URCA PROPOSAL

COMPARISON OF TYPE IA SUPERNOVA MODELS WITH YOUNGEST KNOWN SUPERNOVA REMNANT

ALAN BLACK

Abstract. Type Ia supernovae (SNe Ia) are produced by the thermonuclear explosion of a white dwarf star. These supernovae(SNe) are the source of most iron in the universe. Additionally, the uniform peak brightness of SNe allows for precise distance calculations to remote points in the universe; these distance calculations lend themselves to more precise estimations of the scale of the universe. There have not been any recent observations of SNe Ia in our galaxy, but supernova remnants (SNRs) hold valuable information about the SNe themselves. There is, however, a gap in what we know about SNe and what we know through observing their remnants; the exact mechanism of the explosion is still not understood. By using data from a SN Ia model simulation 100 seconds after the explosion as the initial conditions for a hydrodynamic simulation, we can predict the appearance of the remnant hundreds of years later. Specifically, we aim to compare these results to the youngest known SNR (100 years old) in our galaxy, G1.9+.03 Previous 2D simulations worked on the assumption of spherical symmetry; by starting with a 3D model we may find different result. With our model, we can predict the location of light elements expelled by the blast (carbon and oxygen) as well as moderate (sulfur and silicon) and heavy elements (iron) formed in the SN that produced the remnant. This may also give us some insight into the composition of the interstellar medium surrounding G1.9+.03

1. Introduction

Type Ia supernovae (SNe Ia) are the result of the thermonuclear detonation of a white dwarf star. When gravitationally bound to a companion star, a normal (giant or main sequence) star or another white dwarf, matter from the companion is accreted by the white dwarf(WD). This matter accumulates on the WD until reaching the star's critical mass,

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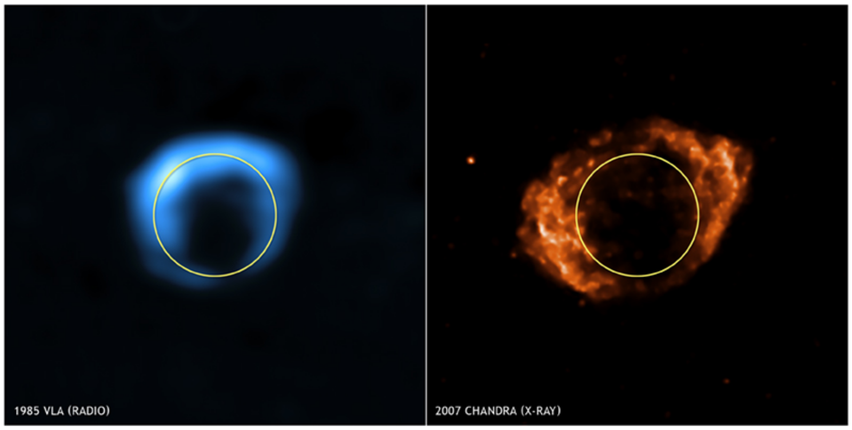
the Chandrasekhar limit. The increase in density and temperature caused by the additional mass restarts thermonuclear fusion by allowing for the fusion of carbon, a previously unfuseable element, in the core of the WD. The WD is unable to regulate this reaction as normal stars do, so a runaway fusion reaction known as carbon detonation may begin. The exact ignition mechanism of this "nuclear flame" is still not understood entirely.

SNe Ia are astronomically important for several reasons. Not only do they produce the majority of iron in the universe, they have a uniform peak brightness (due to the uniform mass of the WD) that allows them to be used as "standard candles" in precise distance calculations. Supernova remnants (SNR) are the leftover matter expanding from the explosion.There have not been any recent observations of SNe Ia in our galaxy, but SNR can give some insight into the SNe themselves.

Figure 1. Credit: X-ray (NASA/CXC/NCSU/S.Reynolds et al.); Radio (NSF/NRAO/VLA/Cambridge D.Green et al.)



A particular SNR of interest is G1.9+0.3, the youngest known SNR in the galaxy. The age of G1.9+0.3 was first determined by comparison between a 1985 radio image and a 2007 *Chandra* X-ray image. (Fig. 1) By comparing the two images and determining the expansion rate of the SNR, an age of roughly 100 years was suggested.(Reynolds et al. 2008) Subsequent radio imaging from the Very Large Array (VLA) agreed with these results (Fig. 2)and the remnant's expansion was later measured precisely using X-ray observation data. The estimated age was determined to be approximately 110 years.(Carlton et al. 2011)

G1.9+0.3 is located very close to the center of the our galaxy in the constellation Sagittarius.(Fig. 3) Although the light from the supernova reached us 100 years ago, the interstellar medium(ISM) surrounding the SNR blocked most of the visible light. Being in the dense dust cloud near the supermassive black hole at the center of the Milky Way, visible light reaching us was about a trillion times fainter than what that of an unobscured SN would be. Further study of this SNR may reveal more about the ISM surrounding it as

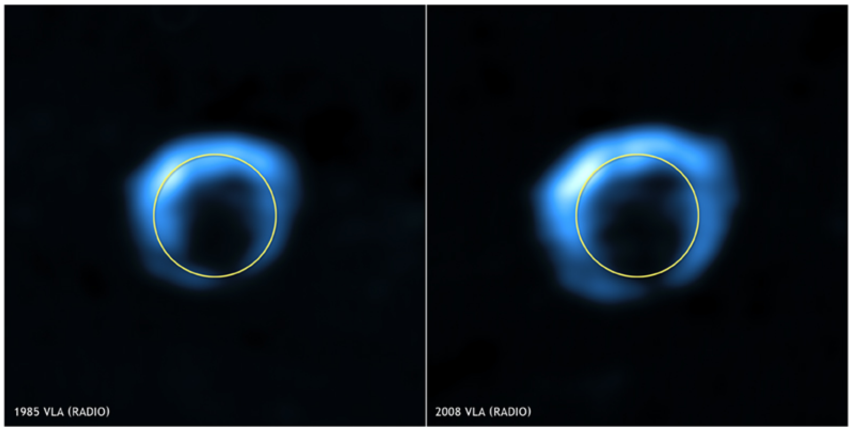


Figure 2. Credit:(NSF/NRAO/VLA/Cambridge D.Green et al.)

the density structure and composition of the surrounding ISM affects the overall structure and composition of the remnant. (Dwarkadas and Chevalier 1998)

The elemental composition of G1.9+0.3 has also been determined by observation of thermal X-ray emission. Spectral lines of Si, S, Fe, and possibly Ar and Ca were detected; this indicates that matter composed of these elements has passed through the reverse shock wave. The presence of radioactive Scandium-44, produced by electron capture from Titanium-44. Unexpectedly, Sc-44 was found in away from the inner ejecta; this indicates that the explosion may have been substantially asymmetric.(Borkowski et al. 2010)

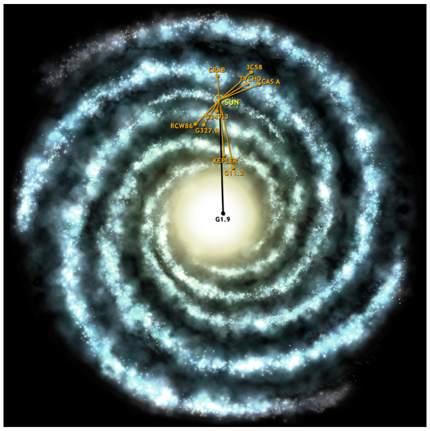


Figure 3. Credit: NASA/CXC/M.Weiss

2. Problem Statement

My project will center around evolving a 3D model of a SNE Ia and comparing it to G1.9+0.3 We will make spatial and kinematic comparisons between the model and our data on the SNR provided by X-ray and radio imaging. Using this model, we will predict the location of light elements expelled by the blast (carbon and oxygen) as well as intermediate (sulfur and silicon) and heavy elements (iron) formed in the SN that produced the remnant. With this data, we may learn more about the ISM surrounding G1.9+0.3 as well as its explosion mechanism. We will test our model to see if it can replicate the presence of the shocked intermediate and heavy elements found in the remnant as well as its observed size and expansion speed.

3. Proposed Work

We will run simulations based on an existing, highly-detailed numerical model set 100 seconds after the beginning of the explosion. The goal is to evolve this model forward in time to an age of 100 years using VH-1, a Fortran-based hydrodynamics code, and attempt to match the observed size and expansion speed of the SNR by adjusting external density.

A two-dimensional simulation like this has been made before, but modeling in three dimensions will operate without the assumption of cyllindrical symmetry used in the 2D simulation.(Griffeth et al. 2011)

4. Summary

The successful outcome of this project will hopefully yield new information on the youngest galactic SNR, SNe Ia in general, and current modeling techniques. The recent observations of G1.9+0.3 will undoubtably continue, allowing for more information with which we can evaluate our model. We will determine whether this SN model (and those like it) can produce something similar to G1.9+0.3 and, if not, how our current models fail. Perhaps most importantly, we may learn more about the explosion mechanism.

