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PLANETARY NEBULAE IN LOCAL GROUP GALAXIES. II. IDENTIFICATIONS, POSITIONS, NUMBER, AND PRODUCTION RATE OF NEBULAE IN NGC 221

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ABSTRACT

We extend the identifications of planetary nebulae in NGC 221 to 21 nebulae; 19 of these are certain identifications. Radial velocity observations show that three of the 19 nebulae belong to NGC 224 and that 11 belong to NGC 221; the remaining five are probable members of NGC 221. Equatorial coordinates are presented for the nebulae and reference stars in the NGC 221 field. The coordinates have an accuracy of at least 1″.0 relative to the AGK 3 and at least 0″.5 relative to one another. The observed number of nebulae is corrected for the losses in the saturated image of the galaxy and for the loss of limiting magnitude in the envelope of the galaxy. With these corrections we estimate that there are 34 planetary nebulae which are brighter than our Hα limiting magnitude. The identifications of planetary nebulae provide a direct observational basis for estimating the rate at which mass returns to the interstellar medium in NGC 221. We estimate that the production rate of planetaries in NGC 221 is $\chi_{\rm pn} \geq 2.8 \times 10^{-3}$ nebulae yr^{-1} and that the rate of hydrogen mass loss from planetaries is $\sim 6 \times 10^{-4}\ M_\odot$ yr^{-1}. Assuming a constant production rate of planetaries for the past 10^{10} years, at least $6 \times 10^6\ M_\odot$ of hydrogen has been returned to the interstellar medium in NGC 221. This is larger than the observational upper limits to the amount of neutral or ionized gas in NGC 221. The possibility of losing the gas through a Mathews-Baker galactic wind is discussed.

Subject headings: galaxies, individual — galaxies, stellar content of — mass loss — planetary nebulae

I. INTRODUCTION

In the first paper of this series (Ford *et al.* 1973; hereafter referred to as Paper I) we presented identifications of planetary nebulae in NGC 185 (4), NGC 205 (12), and NGC 221 (10). In this paper the identifications in NGC 221 (M32) are extended to low-excitation nebulae and to fainter limiting magnitudes. In § II we discuss the observations and identifications. In § III positions are presented for the nebulae and reference stars, and in § IV we estimate the total number of nebulae in M32. In § V we estimate the rate at which the nebulae are returning mass to the interstellar medium in M32, and discuss the possibility that this mass is being blown from M32 in a Mathews-Baker (1971) galactic wind.

II. OBSERVATIONS

Our identification technique, which is based on pairs of on-line and off-line interference-filter photographs, is discussed in Paper I. The identifications in that paper have been extended by using three filters which more effectively isolate Hα and [O III] λ5007. The central wavelengths (λ_c) and the full widths at half-maximum transmission (FWHM) of the filters are λ_c6570 (50 Å FWHM), λ_c6565 (21 Å FWHM), and λ_c5010 (23 Å FWHM). Figure 1 shows the transmissions of the latter two filters as a function of observed velocity for the lines Hα, [N II] λ6584, and [O III] λ5007. The curves include a bandpass shift $\delta\lambda/\lambda_0 \simeq -5.2 \times 10^{-4}$ to allow for the f/5 beam at the prime focus of the 120-inch (3 m) telescope. M32's heliocentric radial velocity of -190 km s^{-1} and the $\pm 1\ \sigma$ velocities for an assumed 35 km s^{-1} radial velocity dispersion are shown in Figure 1. Also shown is the heliocentric component of the rotational velocity of the nearby galaxy NGC 224 (M31) which projects onto the line of sight in the M32 field. Its value, -400 km s^{-1}, was derived from the rotation curve and algorithm given by Rubin and Ford (1970).

Figure 2 (Plate 2) is a reproduction of a 30-minute exposure with the λ_c6570 (50 Å FWHM) filter and Westinghouse WL-30677 image intensifier plus a IIa-D photographic plate. We identified 18 stellar nebulae and seven diffuse nebulae on this plate. As discussed in Paper I, the diffuse nebulae are presumed to be H II regions in the spiral arm of M31 which projects onto the M32 field.

Figure 3 (Plate 3) is a reproduction of a 45-minute exposure with the λ_c6565 (21 Å FWHM) filter and image intensifier plus a IIa-D plate. Comparison of Figures 2 and 3 clearly shows that this plate reaches a fainter Hα limiting magnitude than the preceding plate. We identified 17 stellar nebulae and seven diffuse nebulae on this plate.

