Radiative Shocks in Transient Astrophysical Events

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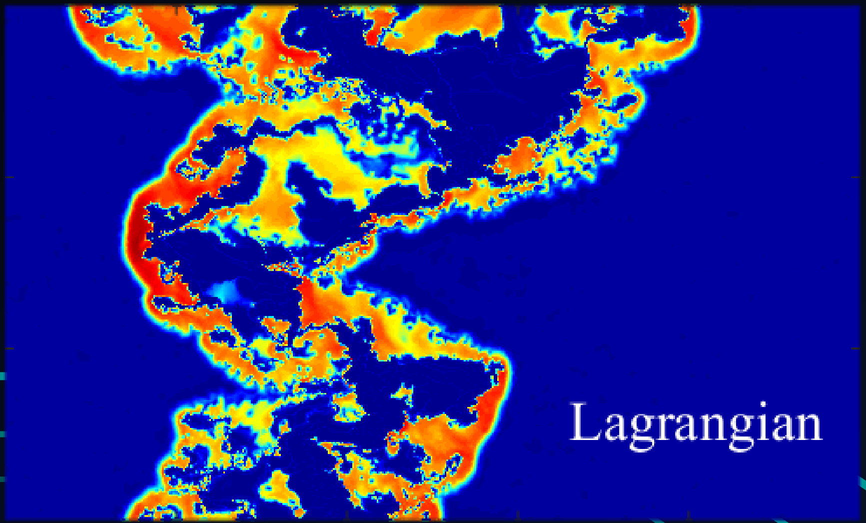
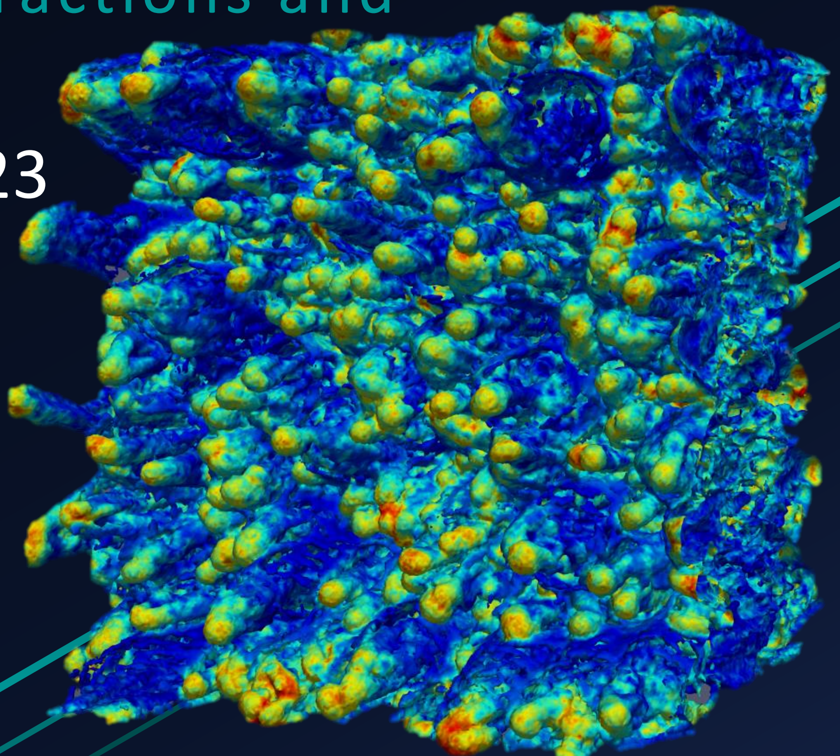
Shocking Supernovae: surrounding interactions and unusual events

https://arxiv.org/abs/1805.03223



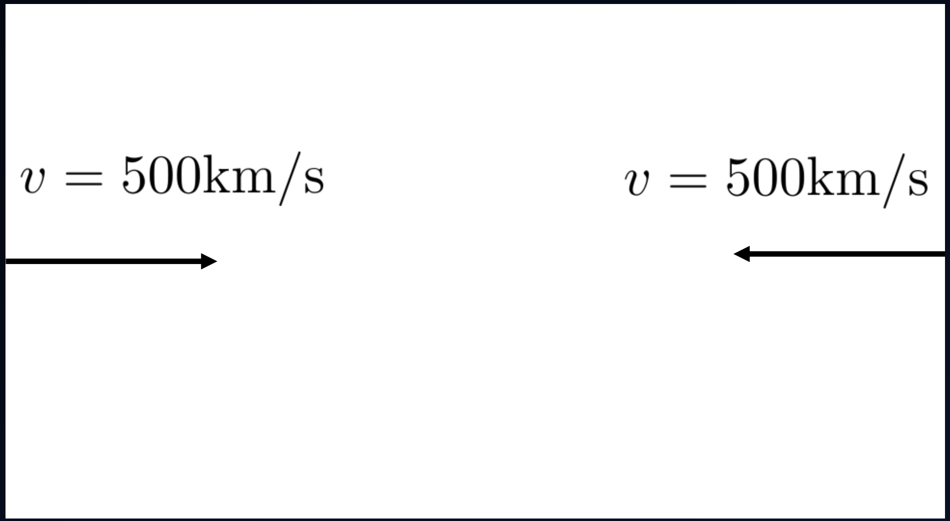


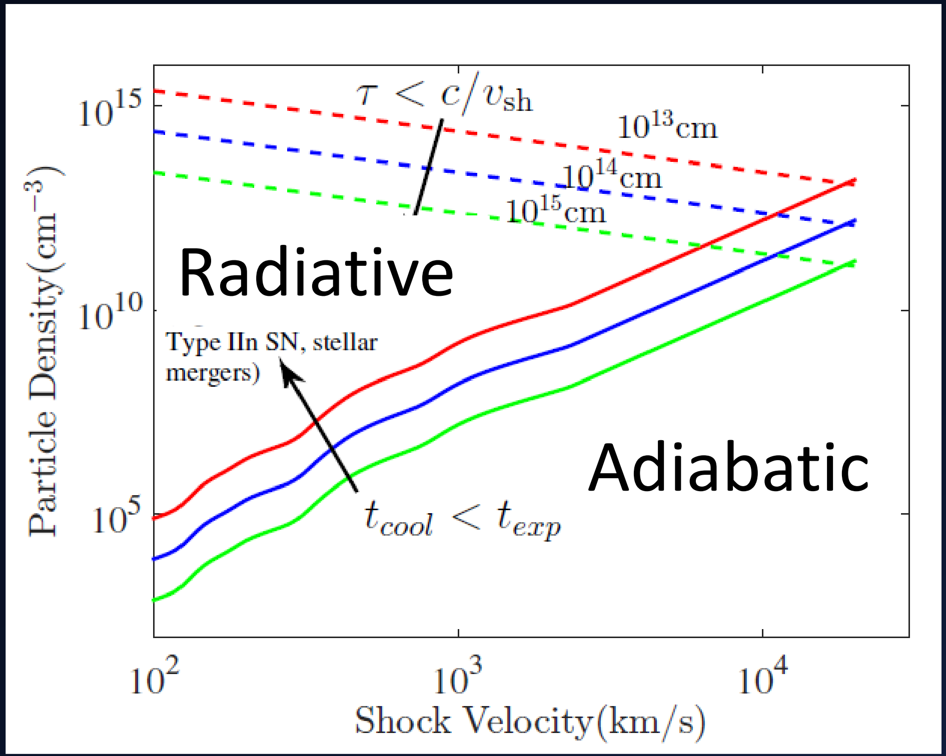
What are radiative shocks?

