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HIGH SPATIAL RESOLUTION STUDIES OF GALAXIES IN THE FAR IR: OBSERVATIONS WITH THE KAO, AND THE PROMISE OF SOFIA

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Providing definitive measurements of the total luminous output of star forming regions, far-infrared continuum observations may be considered pivotal in our understanding of the way in which stars form, and the efficiency with which they do so on a galactic scale. The utility of such measurements for understanding the IR morphology of external galaxies is offset by the difficulty with which they must be made, involving stratospheric or space instruments. This imposes severe constraints on the available aperture size which, at these long wavelengths, implies corresponding constraints on spatial resolution. The largest far-infrared telescope is the 0.91m Kuiper Airborne Observatory (KAO), run by NASA Ames Research Center. At 100μm, this telescope is diffraction limited at 23" (FWHM of Airy disk). While the cryogenically cooled IRAS satellite gave high S/N measurements of the entire sky, it was diffraction limited at a spatial scale several times larger than that of the KAO.

The spatial resolution of the KAO at these wavelengths has only recently been fully exploited. At U.Texas, we have been pursuing a program of high spatial resolution observations from the KAO that, using special guiding and tracking methods to improve the pointing stability, and non-linear deconvolution algorithms to process the data, gives information at the diffraction 'limit'.

Much of our original work on the small scale far-infrared structure of galaxies was done using narrow slit apertures that we scanned back and forth across the sources. Our observations of M51 (NGC5194) (Lester, Harvey and Joy 1986) revealed that much of the far-IR luminosity of this galaxy came from the central 30" (700pc). The data suggested that this emission was coming from a region with a hole in the center — perhaps a ring of emission. Violent processes in the center of M51 may have cleared the core of ISM, and supressed star formation there. Scans of the ultraluminous galaxy Arp220 showed that this luminosity arose from the central 3kpc (Joy *et al.* 1986). The starburst region in M82 was clearly resolved in our data (Joy *et al.* 1987), and the peak emission was found to be larger than the near-infrared nucleus. A study of the Seyfert/starburst nucleus of NGC1068 showed that half the far infrared emission came from the Seyfert nucleus, and half from the surrounding starburst. The extended spiral arms of the galaxy (outside the starburst) were measured as well (Lester *et al.* 1987). The far infrared emission from the radio galaxy NGC5128 (CenA) was resolved into emission from the active nucleus, and a starburst in the plane of the disk (Joy *et al.* 1988). The strong H_2O maser source at the center of the nearby spiral NGC4945 was found to account for nearly all the emission from this otherwise unremarkable galaxy. The surface brightness of the source implied that it is close to being optically thick at 100μm, suggesting several hundreds of magnitudes of visual extinction (Brock *et al.* 1988). Figure 1 is from a recent study by Joy *et al.* (1989) on the structure of

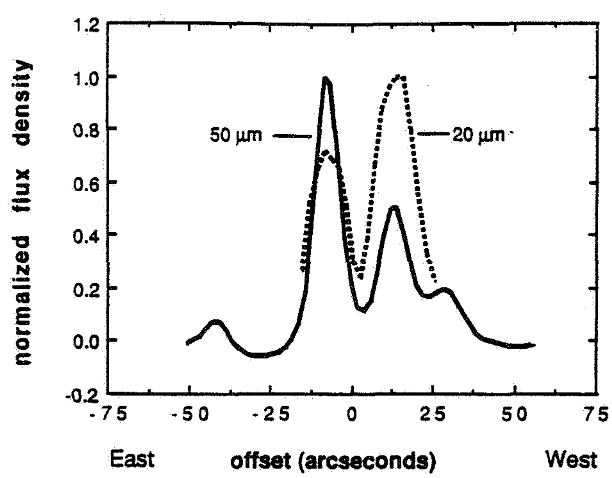

Figure 1: deconvolved 50μm KAO scan across Arp 299 compared with ground-based 20μm scan.

the interacting pair of galaxies in Arp299. Though much of the shocked gas is concentrated around NGC3690 (the westernmost component), and this component has the strongest emission from hot dust at 20μm, our data shows that it is the easternmost component (IC694) that supplies most of the far-IR luminosity.

A new generation instrument, with an array of ^3He cooled bolometers is now in use on the KAO. The detector sizes are $\lambda/2D \times \lambda/D$ allowing us to oversample the profile of a source in one direction. Work with that instrument on the structure of the starburst galaxy M83 is presented elsewhere in these proceedings (Smith *et al.*) With this array, and a new, precise and stable oscillating secondary mirror system for the KAO, observations with higher sensitivity and spatial dynamic range will be possible.

The importance of far infrared emission in tracing star formation in galaxies, and the need to trace out this star formation on spatial scales that can be compared with large scale characteristics of galaxies such as bulges, bars, and spiral arms, are strong drivers for a larger infrared telescope. Even a modest increase in spatial resolution would allow us to investigate the distribution of far IR emission across spiral arms in a number of nearby late-type spirals.

