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ROTATIONAL SYNCHRONIZATION MAY ENHANCE HABITABILITY FOR CIRCUMBINARY PLANETS: KEPLER BINARY CASE STUDIES

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ABSTRACT

We report a mechanism capable of reducing (or increasing) stellar activity in binary stars, thereby potentially enhancing (or destroying) circumbinary habitability. In single stars, stellar aggression toward planetary atmospheres causes mass-loss, which is especially detrimental for late-type stars, because habitable zones are very close and activity is long lasting. In binaries, tidal rotational breaking reduces magnetic activity, thus reducing harmful levels of X-ray and ultraviolet (XUV) radiation and stellar mass-loss that are able to erode planetary atmospheres. We study this mechanism for all confirmed circumbinary (p-type) planets. We find that main sequence twins provide minimal flux variation and in some cases improved environments if the stars rotationally synchronize within the first Gyr. Solar-like twins, like Kepler 34 and Kepler 35, provide low habitable zone XUV fluxes and stellar wind pressures. These wide, moist, habitable zones may potentially support multiple habitable planets. Solar-type stars with lower mass companions, like Kepler 47, allow for protected planets over a wide range of secondary masses and binary periods. Kepler 38 and related binaries are marginal cases. Kepler 64 and analogs have dramatically reduced stellar aggression due to synchronization of the primary, but are limited by the short lifetime. Kepler 16 appears to be inhospitable to planets due to extreme XUV flux. These results have important implications for estimates of the number of stellar systems containing habitable planets in the Galaxy and allow for the selection of binaries suitable for follow-up searches for habitable planets.

Key words: binaries: general – planet–star interactions – stars: activity – stars: rotation – ultraviolet: stars

Online-only material: color figures

1. INTRODUCTION

Seven confirmed planets have been found orbiting six binary stars (Doyle et al. 2011; Orosz et al. 2012a, 2012b; Welsh et al. 2012; Schwamb et al. 2013), igniting interest in the possibility of terrestrial planets in circumbinary radiative habitable zones (RHZs; Mason & Clark 2012; Kane & Hinkel 2013; Clark & Mason 2013). Planetary atmosphere erosion by stellar winds and intense X-ray and ultraviolet (XUV) fluxes must also be considered when assessing circumbinary habitability. These erosive processes could obliterate planetary atmospheres or produce desiccation, akin to Venus (Zuluaga et al. 2013). In this Letter, we present a mechanism by which stellar activity in binaries can be reduced (increased) due to tidal breaking of stellar components, potentially enhancing (restricting) the protection of planetary atmospheres against these stellar aggression factors.

Relations between age, rotation rate, and magnetic activity of single stars have been established both theoretically and observationally (Basri 1987; Wood et al. 2005). Rapidly rotating stars are luminous XUV sources and undergo significant mass-loss (Wood et al. 2005), posing high risks to weakly magnetized planets. These relationships have been used to evaluate the evolution of stellar aggression and its role in terrestrial planet habitability (Grießmeier et al. 2007; Zuluaga et al. 2013). When these relationships are applied to binaries, we find that early tidal spin-down of one or both stars produces an effective stellar rotational aging. Thus reducing stellar aggression, abating mass-loss from planetary atmospheres, and potentially promoting habitability. In other cases the stellar aging effect increases activity and reduces the chances for habitability.

To explore this effect, we extend single star RHZ limits (Kasting et al. 1993; Kopparapu et al. 2013) to planets in circumbinary orbits (Section 2) and investigate the magnitude of stellar aggression toward these planets (Section 3). An ensemble of main sequence binaries with components from 0.2 $M_\odot$ to 1.5 $M_\odot$, and a range of binary periods and eccentricities are modeled (Section 4). Synchronization times are computed for stars in both twin and disparate binaries, including six Kepler binaries with known circumbinary planets (Section 4).

2. CIRCUMBINARY HABITABILITY

Circumbinary habitability is a five-dimensional parameter problem, even for circular planetary orbits. These are the mass of the primary and secondary, M_1 and M_2, binary eccentricity and period, e and P_{bin}, and planetary semi-major axis a. Five dimensions are reduced to four by considering only orbits in the middle of the circumbinary habitable zone.

Two cross-sections of the remaining four variable problem are examined: (1) twins, i.e., $M_1 = M_2$ and (2) binaries with a solar-mass primary and a lower mass companion. Examination of these cross-sections and specific case studies provided by the six Kepler binaries elucidate circumstances for which enhanced, or reduced, habitability induced by the tidal breaking mechanism operates.

2.1. Orbital Stability

Orbital stability is a prerequisite for habitability. To be stable, the semi-major axis of a circumbinary planet must be larger than a critical value a_c. For a large range of binary semi-major axes a_{bin} and eccentricities e, a_c is calculated from numerical fits, such as that provided by Equation (3) of Holman & Wiegert (1999).

