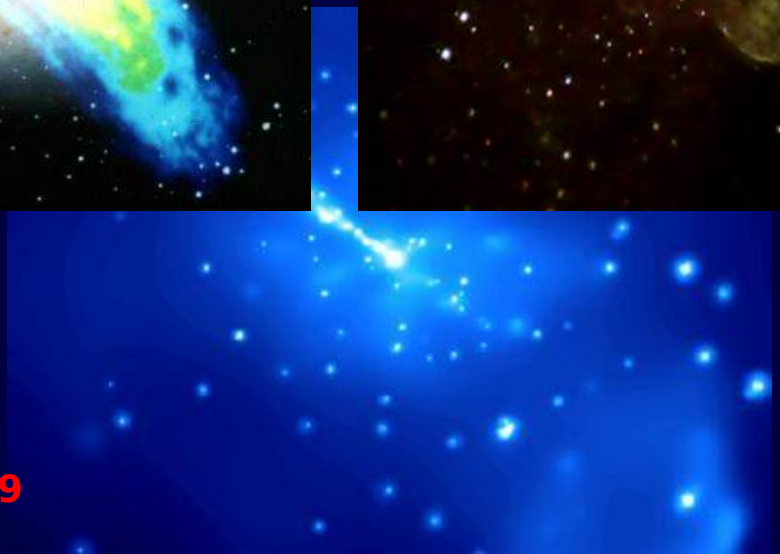
NGC 5128: The Giant Beneath

A giant E galaxy with an old stellar population – and the closest one too!

what is your NGC 5128?

- most people see the “peculiarities”....



what I see is the stars...the old stars

and this

archaeology in a giant E galaxy

why did it take so long to recognize that NGC 5128 is fundamentally an "E galaxy+"?

- Answer 1: it didn't
  - ✓ e.g. Sérsic 1958 – isophotal contours: "In the profiles corresponding to the major axis of the elliptical component… it was found that the colour remained constant, except in the obscured region… This is the same as Dennison found for colours in NGC 3379 and NGC 3384."

NGC 5128 is fundamentally a giant E galaxy

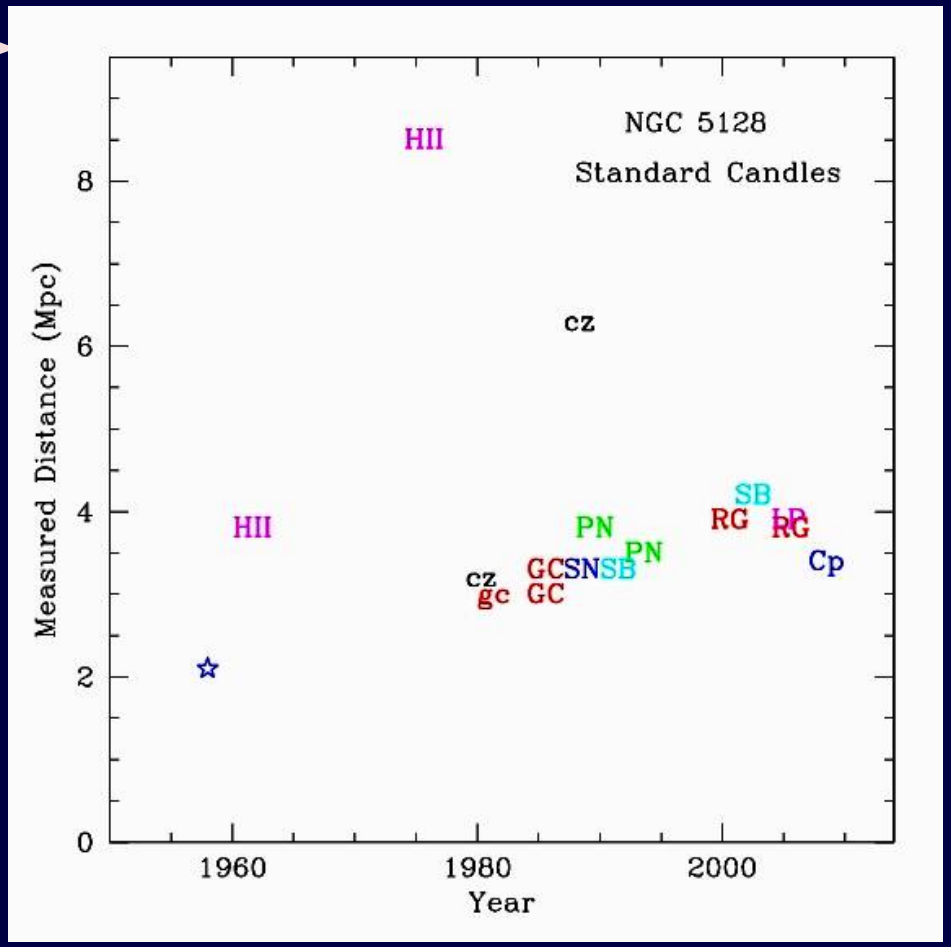
- "NGC 5128 is an unresolved E0 nebula with an unusually strong and wide central absorption band … The curvature of the outer parts of the spiral system and the irregular distribution of the absorbing clouds …clearly indicate tidal distortion by the E nebula" Baade and Minkowski 1954
- "It seems likely that the main radio characteristics of NGC 5128 and the energetic phenomena still going on are *a consequence rather than the cause* of the unusual structural features of the galaxy as a whole." Graham 1974
- "Cen A has probably an undeserved reputation for being one of the most peculiar galaxies in the sky." Ebneter and Balick 1983

why did it take so long to recognize that NGC 5128 is fundamentally “an E galaxy +”?

- Answer 2: lots of reasons early on
  - what distance, luminosity?
  - what galaxy type?
  - why no globular clusters?
  - *other…*
    - ✓ disc/dust lane
    - ✓ strong radio source
    - ✓ halo shell
    - ✓ X-ray emission
- Answer 3: people haven’t paid attention to the answers

what is the distance to NGC 5128?

- standard candles => 2Mpc < d < 8.5Mpc
- i.e. Δ(m-M) > 3mag!
- $M_{gal} \sim -18? -21?$
- stellar candles now consistent with:
  - ✓ d ~ 3.8±0.2 Mpc
  - ✓ (m-M) =27.9
  - ✓ $M_{gal} \sim -21$



linear, angular scale in NGC 5128

- galaxy proximity means large angular scale on the sky
  - ✓ 1° ~ 70 kpc
  - ✓ 1′ ~ 1200 pc
  - ✓ 1″ ~20 pc
  - ✓ $1r_e$ = 5.5′ ~ 6400 pc
  - ✓ $10r_e$ ~ 64 kpc

NGC 5128 – what galaxy type?

- Confusion caused by the dust lane

Galaxy type	source
like NGC 3379 (E1)	Sérsic 1958
E0p?	Morgan 1958
S0p	Freeman 1970
E0p	van den Bergh 1976
E + spiral	Dufour et al. 1979
(E0 + Sb?)	Sandage 1980 (Hubble Atlas)
S0	Sandage and Tammann 1981
S0p	NED database

"data seem to support Morgan's suggestion that the S0 classification type is a repository of physically quite distinct sorts of objects that exhibit only superficial similarities" van den Bergh 1990

dust lane is an “extra”

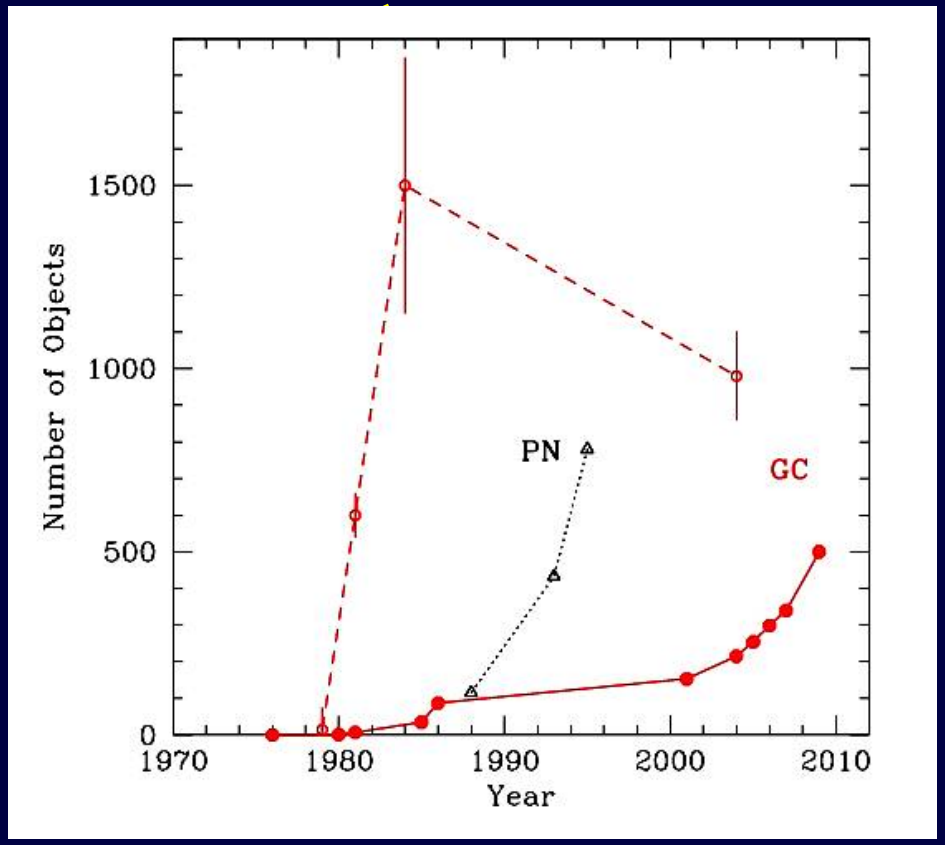
- many studies conclude that the dust lane is a distorted disc affected by the underlying, more massive E galaxy – i.e…
  - “curvature of the outer parts of the spiral system … clearly indicate tidal distortion by the E nebula” (Baade and Minkowski 1954)
  - “NGC 5128 is a giant elliptical in which is embedded an inclined and rotating disk composed partly of gas.” (Graham 1979)
  - “dust lane is found to be well understood in terms of a differentially rotating disk of gas and dust which is warped both along and perpendicular to the line of sight” (Bland et al. 1987)
  - young stars in the dust band corotate with it; no rotation of the E galaxy itself (Appenzeller and Möllenhoff 1980)

where are the GCs?

- if NGC 5128 is a giant E galaxy -> $\geq 10^3$ GCs
- they are hiding in plain sight... S/N ~ 0.02!
  - ✓ proximity problem: at d = 4Mpc, 1° ~70 kpc
  - ✓ wide angular extent dilutes the radial profile
  - ✓ low Galactic latitude (b ~ +18°) means lots of foreground contamination
  - ✓ dilution also means we can see through the halo to background galaxies
  - ✓ but distance is still large enough that GCs are nonstellar at 1" seeing (1" ~20pc)
  - ✓ photometrically it is *quite* difficult to distinguish GCs from halo K stars and galaxies
- then came Graham and Phillips (1980)

...finally the GCs are found

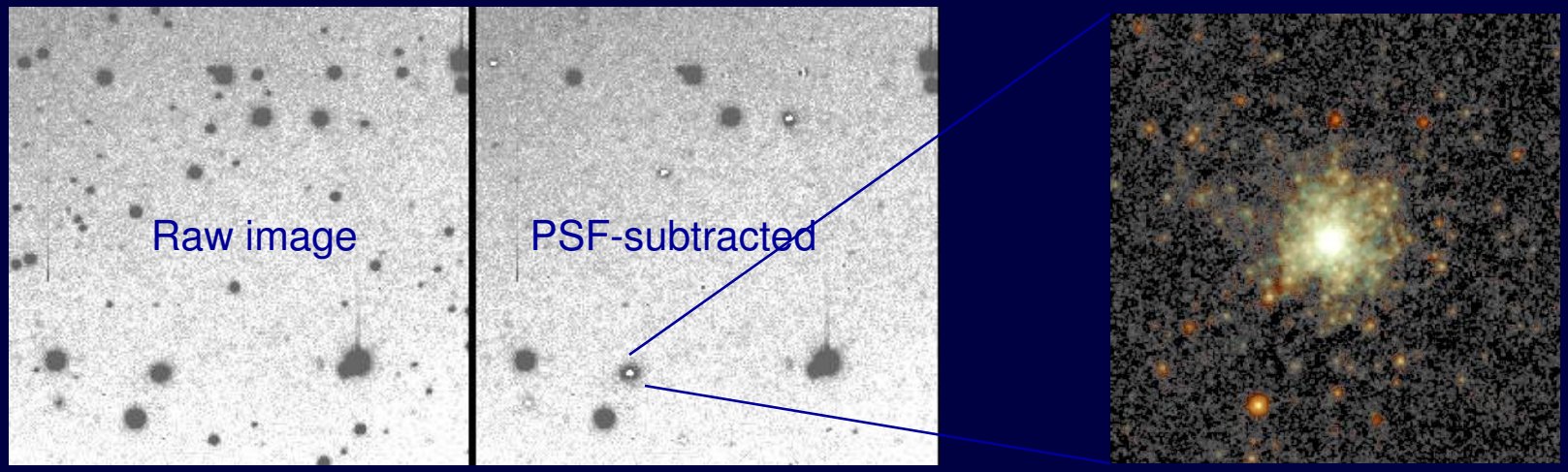
- early searches found none – star counts out to 464" found 15±60 (van den Bergh 1979)
- first GC identified by Graham&Phillips (1980)
- within 10 yr number of confirmed GC ~100
- currently 605 confirmed by radial velocity (556) and/or resolved by HST imaging
- however, clusters are still hard to find on a "global" scale



van den Bergh et al 1981; Hesser et al 1986; Sharples 1988; Rejkuba 2001; Peng et al 2004; Woodley et al 2005; Beasley et al 2006; Woodley et al 2007, 2009

