1 *Article*

2 Planets, Planetary Nebulae, and Intermediate
3 Luminosity Optical Transients (ILOTs)

4 **Noam Soker** [1,2,*]

5 [1] Department of Physics, Technion -- Israel Institute of Technology, Haifa 32000, Israel
6 [2] Guangdong Technion Israel Institute of Technology, Shantou, Guangdong Province, China
7 * Correspondence: soker@physics.technion.ac.il

8 **Abstract:** I review some aspects related to the influence of planets on the evolution of stars before
9 and beyond the main sequence. Some processes include the tidal destruction of a planet on to a
10 very young main sequence star, on to a low mass main sequence star, and on to a brown dwarf.
11 This process releases gravitational energy that might be observed as a faint intermediate luminosity
12 optical transient (ILOT) event. I then summarize the view that some elliptical planetary nebulae are
13 shaped by planets. When the planet interacts with a low mass upper asymptotic giant branch
14 (AGB) star it both enhances the mass loss rate and shapes the wind to form an elliptical planetary
15 nebula, mainly by spinning up the envelope and by exciting waves in the envelope. If no
16 interaction with a companion, stellar or sub-stellar, takes place beyond the main sequence, the star
17 is termed a *Jsolated star*, and its mass loss rates on the giant branches are likely to be much lower
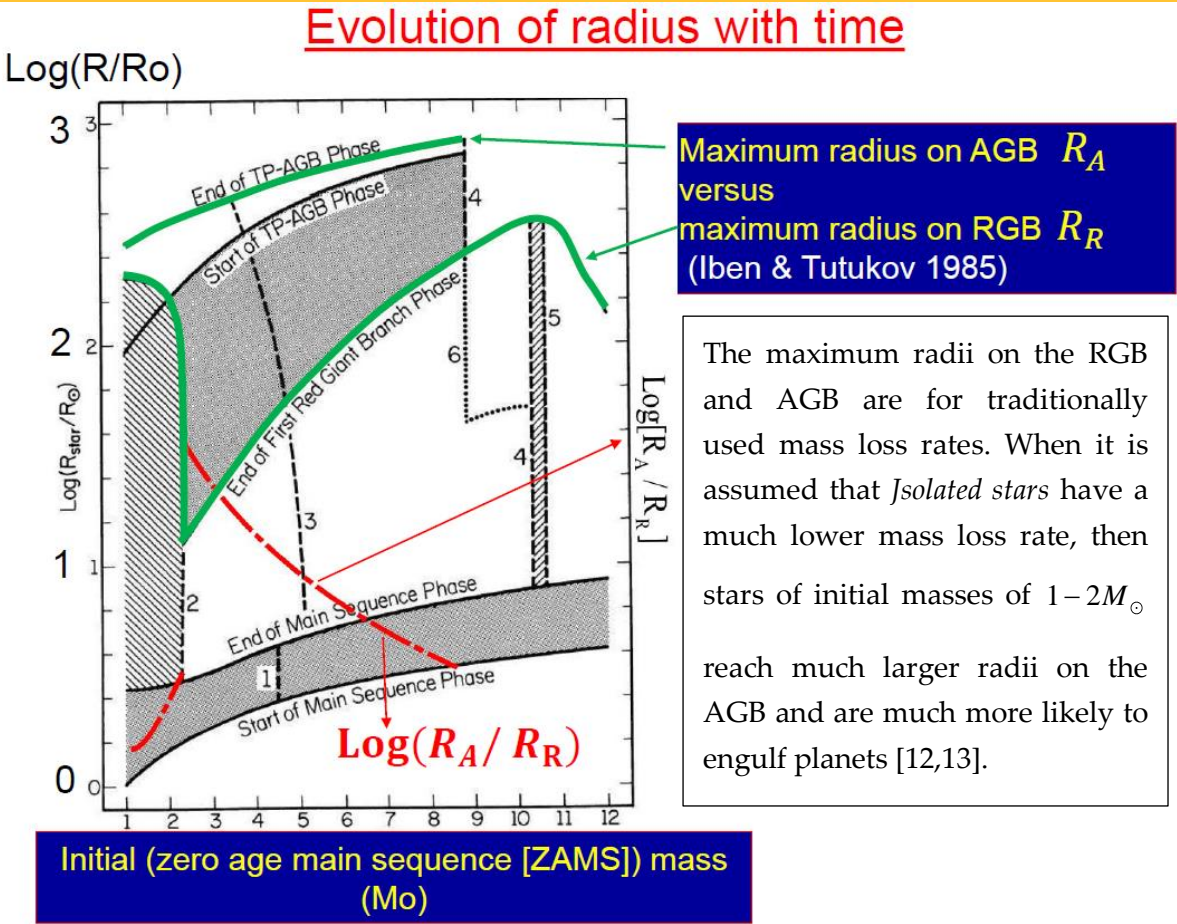18 than what is traditionally assumed.