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URCA RESEARCH PROPOSAL

BREATHING MODE INSTABILITY IN HOYLE-LYTTLETON ACCRETION

ANNA S. CARR

Abstract. Gravitational accretion acts as a ubiquitous source of power for many celestial objects, yet how different conditions affect its fundamental properties remains poorly understood. Proposed in 1939, the Hoyle-Lyttleton model of accretion describes mathematically the behavior of a uniform gas cloud collecting onto a compact star. While this model has been found to predict generally accurate data, it is limited to steady, axisymmetric flow and fails to address many idiosyncrasies present in such a system. [Edgar, 2004] Recent studies of high-resolution simulations of HL accretion demonstrate instability in the mass accretion rate creating breathing mode oscillations of unclear origin. [Blondin and Raymer, 2012] We propose an in-depth investigation of accretion breathing modes using 2D simulations to characterize their nature as a function of changing conditions. By converting 3D simulations created by Blondin and Raymer (2012) into 2D, we will be able to study axisymmetric accretors of smaller radii in a high resolution grid for longer periods of time. We will examine the effects of changing the adiabatic index (γ) with a constant accretor radius and also observe results produced from an increasing mach number. Additionally, predictions made by Foglizzo (2001) will be evaluated during this process in an attempt to find any inherent relationships between variables and explain the mechanism behind breathing mode oscillation.

1. Introduction

As one of the four fundamental forces, gravity is responsible for copious phenomena in our universe and in particular, gravitational accretion. The process of accretion catalyzes innumerable celestial developments including star and planet formation, gamma-ray bursts, and type Ia supernovae. In 1939 Hoyle and Lyttleton aimed to explain climate variations by quantifying the mass accretion onto the sun as it moves through an interstellar uniform

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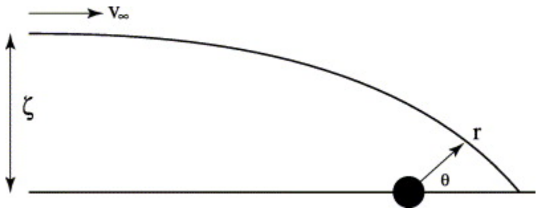

FIGURE 1. *Edgar 2004:* Sketch of the BondiHoyleLyttleton accretion geometry.

gas cloud. They derived equations for the radius of accreted material and the rate at which that material is accreted.

$$\mathrm{R}_a = \left(\frac{2GM}{v_\infty^2}\right) (1)$$

The above equation describes the radius of accreting materials at a velocity of v_∞. Matter will be collected by the point mass at a distance ζ as shown in fig. 1. The equation below shows the rate of mass accreted by the object with the material moving at v_∞ and with a density of ρ_∞.

$$_{HL} = \left(\frac{4\pi G^2 M^2 \rho_\infty}{v_\infty^3}\right)(2)$$

While they failed to achieve their goals of elucidating the fluctuations in Earth's climate, they did deduce a generally accurate model for material accretion of a point mass through a steady medium. A review of Hoyle-Lyttleton accretion was conducted by Richard Edgar in 2004 in which he discusses factors that were not addressed in the original methods, including drag force, flow stability, density and velocity gradients, radiation, and relativistic effects. Recent studies performed with simulations of Bondi-Hoyle-Lyttleton accretion attempting to include these aspects have yielded interesting results.

Simulations in both two and three dimensions of Hoyle-Lyttleton accretion have produced instabilities in the flow of an accreting object. Flip-flop instability in Hoyle-Lyttleton accretion, first described by Matsuda et al. (1987), is characterized by an oscillation in the wake of an accreting object, the flow switching between negative and positive angular momentum. This instability was thought to be a product of methodological errors, however it continued to manifest in more advanced two-dimensional simulations. [Blondin and Pope, 2009] The first high resolution three-dimensional simulations [Blondin and Raymer, 2012] established that with a sufficiently small accretor radius, breathing mode instabilities appear. Oscillations in the mass accretion rate reflect the breathing

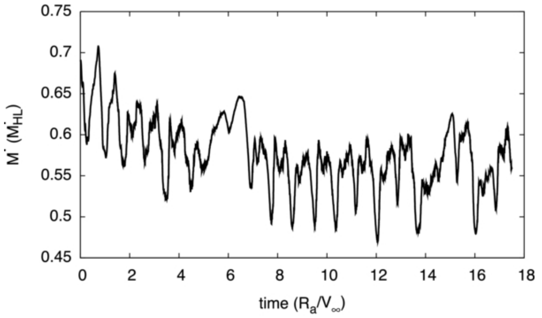

FIGURE 2. *Blondin and Raymer 2012:* Mass accretion rate as a function of time for a small accretion radius.

modes which were observed to have the same period as oscillations in the shock standoff distance. **We aim to investigate this phenomenon in order to uncover the nature and source of these breathing modes.**

The most prominent question of our endeavors is whether the breathing modes are a consequence of the methods of their simulation or if they are catalyzed by an underlying factor. If they are indeed a verifiable product of certain conditions in Hoyle-Lyttleton accretion, further simulations could ascertain their role in our universe and potentially explain rapid variability of accretion driven luminosity in systems ranging from x-ray binaries to quasars. If proven to be a mere result of technique, then science will still benefit from knowledge of exactly the computational mechanism responsible for it. An in-depth examination of breathing modes in HL accretion has yet to be conducted. We are the first to propose an investigation of this sort and our findings could lead to a more comprehensive understanding of the mechanisms and variables involved in gravitational accretion.

2. PROCEDURE

In our simulations, we will use the code VH-1. Originating at the University of Virginia, the version of VH-1 that we will use has been modified extensively by Dr. John Blondin. It is based on the Piecewise Parabolic Method [Collela & Woodward, 1984] and solves Euler's equations of ideal inviscid compressible gas flow. Since it was demonstrated by Blondin and Raymer (2012) that the flow of the accreted material in 3D remained axisymmetric, we intend to begin with the three-dimensional code created by Blondin and Raymer (2012) and modify it to run in two dimensions in order to most effectively to perform the simulation in higher resolution with minimal computing power.

To quantify the instability of breathing modes, we will track the mass accretion rate as a function of time and use this to measure the oscillation period and the amplitude. In Blondin and Raymer (2012), significant instability was only observed in smaller radii of $R_s = 0.01R_a$. We will attempt to find the exact accretion radius at which the flow becomes unstable and use smaller radii to understand the relationship between the intensity and the frequency of the oscillations and size of the radius. Characterizing this relationship will provide insight into why the flow becomes unstable and potentially reveal further conditions to be tested.

Blondin and Pope (2009) found that with a changing adiabatic index, an accretor of a constant radius exhibited instability in γ below a certain threshold. We will use similar methods to discern whether different adiabatic indexes will have a similar effect on the instability in breathing modes. Additionally, by increasing the Mach number (>3), we will be able to observe any effects on level of instability. By simulating these changes we will obtain a greater understanding of the exact way each differing condition affects the instability which will help determine the mechanism that creates breathing modes in Hoyle-Lyttleton accretion.

3. Conclusion

A thorough understanding of the behavior of matter accreting onto an object is essential to furthering our knowledge of the way the universe behaves. To this end we propose a careful investigation of the instabilities produced in previous simulations in order to obtain such an understanding. Our simulations of breathing mode instabilities may demonstrate new relationships among the variables involved in accreting materials or simply prove to be a mistake in previous simulations. Either result will advance our methods and benefit scientists working towards creating reality in computational simulations.

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The Effects of Progenitor Rotation on SASI in Core-Collapse Supernovae

NCSU PHYSICS: UNDERGRAD RESEARCH IN COMP. ASTROPHYSICS

ELLIOT CARTEE

Abstract. Current simulations of core-collapse supernovae (CCSNe) suggest that the post-bounce shockwave stalls at a radius of approximately 100km. This stalled shockwave has been found to be unstable, in what is known as the Spherical Accretion Shock Instability (SASI). Recent numerical simulations suggest that the SASI plays an important role in reviving the explosion and powering CCSNe. Previous simulations involving SASI, however, are limited in their study of how rotation of the progenitor star affects the SASI. We propose to systematically investigate progenitor star rotation in our simulations of CCSNe. We will use the VH-1 hydrodynamics code in two dimensions following the methods described by Blondin and Shaw. Our goal with these simulations is to quantify the effects of rotation on the SASI,by measuring growth rates of the SASI as a function of progenitor rotation.

