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THE BROAD BALMER PROFILES FROM η CARINAE SCATTERED BY DUST OVER THE CAR II REGION

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RESUMEN

Se muestra que los perfiles anchos de Balmer ($\sim$ 650 km s^{-1} FWHM) presentes en la región Car II se originan en la emisión de Balmer de η Car, la cual es dispersada por polvo en la región, como fué sugerido por López y Meaburn (1984*b*). Los perfiles de Hα provenientes de η Car que son dispersados por el polvo interestelar han sido detectados hasta 6 minutos de arco alejados de η Car. Si η Car y la filamentosa región Car II están efectivamente localizados a la misma distancia de 2.7 kpc que generalmente se supone para el complejo de regiones H II y cúmulos abiertos de Carina, entonces las componentes están siendo detectadas tan lejos como 5 pc de η Car. Se describe un método directo para fijar el límite inferior de la distancia de η Car. Este se basa en la variabilidad del perfil Hα de η Car y su reflexión retardada sobre la región Car II. Si la distancia de 2.7 kpc es adecuada entonces la reflexión de la última variación conocida del perfil Hα de η Car debe ser vista sobre Car II para finales de 1986.

ABSTRACT

The broad Balmer profiles ($\sim$ 650 km s^{-1} FWHM) present over the face of the Car II region are shown to have their origin in the dust scattered Balmer emission from η Car, as suggested by López and Meaburn (1984*b*). The scattered Hα profiles from η Car have been traced as far as 6 arcmin away from η Car. If η Car and the filamentary Car II region are indeed located at the same distance as the ordinarily assumed one of 2.7 kpc for the H II region/open clusters complex of Carina then the scattered components are being detectable as far as $\sim$ 5 pc away from η Car. A direct method to set a lower limit for the distance to η Car is described on the basis of the variability of the Hα profile of η Car and its retarded reflection on the Car II region. If a distance of 2.7 kpc is adequate, then the retarded reflection of the last known variation of the Hα profile from η Car should be seen on Car II by late 1986.

Key words: NEBULAE — SCATTERING

I. INTRODUCTION

High velocity components present only in the Balmer (Hα and Hβ) lines in the Car II region were reported by Elliot (1979). Given the available information on the region at the time he suggested a supernova origin for these profiles. López and Meaburn (1984*a*, hereafter Paper I) mapped the region at intermediate and low dispersion to investigate the spatial extent of these profiles and any observational evidence for their suggested origin. They concluded that a supernova event was most unlikely to have occurred in the region. However, they did confirm the presence of the high velocity components (up to $\sim$ 1000 km s^{-1}) in the Hα and Hβ lines, and showed that these profiles were present over practically the whole face of the filamentary Car II region. Several alternative possibilities that could account for the observed Balmer profiles, based mainly on collimated flows driven by stellar winds from the very massive stars that surround the area, were discussed in Paper I. A dust scattering mechanism for the origin of the broad profiles was not considered in Paper I since the structure of the Balmer profiles do vary from one position to another (see Figures 4*a* and 4*b* in Paper I and Figure 1 in Elliot 1979).

Almost simultaneously with publication of Paper I, Ruiz, Melnick, and Ortiz (1984) presented new evidence showing that the Hα profile from η Car had varied on a time scale of $\sim$ 1 year. López and Meaburn (1984*b*, hereafter Paper II) compared the spectral characteristics of the Hα and Hβ emission from η Car with those observed over the face of Car II and concluded that given the great similarity among the profiles and the now proven short term variability of the Balmer emission from η Car, it was plausible to suggest that the "high velocity" components in the Hα and Hβ profiles from Car II represent dust scattered profiles from η Car.

In this paper this suggestion is further considered and analysed in the light of new Hα high dispersion, long-slit observations. These data have for the first time allowed the resolution of key spectral features that show that the dust scattering suggestion is correct. The implications of this result on the derivation of a reliable lower limit for the distance to η Car and an insight into the geometry of the region are also discussed.

II. OBSERVATIONS

The observations were made in April 1985 with an echelle spectrograph (Meaburn *et al.* 1984) mounted at the f/7.9 Ritchey-Chrétien focus of the Anglo Australian 3.9-m telescope. In the instrumental configuration used, instead of a cross disperser, a 90 A bandwidth interference filter centered on Hα was used to isolate one echelle order. The detector was the Image Photon Counting System (IPCS) operated on its mode of 1020 channels (= 30 μm each) in the direction of dispersion and 120 x-sections or windows (each = 1.43 arcsec long) along the slit. Two consecutive exposures (1573 and 2000 secs., respectively) were obtained, which covered a line oriented approximately SE-NW (P.A. 132°) crossing from near η Car to the far end of the filamentary ring. The positions of the slits, labeled I and J, are indicated on Figure 1. This figure is sketch of the region contained in Figure 5 (Plate) which is a reproduction from the blue ESO sky survey. In Paper I images of the same region, but in the light of the Hα + [N II] and [S II] ions, were presented; their comparison is worthwhile.

