Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo

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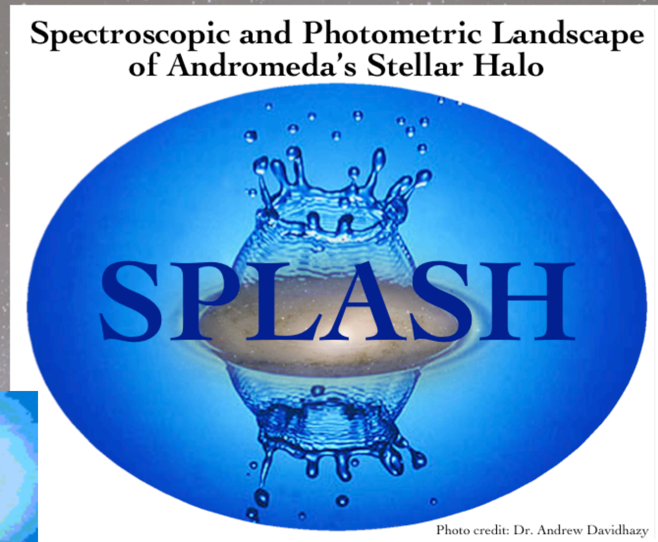
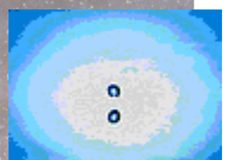
Collaborators

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Tom Brown (STScI), *Mikito Tanaka* (U Tokyo), *Masashi Chiba* (Tohoku U)

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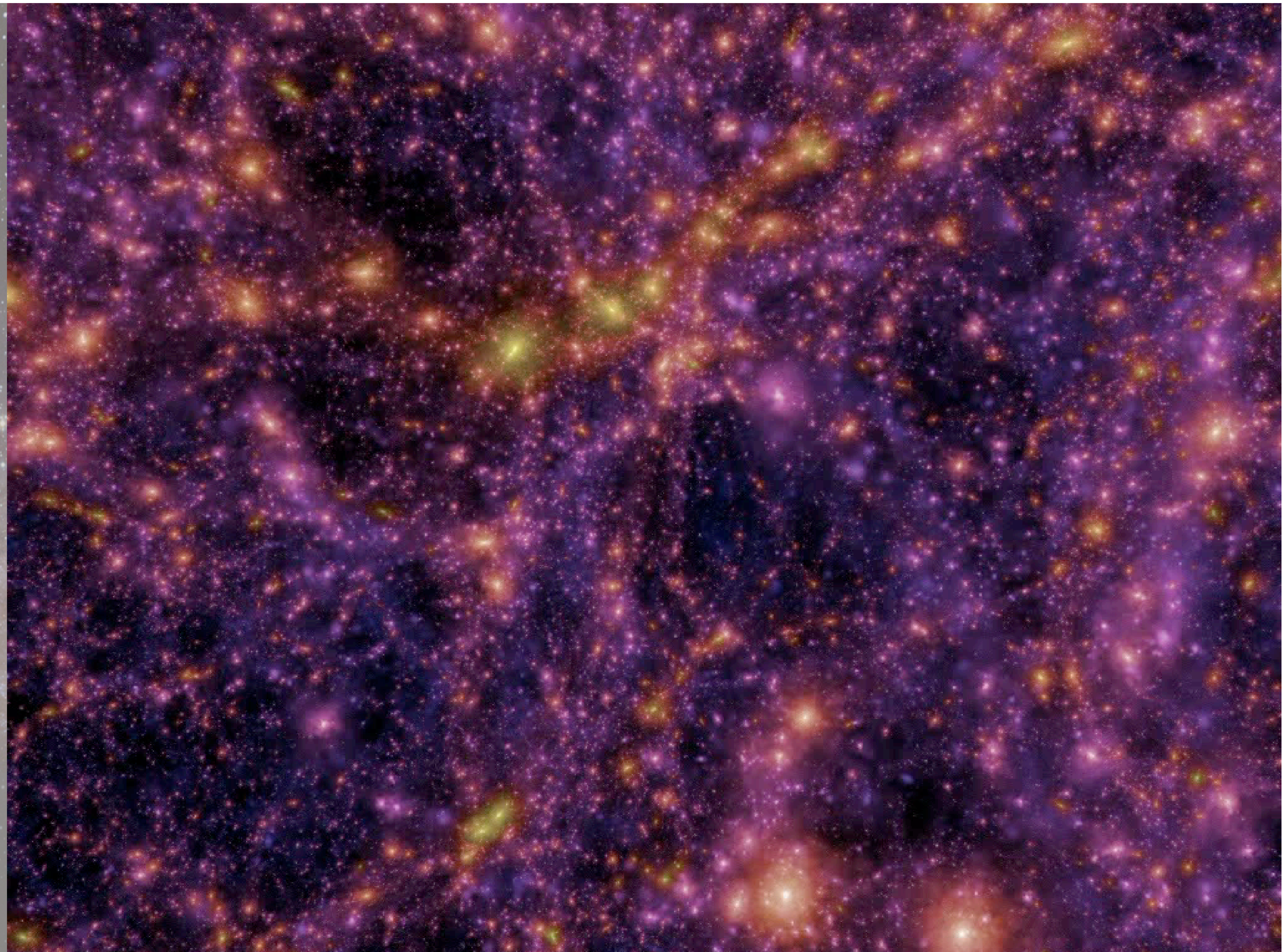
Outline



Stellar halo

- *Background*
- *Our Survey*
- *Radial Surface Brightness Profile*
- *Chemical Enrichment*
- *A Recent Collision: Inner Spheroid*

Related topics

- *Boxy Bulge / Bar*
- *Dwarf Satellites*

Galaxy Formation and Evolution

Direct look-back studies **vs.** **Fossil-record studies**

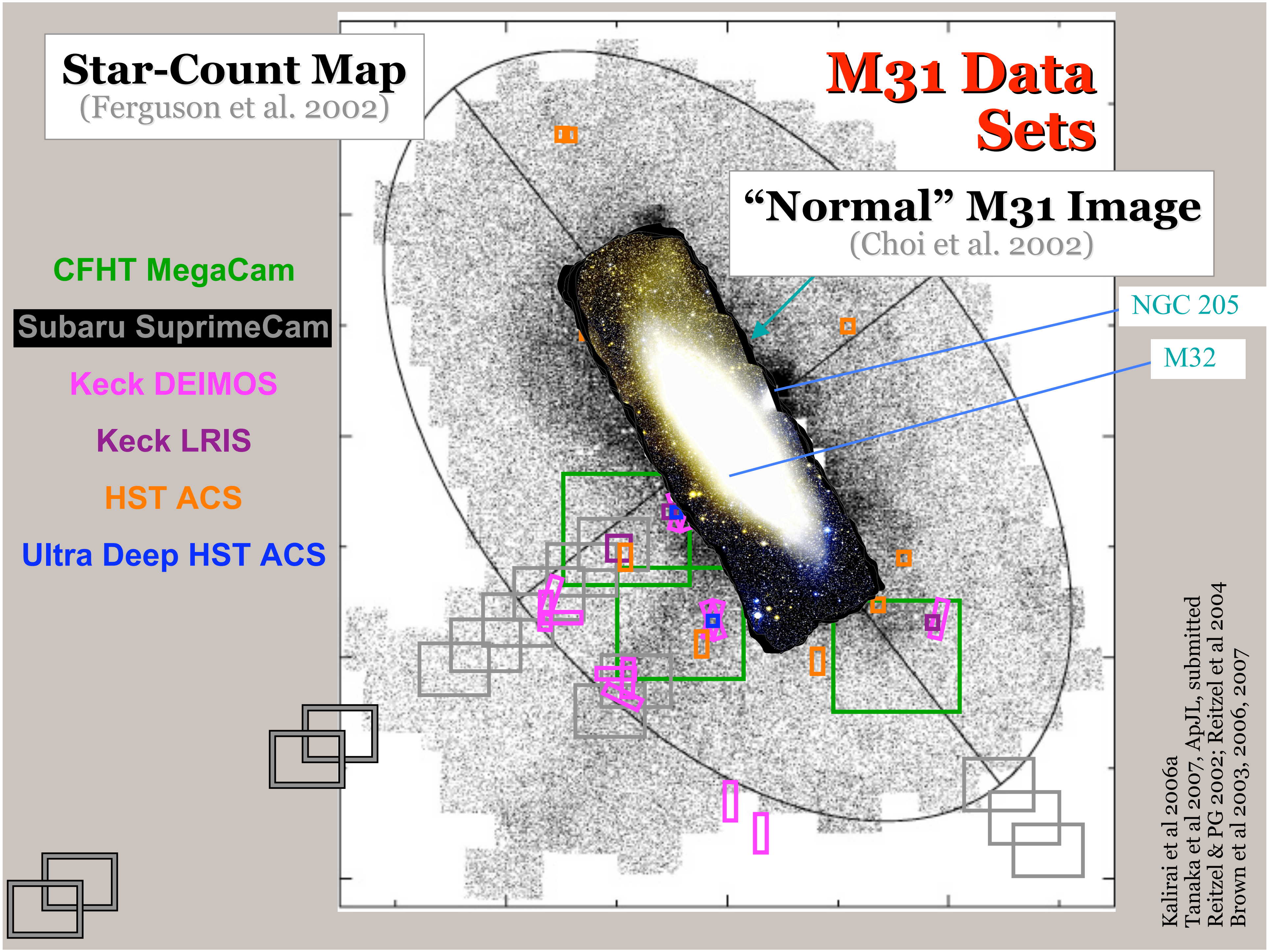
Conclusion from Previous Studies

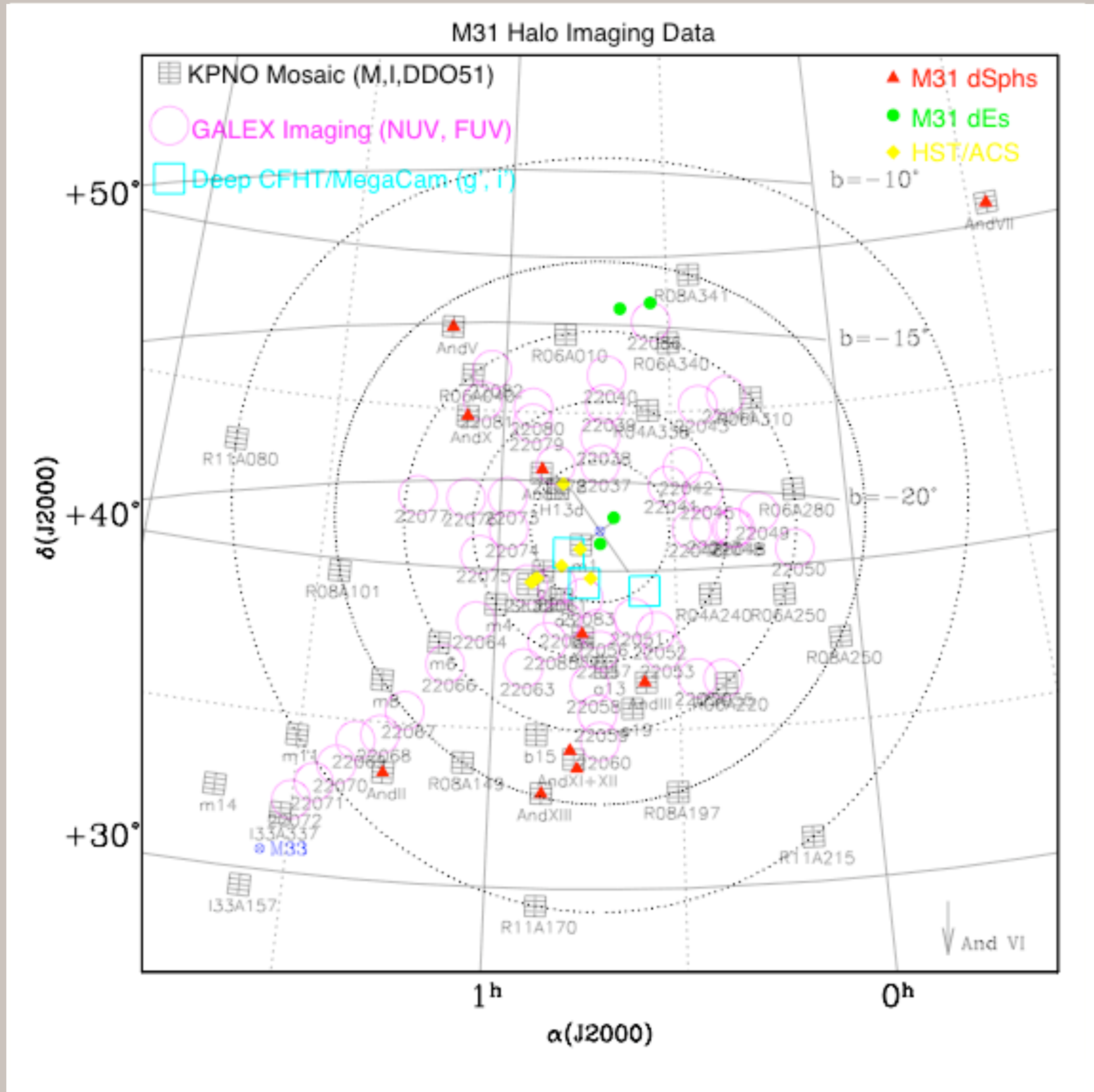
inner spheroid
M31's "~~halo~~" ^ (*R* ~ 10 – 30 kpc) looks <u>nothing like</u> the Milky Way halo

