Dwarf Ellipticals from GALEX to WISE

Deep archival surface photometric study of 252 bright ellipticals ($M_V < -20$), 60 faint ellipticals ($M_V > -20$), and 62 dE's, morphology from RSA/UGC, luminosities from GALEX (NUV), SDSS (ugri), 2MASS (JHK), WISE (W1), Spitzer (3.6), plus 127 MW/M31 globular clusters for comparison/calibration

Science Goals:

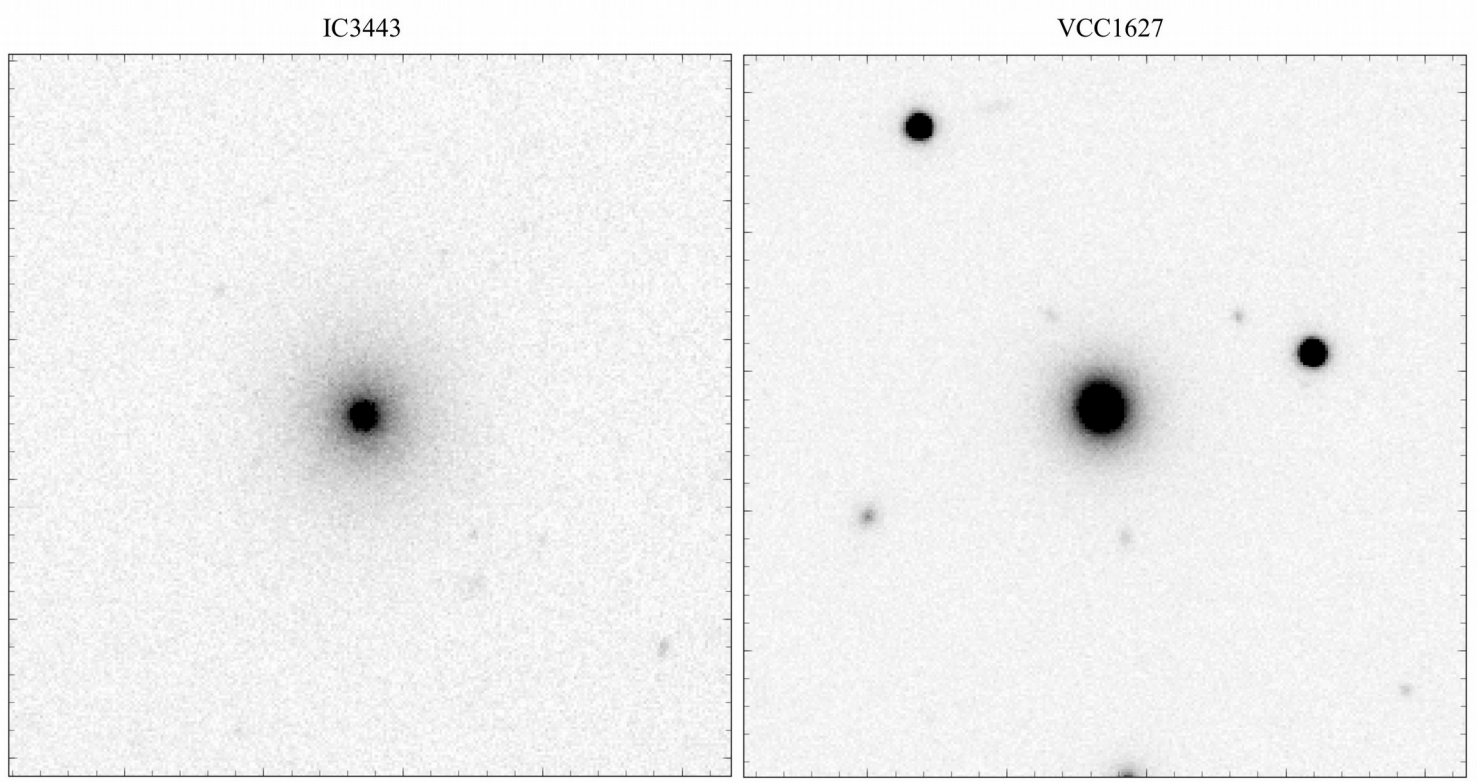
Do ellipticals form one family (structurally or kinematically)?

Do they have a common formation epoch?

Do they have a common evolutionary history?

Tie down the M/L for stars in the oldest populations

(editors note: we will not be answering any of these questions today)

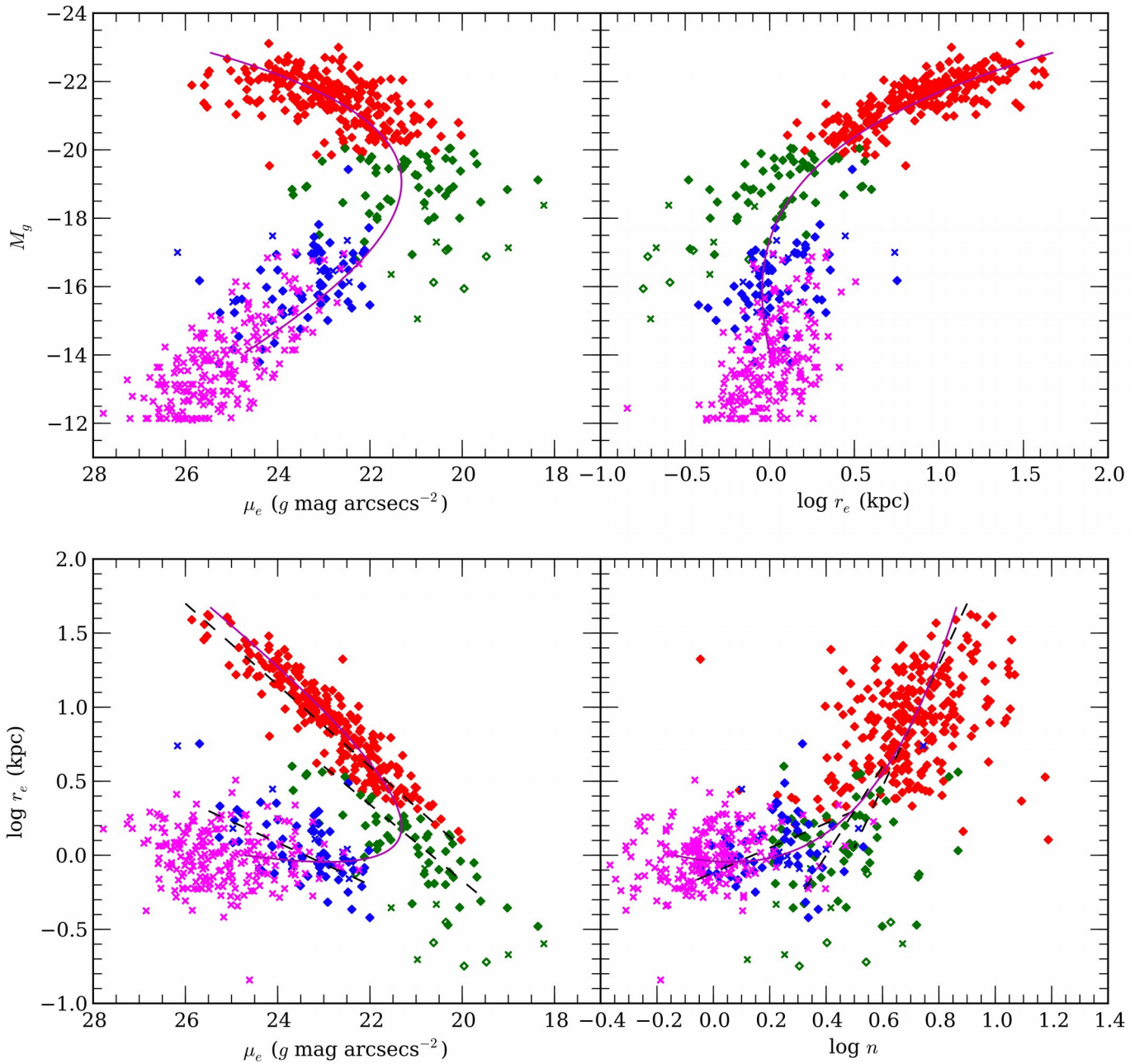


dE on the left, power-law E on the right

same L (m_B = 15.7 and 15.3) and same distance (in Virgo)

morphologists sees “diffuse” nature to dE before any knowledge of distance

Are dE's related to normal ellipticals? Is the dichotomy an artifact of profile fitting?

