



The **SPLASH** Survey

M31's Unusual "Bulge"

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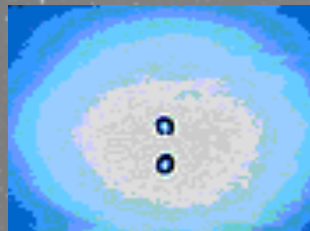
Santa Cruz Galaxy workshop

Outline

M31's unusual extended "bulge"/inner spheroid:

- Main difference between M31 and MW
- Structure: surface brightness profile, bar/boxiness, substructure (tidal debris)
- Resolved stellar kinematics
- Metallicity
- Star-formation history

Summary



Spectroscopic and Photometric Landscape
of Andromeda's Stellar Halo



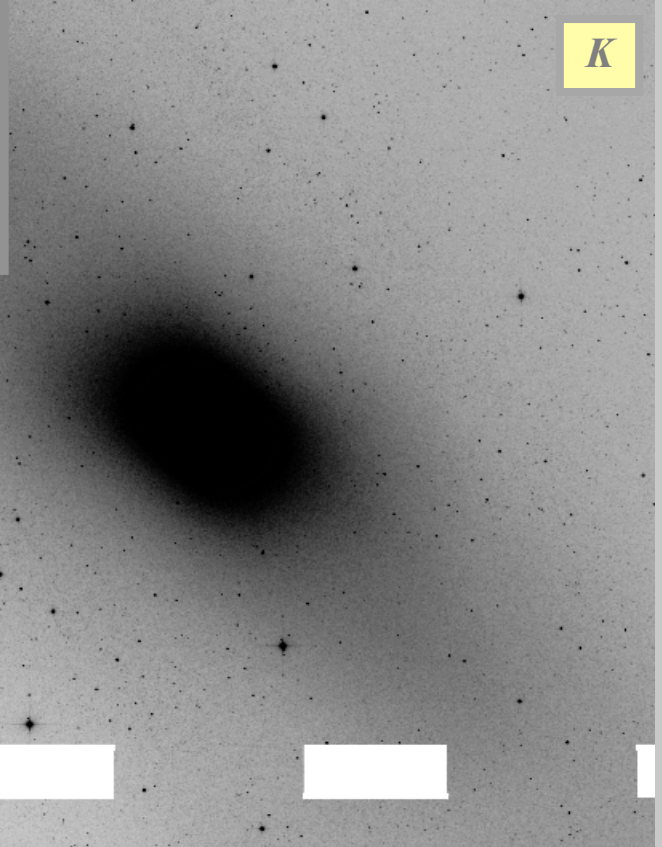
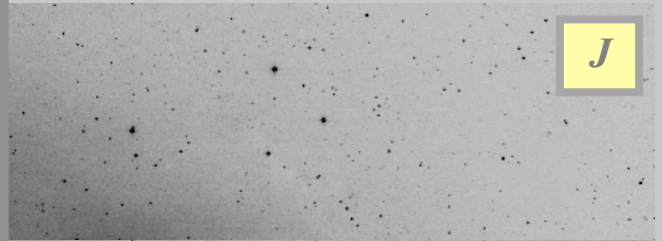
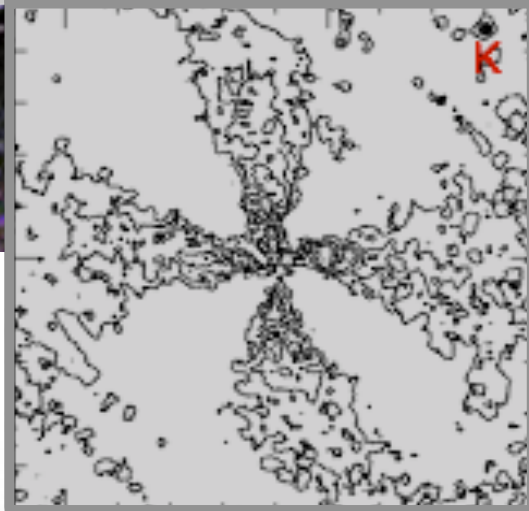
Photo credit: Dr. Andrew Davidhazy



