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Optical identifications of AFCRL rocket infrared sources

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The positions of almost 700 unidentified infrared sources from the AFCRL rocket sky survey have been searched photographically for objects of exceptional redness. Forty-four optical identifications are suggested and finding charts are given.

THE recently completed AFCRL infrared sky survey (Walker and Price 1974) is of great importance to infrared astronomy. The survey has been carried out at wavelengths of 4, 11, and 20 μ using rocket-borne detectors, from altitudes at which the atmospheric emission in the 10-μ region is no longer a limitation to the size of aperture that may be used. Consequently, the rockets have used effective apertures of 10 arcmin by 3 arcmin, compared with typical ground-based systems which have 10–30-arcsec beams, and a sky survey at the longer wavelengths has become practicable.

What types of object are bright at these infrared wavelengths? Many sources from the Two Micron Sky Survey (Neugebauer and Leighton 1969: IRC henceforth) are seen at the longer wavelengths. Many optical H II regions are detected, principally at 11 and/or 20 μ, and, where the obscuration is high, these may be recognized by radio continuum peaks, accounting for quite a few more sources. Making allowance for all these classes of object, there still remain several hundred unidentified AFCRL sources with magnitudes brighter than about +1.7, −0.4, and −2.5 at 4, 11, and 20 μ, respectively.

Theoretically, one can identify one of these sources from the ground by performing a raster about its nominal position until an infrared signal at the appropriate wavelength is detected, and examining the field through the telescope. However, the necessity of using small apertures and sky-chopping techniques at 10 μ renders ground-based systems insensitive to extended sources, unless there exist large spatial second derivatives. Most of the H II regions detected by the survey would not be detected from the ground with small beams, or a weak peak might be located and the existence of an extended source inferred (cf. Cohen and Barlow 1973). A few large H II regions are known to emit much of their 10–20-μ flux through a small number of point-like objects [e.g., the Kleinmann–Low "20-μ object" in Orion A; the sources in W 3 (Wynn-Williams, Becklin, and Neugebauer 1972); the small bright 10-μ peak in M 17 (Kleinmann 1973); see also Frogel and Persson 1974], but it is not clear that such peaks exist in all the smaller regions.

Clearly, some optical discrimination against extended objects would assist in defining that subset of unidentified sources that could most readily be located and studied from the ground. Therefore, the author has undertaken a systematic photographic investigation at the positions of many of these sources using the National Geographic Society–Palomar Observatory Sky Survey prints. The positions of the sources are generally quoted with errors of about ±0.2 min in right ascension and ±2 arcmin in declination, defining typically an error box several square millimeters in area on the prints. Source positions are located with respect to stars in the Smithsonian Astrophysical Observatory Catalog using the methods described by Dewhirst (1963). To recognize possible optical counterparts to AFCRL objects one seeks objects of either peculiar appearance or exceptional redness close to the rocket positions. There is no guarantee that 11- or 20-μ sources will be associated with optical objects, nor that, if they are, these will not be of neutral color. But one does expect to find a component of the population of unidentified long-wavelength sources which represent stars similar to but redder than those found in the IRC, but too faint at 2 μ to have been included in it, and very red optical counterparts do exist for virtually all these near-infrared objects (Cohen 1972). Moreover, the criterion of redness is a natural requirement for a first survey of the AFCRL sources, even if radically new types of object or radiation mechanism are involved.

Several AFCRL sources of peculiar, nonstellar appearance found in this identification program have already been discussed in the literature (Cohen and Barlow 1973; Cohen 1973; M 2–56 in Cohen and Barlow 1974; Cohen *et al.* 1975). This paper suggests photographic identifications for 44 previously unidentified sources on the basis of the second discriminant, namely redness. These possible red stellar candidates were found during an examination of the positions of almost 700 unidentified sources. As yet only a few of the identifications have been confirmed by ground-based photometry, but their generally outstanding colors make them highly probable optical counterparts to the infrared sources. Included among the positions searched are the 27 objects confirmed by the University of Arizona group (Low 1973), for which the improved coordinates facilitate identification.

Optical candidates are included in this paper only if they are either the sole very red object or outstandingly the brightest of several possibilities close to a

TABLE I. Sources and suggested identifications.

