Disrupted Satellites of Andromeda and the Milky Way

The SPLASH, PHAT, & HALO7D Surveys

Raja Guhathakurta

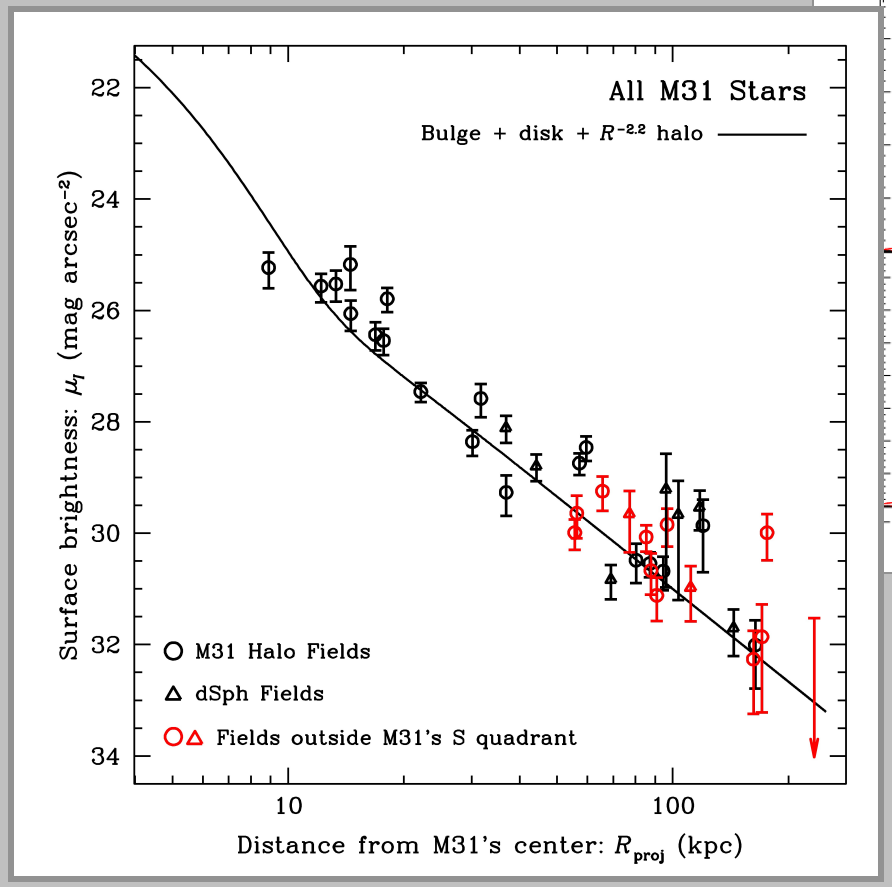
University of California Observatories / Lick Observatory
University of California Santa Cruz

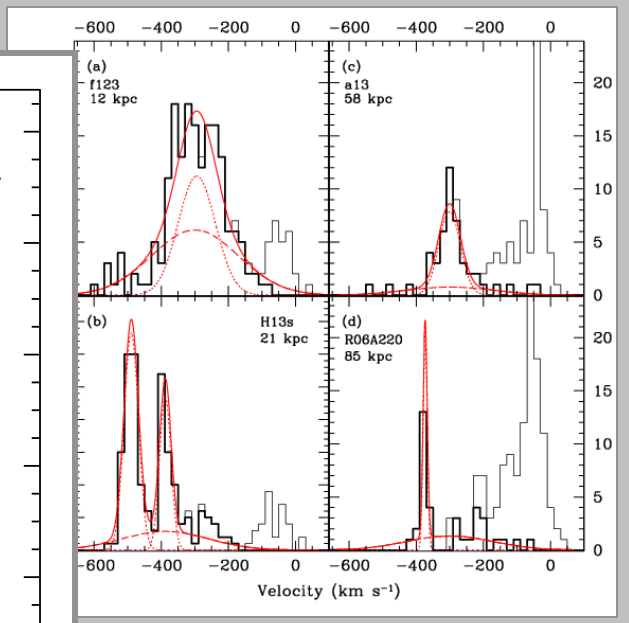
Wednesday August 27, 2014 Satellite Galaxies and Dwarfs in the Local Group
11th Potsdam Thinkshop, Leibniz Institute for Astrophysics Potsdam

Andromeda has a large (virialized?) stellar halo

Spectroscopy allows us to statistically remove substructure (partially digested former dwarf satellite galaxies) in different fields

- Fields in M31's South quadrant
- Fields North of M31's semi-major axis



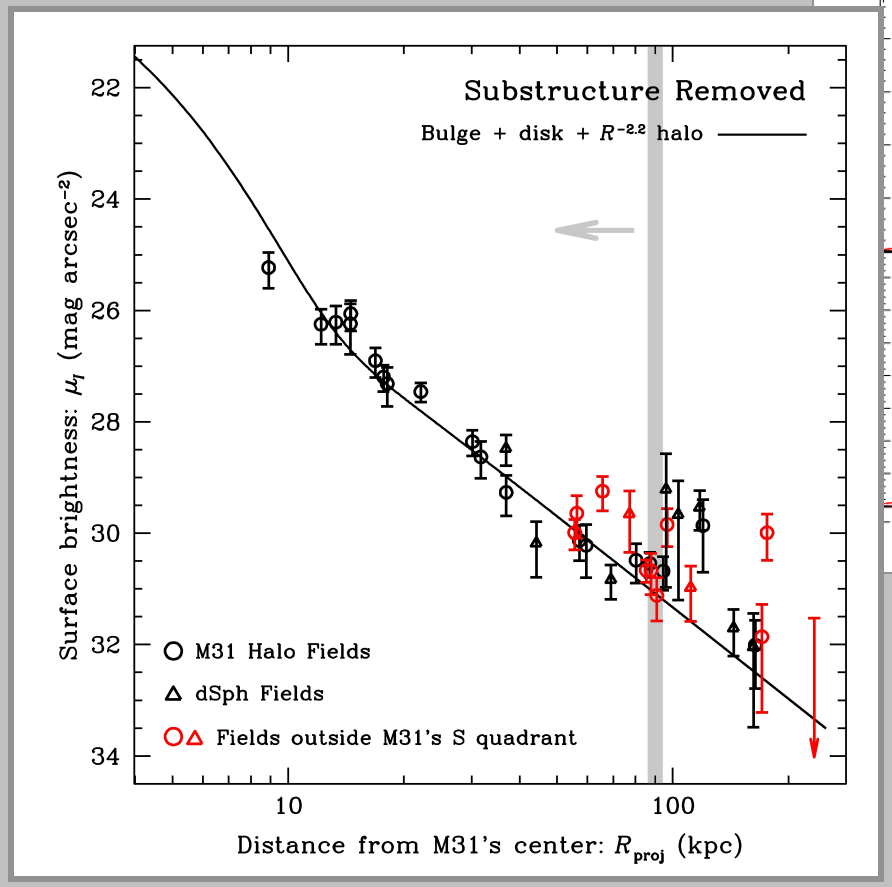


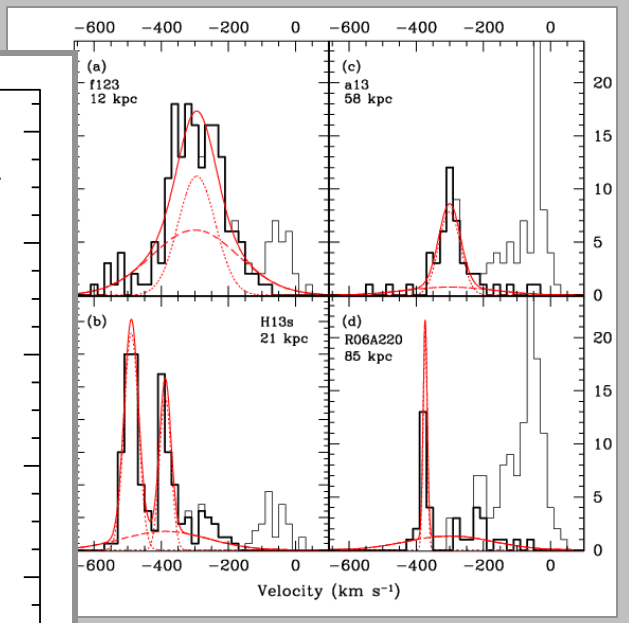
Gilbert et al. 2012

Andromeda has a large (virialized?) stellar halo

Spectroscopy allows us to statistically remove substructure (partially digested former dwarf satellite galaxies) in different fields

- Fields in M31's South quadrant
- Fields North of M31's semi-major axis



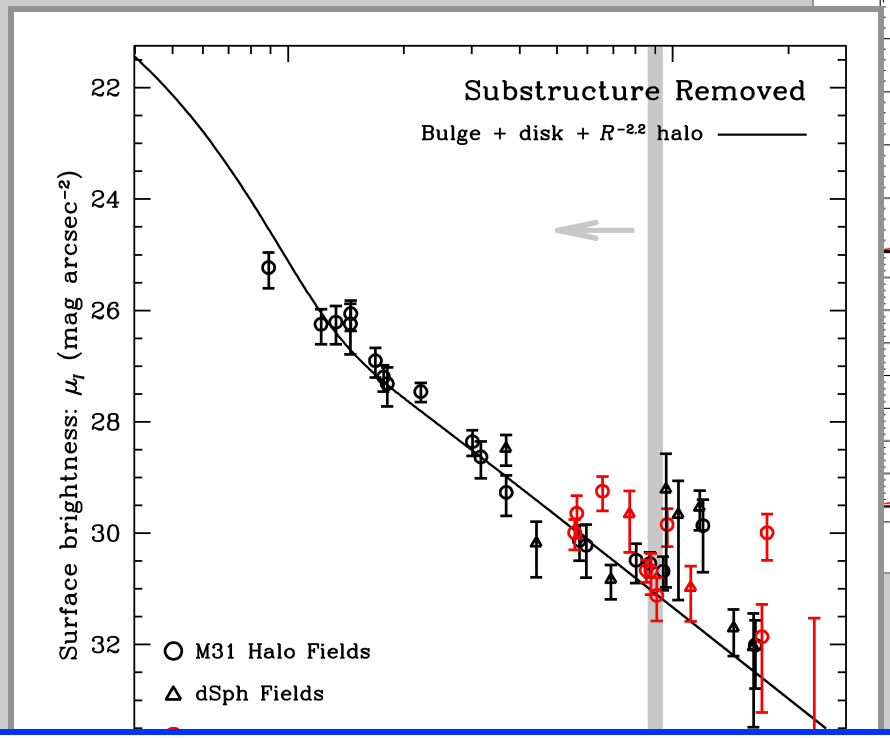


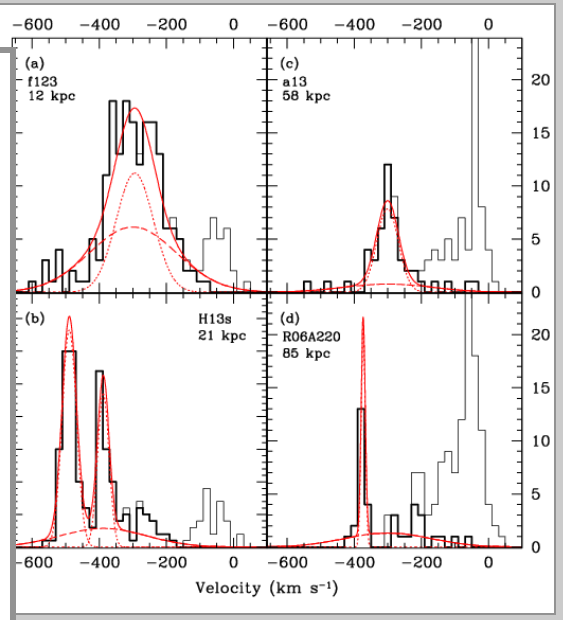
Gilbert et al. 2012

Andromeda has a large (virialized?) stellar halo

Spectroscopy allows us to statistically remove substructure (partially digested former dwarf satellite galaxies) in different fields

