WORKSTATION-BASED PREPROCESSING OF IRAS SKY-FLUX IMAGES

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ABSTRACT

We have developed and implemented computer algorithms to remove two types of degradations in IRAS sky-flux images: slowly varying background illumination (strongly effected by the presence of zodiacal light) and periodic stripes. This paper discusses both algorithms in detail and shows results of its use on various sky-flux images.

Focus of the work was on the implementation within a workstation environment and its value as a preprocessing tool for researchers: Speed of the process, usability of the programs, and correctness of the results were our main goals in developing these tools.

Key words: IRAS sky-flux images—preprocessing—destriping—flattening—Fourier space algorithms

1. Introduction

Researchers working with currently available IRAS (Infrared Astronomical Satellite) sky-flux data have been hampered in their work due to the undesirable effects of slowly varying background illumination within sky-flux plates and of periodic distortions, producing sinusoidal stripes in the image.

The Infrared Processing and Analysis Center, IPAC, is trying to effectively remove these degradations by reprocessing original source data. New sky-flux data are expected in the near future; however, we believe that an independent assessment of background-removal techniques may offer researchers more understanding of the methods involved.

Because products from the IRAS provide major research data sets, it is necessary to remove degradations to utilize sky-flux images to their fullest extent. We succeeded in developing a procedure that would remove these degradations but still preserve essential image information. The procedure we implemented is fast, fully automated, and programmed in Interactive Data Language (IDL) which is becoming a widely used software platform in the scientific community (Stern 1984; Varosi, Landsman, and Pfarr 1990).

Section 2 gives a mathematical and technical explanation of the algorithm for flattening the uneven background flux; Section 3 explains the algorithm to remove stripes and compares the method to the one developed by Van Buren (1987); Section 4 summarizes the effect of the restoration techniques through several examples. The thus-restored IRAS sky-flux images are used at the Center for Astrophysics and Space Astronomy (CASA) as a basis for various astrophysical research efforts, such as in multiwavelength analysis (Sakan, Shull, and Fesen 1990), and an investigation into the use of IRAS images for the detection of Herbig-Haro objects (Domik and Brugel 1990).

2. Flattening of Background Flux

Variation of the position angle between the data-collecting platform and the Sun is the main cause of gradient background flux increase or decrease. This causes problems in the visual and numerical analysis of sky-flux images, because pointlike and extended sources of similar power cannot be compared anymore numerically or visually if they appear sufficiently apart in the image. A sky-flux image, $I$, degraded by varying background flux, can be approximated by equation (1):

$$I(x,y) = F(x,y) + Z(x,y)$$

(1)
where $F$ is the flux image without degradations, $Z$ denotes the slowly varying background values, and $(x,y)$ indicate the two spatial dimensions.

Figure 1(a) shows an example of sky-flux plate 75 (25 μm), centered at a right ascension of 4 hours and a declination of 15°. Flux values at the left upper corner are elevated by an average amount of $6.1 \times 10^6$ Jy/sr compared to the lower-right corner.

The amount of relative flux elevation over the image can be approximated by measuring average flux values in the four quadrants of the sky-flux image, after point sources have been removed. Removal of point sources is performed by a median filter with a large (e.g., $11 \times 11$) window size. The degradation is then modeled from four points of estimated background flux as either a plane (least-squares fit) or a hyperbolic paraboloid (Fig. 1(b)). Approximations of higher order might remove structures not part of the background. Removal of the degradation is accomplished by simply subtracting the background model from the image. In order to keep flux values in their intended range, we elevate the result to the average of the original image.

The algorithm can be summarized by the following pseudocode:

1. $I' = F[I]$, with $I$ = orig image (degraded), $F$ = median filter
2. $Z_i = \text{AVG}[Q_i[I']]$, with $Q_i[I'] = i$th quadrant of $I'$, $\text{AVG} \ldots$ average function
3. $Z = \text{BACKGROUND MODEL}[z_i]$, for $i = 1,4$

Implementation of the above algorithm in IDL is fully automated and fast. Availability of information about minimum and maximum flux and size of image as provided with images previously distributed by IPAC is assumed. The result of flattening the image in Figure 1(a) is presented in Figure 1(c). Computation times are summarized in Section 4.

3. Removal of Sinusoidal Stripes

The cause of these degradations lies in the scanning nature of the survey, nonuniform response across each detector, and differences between detectors of the IRAS scanner (Beichman et al. 1985; Kennealy et al. 1987; Whaley 1989). The differing response from each individual detector gives rise to a high-frequency variation and is strongest in bands 1 and 2. Each separate pass of the sensor across the image caused stripes of lower frequencies (approximately 9–11 stripes per image) and is again most noticeable in bands 1 and 2. Removal of periodic stripes is important for the recognition of faint stars and useful background flux information that might otherwise not be detectable in the image.

