Exploring the Local Universe with TMT

Masashi Chiba

(Tohoku University, Japan)

TMT science study in Japan 2010-11

Science WG on Stars and the Local Group
W. Aoki (PI) and seven members (samurais)

1. Exploring stellar activities and explosions
2. Clarifying galaxy formation with resolved stars

- Supernovae & GRB
- Stellar seismology
- First stars & metal-poor Galactic stars
- The Milky Way and dSphs
- The Local Group and beyond

Science report 2011

TMT science study in Japan 2010-11

Science WG on Stars and the Local Group
W. Aoki (PI) and seven members (samurais)

1. Exploring stellar activities and explosions
2. Clarifying galaxy formation with resolved stars

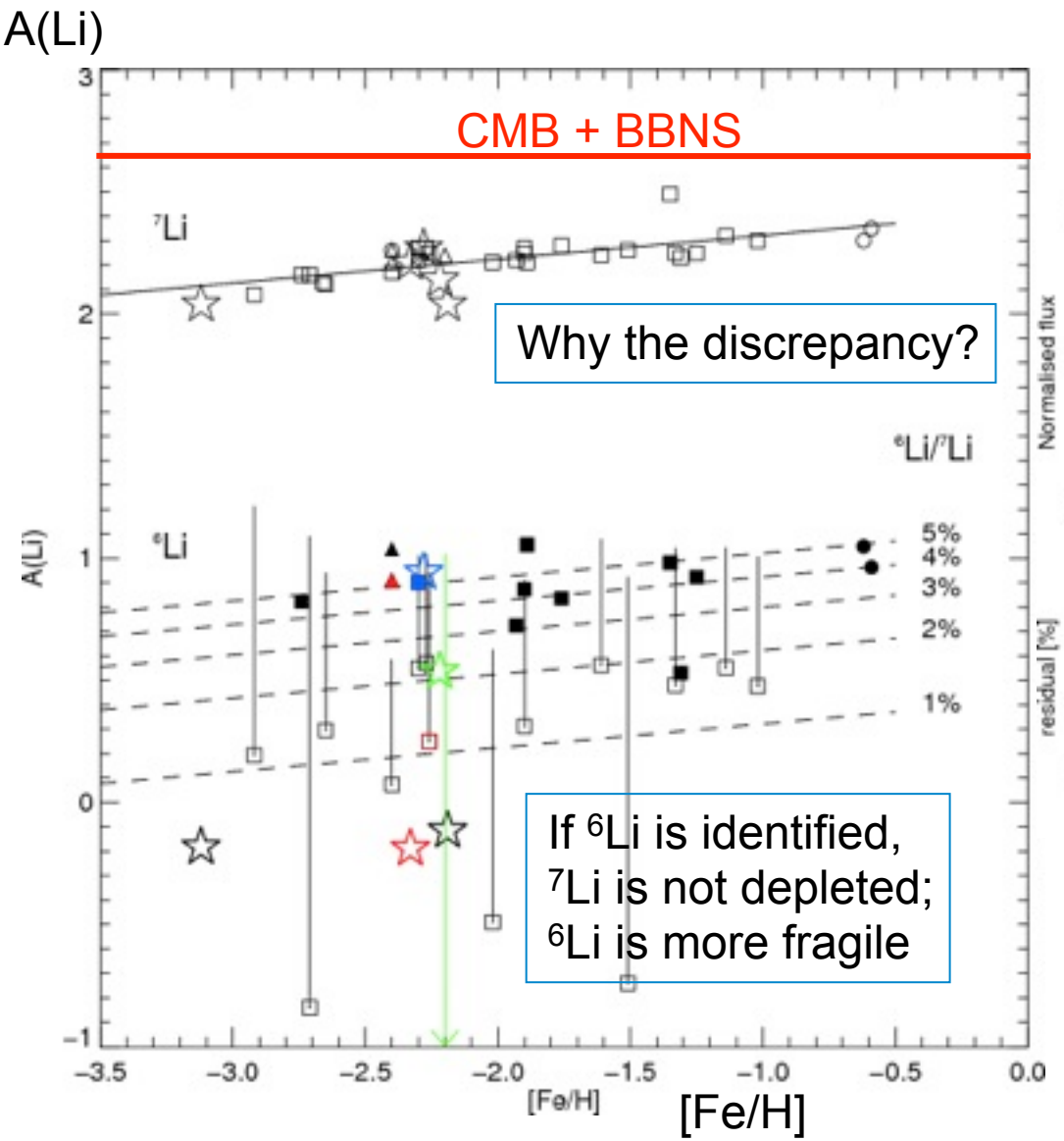
- Supernovae & GRB
- Stellar seismology
- First stars & metal-poor Galactic stars
- The Milky Way and dSphs
- The Local Group and beyond

Science report 2011

First stars & metal-poor Galactic stars

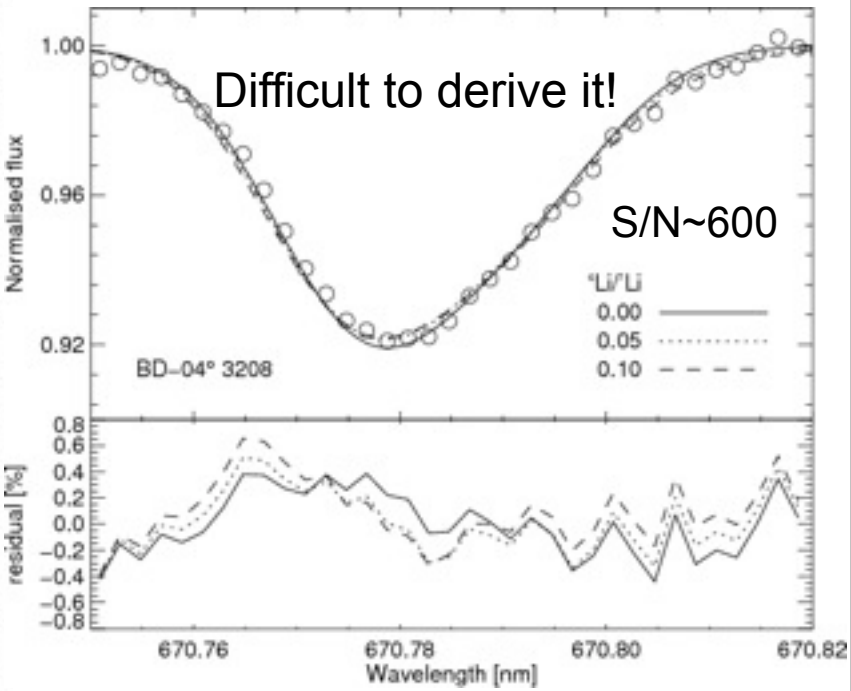
- Li abundance & Big Bang nucleosynthesis
  - Why the discrepancy? Depletion?
  - ^{6}Li measurement for metal-poor stars with [Fe/H]<-3
- Extremely metal-poor stars with [Fe/H]<-3.5
  - Originated from dSphs? Abundance pattern?
  - High res spectra for many EMPs in the MW & dSphs with V>18

Li abundance & Big Bang NS



Garcia Perez+ 2009 (HDS)

^{6}Li measurement



Needs high S/N (~1,000) R~100,000 spectra for metal-poor turn-off stars (with V<13) w TMT

The Milky Way and dSphs

- Globular clusters
  - Nature of multiple stellar populations
- The MW old components
  - Bulge : Nature of metal-rich young population in MS
  - Thick disk and halo : Abundance patterns of in situ field and stream stars (beyond the solar neighborhood)
- dSphs

Multiple populations in GCs

Omega Cen

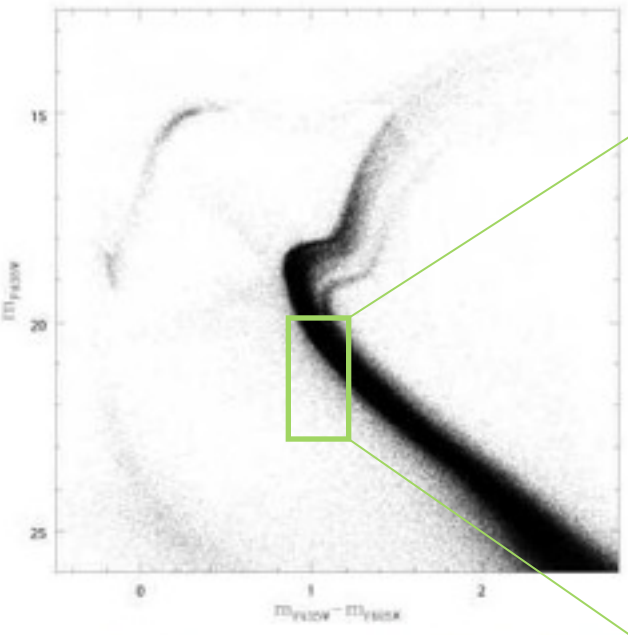


FIG. 1.—Our CMD of ω Centauri, from the photometry of more than a million stars in the central 3 × 3 ACS fields.

Piotto+ 2005

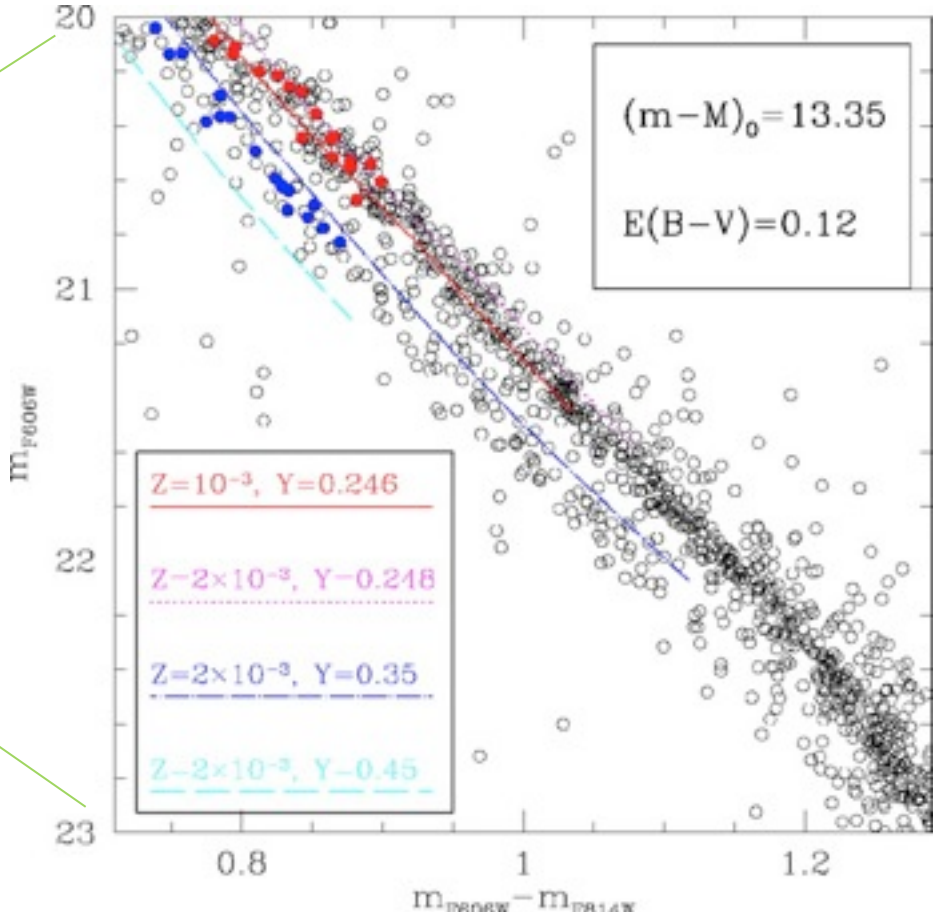
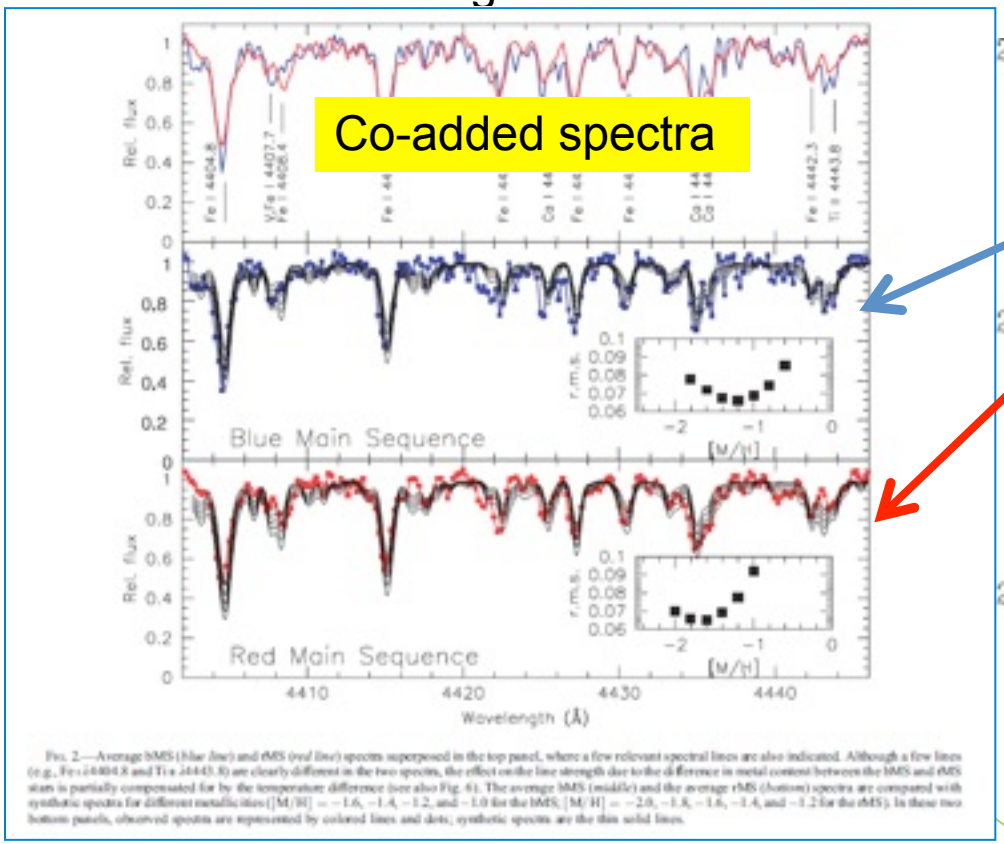


