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Final Technical Report:

“KWIC: A Widefield Mid-Infrared Array Camera/Spectrometer for the KAO”

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KWIC Instrument. The Kuiper Widefield Infrared Camera (KWIC) is an imaging spectrometer designed for use on the Kuiper Airborne Observatory between 18 and 40 μm . The spectral resolution achieving devices are two fully tunable and scanning cryogenic Fabry-Perot interferometers that employ free standing metal mesh as the reflective surfaces. The detective device is a 128×128 pixel Si:Sb BIB array manufactured by Rockwell/Boeing for the SIRTf project. The plate scale for KWIC (one pixel subtends $2.73'' \times 2.73''$) was chosen so as to more than fully sample the KAO beam ($\sim 9''$ at 31.5 μm), to enable effective image restoration techniques to be applied. Even so, KWIC has a rather large ($5.8' \times 5.8'$) field of view. KWIC has both high and low spectral resolution modes that are interchangeable in a few minutes time in flight on the KAO. The high resolution ($R \equiv \lambda/\Delta\lambda = 1000$ to 6000) mode is suitable for detecting weak lines in the presence of strong continuum for Galactic sources, and for resolving broad extragalactic lines. The low resolution ($R \sim 30$ to 100) mode is suitable for imaging in the thermal dust continuum.

KWIC performed very well on each of its five KAO flights. We reached background limited performance in the low resolution mode, and were within a factor of 2 or so in the high resolution mode. Due to limited flight time, most of the data we obtained was in low resolution mode.

KWIC Science. KWIC was successfully developed under the KAO grants program (NASA grant NAG2-800). First funding arrived in November of 1992, and we flew our first two flights in February of 1994 – just 15 months later. These flights were very successful. We imaged the Orion Nebula in the 37.7 μm continuum and [SiII] 35 μm line and imaged M82 and Arp299 in the 37.7 μm continuum. Our Orion image demonstrates that the 37.7 μm continuum arises in the warm dust associated with the photodissociated surfaces (photodissociation regions, or PDRs) of molecular clouds. We use the brightness and color temperature distribution to ascertain the morphology of the Orion PDR. The images of M82 and NGC Arp299 trace the luminosity of embedded star formation regions in these starburst galaxies, thereby providing an extinction free probe of star formation activity. The far-IR continuum distribution in M82 lies within the molecular ring as traced by its bright CO line emission, indicating that the starburst has fragmented the local ISM into small, mostly photodissociated cloudlets. Close inspection of the minor axis profile indicates a weak (2% of the peak) “plateau” of 37.7 μm flux both north and south of the galactic plane. Therefore, there is substantial warm dust at large (~ 300 pc) scale heights, presumably heated by the UV flux that escapes the nuclear starburst along the minor

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axis. Arp 299 is an extremely IR luminous ($L \sim 8 \times 10^{11} L_{\odot}$) interacting galaxy pair. Our high spatial resolution image resolves the system into its two primary sources: "A", the nucleus of IC 694, and "B", the nucleus of NGC 3690. Source "C", the overlap region, is not apparent as a separate source. Our images permit for the first time estimates of the individual source luminosities: $\sim 3.7 \times 10^{11} L_{\odot}$, $1.8 \times 10^{11} L_{\odot}$, and $0.65 \times 10^{11} L_{\odot}$, respectively for sources "A", "B", and "C". The luminosity of the IC 694 nucleus alone is *ten times the luminosity of M82!*

The [SiII] image of Orion encompassed the entire Orion A HII region and its enveloping PDR. Most of the emission in the PDR regions of the map appears to coincide very well with our 37.7 μm continuum map indicating a PDR origin for the [SiII] in agreement with theoretical predictions. The [SiII] line emission is very clumpy in the PDR directly imaging the clump spectrum indirectly ascertained by examining the distribution and flux ratios of [CII] and [OI] far-IR fine structure line, and high J CO emission. We also detected very strong [SiII] line emission from the embedded BN-KL star formation region tracing the morphology and physical conditions of the high velocity shock from these very young stars.

We were awarded three flights with KWIC for FY95, the last year of the KAO operation. These flights were taken out of Christchurch, New Zealand, and were also very successful. Our primary goal was to image the Galactic Center in the 31.5 and 37.7 μm continuum. We were able to image the entire circumnuclear ring (CNR), thermal and non-thermal arches, and sickle/pistol region in the 37.7 μm continuum, and all but the non-thermal arches, and sickle/pistol region in the 31.5 μm continuum. The raw images have a spatial resolution of $\sim 8.5''$ and cover a region roughly $15'$ (RA) by $25'$ (Dec.) in extent. This large data set is split into two parts for publication. The first paper, on the CNR is to appear in ApJ in February, 99. This paper covers the innermost $2.8' \times 3.6'$ (6.9×9.1 pc) regions roughly centered on Sgr A* where the high signal to noise permits image restoration to $\sim 3.6''$ to $5.7''$ spatial resolution at 31.5 and 37.7 μm , respectively. These images clearly delineate the warm dust in the "mini-spiral", but also show an elliptical structure centered on Sgr A* and intersecting the mini-spiral at the western arc that we identify as the photodissociated inner rim of the circumnuclear disk (CND) or ring. This is the first image of the complete disk, and the first image of both the mini-spiral and CND in a single tracer, thereby permitting detailed studies of the intimate association between these two structures. The 31.5/37.7 μm color temperature map indicates that most of the far-UV flux required to heat the dust grains must come from centrally located sources. The cluster of HeI emission line stars recently identified near Sgr A* is sufficient to provide half the heating for the far-IR ring and mini-spiral structures, the balance is likely provided by O and B stars associated with the cluster. We also find ~ 16 color temperature peaks distributed within the CND that we suggest are the locations of early type (B4 to O9) main sequence stars. To match the observed far-IR fluxes from the ring, we require an unusually high 30 to 40 μm dust grain emissivity and/or an unusually high UV albedo.

