# Dynamical Tracing of the Outskirts of Galaxies

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*University of California Santa Cruz*

*and*

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# Technical advantages that TMT is expected to offer for studies of nearby galaxies

- Going beyond the tip of the iceberg: statistical studies with larger sample sizes than currently possible
- Expanding the survey volume: sampling a wider range of galaxy environments than currently possible
- Making measurements of individual objects without having to co-add samples
- Spectroscopy at low surface brightness levels: outskirts of galaxies, faint tidal streams, etc.
- Synergy with JWST, LSST, HSC, WFIRST, Euclid, etc.

# A few examples of what TMT can do for Local Group / Local Volume science

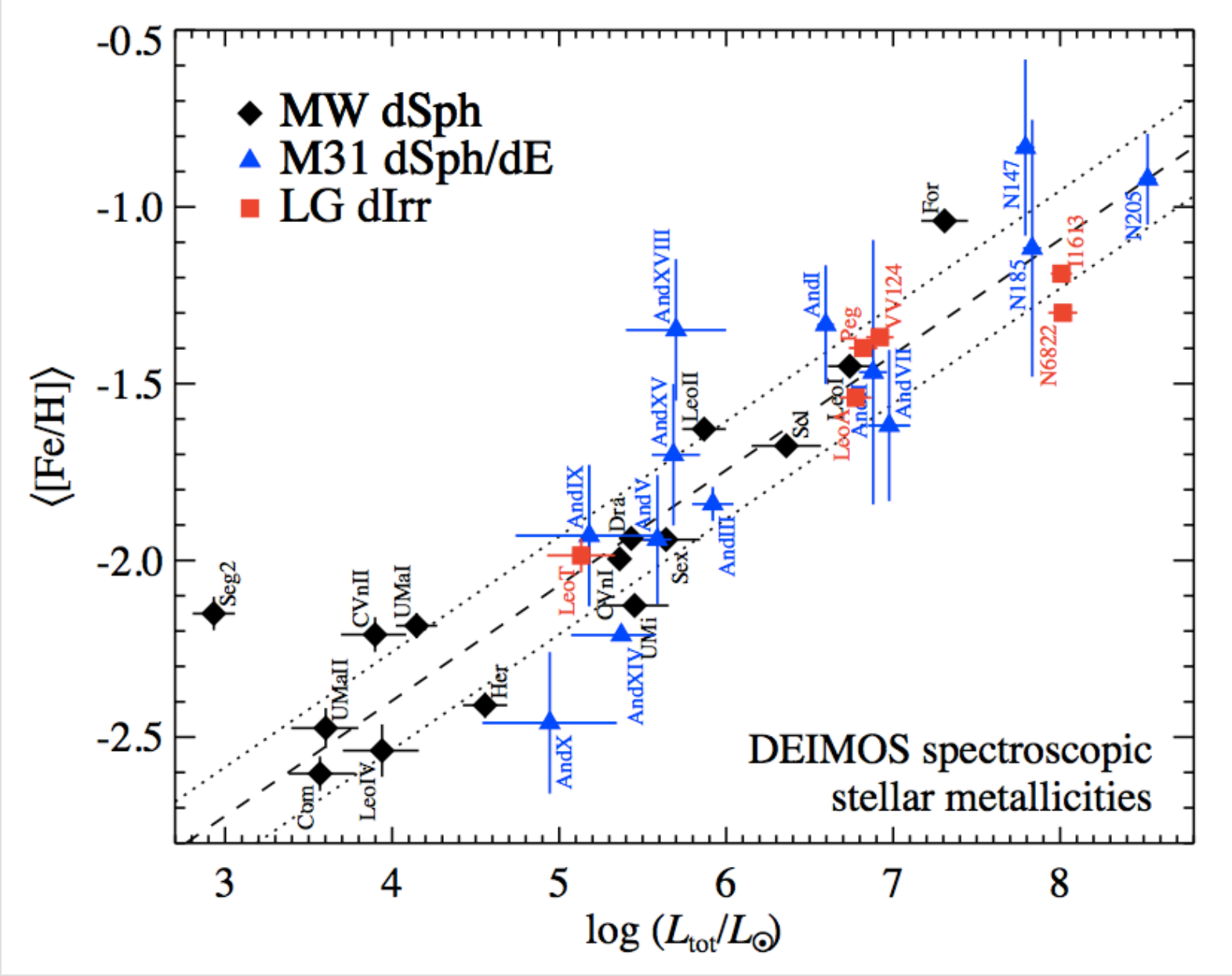
- Dwarf elliptical galaxies: dark matter content; nature of their nuclei; origin of their kinematic anomalies
- Finding, measuring the masses of, and characterizing ultra-faint dwarf galaxies in the Local Group – the smallest dark matter sub-halos and constraints on baryonic physics
- Co-added spectroscopy of partially resolved starlight at low surface brightness levels
- Heating/settling of the disk of M31 and other disk galaxies: stellar velocity dispersion versus stellar age
- Accretion history and mass of the Milky Way

# Characterizing dwarf satellites in the Local Group and Local Volume

– Chemical abundance measurements of old stars are very challenging with Keck

– Metallicity distribution functions of dwarf satellites from spectra of *individual* stars versus mean metallicities of dwarf satellites from *co-added* spectra

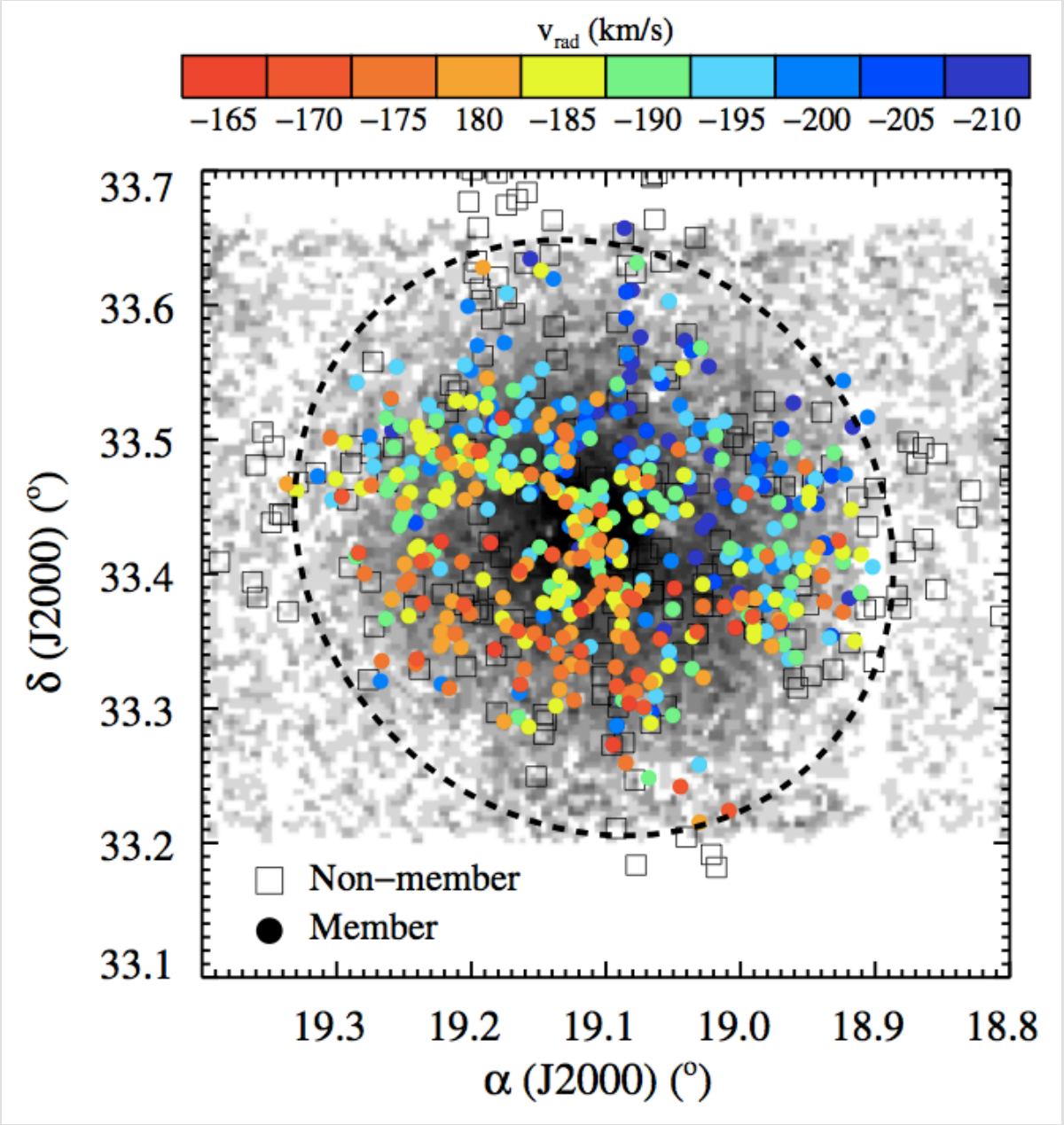
# Andromeda satellites resemble their Milky Way counterparts

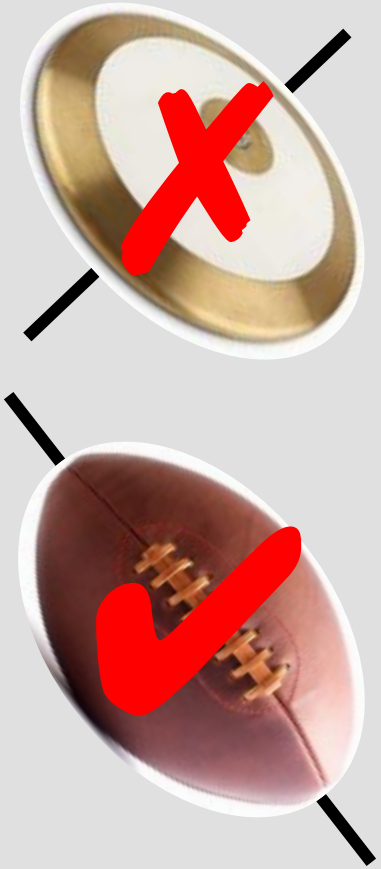



Kirby et al. (2013)

