Starburst - AGN connection.

Giovanni La Mura

Department of Astronomy
University of Padova

S. Ciroi
V. Cracco
F. Di Mille
P. Rafanelli
L. Vaona

- Nuclear (or circumnuclear) gas is often ionized at some level in most nearby galaxies (in particular, disk galaxies).

- There are two fundamental types of nuclear activity:

  (1) **nuclear starburst activity**: nuclear gas is photoionized by massive OB stars

  (2) **nonthermal nuclear activity**: nuclear gas is photoionized by the nonthermal continuum emission of the central active galactic nucleus (AGN) (e.g., Rees 1984).

- According to the recent extensive spectroscopic studies of nuclear regions of nearby galaxies it has been found that:

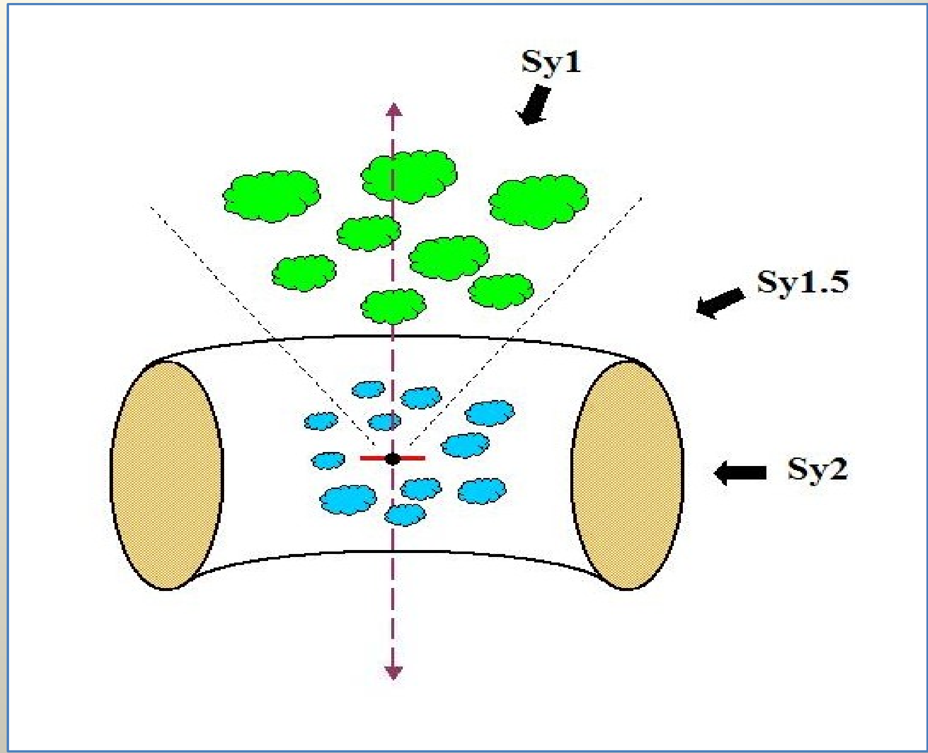
  ≈ 10% of galactic nuclei experience the nuclear starburst activity (SBN) ,

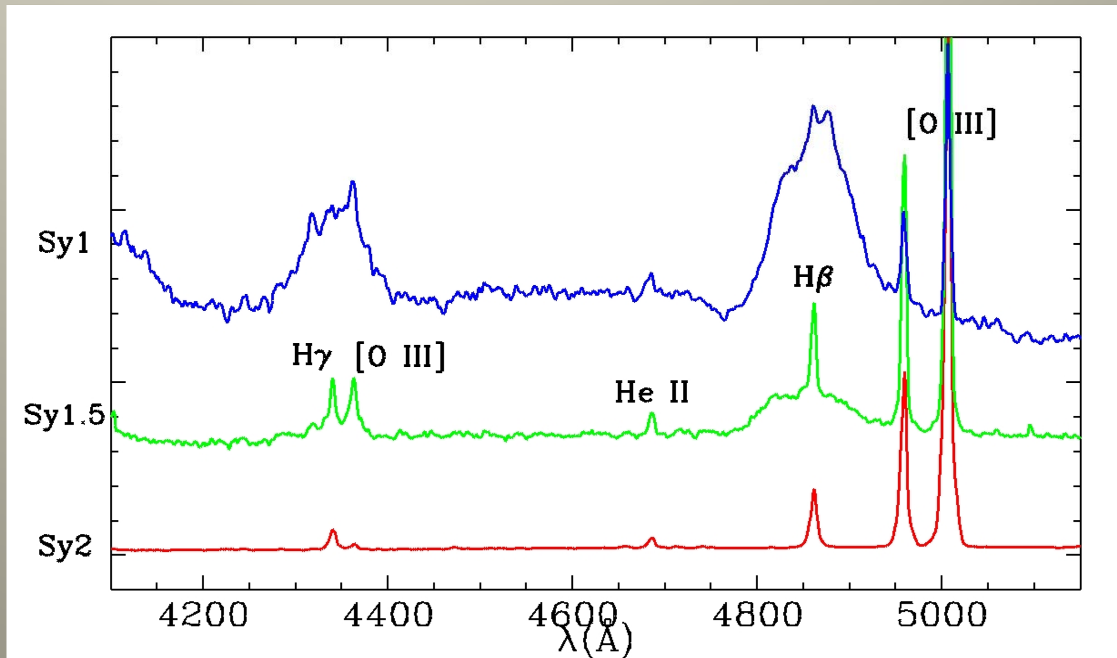
  ≈ 10% of galactic nuclei experience the nonthermal activity (AGN)

  ≈ 80% of galactic nuclei called nearly normal galactic nuclei (NGNs) show little evidence for significantly high level of such activities

  (Taniguchi et al., 2003)

Unified Model





What do active nuclei hide ?

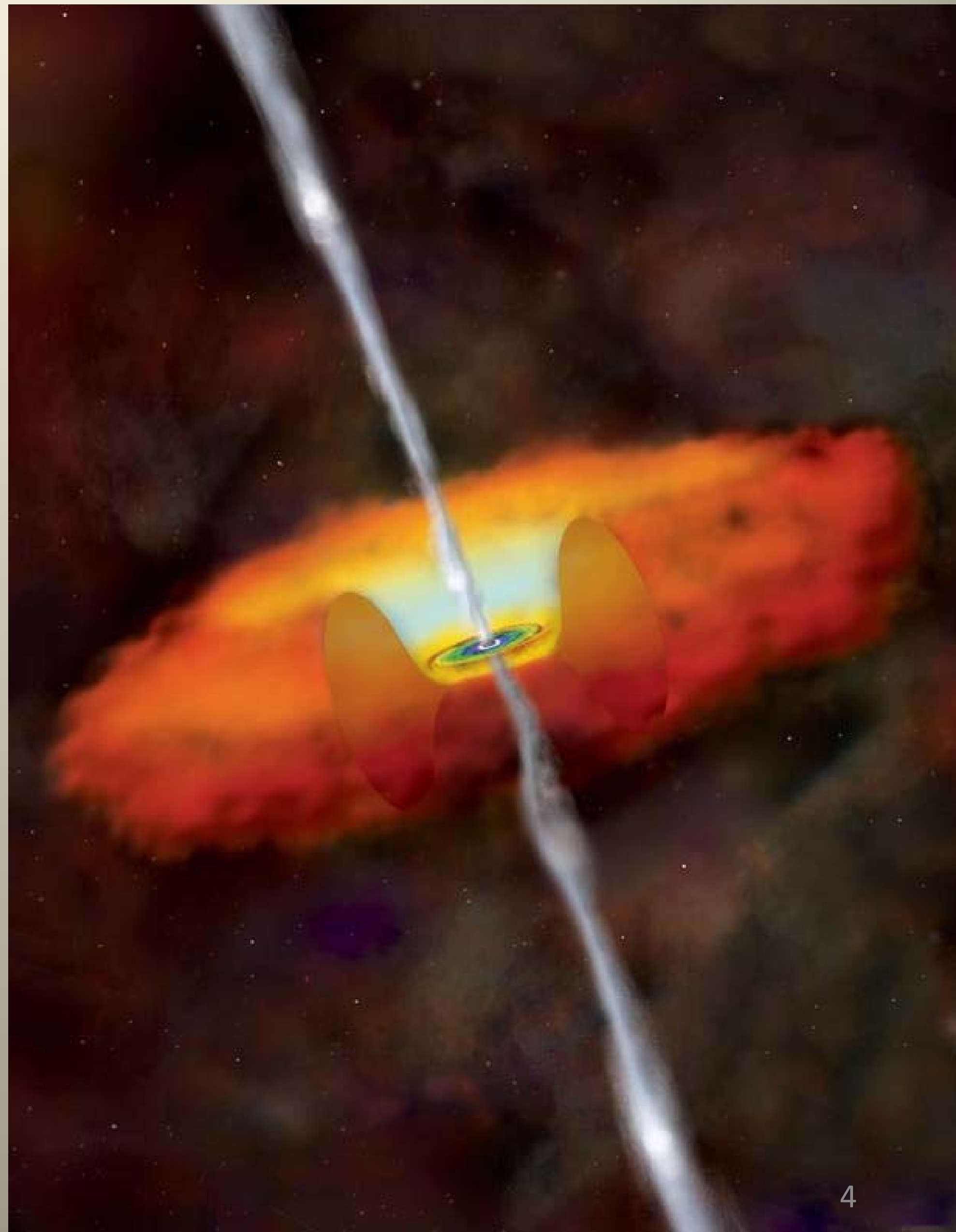
SuperMassive Black-Hole

$M_{SMBH} \sim 10^7 – 10^9\ M_\odot$

Accretion Rate of matter:

$0.2 - 2.0\ \ M_\odot\ yr^{-1}$

$10^{45} - 10^{46}\ erg\ s^{-1}$



- According to the recent extensive spectroscopic studies of nuclear regions of nearby galaxies it has been found that:

  ≈ 10% of galactic nuclei experience nuclear young (i.e., age less than a few 100 Myr) star forming activity (SFN) ,

  ≈ 10% of galactic nuclei experience nonthermal activity (AGN)

  ≈ 80% of galactic nuclei called nearly normal galactic nuclei (NGNs) show little evidence for significantly high level of such activities

  Taniguchi et al. (2003)

- A large number of studies have addressed the issue of star formation around AGNs. Those that have probed closest to the nucleus, typically on scales of a few hundred parsecs, have tended to focus on Seyferts, notably Seyfert 2 galaxies, since these are the closest examples.