Figure 4 (Plate 4) is a reproduction of a 40-minute exposure with the λ_c5010 (23 Å FWHM) filter and image intensifier plus a baked IIIa-J plate. This combination of a narrow filter and a high-information-capacity plate allows us to detect moderate- to high-

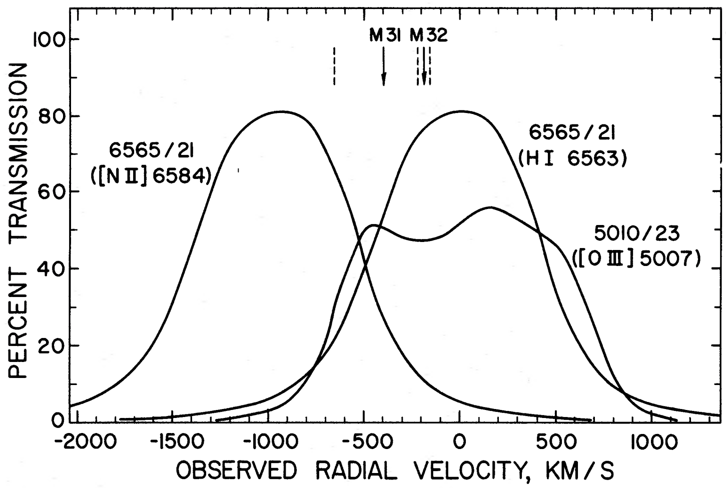

FIG. 1.—Filter transmission as a function of observed radial velocity. The transmission of the interference filter $\lambda_c 6565$ (21 Å FWHM) is shown for the emission lines H I $\lambda 6563$ and [N II] $\lambda 6584$. The transmission of the interference filter $\lambda_c 5010$ (23 Å FWHM) is shown for the emission line [O III] $\lambda 5007$. The two arrows show the heliocentric radial velocity of M32 and the heliocentric component of the rotational velocity of M31 which projects onto the M32 field. The dashed lines bracketing the M32 velocity show the $\pm 1\ \sigma$ velocities for an assumed radial velocity dispersion of 35 km s^{-1}. The leftmost dashed line shows the observed radial velocity of planetary 12.

excitation nebulae against the high surface brightness background of NGC 221. The nebulae NGC 221–20 and NGC 221–21 are identified in a region of the galaxy which is saturated on the IIa-D plates. We identified 12 moderate- to high-excitation stellar nebulae and one diffuse nebula on this plate.

Table 1 summarizes the identifications in NGC 221. Each of the first five columns is headed by, respectively: the plate number, date of the photograph, exposure time, plate type, and filter. The presence of an Arabic numeral in the column indicates that the corresponding nebula was identified on that plate. The sixth column

TABLE 1

IDENTIFICATIONS OF PLANETARY NEBULAE IN NGC 221

ED 2549 1972 July 12/13 42 minutes IIa-D 6573/21	ED 2562 1972 July 13/14 30 minutes IIa-D 5020/57	ED 2649 1973 Aug. 26/27 40 minutes Baked IIIa-J 5010/23	ED 2683 1973 Sept. 27/28 30 minutes IIa-D 6570/50	ED 2684 1973 Sept. 27/28 45 minutes IIa-D 6565/21	Radial Velocity
1..........	1	1	1	1	Yes
	2	2	2	2	Yes
3..........	3	3	3	3	Yes
	4	4	4	4	Yes*
5..........	5	5	5	5	Yes
6..........	6	6	6	6	Yes
	7	7	7	7	Yes
	8	8	8	8	Yes
	9	9	9	9	No
10..........	...	...	10	10	No
	...	...	11	11	Yes
	...	...	12	12	Yes*
13†..........	...	...	13	13	Yes
14†..........	...	...	14	14	Yes
	...	...	15	15	Yes
	...	...	...	(16)‡	...
	...	...	17	17	Yes*
	...	...	18	...	No
	...	...	19	...	No
	...	20	...	...	No
	...	21	...	...	No
	22†	22	...	...	No

* High radial velocity planetaries which belong to NGC 224.

† Not originally identified on this plate; discernible though very faint.

‡ Identified on only one plate—a possible plate flaw.

indicates those nebulae whose radial velocities have been measured (at Hα) with the ITS Cassegrain scanner (Robinson and Wampler 1972*a*, *b*) on the 120-inch telescope at Lick Observatory.

The radial velocities will be discussed in a subsequent paper. However, we note here that the ~ 200 km s^{-1} difference between the radial velocity of the projected M31 field and the radial velocity of NGC 221 allows us to determine kinematically the parentage of the nebulae. We find that three of the 14 nebulae with observed radial velocities belong to M31. The preliminary radial velocities of these nebulae are -409 km s^{-1} (NGC 221–4), -664 km s^{-1} (NGC 221–12), and -423 km s^{-1} (NGC 221–17). The remarkable velocity of NGC 221–12 was determined from the lines [N II] λ6548, Hα, and [N II] λ6584, and was observed during two separate observing runs. The radial velocities of the remaining 11 nebulae cluster tightly around the heliocentric radial velocity of NGC 221.

Table 1 shows that the 10 identifications in Paper I are confirmed by the present work, and that the conclusion in Paper I that the majority belong to NGC 221 can now be stated quantitatively: nine out of 10 belong to NGC 221. Seventeen of the nebulae in Table 1 are identified on two or more plates. The nebulae NGC 221–20 and NGC 221–21, although identified only on the IIIa-J plate (Plate ED 2649), are bright and distinct enough to leave little doubt of their reality. NGC 221–18 and NGC 221–19, which are identified only on ED 2683, are the least certain identifications. Reference to Figure 1 shows that their absence on the λ5007 plates and the deep Hα plate ED 2684 can be explained if they are low-excitation, weak [N II] λ6584 nebulae with high velocities appropriate for the projected M31 field. This explanation is plausible in view of the three nebulae which have observed high velocities; NGC 221–18 and NGC 221–19 will not be counted as members of NGC 221. In summary, there are 21 identified nebulae, 19 of which are certain identifications. Eleven of the nebulae have radial velocities which show that they belong to NGC 221, while three of the nebulae clearly belong to M31. The remaining five nebulae are plausibly associated with NGC 221, giving a total of 16 nebulae which are probable members of NGC 221.

