

# Histoire d'une rencontre galactique







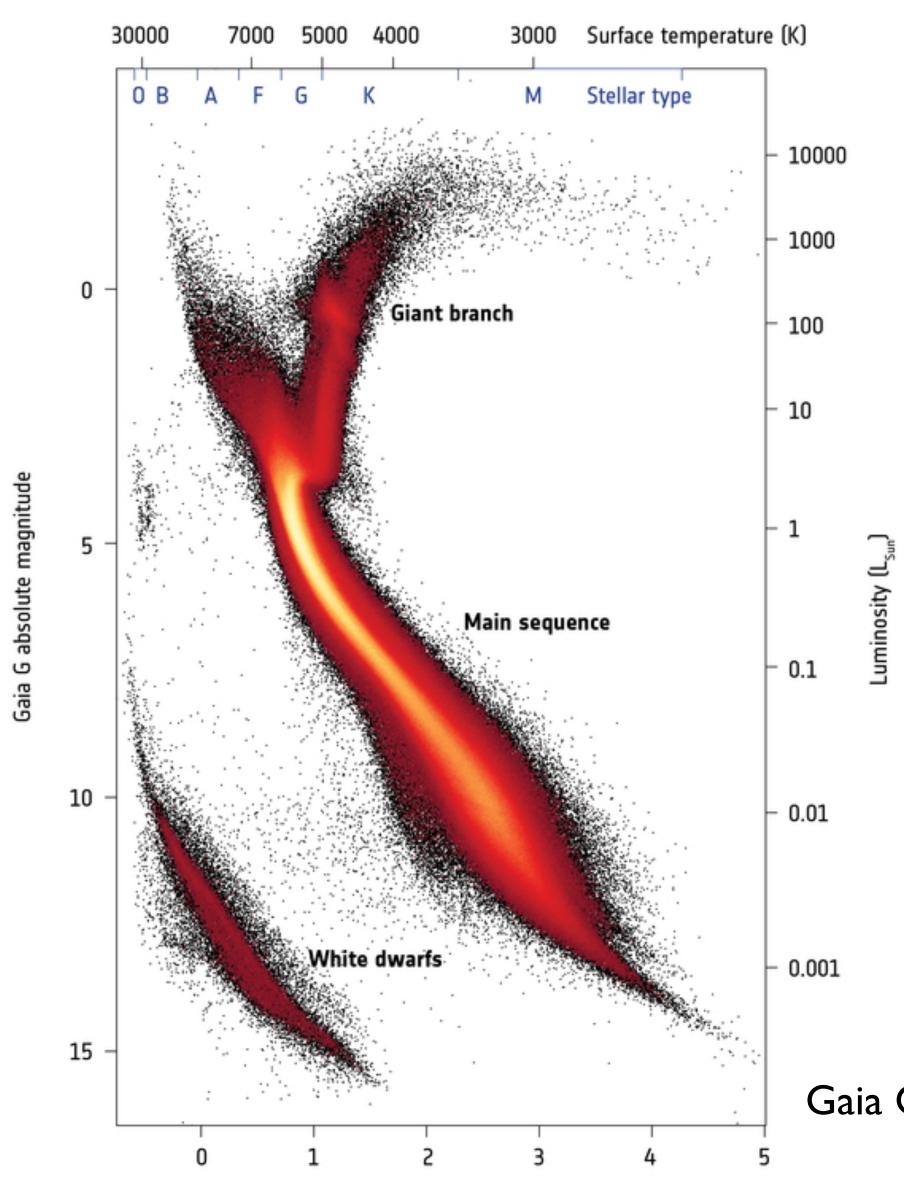
Based on the Gaia Data Release 2 and APOGEE spectroscopic survey

### Articles:

- Gaia DR2 Collaboration papers, 2018
- Haywood et al., 2018
- Di Matteo et al., 2019, 2020

See also Belokurov et al., 2018, Helmi et al., 2018

Context: the accretion history of the Milky Way, what and when satellite galaxies were accreted by our Galaxy?



Gaia BP-RP colour

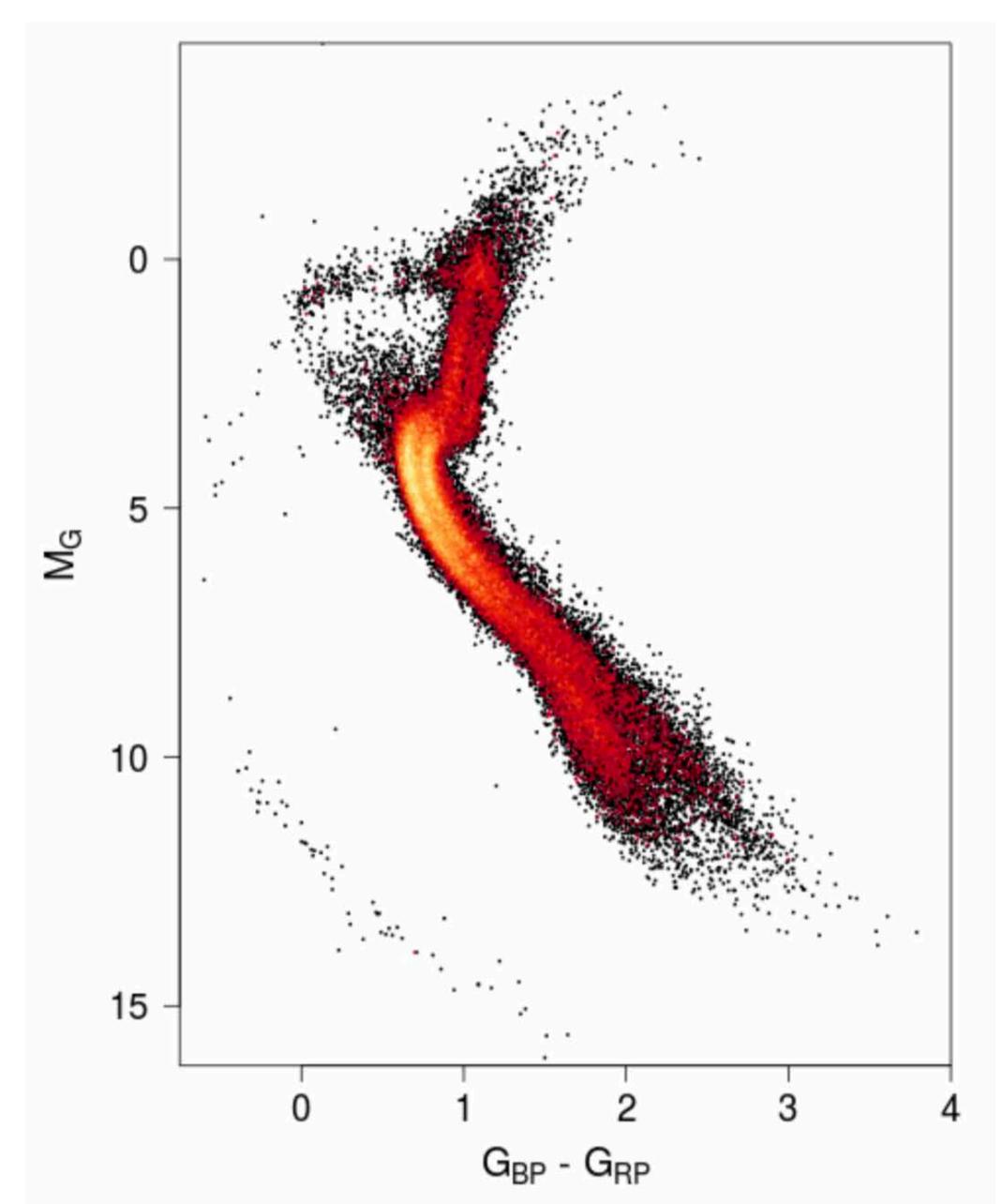
redder --->

← bluer

Gaia color-magnitude diagram

The oldest and most alien stars are hidden in this diagram...

