

THE INFRARED SKY STRUCTURE AND THE ISO DATA ARCHIVE

Cs. Kiss^{1,2}

¹Max-Planck-Institut für Astronomie
Königstuhl 17, D-69117 Heidelberg, Germany

²Konkoly Observatory
P.O. Box 67, H-1525 Budapest, Hungary
E-mail: 1pkisscs@mpia.de

Abstract

ISO observations opened a new window to the studies of the infrared sky background, providing measurements surpassing IRAS in wavelength coverage, spatial resolution, number of photometric bands and spectroscopic capabilities. These measurements - which will remain unique for decades - provide an excellent data base to investigate the physical parameters, dust composition and spatial structure of the astrophysical components of the infrared sky background. In this proceeding I review the ISO Data Archive-based results and future capabilities of Zodiacal Light, Galactic cirrus and extragalactic background studies.

KEYWORDS: *diffuse radiation, infrared*

1. Introduction

The ISOPHOT photopolarimeter (Lemke et al., 1996) was one of the four instruments on-board the ISO satellite (Kessler et al., 1996). Six years after the active measurement phase, the data collected by ISOPHOT and other ISO instruments is stored in the publicly available ISO Data Archive¹, which contains all raw and fully processed scientific, calibration, engineering, up- and downlink data. It includes ~ 30000 individual scientific observations and ~ 110000 observations in the ISO parallel and serendipitous modes, which can be accessed through a user-friendly java interface.

In this proceeding I present our results and discuss the future possibilities on one selected topic, which was extensively studied by ISO, the infrared sky background.

¹<http://www.iso.vilspa.esa.es/ida>

2. The infrared sky background

The definition of the background always depends on the basic characteristics of the actual measurement (wavelength, detector, configuration, etc.). However, there are two fundamental classes: a background can be intrinsically diffuse (e.g. the gas clouds of the Milky Way) or made of accumulated light of unresolved sources (e.g. the Milky Way on the night sky for human's eye). In the former case the background remains diffuse regardless the resolution, while in the latter case higher resolution reduces the number of sources in the background (and therefore causes a lower background level as well). The background - either intrinsically diffuse or made of unresolved sources - limits the detectability of faint sources in two ways. First, the sources must be brighter than the limit set by the background ($S > S_{lim} = k \times \sigma_f$, photometric criterium) and, second, two sources (fulfilling the photometric criteria) must be sufficiently far from each other to be distinguishable ($\theta > \theta_{min}$, source density criterium, see Fig. 2.).

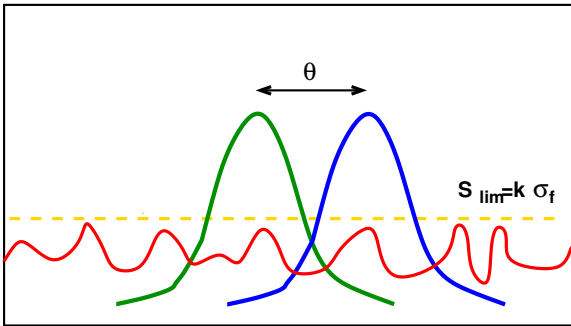


Figure 1: Schematic representation of the photometric and source density criteria for the detection of faint sources

The infrared background can be characterized by the following properties:

- absolute surface brightness
- spatial structure (or fluctuations). This is closely related to the 'physics' of the background. There are two main points-of-view one can consider the fluctuations:
 - Fourier power spectrum
 - confusion noise, i.e. uncertainty in the determination of the point source flux due to the unknown background. The analysis of the confusion noise at a specific spatial separation is equivalent to the selection of one spatial frequency from the power spectrum.

- colour (spectral energy distribution)

The sky background has several components, and it is a very challenging task to separate them. In Fig. 2 we present the contribution of different sky background components (without the extragalactic background, see later) from UV ($0.1 \mu\text{m}$) to $\sim 10^4 \mu\text{m}$ (Leinert et al., 1998).

