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The Star Forming Regions of Orion

Tomokazu Kogure

Bisei Astronomical Observatory, 1723-70, Ohkura, Bisei-cho, Okayama 714-14, Japan

Abstract. The distribution of emission line stars in Orion is presented, based on our recent surveys and other previous ones. Particular attention is given for the central 10×10 square degrees to compare some properties of emission line stars and OB association stars. As a result, a possibility of bimodal star formation is suggested in this region.

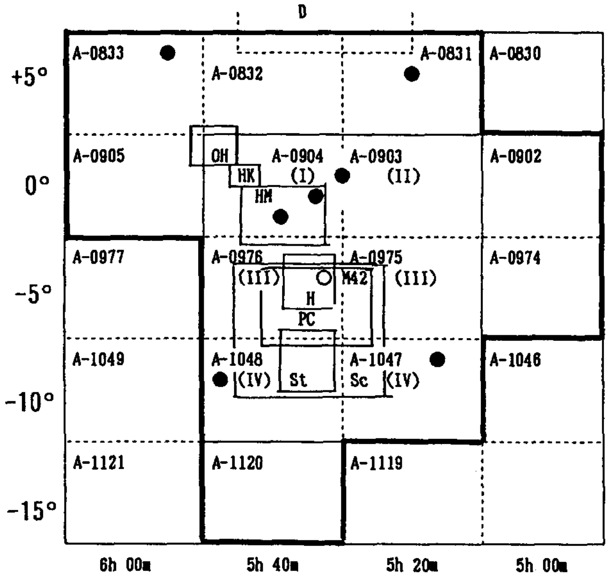
1. Introduction

The Orion complex of molecular clouds and young stars is one of the best known star forming regions. It has been observed extensively over a century and in a wide spectral range. The complex is not limited to the molecular cloud region in the centre of Orion, but markedly extends to the western side as traced by young stars. The total mass of this huge star forming region exceeds 2×10^5 solar masses, and its size is as large as 100 pc in diameter.

Evidence for a large scale activity of star formation comes both from cloud components and young stellar objects. Among these, cloud components, traced as dark clouds (Lynds 1962), molecular clouds (Maddalena et al. 1986), or an Av-map (Tomita 1991), delineate the site of present or recent star formation. In contrast, young stellar objects reveal the historical site of star forming activities for a span of more than 10 Myr. Massive stars constitute the Orion OB1 association (Blaauw 1964; Warren & Hesser 1977 & 1978), whereas low mass stars were first recognized as an Orion population by Parenago (1954), and then as T Tauri stars (Cohen & Kuhi 1979), and flare stars (Gurzadyan 1980). Faint emission line stars have also been observed by many authors as candidates of low mass young stars in this region.

Surveys of emission line stars (ELSs), started from Haro (1953) and Haro & Moreno (1953), followed by Parsamian & Chavira (1982) and others, have been made mostly along the dark cloud region. Using the Kiso Schmidt telescope, we have carried out a survey of ELSs for an extended area and found a number of new ELSs. (Papers I through IV, and recent observations as given by Wiramihardja et al. 1994). In this paper we first present some results of our surveys, and then we discuss the star forming activity in the central region of Orion where most of the OB stars and ELSs are concentrated.

Theoretically, this is related to the problem of the initial mass function (IMF), or, of the bimodal formation of high and low mass stars (see Zinnecker 1993, and references therein). Actually the Orion region is a prototype of simultaneous star forming regions for both OB stars and low mass stars, as compared



OH = Ogura-Hasegawa (1983) HK = Herbig-Kuhi (1963)
HM = Haro-Moreno (1953) H = Haro (1953)
PC = Parsamian-Chavira(1982) St = Strom et al.(1989)
Sc = Schevchenko (1975) D = Duerr et al.(1982)

Figure 1. Kiso sky areas and survey observations. Our surveyed area is shown by the thick boundary

to the Tau-Aur star forming regions in which low mass stars exclusively are formed. It is important to study the formation history of OB and low mass stars in Orion as an observational approach to these theoretical problems. It is widely accepted that the subgroups of Ori OB 1a to 1d are a result of sequential formation of massive stars. Zinnecker (1993) argued that star formation was highly active in region 1a, and declined in 1b and 1c. One of the purposes of our survey is to provide the data needed for an observational study of star formation activities. In conclusion we shall show the possible occurrence of bimodal star formation in this region.

