Star Formation Histories in Andromeda

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Collaborators


Courtesy of Jason Ware:
http://galaxyphoto.com
Stellar archaeology in nearby galaxies

- The most direct age diagnostic comes from resolving both the dwarf and giant stars, including the “main sequence turnover”
- In the 1950s, this technique was applied to star clusters in our own Galaxy
- In the 1990s, such studies were expanded to the satellite galaxies of the Milky Way
- With the launch of the Advanced Camera for Surveys (ACS) on Hubble, it became feasible to apply this technique in populations 1 Mpc away (Andromeda)
$[\text{Fe/H}] = -1.31$
8 Gyr
10 Gyr
12 Gyr

$[\text{Fe/H}] = -0.71$
8 Gyr
10 Gyr
12 Gyr
First M31 deep field

51 arcmin (11 kpc) from nucleus
M31 halo
(11 kpc)
210 x 210 arcsec
800 x 800 pc
Solar analog

RR Lyrae

magnitude

V-I

I

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M31 halo

47 Tuc

[Fe/H] = -0.7
Fitting region
Starfish code
(Harris & Zaritsky 2001)
M31 halo

age = 13 Gyr

$-2.3 \leq [\text{Fe/H}] \leq 0.5$
M31 halo

$11 \leq \text{age} \leq 14 \text{ Gyr}$

$-2.3 \leq [\text{Fe/H}] \leq 0.5$
M31 halo

$2 \leq \text{age} \leq 14 \text{ Gyr}$

$-2.3 \leq [\text{Fe/H}] \leq 0.5$
Halo Distribution in Age and Metallicity

Mergers

- Best-fit model has 40% of the stellar mass younger than 10 Gyr and metal-rich
- Some of the stars belong to the textbook “old metal-poor population”
- At the time, we suggested the intermediate-age stars in the halo originated in a major merger or series of smaller mergers
- We now know what merger that was...
In 2004, we obtained deep fields in the tidal stream and outer disk.

(star count map from Ferguson et al. 2002)
M31 stream
(20 kpc)

210 x 210 arcsec

800 x 800 pc
Distribution of velocities in stream and halo are distinct

Distribution of ages and metallicities in stream and halo are nearly identical

Stream Distribution in Age and Metallicity

Halo Distribution in Age and Metallicity

Star formation history of the stream

• Most likely explanation: the inner spheroid of Andromeda is polluted with debris from the stream’s progenitor (or objects like it)

• This explanation is supported by simulations and kinematic data (Fardal et al. 2007; Gilbert et al. 2007)

• The stream is the merger event that explains the population in our original halo field
In 2006, we obtained new images in the extended halo. 21 kpc field and two 35 kpc fields completed before ACS failure.

(star count map from Ferguson et al. 2002)
M31 halo
(21 kpc)

210 x 210 arcsec

800 x 800 pc
M31 halo (35 kpc)

210 x 210 arcsec

800 x 800 pc
M31 halo
(35 kpc)

210 x 210
arcsec

800 x 800 pc
Distribution of velocities in each field is broad and centered on M31 systemic.

21 kpc field is older and somewhat more metal-poor.

Distribution of velocities in each field is broad and centered on M31 systemic.

35 kpc field is older and somewhat more metal-poor.

Age & Metallicity Distribution in 11 kpc Field

Age & Metallicity Distribution in 21 kpc Field

Age & Metallicity Distribution in 35 kpc Field

Star Formation Histories at 21 kpc and 35 kpc

- These fields span the transition between inner “bulge-like” halo and outer “classical” halo.
- The halo fields at 21 and 35 kpc exhibit lower metallicities and older ages, but are not purely ancient.
  - A population entirely >10 Gyr ruled out at >8 sigma.
- Intermediate-age stars are not surprising, given the myriad streams criss-crossing the halo in wide-field star count maps (McConnachie et al. 2009, Ibata et al. 2007).
Subhalos with star formation continuing past reionization

Tumlinson (2010)
Most subhalos never form stars at all
Luminosity vs Size

Globular Clusters

classical dSphs

ultra-faint dwarfs

M_V (mag)

r_h (pc)

Harris (1996)
Mateo (1998)
Martin et al. (2008)
Luminosity vs Size

Harris (1996)
Mateo (1998)
Martin et al. (2008)

$M_V$ (mag)

$r_h$ (pc)

Globular Clusters

classical dSphs

ultra-faint dwarfs
Ursa Major I
27 orbits

ACS

WFC3

dist = 97 kpc
$M_V = -5.5$
$r_h = 11.3'$
$r_h = 318$ pc
Hercules

M92: 13.7 Gyr
[Fe/H]=-2.3

Leo IV

Ursa Major I

Brown et al. (2012)
Hercules: M92: 13.7 +/- 1 Gyr

Leo IV

Ursa Major I

Brown et al. (2012)
Hercules

Leo IV

Ursa Major I

M92: 13.7 +/- 1 Gyr
[Fe/H] = -3.2

Brown et al. (2012)
Hercules
M92: 13.7 +/- 1 Gyr
[Fe/H] = -3.2

Leo IV

Ursa Major I

Brown et al. (2012)
• Assume spectroscopic metallicity distribution (Kirby et al. 2008; Simon & Geha 2007)

• Allow ages in fine grid of isochrones to float

• Maximum-Likelihood fit to main sequence turnoff and subgiant branch

• Mean age = 13.6 Gyr +/-0.2 Gyr statistical
  +/-0.6 Gyr systematic ([O/Fe])
  +/-0.6 Gyr systematic (distance)
M92: $13.7^{+/-1}$ Gyr

$[\text{Fe/H}] = -3.2$

age(Hercules) = age(M92)

simulated CMD

Brown et al. (2012)
Hercules

M92: 13.7 +/- 1 Gyr
[Fe/H] = -3.2

age(Hercules) = age(M92)
simulated CMD

age(Hercules) = age(M92) - 2.0 Gyr
simulated CMD

Brown et al. (2012)
Hercules

M92: 13.7\(\pm\)1 Gyr
\([\text{Fe/H}] = -3.2\)

age(Hercules) = age(M92)

Brown et al. (2012)
Summary

• All sightlines through the Andromeda halo exhibit intermediate-age stars, indicating an active merger history.

• The Giant Stellar Stream looks remarkably similar to the inner halo, implying the inner halo of Andromeda is polluted by stars stripped from the stream’s progenitor.

• Most dwarf galaxies exhibit extended star formation histories, and the remnants of past mergers can be seen criss-crossing the Andromeda halo.

• New observations of the ultra-faint dwarf galaxies demonstrate they are purely ancient, suggesting the faintest galaxies were truncated by reionization.

• All of our Andromeda data (coadded & resampled images, artificial star tests, photometric catalogs) available at MAST.