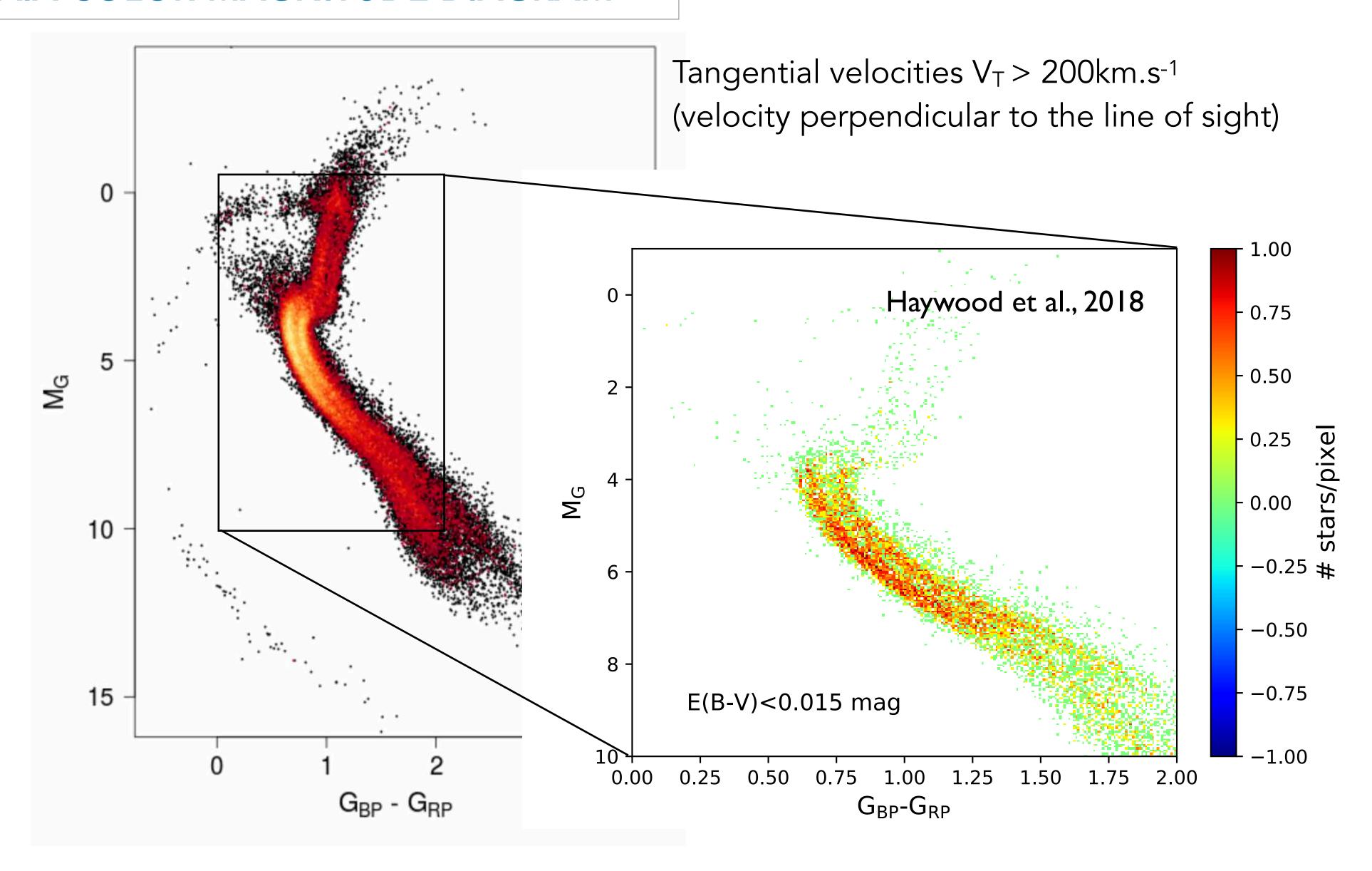
Gaia Collaboration, Babusiaux et al., 2018

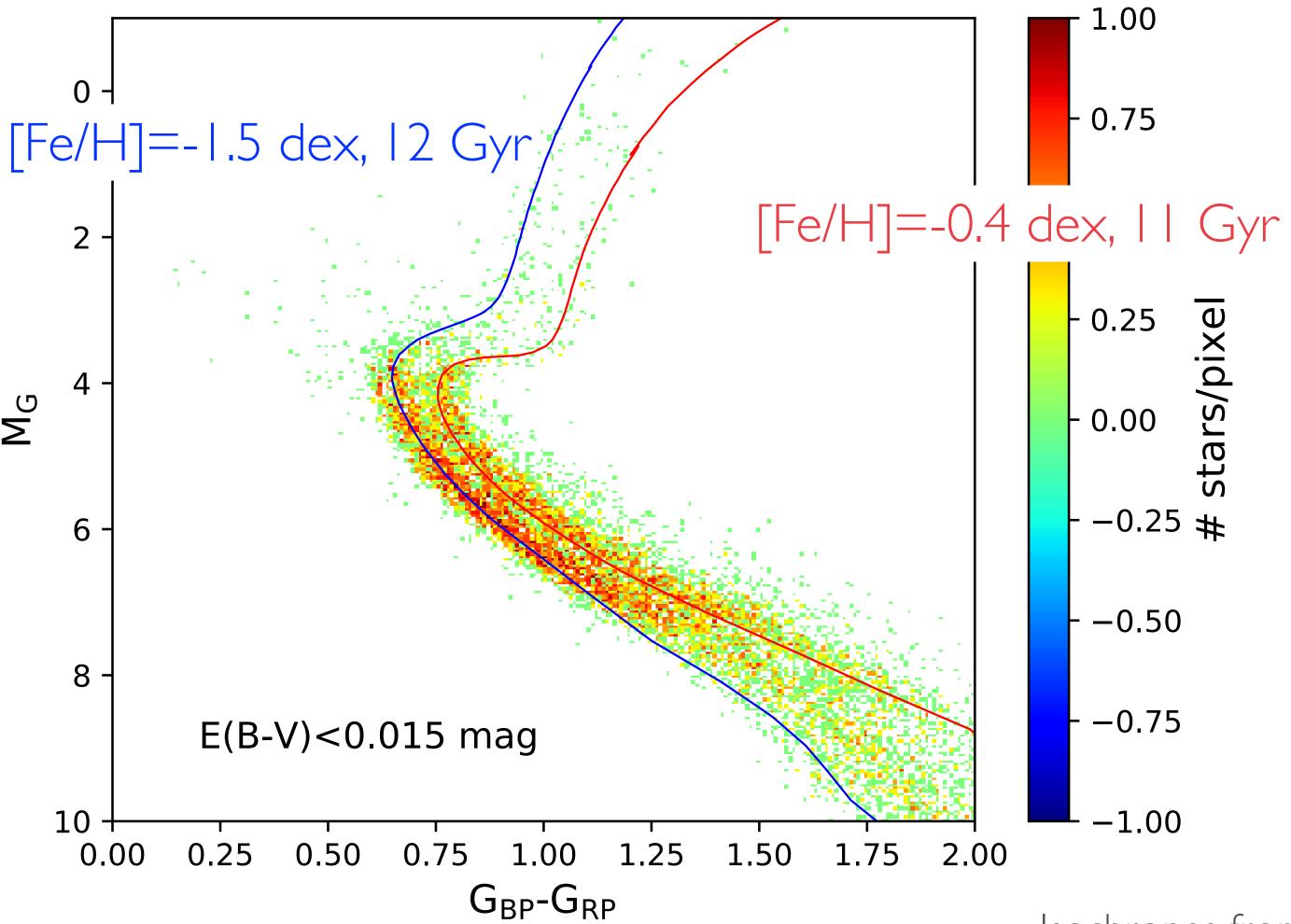


...but they can be made visible by selecting the highest velocity objects

Tangential velocities  $V_T > 200 \, km.s^{-1}$  (velocity perpendicular to the line of sight)

