Evidence for Remnant Circumstellar Disks Around Post T Tauri Stars[1]

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Abstract.

We report infrared imaging photometry at 6.5 and 15 μm of seven Lindroos binaries selected by Pallavicini et al. as "almost certain physical pairs". The photometry was obtained in order to asses whether these adolescent (10—100 Myr) low-mass stars still have infrared excess emission which could be caused by a circumstellar disk. Given the current status of the calibration, we could not perform precise photometry or reliable modeling. We could, however, for the subset of the sample that was well observed, compare the ratio of $F_{6.5}/F_{15}$ for the primaries versus the secondaries. This ratio is significantly higher for the primaries than for the companions, and for the primaries it is close to the expected value for a Rayleigh-Jeans spectrum. While some of the difference is due to the cooler energy distribution of the late-type photospheres, we conclude that a significant part of the difference must come from excess emission at 15 μm, and thus we have found clear evidence for remnant disks.

[1]Based on observations with ISO, and ESA project 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.

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1. Introduction

Post T Tauri (PTT) stars, were originally defined by Herbig (1978) as low-mass pre-main sequence stars that are older than the classical T Tauri stars, i.e. older than $\sim 10\,\mathrm{Myr}$, but that have not yet settled on the main sequence. These stars would be located on the radiative part of the pre-Main Sequence evolutionary tracks.

True PTT stars have proven difficult to find: at first the many *weak-lined T Tauri* stars detected from X-ray surveys (e.g. Montmerle et al. 1992, and references therein) in and near regions of star formation, and identified with stars having weak T Tauri characteristics, were thought to form the PTT population. But further studies have shown that these stars are roughly coeval with the classical T Tauri stars (e.g. Neuhäuser et al. 1995), and thus could not account, in general, for the PTT population in the sense of Herbig (1978). More recently, Palla and Galli (1997) have speculated that the usual assumption of a constant star formation rate, which leads to expecting large numbers of PTT stars, may not be valid, while Brandner and Neuhäuser, using Hipparcos distances to place 15 ROSAT-selected weak T Tauri stars on an H-R diagram, find that some have ages of 5—15 Myr, and appear to be true PTT stars on radiative tracks.

A method of selecting bona fide PTT stars on the basis of their age rather than their spectral properties was conceived by Gahm et al. (1983): it consists of identifying physical binary systems composed of an early-type MS primary together with a late-type companion. Given the youth of the system, determined from the age of the primary, the secondary would still be contracting towards the Main Sequence. Lindroos, in a series of papers culminating with Lindroos (1986), identified 78 such systems, which have henceforth taken his name. More recently, Pallavicini et al. (1992) conducted a spectroscopic survey of 37 Lindroos secondaries with spectral type F2 or later, and of two other companions discarded by Lindroos as optical and not physical. They found that only 9 companions show clear evidence of youth and classified them as *almost certain physical systems*, while another 7 were classified as *possible physical systems*, and the remainder were rejected as *likely optical systems*.

Our goal was to determine whether the PTT stars have detectable amounts of dust in circumstellar disks, and possibly whether a trend can be established between dust mass and age. The final goal is it to determine the timescale for disk dissipation, which could occur either via accretion onto the star or via planet formation, though binarity could also have an effect on the disks. To this end we obtained ~ 6.5 and $\sim 15\,\mu\mathrm{m}$ ISOCAM images of 6 of the systems identified by Pallavicini et al. (1992) as *almost certain physical systems*, and one identified as *possible physical system* from which we extracted photometry and searched for infrared excess emission as an indicator of dusty disks.

Finally, there was the possibility of detecting disks around the primaries, identifying them as Vega-like systems.

2. Observations and Data Analysis

The observations were obtained with ISOCAM through the LW2 and LW3 filters, which are centered roughly at 6.5 and $15\,\mu\mathrm{m}$. Each observation consisted of a 3×3 raster with an integration time of $\sim$ 20 sec per position (the exact integration time depends on the number of valid readouts, which varied between 8 and 10), and which were preceded by a number of stabilization frames which, in most cases, could at least in part be used in the reduction. The observations were performed through the $3''$/pix FOV and using steps of a single pixel. Such small step size was chosen to ensure that the companions would not fall out of the FOV, though at the price of not being able to use the observations for preparing a flatfield. This was not deemed a serious loss since the edges of the field, where the standard flats are least accurate, was not being used.