- Fields in M31's South quadrant
- Fields North of M31's semi-major axis



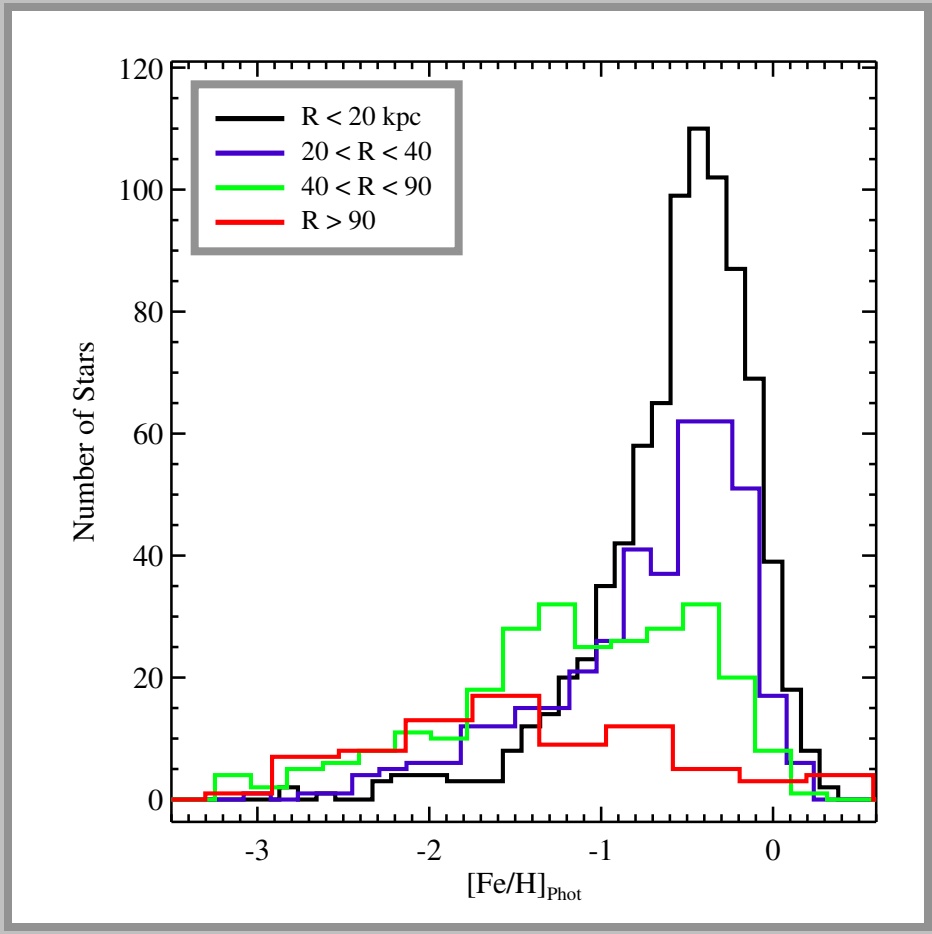


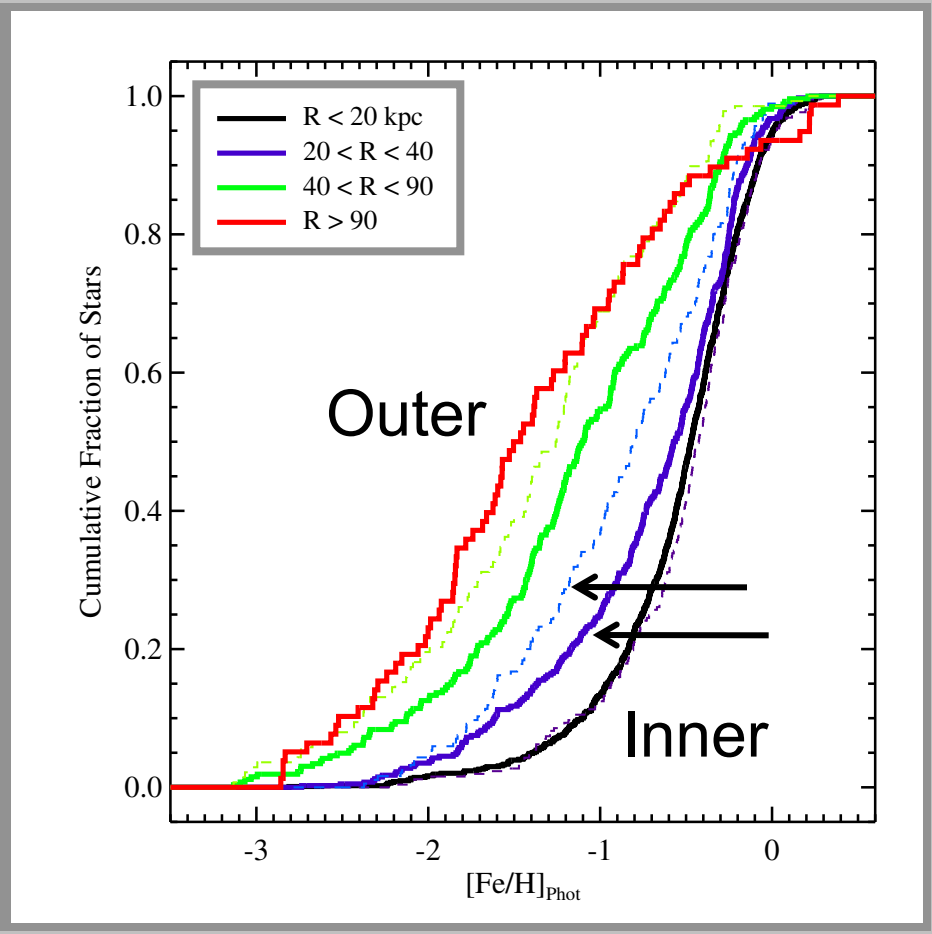
Gilbert et al. 2012

Forensic reconstruction of giant southern stream and associated shell system: (1) constraint on inner potential; (2) indication that star formation was quenched well before tidal disruption started

Series of Fardal et al. & Brown et al. papers

Andromeda's stellar halo gets progressively more metal poor going from the center to the outskirts

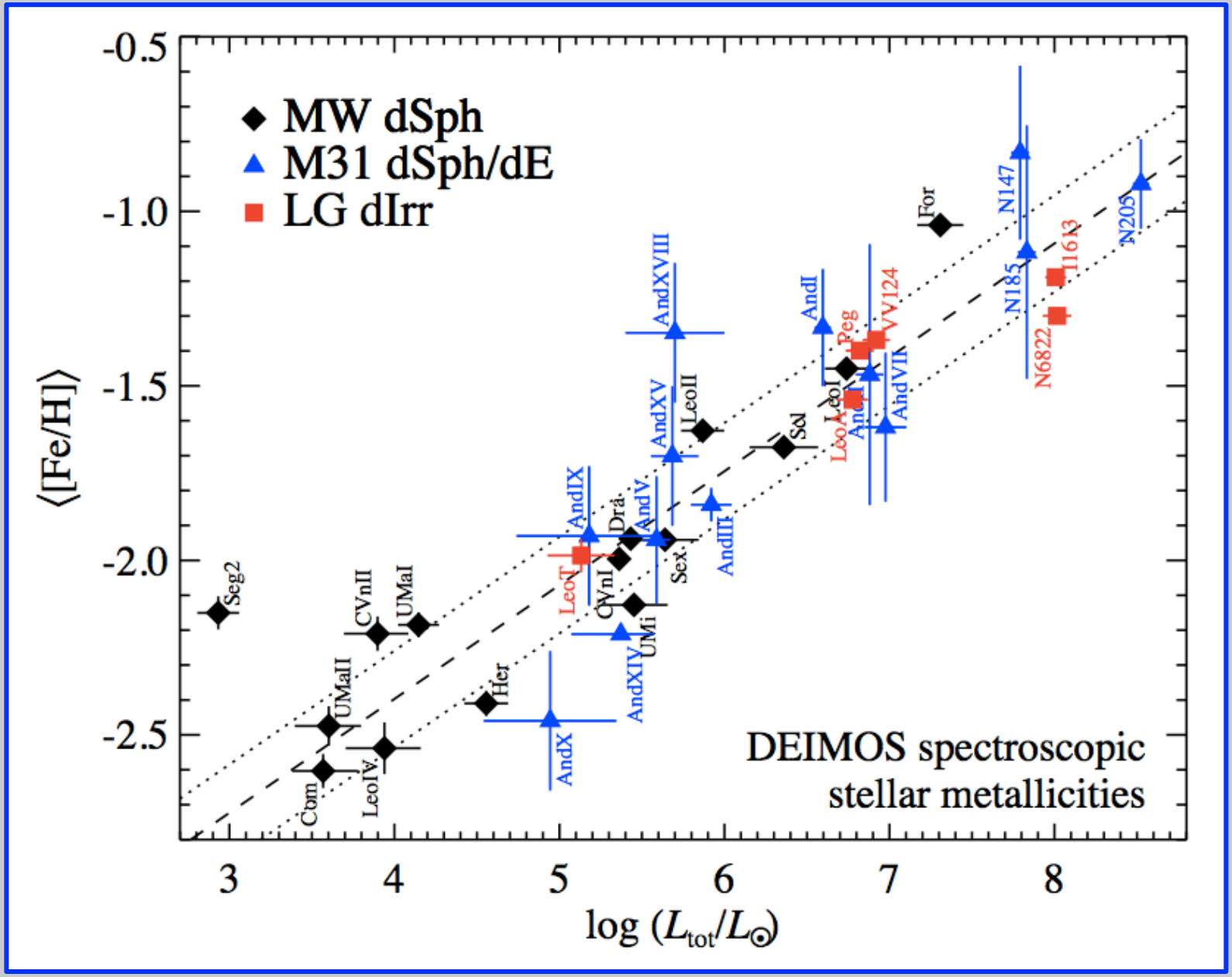




[Fe/H] →

Kalirai et al. (2006, ApJ)
Gilbert et al. (2014, submitted)

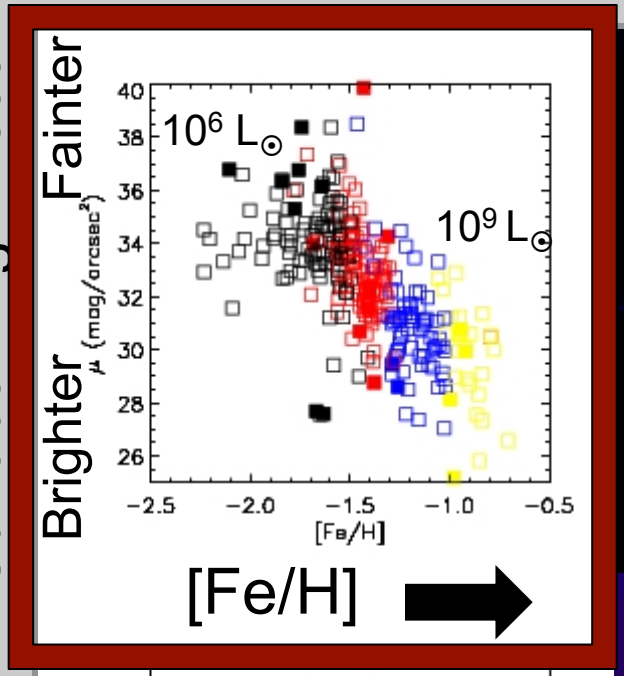
Andromeda satellites resemble their Milky Way counterparts