Structure

M31's Boxy Bulge and Central Bar

An Unobstructed Wide-field View in the Near Infrared



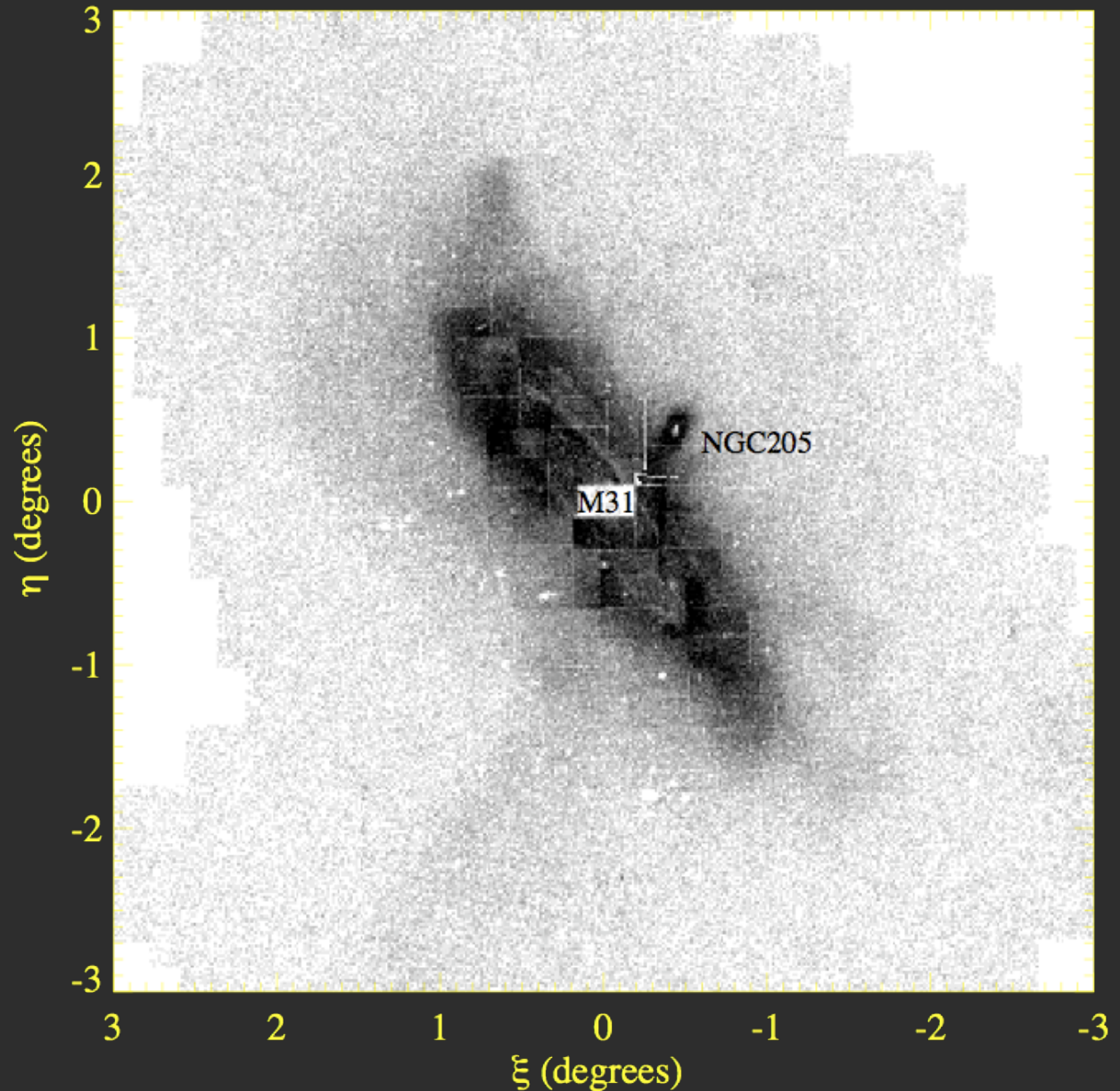
**K-band image
minus ellipse fit**

**Model disk galaxy with central bar,
boxy bulge, and classical bulge
(Athanasoula & Beaton 2006)**

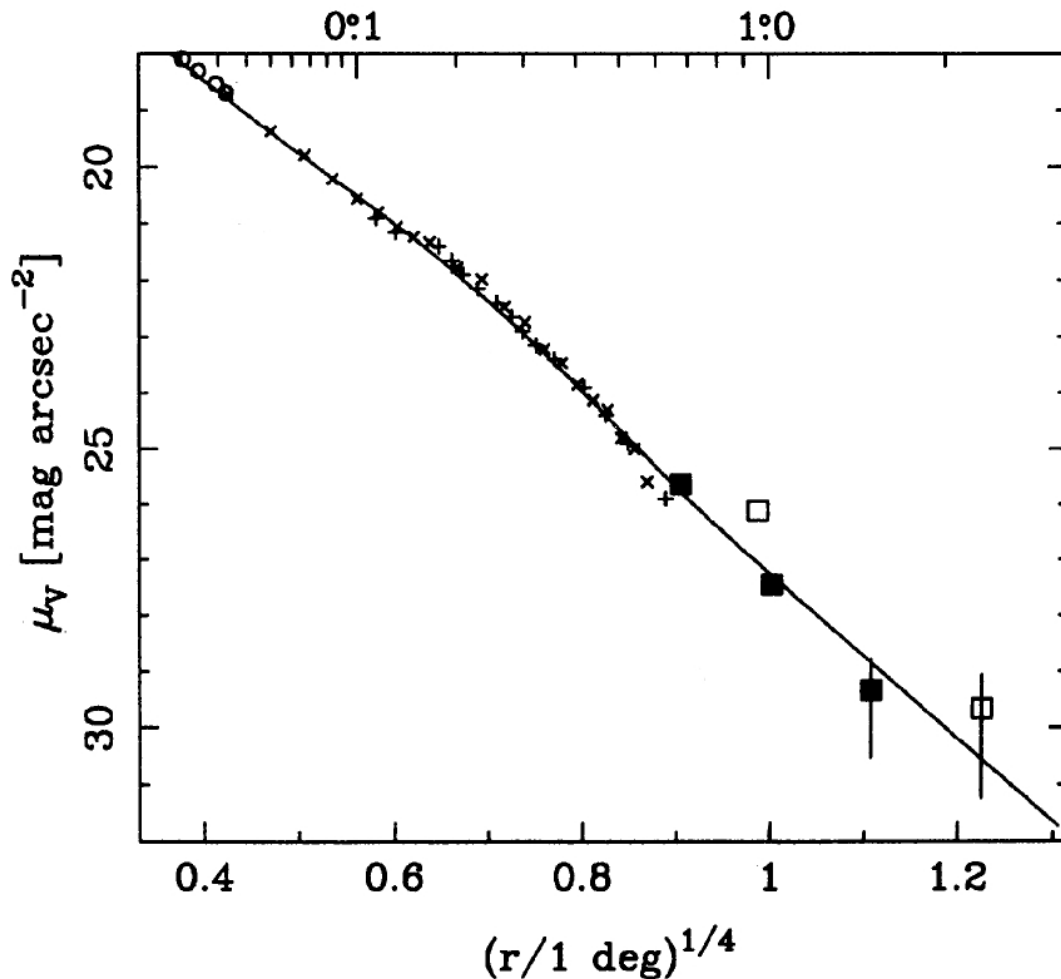
Beaton et al. (2007, ApJL)
Athanasoula & Beaton (2006, MNRAS)

M31 substructure supports violent merger history

- Ibata et al. (2001) discovered a giant stellar debris stream
- Ferguson et al. (2002) found several other significant structures (NE shelf, NGC205 loop, etc.)
- Ibata et al. (2005) found evidence for an “extended disk-like structure” comprising ~10% of the luminous disk mass, extending to ~40 kpc, possibly the result of recent mergers



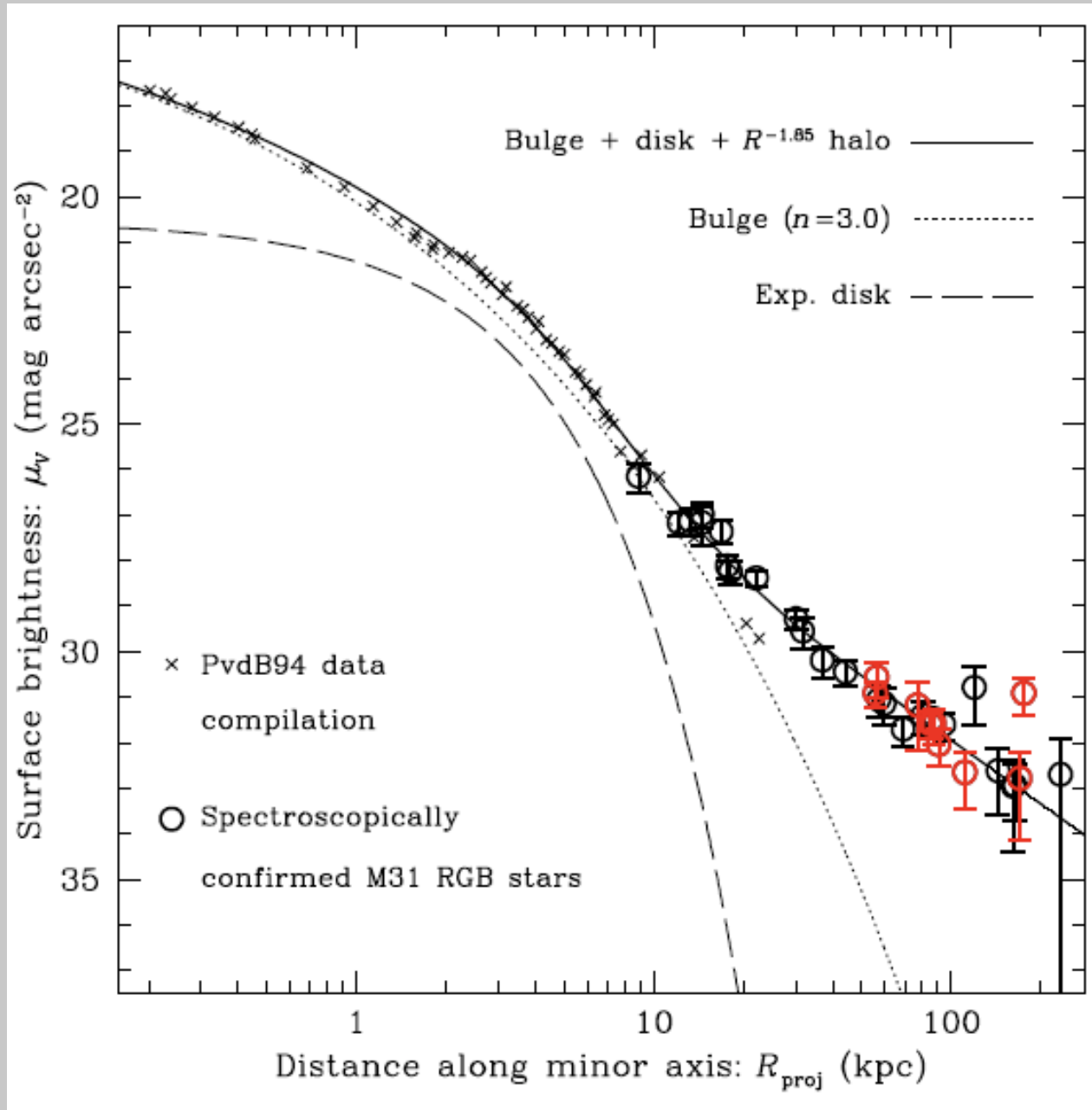
Inner “halo” of M31 looks like a bulge



Pritchett & van den Bergh (1994)

Profile looks like a de Vaucouleurs $r^{1/4}$ law instead of the canonical power-law r^{-2} halo