- The combination of the $r^{1/4}$ law surface brightness profile and high metallicity makes the M31 spheroid look much more like the Milky Way's <u>bulge</u> than its halo
- M31's spheroid has also been likened to elliptical galaxies
- The age and star-formation history of M31's spheroid are unusual —intermediate-age / young population found in Brown et al.'s (2003) ultra-deep *HST* / ACS photometry

Our Survey

M31's Extended Stellar Halo and Inner Spheroid


Star-Count Map
(Ferguson et al. 2002)
M31 Data Sets
“Normal” M31 Image
(Choi et al. 2002)
NGC 205
M32
CFHT MegaCam
Subaru SuprimeCam
Keck DEIMOS
Keck LRIS
HST ACS
Ultra Deep HST ACS
Kalirai et al 2006a
Tanaka et al 2007, ApJL, submitted
Reitzel & PG 2002; Reitzel et al 2004
Brown et al 2003, 2006, 2007

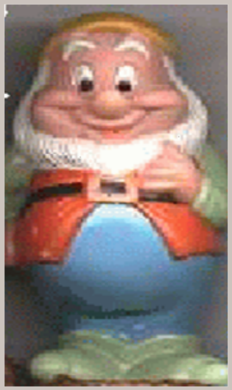


Ostheimer (2002, PhD thesis)
Beaton et al. (in prep)
Kalirai et al. (2006a)
Prochaska, Kalirai & PG (in prep)

Isolating M31 Red Giant Stars

Possible contaminants

(1) Background galaxies

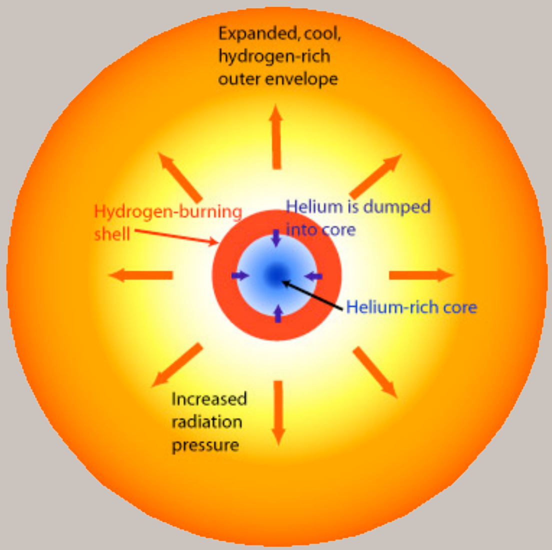


(2) Foreground Milky Way dwarf stars

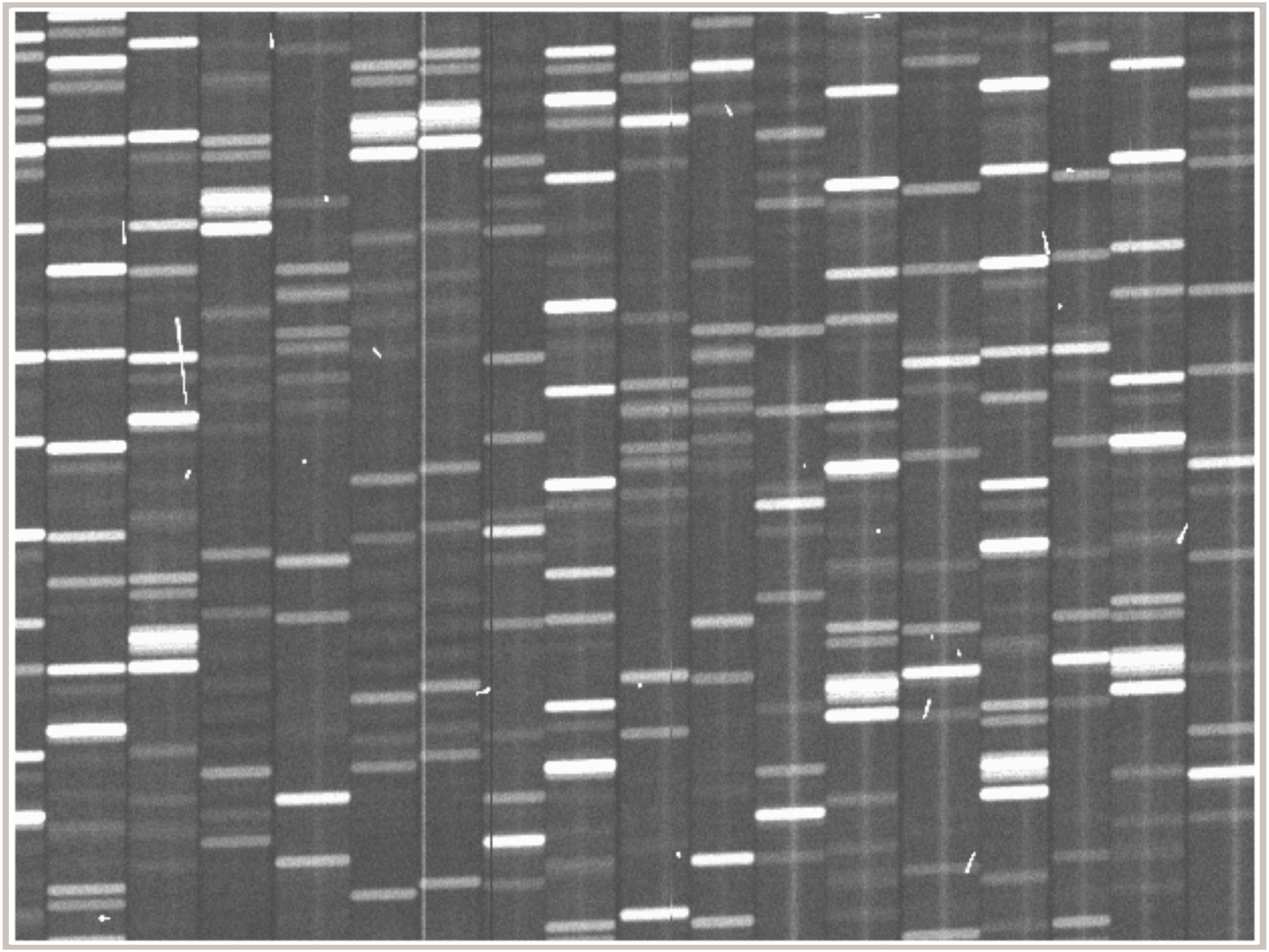
— similar brightnesses/colors

— similar line-of-sight velocities

We expect to find <u>very few</u> (if any) Andromeda red giant branch stars in the remote outer fields; in order to isolate them we need to do a careful job of rejecting the above contaminants



Gilbert et al. (2006, ApJ)

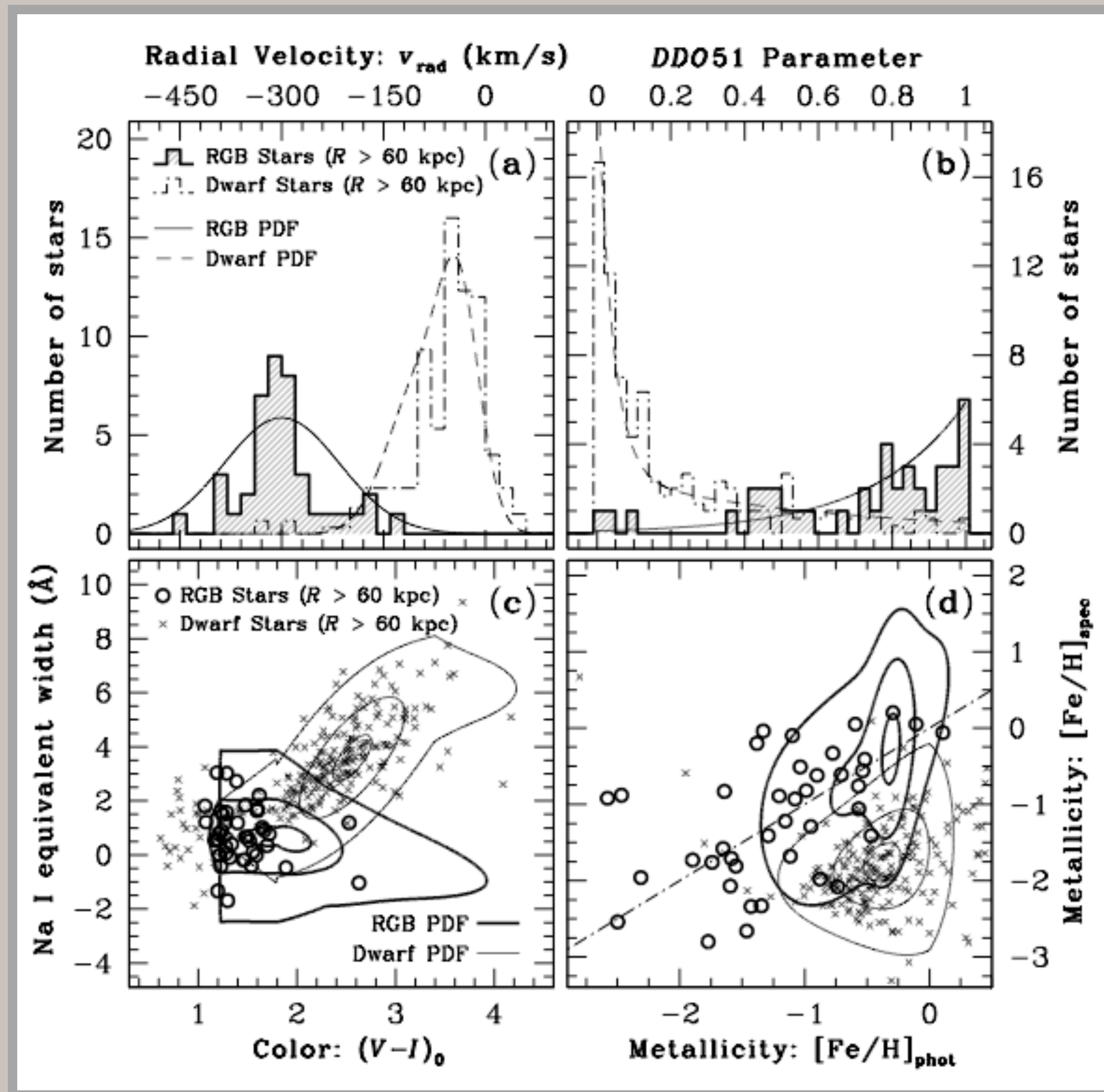


Isolating a clean sample of M31 RGB stars

We use probability distribution functions based on five photometric / spectroscopic diagnostics to eliminate foreground Milky Way dwarf stars. We plan use five more diagnostics in the near future.

