Accessing the HEDP Regime Using a Plasma Liner

By

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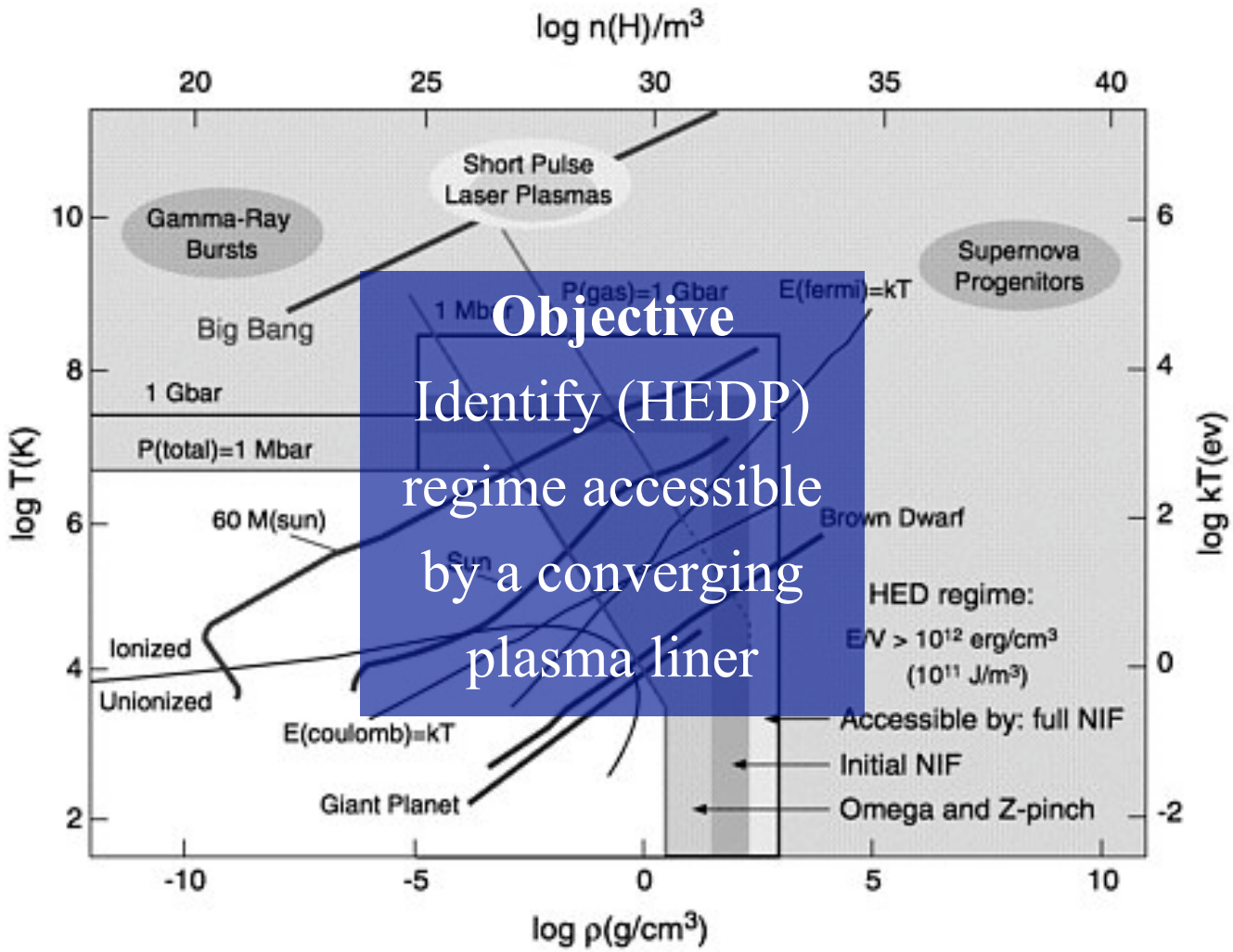
Outline

- Plasma jets driven magnetoinertial fusion
- HEDP regime definition
- Analytical Imploding Shock Models
- Results
- SPHC results
- Plasma jet estimates

Objective

- Identify high energy density physics (HEDP) regime accessible by converging shocks
- Explore feasibility of plasma driven magnetoinertial fusion
- Assess smooth particle hydrodynamics as numerical approach for fusion/HEDP studies

High Energy Density Physics Regime[1]



Objective

Identify (HEDP) regime accessible by a converging plasma liner

[1]Frontiers in High Energy Density Physics: The X-Games of Contemporary Science (2003)

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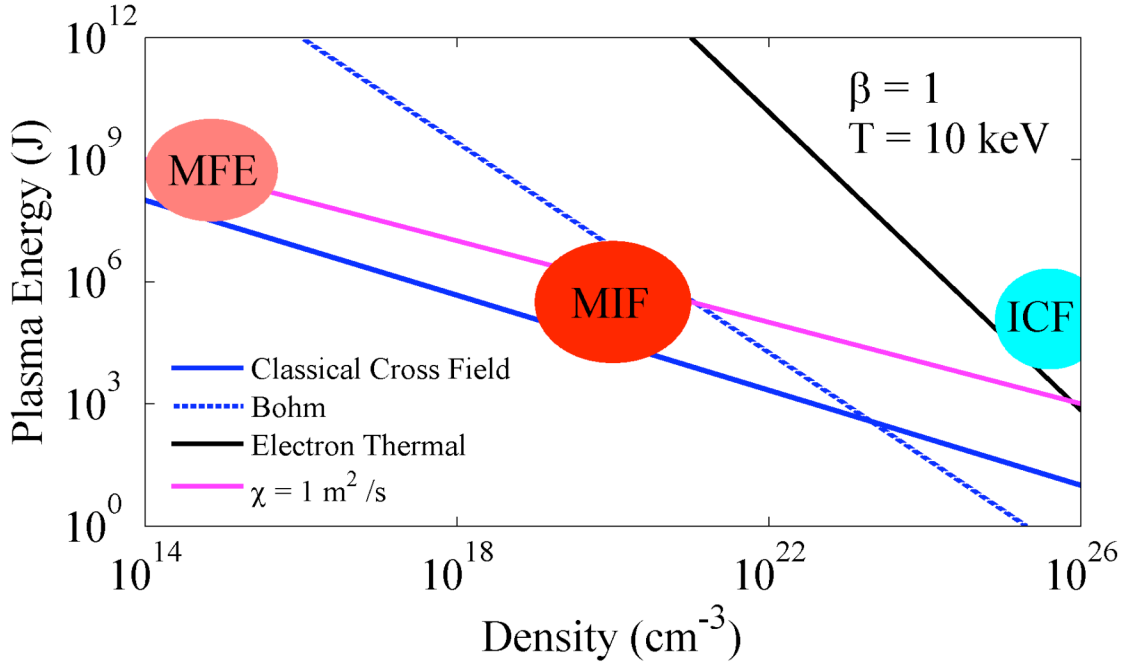
Introduction

Minimum Plasma Energy Required to Ignite the Plasma (Q=1)



The MIF regime is important for the following reasons:

1. fusion reactivity scales as n^2
2. characteristic plasma scale-lengths decrease with density
3. the magnetic field reduces thermal conduction losses, allowing relatively slow compression of the target