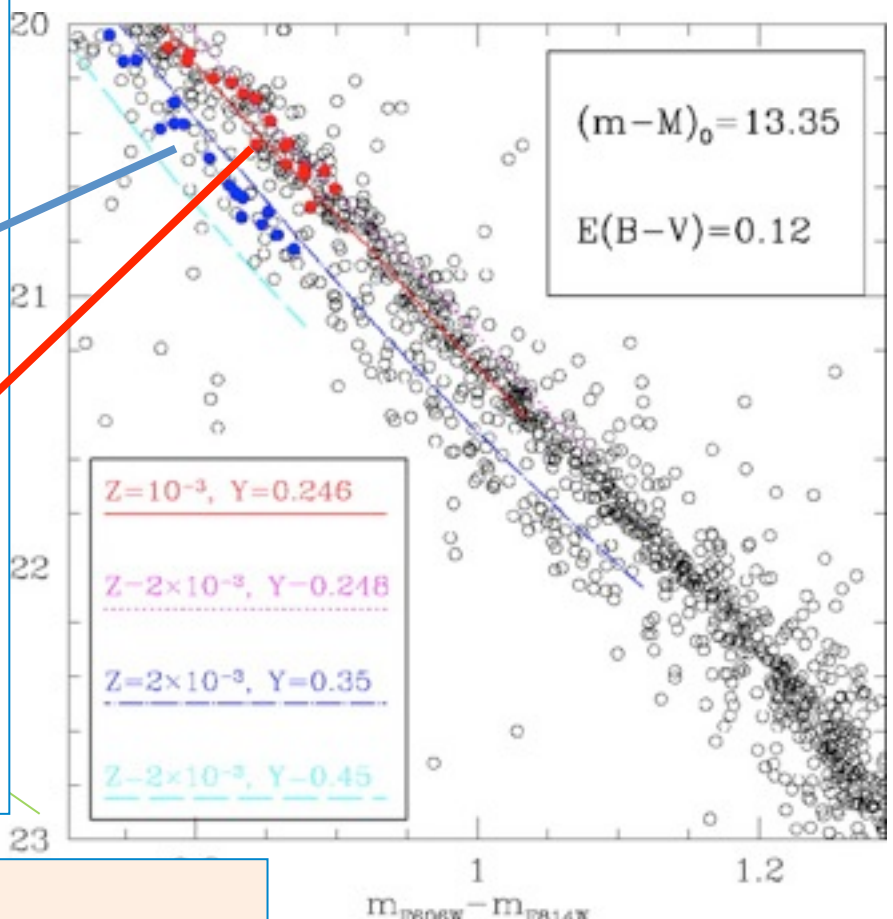
FIG. 7.—Comparison of the ACS CMD of ω Cen (calibrated following Bedin et al. 2005) with isochrones calculated for the metallicity determined in Fig. 1. The bMS can be reproduced only assuming $Y > 0.35$. The blue and red filled dots show the bMS and rMS stars from which we collected our spectra.

Multiple populations in GCs

Omega Cen



Piotto+ 2005

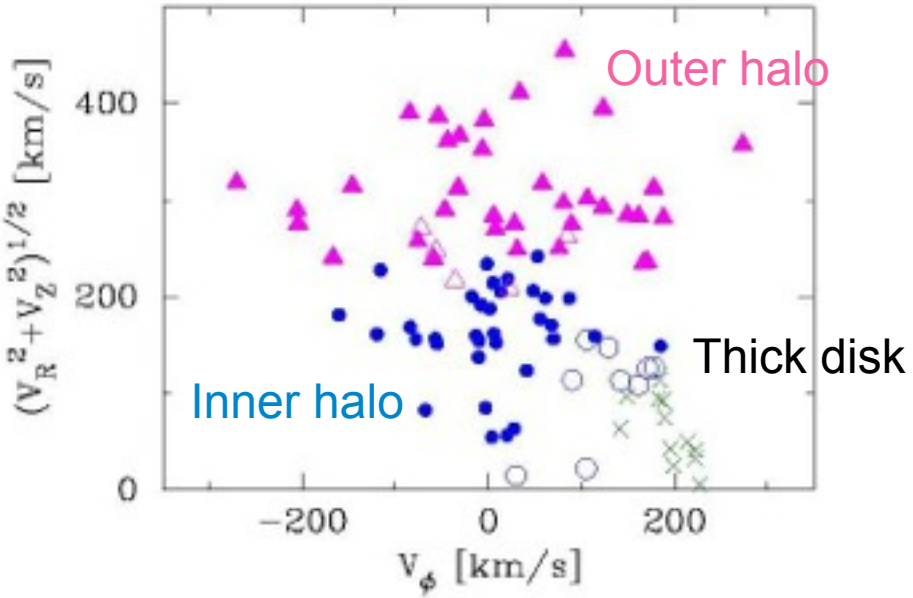


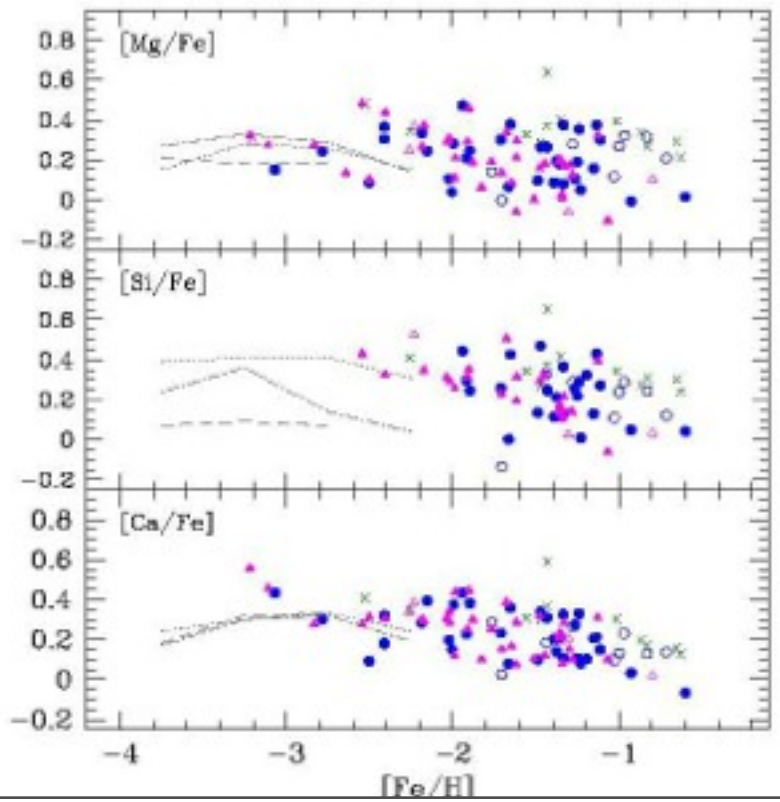
Bluer MS has a higher metallicity?
Detailed abundance pattern?
⇒ needs high res spectroscopy of MS stars w TMT

Chemical abundance in the inner/outer halo

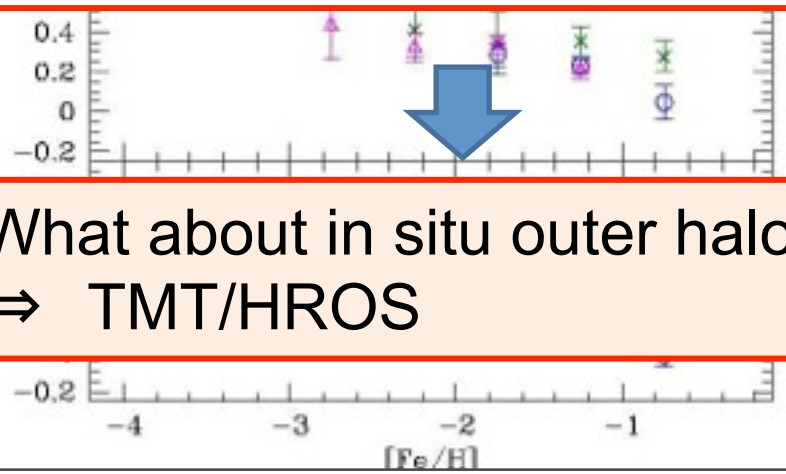
Subaru HDS results
(Ishigaki, Chiba, Aoki 2012, 2013)

Assignment based on kinematics
Thick disk: high α
Halos: mixed in α abundance
if selected by kinematics





Candidate outer halo stars having highly eccentric orbits show similar abundance patterns to inner halo stars