Gaia Collaboration, Babusiaux et al., 2018



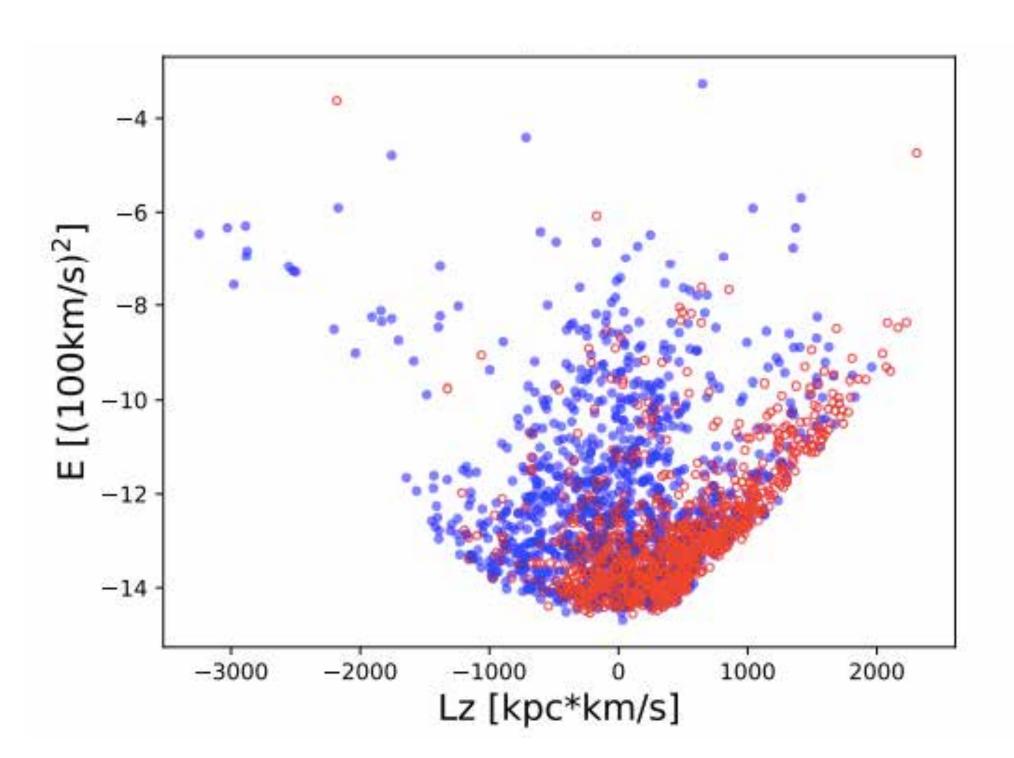


Isochrones from PARSEC library, Marigo et al. 2017

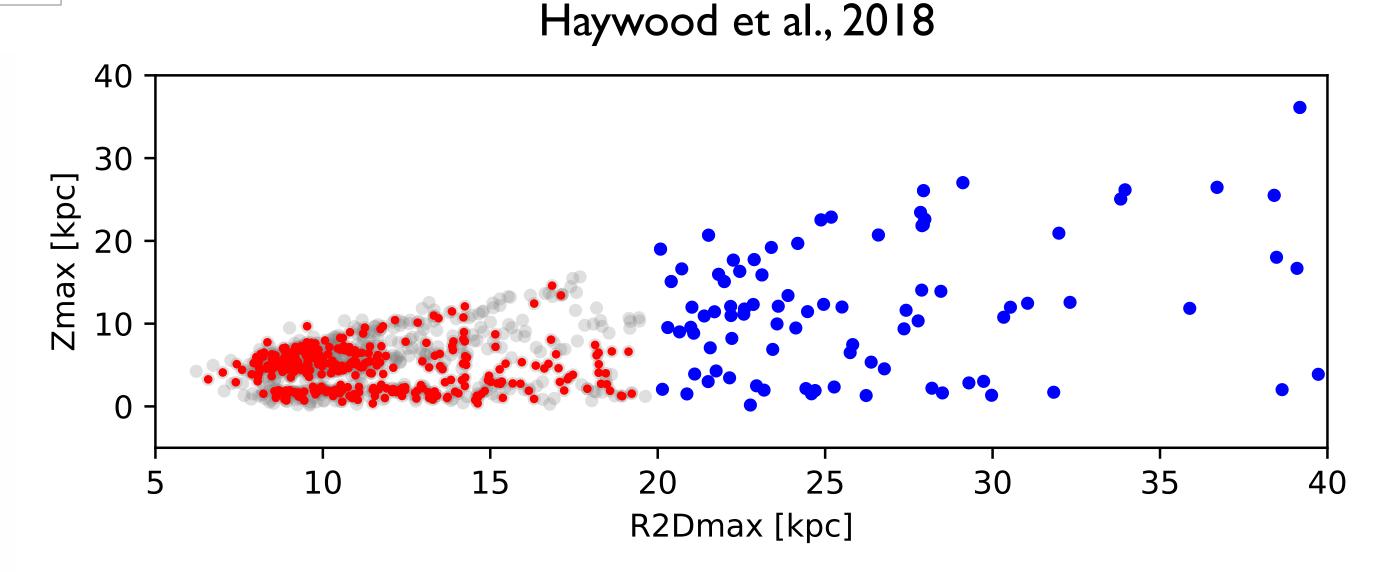
Red sequence: thick disk

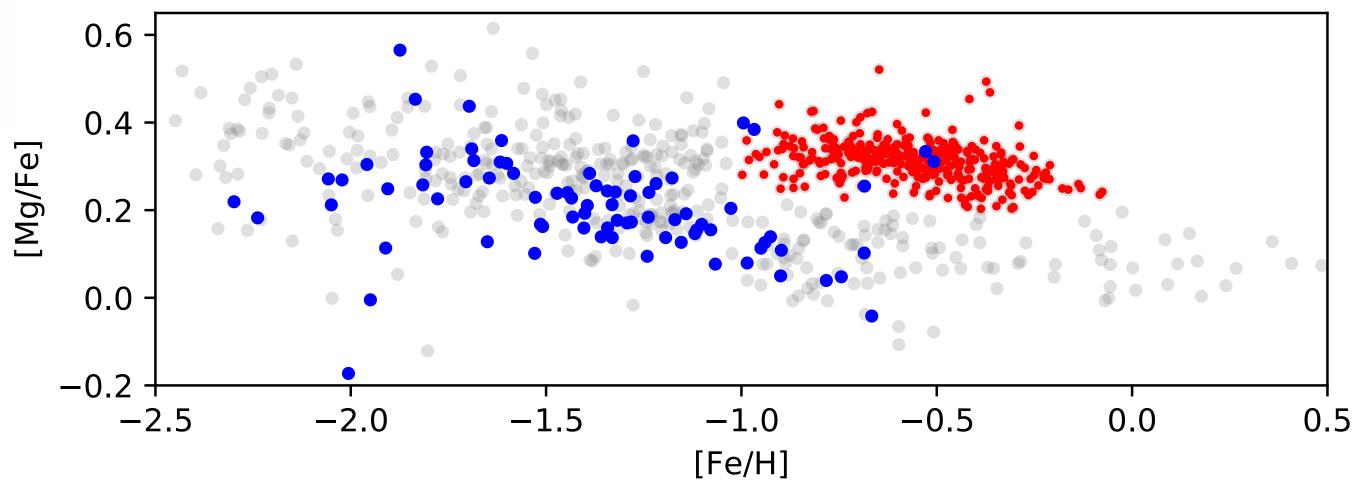
Blue sequence:?