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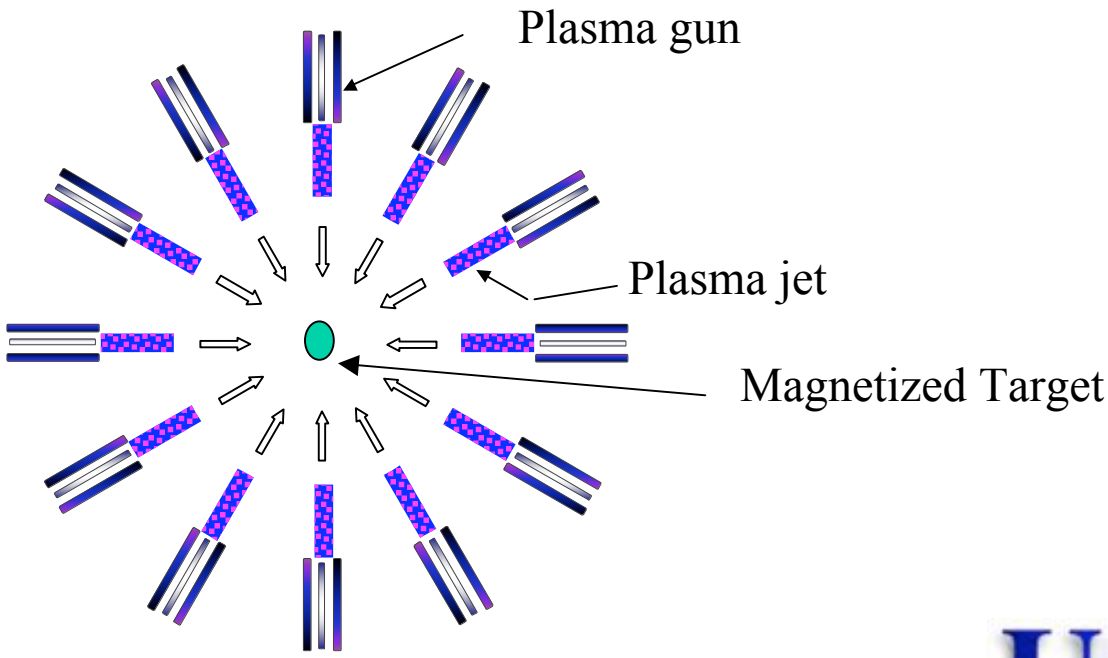
Plasma Liner Implosion

Francis Thio originally conceived a plasma liner as a *standoff* driver for MTF

Advantages of plasma liners:

- **Drivers can be positioned at a safer distance from fusion event**
- **Liner formation is repratable**
- **Potential for secondary fusion burn of the liner material**

Plasma Liner driven MTF in a Cylindrical Geometry



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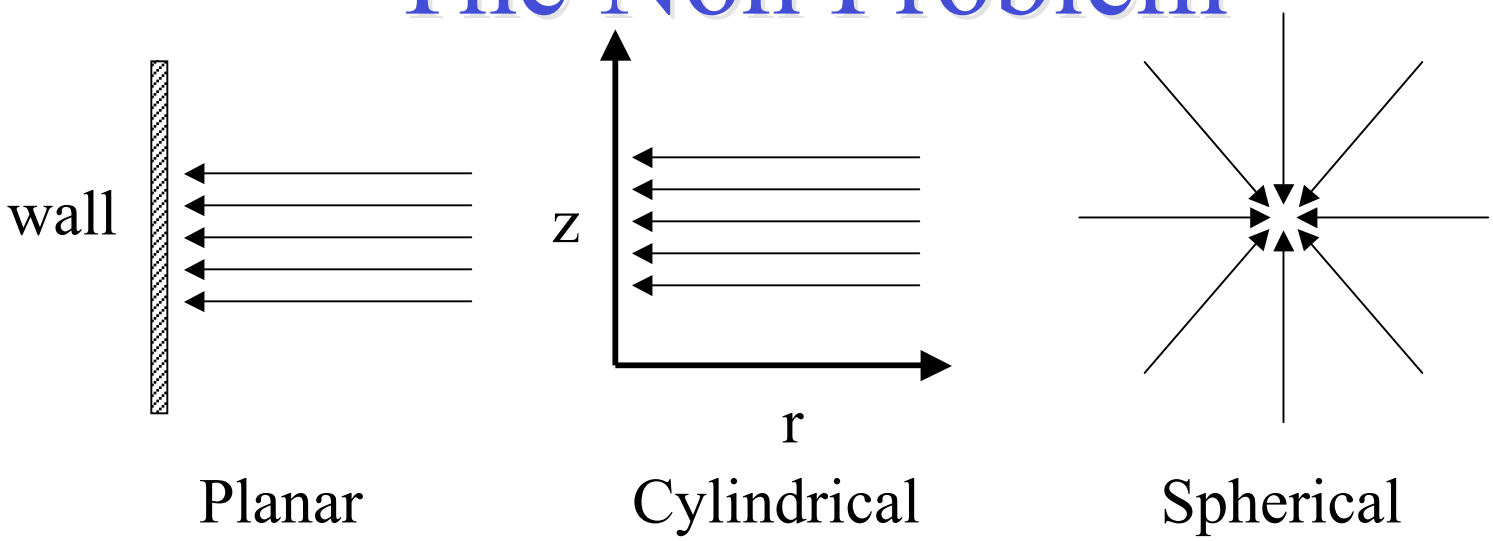
Models

- Analytical Models
  - Noh Problem
  - Self Similar Converging Shock
- Numerical Models
  - SPHC (Lagrangian Hydrodynamic)

The Noh Problem



Symmetry	N
Planar	1
Cylindrical	2
Spherical	3

Shocked Flow Properties

$$\rho_s = \rho_\infty \left(\frac{\gamma+1}{\gamma-1}\right)^{N+1}$$

$$P_s = \rho_\infty u_\infty^{\,2} \frac{(\gamma+1)^{N+1}}{2(\gamma-1)^N}$$

$$D_s = -\frac{1}{2} u_0 (\gamma-1)$$

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Self Similar Converging Shocks

Similarity variable: $y = C + \ln r = \alpha \ln t$

Substitutions:

$$\begin{cases} \rho(r,t) = \rho_0 r^{\kappa} R(y) \\ u(r,t) = -\dfrac{\alpha r}{t} V(y) \\ c(r,t) = -\dfrac{\alpha r}{t} C(y) \end{cases}$$

Resulting ODE's

$$R' + (\kappa + \nu + 1) RV + (RV)'$$

$$2C(\lambda + V) + 2C'(1 + V) + (\gamma - 1) C\left[(\nu + 1)V + V'\right]$$

$$V(\lambda + V) + V'(1 + V) + C\left[(\kappa + 2)C + C' + C'/R\right]/\gamma$$

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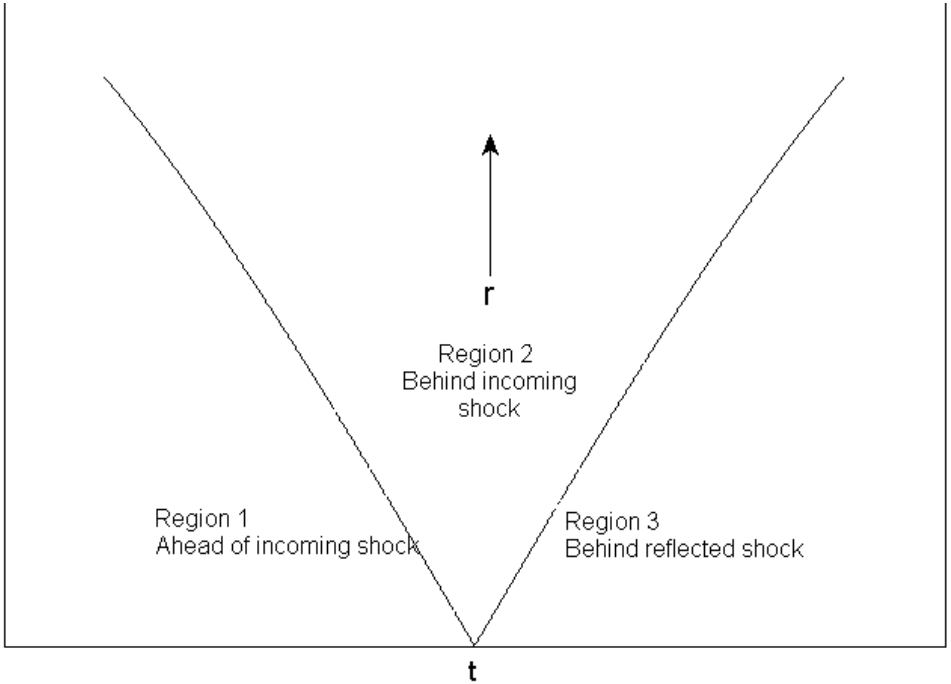
Self Similar Converging Shocks

