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SEYFERT 1 MUTATION OF THE CLASSICAL SEYFERT 2 NUCLEUS NGC 7582[1]

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ABSTRACT

We report the transition toward a type 1 Seyfert experienced by the classical type 2 Seyfert nucleus in NGC 7582. The transition, found at most 20 days from its maximum peak, presents a unique opportunity to study these rare events in detail. At maximum, the Hα line width is about 12,000 km s^{-1}. We examine three scenarios that could potentially explain the transition: capture of a star by a supermassive black hole, a reddening change in the surrounding torus, and the radiative onset of a Type IIn supernova exploding in a compact nuclear/circumnuclear starburst.

Subject headings: galaxies: active — galaxies: individual (NGC 7582) — galaxies: Seyfert — galaxies: starburst — supernova remnants

1. INTRODUCTION

The last decade has seen a significant advance in our way of understanding the phenomenology of various classes of active galactic nuclei (AGNs) under the concept of orientation (see Antonucci 1993 for a review). Unified schemes postulate the existence of a dusty obscuring torus that hides both the broad-line region (BLR) and the continuum-emitting zone when seeing the nuclear region of an AGN edge-on. Types 1 and 2 Seyfert nuclei would then be exactly the same kinds of objects but viewed from different angles, such that the line of sight does or does not cross the dusty torus. This configuration can explain several observables of Seyfert 2 nuclei, such as the detection of broad lines in polarized light at optical wavelengths (Antonucci & Miller 1985; Miller & Goodrich 1990), which are directly detected in near-IR light (Goodrich, Veilleux, & Hill 1994), the presence of kiloparsec-scale ionizing cones (Pogge 1988, 1989; Tadhunter & Tsvetanov 1989), and the steepening and excesses of far-IR colors (Maiolino et al. 1995; Spinoglio et al. 1995; Pérez-García, Rodríguez-Espinosa, & Santolaya Rey 1998).

A problem still arises when analyzing in detail where the blue continuum observed in Seyfert 2 nuclei comes from. Classically, this was regarded to be light scattered by dust or hot electrons in the ionized region illuminated by the nucleus. However, the different polarization levels of broad lines and continuum (e.g., Miller & Goodrich 1990; Tran, Miller, & Kay 1992) and the absence of residual broad lines in directly received optical light argue in favor of the existence of a second continuum source, most probably a region of star formation that surrounds the dusty torus (Goodrich 1989a; Cid Fernandes & Terlevich 1995; Heckman et al. 1995). Starbursts in the nuclei of Seyfert 2 galaxies have indeed been detected through near-IR photospheric absorption features characteristic of red supergiant stars (Terlevich, Díaz, & Terlevich 1990; Oliva et al. 1995). Some of these dominate the observed continuum from the near-UV to the near-IR and have resolved sizes of a few hundred parsecs (Heckman et al. 1997; Colina et al. 1997; González Delgado et al. 1998).

NGC 7582 is a classical Seyfert 2 nucleus, as indicated by the relatively high excitation measured from the [O II] λ3727/[O III] λ5007 ratio plus the simultaneous presence of strong [Ne V] λ3425, He II λ4686, [O I] λ6300, and [N II] λλ6548, 6584 lines. Many of the nuclear properties in NGC 7582 also support a unified scheme. A sharp-edged [O III] outflow in the form of a cone is observed (Morris et al. 1985; Storchi-Bergmann & Bonatto 1991). Optical spectropolarimetry does not reveal a hidden BLR, but since the far-IR colors 60–25 μm are very red, the absence has been taken as support for an edge-on thick torus able to block even the light scattered toward the observer (Heisler, Lumsden, & Bailey 1997). Indeed, a large column density of neutral H also blocks the hard X-rays, implying a large obscuration (Warwick et al. 1993).

The presence of stars in the nucleus is now firmly established. Morris et al. (1985) found a steep gradient of Hα perpendicular to the [O III] cone, which they interpret as a 1 kpc disk of H II regions oriented at 60° from the plane of the galaxy (see their Fig. 10). The CO absorption lines and large near-IR light-to-mass ratio are similar to those of H II galaxies and a factor of 5 larger than those of normal galaxies, indicating that red supergiants dominate the light of the inner 200 pc at those wavelengths (Oliva et al. 1995).

