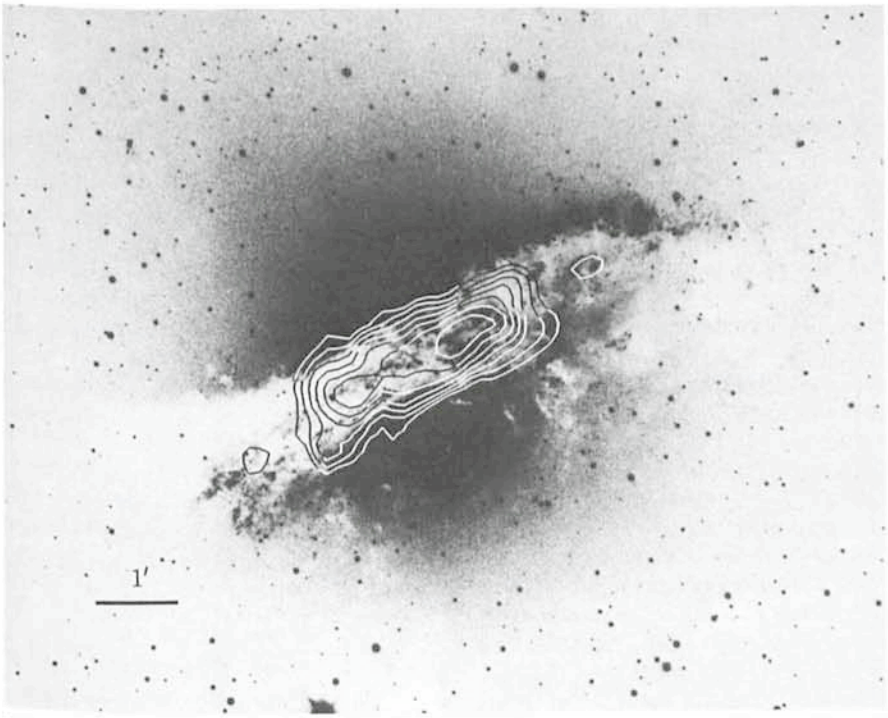

Figure 1: *Contour map of the integrated ^{12}CO J = 1-0 emission of Centaurus A superimposed on an optical image. The emission is well concentrated along the dust lane. Contour intervals are 17.5, 22.5, 27.5, . . . K km s^{-1}. The peak intensity is 54 K km s^{-1}.*

features in the CO lines against the nuclear continuum source.

The main results of these observations are that the bulk molecular material is closely associated with the dust lane and contained in a disk of about 180″ diameter with a total molecular mass of about 2 10^8 $M_\odot$. The total molecular mass of the disk and bulge is of the order of 3 10^8 $M_\odot$. The molecular gas in the nucleus is warm with a kinetic temperature of the order of 15 K and a number density of 10^3 to 3 10^4 cm^{-3}. Absorption features in the ^{12}CO and ^{13}CO lines against the nuclear continuum indicate that the properties of giant molecular clouds are comparable to those in our Galaxy.

Comparison with Other Data

The molecular data have been combined with 100 μm and 50 μm far-infrared emission of Centaurus A in order to study the variations in the gas and dust distributions (Eckart et al., 1989). These far-infrared data were taken with the CPC instrument on board IRAS and show that the dust temperature in the dust lane is about 42 K. The ratio between the far-infrared luminosity and the total molecular mass is 18 $L_\odot/M_\odot$ which is close to the mean value obtained for isolated galaxies. For giant molecular cloud complexes in our Galaxy, this ratio is of the order of 1 to 10 $L_\odot/M_\odot$. A comparison of the ^{12}CO J = 1-0 and the far-infrared data indicates that a considerable amount (about 50 %) of the far-infrared emission at 100 μm is not intimately associated with massive star formation. This emission is larger in extent than the molecular disk and is probably due to diffuse gas clouds in Centaurus A, similar in nature to the "cirrus" emission in our Galaxy.