- Solution is found by splitting problem into 3 distinct regions
- ODE's are decoupled, and different forms used for incoming and reflected shocks



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Smoothed Particle Hydrodynamics

- Gridless Lagrangian technique
- Differential interpolant of a function constructed from its values at the particles using a differential kernel
- Integral interpolant of a function is:

$$A_a(\vec{r}) = \int A(\vec{r}\,')W((\vec{r} - \vec{r}\,'), h)d\vec{r}\,'$$

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Smoothed Particle Hydrodynamics

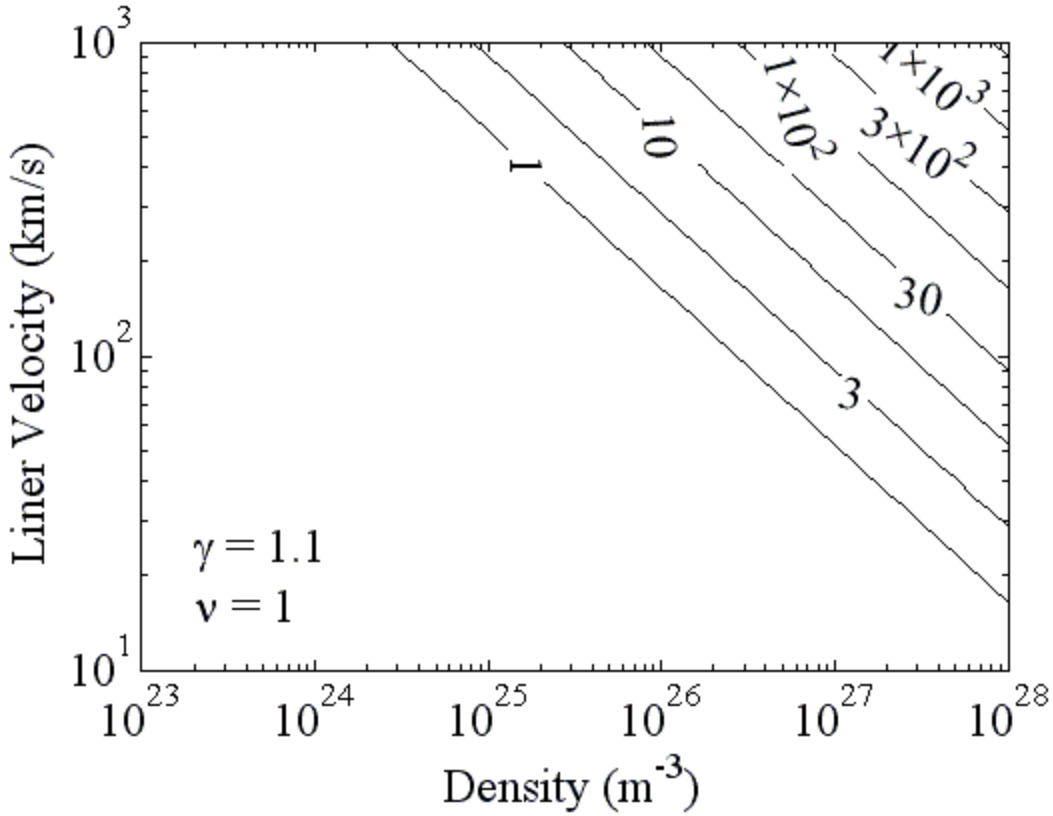
- Integral interpolant can be approximated by summation interpolant

$$A_a(\vec{r}) = \sum_b m_b \frac{A_b}{\rho_b} W(\vec{r} - \vec{r}_b, h)$$

- Derivatives are straightforward

$$\nabla A_a(\vec{r}) = \sum_b m_b \frac{A_b}{\rho_b} \nabla W(\vec{r} - \vec{r}_b, h)$$

Noh Problem
(cylindrical symmetry)



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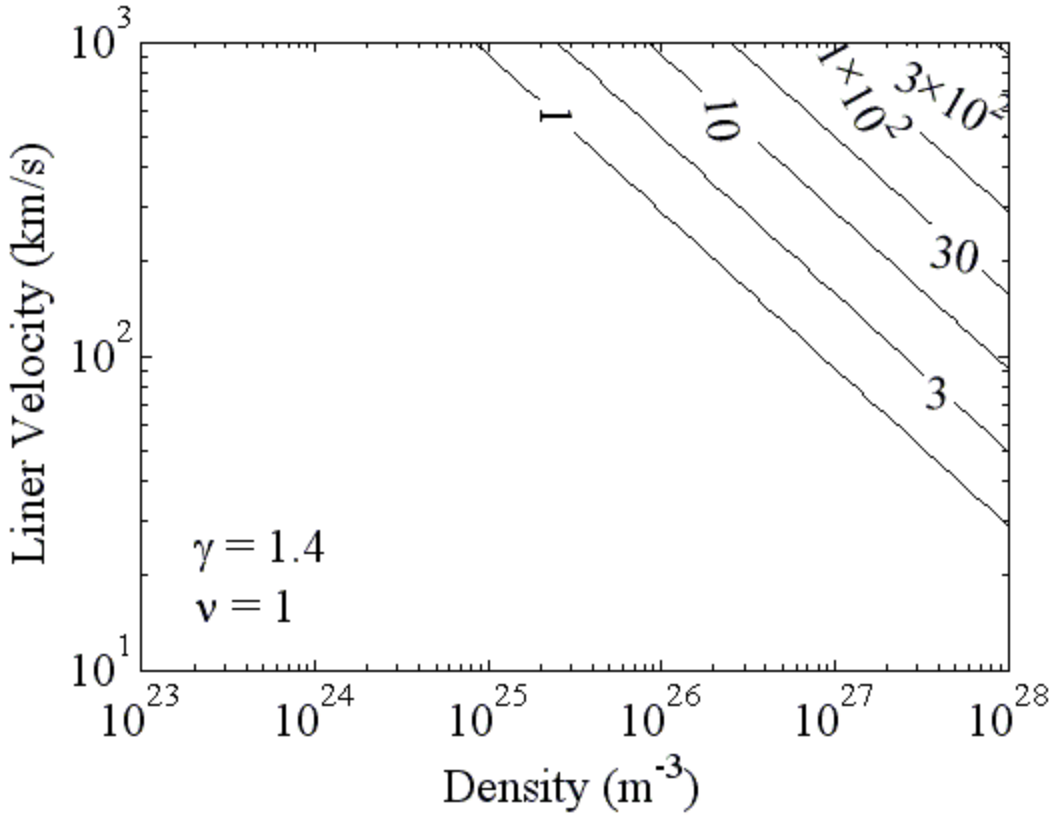

