SIRTF Background Estimation: Methods and implementation

William T. Reach, SIRTF Science Center

May 12, 1998 (concepts and requirements),
May 19, 2000 (methods and results; revised)

I. Introduction

In order to plan observing and calibration programs with SIRTF, one of the important ingredients is the absolute brightness of the sky at the time and place of observation. In particular, to judge the feasibility of detection of astronomical sources in the presence of strong foreground signals from the zodiacal light and interstellar cirrus, observers and the science team will require knowledge of the sky brightness due to sources of emission unrelated to the astronomical source of interest. In this document we will refer to the absolute sky brightness on scales larger than a few arcmin as the "background;" a more rigorous definition is that we include the zodiacal light and emission from the diffuse interstellar medium as sources of the background. For the few arcminute-scale structure of the sky brightness, the best basis is the IRAS skymaps, for which an excellent tool already exists (IRSKY). A complete background estimation tool is already available at IPAC (in IRSKY and as batch inquiry through IBIS). In this memo, I describe the background estimation that was implemented in the SIRTF Planning Observation Tool (SPOT).

II. Methods

The background due to the Solar System and the Galaxy at SIRTF is dominated by two sources: the zodiacal light and interstellar cirrus. At shorter wavelengths, and at low galactic latitudes, starlight is a potential contribution. For the present model, I will neglect starlight, because SIRTF will resolve and detect the vast majority of stars. I estimate the integrated light of undetectable stars to be less than 0.05 μJy/pixel at $b = 30^\circ$, so that starlight is negligible compared to zodiacal light except at latitudes $|b| < 0.2^\circ$ at $l > 30^\circ$ (based on results presented by Leinert et al. 1998). It is unlikely that we could provide an accurate model of the inner galactic plane in any event; galactic plane observers will have to inspect their own ground-based observations or the MSX and 2MASS maps, which are beyond the present scope because they aren't available yet.

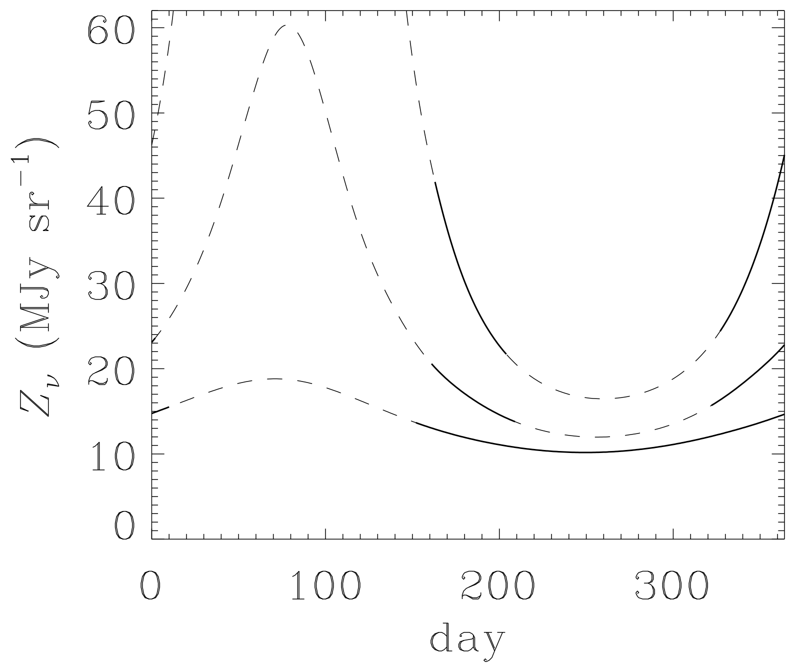

Figure 1: *Annual variation of the brightness of the zodiacal light, as predicted by the DIRBE zodiacal light model for 12 µm wavelength. The three curves are for ecliptic latitudes 0° (upper curve), 30°, and 60° (lower curve); the ecliptic longitude was 0° for all three curves. The part of the year during which each position is within the solar elongation range visible to SIRTF (80–120°) is shown with solid curves; the rest of the year is dashed. An observer would use information like this in order to see the range of zodiacal light that will be present in his observation.*

