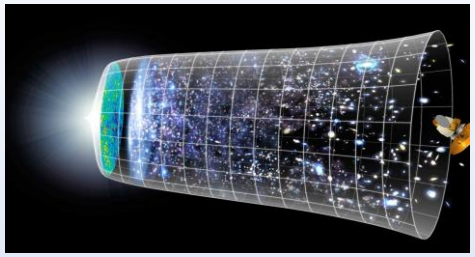
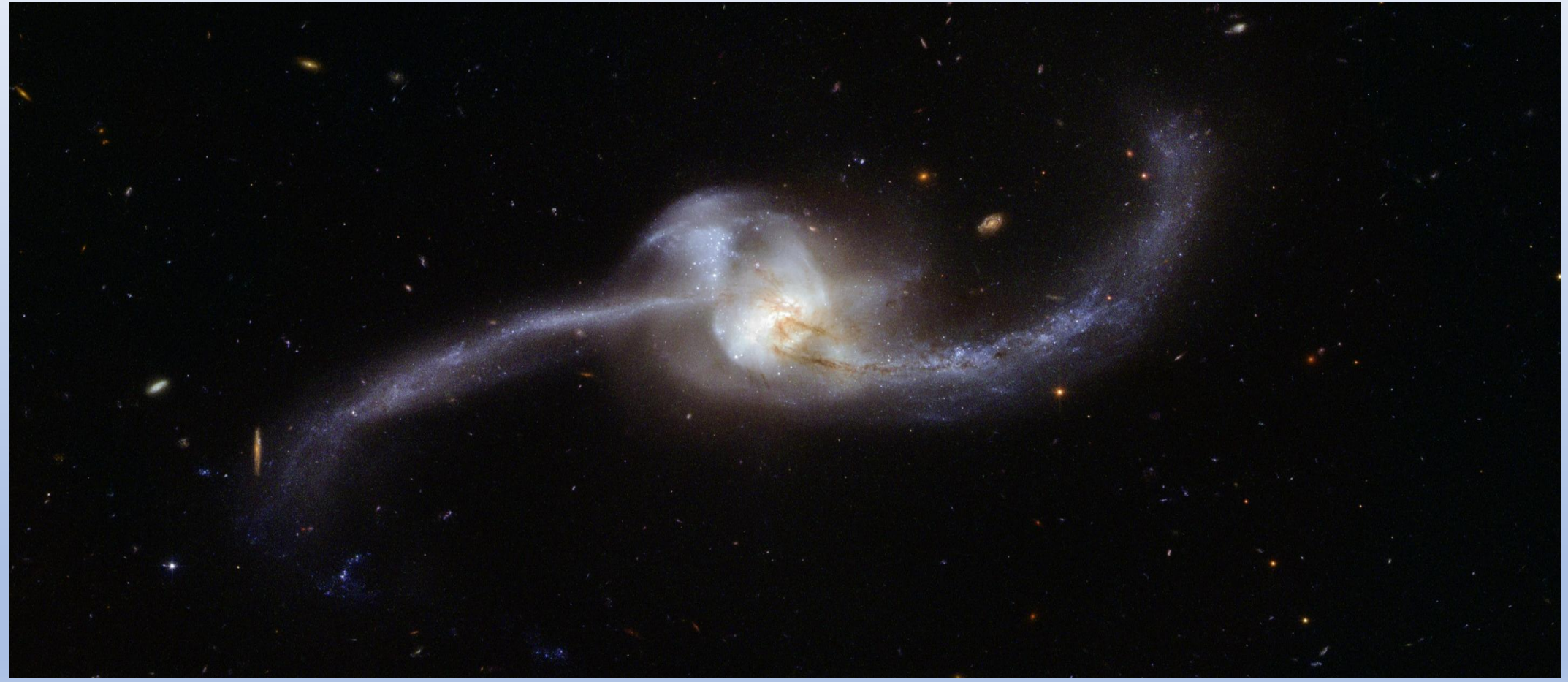


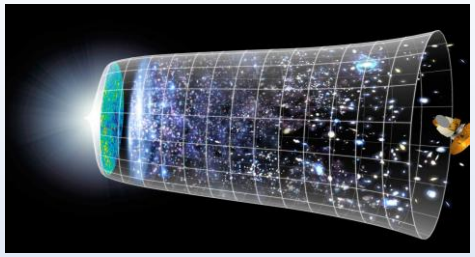
Fusies van sterrenstelsels

Archeologie van de Melkweg



Daedalus praatje 12 januari 2021

Nico Roos



Fusies van sterrenstelsels

Archeologie van de Melkweg

Atacama Large Millimeter/submillimeter Array of telescopes in Chile.

CNN-11-1-2021
ID2299
Atacama

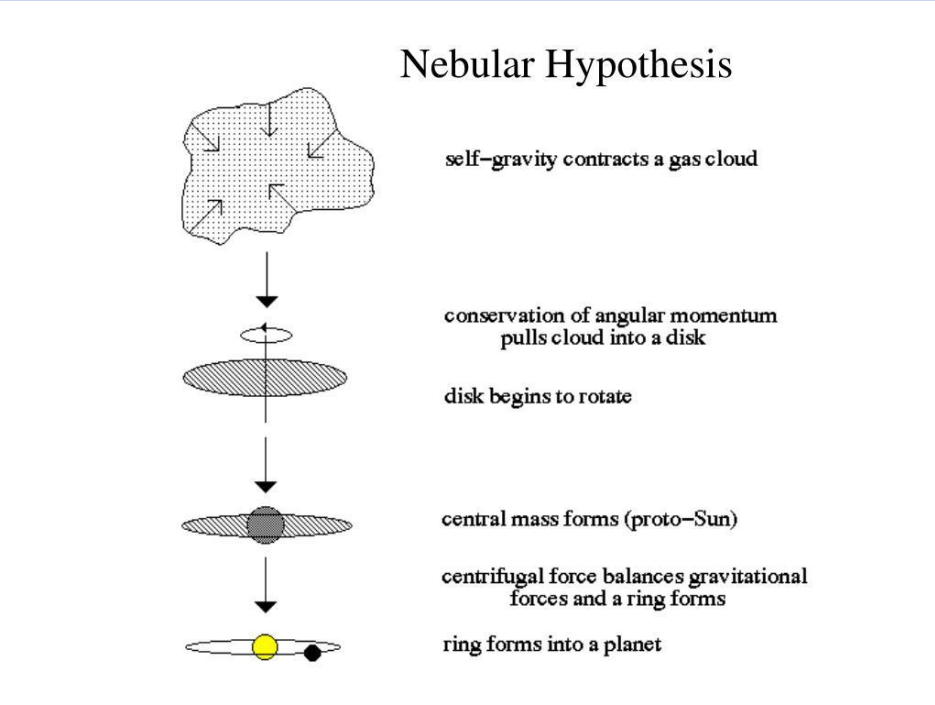
Daedalus praatje 12 januari 2021

Nico Roos

Hoe ontstaan sterrenstelsels?

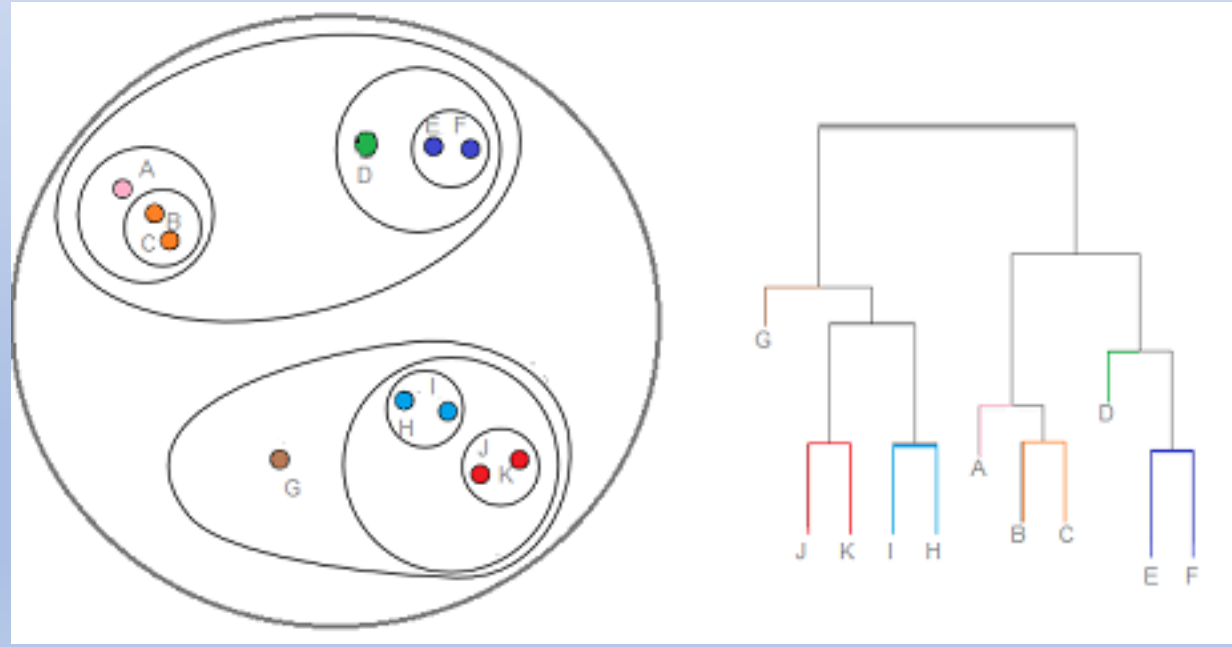
Uit één gaswolk?

Pannekoek model



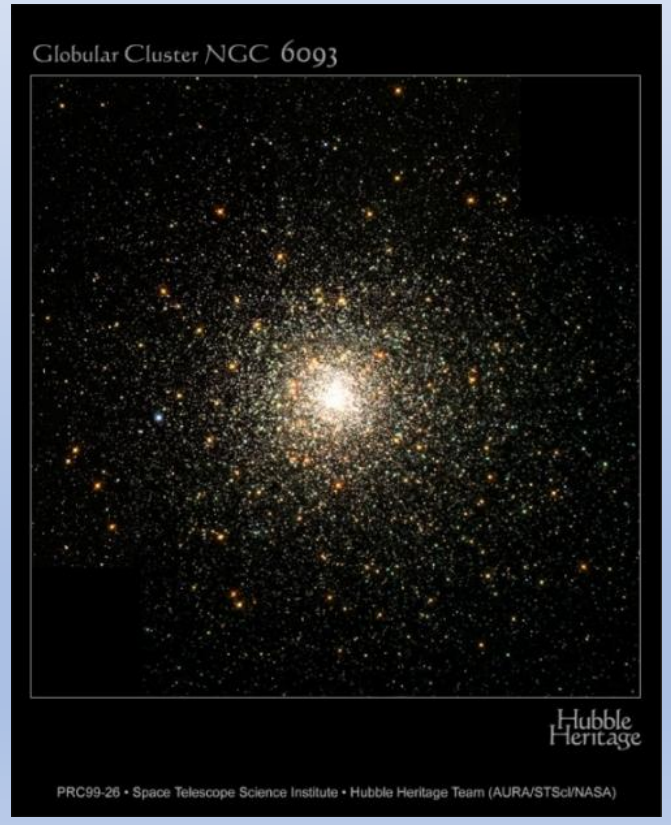
Opbouw uit kleinere elementen?

Hierarchische clustering

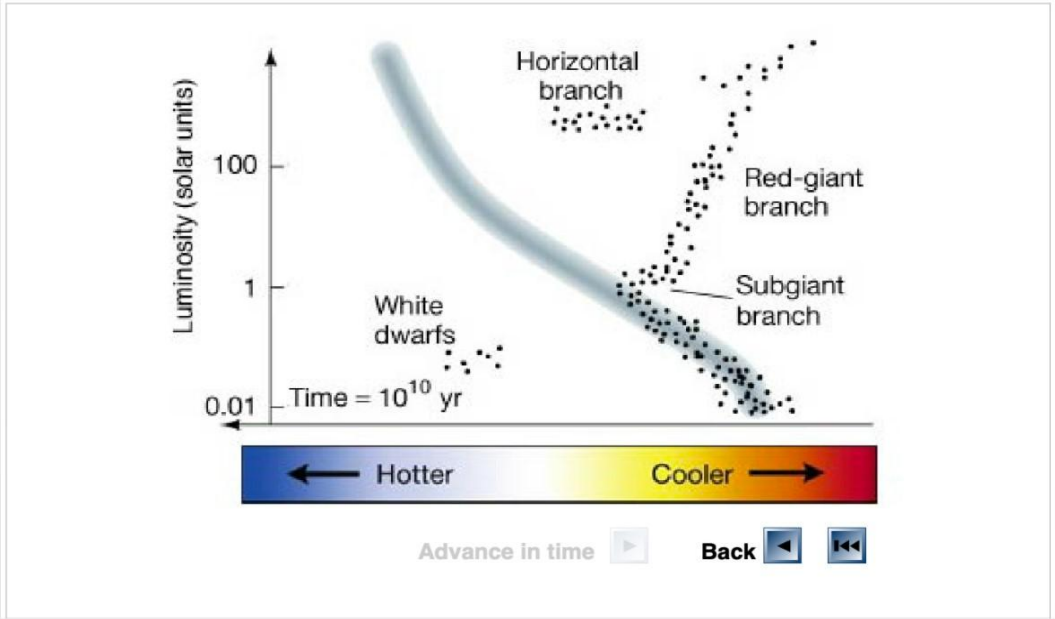


Hoe ontstaan sterrenstelsels?

Evolutie van sterclusters

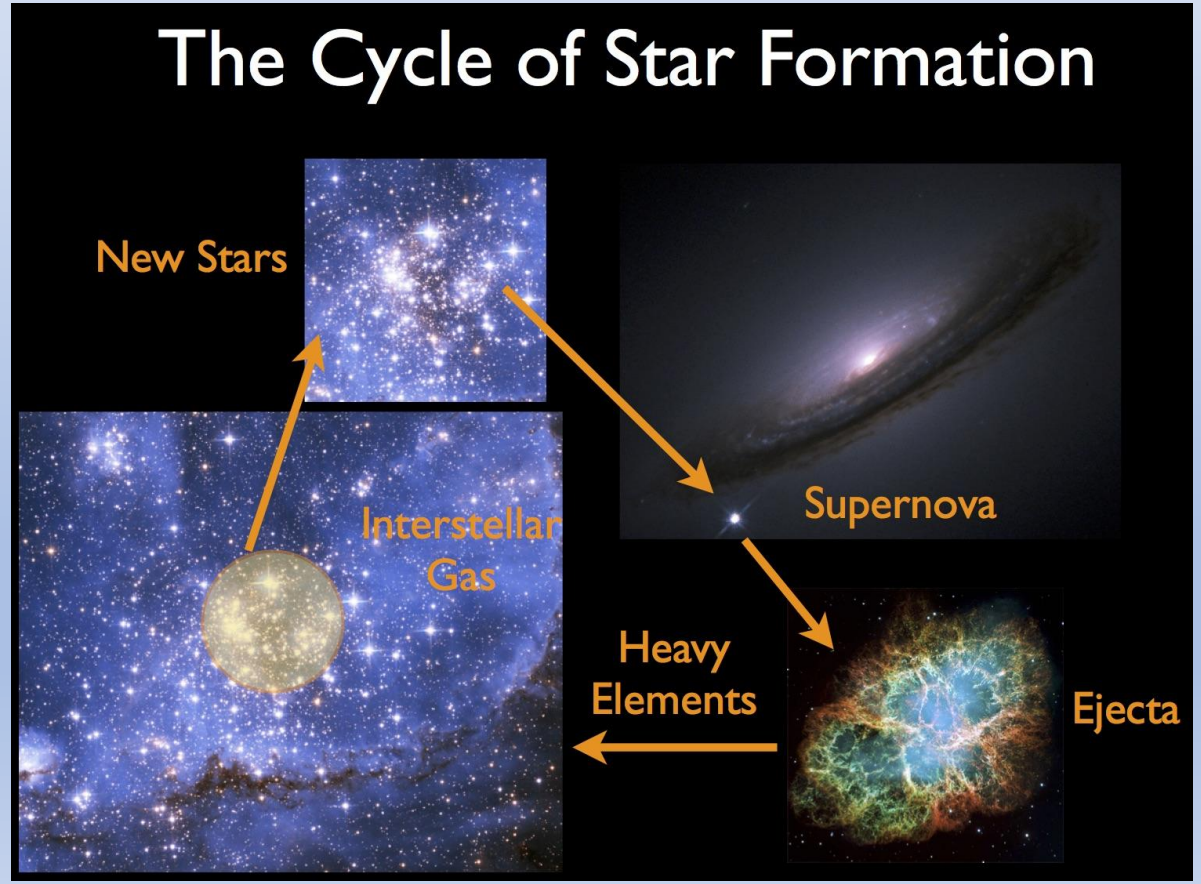


After 10 billion years (10^{10} years), The OBAFG stars are all missing from the Main Sequence, the red giant branch is very well populated, and there are also many white dwarfs. Only K & M stars remain on the Main Sequence.



