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Search for Exozodiacal Dust: Are Vega-like Stars Common?

By

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Abstract: Possible observations of Vega-like stars by the ASTRO-F and the HII/L2 3.5m space telescope are proposed. Vega-like stars are main sequence stars with mid-infrared and/or far-infrared excess. A few of these stars have been observed precisely at various wavelengths and it was found out that they tend to have hot (∼300K) circumstellar dust like the zodiacal dust in our solar system and warm (∼50K) dust ring around 30–50 AU from the central star. In spite of these discoveries, one question still remains; How many Vega-like stars are there? Mid- and far-infrared surveys by the ASTRO-F and the HII/L2 telescope will be the best ones to get the answer to this question. The ASTRO-F/FIS survey could detect 'α Lyr' located at a distance of <50pc, within which roughly 150 of A-type main sequence stars exist. The HII/L2 3.5m telescope survey has the capability to detect much farther, up to 100pc. Thus, the total number of candidates will increase to as many as ∼1000.

1. INTRODUCTION

'Vega-like' stars are main sequence stars having mid-infrared and/or far-infrared excess emission. This kind of excess was first detected by the IRAS observation and was thought to be due to thermal emission from the circumstellar dust (Aumann et al. 1984).
Smith & Terrile (1984) found elongated visible light around β Pic, one of the 'Vega-like' stars, using a coronagraph and suggested that it was due to the edge-on circumstellar disk.

Recently, high resolution images of 'Vega-like' stars were obtained by the Keck telescope and the Hubble Space Telescope. Koerner et al. (1998) took 12.5μm and 20.8μm images of

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HR4796A (A0 67pc) and claimed that the source of the 12.5μm radiation was a few hundred K dust within a few AU from the central star. Schneider et al. (1999) found ring-shaped around HR4796A using NICMOS camera and coronagraph onboard the HST. They suggested the light originated from the star light scattered by the circumstellar dust ring.

Similar dust ring was also found around ϵ Eri (K2V 3.22pc) using the SCUBA at the JCMT (Greaves et al. 1998). The ring of dust had the peak emission at 35–75AU from the central star and the estimated dust temperature was >30K.

It is believed that circumstellar dust disks around protostars vanish within ~1Myr due to Poynting-Robertson drag. However, the ages of 'Vega-like' stars were estimated to be 10–1000Myr (Song et al. 2000). Some kind of replenishment mechanism is needed to explain the existence of 'Vega-like' stars.

Photometric observations of 'Vega-like' stars by ISO suggested that not many stars had mid- and far-infrared excesses (Abraham et al. 1998; Habing et al. 1999). These results do not mean, however, that 'Vega-like' features are peculiar because the number of observed stars was too small (~90) to acquire a general view of 'Vega-like' stars.

2. POSSIBLE OBSERVATIONS

Since the temperature of the circumstellar dust of 'Vega-like' stars is expected to be from several tens to 300K, mid- and far-infrared all-sky survey from space is the most appropriate way to find them.

2.1 Photometry

Photometry is worth doing because it could be done even by a small telescope like ASTRO-F (0.7m diameter). Also the data amount is relatively small, which is important for an observation such as an all-sky survey from space.

One disadvantage of a photometric survey is that absolute photometry is indispensable. To separate circumstellar dust component from total flux, flux from stellar photosphere should be determined in some way. Usually, it is estimated from the extrapolation of ground-based photometry in the near infrared region using some models of spectral energy distribution of stellar photospheric emission. It is clear that absolute fluxes are essential for this kind of approach although precise measurements of absolute fluxes are difficult. Besides this, follow up observations are needed for each star detected in the survey, which would not be easy to realize.

Multicolor observations might be one solution against such kinds of difficulties because spectral indexes are generally determined more accurately than absolute fluxes. At mid-infrared, hot dust emission with a temperature of ~300K has flatter spectral index than that of photosphere. Likewise spectral index of ~50K dust emission is different from that of the photosphere in the far-infrared. The ASTRO-F/FIS, for example, has four photometric bands in the far-infrared (60μm, 90μm, 150μm, and 170μm) which are suitable for detections of warm dust.