a. Zodiacal light

The absolute brightness of the zodiacal light will be taken from a three-dimensional model of the distribution of interplanetary dust and its scattering and thermal emission. The model was normalized to the time-variation of the sky brightness observed by the *Cosmic Background Explorer* (*COBE*) Diffuse Infrared Background Experiment (DIRBE) in 1989-90. The absolute calibration of DIRBE is very secure, and its gain stability was sufficient to allow it to monitor the temporal variation of the sky brightness in each 0.7-degree beamwidth. The temporal variation of the brightness of a fixed celestial position was due to the changing viewing angle through the Solar System dust cloud, which it is a unique signature of the Zodiacal Light. The range of solar elongation (angle between the line of sight and the Sun) was 64–124° for DIRBE, which is essentially the same as that planned for SIRTF. Therefore, the DIRBE observations sample the essentially the same parts of the Solar System that SIRTF will. The wavelength coverage of DIRBE was 1.25–240 μm, which spans the wavelength range of SIRTF. For comparison, the previous best estimator was the zodiacal light model fitted to the *IRAS* data (Good 1994). Differences between the *COBE* and *IRAS* zodiacal light models are certainly present, and they are largely attributed to the absolute calibration errors in the *IRAS* database. The *IRAS* absolute calibration for diffuse emission used offsets (as a function of time) were forced to match a particular model of the zodiacal light brightness of the ecliptic pole. The actual sky brightness measured by *COBE* is different, and it has an annual variation with a different phase than the *IRAS* calibration model. The calibration differences are always less than 20%, and for the purposes of background estimation for proposal planning, the *IRAS* data and model are generally adequate over their range of validity (12–100 μm).

The DIRBE zodiacal light model consists of three distinct components: a smooth dust cloud that extends over most of the Solar System, dust bands that extend from the asteroid belt to the Sun due to dust from the asteroid families, and a dust ring around the Sun at 1 AU due to particles in orbital resonance with the Earth. (Dust trails from short-period comets are bright but have a very low filling factor, so the probability of accidentally seeing one is small.) At each position, the particles are presumed to emit a modified blackbody spectrum, with free emissivities in each band (except for the normalization to unity at 25 μm). The scattering was modeled using a phase function and free albedos at 1.25–3.5 μm. Scattering is negligible at all SIRTF wavelengths except the shortest IRAC filters, where it will produce up to half the zodiacal brightness. The brightness for a time and celestial coordinates is calculated by integrating the model along the line of sight numerically. Preliminary versions of the model are described in some papers (Reach et al. 1995, 1996), and the final version is described by Kelsall et al. (1998).

For the SIRTF/SPOT zodiacal light estimator, we use the DIRBE model for the interplanetary cloud. We had to extend this model to deal with arbitraty wavelengths rather than the fixed 10 DIRBE wavelengths. The DIRBE model for thermal emission takes an assumed blackbody kernel (at each path length element along the line of sight), applies a color correction (again, at each path lenegth element), and then has a free parameter to scale the resulting brightness. This parameter is the "emissivity," and it was measured at 3.5, 4.9, 12, 25, 60, 100, 140, and 240 μm. We made a smooth fit of an analytic function for the emissivity, whcih is shown in Figure 2. The DIRBE model for scattered light takes the solar spectrum times the phase function times a color correction times a free parameter which is the "albedo." For our purposes, we removed the color correction, and we linearly interpolate between the albedos at 1.25, 2.2, and 3.5 microns. We set the albedo to zero at 4.9 microns and longer, and we interpolate between the 0.21 and 0 for wavelengths between 3.5 and 4.9 μm; the resulting values are shown in Figure 2. For the phase function, the DIRBE model has a functional form with three free parameters at three wavelengths (1.25, 2.2, and 3.5 μm). We found that using the same functional form but interpolating the parameter values as a function of wavelength yielded unacceptable results. Therefore, we evaluate the phase function appropriate for the specified scattering angle at each of the DIRBE wavelengths, then we interpolate the phase functions linearly as a function of wavelength. At wavelengths longer than 3.5 μm we adopt the 3.5 μm phase function. For completeness, we also included the visible-light phase function from Hong at 0.55 μm, and we interpolate the albedo and phase function as if it were another DIRBE wavelength. Due to these changes, the model in SPOT will not match the Kelsall et al. (1998)

