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THE STARBURST–AGN CONNECTION IN THE ERA OF THE GTC

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RESUMEN

Dilucidar la relación entre formación estelar violenta y actividad nuclear es crucial para entender la formación de las galaxias y los agujeros negros en las etapas más jóvenes del universo. Hay muchas pruebas que indican que los *starbursts* juegan un papel esencial en la energética de los núcleos Seyfert 2. Sin embargo, aún no se conoce el papel que juegan en AGN más distantes. Esta contribución muestra como observaciones espectrocópicas e imágenes profundas tomadas con OSIRIS y EMIR podrán ayudar a determinar si la relación establecida entre formación estelar violenta y actividad nuclear en galaxias Seyferts cercanas es también válida en AGN más potentes y distantes.

ABSTRACT

Elucidating the relationship between intense star formation and the AGN phenomenon is crucial to our understanding of the formation of galaxies and their supermassive black holes (SMBHs) in the early Universe. There have been many suggestions that starbursts play a powerful role in nearby Seyfert 2 galaxies. However, the role that starburst play in more powerful distant AGN is not known. This contribution shows how deep spectroscopy and imaging taken with OSIRIS and EMIR will help to determine whether the ubiquitous link between star formation and nuclear activity established for nearby Seyferts extends to more powerful distant AGN.

Key Words: **GALAXIES: ACTIVE — GALAXIES: SEYFERT — GALAXIES: STARBURSTS**

1. INTRODUCTION

It is nowadays widely accepted that the energy source of active galactic nuclei (AGN) originates in the accretion of mass onto a central supermassive black hole (SMBH). However, starbursts could also play an important role in the same galaxies (e.g., González Delgado 2001; Veilleux 2001, and references therein). In fact, many examples have been reported in which the two phenomena can coexist, and they contribute in the same fraction to the energy output. In the high luminosity regime, ultraluminous infrared galaxies (ULIRGs) are the best examples (Lutz & Tacconi 1999). However, powerful starbursts are also found in less luminous AGN, such as Seyfert nuclei (Heckman et al. 1997; González Delgado et al. 1998). Recently, the starburst–AGN connection has been suggested from the field of galaxy formation. The ubiquity of supermassive black holes in the nuclei of normal galaxies (Kormendy & Ho 2000) and the proportionality between the black hole and the spheroidal masses (Ferrarese & Merrit 2000; Gerbhard et al. 2000) suggest that the creation of a black hole was an integral part of the formation of ellipticals and the bulge of spirals (Granato et al. 2001). In consequence, violent events of star formation and AGN can coexist and probably did in the past even more often that we observe today.

In the past, the role of starbursts in AGN has been extensively discussed theoretically (Terlevich & Melnick 1985; Perry & Dyson 1985; Norman & Scoville 1988; Terlevich et al. 1992). However, the observational proofs have not been obtained until recently. It was largely because of the spatial resolution and UV sensitivity of the *Hubble Space Telescope* (*HST*) that the existence of powerful starbursts in the central ∼100 pc of some AGN could be established (González Delgado 2001).

Of course, the GTC cannot compete with the *HST* or the *NGST* in terms of spatial resolution; however, its high collecting area and the high sensibility of instruments such as OSIRIS and EMIR will allow us to investigate the "Starburst–AGN connection" in more distant objects with the goal of understanding the physical processes that drove the cosmic evolution of AGN and galaxy populations.

2. STARBURST SIGNATURES

Because of the contribution of AGN to the ionization of the nuclear (broad line region [BLR] and narrow line region [NLR]) and circumnuclear gas (extended narrow line region [ENLR]), the best techniques to find starbursts in AGN must be based on the detection of stellar features provided by young stars. Thus, before showing evidence of starbursts in AGN, I will describe the best starburst signatures at UV, optical, and NIR wavelengths.

UV starburst signatures: Unobscured starbursts are very bright at UV wavelengths. Their UV maps provide direct evidence of the location of the younger stellar clusters. Their UV spectra (Figure 1) show strong P Cygni profiles of resonance lines (e.g., N V λ1240, Si IV λ1400, C IV λ1550) formed in the wind of massive stars. The shape and the strength of these lines reflect the stellar content of the starburst and, thus, they constrain the initial mass function (IMF) and age of the stellar clusters. Photospheric lines (such as S V λ1502, Fe V λ1430, Si III λ1417) are also produced by massive stars. Even though they are much weaker (EW$\leq$ 1 Å), they are also detected in the UV integrated light of starbursts and are thus also useful for constraining the age of the stellar cluster, as well as the metallicity (Leitherer et al. 2001).

