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SEST – the First Year of Operation

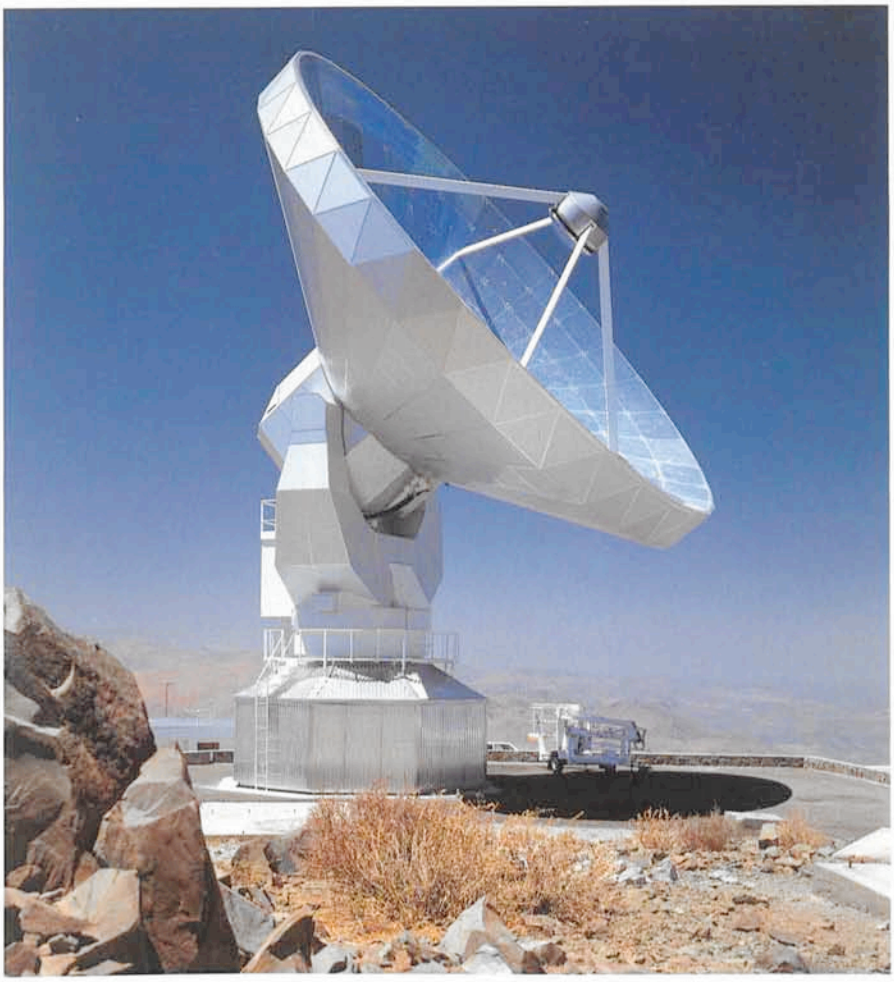
R. S. BOOTH and L. E. B. JOHANSSON, Onsala Space Observatory, Chalmers Tekniska Högskola, Sweden

P. A. SHAVER, ESO

The Swedish-ESO Submillimetre Telescope (SEST) completed one full year of scheduled observations at the end of March this year. Its performance has surprised and delighted many – its trouble-free operation and the clear skies of La Silla combining to effect large volumes of data. Few users of SEST have returned home disappointed. That the telescope has filled an important need is seen clearly in the demand for observing time: its over-subscription, averaged over the year and over ESO and Swedish users, amounted to a factor of about 2.5. This issue of the *Messenger* is devoted in part to summaries of work done with the new telescope. Some of the work described is already published but most is still undergoing analysis; we are grateful to those people who have written the summaries and to those who have provided data prior to publication.

The Telescope and Observing System

Most visitors to La Silla are now familiar with SEST, or at least with its highly reflective surface which often provides a remarkable splash of reflected sunlight from the southern end of the telescope ridge. The telescope has been discussed earlier in these pages (Booth, de Jonge and Shaver, 1987) and a more detailed technical description of the an-



The Swedish-ESO Sub-millimetre Telescope (SEST).

tenna and its observing system has recently appeared in *Astronomy and Astrophysics* (Booth et al., 1989). Here we remind you that SEST is a joint project, funded and operated on a 50/50 basis by the Swedish Natural Science Research Council (NFR) and ESO at a total cost of DM 9.8 M (August 1987). A separate Nordic agreement entitles Finland to 10% of the Swedish time. The 15-m Cassegrain antenna was designed by engineers of the Institut de Radio Astronomie Millimétrique (IRAM) and built under their supervision by French and German industry. It is similar to the telescopes which form the IRAM interferometer on Plateau de Bure and in some ways has become the operational prototype of those antennas. SEST is operated by a dedicated group of seven engineers/astronomers, supplemented by other ESO staff. General (technical) management of the project is in the hands of Onsala Space Observatory, under the direction of Roy Booth with Peter Shaver representing ESO on behalf of the Director General.

