Nonlinear Tidal Dissipation in White Dwarfs

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1 Introduction: White Dwarf Binaries

White dwarfs (WDs) are luminous, long-lasting products of late-stage stellar evolution that are held up by electron degeneracy pressure, a quantum mechanical effect arising from subjecting electrons to immense pressures. They are some of the densest objects in the known universe, behind only neutron stars (NS) and black holes (BH), fitting a solar mass into an Earth-sized sphere. Furthermore, they exhibit various chemical compositions, each of which is subject to different physics, and are found in a variety of interesting systems. As such, WDs are a unique and diverse window into matter under extreme conditions.

WDs are commonly found in binary orbits with companion objects, in which the two orbit their center of mass under their mutual gravitational attraction. The companion object ranges from another WD to a supermassive BH (SMBH), hypothesized to be at the center of galaxies and have mass 10^5–10^6 solar masses. All of these binary systems are very important to astrophysics. WD-WD binaries are most important for being thought to generate *Type Ia supernovae* in which one of the two WDs reaches a critical mass through accreting surrounding matter and collapses under its own gravity, producing a shock wave that tears the WD apart and releases immense amounts of energy. Type Ia supernovae are unique in astrophysics for their near-constancy throughout space and time, consistently occuring at the WD critical mass, and have been used to discover numerous cosmological phenomena such as dark energy.

WD-BH systems are also interesting subjects of study. Studies indicate that as WDs orbit the extreme gravity surrounding BHs, they will produce observable flares induced by gravitational tidal forces[3]. A WD orbiting a SMBH would produce gravitational waves, waves carried by distortions in space-time and generated according to Einstein's general relativity by accelerating massive objects, that are expected to be detected by the space-based *Laser Interferometer Space Antenna (LISA)* when deployed[5]. Gravitational wave astronomy is an increasingly exciting field as the *Laser Interferometer Gravitational-Wave Observatory (LIGO)* continues to make detections since its first in late 2015. As gravitational wave astronomy relies on accurate predictions of the expected signals, it is important to build as accurate models as possible before observation runs begin.

1.1 Tidal Dissipation

The excitation of *internal gravity waves* in the WD by the tidal forces of the companion is an effect seen in all of the aforementioned systems. Internal gravity waves, not to be confused with the gravitational waves discussed above, are internal displacements in the WD that oscillate and propagate due to a restoring buoyancy force. As these waves propagate outward from where they are excited, they are expected to grow in amplitude until they break, as do ocean waves on a shore, and deposit both energy and angular momentum inside the WD.

Previous work predicts that this dissipation mechanism can generate significantly more energy than thermal radiation from the WD surface alone and are thus a significant contribution to the WD energy budget[1]. The exact radial dissipation profile is of enormous interest since it is both sensitive to WD properties and can produce drastically different observable outcomes. One proposed outcome is a *tidal nova*, in which heating in the WD's degenerate hydrogen layer is significant enough to trigger runaway nuclear fusion and a significant, observable explosion[2]. Understanding whether such phenomena occur requires understanding how energy is distributed internally inside a WD.

Internal gravity wave breaking is a nonlinear hydrodynamic phenomenon. Such phenomena are known to require numerical simulation to study. It is therefore paramount to begin numerical study to build dissipation models inside WDs to characterise what phenomena can be observed in which WD models and characteristics.

2 Proposed Research

We propose to study tidal dissipation via nonlinear gravity wave breaking in white dwarfs via numerical simulation.

Our research will consist of computing for various WD models and compositions the energy and angular momentum dissipation profiles inside WDs. Once such profiles are obtained, we intend to add these profiles to existing stellar evolution codes to study the dynamical effects of tidal dissipation. We will attempt to find a compact or even analytical representation of our numerical work to greatly simplify and accelerate such integration. Finally, we will make observational predictions with our results and compare our predictions with existing observed WDs. Any software and results would be made in accordance with best practice and publicly available for the entire community.

2.1 Qualifications

The proposing researcher (YS) and his adviser (DL) are uniquely qualified to pursue such studies. YS has ample research experience in numerical simulation and is continuing to pursue academic study in hydrodynamics, turbulence and computation. He also completed a double Bachelors degree in physics and computer science from the California Institute of Technology. Finally, he has worked in the software industry for a year and continues to follow discussions of best practice far ahead of those in academia and apply them to his own work.

DL is a co-author on much of the latest literature on WD binaries and is an expert on many related subjects such as fluid dynamics in extreme matter and studies of other compact object systems. Cornell University also houses Saul Teukolsky's research group, one of the pre-eminent numerical relativity groups in the world, which will be frequently consulted for numerical best practices.

In terms of software, YS proposes to only implement what is not currently available in the community. Current literature indicates that the spectral hydrodynamic code Dedalus is able to handle instability-driven turbulence with high accuracy and speed, and our preliminary work seems to indicate that Dedalus will be sufficiently accurate to simulate wave breaking dissipation[4]. Modules for Experiments in Stellar Astrophysics (MESA) is a proven stellar evolution code that will likely need only be extended to incorporate the discovered dissipation models[6].

Nevertheless, both codes will require adaptation to be applied to the present problem (YS has already contributed an improvement to Dedalus), a task for which YS is well-equiped.

Should no existing software prove adequate, we are more than able and willing to develop a new code and contribute it to the community. Notably, no GPU-accelerated spectral hydrodynamic code has yet been released, which would be of great value to researchers, and YS is well-versed in GPU programming. Nevertheless, in the interest of the proposed science objectives codes will be developed on an as-needed basis.

2.2 Applications, Interest to the DoD

A robust pipeline coupling nonlinear wave breaking to system evolution would be of interest spanning all fields of physics. Barring BHs, all astrophysical objects exhibit internal waves that can break as they propagate towards the surface. Notable present interests in the astrophysical community include tidal disruption, planet formation and stars. Even in planetary and atmospheric sciences, wave breaking in atmospheres would share many common techniques with the proposed research.

The proposed research is extremely relevant to Department of Defense (DoD) fields of interest. WDs and its energetic phenomena we propose to study e.g. novae of all sorts are natural laboratories of extreme physics that have direct consequences for understanding of plasmas and other technologies integral to propulsion in aeronautics. A theory of nonlinear wave breaking would have far-reaching consequences in turbulence study and atmospheric sciences. Finally, the observation of our predictions could shed light on atmospheric optics, whether as a use for calibration or understanding contamination effects.

References

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