III. POSITIONS OF THE PLANETARY NEBULAE IN NGC 221

Spectrophotometry of planetary nebulae in galaxies as distant as NGC 221 typically requires precise blind offsets. The difficulty of acquiring these faint nebulae is put into perspective by considering the fluxes from planetary nebulae in the Large Magellanic Cloud (LMC). The Hα and [O III] λ5007 fluxes of the third brightest planetary in the LMC (Webster 1969) as seen at the distance of NGC 221 are, respectively, 6.45×10^{-15} and 2.40×10^{-14} ergs cm^{-2} s^{-1}. These values correspond to the fluxes in the V-bandpass from stars with $V = 21.7$ and $V = 20.3$. To facilitate observation of these nebulae, we present their positions and the positions of nearby reference stars. As we shall show, the WL 30677 image intensifier is especially suitable for this work since it has almost no geometrical distortion.

The relatively small field ($\sim 8'.7$) of our image intensifier photographs of M32 does not include stars with known positions. Consequently, as an intermediate step we use two astrograph plates which were kindly taken for us by Dr. Klemola and Mr. MacNamara with the Lick Observatory 20-inch (51 cm) Carnegie astrograph. The plates include the image intensifier field reference stars and stars with cataloged positions (AGK 3). We first transform the measured astrograph positions of the cataloged and reference stars to standard coordinates (van de Kamp 1967), equinox 1975.0, by least-squares fitting the astrograph positions of the AGK 3 stars to their respective standard coordinates with a second-order polynomial. Except for the terms which include the stellar magnitude, we used the polynomial which is appropriate for Eichhorn's (1974) "standard model."

We next linearly least-squares fit the measured positions of the reference stars on the image intensifier plates to their respective standard coordinates. These least-squares fits define the transformations which we use to convert the measured positions of the planetary nebulae to standard coordinates. The latter are converted to right ascension and declination and averaged if a planetary's position was measured on more than one plate.

a) *Equatorial Coordinates of the Nebulae and Reference Stars*

The equatorial coordinates of the nebulae are presented in Table 2. The first column gives the

TABLE 2

COORDINATES OF PLANETARY NEBULAE IN NGC 221

Number (1)	R.A.(1975.0) (2)	Decl.(1975.0) (3)	*N* (4)
1..........	00h41m13s.74	40°44′47″.6	3
2..........	30.85	40 47.1	4
3..........	18.03	42 49.4	5
4*.........	08.91	44 51.9	3
5..........	17.43	44 27.3	5
6..........	18.18	44 30.6	4
7..........	26.00	46 00.4	4
8..........	39.88	41 18.0	4
9..........	17.92	41 28.4	3
10..........	22.81	44 35.0	3
11..........	34.78	42 48.8	2
12*.........	32.37	43 54.4	2
13..........	22.34	39 55.2	3
14..........	18.07	42 47.1	3
15..........	14.33	43 15.4	2
16†.........			
17*.........	04.82	41 28.9	2
18..........	09.27	45 10.0	1
19..........	14.70	41 49.9	1
20..........	19.50	43 18.2	1
21..........	20.06	43 26.1	1
22..........	27.68	42 57.5	1

* High radial velocity planetaries which belong to NGC 224.

† Identified on only one plate—a possible plate flaw.

TABLE 3

REFERENCES STAR COORDINATES IN THE NGC 221 FIELD

Star	R.A.(1975.0)	Decl.(1975.0)	N
a...........	00ʰ41ᵐ34ˢ86	40°45′36″7	5
b...........	31.17	44 03.4	5
c...........	34.01	42 35.3	5
f...........	11.93	40 07.0	4
j...........	11.90	44 58.3	4
l...........	28.93	40 36.0	5
m..........	18.68	43 00.9	4

designation of the nebula, as indicated in Figures 2–4. Column (2) gives the right ascension, and column (3) gives the declination, both for the equinox of 1975.0. The last column gives the number of 120-inch plates used to determine the average equatorial coordinates. Table 3 gives the corresponding data for the reference stars, whose positions are indicated with Roman letters in Figure 2.

b) *The Precision of the Coordinates*

The average standard deviation of the positions in Table 2 is 0″23 in right ascension and 0″15 in declination. These values indicate a high degree of internal consistency, but do not reflect external errors or systematic errors which could be masked by the relative constancy of the centering of the fields.

The absence of AGK 3 stars in our M32 field prevents us from directly checking the external accuracy of our computed coordinates. However, we have made such a check in the NGC 205 field, which includes the star AGK 3 41°65. Our coordinates for this star, determined as for the M32 field, differ from the AGK 3 coordinates by 0″23 in right ascension and by 0″19 in declination.

