# Ultraviolet Color-Magnitude Relations of Early-type Dwarf Galaxies in the Virgo Cluster


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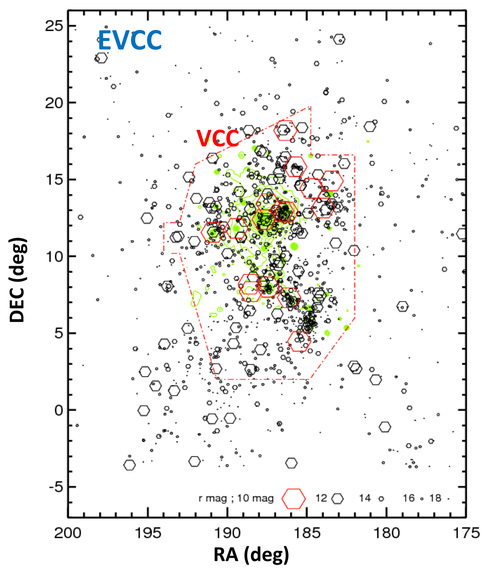
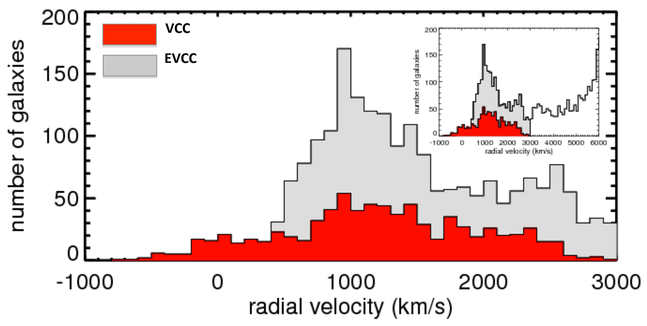
## ABSTRACT

We present ultraviolet (UV) color–magnitude relations (CMRs) of early-type dwarf galaxies in the Virgo cluster, based on *Galaxy Evolution Explorer* (*GALEX*) UV data and the Extended Virgo Cluster Catalog (EVCC). We find that dwarf lenticular galaxies (dS0s) show a surprisingly distinct and tight locus separated from that of ordinary dEs, which is not clearly seen in previous CMRs. The dS0s in UV CMRs follow a steeper sequence than dEs and show bluer UV–optical color at a given magnitude. We explore the observed CMRs with population models of a luminosity-dependent delayed exponential star formation history. The observed CMR of dS0s is well matched by models with relatively long delayed star formation. dS0s are most likely transitional objects at the stage of subsequent transformation of late-type progenitors to ordinary red dEs in the cluster environment. Most early type dwarf galaxies with blue UV colors (FUV-r < 6 and NUV–r < 4) are identified as those showing spectroscopic hints of recent or ongoing star formation activities. In any case, UV photometry provides a powerful tool to disentangle the diverse subpopulations of early-type dwarf galaxies and uncover their evolutionary histories.