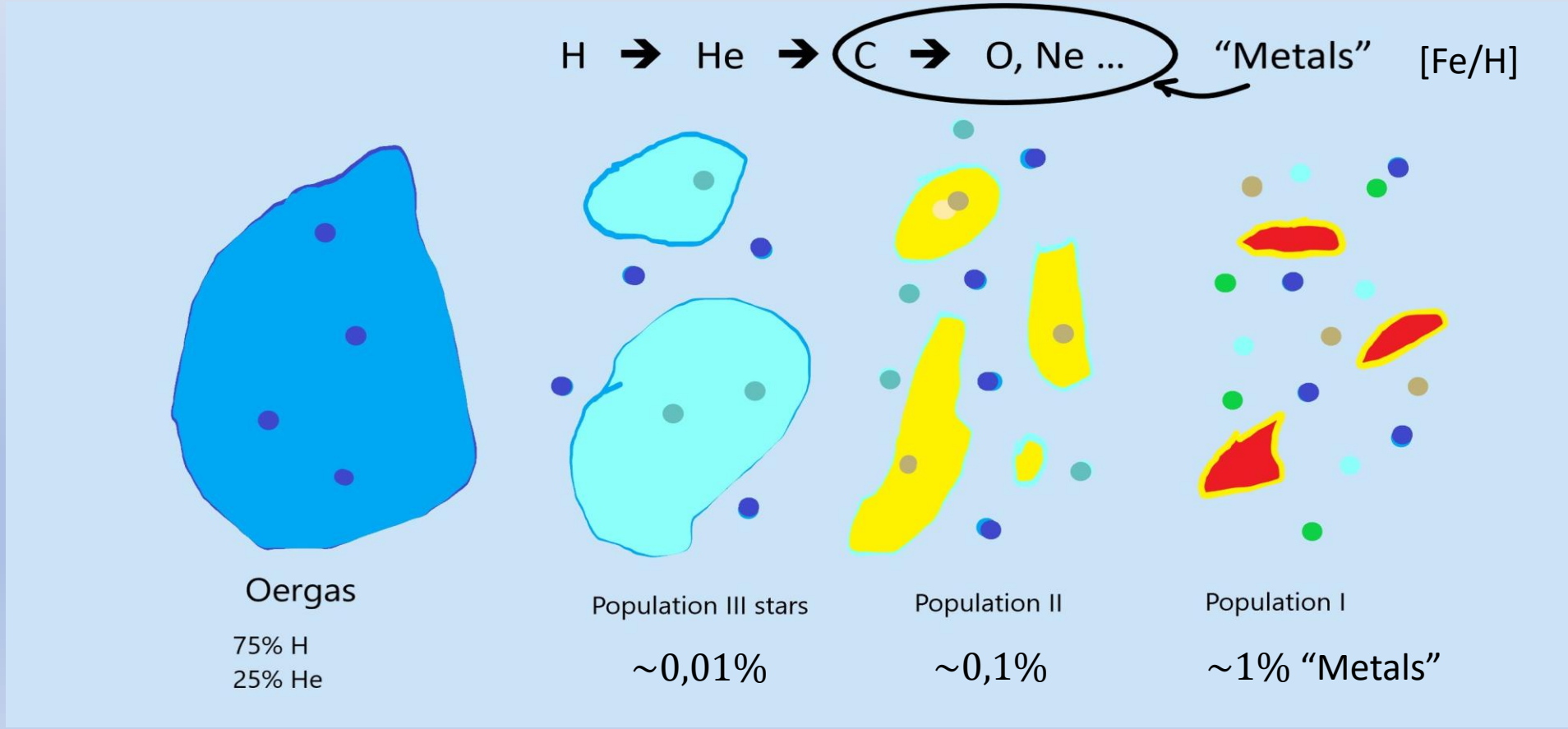
Hoe ontstaan sterrenstelsels?

Ster generaties

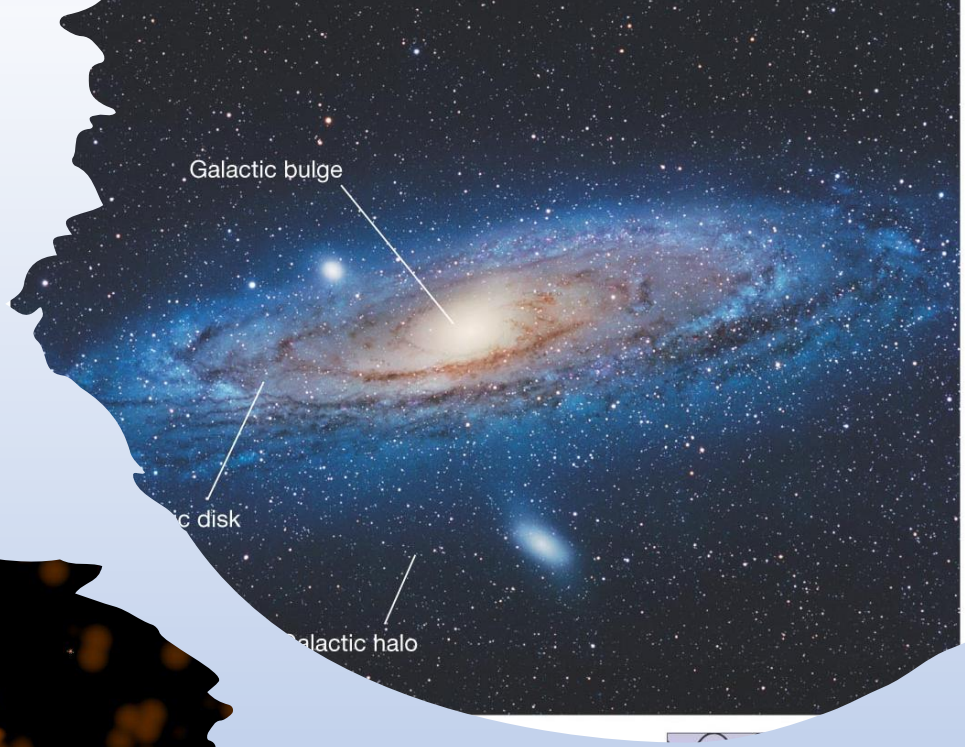


Hoe ontstaan sterrenstelsels?

Ster generaties

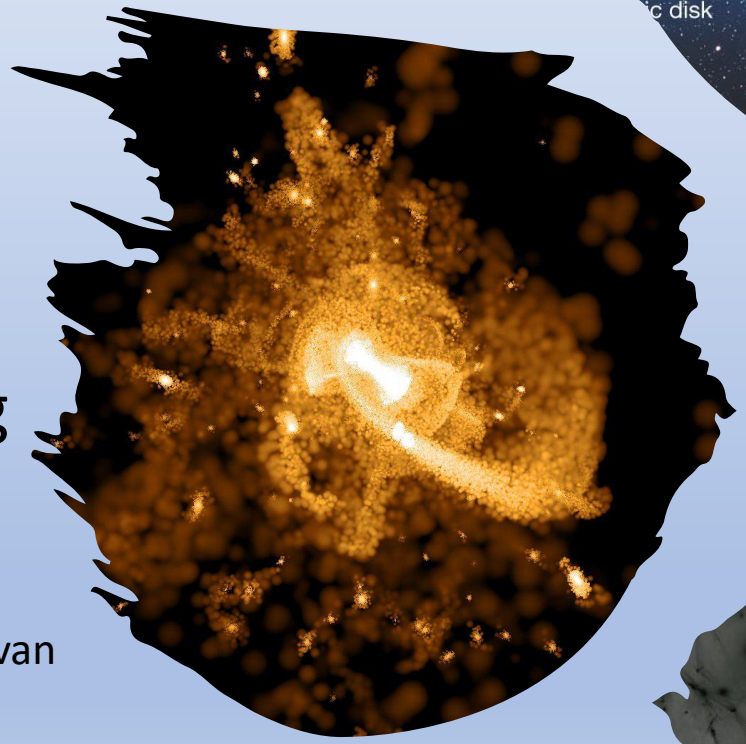


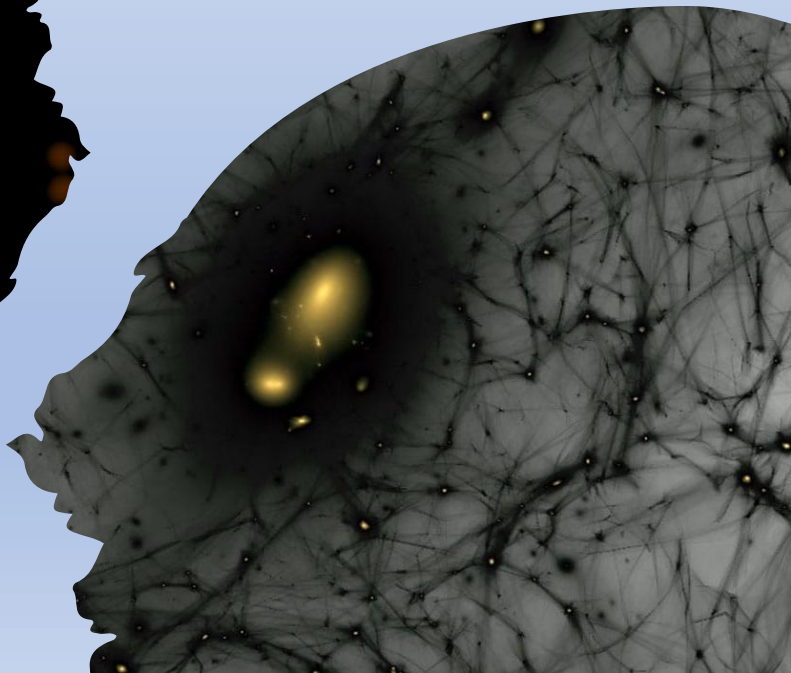
Fusies van sterrenstelsels



Onderwerpen

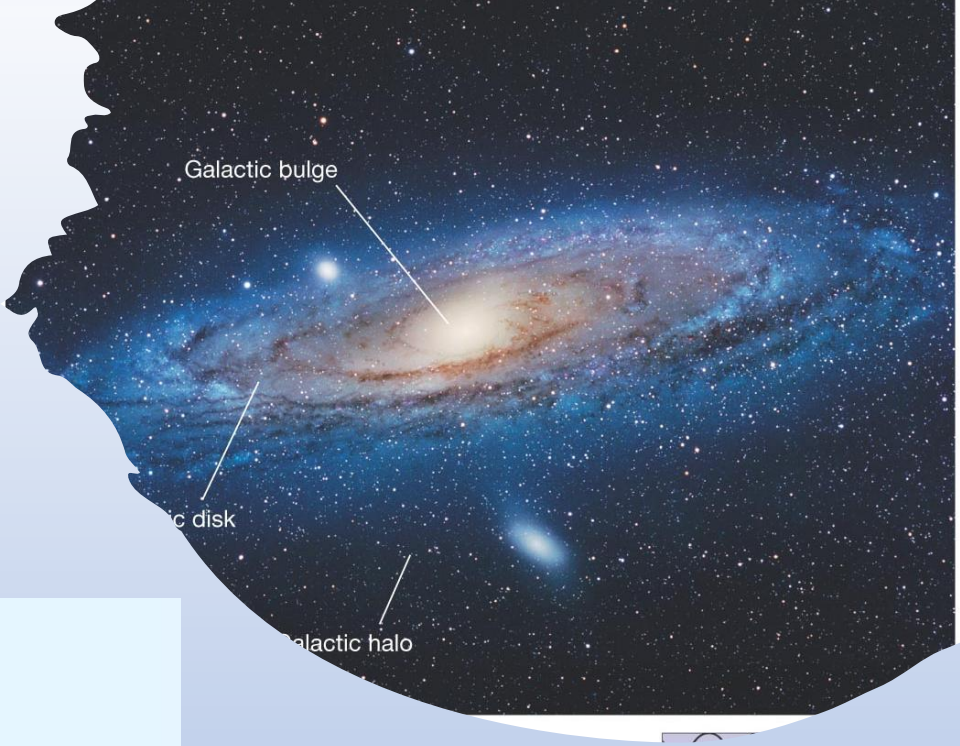
- Intro - Hoe ontstaan sterrenstelsels
- Andromeda en de Melkweg
- Archeologie van de Melkweg





- Van de CMB naar sterrenstelsels en clusters van sterrrenstelsels
- De kernen van Sterrenstelsels

Andromeda en de Melkweg



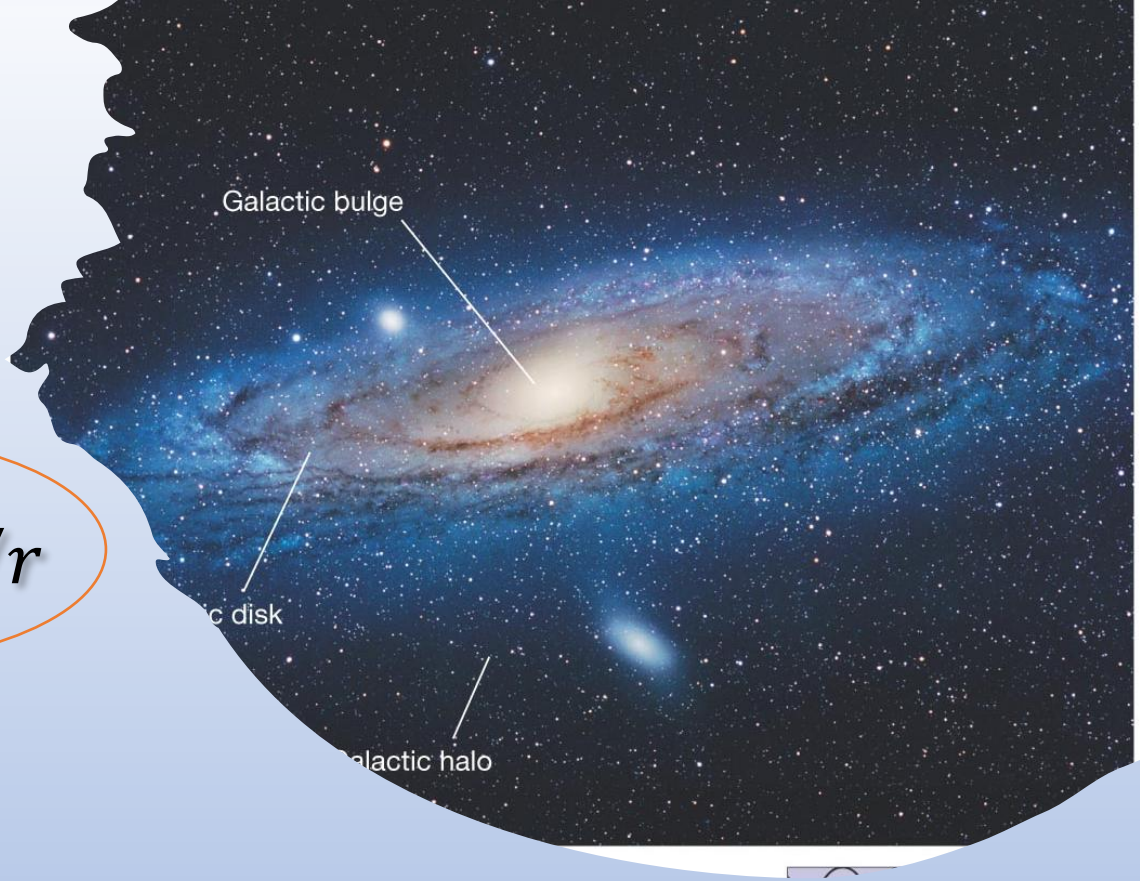
Het “timing” argument

$$v^2 = G\,M/r$$

Systemen in (viriaal) evenwicht $\quad \langle v^2 \rangle = G\,M/\langle r \rangle$

Voor E = 0 (maximaal uitgerekte baan) $\quad v^2 = 2\,G\,M/r$

Andromeda en de Melkweg



Het “timing” argument $v^2 = G\,M/r$

$v = 125\ km\ s^{-1}$

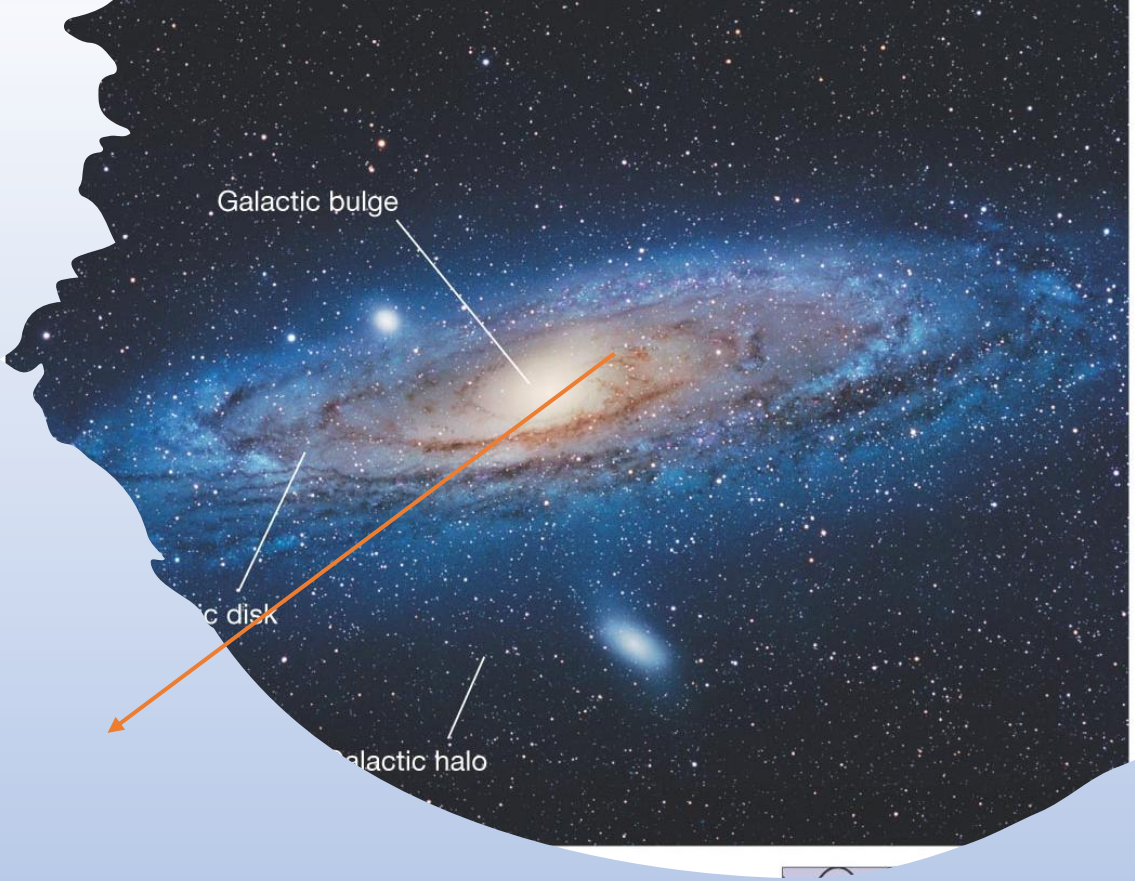
$r = 740\ kpc$

$M \sim 4.10^{12} M_\odot$ Factor 2 onzekerheid

$\sim 10\ x$ de hoeveelheid zichtbare massa

→ Donkere materie

Andromeda en de Melkweg



Het “timing” argument

$$v = 125\ km\ s^{-1}$$

$$r = 740\ kpc$$

$$v^2 = GM\left[\frac{2}{r} - \frac{1}{a}\right] = GM\left[\frac{2}{r} - \left(\frac{4\pi^2}{GMT^2}\right)^{1/3}\right]$$

