Galaxies Inside and Out — The Resolved Stellar Populations of the Milky Way, Andromeda, and Triangulum Galaxies

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Gemini North, NOIRLab, Hilo, Hawaii

Outline

M32±1

- SPLASH
- TREX
- PHAT/PHAST
- PHATTER
- HSTPROMO

MILKY WAY

- HALO7D
- BP3M
- NGVS

NEARBY GROUPS

- PISCeS

Accretion History of the Milky Way's Stellar Halo

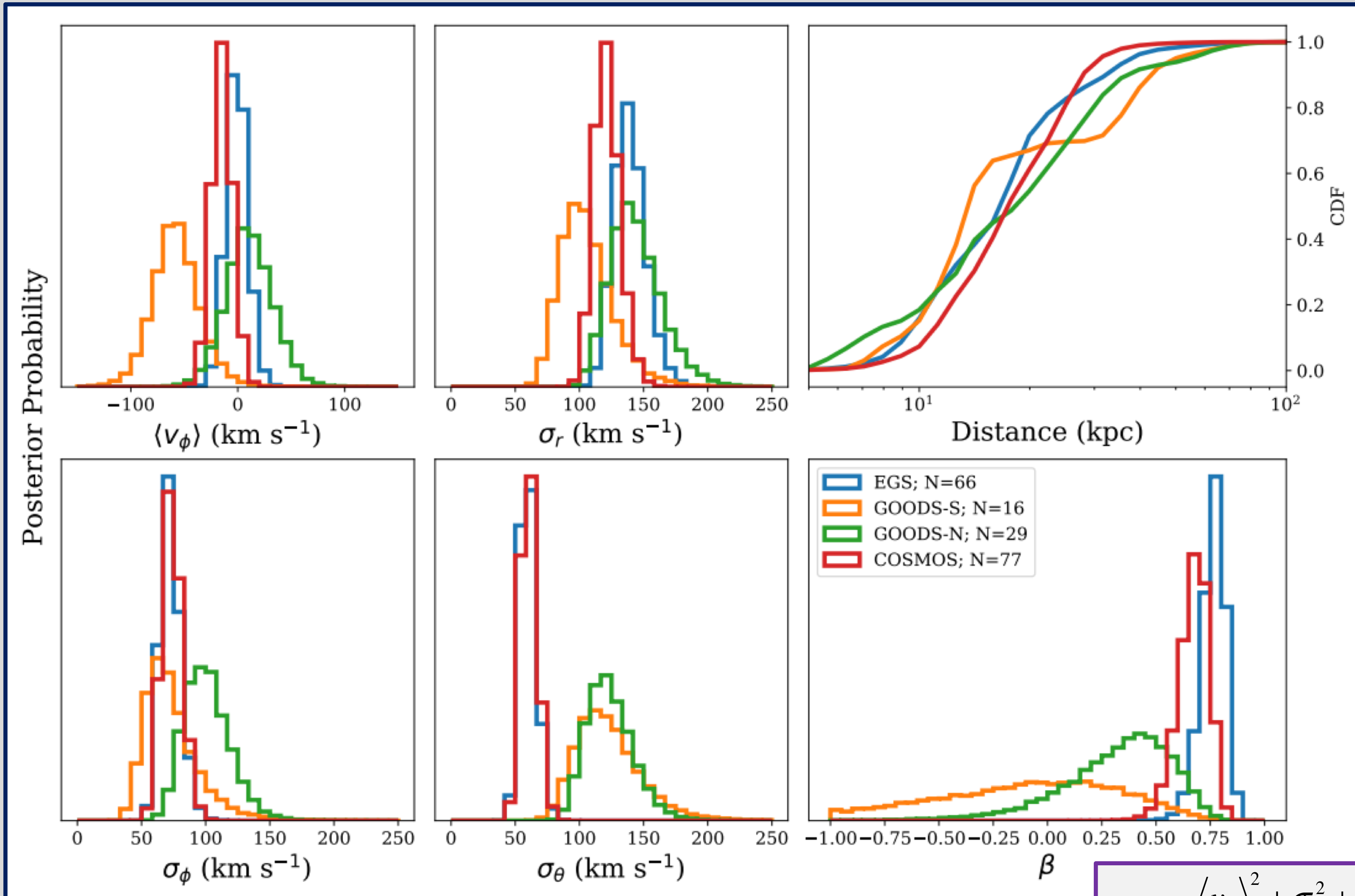
HALO7D survey

Looking at (and through) the remote Milky Way stellar halo

3D … f sight

– *Anderson, Apfel, Cunningham, Deason, PG, Kirby, McKinnon, Rockosi, Sanderson, Sohn, van der Marel, Wetzel*
– *Barro, Conroy, Faber, Guo, Koo, Yesuf*

HALO7D Field to Field Kinematical Variations



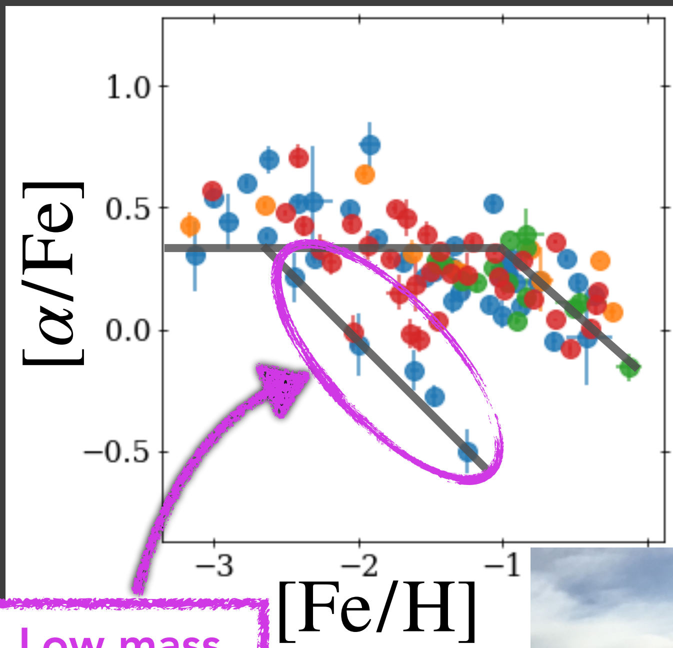
$$\beta = 1 - \frac{\langle v_\phi \rangle^2 + \sigma_\phi^2 + \sigma_\theta^2}{2\sigma_r^2}$$

Cunningham et al. (2019b)

HALO7D CHEMICAL ABUNDANCES

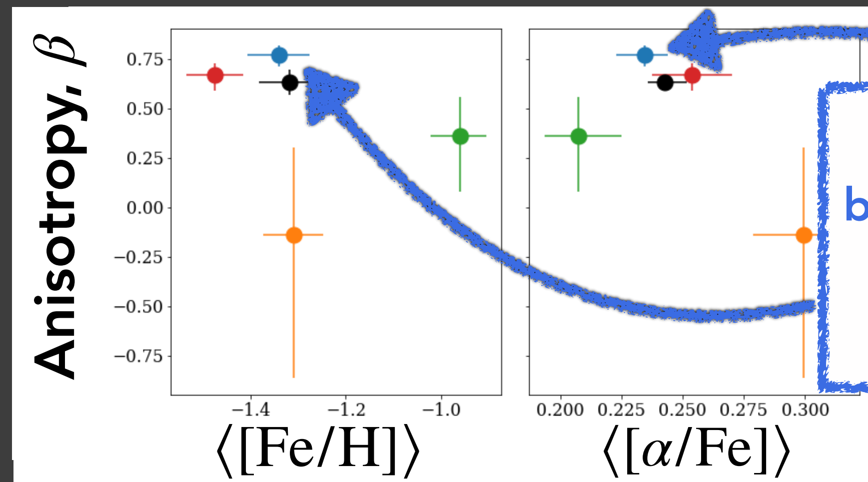
LEGEND:
EGS (N=41)
GOODS-N (N=16)
GOODS-S (N=12)
COSMOS (N=32)
TOTAL (N=101)

Individual Stars



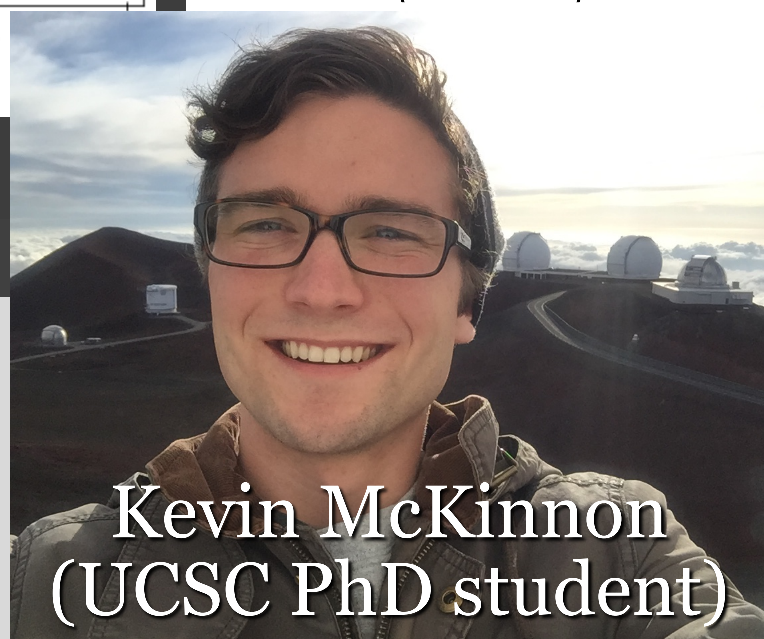
Low mass progenitor?

Line-of-Sight Averages



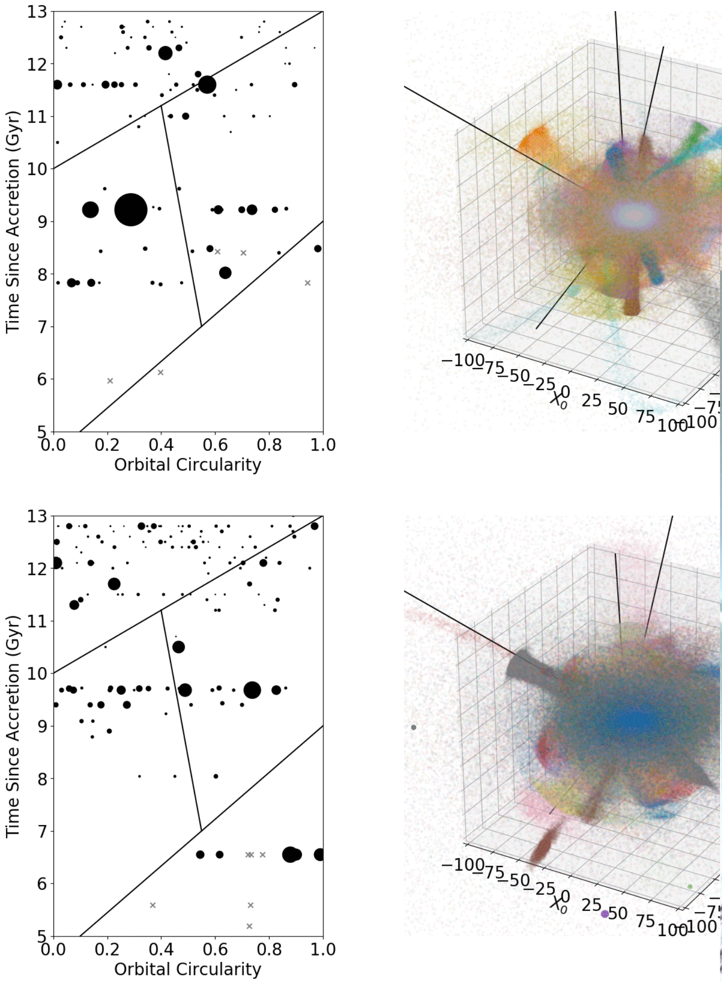
Radially-biased orbits; Gaia Sausage?

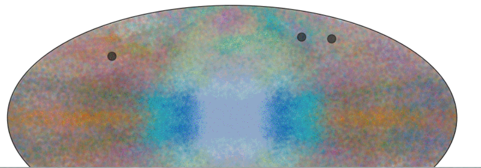
chemistry and kinematics.
D chemodynamics of

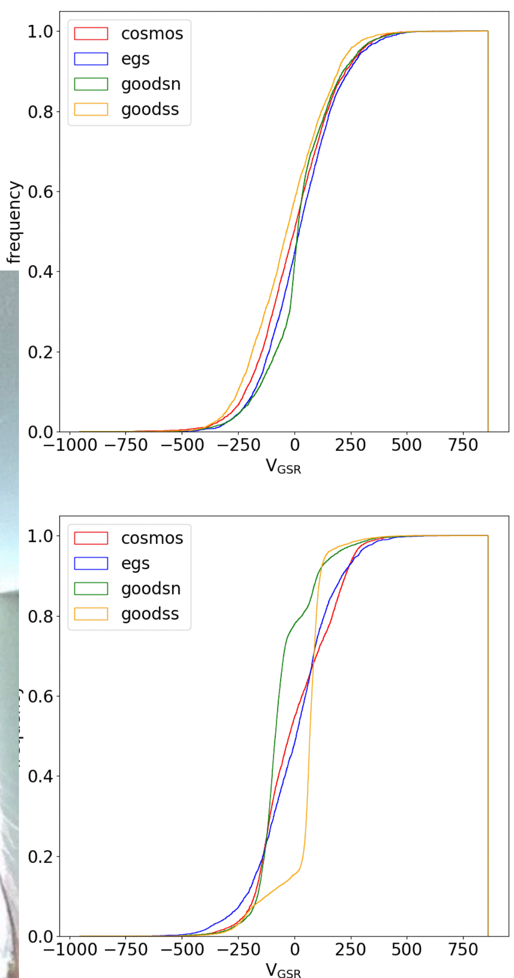


McKinnon et al. (2023)

Constraining the Milky Way Halo Accretion History







Two Bullock & Johnston (2 … atter particles were converted to star partic … et al. 2011)