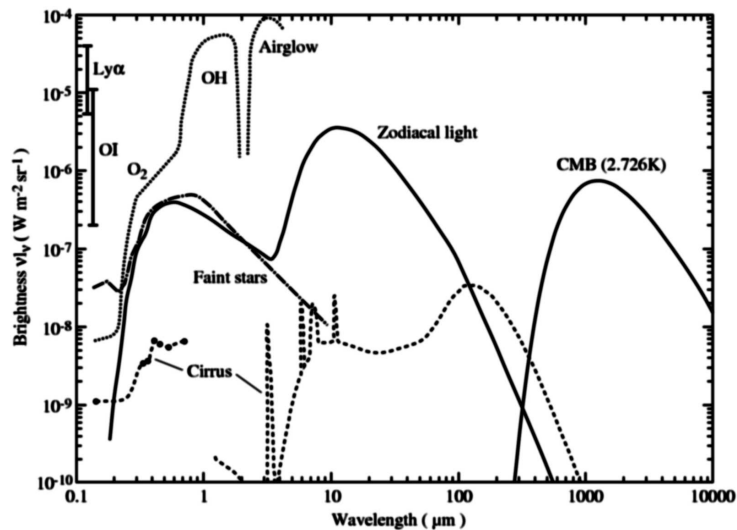


Figure 2: Sky brightness outside the lower terrestrial atmosphere at high ecliptic and galactic latitudes (from Leinert et al., 1998)

In the far-infrared the main astrophysical components of the sky background outside Earth's atmosphere are arisen from the following sources discussed below (see also Fig. 3).

2.1. Interplanetary dust (IPD, Zodiacal Light)

This component is a thermal ($T \approx 270\text{K}$) emission from small, solid particles in the inner Solar System. The particles are originated from comets, collisions of asteroids and from interstellar dust. The IPD forms a flattened, lenticular shaped dust cloud around the ecliptic plane, extending to the orbit of Jupiter. There are some local density enhancements due to comets and asteroids (Reach et al., 1997, Reach et al., 2000). The best IPD cloud model was derived from

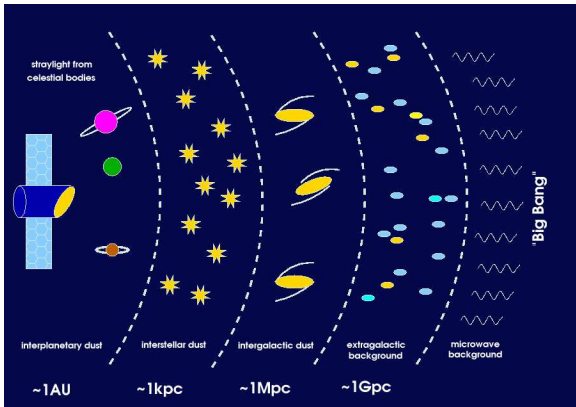


Figure 3: The main astrophysical components of the far-infrared sky background outside the terrestrial atmosphere

seasonal variations observed by COBE/DIRBE (Kelsall et al., 1998). The Zodiacal Light lacks arcminute-scale fluctuations, as was shown by Ábrahám et al. (1997).

2.2. Interstellar dust (Galactic cirrus):

The Galactic cirrus emission was discovered by the IRAS satellite (Low et al., 1984) and was named due to the similarity to cirrus clouds in the terrestrial atmosphere. The cirrus emission comes from dust in low-density galactic HI clouds (Boulanger & Péroul, 1998) and this is the dominant source of the sky structure for wavelengths $\lambda > 60 \mu\text{m}$. Based on COBE/DIRBE measurements a typical colour temperature of $T_d \approx 18 \text{ K}$ has been derived, assuming $\beta = 2$ emissivity law ($F_\nu \propto \nu^2 B_\nu(T)$, Lagache et al., 1998).

The spatial structure of the cirrus emission is similar to that of a fractal. It can be described by a power-law power spectrum $P = P_0(f/f_0)^\alpha$. The first investigation of this structure was carried out by Gautier et al. (1992) based on IRAS $100 \mu\text{m}$ scans and resulted in $\alpha \approx -3$ (see Fig. 4).

