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Signature of Planetary Mergers on Stellar Spins

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ABSTRACT
One of the predictions of high eccentricity planetary migration is that many planets will end up plunging into their host stars. We investigate the consequence of planetary mergers on their stellar hosts' spin-period. Energy and angular momentum conservation yield that a planet consumption by a star will spin-up the star. We find that our calculations align with the observed bifurcation in the stellar spin-period in young clusters. For example, after a Sun-like star has eaten a Jupiter-mass planet it will spin up by $\approx 60\%$ (i.e. spin-period is reduced by $\approx 60\%$), causing an apparent gap in the stellar spin period, between stars that consumed a planet and those that did not. The spun-up star will later spin down due to magnetic braking, consistent with the disappearance of this bifurcation in clusters ($\gtrapprox 300$Myr) . The agreement between the calculations presented here and the observed spin-period color diagram of stars in young clusters, provides circumstantial evidence that planetary accretion onto their host stars is a generic feature of planetary-system evolution.

Key words: exoplanets, stars, young clusters

1 INTRODUCTION

Recent observations showed that many short-period exoplanets are found nearly at, or even interior to, their Roche limit (see figure 1 in Jackson *et al.* 2017), implying that these planets will be consumed by their host star. In the process of spiraling into a star, star-planet tidal interactions tend to spin up the star (e.g., Dobbs-Dixon *et al.* 2004; Jackson *et al.* 2008, 2009; Lanza 2010; Brown *et al.* 2011; Bolmont *et al.* 2012). Further, it was proposed that a shortage of close-in planets around fast rotators (e.g., McQuillan *et al.* 2013) can be attributed to the tidal merger of planets onto a star (e.g., Teitler and Königl 2014; Lanza and Shkolnik 2014).

Driving a planet on a nearly radial orbit seems to be one of the natural consequences of the eccentric Kozai-Lidov mechanism (see for recent review Naoz 2016). In this process, a far away companion can induce large planetary orbit's eccentricity, and plunge it into the star (e.g., Guillochon *et al.* 2011; Naoz *et al.* 2012; Li *et al.* 2014; Rice 2015; Valsecchi and Rasio 2014; Petrovich 2015a,b; Stephan *et al.* 2017). Smaller and moderate eccentricities are expected from planet-planet interactions, but may still result in many planets plunging into the star (e.g., Naoz *et al.* 2011; Antonini *et al.* 2016; Petrovich and Tremaine 2016; Hamers 2017). Here we show that as a planet falls onto a star, it deposits its energy, angular momentum and mass into the star, causing the star to spin up.

Stellar rotation is attributed to a combination of both stellar mass and evolutionary state. Sun-like stars spin down by losing angular momentum to magnetized stellar winds, otherwise known as magnetic braking, during the main sequence stage (e.g., Parker 1958; Schatzman 1962; Weber and Davis 1967; Mestel 1968). Therefore, the stellar rotation-period or the rotational velocity $v_{\rm rot}\sin i$ is frequently used as a proxy for stellar ages (e.g., Barnes 2003a,b, 2007a; Mamajek and Hillenbrand 2008; Meibom *et al.* 2009, 2011; James *et al.* 2010; Mamajek and Hillenbrand 2008; Meibom *et al.* 2009, 2011; van Saders and Pinsonneault 2013; van Saders *et al.* 2016).

Mamajek and Hillenbrand (2008) showed that the spin-period of the Pleiades open cluster (age ≈ 130 Myr) exhibit a bifurcation for the same effective temperature (B-V) values. One group of stars are fast rotators (with a spin-periods of $1-2$ days) and another one, slower rotators (with a spin-periods of $3-9$ days). Mamajek and Hillenbrand (2008) showed that the latter group's spin-period traces the spin fit models adopted from Barnes (2007b). This behavior is also observed in other young clusters such as M35 and M34 (100 Myr and 240 Myr respectively, e.g. Meibom *et al.* 2009; James *et al.* 2010)[1]. Moreover, it seems that fast rotators

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[1] See table 1 for open cluster age estimations.

have a dearth of close-in planets around them (e.g., McQuillan *et al.* 2013; Lanza and Shkolnik 2014). Observations suggest that this bifurcation is suppressed for older clusters such as the Hyades (≈ 625 Myr) and M 48 (≈ 380 Myr) (Saar and Brandenburg 1999; Pizzolato *et al.* 2003; Mamajek and Hillenbrand 2008; Meibom *et al.* 2009; Nardiello *et al.* 2015).