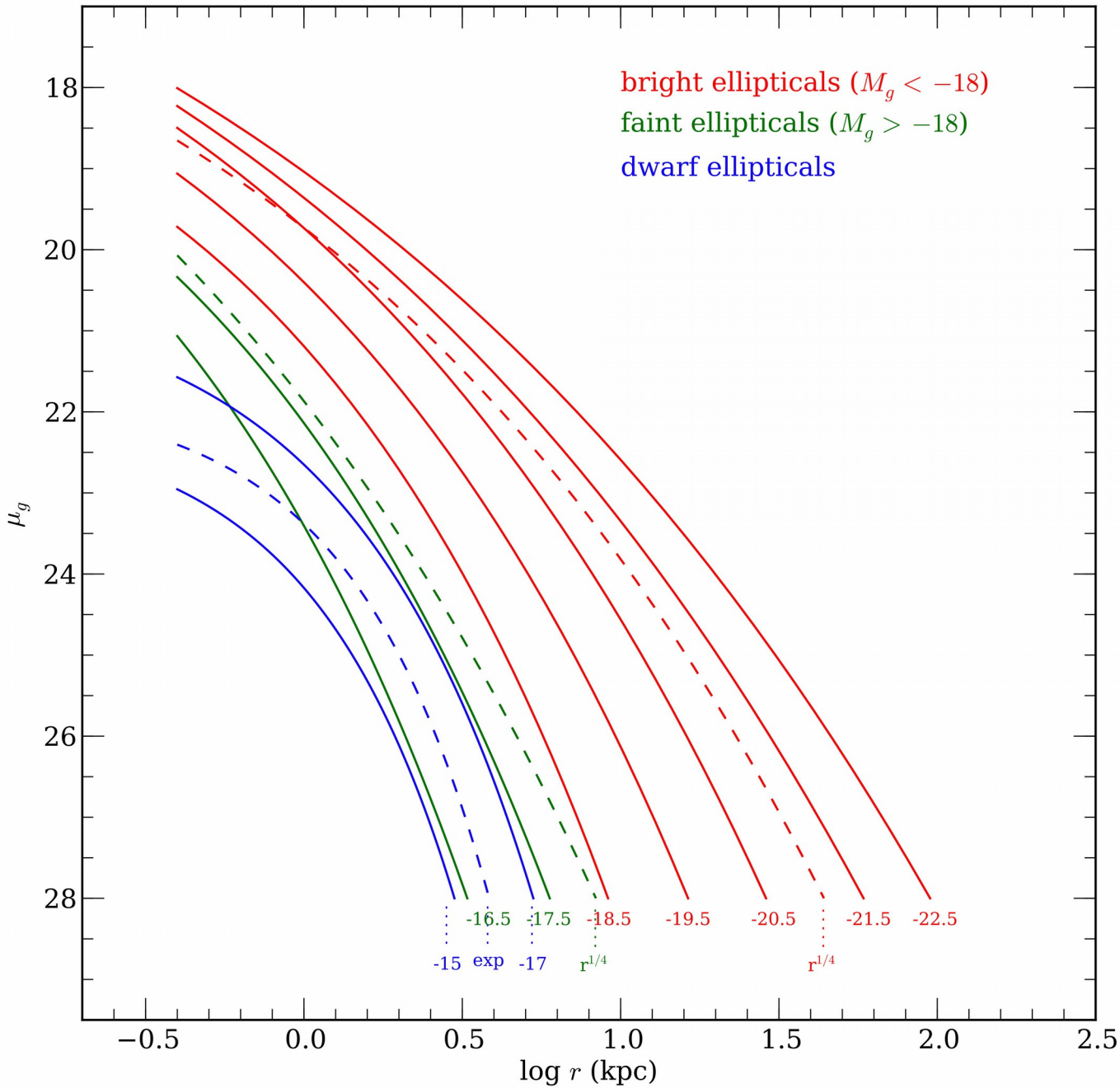


red = bright E
green = faint E
blue = dE (this study)
magenta = Gavazzi dE's

results of Sersic fitting function

r_e = effective radius
s_e = effective surface brightness
n = shape parameter

Graham (2008) – dE and E are continuation of same family

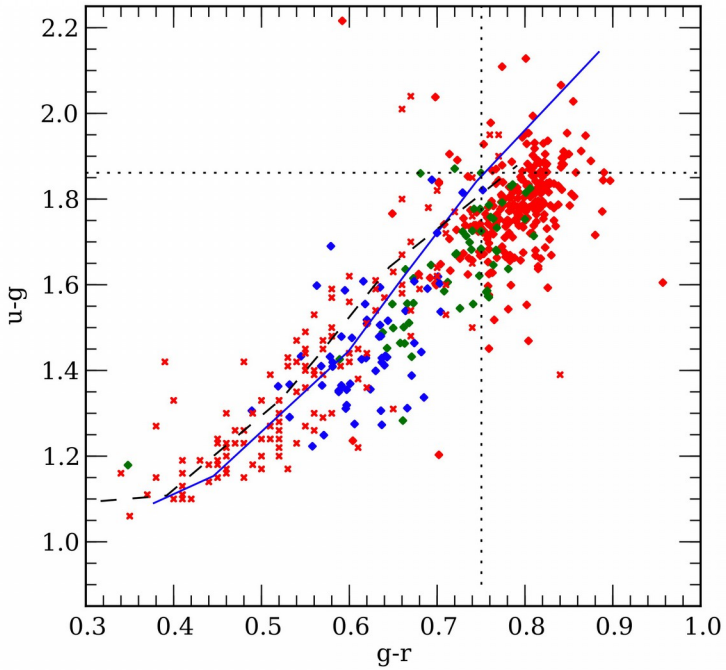


template profiles produced by averaging profiles in luminosity bins, see Schombert (2013)

normal elliptical profiles are smooth function of luminosity, but not self-similar

bright and faint ellipticals are clearly members of the same family (structurally)

dE's have a specific shape that differs from normal ellipticals, i.e., a different family