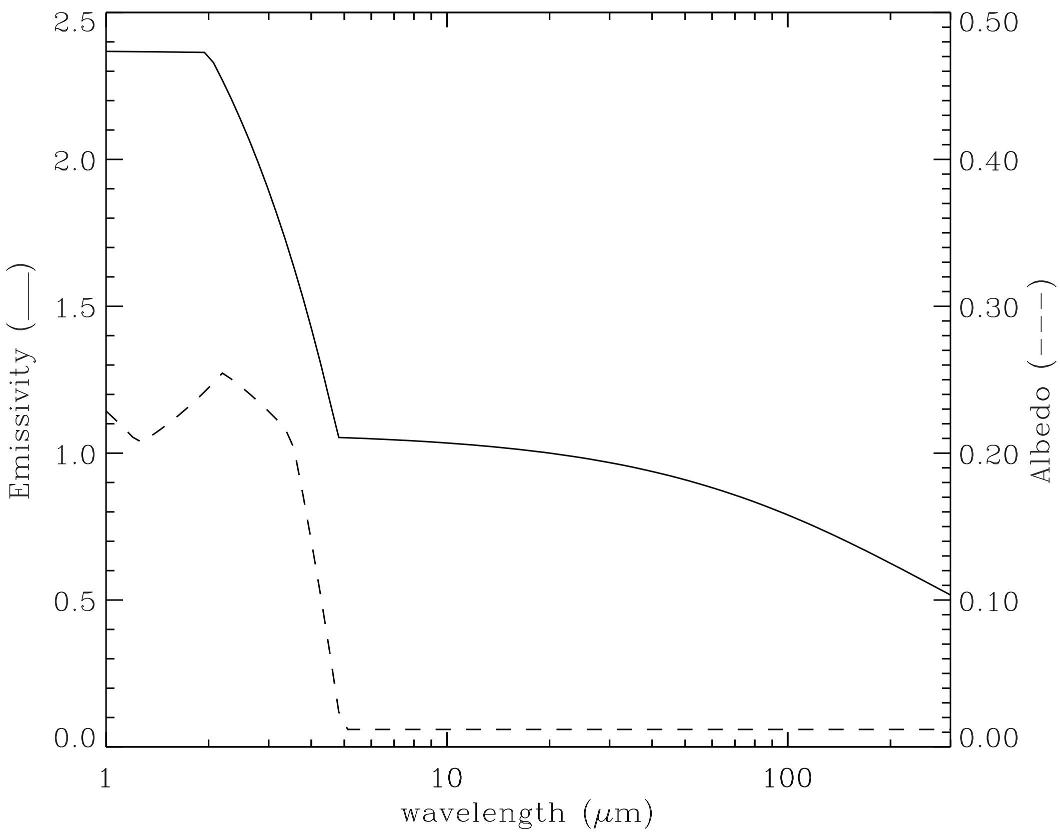

Figure 2: *Emissivity (solid curve, left axis) and albedo (dashed curve, right axis) in the zodiacal light model used for the SIRTF background estimator.*

model precisely, even when evaluated at the same wavelength, coordinates, and time.

One lien against the implementation of the zodiacal light model for SPOT is that we have not taken into account the fact that SIRTF will be rather far from the Earth. Instead, we start integration through the cloud at the Earth. Because the SIRTF orbit is Earth-trailing with a semi-major axis near 1 AU, the distribution of zodiacal light brightness will be similar as seen from SIRTF to what we see from Earth. The most important difference is that the *date* that we give to the zodiacal light estimator should really be the "SIRTF date" which lags from the Earth date by approximately 6 days per year into the mission (using a 0.1 AU per year drift rate of SIRTF from the Earth). The worst errors will be incurred in the ecliptic, and for observations later into the mission, by which time we hope to upgrade the model. For the first year of the mission, the maximum error in the effective observing date is 6 days, which leads to an error in the background brightness of as much as 10% in the ecliptic plane (and less at higher latitudes). A second effect that will cause our background estimate to be inaccurate is that lines of sight from SIRTF will travel through significantly different parts of the Earth's resonant dust-ring. The maximum error due to this effect is less than 5%. In a future release, we will need to start the integration from the location of SIRTF at the time of observation.

b. Interstellar cirrus

Emission from the interstellar medium dominates the sky brightness at wavelengths longer than 70 μm at high galactic latitudes, shifting to 45 μm at galactic latitudes around 10°. In the galactic plane, the interstellar medium dominates at all wavelengths except around 20 μm. The implication for SIRTF is that zodiacal light is the dominant background for IRAC, IRS, and MIPS 24μm except at very low galactic latitude, while the interstellar medium dominates for the MIPS 160 μm.

The distribution of interstellar dust is irregular, so there is no acceptable analytical model even at the factor of 2 level. Therefore we take a different approach, which is to use a template map of the interstellar medium at one wavelength. We will scale this template map by a 'generic' spectrum of the interstellar medium, which can be convolved with each of the SIRTF filters.