M31's Surface Brightness Profile

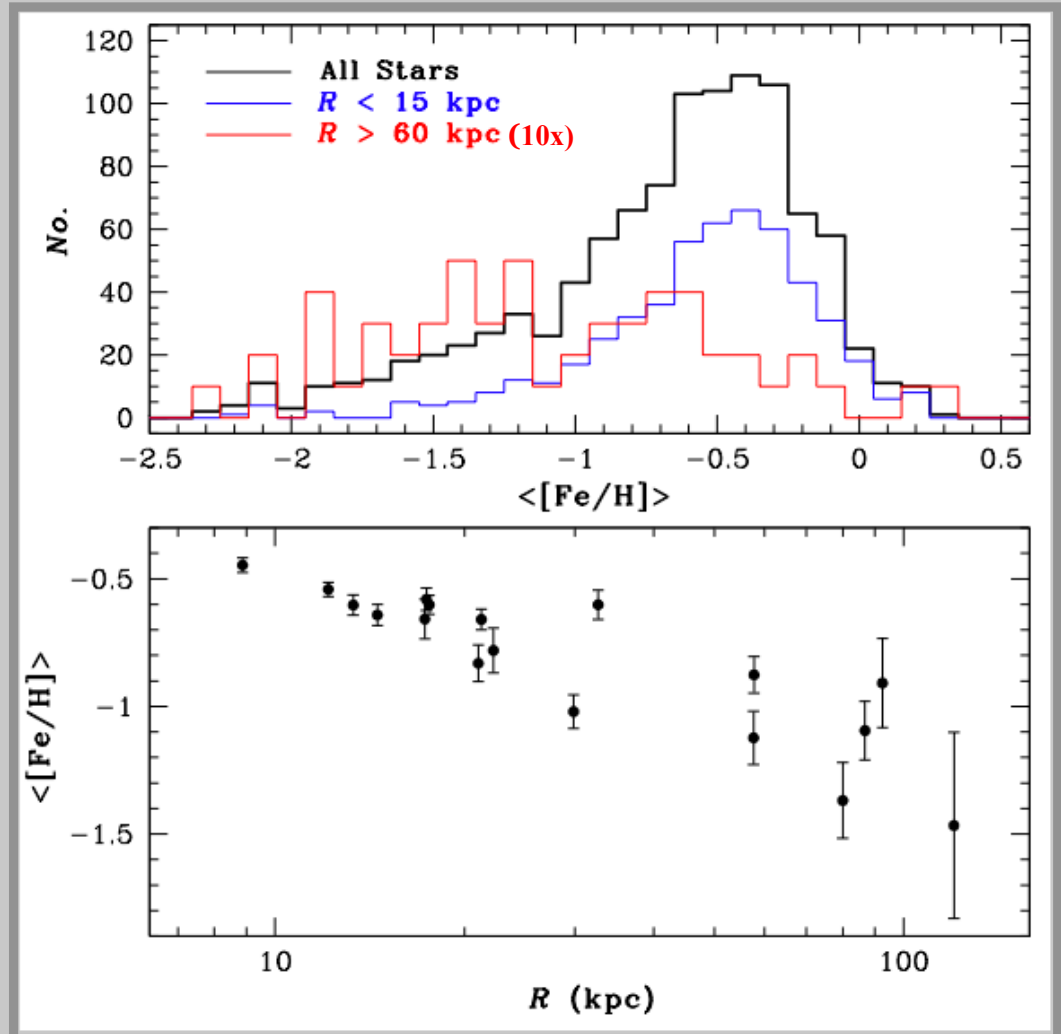
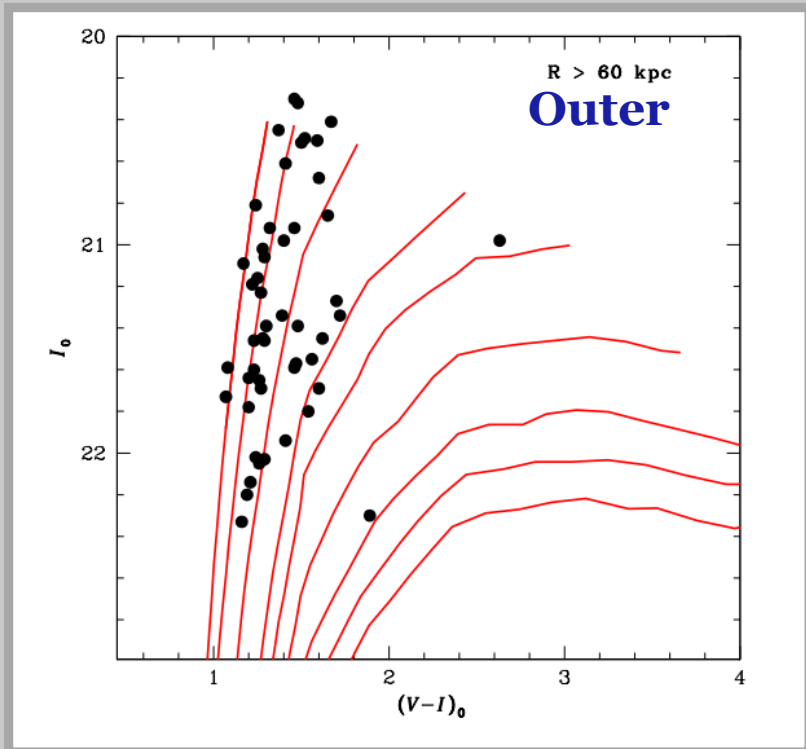


– PG, et al. (2005)
– Gilbert, PG, et al. (2011, in prep)



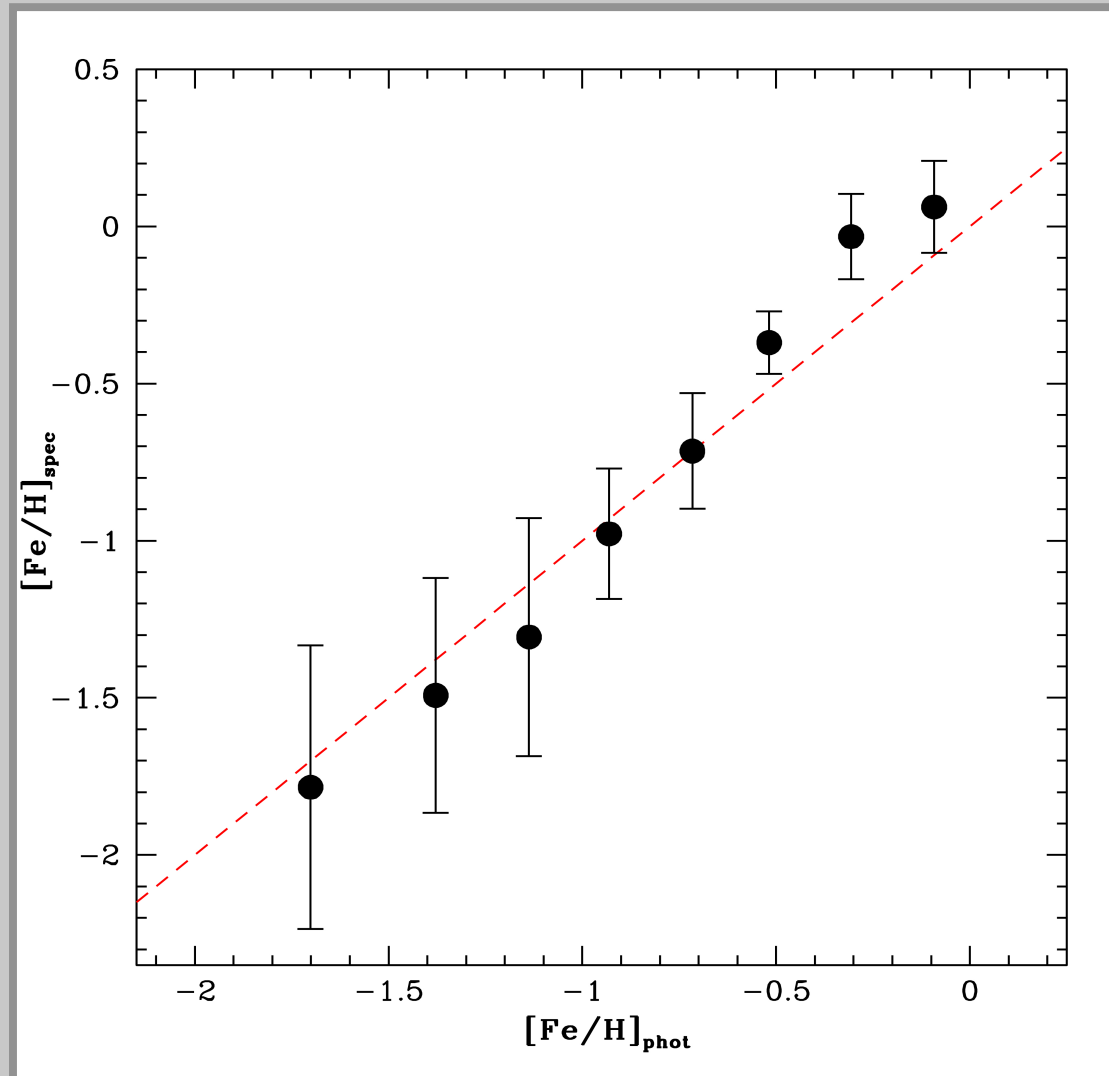
Metallicity

Radial Gradient in Metallicity



Kalirai, Gilbert, PG, et al. (2006b, ApJ); Kalirai, Gilbert et al. (in prep)