This Letter analyzes new spectroscopic and surface photometry data that show that NGC 7582 has experienced a transition to a Seyfert 1 stage. This transition is a challenge to reconcile with unification schemes since the IR–to–X-ray data indicate that we are viewing the nucleus through a large column of obscuring material.

2. DATA ACQUISITION AND ANALYSIS

Three spectra of NGC 7582 were obtained at ESO–La Silla with the Danish 1.54 m and ESO 3.6 m telescopes from 1998 July 11 to October 21. The journal of observations in Table 1 contains the relevant information regarding setups and exposure times. The slit was always centered on the nucleus of the galaxy and oriented at P.A. = 24°. The total integration time per night was split in two or three integrations in order to be able to remove the effect of cosmic rays in the co-added final spectrum. Standard stars were observed all nights, except on October 6. The frames have a scale of 0".39 pixel^{-1} with the 1.54 m telescope and 0".15 pixel^{-1} with the 3.6 m telescope.

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TABLE 1
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Date (1998)	Telescope	Instrument	Slit (arcsec)	Exposure Time (s)	Range (Å)	Resolution (Å)	Seeing (arcsec)
Jul 11	Danish 1.54 m	DFOSC + Loral/Lesser CCD	2.0	2700	3700–6700	3	1.5
Oct 6	Danish 1.54 m	DFOSC + Loral/Lesser CCD	1.5	3600	3700–6700	3	1.5
Oct 21	ESO 3.6 m	EFOSC2 + Lesser CCD	1.5	900	3380–7540	4	1.3

NOTE.—EFOSC is the ESO Faint Object Spectrograph and Camera, and DFOSC is the Danish Faint Object Spectrograph and Camera.

The data were reduced using the IRAF software package in a standard way. The CCD frames were first bias subtracted and then flat-field corrected. Wavelength calibration with He+Ar lamps and flux calibration with the corresponding stars was then performed, and the sky was subtracted using the outermost parts of the slit. The spectra were internally flux-calibrated to the same relative scale using [N II] λ6583 and, independently, also [O III] λ5007, under the standard assumption that the flux of the narrow forbidden lines of AGNs does not vary on such short timescales (e.g., Korista et al. 1995).

Two *R*-band images of 30 and 90 s were also obtained on July 11 and October 21 with the same telescope configuration. The reduction involved bias subtraction and flat-fielding. Calibration with a photometric standard star was obtained relative to the field stars of the frames.

Figure 1 displays spectra that we extracted binning pixels along the spatial direction over 2″, which corresponds to 150 pc at the recession velocity of the galaxy $v_r = 1575$ km s^{-1} (de Vaucouleurs et al. 1991) for $H_0 = 50$ km s^{-1} Mpc^{-1}. The top panel shows a spectrum of NGC 7582 taken well before the transition (Cid Fernandes, Storchi-Bergmann, & Schmitt 1998). This remained unchanged as a Seyfert 2 spectrum until at least 1998 June 20 (Halpern, Kay, & Leighly 1998). Note that the spectrum of October 6 is not flux calibrated.

The spectrum of July 11 clearly shows broad Hα, Hβ, Na I, and Fe II emission, absent in the previous record. The broad component of the Balmer emission lines is well represented by a single Gaussian of FWHM = 12,400 km s^{-1} blueshifted by 1980 km s^{-1} with respect to the narrow FWHM = 260 km s^{-1} lines. By October 6, the broad Hβ has disappeared, but broad Fe II, Na I, and a prominent Hα of FWHM = 7870 km s^{-1} is still present, redshifted by 1570 km s^{-1} with respect to the narrow lines. The October 21 spectrum shows a further decline of the broad Hα line to FWHM = 6660 km s^{-1}. It should be noted that although the broad Hβ line is not apparent in the spectra after October 6, when the bulge population is subtracted, a very weak broad line is indeed present. The continuum flux of the nucleus at 6260 Å decreases by 50% between July 11 and October 6 and increases by 30% between October 6 and 21.