The absorption features detected in the CO emission lines are coincident with known H I, C_3H_2, and H_2CO absorption lines, although the molecular content of gas in red and blue shifted clouds (with respect to the centre velocity of v_{LSR} = 550 km s^{-1}) seem to be different. A combination of new molecular data obtained with the SEST, H_2 emission from an unresolved nuclear source measured with the 3.6-m telescope at La Silla (Israel et al., 1989), and literature data suggest that the nucleus of Cen A is surrounded by a disk of 2 10^7 $M_\odot$. Such a disk, with an outer edge radius of 160 pc and with a density distribution of $n \propto r^{-2}$, is consistent with all existing observations of the nuclear region of Centaurus A.

Future observing programmes that are currently in progress or have already been scheduled will investigate the distribution of the molecular material with the highest possible spatial resolution, the molecular line emission in high density tracers – such as HCN, CS, and HCO^+, as well as the absorption features in those species. A combination and detailed analysis of these data will cast more light on the nature of the interstellar medium and star formation in Centaurus A and elliptical radio galaxies in general.

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Molecules in External Galaxies

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The 15-m SEST telescope is the unique facility to study with high resolution the molecular component of galaxies in the southern sky. One could object that galaxies in the northern sky already give a large enough sample to investigate, but there are outstanding objects that can only be studied from the southern hemisphere; apart from the obvious Magellanic Clouds, it is well known that most beautiful barred galaxies, for example, are at low declinations (NGC 1300, NGC 1365, NGC 1097 . . .). For this first year of operation, extragalactic astronomers have explored all types of galaxies, at all distances, from the nearest spirals (the equivalent of Andromeda in the North), to the outskirts of the detectable molecular sky, at redshifts of $z \approx 0.1$.

1. Nearby Spirals

Nearby galaxies, like the Magellanic Clouds (see the article by F. Israel in this issue of the *Messenger*), give the opportunity to study Giant Molecular Clouds (GMC) one by one, almost un-diluted in the 45″ beam of the SEST at CO (1-0) frequency, and even less with the 23″ CO (2-1) beam. One can then learn whether the physical nature of their clouds is similar or not to the Milky Way's; this is useful in particular to confirm the universality of the $N(H_2)/I(CO)$ conversion ratio, widely used by millimetric radioastronomers (I(CO) is the integrated CO emission).

The NGC 300 galaxy, an Sc spiral in the Sculptor group, is a good object for such a study (45″ = 360 pc). Albert Bosma, from Marseille Observatory (France), has observed 19 positions in this galaxy, corresponding to H II regions. Signals are very weak, lower than 1 Kkm/s in integrated CO emission. The derived H_2 masses in each complex are between 1 and $5 \cdot 10^5 M_\odot$, i.e. even less massive than the GMCs in our own Galaxy. Yet the surface explored in each beam is larger than a GMC's surface. This kind of weak and very narrow profiles has already been seen in northern nearby galaxies, like in M33 and M81. It is important to better study these objects, since their weak abundance of molecules is still a complete mystery.

In the nearby and almost edge-on barred galaxy NGC 4945, J. B. Whiteoak (CSIRO, Australia), M. Dahlem (MPIfR, Bonn, FRG), J. Harnett (CSIRO) and R. Wielebinski (MPIfR) have obtained 270 CO (1-0) spectra. They have identified five velocity components in the central region. Only three of them are in the nucleus, as shown by OH absorption spectra taken at 6 GHz with the Australian radio telescope. The two outside components seem to come from a rotating ring-like structure: they correspond to two peaks at 460 and 640 km/s (on each side of the systemic velocity), separating the rigid rotation curve inside 100″ of radius, from the differential rotation beyond. Such a ring at the radius of maximum rotation velocity is expected in barred galaxies, as discussed now.

