

## Research Article

**Cite this article:** Shevchenko II (2020). Habitable worlds of merging stars. *International Journal of Astrobiology* **19**, 500–504. <https://doi.org/10.1017/S1473550420000282>

Received: 27 April 2020  
Revised: 9 August 2020  
Accepted: 9 September 2020  
First published online: 6 October 2020

### Key words:

Circumbinary planets; contact-binary stars; polymerase chain reaction; tidal chain reaction; SX Phe-type stars; W UMa-type stars

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# Habitable worlds of merging stars

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## Abstract

It is shown that W UMa-type and SX Phe-type stellar populations are both perfectly and uniquely suited for maintaining hyper-effective biopolymer chain reactions (BCR) on their planets once the planet is in the stellar habitable zone. W UMa-type stars are known to be contact binaries, and SX Phe-type stars are presumably post-binaries, i.e., products of stellar mergers. In case of the contact binaries, the eclipse-driven periodic heating/cooling of planetary surfaces has period-amplitude parameters that perfectly satisfy stringent conditions for maintaining BCR-like reactions. In case of the post-binaries, the stars pulsate with periods and amplitudes also perfectly suited for maintaining the reactions. Therefore, the ‘W UMa – SX Phe’ metamorphosis (from a contact binary to a post-binary, via the merger) seems to provide a potential biosystem reboot on planets in these systems.

## 1. Introduction

Our Sun is on the half-way of its main-sequence evolution: its age is about 4.5 Gyr, and about 5 Gyr is left until it leaves the main sequence and becomes a red giant; see, e.g., Ribas (2010). This transformation will have catastrophic consequences for the Solar system inner zone, where the terrestrial planets reside. Indeed, the atmosphere of the red giant will partly engulf it, possibly up to the Earth’s orbit. What is more, the Sun’s luminosity will rise hundreds of times, thus destroying even those planets that will not be engulfed by the Solar atmosphere<sup>1</sup>. However, there exists a chance that, when this catastrophic epoch arrives, the inner rocky-planet zone (including the ‘habitable’ annular band) will be already cleared from any planets. First of all, this concerns the fate of Mercury: it may escape the first (Laskar 1994). Laskar and Gastineau (2009) showed that not only Mercury may escape, but there exist future possible orbits of Venus, Earth and Mars with mutual encounters. In other words, the entire inner Solar system may disintegrate, in a few Gigayears from now. The chaotic disintegration of the Solar system was studied and explained, in a semi-analytical way, in Batygin *et al.* (2015). A similar-kind inner disintegration can be typical for many single-star planetary systems, in which giant planets are peripheral with respect to inner terrestrial planets, as in our Solar system.

Circumbinary planets<sup>2</sup> of main-sequence stars have certain habitability advantages over single Solar-like stars (Shevchenko 2017). What is more, an escape of potentially habitable planets can also be provided in circumbinary systems in due time (Shevchenko 2018), before the central stellar binary evolves up to some violent stage, say, the binary merger.

In this article, we show that there may exist a much more efficient mechanism, specific uniquely for circumbinary systems, which seems to allow for life survival on potentially habitable circumbinary planets during the host stellar binary merger stage.<sup>3</sup> It may provide both a pre-merger conservation and a post-merger revival of the evolved bioinformation on the planets. Note that mergers of companions in evolving main-sequence stellar binaries are quite a usual phenomenon; according to Hwang and Zakamska (2020), more than 90% of the old-population short-period binaries most likely disappear due to the mergers during their main-sequence stage.

## 2. Ubiquity of circumbinary planets

In the currently available sample of two dozens of the observed stellar binaries hosting circumbinary planets, about a half have periods less than several hours, and about a half have periods

<sup>1</sup>Note that the habitability of single stars leaving the main sequence is not generally ruled out, as the radially shifted and enlarged habitability zone (HZ) starts to steadily engulf planetary orbits that are more and more distant from the host star; inside the evolved HZ, planets may belong to the Earth and super-Earth exoplanet classes. Besides, once in the HZ, large satellites of giant planets may also constitute suitable niches for life (see, e.g., Heller and Barnes 2013; Hinkel and Kane 2013; and references therein).

