The Variable Central Star of Planetary Nebula NGC 2346

L. Kohoutek, Hamburger Sternwarte

NGC 2346, known already to Sir William Herschel, has been classified as a planetary nebula by R. Minkowski (1946) on the basis of its appearance on direct photographs. Morphologically it possesses a distinct axial symmetry and belongs to the class of bipolar nebulae (Fig. 1).

The bright central star is of spectral type A (Aller, 1968) and cannot be responsible for the radiation of the nebula: the observed He II λ 4686 nebular emission line requires a source of ionizing radiation of at least 45,000°K. The binary hypothesis for the central star (A + sdO), based on photometry (Kohoutek, Senkbeil, 1973) was supported by Méndez et al. (1978) who found the stellar radial velocity to be variable. Later Méndez and Niemela (1981) derived an orbital period of $15^{d}.995 \pm 0^{d}.025$ for this single-lined spectroscopic binary.

In 1974 we included NGC 2346 in our list of bright central stars which were searched for variability using the ESO 50 cm telescope at La Silla. Between 1974 and 1980 we measured this star in 7 observing runs and found no substantial changes of its brightness ($V \simeq 11^{m}.2$). At present very careful reduction of these observations is being made which would detect even small light variations.

The observing period January–February 1982 at La Silla brought a rather surprising result: we recorded light variations over 2 mag obviously containing parts of two consecutive minima (Kohoutek, 1982). The minimum of February 1982 was broad with a depth of 2.2 mag in V and 2.6 mag in B. We interpreted it as a partial eclipse of the main A-type component and we tentatively classified the system as a semidetached close binary. However, further observations of Gathier using the Dutch 90 cm telescope at La Silla ruled out an eclipse by stars. Méndez, Gathier and Niemela (1982) reported further spectrograms taken in March–April 1982 which did not show any changes of the spectrum of the A-type star, even at light minimum. In addition, the radial velocity at minimum light was significantly larger than expected from the orbital motion. The rotation of the star was proposed to be the cause for this excess. Méndez, Gathier and Niemela suggested that a dust cloud is passing in front of the binary central star of NGC 2346. They derived the parameters of a single model and made the following predictions: the eclipse of the binary system (assuming an isolated spherical cloud) must have started in May or June 1981 and must finish in March or April 1983.

Fig. 1: ESO 3.6 m photograph of NGC 2346, March 12, 1977, 127-04 + RG 630, exp. 90 min, seeing 2.0 arcsec. (Photo: S. Laustsen.)

In January 1983 we obtained new UBV photometric data on NGC 2346 using the Bochum 61 cm telescope (Kohoutek, 1983). The lightcurve of the central star differed substantially from that of 1982: now we observed a narrow maximum reaching $V \simeq 12.5$ mag, $B \simeq 13.0$ mag only, and part of two very broad and deep minima with brightness ranging from 14.8 to 15.3 mag (V), and from 15.3 to 16.0 mag (B), respectively. Unfortunately, the Bochum telescope was too small for accurate photometry of such a faint star at minimum.

The main uncertainty of the photometry of the central star was evidently caused by the nebula (Fig. 2). At maximum the contribution of the nebular radiation, measured through a diaphragm of 18.2 arcsec, was small and the internal errors of the stellar V, B. U magnitudes could be estimated to be ± 0.01 mag, ± 0.02 mag and ± 0.06 mag, respectively. Near minimum light these errors increased to ± 0.10 mag (V) and ± 0.25 mag (B); the stellar U magnitudes were not reliable. In order to eliminate the contribution of the nebular radiation we measured through different diaphragms.

The V brightness of this variable observed in 1982 and in January 1983 are compared in Fig. 3 where the evolution of the lightcurve is clearly visible. Comparing the ascending branch of the minimum of January 1982 with that of February 1982 we can see a shift of 1.63 day: we assume that the total width of the January minimum was 3.26 days smaller than that of February, i.e. 11.6 days. If we extrapolate this evolution back we can estimate November 29 (± 5) 1981 to be the beginning of the present eclipsing behaviour. A similar result – November 1981 – was achieved by Schaefer (1983) according to the archival photographic plates at Harvard College Observatory. The first minimum probably occurred on December 8, 1981 with a total width of only 1.9 day. We suppose that the minimum of February 26, 1982 had already spread over the whole cycle and that the maximum started to diminish. We expect that by the beginning of October 1983 the maximum brightness will drop to 13.5 mag (V) and 14.0 mag (B). The brightness at minimum seems to decline quicker than that at maximum and not linearly with time. At present it is not clear how long the decrease of the minimum will last.

