No. 56 OBSERVATIONS OF "INFRARED STARS"*

by HAROLD L. JOHNSON, EUGENIO E. MENDOZA V.,† AND WIESLAW Z. WISNIEWSKI‡

September 10, 1965

ABSTRACT

We have made photometric observations of the Neugebauer-Martz-Leighton Cygnus object, seven new very red stars found by Haro and Chavira, and four red stars found nearly thirty years ago by Hetzler. Haro and Chavira, and Hetzler, used photographic techniques to discover their stars.

The effective temperatures of these objects have been estimated to range from 1900°K to 1400°K for the Haro-Chavira stars, and from 1950°K to 1550°K for the Hetzler stars. The temperature of the Neugebauer-Martz-Leighton Cygnus object is quite uncertain, but is probably about 1000°K. The spectral-energy curves resemble rather closely those of warmer M-type giants, but are very different from those of carbon stars of similar temperatures.

Preliminary results of the Haro-Chavira survey indicate that the very red stars are restricted to the general region of the Milky Way; this implies that they are distant objects and very luminous.

By permission of the discoverers, we reproduce here finding charts for the seven Haro-Chavira objects (Figs. 3 and 4).

The recent discovery by Neugebauer, Martz, and Leighton (1965) of several "infrared stars," and the results of photometry from 1 to 20 microns (Johnson, Low, and Steinmetz 1965), prompted Haro and Johnson to ask whether similar stars might not be found by photographic observations in the R and I bands. If so, the discovery of infrared stars would be feasible with existing Schmidt telescopes. As a matter of fact, a photographic survey was carried out by Hetzler (1937); he identified several very red stars — redder even than χ Cyg at minimum light.

As a test of the technique, Haro and Chavira obtained with the Tonantzintla (Mexico) Schmidt telescope an R plate and an I plate, both centered on the Neugebauer-Martz-Leighton Cygnus object. They also obtained two similar plates of an adjoining field. The extremely cool infrared star appears very brightly on the I plate and rather weakly on the R plate; we would indeed have found the object easily from these plates. Furthermore, Haro and Chavira found seven more very red stars in these regions, which together have an area of about 40 square degrees. However, none of these additional red objects showed on the plates to be as red as the one discovered by Neugebauer, *et al.*

We have obtained photometric data for these objects over a very wide range in wavelength, with the results given in Table 1. We have also observed four objects identified by Hetzler (1937). The identification charts for the Haro-Chavira stars are given at the end of this paper (Figs. 3 and 4). Data for χ Cyg, near minimum light, and for T Lyr, one of the coolest carbon stars observed by Mendoza and Johnson (1965), are included for comparison. It is evident that these are very red stars, some redder (and cooler) than χ Cyg at minimum light.

If we apply the effective temperature calibration derived by Johnson (1964) to these stars, we obtain the temperatures in the second column of Table 2. The calibration is empirical and is based upon observations of the 10 stars whose apparent angular diameters have been measured; the effective temperatures of the 10 calibration stars range from 10,000°K down to 2000°K. An interpolation formula based upon the gradients of the stellar spectra in the regions of the R, I, J, and K filters (0.7 μ to 2.2 μ), and the differential behavior of black-body curves with temperature, was found to represent the

*Printed with permission of *The Astrophysical Journal.*
†National Astronomical Observatory, University of Mexico.
‡On leave from Cracow Observatory, Poland.

