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FLARE STARS IN THE ORION NEBULA REGION

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SUMARIO

Durante los años 1965-1969 obtuvimos en el Observatorio de Tonantzintla un buen número de placas fotográficas con exposiciones múltiples en donde detectamos 78 nuevas estrellas Ráfaga. En el presente artículo además de presentar cartas de identificación para las 254 estrellas Ráfaga conocidas por nosotros, discutimos algunas de las características más conspicuas de este tipo estelar en la región de Orion, señalando las diferencias y similitudes de las estrellas Ráfaga en Orión con respecto a estrellas Ráfaga en otros agregados estelares. De manera preliminar indicamos las edades aproximadas y extremas de las estrellas Ráfaga en Orión, sosteniendo la hipótesis de que ciertas estrellas de tipo tardío en este agregado estelar se han formado durante diferentes generaciones en un intervalo mínimo comprendido entre $\approx 5 \times 10^5$ años a $\approx 5 \times 10^7$ años.

1. *Introduction*

Since our earliest studies of T Tauri stars and related objects in the Orion Nebula region (Haro 1949; 1953), using low dispersion spectra taken with the objective prism of the Tonantzintla Schmidt camera, we have called attention to the existence of several objects resembling flare-type variables. This suggestion has been amply confirmed in subsequent work done mainly at our Observatory; a summary of the results up to the first months of 1965 is contained in Haro's Chapter "Flare Stars", Vol. VII of *Stars and Stellar Systems* (1968). In this article we present recent results based on multiple ultraviolet direct exposure plates obtained with the Tonantzintla Schmidt camera during part of the years 1965-1969.

Basically, all our previous considerations (Haro 1968; Haro and Parsamian 1969) are confirmed and extended with the new data at hand; fundamentally, we believe that the genetical and evolutionary link which we sketched many years ago between the T Tauri or RW Aurigae type stars and the UV Ceti stars in the solar neighborhood is strengthened.

Furthermore, as some of our colleagues have been asking for identification charts of all the Orion Nebula field flare stars known to us, we are supplying infrared photographic maps on which 254 flare stars are marked and numbered.

2. *New Flare Stars in the Orion Region and repeated Flare-ups in previously known Flare Stars*

The present results deal mainly with the multiple exposure photographic material obtained during the period comprised between December 1965 up to February 1969. The plates (103aO and 103aD Eastman Kodak emulsions behind a Corning 9863 filter) were centered in the Trapezium stars covering a usable area of 16 square degrees, the average ultraviolet limiting magnitude (U) being ~ 17.5. The time of exposure per image was 15 minutes with less than one second between the different exposures in each plate. In the great majority of plates 5 or 6 consecutive exposures were made. Table 1 gives the general data on the aforementioned material, the number of the new flare stars found and the total number of flare-ups detected either in the "new" rapid variables or in the ones previously listed.

TABLE 1

Photographic Observations in the Orion Field (1965-1969)

Spectral Region	*Number of Plates*	*Number of Exposures*	*Total Obs. Time (Hours)*	*New Flare Stars Found*	*Different Flare-ups Observed*
U	235	1285	321^h15^m	78	112

Table 2 summarizes with more detail our new results. In the first column the Tonantzintla serial number is given following the order of the list presented earlier by Haro (1968); the first three flare stars, Nos. 177, 178 and 179, were recently published by Haro and Parsamian (1969) and are again included here just because they belong to the photographic material obtained for this work. The numbers in italics indicate that the flare-up repeats in the given star — either in the "new" flare stars or in the ones listed before. The second column contains Parenago's numbers. Columns three and four, the R. A. and Dec.; columns five and six, the approximate ultraviolet magnitudes (U) at minima and ΔmU during the flare, respectively; column seven, the available spectroscopic data; column eight, the date of the observed flare-up. References are given in column nine.

Figures 1 and 2 give some samples of the Orion stars during the outburst.