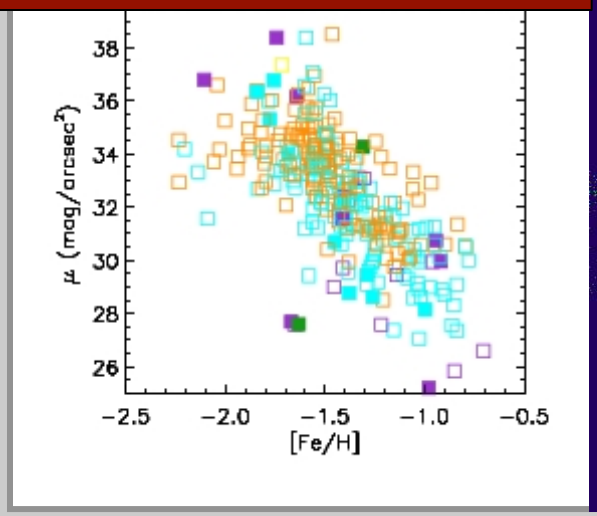


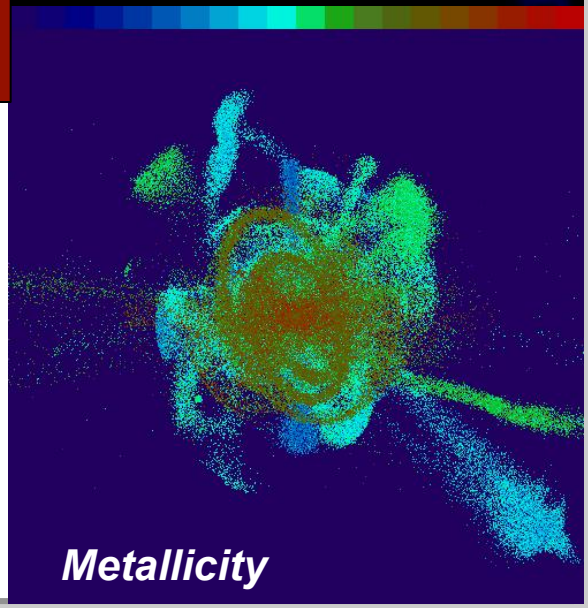
Kirby et al. (2013)

Lucy Cheng (SIP 2011/2012; Harker School / Harvard Univ)

Deducing the statistical properties of disrupted satellites

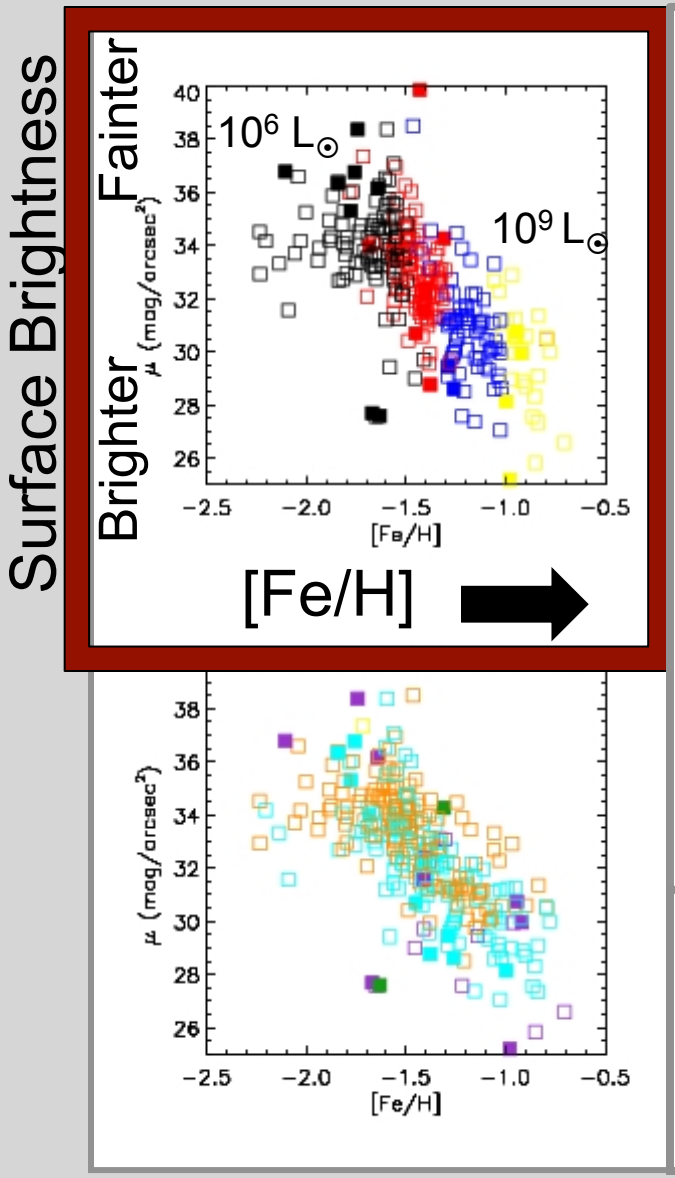


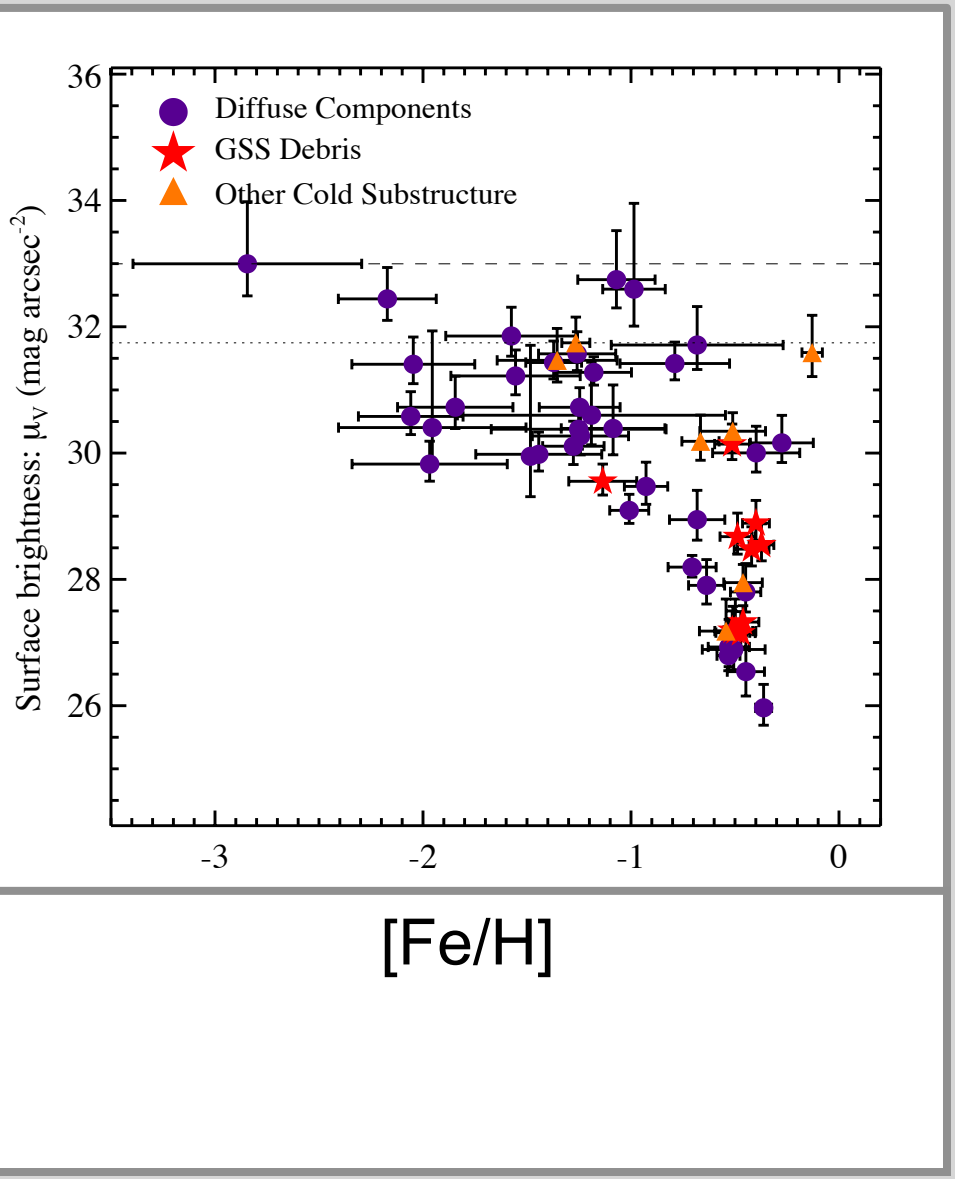




Johnston et al. 2008; Gilbert et al. 2009
Bullock & Johnston (2005) models

Deducing the statistical properties of disrupted satellites





Johnston et al. 2008; Gilbert et al. 2009
Bullock & Johnston (2005) models

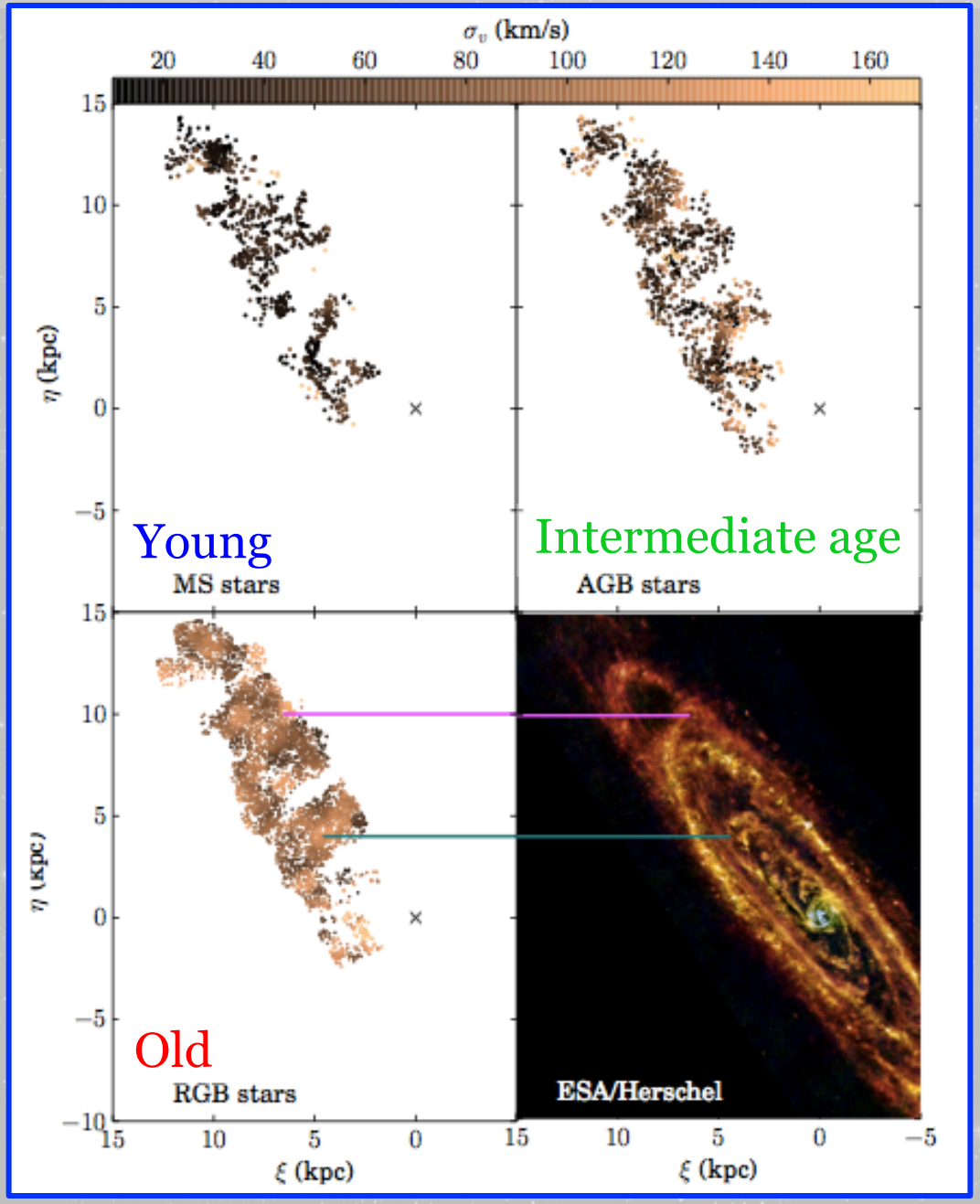
PHAT
PANCHROMATIC HUBBLE ANDROMEDA TREASURY