We have combined the time of two observed minima of 1982 (February and March/April) with the maximum in 1983 and obtained the following photometric elements:

$$\text{Min.hel.} = \text{JD } 244501\ 0.60 + 15^{d}.957 \times E$$
$$\pm .17 \qquad \pm .014 \quad \text{m.e.}$$

We have assumed that the minimum observed in January 1983 occurred at phase 0.50. Nevertheless, this assumption is

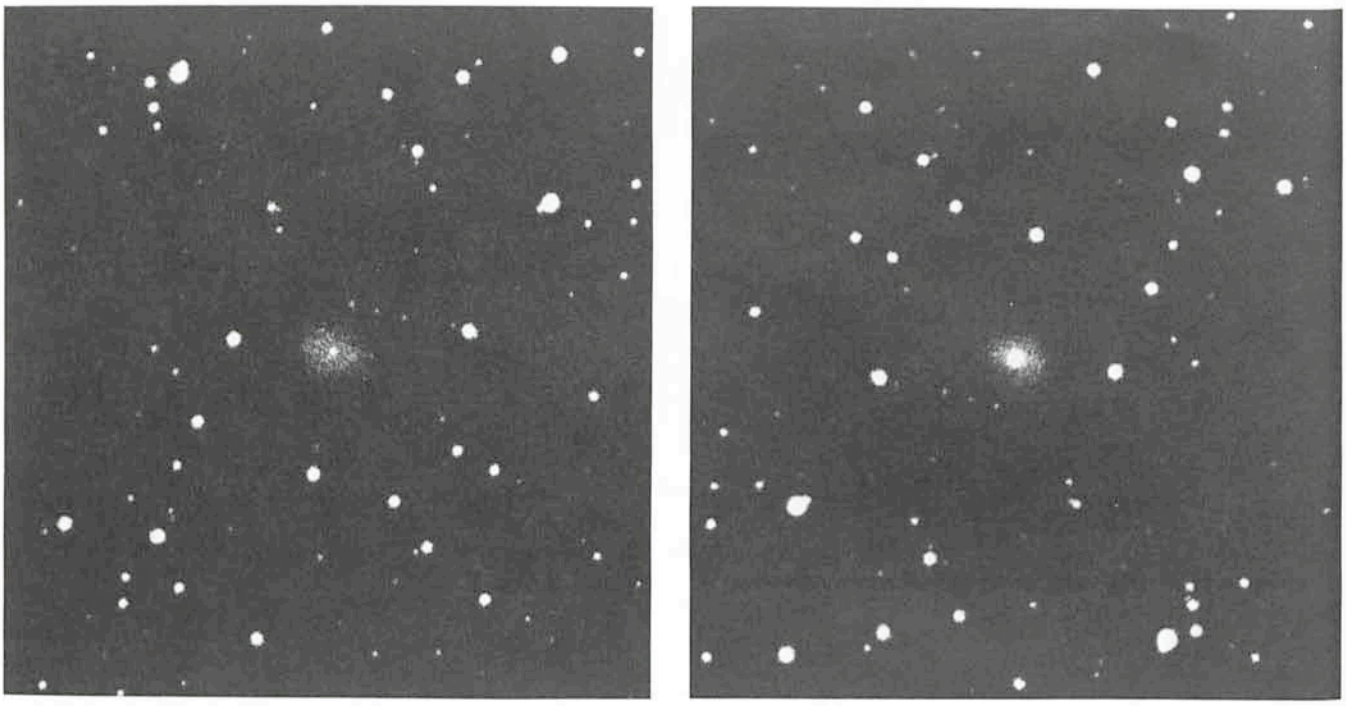

Fig. 2: *Photographs of NGC 2346 with the 80/120 cm Schmidt camera (moved from Hamburg-Bergedorf), DSAZ Calar Alto; 103a-D + GG 11 (V system), exp. 4 min. (a) Dec. 18/19, 1982 – near light maximum; (b) Dec. 11/12, 1982 – near light minimum. (Photo: L. Kohoutek.)*

rather uncertain and the effect of the phase on the derived period is large.

The photometric period is somewhat shorter than the period of the binary system based on the RV curve. At present we do not intend to discuss this small difference of about $0^{d}.04$ because it exceeds only slightly the errors of the period determination. However, a change of period could reflect evolutionary changes of the binary system, so that attention should be paid to this matter in the future.

