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Search for cool circumstellar matter in the Ursae Majoris group with ISO*

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Abstract. We observed the mid- and far-infrared spectral energy distributions of 9 A-type stars from the 300 Myrs old Ursae Majoris group using the ISO satellite and the UKIRT telescope. We found that only 1 out of the 9 stars shows clear signature of circumstellar dust, and we derived an upper limit of 0.05 M_{moon} for the dust mass around the other stars. Our results suggest that the relatively high incidence of Vega-like disks observed among A-type field stars in the solar neighbourhood by IRAS cannot be extrapolated to the rest of the Milky Way. The Vega phenomenon appears to be the exception rather than the rule.

Key words: circumstellar matter – stars: individual: β UMa – infrared: stars

1. Introduction

Young intermediate mass stars are embedded in massive disks/envelopes, as observed around the pre-main sequence Herbig Ae/Be stars. These circumstellar dust structures are eroded in time due to stellar wind, Poynting-Robertson drag, radiation pressure, collisional destruction, sublimation, and coagulation into planets. The erosion does not necessarily lead to zero final mass: IRAS has discovered that main-sequence stars can also be accompanied by dust disks (Vega phenomenon, Aumann et al. 1984; for a comprehensive review see Backman and Paresce 1993). The evolution from the disks/envelopes of Herbig Ae/Be stars to Vega-like disks and/or to planetary systems is not well documented by observations (for attempts using submm observations see Zuckerman & Becklin 1993, and Holland et al. 1998). The evolutionary history, however, would provide information on the lifetime of accretion disks around intermediate mass stars, would define the timescale for planet formation, and could clarify whether the Vega-like disks are built of primordial material from the accretion disks or whether their dust is continuously replenished by the destruction of asteroids and comets. To outline this evolution one has to determine the typical dust content in several stellar groups of different ages. In this paper we contribute to this project by studying the circumstellar dust in the Ursae Majoris (UMa) group.

The UMa group is a stream of stars of the same age, moving at the same rate in the same direction through space in the solar neighbourhood. It is the remnant of an open cluster, whose large fraction has already been dispersed and only the nucleus (formed by βUMa, γUMa, δUMa, ϵUMa, ζUMa, and 80UMa) remained spatially compact at a distance of ≈ 25 pc from the Sun. Because of the well-determined age of the group of ≈ 300 Myrs (Levato and Abt 1978, Eggen 1983), its proximity to the Sun, as well as the low cirrus background at its high galactic latitude, the Ursae Majoris group has already been searched for signatures of circumstellar matter in different wavelength regimes. After the pioneering work of Witteborn et al. (1982) at 10 μm, IRAS discovered strong infrared excess towards βUMa (Aumann 1985). Zuckerman and Becklin (1993) detected no submm emission from A-type stars of the group. Using IRAS co-added data, Yuan and Backman (1993) found no excess infrared emission from individual A-type members of the group – except βUMa –, but averaging for all stars they reported a small 12 and 25 μm excess above the photospheric emission. Lecavelier des Etangs et al. (1997) searched for CaII circumstellar gas, with negative result.

In this paper we present far-infrared observations of 9 main-sequence A-type members of the UMa group, performed with the Infrared Space Observatory (ISO). We used ISOPHOT (Lemke et al. 1996), the photometer on-board ISO, which is well suited for studies of circumstellar dust because of its larger wavelength coverage and higher sensitivity compared to IRAS. The ISO observations have been supplemented by mid-infrared photometry from the ground using the MAX mid-infrared camera at the UKIRT telescope (Robberto and Herbst 1998). Our goal is to determine the typical circumstellar dust parameters of intermediate mass stars at an age of 300 Myrs from the analysis of the incidence and masses of dust disks in the UMa group. A similar study on the incidence of Vega-like disks among nearby ($d \leq 20$ pc) field stars has been performed by IRAS (Backman and Gillett 1987, hereafter 'IRAS BG-survey'). They found that

* Based on observations with ISO, an ESA project with instruments funded by ESA member states (especially the P/I countries France, Germany, the Netherlands and the United Kingdom) with participation of ISAS and NASA.

Table 1. List of programme stars. The data are taken from The Bright Star Catalogue (Hoffleit & Jaschek 1982). 'D' is the separation of visual binaries, 'SB' stands for spectral binary.