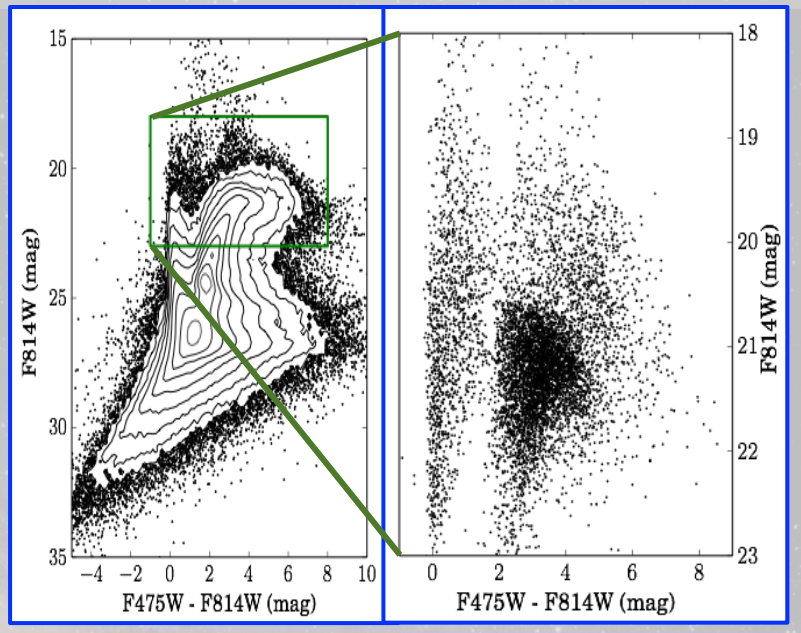
- 828 orbits, 4 years
- 6 Filters (UV-NIR)

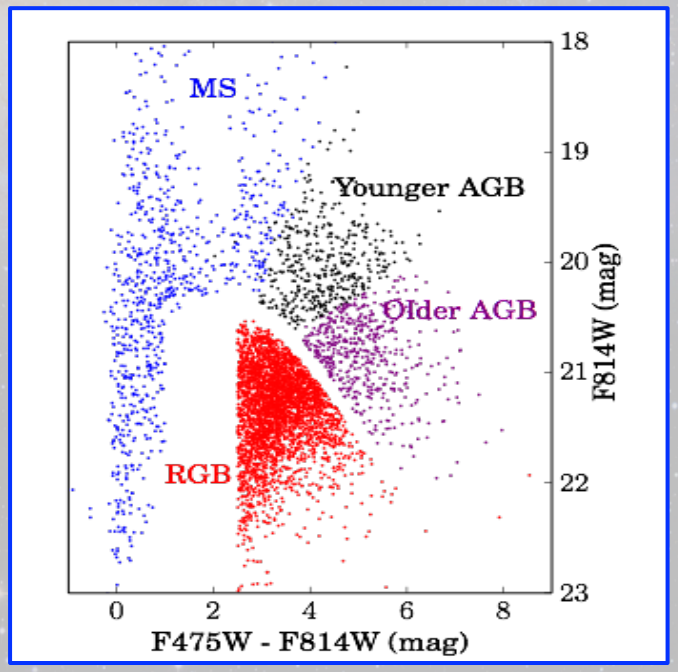
PHAT PI: Julianne Dalcanton
Keck/DEIMOS spectroscopy led by C. Dorman and the UCSC group

Ground-based image: Robert Gendler *Movie created by: Anil Seth*

M31 disk kinematics using stellar tracers of different ages

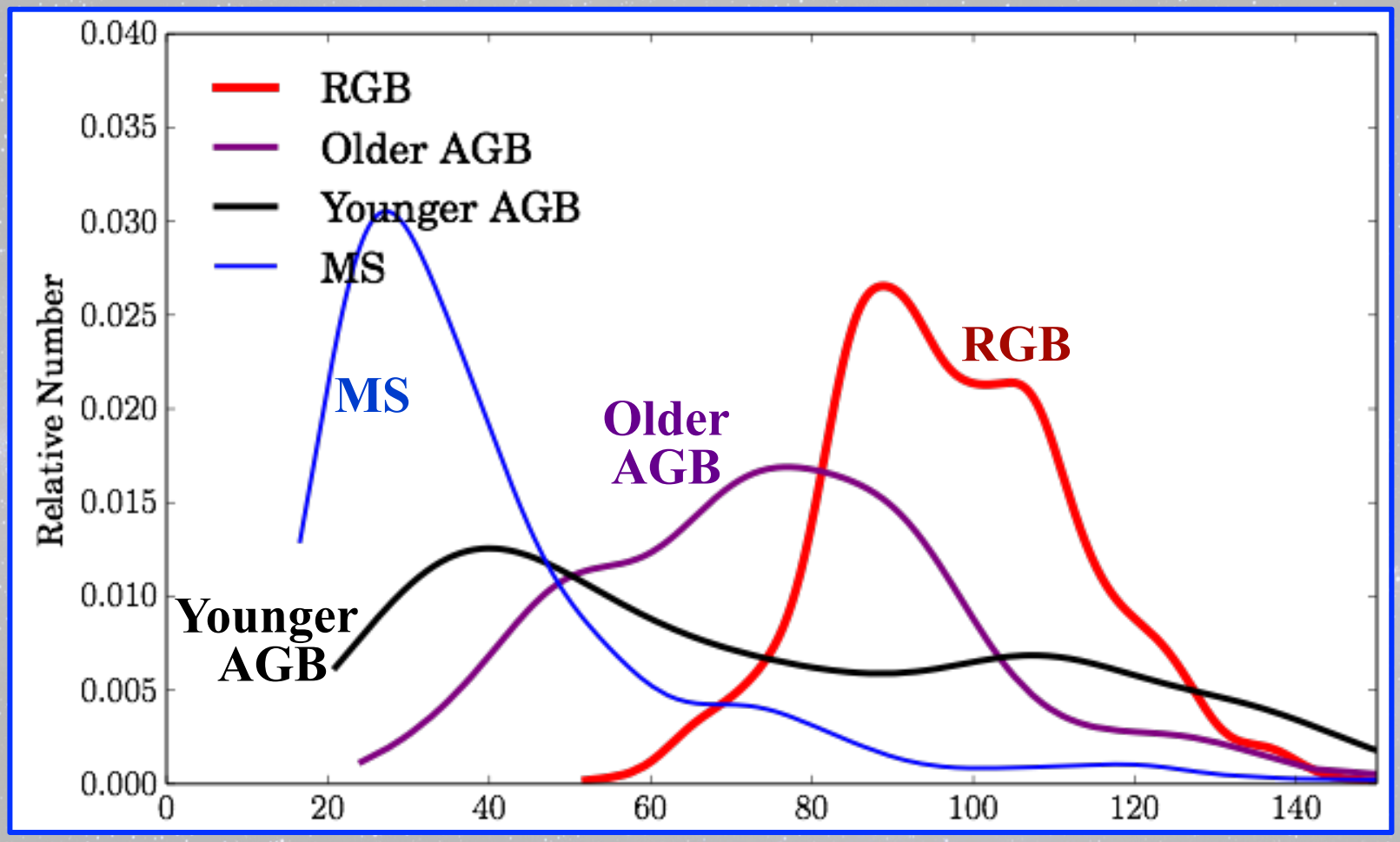






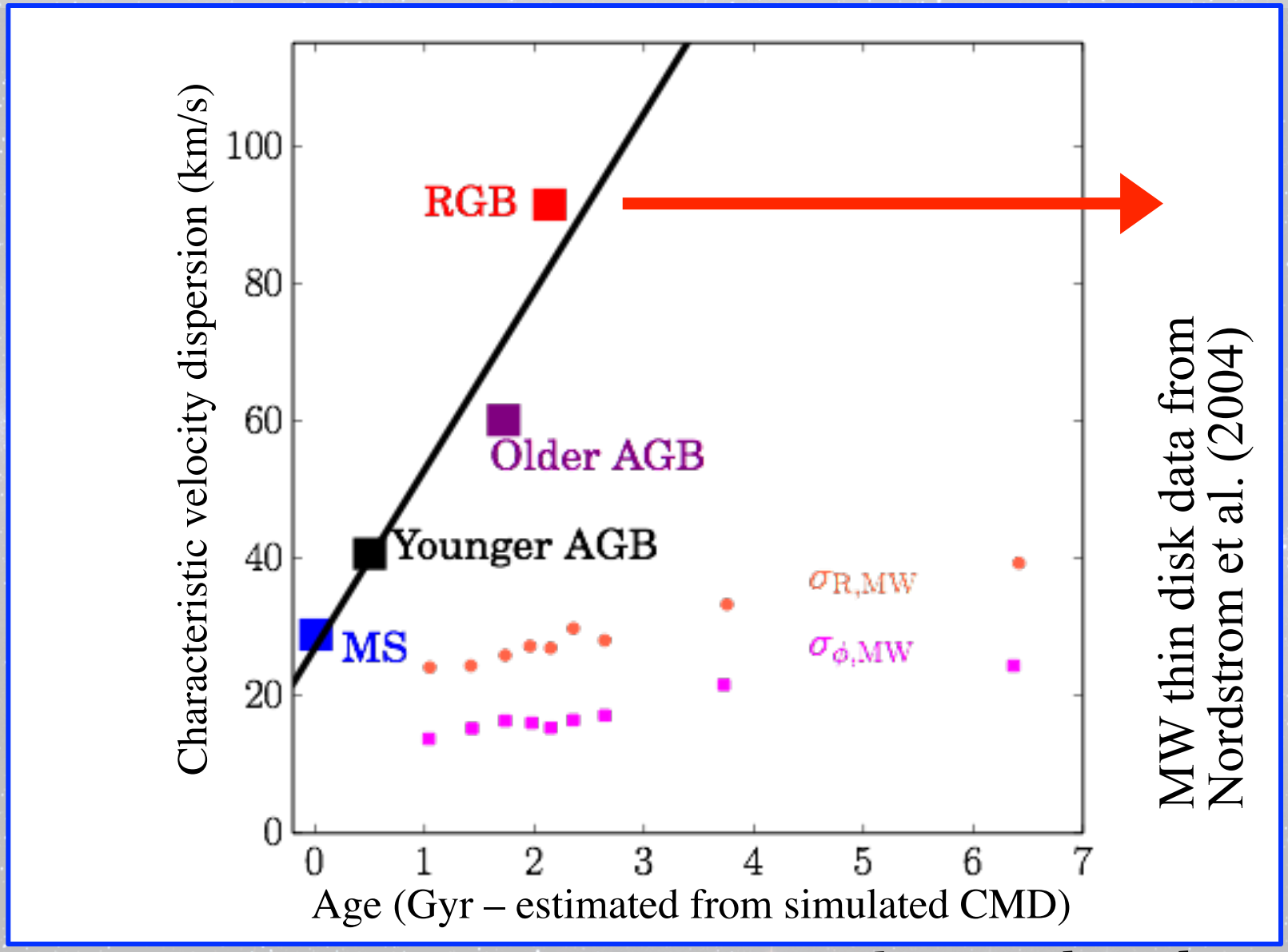
Dorman, PG, et al. in prep.

M31 stellar disk is dynamically hotter than that of the MW



Dorman, PG, et al. in prep.

