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

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Scientific prologue

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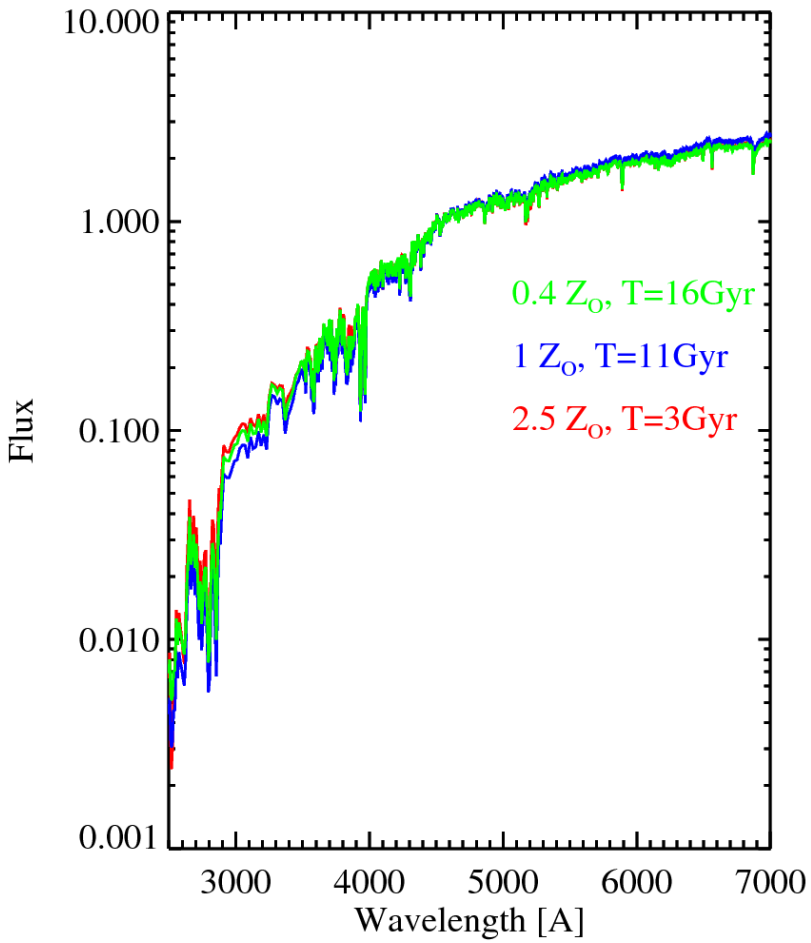
- New observatories like Spitzer and GALEX allow us to **study early-type galaxies (ETGs) from new prospectives**

- 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**

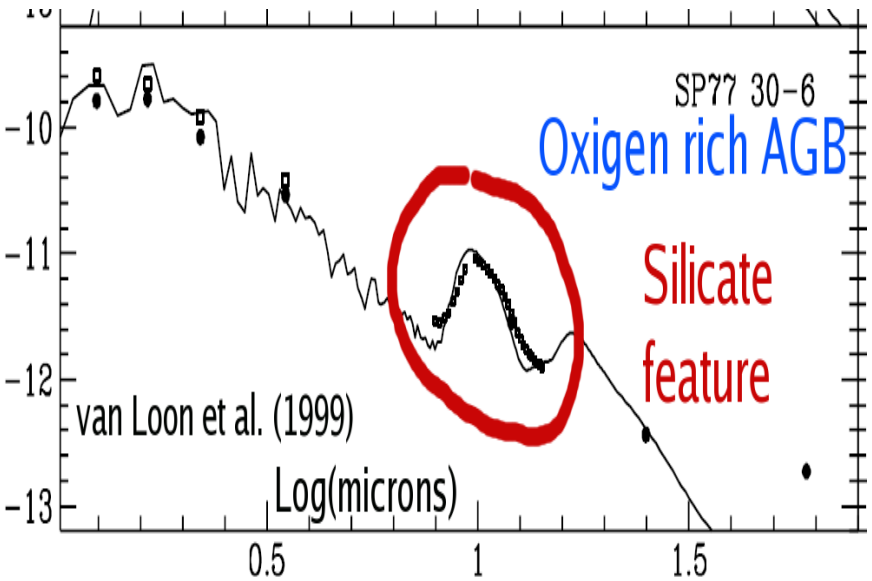
Age / Metallicity degeneracy

- 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 [α/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**

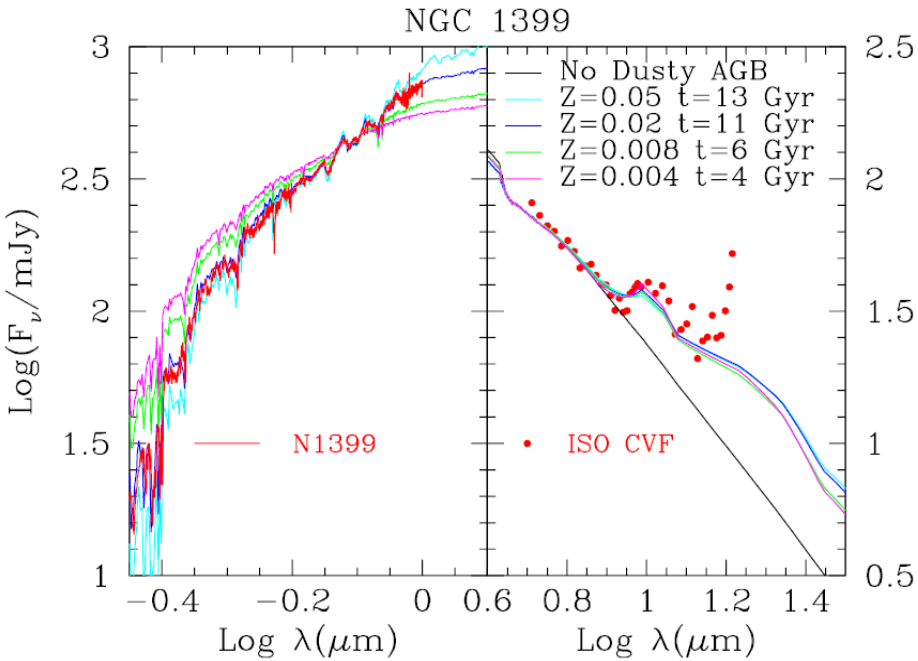


- The 10µm signature should be visible in MIR spectra of early type galaxies
- The AGB contribution **increases with metallicity & decreases with age**

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



Spitzer IRS spectra of Virgo ETGs

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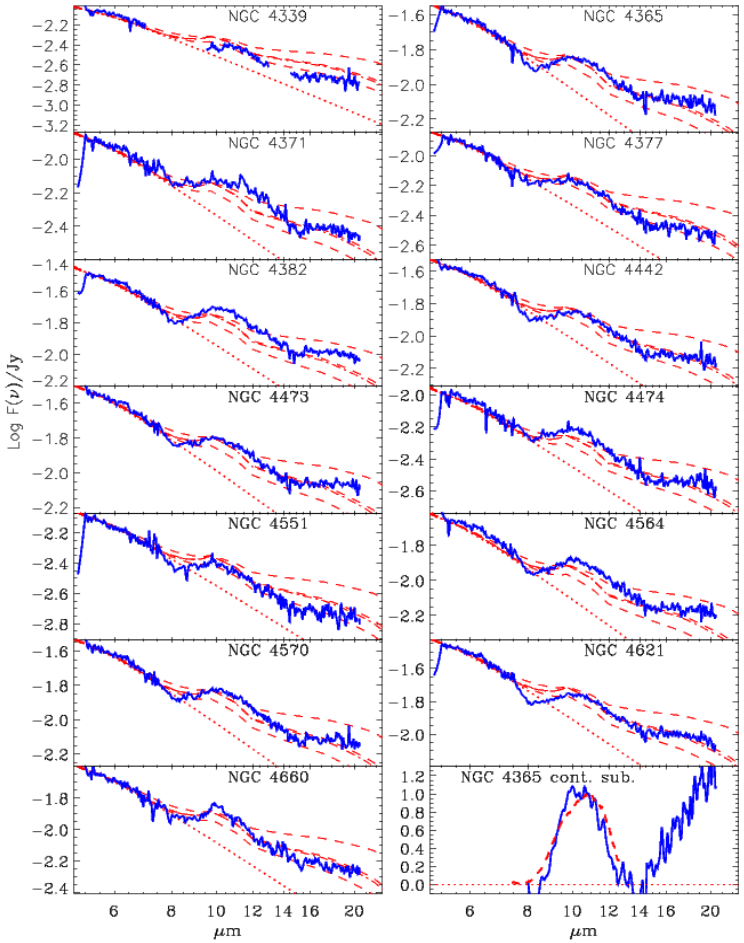
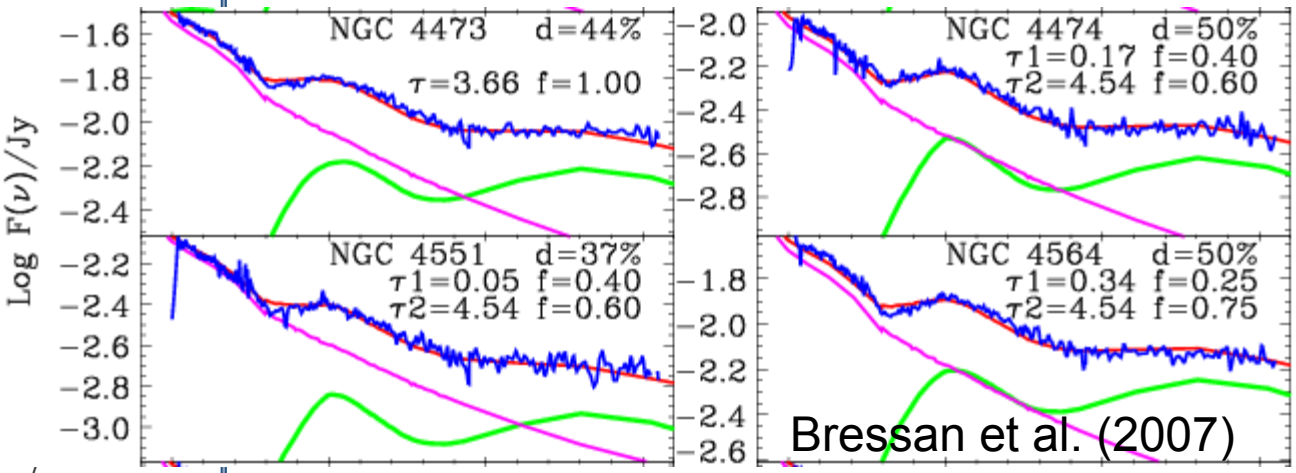
- We observed with IRS-Spitzer 18 ETGs in Virgo
- We demonstrated for the first time **the presence of predicted bump at 10μm in early type galaxies**
- The 10μm emission feature is very similar to observed AGB outfows (Molster et al. 2000) and to Bressan et al. (1998) SSP models
- **¾ of the galaxies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