Running No.	R.A. (1950)	Dec. (1950)	σ_α	σ_δ	AFCRL No.	Wavelengths	Magnitudes* Red	Blue	Weight	Notes
1	0h24m6	+69°23′	±0m4	±2′	412-0258	4, 11	18	21:	3	
2	1 09.6	+63 04	0.4	2	418-0311	20	13	21	3	1
3	2 06.3	+45 55	0.2	1	512-3133	4	12	14½	2	
4	3 20.8	+58 33	0.3	2	902-0162	4, 11	7½	13½	3	
5	3 23.9	+58 35	0.3	2	508-3363	11, 20	20:	>21	3	A
6	4 24.7	+41 49	0.2	1	816-0574	4	16	>21	3	
7	4 32.1	+43 21	0.2	2	901-0474	4	12	15	3	
8	4 39.4	+36 02	0.2	1	819-0636	11, 20	16½	20	2	2, B
9	5 40.5	+32 42	0.2	2	831-0628	4, 11, 20	20	>21	3	C
10	6 51.4	−20 55	0.1	2	509-1548	20	12½	16½	1	
11	8 35.9	−10 18	0.2	3	517-1208	4, 11	19	21:	3	A
12	8 53.3	+32 34	0.2	2	711-2822	4	19½	21	2	
13	14 08.7	− 7 33	0.1	2	712-1551	11	18½	>21	3	A
14	16 36.5	+42 33	0.2	1	705-0663	4	18½	21:	3	
15	17 12.9	− 3 11	0.2	2	733-1088	11, 20	10	13	1	
16	17 34.5	+33 15	0.2	1	718-0722	11	11½	13½	2	
17	18 13.6	−19 00	0.1	2	416-1858	4, 11, 20	19½	21:	3	A
18	18 24.1	+23 26	0.2	2	731-0753	4, 11, 20	17	21	3	A
19	18 28.6	− 9 36	0.2	2	218-1233	4, 11	16	21:	3	A
20	18 31.5	−11 32	0.1	2	409-1816	4, 11	16	21:	3	A
21	19 13.4	+ 9 32	0.1	2	218-0973	4, 11, 20	16	21	3	A
22	19 15.4	+11 48	0.2	2	217-0946	20	12	16½	1	
23	19 24.9	+ 6 58	0.2	2	221-0986	4, 11	16½	>21	3	
24	19 27.3	+46 03	0.2	1	213-0509	4	16	21:	3	3
25	19 36.1	−16 59	0.1	2	416-1625	11, 20	13	18½	3	
26	19 38.0	+33 15	0.2	2	819-2927	4, 11	16½	21:	3	
27	19 51.2	+57 29	0.3	1	217-0367	11	16	21	2	4
28	20 22.6	+47 35	0.2	1	931-3144	4	9½	13½	2	
29	20 27.2	+74 20	0.5	1	222-0173	4, 11	12½	15	1	
30	20 33.1	+38 07	0.0	1	808-2958	4, 11	20	21:	1	
31	20 54.9	+37 13	0.2	1	804-2947	4, 11	12	21:	3	C
32	20 57.1	+27 14	0.1	1	930-2915	4, 11	16	>21	3	
33	21 00.4	+36 30	0.1	1	803-2935	11, 20	12	15	3	5, D
34	21 09.6	+17 12	0.2	2	930-2803	4	20	21:	2	6
35	21 42.8	+19 13	0.2	2	404-1018	11	20:	21:	3	
36	22 00.1	+24 41	0.1	1	404-0921	4, 11, 20	18	21	3	
37	22 17.6	+59 36	0.2	2	916-3282	4, 11, 20	13	19	2	
38	22 36.1	−28 40	0.2	2	933-2267	11	16½	21	3	
39	22 42.9	−25 03	0.1	2	820-2023	11, 20	17½	>21	3	
40	22 51.7	+66 00	0.3	2	915-3376	4, 11	16	>21	2	
41	22 55.5	−32 06	0.2	3	932-2210	11	20	21:	3	
42	23 11.1	+43 10	0.2	1	905-3100	4	9	14	3	
43	23 14.3	−23 05	0.1	2	924-2247	4	16½	>21	3	
44	23 56.7	+74 19	0.6	2	614-3429	11	10	13	1	

Notes to Table I

* When a photographic image is present on the Sky Survey prints at the level of a significant graininess, the limiting magnitude is quoted together with a colon.

A: confirmed by Low (1973); B: confirmed by Caltech; C: confirmed by the author; D: confirmed by Merrill, and the subject of a forthcoming paper (Ney, private communication).

1: could be either of two red images, the fainter having red mag 16 and blue mag 21; 2: appears somewhat nebulous; 3: E component of a very close pair of images; 4: juxtaposition of a red star and a small, very red galaxy; 5: a bright nebulosity oval in shape; 6: Np of a faint pair of stars.

source position. Finding charts are not provided in this paper for the many ambiguous situations. It is hoped that in this manner only those "identifications" most likely to be genuine optical images of infrared sources have been isolated. These criteria have successfully recognized some emission-Hα stars in the AFCRL survey, for example AS 501 (Cohen 1974) and MWC 349.

Table I presents a list of the AFCRL sources for which finding charts are given in this paper. Column 1 contains a running number merely for internal convenience in labelling the charts. Columns 2 and 3 list the 1950 right ascension and declination from the AFCRL catalog, and columns 4 and 5 give the quoted positional uncertainties. Column 6 contains AFCRL source designations. Column 7 indicates at which wavelength (4, 11, or 20 μ) the sources were detected in the survey. Columns 8 and 9 give the approximate red and blue magnitudes of the identifications, estimated from their image diameters on the Sky Survey prints; these are probably accurate to only $\pm\frac{1}{2}$ mag. Column 10 gives this author's subjectively assessed weights for the identifications, based upon proximity to the nominal rocket coordinates, the wavelengths at which the source is seen, and the degree of photographic redness. Column 11 indicates those sources whose existence has been confirmed by ground-based photometry, and those whose images are multiple or nebulous. Where confirmation is by this author, the finding chart should correctly identify the source, but other observers should not be held guilty if a source they have confirmed does not coincide with the object indicated on the appropriate finding chart.