2.2 Imaging

Imaging with high spatial resolution is a better way to separate circumstellar dust emission and photospheric emission. Large ground-based telescope can be employed for such observations for example Koerner et al. (1998). However the circumstellar dust emits mostly in mid- and far-infrared region. For this reason, observations from space telescopes are required.

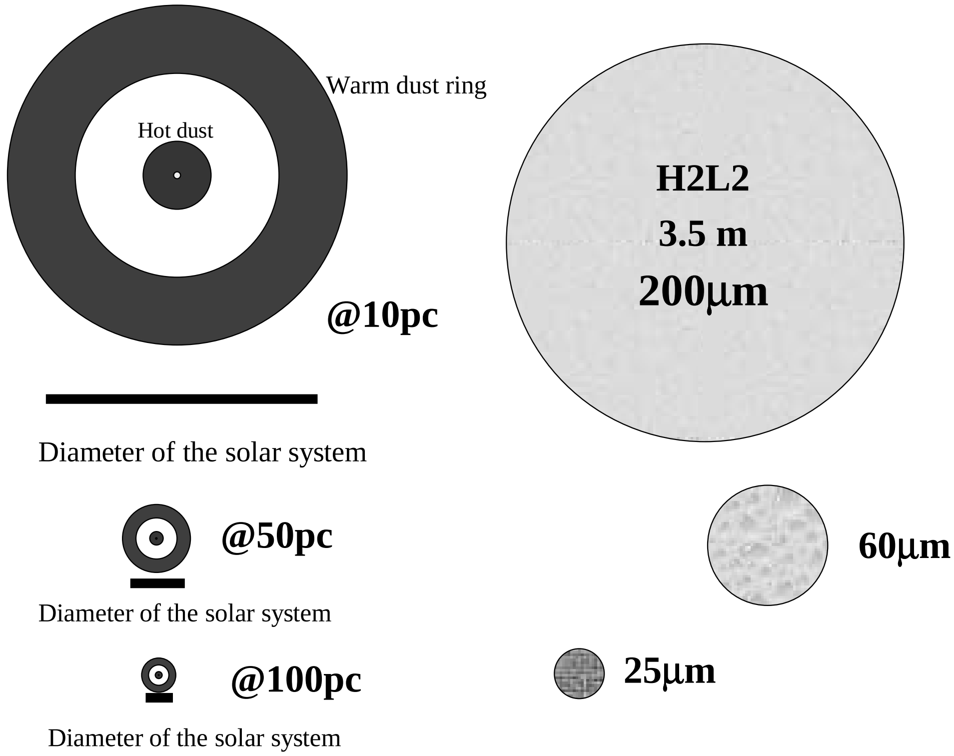

Fig. 1: Face-on views of a star at 10, 50 and 100pc and diffraction limits of 3.5m telescope in space (HII/L2). The star is assumed to have hot dust in inner <∼10AU region and warm dust ring from 30 to 50AU. The diameter of the solar system is shown for reference.

Figure 1 is a comparison of the face-on views of a star at different distances and diffraction limits of a 3.5m telescope in space (HII/L2). The star is assumed to have hot dust in inner <∼10AU region and warm dust ring from 30–50AU. Inner hot dust components of the star at a distance of around 10pc or closer could be resolved at $\sim 25\mu$m or shorter wavelengths. Also, the outer warm dust components are resolved at the wavelengths of 60–100μm. From these observations, temperature distribution as well as density distribution of circumstellar dust can clearly be inferred.

2.3 Spectroscopy

Spectroscopy is useful to reveal the composition of circumstellar dust. Both amorphous and crystalline silicates have spectral features mainly in the mid-infrared region (Draine & Lee 1984; Koike et al. 1993). The spectrum of the Herbig Ae-Be star HD100546 taken by ISO exhibited crystalline silicate features in the mid-infrared while the interstellar silicate dust is mostly amorphous(Malfait et al. 1998).

