

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

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<https://www.astr.tohoku.ac.jp/~chiba/lecture/GA2024/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
7. Future prospects

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

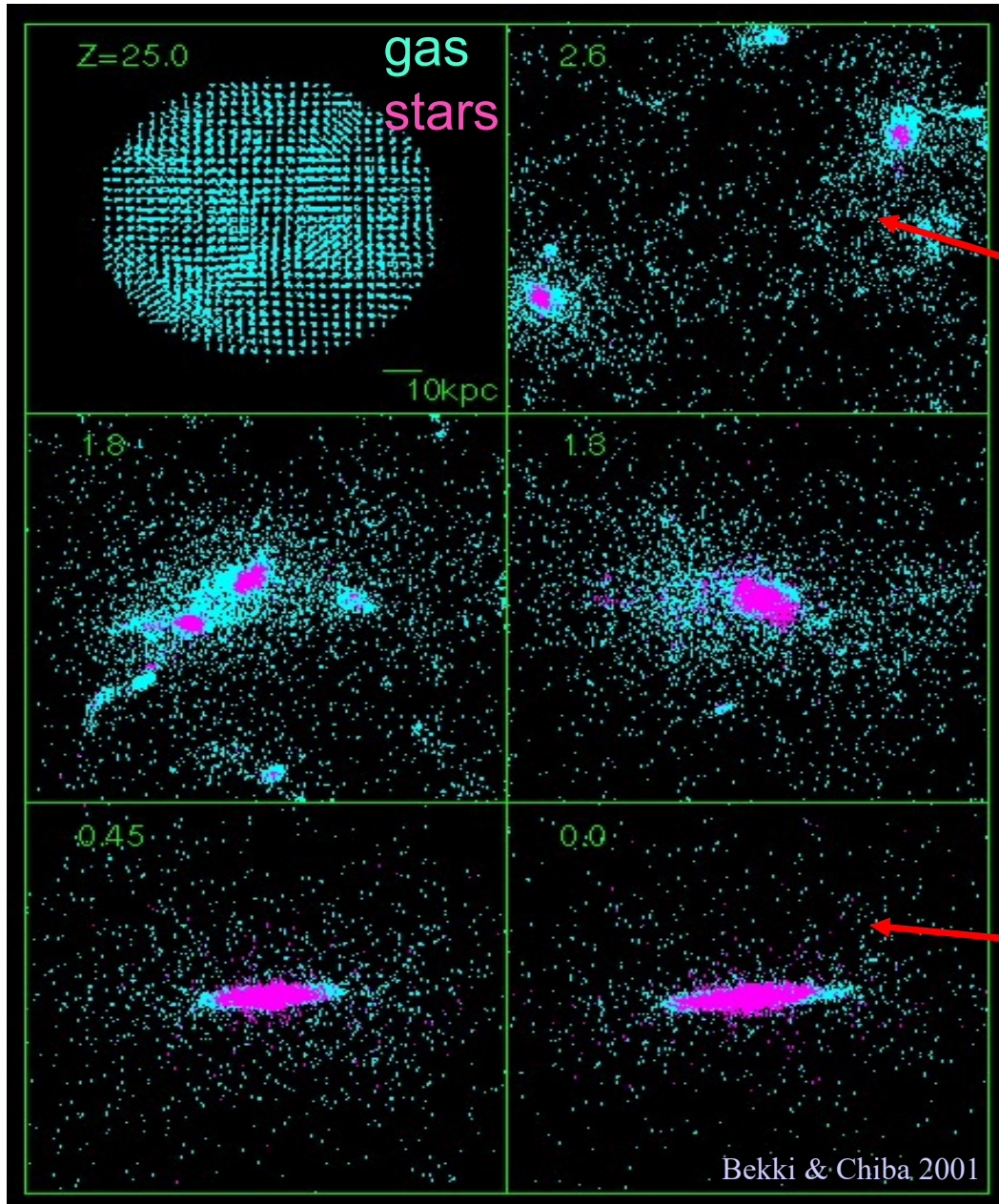
Our Galaxy



Andromeda

Magellanic clouds

Template for understanding the
formation and evolution of galaxies



Galaxy formation and evolution

High-z universe (snapshots of various galaxies)



complementary

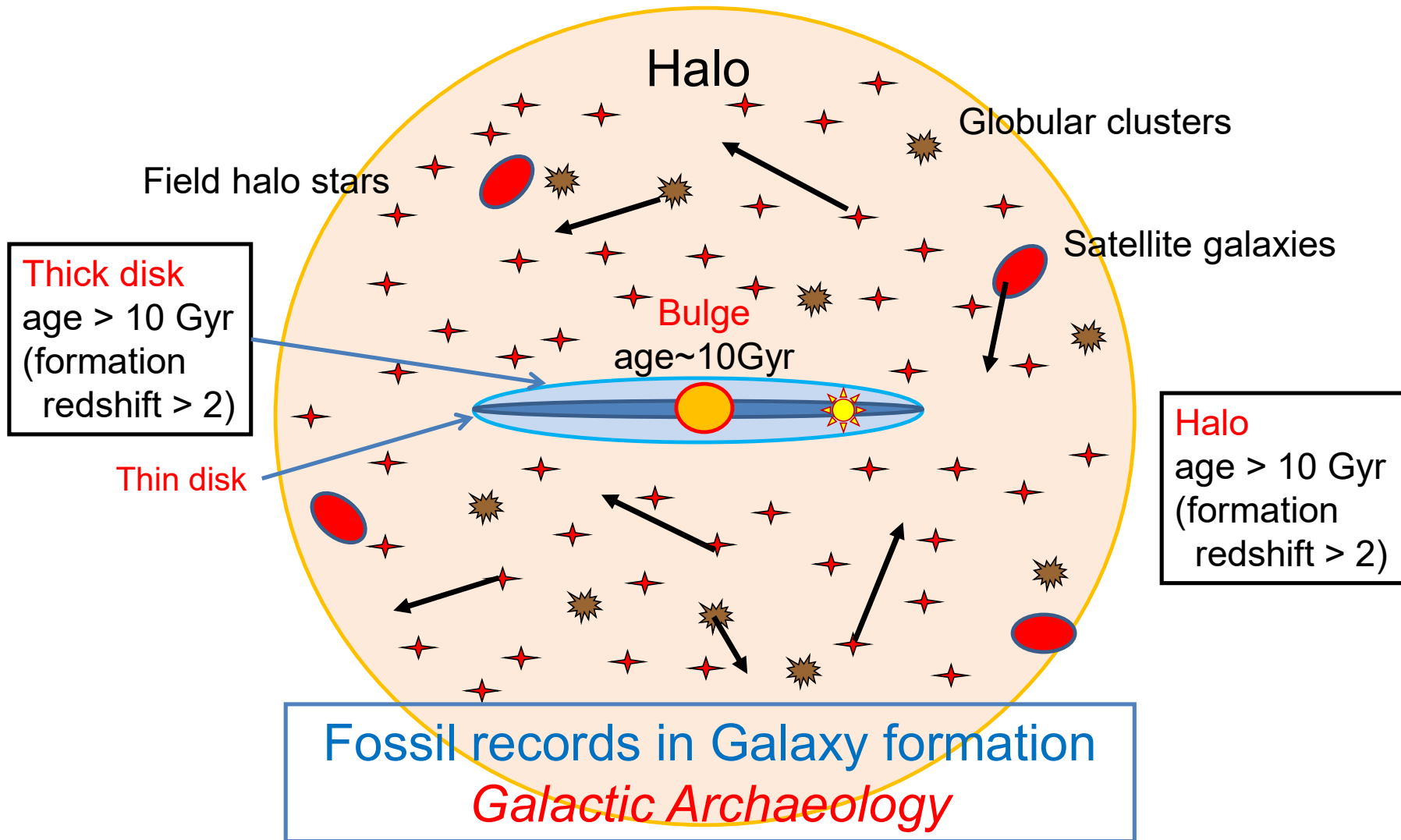
Stellar system in local universe (tracing evolution of a galaxy)

