Responsivity variations in the IRAS survey

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Summary. — The IRAS survey detectors show non-linear characteristics in their gains and baselines. Particularly the 100-μm detectors exhibit photon-induced responsivity enhancements. This behaviour can be described by an exponentially decaying gain enhancement, dependent on previously observed flux. The changes are as large as 16%; the memory effect has a scale length of 35°. Because at 100 μm dust confined to the Galactic plane is the most intense source of emission, these responsibility changes cause considerable deformation of the apparent large-scale Galactic structure. At 12 μm and 25 μm the baseline behaves in a non-linear fashion, but this effect has a much shorter scale length. The baseline behaviour has been modelled by a decaying function composed of the sum of two exponential functions. The scale lengths are 10° and 1°.1 for 12 μm, and 8° and 43° for 25 μm; amplitude changes due to this type of hysteresis are less than 1%. In addition there is a considerable response of all detectors to particles associated with the South Atlantic Anomaly. On-flight attempts to correct for this effect were performed on the 12-μm, 60-μm and 100-μm detectors (but not for the 25-μm ones) in the form of bias boosts. This note presents a correction procedure for the 25-μm detectors.

Keywords: image processing — infrared radiation — instruments.

1. Introduction.

Rather important in the study of large-scale structures using the IRAS all-sky survey maps is the problem of the stability of the detectors over specific time scales. It has been shown (see IRAS Explanatory Supplement, 1985) that the individual detectors were quite stable over long time periods. During calibration, the baseline stability of each detector (which drifted by less than 20% on a time scale of a day) was assumed to vary linearly with time along the scan. Daily corrections were applied, based on observations of the Total Flux Power Reference (TFPR), a region near the north ecliptic pole. Per detector the gain was determined using calibration flashes of the internal stimulator at the start and end of each survey scan. Therefore the baselines and responsivities are known and stabilized on time scales of one survey scan and longer; variations in these two parameters, within a scan, are still present.

The IRAS detectors show three major instrumental effects. The first effect is similar to the conventional concept of hysteresis, in that scanning across a bright source gives a different observed pre-source and post-source background level (see Fig. 1a). The second effect is similar to that involved in pre-flashing a photographic plate; the photon induced responsivity enhancement is such that there is more response to the same intensity level in a high-emission background than in a low one (see Fig. 1b). Both these effects are found for all detectors, but differ in scale length and intensity among the passbands. The third effect, which is predominantly seen at 25 μm, involves the gain response induced by radiation from particles in the South Atlantic Anomaly.

At 12 μm and 25 μm hysteresis is evident in Skyflux maps showing point-like images. Each such image has a cometary tail starting at the 1% source intensity level and fading out over roughly 4 degrees. The scale of this effect does not depend on the local background level. One way to correct for this effect involves deriving a local two-dimensional response curve, i.e. an antenna pattern, from an ensemble of known point sources, and deconvolving the image with this response curve. To allow correct deconvolution, however, the scan coverage and orientation of the empirical antenna pattern should be identical to that of the source we wish to be deconvolved. In general this is not the case. An alternative way to deal with this problem is to describe these tails as a sum of a few exponential functions, for each scan separately. This allows corrections.
To illustrate the large angular extent of the hysteresis effects we compiled maps showing the difference between the HCON1 and HCON3 scans (see IRAS Explanatory Supplement, 1985). These scans are generally separated by about 180° in the scan direction. The top panel of figure 2 shows such a map for the 100-μm material. The bottom panel of figure 2 shows the sky coverage and scan direction for both HCON's. Care must be taken in interpreting such maps, because contamination due to zodiacal emission has not been taken out. The basic problem with zodiacal emission in this map is that the HCON3 observations contain lines of sight at solar-elongation angles that deviate strongly from those used in the HCON1 observations, resulting in a more intense zodiacal surface brightness in the case of the smaller solar-elongation angles in HCON3 (Deul and Wolstencroft, 1988). The detectors should also show the enhancement and hysteresis effects due to the zodiacal emission, but the effects of projection as the Earth travels through the zodiacal dust cloud cause larger deviations. Therefore, we have restricted our analysis to regions of low zodiacal surface brightness differences.

Different regions of the sky, each with different emission characteristics, are represented in figure 2. Region (a) shows the part of the sky, for HCON3 scans, observed after passing over the intense ridge of emission associated with the Galactic equator. The effects of the hysteresis are seen at a maximum level of 16%. Region (b) shows identical differences, but now the HCON1 scans have just passed over the Galactic plane. In region (c) the effects of hysteresis are also present, but cannot easily be unravelled because the scan direction difference between HCON1 and HCON3 scans is generally much less than 180°. Finally, region (d) again shows errors in the range of 16%.