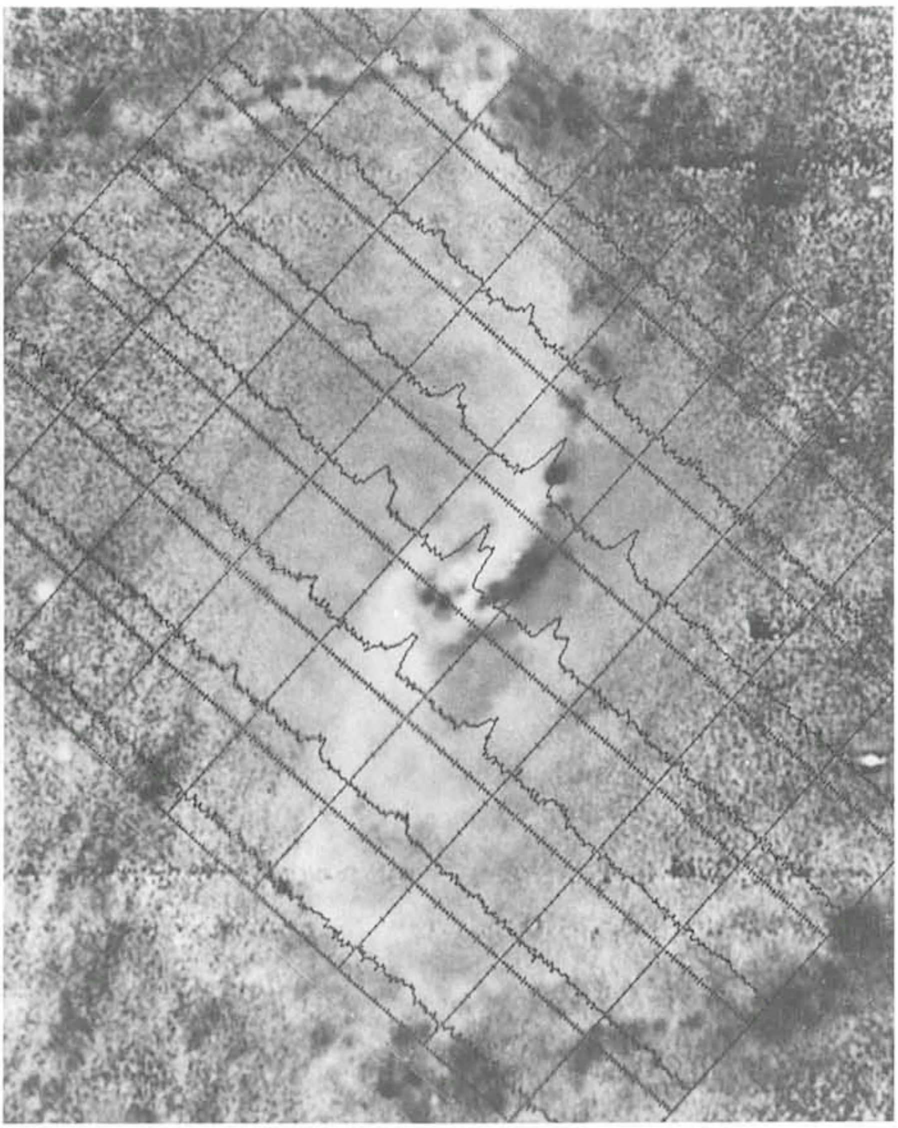

Figure 1: *Gunn z colour image of NGC 1365 showing the dust (light areas) as well as regions with hot stars and H II regions (dark areas). The overlay shows the J = 1-0 CO profiles observed with SEST on a 20″ grid. The velocity scale goes from 950 to 2250 km/s, the antenna temperature scale from −0.12 to 0.36 K.*

2. Barred Galaxies

Barred galaxies possess most of the time strong spiral density waves, and the gas component is essential for the persistence of these waves. The gas behaviour in a barred potential has been the subject of many theoretical studies and hydrodynamic simulations. It is expected that cloud collisions will deflect the cloud orbits with respect to those of stars, that are ellipses aligned with the bar. These gradual deflections produce the spiral wave. The gravitational torque exerted by the bar on the spiral will drive gaseous radial transport from the end of the bar towards the centre. When there exists an inner Lindblad resonance, the gas will accumulate in rings. As the inner resonance always occurs near the maximum of the rotation curve, the ring is predicted to be located there, in good agreement with the nuclear rings that are often observed in hot spot galaxies. The rings contain conspicuous H II regions, tracers of intense star formation.

The molecular clouds are therefore expected by theory to be highly centrally concentrated in barred galaxies, and to follow the spiral structure in the disk. N. Loiseau (INPE, Brazil), J. Harnett (CSIRO, Australia), E. Bajaja (Argentina) and H.-P. Reuter (MPIfR, Bonn, FRG) have started observational projects on barred galaxies, to test these models, and in particular whether the gas reveals peculiar velocities that could be interpreted as inflow towards the centre. It is expected that starburst or even nuclear activity could be triggered by the effect of the bar. Results obtained towards the barred spiral NGC 613 have already been reported by Bajaja and Hummel in the *Messenger* No. **55** (March 1989).

