

RADIO OBSERVATIONS OF H166 α AND C166 α LINES FROM ARECIBOHARRY PAYNE AND YERVANT TERZIAN
National Astronomy and Ionosphere Center, Cornell University*Received 1976 July 16*

Observations of the H166 α and C166 α lines are reported from the sources W49A, W51A, and W51B. These line observations were performed with the upgraded Arecibo 1000-foot radio telescope. Physical parameters are derived for the observed hydrogen and carbon clouds. The analysis of the observations indicate that the carbon clouds can be explained by stimulated emission models.

Key words: recombination lines — galactic radio sources

I. Introduction and Observations

The upgraded Arecibo 1000-foot (305-meter) radio telescope was used to observe the 166 α recombination-line spectra in the directions toward W49A, W51A, and W51B. The H166 α line was detected from all three sources, and the C166 α line was detected from W49A and W51A. Very low upper limits have been placed on the C166 α line from W51B. Here we report the results of these observations, and we combine this work with the Cn α and Hn α lines detected at lower frequencies from Arecibo (Terzian and Pankonin 1974; Pankonin, Parrish and Terzian 1973) and higher frequency measurements made elsewhere (Chaisson and Ball 1971; Palmer et al. 1969) to determine the physical parameters of these sources.

The 166 α -spectral observations were made with the new Arecibo 21-cm line feed which illuminates ~ 700 feet of the antenna. The half-power beamwidth of the system was ~ 3.2 arc minutes and the sensitivity was $\sim 8^\circ$ K of antenna temperature per Jansky. The 21-cm receiver system had a noise temperature of 90° K. An autocorrelator with 252 channels and with a velocity resolution of 1 km sec^{-1} was used for the spectroscopic observations. The theoretical signal-to-noise ratio was in very close agreement with the observations giving $\Delta T_{\text{rms}} = 0.03^\circ$ K for an integration time of one hour. Appropriate gain calibration corrections were applied to the data as a function of zenith angle as established by the observatory staff. Frequency switching was used in such a way that the C166 α -line spectral region appeared in each of the two frequency bands, and thus twice in the final difference spectrum, once as a positive feature and once as a negative feature. The spectra were then folded, shifted in frequency, and averaged together. This method allows the use of frequency switching to stabilize against gain fluctuations without sacrificing integration time, and it also minimizes the baseline curvature of the spectral observations.

The final spectra were produced by subtracting a second-degree polynomial for a baseline from the

detected spectra. The resulting spectra are shown in Figure 1, together with the best fit Gaussian profiles. The measured parameters are summarized in Table I.

