The Variation of the Optical Color Gradients in Early Type Galaxies

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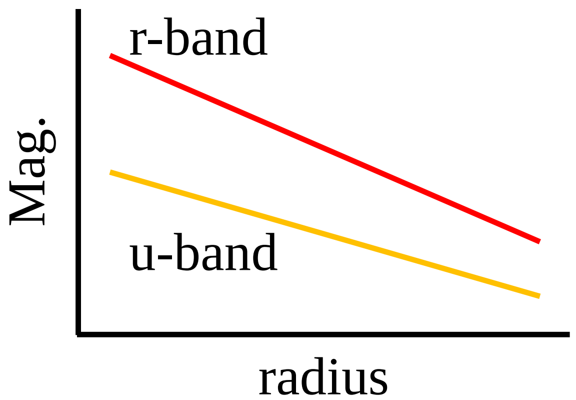
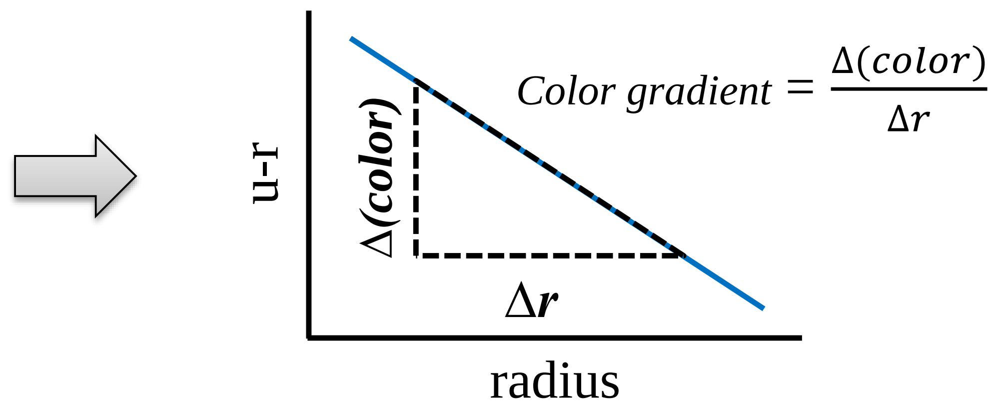
1. Introduction

