

# 近傍宇宙論/銀河考古学

## 近傍銀河宇宙から探る銀河形成史と 暗黒物質の正体

Near-field Cosmology / Galactic Archaeology

Deciphering the formation histories of  
galaxies and the nature of dark matter from  
the local universe

千葉 枉司  
(東北大学)

Masashi Chiba  
(Tohoku Univ)

<https://www.astr.tohoku.ac.jp/~chiba/lecture/GA2023/index.html>

# Outline

0. Introduction (This chapter)
1. Kinematics and dynamics of Galactic stars
2. Stellar populations and chemical evolution
3. The nature of old Galactic components
4. Galactic dark matter ⇒ Colloquium
5. Formation of Galactic structures
6. Formation and evolution of Local Group galaxies

# References

- Galaxy Formation and Evolution (2010)  
by Mo, van den Bosch & White (Cambridge)
- Galactic Dynamics (2008)  
by Binney & Tremaine (Princeton)
- Nucleosynthesis and Chemical Evolution of Galaxies (1997)  
by Pagel (Cambridge)
- Evolution of Stars and Stellar Populations (2005)  
by Salaris & Cassisi (Wiley)
- シリーズ現代の天文学  
4: 銀河I, 5: 銀河II, 7: 恒星 (日本評論社)
- 銀河考古学 (Galactic Archaeology) (2015)  
by 千葉 (日本評論社)