NGC 5128 GCs: needles in a haystack

- typical cluster half-light radius $r_h \sim 0.4''$.
- some appear nonstellar at 1" seeing, most don't;
- can't reduce field contamination substantially just by image morphology



Ground based CCD image (1.1" resolution)

HST/PC1 image (0.1")

N GC 5128 field is ~equal mixture of stellar + nonstellar objects; can't reject anything *a priori*

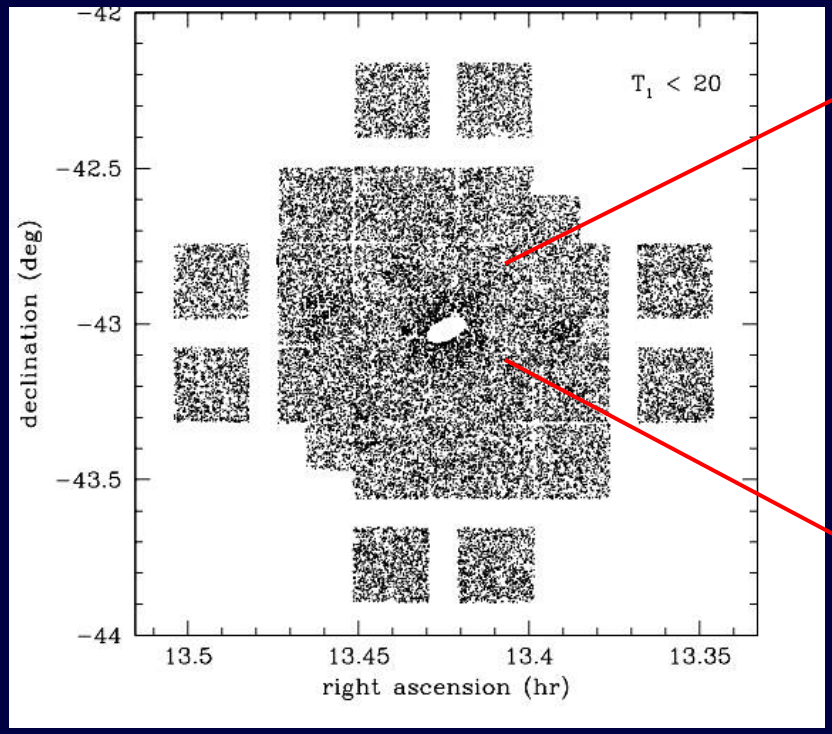
Worst possible set of conditions!

Wide Field CMT_1 Imaging

- total photometric database: psf-fitted magnitudes and colors for 111,000 objects.

- NB innermost excluded bulge region (ellipse with a = 4.2', b/a=0.5, parallel to dustlane)

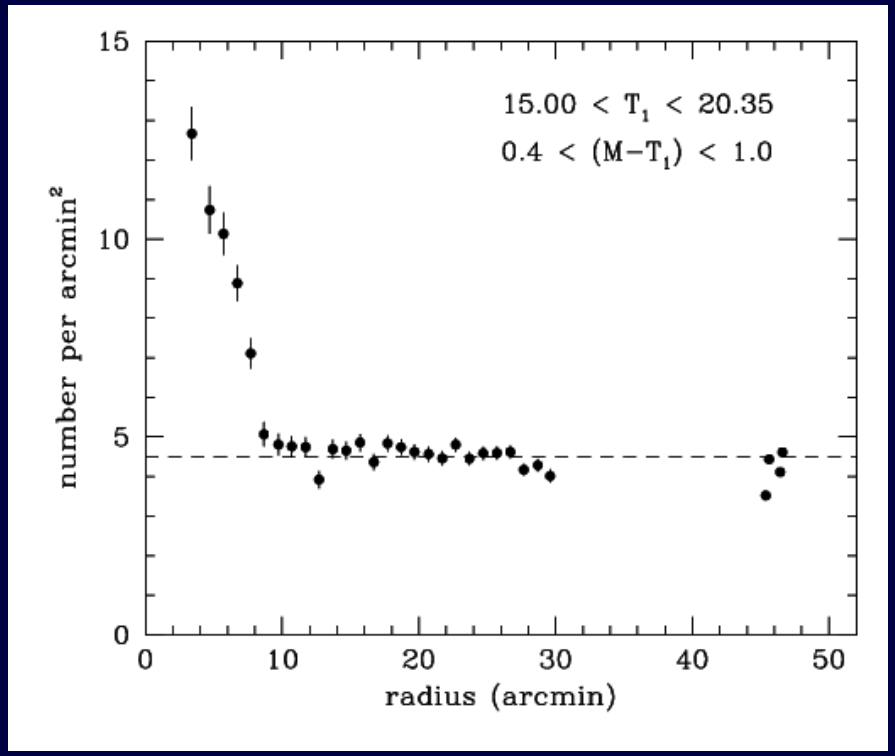
>98 percent of the list is field contamination !



Harris, Harris, Geisler 2004; Harris et al 2004

Density Profile and Total Population

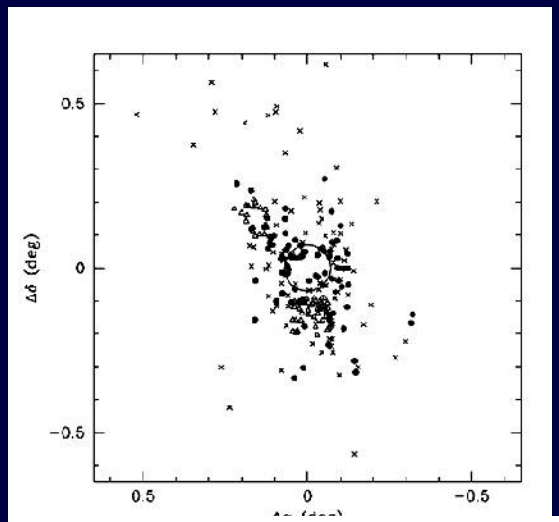
- big reduction in background count level compared with old photographic starcounts
- strong GCS "signal" for r<12' but curiously flat distribution at larger radii (??)
- for r < 12', total residual population after background subtraction: ***N_t = 1200 +- 80***
- represents (magnitude limits etc.) the bright half of the total old-GCS population
- whole galaxy probably contains > 2400 globular clusters

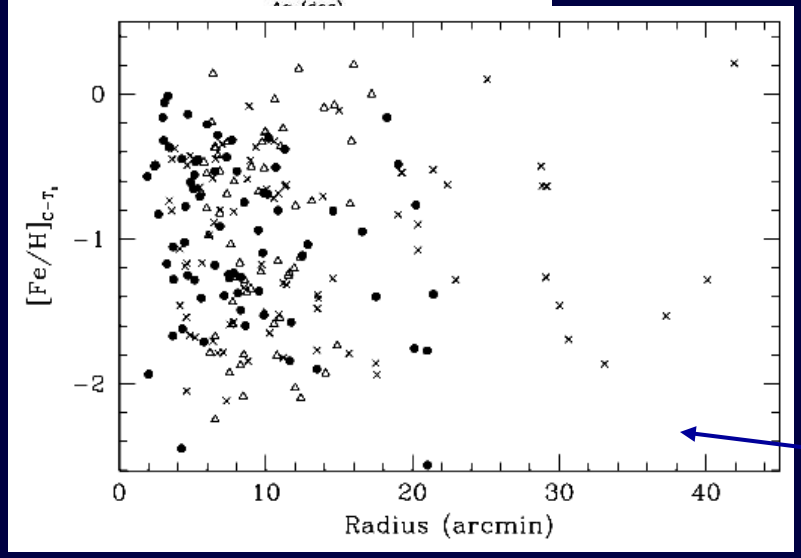


S_N ~ 3.8 (other gE's typically in range 2 – 6)

Metallicity Distribution for NGC 5128 Clusters

CCD for 230 “known” clusters



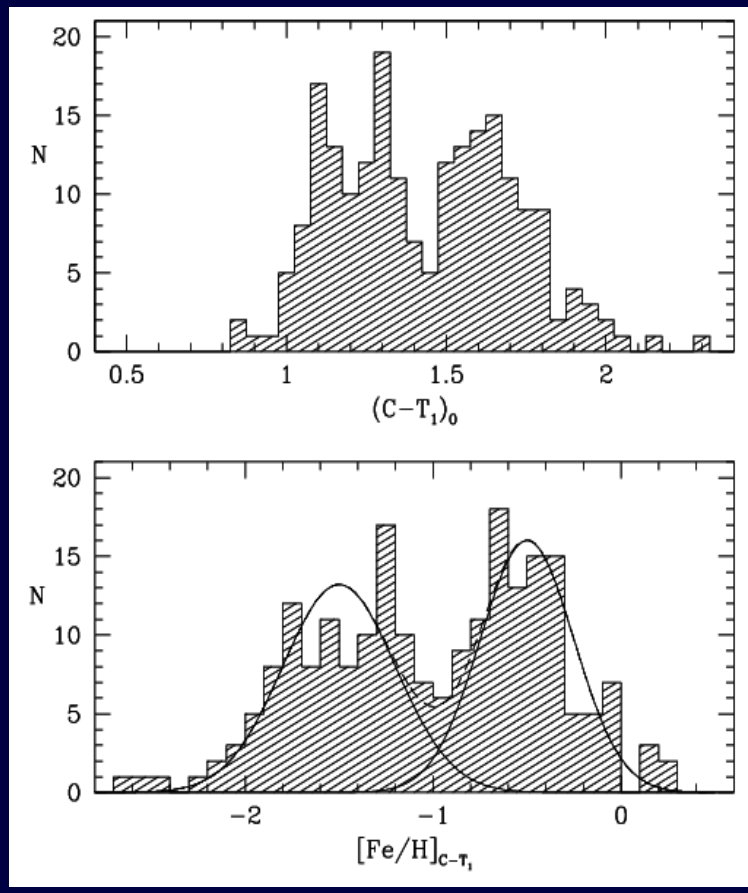


- two main subgroups in MDF;
- favors hierarchical merging?