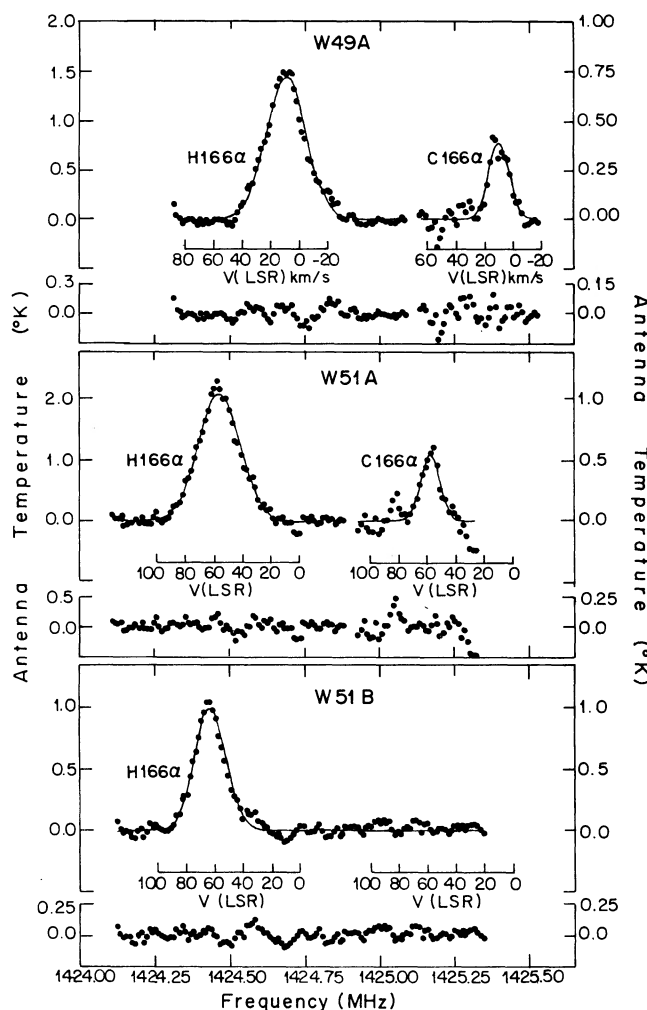


FIG. 1 — The observed recombination spectra. Note that the scales for the C166 α lines are different from the H166 α ones. Best-fit Gaussian profiles are indicated and corresponding residuals are also shown at the bottom of each spectrum. The integration times were $t(\text{W49A}) = 365$ minutes, $t(\text{W51A}) = 145$ minutes, and $t(\text{W51B}) = 110$ minutes.

TABLE I
OBSERVED LINE PARAMETERS

Source	W49A (G 43.2 + 0.0)	W51B (G 49.0 - 0.3)	W51A (G 49.5 - 0.4)
<u>H166α</u>			
T_L/T_c	$(8.2 \pm 1.1) 10^{-3}$	$(11.5 \pm 1.9) 10^{-3}$	$(7.5 \pm 1.1) 10^{-3}$
Δv_L (km/sec)	32.9 ± 3.6	25.5 ± 2.4	33.9 ± 4.0
V_{LSR} (km/sec)	8.4 ± 0.8	61.2 ± 0.7	55.4 ± 2.4
<u>C166α</u>			
T_L/T_c	$(2.2 \pm 0.5) 10^{-3}$	$<1.0 \times 10^{-3}$	$(2.0 \pm 0.8) 10^{-3}$
Δv_L (km/sec)	16.7 ± 3.2	---	15.6 ± 3.2
V_{LSR} (km/sec)	8.4 ± 3.1	---	56.5 ± 1.6

II. The Recombination Lines

Theoretical non-LTE predictions concerning the emission of Cn α lines have been made by Dupr   (1974) and Hoang-Binh and Wallmsley (1974). Although the observed radial velocities of the carbon clouds are normally observed to be close to the velocities of the H II regions which are in the same line of sight, it is assumed that the carbon clouds are physically distinct from the H II regions. The carbon clouds are assumed either to be in front of the H II regions, where in this case stimulated emission makes important contributions to the line intensities, or they can be behind the H II regions where the only background radiation is the cosmic microwave radiation so that spontaneous emission dominates. Our analysis indicates that the carbon clouds observed in this study can best be explained by stimulated emission models.

Physical parameters of the detected carbon clouds in W49A and W51A were deduced by combining the present C166 α observations with previous detections at higher and lower frequencies. The frequency dependence of the integrated line power was compared to the theoretical predictions of Dupr   (1974) and Hoang-Binh and Wallmsley (1974) to determine the type of model which best fit the data, and from the specific model the electron temperature and density were deduced. The normalization of the observations to the theoretical models yielded the emission measure and the apparent size of the carbon clouds, which were assumed to be spherical and homogeneous. The resulting estimated physical parameters for the carbon

clouds are given in Table II. The uncertainties in the estimates of the electron temperature and density are probably less than a factor of two. The other parameters are geometry dependent, and hence somewhat more speculative. The failure to detect C166 α in the direction of W51B, combined with a detection at a lower frequency (see Terzian and Pankonin 1974), indicates that the decrease in line power with increasing frequency is steep enough to rule out any spontaneous emission models. It therefore seems that stimulated emission dominates the carbon-line intensity from W51B.

The H166 α lines were analyzed by using the non-LTE results of Brocklehurst (1970) and the iterative method described by Churchwell, Terzian, and Wallmsley (1976). Sizes for the H II regions were derived from angular sizes measured in the continuum (Schraml and Mezger 1969) and from kinematic distances. The derived physical parameters for the hydrogen clouds are also shown in Table II. The results seem to indicate that our present higher angular resolution line observations yield somewhat higher electron temperatures and densities compared to previous observations obtained with larger beams. This suggests that dense clumps of ionized gas are imbedded inside extended and more tenuous H II regions similar to the model discussed by Mezger, Schraml, and Terzian (1967).