Figure I

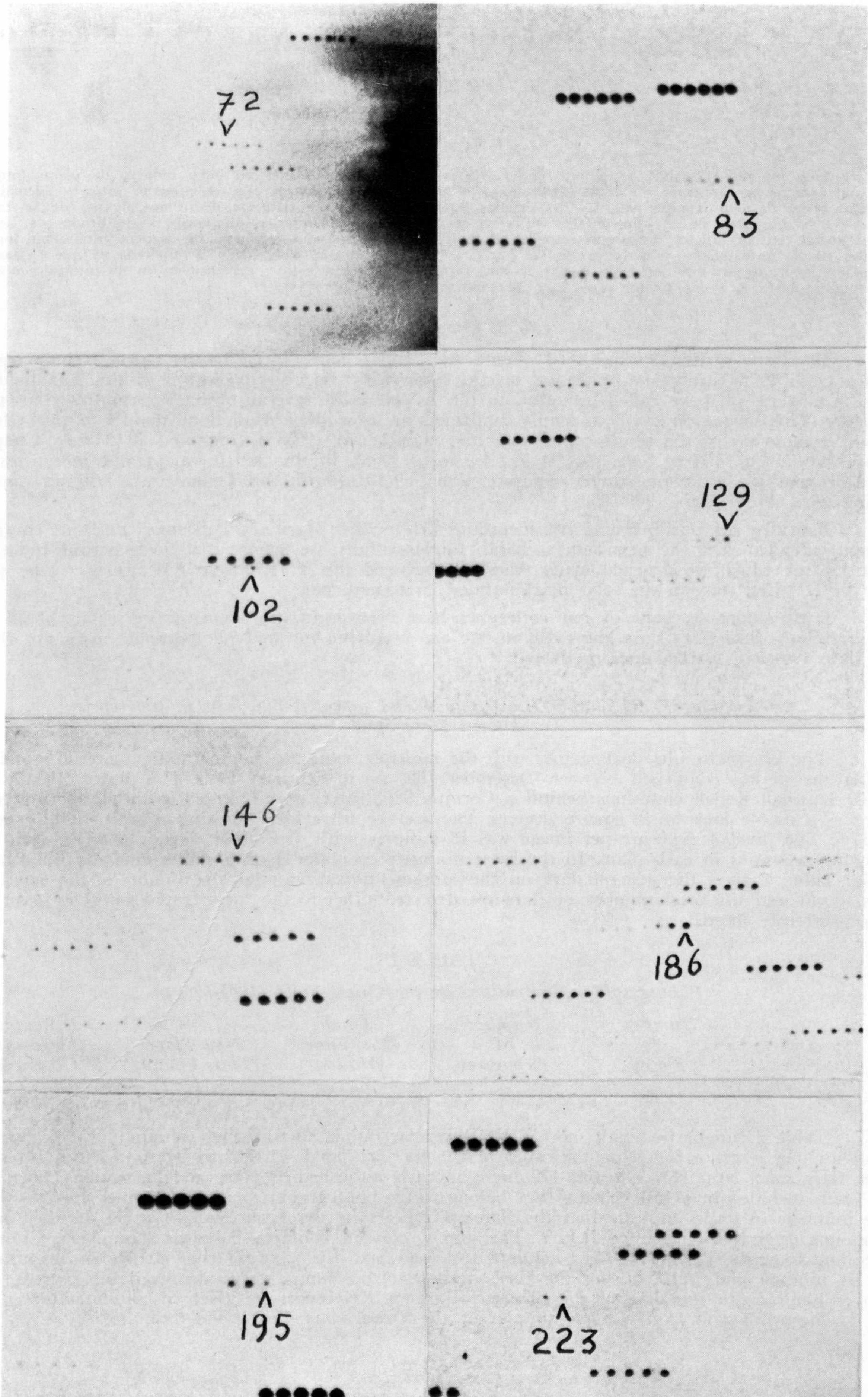

Figure 2

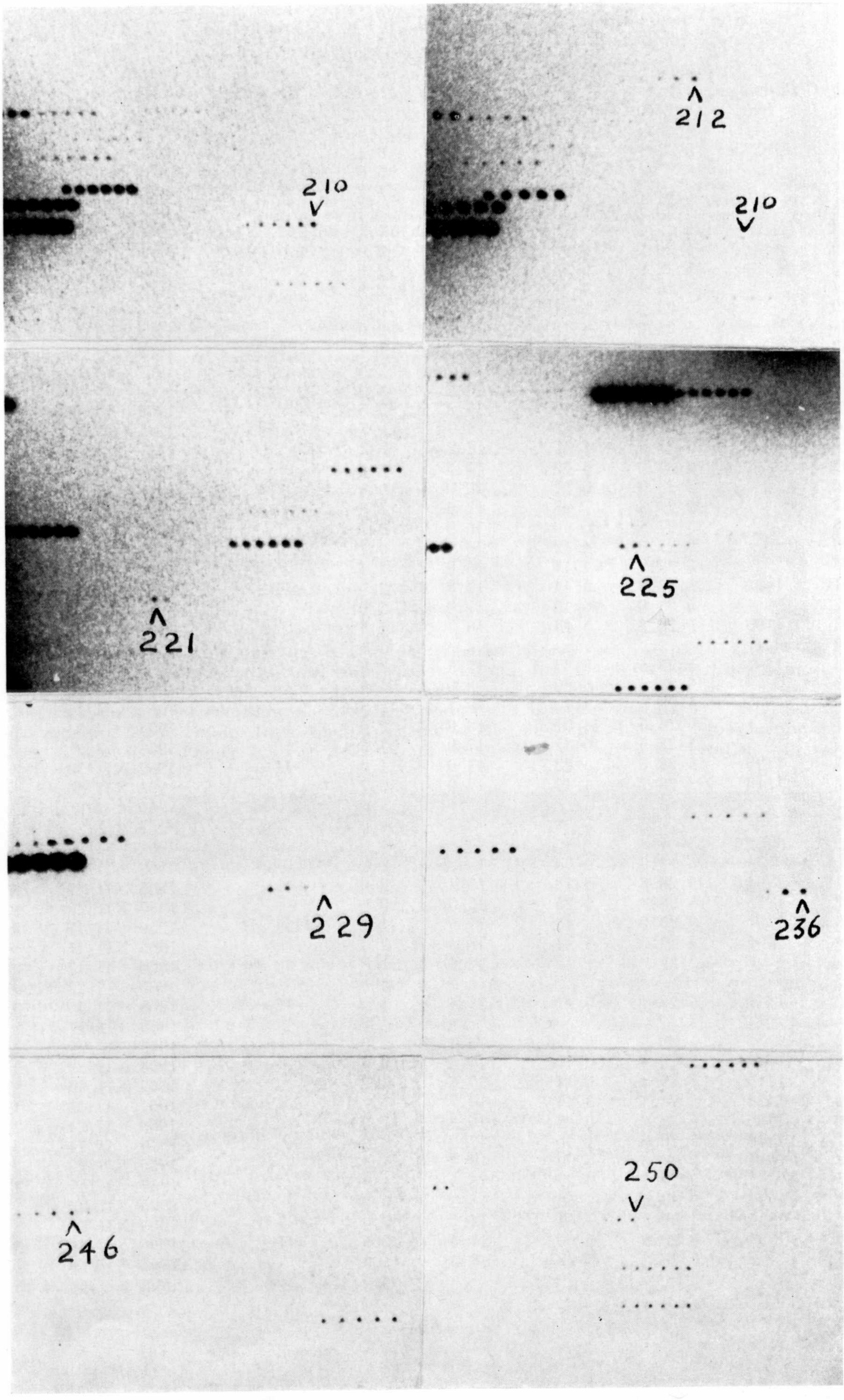

TABLE 2

Orion Flare Stars (1965-1969)

Tonant. No.	*Parenago No.*	*R. A. (1900)*	*Dec. (1900)*	*mU*	*ΔmU*	*Sp. Type eHα*	*Date of Flare-up*	*Ref.*
177	1323	5^h29^m1	−6°40!3	19.7	8.4		1965 XII/27	1
177	”	”	”	”	3.6		1965 XII/28	1
177	”	”	”	”	3.2		1967 II/13	1
178		5 29.1	6 35.0	18.5	2.1		1965 I/30	1
178		”	”	”	2.3		1968 I/3	1
179		5 29.2	6 39.2	18.1	2.9		1968 I/2	1
122		5 22.9	6 56	18.9	2.9		1967 I/6	2
124		5 25.1	4 28	18.7	2.8		1967 II/4	2
180		5 23.3	3 31	15.4	0.8		1965 XII/23	
181		5 23.6	4 12	18.0	2.0		1968 I/5	
182		5 24.0	4 25	18.2	1.7		1968 II/15	
183		5 24.2	3 46	18.7	2.6		1967 I/14	
184		5 24.3	7 4	18.2	3.0		1968 I/3	
125		5 25.7	4 13	17.8	2.5		1966 I/18	2
126		5 25.9	6 57	18.0	1.3		1968 I/5	2
129		5 27.0	4 31	18.2	3.2		1967 II/12	2
185		5 27.0	3 32	17.3	0.6		1968 II/1	
186		5 27.3	6 34	19.0	5.5		1968 I/29	
187		5 27.3	7 08	17.6	2.6		1968 XII/31	
188		5 27.4	6 50	16.9	0.7		1967 II/15	
189		5 27.6	4 12	18.7	3.2		1969 II/8	
190		5 27.7	4 45	18.9	3.5		1968 I/4	
191	1009	5 27.9	5 44	17.8	2.0	eHα	1965 XII/18	3
192		5 28.0	6 43	17.0	2.0		1969 II/16	
193	1109	5 28.3	5 13	16.2	1.5		1967 XII/27	
193	”	”	”	”	0.8		1967 XII/28	
194	1167	5 28.5	5 37	17.5	0.8		1968 I/30	
195		5 28.5	6 09	18.6	4.5		1966 I/16	
16		5 28.5	5 11	18.1	2.5		1967 II/11	2
17		5 28.5	4 07	18.0	2.0		1968 I/31	2
196		5 28.5	6 32	17.0	1.5		1968 I/2	
197	1190	5 28.6	5 22	17.0	1.0	eHα	1967 XII/30	3
198	1215	5 28.7	4 17	17.0	0.7		1965 XII/26	
199		5 28.7	5 28	19.0	3.0		1969 II/9	
20		5 28.7	5 38	18.4	3.0		1965 XII/20	2
22		5 28.8	5 35	17.8	1.0		1969 II/9	2
200		5 28.9	4 56	18.2	2.2	M1—eHα	1969 II/18	3, 4
201	1254	5 28.8	5 18	15.4	2.0	eHα	1965 XII/27	3
202	1255	5 28.8	5 25	16.0	0.6		1967 XII/27	
203	1301	5 29.0	4 42	17.5	1.2	eH&CaII	1966 II/15	3, 5
204	1305	5 29.0	5 11	18.5	2.3		1965 XII/21	
205		5 29.0	6 11	18.4	1.8		1966 II/17	
205		”	”	”	2.5		1969 I/23	
206	1341	5 29.1	5 41	15.4	1.5	eHα	1968 I/5	3
206	”	”	”	”	0.7	”	1968 II/27	
207		5 29.3	6 00	18.4	3.0		1965 XII/27	
208	1412	5 29.4	6 40	14.8	0.6	Geα	1968 II/29	5
141	1410	5 29.4	5 11	17.6	1.2		1967 XII/30	2, 7
209	1428	5 29.4	5 35	16.7	1.0	M2	1967 II/15	4
210	1486	5 29.6	6 04	16.3	2.0		1968 II/24	
211	1500	5 29.6	4 45	17.0	0.8		1966 II/14	
212	1544	5 29.6	6 00	18.4	3.5		1965 XII/20	
37		5 29.7	6 27	18.5	1.8		1966 II/17	2
213	1548	5 29.8	4 52	15.4	0.6		1965 XII/22	
146	1553	5 29.8	5 44	14.7	2.0	K0:,eHα	1965 XII/23	2
214	1599	5 29.8	5 09	17.3	0.5	eHα	1966 I/19	3
215		5 29.8	6 22	18.5	2.0		1967 XII/29	
215		”	”	”	3.2		1968 XII/3	

TABLE 2 (Continued)