Optical starburst signatures: Starbursts also reveal photospheric lines at optical wavelengths, the most notable of these being the high order Balmer series (HOBS) and some He I lines (at λ3819, 4026, 4387, and 4922 Å). They can appear in absorption because of the strong Balmer decrement of the nebular lines, whereas the equivalent width of the stellar absorption lines is constant. The strength of these absorption lines can be used to constrain the age of the starburst (González Delgado, Leitherer, & Heckman 1999). An additional diagnostic is the broad emission features at $\sim$4660 and 5808 Å, that can also be detected in starbursts if they are in the Wolf–Rayet phase. This happens when massive stars ($\geq$ 40 $M_{\odot}$) evolve from the main sequence 3–6 Myr after the onset of the burst. Thus, the detection of these features is an indication of a young cluster.

NIR starburst signatures: At red (λ8600 Å) and NIR wavelengths, the continuum is dominated by stellar features from late-type stars corresponding to the red supergiant (RSG) and asymptotic giant branch (AGB) if the starburst has an age between 10 and 100 Myr. The most notable are the Ca II triplet (λ8498, 8542, 8662 Å) and CO bands (at 1.62 and 2.29 μm).

3. STARBURSTS IN AGN

In a series of studies, we have presented evidence for the existence of young stars in the nuclei of Seyfert galaxies through two different techniques. These results probed the starburst–AGN connection in low luminosity AGN (mainly Seyfert 2).

UV imaging and spectroscopy: *HST* images of Seyfert 2 galaxies have revealed that most ($\geq$ 80%) of the UV continuum is produced by a spatially resolved (extended $\sim$100 pc) nuclear starburst, that shows sub-arcsecond structures that may be produced by super stellar clusters. A more conclusive proof that the UV continuum in AGN is provided by a starburst is obtained by the detection of resonance wind lines. These starbursts provide a bolometric luminosity ($\sim10^{10}$–10^{11} $L_{\odot}$) similar to the estimated luminosity of the hidden Sy1 nucleus. They thus contribute significantly to the energetics of the AGN (González Delgado et al. 1998).

A beautiful example has been reported recently by Colina et al. (2002) in the low luminosity AGN (Seyfert2 or LINER) NGC 4303. The UV image shows a circumnuclear spiraling ring of stellar clusters plus a central knot at the position where the NICMOS images suggest the location of the AGN. The STIS UV spectrum of the central knot shows strong P Cygni wind lines very similar to those detected in the stellar clusters of the ring. The estimated age (4 Myr), mass ($\sim10^5$ $M_{\odot}$), and bolometric luminosity ($\sim$2 $\times$ 10^8 $L_{\odot}$) of this central knot are also very similar to those estimated for super stellar clusters. These observations prove that starbursts and AGN can coexist even in spatial scales of the order of afew parcsecs, which is the size of the central knot.

Optical spectroscopy: Nuclear (corresponding to the central few hundred pc) optical spectra of a sample of 20 powerful (in terms of their nebular emission [O III] λ5007 line and their non-thermal radio continuum flux) Seyfert 2s show the HOBS and He I lines in absorption in about 50% of the objects (González Delgado et al. 2001). The strength of the lines indicates that young and intermediate ($\leq$ a few 100 Myr) age population dominate the nuclear optical continuum.

A more recently example is found in the nucleus of the Seyfert 1 galaxy NGC 3227. The nuclear spectrum clearly shows the HOBS in absorption (Figure 3). The strength of these lines indicate that intermediate age stars contribute significantly to the optical light. However, its UV *HST* + WFPC2 image shows only a central unresolved knot. This morphology suggests that the starburst is obscured, or is very compact, or is at the post-starburst phase.

