AGN host galaxies stellar populations from SDSS data: Lick indices

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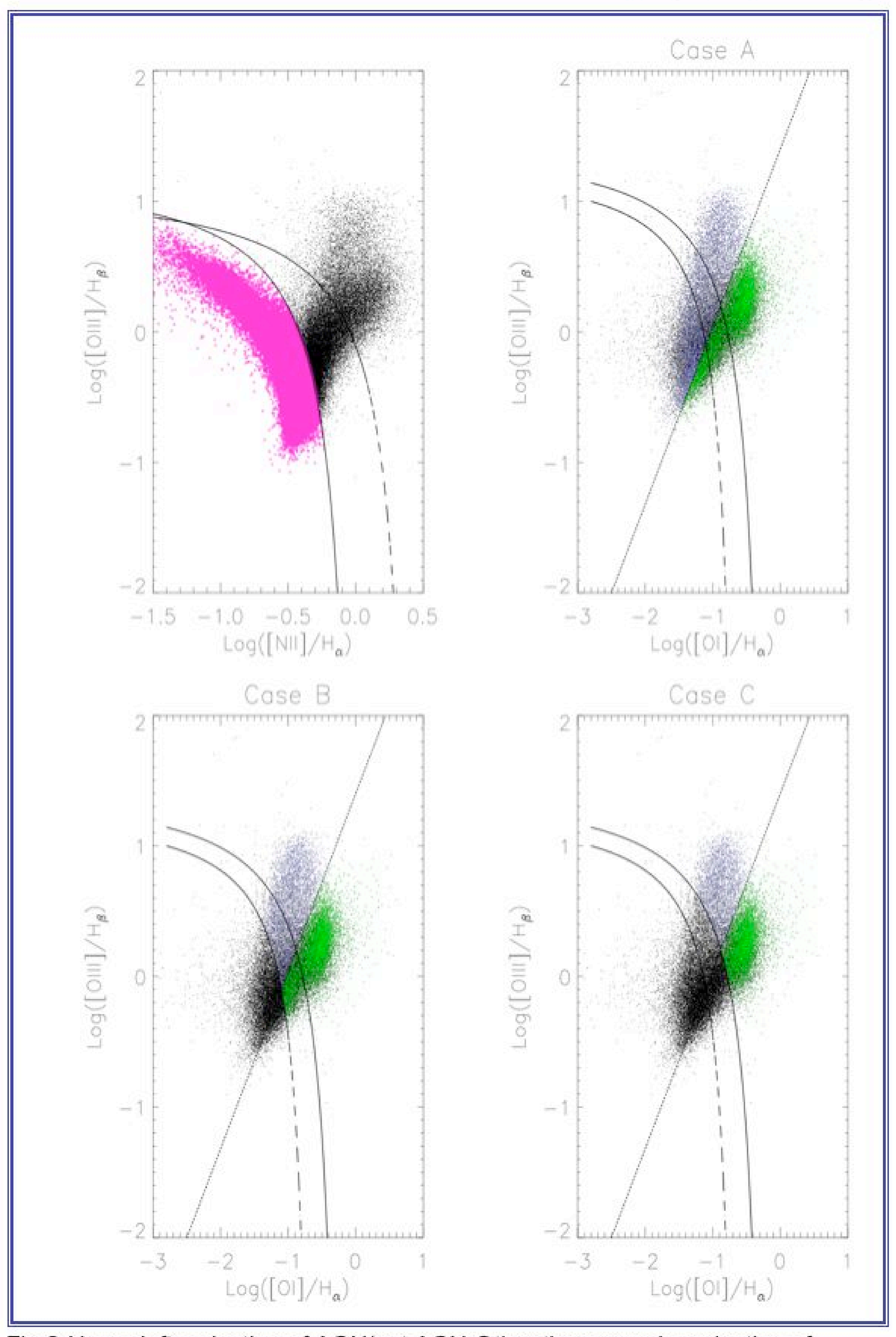


Fig.2 Upper left: selection of AGN/not AGN;Other three panels: selection of Seyfert2/LINERs: **Case A(ur)**- we simply take all active galaxies and use the Groves relation to distinguish between Seyfert 2 and LINERs. **Case B(ll)**: we exclude from our samples galaxies that in this diagram appear normally star--forming by imposing that they lie above the theoretical relation. **Case C(lr)**: finally we clean our sample by imposing an empirical cut.
Going from A to C we have then samples more and more cleaned by effects due to star formation.