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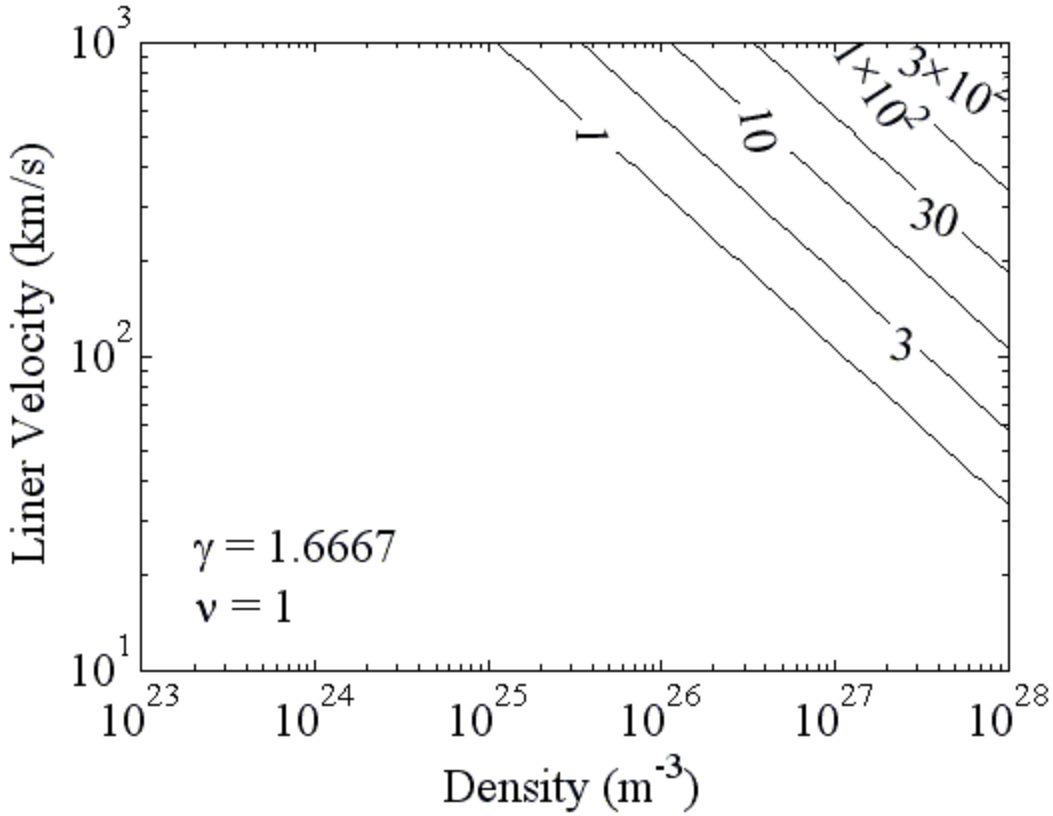

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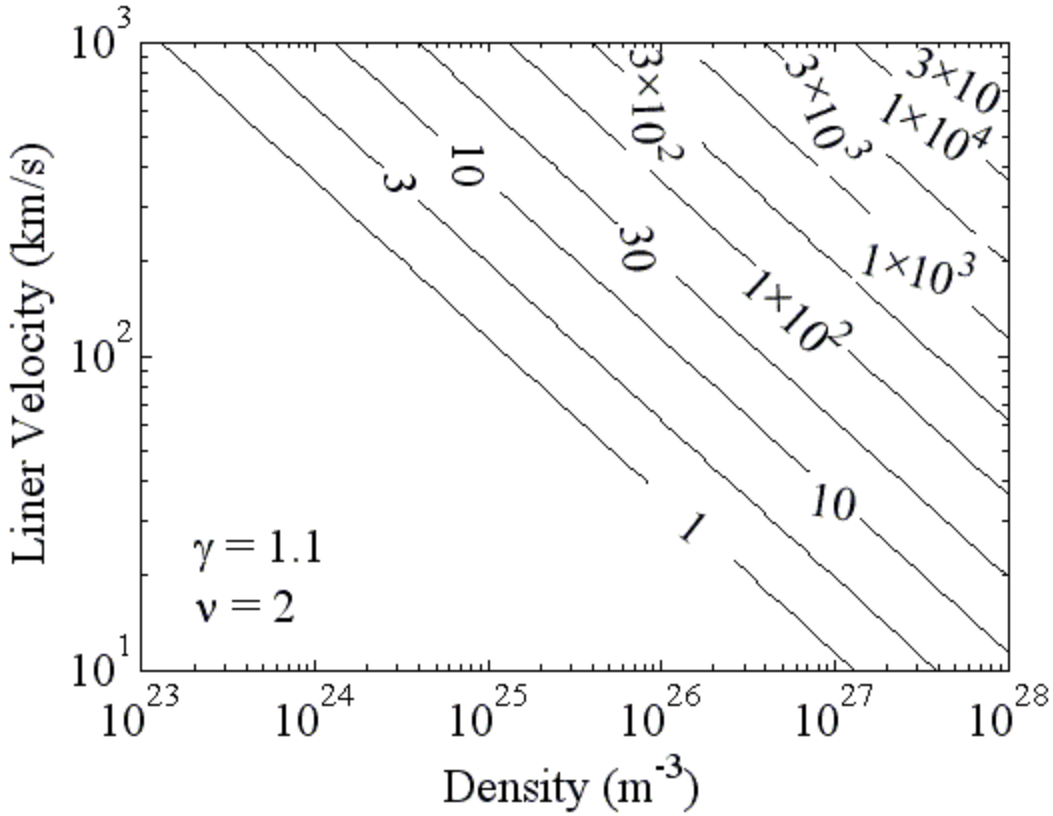
Noh Problem
(spherical symmetry)



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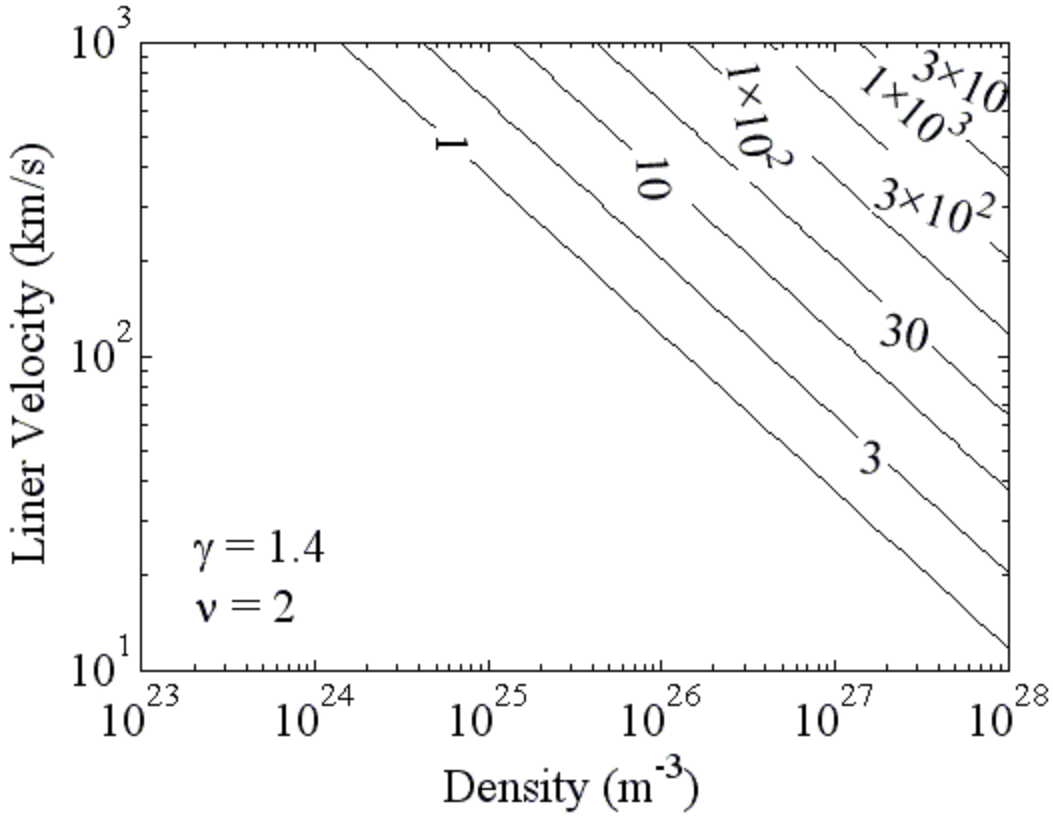