The interstellar template we used is the one developed by Schlegel, Finkbeiner, & Davis (1998), hereafter 'SFD'. The SFD map was created using both the DIRBE far-infrared data (with its accurate calibration) and the IRAS 100 μm map (with its higher angular resolution). SFD have processed the IRAS data even beyond what was done for the ISSA, with an additional deglitching, Fourier destriping, offset correction to the DIRBE offsets, gain scaling based on the DIRBE vs. IRAS correlation, and smoothing to a round $6.5'$ resolution. The SFD maps are all-sky maps of the brightness at 100 μm of the interstellar medium, with a temperature correction factor. The dust temperature was calculated from the DIRBE 100–240μm maps, and the temperature correction factor adjusts the brightness of each pixel in the map by the ratio of a blackbody at the local temperature to that at a nominal temperature of $T_0 = 18.2$ K.

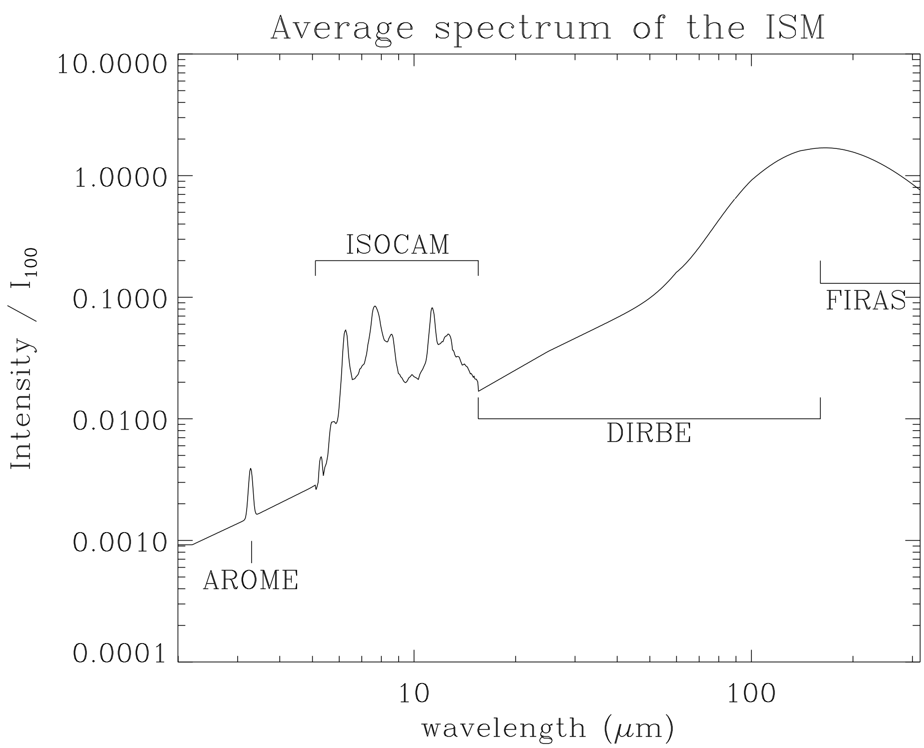

Figure 3: *Average spectrum of the interstellar medium, combining observations from various telescopes as labeled. From 3–5 and 16–100 μm, the continuum is a logarithmic interpolation between broad-band observations at 3.5, 4.9, 12, 25, 60, and 100 μm. From 5–16 μm and longward of 100 μm, actual spectral data were used. At 3.28 μm a synthetic line profile was normalized to match the observed ratio of integrated line brightness to the continuum at 100 μm. This spectrum should be accurate to within at least a factor of 2.*

Table 1: Broad-band spectrum of the Interstellar Medium[a]

wavelength (μm)	3.5	4.9	12	25	60	100	140	240
intensity[b], I_A	0.0018	0.0029	0.046	0.048	0.17	1	1.70	1.30
color corr., K_A	1	1	1.02	1.23	0.91	0.92	0.94	0.99

