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YOUNG AND INTERMEDIATE STELLAR POPULATION IN SEYFERT 2 GALAXIES

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Abstract

We present and discuss near-ultraviolet and optical ground-based spectra of the 20 brightest Seyfert 2 nuclei, and HST ultraviolet images and ultraviolet spectroscopy for a few of them. The goal is to study the starburst-AGN connection and the origin of the featureless continuum. The results indicate that half of the nuclei in the sample harbor a young and/or intermediate age population. These stars are formed in powerful and dusty starbursts of short duration, that have bolometric luminosities similar to the estimated bolometric luminosities of their obscured Seyfert 1 nuclei.

1 Introduction

According with the standard unified scheme for radio-quiet AGN, Seyfert 2 (S2) galaxies contain a Seyfert 1 (S1) nucleus that is obscured by a circum-nuclear torus of dust and gas; but it can be seen in polarized light. Generally speaking the optical continuum of the S2 nuclei can be classified in two types: Those that show a red continuum which is very similar to that of elliptical galaxies, and those that show a very blue continuum in which the stellar lines due to an underlying bulge stellar population are very diluted. In these cases, the blue continuum does not show almost any stellar features and it is call features-less continuum (FC). According with the unified picture, the blue continuum is scatered light from the hidden S1 nucleus. It dominates the ultraviolet continuum and contributes between 10% and 30% to the optical light.

However, this interpretation is not completely correct because after the contribution of the old stars is removed, the remaining optical continuum has a significant lower fractional polarization than the broad optical emission lines (Antonucci

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1993). Therefore other unpolarized component has to contribute to dilute the FC. Tran (1995) suggests that the unpolarized component is optically thin thermal emission from warm gas that is heated by the central hidden source. In contrast, Cid-Fernandes & Terlevich (1995) and Heckman et al. (1995) suggest that the unpolarized component is a young very red stellar population associated with the obscuring torus.

To go deeper in the origin of the FC in S2 galaxies and in the possible connection between Seyfert and the starburst phenomenon we have started a program to study the ultraviolet to near-infrared spectra of a sample of the 20 brightest S2 nuclei with the goal of detecting stellar features from massive stars. Here, we summarize the results from the analysis of the UV continuum of four of these objects that are presented in more detail in Heckman et al. (1997) and González Delgado et al. (1998), and the results from our near-ultraviolet ground based observations of the complete sample.

2 Sample and Observations

We have taken ground-based optical and near infrared spectroscopy with the 4m telescope at Kitt Peak National Observatory for 20 of the brightest Seyfert 2 nuclei selected from the compilation of Whittle (1992). They have been selected by their nuclear [OIII] λ5007 emission line flux and by their non-thermal radio continuum emission at 1.4 GHz. They all satisfy at least one of the two following criteria: log $F_{[OIII]} \geq$ -12.0 (erg cm^{-2} s^{-1}) and log $F_{1.4} \geq$-15.0 (erg cm^{-2} s^{-1}). The criteria used guarantees that the whole sample is unbiased with respect to the presence or absence of a nuclear starburst. HST UV images have been obtained for 9 of the 20 Seyfert 2 nuclei using the Faint Object Camera (FOC). We have also obtained UV spectra of 4 (Mrk 477, NGC 7130, NGC 5135 and IC 3639) of these 9 Seyfert 2 nuclei with the HST Goddard High Resolution Spectrometer (GHRS). They were chosen from the subsample of 9 Seyfert 2 nuclei for having the highest UV flux on arcsec scales.

3 UV imaging

Massive stars emit most of their flux at the UV and far-UV wavelengths. In contrast, older stars contribute significantly to optical and longer wavelengths. Therefore, UV images provide predominantly direct evidence of location of most of the recent unobscured star forming regions. On the other hand, UV images of starburst galaxies show that a significant fraction of the massive stars are formed in very compact stellar clusters (Meurer et al. 1995) that have sizes of a few pcs. Therefore, the morphology of the UV light of S2 can indicate whether these nuclei harbor a starburst.