21

22 1. Introduction

23   Planetary nebulae (PNe) are shaped by stellar and sub-stellar companions (see Jones & Boffin
24 2017 for a recent review [1]). One open question that is with us for more than two decades (e.g.,
25 Soker 1996 [2]) is to what extend sub-stellar objects, and in particular planets, also shape PNe (see De
26 Marco & Izzard 2017 for a recent review [3]). De Marco & Soker [4] took that about quarter of all
27 stars in the initial mass range $1-8M_\odot$ do form PNe, and estimate that about 20% of all PNe were
28 shaped via planets and brown dwarfs. This amounts to about 5% of all $1-8M_\odot$ stars. In light of the
29 general interest in the manner by which planets can influence stellar evolution (e.g., [5-10]), I discuss
30 some issues related to star-planet interaction. The paper is based on a talk I gave at the Asymmetrical
31 Planetary Nebulae (APN) VII meeting (Hong Kong, December 2017), and all figures are from my
32 presentation at the meeting.

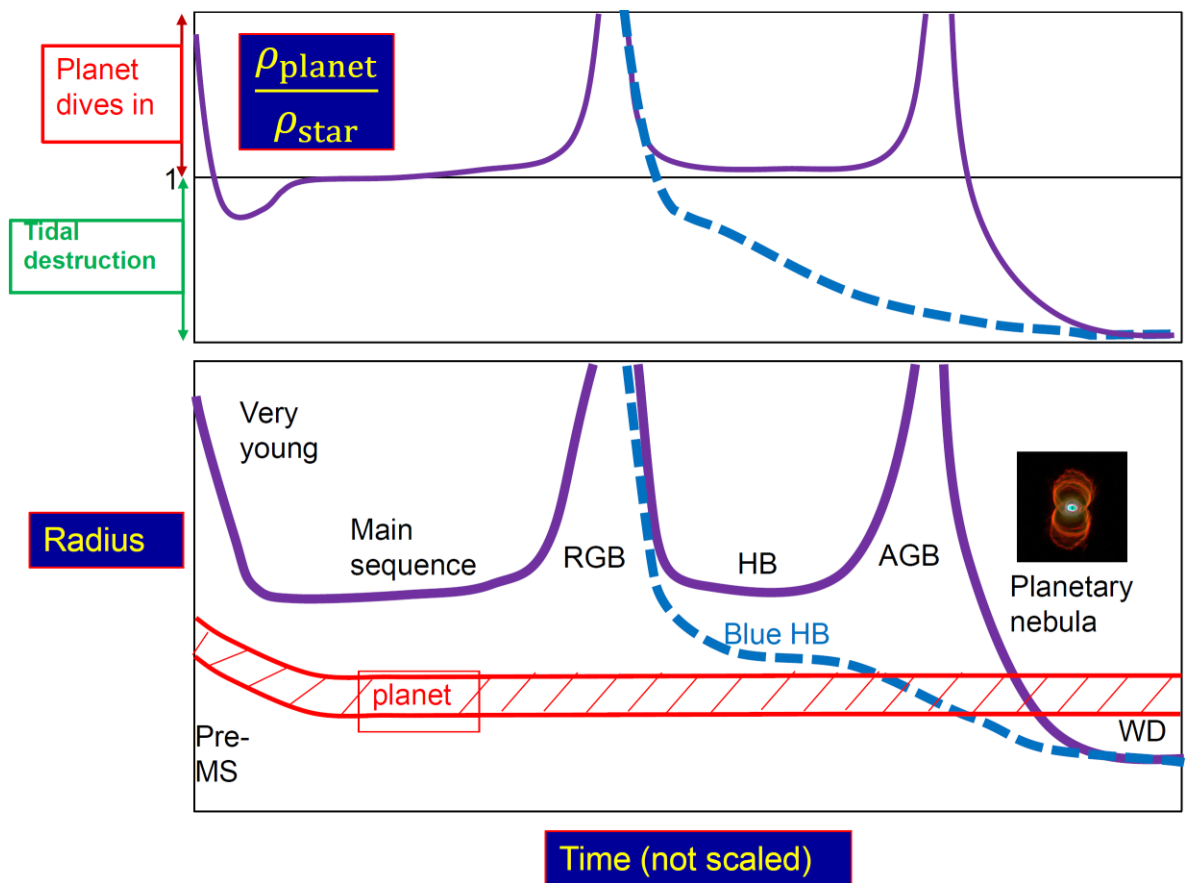## 33 2. Engulfment of Planets by Asymptotic Giant Branch (AGB) Stars

