A&A 500, 133–134 (2009)
DOI: 10.1051/0004-6361/200912151

Astronomy & Astrophysics
Special issue

COMMENTARY ON: ZAHN J.-P., 1977, A&A, 57, 383

A lubricant for tidal friction

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To many astronomers, even within the stellar community, studying the physics of close binary stars is not a desirable enterprise. A common opinion is that binary evolution is too complicated and that it involves too many parameters and possibilities, such that each of them may have low statistical significance. However, this opinion is refuted by how many papers on close binary systems there are among the most successful A&A papers presented in this issue. The work by Jean-Paul Zahn on tidal dissipation discussed here provides a marvelous example for why this is so.

Admittedly, the physics of tidal friction is complicated, as the effects of tidal synchronization and orbital circularization depend on non-adiabatic processes in the stellar envelope. However, the spin of Mercury (Peale & Gold 1965; Goldreich 1965) and the Earth-Moon system both provided a prominent example clearly worth studying (Munk & MacDonald 1960), and spectrographs have become powerful enough to demonstrate tidal spin-down in binary stars. Also, for the first time, stellar evolution in binary systems became a central issue for the community at that time. In those, tides should clearly play an essential role.

While it was suspected at the time that tides were responsible for the slower intrinsic rotation of many binary components compared to single stars of the same type, Zahn worked out which major non-adiabatic processes are responsible for the tidal spin-orbit coupling in main sequence stars. He further elaborated the time scale on which these processes operate and showed that this time scale does explain many observations.

Already in his Ph.D. Thesis, which was supervised by Evry Schatzman, Zahn discovered that the dominant non-adiabatic damping mechanism operating in stars with convective envelopes is turbulent friction (Zahn 1966). Recently, Penev et al. (2007), based on numerical simulations of turbulent convection, have validated the concept of turbulent viscosity applied to that problem. In the paper discussed here, Zahn derives the very often used expression for the time scale of synchronization for low-mass main sequence stars, i.e. those with convective envelopes, such as $\tau_{\rm sync} \sim q^{-2}(a/R)^6$, where q is the mass ratio of the binary components, a their orbital separation, and R the radius of the star to be synchronized.

To obtain results for stars with radiative envelopes required more monumental preparatory work, as in Zahn (1970,1975). Jean-Paul Zahn showed that radiative damping of gravity-mode pulsations that are excited by the oscillation induced by the tidal force in the case of non-synchronous rotation provide the dominant non-adiabatic mechanism for main sequence stars with radiative envelopes. For those stars, Zahn (1975) shows that the synchronization time becomes $\tau_{\rm sync} \sim q^{-2}(1+q)^{-5/6}(a/R)^{17/2}$, an expression repeated in the paper discussed here and used many times in the literature.

It is remarkable that Zahn – clearly a theoretician – undertakes the effort in the paper under discussion to compare his results with observations. He first compares his predictions to observations of rotational velocities in main sequence binary components with convective and with radiative envelopes. He finds evidence that the distinction between these two groups of stars is correct and confirms the predicted synchronization time scale in both cases, or rather the critical orbital separation below which the synchronization is expected to occur during the main sequence evolution. Zahn then even applies his findings to observations of X-ray binaries – just discovered a few years earlier – for which he indeed finds his results suitable.

It is clear from reading the paper discussed here that Zahn realized its fundamental importance. However, he was aware, perhaps better than anybody else, how approximate the presented assumptions and solutions were. For stars with convective envelopes, Zahn was aware that his description of the coupling between convection and the tidal oscillations might be too simple – an issue that has also plagued the theory of asteroseismology until today (see Houdek 2008). Tassoul (1987) argues that the azimuthal variations in the rotational velocity, caused by the loss of axial symmetry in a tidal field, produce mechanically driven currents and consequently the spin-down of the tidally distorted star, much faster than Zahn's prediction and for much wider binary orbits, a view later refuted by Rieutord (1992). Witte & Savonije (2001) argue that resonance effects between the orbital and stellar rotation can significantly accelerate the synchronization for massive binary components. And Toledano et al. (2007) find that Zahn's synchronization time scale for convective stars is realized in intermediate-mass main sequence stars, potentially the result of rotationally generated turbulence in their radiative envelopes.

While this just gives a flavor of the unsolved questions in tidal synchronization theory, it shows that much still needs to be done to understand the picture, and contradictory ideas about the dominant processes involved in spin-orbit coupling are still around at this time. Essential for the success of Jean-Paul Zahn's (1977) paper is certainly that the predicted results have kept on

Article published by EDP Sciences

explaining observations (cf., North & Zahn 2003) thanks to making his results accessible to the wider community.

The breakthroughs in the understanding of the importance of radiative and turbulent frictional damping for the two groups of main sequence stars and the mathematical description of these mechanisms had been provided by Zahn before 1977, however, those were far less valued by the community than the 1977 paper. For the turbulent friction model for convective envelopes, this is easily understood, as this was published in three monumental papers (Zahn 1966), *in French*. Except for those top specialists in the field (Cowling, Kippenhahn, Ledoux), these papers drew little attention. Surely, this was not Zahn's fault, as the national journals were still prevalent, and A&A still had to be founded, exactly to overcome problems like this. Besides the language issue, these papers shared a problem with the breakthrough work on radiative damping (Zahn 1975): they were very technical, hard to digest, and close to incomprehensible for observers.

The real achievements of Zahn's 1977 paper thus seem to be, first, translating the important results from his Ph.D. Thesis into English; second, condensing them and translating them into expressions that are comprehensible for the whole community (even more so: this paper is actually a pleasure to read!); and third, performing the comparison with the then available data himself rather than waiting for others to do this. Quoting Jean-Paul's communication with me: *"The lesson I learned – it is never too late – is that you'd better write your articles not so much for the specialists, but in such a way as to be understood by those who are likely to confirm your predictions."* Indeed, Zahn's paper makes tidal friction so much easier to understand that it is a true lubricant for our minds to think about it. May the success of this approach convince more theoreticians to follow this strategy.

There is no doubt that the success of the work comes from Jean-Paul Zahn. He was obviously influenced by others – from his 1977 paper *"Starting with Jeans (1929), many authors have addressed the problem posed by stellar tides..."* – and by his renowned Ph.D. supervisor. However, he wrote most of his papers, and all the ones of interest here, as a single author. This is remarkable, as seen by looking at the papers in this issue.

Surely, this is a feature of its time; back then, the fraction of single-author papers was much higher than today. And, it is a feature of theory papers, which can be more easily produced by a single person compared to observational papers. Indeed, the vast majority of the papers cited by Zahn (1977) are single-author papers, which is no longer true for theory papers today.

In this context, however, it is important to point out that, although a product of the past, Zahn's paper appears to have been produced for the future. While most papers are cited for some time and then superseded by new results, not so this one. It seems that this paper is appreciated best today, based on its citation rate now being higher than ever. This may have to do with trends in our community, since Zahn's results turn out to be essential for extra-solar planetary systems. In any case, it is easy to predict that Jean-Paul Zahn's paper will still be a strong contender for the next anniversary issue of A&A.

Acknowledgements. I am grateful to Jean-Paul Zahn for giving me some insight into the developments that led him to write the paper discussed here.

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