Near-field cosmology based on resolved stellar system

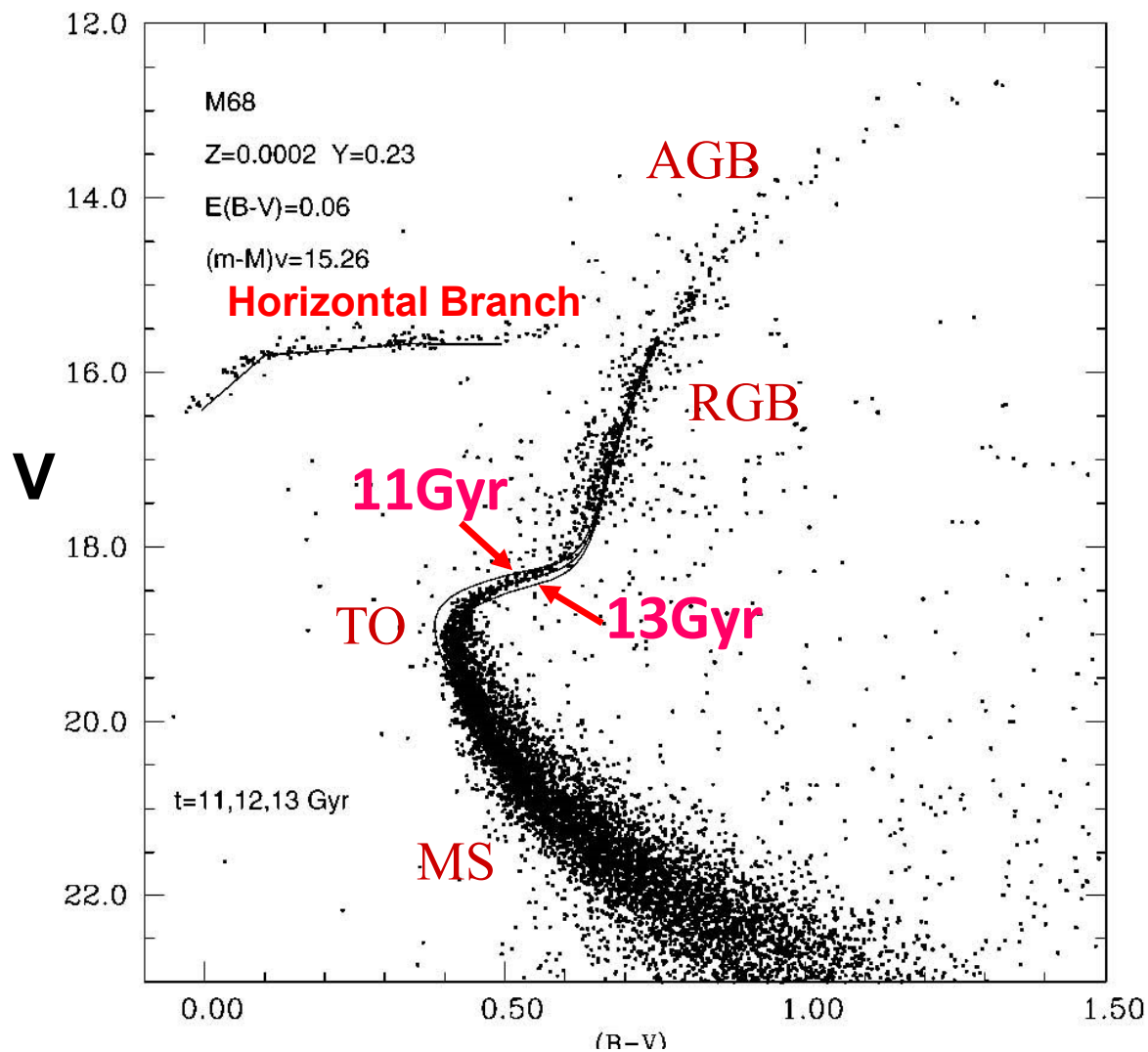
- **Photometry:** magnitude, color (→ color-magnitude diagram : CMD, color-color diagram)
- **Spectroscopy:** metallicity (→ age from CMD), chemical abundance pattern (→ star formation history & chemical evolution), radial velocity (→ 1D kinematics)
- **Astrometry:** proper motion & distance (→ information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