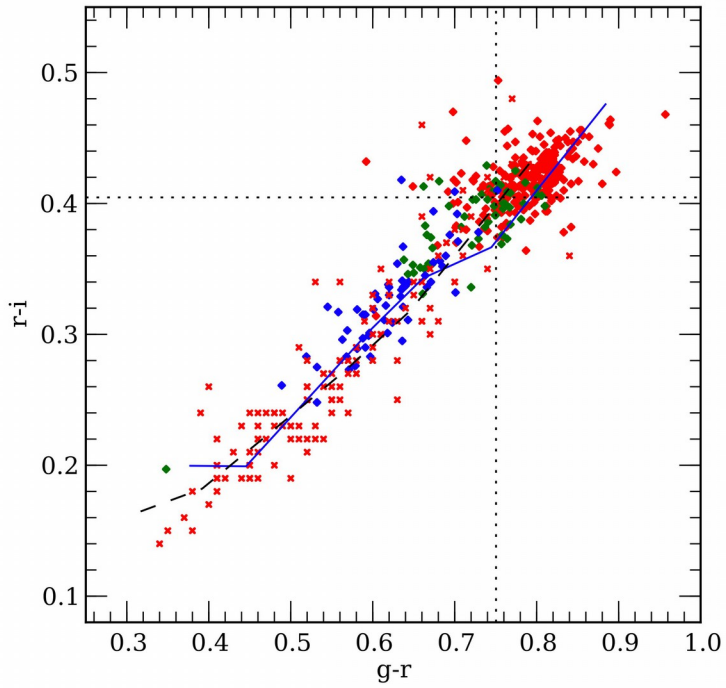
near vs far colors

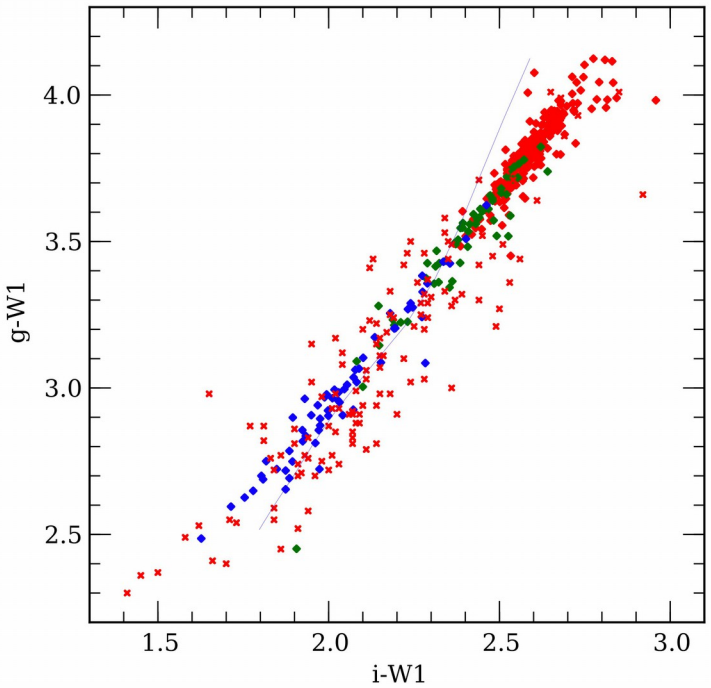
red crosses = MW/M31 globulars

good overlap between globular colors and ellipticals, can calibrate Fe/H scale for normal ellipticals

but, dE's drift into very low Fe/H colors with longer baseline (i.e., g/i – W1)

little to be learned from comparison of colors

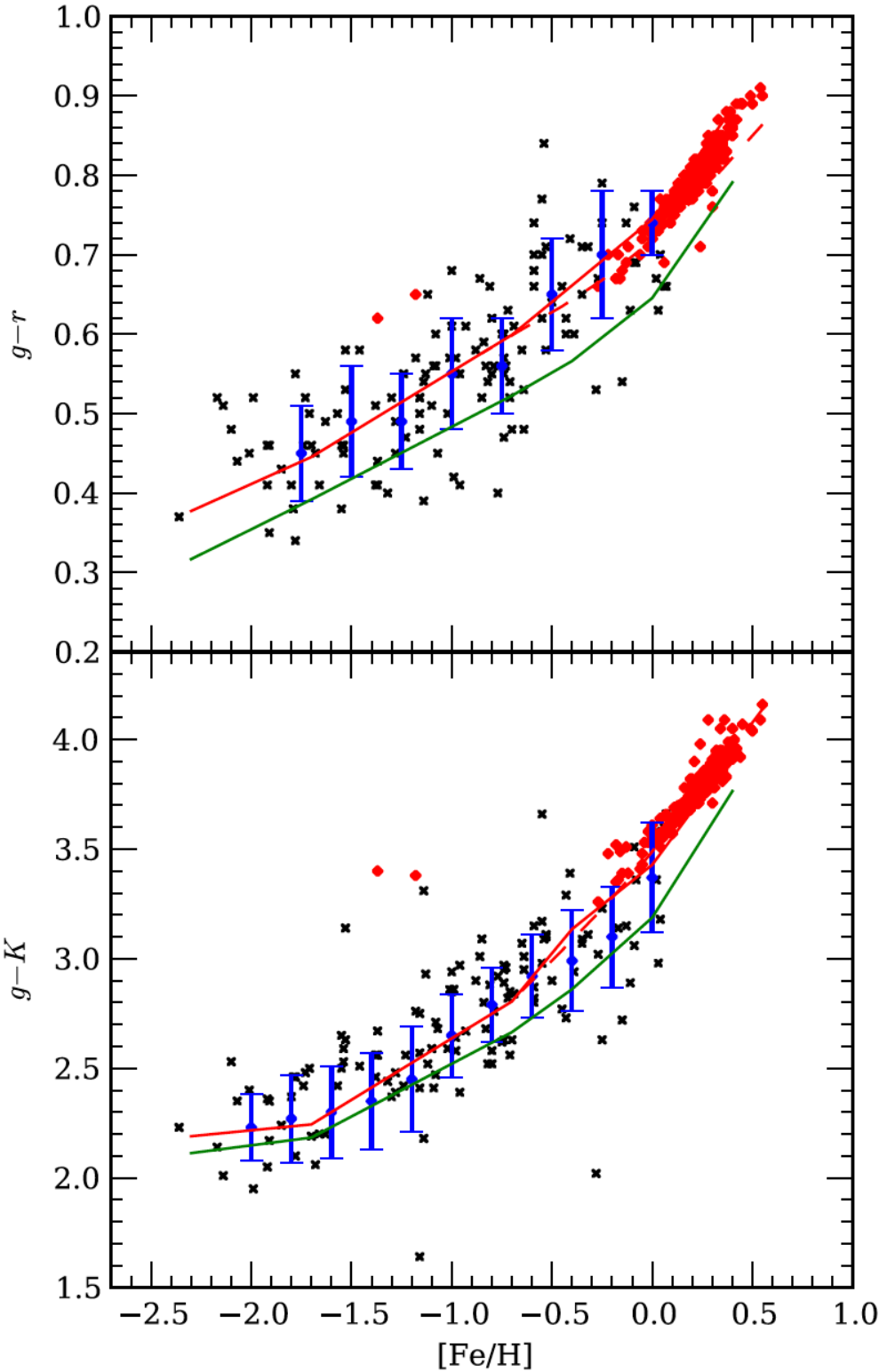




calibrate color to Fe/H relations, guided by SSP models, zeropoint set by globular cluster Fe/H's

red tracks are 12 Gyr pop models, green are 5 Gyrs, blue symbols are averaged globular values, red symbols are deduced elliptical [Fe/H] values

