Gradient Mechanism Initiation of Detonations

... in the context of the GCD model

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Introduction

Who am I?

Basics

- Born and raised in Germany
- 1998-2002 University of Arizona
  B.S. Astronomy/Math/Physics
- 2002-2007 University of Chicago
  Physics Ph.D. candidate
  Advisor Jim Truran
- Generously supported by JINA,
  but also much interaction and support from the FLASH Center

At the ECT* in Trento 2004
Past and Present Research Interests

- Comparative photometry observations of sdB stars in binaries for eclipses, reflection effects etc.
- Discovered new class of long period g mode pulsators (class PG 1716+426)
- Interest in r-process nucleosynthesis
- NSE calculations for Type Ia Supernova flame models
- Neutronization in Type Ia Supernovae
- Initiation and structure of detonations
Rising Bubble, Breakout and Gravitationally Confined Flow
Initiation of a detonation from a hot spot

Temperature profile used

- FLASH3 solves reactive Euler equations (fully compressible, PPM)
- 64 blocks with 16 zones and 7 levels of AMR, blocksize = R
- 13 Species Network
- 1-D Spherical Geometry
- Systematically determined smallest radius for which detonation initiates by bisection
- Varied composition, $T_m$ and $T_0$
Introduction

Initiation of Detonation

NSE for Type Ia Supernovae

Spacetime Diagrams

\[ \rho = 10^7 \text{ g cm}^{-3} \quad T_{\text{max}} = 3.2 \cdot 10^9 \text{ K} \quad T_0 = 4 \cdot 10^8 \text{ K} \quad \text{Oxygen} \]

\[ R = 1.5 \text{ km} \quad R = 1.6 \text{ km} \]
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NSE basics

Nuclear Statistical Equilibrium (NSE) I

- Asymptotic state nuclear matter reaches in detailed balance (fusion reactions are balanced by photo-dissociation)
- At a given temperature, density and electron fraction NSE is well defined
- Timescale to reach NSE much longer than timescale to reach NSQE
- Can now calculated state of the art NSE from any initial state under constraints (constant enthalpy, pressure)
Nuclear Statistical Equilibrium (NSE) II

\[\sum_{i} X_i - 1 = 0 \quad (1)\]

\[\sum_{i} \frac{m_u}{m_i} \left[ (Y_e - 1) Z_i + Y_e N_i \right] X_i = 0 \quad (2)\]

\[X_i = \frac{m_i}{\rho} g_i \left( \frac{2\pi m_i kT}{h^2} \right)^{3/2} \Lambda_i \exp \left[ \frac{Z_i \mu_p + N_i \mu_n + Q_i}{kT} \right] \quad (3)\]

\[\Lambda_i = \exp (-f_i) \quad (4)\]

\[f_i = A_1 \left[ \sqrt{\Gamma_i \left( A_2 + \Gamma_i \right)} - A_2 \ln \left( \sqrt{\frac{\Gamma_i}{A_2}} + \sqrt{1 + \frac{\Gamma_i}{A_2}} \right) \right] + 2A_3 \left[ \sqrt{\Gamma_i} - \arctan \left( \sqrt{\Gamma_i} \right) \right] \quad (5)\]

where \( A_1 = -0.9052 \) and \( A_2 = 0.6322 \) and \( A_3 = -\frac{\sqrt{3}}{2} - \frac{A_1}{\sqrt{A_2}} \).
Effects of Electron Captures

NSE Binding Energies

\[ Y_e = \frac{N_P}{N_P + N_N} = 0.50 \]

\[ Y_e = 0.48 \]
Mass Fractions in NSE along central zone W7 trajectory

$t = 2 \cdot 10^{-6} \text{s}$

$Y_e = 0.50$
$\rho = 2.0 \cdot 10^9 \text{ g cm}^{-3}$
$T = 8.4 \cdot 10^9 \text{ K}$

$t = 0.78 \text{s}$

$Y_e = 0.455$
$\rho = 8.0 \cdot 10^8 \text{ g cm}^{-3}$
$T = 8.2 \cdot 10^9 \text{ K}$
Mass Fractions in NSE along central zone W7 trajectory

$t = 1.2 \text{ s}$

$Y_e = 0.455$
$\rho = 4.4 \cdot 10^7 \text{ g cm}^{-3}$
$T = 4.2 \cdot 10^9 \text{ K}$

$t = 1.5 \text{ s}$

$Y_e = 0.455$
$\rho = 1.3 \cdot 10^7 \text{ g cm}^{-3}$
$T = 2.8 \cdot 10^9 \text{ K}$
Fractional Neutronization Rate: $\log_{10}(\frac{\dot{Y}_i}{\dot{Y}_e})$

$t = 2 \cdot 10^{-6}$ s
$\dot{Y}_e = -4.1 \cdot 10^{-1}$ s$^{-1}$

$t = 2.6 \cdot 10^{-3}$ s
$\dot{Y}_e = -2.6 \cdot 10^{-3}$ s$^{-1}$

$Y_e = 0.50$
$\rho = 2.0 \cdot 10^9$ g cm$^{-3}$
$T = 8.4 \cdot 10^9$ K

$Y_e = 0.455$
$\rho = 8.0 \cdot 10^8$ g cm$^{-3}$
$T = 8.2 \cdot 10^9$ K
Fractional Neutronization Rate: $\log_{10}\left(\frac{\dot{Y}_i}{\dot{Y}_e}\right)$

- $t = 1.2$ s
  - $\dot{Y}_e = -2.0 \cdot 10^{-7}$ s$^{-1}$

- $t = 1.5$ s
  - $\dot{Y}_e = 0$ s$^{-1}$

$Y_e = 0.455$
$\rho = 4.4 \cdot 10^7$ g cm$^{-3}$
$T = 4.2 \cdot 10^9$ K

$Y_e = 0.455$
$\rho = 1.3 \cdot 10^7$ g cm$^{-3}$
$T = 2.8 \cdot 10^9$ K