ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

MARCH 1992, PAGE 721

Astron. Astrophys. Suppl. Ser. **92**, 721-728 (1992)

Herbig-Haro objects in the star formation region NGC 7129

C. Eiroa, A.I. Gómez de Castro and L.F. Miranda

Observatorio Astronómico de Madrid - IGN, Alfonso XII, 3, 28014 Madrid, Spain

Received June 20, 1990; accepted June 29, 1991

Abstract. — We have obtained new deep I, H_α and [SII] CCD images of several fields in the star formation region NGC 7129. The data are presented in the form of grey-level pictures or isocontour plots. A large and complex nebulosity has been discovered in the field around the HH objects GGD 32 and HH 103. The nebulosity is formed by a diffuse component and several "streamers" or filament-like structures and many HH clumps, among which GGD 32 and HH 103 are just the two most outstanding ones. The large nebulosity coincides with the western blueshifted CO peak of the outflow associated with the southern far-infrared source in NGC 7129. In addition, our images reveal some new morphological details about the previously known objects GGD 33-35 and HH 105. A large variety of excitation conditions is suggested by the relative H_α [SII] ratios observed in the HH nebulosities. As a whole, the data show that the outflow activity in NGC 7129 is much more complicated than we expected.

Key words: Herbig-Haro Objects — Interstellar medium: reflection nebulae: NGC 7129.

1. Introduction.

It is widely accepted that Herbig-Haro (HH) objects are shock excited nebulosities formed in the interaction between the stellar winds of yound stars and the surrounding medium. In spite of the progress made in the past decade, the precise nature of this interaction is not yet well known and the theoretical scenarios cannot account for all the observed properties (see Böhm 1989, and Raga 1989, for recent reviews). In addition, the wide variety of morphologies and excitation conditions observed (e.g. Hartmann & Raymon 1984, Solf *et al.* 1986, Mundt *et al.* 1987, Bührke *et al.* 1988, Reipurth & Graham 1988, Reipurth 1989) reveals the need to increase the sample of well observed objects.

NGC 7129 is a reflection nebula located 1 Kpc away from the sun (Racine 1968). The nebula is illuminated by a group of young stars which could constitute a young cluster (Herbig 1960). NGC 7129 has been studied at radio, infrared, and optical wavelengths by several groups. Hartigan & Lada (1985) provided a detailed description of the region, and good schematics and photographs are presented in many works (see e.g. Güsten & Marcaide 1986). Two molecular outflows are observed in NGC 7129 (Edwards & Snell 1983, Liseau & Sandell 1983). Each outflow is associated with a far-infrared source (Bechis *et al.* 1978, Harvey *et al.* 1984), a NH_3 cloudlet (Güsten & Marcaide 1986), and H_2O masers (Cesarsky *et al.* 1978, Rodriguez *et al.* 1980, Sandell & Olofsson 1981). One of the far-IR sources is associated with the Herbig Ae/Be star LKH_α 234; Ray *et al.* (1990) discovered an optical jet emanating from this star. The second far-IR source, FIRS 2, is located $\approx 3'$ south of LKH_α 234 and has no optical counterpart.

5 HH objects are known to exist in NGC 7129: HH 103, HH 105, GGD 32, GGD 34, and GGD 35. The HH nature of these objects has been established by means of spectroscopic observations (Strom *et al.* 1974, Gyulbudaghian *et al.* 1978, Magakyan 1983, Cohen & Fuller 1985, Goodrich 1986) and CCD images using broad-band and emission-line filters (Hartigan & Lada 1985, Strom *et al.* 1986, Ray 1987, Gómez de Castro 1989). Shocked H_2 emission from several of these objects was detected by Wilking *et al.* (1990). A further object, GGD 33, has a controversial nature (e.g. Hartigan & Lada 1985, Goodrich 1986).

In this work we present new CCD images of NGC 7129. Our images are more sensitive and have a better spatial resolution than those published previously. The observational results reveal new morphological information on the known HH objects and also show the existence of many new HH clumps associated with this interesting star formation region.

Send offprint requests to: C. Eiroa.

2. Observations.

CCD images of the NGC 7129 objects were carried out at the prime focus of the 3.5 m telescope on Calar Alto Observatory during August 1985 and July 1988. In 1985 we used a GEC CCD, 17 μm pixel size, providing a field of view of 167″ × 118″ (580 × 410 pixels) and a scale in the focal plane of 0.″288/pixel. We used two broad-band filters, RG830 (I band, $\lambda \approx 0.9$ μm) and RG610 + Calflex X1 (R band, $\lambda \approx 0.7$ μm), and two narrow-band filters H_α ($\lambda = 6580$ Å, FWHM = 100 Å) and [SII] ($\lambda = 6740$ Å, FWHM = 70 Å). In 1988 a RCA CCD of pixel size 15 μm and 1024 × 640 pixels was used; this provides a scale in the focal plane of 0.″254/ pixel and a field of view of 260″ × 162″. This time only the RG830 and the narrow-band filters were used. This set of filters was chosen because they enable us to distinguish the HH emission from the reflection component in the nebulosities (Hartigan & Lada 1985, Strom *et al.* 1986, Reipurth & Graham 1988). The interference filters detect emission line regions, whereas the I filter mainly detects scattered light, since in this spectral range few and faint HH emission lines are present (e.g. Brugel *et al.* 1981) and, therefore, it is a good compromise as a continuum filter. In addition, the I filter can also detect faint highly reddened stars. A journal of the observations is presented in Table 1. The CCD images were reduced later following standard procedures.

