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Discovery of an emitting ring in the Seyfert 1 galaxy UCM 2329+2500

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Abstract. We analyze a rather interesting galaxy discovered during the UCM survey for new Hα emission-line galaxies. The new galaxy UCM 2329+2500 presents a compact core that hosts a Seyfert 1 nucleus. The spectrum of the Seyfert nucleus presents broad components (FWHM=8000 km s^{-1}) and asymmetric profiles at the Balmer lines showing a secondary peak more apparent on the Hβ line and also observed in the Hα deblended line. Only traces of profile variability have been detected during spectroscopic observations at four different dates spanning 29 months.

Eight kpc away from the nucleus, a ring-like structure that surrounds the core is observed. A long slit spectrum at PA 45° has revealed emission lines coming from both sides of the ring. The emission detected is prominent at a condensation observed on the red image. Star formation is the most plausible explanation. A high obscuration is also observed. All this information is coherent with a galactic encounter scenario.

Key words: galaxies: individual: UCM 2329+2500 – galaxies: structure – galaxies: Seyfert

1. Introduction

The conventional view (Rees 1984) for explaining Active Galactic Nuclei (AGNs) is that nuclear activity is caused by accretion onto a massive black hole through a disklike structure. Unfortunately, the expected signatures of this accretion process are rather ambiguous, being asymmetric double-peaked profiles of the permitted lines the most relevant ones. However only a small portion of AGNs shows these characteristics. Prime candidates are radiogalaxies such as Akn 120 (Peterson et al. 1985), 3C 390.3 (Oke 1987), NGC 1097 (Storchi-Bergmann et al. 1993), Arp102B (Chen & Halpern 1989), and 3C 332 (Halpern 1990). All of them show double-peaked Balmer profiles whereas several present profile variability. The most recent candidates are NGC 985 (Rodríguez-Espinosa et al. 1990, Stanga et al. 1991) and IRAS 02366-3101 (Colina et al. 1991). Both objects have a peculiarity: they are AGNs surrounded by a more or less ring-like structure with traces of star formation.

UCM 2329+2500 was found as a result of the Universidad Complutense of Madrid survey (Zamorano et al. 1994) for new Hα emission-line galaxies. It is located at $23^h29^m25\overset{s}{.}3$+25°00′59″ (B1950.0). We present the discovery of a nearly complete annular structure which shows emission at the same redshift that the nucleus. The spectra of UCM 2329+2500 have also revealed remarkable double-peaked profiles of the Balmer lines. At what follows we will discuss (i) the Seyfert 1 nucleus, (ii) the ring and (iii) the promising occurrence of an active nucleus and a ring where star formation is taking place.

2. Observations

The image presented in Fig. 1 was acquired with the 2.2m telescope at Calar Alto Observatory, Spain, on June 3th 1989 through a Gunn-Thuan r filter. The exposure time was 1800s and the seeing was of 2″ at FWHM. The pixel size was equivalent to 0.″35 projected on the sky. The integrate apparent r_{25} magnitude in this band results 15.2±0.1. After coadding original IRAS data the infrared colours obtained pointed to its Seyfert-like nature (Rego et al. 1993).

On June 17th 1991, a spectrum was obtained with the IDS spectrograph mounted on the 2.5m Isaac Newton Telescope, La Palma, Spain. The spectrum confirmed UCM 2329+2500 as a Seyfert 1 at z=0.0297 but its low signal to noise ratio prevented a more refined analysis. Since then, several spectroscopic observations have been made for monitoring this peculiar object. On January 21st 1993 we used the Cassegrain focus of the 2.2m telescope, Calar Alto Observatory, Spain, to obtain three consecutive spectra of 3600s each. The width of the entrance slit was 2.″65 and the effective wavelength resolution 5 Å (300 km s^{-1}).