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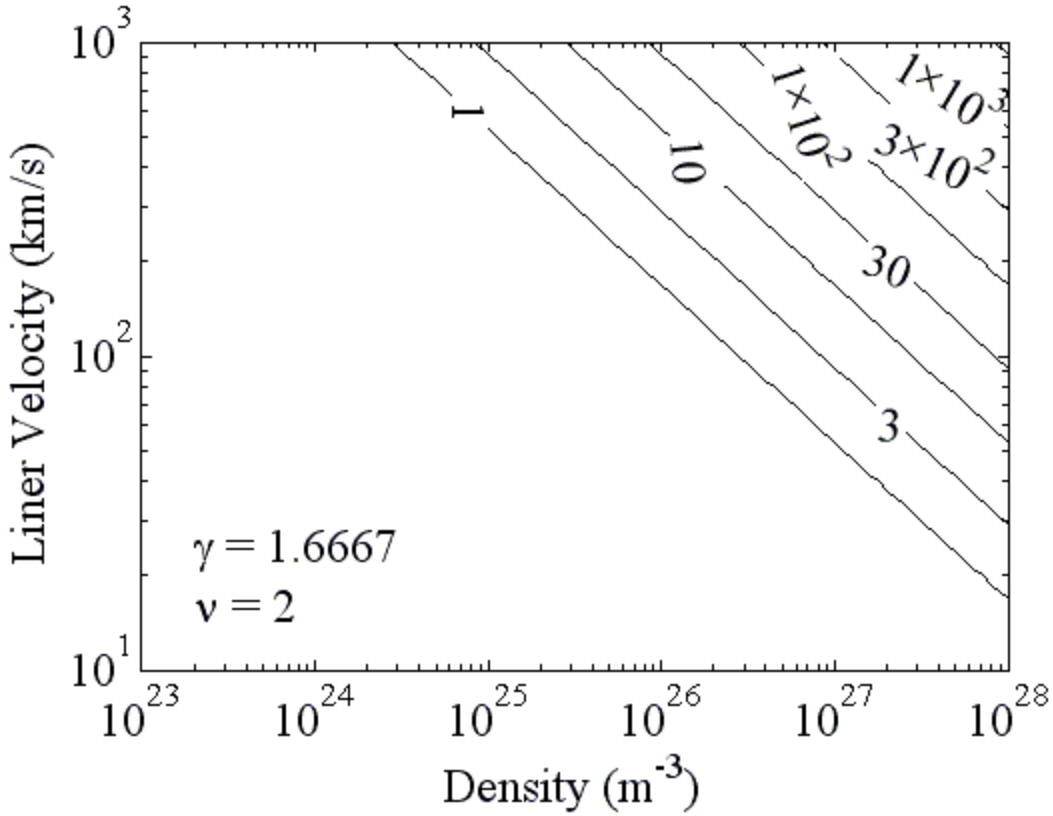

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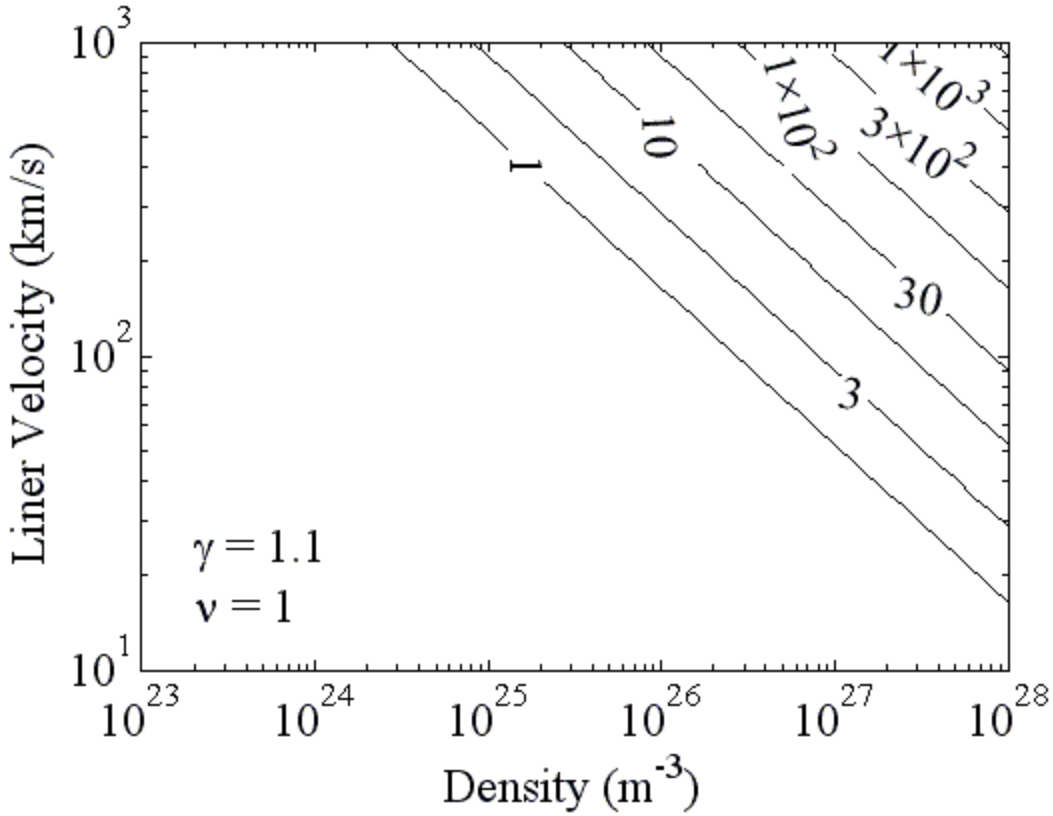

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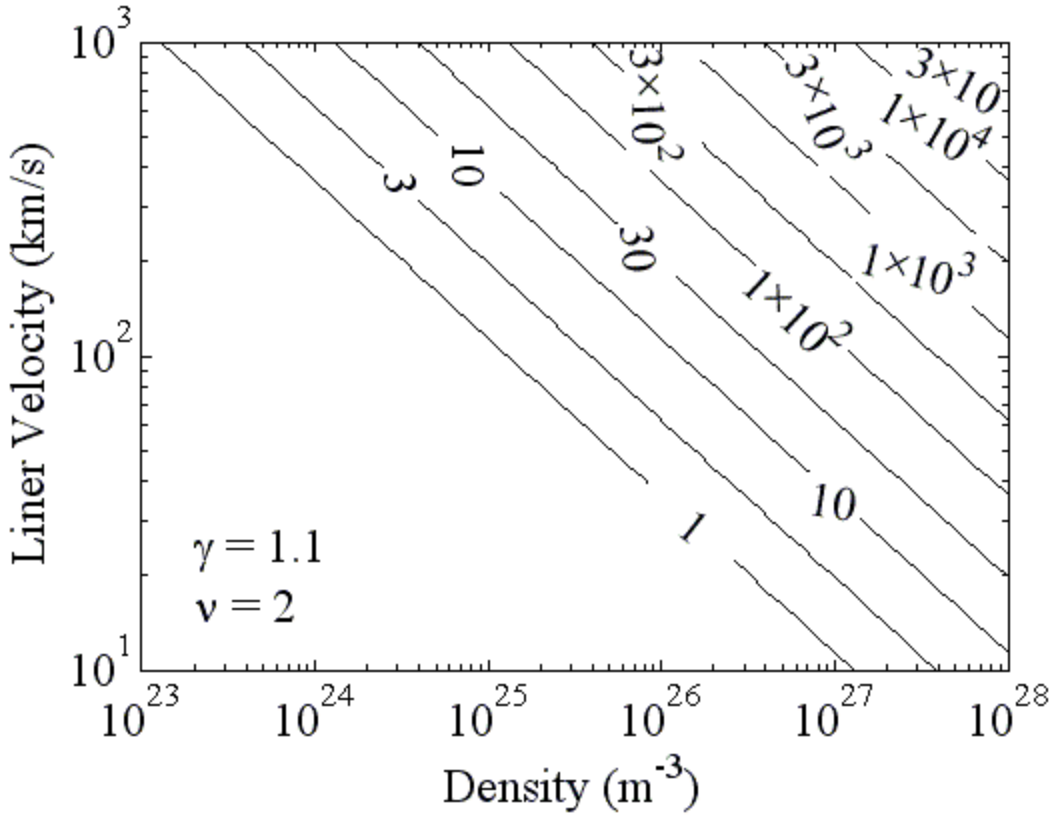

