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Planetary nebulae of low surface brightness : gleanings from the « POSS »

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Summary. — During a systematic search for new planetary nebulae (PN) on Palomar Observatory Sky Survey (POSS) prints, 15 hitherto unknown PN candidates with surface brightnesses ranging from $m_r = 20\overset{m}{.}6/\text{arcsec}^2$ to $m_r = 24\overset{m}{.}4/\text{arcsec}^2$ were found. Positions, finding charts and descriptions are presented together with a discussion of the objects. One nebula deserves special attention : it is of large size ($\phi\, 6'$) and is surrounded by a huge ($\phi\, 0\overset{\circ}{.}4$), extremely faint halo. Five of the objects can be identified with IRAS point sources.

Key words : planetary nebulae — low surface brightness — systematic search.

1. Introduction.

For two decades, « Abell planetaries » represented the most advanced stage in the evolution of planetary nebulae : in a study of objects discovered by him on the POSS, Abell (1966) investigated a great number of candidates, the majority of which turned out to be the oldest representatives of their class. Whereas the low surface brightnesses prove a handicap to detailed observations of the nebulae, they are an advantage for studies of the central stars, which are usually very hot. For recent thorough discussions on PN of this type and an insight into their importance in stellar evolution see Kaler (1983), and Kaler and Feibelman (1985).

Old planetary nebulae are, on the average, nearby objects and consequently are of significance for evaluations of the PN luminosity function, birth rate, scale height, total number in the Galaxy and various parameters dependent on these quantities (see, e.g., Jacoby, 1980). Again, the Abell planetaries play a major role here. Obviously, for all those quantities, a reliable knowledge of the number of nearby PN is necessary. In fact, the authors working in these areas had to rely on Abell's assertion that « those PN... that have surface brightnesses brighter than 26.0 (photographic) or 24.5 (photored) mag/arcsec^2 and with angular diameters greater than 10″ are probably nearly completely identified » (note : both values are only 0.5 mag/arcsec^2 above the plate limit).

Although this claim was soon disproved, the necessary conclusions were not drawn ; newly discovered PN were largely ignored. After occasional discoveries on the POSS (e.g., Arp and Scargle, 1967), Weinberger (1977) reported on 12 new PN candidates and emphasized that a number of PN on the POSS was still waiting for detection. Not surprisingly, a number of PN were found in subsequent years (see Weinberger *et al.*, 1983 and Ref. therein, Ellis *et al.*, 1984). The 15 candidates in this paper come from the second part of a survey started by Dengel *et al.* (1980), in which they examined a quarter of the POSS E prints at medium or high galactic latitudes. The PN or possible PN discussed here were found by searching the remaining prints outside the galactic plane ; a list of most of them containing their coordinates was already presented in Hartl *et al.* (1983). In a future paper, we shall present the result of our investigation of the remaining POSS fields.

Some misidentifications in all these lists are inevitable, of course. Despite this, it now appears that — including an estimate of future PN detections — about half of the old planetaries visible on the POSS were overlooked by Abell (1966). They are, on the average, fainter than his sample and thus manifest even later stages in the evolution of planetary nebulae.

A list of all PN candidates published since 1977 (direct continuation of Weinberger, 1977) can be sent on request.

2. Results of the measurements and observations.

The coordinates of the new planetaries are given in table I. The designations correspond to the system suggested by Perek and Kohoutek (1967) but are only preliminary. The equatorial coordinates were derived

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from the rectangular coordinates on the POSS prints using 6 SAO stars as a reference. The accuracy is $\pm 7''$. The POSS field numbers and the coordinates (in mm) measured from the field's left lower corner are also given. All coordinates refer to the central star if there is any, otherwise to the centre of the nebula.