1. Introduction

Core Collapse Supernovae (CCSNe) are well recognized as playing a vital and important role in the chemical evolution of the universe and our understanding of stellar evolution. Attempts to understand the explosion mechanism of these supernovae through numerical simulations have encountered many difficulties. In particular, after the gravitational collapse of the core, the post-bounce shockwave is known to stall at a radius on the order of 100 km. The existence of CCSNe implies that the shock is revived and continues to explode the star, but the exact mechanism by which the shock is revived is not yet completely determined. Many candidates exist for this mechanism, including interactions with neutrinos from the proto-neutron star (PNS), or convection, but another possible candidate is in the instability of this stalled accretion shock, Known as the SASI.

The SASI was discovered in numerical simulations by Blondin et al.(2003). In these simulations, the SASI was dominated by a sloshing mode related to the spherical harmonic $l = 1$. Further simulations by Blondin (2005) have also shown that there exists a non-axisymmetric spiral wave mode identified by the harmonic $m = 1$. This $m = 1$ spiral wave mode has also been shown to be related to the accretion of significant amounts of

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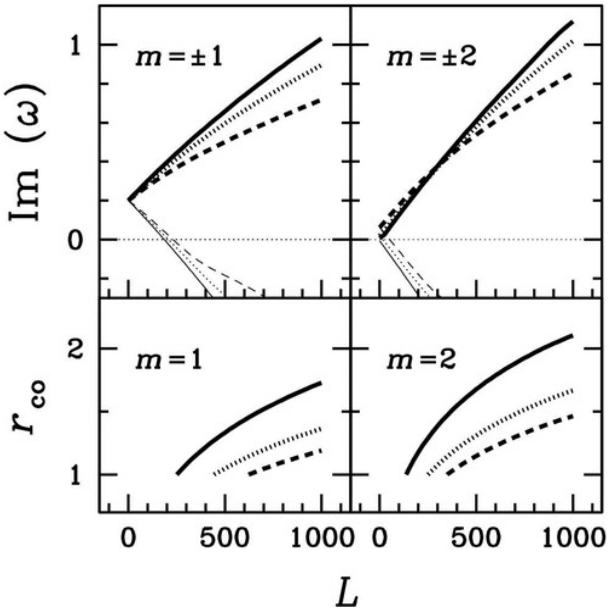

FIGURE 1. From Yamasaki & Foglizzo (2008): "Growth rate and corotation radius as a function of the specific angular momentum L... Thick lines are for the modes with $m > 0$ and thin lines are for $m < 0$... The solid, dotted, and dashed lines are for the fundamental modes and the first and second overtones, respectively..."

angular momentum (Blondin & Mezzacappa 2007), suggesting a possible explanation of the extremely rapid rotation of pulsars created by CCSNe.

The growth rate of the SASI, and specifically these spiral wave modes, have been the focus of much theoretical and analytical study in recent years. Yamasaki & Foglizzo (2008) studied the SASI in a simple toy model with cylindrical geometry, and found that angular momentum of the flow and the growth rates of the spiral modes are almost linearly dependent. They also found that the one-armed spiral mode $m = 1$ is linked to small rotation rates, while the two-armed spiral mode $m = 2$ is linked to stronger rotation rates. They also found that the spiral mode present is found to be rotating in the same direction as the flow, in agreement with numerical simulations by Blondin & Mezzacappa (2007).

2. Motivation

Investigation of the effect of progenitor star rotation rates on the SASI is interesting for a number of reasons. For instance, progenitor rotation has been shown to be in the opposite direction of the spin of the neutron star in 3D simulations of SASI (Blondin & Mezzacappa 2007). So progenitor rotation clearly plays an important role in the conditions of the compact supernova remnant, and is a likely explanation for the rapid rotation rates seen in pulsars created in CCSNe. We also wish to test the theoretical predictions of Yamasaki

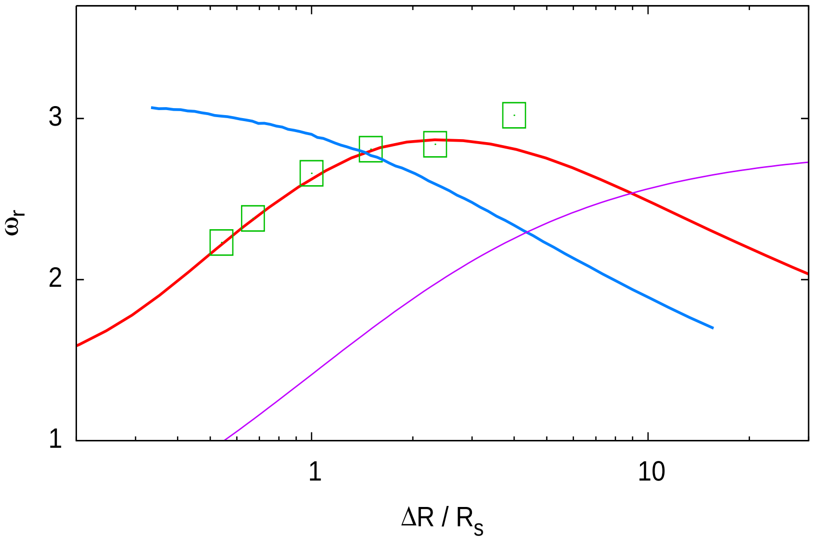

Figure 2. From Blondin: A plot comparing the SASI growth rate (real part of omega from the linear analysis) derived from our non-rotating 2D simulations (squares) with the results of Foglizzo'slinear stability analysis. The red line is the l=1 mode. Delta R is the shock stand-off distance (radius of shock - radius of star).

& Foglizzo (2008), who have used a perturbative analysis to predict a relation between the growth rate of the SASI and the specific angular momentum of the flow. While previous numerical simulations have included progenitor star rotation, and some of its effects, our goal is to actually quantify these effects of rotation, specifically the effect of rotation on the growth rate of the SASI. Also, the work of Yamasaki & Foglizzo used cylindrical geometry. This is a problematic model in that real CCSNe occur in three dimensions, and do not exhibit cylindrical symmetry. This cylindrical geometry also creates problems in that it changes the dependence of the mass accretion rate and other factors upon the radius, which could potentially produce significant changes to the results. So we are interested in not only testing Yamasaki & Foglizzo's predictions in cylindrical geometry, but also expanding our simulations to three dimensions and testing whether these predictions are still valid.

3. Proposed Work

We intend to numerically simulate the SASI in CCSNe using VH-1, a PPMLR code, with cylindrical symmetry. Our work will mainly follow the simulations of Blondin & Shaw (2007), and we will also be using a constant mass accretion rate and uniform specific angular momentum at the outer boundary. We shall also distribute uniform specific angular momentum throughout the initial flow, and a reflecting boundary at the inner radius to model the surface of the PNS. We shall also use a thin cooling layer parametrized by $\alpha = 3/2$ and $\beta = 5/2$. Our first step would be to develop one-dimensional simulations of the accretion shock, in both cylindrical (as in Yamasaki & Foglizzo) and spherical geometries (as in Blondin & Shaw), and use these as initial conditions for later simulations. Then we will develop two-dimensional models without rotation, and compare the growth rates as a function of accretion radius with already published data from Blondin & Mezzacappa. Then we would expand our two-dimensional simulations to include rotation, and cover a two-dimensional parameter space determined by flow angular momentum and accretion shock radius. To measure the growth rate of the SASI, we will follow the technique used in Blondin & Mezzacappa (2006), and fit the simulation data for the shock radius to a function of the form $R_s(t) = R_0 + R_1 e^{\omega_r t} sin(\omega_i t + \delta)$ using least-squares fitting. From this we will obtain the real and imaginary components of the growth rate, ω.

4. Summary

Overall, CCSNe are among the most fascinating and important phenomena in astrophysics, and we wish to learn more about the instability of the stalled accretion shock, as this may provide both a mechanism for reviving and continuing the shock, and also other effects, such as determining the spin of the remnant pulsar. To this end, we propose to numerically simulate the SASI in cylindrical symmetry at different initial rotation rates, and then quantify the effects that this rotation has upon the SASI. Ultimately, we wish to numerically test the theoretical predictions of Yamasaki & Foglizzo (2008) regarding the relationship between specific angular momentum of the flow and growth rates of the SASI, and extend that result to more realistic geometry.

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URCA PROPOSAL

THE CUMULATIVE EFFECTS OF TURBULENCE AND NEUTRINO SELF INTERACTIONS IN CORE-COLLAPSE SUPERNOVAE

KELSEY REPPERT AND NEEL KABADI

Abstract. During core-collapse supernovae explosions large fluxes of neutrinos are emitted from the proto-neutron star formed at its center. As these neutrinos escape the flavor composition evolves: turbulence in the material flowing down upon the proto-neutron caused by the stalled shock wave and the super high neutrino density in core-collapse supernovae both have an effect. To date studies of the two effects have focused upon each separately even though both occur simultaneously. Using new codes for the neutrino evolution and hydro simulations we propose to calculate the neutrino evolution in the core of supernovae incorporating both turbulence and high neutrino density in an attempt to determine whether neutrino signatures of collective effects are modified by the turbulence and whether these changes can be observed. If they are detectable, then this will allow us to have a greater understanding of what is occurring during a future core-collapse supernova.

