Resolved stellar halos in early type galaxies

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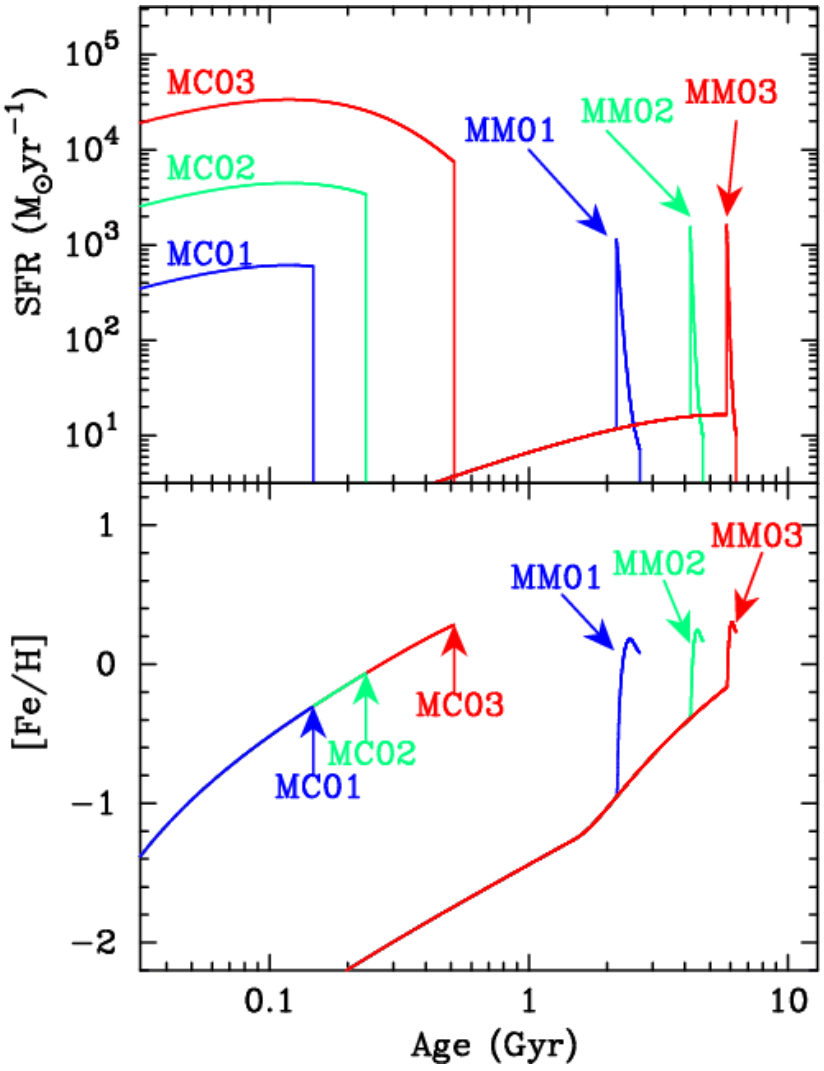
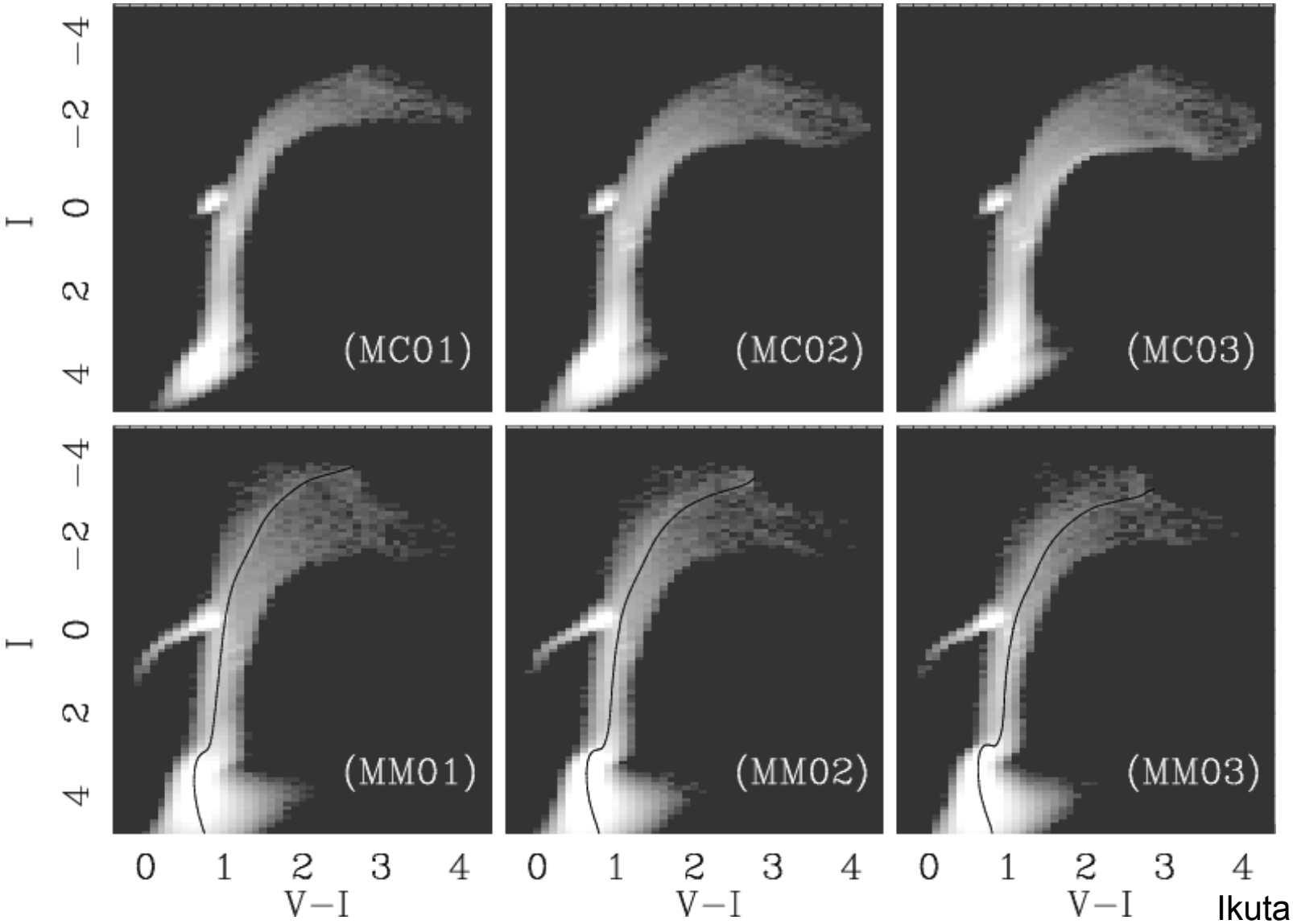
Early type galaxy formation scenarios

- Early monolithic collapse scenario:
  - assembly in a dissipative gaseous collapse, either from a unique cloud or many gaseous clumps, but not out of preexisting stars (e.g. Eggen, Lynden-Bell & Sandage 1962)
- Hierarchical merging scenario:
  - successive non-dissipative mergers of smaller systems over an extended time likely forming from pre-existing disk galaxies' stars (Toomre 1977, Kauffmann+93)



Ikuta 2007

Formation diagnostics from model colour-magnitude diagrams

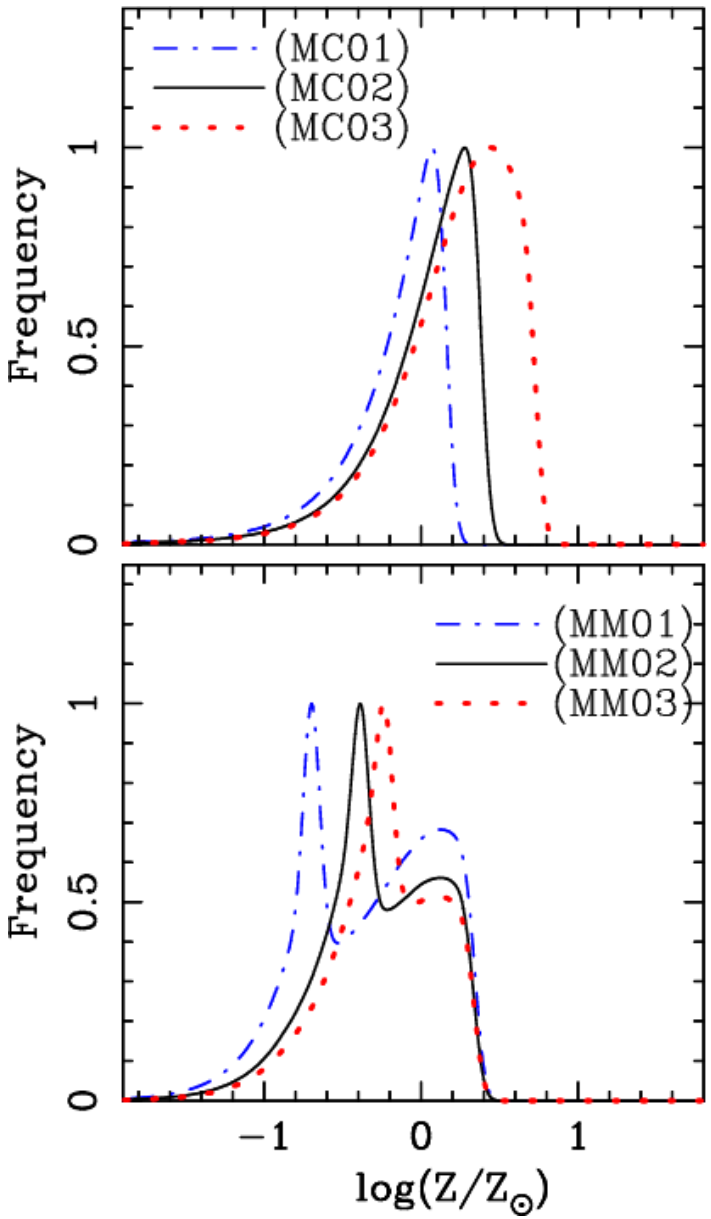


Ikuta 2007

Formation diagnostics from model CMDs

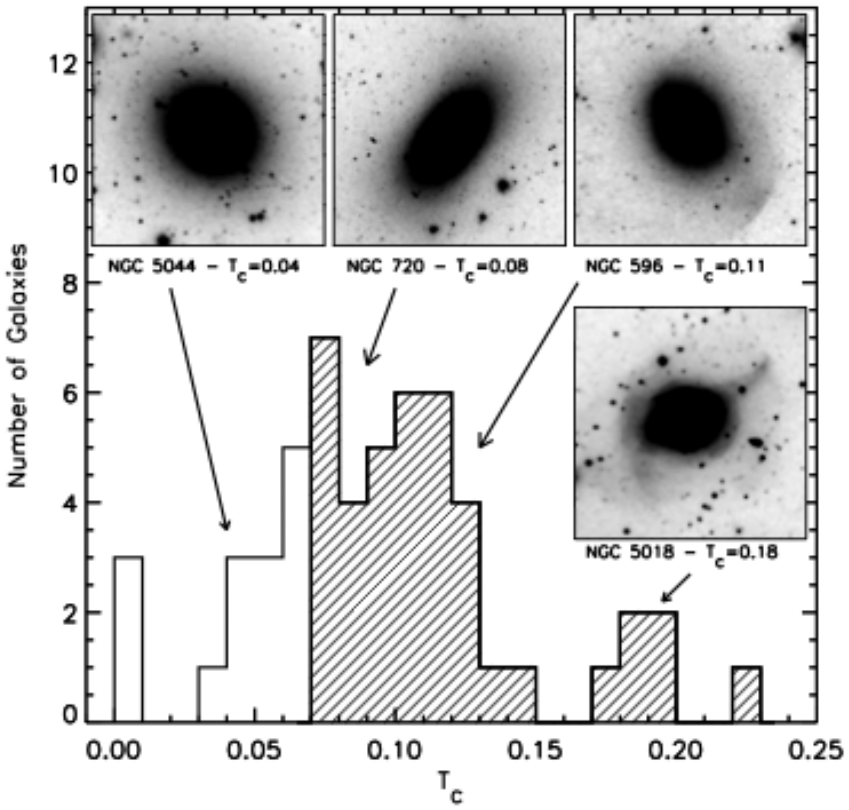
Ikuta 2007:

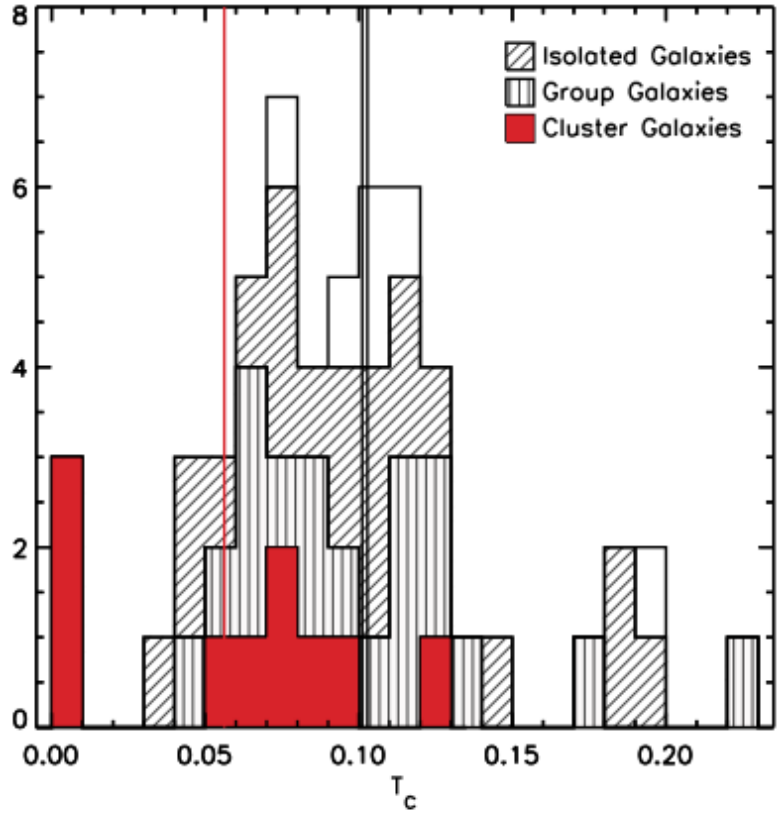
- Early monolithic collapse (MC) scenario:
  - ⇒ **single peak & metal-rich MDF**
  - ⇒ **red HB**
- Hierarchical merging (MM) scenario:
  - ⇒ **two peaks in MDF – higher frequency of metal-poor stars, which are born in the progenitor galaxies**
  - ⇒ **blue (extended) HB**



Frequency of tidal features in nearby luminous elliptical galaxies

Tal et al. 2009: tidal disturbance in 73% of nearby luminous elliptical galaxies
→mass assembly rate of *dM/M* ~ 0.2 per Gyr
→elliptical galaxies grow through mostly "dry" mergers (little star formation)





Name	Type	M_V (mag)	$(m-M)_0$ (mag)	Distance (Mpc)	Environment	Resolved stellar pops studies
Maffei 1	E	-21.6	27.7 A_V~5.1	3.4	Maffei/IC342 group	Davidge+01,02; Wu+14
NGC 5128 = Cen A	E/S0 pec; Sy2	-21.5	27.91	3.8	Centaurus A group	Soria+96; Harris+99, 00,02; Ferrarese+07; Rejkuba+03,05,11,14; Crnojevic+13; Bird+14
NGC 3115	S0	-21.1	30.05	10.2	NGC 3115 group	Elston 1997; Peacock+15
NGC 3379 = M 105	E1	-20.9	30.06	10.2	Leo I group	Sakai+97; Gregg+04; Harris et al. 2007b
NGC 3377	E5	-20.0	30.17	10.8	Leo I group	Harris et al. 2007a
M 87 = NGC 4486	E0 pec; Syfert; cD	-22.5	31.08	16.4	Virgo cluster	Bird et al. 2010