One interpretation for this division in rotation periods is that the fastest rotators have an outer convective magnetic field zone that shears the interior radiative zone and causes the gap in the rotation (e.g. Barnes 2003a,b; Meibom *et al.* 2009; James *et al.* 2010). In other words, this interpretation suggests that fast rotators, possess only a convective field. Thus, they are inefficient in depleting their spin angular momentum. Later, van Saders *et al.* (2016), using evolutionary modeling, suggested that this gap is a result of a weaker magnetic braking process. Their models were able to reproduce both the asteroseismic and the cluster data. Recently, Somers and Stassun (2017), analyzed the radii of single stars in the Pleiades and showed that inflated stars have a shorter spin period. Their statistical analysis included the inflation of young stars by magnetic activity and/or star-spots.

Furthermore, stellar evolution models of zero-main sequence contraction were able to produce consistent results with observations of rotation period in star-forming regions and young open clusters (e.g., Gallet and Bouvier 2013, 2015) . Observations of the young open cluster h Persei, (e.g., Moraux *et al.* 2013), which is ~ 13 Myr old, give a glimpse to the birth rotational period distribution of stars. Unlike the clusters mentioned above, h Persei, ~ 13 Myr, does not show a clear bifurcation signature, but instead a nearly uniform distribution. This is consistent with our proposed model, since giant planet formation is typically expected to occur only after ~ 10 Myr (e.g., Pollack *et al.* 1996), making the h Persei cluster too young for the dynamical processes to take place. Finally, as we show below, our calculation is largely independent of the initial period distribution.

Here we offer an alternative scenario: an increase in stellar rotation of a star due to the consumption of a Jupiter mass planet. A planet may plunge into the star, for example, due to high eccentricity migration. Thus, the star will absorb both the mass of the planet and the planet's orbital angular momentum, and will cause the star to spin up.

We note that the details process at which a planet accretes onto the star is complicated (e.g., Metzger *et al.* 2012, 2017; Pejcha *et al.* 2016; Dosopoulou *et al.* 2017; Ginzburg and Sari 2017). However, our calculations are independent of the process and depend only on the result, because we consider the angular momentum conservation, associated with the merger. We compare our calculations with several observed open cluster period-color diagrams and show that a planet consumed by a star at about 100 Myr fits the observations.

The paper is organized as follow. We begin with considering the effects on the stellar spins (Section 2). In particular we consider magnetic braking (Section 2.1), angular momentum conservation (Section 2.2) and energy arguments (Section 2.3). We then continue with a desciption of the consequences of conception of a planet on the stellar spin-period (Section 3).We finally offer our discussion in Section 4.

2 EFFECTS ON THE STELLAR SPIN

2.1 Magnetic Braking

As mentioned, Sun-like stars undergo spin-down due to magnetic braking (e.g., Parker 1958; Schatzman 1962; Weber and Davis 1967; Mestel 1968). The spin loss rate is evaluated is:

$$\dot{\mathbf{\Omega}} = -\alpha_{mb}\Omega^2\mathbf{\Omega} \ , \tag{1}$$

(e.g., Dobbs-Dixon *et al.* 2004), where

$$\alpha_{mb} = \begin{cases} 1.5\times10^{-14}\ \text{yr} & \text{G stars} \\ 1.5\times10^{-15}\ \text{yr} & \text{F stars} \end{cases} \tag{2}$$

We use `SSE` (single-star evolution) code (e.g., Hurley *et al.* 2000) with the magnetic braking from Equation (1) to calculate the spin evolution of the stars as a function of time for stellar masses between $0.6-1.8\ \mathrm{M}_\odot$ and their corresponding effective temperature.

2.2 Angular Momentum arguments

During the final step of high eccentricity migration, when the planet plunges in, we assume angular momentum conservation. We note that during the dynamical evolution the angular momentum of the inner orbit is not necessarily conserved as an inclined companion can exchange angular momentum with the inner planet (e.g., Naoz *et al.* 2011, 2013). However, the final plunge, the inner orbit decoupled from the outer orbit, and thus it can be characterized with angular momentum conservation (e.g., Naoz and Fabrycky 2014, figure 3). The equation in this case is:

$$\mathbf{L}_i = I_s\mathbf{\Omega}_s + I_p\mathbf{\Omega}_p + \mathbf{L}_{\rm orb} \ , \tag{3}$$

where Ω_s (Ω_p) is the stars (planet) spin rate. The star's and the planet's moments of inertia are $I_s = 0.08MR^2$ and $I_p = 0.26mr^2$, respectively (e.g., Eggleton and Kiseleva-Eggleton 2001), where R (r) is the radius of the star (planet). The subscript "i" denotes the initial (pre-consumption) state. The orbital angular momentum $L_{\rm orb}$ for an orbit with a semi-major axis a and eccentricity e is given by

$$\begin{aligned} L_{\rm orb} &= \frac{Mm}{M+m}\sqrt{G(M+m)a(1-e^2)} \\ &\approx \frac{Mm}{M+m}\sqrt{2G(M+m)R_{\rm Roche}} \ , \end{aligned} \tag{4}$$