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

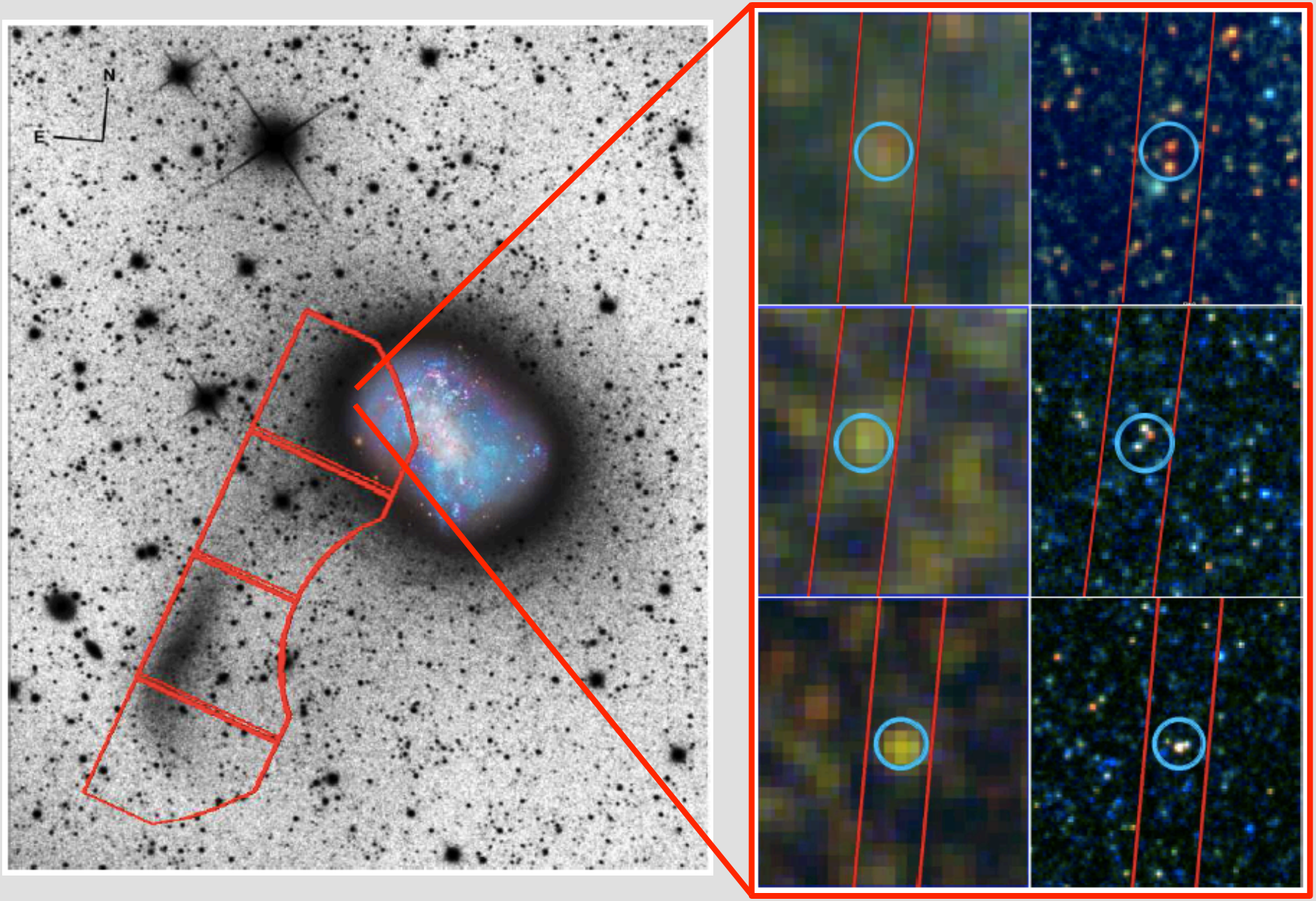
# And II's unusual internal stellar kinematics



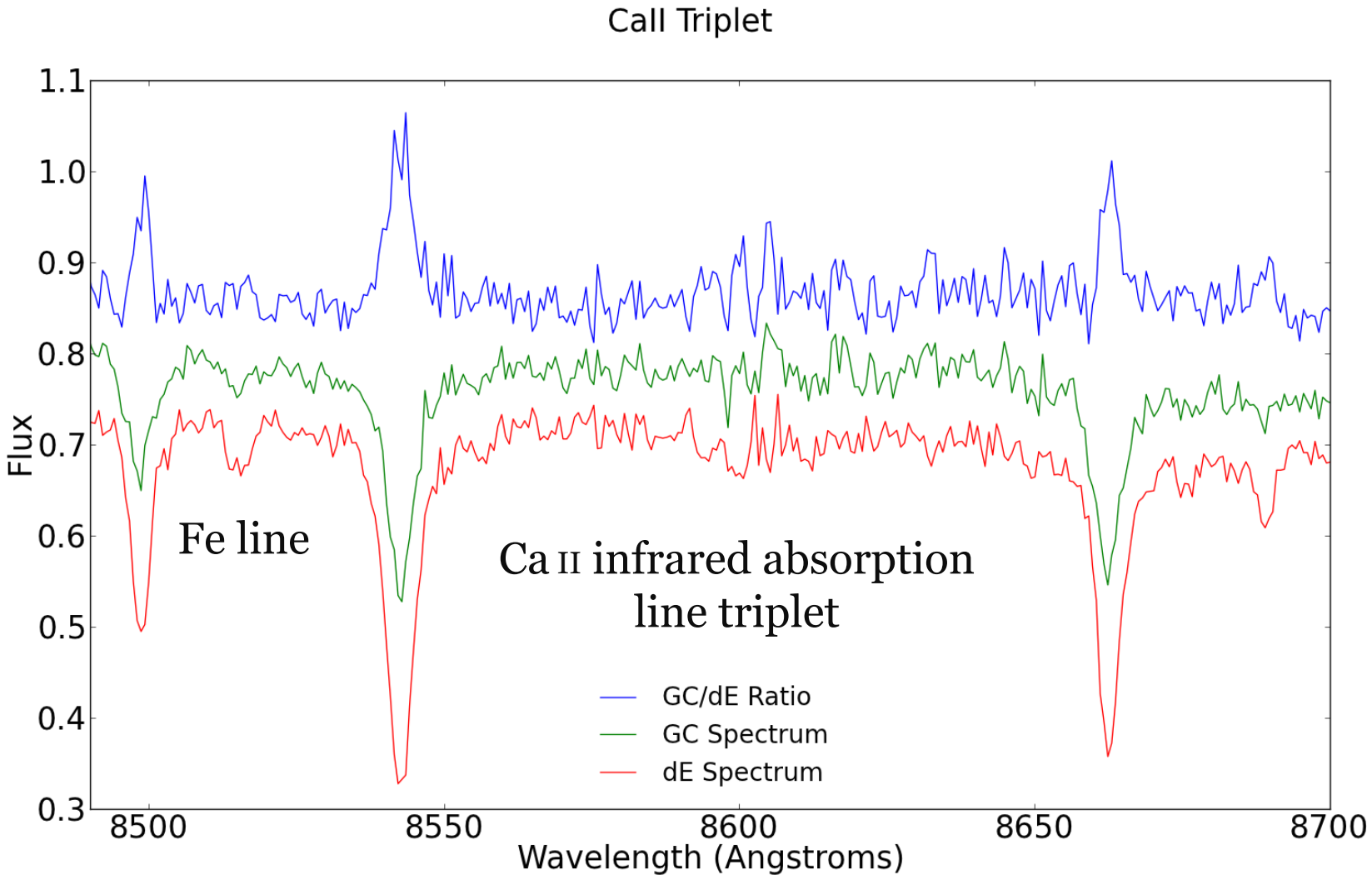
Ho et al (2012, ApJ)

# Coadded spectroscopy of blends in the NGC 4449 stellar stream




Toloba, PG, et al. (2015, ApJ submitted)

# Co-added spectra




Stars comprising the dE nuclei appear to be younger and more metal rich on average than those comprising GC satellites

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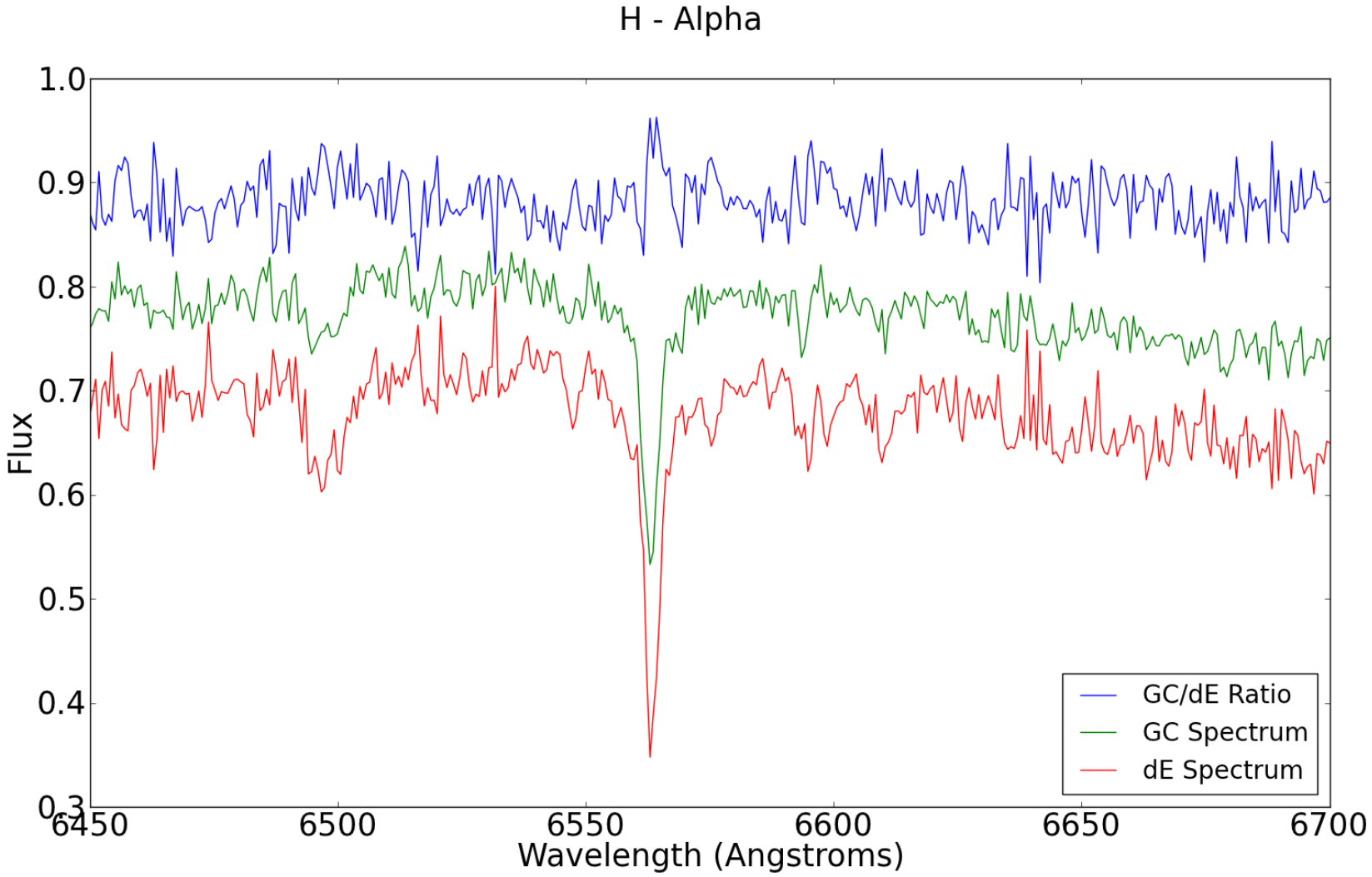