TABLE 1. *Log of the observations.*

Object	Filter	Detector	Expos. time	Seeing	Date
GGD 32/	I	GEC	600	1".5	Aug. 1985
HH 103	R	GEC	900	2."5	" "
	Hα	GEC	1800	2."5	" "
	[SII]	GEC	1800	2."5	" "
	I	RCA	600	1."8	July 1988
	Hα	RCA	1200	1."8	" "
	[SII]	RCA	1200	1."8	" "
HH 105	I	RCA	900	1."8	" "
	Hα	RCA	1200	1."8	" "
	[SII]	RCA	1200	1."8	" "
GGD 33	I	GEC	900	1."5	Aug. 1985
	R	GEC	900	2."5	" "
	Hα	GEC	1800	2."0	" "
	[SII]	GEC	1800	2."0	" "
GGD 34	I	GEC	600	2."0	" "
	R	GEC	900	2."0	" "
	Hα	GEC	1800	2".5	" "
	[SII]	GEC	1800	2."0	" "
GGD 35	I	GEC	600	2."0	" "
	R	GEC	600	2."0	" "
	Hα	GEC	900	2."0	" "
	[SII]	GEC	900	2."0	" "

Figures 1 to 10 show the objects presented in this work as grey-scale pictures and isocontour plots. A wide variety of morphological shapes is found, and the presence of condensations in the HH nebulosities is common. Table 2 gives coordinates of some of these condensations as well as of several stars located in the different fields. Whenever possible, the positions of the stars are taken from Strom *et al.* (1986). We have used these coordinates as reference to estimate the positions of stars not given by those authors and of HH knots and condensations. I magnitudes of some of the stars and a rough quantitative estimate of the excitation of some HH condensations are given by Gómez de Castro (1989).

TABLE 2. *1950.0 Coordinates of stars and HH knots in NGC 7129.*

Field	Object	α (1950.0)			δ			Notes[a]
GGD 32/HH103								
	star 1	21h	41m	14.8s	65°	50'	8"	92
	star 2	21	41	16.3	65	49	46	
	star 3	21	41	12.9	65	49	45	
	HH 103A	21	41	15.0	65	50	1	
	HH 103B	21	41	15.9	65	49	54	
	HH 103C	21	41	15.1	65	49	40	
	star 4	21	41	20.8	65	50	47	
	star 5	21	41	20.0	65	50	53	
	star 6	21	41	16.6	65	50	50	
	GGD 32A	21	41	17.9	65	50	42	
	GGD 32B	21	41	18.5	65	50	43	
	GGD 32C	21	41	18.7	65	50	48	
	GGD 32/1	21	41	20.0	65	50	53	
	GGD 32/2A	21	41	20.5	65	50	41	
	GGD 32/2B	21	41	20.8	65	50	33	
	GGD 32/2C	21	41	19.9	65	50	36	
	star 7	21	41	21.1	65	51	12	103
	star 8	21	41	23.6	65	51	13	105
	GGD 32/3A	21	41	20.2	65	51	11	
	GGD 32/3B	21	41	20.5	65	51	6	
	GGD 32/4	21	41	14.1	65	50	32	
	star 9	21	41	23.5	65	50	43	104
	GGD 32/5	21	41	25.8	65	50	55	
	GGD 32/6	21	41	22.8	65	50	59	
	GGD 32/7	21	41	22.5	65	50	48	
	GGD 32/8	21	41	22.5	65	50	43	
HH 105	star 10	21	42	10.1	65	53	34	
	HH 105A	21	42	13.0	65	53	59	
	HH 105B	21	42	10.7	65	54	5	
GGD 33	GGD 33a	21	41	54.5	65	57	28	
	GGD 33b	21	41	55.8	65	57	22	
GGD 34	star 11	21	42	20.9	65	54	35	
	GGD 34A	21	42	20.8	65	54	50	
	GGD 34B	21	42	17.8	65	54	46	
	GGD 34C	21	42	15.2	65	54	43	
GGD 35	star 12	21	42	34.5	65	54	33	53
	star 13	21	42	36.1	65	54	33	56
	GGD 35A	21	42	33.8	65	54	34	
	GGD 35B	21	42	33.6	65	54	37	
	GGD 35C	21	42	35.1	65	54	42	

(a) Numbers in this column correspond to stars of Strom et al. (1986).

