The evolution of warm debris disks: implications for recent collisions

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ABSTRACT

Our Spitzer program on debris disks around F-type stars revealed four new warm debris disks (T_{BB} > 130 K). Comparing their fractional luminosities and ages with model predictions, three systems are consistent with a steady state disk evolution picture. The infrared luminosity of the fourth one, an old star exhibiting prominent silicate emission features in its IRS spectrum, is more likely related to a recent collisional cascade. Such transient warm disks may be the closest analogues yet to the Late Heavy Bombardment in our Solar System, and could be primary targets for follow-up observations searching for planets.

INTRODUCTION

Many main-sequence stars harbor debris dust disks, whose presence is an implication for a planetesimal belt (Fig. 1).

In the Solar System there are two large reservoirs of planetesimals: the asteroid belt at 2–3.5 AU, and the Kuiper belt at 30–48 AU.

Most known extrasolar debris disks are cold (50–90 K), and are possible extrasolar analogues of our Kuiper belt.

Only a few warm debris disks around solar-like (F,G,K-type) stars - similar to our asteroid belt - have been found.

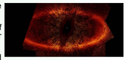

Fig. 1: Optical image of the Fomalhaut debris ring (HST ACS, Kalas et al. 2005)

The Konkoly F-stars program

A large project to characterize temporal evolution of debris disks around F-type main-sequence stars.

One major goal of the program was to discover new warm disks and study their evolution.

78 systems, most of them with indications for infrared excess (IRAS, ISO), were observed with IRS and MIPS.

Infrared excess, a hint for debris disk, was detected in 27 cases. The histogram of disk temperatures (Fig. 2) peaks at 60 K. Four disks, however, are notably warmer. These are new discoveries, significantly increasing the number of known warm disks around sun-like stars.

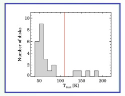

Fig. 2: Temperature histogram of 25 debris disks detected in our F-stars program (based on blackbody fits to the infrared excess). Four disks are noticeably warmer; separated from the others by a temperature gap.

SEDS AND MODELS OF THE NEW WARM DISKS

Figure 3 presents the spectral energy distributions of the four stars harboring warm debris disks. The Spitzer data are supplemented with ground-based and Tycho BV, Cousins I, and 2MASS J,H,Ks magnitudes. Fitting Kurucz models, effective stellar temperatures were derived.

Infrared excess over the photosphere was computed. The IRS spectrum begins to deviate from the photosphere between 8 and 15 μm for all four objects. Three stars were also detected at 70 μm, but none at 160 μm.

Assuming blackbody-like dust grains located in a ring, dust temperature, ring radius and the fractional luminosity of the disk $f_d = L_{dust}/L_{bol}$ were computed:

	T_{dust} [K]	R_{dust} [AU]	f_d [10^{-4}]
FSTAR-2	170	3.4	1.7
FSTAR-25	146	5.6	0.5
FSTAR-56	134	9.2	0.3
FSTAR-60	187	4.4	1.8

The f_d values show that these debris disks are significantly brighter than our zodiacal cloud ($f_d \sim 10^{-8}-10^{-7}$, Dermott et al. 2002)

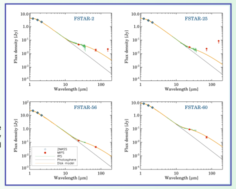

Fig. 3: Spectral energy distributions of the four warm debris disks.

CRYSTALLINE FEATURES

FSTAR-60 shows solid state features in the IRS spectrum. The prominent broad features are around 24, 27 and 34μm; weaker features appear at 11, 16 and 20μm. Most features can be attributed to crystalline olivine (Koike et al. 2003).

The presence of crystalline features in the spectrum of FSTAR-60 imply that small, micron–sized grains are abundant; while the absence features in the other three disks is evidence for depletion of small grains.

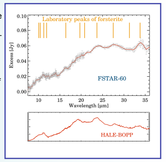

Fig. 4: Smoothed IRS spectrum of FSTAR-60. Positions of forsterite peaks, as measured in laboratory (Koike et al. 2003) are marked by vertical dashes. For comparison, the spectrum of Hale-Bopp (Crovisier et al. 1997), exhibiting similar crystalline features, is shown.

STEADY STATE DISK EVOLUTION AND TRANSIENT EVENTS

In young (<100 Myr) systems the source of warm debris dust in the terrestrial region may be an outwards propagating ring of planetesimal formation and/or massive protoplanet collisions (Kenyon & Bromley 2004; Meyer et al. 2008).

The number of known warm debris disks around older solar-like stars is less than 10. Most of them exhibit relatively high fractional luminosity of > 10^{-4}, which cannot be explained in the framework of a steady state asteroid belt evolution model where the planetesimals are co-located with the warm dust. These systems are probably in transient stage: recent collisions between large asteroids or erosion/sublimation of planetesimals scattered from an outer reservoir into the inner regions could produce the transient warm dust grains (Song et al., 2005; Wyatt et al. 2007).

Based on their fractional luminosity and age, three warm debris systems could be consistent with a steady state disk evolution. Two of them are relatively young (members of the 30 Myr old Tuc-Hor association) and may represent the outwards propagating ring scenario. The third object, FSTAR-56 is about 1 Gyr old.

In contrast, the infrared luminosity of FSTAR-60 is too high to be explained by a steady state evolution (Fig. 5), but it is consistent with a recent collisional cascade. This picture is reinforced by the silicate features (hinting on small grains) present in the IRS spectrum. Note that the appearance of silicate features in other warm disks in transient stage (BD+20 307, HD23514, HD69830, HD72905 and η Corvi) is common.

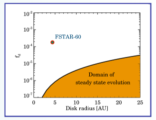

Fig. 5: Domain of fractional luminosity values predicted in the steady state disk evolution model for the age of FSTAR-60 (2.3 ± 0.7 Gyr) as a function of the radius of the dust ring. The disk of FSTAR-60 is >100 times more luminous, which is a strong argument that the debris dust observed in this system, but the grains have been recently formed in a transient event (Wyatt et al. 2007).

SUMMARY AND FUTURE PLANS

We report on the discovery of four warm debris disks, increasing significantly the number of such systems known around F,G,K-type stars.

Based on their fractional luminosity and age, three out of the four warm debris systems are consistent with a steady state disk evolution. The infrared luminosity of the fourth system is too high to be explained by a steady state evolution, but it is consistent with a recent collisional cascade. The latter object shows prominent silicate emission features, which strengthens the scenario that the observed dust was produced in a transient event.

Transient warm disks may be the closest analogues yet to the Late Heavy Bombardment in our Solar System, hinting on the possibility that major orbital rearrangements of the giant planets at late ages may be common. Such systems are primary targets for follow–up observations searching for planets.

References

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