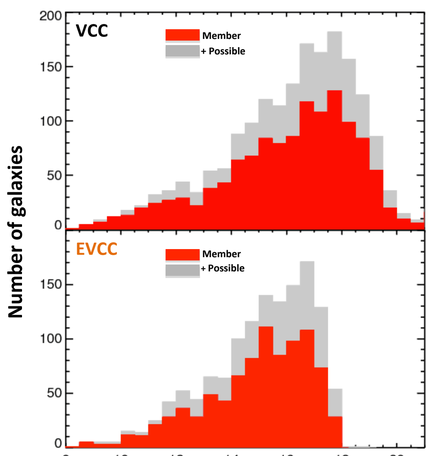

## DATA : Extended Virgo Cluster Catalog (EVCC)



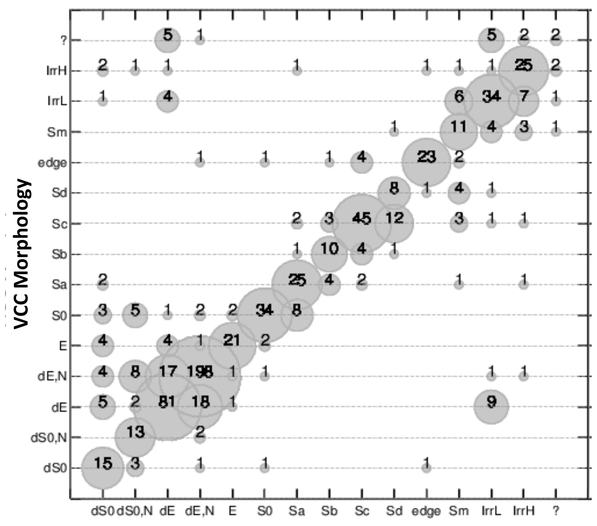

See poster of Suk Kim et al. for the details !




We define the EVCC region (left panel) of the Virgo cluster (black box : 750 deg$^2$) as 175 deg < RA < 200 deg and -4 deg < DEC< 25 deg, which is 5.4 times larger than that of VCC (red contour : 140 deg$^2$). We focus on the sample galaxies with radial velocities that are available in the SDSS spectroscopic data. The selected 1,332 member galaxies have heliocentric radial velocities less than 3,000 km/s (see upper panel).




Luminosity function of galaxies with different morphologies between VCC and EVCC.

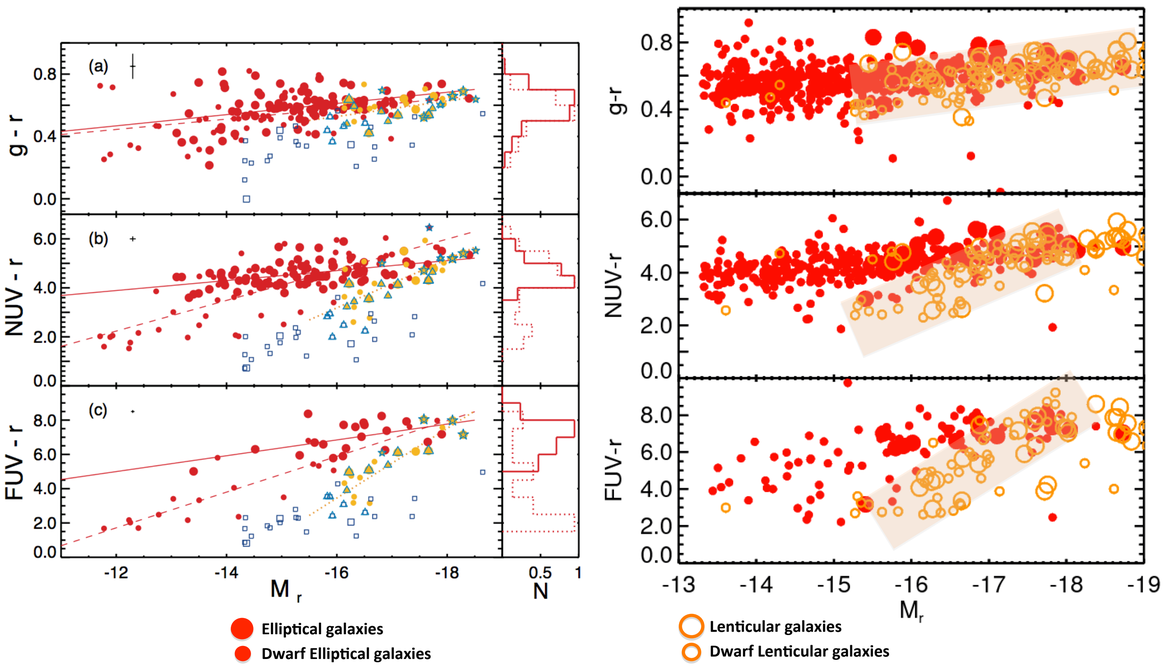



Comparison of morphologies for 776 common objects in EVCC and VCC. Symbol size is the number of galaxies. In most cases, our primary morphologies of the EVCC are well correlated with those of the VCC.