- Upper row: Early massive accretion
- Lower row: Significant late accretion

Apfel, Rockosi, PG, et al. (2023, in prep)

Extent and Kinematics of the Milky Way’s Stellar Halo:

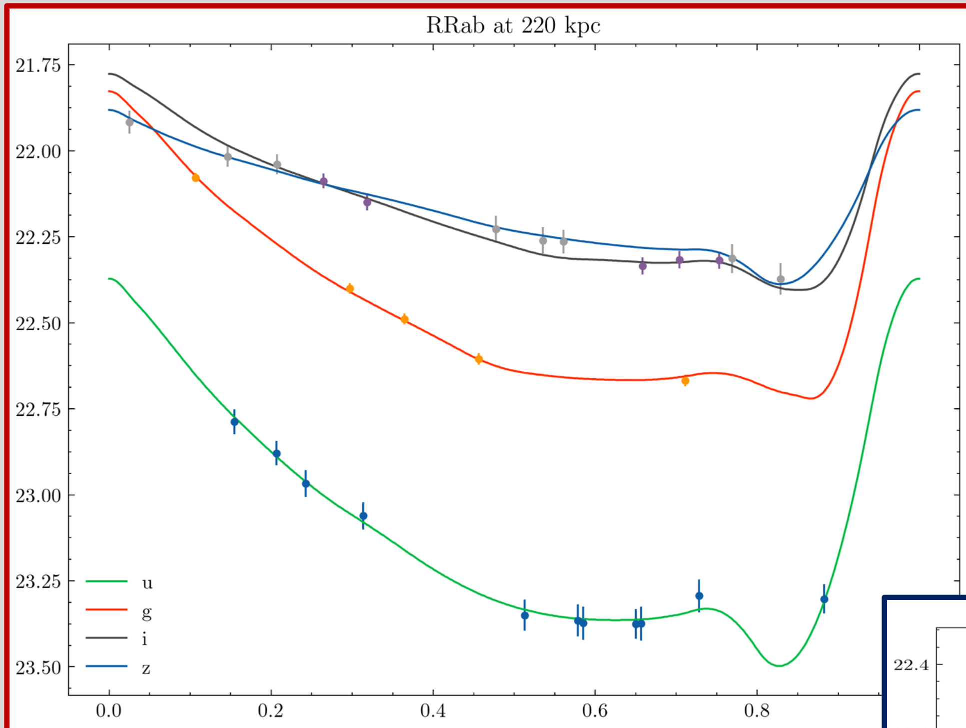
Distant RR Lyrae in the NGVS and Other Time Domain Surveys

Search for Distant Milky Way Halo RR Lyrae Stars in the NGVS Dataset

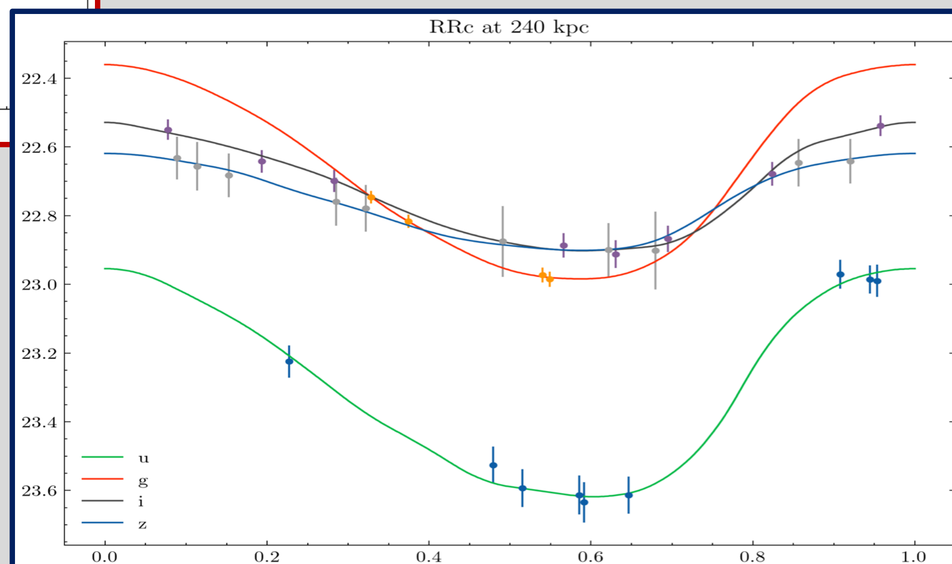
- NGVS = Next Generation Virgo Cluster Survey
- CFHT/MegaCam deep wide field (104 deg^2) *u*giz* imaging of the Virgo cluster
- Time-domain aspect of NGVS data yields foreground MW halo RR Lyrae
- Robust discovery of the most distant RR Lyrae in the MW halo ($R_{\mathrm{MW\ halo}} \sim 0.4\ D_{\mathrm{MW\text{-}M31}}$!)

Feng, PG, Peng, et al. (2023, subm.)

Sample NGVS RR Lyrae Light Curves



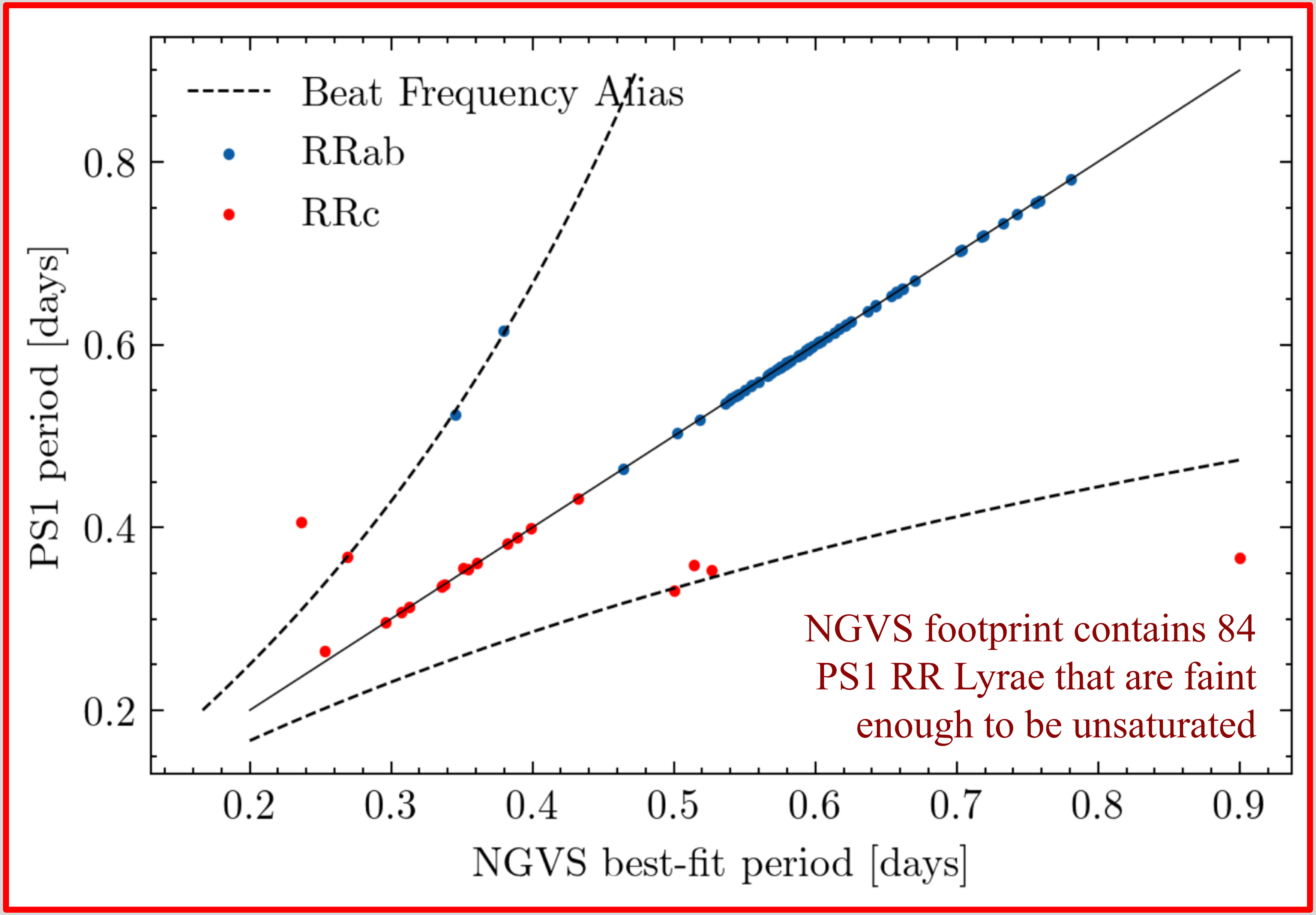
- ~30 data points across four bands (*u***giz)*
- Good photometric precision, especially in the *g* band



RRab stars are easier to find than RRc stars – larger pulsation amplitude and characteristic light curve shape

Feng, PG, Peng, et al. (2023, subm.)

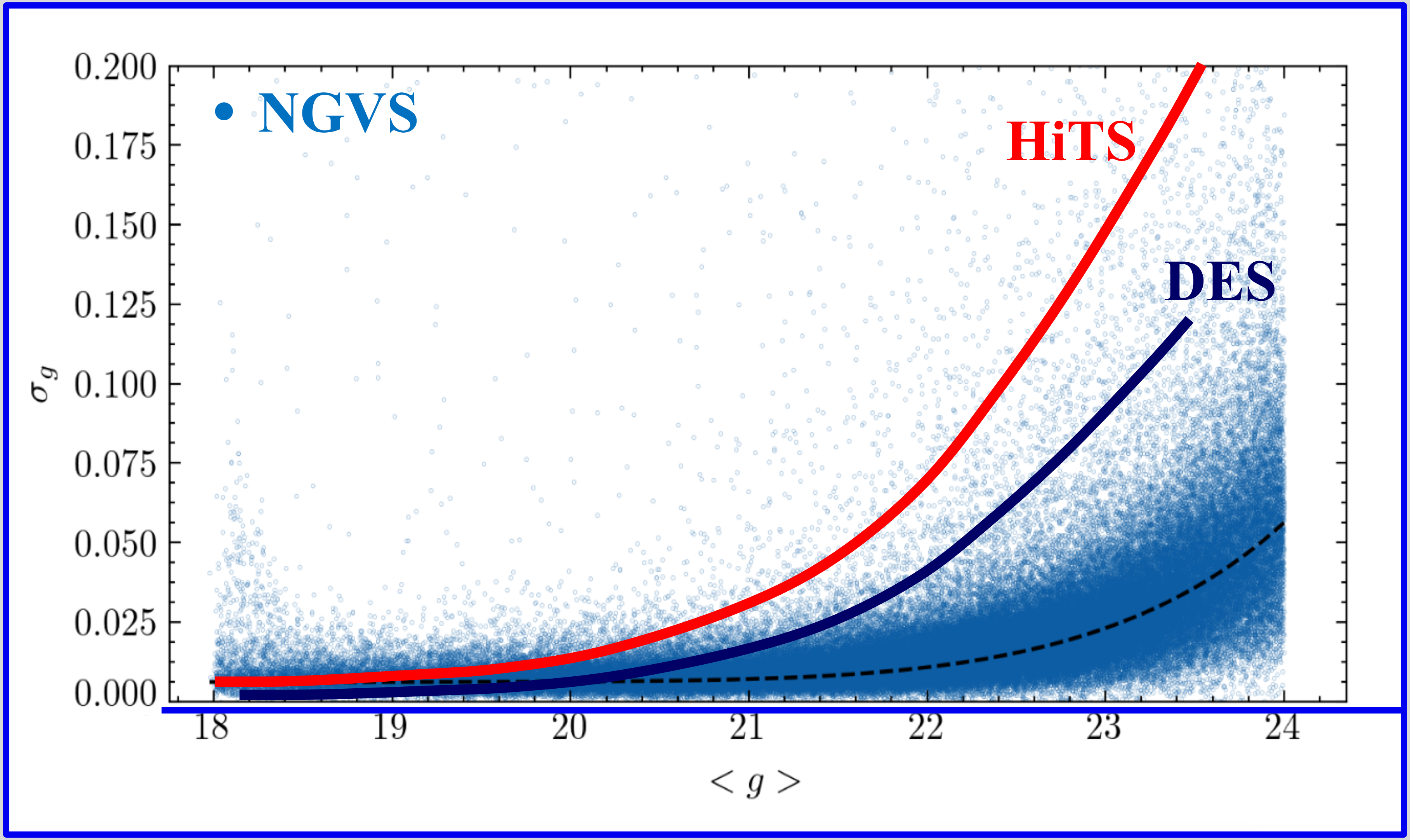
Accurate Measurement of RR Lyrae Periods



PS1 RR Lyrae sample (Sesar et al. 2017)

Feng, PG, Peng, et al. (2023, subm.)

