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Narrow-Band Photographic Observations of the HII Region S296 in Canis Major

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Abstract

The monochromatic images of the HII region S296 taken with the UK Schmidt telescope at the emission lines Hα+[NII], [SII], [OIII], and [OII] are presented, together with some composite images. Based on these photographic images, the overall ionization structure of the HII region is briefly considered.

1. Introduction

The giant HII region S296 and its two companions S292 and S297 make a well defined arc structure of ionized gas in Canis Major. The center of arc nearly coincides with the center of CMa R1 association which is an active site of recent star formation.

Concerning the process of star formation in this area, Claria (1974a, b) first suggested a sequential formation started from the open cluster NGC2353 and propagated to CMa OB1 association in a time span of the order of 10^7 years. Herbst and Assousa (1978) and Assousa and Herbst (1982) claimed the possibility of supernova-induced star formation of the CMa R1 association which occured about 10^6 years ago. Their arguments are mainly based on the evidence of expanding shell which was inferred from HI and [NII] observations. Blitz (1978) dennied the existence of expanding HI shell and insteadly suggested the star formation induced by stellar winds from O stars. Machnik et al. (1980) supported the possibility of supernova explosion as the source of energetic processes in this region, though they failed to detect the pattern of simple expanding motion in their CO observations.

The radio continuum observations by Nakano et al. (1984) showed that S296 is in a state of ionization balance between ionizing energy from exciting stars and the amount of ionized gas in the HII region. This infers that no additional source is needed for the ionizing energy by some kinetic processes such as by expanding shell. In this case, if O or B type stars are responsible for the ionization of S296, then the ionization structure may have some relationship with the spectral types and/or the distribution of exciting stars. The narrow-band images in the photographic survey by Parker et al. (1979) using interference filters are suggestive of showing such ionization structure inside S296.

For the purpose of investigating the ionization and density structure of S296 more closely, we have made the narrow-band photographic observations using the UK Schmidt telescope. In this paper we present the monochromatic images thus obtained, together with some composite images made for emphasizing the distribution of different physical state inside the HII region. Based on these images qualitative discussions will be given on the overall ionization structure of S296.

2. Observations and Results

The photographic observations of CMa HII ragions have been made with the UK Schmidt telescope at the Siding-Spring Observatory, Australia, by the request of the authors. The interference filters given in Table 1 were used for obtaining the narrow-band images. The plate list and the journal of observations are given in Table 2. The field center is approximately at R.A.$=07^h05^m$ and Decl.$= -11^\circ02'$ for all plates.

In Figures 1 through 4 the narrow-band images in the respective emission-lines are shown. In order to enhance the ionizaion structure, some composite photographs were also prepared by the superposition of a positive and a negative image for suitable combination of emission lines. Figures 5 through 7 illustrate the samples of such composite photos, where the designation of, say, [OII]–[OIII] indicates that the [OII]

Table 1. Interference Filters

Filter designation	Central wavelength	FWHM	Size	Emission lines
AAO672	672nm	10nm	130×130mm	[SII] λ6716, 6730
AAO656	656	10	250×250	Hα λ6563 and [NII] λ6548, 6584
AAO500	500	8	130×130	[OIII] λ4958, 5006
AAO372	372	6	130×130	[OII] λ3726, 3728

Table 2. Plate list and the journal of observations

Plate number	Date of observation	Plate+ filter	Exposure time	Emission lines
8986	1984−01−10/11	IIIaF(h)*+AAO656	90min.	Hα+[NII]
9863	1985−01−09/10	IIIaJ(h) +AAO372	210	[OII]
9865	1985−01−10/11	IIIaJ(h) +AAO500	270	[OIII]
9868	1985−01−11/12	IIIaJ(h) +AAO672	210	[SII]

*The letter h in the bracket denotes the hypersensitization of the plates.