The method:

In order to derive meaningful samples of galaxies we took advantage of the big sample offered by the SDSS, and analyze properties of paired objects.
In fact, as demonstrated by Kauffmann et al., 2003 (using the [OIII] luminosity as tracer of the AGN strength and the D4000 break as main age indicator) host galaxies of low luminosity AGN closely resemble early--type galaxies, while high luminosity AGN are hosted by late--type galaxies.

According to these findings we constructed control samples of normal galaxies that have the properties of early and late-type (here star-forming) galaxies, and constructed pairs of active and inactive galaxies by imposing that they have the same redshift ($\Delta z<0.01$), the same stellar mass ($\Delta\log(M/M_\odot)<0.1$) and the same velocity dispersion ($\Delta\sigma_v<15$ Km/s).
We then calculated the offset of each Lick index for each pair of galaxies. The observed index difference depends on errors in singular estimates and in particular can be seen as due to an intrinsic difference plus an observational error, which we took into account.

For each index we calculate then the median of the distribution and give an estimate of the corresponding error by using 200 bootstrap samples (Fig.3 shows the distributions for selected indices when comparing AGN hosts with inactive galaxies sharing the same characteristics in the 3 cases described above).

The first question we faced is whether or not galaxies hosting different types of AGN are similar.
We therefore construct matched pairs of Seyfert 2 and LINERs host galaxies: we end up with 3136 matched pairs in Case A, 1422 in Case B and 702 in Case C.
Another way of visualizing our results is to draw the resulting offset in each index significantly not null in the three cases (see Fig.4).
We conclude not only that galaxies hosting type 2 AGN are on average younger than their parent population hosting LINERs, but also that they are more metal--poor, still having the same enhancement degree ([Mgb/<Fe>]).
As we move along the division line, crossing the region where theoretical models tend to exclude starburst as major sources of the photoionization, every offset become smaller, but no one is changing dramatically (i. e. changing its sign). The selection procedure can introduce transition objects, but this does not change our conclusions. However results concerning purely active galaxies are certainly reliable only in Case C.

Samples selection:

On the basis of their emission lines AGN and star forming galaxies can be "easily" distinguished using the so--called BPT diagram, where the ratio of two pairs of relatively strong emission lines is plotted.
However when dealing with huge samples many galaxies lie in region of the diagram where it is not clear to what extent the star forming contribution is totally ruled out (see Kauffmann et al., 2003). Moreover this demarcation does not take into account any "substructure" in the AGN region, where Seyfert 1 live together with Seyfert 2, LINERs and transition objects.
We then classify our sub--samples according to the line--ratios pairs that show the clearest distinction between AGN and star--forming galaxies, and later on between Seyfert 2 galaxies and LINERs.