The slit width was set to 70 μm (= 0.5 arcsec) and its length to 171 arcsec. The spectral resolution achieved with this instrumental configuration is 6 km s^{-1} at Hα. The spectra were divided by a Quartz exposure to compensate for instrumental response and calibrated in wavelength with a Cu-Ar lamp. The accuracy of the wavelength calibration is better than ± 2 km s^{-1}.

A third exposure on η Car, oriented along the same line as in the previous two cases and with the same slit width, was also obtained. These data require a comprehensive description and analysis on their own and their discussion is deferred to López and Meaburn (1986, in preparation). In the present paper only the central, brightest profile along the slit lenght from this exposure is presented in Figure 2 to permit a direct comparison of the shape of the profile from η Car with those from the Car II region.

III. RESULTS

Figures 6 and 7 (Plates) are grey scale representations of the bidimensional data array of the long-slit spectra, corresponding to slit positions I and J, respectively, indicated in Figure 1. These were photographed directly off an "ARGS" image processing monitor unit. The images are in a logarithmic scale in order to show the full intensity range in them with a minimum loss of detail from the faint regions. In both cases the top of the image corresponds to the SW extreme of the slit (x-section 120) and the bottom to the NE end (x-section 1).

Most conspicuous features in these images are the well known splitting ($\sim$ 40 km s^{-1}) of the nebular lines in the region (c.f. Meaburn, López, and Keir 1984 and references therein) and the faint extended ($\sim$ 1000 km s^{-1}) components on both sides of Hα. Also apparent in both images, and of particular relevance, is the absorption component present on the blue side of the main Hα component. Both, the faint extended "wings" of Hα, and the absorption component have been detected along the full length of both frames. Selected regions where the extended components of Hα are more conspicuous have been labeled and their positions have been correspondingly indicated on Figure 1 and Figures 6 and 7 (Plates).

The bright line parallel to the dispersion axis in the upper half of Figure 6 (Plate) corresponds to the continuum from a star marked as "star" in Figure 1. Note also in Figure 6 the dark band crossing nearly at the center of the frame, separating the two brightest extended areas. This is a real feature. It corresponds to the dark bay that defines the famous "keyhole" shape in this region. This result confirms that this dark cloud is actually in front of the H II region, though most probably closely associated to it.

Figure 2 shows the Hα profile from η Car and a profile from position I3. The latter consists of the co-addition of three x-sections and it is presented at an amplified scale in Figure 2 to facilitate comparison with the profile of η Car which is $\sim$ 100 times stronger in this case. Figure 3 displays a mosaic of profiles (again, cuts across the slit length, 5 x-sections co-added) from the positions indicated in Figure 1 and Figures 6 and 7 (Plates).

IV. DISCUSSION

In order to investigate the origin of the "high velocity components" of the Balmer lines in Car II, it is of interest to discuss the principal characteristics of the Hα profile from η Car and their relation to the Hα profiles observed in Car II.

a) *The Shape and Characteristics of the Profiles*

The temporal variability and unique structure in the Balmer profiles of η Car is appreciated by comparing the high resolution Hα profiles of η Car published by Ruiz *et al.* (1984), Melnick, Ruiz, and Maza (1982), Viotti (1985) and Figure 2 in this paper. The Hβ and Hα pro-

