Using Intermediate-Luminosity Optical Transients (ILOTs) to reveal extended exo-solar Kuiper belt objects

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ABSTRACT

We suggest that in the rare case of an Intermediate-Luminosity Optical Transient (ILOTs) event, evaporation of exo-solar Kuiper belt objects (ExoKBOs) at distances of $d \approx 500 - 10000$ AU from the ILOT can be detected. If the ILOT lasts for 1 month to a few years, enough dust might be ejected from the ExoKBOs for the IR emission to be detected. Because of the large distance of the ExoKBOs, tens of years will pass before the ILOT wind disperses the dust. We suggest that after an ILOT outburst there is a period of months to several years during which IR excess emission might hint at the existence of a Kuiper belt analog (ExoK-Belt).

1. INTRODUCTION

The Kuiper belt in our solar system contains icy bodies (Kuiper belt objects - KBOs) from Neptune to about 50 AU (e.g., Petit et al. 1999). These icy bodies are in fact cometary nuclei. Short period comets have orbital parameters that suggest that their formation is from the Kuiper belt (e.g., Melnick et al. 2001; Stern et al. 1990). The total mass of the belt in the annulus $30 < a < 50$ AU is estimated to be in the range of $0.1 - 0.26 M_{\oplus}$ (e.g., Jewitt et al. 1998; Chen 2006). Around 10^5 KBOs posses a diameter larger than 100 km, the biggest being Pluto with $D_{\rm Pluto} \approx 2400$ km. There are more objects with smaller diameter than 100 km (e.g., Melnick et al. 2001).

The Kuiper belt of the solar system contains different sub groups of icy bodies, such as the cold population (inclination of less than 4 degrees to the ecliptic plane) and the hot population (inclination of more than 4 degrees to the ecliptic plane). The hot population was formed closer to the Sun and was transported into the Kuiper belt. The cold population formation is still under debate. The two main scenarios are local formation and transportation to its current position (e.g., Gomes 2003; Levison & Morbidelli 2003; Levison et al. 2008;

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Morbidelli et al. 2014 and earlier references therein). The belt is usually divided into an inner belt ($a < 40$ AU) and an outer belt ($a > 41$ AU); the area of $40 < a < 42$ AU is dynamically unstable due to secular resonances (e.g., Petit et al. 1999). As noted by Brown & Pan (2004) the plane of the Kuiper belt is affected by many parameters such as the total angular momentum of the solar system, recent stellar encounters, and unseen distant masses in the outer solar system. Therefore, it is quite possible that some stars have very extended Kuiper-like belt. For example, a massive, $\approx 10 M_{\odot}$, disk extending to ≈ 1000 AU was detected recently around the young O-type Star AFGL 4176 (Johnston et al. 2015)

Belts similar to the Kuiper belt exist in exo-planetary systems, like HR 8799 (e.g., Contro et al. 2015). They are detected indirectly through dusty debris resulting from collisions (Greaves et al. 2005). The first discovery was due to an excess emission towards Vega, an A0V star (Aumann et al. 1984) which spectral energy distribution corresponds to cold dust grains at 80 AU from the star (Wyatt et al. 2003). Wyatt et al. (2003) studied stars (and binary systems) within 6 pc from the Sun and found that ϵ Eri and τ Cet have derbris disks of $0.01 M_{\odot}$ at 60 AU and $5 \times 10^{-4} M_{\odot}$ at 55 AU, respectively. Other detections, include ζ^2 Ret (Eiroa et al. 2010) and the G stars HD 38858 and HD 20794 (Kennedy et al. 2015).

The subject of KBOs analogs (ExoKBOs) around post-main-sequence (MS) stars has been investigated before by Jura (2004). They discuss the ice sublimation of ExoKBOs when the star reaches the red giant branch (RGB) phase. This rapid sublimation leads to a detectable infrared excess at $25 \mu m$, depending on the mass of the ExoKBOs.

In the present study we investigate the evaporation of ExoKBOs during a transient brightening event called intermediate-luminosity optical transients (ILOTs). ILOTs are eruptive outbursts with total kinetic energy of $10^{46} - 10^{49}$ erg that last weeks to several years (Kashi & Soker 2015 and references there in). Their peak bolometric luminosity can be of the order of 10^{40} erg s^{-1} (e.g., ILOT NGC 300OT had $L_{\rm bol} = 1.6 \times 10^{40}$ erg s^{-1}, Bond et al. 2009).

