Table 2: *Positions at SEST.*

Telescope Scientist (NFR)	
L. Johansson	Jan 87–June 89
L.-Å. Nyman	July 89–
Astronomer (ESO)	
R. Gredel	Jan 88–
Astronomer (NFR, Finnish Academy)	
M. Lainela	July 87–Dec 87
G. Rydbeck	Jan 88–June 88
B. Höglund	July 88–Dec 88
L.-Å. Nyman	Jan 89–June 89
P. Friberg	July 89–Dec 89
Software Scientist (ESO)	
D.M. Murphy	June 86–June 88
M. Olberg	June 86–April 89
G. Persson	May 88–
R.F. Engineer (NFR)	
M. Hagström	Aug 86–Mars 89
N. Whyborn	Jan 87–May 88
L.-G. Gunnarsson	Jan 89–
Electronic Engineer (NFR)	
G. Delgado	May 87–
Electronic Engineer (ESO)	
M. Anciaux	July 89–
Coopérant (ESO)	
J.-M. Martin	Feb 89–

Recently, more effort has been devoted to reaching the specified reflector surface accuracy. Near-field holography measurements have been tried using a 100 GHz transmitter on the building of the 3.6-m telescope, but the small distance to SEST required that we made an impossibly large map. In addition, holographic observations of the 38 GHz beacon on the Lincoln Labs satellite, LES-8, have been attempted with limited success, but some extra software has to be written before such observations can be conducted properly. We hope that more holography can be carried out in the autumn.

Future receivers for SEST include a 350 GHz SIS receiver, currently under development at Onsala, and we now have funding for a bolometer receiver. We hope that an MPI system can be obtained; discussions to this end are going on with Ernst Kreysa, its designer, and with the MPI directorate. Other projected developments are the replacement of the Schottky diode mixers by superconducting (SIS) mixers and the development of multi-beam receivers. Finally, with the recent successes in millimetre VLBI and the fine maps that will soon appear, we are keen to procure a VLBI recorder and a hydrogen maser for SEST.

Acknowledgements

Many people have contributed to the success of SEST. We are grateful for the continued interest and assistance given by IRAM and thank particularly Albert Greve and Dave Morris who have worked with SEST staff on reflector surface measurements. In this context we also wish to record our gratitude to the Lincoln Labs team under Dr. W. Ward and to Al Richard for this painstaking attention to the satellite control.

The millimetre group of the University of Cologne have maintained a keen interest in the performance of the spectrometers and we thank them also.

The MPI bolometer group not only used their system to obtain some good astronomical results but they wrote a comprehensive report on the telescope performance which has resulted in an improved lateral adjustment mechanism for the sub-reflector. We are grateful for their interest and hard work.

Finally, we wish to express our gratitude to the SEST personnel, to all the staff of ESO both in Chile and Garching who have been called upon to make allowances for this group of 24-hour all-weather radio astronomers and to the staff at Onsala Space Observatory who have provided a professional operating base for the project.

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High-Mass Star Formation

J. MELNICK, ESO

1. Introduction

Massive stars seem to be formed in two different, and indeed quite extreme regimes: a very low-efficiency process (typically less than 1 %) associated with the formation of expanding OB associations, and a much higher efficiency mode (the *starburst* mode) that leads to the formation of bound clusters (Lada, 1985). Clearly, large numbers of massive stars can only form at the density peaks of very massive molecular clouds, while loose OB associations tend to form at the edges of clouds.

Massive star formation is contagious. Both modes of star formation are related to propagatory phenomena. In the case of OB associations, the propagating agents are probably either shock waves associated with the expansion of H II regions (Elmegreen and Lada, 1977), or the collective action of sequential supernova explosions (McCray and Kafatos, 1987).

Very young starbursts are often embedded in very large regions of active star formation called superassociations (Melnick, 1987) and there is ample observational evidence that massive star formation also propagates at the scales of superassociations (hundreds of parsecs). The propagating agents at these scales seem related to stellar winds and supernova explosions (Elmegreen, 1985).

A wealth of information about starburst activity comes from the study of giant extragalactic H II regions. Energetic considerations indicate that the ionizing clusters of these high excitation nebulae must contain hundreds to thousands of very massive stars which must have formed on time scales comparable to the dynamic time scales of the clusters (Melnick, 1987). For this reason, starbursts are also called *violent star-forming regions.* Here I will use both terms indiscriminately.

