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# First results from a photometric infrared survey for Vega–like disks around nearby main–sequence stars*

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**Abstract.** We have undertaken a survey for *Vega*–like disks around nearby main–sequence stars by making photometric measurements with ISOPHOT at four wavelengths between 25 and 180 $\mu$m. Our goal is to establish how common *Vega*–like disks are, and how their presence depends on the fundamental properties of main–sequence stars (mass, age, rotation etc.). Here we present first results that concern *Vega* itself and *g Lup*. We confirm the results obtained by IRAS and give new fluxes at 135 and 180 $\mu$m. We also present a first table of measurements on a larger sample. *Vega*–like disks are common, but not a general feature of all main–sequence stars with masses above 0.9 $M_\odot$.

**Key words:** Stars: Planetary systems – Stars: general – Stars: individual: Vega, g Lup – Infrared: stars

## 1. Introduction

Perhaps the most spectacular, unpredicted discovery by IRAS was made by Aumann & Gillett (see Aumann *et al.* 1984) when they found that the star *Vega* ($\alpha$ Lyrae) and three other main–sequence stars emit much more strongly at 25 and 60 $\mu$m than the stellar photospheres can explain. The origin of this "excess" emission was proposed to be in a disk of dust particles, presumably a left over from the days when the stars formed. This proposition was beautifully verified by a coronographic picture taken in the I–band of the star $\beta$ Pic that showed very clearly a thin disk seen edge on (Smith & Terrile 1984).

After this successful start several groups have thoroughly searched the IRAS database for more examples. Their results have been summarized very well by Backman & Paresce (1993) who present a master list of stars with disks and the conclusion that *Vega*–like disks are common among main–sequence stars. Yet, the master list does not answer any detailed question what "common" means. Does the presence of a disk depend on the mass, on the age or on the rotation velocity of the star? We do not know. It is with these questions in mind that we have begun to use ISO for a photometric survey of the fluxes of nearby main–sequence stars at wavelengths between 25 and 180 $\mu$m. Starting from the list of nearby stars given by Johnson & Wright 1983 we selected (using information from the Gliese (Gliese & Jahreiss 1979) and Bright Star (Hoffleit & Jaschek 1982) catalogues) all stars fulfilling the following set of criteria: The star should be on the main sequence and have spectral type from A to K, its distance from the sun should be less than 25 parsec. We required that the photospheric flux of the star should be more than 30 mJy at 60 $\mu$m so that faint disks could be found and "no detection" still is useful information. Finally we demanded that the star as seen in the ISOPHOT diaphragms should be single, or that any known companion was more than one ISOPHOT diaphragm away. This

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* 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.

left us with only 84 stars all of which we observe in our program. This selection represents therefore a complete sample.

ISO has already made several measurements of stars from our program. Here we present first results. As the calibration of ISOPHOT still presents difficulties our results are preliminary and sometimes qualitative. We expect that ultimately we will achieve the original goals.

## 2. Observations, Data reduction and Results

The observations discussed in this letter were taken during February and March 1996 with the ISOPHOT instrument (Lemke *et al.* 1996). The measurements at the five different wavelengths were concatenated, so that we have in most cases the full set of measurements for each observed star available.

The ISOPHOT observations have been reduced using the PHOT Interactive Analysis package (PIA). At the moment this is imperative since the quality of the data can only be judged from examination of the intermediate steps in the analysis. The calibration was done using measurements of the internal fine calibration sources of the ISOPHOT instrument (FCS). Independently, we have checked the calibration with COBE DIRBE data which gives a good value for the background flux at low resolution. Generally we have found that the FCS calibration leads to a range of different background fluxes for different pixels. The DIRBE measurements are mostly within but at the lower end of this range. We believe that this supplies a valuable error estimate which at the moment is about a factor of two.

