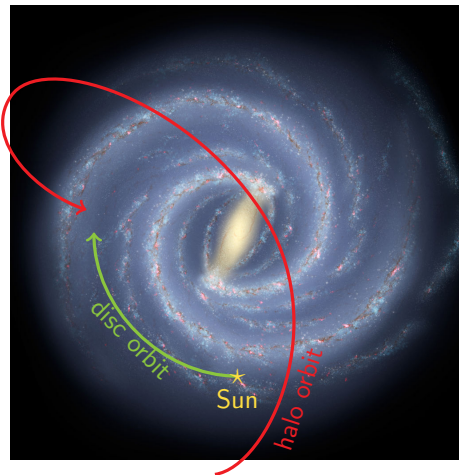# Structures in the space of orbits

Gaia–Enceladus

disc orbit
Sun
halo orbit

circular motion, km/s
high positive spin
200
0
-200
high negative spin

Galactic disc

The Sausage

to the centre of the Galaxy
from the centre of the Galaxy
-200   0   200

radial motion, km/s

debris from a massive
satellite accreted from
an eccentric orbit

Structures in the space of orbits

Gaia–Enceladus

Galactic disc

The Sausage

debris from a massive satellite accreted from an eccentric orbit

circular motion, km/s

radial motion, km/s

high positive spin

high negative spin

to the centre of the Galaxy

from the centre of the Galaxy

$180° \leftarrow$ inclination $\rightarrow 0°$

$1 \leftarrow$ eccentricity $\rightarrow 0$

Sequoia

Sagittarius

polar

circular

circular

retrograde

prograde

in-plane

in-plane

radial

disc population

classification of globular clusters
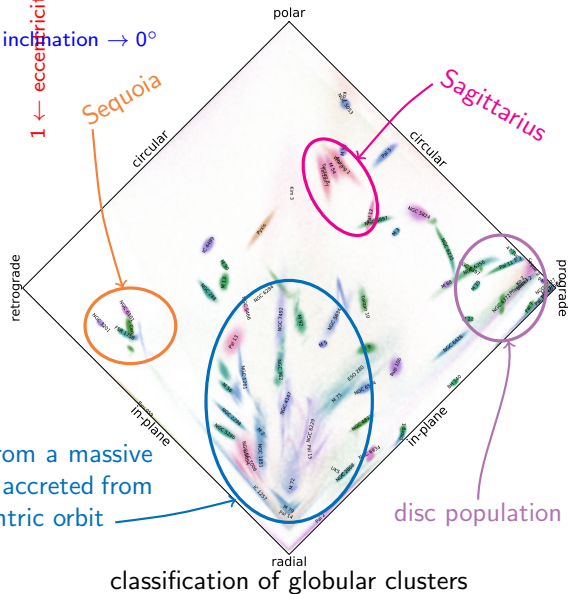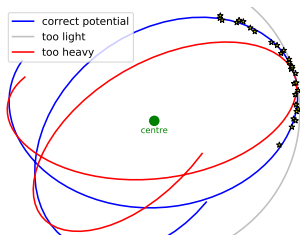
Structures in the space of orbits
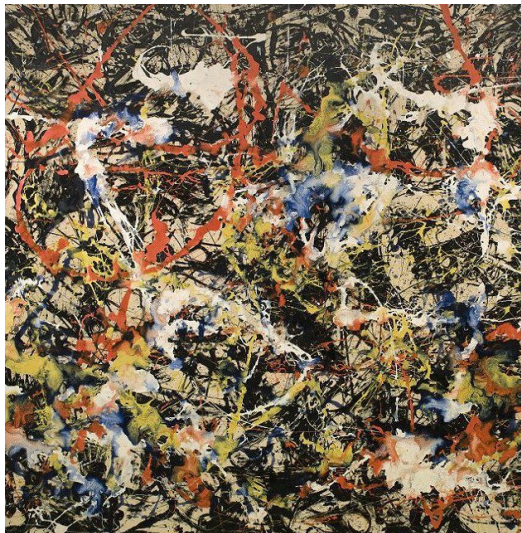
Jackson Pollock, "Convergence"

Kliment Redko, "Uprising"

What do we learn from streams and tidal debris?

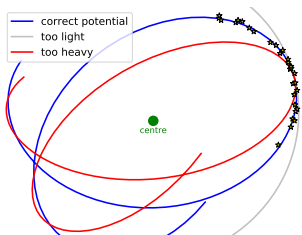▶ use stream orbits as probes of Galactic gravitational potential

stars in the stream travel along the same orbit, orbit depends on the Galactic potential $\implies$ can measure the mass distribution
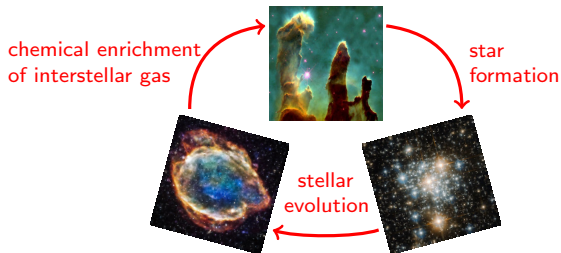
What do we learn from streams and tidal debris?

▶ use stream orbits as probes of Galactic gravitational potential

stars in the stream travel along the same orbit, orbit depends on the Galactic potential $\Longrightarrow$ can measure the mass distribution

▶ understand the chemical evolution of the Universe

chemical enrichment of interstellar gas

star formation

stellar evolution

each accreted satellite has its own unique chemical signature and history of elements

What do we learn from streams and tidal debris?

▶ use stream orbits as probes of Galactic gravitational potential

correct potential
too light
too heavy

centre

stars in the stream travel along the same orbit, orbit depends on the Galactic potential $\Longrightarrow$ can measure the mass distribution
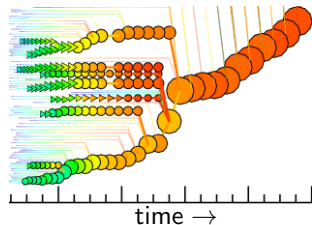
▶ understand the chemical evolution of the Universe

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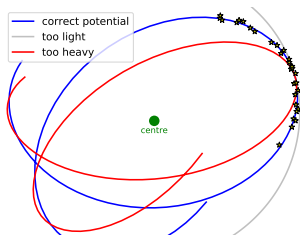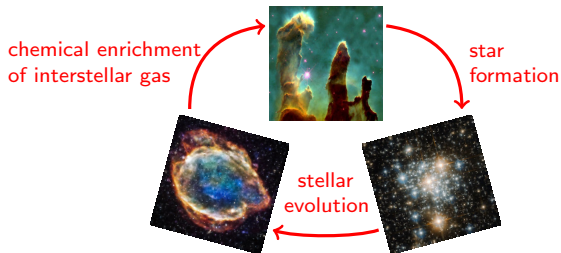
each accreted satellite has its own unique chemical signature and history of elements

▶ discover the assembly history of our Galaxy

time $\rightarrow$

A brief history of the Milky Way

Gaia–Enceladus / Sausage

Sagittarius

11 Gyr   10 Gyr   3 Gyr   0.5 Gyr

splendid isolation

Kraken   Sequoia   Magellanic clouds