# Local Universe



**Andromeda**

Sendai



**Milky Way**

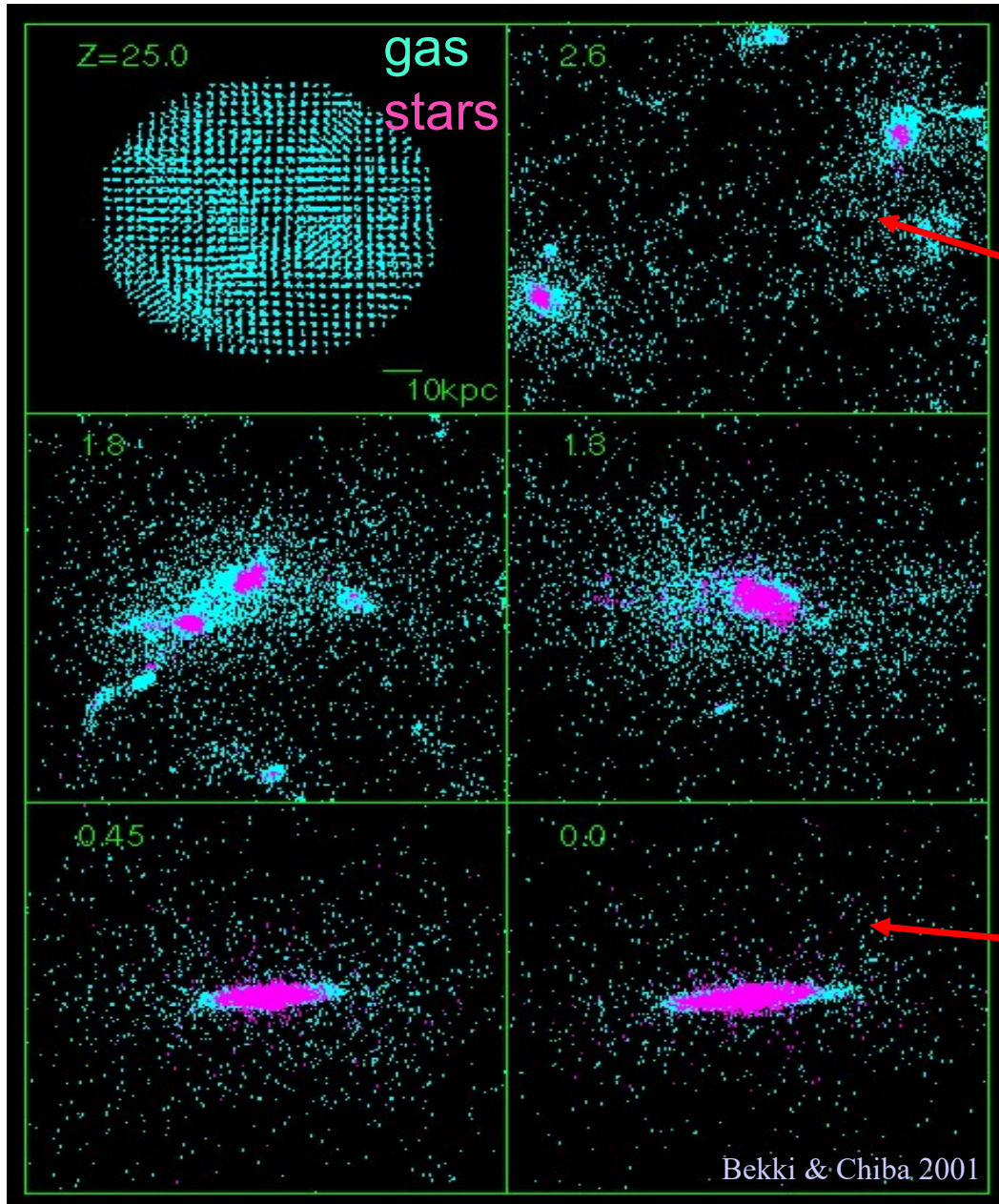
# *Our Galaxy*



Andromeda

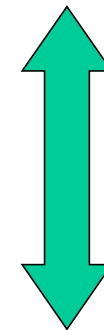
Magellanic clouds

Template for understanding the  
formation and evolution of galaxies



**Galaxy formation and evolution**

**High-z universe (snapshots of various galaxies)**



complementary

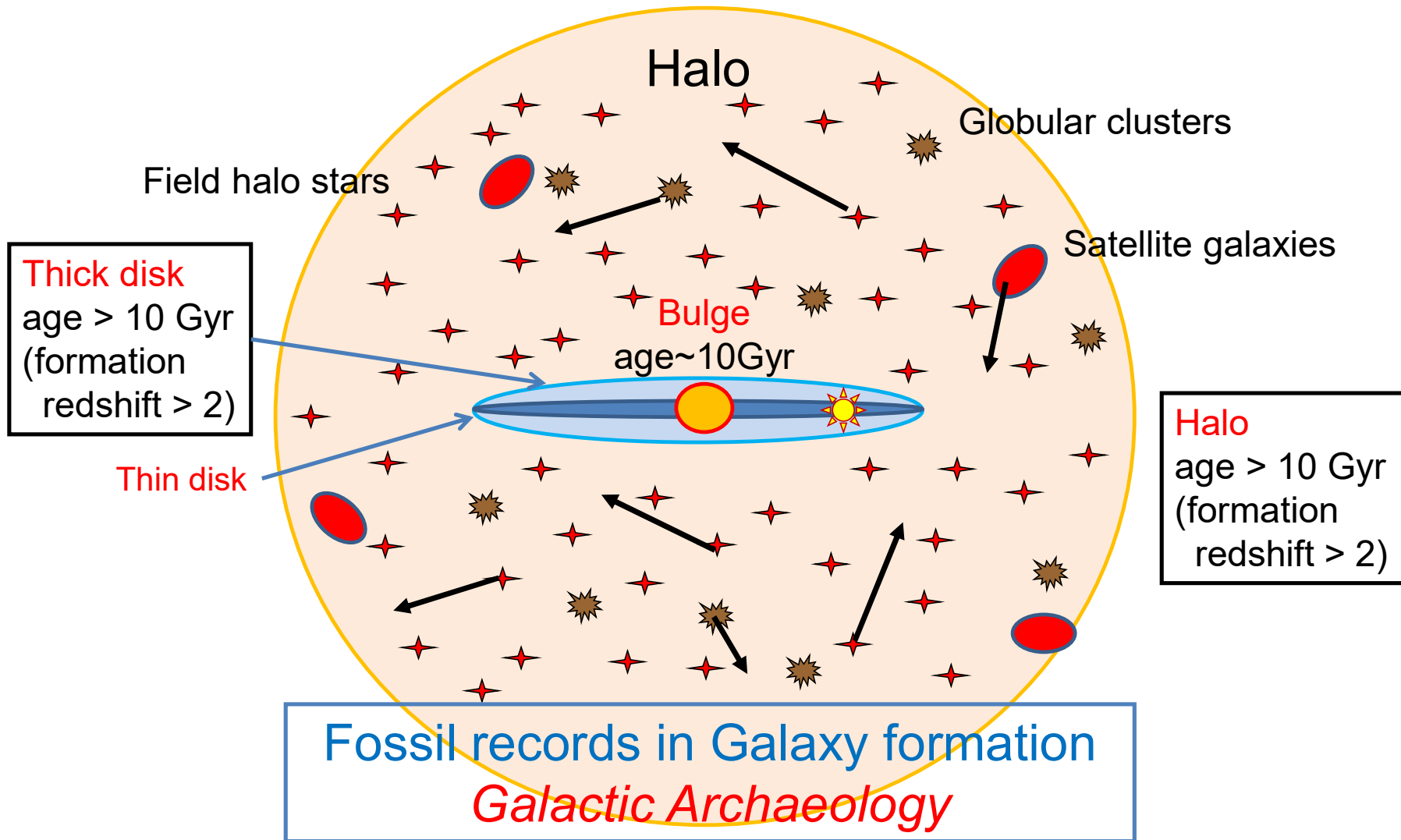
**Stellar system in local universe (tracing evolution of a galaxy)**

## Near-field