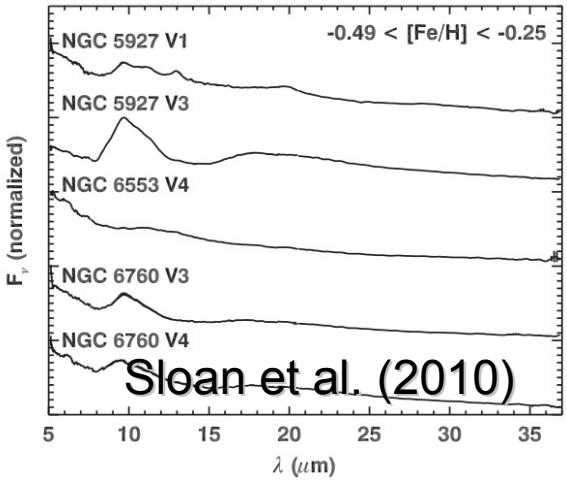


Bressan et al. (2006)

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

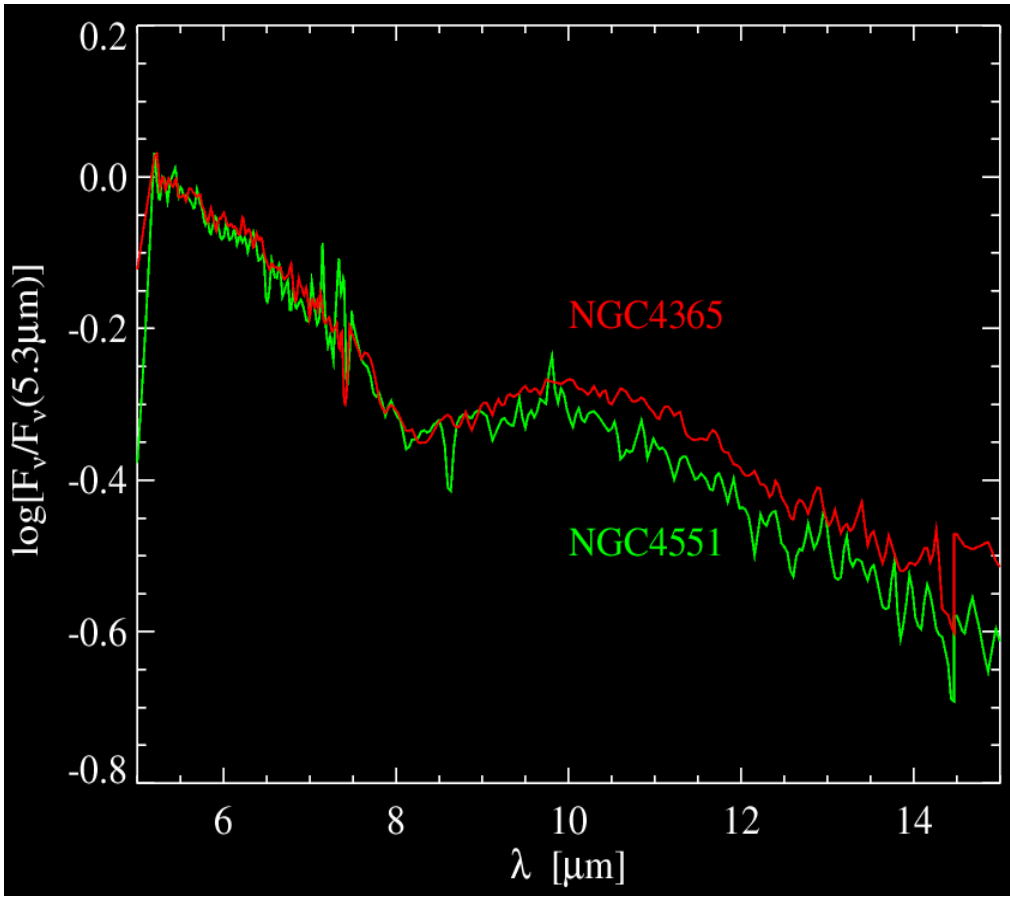




Indices vs AGB emission

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

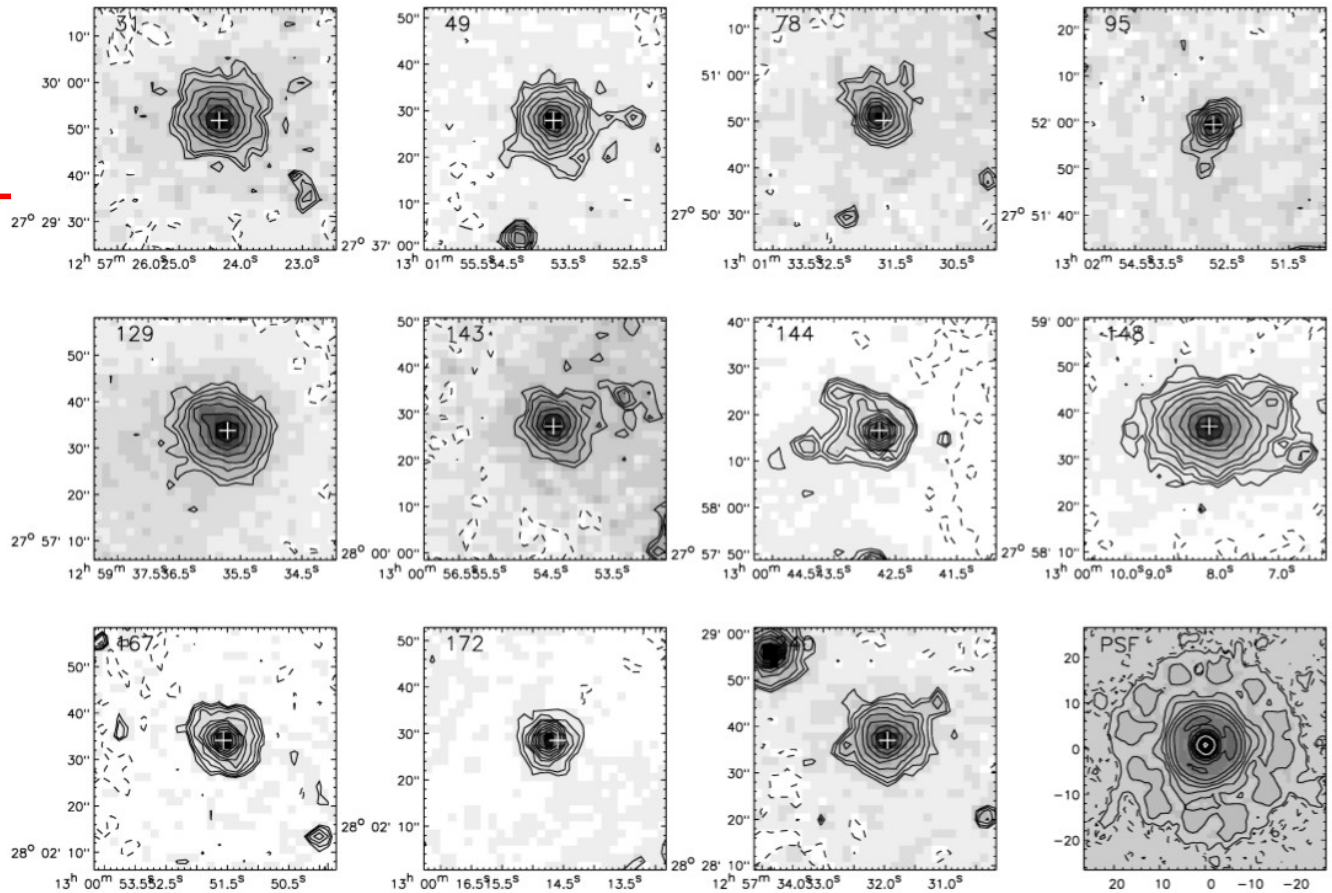
- This would imply a larger AGB feature in NGC4551 than in NGC4365
- **The opposite is seen in our spectra**



MIR imaging of Coma & Virgo

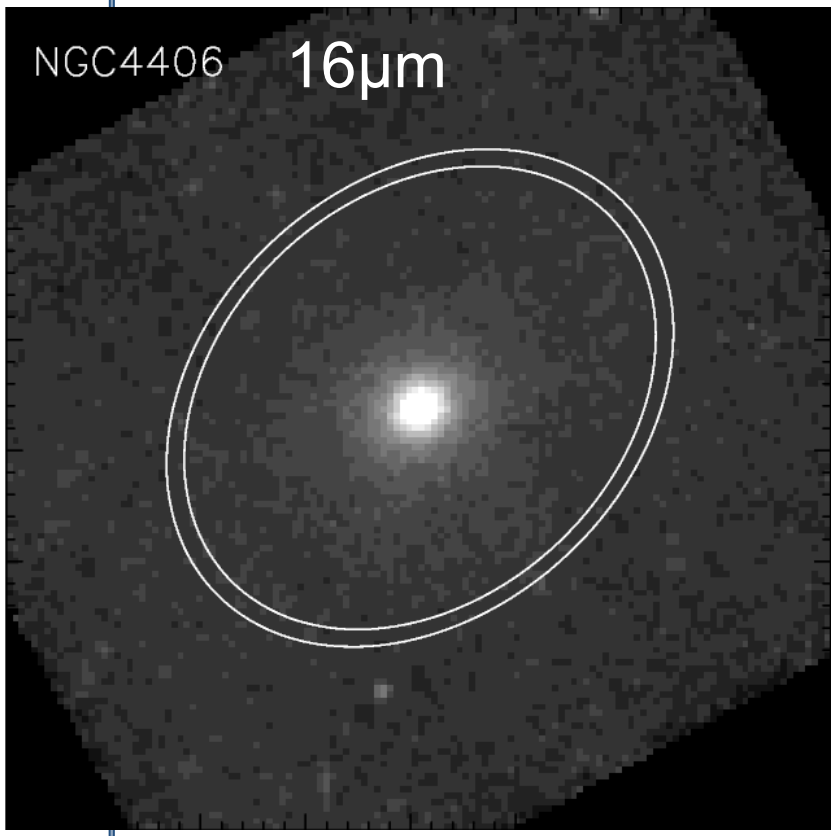
- We extended the study to fainter ETGs with imaging
- IRS peakup (16μm) & IRAC (4.5 & 8μm) campaign of Virgo faint and Coma ETGs (49 hours, 91 galaxies)
  - Clemens et al. (2009), Clemens et al. (2011)