Photometric Depth of the NGVS Dataset

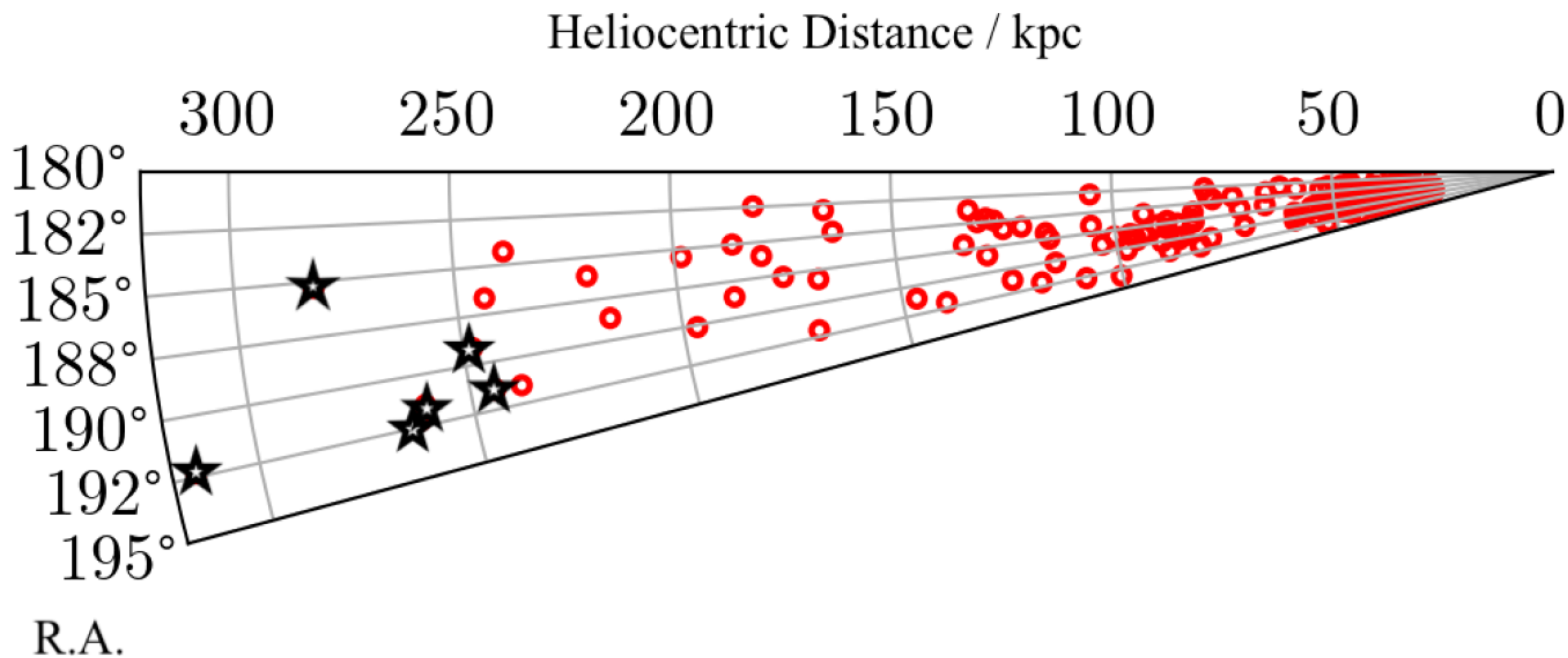


NGVS single-epoch photometry is

- 1.7 mag deeper than DES (Stringer et al. 2019)
- 2.3 mag deeper than HiTS (Medina et al. 2018)

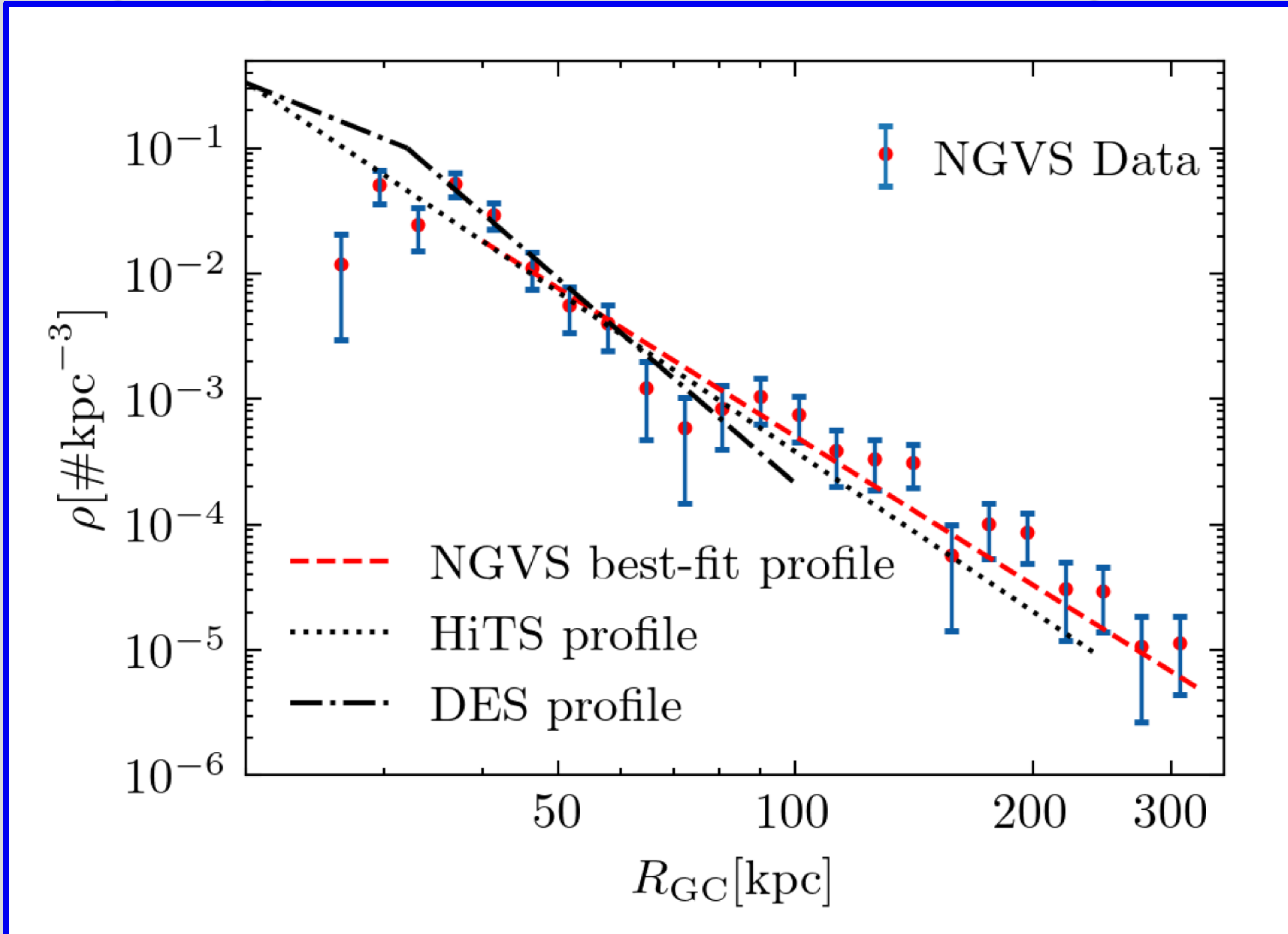
Feng, PG, Peng, et al. (2023, subm.)

Distant Milky Way Halo RR Lyrae in NGVS



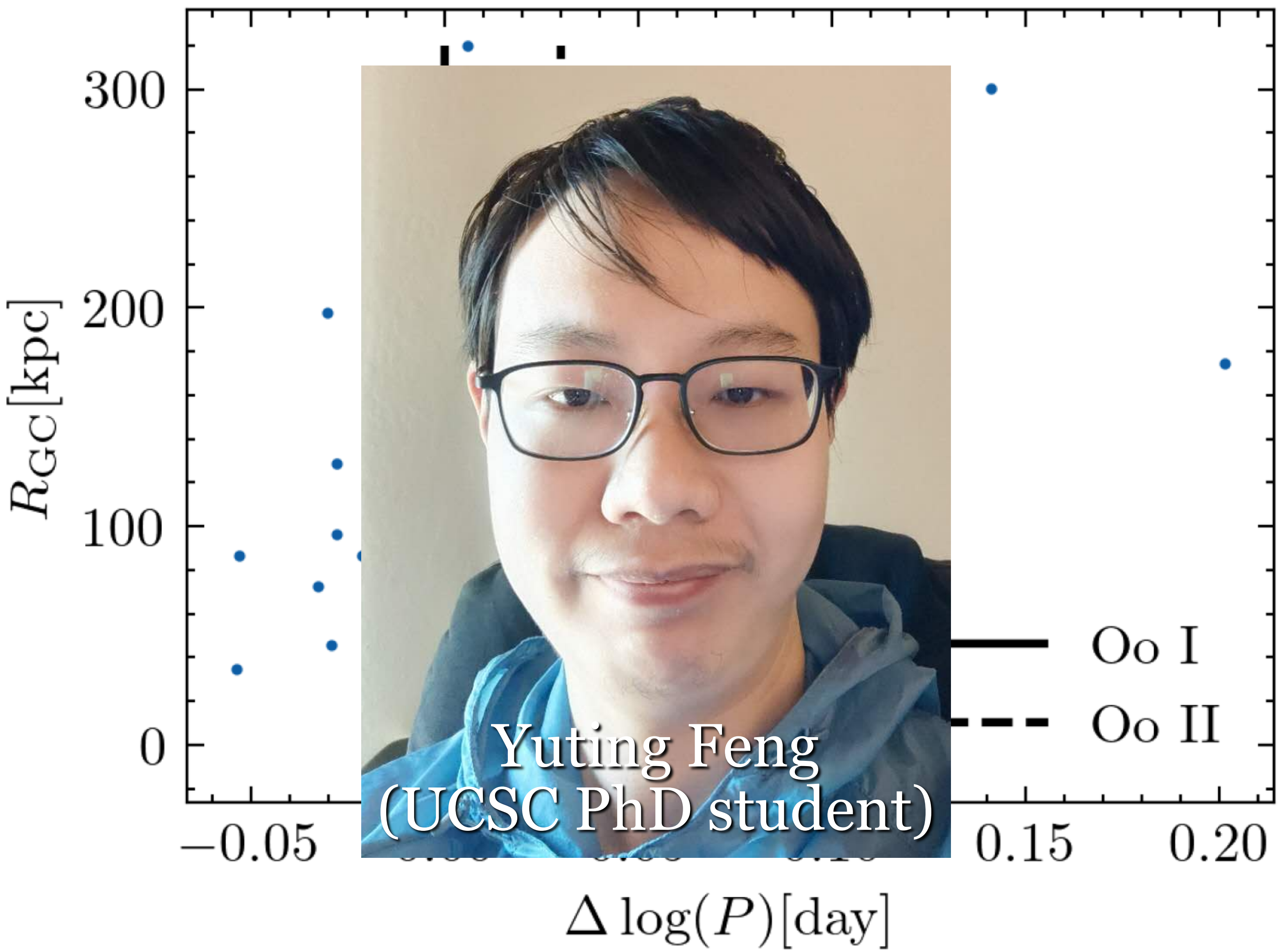
Feng, PG, Peng, et al. (2023, subm.)

Milky Way Stellar Halo Radial Density Profile



Feng, PG, Peng, et al. (2023, subm.)

Milky Way Stellar Halo Radial Metallicity Profile



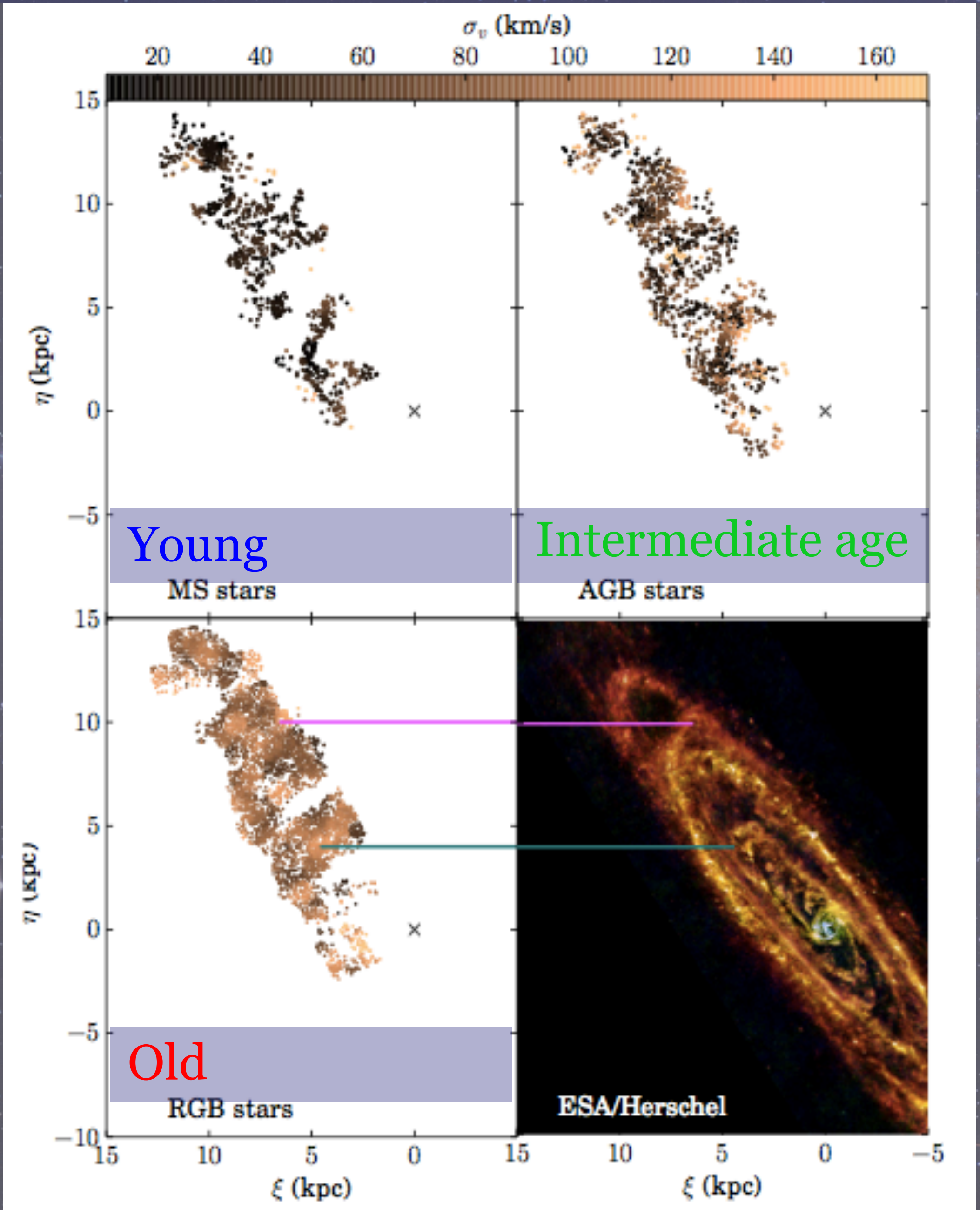
Feng, PG, Peng, et al. (2023, subm.)