$$T = t_{Hubble} - r/v$$

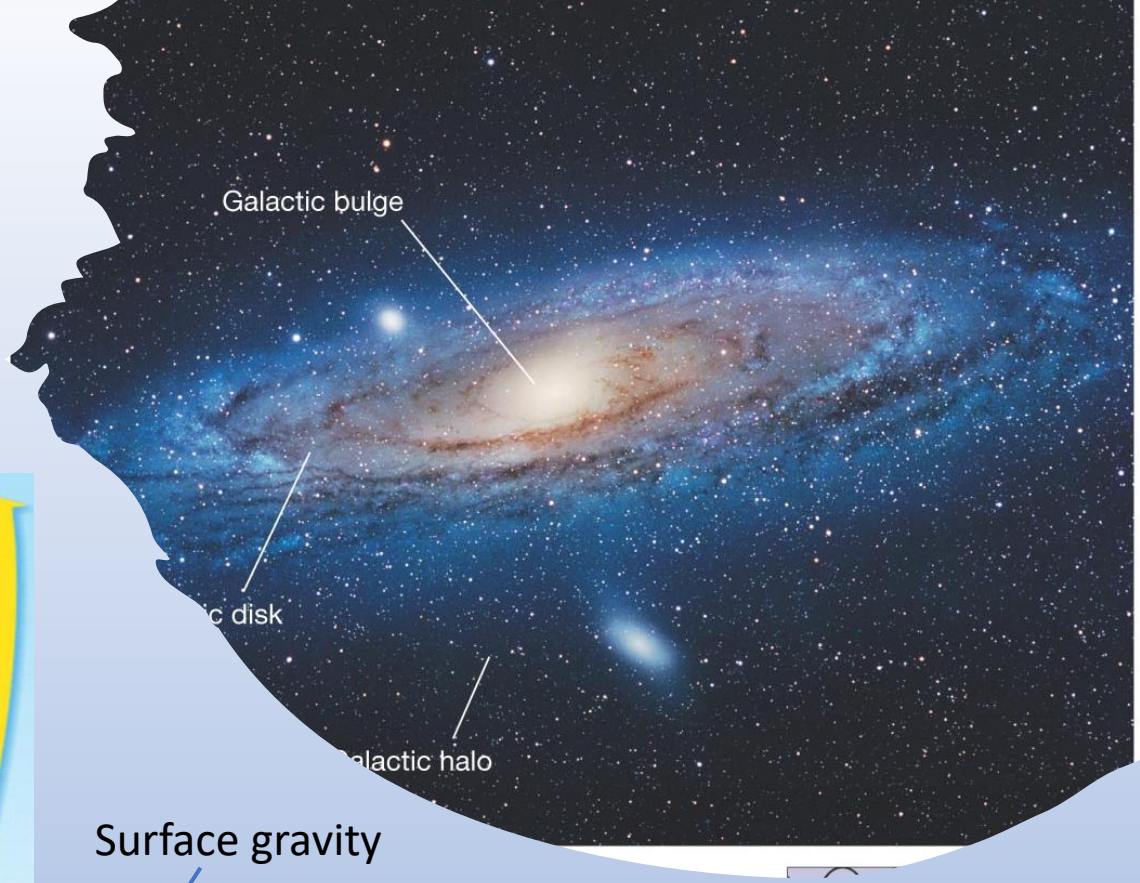
$$M \sim 4.10^{12} M_{\odot}$$

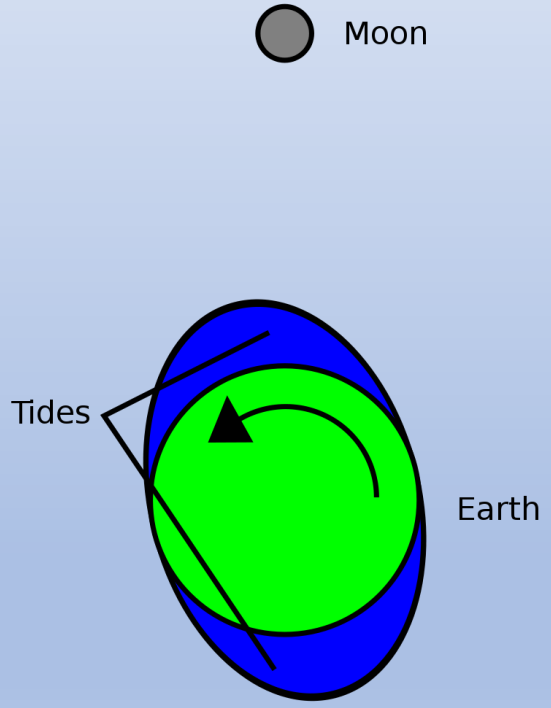
Factor 2 onzekerheid

This video shows a computer simulation of the appearance of two merging spiral galaxies as they would appear through a telescope, including absorption of starlight by interstellar dust. The colors are approximately what would be perceived by the human eye. Credits: Patrik Jonsson, Greg Novak & Joel Primack, University of California, Santa Cruz.

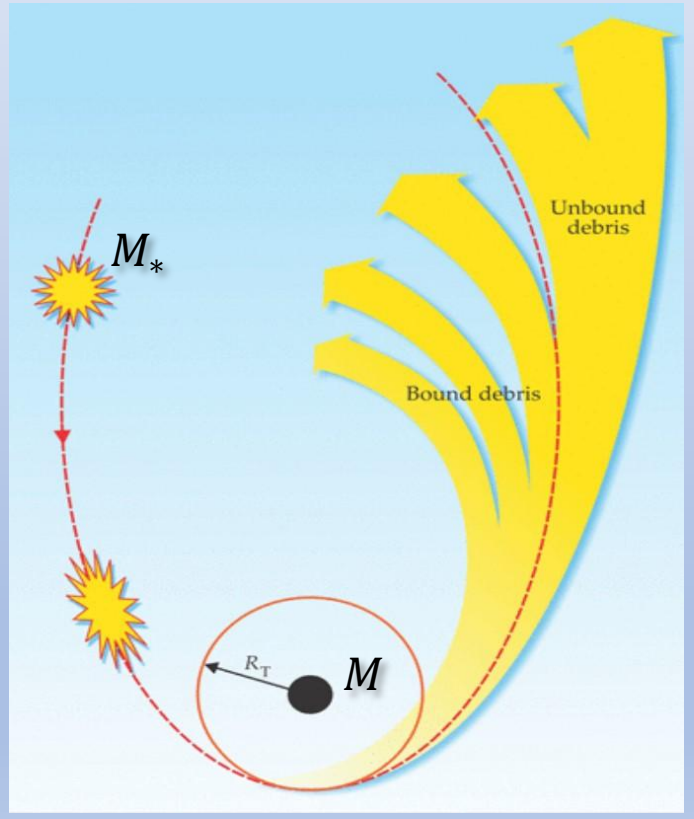
Andromeda en de Melkweg

Getijde krachten → Inelastische botsing





Eb en Vloed



Disruptie door getijde kracht

Surface gravity

$$a_{grav} = G\frac{M_*}{{R_*}^2}$$

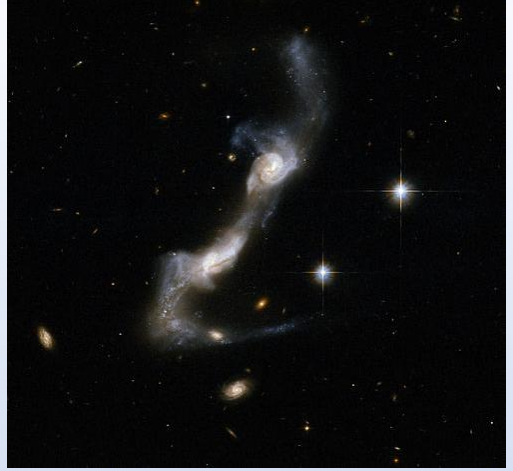
$$a_{tidal} = G\frac{MR_*}{R^3}$$

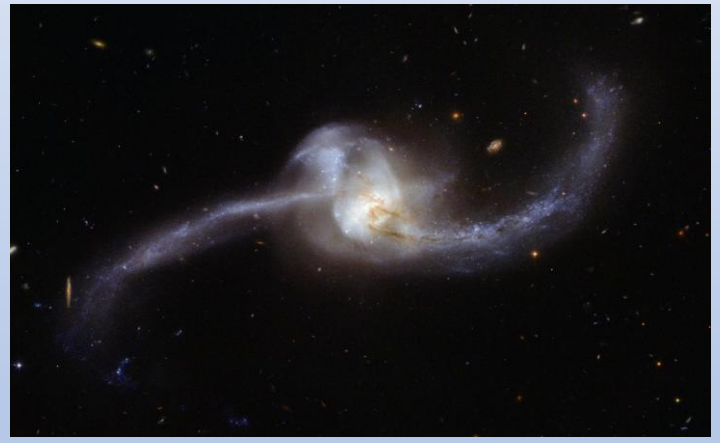
$$a_{tidal} = a_{grav}$$

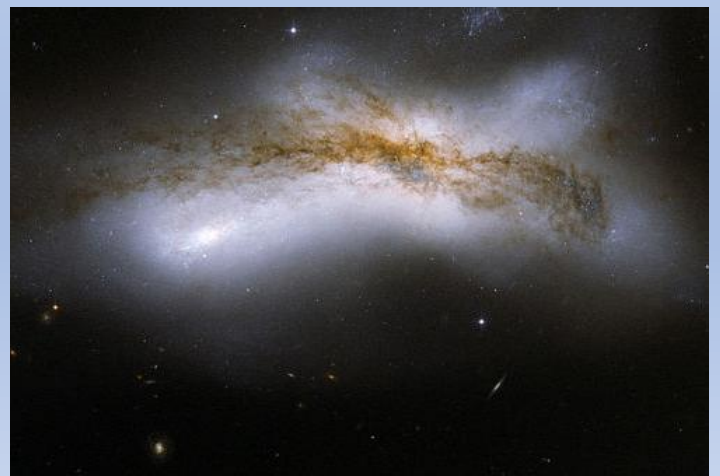
$$\frac{M_*}{{R_*}^3} \sim \frac{M}{R^3}$$