The telescope was handed over to the SEST team on March 13, 1987 and it is a tribute to the readiness and enthusiasm of everyone involved that "first light" was obtained just eleven days later with the detection of the 86 GHz SiO maser in Orion. There then followed a one-year commissioning phase during which the telescope and first receivers were thoroughly tested, the surface adjustment refined and a pointing model established. At the end of this period, experienced millimetre astronomers from the European community were invited to make observations with the system and provide suggestions for improvements. Scheduled observations began on April 1, 1988.

The telescope/receiver situation has remained essentially unchanged throughout this first operational phase and the salient parameters of the system are shown in Table 1. Painstaking direct (theodolite) measurements of the reflector surface by Albert Greve, assisted by Lars Johansson, have resulted in an adjustment of its profile to within some 70 micron rms of the best paraboloid. This probably represents the best which can be obtained using the direct technique, accuracy being limited by the errors of measurement of the radial distances to the surface targets sighted by the theodolite. Further improvements in the surface accuracy await holographic measurements which are referred to later.

The pointing accuracy remains of the order 3 arcsec rms on each axis, falling slightly short of the design specification of 2 arcsec. Blind pointing is characterized by systematic offsets of about 10 arcsec radially but these are stable at the arcsec level over time-scales of hours. Although the most likely cause of these offsets is thermal, no clear pattern is evident. Because of the highly reflecting surface, the telescope has been constrained to never point closer than 60° to the sun.

The SEST receivers were built at Onsala Space Observatory, Department of Radio and Space Science, Chalmers University of Technology, Sweden, and the acousto-optic spectrometers (AOS) were built by the millimetre astronomy group of the University of Cologne. The receivers were designed with the possibility of remote observing in mind and therefore incorporate a remote tuning capability, operated via a simple menu-driven interface. It has proved to be extremely efficient and fool-proof, and most visiting astronomers can tune the receivers without calling in the telescope staff.

Some improvements have been made to the receivers during the year. The receiver bandwidth has been increased and now a full 500 MHz is available in both channels. Also the tuning range of the 230 GHz receiver, previously limited by the lack of a local oscillator multiplier at the high frequency end of the band, now extends to 260 GHz, although its noise temperature is high at this frequency. Further improvements in progress are the substitution of the current intermediate frequency amplifiers, which use field effect transistors, to units employing high electron mobility transistors (HEMT), which will reduce the total system noise.

The first year of SEST operations has been remarkably trouble-free and less than 10% of the scheduled observing time has been lost, even including time lost because of bad weather. Scheduled maintenance amounted to 17 hours a week on average, and even with one full month in October/November entirely devoted to maintenance and development, about 75% of the total time was used for observations. Remember, this means some 18 hours a day averaged over the whole year for a radio telescope. The telescope has thus proven to be highly efficient and a large amount of high quality data has been produced. We attribute this in part to the combination of good telescope, receivers and site but most visitors will also agree that the enthusiastic and willing staff at SEST contributed more than a little to this performance.

Problems

Although SEST has been very successful, it has not been without its problems. Ironically, although the system involves much advanced technology, the most serious loss of time has been caused by the failure of light bulbs – specifically those in the positional encoders. The first incident of this kind occurred only a few days before the first scheduled project, when a bulb failed in the incremental elevation encoder. Such failures require the complete replacement of the encoder; in this case replacement was achieved and a new pointing model determined just in time for the observations to start. A more