- Color gradient of galaxy : radial change of color from center towards the edge





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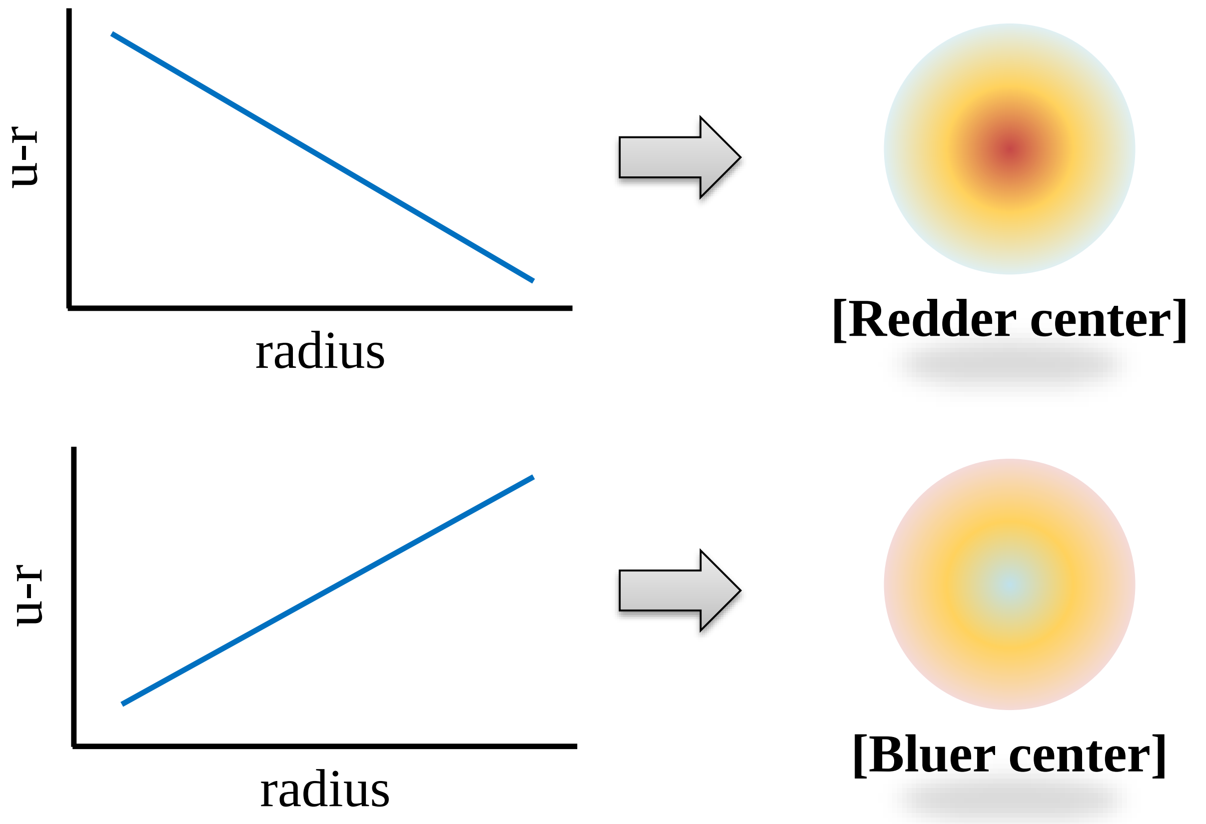
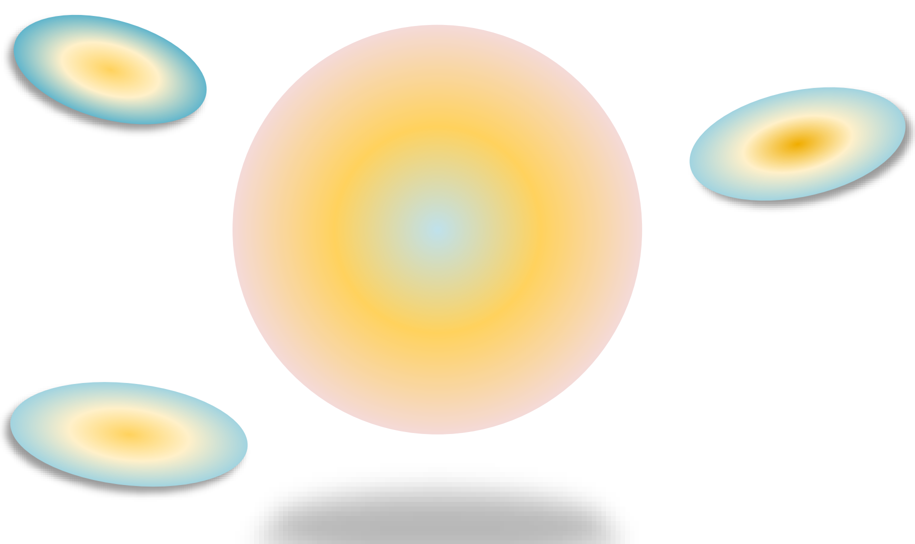


1. Introduction

- Early type galaxies (hereafter ETGs) are distinguished from the spiral galaxies by their spheroidal shape and red color.
- In general, ETGs have negative color gradients, i.e., red core compared to the outer part of a galaxy.
- However, recent studies have discovered blue-cored ETGs which is of great interest.

1. Introduction

- Passively evolved ETGs are expected to have negative color gradient because of age and/or metallicity gradient.
- Several studies (Park & Choi 2005; Suh et al. 2010; Kim et al. 2013) have revealed that a significant fraction of ETGs are blue-cored, which maybe due to the recent star formation.



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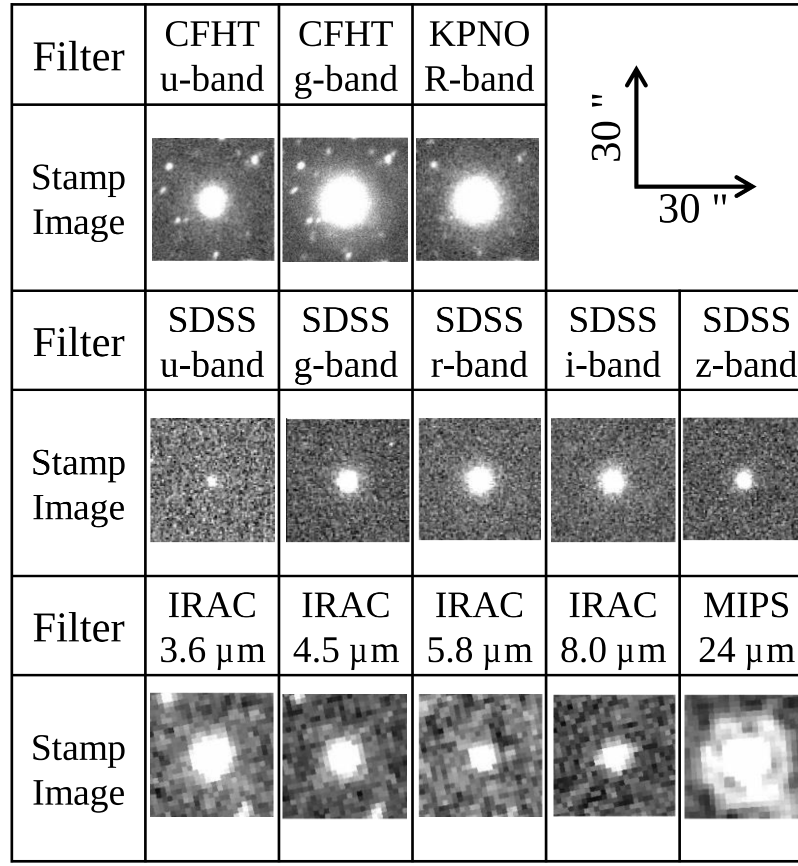
In this work, we investigated whether ETGs having different color gradients show any distinguishable characteristics.

