Imperial College London

CIFS

Perturbed Reflected Shocks related to Shock Ignited ICF

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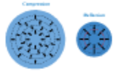
Supervisor
Prof. Roger Evans

Reflected shocks collide

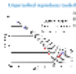
Compression

Reflection

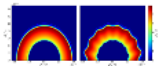


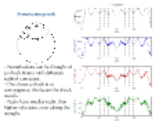
Perturbed shock collision

Analytical and simulated solution

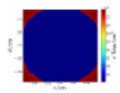


Building 2D simulation

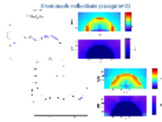




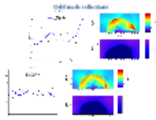
Simulation run



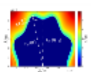
Even mode reflections (except n=2)



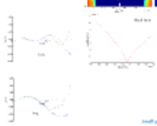
Odd mode reflections



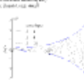
Examining perturbation growth



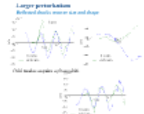
Small perturbation growth compared to theory



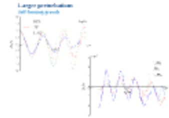
Small perturbation theory - very small perturbations



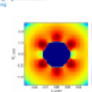
Large perturbation



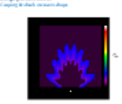
Large perturbation



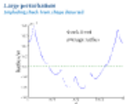
Large perturbation



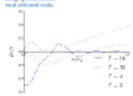
Large perturbation



Large perturbation

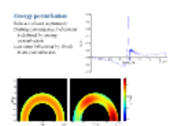


Large perturbation



Multi-mode perturbations

Energy perturbation



What's next?

Conclusions

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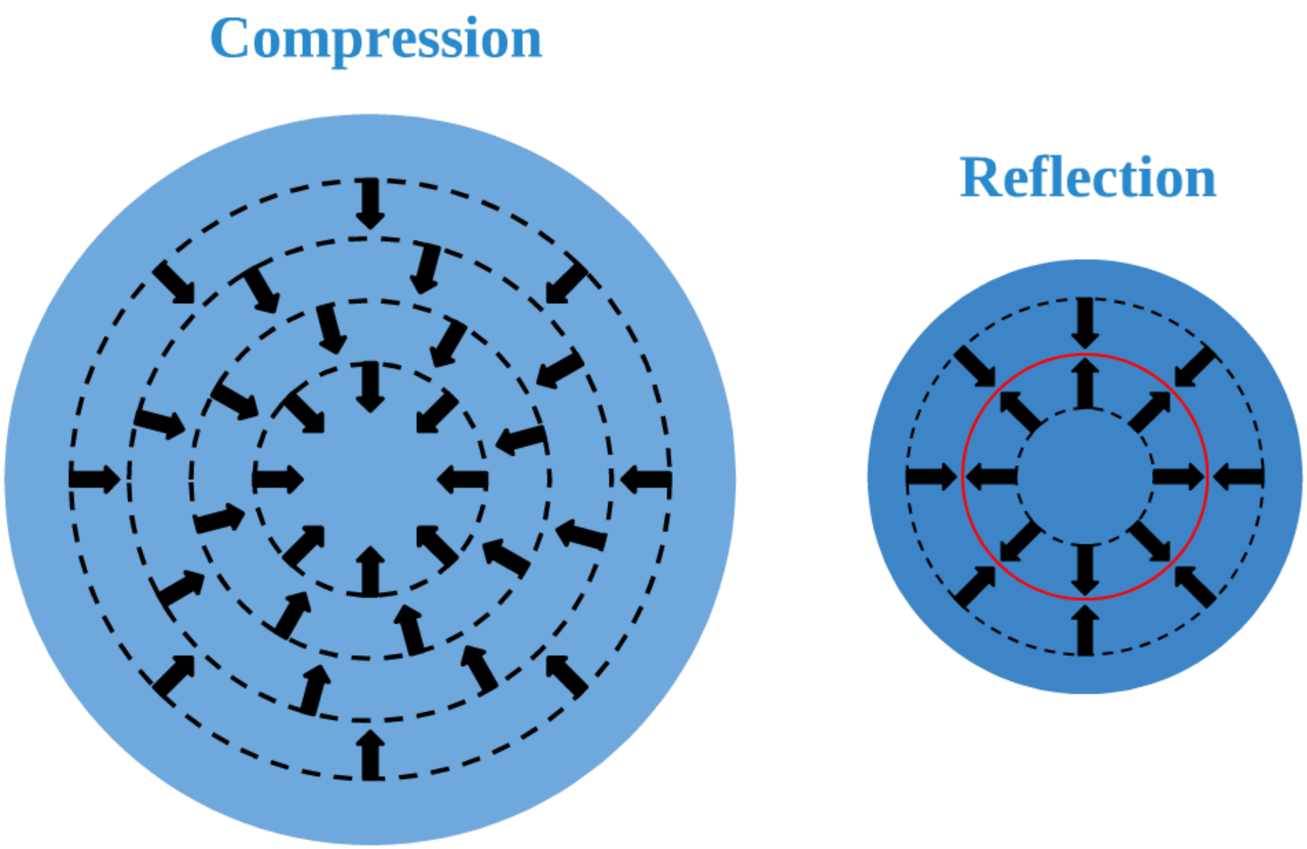
Reflected shocks collide

- Reflection unique to Shock ignition.
- Compression shocks coalesce to form 1 reflected shock.
- Hydrodynamic perturbation growth so far examined during compression, not reflection.

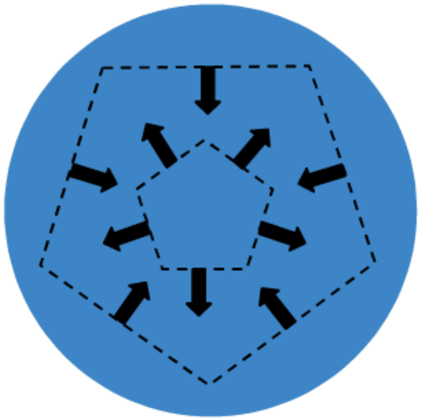


Perturbed shock collision

Shocks may collide at different times, dependent on angle

Inconsistent burn, lowering gain

May cause ignition to fail



Building 2D simulation

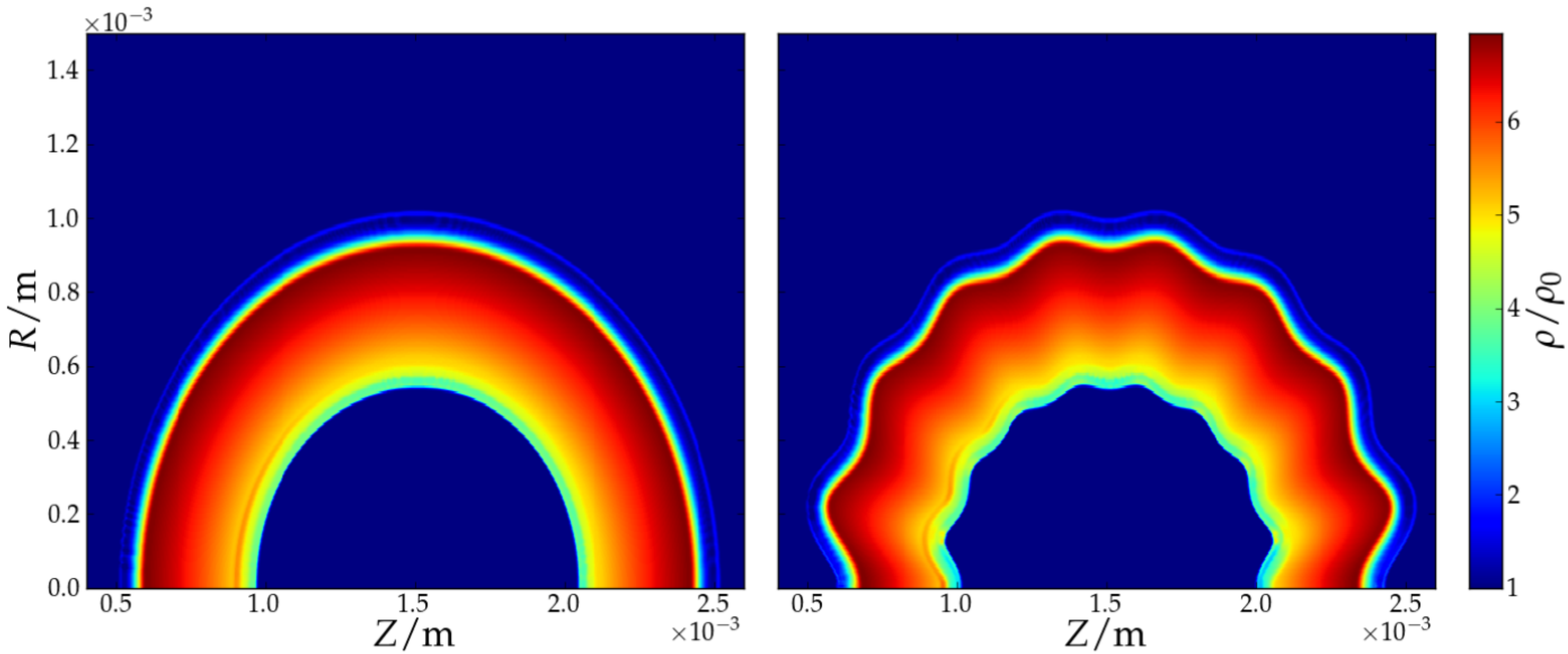
Unperturbed simulation initialised with the density, energy and velocity profiles that correspond to the Guderly solution (using Ribeyre boundary conditions)

Shock front position is perturbed using spherical harmonics.

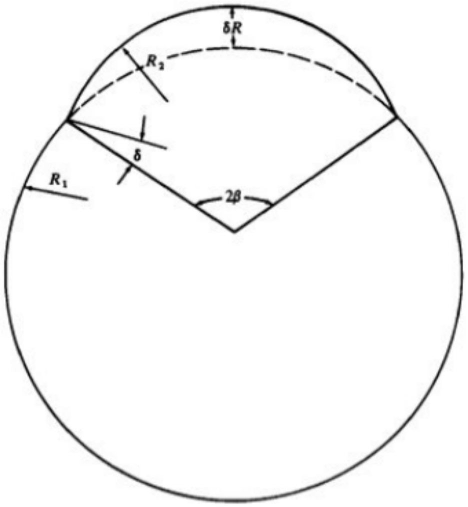
Cylindrical geometry used - solution may not be naturally centred.

Difficulty in initialising the simulation with a single eigenmode.