2. Survey Observations of Emission Line Stars

At Kiso Observatory, we have so far obtained survey observations for Hα emission stars for a total sky area of 325 square degrees (13 fields of 5×5 square degrees), using the 4° objective prism attached to 105/150 cm Schmidt telescope (Papers I–IV). The observational procedure and additional results are given by Wiramihardja et al. (1994). The Kiso sky areas in our survey are shown in Fig.1, together with the areas of previous surveys. In this wide sky area, we have detected 1,220 emission line objects in total, including 29 non-stellar objects. Among these, there are 804 newly detected stars. The Catalogue of ELSs in Orion by Brand & Wouterloot (1991) contains our stars found by 1991.

The distribution of all ELSs, including both our recent surveys and the λ Ori region observed by Duerr et al. 1982), are plotted in Fig. 2. It is seen in Fig. 2 that ELSs are highly concentrated in the region of molecular clouds Orion north and south, as previously expected, and, at the same time, the extension of ELSs to the west side of the cloud region is notable. It seems also evident that ELSs in the main part of Orion make a separate group from the ELSs in the λ Ori region, though the boundary of the distribution of ELSs in both regions has not been well defined by our recent survey.

Among our surveyed areas we shall pay particular attention to the central four Kiso areas, A0903, A0904, A0975, and A0976, where most ELSs and OB association stars are concentrated, so that we can directly compare the formation activities of these ELSs and OB stars. In Figs 3 and 4, the distributions of these stars are shown separately.

Most of the ELSs in this area are taken to be pre-main sequence stars for the following two reasons. Firstly, the brightness distribution peaks at $V \sim 15$, which coincides with the distribution for T Tauri stars placed at the distance of Orion (Papers I–III). Secondly, spectroscopic observations for a sample of ELSs have shown that most of them reveal T Tauri star characteristics in their spectra (Kogure et al. 1992). In the next paragraph, we therefore assume that ELSs are low mass young stars, and compare the statistical behaviour of these stars with those of OB stars.

3. Star Forming Activities in the OB Association Region

Subgroups Ori OB 1a to 1d were extensively studied by Warren & Hesser (1977, 1978) for their membership, colour and spectral features, and for the age of each subgroup. Based on these data, Zinnecker (1993) has discussed the evolutionary state of these subgroups. According to him, the numbers of B stars in 1a, 1b and 1c are 121, 96 and 36 respectively, and the estimated number of supernovae thought to have occurred in 1a and 1b is 9 and 3 respectively. From these figures he argued that subgroup 1a must have been an active site of star formation some 10 Myr ago, much more active than Orion today. This argument can be supplemented using the colour magnitude diagrams of OB stars in Ori 1a to 1c separately, based on Warren and Hesser's data, where we can see that the average magnitude increases from $V = 7.5$ (1a) to $V = 8.4$ (1b) and $V = 9.0$ (1c). This indicates that the activity of massive star formation must decrease along this line.

In order to compare the state of ELSs with OB stars, we consider the subgroup regions in the central area given in Fig. 3. The behaviour of ELSs belonging to the OB 1a, 1b, 1c and 1d areas are compared in Figs 5a, b for the Hα emission strength and V magnitude of stars. The number of ELSs in each subgroup is 263 (1a), 257 (1b), 482 (1c) and 26 (1d). Among these, 1d is a very obscured region around M42, so that a number of ELSs are supposed mostly hidden behind the nebula which makes accurate statistics difficult.

The behaviours of ELSs shown in Figs 5a and b are summarized in Table 1, which gives the numbers of ELSs, rate of strong Hα emission stars in grade 4 (strong) and 5 (very strong), average magnitudes for all ELSs and brightest 10 stars. From these numbers one may see that the formation rates of active (i.e.