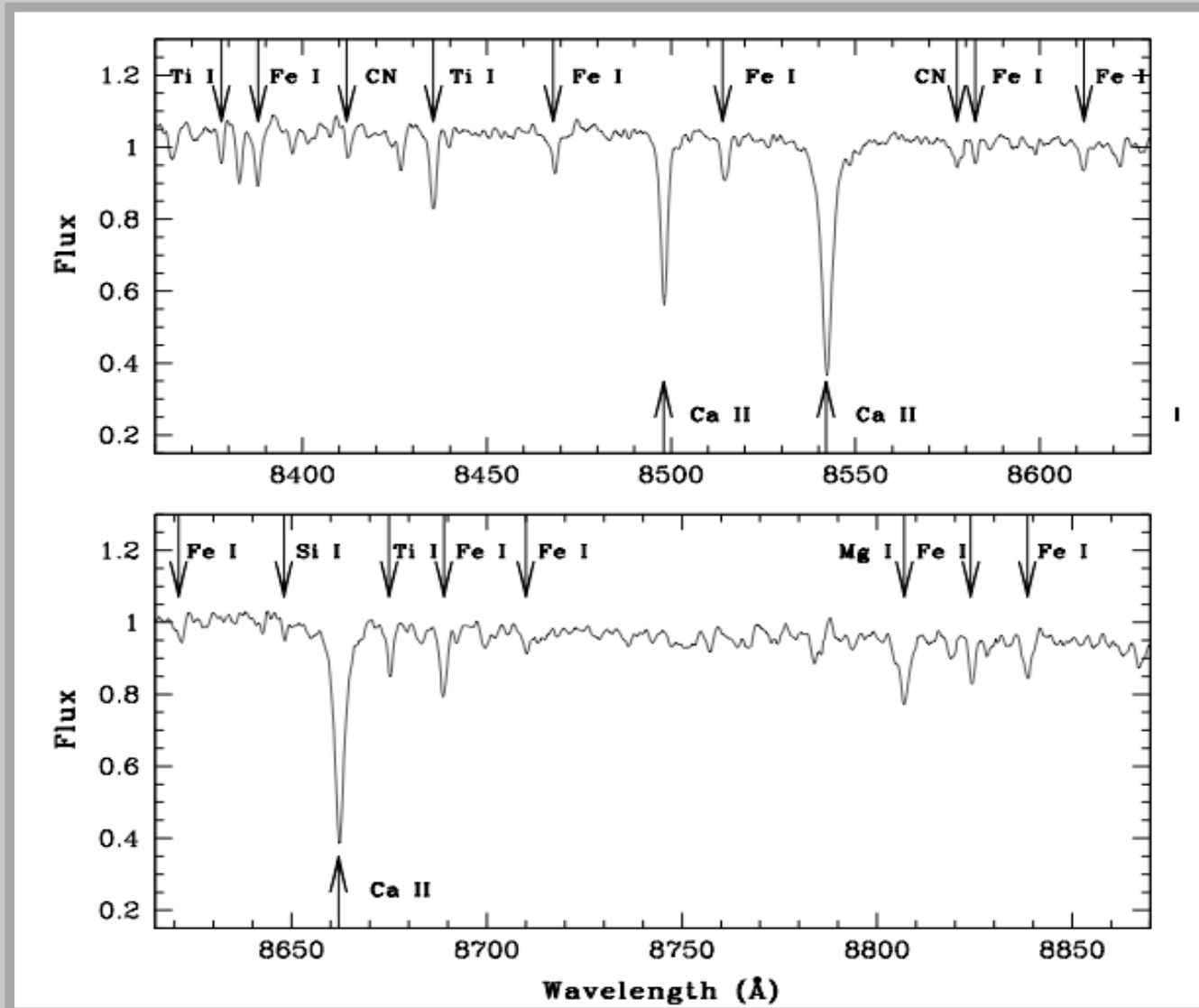
Photometric vs. Spectroscopic [Fe/H] Estimates



Kalirai, Gilbert, PG,
et al. 2006b, ApJ

It is reassuring to see that there is a reasonably good correlation between the photometric and spectroscopic [Fe/H] estimates

Detailed Chemical Abundance Analysis based on Co-added Spectra



Evan Kirby, PhD thesis, UCSC

Detailed chemical abundances from Keck/DEIMOS spectra of individual red giant stars in MW GCs and dSph satellite galaxies:

– Kirby, PG & Sneden (2008, ApJ)

– Kirby et al. (2009–2011, ApJL, and ApJ/ApJS Papers I–IV)

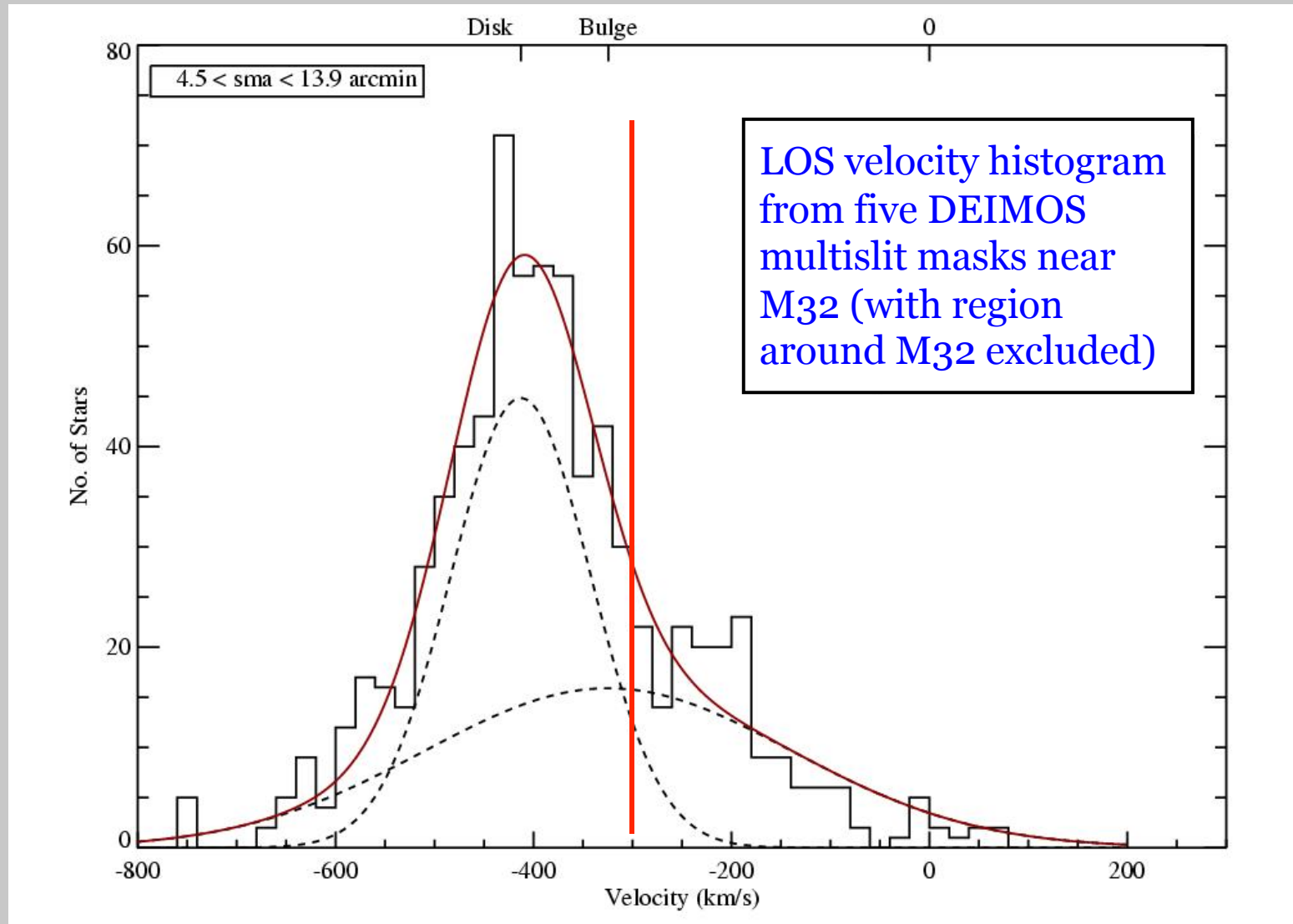
Lei Yang, MS thesis, KIAA/PKU (+ UCSC + Caltech)

Detailed chemical abundances from coadded spectra of RGB stars in M31 dSph/dE galaxies (paper in prep)

A wide-field astronomical image of a galaxy, likely a barred spiral galaxy, viewed from an edge-on perspective. The galaxy's central bar is bright and yellowish, with spiral arms extending outwards, showing some reddish and blueish hues. The background is a dense field of stars, with several prominent bright stars and a few blue stars scattered throughout. The word "Kinematics" is overlaid in the center of the galaxy in a bold, black, serif font.

