The Institute of Space and Astronautical Science
Report SP No.14, December 2000

Observations of Infrared Extragalactic Background Light

By

Toshio MATSUMOTO*

(November 1, 2000)

Abstract: Based on the recent space missions, the observations of infrared extragalactic background light (IREBL) are reviewed. In the near infrared region, IRTS/NIRS data show bright extragalactic background with a stellar like spectrum which is significantly brighter than the integrated light of galaxies. The star subtraction analyses from DIRBE data show the essentially same results besides the uncertainty in the model of zodiacal light. IRTS/NIRS data also show fluctuations of the sky with 100 $\sim$ 200 arcmin. angular scale that could originate in the large scale structure at high redshift. In the far-infrared and submillimeter regions COBE/DIRBE data indicate significant EBL. The obtained submillimeter background can be resolved into point sources by the SCUBA deep survey, while the far-infrared background requires considerable evolution effect as confirmed by ISO deep surveys. The total energy flux of IREBL amounts to 50 $\sim$ 80 nWm^{-2}sr^{-1} which is so bright that unknown energy sources at high redshifts are required.

1. INTRODUCTION

The infrared extragalactic background light (IREBL) has been thought to be an important clue to the understanding of the early universe and the evolution of galaxies. In the near infrared, redshifted star light from high z galaxies constitutes the background, while dust emission causes the far-infrared and submillimeter background. Both emission components are thought to be important parameters to understand the energy generation during the galaxy formation era. It is thought that the near infrared (1 $\sim$ 5 μm) and far infrared/submillimeter (100 $\sim$ 300 μm) regions are useful windows to detect the IREBL since sky brightness is very low there. Many efforts have been devoted to detect the EBL from the ground, but were not successful due to bright foreground emission associated with the atmosphere and instruments themselves. Recent space observations from COBE and IRTS, first enabled us to make a qualitative analysis of the IREBL.

Puget et al. (1996) and Fixen at al. (1998) reported a significant detection of the submillimeter EBL from the COBE/FIRAS data. Furthermore, Hauser et al. (1998) claimed the

* The Institute of Space and Astronautical Science (ISAS) 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan; matsumo@ir.isas.ac.jp

detection of the EBL at 120 and 240 μm from the COBE/DIRBE observations. After these works, several reports based on the COBE data followed, which were essentially consistent with previous ones.

In the near infrared region, Hauser et al. (1998) obtained only upper limits, however, several trials have been made to search for the near infrared EBL by subtracting the stellar contribution from the DIRBE data set. On the other hand, Matsumoto et al. (1999) claimed the significant detection of the EBL spectrum with IRTS/NIRS observations. These results are consistent each other apart from the uncertainty of the model of the zodiacal light.

In this paper, we review the recent work on the IREBL both in the near infrared (section 2) and the far-infrared/submillimeter regions (section 3), and discuss the energetics and its cosmological implication in section 4.

2. NEAR INFRARED OBSERVATIONS

2.1 IRTS/NIRS Observation

The Near InfraRed Spectrometer (NIRS) is one of the focal plane instruments of the InfraRed Telescope in Space (IRTS) and was optimized to observe the spectra of the diffuse NIR background (Noda et al. 1994). The NIRS covers the wavelength range from 1.4 μm to 4.0 μm with a spectral resolution of 0.13 μm. The effective beam size is 8 arcmin. $\times$ 20 arcmin. which is considerably smaller than that of DIRBE.

The IRTS was one of the mission experiments on the small space platform, SFU, that was launched on March 18, 1995. The IRTS observation lasted for about 30 days, and 7% of the sky was surveyed (Murakami et al. 1996). Owing to the narrow beam size, NIRS could identify the stars brighter than 10 mag that resulted in much less contamination due to faint stars than the data of COBE/DIRBE.

The estimation of EBL was made using the physical model of zodiacal light of Kelsall et al. (1998). Figure 1 shows the typical case (2.24 μm). Filled points indicate ecliptic latitude dependence of the observed brightness in which the contribution of faint stars is subtracted based on the model (Cohen 1997). While the solid line shows the expected brightness predicted by the zodiacal light model. Crosses at the bottom show the residual emission, that is, observed brightness minus model brightness. Figure 1 clearly indicates that there remains significant isotropic emission that can not be explained by the known emission components and could be attributed to extragalactic origin.