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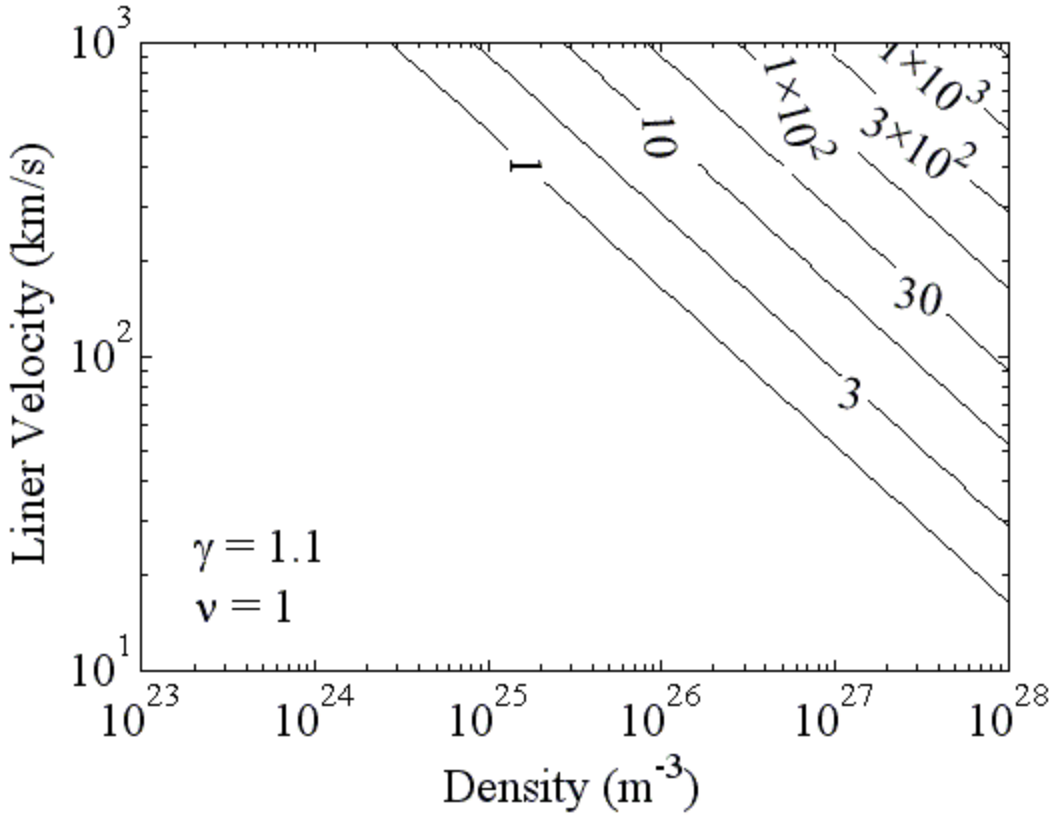
Self Similar Converging Shocks (cylindrical symmetry)



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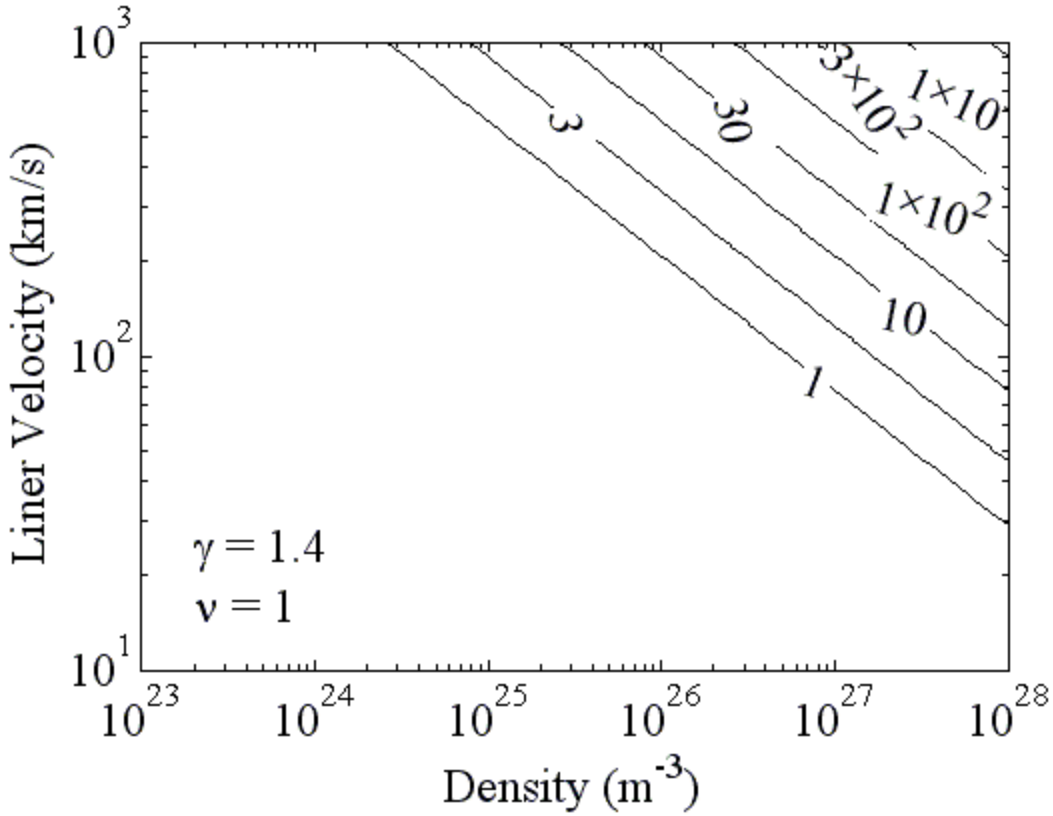

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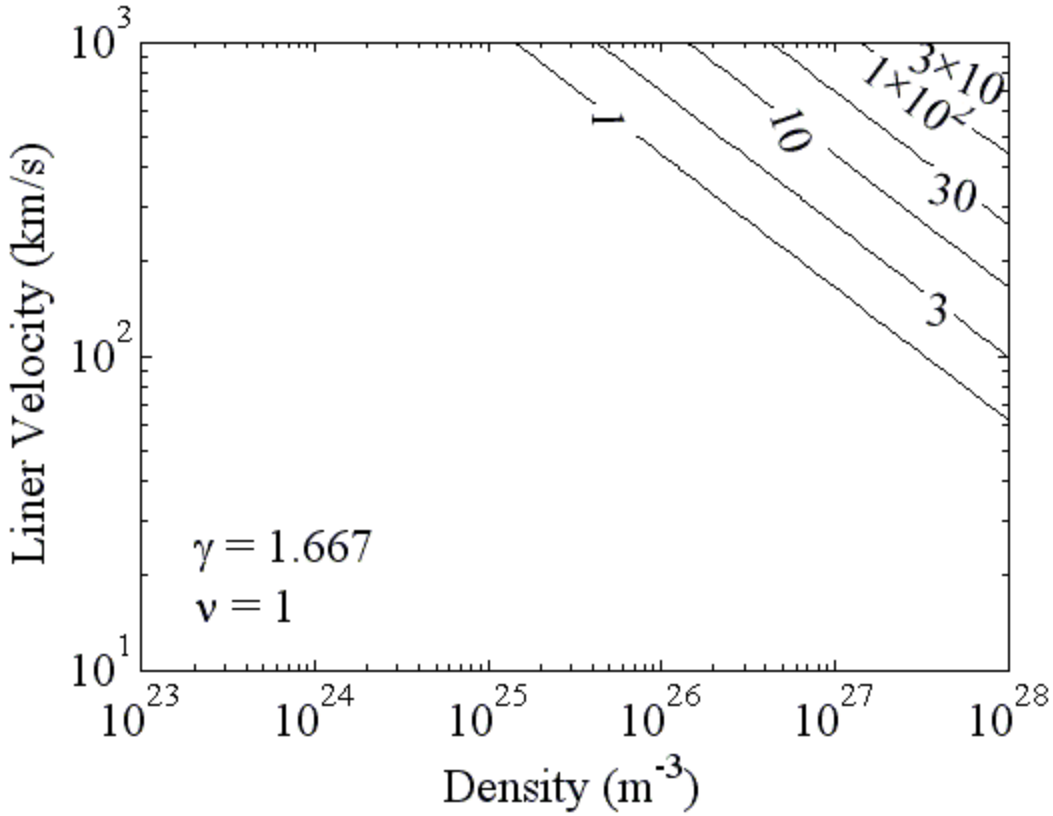