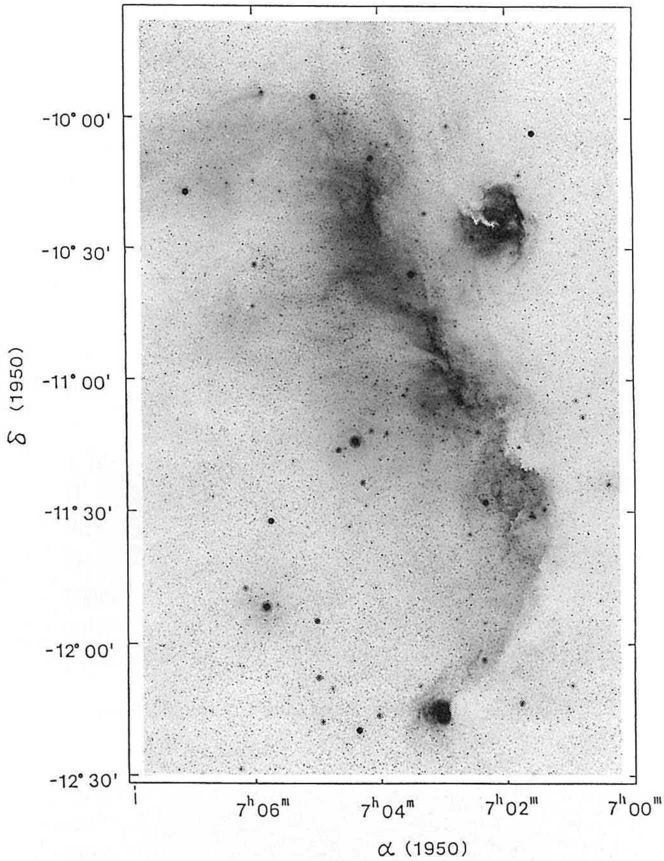

Figure 1 The narrow-band image in the Hα + [NII] band.

image is positive, i.e., brighter part is darker, while the [OIII] image is negative, i.e., bright part is white. The relative strength of dark and white is suitably adjusted by comparing the photographic densities of the respective images, since we have no calibration marks on the plates.

3. Ionization and Density Structure

The distribution of ionized gas in HII regions in the CMa complex can be seen on the radio continuum map at 10 GHz observed by Nakano et al. (1984) which is reproduced in Figure 8, along with the distribution of exciting stars and R1-association members. The candidates of T Tauri stars detected by Wiramihardja et al. (1986) are also superimposed on the map.

From the inspection of Figure 1 through 8 we can roughly divide the S296-S292 region into the following areas from the view point of ionization and density structure of ionized gas.

H: Region of high ionization state, characterized by the relatively strong [OIII] and weak [SII] emissions,

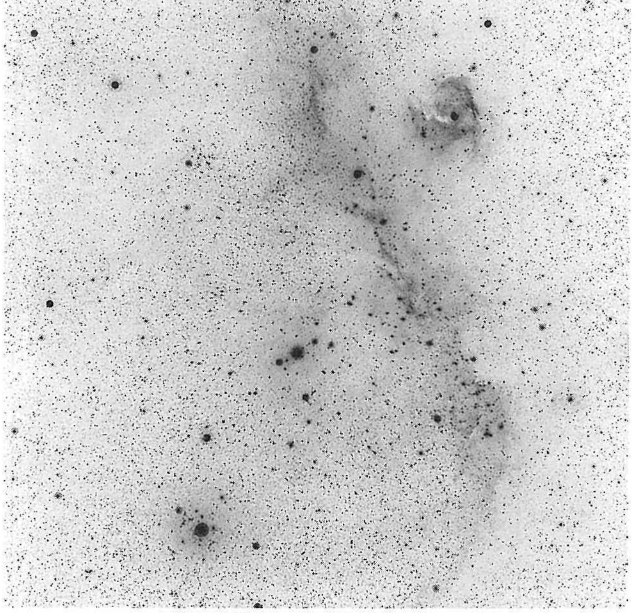

Figure 2 The narrow-band image in the [SII] band.