cosmology based on resolved stellar system

- **Photometry:** magnitude, color (→ color-magnitude diagram : CMD, color-color diagram)
- **Spectroscopy:** metallicity (→ age from CMD), chemical abundance pattern (→ star formation history & chemical evolution), radial velocity (→ 1D kinematics)
- **Astrometry:** proper motion & distance (→ information on 6-dimensional phase space)

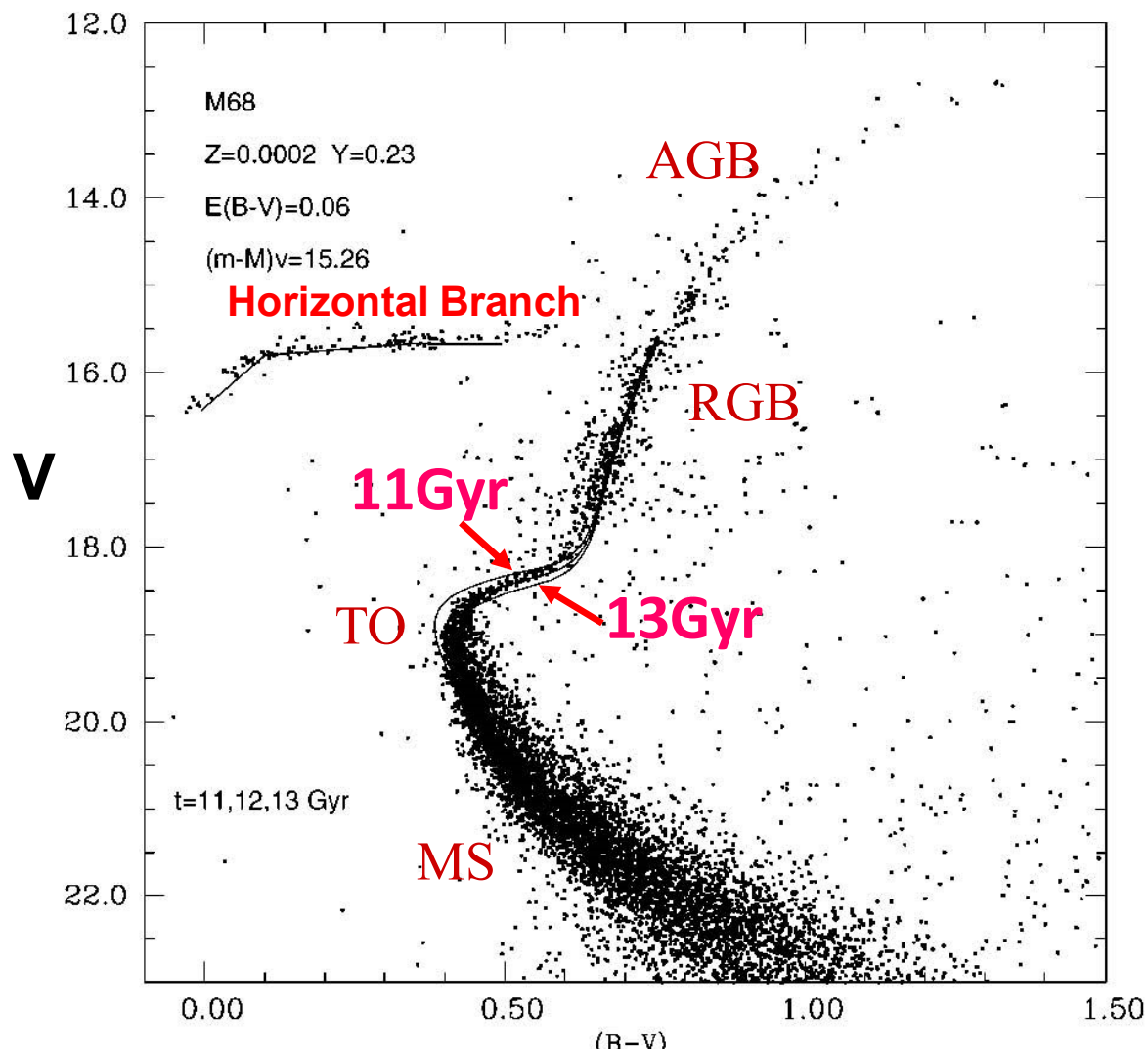
- Formation history of galaxies  
- Nature of dark matter