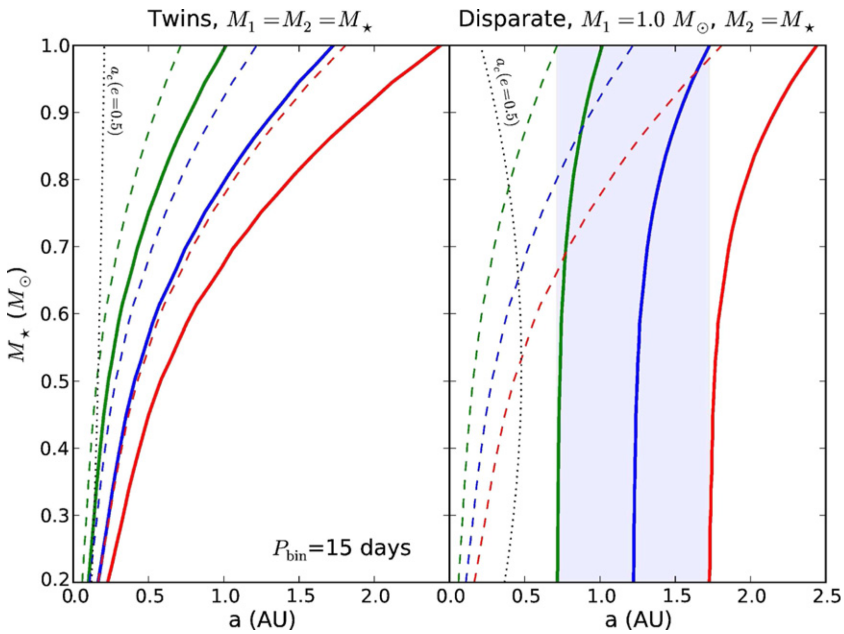

Figure 1. Habitable zones for single stars (dashed lines) and for binaries (solid lines) are shown for twins (left) and solar primaries (right). The vertical axis shows the mass in the twin cases and the secondary mass for the solar primary cases. The binary period is 15 days. The inner RHZ edge is the recent Venus limit (green) and the outer edge is the early Mars limit (red). The average of these extremes is shown in blue. The solar system is shown as the shaded region, on the right, corresponding to the limit of the binary RHZ as the secondary mass approaches 0.0 $M_\odot$. Critical distances for orbital stability assuming an $e = 0.5$ binary orbit are also shown for reference.

(A color version of this figure is available in the online journal.)

Orbital stability within the RHZ is of greatest concern for similar mass binaries with large separations. For twin binaries in circular orbits, i.e., $\mu = 1/2$ and $e = 0$, the stability criterion simplifies to $a_c \sim 2.4\, a_{\rm bin}$. In this case, if $a_{\rm bin} > l_{\rm out}/2.4$, where $l_{\rm out}$ is the outer edge of the RHZ, planets throughout the habitable zone have unstable orbits, rendering the binary uninhabitable.

2.2. Circumbinary Radiative Habitable Zone

RHZ limits are found by calculating fluxes which allow the existence of liquid water. We follow the results of Kopparapu et al. (2013) that, for single stars, provide limiting fluxes $S_{\rm eff}$ (in units of present Earth solar flux) as a function of stellar effective temperature $T_* = T_{\rm eff} - 5780$ K:

$$S_{\rm eff} = S_{\rm eff\odot} + aT_* + bT_*^2 + cT_*^3 + dT_*^4. \quad (1)$$

Here $S_{\rm eff\odot}$, a, b, c and d are constants which depend on the physical criterion defining a given limit and are tabulated in Table 3 of Kopparapu et al. (2013). The most generous limits are obtained by assuming that Venus had surface liquid water until a few Gyr ago (the recent Venus criterion) and that Mars was also habitable at the beginning of solar system evolution (the early Mars criterion).

Limits of the RHZ, either around single stars or binaries, are defined as the distance d where the averaged flux $\langle S(d)\rangle$ is equal to the critical flux:

$$\langle S(d)\rangle = S_{\rm eff}. \quad (2)$$

For single stars, circular orbits, and fast rotating planets, $\langle S(d)\rangle = L_*/d^2$, where L_* is the stellar luminosity in solar units and d is in AU.

In order to apply Equation (1) to binaries, we first verify that an effective temperature can be associated with the combined stellar flux. For twins, the result is trivial, but for disparate binaries, a more complex situation arises. We have verified numerically that the peak flux in disparate systems remains close to that of the primary. So conservatively, we assume that the effective temperature is that of the most luminous star, since it has the dominant effect on the RHZ.