NASA, in collaboration with the West German Science Ministry (BMFT), plan a larger airborne telescope as a successor to the KAO that will achieve these goals. The Stratospheric Observatory for Infrared Astronomy (SOFIA) is entering the final stages of Phase B review with a targeted new start early in the next decade. SOFIA is a 2.7m diameter telescope that is carried in a Boeing 747SP. In addition to having 3 times the spatial resolution of the KAO, and 10 times the light gathering power, it will incorporate improvements over the KAO in lower optical emissivity and better telescope tracking stability. The thin primary mirror will equilibrate quickly to ambient temperature at altitude which, accompanied by airflow improvements across the telescope cavity will result in better image quality. The sensitivity of SOFIA will allow us to see a large number of typical bright galactic HII regions in local group galaxies. The spatial resolution of 8" (FWHM Airy disk) at 100μm will allow these regions to be measured independently, if they are distributed similarly to those in our own galaxy. At this spatial resolution, the disks of normal galaxies will be easily resolved out to distances of several hundred Mpc. This portion of space includes many of the superluminous galaxies discovered by IRAS, and this spatial scale is relevant for studies of the morphology of regions of interaction among the majority of these galaxies that are members of colliding pairs. Figure 2 shows a schematic comparison of SOFIA with the existing KAO.

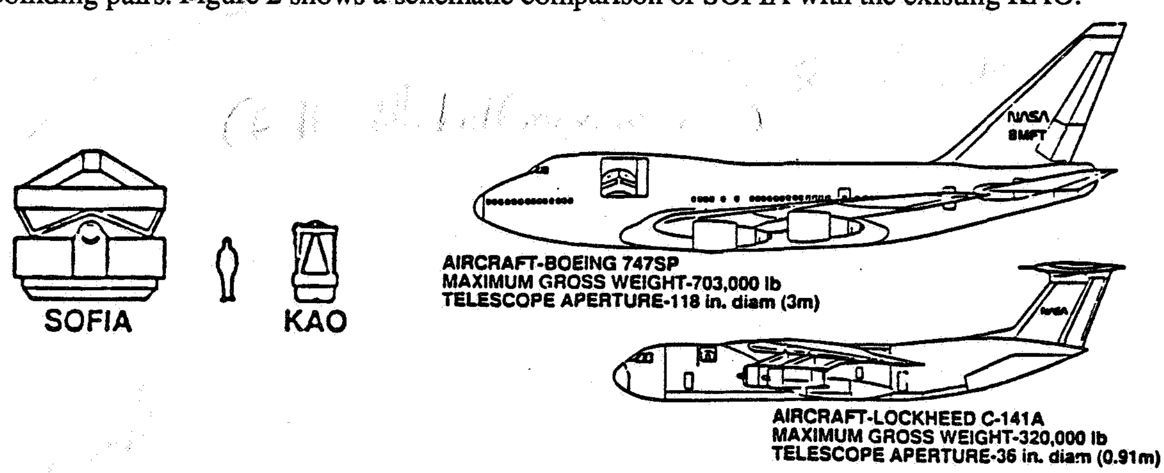

Figure 2: Comparison of 2.7m SOFIA and 747SP with existing 0.91m KAO and C-141

The design for SOFIA relies heavily on the successful technology of the KAO, which has demonstrated excellent stability for an open-port telescope operating at high altitude in a modern jet transport. Studies of telescope structure, mirror technology and support, aerooptics, and servo system design that have been carried out in the US and Germany over the past few years give us confidence that extrapolation of KAO technology to the larger size of SOFIA will be possible. One of the great successes of the KAO during the last 15 years has been the focal plane instrumentation that it has spawned. With instrumentation that is accessible from one flight to the next, and usually even during a flight, instruments become more sensitive and reliable with each flight series, and innovation is encouraged. This innovation has fed directly into the design of space infrared telescopes. Research on SOFIA will follow this tradition. Accessibility of focal plane instruments, and efficient instrument installation between flights are high priorities to the facility designers. The sketch below shows how the telescope will fit into the fuselage of the 747, and the light path from the telescope (at ambient temperature and pressure) through the air-bearing on which it is suspended, into the cabin.

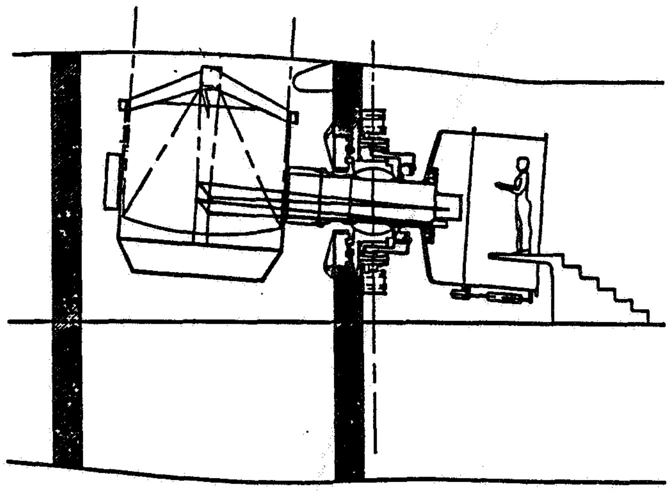

Figure 3: Cutaway view of the lightpath in SOFIA

Several technical challenges are being met by the SOFIA design team. In order to fit inside the fuselage of this airplane, an f/1.2 primary mirror must be fabricated, and in order that the thermal time constant and weight be minimized, the mirror must be very thin. Present plans call for a thin meniscus of low thermal expansion glass. Mirror thicknesses of the order of three inches or less, corresponding to thermal time constants of just two hours have been investigated. Clearly, the support system must be carefully designed, to fulfill the requirement that this mirror be diffraction limited at $\lambda > 30\mu m$. Though such a mirror has never been made, several manufacturers agree that it is possible. The large airbearing that supports the telescope requires special design considerations and innovative engineering but, like the mirror, is achievable with present technology.

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