Kinematics

Stellar Kinematics of M31's Disk & Spheroid

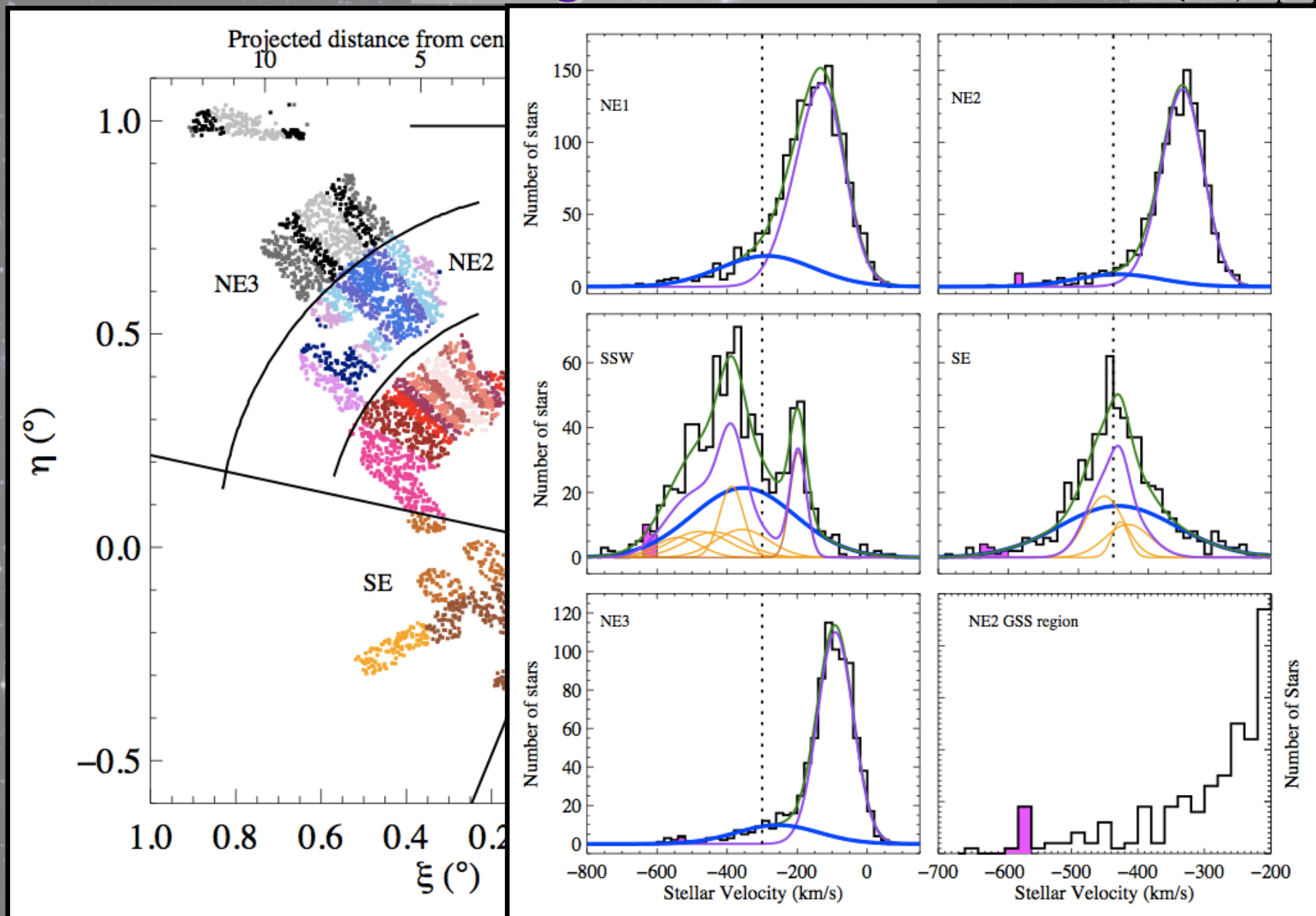


— Well approximated by a cold, rotating disk with a flat rotation curve ($v_{\text{rot}} = 250 \text{ km/s}$) superposed on a hot spheroidal component with low rotation

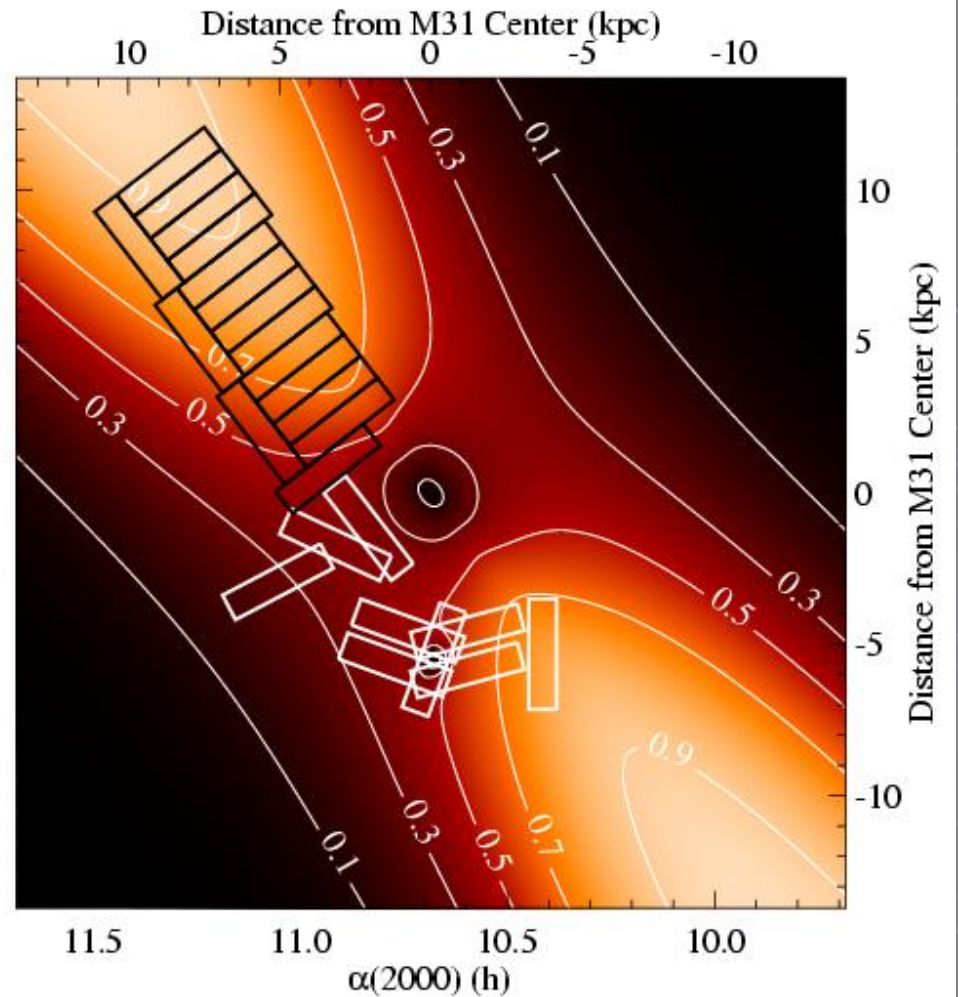
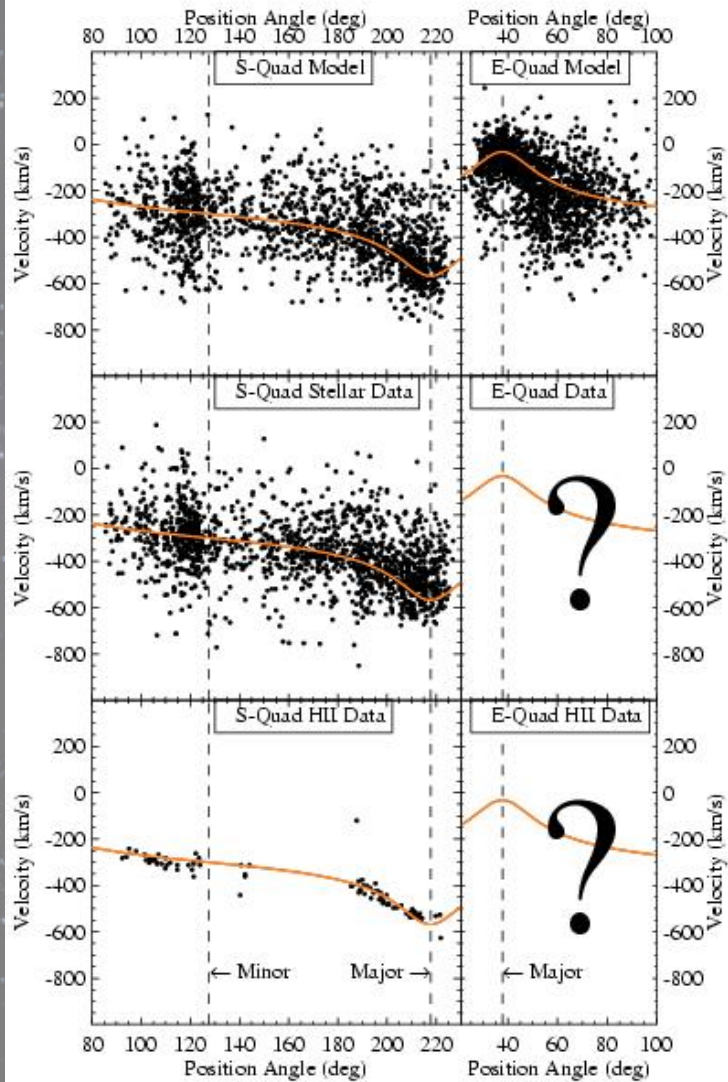
Howley, PG, Kalirai, et al. (2011b, in prep)

Bulge kinematics

Dorman, PG, et al
(2011, in prep)