Fusies van sterrenstelsels

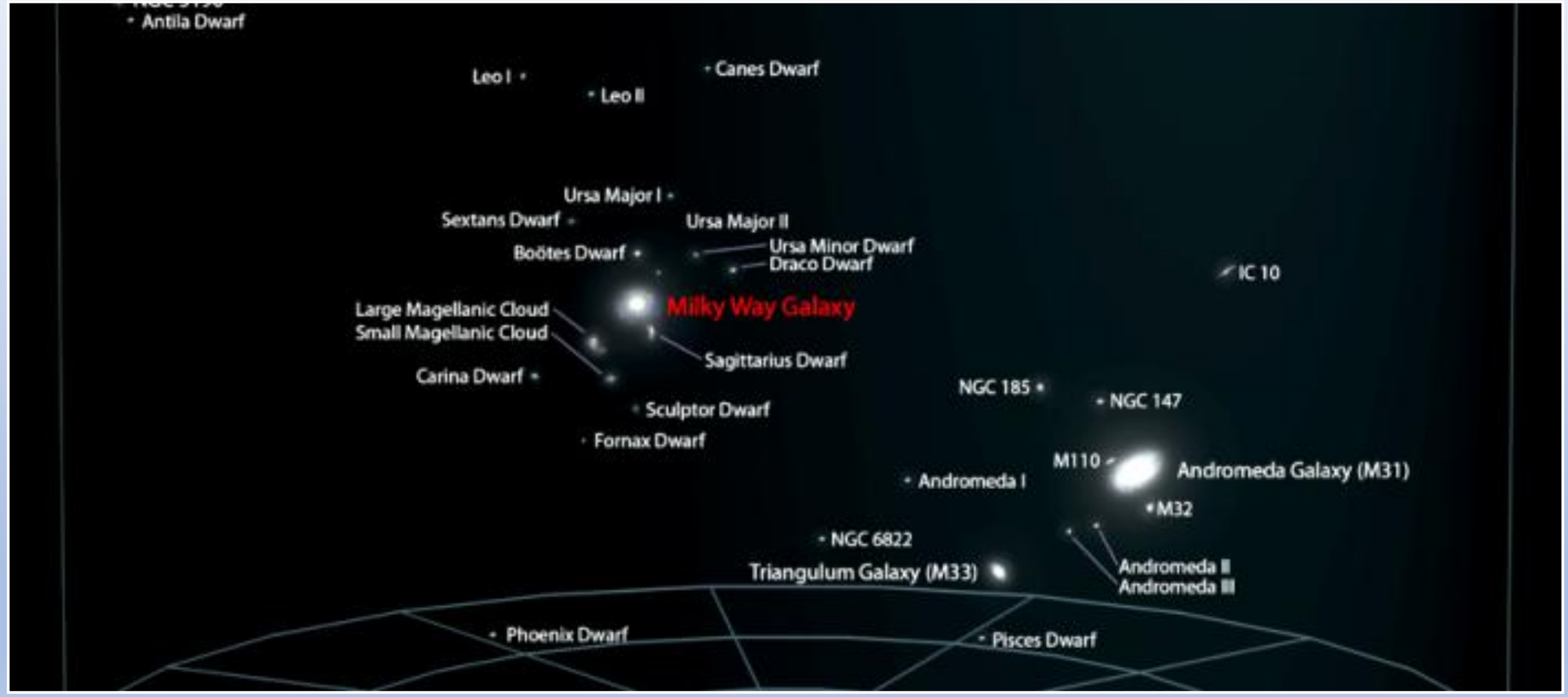
Fusies van sterrenstelsels



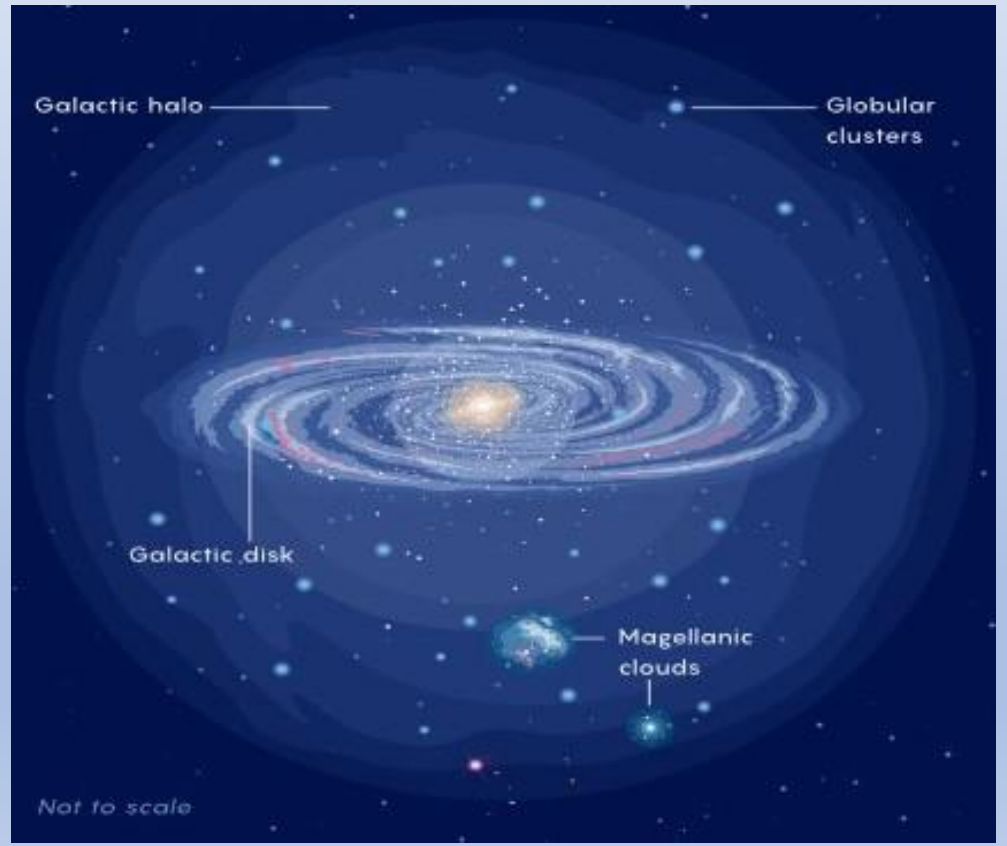


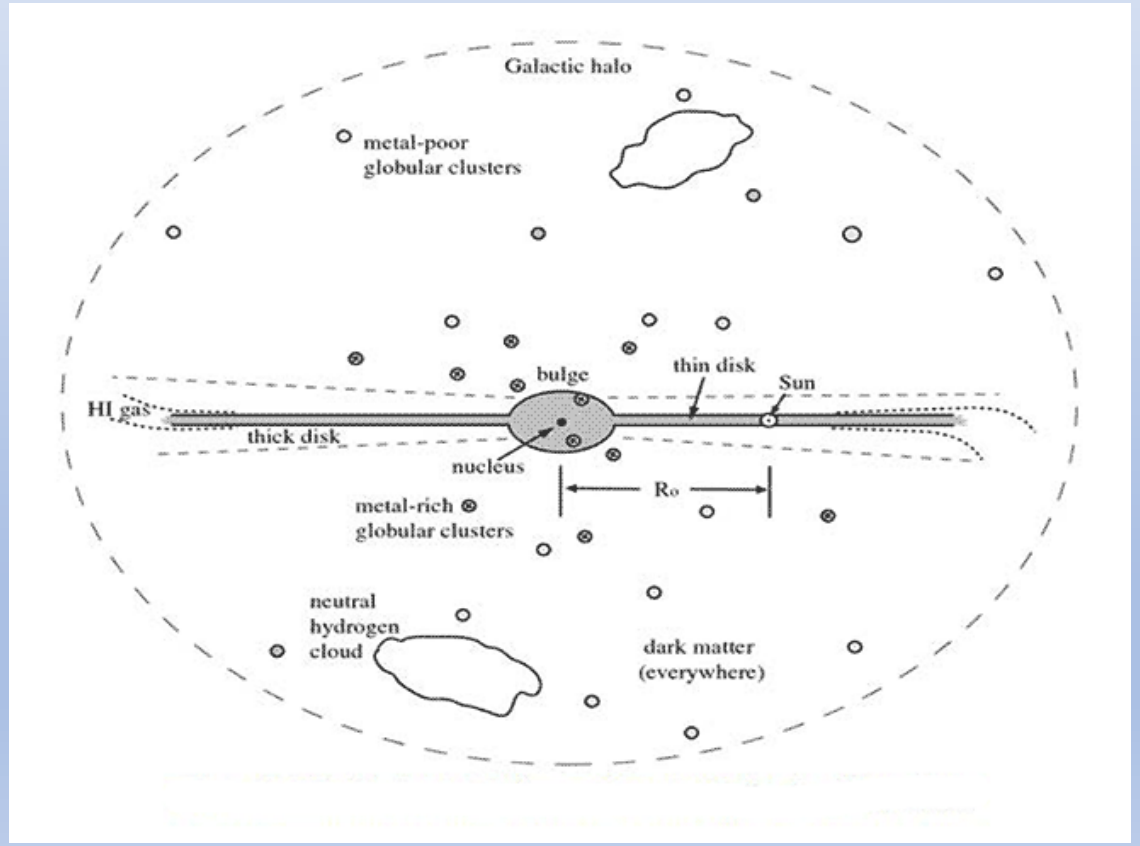


Fusies van sterrenstelsels

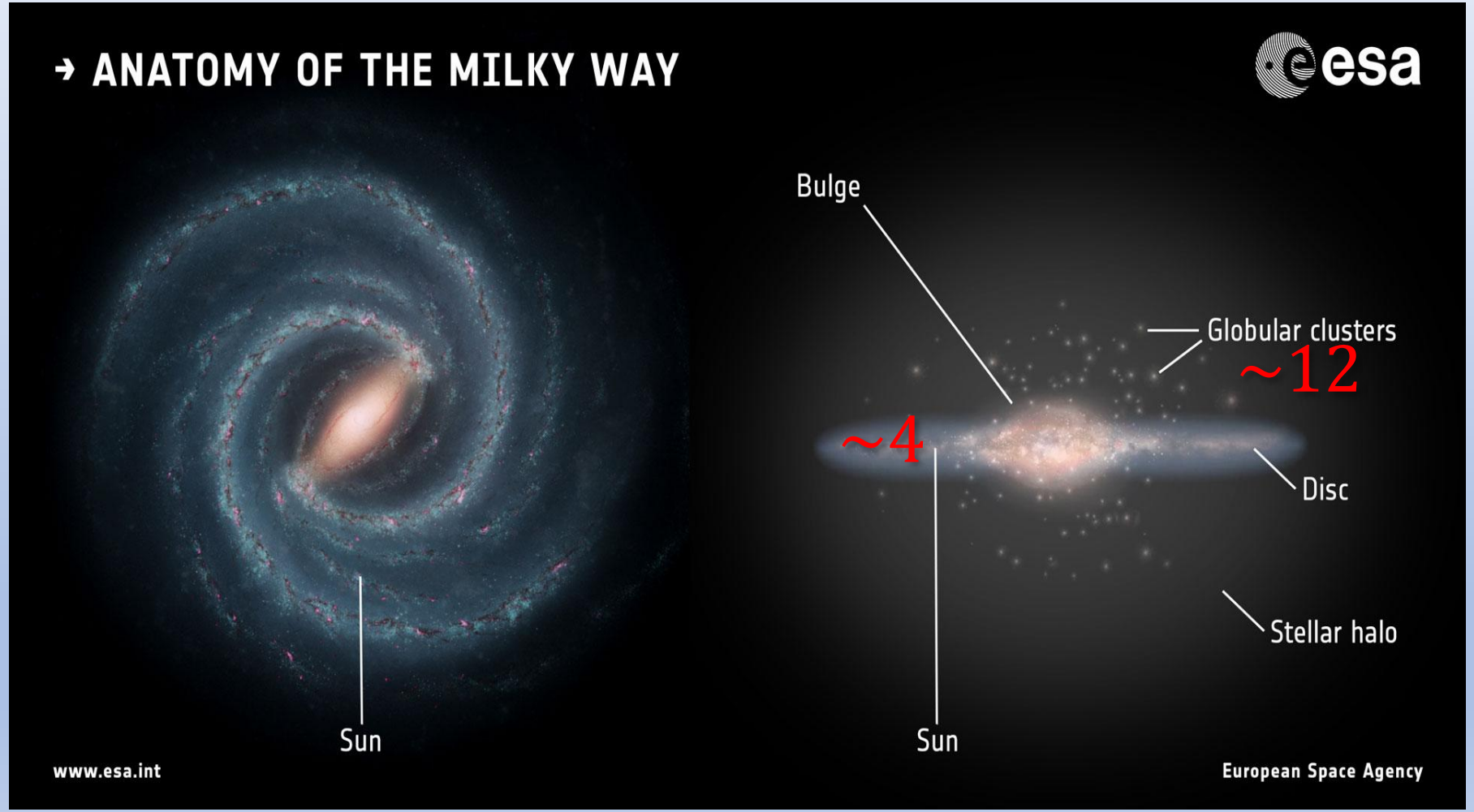


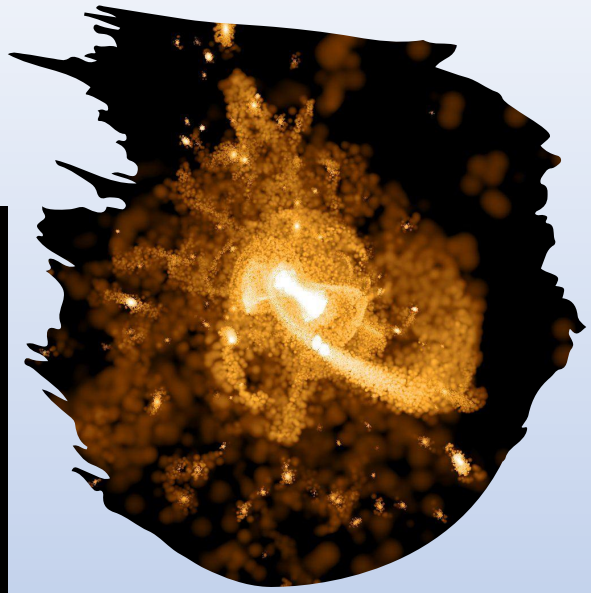
Archeologie van onze Melkweg





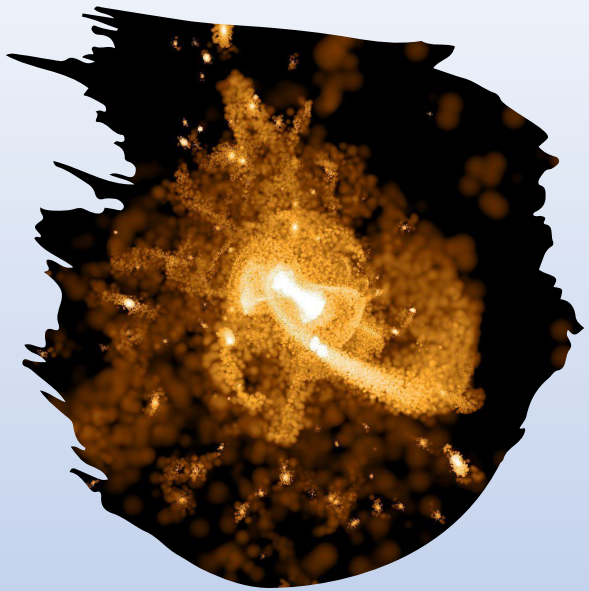
Archeologie van onze Melkweg





leeftijd in miljard jaar

Archeologie van onze Melkweg



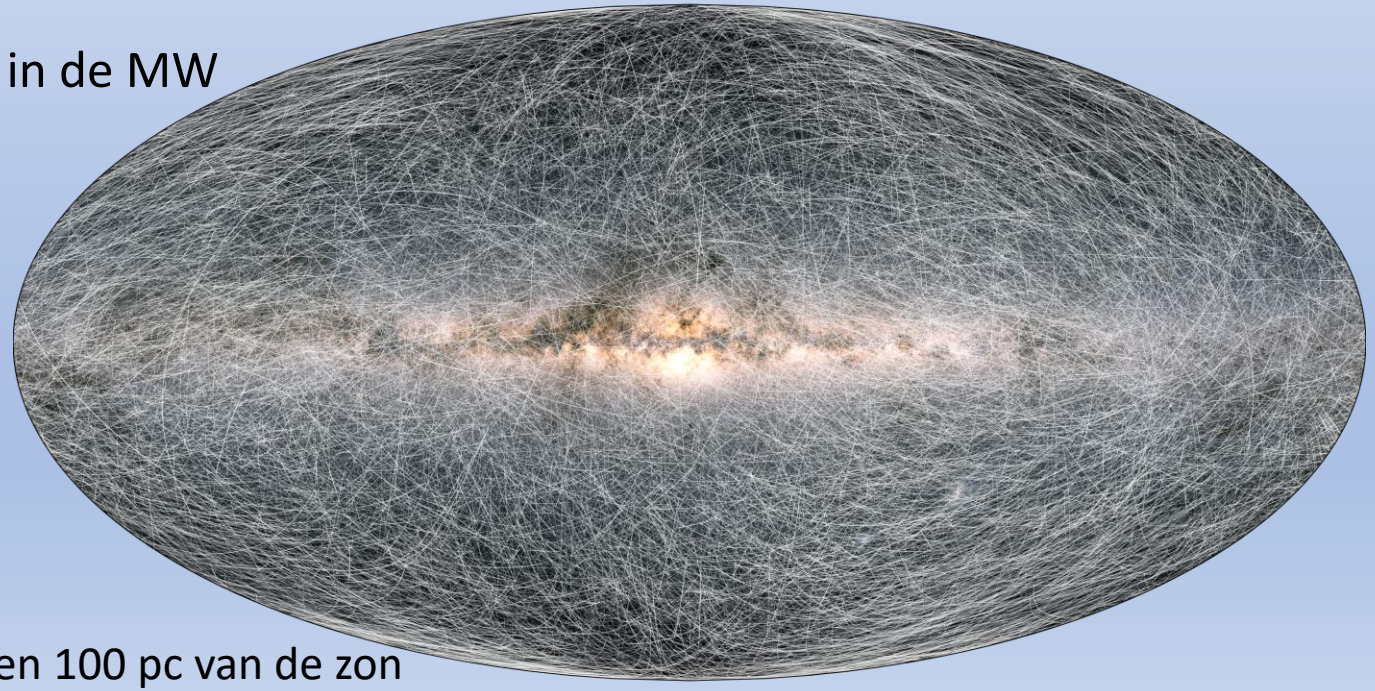
Recente ontwikkelingen: Waarnemingen

Sloan Digital Sky Survey IV (2020)

=> Apogee project 10^5 sterren in de MW

GAIA-ESO project (2018)

- 10^9 bronnen
- Snelheden voor 10^6 sterren
- Banen voor 10^3 sterren



40.000 sterren binnen 100 pc van de zon

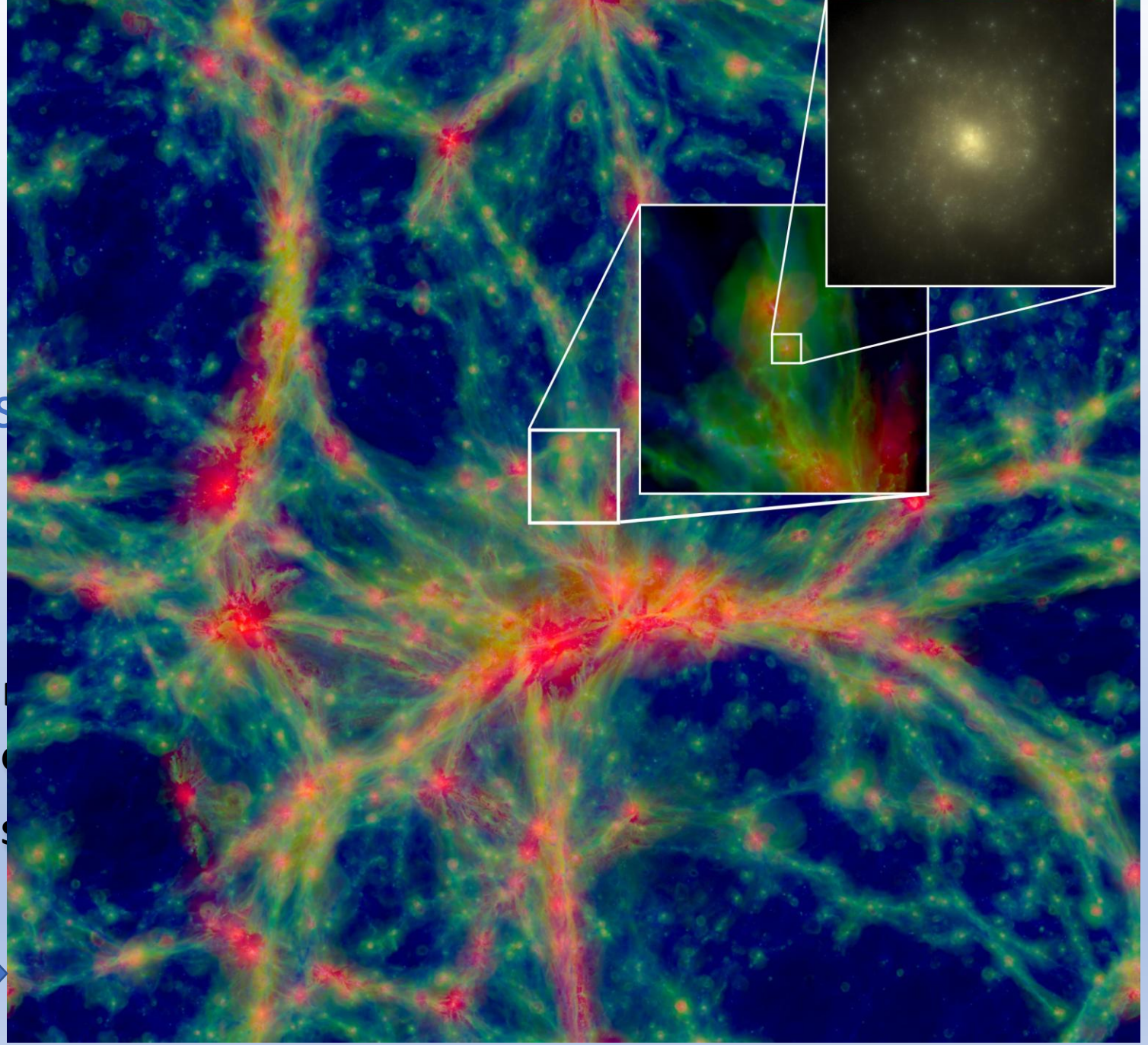
Archeologie van

Recente ontwikkelingen: Kos

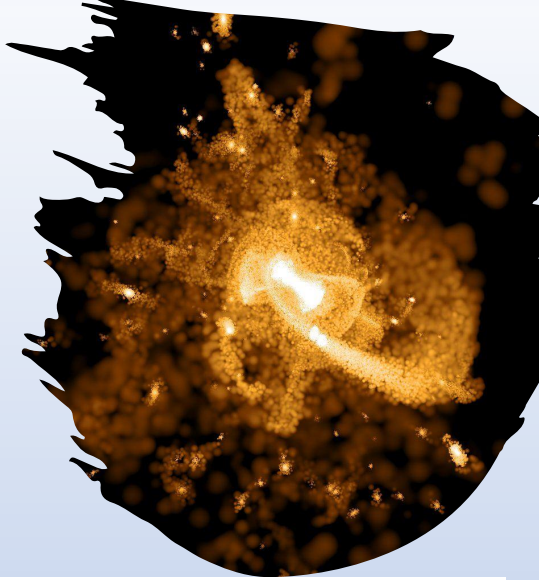
Milennium simulatie

Illustris (2013)

