Interaction of turbulence with shock waves

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Thanks to Prof.Abdikamalov for allowing to use some of his slides

Outline

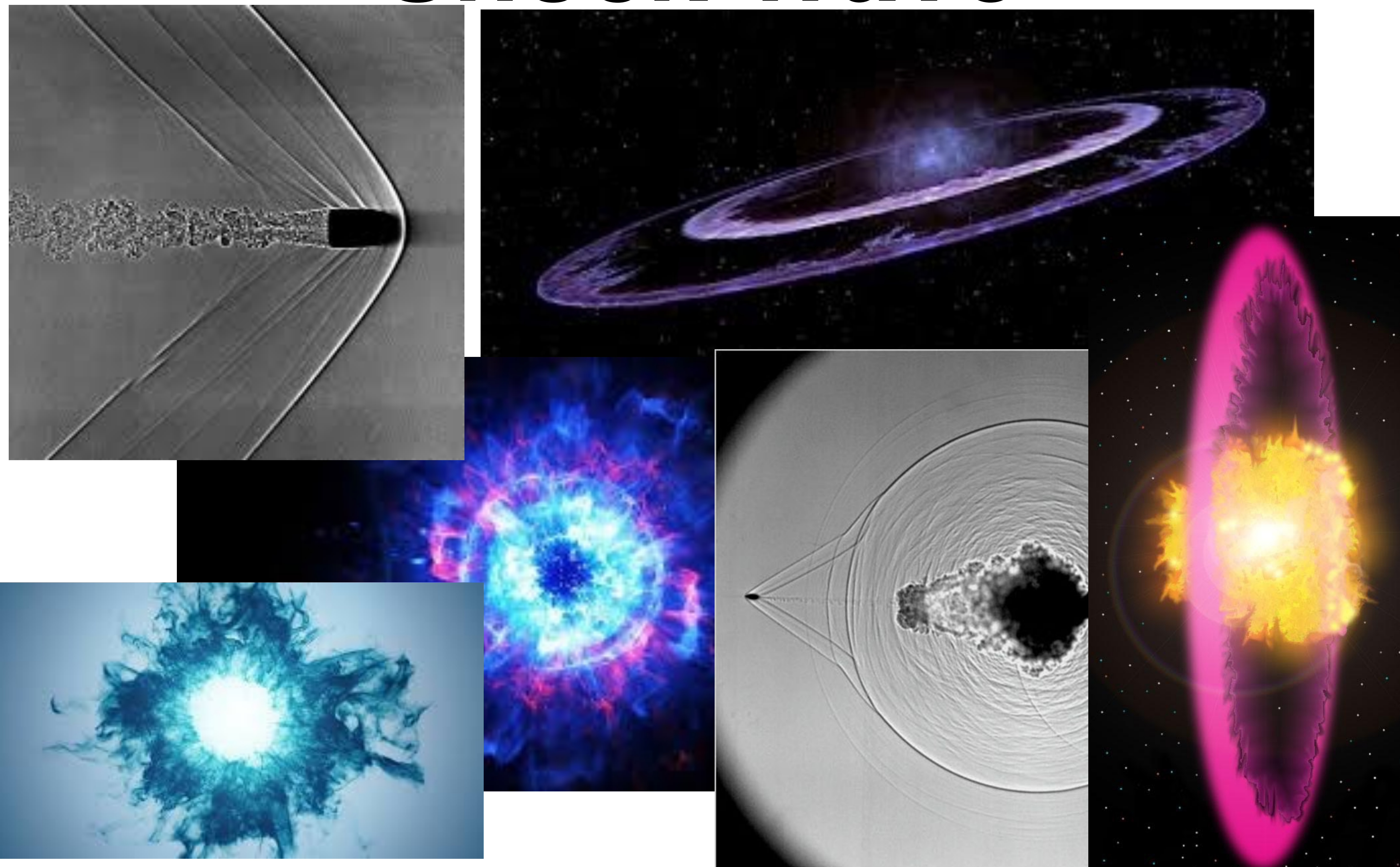
Research work done at