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TABLE II
PHYSICAL PARAMETERS

Source	W49A (G 43.2 + 0.0)	W51B (G 49.0 - 0.3)	W51A (G 49.5 - 0.4)
<u>Carbon Clouds</u>			
T_e ($^{\circ}\text{K}$) *	~ 100	--	~ 100
$\langle N_e \rangle$ (cm^{-3})	~ 10	--	~ 20
E_L (cm^{-6} pc)	130	--	320
Diameter (pc) **	3.8	--	2.4
<u>Hydrogen Clouds</u>			
T_e ($^{\circ}\text{K}$) *	13000 ± 2300	10500 ± 2000	14000 ± 2700
$\langle N_e \rangle$ (cm^{-3})	170	140	300
E_L (cm^{-6} pc)	2.0×10^5	9.3×10^4	3.3×10^5
Diameter (pc) ***	10.6	6.7	5.6

* Corrected for non-LTE effects
** Adopted distances W49A 14.1 kpc; W51B 6.5 kpc, W51A 7.3 kpc.
*** Angular sizes from Schraml and Mezger (1969)

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TWO-PHOTON EMISSION IN PLANETARY NEBULA IC 2149

G. A. GURZADYAN

Garny Space Astronomy Laboratory, Erevan, Armenian SSR, USSR

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An attempt has been made to discover two-photon emission of hydrogen in the ultraviolet spectrum of IC 2149, the first planetary nebula for which the short-wave spectrogram was obtained in space conditions with the help of "Orion-2". This emission has been isolated in the wavelength range 2400 Å–2800 Å. The two-photon emission spectrum and the amount of the emission itself obtained from observations are not in contradiction with data predicted by theory.

Key words: two-photon emission — planetary nebulae — space observations

The history of the two-photon emission of atomic systems goes back nearly 50 years; its fundamental theoretical propositions were worked out as early as 1929 by Göppert-Mayer (1929). Sometime later it became clear that the two-photon emission of hydrogen, originating during the transition of the atom from a metastable level $2S_{1/2}$ to a ground level $1S_{1/2}$, should be of special interest. In 1940 Breit and Teller (1940) worked out the quantitative theory of the two-photon emission of the hydrogen. As this theory was applied to astrophysical problems in the early fifties, it was reconsidered and further elaborated by Kipper (1950) and Spitzer and Greenstein (1951).

The theoretical spectrum of the two-photon emission of hydrogen, continuous by nature, begins with $\lambda = 1216$ Å and extends to $\lambda \rightarrow \infty$. This spectrum displays a well-pronounced maximum about $\lambda = 1400$ Å and falls rapidly toward the long wavelengths. The intensity of the two-photon emission in the optical range is quite small and is of the order of several percent with respect to its intensity at the maximum. It is precisely for this reason that the detection and isolation of the two-photon emission in planetary and diffuse nebulae—the objects with the greatest potential for the generation of that unique emission—meet so many difficulties.

On the other hand, the life of the hydrogen atom in metastable level $2S$ is of very long duration, of the order of one-tenth of a second ($A_{2S-1S} = 8.227 \text{ sec}^{-1}$). To initiate the transition of $2S \rightarrow 1S$ with the emission of two photons, the atom should not be submitted to inelastic collisions during that period of time. This factor (the factor of deactivation) determines the upper limit of the electron concentration of the medium; it must be extremely small—less than 10^4 cm^{-3} (Seaton 1954; Purcell 1952). As far as we know, this should account for the complete lack of experimental evidence, in laboratory conditions, of the possibility of two-photon emission in principle.

An electron concentration of the order of 10^4 cm^{-3}

and less is characteristic of planetary nebulae. Therefore, planetary nebulae seem to offer nearly the only hope of detecting the two-photon emission of hydrogen and prove in this way the possibility of two-photon transitions in atomic systems; diffuse nebulae serve that purpose to a much lesser extent as they contain dust particles in profusion, which cause a heavy continuous spectrum by scattering of stellar emission.

Further, in view of the fact that the major part of the two-photon emission is concentrated in the range of wavelengths shorter than 3000 Å, observation should be made in the ultraviolet rays, i.e., in space conditions.

With the help of the space observatory "Orion-2" we managed to obtain the first short-wave spectrograms of a planetary nebula in 1973; it turned out to be IC 2149, located in the vicinity of β Aurigae. A description of the scientific and accessory equipment and the method of conducting astrophysical observation with the help of that observatory is given by Gurzadyan (1975a) and Gurzadyan et al. (1976).

The short-wave boundary for the spectrogram (still F13) of IC 2149 was as much as 2400 Å. The results of processing and measuring the spectrograms, as well as the preliminary interpretation of the data obtained, were described in a previous paper (Gurzadyan 1975b). However, following the publication of that article we found out that the results obtained almost certainly indicate certainly the presence of the two-photon emission mentioned above.