TABLE 1
THE COLORS OF THE INFRARED STARS

OBJECT	B–K	V–K	R–K	I–K	J–K	K–L	K–M	K–N	K
Neugebauer-Martz-Leighton (Cyg)	18.26:	16.22:	10.88	6.57	4.19	2.29	3.85	5.77	0.38
Haro-Chavira No. 1	—	14.83	9.09	5.34	2.87	0.78	0.83	—	1.04
" No. 2	17.54	13.10	8.12	4.77	2.61	0.67	0.80	—	1.06
" No. 3	—	—	8.22	4.30	2.19	0.66	—	—	4.06
" No. 4	—	—	7.27	3.99	2.33	—	—	—	4.97
" No. 6	—	—	9.17	5.58	3.02	0.60	—	—	2.89
" No. 7	—	—	6.91	3.17	1.92	—	—	—	6.15
" No. 8	—	—	7.75	4.73	2.60	0.40	0.70	—	3.43
Hetzler 1–1	16.95	13.88	8.43	4.53	2.19	0.66	1.07	—	1.48
" 1–2	—	—	7.53	3.71	1.99	0.55	—	—	3.87
" 4–1	15.16	12.16	7.11	3.93	2.06	0.42	—	—	2.60
" 4–2	13.14	10.84	6.54	3.30	1.62	0.40	0.54	—	2.11
χ Cyg (min)	16.13	13.60	7.69	3.71	1.63	0.80	0.85	1.66	−1.76
T Lyr	13.47	7.95	5.01	3.30	2.32	0.76	0.14	0.53	0.23

data satisfactorily. Of course, a considerable extrapolation of this calibration was necessary to obtain the lowest temperature listed in Table 2, and the preliminary estimate of 700°K (Johnson, *et al.* 1965), versus 1290°K from Table 2, suggests that the extrapolation may not be entirely satisfactory for the coolest star. On the other hand, the temperature determination by Johnson, Low, and Steinmetz depends upon the approximate fitting of a black-body curve to the observed points, with most of the weight given to a superposition of the maxima of the two curves. Thus, the 700° determination rests primarily upon the fact that the wavelength for maximum flux is about 4 μ. (Such a procedure can produce temperatures lower than the effective temperatures; for example, the effective temperature of an AO V star is about 9500°K, while the peak radiation of the star occurs around 4200Å, corresponding [Wien's law] to a black-body temperature of 7000°K.) Both temperature determinations are quite crude, and perhaps it is best to adopt $T_e = 1000$°K for the coolest star, the one found by Neugebauer, Martz, and Leighton. On this basis, a smaller correction, toward lower temperatures, may be needed for some of the other stars listed in Table 2.

The spectral-energy curves for two of these infrared stars, Haro-Chavira No. 1 and the Neugebauer-Martz-Leighton Cygnus object, are shown in Figure 1. The curves for χ Cyg and R Hya (data from Mendoza and Johnson 1965) are shown for comparison. The curves were computed with the aid of the absolute calibration derived by Johnson (1965) and have been normalized to unity at the maxima. The effective temperatures for the four objects plotted range from 2540°K for R Hya (Mendoza and Johnson 1965) to 1000°K for the coolest object; the curves are quite similar, with the principal differences among them due to the different effective temperatures.

It is of interest to compare the spectral-energy curves of Figure 1 with those for three carbon stars, T Lyr, U Cyg, and T Cnc; the latter are shown in Figure 2 and were derived from the data of Mendoza and Johnson (1965). Comparison of the curves in Figures 1 and 2 shows striking differences between the energy distributions of the two kinds of stars. In contrast to the curves of Figure 1, the carbon stars exhibit wide, flat maxima; their radiation output is high and approximately constant over nearly a factor of 3 in wavelength. On the short-wavelength side, the curves for the carbon stars rise at about the same wavelength as does that of R Hya, while on the long-wavelength side, they fall at almost

TABLE 2
THE TENTATIVE EFFECTIVE TEMPERATURE OF THE INFRARED STARS

OBJECT	T_e (°K)
Neugebauer-Martz-Leighton (Cyg)	(1290)
Haro-Chavira No. 1	1480
" No. 2	1630
" No. 3	1600
" No. 4	1780
" No. 6	1400
" No. 7	1930
" No. 8	1660
Hetzler 1–1	1550
" 1–2	1850
" 4–1	1790
" 4–2	1950
χ Cyg (min)	1680
T Lyr	2400

