THE ASTROPHYSICAL JOURNAL, 295:L17–L20, 1985 August 1

HIGH-VELOCITY BIPOLAR MASS FLOW IN THE PLANETARY NEBULA NGC 2392

FRANK GIESEKING, INGO BECKER, AND JOSEF SOLF
Max-Planck-Institut für Astronomie
Received 1985 January 24; accepted 1985 May 6

ABSTRACT

Detailed spectroscopic observations of a high-velocity component in the velocity field of the "Eskimo" nebula, NGC 2392, are presented. It is interpreted as a jetlike multiknot bipolar mass flow with a velocity of nearly 200 km s^{-1} and a small angle of collimation less than 10°. Electron density, mass, kinetic energy, and power are estimated.

Subject headings: nebulae: general — nebulae: planetary — stars: mass loss

I. INTRODUCTION

The "Eskimo" nebula, NGC 2392, the well-known high-excitation planetary nebula, belongs to the class of double shell planetaries and has a well-distinguished inner ring surrounded by an outer structure, the "Fur." If placed at a distance of 1 kpc (which is about the average of values taken from Acker 1978 and Maciel 1981, who give 0.94 and 1.1 kpc, respectively), its overall angular radius of 23″ corresponds to a linear radius of 0.11 pc. Its mean electron density and mean electron temperature of 3.6×10^3 cm^{-3} and 1.3×10^4 K (Aller 1982) are rather typical for planetary nebulae. Its central star is of spectral type O7f (Pottasch 1978).

Some studies on the internal motion of the nebula have been done, revealing a relatively large expansion velocity of 53–65 km s^{-1} (Wilson 1950; Weedman 1968; Acker 1976; Welty 1983; Reay, Atherton, and Taylor 1983). Recent observations by O'Dell and Ball (1985) reveal some evidence for a high-velocity stream restricted to a few arc seconds of the central part of the nebula.

In this *Letter* we present the spectroscopic detection of a strongly collimated high-velocity bipolar mass flow extended up to the edge of the outer envelope of the nebula. The flow is confined in a rather narrow range of the position angle and has escaped detection in previous investigations either because the authors did not tune their Fabry-Pérot interferometer to such extraordinary velocities or did not turn their spectroscopic slit to that particular position angle.

Although bipolar mass outflow has been seen from post–main-sequence objects as proto–planetary nebulae like CRL 618 (Carsenty and Solf 1982), symbiotic stars like HM Sge (Solf 1984) and postnova shells like HR Del (Solf 1983), this is the first detection of bipolar jets in a bona fide planetary nebula.

II. OBSERVATIONS

The observations were obtained with the coudé spectrograph of the 2.2 m telescope on Calar Alto, Spain, using the f/3 camera followed by a two-stage image intensifier. At various slit orientations a total of eight unwidened spectrograms of NGC 2392 were collected on 1984 October 12 and 13. The spectra were exposed for 30 minutes on unbaked IIa-O. At a linear reciprocal dispersion of 7.6 Å mm^{-1} a spectral range between 6460 Å and 6770 Å was covered. The spectral resolution is mainly determined by the slit width of 1000 μm, or 2″.2, and corresponds to about 20 km s^{-1}. The spatial resolution along the direction of the slit of 117″ length is seeing-limited of the order to 2″. Additional calibration plates were taken in order to provide photometric calibration (Lyot filter method described by Trefzger and Solf 1978) and a two-dimensional wavelength calibration for the long-slit exposures. All spectra have been measured with a PDS microdensitometer.

III. RESULTS

Figure 1 (Plate L1) shows a portion of a representative spectrum covering the lines of Hα and [N II]. The slit was oriented at position angle (p.a.) 70°. In the following we focus on the line structure of [N II] λ6583 alone. Figure 2 presents intensity contour maps of these lines as obtained at the various slit orientations.

The rather complicated structure of the emission can be subdivided into three different types of substructures, as identified in the third panel of Figure 2.