where M and m are the masses of the star and the planet respectively. In the last transition in Equation (4) we assumed high eccentricity so $e\to1$ and thus, $a(1-e^2)\approx 2a(1-e)\approx 2R_{\rm Roche}$, where $R_{\rm Roche}$ is the Roche limit given by

$$R_{\rm Roche} \sim \eta r\left(\frac{m}{M+m}\right)^{-1/3} \ , \tag{5}$$

where η is a numerical parameter of the order of unity. We adopt $\eta = 1.6$ and note that changing the value of η does not qualitatively change the dynamical nature of the system but rather the efficacy of disruption of planets (e.g., Petrovich 2015a). Angular momentum conservation yields

$$L_i = L_f \ , \tag{6}$$

where

$$L_f = I_{s+p}\Omega_{s+p} \ . \tag{7}$$

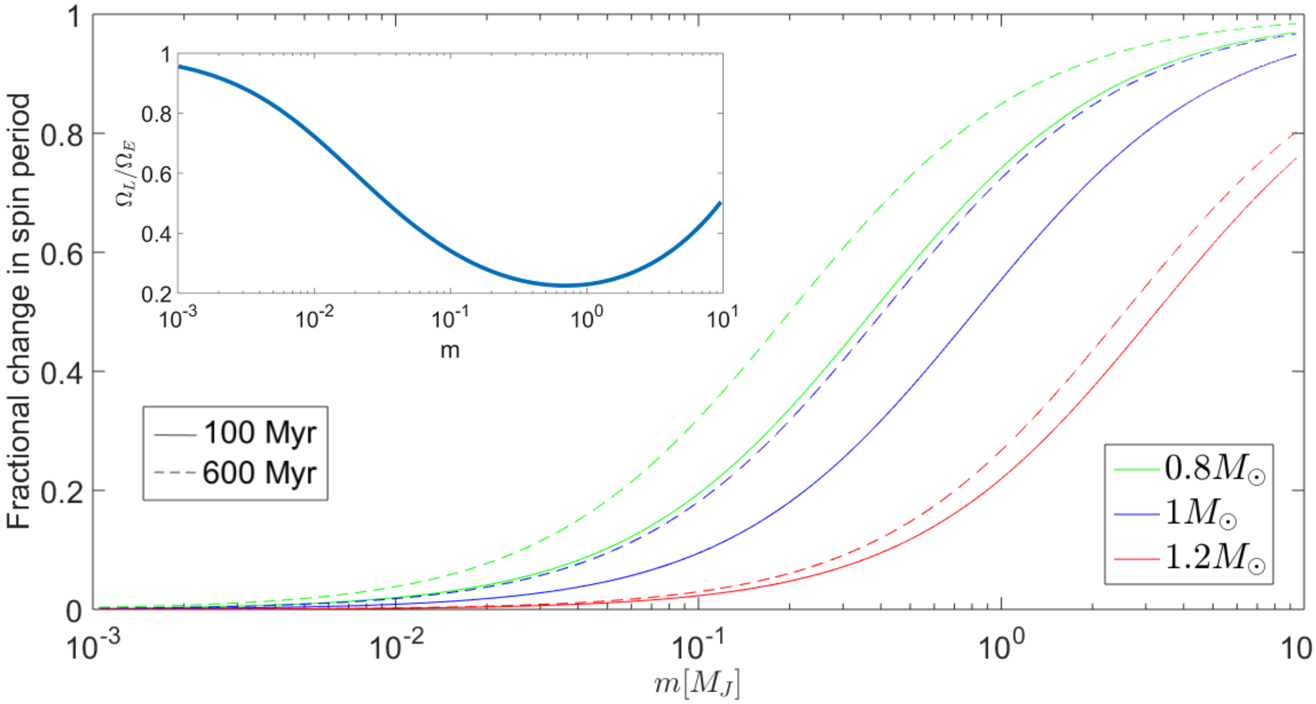

Figure 1. The spin-period absolute percentage change defined as: $|P_{\Omega,i} - P_{\Omega,f}|/P_{\Omega,i}$ as a function of the planet mass. The solid lines depict a merger that took place after 100 Myrs, while the dashed lines represent a merger after 600 Myrs of stellar evolution. The planet was assumed to plunge in from a 5 au distance (as noted above the actual initial distance does not change significantly the results). We consider three representative stellar masses 0.8, 1 and 1.2 $M_\odot$, green, blue and red respectively. In the inset, the ratio of the post-spin for angular momentum over conservation of energy is plotted versus the mass of the planet in terms of M_J.