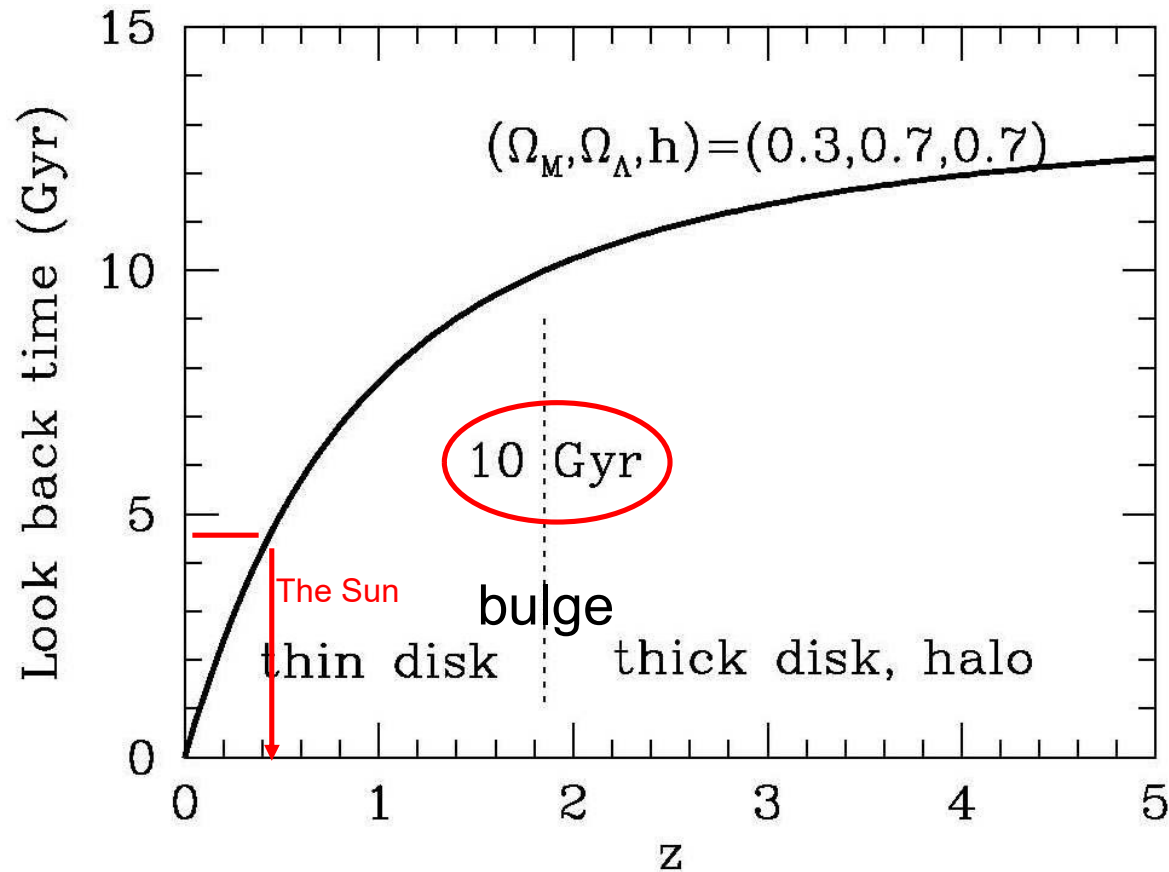


**SF 12 Gyr ago
& stopped**

CMD tells us the
formation history
of a stellar system

B-V

Lookback formation time of stellar components

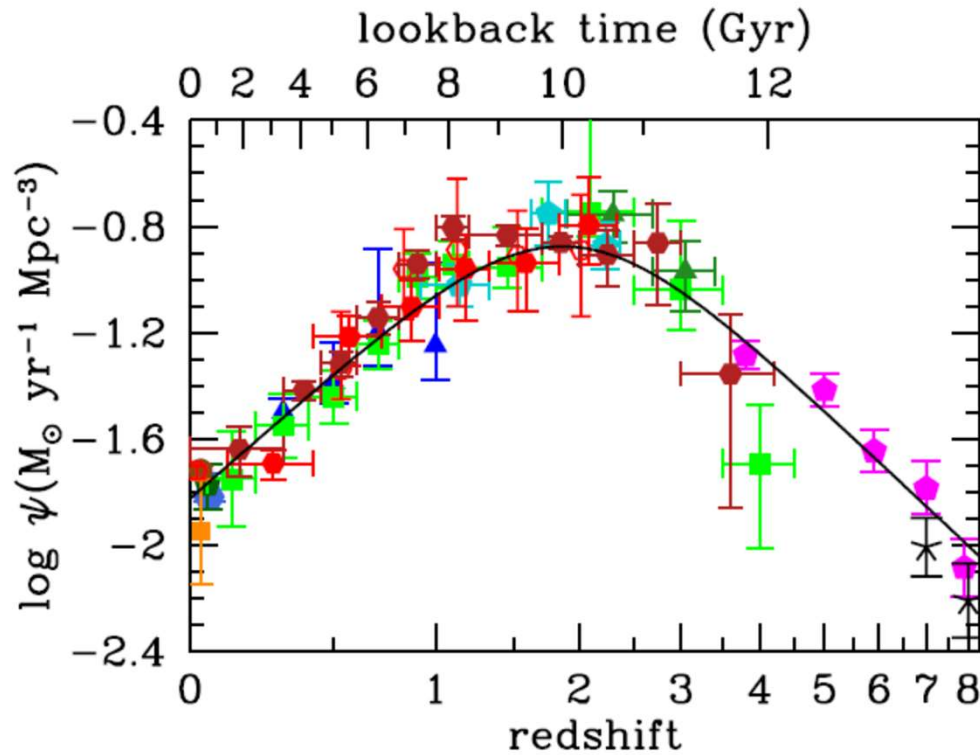


Fossil records of galaxy formation
⇒ Near-field cosmology

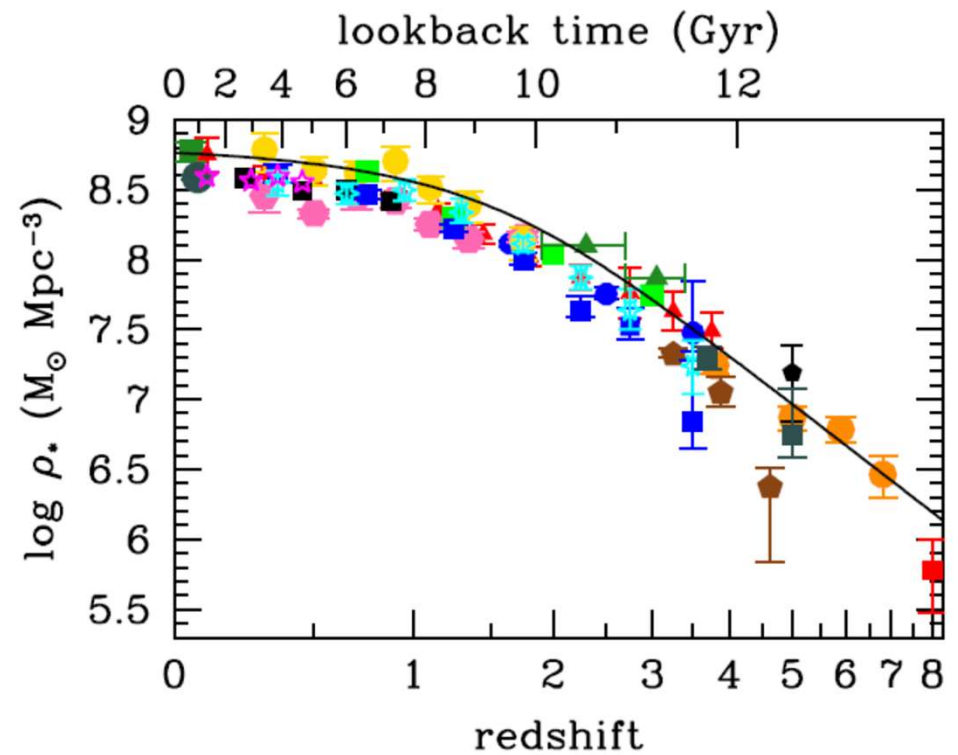
Cosmic star formation history

Madau & Dickinson (2014)

