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Dynamical evolution of two planet systems into the white dwarf phase

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Abstract. In this contribution we present some preliminary results on the dynamical evolution of two planet systems around stellar hosts evolving from the main sequence to the white dwarf phase. The aim is to study the instabilities triggered by stellar evolution that may bring planets onto the stellar surface or produce planetary scale collisions (hence debris) that could explain the metallic atmospheric pollution observed in white dwarfs.

Key words. Stars: white dwarf – Stars: metal pollution – Stars: dynamical evolution

1. Introduction

About one fourth of cool white dwarfs (WDs) ($T_{\rm eff} \leq$ 20,000 K) show metallic absorption lines in their ultraviolet-optical spectra. Because the sinking time of heavy elements in a WD atmosphere is much shorter than the cooling time of the star (Wyatt et al. 2014), it is not expected to observe such features. The accretion of planetesimals is the accepted mechanism (Kilic & Redfield 2007; Gansicke et al. 2006; Vanderburg et al. 2015, among others) to explain the pollution of WD atmospheres. With the aim of understanding the pollution process, in this work, we present preliminary results on the study of the planet-planet scattering process that is triggered by stellar mass loss during the post-main sequence evolution. We explore a wider parameter space (planetary masses, eccentricities, inclinations, etc.) than previous studies (i.e, Veras et al. 2013) on the subject.

2. The sample selection

For the simulations we have selected all systems with two planets reported in the NASA Exoplanet Archive[1] and the Exoplanet Encyclopedia[2]. We then excluded giant or subgiant stars, as well as cataclysmic variables, eclipsing binaries, and pulsars. Our final sample (as of June 2018) contains 364 systems with two planets for which we retrieved the information from the above sources. When information on eccentricity and inclination was not available, we randomly selected them from a Rayleigh distribution with sigma parameters of 0.02 (Pu & Wu 2015) for eccentricity and

[1] exoplanetarchive.ipac.caltech.edu
[2] http://exoplanet.eu

1.12 for inclination (Xie et al. 2016). When the information regarding planet masses or radii was not available we used the FORECASTER model (Chen & Kipping 2017) for the mass-radius relation to calculate it.

3. Simulation setup

In order to solve the dynamics of the systems, we used the MERCURY integrator (Chambers et al. 1999), modified by Veras et al. (2013), which takes into account the change of stellar mass and radius of the central star along its evolution. Since the mean mass of polluted WD is 0.7 $M_\odot$ (Koester et al. 2014), we used a model of a 3 $M_\odot$ star for our simulations considering an initial-final mass function (Kalirai et al. 2008). The mass and semi major axis of the planets are scaled up to keep the Hill stability criteria of the original system. MERCURY does not take into account tidal forces, thus, the first planet is placed at 10 au where those forces are negligible during the main sequence (MS), red giant branch and asymptotic giant branch phases (Villaver & Livio 2009; Mustill & Villaver 2012). The second planet is located at a distance where the semi major axis ratio of the planets is conserved. We performed 10 simulation runs for each system varying the inclination of the planets.

4. Results

A total of 3640 simulations were performed following the evolution of a star from the MS to the WD phase. In Figure 1, we display some illustrative results of the semi major axis evolution with time up to 10 Gy. In the upper left and right panels, we show, respectively, a planetary collision and the ejection of a planet. The lower panel displays a system with planetary orbits that remained stable along the entire simulated time interval. Note that for the two unstable systems instabilities appeared after the formation of the WD ($t > 477$ Myr). We obtained that only 85 (2.33 %) of the 3640 simulations lead to instabilities (collisions, engulfments or ejections) in the WD phase, while 243 cases (6.7%) became unstable during the MS.

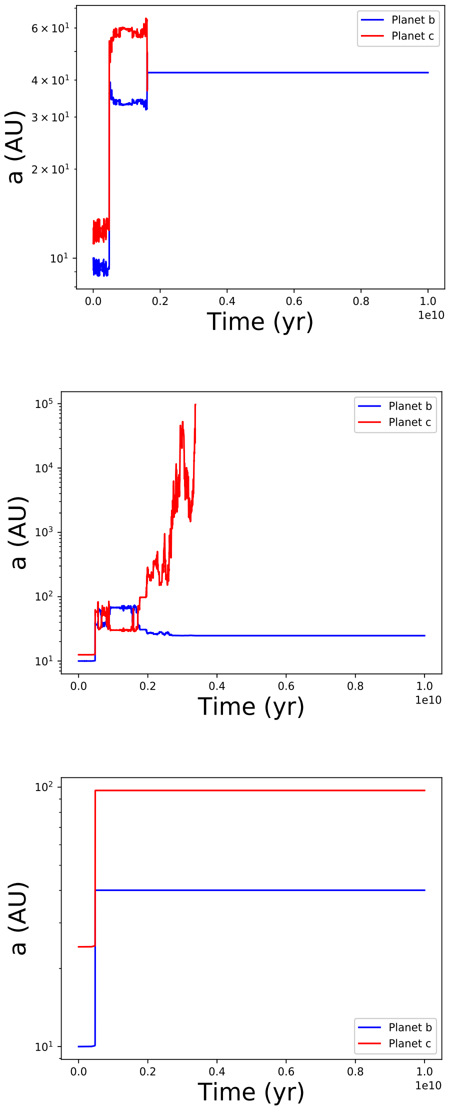

Fig. 1. Semi major axis evolution (in au), as a function of time during the 10 Gyr simulated in each run. The blue and red solid lines show the evolution of the inner and outer planets orbit respectively (at the start of the simulated run). We present 3 examples showing possible outcomes of the simulations: the top panel shows a collision between the planets (Hill unstable system); in the middle panel, we display an instability that leads to the ejection of a planet (Lagrange unstable system); the lower panel shows one system that remains stable in the simulation.

5. Conclusions

The results imply that the observed atmospheric pollution in at least 25% of WDs is hard to explain only by dynamical instabilities in two planet systems of the type conducted here. We are currently performing simulations of three planet systems and early results indicate that the prevalence of instabilities significantly increases. Additionally, the inclusion of planetesimal belts might also partially explain the atmospheric pollution, either by producing planetary orbit instabilities or being themselves destabilized by the effect of the planets (Mustill et al. 2018). In Maldonado et al. 2019 (in preparation), we will provide the details of this investigation.

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