- Head on shocks give rise to a temperature

$$T_{\rm sh} \approx \frac{3}{16}\frac{\bar{\mu} m_p}{k_b} v_{\rm sh}^2 \approx 1.4 \times 10^7\,{\rm K}\left(\frac{v_{\rm sh}}{10^3\,{\rm km\,s^{-1}}}\right)^2$$

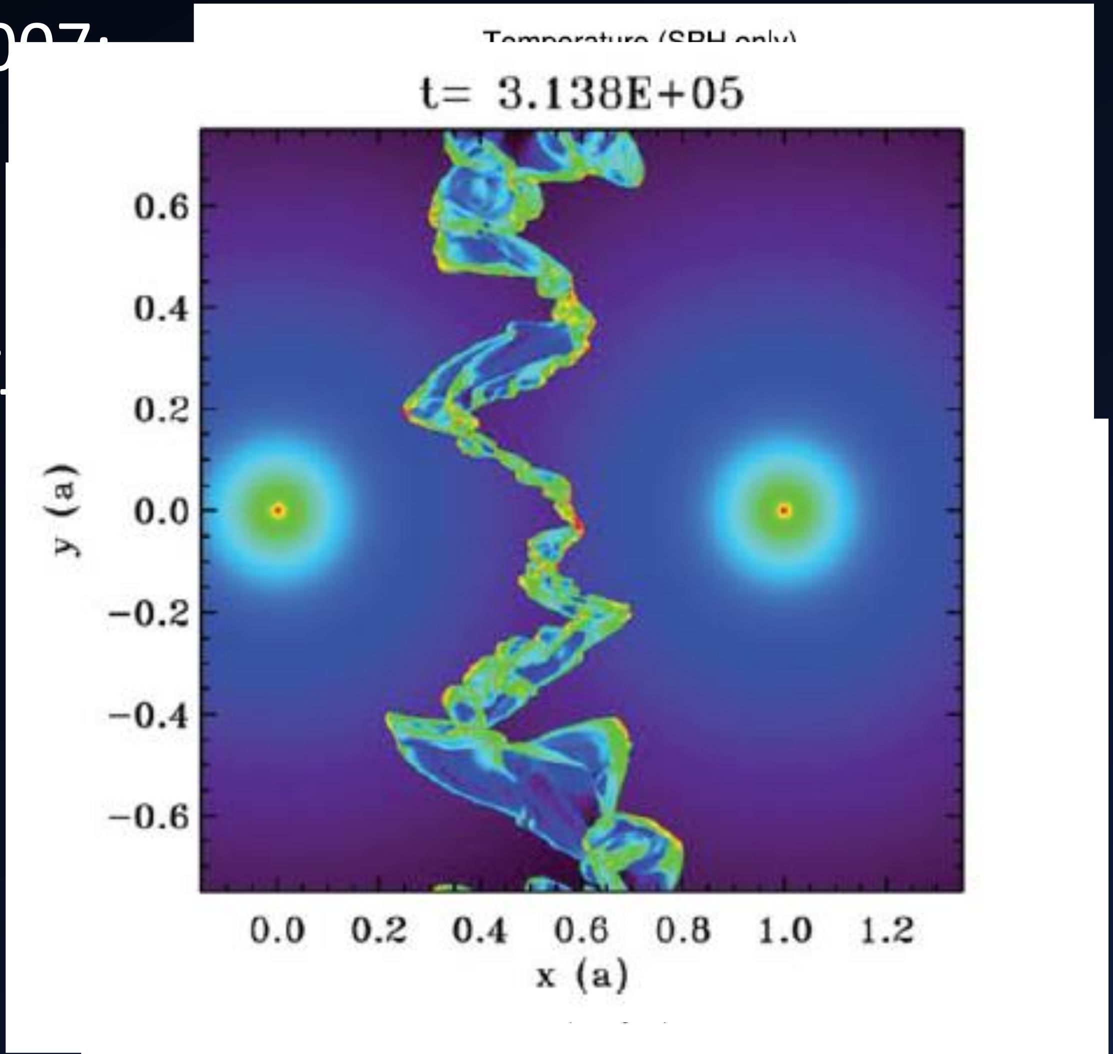
- Gas cools via line emission or free-free.
- Radiative shocks: $t_{\rm cool} \ll t_{\rm exp}$





Radiative Shocks are common

- Type IIn Sne (e.g. Smith & McCray 20
Chevalier & Irwin 2011). High luminosities explained by shocks.
- Classical Nova (e.g. Mukai & Ishida 2
Metzger et al 2014; Martin et al 201
- Merger of binary stars (e.g. Metzger
Pejcha 2017; Pejcha et al 2017).
- Colliding wind binaries (Pittard et al 2005, Lamberts et al 2011)

