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WHAT IS THE CA II FEATURE IN THE NEAR IR TELLING US ABOUT ACTIVE GALACTIC NUCLEI?

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RESUMEN. La absorción de Ca II en $\lambda\lambda$8498, 8542, 8662 A es el rasgo más fuerte en el espectro infrarrojo de estrellas de tipo tardío y de galaxias normales. Su intensidad ha resultado ser un buen indicador de luminosidad para poblaciones estelares ricas en metales (> 0.5 solar). Hemos obtenido datos espectroscópicos para las regiones nucleares de 42 galaxias normales y activas, para poder explorar la conducta de este rasgo y encontrar que, en todas las galaxias Seyfert de tipo 2 de nuestra muestra y aún en algunas Seyfert del tipo 1, la intensidad de las absorciones Ca II IR es igual y en algunos casos más grande que en galaxias elípticas normales. En base a nuestra biblioteca estelar de 106 estrellas de tipo tardío observadas con la misma configuración instrumental, este resultado se explica más naturalmente por la presencia de supergigantes rojas que dominan, o por lo menos contribuyen a la luz nuclear en el infrarrojo. Estos descubrimientos constituyen fuerte evidencia para la existencia de una población estelar substancialmente más joven que aquella observada en galaxias normales de tipo temprano y apoya al escenario de brote estelar para explicar la actividad nuclear.

ABSTRACT. Ca II absorption at $\lambda\lambda$8498, 8542. 8662 A is the strongest feature in the infrared spectrum of late type stars and normal galaxies. Its strength has been found to be a good luminosity indicator for metal rich (> 0.5 solar) stellar populations. We have obtained spectroscopic data for the nuclear region of 42 normal and active galaxies in order to explore the behaviour of this feature and found that, in all the Seyfert type 2 galaxies in our sample and even in some Seyfert type 1, the strength of the IR Ca II absorptions is equal to and in some cases larger than that in normal elliptical galaxies. On the basis of our stellar library of 106 late type stars observed with the same instrumental configuration, this result is most naturally explained by the presence of red supergiant stars dominating, or at least contributing heavily to, the unresolved nuclear light at near infrared wavelengths. These findings constitute strong evidence for a stellar population substantially younger than that observed in normal early type galaxies and give support to the starburst scenario for nuclear activity.

Key words: **GALAXIES-ACTIVE – LINE PROFILES – STARS-EARLY-TYPE**

I. INTRODUCTION

The possible connection between young hot stars and nuclear activity has been recognized by several authors (Adams and Weedman 1975, Harwit and Pacini 1975, Osterbrock 1978) and a continuity or overlap of properties between active and non-active nuclei has also been reported from X-ray and infrared surveys of luminous galaxies (Fabbiano *et al.* 1982, Lawrence *et al.* 1985). More recently, Terlevich and Melnick (1985) have suggested that, at least in the case of Seyfert type 2 galaxies and LINERS, the observed emission line spectrum can be the result of the normal late stage of evolution of a large nuclear burst of star formation at solar or over solar abundances, as opposed to a hot accretion disc circling a central massive black hole, the commonly assumed mechanism at work in all active galactic nuclei.

The relatively faint underlying blue featureless continuum detected in most, if not all, Seyfert nuclei is explained by both hypotheses. This continuum originates in an unresolved point-like nucleus, and its contribution to the total light can be calculated for nearby galaxies (Yee 1983, Malkan and Filippenko 1983).