The interpretation of the derived flux values is different at different wavelengths. Our measurements at 60 and 90 $\mu$m are carried out with the 3x3 pixel C100 in triangular chopping mode. By this way we obtain a small map of the sky around the source, consisting of 27 pixels arranged in a 3x9 rectangle with the central pixel pointing towards the star. Since the measurement includes background measurements on both sides of the source, the background subtraction automatically eliminates any linear gradient in the background. This is unfortunately not possible for the long wavelength measurements (using the 2x2 pixel C200 detector at 135 and 180 $\mu$m) because the field of view is too small. Therefore, the flux derived for these wavelengths may be contaminated by such a linear gradient. We plan to use the maps obtained with the C100 to estimate the background structure around the source and thereby reduce the currently large errorbars on those measurements.

Currently, the overall calibration error of the PHOT observations appears to be at least a factor of two. We therefore limit most of our discussion in this letter to two cases with rather strong excesses: *Vega* and *g Lup*.

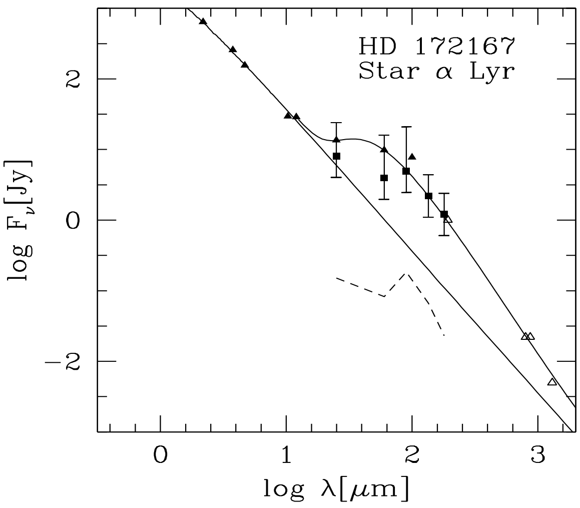


**Fig. 1.** Photometry of *Vega* from infrared to millimeter wavelength. The full triangles indicate standard photometry, IRAS and submillimeter measurements. Open triangles are upper limits. The fluxes are taken from the IRAS point source catalogue and from Becklin & Zuckerman (1990) and Chini *et al.* (1990). The squares are new measurements from ISO and include our current error estimates. The dashed line shows the upper value of cirrus confusion estimate as derived with IRSKY. The solid lines indicate fits of a Kurucz model (Kurucz 1979) to the photosphere and a grey body to the dust emission (see text).

### *2.1. Vega*

*Vega* is of course the prototype of main sequence stars with infrared excess. The IRAS mission has detected excesses at 25, 60, and 100 $\mu$m (Aumann *et al.* 1984, Aumann 1985, Gillett 1986). There also exists a $2\sigma$ measurement at 193 $\mu$m (Harper *et al.* 1985) obtained with the Kuiper Airborne Observatory, and (sub-) millimeter measurements by Becklin & Zuckerman (1990) (0.8mm) and by Chini *et al.* (1990) (0.87 and 1.3mm). Our measurements have now added values at 135 and 180 $\mu$m. All values are shown in Fig. 1. The error bars on the ISO measurements are currently larger than a factor of two, which in this case can be attributed to detector drift effects. As *Vega* is one of the brightest sources, the contrast between source and background is very high and the drift pronounced. At the long wavelengths this is much less a problem (since the flux there is lower) and our measurements there are more accurate. *Vega* has already been modeled by several different authors (for an overview see e.g. Backman & Paresce 1993). A detailed model was derived by Chini *et al.* 1990 which included a grain size distribution $f(a) \sim a^{-3.5}, 18\mu\mathrm{m} < a < 4374\mu\mathrm{m}$, in a disk with $1.8\times10^{-8}\mathrm{M}_\odot$ distributed between 40 and 74 AU from the star. This model does fit the observations obtained before

