An Infrared Study of Herbig Ae/Be Stars*

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Abstract The IRAS and 2MASS associations for 206 HAEBE stars are identified in this paper. From the color-color diagrams and spectral index, it is found that the IR excesses for most samples are due to thermal emission from the circumstellar material. It is also found that the IR excesses at IRAS region for few HAEBE stars and the near-IR excesses for some HAEBE stars are likely attributed to free-free emission or free-bound emission from the circumstellar ionized gas. Moreover, the evolution scenario (from embedded HAEBE stars to \( \beta \) Pictoris-like main-sequence stars) from Malfait et al. (1998) has been checked, our result does not support this evolution scenario.

Keywords Stars: emission-line · Be · Infrared: stars · Stars: pre-main-sequence

1. Introduction

Herbig Ae/Be (HAEBE) stars are thought to be newly formed young stars with intermediate mass (2–9 solar masses) in the pre-main-sequence (PMS). They are usually found in those stars with spectral types A, B and F, in most instances spatially correlated with dark clouds or bright nebulosities (Herbig, 1960; Thé et al., 1994; Waters and Waelkens, 1998). A feature common to all HAEBE stars is the presence of infrared excess due to thermal radiation of circumstellar dust (Strom et al., 1972; Cohen, 1973; Cohen and Kuhi, 1979; Chen et al., 2000). Finkenzeller and Mundt (1984) studied 57 HAEBE stars and concluded that: the IR excesses of HAEBE stars are much stronger than those of ordinary Be stars, and the two groups are well separated in the H-K, K-L two-color diagram. Their IR excess cannot be explained by emission from a hot (10^4 K) ionized gas but is consistent with thermal emission from dust. Based on the analysis of the spectral energy distributions for 47 HAEBE stars, Hillenbrand et al. (1992) classified their samples in three groups. Group I sources includes 30 stars with large IR excess characterized by spectral slopes \( \lambda F_\lambda \sim \lambda^{-4/3} \); group II includes 11 stars with flat or rising infrared spectra; and group III sources includes 6 stars with small IR excess similar to classical Be stars, in which the excess is probably due to free-free emission from a gaseous circumstellar disk or envelope. However the geometry of the dust has been the subject of a long lasting debated (e.g., Hillenbrand et al., 1992; Berrilli et al., 1992; Hartmann et al., 1993; Mannings and Sargent, 1997; Corcoran and Ray, 1998). For late-B, A and F stars, the evidence for the presence of disk geometries is generally accepted. For early-B stars, the matter is less clear. In these systems, the dissipation time scale of the circumstellar spherical envelope is of the order of the PMS lifetime. Disks as well as spherical envelopes might be present (Acke and van den Ancker, 2004). Therefore, infrared study of HAEBE stars would significantly reveal their physical nature and evolutionary status.

The Infrared Astronomical Satellite (IRAS) surveyed about 96% of the sky in four broad bands centered at 12,
25, 60 and 100 μm. This resulted in great expansion of the number of IR sources to about 250,000 (IRAS Point Source Catalog, Version 2, 1988, hereafter IRAS PSC). Furthermore, the Two Micron All Sky Survey (2MASS) which covers 99.998% of the sky and the 2MASS Point Source Catalog (2MASS PSC) contains positions and photometry for 470,992,970 objects at the J (1.24 μm), H (1.66 μm) and K (2.16 μm, hereafter K) near-infrared bands (2MASS Home Page, 2003). Thus from the IRAS PSC and the 2MASS PSC it is possible to make the systematic investigation for HAEBE stars, and to discuss some physical properties and environment of HAEBE stars in the IR region.

In this paper, based on the IRAS PSC, IRAS Faint Source Catalog, |b| > 10, Version 2.0 (Moshir+ 1989, hereafter, IRAS FSC), 2MASS PSC and the HAEBE stars collected from the literature, we have made the cross-identification between the HAEBE star and the IRAS source as well as the cross-identification between the HAEBE star and the 2MASS source. The objective of these identifications is to generate two-group unique homogeneous set of data at 12, 25, and 60 μm from IRAS and at JHK bands from 2MASS. From these data, the processes responsible for the IR excess radiation in HAEBE stars would be better studied.