(1) Radial Velocity
(2) *DDO51* photometry
(3) Na I equivalent width
(4) Position in the CMD
(5) $[Fe/H]_{phot}$ vs $[Fe/H]_{spec}$

(6–7) KI line strengths
(8–10) TiO band strengths



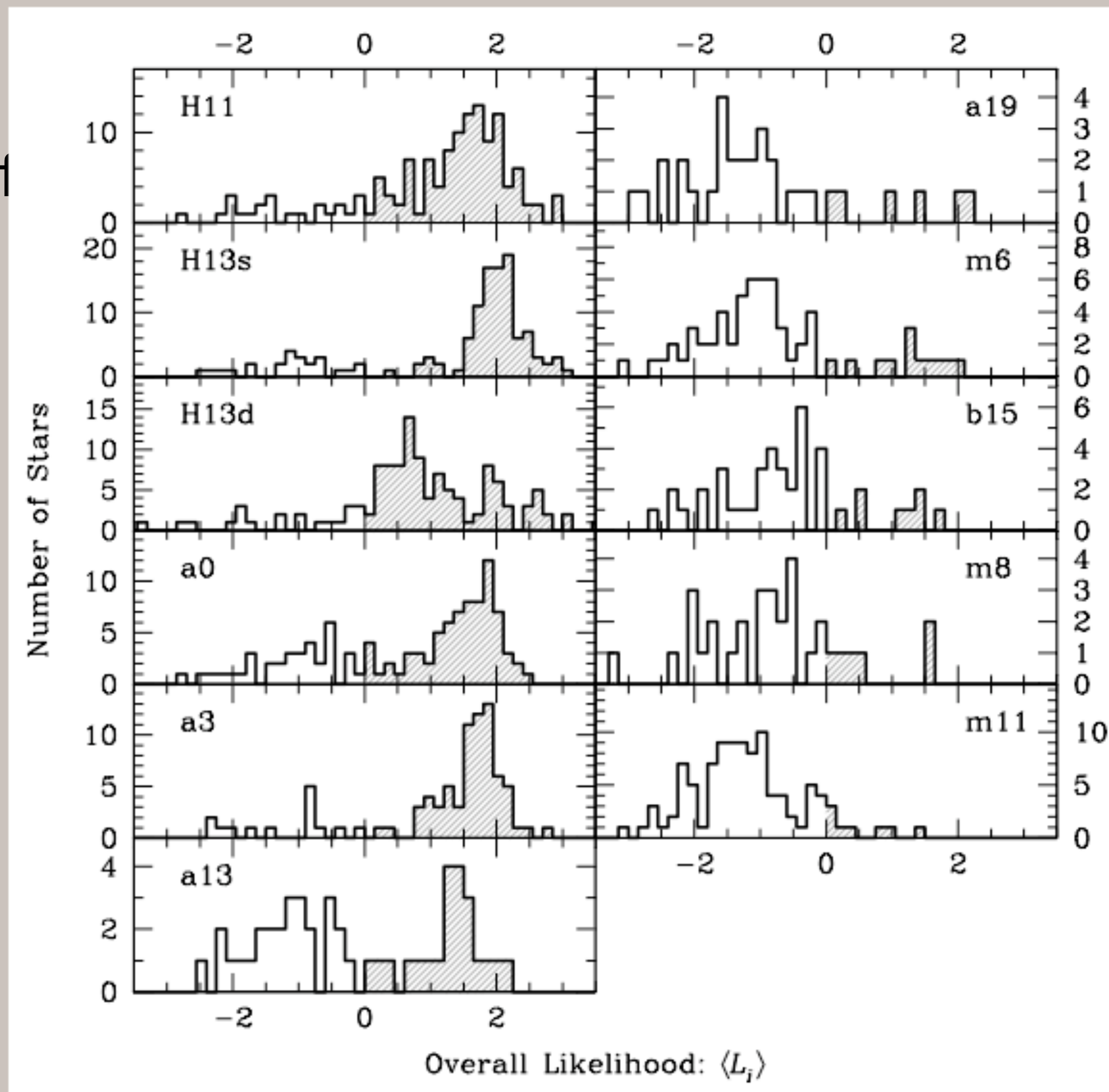
Gilbert et al. (2006, ApJ)

Overall Likelihood Distributions

- Weighted average of the first 5 individual likelihoods
- In general:

  ‹L_i› > 0: M31 RGB

  ‹L_i› < 0: MW dwarf



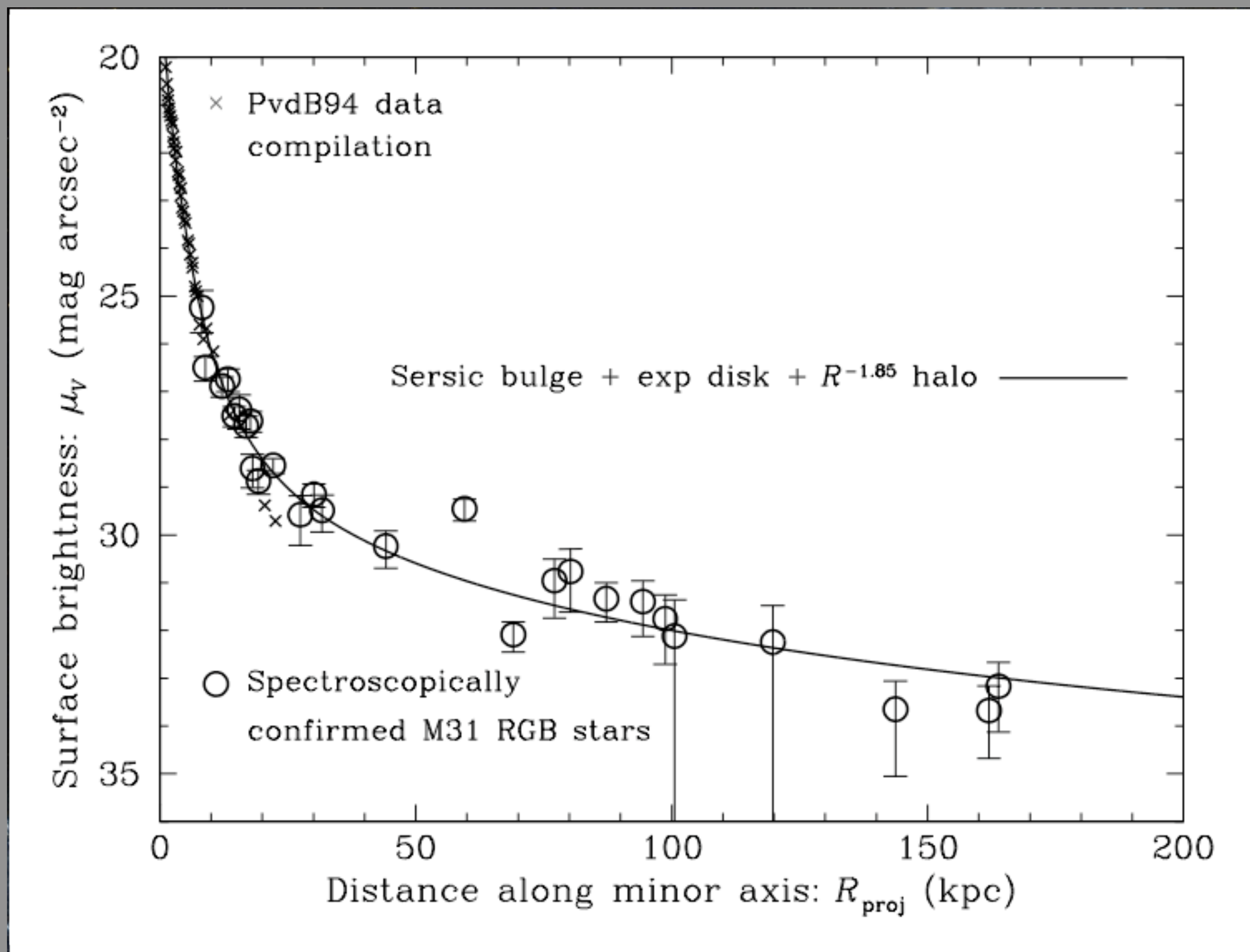
where:

$L_i = \log(P_{\text{giant}}/P_{\text{dwarf}})_i$

Gilbert et al. (2006, AJ)

Surface Brightness Profile of M31

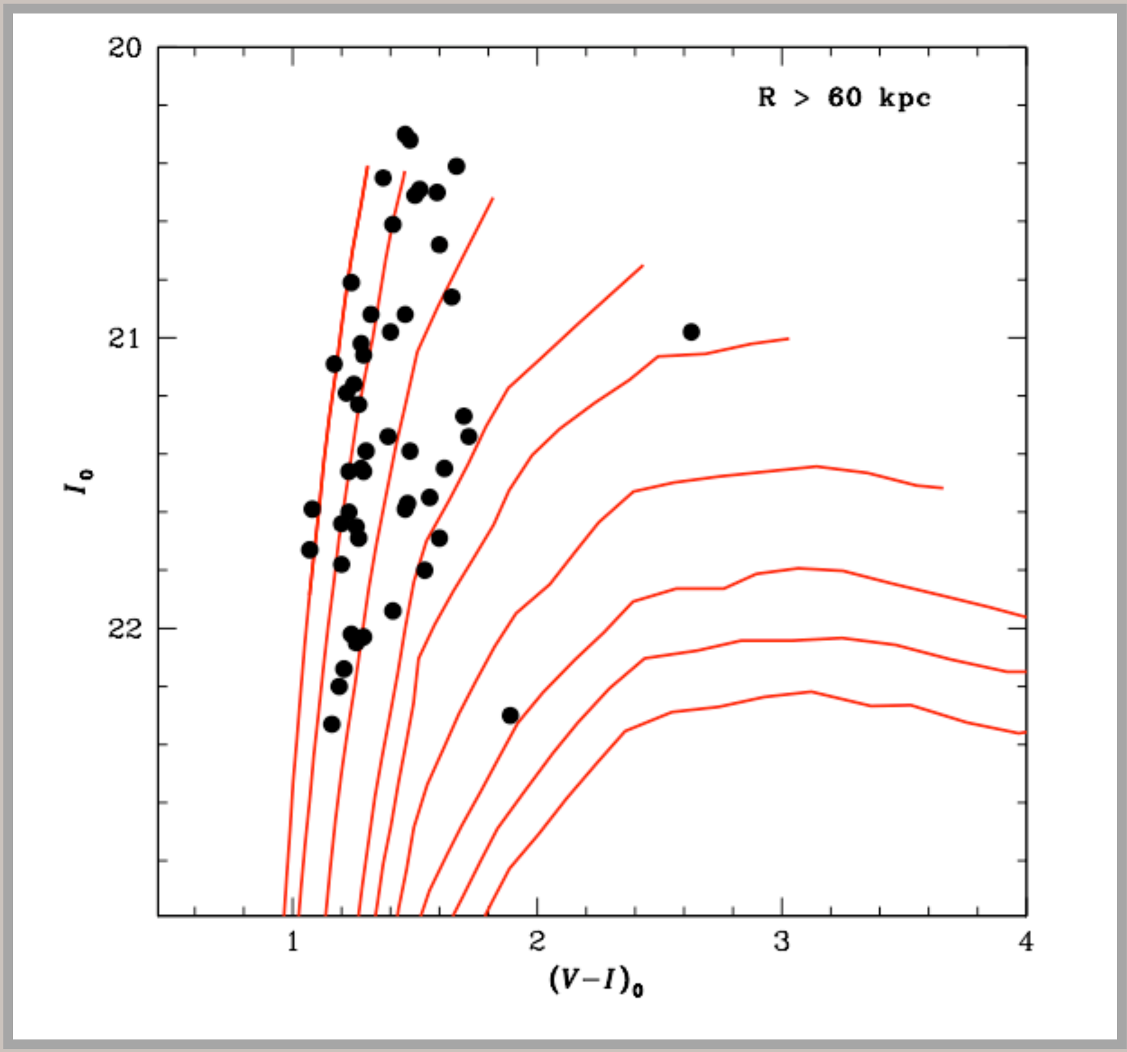
Counts of spectroscopically confirmed M31 RGB stars in outer fields (R = 30 to 150 kpc) lie well above extrapolation of Sersic-law inner spheroid; Best fit: R^{-2} power law halo