In this case the total angular momentum of the system is the star's spin rate Ω_{s+p}, where the $s+p$ denotes the final star and planet object. We solve Equation (6) for Ω_{s+p}. Note that the angular momentum of the pertuber should not have changed during the high eccentricity migration. Moreover, even if a scattering took place and a far away planet was lost from the system, the angular momentum associated with it is orders of magnitude smaller than the ones in Equation (3), and thus do not affect the above analysis. For $m << M$ we find that $I_s\Omega_s$ is larger or comparable to $L_{\rm orb}$, and thus, $\Omega_{s+p,L} \sim$ Const.

As can be seen from the above equations, the key parameter in determining the final spin rate for a given star is the planet's size. This is depicted in Figure 1 where we explore a large range of companion planets' mass from 10^{-3} M_J up to 10 M_J where M_J is the mass of Jupiter. We adopt the following mass radius relation for the planet

$$\frac{m}{M_\oplus} = \left(\frac{r}{R_\oplus}\right)^{2.06} , \quad (8)$$

(e.g., Lissauer *et al.* 2011), where subscript $\oplus$ denotes Earth's value. We also test a simple relation for which $m \sim 3r$ (e.g., Weiss and Marcy 2014), and find consistent results.

In Figure 1, as a proof-of-concept, we initially consider three representative stellar masses, 0.8, 1 and 1.2 $M_\odot$ (red, blue and green lines, respectively in Figure 1). We evolve their spin-period and let each star consume a planet. We consider two merger times, one is after 100 Myr, and the other is after 600 Myr. In Figure 1 we show the fractional change of the spin-period, specifically, $(P_{\Omega,i} - P_{\Omega,f})/P_{\Omega,i}$. Note that $P_{\Omega,i} > P_{\Omega,f}$ and we show the absolute magnitude in the Figure for illustrative purposes. As depicted in Figure 1, a more massive planet is more likely to spin up the star. For example, a Jupiter-mass planet can cause a spin up of about 70% compared to the spin pre-merger for a 1$M_\odot$ star. For a 1.2 $M_\odot$, the change in spin is 20% which is much less than the smaller mass star. On the other hand, an Earth-mass planet yields an insignificant change to the spin-period for any star from 0.8$M_\odot$ to 1.2 $M_\odot$ after 100 Myr and 600 Myr. Below we will examine a mass range between $0.6 - 1.8$ $M_\odot$.

2.3 Energy arguments

In some cases, planets that plunge into their star, may be completely consumed by their star without any heat or radiation loss for the system (unlike systems for which a dusty disk is formed e.g., Metzger *et al.* (2017) or increase their luminosity due to the engulfment of a planet e.g., Metzger *et al.* (2012);MacLeod *et al.* (2018)). In this case, we can assume total energy conservation, and thus before the merger, it can be written as:

$$E_i = -\frac{GMm}{2a} - \frac{GM^2}{R} - \frac{Gm^2}{r} + \frac{1}{2}I_s\Omega_{s,i}^2 + \frac{1}{2}I_p\Omega_{p,i}^2 \ . \quad (9)$$

Energy conservation yields that the energy after the planet has been consumed by the star can be written as:

$$E_i = E_f \quad (10)$$

where E_f is the energy post merger, with the subscript "f"

Name	Age† [Myr]	Metallicity [Fe/H]	Period References	Metallicity References
M35	100	-0.21	Meibom *et al.* (2009)	Barrado y Navascués *et al.* (2001)
Pleiades	130	0.03	Mamajek and Hillenbrand (2008)	Soderblom *et al.* (2009)
M34	240	0.07	James *et al.* (2010)	Schuler *et al.* (2003)
M48	380	0.08	Barnes *et al.* (2015)	Netopil *et al.* (2016)
Hyades	625	0.4	Mamajek and Hillenbrand (2008)	Quillen (2002)

Table 1. Relevant observation parameters for the open clusters used below.† Note that other age estimations exists in the literature, which we refer to below. The other age estimation do not change our results, and we discuss them in the text. The age estimate of M35 in the literature ranges from 70-200Myr. Reimers and Koester (1988) used white dwarf cooling age and estimated a range between 70-100 Myr, later Barrado y Navascués *et al.* (2001) with the same technique, found an age estimated 180 Myr Kalirai *et al.* (2003). Other estimations place M35 at about 150 Myr (e.g., Sarrazine *et al.* 2000; von Hippel *et al.* 2002; Meibom *et al.* 2009; Leiner *et al.* 2015). We note that while the age of M35 might be older than the one we adopt here, the scatter in the bifurcation is consistent with the scatter in the Pleiades. Pleiades age varies from 100 Myr to 180 Myr (e.g., Mamajek and Hillenbrand 2008; Herbst *et al.* 2001; Belikov *et al.* 1998). M34 age is consistent with 240 Myr (e.g., Meibom *et al.* 2011; James *et al.* 2010). M48 age varies from 380 Myr to 450 Myr (e.g., Netopil *et al.* 2016; Barnes *et al.* 2015). Finally, we found that Hyades age estimation can be as high as 750 Myr (e.g., Mamajek and Hillenbrand 2008; Brandt and Huang 2015).

denoting the final (post-consumption) state. The final energy state can be written as:

$$E_f = -\frac{G(M+m)^2}{R} + \frac{1}{2} I_{s+p} \Omega_{s+p}^2 \ , \tag{11}$$

In this case the total energy of the orbit consists of the potential energy and the star's new rotational kinetic energy, which is denoted as Ω_{s+p} to indicate that it is after the star consumed the planet. We then solve for the post merger spin-period $P_{\Omega,f} = 2\pi/\Omega_{s+p}$.