<sup>2</sup>A circumbinary planet (CBP) is a planet that orbits around a stellar binary.

<sup>3</sup>An environment is habitable, if it is able to sustain life in its known forms. Habitability is a necessary, but not sufficient condition for life to be able to emerge in an environment. In this article, we address the habitability problem in a broad sense, including the potential for life to arise de novo. Concerning conditions for the habitability, those for carbon/water-based lifeforms are implied here; the temperature bounds are therefore taken to be accordingly constrained.

that are greater than 5 d (see, e.g., exoplanet.eu). There is a dearth of CBP-hosting binaries with intermediate periods. Indeed, according to (Slawson *et al.* 2011, fig. 8), in a sample of two thousands of eclipsing binaries in the *Kepler* data, more than a thousand have periods less than 7 d, but practically none are known to possess planets.

A number of observational biases are active, but the actual dearth of CBP-hosting binaries with  $P \leq 5$  d seems to be statistically significant (Armstrong *et al.* 2014; Martin and Triaud 2014). Fleming *et al.* (2018) explained the dearth by eventual entrance of CBPs in the circumbinary chaotic zone, in the course of the long-term planet-binary co-evolution. In the tidal scenario of Fleming *et al.* (2018), the circumbinary chaotic zone slowly broadens (because the binary's orbit increases in size, due to the tidal transfer of the angular momentum from the stellar rotation), while the planetary orbit size stays constant. This mechanism of entrance in the chaotic zone is different from that proposed in Shevchenko (2018), where the planetary orbit tidally decays in size, while the chaotic zone size stays constant.

It should be underlined that (1) the observed dearth concerns Neptune-like and Jupiter-like giant planets; observational statistics on terrestrial CBPs, whose sizes are much smaller, is lacking, because such small planets are simply hard to discover; (2) the dearth has an intermediate character: as already mentioned above, CBPs of very close (with periods less than several hours) binaries do exist, although these hosting binaries typically contain evolved stars.

Generally, the close Solar-type binaries with periods less than 10 d are believed to be a product of some long-term dissipative evolution, most likely a tidal friction, which is triggered in hierarchical triples by the Lidov–Kozai oscillations (Armstrong *et al.* 2014; Martin *et al.* 2015; Muñoz and Lai 2015; Hamers *et al.* 2016). On the other hand, the existing correlation between companions' masses and the resemblance between the close-binary fractions for the pre-main-sequence stars and for the main-sequence field stars show that the evolution to the close state is fast, taking  $\leq 5$  Myr, most likely due to the dissipation in primordial gas (Moe and Kratter 2018). Therefore, the potential existence of CBP-hosting main-sequence pre-merger stellar binaries is quite plausible; in any case, it is not ruled out.

### 3. Biopolymer chain reactions

#### 3.1. Polymerase chain reactions

In the authentic polymerase chain reaction (PCR), a periodic cycling between low and high temperatures, with an amplitude of  $\sim 50$ , drives exponential amplification of concentration of DNA molecules: at a low temperature, association is promoted and complementary strands are synthesized (the molecules number doubles), whereas at a high temperature the duplex strands dissociate; when temperature is again decreased, the molecules number again doubles, and the continued cycling amplifies the molecules number in a geometrical progression (Mullis *et al.* 1986). The PCR is used in laboratories for copying and inflating the volume of DNA material for genetic-study and forensic purposes; see Mullis *et al.* (1986); Lathe (2005) for more details and references.

#### 3.2. Tidal chain reactions

Repeatedly drying–wetting tidal pools are thought to be a possible place of origin of self-replicating biopolymers, as such pools provide favourable conditions for concentrating organic molecules;

see Lathe (2004) and references therein. In Lathe (2004, 2005, 2006, 2012), a theory of abiogenesis was proposed, based on a tidal 'boosting' effect for the biomolecules production in such near-shore lakes and ponds. The mechanism is analogous to that represented by the PCR, but, in Lathe's tidal chain reaction (TCR), the water salinity, not temperature, is periodically driven, leading to the same, as in the PCR, exponential amplification of nucleic acids (Lathe 2004, 2005). The association is promoted and complementary strands are synthesized at high salinity, and at low salinity the duplex strands dissociate. What is more, the cyclic changes in salinity may drive periodic breakage and reassembly of micelles, as precursors to cellular life (Lathe 2012).