Plates IV–XI (pp. 167–174) present the finding charts for the 44 possible identifications in the form of pairs of red and blue prints, from the Sky Survey photographs. On the blue print is marked either a cross for the nominal rocket position of the source, or a circle whose radius represents the positional uncertainty from ground-based observations and which should greatly improve the likelihood of isolating the true optical candidate, if any. On the red print, the suggested object is shown.

Of these 44 sources, 28 are detected at 4 μ, and this appreciable near-infrared flux lends credibility to the existence of optical counterparts. Little definitive can yet be said about the large number of unidentified objects, mostly without optical counterparts, at high galactic latitudes, a small fraction of which have been sought unsuccessfully from the ground using smallish beam systems ($\lesssim$30 arcsec). If all are real, then several different classes of object may be represented, for an appreciable number are seen solely at 4, or at 11, or at 20 μ, and quite a few of these long-wavelength sources are extended objects.

ACKNOWLEDGMENTS

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[*Note Added in Proof*. I am grateful to K. M. Merrill for notifying me of his identifications from ground-based photometry of objects 5, 11, 17, and 20, which resolve some possible ambiguities. His identifications for these four sources should replace those in Table I and are indicated on the charts of objects 5, 11, and 17 by arrows. The corresponding red and blue magnitudes of the optical counterparts should be object 5, red $18\frac{1}{2}$, blue 21; object 11, red $17\frac{1}{2}$, blue 20; object 17, red 16, blue $19\frac{1}{2}$. Merrill's position for object 20 lies some 40 arcsec west of the object marked on the photograph in this paper.]

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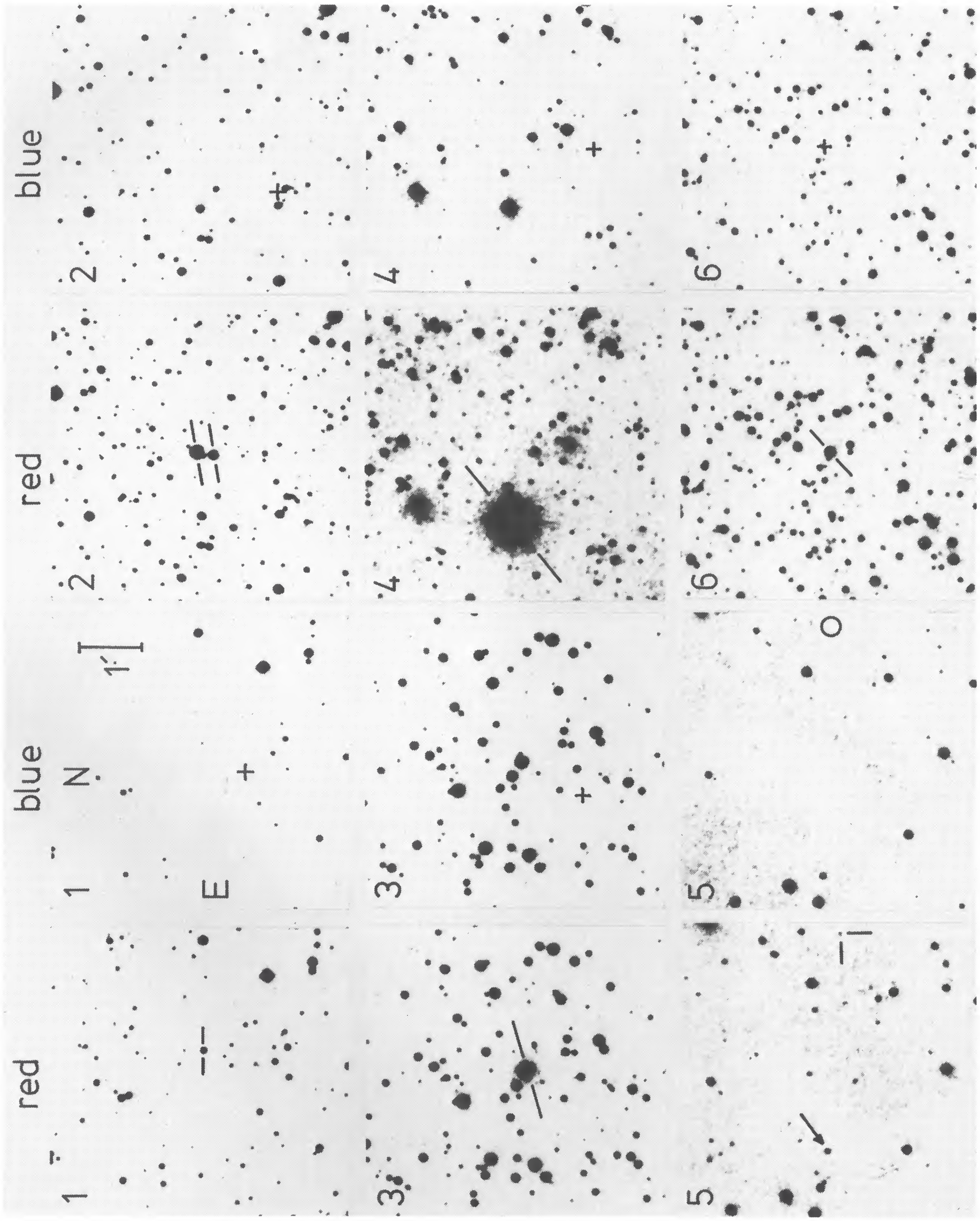

PLATE IV (Cohen, p. 125). Suggested identifications for AFCRL infrared sources. Blue and red pairs of fields 5-arcmin square are reproduced with permission from the National Geographic Society–Palomar Observatory Sky Survey prints. N and E are indicated as is the common scale. The symbols are explained in the text.