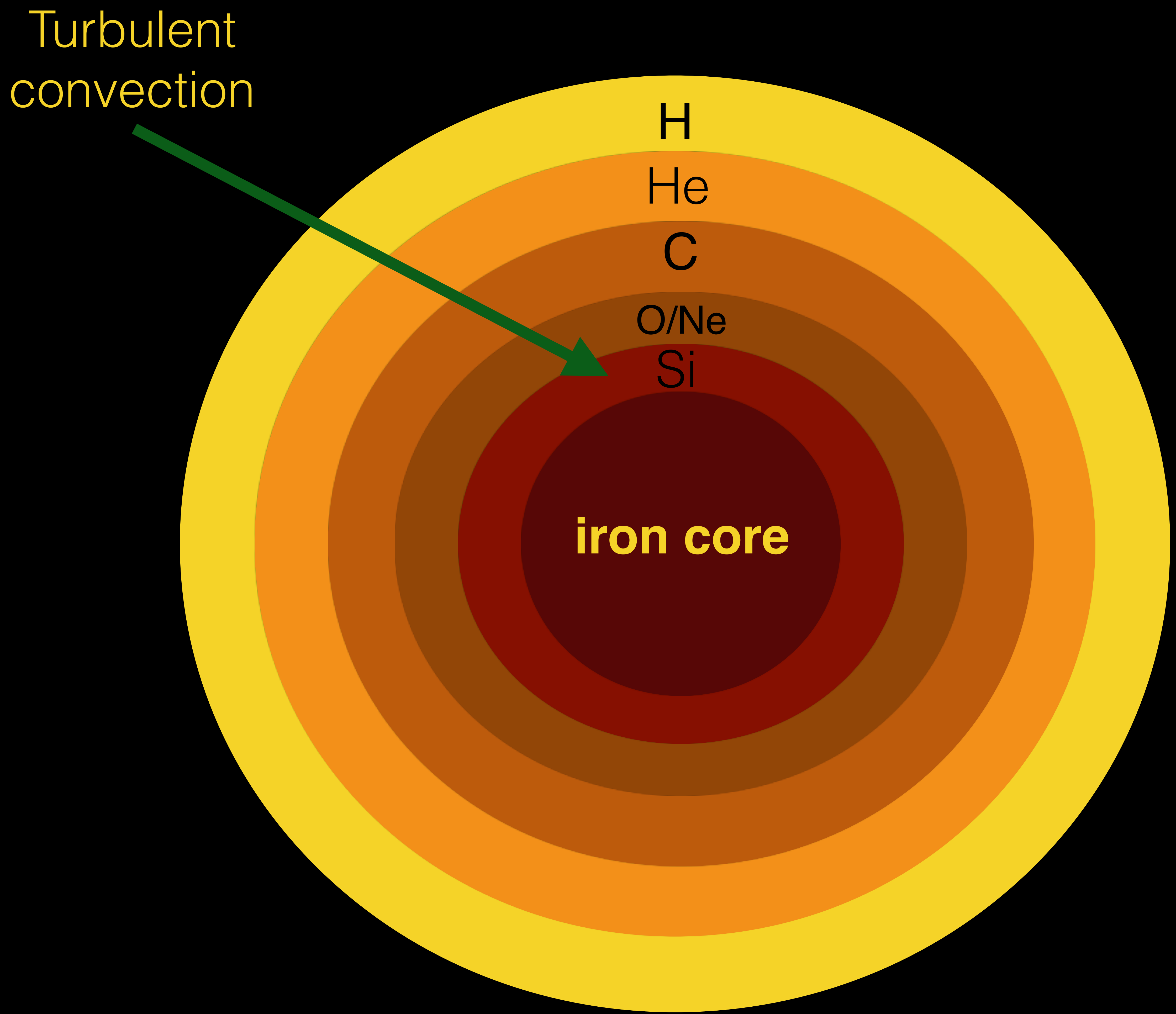
Nazarbayev University

University of Wisconsin-Madison

Turbulence

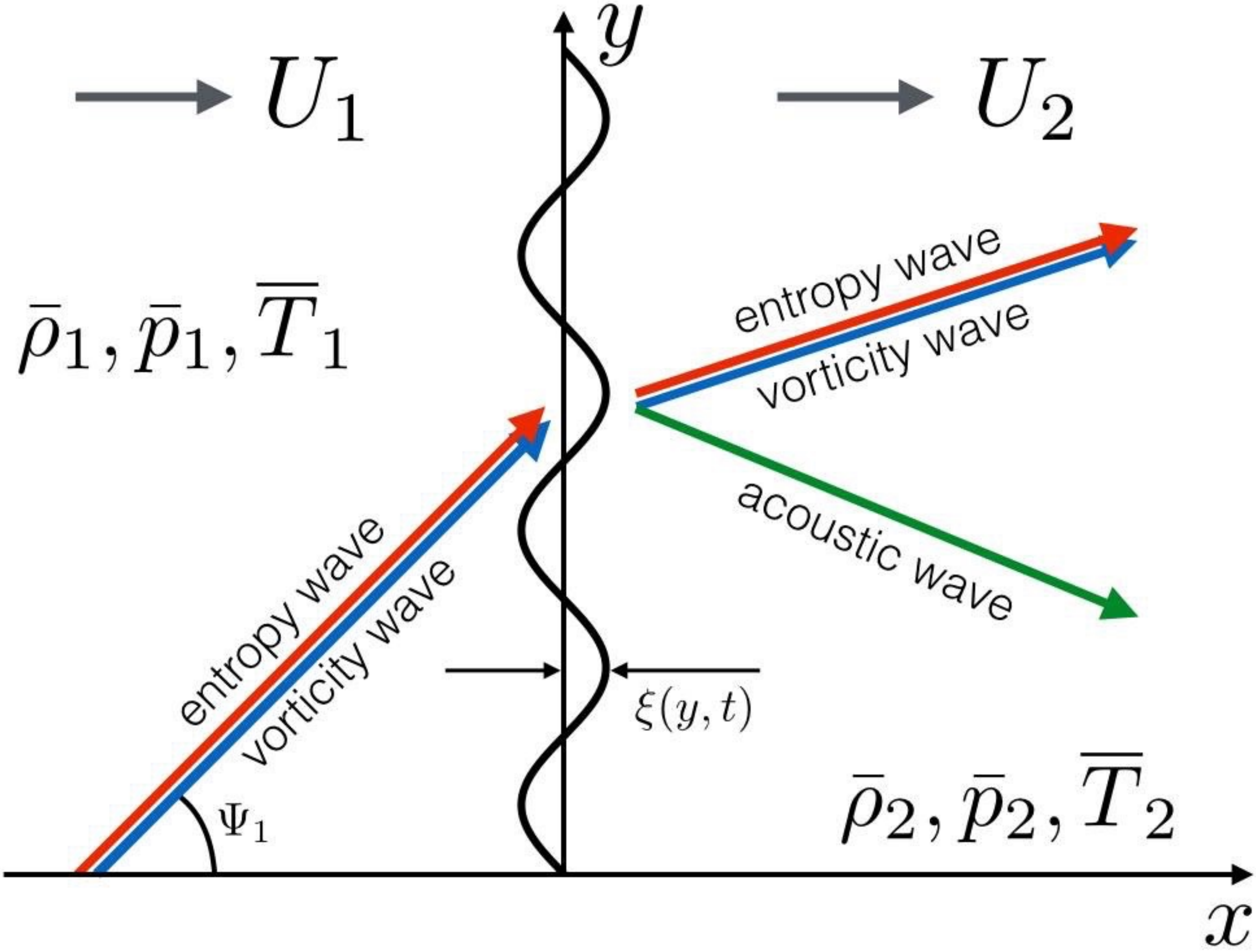
Shock Wave




Turbulent convection
H
He
C
O/Ne
Si
iron core

Linear Interaction Approximation

Source: www.hypersonic-cfd.com



y
U_1
U_2
$\bar{\rho}_1, \bar{p}_1, \overline{T}_1$
entropy wave
vorticity wave
entropy wave
vorticity wave
acoustic wave
$\xi(y,t)$
Ψ_1
$\bar{\rho}_2, \bar{p}_2, \overline{T}_2$
x