Crosscuts through the maps of HCON1 and HCON3 in areas where we know the scan directions to be approximately 180° apart show the effects of different future/history for opposite scans. Panel (a) of figure 3 gives an example of a set of crosscuts, extracted from the figure 2 maps at λ = 265°, showing the Galactic emission as a sharp peak. Subtracting HCON1 from HCON3 data results in the full drawn line of figure 3b. Deviations of order 16% occur in these cases. This value is an estimate of the maximum error, because these scans cross the most intense region in the sky, the Galactic center.

The errors at 12 μm and 25 μm caused by hysteresis can be estimated by averaging the CRDD (Calibrated Raw Detector Data) scans crossing an ensemble of point sources. The deviations become evident at a level of about 1% of the source flux. Figure 4 shows hysteresis effects in the averaged curves for a large number of point sources. To derive these profiles we identified about a hundred individual point sources, away from the Galactic plane and in positions in the sky where the scan did not cross another point source closer than 6° away.
Because the passing of the telescope over the South Atlantic Anomaly is attended by bias boosts in the 12-µm, 60-µm, and 100-µm bands, these detectors lose the memory of the previous incident radiation, giving a fresh starting point for analysis of non-linear effects. The bias boost by itself can be seen as a flash of extremely high photon dosage causing a decaying of the gain enhancement over very long scales (exponential decay times of up to 180° have been derived by IPAC). At 25 µm the effect of near SAA passings is evident in any Skyflux map, extending over at least one whole scan. Figure 5 shows a cross-scan cut through Skyflux HCON1 plate 81 along the ecliptic equator. The vertical scale represents percentage error. These percentage errors were determined by calculating the difference between the lower envelope polynomial fit to the cross-scan cut and the intensity at every point on the cut. The regular pattern is caused by the lunes scanning mode used in HCON1. This pattern is not characteristic only of the 25-µm data; the other wavelengths show similar structure at lower intensity levels.
3. Models describing the gain and baseline changes.

Descriptions of analytical, *ad hoc* approximations to the three main detector effects found in the IRAS observations are given in this section. The enhancement at 100 \(\mu\)m is the result of an increase in the gain of a detector and to a lesser extent is due to true hysteresis effects. The decay of the enhancement shows an exponential behaviour. Therefore, we describe the enhancement as a change in the gain, at a given position, as a function of the previously observed data points, weighted with an exponential decay function. In principle every detector should be considered separately, but because we are mainly interested in the large-scale effects, we use the focal-plane averaged data of the Zodiocal Observation History File. Thus the gain at the time of observation depends on the intensity of the previously observed emission. The flux output for a current data point, \(F_{100}(t)\), may then be written in terms of the focal-plane averaged, infalling flux at the time of the

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obtaining an acceptable fit to the tail-like structures seen in the Skyflux maps at 12 μm and 25 μm required the sum of two exponential functions of different scale lengths. These two exponential functions can appropriately describe the fast decay right after the point source, and the long tail remaining at larger distances. In fact for the CPC observations, a three-component model was necessary to model the observed gain and baseline changes (Wesselius et al., 1985). In all cases examined the intensity of the tails is independent of the background level. Therefore, it must be a baseline effect (hysteresis) instead of a gain change. We could describe the baseline change as

\[ B(f_1, \sigma_1, f_2, \sigma_2, t) = f_1 \exp \left( -\frac{t}{\sigma_1} \right) + f_2 \exp \left( -\frac{t}{\sigma_2} \right), \]

where \( f_1, f_2 \) and \( \sigma_1, \sigma_2 \) are the scaling factors and decay times for both exponentials.

The observed intensities can then be written as

\[ F_{12,25}^{\text{obs}}(t) = G_{12,25}(t) F_{12,25}^0(t) \]

where \( F_{12,25}^{\text{obs}}(t) \) is the observed focal-plane averaged flux at time \( t \), \( F_{12,25}^0(t) \) is the infalling focal plane averaged flux, \( G_{12,25}(t) \) is the gain at time \( t \), and \( t' \) is the time at which the point source responsible for the tail was observed. Least-squares fits of this model to a large number of individual point sources provides the parameters listed in table I.