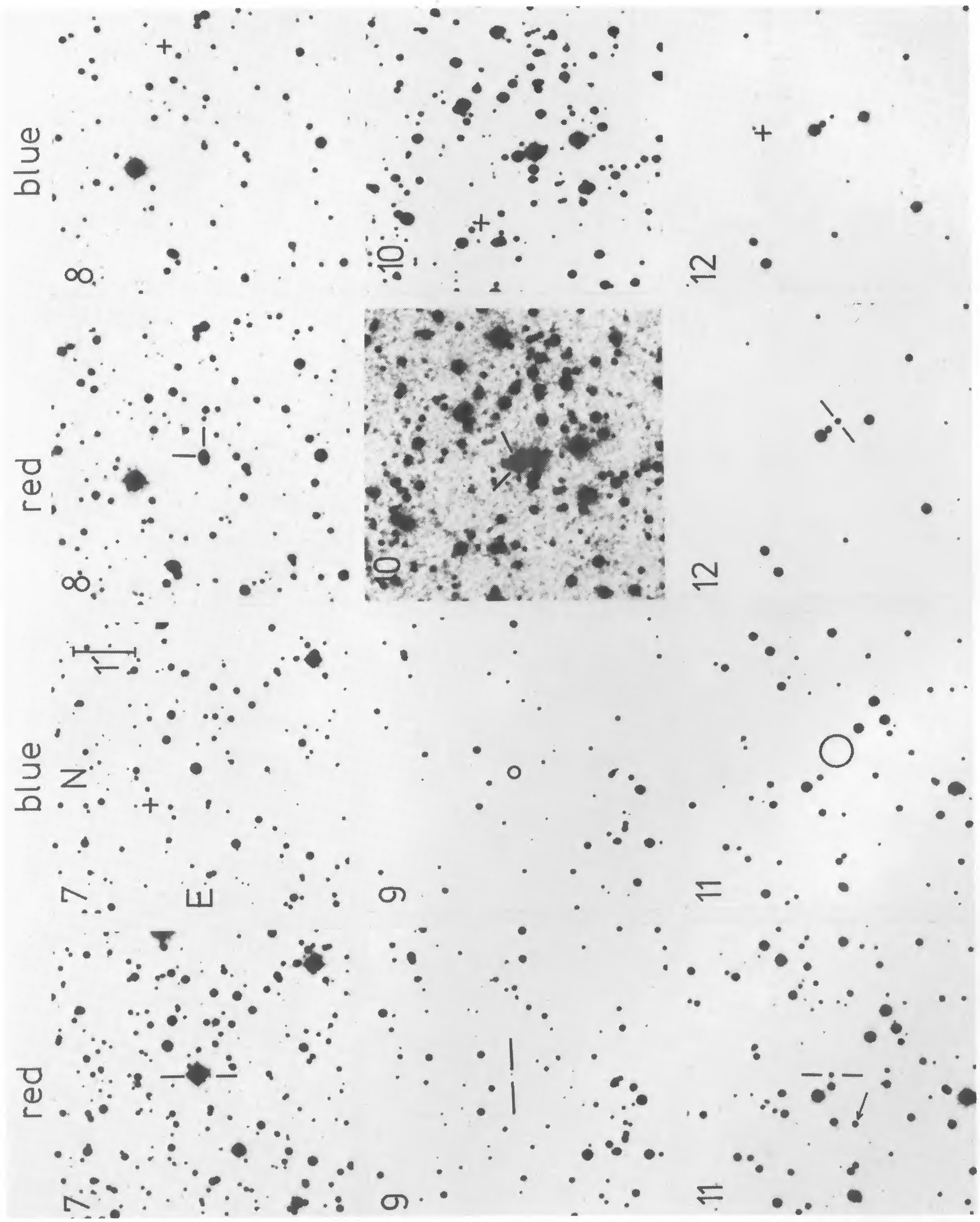

PLATE V (Cohen, p. 125). See Plate IV.