Rankine-Hugoniot conditions at the shock

$$\rho_1 v_1 = \rho_2 v_2, \tag{B1}$$

$$p_1 + \rho_1 v_1^2 = p_1 + \rho_2 v_2^2, \tag{B2}$$

$$\frac{1}{2} v_1^2 + \frac{\gamma p_1}{(\gamma - 1)\rho_1} = \frac{1}{2} v_2^2 + \frac{\gamma p_2}{(\gamma - 1)\rho_2}, \tag{B3}$$

The subscript 1 and 2 denote pre- and post-shock quantities

Rho, p and v are density, pressure and velocity of the flow

$$p = \overline{p} + p'$$

Mean flow

Perturbations

$$\frac{u_1'}{U_1} = lA_v \; e^{ik(mx+ly-U_1mt)}$$

$$\frac{v_1'}{U_1} = -mA_v \; e^{ik(mx+ly-U_1mt)}$$

$$\frac{\rho_1'}{\bar{\rho}_1} = A_e \; e^{ik(mx+ly-U_1mt)}$$

$$\frac{T_1'}{\overline{T}_1} = -\frac{\rho_1'}{\bar{\rho}_1}$$

$$p_1' = 0$$

$$\frac{u_2'}{U_1} = F\mathrm{e}^{\mathrm{i}\tilde{\kappa}x}\mathrm{e}^{\mathrm{i}\kappa(ly-U_1mt)} + G\mathrm{e}^{\mathrm{i}\kappa(Cmx+ly-U_1mt)},$$

$$\frac{v_2'}{U_1} = H\mathrm{e}^{\mathrm{i}\tilde{\kappa}x}\mathrm{e}^{\mathrm{i}\kappa(ly-U_1mt)} + I\mathrm{e}^{\mathrm{i}\kappa(Cmx+ly-U_1mt)},$$

$$\frac{p_2'}{\bar{p}_2} = K\mathrm{e}^{\mathrm{i}\tilde{\kappa}x}\mathrm{e}^{\mathrm{i}\kappa(ly-U_1mt)},$$

$$\frac{\rho_2'}{\bar{\rho}_1} = \frac{K}{\gamma}\mathrm{e}^{\mathrm{i}\tilde{\kappa}x}\mathrm{e}^{\mathrm{i}\kappa(ly-U_1mt)} + Q\mathrm{e}^{\mathrm{i}\kappa(Cmx+ly-U_1mt)},$$

$$\frac{T_2'}{\overline{T}_1} = \frac{(\gamma-1)K}{\gamma}\mathrm{e}^{\mathrm{i}\tilde{\kappa}x}\mathrm{e}^{\mathrm{i}\kappa(ly-U_1mt)} - Q\mathrm{e}^{\mathrm{i}\kappa(Cmx+ly-U_1mt)}.$$