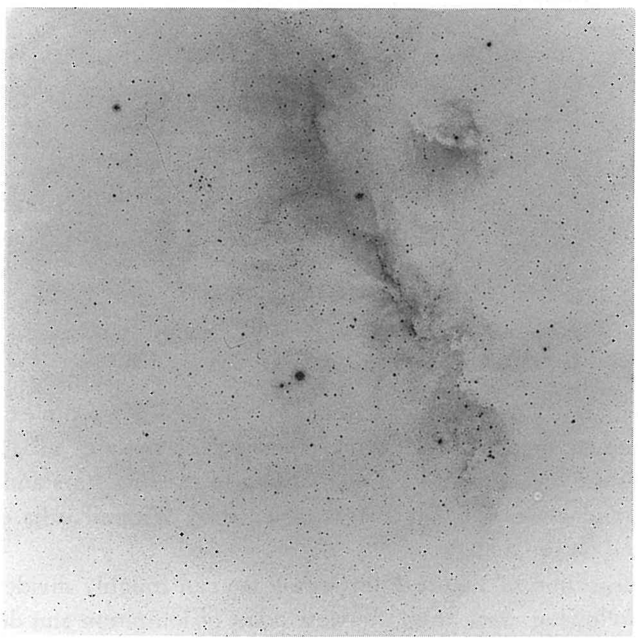

Figure 3 The narrow-band image in the [OII] band.

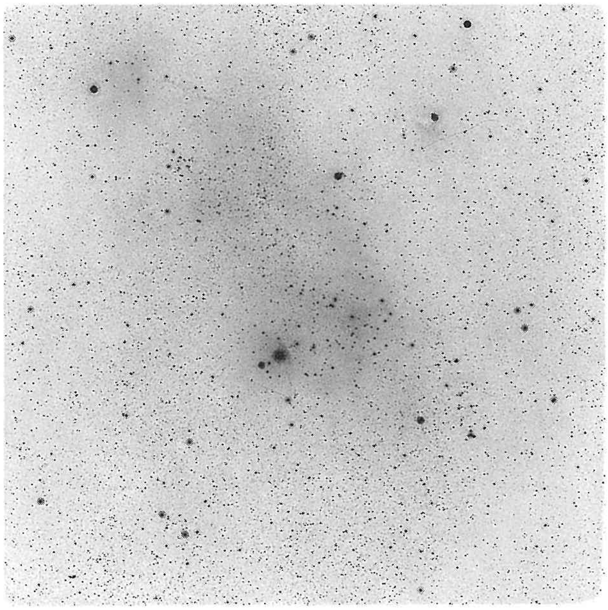

Figure 4 The narrow-band image in the [OIII] band.

Figure 5 The composite photograph (Hα + [NII])−[OIII]. The brighter part in the former and latter band is dark and white on the print, respectively.

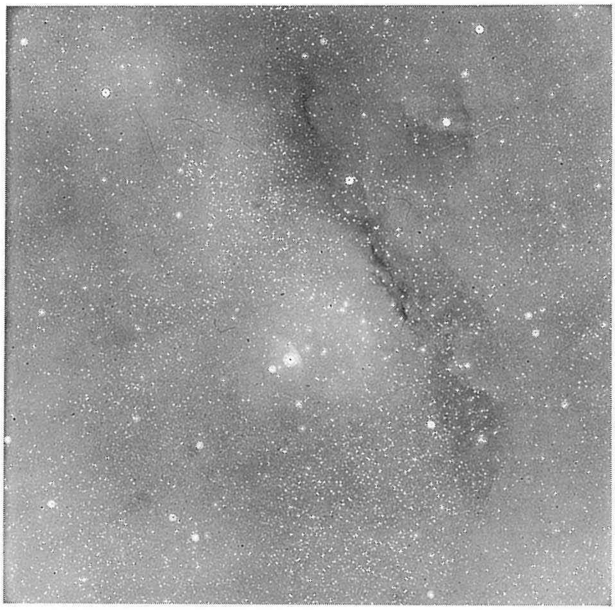

Figure 6 The composite photograph [OII]−[OIII]. Other explanation is the same as in Figure 5.