1. Introduction

The neutrino flux emitted from a core-collapse supernova releases a great deal of the energy in a supernova explosion. Additionally, it is responsible for transferring momentum which causes the stalled shock wave, at a size of 200km in radius, to regain movement [5]. After the explosion ends, these neutrinos are released and will eventually reach the Earth. Since these core-collapse supernovae event only come a few times per century [3], we were not able to obtain a great deal of information from the neutrinos from SN 1987A, as our

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neutrino telescopes were not fully prepared to receive massive amounts of data. Modern neutrino telescopes, however, are capable of collecting data which can tell us a wealth of information concerning the progression of a supernova. But before we can fully understand the next supernova explosion, we must develop theory on how to decode the signals that we recieve from neutrinos. Because there are several different factors which can influence the oscillations of the large number of neutrinos (on the order of 10^{58}) which are emitted in a core-collapse supernova, we must understand them completely so we know what kind of neutrinos were emitted.

2. Analysing the Various Factors

While it is clear that that there are many variables which affect neutrino oscillations, their combined effect has not yet been fully analyzed. It is not certain how much turbulence is necessary to cause significant fluctuations in the neutrino density as the radial distance from the star increases. The extremely high neutrino density and the neutrino-neutrino interactions both have effects upon the changing lepton flavors of the neutrinos, also known as neutrino oscillations. This is seen in a recent study which re-examines data from the collective oscillations from SN 1987A on lepton flavor and found that the neutrinos can provide us with a wealth of information concerning the progression of supernovae by simply observing the oscillations [3]. In addition, there is turbulence generated by the aforementioned stalled shock wave, which also effects the oscillations. By observing these effects, we can determine what effects correlate to energy transfers and other events concerning the neutrino flux. Figure 1 shows the effects of neutrino neutrino interactions on the flux of different energy neutrinos. There is a clear difference in the neutrino fluxes of both electron neutrinos and anti electron neutrinos before and after the addition of interaction effects. We expect that upon the addition of turbulence effects there will be an even greater change in the fluxes of neutrinos of different energies.

3. Proposed Work

We will use new code for the neutrino evolution and hydro simulations to calculate the neutrino evolution in the core of supernovae. This new code will incorporate both turbulence and high neutrino density. This will then allows us to compare results of this joint simulation to simulations of the past. We will be able to determine whether neutrino signatures of collective effects are modified by the turbulence and whether these changes can be observed. The code has already been written so we must first learn the appropriate background material including quantum mechanics and C++. We must learn the basics of neutrino transfer and how they interact with each other as well as surrounding matter. After this we can proceed to run full simulations varying different parameters like the initial distance, final distance, range of energies, the number of calculations, and the radius of the neutron star. This will take the most time as we use data from six super novae profiles. We will run two O-Ne-Mg supernova, two from a 10.8 solar mass model and two from a 18 solar mass model. We will be running each twice in order to vary the time stamp. Depending on the required number of calculations we may need to utilize a local super computer. While varying these inputs we will look for outputs that resemble previous observations and also differences in the outputs of our model when compared to previous models. If we are able to observe and evidence of significant effect we will further investigate the circumstances under which these effects are present. We hope to find that this model including neutrino density interactions as well as turbulence effects will show significant improvements over previous models.

4. Summary

The results of this study will give the astrophysics community a better understanding of neutrino transfer during core collapse supernovae explosions. Current models have only included effects of high densities of neutrinos or turbulence but never both. By including both these effects in our model for the first time we will achieve a more realistic outcome that will be more applicable to the observational world. Our simulations will give a better idea of what to expect to find in neutrino telescopes next time we observe a core collapse super novae and more importantly whether signals we observe will allow us to do backwards calculations so we may be able to input the data from the next observed supernovae and get a better idea of what is going on inside the explosion.

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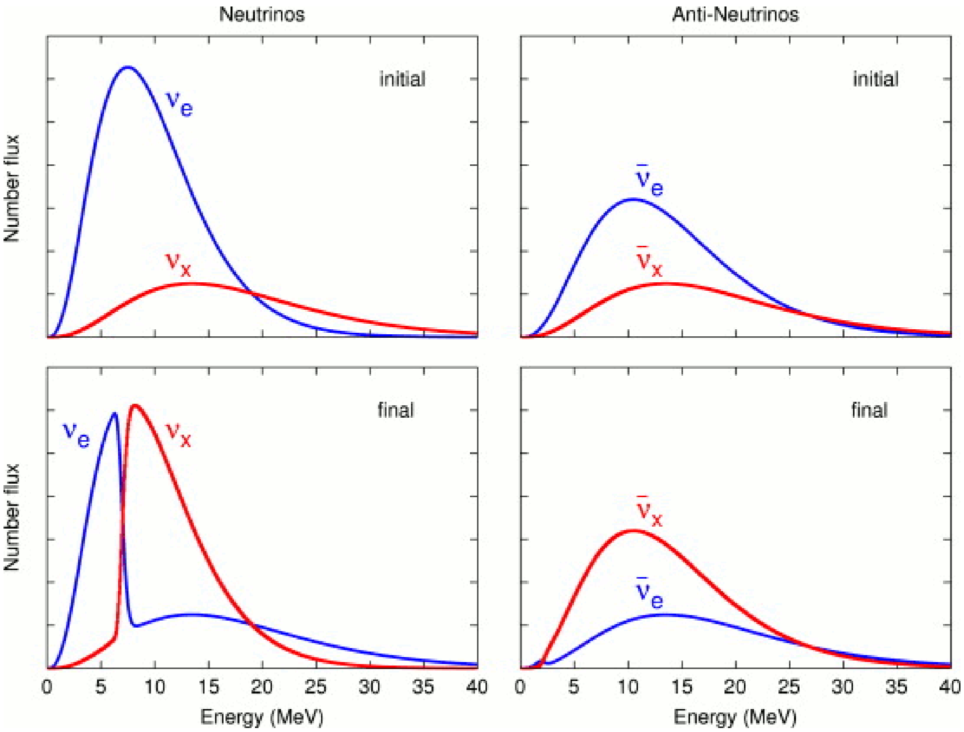

Figure 1. G.G. Raffelt / Progress in Particle and Nuclear Physics 64 (2010) 393399 Fig. 1. Supernova neutrino spectra before and after collective oscillations. This should be changed even more after the addition of turbulence effects.

URCA RESEARCH PROPOSAL

A QUEST FOR AN ELUSIVE COMPANION STAR

SHENGKAI ALWIN MAO

Abstract. The mechanism behind Thermonuclear (Type Ia) Supernovae is believed to involve a white dwarf and a companion star, which could be a normal star (single-degenerate model) or a white dwarf (double-degenerate model). Finding the companion star would show that the companion star was not destroyed in the collision, implying a single-degenerate progenitor. Due to the sheer size of the supernovae and the number of candidate stars contained therein, it is necessary to determine the star's rough location before making an exhaustive search. It is thought that the companion star can be found at the explosion center, but assumptions that the explosion center would be at the remnant's geometric center have proved fruitless. However, these searches did not factor in the possibility that a nonuniform interstellar medium (ISM) density could cause an asymmetric expansion, which would cause the apparent geometric center to shift from the true explosion site. By running numerical hydrodynamics simulations modeling the effects of ISM density gradients, a collection of remnants can be formed, and a more reliable search location can be determined. The results will be applied by examining past searches on two young supernova remnants in order to determine if their search regions were insufficiently vast to account for such shifting.

1. Introduction

1.1. Supernovae, best known for their distinctly high luminosities, are categorized into several groups. One of these classifications is known as Type Ia, defined by a distinct lack of hydrogen and helium spectral lines. Type Ia supernovae are also unique in that they are believed to be thermonuclear explosions of white dwarfs in close binaries which have managed to gain enough mass from a companion star to exceed the Chandrasekhar limit. However, some of the greatest significance of Type Ia supernovae can be found in their importance to cosmology and to understanding the chemical evolution of galaxies. The convenient uniformity of their brightness allows them to be used as standard candles. Then, using Type 1a supernovae as standard candles, distances, redshifts, and velocities can be measured. Such measurements have brought to light the acceleration of the expansion of the Universe. Even our knowledge of the cosmological parameters themselves depends upon the accuracy of these measurements. In addition, Type Ia supernovae are responsible for the majority of iron production in the universe. To better understand Type Ia supernovae is to better understand the chemical evolution of galaxies.[8]

1.2. However, the accuracy and reliability of the results and the understanding garnered from Type Ia supernova studies are arguably questionable. The nature of the companion star is not fully understood, which affects the reliability of necessary assumptions such as those of uniform brightness. In order to better understand the Universe and the galaxies within, it is critical to improve our understanding of Type Ia supernovae, and more specifically, their progenitors.[8]

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1.3. Currently, the two most prominent proposed models are the single-degenerate model and the double-degenerate model. In the single-degenerate model, the white dwarf accretes mass from a non-degenerate companion star. By accreting hydrogen and helium, the white dwarf can gradually increase its mass to the Chandrasekhar mass, at which point the supernova is triggered. Alternatively, according to the double-degenerate model, the companion star is instead a white dwarf. If the two white dwarfs combine, and if they have a combined mass greater than the Chandrasekhar mass, a supernova results. [8]

1.4. Both models have advantages and disadvantages. For example, the single-degenerate model requires the accretion of hydrogen, which has been shown to be difficult to drive.[1] On the other hand, the gradual accretion to a Chandrasekhar mass involved in the single-degenerate model also effectively explains why Type Ia supernovae would be fairly uniform.[8] The double-degenerate model is successful in explaining a lack of hydrogen and helium in Type 1a supernovae, since only carbon-oxygen white dwarfs are involved. However, this model presents the troubling possibility of neutron star formation instead of supernova ignition.