The flux at a distance d from the center of mass (CM), varies with the binary phase angle θ as:

$$S_{\rm bin}(d,\theta) = \frac{L_1}{R_1^2(d,\theta)} + \frac{L_2}{R_2^2(d,\theta)} \quad (3)$$

where R_1 and R_2 are planetary distances to the primary and secondary components. Assuming that the planetary orbit is in the same plane as the binary,

$$R_1^2(d,\theta) = (d + r_1\sin\theta)^2 + r_1^2\cos^2\theta$$
$$R_2^2(d,\theta) = (d - r_2\sin\theta)^2 + r_2^2\cos^2\theta.$$

Here $r_2 = a_{\rm bin}/(1+q)$ and $r_1 = qr_2$ are the average star–CM distances and $q = M_2/M_1$ is the binary mass ratio. To calculate RHZ limits, we compare the combined flux (Equation (3)) averaged over the binary orbit, with the effective flux for a given RHZ edge:

$$\frac{1}{2\pi}\int_0^{2\pi}\left(\frac{L_1}{R_1^2(d,\theta)} + \frac{L_2}{R_2^2(d,\theta)}\right)d\theta = S_{\rm eff}. \quad (4)$$

The result of solving Equation (4) in the case of twins and disparate binaries is presented in Figure 1.

Orbital stability and proper insolation do not guarantee the most important condition for habitability: the presence of a dense and wet atmosphere. Although important intrinsic factors are involved in the formation and preservation of planetary atmospheres, planet–star interactions play key roles in the fate of gaseous planetary envelopes, especially during the early, active, phases of stellar evolution. In the next section, we model several aspects of planet–star interactions and apply them to the survival of circumbinary planet atmospheres.

3. PLANET–STAR INTERACTIONS

Winds from low-mass stars ($M_\star \lesssim 1\,M_\odot$) play a central role in planetary atmosphere retention. Planets could lose their atmospheres or be desiccated on a time-scale much less than that required for the evolution of complex life (Zendejas et al. 2010; Lammer et al. 2011). Even if planets have magnetic fields comparable to Earth, but are located in the RHZ of K–M stars, they could be subject to intense XUV irradiation (Segura et al. 2010). The resulting water loss is important, especially in the case of developing nitrogen-rich atmospheres during early phases of planetary evolution (Lammer et al. 2009). This is not a second-order effect, but can become the dominant factor determining habitability of terrestrial planets.

3.1. Stellar Activity and Rotational Aging

A rigorous treatment of binary stellar winds is challenging (Siscoe & Heinemann 1974). The problem has been extensively studied in the case of early type binaries (Stevens et al. 1992), but less attention has been paid to the case of low-mass stars in binaries. Here, we assume a simplified non-interacting model for the combined stellar wind.

Since for binary periods of $P_{\rm bin} \sim$ 10–20 days, orbital velocities ($v \sim$ 80–100 km s^{-1}) are much lower than wind velocities as measured near the stellar surface ($v_{\rm sw} > 3000$ km s^{-1}), we neglect orbital motion effects in calculating stellar wind properties.

For twins, we assume a wind source with a coronal temperature and wind velocity profile equal to that of a single star. Mass-loss rates are assumed to be double of that calculated for single stars of the same type. For disparate binaries, we simply sum the stellar wind pressure from each component.

Stellar wind properties are calculated using Parker's model (Parker 1958). It has been shown (Zuluaga et al. 2013) that planetary magnetospheric properties computed with this model are only ~10% different than those obtained with more realistic models.

The stellar wind's average particle velocity, $v_{\rm sw}(d)$, at a distance d from the host star is obtained by solving Parker's equation (Equation (35) in Zuluaga et al. 2013). The density profile, $n_{\rm sw}(d)$ is obtained by equating particle velocity and mass-loss rate $\dot{M}_\star$:

$$n_{\rm sw} = \frac{\dot{M}_\star}{4\pi d^2 v_{\rm sw} m}. \tag{5}$$

A procedure to estimate Parker model parameters as a function of stellar age for single stars was devised by Grießmeier et al. (2007). It relies on empirical relationships between age, X-ray flux, and rotation of single stars (Wood et al. 2005). According to these relations, the product of mass-loss rate and wind velocity $\dot{M} v_{\rm sw}$ scale with stellar rotation period $P_{\rm rot}$ following:

$$\dot{M} v_{\rm sw} \propto P_{\rm rot}^{-3.3}. \tag{6}$$

We adapt these results to binaries by introducing the so-called rotational age, $\tau_{\rm rot}$ defined as the equivalent stellar age at which rotational period of a single star $P_{\rm rot,single}$ will be equal to rotational period of a star in the binary $P_{\rm rot,bin}$:

$$P_{\rm rot,single}(\tau_{\rm rot}) = P_{\rm rot,bin}. \tag{7}$$

For non-negligible binary eccentricity, stars eventually reach a pseudo-synchronous state with $P_{\rm rot,bin} = P_{\rm bin}/n_{\rm sync}$ (see Section 3.2) where $n_{\rm sync}$ is a real number depending on eccentricity (Hut 1981).

Applying these isolated star relationships to binaries is reasonable since physical mechanisms connecting rotation, age, and activity would not be different for stars in binaries with separations of tens to hundreds of stellar radii, i.e., for $P_{\rm bin} > 5$ days.