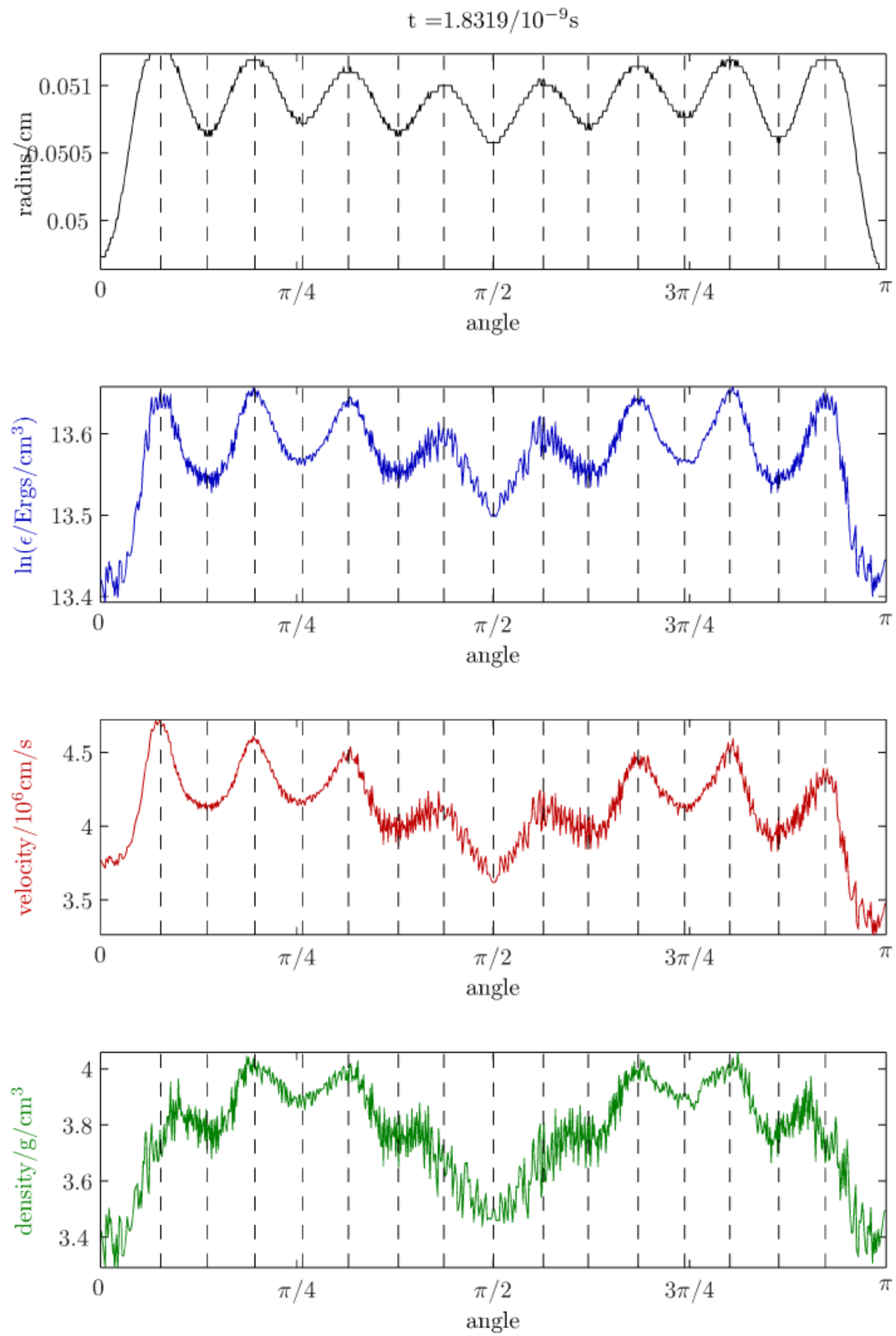
Form of perturbation $\alpha(r,\theta,\phi) = \alpha_0 + \epsilon Y_l^m(\theta,\phi)$



Perturbation growth

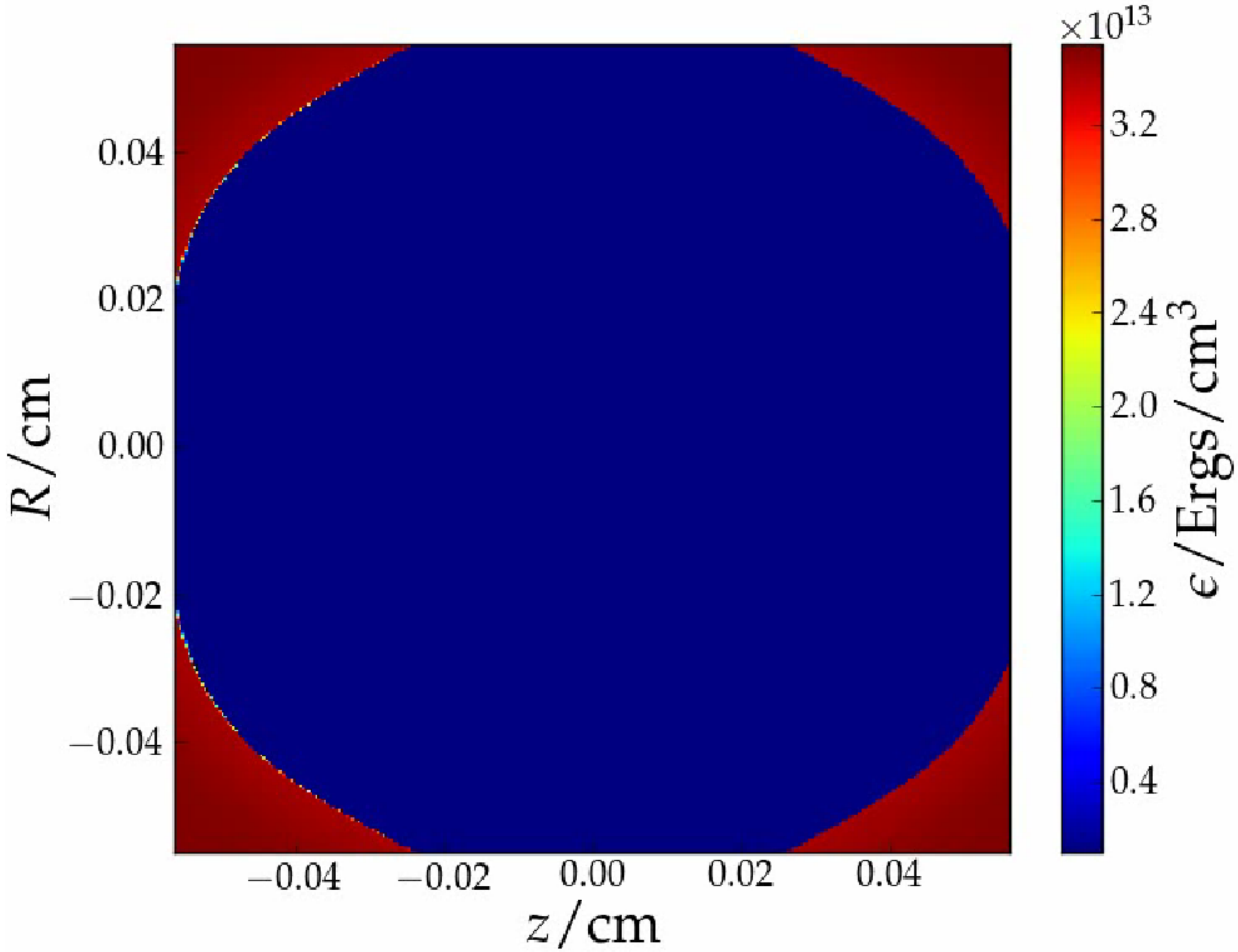


- Perturbations can be thought of as shock fronts with different radii of curvature.
- The closer a shock is to convergence, the faster the shock travels.
- Peaks have smaller radii, thus higher velocities, over taking the troughs.

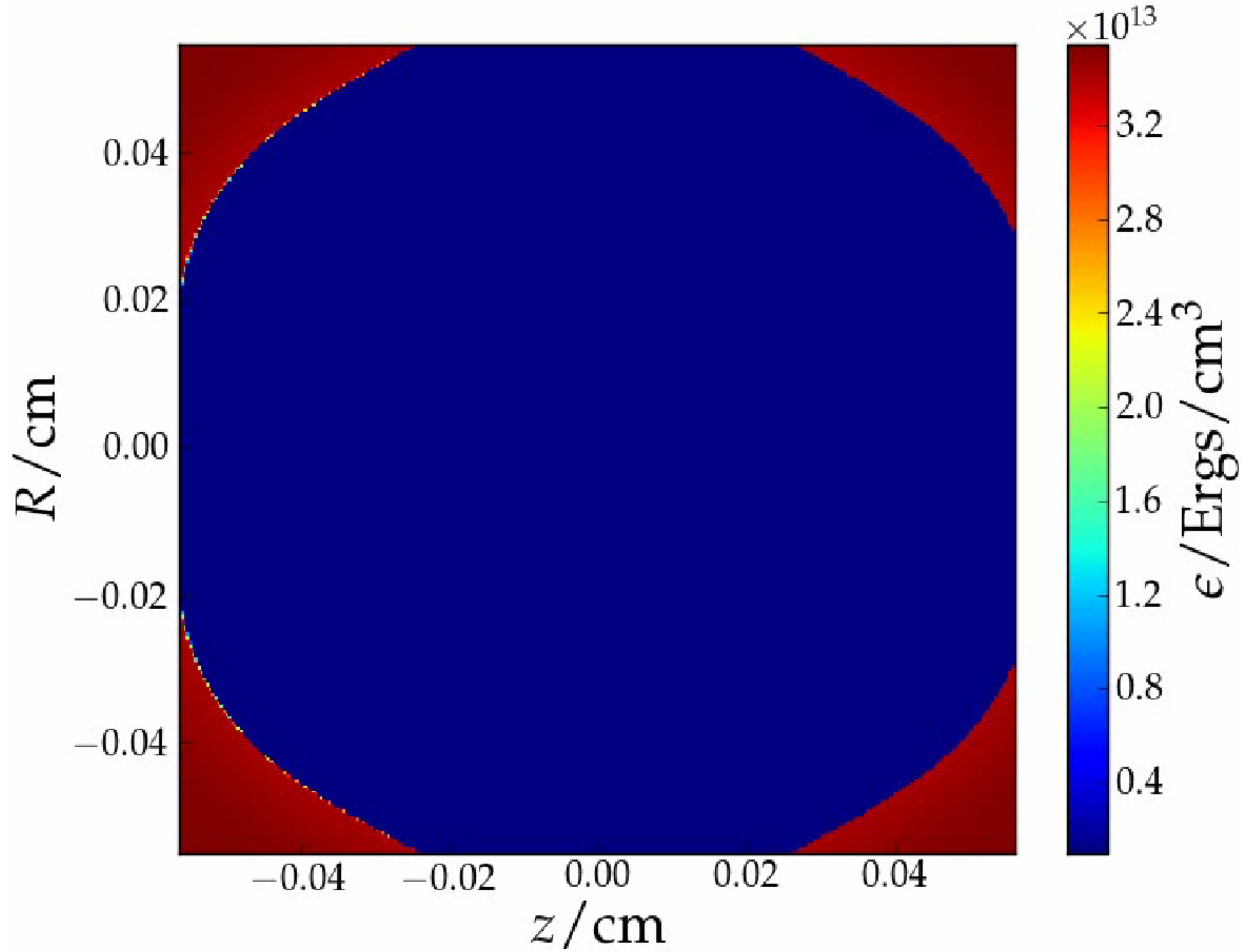


Simulation run

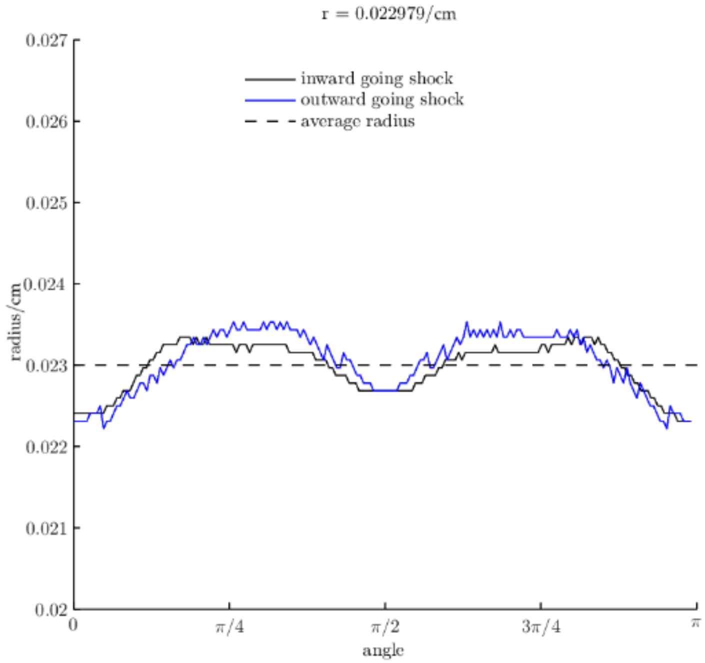
l = 6, 5% of initial perturbation radius