2.3. Intergalactic dust

The first evidence for the existence of thermal dust distributed in the hot X-ray emitting plasma in the intergalactic medium of the Coma cluster was presented by Stickel et al. (1998). However, this emission was quite faint, despite the ongoing merging activity. Extrapolations based on this result suggest a negligible contribution to the infrared sky background from the intergalactic dust in the Local Group.

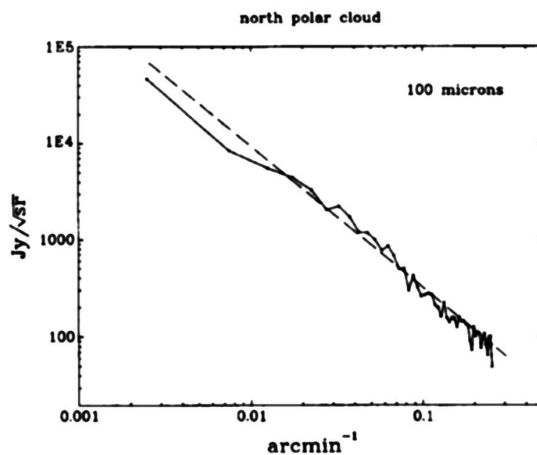


Figure 4: Annular power spectrum of the North Polar Cloud based on IRAS 100 μm scans (Gautier et al., 1992).

2.4. Extragalactic background

The far-infrared extragalactic background or the cosmic far-infrared background (CFIRB) is the accumulated light of distant (redshifted) and unresolved galaxies. The major source of this radiation is starlight, which is absorbed and re-emitted by dust. Another source which is very significant at some IR wavelengths (10-50%) is the contribution of active galactic nuclei (AGN). The X-rays emitted by the AGN are absorbed in the surrounding dust torus and re-emitted in the far-infrared. Mainly sources with $1 \leq z \leq 2$ contribute to the CFIRB, around the maximum of the global star-formation rate in the history of the Universe (see Hauser & Dwek, 2001, for a review). The CFIRB can be detected in three main ways.

Direct measurements of the CFIRB can be performed via very precise absolute surface brightness photometry. This is a very challenging task, mainly due to technical issues. This was done so far only using COBE/DIRBE measurements, after a careful removal of the Zodiacal Light and Galactic cirrus contributions (Hauser et al., 1998).

CFRIB fluctuations show a Poissonian spatial distribution for spatial frequencies $f \geq 1'$. Below this scale the clustering of galaxies becomes dominant resulting in a deviation from the Poissonian (Bond et al., 1986). Detection of CFIRB fluctuations are easier than the direct measurements since these do

not require the precise absolute calibration of the photometric system and it is relatively easy to separate the components in the power spectrum or in the confusion noise distribution. The first detection of CFIRB fluctuations were performed by the ISOPHOT instrument at 90 and 170 μm (Lagache & Puget, 2000; Matsuhara et al., 2000).

Source counts aims to resolve the CFIRB into individual sources. IRAS could only detect the brightest sources due to its relatively poor sensitivity. ISO performed extensive FIR source count investigations in the $90 \leq \lambda \leq 180 \mu\text{m}$ range (Kawara et al., 1998; Puget et al., 1999; Juvela et al., 2000; Dole et al., 2001). These results favoured strong cosmic evolution models.

Since the cosmic microwave background is very strong at longer infrared wavelengths ($\lambda \geq 300 \mu\text{m}$), it should be distinguished from the CFIRB.

3. Results

3.1. Separation of CFIRB and cirrus confusion noise

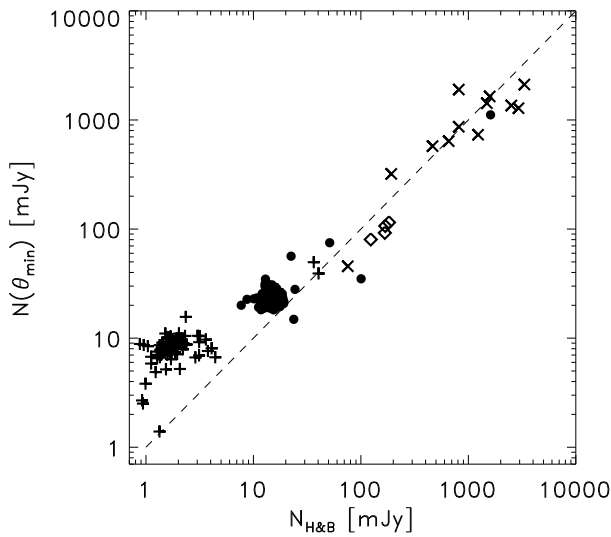


Figure 5: confusion noise at the resolution limit determined by our study as compared to the prediction of Helou & Beichman (1990). The deviation at low confusion noise values is caused by CFIRB fluctuations.

