Final Report on NAS5-32949: "Investigating Galactic Structure with COBE/DIRBE"

1 Abstract

In this work I applied the current version of the SKY model of the point source sky (Wainscoat et al. 1992; Cohen 1993,1994,1995) to the interpretation of the diffuse all-sky emission observed by COBE/DIRBE. The goal was to refine the SKY model using the all-sky DIRBE maps of the Galaxy, in order that a search could be made for an isotropic cosmic background. Arendt et al. (1998) constructed their "Faint Source Model" [FSM] to remove Galactic foreground stars from the ZSMA products. The FSM mimics SKY version 1 but Arendt et al. (1998) concluded that it was inadequate to seek cosmic background emission because of the sizeable residual emission in the ZSMA products after this starlight subtraction. At this point I can only support Arendt et al.'s conclusion, namely that such models are currently inadequate to reveal a cosmic background. Even SKY5 yields the same disappointing result.

On the positive side, our knowledge of the fundamental parameters of stars is increasing through the legacy of the Hipparcos mission. These parameters are critical inputs to any model of the stellar sky and it is my hope to revisit the problem once the new values are available for visual absolute magnitudes and stellar space densities. I also hope to make progress through an independent analysis of Pioneer optical starlight with SKY, under a NASA Heliospheric Mission Guest Investigator proposal (P.I. Witt).

2 Introduction

The DIRBE "ZSMA" products (with the COBE Team's model of the zodiacal foreground removed) were finally released during 1998-99, and the absolute calibration of DIRBE bands 1-6 verified (Cohen 1998) in the scheme developed by my colleagues and me. I decided to benchmark the original version of SKY and several current development variants of SKY version 5 in broad Galactic Polar regions to test the absolute surface brightness predicted by SKY5 against the ZSMA maps.

The vast majority of my effort went into removing the contamination from individual bright point sources from the DIRBE maps by a method different from that described by Arendt et al. (1998). After this processing, which seems to have been very successful, I computed the appearance of the entire sky extensively using SKY5, also with the original version of SKY. Section 2 details the procedures adopted to eliminate bright foreground stars that appear as "spikes" on the diffuse background.

In section 3 I describe the reasons why the original version of SKY contains some basic parameters that are inaccurate, compromising any simple variation of that model's code. I also discuss why the "final" values of many of these fundamental parameters are as yet unavailable although much work is currently in progress to define them.

Section 4 briefly discusses the results of comparing SKY5 with the ZSMA maps and the limitations on this work.

3 Removal of bright foreground point sources from the ZSMA maps

The ZSMA products contain almost 400,000 spatial samples of the sky brightness; far too large a dataset for many applications. To produce something more tractable with finite computing resources, whilst preserving modest resolution, I decided to bin the sky simply into 360 longitude bins by 180 latitude bins, in Galactic coordinates. This produced a mesh of 64,800 points at which the total surface brightness in each DIRBE band was to be computed with SKY. On my SPARC Ultra-1 machine, such an all-sky run with SKY required over 110 hours of total time, per band, integrating from the brightest levels at which single bright point sources could be recognized and expunged from the DIRBE data stream, to the faintest meaningful levels in SKY (30th magnitude at any wavelength).

To compare with SKY on this grid of points necessitated removal of any contaminating point sources. These can be recognized as spikes in surface plots of the ZSMA maps. I chose to resample the full DIRBE maps on this coarser grid by depositing all relevant DIRBE samples within each bin (the maximum number per bin was 13 samples). Fortran codes were written to run through the photometry for all bins, applying Bloom's one-sided statistics to delete outliers. Outliers could be removed readily only when the number of DIRBE brightness samples per bin exceeded 2. The remainder were eliminated by defining 3 by 3 pixel neighborhoods centered on every pixel and substituting the average of all noncontaminated neighbors for any missing pixels (0 samples) or suspected outliers. Surface plots of the resulting maps clearly indicate the vast improvements made in spike removal.

4 Fundamental stellar parameters: astronomy in transition

It has been clear for the past year or more that many of the fundamental parameters embedded in the original SKY model (and indeed in any other model of the point source sky) can no longer be regarded as the most accurate. In particular, the impact of ESA's Hipparcos and Tycho missions on our knowledge of stellar intrinsic colors, absolute magnitudes and hence space densities is ever growing, in spite of occasionally conflicting independent analyses. SKY depends crucially on the set of absolute M_V magnitudes and space densities of stars. It does not explicitly make use of a stellar luminosity function (LF) but such a function is implicit in the model, as demonstrated by Wainscoat et al. (1992). However, there is apparently no unique combination of absolute magnitudes and space densities that leads to the observed LF. Moreover, the assessment of a total surface brightness due to all stars in a given direction can also depend significantly on the faint end of the main sequence, and beyond. In particular, the blossoming field of cool M-dwarfs and brown dwarfs has caused major revisions in, and not a little controversy over, the LF's shape at faint magnitudes.