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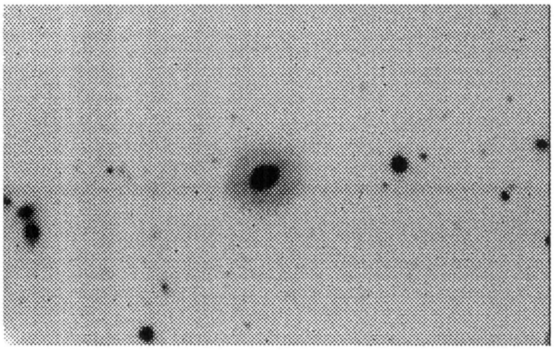

Fig. 1. Direct image of UCM 2329+2500. North is up and East to the left in this $2' \times 3'$ CCD image in the light of the Gunn-Thuan r filter

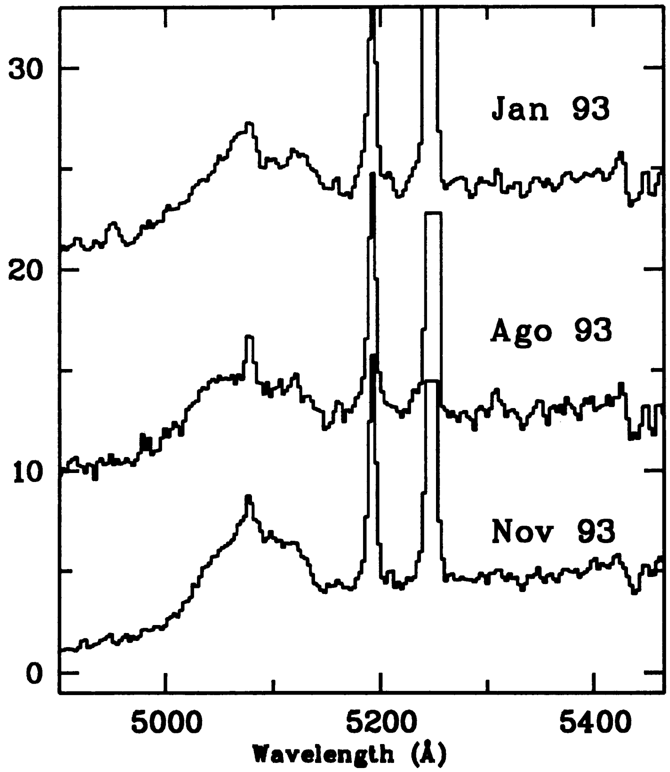

Fig. 2. Spectra of UCM 2329+2500 obtained at three different epochs. For presentation purposes, each spectrum has been shifted vertically and the [OIII]λ5007Å line truncated

The spatial resolution was 1.″43 pixel^{-1}. Another similar spectrum was taken on August 14th 1993.

Finally, on November 14th, another 3600 s spectrum was taken with the 2.5m INT telescope at La Palma. The slit was oriented at PA 45° in order to obtain spectral information of the ring, specially at the NE condensation. This time the spatial resolution and the measured seeing were much better (0.″5 pixel^{-1} and 1.″3 FWHM respectively). The effective wavelength resolution, using a 1″ slit, was 4 Å (240 km s^{-1}). All data have been reduced with the ESO–MIDAS package following the standard reduction process.

3. The Seyfert nucleus

The nucleus of UCM 2329+2500 shows a typical Seyfert 1 spectrum with bright, high ionization emission-lines. Broad and strong Balmer lines (up to 12000 km s^{-1} FWZI) with narrow emission cores are seen. Forbidden lines of various elements and of various degrees of ionization are also present in the spectra. The intrinsic color excess corresponds to E(B-V)=0.6.

The spectra of UCM 2329+2500 obtained on January, August, and November 1993 are shown in Fig. 2 for the Hβ. The final spectrum for January has been obtained by performing an average of the three images. Several main differences between the spectra presented are worth mentioning: (i) the narrow Hβ line is always fixed at the same position and relative intensity, (ii) there is a secondary redward peak which is easily seen in January and August spectra but on November it has almost disappeared, (iii) the blue side seems to be variable and (iv) the continuum level remains constant within 10%.