1. In all line images we find a rather regular, tilted central ellipse, which shows a maximum radial velocity separation near ± 90 km s^{-1} (which is considerably larger than the "expansion velocity" given in the literature). This emission probably originates from an inner region of the nebula, which has been interpreted as a rather elongated ellipsoidal shell with its major axis near the line of sight (Reay, Atherton, and Taylor 1983; O'Dell and Ball 1985).

2. In all spectra we also find outer emission features with relatively small velocity separations, which seem to originate from a ring zone of about 25″–35″ diameter. These features show a complicated structure changing with the position angle consisting of up to three components with typical radial velocity separations of 45 km s^{-1}. (A detailed spatio-kinematical model of features [1] and [2] based on additional observations at other position angles will be discussed in a forthcoming paper by Becker and Solf 1985.)

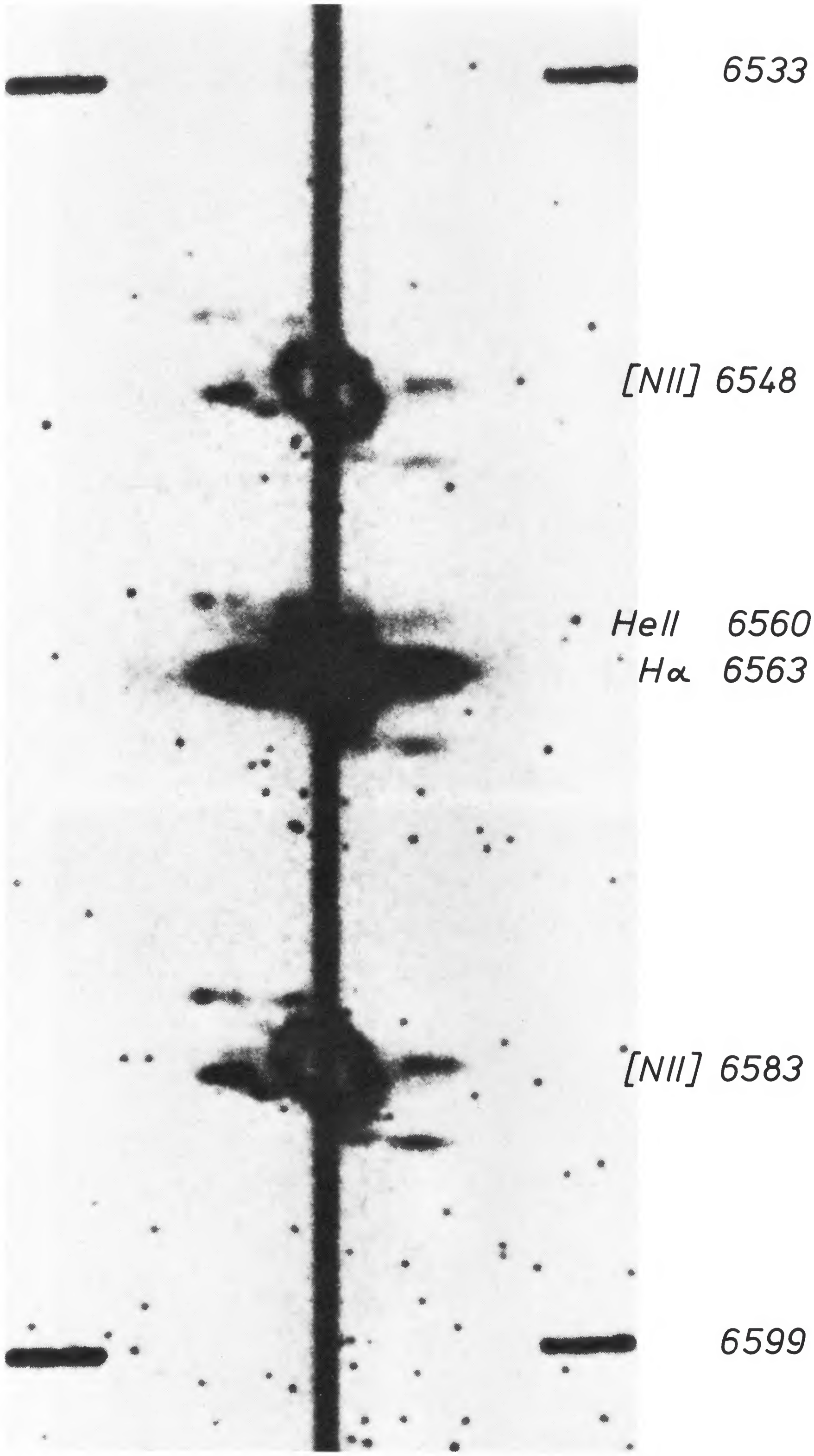

FIG. 1.—Enlarged portion of an unwidened spectrum of the Eskimo nebula NGC 2392 with the slit oriented at position angle 70°, showing Hα and [N II] emissions. Note the high-velocity components (especially prominent in the λ6583 line), which are fragmented into two and three condensations.

GIESEKING, BECKER, AND SOLF (*see* page L17)