Consequently, the basic inputs to SKY - what Wainscoat et al. (1992) refer to as "the source table" containing all colors, absolute magnitudes and space densities - has been in a state of flux for some time. Therefore, any attempt to base predictions for the DIRBE ZSMA maps on SKY1 must be regarded as somewhat suspect, or at best non-unique, for example, Arendt et al.'s (1998) "Faint Source Model" [FSM] to remove Galactic foreground stars from the ZSMA products by mimicking SKY version 1.

The influence of cool and ultracool dwarfs on the surface brightness of the infrared sky is utterly different from that at optical wavelengths, and a clearer empirical (as well as theoretical) sense of their infrared colors and energy distributions is only just becoming available with the advent of elegant new theoretical atmospheric codes.

5 Customization of SKY to DIRBE's bands: the new synthetic library

SKY, even version 1, has always had the capability to predict star counts and sky surface brightness for arbitrary IR filters by using a synthetic library of spectra for its 87 categories of source. That library spanned the range 7.7-22.7 μm in version 1. Cohen (1993) extended this flexibility to the 2-35 μm range in the development of version 3, and that library continues to support versions 4 (Cohen 1994) and now 5.

However, the response functions that characterize DIRBE's bands 1 and 2 (nominally 1.2 and 2.2 μm) extend below 2.0 μm and one could not treat them correctly even with SKY, without building a new library. I have constructed such a library - at least a partial library - based on the Pickles (1998) spectral library and on a variety of theoretical models for AGB stars. The occurrence of more exotic sources than AGB stars in the real sky is relatively infrequent compared with the 30 categories of normal star so even such a partial library is a valuable upgrade of SKY. I can, therefore, generate absolute magnitudes on-the-fly for DIRBE bands 1 and 2 using a library consisting of between 30 and 50 of the full complement of 87 types of source in SKY.

The chief limitation I have found, in my attempt to maintain rigorous self-consistency between hardwired magnitudes such as the K-band and IRAS 12-μm band, and integrations of these passbands over the real spectral library, has been the lack of state-of-the-art models for cool giants and dwarfs.

Whenever possible I have built on the work that I and my colleagues have performed in the field of absolute calibration, replacing the SKY4 K- and early-M-giant spectra by energy distributions whose shapes have been validated by space-based instruments. But the work on absolute calibrators stops at M0III (although we did create an absolute spectrum of β Peg, M2.5II-III), yet SKY requires representations of M0-M7III stars. For these I am still using the spectra created for SKY3's library, assembled from observed spectral fragments with blackbody "bridges" where there were gaps in our knowledge. Recent work from the spectrometers aboard ESA'a Infrared Space Observatory (ISO) points out the presence of a number of newly recognized molecular absorptions in real spectra for these types but current state-of-the-art models for such late-type giants are still inadequate to replace empirical spectra.

The next major limitation to predicting the near- and mid-infrared sky comes from our knowledge of the spectra of M-dwarfs, especially the coolest examples. This field has been in rapid flux for about a year but the dependence on large ground-based telescopes has limited our knowledge to transparent spectral regions in the earth's atmosphere.

Given the recent rapid progress in definitions of absolute magnitudes, space densities, and eenrgy distributions of cool dwarfs, I have so far been unable to upgrade all the interlocking elements of SKY5 to develop a new model that is significantly improved over the older versions for specific application to the DIRBE ZSMA maps. It is my considered opinion that one must assure self-consistency in any model, that is that the underpinning spectral library provides rigorous cross ties (i.e. colors) between the several DIRBE bands but that the set of M_V values and space densities must reflect the ever-changing state-of-the-art in understanding and interpretation of the LF.

6 Which DIRBE bands are useful for constraining Galactic models?

In the mid-infrared (DIRBE bands 5 and 6), the diffuse foreground completely dominates the sky brightness and reradiation by zodiacal dust grains peaks here. The contribution made by all point sources is far below the zodiacal brightness and the residual emission in the ZSMA left after subtracting the zodiacal model is very obvious. In fact, zodiacal residuals are substantial in band 4 (4.9 μm) too. Band 3 (3.5 μm) ought to show a brightness in excess of starlight because of the PAH band at 3.3 μm: this was clearly seen after subtracting SKY's predicted sky brightness maps.

This implies that the search for any cosmic background is best carried out in bands 1 and 2. Unfortunately, the uncertainties in sky brightness that result from the likely uncertainties in stellar space densities and absolute magnitudes are of the same order as the residuals of zodiacal scattered light in the ZSMA maps. Indeed, even at the Galactic poles, the energy distribution of the residuals, after removing foreground stars by SKY5, essentially mimics the spectrum of zodiacal scattered and reradiated light itself.