The cirrus and CFIRB confusion noise can be separated via the surface brightness dependence of the cirrus confusion noise (Kiss et al., 2001). The cirrus confusion noise scales with the surface brightness of the field, but the CFIRB confusion noise remains constant, regardless of the field brightness:

$$\left(\frac{N}{1 \text{ mJy}}\right) = C_0 + C_1 \times \left\langle \frac{B}{1 \text{ MJy sr}^{-1}} \right\rangle^\eta \quad (1)$$

where N is the confusion noise, B is the average, zodiacal light removed surface brightness of the field, and C_0 , C_1 and η are parameters to be fitted. Using the fitted C_0 parameters and some theoretical considerations (Bond et al., 1986) we were able to derive absolute CFIRB levels of $\nu I_\nu = 14 \pm 3 \text{ nW m}^{-2} \text{ sr}^{-1}$ and $\nu I_\nu = 30 \text{ nW m}^{-2} \text{ sr}^{-1}$ at 170 and 90 μm , respectively (the 90 μm value is upper limit).

3.2. Small scale structure of the Galactic cirrus emission

The spectral index α of the galactic cirrus emission is generally believed to be constant and wavelength-independent (Gautier et al., 1992; Helou & Beichman, 1990). We examined the Fourier power spectrum characteristics of cirrus structures in 13 sky fields with faint to bright cirrus emission observed with ISOPHOT in the 90–200 μm wavelength range in order to study the possible variations of α . We found that α varies from field to field with $-5.3 \leq \alpha \leq -2.1$. It also depends on the absolute surface brightness and on the hydrogen column density. The results are presented in Fig. 6. The spectral indices of the same sky region were found to be different for different wavelengths as well (see Fig. 7). Longer wavelength measurements show steeper power spectra. This can be explained by the presence of dust at various temperatures, in particular of a cold, extended component. For the faintest areas of the far-infrared sky we derived a wavelength-independent spectral index of $\alpha = -2.3 \pm 0.6$ for the cirrus power spectrum. This is a precondition for the proper disentanglement of the cirrus foreground of the CFIRB.

3.3. Cirrus confusion noise redictions for current and future far-infrared space missions

Based on an extensive database of ISOPHOT measurement in the $90 \mu\text{m} \leq \lambda \leq 200 \mu\text{m}$ wavelength range we investigated the dependence of the confusion noise on the measurement configuration. We estimated the expected confusion noise