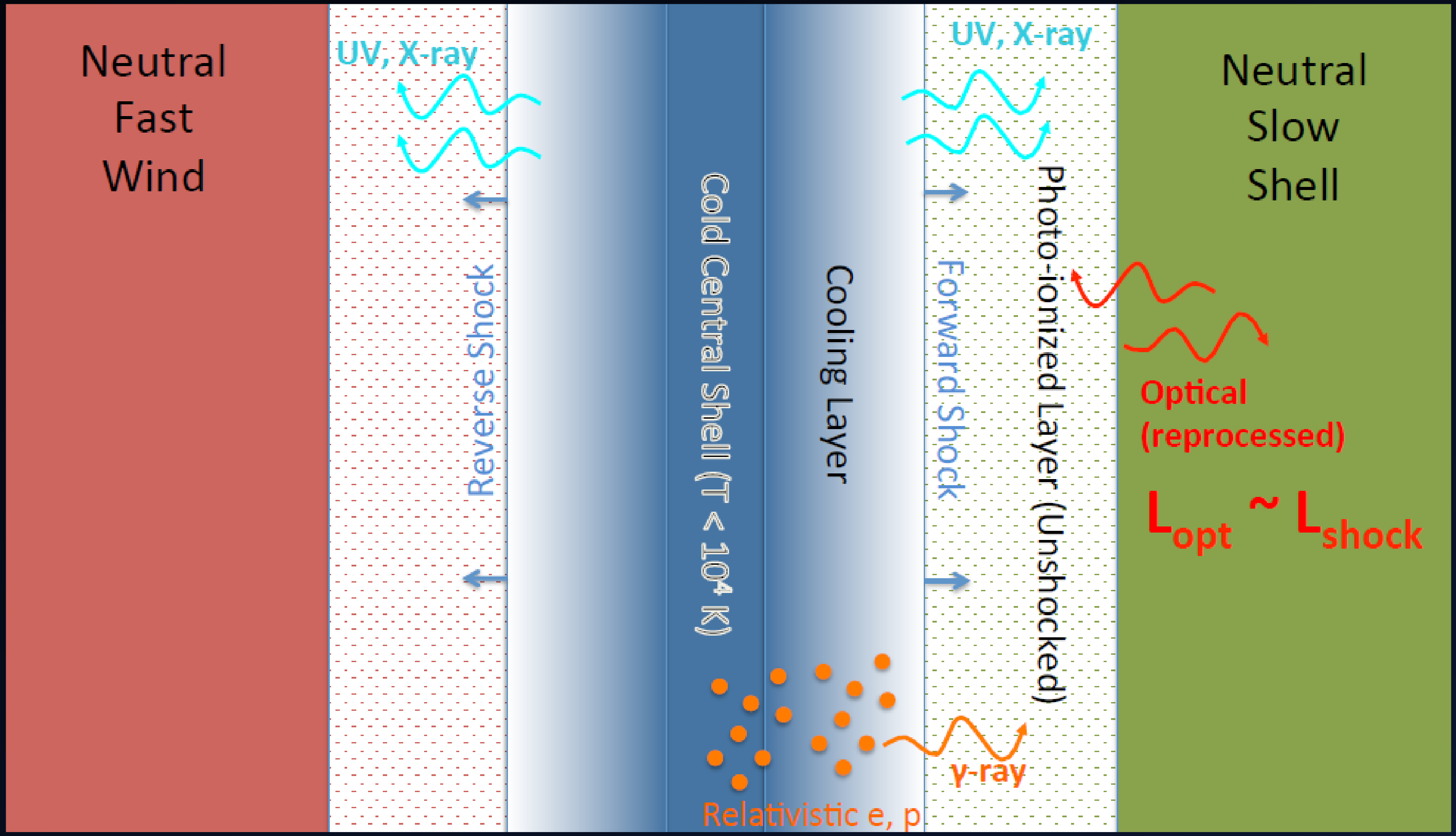


Smith et al 2008

1D picture

Dense cold shell surrounded by hot forward and reverse shocks.

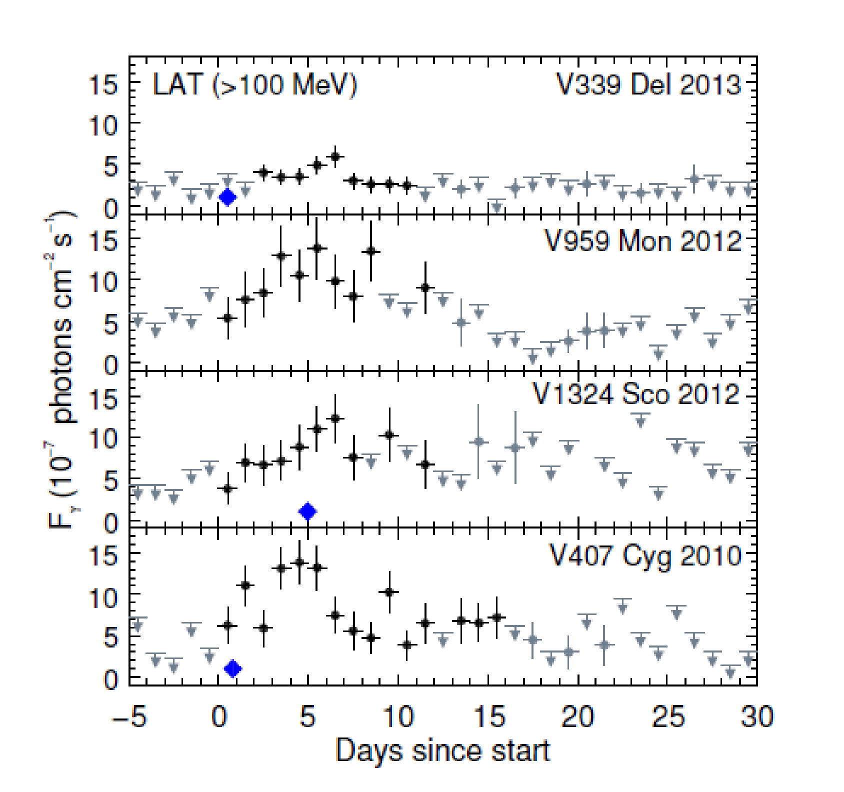
- Efficient thermal X-rays.
- Ion acceleration?



Metzger et al 2014, Vlasov et al 2016, Martin et al 2018.

Puzzling result from classical nova

Gamma ray emission from classical nova.
Most probably arising from ion acceleration (high efficiency and magnetic field required for leptonic scenario). Efficiency 0.005 inferred from ASASSN-16ma

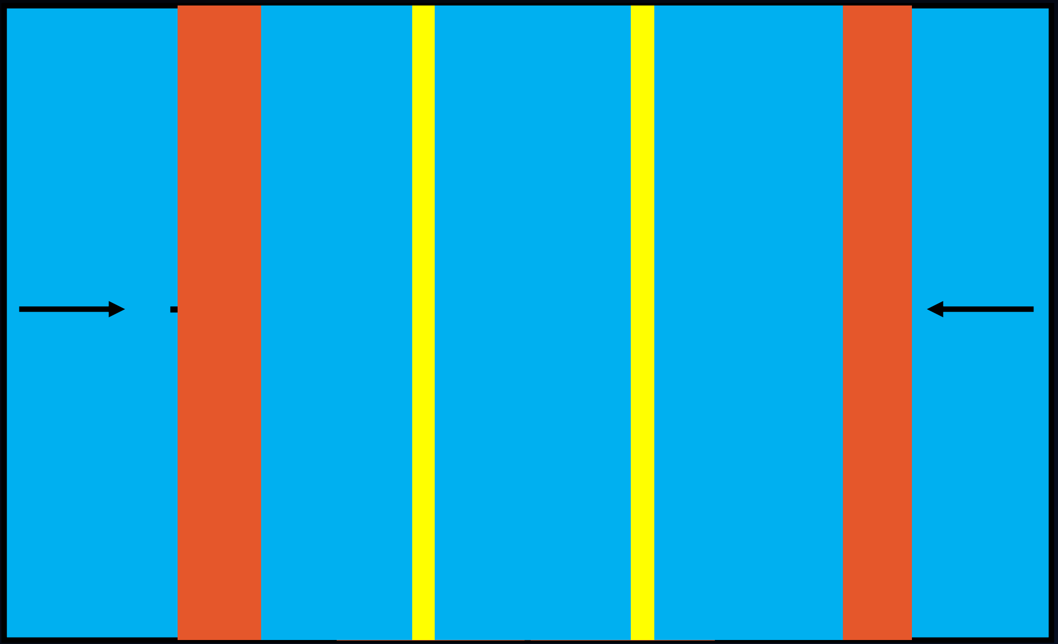


Ackermann et al 2014, Franckowiak et al 2018.

However, Caprioli & Spitkovsky 2014 have shown that ion acceleration requires a magnetic field parallel to the shock normal, unexpected for expanding gas.