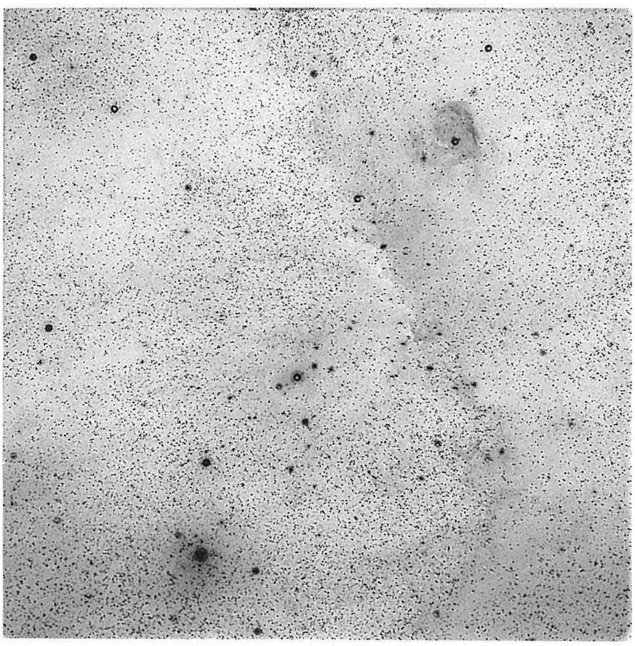

Figure 7 The composite photograph [SII]−[OII]. Other explanation is the same as in Figure 5.

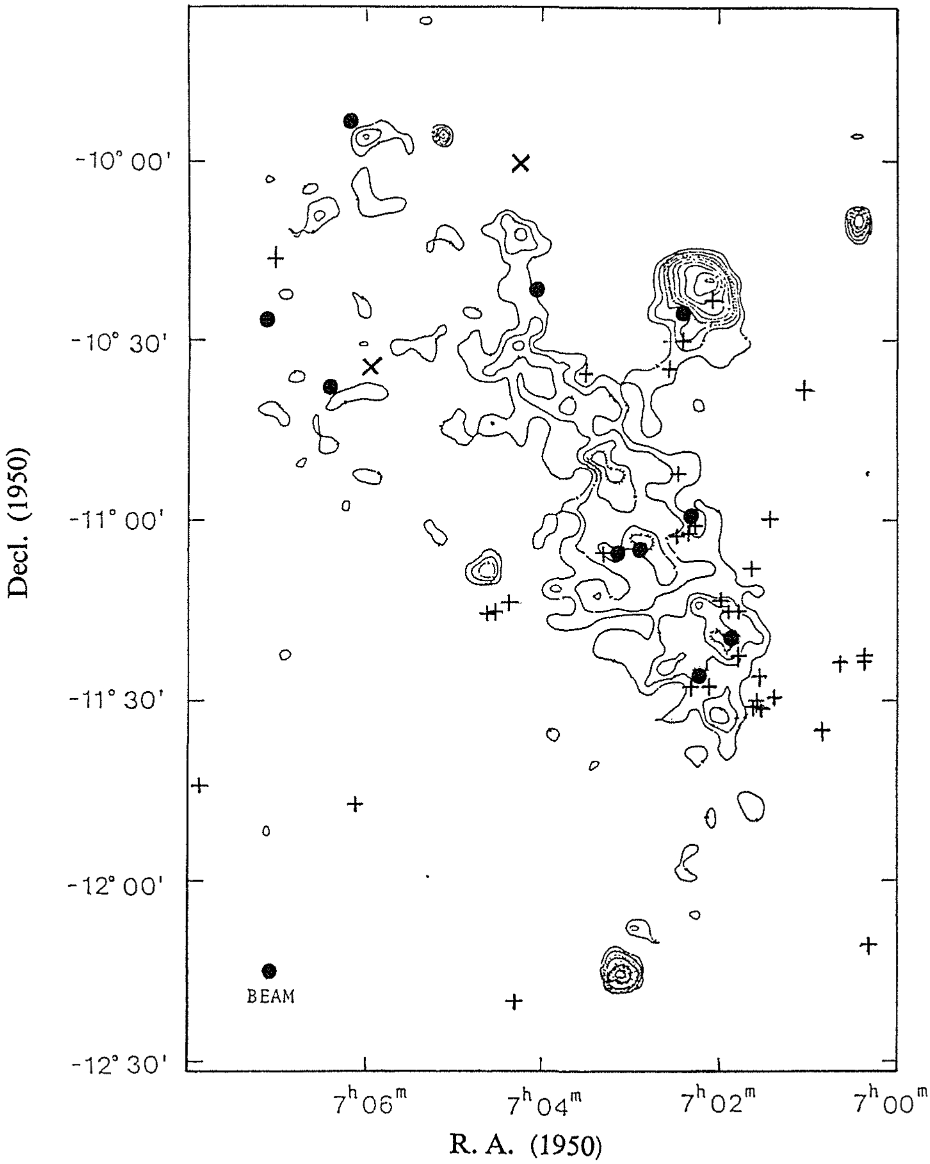

Figure 8 Radio continuum map at 10 GHz taken from Nakano et al. (1984). Plus signs indicate the CMa R1 member stars, filled circles the T Tauri stars, cross denotes the open cluster.