ILOTs that harbor AGB or extreme-AGB (ExAGB) pre-outburst stars, were modeled for a single (e.g., Thompson et al. 2009) and binary systems (e.g., Kashi & Soker 2010; Soker & Kashi 2011, 2012). Mcley & Soker (2014) conclude that such ILOTs are most likely powered by a binary interaction. More generally ILOTs are thought to be powered by gravitational energy released in a high-accretion rate event in binary stars (Kashi & Soker 2015).

ILOTs powered by merging stars can occur in MS stars, such as V838 Mon (Soker & Tylenda 2003; Tylenda & Soker 2006). Since the luminosity, mass-loss rate and dust production in winds from MS stars are several orders of magnitudes below those of AGB stars, the IR excess due to the ExoKBO evaporation will be much more prominent. This holds true despite ILOT event of MS stars being generally shorter than those expected from AGB stars. The merger product itself becomes very red and form dust, but this dust is hotter and concentrated in the center (e.g., Munari et al. 2002; Bond & Siegel 2006; Kamiński & Tylenda 2013; Chesneau et al. 2014; Kamiński et al. 2015).

We start our study by calculating the sublimation of ExoKBOs when the star experiences an ILOT event (Sec. 2), and then in section 3 we address the emission and possible ways to detect this type of evaporation. A short summary of our main conclusions is given in section 4.

2. ILOT SUBLIMATION OF EXOSOLAR KUIPER BELTS (ExoK-Belt)

2.1. Sublimation rate

ExoKBOs/comets have not been directly observed around post-main sequence (MS) stars. Stern et al. (1990) and Saavik Ford & Neufeld (2001) model the ice sublimated from comets with orbital separation of more than 100 AU from stars that evolved along the AGB. Stern et al. (1990) study the detectability of comet clouds during the post-main-sequence phase of stellar evolution and show that the change in luminosity in the post MS stage has a dramatic effect on the reservoirs of comets. They calculate the temperature (see, Stern et al. 1990, eq. 2) at different orbital separations from the post MS star and find out that KBOs will go through intensive mass-loss of water and more volatile species. Objects in the Oort cloud will sublimate volatile species, and depending on the eccentricity of their orbit might go through intensive water sublimation as well. Comets on circular orbits will sublimate mostly volatile species such as CO_2, CO, NH_3, while comets on eccentric orbits that come closer to the star will go through a significant water sublimation. Their model takes into account a star which evolves from the MS to the red giant phase over $\approx 10^8$ yr. At the RGB phase its luminosity is $\approx 300 L_\odot$, a change that increases the water sublimation radius from 2.5 AU at $L = L_\odot$ to ≈ 40 AU at $L \approx 300 L_\odot$.

Once the hydrogen has exhausted and the core contracted, a core-helium flash starts the horizontal branch (HB) phase (the helium flash is inside the core and is too short to influence sublimation). The AGB phase that follows the HB phase lasts for $\approx 10^7$ yr with a luminosity of several thousands solar luminosity. At this stage the water sublimation radius increases to the Kuiper belt and the inner Oort cloud as well. Melnick et al. (2001) agree that the AGB stage affects the Kuiper belt but argue that the Oort cloud is not affected from an increase in luminosity in the range of $100 - 3000 L_\odot$ when the star evolves along the

AGB.

Saavik Ford & Neufeld (2001), that studied IRC $+10216$, and Maercker et al. (2008), who studied M-type AGB stars, argued that the presence of water vapor in carbon rich AGB stars possibly suggests the existence of extrasolar cometary systems.