2. Data and Sample

- ***Spitzer* First Look Survey field**
  - CFHT *u*, *g*-band (Shim et al. 2006)
  - KPNO *R*-band (Fadda et al. 2004)
  - ***Spitzer*** IRAC (3.6, 4.5, 5.8, 8.0 μm) and MIPS (24 μm)

- **ETG candidates selection (*u*-band)**
  - First, B/T > 0.5 (Simard et al. 2011)
  - Second, removed spiral contaminations
  - Finally, selected 211 ETGs ($M_r \geq -24.0$) at 0.01 < z < 0.35

- **MPA-JHU SDSS DR7 catalog**
  - stellar mass, star formation rate, fluxes of emission lines



Example stamp images of an ETG in different filters.

3. Analysis : Surface Brightness Profile

Image ⇨ **Seeing matching** | **Background subtraction** | **Masking** ⇨ **Isophote fitting** ⇨ **Color gradients**

A. Seeing matching

- We applied **IRAF GAUSS SMOOTH TASK** to the *u*, *g*-band images to get consistent seeing as that of the *R*-band images.

B. Background subtraction

- We removed high background in *R*-band images using **Source Extractor**.

C. Masking

- We masked out possible contaminating sources within 2′ around the target ETG using ***YH_maskobj.pro*** created by *Yun Hee Lee[KNU]*.

3. Analysis : Surface Brightness Profile

Image → **Seeing matching** | **Background subtraction** | **Masking** → **Isophote fitting** → **Color gradients**

D. Isophote fitting

- We performed isophote fitting on the ETGs using **ELLIPSE TASK** with the center fixed, the position angle and ellipticity to vary freely.

E. Color gradients

- $\nabla(u^* - g) = \frac{\Delta(u^* - g)}{R_{50}}$ $\qquad \nabla(u^* - R) = \frac{\Delta(u^* - R)}{R_{50}}$

- We calculated the color gradients through least-squares linear fitting over the radius range of [0, R_{50}] in arcsec unit.

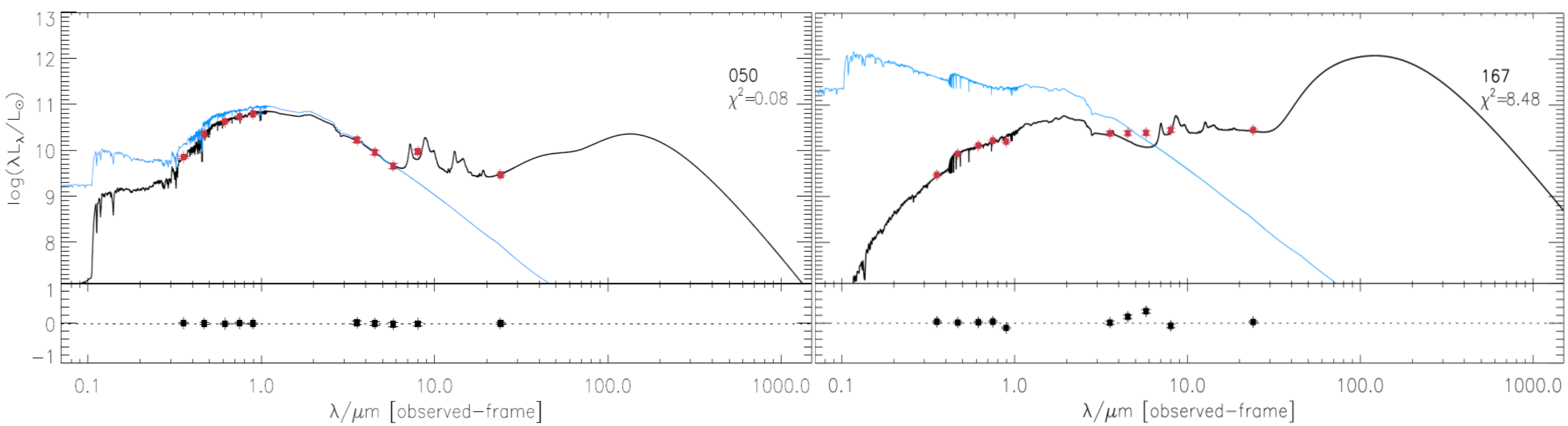
3. Analysis : Spectral Energy Distribution

- **Multi-wavelength Analysis of Galaxy Physical Properties (MAGPHYS) package** (da Cunha et al. 2008)

  - We derived the dust mass of sample ETGs using MAGPHYS package.