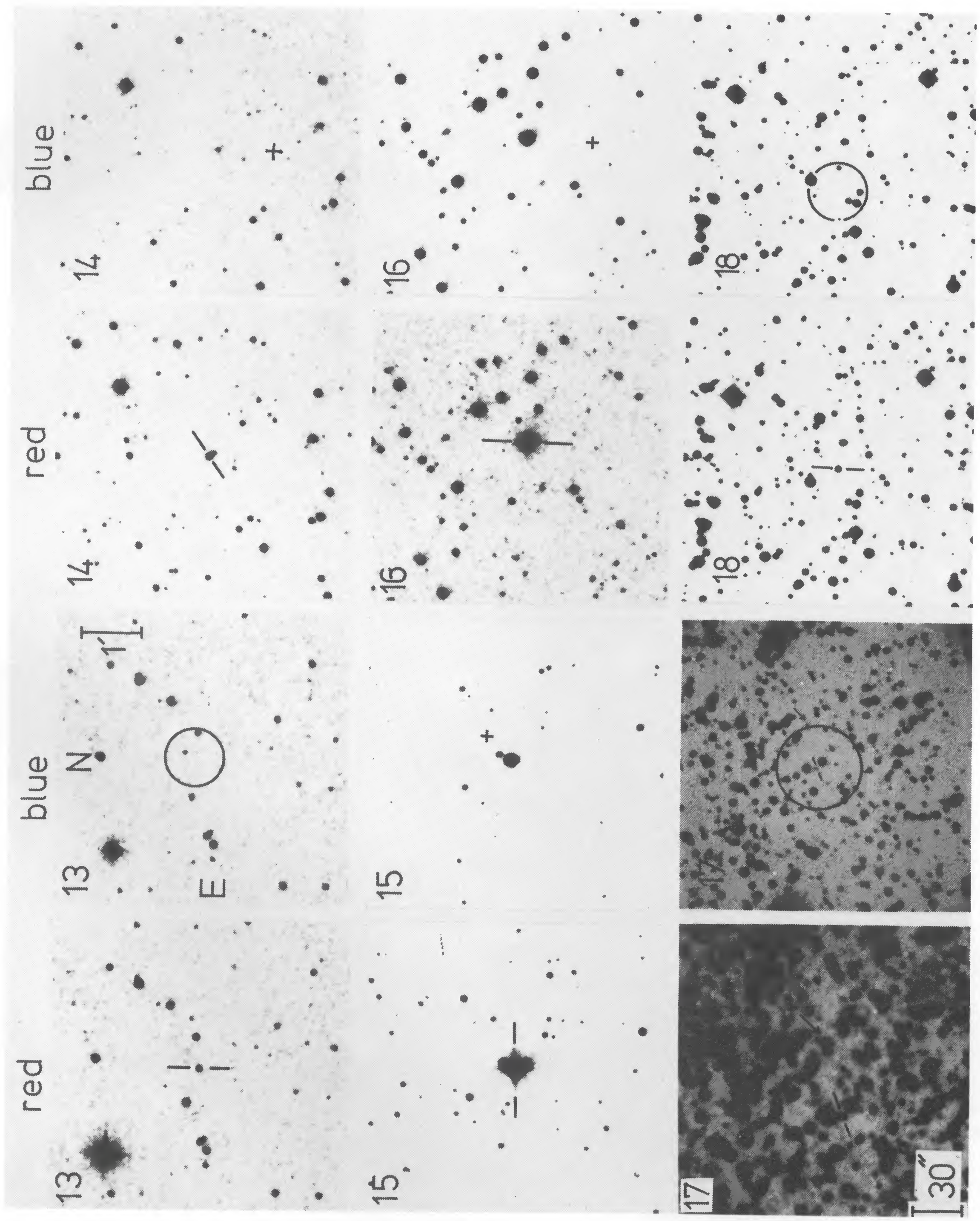

PLATE VI (Cohen, p. 125). See Plate IV. The scale for the red print of source number 17 is larger than the scale of other fields. Due to the presence of nebulosity and the very dense star field in the red, a greater enlargement was made.