A problem with the biopolymer chain reactions is that the reaction product is unstable and decays quite rapidly, as discussed in detail in Lathe (2005) in connection with the TCR abiogenesis scenario for the early Earth affected by the Lunar tides (Lathe 2004, 2005). However, nucleic acids (DNA in particular) in aqueous solutions at high temperatures ( $\sim 100^\circ\text{C}$ ) and elevated salt concentrations demonstrate marked stability, low levels of nucleotide thermodegradation and chain scission (Marguet and Forterre 1994, 2001).

#### 3.3. Relevance to CBPs

One may ask: do there exist 'natural laboratories' anywhere in the Universe, where any PCR-like or TCR-like reactions can be naturally maintained? And how they are ubiquitous? In case of the TCR, the early Earth, subject to Lunar tides, was proposed in Lathe (2004, 2005) as such a natural laboratory. In this article, we argue that PCR-like reactions can be naturally maintained on planets in habitable zones (HZs) of contact-binary and post-binary main-sequence stars.

As shown in Shevchenko (2017), Lathe's tidal mechanism of abiogenesis can be potentially generic for circumbinary planets of main-sequence stars; on them, a photo-tidal synchronization is automatically maintained: variations of insolation are synchronized with tides.

When, in the course of the system orbital motion, a CBP is approached by a tide-raising body (any stellar companion), both the tide driven by the host binary star and the radiation flux from the star raise; therefore, the salinity and temperature are expected to, respectively, decrease and increase in concert; and vice versa. In this way, suitable conditions for PCR and TCR are satisfied synchronously, and the amplification process can be more effective (Shevchenko 2017).

At present, the amplitudes of the Lunar and Solar equilibrium tides are rather similar: they are equal to 0.36 and 0.16 m, respectively (Murray and Dermott 1999). In earlier ages, when the Moon was orbiting much closer to the Earth, the Lunar tides could be much higher; see Lathe (2004, 2005). For a CBP in the HZ of a contact binary formed by Solar-like companions, the amplitudes of the tides raised by the companions would be of the same order as on the Earth.

The tidal phenomena on CBPs of contact-binary stars are however specific, because the tidal bulges raised by the stellar companions in this case are close to each other and strongly overlap; they can be regarded as a single tidal bulge modulated with the binary's rotation frequency. The modulation frequency is effectively doubled if the companions are equal-mass. As shown further on, the driving frequency value is appropriate for maintaining biopolymer chain reactions; further details require a separate analysis, which is beyond the scope of this article.

#### 4. Contact binaries

We consider stellar eclipses in contact binaries as drivers of temperature forcing on CBPs. For the PCR-like reaction to be triggered, the forcing frequency should be large enough. Among the ordinary stellar binaries, the tightest ones are contact binaries, mostly represented by W UMa-type stars. For them, the binary mass is  $\sim 2$  Solar masses, and the binary size (the distance between the companions' mass centres) is  $\sim 2$  Solar radii. Generally, W UMa-type stars belong to F, G and K spectral classes, and their ages range from  $\sim 5$  to  $\sim 12$  Gyr; see Stępień and Gazeas (2012) and references therein. They are rather ubiquitous; thousands of them are catalogued, and they populate the Solar neighbourhood in ratio of  $\sim 2$  contact binaries for a thousand single stars (Rucinski 2006). They are believed to be formed from initially detached binaries, as the size of the latter slowly but inevitably diminishes due to the stellar winds and mutual tides, which transfer the angular momentum away (Stępień and Gazeas 2012). A final merger, manifesting the birth of a rapidly rotating post-binary single, is the natural outcome of this slow evolution.

