Star formation exists in all early-type galaxies – evidence from ubiquitous structure in UV images

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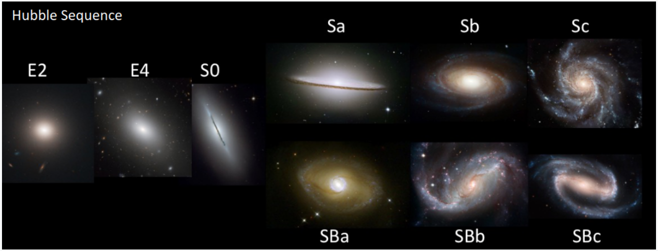
Hubble Tuning Fork diagram



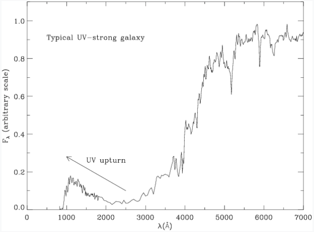
Later-type galaxies (LTGs) tend to be

- lower in luminosity
- more gas rich
- bluer in color

than early-type galaxies (ETGs)

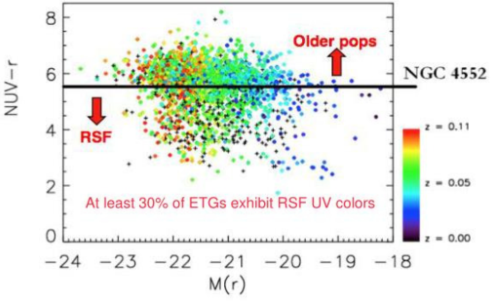
UV emission in ETGs

- Massive ETGs are perceived to be dominated purely with old stellar population due to ‘monolithic evolution’ (e.g. Larson 1974; Chiosi & Carraro 2002).
- Old stellar populations are generally expected to be faint in the UV, some ETGs (typically bright systems in dense environments) show an upturn in flux.
- The source could be main-sequence turn-off or extreme horizontal branch stars.



The composite spectrum of the giant elliptical galaxy NGC 4552 shows a classic example of the UV upturn (Yi S. et al. 2008).

Evidences of recent star formation



NUV — r color-magnitude relations (CMRs) of our early-type galaxies. Galaxies are color-coded according to their redshifts (Kaviraj et al. 2007)

- Detection of many ETGs in GALEX UV observation up to $z \sim 0.5$; a third of them show blue UV-optical color than strongest UV upturn galaxies (Kaviraj et al. 2007)
- $NUV - r \leqslant 5.5$ are very likely to have experienced such recent star formation.

Questions

- Whether the entire UV emission detected in ‘red’ galaxies originating from evolved stellar population?
- What is the fraction of star-forming ETGs in the local Universe?
- Is there a need for a different probe instead of integrated colors to detect recent star formation in ETGs?

Observations - AstroSat/ UVIT & DECaLs

AstroSat/ Ultraviolet Imaging Telescope

We use archival FUV imaging observations ($T_{exp} > 10$ks) from UVIT conducted in the BaF2 (eff.wavelength $= 1541$ Å) or CaF2 (eff.wavelength $= 1481$ Å) broadband filters.

The 3σ/ 5σ point-source detection limit of the UVIT FUV observation with the lowest exposure time (≈11 ks) in our sample is 26.0/25.5 magnitudes.

DECaLS

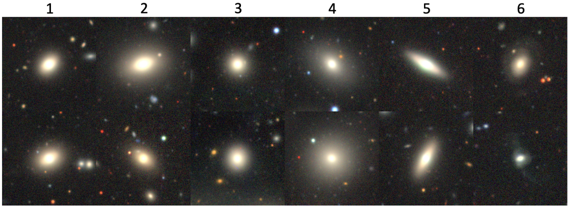
Optical image in r-bands

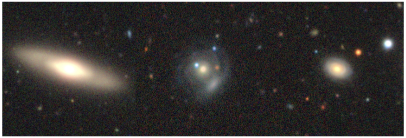
The median FWHM of the DECaLS PSF is 1.3″ is comparable to UVIT.

The 5σ limiting magnitude for a point source within a single frame in *r*-band is ∼23.5 magnitudes.