BS/HR	Name	Sp. type	V $[m]$	D $['']$	SB	$v$sin$i$ [km/s]
710	AB Cet	A6Vp	5.83	12	yes	14
906		A7III-IV	5.95	24.2	yes	41
4295	β UMa	A1V	2.37	no	yes	39
4554	γ UMa	A0Ve	2.44	no	yes	168
4660	δ UMa	A3V	3.31	190	no	177
4905	ϵ UMa	A0p	1.77	no	yes?	38
5062	80 UMa	A5V	4.01	no	yes	218
6254	52 Her	A2Vp	4.82	1.8	no	31
8410	32 Aqr	A5m	5.30	no	yes	19

10 out of 22 A-type stars show significant infrared excess above the photospheric emission, and half of the excesses is stronger than the fractional luminosity of Vega ($\approx 2 \times 10^{-5}$). From this statistics Backman and Gillett concluded that "most main sequence stars have particle clouds emitting in the far-infrared". Although the UMa group is more distant than the limit of the IRAS BG-survey, the higher sensitivity of the ISOPHOT instrument ensures that the incidence of disks in the two samples can be directly compared. Since the field stars in the IRAS BG-survey are probably older than the UMa group, the comparison of the IRAS and ISOPHOT results provides information on the further evolution of circumstellar dust later than 300 Myrs. This comparison is the second goal of the present investigation.

2. Observations and data reduction

The 9 programme stars, selected from the list of Geary and Abt (1970), are listed in Table 1. The spectral types and V magnitudes are from The Bright Star Catalogue (Hoffleit & Jaschek 1982). The sample includes 5 stars from the nucleus and 4 stars from the dispersed part of the group. As also marked in Table 1, most stars are known to be binaries. However, stars of all spectral types exhibit similar Rayleigh-Jeans spectral energy distributions in the far-infrared, therefore the existence of a cold $\lambda \geq 25\mu$m excess cannot be explained by stellar companions. The sample was selected to contain both slow and fast rotators.

2.1. ISOPHOT observations

Between May 1996 and January 1998, multifilter photometry with ISOPHOT was performed for each star, including at least two (12μm and 60μm) and at most 8 filters in the 3.6μm-170μm wavelength range. 20 out of the 46 observations were performed in chopped mode; the others were done in either staring on/off mode or with small maps. At $\lambda \leq 25\mu$m the $52''$ circular aperture was selected; at longer wavelengths we observed with the C100 (3x3 pixels, $46''$/pix) or the C200 (2x2 pixels, $92''$/pix) cameras. The typical on-source measurement time was 32s or 64s per filter.

Data reduction was performed using the ISOPHOT Interactive Analysis (PIA) V7.1 (Gabriel et al. 1997), including corrections for non-linearities of the ramps and for signal dependence on reset intervals, as well as subtraction of dark current and removal of cosmic ray hits. Detector transients were handled by using the drift recognition procedure in PIA. In the case of chopped measurements corrections for signal loss at high chopping frequency and for the inhomogenity of the field of view were applied. All but the 60μm and 90μm observations were calibrated by using the corresponding internal calibration source (FCS) measurements. At 60μm and 90μm we adopted signal dependent responsivities, as we derived from the analysis of faint standard star measurements. For error calculus we compared the statistical measurement uncertainties, represented by the error bars in PIA, with a conservative absolute calibration uncertainty of 25% (Klaas and Radovich 1998), and adopted the higher value. From the 3×3 frames taken by the C100 camera the source's flux was determined from the central pixel's value after correction for the size of the point spread function. Flux densities at $\lambda = 170\mu$m were calculated by adding up the flux densities of all four pixels of the C200 camera, and correcting for the point spread function. Colour corrections were applied by assuming a stellar-like $I_\nu \sim \nu^2$ spectrum.

2.2. Ground-based mid-infrared photometry

M, N, and Q-band observations were obtained for the objects BS 4295, BS 4554, BS 4660, BS 4905 and BS 5062 using the MAX camera at the UKIRT 3.8m telescope on February 5th, 1997. We applied the standard chopping/nodding technique and always co-added 100 separate images (128×128 pixels, 0.273$''$/pixel) each of 6.144 ms to a chopping image within the camera. Depending on the brightness of the object, up to 50 nodding cycles were performed. Since the position of the object on the detector array did not vary during the observations, we simply co-added the individual chopping/nodding images after correction for bad pixels.