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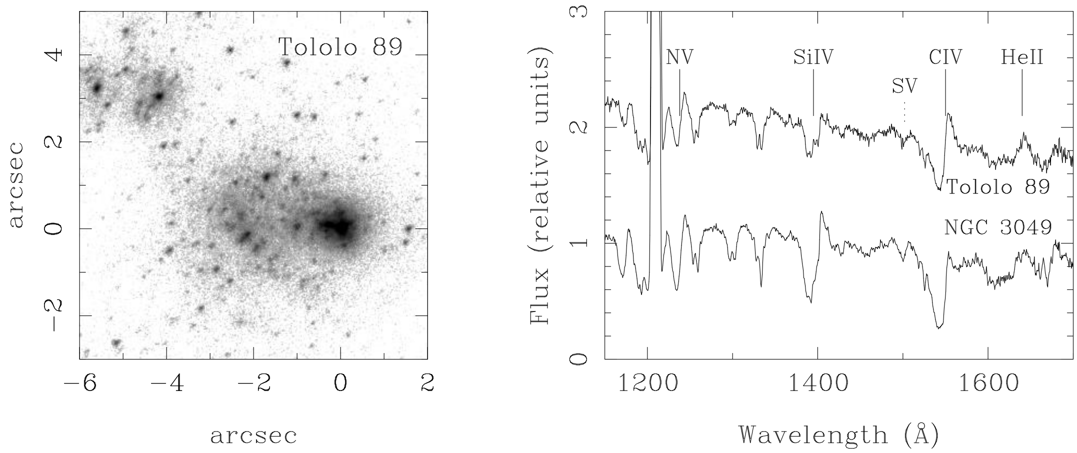

Fig. 1. (a) HST+STIS (UV) image of the starburst galaxy Tololo 89. 1 arcsec corresponds to 80 pc. (b) HST+STIS (UV) spectra of the brighest knot of the starburst galaxies Tololo 89 an d NGC 3049.

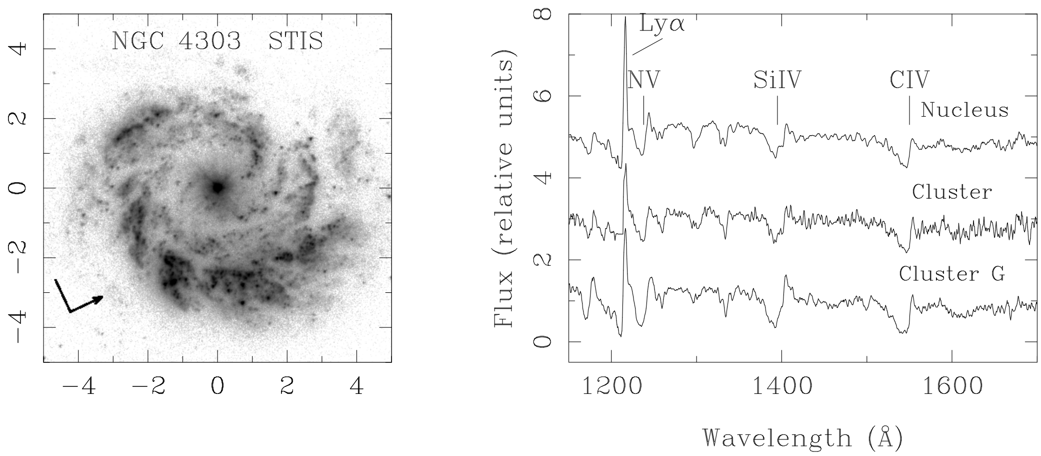

Fig. 2. *HST* + STIS (UV) image (a) of the low luminosity AGN NGC 4303. The spectra (b) of the nucleus (central knot) and two stellar clusters in the ring are shown. 1 arcsec corresponds to 80 pc. The slit width is 0.2 arcsec.

4. STARBURST–AGN CONNECTION WITH THE GTC

To study the starburst–AGN connection in galaxies at intermediate and high redshift is fundamental to understanding the genesis events that lead to the formation of QSO activity. But it is also required to place AGN galaxies in the context of galaxy formation. Only with 10 m aperture telescopes, such as the GTC, is it possible to carry out such a study. As explained above, only techniques based on the detection of stellar features can be successful in the detection of starbursts in AGN. These techniques require spectra with a very high signal-to-noise ratio (S/N $\geq$ 20) in the continuum, in order to compare the observed stellar features with the predictions of evolutionary synthesis models and in this way to constrain the starburst properties (such as age, IMF, etc.). Typical continuum (UV rest-frame) level of high redshift objects is of a few 10^{-18} erg s^{-1} cm^{-2} Å^{-1}. Thus, only high sensitivity instruments, such as OSIRIS and EMIR on the GTC will allow us to obtain this level of S/N with reasonable exposure times.