PG et al. (2005, astro-ph/0502366)

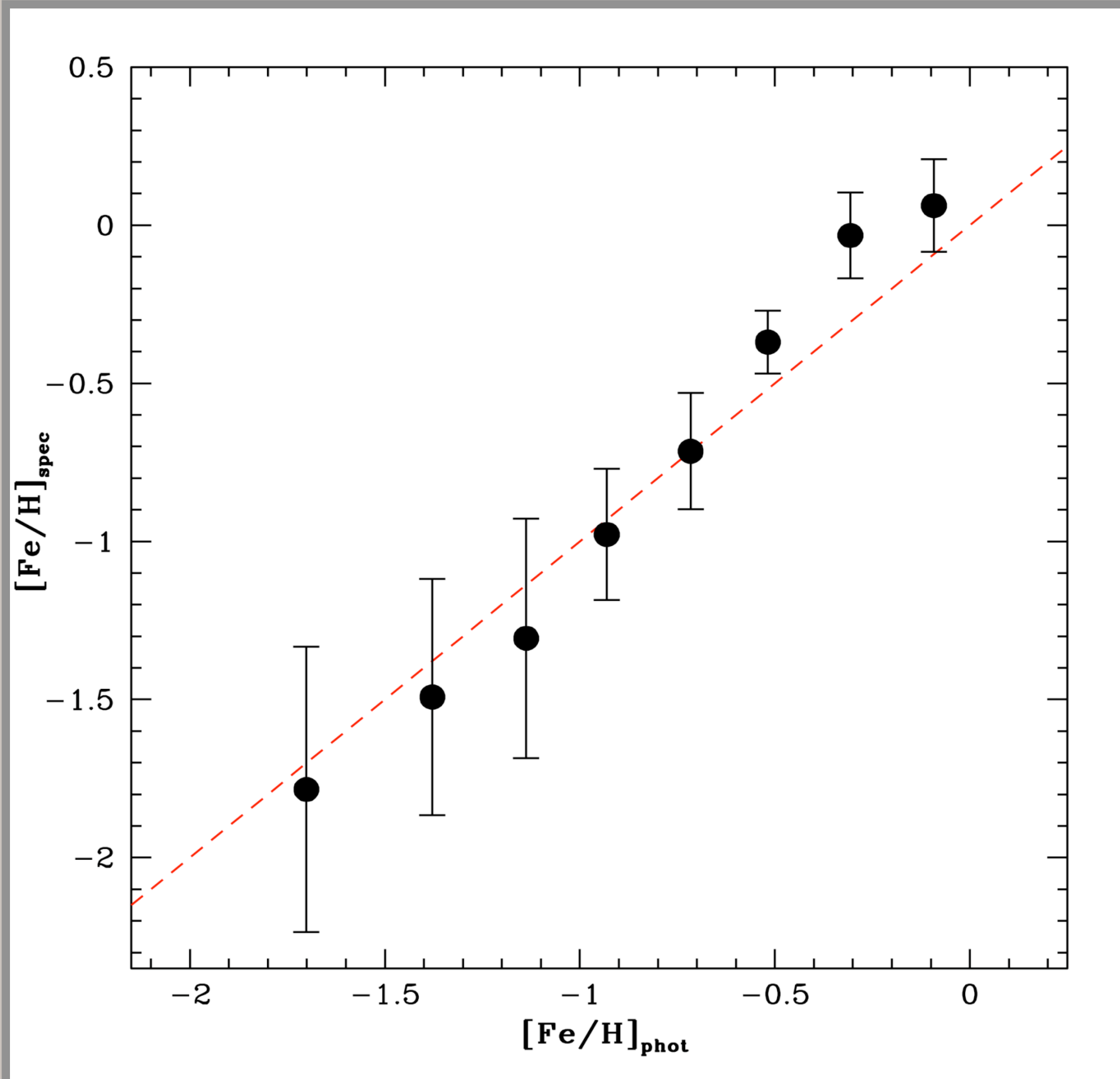
PG et al. (2007, ApJ, in prep)

Radial Gradient in Metallicity



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

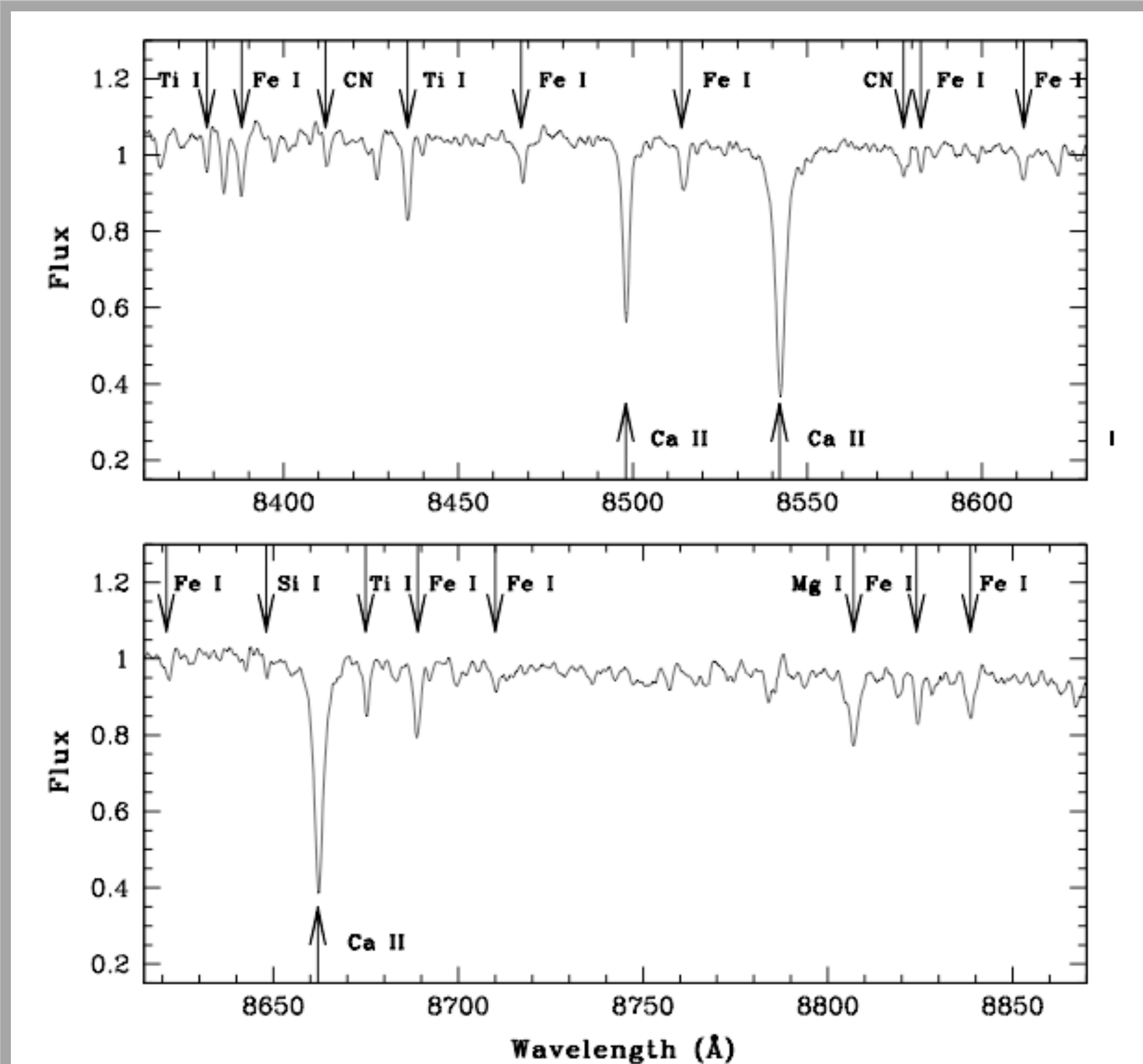
Photometric vs. Spectroscopic [Fe/H] Estimates



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

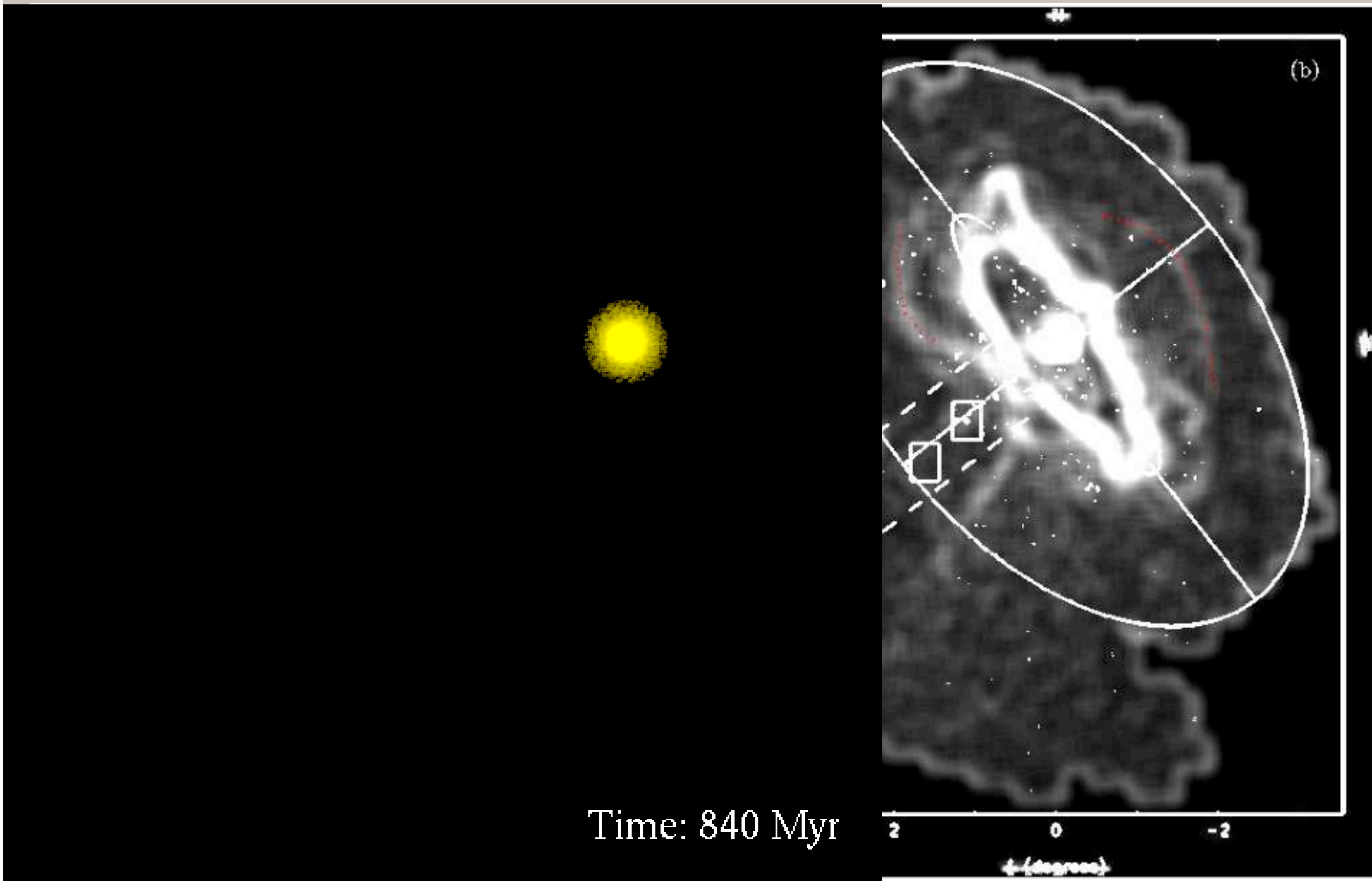
It is reassuring to see that there is a reasonably good correlation between the photometric and spectroscopic [Fe/H] estimates