There is a direct connection between the sublimation rate and the chance of ExoKBOs detection (Jura 2004). We calculate the sublimation rate per unit area per object from the kinetic theory model as customary (e.g., Delsemme & Miller 1971 eq. 7; Cowan & Ahearn 1979 eq. 2; Fanale & Salvail 1984 eq. 8; Prialnik & Bar-Nun 1990 eq. 17; van Lieshout et al. 2014 eq. 12; references therein)

$$\dot{z} = P_{\rm vap}(T_{\rm ExoKBO})\sqrt{\frac{m}{2\pi R_g T_{\rm ExoKBO}}} \ {\rm g\ s^{-1}\ cm^{-2}}, \tag{1}$$

where m is the molecular weight in g mol^{-1}, R_g is the gas constant, $P_{\rm vap}(T_{\rm ExoKBO})$ is the vapor pressure in dyn cm^{-2} and $T_{\rm ExoKBO}$ is the ExoKBO‘s temperature. Note that the sublimation rate per object is a function of the ExoKBO area. We define the sublimation rate for a single ExoKBO

$$\dot{Z}_S = \dot{z}\pi R^2_{\rm ExoKBO}, \tag{2}$$

where $\pi R^2_{\rm ExoKBO}$ is the area of the ExoKBO facing the ILOT. Radii of asteroids and comets can vary significantly, for asteroids disruption near white dwarf (WD) it is customary to take radii in the range of $R_{\rm ast} \approx 1-1000$ km (e.g., Jura 2003; Farihi et al. 2014; Veras et al. 2014). In this paper we scale expression with $R_{\rm ExoKBO} = 5$ km. In order to calculate the sublimation rate per object, we must know the vapor pressure which is derived from the temperature of the ExoKBO and its composition. We address below three molecules, H_2O, CO and CO_2 and assume that the ExoKBO is composed entirely of one type of molecule.

2.2. Vapor pressure

The vapor pressure for volatile species such as CO (e.g., Bujarrabal et al. 2013; Hillen et al. 2015) and H_2O can be described by the *Clausius Clapeyron* relation for sublimation (e.g., Prialnik 2006; Rosenberg & Prialnik 2009)

$$\frac{d\ln P_{\rm vap}}{dT_{\rm ExoKBO}} = \frac{H}{R_g T_{\rm ExoKBO}}, \tag{3}$$

where H is the latent heat (enthalpy) of sublimation (calculated from table 1). We integrate eq. 3 and derive (e.g., Gombosi et al. 1985; Lichtenegger & Komle 1991; Prialnik 2006;

Rosenberg & Prialnik 2009; Gronkowski 2009b)

$$P = A \exp(-B/T_{\rm ExoKBO}), \tag{4}$$

where the relevant constants for three different molecules are given in Table 1 and are derived from CRC Handbook of Chemistry and Physics (where tables of $P_{\rm vap}$ and T are given for each molecule; Lide 2015).

Table 1

Molecule	A[dyn cm^{-2}]	B[K]
CO	1.75×10^{11}	946.91
H_2O	3.69×10^{13}	6151.7
CO_2	1.14×10^{13}	3157.7

2.3. ExoKBO temperature

The temperature of ExoKBOs can be calculated from the energy equation, similar to that used for comets (e.g., Beer et al. 2006; Gronkowski 2009a; Prialnik & Rosenberg 2009):

$$E_{\rm ILOT} = E_{\rm thermal} + E_{\rm sub} + E_{\rm con}, \tag{5}$$

where:

$$E_{\rm ILOT} = \frac{(1 - A_{\rm ExoKBO}) L_{\rm ILOT}}{4\pi d^2}, \tag{6}$$

is the heating flux from the ILOT outburst that is absorbed by the body, $A_{\rm ExoKBO}$ is the ExoKBO albedo, $L_{\rm ILOT}$ is the ILOT luminosity and d is the orbital separation. The terms on the right hand side of equation (5) are as follows.

$$E_{\rm thermal} = \epsilon \sigma T^4_{\rm ExoKBO}, \tag{7}$$

is the cooling by thermal radiation per unit area of the object where, ϵ is the emissivity and σ is the Stefan Bolzman constant,

$$E_{\rm sub} = H \dot{z}, \tag{8}$$

is cooling per unit area by sublimation. Due to the very low temperatures the energy conductivity term $E_{\rm con}$ is insignificant for H_2O, CO and CO_2, and will be neglected here. We note that the area of evaporation and cooling can be $4\pi R^2_{\rm ExoKBO}$ depending if the heat had time to spread over the ExoKBO. Although rotation is possible, since the conductivity is negligible, we assume that most of the cooling and sublimation is from the surface facing the ILOT. Therefore, we take the effective area for energy and mass-loss of one object to be $\pi R^2_{\rm ExoKBO}$.

The supervolatile CO, that is known to exist in comets, can be in its gaseous form even in the low temperatures of the Kuiper belt. The CO sublimation rate for several known KBOs (such as 2060 Chiron,1998 WH24, 7066 Nessus and others) are calculated to be in the order of $\dot{Z}_s \approx 10^{28}$molecules s^{-1} (for more details, see table 6 in Bockelée-Morvan et al. 2001). Due to CO low absorption band it has only been detected on Pluto and Triton (e.g., Schaller & Brown 2007; Brown 2012 and references within). Sublimation of CO can be significant for ExoKBOs around ILOTs (Fig. 1 below).

The dust temperature is calculated by balancing radiation heating and cooling. When the temperature exceeds the sublimation temperature, the dust is destroyed. The sublimation distance of dust particles from an energy source is given by (e.g., Netzer & Laor 1993; Laor & Draine 1993)

$$R_{\rm sub-dust} \approx 24 \left(\frac{L_{\rm ILOT}}{10^6 L_\odot} \right)^{\frac{1}{2}} {\rm AU}. \qquad (9)$$

As we are interested in ExoKBO belt analog (ExoK-Belt) at distance of $\gg 100$ AU, the dust that is carried out by the sublimating gas from the ExoKBOs survives and does not sublimate.

2.4. ExoKBO Sublimation by ILOTs

In order to simplify the calculation we assume that the ExoKBO is composed of one type of gas only. In Fig. 1 we present the ExoKBO temperature as a function of orbital separation from the ILOT according to equation (5). For the ILOT event we scale quantities with a luminosity of $L_{\rm ILOT} = 10^6 L_\odot$ and a duration of $t_{\rm ILOT} = 10$ yr; later we will substitute $t_{\rm ILOT} = 0.1$ yr for the case of ILOTs of MS stars. For the upper AGB phase of the star, we take $L_{\rm AGB} = 10^4 L_\odot$ and an effective duration of $t_{\rm AGBw} = 500$ yr. The effective duration of the AGB star is the time span of the wind in the ExoK-Belt location

$$t_{\rm AGBw} \approx 500 \left(\frac{d}{1000 \ {\rm AU}} \right) \left(\frac{v_w}{10 \ {\rm km \ s^{-1}}} \right)^{-1} {\rm yr}, \qquad (10)$$

where v_w is the AGB wind speed (e.g., Winters et al. 2003). AGB dust that was lost earlier will be further away and be cooler. Since we can not differentiate the dust carried by the AGB wind from the dust carried by the gas sublimating from the ExoKBOs once they are at the same region, we take this effective AGB duration.

We compare the effects of the AGB star and the ILOT event on the temperature (Fig. 1, upper panel), evaporation rate per object with a radius of $R_{\rm ExoKBO} = 5$ km (Fig. 1, middle panel) and total mass evaporated from the object (Fig. 1, lower panel). In the lower panel we calculate the evaporated mass during the AGB effective duration given by equation (10) and during the ILOT outburst (10 yr). The luminosities are given above, $L_{\rm AGB} = 10^4 L_\odot$ and $L_{\rm ILOT} = 10^6 L_\odot$, respectively. In Fig. 2 we zoom on the distance range $d = 10^3 - 10^4$ AU.

Figure 1 indicates that the temperature of a single ExoKBO around the ILOT event is, as excepted, higher than the temperature for the AGB phase for all compositions. For the sublimation rate per object we can see that for each molecule there is "knee" (gap) where the sublimation rate for ExoKBO around the AGB star substantially drops while for the ILOT event it is still significant. For ExoKBOs residing at these distances a prominent IR excess is expected due to ILOT sublimation. We emphasis that this IR excess is not a result of the dust from the ILOT wind but a result of the dust carried by the sublimating gas from the ExoKBOs. This gap in mass-loss is observed in the lower panel which represents the total gas mass from a single ExoKBO. The interesting distance ranges of the ExoKBO where the influence of the ILOT is much larger than that of the AGB star are as follows $d \approx 10^3 - 10^4$ AU for H_2O, $d \approx 3 \times 10^3 - 2 \times 10^4$ AU for CO and $d \gtrsim 3 \times 10^4$ AU for CO_2 , as can be seen from Figs. 1 and 2. Since the ExoKBOs are not composed from a single gas it is hard to predict the exact interesting distance ranges. However, observing the distance of $\approx 1000 - 10000$ AU after an ILOT event during the first few months to years might reveal excess amount of dust and might hint on the presence of an ExoK-Belt. For the purpose of our calculations we choose to look specifically at a distance of $d = 1000$ AU.

We scale the ExoK-Belt total mass $M_{\rm Belt}$ with the solar system one $0.1 M_\oplus$, (e.g., Gladman et al. 2001), so that the number of objects in the ExoK-Belt is

$$N_{\rm obj} \approx 10^9 \left(\frac{M_{\rm Belt}}{0.1 M_\oplus} \right) \left(\frac{\rho_{\rm ExoKBO}}{1 \ {\rm g \ cm^{-3}}} \right) \left(\frac{R_{\rm ExoKBO}}{5 \ {\rm km}} \right)^{-3} , \tag{11}$$

where $\rho_{\rm ExoKBO}$ is the average density of the ExoKBOs. We find that the total mass of the sublimated dust and gas from ExoK-Belt in the outburst around an ILOT event are

$$M_{\rm dust-ILOT} = \eta M_{\rm gas-ILOT} \approx 5 \times 10^{-9} \eta \left(\frac{\dot{z}_{S(1000 \ {\rm AU})}}{3.5 \times 10^7 \ {\rm g \ s^{-1}}} \right) \left(\frac{t_{\rm ILOT}}{10 \ {\rm yr}} \right) \left(\frac{\gamma}{1} \right) \left(\frac{N_{\rm obj}}{10^9} \right) M_\odot, \tag{12}$$

where η is the dust to gas ratio, that is estimated from comets to be $\eta \approx 0.1 - 10$ (e.g., Fulle et al. 2010; Lara et al. 2011; Schmidt et al. 2015), and γ is a scaling factor depending on whether the ILOT event occurs during the AGB or the MS phase. For a MS star the duration of the ILOT event is only ≈ 0.1 yr, so that $\gamma = 0.01$. The distance of the ExoK-Belt was taken at $d = 1000$ AU and the sublimation rate per object ($\dot{Z}_S$) is calculated for H_2O. The ILOT luminosity was taken to be $L_{\rm ILOT} = 10^6 L_\odot$. The average total mass-loss rate from the ExoK-Belt is $\dot{M}_{\rm gas-ILOT} = \dot{Z}_S N_{\rm obj}$.

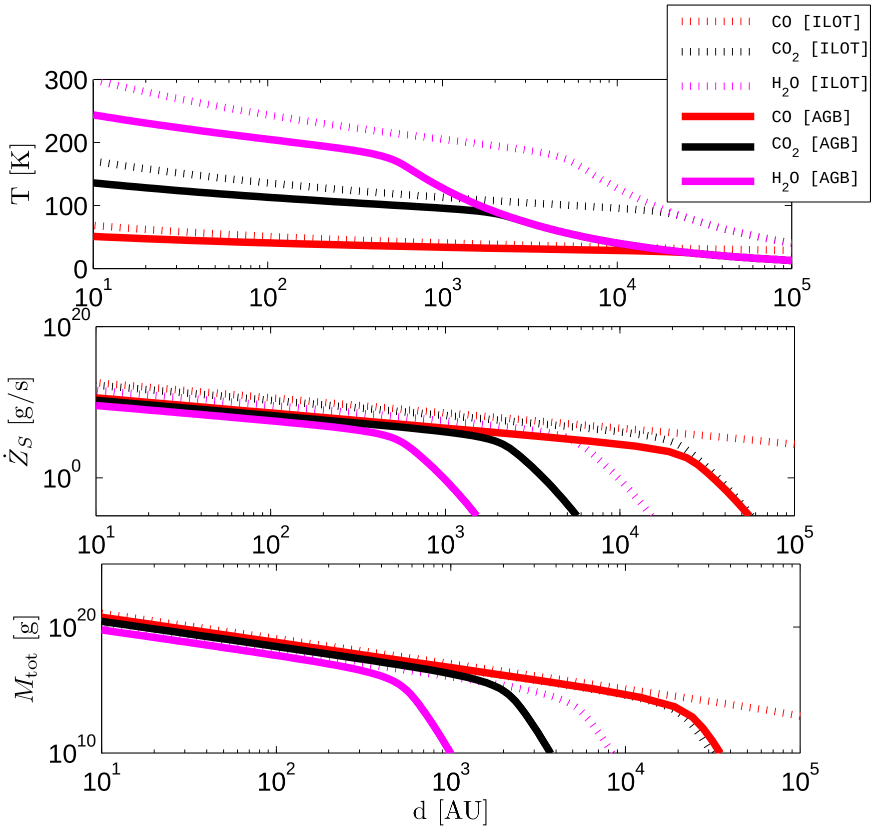

Fig. 1.— Properties of an ExoKBO during an ILOT event and during the AGB phase, as function of its the distance from the ILOT. The upper panel represents ExoKBO temperature, the middle panel depicts ExoKBO sublimation rate per object for $R_{\rm ExoKBO} = 5$ km and the lower panel represents total mass ejected from this object. Two options are considered and represented by different lines: ExoKBO around ILOT (dotted lines) and ExoKBO around AGB stars (solid lines). Red ,black and pink represent ExoKBO made from single molecules CO,CO_2 and H_2O respectively. The vapor pressure parameters for all three molecules for all panels are taken from table 1. For the lower panel, we take the duration of the ILOT event and the AGB effective duration as $t_{\rm ILOT} = 10$ yr and $t_{\rm AGB} = 500$ yr, respectively.

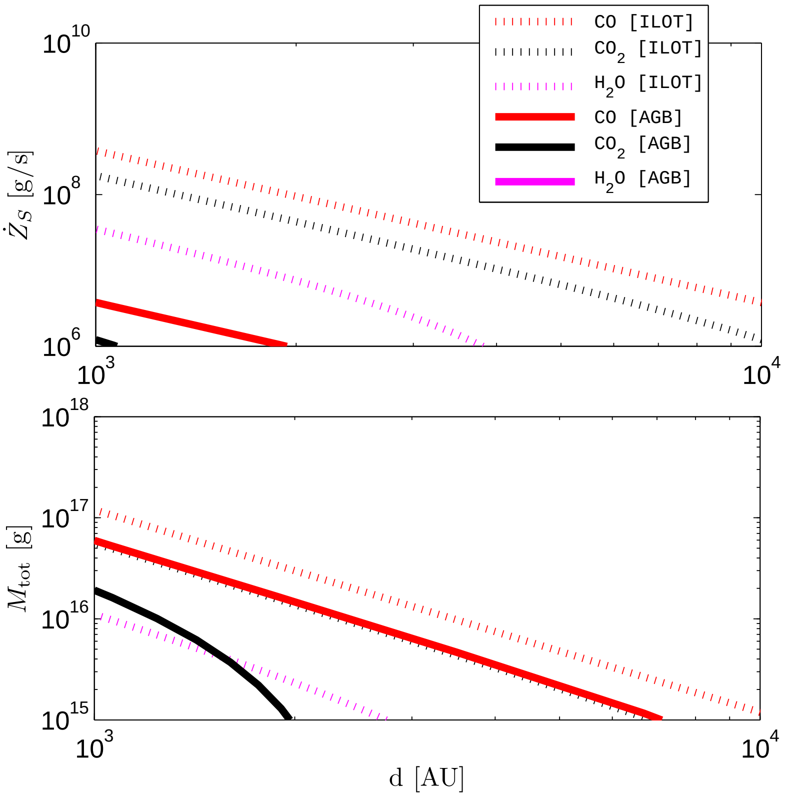

Fig. 2.— The same as the corresponding panels in Fig 1, but zooming on the distances range of $10^3 - 10^4$ AU.

The ratio of the dust mass from the ILOT to the AGB star is an important quantity given by

$$\begin{aligned}\frac{M_{\rm dust-ILOT}}{M_{\rm AGBw}} &= N_{\rm obj}\left(\frac{\dot{Z}_s}{\dot{M}_{\rm AGBw}}\right)\left(\frac{t_{\rm ILOT}}{t_{\rm AGBw}}\right)\left(\frac{\eta_{\rm ILOT}}{\eta_{\rm AGB}}\right) \\ \approx 10^{-3}\left(\frac{\dot{z}_{S(1000~{\rm AU})}}{3.5\times 10^{7}~{\rm g~s^{-1}}}\right)&\left(\frac{\dot{M}_{\rm AGBw}}{10^{-6}M_\odot~{\rm yr^{-1}}}\right)^{-1}\left(\frac{N_{\rm obj}}{10^{9}}\right)\left(\frac{t_{\rm ILOT}}{10~{\rm yr}}\right) \\ &\left(\frac{t_{\rm AGBw}}{500~{\rm yr}}\right)^{-1}\left(\frac{\eta_{\rm ILOT}}{1}\right)\left(\frac{\eta_{\rm AGB}}{0.01}\right)^{-1},\end{aligned} \tag{13}$$

where $\dot{z}_s$ is the sublimation rate of the ILOT at 1000 AU (for H_2O), $\dot{M}_{\rm AGBw}$ is the mass-loss rate of the wind and $\eta_{\rm ILOT}$ and $\eta_{\rm AGB}$ are the dust to gas ratio of the ILOT and AGB respectively. Despite the much lower sublimated dust from the ILOT than that residing in the AGB wind, for the parameters chosen here, the sublimated dust from the ExoK-Belt is concentrated in a particular radius, and hence will have strong emission at a particular temperature. It might possibly be detected, but we estimate that only if the AGB wind has a lower mass-loss rate than chosen here.

More promising might be ILOTs from MS stars (or slightly evolved off the MS), such as V838 Mon, V1309 Sco, and similar events (e.g., Tylenda et al. 2011; Kamiński et al. 2015; Pejcha et al. 2016). In MS stars the wind mass-loss rate is much lower and dust production is less efficient than in AGB stars. Taking the ratio of dust mass for an ILOT and a MS star gives

$$\begin{aligned}\frac{M_{\rm dust-ILOT}}{M_{\rm MSw}} \approx 5000\left(\frac{\dot{z}_{S(1000~{\rm AU})}}{3.5\times 10^{7}~{\rm g~s^{-1}}}\right)&\left(\frac{\dot{M}_{\rm MSw}}{10^{-12}M_\odot~{\rm yr^{-1}}}\right)^{-1}\left(\frac{N_{\rm obj}}{10^{9}}\right) \\ \left(\frac{t_{\rm ILOT}}{0.1~{\rm yr}}\right)&\left(\frac{t_{\rm MS}}{10~{\rm yr}}\right)^{-1}\left(\frac{\eta_{\rm ILOT}}{1}\right)\left(\frac{\eta_{\rm MS}}{0.001}\right)^{-1},\end{aligned} \tag{14}$$

where $\dot{M}_{\rm MSw}$ is the wind mass-loss rate from the MS star, $\eta_{\rm MS}$ is the gas to mass ratio of the MS star, and $t_{\rm MS}$ is the effective duration of the mass-loss phase. Because of the faster MS wind compared to the AGB wind, $v_{\rm MSw} \approx 500~{\rm km~s^{-1}}$, and the closer ExoK-Belt, about 1000 AU, the effective duration is shorter (eq. 10).

3. IR excess

Our solar system contains the asteroid belt and the Kuiper belt. Some of the dust observed in our Solar system results from collisions in the asteroid belt which form 'hot' dust (zodical) at $2-4$ AU at ≈ 270 K and cold dust at $30-50$ AU from the Sun and at a temperature of $50-60$ K which is a result of KBOs collision. Observation of ExoK-Belts is not simple. Beichman et al. (2006) note that inferred IR excess for the solar system Kuiper belt is $L_{\rm IR}/L_\odot \approx 10^{-7}-10^{-6}$ while for the asteroid belt is $L_{\rm IR}/L_\odot \approx 10^{-7}$ (e.g., Beichman et al. 2006 and references within).

The IR excess due to the dust released from gas sublimation can be crudely estimated assuming a uniform distribution of $1\mu m$ - size dust grains (Jura 2004)

$$\frac{L_{\rm excess}}{L_{\rm ILOT}} \approx \frac{\chi M_{\rm dust-ILOT}}{4\pi d^2}, \tag{15}$$

where the opacity is estimated as (Jura 2004)

$$\chi = \frac{\pi a_{\rm dust}^2}{4\pi\rho_{\rm dust}a_{\rm dust}^3/3} \approx 7500 \left(\frac{\rho_{\rm dust}}{1~{\rm g~cm^{-3}}}\right)^{-1} \left(\frac{a_{\rm dust}}{1\mu m}\right)^{-1} ~{\rm cm^2~g^{-1}}, \tag{16}$$

