Critical Collapse of Electromagnetic Waves

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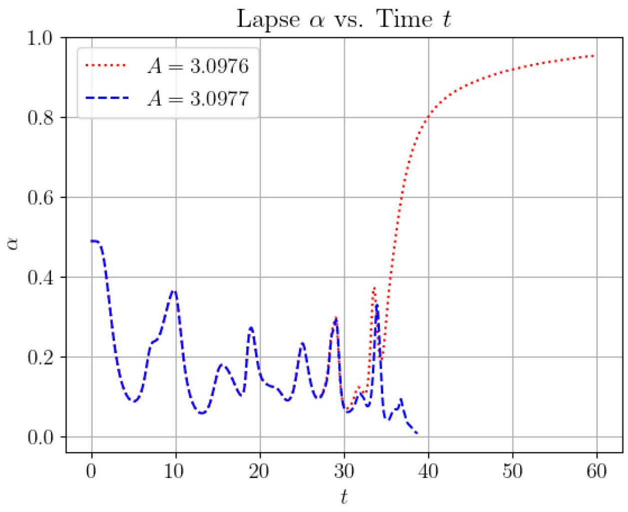
Matthew Choptuik was the first to report critical phenomena in gravitational collapse to black holes. In his seminal 1993 article[1] he explored different families of initial data parametrized by a parameter, say A. So-called critical phenomena can be observed in the vicinity of a critical parameter, A^*, that separates subcritical solutions (i.e those that disperse into infinity and leaving behind flat space in dynamical evolutions) to those that are supercritical (i.e. those that form a black hole).

While many aspects of critical phenomena are well understood in the case of spherical symmetry, the situation is much less clear when the solution is not spherically symmetric, the most important example being the gravitational collapse of vacuum gravitational waves. In our research we study critical phenomena in the gravitational collapse of electromagnetic (EM) waves. EM waves are of interest because they share with vacuum gravitational waves the property that a critical solution cannot be spherically symmetric – and yet they are easier to handle numerically than gravitational waves.

In our research we expanded the work of Prof. Thomas Baumgarte and his colleagues which had focused on dipolar EM waves.[2] This summer, I generalized their findings by considering quadrupolar and octupolar EM waves. Specifically, I used numerical simulations to investigate the behavior of the different waves and analyze how the different types of initial data affect the critical solution.



The picture on the left shows the results of simulations of quadrupolar waves. The lapse function, α , indicates the ratio between proper time and coordinate time. The line that trends towards unity (for A = 3.0976) displays subcritical data, while the one that trends towards zero (for A = 3.0977) is supercritical, and thus indicates the formation of a black hole. By fine-tuning the parameter to its critical value we can identify the critical solution. We found that the critical solution is different for each type of wave (dipolar, quadrupolar, octupolar), which points to non-uniqueness in the critical solution. As one indication of this non-uniqueness, we found that, for dipolar and quadrupolar waves, the collapse happens at the origin, whereas for octupolar waves, the collapse happens away from the origin. We expect that similar effects occur in the critical collapse of gravitational waves, explaining some of the peculiarities that have puzzled researchers for decades.

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References

[1] M. W. Choptuik, Phys. Rev. Lett. **70**, 9 (1993).
[2] T.W. Baumgarte, C. Gundlach, and D. Hilditch, Phys. Rev. Lett. **123**, 171103 (2019).