Gradient Mechanism Initiation of Detonations

... in the context of the GCD model

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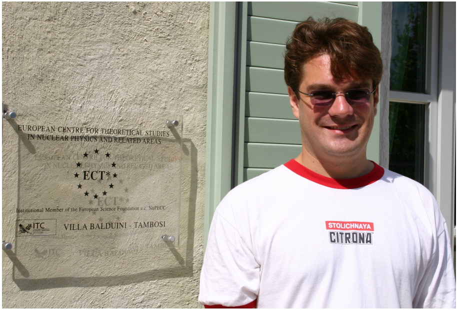
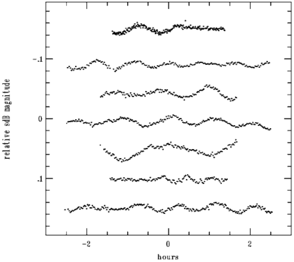
Basics

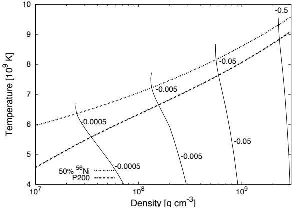


At the ECT* in Trento 2004

- 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

Past and Present Research Interests





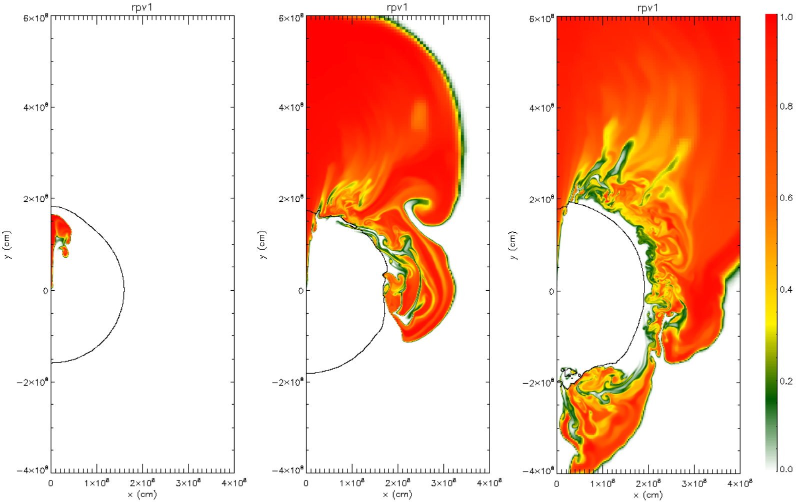
- Comparative photometry observations of sdB stars in binaries for eclipses, reflection effects etc.

  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

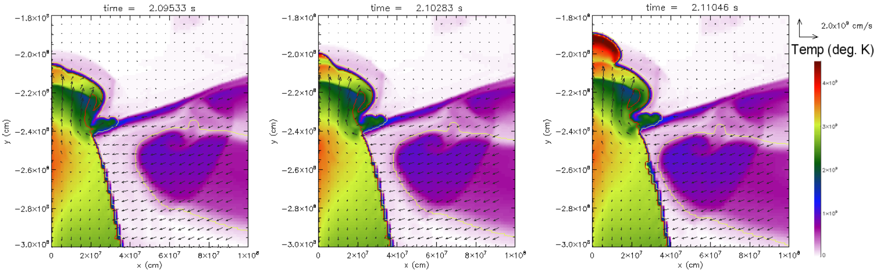
GCD movie

The movie goes here.
Download it here:
http://flash.uchicago.edu/j̃bgallag/6KM_MOVIES/6km_18rb_42off/temp

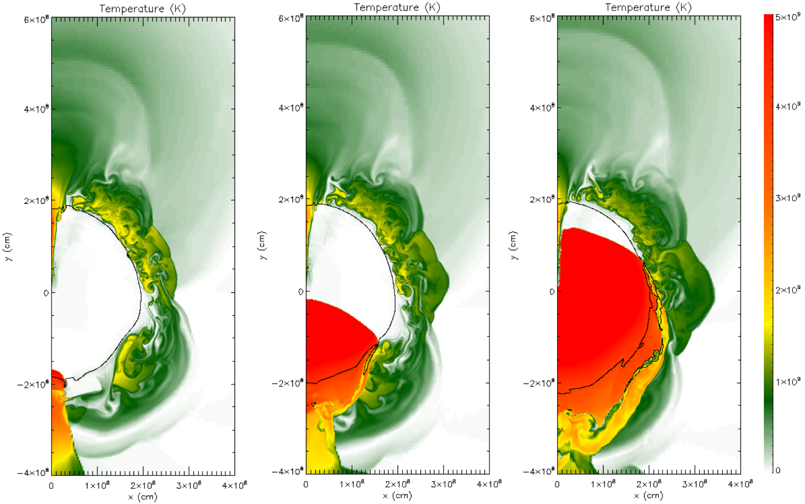
Rising Bubble, Breakout and Gravitationally Confined Flow



