A multi-wavelength study of Early-Type Galaxies in clusters and in the field

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Scientific prologue

• New observatories like Spitzer and GALEX allow us to study early-type galaxies (ETGs) from new perspectives

• While early-type galaxies are often considered as a rather homogeneous population of “red and dead” boring stellar systems, non-optical wavelengths (the infrared in particular) show a surprising variety in this population

• Our approach was to take advantage of these new instruments to shed new lights in the study of stellar populations and of the ISM in early-type galaxies complementing the optical view
The study of the star formation history in early type galaxies is affected by the well known **Age / Metallicity degeneracy**:

- In the optical region, the spectra of old & metal poor populations resemble those of young & metal rich populations.
- Spectral indices can help but are affected by [$\alpha$/Fe], ionized gas and reprocessing.
AGB stars and SSPs in MIR

- AGB stars are luminous evolved stars with dusty envelopes
- Oxygen-rich AGBs show the silicate emissions at 10µm & 18µm emitted by the dusty envelopes
- Bressan et al. (1998) computed SSP spectra including AGBs envelopes
- The 10µm signature should be visible in MIR spectra of early type galaxies
- The AGB contribution increases with metallicity & decreases with age
Breaking the degeneracy using the mid IR

- Age and metallicity have the same effect in the optical region.
- Age and metallicity have opposite effect in the mid infrared region.
- Combining optical and MIR removes the age-metallicity degeneracy.
- Note that the MIR alone still suffers from degeneracy.

- First application was with ISO CVS spectra (Bressan et al. 2001).
- ISO sensitivity and resolution prevented a definitive answer.

![Graph showing Log(Fν/mJy) vs. Log(λ(μm)) for NGC 1399 with different models.](image)
Spitzer IRS spectra of Virgo ETGs

• We observed with IRS-Spitzer 18 ETGs in Virgo
• We demonstrated for the first time the presence of predicted bump at 10µm in early type galaxies
• The 10µm emission feature is very similar to observed AGB outflows (Molster et al. 2000) and to Bressan et al. (1998) SSP models
• ¾ of the galaxies show passive spectra (i.e. no emission lines, no PAHs)
Emission feature analysis

• The emission is well fitted with **optically thick** oxygen-rich envelopes

• Bressan et al. (1998) **SSP models predict smaller optical thickness**
  – The AGB phase is complex and needs a proper modeling
  – Work in progress for new SSP models
  – Spitzer observations of AGB stars in globular clusters (Sloan et al. 2010) will allow to improve dust envelopes models

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**Diagram:**

- Log F(ν)/Jy vs. λ (μm) for various NGC stars (Bressan et al. 2007)
- Normalized F(ν) plots for different NGC stars (Sloan et al. 2010)
Indices vs AGB emission

- Yamada et al. (2006) spectroscopic study indicates that NGC4451 is significantly younger & more metal rich than NGC4365

- This would imply a larger AGB feature in NGC4551 than in NGC4365

- The opposite is seen in our spectra
MIR imaging of Coma & Virgo

- We extended the study to fainter ETGs with imaging
- IRS peakup (16µm) & IRAC (4.5 & 8µm) campaign of Virgo faint and Coma ETGs (49 hours, 91 galaxies)
  - Clemens et al. (2009), Clemens et al. (2011)
• For Virgo, we were able to study color gradients
  – 16µm more centrally concentrated than K
  – K-[4.5] and K-[8] are constant
  – Metallicity effect grows toward the center
• The interpretation of the relation color – magnitude of early-type galaxies was longly debated: is it due to metallicity or to an age effect?
• The diagram $K_s - [16\mu m]$ vs $K_s$ shows that emission of dusty AGBs increases with luminosity/mass.
• The color – magnitude relation is dominated by metallicity.
The interacting galaxy NGC4435

- NGC4435 is an SB0 galaxy in Virgo interacting with NGC4438
- Panuzzo et al. (2007) analyzed the MIR spectrum
  - First decomposition of 17μm PAH complex
    - Detection of C$_{60}$ emission
  - Presence of warm (200K) and hot (630K) molecular gas
Star formation in NGC4435

- We modeled the SED from UV to radio with the code GRASIL (Silva et al. 1998)
- We characterized the star formation episode
  - Age of 180 Myr, in agreement with dynamical simulations
  - Mass of stars formed: $1.4 \times 10^8$ Msun
  - 0.3% of the mass of the old population
  - SFR=0.09 Msun/yr, $<\text{SFR}>$=0.75 Msun/yr
  - Gas with solar metallicity
Synchrotron emission in M87

- We (Buson et al. 2009) decomposed the MIR SED of M87 into:
  - A stellar component with AGB feature
  - A pure power-law synchrotron component

- No torus emission found
- Emission lines are not present in the jet
Early type galaxies in the field

- Rampazzo et al. (2005) & Annibali et al. (2006) compiled a sample of **65 nearby ETGs**
  - $cz < 5500 \text{ Km/s}$
  - 68 % E, 32 % S0
  - 0.1-4 gal / Mpc$^3$ (Tully 1988)