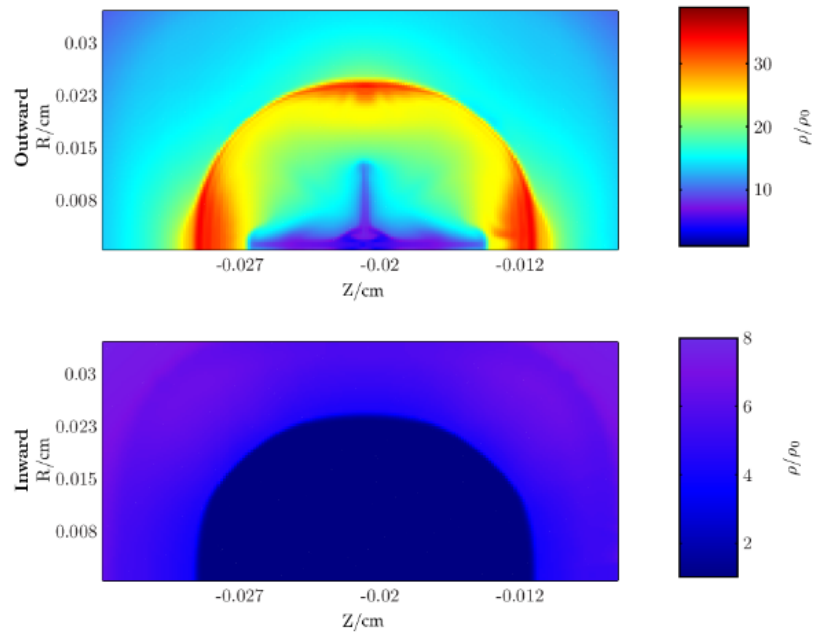


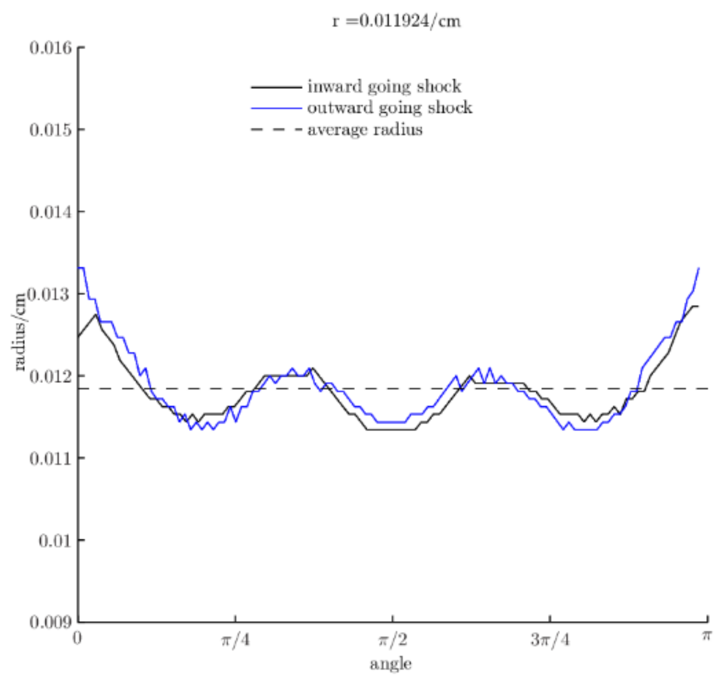
l = 6, 5% of initial perturbation radius

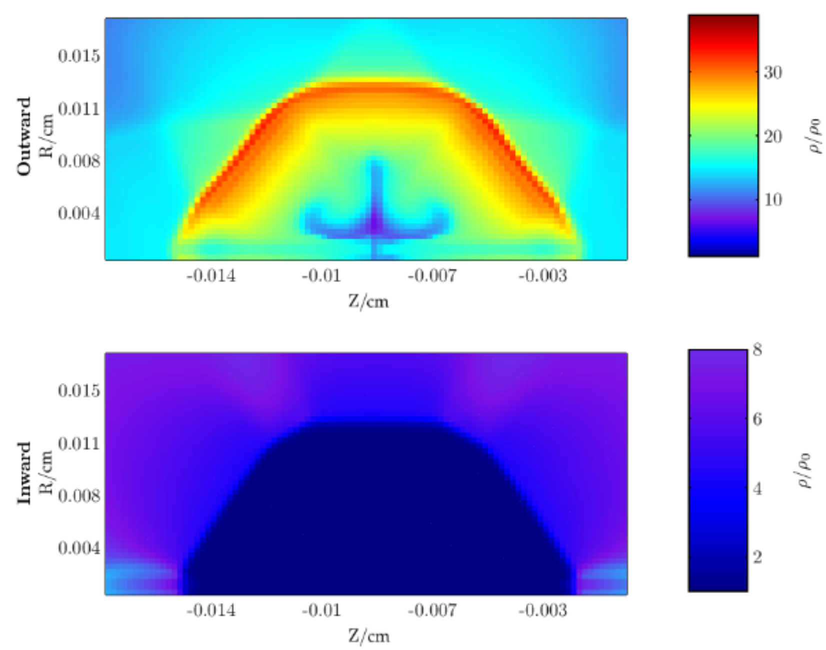


Even mode reflections (except n=2)