Since correlations of the form *mass* $\sim \sigma^4$ *and size* $\sim \sigma^2$, *where* σ is the velocity dispersion, are observed both in giant molecular clouds and in giant H II regions (Melnick 1987 and references therein; Solomon et al. 1987), the time scale argument implies that violent star formation must be very efficient. Otherwise the progenitors of starburst clusters would be too large and the free-fall

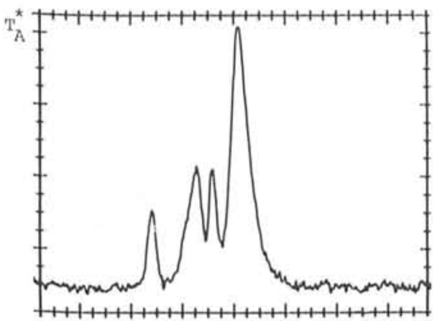

Figure 1: *^{12}CO (1–0) spectrum of the position of RCW 38 E. Maximum antenna temperature is 28° K and the velocity span of the figure is 60 km s^{-1}. (Courtesy of Malcolm Fridlund.)*

collapse times would be longer than the life times of the ionizing stars.

These considerations suggest there must be some physical mechanism to induce giant clouds to undergo free-fall collapse and to form massive stars very efficiently. Elmegreen (1985) suggests that free-fall collapse may be induced by large over-pressures created by expanding stellar wind and supernova bubbles. Silk (1985) postulates that the formation of massive stars inhibits the formation of low-mass stars, but stimulates the formation of more high-mass stars. The feedback of energy from the stars to the interstellar medium, according to Silk, enhances the star-formation rate and efficiency. It is not clear, however, whether this feedback mechanism can work in starbursts where the time scales for massive star formation are very short.

Cloud-cloud collisions have often been invoked as triggering mechanism for massive star formation (e.g. Scoville et al. 1986), but very few detailed calculations have been published so far. Clearly, if this mechanism works, collisions between large clouds could give rise to propagating formation of large clusters of coeval stars.

An attractive speculation is that instead of mechanically, starbursts may be induced chemically. Changes in the chemistry can conceivably alter the cooling function of the molecular gas and therefore reduce the internal pressure. A potentially effective mechanism to generate such changes has been suggested by Roland Gredel from the SEST team. Gredel suggests that very intense cosmic ray fluxes – as would be expected, for example, near multiple supernova explosions – could induce dramatic changes in the chemistry of molecular clouds. It is not easy to predict without detailed calculations, however, if this would lead to an increase or to a decrease of the temperature of the cloud, but clearly supernova-driven chemistry perturbations can be very contagious.

Many of the best cosmic laboratories to investigate the physics of massive star formation are in the southern hemisphere and SEST provides a much needed tool to access these laboratories. Some of the first SEST observations of southern massive star-formation regions are reviewed below.

2. The First Year of SEST

During the first year of operation, SEST was used by several groups to investigate regions of massive star formation both in the Galaxy and in external galaxies. Many groups observed molecular clouds in galaxies of many different types ranging from ellipticals to dwarfs. An account of these observations is beyond the scope of this review, except to note that observations of CO in galaxies show that starbursts are generally located at the edges of massive molecular cloud complexes. This reflects the contagious nature of massive star formation, and indicates that starburst activity is probably not triggered by cloud-cloud collisions.

Detailed studies of Galactic regions of massive star formation were done by A. Pagani and M. Heydari-Malayeri, by M. Fridlund, and by Lars Johansson and myself during the first year of SEST. I should mention that the succinct overview of the observations presented below is based on a preliminary analysis of the data.

Pagani and Heydari-Malayeri observed molecular clouds associated with expanding H II regions. These observations should lead to a better understanding of the formation of OB associations. Through the study of molecules of different isotopes, they should be able to place observational constraints on the physics of sequential star formation.

Fridlund mapped a sample of molecular clouds showing signs of massive star formation. He found that one of these clouds, RCW 38, an H II region in Vela, is one of the most luminous CO and HCO$^+$ sources in the Galaxy. The H II region is ionized by a cluster of OB stars located on the edge of the molecular cloud, a recurring signature. An interesting feature of the molecular cloud is the complex structure of the line profile (reproduced in Fig. 1) which is interpreted by Fridlund as evidence of gas flows in the