Periodic features that show up in the form of sinusoidal waves can be more easily identified in the frequency domain than in the spatial domain, because sinusoidal features transform to impulses in the frequency domain. An impulse can be easily identified and removed without accidentally eliminating important signals as well.
Unfortunately, the Fourier components of point sources spread over most of the frequency domain. Table 1 summarizes the information content of an IRAS sky-flux image and its presentation in the spatial and frequency domain.

In order to remove periodic features but none of the image signals requires that a precise elimination process be applied. We have carefully reviewed the algorithm by Van Buren (1987) and found it very useful in several ways:

1. By removing point sources (using upper and lower cutoff values) before the filtering process one reduces the danger of accidentally removing signals from the point sources during the filtering process.

2. By removing only small "wedges" in the frequency domain one again reduces the risk of removing too much of the signal.

We have improved on the above algorithm in two major ways:

1. In order to remove point sources from the original image the user does not need to prespecify cutoff values; instead, the algorithm is able to identify pointlike objects and remove them from the image. User-defined specification of cutoff values caused two problems: for one, the user needed a clear understanding of what range of flux
values represented periodic striping and, therefore, needed to numerically review a number of image profiles; second, even with specifying a perfect upper cutoff value faint point sources were often hidden in the lower values of the periods of the stripes.

2. The program is able to identify a range of angles signifying the slopes of the stripes automatically. This proves very helpful in the overall restoration algorithm in two ways: first, because the program is able to identify the slopes of stripes more accurately and therefore leads to less signal removal later on; second, this step allows the algorithm to become fully automated; there is no need for any type of measurements before the restoration algorithm is started.

The destriping algorithm presents itself in six stages:

<table>
<thead>
<tr>
<th>Step</th>
<th>Pseudocode</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( B = F - P; F \ldots ) flux image</td>
<td>remove point sources from image</td>
</tr>
<tr>
<td></td>
<td>( P \ldots ) point sources</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>( \alpha = \Phi(B) )</td>
<td>calculate direction of slopes for stripes</td>
</tr>
<tr>
<td>3</td>
<td>( B = \mathcal{F}{B} )</td>
<td>transform background into frequency domain</td>
</tr>
<tr>
<td>4</td>
<td>( B' = B \cdot W(\alpha) )</td>
<td>apply appropriate filter over areas affected</td>
</tr>
<tr>
<td></td>
<td>( W(\alpha) \ldots ) frequency filter</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>( B' = \mathcal{F}^{-1}{B'} )</td>
<td>transform background</td>
</tr>
<tr>
<td>6</td>
<td>( F' = B' + P )</td>
<td>add point sources onto background</td>
</tr>
</tbody>
</table>

Details of each step follow.

3.1 Remove Point Sources from Image

To explain our procedure in more detail we used sky-flux plate 75 (HCON 3, band 2) as an example. Figure 2(a) shows a profile of the image in its original version, but after flattening the background. The profile is taken at a declination of \( 9^\circ 59' \). To separate point sources from the background we first median filter the image with a large window size. The window size of the median filter should be large enough to incorporate the image size of all point sources, but a single "correct" value is not intrinsic to the success of the whole algorithm. The upper cutoff value for point sources is then defined at a fraction of a standard deviation from the median values. Figure 2(b) shows the identification of the background: The broken line signifies values at a distance of \( \sigma/8 \) from the median value, where \( \sigma \) is the standard deviation in the image; the solid line shows the thus-identified "background image".

The cutoff distance should be large enough to still identify high-frequency degradations as "background" but low enough to identify point sources as such. By default, the system uses \( \sigma/8 \); however, \( \sigma/8 \) to \( \sigma/4 \) have been empirically defined as good values. Because of our dynamic definition of cutoff values, point sources can be identified even inside the periodic stripes. A profile of the features identified as point sources is presented in Figure 2(c).

3.2 Calculate Direction of Slopes for Stripes

The automated calculation of slopes defining the stripes is performed using a correlation technique between several image profiles. The image profiles are taken from the median-filtered background image (see Fig. 2(b)); thus, the periodic waves caused by the stripes are easily observable. Correlation is performed by shifting one profile line against another and measuring the difference. The difference translates into an error function, whose minimum value relates to the shift of stripes between the two lines.

Because the slope of the stripes changes in the overall image (specifically at the upper and lower edges of the image compared to its center), a range of angles seems more representative than one specific angle. For example, sky-flux plate 75, HCON 3, band 2 (Fig. 1(a)) was found to have stripes between angles of \( 7^\circ \) and \( 13^\circ \).

3.3 Apply Appropriate Filter over Areas Affected

After transforming the image to the frequency domain the disturbing impulses are removed. The location of these impulses is found rotated 90 degrees from the slopes calculated for the image stripes (Gonzalez and Wintz 1987). Because we assume a range of slopes, we remove (or suppress) the values within two wedges, as suggested in Van Buren (1987). See Figure 3 for a step-by-step presentation of the filtering technique.