TABLE 3
THE MAGNITUDE OF THE INFRARED STARS

OBJECT	B	V	R	I	J	K	L	M	N
Neugebauer-Martz-Leighton (Cyg)	18.64:	16:60:	11.26	6.95	4.57	0.38	−1.91	−3.47	−5.39
Haro-Chavira No. 1	—	15.87	10.13	6.38	3.91	1.04	0.26	0.22	—
" No. 2	18.60	14.16	9.18	5.83	3.67	1.06	0.39	0.27	—
" No. 3	—	—	12.28	8.36	6.25	4.06	3.40	—	—
" No. 4	—	—	12.24	8.96	7.30	4.97	—	—	—
" No. 6	—	—	12.06	8.47	5.91	2.89	2.29	—	—
" No. 7	—	—	13.06	9.32	8.07	6.15	—	—	—
" No. 8	—	—	11.18	8.16	6.03	3.43	3.03	2.73	—
Hetzler 1–1	18.43	15.36	9.91	6.01	3.67	1.48	0.82	0.44	—
" 1–2	—	—	11.40	7.58	5.86	3.87	3.32	—	—
" 4–1	17.76	14.76	9.71	6.53	4.66	2.60	2.18	—	—
" 4–2	15.25	12.95	8.65	5.41	3.73	2.11	1.71	1.58	—
χ Cyg (min)	14.37	11.84	5.93	1.95	−0.13	−1.76	−2.56	−2.61	−3.42
T Lyr	13.70	8.18	5.24	3.53	2.55	0.23	−0.53	0.09	−0.30

exactly the same wavelength as the curve for Haro-Chavira No. 1. These comparisons indicate that the new infrared stars belong to the class of M-type giant stars rather than to that of carbon stars. They appear to be very cool objects of the type of R Hya, *o* Cet (Mira) and χ Cyg.

Table 3 gives the observed magnitudes in the several filter bands, computed from the data of Table 1. The B and V magnitudes for the first object probably represent upper brightness limits since a faint nearby star probably was included in the diaphragm during measurement; the infrared star probably is fainter than $V = 16.6$. The data of Table 3 evince a most remarkable fact — that in the small area of the sky (40 square degrees) that has been covered, there are several stars whose visual magnitudes are such that at least a fairly large telescope is necessary for a person to see them, but which must be listed among the bright stars in the infrared.

This point is emphasized by the statistics of our infrared observing programs: We have observed about 700 stars at magnitude K; of these, 65 are brighter than $K = 0.00$ and about 150 are brighter than $K = 1.00$. Thus, the new infrared stars are well toward the top of the list of the brightest stars at 2.2 μ. At the longer wavelengths, they climb even higher in the list; for example, the Neugebauer-Martz-Leighton object is the brightest star yet observed at N (10.2 μ) — it is about 0.7 mag brighter than α Orionis at this wavelength! Obviously, in the infrared the apparent distribution of bright stars is completely different from that which we see with our eyes.

The photographic survey to discover more of these very red stars is being continued by Haro and Chavira, using the Tonantzintla Schmidt telescope. They have found many more very red stars, although none is as red as the one found by Neugebauer, *et al.* Haro writes:

> We have been unable to find these very red stars in the direction of the North Galactic Pole, and the same can be said for the very dark areas near the Galactic Equator.... It seems as if these very red stars have, in general, a distribution similar to the OB (stars); they appear in regions nearby the Milky Way, where there are no outstanding dark Nebulae, but at the same time they do not appear frequently on the very outstanding star clouds as — for instance — the Scutum Cloud. However, they do not show, as (do)the OB stars, the tendency to appear in very compact groups. Of course, this is a very preliminary impression, which will be confirmed or not when we have sufficient material.

This distribution implies that these objects are quite distant and, therefore, very large and very luminous.

Acknowledgments. This research has been supported in part by the National Science Foundation under Grant GP-3736. One of us (E. E. M.) wishes to acknowledge a grant from the Organization of American States.

REFERENCES

Hetzler, C. 1937, *Ap. J.*, *86*, 509.

Johnson, H. L. 1964, *Bol. Obs. Tonantzintla y Tacubaya*, *3*, 305.

———. 1965, *Comm. LPL*, No. 53.

Johnson, H. L., Low, F. J., and Steinmetz, D. 1965, *Ap. J.*, *142*, in press.

Mendoza V., E. E., and Johnson, H. L. 1965, *Ap. J.*, *141*, 161.

Neugebauer, G., Martz, D. E., and Leighton R. B. 1965, *Ap. J.*, *142*, 399.