normal ellipticals have color ages of 12 Gyrs, solar to 0.3 dex metallicities



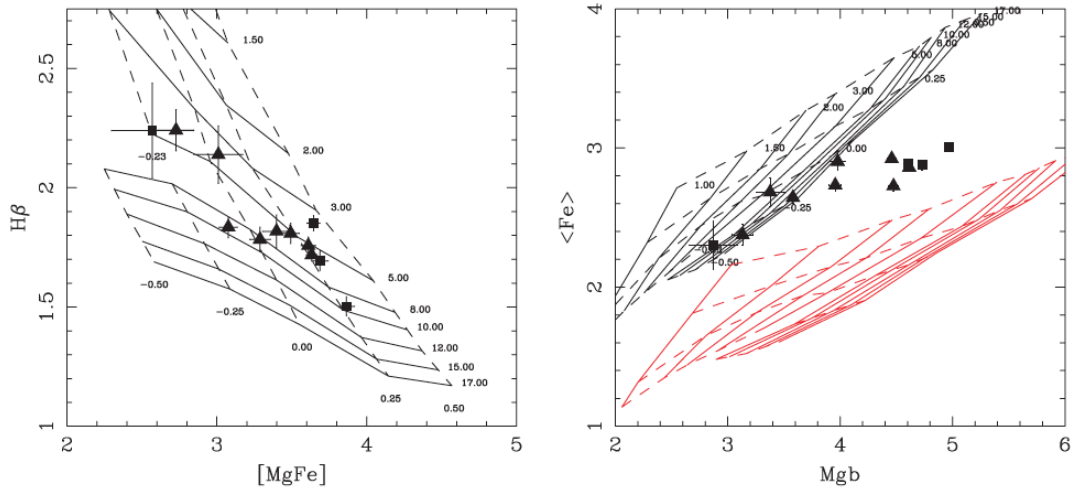
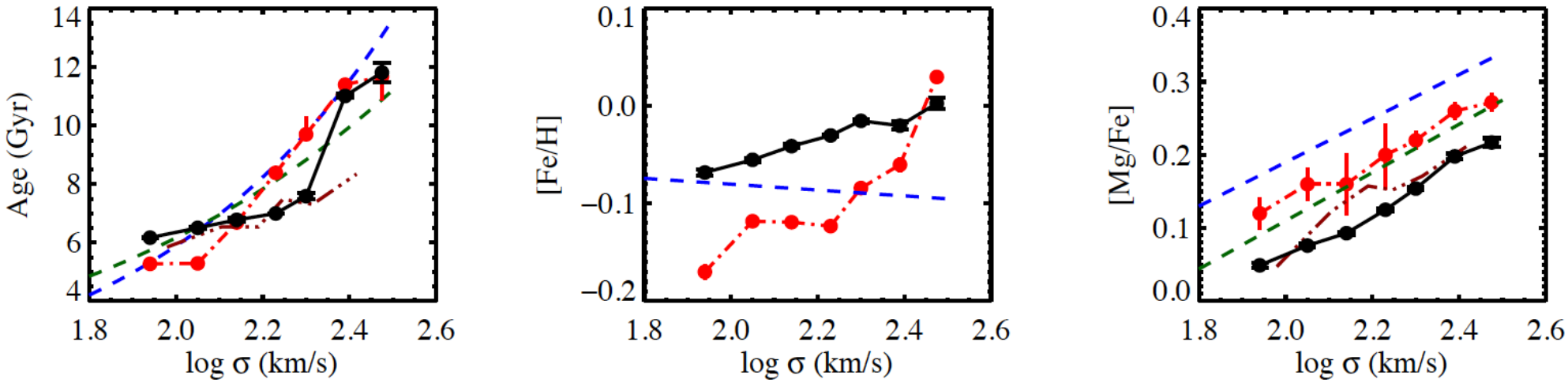


Figure 4. Stellar populations of Coma ETGs observed with LRIS in (Hβ, [MgFe]) and (Mg b, $\langle$Fe$\rangle$) space, where [MgFe] = $\sqrt{\text{Mg}\,b \times \langle\text{Fe}\rangle}$ and $\langle$Fe$\rangle$ = (Fe5270 + Fe5335)/2. Line strengths in this figure are measured through the synthesized 2.7 arcsec diameter aperture. Triangles are S0s, squares are ellipticals. Model grids come from the vanilla Worthey (1994) models, modified for [E/Fe] as described in the Section 3.1. In both panels, solid lines are isochrones (constant age) and dashed lines are isofers (constant metallicity [Z/H]). In the left-hand panels, the models are for solar [E/Fe]; models with higher [E/Fe] have slightly lower Hβ but similar [MgFe]. Therefore this an appropriate grid from which to visually assess age and metallicity, although accurate determinations are made in (Hβ, Mg b, Fe5270, Fe5335) space (see text). In the right-hand panel, grids have [E/Fe] = 0, + 0.3 (upper and lower, respectively). This is an appropriate diagram from which to visually assess [E/Fe].

a great deal of literature using Lick indices deducing young ages and low [Fe/H] for ellipticals



yet colors for those same age/metallicity values are wildly discordant with observed colors

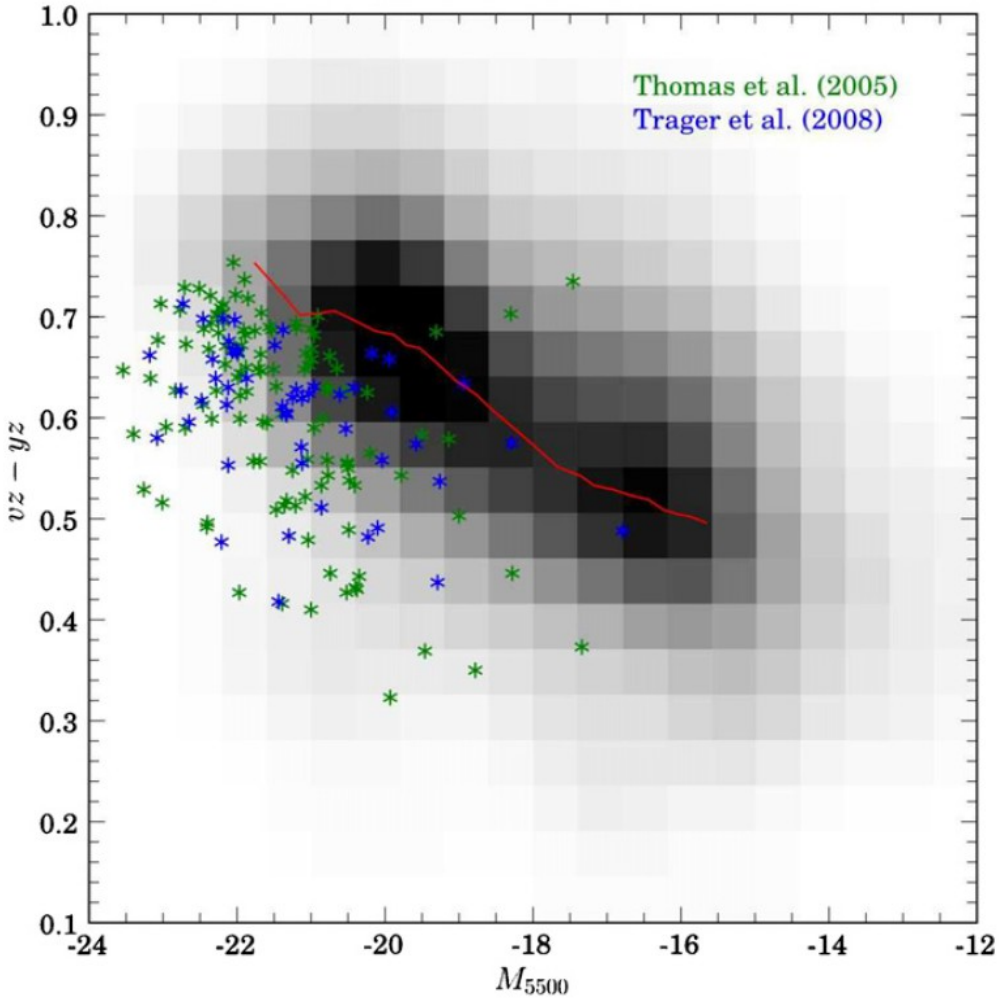


Figure 4. Calculated $vz-yz$ colors for the samples of Thomas et al. (2005; green symbols) and Trager et al. (2008; blue symbols). The spectroscopic ages and metallicities from those studies are used to calculate their $vz-yz$, and then plotted against M_{5500} absolute magnitude. Our $vz-yz$ cluster data and ridgeline (red line) from Figure 2 are also shown. A majority of the spectroscopic data lie blueward of the $vz-yz$ CMR indicating that the spectroscopically measured age and/or metallicity values are in error.