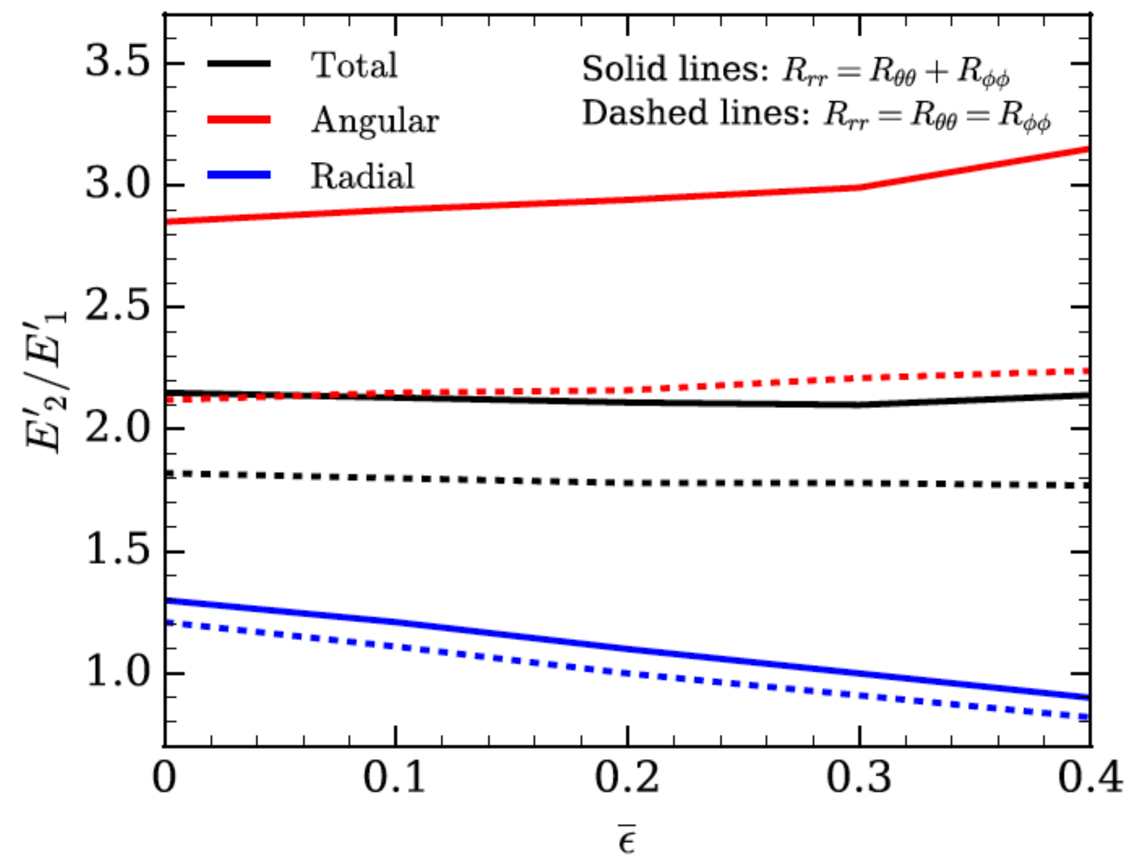
All coefficients (F,G,H and etc) could be found using Rankine-Hugoniot conditions at the shock, the wave equation for in the post-shock region and the linearized Euler equations for the perturbation field

Results

- Total turbulent kinetic energy of perturbations crossing the shock is amplified by a factor ~2, while the average linear size of turbulent eddies decreases by about the same factor

- Above quantities are not sensitive to parameters of the upstream turbulence and the nuclear dissociation efficiency at the shock

- The upstream perturbations can decrease the critical neutrino luminosity for producing explosion by several percent



Ratio of turbulent kinetic energy versus dissociation efficiency

Abdikamalov E, Zhaksylykov A, Radice D and Berdibek S 2016 *Mon. Not. Roy. Astron. Soc.* **461** 3864-3876