The observed changes of the lightcurve and the duration of the present eclipse behaviour are not compatible with the simple model of Méndez et al. (1982). On the other hand, the existence of a dust cloud near the centre of NGC 2346 seems to be very likely. We have plotted the colour B-V versus V and found a linear relation with a slope of 6.6. If we interpret the

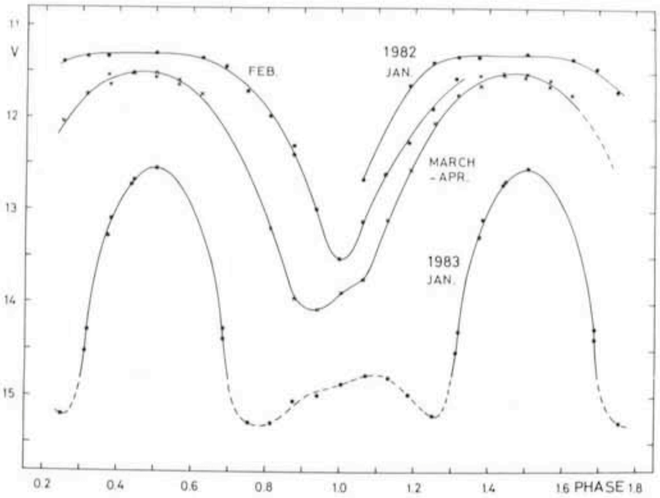

Fig. 3: *V lightcurves of the central star of NGC 2346 from 1982–83 as a function of phase ($P = 15^{d}.957$). Observations of March-April 1982 are from Méndez et al. (1982). Values below $V \sim 14^{m}.5$ are uncertain.*

brigthness drop of the central star as a result of an extinction in the dust cloud, the observed slope is then the ratio R of the total to selective extinction. Deviations up to $R \sim 6$ are well documented for some regions of star formation, but they would be unusual with planetary nebulae. Nevertheless, Greenstein (1981) found an anomalous reddening inside A 30 due to the dust, too.

The slope 0.86 of the relation U-B versus B-V, being greater than the standard value, is also evidence for high internal extinction. In addition, the older infrared observation (Cohen, Barlow, 1975) as well as recent measurements made by W. Wargau exhibit an appreciable near-infrared excess indicating a large amount of dust in NGC 2346.

Generally the internal extinction due to dust is not considered to be high in planetary nebulae. However, there are exceptions which reveal that the role of dust in planetary nebulae may be greater than expected. Let us mention A 30 and A 78, extended planetaries of very low surface brightness, which show a central concentration of IR emission. Cohen and Barlow (1974) suggested that the dust condensed in the outflowing stellar wind from the emission-line nuclei of these nebulae. A dust cloud (or shell) moving from the nucleus and causing the observed light changes can in principle also be imagined for NGC 2346.

The observations of binary and variable central stars can provide us with data which are very valuable for investigating the physical parameters and the evolution of planetary nebulae and their nuclei. NGC 2346 doubtless belongs to the most interesting objects of this class. The stellar lightcurve is rapidly changing, which obviously reflects varying geometrical or physical conditions. More and systematic observations would be necessary in order to understand the nature of the present eclipse phenomenon and the evolution of this puzzling system.

Acknowledgements

I would like to thank J. C. Duflot, R. Kiehling, T. J. van der Linden and H. M. Maitzen for their valuable additional observa-

tions of NGC 2346, and the staff of La Silla Observatory for assistance.

References

Aller, L. H.: 1968, IAU Symp. No. 34 – *Planetary Nebulae* (eds. D. E. Osterbrock and C. R. O'Dell), p. 339.
Cohen, M., Barlow, M. J.: 1974, *Astrophys. J.* **193,** 401.
Cohen, M., Barlow, M. J.: 1975, *Astrophys. Letters* **16,** 165.
Greenstein, J. L.: 1981, *Astrophys. J.* **245,** 124.
Kohoutek, L.: 1982, IBVS Budapest No. 2113 (see also IAU Circ. No. 3667).
Kohoutek, L.: 1983, *Monthly Notices* (submitted).
Kohoutek, L., Senkbeil, R.: 1973, *Mém. Soc. Roy. Sci. Liège*, 6e sér., t. V, 485.
Méndez, R. H., Niemela, V. S.: 1981, *Astrophys. J.* **250,** 240.
Méndez, R. H., Gathier, R., Niemela, V. S.: 1982, *Astron. Astrophys.* **116,** L5.
Méndez, R. H., Niemela, V. S., Lee, P.: 1978, *Monthly Notices Roy. Astron. Soc.* **184,** 351.
Minkowski, R.: 1946, *Publ. Astron. Soc. Pacific* **58,** 305.
Schaefer, B. E.: 1983, IBVS Budapest No. 2281.