A similar behavior is seen in the Hα line. However the blending of [NII] lines prevents a detailed analysis. Different tries of deblending these lines, subtracting scaled [NII] lines models for instance, were rejected due to the subjective nature of the process. That is why we will focus in the Hβ profile.

Although a more intense monitoring of the spectral changes of UCM 2329+2500 would be desirable, we can extract some tentative conclusions. From a purely phenomenological perspective, we take this variation as evidence that there are at least two essentially independent components of the broad-line region. There are several theoretical models for explaining the observed line profiles. The model of Smith (1980) who proposed that the double–peaked broad–line profiles were due to Balmer absorption in a broad line cloud along the line of sight. A big objection for this hypothesis is that it cannot easily explain the change in the relative strength observed of the red and blue sides of the lines. Also the relativistic accretion disk hypothesis where the basic idea is that the gas that originates the broad-line component is spinning in a relativistic accretion disk around a central black hole. The absence of low-velocity gas leads to a pronounced dip at the line center. Using the formalism developed by Chen & Halpern (1989) is not possible to explain a red component brighter than the blue one, as commonly observed. The most believable theoretical explanation is the model of a supermassive binary formed at the nucleus of the galaxy (Gaskell 1988 for a review), with a binary BLR surrounding a pair of orbiting black holes. Monitoring of the line profiles should reveal changes both in the radial velocity of the peaks and continuum level. Unfortunately, the time scale is several years, so no observational confirmation for this suggestion has been obtained yet.

4. The ring

After an inspection of the deep r image shown as Fig. 1, a faint annular structure can be detected at distance of about nine arcsec

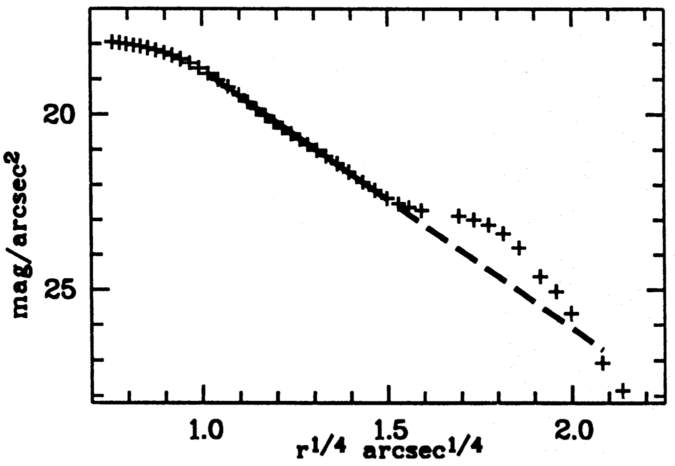

Fig. 3. Brightness profile plotted vs. $r^{1/4}$

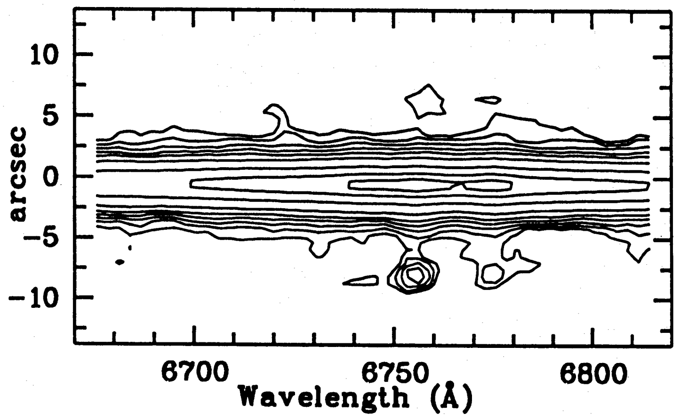

Fig. 5. Contour plot of the two dimensional spectrum in logarithmic scale. Hα and [NII] emission are visible at both sides of the nuclear spectrum