3. Results.

3.1. THE GGD 32/HH 103 FIELD.

Figure 1 presents a grey-scale mosaic built up with the I, [SII], and H_α images taken in 1988 of the GGD 32/HH 103 field. The contrast of the individual images is arbitrary and has been chosen to enhance different interesting features of the region. An extremely complex nebulosity is seen, GGD 32 and HH 103 being the most outstanding objects. The nebulosity, which is located over the secondary peak of the southern CO outflow in NGC 7129 (Edwards & Snell 1983), lies at the southwestern edge of the CO cavity detected by Bertout and collaborators (Bertout 1987) and is more prominent at [SII]. At this wavelength its appearance is that of a faint nebulosity extending from HH 103 in the west towards the east in the direction of the NGC 7129 reflection nebula. Many nebular clumps are seen embedded in the main body of the nebulosity, i.e. the brightest part of the region with a size of $\approx 1' \times 2'$ (0.3pc $\times$ 0.6pc); in addition, several elongated "streamers" or filament-like structures are clearly distinguished. For the sake of their identification, a schematic is presented in Figure 1. One of the filaments, F1, is oriented east-west and apparently joins the body of the nebulosity to the star AGK3 + 65°1138 at the east. Interesting is also the arc extending between HH 103 and the place where GGD 32 is located. At H_α the region presents again a complex and clumpy morphology and practically the same [SII] morphological features are seen. At the *I* band, the large scale nebulosity disappears to a large extent, and only the region close to GGD 32 and the filament F 1 remains prominent.

A comparison of the images suggests that the nebulosity is a large-scale shock excited emission combined with a reflection component. There are several arguments supporting this view: 1) HH objects are known to present strong H_α and [SII] emission whereas they are invisible or very faint in the I spectral range, 2) There are no known OB stars or high luminosity infrared objects associated with or close to NGC 7129 which could produce an HII region by photoionization. 3) The relative H_α [SII] ratio changes significantly among the different knots and filaments; even in some cases, e.g. the arc between GGD 32 and HH 103, GGD 32/2, GGD 32/5, the [SII] emission is stronger than H_α, a fact which can hardly be explained by differential extinction if the lines were formed in a HII region. Thus, we identify the prominent structures in both emission lines as material excited by shocks; in this context, the I counterparts are most probably scattered light usually observed associated with HH objects (e.g. HH 100, Hartigan & Lada 1985).

Figures 2-5 show detailed isocontour plots of the HH objects in the field, including HH 103 and GGD 32. The new discovered HH objects are labelled GGD 32/1, GGD 32/2, and so on. Condensations inside the individual objects are labelled with capital letters. The different H_α [SII] ratios might indicate changes in the excitation conditions. Furthermore, spectroscopic observations indicate that HH 103 and GGD 32 are low excitation objects (Strom *et al.* 1974, Margakyan 1983, Cohen & Fuller 1985); so, the relative H_α [SII] ratio of the new HH objects compared to that of HH 103 and GGD 32 also suggests a low excitation. Since detailed spectroscopic and/or infrared observations are lacking we can not make any definitive statements about the HH object exciting stars, although in a few cases morphological candidates could be suggested, e.g. star 7 as exciting source candidate of GGD 32/3. Special mention deserves the filament which we have called F2, Figures 1 and 4. Morphologically, F2 seems to depart from star 8 -number 105 of Strom *et al.* (1986)- towards the north and appears to be a H_α-jet of dimensions $\approx 33'' \times 7''$ (0.16pc $\times$ 0.03pc) with several embedded knots.

3.2. HH 105, GGD 33, GGD 34 AND GGD 35.

These objects are located towards the northeast of LKH$_\alpha$ 234 and projected against the redshifted CO lobe associated with this star. A kinematical association, however, can probably be excluded, at least in the case of GGD 35 since it has a blueshifted spectrum (Margakyan 1983, Hartigan & Lada 1985).

Figures 6 to 10 show detailed isocontour plots of all four objects and a grey-level picture of HH 105, which reveal some new morphological aspects and features. Morphologically, the objects are very different, although they all appear to have a somewhat curved or bent shape. Different condensations inside the HH objects can be distinguished, and at least in GGD 34C the intensity peak changes its position with the wavelength. As in the GGD 32/HH 103 field, there are changes in the relative H_α [SII] ratios, which suggest different excitation conditions in the HH objects and condensations. Scattered light is noticeable in HH 105, GGD 33 and GGD 34, whereas it is insignificant in GGD 35.

