THE ASTROPHYSICAL JOURNAL, 191:L93–L94, 1974 July 15

OPTICAL POLARIZATION OF SELECTED HERBIG-HARO OBJECTS

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Received 1974 April 22

ABSTRACT

Polarimetric observations of several Herbig-Haro objects provide additional support for the view that these objects are patches of reflection nebulosity illuminated by heavily obscured young stars.

Subject headings: emission-line stars — infrared sources — nebulae — pre–main-sequence stars

I. INTRODUCTION

Until quite recently, Herbig-Haro objects were thought to be manifestations of the earliest observable phases of stellar evolution. Strom, Strom, and Grasdalen (1974*a*) and Strom, Grasdalen, and Strom (1974*b*) have proposed identifying these objects as reflection nebulae illuminated by very young emission-line variable stars similar to the more extreme members of the Orion-variable class. Their arguments rest most heavily on two observational results:

1. The discovery of several infrared sources associated but not spatially coincident with the optical H-H objects. They choose to interpret the infrared sources as extremely young stars ("H-H stars") still embedded in their placental dark cloud material. This material is believed to be distributed quite nonuniformly so that along some paths the embedded star is able to illuminate patches of cloud material. It is these patches that have been identified previously as H-H objects.

2. Photographic estimates of linear polarization which are consistent in magnitude and direction with the hypothesis that the H-H objects are reflection nebulae illuminated by the embedded infrared sources. Polarimetric observations of "classical" reflection nebulae are characterized by high values of linear polarization with the electric vectors oriented in a plane perpendicular to radius vectors drawn from the illuminating stars (see Zellner 1974 and Serkowski 1969 for representative discussions).

II. THE OBSERVATIONS

The photopolarimeter described elsewhere by Kinman (1974) was used in conjunction with the Kitt Peak National Observatory 4- and 2.1-m telescopes to measure the linear polarization of several H-H objects.

The complex of H-H objects (H-H 24 in the numbering scheme recently proposed by Herbig [1974]) in M78 was of primary interest in this investigation because (*a*) its constituent knots of nebulosity are relatively bright for this class of object, (*b*) the knots have a sufficiently extensive spatial distribution so that radius vectors from the illuminating source to the knots cover a wide range in angle, and (*c*) an embedded infrared source has already been located by Strom *et al.* (1974*b*).

A photograph of this complex is reproduced in figure 1 (plate L4). The designations for the individual knots are those given by Strom *et al.* (1974*b*). The infrared source was accurately located by mapping the region surrounding the approximate position cited by Strom *et al.* (1974*b*) using the 12″ beam of the KPNO bolometer system. Its position [$\alpha(1950) = 05^{h}43^{m}34^{s}.5 \pm 0.2$, $\delta(1950) = -00°11'06''.8 \pm 3$] is indicated in figure 1 by the center of the cross. The infrared magnitudes for this object are given in table 1. These data were obtained 1974 January 29 (UT) using the KPNO 1.3-m telescope and the associated bolometer system. The shape of the infrared spectral energy distribution for this object is similar to those observed for the H-H stars observed by Strom *et al.* (1974*b*). This fact further strengthens the identification of this object as an H-H star.

Polarization measurements were made with the 4-m telescope 1974 February 17 (UT) for the knots labeled A and E in figure 1. A diaphragm size of 10″ was used. The spectral response of the system was defined at long wavelengths by the sensitivity of the S-20 photocathode and at short wavelengths by an RG-1 filter. The measured polarization and electric vector orientations for knots A and E are listed in table 2. In order to test the hypothesis that the infrared source illuminates both knots A and E, we plot in figure 1 vectors perpendicular to the electric vector orientations derived above. If the knots scatter light from the embedded infrared source, these vectors should intersect at the source location. The wedge-shaped regions originating at each knot outlined in figure 1 are plotted so that the angle at the apex of the wedge reflects the uncertainty in the *e*-vector orientation. We regard the fact that these vectors cross

* Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

INFRARED MAGNITUDES FOR THE M78 HERBIG-HARO STAR

	2.2μ	3.5μ	4.8μ	8.4μ	10.2μ	11.1μ	12.6μ	20μ
Magnitude.......	10.6 ±0.2	8.6 ±0.2	5.8 ±0.2	4.3 ±0.1	3.9 ±0.6	3.6 ±0.1	3.7 ±0.1	0.5 ±0.2