2. Problem

2.1. Since arguments and debates cannot and have yet to identify the correct model, a different approach must be taken.[7] A distinguishing property between the single-degenerate and double-degenerate models is that the companion star in a single-degenerate supernova should survive, while the combination of two white dwarfs in a double-degenerate supernova will not leave anything.[8] Thus, finding the companion star in a supernova remnant would provide absolute proof of the single-degenerate scenario.

2.2. Unfortunately, this task is in and of itself prone to difficulty and controversy. Although it is possible to identify the progenitor star amongst other stars through its characteristic higher radial-velocity and unusual spectral lines, supernova remnants are enormous, and efforts to find the companion star are too resource-intensive due to the sheer number of candidate stars contained within. In addition, attempting to narrow down the search to the apparent geometric supernova remnant center has proved fruitless. (See Figure 1.) The only claimed discovery of a companion star in a Type Ia supernova was the supposed progenitor of Tycho's supernova of 1572. However, the validity of this result was highly controversial, not absolute.[6][7] Thus, a progenitor of a Type Ia supernova is yet to be found.

3. Proposed Solution

3.1. It is known that density irregularities in the interstellar medium surrounding a supernova remnant can cause the remnant to become non-spherical.[4]As the remnant expands into a nonuniform interstellar medium, the interactions form asymmetric remnants and shift the apparent geometric center of the remnant away from the true supernova origin.[2] Since past searches did not account for these effects, it is possible that past surveys did not consider distances far away enough from the apparent geometric center. Only by factoring in these effects can a more definitive result be attained. By conducting a search in an area which is far more likely to contain the true supernova center, the result will be far more likely to be valid, accepted, and applicable.

3.2. In order to determine a better search location, the possible shift of the apparent center from the true center must be calculated. This will be done by using numerical hydrodynamics simulations to model the expansion of a supernova remnant into a nonuniform interstellar medium with various density gradients. Thus, a collection of remnants can be formed to study the displacement of the apparent center in relation to the interstellar medium density gradient. Then, the hydrodynamics code will be used to attempt to reproduce real supernova remnants in order to predict where their progenitors, if existent, may be found. Since the brightness and mass density of supernova remnants have been found to be correlated[5], observational data of those supernovae can be used to describe their interstellar medium density gradients. Those conditions will be analyzed by hydrodynamic simulations to estimate the apparent supernova remnant center shift.

3.3. I must first learn and familiarize myself with VH-1 hydrodynamics code in order to model the expansion of supernova remnants. In the process, I may have to learn Fortran. Afterwards, I will select different density gradients and starting conditions with which to run simulations. I will record the results in order to better understand how the supernova remnant center shifts. Then, I will adjust the simulation parameters in an attempt to model actual supernova remnants so that I can provide a better location in which to search for a progenitor.

4. Summary

Type Ia supernovae are extremely important for studying cosmology and the chemical evolution of galaxies. This is because of inherent traits such as predictable brightness and high iron production unique to Type Ia supernovae. Since our knowledge of topics, such as the expansion of the universe and the delay time before the formation of iron, hinges on our understanding of those inherent traits, it is paramount to understand the progenitor and mechanism which makes a Type Ia supernova possible. In order to do so, the debate between single and double progenitor scenarios must be settled, and the most definitive way to do so would be to find the progenitor. This can only be achieved through a well-guided rummage of a well-chosen area. Hopefully, through hydrodynamics modeling and consideration of the effects of interstellar medium density gradients, my research can provide what's necessary to answer the progenitor problem.

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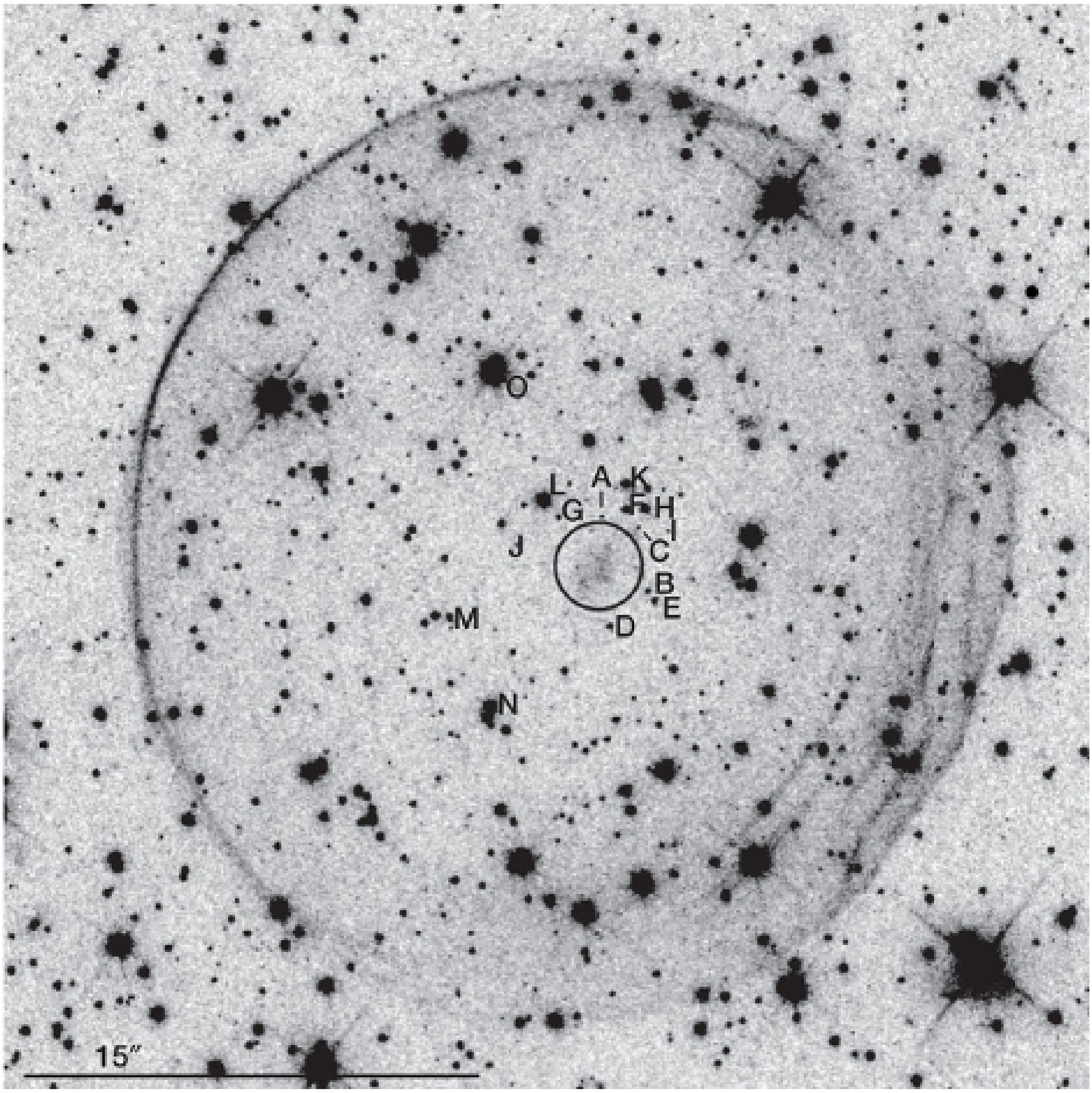

Figure 1. This image of SNR 0509-67.5 reveals the scope of the problem: the vast number of stars that must be checked in a supernova remnant. The circle is a projection of where the progenitor could be, with a 99.73% chance of being within the circle, ignoring the asymmetries in the remnant.[7]

URCA RESEARCH PROPOSAL

TWO- AND THREE-DIMENSIONAL TURBULENCE IN CORE-COLLAPSE SUPERNOVAE

MITHI A. DE LOS REYES

Abstract. The Spherical Accretion Shock Instability (SASI), in which a supernova shock wave stalls and produces a turbulent post-shock flow, has generally been accepted as an important phenomenon in core-collapse supernovae. However, the effects of the turbulence caused by SASI have yet to be thoroughly investigated; indeed, it has been hypothesized that two- and three-dimensional SASI simulations may produce incongruent results due to this turbulence. We therefore propose to use both two- and three-dimensional hydrodynamic simulations of core-collapse supernovae to study the growth of the SASI-driven flows. We will produce and analyze Fourier transform power spectra to quantify energy conversion (i.e. gravitational potential energy to the kinetic energy of turbulent flow) on different length scales. Finally, we hope to compare two- and three-dimensional results to determine if kinetic energy cascades toward small or large length scales, and if turbulence energy saturates at similar levels in two and three dimensions.