GC color < => metallicity

✓ red = metal-rich

✓ blue = metal-poor

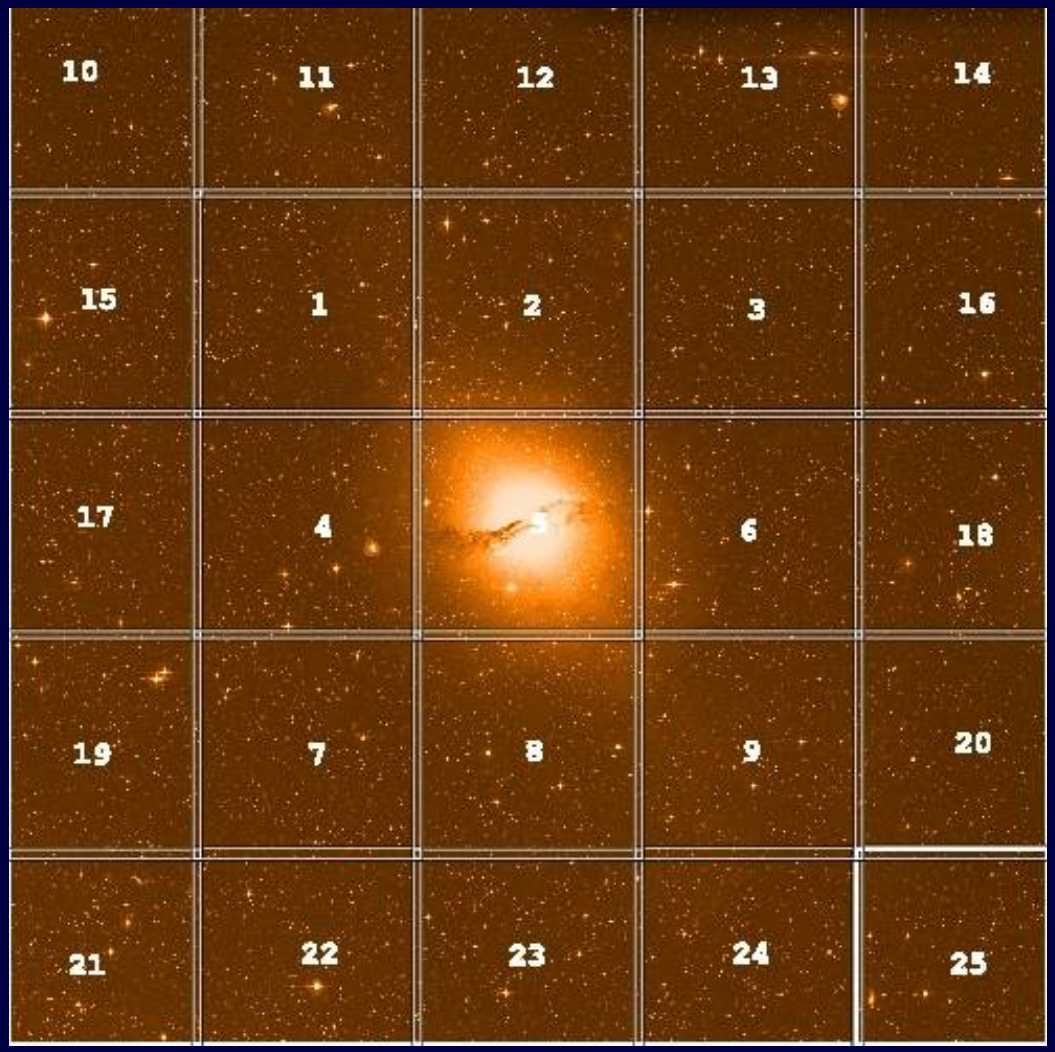


Weak or absent radial gradient

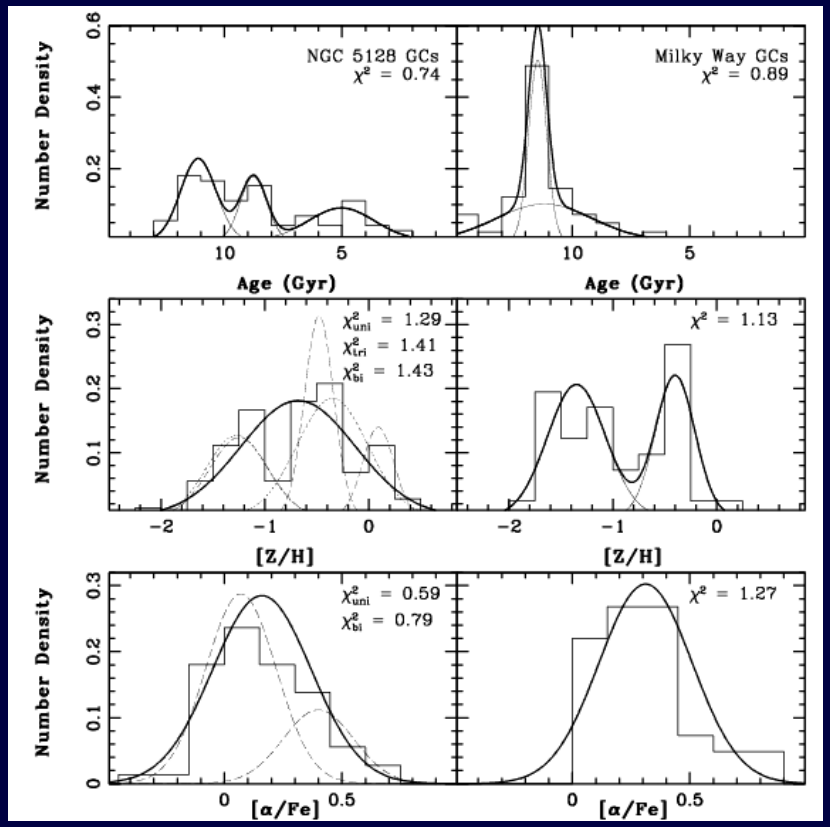
latest attempt at wide field imaging

- ✓ IMAC/Magellan images in BR
- ✓ average seeing ~0.5”
- ✓ “elongated” background galaxies can be eliminated
- ✓ many non-stellar sources remain
- ✓ improved candidate segregation

to be continued



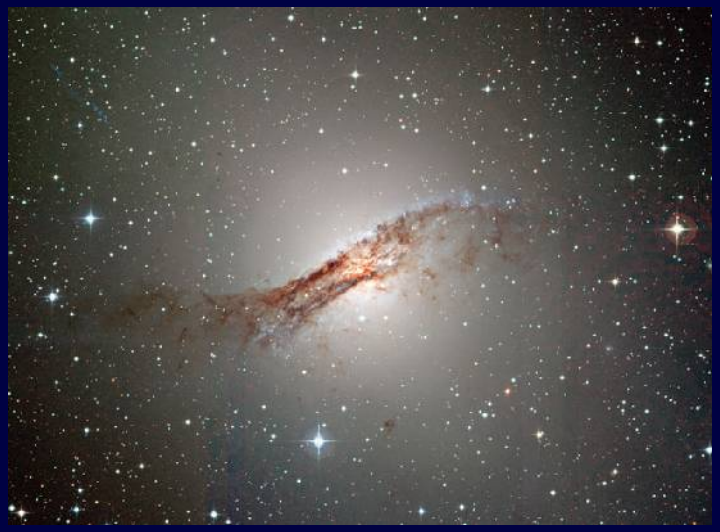
GCs are mostly old



Woodley et al. 2009:

✓Lick-index ages for 72 GCs at S/N > 30; all within 15 kpc of center

✓most are old (9-11Gyr); ~ 20% are younger



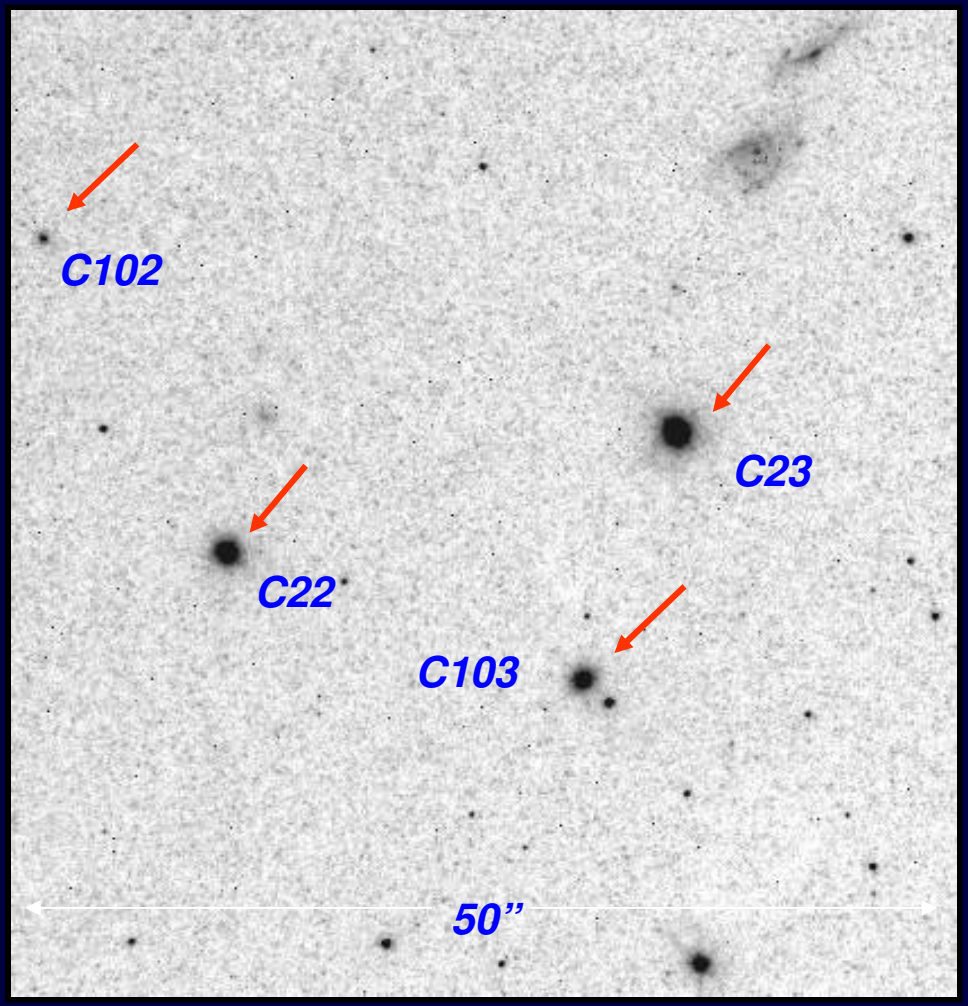
Beasley et al. 2008:

✓Lick-index ages on same system with AAT/2dF, more widely spread sample

✓ 85-90% of their sample are >8 Gy

GC profiles resolvable with HST

- *view from HST/ STIS*
  - ✓ *d ~4Mpc*
  - ✓ *1" ~ 20pc*
- *measurable radial profile for GCs*
- *fit to King models*
- *MW GCs are virialized systems with constant M/L (McLaughlin 2000)*
- *degeneracy between r_C , c, μ, L, M/L => can get E_B from photometry alone*