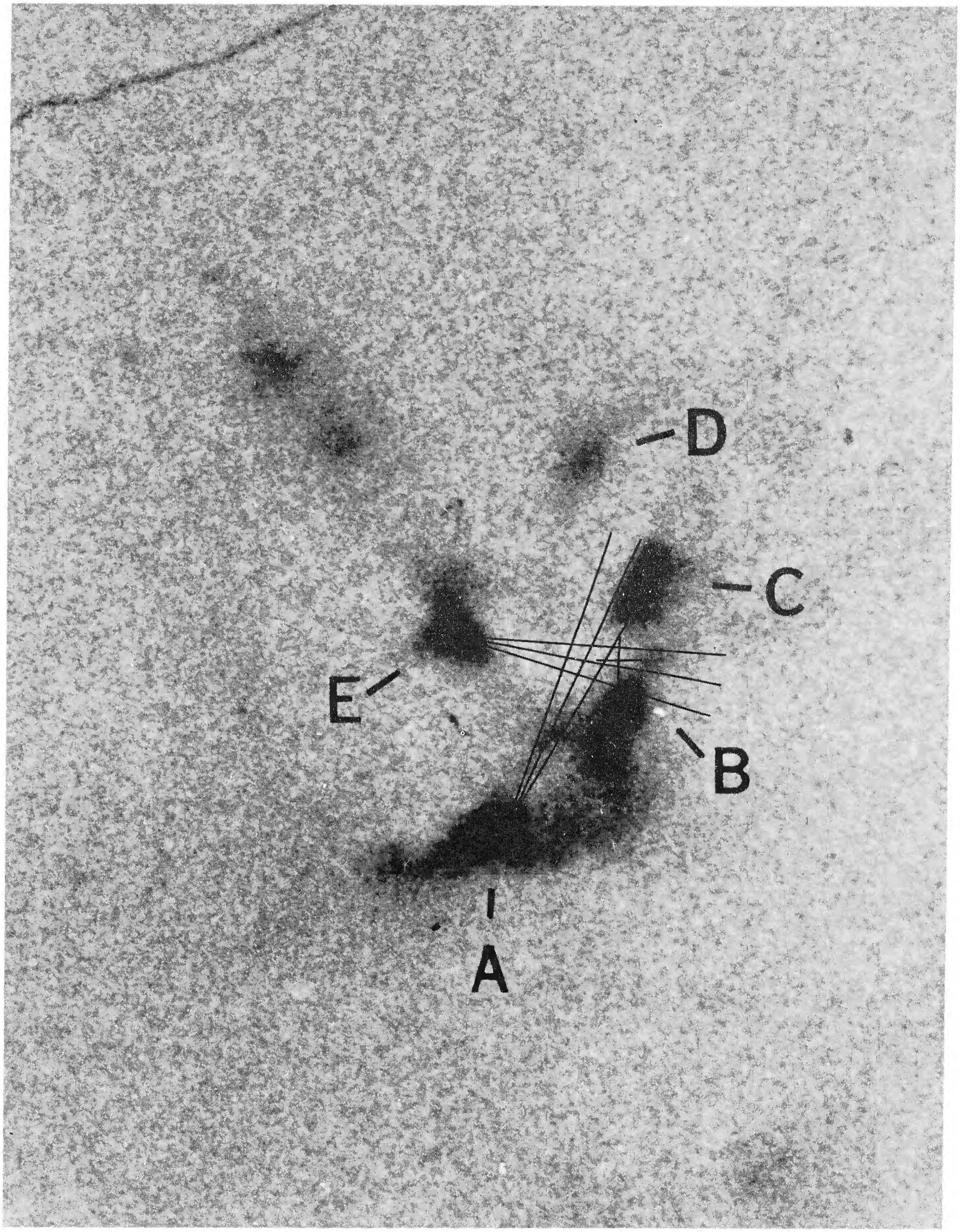

FIG. 1.—An enlargement of a red photograph of H-H 24 in M78 taken with the KPNO 4-m telescope with a water-hypersensitized 098-02 emulsion plus RG-610 filter. Superposed on the photograph are the perpendiculars to the electric-vector directions determined from the observations discussed in this paper; also given is the location of the infrared source discovered in mapping the region near H-H 24. An estimate of the uncertainty ($\pm 4''$) of the infrared position is given by the dimensions of the cross while the angles at the apex of each wedge correspond to the standard deviations in the position angles.