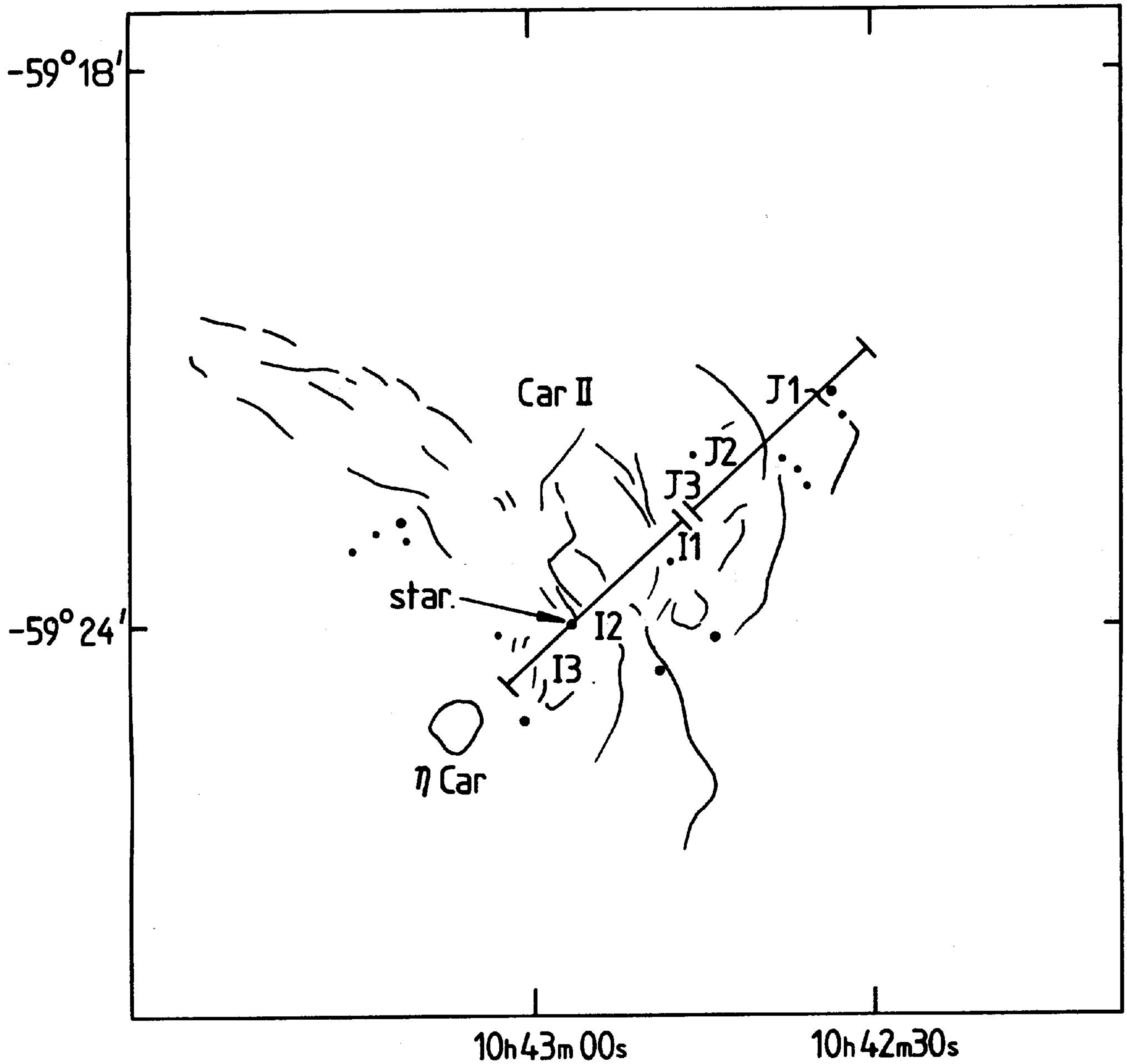

Fig. 1. A sketch of the Car II region and η Car from the blue print shown in Figure 5 (Plate). The position of the slits are included here and regions where the extended components of Hα are most conspicuous are indicated with the labels I3 to J1, according to their position along the corresponding slit. Coordinates are 1950 epoch.

files in Aller and Dunham (1966) are also of interest, as is the Hα profile of Zannela, Wolf, and Stahl (1984).

The high spectral resolution achieved in the present observations allowed for the first time to resolve the fine structure within the "high velocity" components of the Hα profiles from the Car II region. It is apparent from Figure 2 that the overall shape and velocity range of the Hα profile from the I3 region is strikingly similar to the shape of the Hα profile from η Car the main difference being the depth of the absorption component between the profiles of Figure 2.

Maxima labeled as A1 ($\lambda \sim 6561.5$ A) and A2 ($\lambda \sim 6559$ A) by Melnick *et al.* (1982) are indicated in Figure 2 on the profile of η Car. Feature A2 can also be identified in the profile from the I3 region, whereas A1 coincides in this case with the deep blue absorption component. A third maximum on the blue side of the Hα profile of η Car is identified here ($\lambda \sim 6556.5$ A) and has been simply labeled as "A".

A third characteristic of the Hα profile of η Car is its very asymmetric non-gaussian red side of the profile (component E in Melnick *et al.* 1982) with a maximum or shoulder at ~ 6566.6 A. Components A, A2 and E are detectable in most of the profiles in Figure 3.

A fourth characteristic of the Hα profile of η Car is its very extended red wing, extending in fact in Figure 2

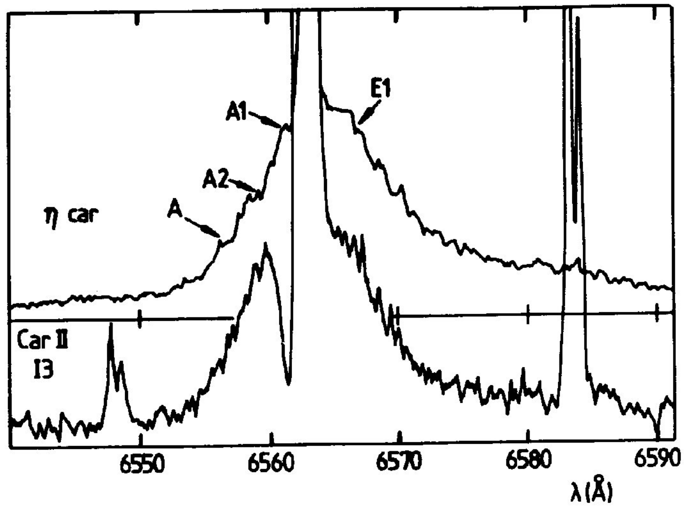

Fig. 2. The amplified Hα profile from the region I3 in Car II and from η Car are shown here together to facilitate comparison. The former profile consists of the co-addition of 3 x-sections along the slit. The similarity of the profiles is remarkable. Maxima labeled in the 1980 Hα profile of η Car by Melnick *et al.* (1982) as A1, A2 and E are indicated here. The feature labeled A is identified in this paper and found to be present, together with A2 and E, all over the face of Car II (see Figure 3). The profile of η Car is ∿ 100 times more intense than the three co-added profiles from region I3.

well beyond the covered wavelength range (note the levels of the continuum on both sides of the profile with respect to the corresponding base lines). This is a real feature, not due to badly corrected instrumental response. This very extended red wing is also clearly present in the coudé spectra of Melnick *et al.* (1982). It is most remarkable that this faint and very extended red wing can also be detected in most of the profiles from the Car II region, up to the most distant slit positions from η Car (see for example the profiles from positions J3 and J2 in Figure 3).

Finally, a fifth unique characteristic of the Hα profile of η Car is its blue shifted absorption component. This component has been presumably formed in the complex expanding circumstellar environment of η Car and is particularly well shown in the profile of March 1982 of Ruiz *et al.* (1984). This blue absorption component is now shown to be present over all the filamentary Car II region (see Figure 3 and Figures 6 and 7, Plates).

The close correspondence of the bright blue nebular patches and filaments with the presence of the extended components of Hα can be readily appreciated by comparing Figure 1 with Figures 5, 6 and 7 (Plates). In these regions the spectral energy distribution of the nebular emission may be expected to be affected by starlight scattered by interstellar dust. In the case of the cloud marked as I3 and I2 in Figure 1 (see also Figure 6) independent proof exists showing that the light of η Car is being scattered within it by dust. This cloud is labeled I1 and I2 in Paper I, where Fe II emission lines from η Car and a steep rise towards the blue in the continuum emission are reported, (see also Walborn and Liller 1977).

These arguments together with the data presented here indicate beyond any reasonable doubt that the filamentary Car II region is reflecting the broad Balmer profiles from η Car. In spite of the intrinsic nebular emission of the region, the scattering effect has become particularly apparent in the Hα emission profile due to the outstanding strength and characteristic shape of the emission from η Car.

The dust scattering mechanism in addition to the temporal variations in the Hα profile of η Car resolve in a natural way the problem of the origin of the very high velocity components present only in the Balmer lines in the Car II region.

b) *The Distance to η Car*

It is pointed out in the previous section that the absorption component in the Hα profile of η Car is only marginally present in April 1985 (Figure 2), whereas this feature is conspicuous in all the Hα profiles from Car II (see Figures 2 and 3). The observations of the Hα profile of η Car indicate that this absorption component has remained practically absent in the previous two or three years. It has diminished in strength from a well defined absorption in early 1982 to a negligible component by March 1983 (Ruiz *et al.* 1984), and it has apparently remained in this state through 1984 (Viotti 1985) and up to at least the last known record to the authors of April 1985, shown in Figure 2. This latest profiles now becomes reminiscent of the 1981 profile presented by Melnick *et al.* (1982). However, it is not known whether or not the distinct changes in the Balmer profiles of η Car are periodic.