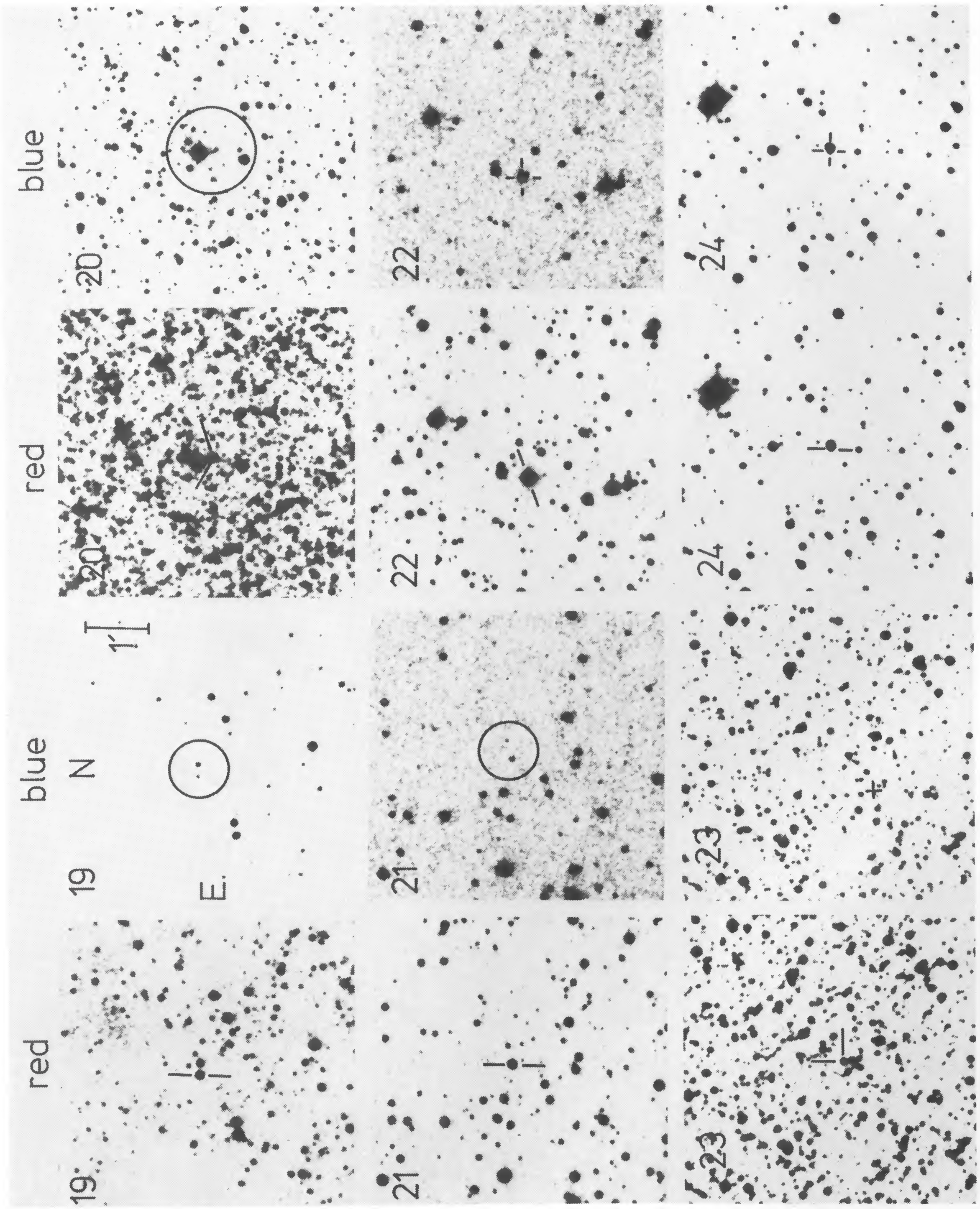

PLATE VII (Cohen, p. 125). See Plate IV.

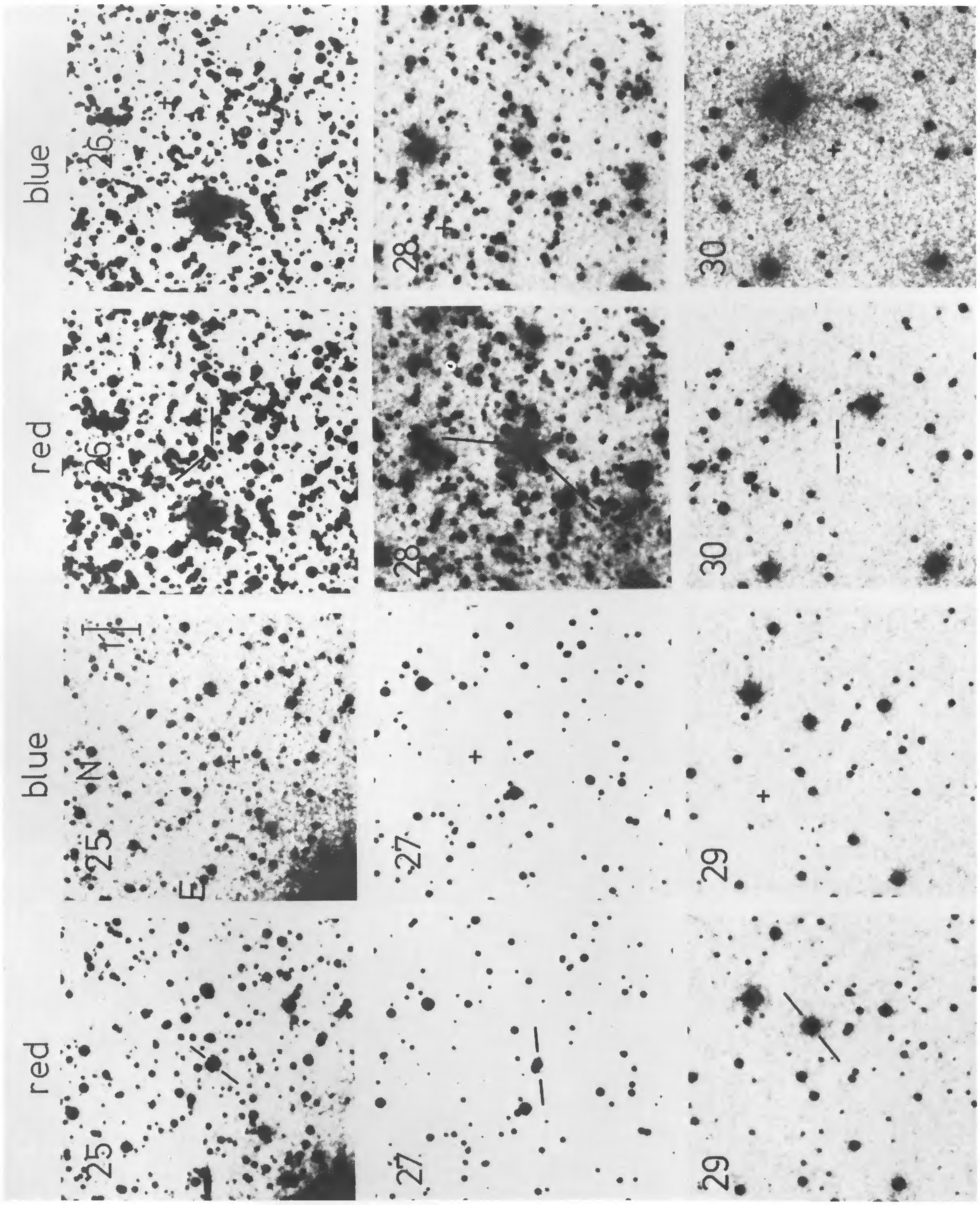

PLATE VIII (Cohen, p. 125). See Plate IV.