Very little or nothing is known about the exciting stars of these objects. Ray *et al.* (1990) provided proper motions of the condensations GGD 34A and GGD 35C, which in principle restrict the location of their exciting sources. In addition, the T-Tauri star V 350 Cep has been suggested as the illuminating source of the enigmatic GGD 33 (Cohen & Schwartz 1983, Goodrich 1986). No exciting source candidate has been suggested for HH 105. Morphologically, star 10 might be proposed as candidate for exciting this HH object. The star is located at the southern end of a bar of reflection nebulosity and also faces a weak, wiggly spike-like emission, which arises from the region between the condensations HH 105A and HH 105B (Figs. 6 and 7). With respect to GGD 33, in our images the condensation GGD 33a appears to be a point-like source from which spike-like features are arising in all filters while GGD 33b is extended ($\approx 10''$ in the $E-W$ direction), Figure 8. Both condensations are joined by a tenuous arm of nebulosity. The spike in [SII] has an apparent size of $\approx 2.2''$ and is bent and directed towards GGD 33b. It would be worthwhile to prove that a stellar source is indeed embedded in GGD 33a, since in this case it would be unnecessary to invoke V 350 Cep as the illuminating source of GGD 33.

4. Conclusions.

In this work we have presented new, very sensitive CCD images of NGC 7129. The main finding of our observations is the discovery of a large nebulosity located towards the southwest of the NGC 7129 reflection nebula, which seems to be shock excited and projected against blueshifted CO emission. The nebulosity is rather complex with many embedded filaments and HH objects. In addition, our images also reveal some new morphological aspects of the previously known HH objects in the region. Summarizing, the new results support the assessment by Hartigan & Lada (1985) about the complex outflow activity of this interesting star formation region.

Acknowledgements.

The Calar Alto Observatory is operated jointly by the Max-Planck-Institut für Astronomie (Heidelberg) and the Spanish Comisión Nacional de Astronomía. We are very grateful to the Calar Alto staff for their help during the observations. We also thank Dr. K. Birkle for the use of the Calar Alto's computers, and ESA for the use of the VILSPA computer facilities. This work has been supported in part by Spanish Grant DGICYT PB87-0167.

References

Bechis K.P., Harvey P.M., Murray F.C., Hoffmann W.F. 1978, ApJ 226, 439
Bertout C. 1987, in IAU Symposium N. 122, "Circumstellar Matter" I. Appenzeller and C. Jordan Eds. (Reidel) p. 23
Böhm K.-H. 1989, in "Structure and Dynamics of the Interstellar Medium" IAU Coll 120, G. Tenorio-Tagle, M. Moles and J. Melnick Eds. (Springer-Verlag) p. 282
Brugel E.W., Böhm K.H., Mannery E. 1981, ApJS 47, 117
Bührke T., Mundt R., Ray T.P. 1988, A&A 200, 99
Cesarsky C.J., Cesarsky D.A., Churchwell E., Lequeux J. 1978, A&A 68, 33
Cohen M., Fuller G.A. 1985, ApJ 296, 620
Cohen M., Schwartz R.D. 1983, ApJ 265, 877
Edwards S., Snell R.L. 1983, ApJ 270, 605
Gómez de Casto A.I. 1989, Tesis Doctoral, Univ. Complutense de Madrid
Goodrich R.W. 1986, AJ 92, 885
Güsten R., Marcaide J.M. 1986, A&A 164, 342
Gyulbudaghian A.L., Glushkov Yu.I., Denisyuk E.K. 1978, ApJ 224, L137
Hartigan P., Lada C.J. 1985, ApJS 59, 383
Hartmann L., Raymond J.C. 1984, ApJ 276, 560
Harvey P.M., Wilking B.A., Joy M. 1984, ApJ 278, 156
Herbig G.H. 1960, ApJS 4, 337
Liseau R., Sandell G. 1983, Rev. Mex. Astr. Astrofis. 7, 199
Magakyan T. Yu., SvA 9, 83
Mundt R., Brugel E.W., Bührke T. 1987, ApJ 319, 275
Racine R. 1968, AJ 73, 233
Raga A.C. 1989, in "Low Mass Star Formation and Pre-Main Sequence Objects", ESO Workshop, B. Reipurth Ed. p. 281
Ray T.P 1987, A&A 171, 145
Ray T.P., Poetzel R., Solf J., Mundt R. 1990, ApJ 357, L45
Reipurth R. 1989, in "Low Mass Star Formation and Pre-Main Sequence Objects", ESO Workshop, B. Reipurth Ed. p. 247
Reipurth B., Graham J.A. 1988, A&A 202, 219
Rodriguez L.F., Moran J.M., Ho P.T.P., Gottlied E.W. 1980, ApJ 235, 845
Sandell G., Olofsson H. 1981, A&A 99, 80
Solf J., Böhm K.-H., Raga A.C. 1986, ApJ 305, 795
Strom K.M., Strom S.E., Wolff S.C., Morgan J., Wenz M. 1986, ApJS 62, 39
Strom S.E., Grasdalen G.L., Strom K.M. 1974, ApJ 191, 111
Wilking B.A., Schwartz R.D., Mundy L.G., Schultz A.S.B. 1990, AJ 99, 344