34   For a planet to influence the envelope of an AGB star the envelope cannot be too massive. This
35 implies a low mass star. However, for traditionally used mass loss rates low mass stars reach very
36 large radii already on their red giant branch (RGB; Figure 1), and are likely to swallow their planets
37 before they even reach the AGB. The way to have many planets to interact with their host star on the
38 AGB is if the mass loss rate on the giant branches is lower than what traditional values are. In that
39 case the stellar core on the AGB and consequently the stellar radius are larger than in traditional
40 calculations, and the star is much more likely to swallow a planet on its upper AGB. Sabach & Soker
41 [12,13] assume that *Jsolated stars*, i.e., those that are not spun-up in their post-main sequence
42 evolution, lose mass at a rate that is smaller than about 30% of the traditional one, and show that in
43 that case low mass AGB stars reach much larger radii and are much more likely to swallow planets
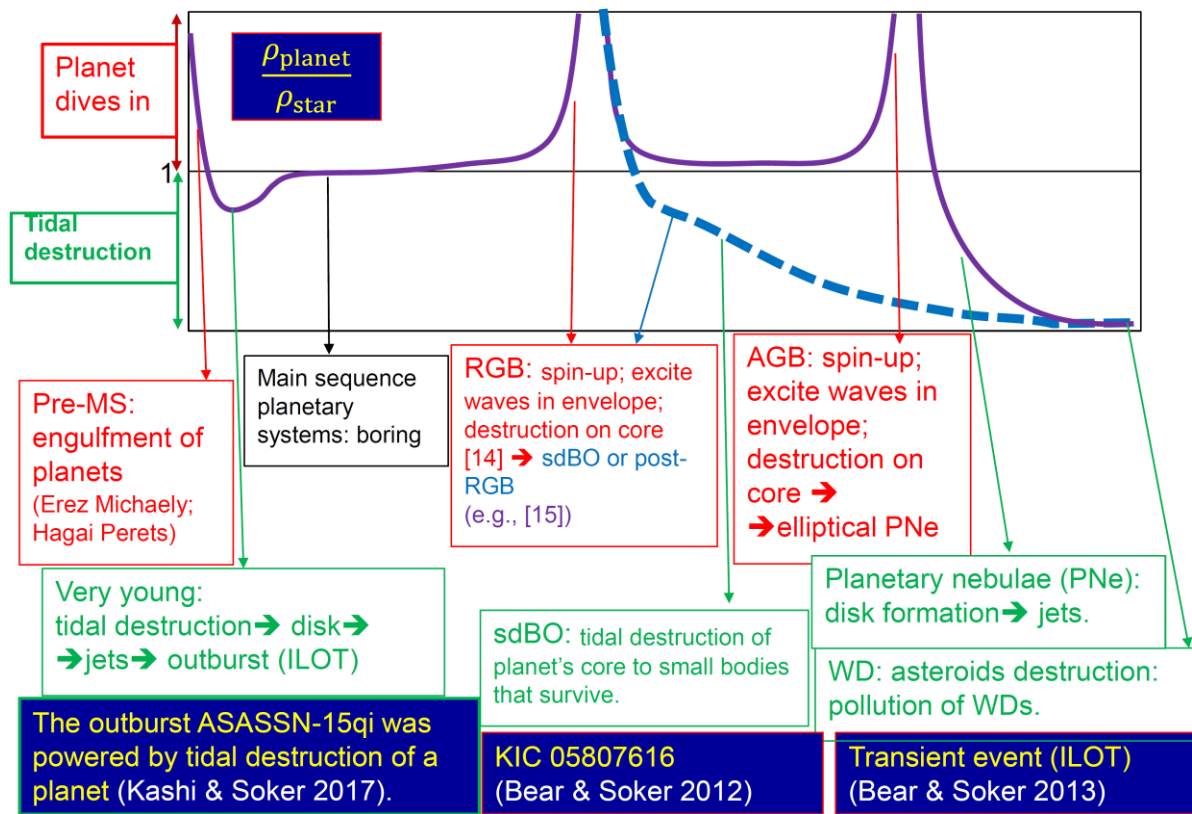44 than in traditional calculations.