Rotational ages for stars in binaries are depicted in Figure 2. We see that F, G, and late K stars ($M_\star > 0.8$) in binaries with orbital periods $P_{\rm bin,rot} < 20$ days, could experience premature aging if they are quickly tidally locked. They would appear as old as single stars with $\tau > 3$ Gyr, in terms of magnetic and stellar activity. Premature aging might be an advantage for circumbinary terrestrial planet atmospheres. On the other hand, lower mass stars in binaries with similar periods exhibit a forever-young effect, i.e., components freeze at rotational ages less than approximately 2 Gyr, thereby reducing habitability.

Stellar XUV luminosity depends on chromospheric and coronal activity, which in turn depends on rotation. Since rotation of single main sequence stars slows down with age, XUV luminosity should also decrease with time (Garces et al. 2011). The rotational aging mechanism will reduce XUV luminosities and their potential harmful effects on planetary atmospheres.

Despite large uncertainties in measured XUV stellar emission (Pizzolato et al. 2003), several authors have developed simple empirical laws expressing XUV luminosities, or its proxy, X-ray luminosity, as a function of age. To be conservative, we use the law by Garces et al. 2011 providing X-ray luminosity of GKM-types as a power-law of stellar age:

$$L_X = \begin{cases} 6.3\times10^{-4} L_\star & \text{if } \tau < \tau_{\rm i} \\ 1.89\times10^{28}\ \tau^{-1.55} & \text{otherwise} \end{cases} \tag{8}$$

where $L_\star$ is the bolometric luminosity and τ_i is the so-called saturation time scaling with $L_\star$ according to:

$$\tau_i = 0.06\,{\rm Gyr}\left(\frac{L_\star}{L_\odot}\right)^{-0.65}. \tag{9}$$

For high X-ray luminosities, we approximate $L_{\rm XUV} \approx L_{\rm X}$ (Guinan & Eagle 2009). Using this model, we verify that XUV Present Earth Level (PEL) is 0.88 erg cm^{-2} s^{-1}, in agreement with the observed value (Judge et al. 2003). We also predict that at $\tau_\odot \approx 1$ Gyr the Earth XUV flux was $F_{\rm XUV} = 8$ PEL in agreement with previous estimates (see, e.g., Kulikov et al. 2006).

3.2. Binary Tidal Interaction

Benefits are maximized if tidal locking occurs, at least for the primary component, before the rise of the secondary planetary atmosphere. For solar system terrestrial planets, this time is estimated as $\tau_{\rm atm} \sim$ 0.3–0.8 Gyr (Hart 1978; Hunten 1993). Therefore, in order to evaluate if circumbinary planets benefit from rotational aging we estimate synchronization times.

For a target star with initial rotational and orbital angular velocities $\Omega = 2\pi/P_{\rm rot}$ and $\omega = 2\pi/P_{\rm bin}$, subject to secondary star tides placed in an orbit with eccentricity e, synchronization time $t_{\rm sync}$ is calculated following Zahn (2008), see Figure 3,

$$\frac{1}{t_{\rm sync}} = \frac{1}{t_{\rm diss}}\frac{f_2(e^2)}{(1-e^2)^6}\left[1 - \frac{(1-e^2)^{3/2} f_5(e^2)}{f_2(e^2)}\frac{\omega}{\Omega}\right] \times \left(\frac{M_{\rm field}}{M_{\rm targ}}\right)^2 \frac{M_{\rm targ}R_{\rm targ}^2}{I}\left(\frac{R}{a}\right)^6 \tag{10}$$

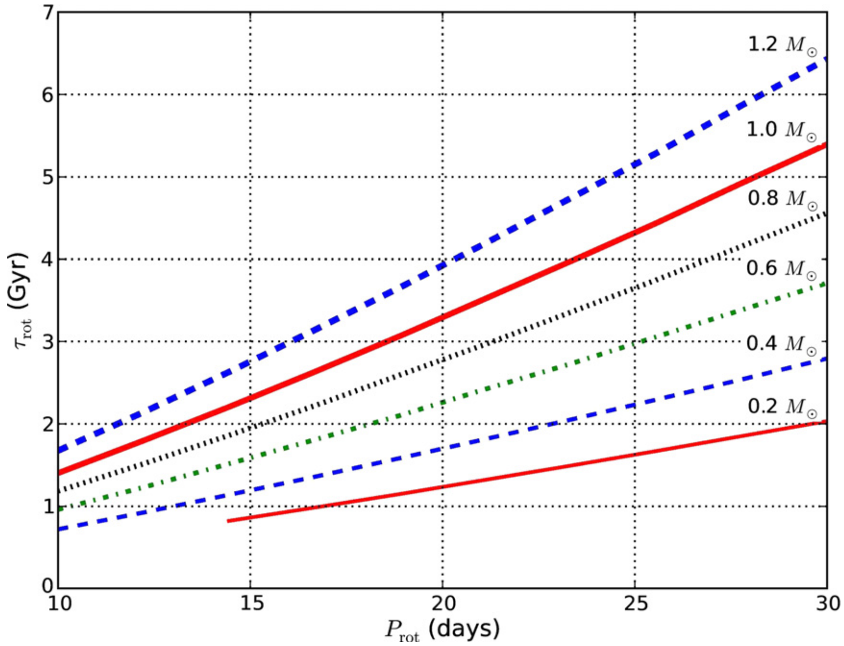

Figure 2. Rotational ages for single stars as a function of rotational period. We assume that a similar relationship applies to stars in binaries where the rotational period is replaced by a multiple of the binary period.