1. Introduction

Supernovae are not only one of the most famous stellar phenomena, but also one of the most scientifically important, due to their importance in nucleosynthesis and the formation of neutron stars and black holes. The less-common type II or core-collapse supernova (CCSN) occurs when a supergiant star can no longer fuse nuclei past iron in its core. The core then collapses in on itself until it reaches nuclear density, at which point it can no longer compress. The consequent core bounce creates a massive shock wave that expands radially

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outward, leaving behind either a neutron star or a black hole, as well as an expanding gaseous supernova remnant (see Fig. 1).

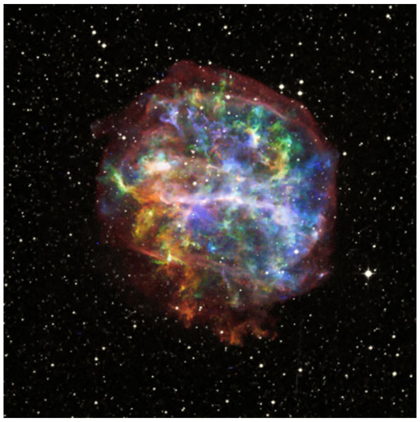

FIGURE 1. Composite X-ray and optical photo of supernova remnant G292.0+1.8. Photo from NASA.gov.

Although this simple definition is widely accepted, the exact process by which these CCSN occur is still not fully understood. Unfortunately, we cannot directly observe the inside of a proto-neutron star (PNS), let alone the inside of a supernova, and so we must rely on numerical simulations based on first principles to shed light on CCSN.

2. TURBULENCE IN CORE-COLLAPSE SUPERNOVAE

Hydrodynamic simulations, in particular, have made important progress in modeling CCSN. Initial hydrodynamic models did not explode (e.g. [Mezzacappa et al. 2001]); instead, the supernova shock wave was found to stall at a radius of approximately 100km, where it would remain until some combination of factors (neutrinos, convection, magnetic fields, etc.) presumably revived it. This standing accretion shock appeared to be stable in spherical symmetry.

Blondin et al. (2003) then found that while one-dimensional accretion shocks are indeed stable, two-dimensional spherical accretion shocks actually produce low-modal (l=1, 2) growing oscillations when perturbed. This Spherical Accretion Shock Instability (SASI) was initially thought to be produced by a vortical-acoustic cycle [Foglizzo 2002]; it was later suggested that the SASI could result from a standing pressure wave that oscillates inside of the cavity of the accretion shock [Blondin & Mezzacappa 2005]. Whatever its origin, the SASI first undergoes a linear regime, in which the accretion shock remains in a roughly spherical shape with a radial post-shock flow. Once the pressure wave in the l=1 sloshing mode grows large enough to distort the accretion shock, the SASI transitions into the nonlinear regime (Fig. 2).

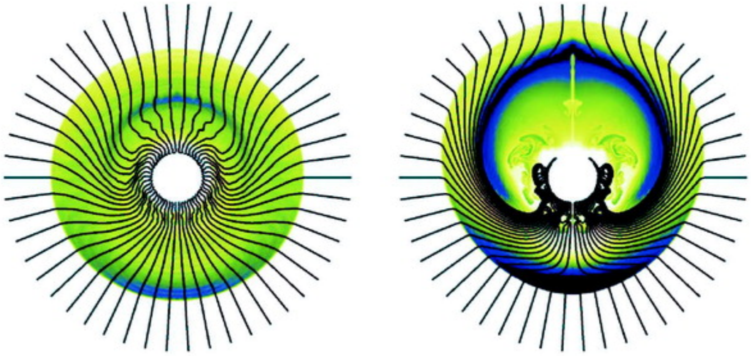

Figure 2. The SASI transitions from the linear phase (left) to the nonlinear phase (right), displaying a characteristic shift from radial to non-radial flow. [Blondin & Mezzacappa 2005]

The nonlinear SASI has been investigated in non-axisymmetric two- and three-dimensional models [Blondin & Shaw 2007, Blondin & Mezzacappa 2007]. In the nonlinear phase, the SASI begins to generate higher-mode turbulence in a positive feedback loop of sorts—turbulent flows drive pressure waves, which in turn propagate around the closed sphere and further distort the accretion shock from its spherical shape, creating further turbulence. This non-axisymmetric SASI displays a spiral mode (m=1), in which the SASI wave propagates around the axis of the PNS and creates a shock front (see Fig. 3).

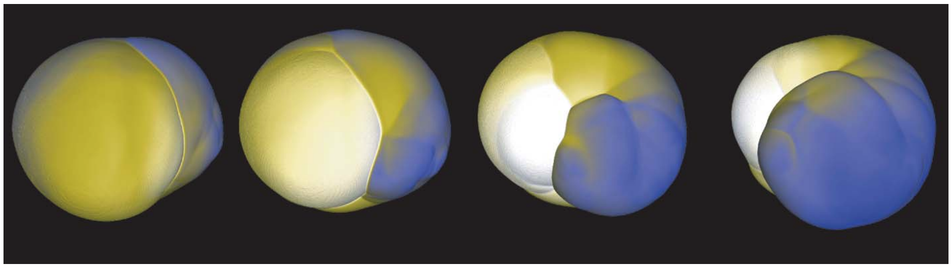

Figure 3. In the non-axisymmetric SASI, the leading front of the SASI wave (shown in blue) propagates around the face of the shock. [Blondin & Mezzacappa 2007]

To conserve zero net angular momentum, a rapid narrow downflow of gas spirals inwards against the direction of the SASI wave, accreting on the surface of the PNS core. This accretion spins up the angular momentum of the PNS, potentially explaining how rapidly-rotating pulsars may form from non-rotating progenitor stars [Blondin & Mezzacappa 2007]. The SASI therefore serves as a method to convert gravitational potential energy from the infalling star into the angular momentum of a pulsar; not only that, but combined with the energy of neutrino heating, turbulent kinetic energy may help revive the stalled shock and power a supernova explosion.

3. Recent questions

The SASI has since been accepted as a valid phenomenon, and recent literature has begun to investigate its role in core-collapse supernovae. In particular, recent work has shown the SASI-driven turbulence may generate or amplify magnetic fields [Endeve et al. 2010, Endeve et al. 2012], which could have implications for the magnetization of neutron stars. However, the post-shock turbulence produced by the SASI is still poorly understood. Since the energy of this turbulence could potentially power a supernova explosion, characterizing the turbulent flows of a CCSN may further our understanding of the supernova mechanism.

Turbulence itself has posed a difficult problem for centuries. Two-dimensional turbulence, though extensively studied through both experimental and numerical methods, is still not entirely understood, let alone the more complex three-dimensional turbulence. In either two or three dimensions, as described by Kolmogorov [Boffetta & Ecke 2012], turbulence is known to be characterized by a vortex cascade. This direct cascade occurs when enstrophy (the integral of vorticity squared over a defined surface) flows to small scales, eventually dissipating as viscosity (see Fig. 4). In more poetic terms, as fluid dynamicist Lewis F. Richardson wrote, “Big whorls have little whorls that feed on their velocity, / And little whorls have lesser whorls, and so on to viscosity.” Furthermore, the enstrophy cascade can be identified by the self-similar energy spectrum $E(k) = k^{-\frac{5}{3}}$, where k represents wavenumber ($k \approx \frac{1}{L}$, where L is the characteristic length scale) [Ishihara et al. 2009].

However, Kraichnan (1967) was the first to show that an inverse cascade can also occur in two dimensions, when small vortices grow—either by a merging or straining interaction—into larger vortices, dissipating energy as friction. The inverse cascade displays an energy spectrum of the form $E(k) = k^{-3}$ that levels off at low k. In two dimensions, then, both cascades must be taken into account, while in three dimensions only the direct cascade should have any effect.