During the observations, one source (HD108767) caused heavy saturation which caused the Instrument Controller to lower the detector gain (from 4 to 1) in real time, and two other sources (HD113703 and HD143939) showed saturation on single readouts. These saturations were due to the bright primaries and do not have a significant effect on the companion photometry.

Data reduction was performed with the CAM Interactive Analysis package[1] and consisted of the following steps: subtraction of library dark frame, deglitching (multiresolution-multimedian method), transient correction (IAS model), flatfielding with a library flatfield, assemblage of the raster, and flux calibration using the library conversion constants. No formal error estimate is available through this step. While the overall absolute uncertainty are of order $\pm 20\%$, most of the error is expected to be systematic, and relative uncertainties could be as low as $\pm 5\%$.

In the reduced and calibrated frames, to each pixel is assigned a flux density expressed in Jy calculated assuming a flat spectral energy distribution at the filter reference wavelength. The images are shown in Fig. 1, where the contrast of each frame has been adjusted for the display.

Photometry was extracted using the IRAF implementation of DAOPHOT in order to properly subtract the wings of the primary from the region of the companion. Since the primary itself could not be used to determine the PSF (there is only one PSF star in each frame, i.e. the primary, and the companion becomes a feature of the PSF), the library PSFs were used for fitting; these have FWHM of $1\farcs52$ at LW2 and $2\farcs65$ at LW3. While the library PSFs probably do not provide the best PSF for each frame, they do provide a certain degree of uniformity in the measurements. The library PSFs were fit with the best analytical model (as determined by DAOPHOT), and the results were used for the fit photometry. In two instances the companion is too close to the primary and/or too faint relative to it for measurement (HD560 in both filters, HD143939 with LW3), and in the cases of the heavily saturated primary the fit was performed using the wings of the profile only.

Ideally the next steps would be (i) to convert the PSF-fit photometry to true aperture photometry, and (ii) to colour-correct the results assuming some appropriate intrinsic energy distribution. But given the current status of the overall CAM calibration, which at this time contains a number of systematic errors which still remain to be corrected, we have decided not to go further with the calibration, but rather to use the derived flux densities as fiducials and to

[1] Cam Interactive Analysis is a joint development of ESA Astrophysics Division and the ISOCAM Consortium