  (Sarzi et al. 2007; Asari et al. 2007; Gonzalez Delgado & Cid Fernandes 2005; Cid Fernandes et al. 2004; Gonzalez Delgado et al. 2001; Gu et al. 2001; Joguet et al. 2001;Storchi-Bergmann et al. 2001; Ivanov et al. 2000).

- The overall conclusion of these studies is that in 30% - 50% of the cases the AGN is associated with young star formation (i.e., age less than a few 100 Myr).

- Here a question arises as:

  Why do some galactic nuclei experience nuclear starformation ?

  Why do some galactic nuclei have an AGN ?

  Why do the majority of nearby galaxies show little evidence for such activities in their nuclear regions ?”

- These fundamental questions can be replaced by a fascinating question:

  “Are there any evolutionary connections among the three types of galactic nuclei ?”

- If this is the case, we have further important questions:

  How are they connected ?

  What are important physical processes in such connections ?”

Indeed, many astronomers have been enslaved by the so-called

Starburst-AGN connection.

Proposed Starburst-AGN connections in Literature

(Taniguchi et al., 2003)

Although many ideas on the starburst-AGN connections have been proposed up to now, they may be broadly classified as follows.

1. **From starburst to AGN through the formation of a supermassive black hole:** This idea suggests that a supermassive black hole (SMBH), which is believed as the key ingredient of the central engine of AGNs, is made through successive mergers among starburst remnants (e.g., Weedman 1983; Norman & Scoville 1988; Taniguchi, Ikeuchi, & Shioya 1999; Ebisuzaki et al. 2001; see also Taniguchi et al. 2002b; Mouri & Taniguchi 2002b).

2. **From starburst to AGN due to the starburst-driven gas fueling onto a super- massive black hole:** This idea suggests that the gas fueling can be supplied either from gaseous envelope of supergiant stars near the supermassive black hole (Scoville & Norman 1988), from supernova ejecta (Taniguchi 1992), or from the gas associated with the nucleus of a merging partner (Taniguchi 1999; see also Taniguchi & Wada 1996).

1. **From starburst to AGN-like phenomena:** This idea is completely different from the above two ideas because the photoionization of nuclear gas is attributed to some descendants of massive stars; e.g., hot Wolf-Rayet stars (Warmers: Terlevich & Melnick 1985), supernovae in dense gas media (Terlevich et al. 1992), shock heating by superwinds (Heckman 1980; Taniguchi 1987; Taniguchi et al. 1999), or hot planetary nebula nuclei (Taniguchi, Shioya, & Murayama 2000a; see also Shioya et al. 2002).

4. **From ULIRGs and/or LIRGs through S2s to S1s**: In this idea, type 2 Seyferts (S2s) are considered as a possible missing link between ULIRGand/or LIRGs (=luminous infrared galaxies) and type 1 Seyferts (S1s) (Heckman et al. 1989; Mouri & Taniguchi 1992, 2002a). The reason for this is that S2s tend to have circumnuclear starburst regions more often than S1s and their starburst ages appears older than those of typical nu- clear starbursts (e.g., Cid Fernandes et al. 2001; Storchi-Bergman et al. 2001; Mouri & Taniguchi 2002a and references therein).

Although all the above ideas may not always work in actual galaxies, it seems better to keep in mind the following points:

- Massive stars formed in a nuclear starburst evolve through hot phases (i.e., Wolf-Rayet stars, plan- etary nebula nuclei, and so on) to supernova explosions inevitably. Therefore, we have to take account of all the evolutionary phases when we discuss the evolution of starburst nuclei.
- Compact remnants (i.e., stellar-sized black holes and neutron stars) are also inevitably remained in the nuclear starburst region. Therefore, we have to think about the dynamical evolution of such remnants under a realistic gravitational potential together with dynamical interactions with existing stars in the concerned region.

These two points make possible to discuss the starburst-AGN connection!!!

- Recently **Davies et. al. (2007)** obtained near-infrared spectra of nine nearby AGNs using Adaptive Optics to achieve high spatial resolution (in several cases better than 10 pc).

  For seven of these, integral field spectroscopy with SINFONI allowed:

  1. to reconstruct the full 2D distribution and kinematics of the stars and gas
  2. to derive STARS evolutionary synthesis models and hence characterize the star formation timescales and ages of the starbursts close around AGNs.

- Their main conclusions can be summarized as follows:

  1. The stellar light profiles show a bright nuclear component with a half-width at half-maximum < 50 pc.
  2. There are two cases that show kinematical evidence for a distinct stellar component, indicating that the nuclear stellar populations most probably exist in thick nuclear disks.
  3. There is abundant evidence for recent star formation in the last 10 - 300 Myr. But the **starbursts are no longer active**, implying that the star formation timescale is short, of order a few 10 Myr.
  4. There appears to be a delay of 50 - 100 Myr (and in some cases perhaps more) between the onset of star formation and the onset of AGN activity.
     - This can be interpreted as an indicator that the starburst has a significant impact on fueling the central black hole:

       outflows from stars might be responsible:

       - While supernovae and winds from OB stars eject a large mass of gas, the high velocity of this gas means that its accretion efficiency is extremely low.
       - Winds from AGB stars ultimately dominate the total mass ejected in a starburst, and the very slow velocities of these winds mean that they can be accreted onto the black hole very efficiently.

Keeping in mind these last results from literature we have analyzed the spectra of a sample of nearby ($z < 0.1$)

Normal galaxies

Emission line galaxies

extracted from the Sloan Digital Sky Survey

Selection of the emission line galaxies

A sample of 119226 emission line galaxies has been extracted from SDSS–DR6 spectroscopic survey (fiber size 3 arcsec) imposing to their spectra to match the following conditions:

1) Presence of the emission lines:
   [OIII]λ5007,
   [OII]λλ3728-3729 ,
   [OI]λ6300.

2) S/N > 3 of the [OI]λ6300 line.

Different families of emission line galaxies have been selected using:

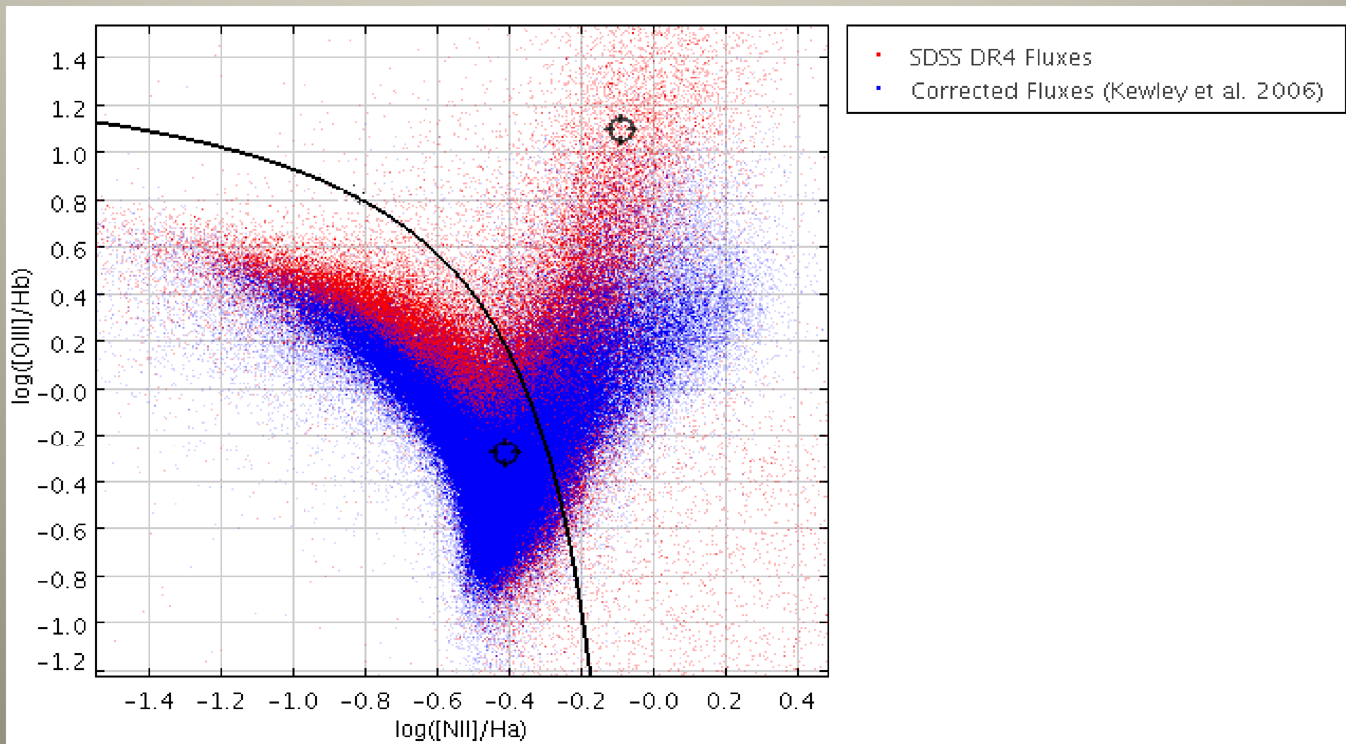
- the classical Veilleux, Osterbrock (VO) diagnostic diagrams.

In the VO diagrams we have used the parametrization of the borderlines between AGNs and star-forming galaxies (SFs) introduced by Kewley et al., 2006.