3. Results

Table 2 and Table 3 present the results of the ISOPHOT and ground-based UKIRT/MAX photometry, respectively. The flux densities, together with colour-corrected IRAS values from the Faint Source Survey (Moshir et al. 1992) and ground-based photometry from Gezari et al. (1993) are plotted in Fig. 1. The good agreement among the different data sets at $\lambda \leq 12\mu$m ensures that the photospheric emission of the stars can be accurately defined (no significant excess is expected in this spectral regime). In order to predict the photospheric emission at longer wavelengths we modelled the 2-200μm spectral energy distribution of the stars as follows: (1) for BS 5062 we used the SED derived by Hammersley (private communication; for the method see Hammersley et al. 1998) using a Kurucz-model with $T_{eff} = 8087$K, log g=4.2 and [Fe/H]=0.00; (2) for the other stars we assumed the same spectral shapes as that of BS 5062, and scaled them to the data points at $\lambda \leq 12\mu$m. Comparing the measured flux densities with the model predictions in Fig. 1, it is easy to identify the cases where significant far-

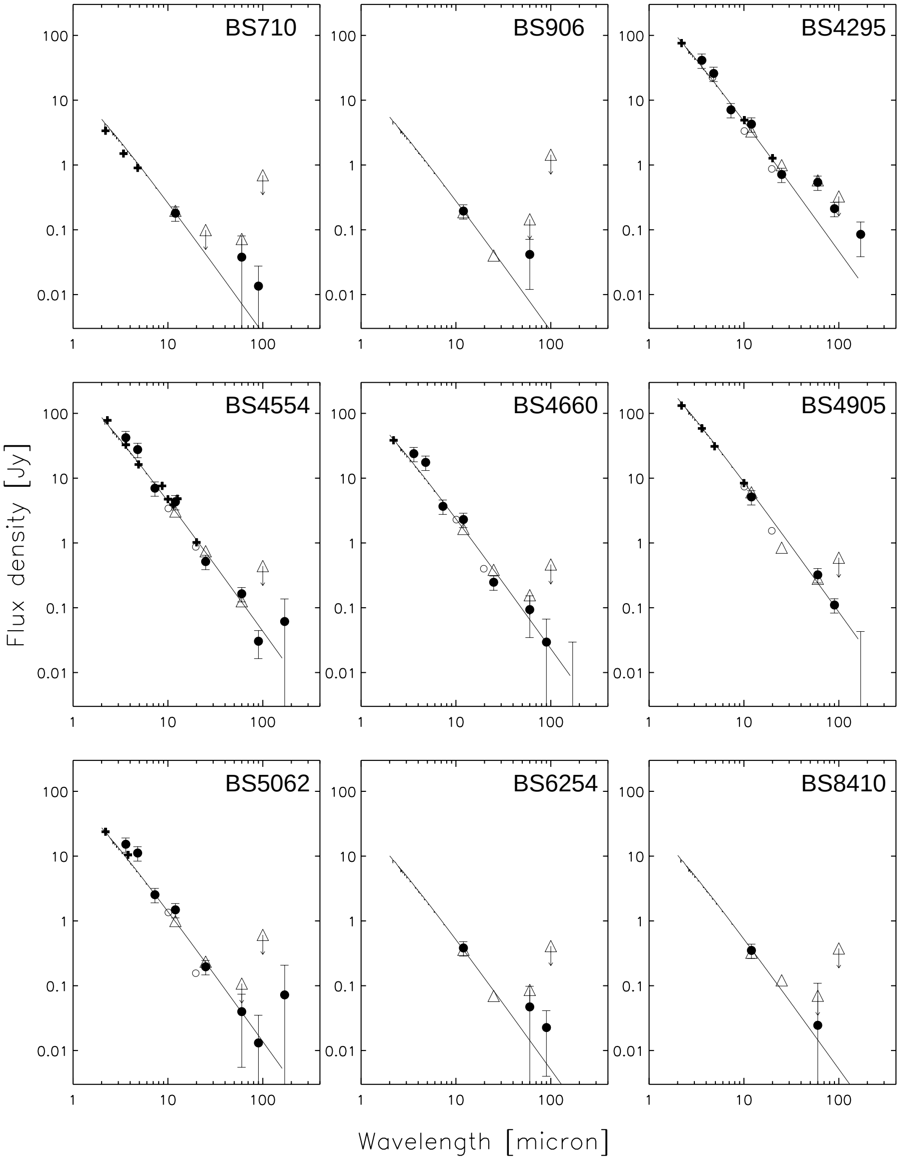

Fig. 1. Spectral energy distributions of the programme stars. *Dots:* ISOPHOT, *Open circle:* UKIRT/MAX, *Triangle:* IRAS FSS, *Plus sign*: ground-based photometry from Gezari et al. (1993). The solid line shows the predicted photospheric emission of the star (Sect. 3).

infrared excess is present. The results are given in Table 4. For 8 stars the 60μm and 90μm flux densities are consistent with pure photospheric emission within the error bars. On the other hand, the far-infrared excess of β UMa, already discovered by IRAS (Aumann 1985), was clearly detected.