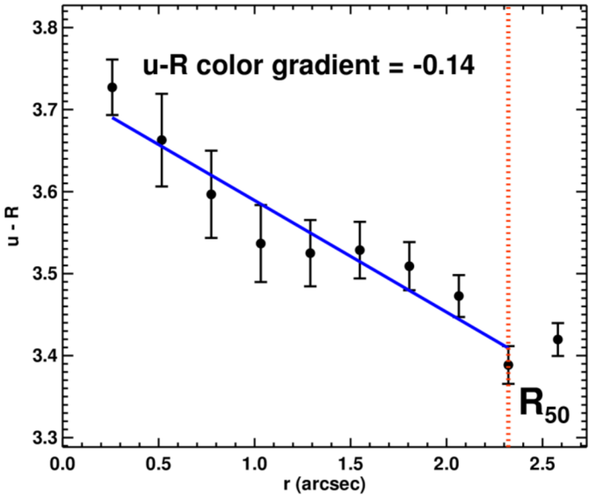
  - The input photometry data points (SDSS ugriz, IRAC 3.6, 4.5, 5.8, 8.0 μm, and MIPS 24 μm) were compared to the model SEDs to find the best fit spectral template of galaxies.

  - The SED fitting results of 110 ETGs with $\chi^2 \leq 2.00$ were used in the following analysis.



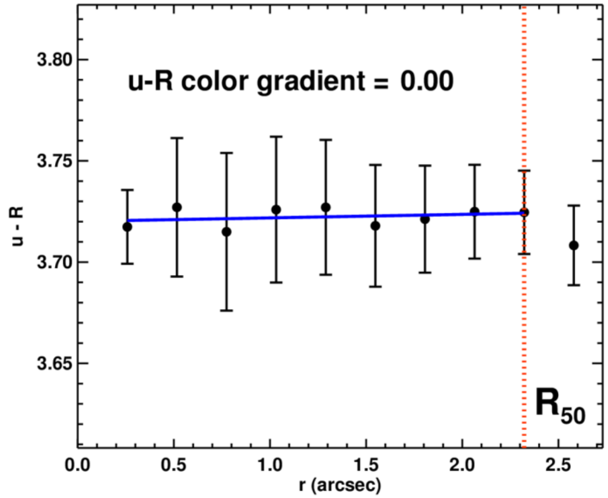
4. Results : Color Gradients Statistics

Red-cores : slope ≤ -0.01



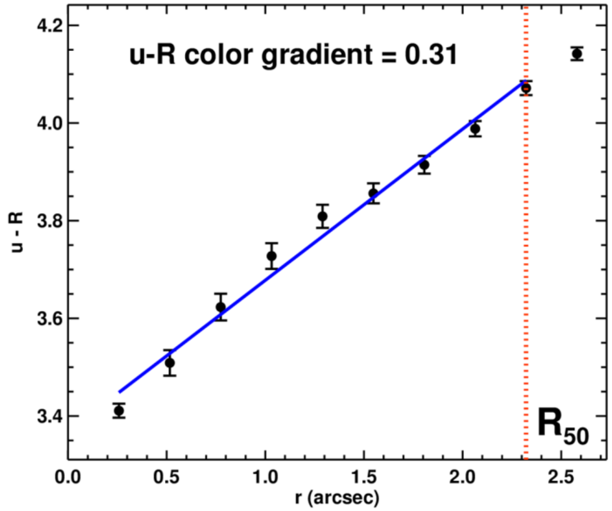
u-g color gradients : 23 ETGs
u-R color gradients : 100 ETGs