The physical properties of the nebulae and the central stars are presented in table II. The dimensions of the planetaries are derived under the assumption of a symmetric shape of the nebulae with the central star in the middle. For example, for object 218-10°1 (no. 7) the model of a sphere was used where only the northern part shaped like an arc is bright enough to be seen on POSS. As a result, the dimensions given in this table are larger for some of the PN than those derived from the appearance on the POSS. The surface brightnesses presented in column three and four refer to the brightest parts of the nebulae and are given in mag/arcsec^2. Abell's (1966) planetaries were taken as standards and the accuracy should be better than $\pm 1^m$. For deriving the integrated brightnesses (column five and six) also those parts of the corresponding PN models (spheres or ellipsoids) which were too faint to be seen on POSS were included using the limiting surface brightness on POSS ($m_r \sim 25.0$, $m_b \sim 26.5$). Assuming that these parts emit absolutely no light, the values for the integrated magnitudes would increase (by a maximum of $1^m.2$ for 149-09°1). In column seven to nine, the distances in pc, the theoretical maximum distances (using a linear diameter of 1.5 pc) and the linear diameters of the nebulae, are given. The distances were calculated applying Abell's (1966) formula and are not corrected for interstellar extinction. As a result these distances and consequently the linear diameters have to be seen as upper limits because some of the objects are obviously strongly reddened. Estimates for the magnitudes of the central stars (column ten and eleven) were obtained by measuring the diameters of the star images on POSS using the standard relation of Dorschner *et al.* (1966) for the conversion. The resulting values for the absolute magnitude can be found in column twelve. A comparison of the brightnesses of the central stars on overlapping POSS prints was possible for objects no. 3, 4, 6, 10, 13 and 15. There was no indication for variability.

For two central stars (PN candidates no. 3 and 4) photographic *UBV* brightnesses were determined. The plates were taken by Prof. Ishida and one of the authors (R. W.) in 1984-1985 with the 105 cm Schmidt telescope at the Kiso Station of the Tokyo Astronomical Observatory. The irisphotometer at Kiso was used for the measurements and stars fainter than $V \approx 14^m$ from NGC 1245 served as standards (Hoag *et al.*, 1961). Due to the relatively small number of standard stars (12 in *B* and *V*), no well defined colour equations could be derived, but they appear to be similar to those determined by Ishida and Weinberger (1987) and were thus used by us :

$$U = u, \quad B = b + 0.09\,(B\text{-}V) - 0.10,$$
$$V = v + 0.14\,(B\text{-}V) - 0.16\,.$$

In October 1984, the central part (ϕ 2′) of our largest PN (no. 4) was observed with a scanning Fabry-Pérot spectrometer (Hippelein and Münch, 1981) attached to the 1.23 m telescope on Calar Alto in the [OIII] (5007 Å) line. For details of such measurements and reductions see Gieseking *et al.* (1986), who investigated a number of highly evolved PN. The observations on no. 4 were done during their program. Only a lower flux limit can be given.

From the dimensions and linear diameters of the nebulae in table II, the radio fluxes to be expected at 5 GHz were calculated following Milne and Aller's (1975) suggestions. According to this rough estimation the largest flux would be 0.04 Jy. Thus it was not surprising that a check of the updated version of Dixon's (1970) « Master List of Radio Sources » did not show a radio source within 10′ of the centre of each of our objects.

3. Discussion of the individual objects.

No. 1 (124+10°1) : Based on the nebula's appearance in E (POSS red) we used as a model for this PN an ellipsoid with the very blue central star in the middle and only the south eastern part bright enough to be seen on POSS. In O (POSS blue) the nebula has the same shape, but is fainter. Most interestingly, there seems to be an association with a small dark cloud at the south and south-eastern rim of the planetary. The emission nebula was previously listed as « bright nebula » by Lynds (1965). It was suggested by Ellis *et al.* (1984) to be a PN. We include this object, which we independently classified as a planetary (Hartl *et al.*, 1983), because we are giving some additional information on it. An IRAS point source ($01^h03^m.6$, $+73°17'$) is located in a position identical to that of the nebula ; at 60 μ, a flux density of 0.49 Jy is given and limits are provided for the residual passbands.

No. 2 (138 + 04°1) : This object, listed as Sharpless 200, appears as a relatively large, slightly deformed ring in E, fainter and more disk-like in O. Most remarkably, there appears to be an extended halo around the PN with a diameter six times as large as the central nebula ; note that the halo's size would then amount to 0°.4, that is 4 pc at a distance of 580 pc ! The brightest part in the south-east of the halo has a red surface brightness of only $\sim 24^m.5$. Although there is no visible blue central star, we suggest that this is a PN due to its enormous brightness in [OIII] according to the Emission Line Survey of Parker *et al.* (1979) ; the halo, however, is not detectable there. A detailed study of nebula and halo is needed.

No. 3 (147–09°1) : One of our most distant objects. Distinct ring in E. Fainter and more disklike in O. The

assumed central star is the only one in our list appearing fainter in O than in E. From two *U*, two *B*, and one *V* Kiso plates we determined $U = 18^m.02$, $B = 18^m.34$, $V = 17^m.68$. Due to a necessary extrapolation of the standard sequence, the total errors are uncertain, but may amount to $\pm 0^m.2 - 0^m.3$. Judging from its position in the two-colour diagram, the star consequently could be an OB star reddened by $0^m.4 - 0^m.5$ in $E(B-V)$ or even be an unreddened F or G star. At 6.7 kpc (taken from Tab. II : it is an upper limit, because the interstellar extinction was neglected), and with $A_v = 1^m.5$, $M_v = +2^m.1$ follows, which is a lower limit, of course. These data are compatible with a central star of a PN. We must, however, admit that this object remains a rather doubtful case. It could well be a galaxy, although the nucleus is not discernible from a star on Kiso plates or POSS prints, and the ring has a very smooth appearance in contrast to the usually more knotty one of a galaxy, at least in the blue region. The star could also be a foreground object.

No. 4 (149 – 09°1) : Sicklelike nebula in the north and east of a rather blue central star in E. Just visible in O. Using the model of a sphere with a diameter of 540 arcsec, where only a small part of the object is visible on POSS, this would be the largest PN of our list (excluding the halo of no. 2). It is also the nearest. From two *U*, two *B*, and one *V* Kiso plates we determined for the central star $V = 17^m.05 \pm 0^m.15$, $U\text{-}B = -0^m.94$, $B\text{-}V = -0^m.15$.

A region 2′ in diameter around the central star was observed with the Fabry-Pérot spectrometer in the [OIII] (5007 Å) line. No flux was recorded, limiting the surface brightness in this line to $> 27.5 \pm 0.5$ mag/arcsec^2.

No. 5 (156–13°1) : Disklike nebula in E with some enhancements of the brightness in the eastern part. Just visible in O. Very blue central star. Using Abell's formula to derive the distance, this object is the most distant of our list. The relatively high galactic latitude ($b = -13°$) and the fact that there are some unreddened galaxies in the neighbourhood indicate that this object, despite its large distance, is nearly unreddened.

No. 6 (156+12°1) : Filled ellipse with two distinct parts of different surface brightness in E. Can barely be seen in O at the very limit of visibility.

No. 7 (218–10°1) : Brightest nebula in our list, both in E and O. As a model we assumed a sphere with the blue central star in the middle where only the sickle-shaped nebula is visible on POSS. The object is coincident in position with an IRAS point source ($06^h21^m.2$, $-10°11'$), which has 1.16 Jy at 60 μ and 2.89 Jy at 100 μ.

No. 8 (192+7°1) : Roughly egg-shaped nebula in E, same form but fainter in O. No visible central star. At the 1.8 m telescope of the University of Padova in Asiago we obtained an uncalibrated spectrum of the nebula, which proved this object to be a PN : The [OIII] line at 4959 Å is just visible ; the flux of [OIII] (5007 Å) is about as high as H_α and [NII] (6583 Å) together, pointing to a high excitation of the nebula. The use of Abell's formula with this object leads to an underestimation of the distance, because contrary to Abell's assumption, [NII] is about as strong as H_α.

No. 9 (236–10°1) : Nebula with the appearance of a half disk in E. It can just be seen on the contrast enhanced photograph on POSS-O in figure 1. Very faint blue central star.

No. 10 (211+18°1) : Disk with uniform surface brightness. Same shape but fainter in O. Extremely blue central star.

No. 11 (358+02°5) : Disc-like nebula in E, the northern half being fainter than the southern half. In O, only the southern half can be seen. No visible central star. Minkowski (1948) described this object as « diffuse nebula ». The nebula was detected as an IRAS point source, but was assumed to be the planetary PK 358+2°4 in the IRAS Point Source catalogue, a wrong assumption, as it now appears.

No. 12 (11–14°1) : Slightly elliptical very small ring in E. Same shape, but much fainter in O. This smallest object of our list is also visible on a SERC *J* plate where in addition to the appearance on POSS a much fainter second ring can be seen in the south-east making the whole object look like an « 8 » with a bright, very red star ($m_r \sim 10.0$, $m_b \sim 13.5$) at the centre. We do not know whether it is a background star or the red companion of a blue central star. In the ESO/Uppsala Survey of the ESO(B) atlas the object is denoted as 524-G ? and described as « S... vBcentre or star ? », and the following information is given : « this star ? appears very red on POSS, like a double-shell planetary ». An IRAS point source ($19^h02^m.6$, $-25°28'$) is coincident with the object's position. Its fluxes are remarkably high : 22.78 Jy at 12 μ, 15.45 Jy at 25 μ, 6.36 Jy at 60 μ and 6.49 Jy at 100 μ.

No. 13 (34–10°1) : Small non-uniform disc in E, just visible in O. Faintest nebula of our list. Blue central star. An IRAS point source ($19^h28^m.4$, $-03°48'$) is located at the very position of the nebula ; it has fluxes of 0.28 Jy at 25 μ and 0.77 Jy at 60 μ.

No. 14 (14–25°1) : Nebula with two distinct parts of different surface brightnesses in E, the brighter one being in the east. Much fainter and more uniform disk-like appearance in O. Very blue central star.

No. 15 (99-08°1) : Elliptical disk in E with enhanced emission at the north-west and south-east ends of the major axis. In the south-east of the planetary, in a distance of about 2′ an additional filament-like nebula can be seen in E, presumably associated with the former PN. In O the PN is diffuse and almost invisible. There is a very blue central star.

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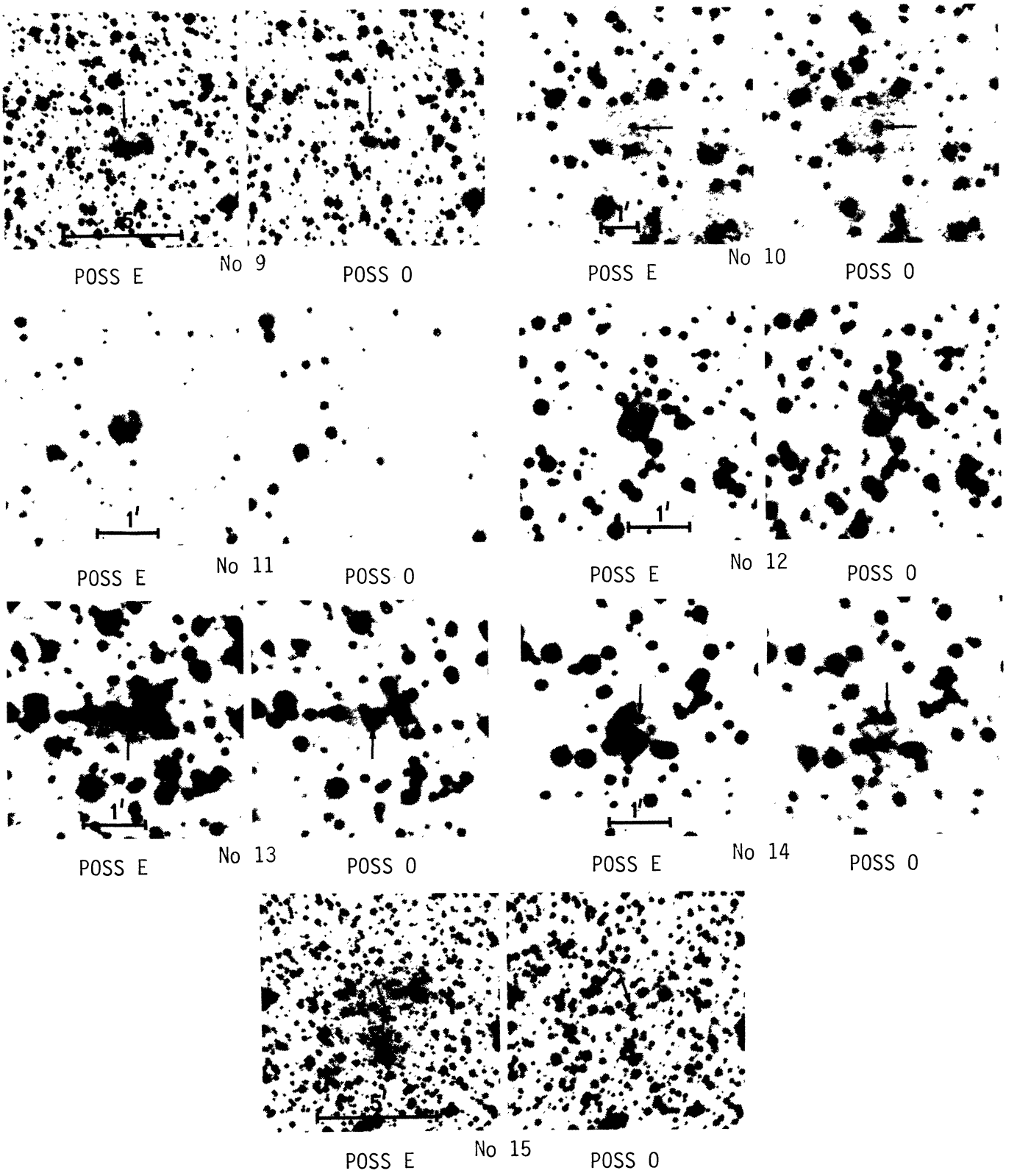
TABLE I. — *Coordinates of the new PN candidates.*