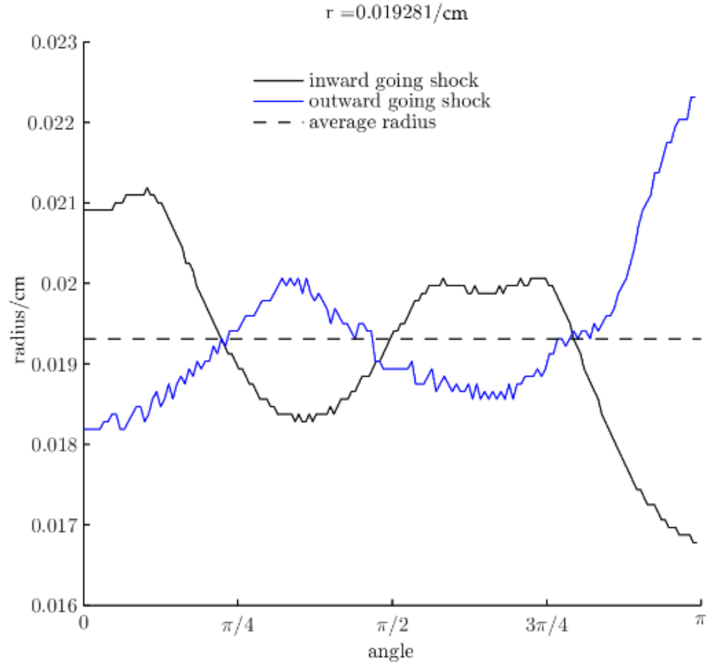


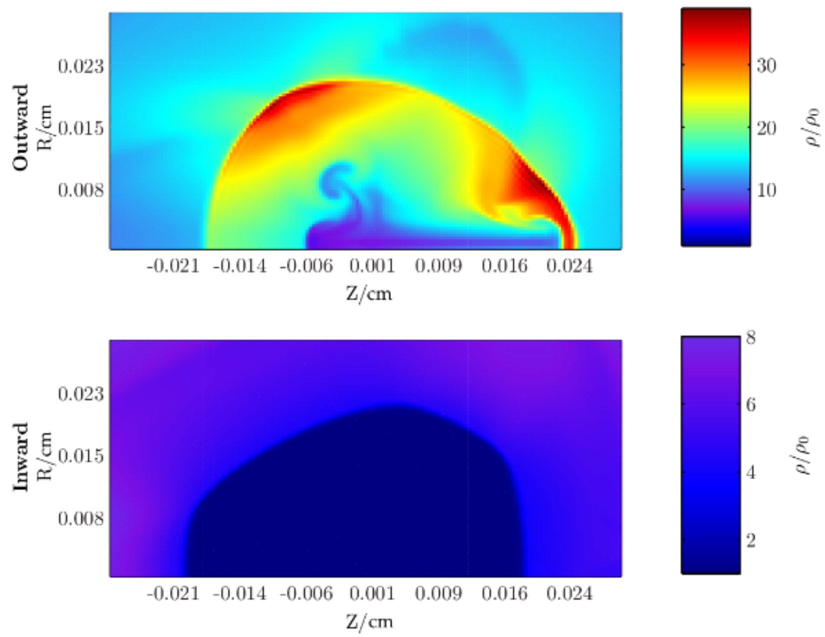


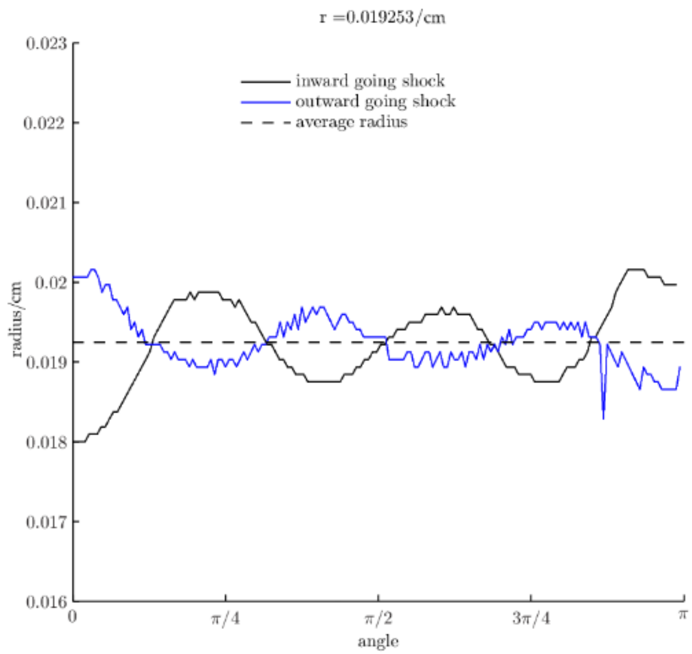


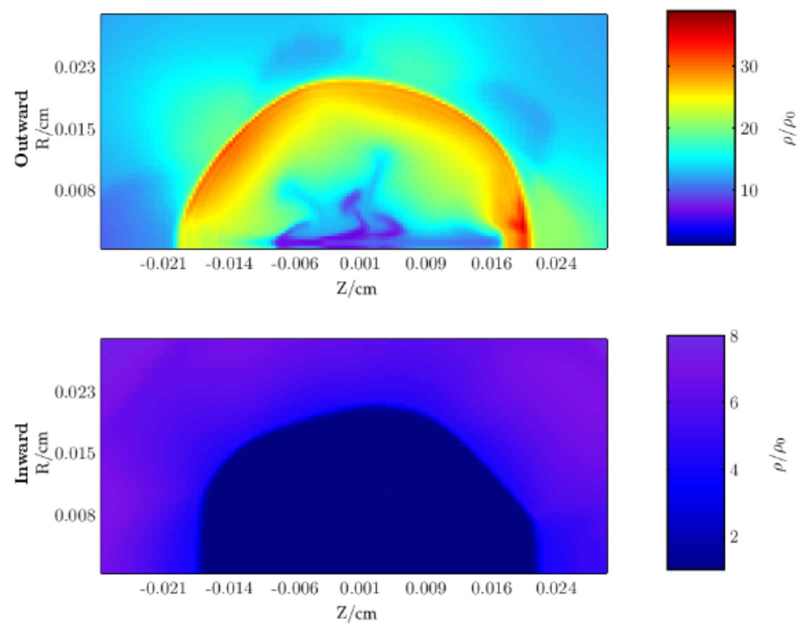


Odd mode reflections



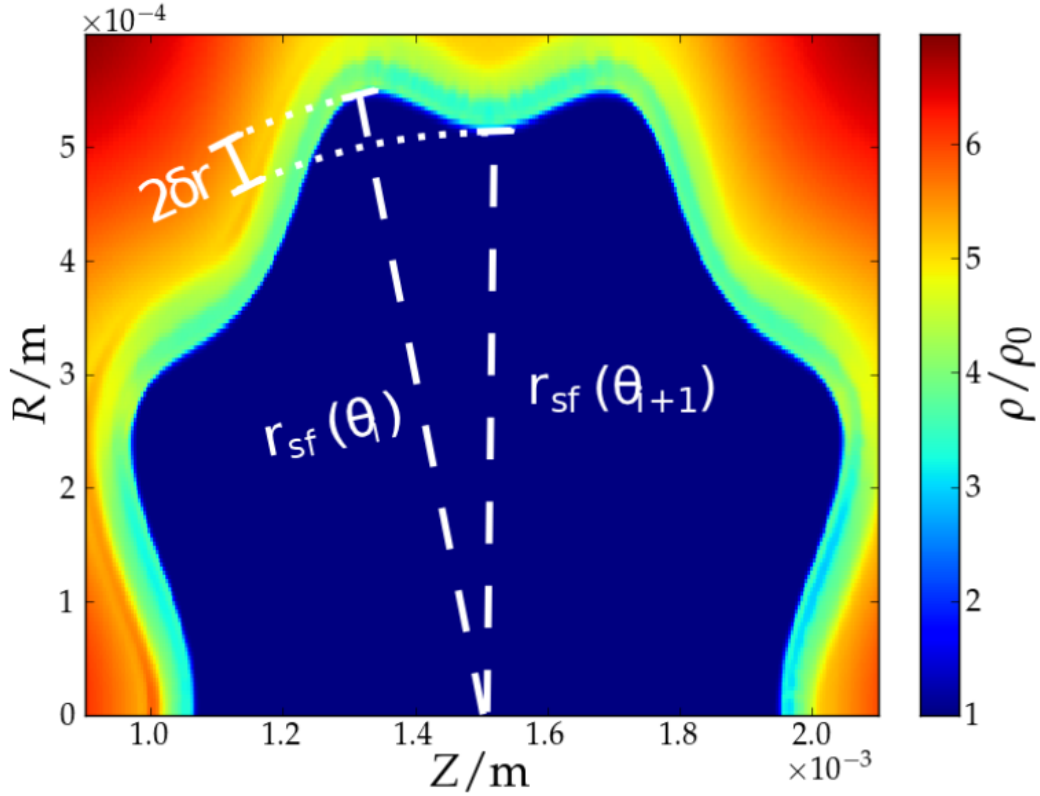


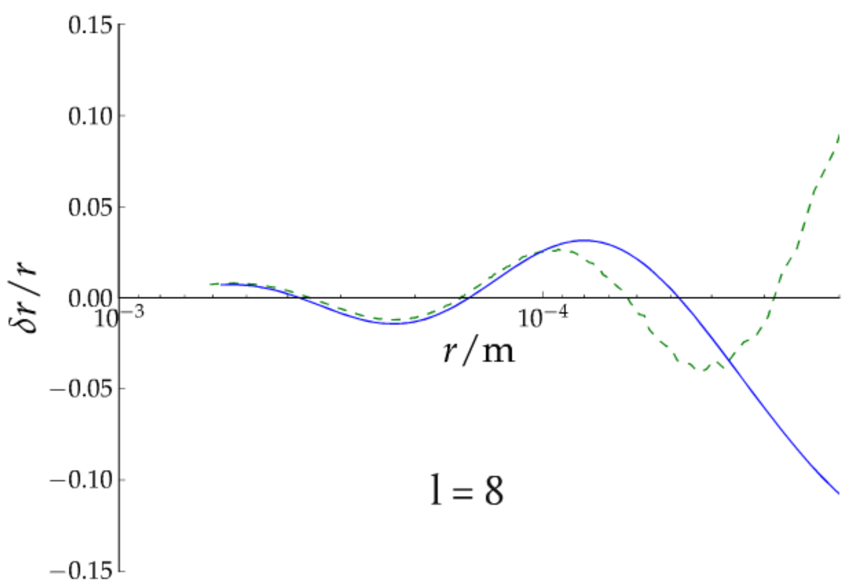


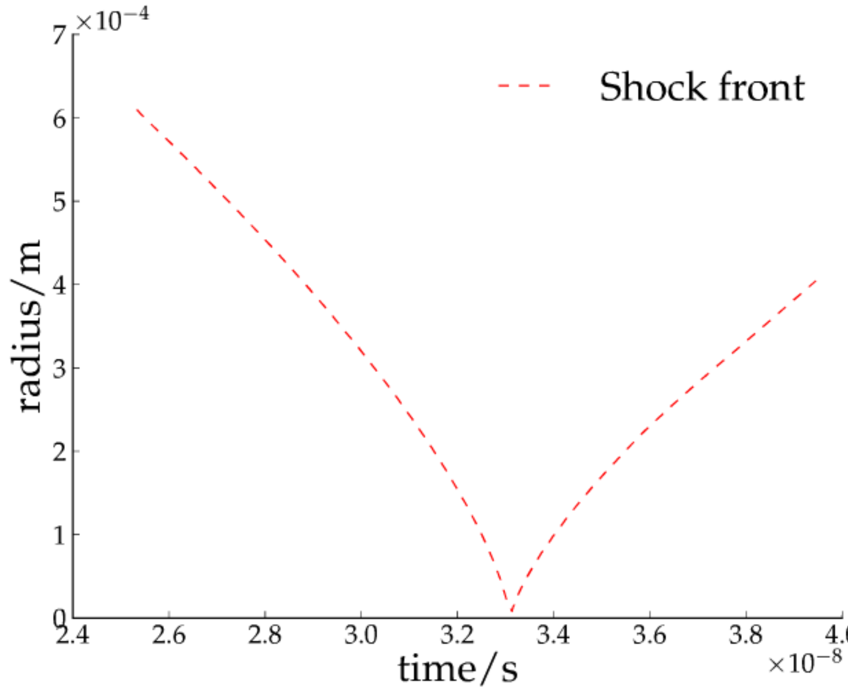


Examining perturbation growth

$$\delta r = \frac{r_{sf}(\theta_i) - r_{sf}(\theta_{i+1})}{2}$$







Small perturbation theory - very small perturbations

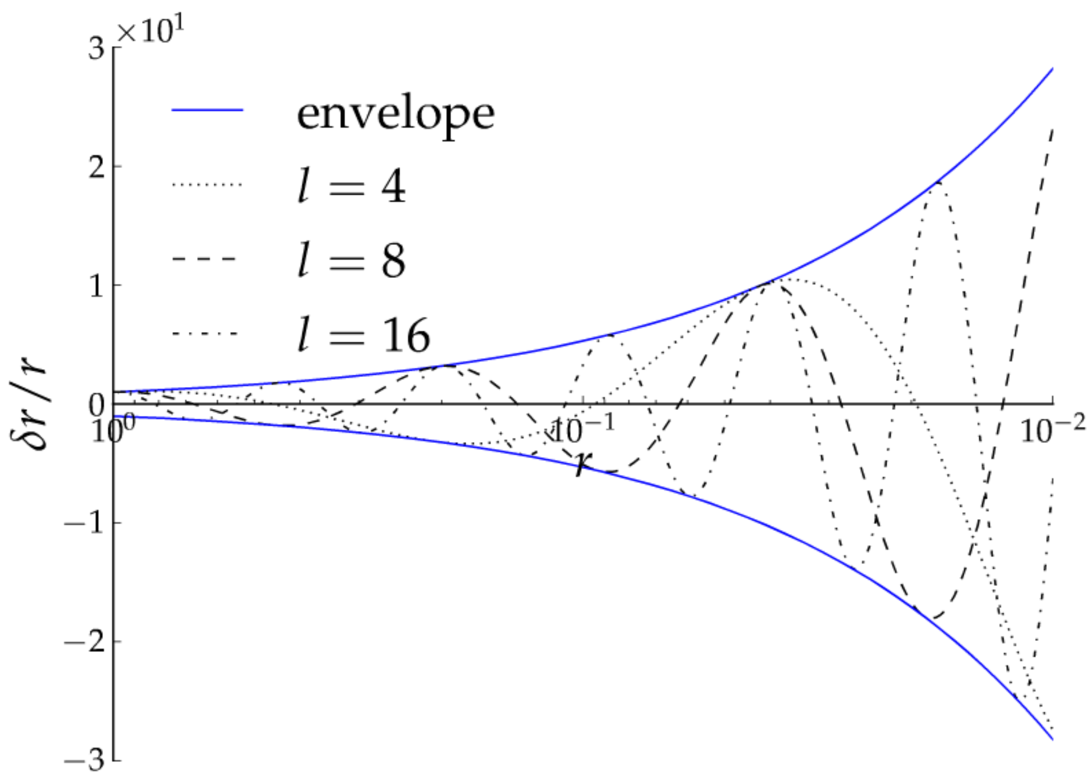
K. Evans, Phys. Rev. E, 1996

Solution:

$$\frac{\delta r}{r} \sim r^{\chi' - 1} \cos\left(\ln(r) a(\gamma, l)\right) \qquad \chi'(\gamma) = 0.27$$