# Old stellar components





# Color-magnitude diagram (CMD) of the globular cluster : M68

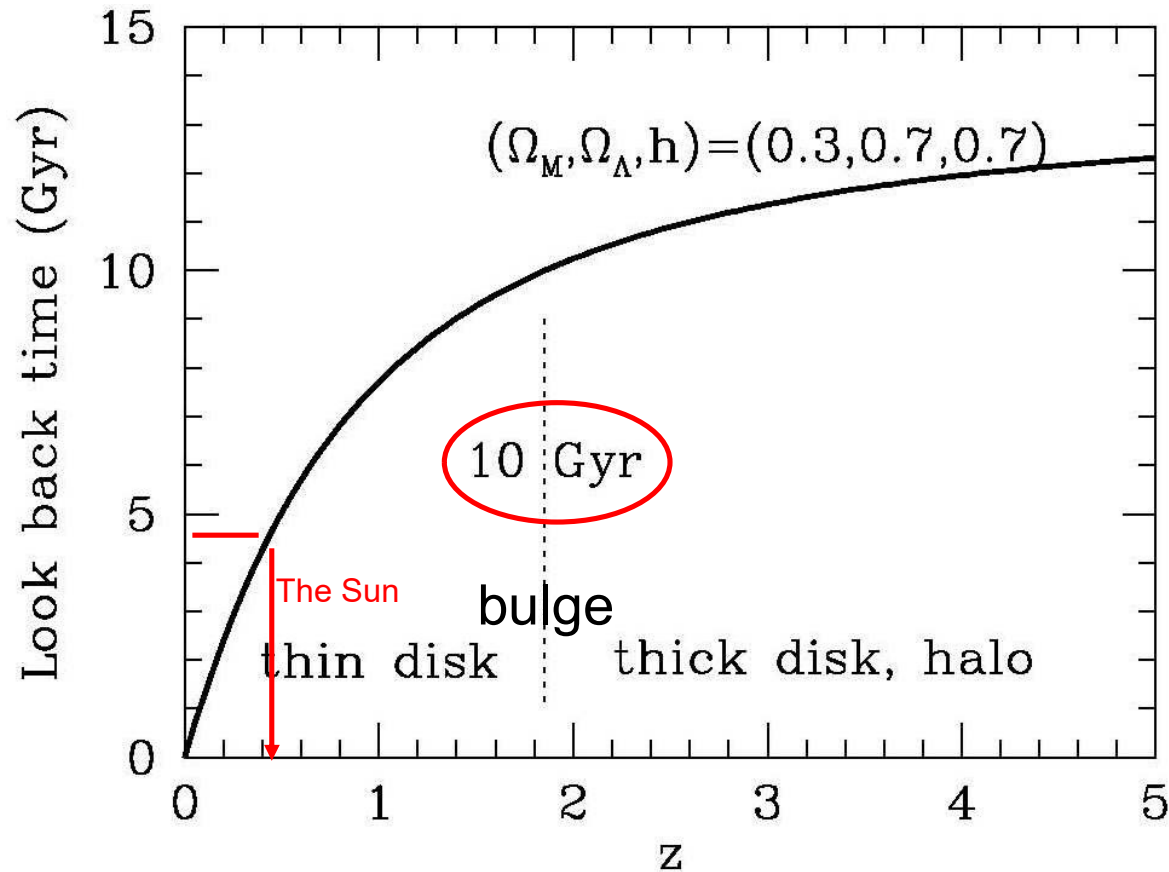


**SF 12 Gyr ago  
& stopped**

CMD tells us the  
formation history  
of a stellar system

**B-V**

## Lookback formation time of stellar components

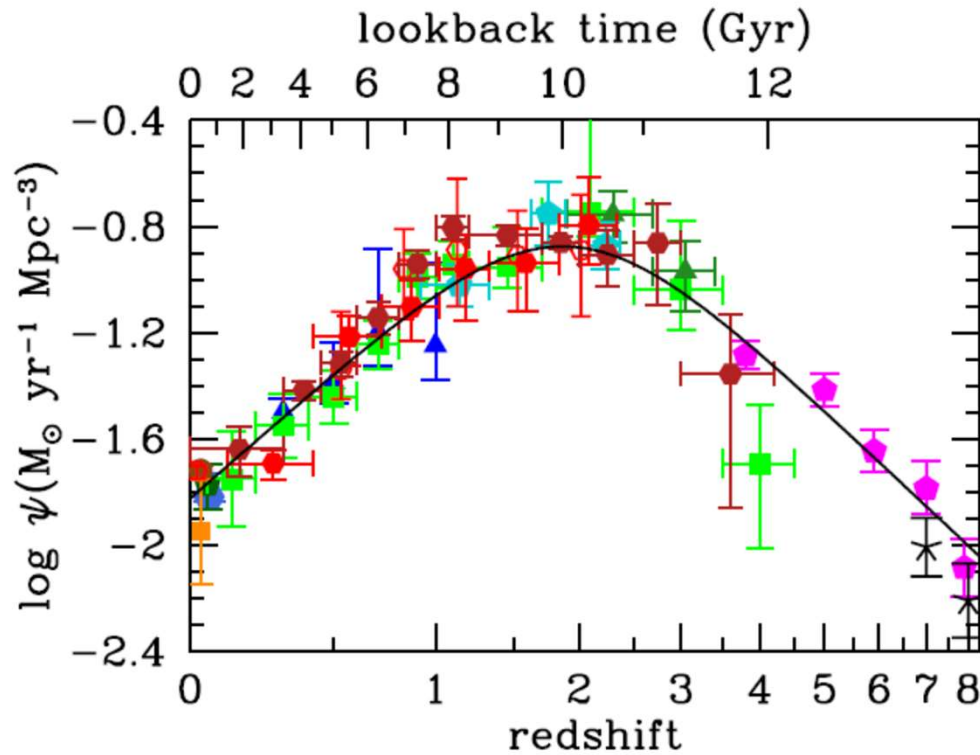


Fossil records of galaxy formation  
⇒ Near-field cosmology

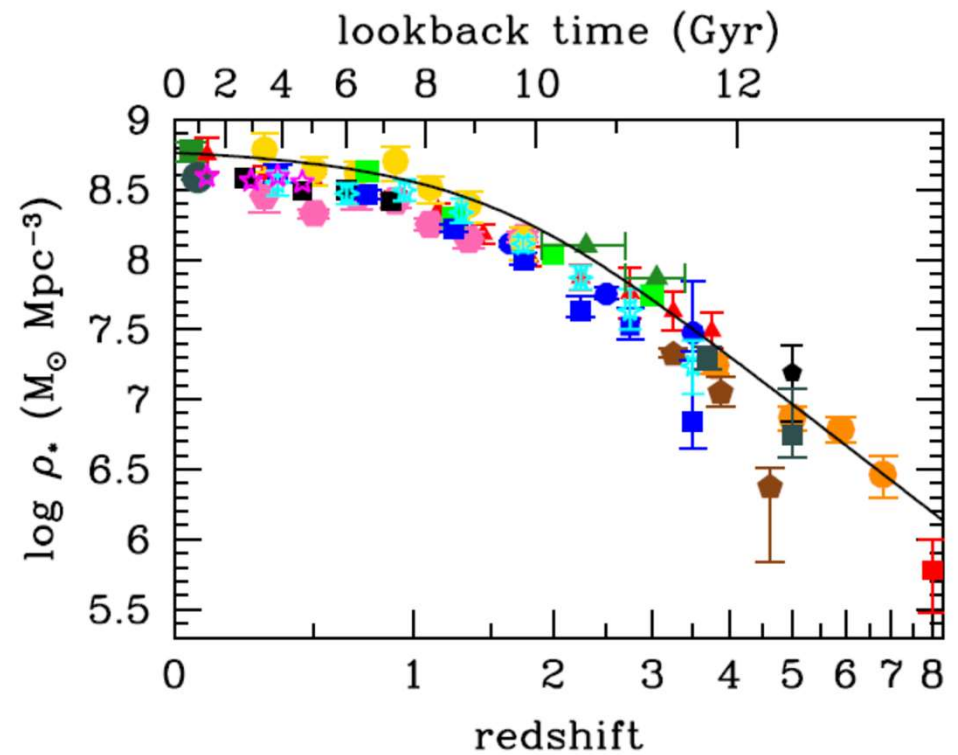
# Cosmic star formation history

Madau & Dickinson (2014)