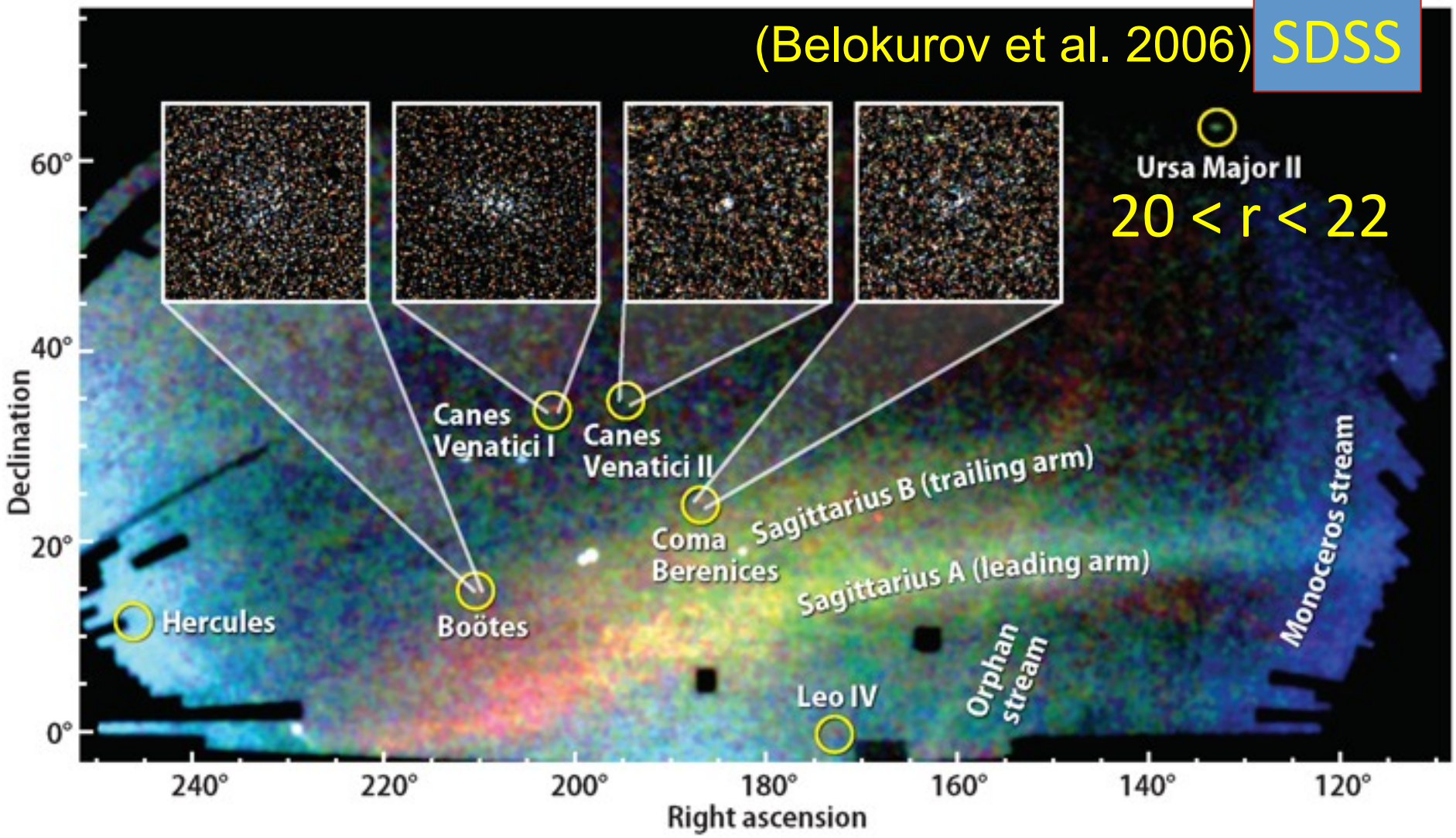


What about in situ outer halo stars?
⇒ TMT/HROS

Stellar streams in the MW halo

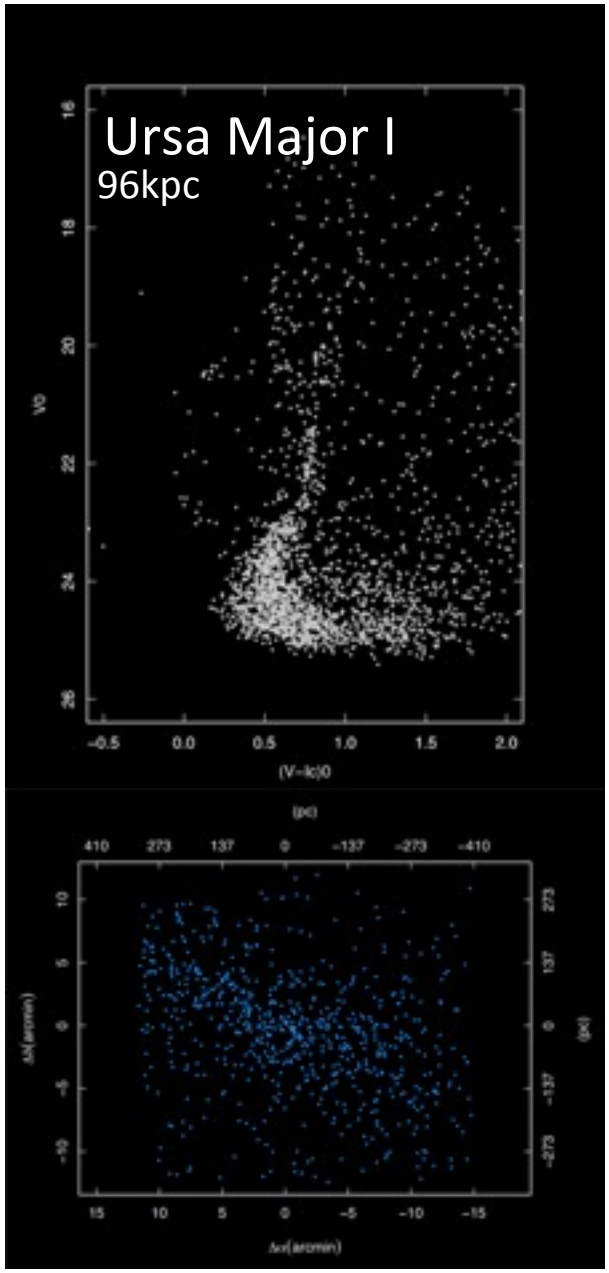
What is the origin? Relation with dSphs?
⇒needs high res spectroscopy w TMT

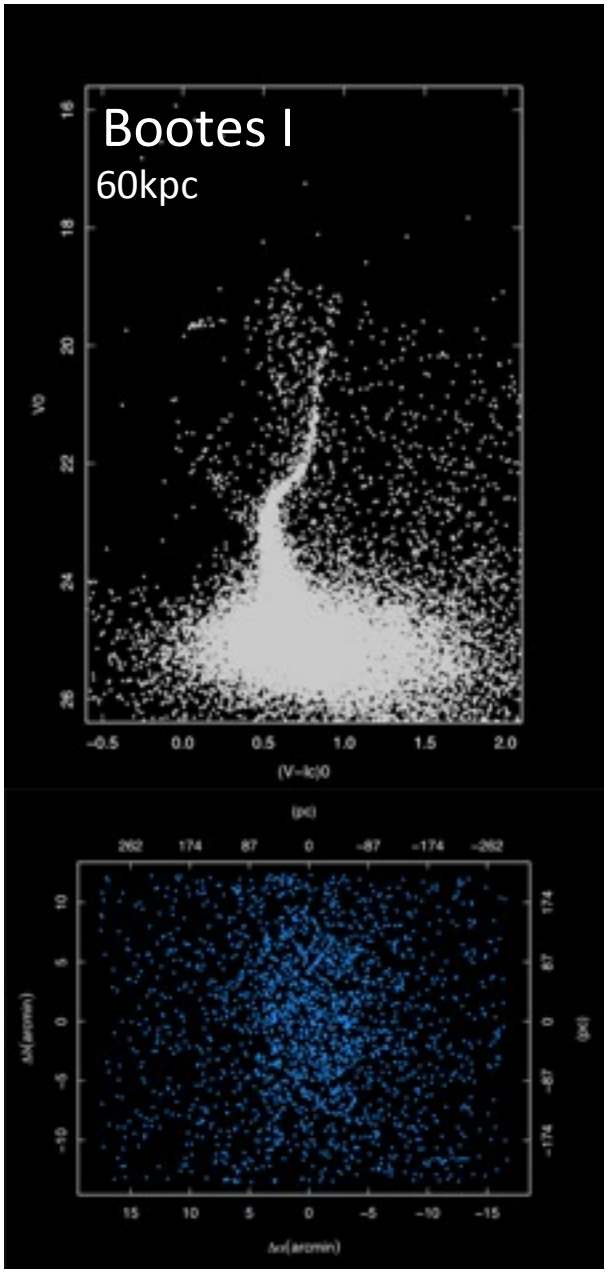
(Belokurov et al. 2006) SDSS

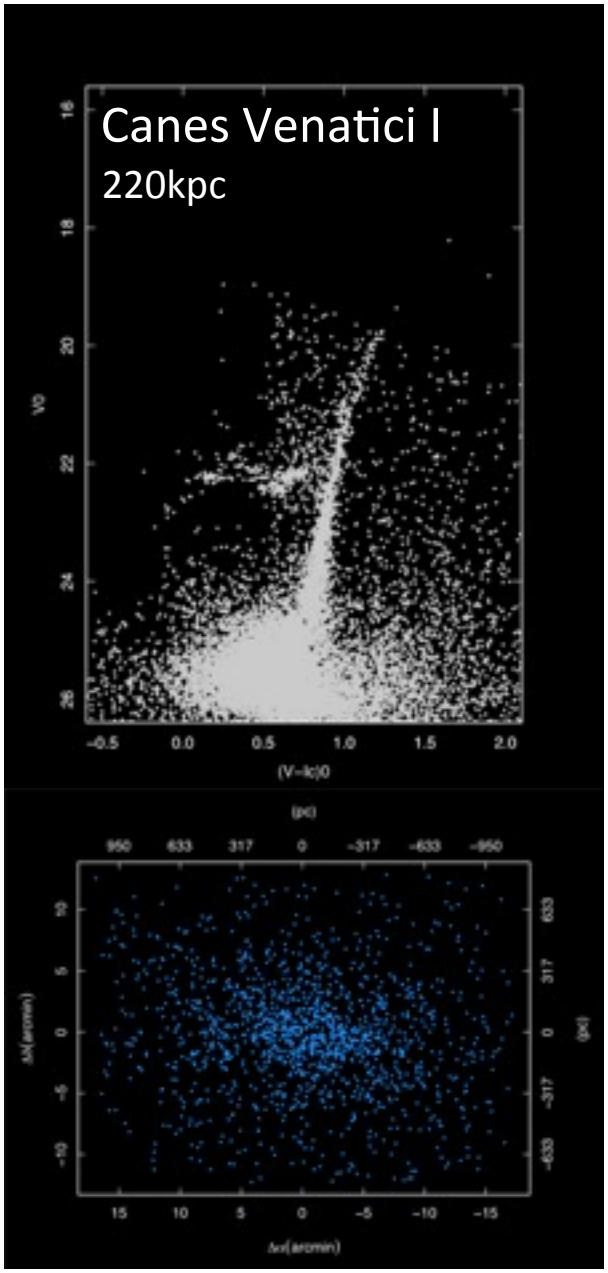


Ultra Faint DSphs (UFDs)

(Suprim Cam data by Okamoto+08)

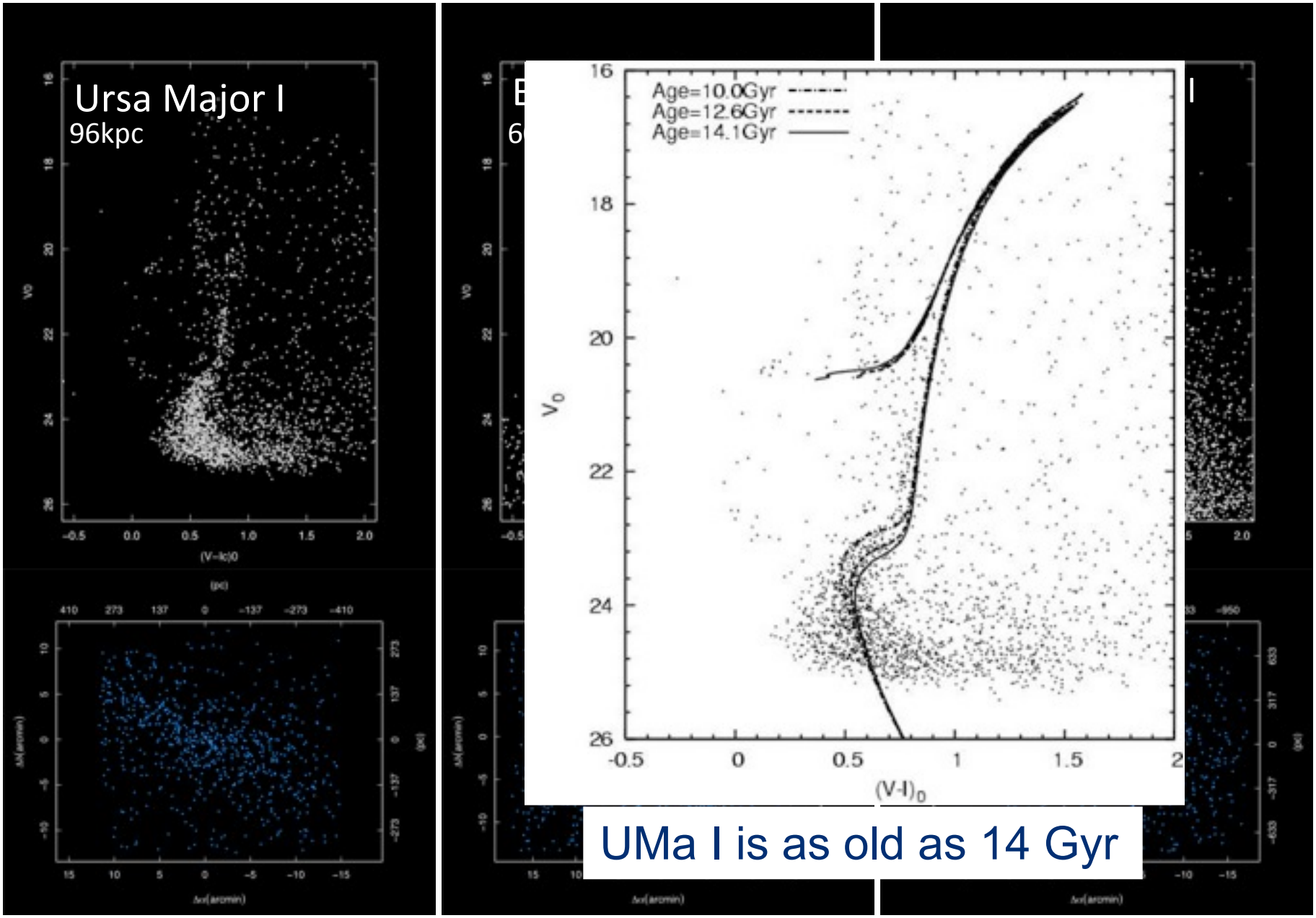






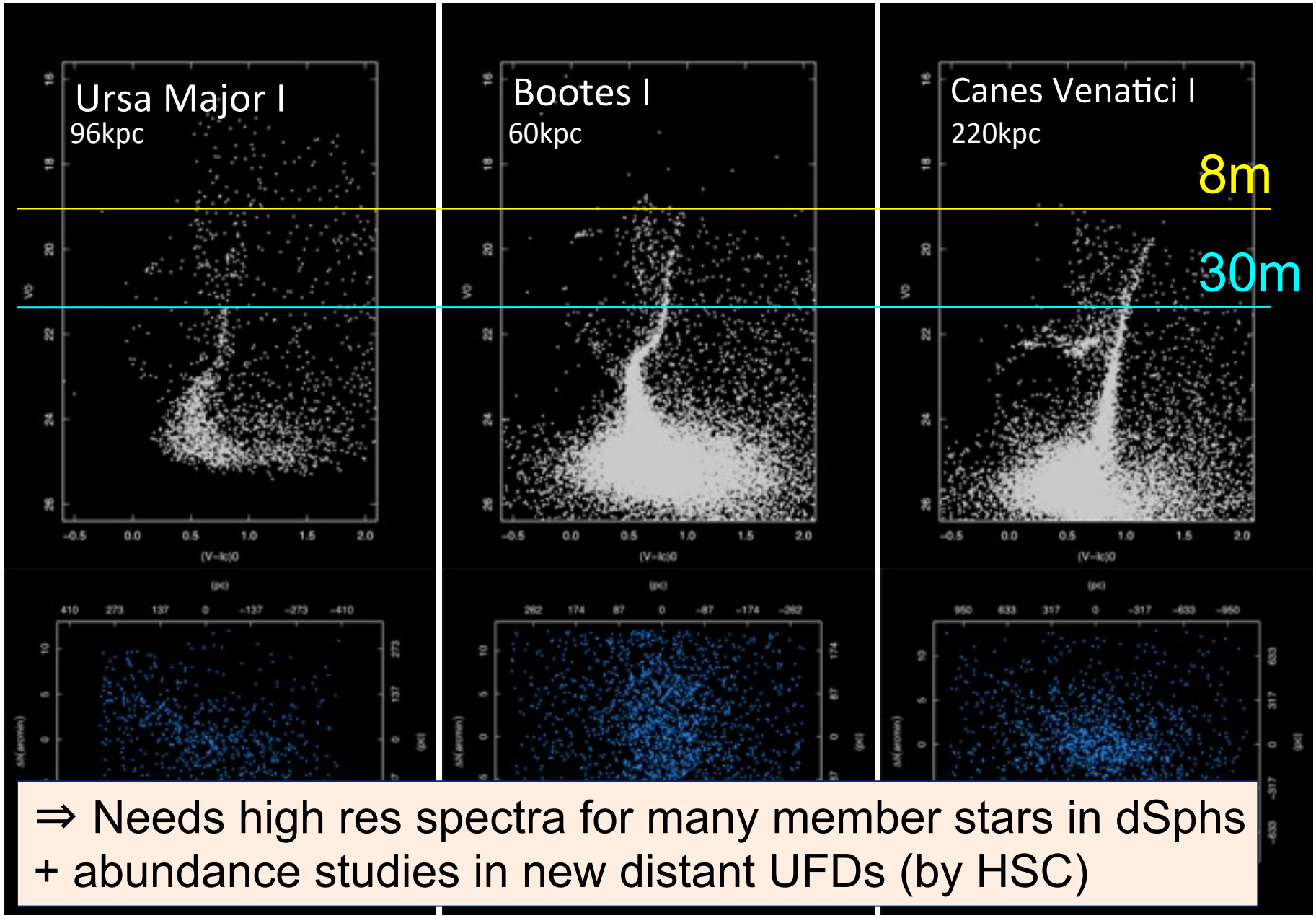
Ultra Faint DSphs (UFDs)