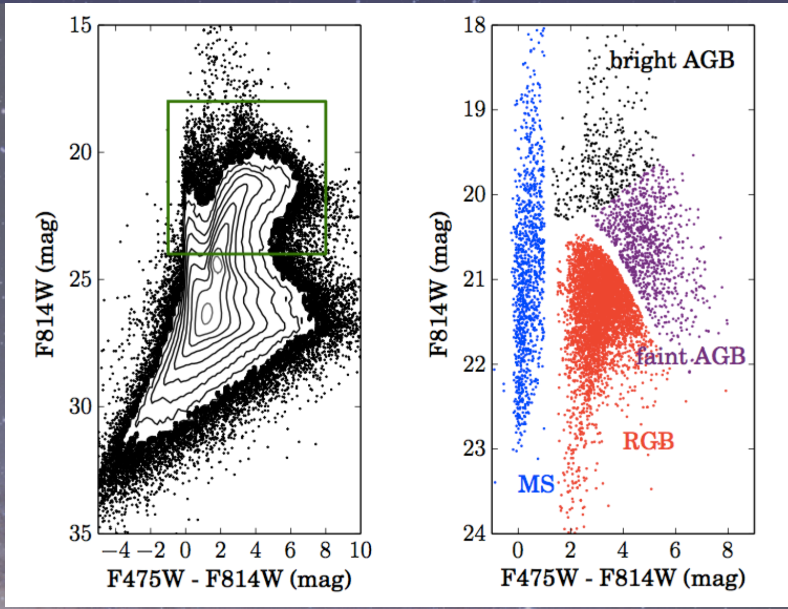
M31's Stellar Disk Dynamics and Satellite Interactions

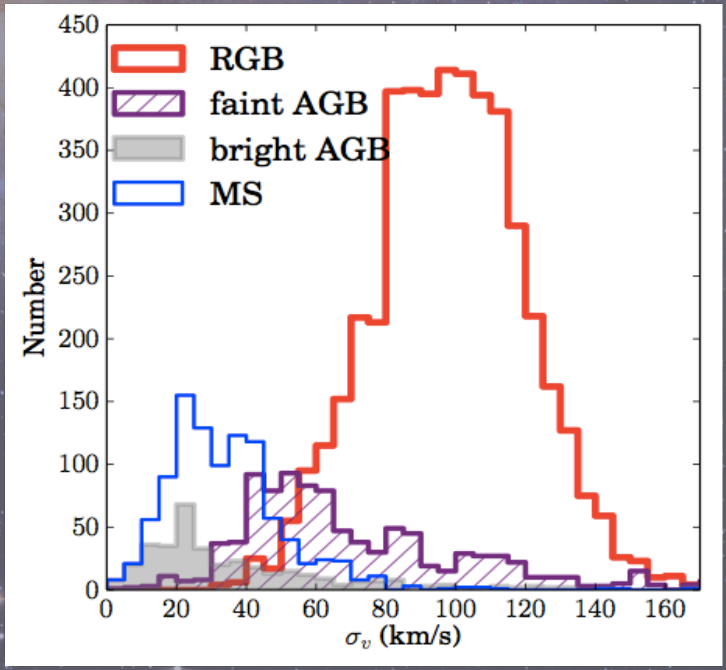
www.hubblesite.org NASA/ESA Hubble Space Telescope; PHAT team

Dynamical Heating of the Disks of M31 and M33

M31 disk kinematics using stellar tracers of different ages

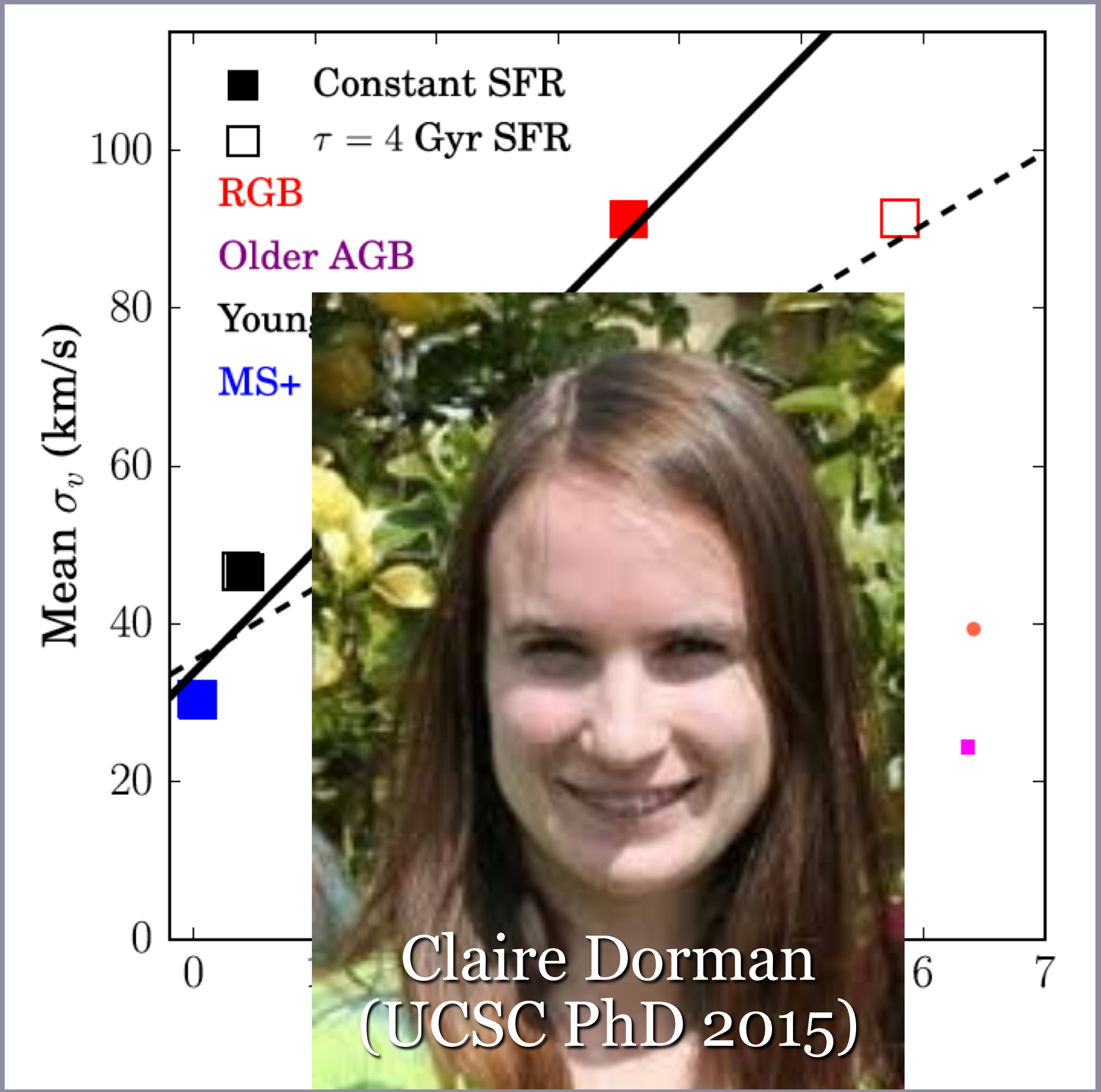






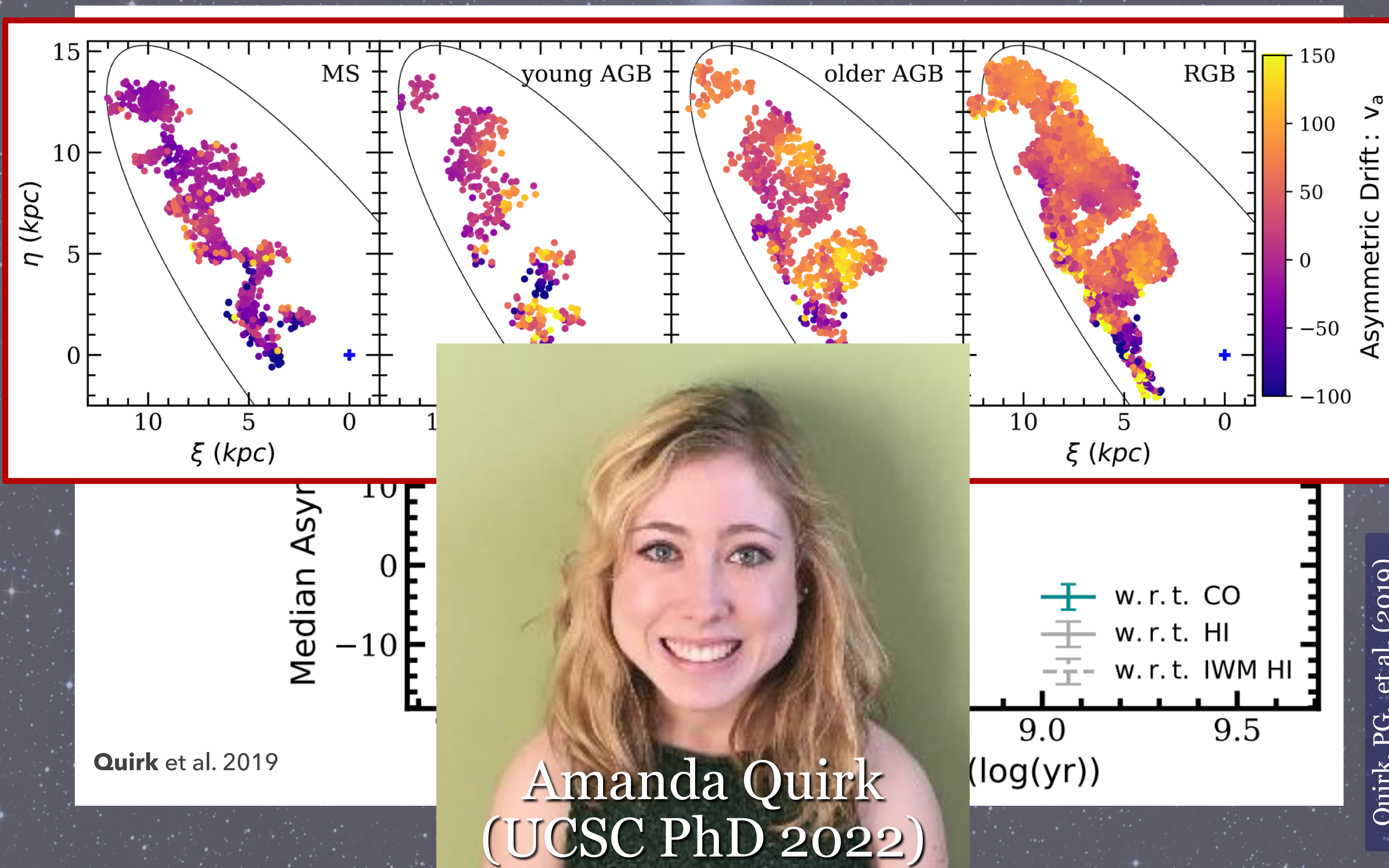
Dorman, PG, et al. (2015)

Longer lived stars display more irregular disk kinematics



Dorman, PG, et al. (2015)

Longer lived stars have a larger asymmetric drift with respect to atomic and molecular gas



Quirk, PG, et al. (2019)

