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Pixon Deconvolution of Far-Infrared Images from the UT Multichannel Photometer

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Abstract. Experiments with Pixon-based image deconvolution demonstrate that this technique can significantly enhance the spatial resolution of two-dimensional images acquired by the UT multichannel far-infrared photometer. A deconvolved 100μm image of the giant HII region NGC 3603 reveals a bright, asymmetrical central peak some 40×55 arcsec in size, possibly surrounded by several secondary peaks. The results using the pixon technique are compared with those obtained using the standard Maximum Entropy and Richardson-Lucy methods.

1. Introduction

The UT multichannel photometer, which is described in detail in an accompanying paper (Harvey *et al.* 1994), consists of a set of 20 ^{3}He-cooled bolometers arranged in two rows of ten. The detector spacing is chosen to be compatible with the diffraction limit of the KAO telescope in the 50μm and 100μm bands. Two-dimensional images are made by scanning the detectors across the source.

The combination of a stable, well-measured point-spread function (PSF) and a good signal-to-noise ratio should make it possible to use deconvolution techniques to achieve significant improvements in the resolution of images of bright sources taken with this instrument. This contribution describes a series of experiments with the promising new Pixon deconvolution technique and the older Richardson-Lucy (RL) and Maximum Entropy (MEM) methods.

2. Input Data Set

The data set chosen for these tests is an image of the bright HII region NGC 3603 taken in the 100μm bandpass on 10 April 1991. The data consist of three sweeps across the source in the direction perpendicular to the length of the detector array. The image was constructed by forming the weighted average of the detector responses, using the **kaoin** task in **MIRIAD** (Wright and Sault, 1993). The PSF was measured by observing the asteroid Ceres in the same way. The Ceres image was then rotated (using IRAF's **rotate** function) to make its mean sweep direction equal to that in the NGC 3603 image. The results are presented in Figure 1a-c.

Comparison of the NGC 3603 image with the PSF shows that the HII region is clearly resolved, and a good candidate for deconvolution. The fact that the valid data in these images are of different sizes and do not fill out the entire image arrays represents a challenge to any deconvolution algorithm. This is especially true since the emission from the NGC 3603 region extends beyond the area measured by the scans, which produces the potential for strong edge effects. The Pixon and RL codes used for this work allow the valid regions of the data array to be specified in order to ameliorate these effects; the MEM code does not.

The uncertainty in the input image is not measured independently of the image itself. Instead, it is chosen to be uniform across the image and large enough to produce a reasonable-looking result in the first goodness-of-fit (GOF) run of the Pixon procedure.

3. Deconvolution Results

3.1. Pixon Method

The Pixon deconvolution method (Pina and Puetter, 1993) is a Bayesian approach based on the concept of the Pixon, defined as the fundamental unit of picture information. Pixons, rather than pixels, represent the degrees of freedom in the image. One seeks the most probable image and model given the data. The deconvolution is carried out by alternating between a simple GOF calculation to find the most probable image given a fixed model, and calculating an improved model while holding the image fixed. The implementation used here is by Pina and Puetter (1993). It permits both the image weights and a mask for the pixels outside the image to be specified. The result from the first iteration is presented in Figure 2a.

3.2. Richardson - Lucy Method

The Richardson - Lucy method is a widely-used iterative approach derived from Bayes' Theorem (Lucy 1974). Unlike the Pixon method, RL requires one to decide how many iterations to perform; the apparent resolution of the deconvolved image increases with the number of iterations as the goal of maximum likelihood of the image is approached, and it is quite possible to overfit the data and produce spurious features. The result is presented in Figure 2b. The implementation used here is from the STSDAS package in IRAF. The edge effects are reduced by allowing the algorithm to extend the area covered by the deconvolved image beyond the region for which there is data.

3.3. Maximum - Entropy Method

Maximum Entropy methods seek to maximize an "entropy" function of the image within the constraints of the data. The entropy is generally defined in terms of an image prior which can incorporate *a priori* information into the deconvolved image. The MEM package used here is from the STSDAS package in IRAF. The number of iterations in these runs is limited to about 110; at this point the