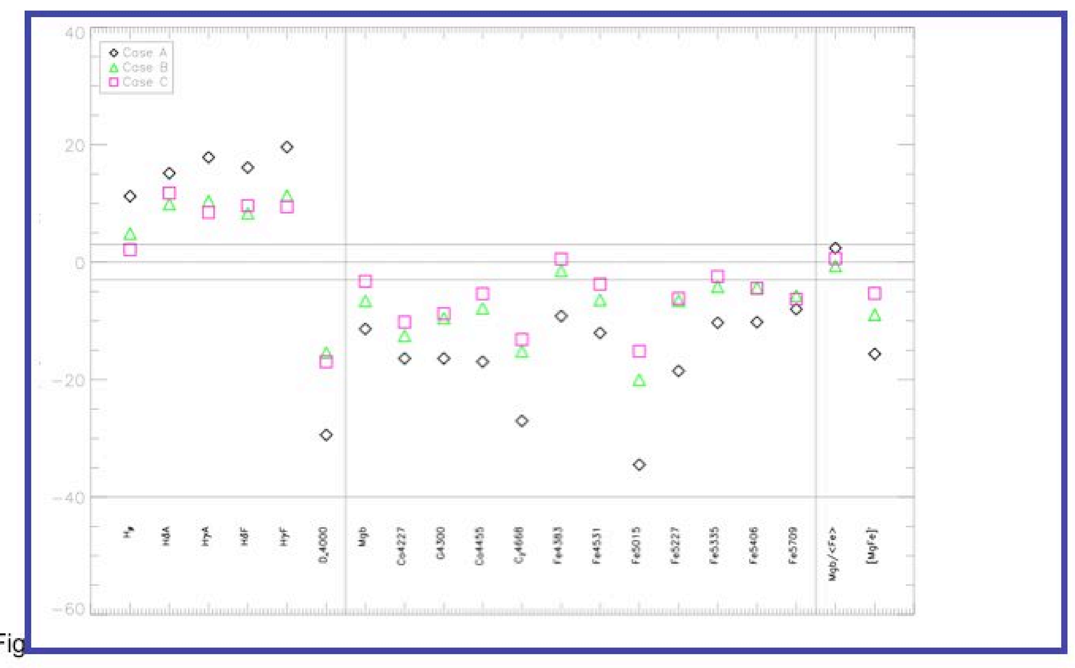
Figure on the lefts shows the first BPT diagram constructed with the chosen pairs of diagnostic lines ([NII]/Hα and [OIII]/Hβ, upper left) where we show only galaxies for which each emission line is measured with a S/N>3.
The black dashed line is the theoretical demarcation between objects that can be explained by photoionization due to young stars, and objects that require the presence of an active nucleus (Kewley et al., 2001).
The continuous one is instead the empirical relation found by Kauffmann et al., 2003 and includes in the "active" region of the diagram a larger number of composite objects.
In our sample we end up with 57176 star forming galaxies, lying under the Kauffmann et al. relation, and 30578 active galaxies.

Among them it is not clear from this diagram how to distinguish between Seyfert 2 galaxies and LINERs; in the other three panels of the figure we show indeed a second diagnostic diagram ([OIII]/Hβ against [OI]/Hα), as we decided to use this one to further select our subsamples.
Black dots in these diagrams are the same galaxies as in the upper left panel.
Colored in blue and green are instead active galaxies having also S/N>3 in the [OI].
The dashed line is the Kewley et al. theoretical demarcation between active and inactive galaxies, while the dotted line is an empirical relation (Groves, private communication) that allows to distinguish pure Seyfert 2 galaxies (in blue) and LINERs (in green).
Active galaxies selected using the first diagnostic diagram clearly dispose in a "prohibited" region in the second BPT diagram. We find in fact that they lie also under the theoretical line describing the limit of photoionization codes.
We therefore decided to construct three different subsamples of Seyfert 2 and LINERs using this second BPT plot (see caption figure 2).

As for the definition of the early--type galaxies we select objects having a ratio between the emission line flux and the relative error lower than 3.0 in each of the involved emission lines but Hα. Including the same criterium on this emission line would bias our sample toward a sample of early--type galaxies at high redshift.

We end up with a sample of 44004 early--type galaxies, 57176 star forming galaxies and 5125, 2872, 1884 Seyfert 2 galaxies and 6513, 5604, 4541 LINERs in Case A, Case B, Case C respectively.

Fig.4: offsets normalized according to their errors: black diamonds are calculated assuming samples as in Case A, green triangles as in Case B, pink squares as in Case C.



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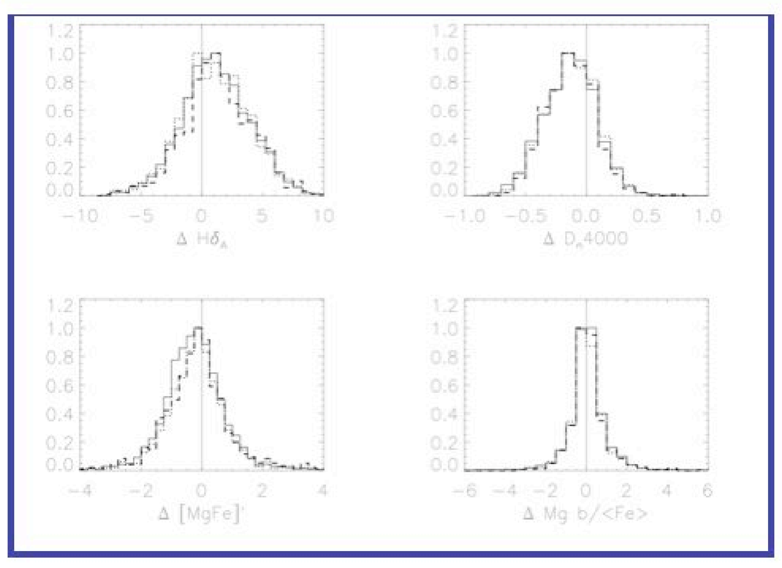


