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THE γ CASSIOPEIAE NEBULAE

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Intercomparison of red and blue plates shows that γ Cas is surrounded by both emission and reflection nebulae. We suggest that the reflection nebulosity lies in the equatorial plane of γ Cas where it is shielded from ionizing Lyman continuum radiation by the disk-like envelope that is believed to surround this Be star.

Intercomparison of direct plates taken 27 years apart shows no evidence for motion or significant structural changes in either the emission or reflection nebulosity near γ Cas.

Key words: emission nebulae—reflection nebulae—Be stars

I. Introduction

The bright Be star γ Cassiopeiae is associated with the moderately bright nebulae, IC 59 and IC 63. They are included in Sharpless' (1953) catalog of emission nebulae (No. 130), and in van den Bergh's (1966) catalog of reflection nebulae (No. 5). Van den Bergh noted that these two nebulae exhibit a marked color difference. The blue nebula to the north of γ Cas shines mainly by reflected light whereas the light from the red nebulosity to the east of the star is dominated by line emission. Both nebulae resemble "elephant trunks" (Spitzer 1954) that point approximately in the direction of γ Cas. The emission nebula has a bright rim (Pottasch 1956) facing γ Cas.

The nebulae are interesting in several respects. γ Cas is known to have a supersonic (1500 km s^{-1}) stellar wind which is highly variable and probably asymmetric (Henrichs, Hammerschlag-Hensberge, and Lamers 1980; Poeckert 1981). The nebulae may represent the interface between this wind and the interstellar medium (ISM). Alternatively, the nebulae may be remnants of a very dense wind which might have existed in the recent past. γ Cas has shown brief periods during which the mass-loss rate appears to increase significantly, for example during the late 1930s (Baldwin 1939; Edwards 1944). Finally they might be interstellar clouds that were compressed by the expanding supernova shell that was produced by the parent of the possible neutron star companion (Marlborough, Snow, and Sletteback 1978) to γ Cas. If so these clouds might be related to the quasi-stationary flocculi that are observed in Cas A.

II. Observations

Direct plates of the γ Cas nebulosity were obtained in the blue (103a-O + GG13) and in the red (103a-E + RG1 and 103a-E + Wr 25) on 1967 January 12 and 1980 July 16 with the 48-inch (1.2-m) Schmidt telescope at the Hale/Palomar observatories. The exposure times were 12 minutes in the blue and 60 minutes in the red. In addition to these four plates we have also consulted the glass copies of the Palomar Sky Survey plates of this field which were taken on 1952 September 16.

Copies of the red and blue plates of the nebulosity near γ Cas are shown in Figures 1 and 2, respectively. In addition to the bright nebulae to the N and ENE of γ Cas some faint emission nebulosity is also visible ~ 50′ E of this star. A marked drop in the density of stars immediately N of γ Cas indicates the presence of a dust cloud in this direction. The Palomar Sky Survey plate of the region shows that there is a complex of dark nebulae around γ Cas, particularly to the north, while the region immediately surrounding γ Cas and to the south of it, appears to be relatively free of obscuration. The tip of the reflection nebula closest to γ Cas has the same outline on both the red and blue plates, whereas a little farther to the west there appears to be emission nebulosity bordering the reflection nebula.

A search for structural changes, brightness variations, and motions in both the emission and reflection nebulae was carried out by examining pairs of plates in the Zeiss blink microscope at the DAO. No morphological changes were seen and motions over the 28-year baseline provided by the present observations are $< 2''$ corresponding to a proper motion $< 0''.07$ yr^{-1}.

The blue plates, including the glass copy of the Palomar Sky Survey, were also scanned with a PDS microdensitometer in the region of the emission nebulosity. We again find no significant motion in the nebula and can set an upper limit of $0''.7$ over the 28-year baseline, corresponding to a proper motion $< 0''.025$ yr^{-1}.

A spectrogram of a 12″ section of the bright tip of the emission nebula near γ Cas was obtained with the 1.8-m telescope at the DAO. This spectrogram, which covers the wavelength range $5640 < \lambda < 6890$ Å at a resolution of 37 Å mm^{-1}, was taken with the slit oriented East-

°Guest Observer Hale/Palomar Observatories.