# **ORBITAL AND CHEMICAL PROPERTIES**



Stars on high energy orbits follow a low star forming efficiency sequence in the  $[\alpha/Fe]$ -[Fe/H] plane.





Name of the accreted galaxy: Gaia Sausage Enceladus (GSE) (Belokurov et al., 2018, Helmi et al., 2018)

# Three questions:

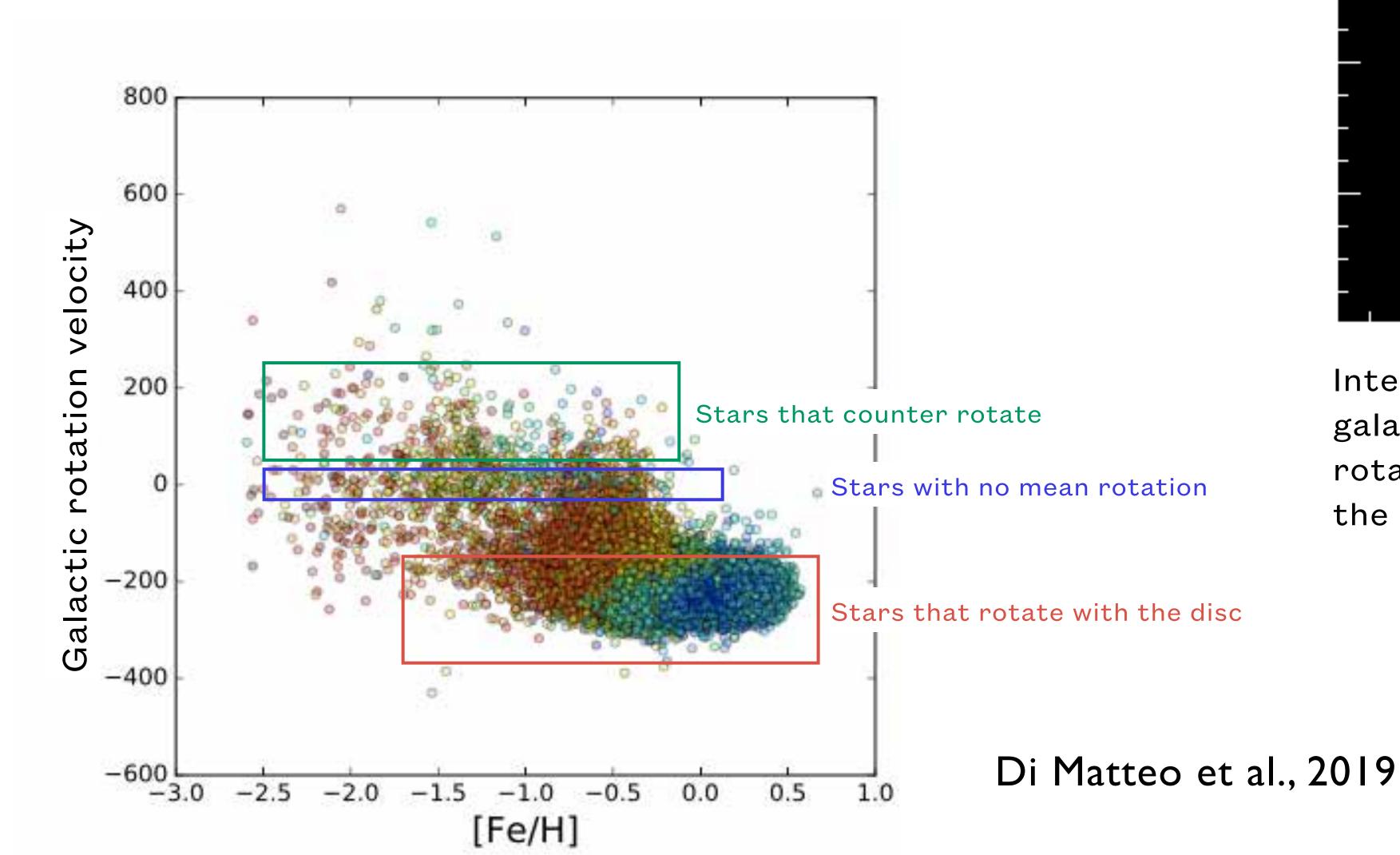
When did the accretion occur?

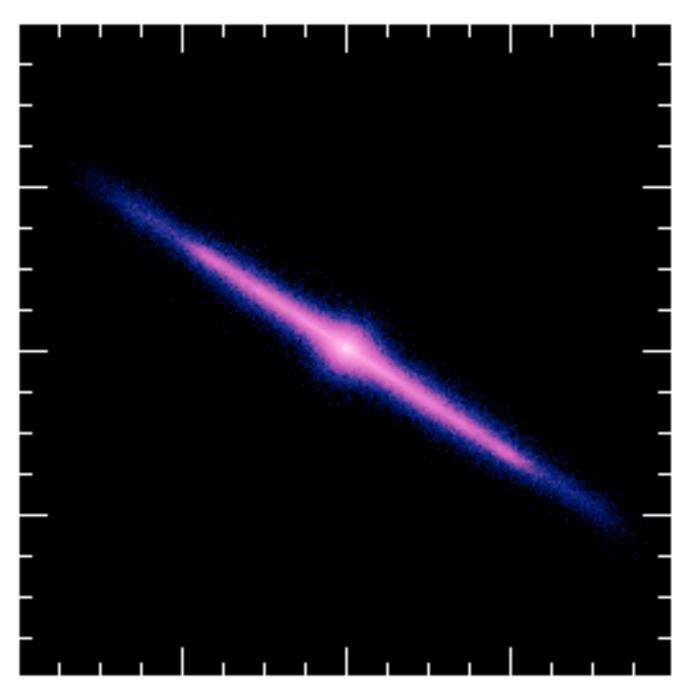
How massive was the satellite?

What is the Milky Way stellar halo made of?

