TRIGGERED STAR FORMATION IN S235

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1. Agenda

Star formation can be stimulated by global phenomena like the propagation of spiral density waves and by local events like the expansion of supernova remnant or HII regions around young massive stars. In last scenario is known as 'collect-and-collapse' model, proposed by Elmegreen and Lada several decades ago. We found that the process of star formation around the HII region Sh2-235 (S235) might be explained by this scenario. We present kinematical and morphological arguments in favor of this idea.

2. HII region S235 and its environment. First studies

S235 is the brightest HII region in a large molecular complex (see Fig.1). The complex contains several HII regions as well as objects at the earliest stages of star formation. This is confirmed by the presence of methanol and water masers. Young stellar clusters, detected by Spitzer (Hora et al.), are distributed around S235. This prompts that formation of the clusters might have been triggered by an expansion of S235.

Fig.1 – Optical image of the HII regions taken from DSS (red)

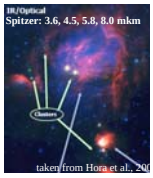


Fig.2 – Optical (blue), IR (red) image of S235 and young stellar clusters

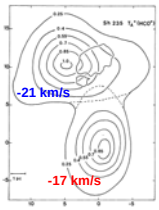


Fig.3 – Map of HCO+ emission from the S235 region taken from Lafon et.al (1984)

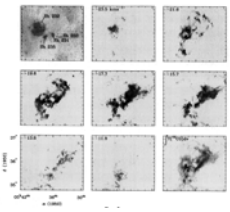


Fig. 4 – Map of 13CO(1-0) emission from the molecular complex containing S235 in several velocity channels

First studies of molecular gas around S235 by Evans et.al (1981) and Lafon et.al (1984) reported about existence of two individual molecular clouds with different redial velocities (see Fig.3). Large-scale mapping of CO emission in the whole molecular complex done by Heyer etal. (1996) showed that it has complicated kinematical structure (see Fig.4) and consists of several filaments

3. IR star counts

We studied the distribution of stellar density in the region using data of the 2MASS catalogue which allows us to investigate population of the young stellar population in the S235 complex of star formation. The result is shown in Fig.5. We found seven clusters and five of them are located in the immediate vicinity of S235. Three clusters are found just around the HII region. The arrangement of these objects is

a good argument in favor of the assumption that formation of some clusters was triggered by an expansion of S235. We decided to check this idea with observations of molecular gas and find specific kinematical features inherent to the triggered star forming process.

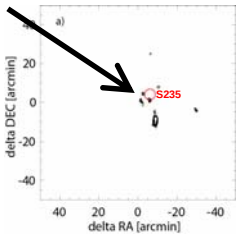
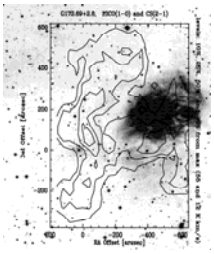


Fig.5 – Map stellar density distribution made with the 2MASS catalogue (contours), S235 is represented by a red circle



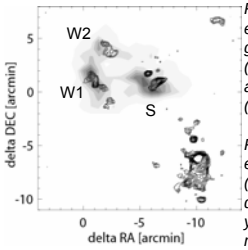


Fig. 6 – Map of ^{13}CO(1-0) emission from molecular gas surrounding S235 (contours) superimposed on an optical image of S235 (left)

Fig. 7 – Maps of CS(2-1) emission from same region (grey) and stellar density distribution (cont.). The young clusters are designated as W1 (West1), W2 and S (South)

4. Observations

We observed ^{13}CO(1-0) and CS(2-1) emission with the 20m Onsala telescope in 2005 and 2006. Maps of the southern and eastern parts of S235 has been made. Ammonia emission was observed with the 100m Effelsberg Telescope in 2007 in order to measure kinetic temperature and ammonia column density of the molecular gas.