Figure 1. Maximum radii stars reach on their RGB and AGB as function of their initial mas for traditional mass loss rates (from [11]).

3. The Fate of a Planet: Tidal Destruction versus Engulfment

The fate of the planet as it comes close to the envelope of a star depends on the density ratio. If the density of the planet is larger than that of the star it dives in to the envelope as one entity and starts a common envelope evolution. It will later be destroyed near the core, either by tidal forces or evaporation. If the density of the planet is lower than that of the star, it is tidally destroyed and forms an accretion belt (or a disk) around the star. In Figure 2 I present a schematic evolution of the planet and the stellar radii and densities, and mark which of the two outcomes takes place. I give more details of the outcomes in Figure 3.

Figure 2. A schematic evolution of the radii and densities of planets and stars from the pre-main sequence phase to the WD phase. Upper panel: the ratio of the planet density to the stellar density. If the ratio is above 1 the planet dives-in to the envelope as one entity. If the density ratio is below 1 the planet is tidally destroyed and forms and accretion belt/disk around the star. Lower panel: The planet and stellar radii as function of time.
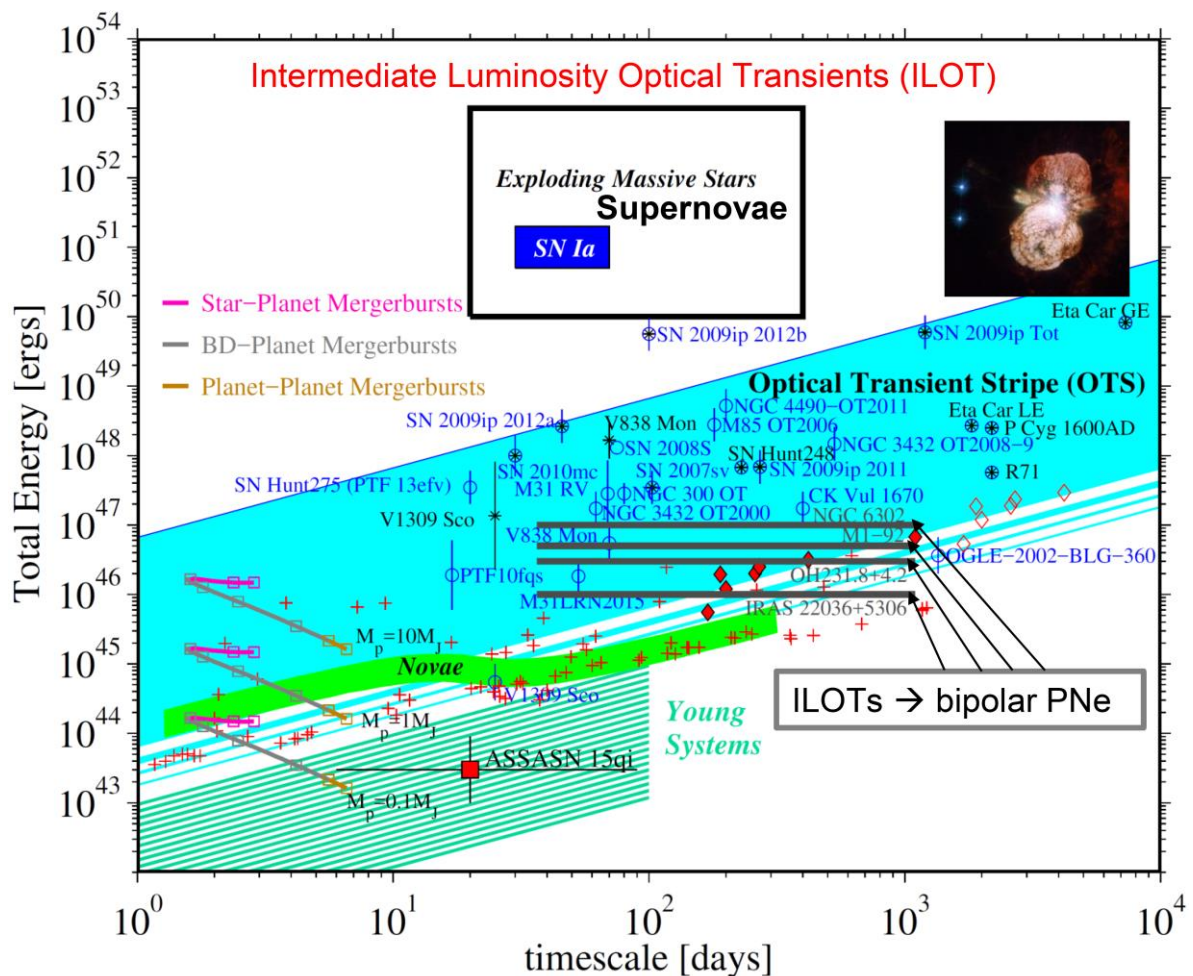