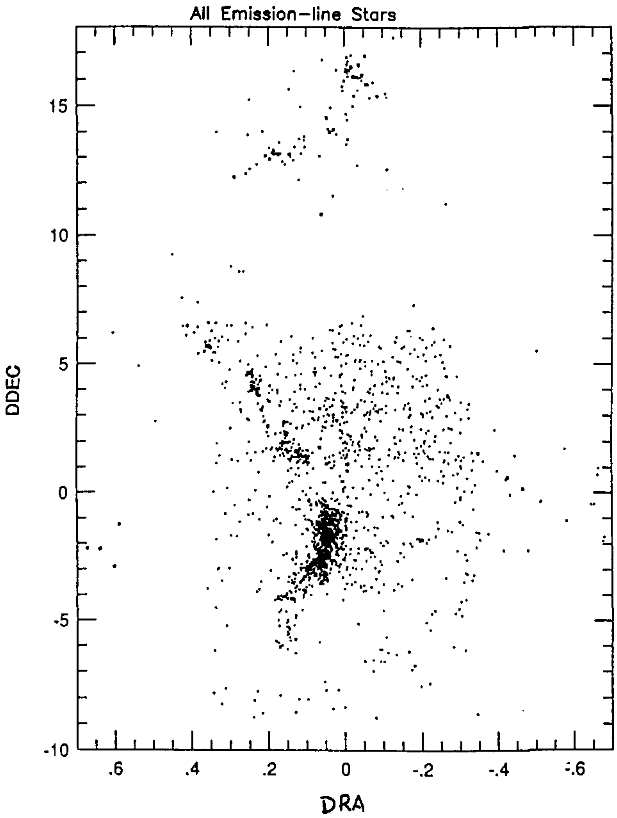


Figure 2. Distributions of all emission line stars in the Orion region

strong Hα) and massive (i.e. brighter) stars have increased from 1a to 1c. This is just the opposite tendency to the case of OB stars mentioned above, implying the possibility of bimodal star formation of massive and low mass stars in the OB association region of Orion.

4. Summary and Future Problems

In the first part of this paper the overall distribution of ELSs in a wide field of Orion is presented. It is seen that the ELSs are distributed well outside the molecular cloud region particularly on the western side, nearly overlapping with the region of OB star association. It is also evident that ELSs in the λ Ori region form a different group to those in our surveyed area.

The relationship between ELSs and OB stars in the region of Ori OB1 association has also been considered, assuming that ELSs are low mass young stars. It is suggested that, in contrast to Zinnecker's argument that the activities of OB star formation have declined from OB 1a to 1c, the formation activity of low mass stars must have increased in the opposite sense to the OB

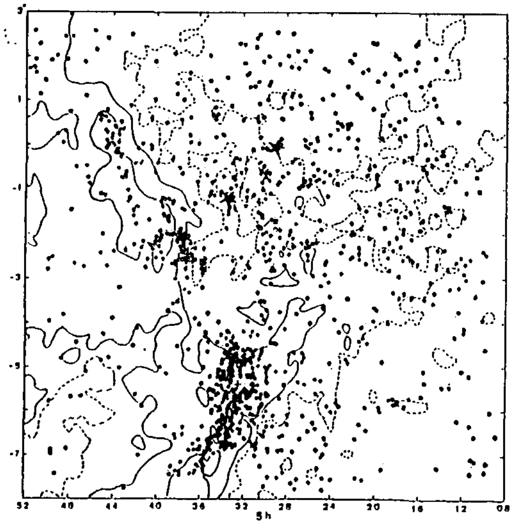


Figure 3. Distribution of emission line stars in the central area of the Orion complex. Contours show the interstellar extinction in Av = 0.5. 1.0. and 2.0 (Tomita 1991).