Figure 2 shows the spectrum of the isotropic emission thus obtained in which other observations (see next section) and theories are compared. The spectrum looks stellar and is significantly brighter than the integrated light of galaxies (Pozetti et al. 1998) and theoretical predictions (Yoshii and Takahara 1988).

Fluctuation of the extragalactic background light is another important clue in the study of the formation and evolution of galaxies. The effective beam size of 8 arcmin. $\times$ 20 arcmin. is an adequate scale to investigate the clustering of galaxies at high redshift (Kashlinsky et al. 2000). Figure 3 shows the rms fluctuation of the isotropic emission. Although detector read out noise is dominant in the long wavelength bands, clear fluctuation was found on the short wavelength side. The detected fluctuation is marginally consistent with DIRBE/COBE for the J and K bands (Kashlinsky et al. 2000), although the beam size is different.

The zodiacal component can not explain this fluctuation. The fluctuation of zodiacal emission has not been detected in the mid infrared region and is less than 1 % for various beam sizes

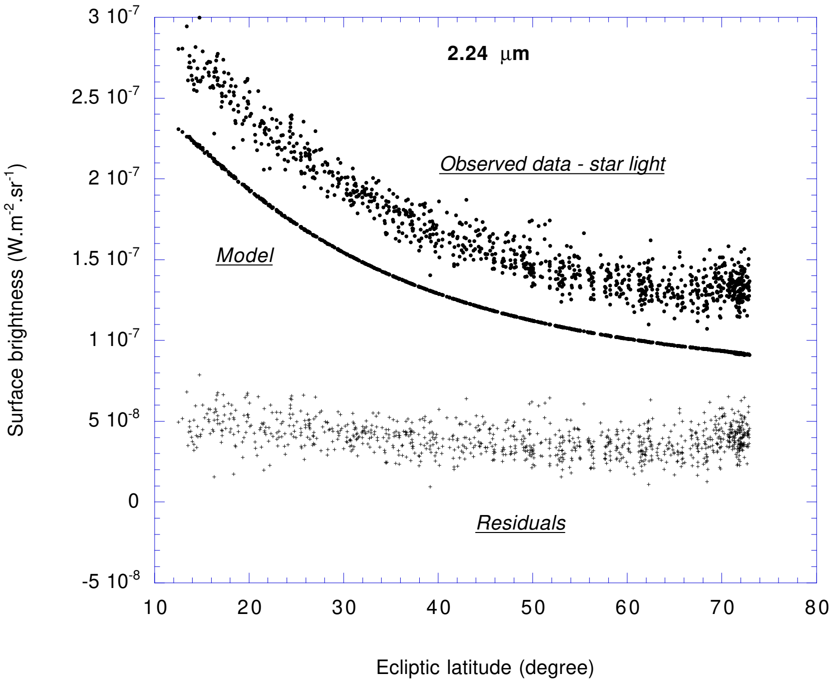

Fig. 1: Dependence on the ecliptic latitude for the data at 2.24 μm. Dots, solid lines, and crosses indicate "star subtracted data", model prediction, and residual brightness, respectively.

(IRAS, Vrtilek & Hauser 1995; COBE, Kelsall et al. 1998; ISO, Abraham et al. 1998). The upper limits thus obtained are much smaller than the observed fluctuating component, that is, 1/4 of isotropic emission and 1/20 of the total sky brightness. The fact that the fluctuation of the residual emission in Figure 1 has no dependence on the ecliptic latitude is further evidence that the observed fluctuation is not interplanetary in origin.

The two point correlation function is defined as $C(\theta) =< \delta F(x+\theta)\delta F(x) >$, where $\delta F(x)$ is fluctuating component of the "wide band brightness", θ is the angular distance in arcmin. between two points, and x is the coordinates of the observed points. Figure 4 shows the result of two point correlation function for the integrated brightness of the short wavelength bands from 1.43 μm to 2.14 μm, and the right panel of Figure 5 shows the power spectrum derived from the two point correlation function. The result clearly indicates there is structure at $100 \sim 200$ arcmin. angular scales. This could be an indication of the large scale structure at high redshift.

2.2 Subtraction of Stars from COBE/DIRBE Data

Hauser et al. (1998) obtained only upper limits for the EBL in the near and mid wavelength bands of DIRBE. The main difficulty was an uncertainty in the estimation of the contribution of faint stars due to large beam size of DIRBE. However, several trials have recently been attempted to subtract stellar the contribution more accurately.

Dwek and Arendt (1998) made a correlation study for the K and L bands, and obtained a lower limit for the L band that is fairly consistent with IRTS/NIRS result. Gorjian et al. (2000) made star counts towards the DIRBE dark spots and subtracted their contribution from the DIRBE data. Wright (2000) extended this work using 2MASS data, which are consistent with each other, giving an EBL brightness of 27.8 ± 14.5 nWm^{-2}sr^{-1} and 19.9 ± 5.3 nWm^{-2}sr^{-1} for

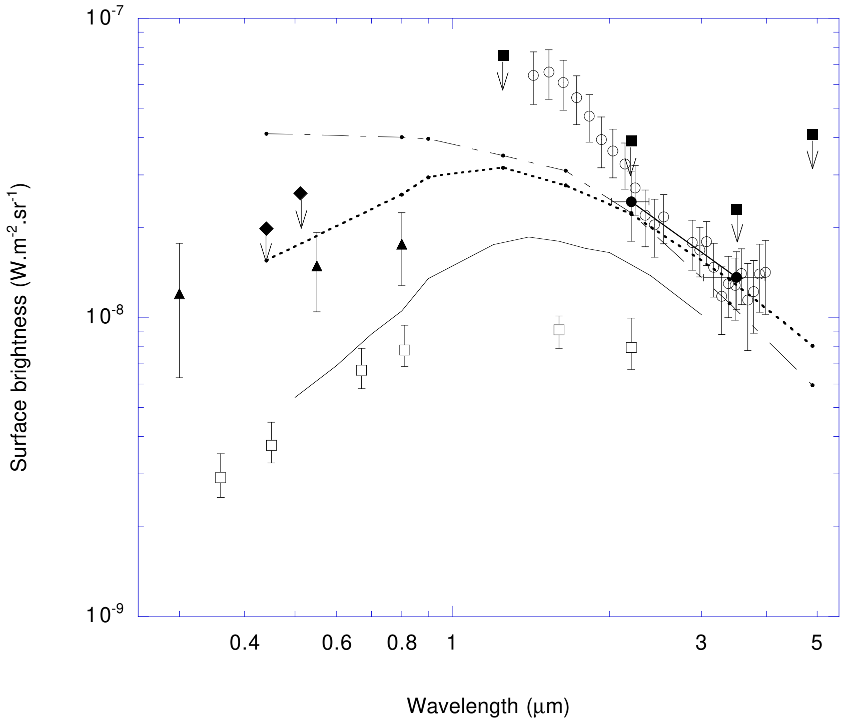

Fig. 2: Spectrum of observed isotropic emission is shown by open circles. Filled squares indicate upper limits by COBE/DIRBE Hauser et al. (1998). Filled circles show the detection of EBL reported by Gorjian et al. (2000). Open squares represent integrated light of galaxies (Pozzetti et al. 1998). Upper limits of the optical EBL by Dube et al. (1979) and Toller (1983) are shown by filled diamonds, while the recent detection of EBL by Bernstein et al. (2000) is indicated by filled triangles. Solid line represents prediction by Yoshii & Takahara (1988). The recent theoretical model by Jimenez and Kashlinsky (1999) for two cases (dashed line : $z_f = 10, H_0 = 80$, and dot-dashed line : $z_f = 3, H_0 = 80$) is also shown

.

the J and K band, respectively. These values are a little smaller than the IRTS/NIRS result due to the Different zodiacal light model assumed. If we apply Kelsall's model to them, their values are modified to 60.8 ± 14.5 nWm^{-2}sr^{-1} and 28.2 ± 5.5 nWm^{-2}sr^{-1} for the J and K band, respectively, which are fairly consistent with the IRTS/NIRS result.

Matsumoto et al. (in preparation) made a similar observation in the J band with the Kiso Shmidt Telescope towards the DIRBE dark spot. They subtracted all detected stars brighter than 14 mag. and estimated the contribution of fainter stars by Cohen's sky model (Cohen 1997). They obtained 60.1 ± 15 nWm^{-2}sr^{-1} in the J band which is fairly consistent with Wright (2000), if the same model is applied.

Table 1 shows a summary of the observations in which the difference of model is also shown. COBE/DIRBE and IRTS/NIRS render the same result for the sky brightness, however, the difference of the model causes a serious difference in the estimation of the EBL, especially for the short wavelength bands. In Figure 2, the results based on Kelsall's model (Kelsall et al. 1998) are plotted for consistency.

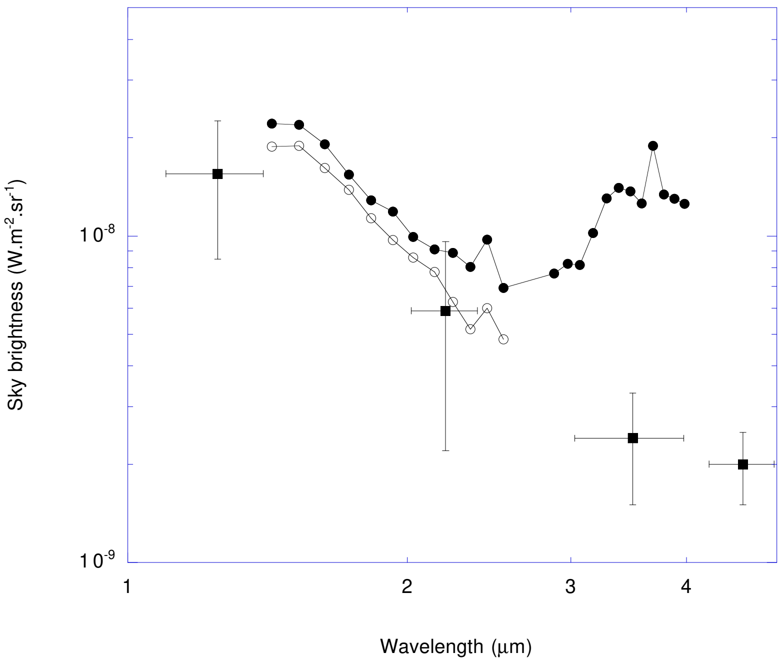

Fig. 3: Spectrum of one sigma fluctuation observed by the IRTS is shown by filled circles. Open circles indicate the excess fluctuation after subtracting the read out noise and stellar fluctuation. Squares indicate rms fluctuation obtained by Kashlinsky et al. (2000) for the DIRBE data.

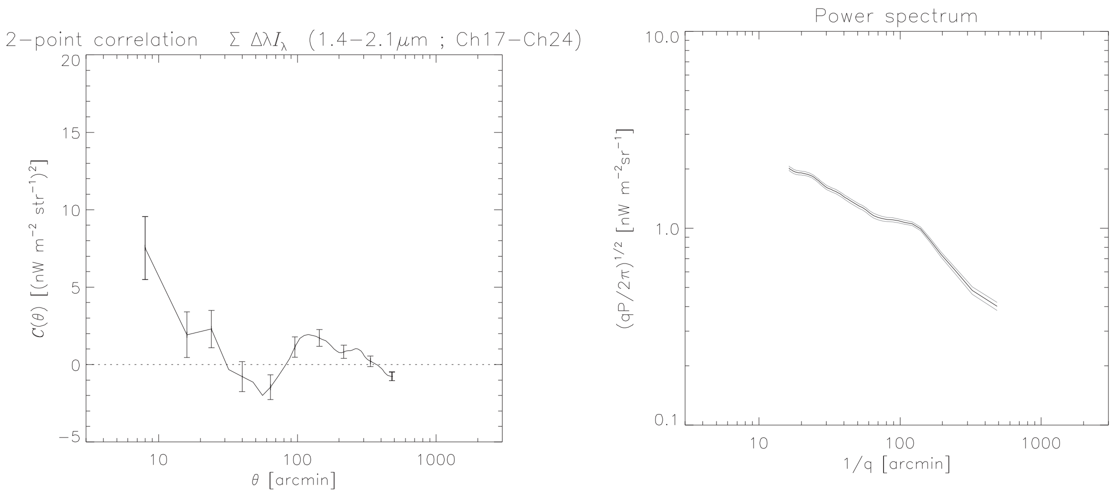

Fig. 4: Left: Two point correlation function is shown as a function of angular distance, θ. Right: Power spectrum $(qP(q)/2\pi)^{1/2}$ is shown as a function of $1/q$.

Table 1: Summary of observations of DIRBE minus stars. Units are $nWm^{-2}sr^{-1}$. Numbers in parenthesis indicate the corrected brightness with Kelsall's model

Authors	J band	K band
Gorjian et al. (2000)		16.2 ± 6.4 (24.5 ± 6.6)
Wright (2000)	27.8 ± 14.5 (60.8 ± 14.5)	19.9 ± 5.3 (28.2 ± 5.5)
Kiso star count	60.1 ± 15	
IRTS/NIRS		27.5 ± 5 at 2.24 μm

3. FAR-INFRARED AND SUBMILLIMETER OBSERVATIONS

In Figure 5, recent results of the submillimeter and far-infrared EBL are shown. Puget et al. (1996) first reported the detection of the EBL in the submillimeter region with DIRBE data, which was later confirmed by Fixen at al. (1998). In far-infrared region, Hauser et al. (1998) reported significant detection of the EBL at 140 and 240 μm and upper limits at 60 and 100 μm. Lagache et al. (2000) carried out careful analysis and obtained EBL at 100, 140 and 240 μm which are consistent with Hauser et al. (1998). Recently, Finkbeiner et al. (2000) introduced a new analysis to subtract the zodiacal component and reported a detection of the EBL even at 60 μm. The obtained brightness 28 ± 8 $nWm^{-2}sr^{-1}$ is so bright that it causes a serious problem to explain it. The energy flux of the submillimeter and far-infrared EBL is estimated to be $30 \sim 50$ $nWm^{-2}sr^{-1}$.

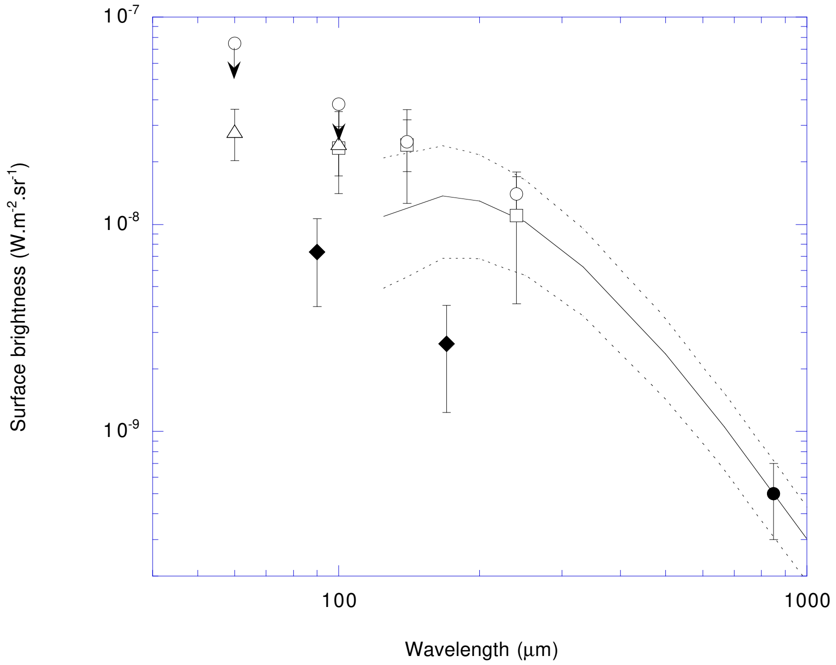

Fig. 5: Recent results on the far-infrared and submillimeter EBL. Open circles, open squares, open triangles are results by Hauser et al. (1998), Lagache et al. (2000), Finkbeiner et al. (2000), respectively. Estimations of EBL based on the galaxy number counts are shown by filled circle (Blain et al. 1999) and filled diamond (Matsuhara et al. 2000)

The observed EBL should be compared with the integrated light of point sources. At 850 μm, deep surveys with SCUBA have been carried out. Blain et al. (1999) made the deepest survey with using lensing effects, and reported that SCUBA sources can explain the submillimeter background. In the far-infrared regions ISO surveys are the unique observation for this work. The detection limits of ISO surveys were not deep enough to estimate the contribution of the point sources to the EBL. However, Matsuhara et al. (2000) made a fluctuation analysis using a deep survey towards the Lockman hole where the column density of the neutral hydrogen is minimum. They first detected fluctuation due to faint galaxies and obtained galaxy number counts down to a few times lower level than the detection limits of ISO. They found that strong evolution is required to explain the detected fluctuation. The background due to faint galaxies in their model is also shown in Figure 5 which is significantly lower than observed EBL. Deeper surveys to fainter levels are needed to confirm the strong evolution effect.