Detailed Elemental Abundances from Coadded Spectra




Dissecting a Recent Collision

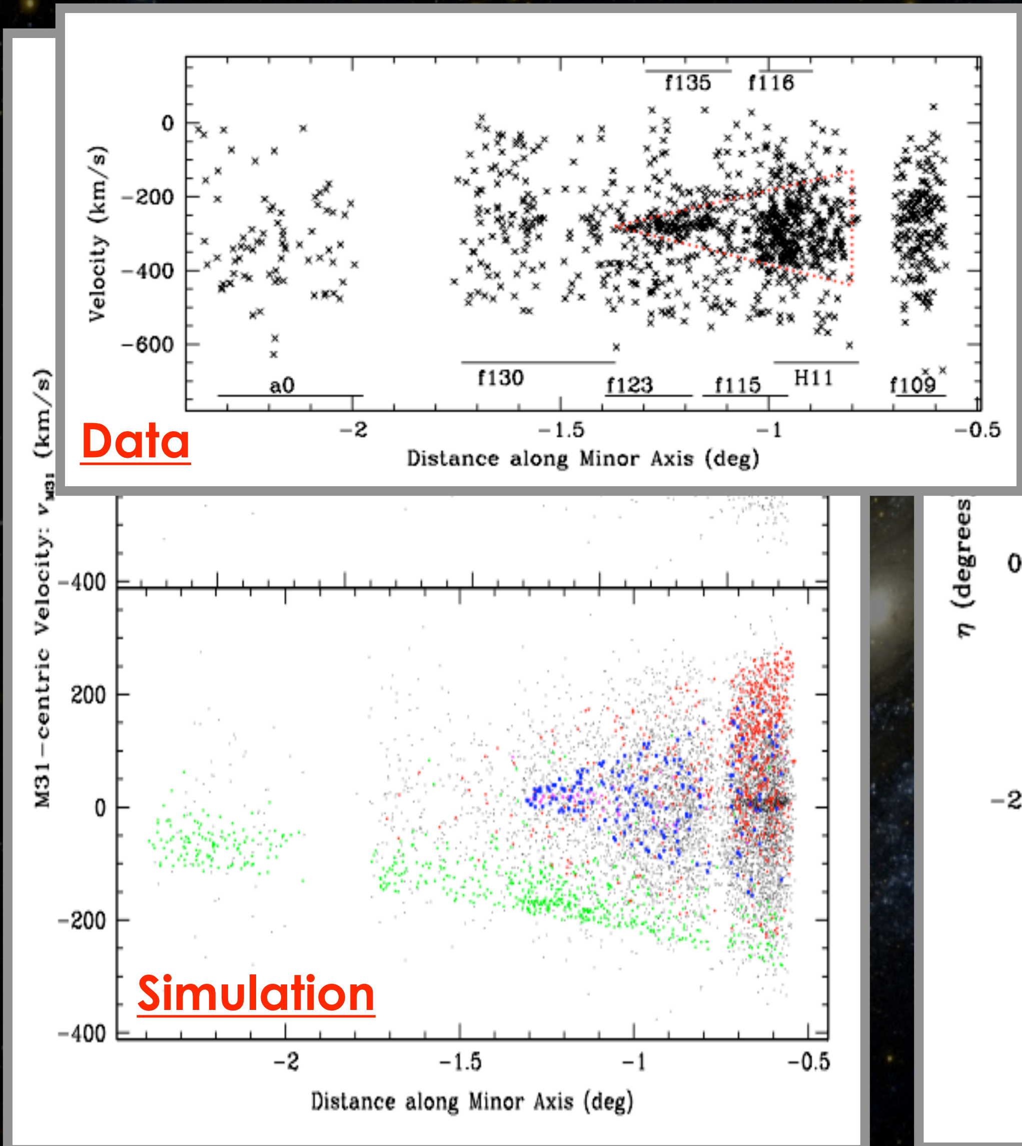
Giant Stream and Young Shell System in M31



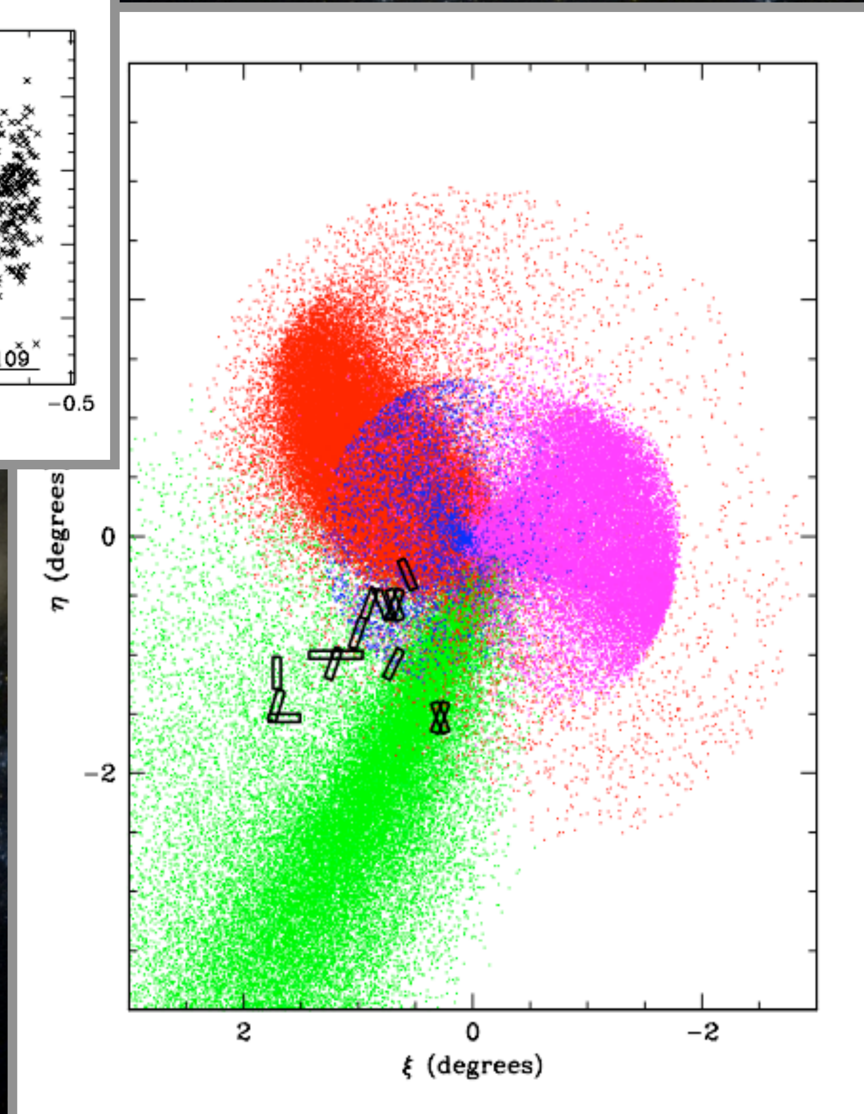
Fardal et al. (2007, MNRAS, in press; astro-ph/0609050)

See poster #31 by Gilbert et al.

Dissecting a Recent Collision in M31



Fardal et al. (2007, MNRAS, in press; astro-ph/0609050)

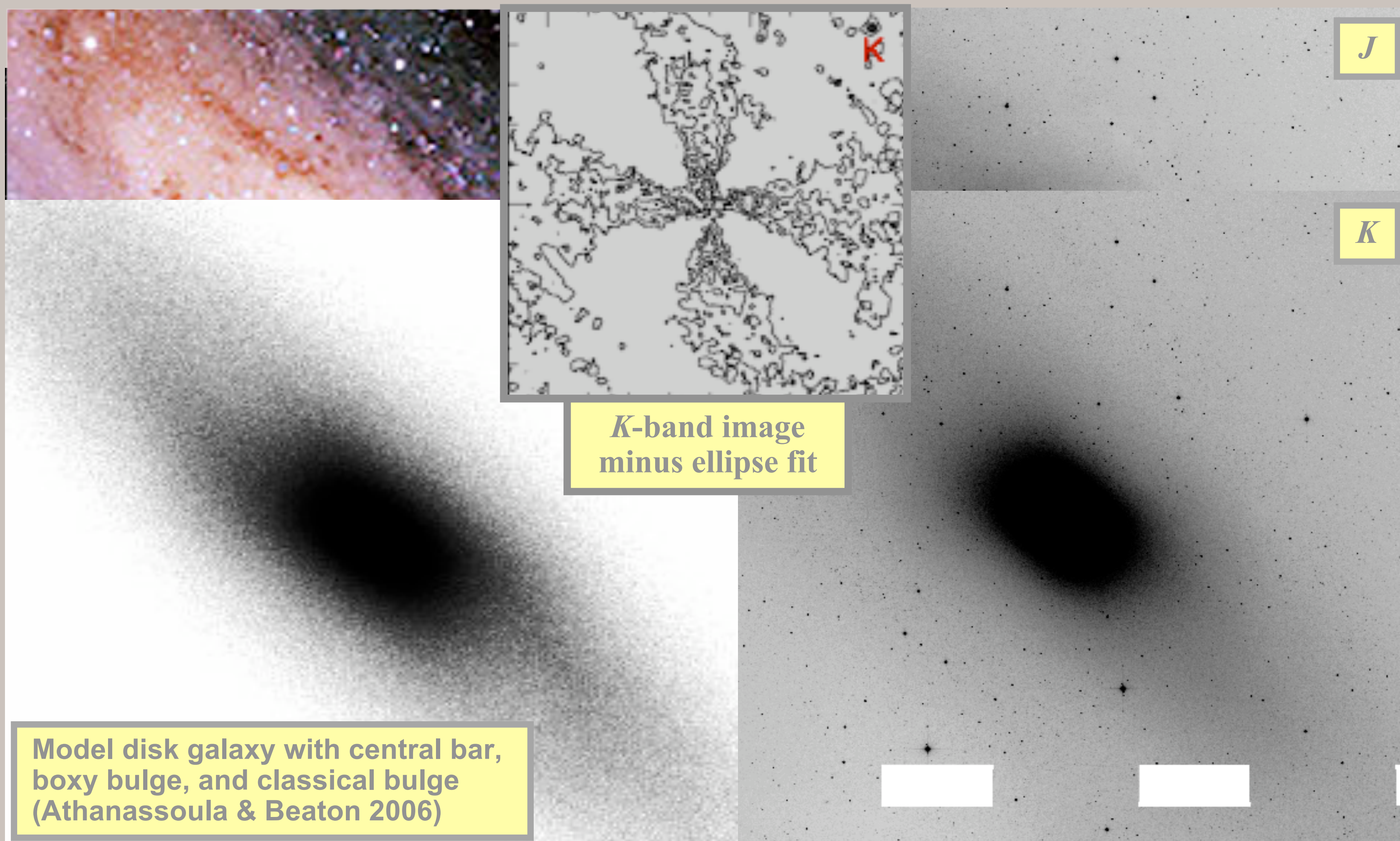


Gilbert et al. (2007, ApJ, submitted; astro-ph/0703029)
See poster #31 by Gilbert et al.