Kraichnan also proposed that an inverse cascade in two dimensions could effectively stall without a way to dissipate energy on large scales. This would lead to a condensate in which energy and enstrophy are concentrated around the minimum wavenumber, creating a power spectrum with a constant scaling of k^{-3}. This condensate appears as two strong vortices of opposite sign, a scenario that would not be implausible in a supernova shock wave, since turbulent flows in atmospheres and other geophysical flows have often been characterized by large-scale vortices [Boffetta & Ecke 2012].

Endeve et al. (2012) began preliminary investigations of SASI-driven turbulence by plotting the kinetic energy spectra, confirming the existence of the direct cascade in three dimensions. Their work found that the log-log power spectra had a slope of $-\frac{4}{3}$; once

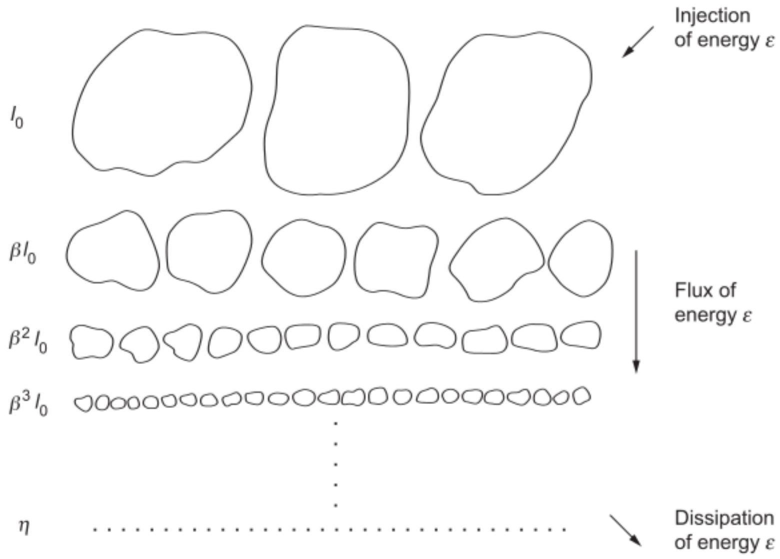

FIGURE 4. Direct cascade, in which enstrophy flows to smaller scales and is dissipated as viscosity. β is the scaling factor, here taken to be $\frac{1}{2}$. [Ecke 2005]

corrected for density stratification, the scaling became $k^{-\frac{5}{3}}$, matching the Kolmogorov scaling law [Ishihara et al. 2009]. However, given that their earlier observations of velocity probability distribution functions (PDFs) implied intermittency due to their skewed non-Gaussian forms, we believe that the Kolmogorov assumption of self-similarity is invalid in this situation, and that the Kolmogorov scaling laws may require some correction.

Furthermore, Endeve et al. gave the impression that the peak of the spectrum moved to smaller k over time and used this observation as evidence to support the conclusion that energy cascaded from large to small scales. Since wavenumber k and length scale L are inversely proportional [Boffetta & Ecke 2012], this conclusion is a direct contradiction of the data, and either the presentation or the interpretation of this data must be incorrect.

4. PROPOSED WORK

We therefore aim to clarify and extend the work of Endeve et al. by comparing both two- and three-dimensional turbulence. We will use VH-1, a multidimensional FORTRAN code, to numerically solve the idealized Euler equations of gas flow. VH-1 uses the piecewise parabolic method to solve the finite-difference versions of these differential equations in Lagrangian coordinates, then remaps them onto the original Eulerian grid (see [Blondin et al. 2003] for further details regarding VH-1).

From the data produced by VH-1, we will create power spectra of turbulent velocity using the 3DEX code for spherical Fourier-Bessel decomposition (details of this code are presented in [Leistedt et al. 2012]). By measuring the peaks of the spectra at successive times, we can quantitatively measure the length scale of greatest energy conversion (i.e. gravitational potential energy to kinetic turbulence energy). We hope to determine conclusively whether the spectrum peaks shift towards lower (see Fig. 4) or higher wavenumbers (longer or shorter length scales, respectively) in our model, which will help to clarify Endeve et al.'s conflicting data.

We will then analyze the log-log plots of two- and three-dimensional power spectra to determine the slope. We will compare this scaling with Kolmogorov's universal law of $k^{-\frac{5}{3}}$ and the Kraichnan's proposed scaling of k^{-3} for two-dimensional turbulence. Deviations from either scaling may suggest that either scaling law makes assumptions that are invalid in the case of turbulence in CCSN.

Finally, to investigate claims of anomalous scaling due to intermittent turbulent flows, we will also compare probability distribution functions (PDFs) of a single velocity component with Gaussian distributions; highly non-Gaussian PDFs will suggest strong intermittency, so that proposed logarithmic corrections [Boffetta & Ecke 2012] are required for the theoretical value to match the experimental data.

5. Summary

To better understand turbulence length scales in core-collapse supernovae, we propose to use VH-1 code to produce two- and three-dimensional hydrodynamic simulations of the SASI. We will use the Fourier-Bessel decomposition outlined in 3DEX code to create power spectra, and we will use these power spectra of the turbulent velocity to determine the direction of cascade of turbulent energy—whether it is from small scales to large scales (inverse cascade) or large to small (direct cascade)—thus resolving an apparent contradiction in the work of Endeve et al. (2012). We will also create PDFs of velocity components to determine the extent of intermittency in the SASI-driven turbulence.

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URCA RESEARCH PROPOSAL

REDSHIFT AND ANGULAR EFFECTS ON THE DETECTED DURATION OF GAMMA-RAY BURST LIGHT CURVES

MICHELLE VILLENEUVE

Abstract. As some massive stars evolve, it is thought that long-duration (>2 sec) GRBs are produced from relativistic jets from the poles of the star before the star collapses forming a black hole. The length of time these jets produce these gamma-rays (T_{engine}) was always thought to be the same length of time that the bursts were detected (T_{90}). By creating GRB simulations at different redshifts, introducing noise and observing angle, the light curve and therefore detection of the burst changes. These simulations can show that bursts produced by the same stellar explosion could have different T_{90} times, depending on the distance and observing angle.

1. Introduction

There are two types of gamma-ray bursts observed in space. The short bursts (SGRBs) last less than 2 seconds, while the long duration bursts (LGRBs) last longer than 2 seconds and up to a few hundred seconds. Figure 1 shows different light curves, based on detected GRBs. The LGRBs are associated with jets that form at the poles of a massive star, that is rotating very fast, at the end of its life as it collapses to form a black hole. LGRBs are seen at redshifts up to $z = 8.2$ (Lazzati et al. 2010a) because of the intense energy emitted. The time the relativistic jets produce a gamma-ray burst is called T_{engine}. The gamma-ray burst is detected and a light curve is made plotting the number of photons per second vs time. The time it takes 90 percent of the photons to be collected is widely considered to be the same time that the burst is emitted.

2. Redshift and Angular Effects

The effects of redshift and viewing angle of the gamma-ray jets can distort the detection of the burst to almost non-recognition. The light curve of the LGRB, as the redshift value changes, changes such that the curve is not distinctly defined. As redshift increases, noise throughout the curve increases. This can greatly effect the detection of the LGRB in that the start and end time of the burst may change due to this noise. The angle that the burst makes with the detector will also change the light curve. Based on work by Morsony et al. (2010) , for angles <5 degrees, increasing the angle leads to a decrease in the luminosity throughout the curve. Previous work has made the assumption that the observed duration of GRBs is characterized by T_{90} (Bromberg et al. 2012). LGRBs are thought to follow the Collapsar model, where a jet starts at the center of a massive