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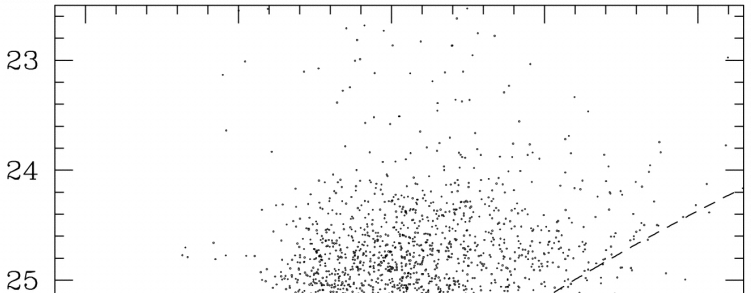
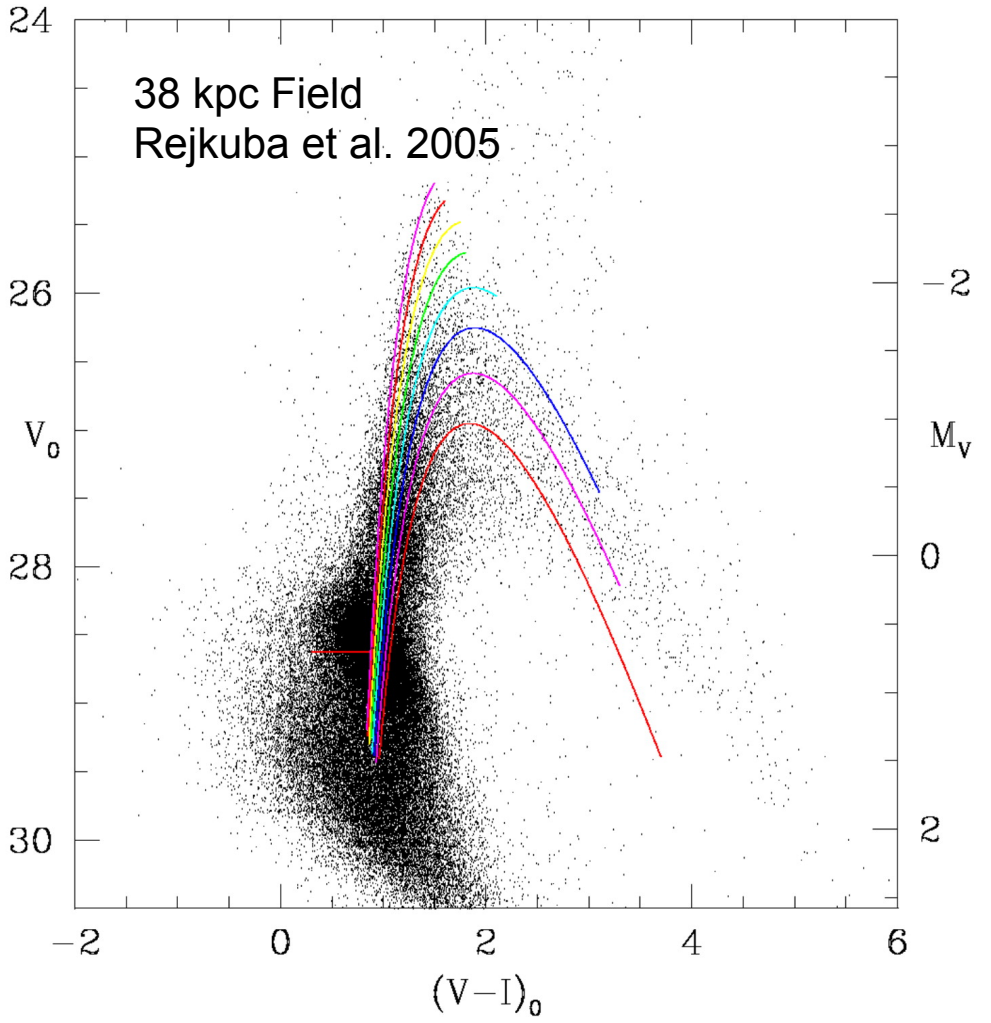
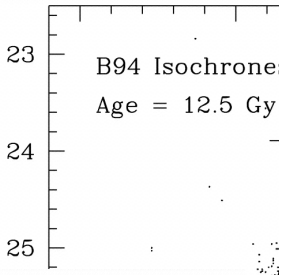
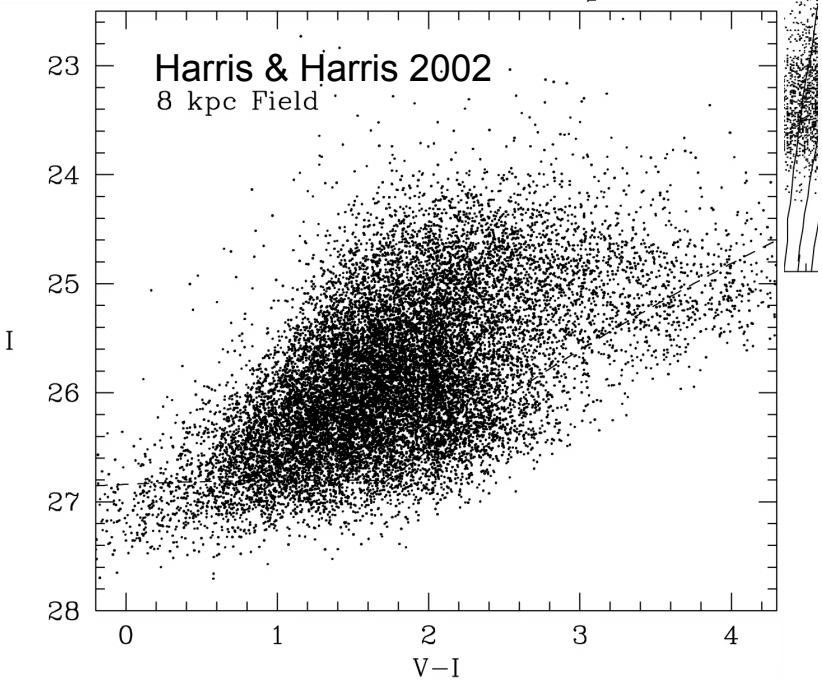
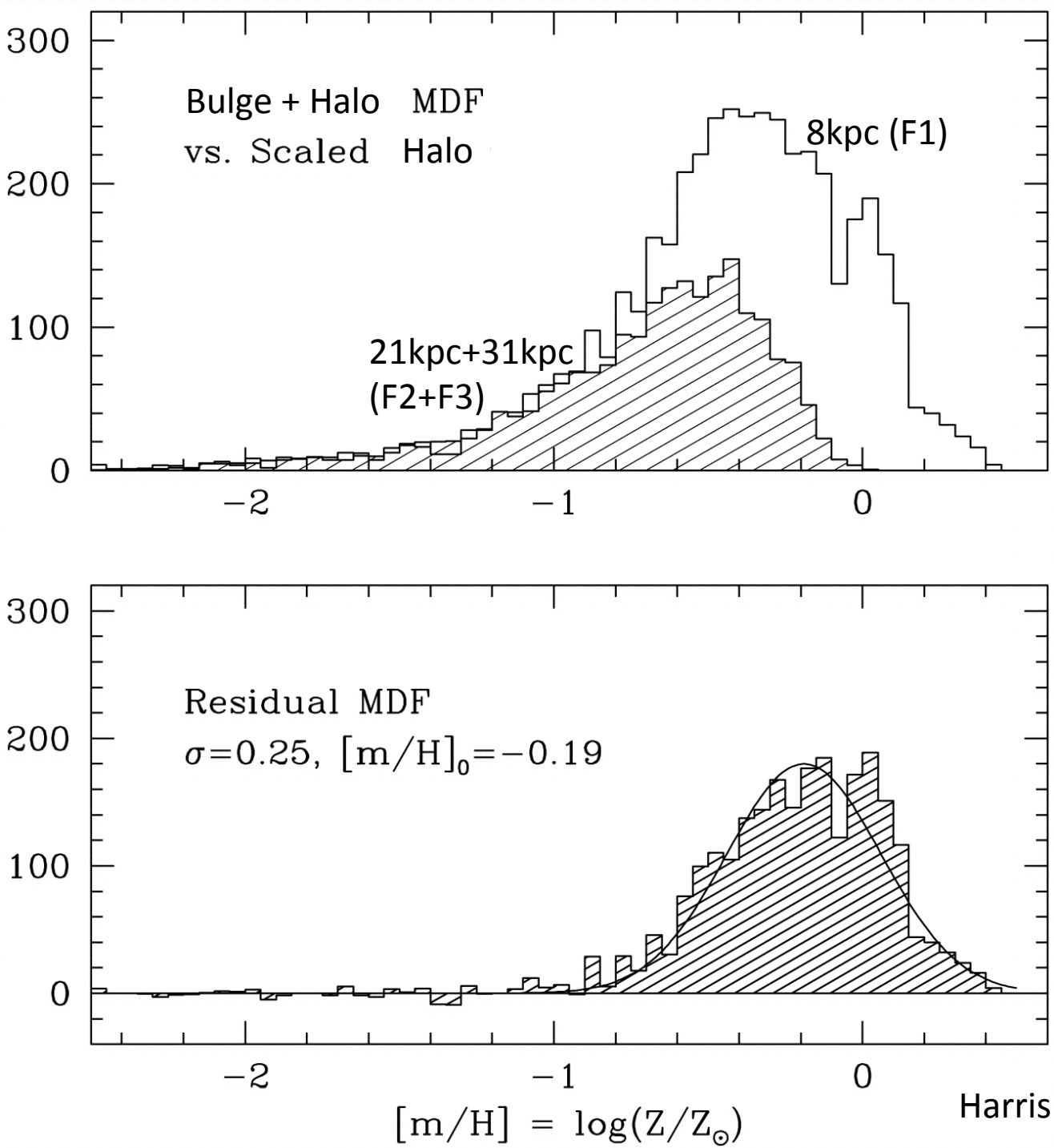
NGC 5128 CMDs





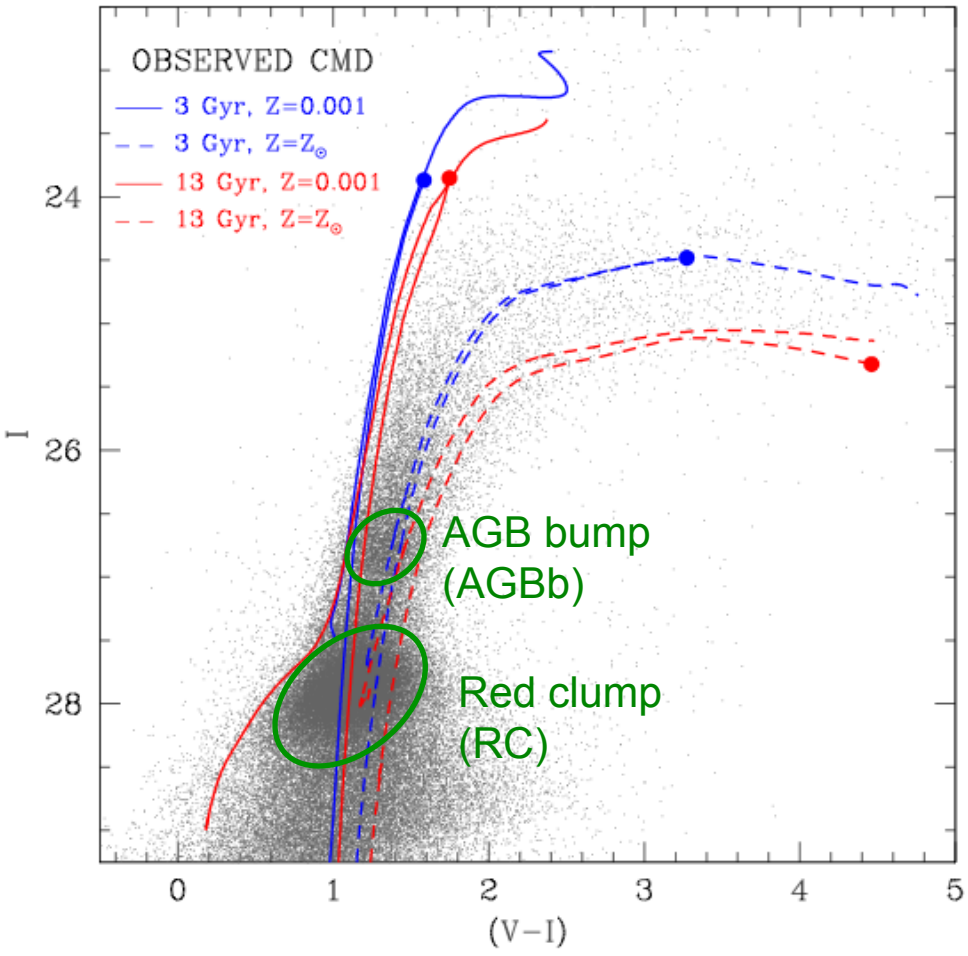


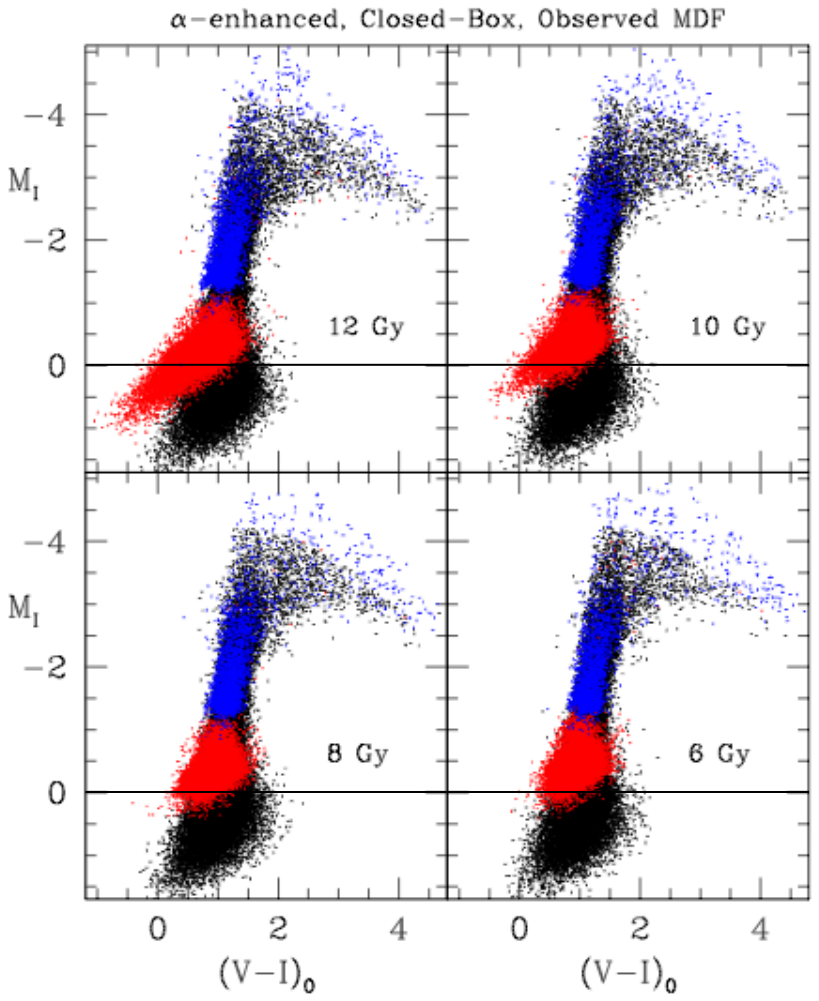




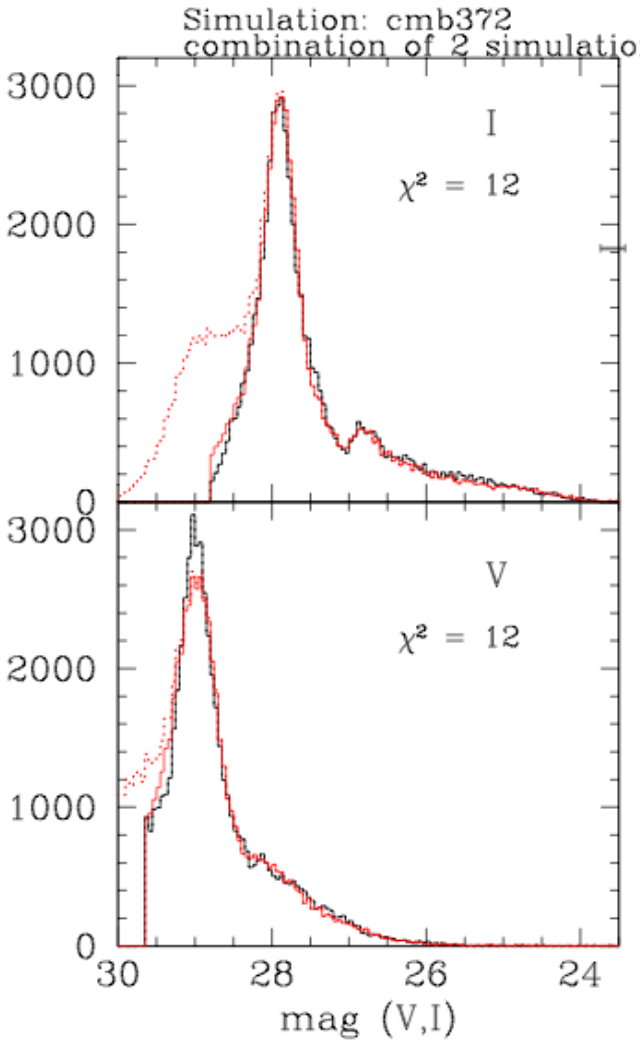
Harris + Harris 2002

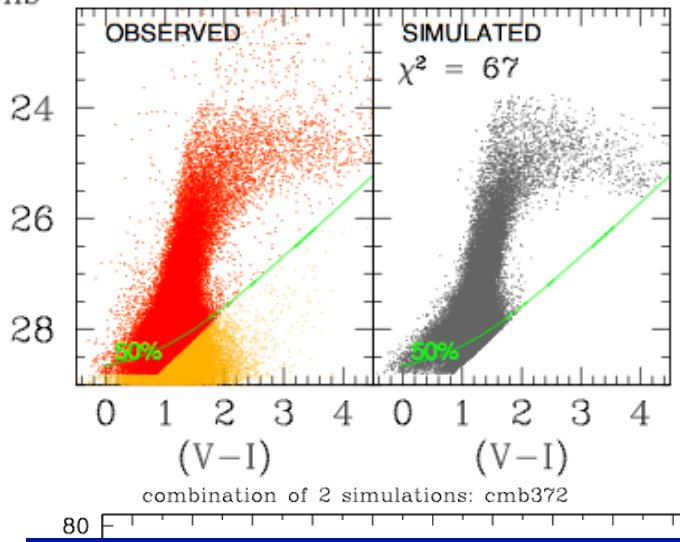
Getting a handle on age





Two bursts



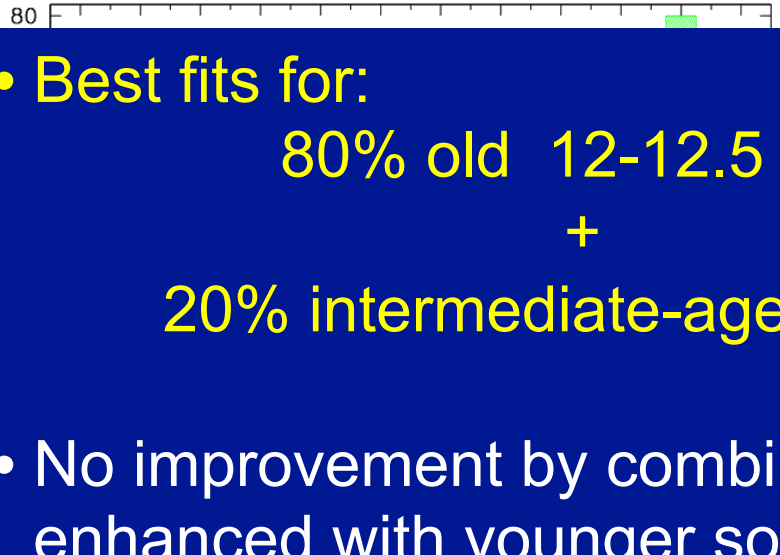


Combining single age simulations in different proportions:

80% 12 Gyr

+

20% 3Gyr



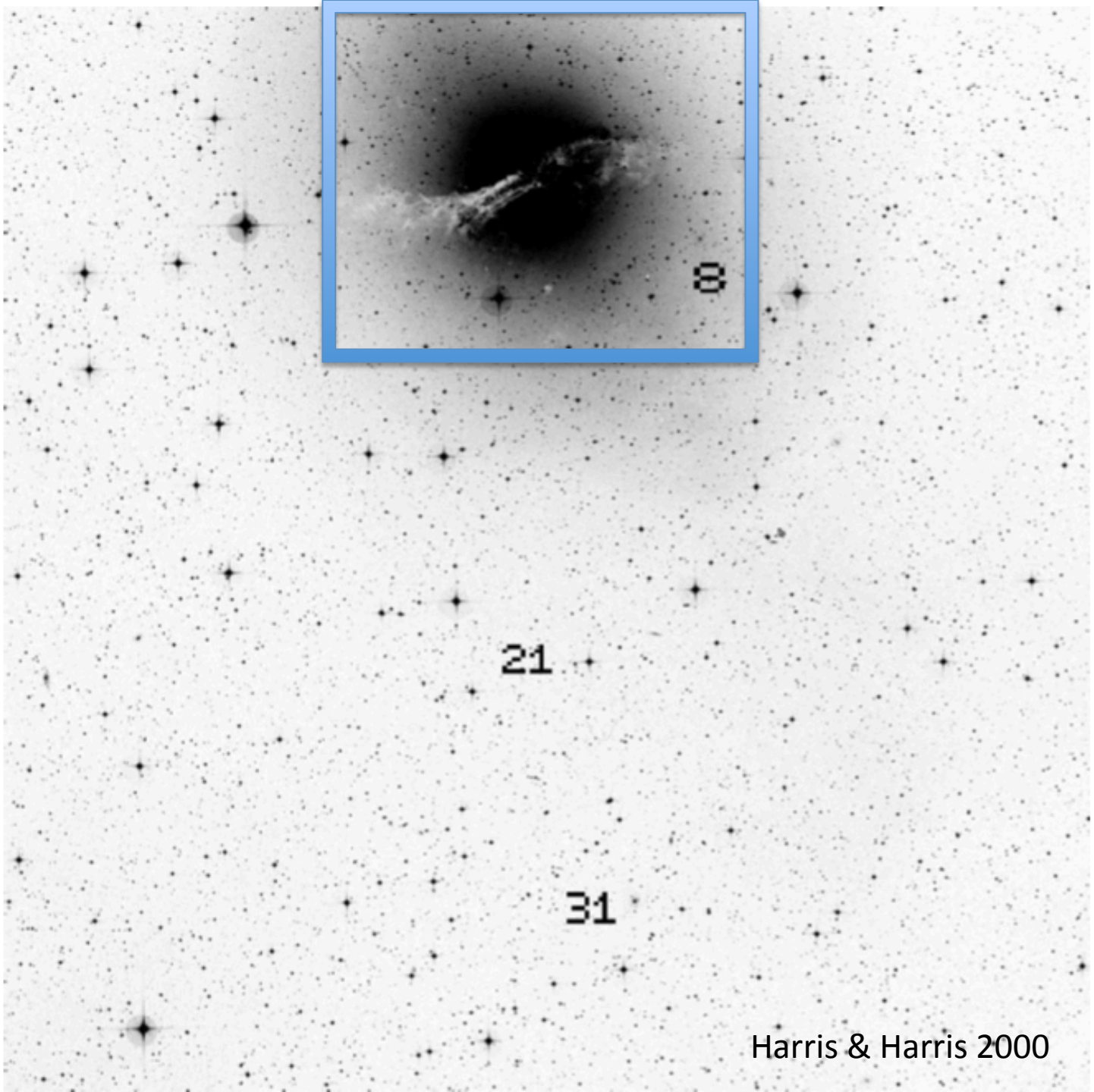
- Best fits for:

  80% old 12-12.5 Gyr

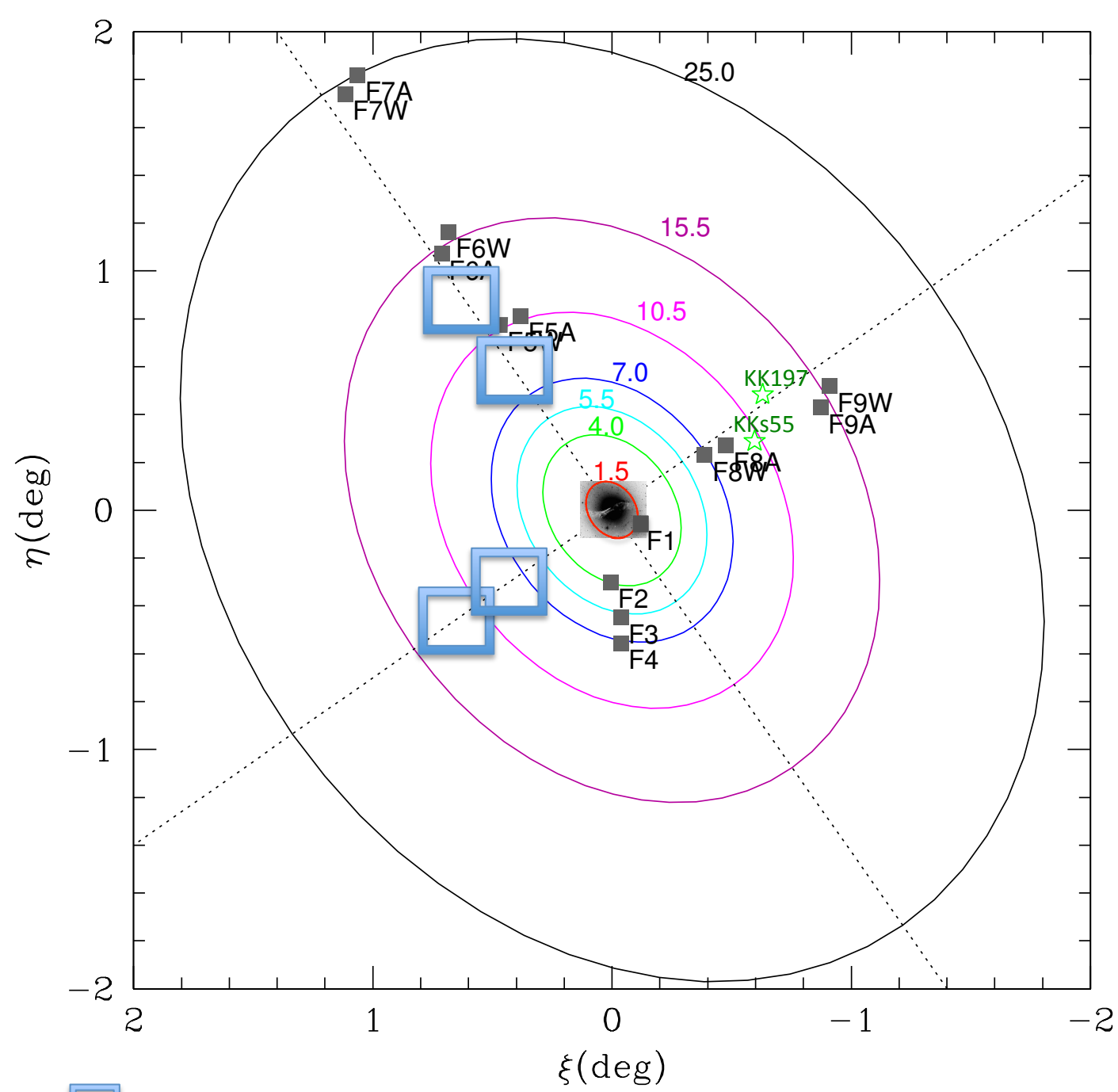
  +

  20% intermediate-age 3-4 Gyr

- No improvement by combining old α-enhanced with younger solar scaled simulations



Harris & Harris 2000



F1: 8kpc, 1.5 Reff
PC (WFPC2)
Harris & Harris 2002

F2: 21kpc, 4 Reff
WFPC2
Harris et al. 1999

F3: 31kpc, 5.5 Reff
WFPC2
Harris & Harris 2000

F4: 38kpc, 7 Reff
ACS
Rejkuba+05, 11

Cycle 20, ACS+WFC3:

F8: ~7-8 Reff
(similar to F4)

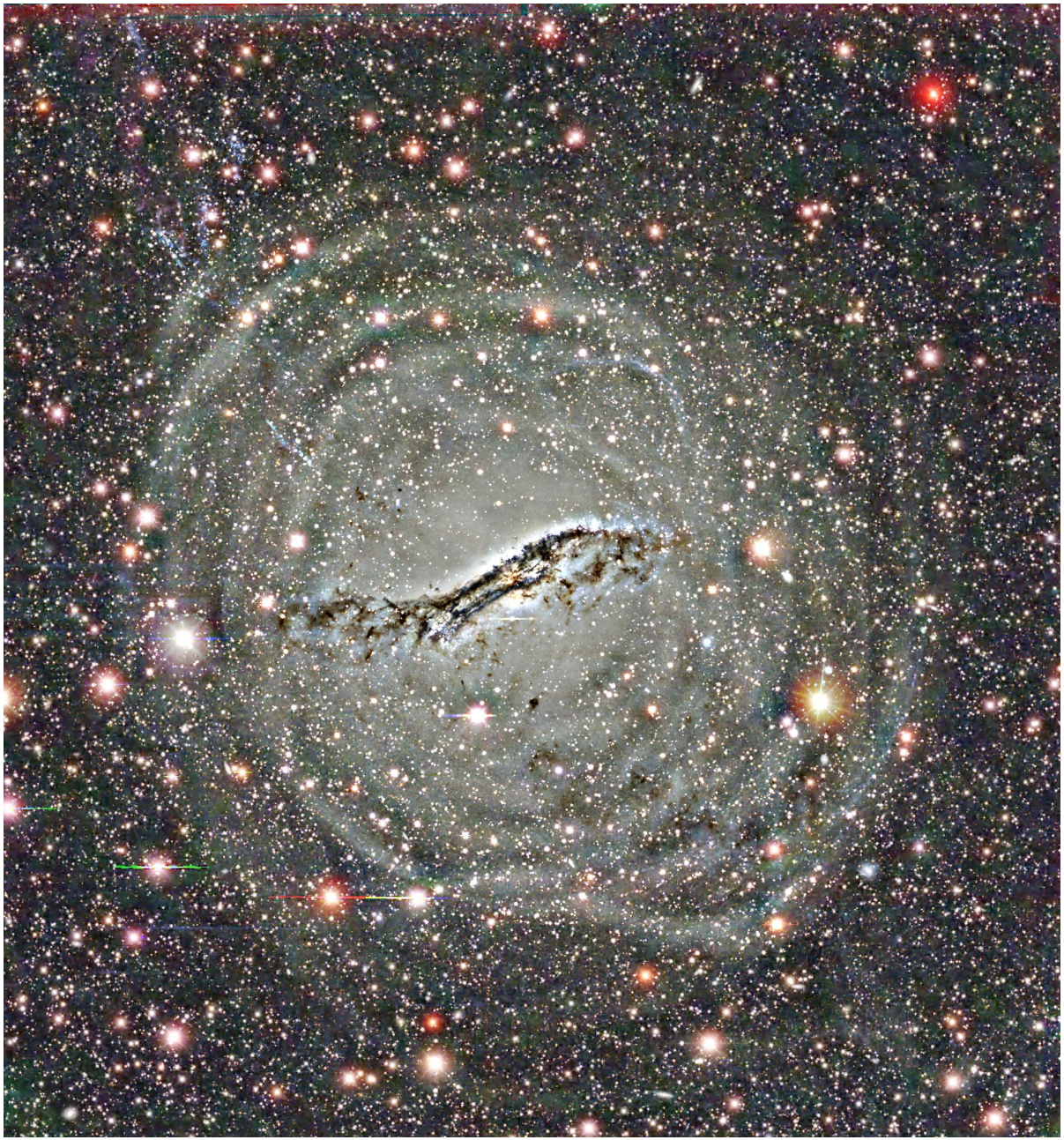
F5: ~10.5 Reff (60 kpc)
major axis

F6 & F9: ~15.5 Reff
major+minor (90kpc)