Tonant. No.	*Parenago No.*	*R.A. (1900)*	*Dec. (1900)*	*mU*	*ΔmU*	*Sp. Type eHα*	*Date of Flare-up*	*Ref.*
216	1611	5ʰ29ᵐ9	−4 40	16.0	1.2	*e*Hα	1967 II/2	3
216	,,	,,	,,	,,	2.5	,,	1967 II/14	
217	1613	5 29.9	5 46	17.0	3.0		1968 II/28	
218	1616	5 29.9	5 50	18.2	3.3	*e*Hα	1966 II/17	3
219	1609	5 29.9	6 26	16.8	0.7		1966 I/16	
219	,,	,,	,,	,,	0.8		1968 II/1	
220		5 30	4 31	20.2	4.4		1966 II/25	
221		5 30.1	5 57	18.4	3.4		1968 II/24	
222		5 30.1	6 50	17.9	1.5		1968 I/2	
152	1715	5 30.1	6 00	18.5	2.5		1965 XII/22	2
223	1764	5 30.2	5 11	17.6	2.5		1965 XII/23	
223	,,	,,	,,	,,	2.0		1966 I/19	
224	1790	5 30.3	6 09	16.2	1.0		1966 I/14	
225	1878	5 30.3	6 09	15.2	1.7		1967 XII/29	
226	1930	5 30.4	5 54	18.0	1.7	*e*Hα	1966 I/16	3
227	2063	5 30.6	4 24	16.2	0.7		1967 II/14	
228		5 30.7	7 21	15.9	0.7		1968 II/3	
60		5 30.7	6 16	18.6	2.6		1965 XII/22	2
229		5 30.7	6 21	17.6	2.5		1966 I/16	
230	2185	5 30.8	5 40	15.2	1.0		1968 II/20	
66		5 30.9	4 28	17.0	0.7	K7;	1967 II/15	2
72	2246	5 30.9	5 20	14.8	0.8	K: (e),*e*Hα	1969 II/13	2, 3, 6
83		5 31.2	5 29	17.4	1.0		1966 I/16	2
83		,,	,,	,,	2.3		1968 II/23	2
88		5 31.3	5 26	18.4	3.0		1966 I/15	2
231	2368	5 31.3	5 16	15.3	1.5	K4*e*IV–V	1968 II/24	7
232		5 31.4	4 25	18.8	3.3		1968 I/29	
233		5 31.4	6 33	18.4	1.8		1969 II/16	
92		5 31.5	5 11	18.3	2.2		1968 I/31	2
234	2394	5 31.6	4 31	17.6	2.7		1968 I/4	
235		5 31.7	4 25	18.5	2.5		1967 XII/27	
236		5 31.7	5 41	18.5	5.0		1966 I/15	
237		5 31.8	6 20	18.6	3.0		1966 I/17	
102	2455	5 32.0	5 04	17.3	1.0	M2	1966 II/14	2, 4
238		5 32.0	6 25	18.2	1.5		1969 II/15	
104	2470	5 32.1	5 27	16.5	1.5	*e*Hα	1968 I/31	2, 3
239		5 32.3	4 48	19.5	4.0		1966 II/14	
240		5 32.3	6 49	18.6	2.6		1968 II/20	
241	2502	5 32.3	6 39	16.9	0.5		1967 XII/27	
242		5 32.4	6 23	19.0	4.2	M	1967 I/7	
243		5 32.5	6 16	18.8	3.5		1968 II/24	
244	2532	5 32.5	5 08	15.3	0.8		1968 II/29	
245		5 32.6	5 35	19.0	2.7		1969 II/16	
246		5 32.7	7 07	17.5	3.0	*e*Hα	1965 XII/22	
247	2663	5 33.4	5 09	15.9	2.0	M0:	1965 XII/23	
248		5 33.6	7 12	17.6	1.5		1968 I/4	
171		5 34.4	6 52	18.5	2.0		1968 I/2	2
249		5 34.9	4 59	18.4	2.0		1966 II/14	
250		5 35.2	6 31	21.0	6.0		1967 II/7	
251		5 35.6	6 19	17.8	2.3		1968 I/31	
252		5 37.5	5 40	>20.0	4.0		1969 II/16	
253		5 37.5	7 13	20.0	3.5		1968 I/5	
254		5 38.0	5 51	16.0	1.0		1968 II/28	
176		5 38.1	7 21	16.4	0.6	M2	1968 I/4	2

* References: (1) Haro and Parsamian (1969); (2) Haro (1968); (3) Haro (1953); (4) Blanco (1963); (5) Herbig (1962 a); (6) Herbig (1962 b); (7) Walker (1969).

3. *Remarks and Comments to the Tonantzintla Flare Star lists*

A good number of the Flare stars listed in Tables 1A — 1B (Haro 1968) and in Table 2 of the present article show some characteristics which are rare or absent in the flare stars found in older stellar aggregates as are the Pleiades, Coma Berenices, Praesepe, Hyades and the flare stars in the solar vicinity.

i) First of all, the spectral types of the flare stars in the Orion Nebula region go from G up to early M's. The great majority have a K-type spectrum and although many of them lie far above the mainsequence in the *V vs. B—V* diagram, there are some that lie very near or even below it. Good examples of these flare stars lying below the photographic color-magnitude main-sequence are the following: Nos. 39, 45, 51, 78, 80, 101, 144, 151, 157, 203, 245, 246. Without exception, in all of these flare stars the Hα emission line —with different intensities— has been observed. In our 3-color plates *(UBV)* they also show rather conspicuous and more or less permanent ultraviolet excesses. One of these flare stars, No. 144 (XX Ori), has been observed photoelectrically by Walker (1969) who obtained the following values: $V = 14.87$, $B-V = +1.01$ and $U-B = -0.38$. Stars Nos. 144 (XX Ori), 157 (NS Ori) and 203 (SU Ori) were previously presented as bright-ultraviolet T Tauri stars by Haro and Herbig (1955).

ii) All the flare stars listed in Tables 1A — 1B (Haro 1968) and in Table 2, showing *e*Hα in the Sp. Type column, were observed on red plates taken with the objective prism of our Schmidt camera. A large number of these Hα emission line stars are contained in an early publication by Haro (1953). Although some flare stars have shown the Hα in emission only once in our plate collection —an event corresponding probably to a flare-up— there are others that permanently show this bright line even if its relative intensity varies. Of the 254 flare stars listed, emission lines have been detected in at least 44 stars using rather small dispersions.

iii) About 25% of all the Orion region flare stars in our lists are recognized, at the same time, as irregular "normal" variables of the T Tauri or RW Aurigae type. In such cases, the flares can be distinguished only by taking into account the "normal" shape of the irregular light curves and the remarkable rapidity and conspicuousness of the superposed outburst. Moreover, this particular type of flare stars show noticeable variations during their "normal" irregular changes in the *UBVRI* light yet not a single flare-up has been detected in the near infrared (Haro 1964). A more detailed study is under preparation and probably the percentage of "normal" irregular variables which show the superposed rapid outbursts would increase. At present it might be safe to state that about 70% of the listed objects in Orion can be classified as "pure", "fast" flare stars, according to Haro's definition (1964, 1968).

iv) Of all the 254 Orion flare stars in our lists, only 7 have shown the "slow" flare-up features (Haro 1968; Haro and Parsamian 1969). These seven "slow" flare stars, in which the rise from "normal" minimum to maximum lasts more than 45 minutes, are Nos. 66, 92, 149, 153, 177, 229 and 239. As has been said before (Haro 1968), three of these "slow" flares (Nos. 66, 149 and 153) have also shown the "fast" flare features.

v) Three of Blanco's M stars in I ORI (1963), namely Nos. 3, 5 and 15, correspond to our flare stars Nos. 102, 200 and 209, respectively. All three of them, according to Blanco, lie high above the M_{bol} *vs.* log. T_e main-sequence and their ages are estimated to be $t \approx 7 \times 10^5$ years. It is strikingly noticeable that in our long exposure hypersensitized infrared spectral plates and up to the $\sim$ 15 infrared magnitude *(I)* not a single Orion flare star shows the easily detectable more advanced M spectral types.

vi) The incidence of flare-ups in the Orion flare stars is illustrated in Table 3.

TABLE 3

Incidence of Flare-ups in the Flare Stars Listed

Total Number of Flare Stars Listed	*Stars with One Flare-up Observed*	*Stars with Two Flare-ups Observed*	*Stars with Three Flare-ups Observed*	*Stars with Four Flare-ups Observed*	*Stars with Seven Flare-ups Observed*
254	203	41	8	1	1

vii) In general, the brightest flare stars during minima tend to show outbursts of smaller apparent amplitudes than the fainter ones. That does not necessarily mean that the absolute intensity of the outburst is always greater in the faint stars than in the brighter ones.

4. *Further Comments and Summary*

From what has been said before, in the Orion Nebula region there are at least four different kinds of flare stars: *a)* typical T Tauri stars in which, during long periods, the strong emission lines of H, CaII and some other bright lines, plus a rather strong ultraviolet continuum, are observed; *b)* nebular irregular variables with possible fainter emission lines and without conspicuous ultraviolet excesses during the non-flare stage of variability; *c)* The "slow" flare stars as defined by Haro (1968) and by Haro and Parsamian (1969); *d)* the "pure" "fast" flare stars which have not been previously identified as classical T Tauri, RW Aurigae or Orion type variables. The majority of the flare stars listed belong to this last group.

It seems to us quite plausible and reasonable that if all the flare stars found in the Orion Nebula region were observed spectroscopically —obtaining slit spectrograms of about 200 A/mm dispersion and with the equivalent spectral resolving power that Kraft and Greenstein (1969) used in their Pleiades star observations— even during minimum at least the very great majority would show emission lines, especially those of CaII. The combined study of several relevant characteristics of the flare stars, such as richness and intensities of the emission line spectrum, the strength of the ultraviolet continuum, the more or less prolonged steadiness of these particular features and, if possible, the position of the flare stars during minima in the M_{bol} *vs.* log. T_e diagram, will undoubtedly reveal the age or the evolutionary stage of the different flare stars under consideration.

Even with the available data at hand it seems unavoidable to conclude that in the Orion Nebula aggregate there are flare stars that represent very different stages of evolution and, therefore, quite different ages or generations. In any case, even if we accept that the flare stars in Orion represent a relatively wide sample of ages or evolutionary states, one has the feeling that the oldest or the more evolved flare stars in this particular stellar aggregate cannot, in the most extreme case, be significantly older ($\approx 5 \times 10^7$ years) than the flare stars in the Pleiades. This feeling is supported when comparing the Orion flare stars with the flare objects found in the Pleiades and in some other still older stellar groups. As an opposite extreme, we note that the presumably very young flare stars found in Orion ($\approx 5 \times 10^5$ years) are certainly absent from the Pleiades.

Regardless of the unprecise quantitative data and the very rough evolutionary time range provisionally adopted for the Orion flare stars, it seems unquestionable that they give a very strong support to the idea of the non-coeval formation of the late type stars in this particular stellar aggregate. Most probably all the stars as late as or later than G5 — K0 and up to the earliest M's belonging to the Orion association are, potentially, flare stars. In this argument we are not considering the extreme T Tauri stars which behave, very likely, as under a permanent strong flare activity. At least it is tempting to speculate in this direction and suggest that photoelectric observations of extreme T Tauri stars may perhaps reveal the very rapid succession of flickering events in a matter of seconds or milliseconds — the integrated overall of which should appear as a "permanent" flare phenomenon.