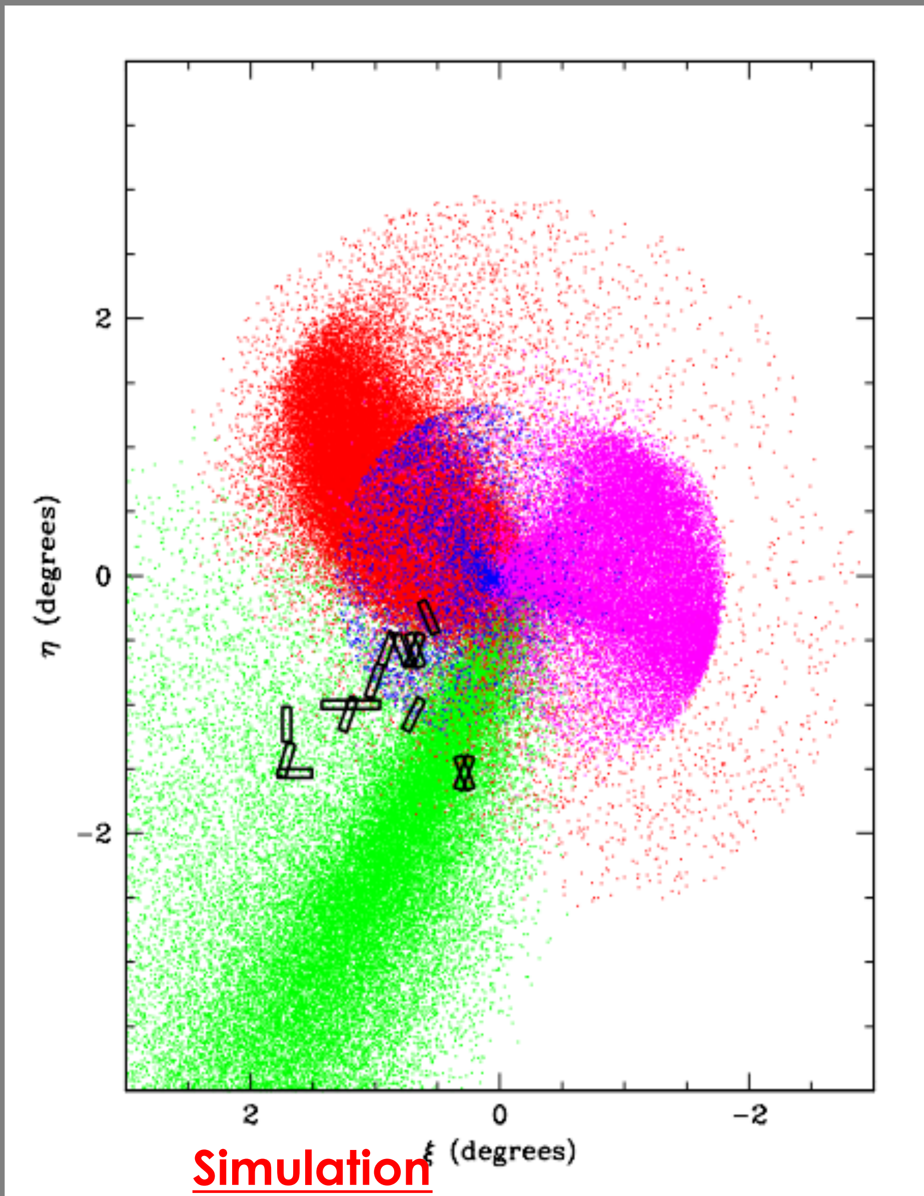
A Particular Minor Merger Event in M31

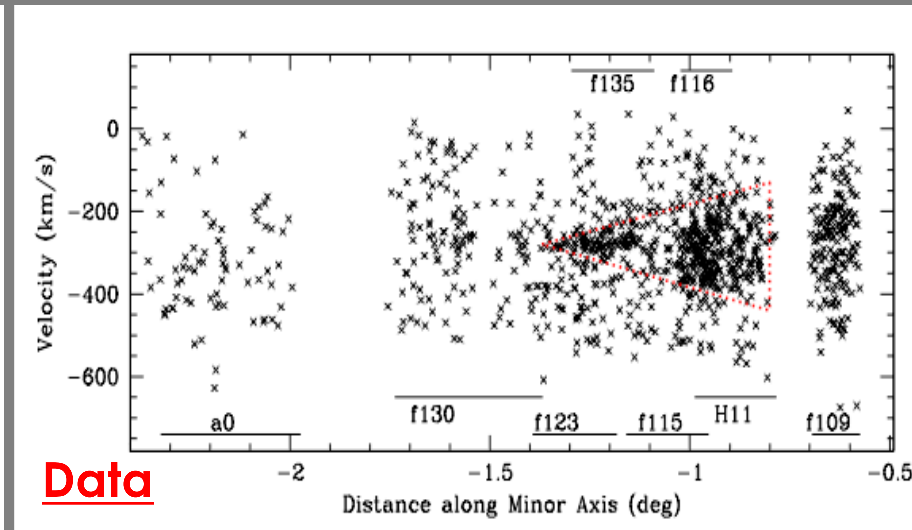
Forensic reconstruction of the Giant Stellar Stream

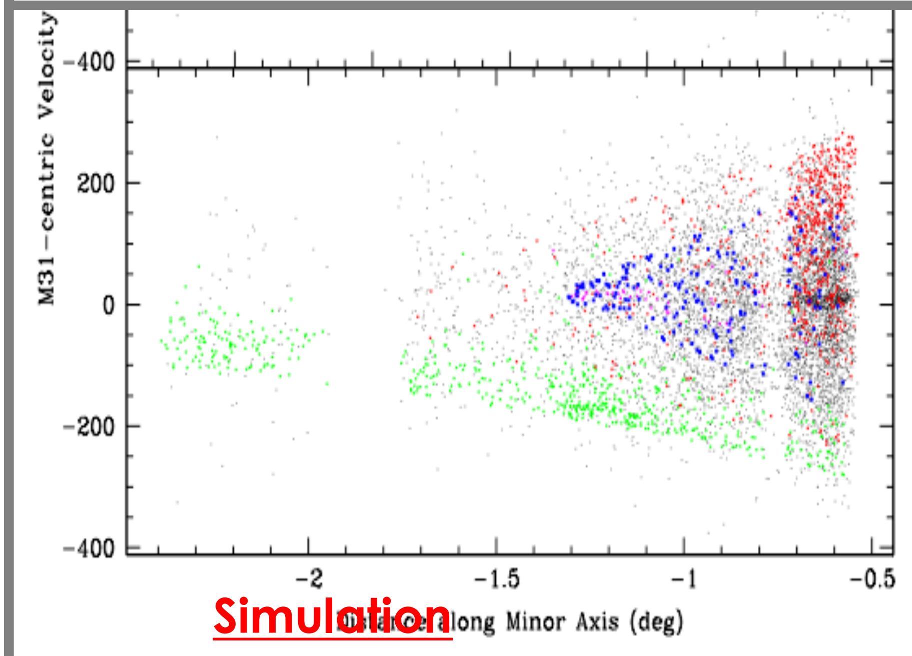
Giant Stellar Stream (GSS) debris in M31 can be traced kinematically through three pericentric passages and forms an elaborate system of shells

Gilbert et al. (2007); Fardal, PG, Babul & McConnachie (2007); Gilbert, PG, et al. (2009); Fardal, PG, et al. (2012); Escala, Gilbert, Fardal, PG, et al. (2022a)

Giant Southern Stream and Young Shell System in M31



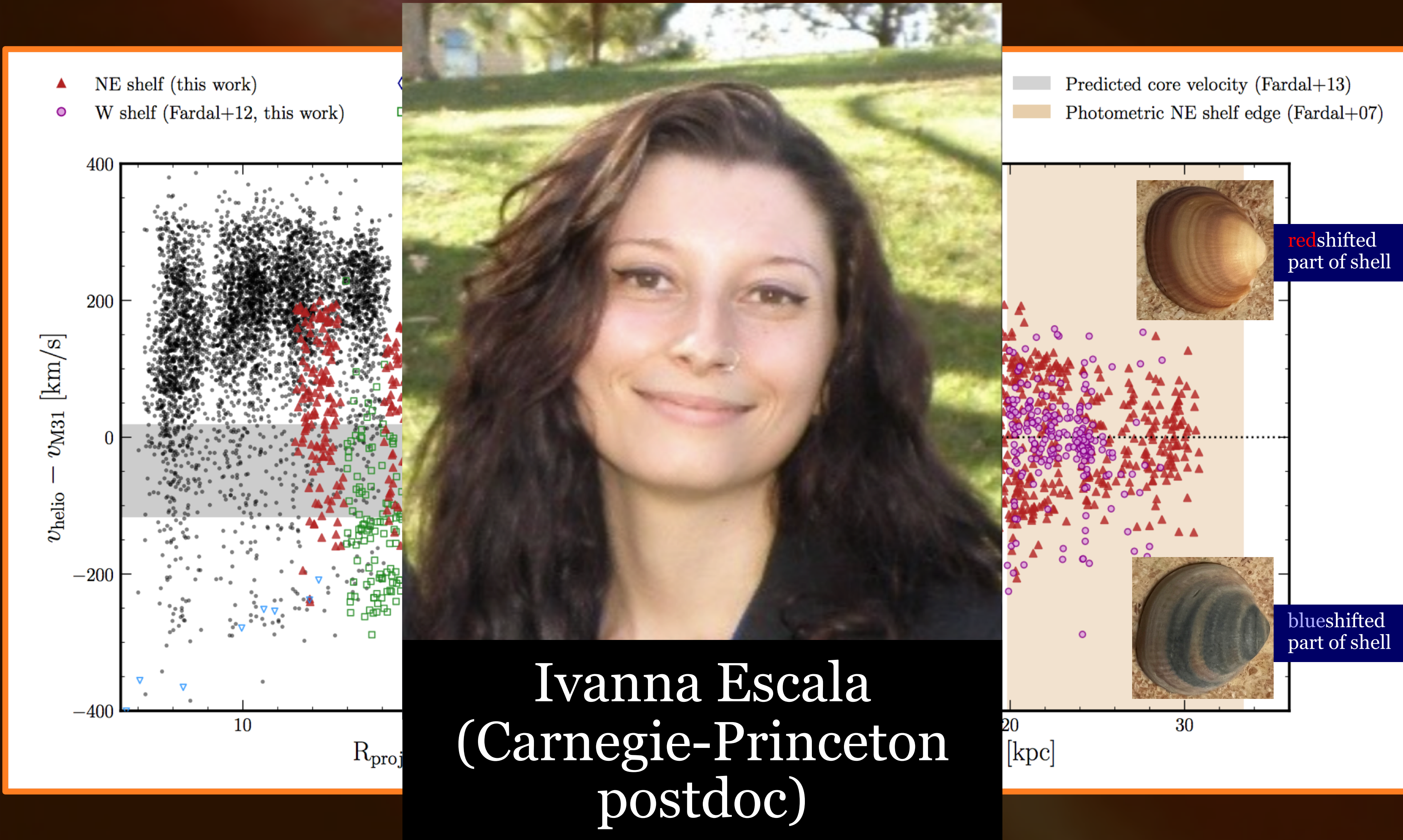




Fardal et al. (2007, MNRAS)

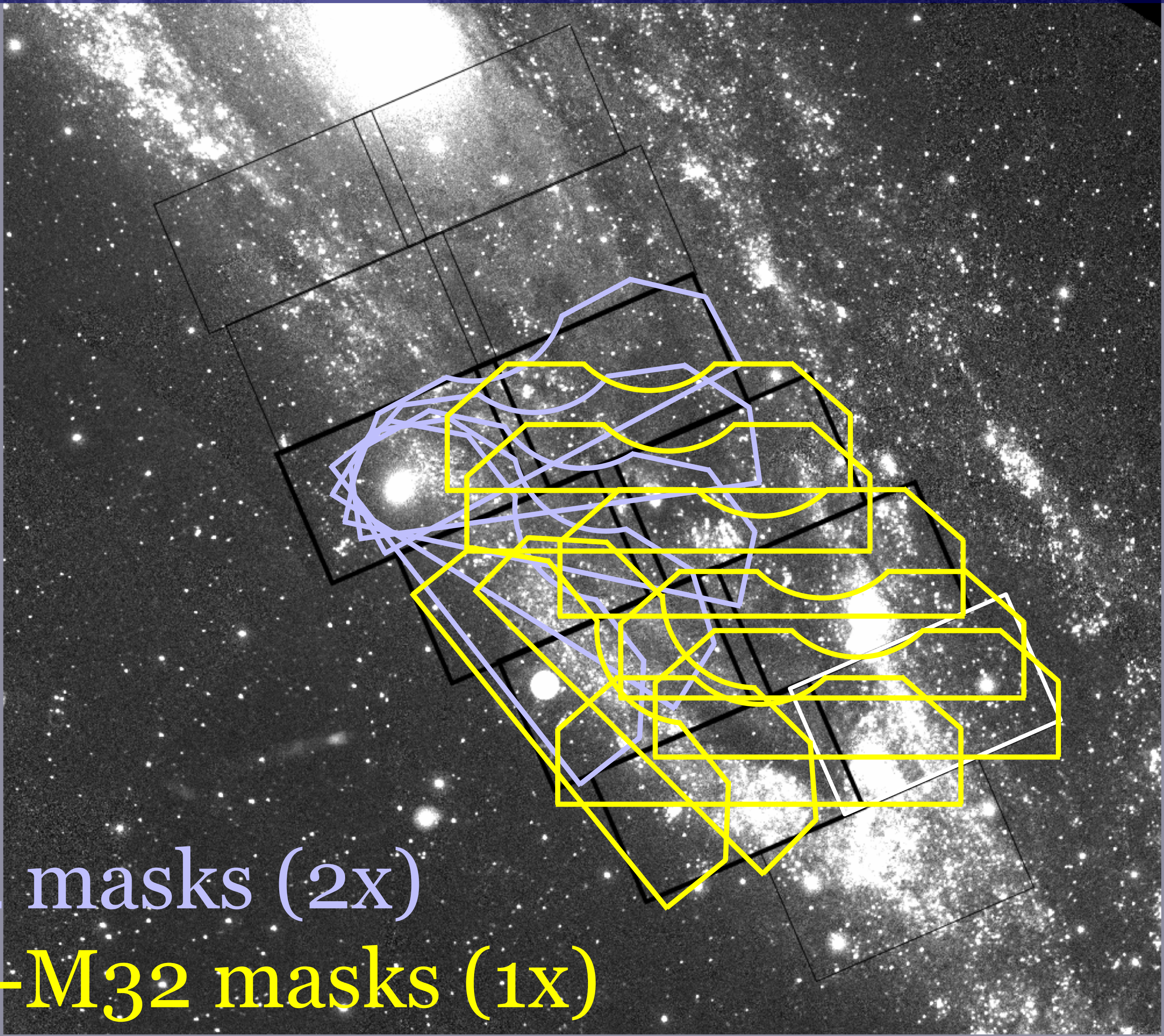
Gilbert et al. (2007, ApJ)

Kinematics of the GSS and Shells in M31



Escala, Gilbert, Fardal, PG, et al. (2022a)

Recent Keck DEIMOS spectroscopy of M32 and M31 disk



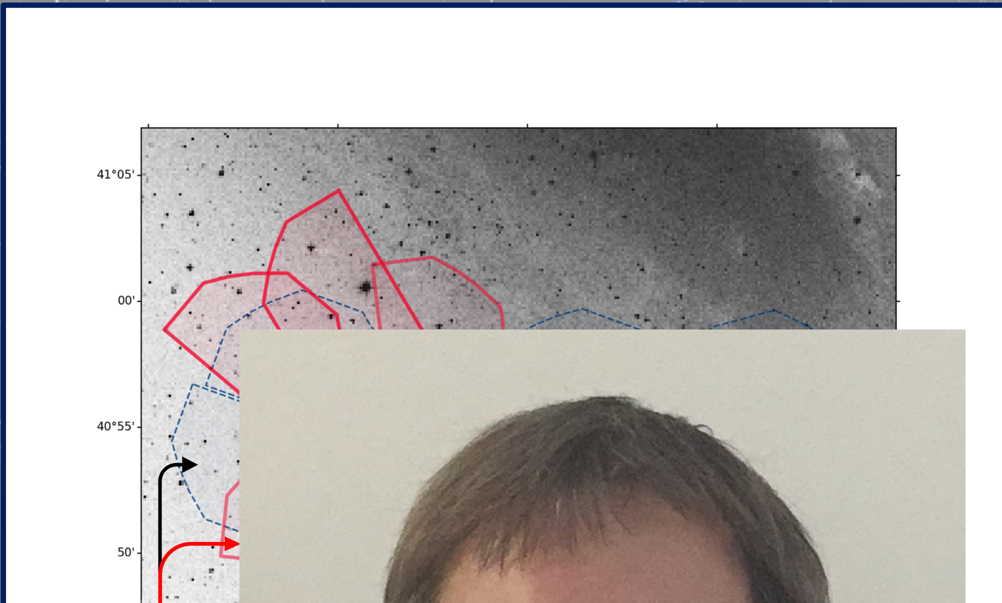
M32 masks (2x)