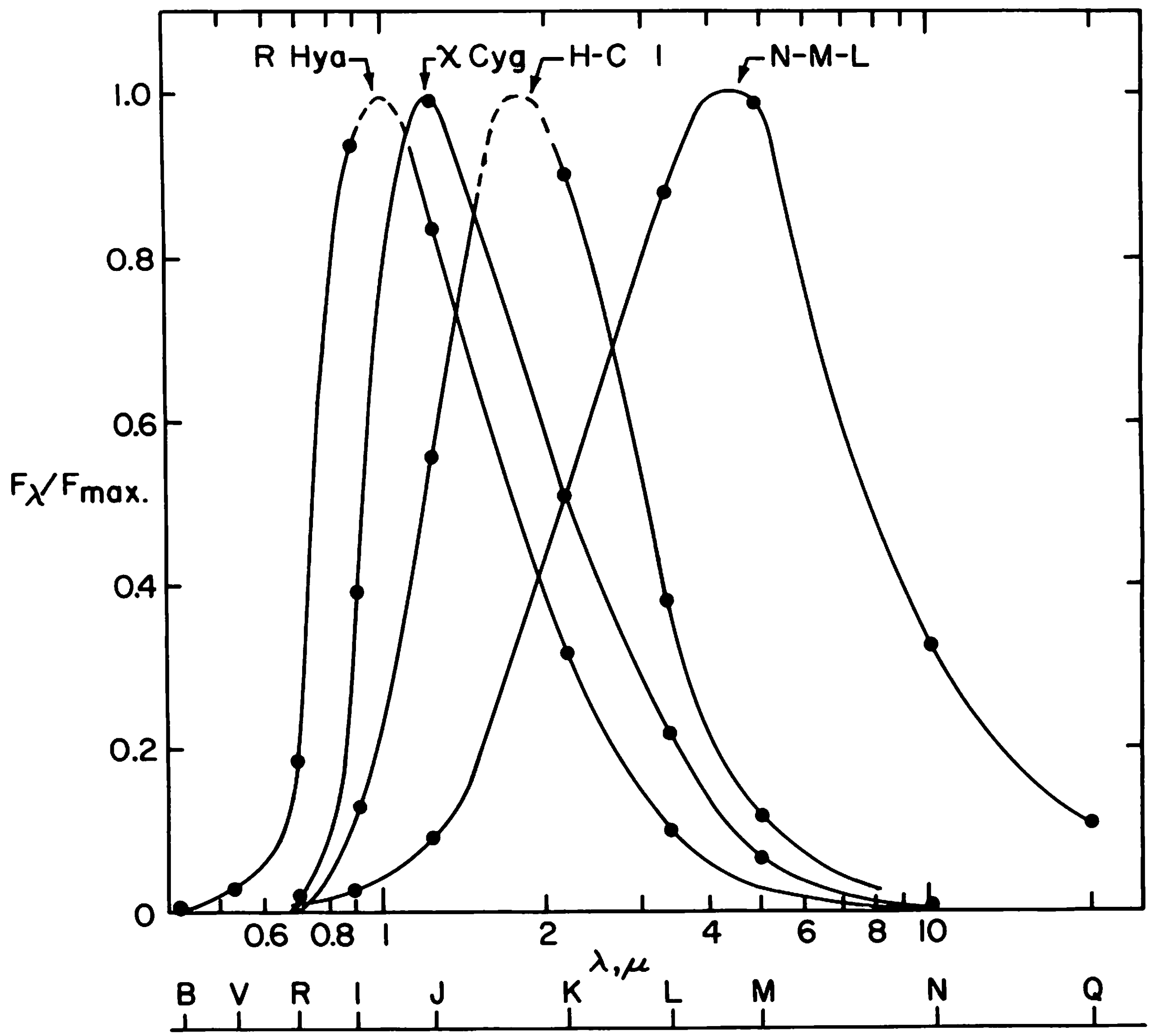

Fig. 1 The spectral-energy curves for R Hya, χ Cyg, Haro-Chavira No. 1 and the Neugebauer-Martz-Leighton Cygnus object.