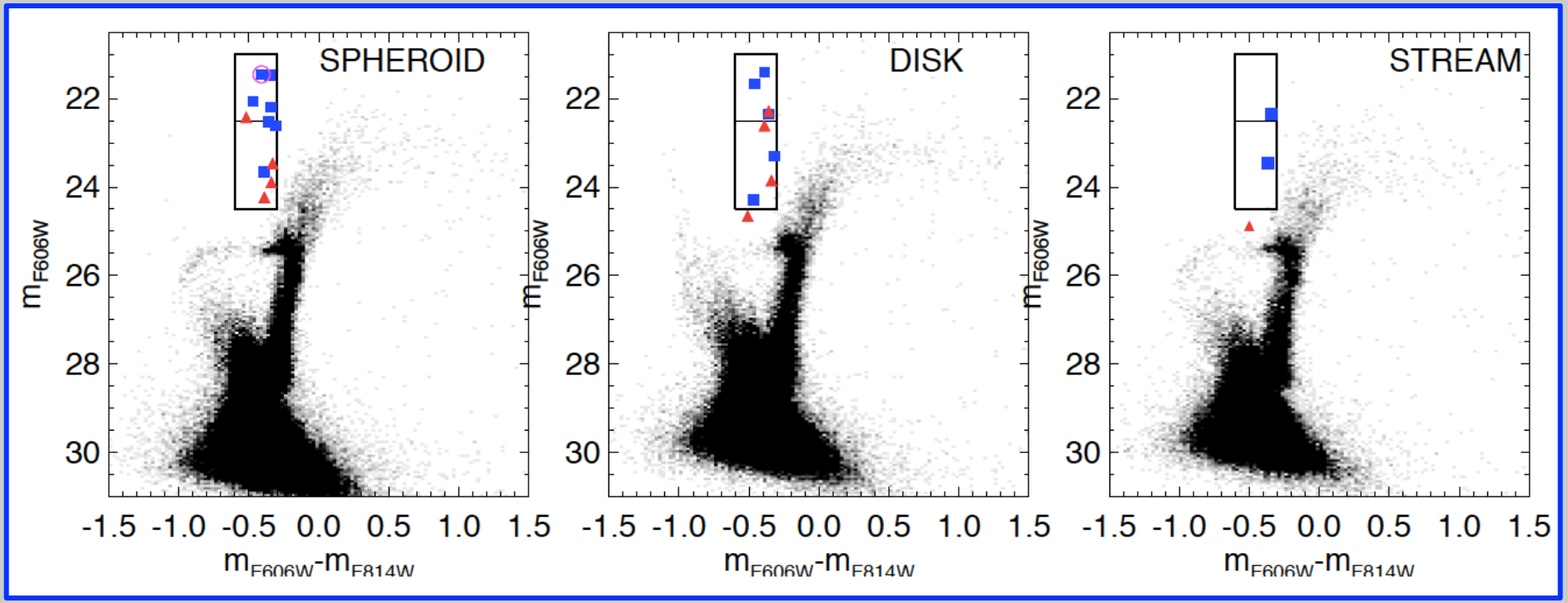
M31 stellar disk is dynamically hotter than that of the MW



Result of M31 having a more active merger history than the MW?
(as indicated by their stellar halos)

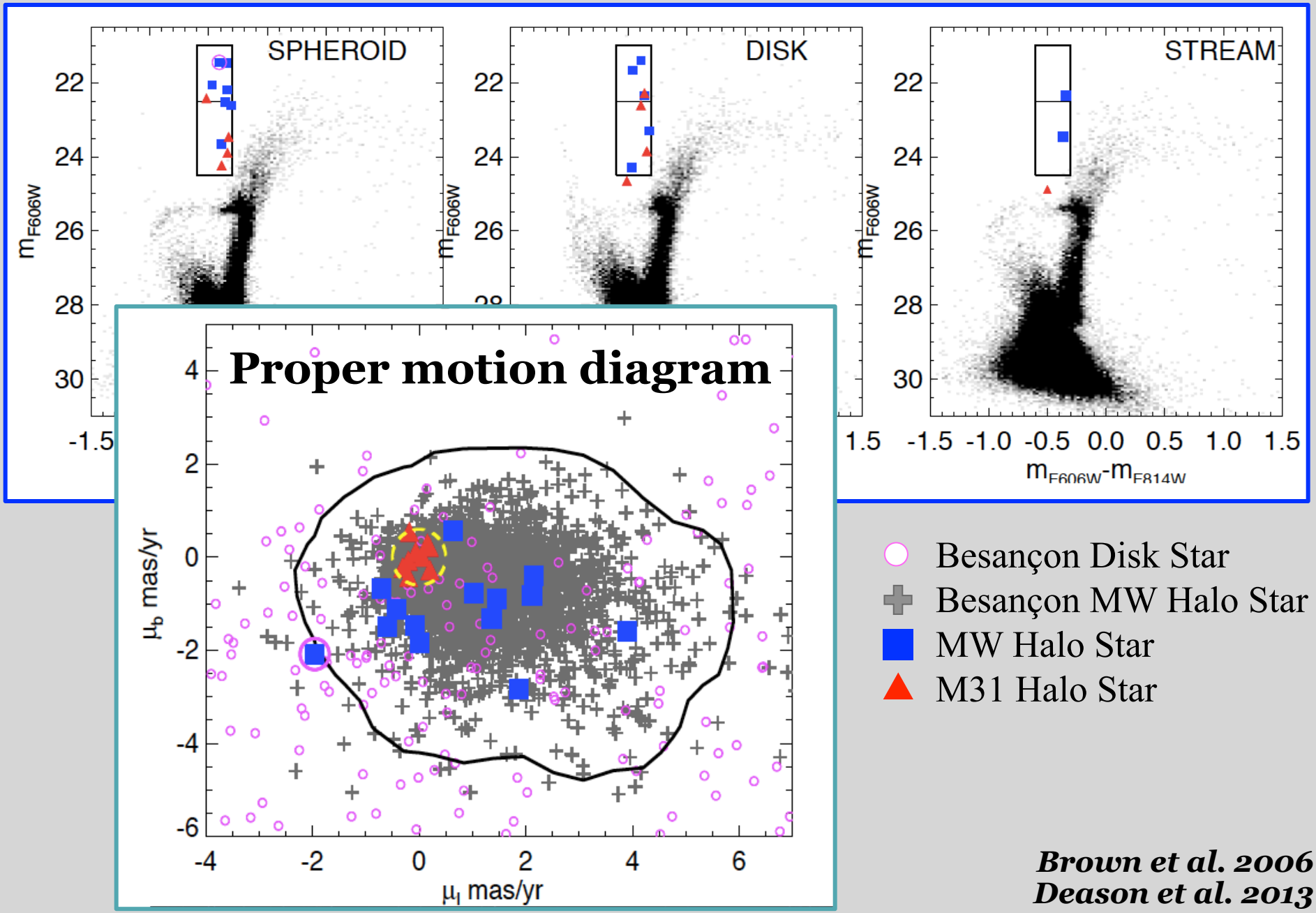
Dorman, PG, et al. in prep.