Effects of the subtraction of the galactic component

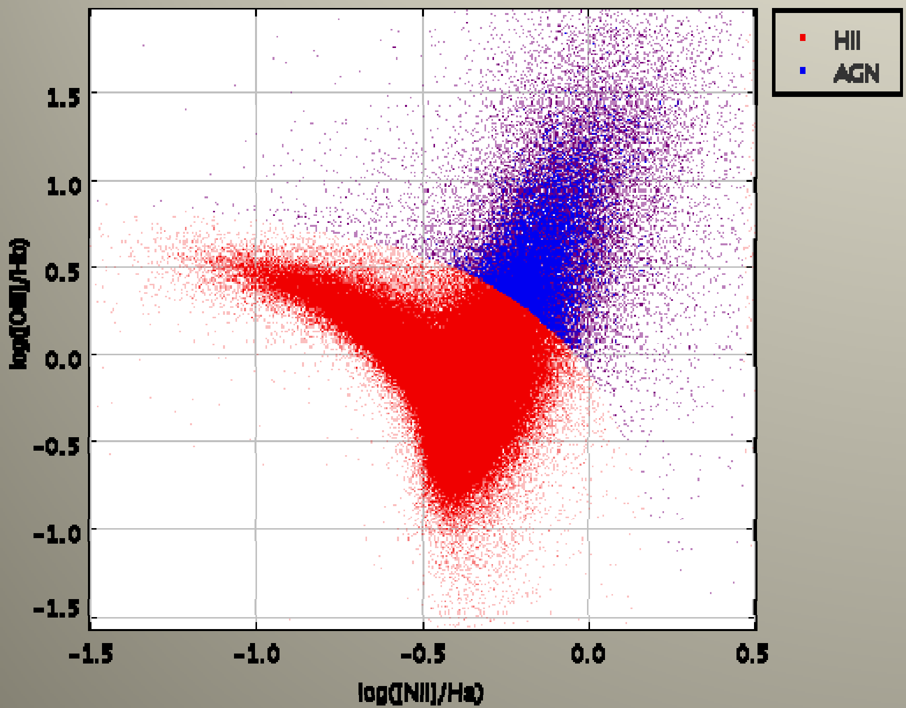
The diagnostic line ratios, like [NII]6548-83/Hα - [OIII]5007/Hβ etc., have been derived measuring the intensity of the emission lines after subtraction of the stellar component from the spectra of the selected galaxies. This procedure allows to avoid the influence of the underlying absorption conponent in the determination of the intensity of the recombination lines. The effects of such subtraction are shown in the following figure, obtained analyzing the data published by Kewley et al. (2006).

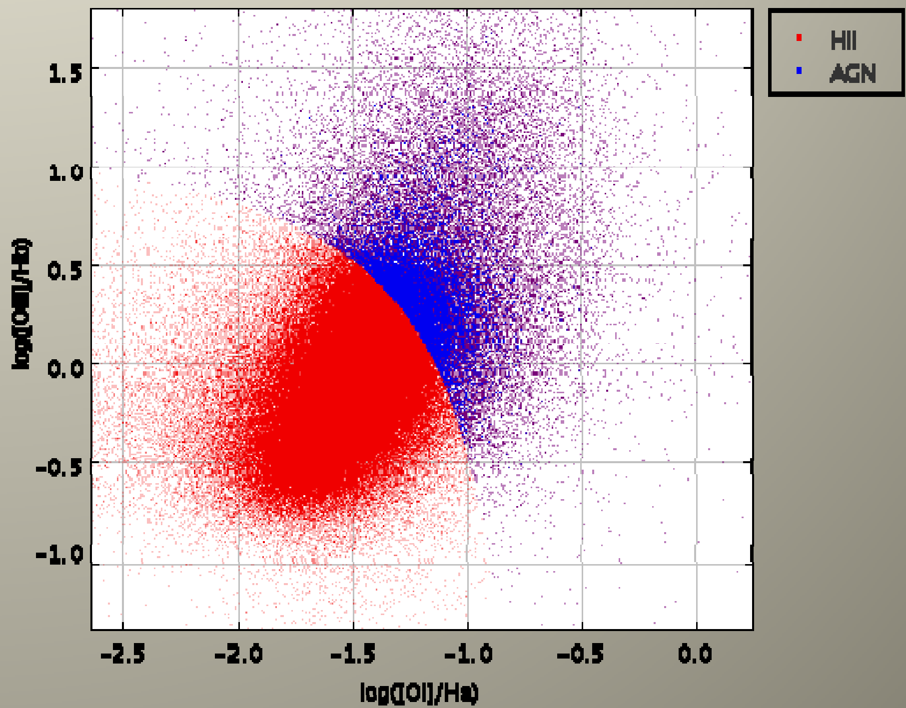
As an example, it is shown that the point representing the line ratios of an object moves from top to bottom and from right to left after subtraction of the galactic stellar component.



The absence of any subtraction of the stellar continuum tends to move in the VO diagrams some line ratios from the SF region to the AGN region.

A pre-classification of the whole sample would then isolate most of the SF galaxies, but not all.



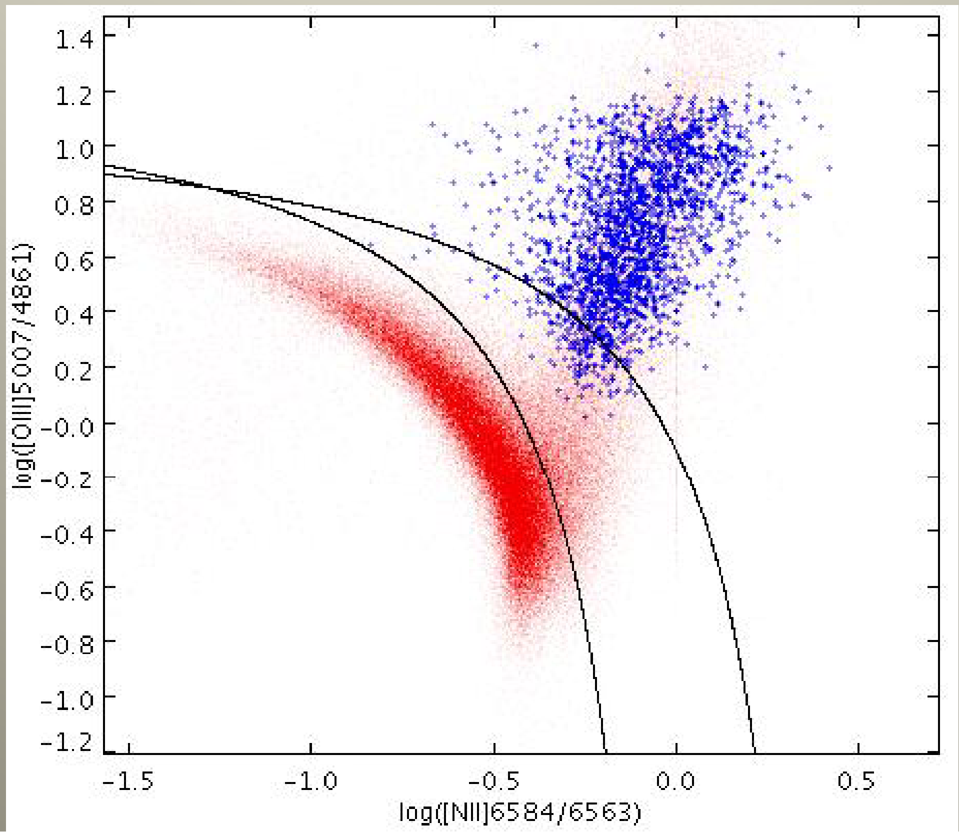


SEYFERT-2

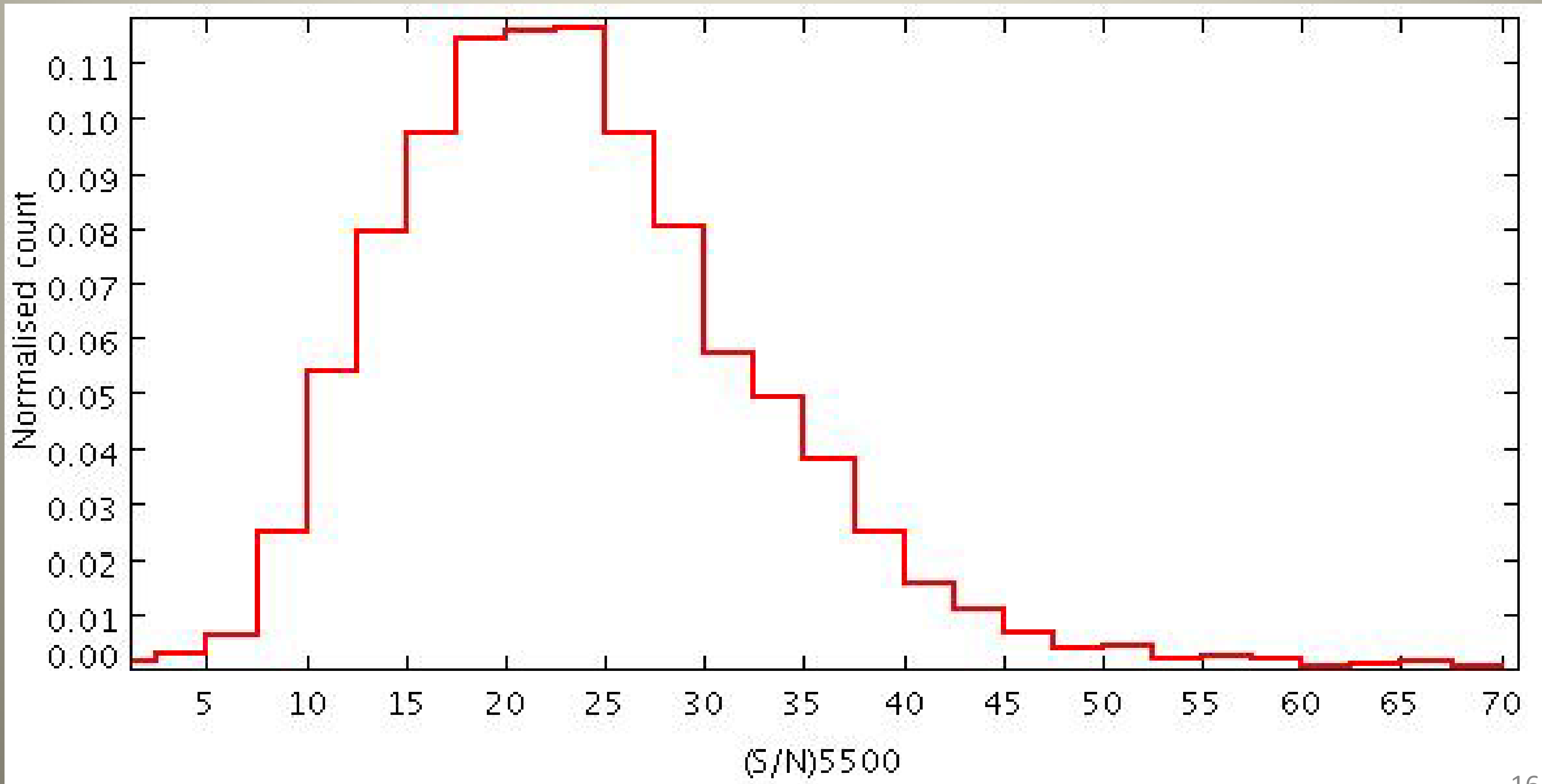
1) In the range 0.04 < z < 0.08 (2.4-4.8 kpc within 3 arcsec aperture) we find 3064 AGNs and 44606 SF.

