Abundances and Kinematics of M31 Giants along the Minor Axis

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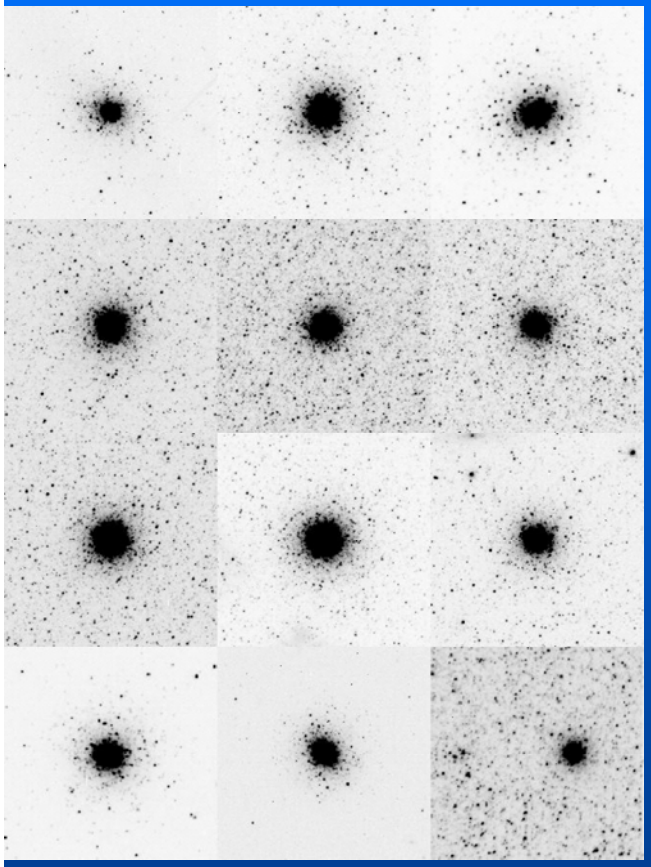
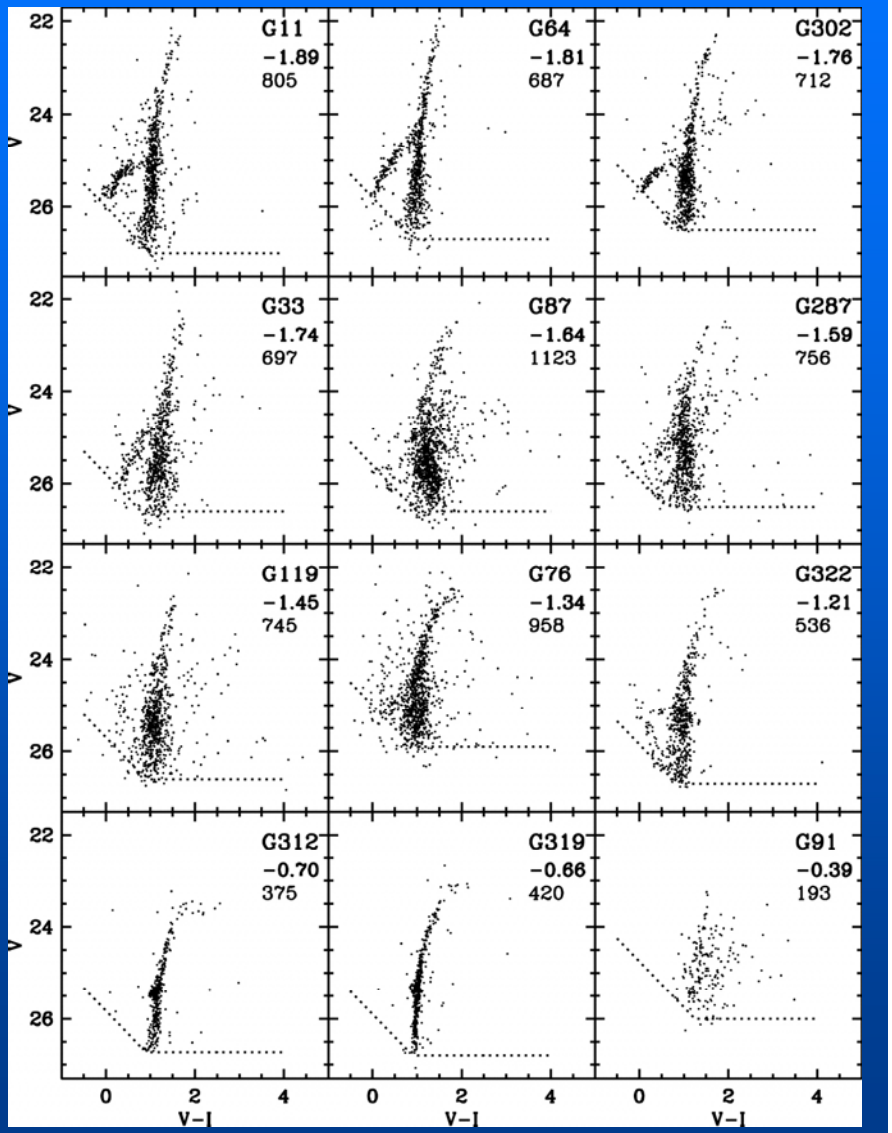
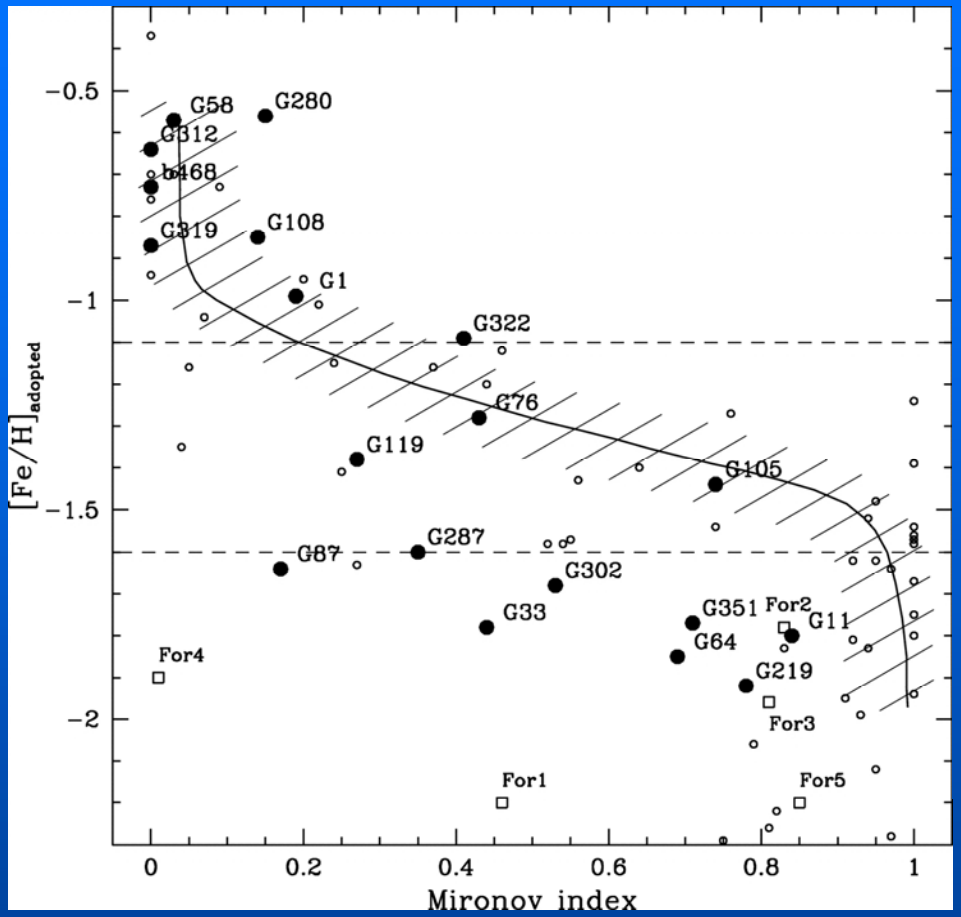
M31 halo once thought old, like the Milky Way, but metal rich



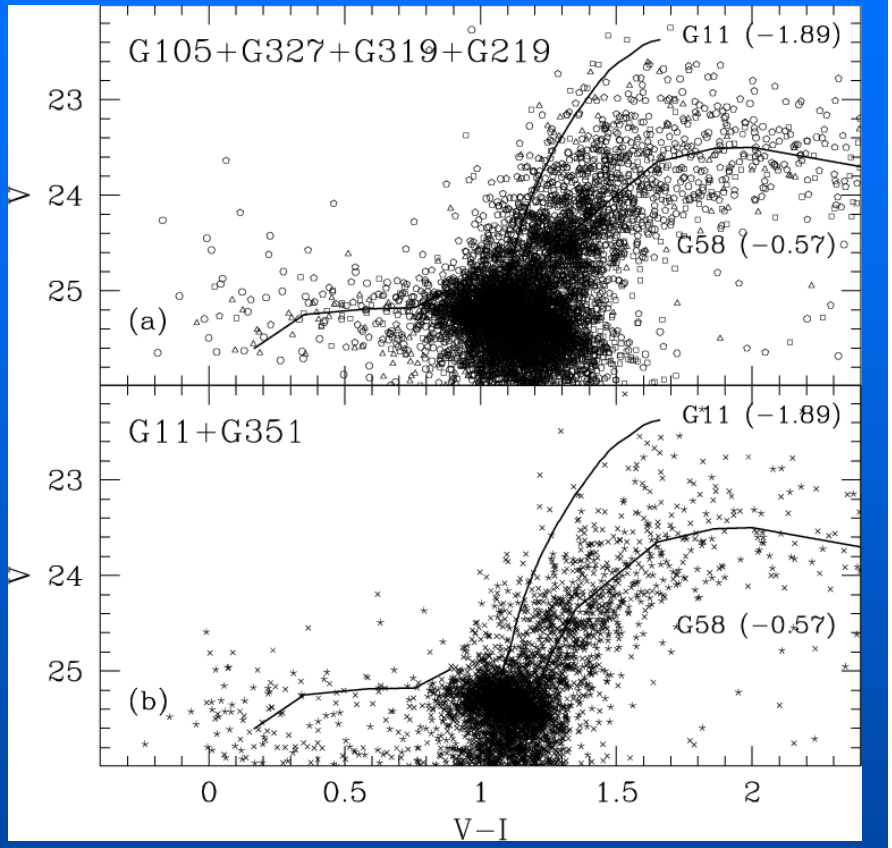
M31 Globular clusters

Rich et al. 2005



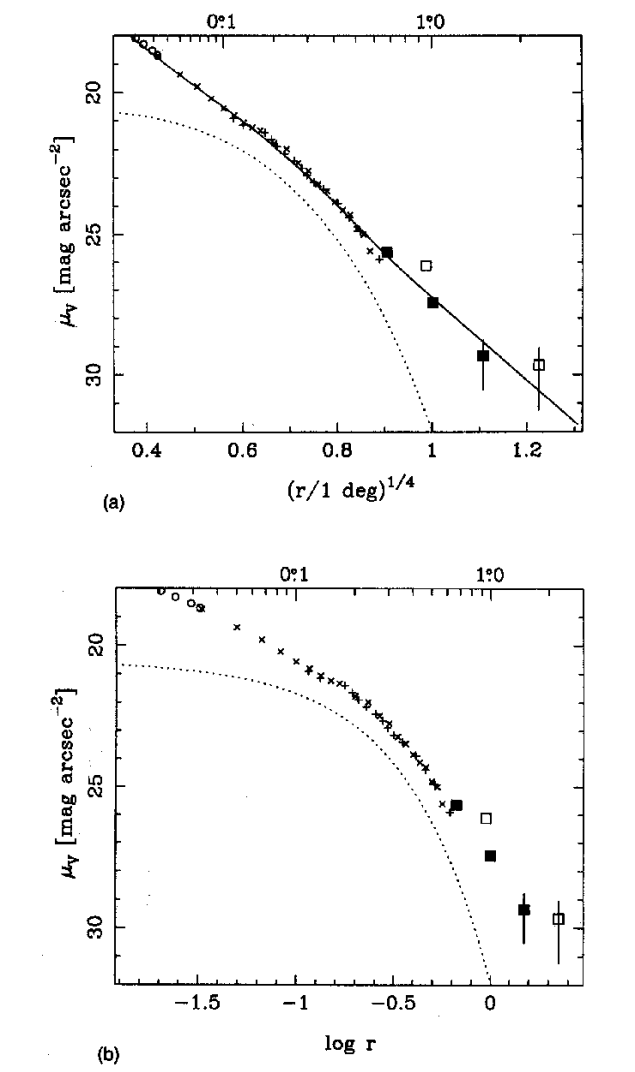


Rich et al. 2005

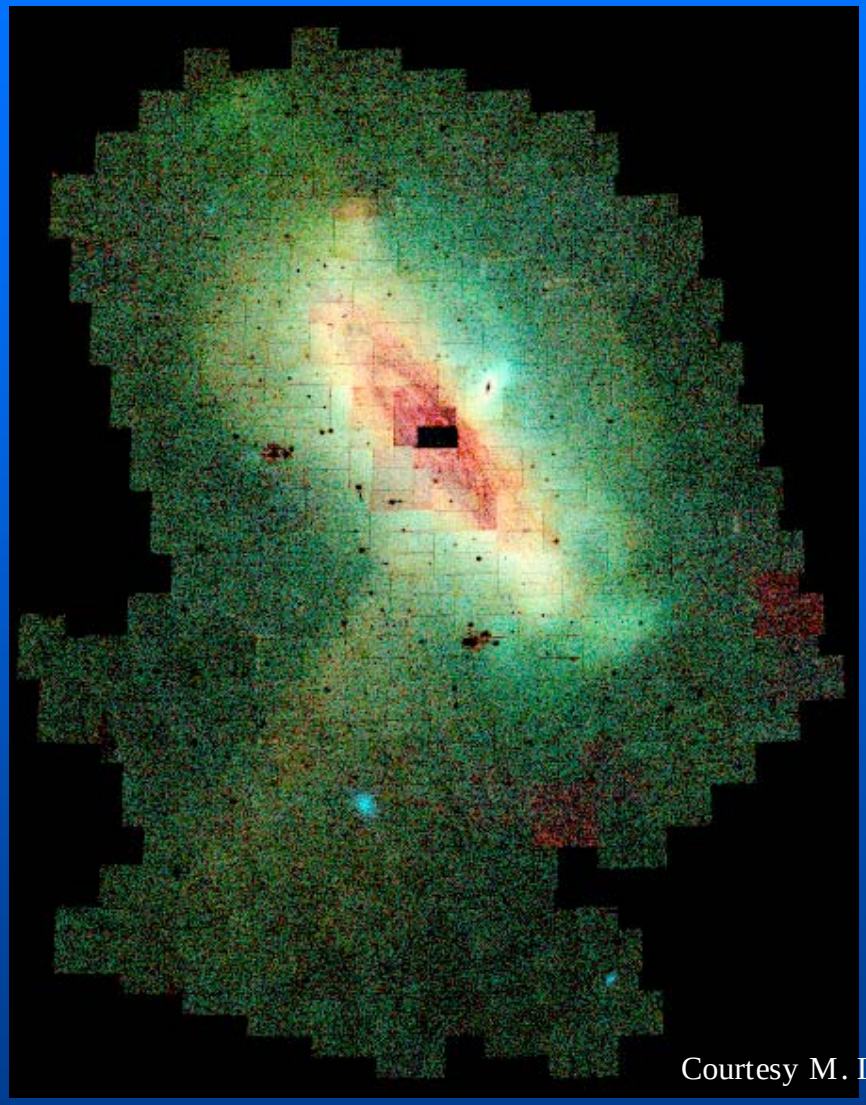


Bellazzini et al. 2003 (Mould & Kristian 1986)

But M31 field is neither regular nor old



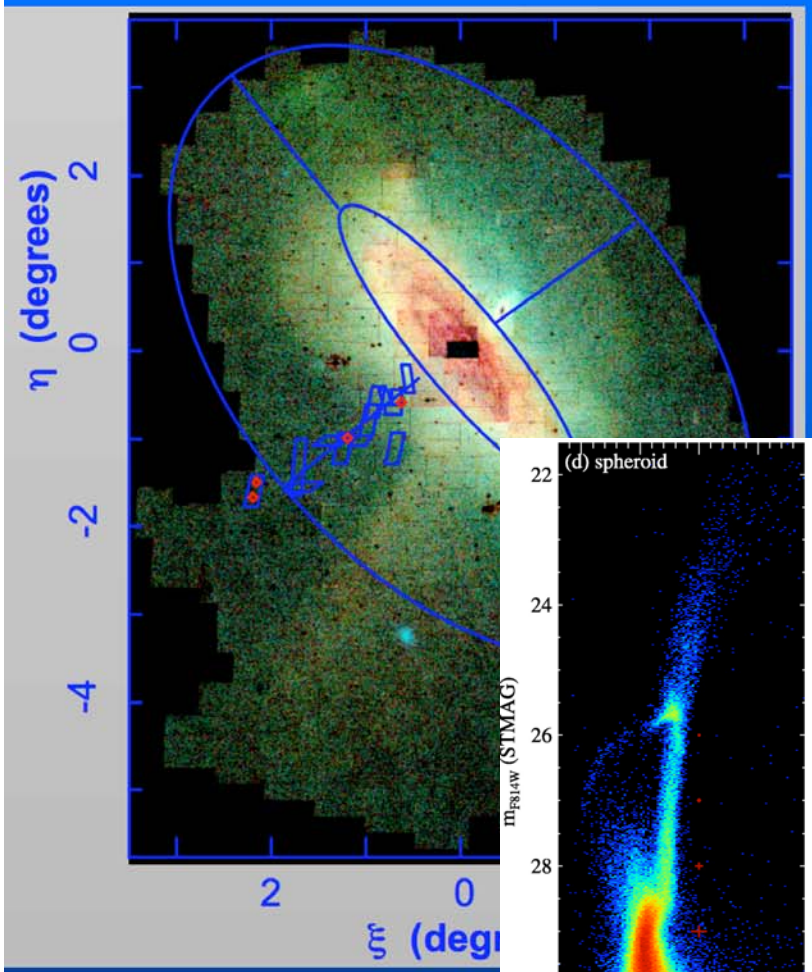
Pritchet & Van den Bergh (1994)



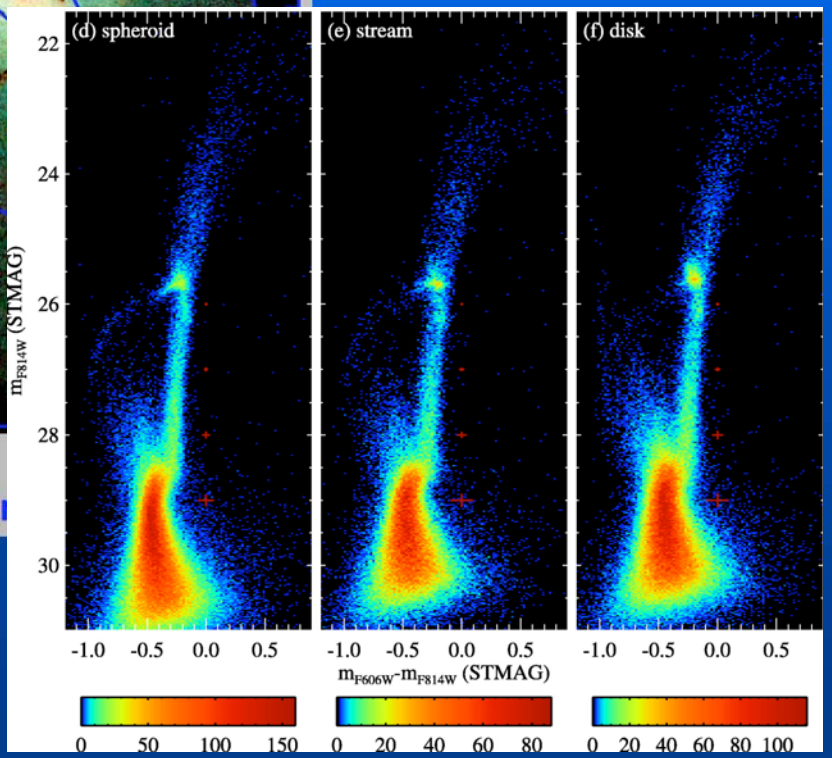
Courtesy M. Irwin

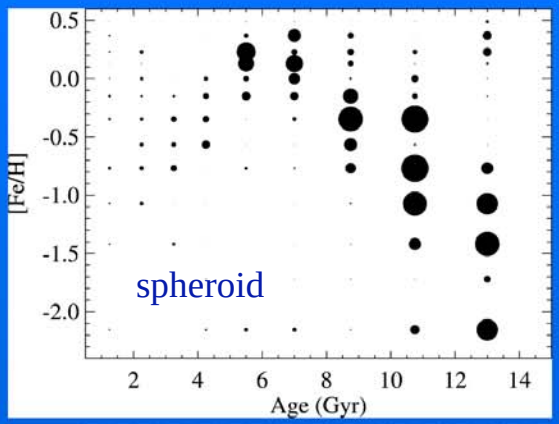
Ibata et al. 2001; Ferguson et al. 2003; Ibata et al. 2005 find 35 kpc rotating “disk” structure