CMDs and PMs along three M31 lines of sight



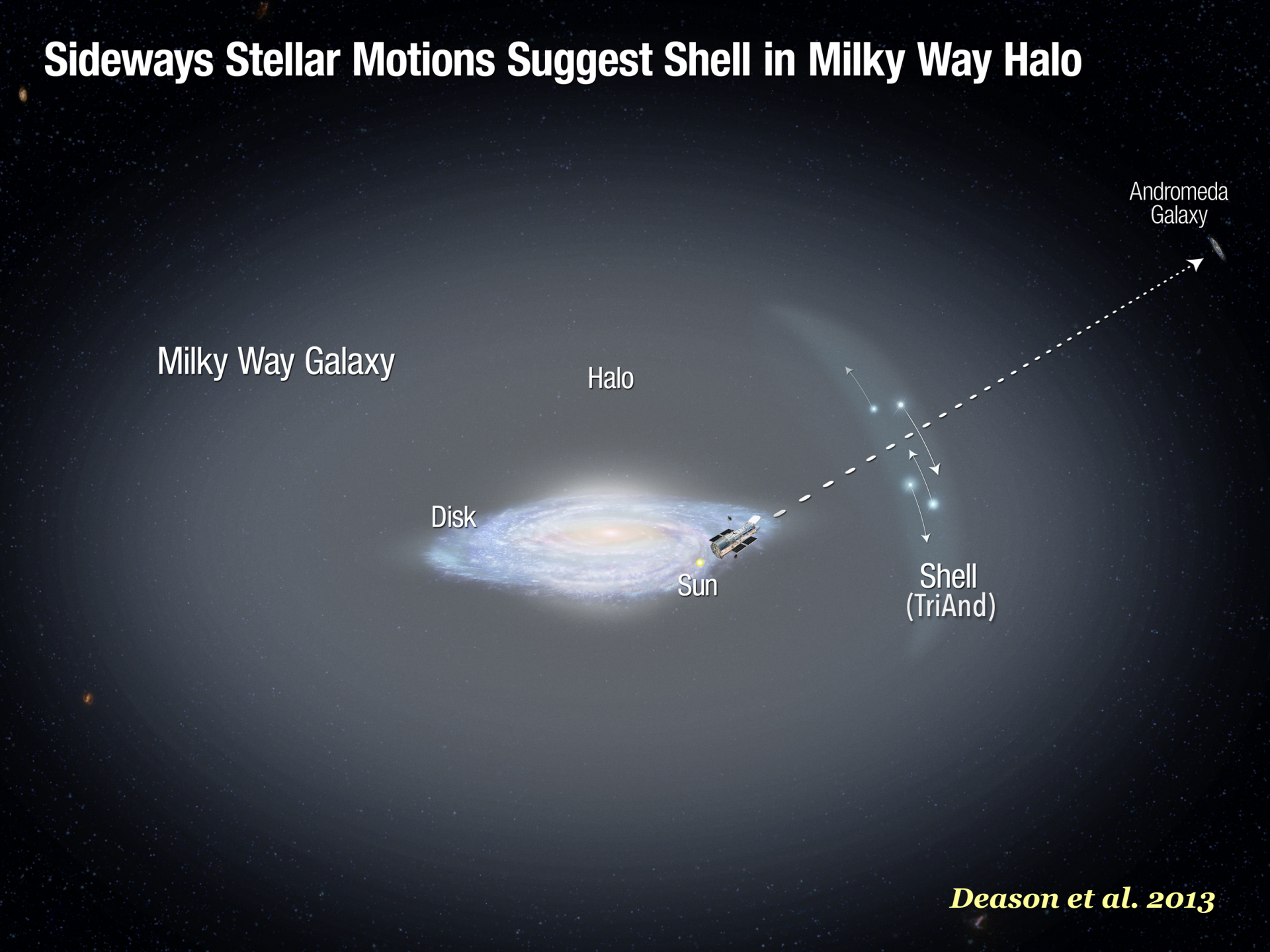
Brown et al. 2006
Deason et al. 2013

CMDs and PMs along three M31 lines of sight



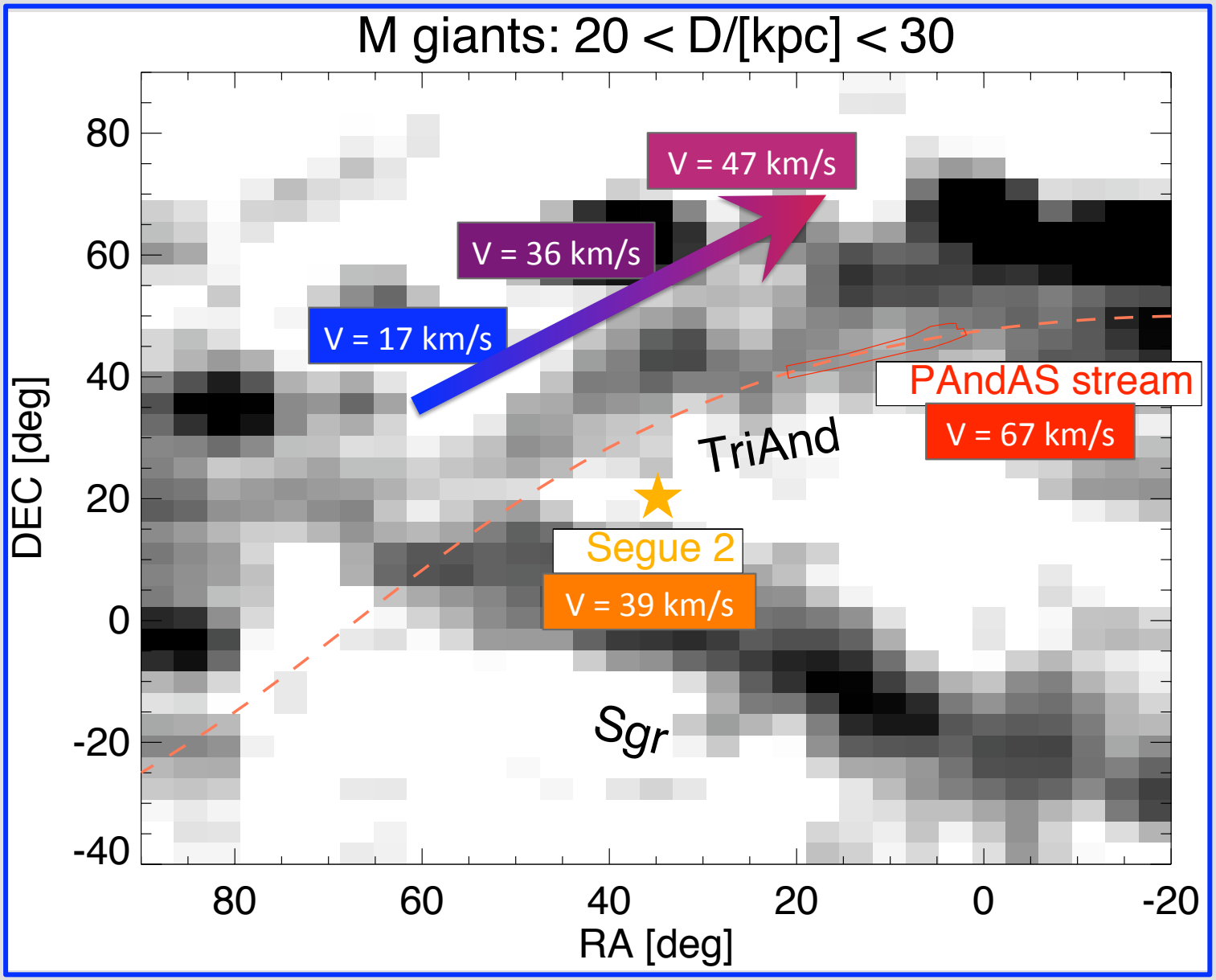
Brown et al. 2006
Deason et al. 2013

Sideways Stellar Motions Suggest Shell in Milky Way Halo



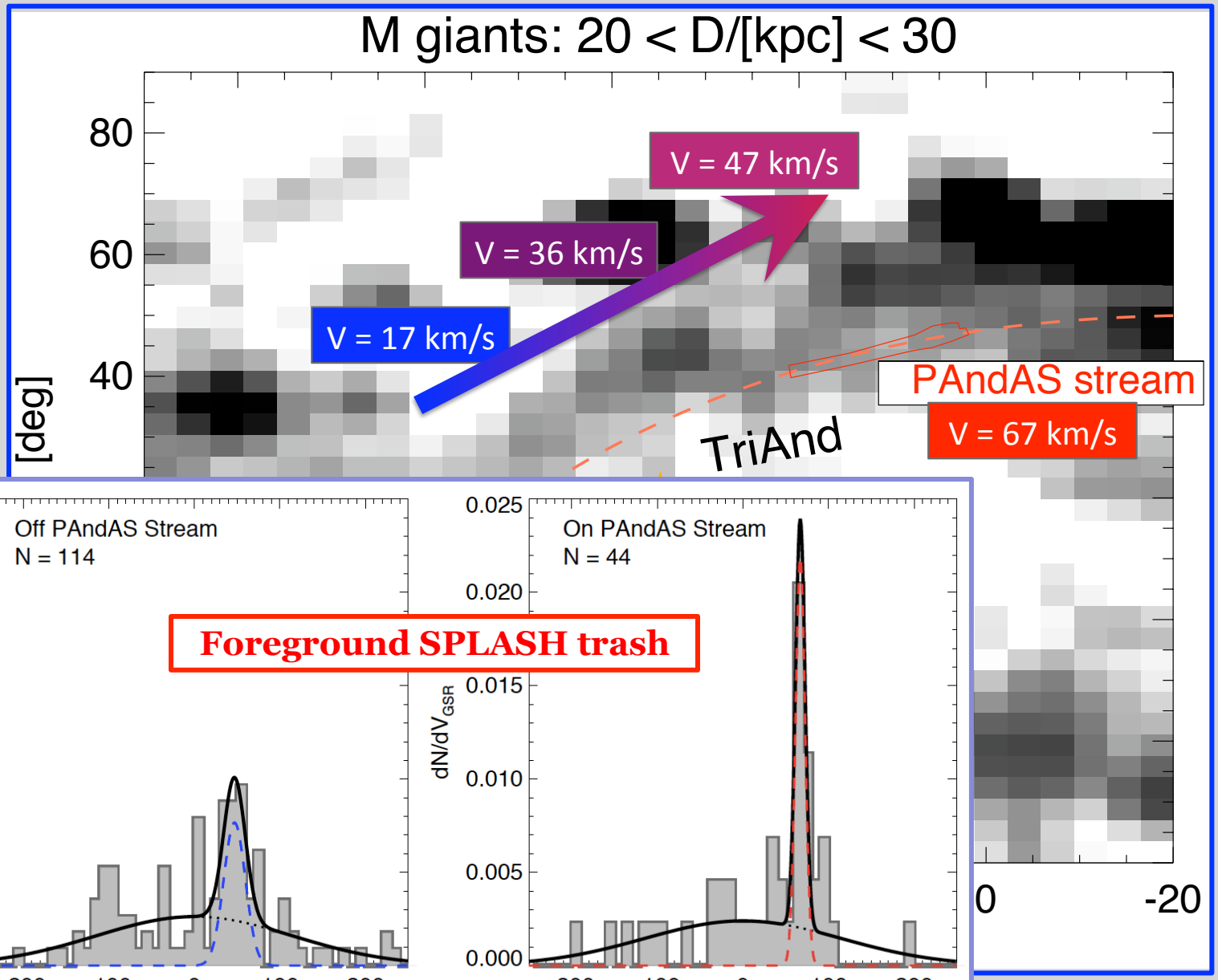
Deason et al. 2013

MW substructure in 2MASS, SEGUE, and SPLASH



Deason et al.
(2014, MNRAS, in press)

MW substructure in 2MASS, SEGUE, and SPLASH



Deason et al.
(2014, MNRAS, in press)

HALO7D survey

HST archival legacy program

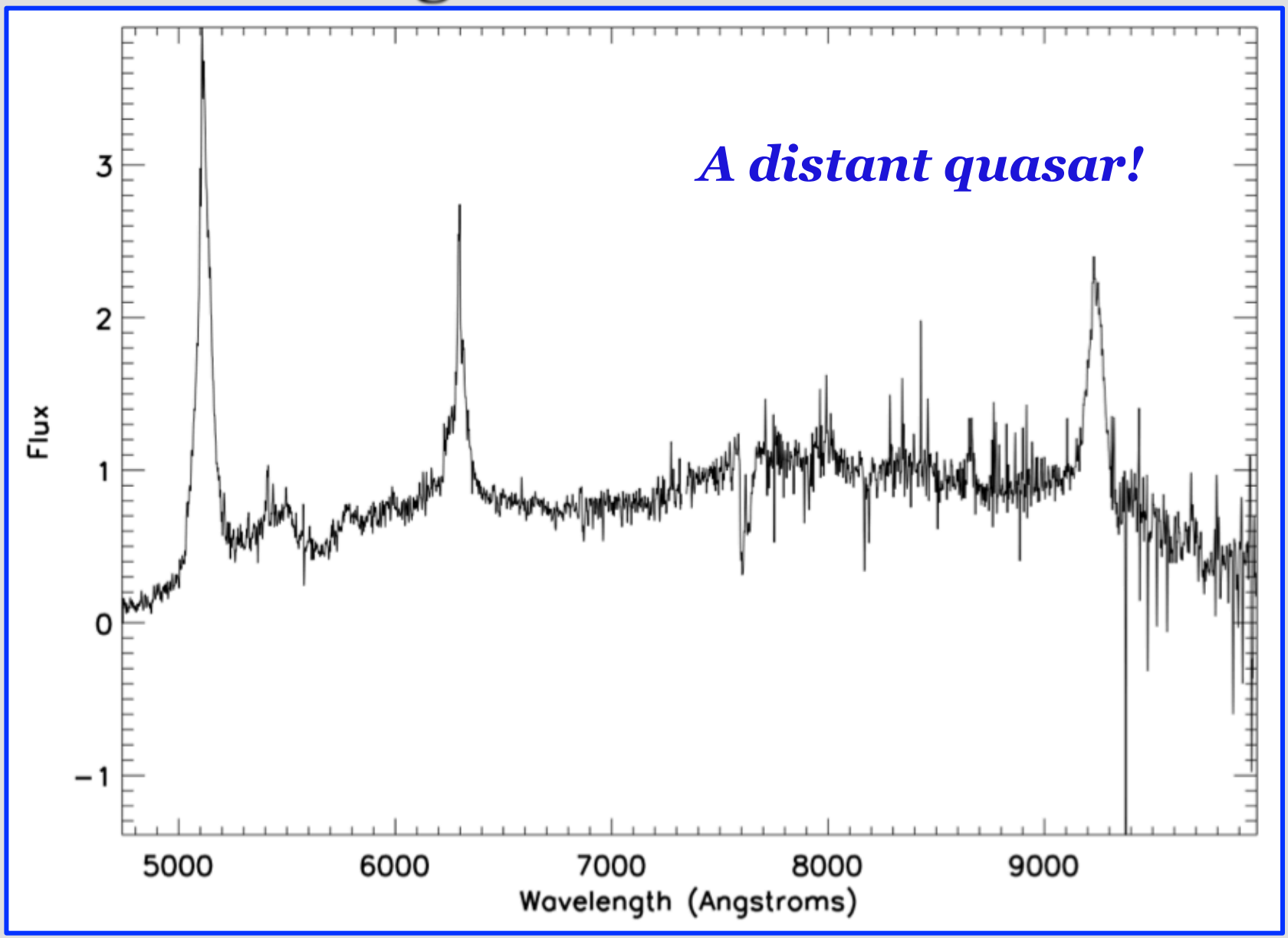
- Deep multi-epoch HST imaging
- Use distant galaxies as "wall paper"
- Proper motion of ~ 1000 MSTO stars in the MW halo