Four of our NGC 5128 Globular Clusters

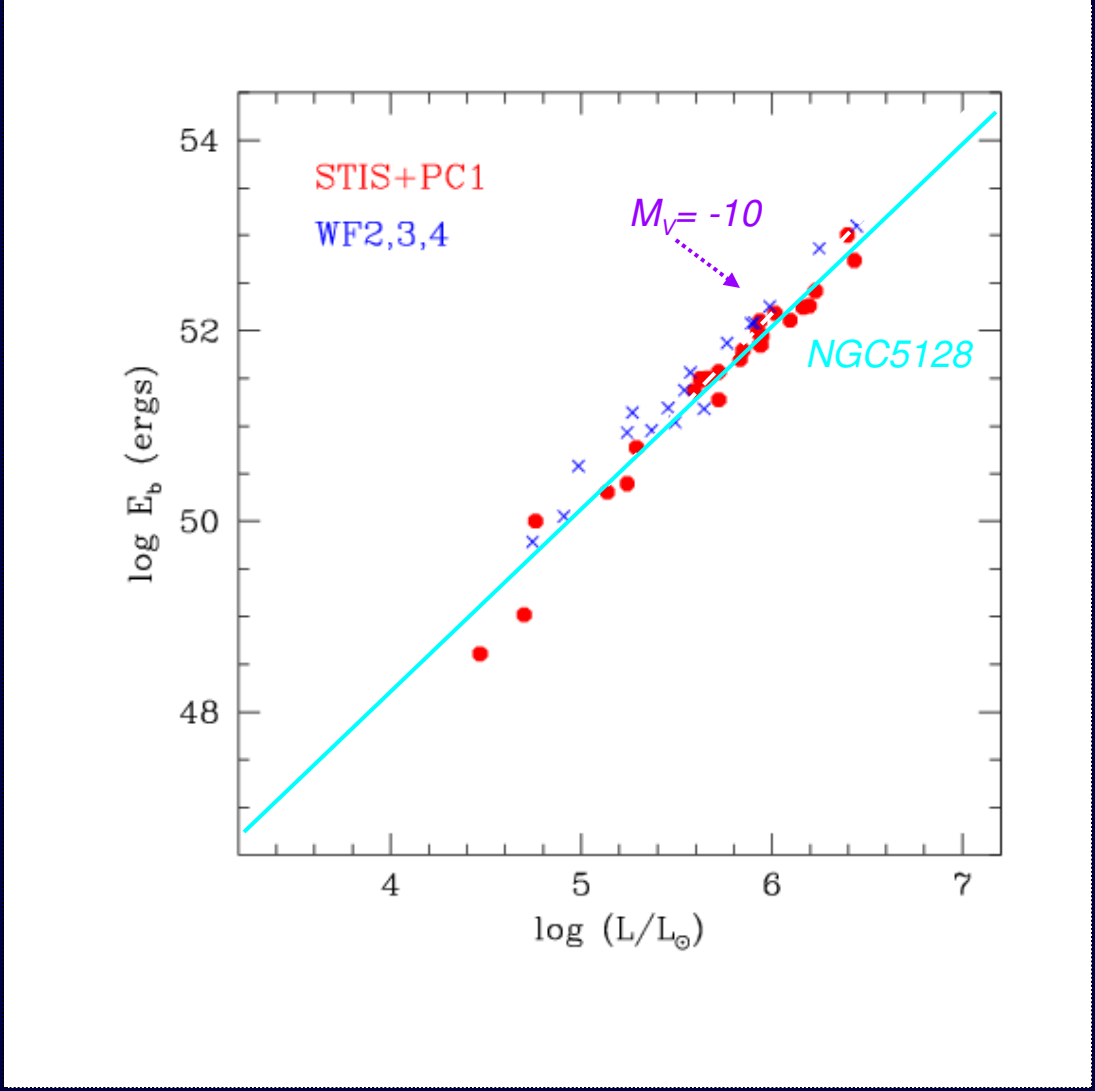
binding energy results

- *results for 43 GC in NGC 5128*

- *MW and NGC 5128 correlations(E_B vs L) essentially identical*

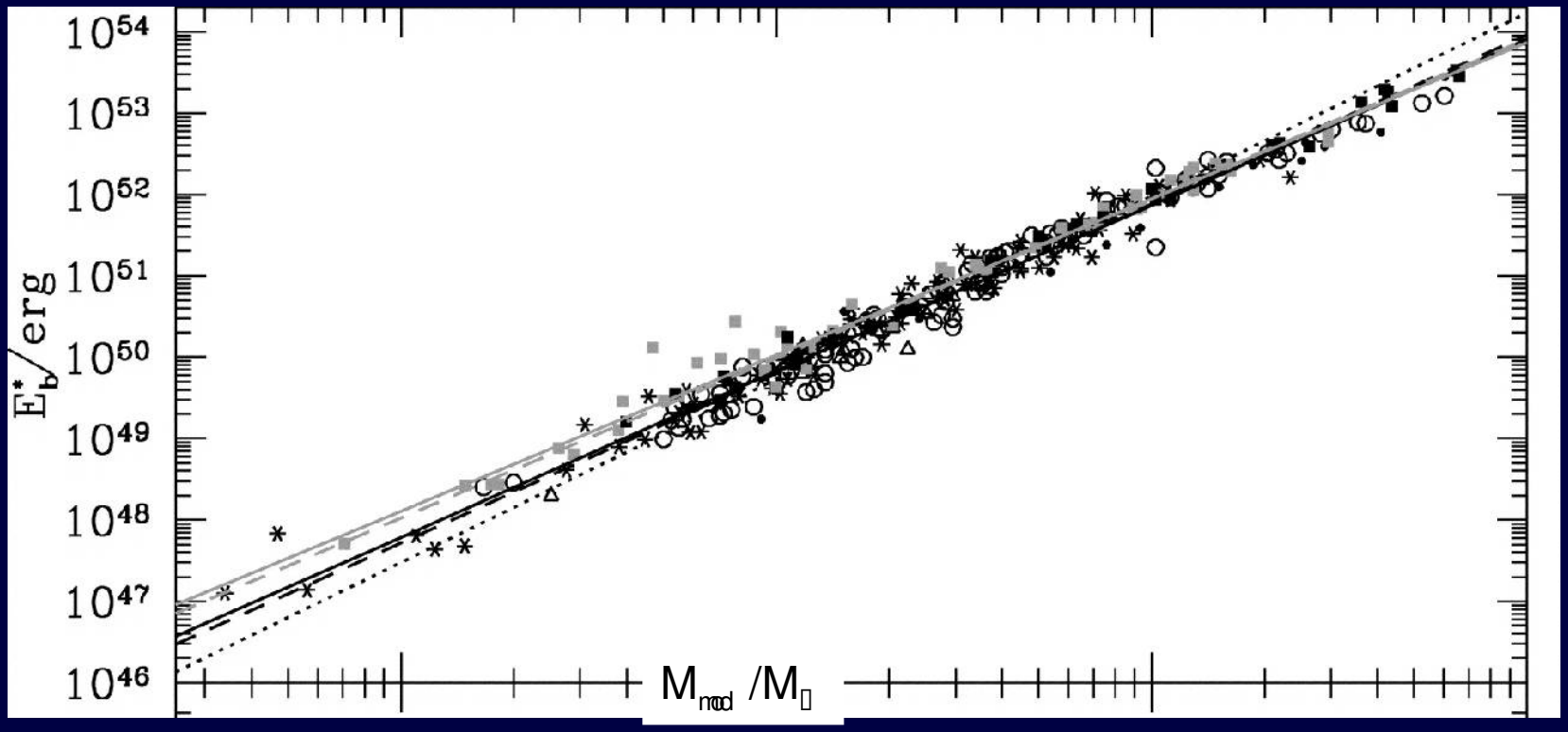
- *reminder: E_b scale for NGC 5128 "set" by assuming same M/L as for MWGCs*

- *NGC 5128 data extend to more massive clusters than MW*



Harris et al. 2002

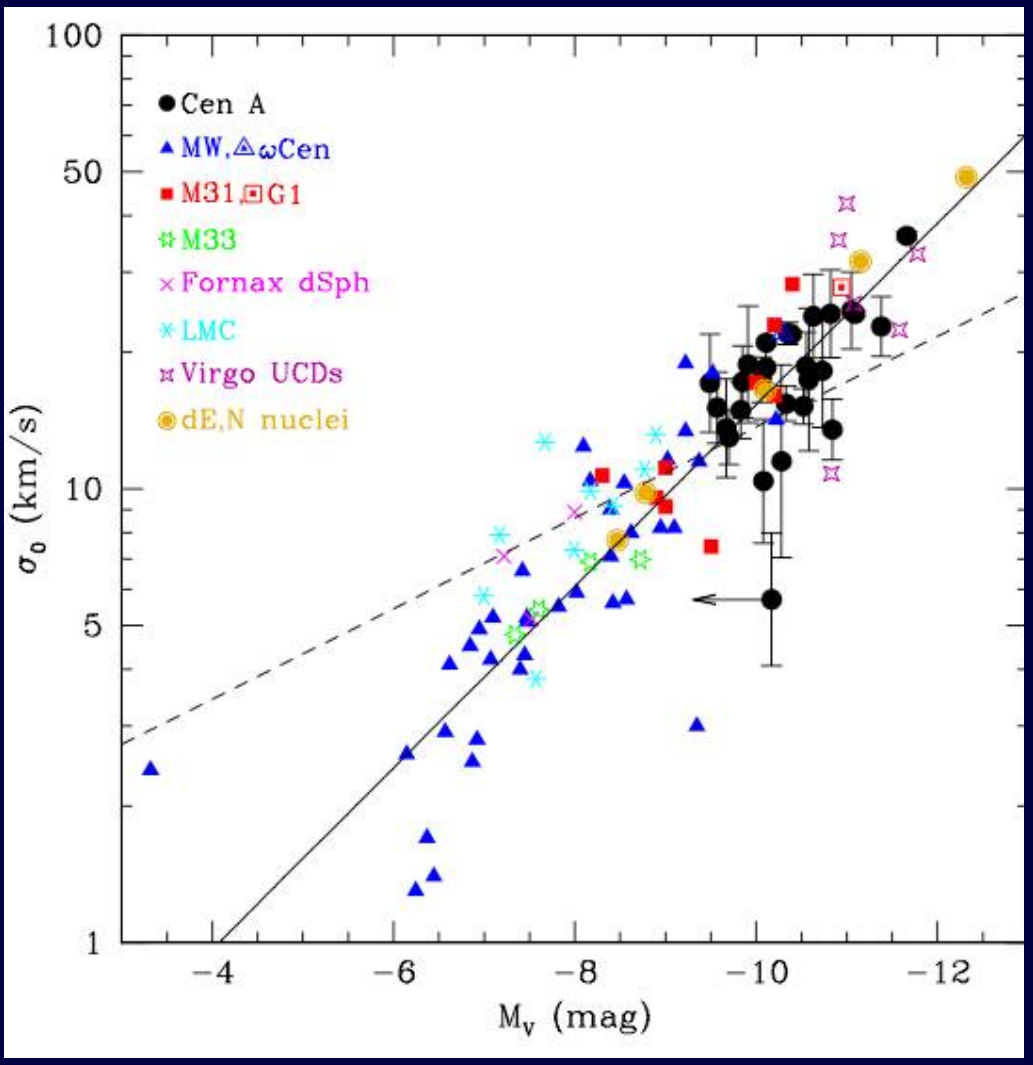
MW, M31, NGC 5128 GCs “same animal”



“The homogeneous and intensely precise data we can now work with … have established the trend of the fundamental plane securely, showing that GCs in all these environments follow the first-order trend $E_B \sim M^2$ quite accurately.”

(Barmby et al. 2007)

Central velocity dispersion vs. V-band magnitude



Rejkuba et al. 2007

Solid line:

$\log \sigma = -0.815 - 0.2 * M_V$

Galactic globular clusters:

(McLaughlin & van der Marel 2005)

Dashed line:

$\log \sigma = +0.136 - 0.1 * M_V$

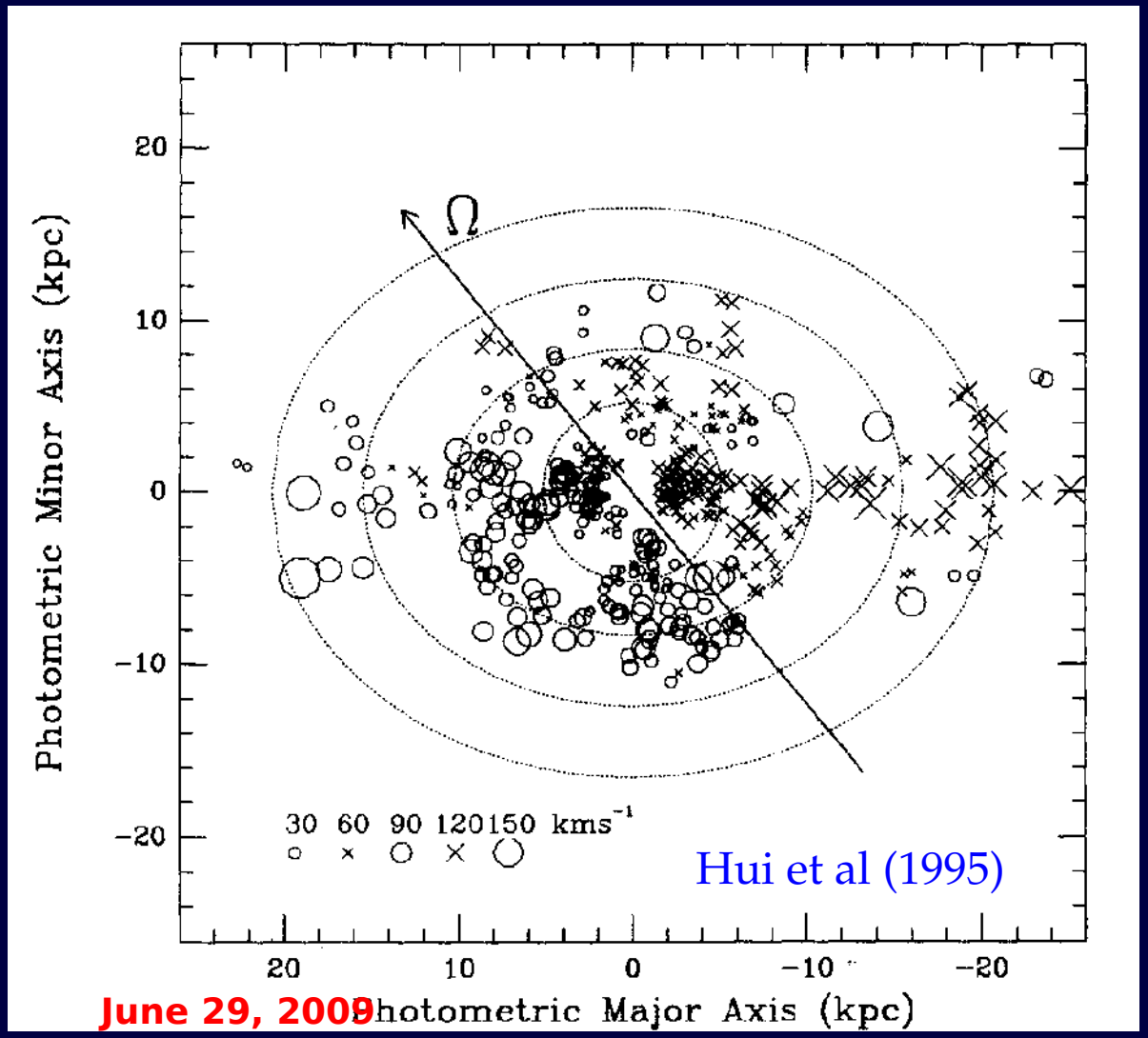
Faber-Jackson relation for bright ellipticals