- Lick indices (e.g., H$\beta$, Mg2, Mgb, Fe5335, Fe5270) from optical spectra (3700-7000 Å, FWHM~8 Å) as function of radius

- Annibali et al. (2007) derived ages, metallicities, [$\alpha$/Fe] and their relations with the mass and the environment
The GALEX view

- We observed 12 galaxies with GALEX, 28 taken from the archive (Marino et al. 2011)
- Some objects show rings/arms
  - Recent star formation
- Galaxies are bluer in the center
  - Sign of metallicity gradient
Spitzer-IRS observations of field ETGs

- We observed 18 galaxies with IRS-Spitzer, 22 were found in the archive
  - IRS spectra uniformly reprocessed (Panuzzo et al. 2011)
- Contrary to the cluster, >\(\frac{3}{4}\) of galaxies in the field show nebular emission lines or PAH features
MIR Spectra classification

Class 0: passive (20%)

Class 1: passive with lines (17%)

Class 2: anomalous PAHs (50%)

Class 3: star forming (7.5%)

Class 4: AGN (5%)
Passive galaxies vs SSP models

Silicate emissions

Interstellar dust?

Flux/Flux(H)

Rest Wavelength [μm]

Passive Temp.

SSP, z=Z_{surf}
Age=12 Gyr
PAH in Class 2 objects

- We analyzed the PAH features in 4 class 2 galaxies with strong $\text{H}_2$ lines (Vega et al. 2010)
- No ionized PAH features
  - so not powered by star formation
- They show some features observed in Carbon stars
  - Post starburst (300Myr – 1.3Gyr) objects?
  - Ratio between star forming and class 2 objects is consistent

Vega et al. (2010)
Evolutionary scenario after accretion

• We propose an evolutionary scenario started by interaction/accretion events
• We associated a MIR spectral class to each evolutionary phase

Panuzzo et al. (2011)
**Warm H\(2\)**

- **Half of the sample** (mainly class 2) shows rotational lines from warm H\(2\).
- **This gas is most probably heated by shocks**
  - What is the origin of these shocks?
  - All class 2 galaxies are optical LINERs.
• The MIR diagnostic diagram NeIII/Nell vs SIII/Sill shows that Class 2 objects are not powered by star formation.

• But it is not able to distinguish between AGN and shock.
Optical emission lines

- Analysis of emission lines in Annibali et al. (2010)
  - Computation of the emission lines requires careful subtraction of the underlying stellar spectrum
  - Galaxy spectra are fit with new SSPs (Bressan (unpublished), Clemens et al. 2009, Chavez et al. 2009) based on the MILES empirical stellar library
Diagnostic diagrams

- Emission lines studied as function of radius
- Moving outwards, EW of lines and the [NII]/Hα decrease

- It could be interpreted either with a decrease in the nebular metallicity, or with a progressive “softening” of the ionizing spectrum
Ionization mechanism in LINERs nuclei

- From the nuclear EW, only 22% of galaxies classified as LINERs/Composites can be explained with photoionization by post-AGB stars.

- High resolution X-ray and/or radio data suggest the presence of low accretion rate AGNs in ~ 60% of LINERs.

- If shocks are important, which is their origin?
Conclusion

• I have shown how a multi-wavelength view allows to put into evidence many different aspects of early-type galaxies

• The MIR region is particularly interesting for the study of early-type galaxies because it contains the emission from oxygen rich AGBs and it is very sensitive to the presence of ISM.
  – We used the MIR region to characterize the stellar populations of ETGs and to differentiate between cluster and field environments and between different nuclear activities

• Crossing together the information from different wavelengths in a single picture is clearly the challenge for the next future
Future directions (1)

- Study of stellar populations in ETGs:
  - Test formation and evolution models
  - Compare ETGs in clusters with ETGS in low density environments
    - Improve models of dusty envelopes with Spitzer observations of AGB
    - Construction of “complete” and “detailed” SED
      - A sample of 10 galaxies observed with Xshooter, data under analysis

![Graph of Log(Fd) vs Wavelength [μm] for NGC4365]
Future directions (2)

• Study of the “evolutionary scenario”:
  – Confirm the evolutionary scenario from MIR classes
    • Class 2 objects seem rejuvenated from H\(\beta\)

– Understand the physical processes in ISM due to interactions-accretions, in particular in class 2 objects
  • 2D Spectroscopy (SINFONI) to trace possible shocks and warm H\(\text{H}_2\)
  • CO (IRAM, ALMA) to trace cold molecular gas
  • Imaging dust distribution (MIPS, Herschel)

• Understand ionizing power origin in LINERs

<Diagram showing classification of MIR classes (Class 0, Class 1, Class 2, Class 3, Class 4) with H\(\beta\) and [MgFe]' (5'') axes.
Herschel view

Galassia ellittica: NGC 4473

Class 0: Herschel infrarosso

Class 2: NGC4636 FIR (SPIRE)

Dust lane: NGC5363 FIR (SPIRE)

Clemens et al. 2010