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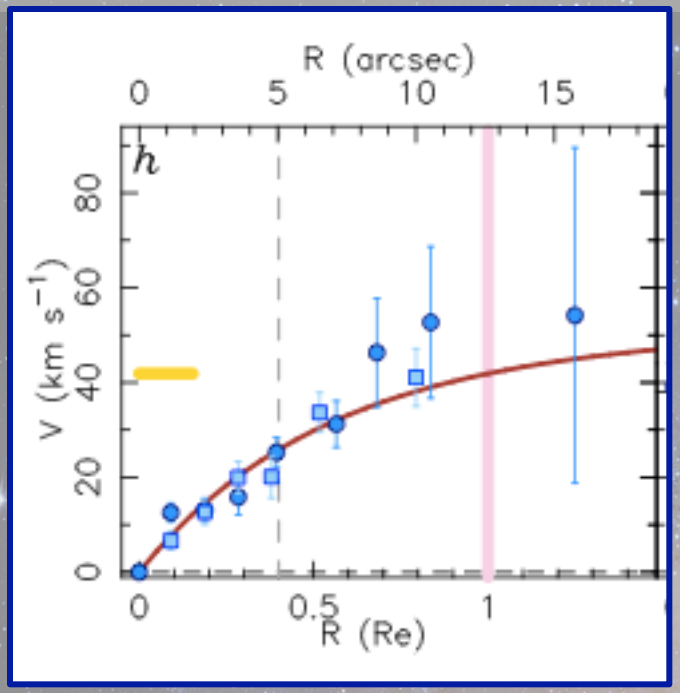
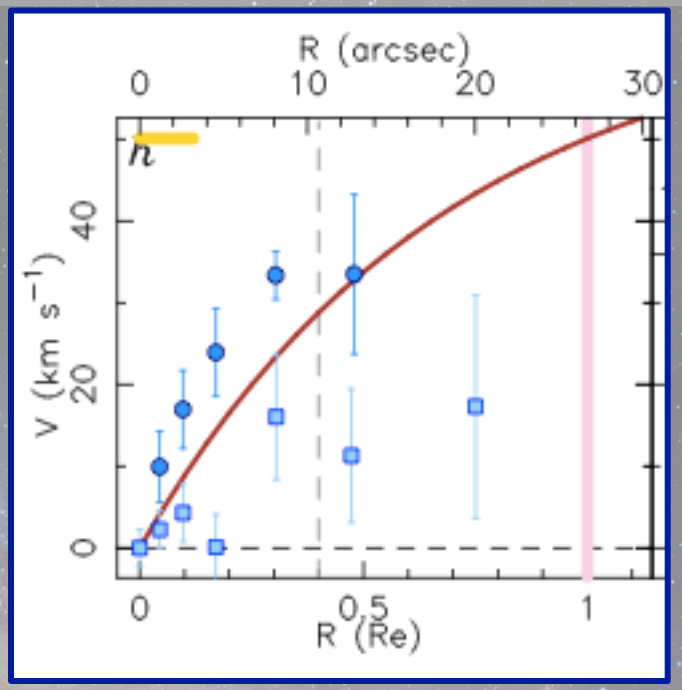
# Dwarf early-types often show asymmetric “rotation curves”




SMAKCED survey:
Toloba, PG, et al. ApJ, submitted

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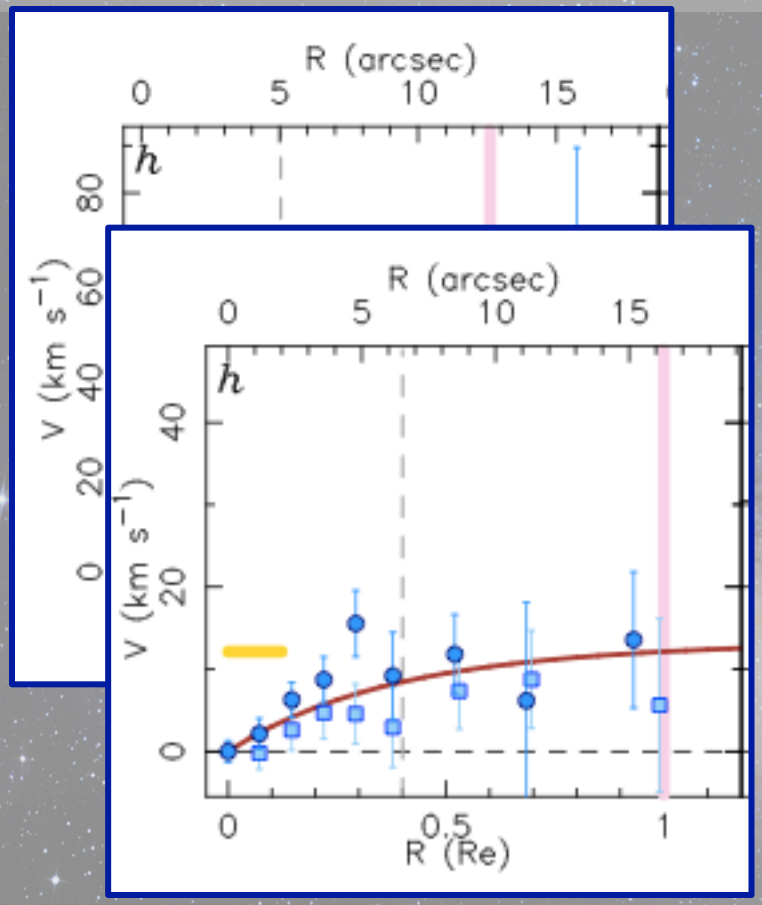


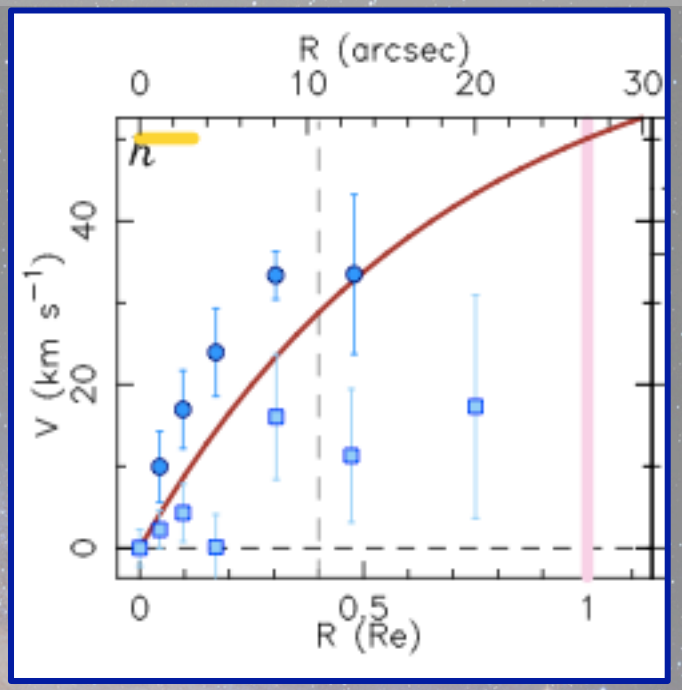


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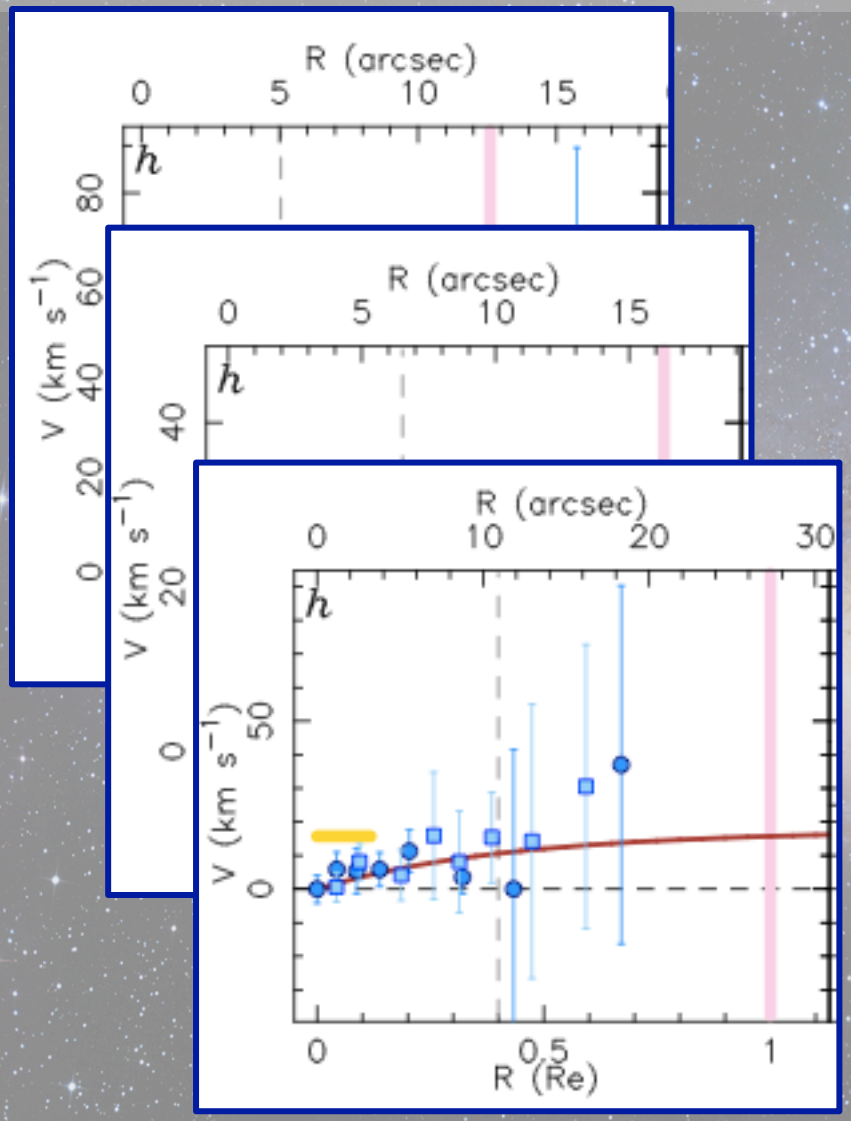