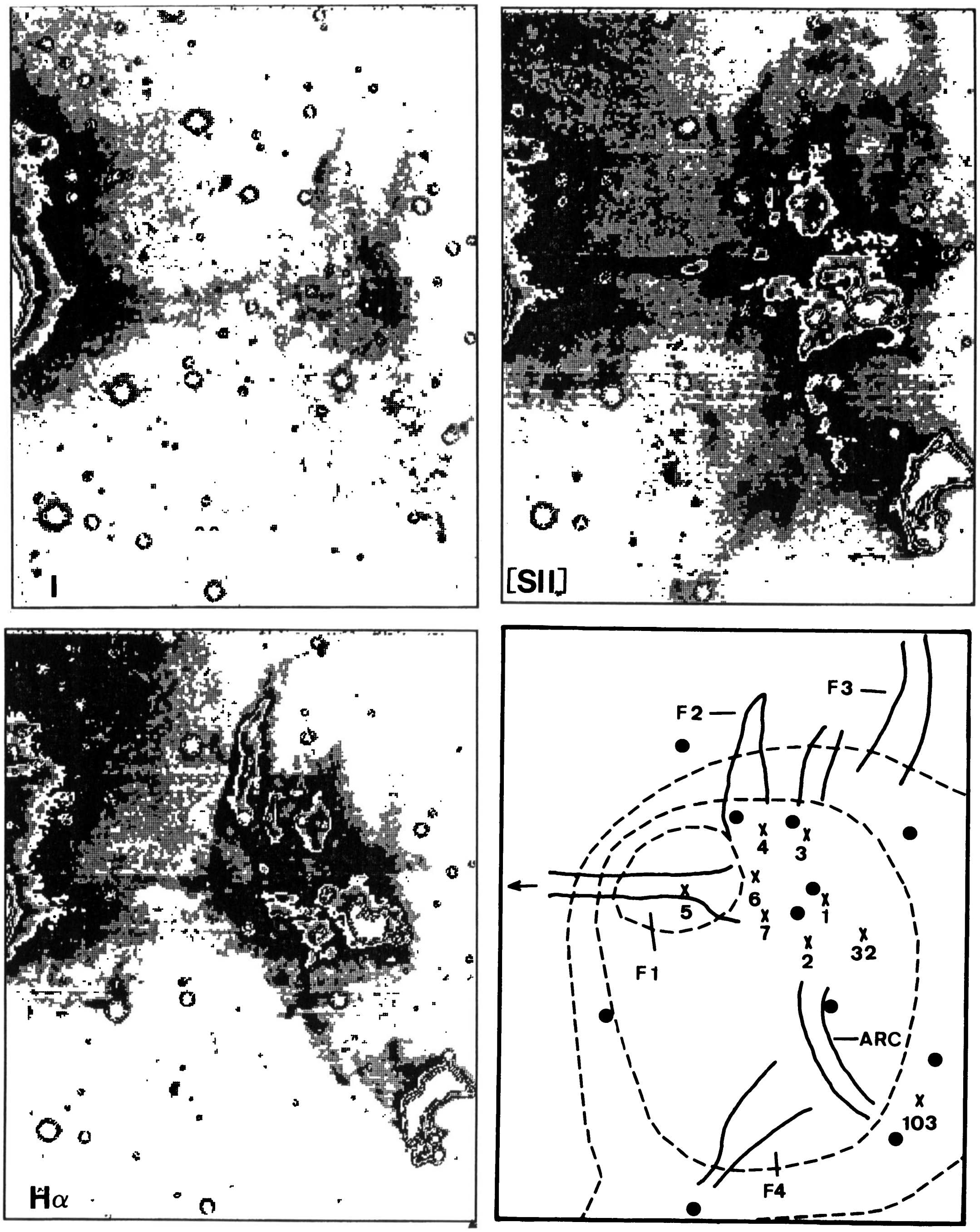

FIGURE 1. The GGD 32/HH 103 field. Filters are indicated in the individual images. The contrast of the images is arbitrary. The size of the field shown is 130″ × 160″. The I filter detects scattered light, whereas the line filters mainly detect emission due to shocks. A shematic showing some of the individual HH clumps and nebulous structures is included. F1,..., F4 correspond to filament-like structures. 32 and 103 correspond to GGD 32 and HH 103 respectively, whereas 1,..., 7 correspond to the HH clumps GGD 32/1,..., GGD 32/7. Dots represent some stars of the field and the dashed line represents the blueshifted CO emission detected by Edwards & Snell (1983). North is at the top and east to the left (this convention is used throughout the paper).