References:
- MW, LMC and Fornax dSph: McLaughlin & van der Marel'05
- M33: Larsen+02
- Virgo UCDs: Hasegan+05
- dE,N nuclei: Geha+02
- ω Cen & G1: Meylan+95, +01
- Cen A solid dots: Rejkuba+07

planetary nebulae

- “easily” identifiable at almost any distance from galactic center via [OIII] emission line
- “relatively easy” radial velocity confirmation
- origin ~1-8$M_\odot$ – wide PN age range possible
- excellent halo dynamical tracers
- # confirmed PN > # confirmed GS

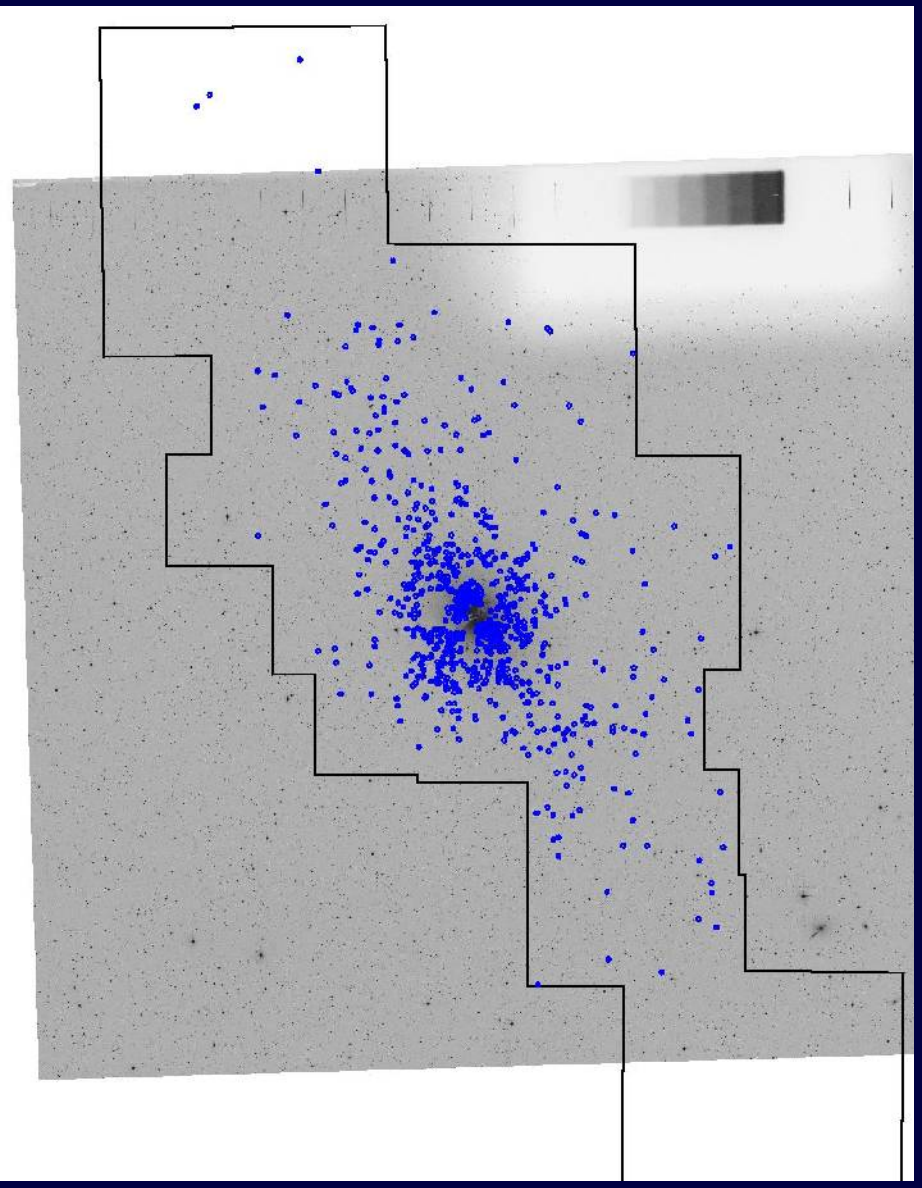
Results from Original PN Survey



- ✓ By far largest PN sample
- ✓ 1.5 mag down PNLF
- ✓ PNLF distance of 3.5 Mpc
- ✓ Significant rotation
- ✓ Misaligned kinematic axis
- ✓ Dark matter halo

Hui et al 1993

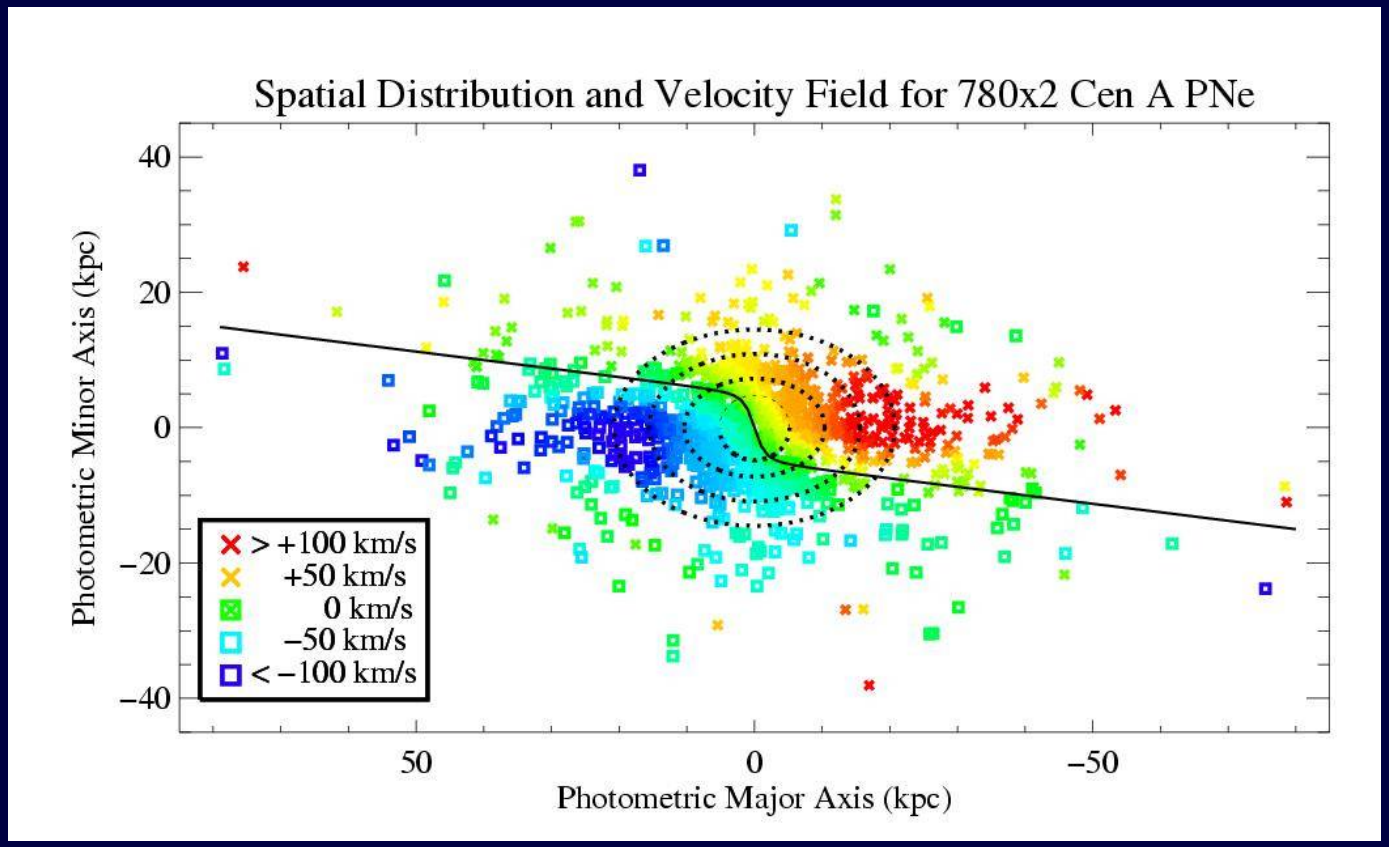
PN Surveys:Version 2



- Extended survey probing outer halo
- Covers 2.9 sq deg
- Major axis: 100 kpc
- Minor axis: 40 kpc
- 1141 detected
- 780 confirmed
- 3 PNe at 80 kpc, NE
- 0 PNe > 60 kpc, SW

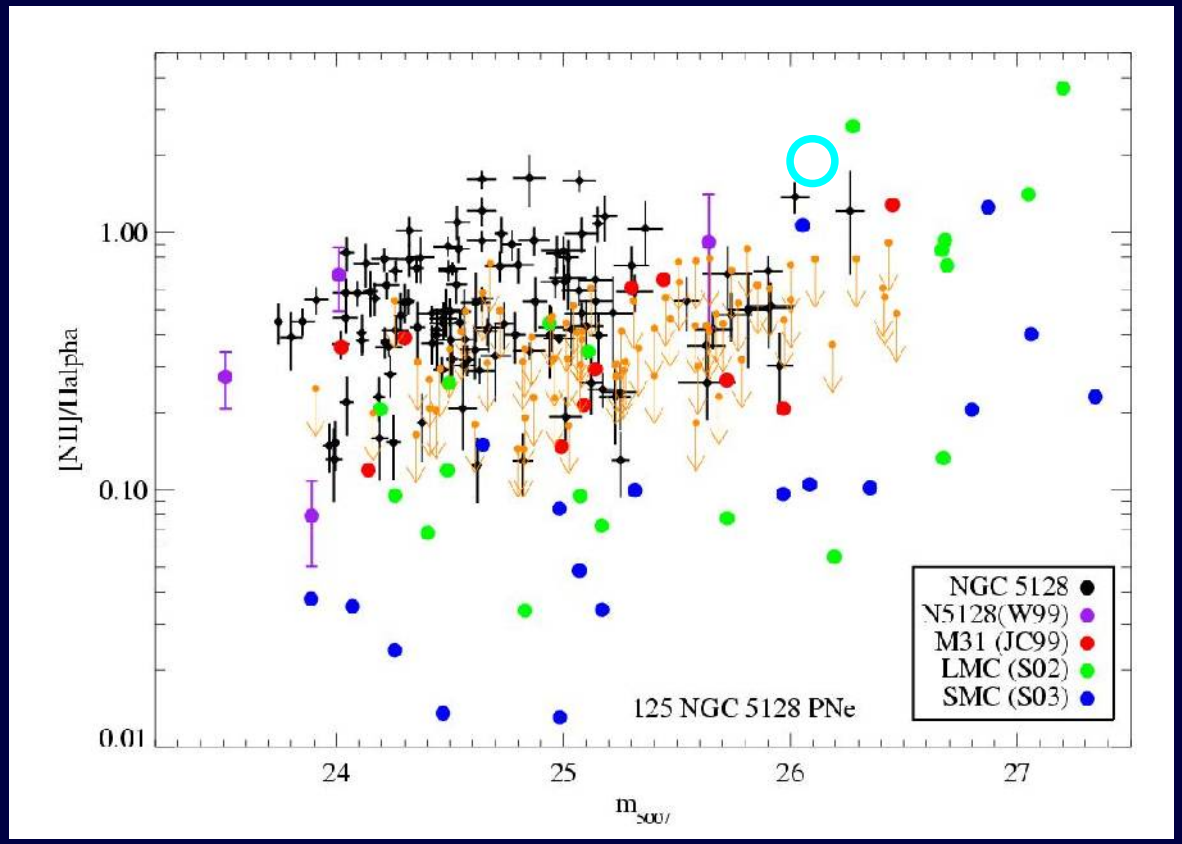
Peng, Ford & Freeman (2004a)

Two-Dimensional Velocity Field



- ✓ potential is likely triaxial (tending toward prolate)
- ✓ twist, then flat

PN abundances...