Let  $F_{\min}$  and  $F_{\max}$  be the observed minimum and maximum stellar fluxes during the eclipse cycle of a stellar binary (for an observer on a CBP in an orbit coplanar with the binary's orbit; this coplanarity is typical for the observed CBPs). The corresponding stellar magnitude variation is  $\Delta m = 2.5 \log_{10}(F_{\max}/F_{\min})$ . Therefore, if the ratio of fluxes is  $F_{\max}/F_{\min} \approx 2$ , then the lightcurve relative amplitude  $\Delta m \approx 0.75$ . This value is rather typical for the observed lightcurves of W UMa-type stars, see Terrell *et al.* (2012). This reflects the fact that the companions in the contact binaries have similar sizes, and, besides, the orbital planes of many such binaries are rather moderately inclined to the line of sight, due to selection biases.

Now, let  $F_{\min}$  and  $F_{\max}$  be the minimum and maximum stellar fluxes at the surface of a CBP during the eclipse cycle. In a simplest model setting, the temperature variation is determined by the Stefan–Boltzmann law:

$$\frac{\Delta T}{T_{\min}} = \left( \frac{\Delta F}{F_{\min}} + 1 \right)^{1/4} - 1, \quad (1)$$

where  $\Delta T = T_{\max} - T_{\min}$ ,  $\Delta F = F_{\max} - F_{\min}$ . For  $\Delta F/F_{\min} = 1$  one has, then,  $\Delta T/T_{\min} = 0.189$ . Therefore, for  $T_{\min} \approx 300$  K (i.e., for a planet in the HZ) one has  $\Delta T \approx 57^\circ$ .

More specifically, for  $\Delta m = 0.7$ – $0.9$ , typical for W UMa-type stars (Terrell *et al.* 2012), one has  $\Delta F_{\max}/F_{\min} = 0.91$ – $1.29$  and, therefore,  $\Delta T \approx 50$ – $70^\circ$ . For maintaining the authentic PCR, similar temperature amplitudes are perfectly suited; see Mullis *et al.* (1986); Lathe (2004, 2005).

In case of a twin (equal-mass equal-radius) binary the lightcurve period is effectively two times less than the binary's orbital period. The heating/cooling period at the planetary surface is therefore equal to one half of the binary's period. For example, let the orbital period be 8 h = 0.33 d (as in case of the W UMa prototype), then the lightcurve (eclipse) period is 4 h, and the heating/cooling period is 4 h.

The binary orbital period  $P$  is given by the Keplerian equation

$$P^2 = \frac{4\pi^2 a^3}{\mathcal{G}(m_1 + m_2)}, \quad (2)$$

where  $\mathcal{G}$  is the gravitational constant,  $m_1 \geq m_2$  are the masses of the companions,  $a$  is the binary size (the distance between the

companions' mass centres). Let  $r_1 \geq r_2$  be the radii of the companions, and  $\alpha = r_2/r_1$ . Then, for a contact binary whose companions have equal mean densities  $\rho$ , one has

$$P^2 = \frac{3\pi}{\mathcal{G}\rho} \cdot \frac{(1 + \alpha)^3}{(1 + \alpha^3)}, \quad (3)$$

and, for a twin contact binary ( $\alpha = 1$ ),

$$P = 2 \left( \frac{3\pi}{\mathcal{G}\rho} \right)^{1/2}. \quad (4)$$

Using equation (4) and data for masses and radii for red dwarfs as given in (Kaltenegger and Traub 2009, table 1), one obtains the orbital periods equal to  $\approx 200$  and  $\approx 27$  min for twin contact binaries of spectral classes M0 and M9, respectively. Therefore, the heating/cooling periods are  $\approx 100$  and  $\approx 14$  min, respectively. For maintaining the authentic PCR (Lathe 2004, 2005; Mullis *et al.* 1986) such periods are perfectly suited.