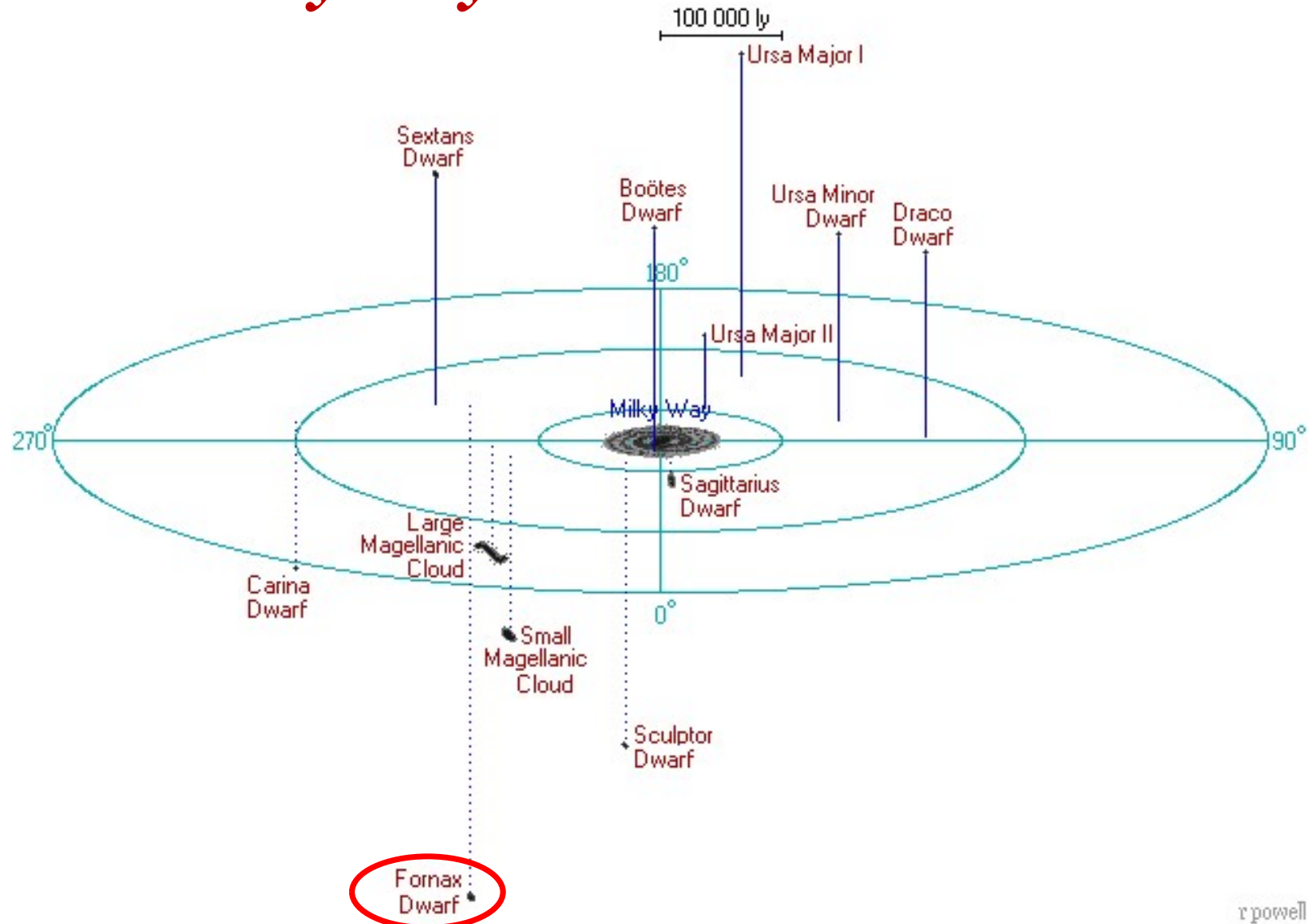
Star Formation Rate Density evolution



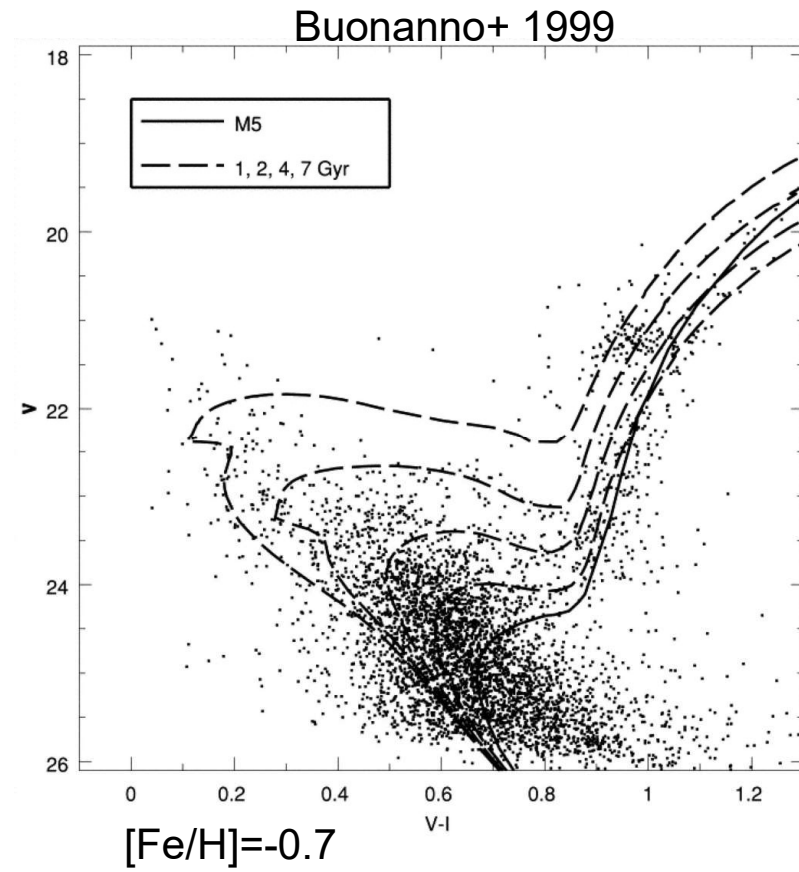
Stellar Mass Density evolution



# *Milky Way & Galactic satellites*



# Fornax dwarf spheroidal galaxy ( $D=138$ kpc)



# Dwarf galaxies

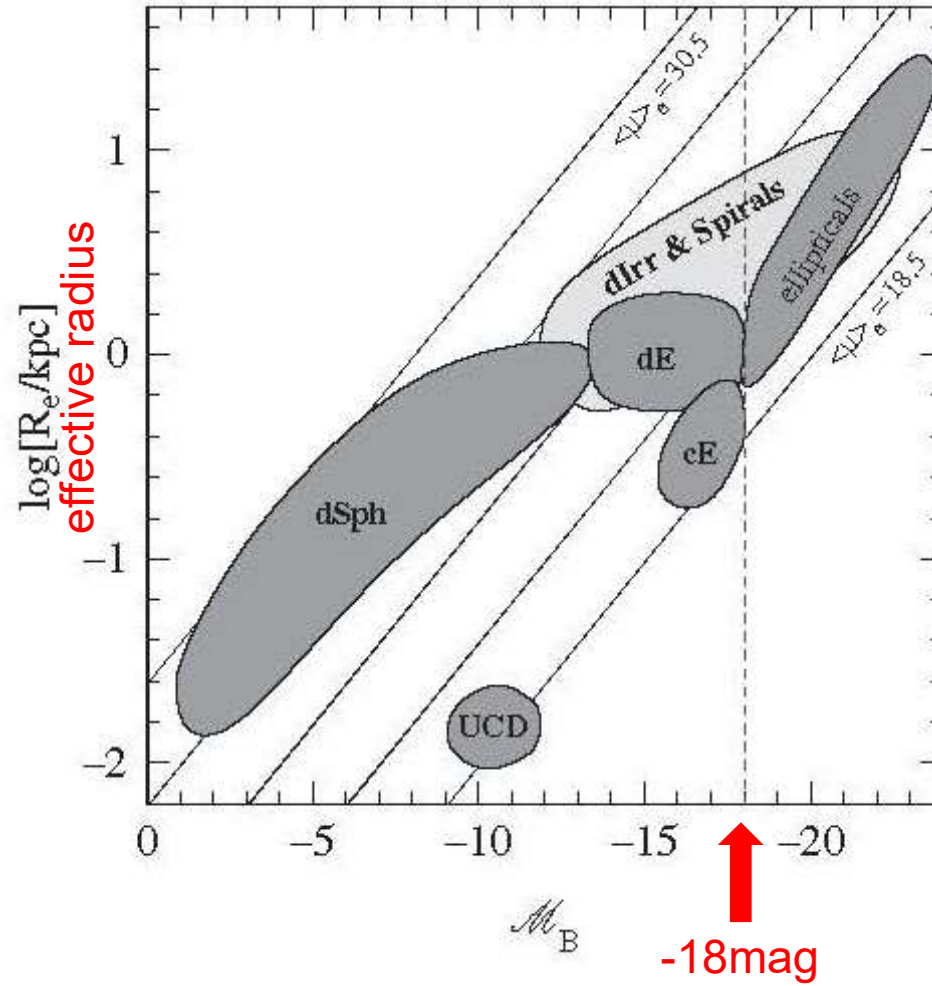
dwarf spheroidal galaxies  
(dSphs 矮小橢圓體銀河)