As implied from Equation (9), the planet's orbital energy is much smaller than the star's internal energy, and thus it can be neglected. We adopt a high eccentricity migration, which often results in near radial planetary orbits, and set the planet's initial semi-major axis to be 5 au. However, from the mentioned orbital energy arguments, the calculation below is valid for a wide range initial separations. We have also confirmed that our calculations are consistent with the results, when setting the planet to be as close as 0.02 au. In fact, as apparent from Equations (9) and (11) for a given stellar mass, the main parameter that affects the final stellar rotation in this scenario is the planet's mass.

Adopting a simple mass-radius relation as before ($m \sim r^\beta$), we find that the final spin period for very small mass planets ($m << M$) depends on the mass of the planet i.e.,

$$\Omega_{s+p,E} \sim m^{1-\frac{\beta}{2}} \ , \tag{12}$$

where the subscript "E" stands for energy argument. In the inset of Figure 1 we show the relation between the resulted spin due to the energy or angular momentum conservation. As depicted in the Figure 1, Ω_L/Ω_E is almost 1 for $M_J/1000$ ($M_\oplus$) and reaches a minimum near the mass of Jupiter.

3 CONSUMPTION OF A PLANET BY ITS STAR

We compare our model to the period distribution of stars for five open clusters that span a range of ages. Specifically, we chose (from $\approx$ 100 Myr to 625 Myr): M35, Pleiades, M34, M48, and Hyades, see Table 1 for the relevant parameters. We focus on a stellar mass range of $0.6 - 1.8$ $M_\odot$. As apparent from Figure 2 all the young clusters appear to have a bifurcation in their period distribution. However, the old clusters do not have a fast rotating population.

As illustrated in Figure 1 the largest spin-up effect will happen if a star will merge with a massive planet. We adopt a Jupiter-mass planet and explore the consequences of planet consumption on the spin-period as a function of the B-V. For each cluster, we evolve the spin-period up to the cluster age, as explained above. As can be seen in Figure 2, the stellar evolution model (SE) agrees with the slow rotators (long period) population[2]. We also adopt an ad-hoc consumption time consistent with the youngest cluster (M34, which is $\approx$ 100 Myr). We calculate the spin-period of the star after a merger with a Jupiter sized planet has taken place, using angular momentum conservation, for all clusters (dashed lines, labeled "Merger" for a spin up). As shown in this Figure, the resulted post-consumption spin-period is consistent with the observed fast rotators (short spin-period) stars in the young clusters (top three panels). Based on these five cluster examples it seems that the bifurcation is eliminated by $\approx$ 300 Myr (roughly the age of M48).

We also show that the spin period from energy conservation arguments (see Section 2.3), labeled "EC", agrees with the short period stellar population in young clusters. In fact the shortest spin periods seem to be in a better agreement with the energy conservation arguments than with the angular momentum arguments period predictions. This suggests that near radial orbits during high eccentricity migration (e.g., Naoz 2016) is common.

It is worth noting that for a given mass, the initial spin of the star plays an insignificant role in determining the post consumption, for both the energy and angular momentum approach (as can be seen from the equations). Thus, taking h Persei young open cluster as a birth population, or even setting the consumption time to be 13 Myr, does not change our results. However, if consumption would have taken place after 13 Myr, then our scenario predicts a clear bifurcation signature which does not exists in h Persei (see, for example, figure 10 in Moraux *et al.* 2013). Thus motivated with

[2] Some of these clusters have large range of age estimations in the literature, see table 1. In Figure 2 we show that the SE model for the maximum age estimates for these clusters.