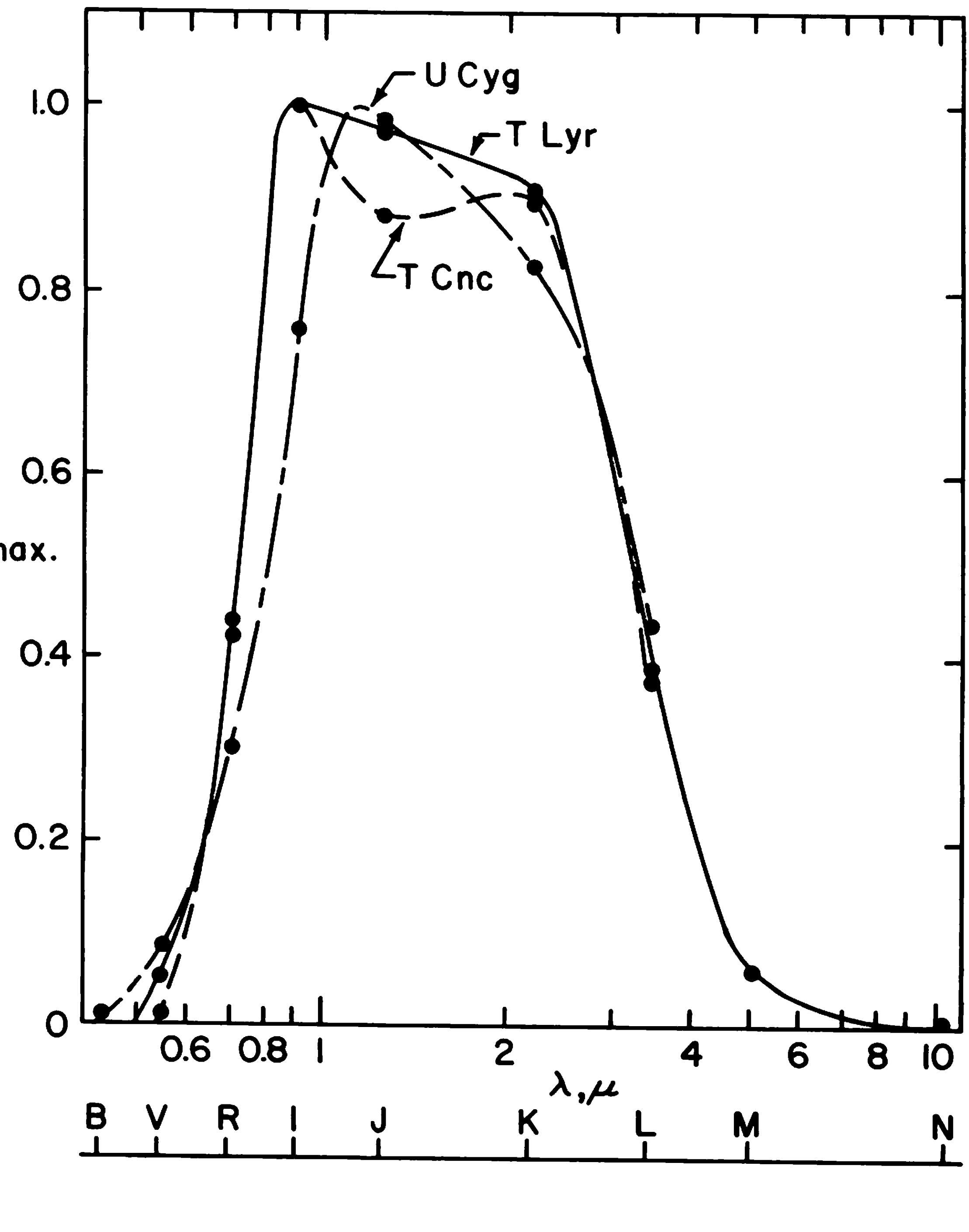

Fig. 2 The spectral-energy curves for T Lyr, U Cyg and T Cnc, all carbon stars.