Although it is quite attractive and plausible to assume that in the Pleiades group all members later than K 3.5 are flare stars (Haro and Chavira 1969; Ambartsumian 1969) and the same can be stated regarding the dMe stars in the solar neighborhood, in the general field or in some stellar aggregates older than the Pleiades it would be more difficult and apparently less obvious to postulate the non-coevality of formation and evolution of these later groups of flare stars. Probably the difference between the stellar groups in which the late type stars are or are not coeval would depend on some initial physical parameters as, for instance, a given critical primaeval total mass from which the stars of a given aggregate were or are formed. Of course in an advanced stage of evolution for a given stellar aggregate, independently of the original differences in total masses or the coeval or not coeval star generations, the last vestiges for the flare objects would be represented by late type dMe stars.

The infrared excesses observed in T Tauri stars and related objects, including some flare stars (Mendoza 1966, 1968), have led several authors to speculate about a possible thick circumstellar dust cloud which absorbs the visual radiation and reradiates in the infrared the energy produced by the parent stars. According to Poveda (1965) —who predicted these infrared excesses— one would expect that all the stars surrounded by a compact circumstellar dust nebula would appear underluminous and below the main-sequence. If this interpretation is correct, for a given spectral type the faint "blue" T Tauri stars (including the flare stars) lying below the main-sequence will show larger infrared excesses than the ones that lie high above.

From our experience, the flare stars mentioned in section 3 of this article and some faint "blue" T Tauri type stars lying below the photographic color-magnitude main-sequence do not show in the *V—I* color a more conspicuous difference than the flare stars which are above, but probably the contrary is true. It would be of importance to observe these particular stars in the *JKLM* photoelectric system. In general, a comparative photoelectric photometry in the *UBVRIJHKLM* bands for

T Tauri like objects lying above as well as below the main-sequence in the V *vs.* $B-V$ diagram is quite desirable.

5. *Identification Charts for the Flare Stars*

Although many of the flare stars contained in our Tonantzintla lists can be easily identified due to their Brun and Parenago numbers, we are supplying photographic charts for all of them. In these photographic charts —which are copies of an infrared *(I)* Mount Palomar 48″ Schmidt camera plate— the flare stars are marked and numbered following the approximate order in R.A. of the original 3 different lists: Tables 1A and 1B (Haro 1968) and Table 2 in this paper. In the above mentioned three tables we have followed a continuous serial numbering from 1 to 254, but as in each list we have started from the minor value in R.A. it happens that the final numbering can appear in the charts completely mixed up; for example star No. 32 which belongs to Table 1A (Nos. 1 to 121) is near star No. 145 of Table 1B (Nos. 122 to 176) and also near star No. 214 of the present **Table 2** (Nos. 177 or 254), and so on. (Figures 3 to 14).

All the charts are orientated with North at the top and West to the right. The approximate scale of the maps is 1′ = 0.4 cm. In the original lists there are a few mistakes regarding Parenago's numbers, which can be corrected using these general identification charts.