L: Region of low ionization state, characterized by the relatively strong [SII] and weak [OIII] emissions,

D: Zone of radio continuum depression, running nearly from east to west, around $\delta = -11°15'$ as seen in Figure 8,

R: Ridge of the ionized gas in the main body of S296, determined on the radio continuum map in Figure 8.

Figure 9 illustrates the schematic map of this division, together with some other features such as *F*: Region of filamentary structure, and *M*: Bright and dark rim system along the western edge of S296.

(1) Region of high (*H*) and low (*L*) ionization state.

The regions *H* and *L* in Figure 9 are characterized by the relatively strong emission of [OIII] and [SII] lines, respectively. The [OIII] image in Figure 4 reveals amorphous distribution of doubly ionized oxygen without showing any filamentary structure along the arc of S296, and it extends mostly north of the central depression zone *D* and east of ridge *R*. In contrast, south of zone *D* and east of ridge *R* shows the enhancement of [SII] as seen on the composite image in Figure 5.

The separation of *H* and *L* regions in S296 can be explained by the different spectral types of exciting stars responsible to the respective regions. According to Hawley's (1978) observations, the nebular lines of [OIII] λλ 4958 and 5007 are fairly

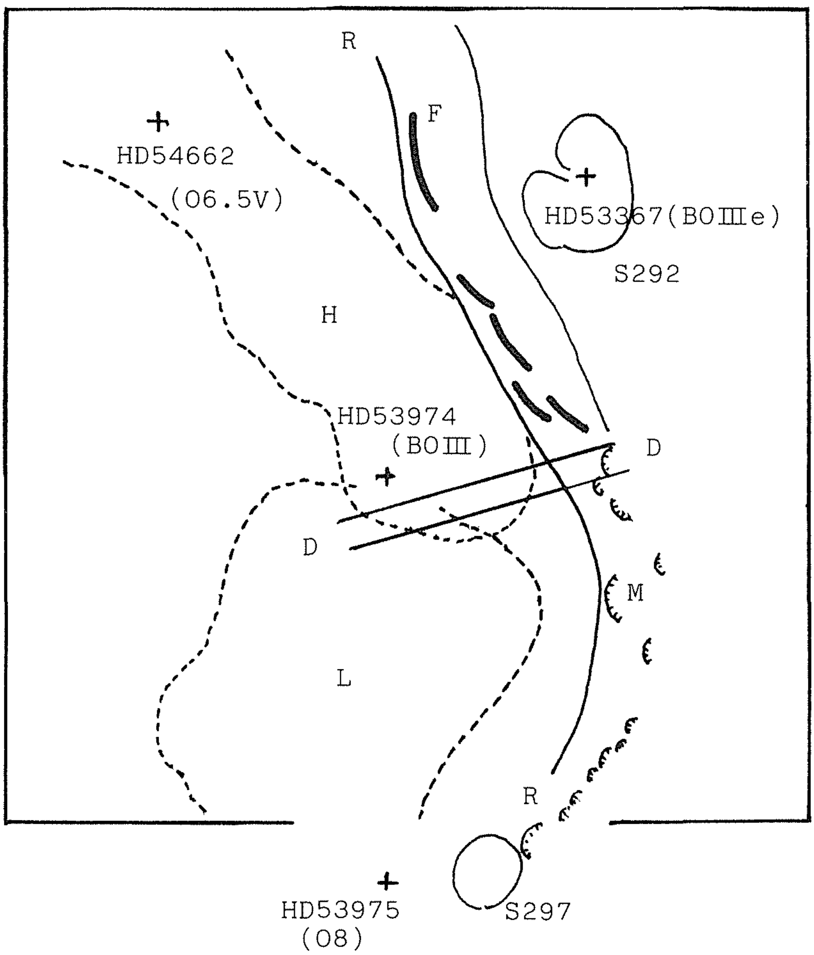

Figure 9 Schematic map of the ionization and density structure of S296 and S292. Explanation of symbols is given in the text.