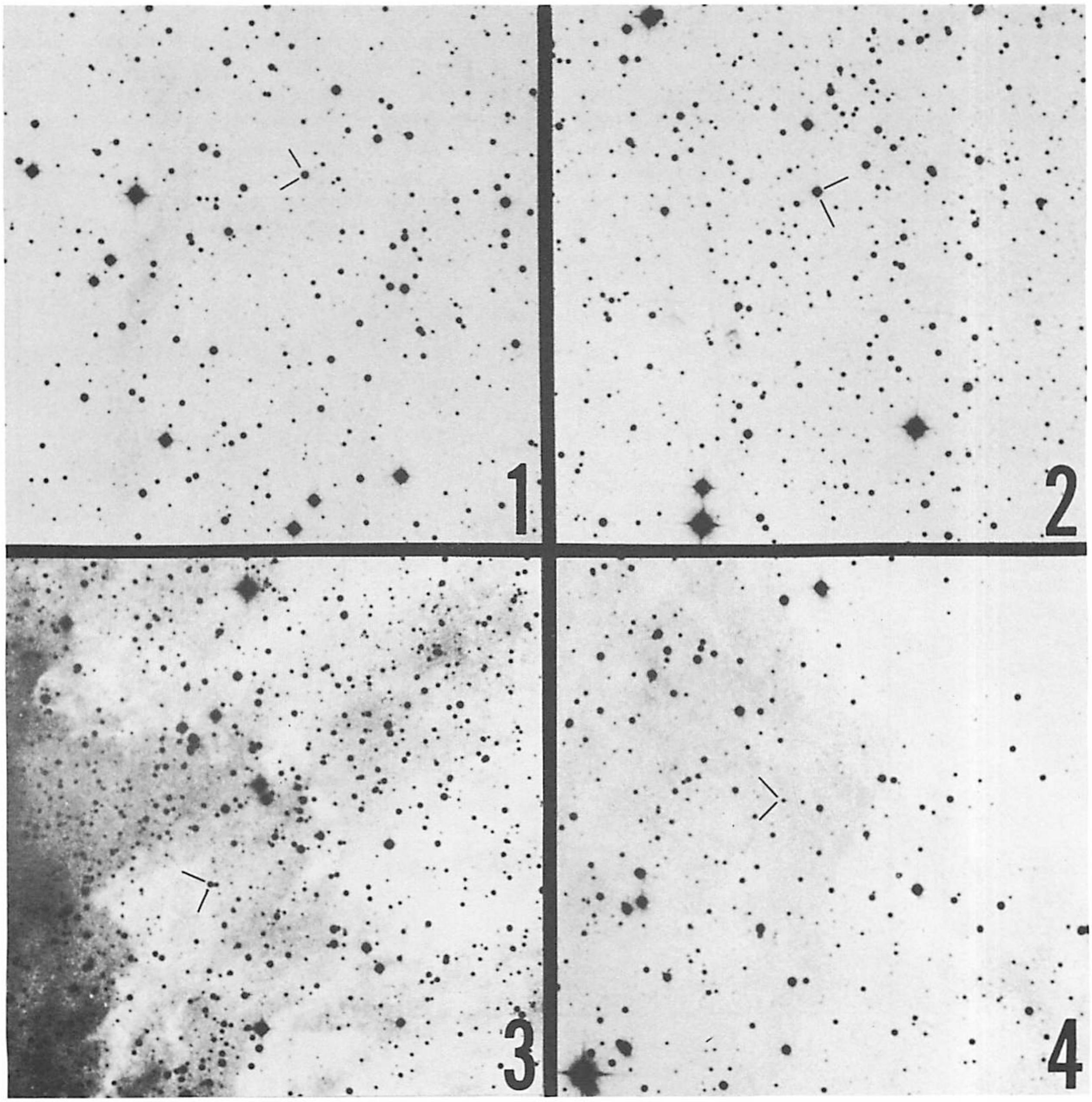

Fig. 3 The finding charts for Haro-Chavira objects. The positions (1965) are:

	RA	DEC
No. 1	$20^h32^m.6$	$+42°14'$
No. 2	20 31 . 2	+40 30
No. 3	20 24 . 3	+40 37
No. 4	20 25 . 4	+39 42

Charts for Nos. 1, 2, and 3 were copied from the red Palomar Survey plates; No. 4, from the blue plate.