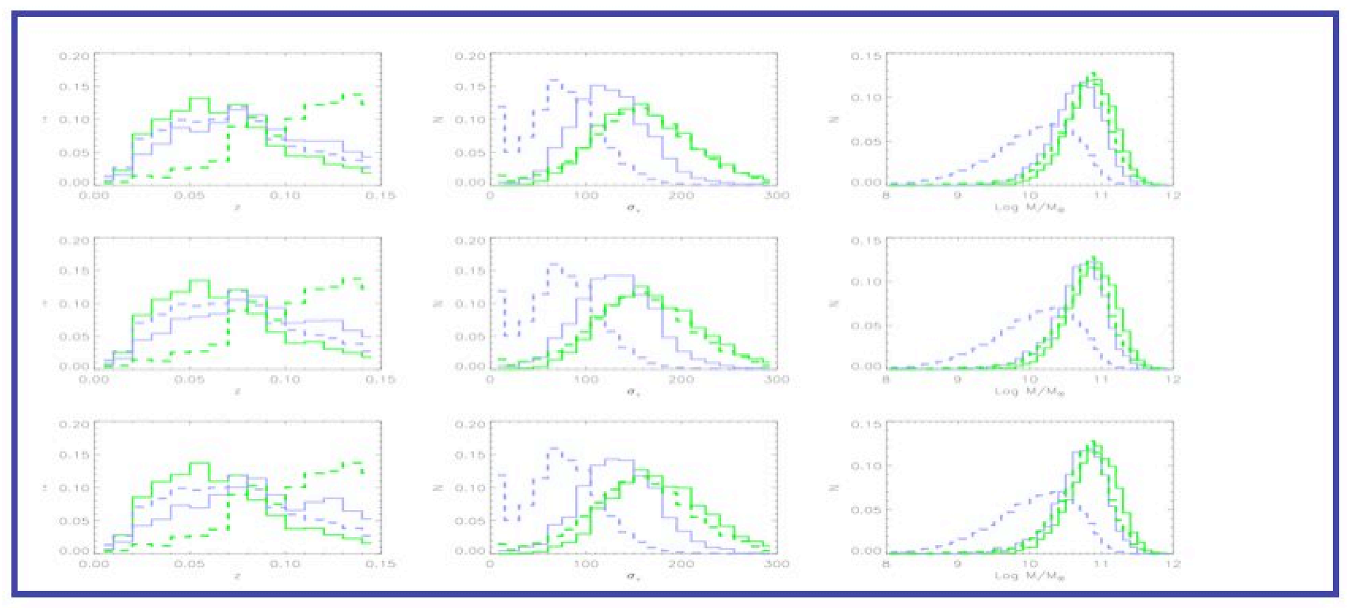
The dataset:

In this work we analyze subsamples of objects taken from the second data release of the SDSS, which contain spectra for 261054 galaxies with Petrosian magnitudes 14.5<r<17.77. The foreground galactic extinction has been taken into account using the reddening maps by Schlegel et al., 1998.

For these galaxies stellar masses and stellar surface densities have been calculated according to Kauffmann et al., 2003, while emission and absorption line measurements are calculated using the procedure described in Tremonti et al., 2004. We recall here that nebular emission lines are measured after subtracting the stellar continuum, which comes from the mix of stellar population best fitting the observed ones.
Absorption lines are measured instead on this stellar spectrum after the subtraction of all the emission lines.

We characterize the AGN host galaxy stellar population through the Lick indices (Worthey, 1994; Trager et al., 1998) including the high order Balmer lines (Worthey and Ottaviani, 1997) and the 4000 Å break as defined by Balogh et al., 1999. This latter has been widely used in the recent past (Kauffmann et al., 2003; Brinchmann et al., 2004; Gallazzi et al., 2005) to infer ages of stellar populations, since it is an excellent indicator of the present- to past-averaged star formation rates in galaxies.