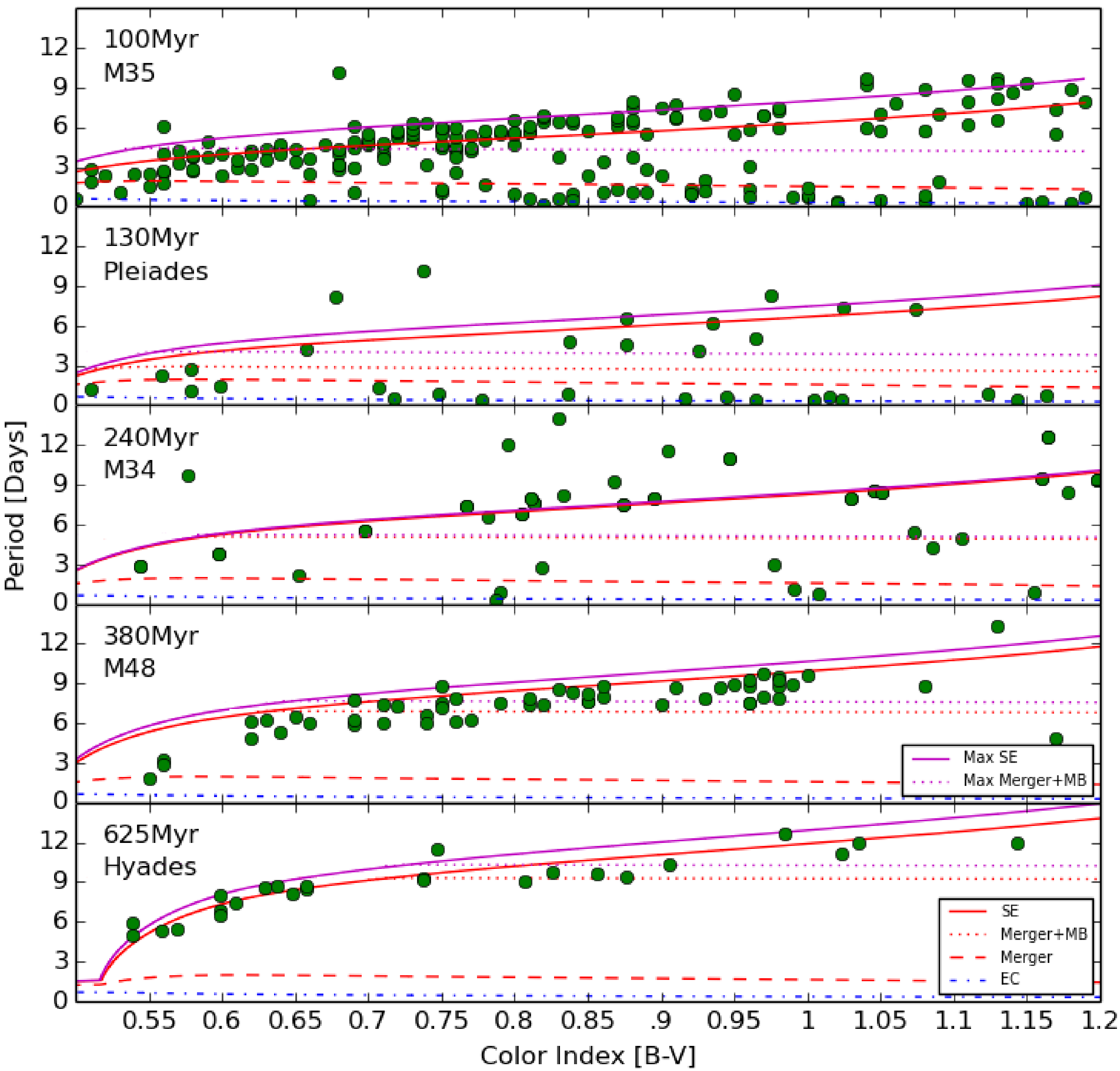

Figure 2. The spin-period as a function of B-V. The solid, red, lines depict the expected period of stars for their clusters' respective ages (labeled "SE" following stellar evolution). The dashed lines represent the spin-period post-merger at the time of the Jupiter mass planet merger, using angular momentum arguments, labeled "Merger" (adopted to be consistent with the youngest cluster age of 100 Myr). We also consider the post-merger spin period using energy conservation arguments, labeled "EC", blue, short dashed-dotted line. The dotted red line depicts the expected spin-period that have undergone a merger at 100 Myrs and subsequently went through magnetic braking process to reach their cluster present age (labeled "Merger + MB"). We also consider the expected spin period due to stellar evolution for the maximum published age of each cluster (see Table 1), purple, solid lines, labeled "Max SE". The post merger spin period (using angular momentum arguments), followed by magnetic period all the way to the maximum age estimation is shown in dotted, purple lines, labeled "Max Merger + MB". The green dots are observed rotations periods of confirmed members of the above clusters adopted from Meibom *et al.* (2009); Mamajek and Hillenbrand (2008); James *et al.* (2010) and Barnes *et al.* (2015), see Table 1.

observation, and consistent with theoretical arguments (e.g., Naoz *et al.* 2012; Stephan *et al.* 2017), we are set the connip-tion time at 100 Myr, which is roughly the age of M34, where the earliest bifurcation of rotation periods is observed.