Flat-cores : -0.01 < slope< 0.01



u-g color gradients : 2 ETGs
u-R color gradients : 15 ETGs

Blue-cores : slope ≥ 0.01



u-g color gradients : 5 ETGs
u-R color gradients : 66 ETGs

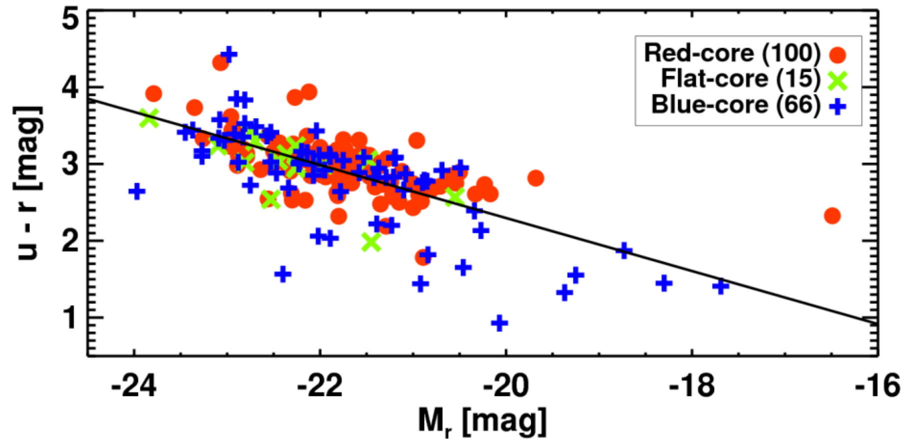
4. Results : Color Gradients Statistics

- **Compare blue-cored ETGs fraction with other researches**

Research	Blue cores	Color gradient	Method	Mag. limit
Our work	36.3% (210)	$\nabla(u - R)$	Isophote fitting	$M_r \leq -16.5$
Park & Choi (2005)	~10% (1982)	$\nabla(g - i)$	Measuring color difference	$r \leq 15.9$
Suh et al. (2010)	~30% (5002)	$\nabla(g - r)$	Isophote fitting	$r < 17.5$
Kim et al. (2013)	~50% (196)	$\nabla(g - K)$, $\nabla(r - K)$	Isophote fitting	$M_r < -20.5$

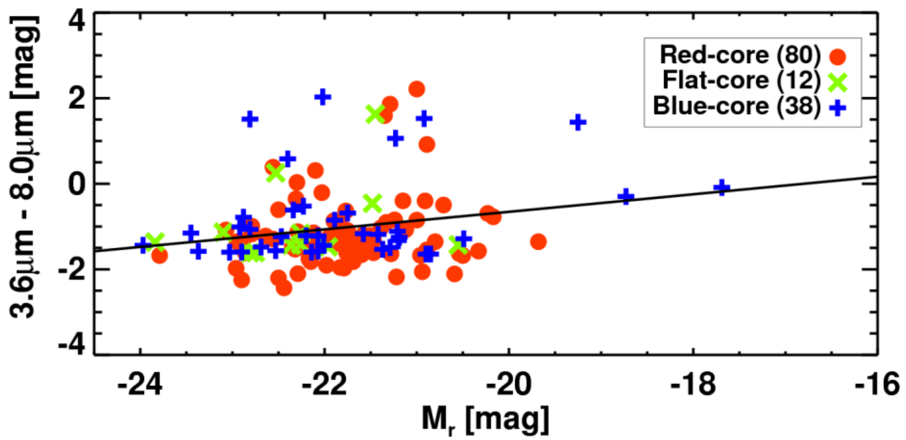
4. Results : Color-Magnitude Relation (CMR)

- ETGs with redder optical colors are more luminous.
- Tight optical CMR indicates that ETGs have evolved passively.
- Scatters in the CMR may have arisen from recent star formation activity.



[Optical CMR]

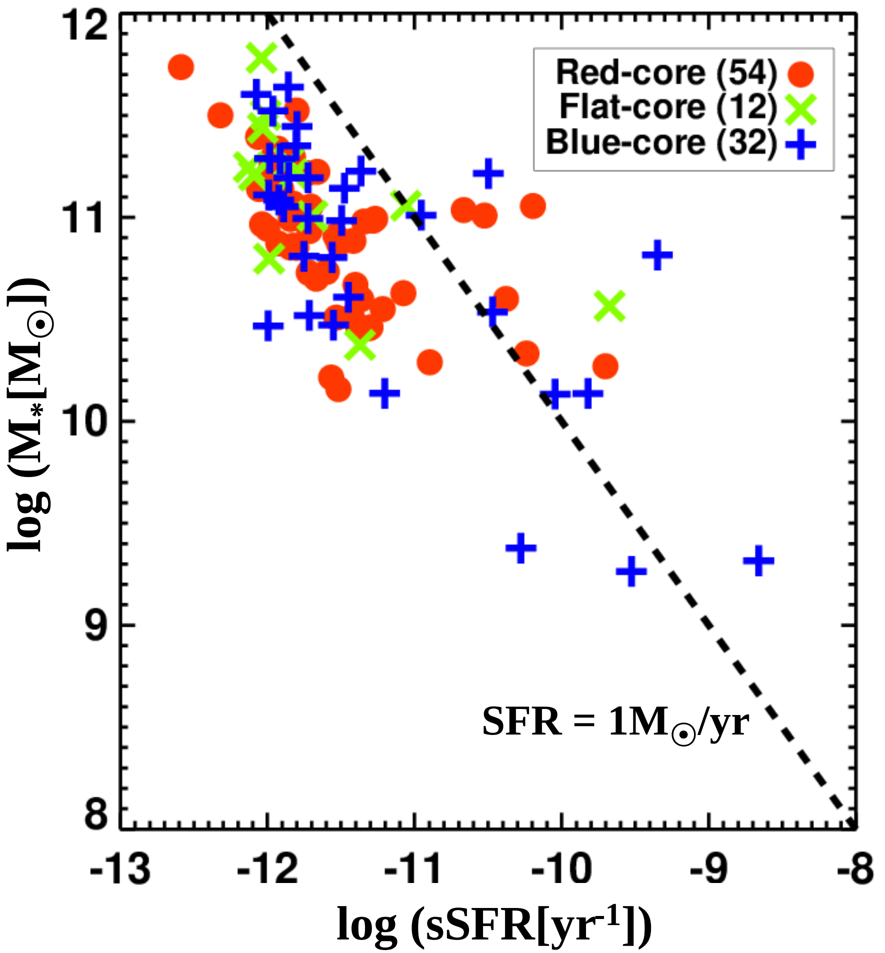
- The CMR exists not only in optical but also in mid-infrared. (Ko et al. 2009)
- The redder MIR color of blue-cored ETGs compared to that of red-cored ETGs is thought to be resulted from the star formation.



