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IMAGE RESTORATION AND SUPERRESOLUTION AS PROBES OF SMALL SCALE FAR-IR STRUCTURE IN STAR FORMING REGIONS

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This paper reports on far-infrared continuum studies from the Kuiper Airborne Observatory that are designed to fully exploit the small-scale spatial information that this facility can provide. This work gives us our clearest picture to date on the structure of galactic and extragalactic star forming regions in the far infrared. Our work is presently being done with slit scans taken simultaneously at 50 and 100μm, yielding one-dimensional data. Scans of sources in different directions have been used to get certain information on two dimensional structure. Planned work with linear arrays will allow us to generalize our techniques to two dimensional image restoration.

For faint sources, spatial information at the diffraction limit of the telescope (λ/D~23" at 100μm) is obtained, while for brighter sources, nonlinear deconvolution techniques have allowed us to improve over the diffraction limit by as much as a factor of four. Information on the details of the color temperature distribution is derived as well. This is made possible by the accuracy with which the instrumental point-source profile (PSP) is determined at both wavelengths. While these two PSPs are different, data at different wavelengths can be compared by proper spatial filtering as described below.

Our ability to do image restoration in the far-IR depends on having PSPs that are stable and well determined. Three effects can determine the shape and size of our PSPs; seeing, telescope tracking and scanning errors, and diffraction. The first may be considered to be <2", assuming that the usual wavelength scaling law can be applied to the visual seeing. Using our technique of focal plane tracking with reflected stage motion, the second effect is held to this amount as well. Since the far infrared image profile on the KAO is therefore dominated by diffraction, and since the geometry of the telescope and photometer optics is invariant, it is not surprising that the PSPs are, in practice, extremely reproducible. Intercomparison of independent PSP data sets justifies the above discussion. On this spatial scale, the only sources in the sky that are justifiably good point sources in the far-IR are bare rocks in the solar system such as asteroids and moons, which subtend less than an arcsecond on the sky . We have used bright asteroids and Galilean satellites for this purpose with considerable success.

Scans at 50 and 100μm are compared using a beam matching procedure that is described in Lester *et al.* 1986 (Paper 4). This is based on a restoring function derived directly from the spatial transforms of the respective PSPs that, when convolved with the 50μm data, produces that 50μm profile that *would have been seen* had the 50μm data been taken in a beam with exactly the same shape as the 100μm beam. Effectively, this degrades the resolution of the diffraction limited 50μm profile to match that at 100μm, so the resulting ratio gives color temperature information on the scale of the 100μm beam. This analysis is of value not only for obtaining temperature information on a small scale, but for large scales as well, in which low flux levels surrounding a bright source would otherwise be confused by the wings of the beam. This latter point is well illustrated in Paper 4, in which a steep temperature rise near the ionization front in the S140 molecular cloud was clearly detected, even though the front is only 1 arcminute away from a cluster of compact sources (the protostellar cluster) that are factor of 20-50 brighter through our slits.

Considerable effort has been devoted to implementing deconvolution algorithms. Non-linear deconvolution methods offer the potential of superresolution -- that is, inference of power at spatial frequencies that exceed D/λ. This remarkable potential is made possible by the implicit assumption by the algorithm of *positivity* of the deconvolved data, a universally justifiable constraint for photon processes. We have tested two nonlinear deconvolution algorithms on our data; the Richardson-Lucy (R-L) method and the Maximum Entropy Method (MEM). We have found MEM to be mathematically superior though R-L can be computationally more advantageous. A comparative discussion of these methods in the context of our data on M51 can be found in Lester, Harvey and Joy (1986, Paper 1).

What are the limits on the spatial resolution that can be achieved through image deconvolution? The answer is clearly a function of S/N on the object in question, but is also inextricably connected to the accuracy with which the PSP is known, and its stability between calibration objects. Even for infinitely bright objects, positional errors (in tracking and scanning) limit the resolution that can be achieved. While numerical image modelling experiments can give a general answer to this question that can be applied to different situations, our work on deconvolving independent PSPs with each other, and our work on the bright and (evidently) point-like object IRC+10216 (Lester, Harvey and Joy 1986, Paper 2) give similar limits that are derived in a more practical way. Our deconvolution of IRC+10216 at 50 and 100μm indicates a profile with FWHM<3" at 50μm and <6" at 100μm. *These limits are nearly a factor of four smaller than the FWHM of the diffraction spot of the telescope , approach that obtainable at other wavelengths , and are nearly a factor of five smaller than that previously achieved in the far -infrared.*

Our techniques have revealed the presence of a far-IR hole in the center of the spiral galaxy M51 (Paper 1) that indicates a deficit of star formation there. We have shown that the extended molecular outflow source IRC+10216 is remarkably compact compared with the molecular cloud that surrounds it. Substantial revision of the grain heating model for this source will be required to account for the invisibility of the surrounding cloud in the far-IR. In this same paper, we have shown that the distribution of cool dust in the planetary nebula NGC7027 is essentially identical to that of its ionized gas. While cold dust may surround this planetary, most of the luminosity arises from within the ionized region (Paper 2). Our observations of the extraordinary IRAS galaxy Arp 220 have been used to set limits on the size of the starburst there that are a factor of three smaller than those found from the IRAS data. When converted to optical depth, our size, flux and temperature information indicates that $A_v>25$ towards the center of this source (Joy *et al.* 1986, Paper 3). Our measurements of the protostellar cluster in S140 (described in part above), whose three near-IR components are separated by 10-20", has resulted in total bolometric luminosities for each of the cluster members, as well as the temperature distribution of the cloud around them (Paper 4). Deconvolved slit scans parallel and perpendicular to the bipolar structure in the outflow region S106 show evidence for a doughnut-like structure with its axis oriented parallel to the outflow when the 50 and 100μm data are combined to give column density profiles. This is the first far infrared detection of such a disk (Harvey, Lester, and Joy 1986 ApJ, submitted).

Joy, M., Lester, D.F., Harvey, P.M., and Frueh, M. 1986 *Ap.J.*, in press Aug.1. (Paper 3)
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