Because we start off with a flattened background, the most prominent features both visually and numerically are the periodic stripes (Fig. 3(a)). They are even more obvious in the frequency domain (Fig. 3(b)), where they give rise to a series of impulses orthogonal to their direction in the spatial domain. After affected areas have been blocked off (Fig. 3(c)), and an inverse Fourier transform is performed, the image shows reduced periodic degradations. However, depending on processes applied to the raw image, stripes hidden in the background before the process may become visible now. Subsequent passes will remove such stripes, but it is up to the scientist to balance...
eventual loss of signal versus the level of destriping desired. Figure 3(d) shows the level of destriping (7° to 18°) chosen by the authors.

Because the original dynamic range in sky-flux images is usually found between $1.0 \times 10^7$ Jy/sr and $1.0 \times 10^2$ Jy/sr, this would give rise to high values in the frequency domain. Therefore, we normalize the image values by shifting them into the range of [0..1] before taking the Fourier transform. The Fourier-transformed values then lie between a controlled area instead of being data dependent. This facilitates the filter design, which is either a simple mask to set the values inside the wedges to zero or a specifically designed filter affecting only the disturbing impulses in the frequency domain.

3.4 Add Point Sources Back onto Background

After the filtering step discussed above, the background is unfolded into its original dynamic range and point sources are added back into the restored background image. Figure 4(a) shows a profile of the restored image, but before adding point sources. Figures 4(b) and 3(d) show the restored image after adding point sources: Even though the periodic degradations are eliminated, the information of the sky-flux images seems fully contained.

4. Examples of IRAS Preprocessing and Outlook

In order to prove the value of the above-described procedures, we have preprocessed a set of well-published IRAS sky-flux images. Figure 5 shows a series of images from sky-flux plate 77, before and after preprocessing. Note, again, that all the preprocessing is done without user interaction. Overriding the range of slope values by user-identified values before filtering is possible. CPU times for removal of the background is 0.6 minute (Fig. 1(a) to Fig. 1(c)); for destriping we measured 2.6 minutes per 500 × 500 sized sky-flux image (Fig. 3(a) to Fig. 3(d)). CPU times were measured on a heavily used VAXserver 3500.

We believe that the automation of the restoration process, its speed, and its accuracy lend itself to a wide use of applications for researchers dealing with IRAS sky-flux
images. One of the applications of the above-mentioned preprocessing technique at CASA is the use of multiwavelength data in the infrared range to identify Herbig-Haro objects. This research interest evolves from work by E. W. Brugel in the ultraviolet range and will investigate the possibility of color-coding techniques to identify Herbig-Haro objects in IRAS images. Preprocessing as explained in this report is a necessary step if visual interpretation of flux images is to be meaningful. A forthcoming publication will discuss this project in more detail (Domik and Brugel 1990).

Algorithms described in this paper will be made available to the astronomical community as documented and tested IDL programs through the "IDL Astronomical User's Library" (Varosi et al. 1990) by the end of 1990. Inquiries about progress and availability should be directed to Gitta Domik1.

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Fig. 2—Profile at a declination of 9°59' of sky-flux plate 75, HCON 3, band 2, after flattening background. (c) Point sources in the same profile line.

Fig. 3—Sky-flux plate 75, HCON 3, band 2. Right ascension is 4 hours, declination 15° at center of plate. Sky-flux image has been zoomed in to improve visual identification of degradations and enhancements. (a) Flattened background only; most stripes show up at an angle between 7° and 13°.

Fig. 3—Sky-flux plate 75, HCON 3, band 2. Right ascension is 4 hours, declination 15° at center of plate. Sky-flux image has been zoomed in to improve visual identification of degradations and enhancements. (b) Transformation of background image to the frequency domain: Stripes appear orthogonal to original image in the form of a series of impulses.
Fig. 3—Sky-flux plate 75, HCON 3, band 2. Right ascension is 4 hours, declination 15° at center of plate. Sky-flux image has been zoomed in to improve visual identification of degradations and enhancements. (c) Fourier spectrum of image with wedges shown over affected areas.
Fig. 3—Sky-flux plate 75, HCON 3, band 2. Right ascension is 4 hours, declination 15° at center of plate. Sky-flux image has been zoomed in to improve visual identification of degradations and enhancements. (d) After filtering, the sky-flux image shows strongly reduced stripes.
Fig. 4–Profile at a declination of 9°59' at sky-flux plate 75, HCON 3, band 2. (a) After destriping, but before adding point sources (compare to profile line in Fig. 2(b)). Even though the periodic degradations are eliminated, the information of the sky-flux images seem fully contained.
Fig. 5(a)—Original sky-flux image, plate 77, HCON 3, band 1.

Fig. 5(b)—Plate 77, HCON 3, band 1 after flattening and destriping.
Fig. 5(c)—Original sky-flux image, plate 77, HCON 3, band 2.

Fig. 5(d)—Plate 77, HCON 3, band 2 after flattening and destriping.
Fig. 5(e)–Original sky-flux image, plate 77, HCON 3, band 3.

Fig. 5(f)–Plate 77, HCON 3, band 3 after flattening. No destriping necessary.