However, in the entire sample of the known to date thousands of contact binaries, the shortest measured orbital period is  $\approx 0.22$  d = 5.28 h (Stępień 2006), corresponding to the heating/cooling period  $\approx 2.6$  h  $\approx 160$  min. The shortest orbital period belongs to CC Com. The absence of observed contact binaries with shorter periods is generally attributed to the slowness of M-dwarf binary inspiralling; it is therefore believed that M-dwarf contact binaries have not yet formed (Stępień 2006). Comparing the age of the Universe and the time needed to reach the Roche lobe overflow at various stellar masses, one may estimate the expected total (for the two companions in sum) lower mass limit for the observed contact binaries to be  $\approx 1.0$ – $1.2$  in Solar units (Stępień 2006), in accord with the mentioned lower period limit  $\approx 0.22$  d. If the given explanation of the contact binary period distribution cut-off is valid, then the massive biopolymer chain reaction scenario may come into play only in a far (Gigayears ahead) future.

#### 5. Biomass inflation

PCR is hyper-efficient to inflate biomass and, therefore, to provide better storage of evolved bioinformation. In a DNA molecule, there are 2400 million atoms in a single strand of a chromosome; thus, its mass is  $\approx 7 \cdot 10^{-14}$  g. On the other hand, the volume of the World Ocean on the Earth is  $\approx 1.3 \cdot 10^{24}$  cm<sup>3</sup>; and its mass is  $\approx 1.3 \cdot 10^{24}$  g. Therefore, the time needed to produce, starting from one DNA molecule, a World Ocean mass (as an example) of copied molecules (provided that the precursor material is enough) is equal to only  $\approx \log_2 10^{37} \sim 100$  eclipse cycles.

In case of Solar-like G-dwarf twin contact binaries, the hundred cycles take  $\sim 400$  h  $\sim 2$  weeks; and, in case of M-dwarf twin contact binaries, the hundred cycles take only  $\sim 1$  d. Thus, the biomass inflation time is negligible in comparison with cosmogonical timescales; therefore, possible activity of host stars does not inflict the process.

There exists an obstacle: planets rotate, and, therefore, there may exist periodic time intervals when the rapid heating/cooling cycle is inactive, and this may break the chain reaction. Note, however, that the day-side polar region would be mostly unaffected, if the planet's rotation axis is inclined. Moreover, in case of red-dwarf hosting binaries, the planets inside the HZ are expected to be tidally locked (Barnes 2017), i.e., reside in synchronous spin-orbit resonance. This would permit the chain

reactions on the planet's day side to be continuous. Note that in case of late-type M dwarfs there may be even no need for the planet to be tidally locked, because the amplification process saturates in less than a day.

Apart from PCR-type reactions, the TCR may also be active, due to what in the Earth case is called the *lunitidal interval* – the time lag of the tide maximum after the geometrically closest passage of the Moon. The lunitidal interval on Earth can be as large as  $\sim 2$  h; generally, it may take a whole spectrum of values, depending on many local and global geophysical factors (Grant Gross 1971). Therefore, at least at some localities on a planetary surface, PCR and TCR may well act in concert<sup>4</sup>.

Note that, inside the HZ, the entire spectrum of temperatures, from zero to  $\approx 100^\circ\text{C}$ , allowing for the water liquid state, can be maintained, depending on the planetary orbital radius. Besides, the broad range of temperatures can be maintained on any planet inside the HZ. For example, for a tidally locked planet<sup>5</sup>, the temperature would be maximum in the planetary surface locations where the host star is in zenith, and would sharply decrease towards the day-night line. Therefore, suitable locations for maintaining biopolymer chain reactions seem to be always potentially present, both in the orbital space inside the HZ and in the planetary surface areas.

During the W UMa stage, the possible enormous production of biomaterial on CBPs in HZs would inevitably force the biomaterial to penetrate throughout the planetary surfaces and close-to-surface inner volumes, thus providing safer shelters allowing for the survival of the bioinformation during any violent space weather storms associated with the host binary star merger. As in any extinction event, the more material is stored beforehand (especially in safe shelters), the more material is expected to survive.