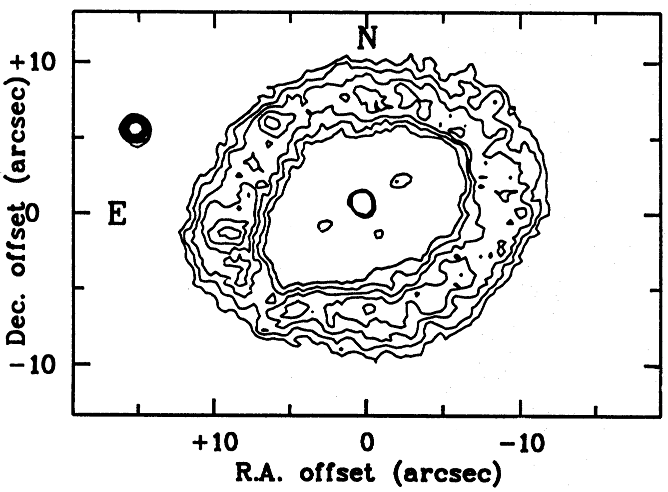

Fig. 4. Contour plot of the image obtained after subtracting the model to the original CCD image

from the center of the galaxy. The existence of a "light bump" at such distance (8 kpc) is evident when the surface brightness profile is plotted. The best fit obtained by a $r^{1/4}$ law is shown (thick line) along with the brightness profile in Fig. 3. When a galaxy model is constructed from the brightness profile fit and subtracted from the galaxy, the existence of an elongated and almost complete ring with several substructures is unambiguously established (Fig. 4). It is centered with respect to the galaxy and appears at a position angle PA 135°. Its edges are sharp being the internal and external diameters 15″ and 22″ at PA 135°and 12″ and 20″ at PA 45°. Assuming an intrinsic circular shape the inclination from the observer's line of view is ~30°.

Our first spectroscopic data of the ring was obtained at the INT on November 14th. A contour plot of the two dimensional spectrum showing the Hα+[NII] region is presented in Fig. 5. Despite the high signal present at the center corresponding to the Seyfert nucleus, at both sides can be easily seen not only Hα even [NII] emission lines at the same redshift of the nucleus and at the distance of the ring. The strongest emission corresponds to the knot situated at PA 45° .

The emitting gas responsible for the emission observed in the ring could be ionized by a shock front or photoionized by young stars during star formation processes. It is difficult to explain the observed ratio [NII]6583/Hα=0.4 as the result of a shock ionization process. Moreover, star formation is a more plausible explanation since the Hβ line in the ring is not observed, which indicates a large amount of obscuration. The Hα/Hβ ratio derived from a 2σ upper limit to the Hβ flux density is 6. Assuming the recombination value of 2.87 for Hα/Hβ ratio of a typical HII region at T=10^4 K, a lower limit to the true extinction E(B-V)=0.7 (A_v=2.2) is obtained.

The Hα flux measured on the projected slit of 1″× 3″ is (0.36±0.02) × 10^{-15} erg cm^{-2} s^{-1}, that corresponds to 1.9 × 10^{-15} erg cm^{-2} s^{-1} corrected flux. In order to obtain a raw estimate of the total star formation taking place on the ring, this flux can be scaled using the direct image as reference. As the r filter includes both continuum and emission lines, this scale factor (85×) would be reliable only if the equivalent width of Hα were constant along the ring. The total Hα luminosity derived amounts to 6.1 × 10^{41} erg s^{-1}. Following Kennicutt (1992) we obtain a star formation rate SFR ~ 2 $M_\odot$ yr^{-1} if stars more massive than 2 $M_\odot$ are included. This value should be taken also as a lower limit. Finally, the value observed for the equivalent width of Hα, i.e. EW(Hα)= 40 Å, points to a stellar population not very young. The general behavior is a process of enhanced star formation in a dusty environment several gigayears old. From the r image intensity, all the ring seems to have a simultaneous age but this can not be proved with our observations.