Keck/DEIMOS spectroscopy program

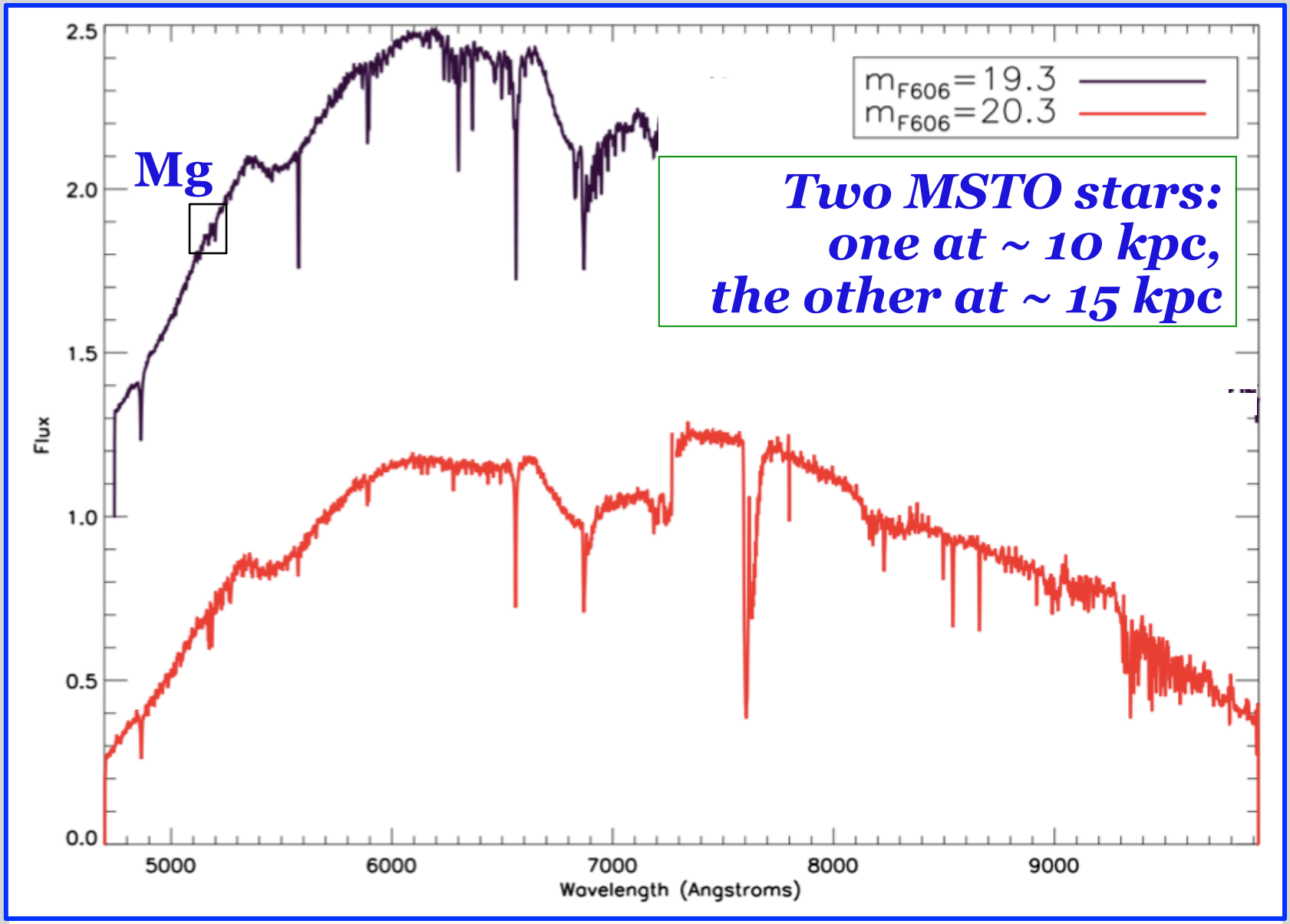
- 8- to 32-hour integrations of ~ 350 MW halo MSTO stars in three northern CANDELS fields
- Future extensions: M31 foreground fields? Fronter Fields?
- Radial velocities
- Chemical abundances and LOS distances
- Fillers: exquisite quality spectra of ~ 1500 distant galaxies

Cunningham, Deason, Anderson, Barro, Brown, Conroy, Cheung, Choi, Faber, Gilbert, Guo, Kirby, Koo, Rockosi, Sohn, Toloba, van der Marel, Yesuf

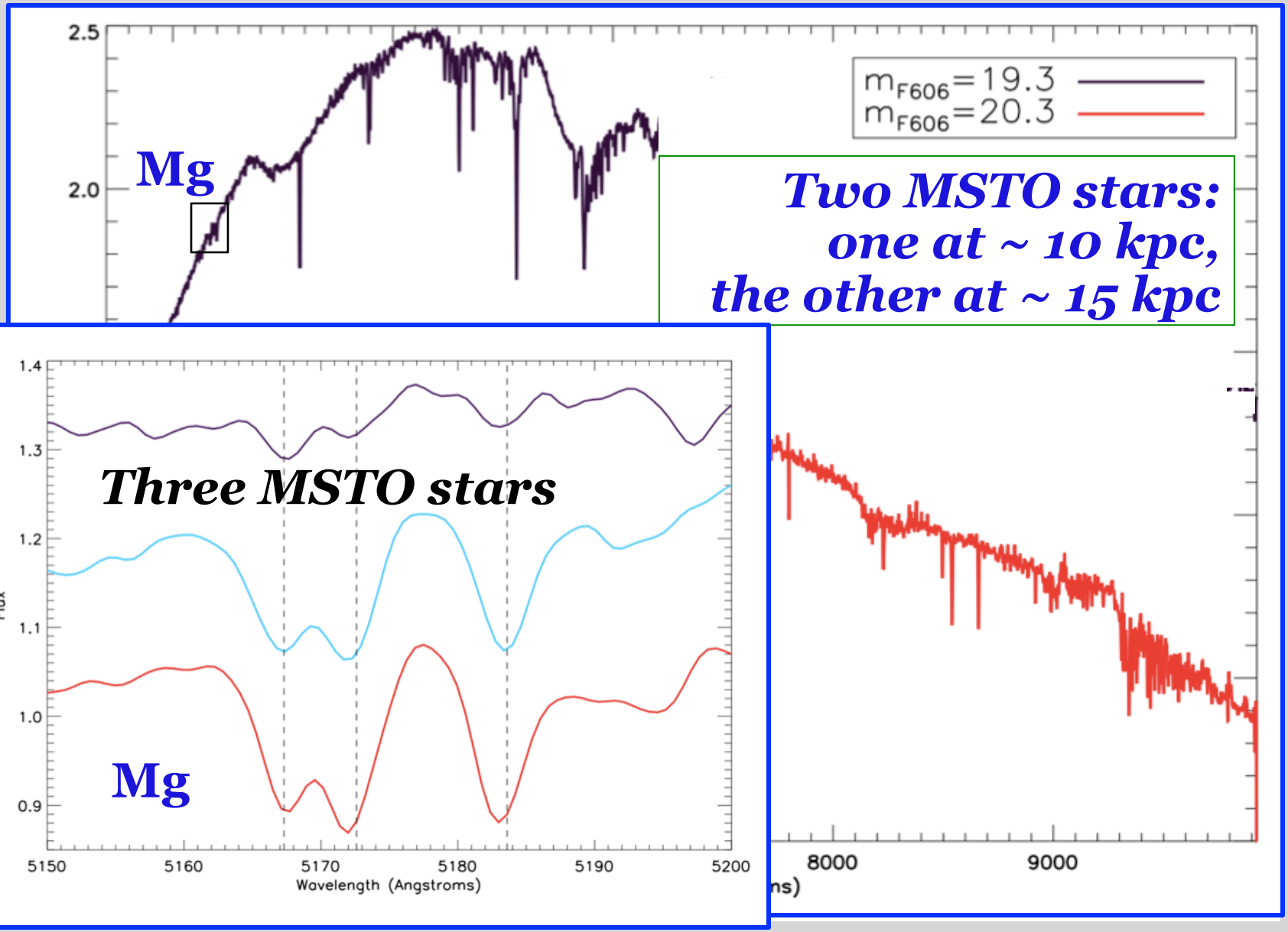
Sample spectra from ~ 6 hours of integration in the EGS



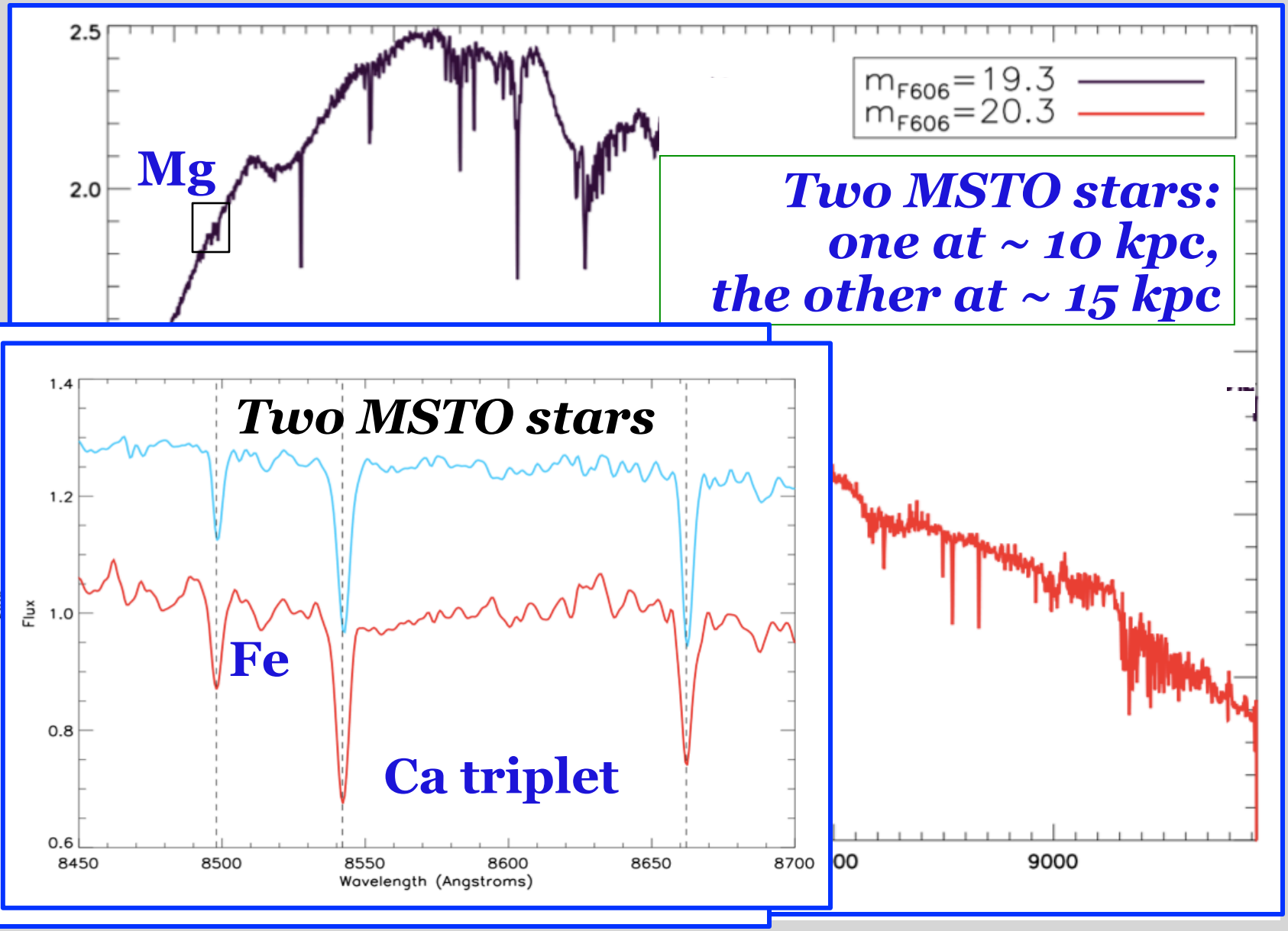
Sample spectra from ~ 6 hours of integration in the EGS