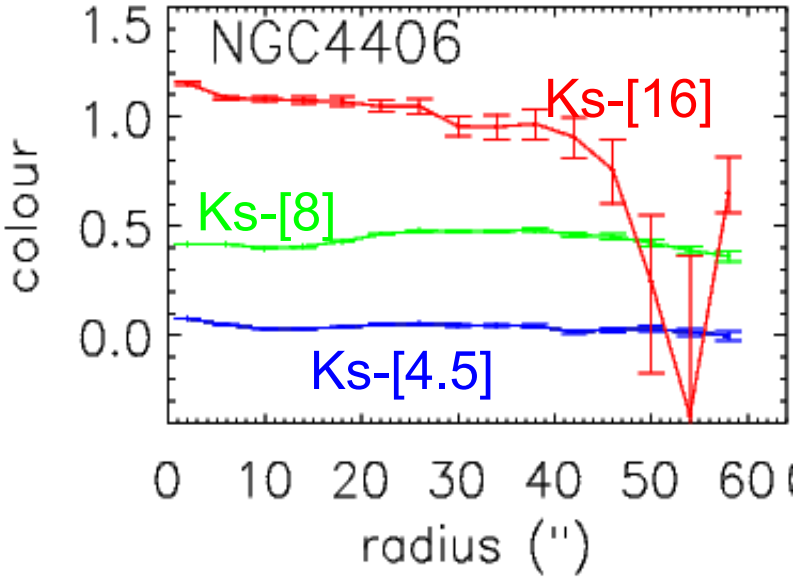
ETGs in Coma at 16μm



Color gradients

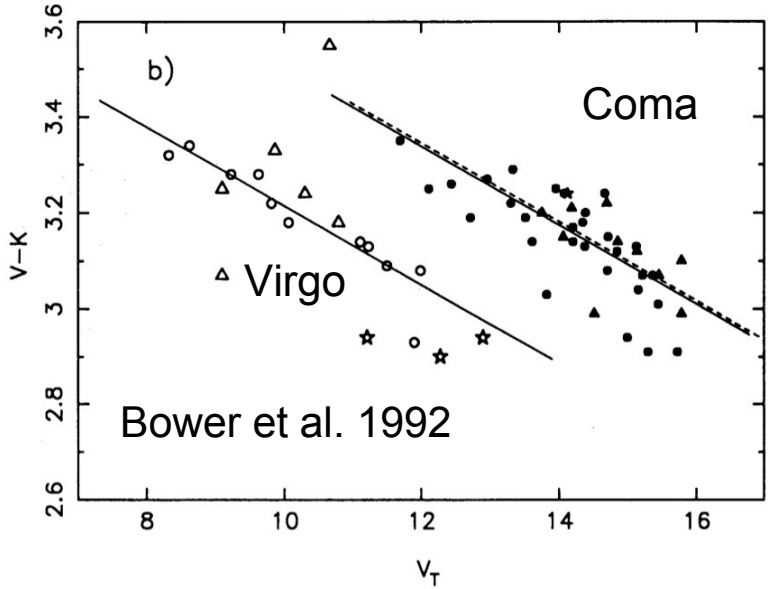
- For Virgo, we were able to study color gradients
  - **16µm more centrally concentrated than K**
  - K-[4.5] and K-[8] are constant
  - Metallicity effect grows toward the center

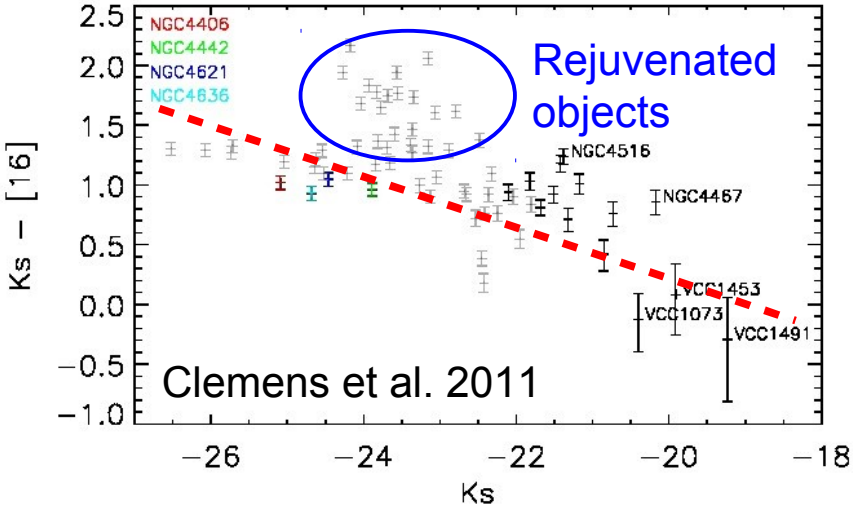




Color - magnitude relation of ETGs

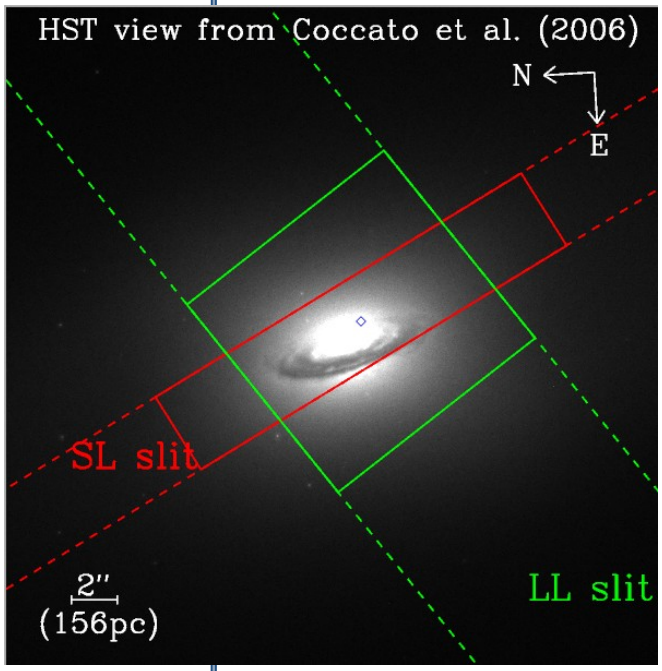
- The interpretation of the **relation color – magnitude of early-type galaxies** was longly debated**: is it due to metallicity or to an age effect?**
- The diagram **Ks−[16μm] vs Ks** shows that emission of dusty AGBs increases with luminosity/mass
- **The color – magnitude relation is dominated by metallicity**

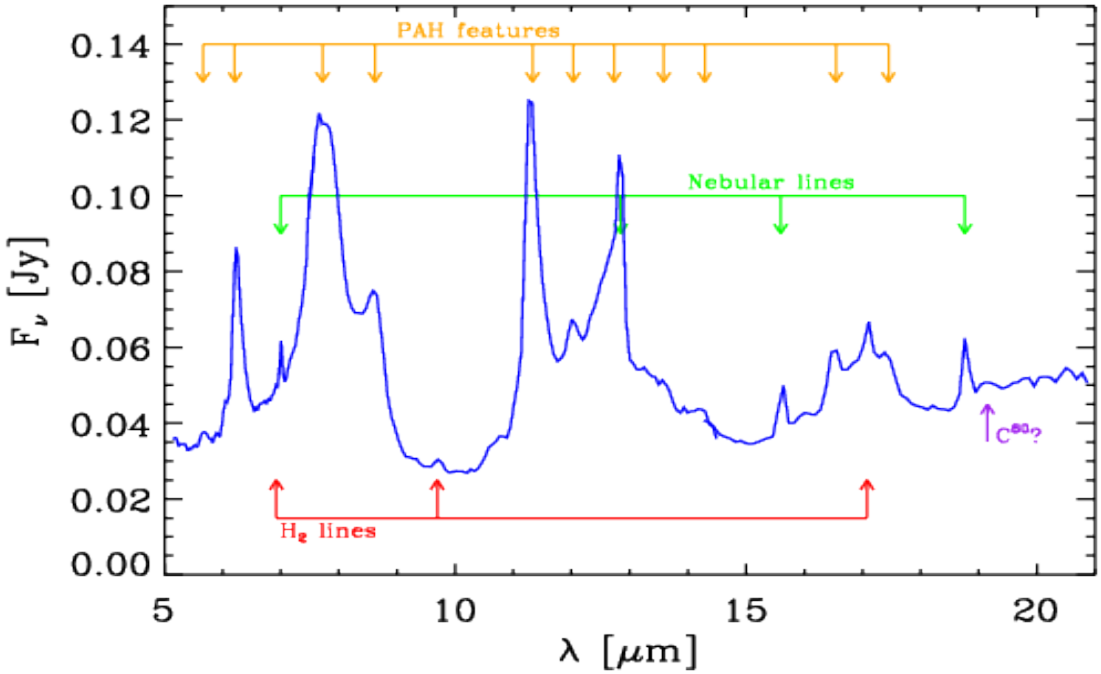




The interacting galaxy NGC4435

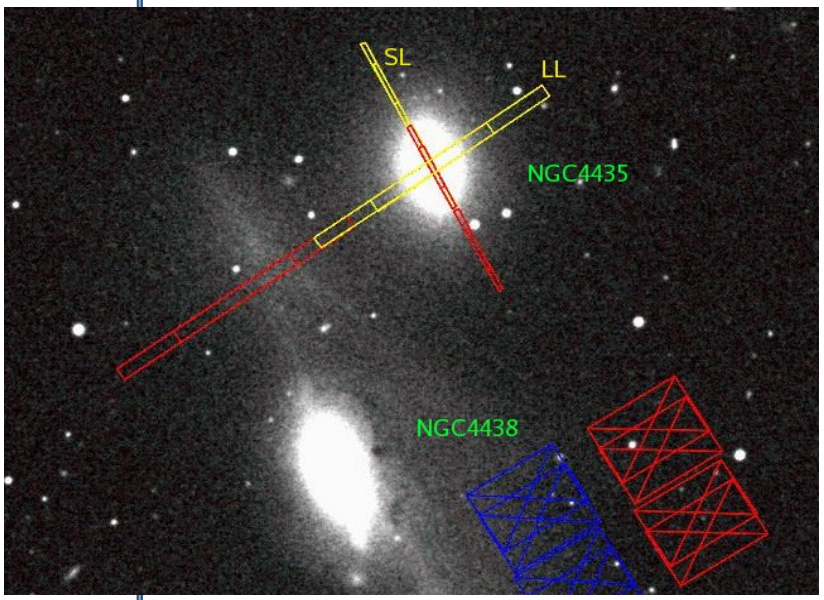
- NGC4435 is an SB0 galaxy in Virgo interacting with NGC4438
- Panuzzo et al. (2007) analyzed the MIR spectrum
  - First decomposition of 17μm PAH complex
    - Detection of C^{60} emission
  - Presence of warm (200K) and hot (630K) molecular gas