[a]based on Arendt et al. (1998) [b]relative to that at 100 μm

We can therefore create an all-sky, any-wavelength estimate of the brightness of the interstellar medium with the following model:

$$I_\nu(l,b) = \frac{D^Q_{100}(l,b)}{K_{100}(T[l,b])}\frac{B_\nu(T[l,b])}{B_{100}(T[l,b])}(100/\lambda)^2, \tag{1}$$

where D^Q_{100} is the SFD 100 μm DIRBE+IRAS map, $B_\nu(T)$ is the Planck function at frequency ν and temperature T, λ is the wavelength, and $K_{100}(T)$ is the color correction factor for a source with a $\nu^2 B_\nu(T)$ spectrum in the DIRBE 100 μm waveband. The index (l,b) represents galactic coordinates. The temperatures $T(l,b)$ for each sky region were calculated by SFD. Using the final 'dust map,' D^T, of SFD, we can rewrite the previous equation as

$$I_\nu(l,b) = D^T(l,b)\frac{B_\nu(T[l,b])}{K_{100}(T_0)B_{100}(T_0)}(100/\lambda)^2, \tag{2}$$

where $T_0 = 18.2$ is the nominal dust temperature. This version is more simple to evaluate because D_T is already provided by SFD, and the only color correction needed is at the nominal temperature.

The interstellar background model described in the previous paragraph will only account for the part of the sky brightness due to large grains in thermal equilibrium with the interstellar radiation field. In the mid-infrared, a different population of grains dominates the sky brightness (by many orders of magnitude). This emission consists is due to cooling of grains and large molecules that are heated to high temperatures by single interstellar photons. The spectrum contains strong, broad features at 3.3, 6.2, 7.7, 8.6, 11.3, and 12.6 μm. The brightness of the average interstellar medium was well determined in broad bands by DIRBE. The brightness of the interstellar medium, I_A, scaled to a 100 μm brightness of 1 MJy sr^{-1} is shown in Table 1. We also include color correction factors for each of these, using the tables from the DIRBE Explanatory Supplement (Hauser et al. 1998) and the local spectral shape of I_A. A broad-band estimate of the interstellar spectrum relative to 100 μm, within the range 3.5–240 μm, can be obtained by interpolating I_A/K_A to the desired wavelength. We will use a logarithmic interpolation (i.e. interpolate in $\log\lambda$ vs. $\log I_\nu$). From 5 to 16.5 μm, we can do better by using the spectrum of a diffuse cloud measured by *ISO*. The spectrum of a small cloud in the ρ Oph region, reported by Boulanger et al. (1996), was scaled so that its integral over the DIRBE 12 μm waveband matches the value of I_A/K_A listed in Table 1. The final resulting spectrum is shown in Figure 3 (Reach & Boulanger 1997)). The spectrum longward of 16 μm is very smooth because we have not included an spectral lines. Spectral lines due to dust are known to exist in this range, but it is not known whether such features are generic for interstellar dust or are present only in the special regions so far observed. These features are generally of low-contrast, less than 20% on average. Shortward of 5 μm, there are no sensitive spectra of the diffuse interstellar medium, but we can at least include the very strong 3.3 μm feature, normalized to match the observations made with the *Arome* balloon telescope (Giard et al. 1994). We presume a line centered at 3.28 μm with a full-width at half-maximum of 0.1 μm.

One problem with the background model described here is that the mid-infrared and far-infrared emission have been found not to be perfectly correlated on the sky. Therefore, the use of a single generic spectrum for the interstellar medium can be questioned. Boulanger et al. (1988, 1990) have found that the ratio of 12 μm to 100 μm brightness varies from 0.25 to 5 times the average value. The color variations were found in studies of molecular clouds and the environment of an H II region. It is likely that the range of variation away from such regions is smaller, although a significant range has also been found for isolated, low-column density clouds (Heiles et al. 1988). In light of this problem, it would certainly seem better to use actual mid-infrared data for the background estimator, rather than scaling the far-infrared data. However, the mid-infrared observations of the interstellar medium are of significantly lower quality than the far-infrared data, and are only useful for clouds near stars or in the galactic plane. For such regions, the observer will have to resort directly to the IRAS data at 12 μm, which we can expect them to do in any event because such regions are also very complicated spatially. At higher galactic latitudes, Arendt et al. (1998) found the 12 μm broad-band intensity (which contains several PAH lines) to be well-correlated with that at 100 μm, and Giard et al. (1994) found that the 3.3 μm PAH line brightness does not vary strongly with respect to the 100 μm brightness on large scales over a significant portion of the galactic plane. Therefore, except around regions locally excited by starlight, our model is likely to be be accurate to better than a factor of 2, which will suffice for the uses we envision here.