Eagles simulatie (2014)
Virgo consortium o.a. Leiden

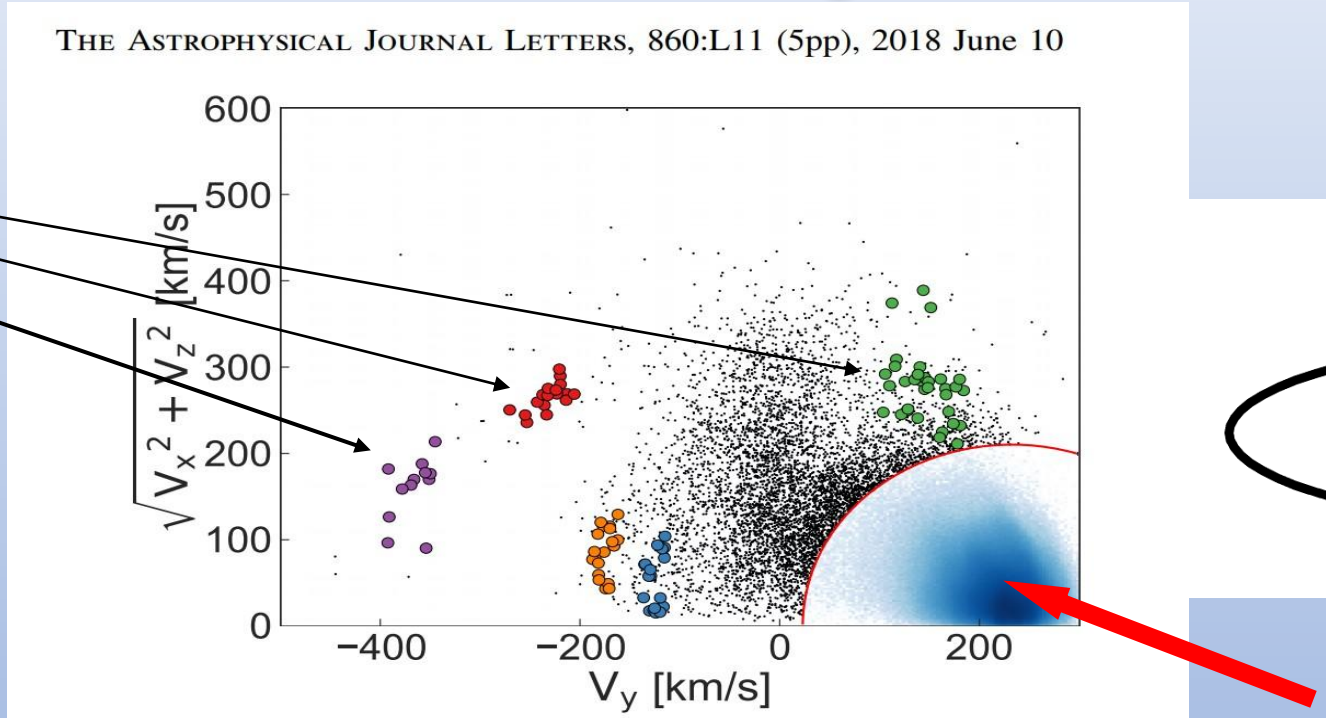


Archeologie van onze Melkweg



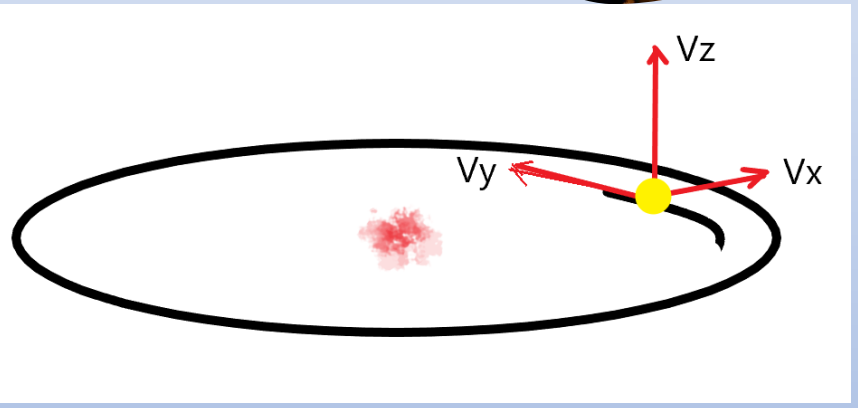
GAIA-ESO : De Halo van de Melkweg

substructuur



THE ASTROPHYSICAL JOURNAL LETTERS, 860:L11 (5pp), 2018 June 10

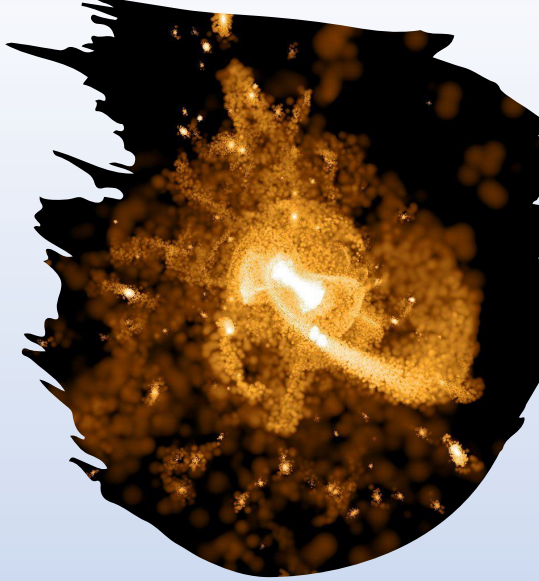
Figure 1. Toomre diagram used to identify nearby halo stars (black dots and colored circles), defined as those that satisfy $|V - V_{LSR}| > 210$ km s^{-1}, for $V_{LSR} = 232$ km s^{-1}. The density map shows the distribution of all *Gaia* DR2 stars within 1 kpc from the Sun. We consider only stars with relatively accurate parallaxes, i.e., with $\varpi/\epsilon_\varpi > 5$.



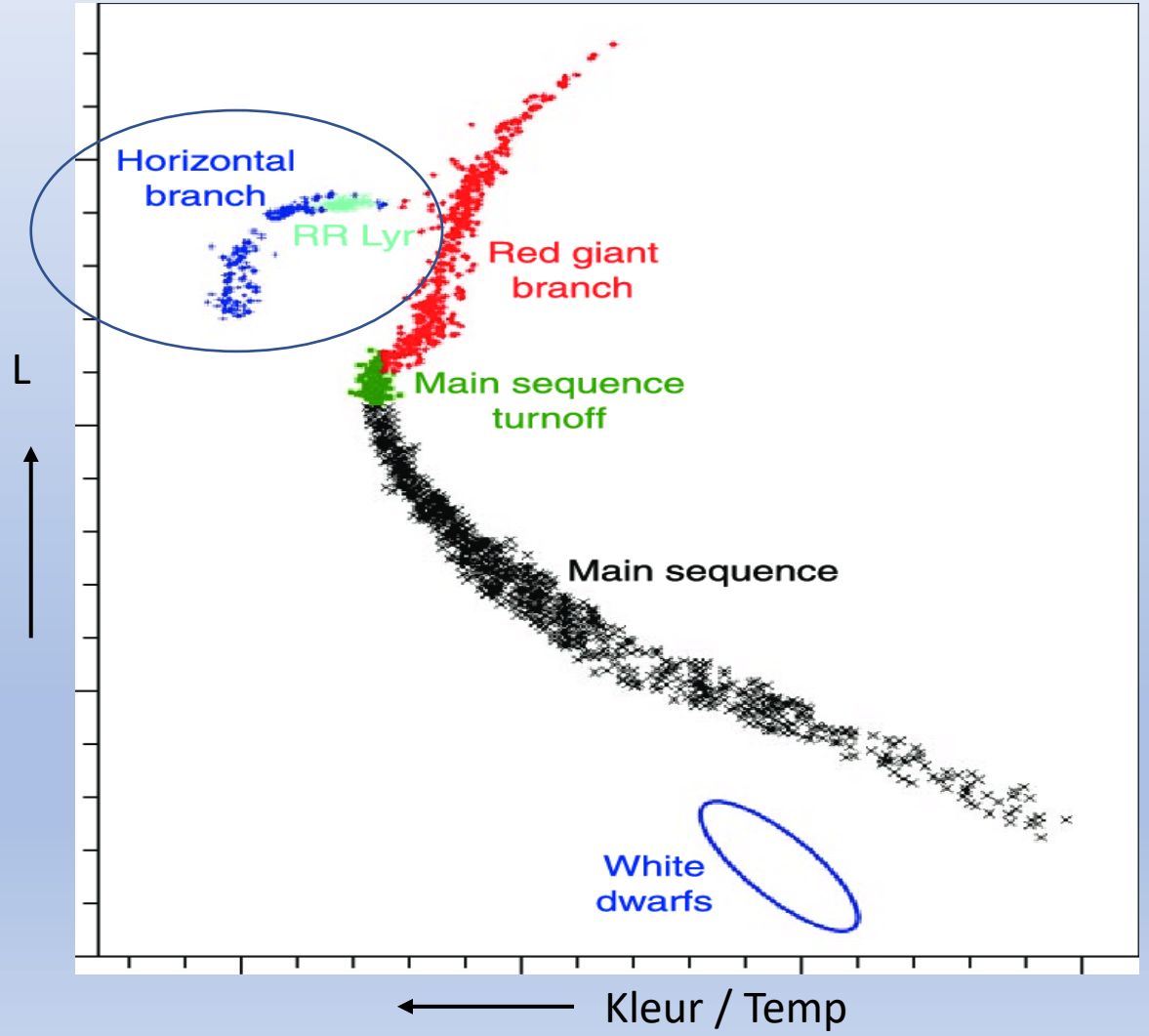
Sterren (binnen de rode cirkel)
die met die met zon
mee bewegen in de schijf

Sterstromen in de halo (Koppelman et al. 2018)

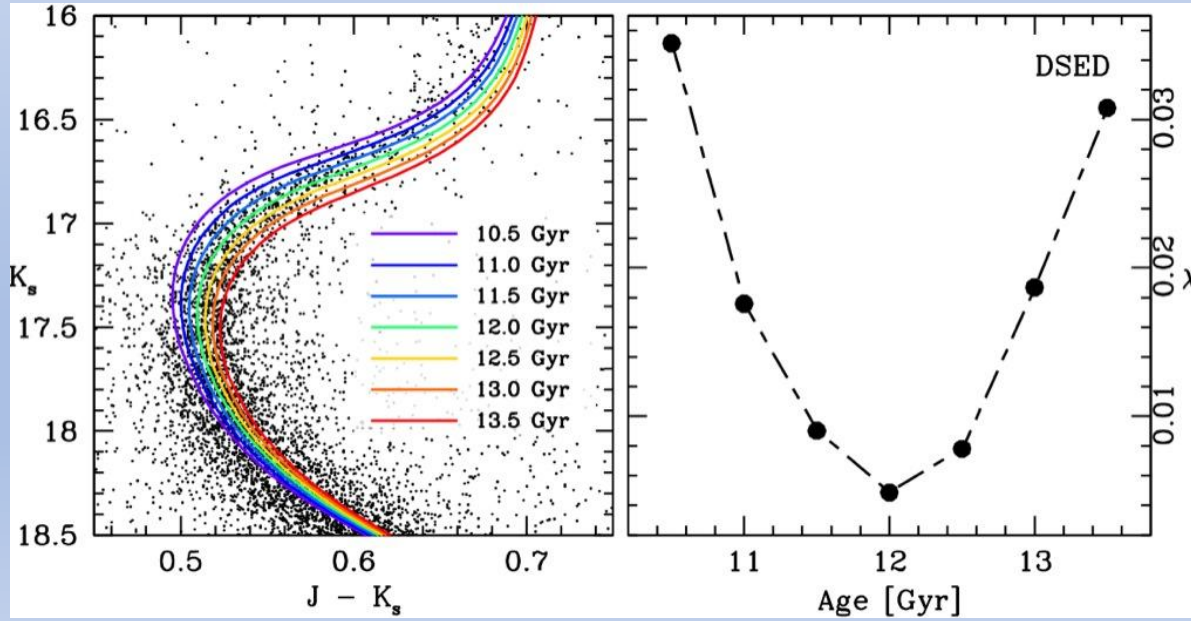
Archeologie van onze Melkweg



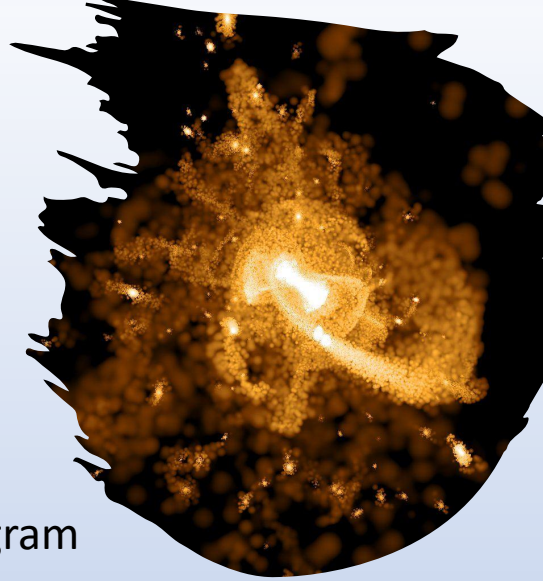
Leeftijd bepaling Globular Cluster



Hertzsprung – Russel diagram voor een Globular Cluster (ongeveer 12 miljard jaar oud)

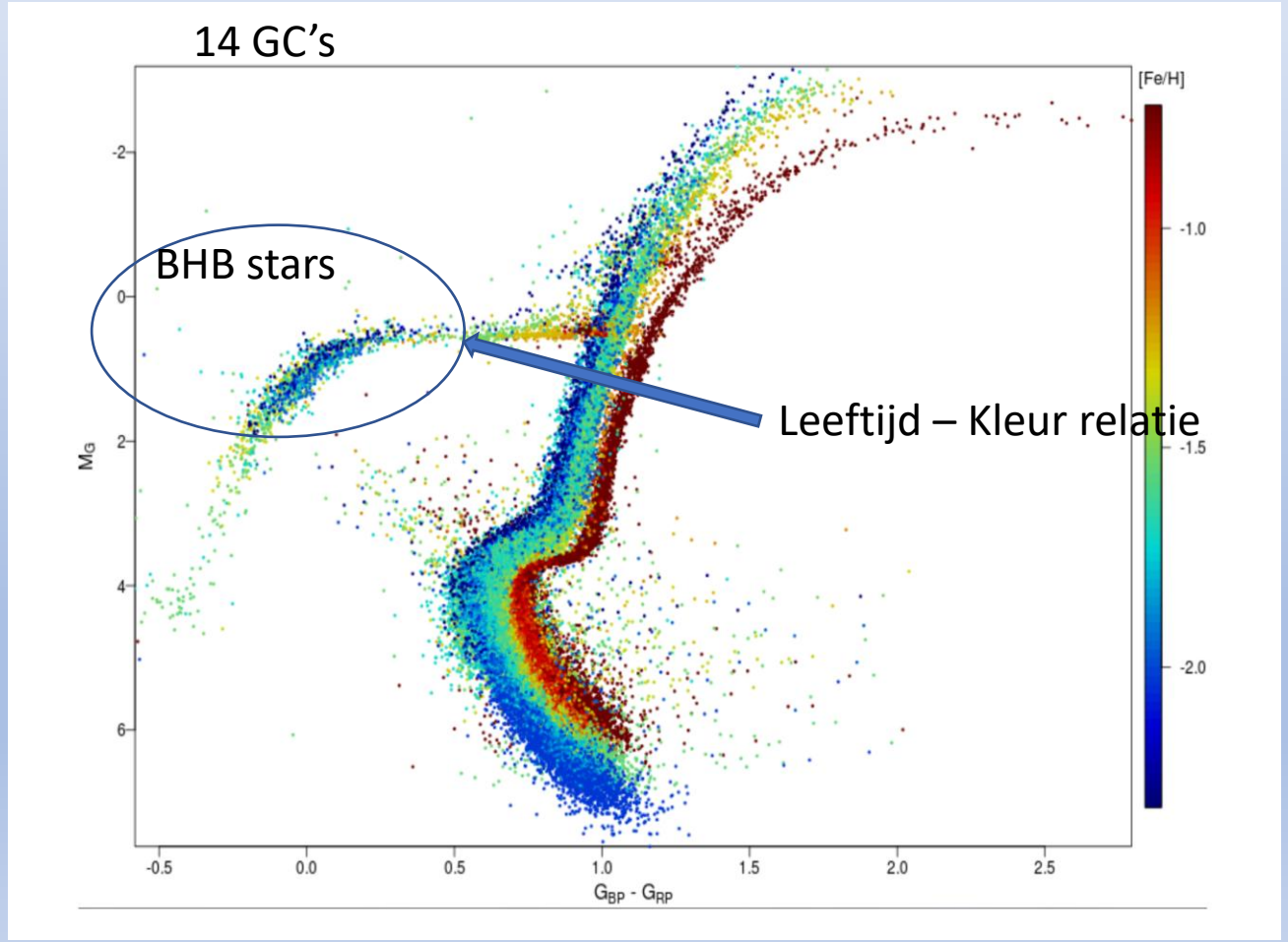


Archeologie van onze Melkweg

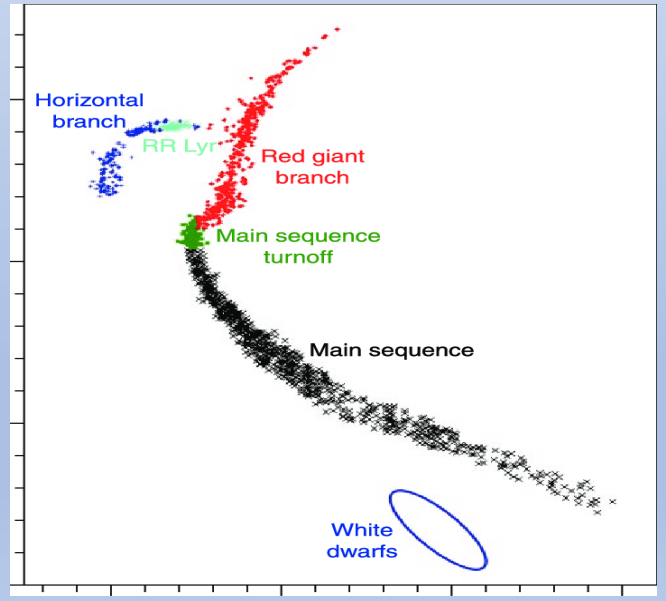


Leeftijd bepaling Globular Cluster

GAIA data release 2 (2018)



Hertzsprung – Russel diagram voor een Globular Cluster (ongeveer 12 miljard jaar oud)



