Explaining Two Recent Intermediate Luminosity Optical Transients (ILOTs) by a Binary Interaction and Jets

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ABSTRACT

We propose that two recent intermediate luminosity optical transients (ILOTs), M31LRN 2015 and SN 2015bh (SNHunt 275; PTF 13efv) can be accounted for with a stellar binary model involving mass transfer that leads to the launching of jets. We inspect observations of the ILOT M31LRN 2015 and conclude that it cannot be explained by the onset of a common envelope evolution (CEE). Instead we conjecture that a $M \approx 1–3 \, M_\odot$ main sequence star accreted $\approx 0.04 \, M_\odot$ from the giant star, possibly during a periastron passage. The main sequence star accreted mass through an accretion disc, that launches jets. The radiation from the disk and the collision of the jets with the ambient gas can account for the luminosity of the event. Along similar lines, we suggest that the 2013 eruption of SN 2015bh (SNHunt 275) can also be explained by the High-Accretion-Powered ILOT (HAPI) model. In this case a massive secondary star $M_2 \gtrsim 10 \, M_\odot$ accreted $\approx 0.05 \, M_\odot$ from a much more massive and more evolved star during a periastron passage. If the much more energetic 2015 outburst of SN 2015bh (SNHunt 275) was not a supernova explosion, it might have been a full almost head-on merger event, or else can be accounted for by a the HAPI-jets model in a very highly eccentric orbit.

Key words: stars: jets — stars: variables: general — binaries: general

1 INTRODUCTION

Eruptive stars with peak luminosity values between the typical luminosities of novae and supernovae (SN) form an heterogeneous group (e.g. Mould et al. 1990; Rau et al. 2007; Ofek et al. 2008; Prieto et al. 2009; Botticella et al. 2009; Smith et al. 2009; Berger et al. 2009; Kulkarni & Kasliwal 2009; Mason et al. 2010; Pastorello et al. 2010; Kasliwal et al. 2011b; Kasliwal 2011; Tylenda et al. 2013; Kasliwal 2013). Some of these objects are low luminosity SNe and related objects, such as Ca-rich transients and Ia SNe, many of which are powered by thermonuclear outbursts and explosions.

The remaining gap objects that are not supernovae are part of a still heterogeneous group that is generally termed Intermediate Luminosity Optical Transients (ILOTs; Berger et al. 2009; Kashi & Soker 2016). Kashi & Soker (2016) further classified ILOTs into three types of objects:

(i) Intermediate-Luminous Red Transients (ILRT). These are ILOTs of evolved stars, such as asymptotic giant branch (AGB) or extreme-AGB (ExAGB) stars, like NGC 300 OT2008-1 (NGC 300OT; Monard 2008; Bond et al. 2009; Berger et al. 2009) and SN 2008S (Arbour & Boles 2008).

(ii) Giant eruptions of luminous blue variables (LBV) and SN Impostors. Examples include the Great Eruption (GE) of $\eta$ Carinae in the years 1837–1856, and the pre-explosion eruptions of SN 2009ip. Within the context of the binary model LBV giant eruptions might be considered in some sense to be the massive relatives of ILRTs (Kashi & Soker 2016).

(iii) Luminous Red Novae (LRN) or Red Transients (RT) or Merger-Bursts. These outbursts are powered by a full merger of two stars. The process of destruction of the less dense star, on to the denser star or inside its envelope, releases gravitational energy that powers the transient. Examples include V838 Mon and V1309 Sco. Merger events of stars with sub-stellar objects are also included.

As more ILOTs are being discovered we add them to the Energy-Time Diagram$^1$ (ETD), which shows their total energy against the eruption duration (Kashi & Soker 2016).

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$^1$ An updated version of the ETD is available at http://physics.technion.ac.il/~ILOT/
Many of the ILOTs sit on the Optical Transient Stripe (OTS) in the ETD, suggesting they are powered by a similar source of energy.