In order to compare our results with the IRAS BG-survey we determined an upper limit for the fractional luminosity of each star's circumstellar dust f, i.e. the ratio of the far-infrared excess to the star's bolometric luminosity. The results, calculated using the formula of Backman and Gillett (1987), are listed in Table 4, and are also plotted in Fig. 2 as a function of the V-magnitudes of the stars. For comparison we plotted the fractional luminosity of dust disks detected around A-type stars in the IRAS BG-survey. Fig. 2 indicates that our sensitivity is high enough to observe the same kind of disks in the UMa group as detected in the IRAS survey, therefore the incidence of disks in the two samples may be directly compared.

The source β UMa was among the first stars reported by IRAS to show strong far-infrared excess. Our photometry (1) confirmed the 60μm excess; (2) detected the excess at 90μm (IRAS had only upper limit); and (3) provided a 2σ measurement at 170μm. A simple blackbody fit to the 25μm, 60μm, 90μm, and 170μm excesses, shown in Fig. 3 (long dashed line), is not consistent with the very low submm flux density at 800μm (-12 ± 10 mJy) measured by Zuckerman and Becklin (1993). The data seem to favour a modified blackbody $B_\nu(T)\nu^\beta$ with $\beta = 1 \ldots 2$ (Fig. 3). The derived dust temperature is in the range of 50-80 K depending on the β emissivity factor used. These values are lower than those calculated from IRAS data alone (90-150 K, Coté 1987), and are at the lower end of the temperature distribution of Vega-like disks (60-120 K, Backman and Paresce 1993), showing that the β UMa disk is relatively cold. The data point at 170μm, however, clearly excludes the presence of an extra very cold dust component in this system.

Table 2. Results of ISOPHOT photometry

Object	3.6μm [Jy]	4.8μm [Jy]	7.3μm [Jy]	12μm [Jy]	25μm [mJy]	60μm [mJy]	90μm [mJy]	170μm [mJy]
BS 710				0.18 ± 0.05		38 ± 43	14 ± 14	
BS 906				0.19 ± 0.05		42 ± 30		
BS 4295	41.2 ± 10.3	25.8 ± 6.5	7.10 ± 1.77	4.27 ± 1.07	713 ± 178	539 ± 135	212 ± 53	85 ± 47
BS 4554	42.2 ± 10.5	27.6 ± 6.9	7.00 ± 1.75	4.31 ± 1.08	516 ± 129	164 ± 41	30 ± 14	61 ± 75
BS 4660	23.9 ± 6.0	17.5 ± 4.4	3.68 ± 0.92	2.30 ± 0.57	247 ± 62	94 ± 59	30 ± 37	-21 ± 50
BS 4905				5.13 ± 1.28		322 ± 81	110 ± 28	-6 ± 49
BS 5062	15.2 ± 3.8	11.2 ± 2.8	2.54 ± 0.63	1.48 ± 0.37	196 ± 49	40 ± 34	13 ± 22	72 ± 135
BS 6254				0.38 ± 0.10		47 ± 51	23 ± 19	
BS 8410				0.35 ± 0.09		25 ± 85		

Table 3. Results of ground-based UKIRT/MAX photometry

Band	BS 4295	BS 4554	BS 4660	BS 4905	BS 5062
M [mag]	2.11 ± 0.08				
M [Jy]	22.30 ± 1.58				
N [mag]	2.65 ± 0.06	2.62 ± 0.08	3.06 ± 0.08	1.78 ± 0.08	3.63 ± 0.10
N [Jy]	3.34 ± 0.19	3.41 ± 0.24	2.29 ± 0.17	7.40 ± 0.57	1.35 ± 0.13
Q [mag]	2.67 ± 0.10	2.67 ± 0.10	3.52 ± 0.2	2.06 ± 0.07	4.54 ± 0.4
Q [Jy]	0.87 ± 0.09	0.87 ± 0.09	0.4 ± 0.08	1.54 ± 0.11	0.16 ± 0.06