## 6. Post-binary potential biosystem reboot

SX Phe-type stars are A–F type main-sequence stars that pulsate with short periods (down to 0.03 d) and large amplitudes (up to 0.8m); see Eggen and Iben (2009); Nemec *et al.* (2017); McNamara (2011). These properties provide almost the same, as in the W UMa-type stars case, conditions for maintaining the BCR on their planets in habitability zones. In fact, the shortness and general similarity of periods of the contact-binary rotations and the post-binary pulsations seem to be not at all accidental: indeed, the fundamental mode pulsations of a post-binary star have the period  $P \sim (\mathcal{G}\rho)^{-1/2}$ , which coincides with the period given by equation (4) for the pre-merging contact-binary rotation.

Thus, the post-binary stars pulsate with periods and amplitudes well suited for maintaining the BCR. The SX Phe-type stars are presumably post-binaries, i.e., products of stellar mergers. Therefore, the 'W UMa–SX Phe' metamorphosis (from a contact binary to a post-binary, via the merger) may potentially provide a potential biosystem reboot on planets in these systems.

<sup>4</sup>One may presume that life on Earth emerged from hyperthermophiles principally in an aqueous environment, and the ocean temperatures at that epoch were close to  $100^\circ\text{C}$ . Then, the temperature variations are naturally constrained from above by the water boiling limit. From below, the allowed temperature limit is uncertain, but could be lower, depending on planetary surface locations. (An uncertainty arises because the atmospheric pressure, affecting the boiling point of water, can be different in different time epochs and on different planets.) However, on the considered types of planets, the TCR-driving salinity variations (evoked by the drying and tidal cyclicality) and the PCR-driving temperature variations (evoked by the incident radiation cyclicality) can be rapid enough to drive the both reactions efficiently.

<sup>5</sup>The tidal lock is expected for planets in HZs of M-dwarfs.

Note that after the host binary merger, the excessive angular momentum is transferred away by a circumstellar excretion disk newly formed of ex-stellar material. New young planets may form in such disks (Melis *et al.* 2011; Martin *et al.* 2011; Stepień and Kiraga 2013). One may speculate that, before the merger, by means of BCR the bioinformation is massively stored to provide a post-merger bio-evolution revival in the old or a newly formed planetary system. After the merger, the survived bioinformation may serve as a basis for a further bio-evolution under a more massive and quiet star – a post-binary single. Contact-binary stars and post-binary single stars (presumably, red, yellow and blue stragglers) may therefore be of especial observational interest as potential hosts of biomarked planets.

The stellar activity, especially the pre-merger one in W UMa-type systems may hinder the detection of biosignatures; therefore, SX Phe-type systems can be chosen as observational targets in this respect first of all.

Generally, in comparison with W UMa-type systems, SX Phe-type ones are expected to possess more quiescent space weather environmental conditions, maybe calm enough to allow for a prokaryotic biosphere similar to that of the early Earth. An evolved biosphere, resembling that of the present-day Earth, may be expected Gigayears later on.

The bio-evolution should include compartmentalization, with self-replicating biopolymers being then contained within protocells. Hypothetically, this step may be not favoured during the W UMa stage, especially for M-dwarf binary systems, due to the potentially active pre-merger behaviour of the stars. However, during the subsequent SX Phe stage, the host star is expected to be calmer, and the bio-evolution may proceed further on.

To author's knowledge, apart from W UMa-type and SX Phe-type stars, no other type of stellar objects may provide suitable periodic variation in heating/cooling radiation fluxes and, therefore, be efficient for maintaining the BCR on planets.

## 7. Conclusions

Concluding, we have shown that planets of contact-binary and post-binary (W UMa-type and SX Phe-type) stars represent perfect places for maintaining biopolymer chain reactions once the planet is in the stellar HZ.

Indeed, on such planets, the two basic conditions for biopolymer chain reactions are potentially satisfied: universal suitable amplitudes,  $\sim 50\text{--}70^\circ$ , and universal suitable periods,  $\sim 0.3\text{--}3$  h, of the surface temperature variation. Contact-binary red dwarfs and their immediate post-binary descendants are especially favoured, as they provide (1) ultra-short periods of the temperature forcing, and (2) tidal locking of planets in the HZ.

