Cnoidal waves for accessible high power and wide-band microresonator frequency combs

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Pumped Kerr microresonators have recently emerged as a promising source of optical frequency combs [1]. The production of octave-spanning spectrum by dispersive waves [2] and consequent demonstration of carrier-envelope phase locking has paved the way toward a wide field of comb applications. Nevertheless, there remain some obstacles before the goal of a simple off-the-shelf comb source is achieved. Current microcomb implementations rely on cavity solitons, and several of the present limitations of microcombs are tied to those of soliton waveforms. Cavity solitons exist only in a small red-detuned region of the pump parameters, where waveforms suffer from thermal instabilities. Furthermore, solitons are always obtained in the multistable regime, and therefore cannot be continuously connected to cw, so that elaborate, often non-deterministic, access protocols are needed to produce them. Another issue is that because solitons are accompanied by a strong pedestal, their comb power efficiency is low.

For these reasons there is an ongoing search for waveforms that are better comb sources. Here we study microcombs generated by cnoidal waves (CnW), also known as Turing rolls. CnW are generated readily in microresonators as pump power is increased beyond the modulational instability threshold, but have been generally overlooked, since the near threshold combs are narrow, while further increasing pump power quickly leads to more instabilities and chaos. However, as we show here by a systematic computational study, there is a much larger family of stable CnW and associated combs than previously realized; in fact, for each set of pump parameters there is a *band* of CnW with continuously varying periods. Fig. 1 shows projections of the CnW bands, optimized with respects to comb power efficiency and bandwidth. It follows from this analysis that comb power is optimized for highly red-detuned and intermediate strength pump, reaching 90% of total power, with comb bandwidth on par with that of solitons. An even larger bandwidth can be obtained for thermally-resilient blue-detuned CnW, although the comb tails are weaker. Importantly, most of the CnW manifold, including optimal CnW, are directly accessible from cw, unlike solitons. Thus, CnW offer several practical advantages over solitons, while their only significant disadvantage, the high repetition rate, can be dealt with using the dual resonator method recently demonstrated in [3].

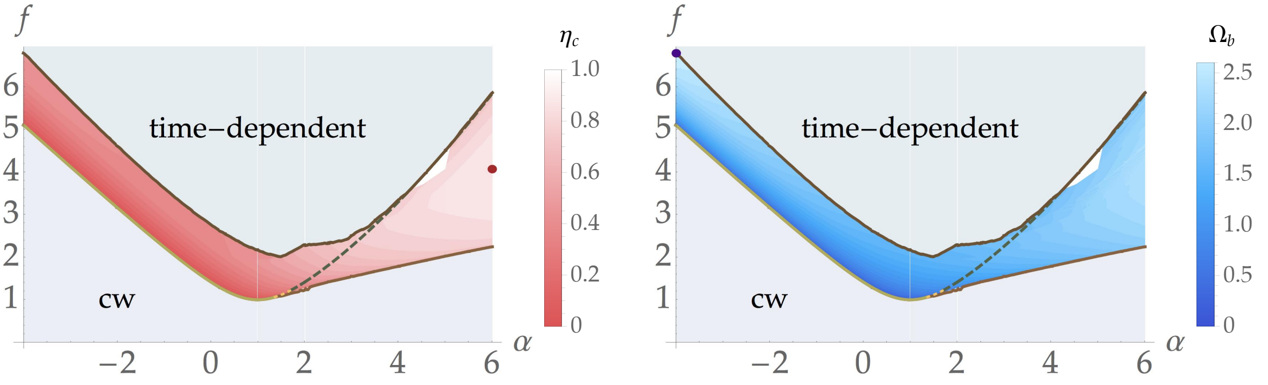

Figure 1: Colored regions are the projection of the domain of stability of cnoidal waves on the pump parameter space, detuning α and amplitude f. Each point is colored by the maximal CnW comb power efficiency η_c (left) or RMS bandwidth Ω_b (right, natural units). Points of optimal power efficiency and bandwidth are shown in red and blue, respectively.

[1] T. J. Kippenberg et al., Science 361, eaan8083 (2018). DOI: 10.1126/science.aan8083

[2] V. Brasch et al., Science 351, 357–360 (2016).

[3] D. Spencer et al., Nature 557, 81–85 (2018)