Systematic image intensifier distortion which is not represented by a linear transformation may introduce errors considerably larger than those obtained for AGK 3 41°65. As a measure of such errors we have computed the average standard deviation for 118 planetaries in M31 which have been measured in two or more overlapping fields. The averages and their standard deviations are 0″31 ± 0″19 in right ascension and 0″28 ± 0″17 in declination. These values show that there is no geometrical distortion in the image intensifier on a scale larger than 0″5 (25 μ on the anode).

We conservatively estimate that the coordinates in Tables 2 and 3 have an external accuracy relative to the AGK 3 of at least 1″0. When the coordinates in Tables 2 and 3 are used differentially, we expect the precision to be at least 0″5.

IV. THE ESTIMATED NUMBER OF PLANETARY NEBULAE IN NGC 221

The number of nebulae which we observe in NGC 221 is less than the true number for several reasons. First, nebulae cannot be detected in the saturated image of the central part of the Galaxy, and the fainter nebulae are lost in the bright, unsaturated portions of the image of the Galaxy's envelope. Second, part of the nebular luminosity function is fainter than our limiting magnitude. Finally, the galaxy is larger than the field of our plates. We will consider the effect of each of these problems.

We first estimate the number of faint nebulae which are brighter than our limiting magnitude in the sky-limited outer portions of the plate, but are lost near the galaxy because of its increasingly bright envelope. In order to include both high- and low-excitation nebulae, we restrict our attention to the Hα plates.

The outer radius (r_s) of the annulus in which faint planetaries are lost is the distance at which the galaxy and sky brightness are equal. External to this there will be a constant limiting magnitude if the photocathode has uniform sensitivity. Densitometry of plates exposed with a uniformly illuminated photocathode shows that the center-to-edge sensitivity variation of the Westinghouse image intensifier is less than 0.12 mag; this small variation will be neglected. The inner radius (r_m) of the annulus is the distance at which the brightest planetaries could be detected against the envelope of NGC 221. We estimate r_m and r_s to be 26″ and 72″ on the Hα plate ED 2683.

We assume that our limiting magnitude for $r \leq r_s$ is proportional to the surface brightness of NGC 221, and that the nebular luminosity function is uniformly populated between the brightest and faintest detectable nebulae. For the surface brightness we adopt de Vaucouleurs's (1959) reduced luminosity curve. When combined with the totality of modern photoelectric data (de Vaucouleurs 1975), the equation becomes

$$m_B(r) = 12.07 + 8.326\,(r/30)^{1/4}\,, \qquad (1)$$

where m_B is the isophotal surface brightness of an ellipse ($e = 0.8$) with semimajor axis r. With our assumptions and appropriate integration of equation (1), the six planetaries in the annulus should be increased to 10. This increases the 13 probable members (seen on the Hα plates) of NGC 221 exterior to the saturated central image to 17. The major sources of uncertainty in this estimate are the assumption of a uniformly populated nebular luminosity function and statistical fluctuations in small numbers, rather than the precise choice of r_m and r_s.

To estimate the number lost in the central image, we multiply the estimated 17 nebulae by the ratio of the light interior to r_m to that between r_m and the edge of the field. Numerical integration of equation (1) shows the ratio to be 0.94. We thus predict 16 planetaries in the saturated image, and estimate the total number of planetaries in the field to be 33.

Though the tidal radius of NGC 221 is uncertain, its precise value has little effect on the estimate of the number of planetaries external to our photographs. If we assume $r_{\max} \approx 10'$, then 95 percent of the light is contained in the field of our photographs. This results in a formal estimate of one planetary outside our field and the conclusion that at most only a few planetaries brighter than our limiting magnitude are outside our field. We thus estimate that there are 34 nebulae in NGC 221 which are brighter than our Hα limiting magnitude.

The difference in magnitudes between the brightest and faintest detected planetaries is equal to the difference between the surface brightness at r_m and that at r_s. We thus determine (cf. eq. [1]) that we have sampled approximately 2.3 mag of the nebular luminosity function.

The distribution of nebular magnitudes in NGC 221 is a function of the production rate of nebulae, the evolution of the central stars of the nebulae, and the expansion of the nebulae after becoming optically thin. Lack of a reliable quantitative description of the evolution of the central star of a planetary nebula prevents us from using the observed number of nebulae to infer the number of nebulae which are a specified number of magnitudes fainter than our limiting magnitude. Comparison of Figures 2 and 3 shows that ED 2684 reached a fainter limiting magnitude than ED 2683. In spite of this (cf. Table 1), ED 2684 has the same number of probable members (13) as ED 2683. This implies that our assumption of constant density for the luminosity function overestimates the number of faint nebulae. Consequently, our estimate of 34 nebulae within 2.3 mag of the brightest nebula is probably an upper limit to the true number.

In summary, our Hα plates show 13 planetary nebulae which are probable members of NGC 221. We determine that there is an interval of approximately 2.3 mag between our brightest and faintest nebula on ED 2683. We apply a small correction to the observed number of nebulae to estimate 17 nebulae brighter than the plate limit which are exterior to the unsaturated image of the galaxy. Multiplication of this number by the ratio of light in the saturated image of the galaxy to that in the unsaturated image predicts 16 undetected planetaries in the center of NGC 221. We formally estimate one planetary external to our field. The combined numbers result in an estimate of 34 planetary nebulae in NGC 221 which are brighter than our Hα limiting magnitude. From comparison of our two Hα plates we conclude that the nebular luminosity function is not strongly populated below our limiting magnitude.