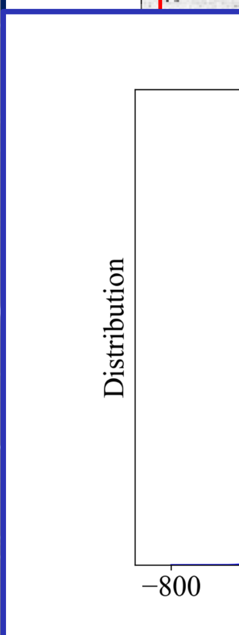
Non-M32 masks (1x)

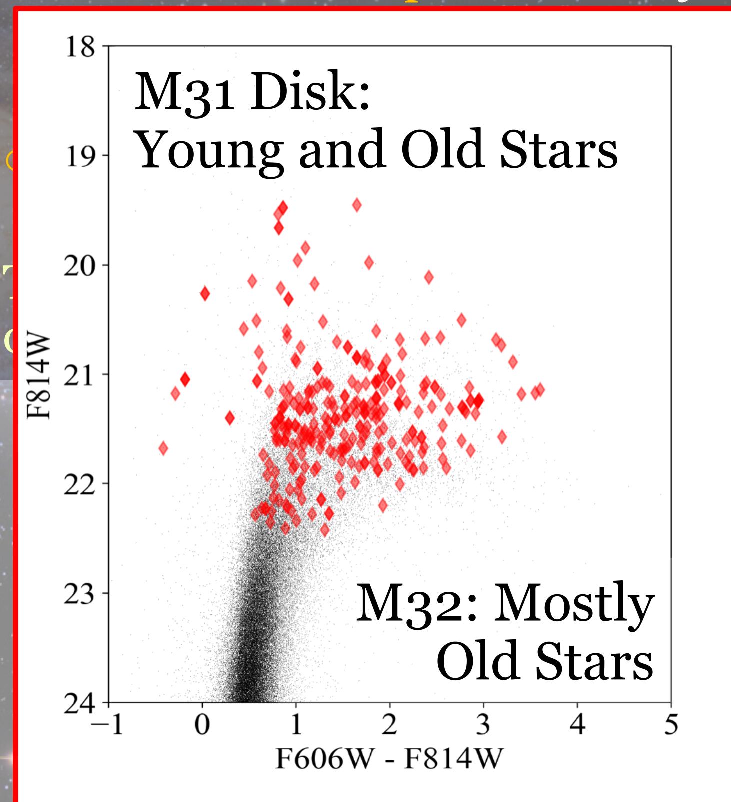
Interaction Between M32 and M31's Disk

Goal: Measure the relative and absolute proper motion (PM) of M32 and the local M31 disk using

- Multi-epoch HST images: *PMs of stars relative to distant galaxies, color-magnitude diagram*
- Keck DEIMOS spectra: *line-of-*

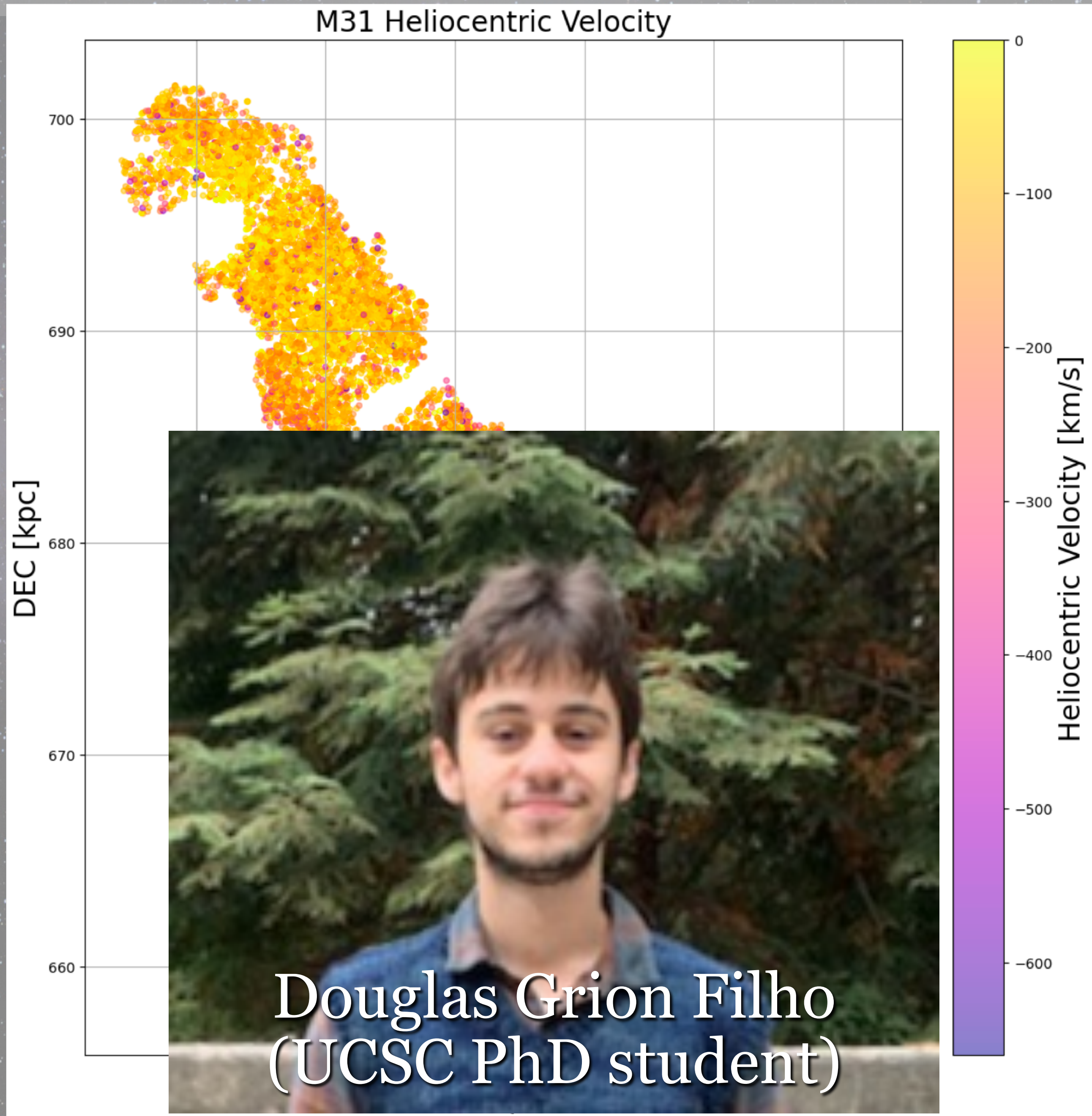






Fardal, PG, et al., in prep

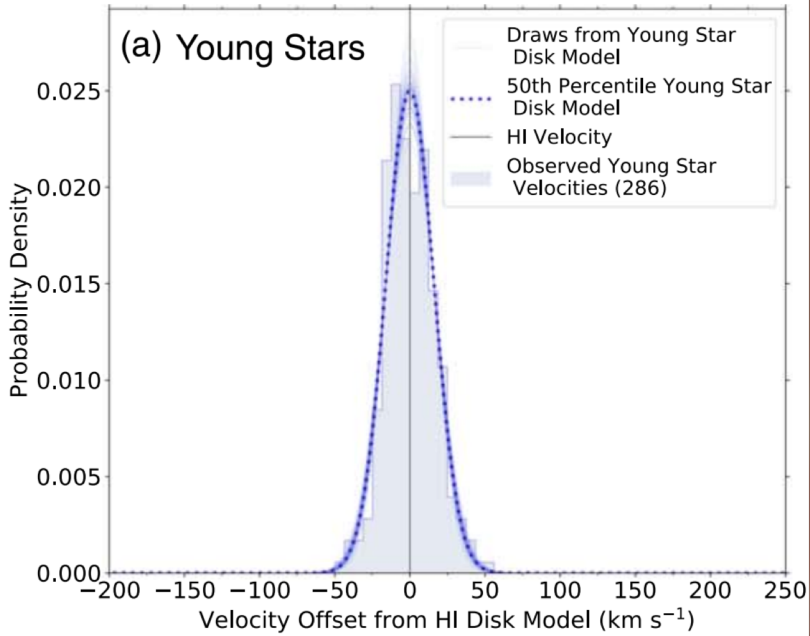
Expanded Coverage of M32 and M31's Southern Disk