4. Discussion

Recent ISOPHOT and submm studies demonstrate that the masses of the most prominent Vega-like disks fall in the 0.5-20 M_{moon} range (Heinrichsen et al. 1997, Heinrichsen et al. 1998, Holland et al. 1998). For comparison we also calculated dust masses (or in most cases upper limits) for the UMa group stars from the measured 60μm excess by assuming optically thin emission and using the formula

$$M_d = \frac{F_\nu D^2}{\kappa(\nu) B_\nu(T_d)} \qquad (1)$$

where F_ν is the flux density, D is the distance of the star, $B_\nu(T_d)$ denotes the Planck function, and κ is the dust absoption coefficient. In order to be consistent with the mass calculation of Holland et al. (1998), we assumed $\kappa(\nu) \sim \nu^{+1}$ with $\kappa(850\mu m) = 1.7\,\mathrm{cm^2 g^{-1}}$. For all disks $T = 70\,\mathrm{K}$ and $D = 25\,\mathrm{pc}$ were adopted. The resulting mass estimates are listed in Table 4.

Compiling available submm data, Holland et al. (1998) sketched the evolution of circumstellar dust around intermediate mass stars. In Fig. 4 we show their trend in comparison with the masses derived for the UMa group. From the figure we conclude that (1) the circumstellar dust mass of β UMa is close to the main trend; (2) eight UMa stars can only have circumstellar disks less massive than an average upper limit of 0.05 M_{moon}, a factor of about 5 lower than the mass of the β UMa disk. Since in our sample of 9 stars only 1 star, β UMa, shows an observable Vega-like disk, the average disk mass must be very low, but the mass distribution seems to have a tail towards higher masses. The very low average dust mass indicates that by the age of 300 Myrs the majority of stars in the UMa group is almost completely free from circumstellar dust, while a small fraction, 1 out of 9 in our case, is able to preserve significantly more circumstellar matter than the others do. To find out the physical reasons behind this bimodal behaviour requires the analysis of a larger sample of stars than we have.

In Sect. 3 we demonstrated that our small survey of 9 UMa stars is comparable to the IRAS BG-survey in terms of sensitivity (Fig. 2). IRAS found that 10 out of 22 A-type field stars are surrounded by Vega-like disks in the solar neighbourhood. This incidence of disks (45%) is significantly higher than our result in the UMa group (1 out of 9 stars). Alternatively, comparing the two samples by fractional luminosity, we detected no stars above the treshold of 2×10^{-5} in the UMa group, with respect to 23% in the IRAS BG-survey. One possible explanation for this discrepancy would be that the UMa sample does not represent the average A-star population at an age of ≈ 300 Myrs. We checked that the UMa stars do not show peculiar metallicity (Soderblom & Mayor 1993). The number of slow and fast rotators in the UMa group (6:3, separating at 100 km/s) is comparable to the corresponding ratio in the IRAS BG-survey (5:5 for A-type stars). A clear characteristic of our sample is the very high rate of binaries (8 out of 9, Table 1), while only 30-40% the A-type stars in the IRAS BG-survey belong to multiple systems. Binarity, however, is not believed to anticorrelate with the presence of Vega-like disks (Sadakane & Nishida 1986); and we note that the only star in the UMa group with disk, β UMa, is also a spectroscopic binary. Another possibility would be that the difference between the two samples is caused by their different ages. Field stars are expected to be older than the UMa group, therefore this hypothesis would require a non-monotonic temporal dust evolution with minimum disk masses at ≈ 300 Myrs and with increased masses later. The Moon cratering data of Hartmann (1972), however, do not show this kind

Table 4. Measured far-infrared excesses

Object	60μm	90μm	f	Mass $[M_{moon}]$
BS 710	no	no	$< 2.6 \times 10^{-5}$	< 0.04
BS 906	no		$< 2.4 \times 10^{-5}$	< 0.03
BS 4295	3.0σ	2.9σ	5.0×10^{-6}	0.22
BS 4554	no	no	$< 9.6 \times 10^{-7}$	< 0.05
BS 4660	no	no	$< 2.9 \times 10^{-6}$	< 0.05
BS 4905	no	no	$< 1.1 \times 10^{-6}$	< 0.09
BS 5062	no	no	$< 2.5 \times 10^{-6}$	< 0.02
BS 6254	no	no	$< 1.0 \times 10^{-5}$	< 0.05
BS 8410	no		$< 1.9 \times 10^{-5}$	< 0.05