ISO except for the 193 $\mu$m measurement[2]. However, our determination of the flux at 180$\mu$m is in close agreement with the value given by Harper *et al.* 1985, indicating a decline of the IR emission clearly steeper than a Rayleigh-Jeans slope in the region beyond 100$\mu$m. This supports a recent result from van der Bliek *et al.* (1994). They showed that the *Vega* shell is considerably larger than previously assumed (35 arcsec instead of 23). This result largely removes the lower limit on grain sizes derived by Aumann *et al.* (1984). The steep decrease of infrared emission can well be attributed to grains considerably smaller than the relevant wavelength. The fit shown in Fig. 1 is a simple one-grain-one-temperature model. We assumed the grains to reside at a distance of 140 AU from *Vega* (corresponding to the 35 arcsec source diameter) and calculated the grain temperature with the assumption of a 2–power law–absorption efficiency with $Q(\lambda)$ = const for $\lambda < \lambda_0$ and $Q(\lambda) \sim \lambda^{-1}$ for $\lambda > \lambda_0$. The best fit in the infrared region is obtained for $\lambda_0 = 20\mu$m. The resulting grain temperature is 84K. According to Mie theory, $\lambda_0 \simeq 2\pi a$, were $a$ is the grain radius. Thus, our fit indicates a typical grain size of the order of only 3$\mu$m, although the factor $2\pi$ is correct only for strongly absorbing materials and may be somewhat smaller, depending on the grain material. The grains are thus much smaller than the original estimate by Aumann *et al.* 1984 and in good agreement with the estimates by van der Bliek *et al.* 1994. The simple fit also matches the millimeter data reasonably well. This, however, is fortuitous since we did not use the mm points in our fit. Furthermore the millimeter fluxes are certainly higher than shown in Fig. 1 because those values have not yet been beam–size corrected for the larger source diameter.

### *2.2. g Lup*

The star *g Lup* (HD 139664) has already been identified in several of the IRAS point source studies as a candidate of a *Vega*–type star with excess at 60 $\mu$m. The problem with *g Lup* is that it resides in a region of very high and structured galactic cirrus. The statistical estimates for the cirrus confusion noise as derived from IRSKY for this region are quite high. However, we conclude that the excess seen is connected with the source for the following reasons: Maps of the observations at 60 $\mu$m obtained with HIRAS (Bontekoe *et al.*, 1994) show that the excess is clearly centered on the position of the star and clearly separated from a nearby cirrus fragment. This is confirmed by our measurements in particular at 60 $\mu$m which shows clearly a strong detection in the central pixel of the C100 detector but a relatively flat field in all the other pixels as well as in the off-source positions. In the observation with the C200 such an independent estimate for the background is not possible as the source is seen equally in all four pixels. Furthermore, as discussed above, the measurement with the C200 is susceptible to linear gradients in the background. Therefore, the measured fluxes at 135 and 180 $\mu$m must have a much larger uncertainty. We have indicated this in Fig. 2 with additional error bars. The impression that the measured flux at 135 and 180 $\mu$m is much higher than at 60 and 90 $\mu$m (pointing to much lower dust temperatures than in other known examples of *Vega*–like stars), may be premature. This can only be confirmed by mapping the region around the source at these wavelengths which we plan to do in the near future.

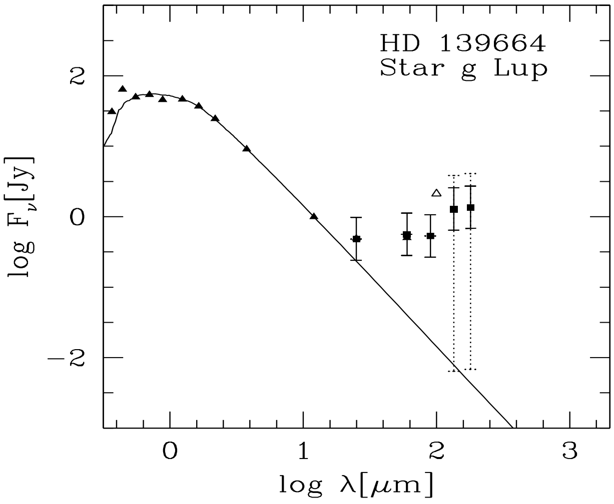


**Fig. 2.** Photometry of *g Lup* from visual to infrared wavelengths. The symbols have the same meaning as in Fig. 1. The additional error bars (dotted lines) reflect the high level of background confusion noise which affects mainly the measurements with the C200 detector.