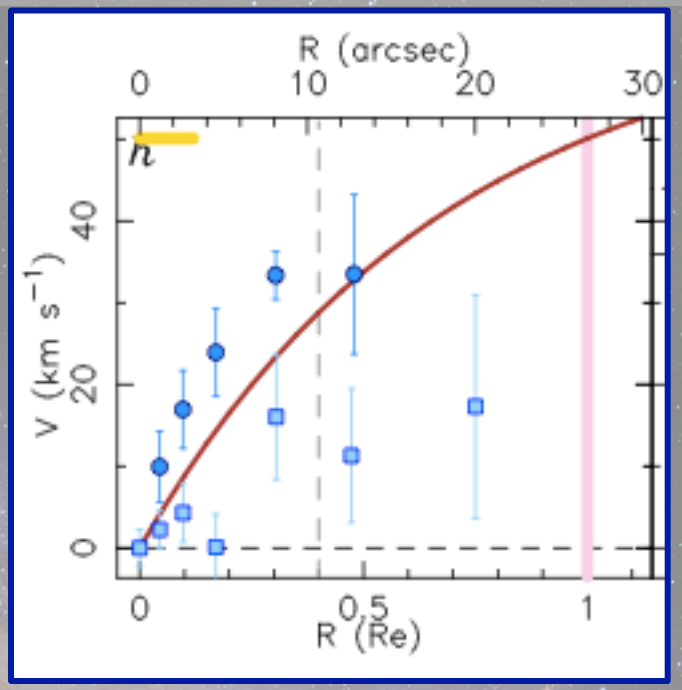


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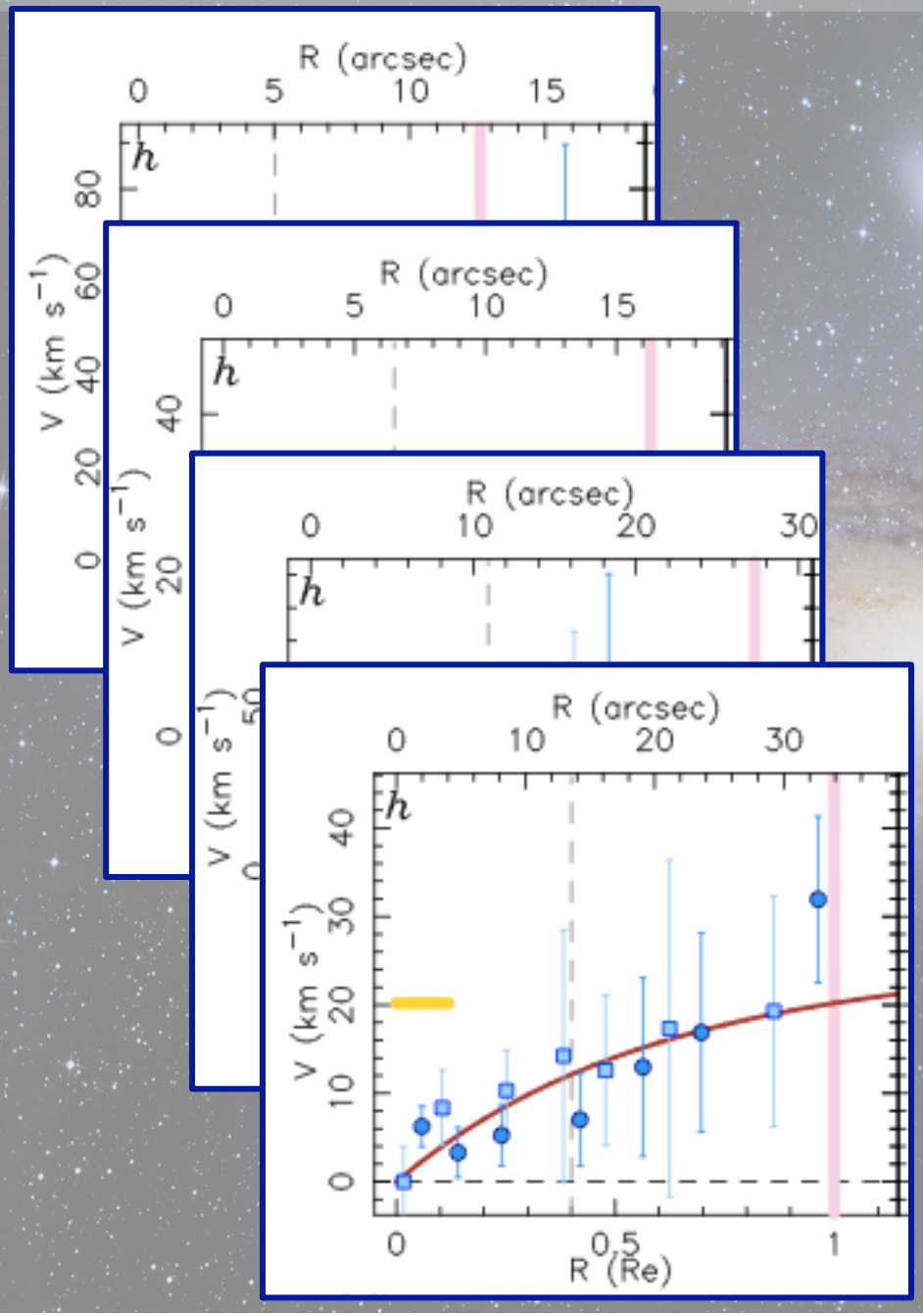


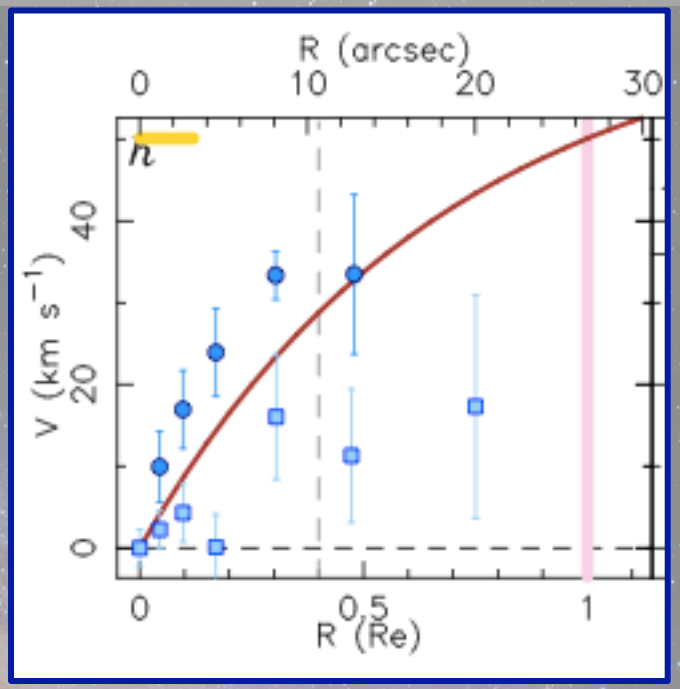


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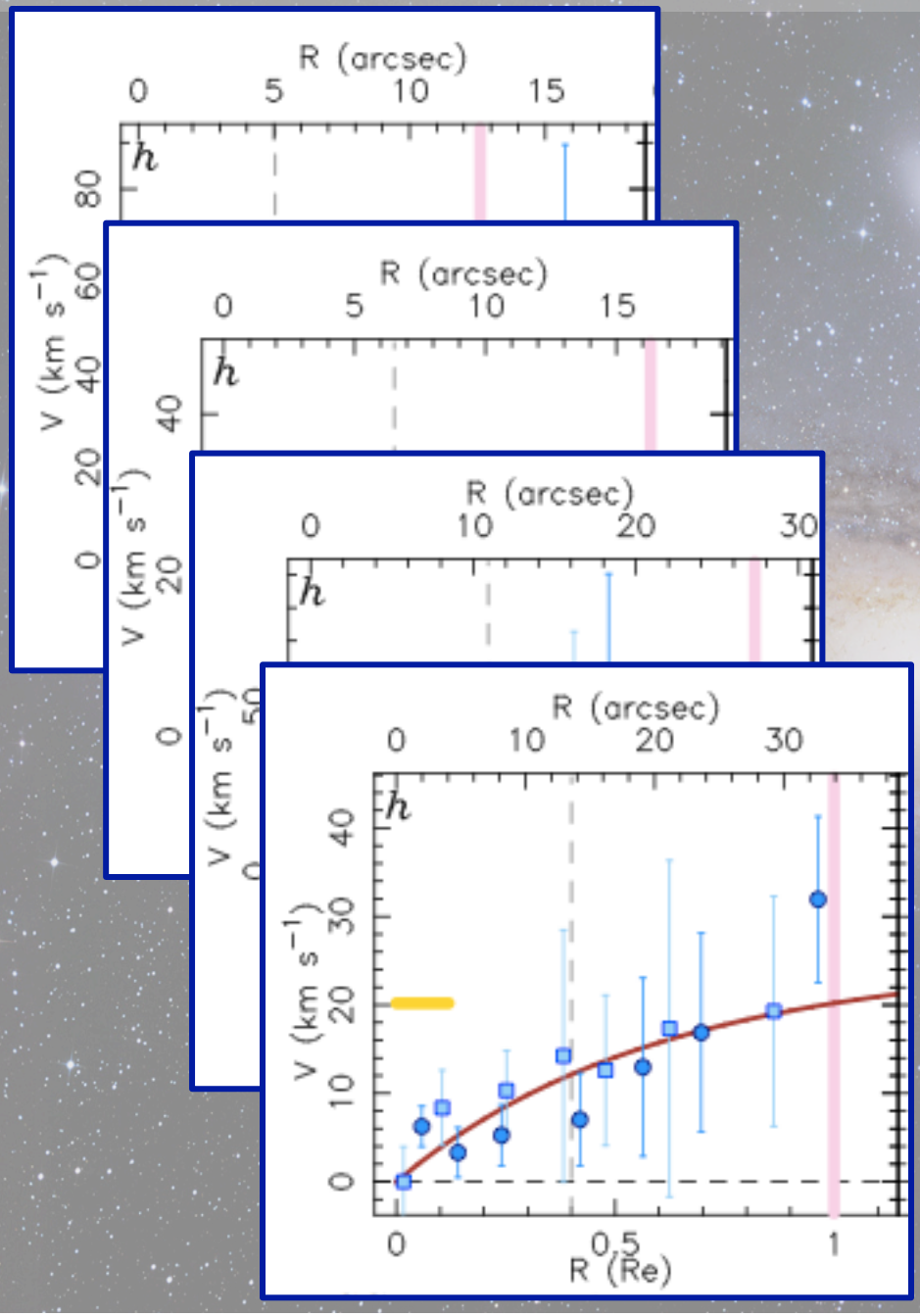