where $a_{\rm dust}$ is the dust radius. We note that Jura (2004) takes into account different models for the mass-loss rate of KBOs. He differentiates between large and small populations of KBOs and follow their evolution along with the change in luminosity of the host star. Since our outburst is short and we assume that its duration is only $0.1-10$ yr, we do not differentiate and simply take the sublimation rate per object from the energy equation (eq. 1) for a uniform distribution of ExoKBOs. Substituting eq. (16) into eq. (15) yields

$$\frac{L_{\rm excess}}{L_{\rm ILOT}} \approx 10^{-5} \left(\frac{M_{\rm dust-ILOT}}{5\times10^{-9}M_\odot}\right) \left(\frac{d}{1000~{\rm AU}}\right)^{-2} \left(\frac{a_{\rm dust}}{1\mu m}\right)^{-1} \left(\frac{\rho_{\rm dust}}{1~{\rm g~cm^{-3}}}\right)^{-1}. \tag{17}$$

It serves as a lower limit and can be higher depending on composition, grain size, ILOT duration and mass of the ExoK-Belt. Riviere-Marichalar et al. (2014) observe a tiny IR excess of $L_{\rm IR}/L_\odot = 2\times10^{-6}$ around the young star HD 29391 (a F0IV star, Abt & Morrell 1995), that is part of the beta Pictoris moving group (BPMG). This IR excess suggests a derbis disk with a lower limit on the inner radius of 82 AU. We note that Eiroa et al. (2010) report an initial result of the presence of a dust ring at ≈ 100 AU from the solar type star ζ^2 Ret with $L_{\rm excess}/L_* \approx 10^{-5}$. These observations indicate that the IR excess which results from ExoKBOs sublimation due to an ILOT event is within the Spitzer sensitivity as of today.

4. SUMMARY

In the present study we studied the influence of ILOT events, in both post-main sequence (MS) stars and MS stars, on very small substellar objects. We considered the sublimation of comets and similar objects, Kuiper belt analogue (ExoK-Belt), by rare cases of ILOTs that might last weeks to years. Such ILOTs can take place in AGB stars, (e.g., NGC 300OT Monard 2008; Berger et al. 2009; Bond et al. 2009), and during earlier phases of the evolution, including the main-sequence. Although ILOT events are rare, metal pollution of WDs show that many planetary systems survive the post-MS evolution (e.g., Jura 2006; Jura et al. 2007; Jura 2008; Debes et al. 2012; Farihi et al. 2011, 2012; Melis et al. 2012; Farihi et al. 2014). So, we expect that sublimation of comet-like bodies as far as few thousands AU from the star will take place in ILOT events, and dust will be released (eq. 12).

If the ILOT event lasts for several weeks (in MS stars) to several months and years (in AGB stars), enough dust might be ejected from these bodies (eqs. 13 and 14) for the IR emission to be detected (eq. 17). This dust is concentrated at the ExoK-Belt and therefore might be distinguished from the dust formed in the stellar wind. Although a star spends millions of years on the AGB with high luminosity, there is a region where ILOT events will release gas and dust from comets, but not AGB stars (Fig. 2).

The extra dust that might be observed at thousands of AU from the ILOT event is the dust formed by the sublimating ExoKBOs. Lots of dust is formed in the ILOT event, but it will take it tens of years or longer to reach the ExoK-Belt region discussed here. The excess IR luminosity should be searched for months to years after the ILOT event. The phenomenon can be observed where the influence of the ILOT is much larger than that of the AGB star. Although ILOTs themselves turn red, their typical temperature at early times is hotter than that of the sublimated dust at large distances studied here. So spectroscopically the sublimated dust can be distinguished from the IR emission of the ILOT event itself. At distances of thousands of AU from the ILOT, such IR emission might be even resolved with future instrumentation.

ILOT events in MS stars last only several weeks. However, the MS stellar mass-loss rate and dust production in the wind are several orders of magnitudes below those of AGB stars. Therefore, the IR excess due to the ExoKBOs evaporation might be much more prominent than for ILOTs in AGB stars.

To summarize, we encourage the search for evaporated Kuiper-like belts around ILOTs within several years after outburst.

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