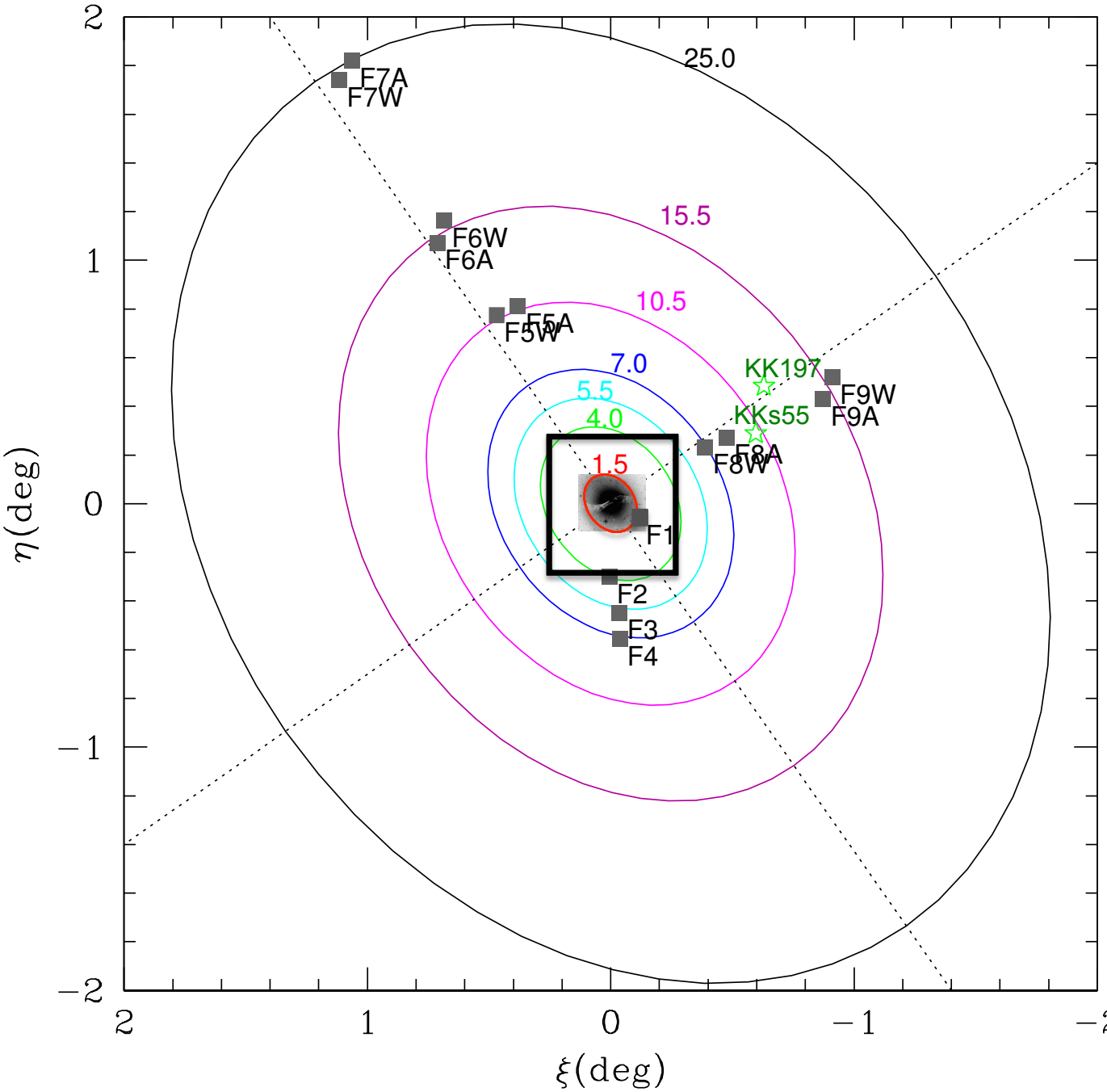
F7: 25 Reff (140 kpc)
major axis

Rejkuba et al. 2014

Crnojević et al. 2013, VIMOS wide field study of NGC5128 halo



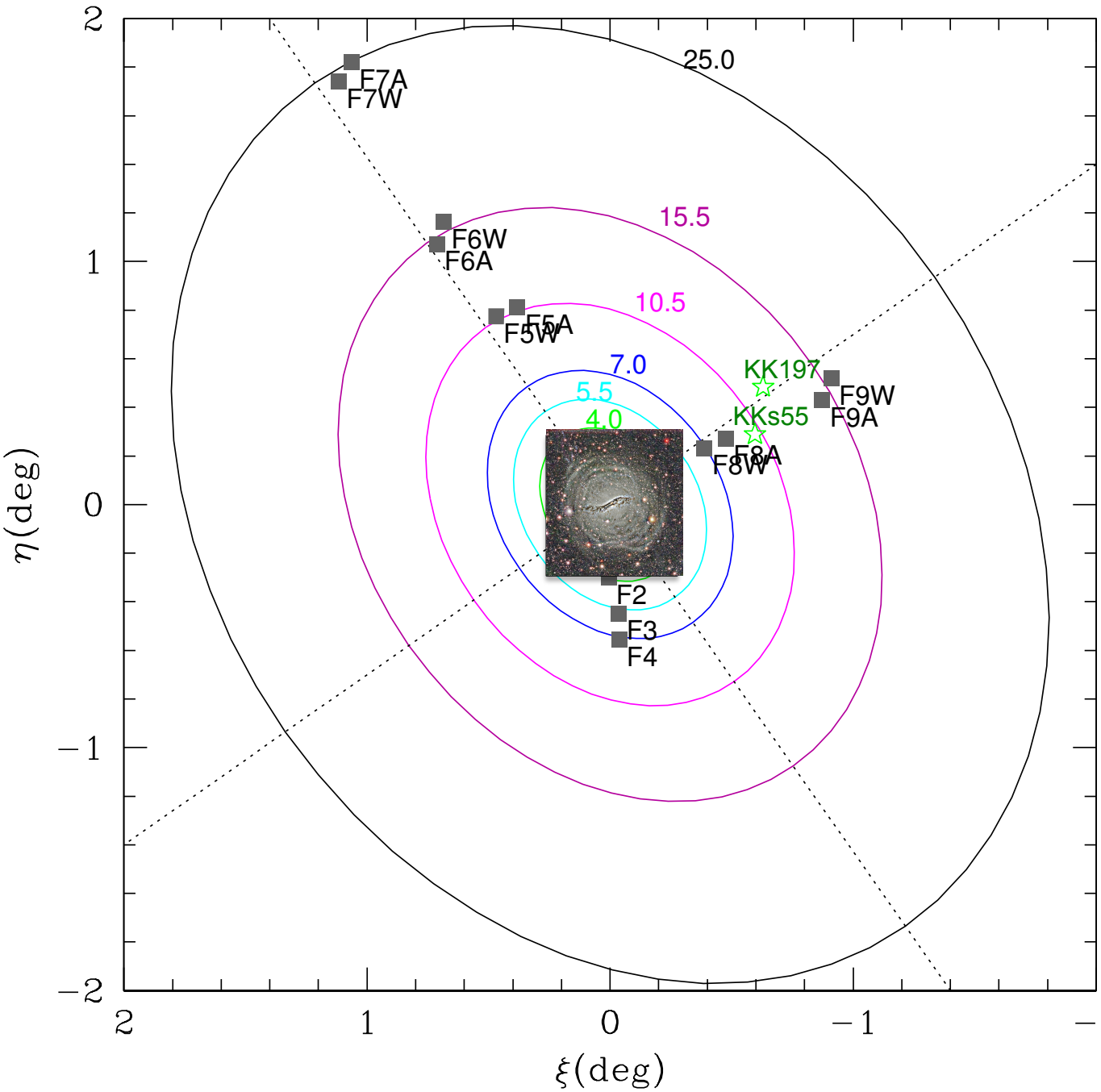
Peng et al. 2002



F1: 8kpc
1.5 Reff
F2: 21kpc
4 Reff
F3: 31kpc
5.5 Reff
F4: 38kpc
7 Reff

Major axis:
F5: ~10.5 Reff
60 kpc
F6: ~15.5 Reff
90kpc
F7: 25 Reff
140 kpc

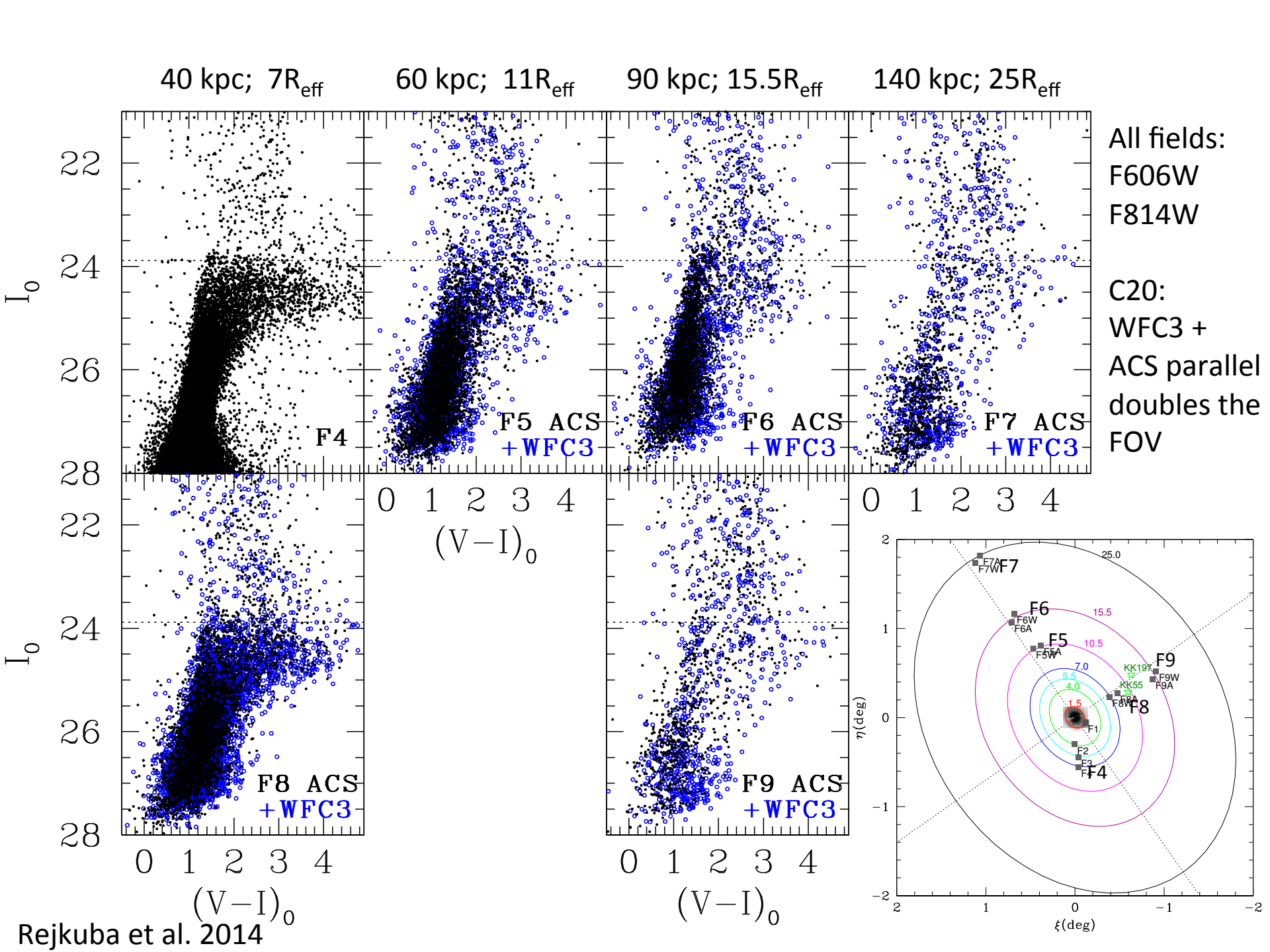
Minor axis:
F8: ~ as F4
F9: ~ as F6



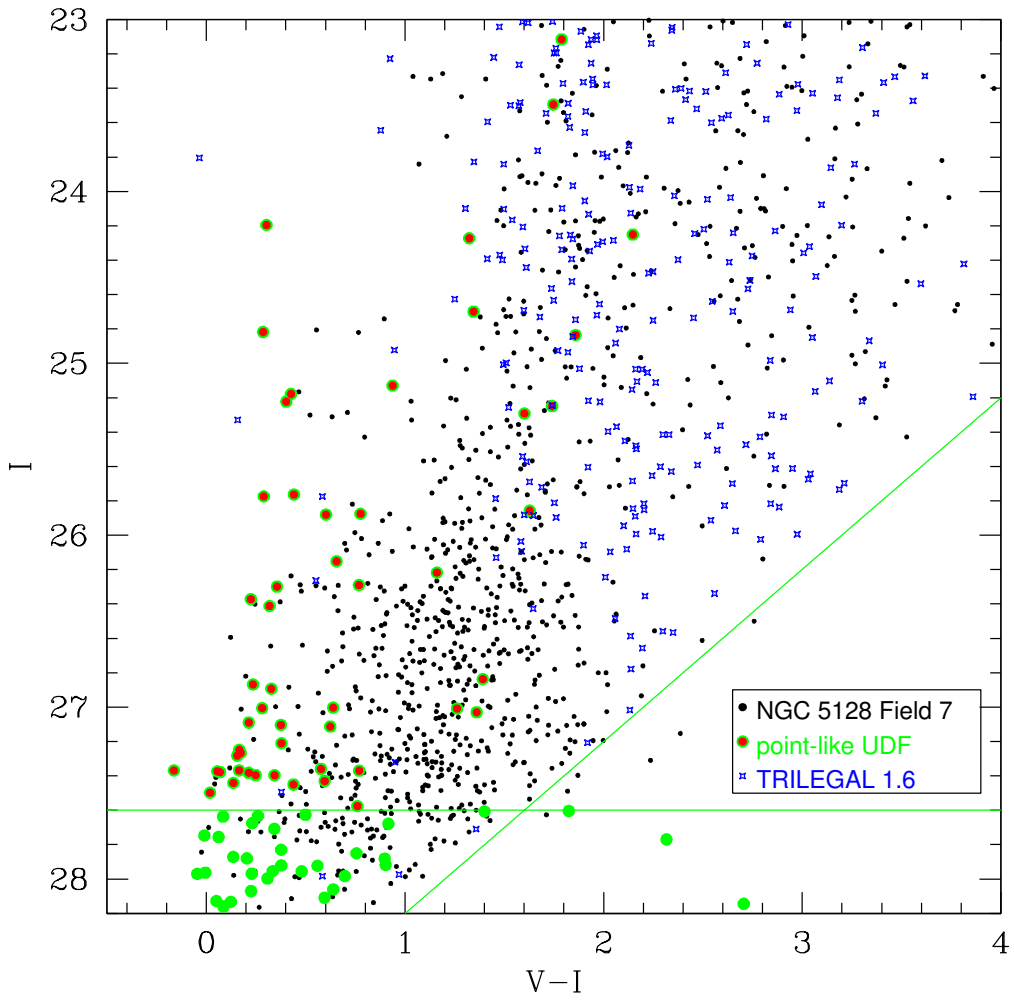
F1: 8kpc
1.5 Reff
F2: 21kpc
4 Reff
F3: 31kpc
5.5 Reff
F4: 38kpc
7 Reff

Major axis:
F5: ~10.5 Reff
60 kpc
F6: ~15.5 Reff
90kpc
F7: 25 Reff
140 kpc

Minor axis:
F8: ~ as F4
F9: ~ as F6

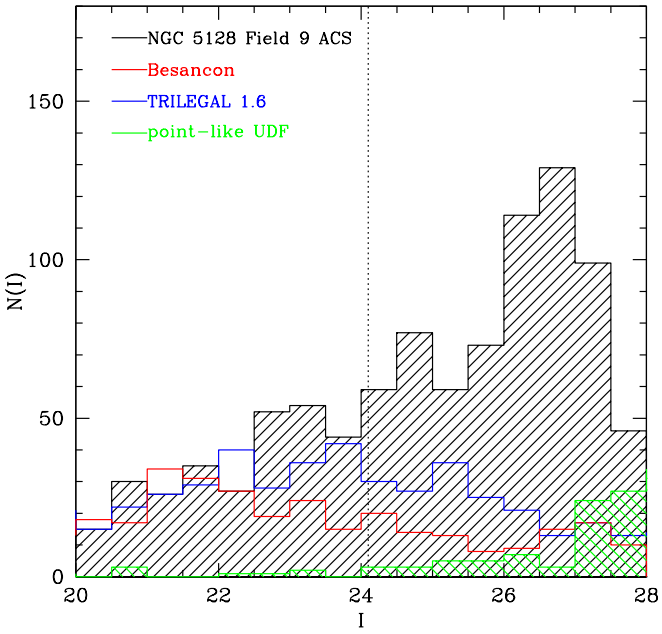

40 kpc; 7R_eff
60 kpc; 11R_eff
90 kpc; 15.5R_eff
140 kpc; 25R_eff
All fields:
F606W
F814W
C20:
WFC3 +
ACS parallel
doubles the
FOV
F4
F5 ACS +WFC3
F6 ACS +WFC3
F7 ACS +WFC3
F8 ACS +WFC3
F9 ACS +WFC3
I_0
(V−I)_0
η(deg)
ξ(deg)
Rejkuba et al. 2014

Foreground + background contamination

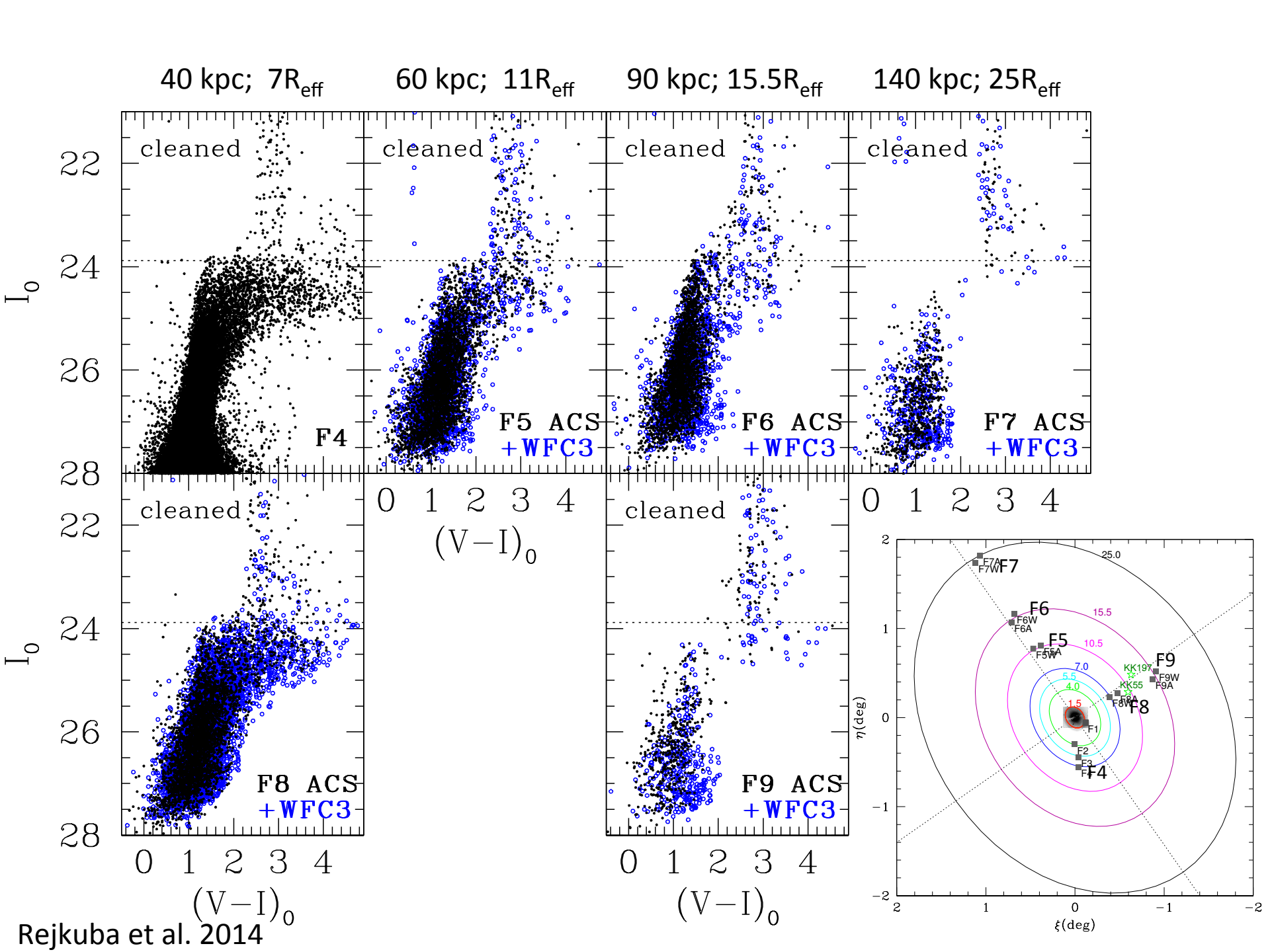


Field 7 (140 kpc; 25 Reff)
observations:
ACS: 806 stars (I>24)
WFC3: 480 stars (I>24)