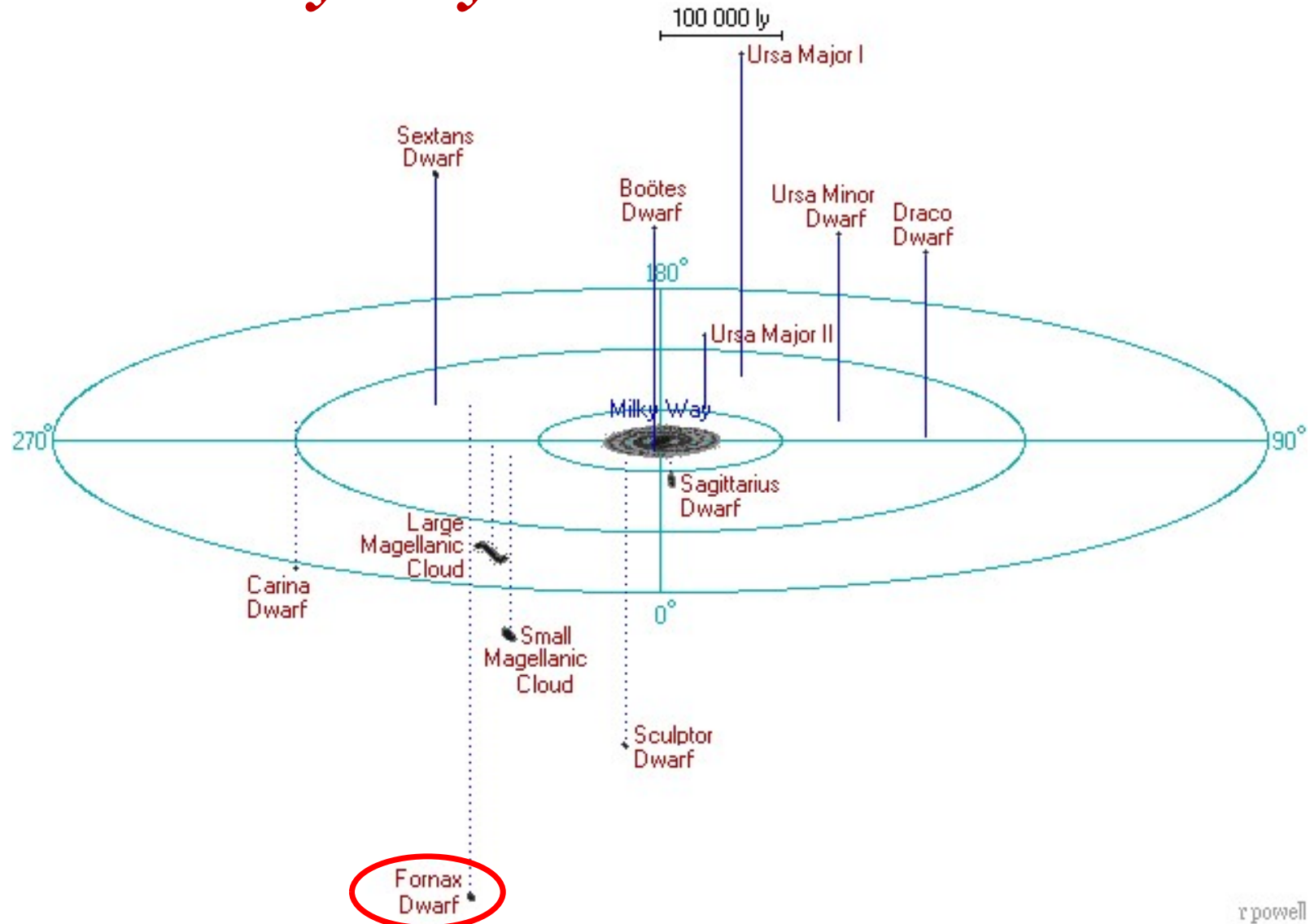
Star Formation Rate Density evolution



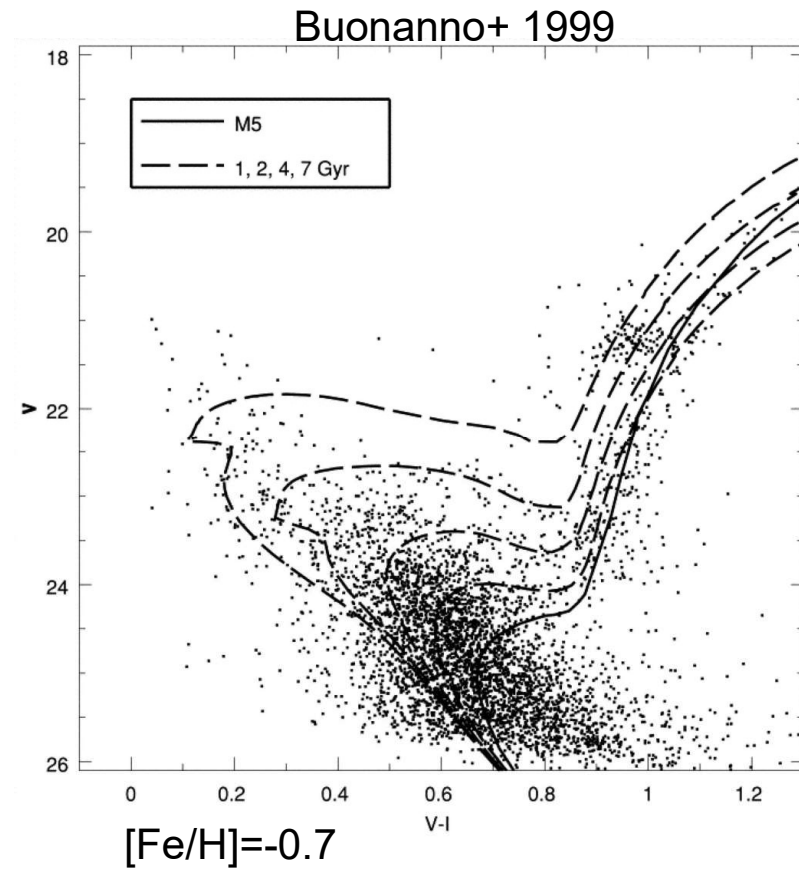
Stellar Mass Density evolution



Milky Way & Galactic satellites



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



Dwarf galaxies

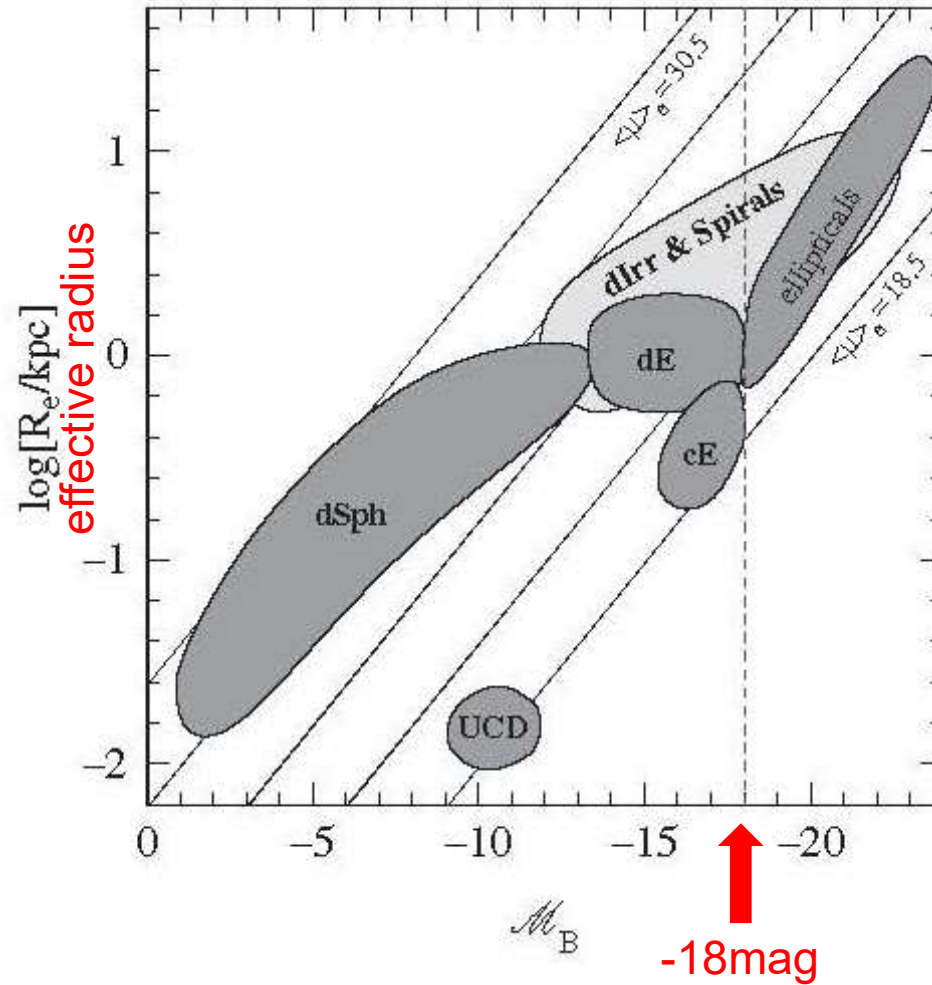
dwarf spheroidal galaxies
(dSphs 矮小橢圓體銀河)