## Ultraviolet Color-Magnitude Relations

**Virgo Cluster Catalog**
**(Binggeli+85)**
**+ GALEX GR3 NUV & FUV data**
Kim et al. (2010)

→ **Extended Virgo Cluster Catalog**
**(Kim et al. in prep)**
**+ GAELX GR6 NUV &FUV data**
Rey et al. in prep

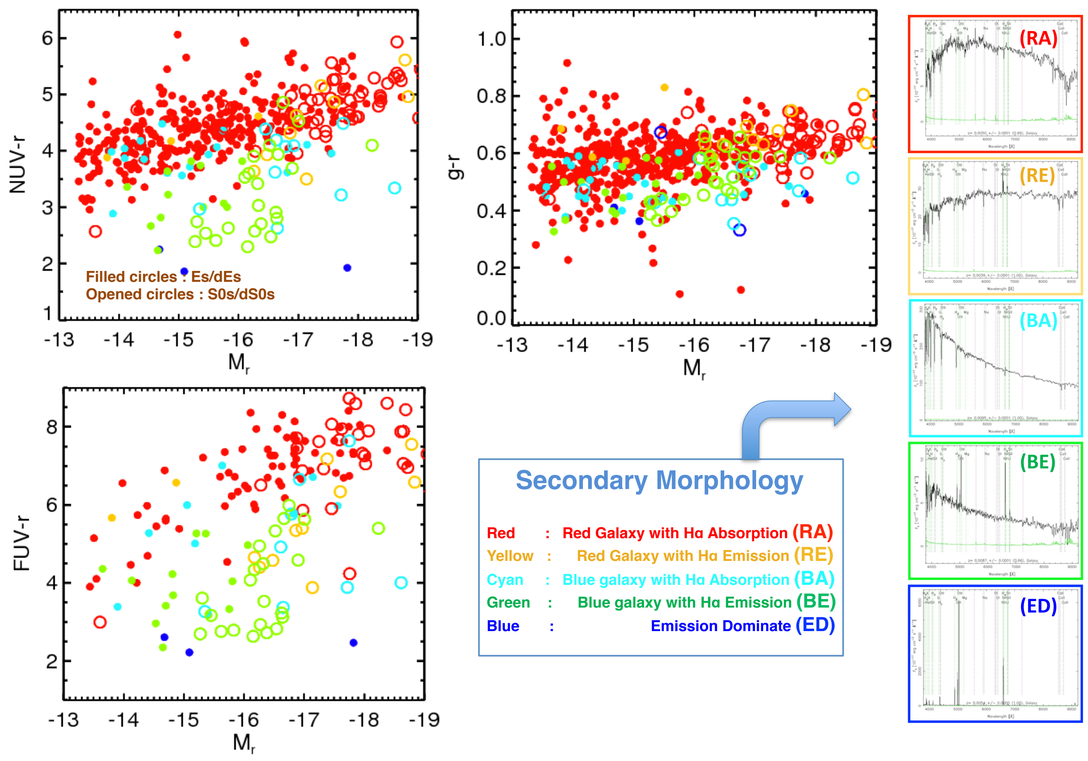



✔ In our UV CMRs, dS0s form a tight sequence which is clearly distinct from that of normal dEs. dS0s in UV CMRs follow a steeper sequence than dEs and show bluer UV–optical color at a given magnitude (left panels: see Kim et al. 2010).

✔ Based on our brand new catalog, the Extended Virgo Cluster Catalog (EVCC), we secure larger number of dwarf galaxies in new UV CMRs (right panels).