In view of the outstanding properties of W UMa-type and SX Phe-type stars, one may hypothesize that the 'W UMa–SX Phe' metamorphosis provides a potential biosystem reboot on planets in these systems.

The PCR-induced potential inflation of biomass from one biopolymer molecule mass to a World Ocean mass, if there are enough precursors, is complete in  $\sim 100$  stellar eclipse or pulsation cycles, i.e., it is instantaneous in comparison with cosmogonical timescales.

Contact-binary and post-binary stars (presumably, red, yellow and blue stragglers) can be of especial observational interest as potential hosts of biomarked planets.

**Acknowledgments.** The author is grateful to the referees for useful remarks and comments. This work was supported in part by the grant "Theoretical and

experimental studies of the formation and evolution of extrasolar planetary systems and characteristics of exoplanets' (grant number 13.1902.21.0039) of the Ministry of Science and Higher Education of the Russian Federation.

**Financial support.** No competing financial interests exist.

**Conflict of interest.** The author reports no conflict of interest.

## References

- Armstrong DJ, Osborn HP, Brown DJA, Faedi F, Gómez Maqueo Chew Y, Martin DV, Pollacco D and Udry S (2014) On the abundance of circumbinary planets. *Monthly Notices of the Royal Astronomical Society* **444**, 1873–1883.
- Barnes R (2017) Tidal locking of habitable exoplanets. *Celestial Mechanics and Dynamical Astronomy* **129**, 509–536.
- Batygin K, Morbidelli A and Holman MJ (2015) Chaotic disintegration of the inner Solar system. *The Astrophysical Journal* **799**, 120 (16pp).
- Eggen OJ and Iben I (1989) Starbursts, blue stragglers, and binary stars in local superclusters and groups. II. The old disk and halo populations. *Astronomical Journal* **97**, 431–457.
- Fleming DP, Barnes R, Graham DE, Luger R and Quinn TR (2018) On the lack of circumbinary planets orbiting isolated binary stars. *The Astrophysical Journal* **858**, 86 (24pp).
- Grant Gross M (1971) *Oceanography*, 2nd Edn. Columbus, Ohio: Charles E. Merrill Publishing Co., p. 114.
- Hamers AS, Perets HB and Portegies Zwart SF (2016) A triple origin for the lack of tight coplanar circumbinary planets around short-period binaries. *Monthly Notices of the Royal Astronomical Society* **455**, 3180–3200.
- Heller R and Barnes R (2013) Exomoon habitability constrained by illumination and tidal heating. *Astrobiology* **13**, 18–46.
- Hinkel NR and Kane SR (2013) Habitability of exomoons at the Hill or tidal-locking radius. *The Astrophysical Journal* **774**, 27.
- Hwang H-C and Zakamska NL (2020) Lifetime of short-period binaries measured from their Galactic kinematics. *Monthly Notices of the Royal Astronomical Society* **493**, 2271–2286.
- Kaltenegger L and Traub WA (2009) Transits of Earth-like planets. *The Astrophysical Journal* **698**, 519–527.
- Laskar J (1994) Large-scale chaos in the Solar system. *Astronomy and Astrophysics* **287**, L9–L12.
- Laskar J and Gastineau M (2009) Existence of collisional trajectories of Mercury, Mars and Venus with the Earth. *Nature* **459**, 817–819.
- Lathe R (2004) Fast tidal cycling and the origin of life. *Icarus* **168**, 18–22.
- Lathe R (2005) Tidal chain reaction and the origin of replicating biopolymers. *International Journal of Astrobiology* **4**, 19–31.
- Lathe R (2006) Early tides: Response to Varga *et al.* *Icarus* **180**, 277–280.
- Lathe R (2012) Tidal cycling and the origin of the genetic code. In J Seckbach (ed.), *Genesis, in the Beginning*. New York: Springer, pp. 691–707.