5. Summary and discussion

We have been dealing with two unusual features associated with the galaxy UCM 2329+2500: One spectroscopic, the other morphological. The former is the double-peaked appearance of the broad emission-line profiles in the spectrum of the Seyfert 1 nucleus itself; the latter is the ring-like structure extending about

10″ from the core. Both of these phenomena, though apparently rare among active galaxies, are nevertheless of general interest. It is even possible that the two are related. Our results of the two different observational phenomena we have been discussing are in some sense converging.

Certainly one of the most plausible mechanisms for the accretion disk or even a possible supermassive binary is through the merger of two galaxies. In a merger, the two nuclei coalesce rapidly and the characteristic time scale for the formation of a long–lived supermassive binary can be short compared with the lifetime of large–scale signatures of the interaction, such as tails or rings. Thus, if the broad–line profiles are indeed indicative of a supermassive binary, this binary may have resulted from the same interaction responsible for the ring. Evidence that strong interactions and mergers may be important in triggering nuclear activity in galaxies has been discussed for nearly a decade (see Stockton 1990 for a review). It is important to emphasize that interactions have several possible signatures (bridges, rings, enhanced star formation, etc). Whether any one or more of these is produced in any given case depends on such factors as the relative masses of the interacting galaxies, the gas content or the relative orientations of the participants.

Given the special case of UCM 2329+2500 it could be addressable to think about an old encounter between two galaxies. Both of them with small gas content. Moreover, the field is crowded with faint galaxies, indicating a not small probability for this phenomena. There are several evidences pointing to an old merging process. The possible burst of star formation observed on the ring is not very young as deduced from the observed equivalent width of Hα, and the ring itself is well marked. This process may as well have been relevant for the onset of Seyfert activity in the nucleus (Weil and Hernquist 1993). So far similar cases have been found at low–redshift QSOs as OX169 (Stockton and Farnham 1991) 3C48 (Stockton 1990) or Mrk 1014 (Stockton 1990 and references therein). Our observations of UCM 2329+2500 suggest that our object may be only the less luminous extreme of a distribution ranging the Seyfert phenomena, with the fainter examples virtually undetectable unless special conditions.

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References

Chen K., Halpern J.P., 1989, ApJ, 344, 115
Colina L., Lípari S., Macchetto F., 1991, ApJ. 382, L63
Gaskell C.M., 1988, in Active Galactic Nuclei, ed. H.R. Miller & P.J. Witta (Berlin:Springer), 61
Halpern J.P., 1990, ApJ Letters 365, L51-L54
Kennicutt R.C. Jr., 1992, ApJ, 388, 310
Oke J.B., 1987, in Superluminal Radio Sources, ed. J.A. Zensus and T.J. Pearson, Cambridge Univ. Press, 267
Peterson B.M., Meyers K.A., Capriotti E.R., et al. 1985, ApJ, 292, 164
Rego M, Cordero-Gracia M., Zamorano J., et al. 1993, ARA&A, 19, 137
Ress M.J., 1984, ARA&A, 19, 137
Rodríguez Espinosa J.M., Stanga R.M., 1990, ApJ 365, 502
Stanga R.M., Rodríguez Espinosa J.M., Mannucci F., 1991, ApJ, 379, 592
Smith H.E., 1980, ApJ, 241, L137
Stockton A., 1990, in Dynamics and Interactions of Galaxies, ed. R. Wielen Heidelberg: Springer-Verlag
Stockton A., Farnham T., 1991, ApJ, 371, 525
Storchi–Bergmann T., Baldwin J.A., Wilson A.S., 1993, ApJLetters, 410, L11
Weil M.L., Hernquist L., 1993, ApJ, 405, 142
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