### *2.3. Stars observed so far*

In Table 1 we show a summary of the stars in our sample observed and reduced so far. Due to the current uncertainties in the fluxes, we have restricted the table to a basic yes/no flag. Stars are marked "++" if there is no doubt that they have an excess. A "+" indicates that we think we see an excess, but further checking is required. Many of these cases are based on the following consideration: Looking at the signals in the ISOPHOT measurement, it is possible to recognize clear detections by the signal pattern in the different pixels. This procedure allows in this case to reject the possibility of cirrus confusion in the C100 data. If we see such a clear detection for a star whose predicted photospheric flux is below the detection limit of ISOPHOT at that wavelength, this star should have an excess emission. All cases in Table 1 are based on the 60 $\mu$m and 90 $\mu$m measurements because they are less susceptible to cirrus confusion, as discussed above. The 5$\sigma$ detection limits at 60 and 90 $\mu$m are 60 and 50 mJy, re-

[2] The model neither fits the measurement by Becklin & Zuckerman 1990, see discussion in Chini *et al.* 1990

**Table 1.** Observations analyzed so far

| HD number | Name | Excess[a] | IRAS excess[b] |
|---|---|---|---|
| 90839 | 36 UMa | + | 0 |
| 95128 | 47 UMa | 0 | 0 |
| 126660 | $\theta$ Boo | 0 | 0 |
| 128167 | $\sigma$ Boo | +? | ++ |
| 134083 | c Boo | 0 | 0 |
| 139664 | g Lup | ++ | ++ |
| 142860 | $\gamma$ Ser | +? | ++ |
| 149661 | 12 Oph | +[c] | 0 |
| 156026 | 36 Oph C | 0 | 0 |
| 157214 | w Her | + | 0 |
| 160691 | $\mu$ Ara | ++ | ++ |
| 166620 | | 0 | 0 |
| 172167 | $\alpha$ Lyr | ++ | ++ |
| 173667 | 110 Her | + | 0 |
| 185144 | $\sigma$ Dra | 0 | 0 |
| 185395 | $\theta$ Cyg | + | 0 |
| 187642 | $\alpha$ Aql | 0 | 0 |
| 203280 | $\alpha$ Cep | 0 | 0 |
| 203608 | $\gamma$ Pav | 0 | 0 |
| 207129 | | ++ | ++ |
| 209100 | $\epsilon$ Ind | 0 | 0 |

a) ++ certain, + likely, +? likely with doubt, 0 undecided.
b) From the master list in Backman & Paresce (1993)
c) Uncertain because of possible cirrus confusion

spectively, for 256 seconds integration time. We have also included stars in this category where an observed flux at 135 or 180 $\mu$m is higher than the cirrus confusion estimate taken from IRSKY. The "0" category contains stars where we either have no clear detection or where the measured fluxes are not in excess of the photospheric flux. Table 1 shows that we confirm all the examples with strong excesses already detected by IRAS. Table 1 contains at least four to five more cases which we label as likely excesses, implying that they still have to be confirmed[3]. At some stage, with clearly established calibration, a few more of the undecided cases might reveal very small excesses. It is worth noticing that we have currently no evidence for an excess in *47 UMa* or HD95128, that is accompanied by a planet (Butler & Marcy1996).

## 3. Conclusions

We present first results of a program to look for stars in the solar neighborhood with *Vega* type excess below the IRAS detection limits. Due to un-finalized calibration the amount of reliable information obtained is limited. New measurements at 135 and 180 $\mu$m of *Vega* and *g Lup* have been presented. The measurements of *Vega* are consistent with an early measurement by Harper *et al.* (1985) and indicate a relatively steep decrease of the *Vega*-excess beyond 100$\mu$m. This implies that the infrared excess up to 100$\mu$m is due to grains with radii for the order of 10$\mu$m or less. Among the 21 stars for which we have analyzed the ISO measurements, we rediscover 5 known and find at least 4-5 (to be confirmed) candidates of new excesses. This shows that the *Vega* phenomenon is indeed a common feature of main sequence stars; however, it does not seem to be ubiquitous. We expect that much more detailed results will become available in the near future.

[3] At a recent conference we had reported tentatively an additional excess for HD 166620; we now withdraw this after discovering a mistake in the data reduction.

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