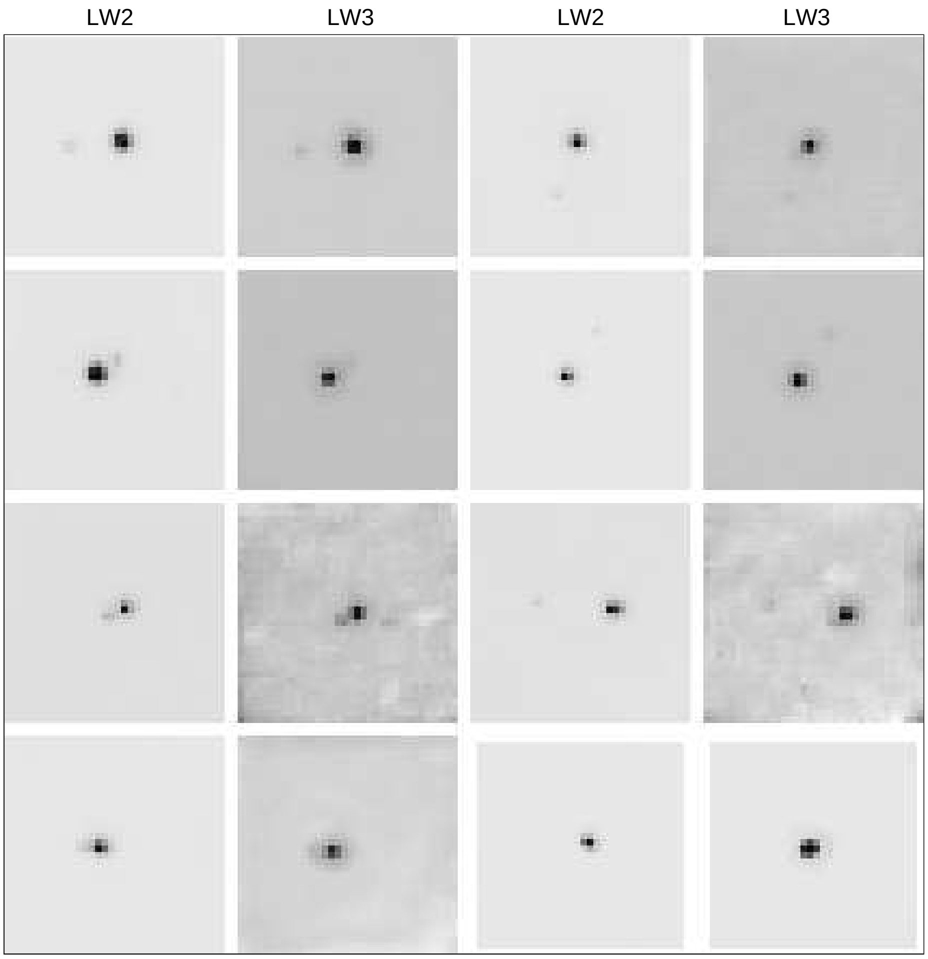

Figure 1. ISOCAM images of 7 Lindroos binary systems and of PSF. For each system there are two panels: LW2 on the left on a lighter background, and LW3 on the right on a darker background. Thus, in pairs and from left to right, the sources are: HD108767 and HD127304 (top row), HD113703 and HD113791 (second row), HD143939 and HD129791 (third row), and HD560 and PSF (bottom row). The images of the binaries are mosaics and 34×34 pix, while the PSF images are 32×32pix. The contrast of each panel has been set arbitrarily for the display. Cardinal directions are different for each image and are not aligned with frame boundaries.

consider only their ratios. In the remainder of this paper we will call the flux densities $F_{6.5}$ and F_{15} for LW2 and LW3, respectively, with the understanding that these are, per band, proportional to the correct values, and we will primarily be interested in the ratio $R = F_{6.5}/F_{15}$. The results of the photometric measurements are summarised in Table 1, where the system ages (from Lindroos 1986) and distances (from Hipparcos, ESA 1997) are also listed.

3. Results and Discussion

From Table 1 we find that $\langle R \rangle = 5.7$ for the three well measured primaries and 3.4 for the five well measured companions; this difference we consider significant. For comparison $R \approx 5.0$ for a hot (10,000 K) star and $R \approx 4.5$ for a cool (4,000 K) star (where actually these ratios have been computed from blackbodies at the stated temperatures), indicating that the different spectral energy distribution of the photospheres is not sufficient to account for the observed differences (a blackbody at 1600 K would give $R = 3.4$). We thus conclude that most of the difference is due to an excess of emission at 15 μm, and we interpret this as clear evidence for remnant cool circumstellar disks around these *adolescent* stars.

Table 1. Photometric Results

HD number	age [Myr]	dist.[a] [pc]	$F_{6.5}$ [Jy]	F_{15} [Jy]	R	sep.[b] [″]
560	< 50	100 ± 8	too close		–	–
108767-A	< 110	27 ± 5	‡7050	575	‡12.2	
-B			300	60	6.0	24.8
113703-A	< 35	127 ± 12	†990	120	†8.1	
-B			42	12	3.5	10.6
113791-A	< 11	126 ± 13	1000	135	7.4	
-B			52	14	3.7	24.9
127304-A	< 79	107 ± 8	290	50	5.7	
-B			18	5	3.6	25.8
129791-A	< 18	130 ± 16	165	40	4.1	
-B			14	5	2.8	35.3
143739-A	< 32	168 ± 27	†133	too	–	
-B			28	close	–	8.9

[a] Distances from Hipparcos
[b] Mean of LW2 and LW3 images
† primary is weakly saturated
‡ primary is heavily saturated

We do not believe that we can go much beyond this conclusions at present, though some improvement of the reduction (better selection of the frames used in the raster, better transient correction) is expected to improve somewhat the images, and resolving the systematic errors in the photometry will allow a more accurate determination of the true flux densities. We expect that the problem of extracting the photometry from the images will be the major source of error in the end. Nevertheless, with an improved calibration some simple modeling will be possible, and a range of reasonable temperatures for the excess, for instance, could be derived.

Given the small observed sample and that the ages are all upper limits, it is impossible at this time to make statements about correlation with age, though we do note that the source with the highest upper limit in age is also the one with the highest value of R. Observations of another star in our sample, HD90972, with an age of 100Myr, could have allowed us to make a more definite statement, but it was not observed and will no longer be visible by ISO. For the moment we can only say very tentatively that circumstellar disks may have dissipated by an age of 100 Myr.

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