# **AGE-DATING THE ACCRETION**

Sample of stars from Gaia DR2 and APOGEE crossmatch

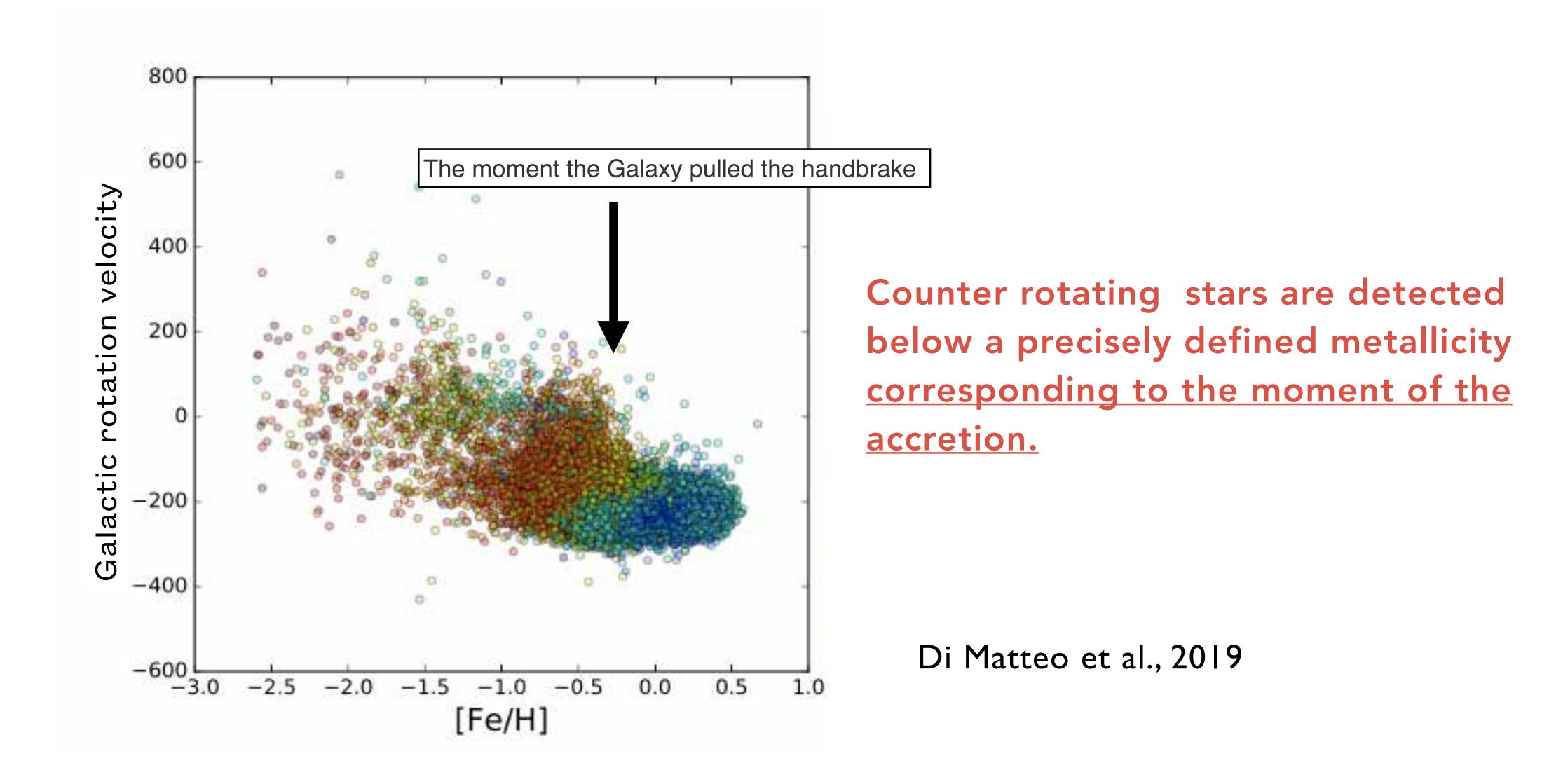




Interaction with a satellite galaxy slows down galactic rotation of stars present in the disc at that moment

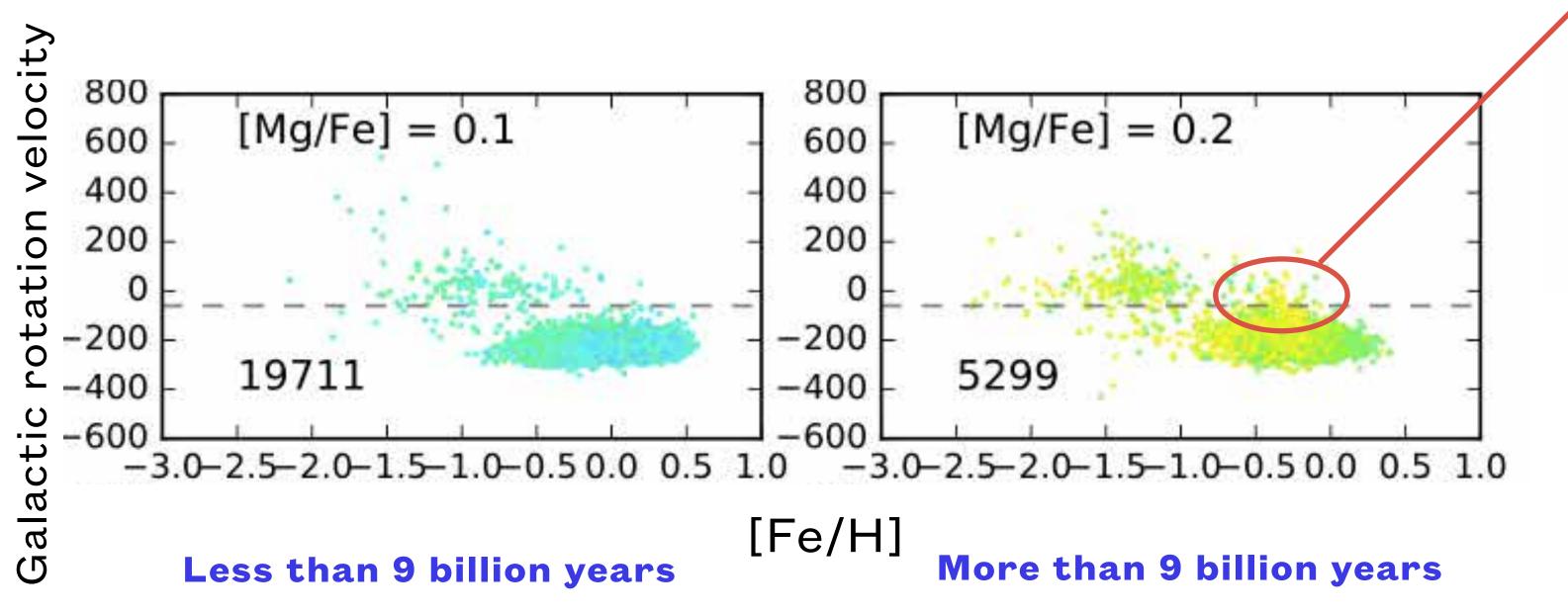
# **AGE-DATING THE ACCRETION**

Sample of stars from Gaia DR2 and APOGEE crossmatch



#### **AGE-DATING THE ACCRETION**

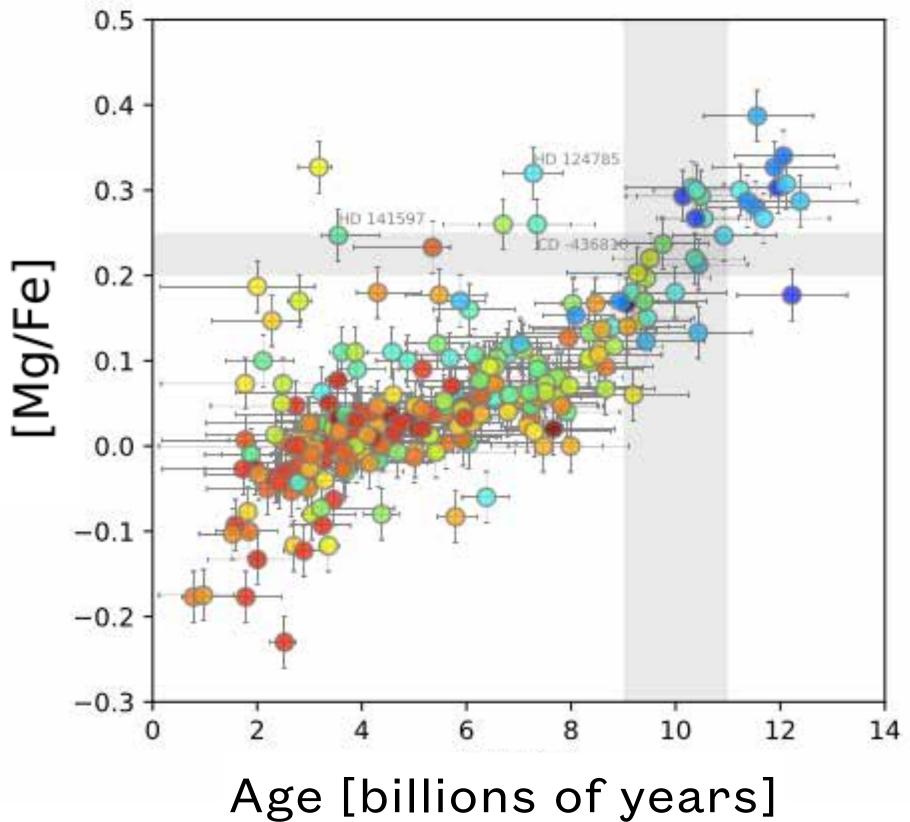
Metallicity [Fe/H]≤-0.3 corresponds to [Mg/Fe]≥0.2