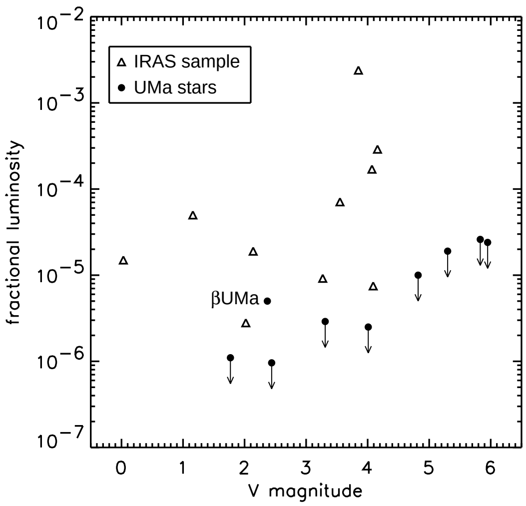

Fig. 2. Comparison of fractional luminosities of circumstellar dust disks around A-type stars in the UMa group (this work) and within 20 pc from the Sun (IRAS BG-survey)

of non-monotonic behaviour in our Solar System, and it would also be difficult to identify mechanisms which can produce this behaviour. A third possibility for explaining the discrepancy between the incidence of dust disks in the two data sets would be assuming that some IRAS detections are contaminated due to the large beam, and the derived disk frequency is overestimated. Such an opinion was published by Kalas (1996) on the basis of optical studies.

Our results suggest that the high incidence of Vega-like disks observed in the solar neighbourhood by IRAS cannot simply be extrapolated to the rest of the Milky Way. If the low incidence of circumstellar disks observed in the UMa group is proved in further studies on larger statistical samples, then the Vega phenomenon may turn out to be the exception rather than the rule, and it is also possible that IRAS has already detected practically *all* Vega-like systems in the solar neighbourhood.

5. Summary

We observed 9 A-type members of the ≈ 300 Myrs old Ursae Majoris group with ISOPHOT and UKIRT/MAX. Our results are the following:

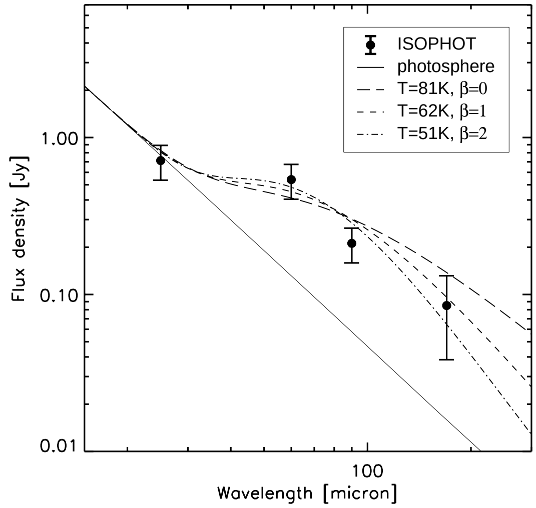

Fig. 3. Single temperature fits to the far-infrared excess of BS 4295 (β UMa) using a modified blackbody $B_\nu(T)\nu^\beta$

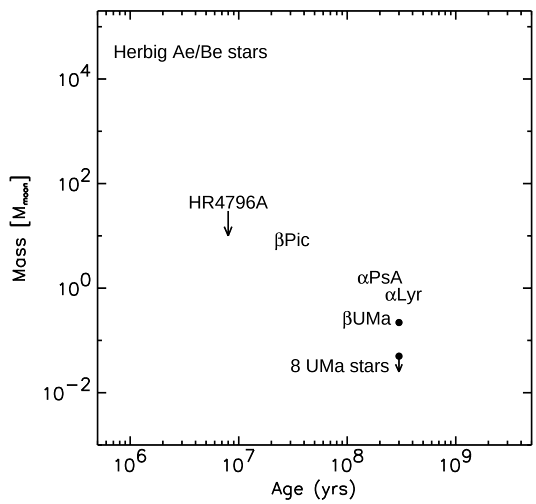

Fig. 4. Temporal evolution of circumstellar dust around intermediate mass stars (Holland et al. 1998). Mass values for the UMa stars are from this work (Table 4).

- only 1 out of the 9 stars shows clear signature of circumstellar dust, in contrast to the higher percentage expected on the basis of IRAS measurements.
- the majority of the A-type stars in the UMa group are surrounded by less than 0.05 M_{moon} dust, while one star (β UMa) exhibits the Vega phenomenon and harbours a dust disk of about 5 times the average mass.
- the high incidence (45%) of Vega-like disks observed among A-type field stars in the solar neighbourhood by IRAS cannot be extrapolated to the rest of the Milky Way. The Vega phenomenon appears to be the exception rather than the rule.

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