ISOPHOT OBSERVATIONS OF VEGA AND VEGA-LIKE STARS

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Abstract. Detailed ISOPHOT observations of the far infrared excess of α Lyrae (Vega) are presented. The data comprise photometry in the range 25μm to 200μm and high resolution 60μm scan data to compare with 60μm and 90μm oversampled maps. The dust disk around Vega is clearly resolved. In addition similar maps of HD98800, SAO226057, SAO186777 and α Piscis Austrinus (HR8728) are evaluated, resolving the disks of two Vega-like stars/candidates and providing upper limits for the size of the other two.

1. Introduction

One of the most exciting discoveries of the IRAS satellite was the fact that many evolved main sequence stars including Vega show a strong far infrared excess (Aumann *et al.*, 1984), (Walker and Wolstencroft, 1988).

ISO [1] (Kessler *et al.*, 1996) and especially its photometer instrument, ISOPHOT (Lemke *et al.*, 1996), with its better wavelength coverage and

[1]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.

improved resolution now opens the possibility to study this phenomenon in more detail.

2. Observations

Vega has been observed in detail using the ISOPHOT P3 detector to perform high resolution 60μm scans. In order to obtain the instrumental beam profile, the calibration star HR6705 (γ Draconis), a point source of similar brightness, was observed. The $23''$ aperture was used in a 2×31 ISO raster, with a $6''$ step size and a dwell time of 64s per raster point. This ensures that the scans are sufficiently long to derive a reliable background baseline (3.5 times the size of the Airy disk), and that detector memory and hysteresis effects can be assessed by the repetition.

Far infrared photometry using the C100 and C200 detectors at $\lambda_c =$ 60, 80, 100, 120, 150, 170, 200 μm was obtained in chopped mode using the PHT22 AOT (Klaas *et al.*, 1994). In addition P2 and P3 staring mode photometry at 25 and 60 μm was obtained using the PHT03 and PHT04 AOTs on Vega and a suitable background position. For the photometry the beam sizes used are $135'' \times 135''$ and $180'' \times 180''$ for C100 and C200 respectively and $d = 180''$ for P2 and P3.

Finally we present multi-filter mapping observations of Vega and other Vega-like stars and candidates (Walker and Wolstencroft, 1988), namely HD98800, SAO226057, SAO186777 and HR8728 (α Piscis Austrinus), which are part of larger ISO Open and Guaranteed Time programmes of the authors, to investigate the Vega-like dust disk phenomenon. The PHT32 oversampled C100 maps have been obtained with the maximum possible resolution of $15''$ at $\lambda_c = 60$ and 90 μm. As a point source calibration reference a similar PHT32 map of HR5340 (α Boötis) at 60μm was used.

3. Data Reduction

The data were reduced from Edited Raw Data (ERD) level using the ISOPHOT Interactive Analysis Software Package (PIA) [2] (Gabriel *et al.*, 1996), version 6.2. The calibration is based on the general calibration files (CAL-G) version 3.02. Standard corrections for Cold-Readout-Electronics (CRE) non-linearity, de-glitching and signal derivation were applied. Detector transients were excluded using drift detection. The data were converted into flux units (Jy/beam) using the Fine Calibration Source (FCS) calibrations and related CAL-G files.

[2] PIA is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium led by the Max Planck Institute for Astronomy (MPIA), Heidelberg. Contributing ISOPHOT Consortium institutes are DIAS, RAL, AIP, MPIK, and MPIA.

The FCS measurement of the C200 photometry of Vega showed very serious detector transients on each chopper plateau due to an imperfect setting of the FCS electrical power. Drift fitting using an Offset Exponential function has, therefore, been applied in this special case. The resulting correction factor of 0.76 for the obtained fluxes has been used. The scan results were at this stage extracted from PIA and the further data reduction was performed using dedicated IDL routines. The photometry data were further processed by subtracting the background, co-adding of the 9 or 4 pixels of C100 or C200 respectively, and correcting for the point spread function losses. A special correction for the signal losses due to the strong detector transients in chopped measurements of $\times 1.8$ was applied for C100 based on the P3 staring measurement at the same wavelength. All oversampled maps were produced and flat-fielded by the PIA AAP package. The measured disk sizes were derived by fitting a two dimensional Gaussian to the map. Due to the strong transients induced by the fast chopper movement along the spacecraft Y-axis, only the widths measured along the other axis gave consistent results and were used.