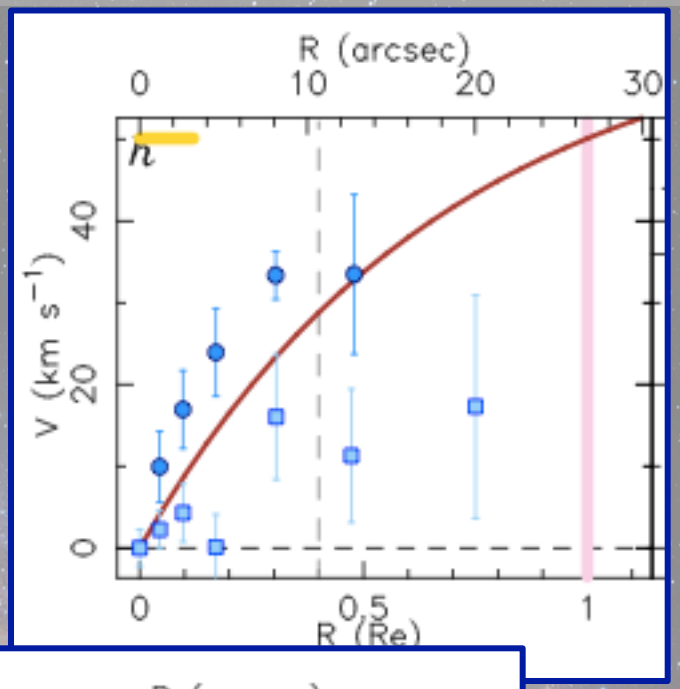


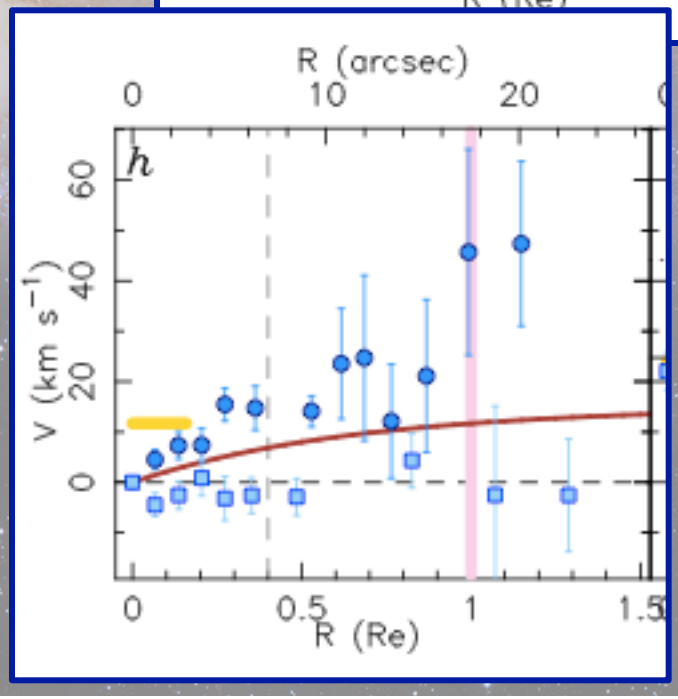


SMAKCED survey:
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# Accretion history and mass of the Milky Way

– Leveraging the remarkable *astrometric* potential of deep, multi-epoch HST images (and ultimately JWST images?)

– Need TMT to measure radial velocties of faint blue main sequence turnoff stars in the MW outer halo

# "7D" mapping of the Milky Way halo: Accretion history and mass estimate

- Proper motions from multi-epoch HST imaging and, in the future, Gaia
- Need TMT/WFOS to measure radial velocities (and especially chemical abundances) of faint MSTO stars
- Very long integrations required with Keck/DEIMOS (8 to 32 hours per mask!)

*HALO7D Collaboration*
*HSTPROMO: The HST Proper Motion Collaboration*
Alis Deason, Emily Cunningham, Connie Rockosi, PG (*UCSC*), Evan Kirby (Caltech)
Roeland van der Marel, Jay Anderson, Tony Sohn (*STScI*)

# HALO7D survey

## Looking at and through the Milky Way

*HST archival legacy program*

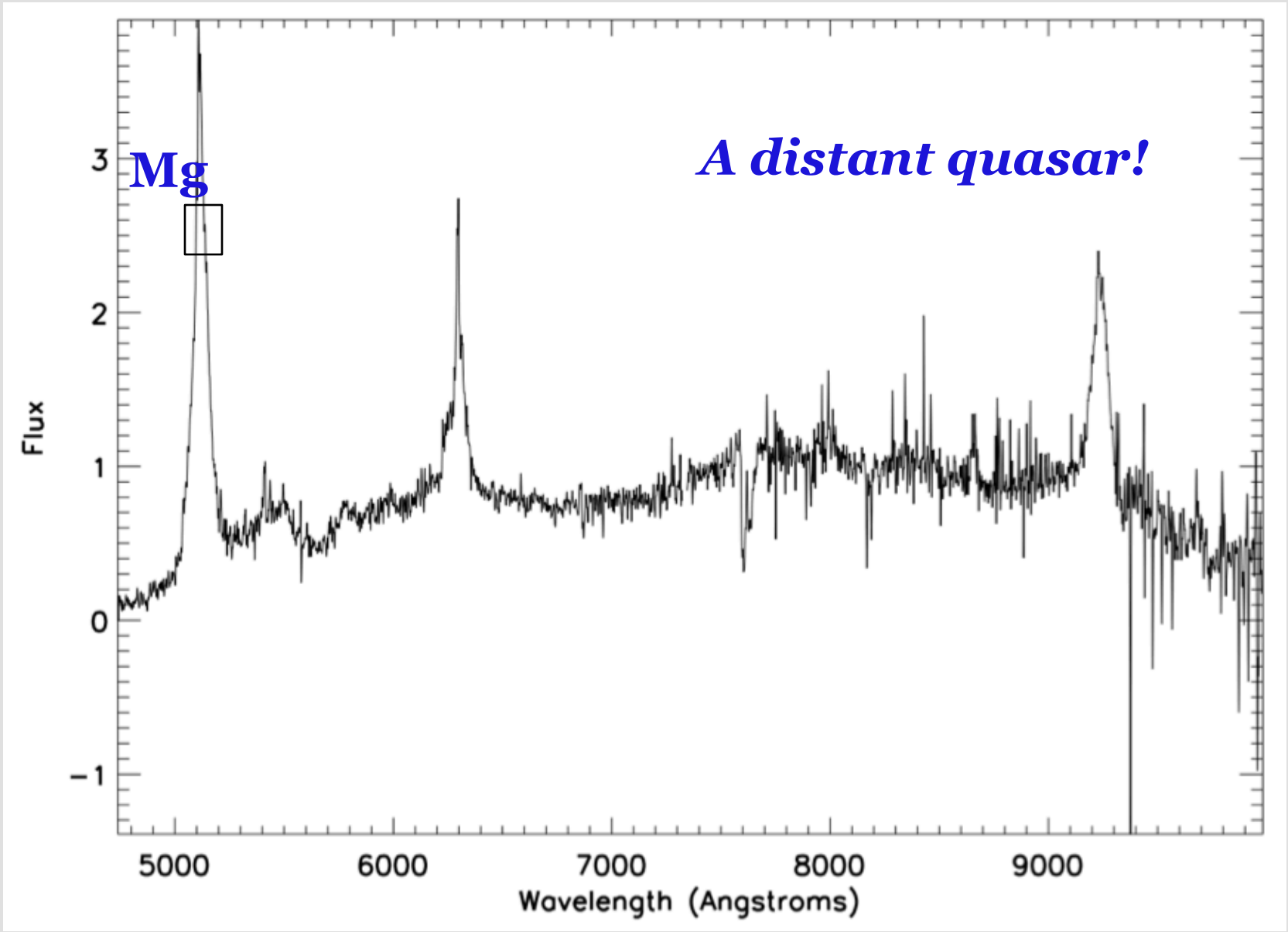
- Deep multi-epoch HST imaging
- Use distant galaxies as "wall paper"
- Proper motion of ~ 1000 MSTO stars in the MW halo