The brightness of the central star (nucleus) of nebula IC 2149 is approximately the same ($\sim 10^m$) as the integral brightness of the nebula itself. Therefore the spectrogram obtained proved to be two superimposed spectra—the continuous spectrum of the nucleus and both the emission-line spectrum and continuum of the nebula. Separating those two components from each other we obtained, in particular,

the observed spectrum of the nucleus. After making corrections for the effect of interstellar absorption, we found this spectrum to be, over most of its extension, in good agreement with the theoretical model of Mihalas (1965) for a photosphere of an O7 class star at an effective temperature $T_{\text{eff}} = 50,000^\circ \text{K}$. It should be noted that earlier the spectral class of the central star of this nebula was determined as O7 (Vorontsov-Velyaminov 1947) and O7.5 based on quantitative measurements (Wilson and Aller 1954), while the temperature was estimated, in one case, as $43,000^\circ \text{K}$ (Gurzadyan 1969) and $66,000^\circ \text{K}$ in another (O'Dell 1962).

Figure 1 illustrates the energy distribution we have established in the ultraviolet of the continuous spectrum of the central star of nebula IC 2149. This graph, plotted after obtaining the results of the more ac-

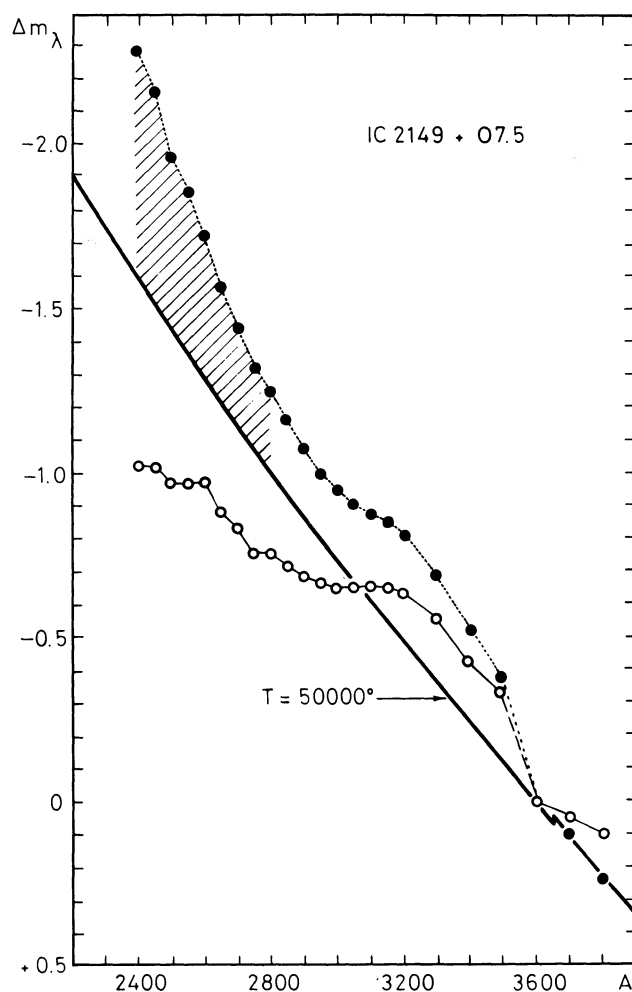


FIG. 1—Energy distribution in the ultraviolet of the continuous spectrum of the central star of planetary nebula IC 2149; open circles, observation; filled circles, corrected for the effect of interstellar absorption; solid line, theoretical spectrum at $T_{\text{eff}} = 50,000^\circ \text{K}$; shaded area, excess radiation—the part of the continuous spectra used in quantitative analysis.

curate measurements of the few microphotometric recordings, obtained from one not uniformly broadened spectrogram (still F13), does not differ in structure from the one published by Gurzadyan (1975b). It will be noted that the ordinate in Figure 1 pictures the relative flux of radiation at the given wavelength, λ , expressed in stellar magnitudes, Δm_λ , taking the flux at $\lambda = 3600 \text{ Å}$ (before the jump) as the unit, i.e., $\Delta m_\lambda = -2.5 \log (F_\lambda / F_{3600})$.