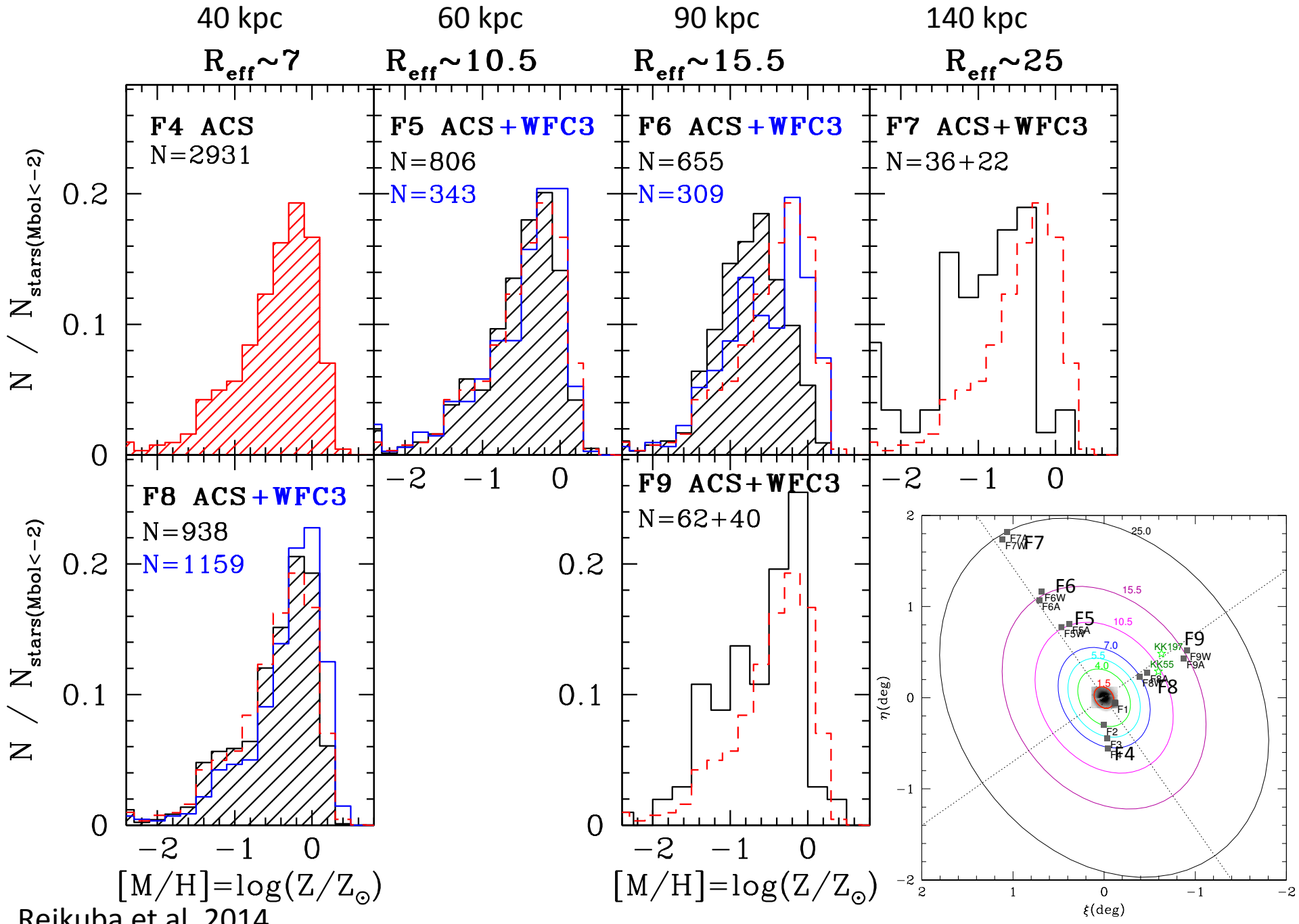
MW foreground simulation:
TRILEGAL 383+224 (I>24)
Besancon 103+68 (I>24)



Rejkuba et al. 2014

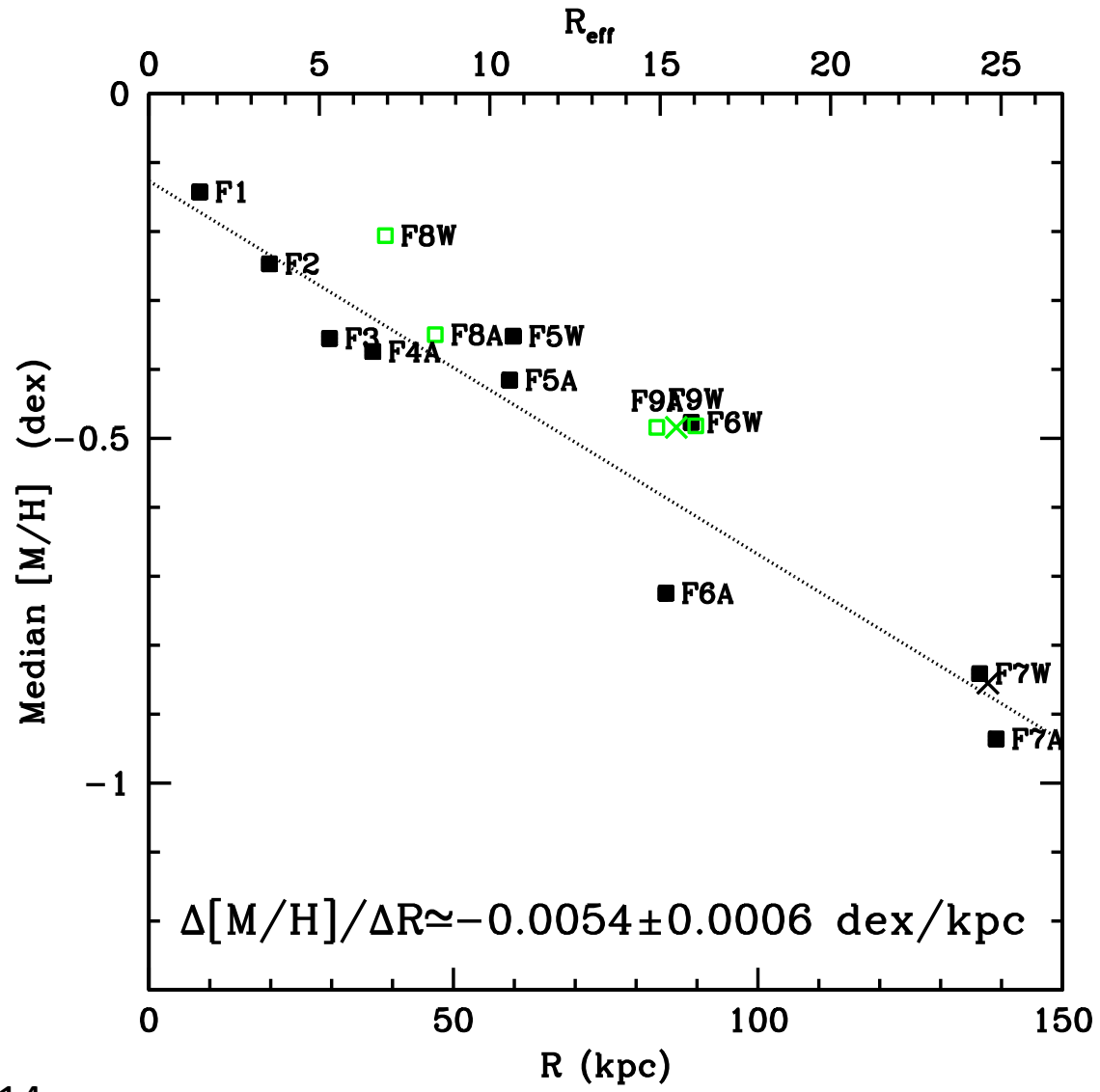


Rejkuba et al. 2014



Rejkuba et al. 2014

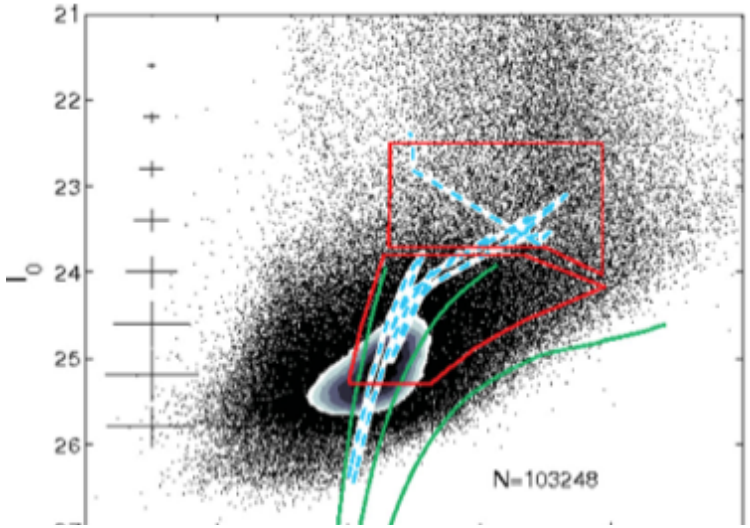
NGC 5128 Stellar Halo Metallicity Gradient