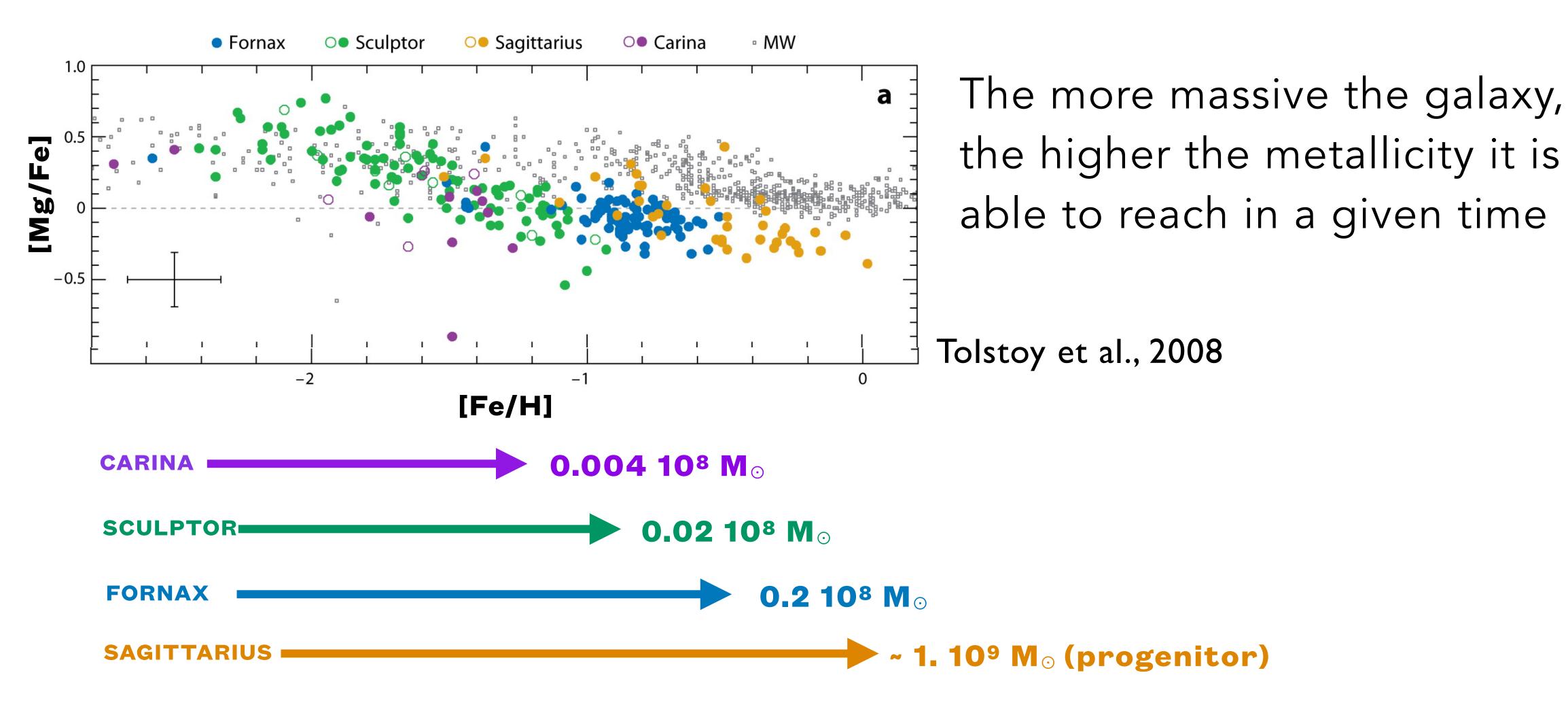
Disc stars with [Fe/H]~-0.3 and [Mg/Fe]~0.2 correspond to ages ~ 9-10 billions years,

the probable epoch of the accretion of Gaia Sausage

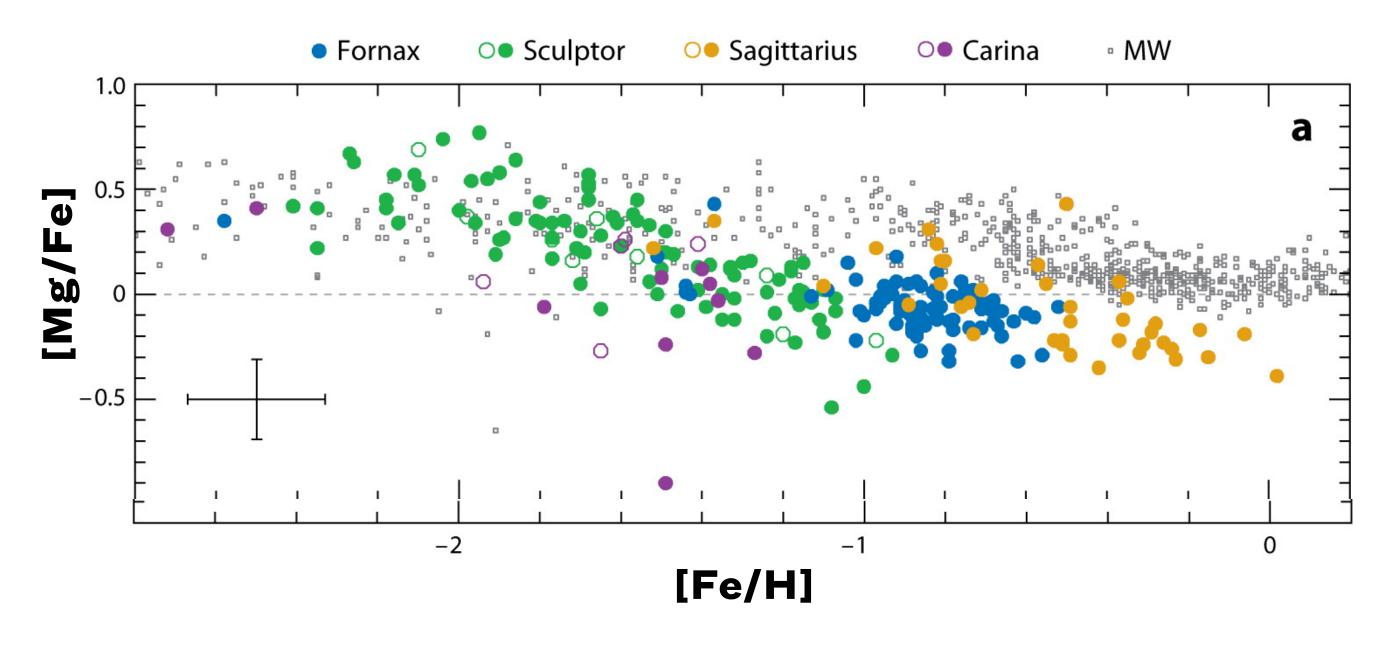
Disc stars that have been slowed down by the accretion