Many of the clusters are older than the consumption time, and one can expect that post-merger stars will continue spin down due to magnetic braking. This process may be different than the nominal magnetic braking as the new mass might not be evenly distributed or the metallicity and magnetic field may change. Nonetheless, for simplicity we only follow the regular magnetic braking evolution (as described above, labeled "Merger + MB"), and caution that

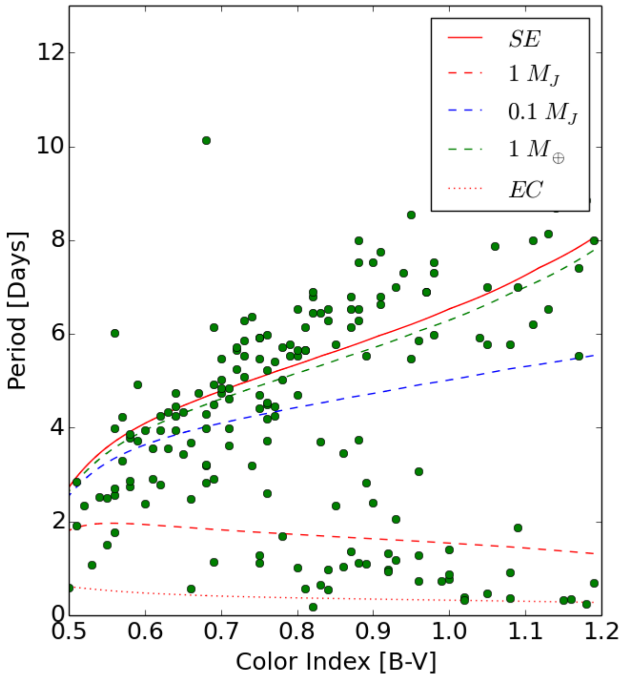

Figure 3. The spin-period as a function of the B-V values for M 35 open cluster. The solid line depicts the expected spin-period as a result of magnetic braking spin evolution after 100 Myr, while the dashed lines represent the spin-period post-merger of a planet with mass of M_J, $M_J/10$ and $M_\oplus$ (from bottom to top)f. The dotted line represents a merger of 1 M_J mass planet based on energy conservation (EC).

this treatment is incomplete, as it does not include the stellar evolution complexities that SSE considers. This estimation should only be used as an order of magnitude approximation. The result is shown as a dashed-dot line in Figure 2. And can be seen to perhaps match the scatter in those plots.

We note that the stellar evolution is calculated in term of the effective temperature. We then convert the theoretical effective temperature to B-V colors following Sekiguchi and Fukugita (2000) fit equation. This fit depends on the metallicity of the cluster.

As shown in Figure 2 a Jupiter-mass planet accreting onto a star at early times ($\approx$ 100 Myr) is consistent with spin up of these stars. As the cluster grows old the star spin down and approaches the nominal stellar evolution time.

As mentioned, some of these open clusters have a range of published ages (see Table 1). In Figure 2 we also consider the maximum age estimation, and show that our models are consistent with the observed scatter in spin period. In particular, we show the spin period as a result of the stellar evolution model for its maximum age estimate (labeled "Max SE"), purple lines). We also calculate the spin down of a star post planet conception, using angular momentum conservation, (purple dotted line, labeled "Max Merger + MB"), which also agrees with the observed cluster. Thus, we conclude that range of age estimation does not alter our results.

We also speculate that accretion of various planetary masses may account for the scatter in the spin-period observed for young clusters. This is illustrated in Figure 3, where we calculated the post merger spin-period of a star after the consumption of $M_J/10$ and an Earth mass ($M_\oplus$) planet. As depicted in Figure 3, the scatter in the young cluster is consistent with accretion of various planetary masses.

4 DISCUSSION

We presented a proof-of-concept calculation that shows that the observed spin-periods bifurcation in young clusters is consistent with stars that consumed a planet. We considered angular momentum conservation arguments and showed that conception of a planet can significantly spin up the star (lowering the spin-period). Energy conservation arguments (where a planet is being plunged almost radially into the star) give consistent results. Both angular momentum and energy arguments yield a faster rotation after a consumption of a massive planet, like a Jupiter-mass one.

One of the predictions from high eccentricity migration is that planets will end up consumed by their parent star in the range of $10-100$ Myrs (e.g., Rasio and Ford 1996; Chatterjee *et al.* 2008; Guillochon *et al.* 2011; Naoz *et al.* 2012; Li *et al.* 2014; Rice 2015; Valsecchi and Rasio 2014; Petrovich 2015a,b; Stephan *et al.* 2017). Observationally, many giant planets seems to exist on decaying orbits, or on orbits that are interior to their Roche-limit (Jackson *et al.* 2017, Figure 1), consistent with high eccentricity migration. Thus, planets plunging into a star may be a generic feature of planetary evolution. While the details of a planet accreting onto a star may be complicated (i.e., either disrupting and forming a disk or simply colliding Dosopoulou *et al.* 2017), our calculations focus only on the consequences of planet consumption and hence we used energy and angular momentum conservation arguments, and we are independent of the details of the merger process.