Fig.1 Redshift (cut at 0.15), central velocity dispersion and mass distribution of our samples: in green are LINERs and early-type galaxies (continuous and dashed) and in blue Seyfert 2 and late type galaxies (continuous and dashed).
First row is for galaxies selected according to our more restricted sample (case A), second row for case B, third for Case C.



Caveat: Our findings might be strongly dependent on the underlying age-metallicity relation.
In order to check how much this relation influence our results we then performed the same analysis on pairs of galaxies having the same age.
By this we intend here simply galaxies that show the same width of an age indicator index, in this study H_β or $H_{\delta A}+H_{\gamma A}$.Both indicators have been used in the past to infer ages of stellar populations.
We first study pairs of Seyfert 2 - LINERs imposing them to have the same H_β. The number of pairs obviously decreases, and we end up with 544, 157, 58 pairs in Case A, B and C respectively.
When fixing the other age indicator we are left with 399, 105 and 43 pairs.
In both cases it can be seen that indices offsets are much lower than in Fig.4, meaning this that part (half) of the calculated differences between our two samples are due to age.
Offsets calculated imposing an age constraint lead then to slightly different conclusions: if we trust H_β we find Seyfert 2 galaxies still younger than LINERs and revealing traces of a recent starburst which can be seen from the positive offsets in the high order Balmer lines. The D_n4000 shows a negative offset than can be interpreted as an evidence of a recent--to--past star formation rate higher in Seyfert 2 than in LINERs. Light element to iron ratio, as well as the global metallicity traced by [MgFe]' are consistent with a zero offset.
If we trust instead the other age indicator the age of our two samples of active galaxies is the same, and Seyfert 2 are slightly more metal rich and more enhanced than LINERs.
The fix-- H_β sequence from A to B to C do not converge, while the fix-- $H_{\delta A}+H_{\gamma A}$ does: this implies that the sequence A--B--C is due to age, but also to some extent to the metallicity of the host galaxy.
Finally, in both cases Seyfert 2 have Fe5015 and C_24668 smaller than LINERs.

Fig.5: Lick indices offsets in active galaxies fixing an age indicator (H_β in the upper panel, $H_{\delta A}+H_{\gamma A}$ in the lower panel)