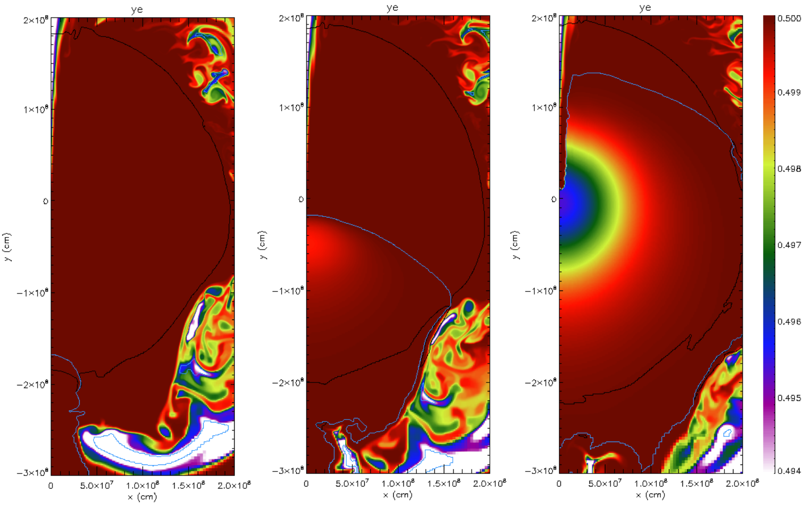
Zoom of South Pole Region



Detonation Sweeping across WD



Neutronization

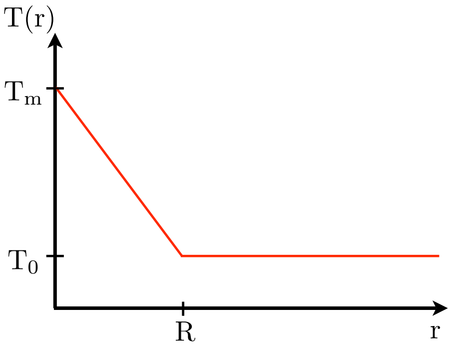


Zel'dovich gradient mechanism

Zel'dovich et al. (1970,1988,1990) and Lee et al. (1978) suggested that induction time gradients may be responsible for a wide range of detonation initiations. The induction time gradient leads to a spatial time sequence of energy release, leading to a compression wave which subsequently steepens into a shock. This is also known as the SWACER (Shock Wave Amplification by Coherent Energy Release) mechanism.

Aforementioned 3D and 2D simulations don't resolve relevant scales of initiation of detonation.

Initiation of a detonation from a hot spot

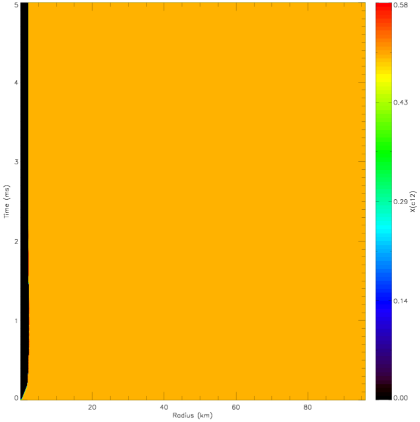


Temperature profile used

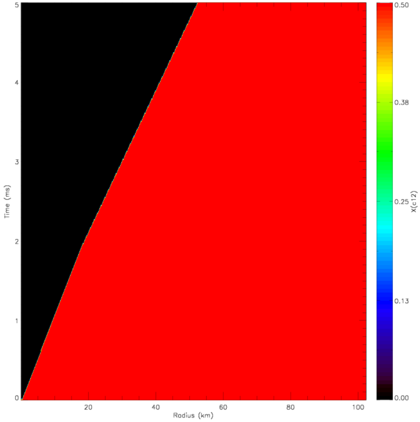
- FLASH3 solves reactive Euler equations (fully compressible, PPM)
- 64 blocks with 16 zones and 7 levels of AMR, blocksize = R
- 13 Species Network
- 1-D Spherical Geometry
- Systematically determined smallest radius for which detonation initiates by bisection
- Varied composition, T_m and T_0

$\rho = 10^7$ g cm^{-3} $T_{\max} = 3.2 \cdot 10^9$ K $T_0 = 4 \cdot 10^8$ K Carbon

$R = 1.5$ km



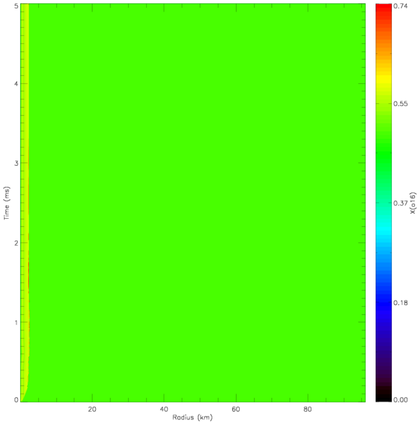
$R = 1.6$ km



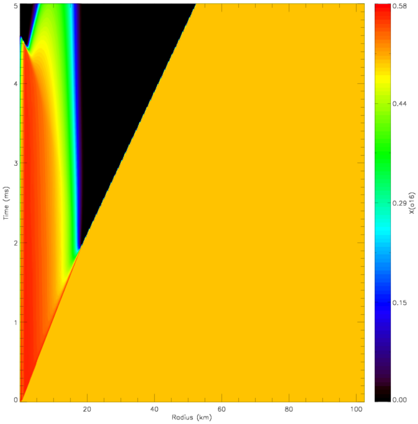
Spacetime Diagrams

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

R = 1.5 km



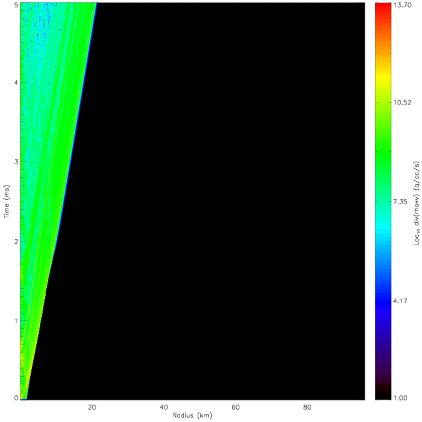
R = 1.6 km



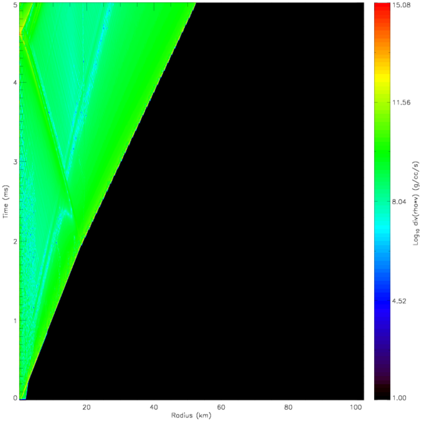
Spacetime Diagrams

$\rho = 10^7$ g cm^{-3} $\quad$ $T_{\mathrm{max}} = 3.2 \cdot 10^9$ K $\quad$ $T_0 = 4 \cdot 10^8$ K $\quad$ $\nabla \cdot (\rho v)$

R = 1.5 km



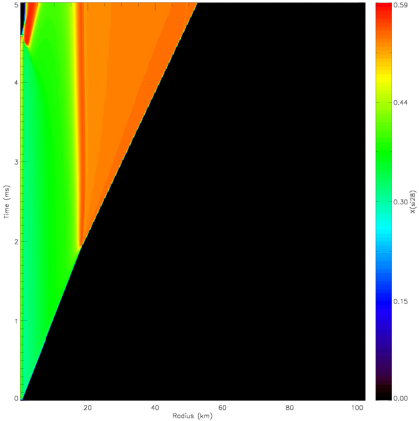
R = 1.6 km



Spacetime Diagrams

$\rho = 10^7$ g cm^{-3} $\quad$ $T_{\max} = 3.2 \cdot 10^9$ K $\quad$ $T_0 = 4 \cdot 10^8$ K $\quad$ Si & Ni