(Suprim Cam data by Okamoto+08)



Ultra Faint DSphs (UFDs)

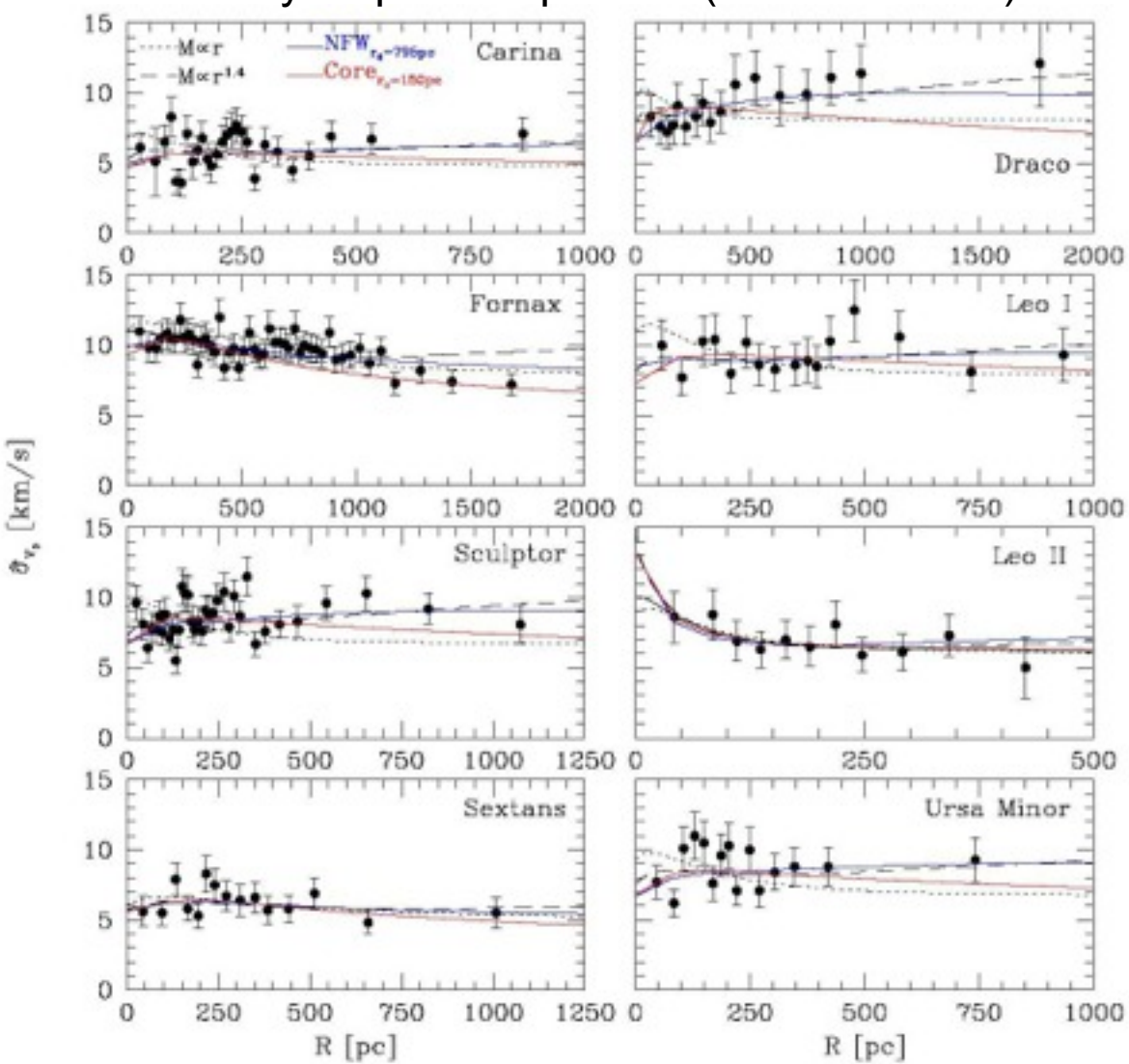
(Suprim Cam data by Okamoto+08)



⇒ Needs high res spectra for many member stars in dSphs
+ abundance studies in new distant UFDs (by HSC)

Dark matter halo in dSphs

Velocity dispersion profiles (Walker+ 2009)



$\rho(r) \propto r^{-\gamma}$

at inner parts

NFW: γ=1

Cored: γ=0

Cusp or cored?

Global distribution?

Velocity anisotropy $\beta(r)$?

High res velocity data for many (faint) member stars

Radial velocities

Proper motions?

~0.03mas/yr for stars

(10km/s at D=70kpc)

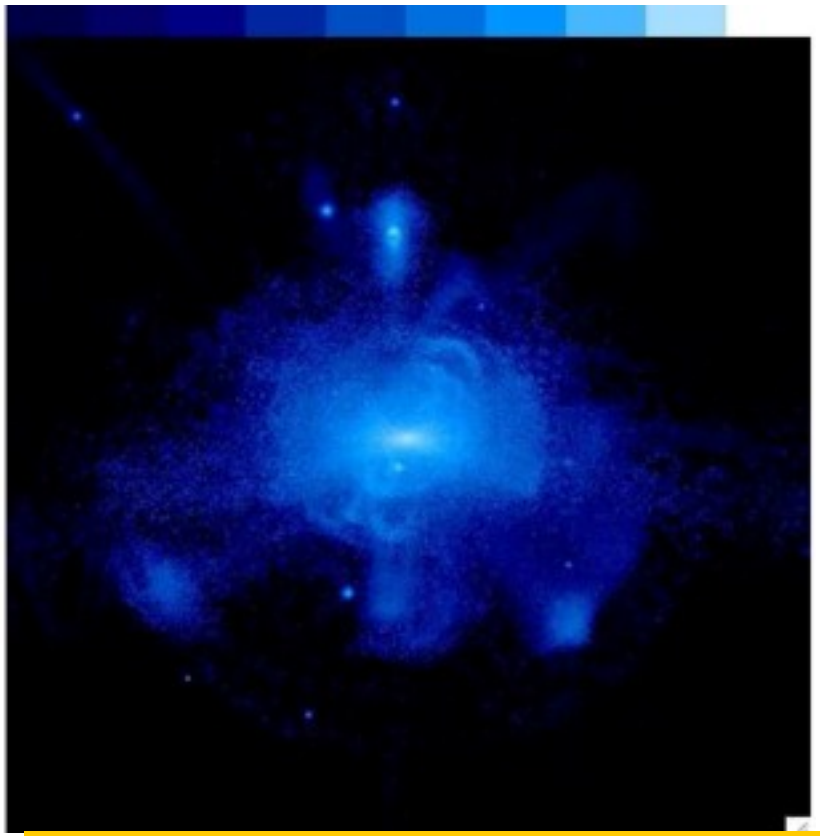
The Local Group and beyond

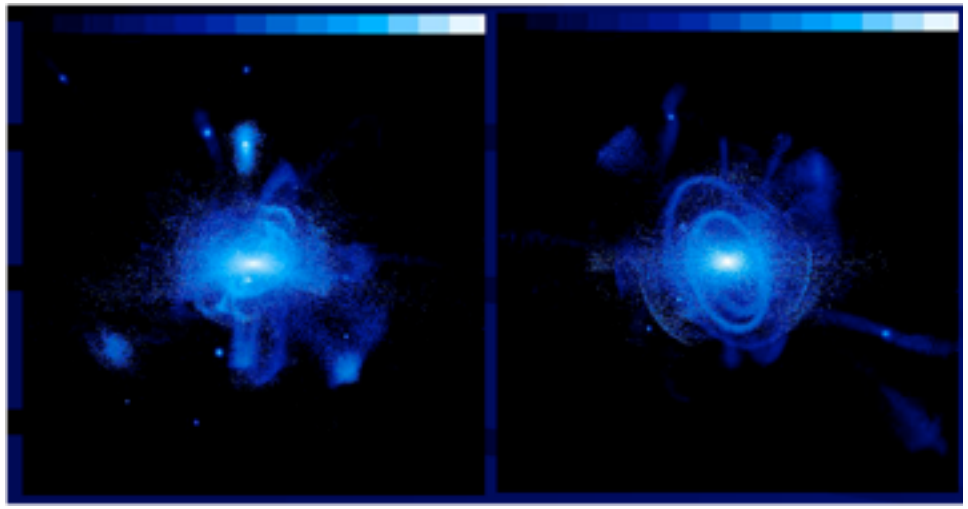
- Andromeda
  - Abundance patterns of field halo stars, stars in dSphs and globular clusters
- dIrrs in the Local Group
  - Phoenix, NGC 6822, IC 10
- Galaxies in nearby groups and beyond
  - Disk galaxies in Sculptor group, Maffei group, M81 group
  - Elliptical galaxies NGC5128 (Cen A), Maffei 1 and more in

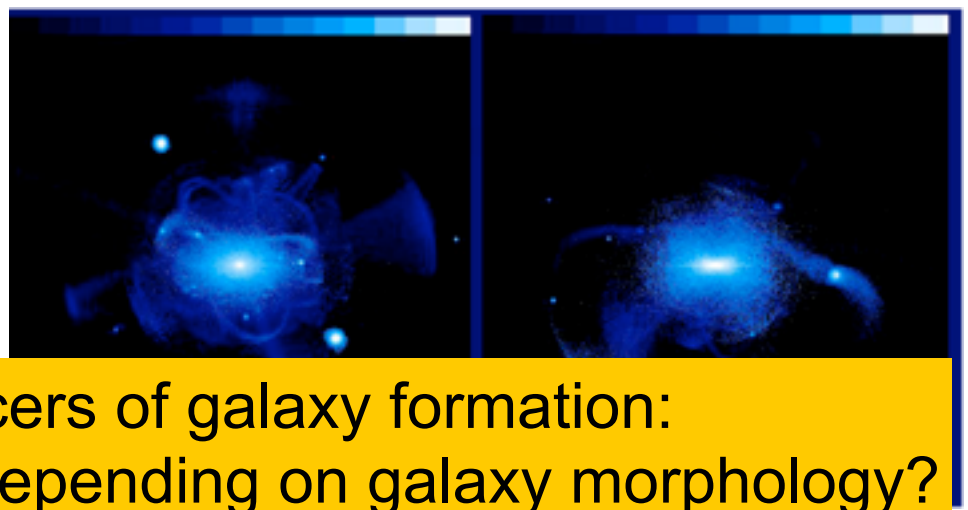
Stellar halos in galaxies

Halo formation model
(Bullock & Johnston 2005)