The gain enhancement due to near approaches to the SAA, most obvious at 25 μm, may be simply modelled assuming that the gain change is dependent on the longitudinal distance between the geographic longitude of the scan and that of the central SAA longitude. The calibration team at IPAC have found that a dependence of this sort is present in the data. A full description of this effect will be available when the Super Skyflux data version is prepared. We assume, furthermore, that the gain change is constant throughout the scan; this is reasonable because it is clear from the all-sky maps that the gain change does not vary significantly throughout a scan at 25 μm. It was found that the gain change for each scan could be described by

\[ G_{25}(t) = \left( \frac{f}{1 + |D(t)|} + 1 \right) G_{25}^0, \]

where \( G_{25}(t) \) is the gain at time \( t \) (the time of the mid-scan point), \( D(t) \) is the geographic longitudinal distance of the telescope at time \( t \) toward the SAA longitude, and \( f \) is a scaling factor. \( D(t) \) is

\[ D(t) = \text{Mod} \left( 360, \frac{t_0 + t}{0.1139696} \right) - \lambda_{\text{SAA}}, \]

where \( t_0 \) is the starting time such that \( D(t_0) = 0.0 \), the constant defining the orbital period in (degrees geographical longitude)/sec., and \( \lambda_{\text{SAA}} \) is the central SAA geographical longitude (325°). The values derived for \( f \) and \( t_0 \) are 0.04 and 63080400 seconds after 0 hours 1 January 1981 UT. This \textit{ad hoc} method reduces the large-scale errors to 2-3% as illustrated in figure 4.

4. Summary.

IRAS detector reliabilities on time scales of order one survey scan and less have been addressed. We find that photon-induced responsivity enhancement and hysteresis effects occur at all wavelengths, with different scale lengths in each IRAS band. Corrections for these effects have been derived in an \textit{ad hoc} fashion.

At 100 μm the photon induced responsivity enhancement can be fit using a gain enhancement function described by a
decaying exponential that weights the previously observed flux to create the observed memory effect. An exponential decay time of 530 seconds and a maximum error of 16% were derived.

The hysteresis effect, at 12 µm and 25 µm, gives rise to a short-scale exponentially decaying baseline offset. The tail-like structure observed after each point source can be modelled using a decaying function composed of two exponential functions. The least-squares decay times for the longer scale exponentials are 1°1 and 0°72 for 12 µm and 25 µm, respectively. The tail structures become important at a level of 1% of the source flux.

The enhancement effect on the gain caused by near approaches to the SAA was modelled at 25 µm using an inverse proportionality of the distance modulus between the central SAA geographical longitude and the geographical longitude of the orbit considered. This allowed a reduction of the observed striping to 2-3% of the general background.

For the creation of all-sky maps we need infrared data which are relatively free of the instrumental effects considered here. Because the algorithms work on scan data only, and because we are mainly interested in the large-scale structure of the infrared sky, we have applied the corrections to the Zodiacal Observation History File material. The long-scale hysteresis and baseline effects at passbands other than 100 µm are known to be much smaller (see IRAS Explanatory Supplement, 1985). Because we were unable to derive any quantitative measure for these effects at 12 µm, 25 µm and 60 µm, we applied the first algorithm to the 100-µm data only. The second algorithm (point source tails at 12 µm and 25 µm) proved to insignificantly correct the data. Therefore, we refrained from applying this correction to the full IRAS dataset. The third algorithm (for near approaches to the SAA) was applied to the 25-µm data only, because only for this wavelength does near SAA passage cause detectable effects. The resulting dataset is organized similarly to the Zodiacal Observations History File, but has corrections applied to the 25-µm and 100-µm data.

We are thus able to create all-sky maps which are relatively free of detector effects (Fig. 6 presents for all IRAS passbands a selected area of the sky in Galactic coordinates). We have created sky maps in Galactic coordinates, covering the entire longitude range and spanning from −60° to +60° in Galactic latitude. The sampling interval is 0°25 in both coordinates. These maps will be used in the further analysis of the large-scale infrared structure of the Galaxy.

References


| 12 µm | 0.01 ± 0.05 | 10' ± 2' | 0.0025 ± 0.0003 | 1'1 ± 0'1 |
| 25 µm | 0.01 ± 0.005 | 8' ± 2' | 0.0025 ± 0.0003 | 43' ± 5' |
FIGURE 6. — Grey scale and contour plots of the four IRAS bands for all Galactic longitudes ranging from $-24.5 \leq b \leq 24.5$. Contour range from 1.0 to 8103 MJy sr$^{-1}$ (100$\mu$m), 4447 MJy sr$^{-1}$ (60$\mu$m), 2321 MJy sr$^{-1}$ (25$\mu$m), and 2539 MJy sr$^{-1}$ (2$\mu$m) in logarithmic steps, respectively. These maps have the zodiacal light subtracted according to the model of Deul and Wolstencroft (1988). They show that, after responsivity correction as discussed in the text, little instrumental artifacts remain other than those corresponding to the inaccuracy of the zodiacal model.
FIGURE 6 (continued)