Leo I



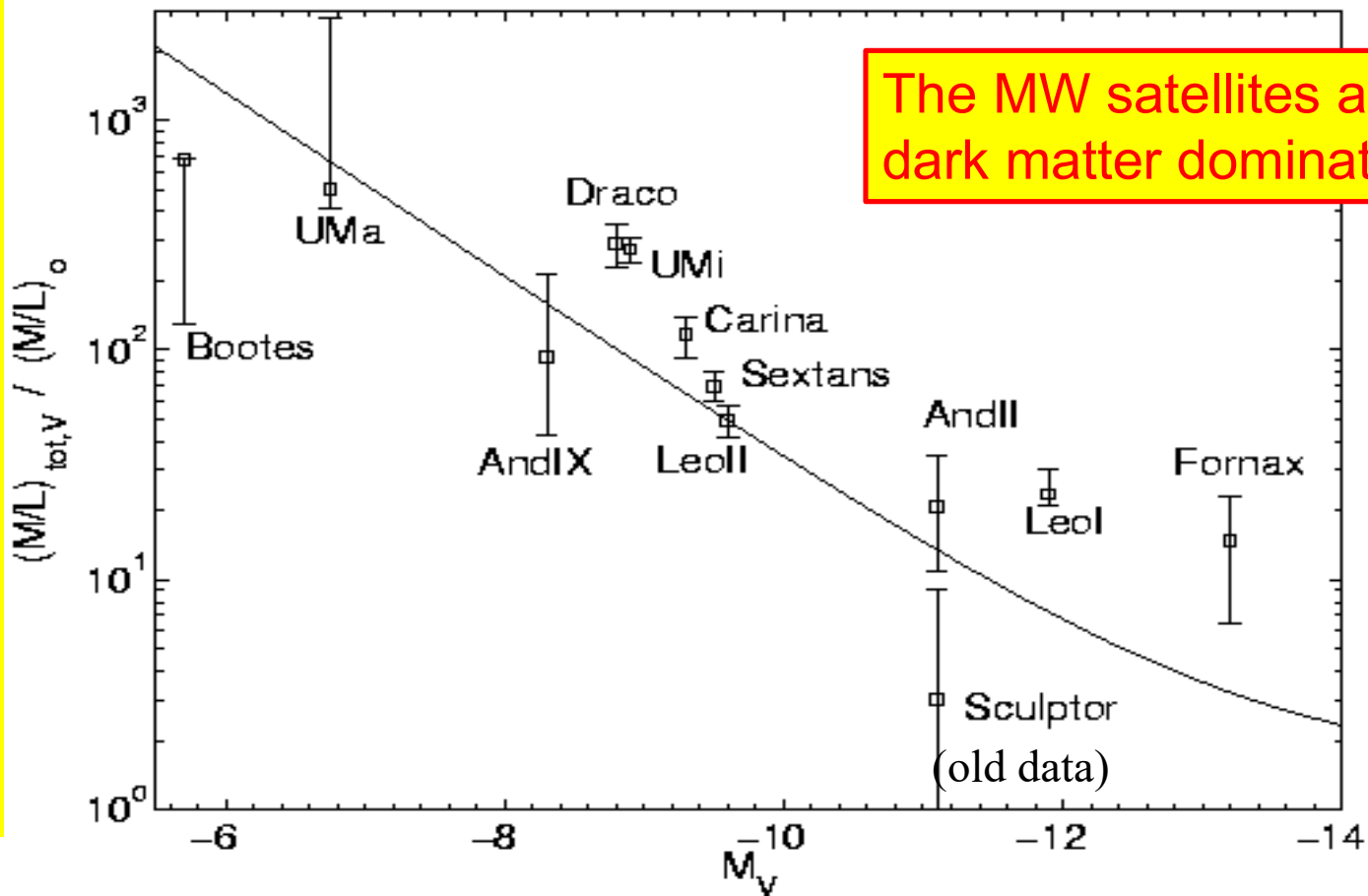
Carina



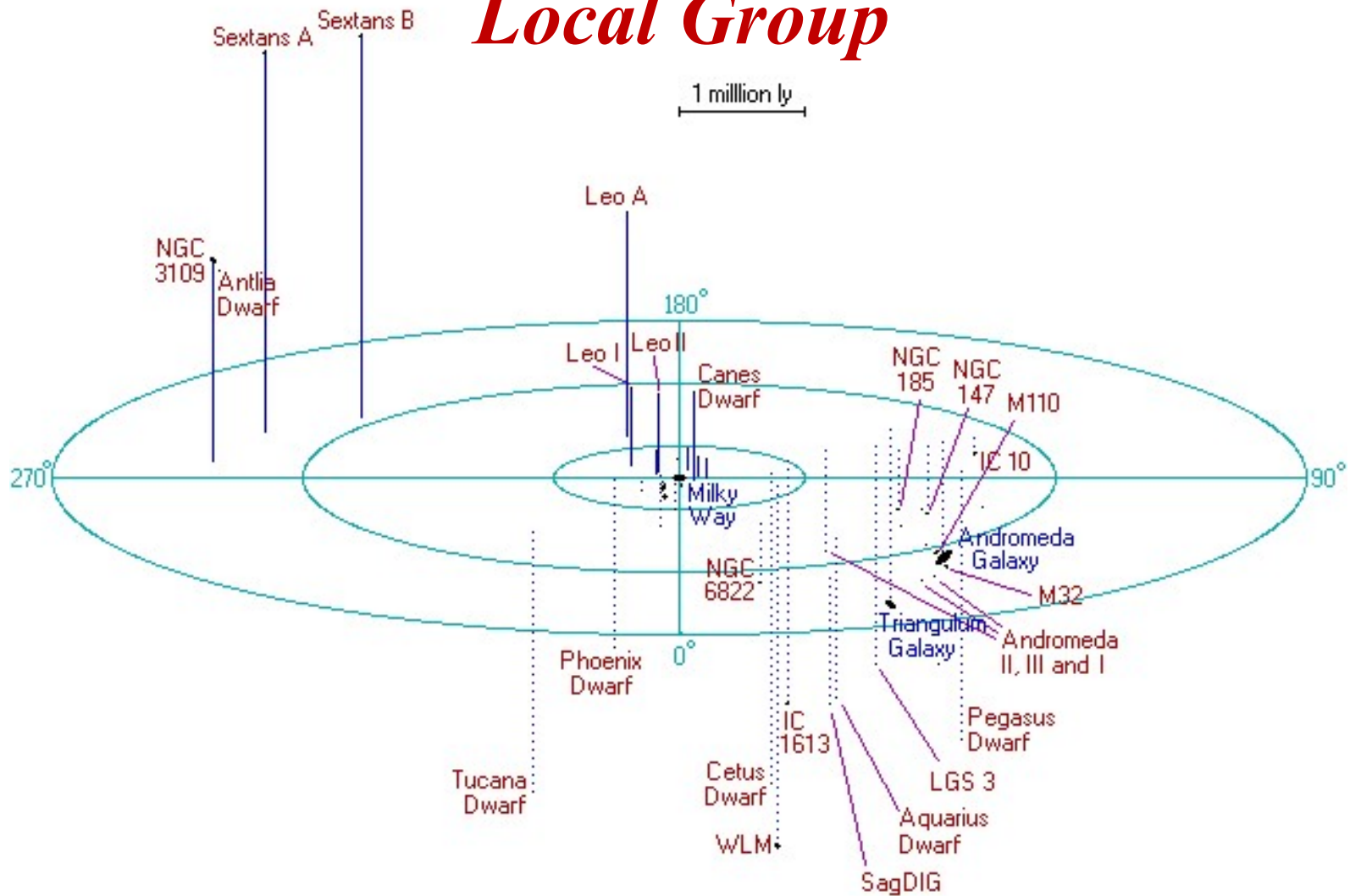
# Dark matter in the MW dwarf satellites

(Mass enclosed within stellar extent  $\sim 4 \times 10^7 M_{\odot}$ )