✔ In our new UV CMRs, we also confirm distinct dS0s sequence clearly separated from normal dEs.

## UV CMRs vs. Secondary Morphology

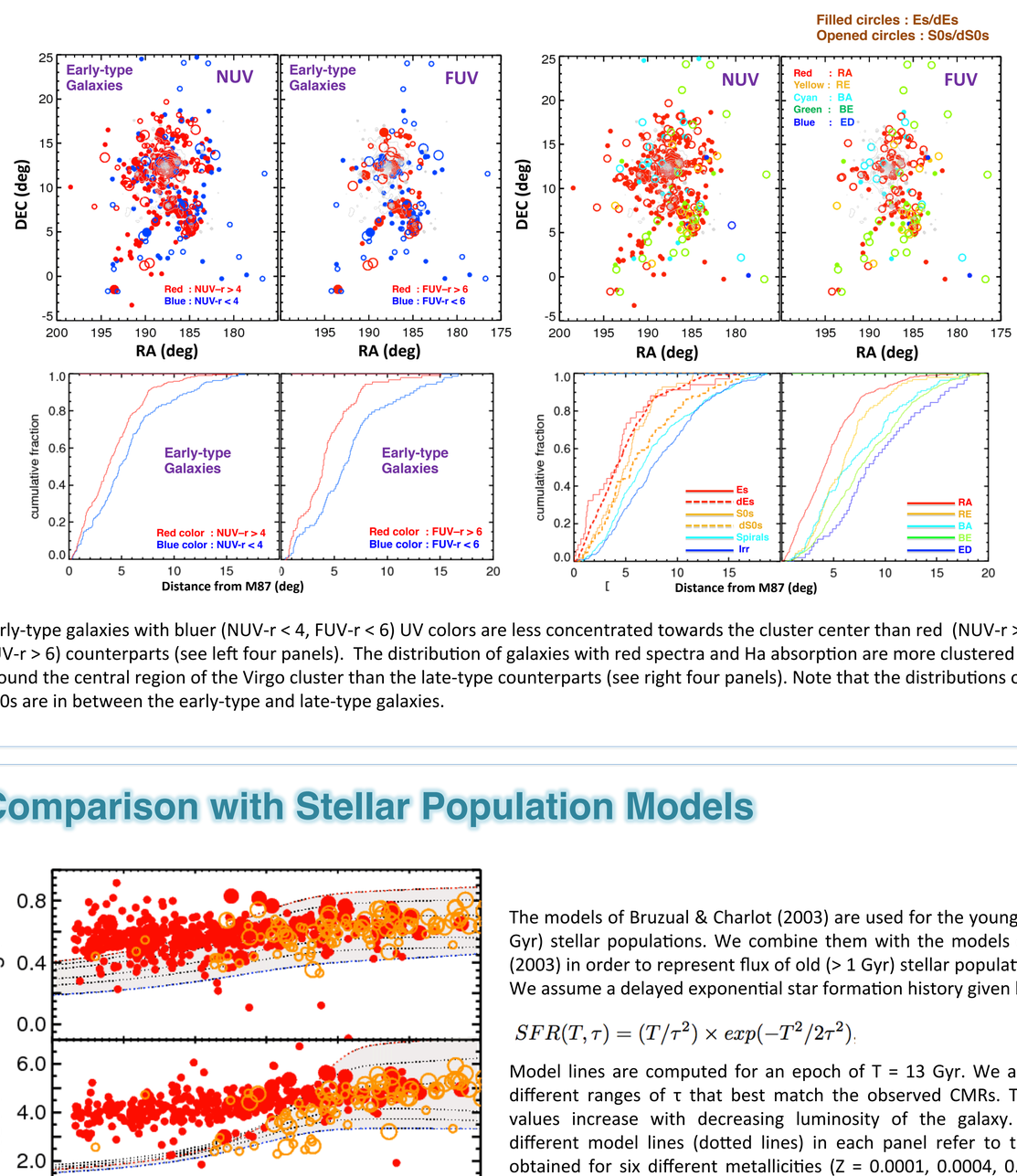



**Secondary Morphology**

Red : Red Galaxy with Hα Absorption (RA)
Yellow : Red Galaxy with Hα Emission (RE)
Cyan : Blue galaxy with Hα Absorption (BA)
Green : Blue galaxy with Hα Emission (BE)
Blue : Emission Dominate (ED)