4. Results

The ISOPHOT photometry of Vega is shown in Figure 1. A smooth energy distribution is derived for the whole far infrared region, which is very well described by a modified blackbody with a temperature of 72.8K and an emissivity law of $Q(\lambda) \sim 1/\lambda^{1.1}$. The fit was using only the ISOPHOT data, but matches nicely also the available submillimeter data (Chini *et al.*, 1990), (Zuckerman and Becklin, 1993). It can be shown that a pure blackbody, or a modified blackbody with an emissivity law of $Q(\lambda) \sim 1/\lambda^2$, does not describe the data adequately.

Using the high resolution Vega scans (Figure 2) we derive a disk size of $19''$ Gaussian width by simple quadratic deconvolution according to $\Theta^2_{disk} = \Theta^2_{obs} - \Theta^2_{psf}$.

The evaluation of the PHT32 maps (Figure 3) of Vega and α Boötis, which have a lower resolution than the scans, yields a Gaussian width for the Vega dust disk of $22''$ ($26''$ FWHM). The slightly higher value is probably due to residual detector transients. The results prove, however, the feasibility of this method of determining disk sizes from the PHT32 maps, and give a good indication of the uncertainties that can be expected.

Table 1 summarizes the results of the evaluation of the 60μm and 90μm PHT32 maps of Vega, HD98800, SAO226057, SAO186777 and HR8728.

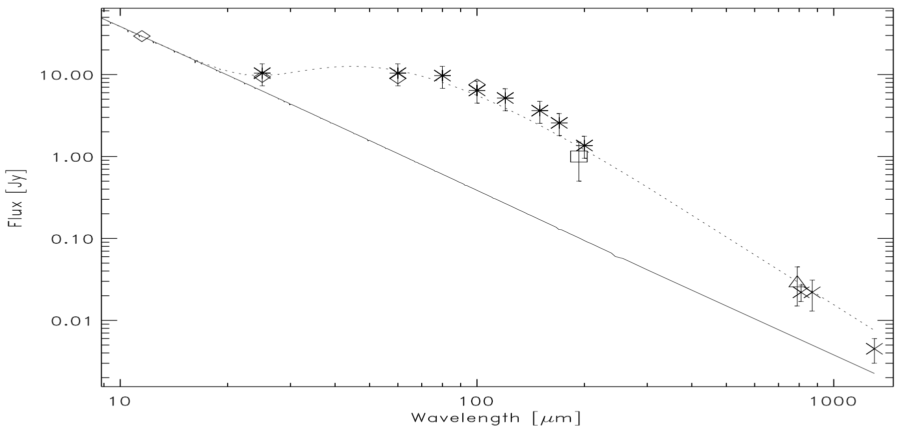

Figure 1. Spectral energy distribution of Vega. Stars ISOPHOT measurements from this paper, diamonds IRAS (Walker and Wolstencroft, 1988), the square KAO (Harper *et al.*, 1984), the triangle and crosses are submillimeter data from Zuckerman and Becklin, (1993) and Chini*et al.*, (1990). The solid line shows the flux from the model photosphere (Cohen *et al.*, 1992). A 30% error that has been adopted for the ISOPHOT data is shown. The dotted line shows a the best fit modified BB with T=72.8K with an emissivity law of $Q(\lambda)$ ¸ $1/\lambda^{1.1}$ to the data.