Stellar and ionized gas kinematics

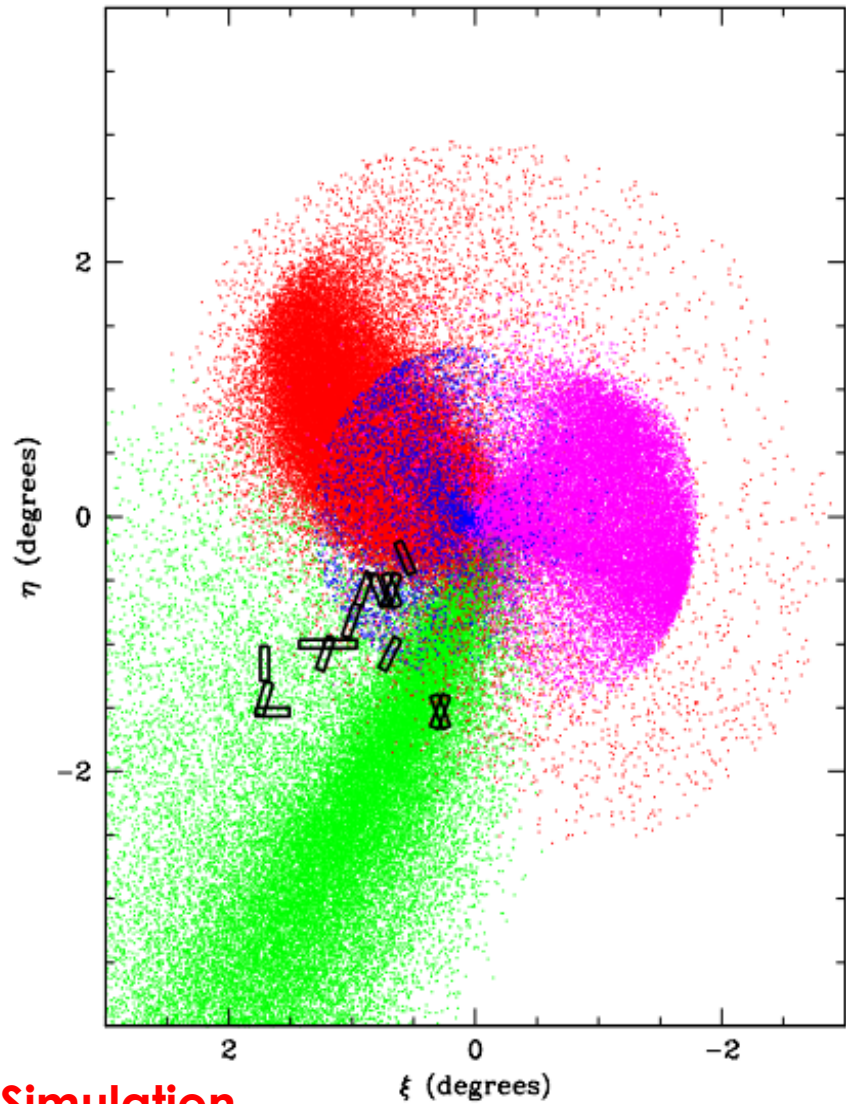


Dorman, PG, et al (2011, in prep)
Howley, PG, Kalirai, et al. (2011b, in prep)

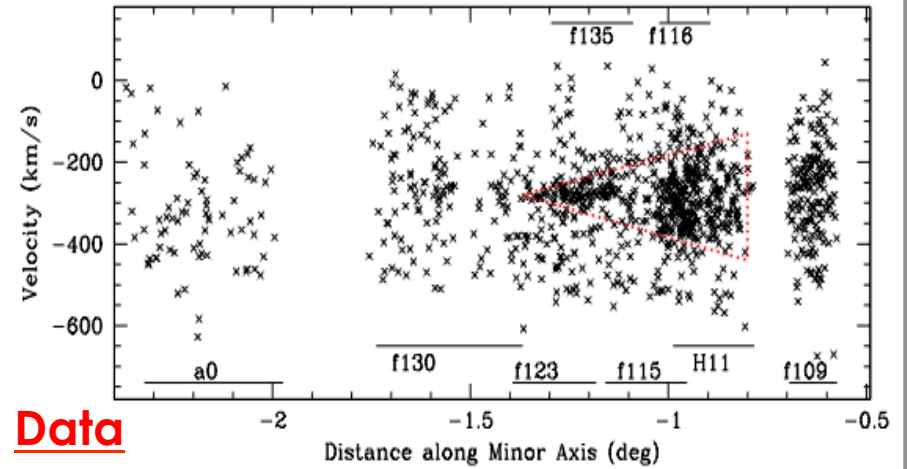


Tidal debris

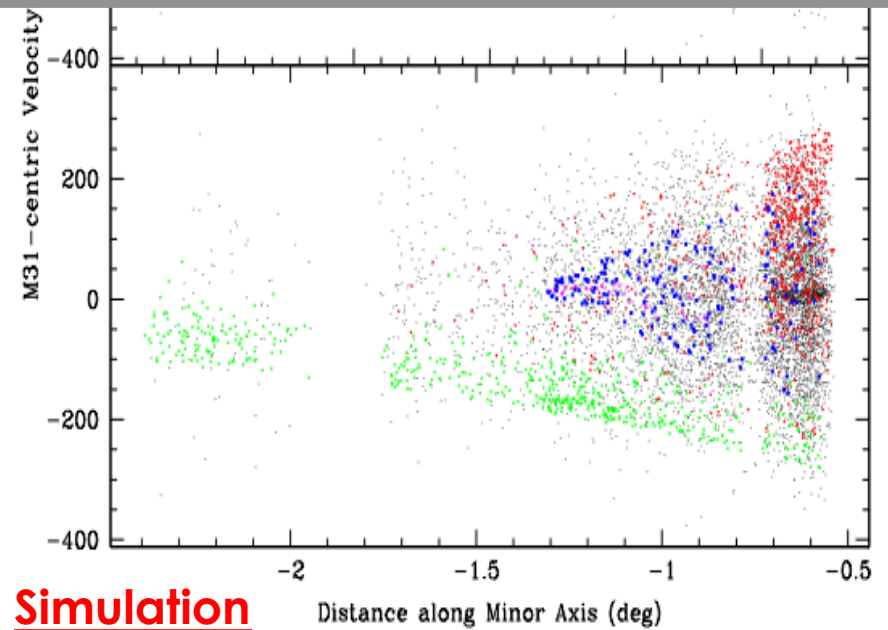
Giant Southern Stream and Young Shell System in M31