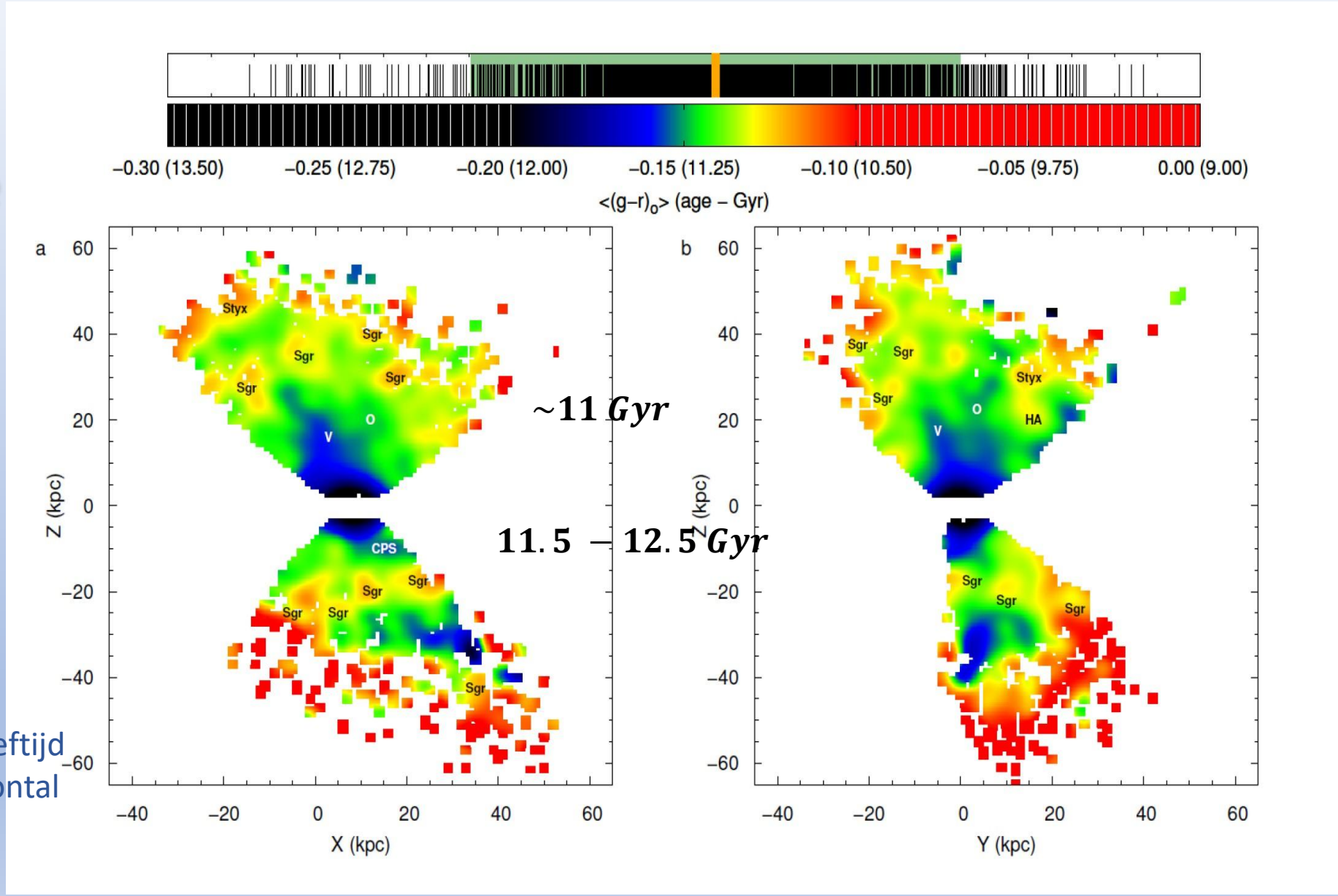
Archeologie van onze Melkweg

SDSS IV :

De Halo van de Melkweg

Carollo et al. (2016)
130.000 BHB stars,
Tot 15 Kpc vanaf het centrum van de MW

Relatie Metallicity [Fe/H] – leeftijd Voor BHB sterren (Blue Horizontal Branch)



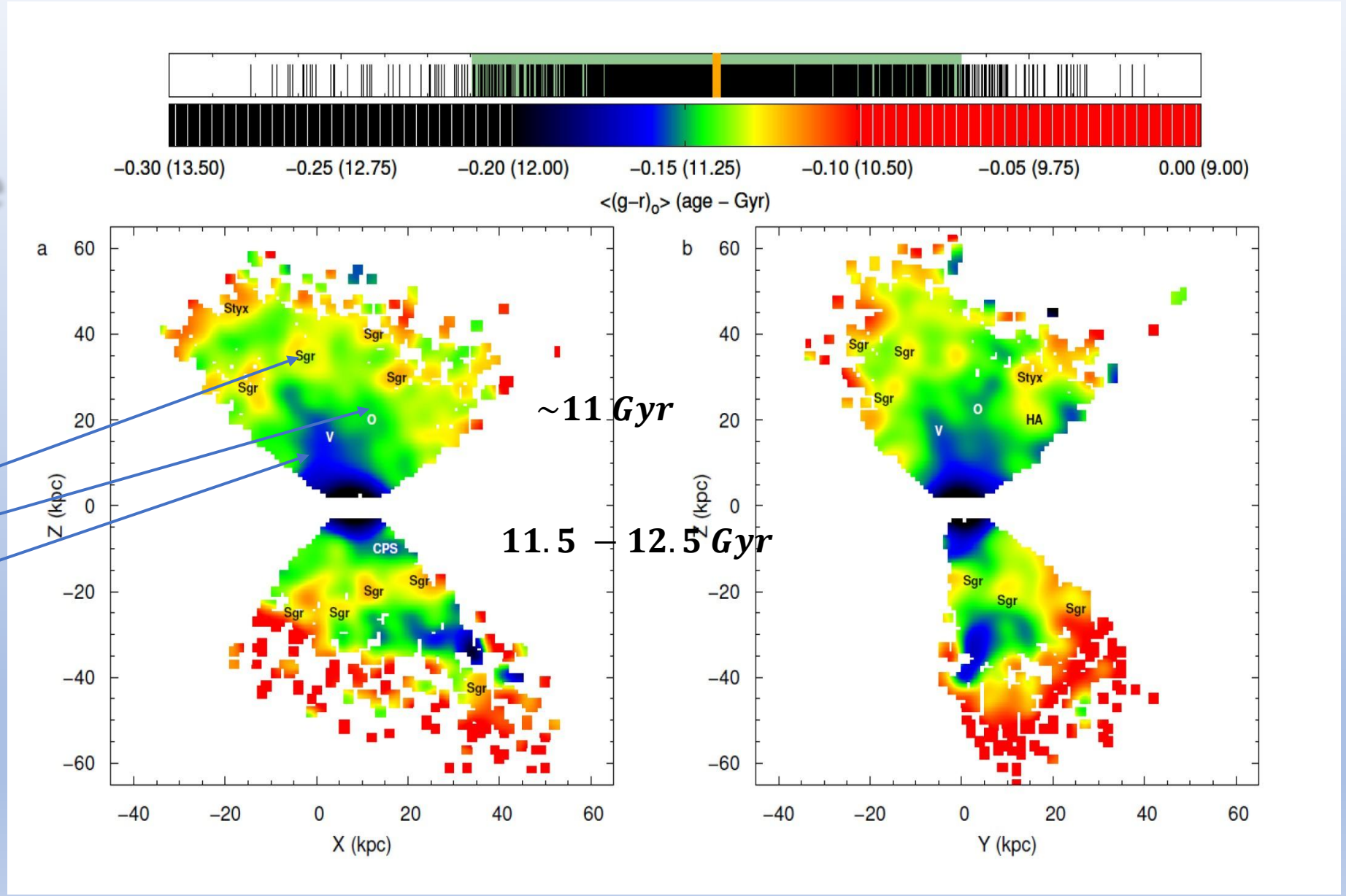
Archeologie van onze Melkweg

SDSS IV :

De Halo van de Melkweg

Substructuren:

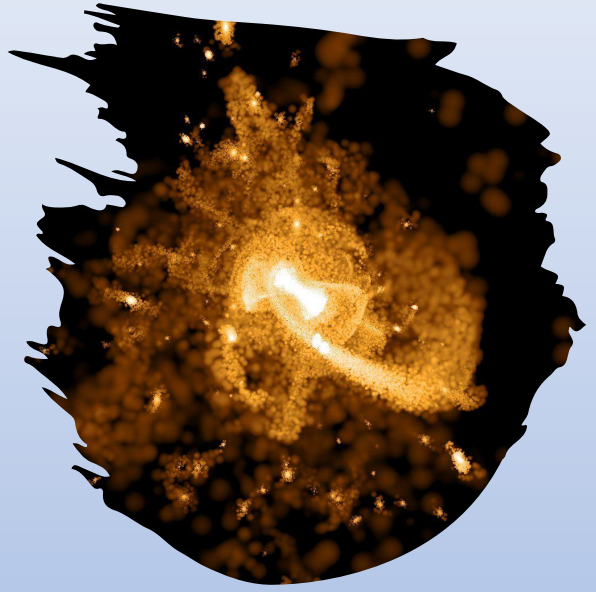
- Sagittarius stream
- Orphan stream
- Virgo-Monoceros
- Styx



Archeologie van onze Melkweg

Substructuur in de Melkweg (Halo, Bulge en Schijf)

- Sterhopen
- Sterstromen



GAIA: 5000 metaal-arme sterren (oud) Verschillende leeftijden

-- 10% in de Schijf, 90% in de Halo

-- 50% van de sterren (sterhopen) in de halo binnen 20 kpc

=> restanten van Globular Clusters en dwergstelsels. > 5 groepen, o.a.

- **Gaia – Enceladus (10 miljard jr)**
- **Helmi**
- **Sequoia**
- **Sagittarius**

Archeologie van onze Melkweg

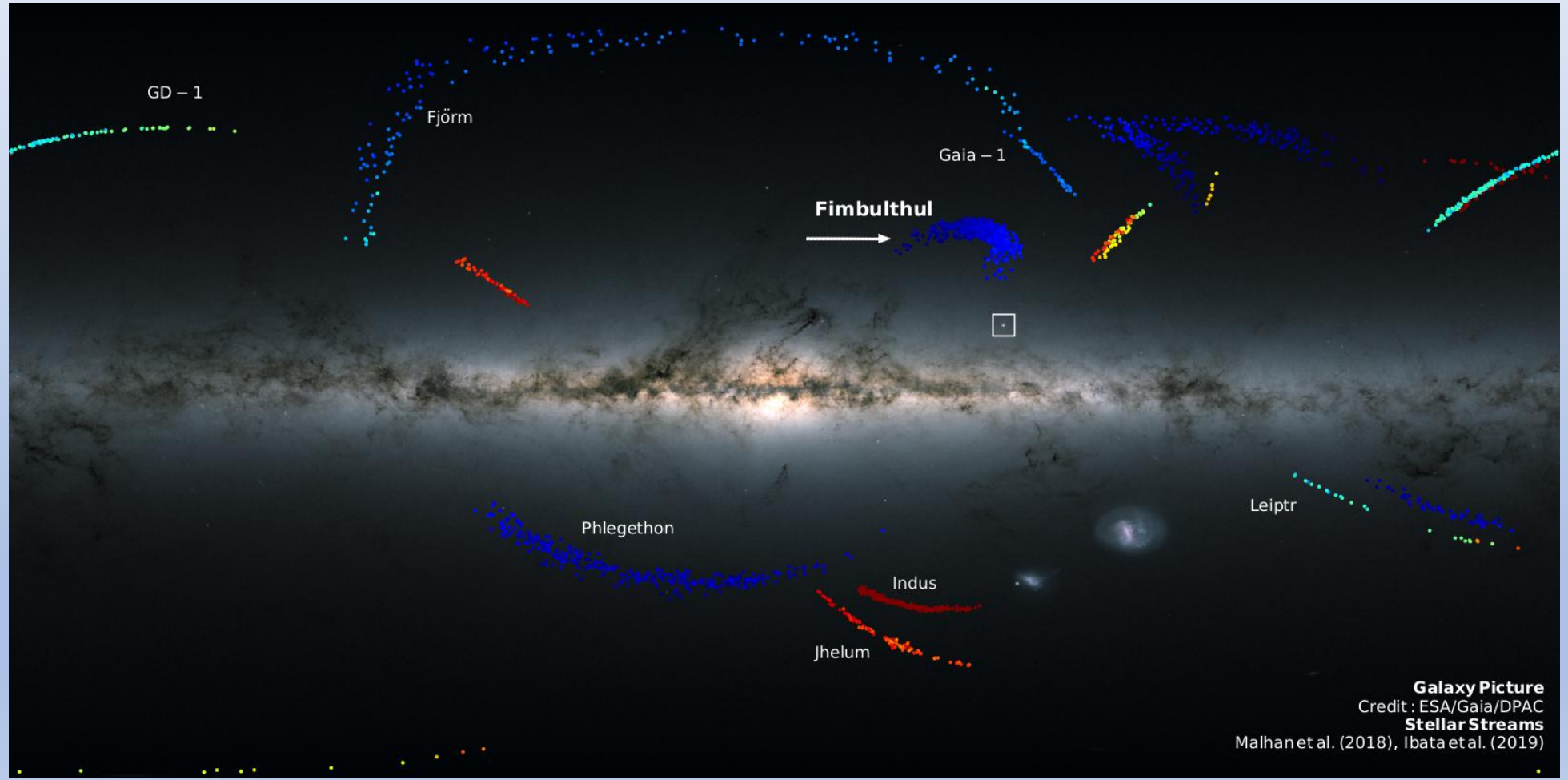
Substructuur in de Melkweg (Halo, Bulge en Schijf)

- Sterhopen
- Sterstromen

Verschillende leeftijden

Tidal streams:

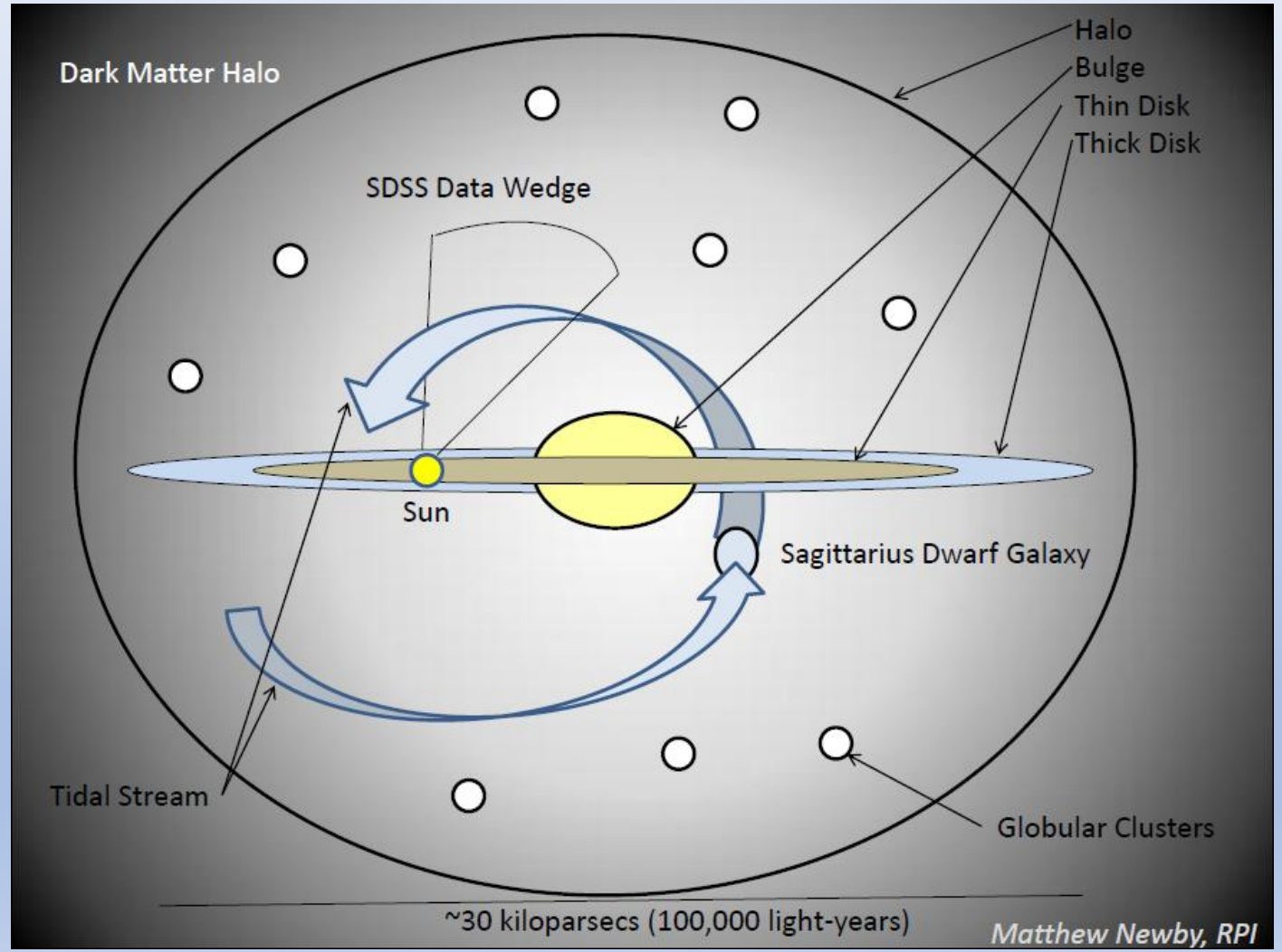
Found by the Streamfinder algorithm

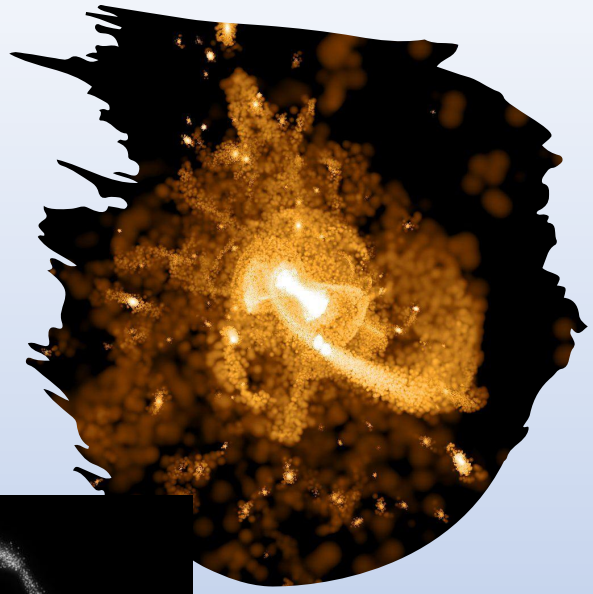


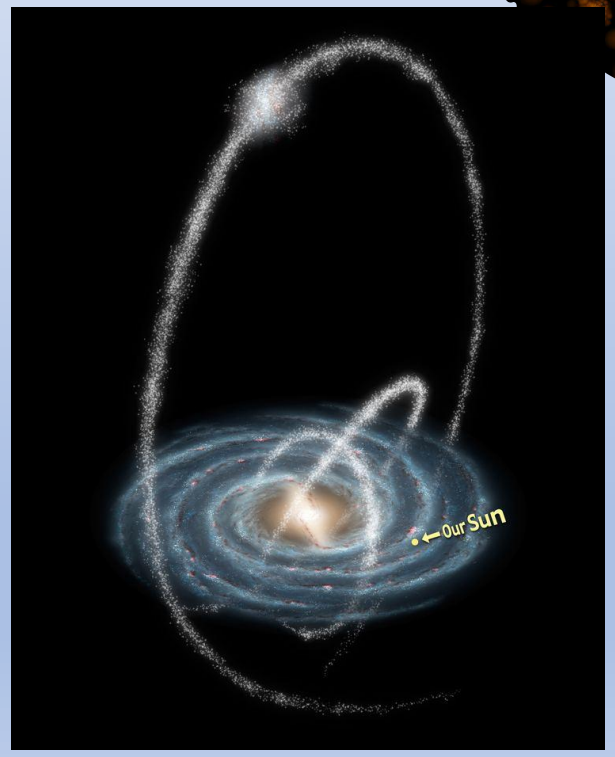
Fimbulthul is the stream from Omega Centauri