[MIR CMR]

4. Results : Stellar mass and sSFR

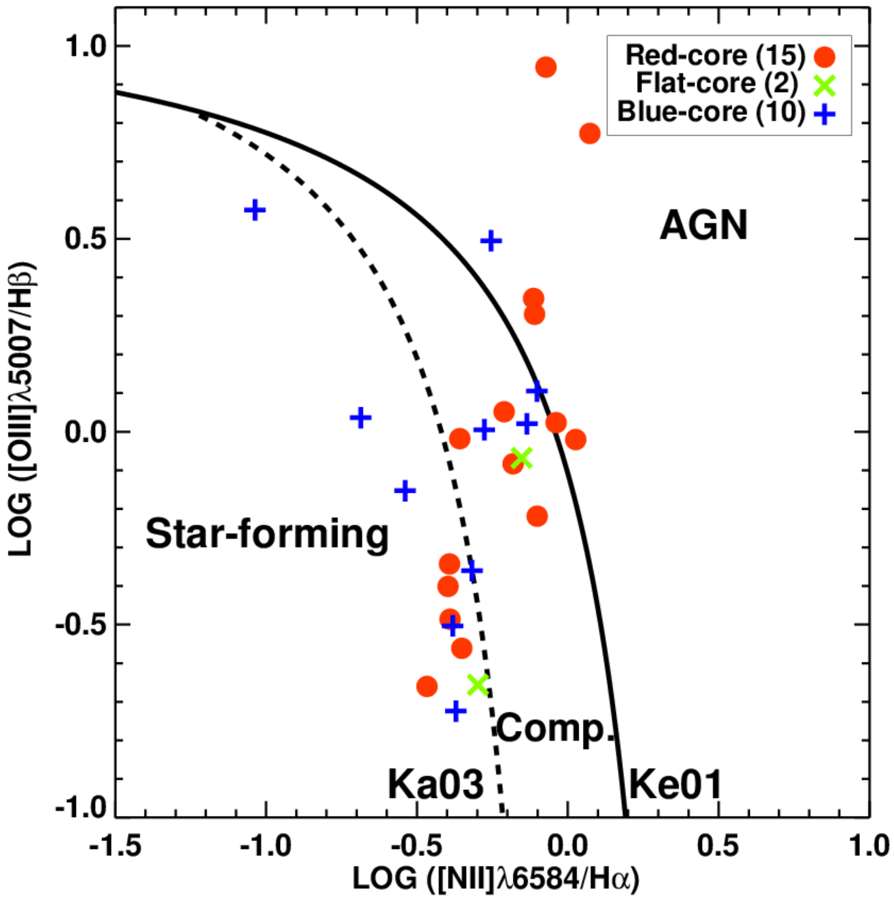
- Stellar masses are comparable for red-cored and blue-cored ETGs with each other.
- Blue-cored ETGs have higher sSFR compared to the red or flat-cored ETGs.