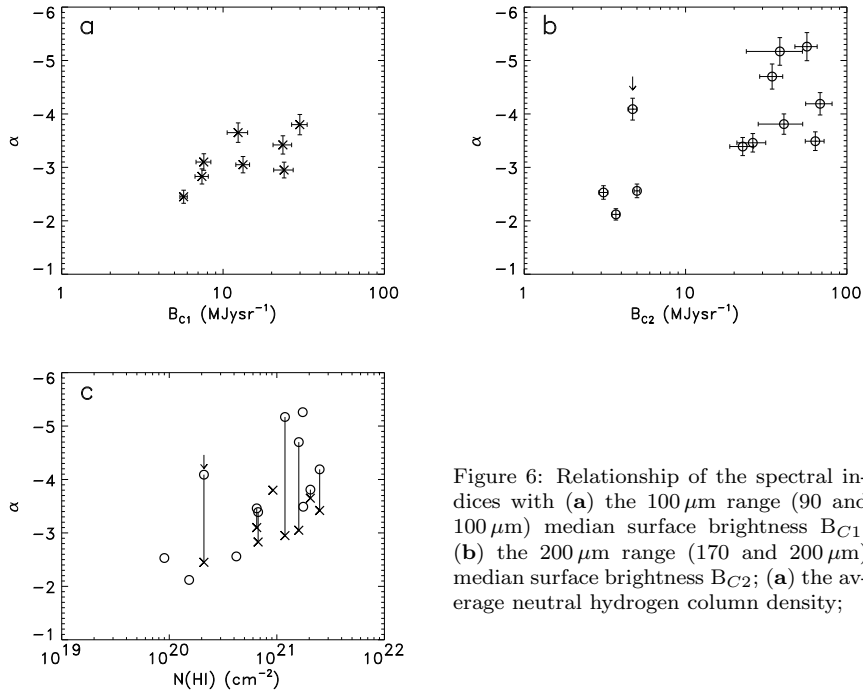


Figure 6: Relationship of the spectral indices with (a) the 100 μ m range (90 and 100 μ m) median surface brightness B_{C1} ; (b) the 200 μ m range (170 and 200 μ m) median surface brightness B_{C2} ; (c) the average neutral hydrogen column density;

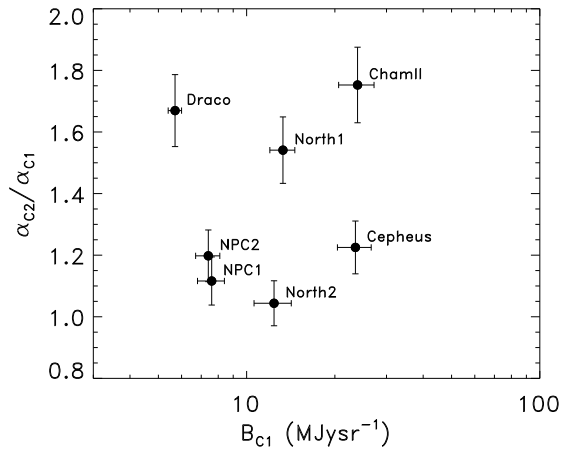


Figure 7: Ratio of the spectral indices of the sky regions measured in both a long (170–200 μ m) and a short (90–100 μ m) wavelength filter versus the average surface brightness in the C100 filter B_{C1} .

at a specific surface brightness level for each possible measurement configura-

tion. We also found, that the favorable measurement mode is the mini-map (see Laureijs et al., 2003) for photometry of individual point sources. Fluxes of (point) sources in larger maps can be derived by the lowest confusion noise contamination using annular apertures ('aperture photometry'). This mode significantly reduces the confusion noise relative to flux extraction methods similar to triangular or rectangular chopping (Laureijs et al., 2003). A synthesis of these ISOPHOT results and the analysis of simulated fractal maps seen by various instruments provides cirrus confusion noise predictions for the current and future infrared space instruments (Spitzer/MIPS, ASTRO-F/FIS, Herschel/PACS). An example comparing the capabilities of four FIR instruments is presented in Fig. 8 (Kiss et al., 2004, in prep.).