Models for ILOTs include single-star models (e.g., Thompson et al. 2009; Kochanek 2011 for ILRTs and Ofek et al. 2013 for a SN impostor), and binary stellar models (e.g., Kashi & Soker 2010b; Soker & Kashi 2011, 2012, 2013; Mcey & Soker 2014). We note that Adams et al. (2016) cast doubt that the progenitor star of the ILRTs NGC 3000T and SN 2008S survived the ILRT event. In a merger processes the secondary star can survive the first encounter, in which case the two stars form a common envelope (CE), or alternatively be destroyed on encounter. The close binary interaction can lead to enhanced mass loss and mass transfer. Pejcha et al. (2016a) and Pejcha et al. (2016b) based their model for ILOTs on a high rate of mass loss through the second Lagrangian point. The collision of equatorially ejected mass transfers kinetic energy to radiation. No jets are considered in their model.

A mass transfer process, whether in close detached systems, or in the grazing envelope evolution (GEE), or during the CE evolution (CEE), can lead to the formation of an accretion disc or an accretion belt around the more compact star. Such a disc might launch jets. The powering of ILOTs by accretion onto the more compact star in a binary system is termed the High-Accretion-Powered ILOT (HAPI) model, and was developed by us in an earlier paper (Kashi & Soker 2016b). The HAPI model was then applied to the formation of ILOT events during the GEE (Soker 2016). In some cases the interacting system is in fact a triple stellar system. The tertiary star might induce orbital instabilities and causes the two inner stars to interact, and in other cases all three stars can participate in the mass transfer process.

Several ILOTs have been attributed to the CEE of a binary stellar system, or to the onset of the CE. Soker & Tylenda (2003) and Tylenda & Soker (2006) attributed the ILOT V838 Mon to a merger process of two stars where the low mass star had been destroyed. Retter & Marom (2003) and Retter et al. (2006), on the other hand, suggested that V838 Mon was powered when planets entered the envelope of the star and formed a CE. Scenarios of CEE with a stellar companion followed with the ILOTs OGLE-2002-BLG-360 (Tylenda et al. 2013), V1309 Sco (Tylenda et al. 2011; Ivanova et al. 2013a; Nandez et al. 2014; Kamiński et al. 2016), and recently M31LRN 2015 (MacLeod et al. 2016). In section 2 we study the CEE scenario that was proposed by MacLeod et al. (2016) to account for M31LRN 2015 and propose the HAPI model as an alternative explanation for the same ILOT.

In some cases the two jets that are launched from the compact companion might expel more mass from the system, and form an expanding bipolar nebula (Kashi & Soker 2010a), such as the bipolar nebula of η Carinae, the Homunculus, that was formed in the GE (e.g., Humphreys & Martin 2012). η Carinae is known to be a binary systems (Damineli 1996) that did not enter a CEE. The sharp peaks in the light curve during the GE occurred around periastron passages of the binary system (Damineli 1996; Kashi & Soker 2010a; Smith & Frew 2011). Soker & Kashi (2013) speculated that the progenitor of SN 2009ip was in a binary system, and suggested that the pre-explosion outbursts of SN 2009ip occurred during, and as a result of, periastron passages.

In section 3 we analyze the ILOT SN 2015bh (aka SNHunt 275; PTF 13evf; PSN J09093496+3307204) that had at least two outbursts. It is not clear yet whether the last peak was caused by a real SN (e.g., Postigo et al. 2015) or an impostor. Several works (e.g., Elías-Rosa et al. 2015, 2016; Richardson & Artigau 2015; Thöne et al. 2016) noticed that SN 2015bh has some similarities with SN 2009ip. Ofek et al. (2016) analyzed the behavior of SN 2015bh and discussed its behavior within the context of a single star suffering an outburst with a super-Eddington luminosity. We instead propose a binary model.

In section 4 we summarize by concluding that a binary model based on jets, the HAPI-jets model, seems to explain the best many of the properties of ILOTs.

### 2 THE ILOT M31LRN 2015

The ILOT M31LRN 2015 was discovered in January 2015 (Shumkov et al. 2015), was compared to the merger-burst (LRN) V838 Mon (e.g., Kurtenkov et al. 2015), and was suggested to be a result of a merger process (e.g., Dong et al. 2015; Williams et al. 2015), i.e., be an LRN (RT; or merger-bursts). The bolometric light curve can be divided into two parts. A rise to the peak and decline, lasting from about -10 days to +10 days relative to the peak, and a plateau phase of about constant luminosity lasting for about another 40 days.

#### 2.1 A merger-burst model

In a recent paper MacLeod et al. (2016) propose a scenario for M31LRN 2015 where a main-sequence (MS) secondary star of mass $M_2 = 0.1-0.6 \ M_\odot$ entered a CEE with a giant primary star of mass $M_1 = 3.5-5.5 \ M_\odot$ and a radius of $R_1 \approx 35 R_\odot$. The process that leads to the CEE, according to their model, is the Darwin instability. They further suggest that the main energy source of the radiated energy of $5 \times 10^{45} \ erg$ during the plateau phase, about 10 to 50 days past the peak, is the recombination of the ejected mass. According to their model, this requires that the ejected mass that recombined amounts to at least $\Delta m_{\rm ej,\ plateau} = 0.17 \ M_\odot$. We see several problems in the model proposed by MacLeod et al. (2016), as we explain in the following subsections. We then propose an alternative scenario.

#### 2.1.1 Energy considerations

ILOTs that are powered by merger (merger-bursts) need not be powered by accretion of mass onto the compact companion. Such is V1390 Sco (Tylenda et al. 2011). However, there are significant differences between V1390 Sco and the model MacLeod et al. (2016) propose for M31LRN 2015. The binary orbital period of the progenitor of V1390 Sco was 1.4 day, with a radius of the primary star of 3–5 $R_\odot$. The process that leads to the CEE, according to their model, is the Darwin instability. They further suggest that the main energy source of the radiated energy of $5 \times 10^{45} \ erg$ during the plateau phase, about 10 to 50 days past the peak, is the recombination of the ejected mass. According to their model, this requires that the ejected mass that recombined amounts to at least $\Delta m_{\rm ej,\ plateau} = 0.17 \ M_\odot$. We see several problems in the model proposed by MacLeod et al. (2016), as we explain in the following subsections. We then propose an alternative scenario.
magnitude higher than the radiated energy during the outburst (Tylenda et al. 2011)

\[ Q_v(V1390\ Sco) \equiv \frac{E_{\text{orb}}}{E_{\text{rad}}} \approx 70-2000. \]  

The energy stored in the orbital motion of the progenitor of V1390 Sco can easily account also for the kinetic energy of the ejected matter which is about 10 times as large as the radiated energy, and for the energy required to inflate the envelope (Tylenda et al. 2011).

In the model of MacLeod et al. (2016) for M31LRN 2015 the energy stored in the orbital motion is \( E_{\text{orb}} \approx 0.2-1.8 \times 10^{47} \) erg. The radiated energy during the peak and plateau combined is \( E_{\text{rad}} \approx 8 \times 10^{45} \) erg, and we find

\[ Q_v(M31LRN) \approx 2-22. \]  

The typical value of \( Q_v \) for V1390 Sco is \( \approx 50 \) times larger than what the binary progenitor model proposed by MacLeod et al. (2016) gives for M31LRN 2015. We note that the relevant energy to consider is the energy released by the binary system as the secondary stars spirals-in deep to the giant star. This is done in section 2.1.2. Furthermore, neither the scenario proposed by MacLeod et al. (2016) nor the one we propose attribute a specific role to the value of \( Q_v \). Despite these two limitations, the large ratio \( Q_v(V1390\ Sco)/Q_v(M31LRN) \approx 50 \) suggests that V1390 Sco cannot be used to characterize M31LRN, or to conclude that it was powered by the onset of a CEE. The particular binary parameters adopted in the model of MacLeod et al. (2016) are weakly constrained by observations, and the energy range they provide is quite large. Only if the maximum value applies we can get \( Q_v(V1390\ Sco) \approx 3Q_v(M31LRN) \). This is very unlikely.

The quantity \( E_{\text{orb}} \) is the relevant energy if the secondary star motion is slowed down rapidly in the outer regions of the primary star. However, the large radius of the progenitor of M31LRN 2015 of \( R_1 \approx 35 \, R_\odot \) (MacLeod et al. 2016) implies that the density in its envelope is very low, and the much denser MS companion will not slow down much in the outer envelope. The secondary star must penetrate deep into the envelope.

Based on crude energy considerations alone, namely that \( Q_v(M31LRN) \ll Q_v(V1390\ Sco) \), we conclude that it is unlikely that the merger-burst model that applies to V1390 Sco can be scaled to explain the outburst of M31LRN 2015.

### 2.1.2 Ejected mass

For about 30 days, from the peak to 30 days post-peak, the photosphere of the ejected material expands with a velocity of \( v_{\text{ej}} \approx 400 \, \text{km} \, \text{s}^{-1} \) (MacLeod et al. 2016). As according to their model the radiated energy is recombination energy, the recombing gas in the first 30 days must move at about this velocity. The recombing gas in the last 20 days can move at a lower velocity of \( \approx 300 \, \text{km} \, \text{s}^{-1} \). Overall, the kinetic energy of the ejected gas in their model is \( E_{k,ej} \approx 2 \times 10^{47} \) erg.

The most massive secondary in their model has a mass of \( M_2 = 0.6 \, M_\odot \). The secondary star has to spiral-in to a radius of \( r_{2,ej} \) to account for the kinetic energy, given by

\[ E_{k,ej} = \frac{GM_1(r_{2,ej})M_2}{2r_{2,ej}} \approx \frac{GM_1M_2}{2R_1} \approx 3.6 \times 10^{47} \text{erg}. \]  

In the above equation part of the energy on the right-hand-side must go to radiation, and for that we used the ‘<’ sign. However, as mentioned above, the radiated energy is much smaller than the kinetic energy so we can neglect it. Taking \( M_1 = 5 \, M_\odot \), \( M_2 = 0.6 \, M_\odot \), and \( R_1 = 35 \, R_\odot \) gives that the final orbital energy of the binary system at the final orbit of the secondary star is

\[ E_{2,t} = \frac{GM_1M_2}{2R_1} \approx 3.6 \times 10^{47} \text{erg}. \]  

With the goal to assess the mass enclosed in each radius, we run a model of a \( M_{\text{ZAMS}} = 5 \, M_\odot \) star using MESA ( Paxton et al. 2011) and let it evolve to the AGB stage, to the point when its radius is \( R_1 \approx 35 \, R_\odot \), as estimated by MacLeod et al. (2016). Our model is shown in Figure 1.

To satisfy equation (4) the secondary star must spiral-in to a radius of

\[ r_{2,ej} \approx 3.8 \left[ \frac{M_1(r_{2,ej})}{1.2 \, M_\odot} \right] \left[ \frac{M_2}{0.6 \, M_\odot} \right] \left[ \frac{E_{2,t}}{3.6 \times 10^{47} \text{erg}} \right]^{-1} \, R_\odot, \]  

where the radius \( r_{2,ej} \) and mass \( M_1(r_{2,ej}) \) are scaled according to the solution of equation (5) with the model presented in Figure 1.

The mass of the primary star that resides above radius \( r_{2,ej} \approx 3.8 \, R_\odot \) is \( M_1(R_1) - M_1(r_{2,ej}) \approx 3.8 \, M_\odot \). If we take half the above value of kinetic energy, \( E_{k,ej} \approx 10^{47} \) erg, we get \( r_{2,ej} \approx 8.7 \, R_\odot \) and the mass above it is \( M_1(R_1) - M_1(r_{2,ej}) \approx 2 \, M_\odot \). Even if we consider that not all this mass was ejected, these values are still much larger than the ejected mass of \( \Delta m_{\text{ej,plateau}} = 0.17 \, M_\odot \) according to the model of MacLeod et al. (2016). Namely, the secondary star deposits its orbital energy to a mass much larger than a 0.17 \( M_\odot \). So for the 0.17 \( M_\odot \) to acquire a kinetic energy of \( E_{k,ej} \approx 1 - 2 \times 10^{47} \) erg, the secondary must release more gravitational energy. This implies that it spirals-in deeper than \( r_{2,ej} \) estimated above. It is not clear at all that under...
these conditions, where the energy is distributed among several solar masses, a small mass of $\Delta M_{\text{hyd, plateau}} = 0.17 M_\odot$ can escape with a velocity that is about twice the escape velocity from the binary system.

2.1.3 Time scale

Another problem we see in in the model proposed by MacLeod et al. (2016) concerns the time scale of envelope ejection. In the case of a powering by recombination the photosphere moves inward in the mass coordinate. Hence, most of the ejected mass was ejected at the same time and at the same velocity of $v_{ej} \approx 400$ km s$^{-1}$. However, as was shown in section 2.1.2 the secondary star needs to spiral-in to a very small radius. This requires at least one dynamical time at the surface, and likely much more. Namely, the ejection time will last over a time longer than 10 days. This is a substantial fraction of the 30 days during which the photosphere expands with a constant velocity. This does not fit the observations, unless later ejecta are moving at higher velocities than $v_{ej} \approx 400$ km s$^{-1}$ and catch-up with the photosphere. But this makes the energy and mass problems discussed in the previous subsections even more severe.

2.2 An alternative ILRT model

We propose that the ILOT M3LRN 2015 was not powered from the merger process itself, but rather by accretion onto a companion. Namely, instead of a merger-burst (or LRN or RT; see section 1 for terminology), it was powered by a companion accreting mass from a giant star, namely, an ILRT. As for powering the radiation, instead of recombination energy we suggested that the accreted energy is channelled to radiation and kinetic energy of jets (winds). The collision of jets with previously ejected mass can convert a substantial fraction of the 30 days during which the photosphere expands with a constant velocity. This does not fit the observations, unless later ejecta are moving at higher velocities than $v_{ej} \approx 400$ km s$^{-1}$ and catch-up with the photosphere. But this makes the energy and mass problems discussed in the previous subsections even more severe.

3 THE ILOT SN 2015bh (SNHunt 275)

3.1 The single-star super-Eddington model

The ILOT SN 2015bh (SNHunt 275) holds several puzzles (e.g., Postigo et al. 2015; Elias-Rosa et al. 2015, 2016; Richardson & Artigau 2015; Ofek et al. 2016; Thöne et al. 2016). It underwent a strong outburst in 2015, a weaker one in 2013, and possibly an earlier one in 2009. First and most important is whether the last outburst was a terminal SN explosion. Ofek et al. (2016) bring arguments that might suggest that it was not a SN explosion. We here accept this view, and examine its consequences. We note though that Elias-Rosa et al. (2016) argue that the last outburst was a faint SN explosion. The second puzzle is whether the detection on 2009 Sep 30 that looks like an outburst is real. Ofek et al. (2016) analyzed it and conclude that it is not an outburst, but rather it is likely a bad pixel or radiation hit event (i.e., cosmic ray). We accept this conclusion, despite three interesting coincidences that otherwise might have hinted at a real detection.

(i) The luminosity of the one-point 2009 peak (MJD 55084.5089) was only $\approx 7$ per cent above the maximum one in the 2013 outburst.

(ii) The time of the detection in 2009 took place $\approx 2250–2070$ day before $t_0 = 2457157.36$ (the time of the eruption in 2015). This is about 4 times the interval of $\approx 530$ day between the 2013 and 2015 peaks.

(iii) The one point detection before and one point detection after the 2009 peak are more luminous than the others points outside the peak in 2009.

The new light-curve presented by Thöne et al. (2016) indicate that there is high emission earlier in 2009. The light-curve also presents an earlier outburst in 2008, and a general complicated behavior. With the present data we refrain...
from fitting an orbital period for the system, and leave this question open.

Ofek et al. (2016) discuss the behavior of SN 2015bh within the context of a single star suffering an outburst with a super-Eddington luminosity following the model proposed by Shaviv (2000, 2001). We calculate the optical depth of the super-Eddington outburst model of Ofek et al. (2016). According to their results, the mass lost in the 2013 eruption is $M \approx 4 \times 10^{-3} M_\odot$. Accounting for $\Delta t \approx 20$ day the average mass loss rate is $\dot{M} \approx 7 \times 10^{-4} M_\odot$ yr$^{-1}$. Taking their observed ejecta velocity $v = 1000$ km s$^{-1}$, their photospheric radius$^2$ $r = 1.4 \times 10^{14}$ cm, opacity of $\kappa = 0.4$, and assuming spherical symmetry, the optical depth for a wind blown for a very long time is

$$\tau_{2013} \approx 0.1 \left( \frac{\kappa}{0.4 \text{ cm}^2 \text{ g}^{-1}} \right) \left( \frac{r}{1.4 \times 10^{14} \text{ cm}} \right)^{-1} \left( \frac{\dot{M}}{7 \times 10^{-4} M_\odot \text{ yr}^{-1}} \right) \left( \frac{v}{10^4 \text{ km s}^{-1}} \right)^{-1}.$$  

This is too low to account for a photosphere. We see this as a challenge to the single-star-super-Eddington outburst model.

3.2 An alternative binary model

We propose that instead of a super-Eddington outburst, SN 2015bh is (or was) a massive eccentric binary stellar system that underwent a giant eruption in 2013, followed by a strong eruption in 2015, which might have been a SN or a stellar merger event. The binary period might be either $\approx 530$ day or a simple fraction of this number. This raises the possibility that the mechanism behind the 2013 outburst is similar to the mechanism behind the GE of $\eta$ Carinae.

If the 2015 peak was not the result of a terminal event, i.e., a SN explosion or a stellar merger event, then the binary model allows for another eruption at the next periastron passage. If the orbital period is indeed $\approx 530$ day, the next event might take place in October 2016.

Applying the HAPI-jets model, the energy of the 2013 eruption, and the 2015 eruption if was not a terminal event (which we consider unlikely), came from accretion of gas to the binary companion, which lead to the formation of accretion disk and the launching of jets. A prediction of the model is a bipolar gas-ejection morphology, such as that during the GE of $\eta$ Carinae.

As an illustrative example we assume that the energy results from accretion onto a MS secondary of $M_2 = 10 M_\odot$ and radius $R_2 = 4 R_\odot$, and the radiated energy of the eruption is a fraction $\beta$ of the accretion energy. The secondary star can be more massive, but the gravitational potential on its surface will not changes much if it is a MS star. We can then estimate the accreted mass in the 2013 eruption to be

$$M_{\text{acc,2013}} \approx 0.05 \left( \frac{\beta}{0.1} \right)^{-1} \left( \frac{E_{\text{rad,2013}}}{2.4 \times 10^{48} \text{ erg}} \right) \left( \frac{R_2}{4 R_\odot} \right) \left( \frac{M_2}{10 M_\odot} \right)^{-1} M_\odot.$$  

For an event length of $\approx 0.1$ yr, the implied accretion rate is $\approx 0.5 M_\odot$ yr$^{-1}$. According to their results, the mass lost in the 2013 eruption is $M \approx 4 \times 10^{-3} M_\odot$. Accounting for $\Delta t \approx 20$ day the average mass loss rate is $\dot{M} \approx 7 \times 10^{-4} M_\odot$ yr$^{-1}$. Taking their observed ejecta velocity $v = 1000$ km s$^{-1}$, their photospheric radius$^2$ $r = 1.4 \times 10^{14}$ cm, opacity of $\kappa = 0.4$, and assuming spherical symmetry, the optical depth for a wind blown for a very long time is

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$$M_{\text{acc,2013}} \approx 0.05 \left( \frac{\beta}{0.1} \right)^{-1} \left( \frac{E_{\text{rad,2013}}}{2.4 \times 10^{48} \text{ erg}} \right) \left( \frac{R_2}{4 R_\odot} \right) \left( \frac{M_2}{10 M_\odot} \right)^{-1} M_\odot.$$  

Taking $\beta = 0.3$ can lower this estimate to $\approx 1.3 M_\odot$. However, Thöne et al. (2016) estimate the total radiated energy of the 2015 eruption to be $\approx 1.8 \times 10^{49}$ erg. The HAPI model cannot account for such radiated energy in this system.