(A color version of this figure is available in the online journal.)

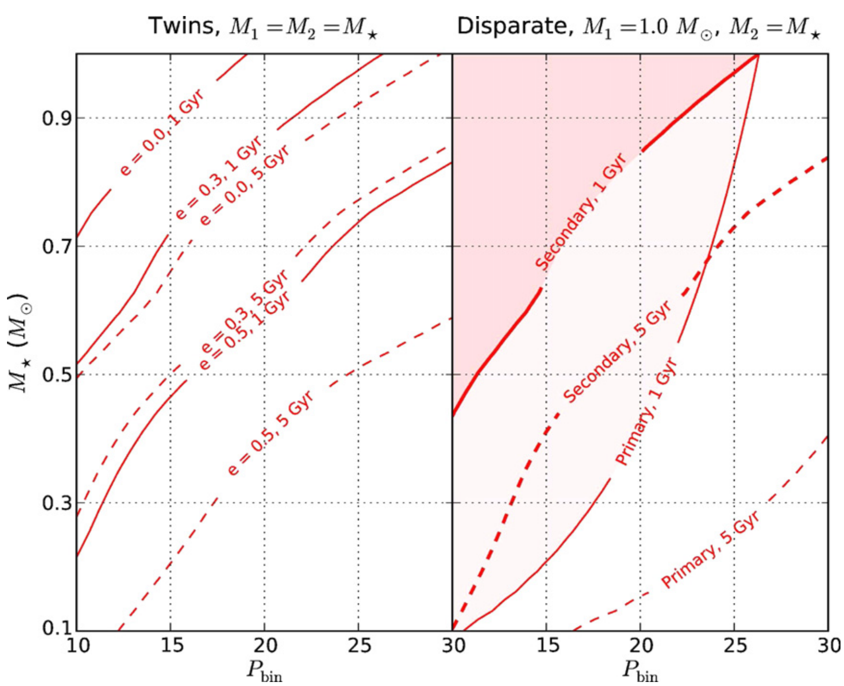

Figure 3. Rotational synchronization times. The mass of twin stars (left) and the mass of the secondary, with a solar type primary, (right) is on the vertical axis. Left: 1 Gyr (solid lines) and 5 Gyr (dashed lines) synchronization times for eccentricities 0.1, 0.3, and 0.5 are shown. Stars in binaries with high eccentricities become rotationally synchronized quicker than those with low eccentricities. Right: shaded regions show where one or both stars become tidally locked during the first Gyr.

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where:

$$f_2(e^2) = 1 + \frac{15}{2}e^2 + \frac{45}{8}e^4 + \frac{5}{16}e^6$$

$$f_5(e^2) = 1 + 3e^2 + \frac{3}{8}e^4.$$

Here I is the moment of inertia of the target star, and $M_{\rm targ}$ and $R_{\rm targ}$ are its mass and radius. $M_{\rm field}$ is the mass of the star producing the tidal field. Moments of inertia MoI $\equiv I/MR^2$ have been calculated from stellar evolution models (Claret & Gimenez 1990). Zero-age main sequence values of MoI $= 0.08$ for solar-mass stars, MoI $= 0.1$ for a 0.8 $M_\odot$ star and MoI $= 0.14$ for 0.6 $M_\odot$ stars have been used to interpolate the value of this parameter for other masses. For less massive stars, we use values close to 0.23, which is the limit for less centrally concentrated substellar objects (Leconte et al. 2011).

Since we are interested in low-mass binaries, i.e., $M_\star < 1.5 M_\odot$, for which convection happens in the whole star or

