# SMALL-SCALE STAR FORMATION AT LOW METALLICITY

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## Summary

Massive star formation on small scales in a low metallicity environment is investigated by studying the morphology of HII regions in the Small Magellanic Cloud. A classification scheme based upon the symmetry of form in the light of H$\alpha$ is devised to make possible an examination of the properties of blister candidates with respect to nebulae embedded in a more uniform medium. As in the Milky Way, the asymmetrical surface brightness distribution of many HII regions demonstrates that massive stars often form at the edge of dense neutral clouds. However, the existence of many symmetrical nebulae with similar sizes, luminosities, and surface brightnesses shows that massive star formation often occurs well within clouds. Nevertheless, the statistics of the two different forms indicate that the rate of massive star formation declines less steeply with radius across host clouds than in the Milky Way, suggesting that triggering is predominated by a different mechanism.

## Background

Much can be learned about massive star formation by studying HII regions ionized by so few stars that the energy input has not been sufficient to disrupt the connection between the ionized gas and the host molecular cloud. The morphology of such HII regions can yield valuable clues about the location of star formation sites in molecular clouds, and thereby can help to identify important triggering mechanisms. For example, asymmetrical Orion-like nebulae with diffuse emission falling away from a bright core or ridge arise from star formation at the edge of a molecular cloud, perhaps initiated by an external trigger such as a collision with another more diffuse cloud or an encounter with a supernova shock front. On the other hand, the existence of symmetrical Trifid-like HII regions shows that massive stars can form well within clouds, and suggests that an external trigger is not necessarily needed.

The Small Magellanic Cloud is an ideal laboratory for studying these important star formation issues at low metallicity. Considering the peculiarities of the molecular make-up of the interstellar medium and the consequences for heating and cooling, routes to star formation may be quite different than in the Milky Way. Certainly, with the reduced dust content, star formation occurring deep within molecular clouds is more readily observable. Most important, because of the advantages in resolution and detectability resulting from proximity, the SMC offers unique opportunities to gain insights into star formation in the early universe.

## Observations

The authors have conducted an H$\alpha$ imaging survey of small HII regions in the Small Magellanic Cloud. Observations of HII regions smaller than about 2.0 arcmin (38 pc) were made with the CCD camera of the University of Toronto Southern Observatory at Cerro Las Campanas, Chile. Reductions and measurements were carried out using IRAF. A total of 15 fields were surveyed, containing a total of 26 distinct objects.

Following upon concepts developed for HII regions in the Milky Way, a two-stage classification system was designed to segregate objects on the basis of symmetry of form. From this system, it was possible to identify objects most likely to be Orion-like "blisters" (Type O) at the edge of molecular clouds and Trifid-like Stromgren spheres (Type T) located well within clouds. In addition to measuring total fluxes, the physical characteristics of the HII regions were evaluated by examining isophotes at a fixed percentage of the peak surface brightness. The diameter and surface brightness of such isophotes are directly related to parameters controlling the radius of a Stromgren sphere.

## Results

While many SMC HII regions have the morphology of blisters, just as many show a degree of symmetry which precludes formation in a nonuniform medium. Examples of each type are shown in Figure 1. Neither the H$\alpha$ fluxes nor surface brightnesses of Type O HII regions differ systematically from those for Type T, demonstrating that covering factors, temperatures of ionizing stars, and extinction levels are probably comparable. Fluxes don't vary significantly with diameter, so variations in stellar temperatures can't be at the root of the diameter sequences. Since surface brightnesses decline with diameter, the sequences probably arise from variations in the gas density.

Whether or not massive star formation preferentially occurs at the edges of molecular clouds can be judged from the number of HII regions of Type O relative to Type T. For this purpose, it is useful to approximate the sites of massive star formation as a collection of identical spherical molecular clouds of radius $R$ and to represent the probability of star formation at a particular point in a cloud as a power law in radius, i.e.

$$P = P_0(r/r_c)^\beta$$

where $r$ is the distance from the centre of the cloud and $P_0$, $r_c$, and $\beta$ are constants. If HII regions of Type O exclusively arise from star formation in a shell of width $\Delta R$ at the edge of the clouds and if HII regions of Type T come from star formation within radius $R - \Delta R$ from the centres, then integration of the probability function yields

$$-\beta = 3 + \log(1+q)/\log(1-\Delta R/R)$$

where $q = N(\text{Type O})/N(\text{Type T})$. Type O objects become common at sizes above 10 arcsec, suggesting that the ionizing stars formed within 5 arcsec (1.5 pc) of the cloud boundaries. The size of the biggest Type T HII regions suggests that cloud radii must be much larger than 20 arcsec (6 pc). Thus, $\Delta R/R < 0.25$. Of the HII regions with sizes

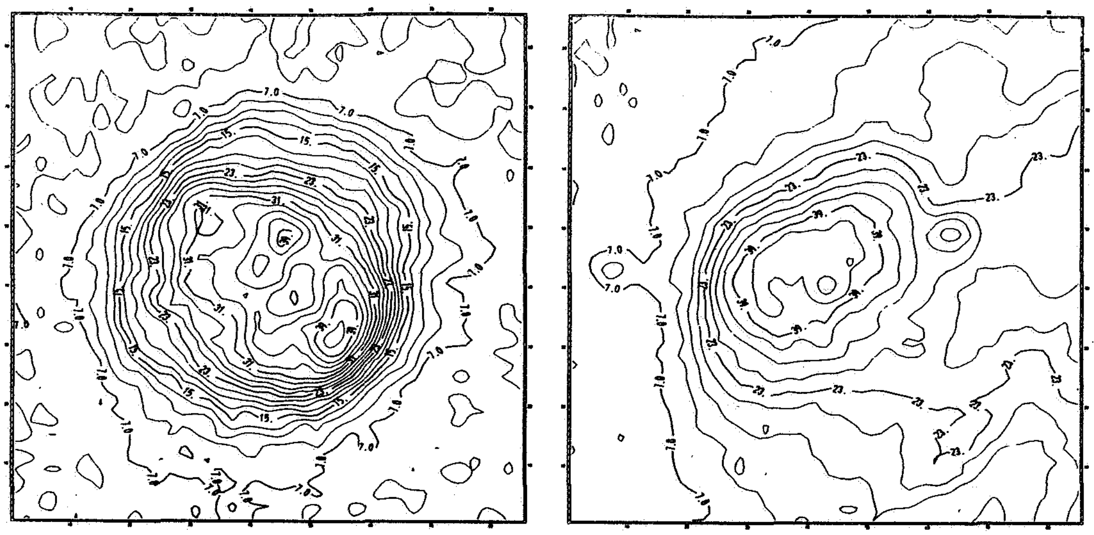

**Figure 1.** Examples of HII regions of Type T (left) and Type O (right) in the Small Magellanic Cloud, in the light of H$\alpha$. The sides of each box are 44 arcsec in length.

between 10 and 40 arcsec, eight are of Type O and nine are of Type T, so $q = 0.89$. Therefore, $\beta > -0.8$, compared with $-1$ to $-2$ in the Milky Way (Waller, W. H., Clemens, D. P., Sanders, D. B., and Scoville, N. Z. 1987, Ap. J., **314**, 397).

The number of Type T objects is too great to accommodate a theory restricting massive star formation to the boundaries of molecular clouds. However, the observations suggest that the gradient in the star formation rate with radius through molecular clouds is shallower, and may even be inverted, with respect to that observed across clouds in the Milky Way. Thus, in the SMC, external triggers may play a larger role in initiating star formation.