A beautiful southern barred spiral is the Seyfert galaxy NGC 1365. Sandqvist et al. (1989) are in the process of map-

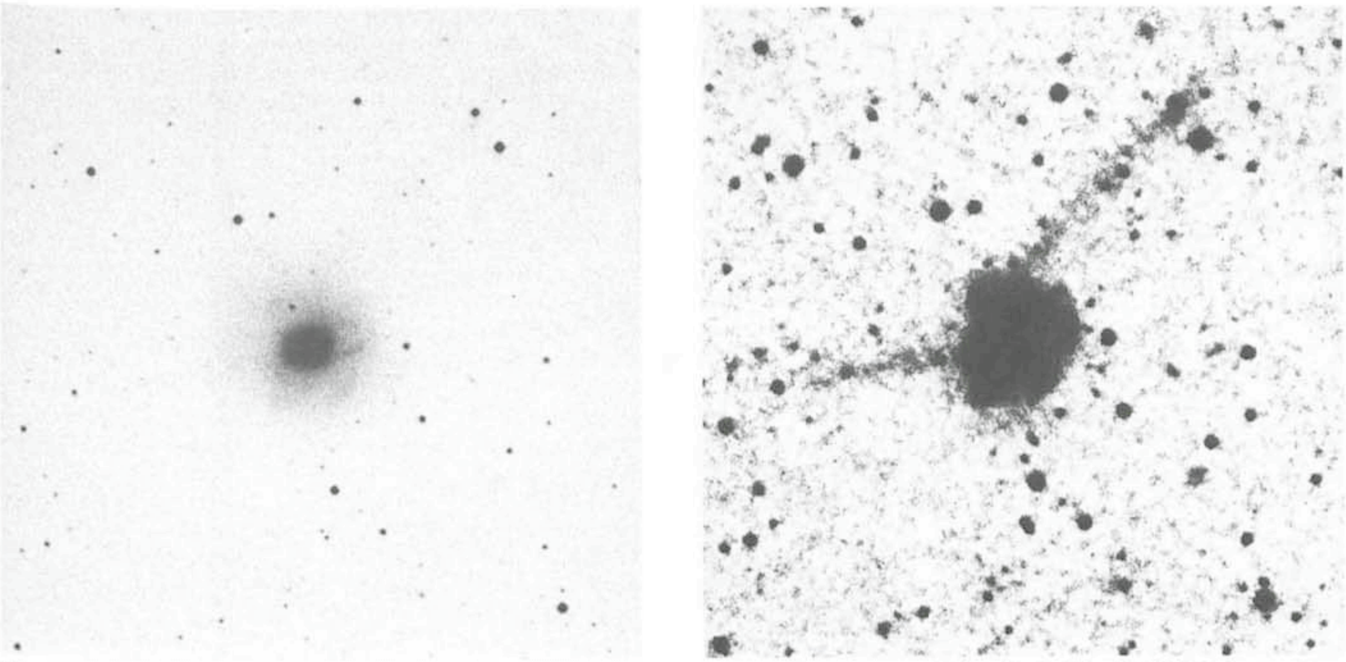

Figure 2: *Optical photograph of NGC 7252, reproduced from IIIa-F + RG 630 plate, obtained for the ESO red half of the ESO/SERC Survey of the Southern Sky. (a) inner structure; (b) showing outer arms. Photographic work by H. Zodet.*

ping it in the two CO lines (1-0) and (2-1). On the photograph in Figure 1 is superimposed a map of CO (1-0) spectra obtained so far. An interesting result is that spectra in the centre present two velocity components, revealing a deficiency of CO emission at the systemic velocity. This behaviour suggests the presence of a ring of molecular clouds inside the bar, supporting the results of hydrodynamical models in barred systems (Schwarz 1984, Combes and Gerin 1985).

In collaboration with M. Gerin (Paris), N. Nakai (Nobeyama) and J.M. van der Hulst (Groningen) we have mapped the barred galaxy NGC 1097, which is the prototype of the nuclear ring barred spiral. From previous observations with the 45-m of Nobeyama (Japan), and the 30-m of IRAM, we determined that molecular clouds are tracing the nuclear ring (Gerin et al., 1988). With the SEST 15-m we mapped the whole extended disk, and discovered that most of the mass has accumulated towards the centre: about 50% of the mass is found in the central beam, i.e. within a radius of 1.7 kpc, and we know that it is evenly diluted in the central beam, according to the higher resolution observations. Bars are indeed able to drive the gas inwards, as predicted by theoretical models.