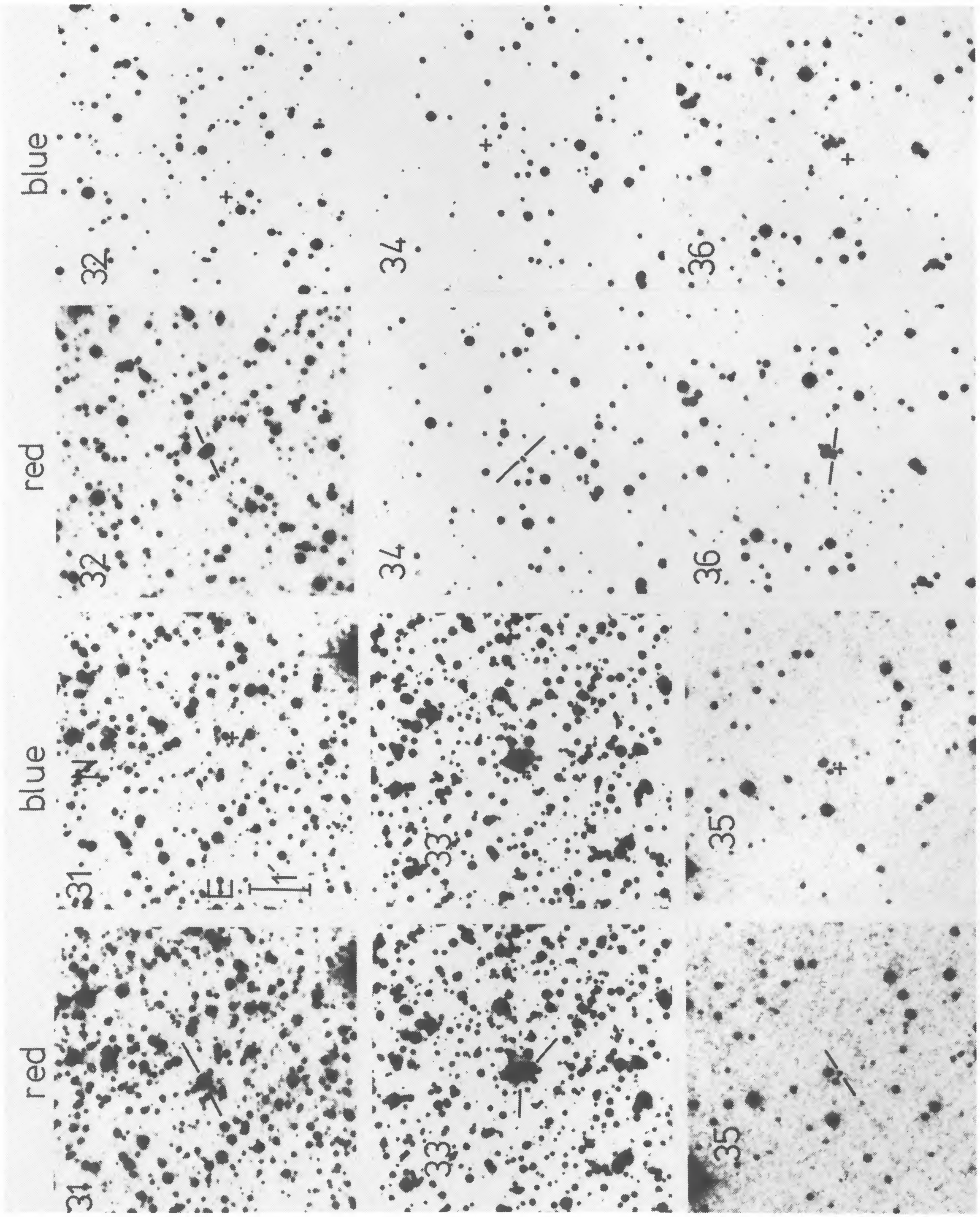

PLATE IX (Cohen, p. 125). See Plate IV.