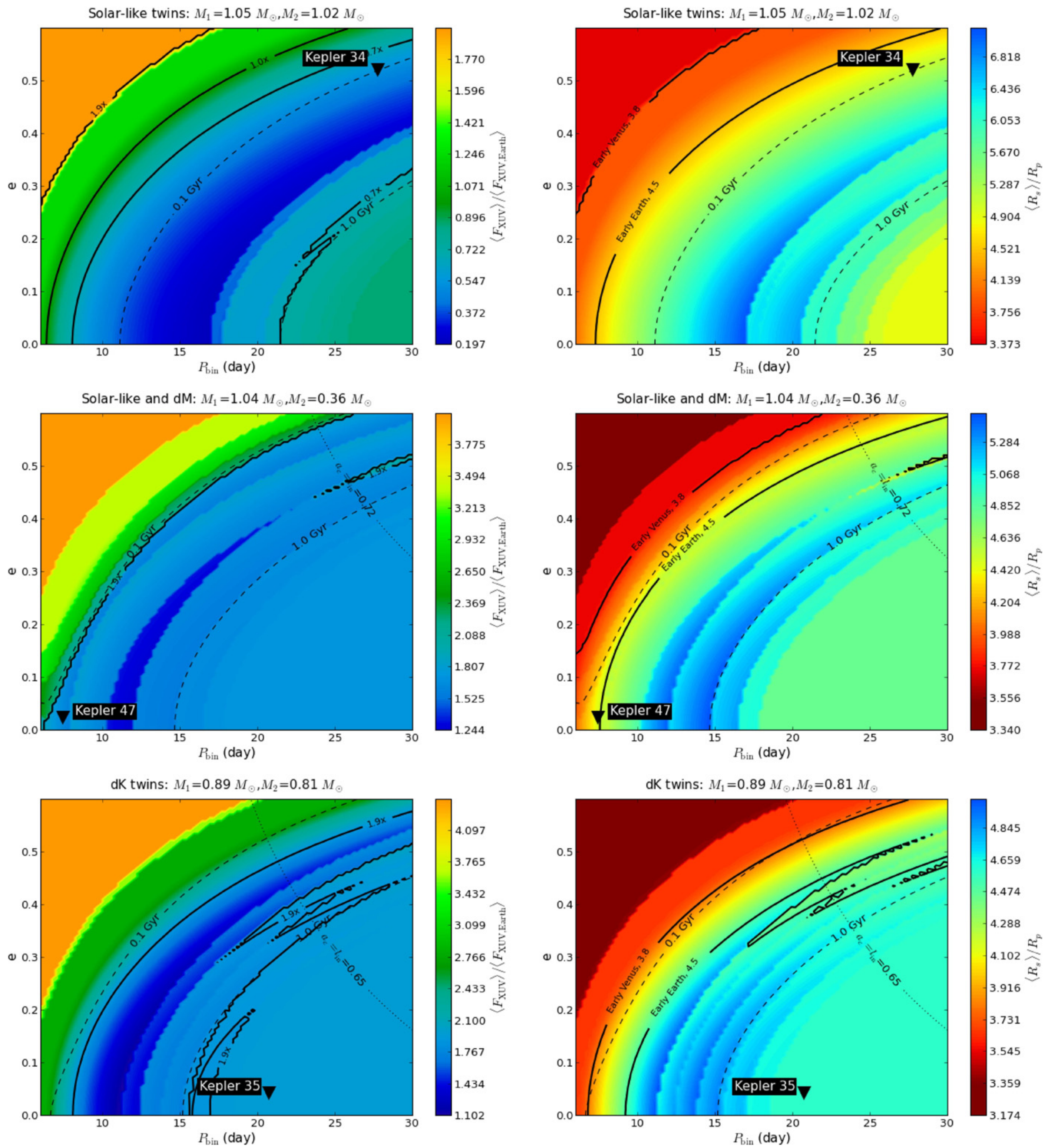

Figure 4. Kepler binaries with enhanced habitability in the e–$P_{\rm bin}$ plane. Binaries above and to the left of the 1 Gyr lines have primaries that synchronize in less than 1 Gyr. Those to the right and above and the dotted lines do not have stable orbits in the habitable zone.

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in the outer envelope (Chabrier & Baraffe 1997), we assume that turbulent convection is the dominant tidal dissipation mechanism. We compute the viscous dissipation time $t_{\rm diss}$ directly from convection overturn times following Equation (2.8) in Zahn (2008).

For non-negligible eccentricities, tidal breaking drives stars to a pseudo-synchronous final state where rotational angular velocity is not exactly the average orbital angular velocity. Final rotational velocity in eccentric binaries is obtained when the term in the square brackets in Equation (10) becomes zero:

$$n_{\rm sync} \equiv \frac{\Omega_{\rm sync}}{\omega} = \frac{1 + \frac{15}{2}e^2 + \frac{45}{8}e^4 + \frac{5}{16}e^6}{(1-e^2)^{\frac{3}{2}}\left(1 + 3e^2 + \frac{3}{8}e^4\right)}. \quad (11)$$

For eccentricities in the range 0–0.5, $1 < n_{\rm sync} < 2.8$. Note that this equation is also Equation (42) of Hut (1981), where we