Nevertheless, these recent variations in the Balmer emission from η Car and its reflection over the face of the Car II region, represent now a good opportunity to measure directly the distance to η Car and the scattering regions. A situation arises where the Balmer emission profile is having to travel a considerable distance, from ∿ 1 pc for regions I3, to 5 pcs for region J1; adopting a distance to Carina of 2.7 kpc (Turner *et al.* 1980) before being scattered and detected elsewhere. In this conditions the Hα profile observed in, for example, the I3 region of Car II, presented in Figure 2 may be assumed to be the one corresponding to the profile emitted by η Car a few years ago. It is interesting to compare the March 1982 profile of Ruiz *et al.* 1984, with the April 1985 profile of region I3 in Figure 2. Their similarity is absolutely remarkable. Cloud I3, I2 apparently the nearest to η Car, seem then not to have responded yet to the variation in the Hα profile from η Car that occurred between 1982-1983, when the Hα profile lost its conspicuous absorption component. This suggests that this latest known variation of the Hα profile of η Car, is taking at least more than three years to encounter cloud

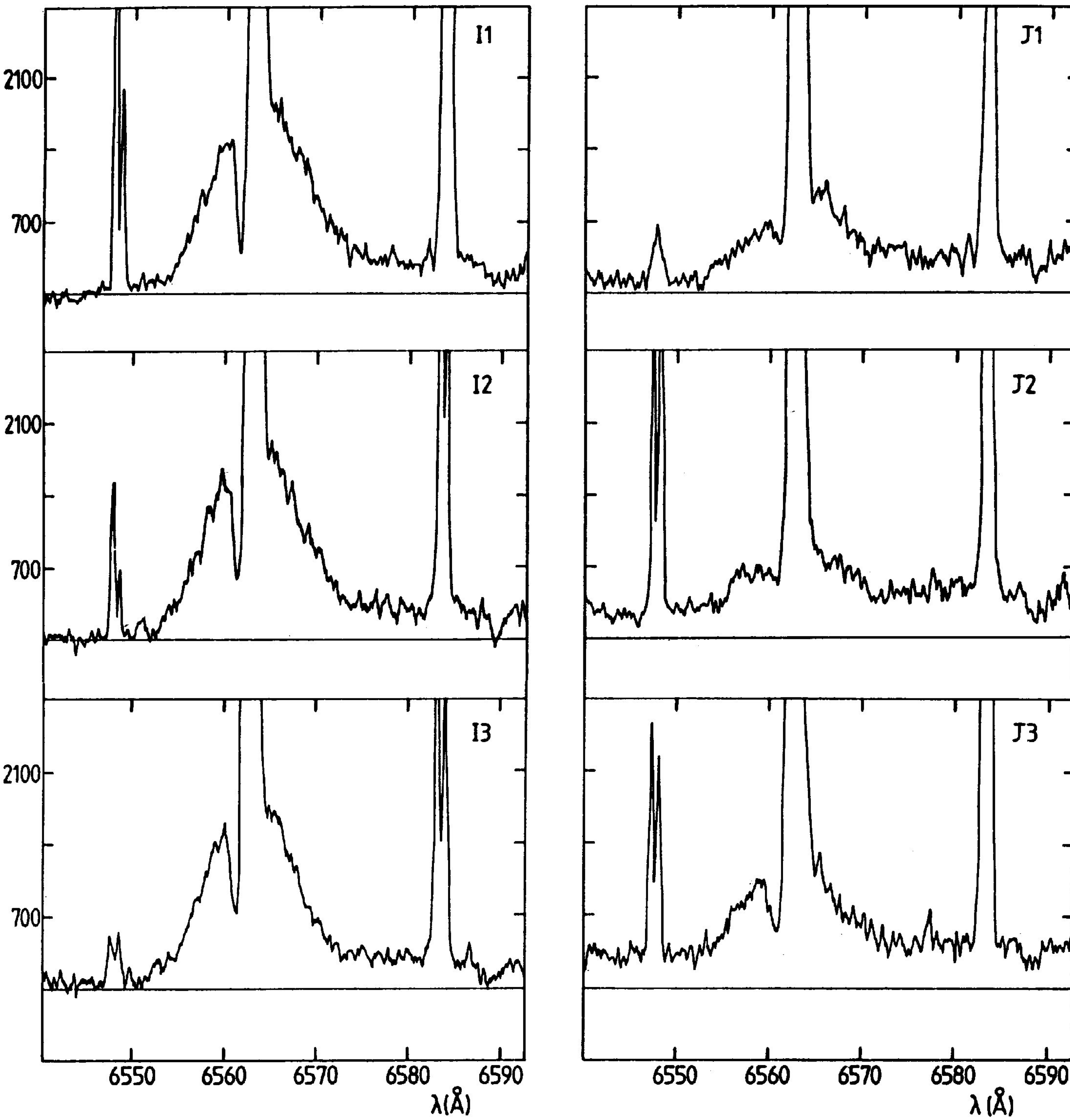

Fig. 3. A mosaic of profiles from regions I3 to J1, indicated in Figure 1 and Figures 6 and 7 (Plates). The profiles consist of 5 x-sections co-added. The persistency of the unique characteristics of the Hα profile from η Car in these profiles that cross all over the filamentary nebulosity, confirms that the Hα emission from Car II is contaminated by scattered Hα radiation from η Car.

I3,I2, which sets a lower limit for the distance of η Car to cloud I3,I2 of ∿ 1 parsec and a corresponding lower limit of ∿ 2 kpc for the Sun – η Car distance.

If a distance Sun-Carina of 2.7 kpc is adopted, then the distance to cloud I3 is ∿ 1.25 pc. Therefore, one should expect to note the corresponding variation on the scattered profile from cloud I3 in 4.08 years. This means that a Hα profile with a very diminished, or absent, absorption component should be observed in cloud I3 between March 1986 and March 1987. Observations monitoring Hα in cloud I3, I2 in the coming months are therefore highly desirable.

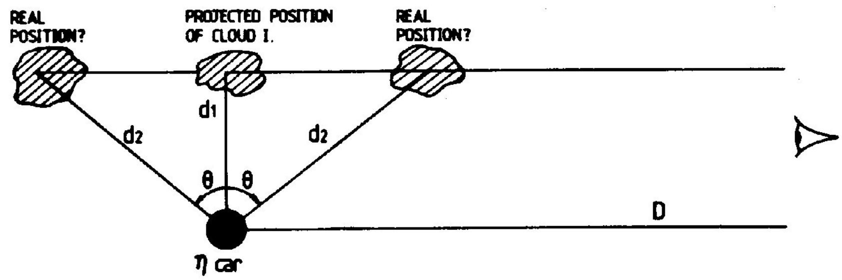