c. Cosmic Background

There is at least one source of extragalactic background that we should include in our estimator for SIRTF. It is *not* the well-known cosmic microwave background radiation, because its maximum brightness for SIRTF is 7 orders of magnitude fainter than the faintest interstellar medium. The important extragalactic background in the infrared is the integrated light of unresolved galaxies, which has recently been measured by the *COBE* satellite. The spectrum of the infrared background longward of 200 μm was measured using the FIRAS data (Puget et al. 1996, Fixsen et al. 1998), and the brightness from 1.25 to 240 μm was limited or detected in 10 broad bands using the DIRBE data (Hauser et al. 1998). The background was detected at 140–240 μm, but only an upper limit was possible at 100 μm and shorter wavelengths. For our background estimator, we can use a simple fit to the FIRAS spectrum. The DIRBE results are actually 26% higher than the FIRAS results at 240 μm. This is an area of active current research, and it cannot be resolved simply here. For now, we only need to have some estimate of the background that is reasonable accurate at the longest SIRTF wavelength, 160 μm; at all other SIRTF wavelengths, only an upper limit on the extragalactic background is known. A somewhat arbitrary sum of the simple fit to the FIRAS results from Fixsen et al. (1998) and another modified blackbody that brings the total up to match the DIRBE results at both 140 μm and 240 μm,

$$I_\nu = 1.3 \times 10^{-5} \left(\frac{100}{\lambda}\right)^{0.64} B_\nu(18.5) + 9 \times 10^{-6} \left(\frac{100}{\lambda}\right)^{2} B_\nu(22)\ \ \mathrm{MJy\ sr^{-1}}, \tag{3}$$

is a smooth curve that matches the existing observations.

A cosmic infrared background in the near-infrared has been tentatively detected (Dwek & Arendt 1998). We have not yet included the near infrared background in our model. It is significantly fainter than the zodiacal light, so this should not be a severe error. The Dwek & Arendt background brightness is about 0.01 MJy/sr at 3.5 μm, which is 5% of the zodiacal light in the ecliptic plane and up to 25% of the brightness at the ecliptic pole. As the near-infrared background gets better characterized, we will need to update the SPOT background estimator. In order to include the background, however, we need to estimate what fraction of the total light of galaxies would actually be resolved into individual point sources. For the far-infrared background, this is also an important question, because current estimates show that reasonably deep 160 μm observations may resolve of order half of the background at that wavelength. But for the near-infrared observations the resolved fraction has not been evaluated, and it could be significant. SIRTF observers would not need to know the total light of all sources, but only the fraction that will be undetected into individual point sources.

III. Implementation

The background model described in this memo requires the following user inputs:

- coordinates
- wavelength
- date of observation.

Using these inputs, the background estimator can

- evaluate the zodiacal light model
- extract nearest value from the interstellar medium map
- scale interstellar medium map by average spectrum, and
- add all these together with the cosmic background.

The first task involves a numerical integration of a parameterized function. The second task involves a table look-up through two 4096×4096 pixel FITS files (north and south galactic hemispheres). Figure 4 shows the spectra of the background at two different positions and dates.