No.	Design.	R.A. 1950	DEC. 1950	POSS Field	x mm	y mm
01	124+10°1	01h03m31s.2	73°17'22"	1218	218	219
02	138+04°1	03 06 51.7	62 36 43	968	152	296
03	147−09°1	03 13 7.4	46 42 35	1249	336	92
04	149−09°1	03 23 48.9	45 13 54	643	291	331
05	156−13°1	03 42 10.1	37 39 27	1302	256	244
06	156+12°1	05 33 45.9	55 30 24	664	293	259
07	218−10°1	06 21 15.5	−10 11 45	1506	268	275
08	192+07°1	06 37 10.2	21 27 45	23	154	43
09	236−10°1	06 52 26.0	−25 17 20	1335	254	109
10	211+18°1	07 52 27.6	09 41 09	1003	28	62
11	358+02°5	17 28 36.9	−28 39 47	S88	126	249
12	11−14°1	19 02 37.8	−25 28 14	1155	246	87
13	34−10°1	19 28 29.2	−03 48 47	835	339	279
14	14−25°1	19 55 10.3	−26 36 24	1107	238	26
15	99−08°1	22 28 27.8	47 16 01	590	316	109

TABLE II. — *Physical properties of the nebulae and their nuclei derived from the POSS.*

No.	Dimension	Surface brightness		Integr. brightness		Dist.	Dist. max.	Diam.	Central Star		
	arcsec	m_r	m_b	m_r	m_b	pc	pc	pc	r	b	M
01	300x240	22.5	25.2	11m.1	13m.7	610	1050	0.87	16m.6	16m.3	7m.4
02	340x340	23.4	26.2	11.7	14.0	580	920	0.94	–	–	–
03	30x 30	24.0	25.8	17.2	18.9	6720	9980	0.99	17.0	18.6	4.5
04	540x540	24.2	26.2	11.4	12.1	410	580	1.07	17.0	16.6	8.5
05	47x 24	23.7	26.4	17.1	19.2	6750	9300	1.09	17.1	17.0	2.9
06	128x 87	24.0	26.3	14.5	16.6	2010	2890	1.04	16.7	16.7	5.2
07	94x 94	20.6	23.8	12.7	15.6	1480	3290	0.67	16.9	16.8	6.0
08	87x 67	23.7	25.9	14.5	16.7	2430	4020	0.91	–	–	–
09	148x148	23.9	>26.5	13.9	15.9	1410	2090	1.07	19.8	19.8	8.9
10	94x 94	24.4	26.3	14.8	16.7	2190	3290	1.00	17.1	16.6	4.9
11	37x 37	20.4	25.4	13.2	18.3	2870	8370	0.51	–	–	–
12	27x 27	22.5	25.3	16.4	18.9	6213	11510	0.81	–	–	–
13	47x 47	24.5	>26.5	16.4	18.4	4460	6580	1.02	16.6	16.6	3.4
14	54x 40	22.7	26.3	15.1	18.3	3650	6580	0.83	18.0	17.7	4.9
15	222x134	24.4	26.5	13.5	15.6	1260	1740	1.08	18.3	18.0	7.5



(a)

FIGURE 1. — Reproductions from POSS red (E) and blue (O) prints by permission of the California Institute of Technology. North is at the top, east to the left. The arrows mark blue central stars.