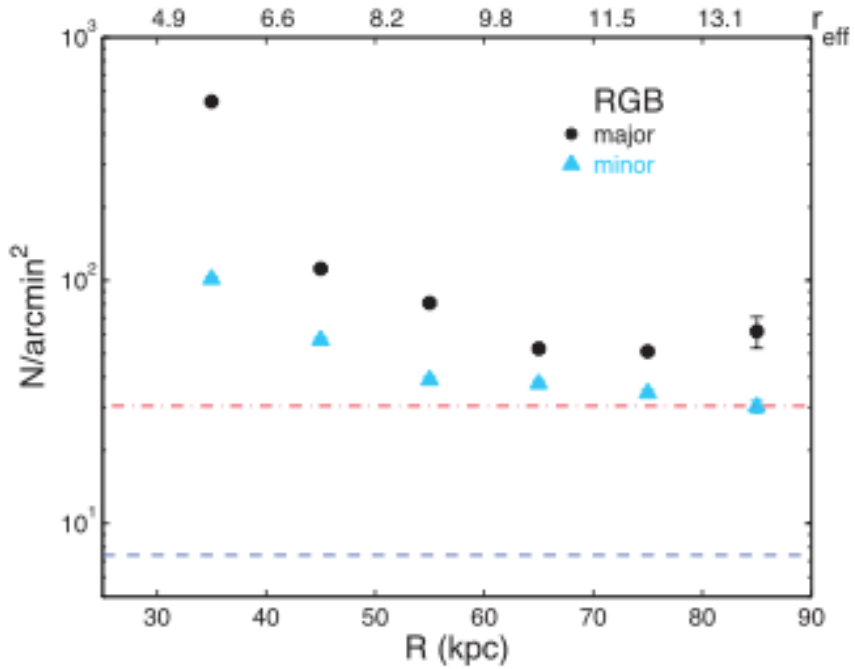


Rejkuba et al. 2014

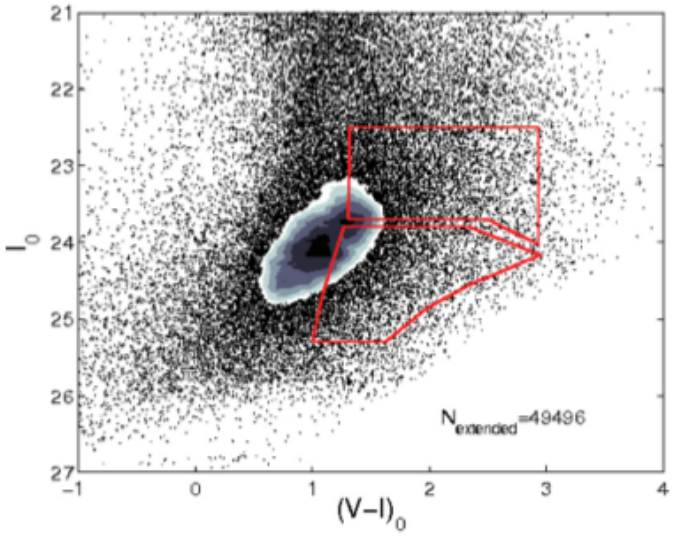
Cen A halo + foreground + background

MW unresolved galaxies

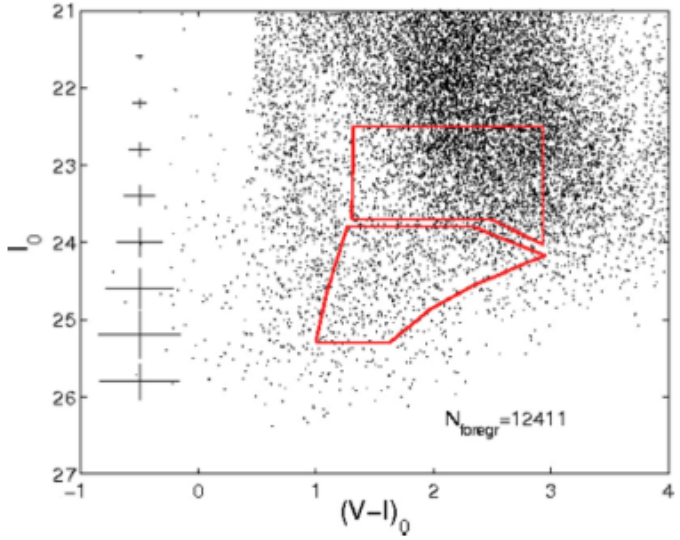




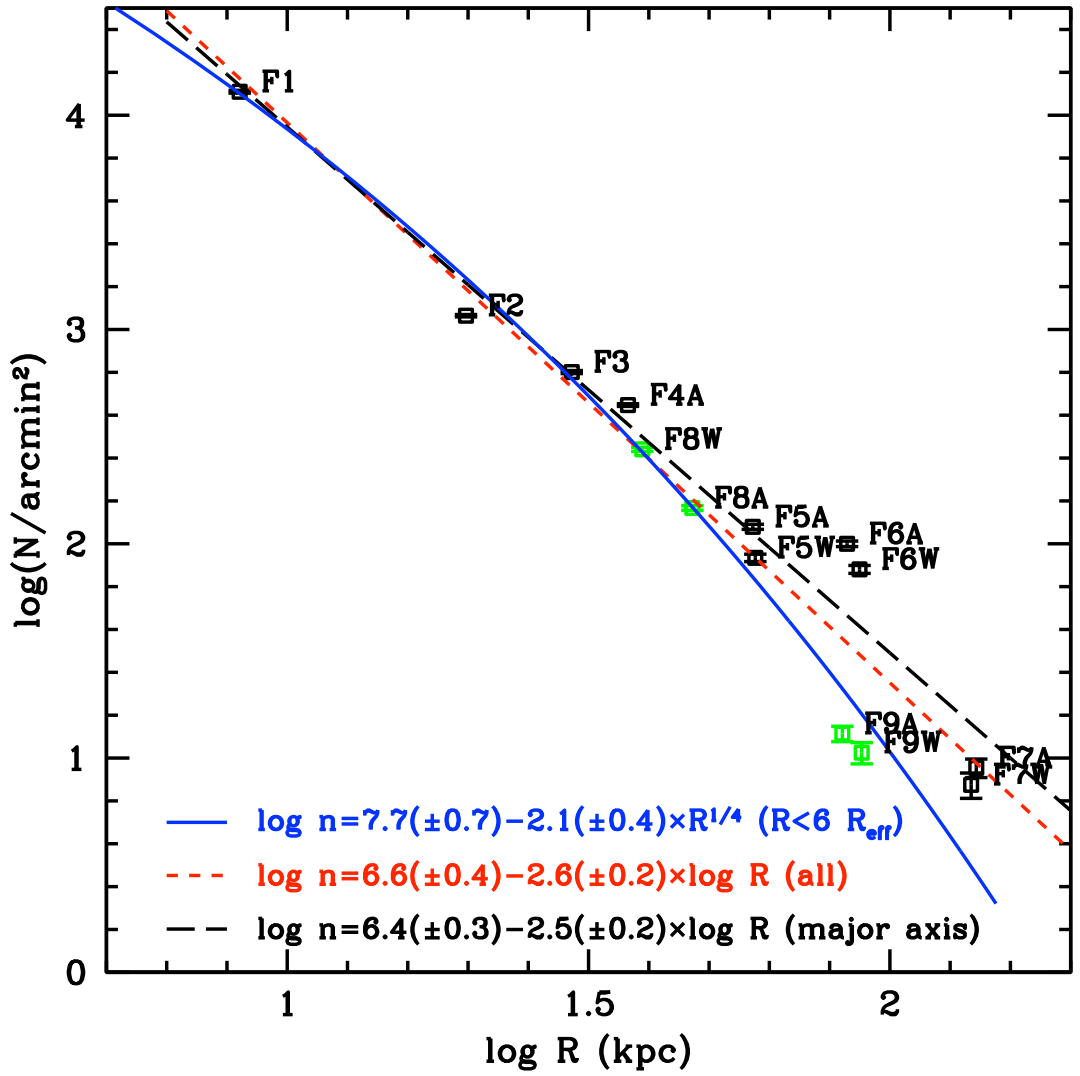
extended sources

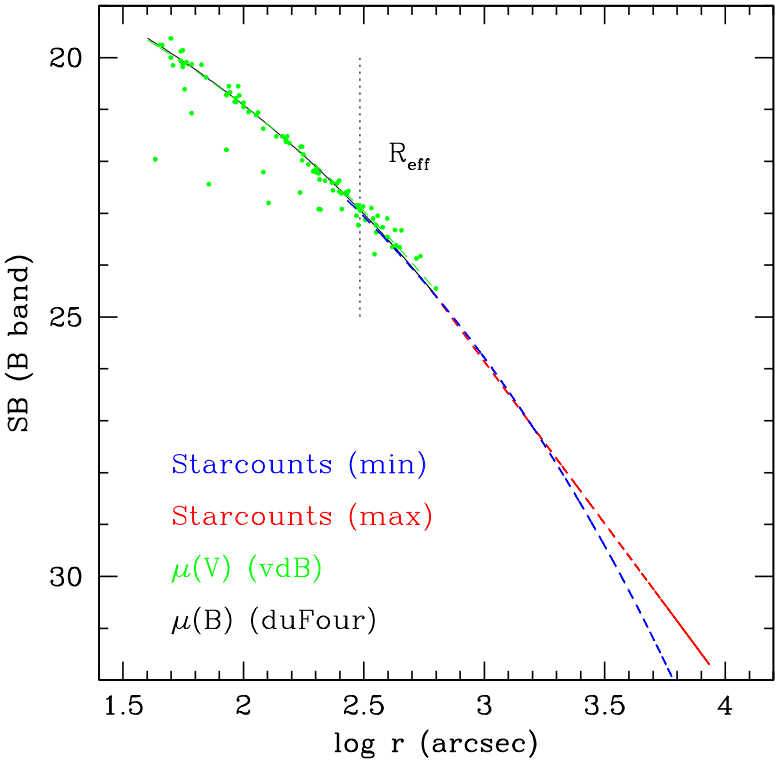


MW foreground (Besancon simulation)



NGC 5128: Stellar Density Gradient





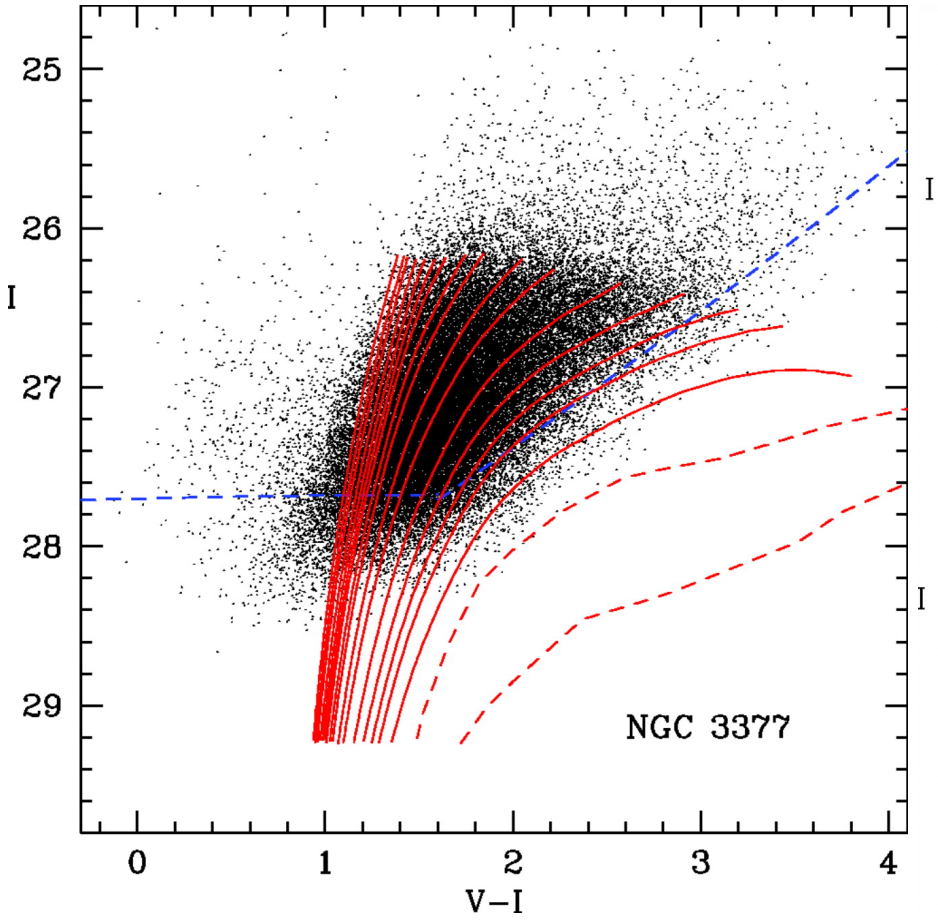
Rejkuba et al. 2014

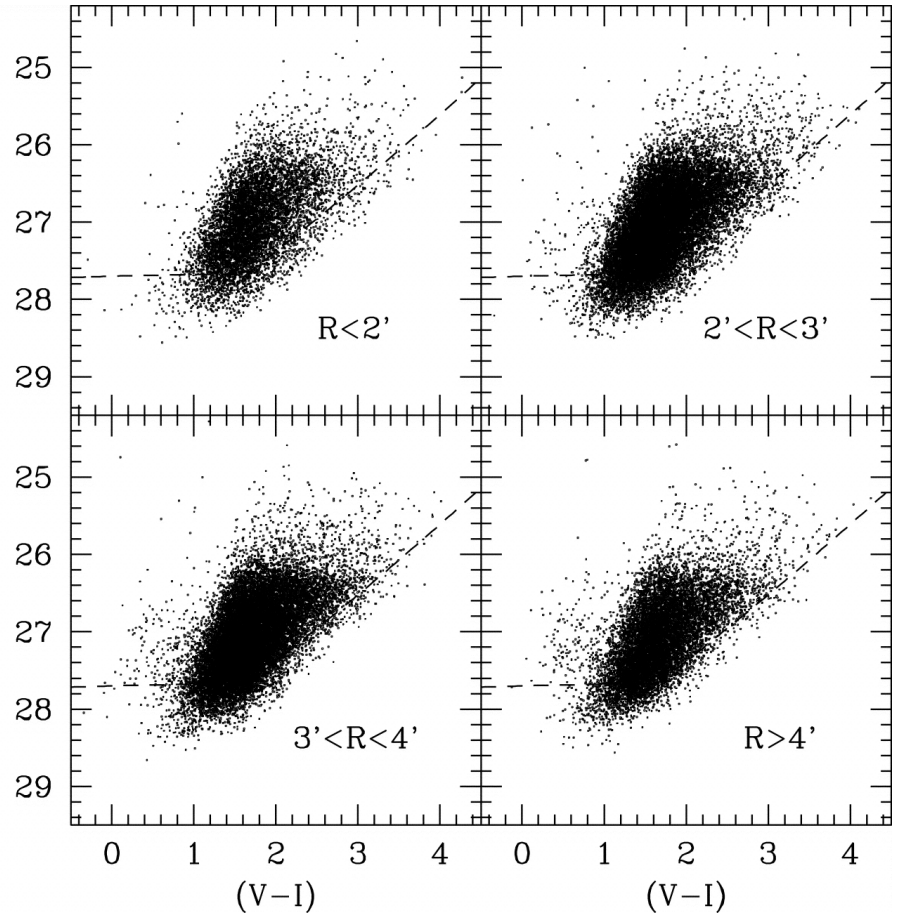
Summary: NGC 5128

- The bulk of the halo stars formed at redshift $z \gtrapprox 2$
- Fast chemical enrichment: ~12 Gyr old stars have super-solar metallicity

- Metallicity and stellar density gradients mapped to 25 R_{eff}
- Halo extends over the entire surveyed area:
  - 140 kpc along the major axis
  - elongated halo
  - high average metallicity
  - we have not reached the end of the galaxy halo

NGC 3377: an intermediate-mass elliptical





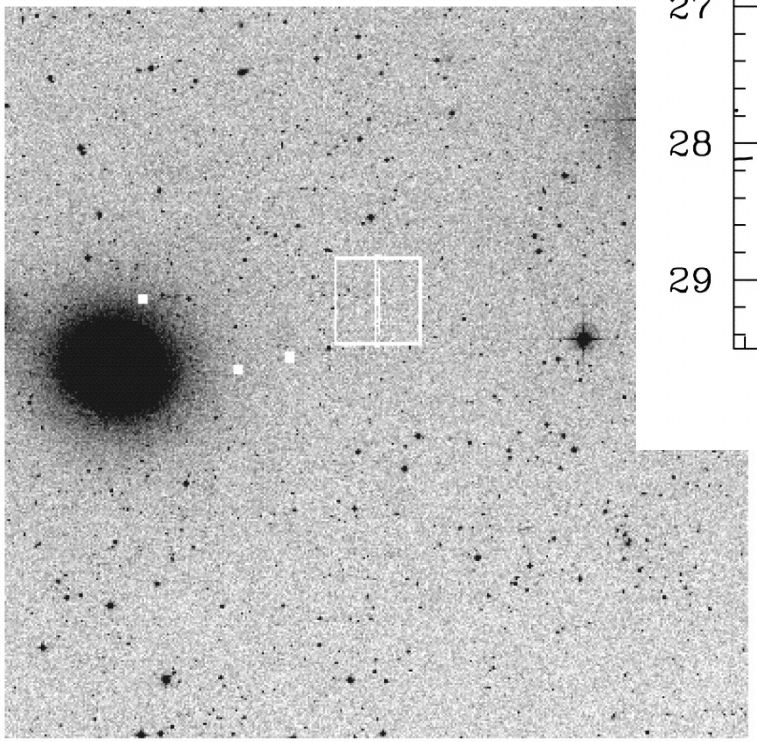
Harris+2007a

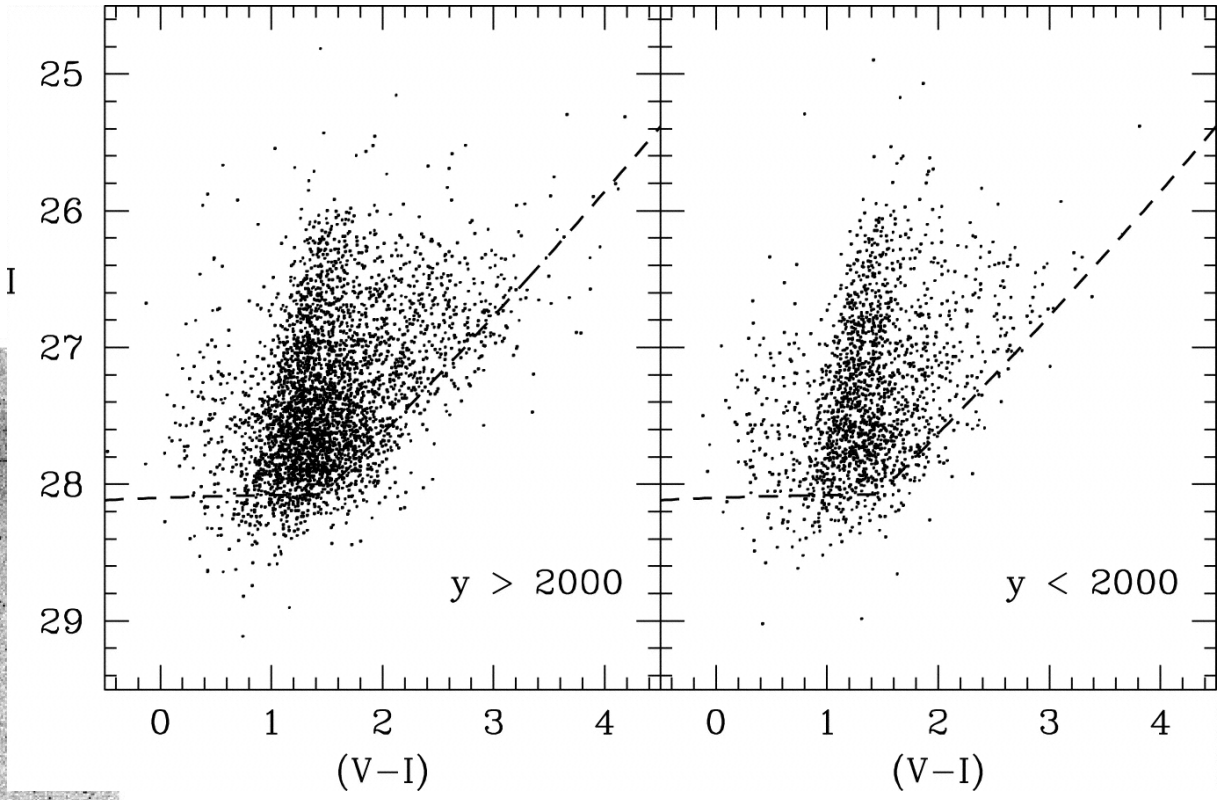
M_V=-20; R_{eff}=1.1'; 3.8' is equivalent to 12kpc

NGC 3379: transition to a metal-poor halo

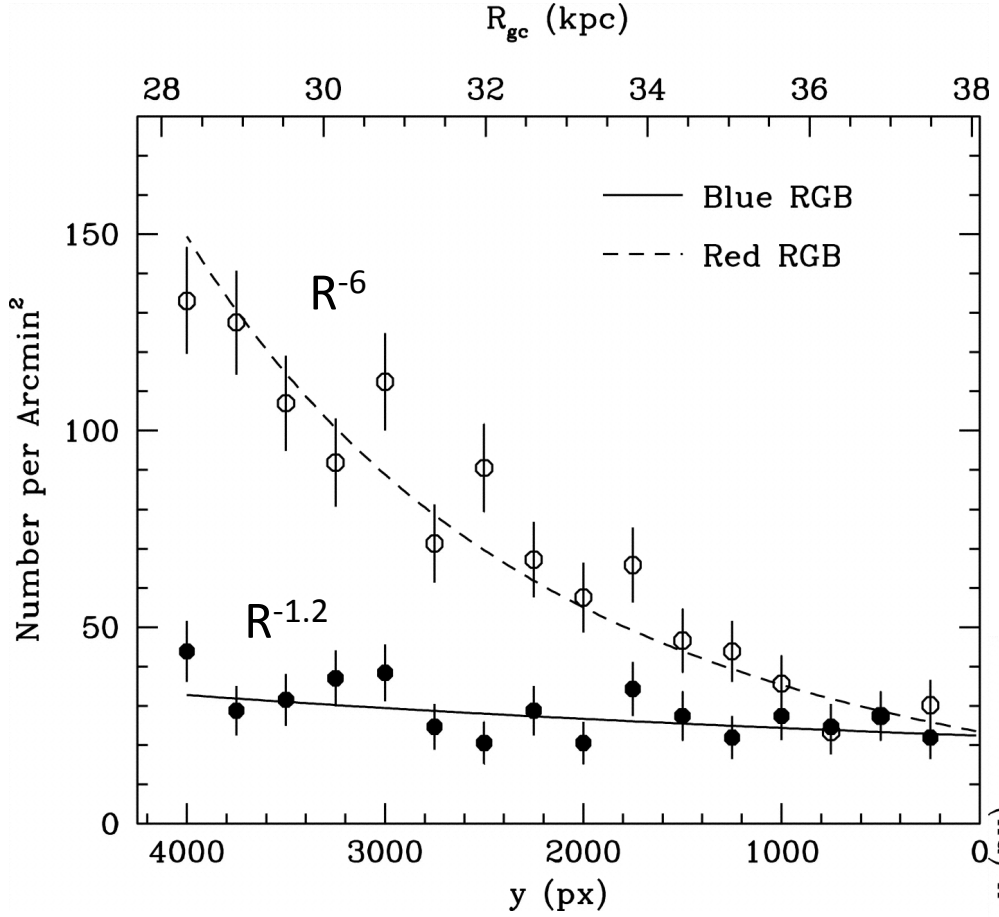
Re=0.93’ (2.8 kpc)
Field location: 10.9 – 33 kpc