4. Results : AGN

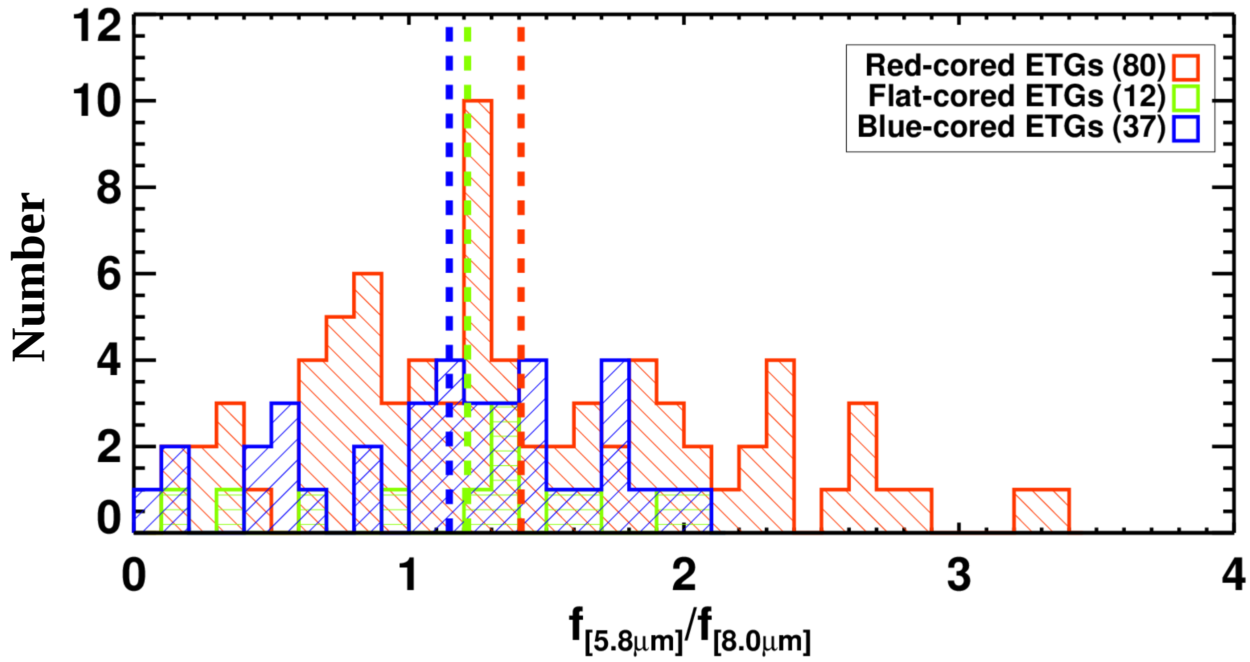
- Several studies (Treu et al. 2005, Lee et al. 2006, 2010) suggested that a portion of the blue-cored ETGs are powered by AGN activity.

- Based on the emission line diagnostics, our result shows that blue-cores are classified as star-forming galaxies rather than AGN.