Leo I



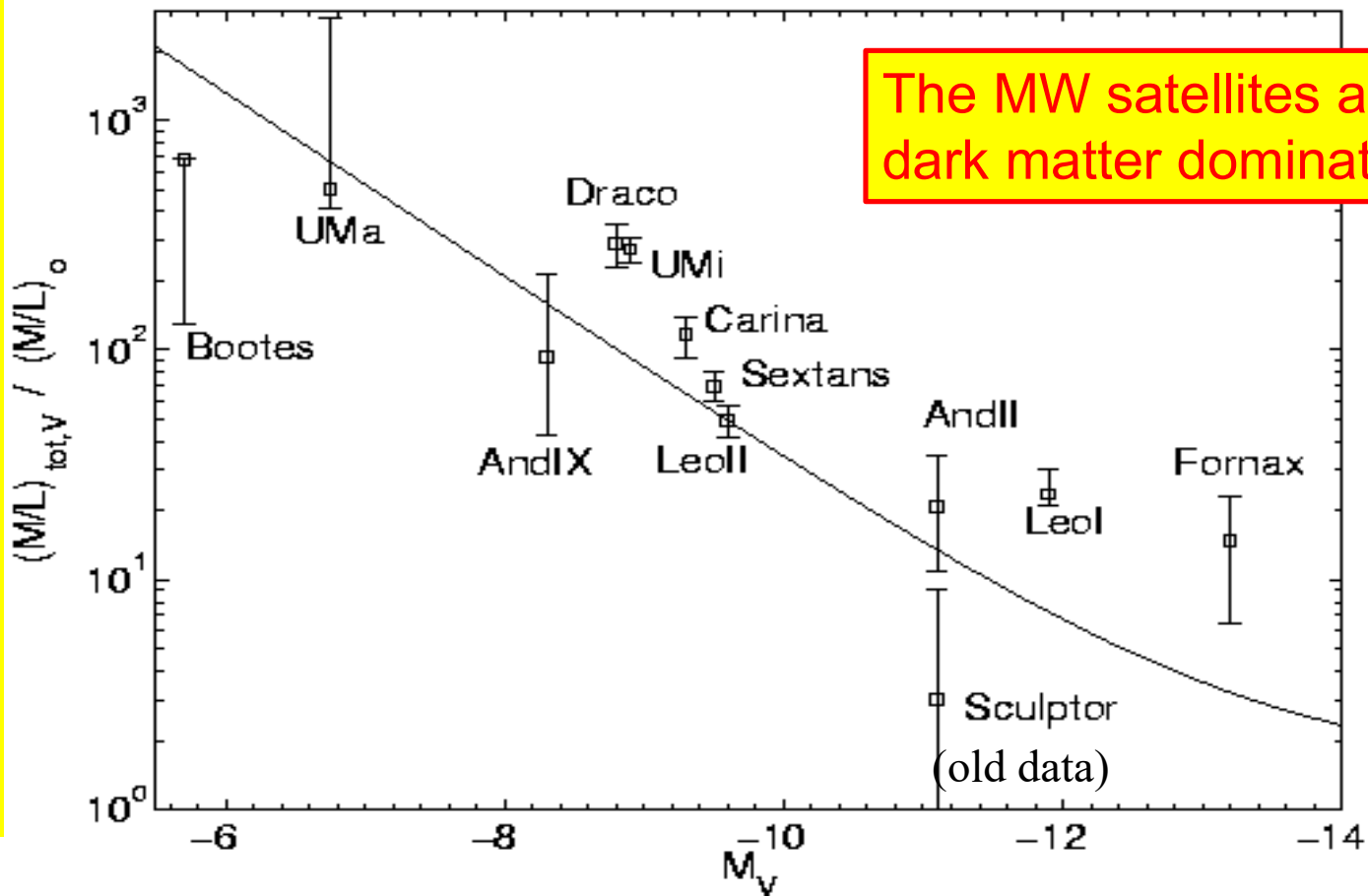
Carina



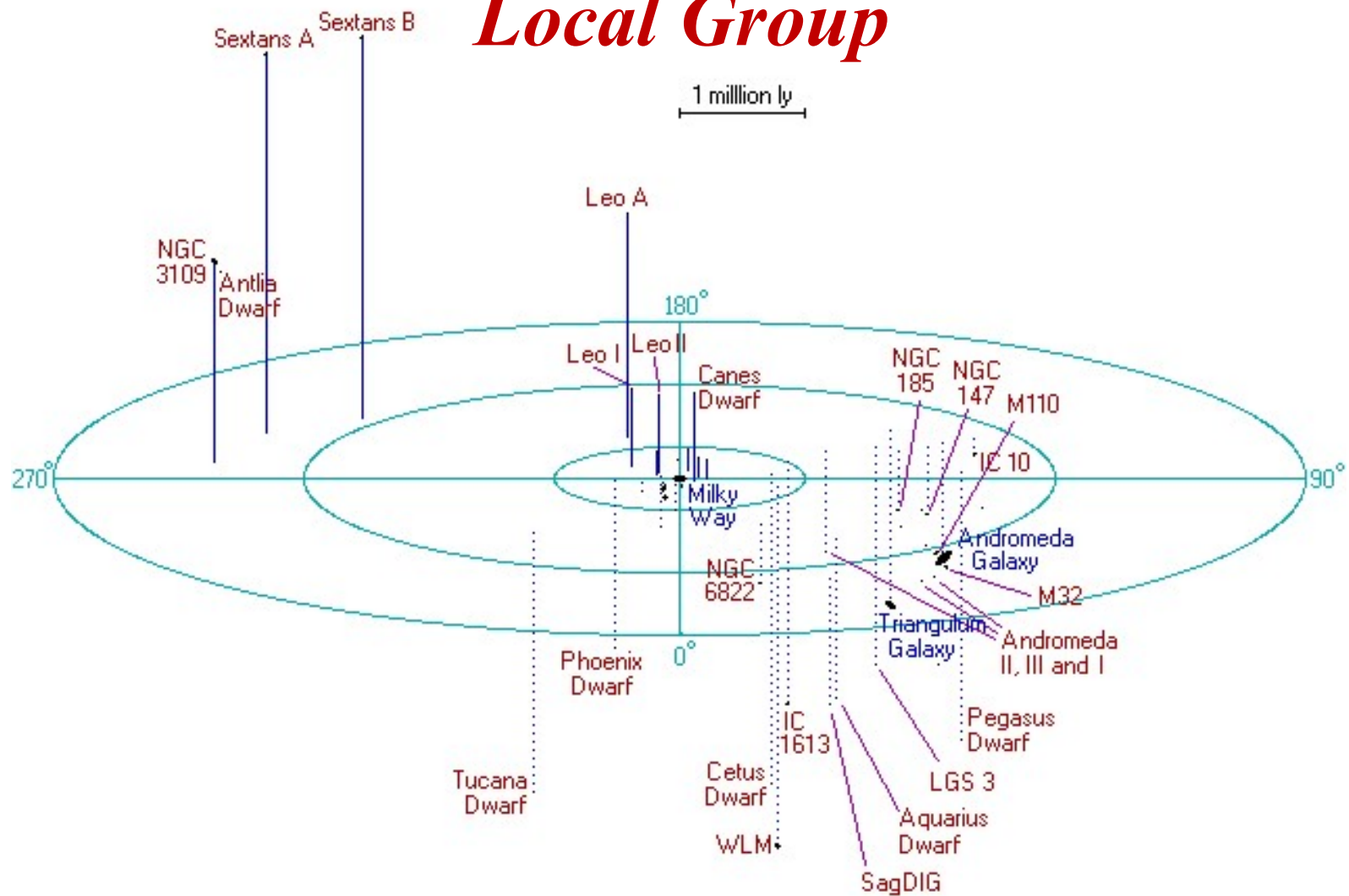
Dark matter in the MW dwarf satellites

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

Mass ratio between DM and stars



Local Group



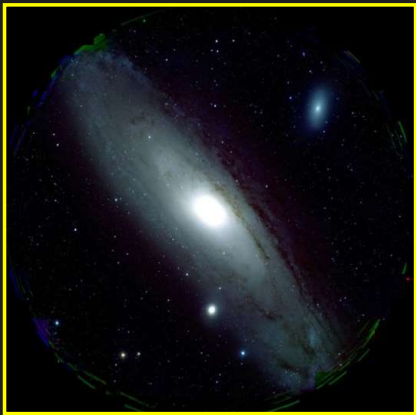
Stellar halos in M31/M33

PAndAS survey

[Fe/H] ~ -2.3