On consideration of our analysis, the choice of the theoretical nonblanketing Mihalas model (solid curve in Fig. 1), discounting the blocking effect of the absorption lines, has not been casual. The point is that in the theoretical model of Hummer and Mihalas (1970), specially designed for the central stars of planetary nebulae, the only continuous absorption which is taken into account is that caused by hydrogen, helium, and four other elements in the wavelength range shorter than 1000 Å , and which originates during the transitions of atoms and ions from ground and excited levels into the ionized level. On the other hand, in Hickok and Morton's model (1968) (for stars of the O5 V class) the effect of absorption lines is considered only in the wavelength range $912 \text{ Å} < \lambda < 1700 \text{ Å}$. As we see in both cases, data on the theoretical distribution of energy for O7 stars with due account of the blocking effect and in the wavelength range concerned ($2000 \text{ Å} - 3000 \text{ Å}$) are simply lacking.

If it is well known, on the other hand, that in general the effect of absorption lines on the continuous spectrum of O-type stars is small (Hickok and Morton 1968). It will therefore be assumed that the nonblanketing Mihalas model (1965) should best correspond in the present case to the real photospheres of very hot stars such as the nuclei of planetary nebulae. Now the stellar continuum is to be separated from that of the nebula, is a matter of consequence. The continuous spectrum level of the nebula shows a minimum in the wavelength region just longward of the Balmer jump (at $\lambda = 3646 \text{ Å}$, or conditionally at about 3600 Å). Therefore both the model of the continuous spectrum of the star and the observed spectrum of the nebula are combined at $\lambda = 3600 \text{ Å}$ in Figure 1. It follows from this figure that beginning with $\lambda \sim 3500 \text{ Å}$ up to the short-wave boundary of our measurements (2400 Å) substantial deflection from the theoretical distribution is noted, in the sense that the observations yield a greater value for the flux than theory itself, i.e., there appears an *excess* in the radiation.

We believe that the marked *excess emission* bears no relation to the central star of the nebula. Nor it is likely that its formation can be accounted for in terms of the influence of dust particles which are supposed to be available in planetary nebulae.

We assume that a part of this excess radiation can be the two-photon emission in question, generated by hydrogen atoms in the nebula itself.

To select the two-photon radiation from the observed spectrum of the nebula, a complete picture of the continuous spectrum of IC 2149 should be made up for the region of ultraviolet wavelengths, shorter than $3646 \text{ \AA}$, using the known data for electron concentration, n_e , and electron temperature, T_e . We have for this nebula: $n_e = 3.2 \cdot 10^3 \text{ cm}^{-3}$, obtained by the method of the $[\text{O II}] \lambda 3727$ doublet ratio (Osterbrock 1960), and $T_e = 12,400^\circ \text{ K}$ (Kaler 1970).

The optical emission-line spectrum of IC 2149 indicates that the nebula belongs to the moderately excited objects; in all cases the line of doubly-ionized helium, $\text{He II } \lambda 4686$, is absent in its spectrum (Aller 1951). This fact may be taken as a criterion that the role of the ionized helium continuum is negligible because of the very small amount of ionized helium atoms; it is well known that if even a small fraction of the helium were doubly ionized $\lambda 4686$ would be strong (Kaler 1970; O'Dell 1963). Therefore hereafter we will take into account only three components for the continuum of IC 2149 (in the region $\lambda < 3646 \text{ \AA}$): the Balmer continuum of hydrogen, $J(\text{H I})$, neutral helium, $J(\text{He I})$, and two-photon radiation of hydrogen, $J(2q)$.

Further, using the emission coefficient data for H I , He I , and $2q$ -photon radiation (Brown and Mathews 1970) the ultraviolet continuous spectrum is recalculated (on a wavelength scale) for the nebula IC 2149 at $T_e = 12,000^\circ \text{ K}$ and in the wavelength region $2400 \text{ \AA}$ – $3800 \text{ \AA}$. The results are presented in Figure 2, where the curves are the different components of the continuous spectrum. (in the case of He I it was taken that $n(\text{He})/n(\text{H}) = 0.1$). The heavy line is the summary intensity, which proved to be practically independent of the wavelength in the region of wavelengths under study. It is necessary to note that the influence both of the neutral helium continuum, $J(\text{He I})$, and ionized helium continuum, $J(\text{He II})$, on the outcome intensity of the continuum is practically the same.