$R = 1.6$ km



$R = 1.6$ km

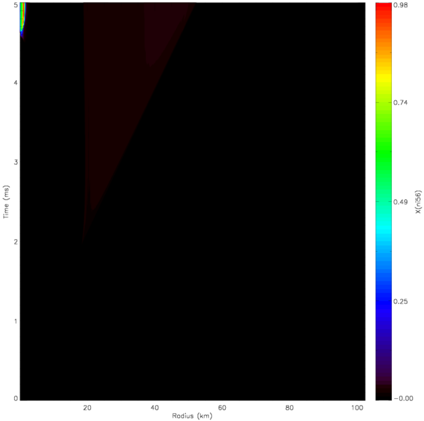
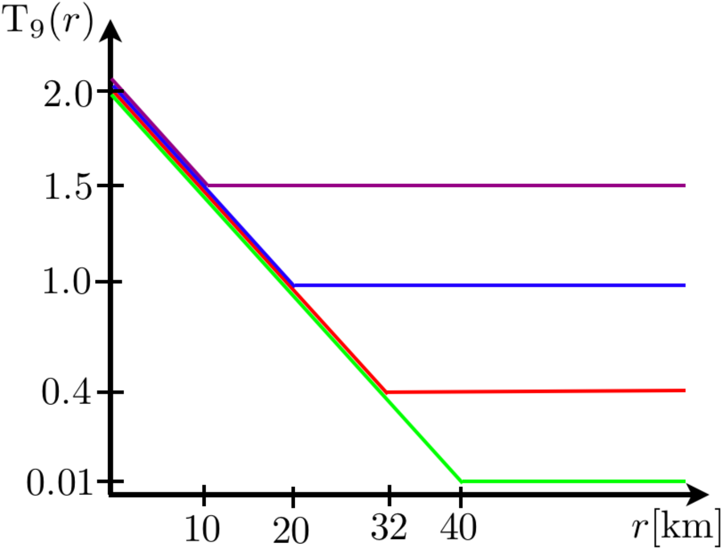


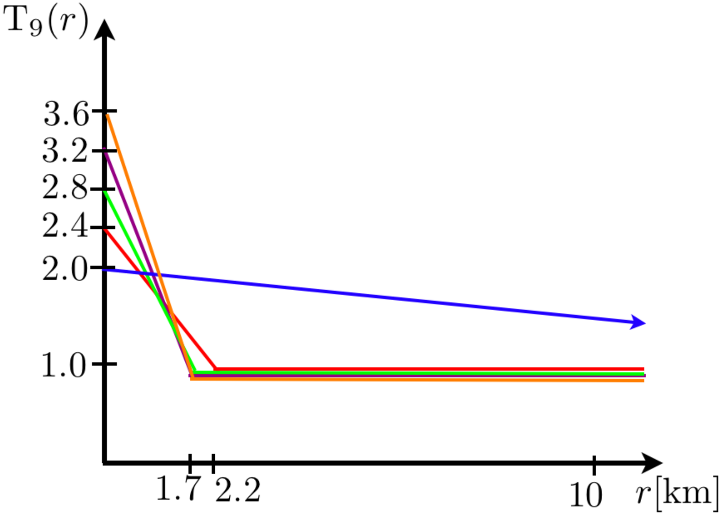
Table excerpt

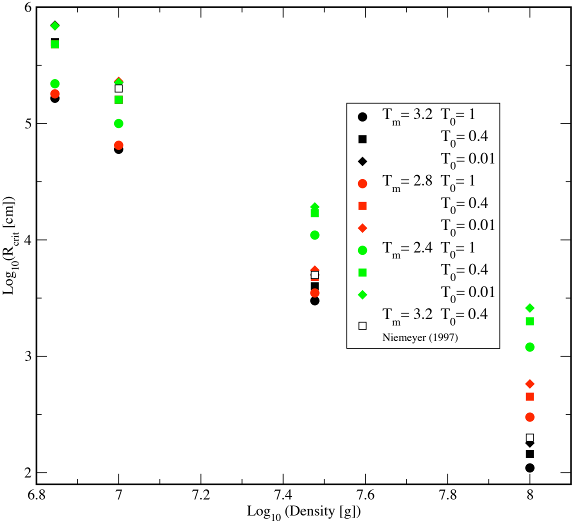
Density	T_{max}	T_0	$R_{crit,min}$	$R_{crit,max}$	$\log(-m = \frac{T_0 - T_{max}}{R_{crit,max}})$
[10^6 g cm^{-3}]	[10^9 K]	[10^7 K]			
10.0	3.6	1.0	2.25km	2.30km	4.19
...	...	40.0	1.5km	1.6km	4.30
...	...	100.0	550m	600m	4.64
...	...	150.0	180m	190m	5.04
...	3.2	1.0	2.20km	2.25km	4.15
...	...	40.0	1.5km	1.6km	4.24
...	...	100.0	550m	600m	4.56
...	...	150.0	180m	190m	4.95
...	2.8	1.0	2.25km	2.3km	4.08
...	...	40.0	1.5km	1.6km	4.18
...	...	100.0	600m	650m	4.44
...	...	150.0	180m	190m	4.84
...	2.4	1.0	2.20km	2.25km	3.79
...	...	40.0	1.4km	1.5km	4.13
...	...	100.0	0.9km	1.0km	4.15
...	...	150.0	550m	600m	4.18
...	2.0	1.0	17km	18km	3.04
...	...	40.0	14km	15km	3.03
...	...	100.0	9.0km	10km	3.00
...	...	150.0	4.0km	5.0km	3.00