The debris and shells from this collision provide a natural explanation of the Brown et al. (2003, 2006, 2007) findings on stellar age / metallicity distributions from ultra-deep HST/ACS studies of the MSTO

M31's Boxy Bulge and Central Bar

An Unobstructed Wide-field View in the Near Infrared



Beaton et al. 2007, ApJL
Athanassoula & Beaton 2006, MNRAS

M31’s Dwarf Satellites

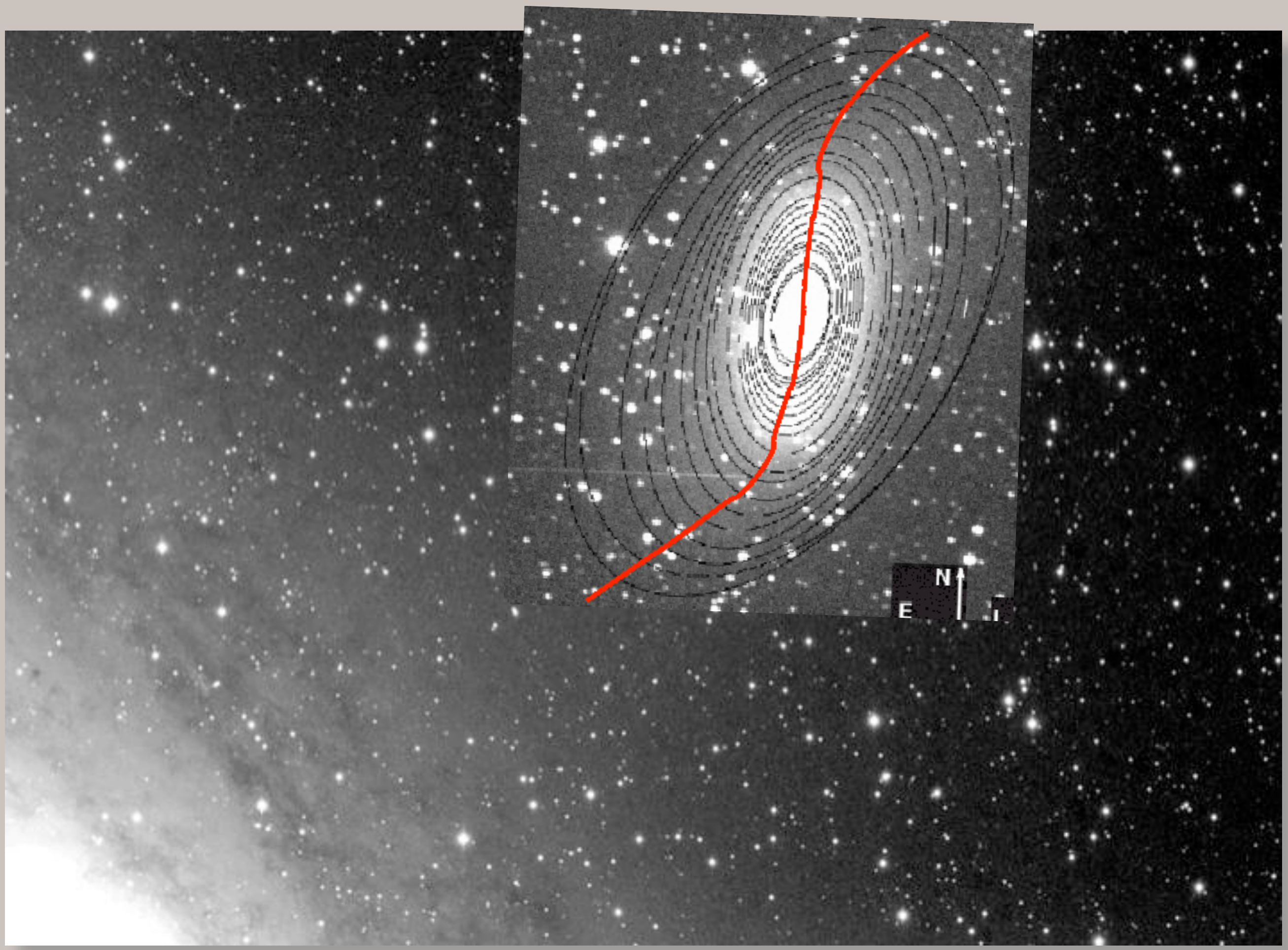
NGC 205 Observations

Keck / DEIMOS multislit spectroscopy

• Integrated light spectra cannont probe beyond effective radius

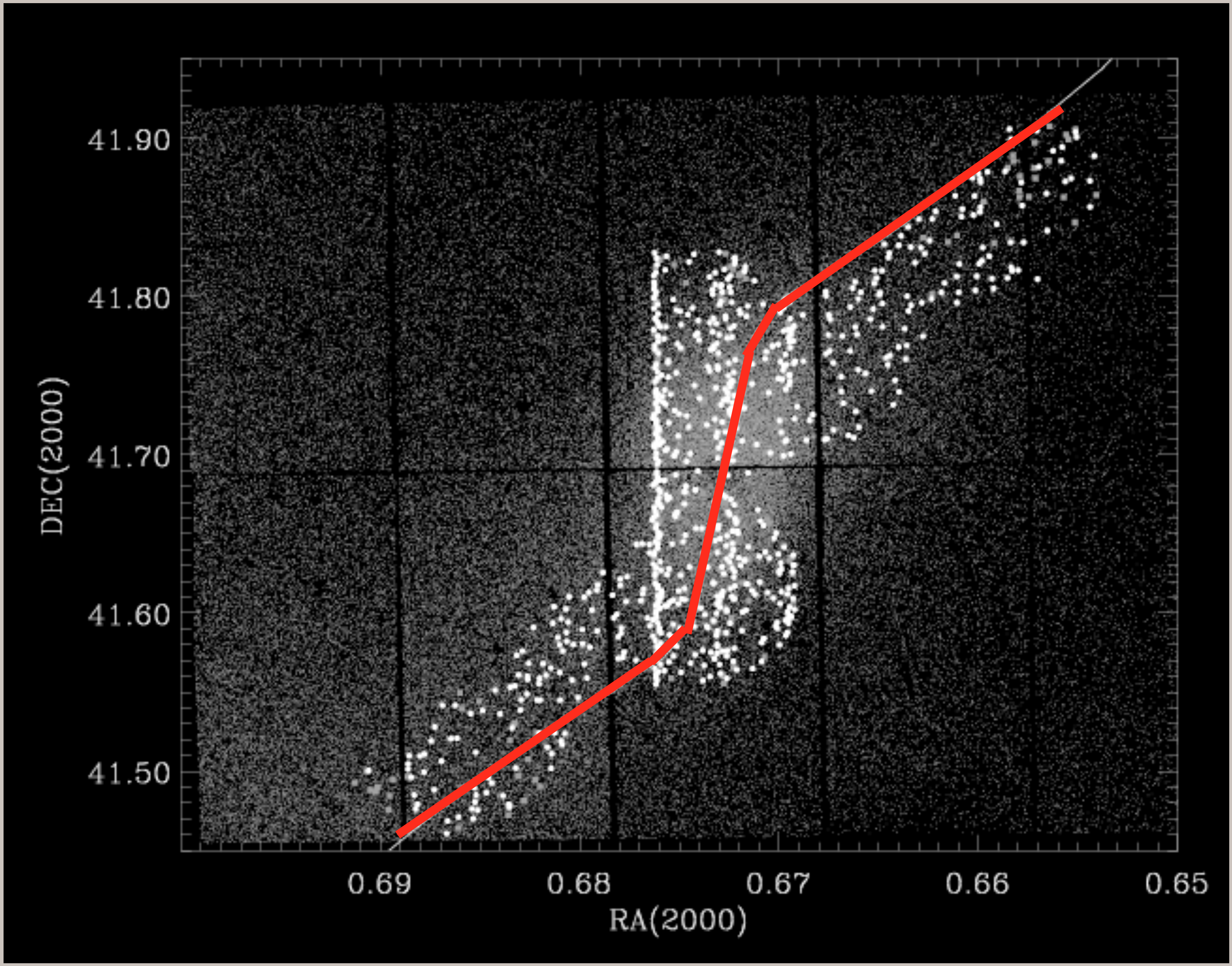
• We have targeted individual red giant branch stars

• Accurate radial velocities for 723 red giant stars in NGC 205

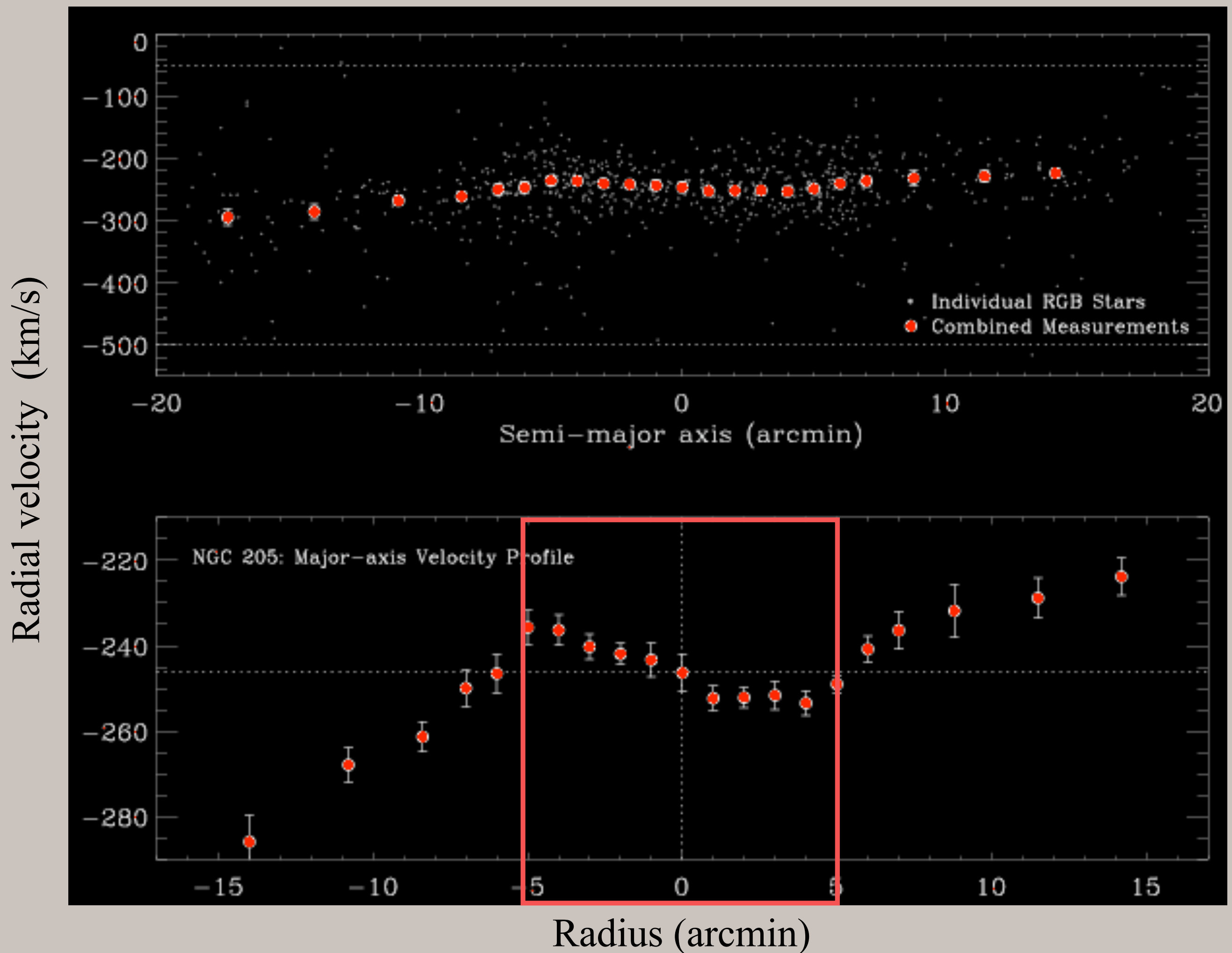


Choi, PG & Johnston (2002, AJ)
Geha, PG, Rich & Cooper (2006, AJ)