We have also undertaken a survey of galaxies with Hα rings, to check the prediction that most molecular clouds may be accumulating in these features (Combes, Gérin and Buta, 1989). CO rings cannot be seen directly but they are revealed by typical two-horn-profiles (such as seen in NGC 1365).

NGC 1808 is a spectacular barred galaxy, where dust filaments seem to emerge from the plane. It was mapped in CO by M. Dahlem, U. Mebold, U. Klein (MPIfR, Bonn, FRG) and R. Booth (Onsala, Sweden). The central area shows ring-like rotation. The velocity peaks correspond to the maximum of the rotation curve. The optical filaments have a molecular gas counterpart: CO outflows are normally observed to the major axis. Is the central starburst the cause of this gas ejection, as is proposed in M82?

3. Interacting Ring Galaxies

Another kind of ring morphology is obtained with nearly head-on collisions between galaxies. The prototype of these objects is the Cartwheel. The tidal phenomenon has been simulated with great success by Lynds and Toomre (1976) and Theys and Spiegel (1976). The main observational difference with previous rings is that stars participate in the ring structure, and not only the gas. Also the radii of these rings are much larger than those of the gaseous nuclear rings. Is the gas compressed in the density wave that corresponds to the ring? Sometimes the ring can be decomposed in knots: do they correspond to star formation? We have discovered CO emission in two of these ring galaxies, IC 4448 and AM 064-741 (F. Casoli, F. Combes, C. Dupraz from the Paris group). The 45″ resolution does not enable us to distinguish between nuclear or ring emission, but in AM 064-741 the kinematics suggest that the CO emission comes from the nucleus. Further observations (in particular in CO (2-1)) are needed.

4. IRAS Galaxies and Mergers

Far-infrared observations by IRAS have revealed that galaxy mergers can trigger huge starbursts: most of the ultraluminous IRAS galaxies, that radiate 90% or more of their total luminosity in the infrared, are interacting galaxies and mergers.

One problem in these actively star-forming objects is to determine the gas excitation. Indeed, it is likely that the gas is heated by the starburst, and becomes less optically thick in the CO lines. This would yield an overestimation of the total molecular mass, if standard $N(H_2)/I(CO)$ conversion ratios were used. Such a phenomenon occurs in the central part of Messier 82, where the CO (2-1)/CO (1-0) integrated emission ratio R between the two rotation lines of CO, reaches 4 in some regions, indicating a large fraction of hot optically thin gas.

NGC 3256 has been observed by C. Dupraz, F. Casoli and M. Gerin in the two CO lines with the SEST 15-m telescope. The ratio R is about 1, but the surprise was in the weakness of the ^{13}CO (1-0) emission with respect to the ^{12}CO (1-0) one. The integrated emission ratio between the two isotopic molecules is about 30, while it is around 10 in most ordinary galaxies. This high ratio indicates that the gas is optically thinner than usual. The very peculiar line ratios in this object may be due to it being a

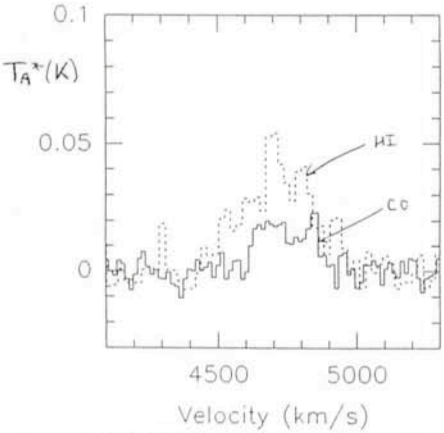

Figure 3: *NGC 7252: CO (1-0) and HI profiles towards this newly-born elliptical galaxy.*

merger between two equal-mass spiral galaxies, as suggested by its very perturbed appearance, with two tidal tails.