[Fe/H] ~ -1.4

[Fe/H] ~ -0.7



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

Northern Spur

M31

North Western Stream

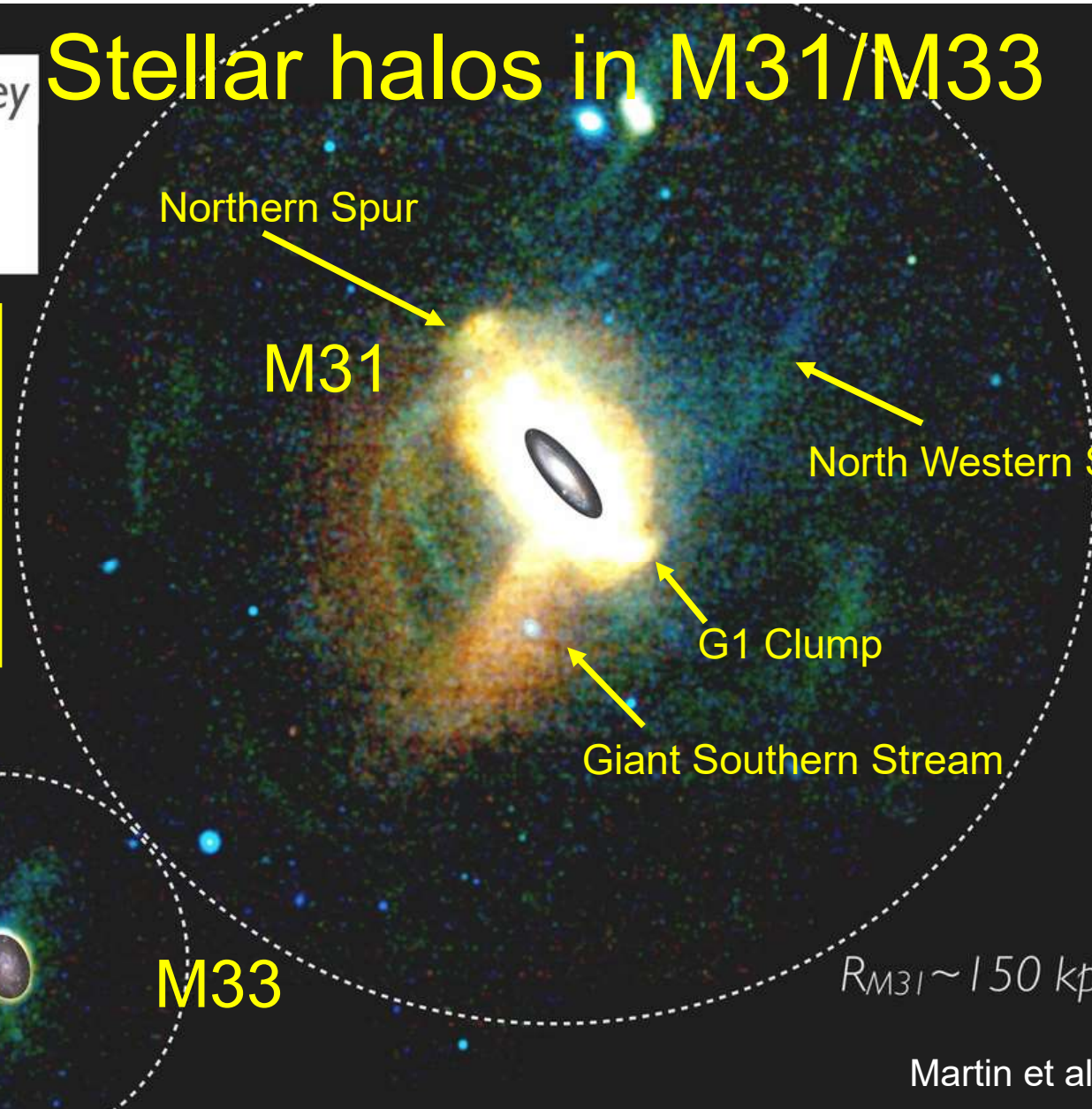
G1 Clump

Giant Southern Stream

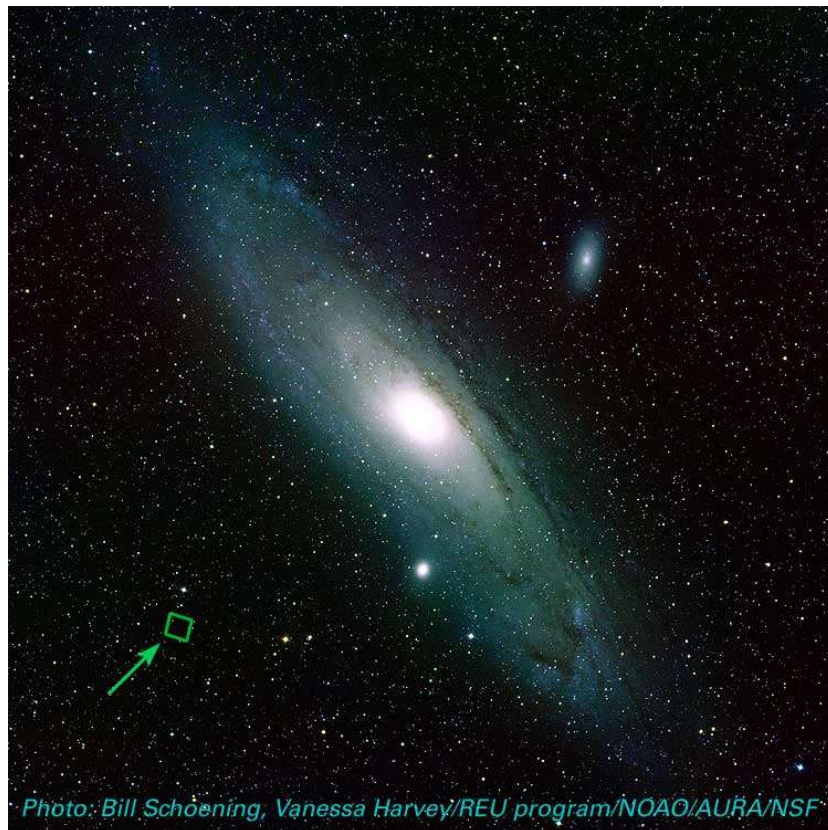
M33

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

Martin et al. 2013