#### HOW MASSIVE WAS GAIA SAUSAGE ENCELADUS?



#### HOW MASSIVE WAS GAIA SAUSAGE ENCELADUS?



Gaia Sausage reached only [Fe/H]~-0.5, but stopped its evolution ~ 9-10 Gyr ago

Gaia Sausage —

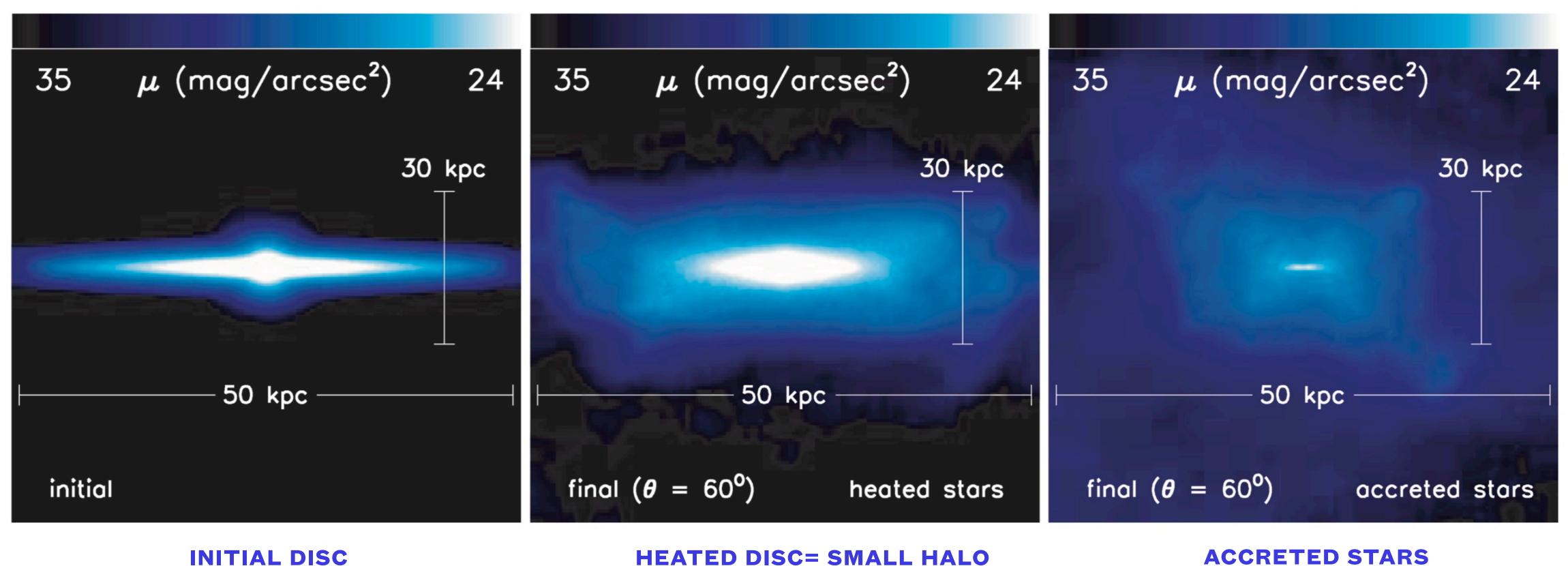
Tentative stellar mass ~ 109M<sub>☉</sub>?

SAGITTARIUS ———

~ 1. 10<sup>9</sup> M<sub>☉</sub> (progenitor)

#### WHAT IS THE STELLAR HALO OF THE MILKY WAY MADE OF?

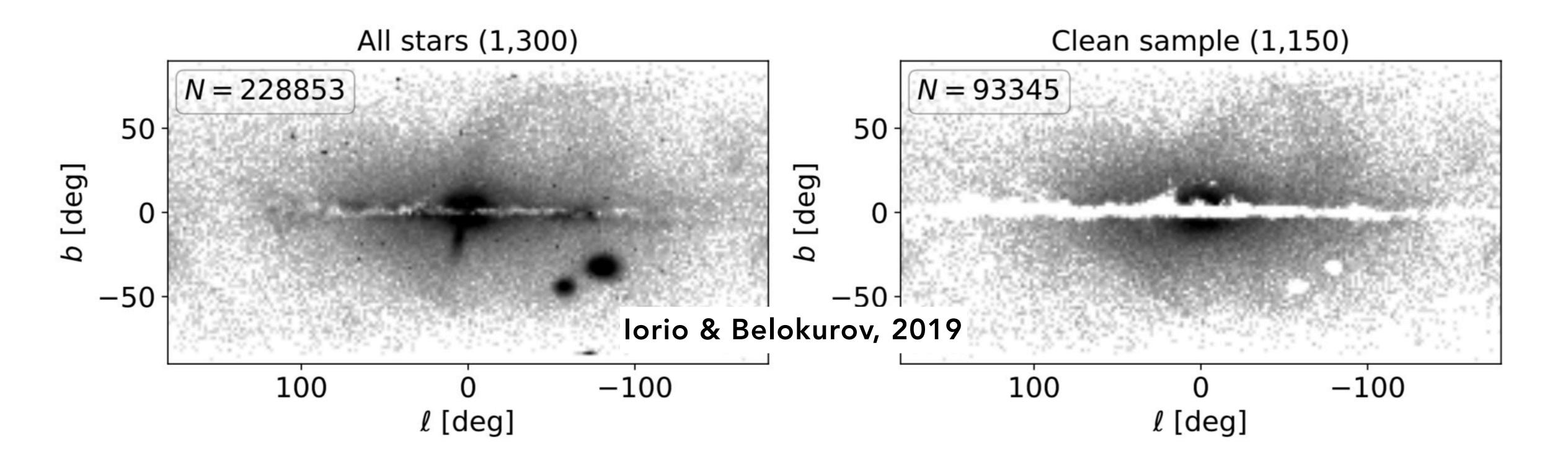
Simulation of a prograde infall satellite with an orbital inclination of 60°, Purcell et al., 2010



The inner (<30kpc) Galactic halo is made, mainly, of heated disc stars and of Gaia Sausage Enceladus accretion

Cf also GalMer simulations, in particular Qu et al., 2011, 2012

#### WHAT IS THE STELLAR HALO OF THE MILKY WAY MADE OF?



Analysis of RR Lyrae stars shows that at least 50% of the stellar halo within 30kpc is made of Gaia Sausage Enceladus, see Iorio & Belokurov (2019, 2020)

Most of the rest is made of heated thick disc stars

Does a primordial collapsed halo exist in the Milky Way?

#### WHERE ARE THE MOST PRIMORDIAL STARS IN THE MILKY WAY?

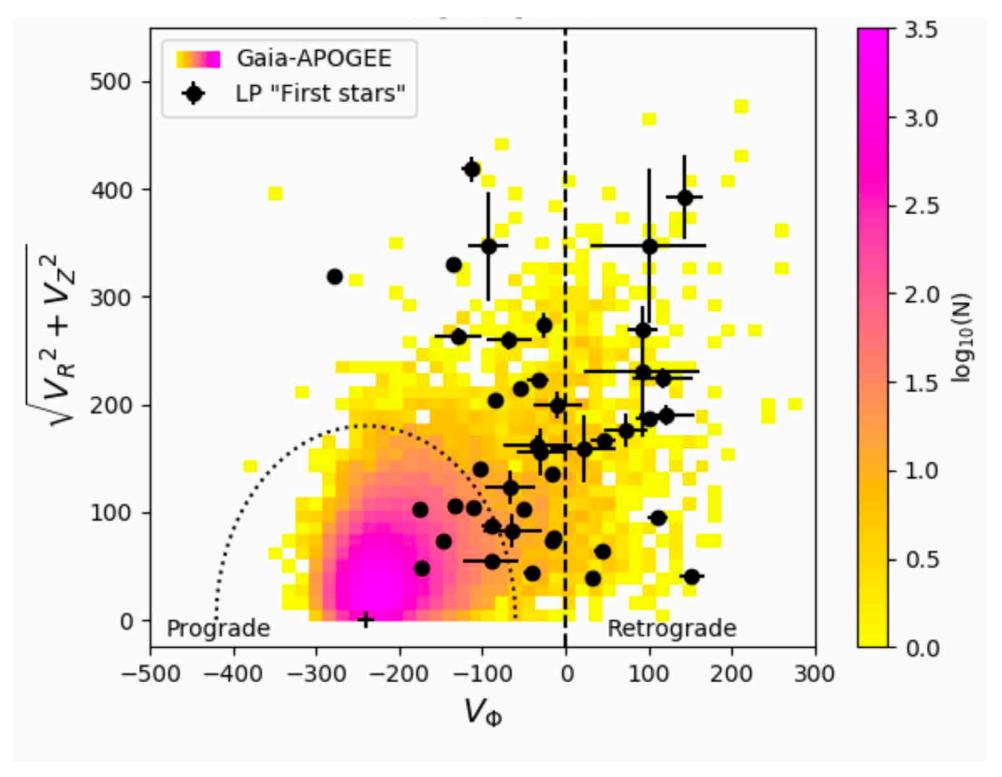
The most metal-poor stars ([Fe/H] < -4) in the Galaxy are (very) rare, and so usually distant