We calculated the effects of a planetary merger on the host stellar spin, using magnetic braking, and angular and energy conservation arguments. We adopted an adhoc consumption time consistent with the youngest cluster ($\approx$ 100 Myr) The planet's orbital angular momentum is absorbed by the star, causing the star to spin up. Similarly, energy conservation arguments yield that the planet's binding energy is being absorbed by the star, causing the star's spins up. We note that during the planet consumption process energy might not be conserved (e.g., Metzger *et al.* 2017), but angular momentum should be conserved[3]. Note that some planets may plunge directly into their host star, consistent with minimum energy loss. The consumption of a more massive planet (i.e., Jupiter mass) will cause a more significant spin up (as depicted in Figure 1).

We compared our calculations with the observed spin period of stars in five open clusters. We find that the observed stellar rotation period bifurcation in young clusters is consistent with the spin up due to a merger of a Jupiter-mass planet (see, Figure 2). The agreement of our calculations with observations suggests that dynamical planetary accretion onto their host stars is a common characteristic in high eccentricity planetary-systems evolution (as predicted

[3] Note that the angular momentum that is carried out by the planet mass loss during the merger is significantly smaller than the orbital angular momentum.

by theoretical models, e.g., Naoz *et al.* 2011; Guillochon *et al.* 2011; Naoz *et al.* 2012; Li *et al.* 2014; Valsecchi and Rasio 2014; Rice 2015; Storch and Lai 2015; Muñoz and Lai 2015; Petrovich 2015a,b; Stephan *et al.* 2017).

The observations presented in Figure 2 show a reduction in the bifurcation strength with time. In other words, as the cluster ages, there are fewer fast rotators. Motivated by the observations, we adopted a merger time of 100 Myr which is the youngest cluster considered. Interestingly, this merger time also approximately consistent with the expected merger time from high eccentricity migration simulations (e.g., Stephan *et al.* 2017).

Note, that is was also suggested that disk migration will, in some cases, result in plunging Earth and super Earth type planets onto their host stars (e.g., Batygin and Laughlin 2015)[4]. The consumption of these planets yield a smaller change in the spin-period of stars (as shown in Figures 1 and 3). On the other-hand, consumption of smaller planets, or different consumption times, may account to some of the observed scatter in the fast rotators' typical spin-period value (as depicted in Figure 2).

We can also estimate the efficiency with which our mechanism is producing fast rotators. We note that the number below is highly uncertain and should only be considered at the order of magnitude level. The fraction of stars that will consume a planet is defined as:

$$f = f_b f_p f_{\rm merge} \ , \tag{13}$$

where f_b is the fraction of stars in binary systems, f_p is the fraction of stars with planets that may undergo high eccentricity migration and finally, $f_{\rm merge}$ is the fraction of planets that merged for a specific high eccentricity migration. We estimate $f_b \sim 0.5$ (e.g., Raghavan *et al.* 2010), though this is an underestimation since planets can also cause planets to merge with their host stars (e.g., Naoz *et al.* 2011; Petrovich 2015b). The occurrences of planets is estimated roughly as $f_p \sim 0.07 - 0.1$ Jupiter-mass planets formed at a few au from their star (e.g. Wright *et al.* 2012; Bowler 2016) up to $f_p \sim 1$ for Neptune-mass planets (the solar system, for example, has two, Uranus and Neptune). Finally, the merger fraction is estimated as between $f_{\rm merger} \sim 0.15 - 0.25$ depending on the parameters of the system, and roughly independent on the mass of the planet (e.g., Naoz *et al.* 2012; Petrovich 2015a; Stephan *et al.* 2017). This gives $f \sim 0.013 - 0.13$ The fraction of fast rotators in the cluster population is estimated from the presented data about 30%. This implied that about $4 - 42\%$ of all fast rotators are plausible to result from the process of feeding on their planets. The fraction may increase significantly if we consider the full range of planetary masses and the full high eccentricity migration scenarios (for example, allowing for a range of companions, such as planets).

If indeed the primary driver for plunging Jupiter size planets into a star is high eccentricity migration, then the calculation presented here suggests that the fast rotators are more likely to have a far away companion (either a star, a planet or a brown dwarf, e.g., Rasio and Ford 1996; Naoz *et al.* 2011, 2012; Stephan *et al.* 2017). This prediction may help disentangle between the scenario suggested here and magnetic origin for the fast rotators.

[4] High eccentricity migration can also redult in plunging Earth-size planets onto their host star (Rice 2015).

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