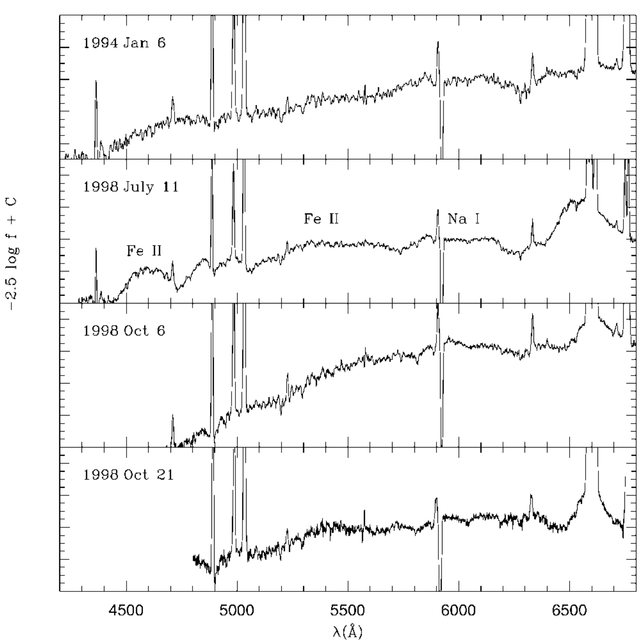

FIG. 1.—Spectra of NGC 7582's nucleus

In order to check if the transition is actually nuclear, we have calculated the astrometry of the nucleus relative to field stars in our *R*-band images obtained after the transition and in an archival image taken on 1995 June 16 (before the transition) with the Wide Field Planetary Camera 2 (WFPC2) of the *Hubble Space Telescope* (*HST*). We find that the centroid of the nucleus is at the same position, inside an error box of 0″.16, i.e., 12 pc.

3. DISCUSSION

Figure 1 shows that shortly before July 11 the nucleus of NGC 7582 developed broad permitted lines characteristic of a Seyfert 1 nucleus (Joguet, Kunth, & Terlevich 1998). While variability is a common characteristic of Seyfert 1 nuclei and QSOs, which are known to undergo prominent variations (e.g., Peterson 1993) that lead even to the temporal disappearance of broad lines (e.g., Antonucci & Cohen 1983; Penston & Pérez 1984; Alloin et al. 1986), it is actually a rarity among Seyfert 2's and LINERs. Apart from the transition experienced by NGC 7582, reported here, three other classical Seyfert 2 nuclei and one LINER developed broad lines in the past: Mrk 6 (Khachikian & Weedman 1971), Mrk 993 (Tran, Osterbrock, & Marel 1992), Mrk 1018 (Cohen et al. 1986), and NGC 1097 (Storchi-Bergmann, Baldwin, & Wilson 1993). The nucleus of NGC 7582 is, however, the only one caught *in fraganti* at such an early stage in the transition.

In some cases the sudden development of broad lines has been interpreted in the literature as transients associated with the disruption and capture of stars by a supermassive black hole. The frequency of such events in a normal spiral galaxy is predicted to be 10^{-4} yr^{-1} (Rees 1988). The number of narrow-lined AGNs registered in the Véron-Cetty & Véron (1998) catalog is 701, including those with reported obscured or scattered broad lines. The probability of five of them undergoing a capture phenomenon in the last 30 yr is 4%, assuming a Poissonian temporal distribution of the captures and a continuous monitoring or long-lasting events. In the case of NGC 7582, this could be possible if the idea of the dusty torus around the nucleus is dropped. A torus would otherwise block all the optical light coming from the surroundings of the black hole.