2) The AGN have been corrected for the underlying continuum using STARLIGHT (Cid Fernandes et al. 2005) and we have measured the fluxes of all lines with S/N > 5.

3) With multiple Gaussian fits we have isolated the sources having only narrow line profiles and classified as Sey2 in the VO diagnostic diagrams. We obtained in this way our final sample of 1996 Seyfert 2 galaxies.



Distribution of the S/N ratio of the continua of S2 galaxies at $\lambda = 5500$ Å.



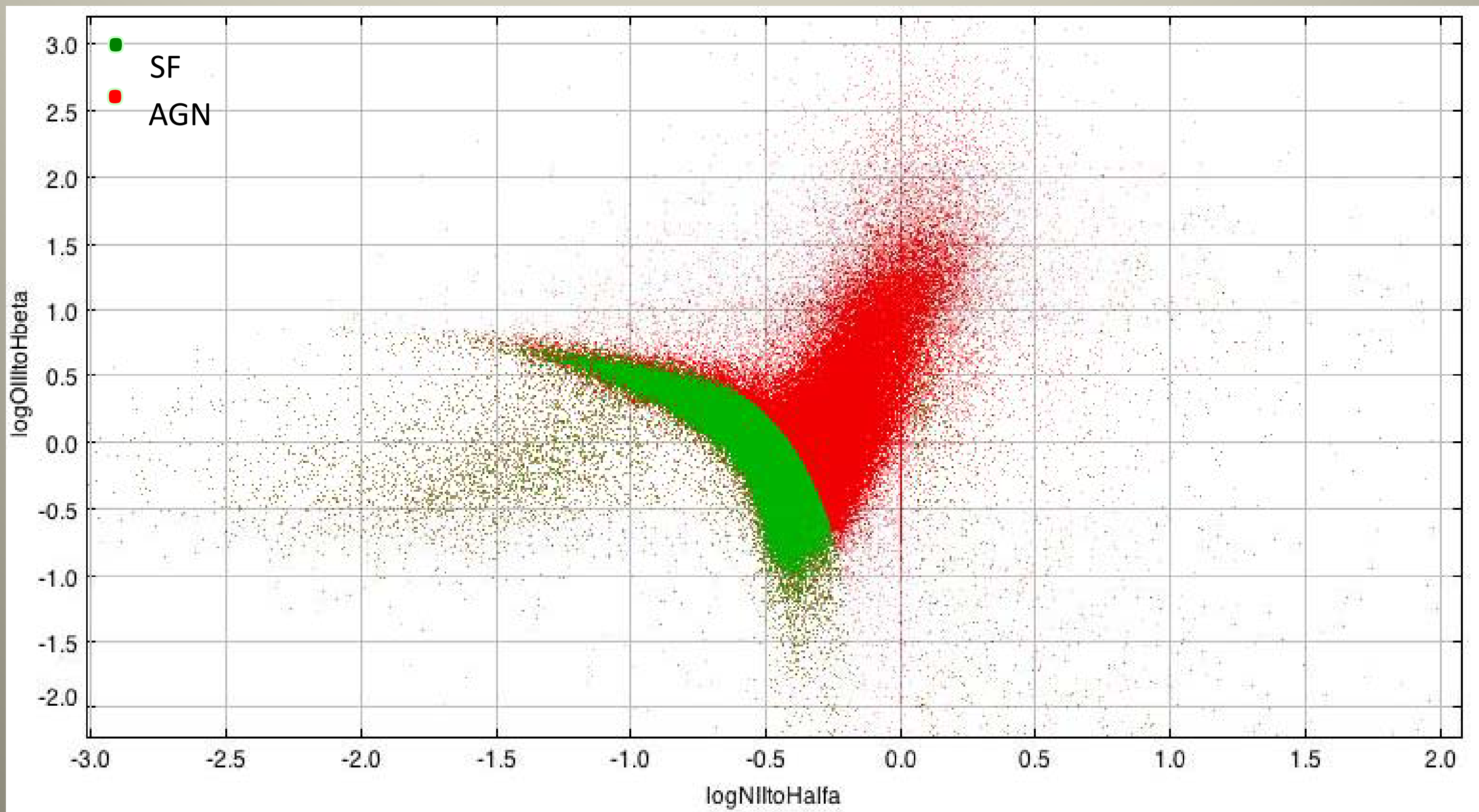
Star forming galaxies

1302 SF galaxies (S/N > 10 on the continuum at $\lambda = 5500$ Å) have been selected from the previous sample using the VO diagrams and imposing the following conditions:

$$\log([OIII]/H\beta) < 0.61/[\log([NII]/H\alpha)] + 1.3$$

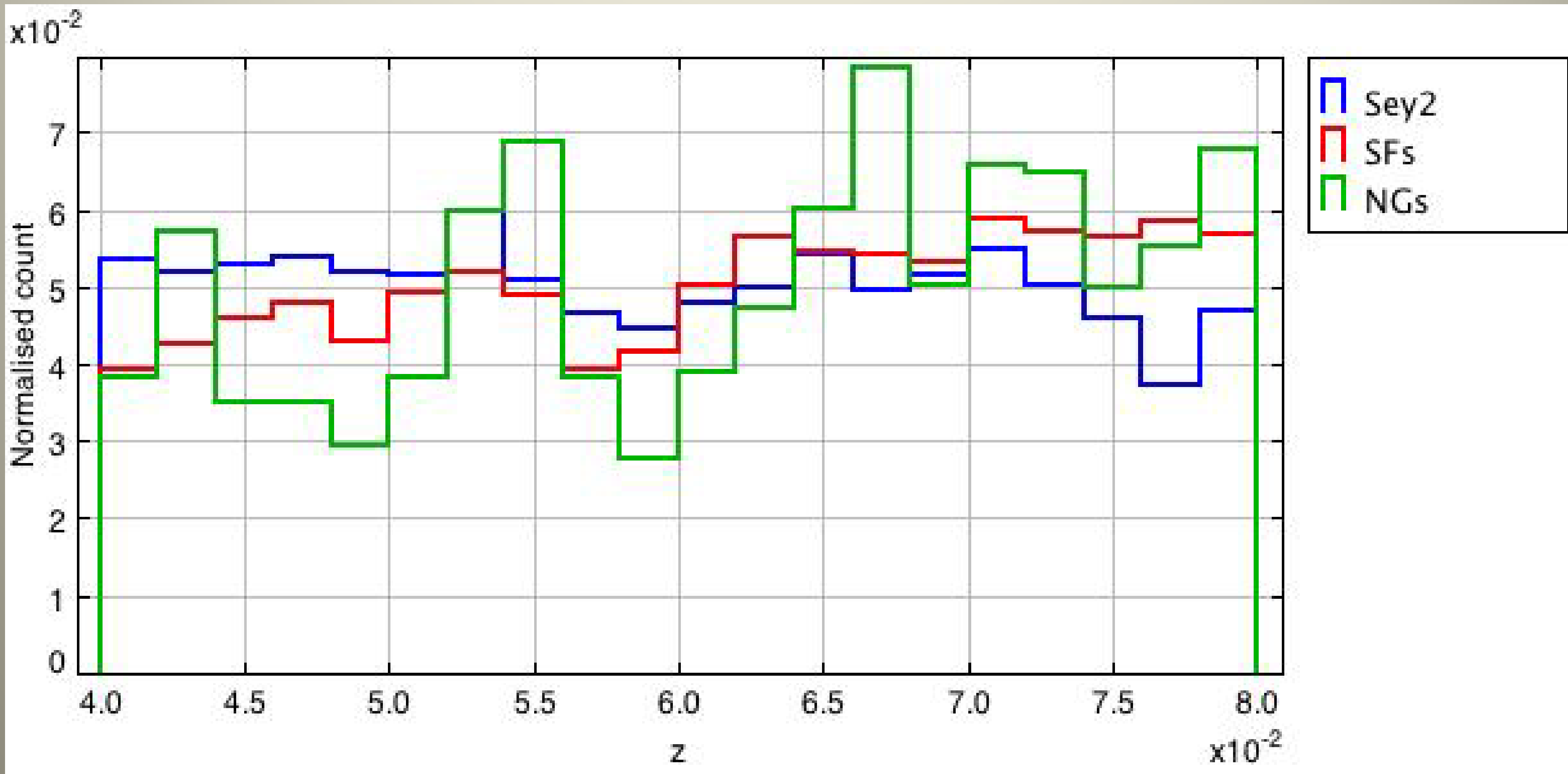
$$\log([OIII]/H\beta) < 0.72/[\log([SII]/H\alpha)] + 1.3$$