TABLE 1: *SEST system (status by May 1989).*

Antenna		
Surface accuracy	≃ 0.07 mm (rms)	
Radial pointing accuracy (incl. systematic offsets)	4″ (rms)	
Main beam efficiency	0.71	(115 GHz)
	0.50	(230 GHz)
FHPBW	44″	(115 GHz)
	23″	(230 GHz)
Receivers (dual polarization Schottky mixers)		
Receiver temperatures	240–500 K	(70–120 GHz)
	600–1200 K	(210–260 GHz)
Backends (split mode available)		
High resolution AOS	100 MHz	2048 channels
Low resolution AOS	1 GHz	1728 channels
Possible observing modes		
Total power	up to 60 MHz	
Frequency switching	12′ (wide)	
Beam switching (single, dual)	3′ (narrow)	
Load switching		
Sky switching		

SEST and its control building.

serious incident occurred in July when a similar failure resulted in the replacement encoder being inadvertently bolted down too tightly. This resulted in a 60″ offset in elevation, the sign of which depended on position relative to transit. These offsets were not immediately associated with the encoder change and it took some time to track down the problem. This failure accounts for the major loss of observing time. Further problems have occurred in the compressors which drive the receiver coolers and in the 230 GHz receiver local oscillator multipliers, but these have caused only minor hold-ups.

Observations

Observations with SEST have covered a wide range of subjects with molecular line studies of galaxies dominating, particularly if we include the SEST key project to map the CO distribution in the Magellanic Clouds. As the sensitivity of millimetre telescopes has improved, the volume of the universe available to molecular line observation has increased dramatically and CO has been detected in galaxies with redshifts, z, greater than 0.15. The current record with SEST is $z = 0.09$. The large molecular mass of these high-luminosity infrared galaxies and the possible evolutionary link of these merging systems with quasars is of great interest.

In the nearest system of galaxies important results are also emerging as SEST observations confirm earlier suggestions that the CO : H_2 ratio is less than that in the Milky Way by a factor of about 5, probably as a result of the difference in metallicity. An additional result of some interest is the low level of $C^{18}O$ in the LMC.

The other major areas of molecular line research have been well represented in the SEST observational programme. Observations of regions of star formation have resulted in the discovery of many new bipolar flows, some of them associated with spectacular optical indicators of jets and bow shocks. Systematic work on evolved stars is providing better statistics on the chemistry and physics of the stellar envelopes and a data base of molecular properties of evolved stars detected by IRAS should highlight interesting targets for ISO observations.

Finally, a small percentage of time has been devoted to continuum observations. These have concentrated in the main on quasars and AGNs, to extend spectral data and to search for variability. A group from the Max-Planck-Institut für Radioastronomie, however, installed a 1-mm bolometer on SEST in August 1988 and observed interstellar dust and emission from early stars. They also detected emission from SNR 1987 A using this system.

The Staff

At the beginning of 1987, the operation of SEST was carried out by a team comprising two software scientists, two microwave engineers and a telescope scientist as team leader. A digital engineer joined the team in May and later replaced one of the microwave engineers, called back to Sweden to lead the receiver development group. The team was finally brought up to strength by an assistant astronomer and an ESO fellow. The assistant astronomer is funded by Onsala Space Observatory or, occasionally, by the Finnish Academy of Science. All members of the original SEST team were on two/three-year contracts in Chile and by June 1989 they had all been replaced. However, most of them now have positions at Onsala and help to form a knowledgeable SEST liaison group at the observatory. The new team has been built up over a period so that a high level of expertise has been maintained. Table 2 gives a summary of the staff situation at SEST.

The SEST team is basically divided into two shifts, each shift working alternate standard ESO schedules from Tuesday to Tuesday. Holiday and sickness permitting, each shift comprises an astronomer, a receiver engineer and a software specialist. No operators are provided at SEST, the observing system having been designed for easy operation by the astronomer, which has been very successful. Since operations are conducted around the clock, introductions to the system, usually performed by the telescope scientist or ESO astronomer, have to occupy some observing time, but since the system is rather user-friendly, little time is lost.

Future Developments

The SEST team is continuously working to improve the observing system, to simplify and streamline it. A menu-driven interface for the control system is almost complete, the receiver tuning software has been improved and an on-line data reduction system is now in operation. In addition, an alarm system to warn the staff of the more serious malfunctions is in operation and undergoing further development. More internal memory, as well as extra disk space, has been installed on the HP A 900. New software makes it possible to use both wide and narrow band AOS's simultaneously (both in split mode if required), and they may be centred at different frequencies or velocities.

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.

References

Booth, R.S., de Jonge, M.J., and Shaver, P.A. 1987, *The Messenger* No. **48,** p. 2.
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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* ~ σ^4 *and size* ~ σ^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