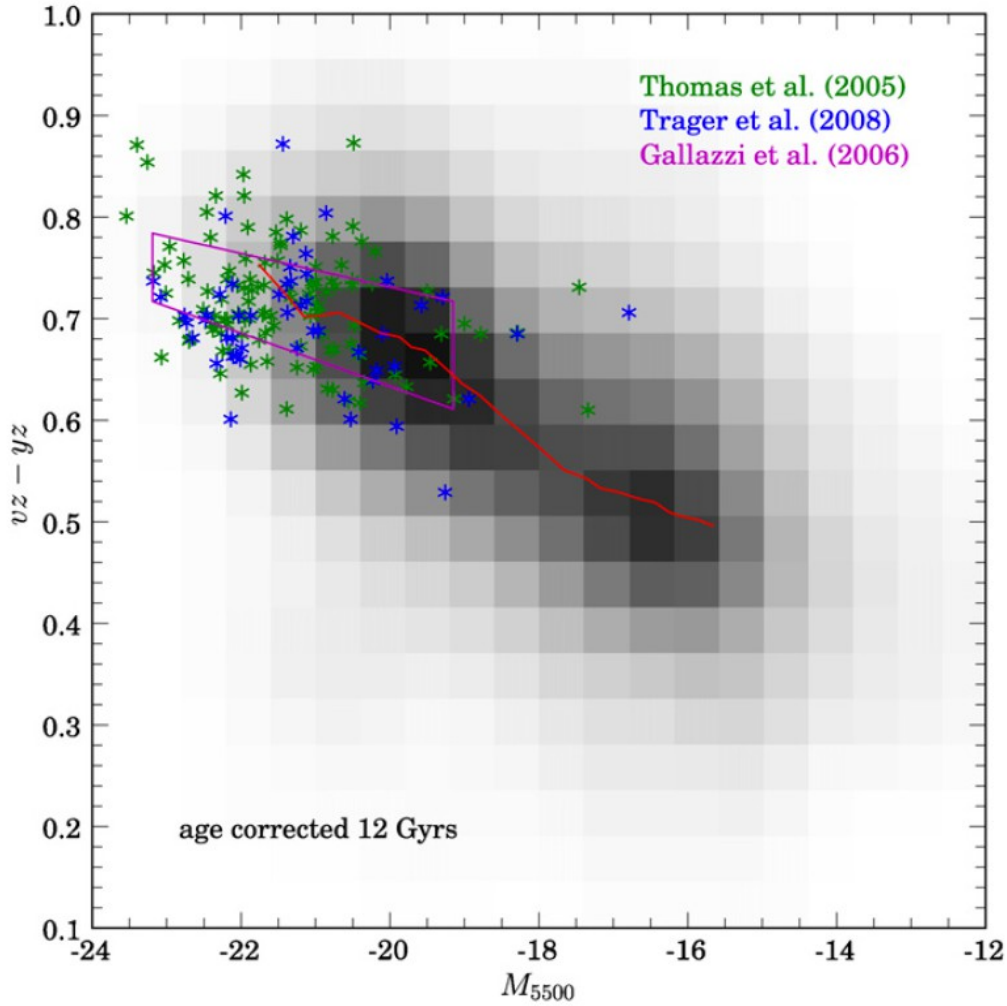


Figure 7. Age corrected CMR for all three spectroscopic samples. These are the same samples as Figures 5 and 6; however, the galaxy colors are calculated using an assumed age of 12 Gyr rather than the spectroscopically determined ages. The spectroscopically determined metallicity values are used, although an older age would imply slightly lower [Fe/H] values as calculated from metallicity indices such as MgFe. All three spectroscopic samples are now in agreement with the CMR.

colors vs Lick indices are surprisingly consistent with old (12 Gyrs) ellipticals, above solar metallicities