*Keck/DEIMOS spectroscopy program*

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

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

# Sample spectra from ~ 6 hours of integration in the EGS



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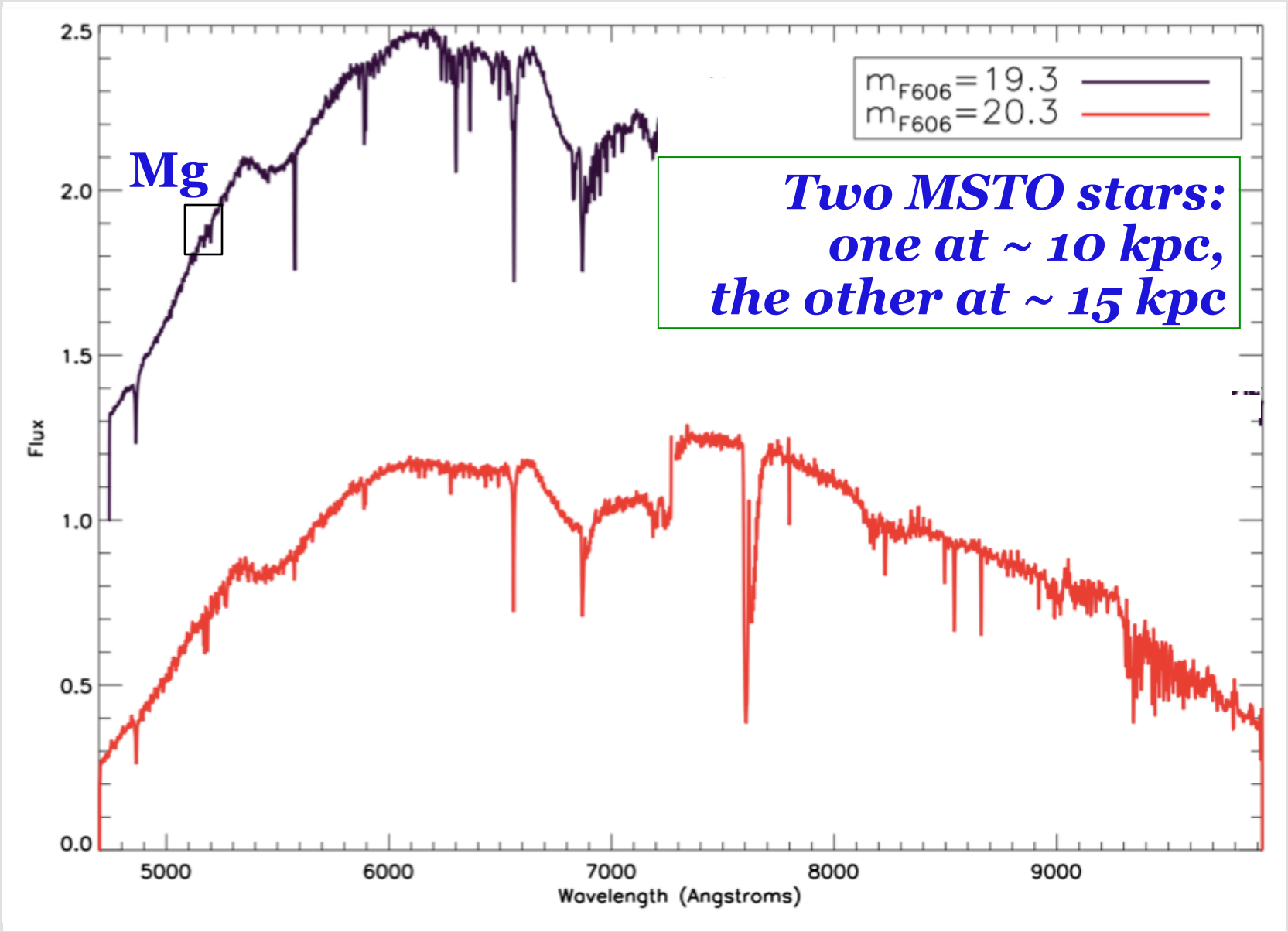

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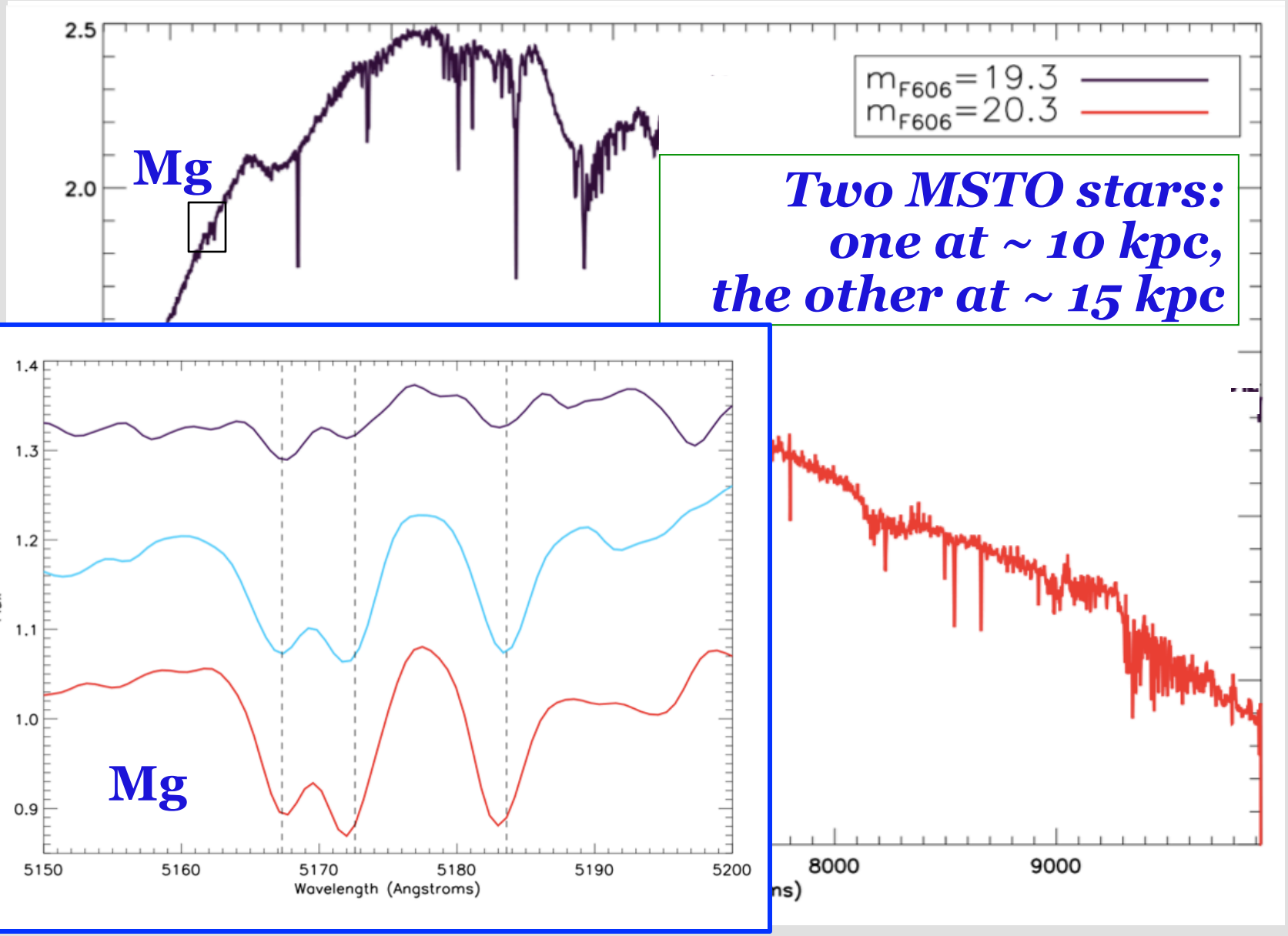