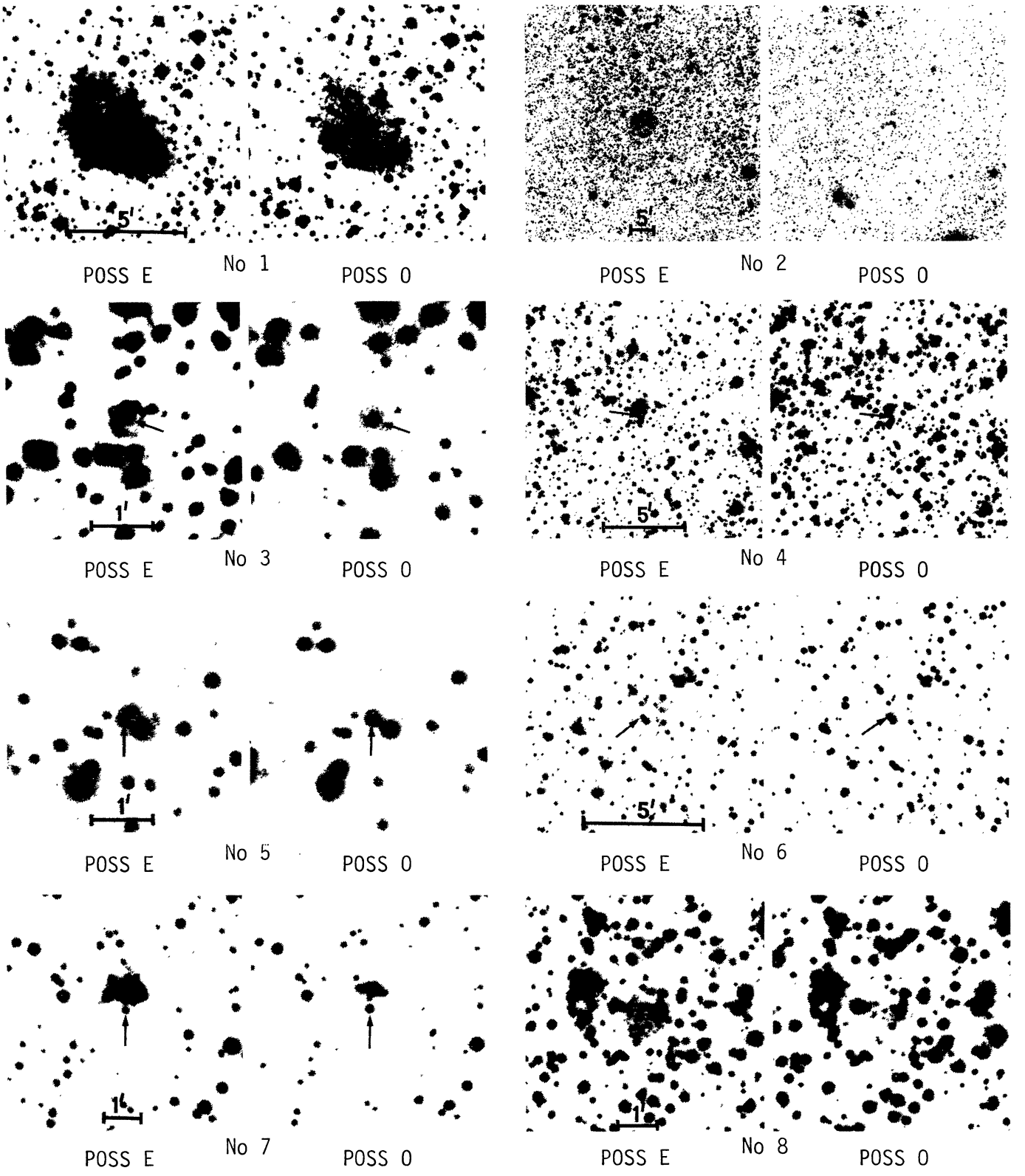


FIGURE 1(b).