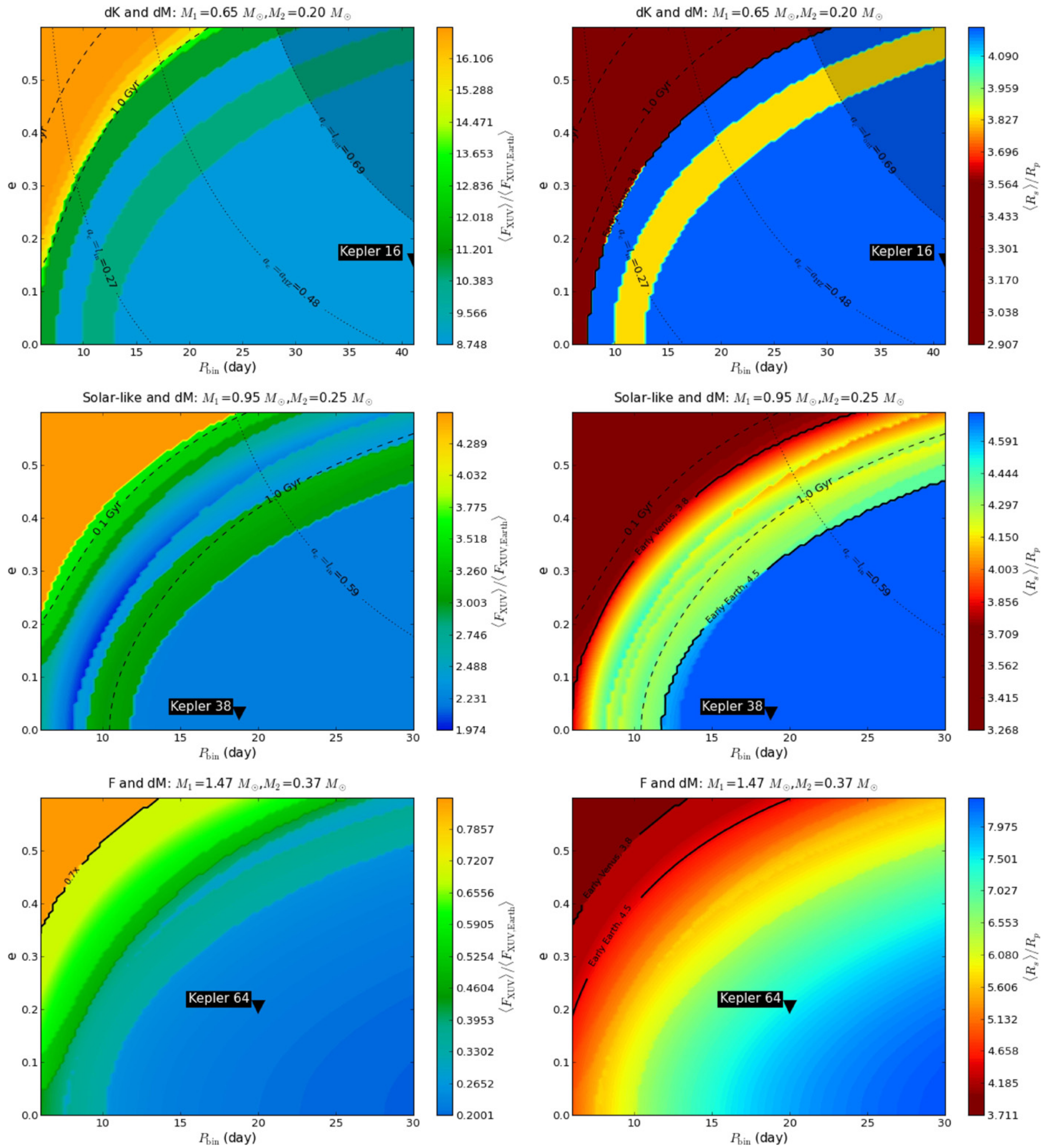

Figure 5. Same as Figure 4, for Kepler 16, 38, and 64 (see the text for details).

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use average angular velocity rather than instantaneous periastron velocity.

3.3. Planetary Magnetospheres

For magnetic protection, we use the models of Zuluaga et al. (2013). Magnetosphere sizes, quantified by stand-off distance R_S, are scaled with stellar wind dynamical pressure $P_{\rm sw} = mn_{\rm sw}v_{\rm sw}^2$ and the planetary dipole moment $\mathcal{M}$ according to:

$$\frac{R_S}{R_\oplus} = 9.75\left(\frac{\mathcal{M}}{\mathcal{M}_\oplus}\right)^{1/3}\left(\frac{P_{\rm sw}}{P_{\rm sw\odot}}\right)^{-1/6} \quad (12)$$

where $\mathcal{M}_\oplus = 7.768 \times 10^{22}$ A m^2 and $P_{\rm sw\odot} = 2.24 \times 10^{-9}$ Pa are the present Earth dipole moment and the average dynamical pressure of the solar wind at Earth. We note that during the first two Gyr, our thermal evolution models predict a dipole moment for Earth analogs of around 0.6 $\mathcal{M}_\oplus$ (see Figure 4 in Zuluaga et al. 2013).

Strong magnetic fields were probably required to create magnetosphere cavities large enough to protect early bloated atmospheres. For a magnetosphere comparable in size, or smaller than, that predicted for early Venus ($R_{\rm S,Venus} = 3.8\,R_p$), subject to similar levels of XUV radiation, we assume magnetic protection is insufficient to prevent water loss similar to Venus. On the other hand, if magnetospheres are larger than that of early Earth $R_{\rm S,Earth} = 4.5\,R_p$, the planet is magnetically protected.