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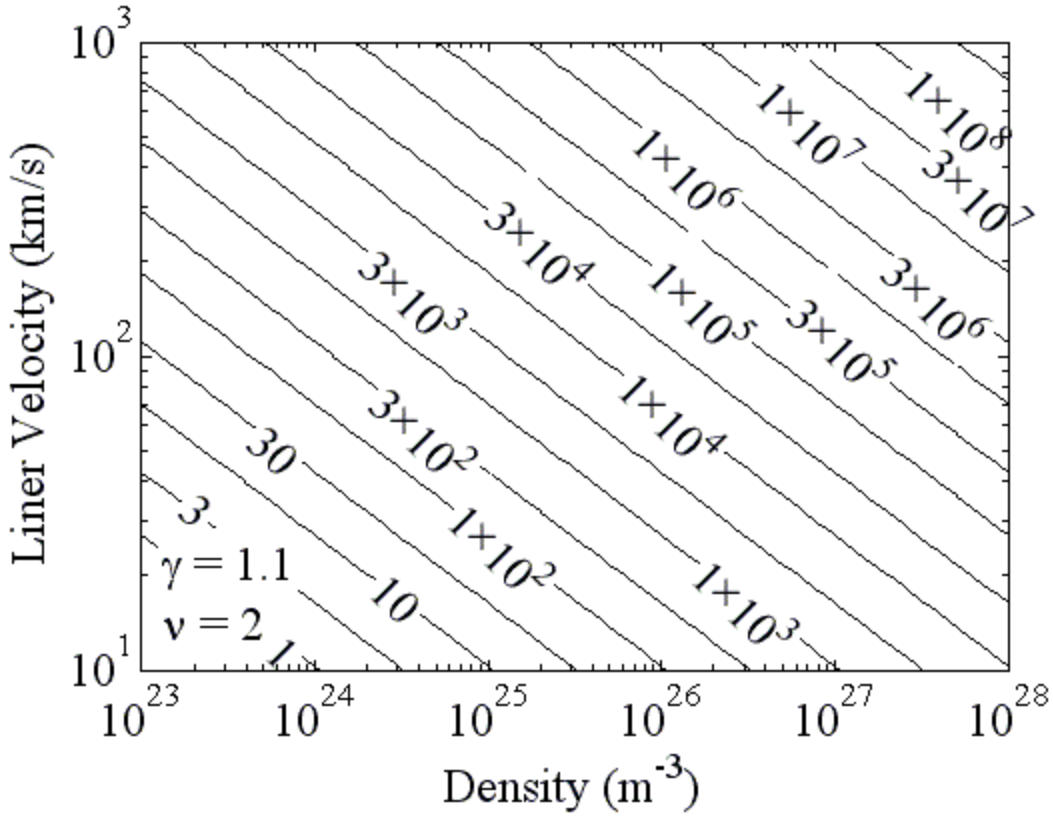

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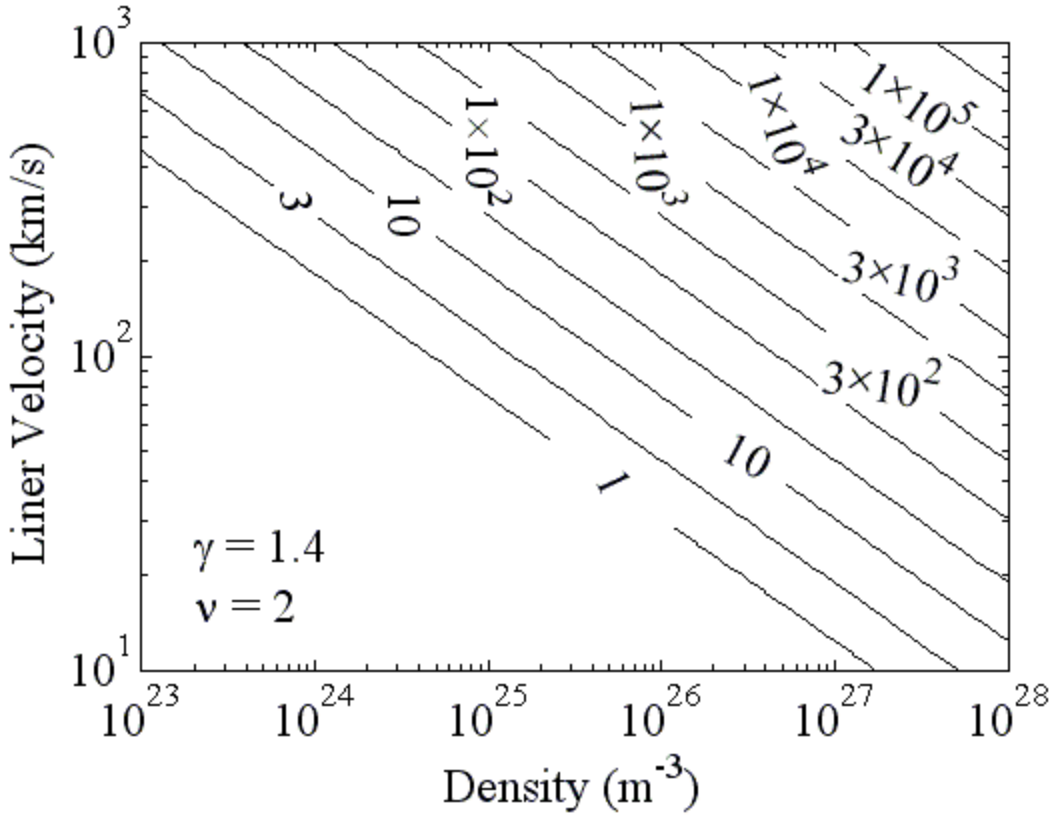