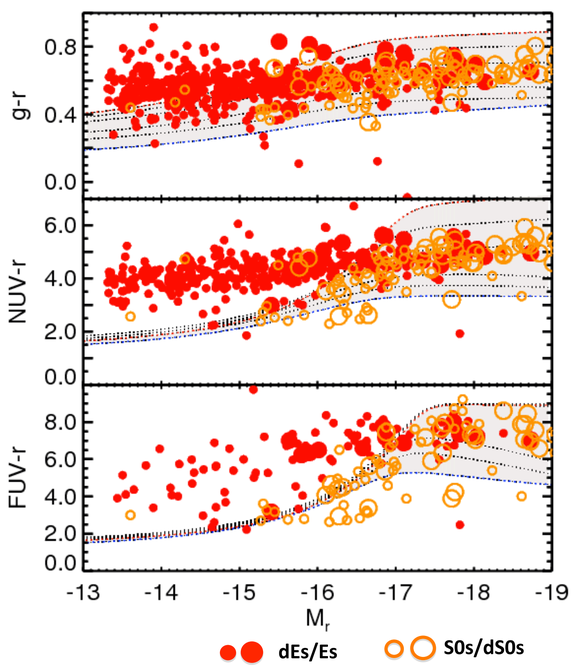
In addition to the traditional morphological classification based on optical images ("Primary Morphology"), we also characterized galaxies from their spectroscopic features ("Secondary Morphology"). The secondary morphology relies on the SED shape and presence of emission/absorption lines returned from SDSS. Most early type dwarf galaxies with blue UV colors (FUV-r < 6 and NUV–r < 4) are identified as those showing recent (blue galaxy with Hα absorption: BA) or ongoing (blue galaxy with Hα emission: BE) star formation activities. UV color is a good tracer of recent star formation activities and plays a role to discriminate early-type dwarf galaxies with residual recent star formation from passively evolving counterparts.

## Environmental Effect




Early-type galaxies with bluer (NUV-r < 4, FUV-r < 6) UV colors are less concentrated towards the cluster center than red (NUV-r > 4, FUV-r > 6) counterparts (see left four panels). The distribution of galaxies with red spectra and Ha absorption are more clustered around the central region of the Virgo cluster than the late-type counterparts (see right four panels). Note that the distributions of S0s/dS0s are in between the early-type and late-type galaxies.

## Comparison with Stellar Population Models




The models of Bruzual & Charlot (2003) are used for the young (< 1 Gyr) stellar populations. We combine them with the models of Yi (2003) in order to represent flux of old (> 1 Gyr) stellar populations. We assume a delayed exponential star formation history given by

$$SFR(T,\tau) = (T/\tau^2) \times exp(-T^2/2\tau^2).$$

Model lines are computed for an epoch of T = 13 Gyr. We adopt different ranges of τ that best match the observed CMRs. The τ values increase with decreasing luminosity of the galaxy. The different model lines (dotted lines) in each panel refer to those obtained for six different metallicities (Z = 0.0001, 0.0004, 0.001, 0.004, 0.01, 0.02 from bottom to top)

The observed CMRs of dS0s are well matched by model lines with large τ range (1 < τ < 7 Gyr), describing well the steep sequence of dS0s. Therefore, we conclude that dS0s have likely experienced relatively long delayed star formations. This is consistent with observational results indicating residual or ongoing star formation activities (Lisker et al. 2006a, b, 2007; Boselli et al. 2008).