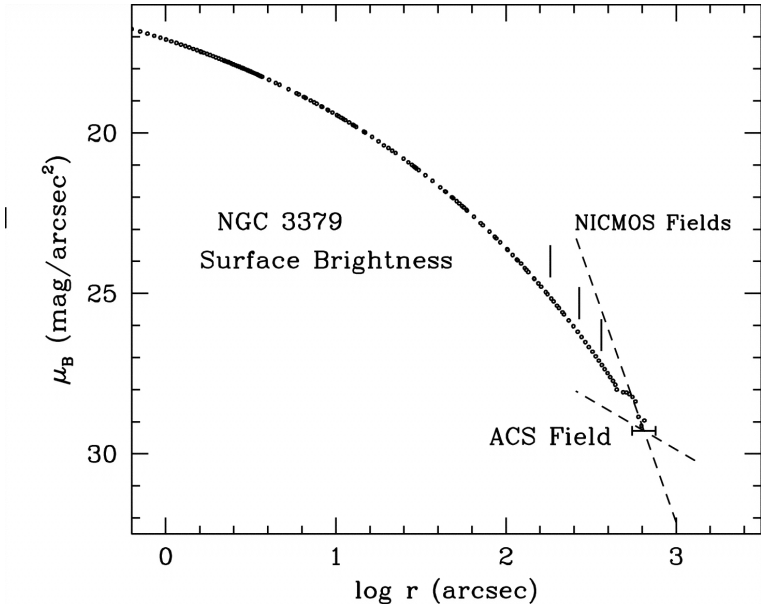
Harris et al. 2007b

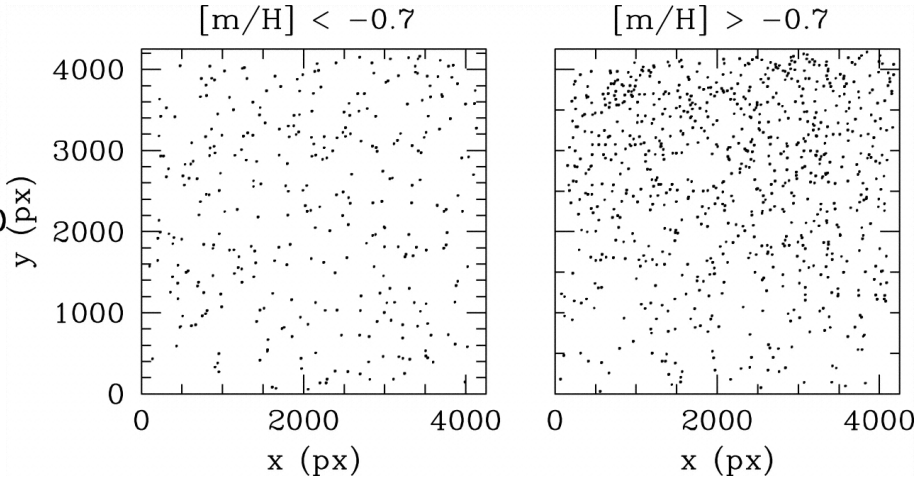




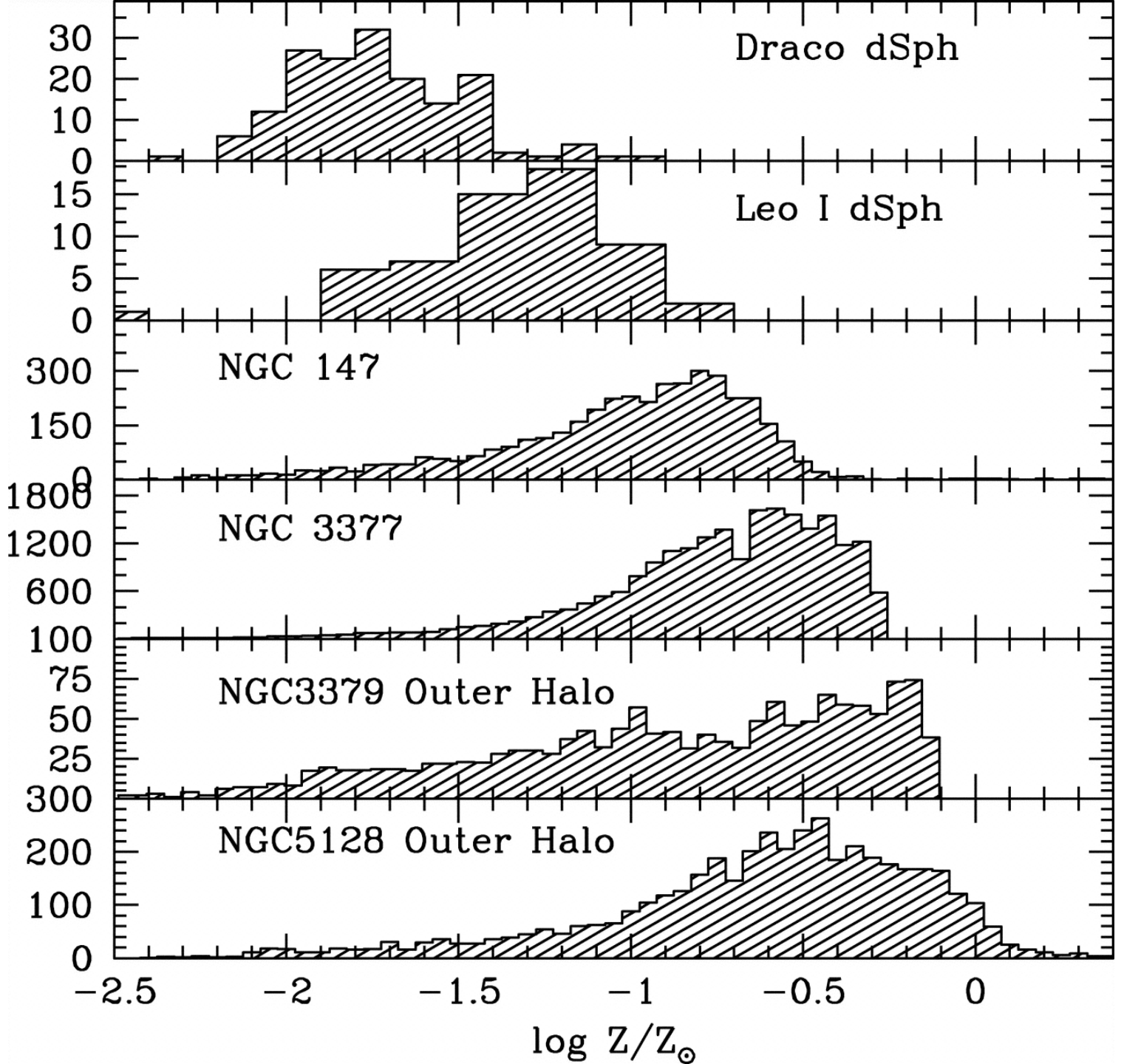
NGC 3379: transition to a metal-poor halo



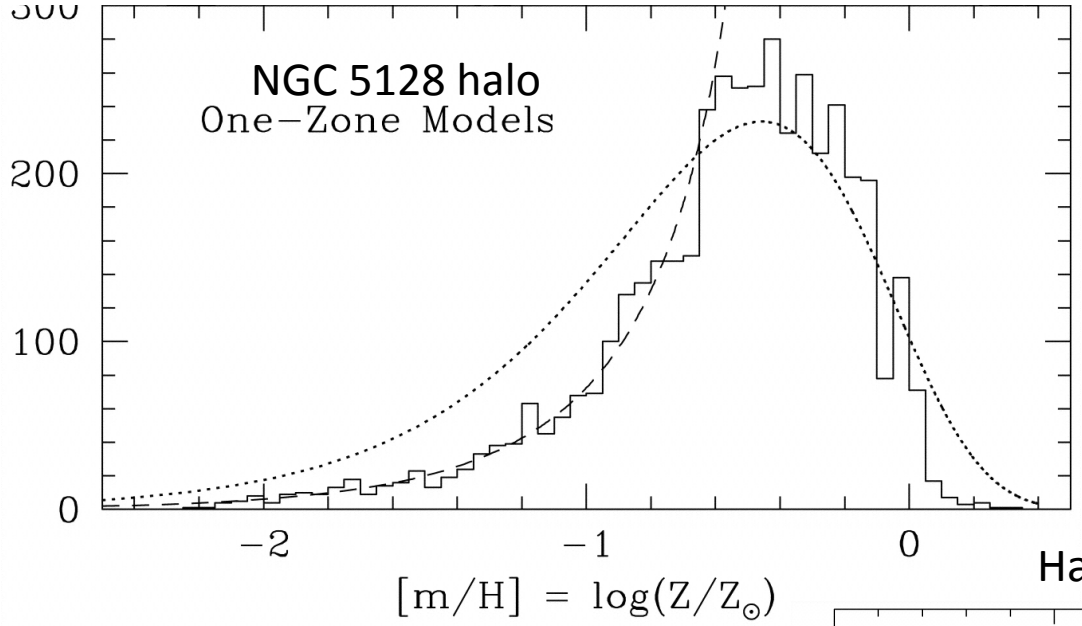




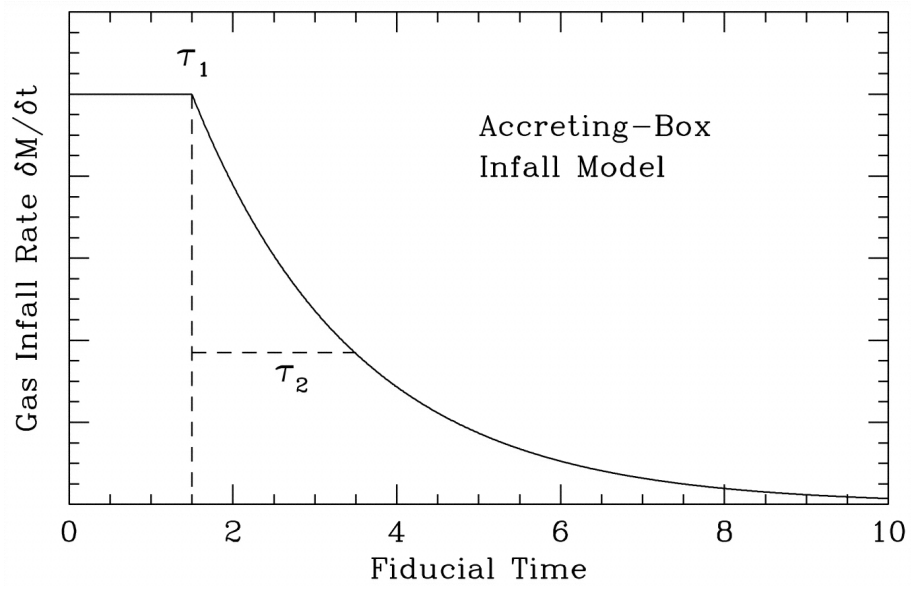
Harris et al. 2007b

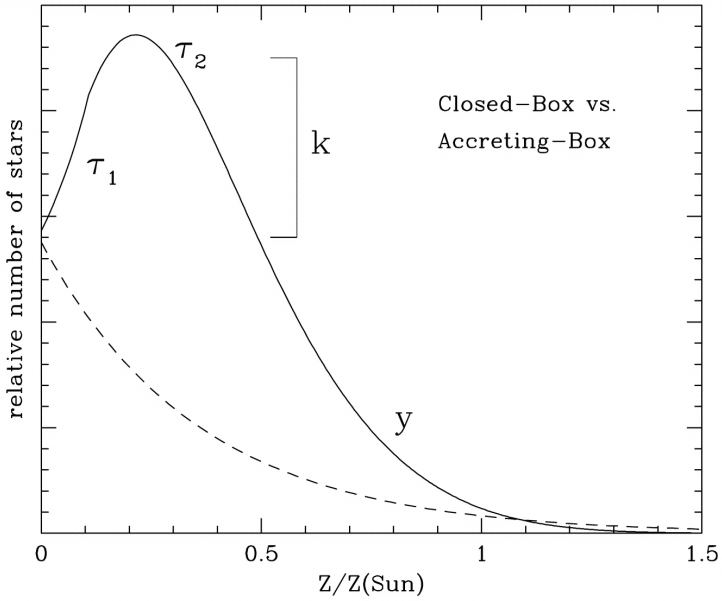

Draco dSph
Leo I dSph
NGC 147
NGC 3377
NGC3379 Outer Halo
NGC5128 Outer Halo
30
20
10
0
15
10
5
0
300
150
0
1800
1200
600
100
75
50
25
300
200
100
0
−2.5
−2
−1.5
−1
−0.5
0
log Z/Z⊙

Comparison with chemical evolution models



Harris+Harris 2000, 2002





Comparison with chemical evolution models

Harris+Harris02 NGC 5128

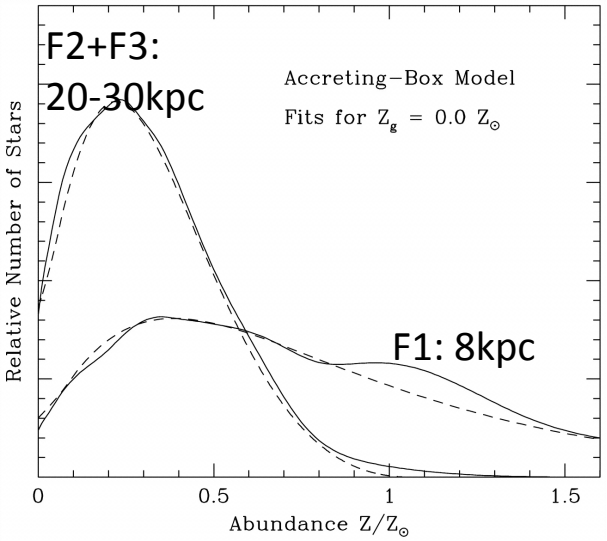
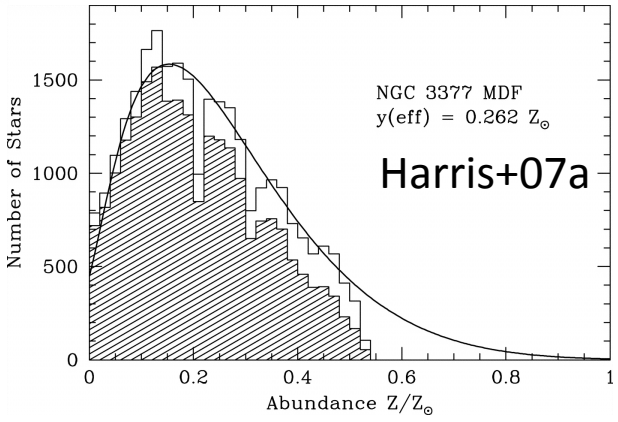


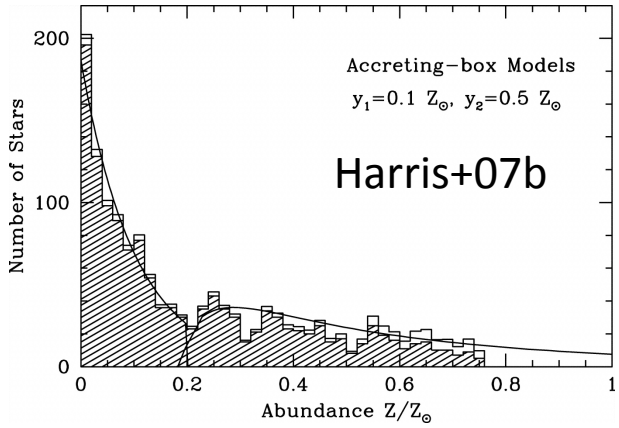
TABLE 2
FITTING PARAMETERS FOR ACCRETING-BOX MODELS