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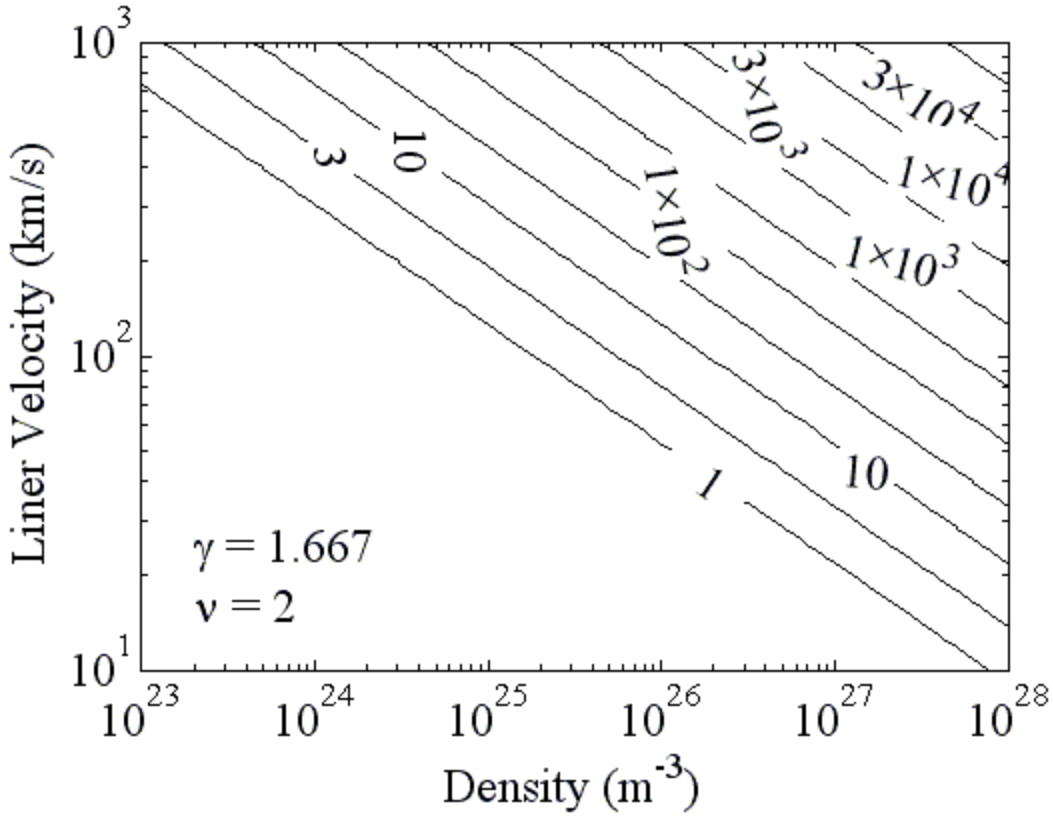

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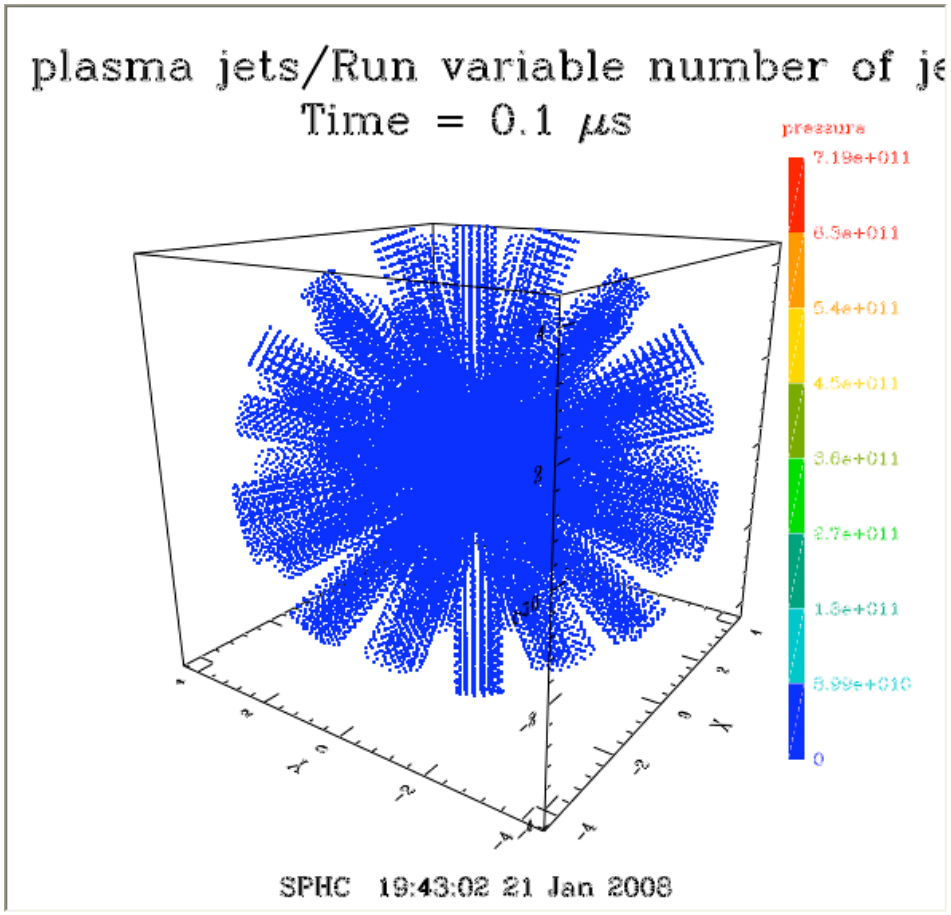
SPHC
60 jets, 200 km/s, γ=1.67



Peak pressure is ~0.7 Mbar

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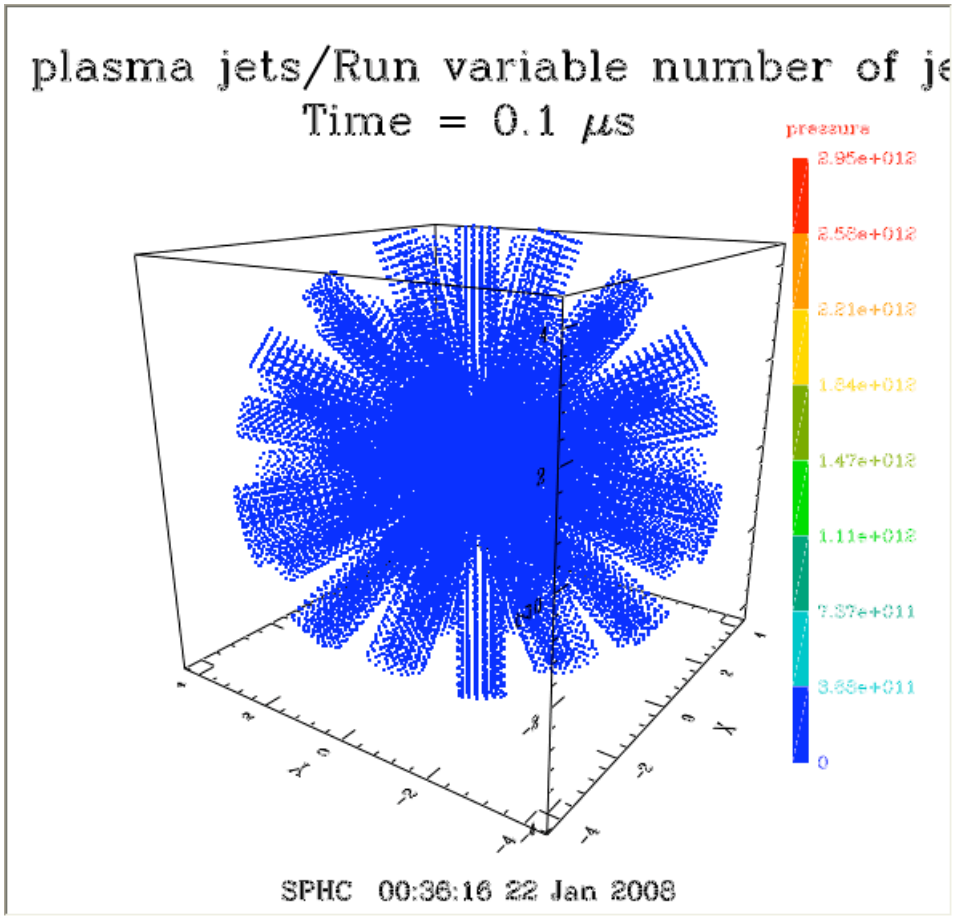
SPHC
60 jets, 200 km/s, γ=1.40



Peak pressure is ~3.0 Mbar

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Some Rough Estimates of Plasma Jet Requirements for Accessing HEDP

- Spherical symmetry
- High Z liners so effective $\gamma<5/3$
- Jet Velocities of ~200 km/s
- Initial Density of > 10^{25} m^{-3}

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