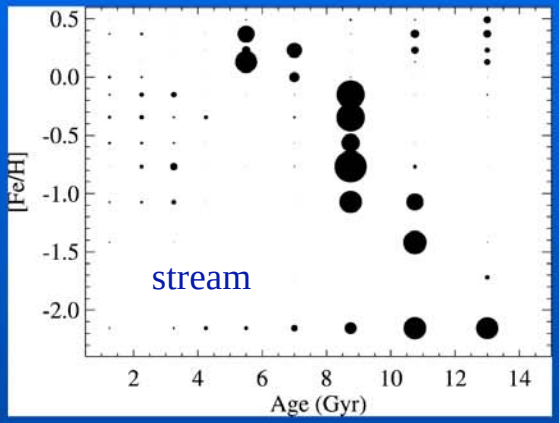
And an age/abundance range

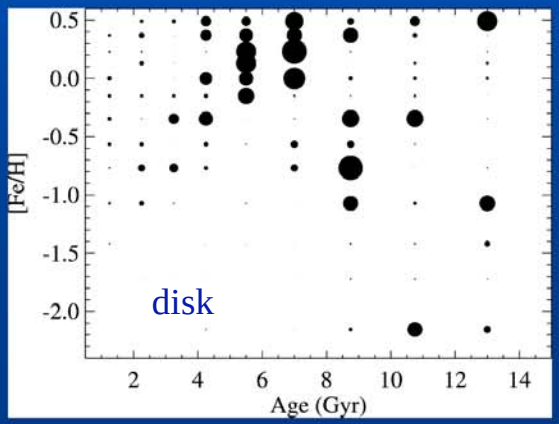


Brown et al. 2003, 2006, 2007

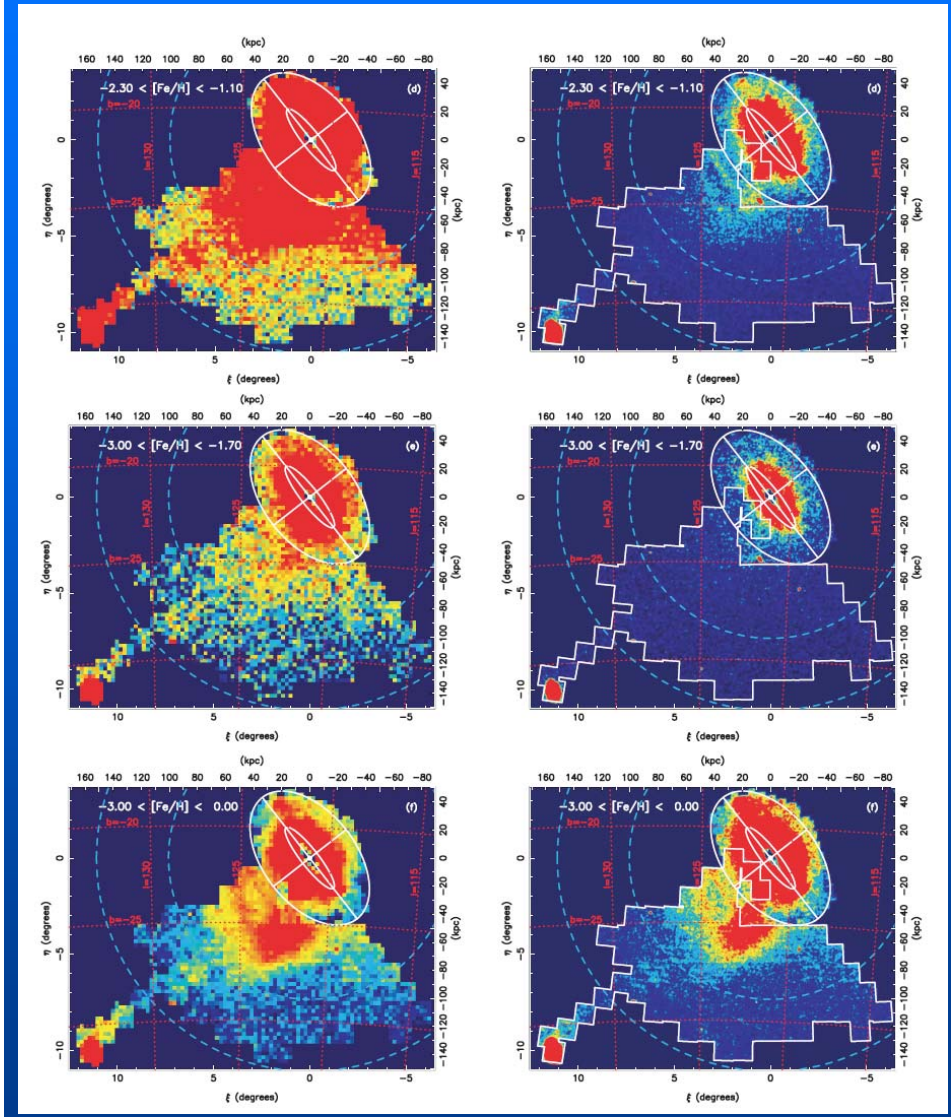




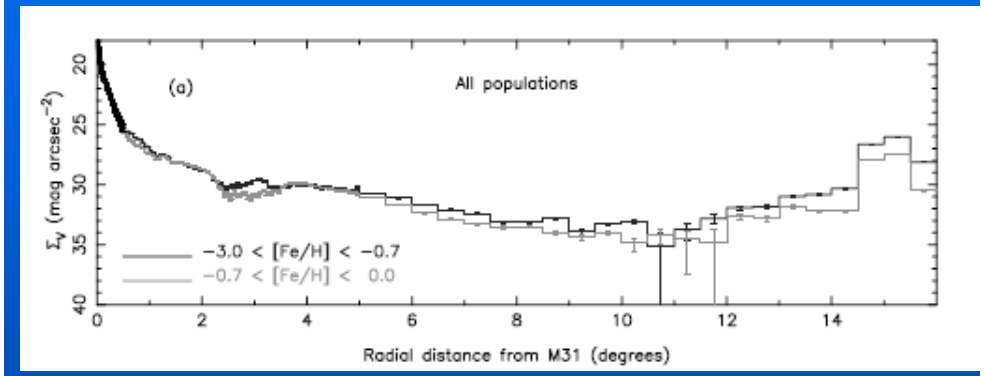




M31 has structures and extent that overlaps M33

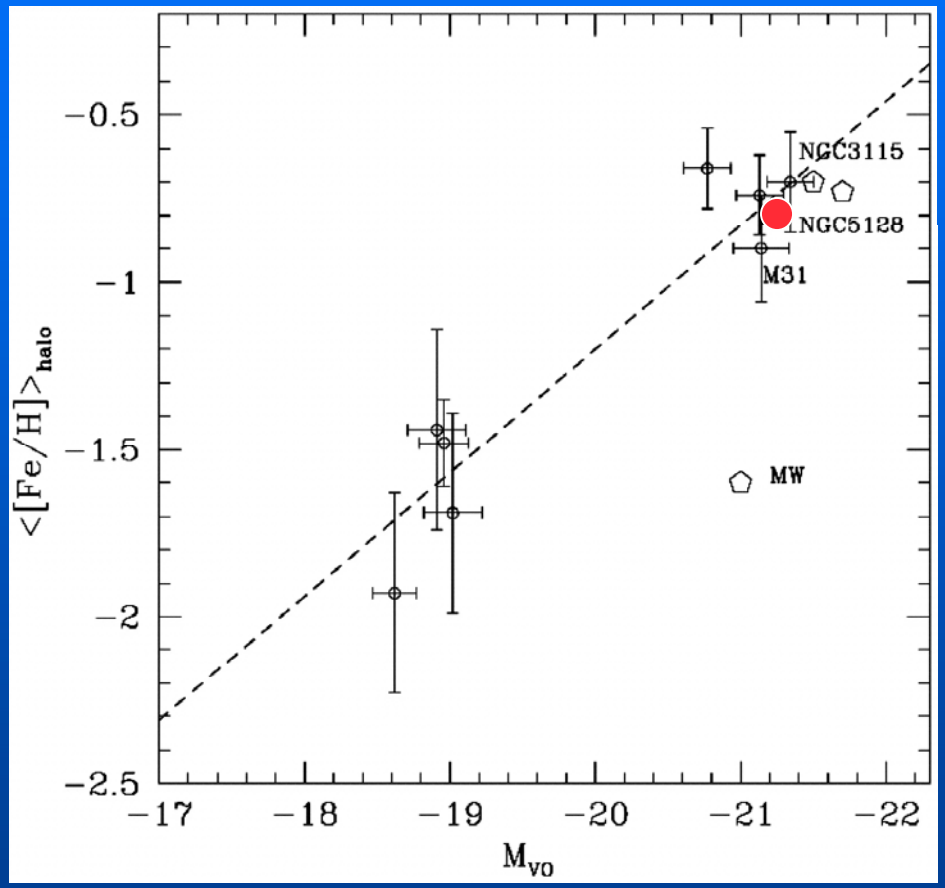


Ibata et al. 2007



M31 halo in context

Mouhcine, Ferguson, Rich, Brown, Smith 2005



?

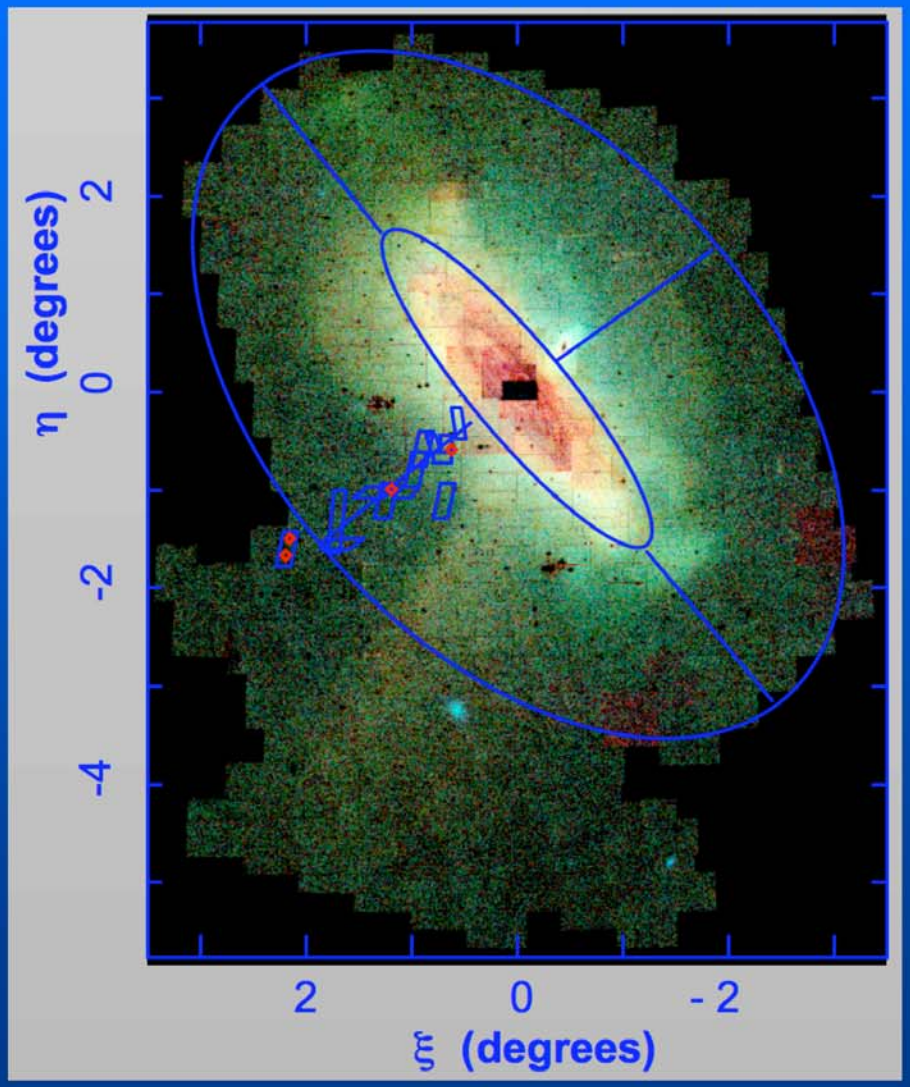
Halo population from bulge?

Low luminosity spirals have only metal poor halo?

Or halo dominated by debris?

M31 halo connected to the formation of the bulge?

Abundances/Kinematics on minor axis including deep HST fields: Is the giant stream progenitor responsible for the whole metal rich halo?



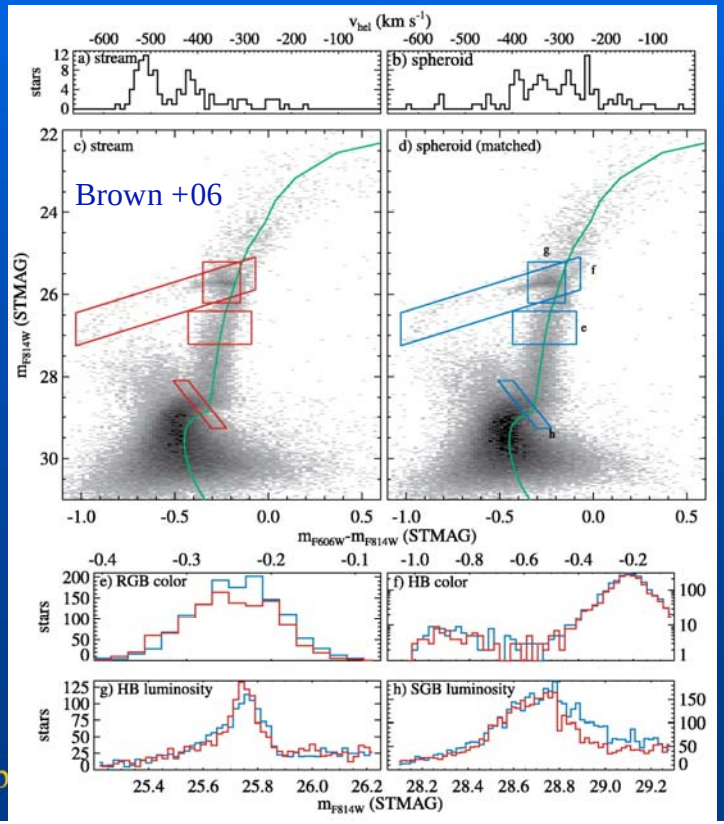
Keck/Deimos 2002-2005

Some results in Gilbert et al. 2006, 2007

Inner halo fields: slitmasks from CFHT imaging by Guhathakurta

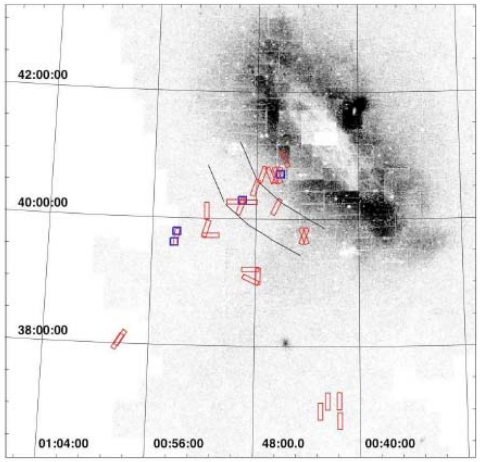
Outer halo fields: Photometry from Ostheimer Ph.D. thesis

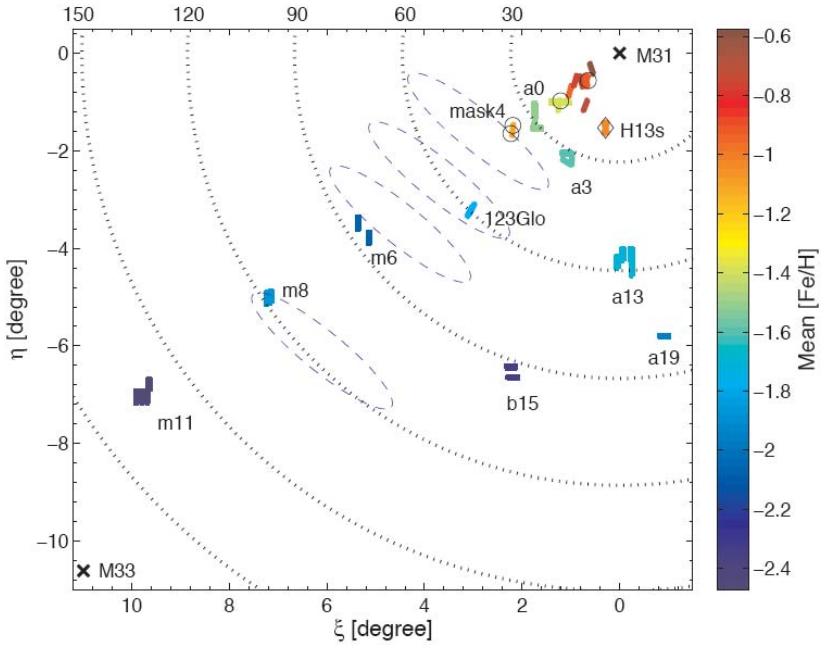
New use of Ca IR triplet method (Koch et al. 2007 in prep.