Seaton (1955, 1960) was the first to make an attempt to identify two-photon radiation in emission in planetary nebulae by the magnitude of the Balmer jump. However, as it follows from Figure 2, the intensity of two-photon emission at $\lambda = 3646 \text{ \AA}$ is at least 5–6 times as small as the full intensity due to both the hydrogen and helium continuums at the jump. At the same time the intensity of two-photon emission, for example, at $\lambda = 2400 \text{ \AA}$, consists of more than half ($\sim 60\%$) the total intensity of the continuum. That is why the Balmer-jump method cannot be considered as sensitive enough to make the discovery of two-photon emission rather reliable. A reliable solu-

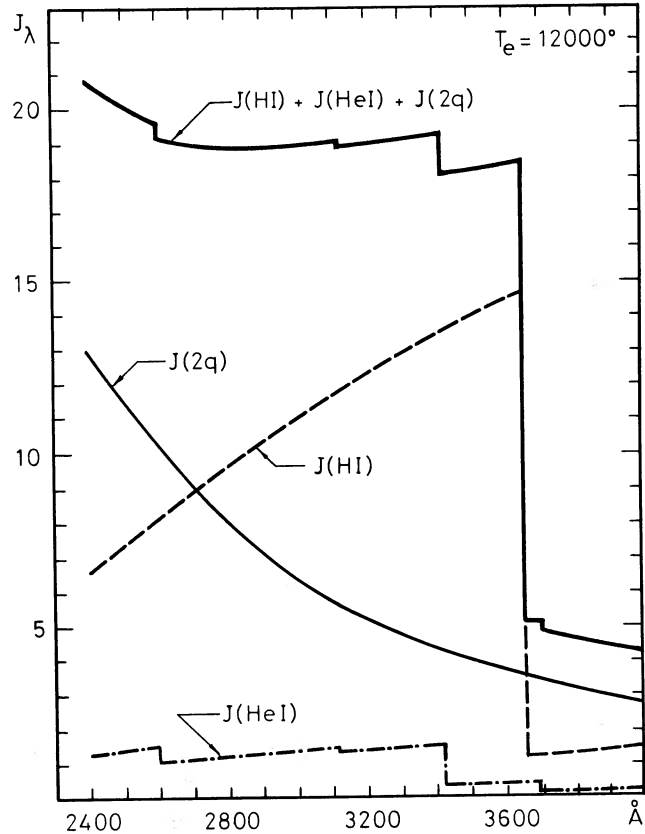


FIG. 2—The established view of the components of the continuous emission in the ultraviolet region of the spectrum for the planetary IC 2149 ($T_e = 12,000^\circ \text{ K}$, $n_e = 3.2 \cdot 10^3 \text{ cm}^{-3}$): Balmer continuum of hydrogen (H I), neutral helium (He I) (at $n(\text{He})/n(\text{H}) = 0.1$), and two-photon emission ($2q$). The heavy line is the total spectrum in the wavelength region $2400 \text{ \AA}$ – $4000 \text{ \AA}$. The ordinate is in units of $10^{-28} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$.

tion of this problem should be looked for in the derivation and analysis of ultraviolet spectrograms (shorter than $3000 \text{ \AA}$) of planetary nebulae.

Now we can compare the observed spectrum of additional emission in Figure 1, which is a mixture of two types of continua and $2q$ emission in the wavelength region of $2400 \text{ \AA}$ – $3500 \text{ \AA}$, with the theoretically recalculated spectrum (bold line in Fig. 2). Such a comparison is shown in Figure 3. As we see, the accordance of observation and theory may be considered quite good, in view of the difficulties of measuring the spectra in the farthest ultraviolet end.

An alternative to check the plausibility of the conclusions drawn is based on the estimation of the total amount of the additional emission and its comparison with the theoretically expected value for two-photon radiation. For this we obtain at first the observed value of the ratio $Q(\lambda_1 \lambda_2)/N^*(\lambda_1 \lambda_2)$, where $Q(\lambda_1 \lambda_2)$ is the amount of additional emission (number of photons) in the observed wavelength region, from λ_1 to λ_2 , and $N^*(\lambda_1 \lambda_2)$ is the number of photons emitted by the

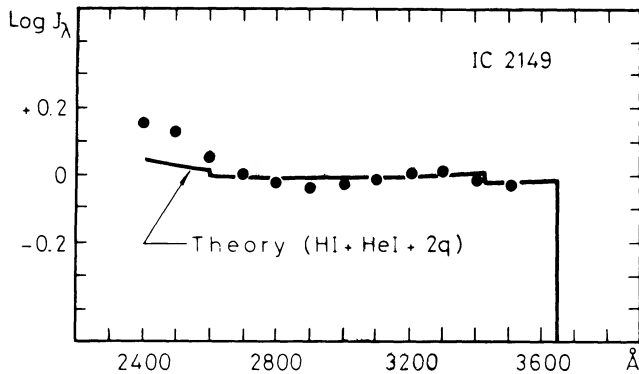


FIG. 3—A comparison of the observed spectrum of continuous emission (filled circles) in the wavelength region of 2400 Å–3500 Å in the spectrum of the planetary nebula IC 2149 with the theoretical spectrum (heavy line, taken from Fig. 2).