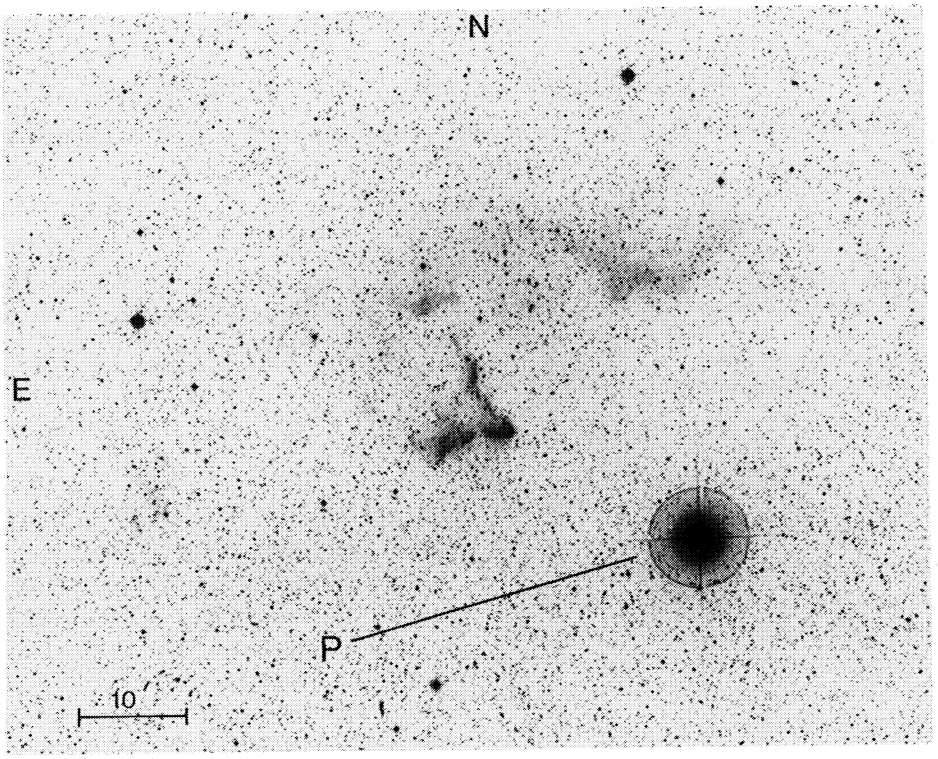


FIG. 1—Red plate (103a-E + RG1) of the γ Cas nebulosity taken in 1967. The line marked P shows the position angle and intrinsic polarization which, on the plane of the sky, should be parallel to the stellar axis of rotation.

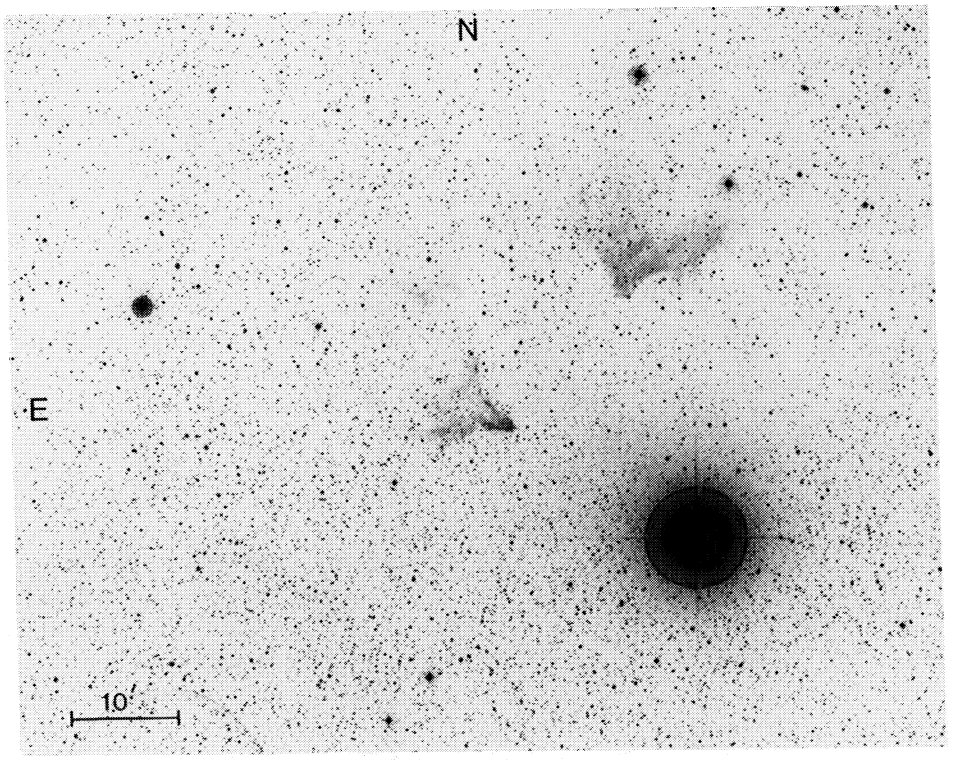


FIG. 2—Blue plate (103a-O + GG13) of the nebulosity surrounding γ Cas.