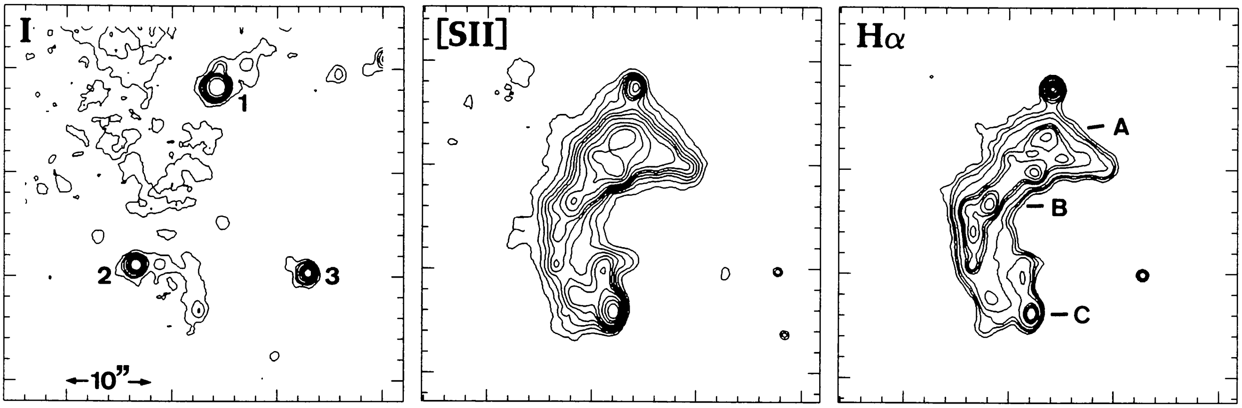

FIGURE 2. Isocontours plots of HH 103. The contours are arbitrary and have been chosen to enhance the condensations inside HH 103. The scale is shown in the I frame. Stars are indicated in the I frame, whereas HH condensations are pointed out in the H_α frame (this convention is used throughout the paper unless specified otherwise).

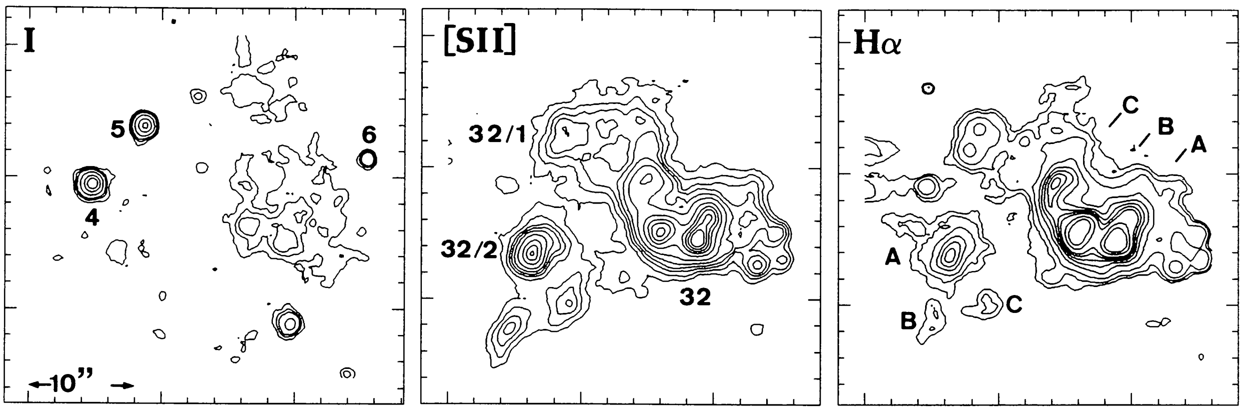

FIGURE 3. Isocontour plots of GGD 32, GGD 32/1, and GGD 32/2. The individual HH objects are indicated in the [SII] frame, whereas the condensations inside the HH objects are shown in the H_α frame. Rest as in Figure 2.

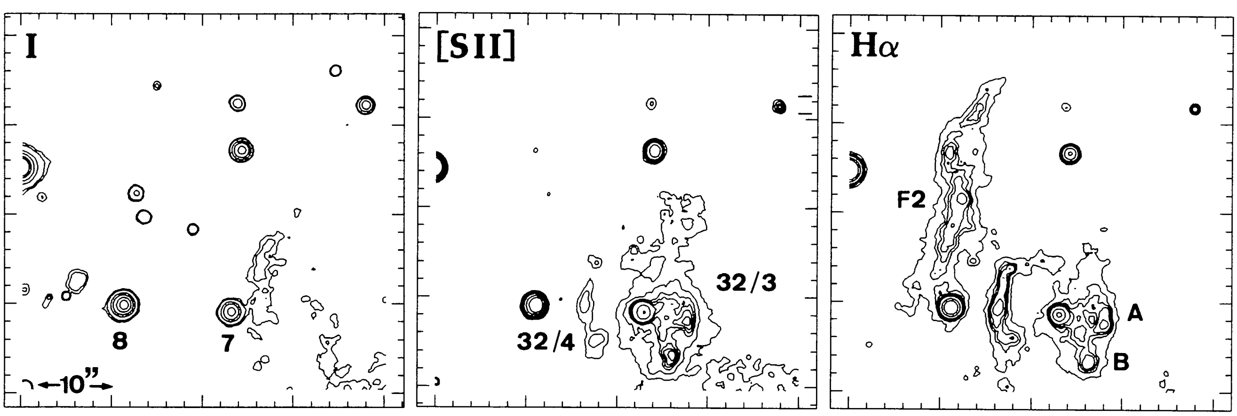

FIGURE 4. Isocontour plots of GGD 32/3, GGD 32/4 and of the filament F2 (shown in the H_α frame). Rest as in Figures 2 and 3.