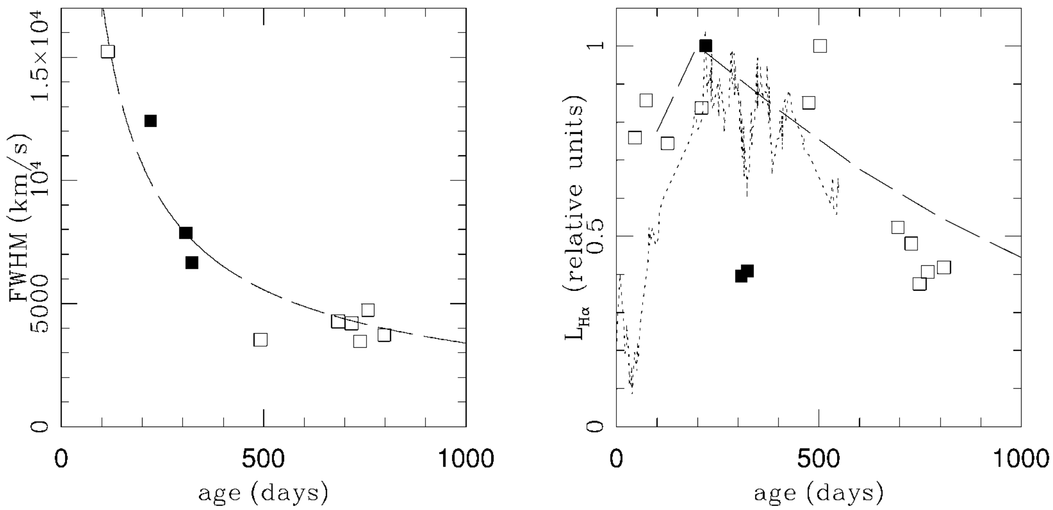

FIG. 2.—Evolution of Hα line width and luminosity for NGC 7582 (*filled squares*), SN 1988Z (*empty squares*), NGC 5548 (*dotted line*) and the semianalytical solution for a cSNR (*dashed line*).

As a matter of fact, two of the transition cases mentioned above (Mrk 993 and Mrk 1018) have been proposed to be explained in the framework of unification by patchy dusty tori that suddenly let the nuclei be directly seen through regions with small covering factors or light obscuration. Goodrich (1989b, 1995) finds evidence for a very weak, previously unnoticed, broad Hα line before the transitions to Seyfert 1 stages in these two nuclei and argues that the flux changes derived from continuum bands and broad lines at different wavelengths are consistent with the simple hypothesis of a change in reddening. In the case of NGC 7582, the BLR reddening before and after the transition cannot be checked since we find no evidence of a weak broad line before the transition. The continuum change measured at 5026 and 6260 Å is, however, inconsistent with a reddening change given by a local reddening law: the fluxes at 5026 Å of the 1994 January 6 and 1998 July 11 spectra, after bulge subtraction, imply $\Delta E_{B-V} \approx 0.3$ mag and at 6260 Å imply $\Delta E_{B-V} \approx 1.3$ mag. Some residual stellar light must still be present here, since young stellar populations are located near the nucleus. Schmitt, Storchi-Bergmann, & Cid Fernandes (1999) account these to be at least 6% of the total nuclear light. If we assume a continuum shape typical of starbursts, $f_\nu \propto \nu^\beta$ with $\beta \approx 0$–1 at an age $\lesssim 10^7$ yr (e.g., Leitherer et al. 1999), we still have reddening changes ranging from $\Delta E_{B-V} \approx 1.1$ to 2.3 mag at 5026 Å and from $\Delta E_{B-V} \approx 3.3$ to 3.5 mag at 6260 Å, inconsistent with one another. Furthermore, it would be difficult to understand how the BLR light has managed to traverse a torus with about 200 mag of extinction (A_V), as derived from X-ray absorptions. However, the column density of absorbing material has been reported to change even a factor of 3 in the last 13 yr (Warwick et al. 1993; Xue et al. 1998). X-ray data will shed new light into the possibility of a reddening change in the torus. Possible caveats of the optical estimations are, on one hand, that these are based on the local reddening law and, on the other, that the contamination of the young nuclear/circumnuclear stellar component has been removed through modeling in the absence of high spatial resolution and/or a wider spectral coverage.

A more fundamental concern in this analysis is whether the BLR and the continuum light will actually be crossing the same obscuring regions of the torus. In principle, a model could be built in which the BLR light might pass through clearance zones not reached by the continuum light. This, however, seems rather ad hoc.

An alternative possibility to explain the transition can be found resourcing to phenomena that might occur around the torus and that are not necessarily related to the central engine of the AGN. The nuclear/circumnuclear starburst, detected at a radius $r < 100$ pc (Oliva et al. 1995), is a possible source, since it must produce supernova (SN) explosions.