Keck / DEIMOS Targets



NGC 205: Major-axis Velocity Profile



Inner rotation speed: ≈ 10 km/s

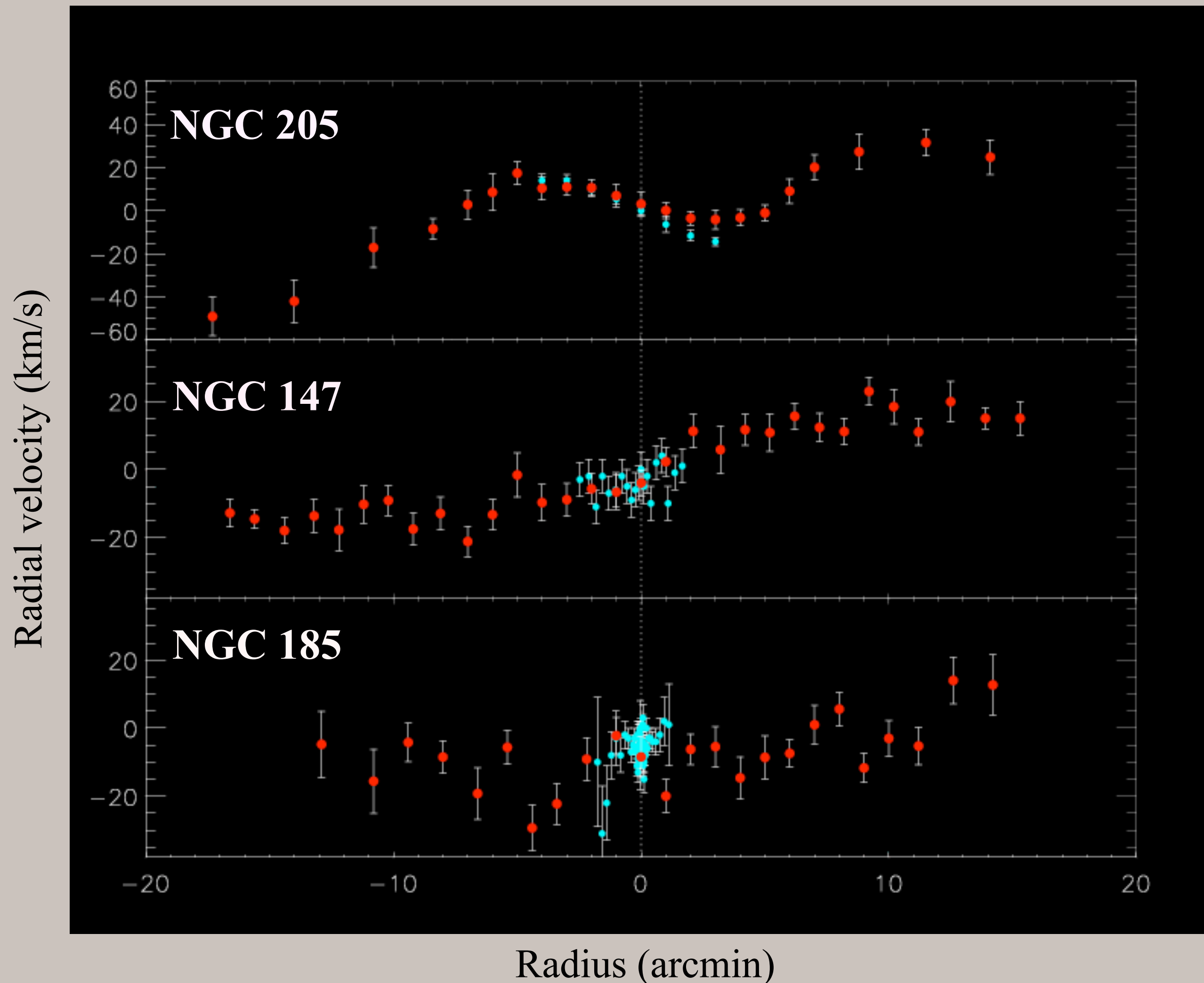
Radial velocity curve turns over beyond 2.5 r_{eff} (≈ r_{tidal})

Velocity turnover is coincident with radius at which isophotal twisting starts to occur

Dynamical modelling of these data using a genetic algorithm indicates that NGC 205 is approaching from the NW, on a very eccentric prograde orbit, possibly on its first close passage

Geha, PG, Rich & Cooper (2006, AJ)
Howley et al. (in prep)

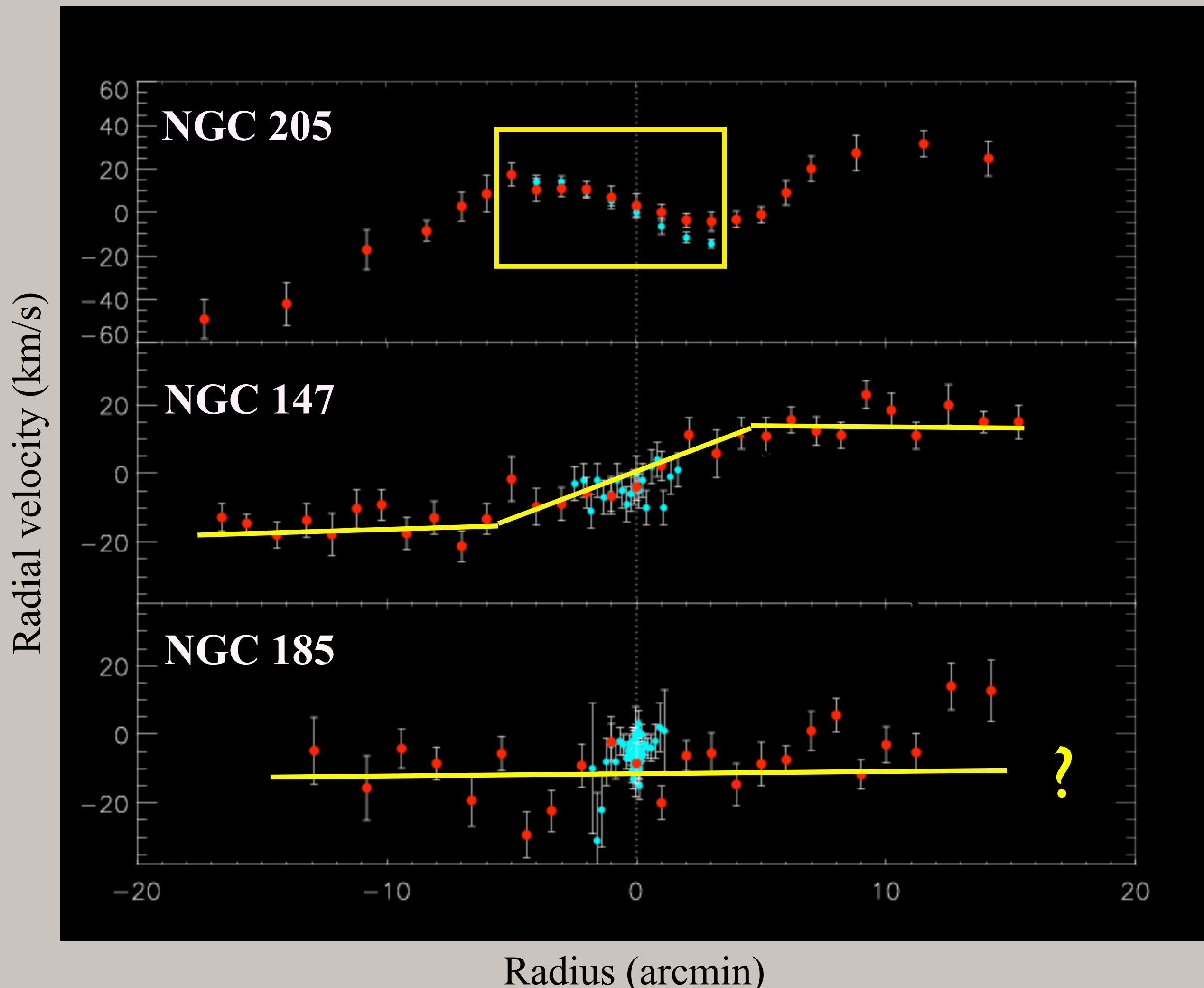
M31 dE Rotation Curves

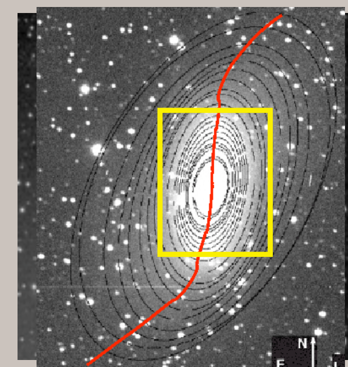


Simien & Prugniel (2000)

Geha et al. (2006, 2007)