Simulation



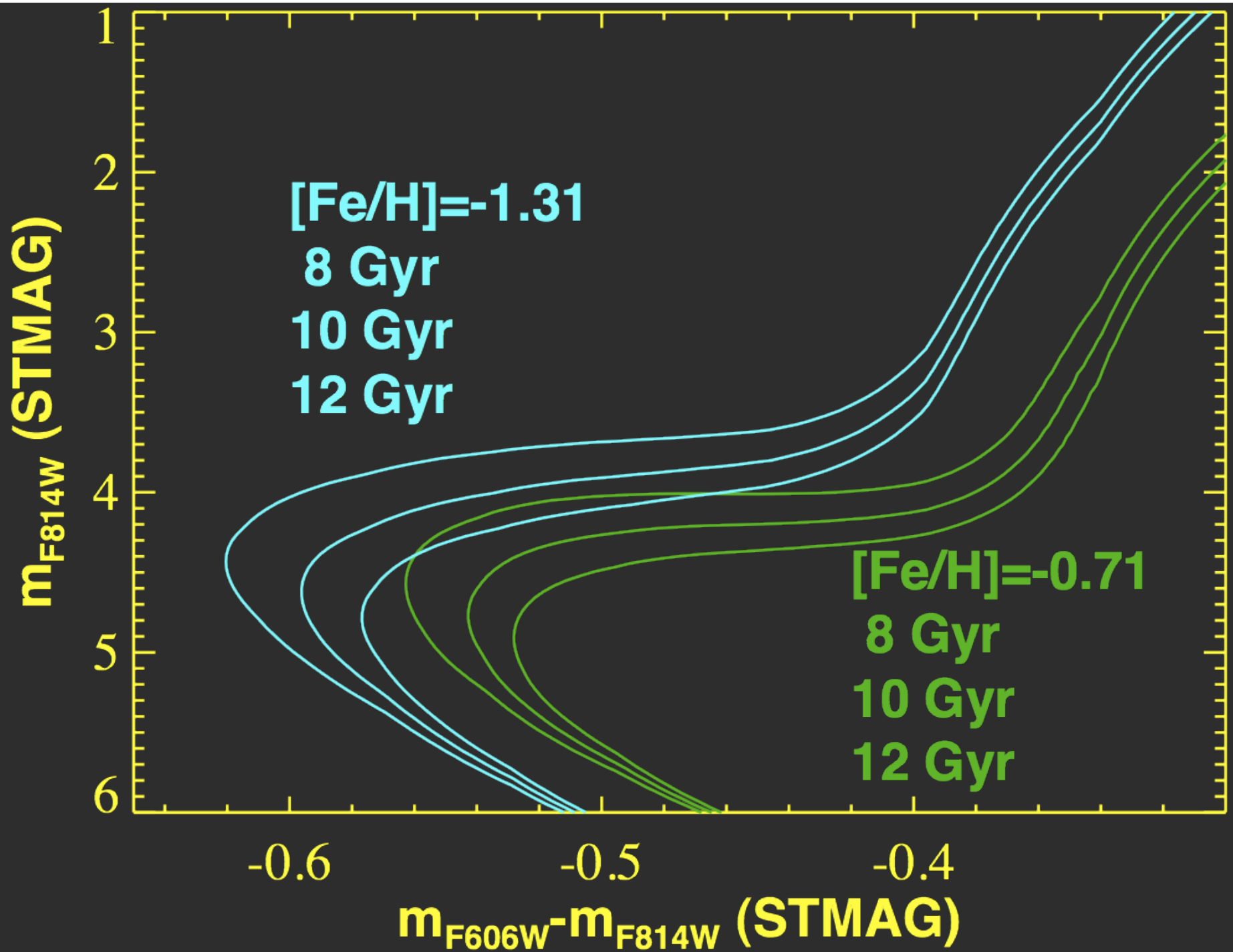
Data

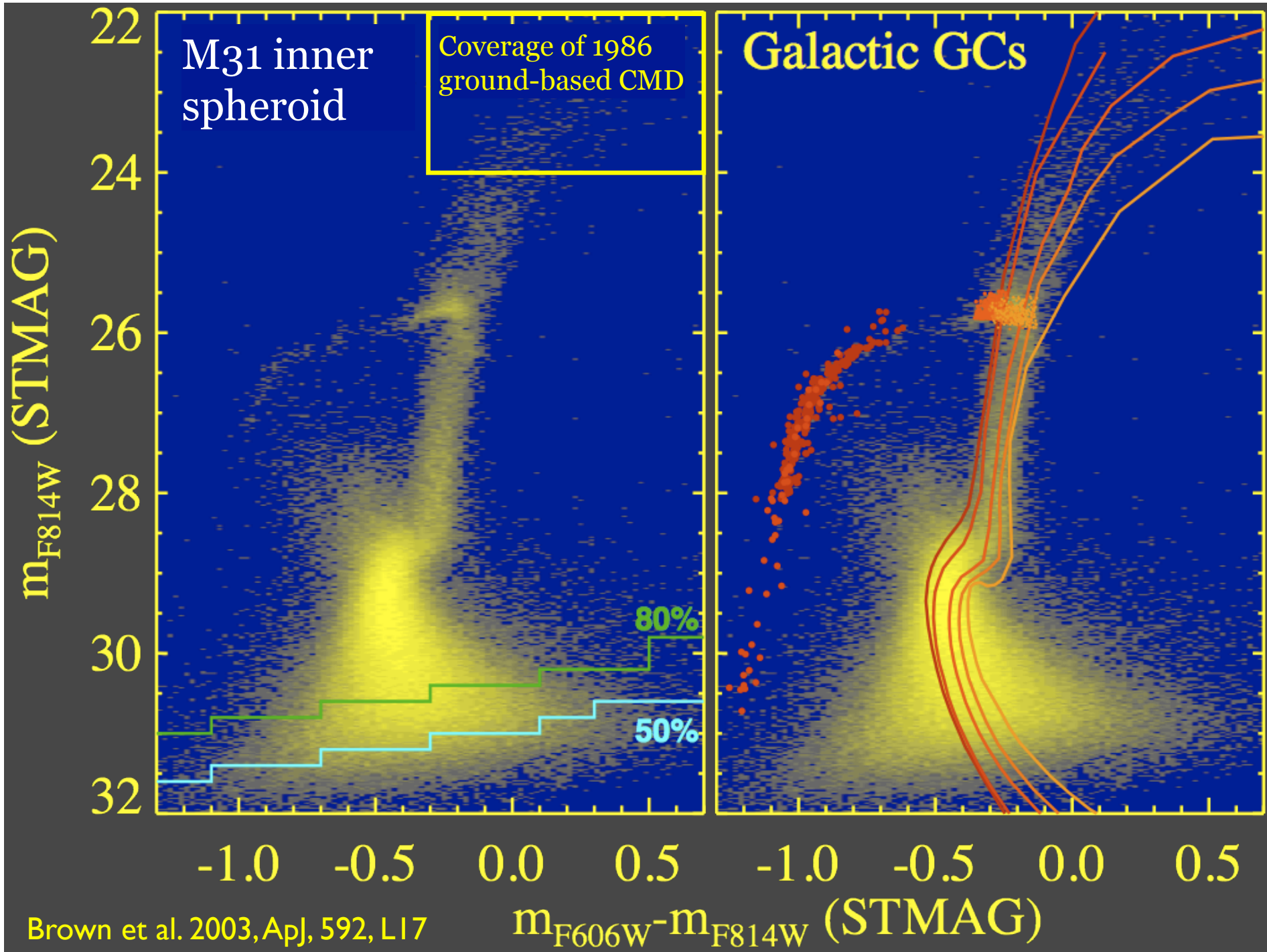


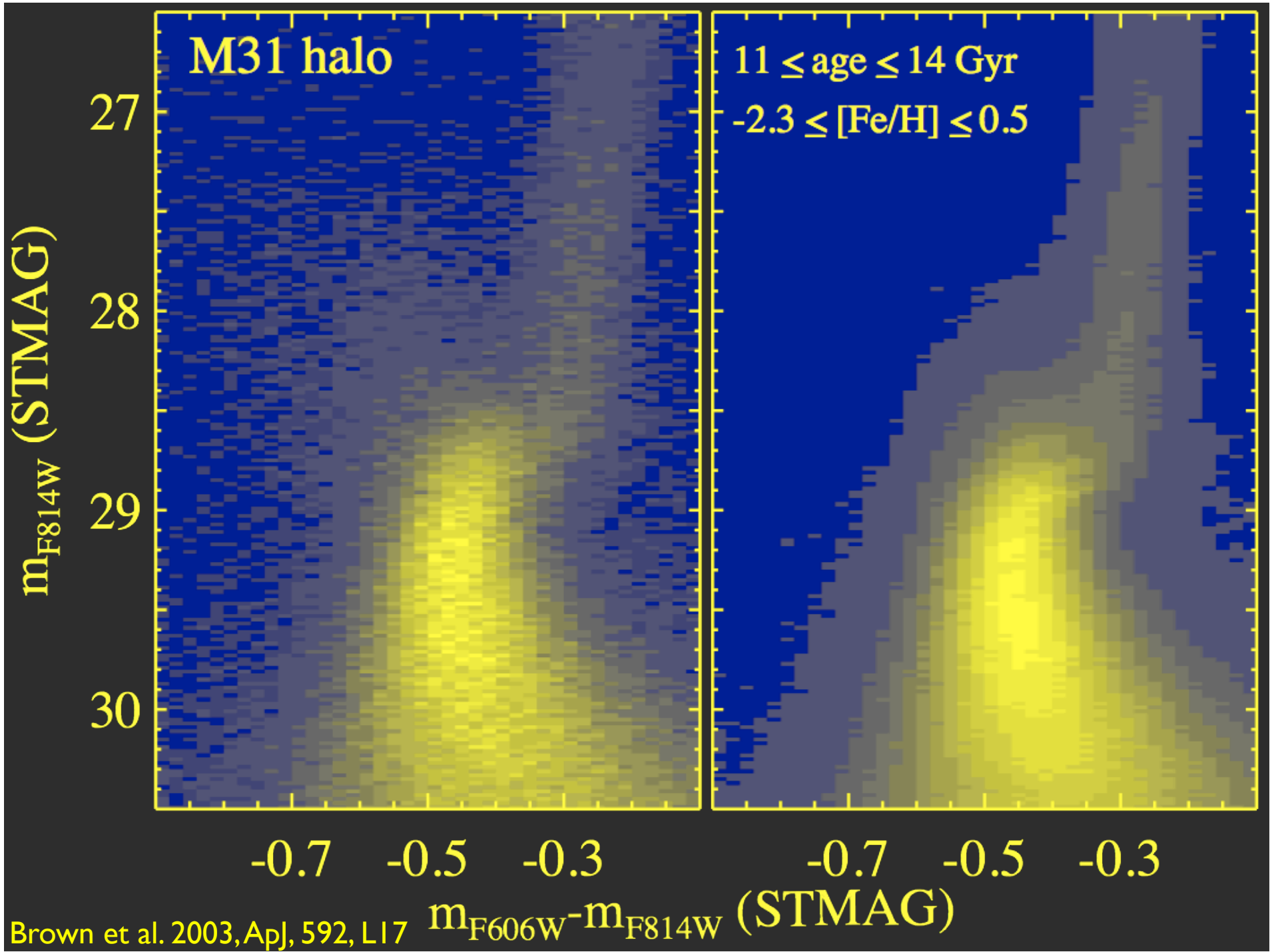
Simulation

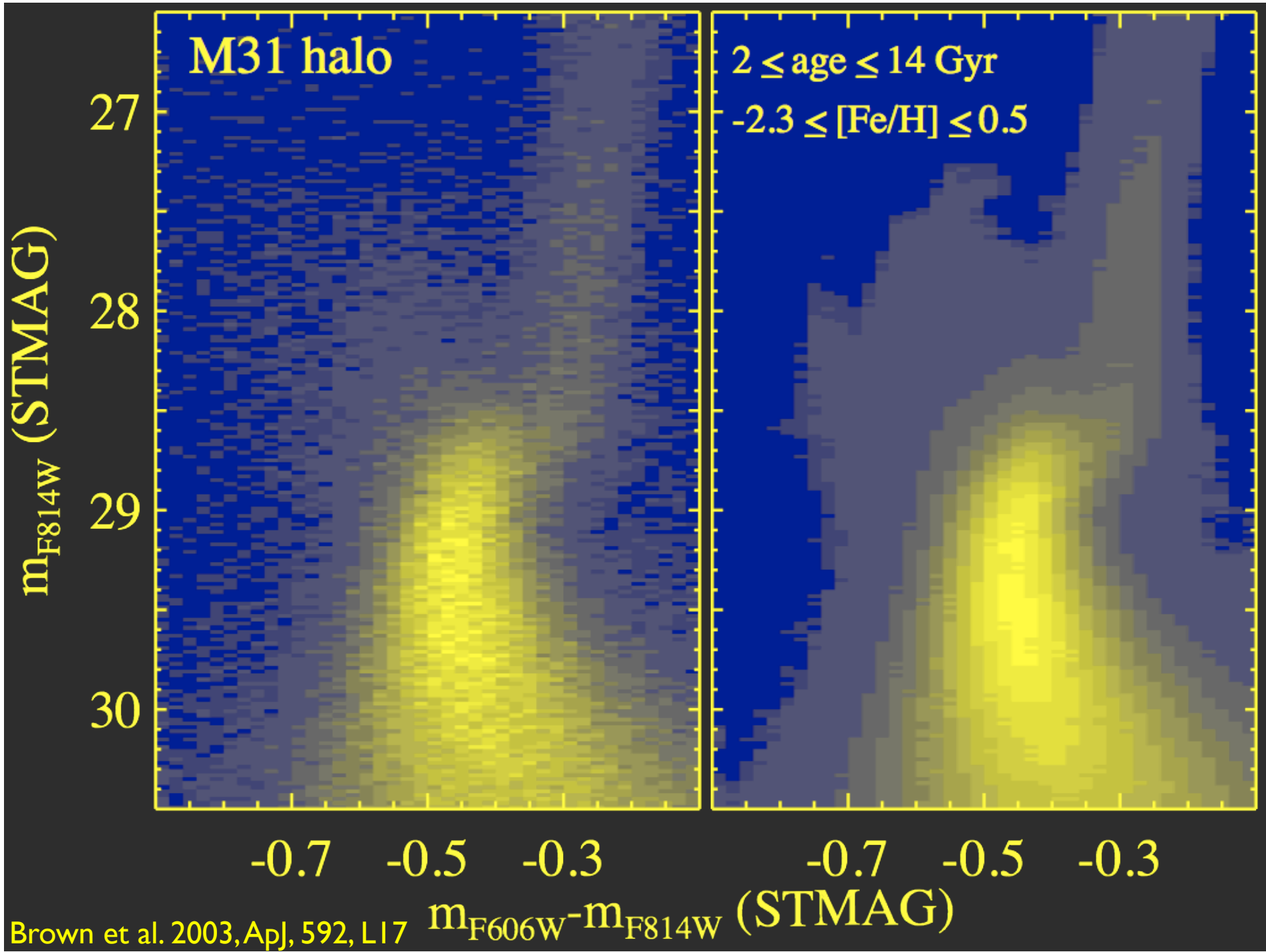
The image shows a large, diffuse galaxy with a central bright region and a prominent, irregularly shaped star-forming region. The star-forming region is characterized by a dense concentration of blue and white stars, indicating recent star formation. The galaxy is set against a dark background filled with numerous other stars of various colors and sizes. The text "Star-formation history" is overlaid in the center of the image in a bold, black, serif font.

Star-formation history