$$\log([OIII]/H\beta) < 0.73/[\log([OI]/H\alpha)] + 1.33$$



Normal galaxies

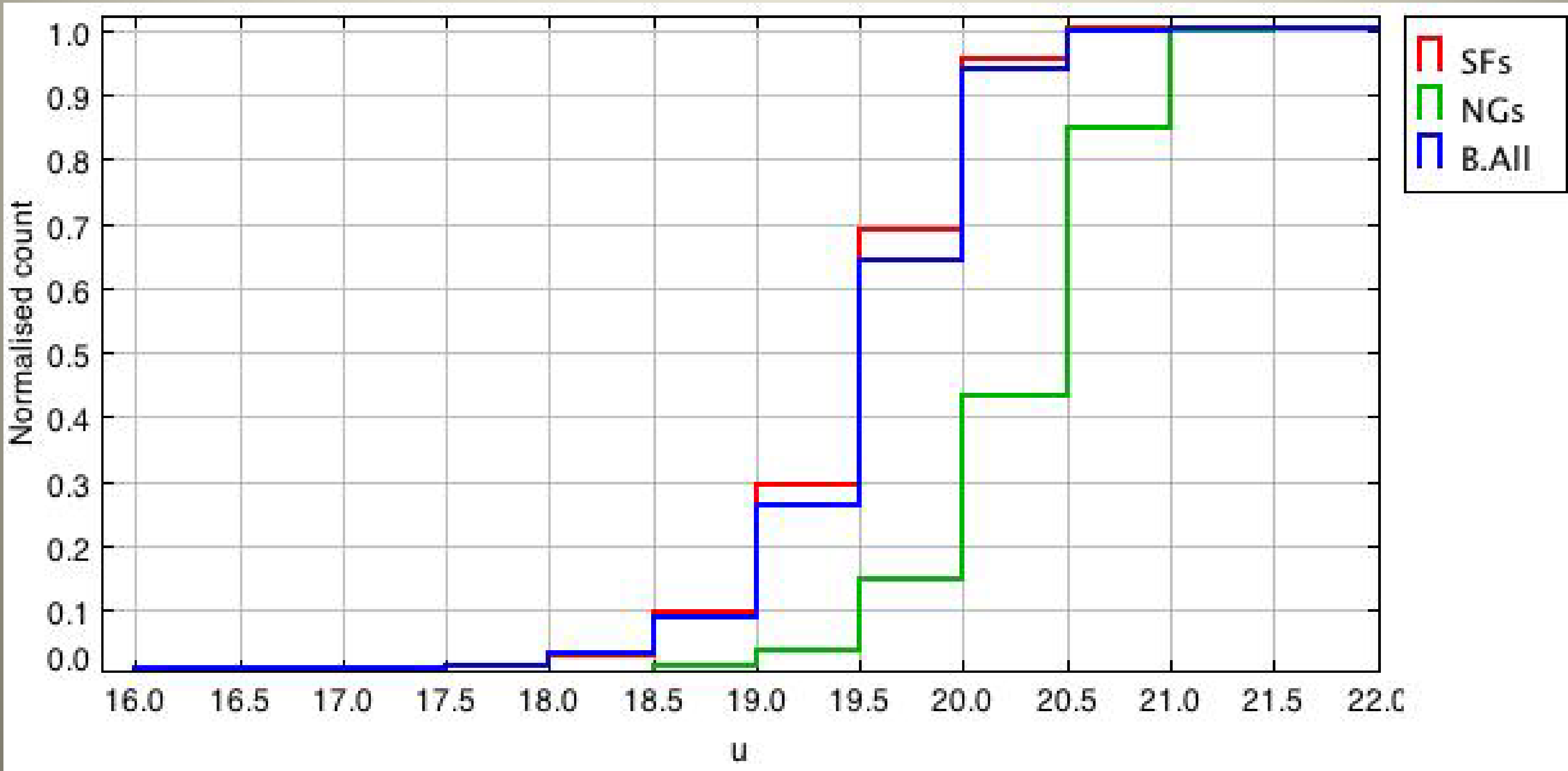
2000 normal galaxies (NGs) have been extracted from SDSS catalogue imposing 0.04 < z < 0.08 and S/N > 10 on the continua at λ = 5500 Å.



Redshift distribution in the [0.04, 0.08] interval for the three samples.

Cumulative magnitude distribution

Cumulative *u* magnitude (magnitude within 1 R_p) distribution for the three samples.

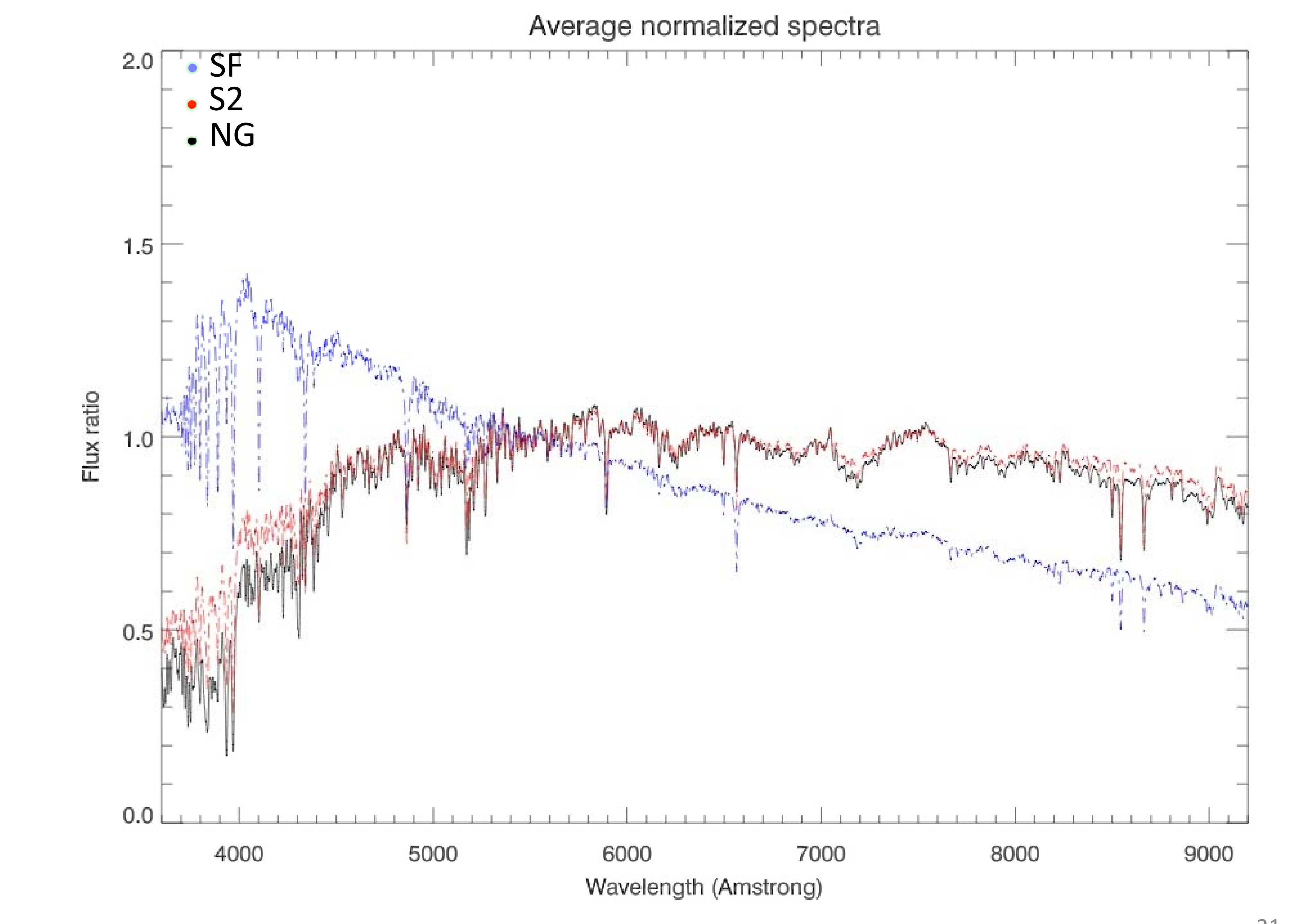


STELLAR CONTINUUM

The observed spectra of all galaxies have been analysed using the code STARLIGHT (Cid Fernandes et al. 2005) which fits the observed spectrum using a linear combination of simple theoretical stellar populations (coeval and chemically homogeneous) computed with evolutionary synthesis models at the same spectral resolution as that of the SDSS.

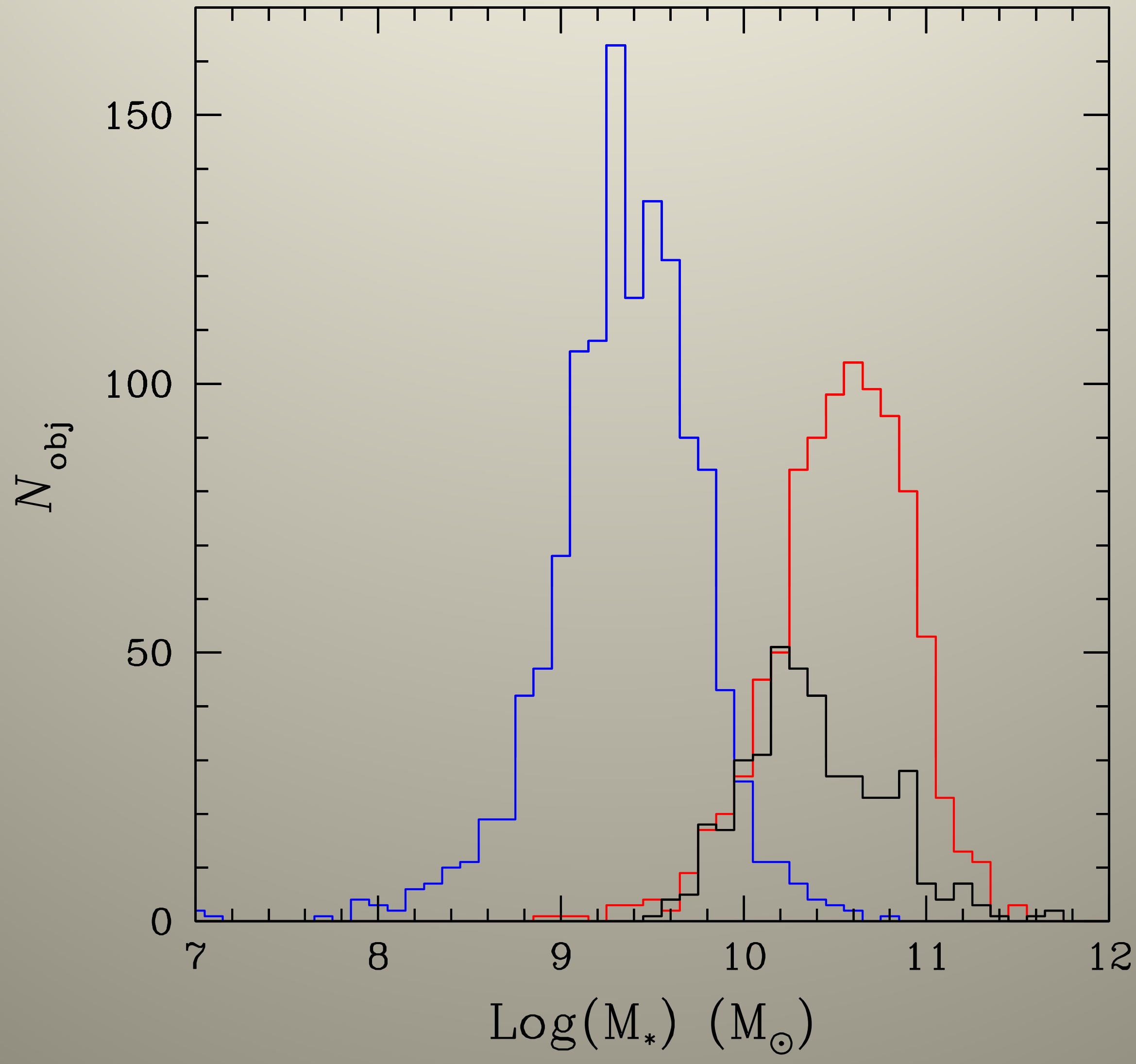
In this way we have reproduced the stellar spectrum of all our galaxies: S2, SF, NG.