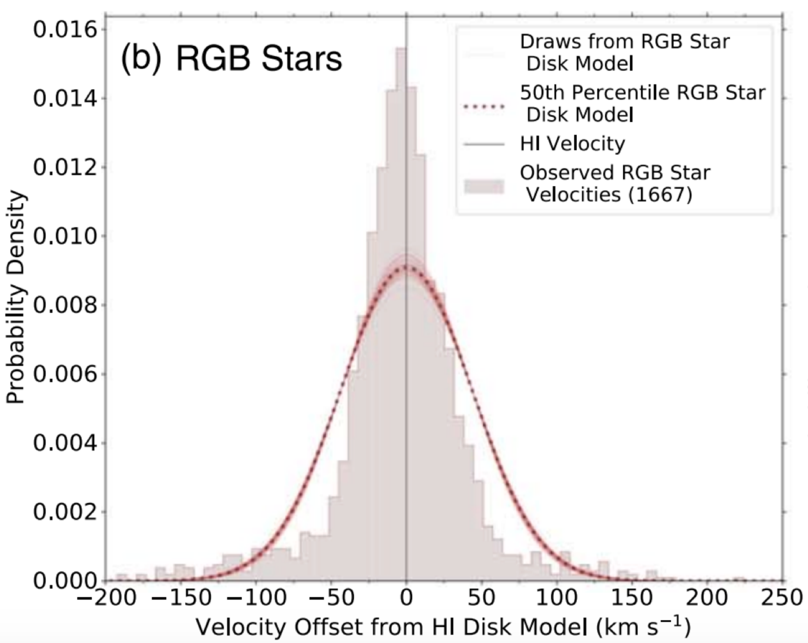


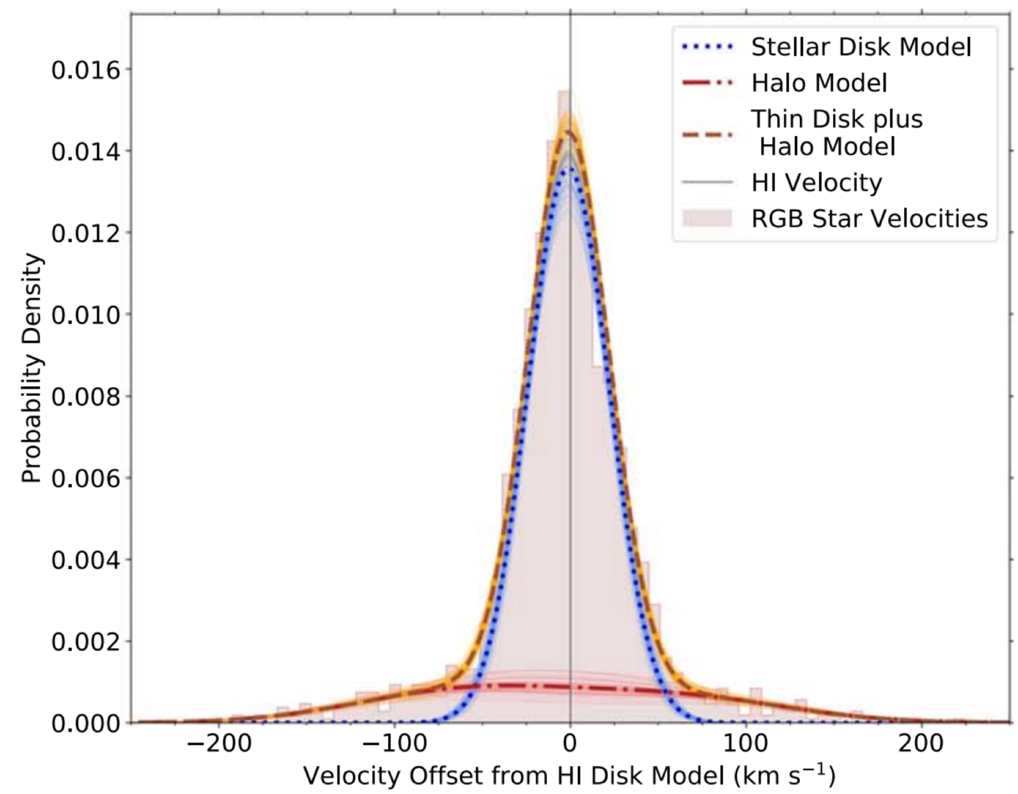
Grion Filho, PG, et al., in prep

M33 Stellar Disk and Halo Dynamics

Stellar Kinematics of the Disk of M33

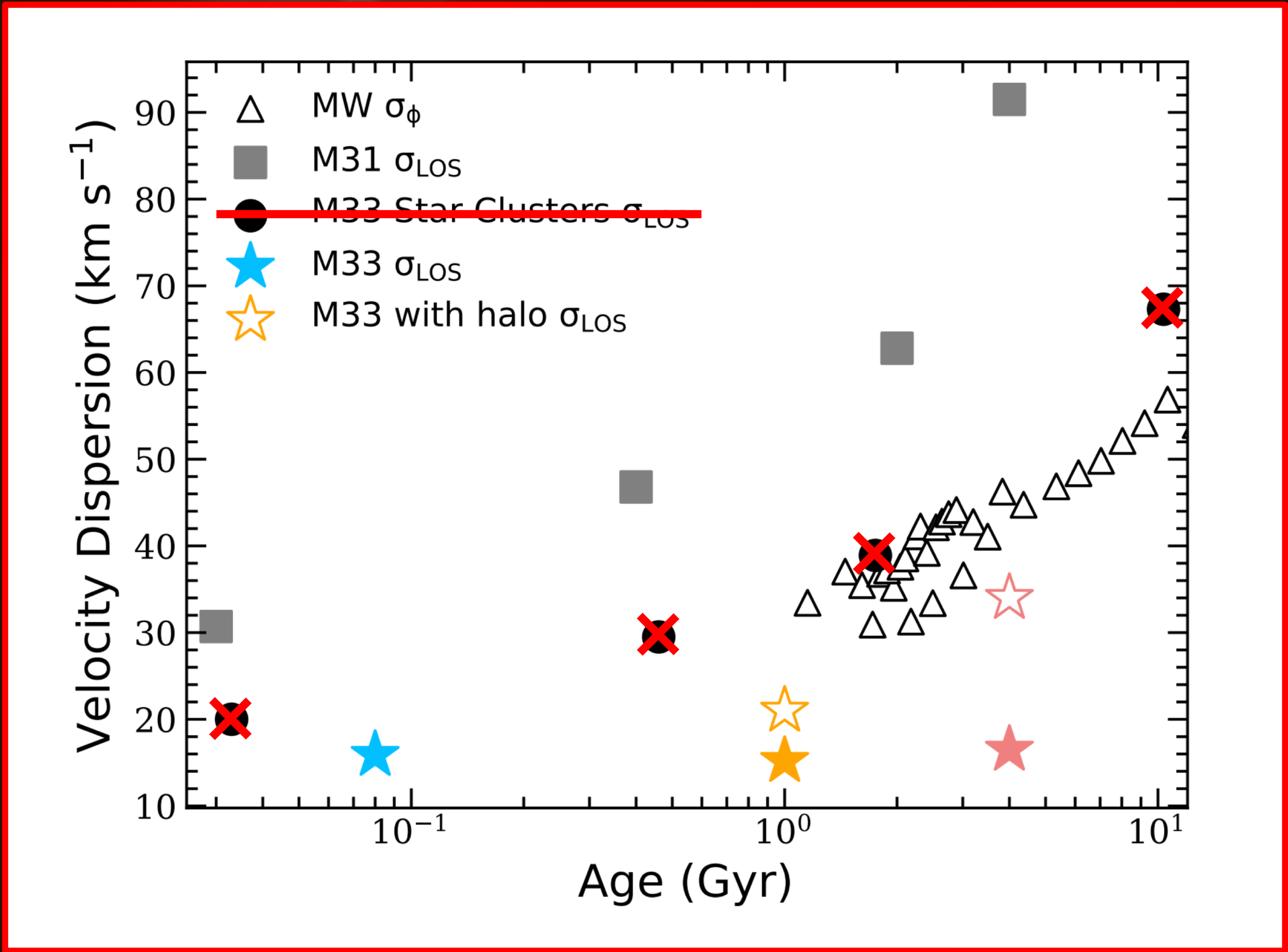






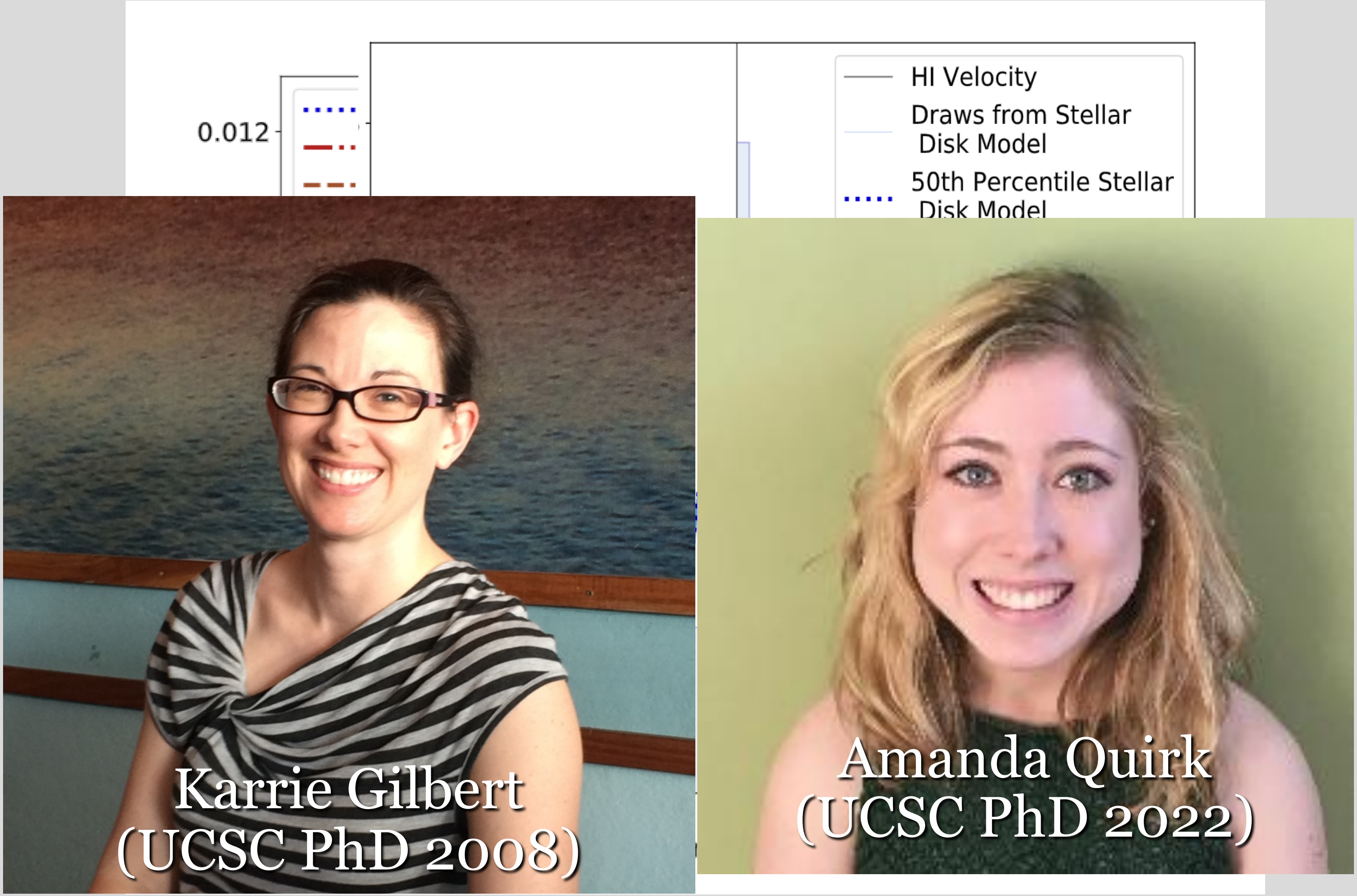
Gilbert, Quirk, PG, et al. (2022)

Dynamical Heating of MW/M31/M33 Stellar Disks



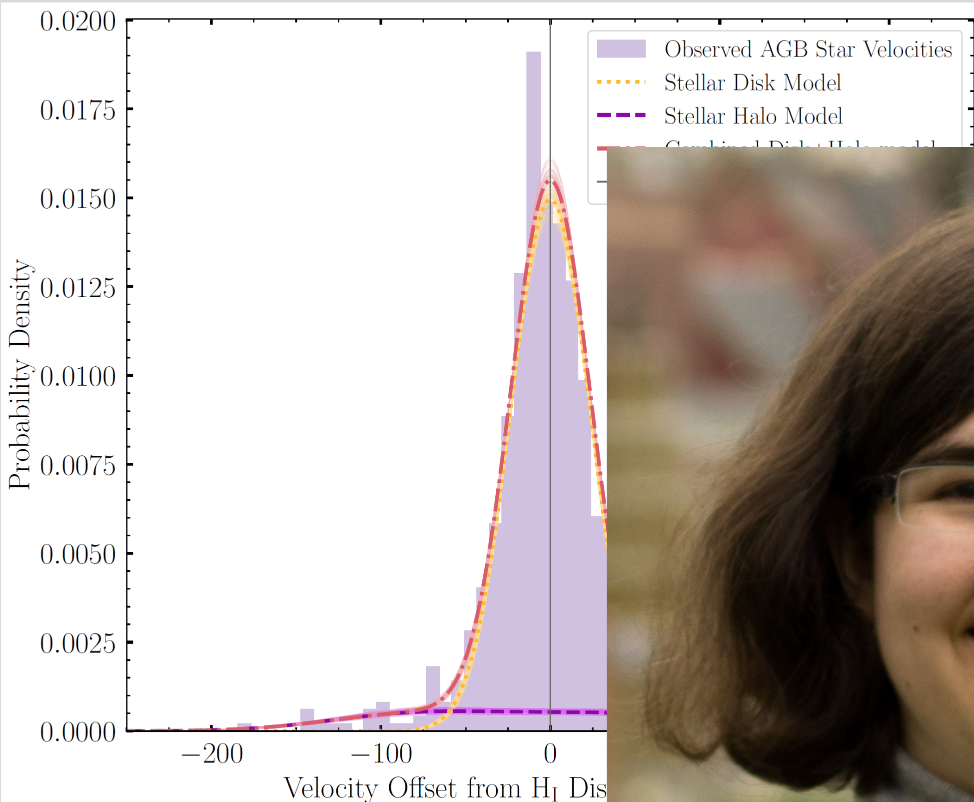
Quirk, PG, Gilbert, et al. (2022)

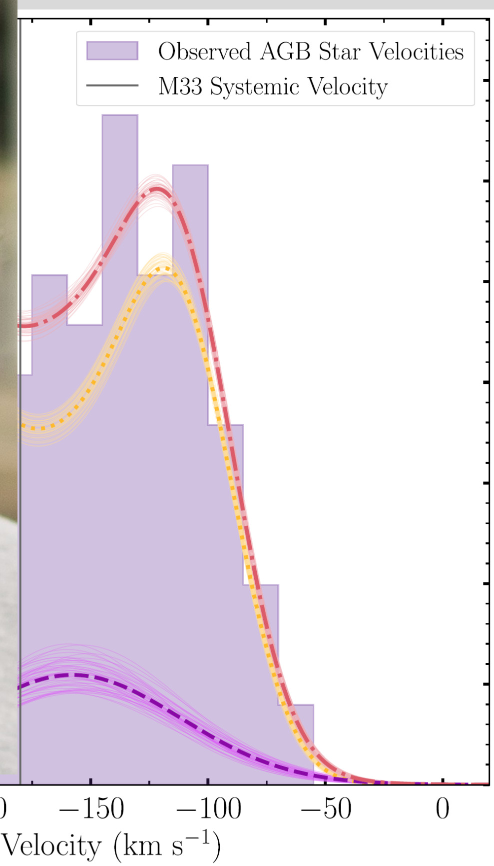
Kinematics of Young and Old M33 Stars



Gilbert, Quirk, PG, et al. (2022); Quirk, PG, Gilbert, et al. (2022)

Kinematics of Intermediate Age M33 Stars

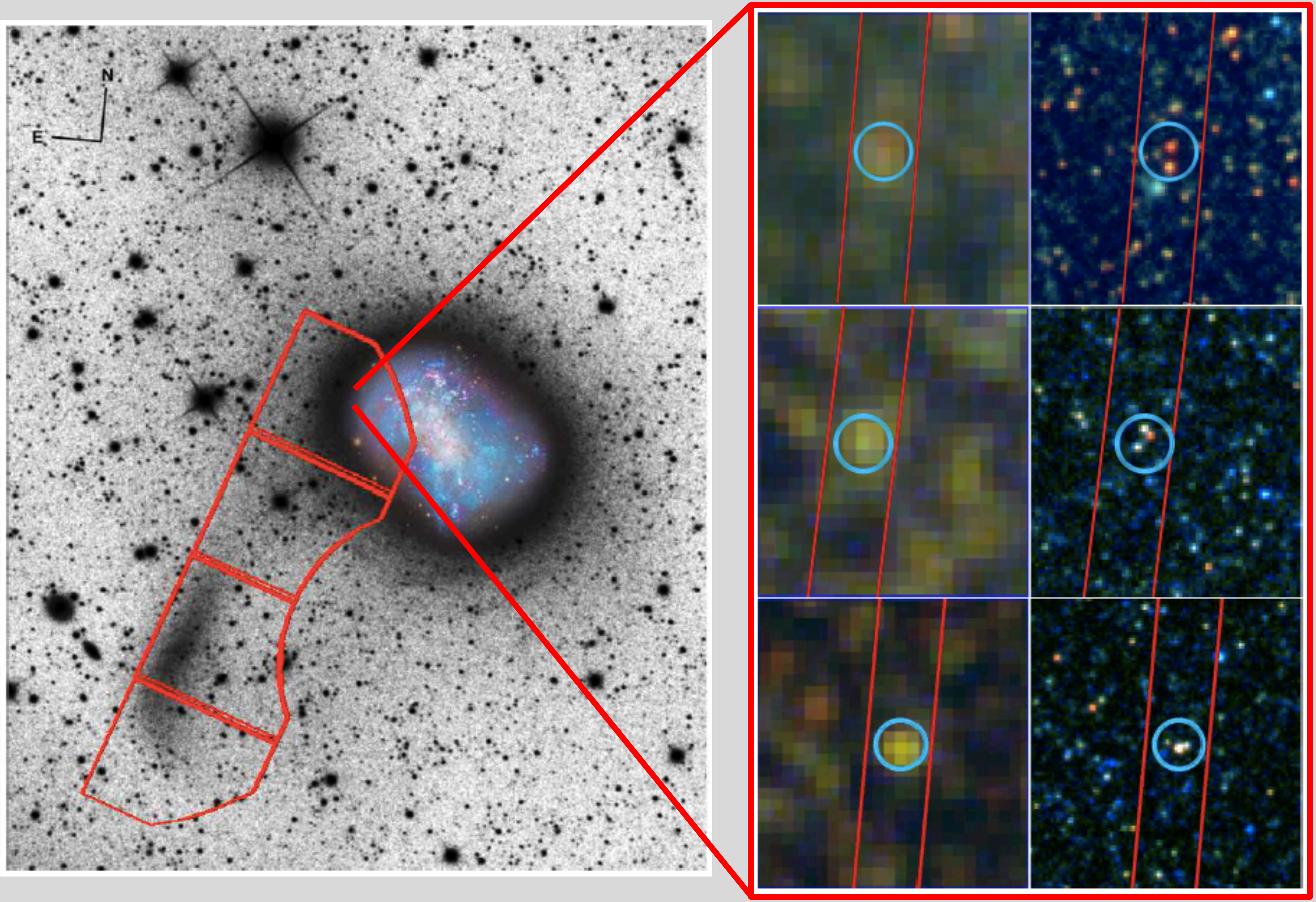




Cullinane, Gilbert, PG, et al. (2023, in press)