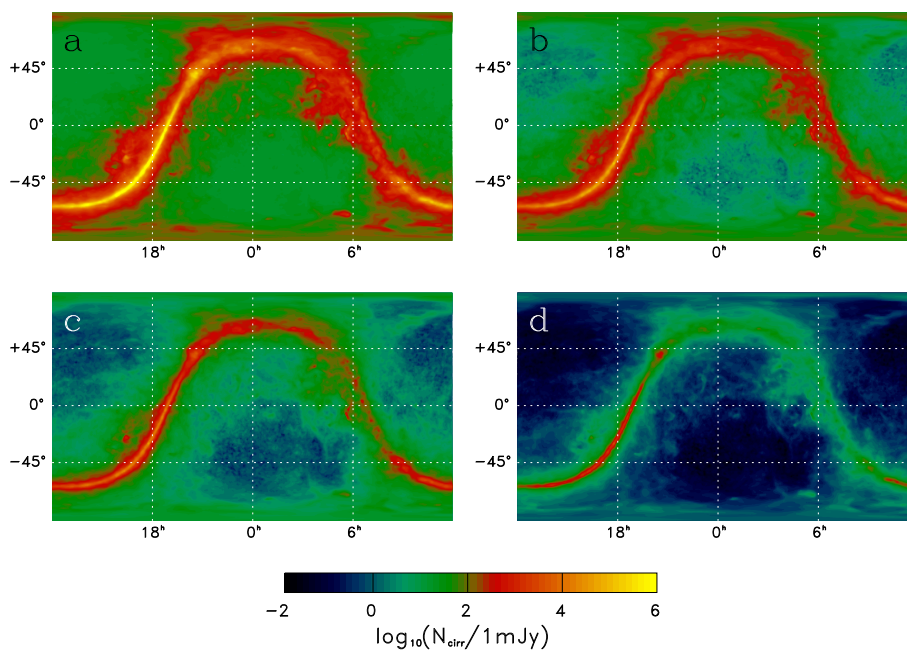


Figure 8: Comparison of predicted cirrus confusion noise levels of four different FIR instruments at their resolution limits. Confusion noise levels are displayed over the range as given by the colour-bar. All maps were constructed with *no* DIRBE-*ISOPHOT* conversion applied and with *constant* α and are presented in *equatorial* coordinate system (J2000). (a) ISO/*ISOPHOT* C200 camera, $170\ \mu\text{m}$; (b) ASTRO-F/*FIS* $170\ \mu\text{m}$; (c) Spitzer/*MIPS* $160\ \mu\text{m}$; (d) Herschel/*PACS* $175\ \mu\text{m}$

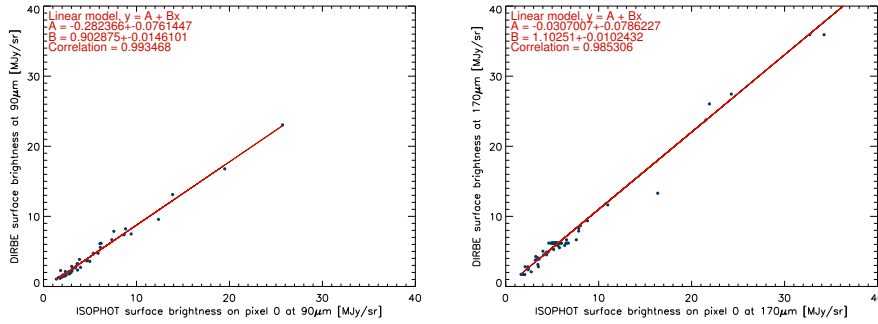


Figure 9: Example of the ISOPHOT–COBE/DIRBE surface brightness photometric comparison. (a) $90\ \mu\text{m}$; (b) $170\ \mu\text{m}$;

4. Prospects for far-infrared studies using the ISO Data Archive

4.1. Absolute surface brightness calibration of ISOPHOT

The final aim of the absolute surface brightness calibration – apart from its technical relevance – is the *direct* detection of the cosmic far-infrared background (see Sect. 2.4). Although ISOPHOT has not been especially designed to perform absolute photometry, this can be done in some selected and well calibrated observing modes. This work is still in progress at Konkoly Observatory (Budapest) in collaboration with German (ISOPHOT Data Centre, MPA, Heidelberg) and Finnish (University of Helsinki Observatory) astronomers. The most promising observing mode in this respect is the *mini-map* mode, which was almost exclusively used for point-source observations. In the *mini-map* mode the detector (C100 or C200) ‘moved around’ the source in a way that the source was centered at each detector pixel once during the measurement (see Laureijs et al., 2003, for a detailed explanation). This mode is proved to be very powerful for precise point-source photometry (Moór et al., 2004a, in prep.). However, in parallel with the flux of the point source, one can obtain a precised background value as well. In Fig. 9 preliminary results of the ISOPHOT – COBE/DIRBE photometric system comparison are presented (Moór et al., 2004b, in prep.).

4.2. Fluctuation studies:

Studies of the sky background fluctuations are limited at high spatial frequencies by the maximal achievable resolution of the instruments (46'' and 92'' for the C100 and C200 cameras, respectively) and by the final extension of the ISOPHOT maps at low spatial frequencies. This latter can be extended to lower spatial frequencies by the utilization of the ISOPHOT Serendipity slews which extend to a typical length of several degrees (Bogun et al., 1996).