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Figure 3

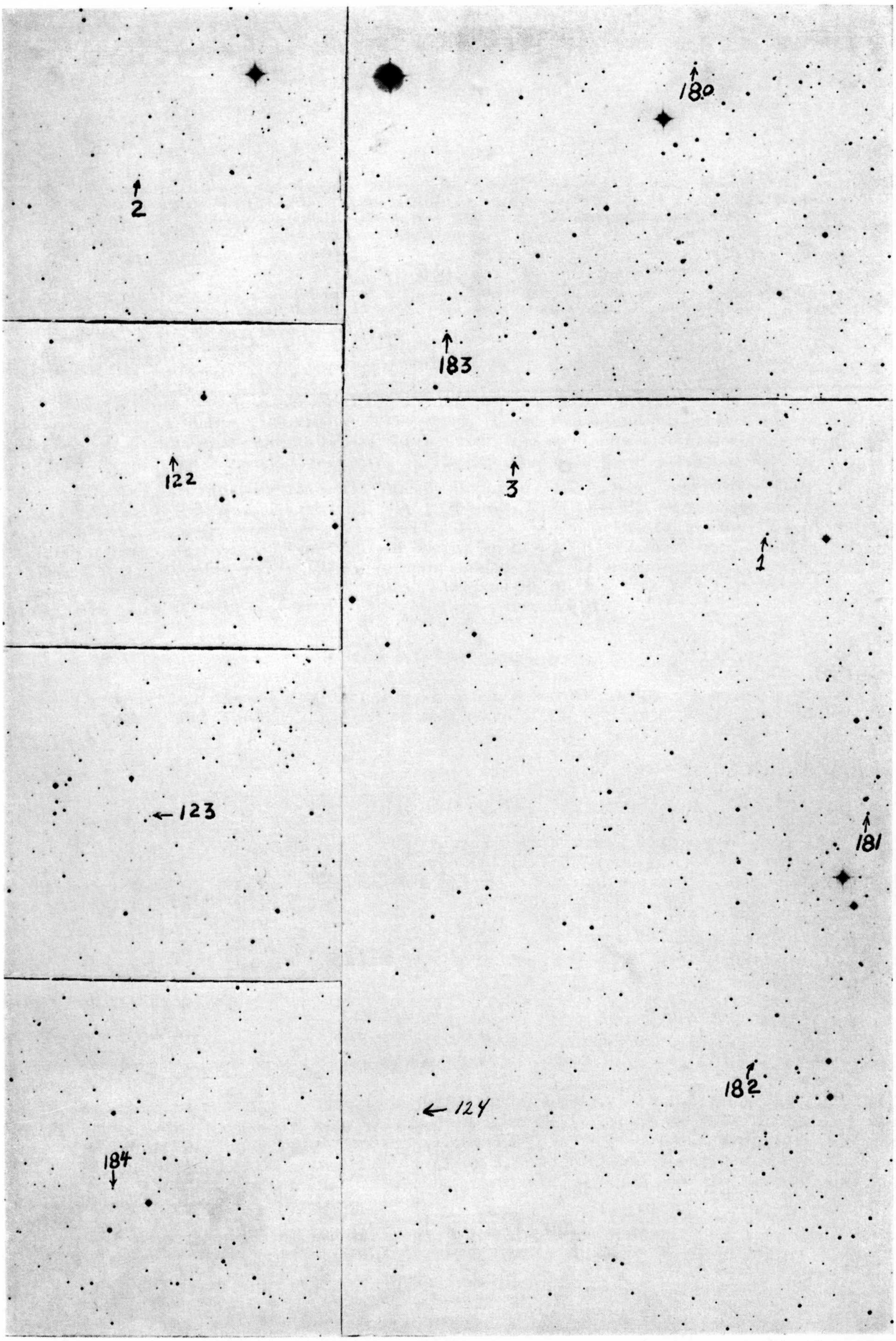


Figure 4

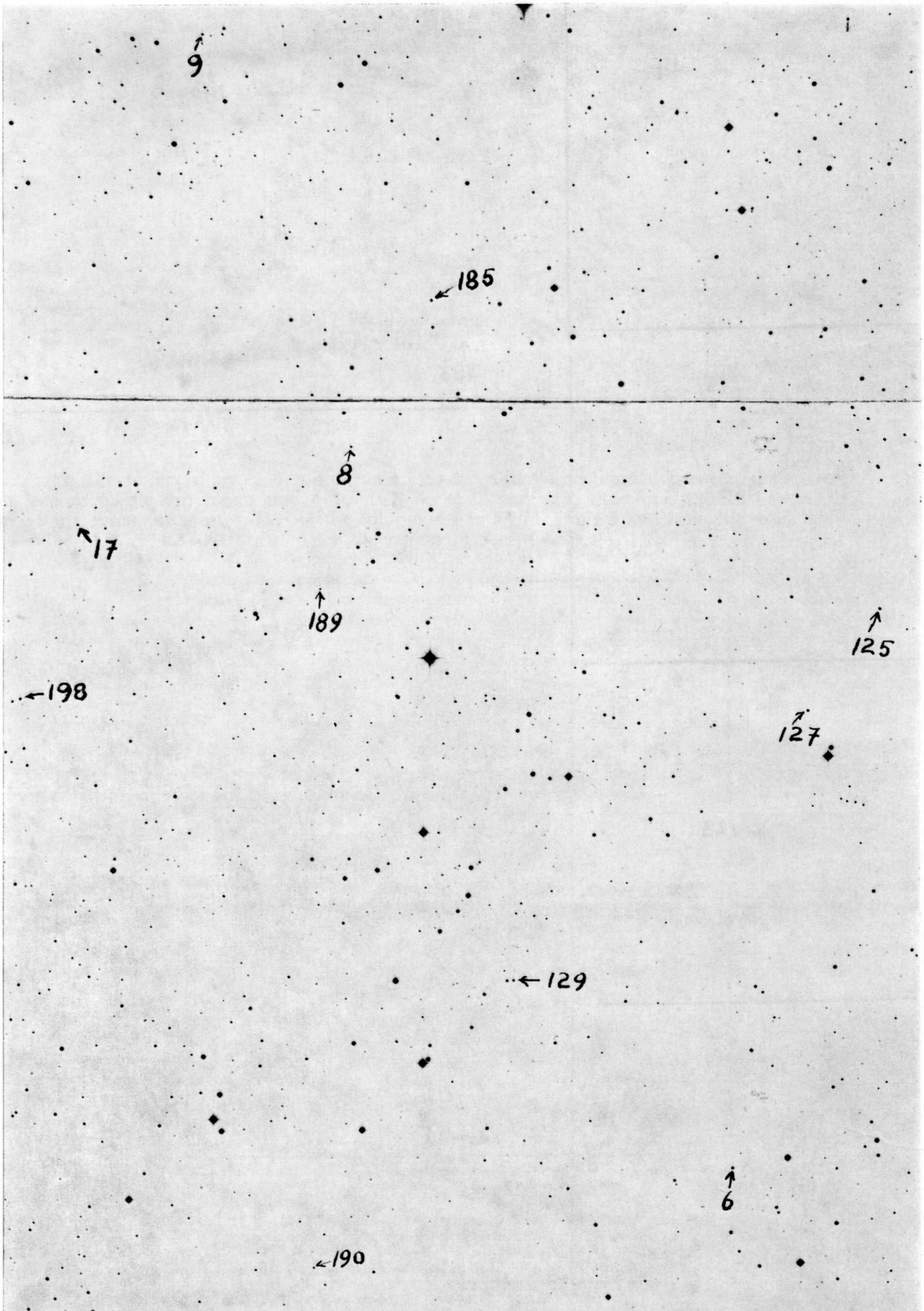
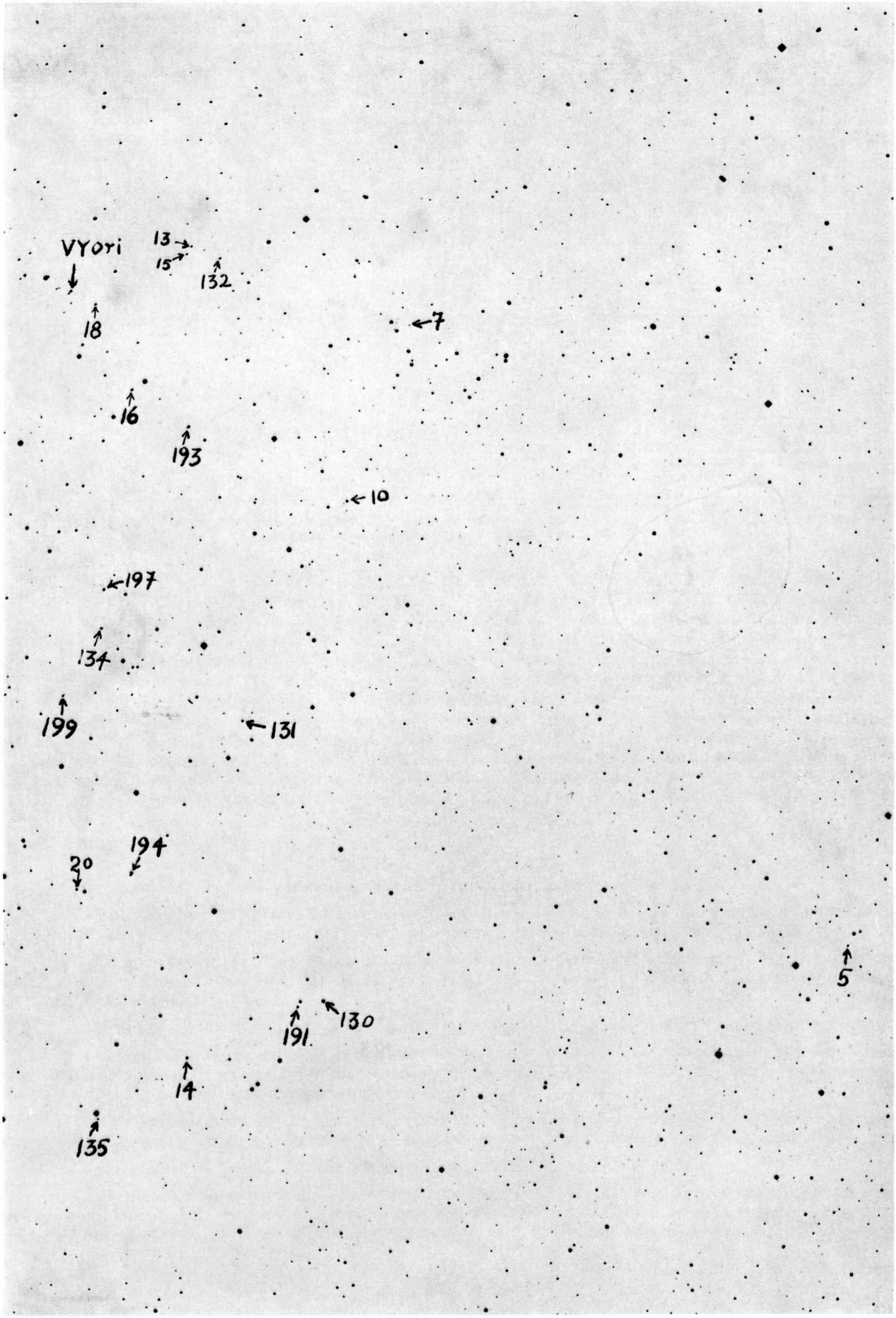


Figure 5



VYOri
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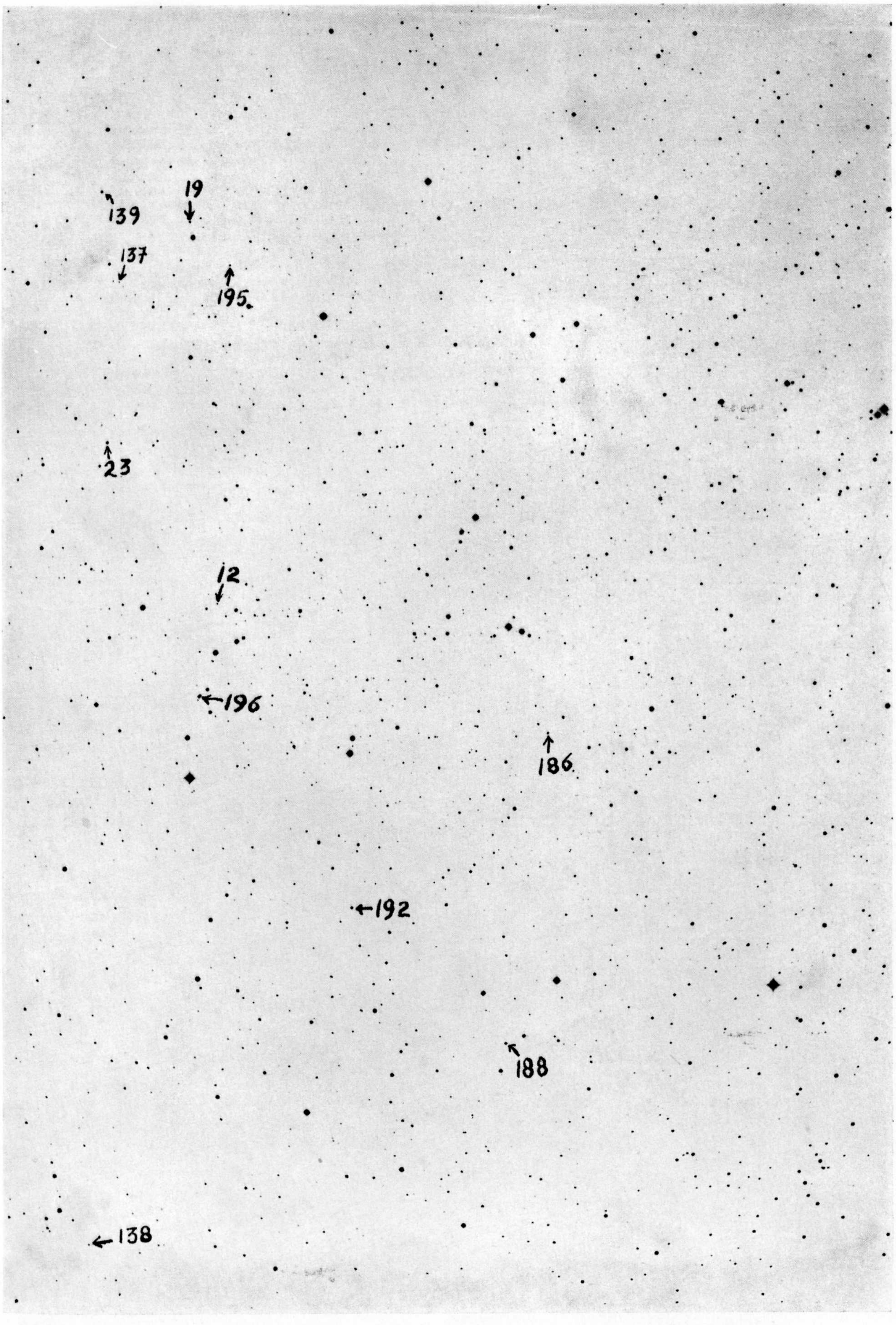
Figure 6