CCD Pictures of Peculiar Galaxies with Jets or Extensions

H. Sol, Observatoire de Paris-Meudon

Astrophysical Jets

The phenomenon of "jets" seems to be rather universal in astrophysics. The astrophysical jets are seen in different wavelengths, from radio to X-rays. Their more general definition is "some emitting material well collimated along a straight or curved line". Such features appear on very different scales. Jets having a length of the order of a megaparsec and of a kiloparsec have been detected in different extragalactic systems, respectively QSO (e.g. 4C18.68; Gower, Hutchings, *Ap. J.* **253,** L1, 1982) and radio galaxies (e.g. PKS 0521-36; Danziger et al. *MNRAS,* **188,** 415, 1979). Jets of a few parsecs have also been suspected in galactic objects as the exotic SS 433, Sco X-1 and R Aquarii. Königl (*Ap. J.,* **261,** 115, 1982) even proposed to call jets the asymmetrical outflows which appear in the models of bipolar nebulae, bipolar CO emission lobes and aligned Herbig-Haro objects. Part of the galactic jets could be miniature models of some of the extragalactic ones.

Jets in Galaxies

The presence of jet asymmetry is relatively frequent in the nuclei of galaxies. 50 % of the high-luminosity radio sources and 10 % of the low-luminosity ones show a jet of a few kiloparsecs; all strong X-ray radio galaxies could have a jet; and the asymmetry of the VLBI structures is usually the rule (Fomalont, Workshop on Astrophysical Jets, Turin, 1982). Precessing radio jets in the centre of our own galaxy have also been reported.

Difficulties arise if one tries to precise the first mentioned general definition and to classify the different cases of observed jets, because they do not seem to form a very homogeneous class of objects. In particular, their spectral properties are not well defined. A great number of jets is seen only in radio, but radio-quiet jets exist too, as the optical jets of NGC 1097 (Wolstencroft, ESO/ESA Workshop on Optical Jets, 1981). Other jets emit in both energy ranges, as the well-known jet of M87. Strong optical emission lines can be present without any continuum counterpart (NGC 7385), although cases with an optical continuum and no lines (M87) are also found, as well as intermediate cases with both optical continuum and line emission (3C277.3; Nieto, Workshop on Astrophysical Jets, Turin, 1982). That diversity implies that the materials and the radiation processes are not the same in all jets. The jet of M87 is probably made of a plasma which emits synchrotron radiation, while some other jets could be a mixture of stars and gas.

The first duty of a theoretical model of jets is to propose a way to break the usual spherical symmetry of many astrophysical phenomena. Astronomers found different possibilities: rotation of a compact object, anisotropy of the ambient medium, two-body interaction, magnetic field, etc. Two main families of jets have been suggested in the literature (i) matter ejected from an active nucleus, as the M87 jet, or relics of such an ejection, (ii) tidal extension or bridge due to gravitational interaction or collision of galaxies, as in the case of IC1182 (Bothun et al., 1981, *Ap. J.,* **247,** 42). Cases concerning both of those families could also exist, since for example the activities of galactic nuclei are expected to be enhanced during a collision event.

CCD Observations

Only a small number (< 20) of optical jets in galaxies have been studied in some detail until now. But a greater number of galaxies have been suspected by visual inspection of Schmidt plates to have a jet and are classified in different catalogues as "jet-galaxy" or "galaxy with extension". Last year I made a CCD survey of 50 of those suspected cases in order to search for and to study optical jets in a statistical way. Some jet galaxies already described in the literature have also been observed to be used as references: M87, 3C273, 3C120, IC1182, PKS0521-36. At the same time, new information has been obtained about them. The jet of 3C273 appears to be composed of 3 regions which coincide with the radio wiggles. The westward 4 arcsec optical elongation of 3C120 as well as the jet nature of the feature seen in PKS0521-36 are confirmed (Sol, Workshop on Astrophysical Jets, Turin, 1982.

The observations were made at the 1.5 m Danish telescope equipped with ESO's CCD during three different runs in January, July and November 1982. The CCD was still in its testing phase for the first two runs. Pictures of the galaxies have been obtained in different colours, using a set of broad-band filters which covers the wavelength range of the CCD response, from 4000 Å to 1 micron (B and V Johnson's filters and g, r, i and z filters described in Wade et al., *PASP,* **91,** 35, 1979).

As mentioned by Pedersen and Cullum in the *Messenger* of December 1982, the CCD data reduction is not completely without problems if one wants to optimize the CCD capabilities. The first difficulty to face is the correction of several effects as the discrepancy in sensitivity of the different pixels, the non-linearity of the cold columns and the interference rings due to the night sky emission lines. A good and easy way to clean the pictures from those three effects is simply to divide the frame of scientific interest by a correction frame, the offset and dark current being first subtracted from both frames respectively. The correction frame is a picture of the night sky obtained by