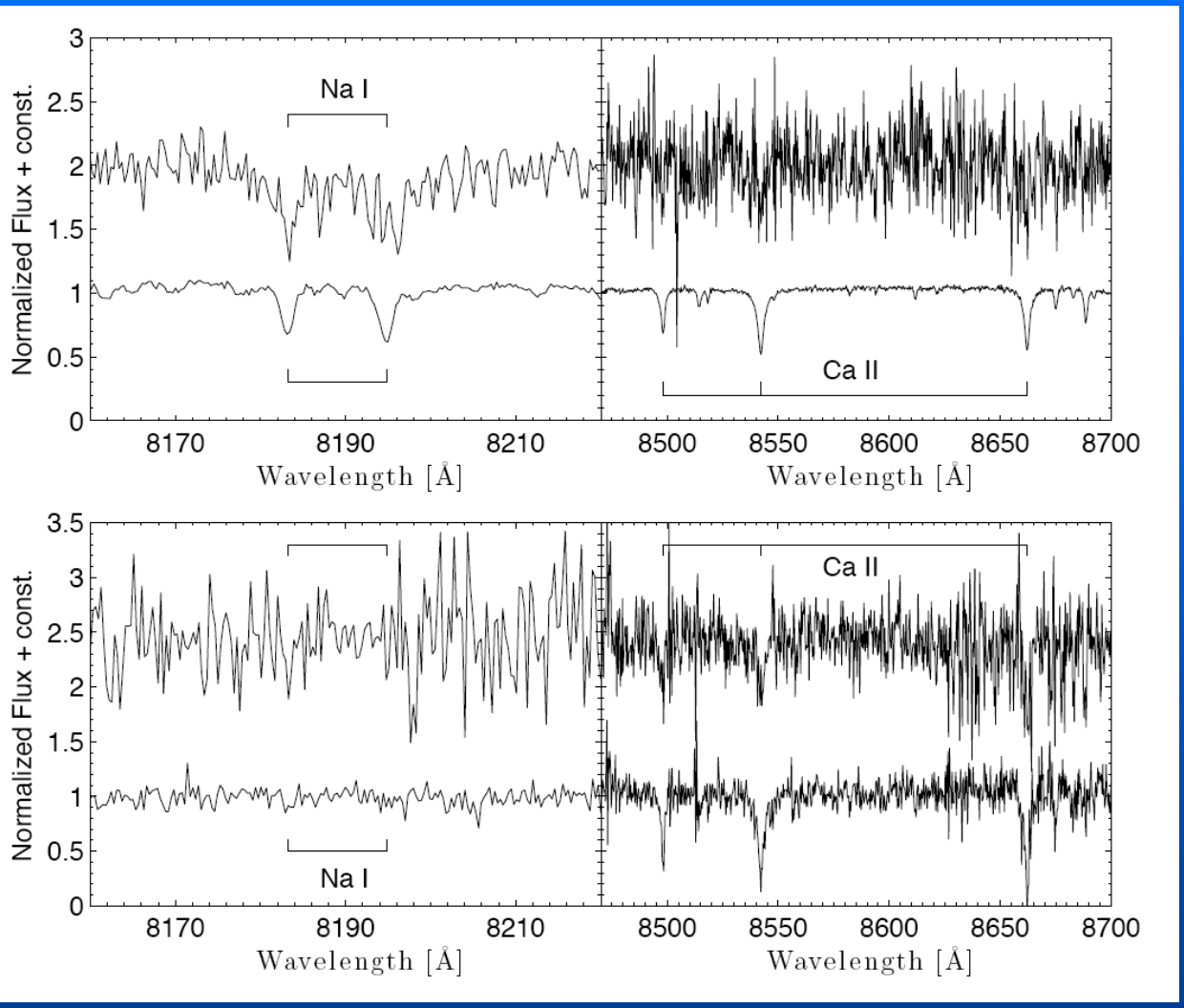
KITP 14 Octob

M31 Fields Surveyed



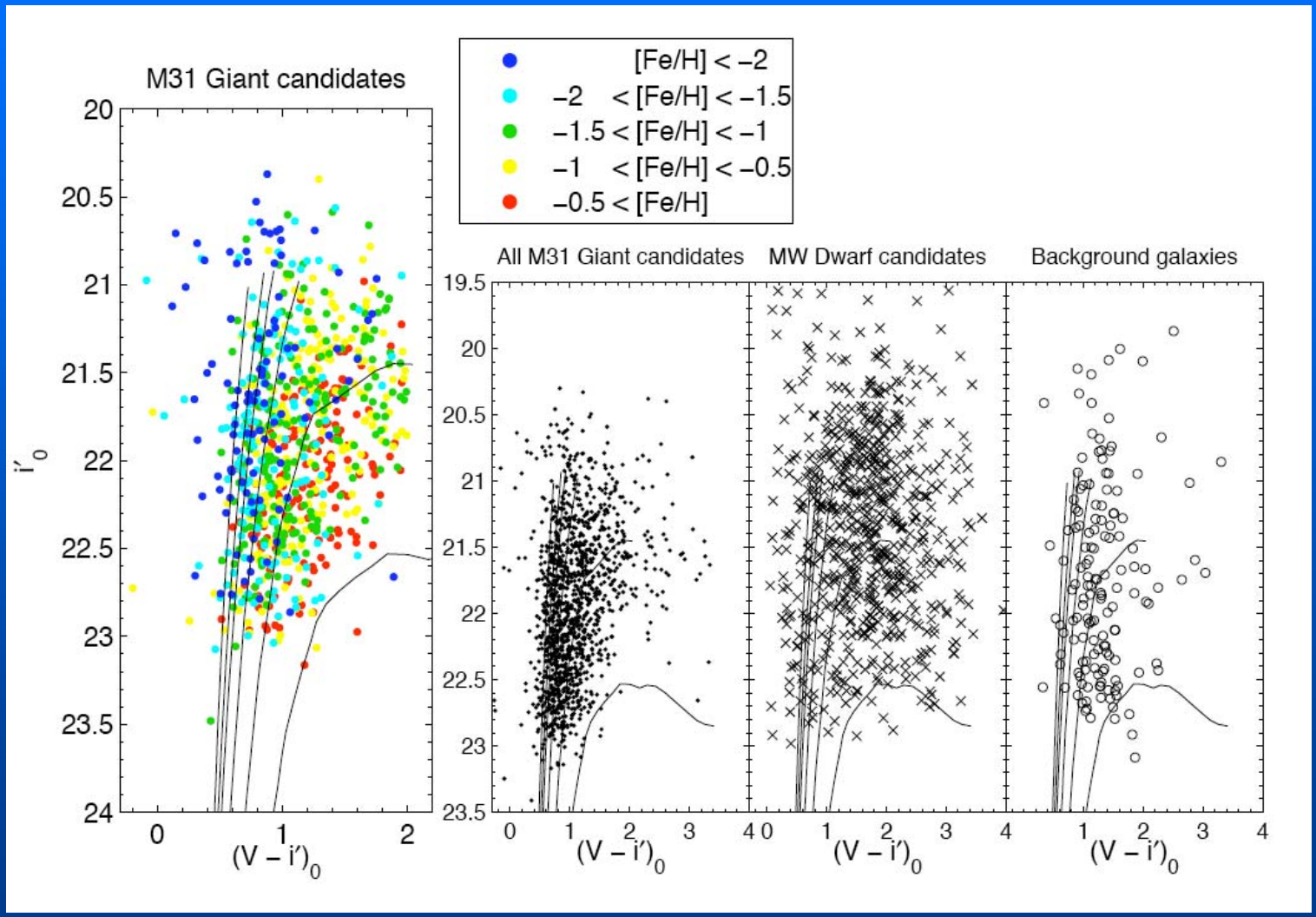


M31 giant spectra

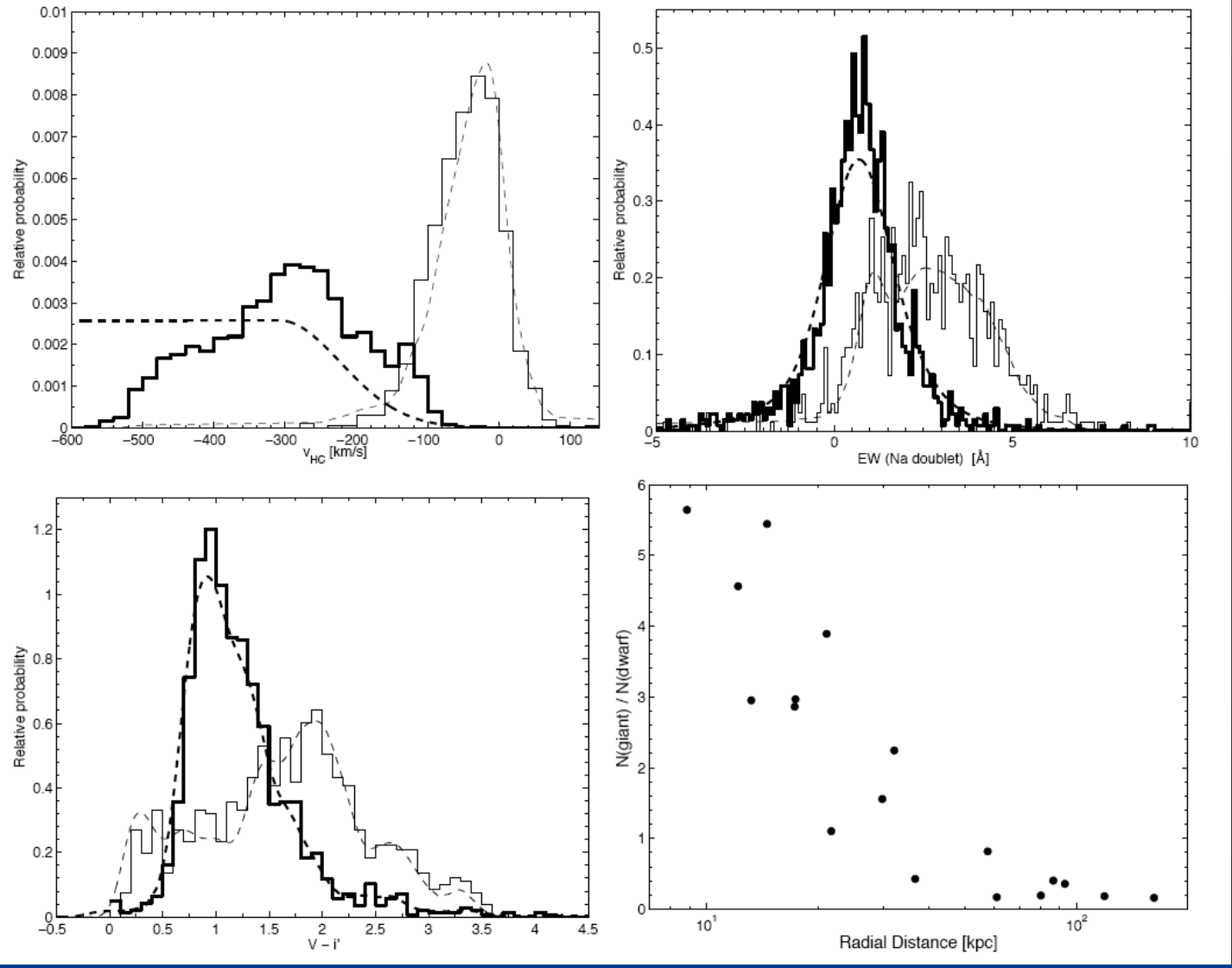


Na used in dwarf/giant sep; Ca in velocities

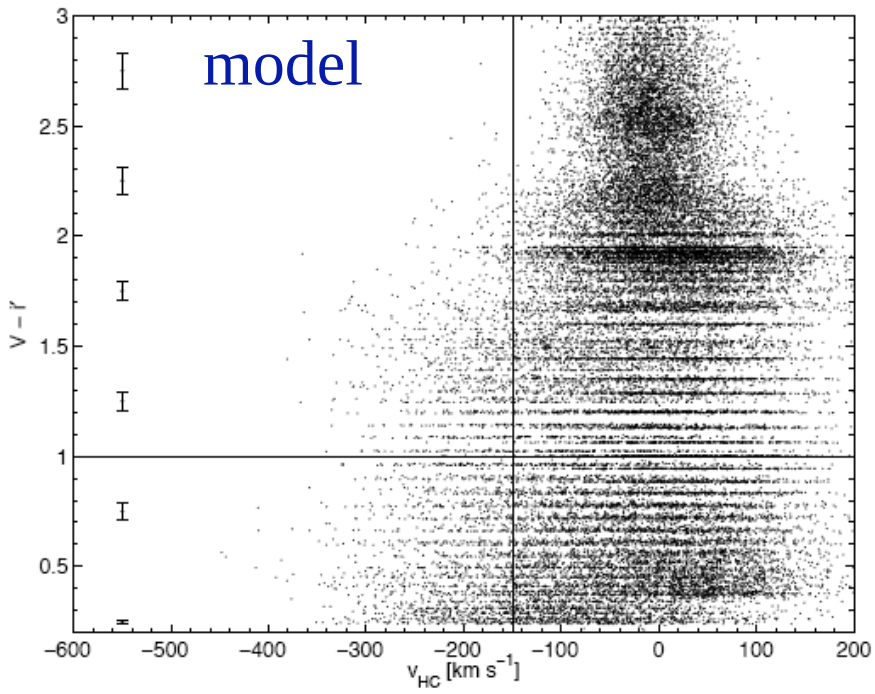
Population separation

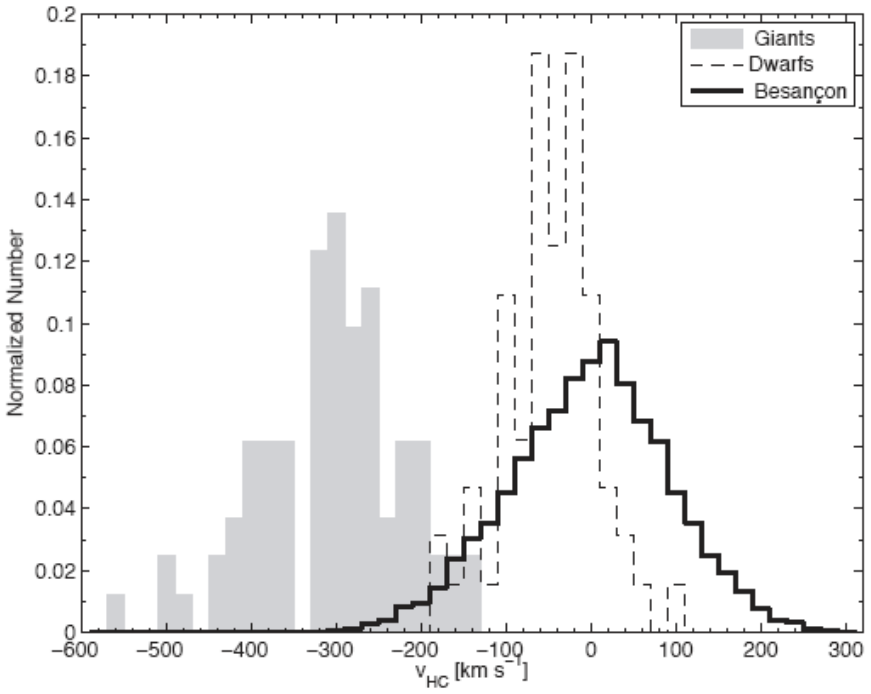


Dwarf/giant separation (after Gilbert et al. 06)



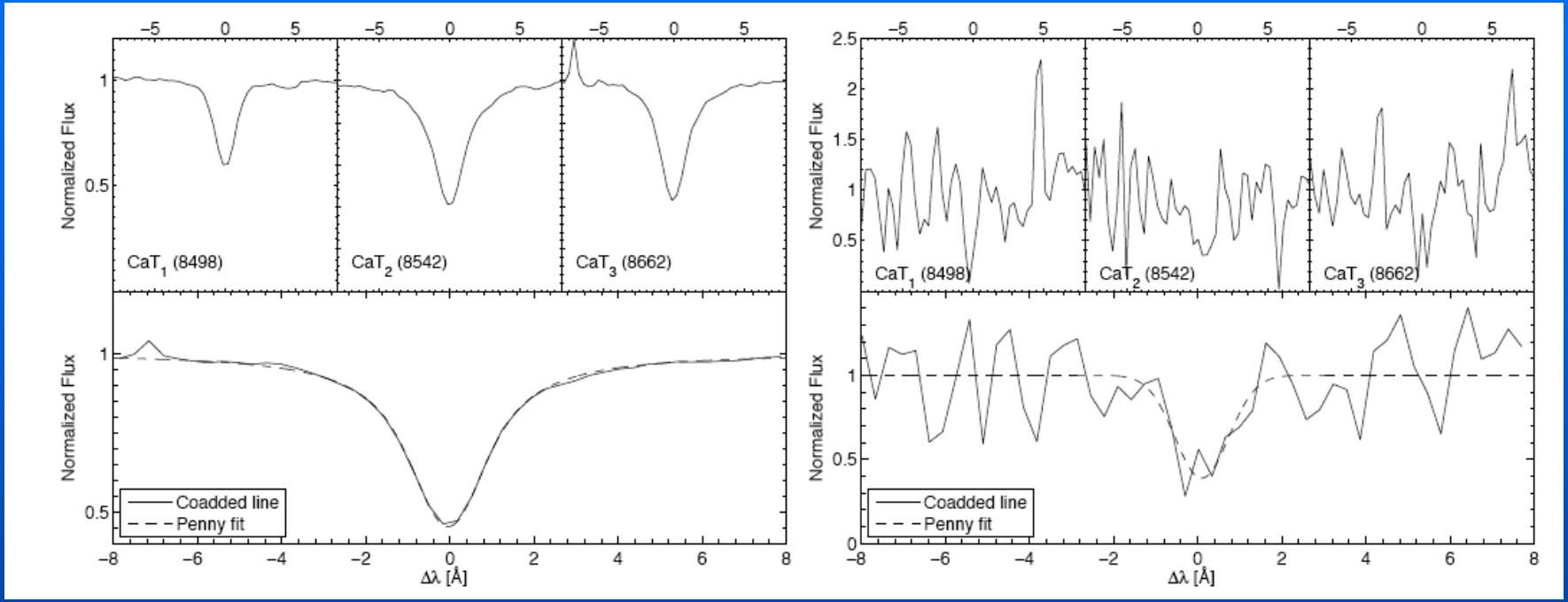
Blue dwarf contamination





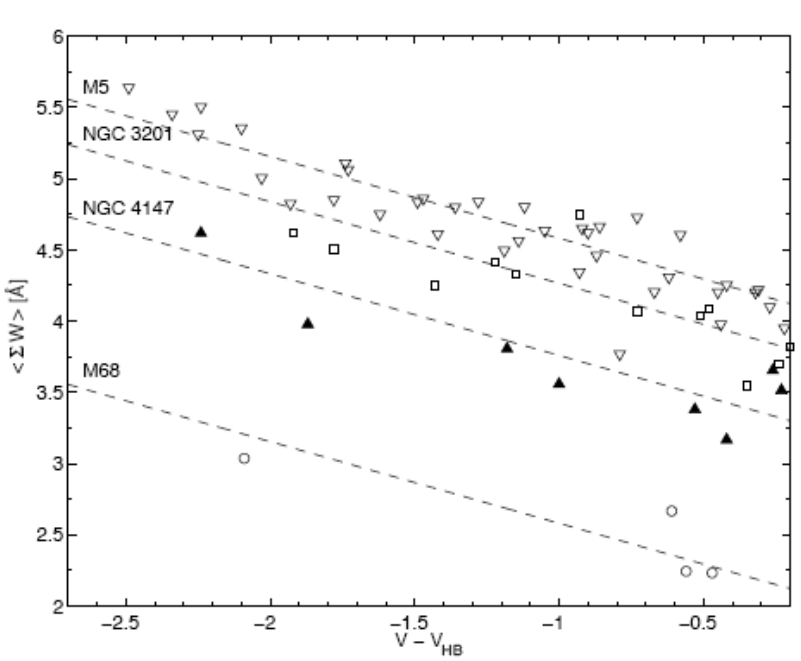
Blue dwarf stars are a potential problem because they have spectra similar to metal poor M31 halo members. But the Besancon model and Martin et al.'s (2008) modeling argue that their contribution is negligible.

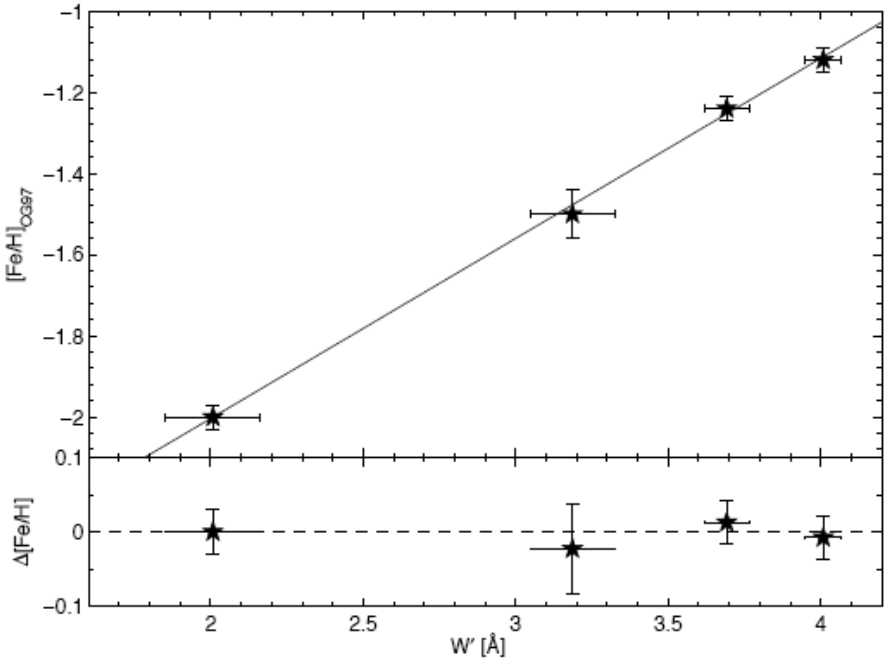
Ca Triplet coaddition method



Penny profile (Gauss+Lorentz) fit

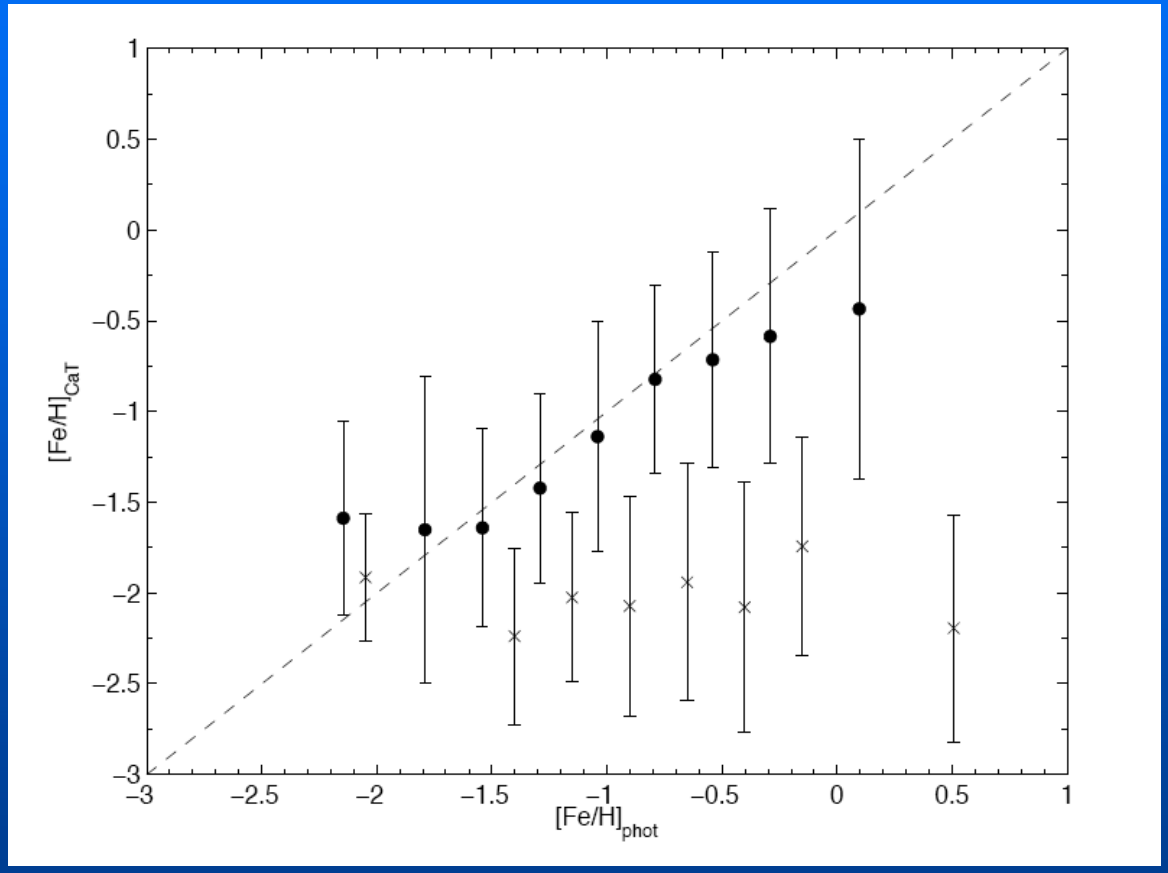
Ca triplet coaddition calibration





FLAMES cluster data; Caretta-Gratton 97 scale

Spec vs. Phot metallicities



Mori & Rich 2008 Simulations

Much of the substructure on the SW minor axis, especially the Giant Stream, is likely debris from a disrupted satellite (Fardal et al. 2006, 2007).

Fardal et al. 2008 also model a disk collision and explain more distant structures.

They assume static potentials for the bulge, disk, and halo.

Mori & Rich 2008 adopt Fardal et al. collision geometry, but use a live N-body disk, bulge, and halo. Did the collision disrupt the disk and eject disk stars into the halo, accounting for the observed age range? Can other structures be remnants of more ancient collisions?