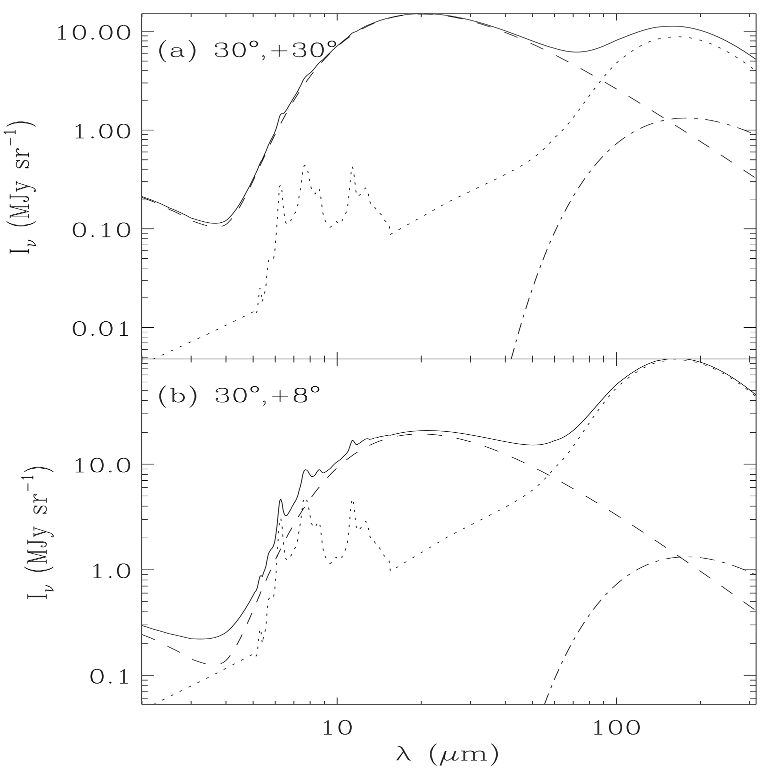

Figure 4: *Background spectrum on April 10 for two different sky positions, at galactic coordinates* $(30°, 30°)$ *for panel (a) and* $(30°, 8°)$ *for panel (b). In each panel, the total brightness is shown as a solid curve, the contribution from zodiacal light as a dashed curve, the contribution from the interstellar medium as a dotted curve, and the extragalactic background as a dash-dotted curve.*

When the date of observation is not known, the background estimator will determine the minimum and maximum zodiacal light brightness expected for the given target. To do this, the program finds the dates when the solar elongation of the observation would be at the edges of the 80–120° viewing swath. There are two swaths, corresponding to observations leading and trailing the Earth in its orbit, so there are 4 dates. The zodiacal light model is evaluated for each date, and the minimum and maximum brightness are returned. For ecliptic latitudes above 80°, the field is always visible, so we use the amplitude of a sinusoidal fit to the sky brightness as a function of date. Thus a typical use of the background estimator in SPOT, for a typical observer (who will not be fixing the observation date), is to find the range of background brightnesses possible for the target coordinates and wavelength of observation. It is up to the judgment of the observer to decide whether to use the average background or the maximum background (to be conservative), and the choice should be specified when explaining how backgrounds were used in a proposal.

IV. Guidelines for SIRTF observers

The background estimator in SPOT can be used to predict the background for SIRTF observations to an accuracy of about 20%. Thus for most purposes, it will be adequate for observation planning. Some exceptions occur as follows.

In the galactic plane, stars will merge together and become confused; at this point one could speak of a background due to starlight, which we have not included. To address this problem, observers should inspect *POSS* and *2MASS* images or consult a model for the density of stars.

For lines of sight passing near young massive stars, the contributions of H II regions and photodissociation regions will not be accurately traced by our interstellar cirrus map. To address this problem, observers should inspect the *IRAS* and *MSX* images at the wavelength closest to their planned *SIRTF* observation.

Direct reporting of brightness from other space missions

The archival sources of background measurements that are of greatest interest for SIRTF are *IRAS*, *MSX*, and *2MASS*. The *2MASS* will be useful for identifying bright sources in potential *SIRTF* fields, and for giving accurate source counts, especially for stellar sources. The *MSX* galactic plane survey will will be the primary source of background information for galactic plane observers in the near- to mid-infrared.

The *IRAS* data are served by the IRSKY program in a very user-friendly and accurate manner. Observers are encouraged to look at their fields using IRSKY. They will obtain the sky brightness, after zodiacal light subtraction in 4 wavebands centered on 12, 25, 60, and 100 μm. They can then add this brightness to the zodiacal light model described above. In this way, the SPOT-implemented empirical model for the interstellar medium (which involved a far-infrared spatial template and a single spectral template) can be replaced by actual sky brightness observations with 2–5′ resolution. However this method will only work for regions where the sky is bright. This applies to only a relatively small fraction of the sky (¡ 10%). Also, observers should add the zodiacal light into their background estimate; they should do so using the model in SPOT.

The background estimator built into IRSKY/IBIS is already a comprehensive tool that can predict the sky brightness as a function of position and wavelength. It contains a zodiacal light model (Good 1995; fitted to the *IRAS* data), moderate-resolution maps of the sky, and a means of interpolating from the IRAS wavelengths to any other. Some limitations of the existing tool are

- it does not use the observing date to specify the line of sight for the zodiacal light model, leading to a factor of up to 2 uncertainty in the zodiacal light brightness for a particular observation;
- the *IRAS* zodiacal light model and data are known to have absolute calibration errors;
- the zodiacal light model was based only on data longward of 12 μm and cannot be expected to be accurate at shorter wavelengths;
- the interpolation scheme from the IRAS wavelengths to arbitrary other wavelengths is highly uncertain above 20° galactic latitude because the IRAS 12–60 μm zodiacal-subtracted sky brightnesses are highly uncertain.