We have observed 9 objects with the FOC through the filter F210M. This filter does not include any strong emission lines; therefore, the emission is dominated by the UV continuum at 2150 Å. In four of the targets (Mrk 477, NGC 7130, NGC 5135 and IC 3639) the morphology suggests that they harbor a nuclear starburst

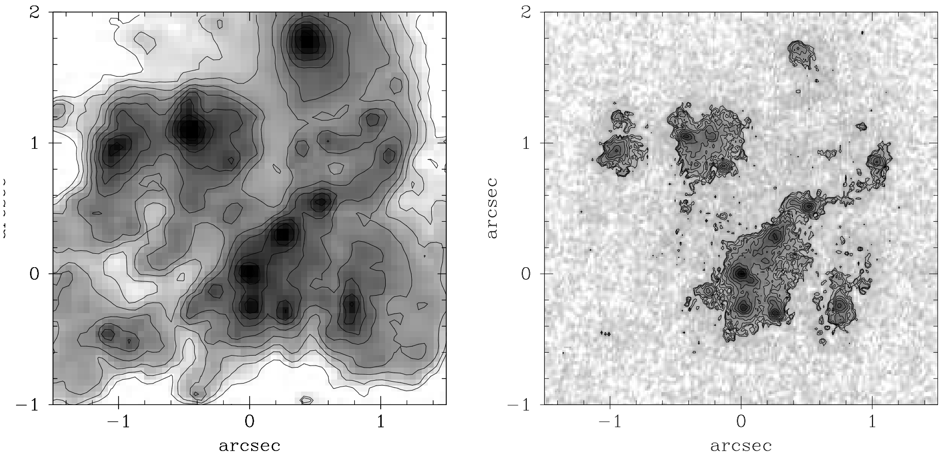


Fig. 1. Central 3×3 arcsec^2 (540 by 540 pc) field of NGC 5135, (left): WFPC2 through F606W, (right): FOC through F210M. The origin of this plot is the pixel with the highest UV surface brigtness. Based on the morphology of the WFPC2 image, we believe that the nucleus is the knot located at 1.05 arcsec North and 0.4 arcsec East. The UV emission is resolved in knots suggesting that the nucleus of NGC 5135 harbors a starburst.

(Figure 1). In these cases, the UV continuum is spatially resolved, showing sub-arcsec structure. The effective radius (50-200 pc) of the UV emission is similar to the size of the NLR. At the position where HST+WFPC2 (F606W) suggests that the nucleus is located, the UV images show very little emission (less than 15% of the total). This result suggests that even at UV wavelengths the S1 nucleus is still obscured. In other four targets, the emission is very weak and the morpholgy is very uncertain. In contrast, in Mrk 463E, the UV emission is extended 1 Kpc and it looks like scattered light of the hidden S1 nucleus (Figure 2).

4 UV spectroscopy

The UV spectrum of a starburst is very rich in absorption lines, many of them are formed in the wind of massive stars (Weedman et al. 1981). A conclusive evidence that the UV emission in the S2 nuclei comes from a starburst is obtained if stellar wind resonance lines (as NV λ1240, SiIV λ1400 and CIV λ1540) are detected in their spectra. The four brighest UV S2 of our sample were observed with the GHRS and the G140L grating, which has a nominal dispersion of 0.57 Å/diode, using the Large Science Aperture (LSA, 1.74×1.74 arcsec) and covering 1150-1600 Å. The spectra show the typical absorption features of starburst galaxies, indicating that the UV light is dominated by the starburst component (Figure 3). Comparing the strength of the wind lines with those predicted by evolutionary synthesis models (Leitherer et al. 1995), we conclude that in these S2 nuclei, the starbursts are of short duration with ages between 4 and 6 Myr. We find that, after correcting the

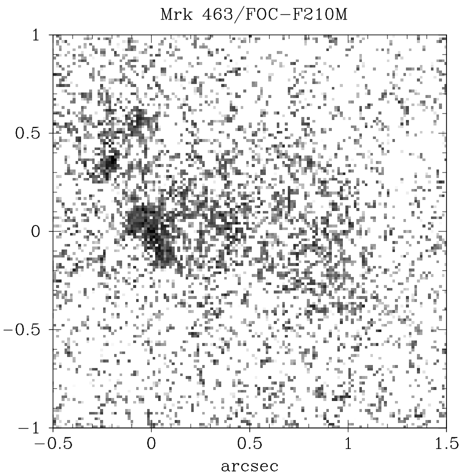
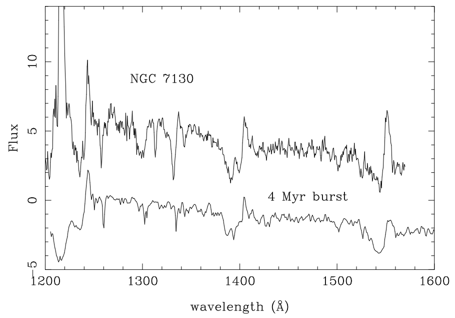


Fig. 2. *HST*+FOC (through F210M) image of the central 2×2 arcsec^2 (2 by 2 Kpc) of Mrk 463E. The origin of this plot is the brightest UV knot which nature is unknown. Most of the UV flux comes from 1 Kpc extended emission.