strong relative to Hβ in the HII regions excited by O7 or earlier type stars, whereas they are very weak or absent in the HII region excited by O8 or later type stars. This is just corresponding to the case of S296, where the exciting stars are, as indicated in Figure 9, principally two O stars of HD54662 (O6.5) for northern part and HD53975 (O8) for southern part. This is qualitatively in good agreement with the separation of *H* and *L* regions. In this way we can regard zone *D* as the border of two different ionization regions.

If we accept this explanation, we can estimate the average electron densities in two regions of *H* and *L* as follows. The distance between O stars and zone *D* is about 30 pc for HD54662 and 26 pc for HD53975 for the adopted distance of 1.15 kpc of CMa R1 from the sun. If we regard these distances as the Strömgren radii of the respective O stars with the excitation parameters of u(O6.5)=60 pc · cm^{-2} and u(O8)=45 pc · cm^{-2} (Georgelin et al. 1975), then the average electron densities are given as

$$\langle n_e \rangle = \begin{cases} 2.8\ \mathrm{cm}^{-3} \text{ for } H \text{ region,} \\ 2.2\ \mathrm{cm}^{-3} \text{ for } L \text{ region.} \end{cases}$$

These values are an order of magnitude lower than the electron density of the central nebulosity of $n_e = 27\ \mathrm{cm}^{-3}$ deduced from the radio continuum observation (Nakano et al. 1984). However, the radio data give the value in the dense part around the ridge *R* of S296, while the above values of $\langle n_e \rangle$ are those averaged for the respective ionized regions as the whole, so that these two set of values may not be inconsistent as the typical value of electron density in this area.

(2) Central depression zone *D*.

The radio continuum map in Figure 8 shows that zone *D* is a zone of low column density of ionized gas. As seen above, this zone makes a border of the two ionization regions *H* and *L*. In addition, zone *D* seems to have much deeper implication, directly related to the star formation processes in this region. The reasons are as follows.

a) There exist marked star-formation regions north and south of this zone, characterized by the clustering of R1 association members and T Tauri stars as seen in Figure 8. In particular, young stars in north side seem to be aligned in parallel to zone *D*.

b) CO molecular clouds associated with CMa complex reveal different behaviors in northern and southern sides of this zone as shown by Machnik et al. (1980) and by Nakano et al. (1986, private communication), i.e., the CO cloud in northern side makes a part of the giant CO cloud, extending to north and west, which is designated as S296-cloud by Blitz (1978) and has the radial velocity of about 16–19 km/s. In contrast CO molecules in south side are concentrated into several cloudlets with different radial velocities. According to Nakano et al. (private communication), there are at least three CO clouds in the south vicinity of zone D, having the radial velocities of 10, 13, and 15 km/s.

c) Finally there appears a different feature along the central ridge *R* for the north and south of zone *D* as schematically shown in Figure 9. That is, a filamentary system is developed in its north while rim structure is prevalent in the south. If we notice that these features mostly appear in the west slope of the central ridge *R*, we are inclined to guess that these features are formed as a result of interaction between ionized gas of S296 and dark cloud, caused by some westward motion of S296. This is one of the arguments supporting the supernova origin of this star-forming complex. On the other hand one should also notice the difference between north and south of zone *D* mentioned above. The form of interaction is evidently different, suggesting some different mechanisms of formation more or less related to the origin of other structural differences in both sides of zone *D*.

4. Summary

The narrow-band images of the main part of S296 at the four emission-line regions are presented together with some composite photos prepared to emphasize the ionization structure of ionized cloud.

It is found that the ionization stage in S296 is higher in its northern half than in southern half on the east slope of the main body of S296. The location of the two exciting O stars may be responsible on this ionization structure. In addition, the central depression zone found in radio continuum map is shown to have a deep implication on the star formation processes in this area.

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