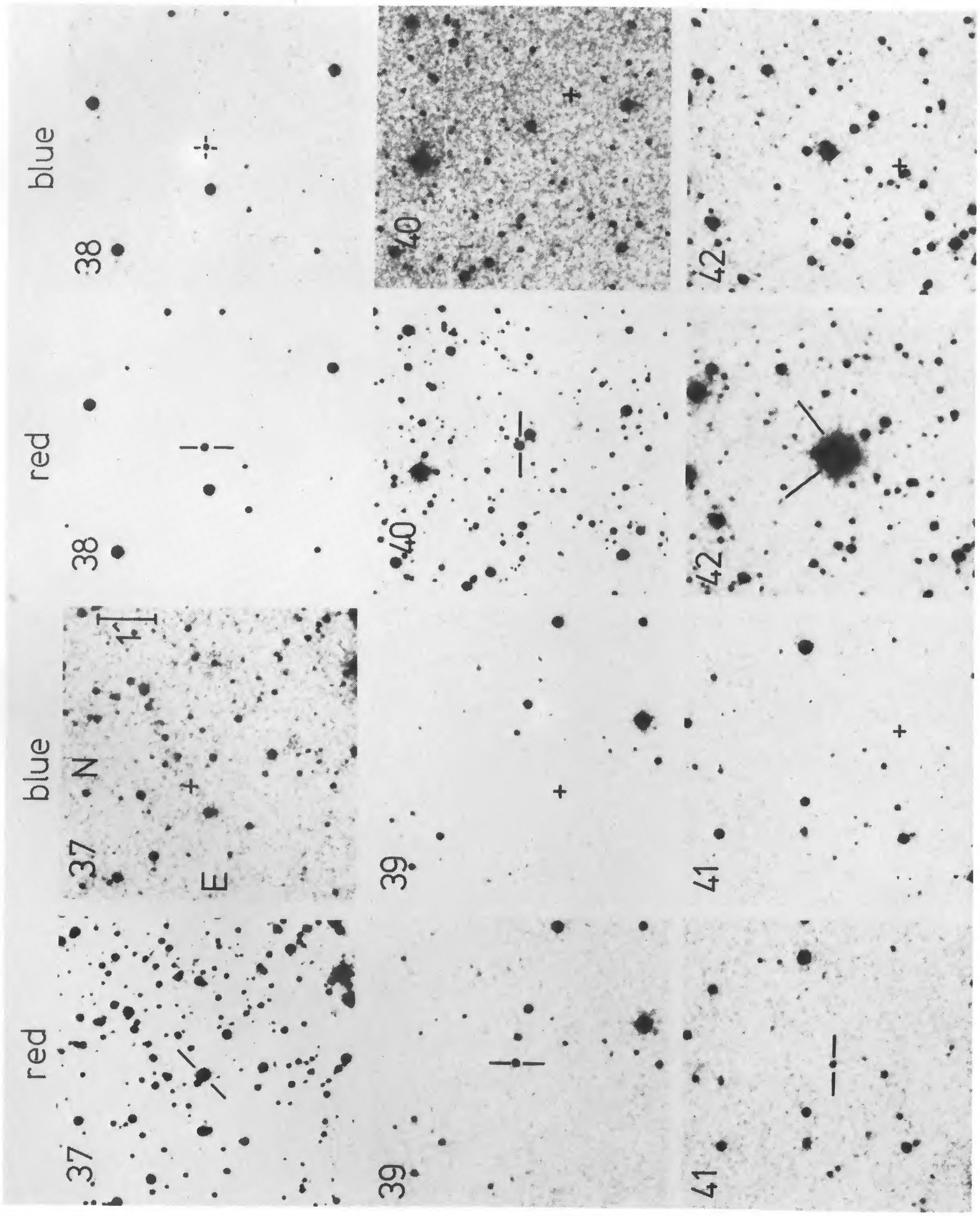

PLATE X (Cohen, p. 125). See Plate IV.

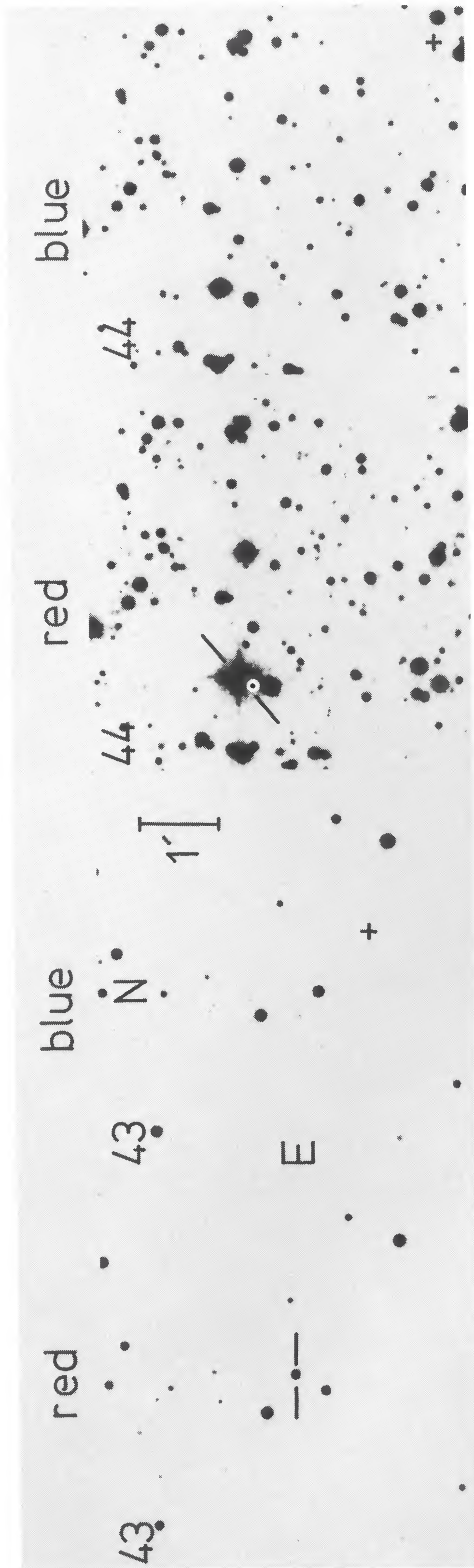

PLATE XI (Cohen, p. 125). See Plate IV.