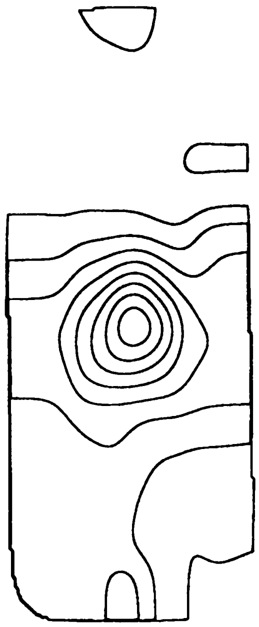

Figure 1a
Input Image

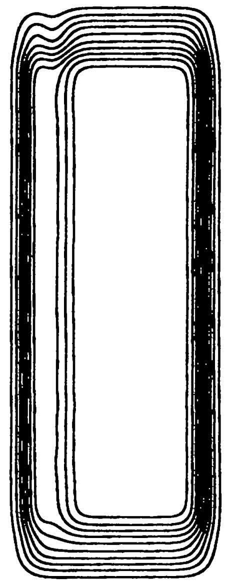

Figure 1b
Image Weights

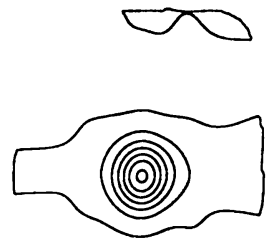

Figure 1c
Ceres PSF

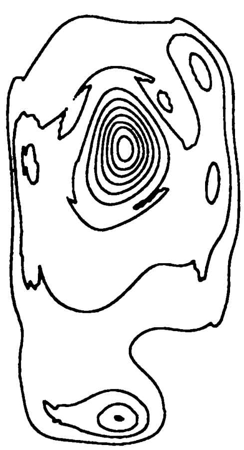

Figure 2a
Pixon

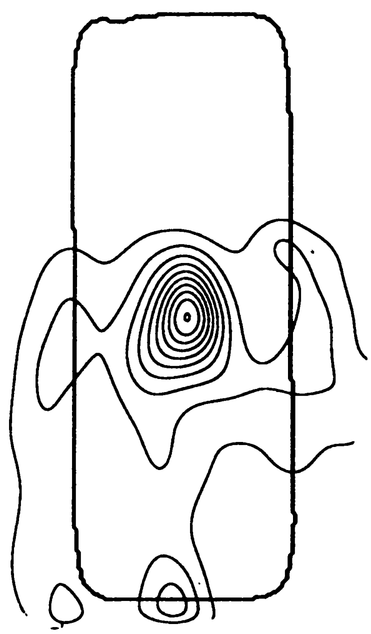

Figure 2b
Richardson-Lucy

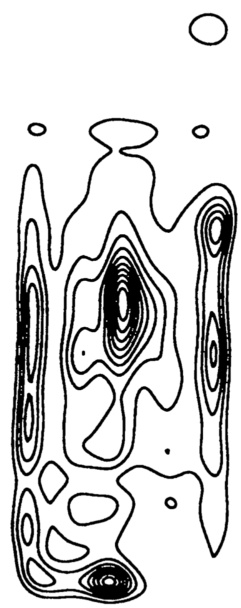

Figure 2c
Maximum Entropy

χ^2 value approached, but did not reach, its expected value. This may be an indication that the noise level has been somewhat underestimated.

The deconvolved image, presented in Figure 2c, is strongly affected by edge effects which are manifested as spurious emission which roughly traces out the edges of the valid data. The overfitting of the data is reduced somewhat as the size of the Intrinsic Correlation Function (ICF) is increased, but a really satisfactory deconvolution is never achieved.

4. Conclusions

It is clear from the numerical tests presented here that the resolution of the input image can be usefully increased by deconvolution. The three deconvolution techniques produce results which appear basically consistent with each other. In all three cases the deconvolved image consists of a bright asymmetrical central peak roughly 20×35 pixels in size and roughly triangular in shape. This result seems consistent with what is expected from a simple visual comparison of the input image with the PSF.

For the present data set, which is typical of many images constructed from data acquired with the UT multichannel far-infrared photometer, the most important determinant of the success of a technique appears to be the inclusion of some mechanism for specifying the range of pixels over which the data are valid. When this is not done, strong edge effects result which influence the shape of the central peak in the reconstructed image.

The Pixon and Richardson-Lucy methods do best, probably by virtue of their implementations' inclusion of image weights. The best RL reconstructions appear nearly free of edge effects within the region of the image which corresponds to the original measurements. It has the further advantage of requiring much less computer time to run (minutes *vs.* hours). These properties make it the most suitable technique of the three for the present data set. The more sophisticated handling of image noise by the Pixon method may give it an advantage when working with data of lower quality.