Halo realizations

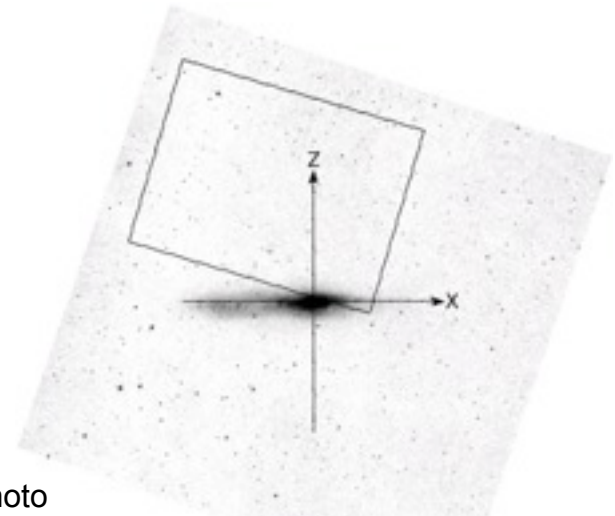


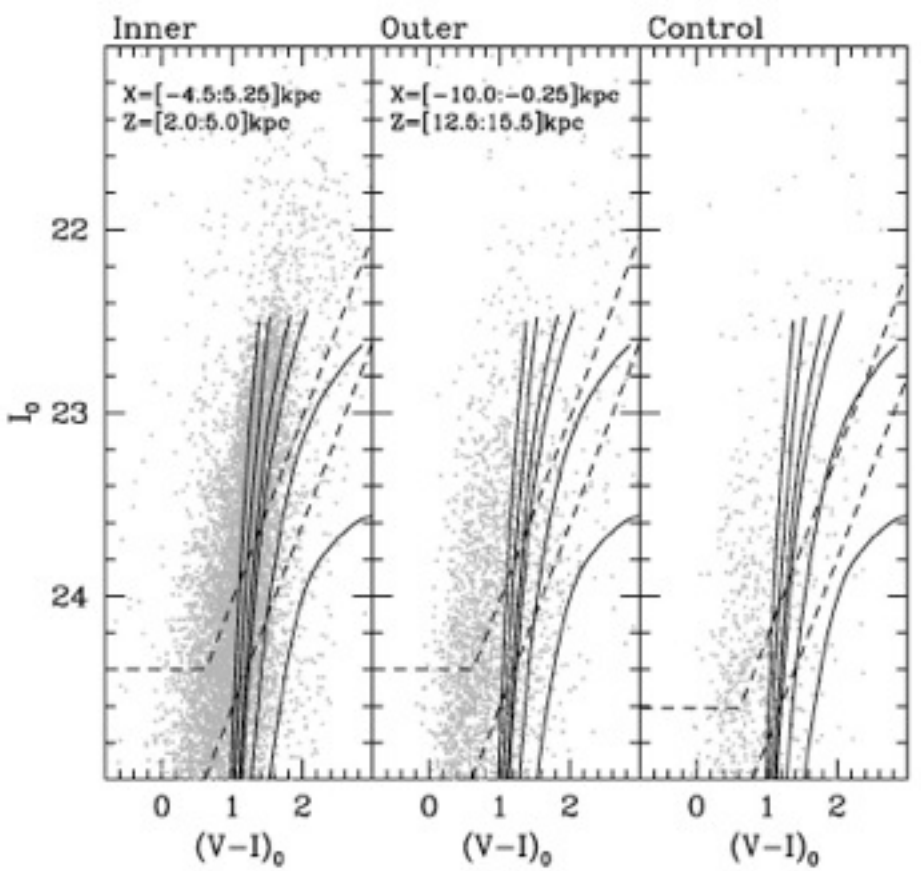




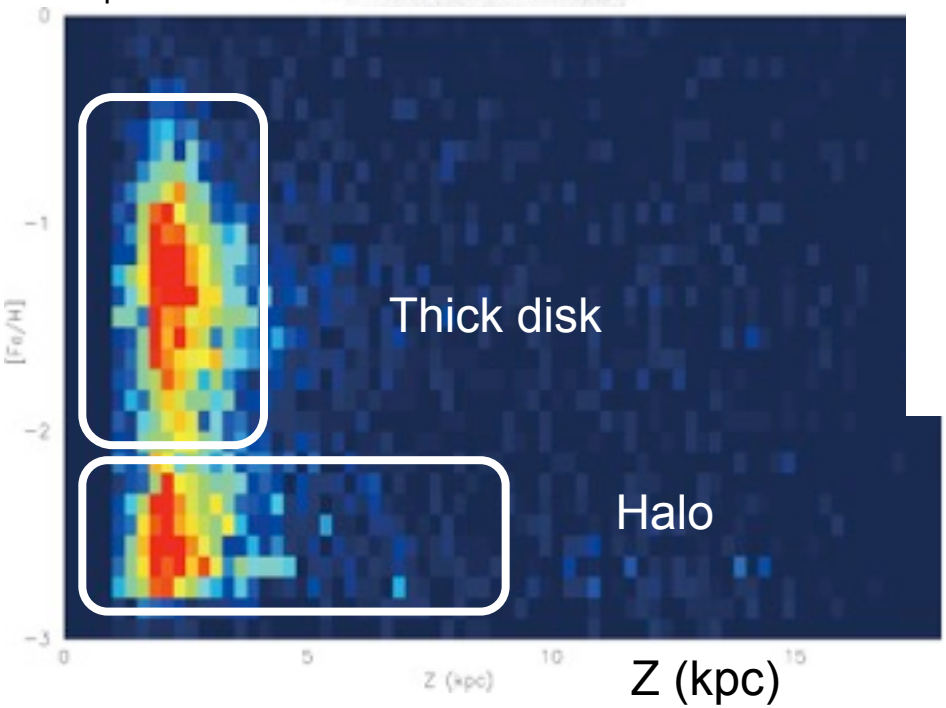
Stellar halos as tracers of galaxy formation:
Having different structures depending on galaxy morphology?

NGC 55 @ D=2.1Mpc (Sculptor group)
(Subaru/SuprimeCam: Tanaka+2011)



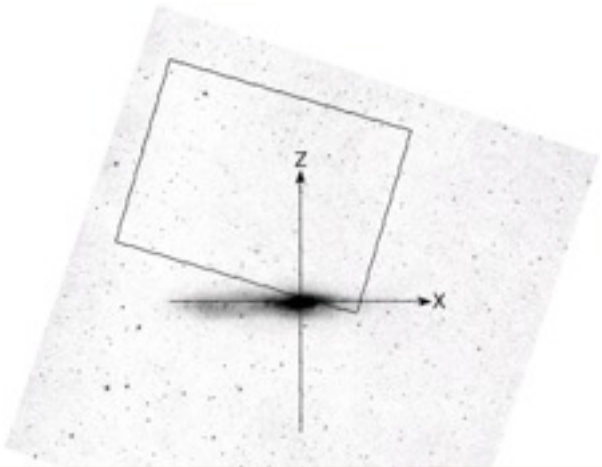


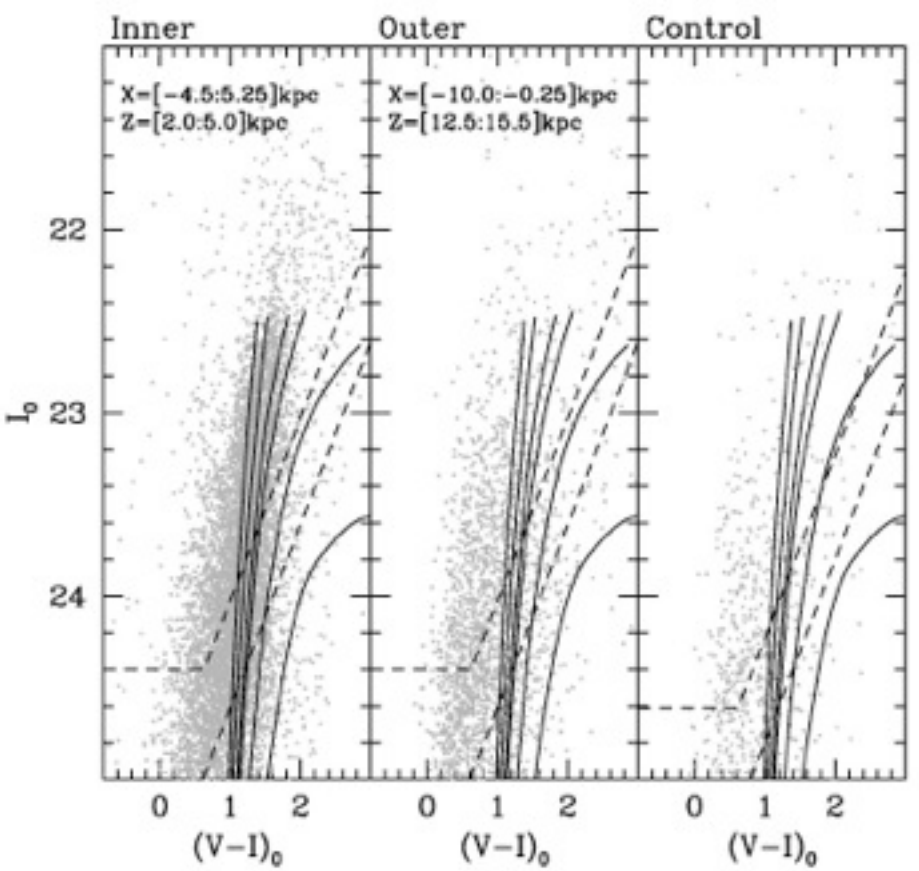
$[Fe/H]_{photo}$

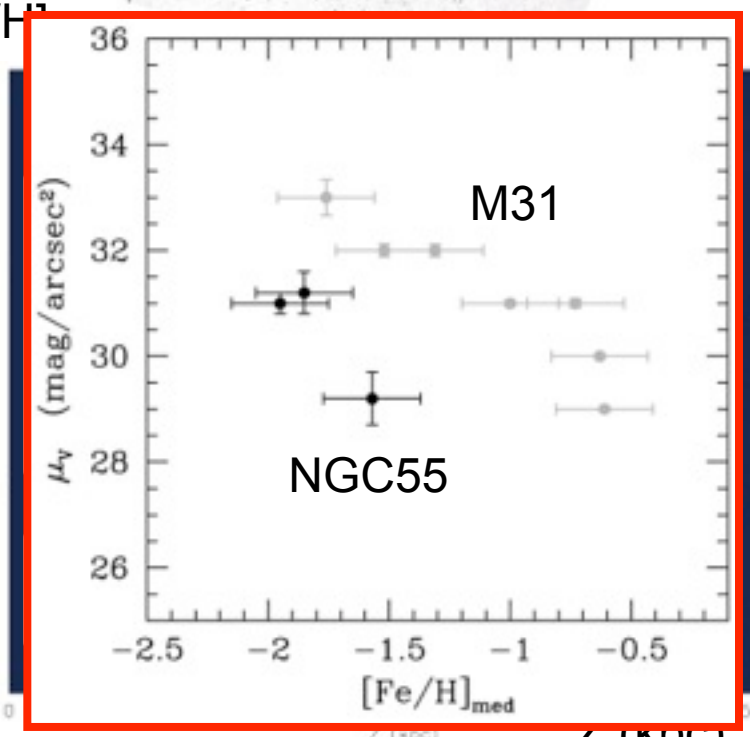


Z (kpc)

NGC 55 @ D=2.1Mpc (Sculptor group)
(Subaru/SuprimeCam: Tanaka+2011)



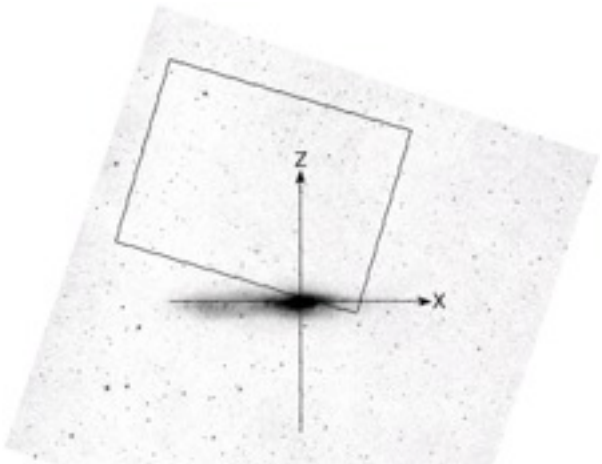


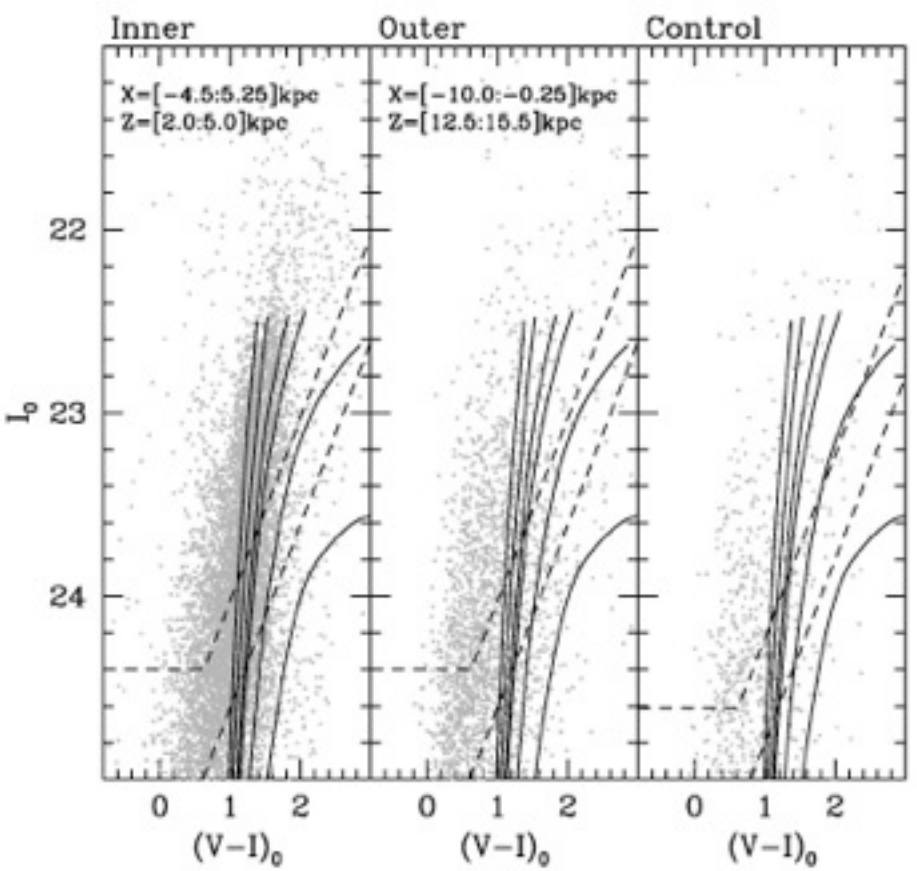


[Fe/H]