West. Due to sky background it is not possible to estimate the strength of Hα in this spectrogram. Perhaps the most interesting feature of the spectrum of this nebulosity is the great strength of [S II] λλ6716, 6731. We estimate that each of these lines has ~ 0.6 times the strength of [N II] λ6583. The great strength of [S II] emission in the γ Cas nebulosity suggests that this nebulosity has been shock excited (Daltabuit, D'Odorico, and Sabbadin 1976). The ratio of the [S II] line strengths, $E_{6731}/E_{6717} = 0.7 \pm 0.1$, gives an electron density of $< 10^3$ cm^{-3} (Saraph and Seaton 1970).

The radial velocity of the nebulosity as determined from the [S II] λλ6716, 6731 and [N II] λ6583 lines is 26 ± 7 km s^{-1}, whereas the radial velocity of γ Cas is −3.5 ± 6.5 km s^{-1} (Cowley, Rogers, and Hutchings 1976).

III. Discussion

In a previous paper (van den Bergh 1966) it was suggested that the existence of both emission and reflection nebulosity near γ Cas might be due to local variations in the gas-to-dust ratio. Recent polarization observations (Poeckert and Marlborough 1976) suggest that the observed variation in the emission-to-reflected-light ratio might, in fact, be due to absorption in the ultraviolet by a relatively dense disk in the equatorial plane at this rapidly rotating star.

In rapidly rotating Be stars disks extend to one or two stellar radii perpendicular to the equatorial plane and to tens of stellar radii in the plane. These disks expand relatively slowly and probably confine high-velocity stellar winds to polar and midlatitude directions (Poeckert 1981). Since such disks are opaque to Lyman continuum radiation (Poeckert and Marlborough 1982) no far uv radiation (and no high-velocity wind) leave the vicinity of a Be star in or near its equatorial plane.

According to Poeckert and Marlborough (1976) the intrinsic polarization of γ Cas has a position angle of 108°. Inspection of Figure 1 shows that this direction is perpendicular to that toward the reflection nebulosity north of γ Cas. The intrinsic polarization observed for classical Be stars arises from electron scattering in the circumstellar disk and the direction of polarization is perpendicular to the disk (Coyne 1981). We therefore suggest that the reflection nebula is in the equatorial plane of the Be star γ Cas. It is not an emission nebula because the circumstellar disk around γ Cas shields the nebula from the Lyman continuum radiation of the star. On the other hand, the emission nebula is probably situated at midlatitudes where the Lyman continuum flux is strong. This model for γ Cas (Poeckert and Marlborough 1978) predicts that a spectrum of the reflection nebula should show the characteristics of a Be shell star, i.e., strong Balmer emission with deep reversals and shell absorption lines (most probably He I and Fe II). In this respect γ Cas is the only classical Be star viewable from different inclinations. If spectrograms of sufficient quality can be obtained it may even be possible to measure the rotational velocity of γ Cas as seen from the reflection nebula. Such a measure of $V \sin i$ could be used to evaluate the geometrical relation between the nebula, γ Cas, and the observer. If the nebula is in the equatorial plane the $V \sin i$ should be about 450 km s^{-1}.

If the reflection nebula is located in a plane perpendicular to the line of sight passing through γ Cas an increase in the brightness of this variable will be visible 5.6 years after the event (assuming a distance of 250 pc). Such a light echo, resulting from the $0^m.8$ brightness increase observed in 1937 (Huffer 1939), might be seen on plates obtained during the 1940s. In principle it should be possible to map out the three-dimensional structure of the nebula by observing the light echos during the next outburst. Spectral changes, such as the recent V/R variations in the Balmer emission lines (Cowley et al. 1976), might also be observed in the reflection nebula. It should be kept in mind that it does not automatically follow that when γ Cas is observed to brighten the nebula will also brighten. The reflection nebula may in fact fade because it "sees" the star through an envelope of increasing opacity. Simultaneously an observer on Earth who is looking down onto the disk, would see the star becoming brighter.

Ferlet et al. (1980) have used the *Copernicus* satellite to study the interstellar medium in the direction toward γ Cas. They conclude that the line of sight toward this star traverses one main warm (10^4 K) cloud and three lesser clouds. Two of these secondary clouds appear to have been shocked and possibly show abundance anomalies consistent with their having been contaminated by supernova ejecta. The relatively low velocities of these clouds militate against the suggestion that they were recently shocked by the supernova explosion that produced the neutron star companion to γ Cas postulated by Marlborough et al. (1978).

IV. Summary

Polarization observations of γ Cas are consistent with a model in which the reflection nebula lies in the equatorial plane of this Be star where it is shielded from ionizing radiation by the circumstellar disk around γ Cas. The spectrum of the reflection nebula should be different from the spectrum of γ Cas because an observer on Earth and the reflection nebula view the star from different inclinations. It should be possible to observe a light echo (or spectrum echo) whenever γ Cas undergoes a dramatic spectrum or brightness change such as that which occurred in the late 1930s. On Earth this echo should be visible ~ five years after the event.

Intercomparison of plates taken during the last quarter century shows no significant morphological changes or motion of any of the nebulosity near γ Cas.

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