Earth and Venus limits are drawn in the contour plots for R_S in Figures 4 and 5. We stress that while R_S depends on the dipole moment, an intrinsic planetary property, it also depends on the stellar wind pressure and velocity. This is the reason why we can display R_S in the e–$P_{\rm bin}$ plane for Earth-like magnetic properties.

4. RESULTS AND DISCUSSION

Relevant models are applied to study tidal synchronization effects on circumbinary habitability. Results for Kepler 34, Kepler 47, and Kepler 35, showing enhanced habitability are given in Figure 4. Kepler 16, Kepler 38 and Kepler 64 results, are given in Figure 5. Kepler binaries (black triangles) are plotted along with the level of stellar aggression experienced by planets in the middle of the RHZ. Dark blue areas in the e–$P_{\rm bin}$ plane correspond to binaries with reduced early XUV flux and enhanced magnetic protection (large R_S). We stress that known Kepler binary system planets are not studied here, rather hypothetical Earth-like planets in circumbinary habitable zones are illustrated.

Solar-mass twins, like Kepler 34 (black triangle in upper left panel of Figure 4), for example, provide a RHZ that has ∼60% of the averaged XUV flux of early Earth $\langle F_{\rm XUV,Earth}\rangle$. However, there is a spot, a binary habitable niche, at $P_{\rm bin} \sim 15$ days and $e = 0$ for which a mid-RHZ potentially habitable planet receives merely 20% of the XUV flux of early Earth. Fluxes less than that experienced by Venus exist for planets at mid-RHZ for all but the shortest period and highest eccentricity solar twins (orange region). Magnetospheric stand-off radii show a similar trend. Binaries that synchronize in less than 1 Gyr may provide reduced stellar aggression. However, this is true only if the synchronization time is not too short (see the upper left corner of the e–$P_{\rm bin}$ plane) due to the forever-young effect. In fact, Earth-like conditions exist near the inner edge of the RHZ for solar-like twins. A Venus-like planet with less magnetic protection than Earth could potentially maintain habitability in a system that could also have an Earth-twin and even a water world farther out in the RHZ. Hence multi-planet habitability is possible.

Lower mass twins or binaries with solar-like plus low-mass companions, Kepler 35 and Kepler 47, respectively, provide habitable conditions for certain binary period and eccentricity combinations. However, the trend is toward less habitable conditions for lower mass binaries. Kepler 35 consists of $0.89\,M_\odot$ and $0.81\,M_\odot$ stars in a nearly circular orbit with a 21 day period. Its RHZ is exposed to about twice the XUV flux as early Earth, but still is magnetically protected. The same result applies in Kepler 47. Binary habitable niches for analogs of those systems are found around $P_{\rm bin} \sim 12$ days and $e \sim 0.2$.

Results for Kepler 16, Kepler 38, and Kepler 64 binaries are shown in Figure 5. These range from the very inhospitable, Kepler 16 with two low-mass stars, to the planet friendly Kepler 64. A dwarf K and M pair (dK and dM), like Kepler 16, have RHZs which are exposed to much higher XUV flux than Earth. Kepler 38 ($M_1 = 0.98\,M_\odot$ and $M_2 = 0.25\,M_\odot$) is a marginal case with Venus-like conditions at best. Single dM stars are generally considered inhabitable based on their deadly XUV flux, however, if paired with a solar companion, the dM star may synchronize the primary, thereby providing a reduction of XUV flux. Kepler 64 ($M_1 = 1.53\,M_\odot$ and $M_2 = 0.38\,M_\odot$) provides reduced XUV flux and enhanced magnetic protection. It is, however, limited by the relatively short lifetime of the primary star.

Our results show that if tidal locking is capable of rotationally synchronizing stars in binaries within the first Gyr, then the RHZs may have reduced XUV and stellar wind flux. Planets with Earth-like magnetic fields in the RHZ of these binaries will likely retain atmospheric water. This effect is especially strong for solar-like (or larger) primaries. Planets that are less magnetically protected than the Earth may survive desiccation even in the inner region of the binary habitable zone.

Not only is it possible for Earth-like planets to exist in circumbinary orbits for a wide range of binary parameters, but also atmospheres experiencing less erosion than Earth are possible. This has implications for both the number of habitable planets in the Galaxy as well as the number of habitable planets per stellar system. We suggest that the paradigm that binaries are not as suitable as single stars for life, should be shifted to include a significant number of potentially habitable circumbinary planets.

Visit http://astronomia.udea.edu.co/binary-habitability for additional material and updates. We appreciate comments by René Heller and an anonymous referee. This research is supported in part by NSF Grant 0958783. J. I. Zuluaga and P. A. Cuartas-Restrepo are supported by CODI-UdeA.

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