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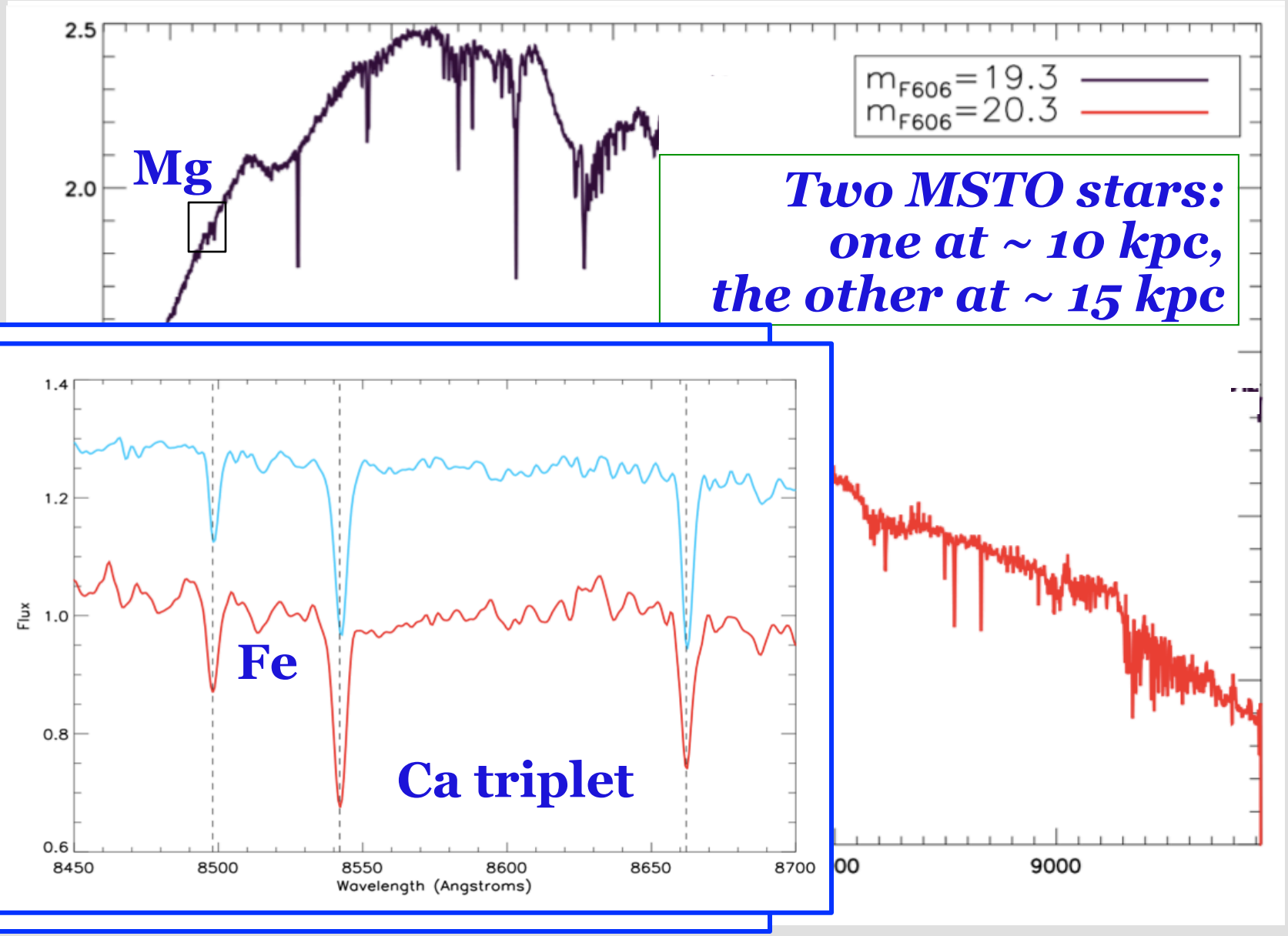
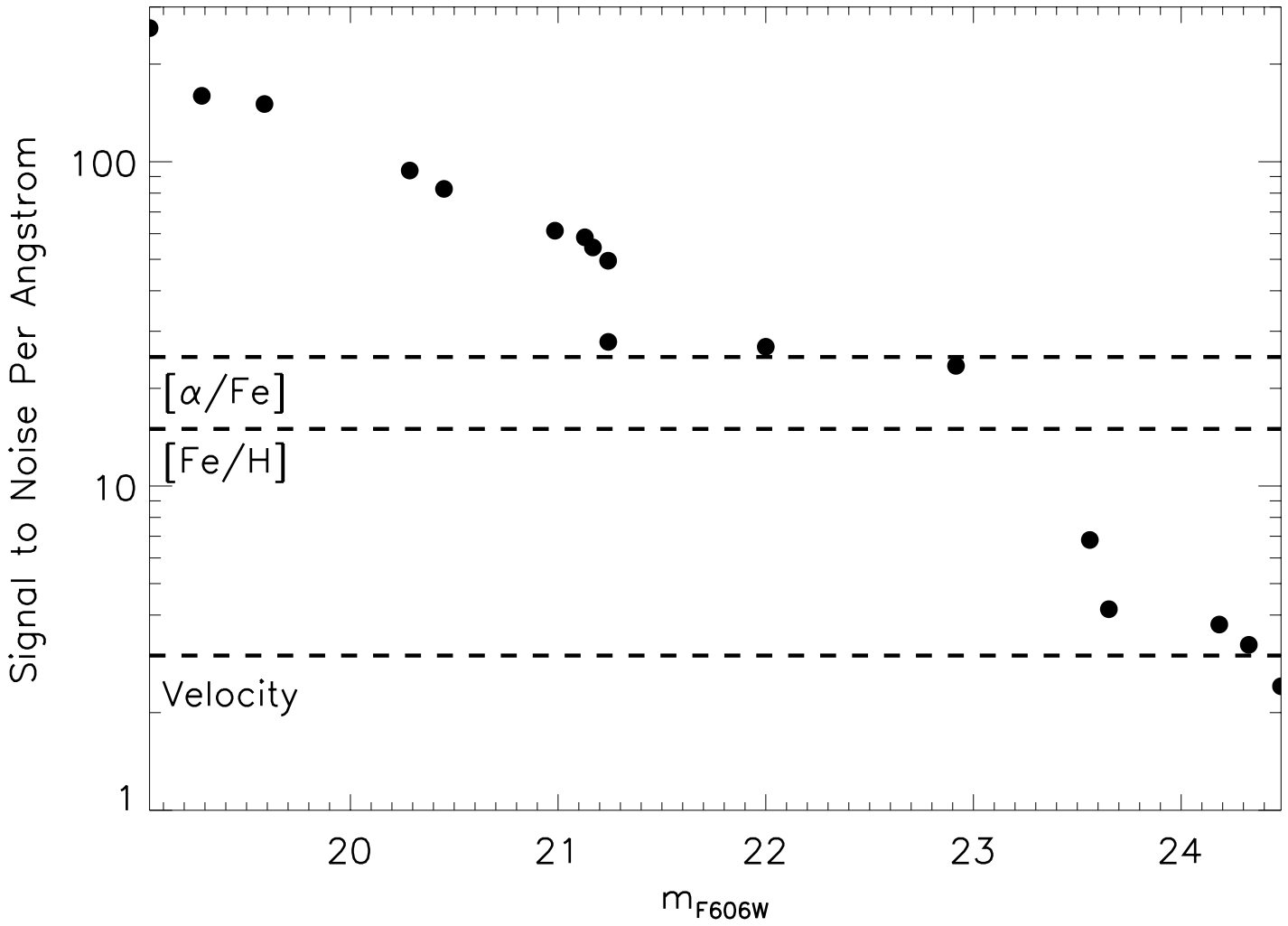
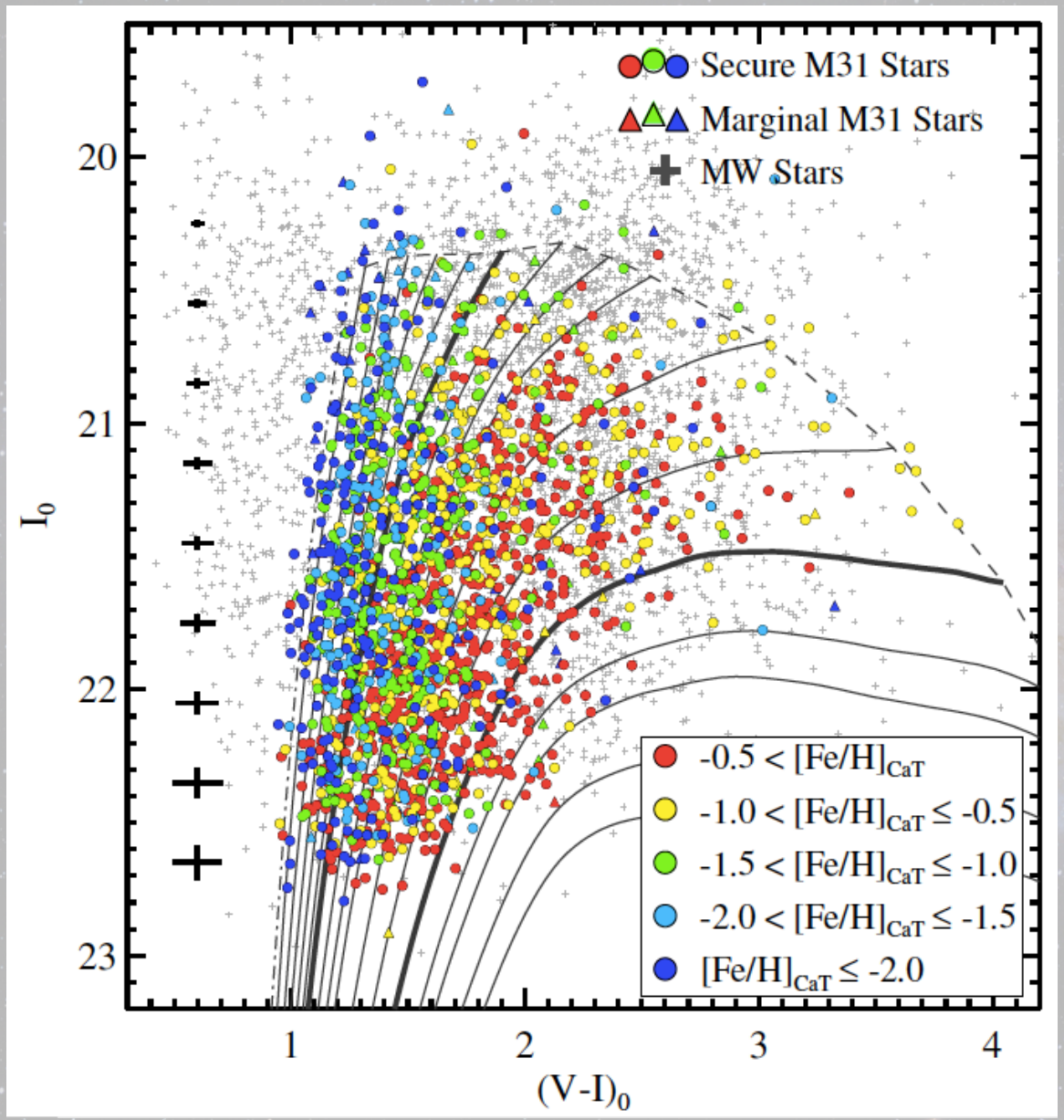