Model elements

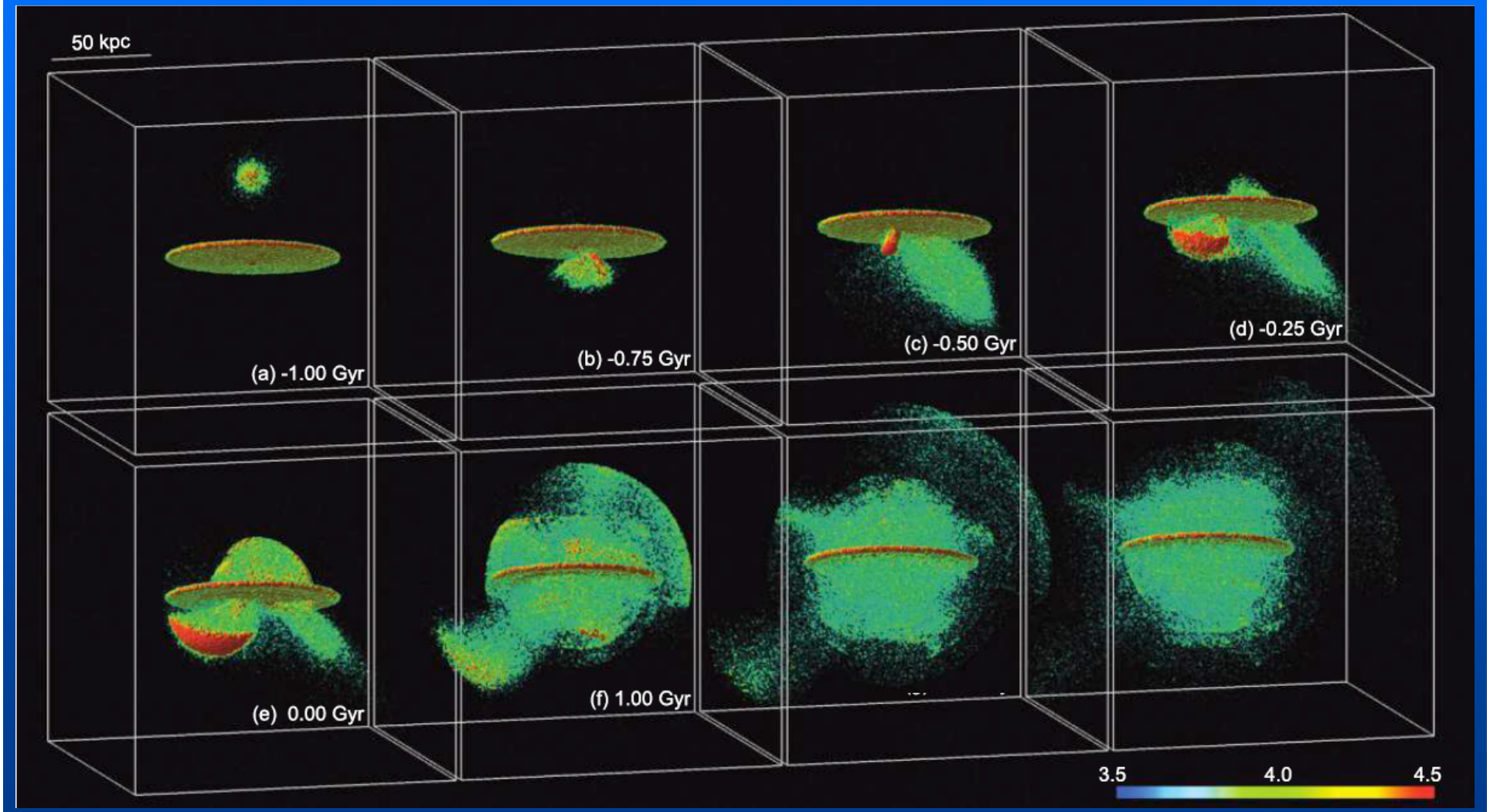
Adopt Fardal et al. orbit
Limit on Satellite mass <5e9; disk not disrupted

Mdisk 7e10 parameters Widrow et al. 2003
King bulge 2.5e10
DM halo lowered Evans 3.2e11, r_t=80kpc

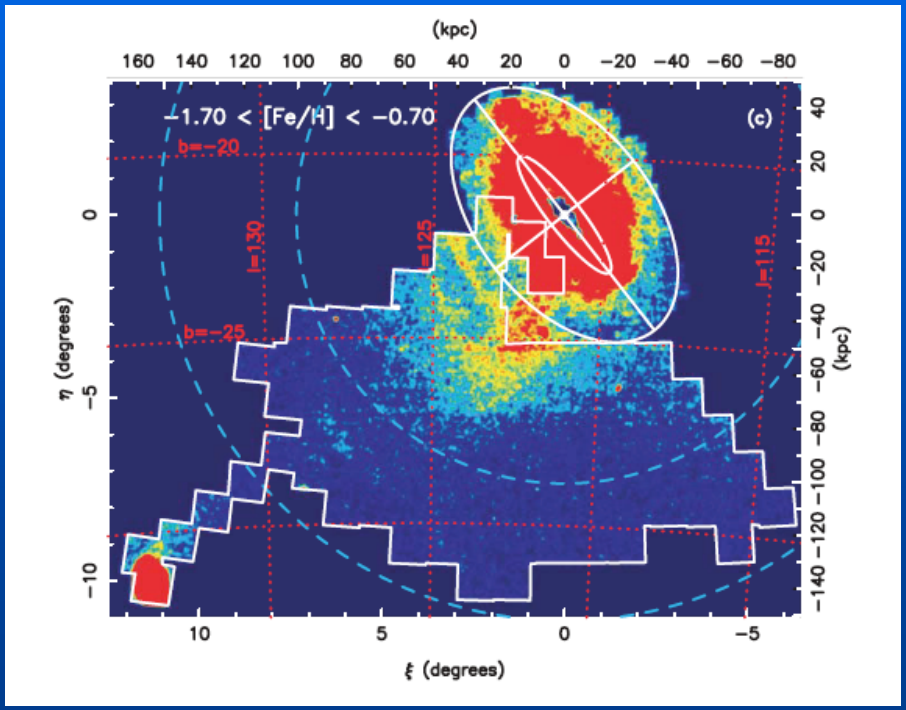
Satellite is Plummer sphere 1e9, 5e9, 1e10

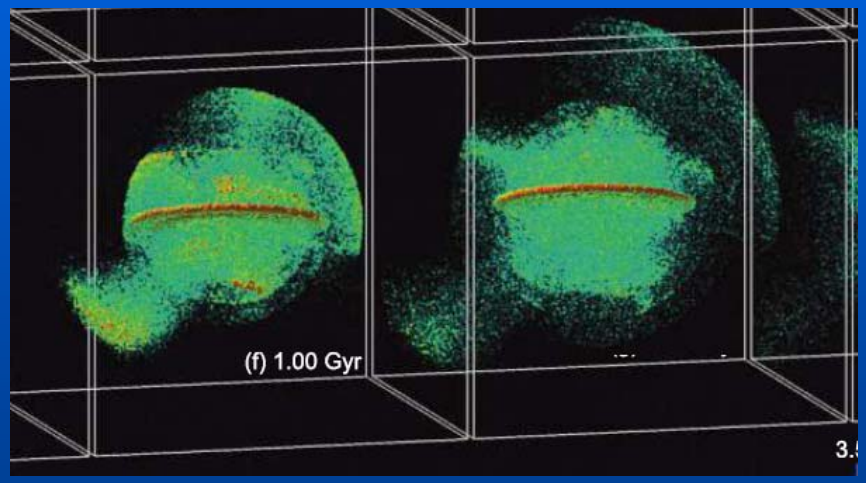
GADGET-2 (Springel)
7e6 particles for disk
2.5e6 bulge
3e7 halo
1e5, 5e5, 1e6 particles for sat

Collision Evolution offers one explanation for arcs

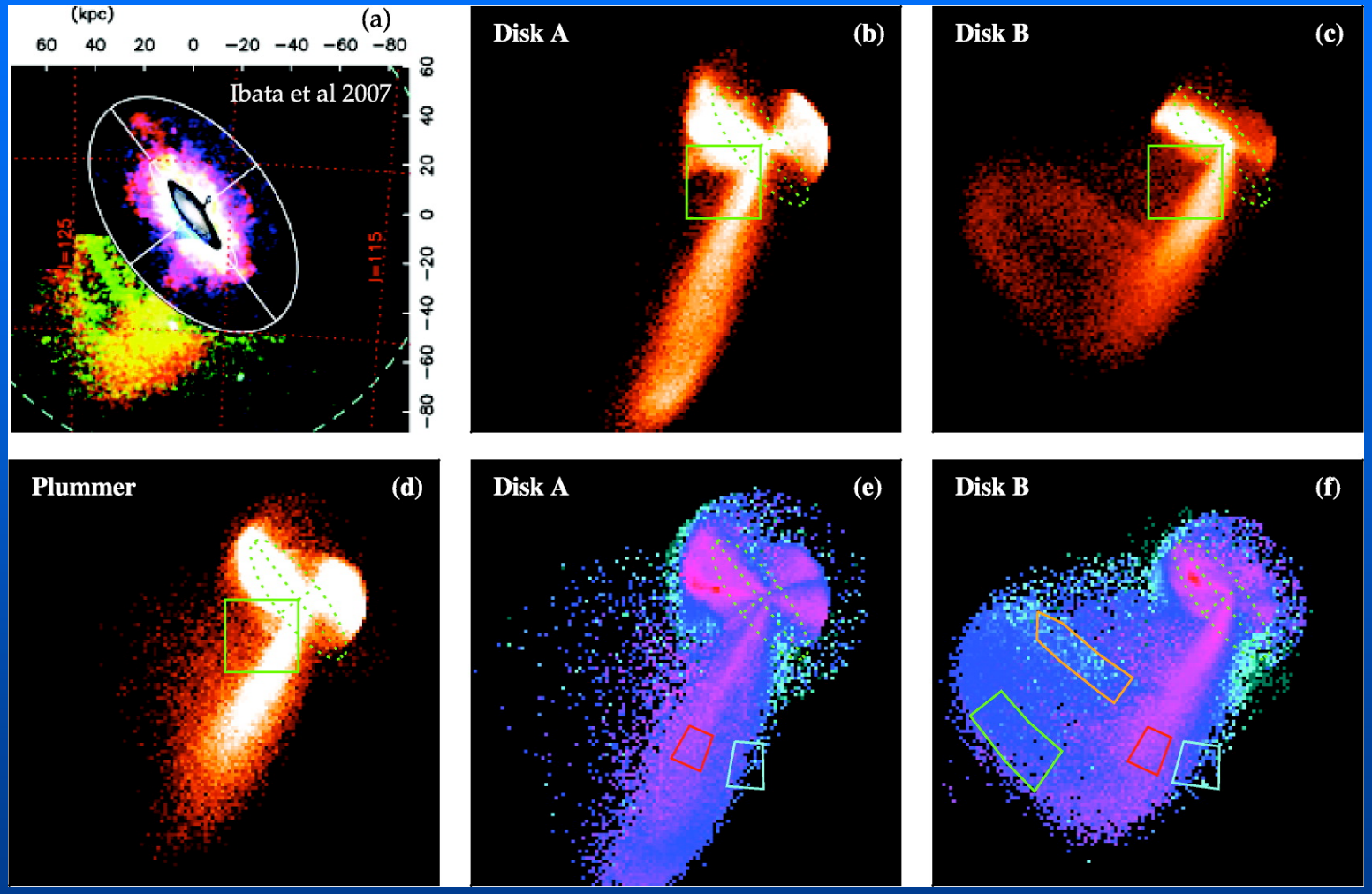


The arcs may be the remnants of a similar but ancient collision, >1 Gyr old



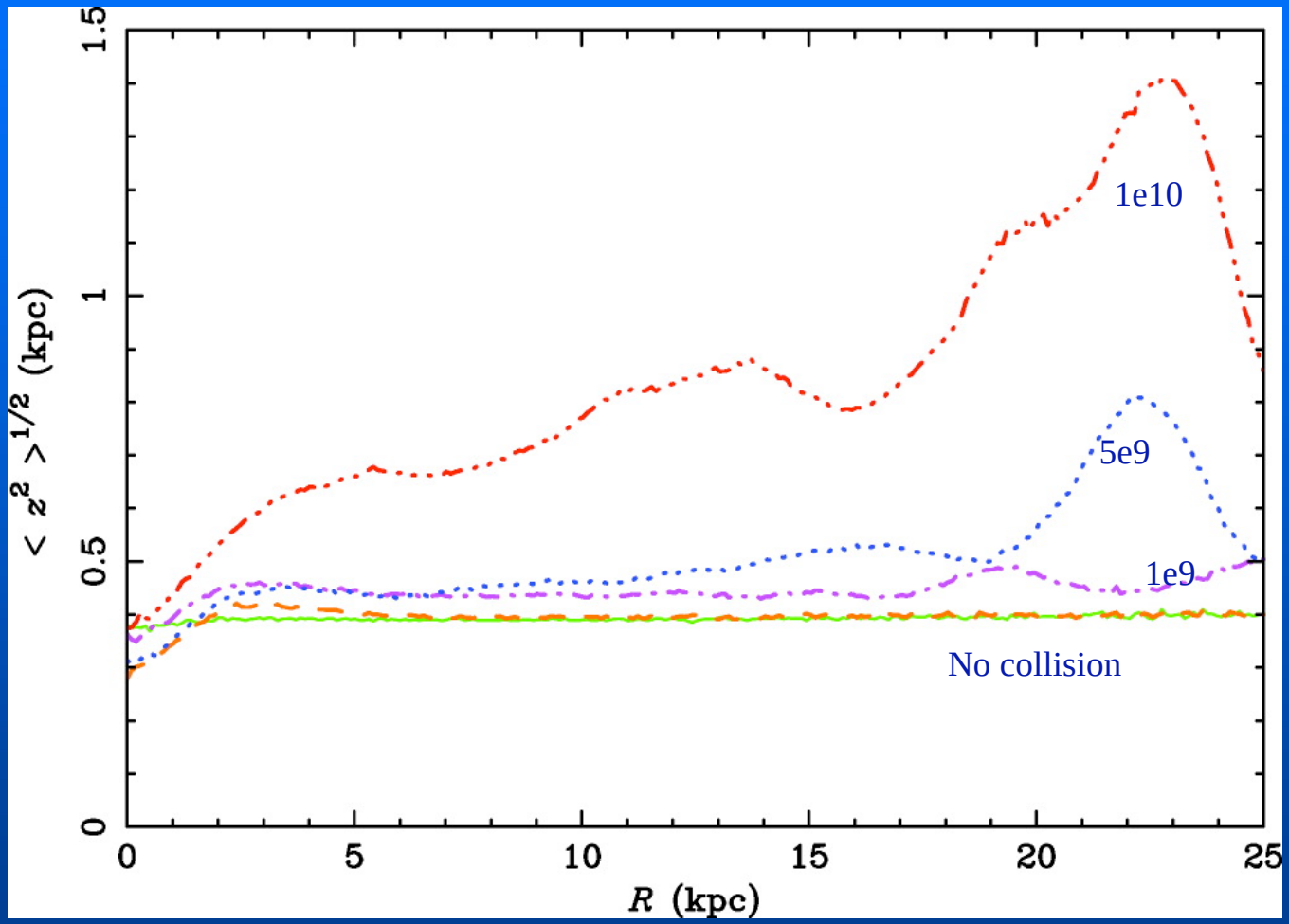


Or they may be part of the same collision if the satellite was a massive disk

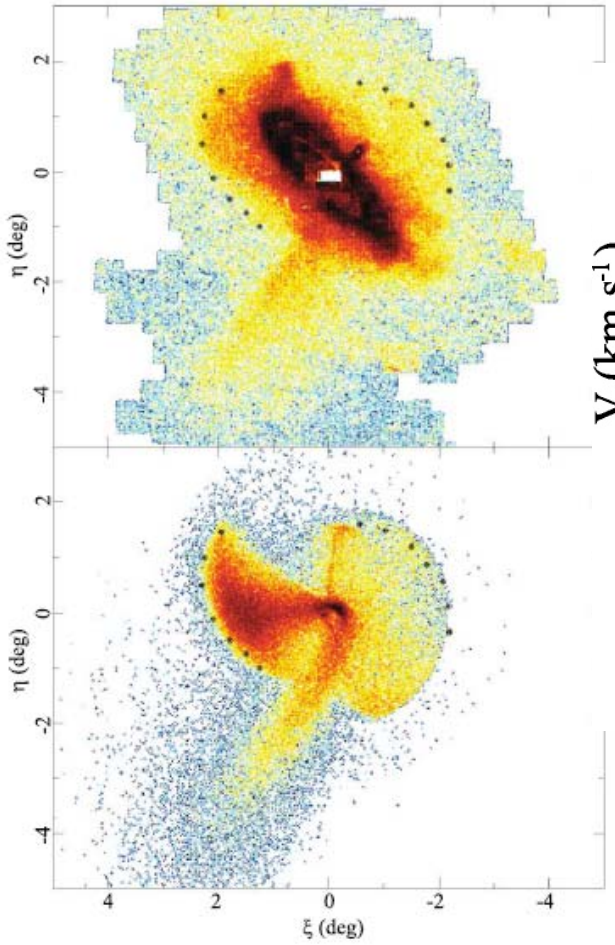


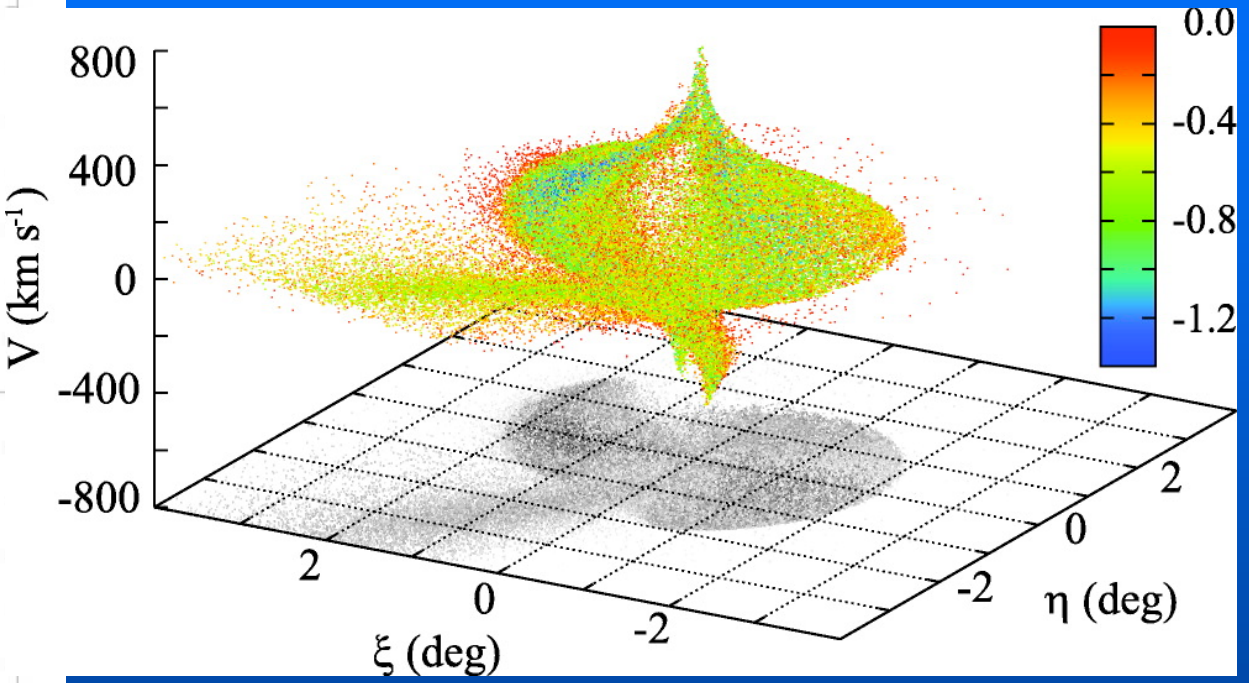
Fardal et al. 2008

But the simulations predict that no significant numbers of disk or bulge star are ejected



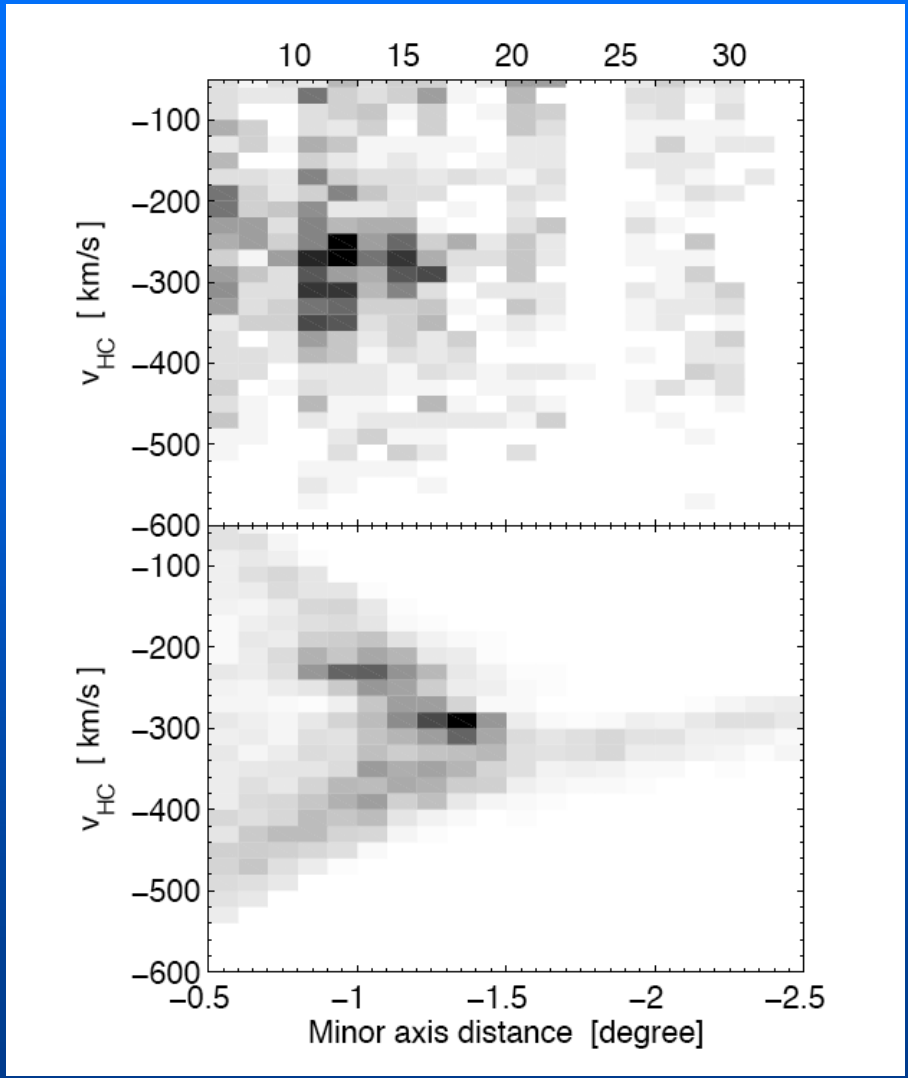
Model produces shell structures
Is the minor axis dominated by debris?