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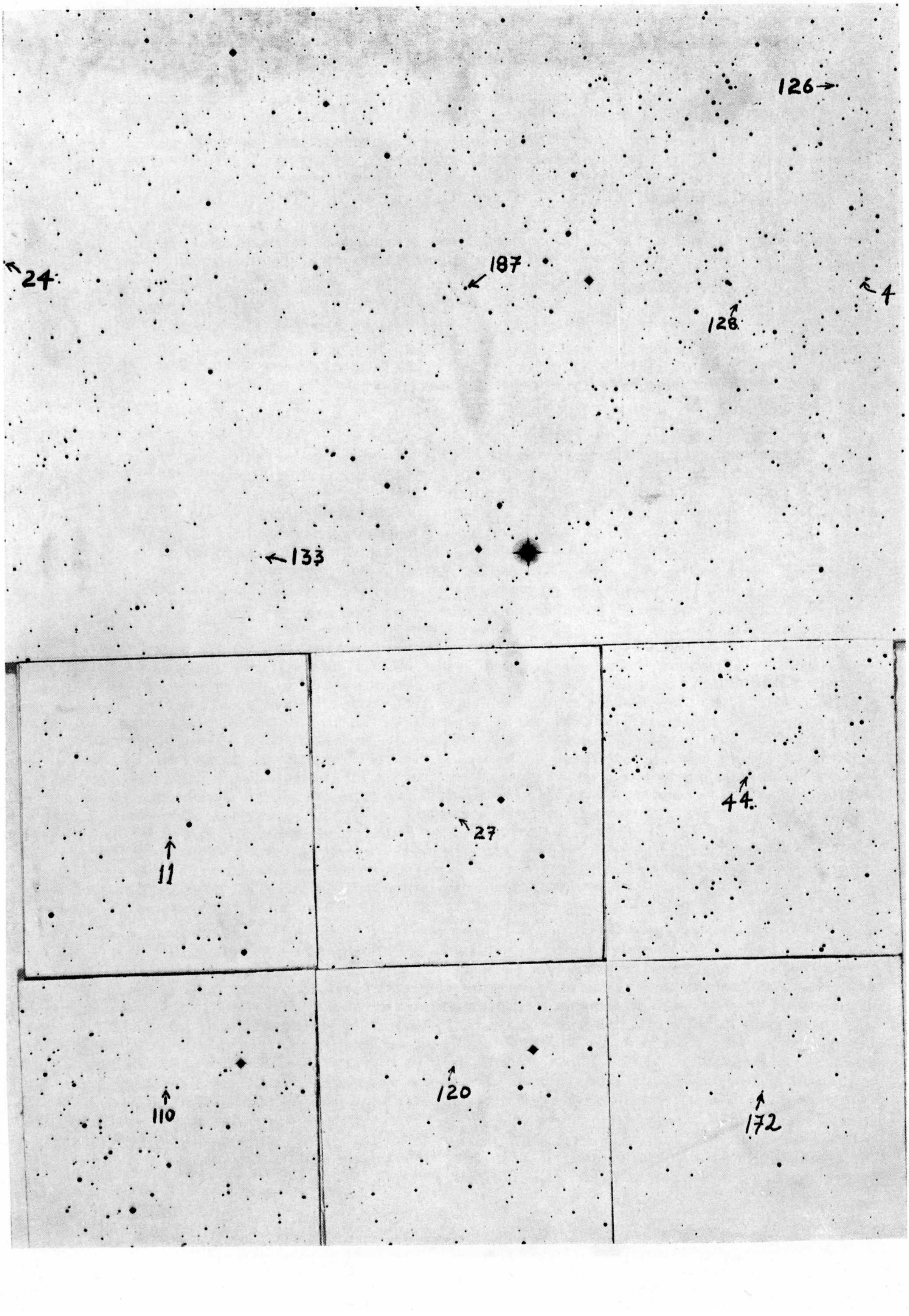

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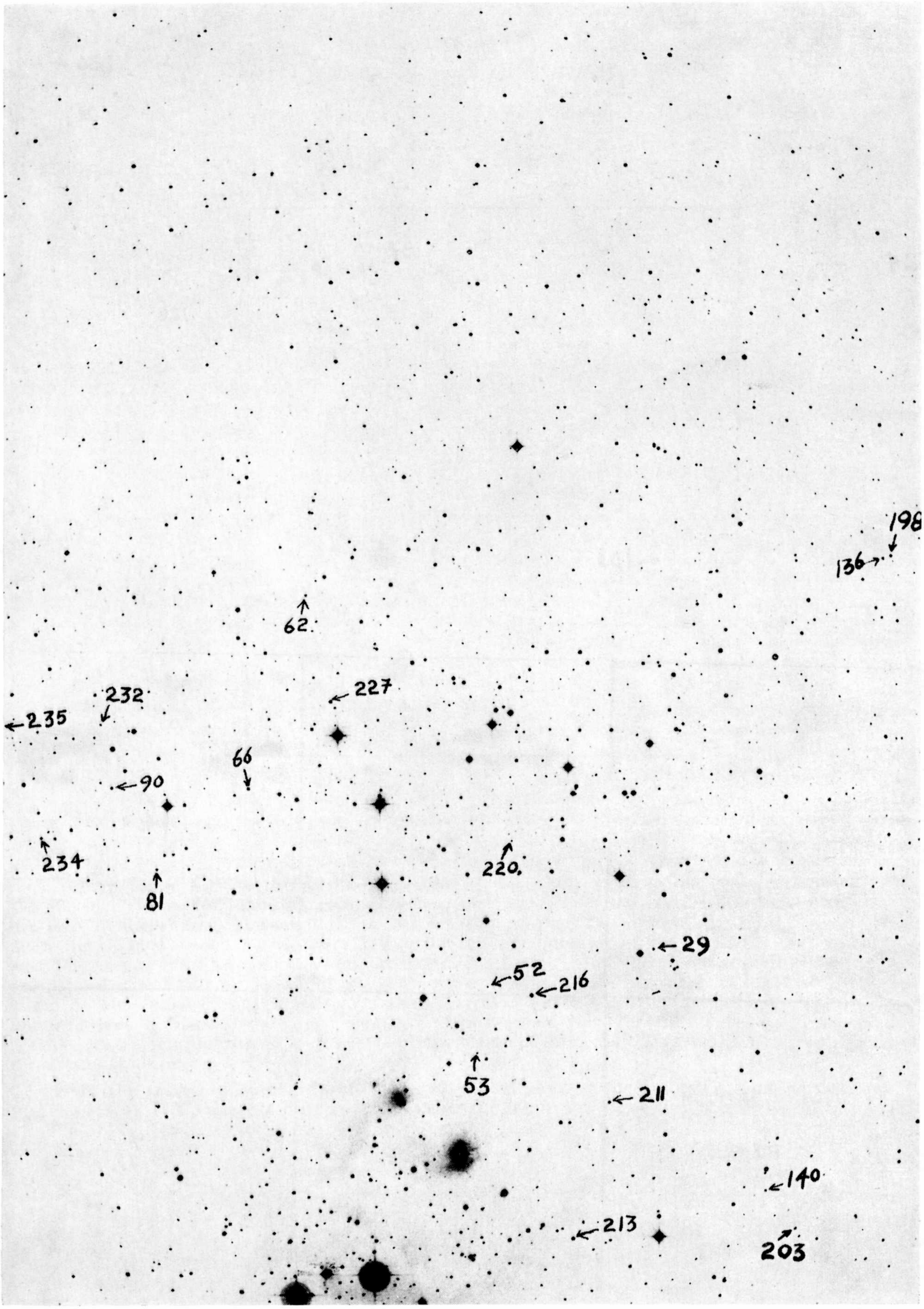