OSIRIS capabilities: The long slit spectroscopy (or MOS) and tunable filter (TF) imaging capabilities of OSIRIS are unique for observing:

- *Rest-frame UV spectra of AGN at $2 \leq z \leq 5$.* To detect wind resonance lines (such as N V, Si IV, C IV, etc.) and photospheric lines (such as S V, Fe V, etc.). To get an S/N $\geq$ 20 at the continuum several hours of integration time is required for objects of V sim23 mag.

- *Rest-frame UV continuum and Lyα images of AGN at $2 \leq z \leq 5$.* Lyα haloes can tell us about the formation events in these galaxies;

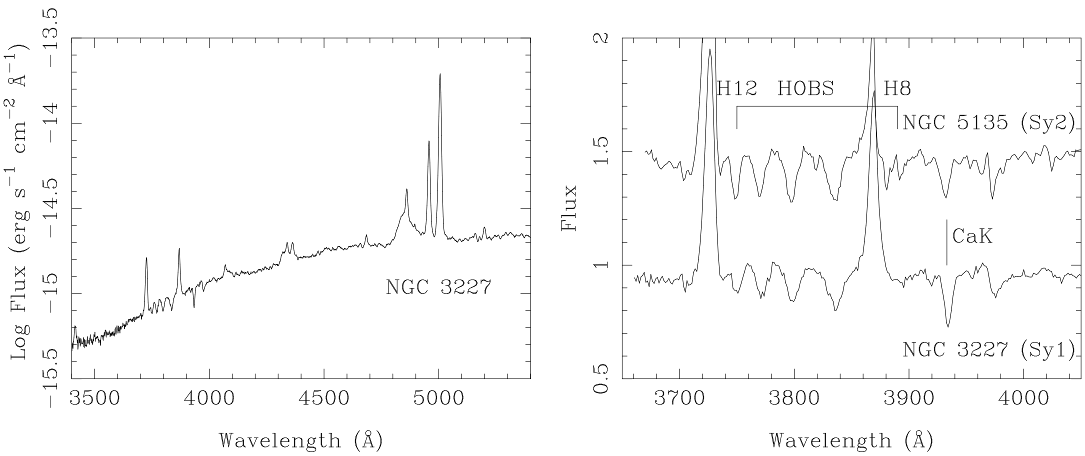

Fig. 3. a) NOT + ALFOSC spectrum of the Seyfert 1 nucleus NGC 3227. The slit width is 1 arcsec (corresponding to 75 pc). b) Nuclear normalized spectrum of NGC 3227 compared with the nuclear spectrum of the Seyfert 2 galaxy NGC 5135. It is known that NGC 5135 harbors a nuclear starburst.

e.g., through merging of smaller starburst systems. TFs tuned between 3600 to 6000 Å and 6200 to 7750 Å can observe Lyα and UV continuum for AGN at $z = 2$–4. For typical Lyα emission ($\geq 10^{-16}$ erg s^{-1} cm^{-2}), an exposure of 1800 s is enough to get S/N $\geq$ 15.

- *Rest-frame optical spectra of AGN at* $z \leq 0.4$. To detect HOBS and He I lines in absorption. Because these lines can be partially filled by the nebular emission, the only available information could be the faint absorption *wings*. With these constraints, an S/N $\geq$ 30 is required to estimate ages of the starbursts. This ratio is achieved in $\sim$ 1 hr, for typical continuum level of $\sim 10^{-17}$ erg s^{-1} cm^{-2} Å^{-1}.

EMIR capabilities: These are unique for observing:

- *NIR spectroscopy of AGN up to* $z \leq 2$. Since the pioneering work by Terlevich, Díaz, & Terlevich (1990), the calcium triplet (CaT) has been extensively observed in Seyfert galaxies. Terlevich et al.'s results indicate that the CaT is very strong and the Mg lines are weak in most Seyfert nuclei. Dilution by a power law cannot explain these two stellar properties, but stabursts younger than 100 Myr can account for them. The CaT can be observed with EMIR in AGN up $z \leq 2$.

- *H and K spectroscopy of AGN up to* $z \leq 0.4$. The CO (2.29 μm) index has been successfully used to detect starbursts in Seyfert galaxies. However, because of the dilution of CO λ 2.29 μm by dust (heating by the AGN) thermal continuum emission, Oliva et al. (1999) have proposed using the stellar mass-to-light ratio in the H band as a starburst diagnostic. The mass is estimated from the stellar velocity dispersion measured through CO λ1.62 μm, which is less affected by the dust emission. A resolving power better than 2000–3000 is required.

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