Fig. 4. A simple visualization of the likely geometry of cloud I (regions I3 and I2) with respect to η Car and the line of sight. Cloud I is most probably located either behind or in front of the plane of the sky suggested by d_1. The true distance d_2 from η Car to cloud I is then increased by a factor $d_2 = d_1/\cos\theta$, and the time delay of information traveling from η Car would be given by $\Delta t = d_2/c\,(1-\sin\theta)$. Therefore, the derivation of the distance to η Car from the reflection of its varying Hα profile on cloud I is a true lower limit.

Naturally, the distance that results from measuring the time taken by the varying Hα profile of η Car to be reflected by a cloud in Car II, say regions I3 and I2, hereafter called cloud I, is obtained under the assumption that the projected position of cloud I makes a 90° angle with the line of sight to η Car. If this is not the case, as it is most probable, then the real distance of cloud I to η Car is affected by a $1/\cos\theta$ factor, where θ is the angle subtended between the line that joins η Car to the projected position of cloud I (θ = 0) and the line joining η Car with the real position of cloud I (see Figure 4). Similarly, the corresponding time delay Δt would be given by

$$\Delta t = d_2/c\,(1-\sin\theta) \ ,$$

where c is the velocity of light and d_2 and θ are as in Figure 4. This implies that the distance to η Car obtained by this method represents a true lower limit.

In fact, given the apparent very high efficiency with which Car II is scattering light from η Car and that the lowest efficiency in the scattering mechanism is achieved at a 90° angle, it is reasonable to expect that the Car II region, is located on a plane either behind or in front of η Car, and that a high efficiency multiple scattering mechanism, aided by the apparent high volume density of scatterers in the region, is in operation. The large dimensions of the region together with the brightness of the scattered emission make of Car II an ideal target for a detailed spectropolarimetric and photometric investigation that should surely yield important information on the geometry and physical properties of the scatterers in this outstanding region of massive star formation.

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