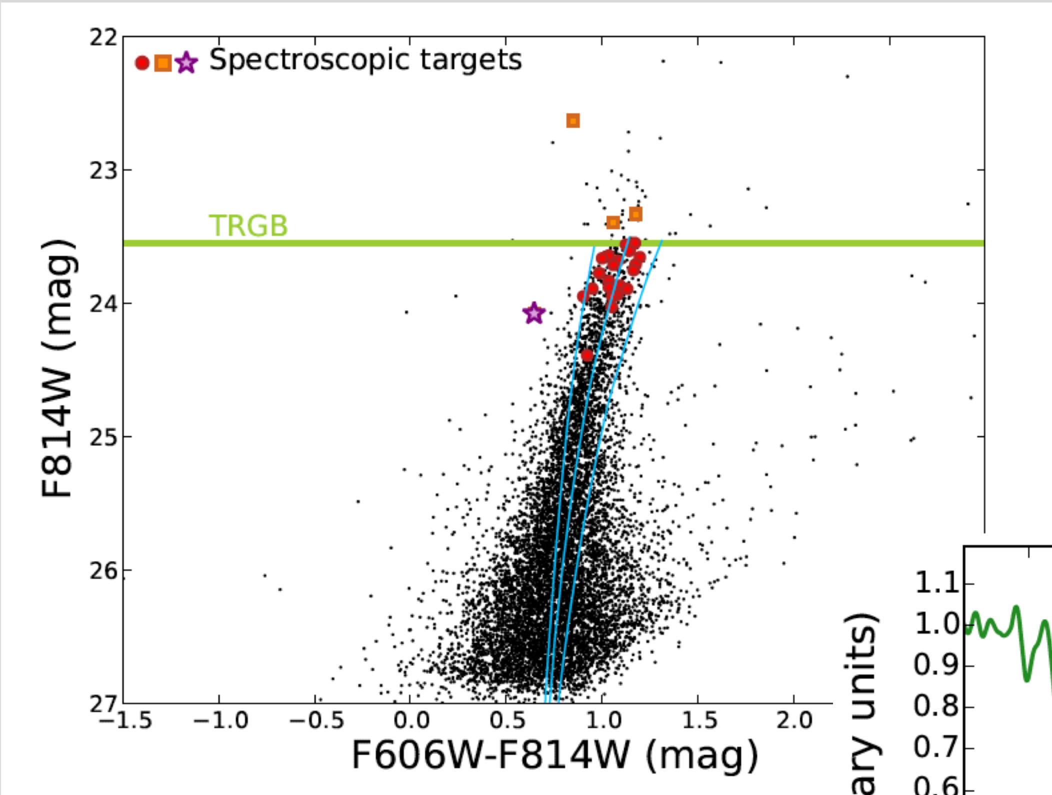
Beyond the Local Group:
Deep Coadded Spectroscopy of Surface Brightness Fluctuations

Co-added spectroscopy of upward SBFs in a LSB stellar stream



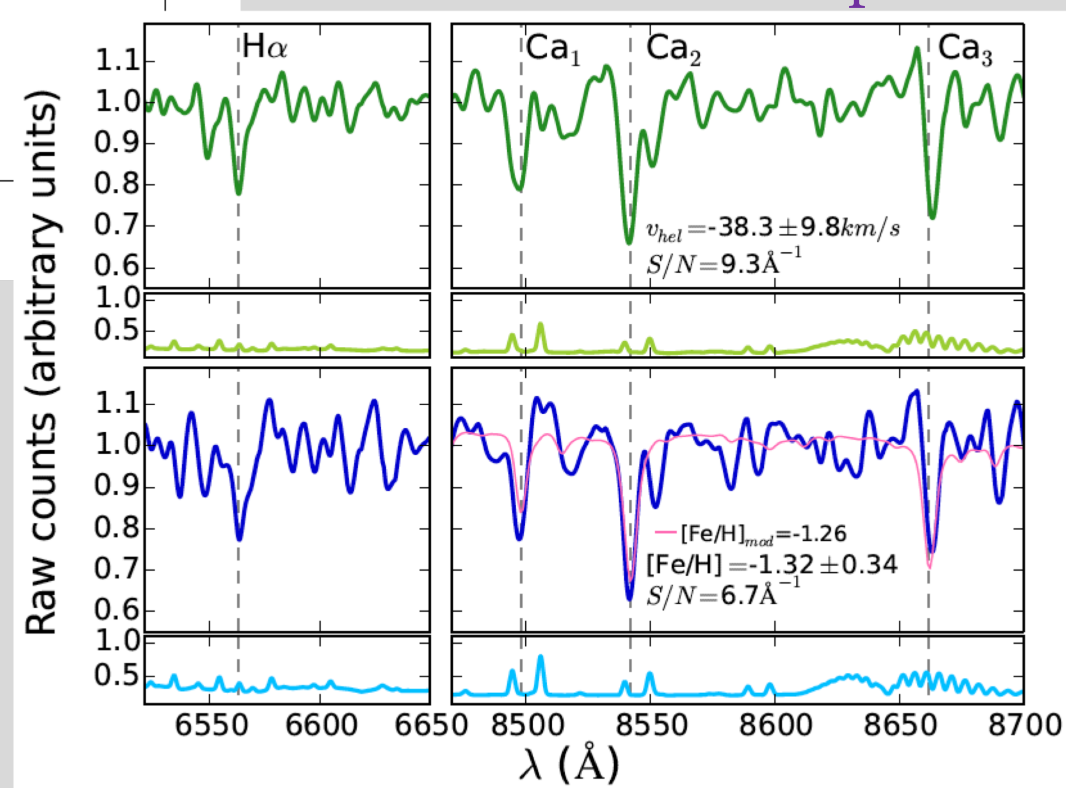
Toloba, PG, et al. (2016a)

Coadded spectroscopy of stars & blends in an M81 dwarf satellite



CMD of individual stars and blends in M81 dwarf satellite

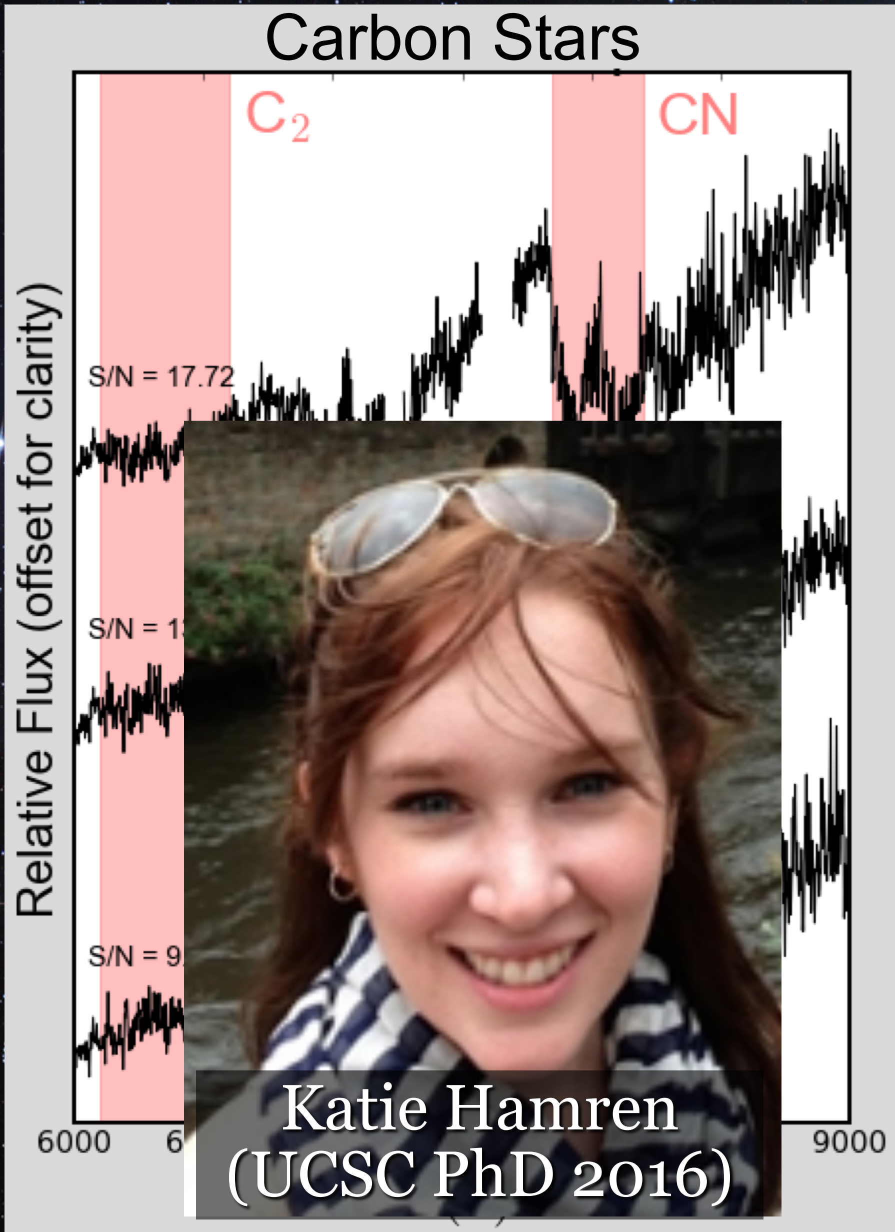
Obvious H-alpha and Ca triplet absorption in the coadded spectrum

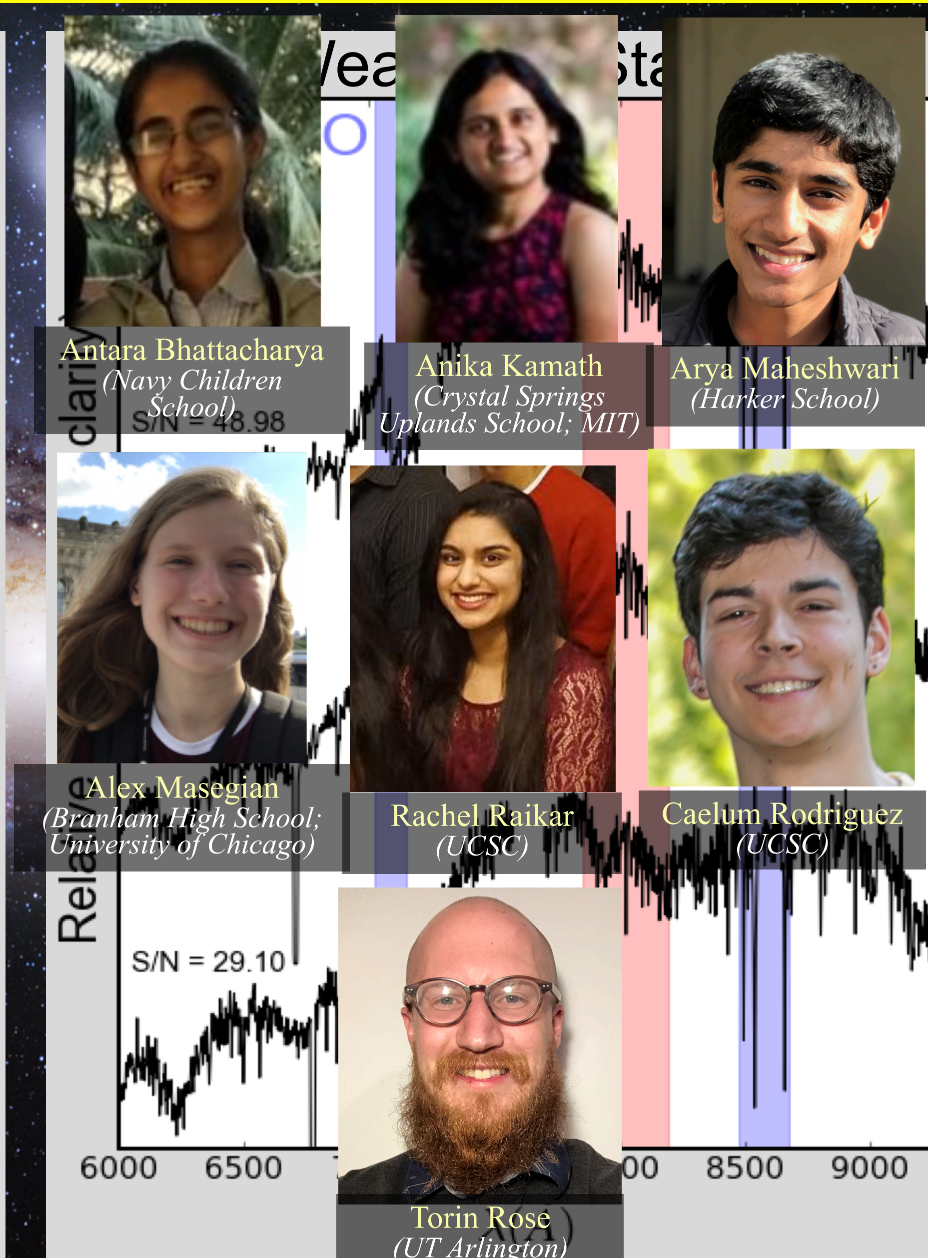


Toloba et al. (2016c)

Rare Stellar Populations in M31 and M33

Spectra of Carbon Stars and “Weak CN” Stars





Summary

- Accretion history, chemical enrichment, and extent of the Milky Way stellar halo
  (HALO7D, BP3M, NGVS)
- M31 stellar disk dynamics and satellite interactions
  (SPLASH, PHAT/PHAST, HSTPROMO)
- M33 stellar disk dynamics and evidence of a dynamically hot, non-rotating halo
  (TREX, PHATTER)