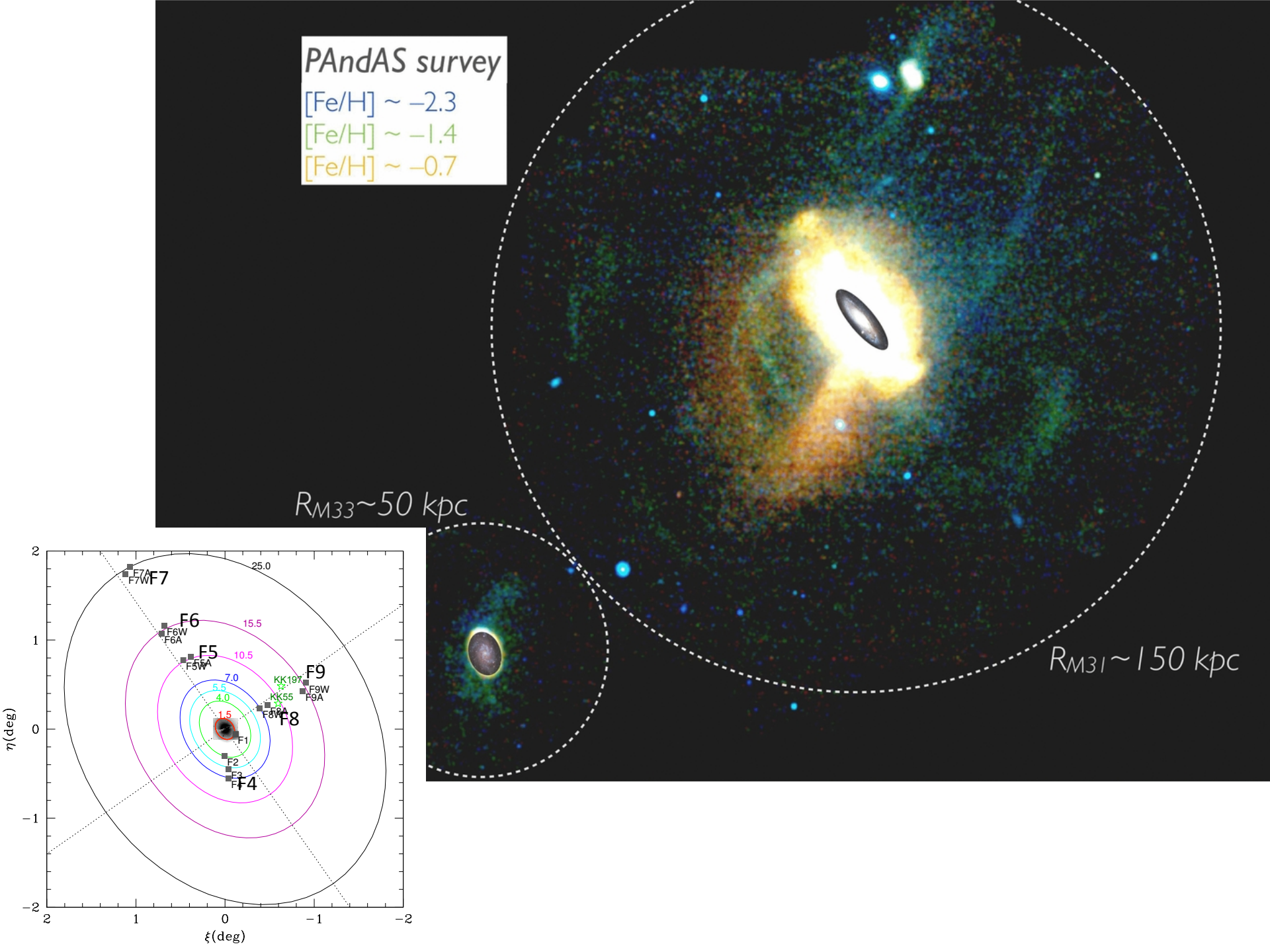
Parameter	Outer Fields	Inner Field	Outer Fields	Inner Field
Z_g ($Z_\odot$)...	0.0	0.0	0.2	0.2
y ($Z_\odot$)...	0.32	0.87	0.25	0.81
τ_1/δ_t...	7	5	1	0
τ_2/δ_t...	35	20	19	12
M_f/M_0...	3.5	3.9	1.9	2.4
Maximum SFR (1 $M_\odot/y$)...	225	155	240	158

NGC 3377



NGC 3379




PAndAS survey
[Fe/H] ~ –2.3
[Fe/H] ~ –1.4
[Fe/H] ~ –0.7
RM33~50 kpc
RM31~150 kpc
F1
F2
F3
F4
F5
F5W
F5A
F6
F6W
F6A
F7
F7W
F7A
F8
F8W
F8A
F9
F9W
F9A
KK197
KK55
25.0
15.5
10.5
7.0
5.5
4.0
1.5
ξ(deg)
η(deg)

Conclusions

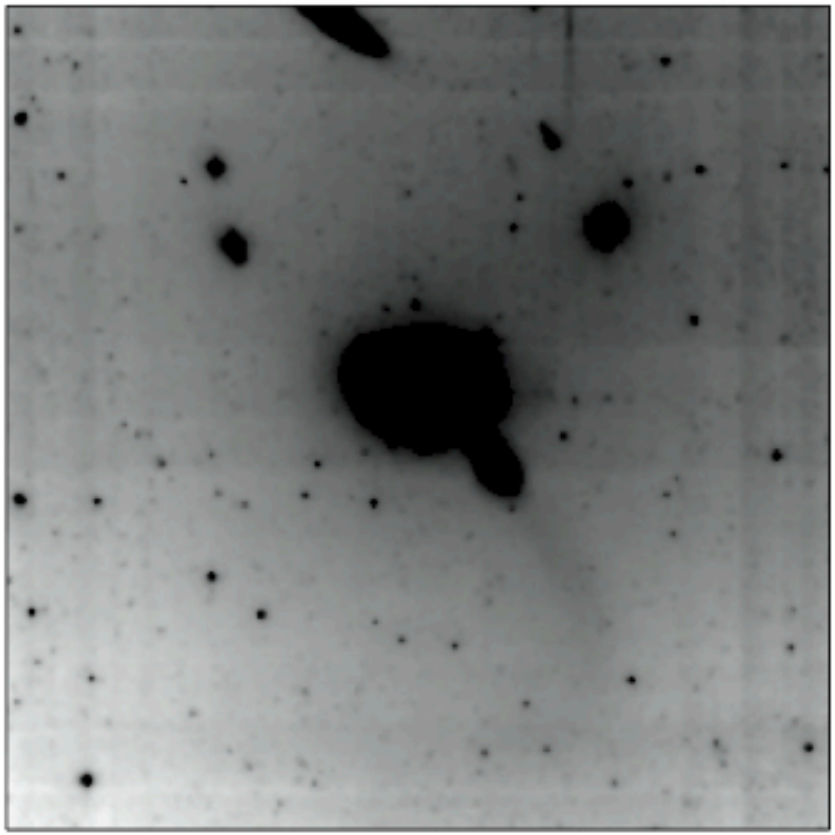
- MDFs in the halo are broad
- Accreting box infall model: Assuming gas consumption within ~2Gyr → SFR~150-250 $M_{\odot}$/yr

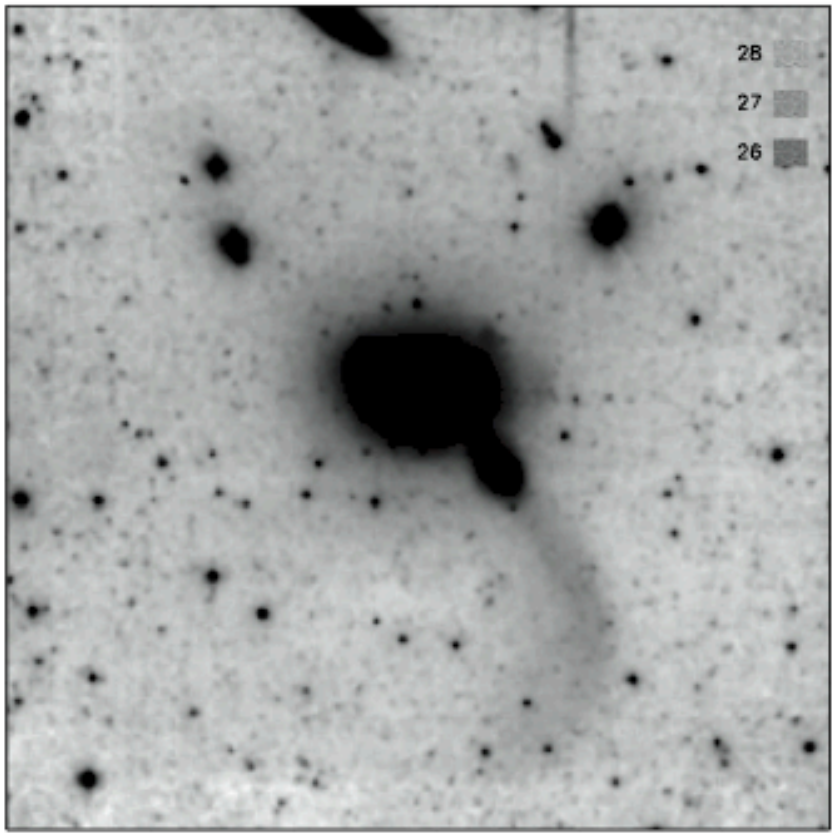
- Transition to the metal-poor halo beyond ~12 Re?

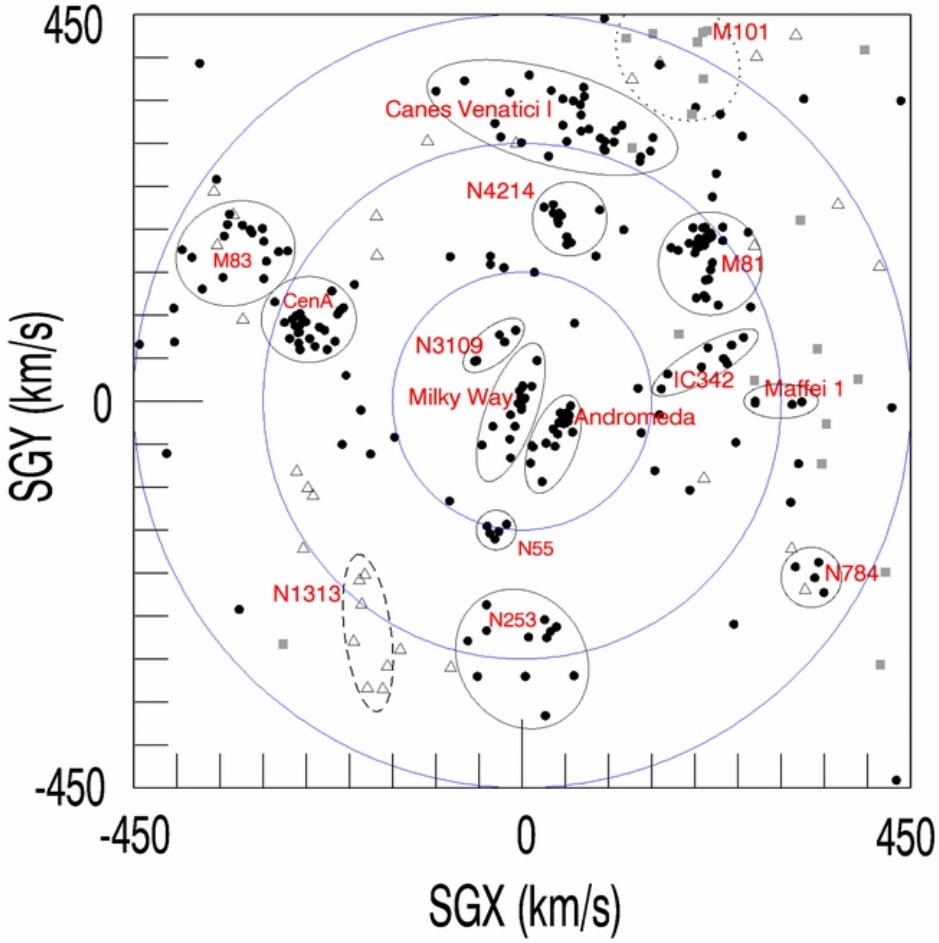
- Smooth halo or accretion of low-mass satellites
- Complementarity of the wide field and deep observations: know where and what you are looking at

Nearby luminous elliptical galaxy outskirts

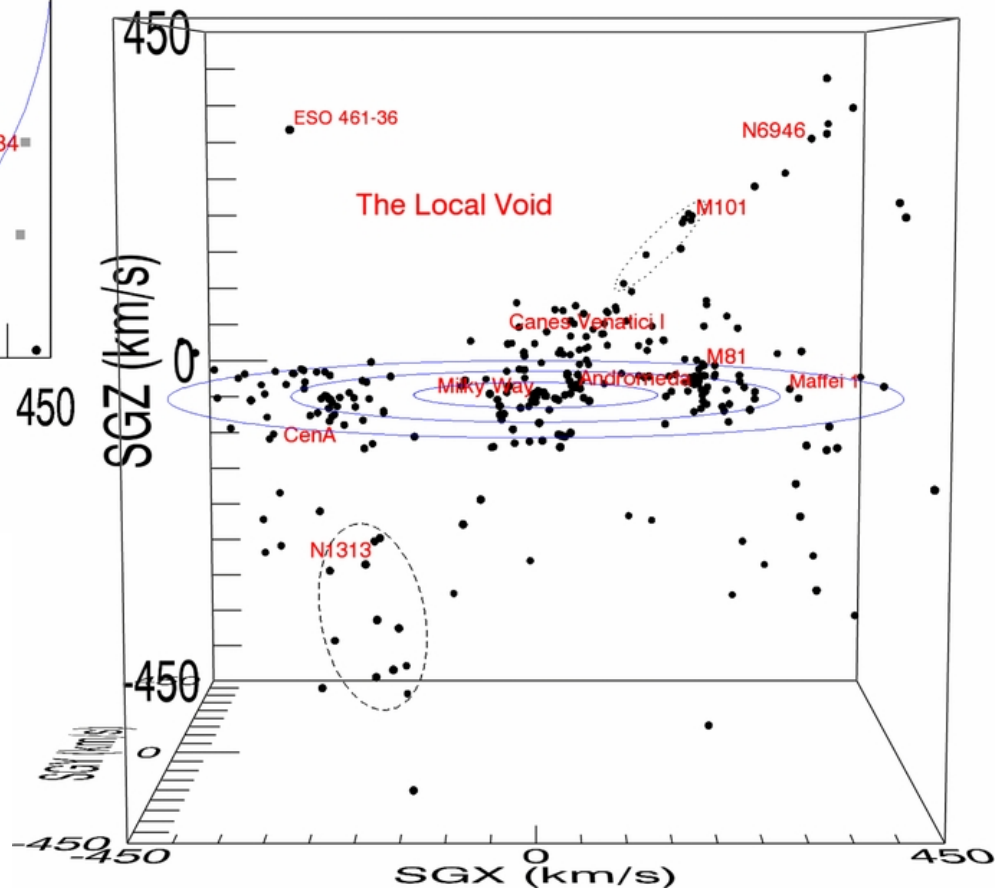
Tal et al. 2009: complete sample of luminous elliptical galaxies ($M_B < -20$) at distances 15–50 Mpc, selected from the Tully catalog of nearby galaxies

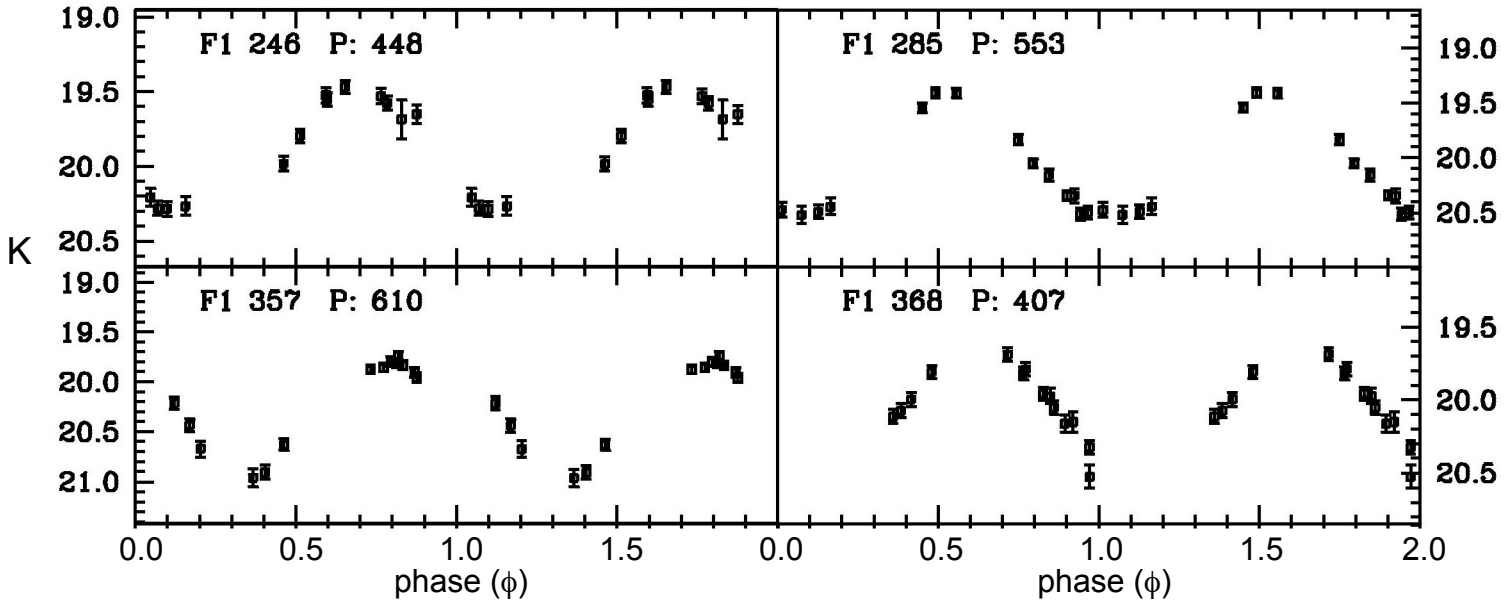






Courtois et al. 2013





Rejkuba+03

Long Period Variable stars:
bright AGB above the RGB tip

Mira long period variable stars period distribution - comparison of the old and intermediate-age populations