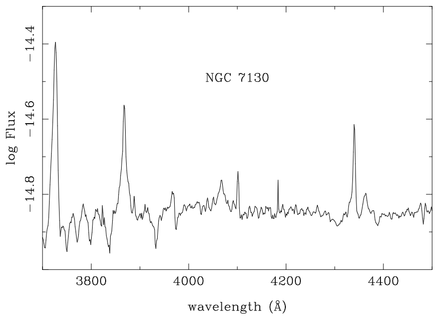


Fig. 3. (Left): UV (HST+GHRS) spectrum of NGC 7130 dereddened and the synthetic 4 Myr burst model (in relative units) that fits the wind resonance stellar lines. The IMF slope assumed in the model is Salpeter and M_{upp}=80 M$\odot$. (Right): Ground-based optical spectrum of NGC 7130 obtained through a 1.5×3.5 arcsec^2 aperture. It shows the higher order terms of the Balmer series and HeI lines in absorption.

observed UV continuum for dust extinction using the starburst attenuation law (Calzetti et al. 1994), the bolometric luminosity of these starbursts ($\sim 10^{10}$ L$\odot$) is similar to the estimated luminosity of the hidden S1 nucleus.

5 Near-ultraviolet and optical spectroscopy

These results obtained for the brightest UV S2 of our sample indicate that these nuclei harbor a starburst. However, they do not demonstrate that starbursts are an ubiquitous part of the Seyfert phenomenon. To investigate deeper about the possible role that massive stars and starburst play in the energetics of Seyfert nuclei, we have looked for starburst signatures in the near-ultraviolet spectra of our whole sample. Massive stars also show photospheric lines at near-ultraviolet and optical wavelengths. The most notably are those of the H Balmer serie and HeI lines. In the spectra of starbursts, these lines are coincident with the nebular emission lines. However, the higher order terms of the Balmer series can be easily detected in absorption because the strength of the Balmer series in emission decreases rapidly with decreasing wavelength, but the equivalent widths of the absorption lines are constant with wavelength (González Delgado et al. 1999). Then, the detection of these absorption lines in the spectra of S2 nuclei can indicate that these objects harbor a starburst.

Three (NGC 5135, NGC 7130 and IC 3639) of our four S2 that show stellar wind resonance lines at the UV, also show the higher order terms of the Balmer series and HeI (λ3819,4387 and 4922) in absorption. In the other object, Mrk 477, the Balmer and HeI stellar features are overwhelmed by the corresponding nebular lines. However, it shows a very broad HeII λ4686 emission line that is formed in the stellar wind of Wolf-Rayet stars. These results indicate that a method to infer the presence of a starburst in the nucleus of S2 is through the detection of the higher order terms of the Balmer series and HeI lines in absorption and the Wolf-Rayet feature at 4680 Å. The inspection of our ground-based spectra show that six of our 20 targets show these photospheric features in their nuclear spectra (e.g. Mrk 1066, see Figure 4). In three more objects the stellar features are detected when the contribution of the nebular emission lines are subtracted from the spectra. Thus, we conclude that at least about half of the S2 of our sample show starburst characteristics in their near-ultraviolet spectra. In the other half of the sample, the optical continuum show only stellar features due to an underlying old bulge stellar population.

In order to investigate more about the origin and the contribution of the FC to the near-ultraviolet optical continuum, we have measured the variation of the equivalent widths (Ew) of the absorption line CaII λ3933 and G band at 4300 Å toward the nucleus. In the objects where we detect the higher order terms of the Balmer series in absorption, the Ew of the CaII and G band decreases significantly toward the nucleus (e.g. in NGC 5135, Figure 5). In the other objects, they do not show dilution at all or it is very small (less than 10%) (e.g. in Mrk 3, Figure 5). These results suggest that the origin of the FC in half of the sample is produced by a nuclear starburst. In the other half, the FC is weak relative to the light from a normal old bulge stellar population and their origin is not clear, but it could be produced by scattered light from the hidden S1 nucleus, because their contribution to the optical light is similar to the fractional polarization degree detected in these types of objects.