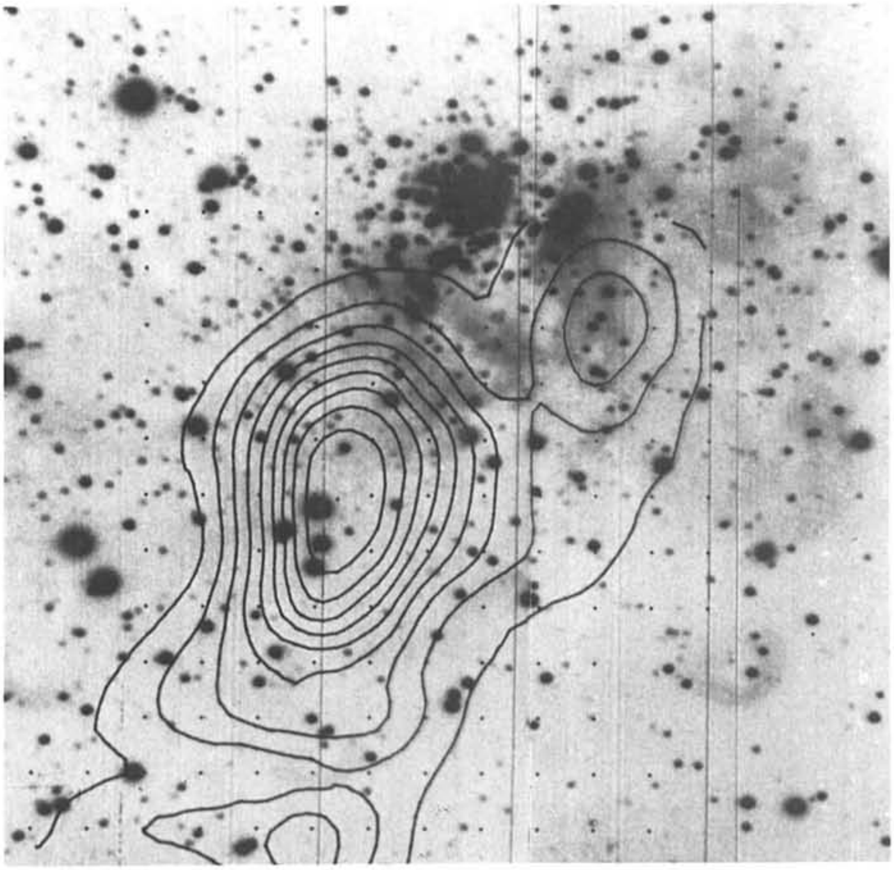

Figure 2: *^{12}CO (1–0) map of NGC 3603 superimposed on a mosaic of 2 CCD images of the complex in blue light. The grid spacing of the map is 20″ and the beam size 44″. The image covers an area of 6′ × 6′. North is on top, East to the left.*

Figure 3: *^{12}CO profiles in NGC 3603. The antenna temperatures range from −2 to 18° K and the radial velocity range covers 100 km s^{-1}. The grid spacing and orientation are as in Figure 2.*

region. Fridlund concluded that the molecular cloud is a new site of massive star formation in this active region.

My own research was aimed at understanding the mechanisms of formation of very massive starburst clusters. I selected the giant H II region NGC 3603, one of the most massive in the Galaxy, and the 30 Doradus superassociation in the LMC, but this region is at present being investigated by the SEST Magellanic Cloud consortium.

In collaboration with Lars Johansson and Andrea Moneti, I started a programme of SEST, IR, and optical observations of the NGC 3603 complex. Figure 2 shows a mosaic of 2 CCD images of the region in blue light on which our ^{12}CO (1−0) map is superimposed. As is the case for RCW38, for 30 Doradus, and for extragalactic violent star formation regions, the young cluster is located at the edge of the molecular cloud. The size and velocity dispersion of the cloud are consistent with that of other galactic molecular clouds and fit well the *(size − σ)* relation. ^{13}CO(1−0), C^{18}O(1−0), and ^{12}CO(2−1) observations suggest the NGC 3603 molecular cloud is similar to LMC molecular clouds associated with violent star formation regions.

The line profiles in the direction of NGC 3603, illustrated in Figure 3, are very complex, and are particularly complex in the region where (in projection) the giant H II region meets the molecular cloud. NGC3603, however, lies very close to the galactic plane in the direction of Carina, so it is not clear whether the complex velocity structure is intrinsic to the source or is due to contamination by background sources.

Massive star formation is presently taking place in the molecular cloud. Figure 4 shows a true colour JHK infrared mosaic of the region obtained by Andrea Moneti and Hans Zinnecker. These images show the presence of a small cluster of massive stars located halfway between the starburst and the core of the molecular cloud. One of the goals of our work is to determine whether and how the formation of this cluster has been triggered by NGC 3603.

Figure 4: *True colour JHK mosaic of infrared images of NGC 3603 obtained by A. Moneti and H. Zinnecker with the IR camera at the 1.5-m telescope of CTIO. (Courtesy of Andrea Moneti.)*

3. The Future

Much of the progress of astronomy in the past two decades has been driven by improvements in observational technology and, in particular, by the opening of new windows to the Universe made possible by advances in radio and infrared instrumentation, and by the advent of space observatories. The timely arrival of SEST opens a new window to the southern skies. Together with the other powerful instruments available on La Silla and other observatories, SEST will certainly provide a definitive impulse to the understanding of massive star formation.

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