V. DISCUSSION

a) The Production Rate of Nebulae and the Interstellar Medium in M32

Recent observations (Gallagher 1972; Hills and Klein 1973; Knapp *et al.* 1973) have set upper limits to the amount of neutral and ionized hydrogen present in some globular clusters and elliptical galaxies. The upper limits are considerably smaller than the estimates of the amount of interstellar hydrogen which accumulates as a result of mass loss from evolving stars. Our identifications of planetary nebulae provide a direct observational basis for estimating the rate at which mass returns to the interstellar medium in M32.

We first estimate the birthrate $\chi_{\rm pn}$ of planetaries in M32. We assume that the fainter nebulae evolve from the brighter nebulae. Though the nebulae are probably optically thin, as a first approximation we assume the luminosities of the nebulae are determined solely by the evolving luminosities of the central stars. With this assumption we can use Seaton's (1966) evolutionary sequence for the central stars of galactic planetaries as a working hypothesis which allows us to estimate the increase in nebular size during the evolution from our brightest to our faintest detectable nebulae. Referring to Figure 6 of Seaton's paper, we estimate a probable change in size from $R = 0.1$ pc to $R = 0.2$ pc for 2.3 mag of evolution of the nebular brightness and estimate a change from $R = 0.06$ pc to $R = 0.30$ pc as an upper limit to the evolution of R. Assuming a typical expansion velocity is 20 km s^{-1}, the evolutionary times are, respectively, 5000 and 12,000 years. The "observed" and estimated production rates are respectively 16 and 34 nebulae divided by the evolutionary time. We conservatively adopt the longer evolutionary time, which gives $\chi_{\rm pn\,``observed"} \geq 1.3 \times 10^{-3}$ nebulae per year, and $\chi_{\rm pn,\,estimated} \geq 2.8 \times 10^{-3}$ nebulae per year.

The choice of a mass for planetary shells is somewhat arbitrary in view of the uncertainties in the observational determinations and the likelihood that there is a considerable range of masses. We assume that the hydrogen masses of the planetaries in M32 are between 0.1 and 0.4 $M_\odot$, and adopt 0.2 $M_\odot$ as a reasonable mean value. The product of this mass times the production rates gives $(dM/dt)_{\rm ``observed"} \geq 2.6 \times 10^{-4}$ $M_\odot$ yr^{-1}, and $(dM/dt)_{\rm estimated} \geq 5.6 \times 10^{-4}$ $M_\odot$ yr^{-1} for the rate of hydrogen mass loss from planetaries in M32. During the past 10×10^9 years, the mass of a star with solar composition which has completely evolved will change from approximately 2 $M_\odot$ to slightly more than 1 $M_\odot$ (Iben 1966). We assume that all stars in this mass range produce planetaries and that there is little change in the mass function of M32 between 1 $M_\odot$ and 2 $M_\odot$. With these assumptions, at least 2.6×10^6 $M_\odot$ of hydrogen has been returned to the interstellar medium in M32, and more likely at least 5.6×10^6 $M_\odot$.

Our conservative estimates, which are based on observations, are consistent with Hills and Klein's (1973) theoretical estimate of 10^7 $M_\odot$ of hydrogen (1.4×10^7 $M_\odot$ total). Their 3.8-cm observations of M32 failed to detect free-free emission from ionized gas. Their assumption that the gas is at a temperature of 10^4 K and strongly concentrated to the center of M32 requires that there be less than 10^4 $M_\odot$ of ionized gas to be compatible with their null observations. This upper limit to the amount of ionized gas in the center of M32 is also required by the absence of optical emission lines in the nucleus of M32.

Wentzel and van Woerden (1954) used 21-cm observations of M32 to set an upper limit $M_{\rm H\,I} < 2.5 \times 10^7$ $M_\odot$ to the neutral hydrogen mass in M32. This upper limit is proportional to the 21-cm line half-power width, which they assumed was $\Delta v_{1/2} = 200$ km s^{-1}. Such a large value is no longer tenable, either on observational or on physical grounds. Our radial velocity observations of the planetaries in M32 suggest that $\Delta v_{1/2} \simeq 80$ km s^{-1}.

More importantly, collisions between the ejected planetary shells will shock the gas to temperatures $\sim 10^5$ K. At this temperature the gas will rapidly cool; consequently, in the absence of heat sources other than the kinetic motion of the stars, the gas will sink to the center of the galaxy and come to an equilibrium temperature which is considerably lower than the kinetic temperature of the stars. The resultant upper limit to $M_{\text{H I}}$ will then be at least a factor of 10 lower than Wentzel and van Woerden's estimate and lower than either of our estimates of the amount of hydrogen in M32.

