[1]1 µm $G$\textsuperscript{10}$^{-10}$ W cm$^{-2}$-1 sr$^{-1}$bl et al. [1]1 $\sigma$ Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA [1]1 [1]1

Unidentified Infrared Bands in the Interstellar Medium across the Galaxy J. Kahanpää1, K. Mattila1, K. Lehtinen1, C. Leinert2 D. Lemke2 J. Kahanpää UIBs in the Interstellar Medium across the Galaxy J. Kahanpää, jere.kahanpaa@helsinki.fi

Observatory, University of Helsinki, Po. Box 14, FIN-00014 Helsingin yliopisto, Finland Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

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We present a set of 6-12 ISOPHOT-S spectra of the general interstellar medium of the Milky Way. This part of the spectrum is dominated by a series of strong, wide emission features commonly called the Unidentified Infrared Bands. The sampled area covers the inner Milky Way from $\lambda$ = -60 to +60 with a ten-degree step in longitude and nominal latitudes $\pm$ 1. For each grid position the actual observed direction was selected from IRAS 100 maps to minimize contamination by point sources and molecular clouds. All spectra were found to display the same spectral features. Band ratios are independent of band strength and Galactic coordinates. A comparison of total observed flux in band features and IRAS 100 emission, a tracer for large interstellar dust grains, shows high correlation at large as well as small (1) scales. This implies a strong connection between large dust grains and the elusive band carriers; the evolutionary history and heating energy source of these populations must be strongly linked. The average mid-infrared spectrum of the Milky Way is found to be similar to the average spectrum of spiral galaxy NGC 891 and the spectra of other spirals. The common spectrum can therefore be used as a template for the 6-12 emission of late-type spiral galaxies. Finally, we show that interstellar extinction only weakly influences the observed features even at $\lambda$ = 10 , where the silicate absorption feature is strongest. ISM: lines and bands – ISM: dust,extinction – Infrared: ISM – The Galaxy: disk – Galaxies: ISM

Introduction

The 3–13 spectra of diffuse objects such as HII regions, planetary and reflection nebulae and Milky Way cirrus clouds include a series of emission bands collectively known as the unidentified infrared bands (UIR bands or UIBs). These structures have also been observed in external galaxies. Since the first detection of the 11.3 band by Gillett et al. (Gillett73) more than a dozen bands have been identified in various astronomical spectra. Main bands always occur together, at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 . Sometimes fainter companions at 3.4, 5.25, 5.65, 6.9, 9.7, 13.6, 14.1 and 16.5 are seen. The relative strengths of bands depend on the observed object. This variation is probably related to changes in age and chemical abundances in carrier molecules since band ratios do not depend strongly on strength or hardness of the local UV field (Chan et al. Chan01; Uchida et al. Uchida00).

The exact nature of the carriers of the UIR bands is still unknown. It is generally agreed that the main bands are caused by bending and stretching modes of carbon-carbon and carbon-hydrogen bonds in large organic molecules; Holmlid (Holmlid00) has, however, proposed an alternative scenario based on de-excitation of Rydberg matter. The polyaromatic hydrocarbon (PAH) model, originally proposed by Léger & Puget (Leger84) and Allamandola et al. (Allamandola85) is frequently used for analysis of the observed band widths and band ratios but other proposed carriers like coal (Papoular et al. Papoular89), hydrogenated amorphous carbon (Duley & Williams DW81) and quenched carbonaceous composite (Sakata et al. Sakata84) can not be ruled out at present.