Many of the 'Vega-like' stars are possibly evolved from Herbig Ae-Be stars. From this point of view, mid-infrared spectroscopy of 'Vega-like' stars is important. Follow-up observations of 'Vega-like' stars discovered by the ASTRO-F/FIS survey should be carried out by the ASTRO-F/IRC and HII/L2 telescope.

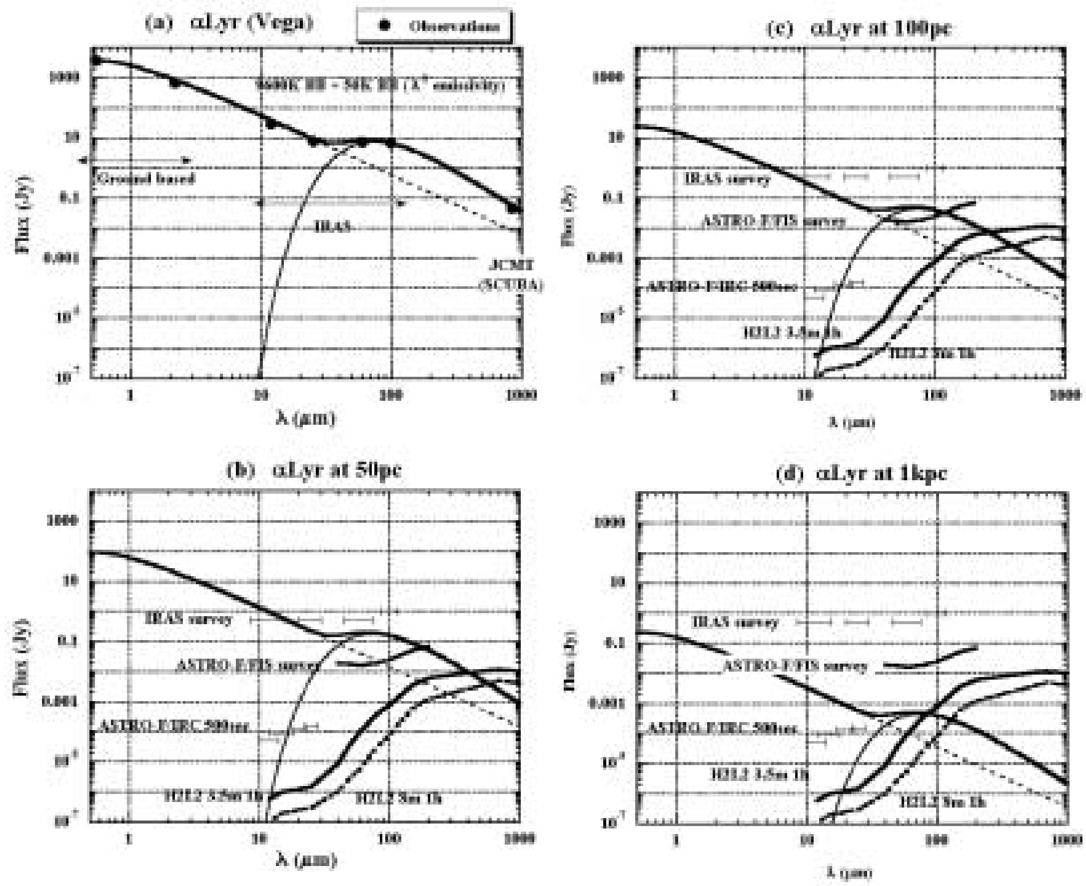

Fig. 2: Comparison between spectral energy distributions (SED) of α Lyr at different distances and detection limits (5σ) of the IRAS, the ASTRO-F and the HII/L2. (a) The SED (9600K BB (dashed line) and 50K BB (thin solid line) with λ^{-1} emissivity) derived from the observed fluxes. V, K-band and IRAS (12, 25, 60 and 100μm) data are taken from Aumann et al. (1985). 850μm data is taken from Holland et al. (1998). (b)–(d) The SED of α Lyr at 50pc, 100pc and 1kpc respectively.