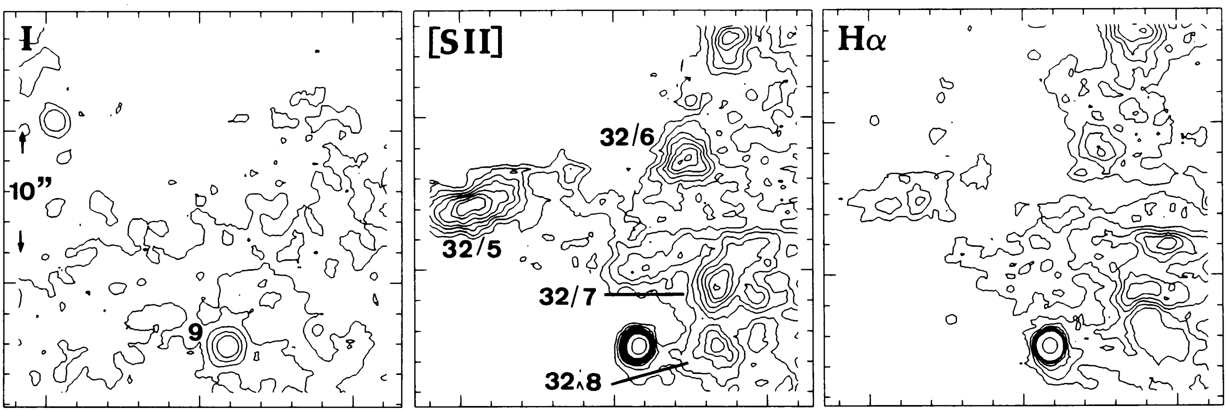

FIGURE 5. Isocontour plots of GGD 32/5, GGD 32/6, GGD 32/7, and GGD 32/8. Rest as in Figures 2 and 3.

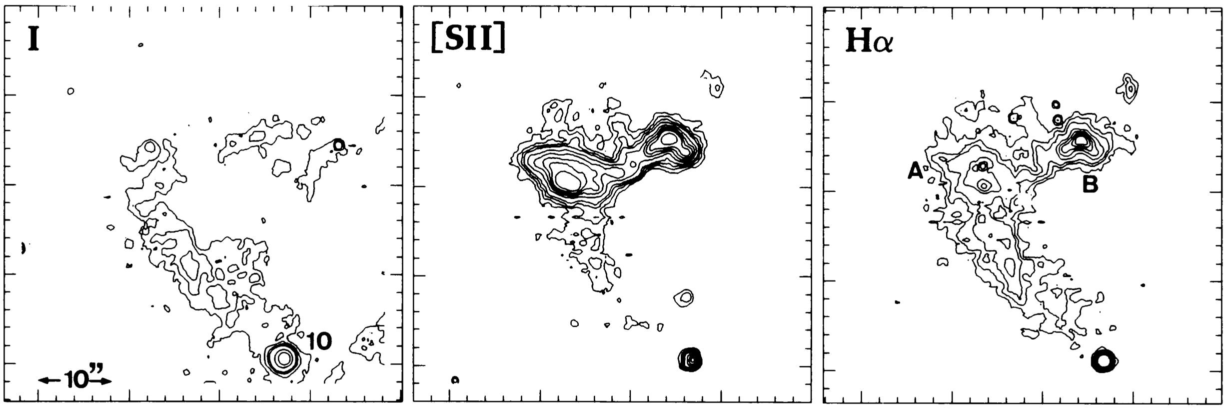

FIGURE 6. Isocontour plots of HH 105. Rest as in Figure 2.

FIGURE 7. Grey-scale picture with arbitrary contrast of HH 105. Note the spike-like protusion emerging from the center of the bar with the HH condensations and facing star 10. The field size is 75″ × 65″.