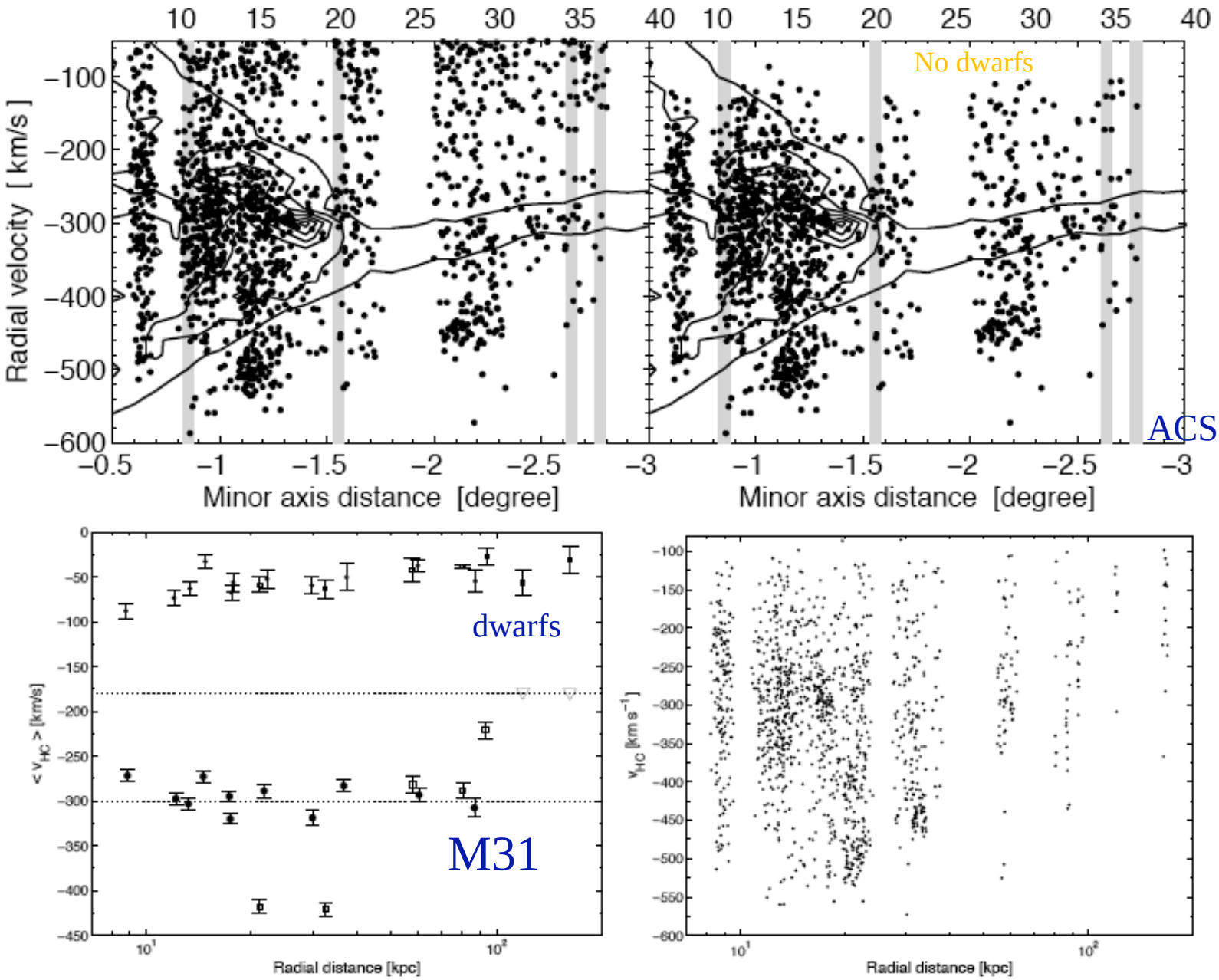




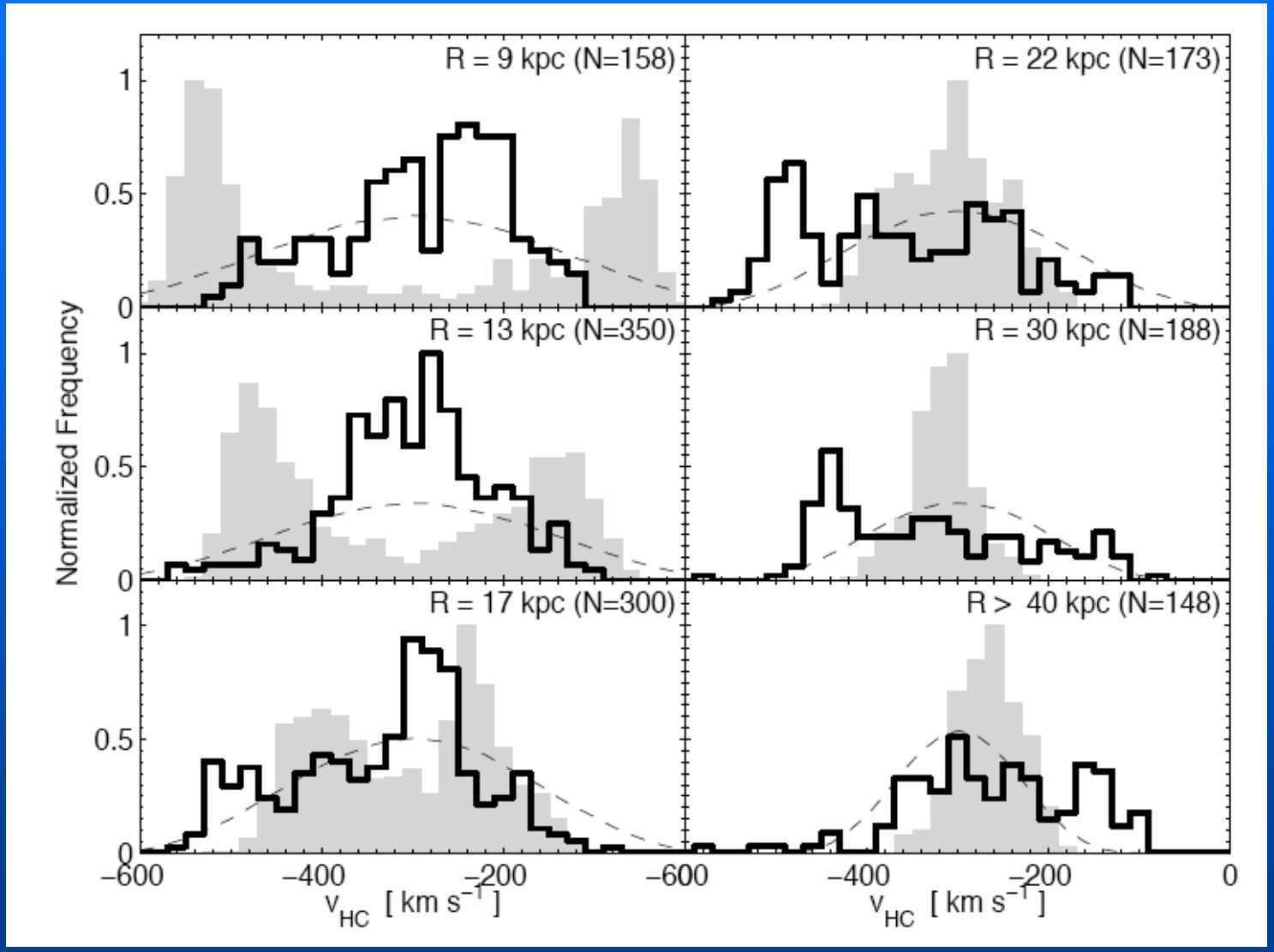
Model predicts present day location of stars based on their depth in the potential

Inner halo vs. model

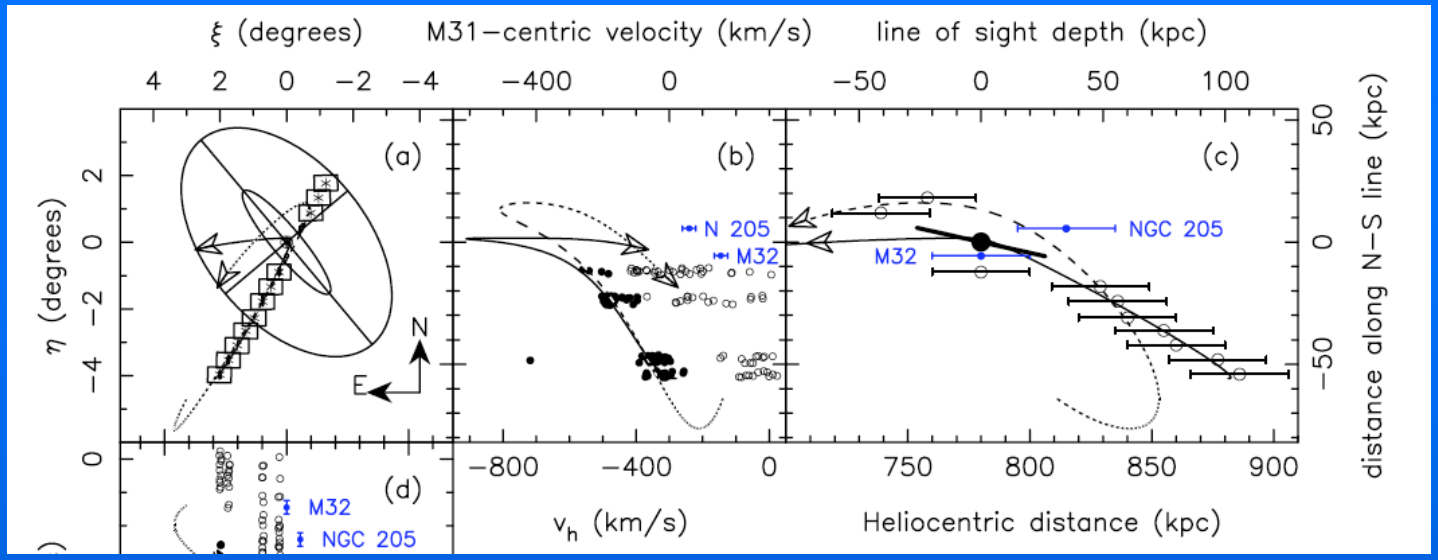


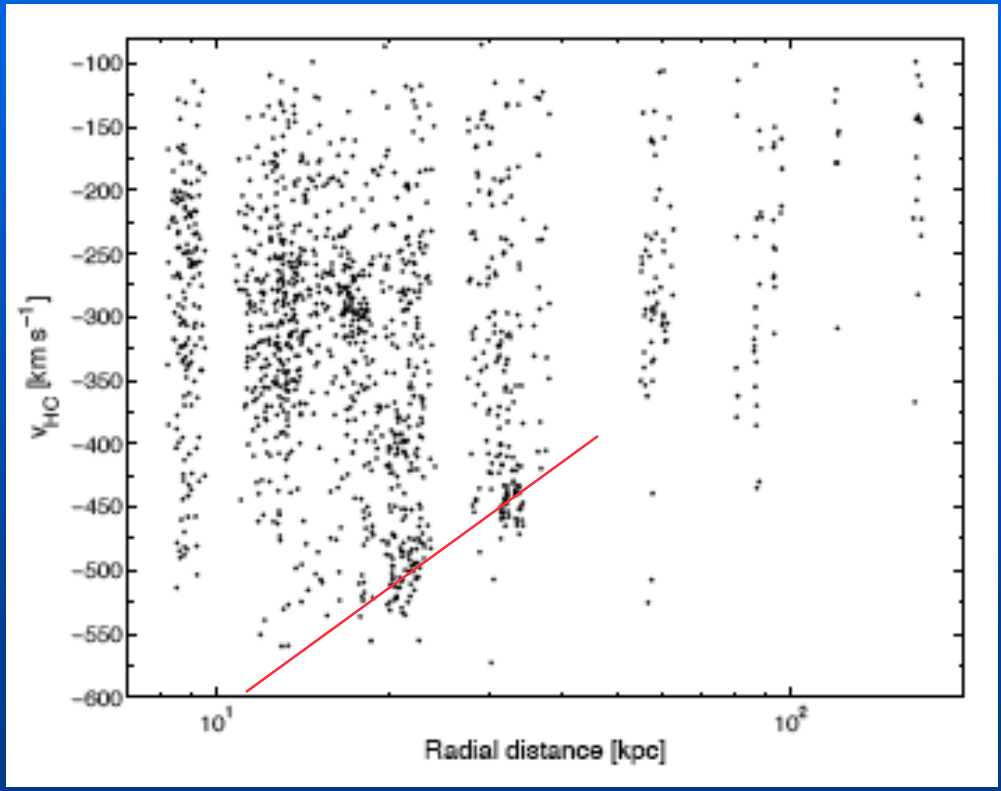

No dwarfs
ACS
Radial velocity [km/s]
Minor axis distance [degree]
Minor axis distance [degree]
dwarfs
M31
Radial distance [kpc]
Radial distance [kpc]

Model vs data

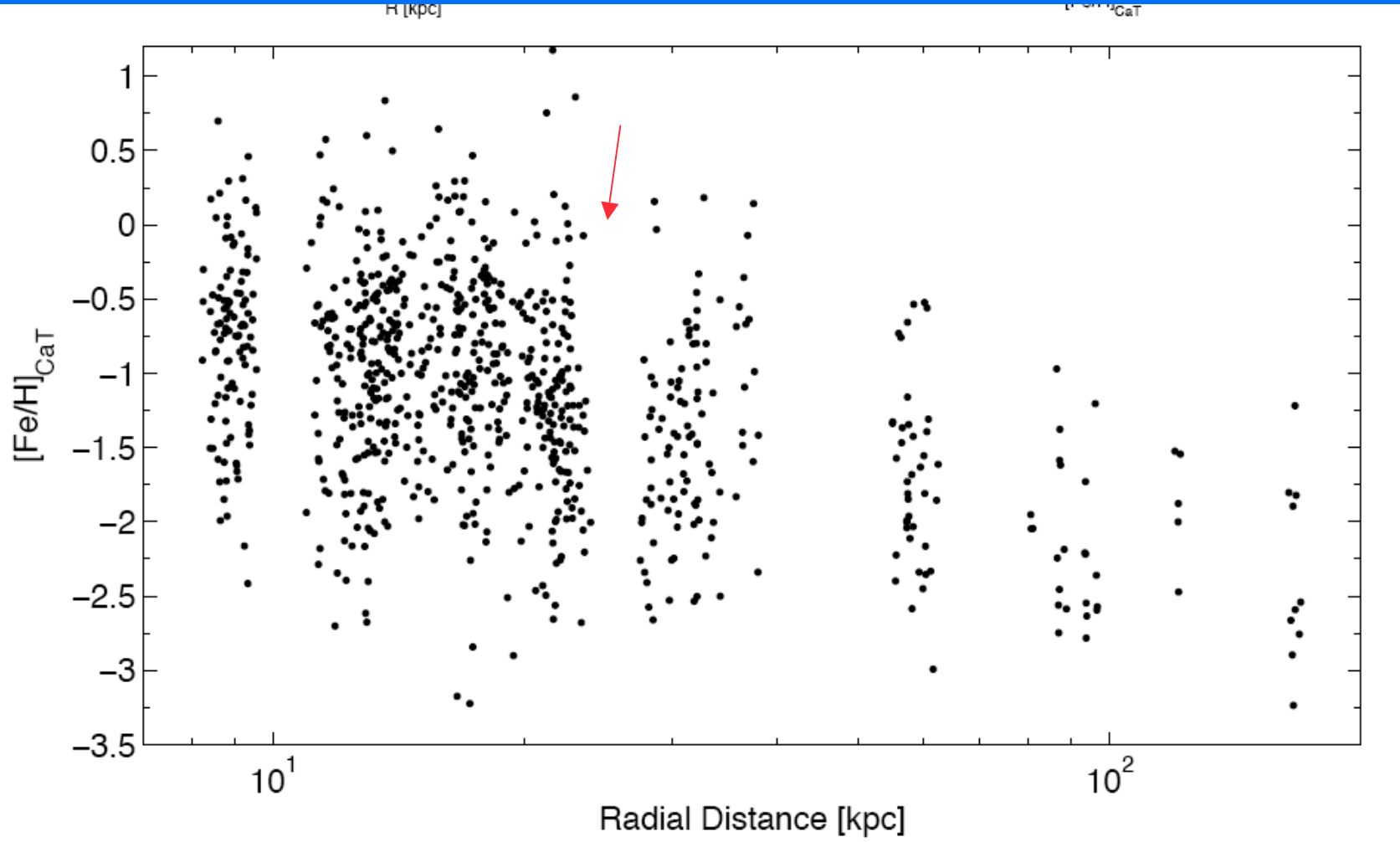


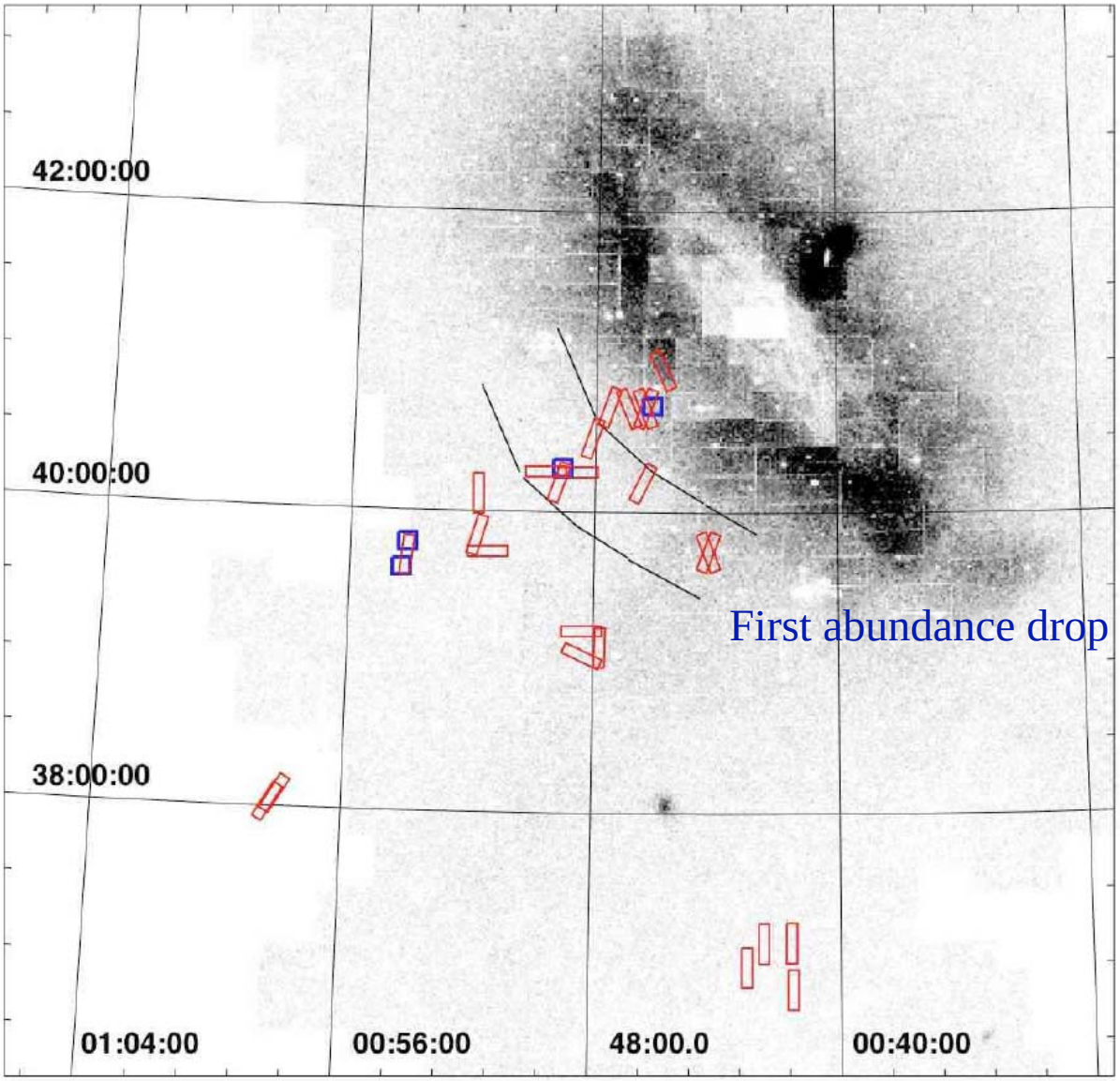
Ibata 04 Simple orbit



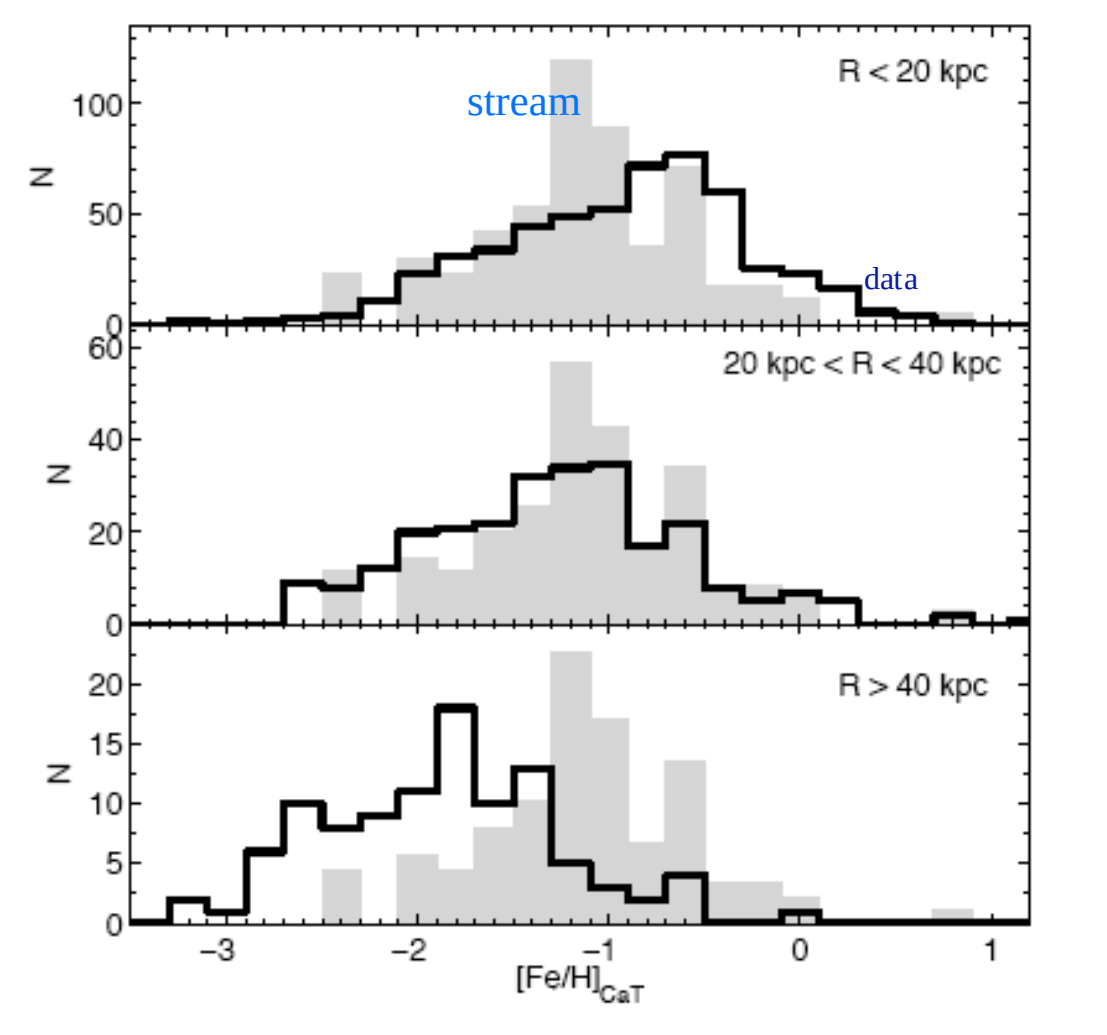


Abundance Gradient

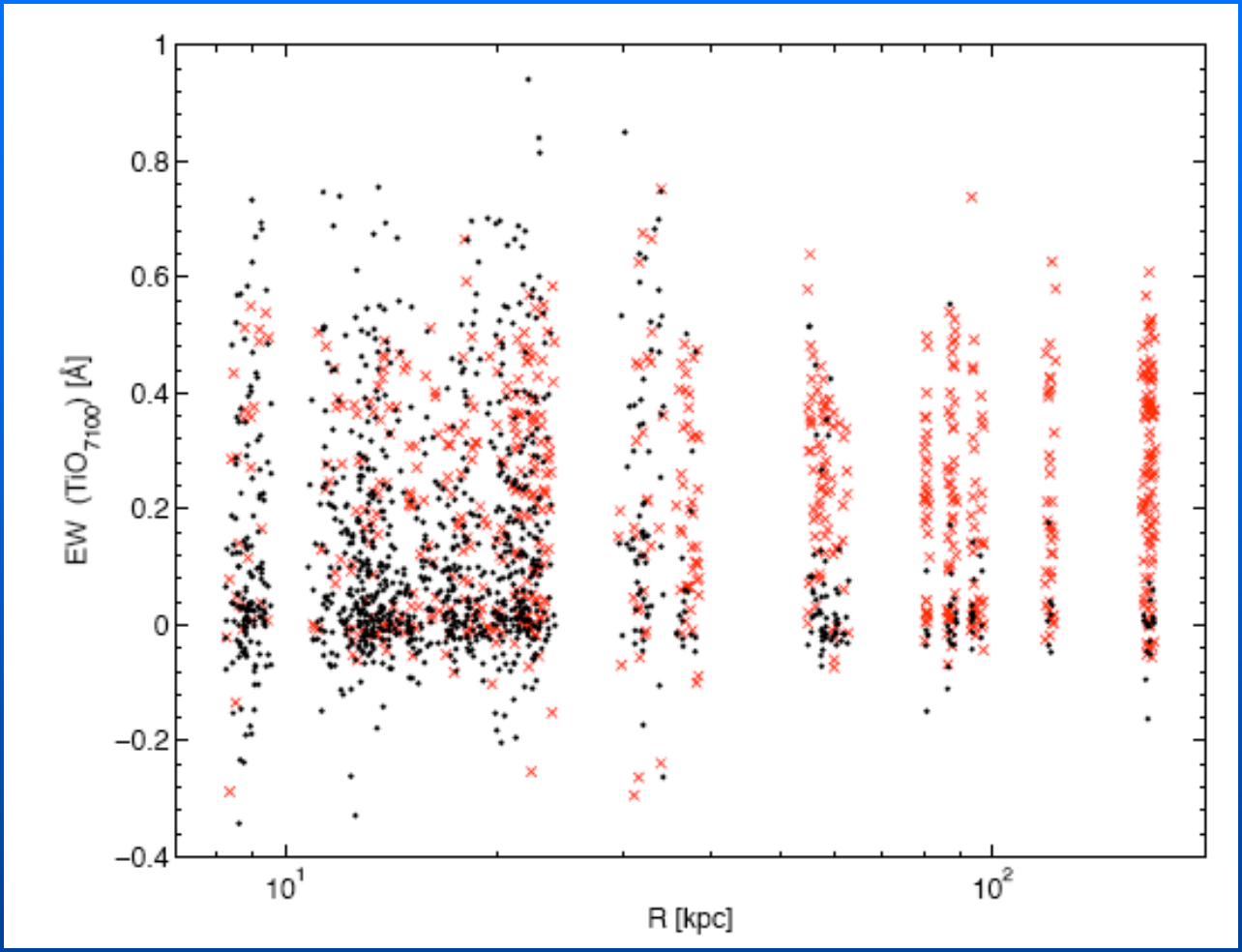



42:00:00
40:00:00
38:00:00
01:04:00
00:56:00
48:00.0
00:40:00
First abundance drop

Inner halo metal rich; no fields=stream

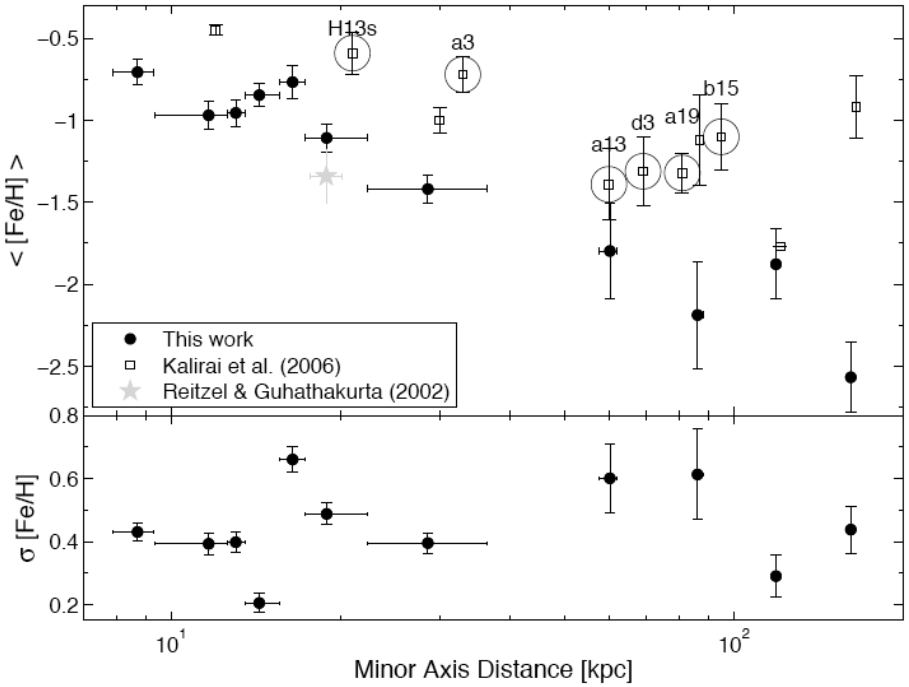


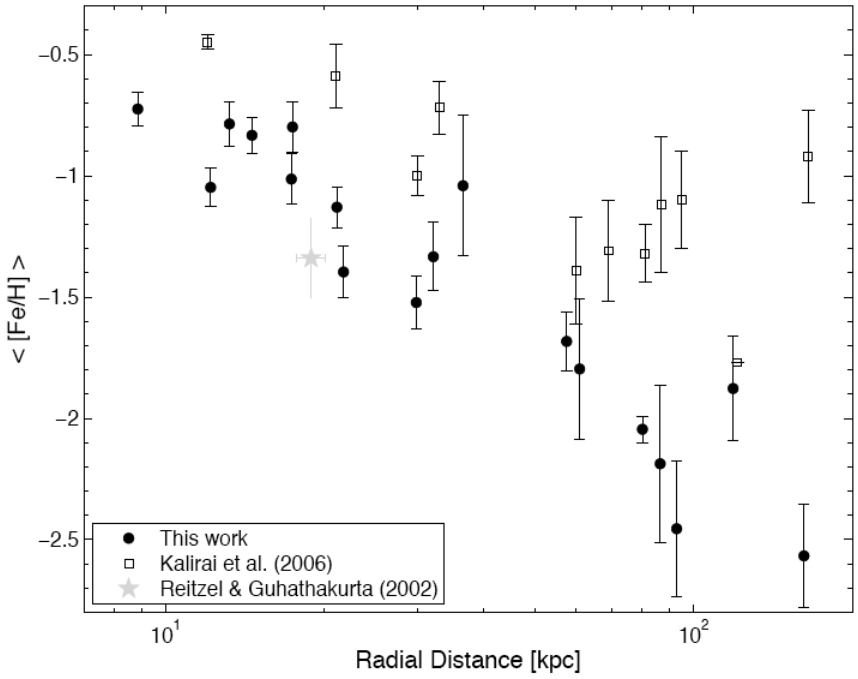
Gradient not due to dwarfs



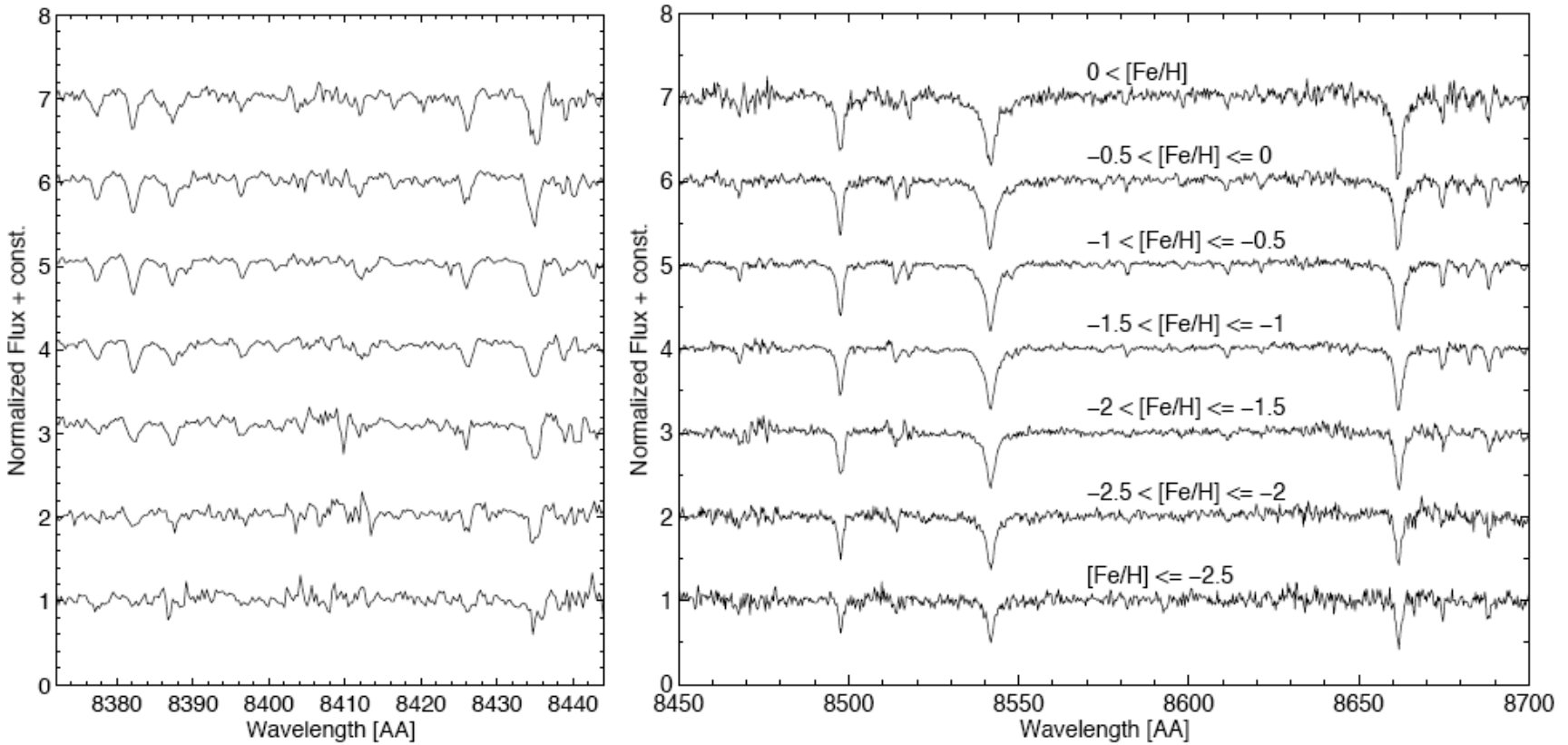
Dwarfs- red X - span full TiO range over all radii
Halo stars don't.