central star in the same wavelength region. Taking the region $\lambda_1 - \lambda_2$ as far as possible into the short-wave part of the spectrum we can increase the relative amount of $2q$ -photon emission, raising in this way the reliability of its discovery.

Further, we can obtain the ratio $Q(2q)/Q(\lambda_1\lambda_2)$ from the theoretical spectrum of two-photon radiation, where $Q(2q)$ is the total number of $2q$ -photons all through the wavelength region—from $\lambda = 1216$ Å to $\lambda \rightarrow \infty$.

Finally, denoting by N_c the number of photons in the Lyman continuum ($\lambda_0 \leq 912$ Å) emitted by the nucleus per second, we can derive the following relationship between the ratio $Q(2q)/N_c$ and the temperature of the nucleus T_* , some kind of an analog of Zanstra's formula for two-photon emission.

$$\frac{Q(2q)}{N_c} \sim \frac{Q(\lambda_1\lambda_2)}{N^*(\lambda_1\lambda_2)} \frac{Q(2q)}{Q(\lambda_1\lambda_2)} \frac{\int_{\lambda_1}^{\lambda_2} \frac{x^2 dx}{e^x - 1}}{\int_{\lambda_0}^{\infty} \frac{x^2 dx}{e^x - 1}}, \quad (1)$$

where $x = hc/\lambda k T_*$. In our case we have $\lambda_1 = 2400$ Å, $\lambda_2 = 2850$ Å. Further, we obtain $Q(\lambda_1\lambda_2)/N^*(\lambda_1\lambda_2) = 0.50$ from Figures 1 and 2, and $Q(2q)/Q(\lambda_1\lambda_2) = 14$ from the theoretical spectrum of $2q$ -photon emission. Using these data we derive from equation (1) for $Q(2q)/N_c$, at two probable values of the nucleus temperature,

T_*	$Q(2q)/N_c$
55,000° K	0.67
66,000° K	0.45

According to the theory, approximately 0.33 of the hydrogen atoms formed by recombination (at $T_e = 12,000^\circ$ K) to all levels starting with the second enter

the $2S$ state, inducing $2q$ -transitions. Therefore in the “pure” case, that is the collisions are neglected, we have for the theoretical ratio $Q(2q)/N_c = 2 \times 0.33 = 0.66$, assuming of course $\tau_0 > 1$ for the optical depth of the nebula in the frequencies of the Lyman continuum. Taking into account the collisions (deactivation factor, Purcell 1953) we shall obviously have (Purcell 1952; Brown and Mathews 1970)

$$\frac{Q(2q)}{N_c} = \frac{0.66}{1 + 0.63 \cdot 10^{-4} n_e}. \quad (2)$$

We have $n_e = 3.2 \cdot 10^3 \text{ cm}^{-3}$ for IC 2149, and then we obtain from equation (2): $Q(2q)/N_c = 0.55$, which is in good agreement with observations. If there are large fluctuations in density, the effects can be complicated because the recombination spectrum is favored since it goes as $n(\text{H}^+)\eta_e$ while two-quantum emission is disfavored.†

Thus, two independent methods, both the spectral distribution and the amount of radiation emitted, point to the existence of hydrogen two-photon emission in the nebula IC 2149.

The spectral resolution of our spectral images at $\lambda \sim 3500$ Å is too small (~ 50 Å) in order to make possible the detection and measurement of the Balmer jump itself in this case.

We are not familiar with the precise form of the extinction curve in the ultraviolet for the specific line of sight—the direction of the nebula IC 2149—and this precise form is hard to predict. Therefore, in correcting the observed values Δm_λ we handled the effect of interstellar selective absorption in the ordinary way, viz., we made use of the extinction curve given by Bless and Savage (1972), say, in the direction of the star α Camelopardalis (as the closest to the region of the sky where the nebula is located) with a typical absorption maximum at $\lambda \sim 2200$ Å. As we introduced the corresponding reduction we assumed the distance of IC 2149 to be equal to 1300 pcs (Krueger, Aller, and Gzyzak 1970).