4. DISCUSSION

The most important issue of the recent observations of the EBL is energetics. The combined NIR and FIR/submillimeter EBL, total energy flux is estimated to be $50 \sim 80$ nWm^{-2}sr^{-1}. Assuming a single star burst at a redshift z_f, the following simple expression is obtained.

$$\sim 10\left(\frac{h^2\Omega_{\rm B}}{0.02}\right)\left(\frac{\Delta X}{0.01}\right)\left(\frac{5}{1+z_f}\right)\mathrm{nWm^{-2}sr^{-1}}$$

Where, $\Omega_{\rm B}$, ΔX, are the mean baryon density parameter and conversion factor from Hydrogen to Helium, respectively. Since $\Omega_{\rm B}$ and ΔX are seriously constrained by nuclear synthesis and metal abundance, it does not look easy to explain observed EBL by known objects. The observed IREBL requires new energy sources and/or hidden objects.

Fall et al. (1996) first presented an estimation based on the FIR EBL. They assumed a few types of models of star formation history at high redshift and found that a bright near infrared EBL must exist to interpret the far-infrared EBL.

Jimenez and Kashlinsky (1999) made a detailed calculation with more realistic models. Their estimation depends on the model parameters, however, the prediction shows a much brighter EBL than previous models (see Figure 1).

Another important observational evidence is the significant detection of fluctuations in the NIREBL. The observed rms fluctuation level is fairly large ($\sim 1/4$ of isotropic emission) and the fluctuating component has a similar spectral shape as that of the isotropic emission. On the other hand, the detected two point correlation and PSD show typical angular scales of $\sim 2^\circ$ whose scale and amplitude are marginally consistent with the model by Jimenez and Kashlinsky (1999).

These observational results suggest that the observed EBL originates in a short period at high redshift. Observed fluctuations may reflect the clustering of galaxies at that epoch.

At present, the origin of the observed IREBL is not clear, but future space missions, such as NGST, HII/L2, and FIRST, will be powerful tools to finally solve the enigma of IREBL.

ACKNOWLEDGMENT

The author thanks IRTS members for their encouragement and useful discussions.

REFERENCES

Abraham, P. et al. 1998, in: ESA SP-427, The Universe as seen by ISO, ed. P. Cox & M. Kessler (Noordwijk: ESA), 145

Bernstein, R. A., Freedman, W .L., & Modore, B. F. 2000, ApJ, submitted

Blain, A. W. et al. 1999, ApJ, 512, L87

Cohen, M. 1997, in: ASP Conf. Ser. 124, Diffuse Infrared Radiation and the IRTS, ed. H. Okuda, T. Matsumoto, & T. Roellig (San Francisco: ASP), 61

Dube R. R., Wickes, W. C., & Wilkinson, D. T. 1979, ApJ, 232, 333

Dwek, E. & Arendt, R. G. 1998, ApJ, 508, L9

Fall, S. M., Charlot, S., & Pei, Y. 1996, ApJ, 464, L43

Finkbeiner, D. P., Davis, M., & Schlegel, D. J. 2000, preprint(astro-ph/0004175)

Fixen, D. J. et al. 1998, ApJ, 508, 123

Gorjian, V., Wright, E. L., & Charry, R. R. 2000, ApJ, 536, 550

Hauser, M. G. et al. 1998, ApJ, 508, 25

Jimenez, R. & Kashlinsky, A. 1999, ApJ, 511, 16

Kashlinsky, A., Mather, J. C., & Odenwald, S. 2000, ApJ, 528, 74

Kelsall, T. et al. 1998, ApJ, 508, 44

Lagache, G. Haffner, L. M., Reynolds, R. J., & Tufte, S. L. 2000, A&A, 354, 247

Matsumoto, T. et al. 1999, in: ISO Surveys of a Dusty Universe, ed. D. Lemke, M. Stickel, & K. Wilke (Heidelgerg: Springer), 96

Matsuhara, H. et al. 2000 A&A, 361, 407

Murakami, H. et al. 1996, PASJ, 48, L41

Noda, M. et al. 1994, ApJ, 428, 363

Pozzetti, M. et al. 1998, MNRAS, 298, 1133

Puget, J. -L. et al. 1996, A&A, 308, L5

Toller, G. N. 1983, ApJ, 266, L79

Vrtilek, J. M. & Hauser, M. G. 1995, ApJ, 455, 677

Wright, E. L. 2000, preprint(astro-ph/0004192)

Yoshii, Y. & Takahara, F. 1988, ApJ, 326, 1