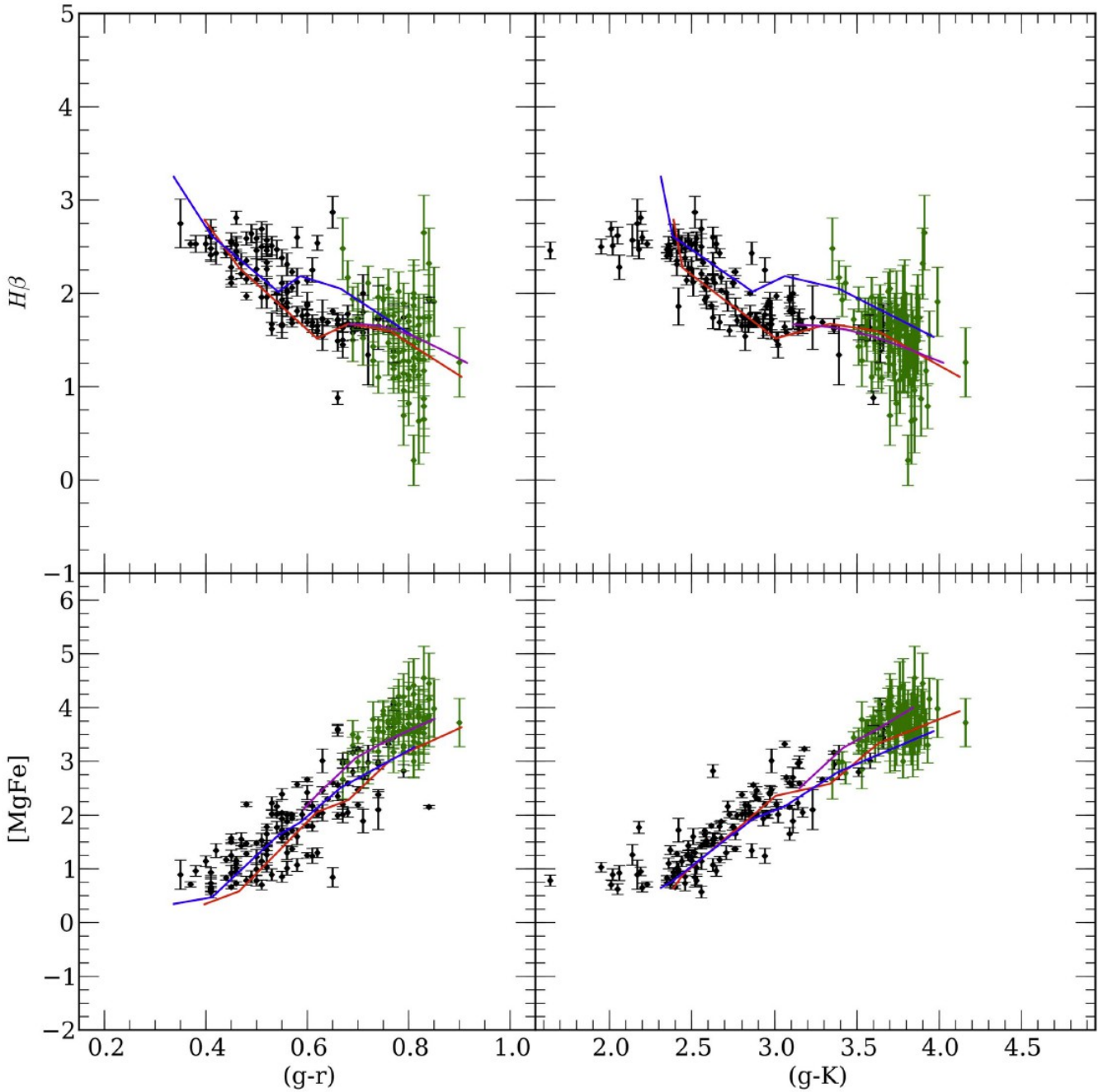
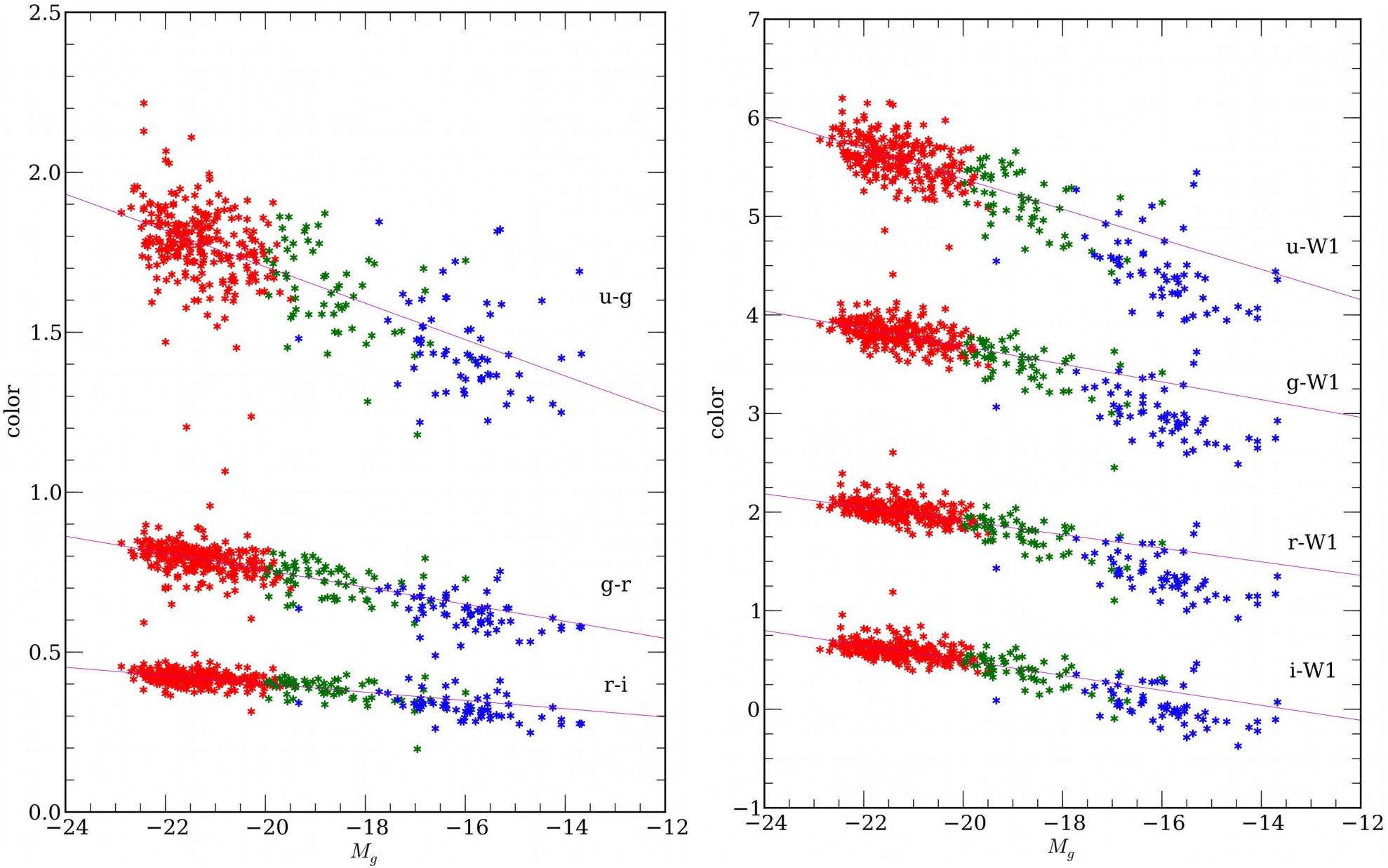
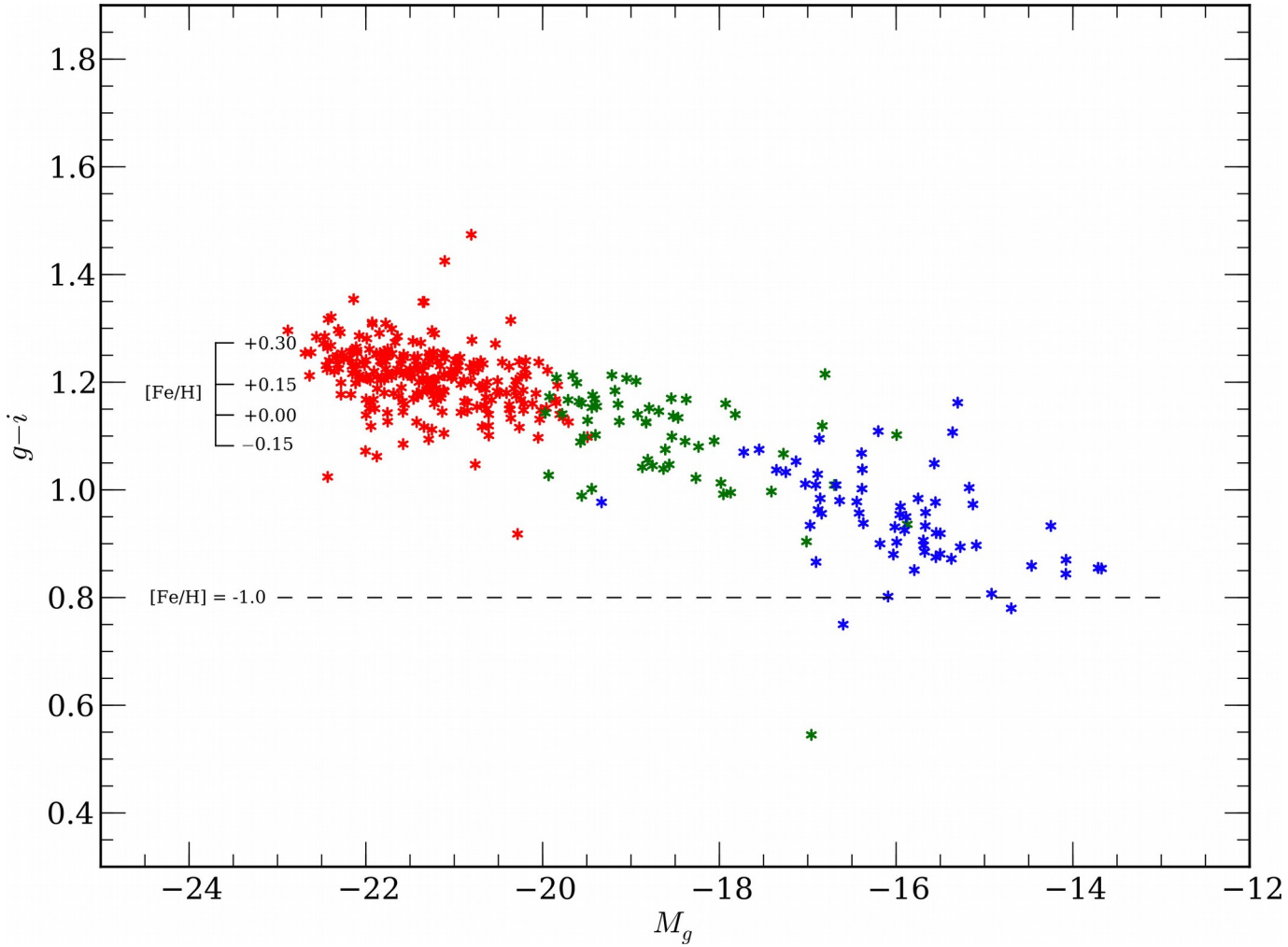
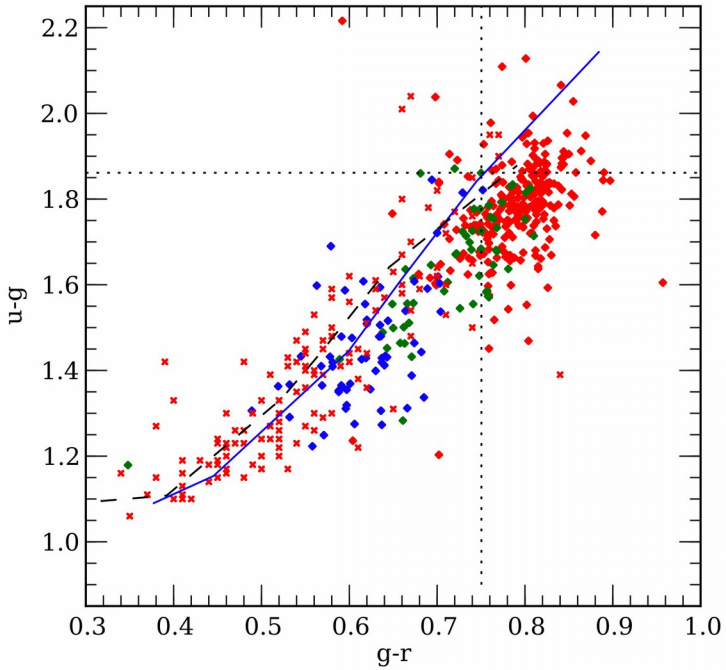