In Puget85, Puget et al. proposed that the IRAS 12 excess, first reported by Boulanger et al. (Boulanger85), is caused by a UIB component in the diffuse Galactic emission. This hypothesis was supported by detections of the 3.3 and 6.2 bands in the Galactic emission with a balloon-borne instrument, AROME (Giard et al. Giard88; Ristorcelli et al. Ristorcelli94) and later confirmed by detailed spectrophotometry by the ISO and IRTS satellites (Mattila et al. Mattila96; Onaka et al. Onaka96; Tanaka et al. Tanaka96) and by the detection of UIB emission from a single high-latitude cloud (Lemke et al. Lemke98). It has hence become clear that the UIB carriers are also common in the low-density (0.01-100 \[ \frac{H \text{ atoms}}{\text{cm}^{-3}} \]) low energy density regions known collectively as the diffuse interstellar medium. Further support is provided by detection of the interstellar 6.2 band in absorption in the IR spectra of Wolf-Rayet stars (Schutte et al. Schutte98)
Most studies of properties of the UIBs and their carriers are based on observations of high-density and high energy density environments such as reflection or planetary nebulae, where the UIB carriers are expected to be newly formed. The diffuse ISM provides us with a complementary set of properties: there the UIB carriers are expected to be old and all volatile species should have evaporated. The low energy density limits the number of possible carrier species. As equilibrium temperatures are not high enough to produce these bands, transient heating of very small particles by single photons must be considered (Greenberg68; Lemke et al. Lemke98; Boulanger et al. Boulanger98b).

In this paper we present the results of an ISO guaranteed time project on the distribution and properties of UIB carriers in the general interstellar matter of the Galactic disk. Our aim is to answer the following questions:

All observations at a given Galactic longitude were done within the same ISO revolution to minimize variations in the zodiacal emission foreground due to changes in solar aspect angle. The contribution of Galactic emission in the OFF-positions was minimized by choosing the darkest positions in IRAS 12 and 100 maps close to the nominal (, ) positions. For the ON-positions the IRAS maps were checked for point sources and the exact positions were then selected in regions with no known Galactic or extragalactic IR sources. CO maps were also consulted and regions with major molecular gas complexes were avoided. The resulting positions should be a reasonable sample of the general ISM: emission from the tenuous diffuse ISM dominates even if regions with molecular gas can never be completely avoided in this kind of sampling.

Each observation consists of a small raster map made with ISO Astronomical Observing Template P40 (see Laureijs et al. Laureijs00); a standard 32-second dark current and memory effect checking integration was followed by 64-second sky measurements arranged in a small raster map. For the ON-positions the map size was 2 × 2 pixels, for OFF-positions 2 × 1 pixels. The distance between raster points was equal to the PHT-S aperture size (24 × 24).

Data reduction was done with the ISOPHOT Interactive Analysis (PIA) program Version 9.0.1.

A few observations were first processed manually to find the optimal reduction procedure and the PIA batch processing mode was then used to create a homogeneous set of calibrated spectra. Fig. fig:reduction steps illustrates the reduction process:

1. Threshold deglitching (i.e., detecting and removing cosmic ray events from raw data).
2. Fitting ramps. Using the ramps subdivision technique tripled the number of usable data points and made the next step feasible.
3. Removal of deviating points caused by detector glitches. The first 15 seconds of each measurement were always discarded as values in this range are strongly affected by drift of the detector.
4. Subtraction of dark current. We used the default orbital position-dependent dark current model as the dark measurement in the P40 observing mode is dominated by memory effects. The top panel (a) in Fig. fig:reduction steps shows the resulting spectrum for each of the four pixels in the +30+0 2 raster map.
5. Calibration from instrumental (V/s) to physical units ( ). The default calibration scheme in PIA 9.0.1 was used. The P40 observing mode is well suited for use of the new ISO dynamic calibration method, but since all observed fields are very faint, the resulting calibration was practically independent of the chosen calibration method.
6. Each 22 raster map was checked for pixels with systematically higher values in either the short- or the long-wavelength part of the spectrum. If such a discrepancy was found the deviating pixel was rejected from further analysis. Only one position (-15+1) had signs of point source contamination in one of the four pixels.
7. The final search point in the (,)-grid was obtained by averaging over all good pixels in the raster maps. The second panel (b) in Fig. 1 presents the calibrated spectrum for +30+0 in physical units ( ).
8. The contribution from zodiacal dust was estimated from the OFF-position spectra at = ±5. We fitted a 2nd degree polynomial to the foreground emission measurements and subtracted the resulting smooth approximation of the zodiacal emission spectrum from the ON-position spectra. Panels c and d in Fig. fig:reduction steps show the individual spectra at 30, = +5 and −5, respectively. The next panel (e) shows the average zodiacal spectrum at position +30 + 0.