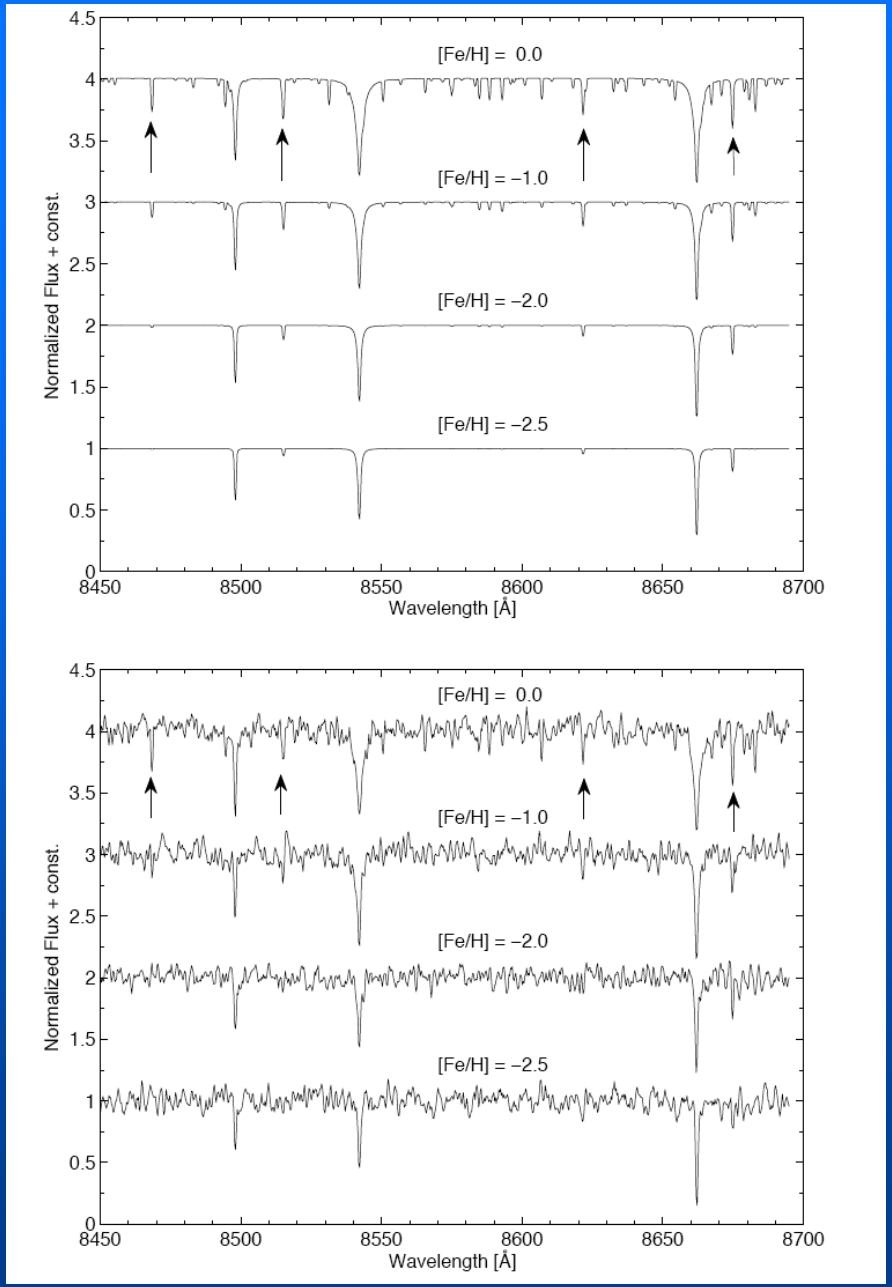
New Abundance Gradient





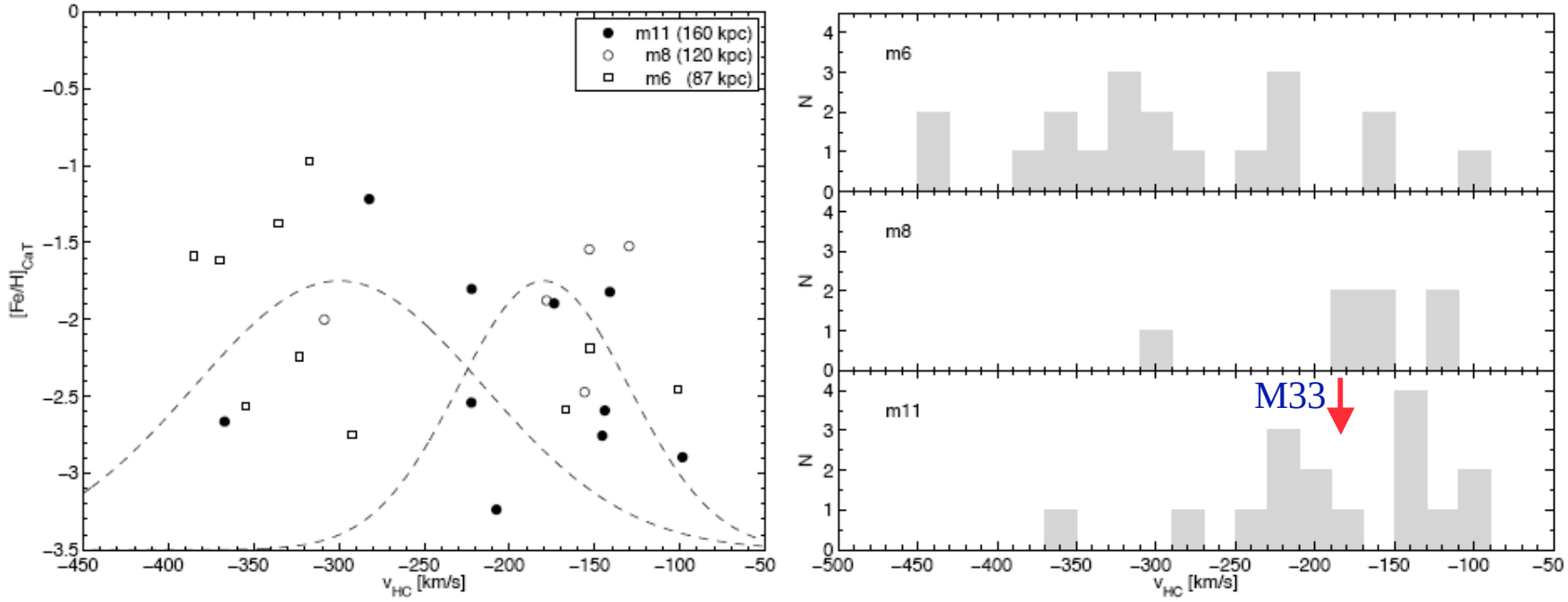
Is the gradient real? Grouped spectra



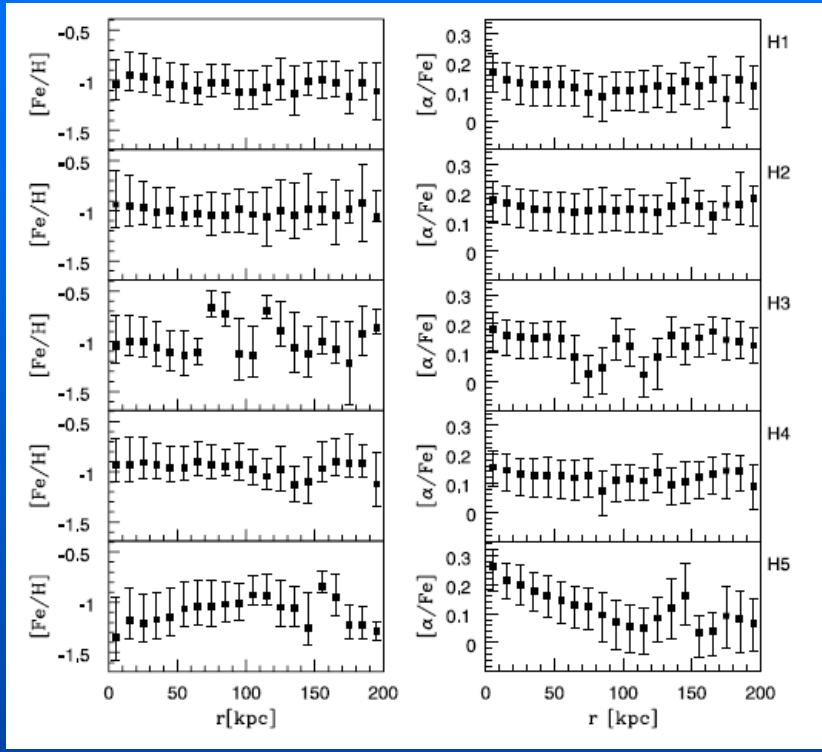


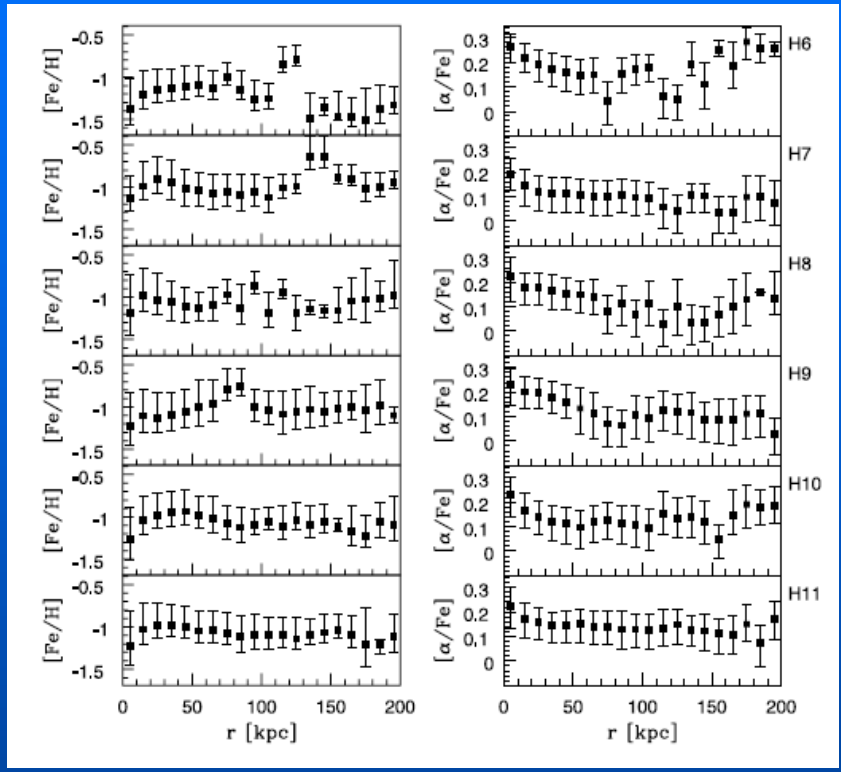
Iron lines observed to decrease, as predicted in model atmospheres

M33's overlapping halo at >100 kpc

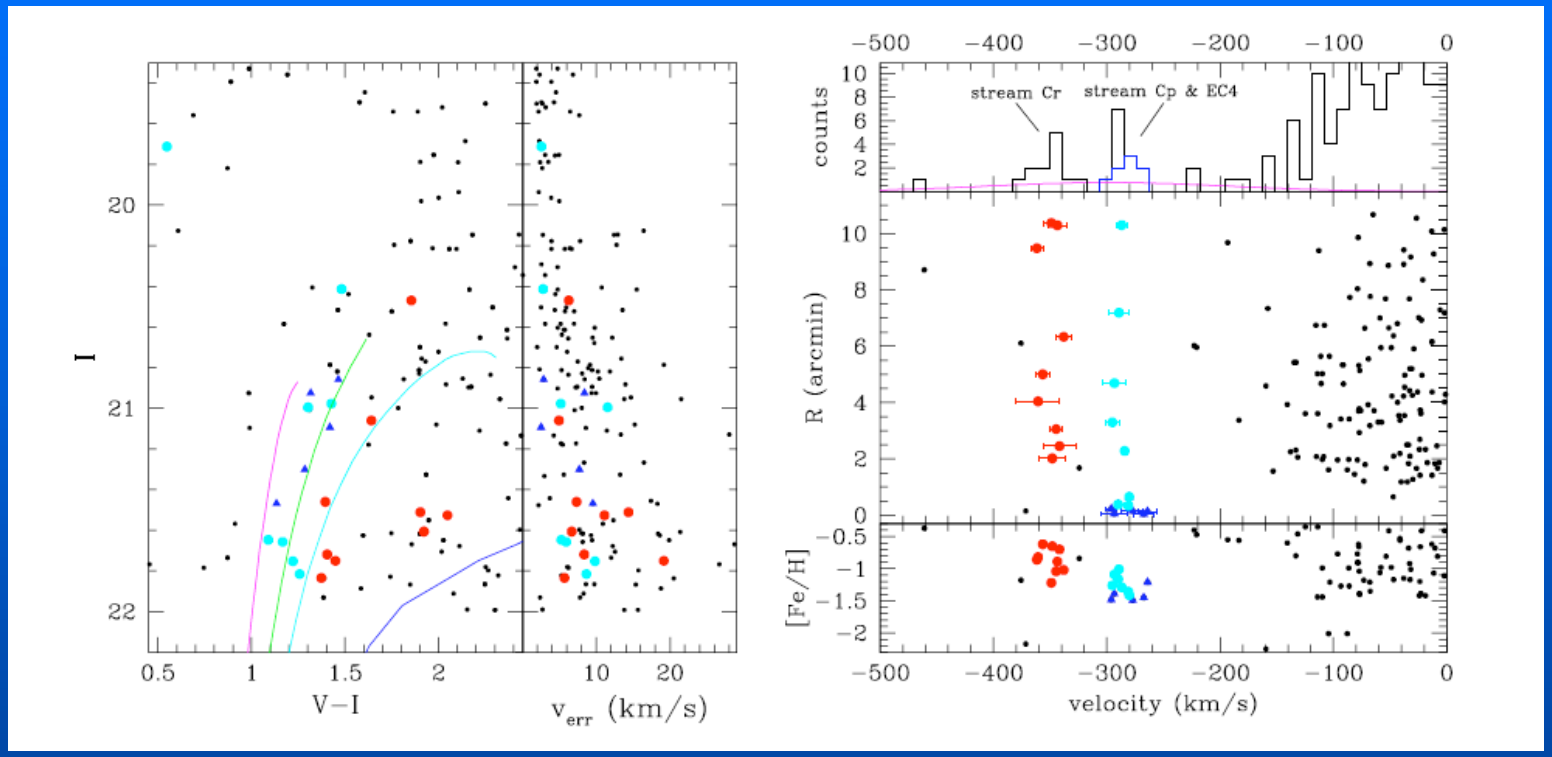


Simulated gradients- large gradient rare Font et a. 2006

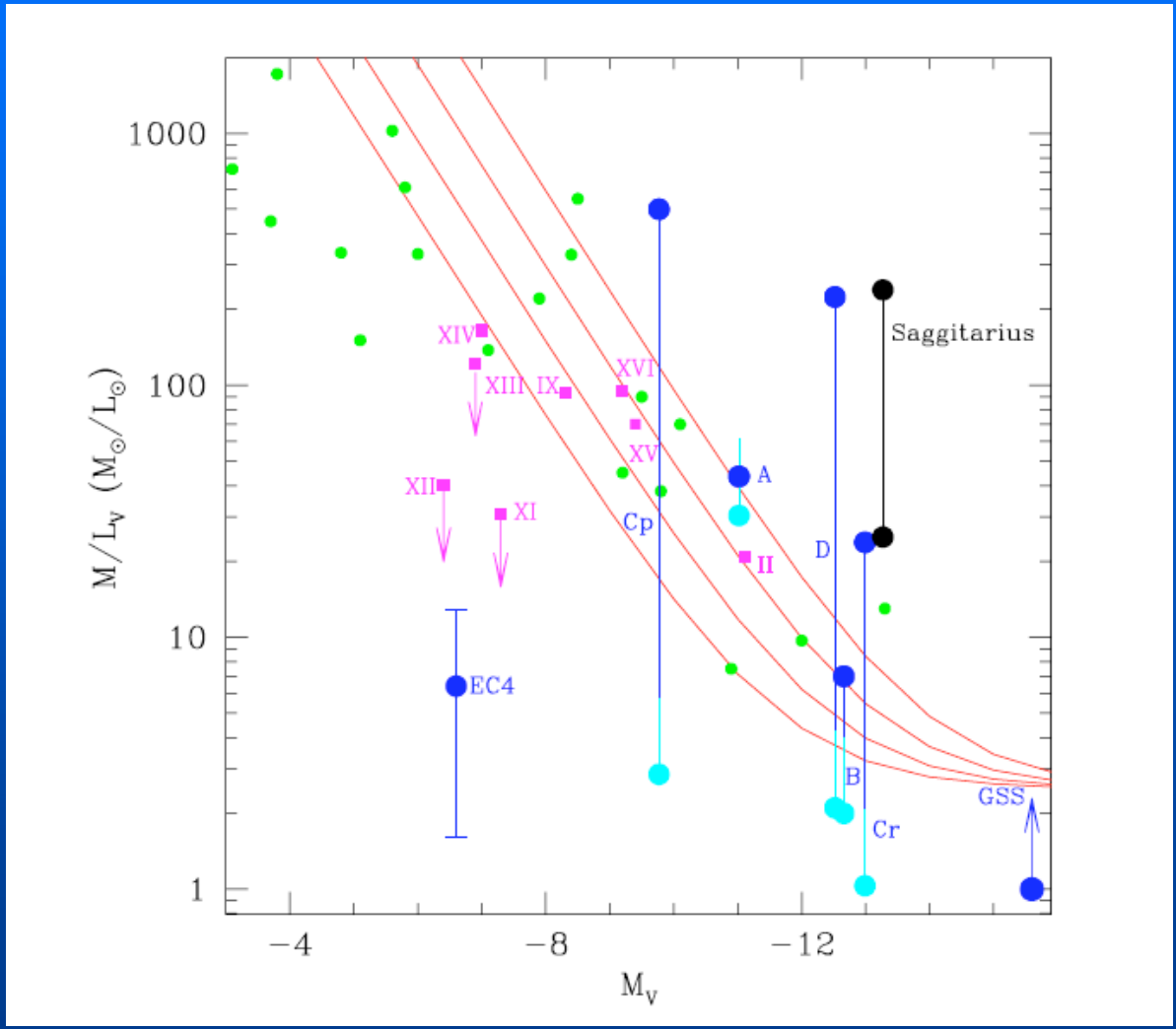




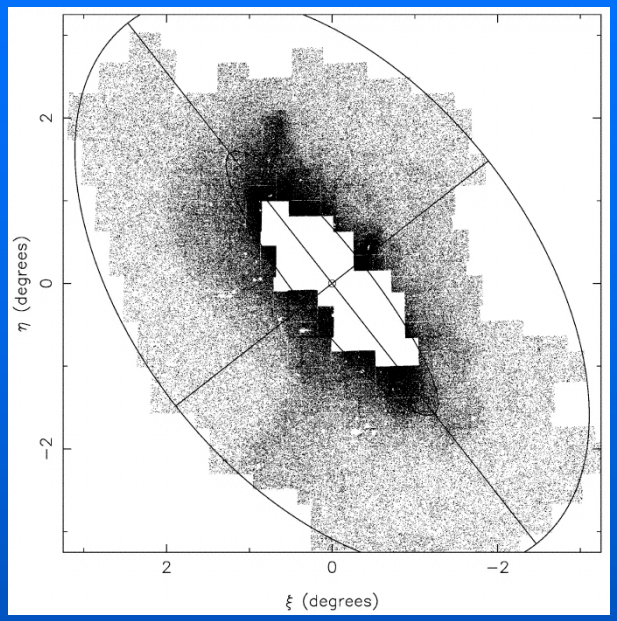
Chapman et al. 08



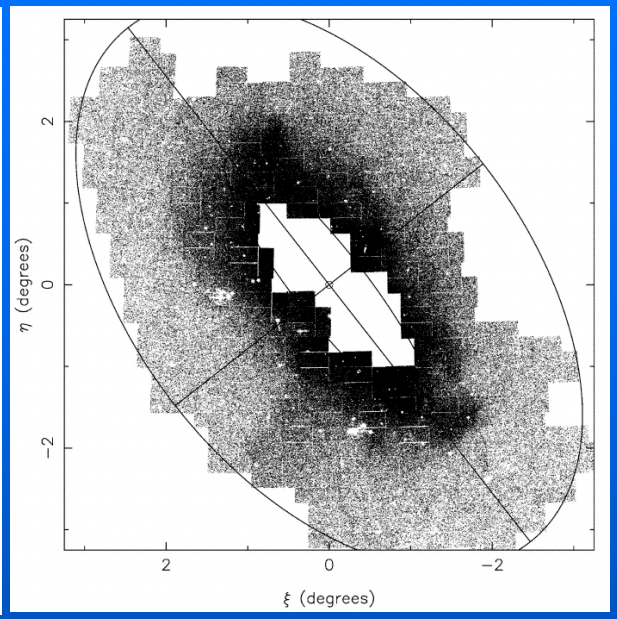
If wishes were fishes, and streams were sats



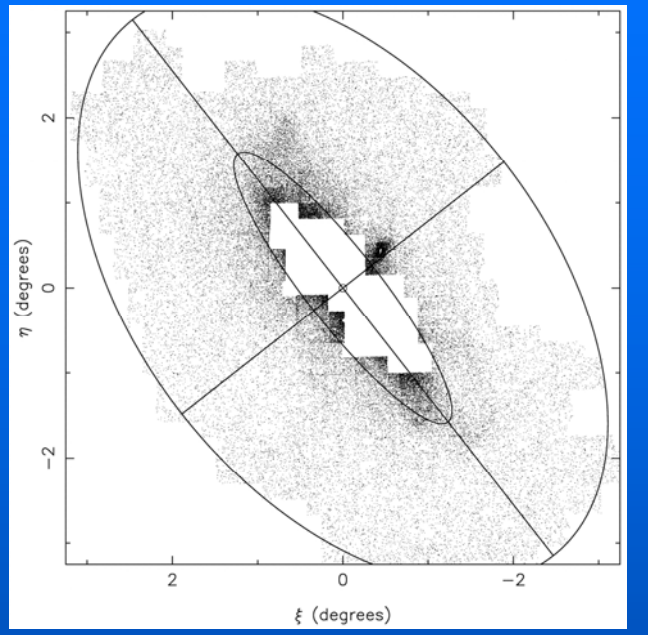
Ferguson et al. found differing structure with age/metallicity



Metal rich (red)



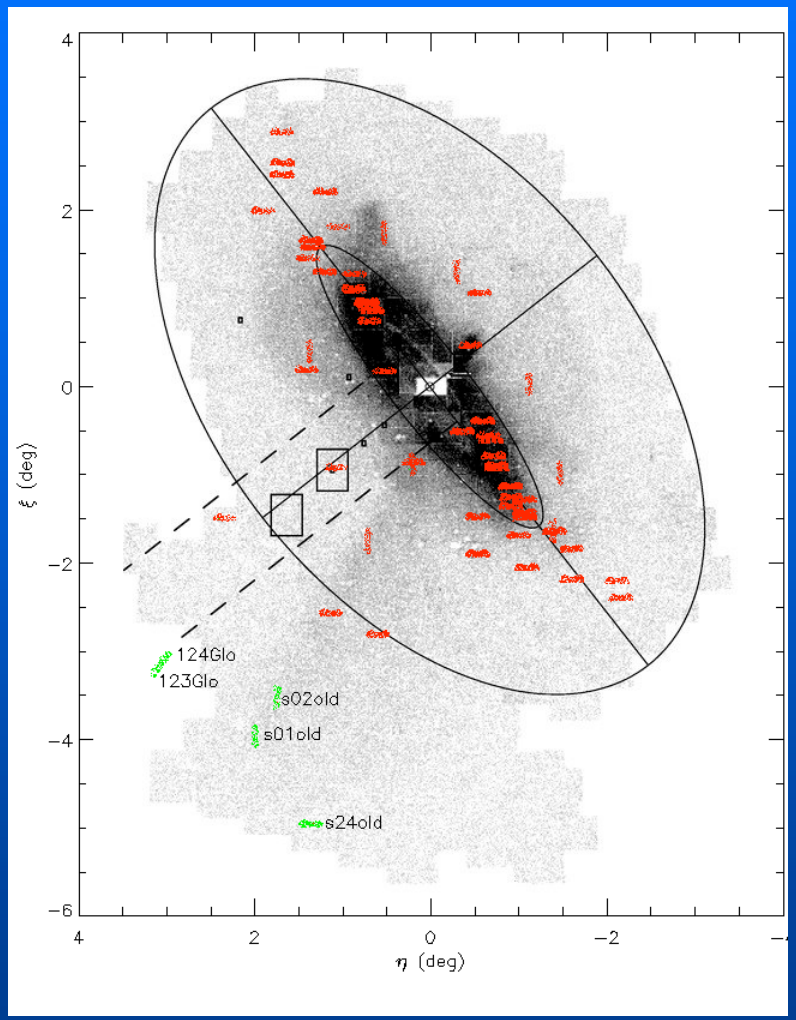
Metal poor (blue)

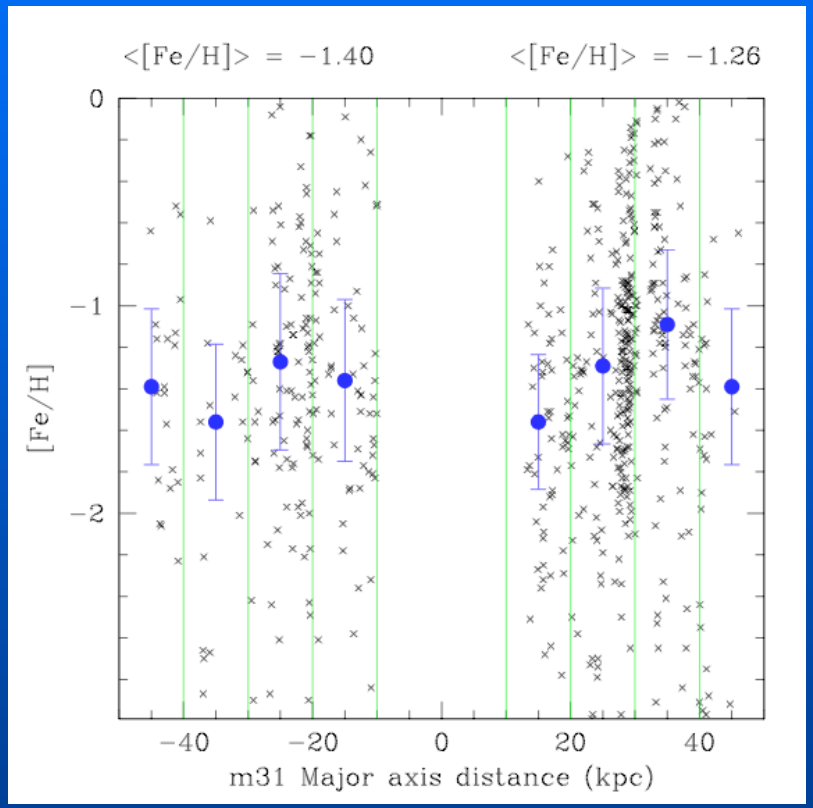


Int age(?) bright

Spatial, kinematic (cold streams + rotating disk) substructures argue against one stream progenitor polluting all of halo.