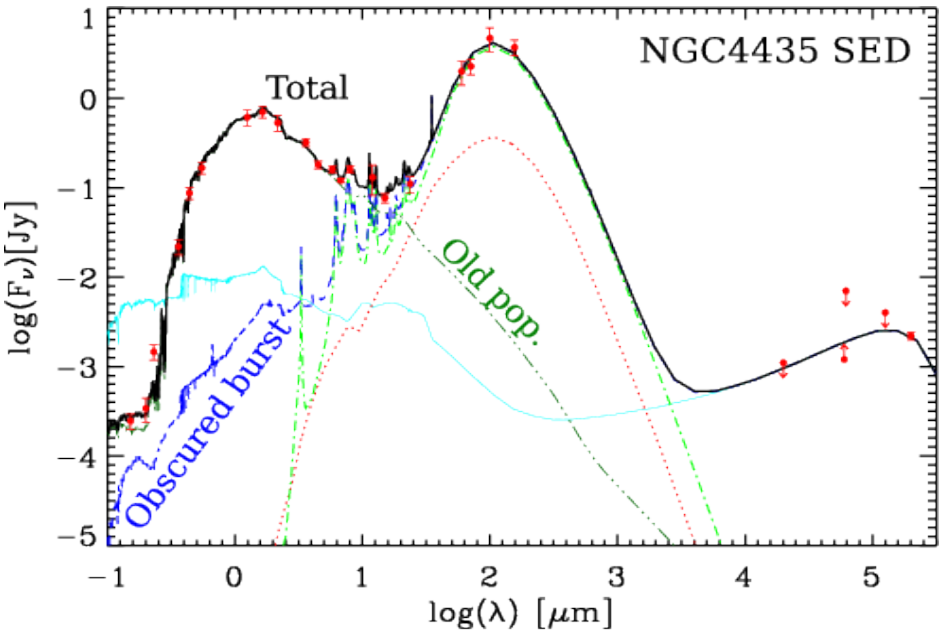




Star formation in NGC4435

- 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: 1.4×10^8 Msun
  - **0.3%** of the mass of the old population
  - SFR=0.09Msun/yr, <SFR>=0.75Msun/yr
  - Gas with solar metallicity

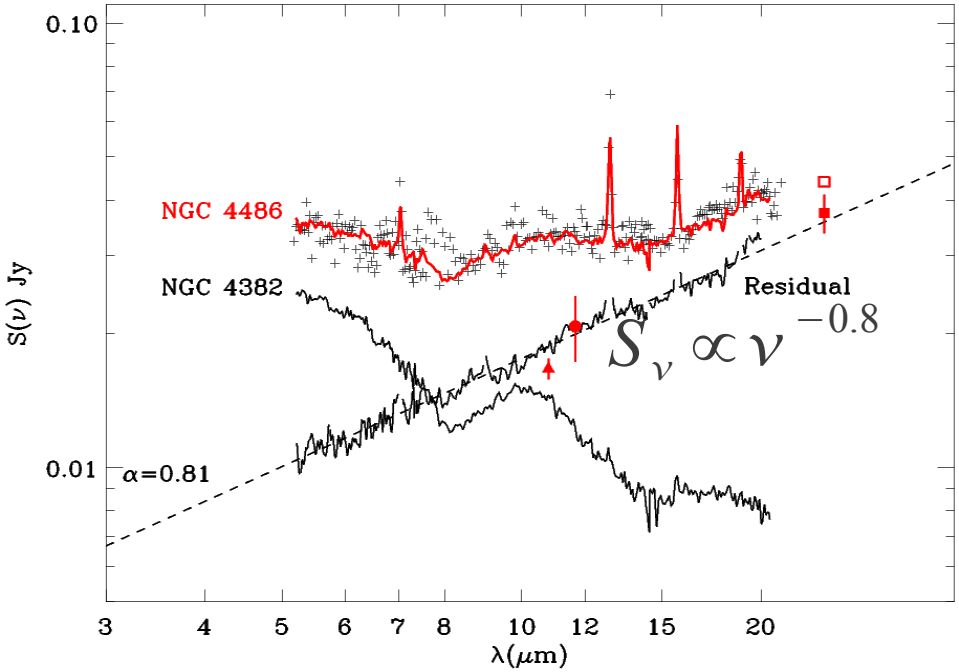


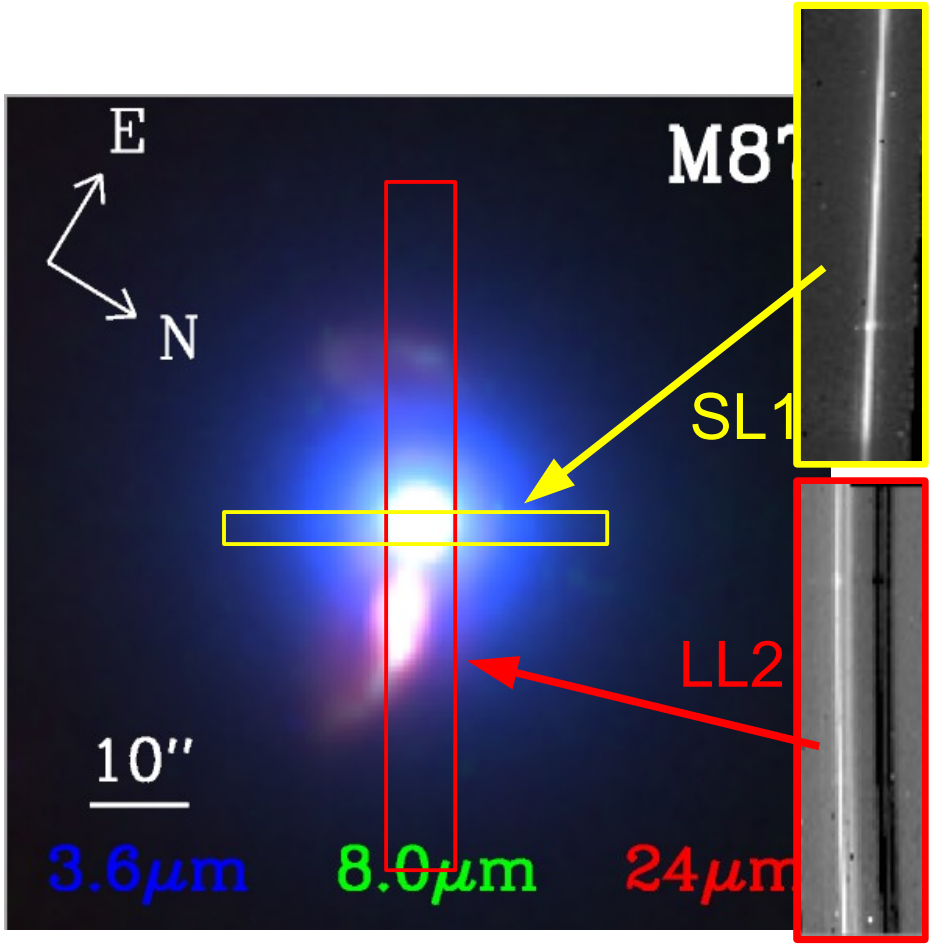


Synchrotron emission in M87

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

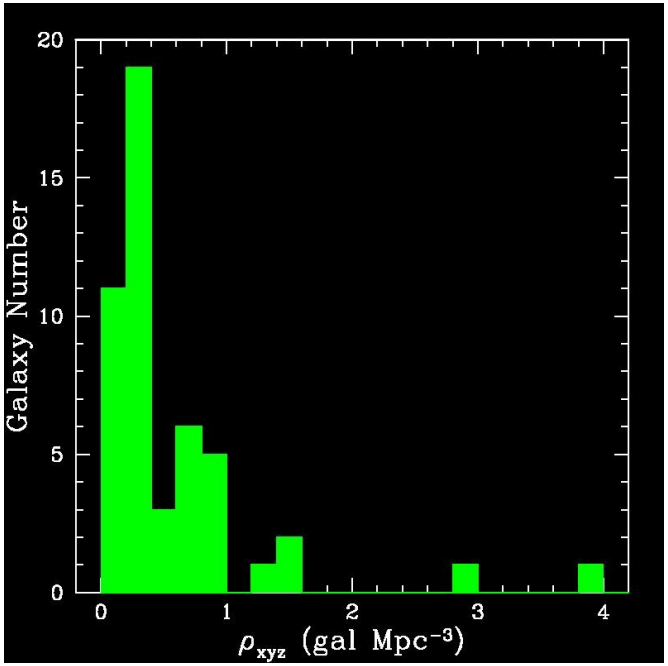
- **No torus emission found**
- Emission lines are not present in the jet





Early type galaxies in the field

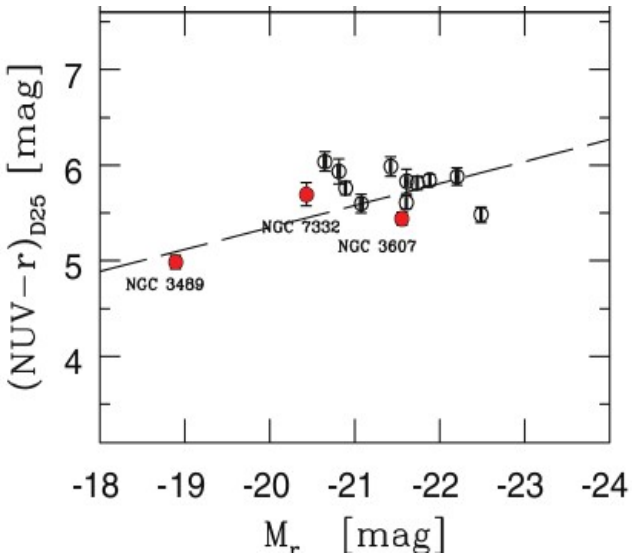
- Rampazzo et al. (2005) & Annibali et al. (2006) compiled a sample of **65 nearby ETGs**
  - cz < 5500 Km/s
  - 68 % E, 32 % S0
  - 0.1-4 gal / Mpc^3 (Tully 1988)
- Lick indices (e.g., Hβ, Mg2, Mgb, Fe5335, Fe5270) from optical spectra (3700-7000 Å, FWHM~8 Å) **as function of radius**