Our observations of mass loss through planetaries, in combination with the observational upper limits to the amount of neutral or ionized hydrogen in M32, require disposal of the gas through mechanisms such as efficient low-mass star formation (Gallagher 1972) loss through interaction with stellar winds which exceed the escape velocity in M32 (Hills and Klein 1973), or loss from a galactic wind (Mathews and Baker 1971). Though low-mass star formation and stellar winds may prove to be important in elliptical galaxies, the suggestions are *ad hoc* and provide little basis for a discussion of the interstellar medium in M32. Mathews and Baker's theory of galactic winds in giant ellipticals is well developed and consequently provides a basis for discussing the problems in M32.

b) *A Galactic Wind in M32?*

Mathews and Baker have computed models of galactic winds which are heated by adiabatic shocks resulting from the propagation of supernova shells through the interstellar medium in elliptical galaxies. This theory is particularly attractive in that the proposed heat source (supernovae) is observed in elliptical galaxies. Unfortunately, their models for giant ellipticals are not appropriate for M32. Whereas in giant ellipticals the large velocity dispersion of the stars ($v_{\text{rms}} \approx 300$ km s^{-1}) will cause the ejected gas to be adiabatically shocked to temperatures $\sim 2 \times 10^6$ K, in M32 the smaller stellar velocity dispersion will result in the gas being shocked to temperatures $\sim 2 \times 10^5$ K. At this temperature, and in the absence of other heat sources, the gas will cool rapidly and become strongly concentrated in the center of M32.

If we can show that the cooling time (t_c) at $T \sim 2 \times 10^5$ K is long compared to the time required to set up a steady-state wind, we will have evidence that a galactic wind in M32 is a self-consistent hypothesis. Mathews and Baker find that the time required to reach a steady-state flow is the same as the flushing time (t_{fl}), which is defined as the time required for a fluid element to move from the center of the galaxy to the radius at which the flow becomes supersonic. The amount of gas which will accumulate during the time required to reach a steady state will be $t_{\text{fl}} \times 2.6 \times 10^{-4}\, M_\odot$ yr^{-1}. We assume this gas fills the galaxy to an estimated tidal radius $r = 6'$; the mean density is then $\bar{n} = t_{\text{fl}} \times 1.5 \times 10^{-12}$ cm^{-3}. By applying King's (1966) theoretical models to M32 we find the central density to be given by $n_c \approx 2 \times 10^5 \times \bar{n}$. For a temperature $T \sim 10^5$ K the cooling time at the center will be $t_{\text{cool}} \approx 2.6 \times 10^3$ years/n_c (Mathews and Baker). We can now express the condition that $t_{\text{cool}} \gg t_{\text{fl}}$ as the inequality $t_{\text{fl}} \ll 9.5 \times 10^4$ years. This requires that the flushing time be of the same magnitude as the time required for a supernova shell to cross the galaxy at supersonic speed. We thus contradict our initial assumption of a subsonic steady-state flow. This inconsistency precludes those models in which the galaxy is filled with gas at the stellar kinetic temperature and then heated by supernova shocks. A galactic wind is still possible, however, if it can be shown that the supernova shells can directly heat the planetary shells to temperatures of a few million degrees before they suffer substantial collisions with other planetary shells. Such a demonstration will require models which properly account for the stellar dynamics in M32.

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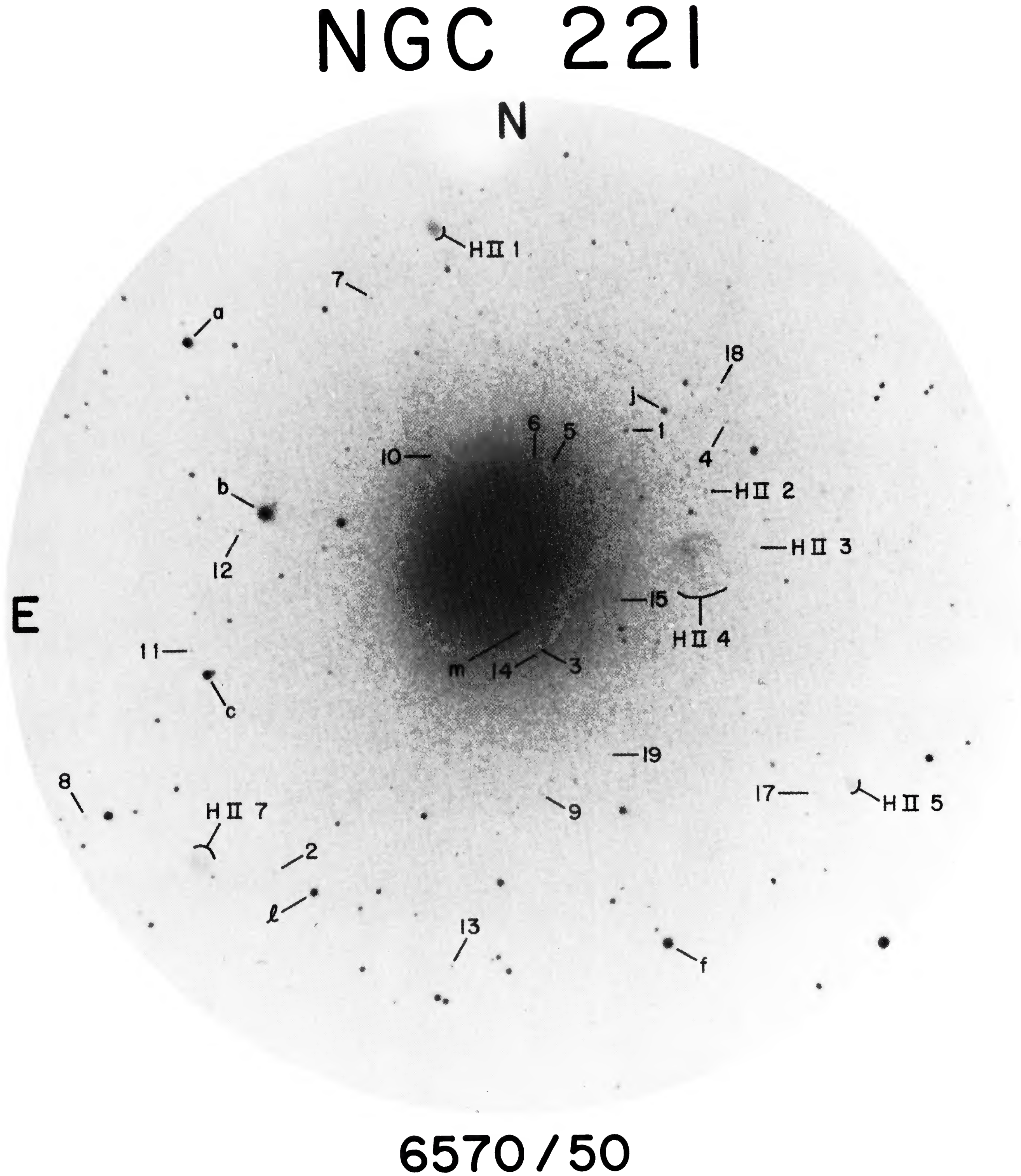