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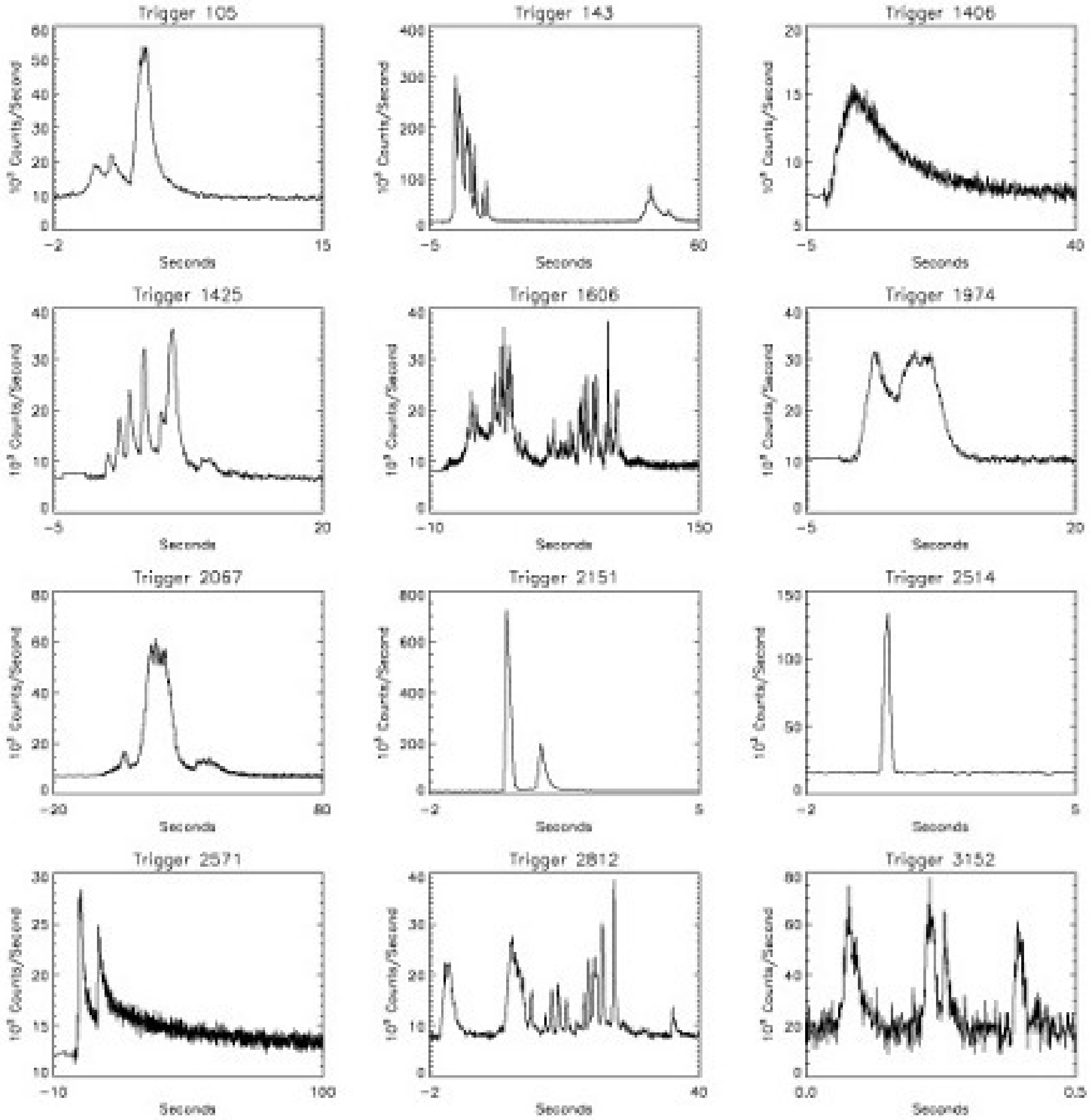

FIGURE 1. This shows the different types of gamma-ray bursts, no two bursts are the same. (Credit: J.T. Bonnell (NASA/GSFC))

star and breaks through the outer envelope of stellar material. This also suggests that SGRBs are from non-Collapsar progenitors. However, Figure 2 shows the effect that the observed angle has on the light curve of a single simulated stellar burst. At least some of the SGRBs detected are due to progenitors of LGRBs that are observed at large angles of 40-50 degrees (Lazzati et al. 2010a).

3. TECHNICAL PLAN

The luminosity of a progenitor is converted to flux, as a function of redshift, as seen from a detector. This is because the detector only collects the redshifted version of the burst and flux decreases as distance squared, where the distance is a function of redshift, mass distribution and the cosmological constant (Carroll et al. 1992). Random noise is added to the light curve proportional to the value of z from the redshift. An algorithm to detect the begining and end of the burst will

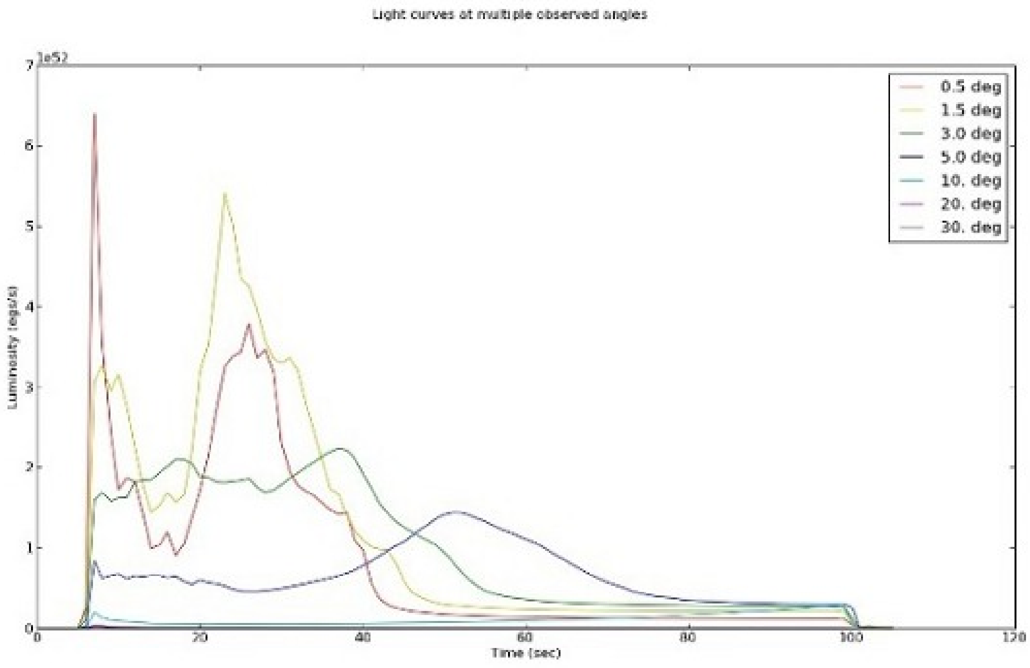

Figure 2. These light curves are from the same simulated stellar explosion observed at different angles. At angles less than 5 deg, it is easy to see how the light curve changes, where at larger angles, the burst is almost undetected.(Credit: Lazzati, Davide)

be coded. This code will calculate T_{90} of the burst. Through this we will obtain a relationship between T_{engine} and T_{90} as a function of redshift and observing angle. This part of the project is scheduled for completion by June 22nd 2012. The next part of the project is to show the effects of the observing angle of the jet to the detector by placing the same simulated progenitor at different observed angles and redshift through the star formation rate. A faux database will be compiled showing the different T_{90} times that are "detected." The duration distribution rate will be graphed and be compared to observed catalogs, such as the one in Figure 3. This part of the project is set for completion by July 30th 2012.

4. Summary

This project would further advance the study of gamma-ray bursts, a field that is so diverse that it has been studied for decades and still little is known. By working forward from simulations of relitavistic jets producing gamma-ray bursts from the engine to the surface of the star, this project simulates the burst traveling through space and being detected on earth. Compiling a faux database of these gamma-ray bursts would give insight into the posibility that most SGRBs are in fact from LGRB progenitors as seen from different angles and distances.

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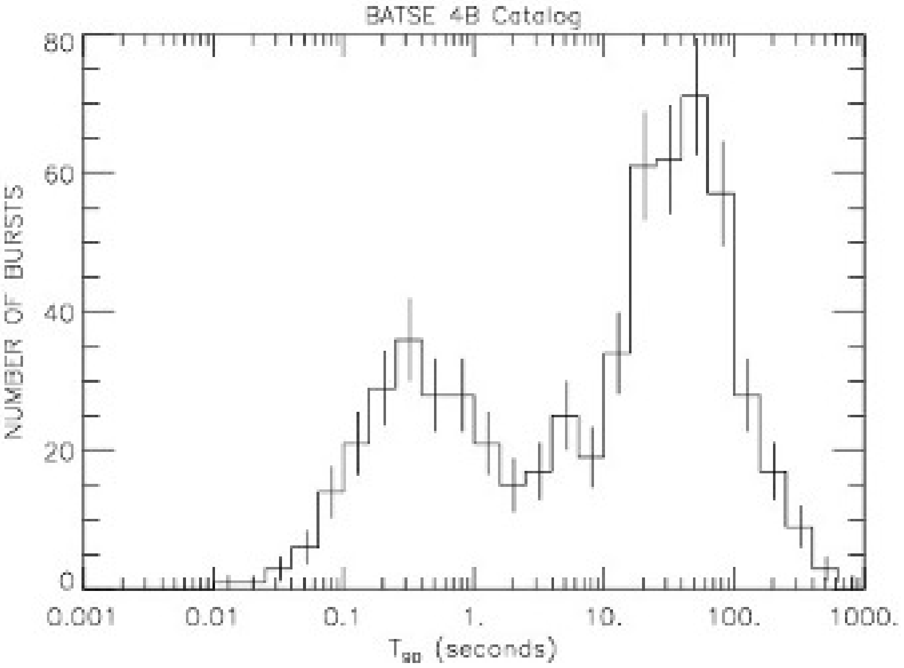

Figure 3. This is the distribution of T_{90} duration times as observed by BATSE. (Credit: NASA)