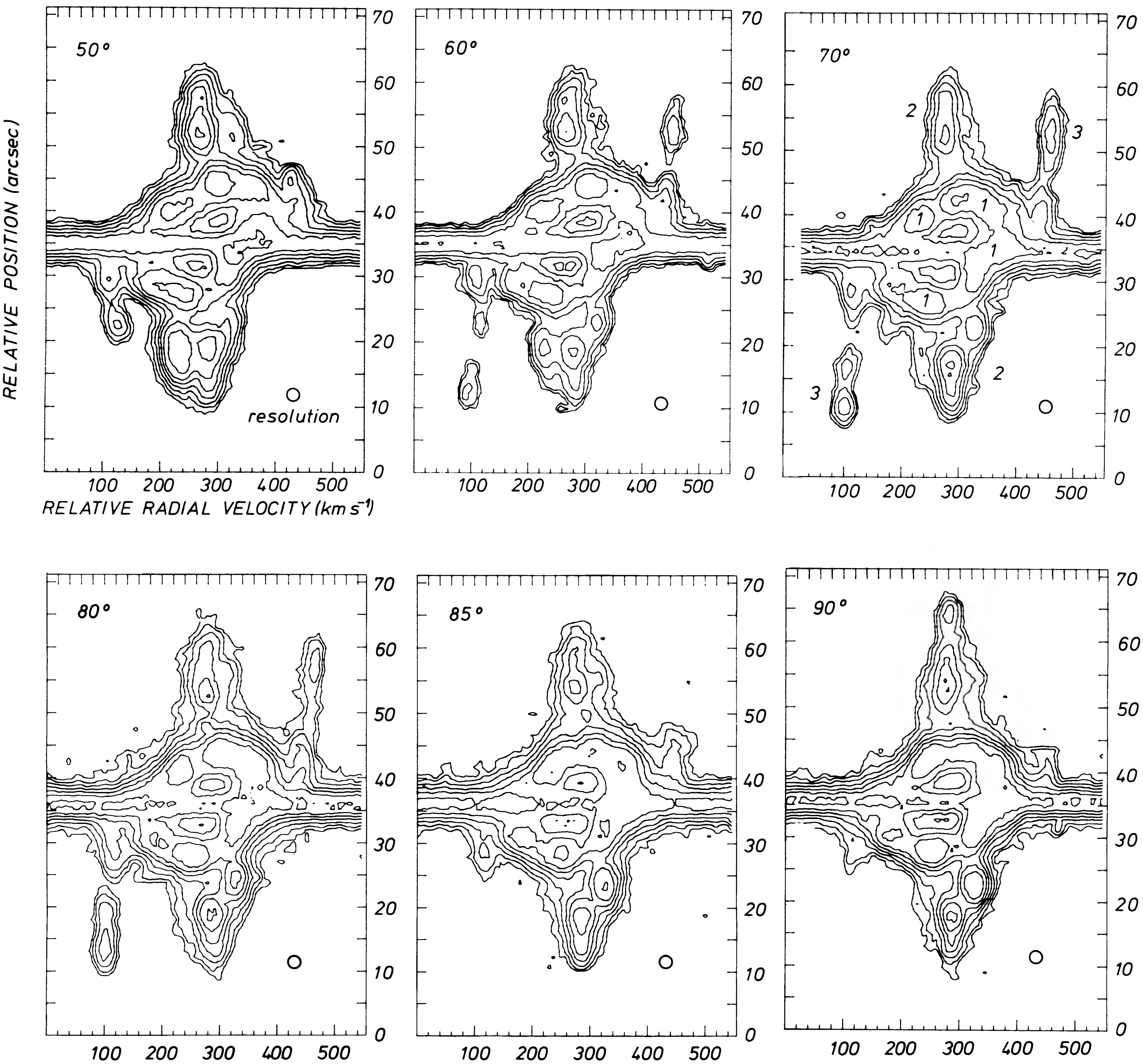

FIG. 2.—Intensity contour maps of the [N II] λ6583 emission observed at the various position angles of the spectrographic slit, as shown in the upper left corner. In all cases the slit was centered on the central star of the nebula. The contours have a logarithmic scale with steps of a factor of 2. Position and velocity scales are chosen such that the sizes of the spatial and velocity resolutions are the same, yielding a resolution circle as shown in each panel at lower right.

3. In some of the spectra we see a remarkable third structure: Two narrow high-velocity features extending from the central star up to 23″ on either side but detectable only in a small range of the p.a. of the slit (60°–80°). These features seem to consist of several condensations with radial velocities of 150–185 km s^{-1} at p.a. 70° (with respect to the star) and -150 to -185 km s^{-1} at the opposite direction. This line component apparently originated from a jet-type bipolar mass flow of extraordinarily large velocity, unknown so far to occur in planetary nebulae.

The spectral width of these high-velocity features is mostly of the order of the spectral resolution, which implies a very small velocity dispersion of less than 20 km s^{-1} in the blobs. Furthermore, their spatial extent is mostly well resolved. Some of them can be followed up to nearly 10″.

The full angular extent of the bipolar mass flow ($\pm 23''$) is observed only between p.a. 60° and 80°. However, at p.a. 50° and 90°, high-velocity condensations near the star ($\pm 10''$) are still present in the line images. Spectra obtained by Becker and Solf (1985) at p.a. 0°, 30°, 120°, and 150° show that high-velocity gas is unlikely to exist outside the range of p.a. 60°–80° and outside an angular distance more than about 5″ from the central star.

For a further refinement of the location of the bipolar flow, two additional spectra have been taken with an offset of $\Delta\alpha = \pm 17''$ and $\Delta\delta = \pm 5''$ from the central star at p.a. −15° of the slit. At this orientation the slit is nearly perpendicular to the axis of the bipolar flow and centered on the outermost condensations. The observed intensity contour maps of [N II] λ6583 are shown in Figure 3. Besides the extended line features due to the main structure of the nebula, we clearly recognize both bipolar components by their large Doppler shifts. From the slight displacements of both features from the center in the diagrams, we can derive a p.a. of 65° and 245° for the outermost components of the bipolar flow and estimate an angular width of 6″–7″ perpendicular to the flow direction. These values are consistent with the range of about 20° in p.a. as inferred above from Figure 2.