For example, near the galactic plane or any bright interstellar cloud, the actual observed brightnesses from the *IRAS* wavebands will be give a more accurate description of the sky brightness than the model implemented in SPOT. This is because our proposed model uses only a single spectral shape for the interstellar medium, whereas in fact the spectrum varies. Therefore, in addition to using model proposed here, we strongly recommend that proposers use IRSKY/IBIS to extract the *IRAS* observations at 12, 25, 60, and 100 μm.

V. REFERENCES

Arendt, R. G. et al. 1998. The COBE Diffuse Infrared Background Experiment search for the cosmic infrared background: III. Separation of Galactic Emission from the Infrared Sky Brightness, submitted.to ApJ

Boulanger, F., et al. 1996. Mid-Infrared Imaging Spectroscopy in the Ophiucus Cloud. *A&A* **315**, L325.

Boulanger, F., Beichman, C., Désert, F.-X., Helou, G., Pérault, M., & Ryter, C. 1988. Small Grains and IRAS Colors. *ApJ* **332**, 328.

Boulanger, F., Falgarone, E., Puget, J.-L., Helou, G. 1990. Variations in the abundance of transiently heated particles within nearby molecular clouds. *ApJ* **364**, 136.

Dwek, E., & Arendt, R. G. 1998. A tentative detection of the cosmic infrared background at 3.5 μm from COBE/DIRBE observations. *ApJ* **508**, L9.

Giard, M., Lamarre, J.-M., Pajot, F., Serra, G. 1994. The large scale distribution of PAHs in the Galaxy. *A& A* **286**, 203.

Gautier, T. N. III, Boulanger, F., Pérault, M., & Puget, J.-L. 1992. A Calculation of Confusion Noise Due to Infrared Cirrus. *AJ* **103**, 1313.

Good, J. C. 1994. Zodiacal dust cloud modeling using IRAS data. In *IRAS Sky Survey Atlas: Explanatory Supplement* (S. L. Wheelock, T. N. Gautier, J. Chillemi, D. Kester, H. McCallon, C. Oken, J. White, D. Gregorich, F. Boulanger, and J. Good, Eds.), pp. G1–G14. JPL Publication 94-11, Pasadena.

Hauser, M. G., Kelsall, T., Leisawitz, D., & Weiland, J. 1998. *COBE Diffuse Infrared Background Experiment Explanatory Supplement, version 2.3*, COBE Ref. Pub. (Greenbelt, MD: NASA/GSFC),
`ftp://cobe.gsfc.nasa.gov/dirbe/doc/des_v2_3_tar.Z`

Kogut, A., Banday, A. J., Bennett, C. L., Gorsky, K. M., Hinshaw, G., & Reach, W. T. 1996. High-Latitude Galactic Emission in the COBE Differential Microwave Radiometer 2 Year Sky Maps. *ApJ* **460**, 1.

Heiles, C., Reach, W. T., & Koo, B.-C. 1988. Molecules, Grains, and Shocks: A comparison of CO, H I, and IRAS data. *ApJ* **332**, 313.

Kelsall, T., et al. 1998. The COBE Diffuse Infrared Background Experiment search for the cosmic infrared background: II. Model of the Interplanetary Dust Cloud, submitted.to ApJ

Leinert, Ch. et al. 1998. The 1997 reference of diffuse night sky brightness. *A&AS* **127**, 1.

Puget, J.-L., Abergel, A., Bernard, J.-P., Boulanger, F., Burton, W. B., Désert, F.-X., & Hartmann, D. 1996. Tentative detection of a cosmic far-infrared background with COBE. *A& A* **308**, L5.

Reach, W. T., & Boulanger, F. 1997. Infrared emission from interstellar dust in the local interstellar medium. In *The Local Bubble and Beyond* (D. Breitschwerdt, M. J. Freyburg, & J. Trümper, Eds.), pp. 352–362. Springer, Berlin.

Reach, W. T., Franz, B. A., Kelsall, T., and J. L. Weiland 1996. DIRBE Observations of the Zodiacal Light. In *Unveiling the Cosmic Infrared Background* (E. Dwek, Eds.), pp. 37–46. AIP, New York.

Reach, W. T., Franz, B. A., Weiland, J. L., Hauser, M. G., Kelsall, T. N., and Rawley, G. 1995. Observational confirmation of a circumsolar dust ring by the COBE satellite. *Nature* **374**, 521–523.