Average spectra



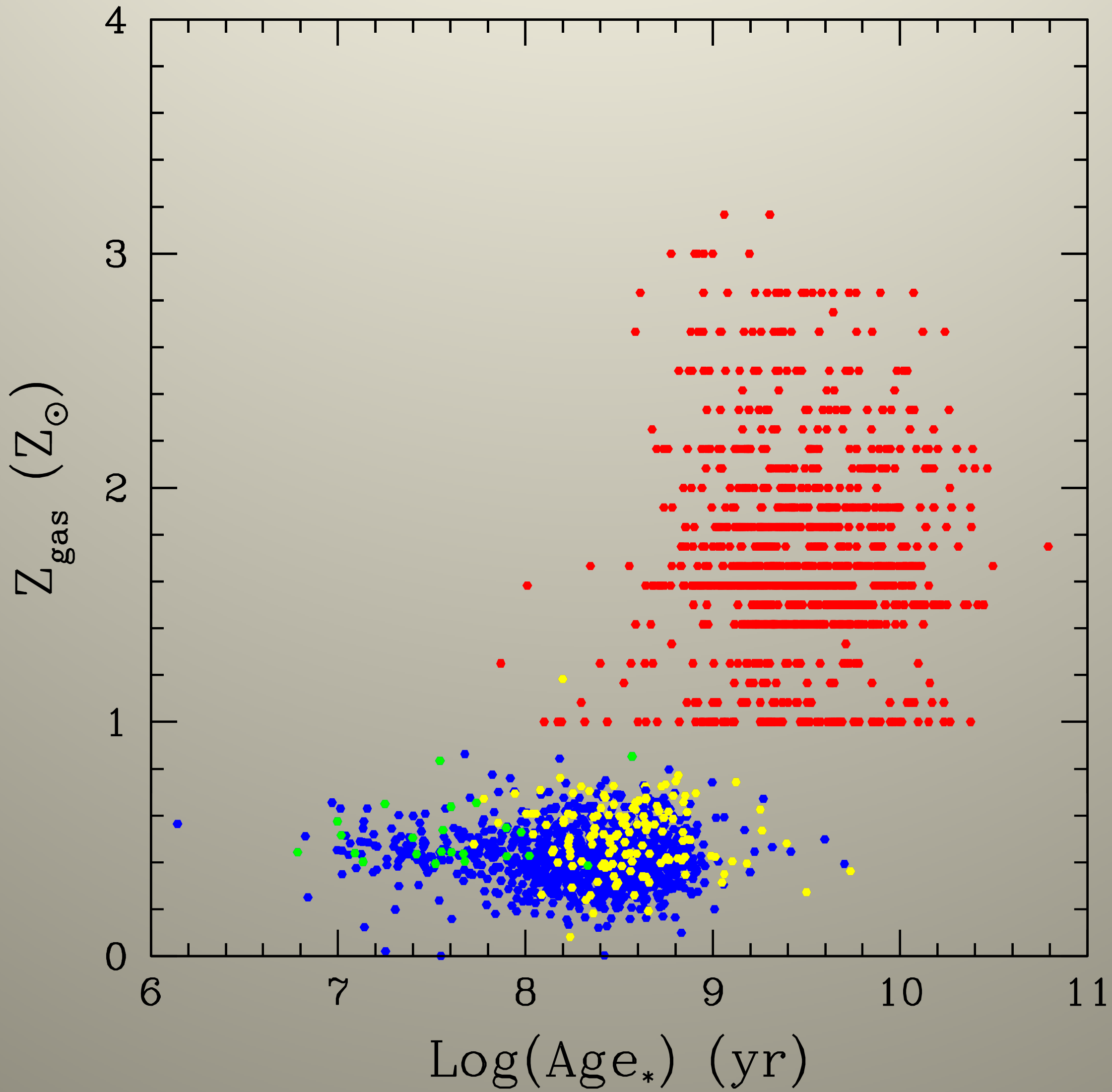
Distribution of the total stellar masses observed in galaxies hosting a SF (blue histogram) or S2 nucleus (red histogram), compared to the normal galaxies sub-sample (black histogram)

$$M_*(NG) \approx M_*(S2G) \geq M_*(SFG)$$



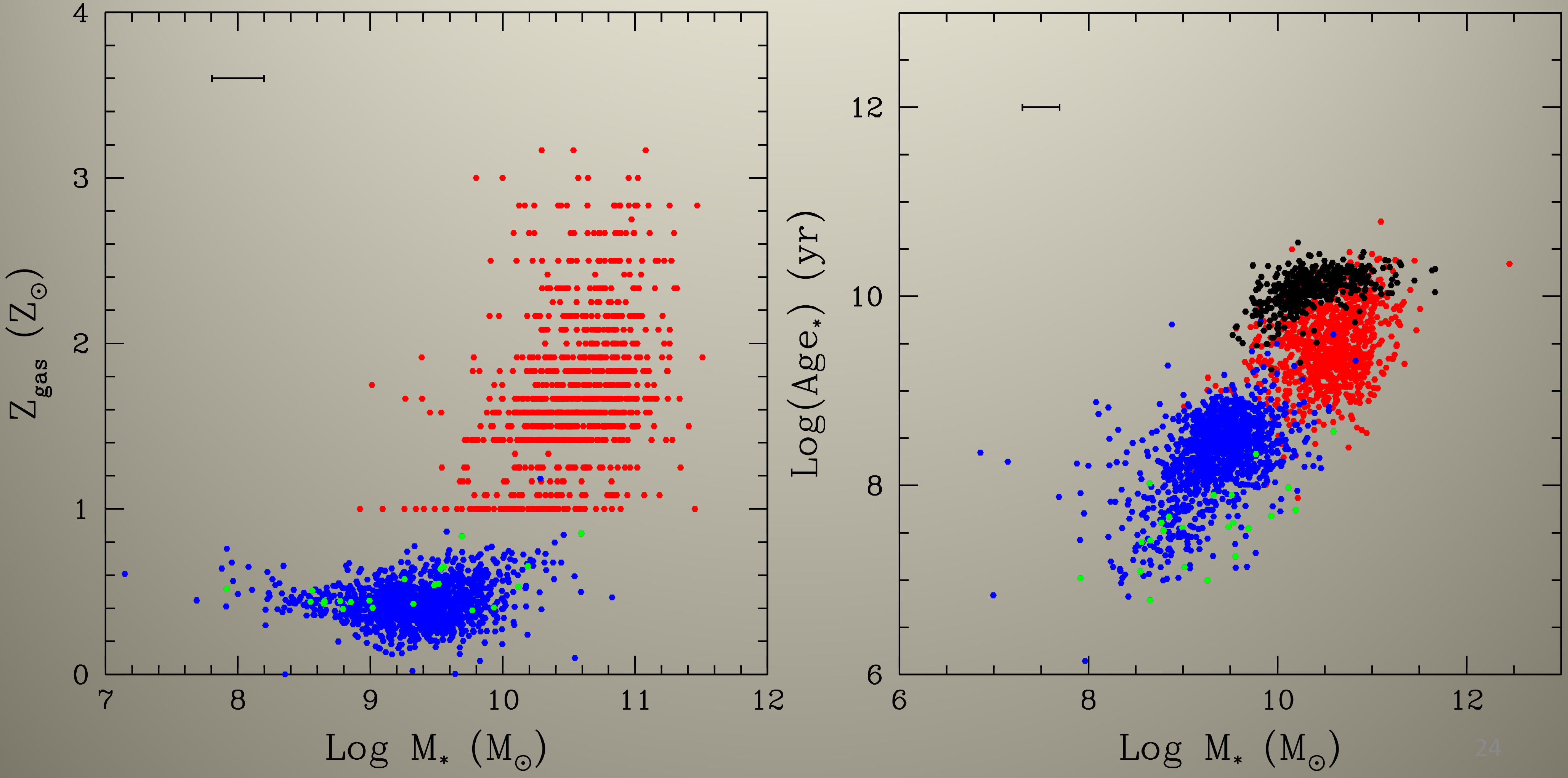
- The NLR gas in Seyfert 2 galaxies is an evolved medium, with a chemical composition clearly different from the gas phase of SFGs.

- The mean age of stellar population increases along the SBG – SFG – S2G sequence.