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Figure 9

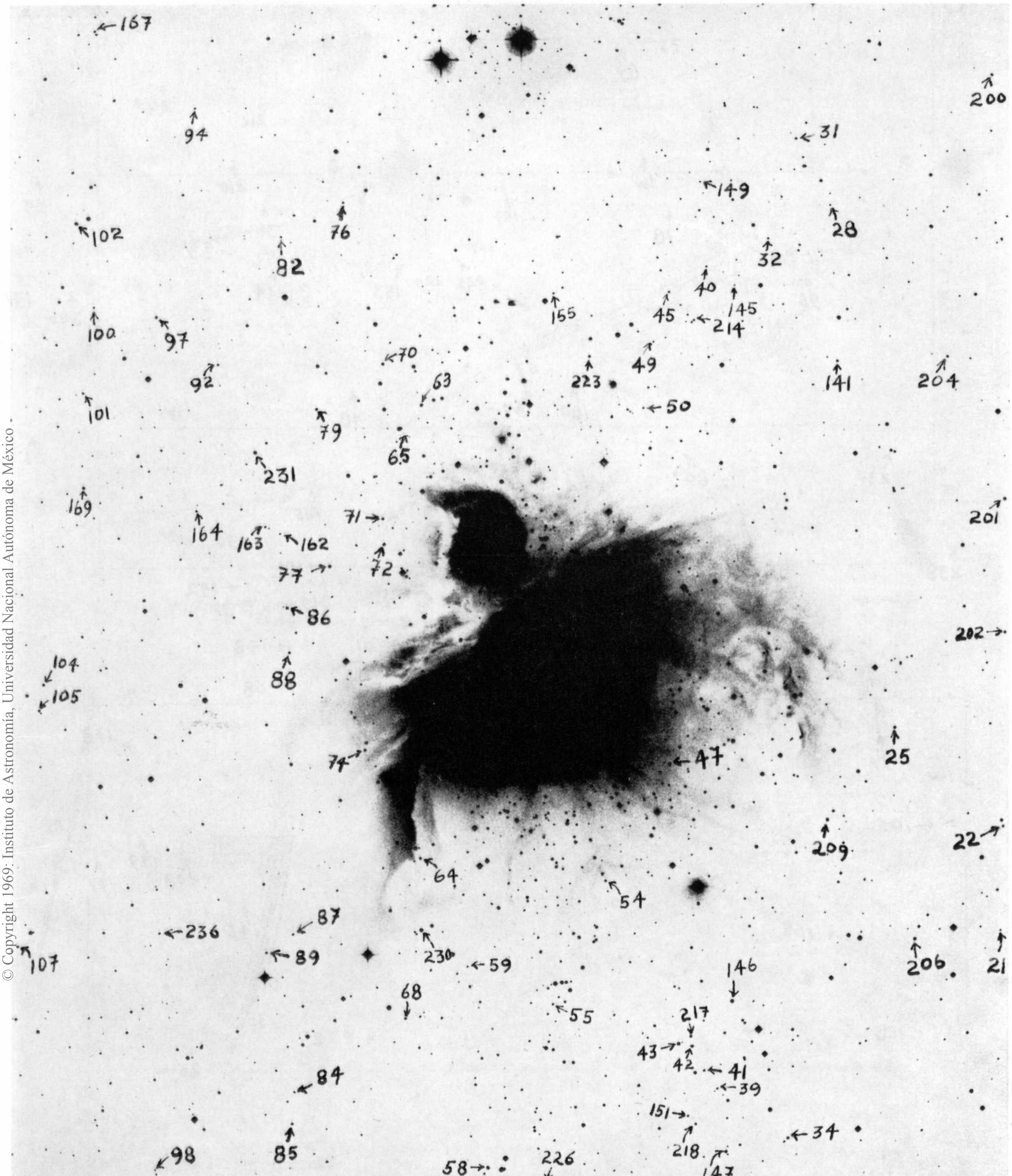
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Figure 10

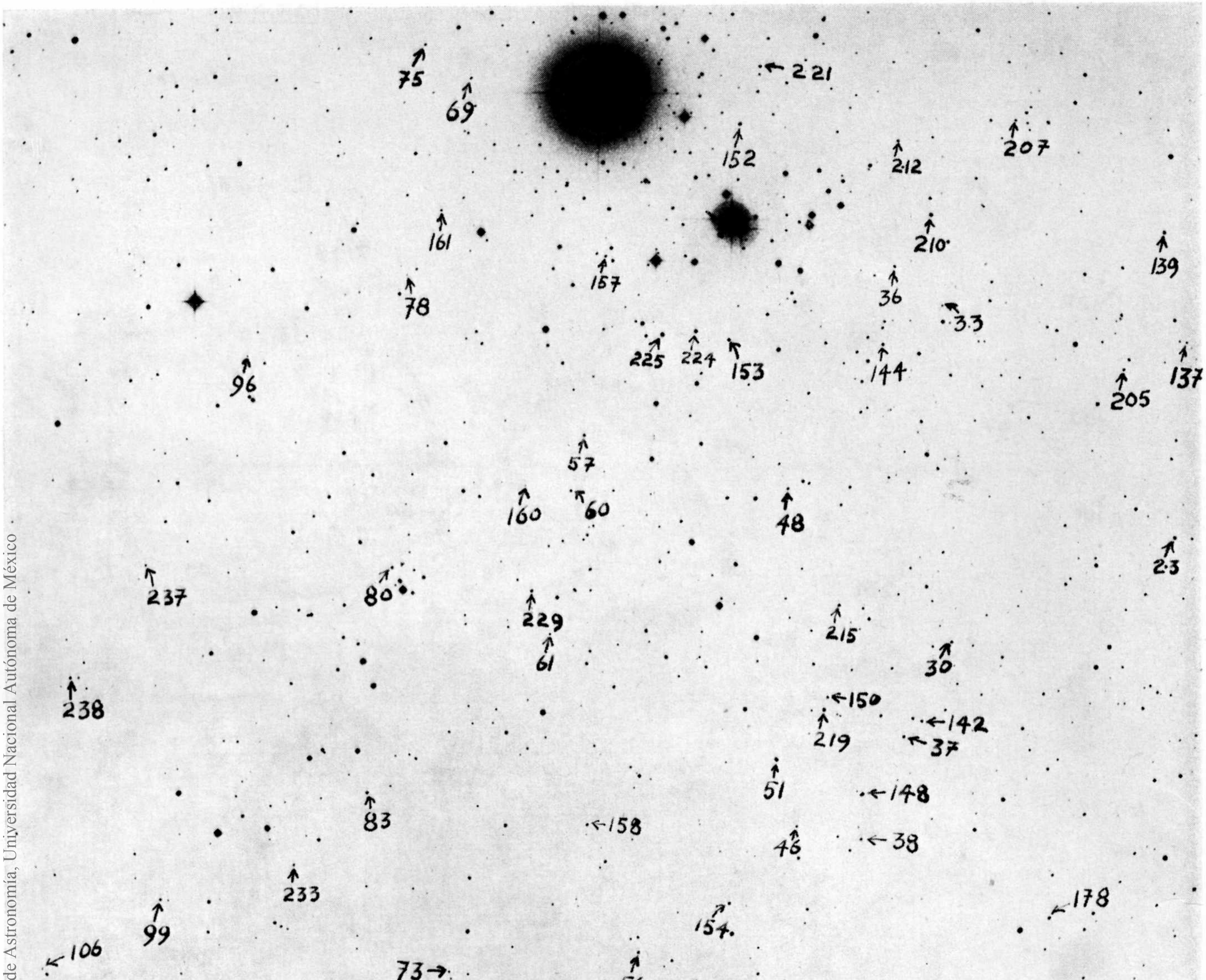
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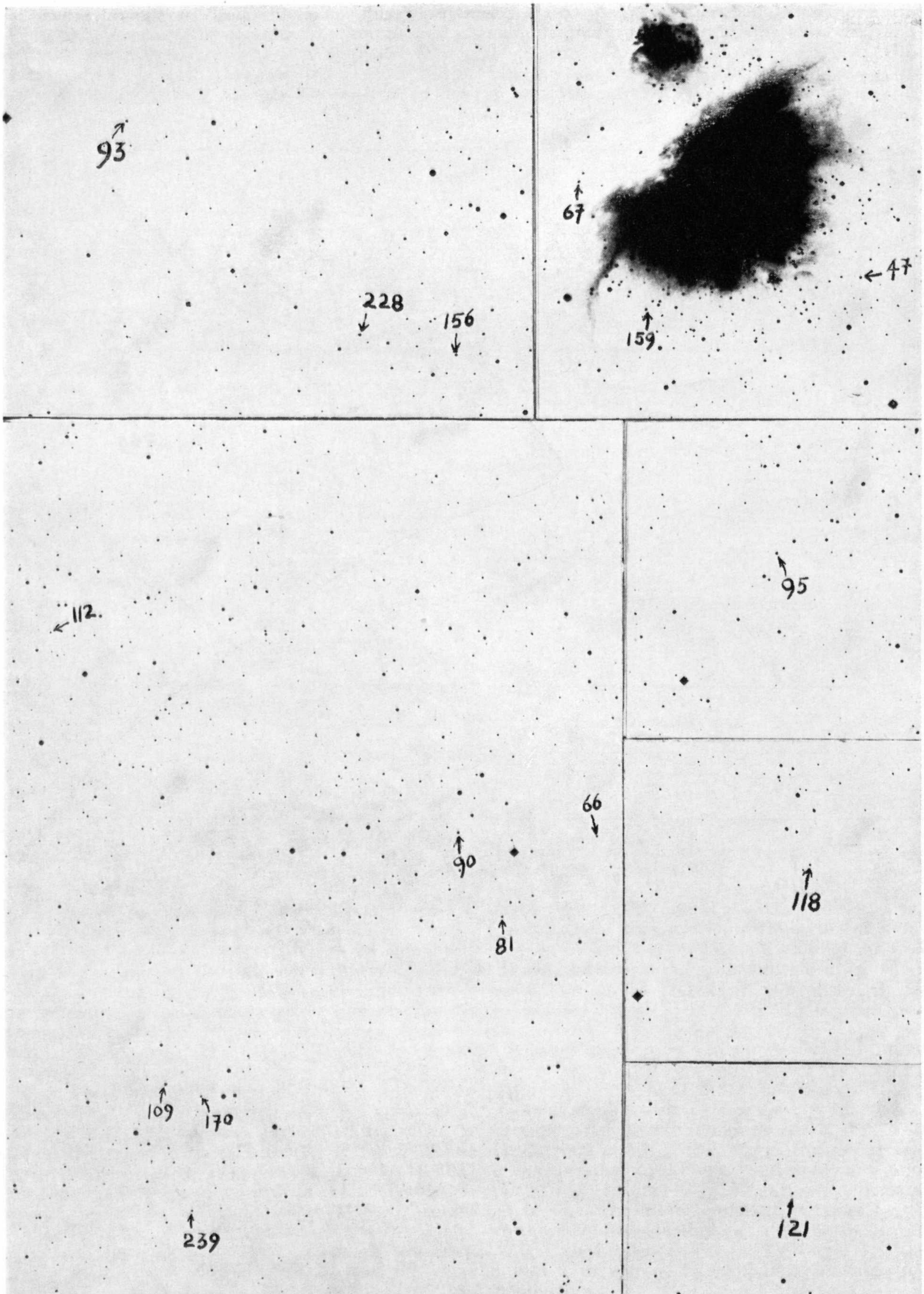
Figure 11