4.3. Cirrus studies

A pilot study by del Burgo et al. (2003) has shown that the far-infrared emissivity of big dust grains (τ_{200}/A_V) changes with the ambient temperature: dust grains emit more FIR photons at lower temperatures than expected from their visual extinction properties. There is an on-going study looking for these variations in interstellar clouds with physical parameters (density, temperature) different from the ones analysed in del Burgo et al. (2003). Our study also aims to investigate the relation between the changes in dust emissivity τ_{200}/A_V and the ratio of total over selective extinction R_V (see e.g. Krügel et al., 2003, for a detailed description of R_V).

Acknowledgments

This work was partly supported by the ESA PRODEX programme (No. 14594/00/NL/SFe) and by the Hungarian Research Fund (OTKA, No. T037508). The author acknowledges the financial support of the N+N workshop.

References

- Ábrahám, P., Leinert, Ch., Lemke, D., 1997, A&A 328, 702
Bogun, S., Lemke, D., Klaas, U., et al., 1996, A&A 315, 71
Bond, J.R., Carr, B.J., Hogan, C.J., 1986, ApJ 306, 428
Boulanger, F., Péroult, M., 1988, ApJ 330, 964
del Burgo, C., Laureijs, R.J., Ábrahám, P., Kiss, Cs., 2003, MNRAS 346, 403
Dole, H., Gispert, R., Lagache, G., et al., 2001, A&A 372, 364
Gautier III, T.N., Boulanger, F., Péroult, M., Puget J.L., 1992, AJ 103, 1313
Hauser, M.G., Arendt, R.G., Kelsall, T., et al., 1998, ApJ 508, 25
Hauser, M.G., Dwek, E., 2001, ARA&A 39, 249

- Helou, G., Beichman, C.A., 1999, The confusion limits to the sensitivity of submillimeter telescopes, in: From Ground-Based to Space-Borne Sub-mm Astronomy, Proc. of the 29th Liège International Astrophysical Coll., ESA Publ., p. 117.
- Juvela, M., Mattila, K., Lemke, D., 2000, A&A 360, 813
- Kawara, K., Sato, Y., Matsuhara, H., 1998, A&A 336, L9
- Kelsall, T., Weiland, J.L., Franz, B.A., 1998, ApJ 508, 44
- Kessler, M.F., Steinz, J.A., Anderegg, M.F., et al., 1996, A&A 315, L27
- Kiss, Cs., Abraham, P., Klaas, U., Juvela, M., Lemke, D., 2001, A&A 379, 1611
- Kiss, Cs., Abraham, P., Klaas, U., et al., 2003, A&A 399, 177
- Lagache, G., Abergel, A., Boulanger, F., Désert, F.X., Puget, J.-L., 1999, A&A 344, 322
- Lagache, G., Puget, J. L., 2000, A&A 355, 17
- Laureijs, R.J., Klaas, U., Richards, P.J., Schulz, B., Abraham, P., 2003, The ISO Handbook Vol. IV.: PHT – The Imaging Photo-Polarimeter, Version 2.0.1, ESA SP-1262, European Space Agency
- Leinert, Ch., Bowyer, S., Haikala, L.K., et al., 1998, A&AS 127, 1
- Lemke, D., Klaas, U., Abolins, J., et al., 1996, A&A 315, L64
- Low, F., Beintema, D.A., Gautier, F.N., et al., 1984, ApJ 278, L19
- Matsuhara, H., Kawara, K., Sato, Y., 2000, A&A 361, 407
- Puget, J. L., Lagache, G., Clements, D. L., 1999, A&A 345, 29
- Reach, T.W., Franz, B.A., Weiland, J.R., 1997, Icarus 127, 461
- Reach, T.W., Sykes, M.V., Lien, D., 2000, Icarus 148, 80
- Stickel, M., Lemke, D., Mattila, K., Haikala, L.K., Haas, M., 1998, A&A 329, 55