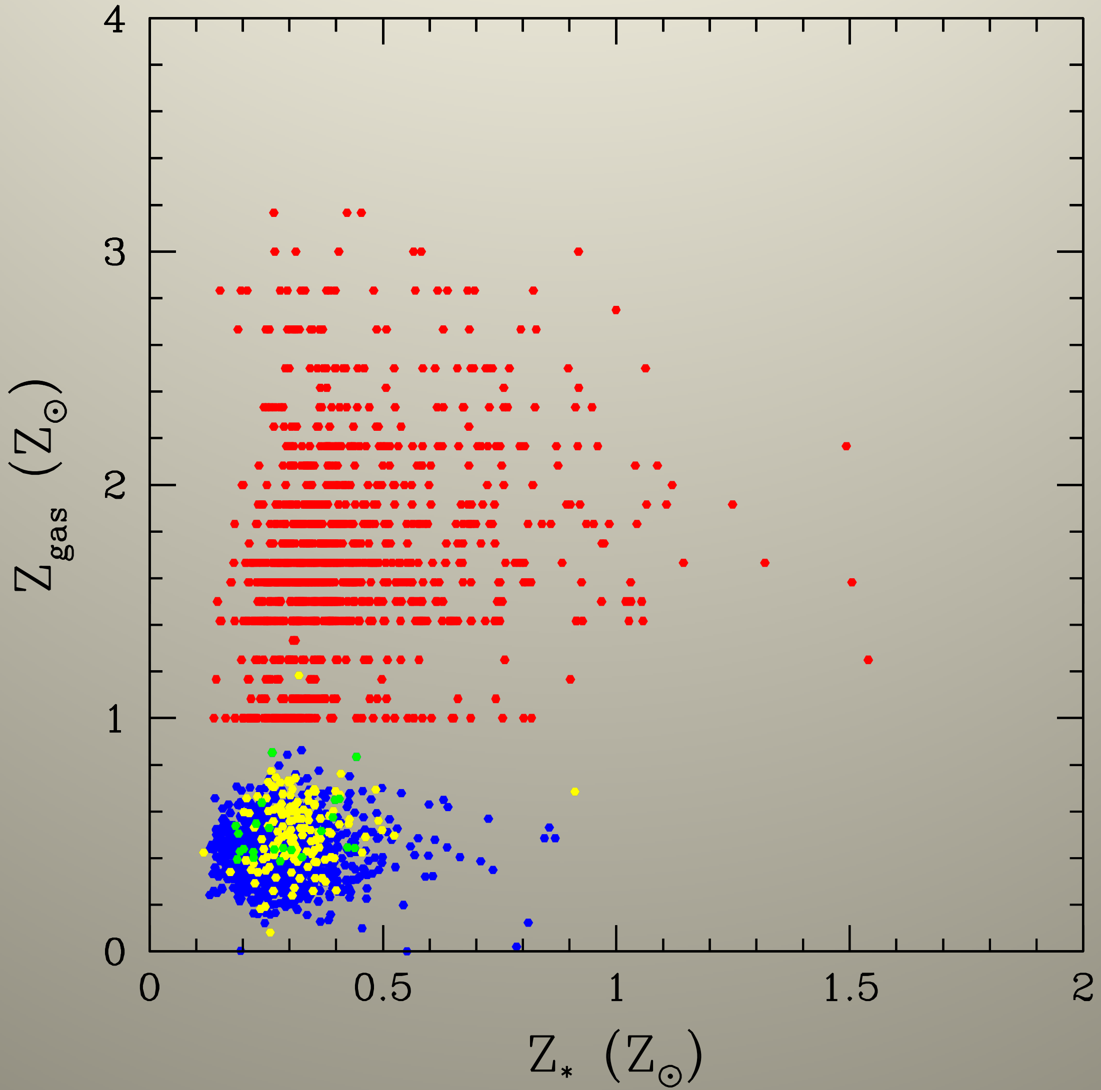
- The SBGs/SFGs have low masses and unevolved gas, while S2Gs show large masses and chemically enriched medium
- The mean age of stellar populations increases with mass from SFGs to S2Gs, while NGs have masses like S2gs and older stellar populations

The mass overlap suggests a sequence of star formation and nuclear activity, which stops in the domain of normal galaxies. There are no indications of logical connections, but, since $\tau_{SF} < \tau_{AGN}$, a sequence running from SFN to AGN in galaxies with similar masses is possible.



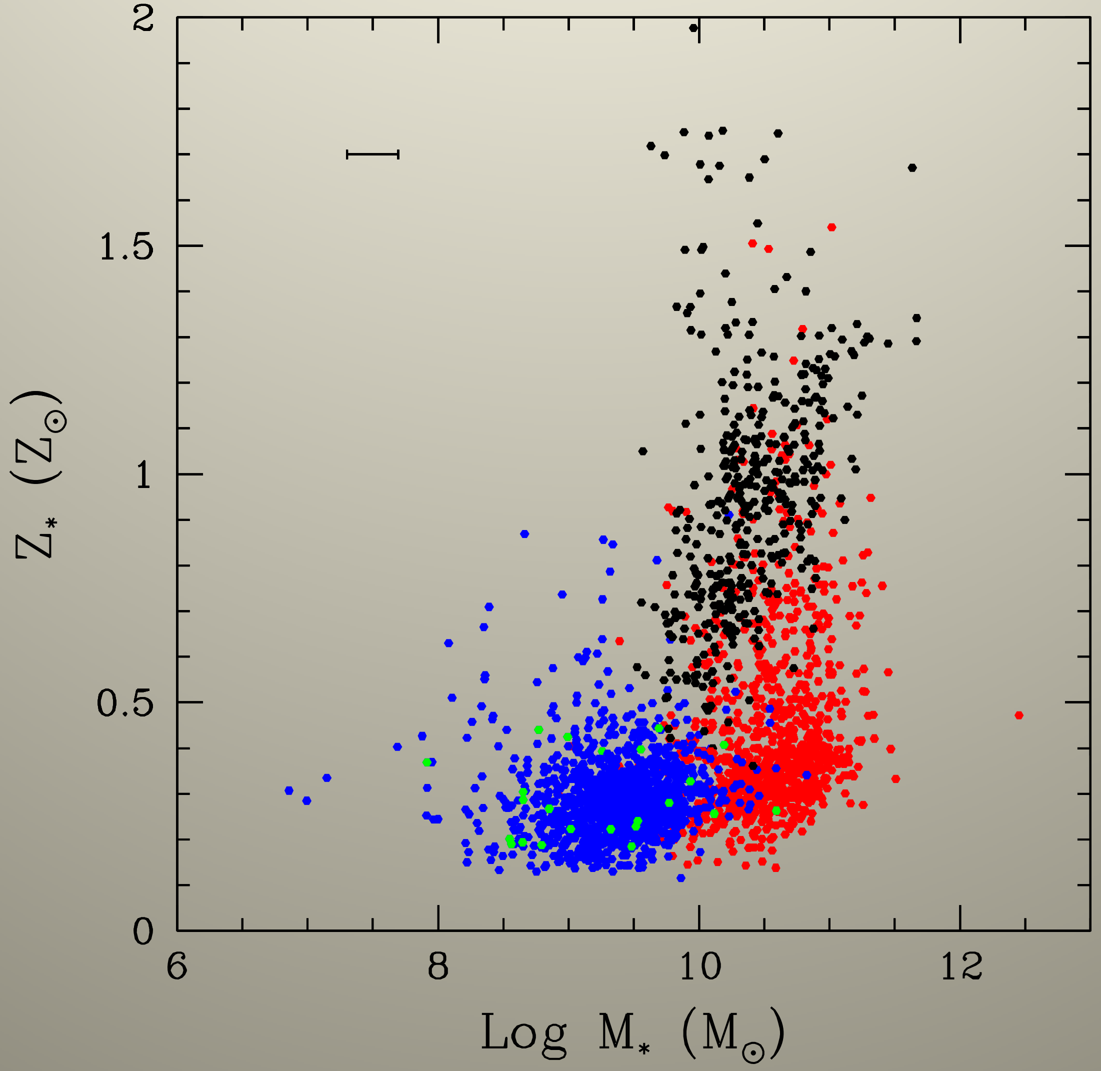
Despite the chemical composition difference in the gas, the stellar population metallicities are very similar:

Stellar populations in SFGs and S2Gs belong to the same generation, though O/B stars evolved off the MS in S2Gs. Ionization from the AGN might have become dominant a few 10^6 yr after star formation.



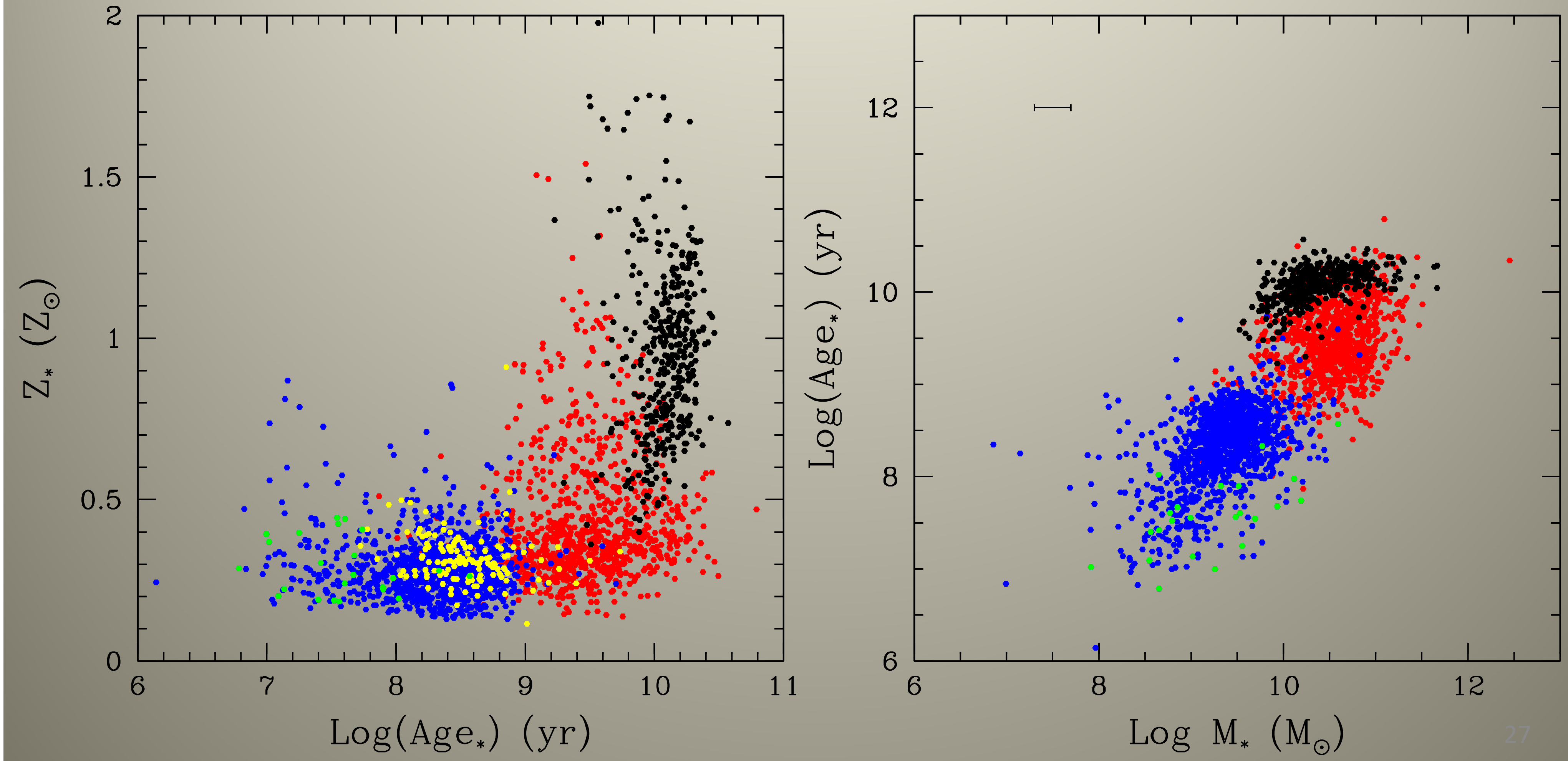
Most of the SFGs and S2Gs show similar stellar metallicity (with a weak dependence on mass). The two samples overlap over a mass range 9.8 < Log($M_*/M_\odot$) < 10.3, which is also typical of **ULIRGs**.