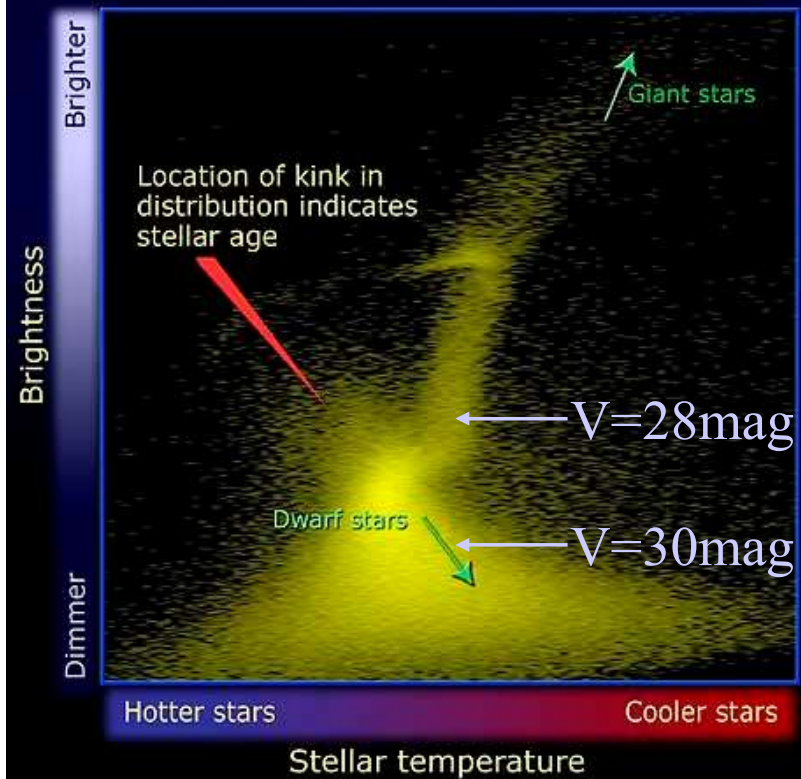


ACS/HST photometry of M31's halo (using 120 HST orbits!)



Hubble Space Telescope helps scientists track stellar population in M31 halo

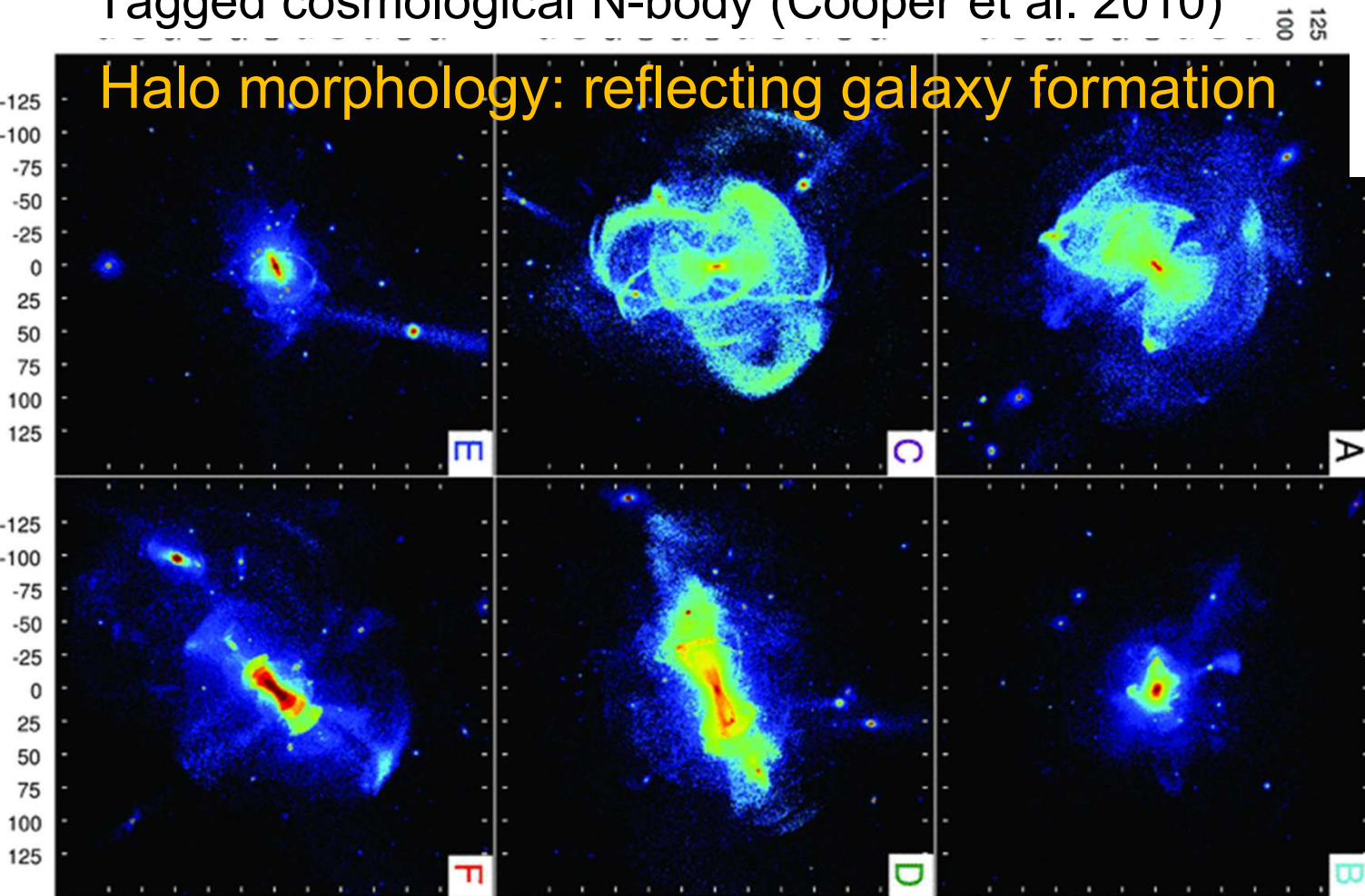
Stars in M31 halo have a wider age range (6–13 billion years) than those in the Milky Way halo (11–13 billion years).



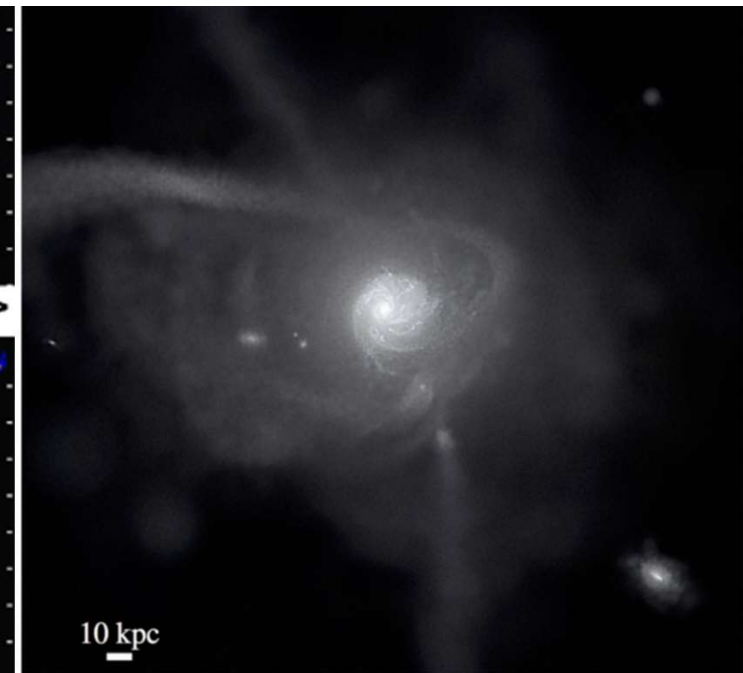
Comparison with Λ CDM models

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

Halo morphology: reflecting galaxy formation



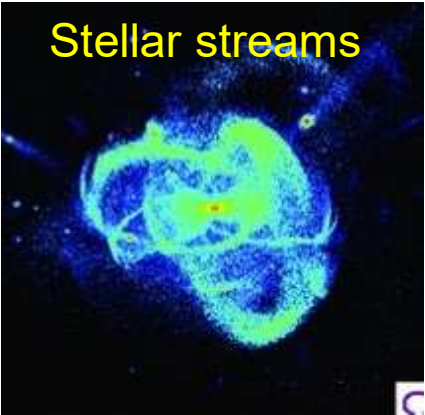
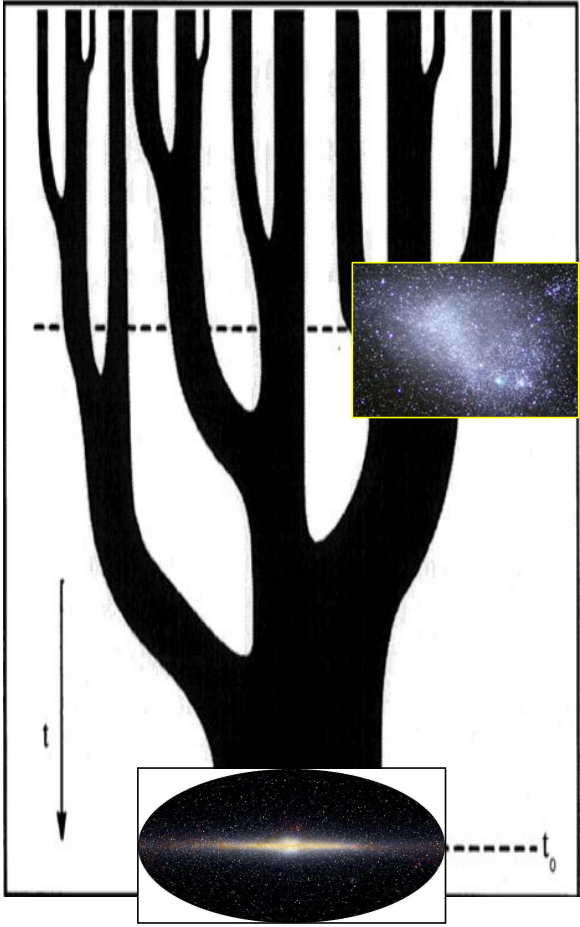
Cosmological hydrodynamics
(Sanders et al. 2020)



Galactic Archaeology

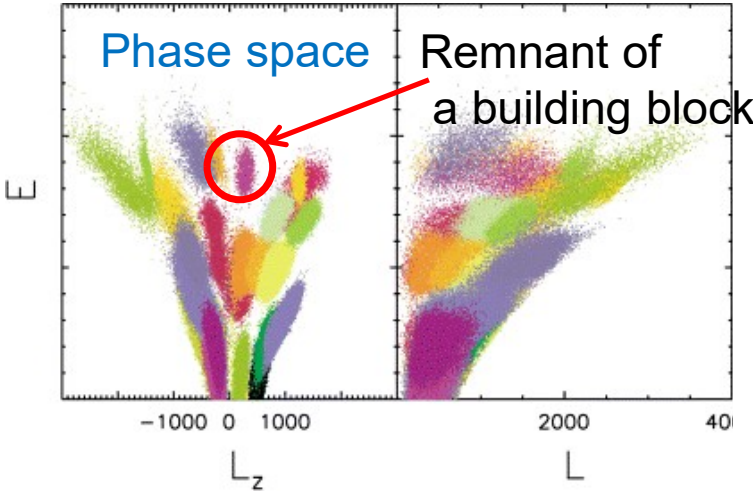
Hierarchical merging

Merger tree



Stellar streams

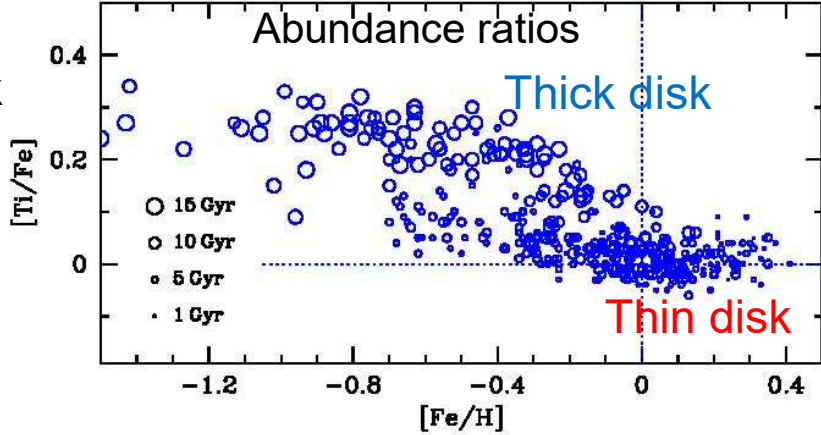
- Spatial distribution and dynamics of stars
 - ✓ Galaxy collapse and merging
 - ✓ Distribution of dark matter
- Chemical abundance of stars
 - ✓ Star formation and chemical evolution



Phase space

Remnant of a building block

Helmi & de Zeeuw 2000



Abundance ratios

Thick disk

Thin disk

Bensby et al. 2014