Figure 3. Outcomes of planet-star interaction.

4. Intermediate Luminosity Optical Transients (ILOTs) with planets

ILOTs are outbursts of a star or a binary system with a peak luminosity mostly between those of novae and supernovae (other names for these events are red novae, luminous red novae, and intermediate luminous red transients). Several studies have proposed that the interaction of a planet with a star can account for a minority of ILOTs. Retter & Marom (2003 [16]) proposed that V838 Mon was a result of planets entering a common envelope with a star. Bear et al. (2011 [17]) proposed that the destruction of a planet on to a brown dwarf or a low mass main sequence star can result in an ILOT evet. Kashi & Soker (2017 [18]) proposed that the outburst of the young stellar object ASASSN-15qi was an ILOT event where a sub-Jupiter young planet was tidally destructed on to a young main-sequence star. Because the system was young, the density of the planet was smaller than that of the star (Figure 3), and the planet was tidally destructed. This, they suggested, resulted in the formation of an accretion disc and a gravitationally powered ILOT. The mass of the planet was too small to inflate a giant envelope, and hence the ILOT was hot, rather than red. As well, its energy was below those of classical novae.

Bear et al. (2013 [19]) discussed the possibility of observing the transient event that might result from the tidal destruction process of an asteroid near a WD. But this event is much weaker than typical ILOTs.

Figure 4. Observed transient events on the energy time diagram. Blue empty circles represent the total (radiated plus kinetic) energy of the observed transients as a function of the duration of their eruptions, i.e., usually the time for the visible luminosity to decrease by 3 magnitudes. The Optical Transient Stripe is populated by ILOT events that we [18] suggest are powered by gravitational energy of complete merger events or vigorous mass transfer events.

77   **5. Intermediate Luminosity Optical Transients (ILOTs)**

78   In figure 4 I present the energy-time diagram of ILOTs as Amit Kashi and I have been developing
79   in the last several years (see http://phsites.technion.ac.il/soker/ilot-club/ for an updated diagram).
80   We suggest ([18] and references therein) that these ILOTs are powered by gravitational energy in
81   one of several types of processes. (1) The secondary star is completely destroyed and part of its mass
82   is accreted onto the primary star, e.g., as a planet destruction onto a brown dwarf. (2) The secondary
83   star enters the envelope of a companion but stays intact and forms a common envelope, e.g., as
84   Retter & Marom (2003 [16]) suggested. (3) The secondary star accretes mass while outside the
85   envelope of the primary star, e.g., as our mode for the Great Eruption of Eta Carinae or our
86   suggested scenario for some PNe [18].
87   With Amit Kashi [20] we suggest that the binary progenitors of some bipolar PNe experienced
88   ILOT events that shaped the PN. The several months' long outbursts were powered by mass transfer
89   from an AGB star on to a main-sequence companion that orbits outside the AGB envelope. Jets
90   launched by an accretion disk around the main sequence companion shaped the bipolar lobes. Four
91   such bipolar PNe are marked of Figure 4.