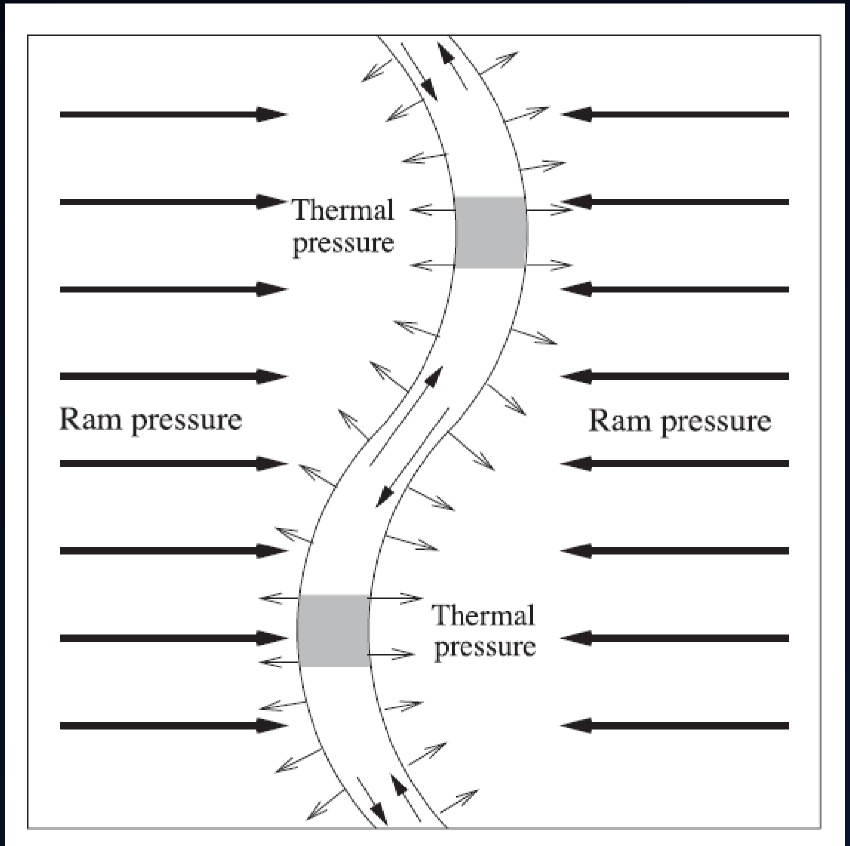
NTSI

Thermal instability



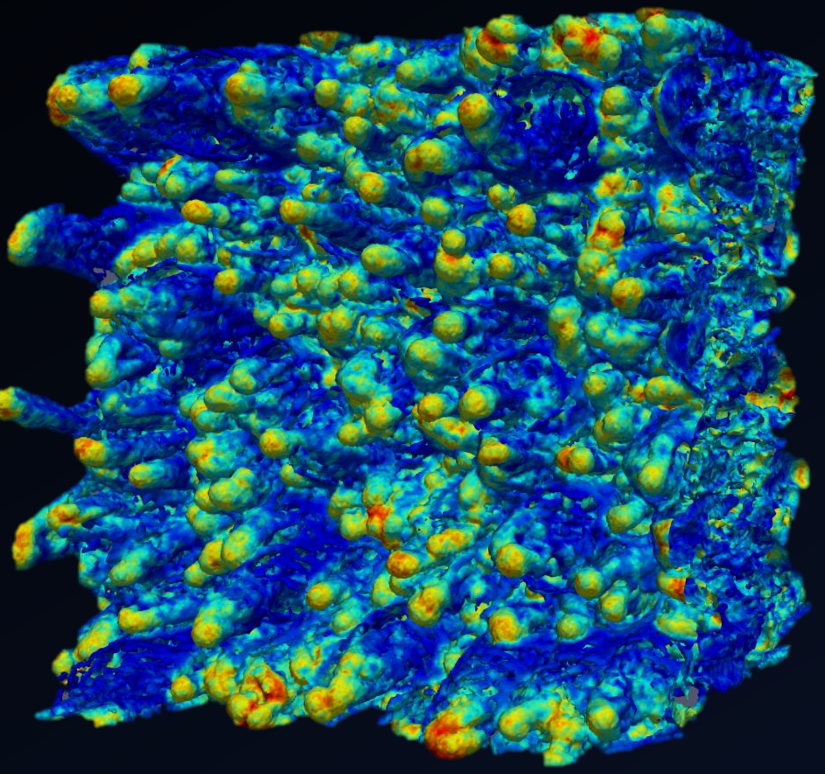
Stability criteria: $\Lambda \propto T^{\alpha} \quad \alpha < 0.4$

