Galaxy Evolution and Resolved Stellar Populations

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How do Galaxies form?
Galaxies the Building Blocks of the Universe
The Challenge of Studying Galaxies in Detail

Distant galaxies in *Hubble Space Telescope* Image

*Hubble Ultra-Deep Field*
The Challenge of Studying Galaxies in Detail

Distant galaxies in *Hubble Space Telescope* Image

Zoom-in

giant “blob”
can’t see individual stars
The Challenge of Studying Galaxies in Detail

Nearby galaxy - Large Magellanic Cloud
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Nearby galaxy - Large Magellanic Cloud

Zoom-in

individual stars!
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- These are complementary approaches
What do we want to know about Galaxies?

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• Star formation histories and chemical evolution throughout the galaxy
What’s in our toolbox?

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• **Models/Simulations**: important to understand the mechanisms going on in the galaxy
Important Conclusions So Far

**Milky Way Disk**

- Detailed structural and chemical mapping of the MW disk
- $\alpha$-abundance bimodality (thin/thick disk) throughout the disk
- Old, high-$\alpha$, thick disk stars formed early on in inner galaxy and later dispersed throughout the disk.
- Thin disk formed more slowly later on, radial metallicity gradient
- First evidence of radial migration playing an important role in the evolution of the disk
- Origin of thick disk debated but likely not from a large stellar accretion event

Martig et al. (2016)

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**Milky Way Halo**

- Discovery of many new stellar streams and dwarf satellites (~45 and counting), hierarchical galaxy formation
- Still not enough to fully solve the missing satellites problem
- Halo traced to ~100 kpc. Significant fraction of halo comes from a small number of “massive” accreted satellite
Important Conclusions So Far

**Bulges**

- Both MW+M31 have boxy bulges dominated by bars, MW has X-shaped bulge
- MW bulge chemistry very similar to inner thick disk
- MW bulge likely just the bar formed from thin/thick disks

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**Images**

- **MW X-shaped Bulge**
  - Filtered WISE imaging
  - Ness & Lang (2016)

- **MW bulge disk model**
  - APOGEE
  - MODEL
  - Beaton et al. (2007)

- **M31 Boxy Bulge/Bar**
  - Fragkoudi et al. (2018)
Magellanic Clouds + dwarfs

- MCs very likely have their own system of satellites, very extended stellar populations, hierarchical galaxy formation.
- MCs fell into MW potential a couple Gyrs ago.
- Will contribute $10^9 \, M_\odot$ masses of gas to hot halo and eventually to the MW disk.
- LMC has very extended stellar component, formed “outside-in”. Very extended old disk, SF disk shrunk over time as gas used up. Same in other nearby dwarf galaxies.

**Important Conclusions So Far**

**HI Magellanic Stream**

Nidever et al. (2010)

**Extended LMC Stellar Populations**

Mackey et al. (2016)

**LMC SFH - shrinking SF disk**

Meschin et al. (2014)
Important Conclusions So Far

M31

- Thickened disk with persistent star formation ring at 10 kpc over 500 Myr
- Global and massive SF event 2-4 Gyr ago likely due to significant interaction event
- Global halo mapped, signs of multiple large interactions and debris

M31 Halo Metallicity Map

M31 10 kpc star forming ring

Martin et al. (2013)

Lewis et al. (2015)
Important Conclusions So Far

M31+MW

• Very different halo masses/shapes/metallicities, from different accretion histories, even though similar total masses and neighbors

Planes of satellites

• Satellites arranged in planes (some co-rotating) around MW+M31 and other galaxies

M31 Stellar Halo - $M=8\times10^{9}$

$\alpha=3.2$

MW Stellar Halo - $M=7\times10^{8}$

$\alpha=4.0$

Gilbert et al. (2012)
Cohen et al. (2017)

Pawlowski et al. (2015)
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• Was there a “Magellanic group” of galaxies that fell into MW.
What we need to do the science

- **Want to reconstruct the detailed formation of the MW**
  - Large spectroscopic surveys: *SDSS-V, 4MOST, MOONS, WEAVE*
  - Large asteroseismic surveys of ages: *TESS+Plato*
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• Analysis Environment: Flexible and user-friendly analysis environment to work with big data and simulations.
The End