Higher modes oscillate more rapidly

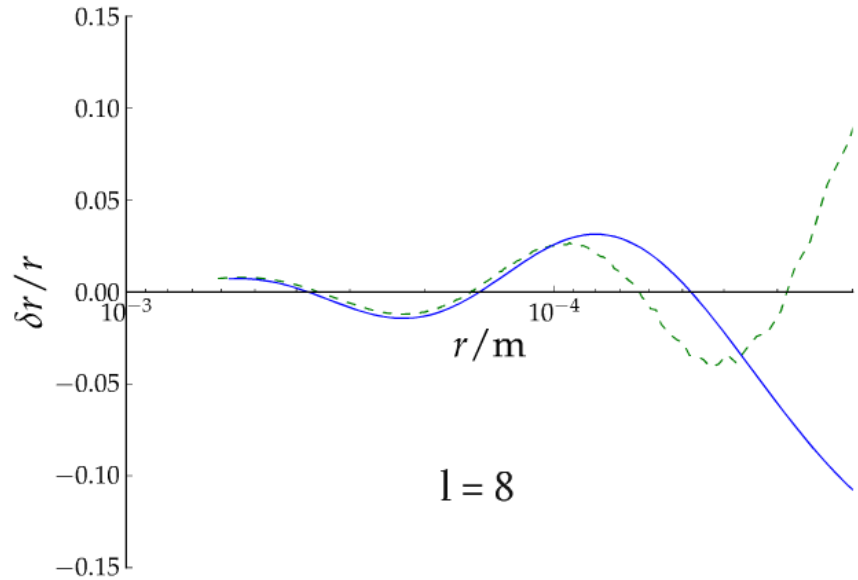
Always grows, doesn't stay small

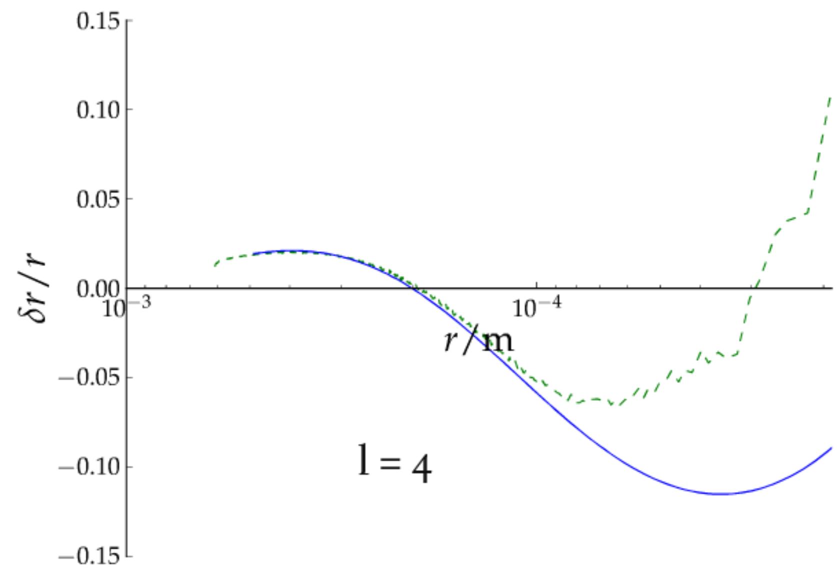


Small perturbation growth compared to theory

- As shock converges, solution will diverge from the linear solution due to increase in perturbation amplitude relative to the shock radius.
- "Small" depending on l?

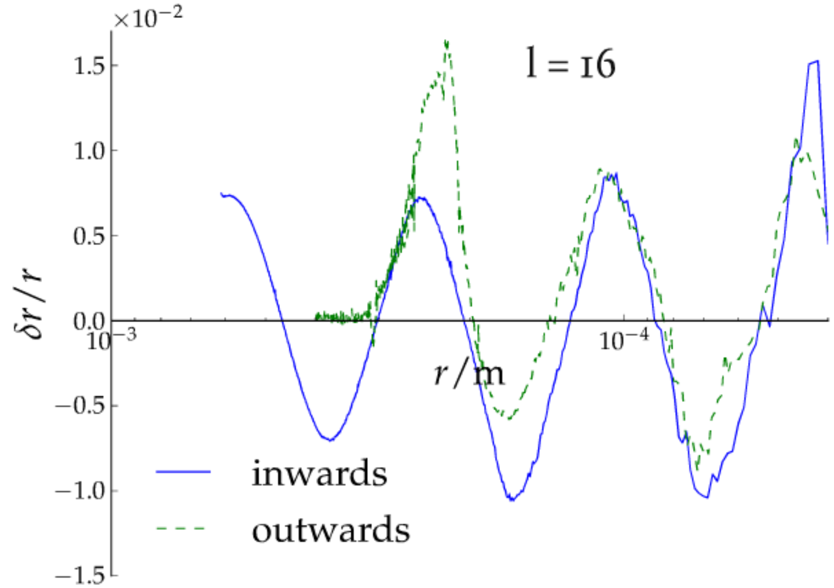
$$l\frac{\delta r}{r} \approx \epsilon$$