Chevalier & Imamura 1982



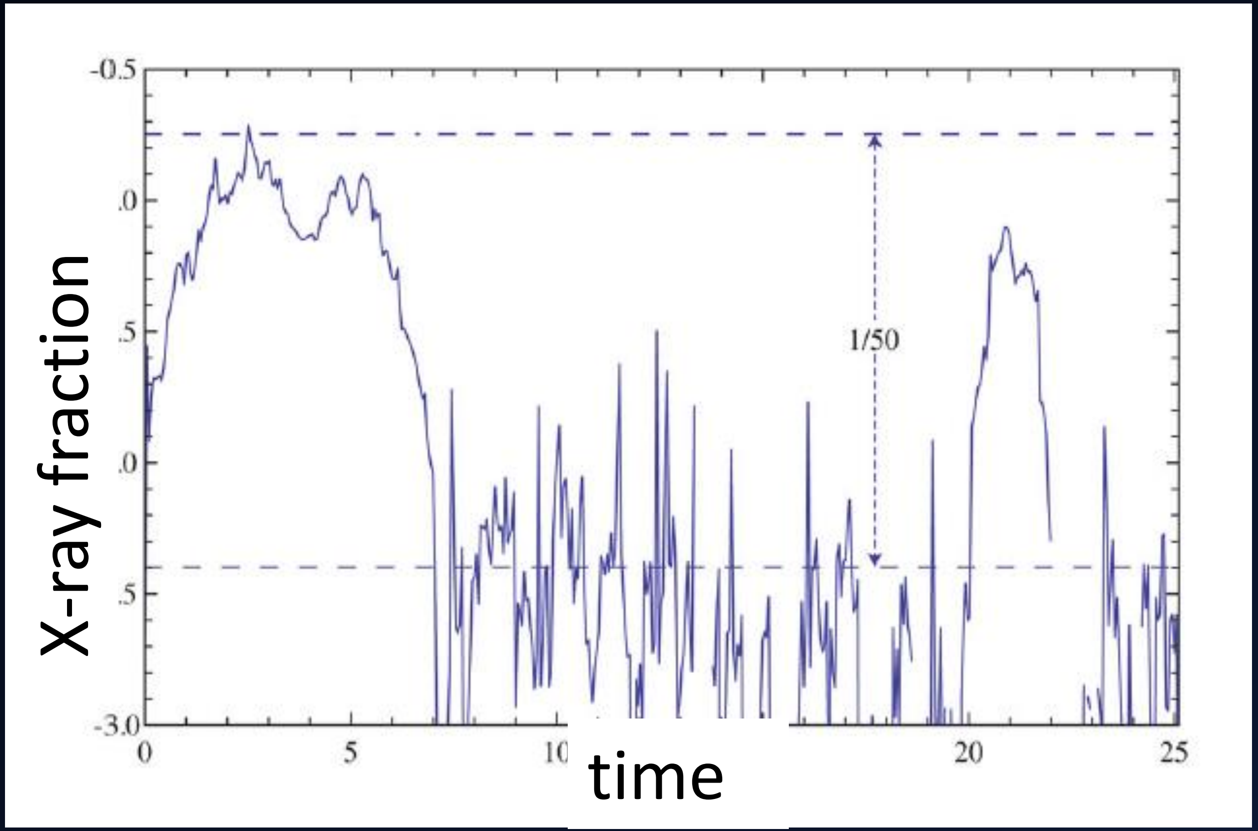
Vishniac 1994, McLeod & Whitworth 2013

2D/3D picture



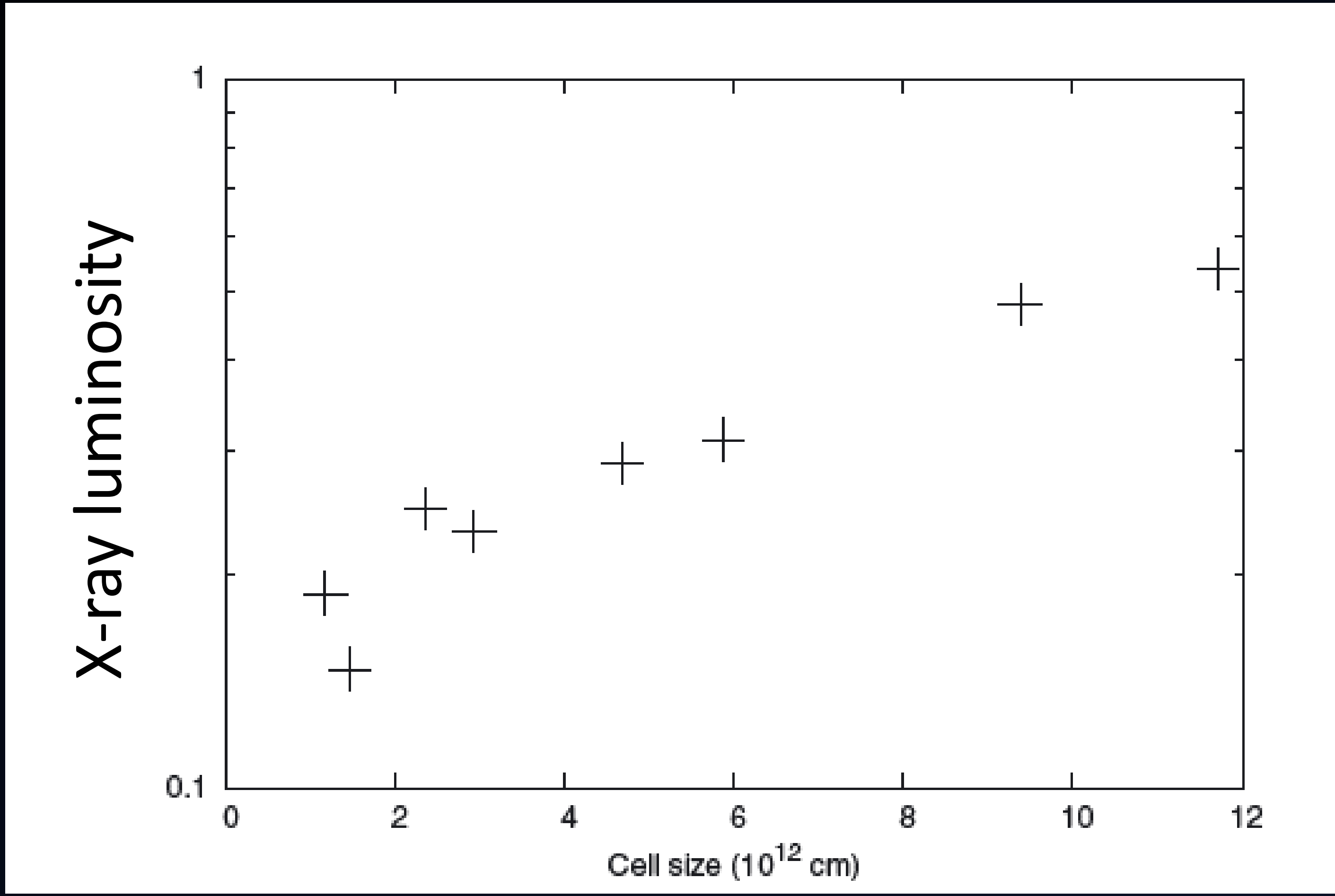
Steinberg & Metzger 2018

Corrugated shock front gives rise to lower emission temperature but enables ion acceleration.