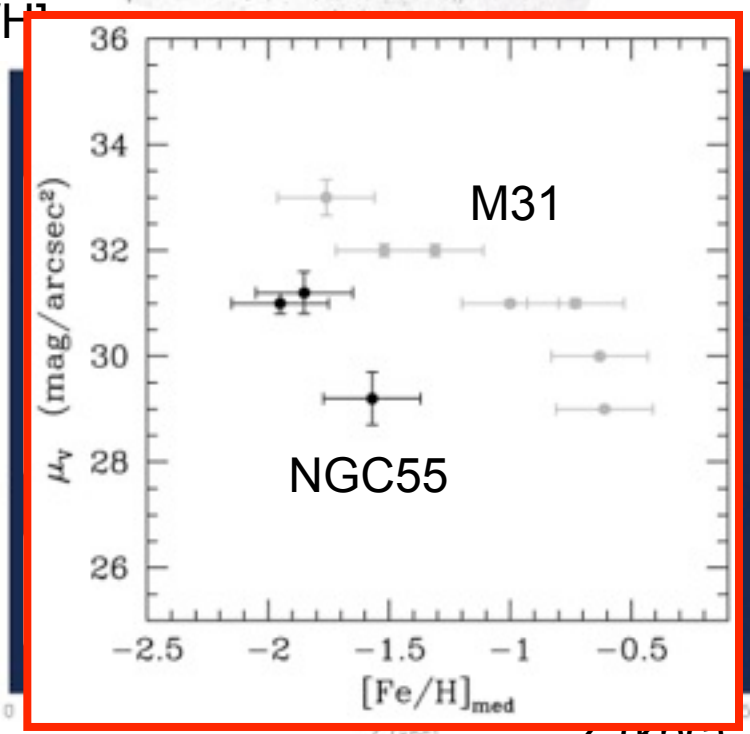
Z (kpc)

NGC 55 @ D=2.1Mpc (Sculptor group)
(Subaru/SuprimeCam: Tanaka+2011)





[Fe/H]



Z (kpc)

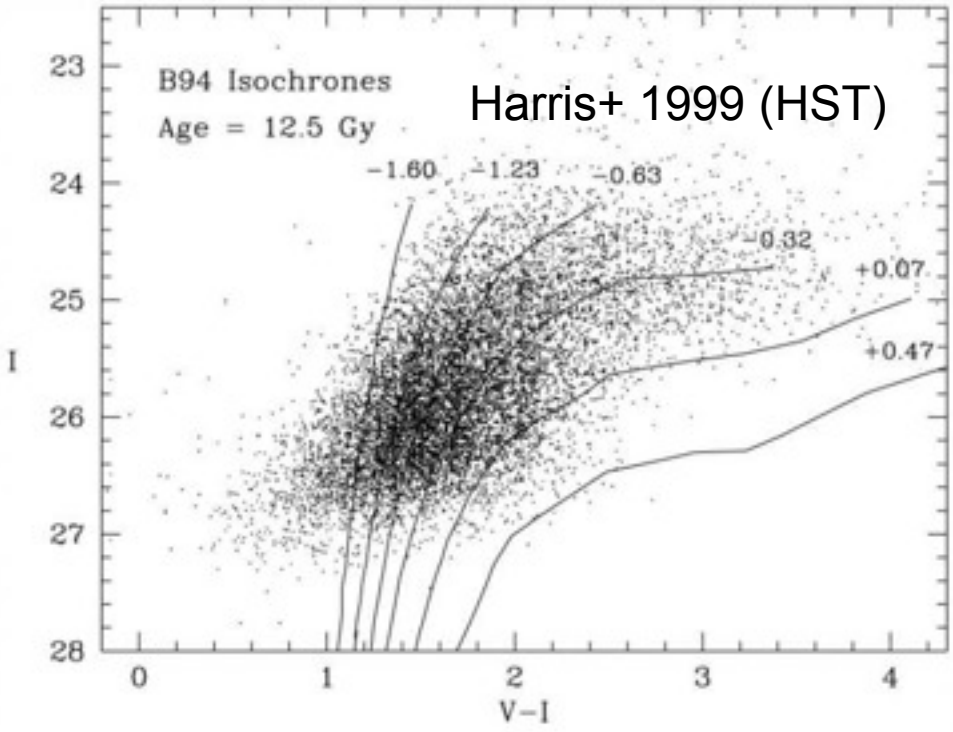
Deep imaging + medium res spectra with TMT
⇒ stellar age, abundance and velocity

M81 @ D=3.6Mpc
(Subaru/SuprimeCam: Barker+ 2009)

Nearby elliptical galaxies
NGC5128 (Cen A)

DEC=-43
D=3.6Mpc

Peng+ 2002 (Blanco T.)



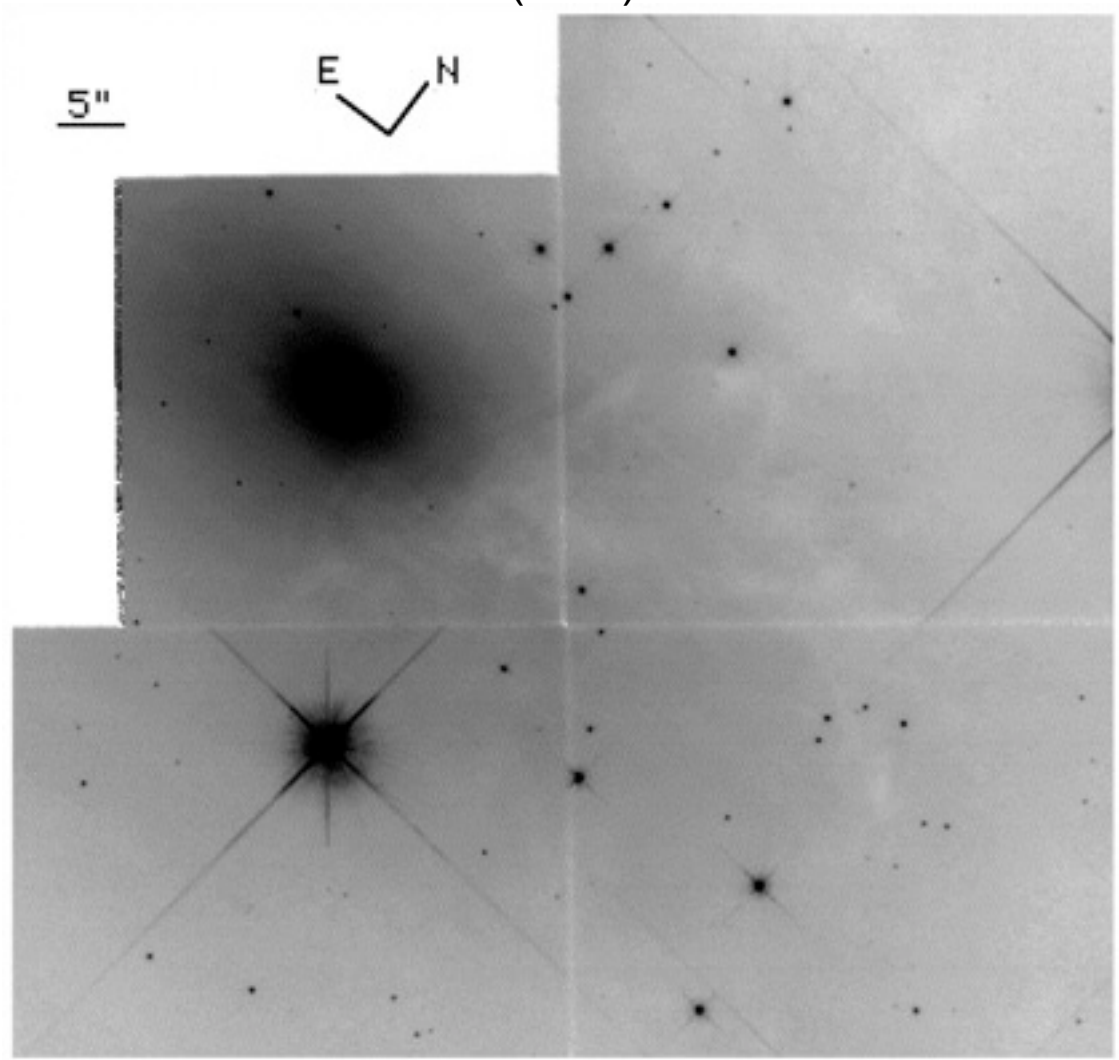
Harris+ 1999 (HST)

Deep imaging + medium res spectra with TMT
⇒ stellar age and abundance

Nearby elliptical galaxies
Maffei 1

Buta+ 2003 (HST)

b=-0.5
D=3.0Mpc

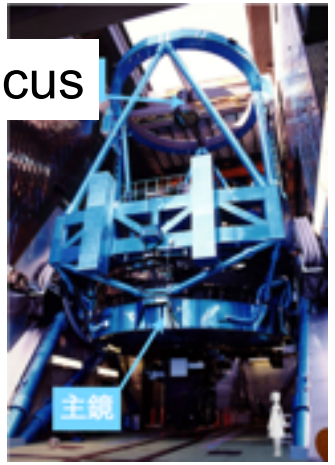


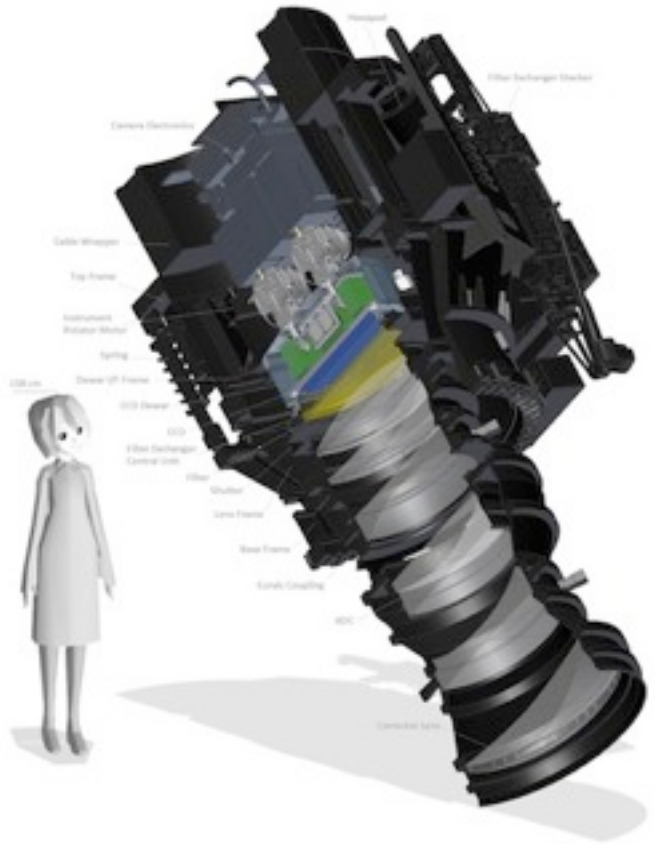
Subaru for TMT

- Hyper Suprime Cam (HSC) provides
  - The MW's (faint) halo map + new UFDs and stellar streams
  - More basic data of Andromeda's halo
- Prime Focus Spectrograph (PFS) provides
  - Candidate extremely metal-poor stars
  - More member stars in dSphs and Andromeda

HSC
(Hyper Suprime Cam)

Prime focus





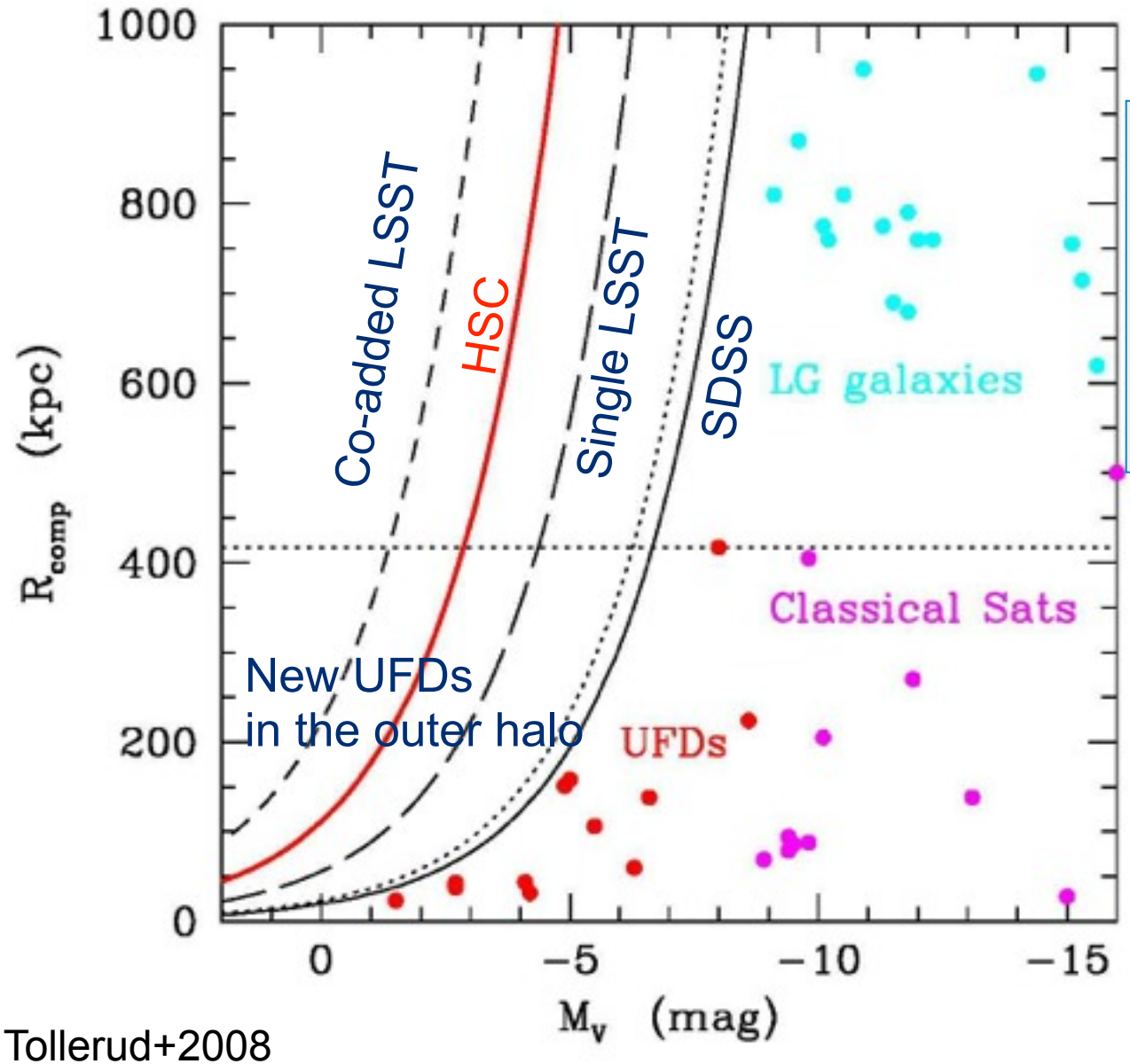
FOV: 1.77 sq deg
(1.5 deg diameter)
Pixel scale: 0”.17/pix
Filters: grizy
+ several NB
Operation: 2013~

