Zodiacal light disk around Sirius?

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Abstract

We have detected a far-infrared excess in the ISOPHOT measurements of the brightest star of the night sky, Sirius. The most plausible explanation of this excess would be the presence of a dust disk in the Sirius system. Calculations have shown that the parameters of the possible dust disk are intermediate between that of the solar system's zodiacal light cloud and that of Vega-type stellar systems. This is lowest mass disk ever detected ($M_{disk} \approx 1/500 \times M_{Moon}$) and may be the first example of very low mass disks outside our solar system. If these kind of disks are common around A-type stars, the detection of planets by mid-infrared interferometry might be limited by the radiation of the disk as well.
KEYWORDS:*circumstellar dust, VEGA-like stars, individual objects: α CMa*

1. Introduction

Sirius, the brightest star of the night sky has been a major celestial object for many cultures for thousands of years in man's history. Today it is an important calibrator star especially in the mid-infrared, after the discovery of the dust disk around Vega (Cohen et al. (1987)). As part of the calibration work on ISOPHOT (Lemke et al. (1996)) the photometer on-board the Infrared Space Observatory (Kessler et al. (1996)), we have checked the photometric accuracy of point source fluxes derived from small far-infrared maps. While most standard stars investigated we obtained flux densities closed to the model predicition, Sirius showed systematically too high flux densities at both 60 and 100 μm.

Systematic studies performed by the IRAS and ISO satellites revealed far-infrared access in a significant fraction of main-sequence stars. It is generally

believed that this far-infrared excess is originated from a circumstellar disk mainly build up of dust particles. The first example of such a disk around a star was α Lyr, Vega (therefore the name 'Vega-phenomenon', for a detailed description see e.g. Backman & Paresce (1993) and Habing et al. (1999)). Using the ISOPHOT instrument the spatial extension of the dust was detected in the case of two stars with nearly edge-on disks, Vega (Walker et al. (1999)) and β Pic (Heinrichsen et al. (1999)). The disk temperatures detected so far were between 60 and 120 K, and have about the mass of the Moon. In most cases the spectral energy distribution of the dust disk can be described by a modified blackbody, with $\beta=-1$ emissivity law ($F_\nu = \nu^\beta \cdot B_\nu(T)$). Direct imaging of HR 4796A at near- and mid-infrared wavelenghts (Telesco et al. (2000)) revealed that the bulk of the circumstellar disk resides in a sharply definied ring with a radius of ~ 70 AU.

A similar picture may be valid for other Vega-type systems, too. In the case of the known systems the dust particles absorb $10^{-4} - 10^{-5}$ part of the stellar radiation which is reemitted in the infrared. The mass, size and fractional luminosity values are several orders of magnitudes higher than the corresponding parameters of the closest circumstellar disk, the Solar System Zodiacal Light cloud ($M \approx 1/500 \, M_\odot$, $R = 2 - 3$ AU, $f \approx 2.1 \cdot 10^{-7}$). There are no circumstellar disk with parameters similar to that of the zodiacal light cloud detected so far. However, due to the low fractional luminosity, such systems would show only a small deviation from the flux density of the stellar photosphere, which is hard to detect. Therefore it is a question how much fraction of the stellar systems can harbour a faint disk. The best candidate for the detection of a faint disk would be a nearby star which is bright enough even in the far-infrared to have on excess over the detection limit. And Sirius is so...

2. Observations and data analysis

In the ISOPHOT archive we found Sirius observation at 3.3, 12, 25, 60, 100 and 170 μm, performed in various observing modes. Up to 25 μm the derived flux densities followed the model predictions within the uncertainities. At 170 μm the derivation of the absolute flux is very uncertain due to the very strong cirrus field around the star. At 60 and 100 μm the extracted flux densities were significantly higher than the predicted flux of the photospere. In order to check if the excess is real, we have selected some stars (HR 617, HR 1657, HR 6705, HR 7557, HR 7980) having a brightness similar to that of Sirius and reduced their observations as well. We were using these observations to calibrate the

Sirius measurements independently from the standard calibration process. We used the Phot Interactive Analysis (PIA) software for the data reduction. In the case of minimaps we used the 'pairwise' [1] method for deglitching. Finally we derived an excess flux density of $\mathbf{E_{60} = 205 \pm 70\,mJy}$ at $60\,\mu m$ and $\mathbf{E_{100} = 120 \pm 56\,mJy}$ at $100\,\mu m$. In the following we use these parameters to determine the properties of a possible dust disk in the Sirius system. In order to improve the calibration in the range of bright stars, a reprocessing of all the available data and an extension to measurements which were not in use before is still in progress, therefore the final excess values and all the derived properties may change considerably.
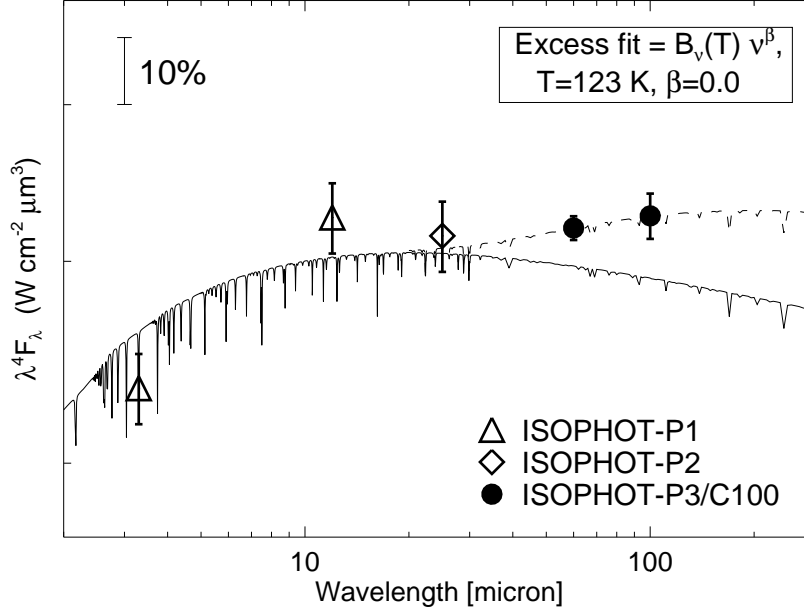