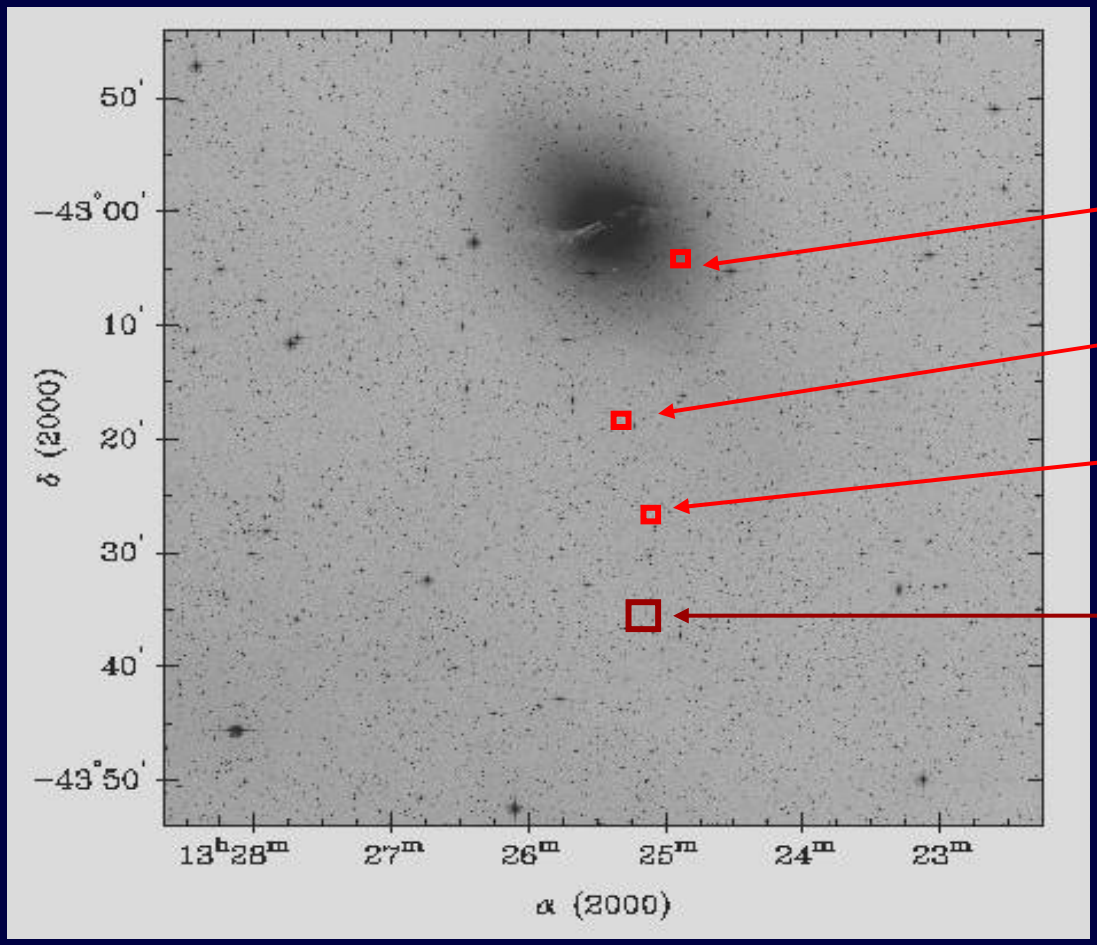


- ✓ NGC 5128 generally more metal-rich
- ✓ no obvious outliers in [NII]/Halpha
- ✓ none found younger than ~1Gr

halo stars

- at ~4Mpc they can be resolved – mostly HST imaging data
- 4 (5) fields studied to date
- VI CMDs of stars up to 2-4 mag below the RGB tip

halo star fields



HST imaging

8 kpc WFPC2
1.4 R_e

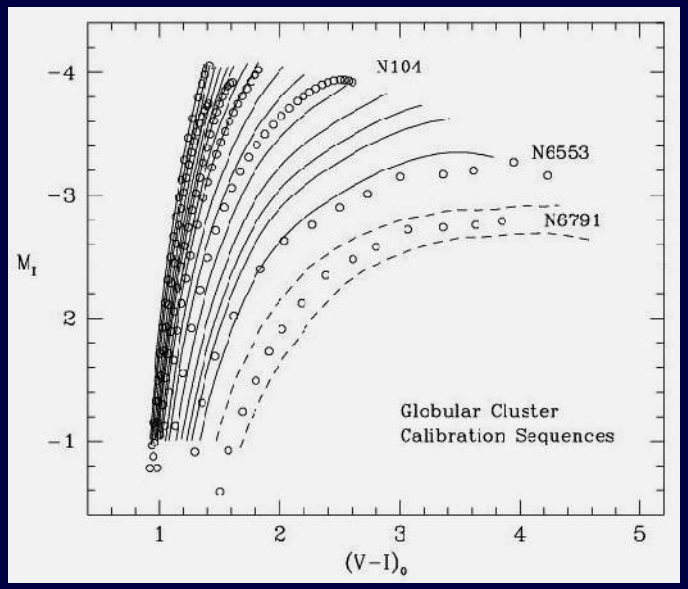
20 kpc WFPC2
3.7 R_e

30 kpc WFPC2
5.4 R_e

40 kpc ACS/WFC
6.7 R_e

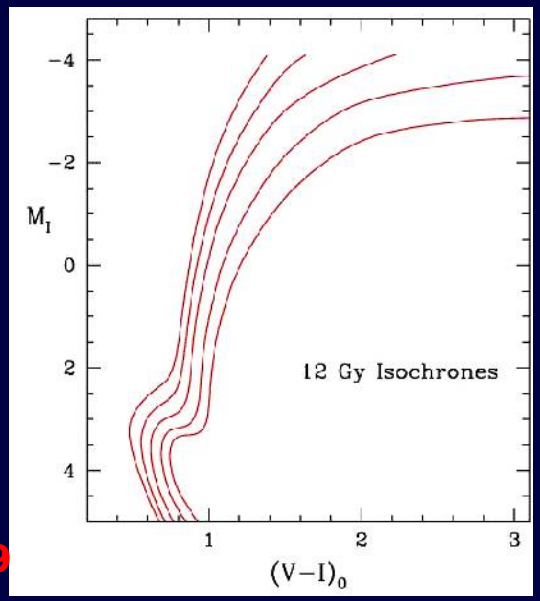
(NB: PNe extend twice this far out)

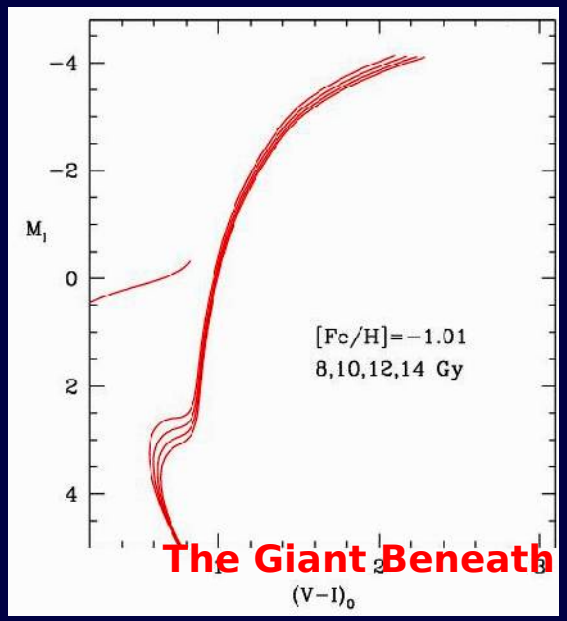
CMDs – age vs metallicity



- ✓(V,I) photometry works well: high metallicity sensitivity and takes full advantage of the optical cameras
- ✓ interpolate within RGB tracks (calibrated onto Milky Way GC grid)
- ✓ a fast, efficient way to derive a first order Metallicity Distribution Function

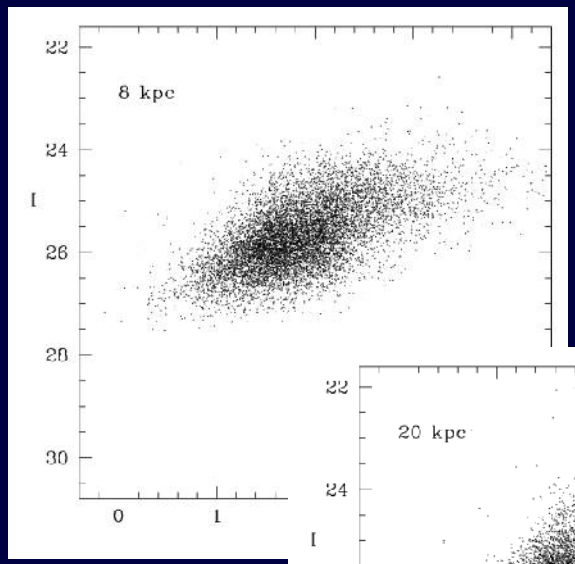
Metallicity

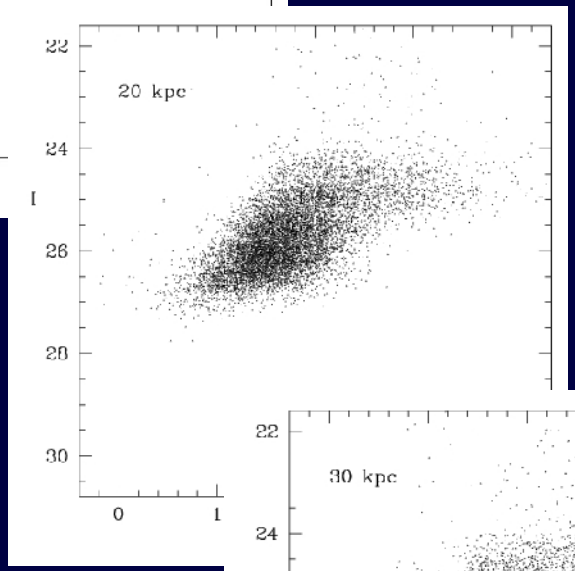


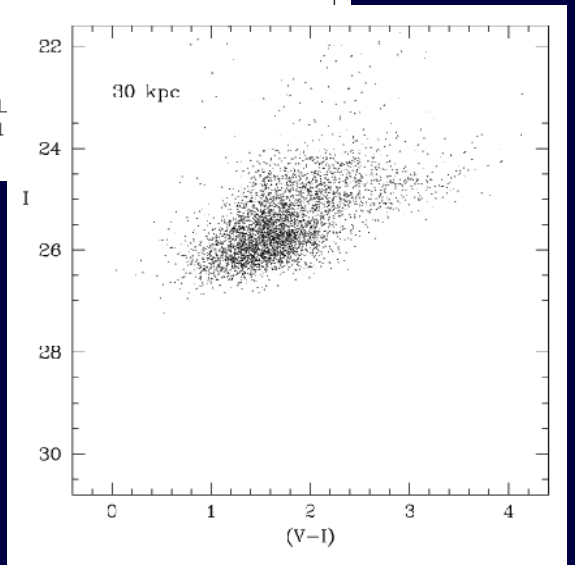


Age

CMD results for halo fields







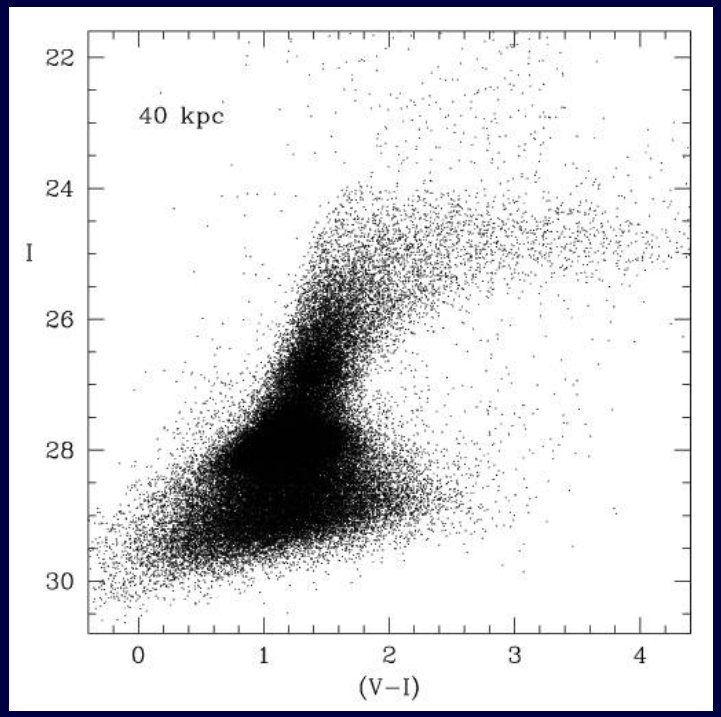
Harris, Poole, & Harris 1998, AJ 116, 2866

Harris, Harris, & Poole 1999, AJ 117, 855

Harris & Harris 2002, AJ 123, 3108

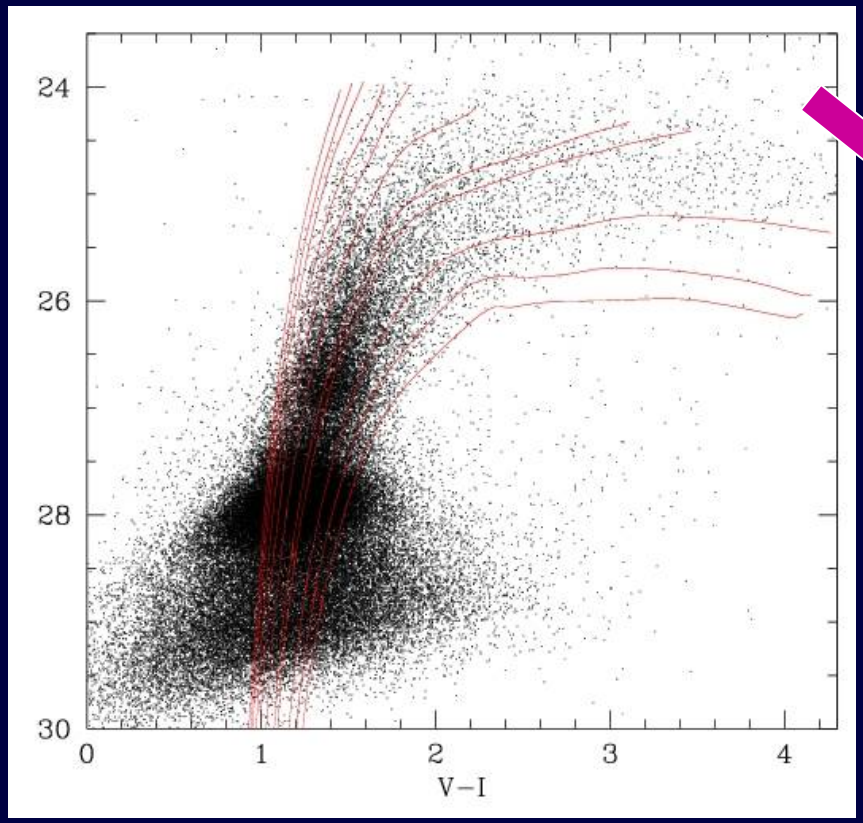
Rejkuba et al. 2005, ApJ 631, 262

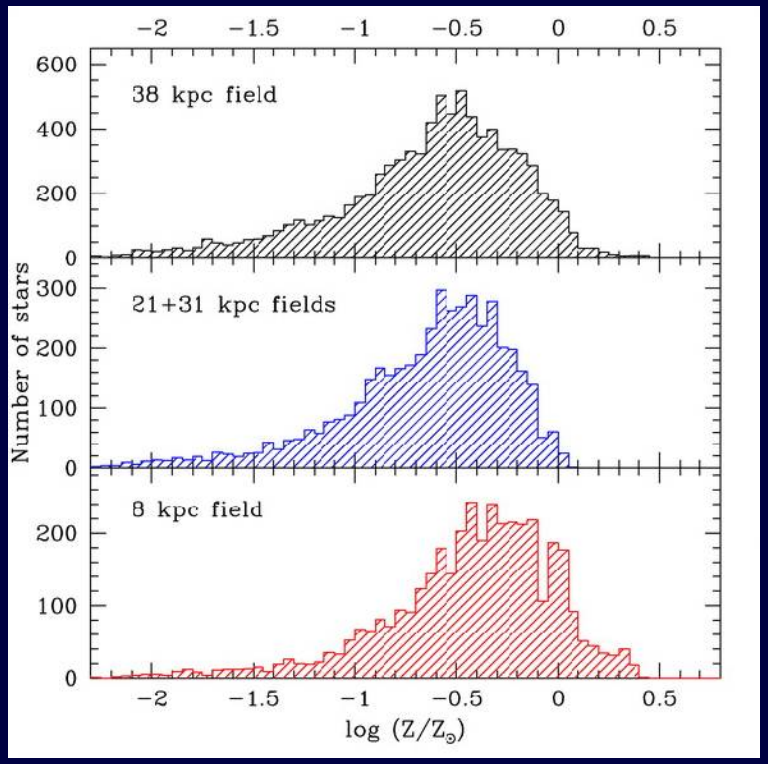
Rejkuba, Harris, Greggio & Harris in progress



a unique dataset for gE's

grid interpolation to get star-by- star metallicities

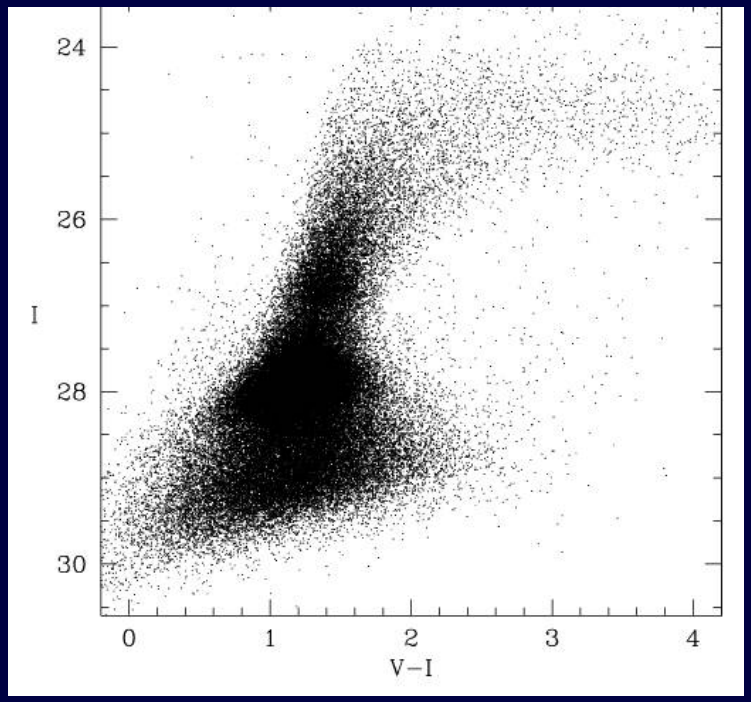




RGB stars: → ***broad and predominantly metal-rich MDF with little radial gradient***

halo stars and age

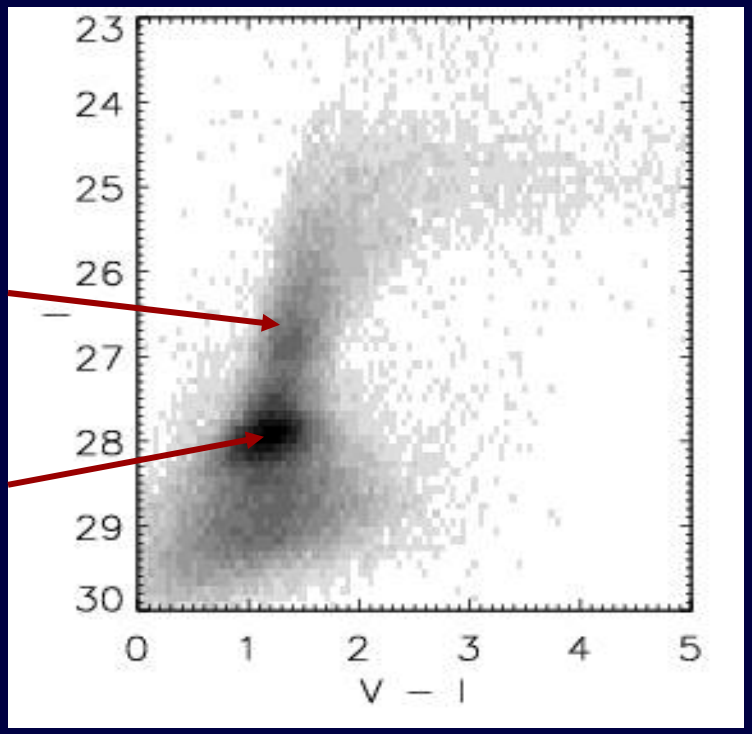
- various features of CMD sensitive to metallicity and/or age: RGB, RC, AGB
- at present, only the 40 kpc field has enough leverage for both age and metallicity distributions simultaneously



construct CMD simulations to narrow down age and metallicity distributions (Rejkuba)

AGB bump

RHB (red clump)



✓luminosity function in both I and V

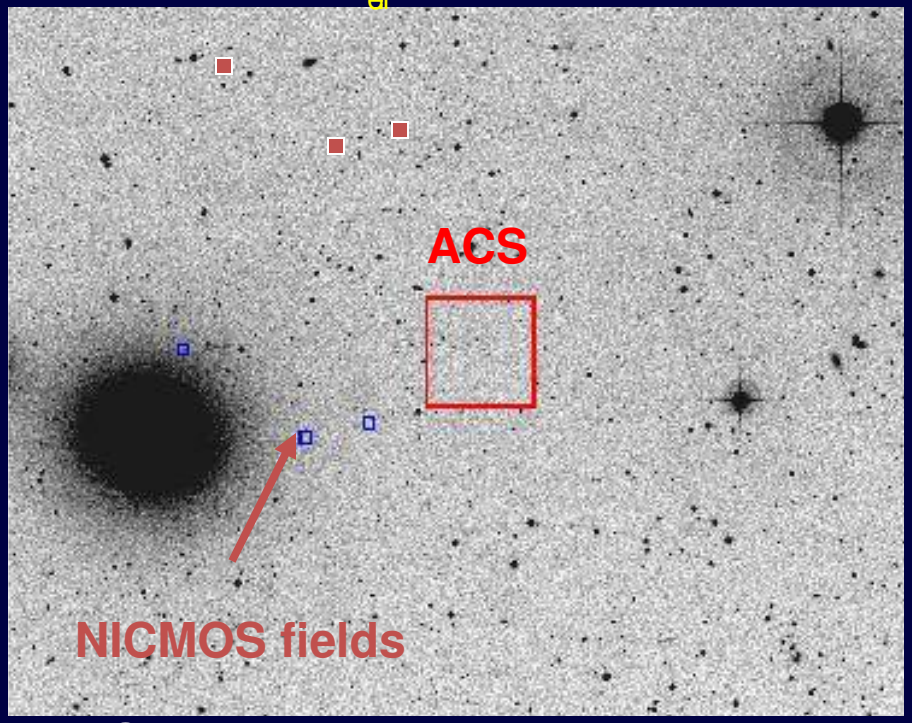
✓full distribution across CMD

Halo stars in NGC 3379

M_V = -20.9

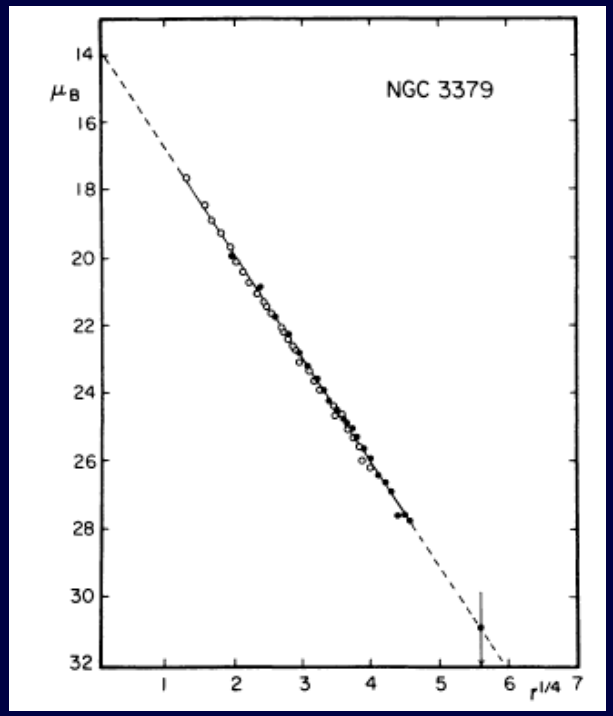
field center at 33 kpc:

10.3 → 13.6 R_{eff}



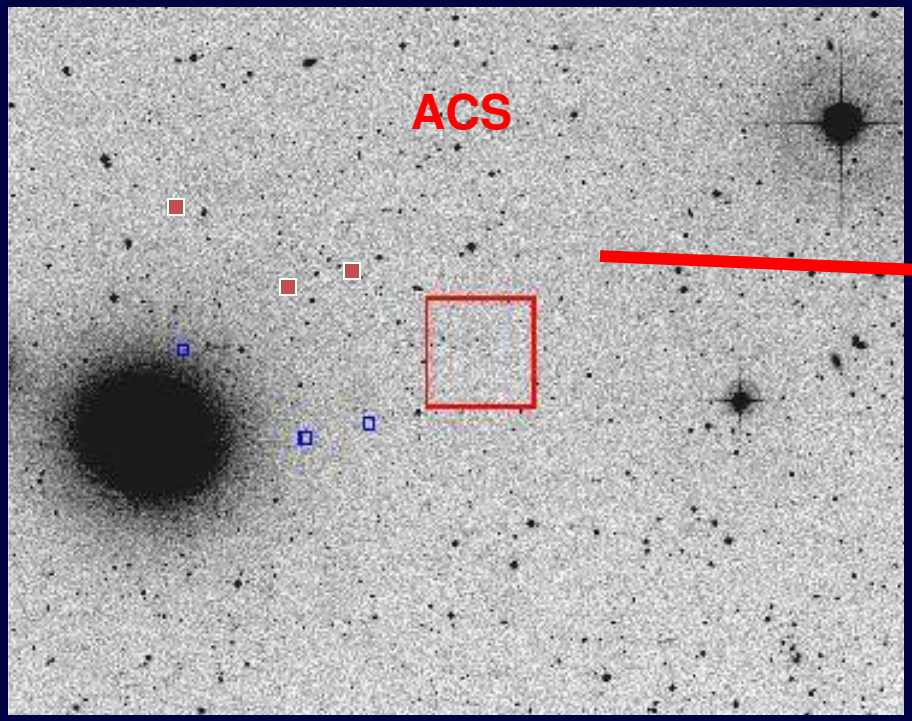
Gregg et al. (2004):
old and high-Z

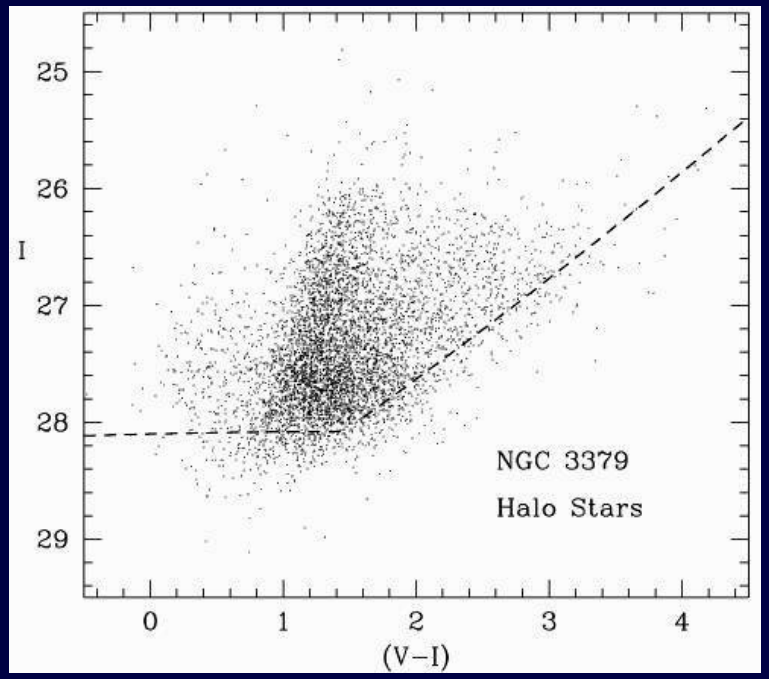
textbook standard giant elliptical!
"A walking advertisement for the deVaucouleurs law" (Statler & Smecker-Hane 1999)



DeVaucouleurs & Capaccioli 1979:
"note close agreement with $r^{1/4}$ law"

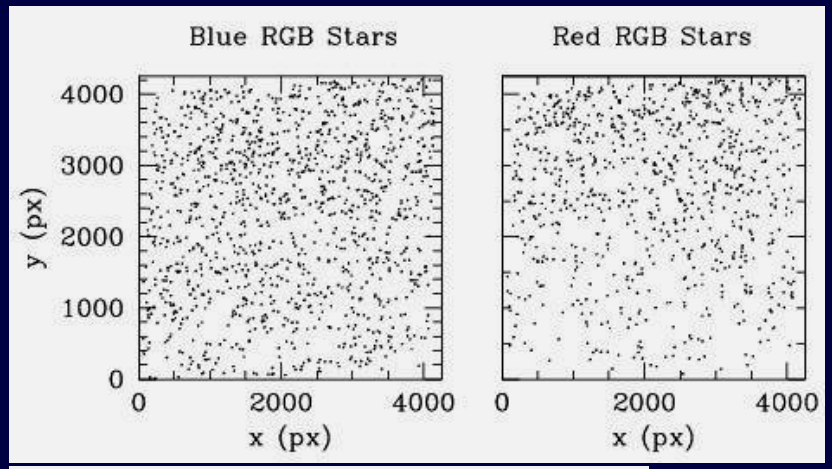
a comparison: halo stars in NGC 3379

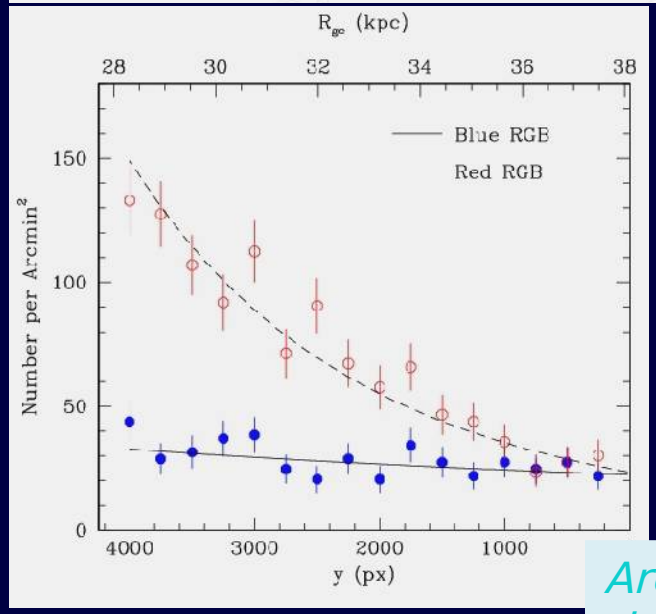


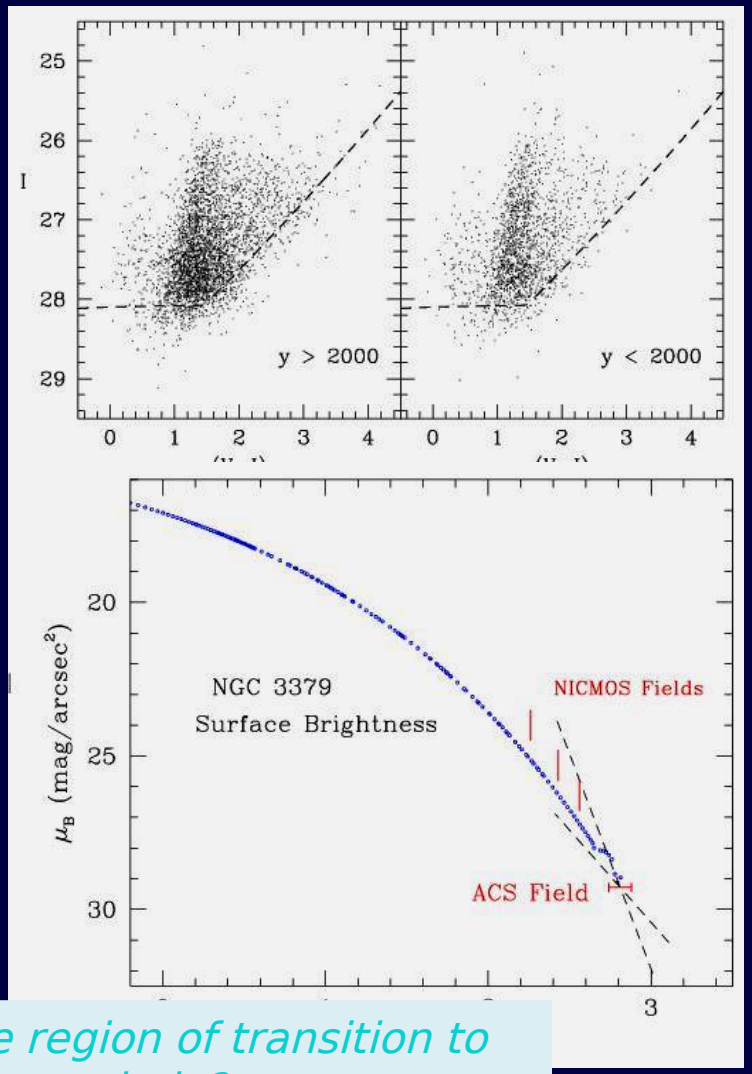


- significant metal-poor population
- metal-rich/metal-poor combo = new for large E galaxy

blue/red halo stars in NGC 3379 have different spatial distributions







Are we seeing the region of transition to the classic metal-poor halo?

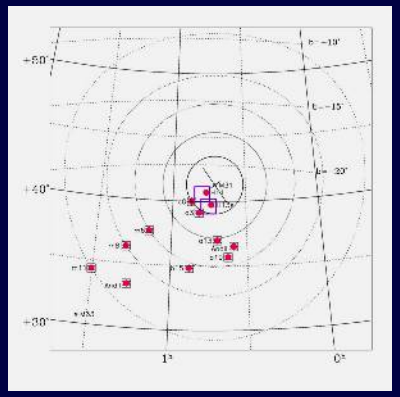
where is the metal-poor halo?

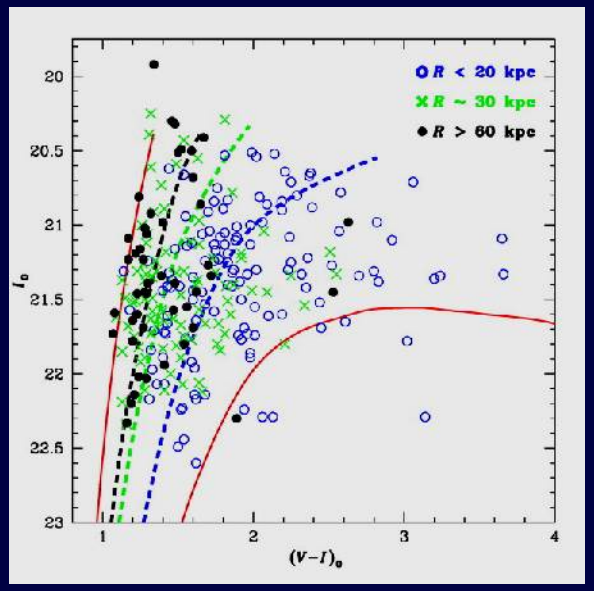
- ✓ *are we seeing the region of transition to the classic metal-poor halo?*
- ✓ *why didn't we see it in the others?*
- ✓ *are we looking at two distinct components ?? (bulge + halo)*

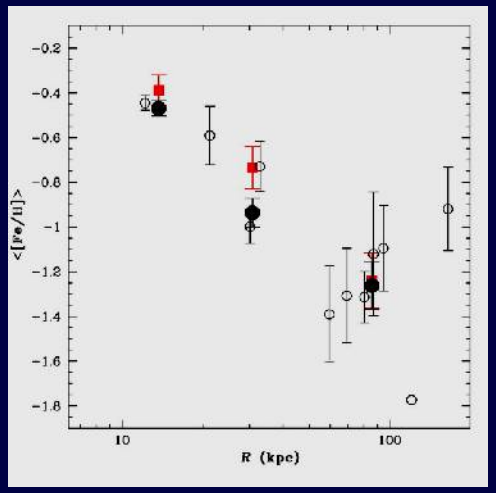
NGC 3379 10.3 → 13.6 R_{eff}

NGC 5128 1.4 → 6.7 R_{eff}

Should we expect to find the transition starting routinely around **12 R_{eff}** ?







Kalirai et al. 2006 &&

M31 halo Z-gradient

Metal-poor past R > **10 R_{eff}**

summary

- distance now well known from stellar candles
- GCs consistent with “normal” E galaxy populations
- MDF “bimodal” with ~50/50 metal-rich/metal poor
- halo stars dominantly metal-rich
- both populations mainly ≥8-10Gyr
- PN show inner “twist”, flat outer rotation
- GC kinematics different; similar to group?
- % metal-poor halo stars/GC << metal-rich ….why??
- NGC 5128 is providing important clues as to the history of a large E galaxy