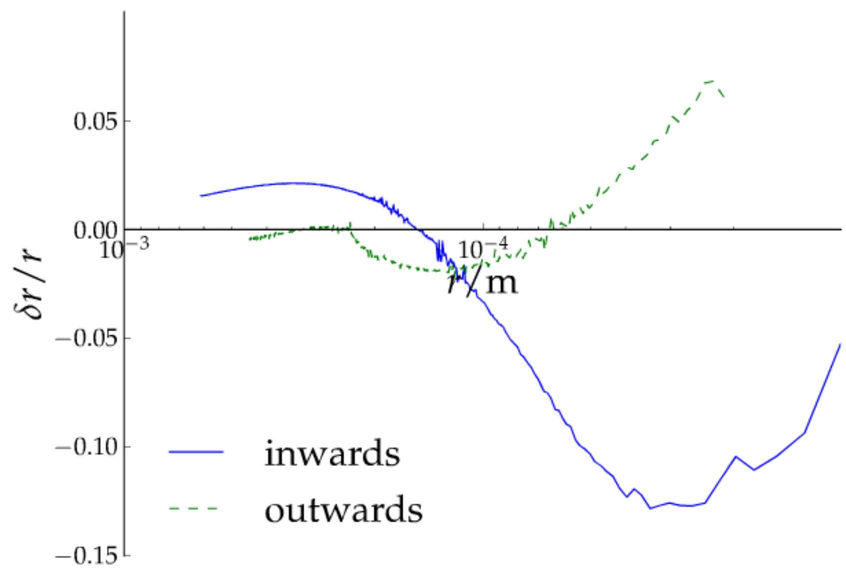




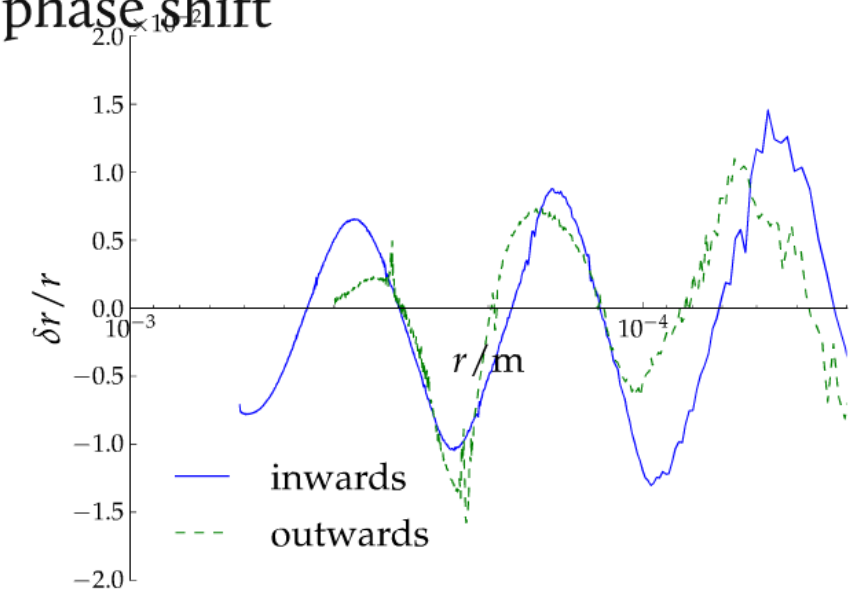
Larger perturbations

Reflected shocks recover size and shape



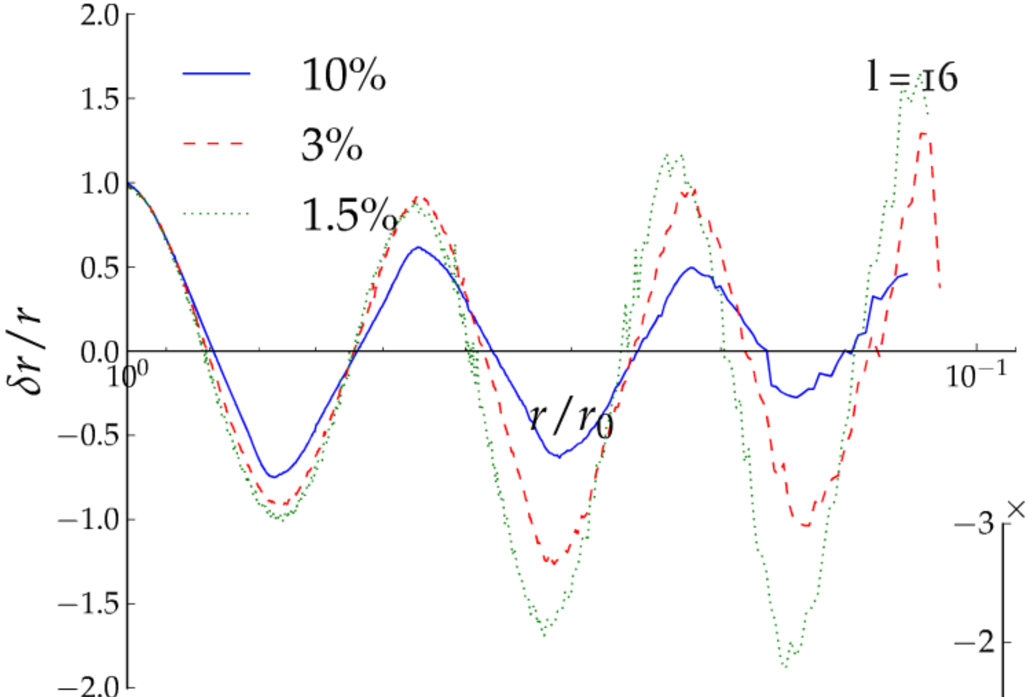


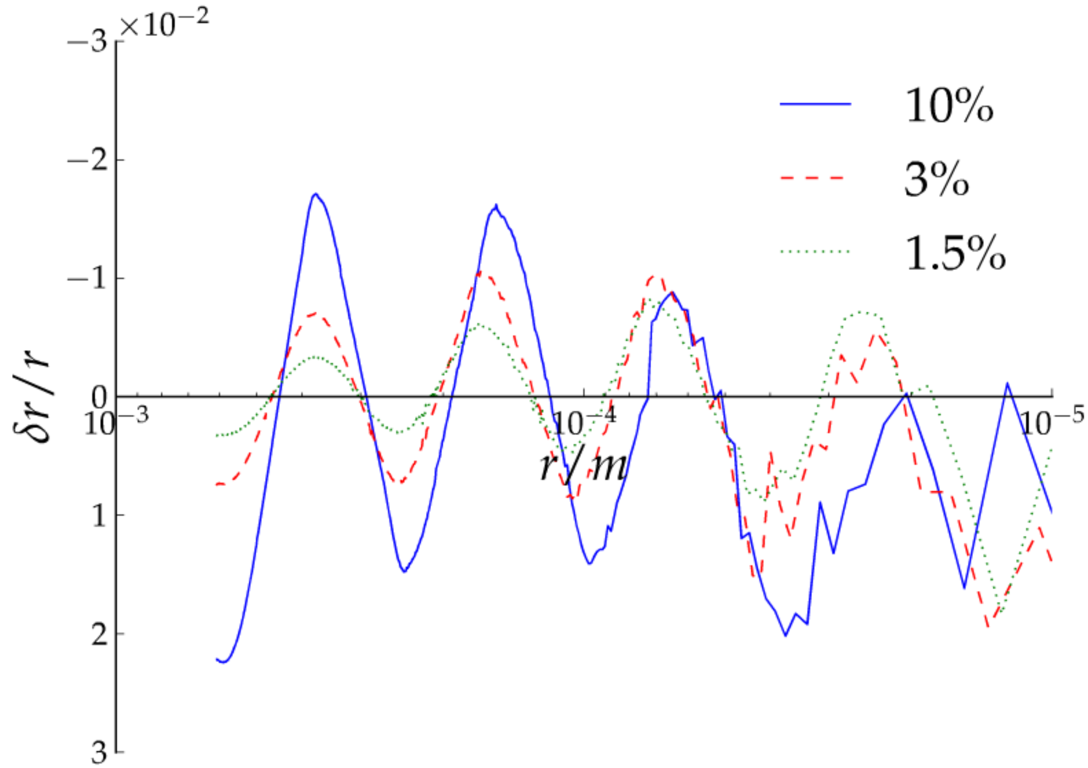
Odd modes acquire a phase shift



Larger perturbations