If the infrared luminosity L_{IR} is re-radiated by dust heated by the recent star formation, the ratio $L_{IR}/M(H_2)$ is an indicator of star-formation efficiency. These interacting and merging galaxies have the highest known ratios: $L_{IR}/M(H_2)$ of the order of 50 or greater, while it is of the order 1-3 in normal galaxies. There is also the possibility that a significant part of L_{IR} comes from dust heated by an active nucleus (in that case the emission region is highly confined towards the centre), so that the ratio $L_{IR}/M(H_2)$ is not a good indicator of star-formation efficiency. However, high $L_{IR}/M(H_2)$ ratios are still found in galaxies without nuclear activity.

The life time of the star burst can be extrapolated from these efficiencies. In time scales of a few 10^8 yrs, the merger remnants should become devoid of molecular gas. This result supports the currently well-developed idea that the merging of two spirals will form an elliptical galaxy, devoid of cold gas. An ideal object to test this hypothesis is the southern merger remnant NGC 7252, one of the pet galaxies of François Schweizer (1982). This object is conspicuous by its two tidal tails, that represent the "smoking gun" evidence of the merging of two spiral galaxies (Fig. 2). Numerous loops, shells and ripples add to the evidence. The luminosity profile is surprisingly regular and follows the $r^{1/4}$ law, characteristic of ellipticals, until a large distance. Yet this object was seen to be very rich in molecular gas (Dupraz et al. 1989): about $3\ 10^9\ M_\odot$, within 7 kpc. The observed line shape suggests that the CO emission comes from matter confined to a disk, which is also observed in $H\alpha$. This surprising result indicates that not all of the molecular gas is consumed in the star burst, as previously thought, or that matter continues to fall down onto the disk, long after the merging event.

At higher redshifts, the galaxies that can be detected in CO are all monsters: huge starburst galaxies, corresponding to interacting or merging objects, the frequency of mergers being probably higher in the past. The ultraluminous IRAS objects have luminosities larger than $10^{12}\ L_\odot$. Mirabel et al. (1988) have detected four of these monsters, possessing 1-6 $10^{10}\ M_\odot$ of molecular gas. Their $L_{IR}/M(H_2)$ ratio is between 20 and 80, much larger than in classic starburst galaxies, like Messier 82. The highest systemic velocity among these objects is 27,500 km/s, which demonstrates the ability of the SEST 15-m telescope to detect faint and broad emission lines.

This brief survey, far from exhaustive, already shows how exciting extragalactic work can be with the SEST 15-m telescope!

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Extragalactic Continuum Sources

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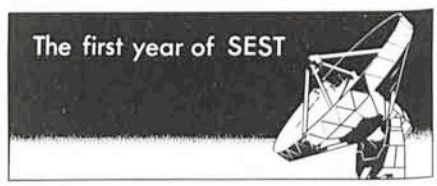

Introduction

As with most other high-frequency radio telescopes, continuum work occupies only a small fraction – currently about 5 % – of SEST's total time. The importance of these observations in increasing our understanding of quasars and other extragalactic sources is, however, large.

The millimetre-to-IR observations probe the innermost parts of the radio-emitting regions of active galactic nuclei: the radio cores, possibly the beginnings of radio jets, become optically thin on mm-wavelengths, where also the outbursts reach their maximum stages. As these regions remain below the resolving power and above the standard frequencies of VLBI, high frequency flux measurements give us our only glimpses of the very cores, the still mysterious sites of energy generation and channelling in active galaxies. Long wavelengths ("long" in the case of quasars meaning everything longer than one centimetre) show only evolved structures, such as old, ejected knots; the millimetre regime is where the real action is.

Most events seen at centimetre wavelengths have their precursors on higher frequencies. This forewarning capacity is especially useful for space VLBI purposes in choosing the best "targets of opportunity" for observations. The millimetre spectrum and its variations can also tell if compact structure is present in the source, and whether it will be a good candidate for VLBI observations; with sufficient flux data it may even be possible to produce model maps of the sources. Clues to the nature of different radio sources must also be searched at high frequencies.

While SEST opens up completely new southern vistas, its location also presents some problems in continuum work. The continuum observer dreams of uninterrupted multifrequency lightcurves revealing the various constituents and processes found in Active Galaxy Nuclei (AGN), but the reality usually shrinks to a scatter of isolated flux measurements. In most cases, one would greatly benefit from supporting data on other frequencies, but there are not many Southern telescopes available for that purpose.

SEST Measurements

During its first year SEST has been used for most of the purposes outlined