International collaboration: Japan, Princeton, Taiwan

HSC

Wide-field FoV is essential for mapping stars

Search for new Galactic satellites with HSC



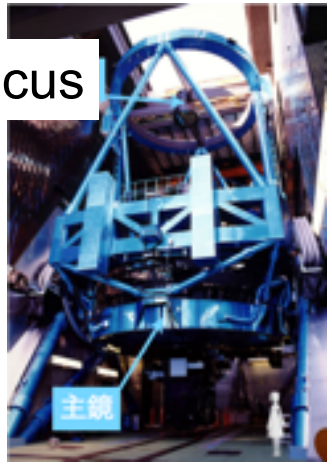
Tollerud+2008

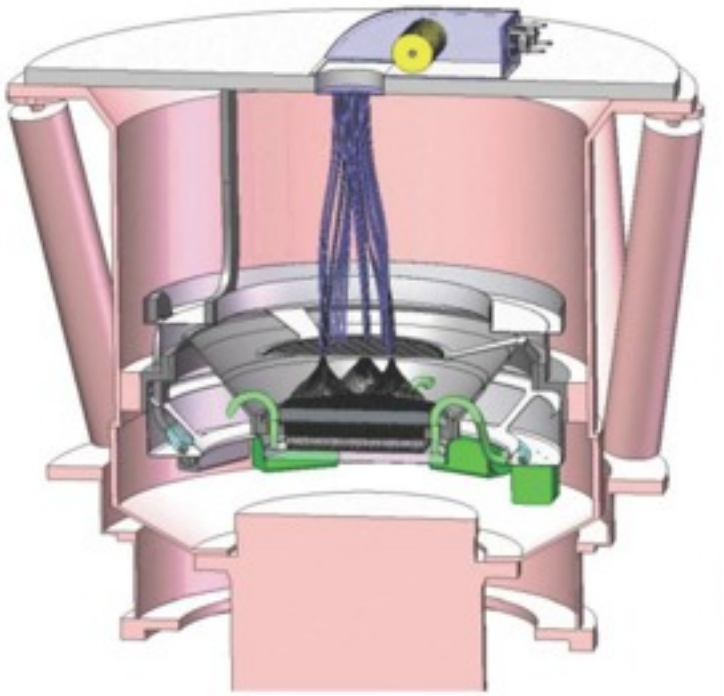
Wide-field survey of the MW outer halo

(g, r, i) ~ 26 mag
over ~1400 deg^2
Discovery of new UFDs
and stellar streams

Single LSST:
r_{lim} = 24.5
Co-added LSST:
r_{lim} =27.5
Subaru/HSC
(wide-f. survey):
r_{lim}~26

PFS
(Prime Focus Spectrograph)





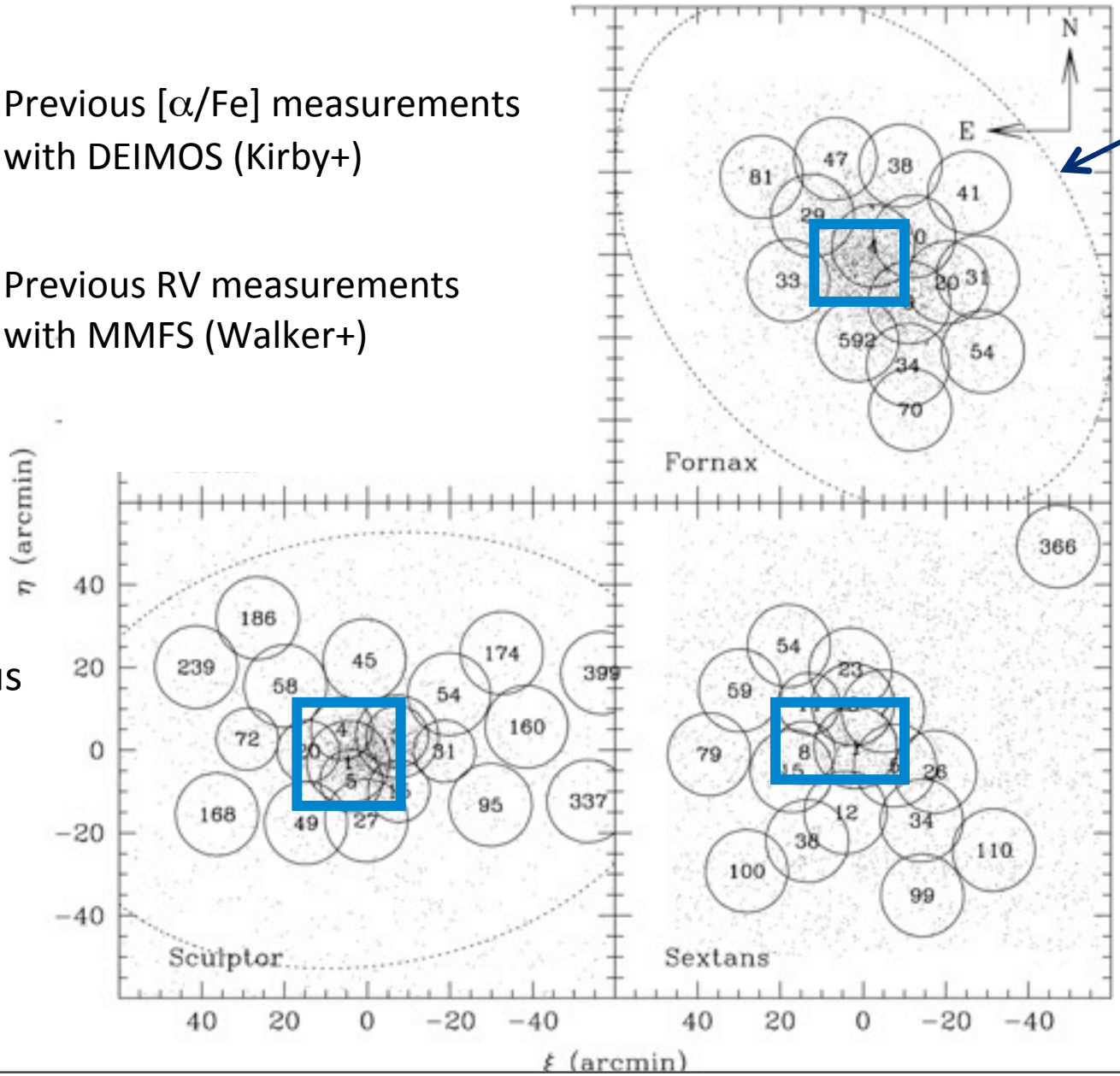
FOV: 1.3 deg in diameter
2400 fiber positioners
λ: 380~1,300 nm
(3 channels: Blue, Red, IR)
R: ~3,000 (LR) 5,000 (MR)
First light: 2016~17

International collaboration: IPMU, NAOJ/Subaru,
Caltech/JPL, Princeton, JHU, LAM, UK, Brazil, Taiwan +

Scuplto r, Fornax, Sextans

Previous [α/Fe] measurements with DEIMOS (Kirby+)

Previous RV measurements with MMFS (Walker+)



Tidal radius
r_t ~ 71’

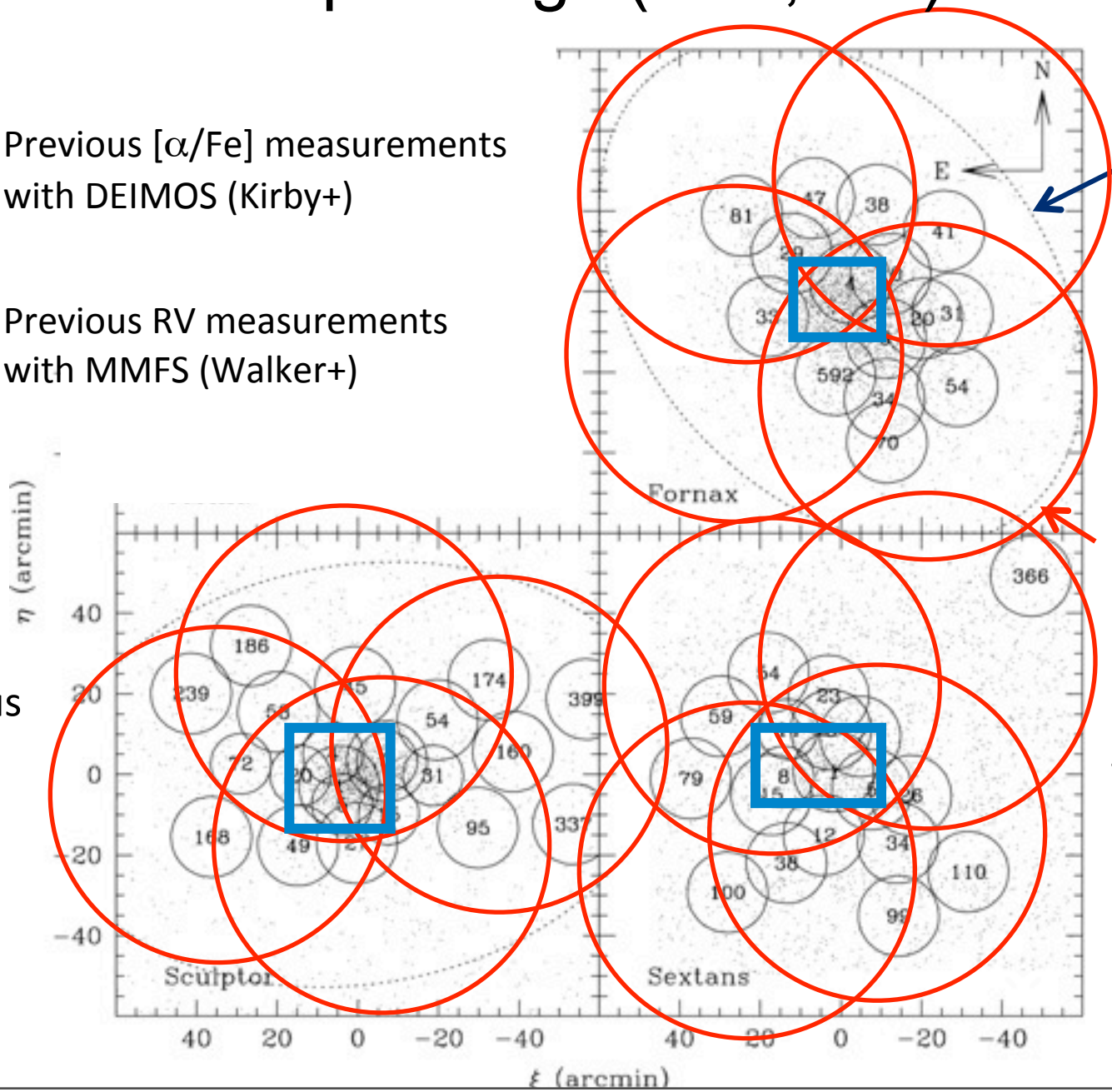
Tidal radius
r_t ~ 76’

Tidal radius
r_t ~ 160’

PFS pointings (R=5,000)

Previous [α/Fe] measurements with DEIMOS (Kirby+)

Previous RV measurements with MMFS (Walker+)



Tidal radius
r_t ~ 71’

PFS pointing

Tidal radius
r_t ~ 76’

Tidal radius
r_t ~ 160’