Kee et al 2014

Numerical difficulties



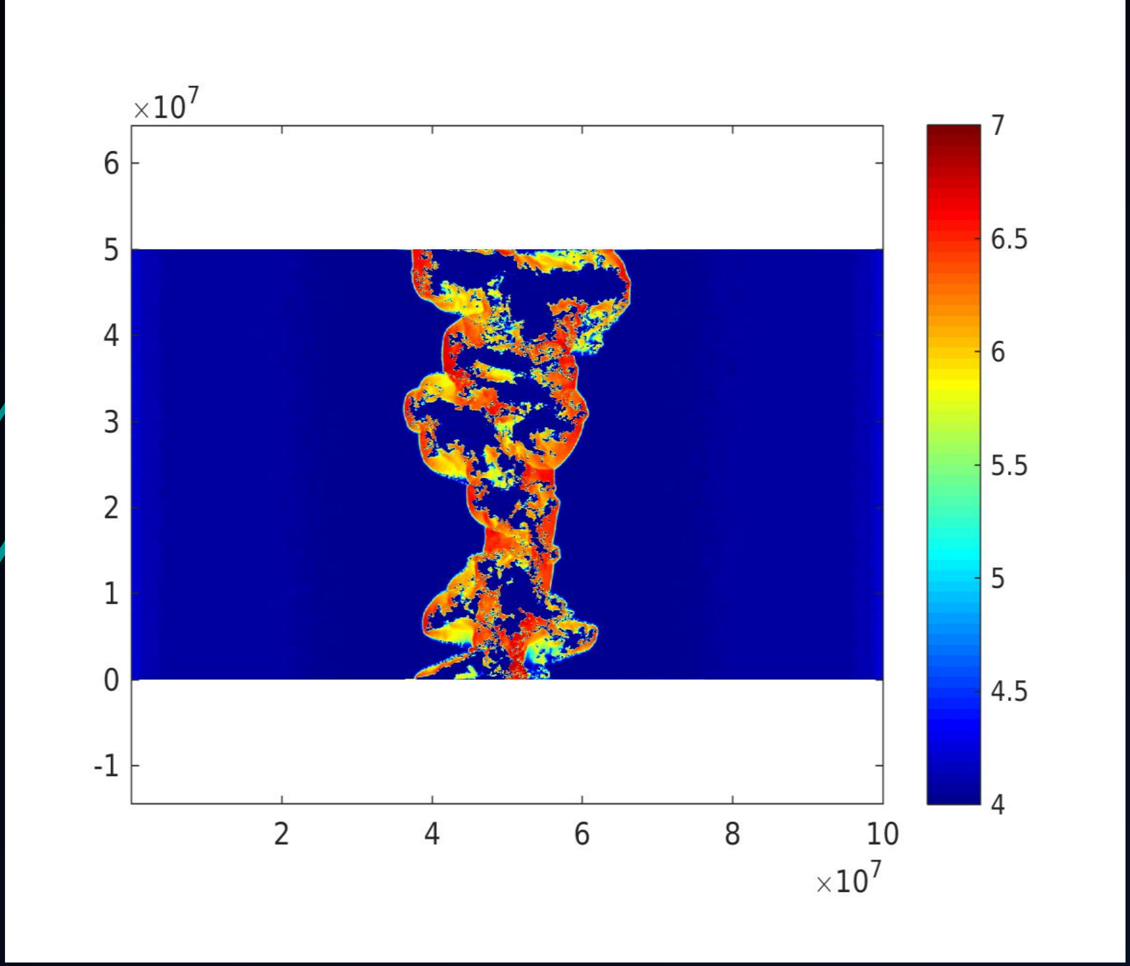
Parkin & Pittard 2010

Numerical mixing of hot and cold gas artificially enhance the cooling rate of the hot gas phase (Parkin & Pittard 2010).

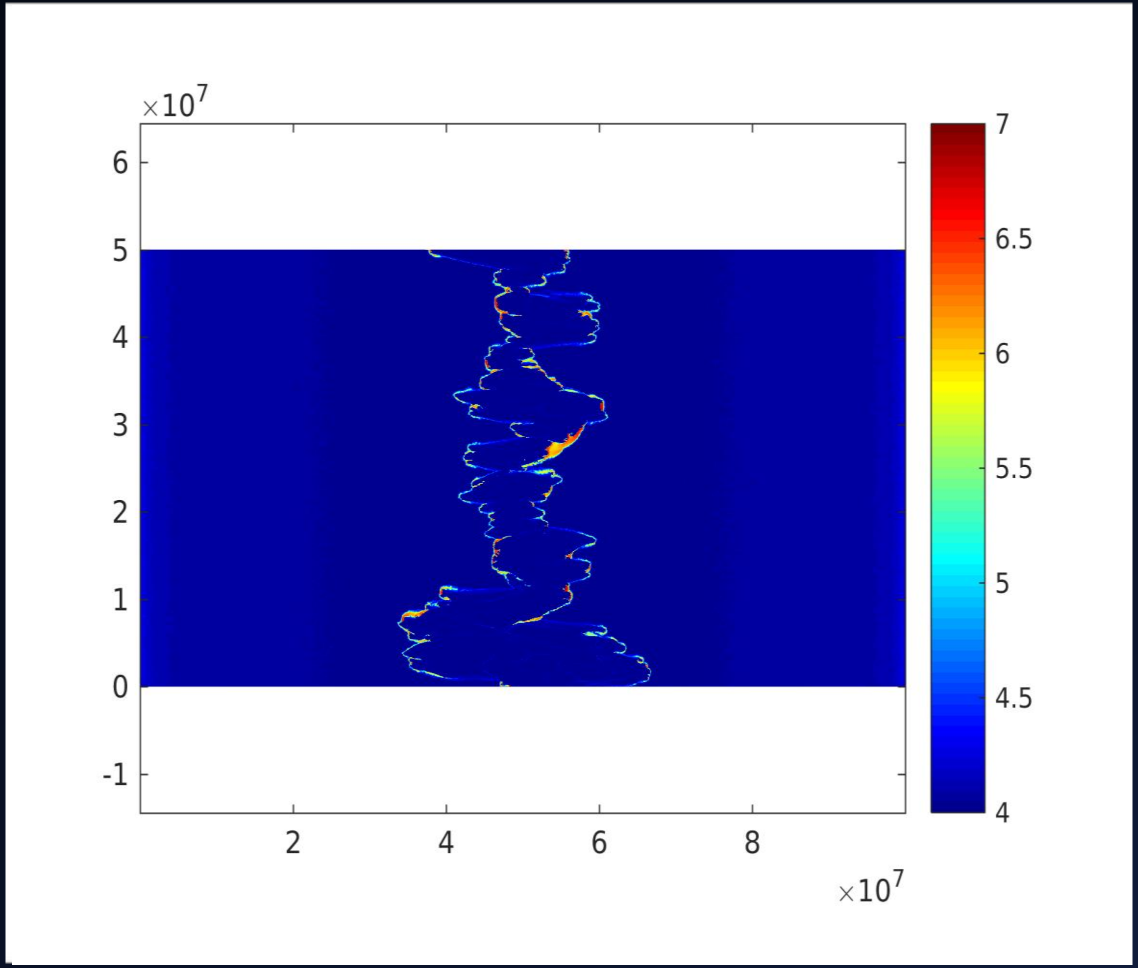
Solution:
Lagrangian Voronoi Moving Mesh (Yalinewich, Steinberg & Sari 2014, Steinberg & Metzger 2018).