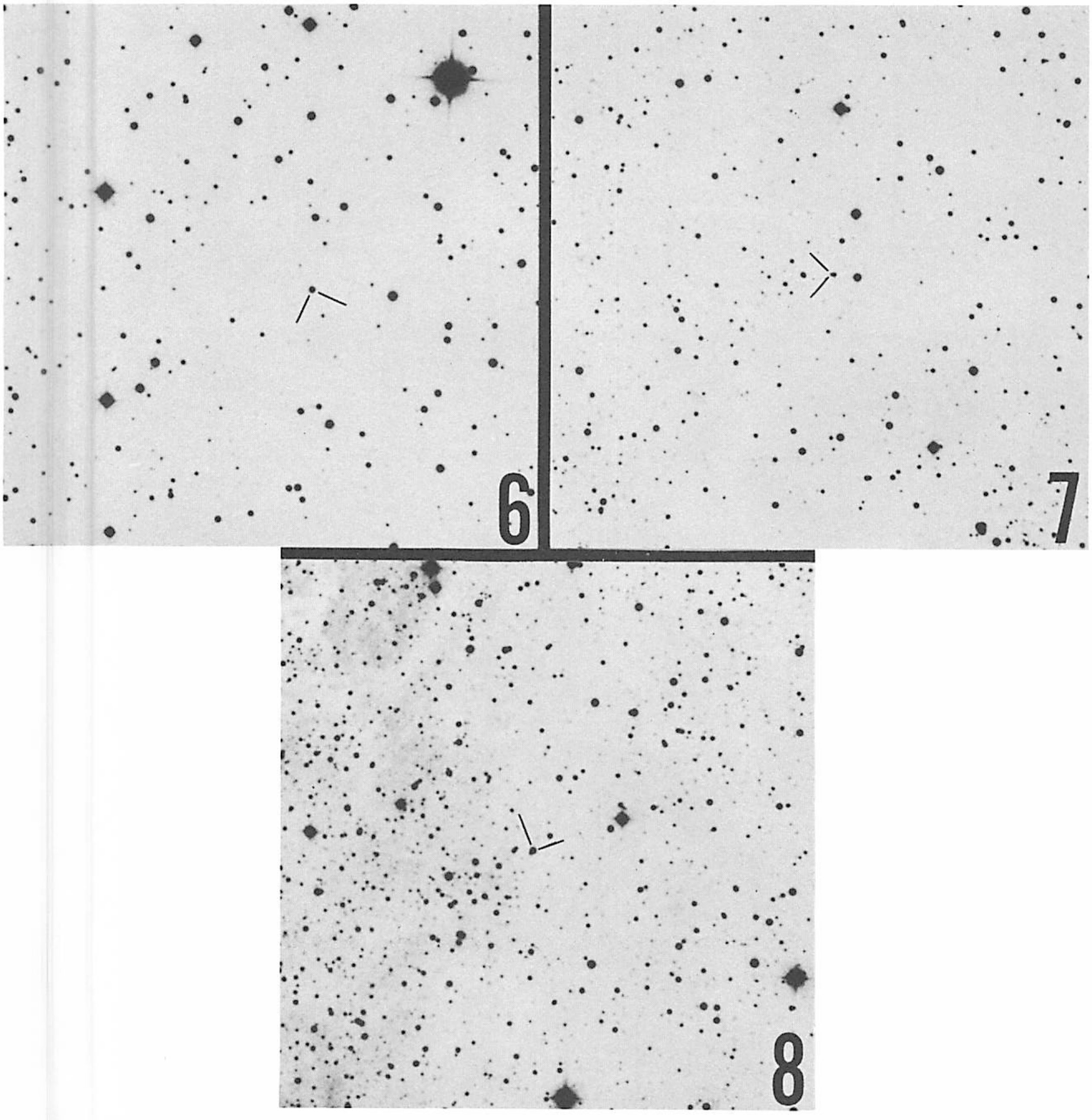

Fig. 4 The finding charts for Haro-Chavira objects. The positions (1965) are:

	RA	DEC
No. 6	$20^h39^m.6$	$+40°57'$
No. 7	20 40.8	+40 14
No. 8	20 42.4	+40 46

The charts were copied from the red Palomar Survey plates.