In the massive black hole scenario, all the stellar absorption features should be weaker than in normal galaxies by an amount that is wavelength dependent, since the underlying continuum is featureless and bluer than the old stellar population of the galactic bulge. In the starburst case the blue continuum originates in a reddened young stellar cluster; therefore dilution is expected in Ca II K (λ3933 A), λ4000 A break, G-band (λ4303 A), MgIb (λ5175 A) and NaI doublets (λλ5890, 5896 A and λλ8193, 8195 A) since these features are weak or absent in early type stars. There is nevertheless a clear discrepancy between the predictions of both hypothesis for the near infrared Ca II triplet[1] (λλ8498, 8542, 8662 A) which is strongest in red supergiants due to its high sensitivity to surface gravity (Jones *et al.* 1984, Díaz *et al.* 1989). Therefore, in the starburst scenario, the Ca II lines could be undiluted, or even stronger than in an old stellar population, if they originate in young red supergiants associated with the burst, instead of in the bulge old giants (Campbell and Terlevich, 1985).

II. OBSERVATIONS AND RESULTS

In order to test the predictions of the starburst hypothesis, we have obtained intermediate resolution spectra for 42 galaxies in the near infrared region covering the Ca II triplet (7800-9300 A), and 106 late type stars with published metallicity determinations. The galaxies observed comprise Seyfert types 1 and 2, LINERS, starbursts and normal galaxies. The Seyfert type 2 nuclei were selected among those showing the weakest optical absorption lines, i.e., with the strongest underlying blue continuum (Koski 1978, Malkan and Filippenko 1983). The data were obtained with the INT at the Roque de los Muchachos Observatory, La Palma, Spain using the Intermediate Dispersion Spectrograph and a GEC CCD detector. The spectral resolutions attained were from 3-6 A.

The reduction of the data, using standard software packages, included the usual steps of flat fielding, sky subtraction and wavelength calibration; no flux calibration was performed.

A pseudo equivalent width of the Ca II lines (EW) was measured (Terlevich *et al.* 1990). The continuum is defined by a linear fit to the mean fluxes in chosen side-bands, relatively free of absorption features. A correction is applied to the measured EW for the effect of "smearing" produced by unequal broadenings of the lines due to different velocity dispersions in the galaxies. We estimate the errors of the EW to be less than 5 percent.

Analysing the stellar spectra, we found (Díaz *et al.* 1989) that the near IR Ca II triplet shows a bi-parametric behaviour, depending on both [Fe/H] and log g. Figure 1 shows the relation between the equivalent width