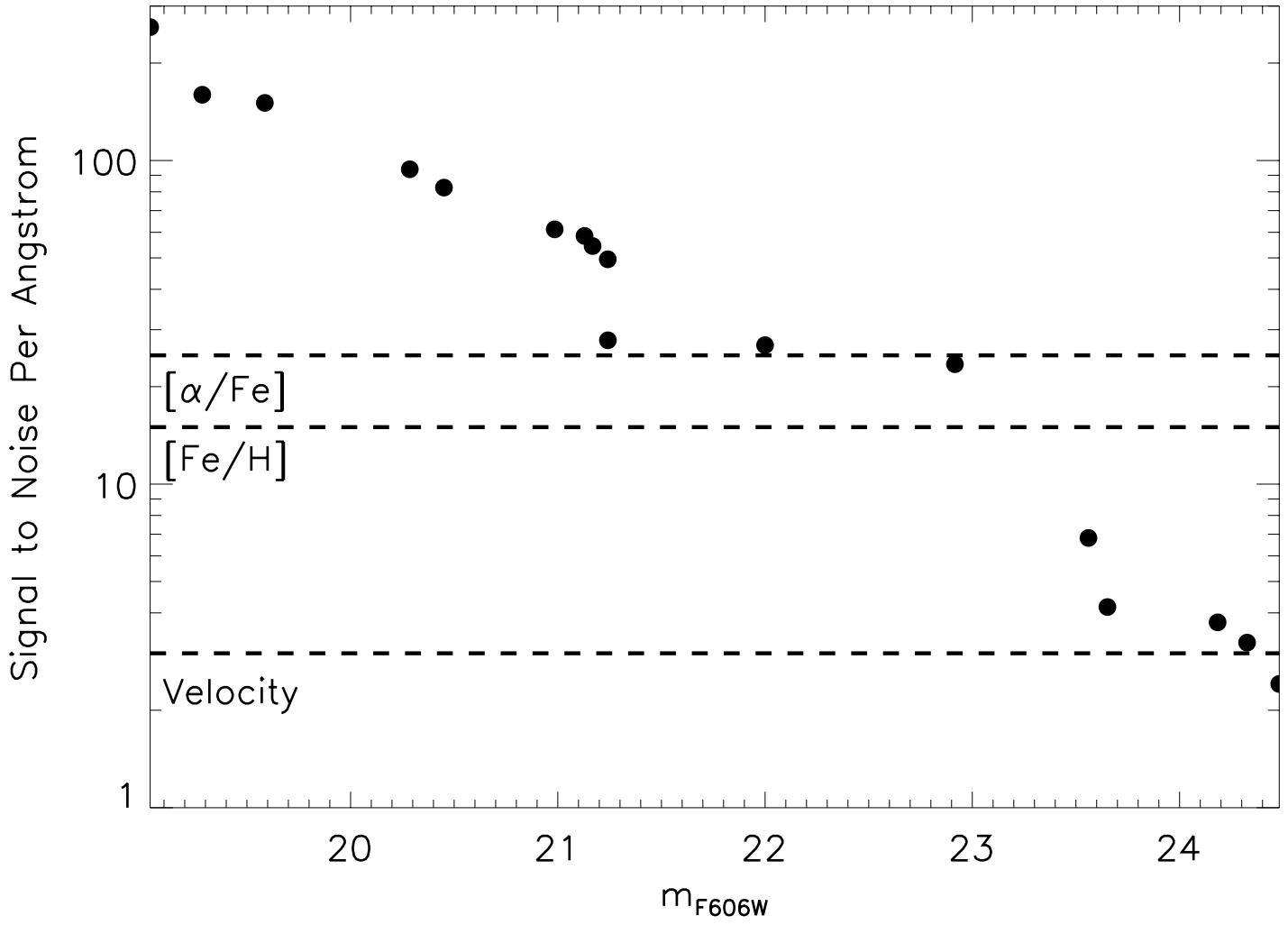
Sample spectra from ~ 6 hours of integration in the EGS



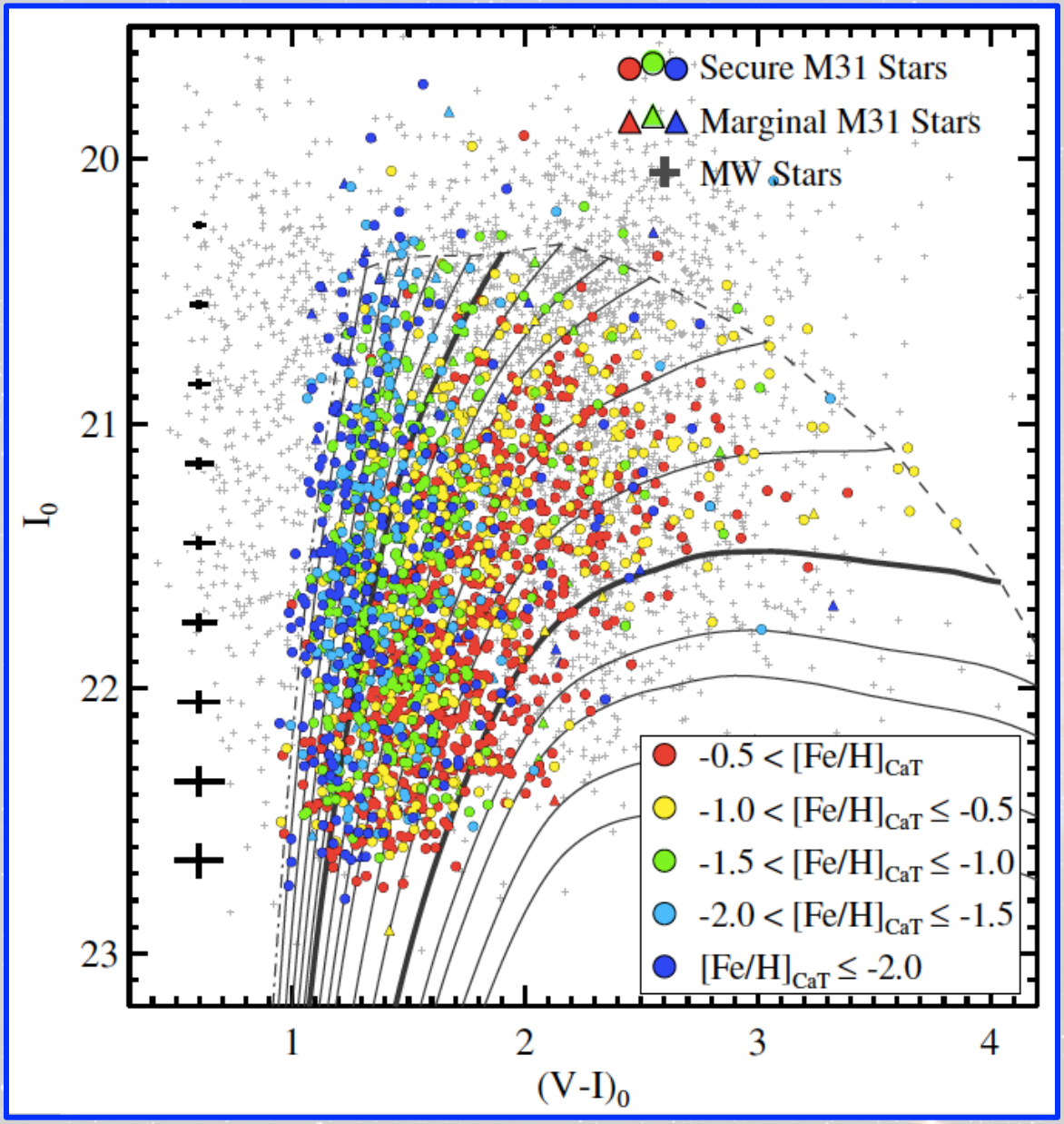
Sample spectra from ~ 6 hours of integration in the EGS



Typical S/N ratio at 6500Å based on ~ 6 hours of integration in the EGS



Detailed chemical abundances of M31 RGB stars

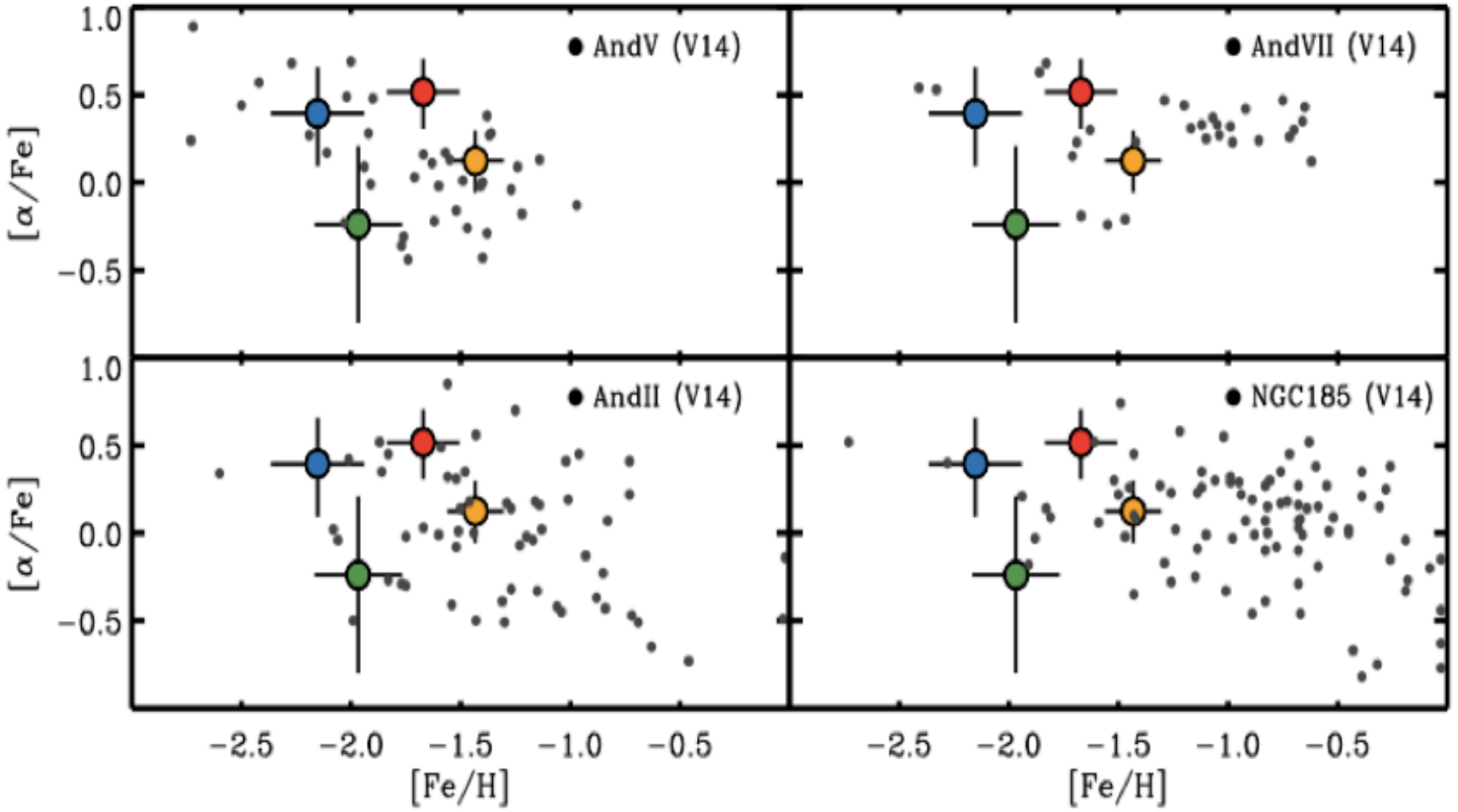


Color coding of RGB stars corresponds to CaT-based proxy for metallicity [Fe/H]

Gilbert et al. (2014, ApJ, submitted)
Ho et al. (2014, ApJ, submitted)

Vargas et al. (2014a, ApJ)
Vargas et al. (2014b, ApJL, submitted)

Detailed chemical abundances of M31 RGB stars



Number of direct [Fe/H] and [α/Fe] measurements will go from *four* M31 field halo stars and *few tens* of members of luminous satellites to *few hundred* RGB stars in the spheroid, outer disk, and giant stream

Gilbert et al. (2014, ApJ, submitted)
Ho et al. (2014, ApJ, submitted)

Vargas et al. (2014a, ApJ)
Vargas et al. (2014b, ApJL, submitted)

Summary

– SPLASH / PHAT: Andromeda galaxy

❖ *Discovery and characterization of vast stellar halo*

❖ *Why is the stellar disk dynamically hot and clumpy?*

– HALO7D: Looking at and through the Milky Way

❖ *MW halo mass and accretion history:*
6D position/velocity and chemical abundance measurements

❖ *Distant galaxy evolution:*
outflows, integrated properties of their stellar population

– HALO7D extension this fall should yield detailed chemical abundances of a few 100 of M31 red giant stars

Time-lapse movie of the Milky Way

Courtesy Jon Rockman, Castilleja School, Palo Alto, California — jrockman@castilleja.org