Temperature – v=500 km/s, cs=10 km/s

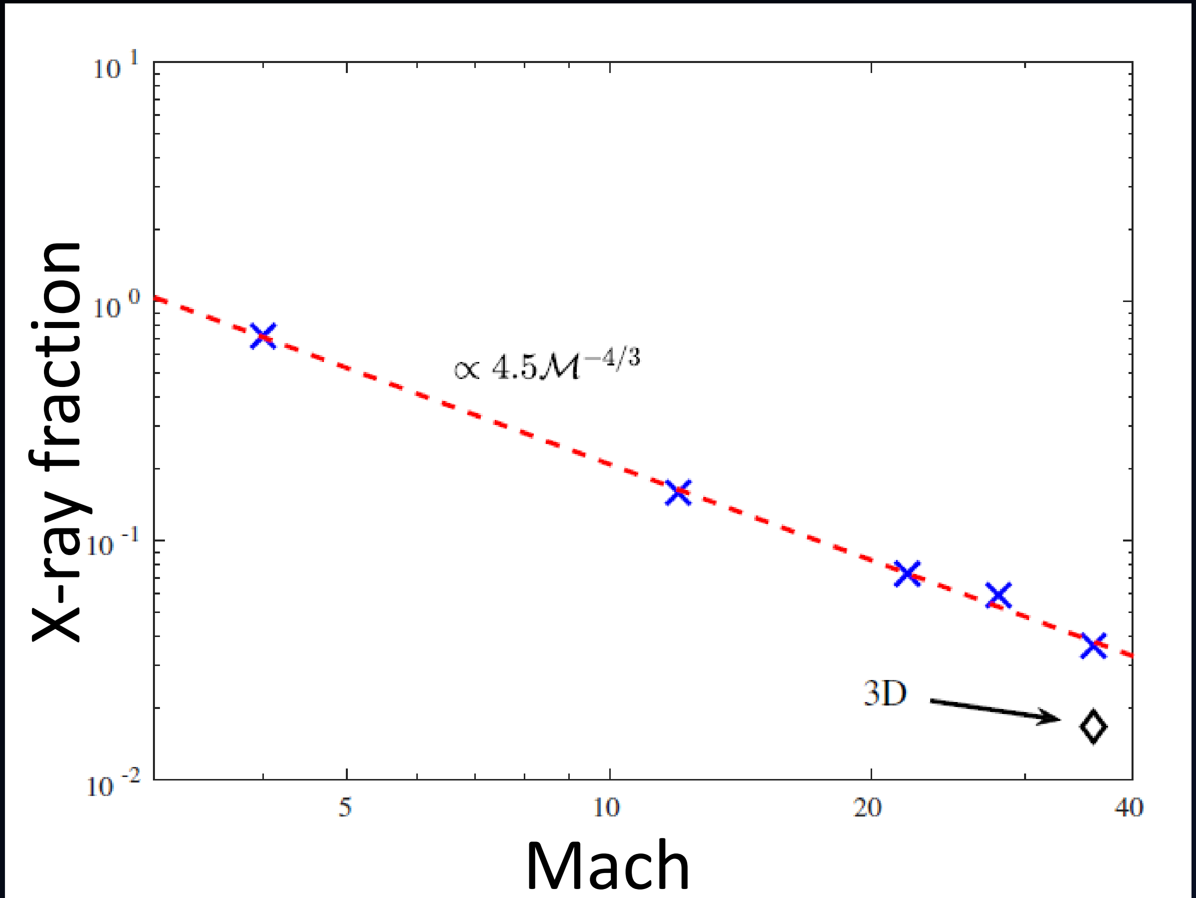
Lagrangian

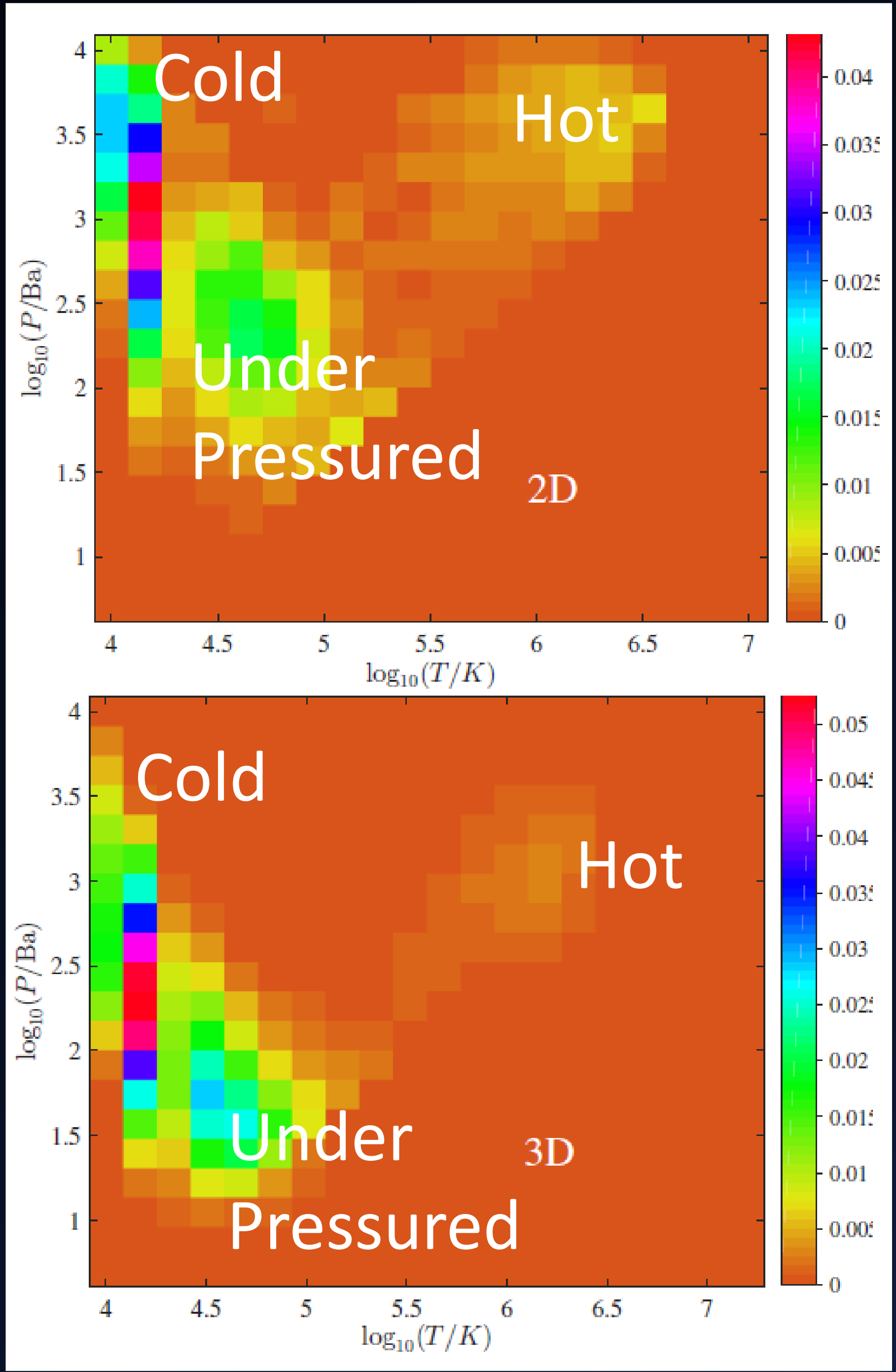


Semi-Lagrangian



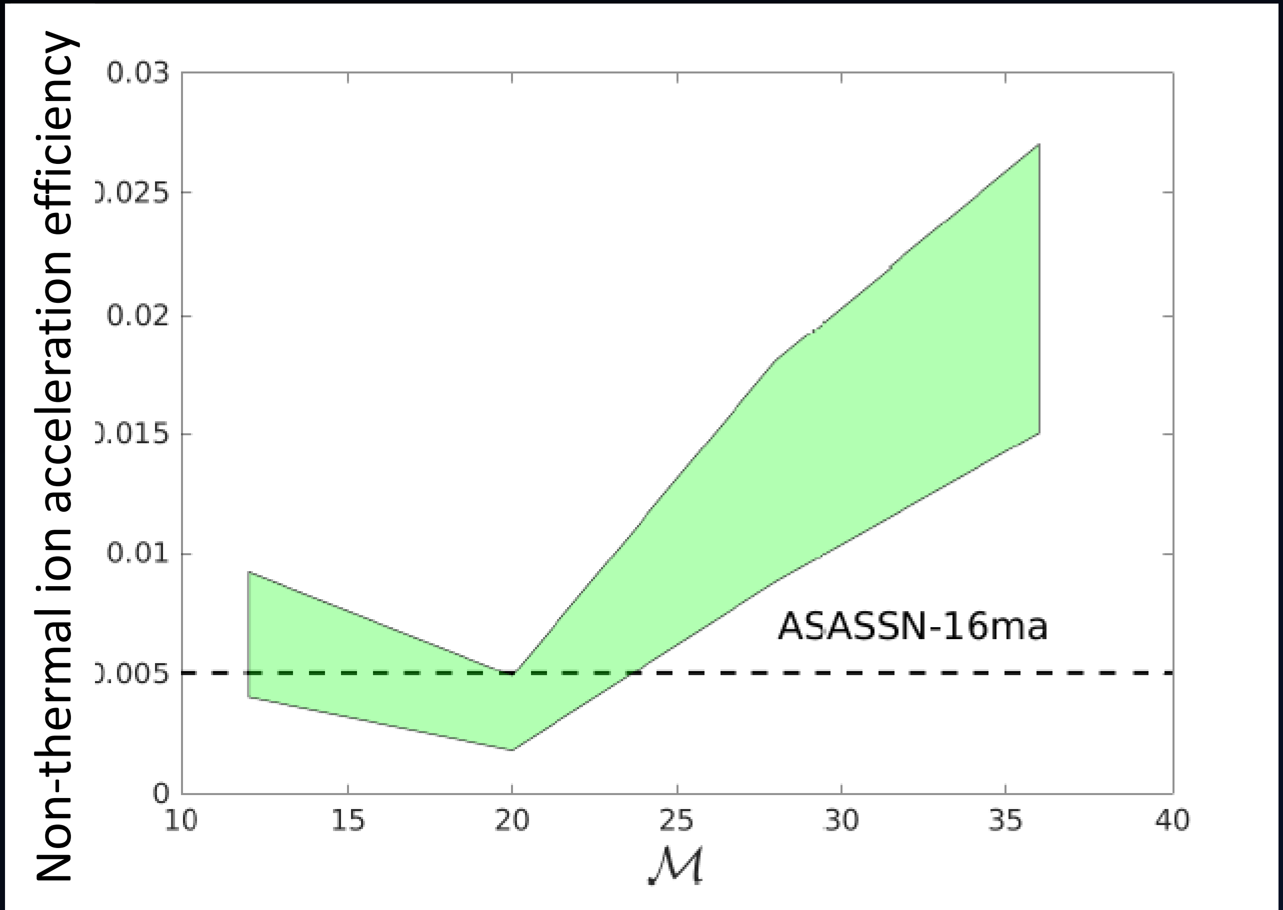
Results

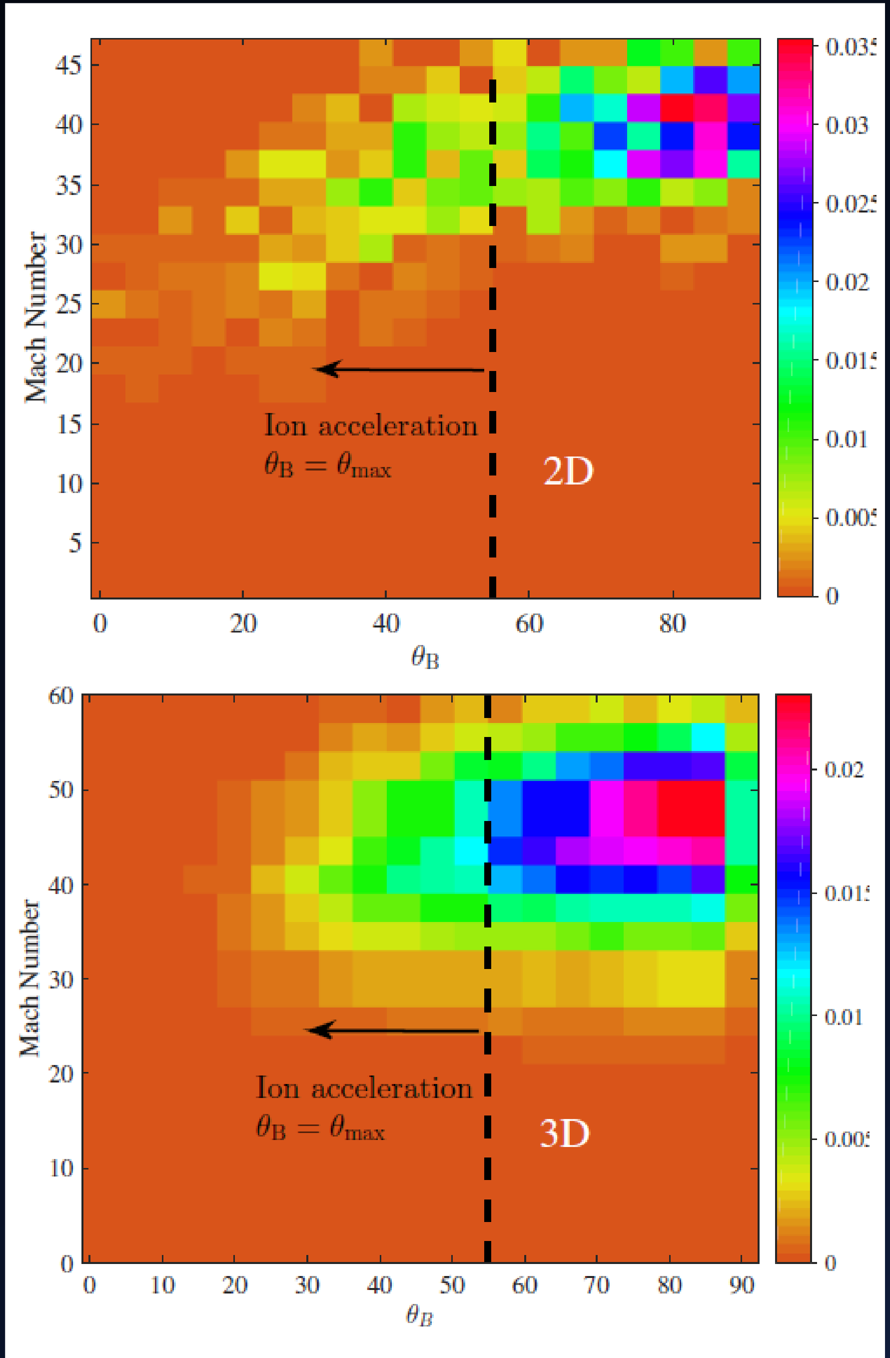




Avg emitting temperature is reduced due to PdV work of hot gas on cold under pressured

Implication for ion acceleration





Corrugated shock structure allows efficient ion acceleration.

Conclusion

- The novel Lagrangian Voronoi Moving Mesh method enables accurate simulations of radiative shocks.
- Hydrodynamical instabilities corrugate the shock fronts.
- Overpressure hot gas cools mainly by PdV work on cold gas, thus reducing the average emitted temperature, factor of 100 for Mach 100.
- The corrugated shock structure enables favorable inclinations between the shock front and the magnetic field, enabling ion acceleration, $\epsilon_{nth} \approx 0.01$.