Constant Slope Regime $\rho = 7 \cdot 10^6$ g cm^{-3} C/O



Constant Radius Regime $\rho = 7 \cdot 10^6$ g cm^{-3} C/O



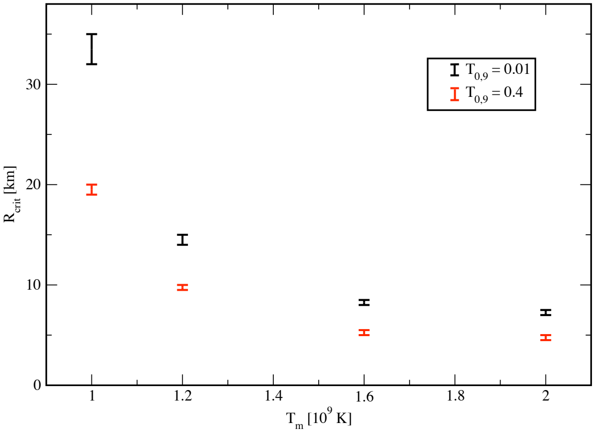


At low densities raising ambient background temperature T_0 has large effect on decreasing the critical radius. At high densities peak temperature T_m is dominant factor.

Density [g]	R_{NW}	R_{IRS}
$1.0 \cdot 10^7$	1.0 - 2.0 km	1.5 - 1.6 km
$3.0 \cdot 10^7$	25 - 50 m	38 - 40 m
$1.0 \cdot 10^8$	1 - 2 m	1.40 - 1.45 m

Code to code comparison with Niemeyer & Woosley 1997 positive.

Critical Radii for 43% ^{16}O, 43% ^{12}C and 14% ^{4}He



$\rho = 10^6$ g cm^{-3}

Adding ^{4}He reduces peak temperature and density required to initiate a detonation.

^{4}He present at surface of star would detonate earlier (more compact) leading to different nucleosynthetic yield.

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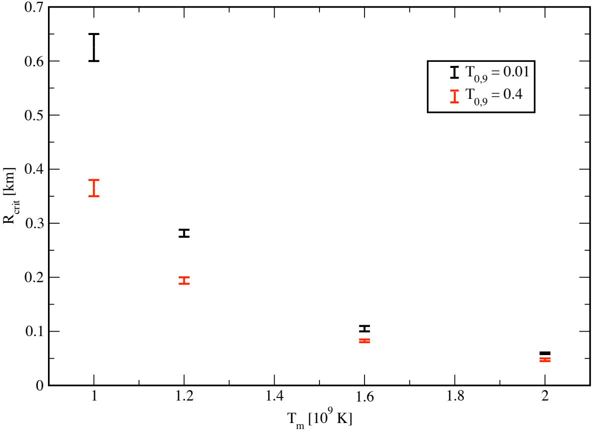

$\rho = 10^7$ g cm^{-3}

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Let’s recapture the most important points:

- Reproduced results of Niemeyer & Woosley (1997) and extended their work
- Found interesting regimes of constant temperature gradient and constant critical radius
- GCD model produces apparently more or less static gradient of induction timescales required for initiation of detonation

What's next?

- Extend range of table (in progress)
- Try to find theoretical explanation for constant radius regime
- Perform similar runs in cartesian coordinates to get feel for curvature effects
- Employ self consistent initial conditions for initiation of detonation study
  - Requires direct numerical simulations of feedback of nuclear burning on hydrodynamic flow
  - Try to run cold fuel into wall or up a steep density gradient

You would not have seen this talk without ...

... the funding agencies:

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