The estimate for $M_{\text{acc,2015}}$ is similar to the estimate of $3.7 M_\odot$ for the mass accreted onto the companion of $\eta$ Car during the GE (Kashi & Soker 2010a). Though in the case of $\eta$ Car the eruption lasted for about twenty years, most of the accretion probably occurred very close to 2–4 periastron passages, making the accretion time in the order of a week or two. However, the 2015 event was short, $\approx 0.05$ yr, and the implied accretion rate is huge, $\approx 4 M_\odot$. We therefore regards the HAPI model less likely for the 2015 event. The 2015 event is more likely a true supernova or a violent merger event. We next consider a violent head-on (or almost head-on) merger.

Adopting the accretion model for the 2015 eruption of SN 2015bh we would need a strong stretching of the parameters, in particular a much more massive MS companion. Instead, it is easier to account for the energy of the 2015 eruption if it came from a merger of the two stars. The merger is actually an almost head-on collision of the two stars that were in a very high eccentric orbit before merger. It is different from the onset of a CE phase. In the head-on collision case the gas-ejection morphology will be highly non-spherical. If the secondary star is completely stopped as it hit the primary envelope in the head-on collision, then the energy that is released is

$$E_{\text{merge}} \approx 3 \times 10^{49} \left( \frac{M_1}{50 M_\odot} \right) \left( \frac{M_2}{10 M_\odot} \right) \left( \frac{R_1}{50 R_\odot} \right)^{-1} \text{ erg}.$$  

A fraction of 10 per cent will be enough to account for the radiated energy deduced by Ofek et al. (2016), and a fraction of $\approx 50$ per cent is needed for the radiated energy calculated by Thöne et al. (2016). Namely, if during the very short time of the collision, a fraction of the orbital period, the velocity of the secondary star is reduced by $\approx 5 – 30$
per cent, the released energy can account for the energy of the outburst. In the case of a merger-burst event, no further outbursts will take place.

4 SUMMARY AND DISCUSSION

We discussed two recent ILOTs in the context of the binary model. In section 2 we discussed the ILOT M31LRN 2015. We critically studied the model proposed by MacLeod et al. (2016), according to which a low mass MS star entered a common envelope phase with a giant star of radius $\approx 35 R_\odot$. The kinetic energy of the ejected gas results from the spiraling-in process of the companion into the envelope, and the radiation comes from the recombination of the ejected mass. We found severe problems with that model. We suggested instead that M31LRN 2015 was an ILOT powered by a MS companion accreting from a giant, i.e., an ILRT type of ILOT (see section 1 for terminology). The accretion is through an accretion disc that launches jets. The jets carry most of the energy, such that the accreting star itself does not radiate much above its Eddington luminosity (Shiber et al. 2016). The source of the radiated energy is the radiated energy by the disk and the conversion of kinetic energy to radiation when the jets collide with the material that was ejected a short time earlier. In many cases accretion might be more efficient than recombination in powering ILOTs (Soker 2016). In the case of the ILOT M31LRN 2015 the companion needs to accrete a mass of $\approx 0.04 M_\odot$ (Equation 6).

In section 3 we discussed the ILOT SN 2015bh (SNHunt 275) that underwent two eruptions, one in 2013 and another in 2015. We raise the possibility that the 2015 outburst might have been a head-on collision, though it was more likely a terminal supernova explosion. We examined the super-Eddington single star model as proposed by Ofek et al. (2016) for this ILOT. We found that the mass ejected according to the super-Eddington single-star model in the 2013 outburst is insufficient to account for the radius of the photosphere at $\gtrsim 10^{14}$ cm. Here as well we suggested the HAPI-jets model, where the 2013 eruption was powered by accretion onto a companion in an eccentric orbit. In case that the 2015 outburst was not a terminal supernova explosion, we speculated that the very energetic outburst might have been a head-on merger event of two massive stars (Equation 11). Overall, with the presently available observations we cannot tell conclusively whether the 2015 was a SN explosion, a terminal merger event, or an accretion event that left the binary system intact.

Over all, the binary model for ILOTs can account for different types of outbursts, but one should be careful in identifying the exact process. Namely, which of the following processes takes place in each case (few of them can occur simultaneously): CEE, GEE, mass transfer, merger, and jet launching.

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