Figure 13. The color-Lick/IDS indices diagrams for [MgFe] (the metallicity index) and Hβ (the age index). The black symbols are the globular clusters with available spectral data. The red symbols are 91 ellipticals in common between our sample and spectral studies. The red and blue tracks are 5 and 12 Gyr SSP tracks. The magenta line is a 12 Gyr multi-metallicity track.



color-magnitude relations → mass-metallicity, bright+faint ellipticals consistent with linear relationship, dE's fall bluer than linear fits to the bright end


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
$g-i$
[Fe/H]
+0.30
+0.15
+0.00
−0.15
[Fe/H] = -1.0
−24
−22
−20
−18
−16
−14
−12
M_g



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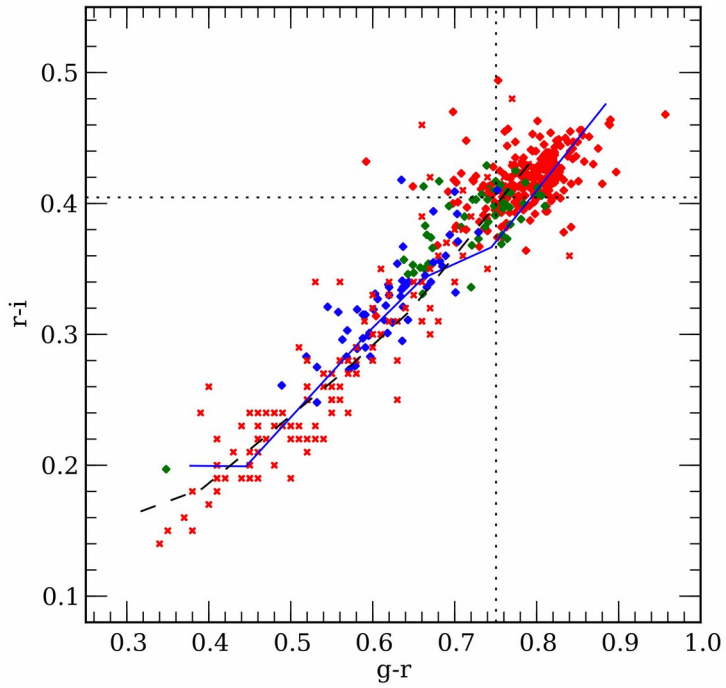
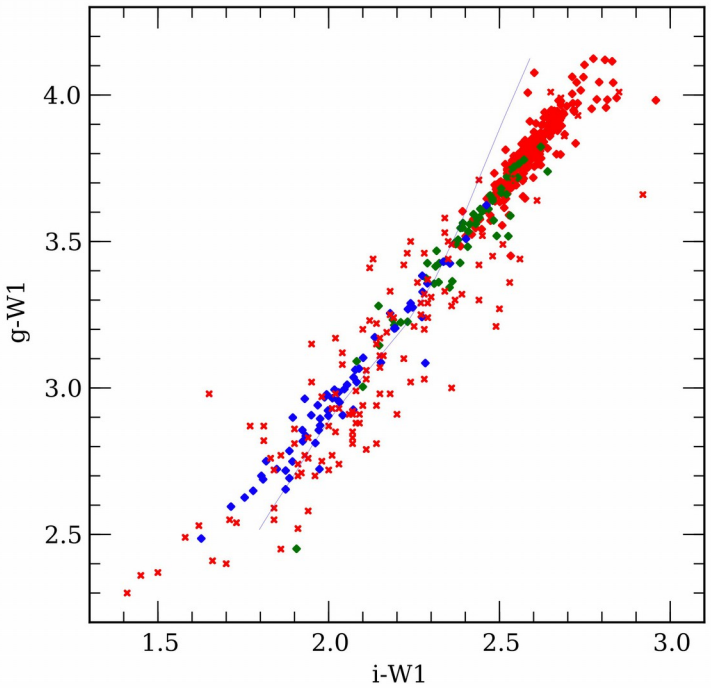
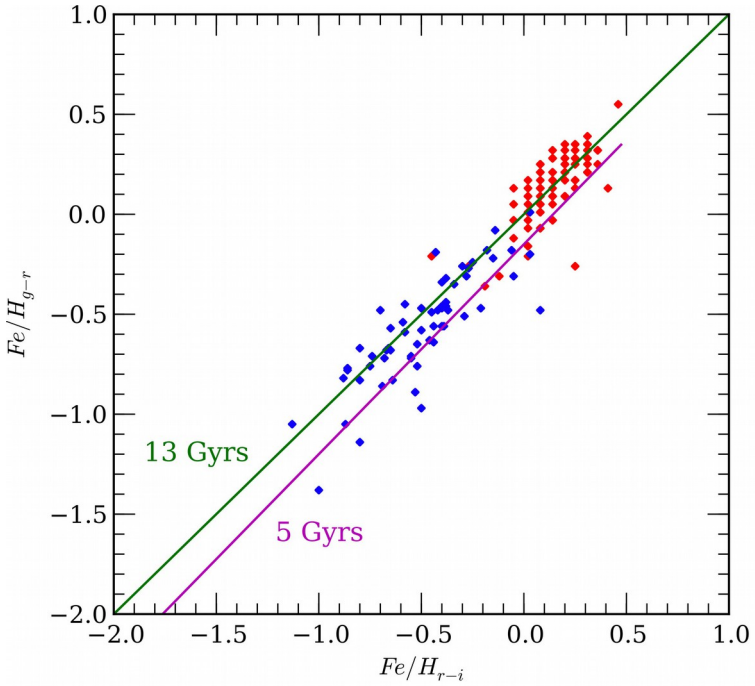
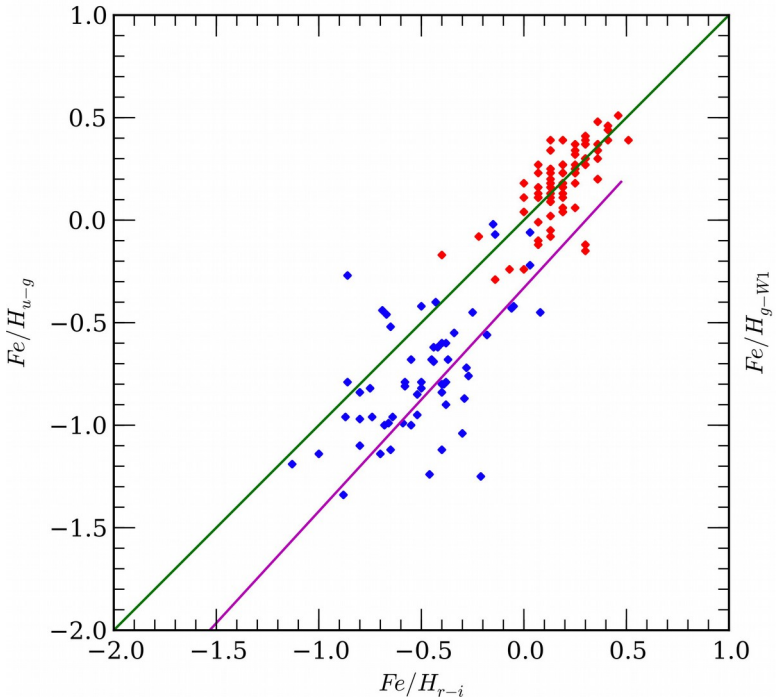