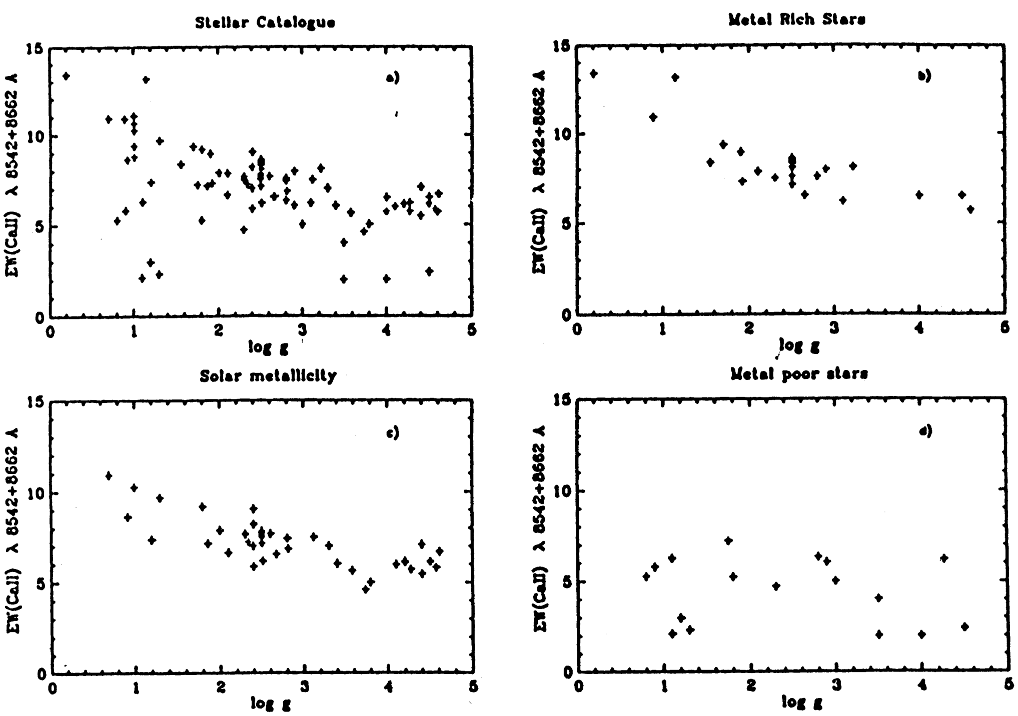

Fig. 1. EW in A of Ca II (λλ8542,8662 A) as a function of surface gravity for the stellar sample.

1. Those present at the meeting heard Mendoza complaining about the liberal misuse, by observers, of atomic terms. Different spectral series were named during early days of spectroscopy by Rydberg and others; we will follow the tradition and continue to call the feature a triplet, as it consists of three lines.

in A of the Ca II lines (λλ8542,8662 A) and log g, a) for our whole star sample, b) for the metal rich stars ([Fe/H] > 0.1), c) for solar metallicity stars (−0.3 < [Fe/H] ≤ 0.1) and, d) for metal poor stars ([Fe/H] ≤ −0.3). The arrow refers to a star with log g = −2.0. It can be seen from the figure that in the high metallicity regime that corresponds to the nuclear region of galaxies, the Ca II triplet strength depends solely on luminosity. Supergiants show the largest Ca II strengths, twice the values found in dwarfs.

Figure 2 shows reduced spectra of galaxies of different types: Seyfert 1, Seyfert 2, LINER and a normal spiral; a star is also shown for comparison. The figure clearly shows that these galaxies have comparable nuclear Ca II triplet strengths and line widths.

Figure 3 shows the distribution of the strength of the Ca II lines (λλ 8542+8662 A) versus galactic nuclear types. It can be seen from this diagram that a good number of the Seyfert type 2 galaxies observed have Ca II triplet strengths which are greater than those observed in normal spirals (e.g. M31) and in the metal rich elliptical NGC 4472. Even the Seyfert 1 galaxies NGC 3516 and NGC 4151 have an IR Ca II triplet of strength comparable to that in normal nuclei. However, as pointed out above, substantial dilution of the blue-yellow stellar absorptions is observed in most Seyfert nuclei including those in our sample (Boksenberg and Netzer 1977, Koski 1978 and Malkan and Filippenko 1983). This dilution is usually attributed to the above mentioned featureless continuum.