FIG. 2.—Identifications of 17 planetary nebulae and six H II regions in the NGC 221 (M32) field. The IIa-D plate isolates Hα and [N II] λλ6548, 6584 with the interference filter λ_c6570 (50 Å FWHM). Reference stars are labeled with Roman letters; the equatorial coordinates of the reference stars are presented in Table 3. The field is 8.′7 in diameter.

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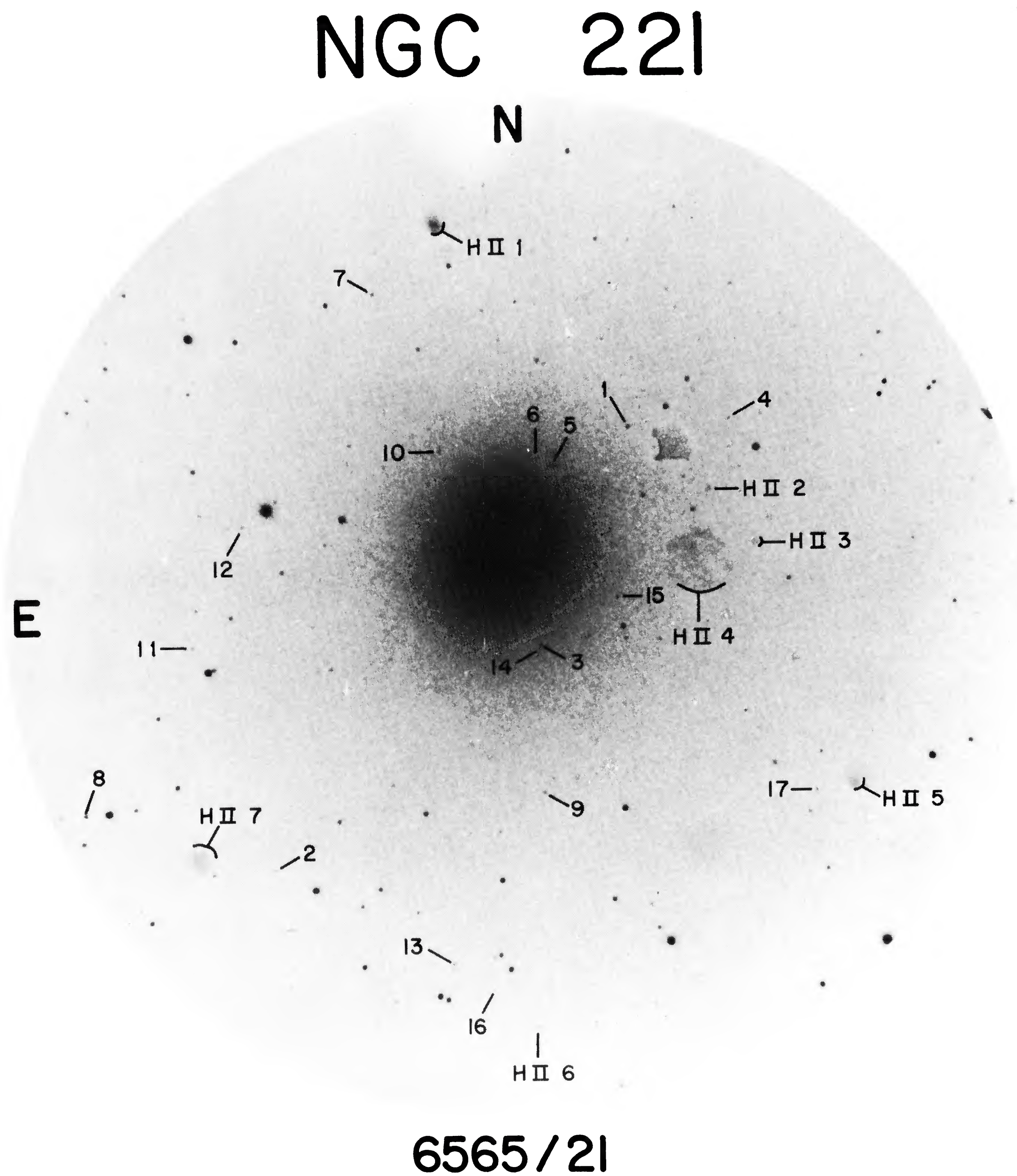