Figure 1: Spectral energy distribution of the Sirius model by M. Cohen (continous line), with ISOPHOT measurements overplotted

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3. A disk around Sirius?

Assuming that the observed far-infrared excess is real, we checked it the measured excess could originate from the with dwarf companion of Sirius A. Following the method by (Plets & Vynckier (1999)) we calculated the FIR flux density of Sirius B (B=8.41, V=8.44), and obtained $0.47\,\mathrm{mJy}$ at $60\,\mu\mathrm{m}$, two orders of magnitudes below the measured value. We also calculated how bright a giant planet (like Jupiter) would be at $60\,\mu\mathrm{m}$, but the calculated flux density is even lower than that of the white dwarf. Thus the most plausible explanation for the excess is a circumstellar dust disk.

Radius. In order to get an idea about the spatial and angular extension of the dust disk, we modelled it by assuming a ring-like density distribution, and calculated the inner and outer radii of the ring considering different particle sizes and different surface density gradients. It was requested that the emissions of the ring at 60 and $100\,\mu\mathrm{m}$ match the ISOPHOT results. The simulations showed that the inner radius of the ring is basically determined by the grain size distribution. The calculated 60 and $100\,\mu\mathrm{m}$ emission is not very sensitive to the outer radius, therefore this quantity is only poorly constrained by our calculations.

We assumed three different types of dust particles: black body graines, medium-sized graines and small grains. The inner radius values, derived for the dust populations are 24-29 AU ($9''$-$11''$ at the distance of Sirius), 100-125 AU (38-$47''$) and 215 AU ($82''$), respectively. If the disk has the same inclination to line-of-sight as the binary orbit, i.e. nearly face-on, then it must fit within the ISOPHOT beam, otherwise it could not be detected. Since the inner radii calculated from medium- and small-sized grains exceed considerably the size of the beam of $43''\times43''$ at 60 and $100\,\mu$, our modelling strongly favours large particles which radiate as blackbodies even at longer wavelengths.

Temperature. The 60 and $100\,\mu\mathrm{m}$ excess values define a balckbody color temperature of $123\,\mathrm{K}$. A comparison of this value with the literature demonstrates that temperature of the Sirius disk falls in the upper end of the range observed in other Vega-type disks (60 and $120\,\mathrm{K}$).

Disk mass. The mass of circumstellar dust was calculated assuming an absorption coefficient $\kappa(60\mu\mathrm{m}) = \kappa(850\mu\mathrm{m}) = 1.7\,\mathrm{cm}^2\mathrm{g}^{-1}$. The result is $\sim 1/500$ of the mass of the Moon, showing that the Sirius disk may be the least massive

circumstellar disk ever detected. This value is very closed to that of the zodiacal light cloud of the Solar System.

The fractional luminosity. Fractional luminosity, f, is the ratio of the far-infrared excess to the star's bolometric luminosity. We calculated this value by using the formula of Backman et al. (1987). The result of $2.3 \cdot 10^{-7}$ is very closed to the typical fractional luminosity of the Solar System's zodiacal light cloud, but singificantly lower than that of Vega-type disks. This result (and the blackbody SED) may indicate that the circumstellar disk of Sirius is more similar to the zodiacal light cloud than to other Vega-type disks. As far as we know, the Sirius disk would be the first detection of an 'exo-zodiacal' cloud.

4. Consequences

It is a question if disks similar to Sirius' are common around main sequence stars. If the answer is 'yes', the existence of such disks may have a major impact on the direct detection of 'exoplanets' using mid-infrared interferometry, since at those wavelenght the disk can be brighter than the planets themselves.

5. Summary

We detected excess emission above the photosphere of Sirius at both 60 and $100\,\mu$m on the 2–3σ level. This is interpreted as the emission of a circumstellar disk. The circumstellar cloud has a fractional luminosity very similar to that of the zodiacal light cloud in the Solar System, but its temperature and size are most consistent with the parameters of other Vega-type disks. The mass of the Sirius disk is 1/500 of the mass of the Moon. The derived physical parameters place the Sirius disk between the Vega-type disks observed by IRAS and ISO and the Zodiacal Light Cloud in out Solar System. This might be the first example for a class of very faint disks which could be ubiquitious around main sequence stars.

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