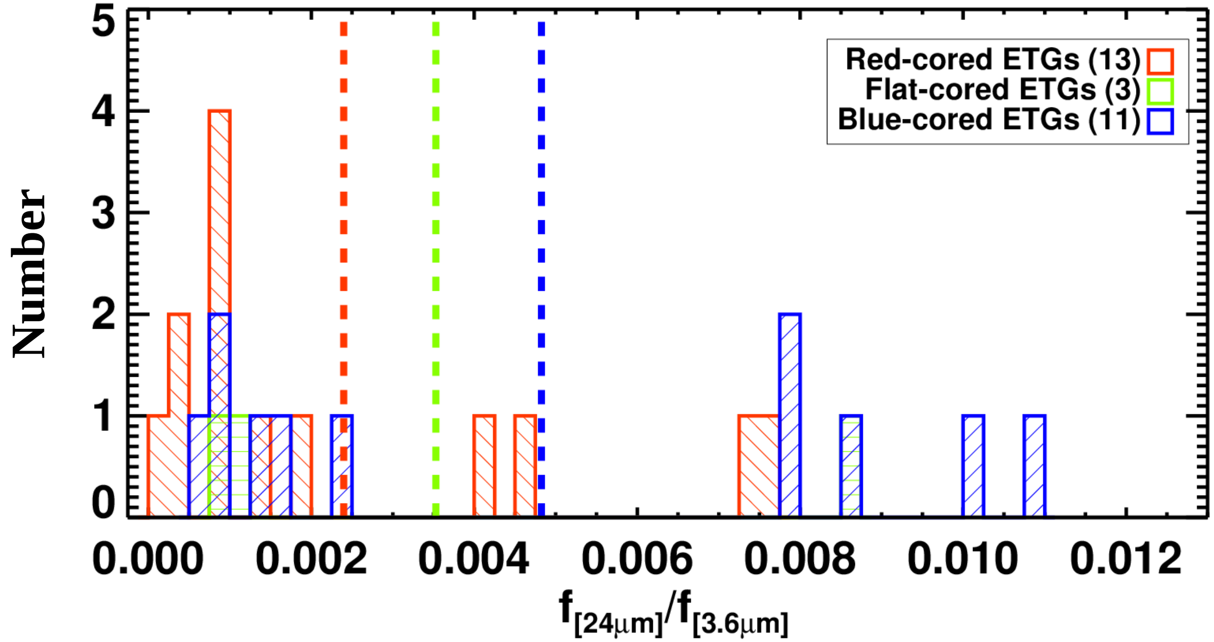
4. Results : MIR Flux Ratio 1

- The 8.0 μm flux is proportional to the emission from polycyclic aromatic hydrocarbons (PAHs) which are universal in the ISM of galaxies.
- Strong PAH emission is an indicator for the star formation in galaxies (Smith et al. 2007).
- Blue-cored ETGs have stronger PAH emission than red-cored ETGs.



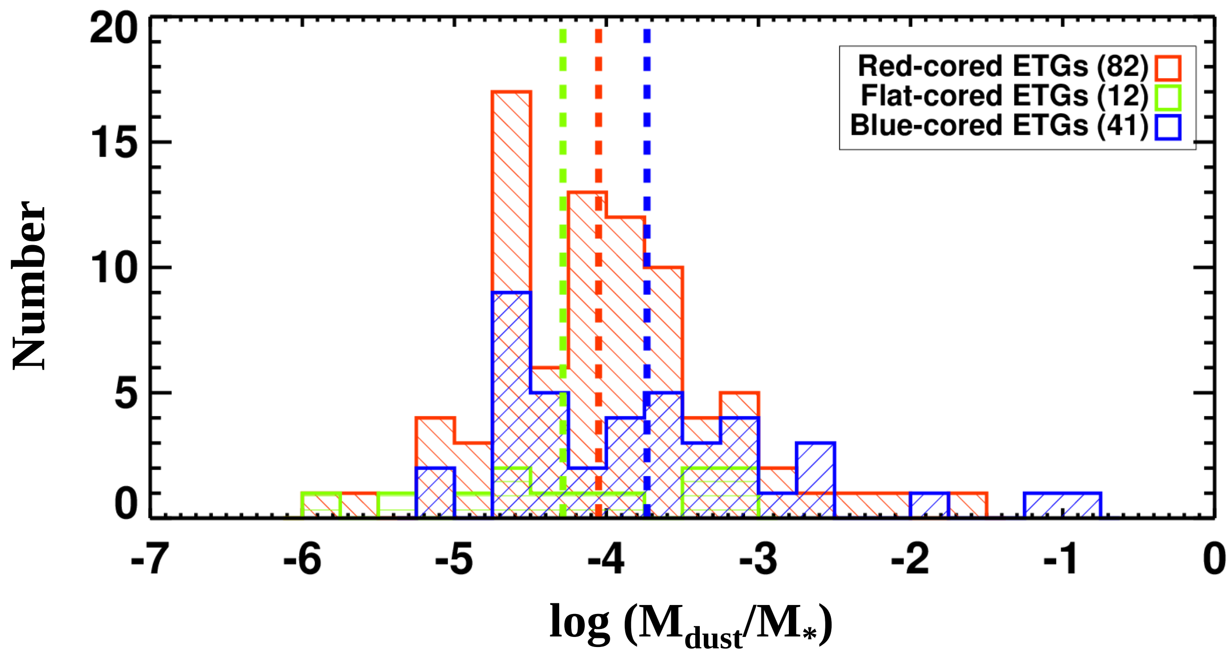
4. Results : MIR Flux Ratio 2

- Flux in 24 μm reflects black body radiation from hot dust (≤100K) component in galaxies.
- Star formation and/or AGN activity are sources of 24 μm emission (Calzetti et al. 2007; Prescott et al. 2007).
- Blue-cored ETGs show stronger 24 μm emission than red-cored ETGs.



4. Results : Dust Mass

- Blue-cored ETGs have more dust than red-cored ETGs.
- This support the idea that blue-cored ETGs are likely to host ongoing star formation.



5. Summary

- We derived the $\nabla(u - g)$ for 30 ETGs and $\nabla(u - R)$ for 181 ETGs in FLS field.
- The optical and MIR CMRs support that blue-cored ETGs have younger stellar population than red-cored ETGs.
- The sSFR of blue-cores is higher than that of red-cores. In addition to that, blue-cored ETGs have more dust than red-cored ETGs.
- From emission line diagnostics, we conclude that red-cored ETGs are more probable to be powered by AGNs.
- MIR emissions in blue-cored ETGs show strong contribution from dust accompanied with star formation.

The conclusion is that while ETGs in general go through the passive evolution, blue-cored ETGs have experienced recent star formation activity (in their center).


Thank You!