5. Embedded stellar clusters and kinematics of the molecular gas

The molecular gas shows a shell-like morphology around S235 (see Fig.6). Shock wave which developed due to expansion of the HII region compressed the surrounding molecular gas and formed dense clumps. Emission of CS(2-1) shows three peaks which are coincident with the positions of the young clusters (see Fig.7). So, the clusters possibly formed by the expansion of S235 are still associated with their parent molecular clumps. The southern cluster is associated with the well-known star-forming region S235A-B and seems not to be related to the expansion of S235.

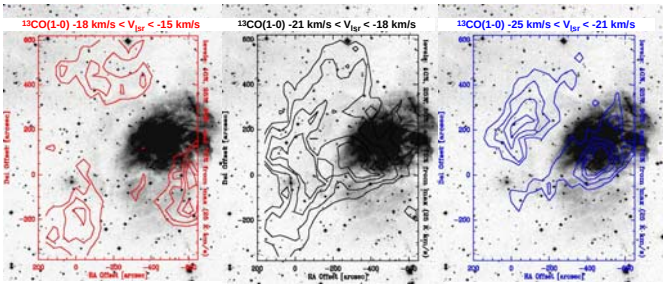
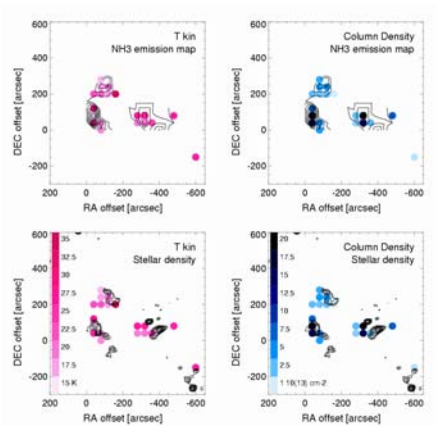


Fig. 8 – Maps of 13CO(1-0) emission: (a) -18km/s < V_{lsr} < -15km/s, (b) -21km/s < V_{lsr} < -18km/s, (c) -25km/s < V_{lsr} < -21km/s

We distinguished three components of ^{13}CO(1-0) emission which might be related to process of formation of the young clusters. First component with characteristic velocities in the range -18 km/s < V_{lsr} < -15 km/s contains clumps located far from the clusters and, probably, represents low density undisturbed gas. Second one (-21 km/s < V_{lsr} < -18 km/s) might be gas which was involved in motion by expansion of S235. Its velocities are in agreement with velocities of dense gas around young clusters. Third component (-25 km/s < V_{lsr} < -21 km/s) is associated with the borders of two young clusters and might constitute gas blown up by stellar wind from them. We suppose that revealed kinematical pattern "quiet gas -> disturbed by a HII region gas -> and gas, disturbed by young clusters" which is characteristic of the process of triggering of star formation by an expanding HII region.

6. Physical conditions in molecular gas

The kinetic temperatures (T_{kin}) and ammonia column densities $N(NH_3)$ were measured by us in the molecular gas surrounding S235. The results are shown by colors in Fig.9 together with maps of (a) ammonia emission (NH_3(1,1)) and (b) stellar density distribution. We find that clump W1 contains cold gas with a high ammonia column density. The coldest and densest region in this clump is associated with the peak of stellar density distribution. Clump W2 does not show high $N(NH_3)$, but quite high T_{kin}. The maximum of $N(NH_3)$ is shifted with respect to the maximum of the stellar density distribution in cluster S as well as in cluster W2. This could be related to the beginning of an expulsion of parental molecular gas by the stellar wind from the cluster.



Last assumption is in agreement with conclusion about third component of ^{13}CO(1-0) emission. Data on ammonia emission shows that the clusters might be at the different stages of evolution.

Fig.9 – Maps of NH_3(1,1) emission and stellar density distribution superimposed on positions were kinetic temperature and ammonia column density where measured.

7. Plans for future

We are going to investigate the chemical composition of the clumps in the region around S235 by observations of molecular emission representing C-bearing, N- and S-bearing chemistry. This will allow us to explore possible chemical differences between the quiscent gas, the gas disturbed by the expansion of S235, and between the dense molecular clumps associated with the young clusters.

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