We now try to estimate the true angle of collimation of the mass flow. The 20° quoted above is an upper limit, if we assume the inclination of the flow direction with respect to the line of sight to be rather small. A first argument in favor of a small angle of collimation is the unresolved velocity dispersion of the flows (< 20 km s^{-1}), which is at least 10 times smaller compared to the radial velocity of the features. For a more accurate estimate of the collimation, we need to know the space orientation of the flows. A reasonable assumption may be that it is correlated to the longer axis of the above-mentioned inner ellipsoidal structure. As will be shown by Becker and Solf (1985) quantitative models of the inner ellipsoidal shell yield reasonable values of 20° for the inclination of the major axis to the line of sight and a kinematical age of 1500 ± 500 yr. (An independent estimate of the kinematical age, based on measured proper motions by Liller and Liller 1968, yields a kinematical age for the inner structure of about 1000 yr and for the fur of about 2000 yr.) We can obtain an independent estimate of the inclination angle of the bipolar flow if we assume that the kinematical age of the outermost clumps and that of the inner ellipsoidal structure are the same. If we adopt an age of 1500 yr for these clumps, their projected linear distance of 0.1 pc from the central star and the measured radial velocity of ±180 km s^{-1} implies an inclination angle of 20°, in good agreement with the presumed orientation of the inner shell mentioned above. This result indicates a true expansion velocity of about 190 km s^{-1} of the bipolar flow and an angle of collimation of only about 7° seen from the center.

If we assume that the axis of the bipolar flow has not changed significantly in the past, we inevitably get widely different kinematical ages for the individual knots, so that the outermost ones are about 4 times older than the innermost ones. Thus we find that the bipolar flow activity has occurred over a remarkably large time span between 400 and 1500 yr!

We now estimate the electron density of the bipolar mass flow from the intensity ratio of the lines [S II] λλ6717, 6731, sufficiently exposed on two spectra (p.a. 70° and 80°). In order to improve the signal-to-noise ratio, we have integrated the line intensity along the direction of the slit in a strip of 12″ width for each of the high-velocity features. We obtain a mean value for the ratio [S II] 6717/6731 of 1.2, which corresponds to the low electron density of 200 cm^{-3}, if we adopt the data of Pottasch (1984). This value is rather small compared to the density of typically 2000 cm^{-3} we have deduced for the low-velocity line features (indicated by the number 2 in Fig. 2), which are attributed to the ring-type shell (Becker and Solf 1985).

Finally, we make a very rough estimate of the kinetic energy and power of a typical pair of clumps observed in the bipolar flow. The angular extent of the outermost pair is about 6″–7″ corresponding to 0.03 pc. With this linear dimension we estimate the order of magnitude of the volume. Together with the above determined electron density of 200 cm^{-3} we

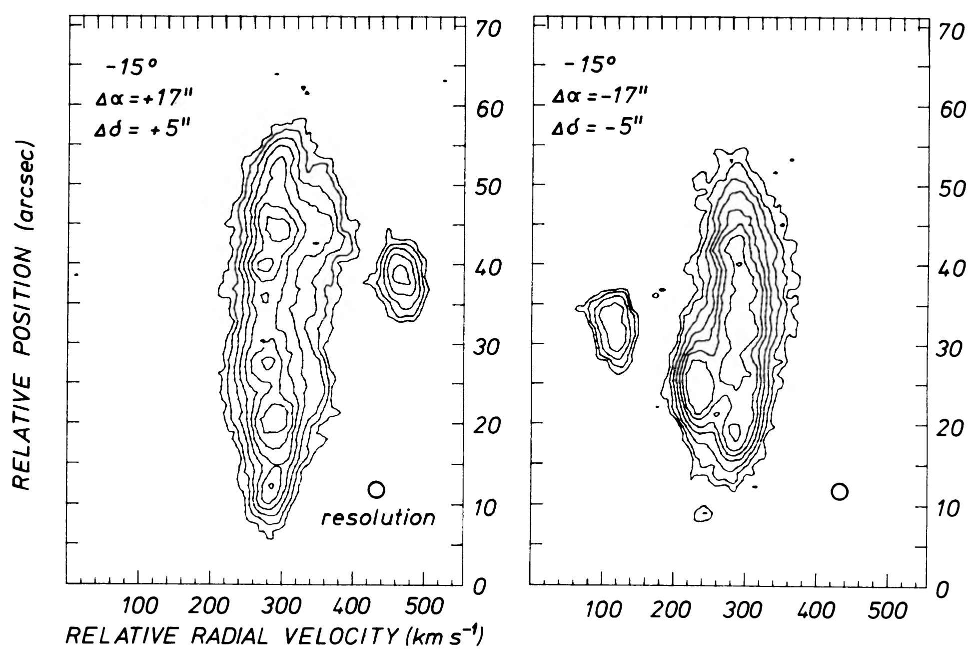

FIG. 3.—Intensity contour maps of the [N II] λ6583 emission observed at the two indicated offsets