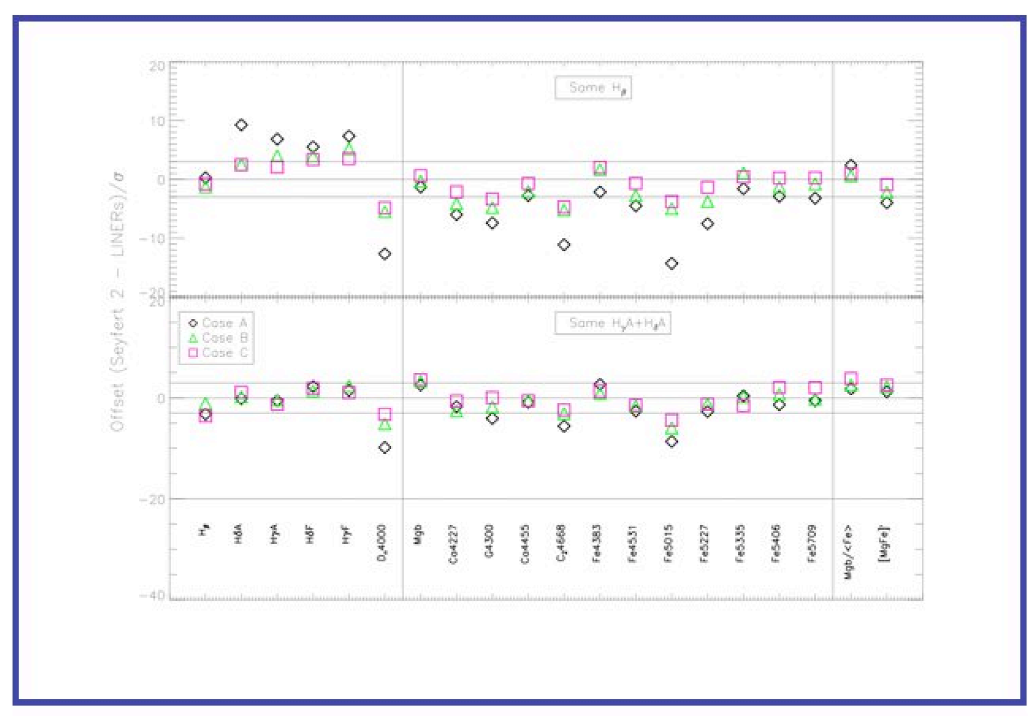
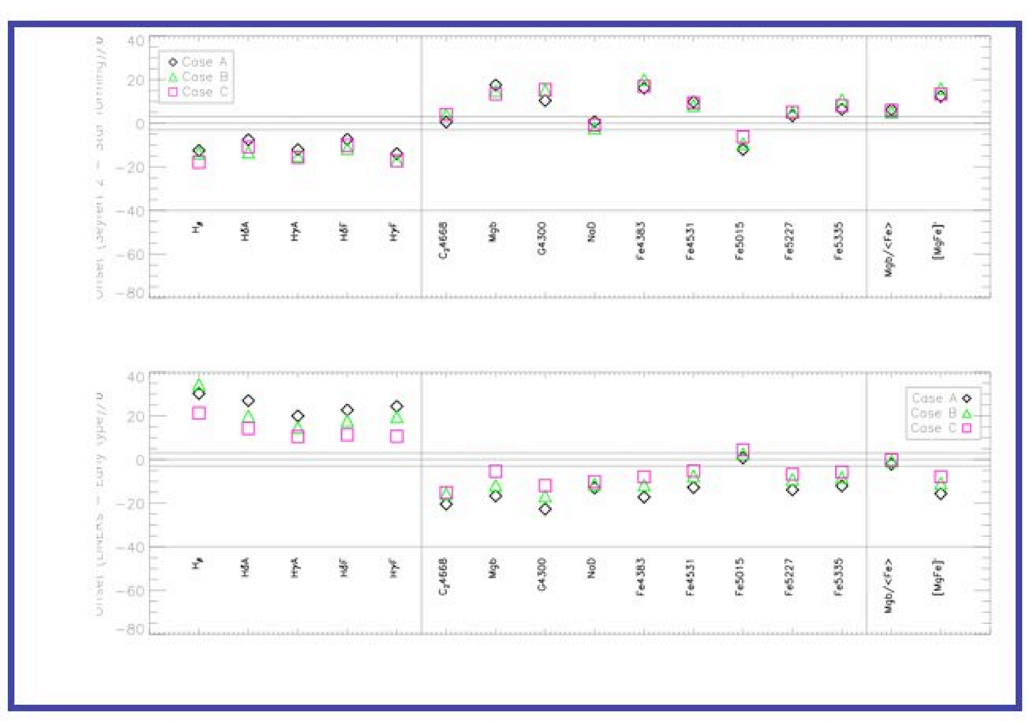