Major axis (Chapman et al. 2007)

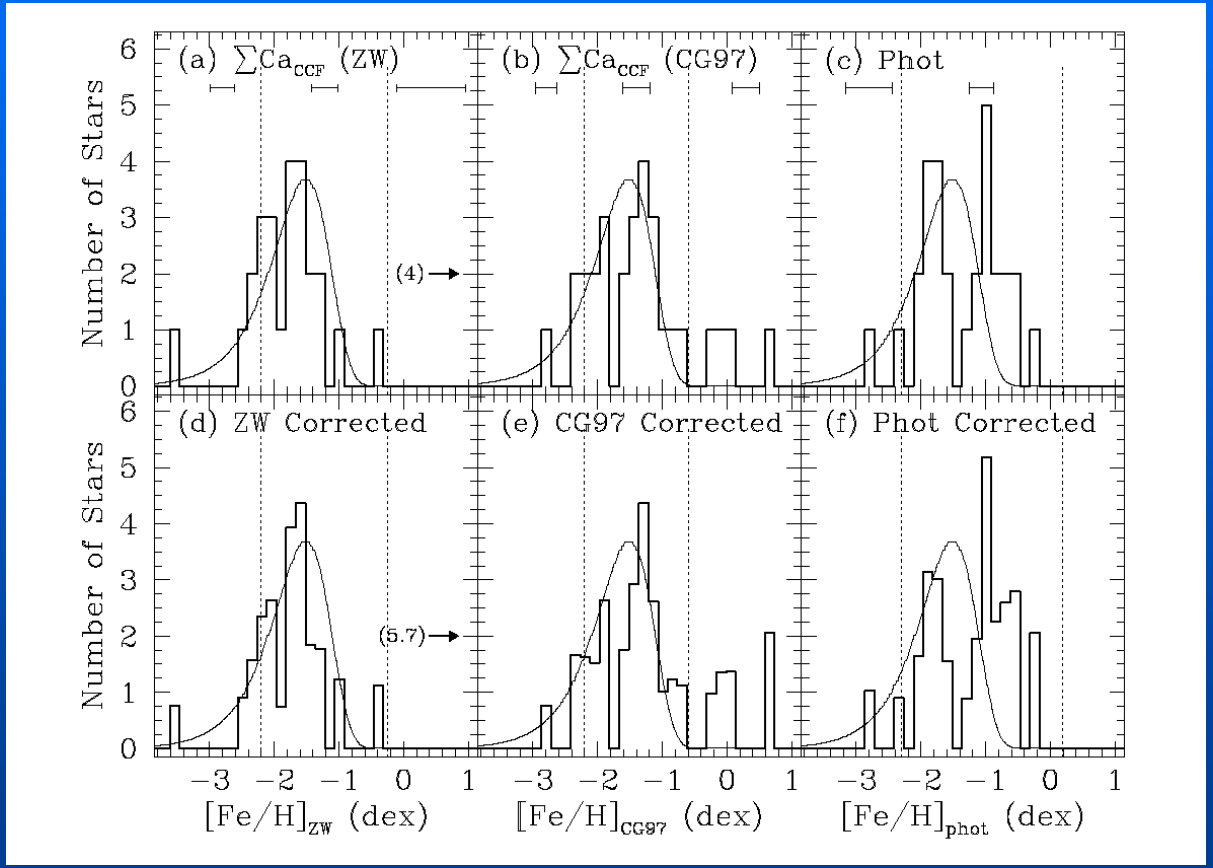




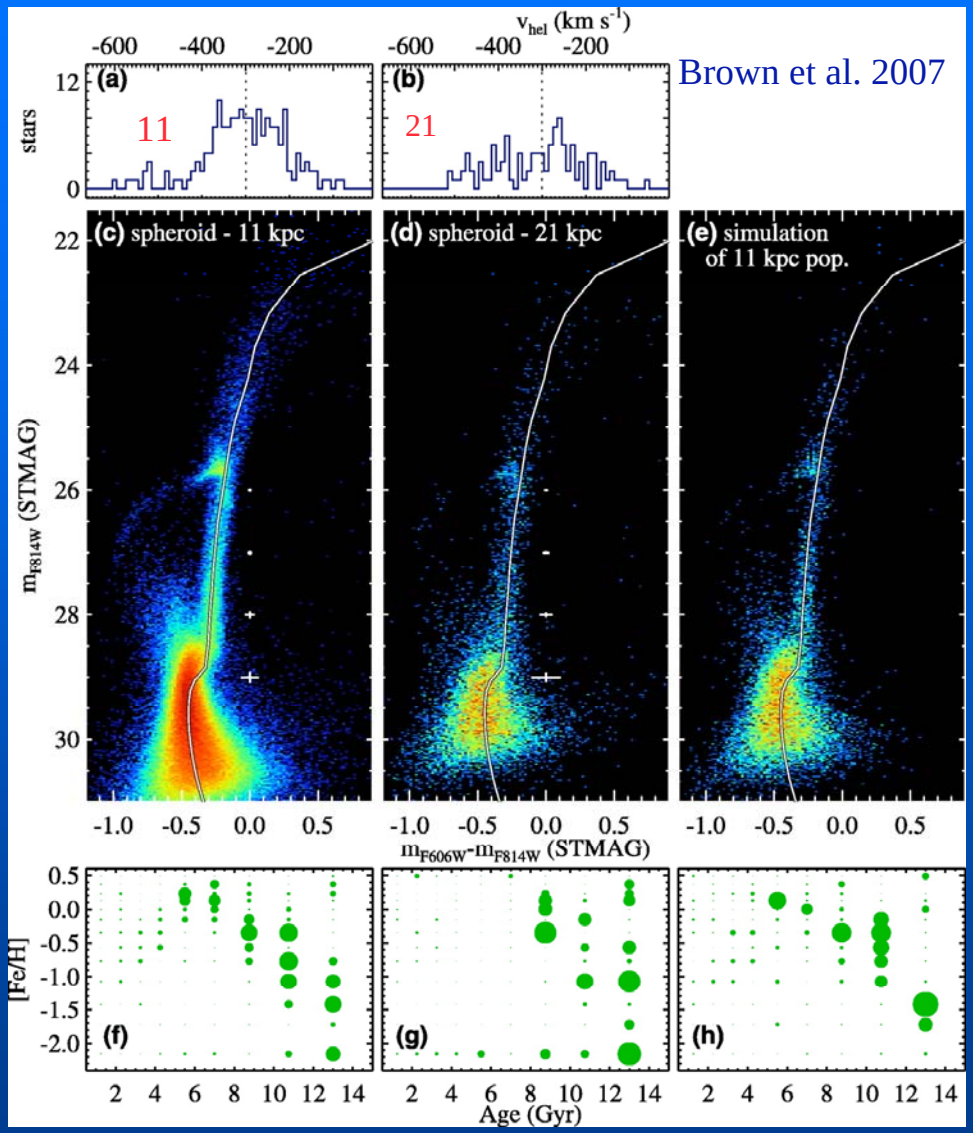
Kinematically selected spheroid stars

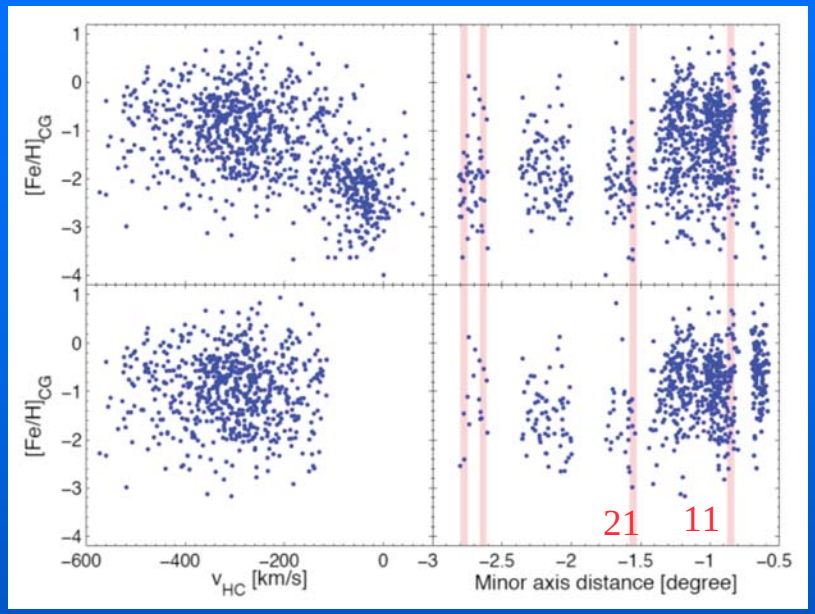
Implications

Reitzel & Guhathakurta (2002) (Reitzel's Ph.D. Thesis)
19 kpc minor axis Ca triplet: Now looks correct



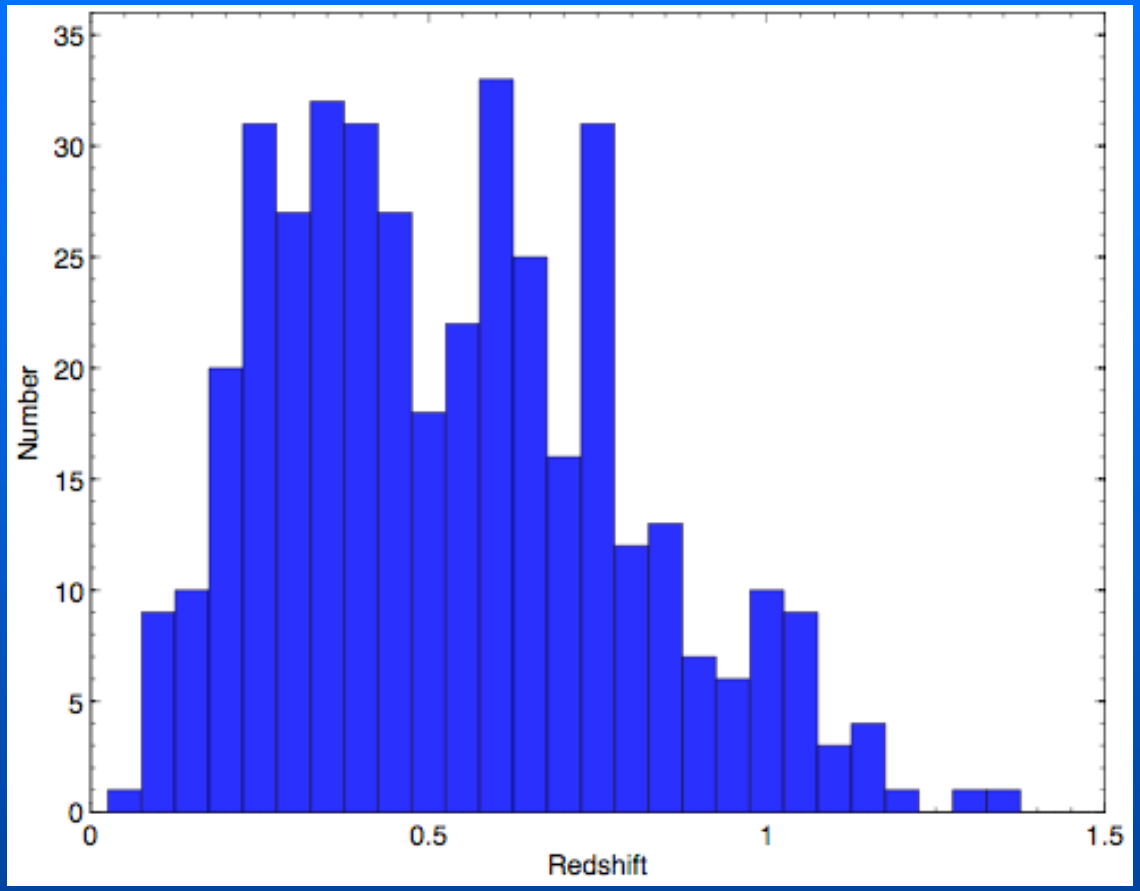
Implications





Brown et al.'s metallicity distribution from the deep HST CMD agrees qualitatively with the Ca T findings; suggest age gradient/transition

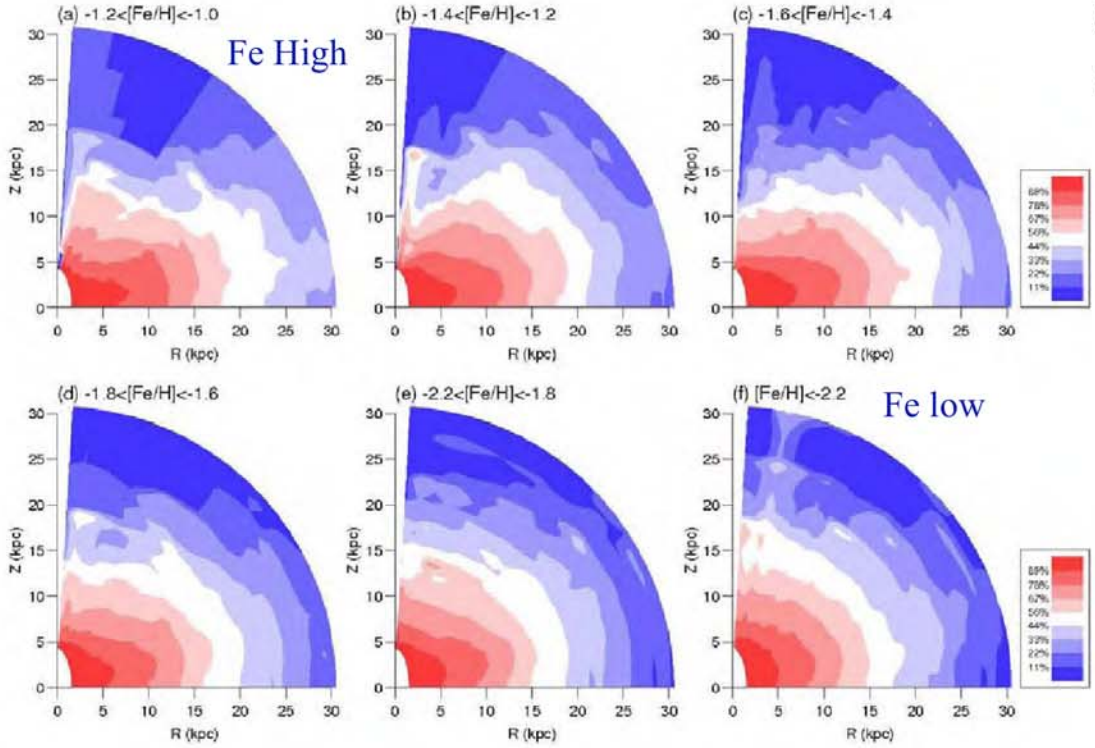
Near Field Cosmology

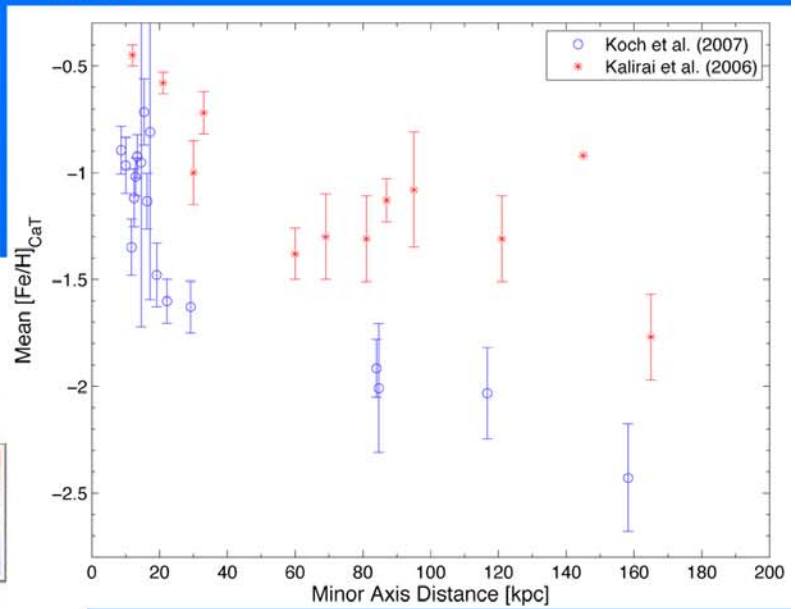


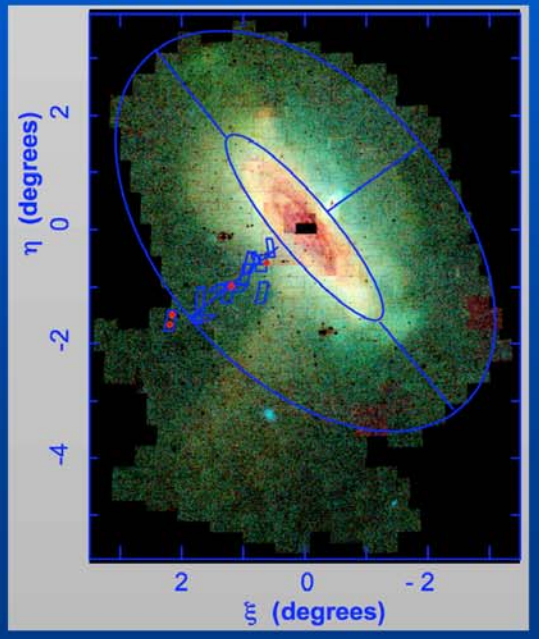
Many galaxies with serendip spectra (~500) roughly
Deep 1hr masks

Inner vs. Outer Halo?

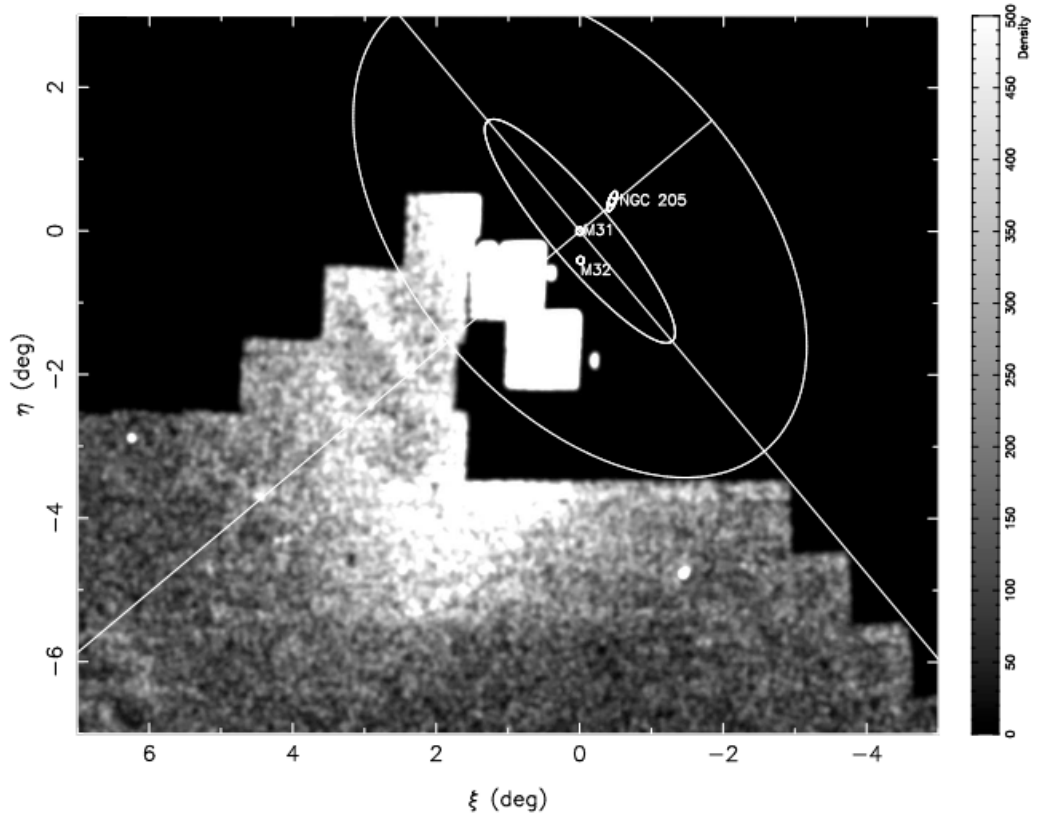
D. Carollo et al. 2007 Nature (Milky Way)







Streams in M31 outer halo



Martin et al. 2007

Conclusions

Survey of M31 distant giants on minor axis completed, with new abundances from Ca infrared triplet

Transition at 20 kpc (boundary of disturbed region) where metal rich population ends; abundances confirmed in major axis fields

Outer halo gradient of Kalirai et al. confirmed but we find more metal poor

New simulations of infall event have been done

Comparison with simulation, deep HST data, suggests that no single progenitor polluted entire inner or outer halo

M31 may be like Milky Way (Carollo et al. 2007) in having inner/outer halo dichotomy.