Star formation appears to be delayed in low mass galaxies, with respect to high mass ones. We observe that normal galaxies and some massive S2Gs show stellar populations originated from the evolved medium.



SFGs and S2Gs show comparable stellar metallicities, but the S2 sample has a high metallicity tail, connected to the domain of NGs.

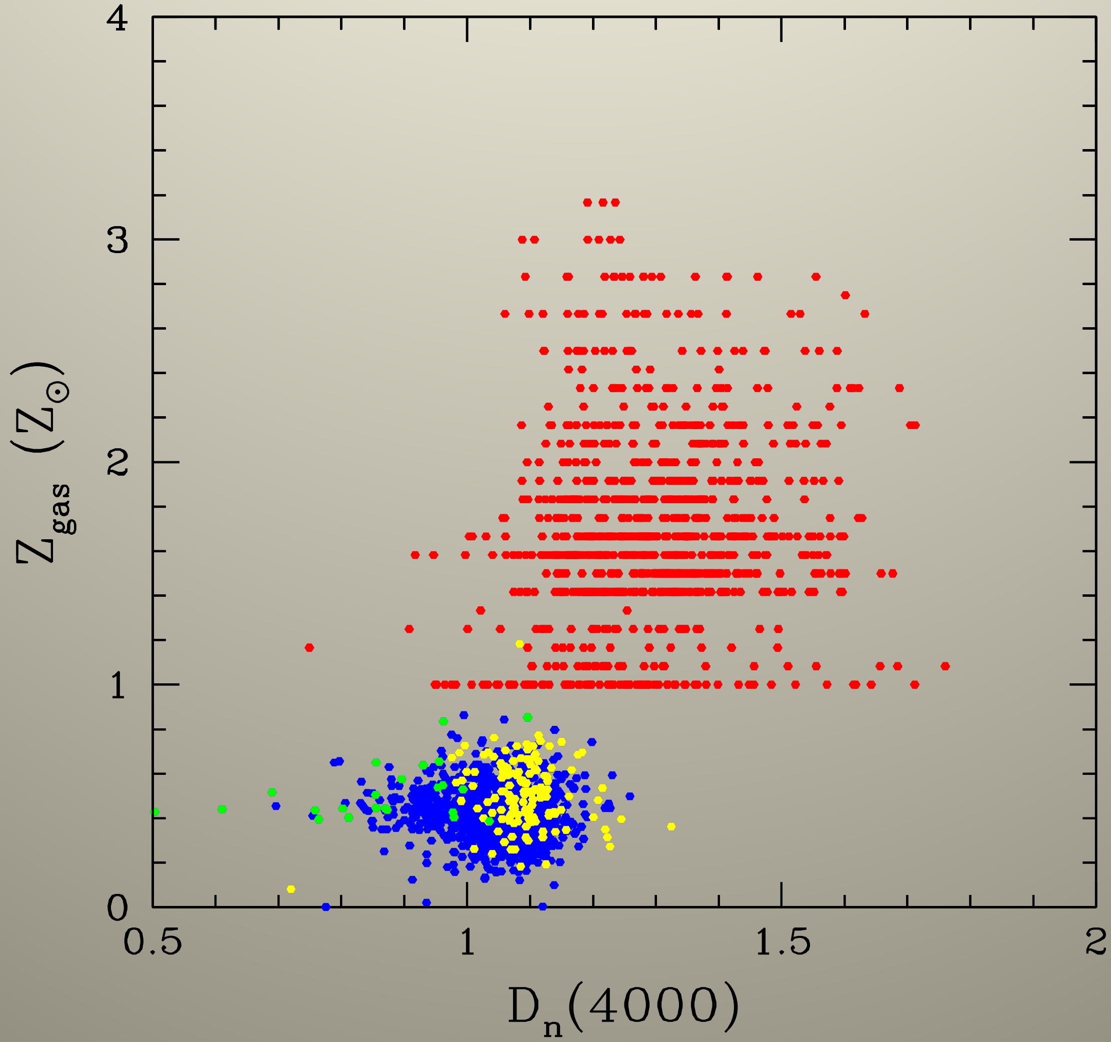
SFGs with masses in the overlapping range of the right diagram have been identified in the left plot (yellow points).



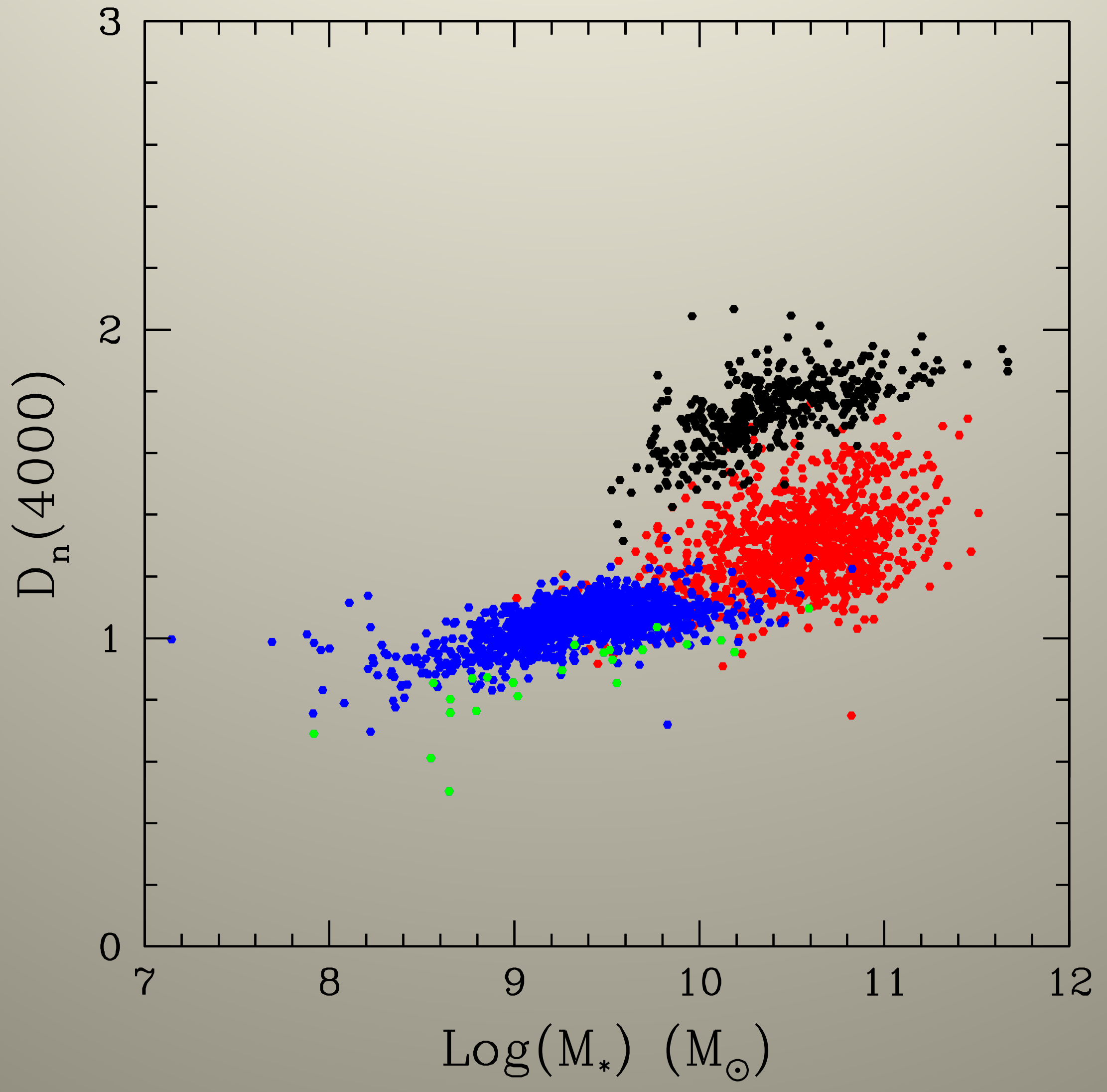
The $1.0 < D_n(4000) < 1.6$ distribution over different gas phase metallicities could be the result of:

1. subsequent episodes of star formation
2. an intense starburst event

The second hypothesis is preferred, otherwise we would expect a stellar population stratification, which is not observed.



The stellar populations are older and older going from SFGs through S2Gs and towards increasing masses.
At equal masses SBGs have systematically lower $D_n(4000)$ than SFGs, that may be explained as an excess of O/B stars.
Notice the distinction among S2Gs and NGs that was previously outlined on the average spectra.



Final Remarks

- In the range of total masses 9.8 < $\mathrm{Log}(M_*/M_\odot)$ < 10.3 galaxies hosting a Star Forming Nucleus and galaxies hosting an Active Galactic Nucleus are characterized by
  - **Circumnuclear** stellar populations approximately of the same age.
  - Similar abundance of heavy elements in the **circumnuclear** gaseous component.
- Stellar population ages of the **circumnuclear region** of galaxies in this range of total masses correspond to
  - the **oldest** in the SFG class
  - the **youngest** in the AGN class
- The metallicity of gas and stars in the **circumnuclear regions** of SFG of total mass

  9.8 < $\mathrm{Log}(M_*/M_\odot)$ < 10.3 are indistinguishable from those of the objects of lower mass of the same class, as confirmed from the plots Z_* - Z_{gas} Z_{gas} – M_*
- Stars in the **circumnuclear regions** of SFG of total mass 9.8 < $\mathrm{Log}(M_*/M_\odot)$ < 10.3 are more evolved than in the objects of lower mass as shown by the plots Z_{gas} - $D_n(4000)$ and M_* - Age

*Anyway as pointed out before the metallicity of the stars seems to be independent from the mass of the whole galaxy and from the age of the circumnuclear stellar population as it is the case for the gaseous component. This suggests that we are observing **different stages** of the evolution of the **same star formation process**.*

- Concluding the circumnuclear regions of SFG with mass 9.8 < $\mathrm{Log}(M_*/M_\odot)$ < 10.3, which clearly are in a more advanced evolutionary stage than lower mass SFG, seem to be the most probale candidates for being the closest precursors of an AGN, if there is any causal link between the two phenomena. This result fits very well with the conclusions of Davies et. al (2007), which demonstrate the evidence of a causal link and a well defined time evolution from nuclear star formation to nuclear activity.