Fig.6



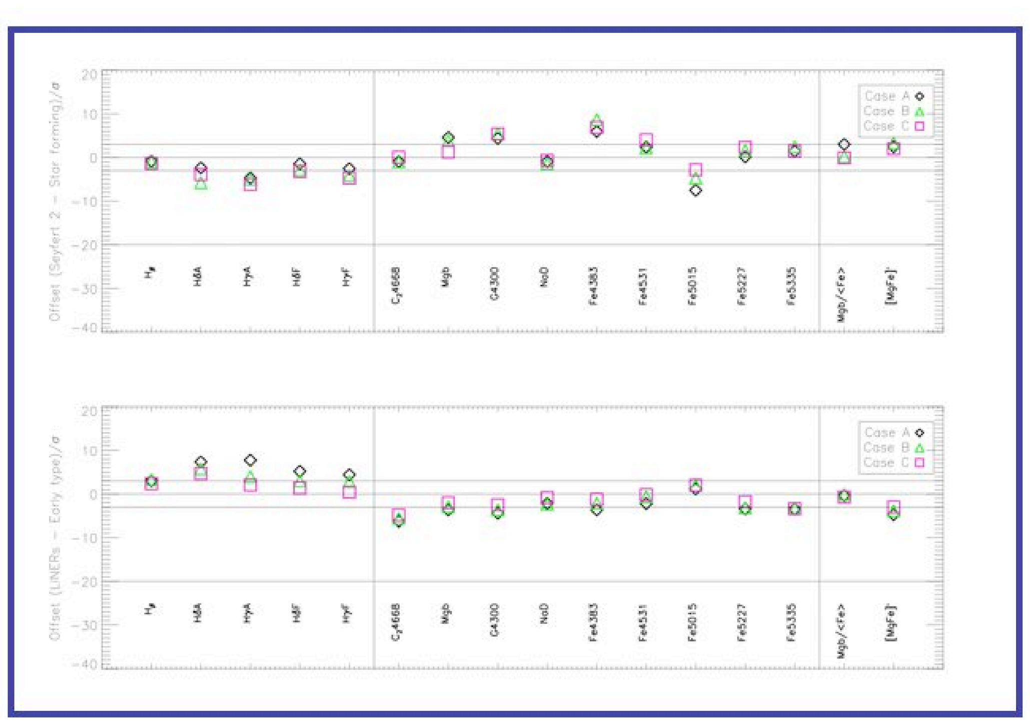
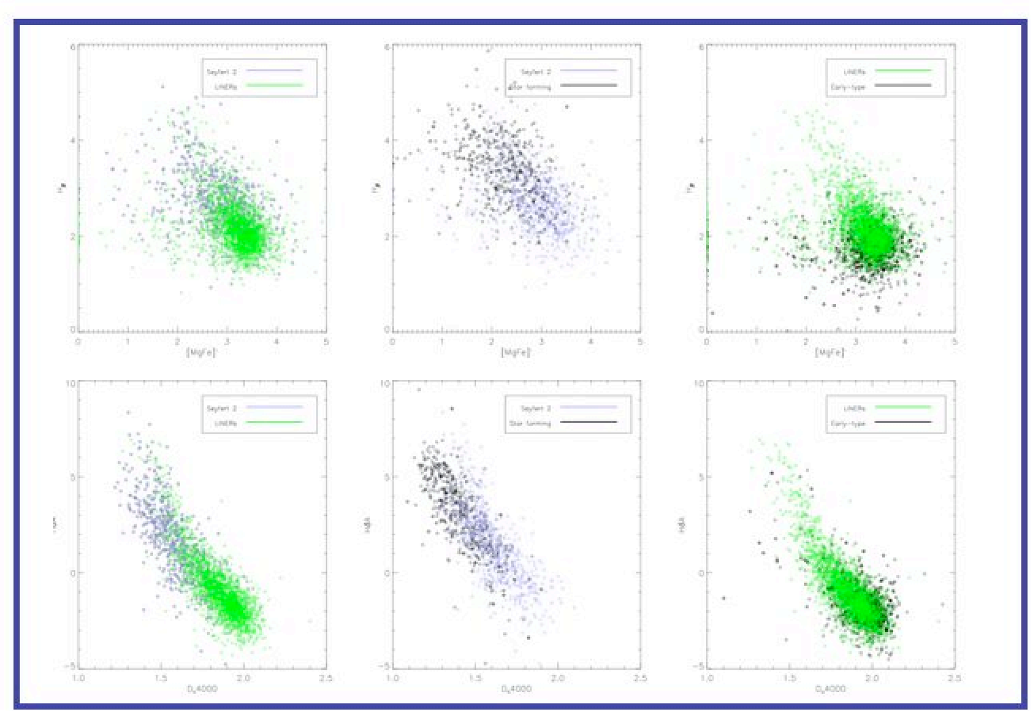


Fig.7 (Fixing H_β)