Two exceptions to this dual clasification are Mrk 477 and Mrk 463E. Both objects show a very blue continuum, very diluted stellar absorption features and very broad HeII λ4686 emission (Figure 6). In the case of Mrk 477, our UV images and spectroscopy indicate that it harbors a powerful red nuclear starburst,

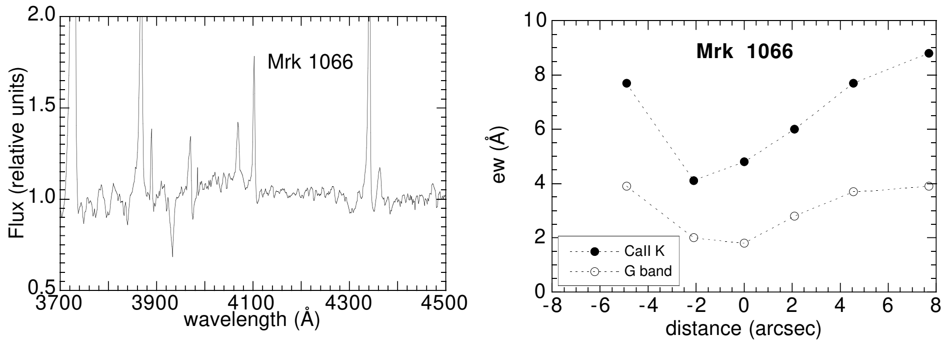


Fig. 4. (Right): Ground-based optical spectrum of Mrk 1066. It shows the higher order terms of the Balmer series in absorption, as NGC 7130. (Left): Spatial distribution of the equivalent widths of the stellar lines CaII K and G band of Mrk 1066. Note the dilution of these lines toward its nucleus (origin of the plot).

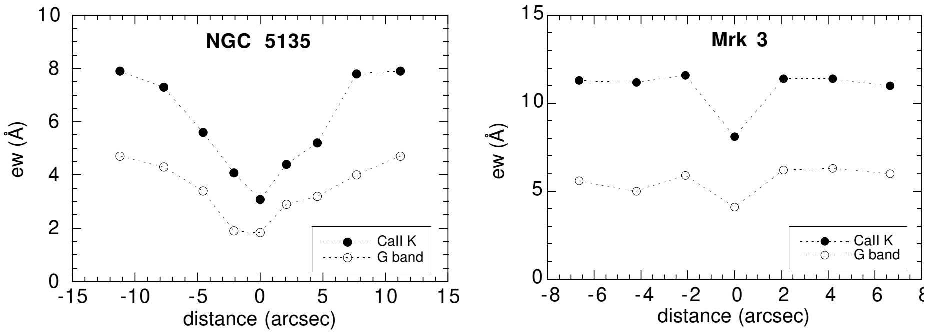


Fig. 5. As Figure 4 for NGC 5135 (left) and Mrk 3(right). The strong dilution of the stellar lines toward the nucleus in NGC 5135 is due to the existence of a starburst, but in Mrk 3 it is probably due to scattered light from the hidden S1 nucleus.

and the HeII emission is due to Wolf-Rayet stars. In the case of Mrk 463E, the interpretation is more controversial. Like in Mrk 477, in Mrk 463E, the polarized spectrum does not show HeII emission, and the fractional degree of polarization is only a few percent. Then, the origin of the broad emission at $\lambda 4686$ can not be due to scaterred light from the hidden S1 nucleus; therefore, it could due to Wolf-Rayet stars, as in Mrk 477. However, the morphology of the UV emission of Mrk 463E is very different to that of those S2 that show starburst characteristics (Figure 1). Thus, we have to conclude that the origin of its FC is an enigma and Mrk 463E is a very challanging object. HST+STIS observations will help to futher inquire about the origin of the FC in this object.