Probably born within less than 0.5 Gyr after the Big Bang

Sestito et al., 2019

100
80
60
20
7
10
30
60
60
60
7
10
20
300

Di Matteo et al., 2020



A significant fraction (~ 20%) of all known ultra metal-poor stars ([Fe/H] < -4 dex) are on prograde orbits confined within 3 kpc of the Milky Way plane

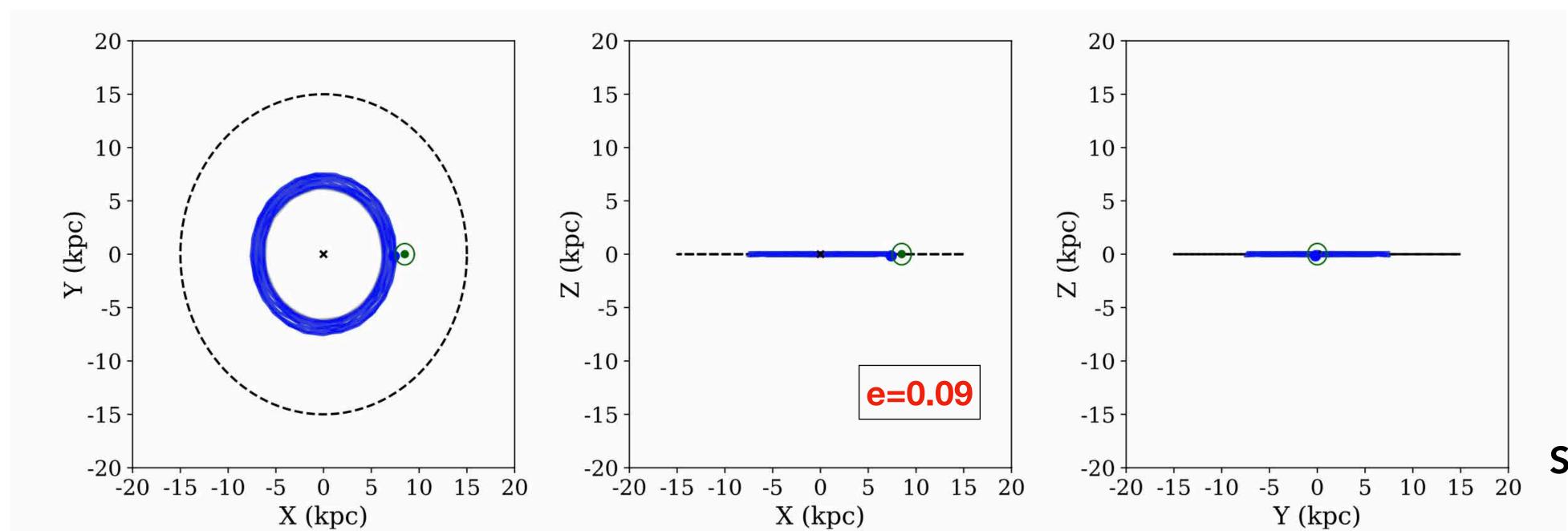
The properties of these stars are in continuity with thick disc and GSE stars at higher metallicities

#### WHERE ARE THE MOST PRIMORDIAL STARS IN THE MILKY WAY?

#### 2MASS J18082002-5104378

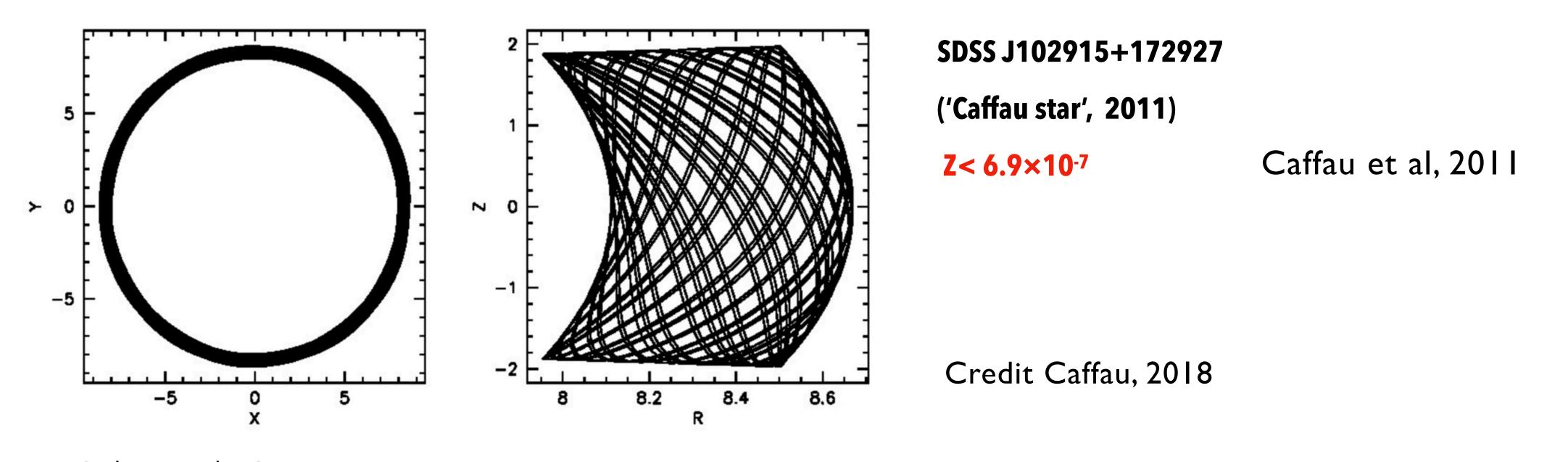
('Melendez star', 2016)

[Fe/H] = -4.07



Sestito et al., 2019

#### WHERE ARE THE MOST PRIMORDIAL STARS IN THE MILKY WAY?



Orbit with Gaia parameters

The most metal-poor star known has a disc orbit with eccentricity ~ 0.044!

Are the most primitive stars in the Galaxy a disc population?

# CONCLUSIONS

One of the important aims with Gaia EDR3, DR3, etc, and spectroscopic surveys is to determine the accretion history of the Milky Way

How many galaxies have merged with the Milky Way? At what epochs?

The first step was made with Gaia Sausage Enceladus. We have first estimates of:

- the amount of stellar mass brought in the MW by GSE
- the epoch of its accretion

Things we would like to know:

- How much gas was brought by the satellite?
- Has the accretion stimulated star formation?
- The state of the MW disc at the epoch of the accretion
- Is a primordial collapsed halo present in the data or was the first Galactic population to form a disc population?