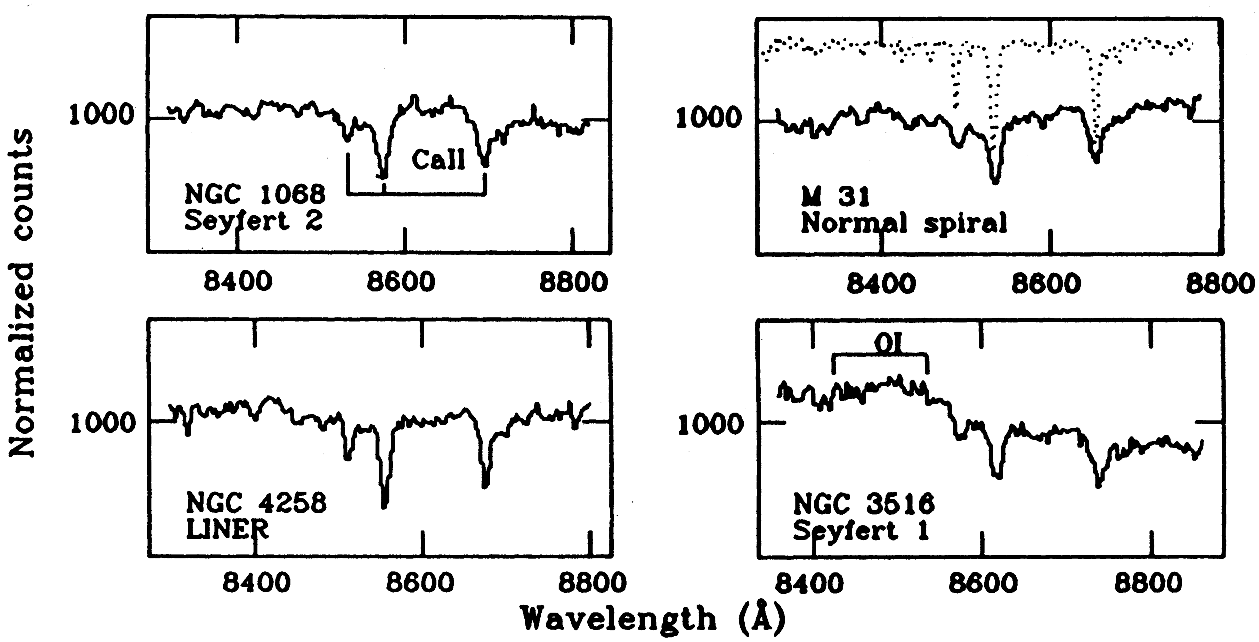

Fig. 2. Normalized CCD spectra of galaxies of different nuclear type; a gK star is also shown for comparison (dotted line).

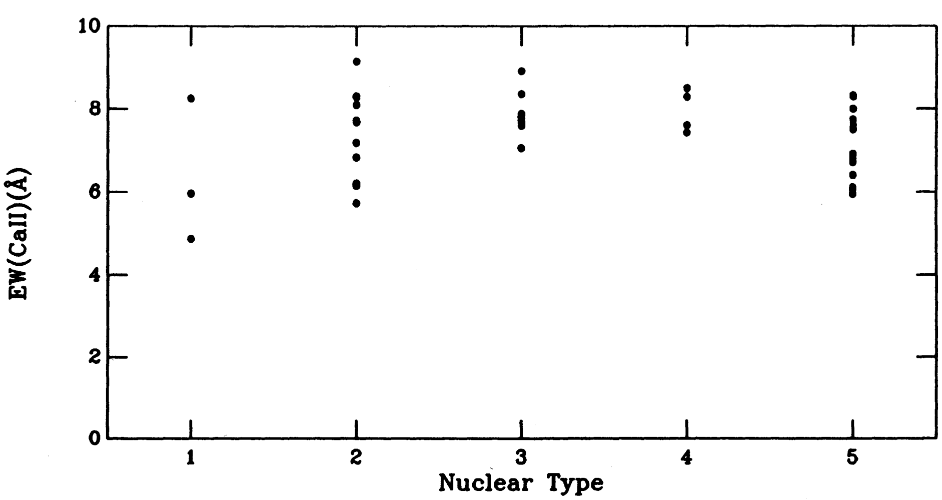

Fig. 3. EW Ca II (λλ8542,8662 A) vs nuclear type defined as: 1 = Seyfert 1; 2 = Seyfert 2; 3 = LINERS; 4 = Starburst nuclei; 5 = normal.

For a sample of Seyfert galaxies, Malkan and Filippenko (1983) find that fractions of the total light at 5400 A between 21 and 85 percent, coming from this continuum, can account for the observed dilution of the optical absorption lines. Applying Malkan and Filippenko's methods we find that, for all the Seyfert galaxies in our sample, a large fraction of the IR light inside a 4 arcsec aperture comes as well from an unresolved nuclear component. This can be seen in Figure 4 where radial brightness profiles are plotted at 6300 A (*R*) and 8500 A (*IR*) for NGC 3227 for which we have complementary data in the wavelength range 6000-7500 A. Also shown is the seeing profile as deduced from stellar observations. For the galaxy both profiles are similar and show a spatially unresolved nuclear component above the extrapolated disc light distribution represented by the straight line. This unresolved component effectively dominates the nuclear light. Yet no dilution in the IR Ca II lines is observed.