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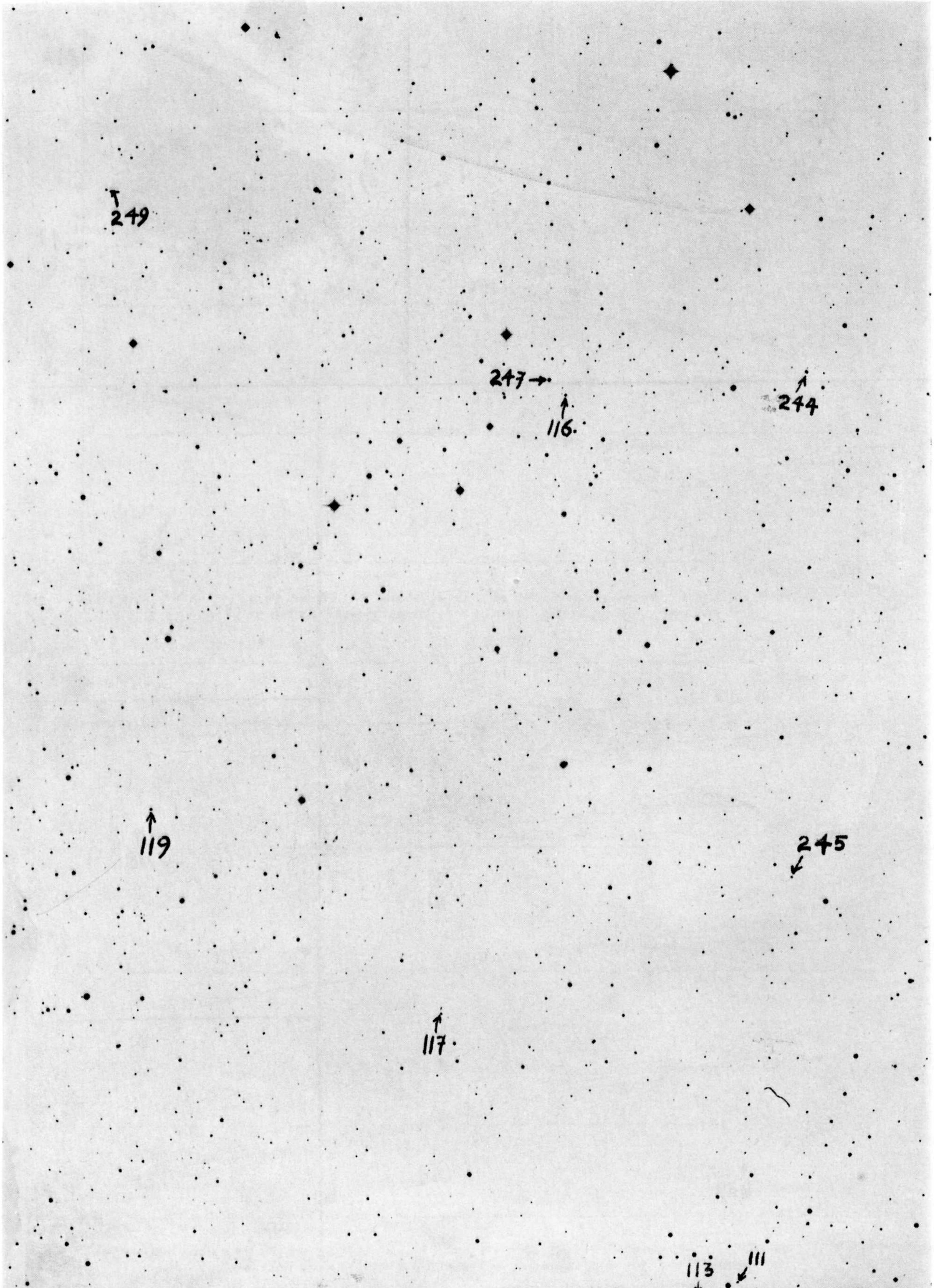

Figure 13

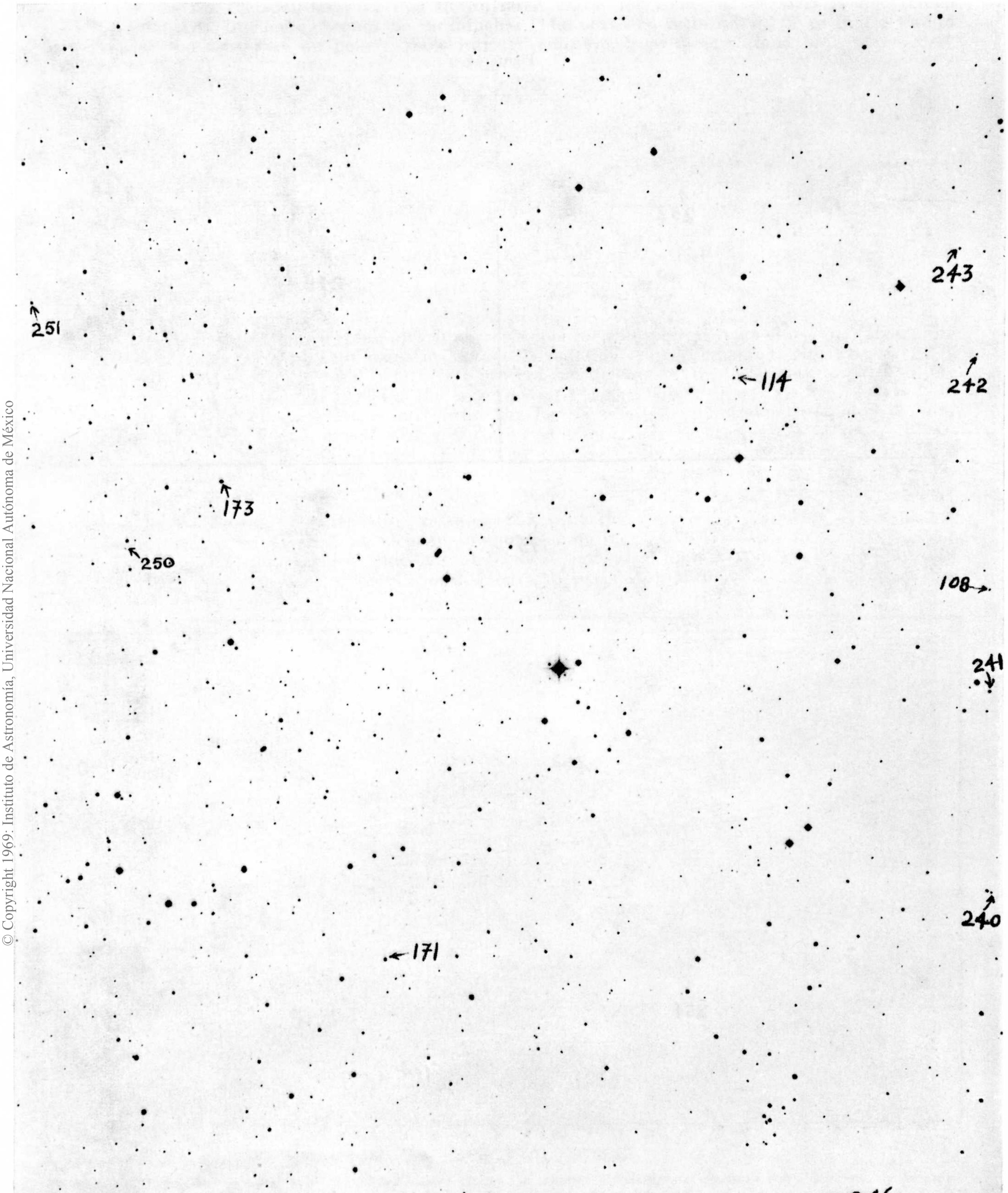

Figure 14