UV-substructure in Early type galaxies

- Scanned over 100 FoVs of UVIT FUV observation to prepare a sample
- Essential criteria: $S/N_{pixel} \geqslant 2$, $R_{20} > 2\,pix$, linear resolution < 1 kpc
- Referred to Galaxy Zoo for morphological classification
- Obtained a sample of 32 ETGs fulfilling the criteria





Estimated parameters

$$\text{Concentration}(C) = 5 \times \log_{10}\left(\frac{R_{80}}{R_{20}}\right) \tag{1}$$

$$\text{Assymetry}(A) = \frac{\sum_{i,j} \mid I_{\text{ij}} - I_{\text{ij}}^{180} \mid}{\sum_{i,j} \mid I_{\text{ij}} \mid} - A_{\text{bgr}} \tag{2}$$

$$\text{Clumpiness}(S) = \frac{\sum_{i,j} I_{\text{ij}} - I_{\text{ij}}^{\text{S}}}{\sum_{i,j} I_{\text{ij}}} - S_{\text{bgr}} \tag{3}$$

Sérsic function

$$I(R) = I_e \exp\left\{ -b_{\text{n}}\left[\left(\frac{R}{R_{\text{e}}}\right)^{\frac{1}{n}} - 1\right]\right\}, \tag{4}$$

where R_{e} is the radius enclosing half the light of the galaxy, I_{e} is the intensity at R_{e} and b_{n} is a function of the Sérsic index (n).

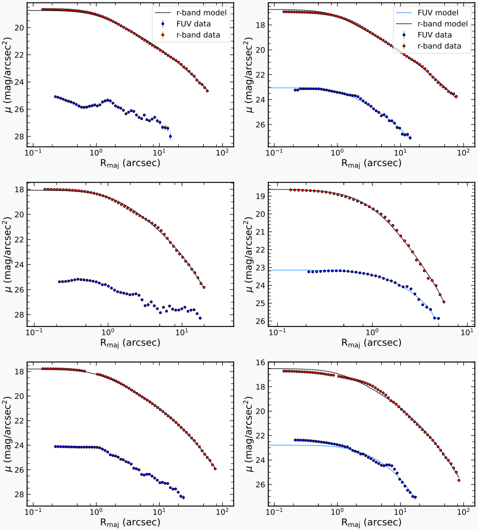
CAS for different type galaxies

Averages and 1σ Variations of Structural Parameters for Galaxy Types

Type	C(R)	A(R)	S(R)
Ellipticals	4.4±0.3	0.02±0.02	0.00±0.04
Early-Type Disks (Sa - Sb)	3.9±0.5	0.07±0.04	0.08±0.08
Late-Type Disks (Sc - Sd)	3.1±0.4	0.15±0.06	0.29±0.13
Irregulars	2.9±0.3	0.17±0.10	0.40±0.20
Edge-On Disks	3.7±0.6	0.17±0.11	0.45±0.20
ULIRGs	3.5±0.7	0.32±0.19	0.50±0.40
Starbursts	2.7±0.2	0.53±0.22	0.74±0.25
Dwarf Ellipticals	2.5±0.3	0.02±0.03	0.00±0.06

Conselice et al. 2003

Isophotal distribution of ETGs

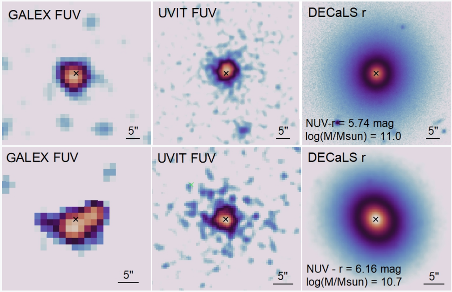


Close to 55% of FUV isophotes were not smooth enough to fit sérsic function

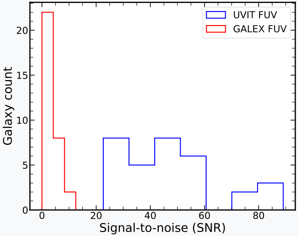
Previously done analysis:

- Mager et al. 2018 conducted a similar study by comparing the CAS parameters of GALEX and HST observation of ETGs.
- $C_{FUV} = 2.9$, $A_{FUV} = 0.4$, $S_{FUV} = 0.1$ (ETGs)
  $C_{FUV} = 2.4$, $A_{FUV} = 0.6$, $S_{FUV} = 0.35$ (LTGs)
- Drawbacks: Different PSF resolution of GALEX (FWHM $\sim 6''$) and HST (FWHM $\sim 0.2''$)

Comparison of UVIT sample with GALEX

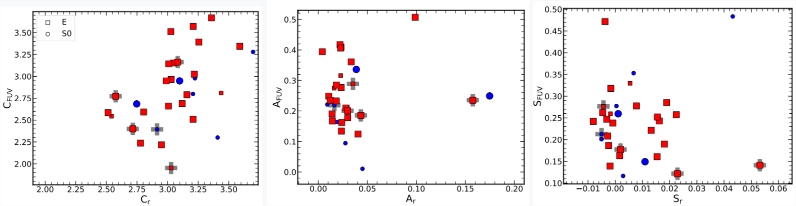


Left to Right: GALEX FUV, UVIT FUV and Decals r-band



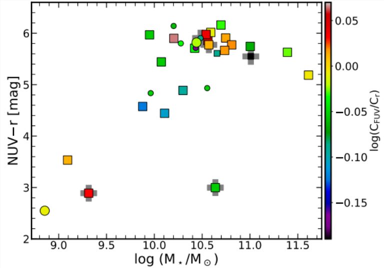
Optical vs. FUV parameters

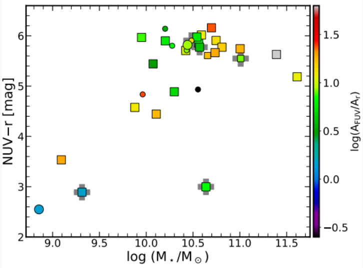
We measure CAS parameters in the same region for UVIT FUV and Decals r-band.



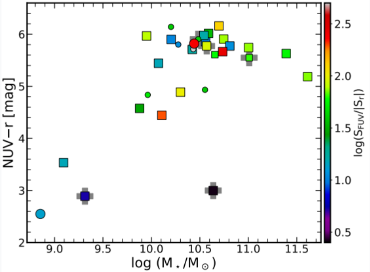
$C_r = 3.05 \pm 0.28$, $A_r = 0.035 \pm 0.037$, $S_r = 0.007 \pm 0.014$
$C_{FUV} = 2.82 \pm 0.42$, $A_{FUV} = 0.247 \pm 0.104$, $S_{FUV} = 0.241 \pm 0.085$

UV/ Optical parameters as function of NUV−r vs. $M_\star$



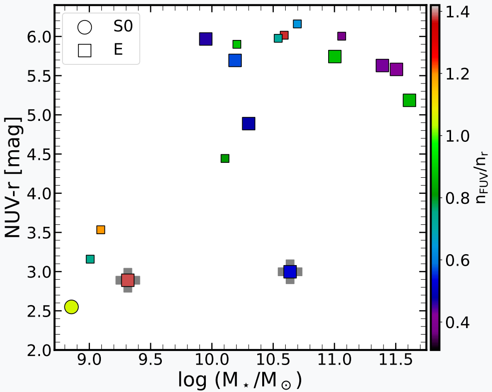


Regardless of stellar mass, (NUV−r) or the presence of an interaction, A and S of ETGs is typically significantly larger in the UV than in the optical.



Results with Sérsic Index

The Sérsic indices of ETGs are lower in the UV than in the optical, suggesting the presence of disky structures. (mean n_{FUV} = 2.0, n_r = 3.21)



Conclusion

- Regardless of stellar mass, UV-optical colour or the presence of an interaction, the asymmetry and clumpiness of ETGs is typically significantly larger in the UV than in the optical. The mean FUV to optical ratios of asymmetry and clumpiness are ~13 and ~82 respectively.
- The significant amounts of UV structure indicates that the UV flux in *all* ETGs in our sample is either dominated by, or has a significant contribution from, young stars.
- Interestingly, the trends above are also seen in seven ETGs which are classified as UV upturn systems in the literature i.e. galaxies in which the UV flux is assumed to be driven solely by old stars. This assumption appears incorrect, at least in these ETGs.

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Thank you