find a mass of a bipolar pair of 5×10^{29} g and combined with the expansion velocity a kinetic energy of 10^{44} ergs. From length scale and velocity of a typical condensation, we estimate its power to be about 2×10^{34} ergs s^{-1} or about 5 $L_{\odot}$. Comparing this with the luminosity of the central star of NGC 2392 of nearly 500 solar luminosities (Pottasch 1983), the power of a pair of one of the observed bipolar blobs is about 10^{-2} of the available radiant power of the energy source.

IV. CONCLUSION

A bipolar mass flow of high velocity and high collimation has been discovered in the planetary nebula NGC 2392. This flow cannot be attributed to a single ejection event but appears to have occurred during a large period within the last 1500 years. Many properties such as velocity, collimation, and its appearance in a multiknot pattern compare very well with stellar jets in the pre–main-sequence phase of stellar evolution (Mundt 1984). Their power is larger by the same factor as the radiant power of the responsible energy source.

The fact that a new jetlike structure could be discovered in one of the very well-studied planetary nebulae lets us suppose that such phenomena could also be hidden in other prominent objects. Therefore we find it worthwhile to search also for such features in other planetary nebulae with similar morphology.

REFERENCES

Acker, A. 1976, *Pub. Obs. Strasbourg*, **5**.

———. 1978, *Astr. Ap. Suppl.*, **33**, 367.

Aller, L. H. 1982, in *Landolt-Börnstein*. Vol. **VI / 2b**, ed. K. Schaifers and H. H. Voigt (Heidelberg: Springer), p. 364.

Becker, I., and Solf, J. 1985, in preparation.

Carsenty, U., and Solf, J. 1982, *Astr. Ap.*, **106**, 307.

Liller, M. H., and Liller, W. 1968, in *IAU Symposium 34, Planetary Nebulae*, ed. D. E. Osterbrock and C. R. O'Dell (Dordrecht: Reidel), p. 38.

Maciel, W. J. 1981, *Astr. Ap. Suppl.*, **44**, 123

Mundt, R. 1984, in *Protostars and Planets II*, ed. D. Black and M. Matthews (Tucson: University of Arizona Press), in press.

O'Dell, C. R., and Ball, M. E. 1985, *Ap. J.*, **289**, 526

Pottasch, S. R. 1978, in *IAU Symposium 76, Planetary Nebulae*, ed. Y. Terzian (Dordrecht: Reidel), p. 93.

———. 1983, in *IAU Symposium 103, Planetary Nebulae*, ed. D. E. Flower (Dordrecht: Reidel), p. 391.

———. 1984, *Planetary Nebulae* (Dordrecht: Reidel), p. 51.

Reay, N. K., Atherton, P. D., and Taylor, K. 1983, *M.N.R.A.S.*, **203**, 1087.

Solf, J. 1983, *Ap. J.*, **273**, 647.

———. 1984, *Astr. Ap.*, **139**, 296.

Trefzger, Ch., and Solf, J. 1978, *Astr. Ap.*, **63**, 131.

Weedman, D. W. 1968, *Ap. J.*, **153**, 49.

Welty, D. E. 1983, *Pub. A.S.P.*, **95**, 217.

Wilson, O. C. 1950, *Ap. J.*, **111**, 279.

INGO BECKER, FRANK GIESEKING, and JOSEF SOLF: Max-Planck-Institut für Astronomie, Konigstuhl, D-6900 Heidelberg 1, Federal Republic of Germany