We adopt then the same procedure of pairing to derive properties of galaxies hosting AGN and their corresponding (in terms of mass, velocity dispersion, redshift) parent galaxies that do not contain an active nucleus.
In particular we evaluate differences between Seyfert 2 host galaxies and normal star--forming galaxies, and between LINERs host galaxies and early--type galaxies. After imposing the criteria on the mass, redshift and velocity dispersion difference we end up with 3043, 1281 and 627 pairs of Seyfert 2--star forming galaxies in Case A, B and C respectively, while we have 3391, 2759 and 2095 pairs of LINERs--early type galaxies.
We calculate for these samples the median difference for all the Lick indices, and the corresponding errors and intrinsic spread.
Seyfert 2 and star--forming galaxies (Fig. 6 upper panel)
The largest differences arise for indices tracing the galaxy age, namely the Balmer lines indices (from H_β to the higher order Balmer lines). These values indicate that galaxies hosting Seyfert 2 are older than a normally star forming galaxy, since they show smaller values of the Balmer lines. Moreover those offsets increase when moving from Case A to C, i.e. when we go from a zone where some degree of contamination may affect the sample of active galaxies toward a zone where the presence of an AGN is not questionable.
This means that star forming galaxies and Seyfert 2 are characterized by stellar populations having different ages: while star forming galaxies are dominated by an episode of recent star formation their corresponding active galaxies have an underlying stellar population on average much older, and this is more true when we select pure samples (Case C).
Seyfert 2 galaxies are then on average older, more metal rich, and slightly more enhanced than their counterpart not hosting an AGN.
LINERs and early--type galaxies (Fig. 6 lower panel)
Here we notice first that all offsets are more significant than the corresponding ones for pairs involving Seyfert 2.
Moreover they go in the exactly opposite direction, namely galaxies hosting LINERs are younger than the corresponding non active galaxies, and more metal poor.
As for the trend of these variations as a function of their "contamination degree", we can see that they are smaller and smaller the more the LINERs sample is clean.
This is not unexpected, and simply says that a galaxy contaminated by star formation is greatly different from an early--type galaxy (being much younger, and more metal rich).
However this trend is conserved in the clean samples and remains particularly not null for the age indicators, and for indices tracing carbon, while it goes to zero for magnesium and iron.
The net effect on the global properties of these galaxies is also an identical degree of enhancement.
Fixing the age (Fig. 7)
As a general comment here as well offsets decrease strongly with respect to the general case where we do not fix any age indicator.
When fixing H_β the offsets between active and inactive galaxies as a function of the distance from the contaminated region (Case A, B, C) become more and more smaller in the case of LINERs and are finally consistent with zero for all the indices but the other age indicators: *the main difference between these galaxies reside in the presence of a "recent" burst, which leaves traces in the D_n4000 and in the high order Balmer lines.*
When considering pairs of Seyfert 2-- star forming galaxies the overall picture is not so clear: some metallicity indicators go to zero, but some other do not. Moreover when looking at age indicators the less samples are affected by contamination the higher are these offsets.
It is clear that the more we proceed along the division line in Case A, B, C the more we isolate galaxies which are pure AGN, and the offsets we find are typical of the AGN presence.
This evidences not only through indices tracing the burst properties (that can be due even to a normally star forming event), but also through metallicity differences, which tells us that galaxies hosting an AGN are slightly more metal rich than inactive galaxies (maybe this could be the sign of an intermittent activity in the past).

Fig.8: Sequences of age/metallicity in our samples: At the extremes of every distribution are located early and late--type galaxies not containing AGN: early--type galaxies are, as expected, old and metal rich. At the opposite late--type, normally star forming galaxies are young and metal poor. Galaxies hosting AGN are somewhat in the middle, and constitute then a sort of evolutive sequence, where LINERS differ from early--type galaxies less than do Seyfert 2 with respect to star--forming ones (see Boisson et al., 2000, 2004).



The interpretation of our results depends on what age indicator we trust more:on one hand we have the H_β, which has been universally adopted in galaxy studies in the past, that is not very efficient in tracing the oldest stellar populations (since it does not vary for ages older than some Gyr), but at the same time do not show big variations with the metallicity.
Furthermore this index may suffer from a poor subtraction of the star forming emission component.
On the other hand the combination of the two higher order Balmer lines is highly sensitive to age, but also to metallicity (and even to the enhancement degree).

It is clear then that when imposing to our samples to have the same $H_{\delta A}+H_{\gamma A}$ we are somehow forcing galaxies to have even the same metallicity: what we find in fact is that paired galaxies in this case show very small metallicity offsets (both for active pairs and for active-inactive pairs).
In the case of LINERS--Early type pairs H_β, D_n4000 and the Mg indices do not converge to zero.
This could mean that some other difference in the older stellar population exist between galaxies hosting a LINER and galaxies that do not host it.
Whether this difference is completely due to age or, to some extent, to metallicity is not easy to derive using this age indicator.
In any case all the measurements we have presented here converge toward a scenario in which an age-metallicity sequence exist among active and inactive galaxies of different types, as can be seen from Fig.8, where we show some two indices diagnostic diagrams involving age and metallicity indicators.
The large sample provided by the SDSS allows here for the first time the determination of an age and metallicity sequence among galaxies hosting (and not hosting) AGN.