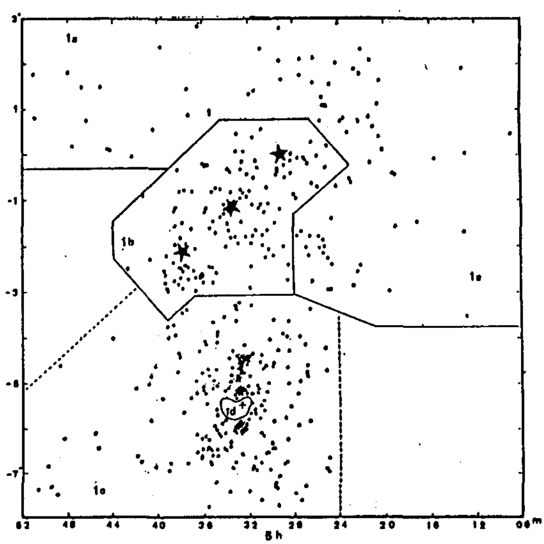


Figure 4. Distribution of OB association member stars in each subgroup of OB 1a–1d, together with the boundary of these subgroups defined by Warren & Hesser (1977).

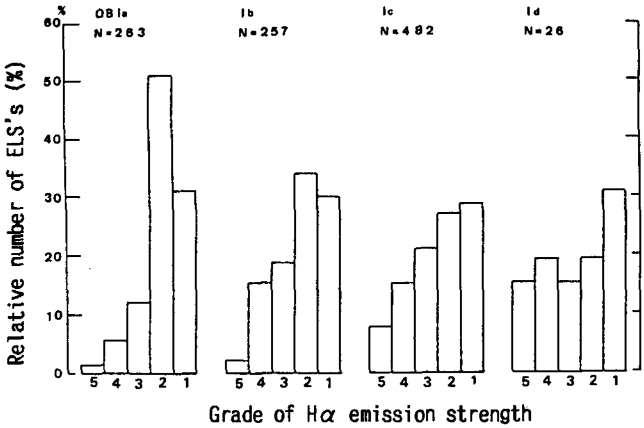
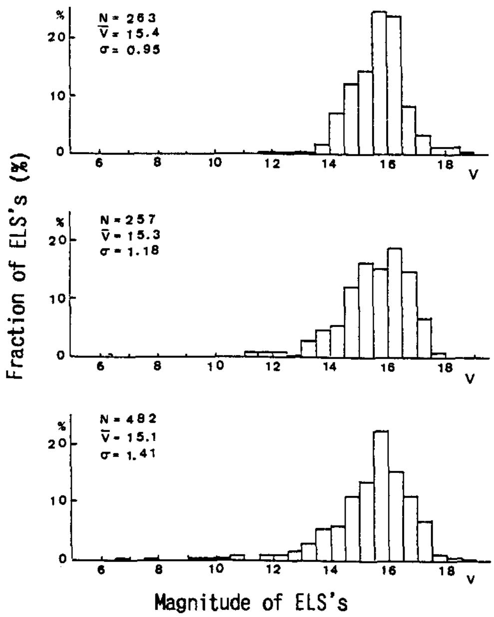


Figure 5. (a) Histogram of the Hα strength expressed by the grade 5 (very strong), 4 (strong), 3 (medium), 2 (weak) and 1 (very weak).



(b) Histogram of the magnitude distribution ELSs in OB1a, 1b and 1c regions.

Table 1. ELSs in OB subgroup regions

Subgroup OB	1a	1b	1c	1d
Number of ELSs	263	257	482	26
Rate of strong Hα emission stars (grade 4 & 5)	7.2%	17.5%	24.0%	34.6%
Average mag.(V)	15.4	15.3	15.1	–
Mag.dispersion	0.95	1.18	1.41	–
Brightest 10 stars average mag.(V)	13.1	12.0	9.5	–
dispersion	0.80	0.76	1.55	–

stars. This implies the possibility of bimodal star formation in Orion. Further studies, including follow up observations of ELSs and their proper motion studies, are desired for the elucidation of the physical processes in the bimodal star formation.

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Discussion

Lee Son Gak: What physical conditions do you think are the cause of bimodal star formation, based on your observations ?

Kogure: Several conditions have so far been proposed theoretically, such as the difference in the initial gas density or temperature of parent molecular clouds, or an effect of local magnetic field. In this study I only suggested a possibility of bimodal star formation in the region of Orion OB association. To find the physical conditions in such star formation process should be a future problem.