Exploring the local universe with TMT: Summary

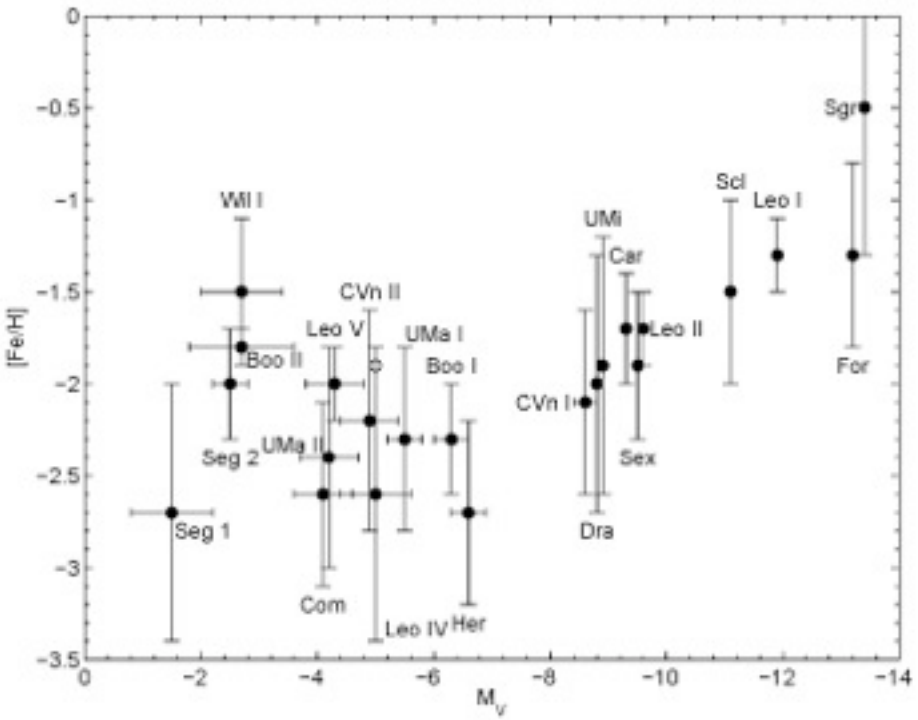
- Stars in the MW's old components (D < 50 kpc)
  - High res spectra for MS, MSTO and RGB stars in the bulge, thick disk and inner halo
- Remote Galactic halo stars and dSphs (D < 500 kpc)
  - High res spectra for RGBs in the outer halo
  - Medium res spectra for Galactic HBs and for dSphs' RGBs
- Andromeda and other Local Group members (D < 1Mpc)
  - High res spectra for brightest RGBs
- Other group galaxies (3Mpc < D)
  - Medium res spectra for RGBs

Chemo-dynamical information of nearby galaxies
⇒ galaxy formation

END

Chemical abundance of dSphs

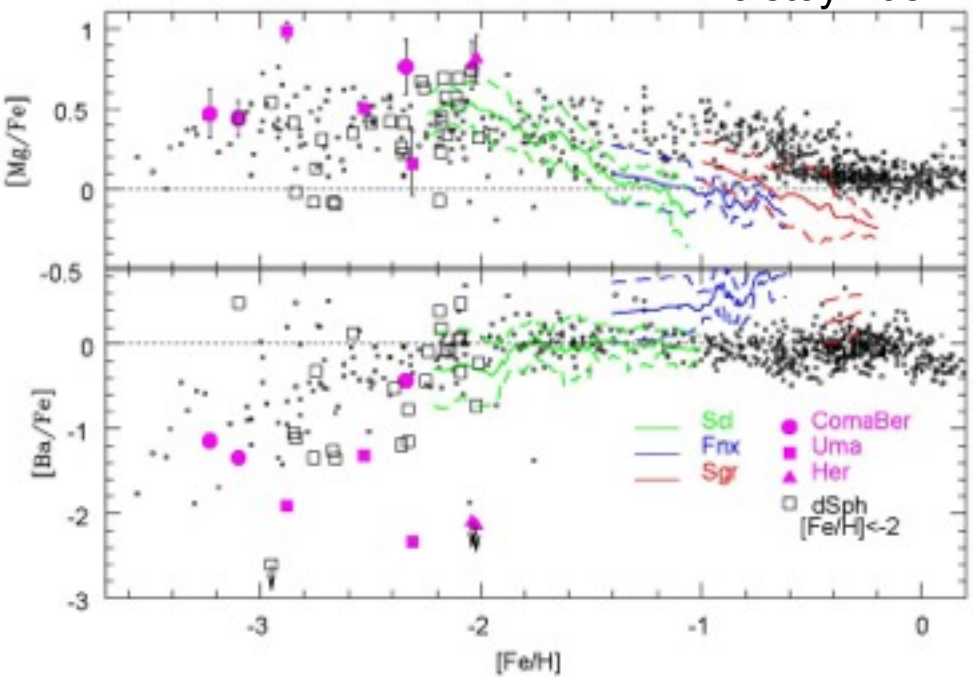
Mean metallicity vs. luminosity



UFDs show different mean metallicities?

Abundance ratios in dSphs

Tolstoy +08



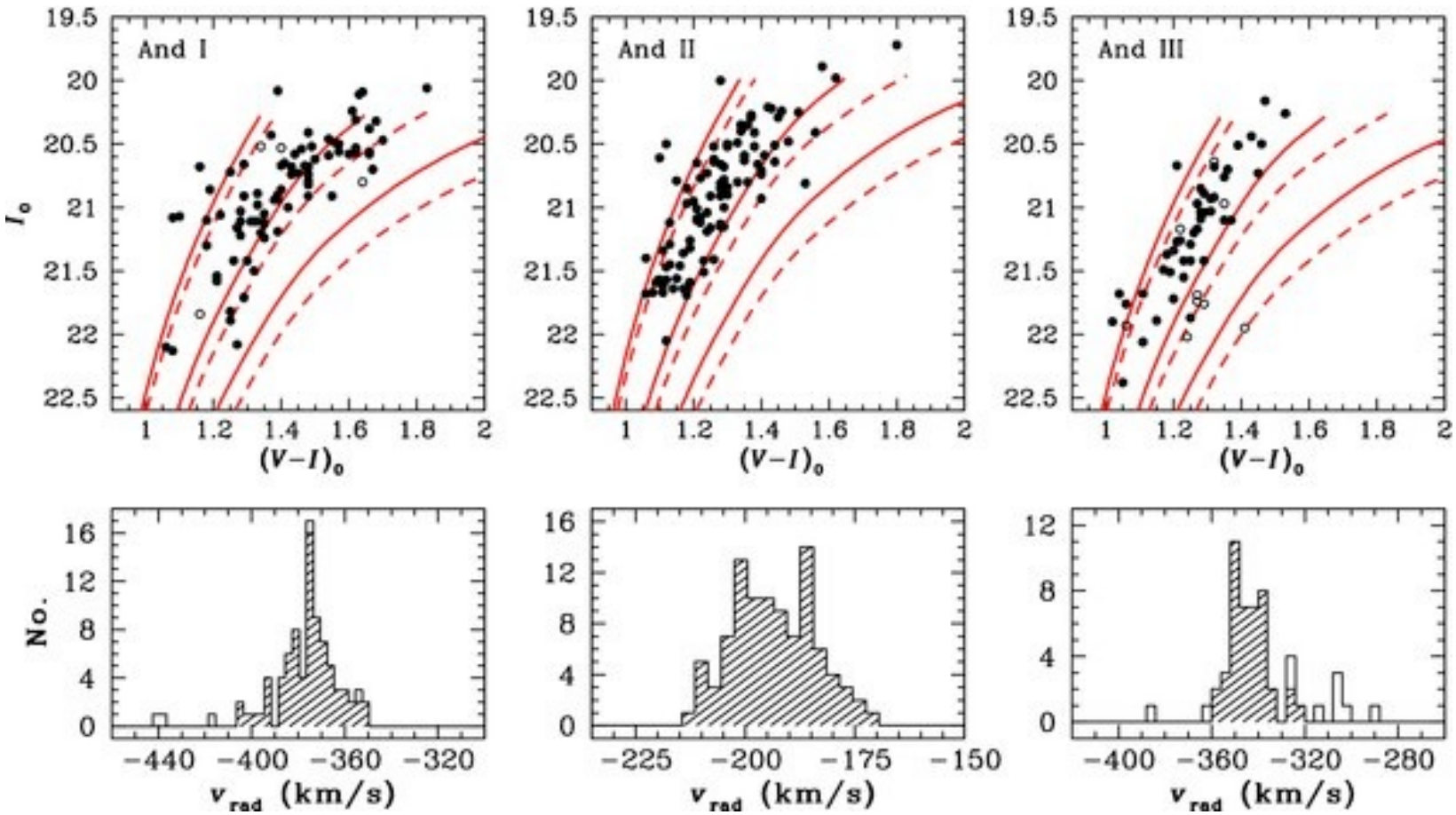
Similar to or different from halo stars?

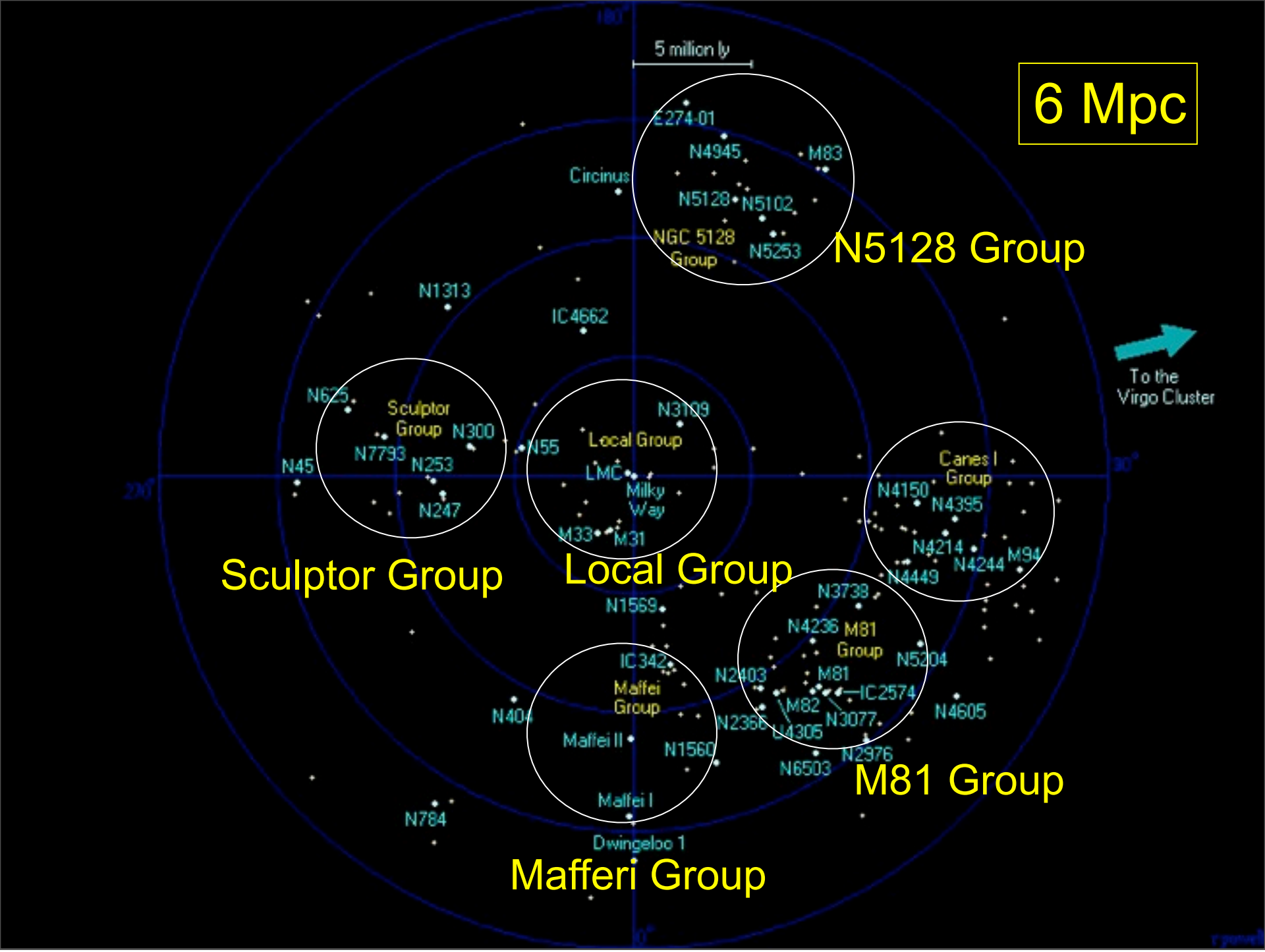
⇒ Needs high res spectra for many member stars in dSphs
+ abundance studies in new distant UFDs

dSphs in Andromeda
Keck/DEIMOS sample

Chemical abundance pattern?
⇒ needs high res abundance of bright RGBs

Kalirai et al. 2010




6 Mpc
5 million ly
E274-01
N4945
M83
Circinus
N5128
N5102
NGC 5128
Group
N5253
N5128 Group
N1313
IC4662
To the
Virgo Cluster
N625
Sculptor
Group
N300
N7793
N253
N45
N247
Sculptor Group
N3109
N55
Local Group
LMC
Milky
Way
M33
M31
Local Group
Canes I
Group
N4150
N4395
N4214
N4244
M94
N4449
N3738
N1569
N4236
M81
Group
N5204
IC342
N2403
M81
Maffei
Group
IC2574
M82
N3077
N4605
N404
N2366
N4305
Maffei II
N1560
N2976
N6503
M81 Group
Maffei I
N784
Dwingeloo 1
Mafferi Group