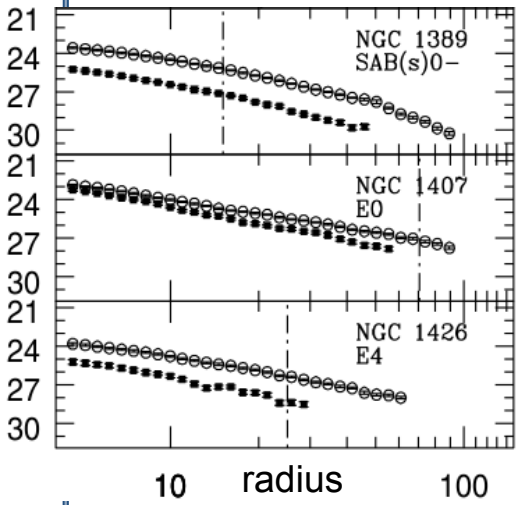


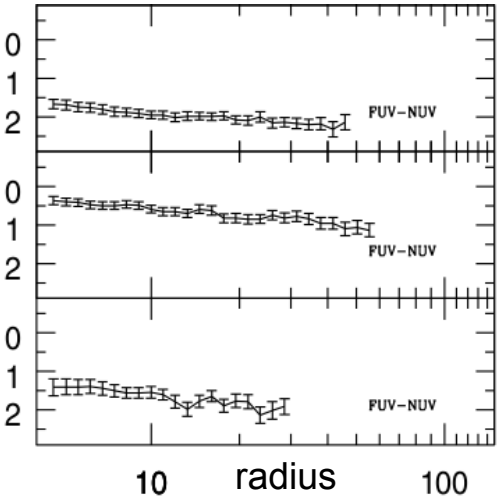
- Annibali et al. (2007) derived ages, metallicities, [α/Fe] and their relations with the mass and the environment

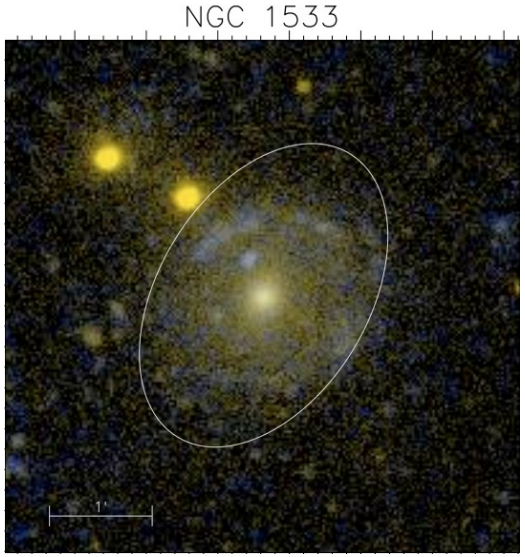
The GALEX view

- 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

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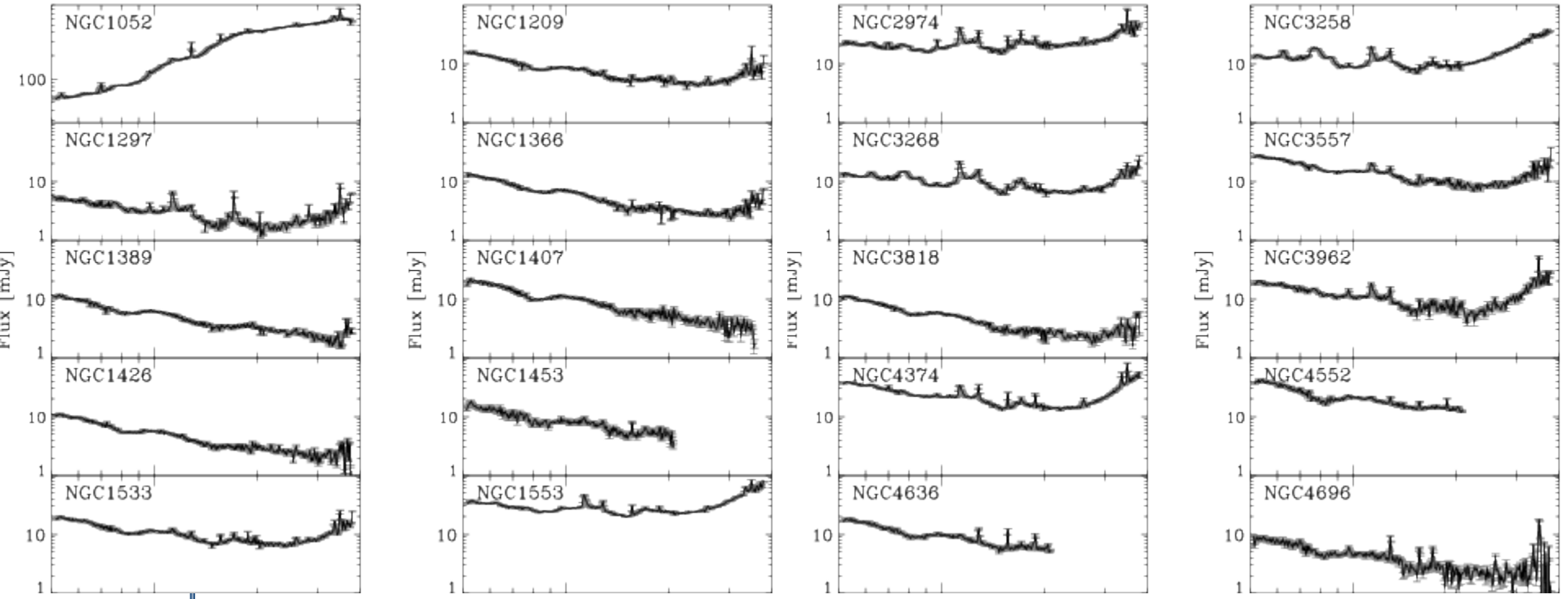
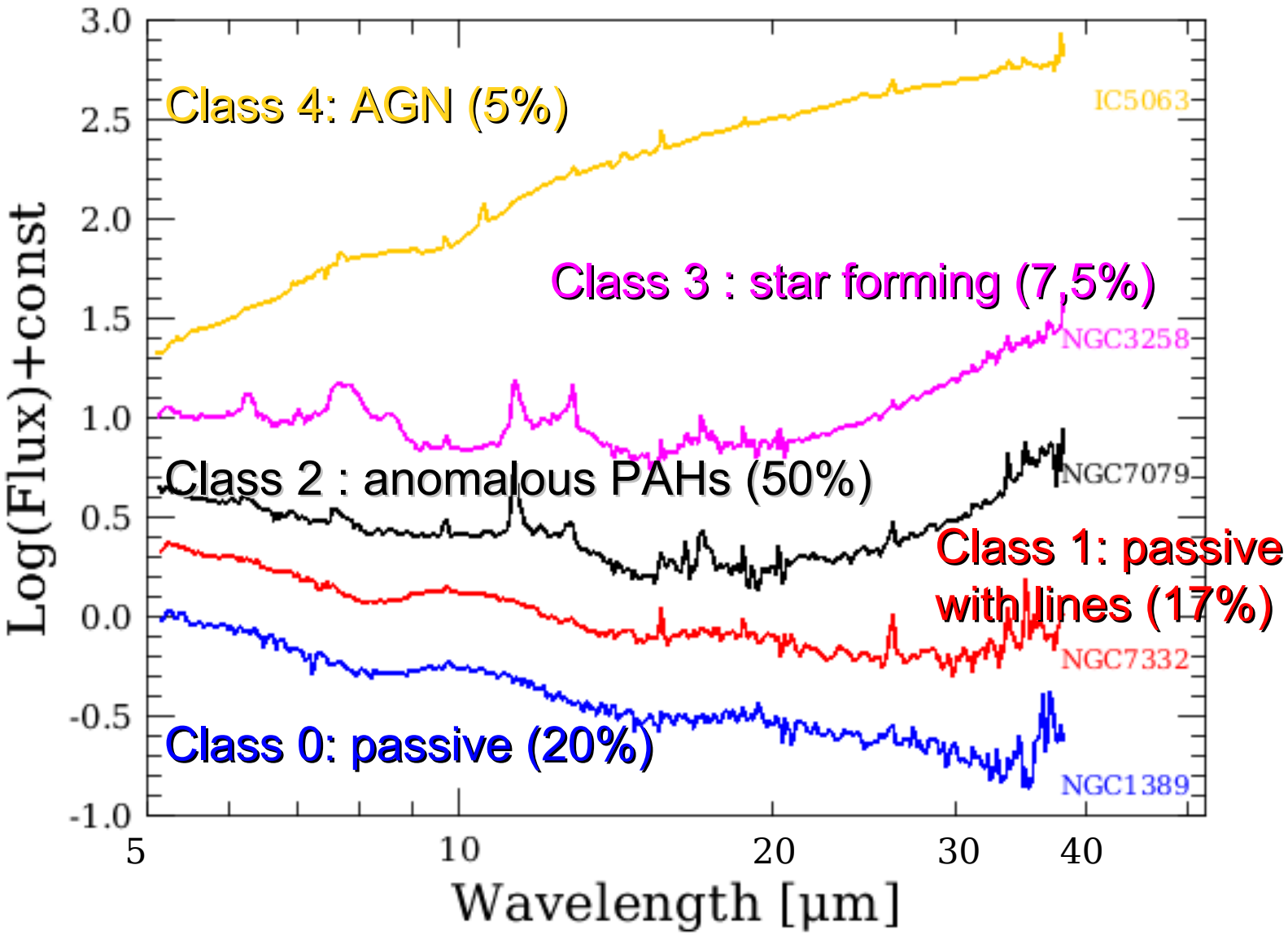
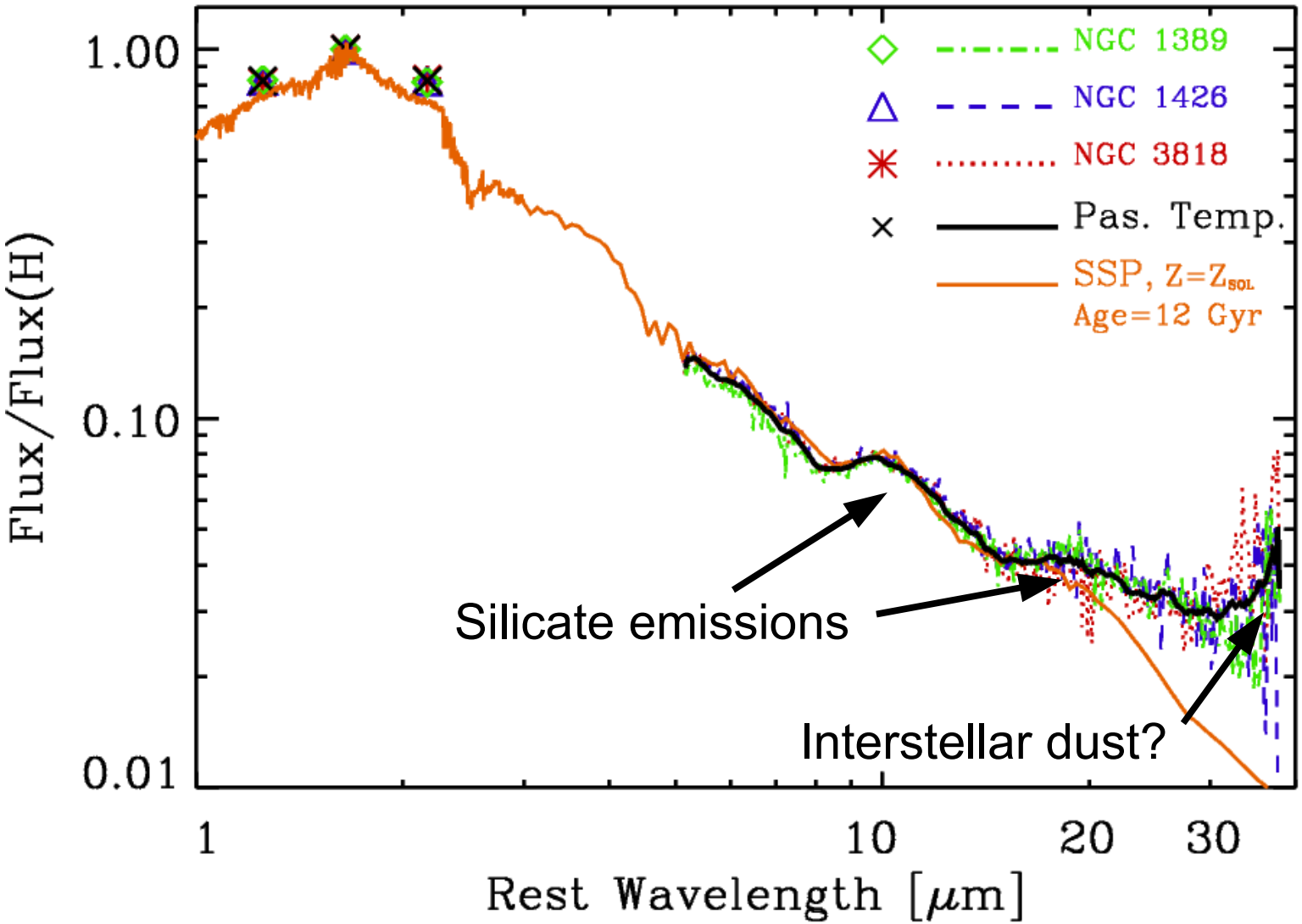
- We observed 18 galaxies with IRS-Spitzer, 22 were found in the archive
  - IRS spectra uniformly reprocessed (Panuzzo et al. 2011)
- Contrary to the cluster **>¾ of galaxies in the field show nebular emission lines or PAH features**