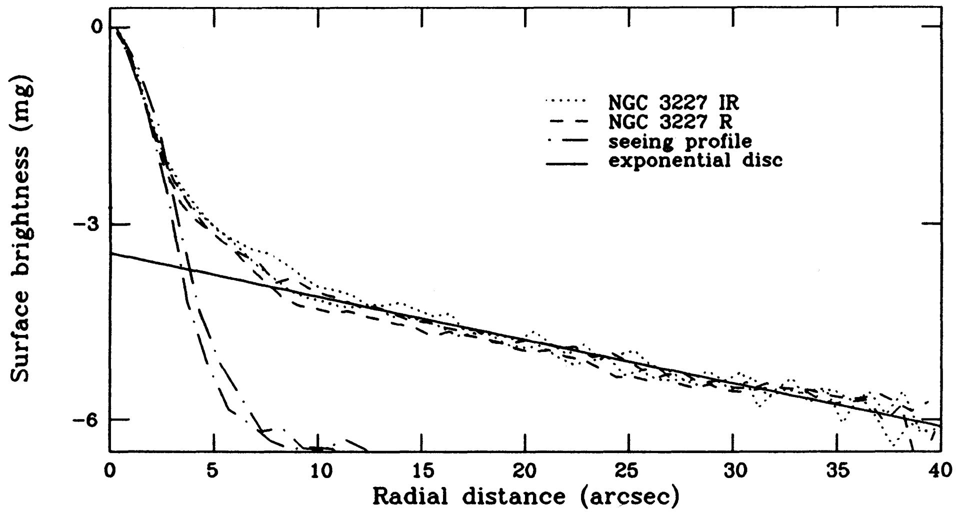

Fig. 4. Normalized radial brightness profiles at 6300 A and 8500 A for NGC 3227. The seeing profile is shown for comparison. The straight line corresponds to an exponential disk.

The lack of dilution of the Ca II absorption lines in the nuclear spectra leads naturally to the suggestion that the supposedly featureless continuum is not totally featureless but rather shows the presence of Ca II absorption lines, since the light is clearly dominated by the point-like component. Other possibilities like a contribution from interstellar gas and the presence of a super metal rich stellar population can be ruled out; the first due to the high excitation potential of Ca II ; the second due to the lack of sensitivity of the Ca II triplet to metallicity in metal rich systems (Díaz *et al.* 1989), and the absence of a very strong Mg2 index, a good metallicity indicator for galaxies (Mould 1978, Burstein 1979 and Terlevich *et al* 1981). It might be argued that the Ca II triplet absorptions could originate in the cool outermost part of an accretion disc. But the fact that the line profiles are almost gaussian in all cases and, more importantly, that the observed line widths are similar to those found in normal galactic nuclei, strongly suggests a stellar origin.

Based on the behaviour of the Ca II triplet we conclude that in all our normal nuclei the infrared light seems to be dominated by giants (see Figures 1 and 3), in agreement with previous work (Faber and French 1980 and references therein). According to this and our previous discussion, the most likely interpretation of the large equivalent widths of the Ca II lines found in our sample Seyfert nuclei implies the presence of young red supergiant stars dominating, or at least contributing heavily to, the unresolved nuclear light at near infrared wavelengths.

These findings constitute good evidence for a stellar population substantially younger than that observed in normal early type galaxies giving support to the starburst scenario for nuclear activity. Several important questions still remain to be answered regarding the intrinsic properties of the nuclear component. The presence of other indicators of a young stellar population, such as a weak 4000 A break together with an absorption component in the Balmer lines in the nuclei of Seyfert galaxies should be investigated, and the behaviour of the Ca II triplet in starburst galaxies studied in detail.

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