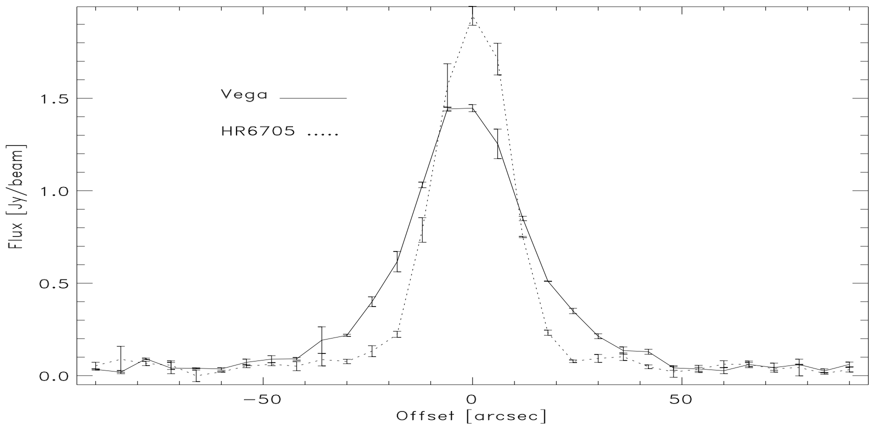

Figure 2. 60μm high resolution scan of Vega and HR6705. Units are Jy per 23^{00} ISOPHOT P3 beam.

5. Discussion

The photometric data of Vega are very well described by a modified blackbody with a temperature of 72.8K and an emissivity law of $Q(\lambda) \sim 1/\lambda^{1.1}$, indicating the presence of large dust particles in the disk. This was already

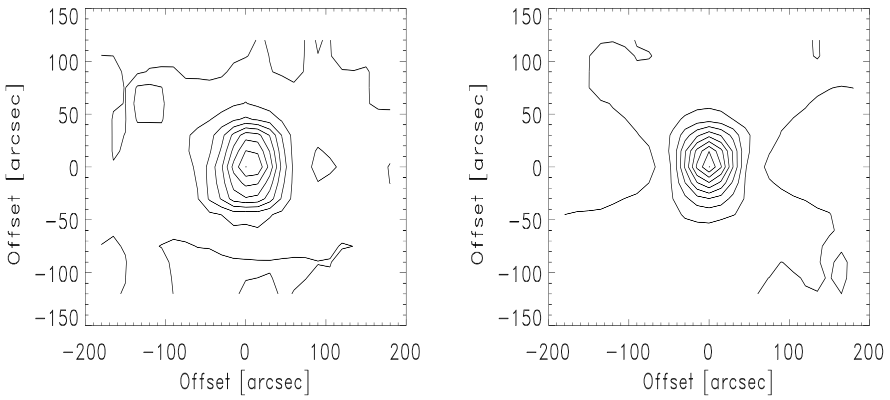

Figure 3. Contour plots of the C100 PHT32 oversampled maps of Vega at 60μm (left), the calibration point source α Boo at 60μm (right). The data is normalized to the maximum and contours with linear 0.1 steps are plotted.

TABLE 1. Disk Sizes of Vega-like Stars

Object	Distance [pc]	Disk Size 60μm [$''$]	Disk Size 60μm[AU]	Disk Size 90μm [$''$]	Disk Size 90μm[AU]
Vega	7.8	26	102	42	164
HD98800	46.9	0	0	0	0
SAO226057	111.	0	0	0	0
SAO186777	286.	17.5	2100	23	3300
HR8728	7.7	27	104	37	142

Disk sizes are in FWHM of the best fit 2-dimensional Gaussian, using only the information along the the spacecraft Z-axis. The distances are from the Hipparcos or Tycho catalogue. A zero in the table indicates that the source is unresolved.

predicted by the submillimeter observations (Chini *et al.*, 1990) and can now be confirmed by the consistent far infrared data out to 200μm.

Disk sizes were derived at 60μm and 90μm for Vega and α PsA, these are very similar, both with respect to the absolute sizes, and the 60μm to 90μm ratio of the radii, indicating a very similar nature of the disk material and geometry. The fact that the disks of SAO226057 and HD98800 could not be resolved is consistentwith a similar or smaller disk size.

It is remarkable that the observations of SAO186777 show a resolved disk, both at 60μm and 90μm. Given the distance of SAO186777, the resulting absolute sizes of the disk are several thousand AUs, comparable to the size for the circumstellar envelopes of T Tauri stars like HL Tau.

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