- Marguet E and Forterre P (1994) DNA stability at temperatures typical for hyperthermophiles. *Nucleic Acids Research* **22**, 1681–1686.
- Marguet E and Forterre P (2001) Stability and manipulation of DNA at extreme temperatures. *Methods in Enzymology* **334**, 205–215.
- Martin DV and Triaud AHMJ (2014) Planets transiting non-eclipsing binaries. *Astronomy and Astrophysics* **570**, A91 (19pp).
- Martin EL, Spruit HC and Tata R (2011) A binary merger origin for inflated hot Jupiter planets. *Astronomy and Astrophysics* **535**, A50 (6pp).
- Martin DV, Mazeh T and Fabrycky DC (2015) No circumbinary planets transiting the tightest Kepler binaries – a possible fingerprint of a third star. *Monthly Notices of the Royal Astronomical Society* **453**, 3554–3567.
- McNamara DH (2011) Delta Scuti, SX Phoenicis, and RR Lyrae stars in galaxies and globular clusters. *Astronomical Journal* **142**, 110 (22pp).
- Melis C, Gielen C, Chen CH, Rhee JH, Song I and Zuckerman B (2010) Shocks and a giant planet in the disk orbiting BP Piscium?. *The Astrophysical Journal* **724**, 470–479.
- Moe M and Kratter KM (2018) Dynamical formation of close binaries during the pre-main-sequence phase. *The Astrophysical Journal* **854**, 44 (21pp).
- Mullis K, Faloona F, Scharf S, Saiki R, Horn G and Erlich H (1986) Specific enzymatic amplification of DNA in vitro: the polymerase chain reaction. *Cold Spring Harbor Symposia on Quantitative Biology* **51**, 263–273.
- Muñoz DJ and Lai D (2015) Survival of planets around shrinking stellar binaries. *Proceedings of the National Academy of Sciences* **112**, 9264–9269.
- Murray CD and Dermott SF (1999) *Solar System Dynamics*. Cambridge: Cambridge University Press.
- Nemec JM, Balona LA, Murphy SJ, Kinemuchi K and Jeon Y -B (2017) Metal-rich SX Phe stars in the Kepler field. *Monthly Notices of the Royal Astronomical Society* **466**, 1290–1329.
- Ribas I (2010) The Sun and stars as the primary energy input in planetary atmospheres. In AG Kosovichev, AH Andrei and J-P Rozelot (eds), *Solar and Stellar Variability – Impact on Earth and Planets* (Proc. IAU Symp. 264). Cambridge: Cambridge Univ. Press, pp. 3–18.
- Rucinski SM (2006) Luminosity function of contact binaries based on the All Sky Automated Survey (ASAS). *Monthly Notices of the Royal Astronomical Society* **368**, 1319–1322.
- Shevchenko II (2017) Habitability properties of circumbinary planets. *Astronomical Journal* **153**, 273 (14pp).
- Shevchenko II (2018) Tidal decay of circumbinary planetary systems. *Astronomical Journal* **156**, 52 (8pp).
- Slawson RW, Prša A, Welsh WF, Orosz JA, Rucker M, Batalha N, Doyle LR, Engle SG, Conroy K, Coughlin J, Gregg TA, Fetherolf T, Short DR, Windmiller G, Fabrycky DC, Howell SB, Jenkins JM, Uddin K, Mullally F, Seader SE, Thompson SE, Sanderfer DT, Borucki W and Koch D (2011) Kepler eclipsing binary stars. II. 2165 Eclipsing binaries in the second data release. *Astronomical Journal* **142**, 160 (14pp).
- Stepień K (2006) The low-mass limit for total mass of W UMa-type binaries. *Acta Astronomica* **56**, 347–364.
- Stepień K and Gazeas K (2012) Evolution of low mass contact binaries. *Acta Astronomica* **62**, 153–177.
- Stepień K and Kiraga M (2013) The ultimate fate of low-mass contact binary evolution: planetary system? *Central European Astrophysical Bulletin* **37**, 381–390.
- Terrell D, Gross J and Cooney WR (2012) A BVR<sub>CLC</sub> survey of W Ursae Majoris binaries. *Astronomical Journal* **143**, 99 (7pp).