2.4 Candidates

One of the important points for the study of 'Vega-like' stars is to observe as many stars as possible. Figure 2(a) shows the spectral energy distribution (SED) of α Lyr (A0V 7.76pc, Vega). The observed fluxes of α Lyr are well fitted by two components, 9600K blackbody and 50K graybody with λ^{-1} emissivity. This is not the best fit, but good enough to explain the SED of α Lyr. If α Lyr is placed at 50, 100 and 1000pc, SEDs and the detection limits of IRAS, ASTRO-F and HII/L2 are as shown in Figure 2(b)–(d). The ASTRO-F/FIS survey could detect such objects up to a distance of <50pc. With 500sec integration, ASTRO-F/IRC (10–20μm channel) might detect the dust emission, although the photospheric emission is 10–100 times brighter.

Objects like β Pic (A5V 19.3pc), younger 'Vega-like' star, have even larger excesses as shown in Figure 3(a). The observed data were explained by a three components fit. Again, this was just shown to express the rough SED of β Pic. The excess emission from 'β Pic' at

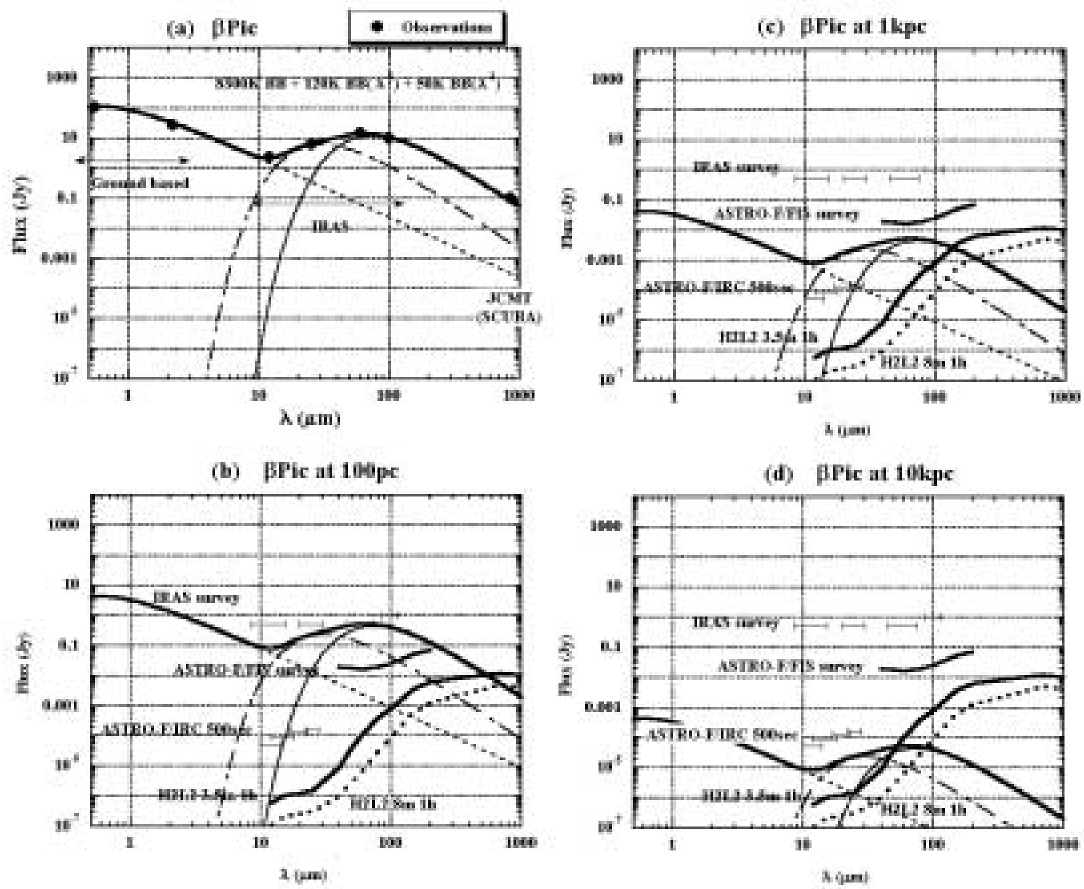

Fig. 3: Comparison between spectral energy distributions (SED) of β Pic at different distances and detection limits (5σ) of the IRAS, the ASTRO-F and the HII/L2. (a) The SED (8300K BB (short-dashed line), 120K BB (dash-dotted line) and 50K BB with λ^{-1} emissivity (thin solid line)) derived from the observed fluxes (Aumann 1985; Holland et al. 1998). (b)–(d) The SED of β Pic at 100pc, 1kpc and 10kpc respectively.

100pc can easily be detected by the ASTRO-F/FIS survey. Using the HII/L2 3.5m telescope, much more distant, up to several hundred pc, 'β Pic-like' objects could be found. Because of its high sensitivity, mid-infrared spectroscopy of these objects would be worth carrying out.

The next question is how many candidates do we have for the mid- and far-infrared survey of 'Vega-like' stars? Many of the 'Vega-like' stars are A-type stars. A0–A9 stars have been selected from the Hipparcos catalog (ESA 1997) and the V-band apparent magnitudes of A-type stars versus distance from the earth are plotted in Figure 4. The distances were calculated from the measured parallaxes. Stars that had more than 30% error on distance were excluded. Main sequence stars ($0.5 < M_v < 2.4$) are shown as black diamonds while the other A-type stars as gray crosses.

Figure 5 shows the number of A-type main sequence stars in the Hipparcos catalog as a function of distance. Because of the limited accuracy of the distance determination in the Hipparcos observations, the number begins to decrease at 200pc or farther. These numbers should be treated as the minimum values.