From an age of 10–60 Myr, a starburst sustains an SN rate directly proportional to the blue light emitted by the stars in the cluster (Aretxaga & Terlevich 1994). The luminosity of the inner 3″ of NGC 7582 before the transition is $V = 15$ mag (Kotilainen, Ward, & Williger 1993). The luminosity profile at this stage is not very peaked, as shown in *HST* images (Malkan, Gorjian, & Tam 1998) in which the luminosity of the nucleus changes by 3 mag when using apertures ranging from 0″.5 to 0″.1. The stellar populations of the nucleus at optical wavelengths are best represented by old ages ($t > 100$ Myr) with 6%–12% contamination by a reddened $E_{B-V} \approx 0.6$ mag starburst + featureless continuum (Schmitt et al. 1999). Therefore, the intrinsic luminosity of the starburst nucleus is about $M_B \approx -17$ mag, and the SN rate would then be $\nu \approx 0.02$ yr^{-1}. If all the SN explosions generate broad lines, there is a 33% probability of having detected a transition to a Seyfert 1 stage in the last 30 yr.

A typical SN can increase the luminosity of the host cluster by about 2 mag. Classical Type II SNe, however, show spectral features, like P Cygni profiles, which do not compare with the observed Gaussian profiles of the Balmer lines in NGC 7582. The only possible exception could be SN 1983K, which showed prominent broad emission lines at maximum and a typical plateau evolution of about 100 days (Phillips et al. 1990).

On the other hand, since the discovery a new kind of SN with spectral features similar to those of Seyfert 1 nuclei (Filippenko 1989), there has been a wide record of new events in SN catalogs and a body of studies that highlight their exceptional characteristics. The new SN group, named SN IIn (Schlegel 1990; Filippenko 1997), shows variable broad emission lines of up to FWHM $\approx$ 20,000 km s^{-1}, sitting below prominent narrow emission lines (hence the "n"), and a light decay much flatter than typical SN. The absence of the characteristic P Cyg profiles of expanding atmospheres throughout their evolution is remarkable. Some of these SN IIn are exceptionally bright at radio, optical, and X-ray wavelengths, with total radiated energies of several times 10^{51} ergs in less than a decade (Aretxaga et al. 1999), i.e., 2 orders of magnitude more than typical SN events. These properties have been interpreted in the light of quick reprocessing of the kinetic energy released in the explosion by a dense circumstellar medium (Chugai 1991; Terlevich et al. 1992) and thus explain the phenomenon as a young and compact supernova remnant (cSNR) rather than an SN.

There is little doubt that if a SN IIn explodes in the center of a normal galaxy, the nucleus would be classified as a Seyfert 1, while the prominent broad lines remain visible. In fact, there has been a succession of theoretical works that explain the phenomenology of lines and continuum at UV to near-IR wavelengths in Seyfert 1 nuclei in terms of a starburst that undergoes SN IIn explosions (e.g., Terlevich et al. 1992, 1995; Aretxaga & Terlevich 1994).

Figure 2 plots the evolution of the Hα line width and luminosity as a function of time compared with the values found in one of the best followed-up SN IIn, SN 1988Z (data from Aretxaga et al. 1999), and the Hβ luminosity evolution of the Seyfert 1 NGC 5548 (data from Korista et al. 1995). The time axis for the comparison is uncertain. We have opted to match the light curves of SN 1988Z, NGC 7582, and NGC 5548 at the maximum light. This also matches the minimum in the light evolution of NGC 5548 as the onset of the "elementary unit of variation" in Seyfert 1 nuclei proposed by Cid Fernandes, Terlevich, & Aretxaga (1997). All fluxes have been normalized to the maximum value. The line-width evolution of NGC 7582 closely resembles the early evolution of SN 1988Z, but the early evolution of the line intensity seems much steeper than that experienced by SN 1988Z or NGC 5548.

A close multiwavelength monitoring of this object is thus required if we want to elucidate the mechanism that has created the broad lines despite the thick torus that supposedly still exists, which blocks the inner nuclear region from the line of sight. In particular, it would be interesting to check if the evolution of the flare experienced by NGC 7582 shows a behavior similar to SN 1988Z or NGC 5548 (common to other Seyfert 1's), represented in Figure 2. This is not necessarily the case if the variation is driven by a change in the column of obscuring material that crosses our line of sight.

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