Mass ratio between DM and stars



# Local Group





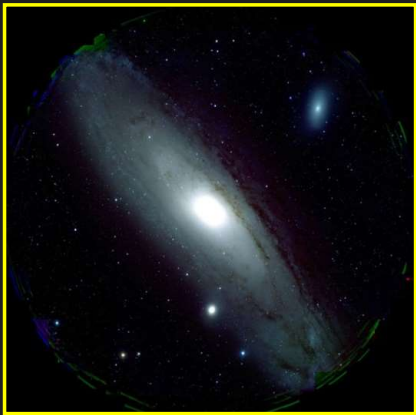
# Stellar halos in M31/M33

PAndAS survey

[Fe/H]  $\sim -2.3$

[Fe/H]  $\sim -1.4$

[Fe/H]  $\sim -0.7$



$R_{M33} \sim 50 \text{ kpc}$

Northern Spur

M31

North Western Stream

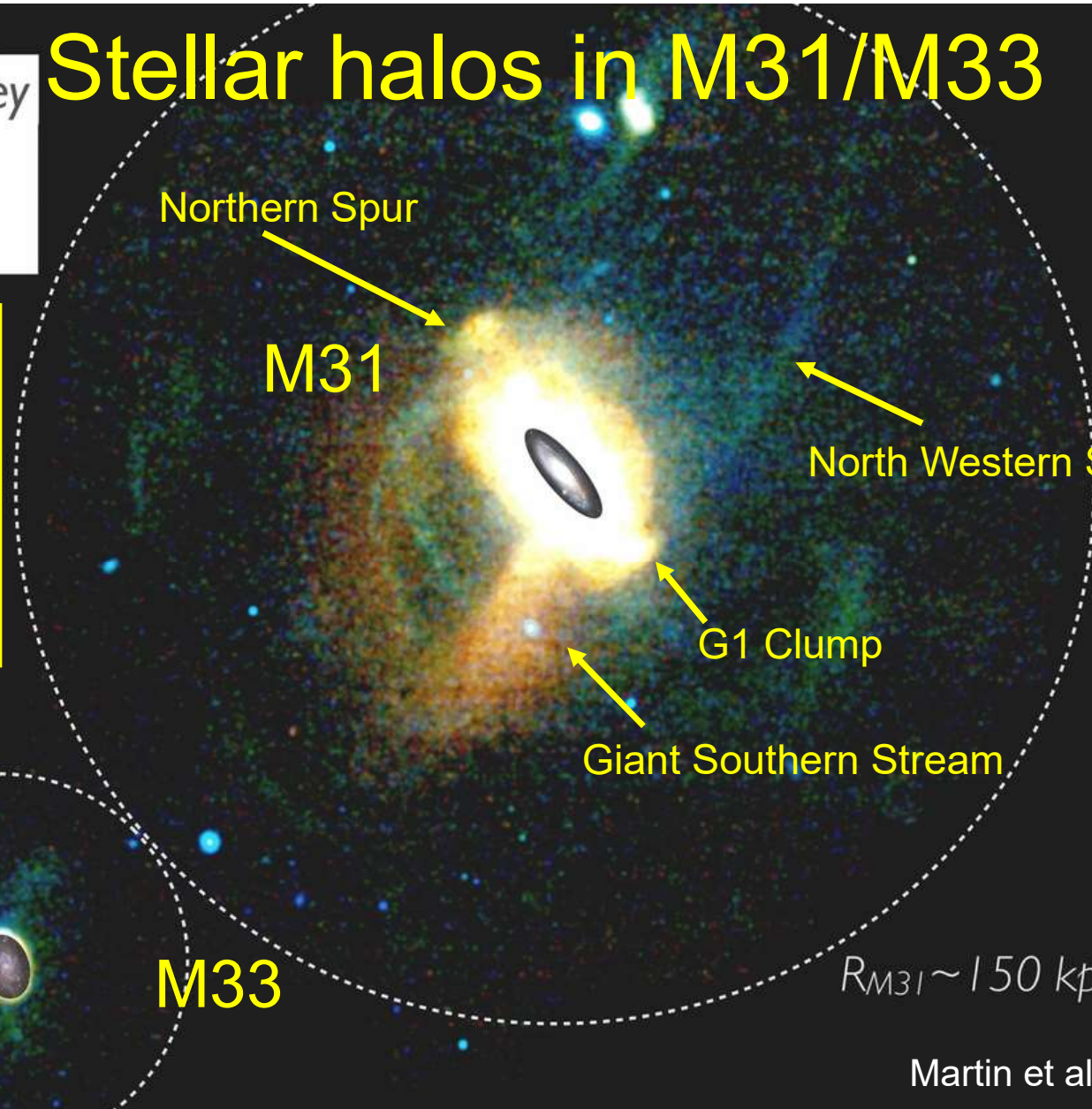
G1 Clump

Giant Southern Stream

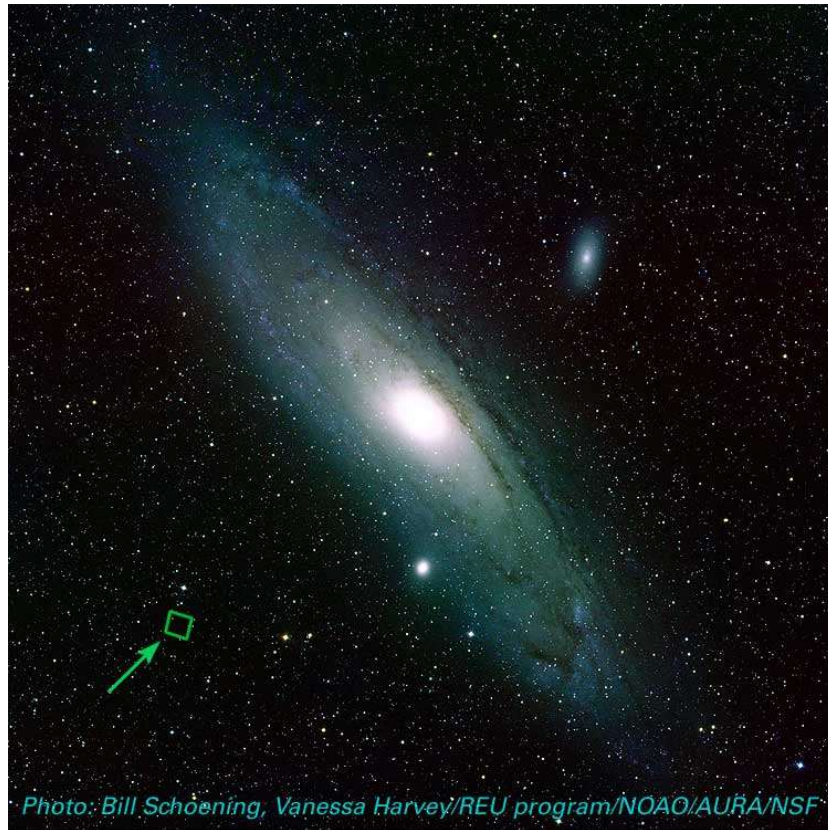
M33

$R_{M31} \sim 150 \text{ kpc}$

Martin et al. 2013

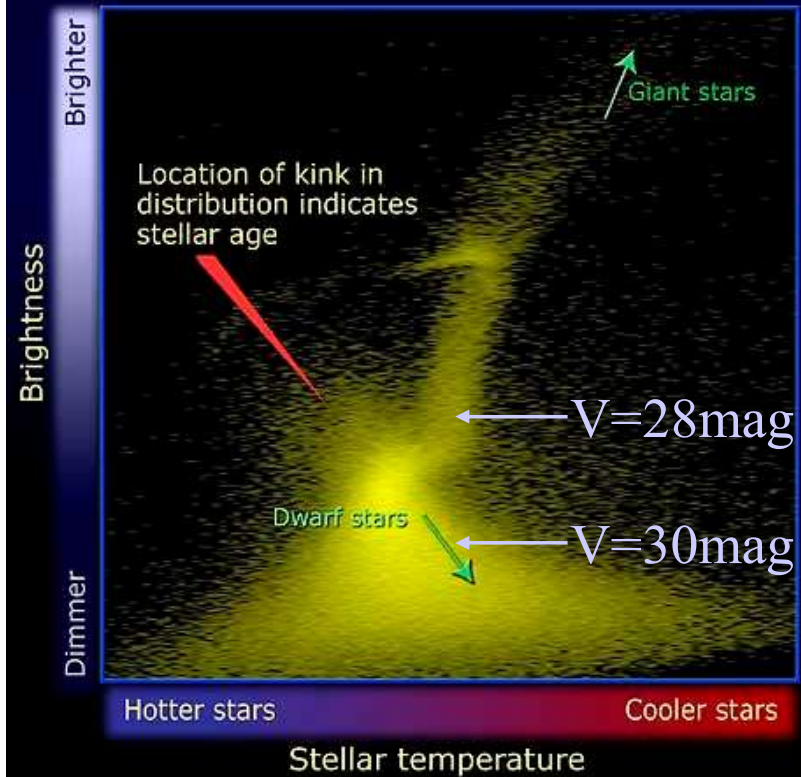