M31 dE Rotation Curves



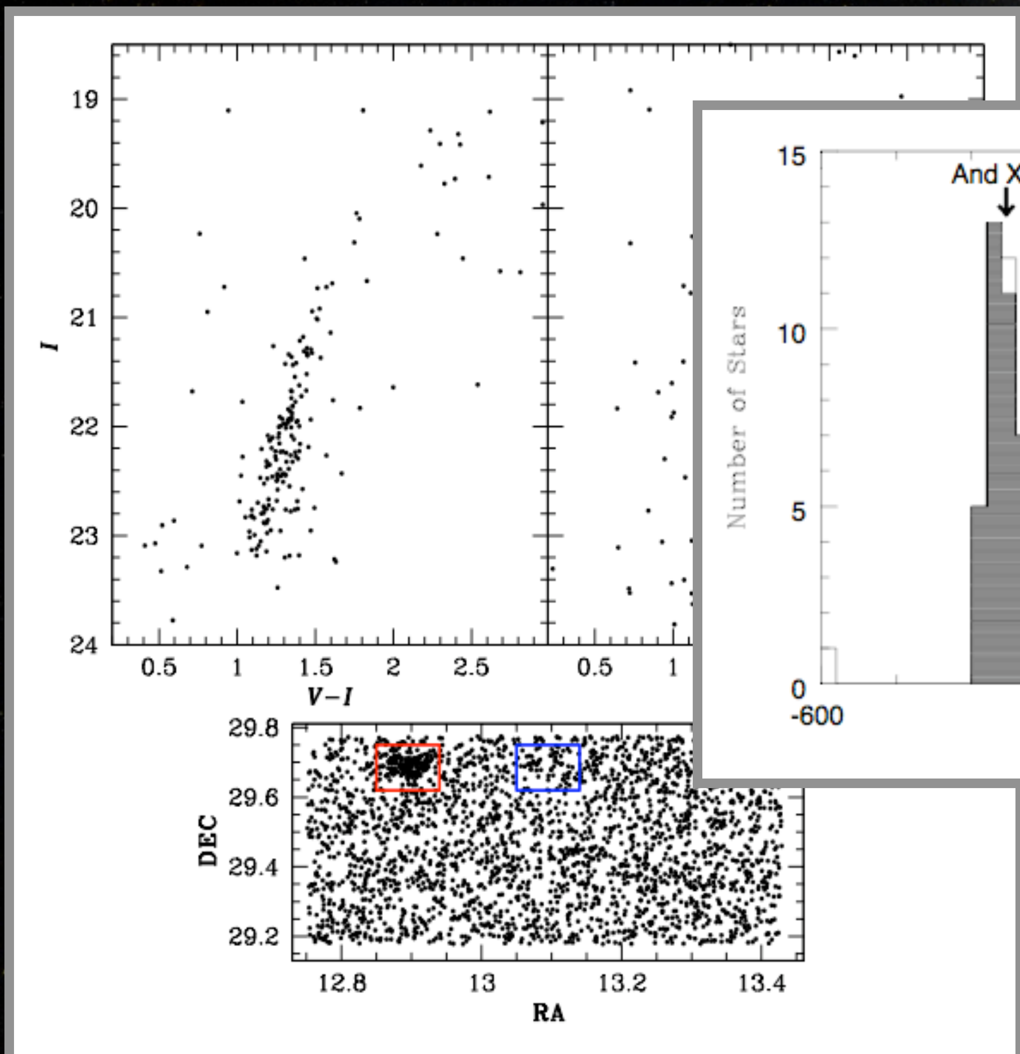


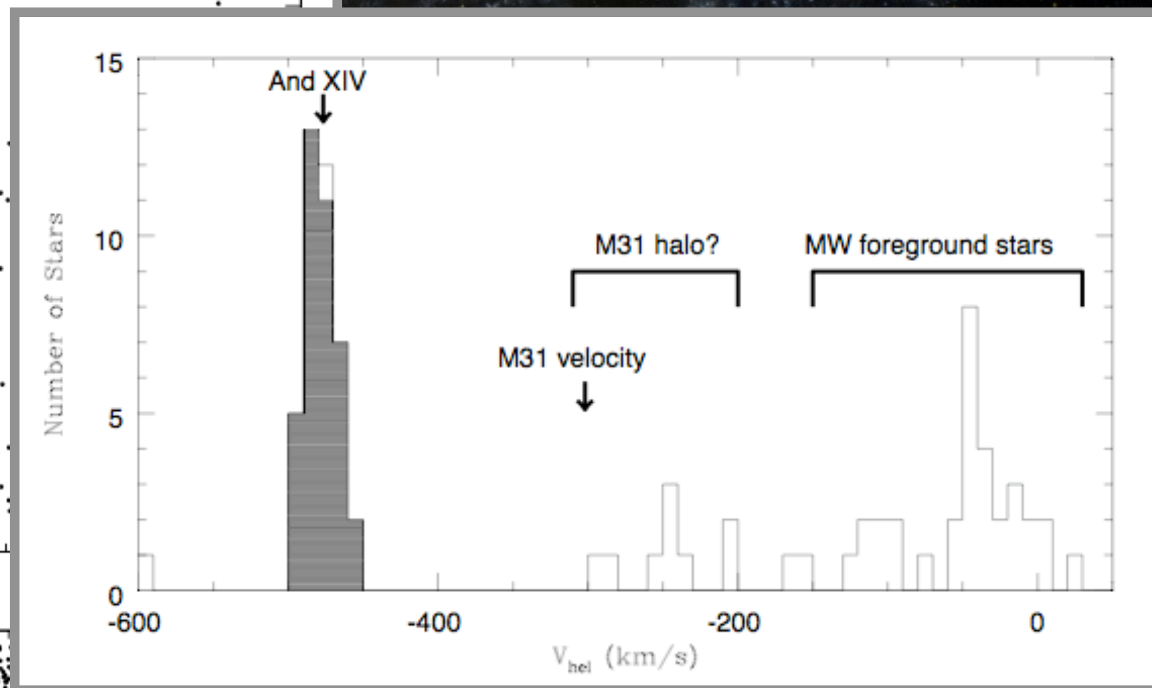
In progress:
Dynamical modelling (Geha, van der Marel, et al.)
Chemical abundance studies (Kirby et al.)

- Simien & Prugniel (2000)
- Geha et al. (2006, 2007)

Dwarf Spheroidal Building Blocks

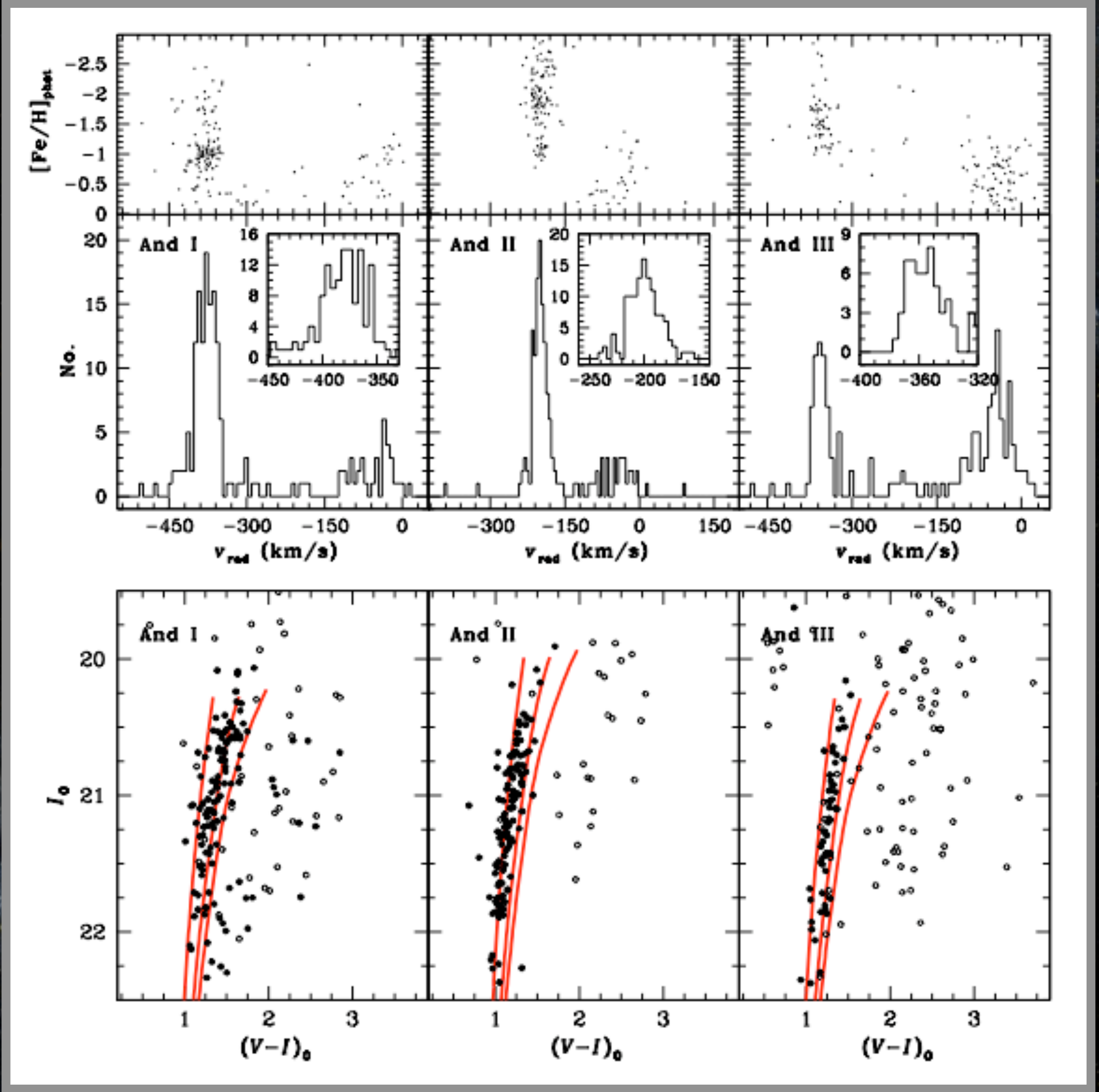
→ The discovery of an M31 dSph satellite with extreme orbital properties: And XIV !





— Majewski et al. (2007, ApJL, submitted; astro-ph/0702635)
— Geha et al. (in prep)

Dwarf Spheroidal Building Blocks



Keck/DEIMOS studies of And I, II, and III

Kalirai et al. (2007, ApJ, in prep)

Summary

Stellar halo (and inner spheroid)

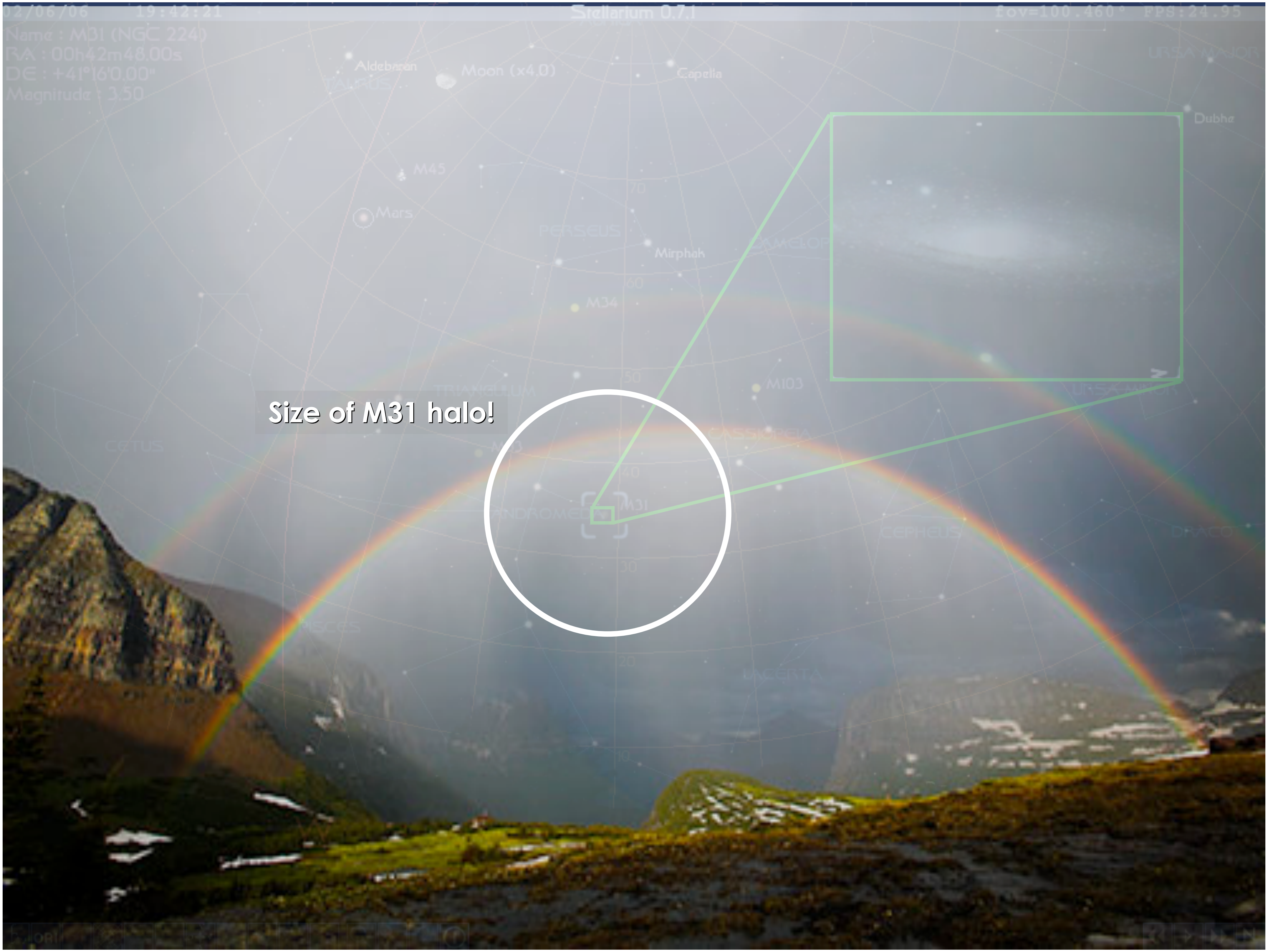
- *Discovery*
- *Global structure*
- *Chemical enrichment; star formation history*
- *Tidal debris from past accretion events*
- *Other features: bar, boxy bulge, star-forming ring*
- *Global dynamics*

Dwarf satellites

- *Tidal disruption*
- *Tracers of M31's gravitational potential*
- *Properties of these building blocks*

Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo

SPLASH



Stellarium 0.7.1
Name : M31 (NGC 224)
RA : 00h42m48.00s
DE : +41°16'0.00"
Magnitude : 3.50
Aldebaran
Moon (x4.0)
Capella
Dubhe
M45
Mars
PERSEUS
Mirphak
M34
M103
CASSIOPEIA
ANDROMEDA
M31
CEPHEUS
Size of M31 halo!