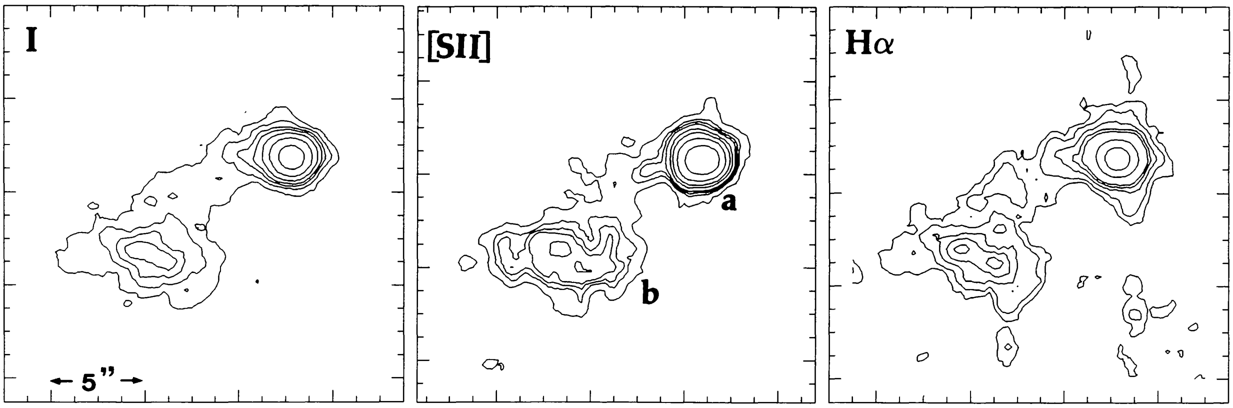

FIGURE 8. Isocontour plots of GGD 33. The individual condensations are indicated in the [SII] frame. Note the bent [SII] protusion departing from GGD 33a.

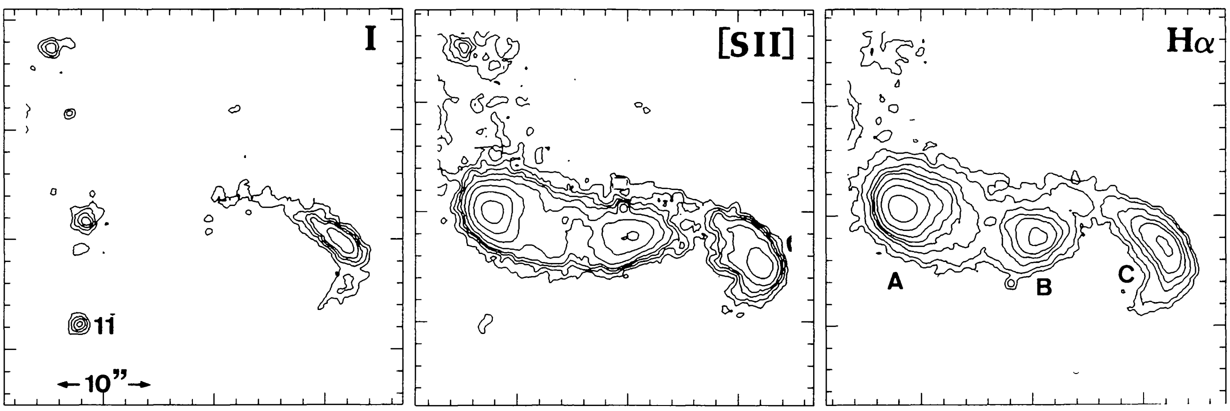

FIGURE 9. Isocontour plots of GGD 34. The peak of GGD 34C changes its position with the wavelength. Rest as in Figure 2.

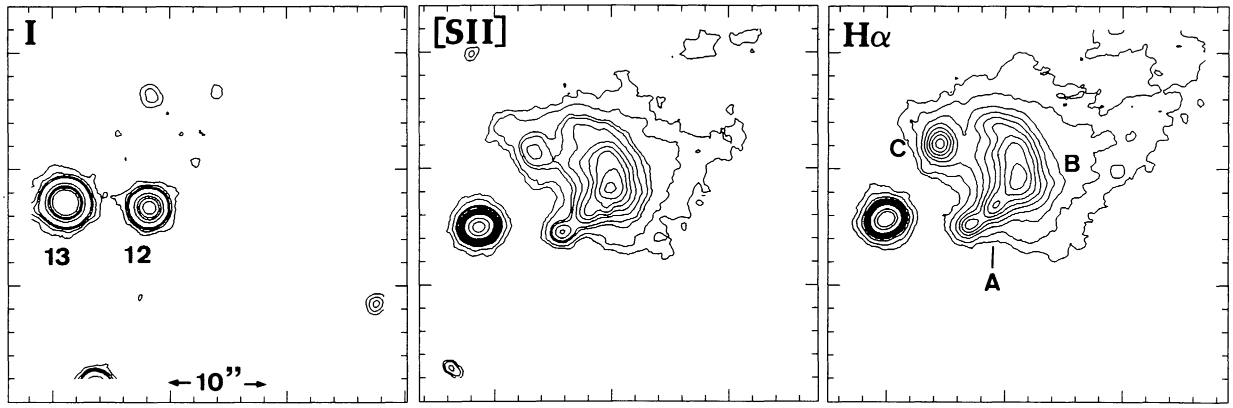

FIGURE 10. Isocontour plots of GGD 35. Rest as in Figure 2.