Magnetic Mirror

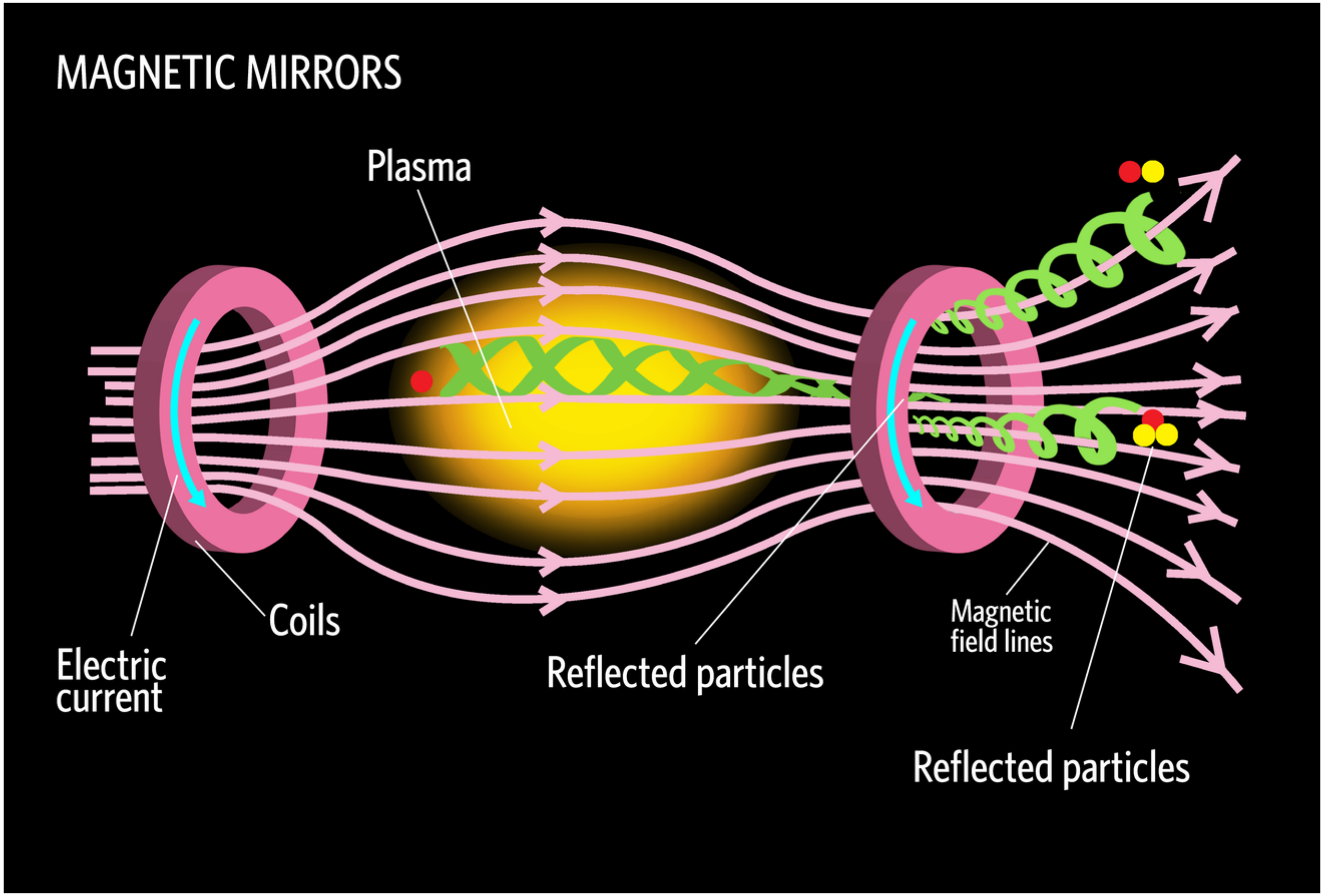
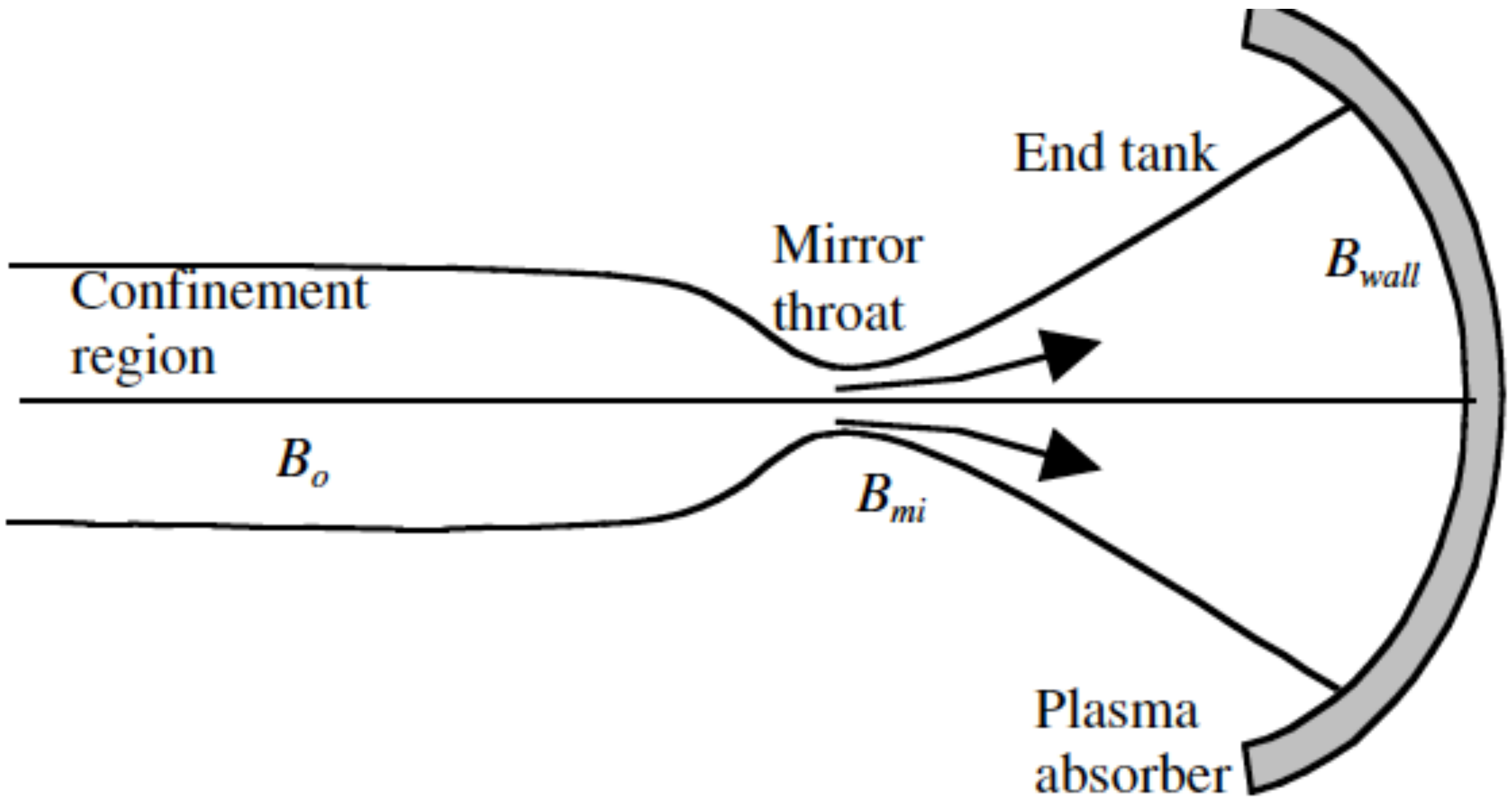
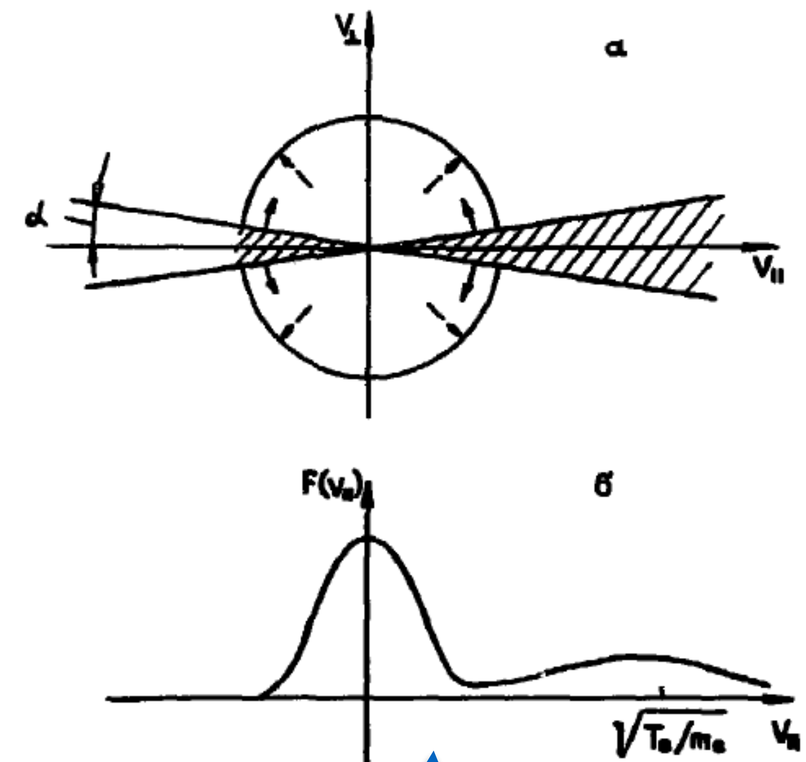


Image credits: Anton Banulski

Plasma beyond mirror throat



Schematic of the end section



Electron distribution in beyond mirror throat region

Mirnov, V. and Ryutov, D. *Gasodynamic trap* (IYaF—88-70) USSR 1988

Similar to core-strahl electron distribution in the Solar Wind