FIG. 3.—Identifications of 16 planetary nebulae and seven H II regions in the NGC 221 field. The IIa-D plate isolates Hα with the interference filter λ_c6565 (21 Å FWHM). The quadrilateral feature between NGC 221–1 and H II 2 is a plate flaw.

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PLATE 4

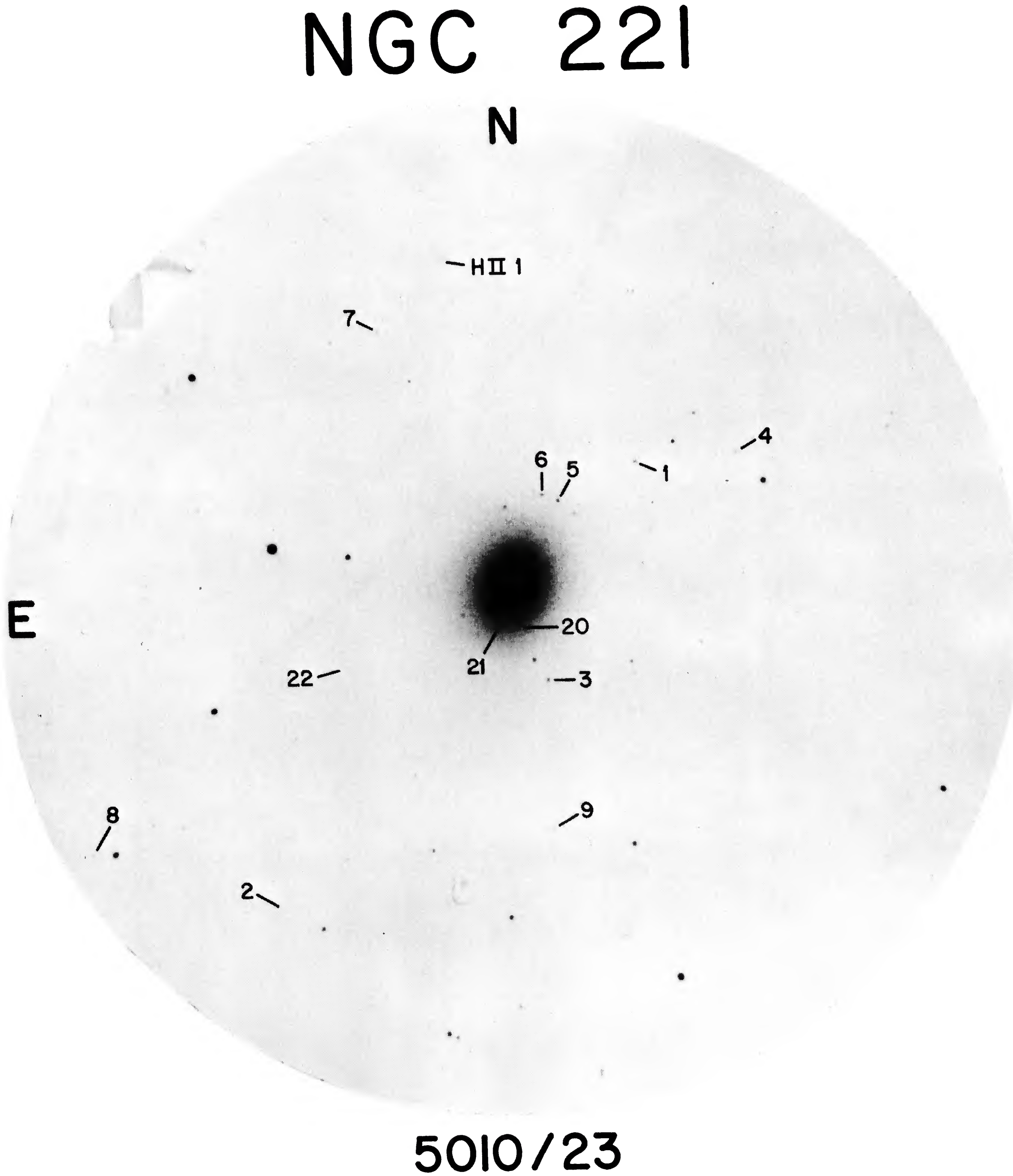

FIG. 4.—Identifications of 12 planetary nebulae and one H II region in the NGC 221 field. The IIIa-J plate isolates [O III] λ5007 with the interference filter λ_c5010 (23 Å FWHM).

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