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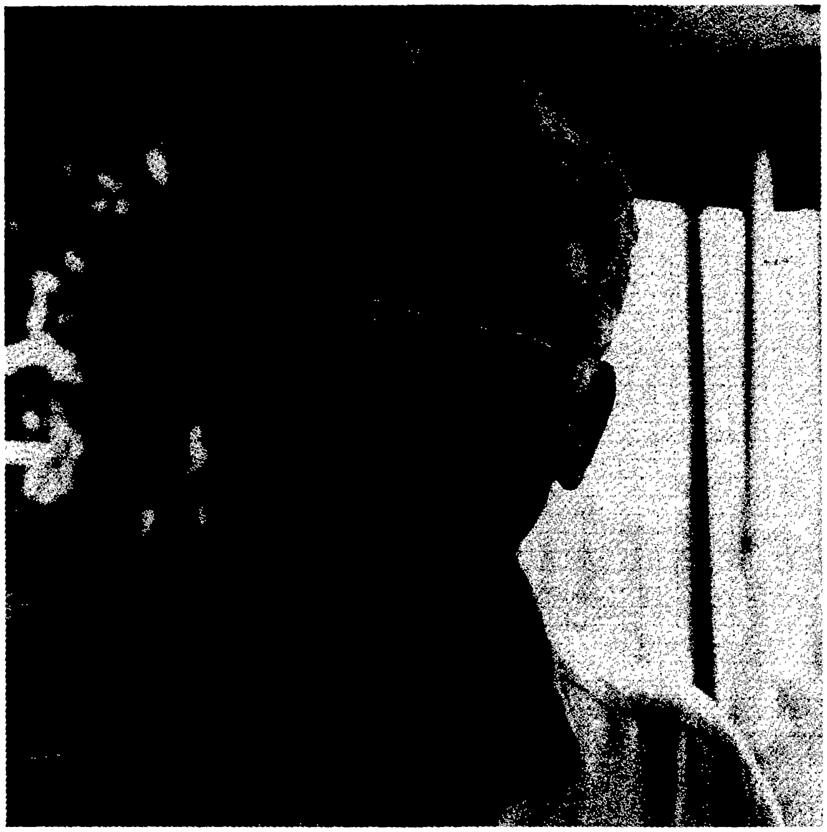

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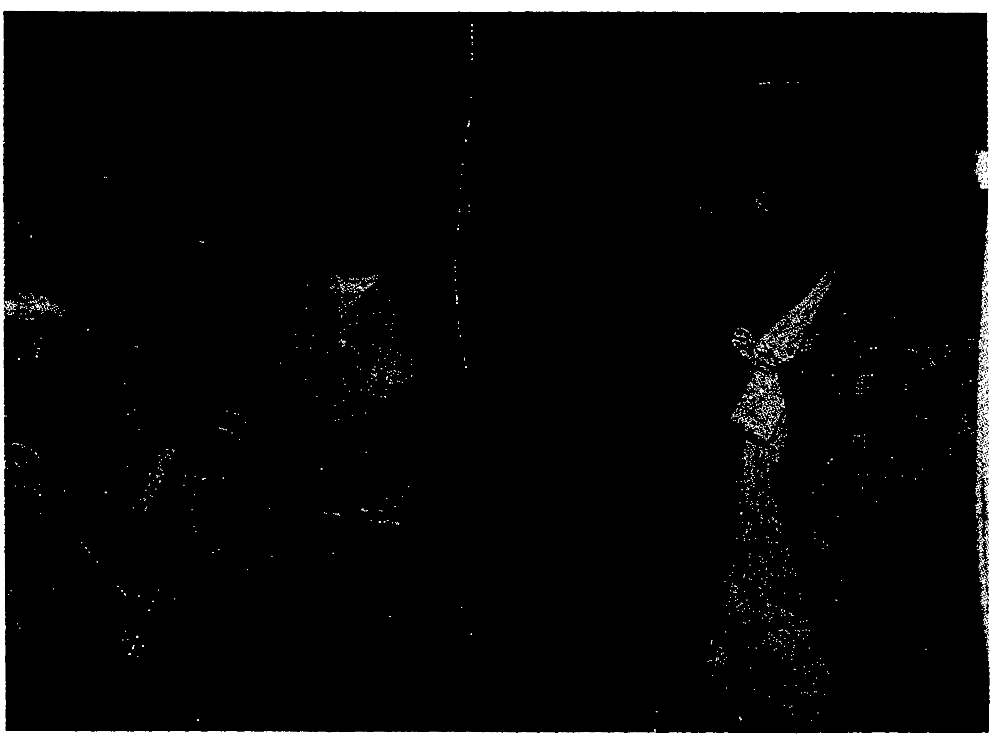

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