92   **6. Planet-Shaped Planetary Nebulae**

93   When a planet spirals-in inside the loosely bound envelope off an upper AGB star it can excite
94   waves in the envelope and spin-up the envelope, both of which can cause asymmetrical mass lose.
95   Finally, when the planet is destroyed near the core it might lead to further asymmetrical mass loss
96   from inside the envelope, e.g., jets that might be launched by the core.
97   I started the paper with the discussion of the general interaction of planets with evolving stars, I
98   then moved to discuss the formation of ILOTs with planet companions, and in section 5 I mentioned
99   some bipolar PNe that can be shaped by ILOT events with a stellar companion to the AGB
100 progenitor of the PN. I now end the discussion of planet-shaped PNe by listing the evolutionary
101 channels and the resulting PN types. For that I use a table from De Marco & Soker (2011 [4]), which I
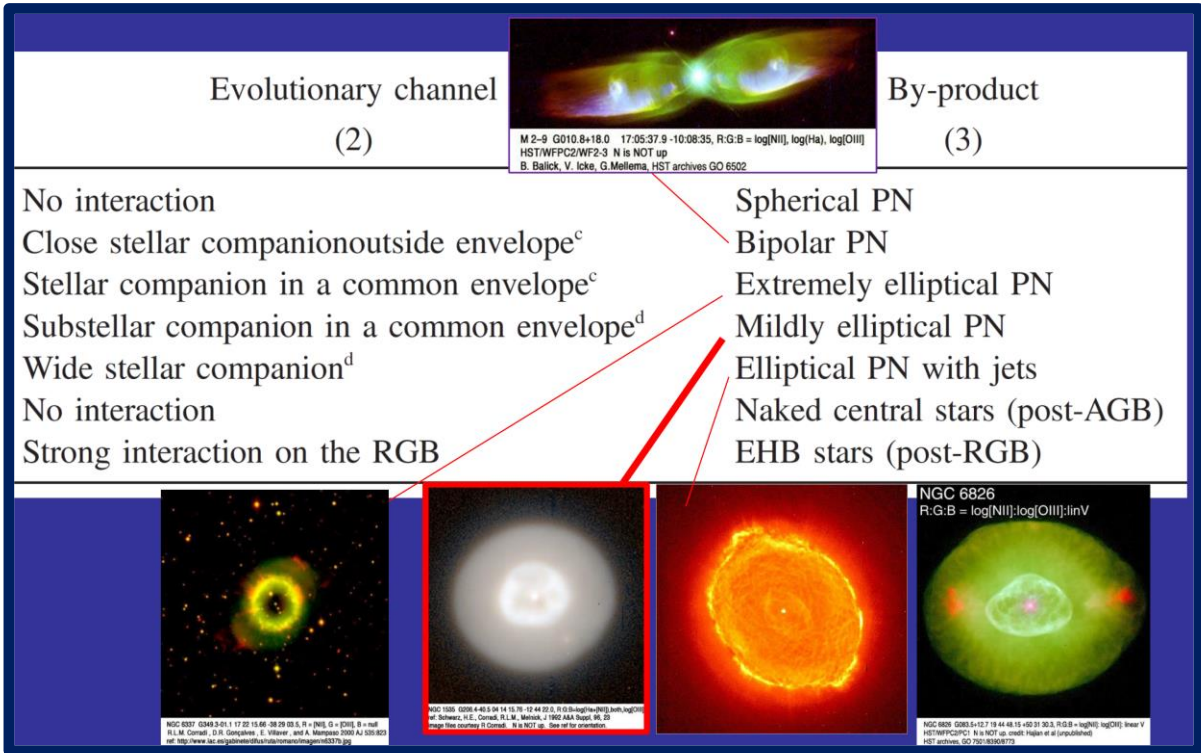102 present here as Figure 5.

103
104 **Figure 5.** The evolutionary channels and the PN types that result from them (based on De Marco &
105 Soker 2011 [4]).

7. Discussion

I discussed some aspects of the influence of planets on late stellar evolution, and its relation to some aspects of stellar binary interaction. The main claim of this presentation is that planets can influence the evolution of low mass stars, in, e.g., enhancing the mass loss rate of RGB and AGB stars (that without any companion are *Jsolated stars* that have low mass loss rates, lower than what is usually assumed), in forming some ILOTs, and in shaping PNe. There are other aspects I did not get into, such as the strength of the tidal interaction between the planet and the star, some aspects of which can be found in reviews from earlier related meetings (e.g., [21]).

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