# ACS/HST photometry of M31's halo (using 120 HST orbits!)



Hubble Space Telescope helps scientists track stellar population in M31 halo

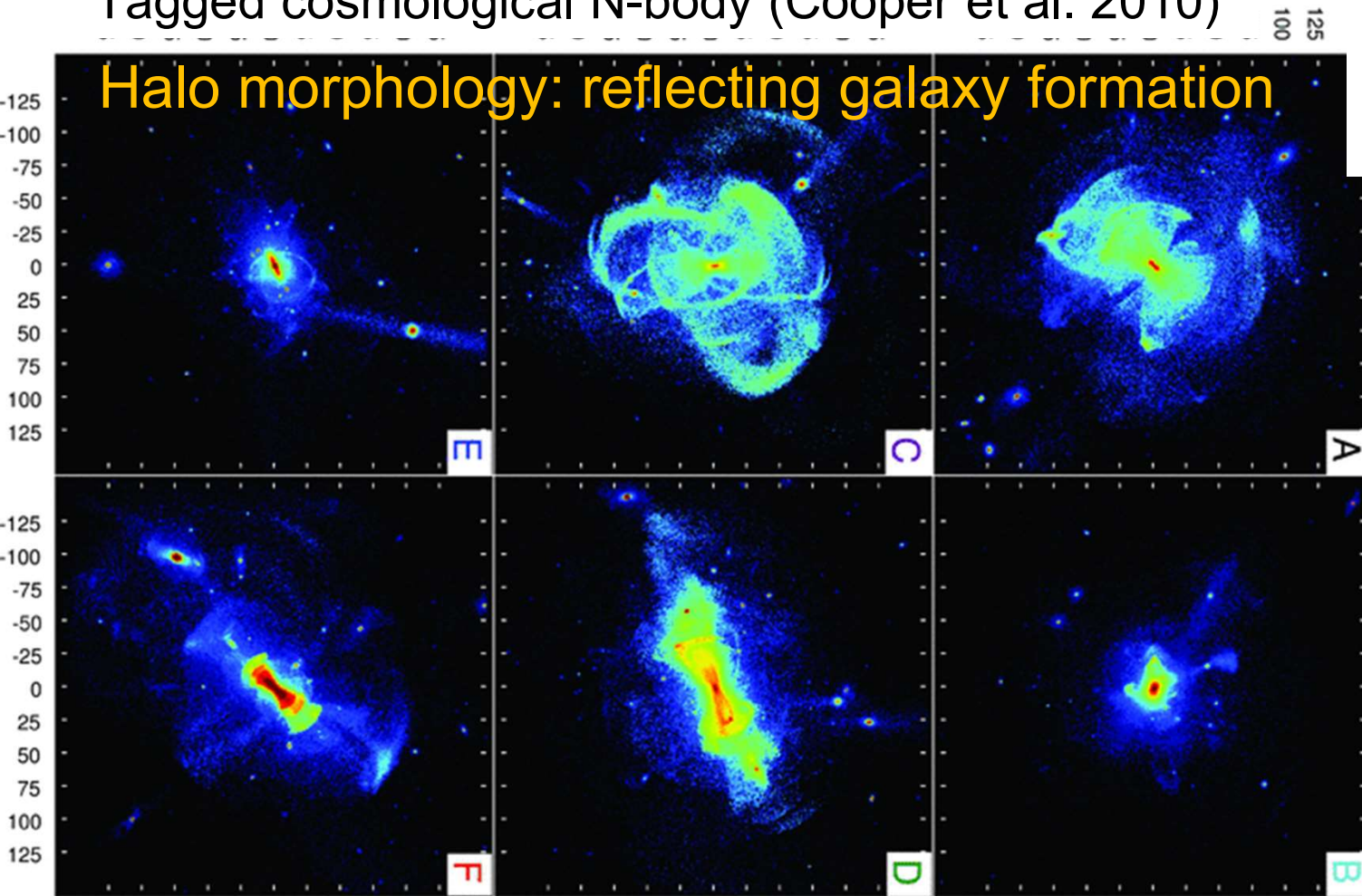
Stars in M31 halo have a wider age range (6–13 billion years) than those in the Milky Way halo (11–13 billion years).



# Comparison with $\Lambda$ CDM models

Tagged cosmological N-body (Cooper et al. 2010)

Halo morphology: reflecting galaxy formation



Cosmological hydrodynamics  
(Sanders et al. 2020)