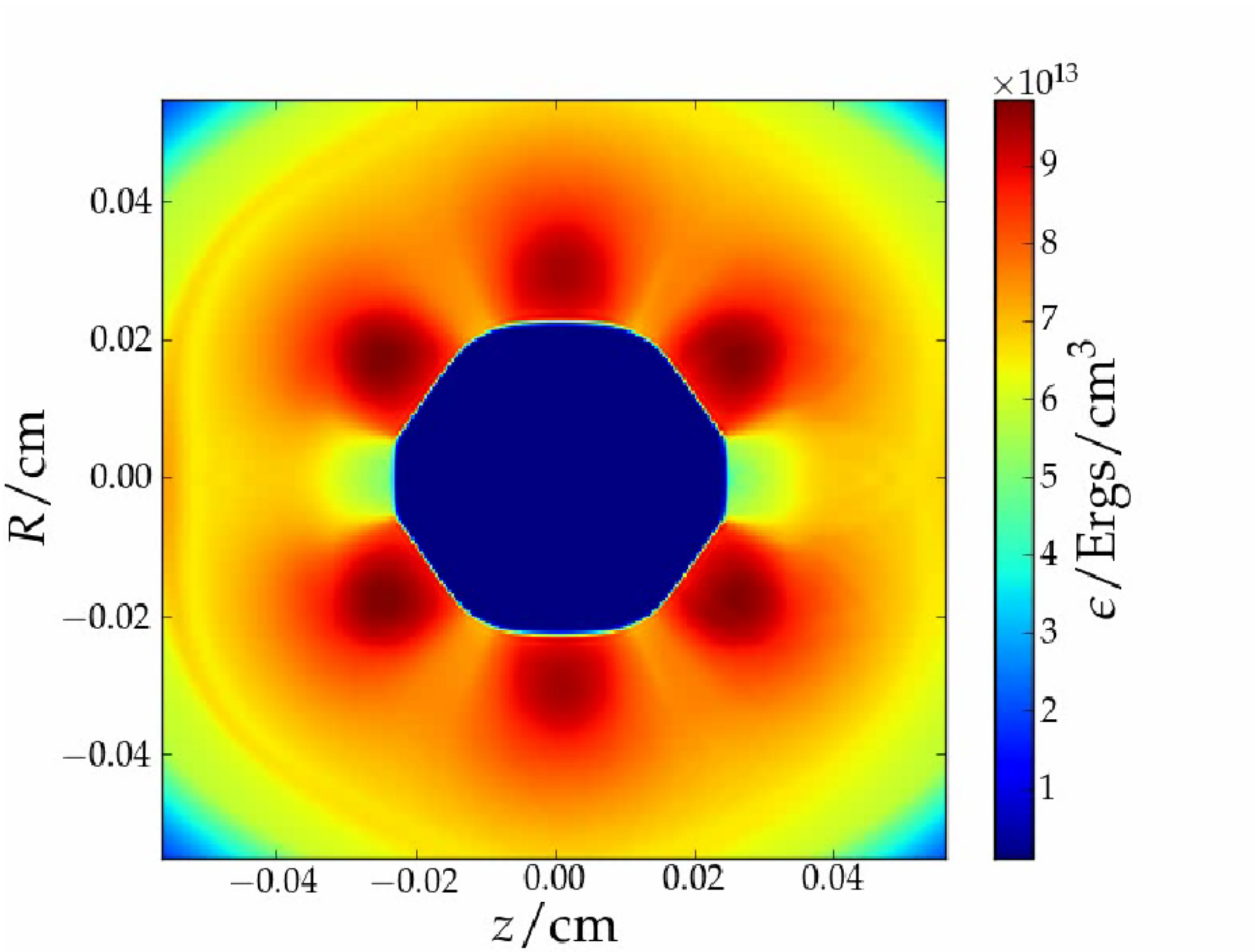
Self-limiting growth

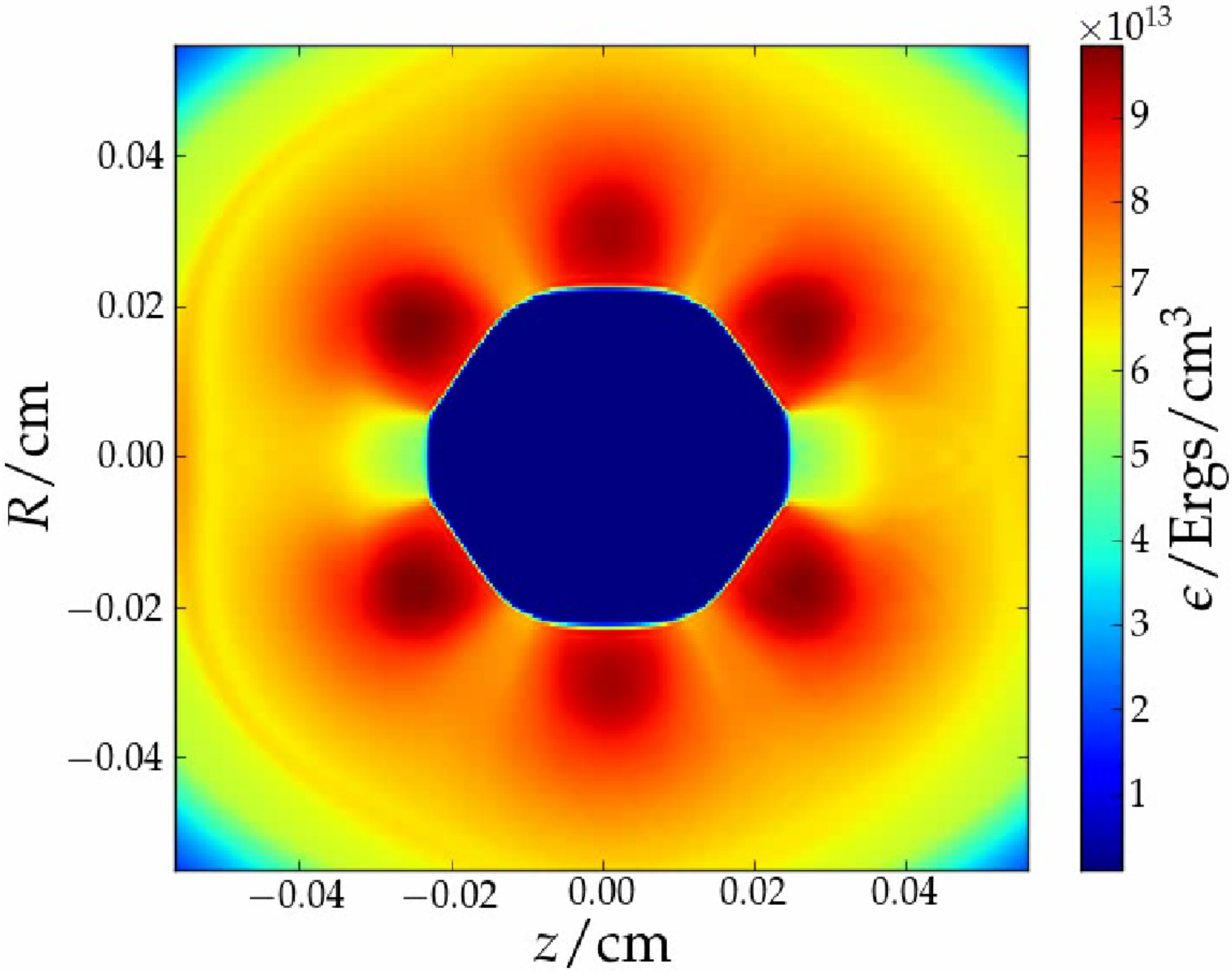




Larger perturbations

Jetting

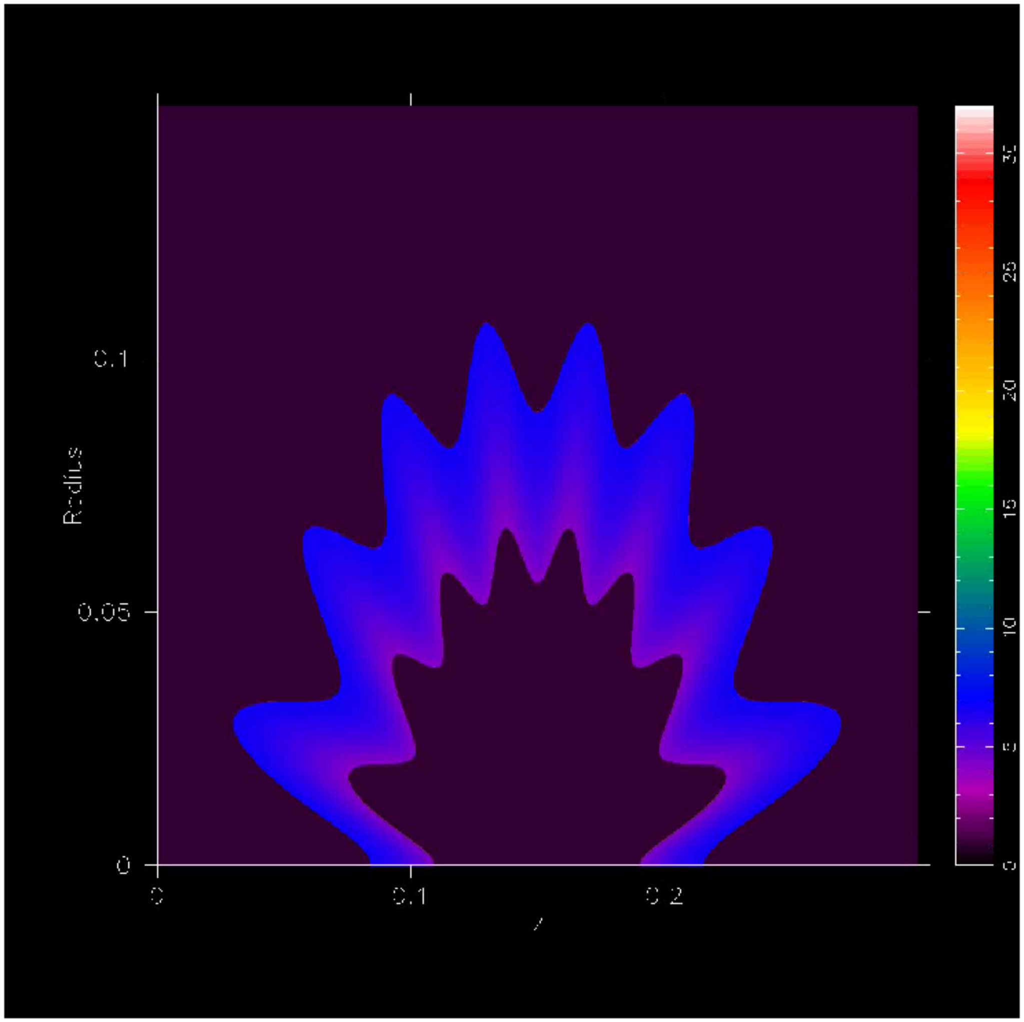




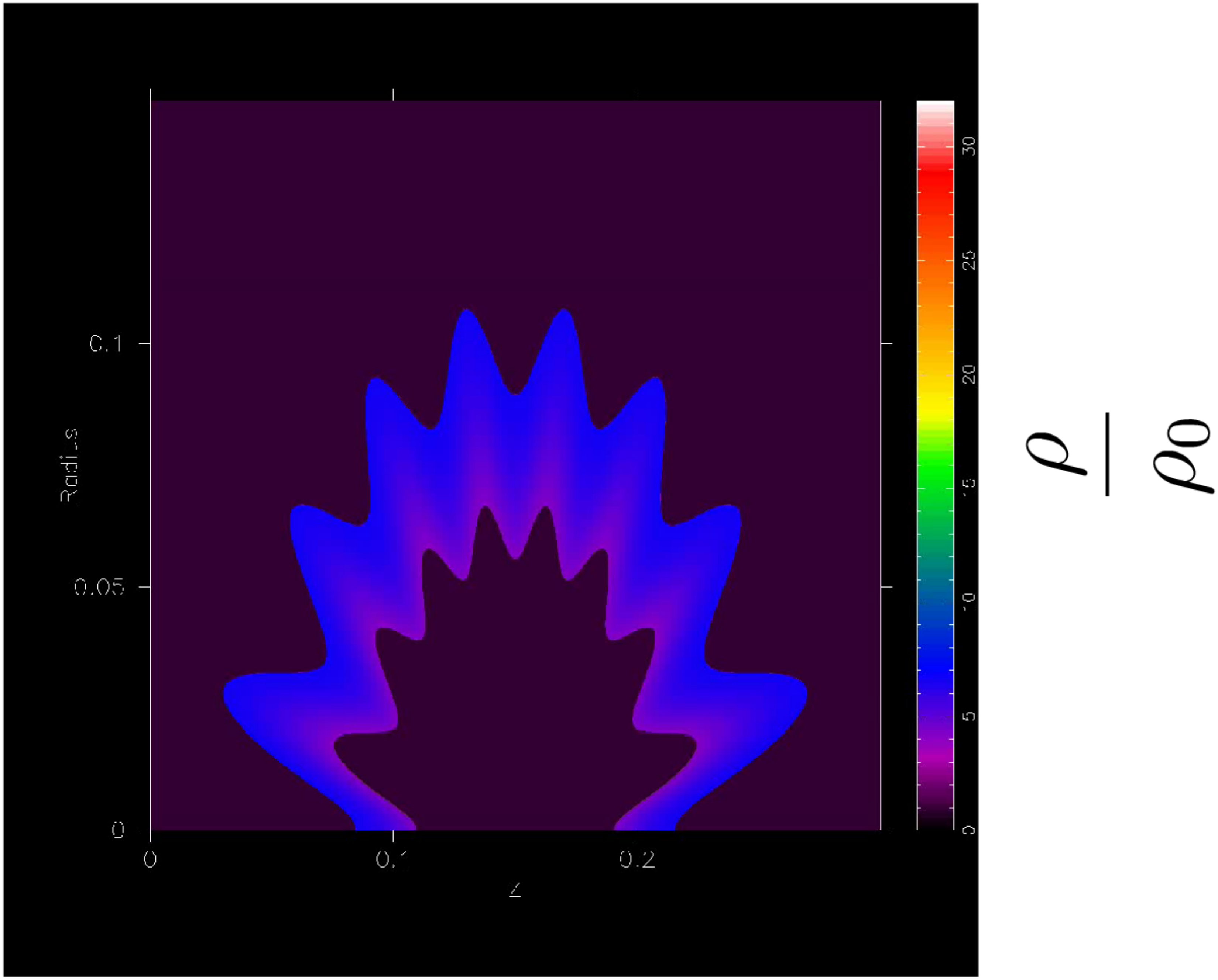
0.04
0.02
0.00
−0.02
−0.04
R / cm
−0.04
−0.02
0.00
0.02
0.04
z / cm
×10^13
9
8
7
6
5
4
3
2
1
ϵ /Ergs/cm^3