# Typical S/N ratio at 6500Å based on ~ 6 hours of integration in the EGS



# 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)
Ho et al. (2015, ApJ)

Vargas et al. (2014a, ApJ)
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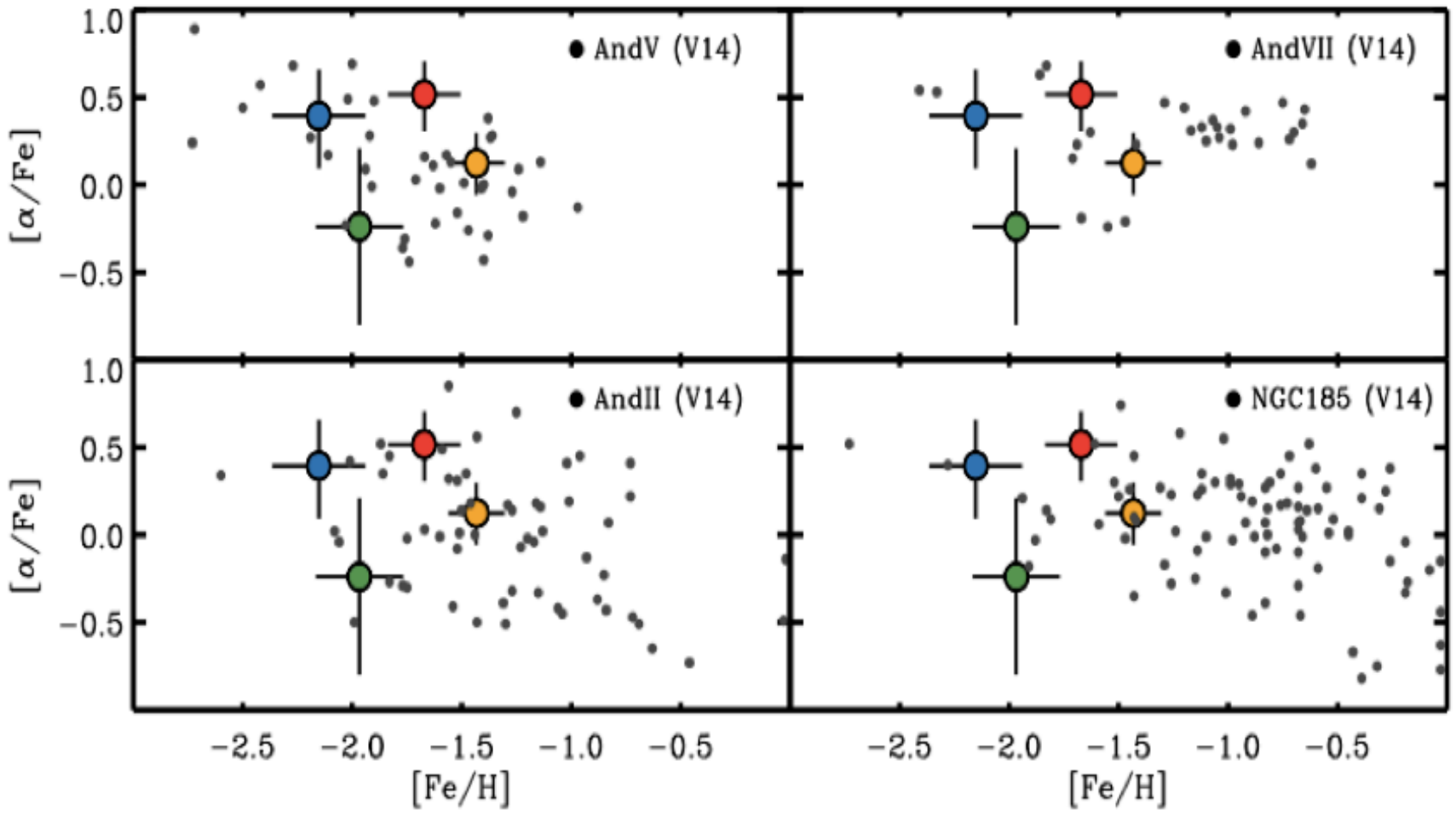


Number of direct [Fe/H] and [α/Fe] measurements will go from *four* M31 field halo stars and *few tens* of members of luminous satellites to *few hundred* RGB stars in the spheroid, outer disk, and giant stream

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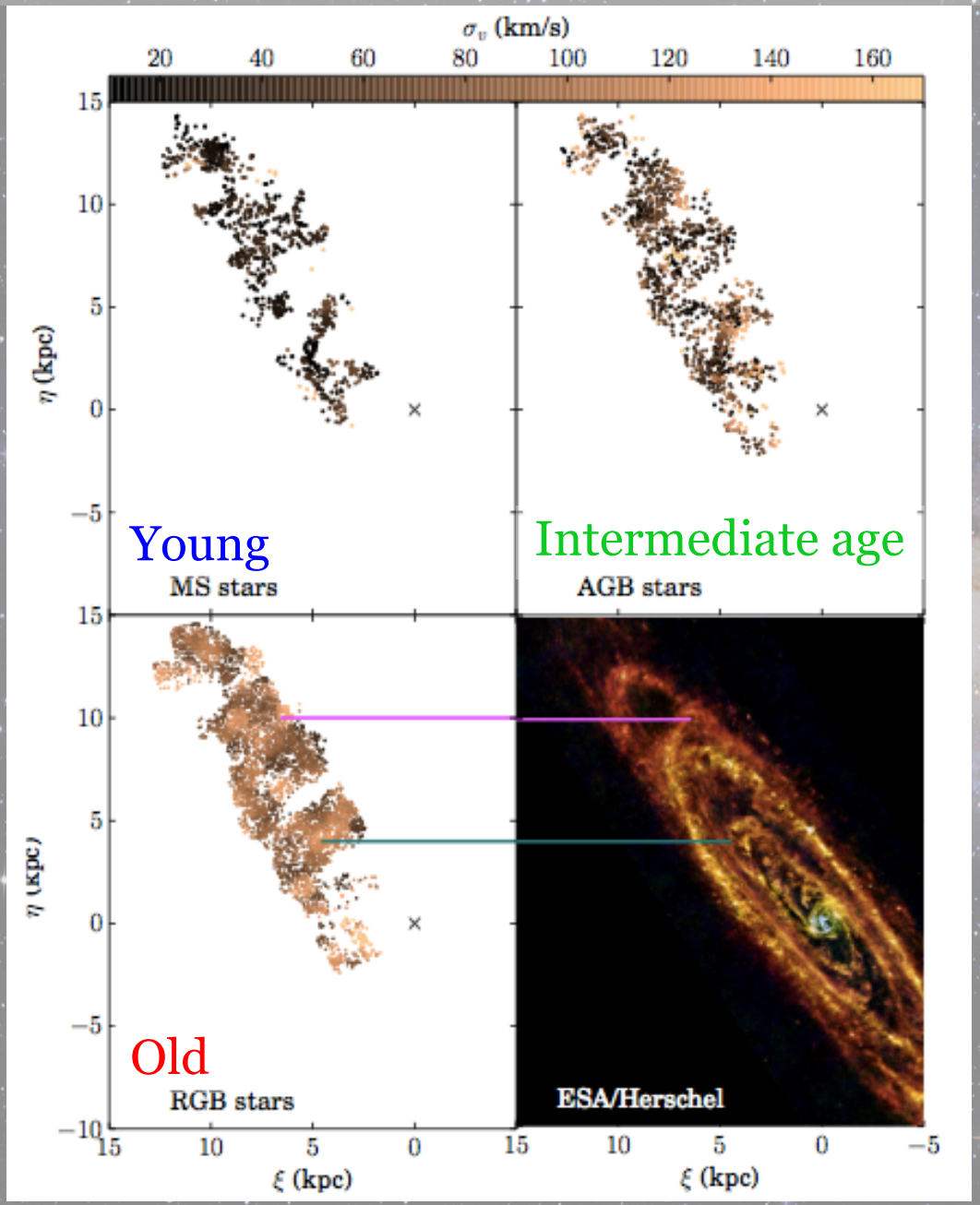
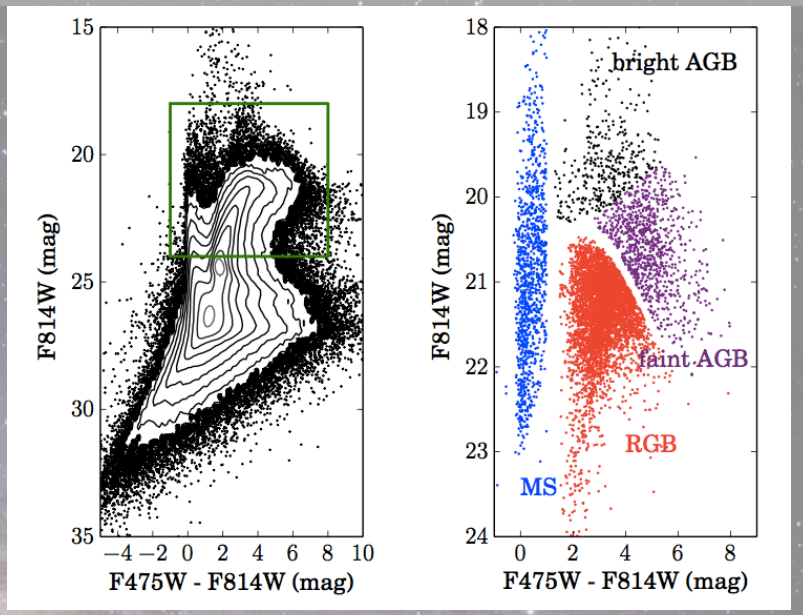
PHAT
PANCHROMATIC HUBBLE ANDROMEDA TREASURY

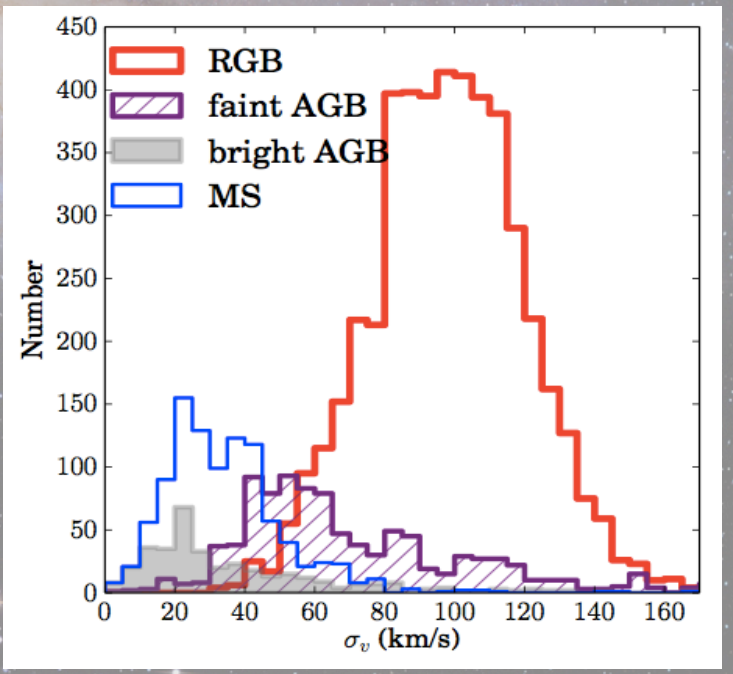
- 828 orbits, 4 years
- 6 Filters (UV-NIR)

*PHAT PI: Julianne Dalcanton*
*Keck/DEIMOS spectroscopy led by UCSC*

# M31 disk kinematics using stellar tracers of different ages




Dorman, PG, et al. in prep.

# Summary: Examples of what TMT can do for Local Group / Local Volume science

- Dwarf elliptical galaxies: dark matter content; nature of their nuclei; origin of their kinematic anomalies
- Finding, measuring the masses of, and characterizing ultra-faint dwarf galaxies in the Local Group – the smallest dark matter sub-halos and constraints on baryonic physics
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