2. Sample and data

This study is restricted to the HAEBE stars presented in the literature (e.g. Thé et al., 1994; Vieira et al., 2003; and so on, about 260 in total). The main aim of this paper is to identify the IRAS and 2MASS associations of these HAEBE stars, to obtain the fluxes at 12, 25, and 60 μm from IRAS PSC or IRAS FSC and the magnitudes at JHK bands from 2MASS PSC for HAEBE star with IRAS and 2MASS association, and to discuss some physical properties and environment of HAEBE stars according to their nature in the infrared.

First, by using the USNO-B1.0 Catalog (Monet+ 2003, hereafter USNO), and/or the GSC 2.2 Catalogue (STScI, 2001, hereafter GSC), the positions of all HAEBE stars collected from the literature are corrected. Then the IRAS association is searched for each HAEBE star according to the method used by Chen (1996). In order to ensure the reliable association between a HAEBE star and the related IRAS source, the position of the related IRAS source together with its error ellipse is plotted on the Atlas of the USNO or the Atlas of the GSC to find out whether the HAEBE star concerned is in the error ellipse of a certain IRAS source or not. If so, the association between the HAEBE star and the related IRAS source is confirmed. Second, based on the position in USNO and/or GSC, we use a 5′ searching circle to search the counterpart of 2MASS for the samples associated with IRAS. If there is only a 2MASS source in this circle, the cross-identification is almost positive. It should be pointed out that in few cases of more than one 2MASS sources in the error circle, the distance between the position of a star and the position of 2MASS sources as well as the visual magnitude of the star are considered as the references to extract the best one to be the 2MASS counterpart. If necessary, as the reference the Simbad database is also used in the identification. Finally, 206 HAEBE stars are found to have the IRAS and 2MASS associations that are listed in Table i.

It should be notable that there are some IRAS misidentifications of HAEBE stars in the literature, for example, V633 Cas and IRAS 00087+5833, V590 Mon and IRAS 06379+0950, HBC 552 and IRAS 07178–4429, HD 76534 and IRAS 08533–4316, Herbst 28 and IRAS 08566–4313, GSC 8593–2802 and IRAS 09410–5601, HD 87403 and IRAS 10012–5902, GSC 8618–2363 and IRAS 10501–5556, HD97048 and IRAS 11066–7722, GSC8645–1401 and IRAS 12150–5927, GSC8993–0397 and IRAS 13002–6157, WRAY15–1090 and IRAS 13168–6208, HD124237 and IRAS 14109–6134, HD132947 and IRAS 15008–6256, HD140863 and IRAS 15448–5728, MWC 361 and IRAS 21009+6758, V373 Cep and IRAS 21418+6552, MWC 1072 and IRAS 22457+5751, BHJ 71 and IRAS 23030+6158, and so on. Any of these HAEBE stars is clearly out of the error ellipse of the related IRAS source, while according to IRAS Catalog and Atlas Explanatory Supplement (1988, IRAS ES), this error ellipse has a reliability of over 95%.

All identified IRAS and 2MASS associations of the HAEBE stars are listed in Table 1. The items in the columns of Table 1 are listed as follows: (1) number in this study; (2) star name; (3) reference to star name; (4) IRAS name; (5) and (6) the R.A. and Dec. from 2MASS PSC at the epoch of 2000 respectively; (7) spectral type; (8) reference to spectral type; (9) and (10) V magnitude and observed color B-V respectively; (11) reference to V and B-V; (12) the interstellar extinction at visual wavelength; (13) reference to Av. In Table 2, we give the IRAS and 2MASS observations of the samples: (1) number; (2) (4) IRAS flux densities at 12, 25 and 60 μm. Only good quality ones are presented; (5) and (6) J magnitude and its total magnitude uncertainty from 2MASS PSC; (7) and (8) H magnitude and its total magnitude uncertainty from 2MASS PSC; (9) and (10) K magnitude and its total magnitude uncertainty from 2MASS PSC; (11) the power spectral index with its uncertainty between J and K bands. It is noted that if in columns (5), (7) and (9) there is “#” at the end of the magnitude, this means that the magnitude given in the 2MASS is only the upper-limited value.

3. Interstellar extinction correction

In the near IR region, the reddening due to interstellar material along the line of sight to the star cannot be neglected in particular for stars, like most HAEBE stars, close to the