Archeologie van onze Melkweg

Invangst van Sagittarius







Archeologie van onze Melkweg

Invangst van Sagittarius numerieke simulatie

Archeologie van onze Melkweg

Gaia – Enceladus: numerieke simulatie

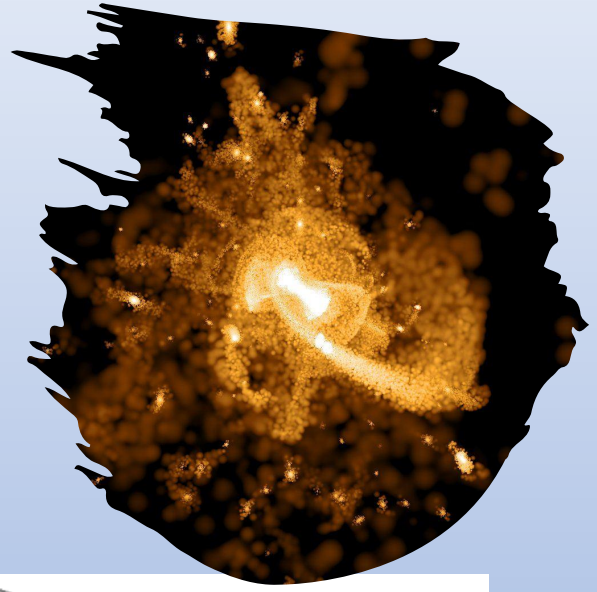
Credit: Koppelman, Villalobos & Helmi, Kapteyn Astronomical Institute, University of Groningen, The Netherlands

Archeologie van onze Melkweg

Substructuur in de Melkweg (Halo, Bulge en Schijf)

- Sterhopen
- Sterstromen

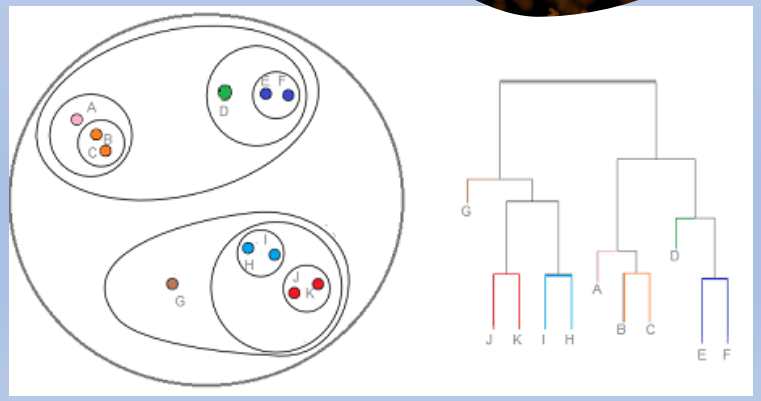
Verschillende leeftijden



Hierarchische Clustering

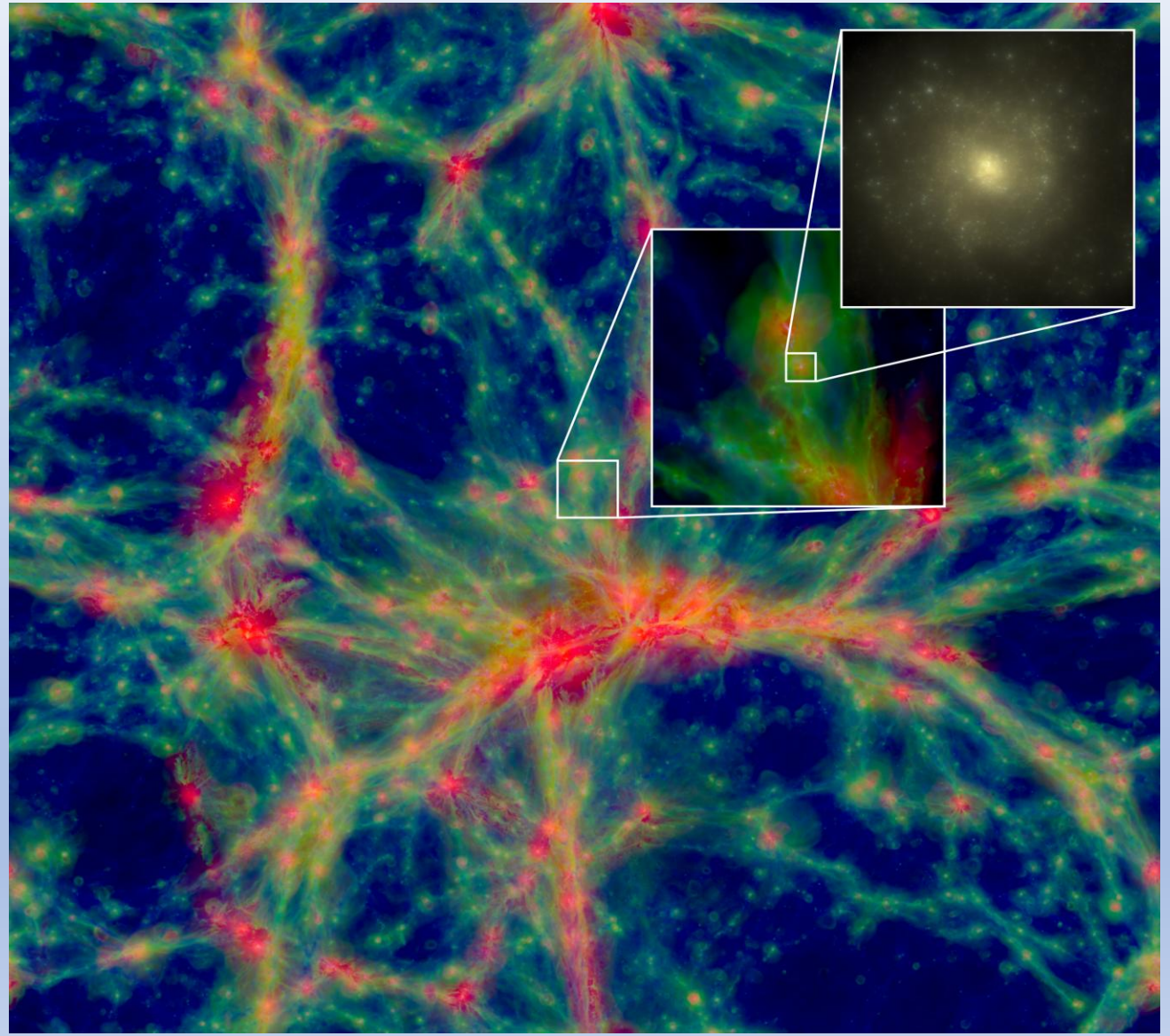
Groei door invang van kleinere eenheden

Globular Clusters, Dwergstelsels, gas



Archeologie van onze Melkweg

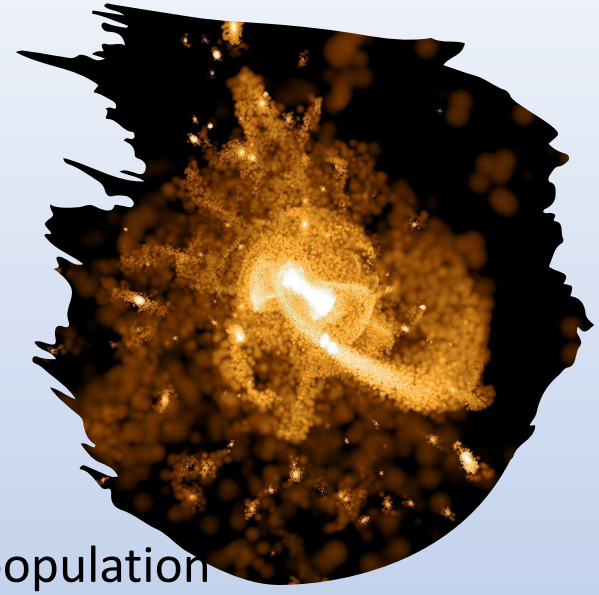
Kosmologische simulatie: Vorming van een spiraalstelsel



Archeologie van onze Melkweg

De stamboom van de Melkweg (Merger Tree)

Kruijssen et al. (2020)



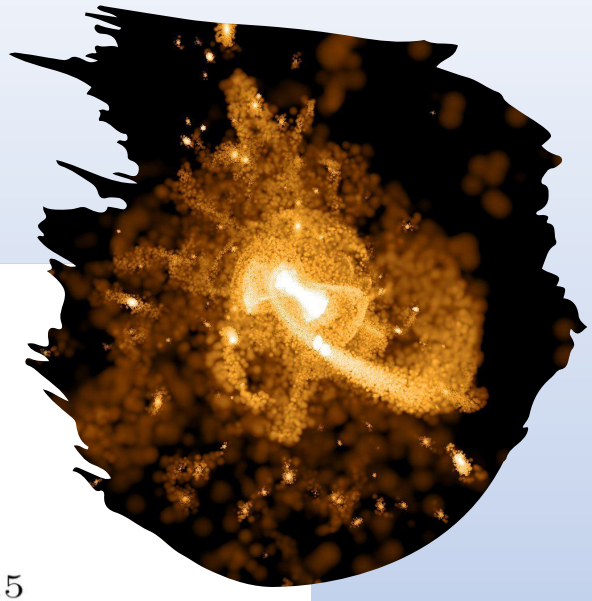
Input

- GAIA informatie : stars, GC's, posities, snelheden
- E-MOSAICS cosmological simulation with complete model for GC population
- Bekende fusies: Kraken, Gaia-Enceladus, Sagittarius, Helmi, Sequoia.

Gebruik de E-MOSAICS simulaties om een AI netwerk te trainen
om de eigenschappen van GC's behorende bij Ingevangen satellieten te herkennen.
Laat het netwerk vervolgens de patronen herkennen in de groepen GC's die horen bij de bekende satellieten.

→ **Massa's en tijdstip van accretie?**

Archeologie van onze Melkweg



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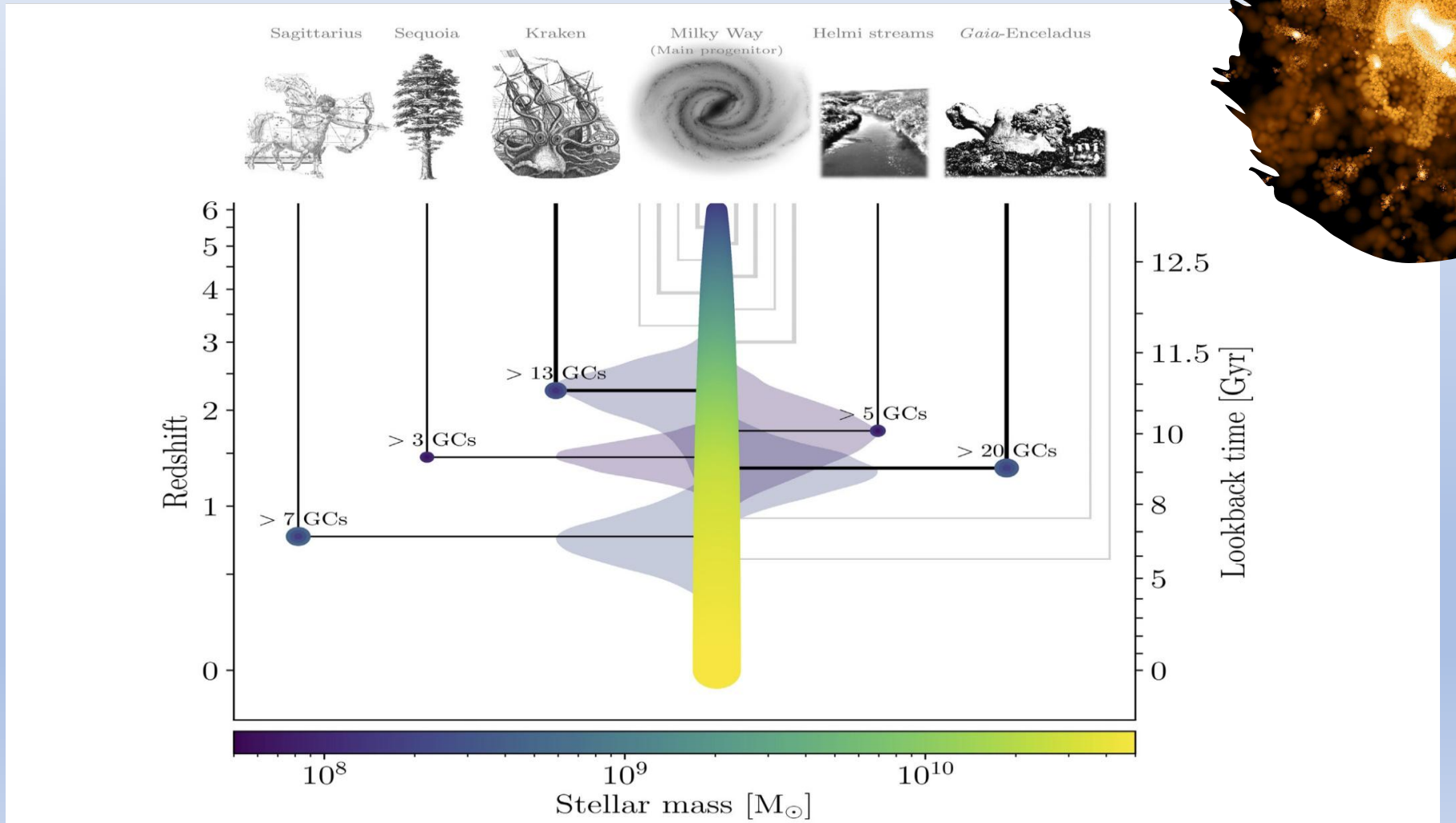
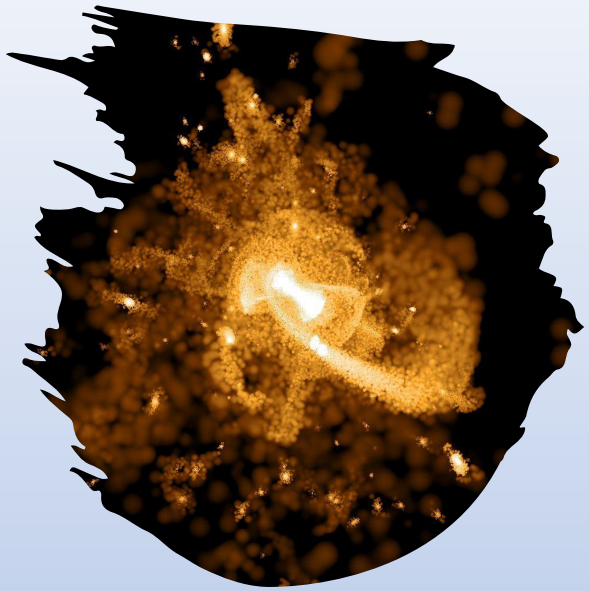


Archeologie van onze Melkweg



Conclusies:

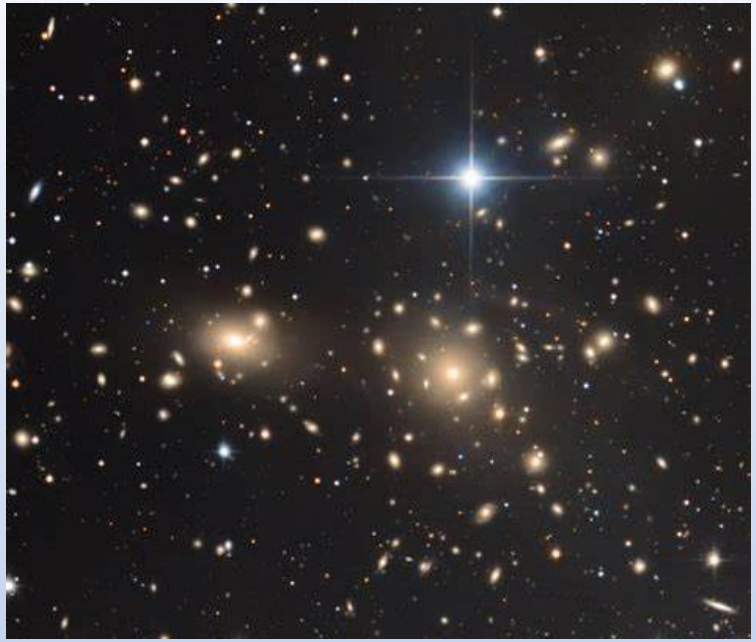
Het ΛCDM model is een model van hiërarchische Clustering aangedreven door Dark Matter.