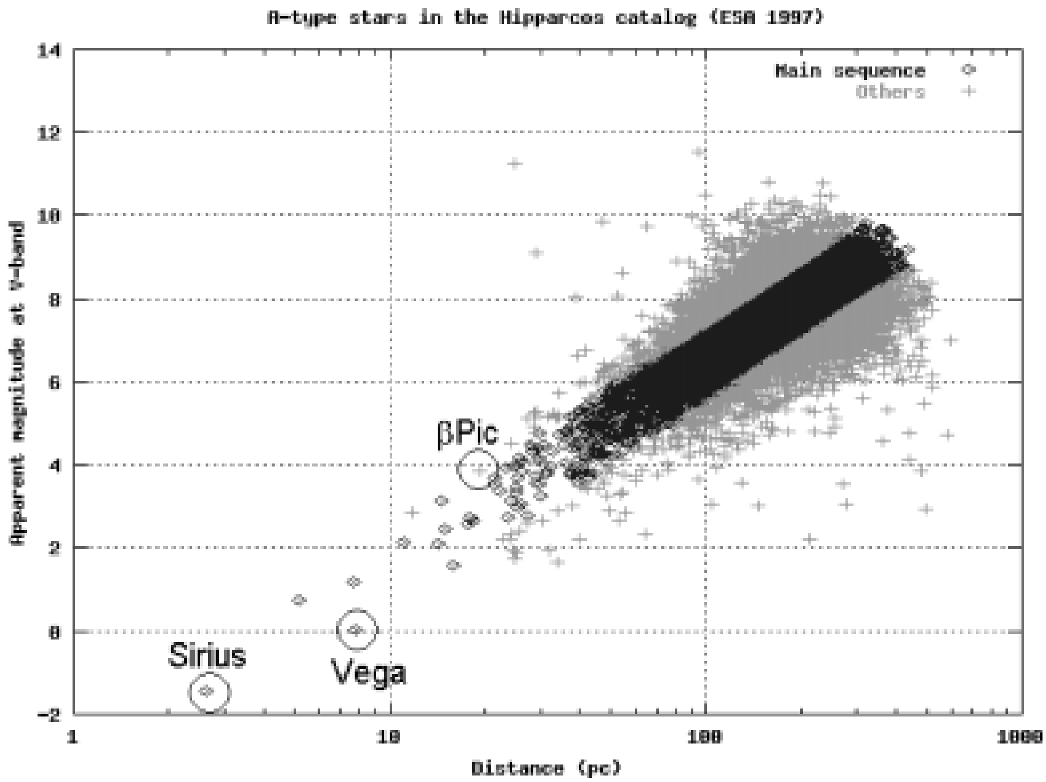

Fig. 4: V-band apparent magnitudes of A-type stars versus distance. A0–A9 stars were selected from the Hipparcos catalog (ESA 1997). Black diamonds represent main sequence stars ($0.5<M_v<2.4$).

The ASTRO-F/FIS survey could detect 'α Lyr-like' objects located at a distance of <50pc as stated before. In this region, roughly 150 A-type stars exist. This number is relatively small compared to the total number of the plotted stars. However, complete survey of these stars is still meaningful since only ~90 stars have been observed to date at mid- and far-infrared wavelength (Abraham et al. 1998; Habing et al. 1999). The 3.5m telescope survey (HII/L2) will find 'α Lyr-like' stars much farther, say up to 100pc, . Therefore, the total number of candidates is as many as ~1000!

It should be noted that not only A-type stars but also some G- and K-type main sequence stars show 'Vega-like' feature (Aumann 1985; Greaves et al. 1998). This means F-, G- and K-type main sequences should also be the targets.

3. CONCLUSION

Future space missions such as the ASTRO-F, the HII/L2 telescope have the capability to detect much farther 'Vega-like' stars than the current instruments have observed. Large samples are needed to establish whether 'Vega-like' phenomena commonly occur or not. All sky survey would be the best way to get an answer to this question. The ASTRO-F/FIS survey is one of the key projects for studies of 'Vega-like' stars. More precise studies like spectroscopy by the HII/L2 telescope will be good follow-up. Information from these observations must be

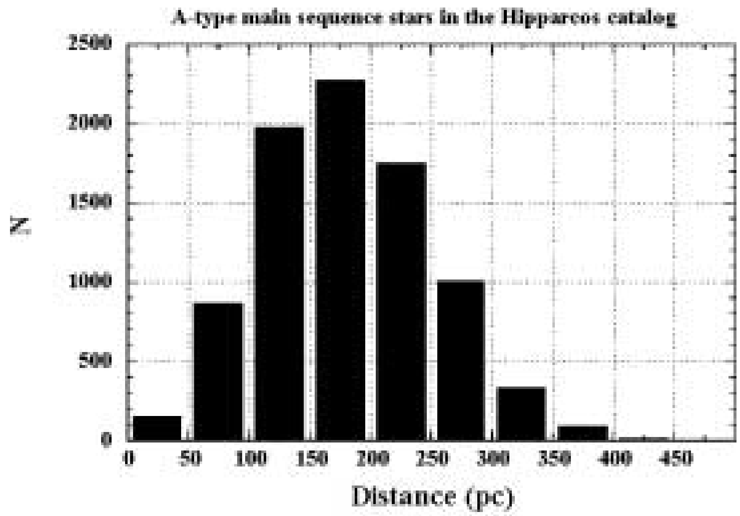

Fig. 5: The number of A-type main sequence stars in the Hipparcos Catalog as a function of distance. Stars that have more than 30% error on distance are excluded.

valuable for the study of stellar evolution and planet formation.

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