It should be added forthwith, however, that the assumptions made are of no decisive value if we are concerned only with the isolation of excess emission from the general spectrum of the central star of the nebula. The point of importance is as follows: any attempt to achieve accordance of the long-wave part of the observed spectrum of the central star with theory is invariably confronted with the fact that its short-wave end protrudes distinctly above the theoretical curve, provided reasonable combinations of the original parameters are chosen.

†My thanks to an anonymous referee for having pointed this out.

The above considerations enable us to offer an independent mode for the determination of the dilution coefficient, W , of the nebula or the radius of its nucleus, R_* . This mode is based on the determination from observations of the ratio $I_n(\lambda)/I_*(\lambda)$, where $I_n(\lambda)$ and $I_*(\lambda)$ are the intensities of the radiation of nebula and star correspondingly, at a given wavelength, λ , shorter than 3600 Å.

We have for the intensity of continuous radiation of the nebula (Brown and Mathews 1970):

$$I_n(\lambda) = n_e^2 \gamma_{\text{eff}}(T_e) V, \quad (3)$$

where V is the volume of the nebula, $\gamma_{\text{eff}}(T_e)$ is the total emission coefficient for all types of continua, and $2q$ is the two-photon radiation.

The radiation of the central star in the short-wave range can be approximated with fair accuracy by the Planck law at the effective temperature T_{eff} . We have

$$I_*(\lambda) = 4\pi R_*^2 B_\nu(T_{\text{eff}}). \quad (4)$$

From equations (3) and (4) we obtain

$$\frac{I_n(\lambda)}{I_*(\lambda)} = \frac{h_e^2 \gamma_{\text{eff}}(T_e)}{24 B_\nu(T_{\text{eff}})} \frac{D_n}{W}, \quad (5)$$

where D_n is the linear diameter of the nebula. For IC 2149 we have: $I_n/I_* = 0.93$ at $\lambda = 2400$ Å (see Fig. 1); $T_{\text{eff}} = 55,000^\circ \text{K}$; $D_n \approx 2.10^{17} \text{ cm}$ (for angular sizes of the nebula $6'' \times 12''$ and distance $r = 1300$ pcs); $\gamma_{\text{eff}}(12,000^\circ \text{K}) = 12.10^{-40} \text{ erg cm}^3 \text{ s}^{-1} \text{ Hz}^{-1}$. Using these data we obtain from equation (5): $W = 2.7 \cdot 10^{-15}$ and $R_* = 0.15 R_\odot$.

In a recent paper Bohlin, Marionni, and Stecher (1975) deal with the description and analysis of the ultraviolet spectrum of NGC 7027, which ranks second as a planetary nebula observed from space, next to IC 2149. This spectrogram was obtained in the wavelength range 1200 Å–3000 Å with a rocket-borne telescope. A passing reference is also made to an ultraviolet spectrogram, derived in the same way, of another planetary nebula NGC 7662. Incidentally, they have observed in the second case the occurrence of a strong Ne IV doublet at $\lambda 2440$ in the spectrum of the nebula, and this result is in complete agreement with the one we had in the case of IC 2149 in the spectrum of which the above doublet had been discovered for the first time (Gurzadyan 1975c).

As to NGC 7027, it is hard to trace signs of two-photon emission on the published microphotometric record of its spectrum. This was to be expected by virtue of the following two reasons. First, the electron concentration in the nebula NGC 7027 is very great (from 2.10^4 cm^{-3} to 8.10^4 cm^{-3} according to the various estimates) and over one order greater than in IC 2149.

That is why the deactivation in the case of NGC 7027 will be much stronger, which will result in a sharp depression of the intensity of the two-photon emission. Second, and more importantly, nebula NGC 7027 is very heavily obscured by interstellar material; the value of the relative extinction, $A_\lambda - A_\beta$, attains, by the estimate made by Bohlen et al. (1975), up to 5–6^m(!) in the wavelength range 2400 Å–1500 Å. Under such conditions only the stronger emission lines can be established, and one can hardly hope for a detection of the continuous spectrum of two-photon origin. In general, both nebulae essentially differ from one another in overall structure of the spectrum as well as in composition and power of the emission lines in the range 2400 Å–3000 Å. This is to be expected if we realize the fact that IC 2149 figures as a weakly excited nebulae while NGC 7027 is known as a strongly excited nebula, and this difference will manifest itself more prominently in their short-wave spectra.

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