Large perturbations

Cusping & shock recovers shape



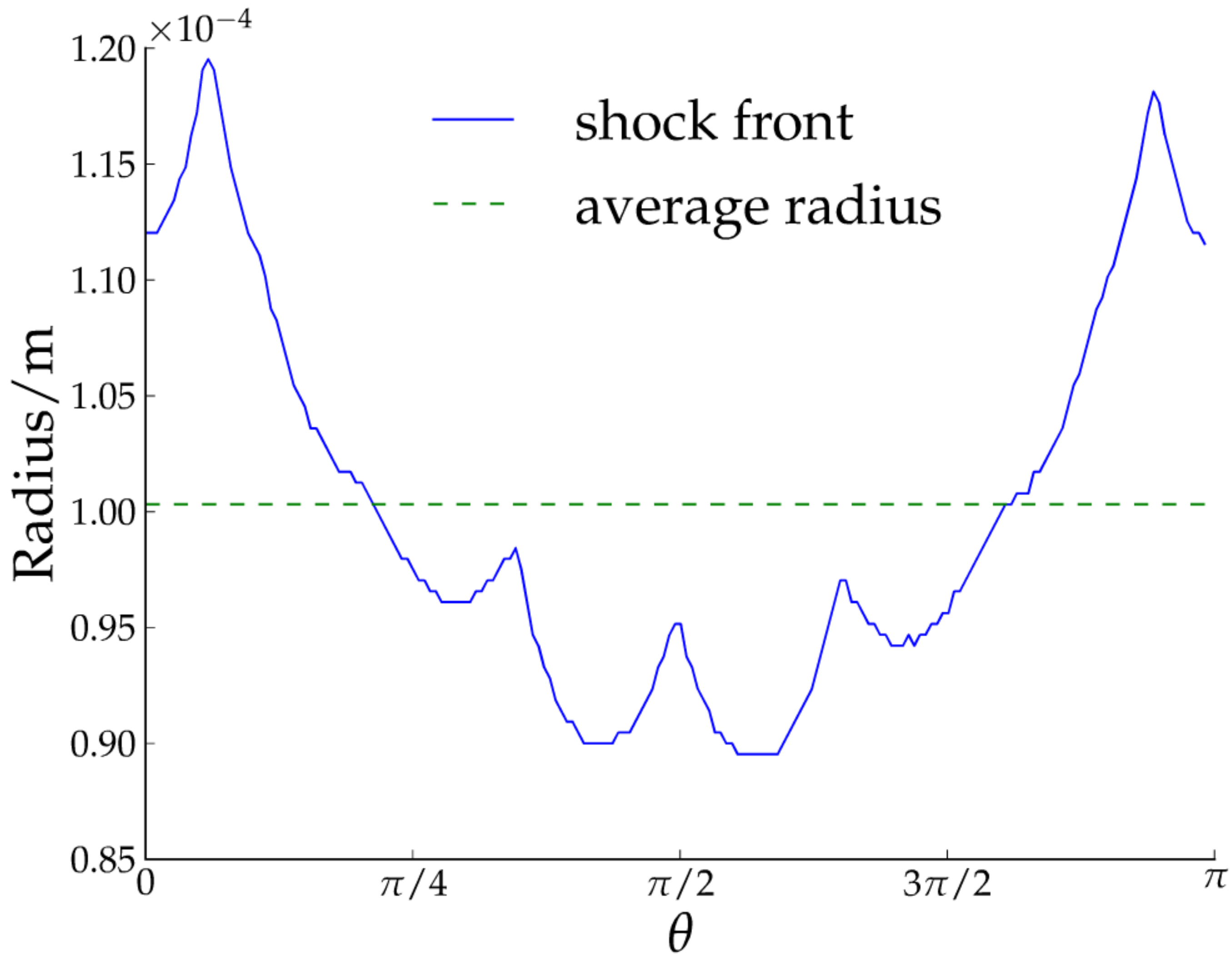
$$\frac{\rho}{\rho_0}$$



0.1
0.05
0
0
0.2
Z
30
25
20
5
$\frac{\rho}{\rho_0}$

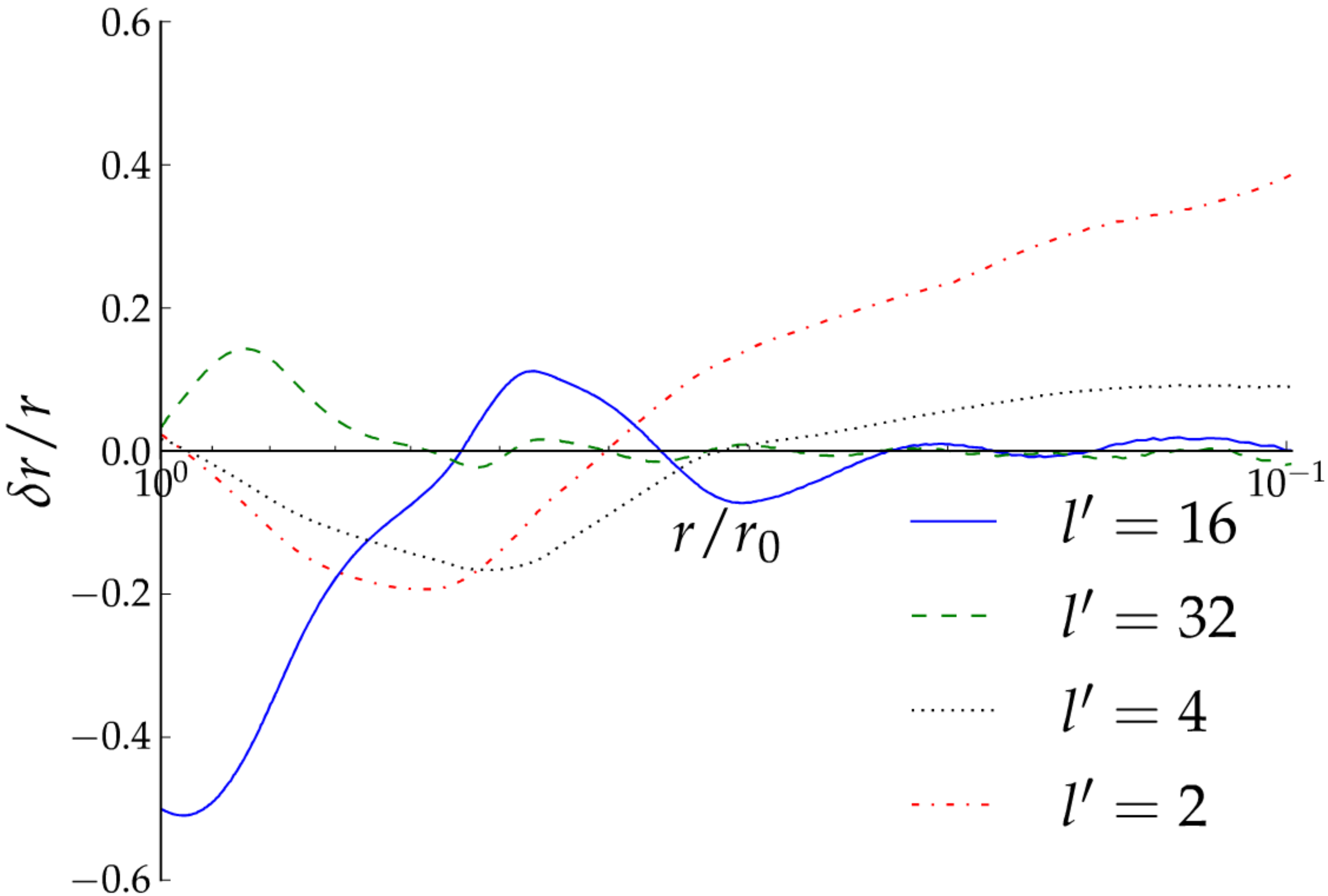
Large perturbations

Imploding shock front shape distorted



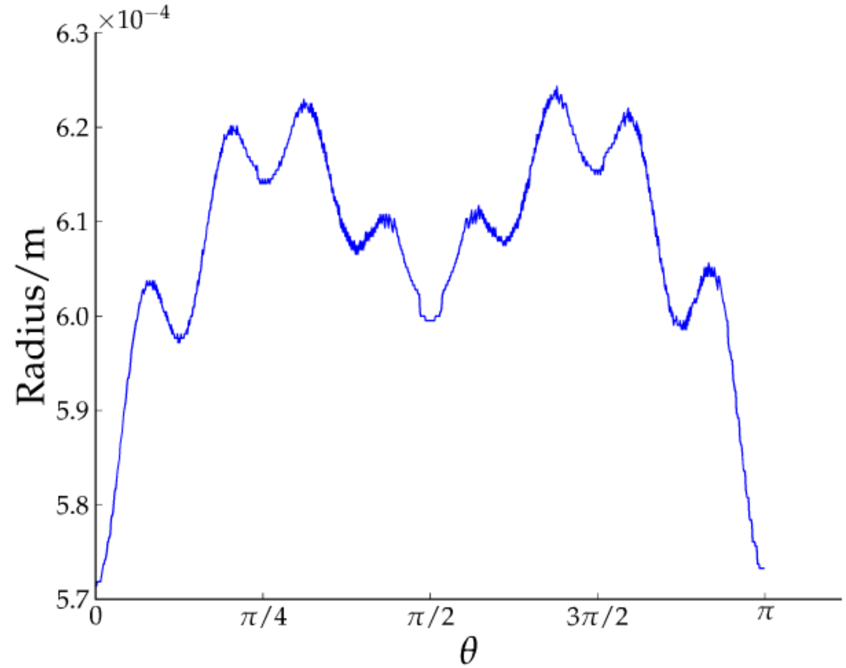
Large perturbations

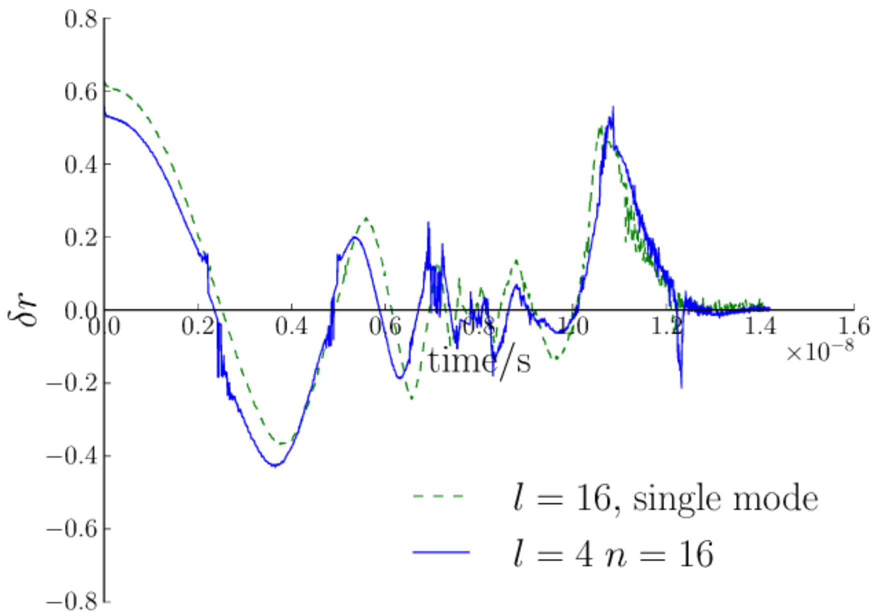
Seeds additional modes



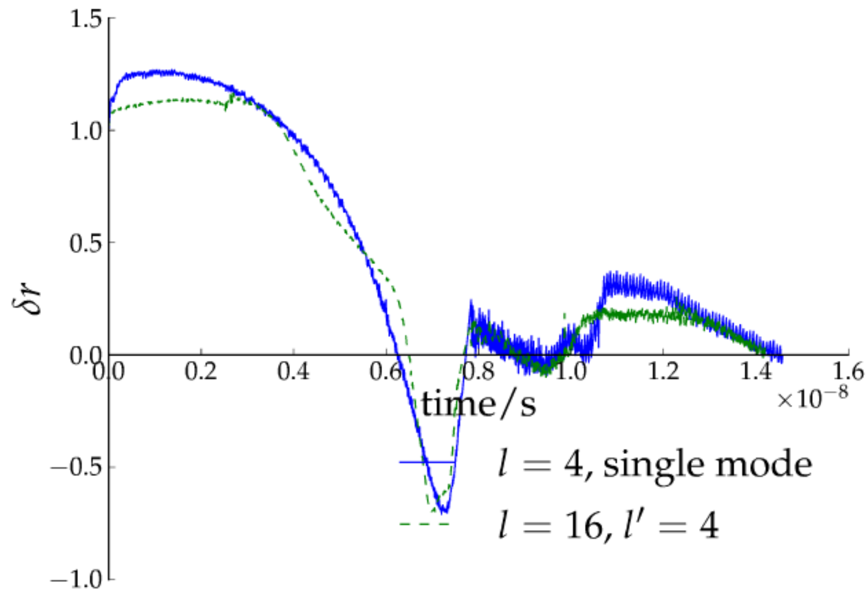
Multi-mode perturbations

Medium size
Retains individual mode behaviour
Additional mode seeding not much greater than individual modes





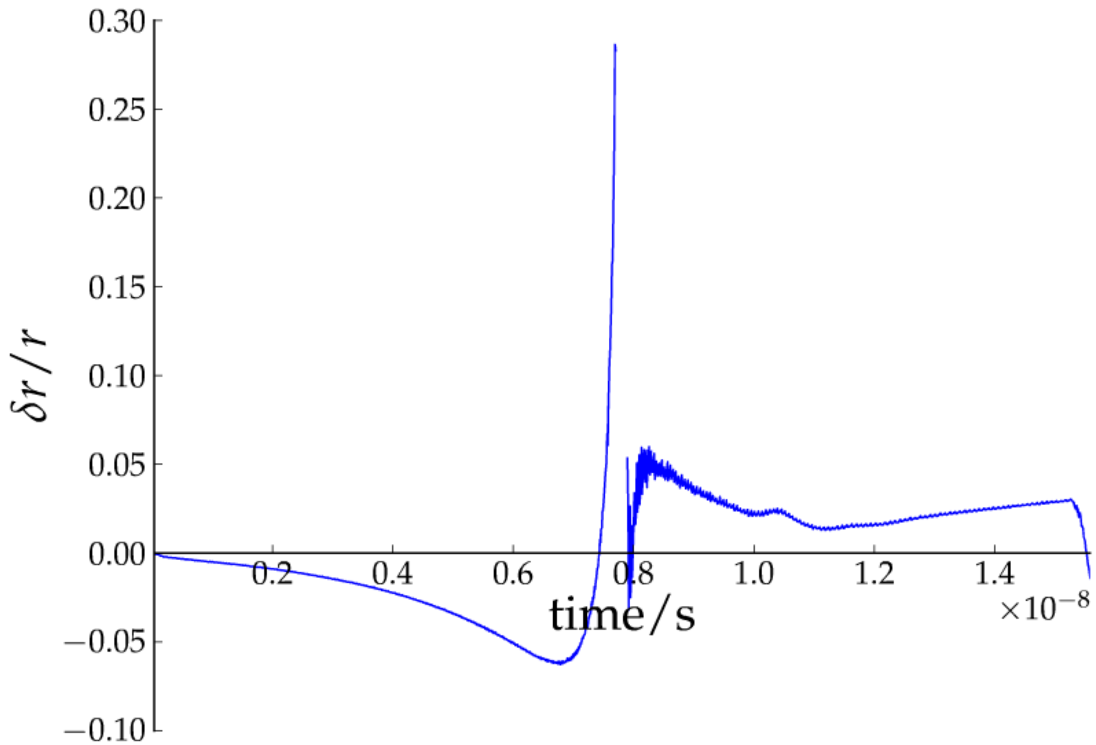
l = 16 equivalent peaks

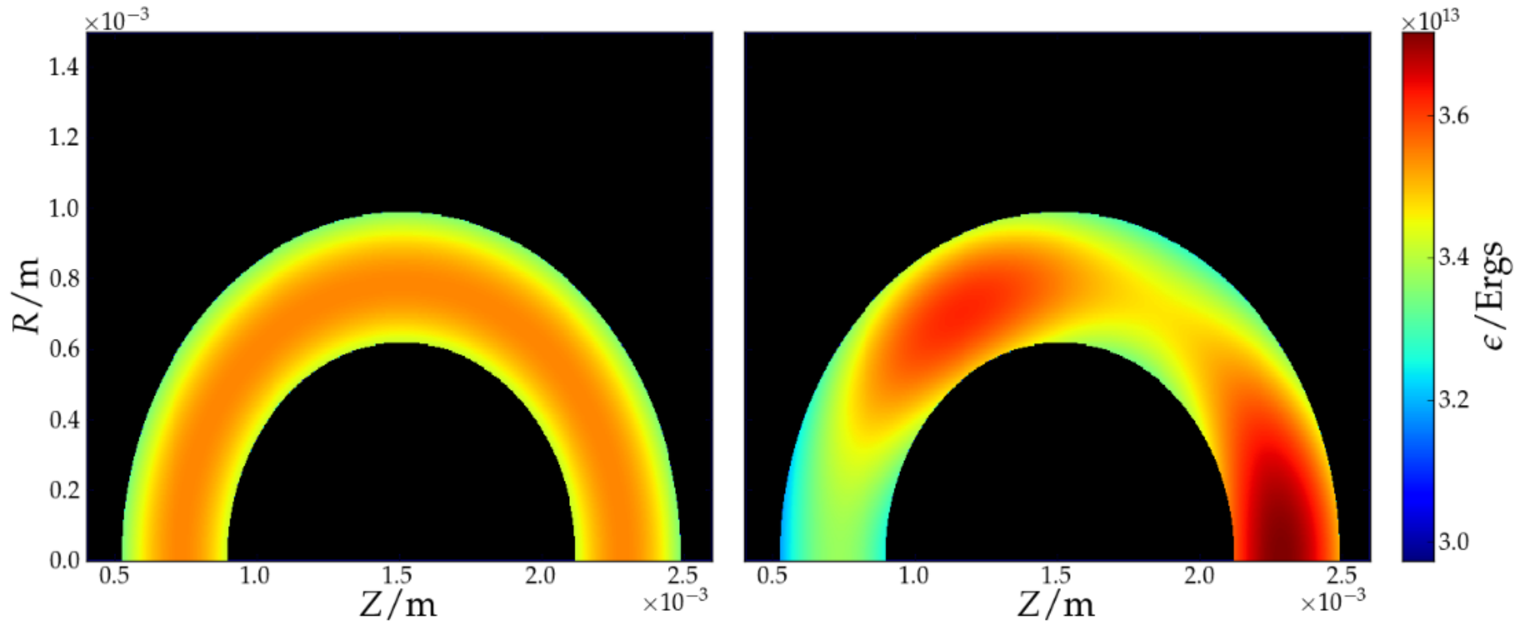


l = 4 equivalent peaks

Energy perturbation

Relates to laser asymmetry
During convergence, behaviour is defined by energy perturbation
Late time behaviour by shock front perturbation





Where next?

- get parallel Zeus running with very small perturbations
- figure out what the energy perturbation is doing
-driving shocks through perturbed 'ablators'

Conclusions

- information about the shape of the perturbation is preserved during convergence and reflection

- shock front perturbations have the same amplitude, at the same radius, coming in and going out

- for $n > 2$, odd mode perturbations add a phase shift

- perturbations do not destroy spherical behaviour of the shock front

- small multi-mode perturbations retain much of the single mode behaviour