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TABLE 2

POLARIZATION MEASUREMENTS FOR SELECTED HERBIG-HARO OBJECTS

Object	Telescope (meters)	UT Date	p (%)	θ	Red Mag.
H-H 1......	4	1974 Feb. 17	2.9±1.0	98°±10	
H-H 1......	2.1	1974 Jan. 16	3.0±0.8		14.8
H-H 2......	2.1	1974 Jan. 16	4.4±1.4		15.2
H-H 24A...	2.1	1974 Jan. 15	26.4±3.0		16.9
H-H 24A...	4	1974 Feb. 17	21.9±3.8	66°± 5	
H-H 24C...	2.1	1974 Jan. 16	19.2±8.0		18.9
H-H 24E...	2.1	1974 Jan. 16	10.5±2.4		17.2
H-H 24E...	4	1974 Feb. 17	11.1±2.7	170°± 7	
H-H 30....	2.1	1974 Jan. 16	7.5±2.2		17.0

NOTE.—The aperture size used on the 4-m telescope corresponded to approximately 10″ on the sky while the aperture size used at the 2.1-m was approximately 13″. In both cases, the sensitivity of an S-20 photocathode and an RG-1 filter defined the bandpass.

at a point nearly coincident with the infrared position as strong confirmation of the reflection nebula hypothesis.

Observations of several additional H-H objects are listed in table 2. The numbering scheme proposed by Herbig (1974) is used in identifying these objects. In most cases, we have listed the magnitude of polarization for an object but not the orientation. An unfortunate hardware problem resulted in our losing position-angle information for observations carried out 1974 January 15 and 16 (UT). The agreement in magnitude of the observed polarizations with objects reobserved on the 4-m telescope 1974 February 17 is, however, quite satisfactory. A sufficient number of standard stars were observed 1974 January 15 and 16 so that crude (± 0.2 mag) red ($\lambda_{\text{eff}} \sim 6800$ Å) magnitudes could be derived for the H-H objects; these magnitudes are listed in table 2. Included within the red filter bandpass are the emission features at Hα, [N II], [S II], and [O I] characteristic of the H-H objects.

The measured polarizations, except for H-H 1 and H-H 2, are reminiscent of the high values which are characteristic of reflection nebulae. However, the small polarization values measured for H-H 1 and H-H 2 are somewhat surprising to us. Possible explanations are: (1) These objects, although spectroscopically and morphologically similar to H-H objects showing large polarization, are nevertheless members of a physically distinct class. We emphasize that no infrared source has been detected in either case to a 3 σ limit of $K = 11.0$ at a position coincident with the source. This observation would appear to rule out the possibility that H-H 1 and H-H 2 are H-H stars located outside their placental clouds. (2) The H-H stars are intrinsically polarized. If this were true, one can imagine situations in which the net polarization of the scattered light is reduced. In this regard, we note that many Orion-population variables are intrinsically polarized (Serkowski 1969; Breger 1974). Moreover, we observe HL Tau, a presumed evolutionary descendant of an H-H star, to have a polarization of 12.6 percent. (3) Multiple scattering is more important in the cases of H-H 1 and H-H 2 than in other objects of the class thus reducing the observed polarization. (4) Polarization arising in intervening cloud material reduces the polarization observed for the H-H objects.

The last two possibilities seem unlikely if the small reddening values obtained by Böhm, Perry, and Schwartz (1973) from analysis of the emission-line intensities in H-H 1 are characteristic. It is, however, conceivable that the interstellar extinction in the very dense regions surrounding the H-H objects is considerably less selective than in more typical regions of the interstellar medium. If this were true, Böhm *et al.* would have underestimated the total visual extinction from their derived selective extinction values. Some evidence in favor of this view has been reported by Carrasco, Strom, and Strom (1972).

III. CONCLUSIONS

Large linear polarizations have been observed for several H-H objects. In the case of H-H 24, the electric vector directions observed for two knots are oriented perpendicular to radius vectors drawn from the embedded H-H star thought to be the illuminating source for the optical knots. These observations lend considerable support to the view that optical H-H objects are patches of reflection nebulosity.

We wish to thank Mr. C. Mahaffey both for his assistance at the telescope and for his essential role in developing the computer software for operating the photometer, and Dr. G. L. Grasdalen for many illuminating discussions.

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