Our second paper addresses the source of ionization for the thermal arches. The paper is based on the large scale KAO image, but also includes [NeII] (12.81 μm), [SiV] (10.52 μm), and 11.3 μm UIR spectra spectra taken with SpectroCam-10 on the Hale 200" telescope. Our data strongly supports internal ionization for most of the thermal arches. The overlap of [NeII], radio continuum, and far-infrared continuum emission from the arches, the progression of widths

([NeII] is narrowest, far-infrared is widest), and temperature peaks on the arches are naturally explained by internal heating. If the stars are embedded, the generally uniform luminosity and temperature of the arches places an upper limit of O9 or B0 for the luminosity of the stars. This is consistent with the upper limit determined from the non-detection of [SIV] and the observed [NeII] line flux. The far-infrared luminosity and radio continuum emission integrated over the thermal arches are consistent with an embedded star cluster with its main sequence headed by ~ 57 O9 stars. The morphological and age problems generally associated with internal ionization of the arches may be solved if the arches are taken to be tidally stretched clouds which are older than a few million years. This paper was just recently submitted to the Astrophysical Journal.

We also obtained two color images of the 30 Doradus region of the Large Magellanic Cloud (LMC) and deep images of the η Carinae nebula. These data were obtained very late into this grant, and were primarily analyzed under the follow-up data analysis grant "KIWC: A Widefield Mid-Infrared Array Camera/Spectrometer for the KAO", NAG2-1072.

The KWIC grant produced one PhD: "High Spatial Resolution Mid and Far-Infrared Imaging of the Galactic Center" by Harri Michael Latvakoski. and has already or will soon result in over thirteen publications including:

"KWIC: A Widefield Mid-Infrared Array Camera/Spectrometer for the KAO" G. J. Stacey, T. L. Hayward, H. Latvakoski, & G. E. Gull, *Infrared Detectors and Instrumentation*, SPIE Proceedings, 1946, 238 (1993).

"The Kuiper Widefield Infrared Camera (KWIC)", G. J. Stacey, T. L. Hayward, H. Latvakoski, L. Peng & G. E. Gull, in proceedings of the Second Cologne - Zermatt. Symposium on the Molecular Clouds, 362 (1995).

"The Kuiper Widefield Infrared Camera (KWIC)", H. Latvakoski, G.J. Stacey, T. L. Hayward, G.E. Gull, & L. Peng, in Proceedings of the Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust, ed. M.R. Haas, J.A. Davidson, & E.F. Erickson, (San Francisco: ASP), 539 (1995).

"KWIC Imaging of the Orion Nebula", G.J. Stacey, G.E. Gull, T.L. Hayward, H. Latvakoski & L. Peng, in Proceedings of the Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust, ed. M.R. Haas, J.A. Davidson, & E.F. Erickson, (San Francisco: ASP), 215 (1995).

"38 Micron Images of Galaxies: The Infrared Luminosity", G. J. Stacey, T. L. Hayward, G. E. Gull, & H. Latvakoski, in "New Extragalactic Perspectives in the New South Africa: Changing Perceptions of the Dust Content, and Dust to Gas Ratio in Galaxies", ed. D. Block (Kluwer Academic), 513 (1996).

"KWIC Imaging of the Galactic Center", H. M. Latvakoski, G. J. Stacey, T. L. Hayward, & G. E. Gull, in 4th ESO/CTIO Workshop: The Galactic Center, ed. R. Gredel (San. Francisco, ASP 102) 106, (1996).

"Kuiper Widefield Infrared Camera Far-Infrared Imaging of the Galactic Center: The Circumnuclear Disk Revealed", H.M. Latvakoski, G.J. Stacey, G.E. Gull, & T. Hayward, Ap.J. 511, 000 (1999).

"High Resolution Far-infrared Observations of the Galactic Center Arches: A Case for Internal Heating", H.M. Latvakoski, G.J. Stacey, G.E. Gull, & T. Hayward, submitted to ApJ (1999).

"Mid-Infrared Imaging of the Circumnuclear Ring: Clumps and Streamers at Arcsecond Resolution" H.M. Latvakoski, G.J. Stacey, G.E. Gull, & T. Hayward, to be submitted to ApJ (1999).

High Spatial Resolution Far-IR Imaging of the Orion Nebula: Clumps and Jets at the 0.02 pc Scale", G. J. Stacey, G. E. Gull, T. L. Hayward, H. Latvakoski, and L. Peng to be submitted to ApJ (1999).

"A Comprehensive KAO/ISO Far-Infrared Study of M82: Defining the Starburst" C.M. Bradford, H. Latvakoski, G. E. Gull, T. L. Hayward, L. Peng, and G. J. Stacey in prep.

"[SiIII] Imaging of the Orion Nebula: Clumpy Structure of the Interface and a Dissociating Shock at KL" G. J. Stacey, G. E. Gull, T. L. Hayward, H. Latvakoski, and L. Peng in prep.

"Far-Infrared Imaging of the 30 Doradus Starformation Region" T. L. Hayward, G. E. Gull, H. Latvakoski, and G. J. Stacey in prep.

There were no inventions under this grant.