

# Stability of Supermassive Stars

Satya Butler, 2019

Throughout the summer, I worked with Alicia Lima (2019) and Professor Thomas Baumgarte (William R. Kenan Professor of Physics) on a project investigating the stability of supermassive stars. Supermassive stars are hypothetical stars on the order of thousands, millions, or more times as massive as our sun. They are not actual stars in that no nuclear fusion occurs in their cores. Instead, they are simply giant gas clouds. Also, there is no experimental evidence that they exist. Despite this, we examine them as a potential candidate for the formation of supermassive black holes.

The evidence that supermassive black holes exist is overwhelming. However, we do not know how these behemoths formed. One theory that attempts to explain this issue is the collapse of a supermassive star.

Previous work by Professor Baumgarte and Dr. Stuart Shapiro of the University of Illinois examined the stability of supermassive stars by considering radiation pressure (pressure created by photons) within the star, rotation, Newtonian gravity, and relativistic gravity.<sup>1</sup> From Professor Baumgarte and Dr. Shapiro's work, we learn that there is a uniform mass and central density combination, which we call a critical configuration, at which a supermassive star becomes dynamically unstable to radial perturbations. This instability precipitates collapse into a black hole. There is also a unique ratio between the polar radius and the mass of the star at this critical point.

Our research this summer aimed to determine how consideration of gas pressure, dark matter, and a cosmological constant may affect the stability of a supermassive star. We found that gas pressure, which is pressure created by individual particles bouncing off each other, has a small stabilizing effect on supermassive stars. This effect, however, is dependent on the mass of the star, and the greater that mass is, the less important gas pressure becomes. Dark matter is similar to gas pressure. It also has a stabilizing effect that reduces as the mass of the star increases, but this effect is tiny. Concerning the critical point mentioned above, the ratio of the polar radius and the mass of the star decreases slightly under stabilizing effects. This change is dependent on the mass of the star, which means (using future gravitational wave detectors) we can determine the mass of a supermassive star from its gravitational wave signal, or "chirp," when it collapses.

Contrary to gas pressure and dark matter, we found that a cosmological constant would have a destabilizing effect on a supermassive star. This effect is again dependent upon the mass of the star, but grows as the mass of the star increases. The effect is so small, however, that even a star of billions of times the mass of our sun would not be appreciably affected by a cosmological constant.

**Faculty Mentor: Thomas Baumgarte**

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<sup>1</sup> Thomas W. Baumgarte and Stuart L. Shapiro. (1999). Evolution of Rotating Supermassive Stars to the Onset of Collapse. *The Astrophysical Journal*, 526(2), 941.