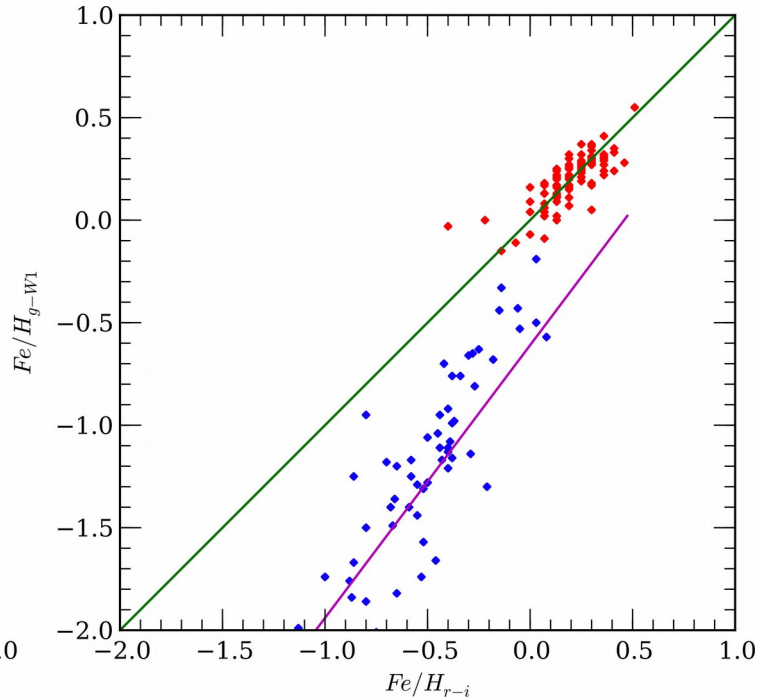




dE's deviate from the color-metallicity relations (set by globulars, defined by normal ellipticals) in a systematic fashion that indicates an age effect

Stellar populations in dE's are between 3 to 7 Gyrs younger in <u>mean</u> age than normal ellipticals





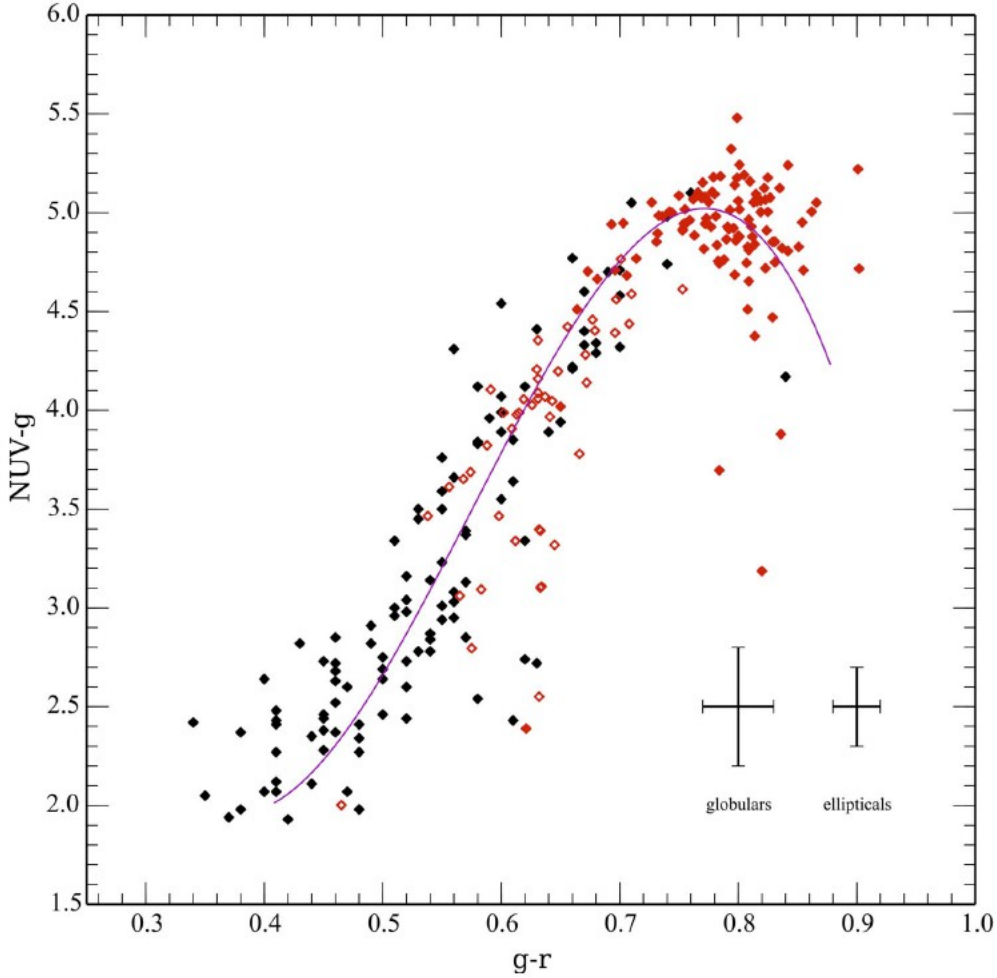


Figure 17. The clearest signature of unusual UV color behavior is seen in $NUV - u$ and $NUV - g$. The $NUV - g$ vs. $g - r$ colors of globulars (black symbols), normal ellipticals (solid red symbols), and dwarf ellipticals (open red symbols) are shown. A normal increase in color for the globulars is evident; however, the $NUV - g$ color behavior reverses near $g - r = 0.75$ where low luminosity ellipticals increase in $NUV - g$ color and high luminosity ellipticals display decreasing $NUV - g$ color with $g - r$ color. The model track displays BHB models of Yi et al. (1998) where we have converted their [Fe/H] values (from -1.7 to 0.3) into $g - r$ color. The agreement with the data is excellent, even predicting the change in $NUV - g$ color behavior with elliptical color.

Summary

- dE's form a separate family from normal ellipticals (power-law vs exponential)
- Colors from NUV to W1 display overlap from globulars to dE's to normal ellipticals, agree with SSP models, [Fe/H] zeropoint set by globular colors
- Normal ellipticals are old (12 Gyrs) with solar to 0.3 dex [Fe/H], period, no debate.
- CMR is linear for normal ellipticals, turns to bluer colors for dE's
  - lower Fe/H for their stellar mass, or
  - younger for their metallicity color
- Comparison across colors demonstrates an age effect, if dE's follow the same mass-metallicity relation as normal ellipticals, then their ages are 4-8 Gyrs younger normal ellipticals
- bright ellipticals built by mergers? then they have to do it before 12 Gyrs ago
- mergers with other 12 Gyrs ellipticals, does not explain coherent color gradients
- low luminosity ellipticals quench later? suggested by α/Fe ratios