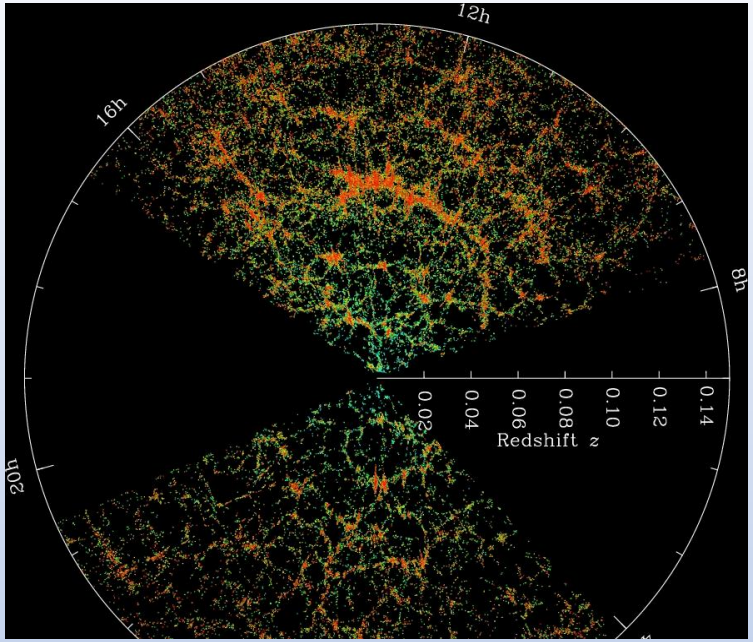
De gewone materie (gas) valt in de potentiaalputten gevormd door CDM en vormt sterrenstelsels (bolhopen, schijfstelsels).

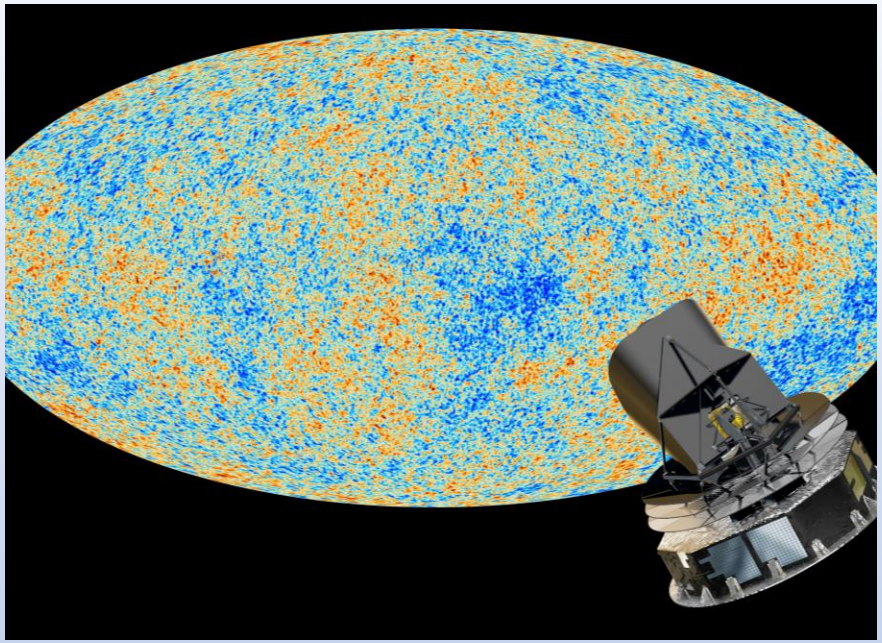
De sterren verrijken de interstellaire materie en het gas wordt rijker aan “metalen”.

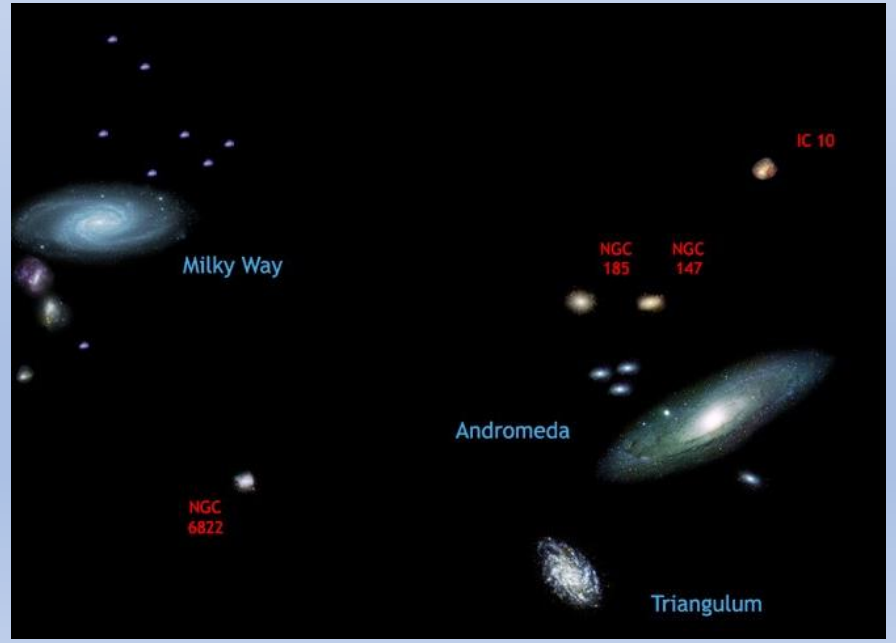
De sterrenstelsels (met het gas) fuseren (=> nieuwe stervorming) en vormen uiteindelijk elliptische sterrenstelsels.

Clustervorming neemt meer tijd. De snelheden in grote clusters zijn groter dan $\sim 1000\ km\ s^{-1}$ waardoor de botsingen minder inelastisch worden.



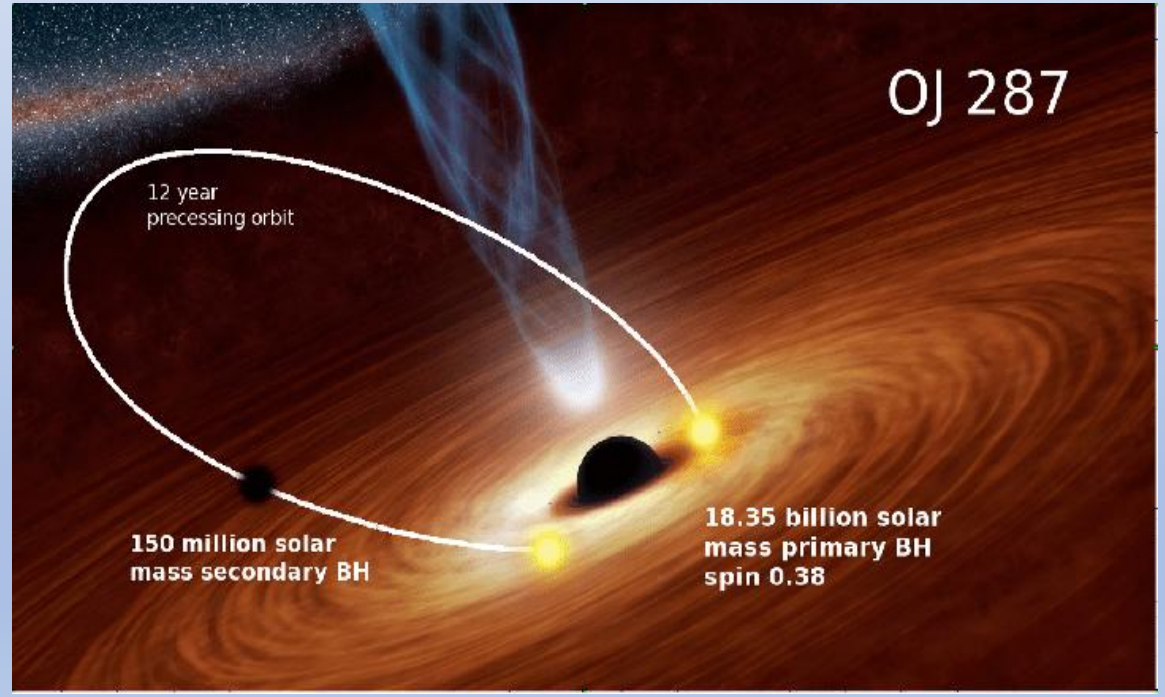






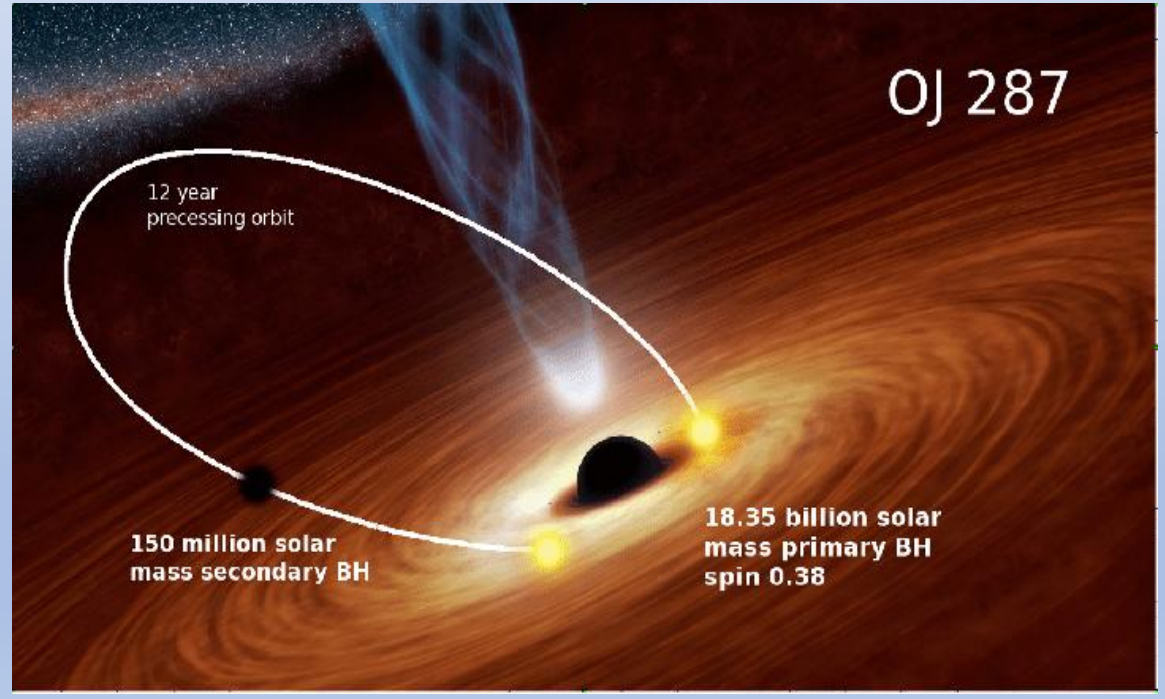
Van de CMB naar de Local group

Massive Binary Black Holes ➔ QSOs

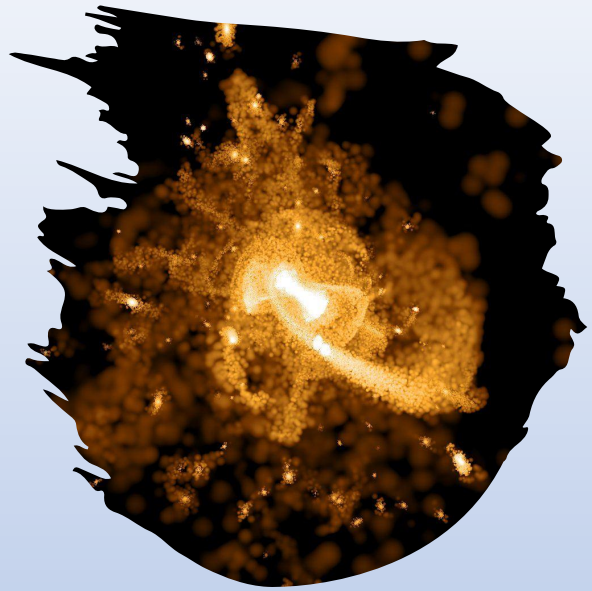


Massive Binary Black Holes ➔ QSOs

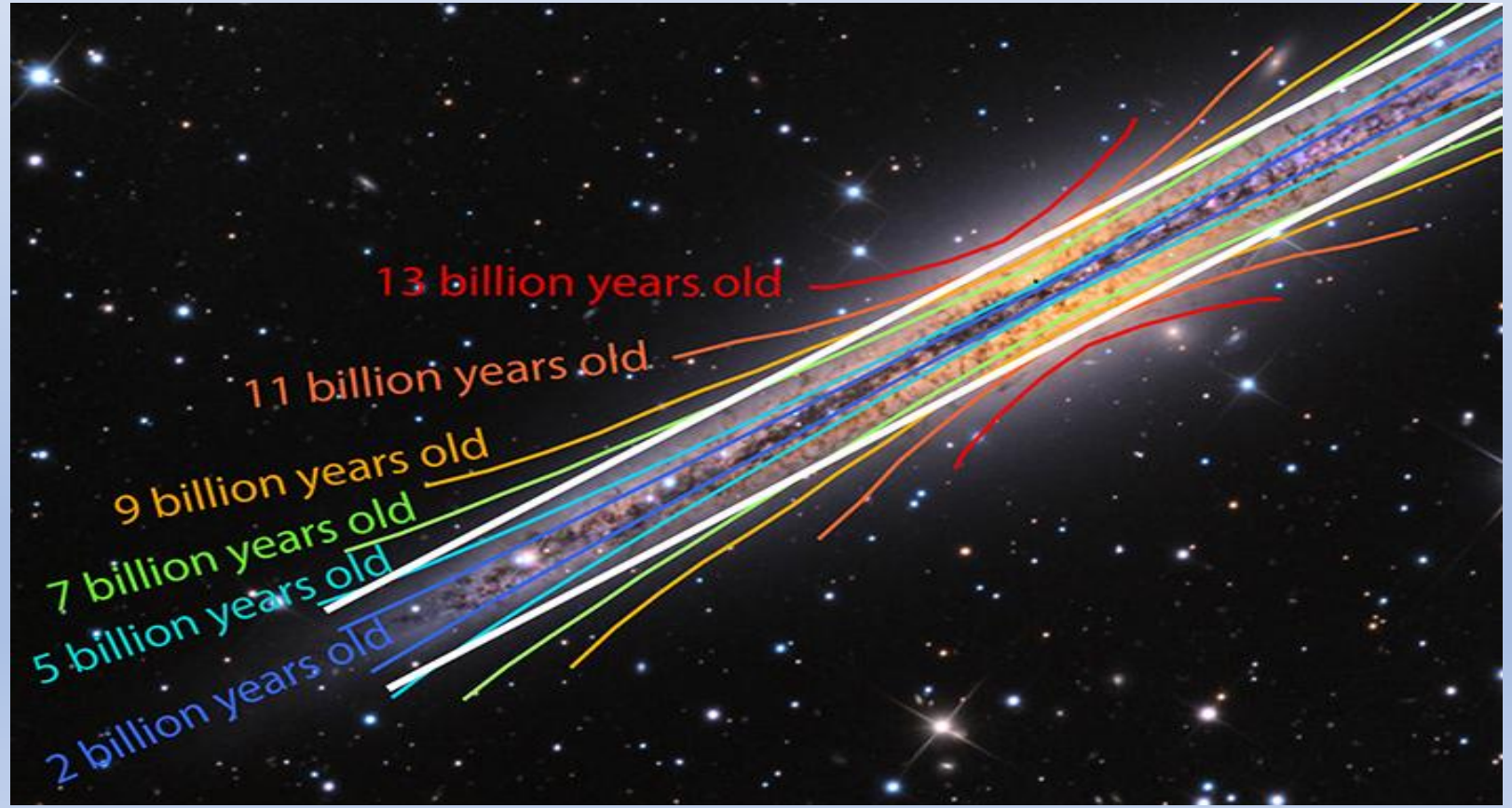
Tot de volgende keer !



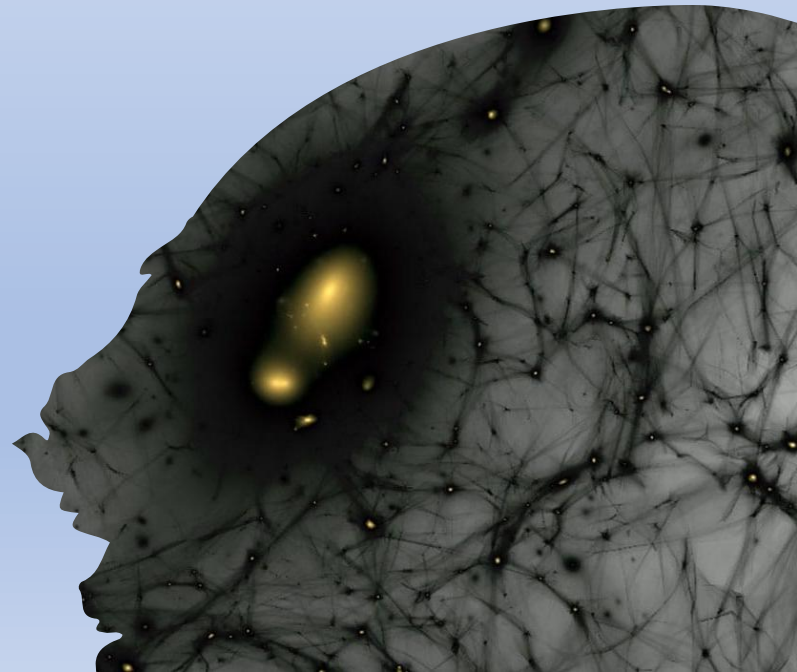
- Archeologie van onze Melkweg



De schijf van NGC 891



- Van de CMB naar sterrenstelsels en clusters van sterrrenstelsels



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