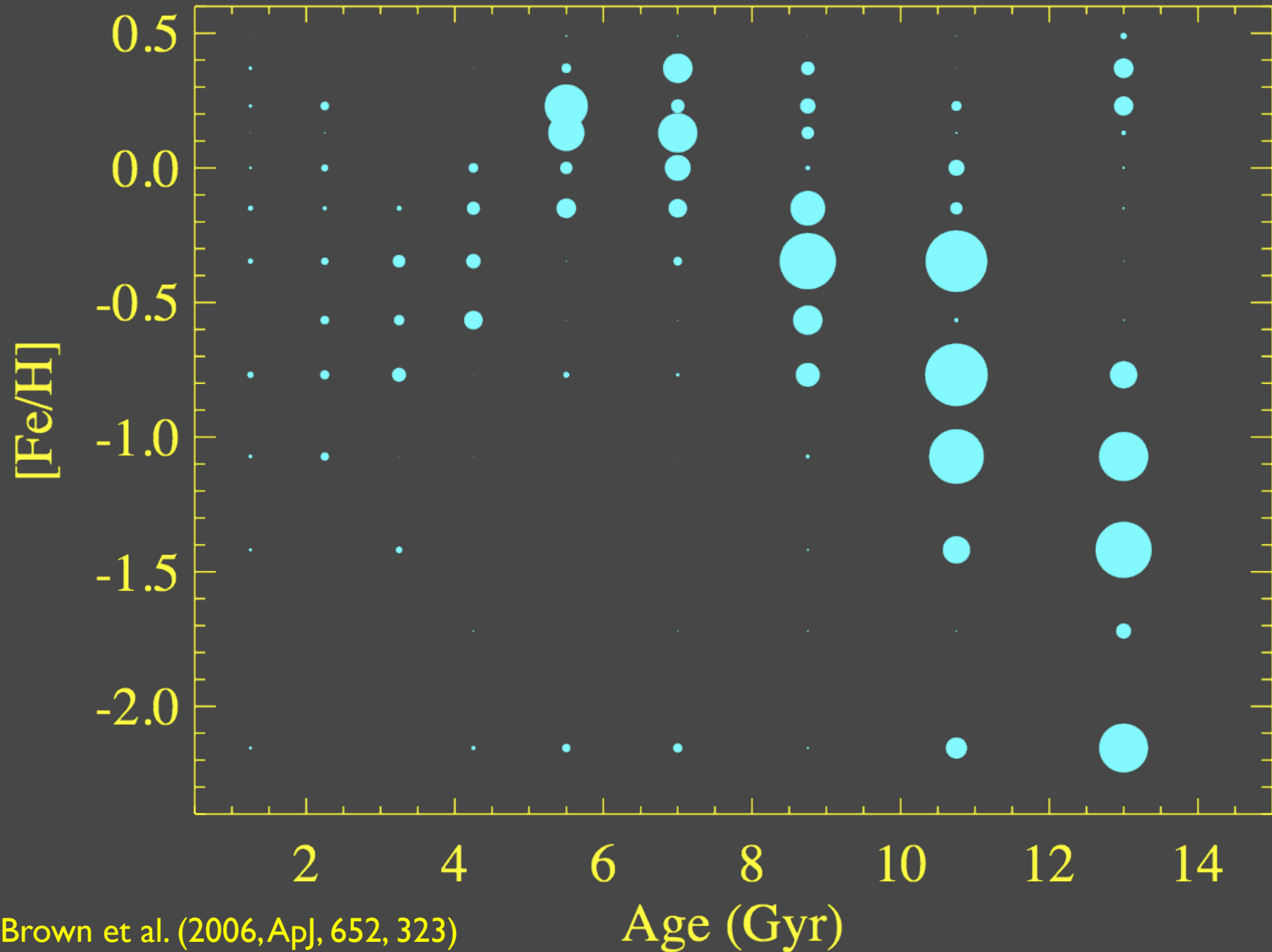








Inner Spheroid Distribution in Age and Metallicity



Brown et al. (2006, ApJ, 652, 323)

Summary

Andromeda's unusual bulge:

- Stars formed *in situ* versus accreted stellar systems
- No structural subcomponent like it in the Milky Way
- Boxy bulge and bar: pseudo-bulge + classical bulge
- Sersic profile with $n = 3$ dominates out to $R \sim 20\text{--}30$ kpc on the minor axis
- Metal-rich: $\langle [\text{Fe}/\text{H}] \rangle \sim -0.7$ with a large spread
- Dynamically hot ($\sigma_{\text{los}} \sim 130$ km/s) with a hint of rotation
- Kinematical detection of tidal debris associated with a recent merger event
- Most stars are old but about 20% are of intermediate age