MIR Spectra classification

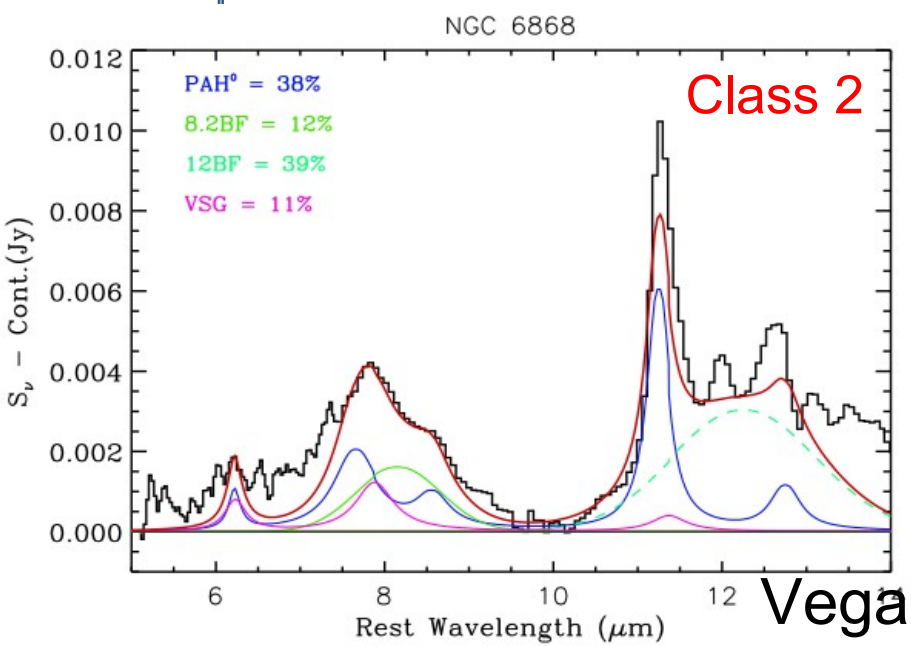


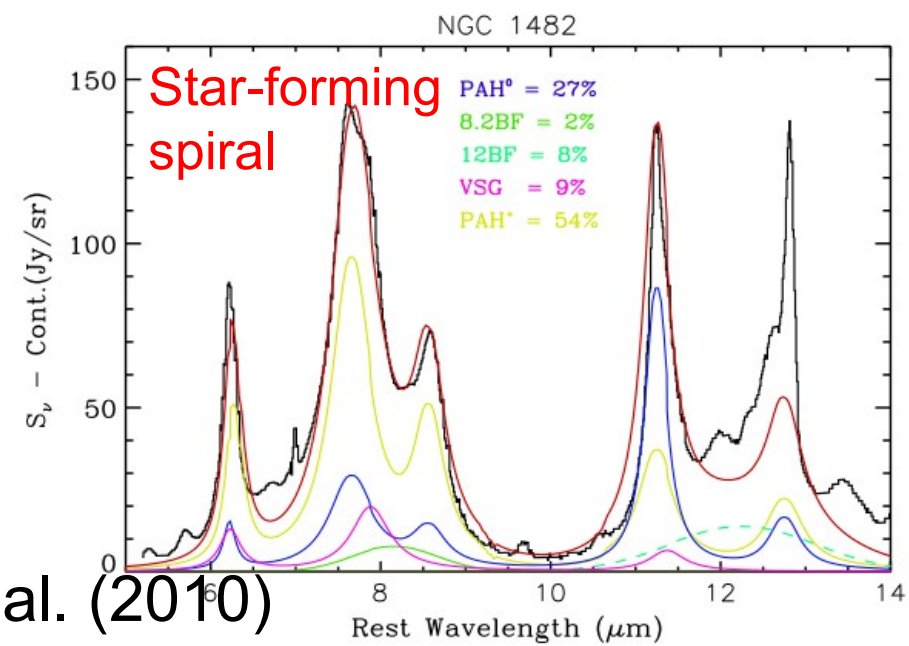
Passive galaxies vs SSP models



PAH in Class 2 objects

- We analyzed the PAH features in 4 class 2 galaxies with strong 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)

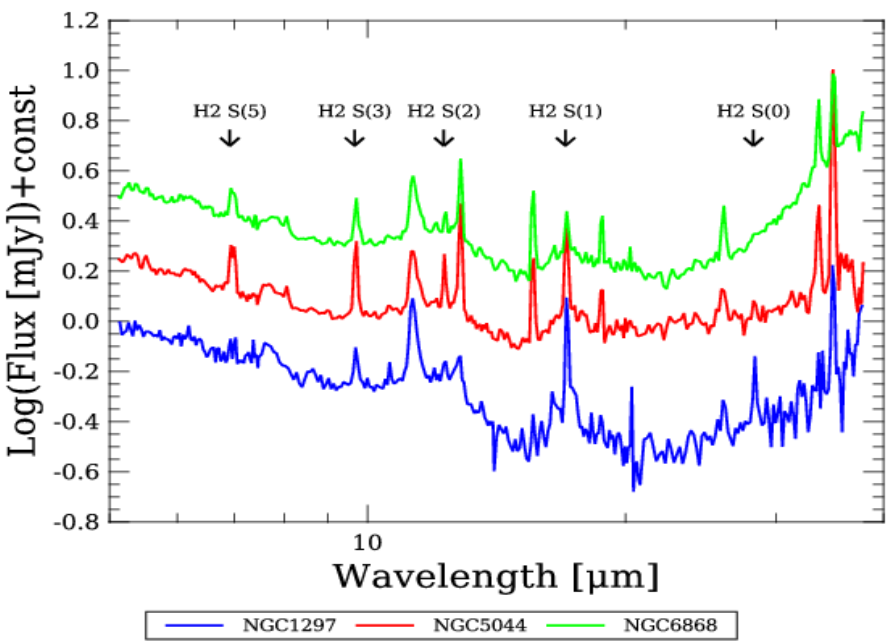
Evolutionary scenario after accretion

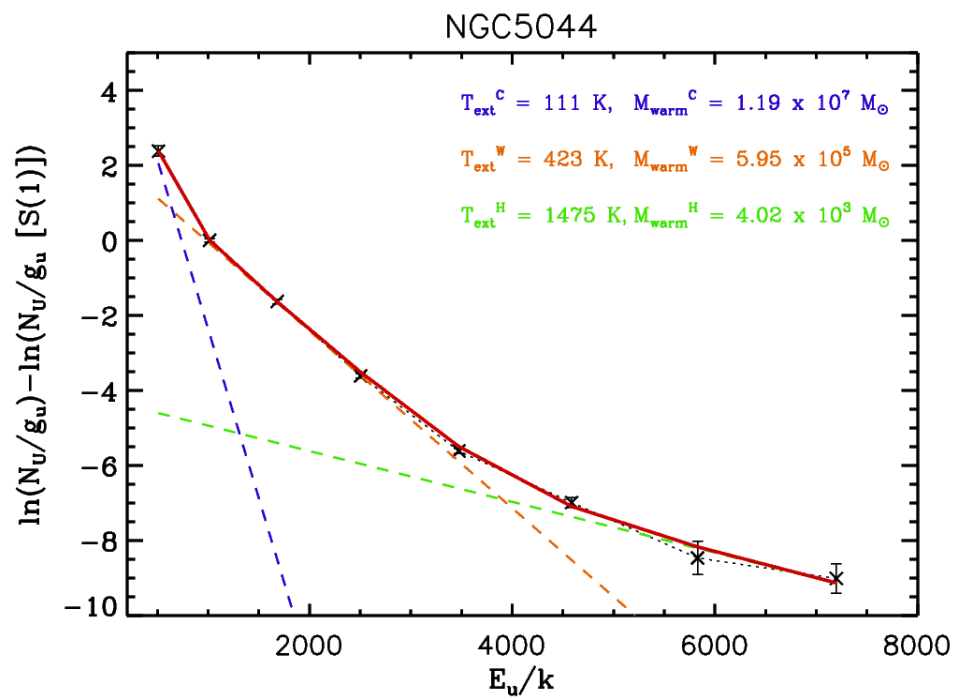
- We propose an **evolutionary scenario started by interaction/accretion events**
- We associated a **MIR spectral class to each evolutionary phase**

Panuzzo et al. (2011)

Warm H2

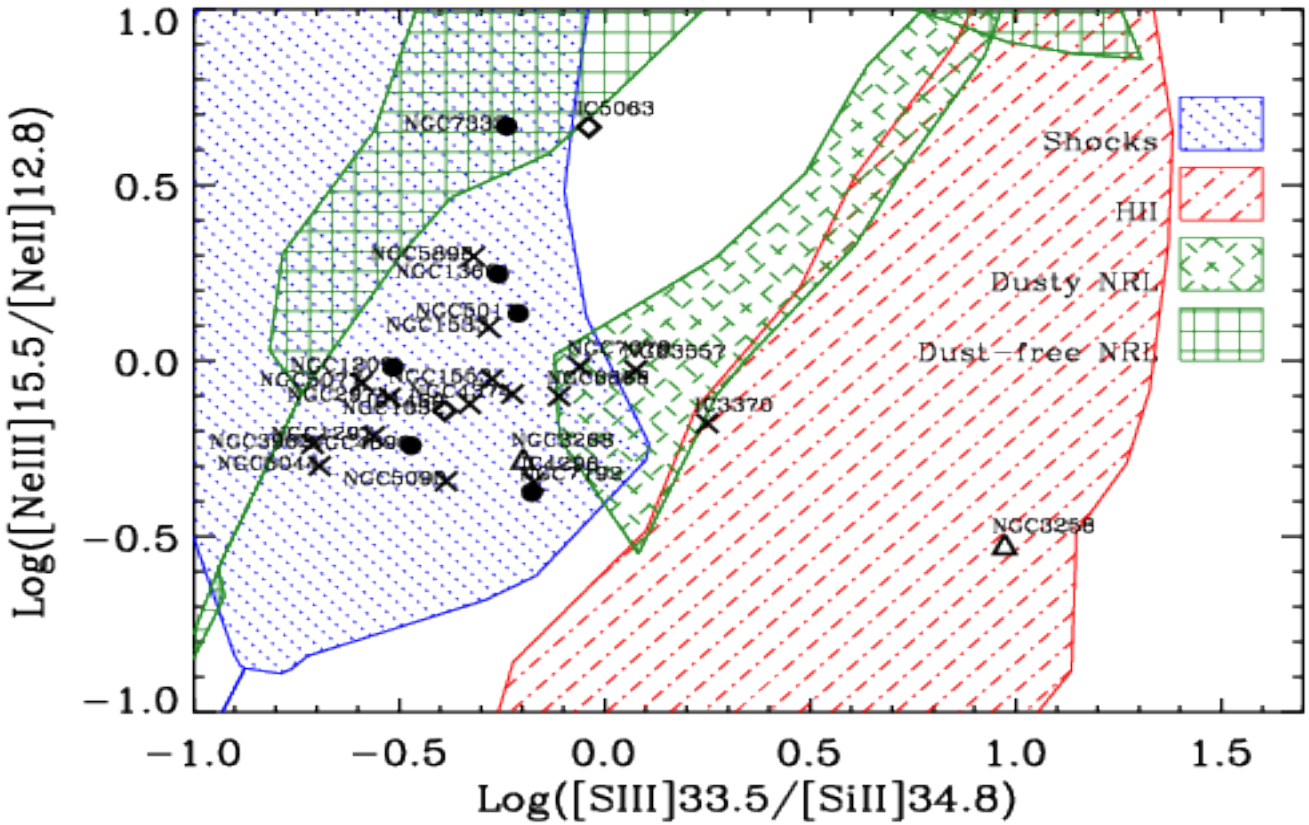
- **Half of the sample** (mainly class 2) **shows rotational lines from warm H_2**
- This gas is most probably **heated by shocks**
  - What is the origin of these shocks?
  - All class 2 galaxies are optical **LINERs**





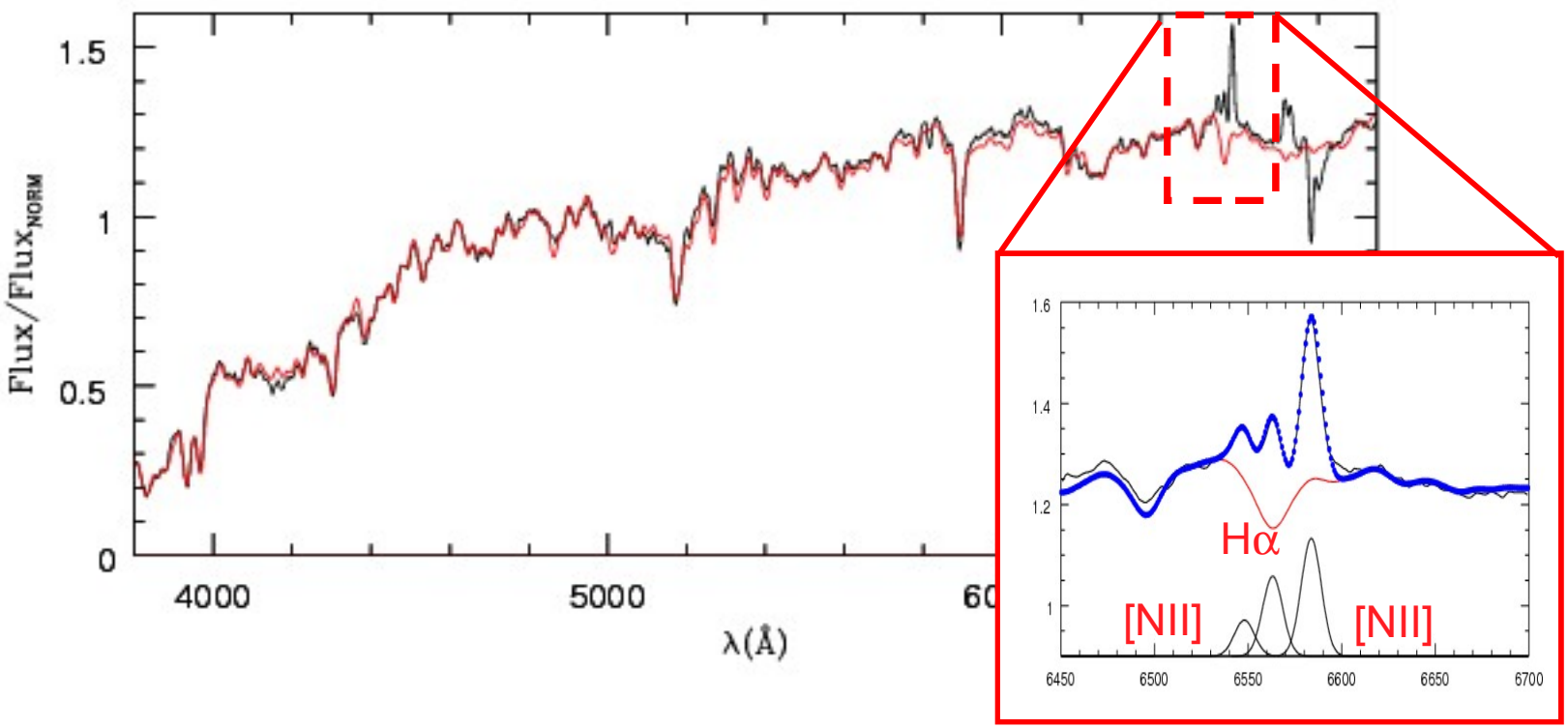
MIR diagnostic diagram

- The MIR diagnostic diagram NeIII/NeII vs SIII/SiII shows that Class 2 objects are not powered by star formation
- But it is not able to distinguish between AGN and shock



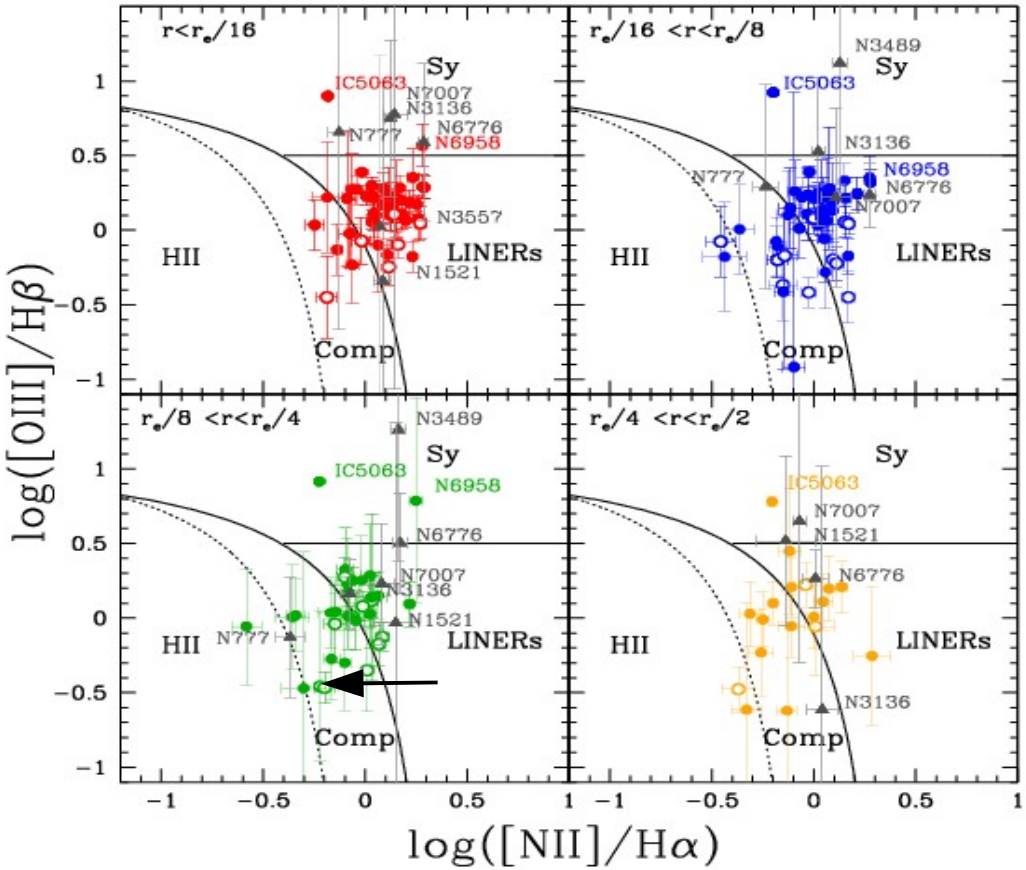
Optical emission lines

- 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**

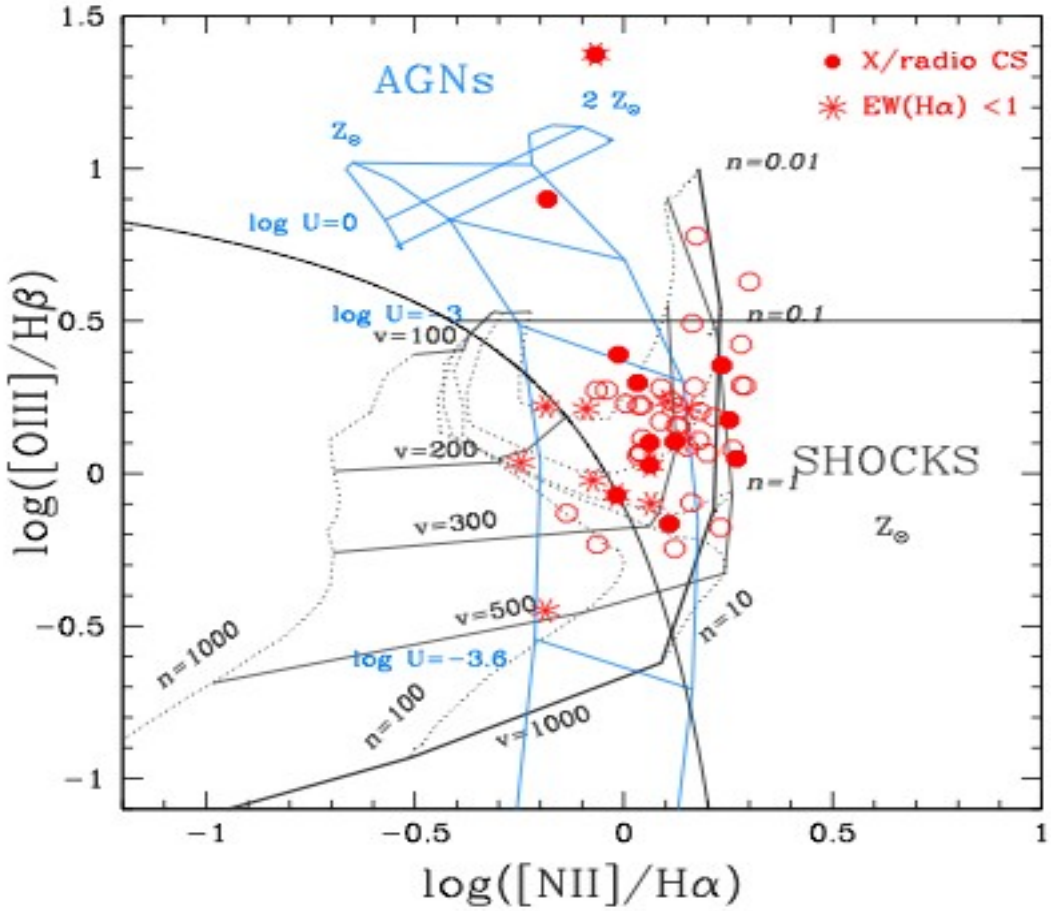


- It could be interpreted either with a **decrease in the nebular metallicity, or with a progressive "softening"** of the ionizing spectrum

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

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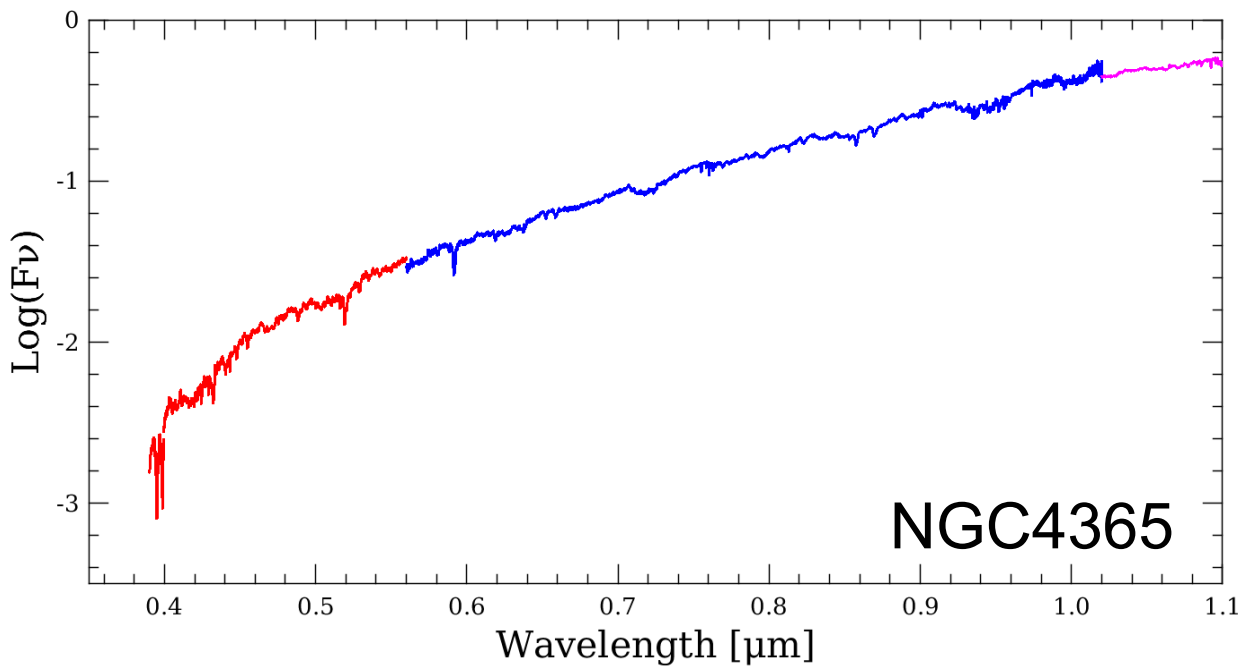
- I have shown how **a multi-wavelength view** allows to put into evidence many **different aspects of early-type galaxies**
- **The MIR region is particularly interesting for the study of early-type galaxies** because it contains the emission from oxygen rich AGBs and it is very sensitive to the presence 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

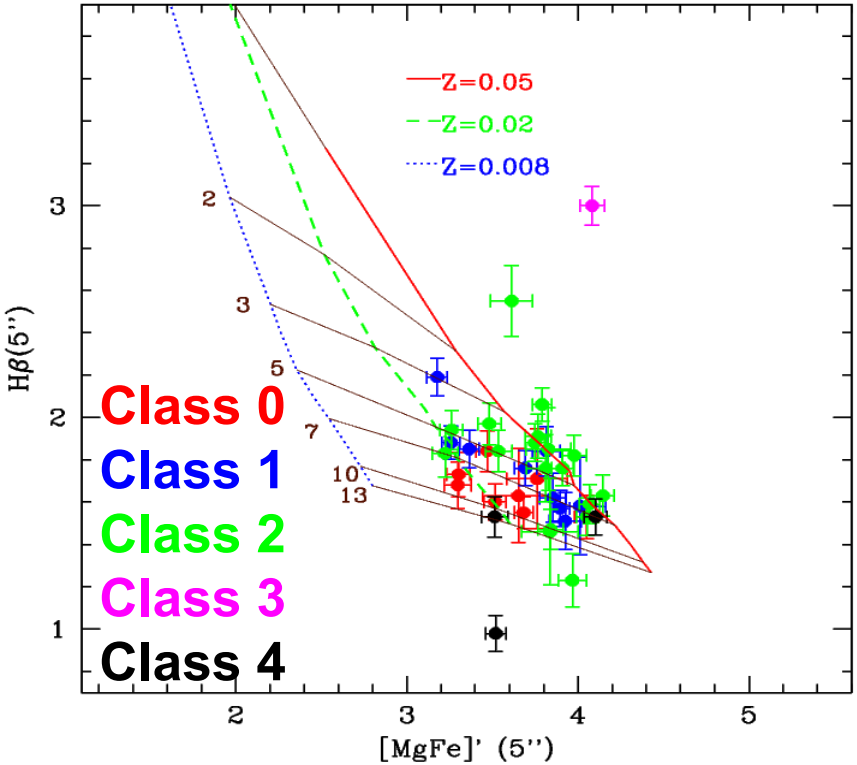
Future directions (1)

- 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 envelops with Spitzer observations of AGB
    - Construction of “complete” and “detailed” SED
      - A sample of 10 galaxies observed with Xshooter, data under analysis



Future directions (2)

- Study of the "evolutionary scenario":
  - Confirm the evolutionary scenario from MIR classes
    - Class 2 objects seem rejuvenated from Hβ



  - **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_2
    - CO (IRAM, ALMA) to trace cold molecular gas
    - Imaging dust distribution (MIPS, Herschel)
- Understand ionizing power origin in LINERs

Herschel view

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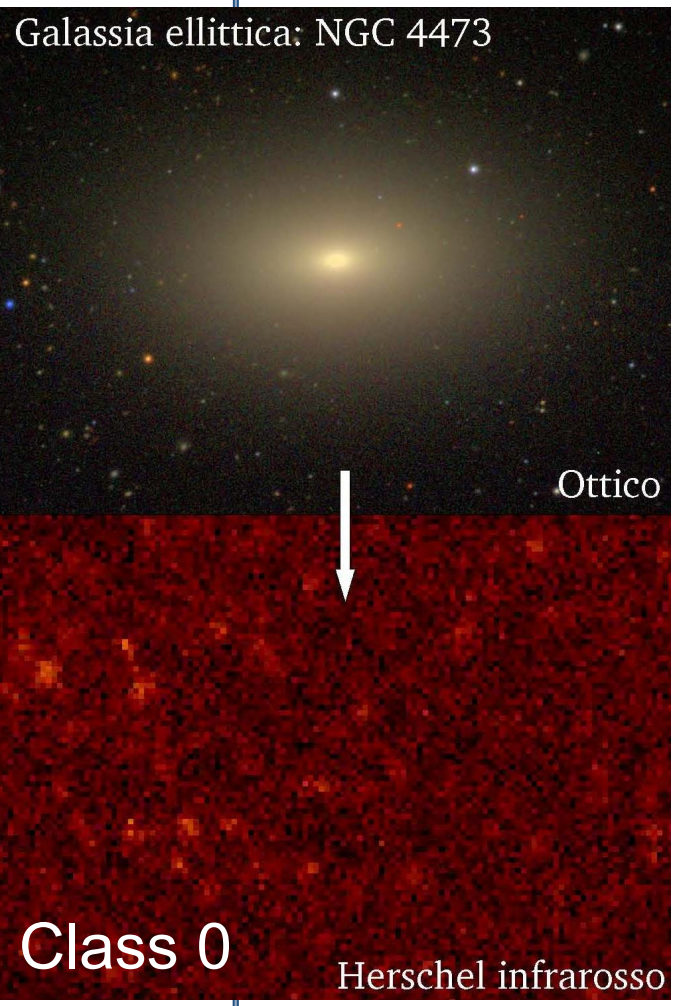

Clemens et al. 2010