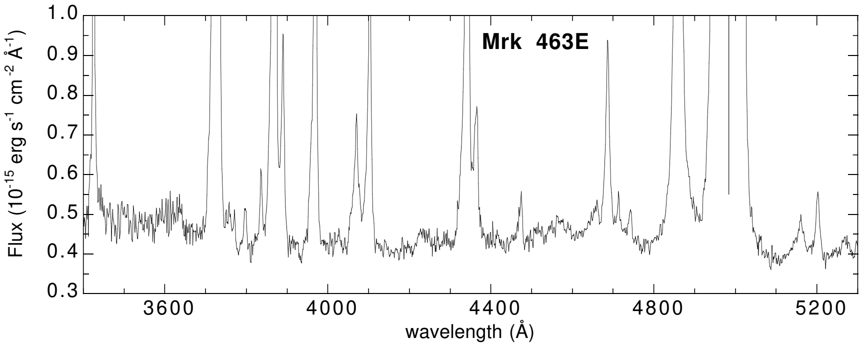


Fig. 6. Ground-based optical spectrum of Mrk 463E. It shows a broad emission feature at 4680 Å which origin is unkown but that it could be produced by Wolf-Rayet stars.

6 Conclusions

Our near-ultraviolet spectroscopy indicate that at least half of the brighest S2 show the higher order terms of the Balmer series and HeI lines in absorption. The analysis of the profiles of these lines using evolutionary synthesis models indicate that at near-ultraviolet wavelengths, the continuum is dominated by young and intermediate age population (Figure 7). The UV images and spectroscopy suggest that these Seyfert 2 galaxies harbor a nuclear starburst that is responsible for the FC in these objects. These nuclear starbursts are red and powerful. Their bolometric luminosities are similar to the estimated luminosities of their hidden S1 nuclei. This suggests that more powerful AGN may be related to more powerful central starburst. In the other half of the sample, the FC is weak and their origin may be related to scattered light from their obscured S1 nuclei or to nuclear starbursts that is much less conspicuous. These results are also in agreement with those found by Cid-Fernandes et al. (1998) and Schmitt et al. (1999) in a related work analyzing S1, S2 and Liners. They found that in 40% of the S2 targets of their sample the nuclear spectrum show stellar signatures from a young and/or intermediate age population.

Two special cases are Mrk 477 and Mrk 463E. They both show a very blue continuum, the stellar features very diluted and broad emission at 4680 Å. Recently, this broad emission has been found in other Seyfert galaxies (Storchi-Bergmann et al. 1998, Tran et al. 1999, Contini these proceedings). In all these cases, the broad emission is attributed to Wolf-Rayet stars. However, like in Mrk 463E, there is not an additional evidence of the presence of a starburst in the nucleus of these Seyferts. The exception is Mrk 477 (Heckman et al. 1997) where we detected ultraviolet resonance lines formed in the wind of massive stars. Additional HST+STIS observations are necessary to confirm that Mrk 463E and similar objects are really Wolf-Rayet-Seyfert galaxies.

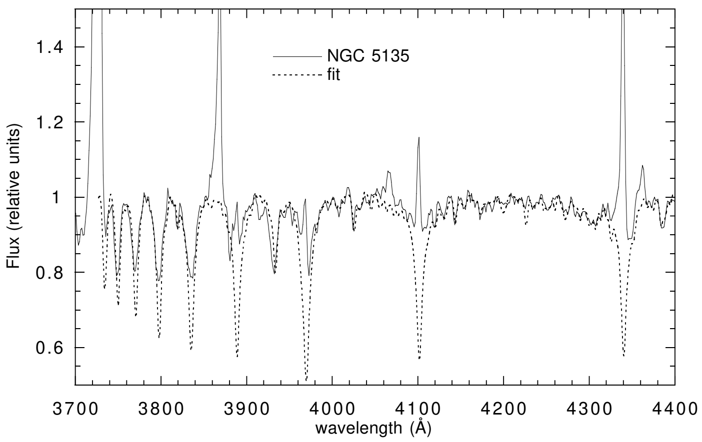


Fig. 7. Ground-based optical spectrum of NGC 5135 and the synthetic composite model that fit the profile of the stellar Balmer and HeI lines, and the strength of the CaII K and G band. The model has the contributions of a young starburst (3 Myr old), and an intermediate (a few hundred Myr old) and an old stellar population. The relative contributions of these components to the total light at 4400 Å is 50%, 40% and 10%, respectively.

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