Arendt et al. (1998) constructed their "Faint Source Model" [FSM] to remove Galactic foreground stars from the ZSMA products. Their FSM mimics SKY version 1 and they concluded that it was inadequate to seek cosmic background emission directly, because of the sizeable residual emission after this starlight subtraction. I have discussed directly with Dr. R. Arendt the way the DIRBE team removed bright stars from the all-sky maps, and the limitations imposed by the COBE zodiacal model. At this juncture, I can only support Arendt et al.'s conclusion, namely that the FSM is inadequate to reveal a cosmic background. Even SKY5 yields the same rather disappointing result and so far I have been unable to improve on the DIRBE Team's upper limits quantitatively.

7 Galactic structure

The time necessary to construct the partial spectral library and to develop a variant of SKY5 adequate to run SKY in DIRBE bands 1 and 2 with some rigor left essentially no time to digest any structure of the Galactic plane inherent in the ZSMA maps. I simply ran out of time and resources.

8 Conclusions

It is thus with a great deal of disappointment that I am unable, as yet, to include in this report any significantly new perspective on a near-infrared cosmic background from DIRBE data or, indeed, to offer any substantively new version of SKY that incorporates Galactic structure not previously discerned in these maps (e.g. Hammersley et al. 1994; Freudenreich 1998). The magnitude of the task was grossly beyond my expectation. For the first time in any of my awards from the agency I cannot achieve any of the anticipated conclusions.

However, I am optimistic that eventually an updated version of SKY can be developed and could be applied more effectively to the ZSMA data. My basis for this optimism is that, in a parallel investigation under NASA HMGI funds (P.I. Witt, University of Toledo) we are applying SKY5 to the interpretation of diffuse blue and red sky brightness as measured by the Pioneers beyond 3 AU from the sun. The advantages here are the negligible zodiacal light, which greatly facilitates comparisons of the measured and predicted sky brightness, and the much more direct handle on visual absolute magnitudes (the Pioneer B and R bands straddle the usual ground-based V-band). If this HMGI study is successful, then it offers the prospect of greatly reducing the number of still poorly-known fundamental parameters essential to interpret the infrared sky using the SKY model.

A second powerful combination of techniques ought to result once a new version of SKY is applicable to the ZSMA data because S. Jayaraman (Vanguard Research Inc.) has an independent NASA ADP contract to work on modeling the zodiacal radiation. It is our mutual hope, one day, to iterate by first accepting the ZSMA products, then removing starlight with the future SKY model, examining the zodiacal residuals, and then refining the modeling of both SKY and of the zodiacal brightness.

9 References

References

Arendt, R.G. et al. 1998, ApJ, 508, 74

Cohen, M. 1993, AJ, 105, 1860

Cohen, M. 1994, AJ, 107, 582

Cohen, M. 1995, ApJ, 444, 874

Cohen, M. AJ, 115, 2092, 1998

Freudenreich, H.T. 1998, ApJ, 492, 495

Hammersley, P.L. et al. 1994, MNRAS, 269, 753

Pickles, A.J. 1998, PASP, 110, 863

Wainscoat, R. J., Cohen, M., Volk, K., Walker, H. J., & Schwartz, D. E., 1992, ApJS, 83, 111

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
SEPTEMBER 1999

3. REPORT TYPE AND DATES COVERED
FINAL: 21 AUG 1995 - 20 AUG 1999

4. TITLE AND SUBTITLE Investigating Galactic Structure With COBE/DIRBE and Simulation

5. FUNDING NUMBERS
NAS5-32949

6. AUTHORS DR. MARTIN COHEN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
VANGUARD RESEARCH, INC.
10400 EATON PLACE, SUITE 450
FAIRFAX, VA 22030

7. PERFORMING ORGANIZATION REPORT NUMBER
FINAL REPORT

8. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD 20771

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In this work I applied the current version of the SKY model of the point source sky (Wainscoat et al. 1992; Cohen 1993,1994,1995) to the interpretation of the diffuse all-sky emission observed by COBE/DIRBE. The goal was to refine the SKY model using the all-sky DIRBE maps of the Galaxy, in order that a search could be made for an isotropic cosmic background.
Arendt et al. (1998) constructed their "Faint Source Model" [FSM] to remove Galactic foreground stars from the ZSMA products. The FSM mimics SKY version 1 but Arendt et al. (1998) concluded that it was inadequate to seek cosmic background emission because of the sizeable residual emission in the ZSMA products after this starlight subtraction.
At this point I can only support Arendt et al.'s conclusion, namely that such models are currently inadequate to reveal a cosmic background. Even SKY5 yields the same disappointing result.

14. SUBJECT TERMS
COBE/DIRBE SKY MODEL GALACTIC STRUCTURE

15. NUMBER OF PAGES
6

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR