



PIC simulations of shock at novae

(concerning the high-energy gamma-ray emission)

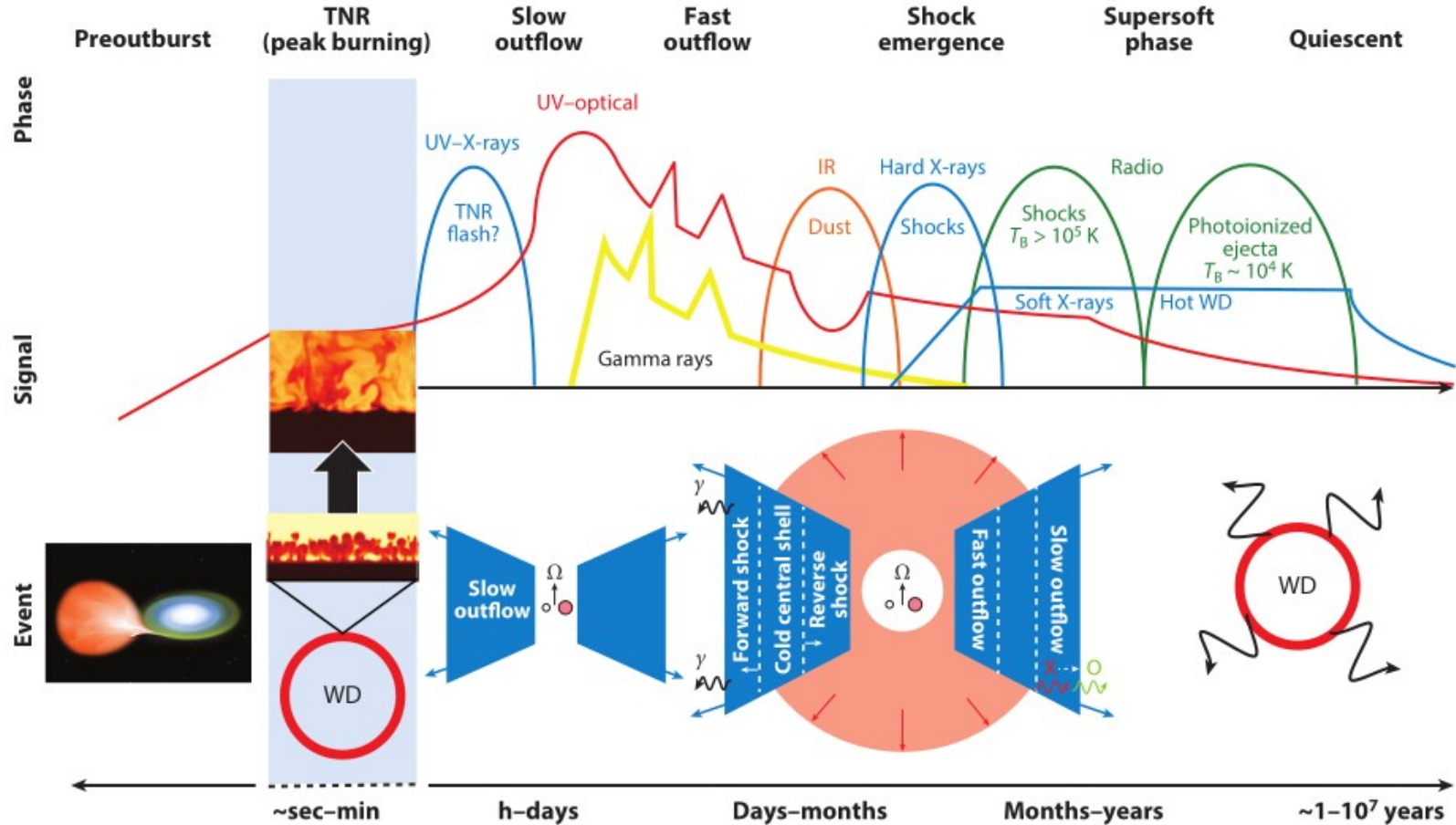
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Discussions and synergies on astrophysical plasma with PIC simulations

Prague, September 29 – October 2, 2026

Schematic timeline of nova explosion



Mechanisms of γ -ray emission

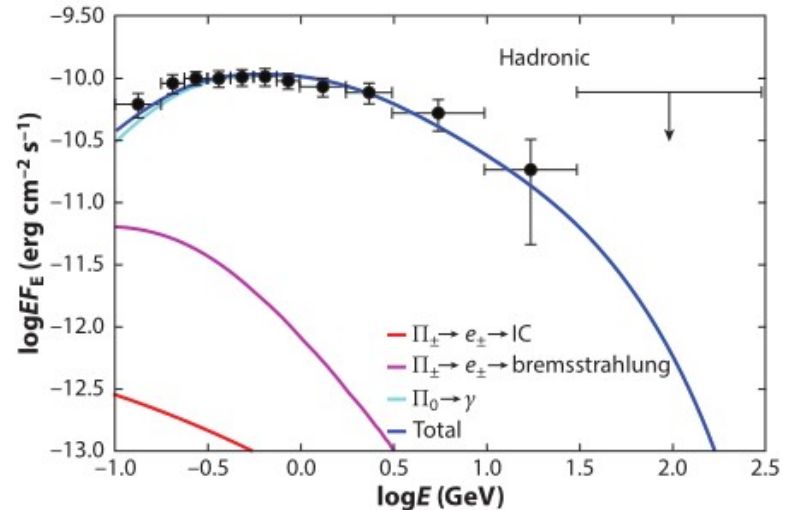
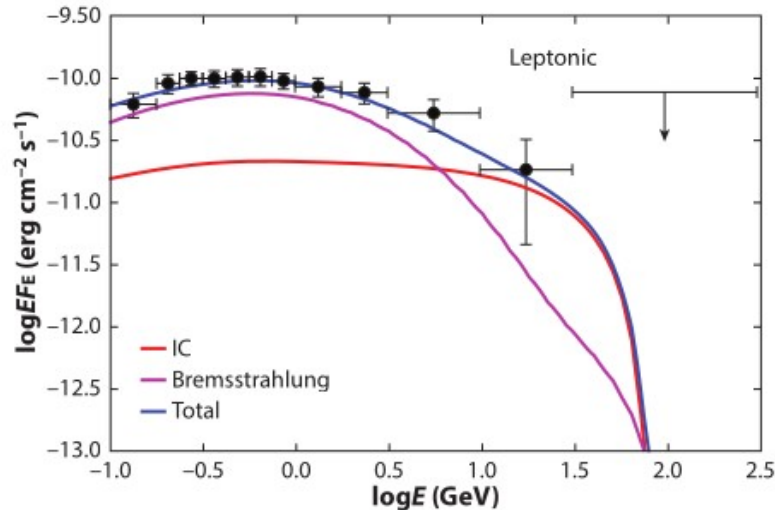
- Leptonic: $e^{\pm} + p \rightarrow e^{\pm} + p + \gamma$; $e^{\pm} + e^{-} \rightarrow e^{\pm} + e^{-} + \gamma$

$$e^{\pm} + \gamma_{\text{opt}} \rightarrow e^{\pm} + \gamma$$

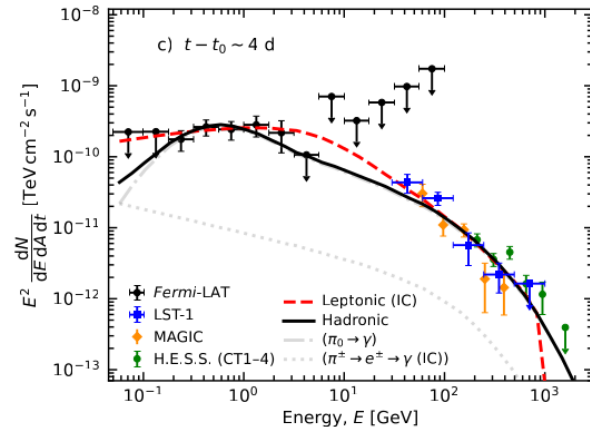
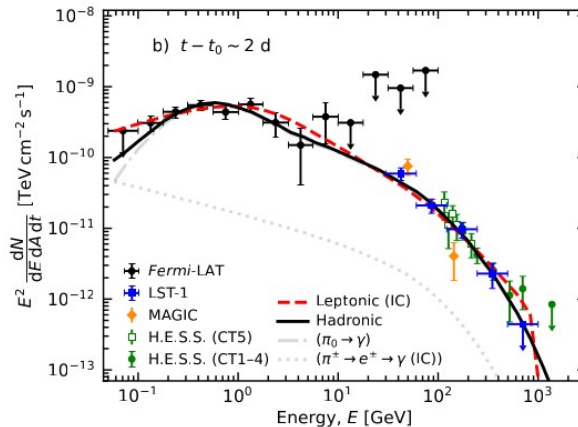
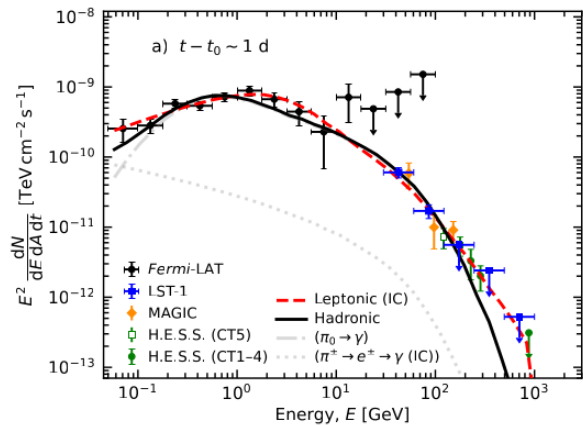
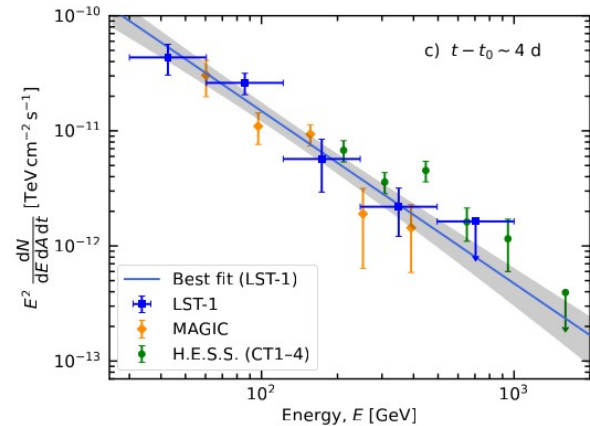
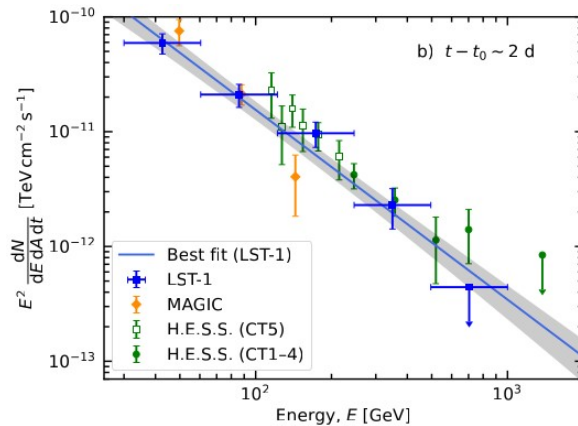
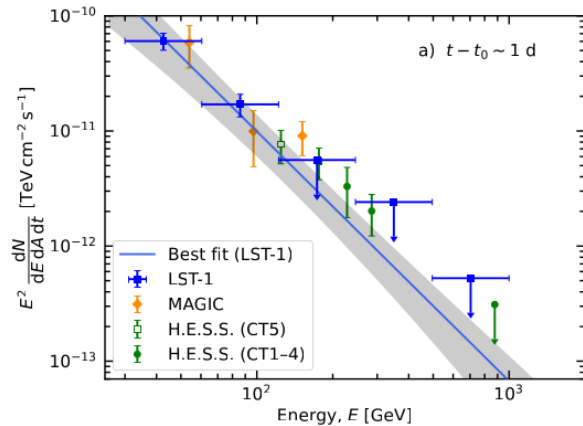
- Hadronic: $p + p \rightarrow \pi^0 \rightarrow \gamma + \gamma$

$$\rightarrow \pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \rightarrow e^{\pm} + \nu_e + \nu_{\mu}$$

Fermi-LAT
V5856 Sgr

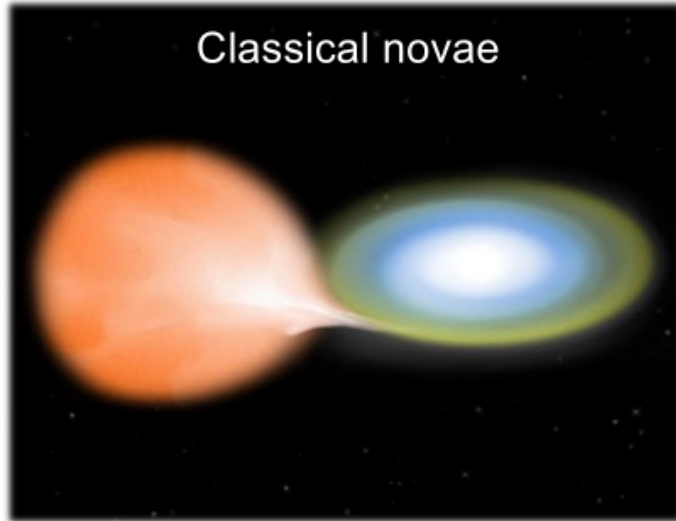


HE/VHE γ -ray emission from RS Oph



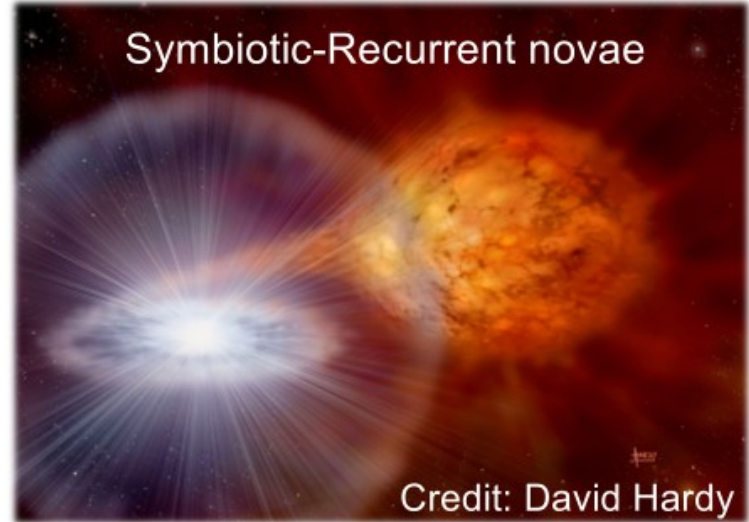
Types of novae

Roche lobe overflow



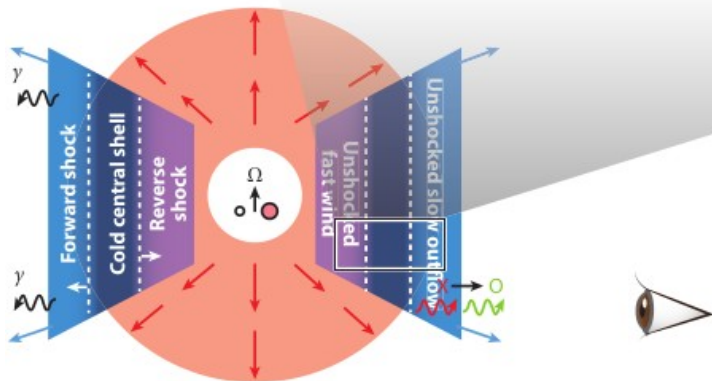
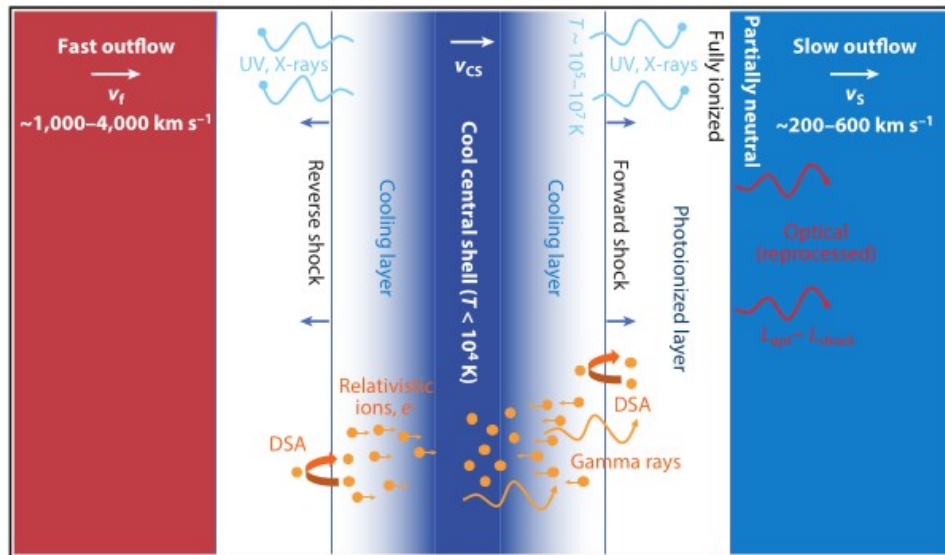
- separations $\sim R_{\odot}$
- orbital periods $\sim$ hours
- recurrence times $\gtrsim 10^4$ yr
- rate $\sim 30 - 50$ / yr in Galaxy

accretion from red giant wind

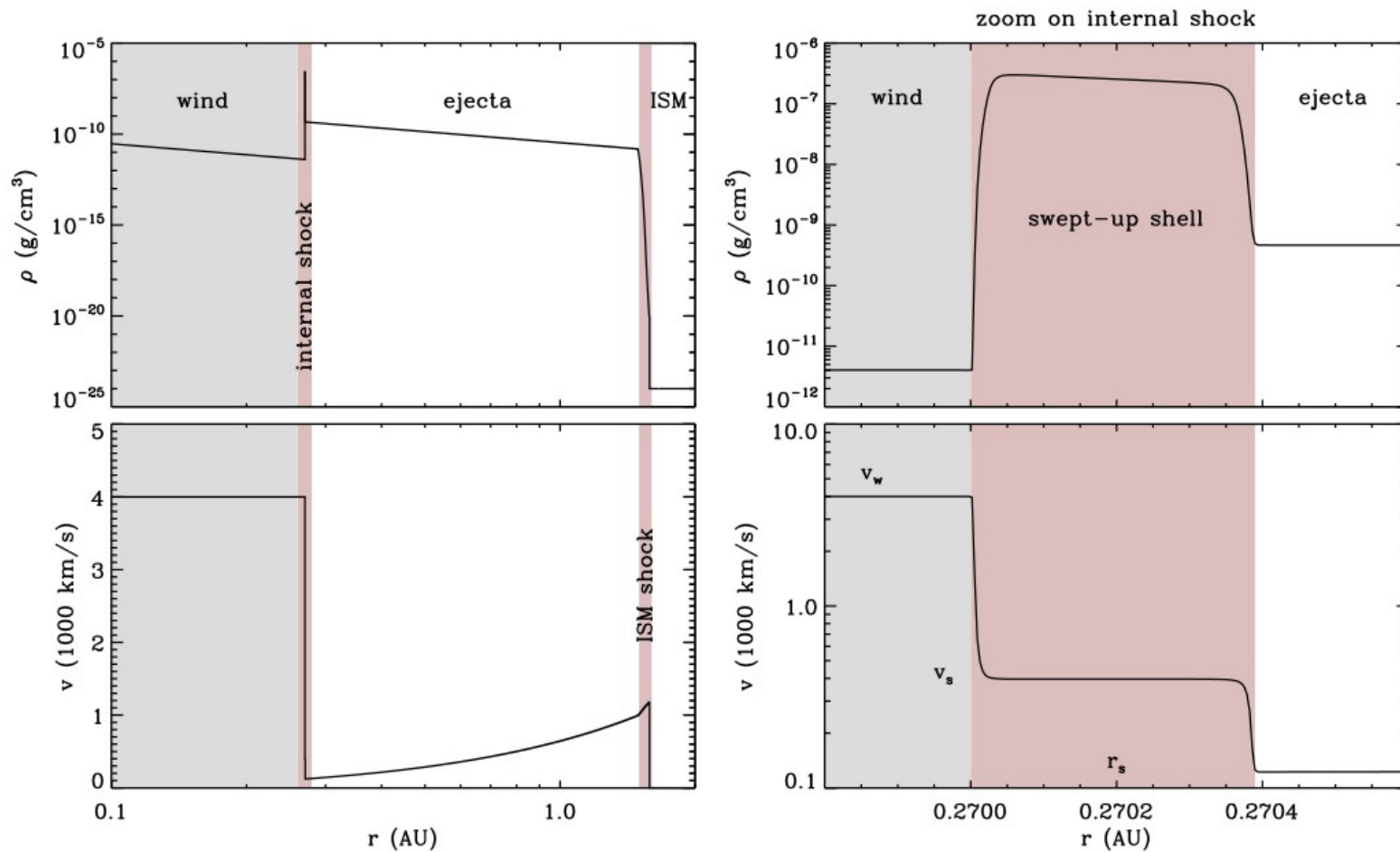


- separations ~ 100 's $R_{\odot}$
- orbital periods $\sim$ years
- recurrence times < 100 yrs
- ~ 10 known symbiotic/recurrents

Structure of nova shock

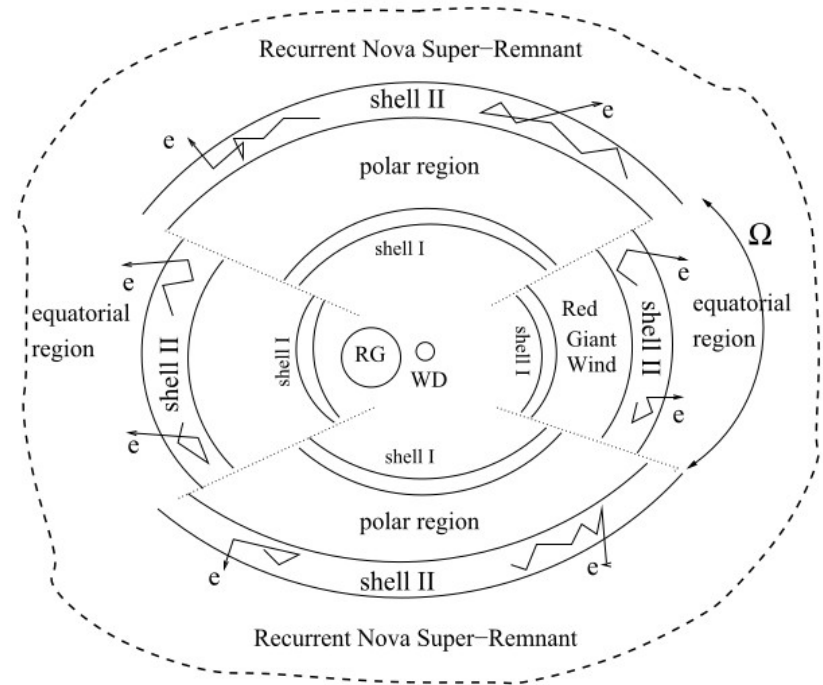
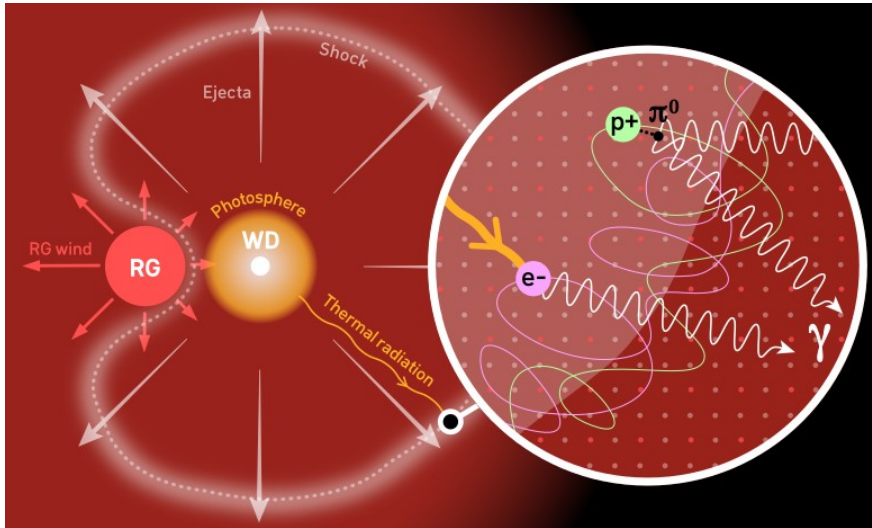


MHD modelling of nova shock system



RS Oph shock system

- Shock wave from each new explosion propagates in the material ejected at previous explosion



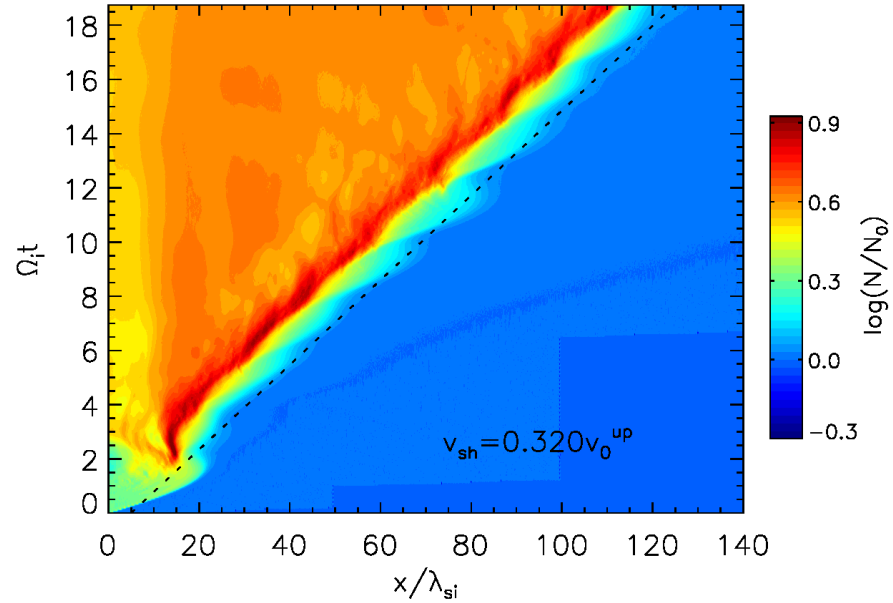
PIC simulation of nova shock

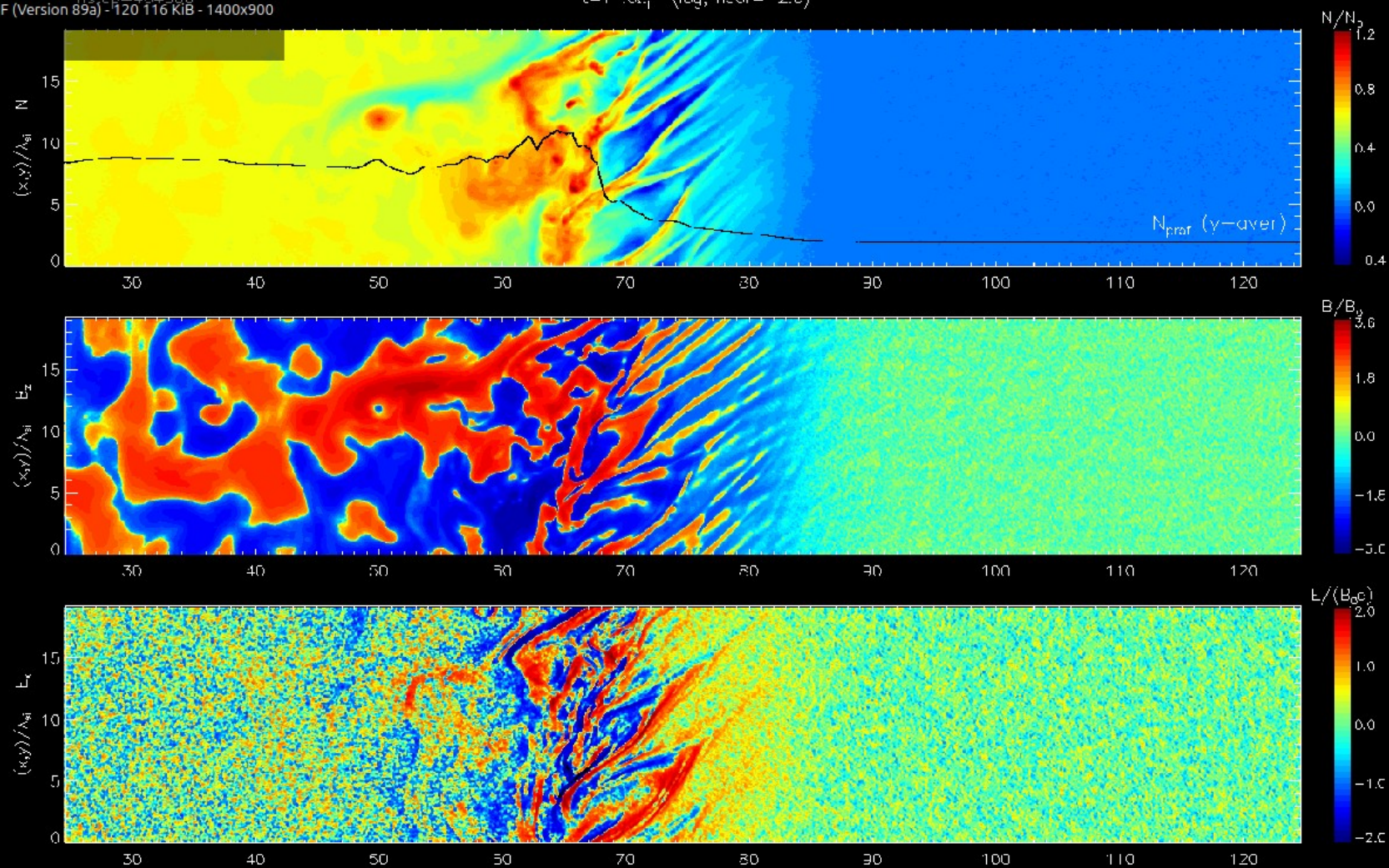
- Typical properties:

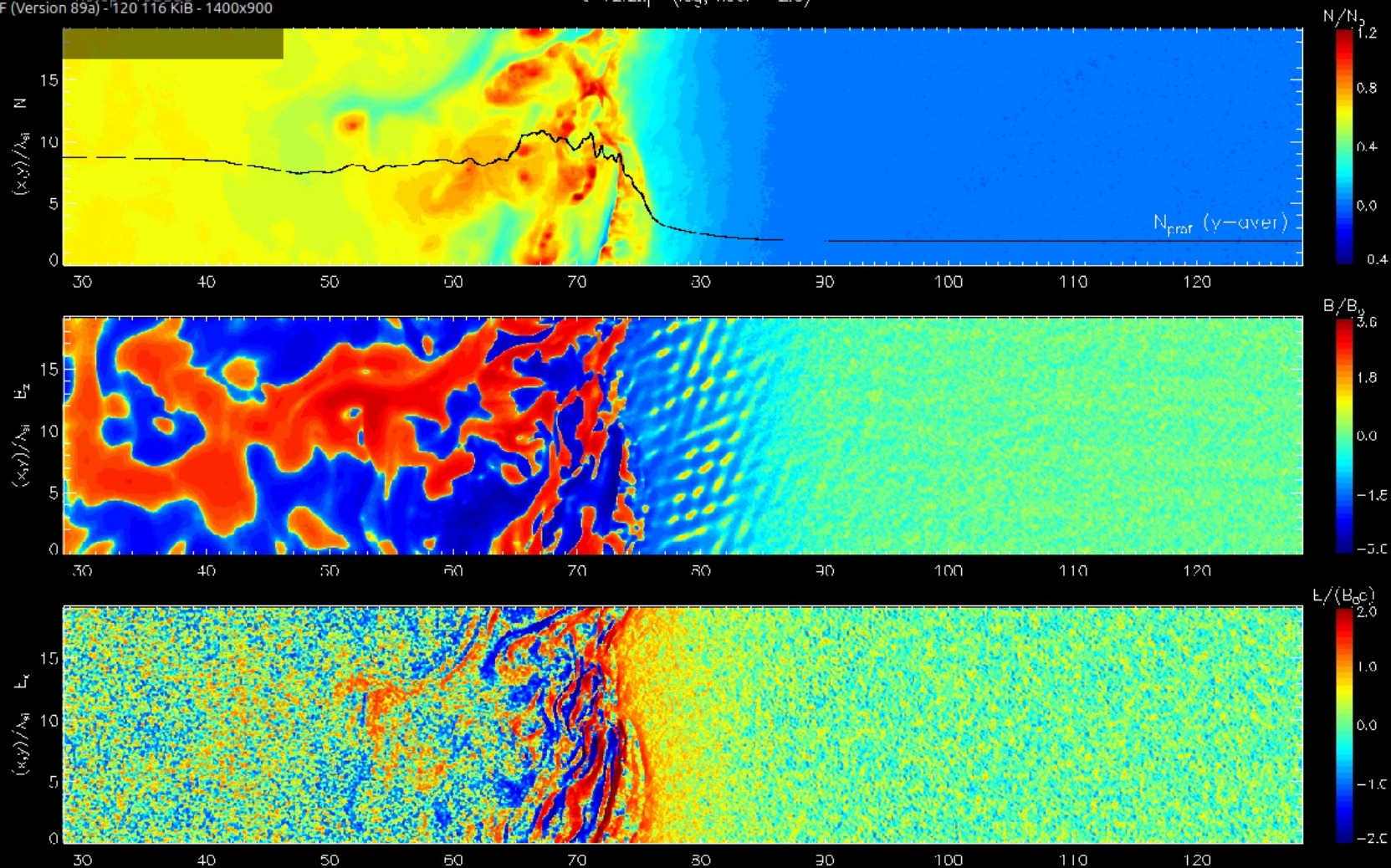
Nova System / Shock Type	Upstream Medium	Mach Number (M)	Plasma Beta (β)
RS Oph (External)	Dense, highly magnetized, warm Red Giant Wind	High (M ~ 100)	Low to Balanced ($\beta \leq 1$)
RS Oph (Internal)	Pre-heated, hot internal early ejecta	Low (M ~ 3 - 10)	Very High ($\beta \gg 1$)
Classical Novae (Internal)	Cold, expanding, diluted early ejecta	Moderate-High (M ~ 50 - 100)	Extremely High ($\beta \gg 1$)
V407 Cyg (External)	Massive, extended, cold Mira Wind	Ultra-High (M > 300)	Intermediate ($\beta \sim 1 - 10$)

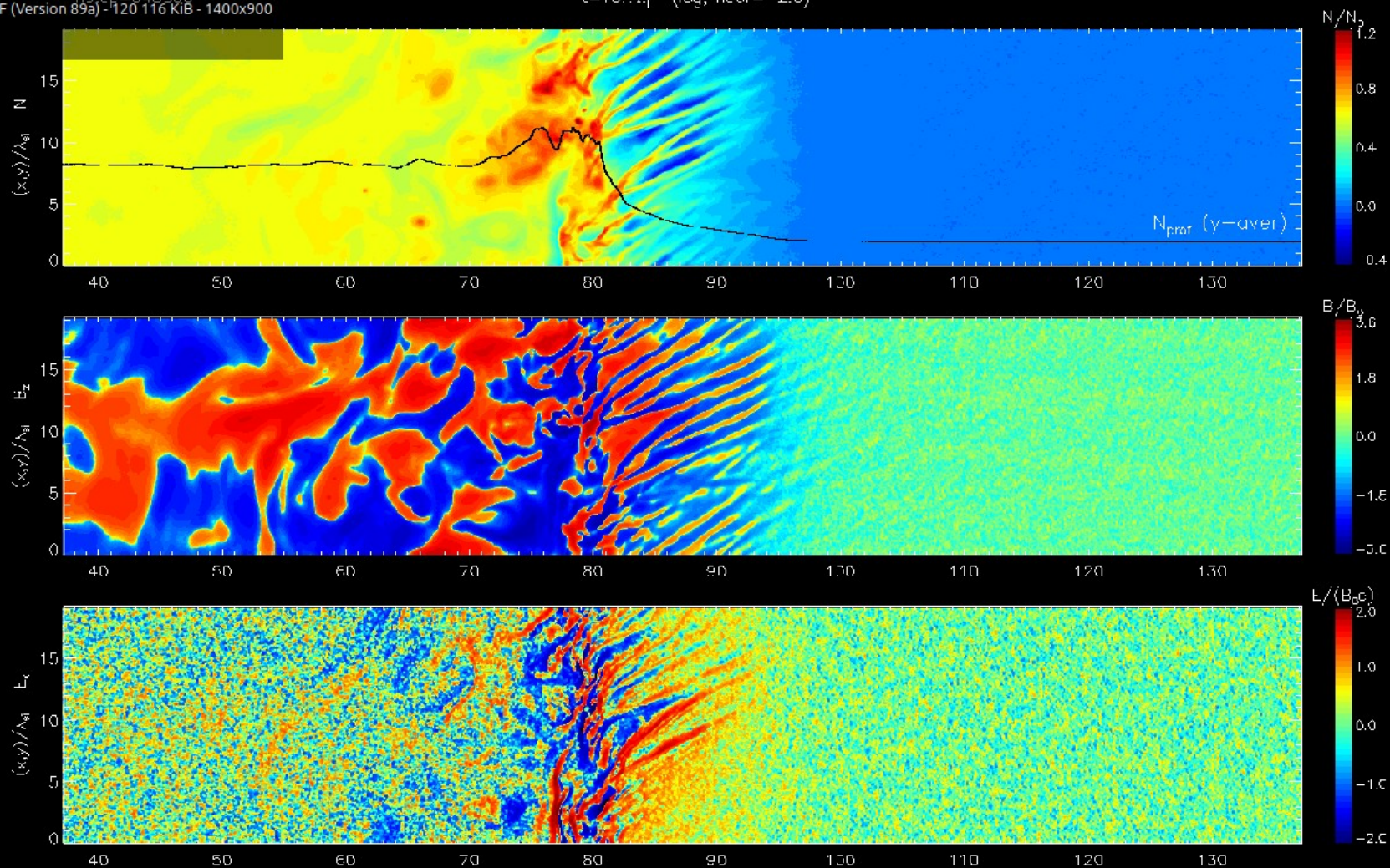
- Simulated parameters: $m_i/m_e=100$ $M=25$ $\beta = 1.28$

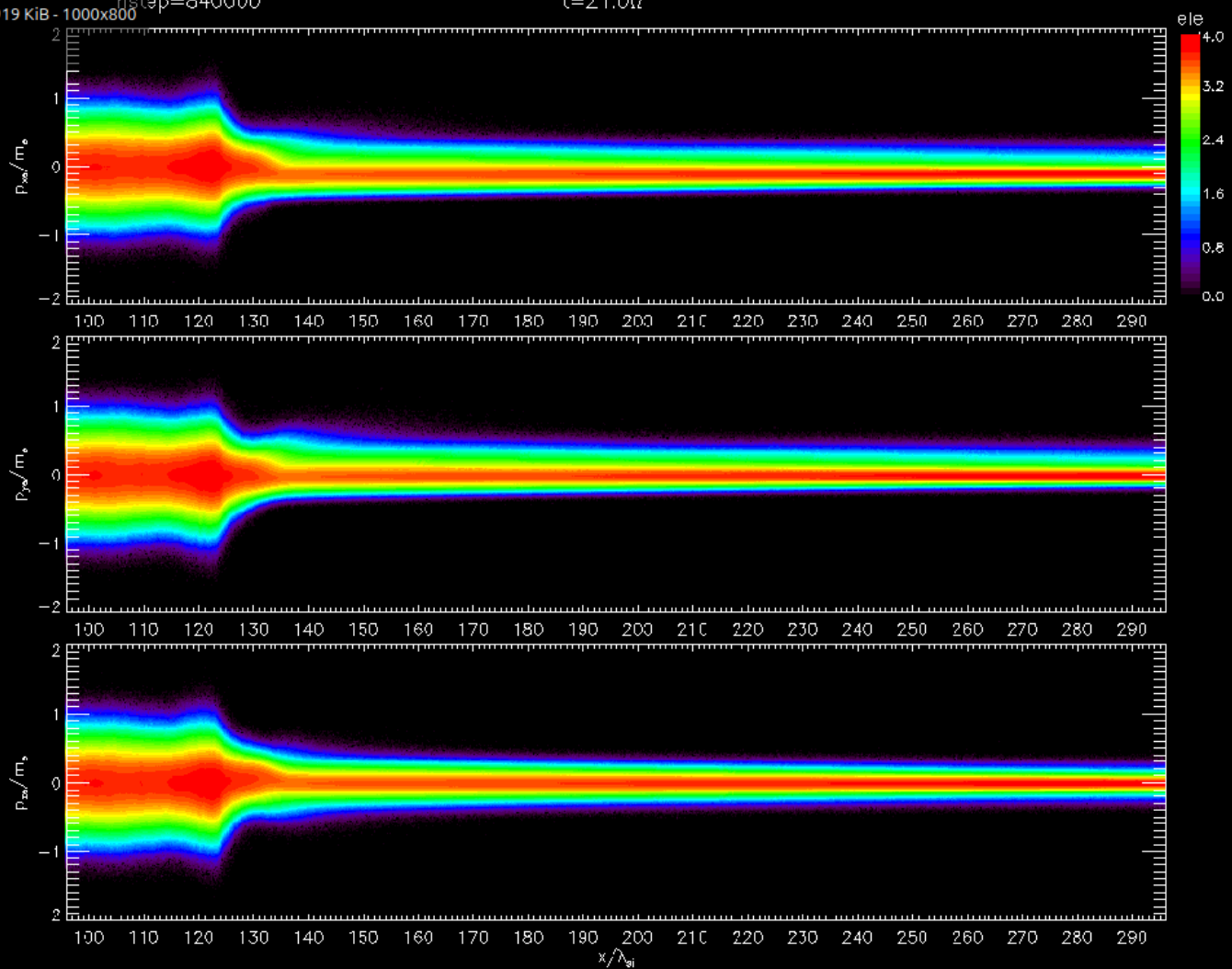
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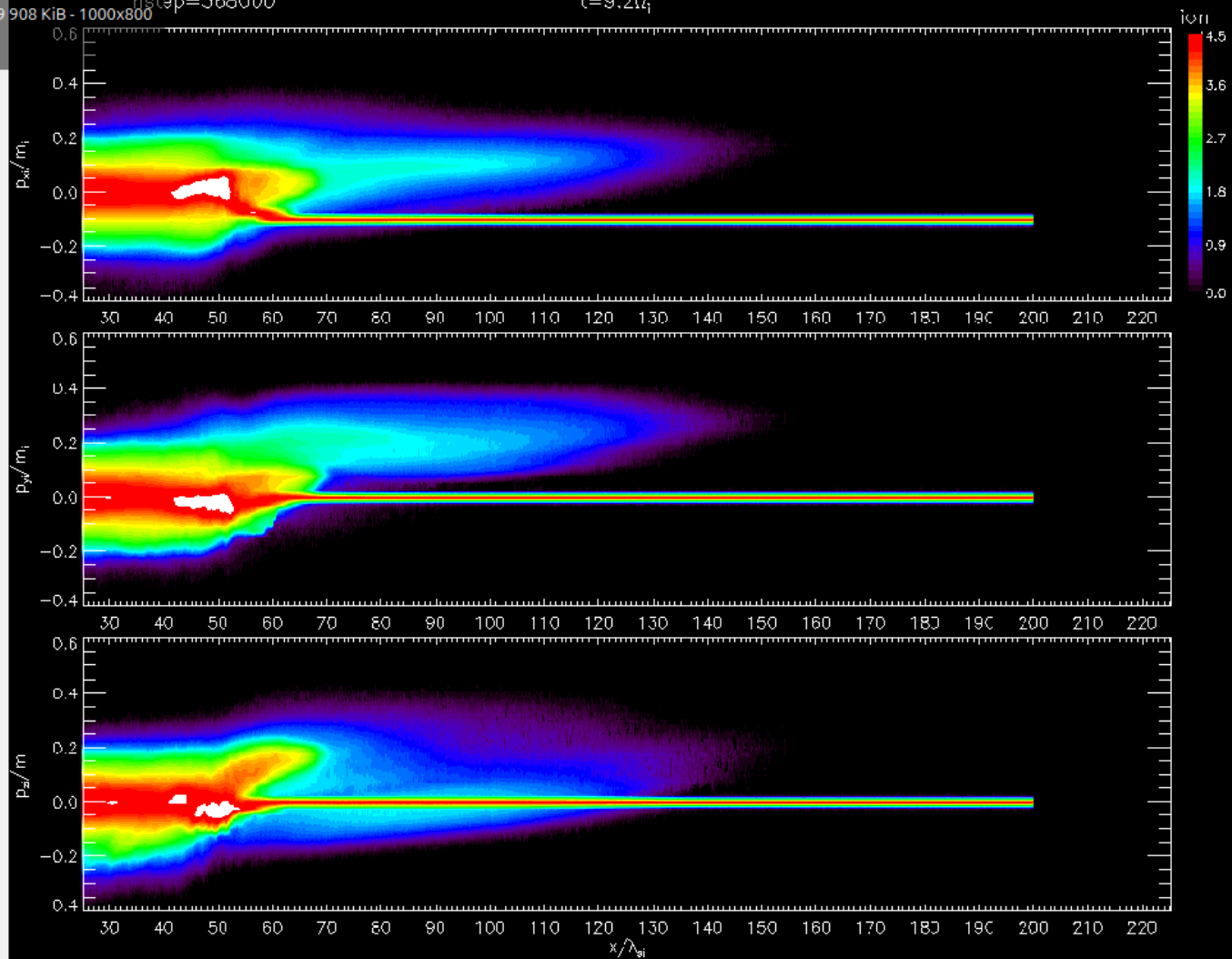


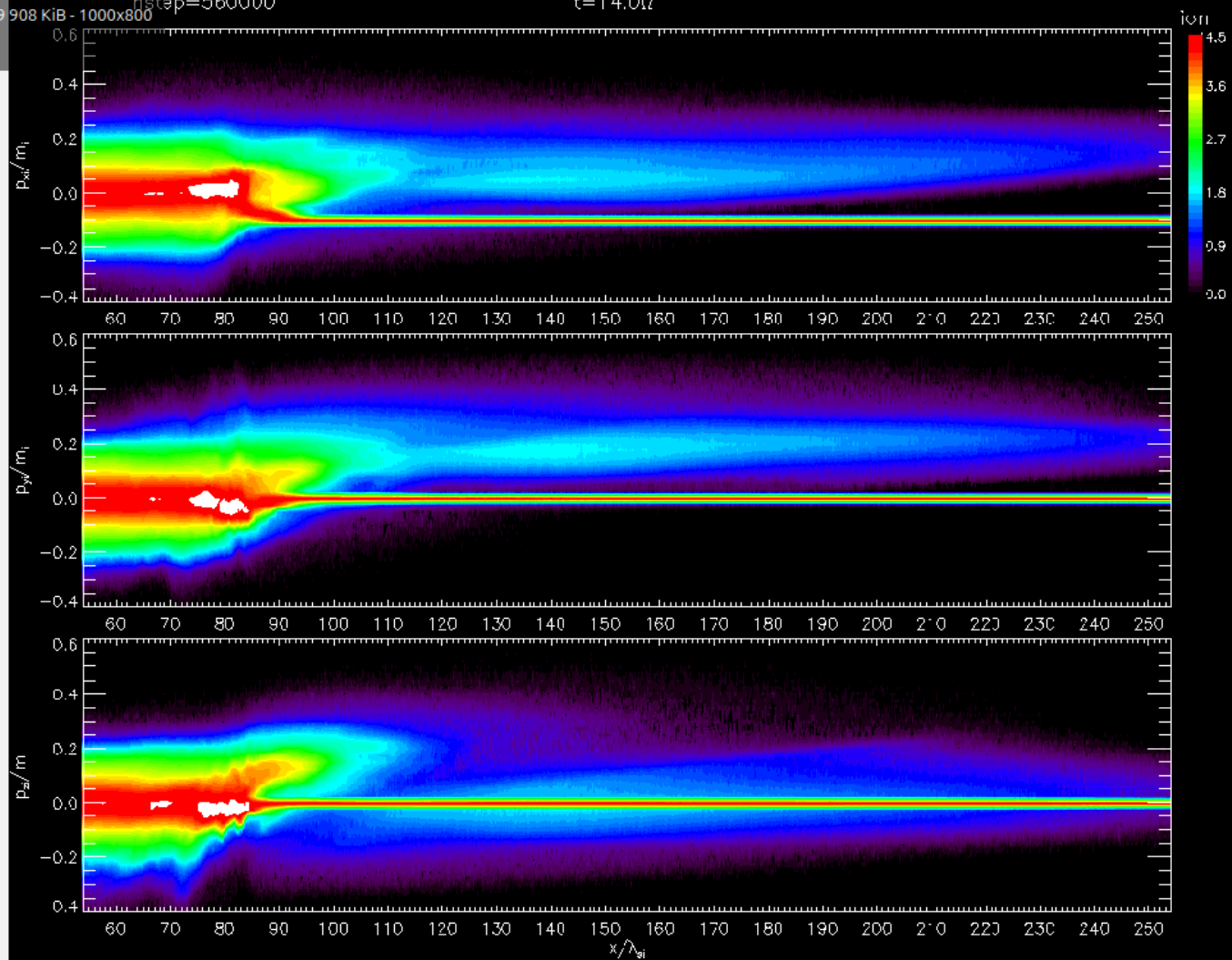


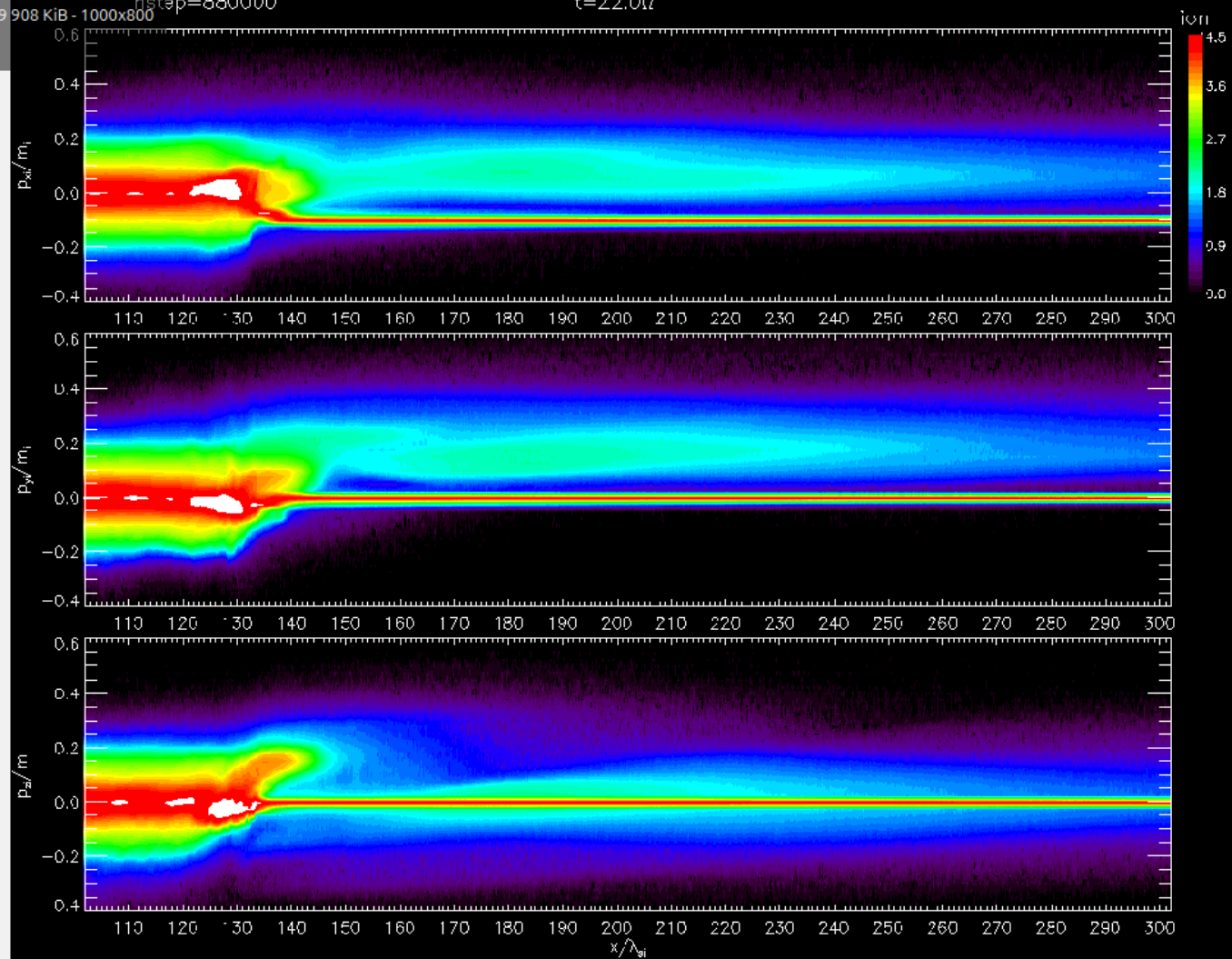


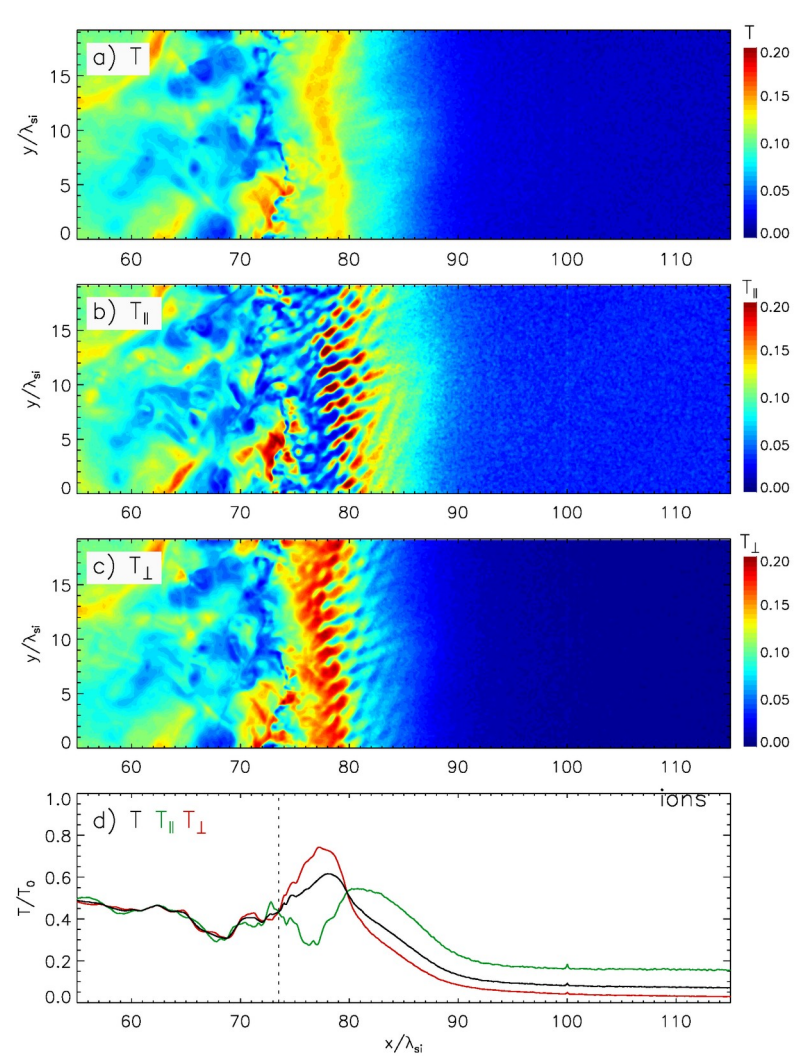
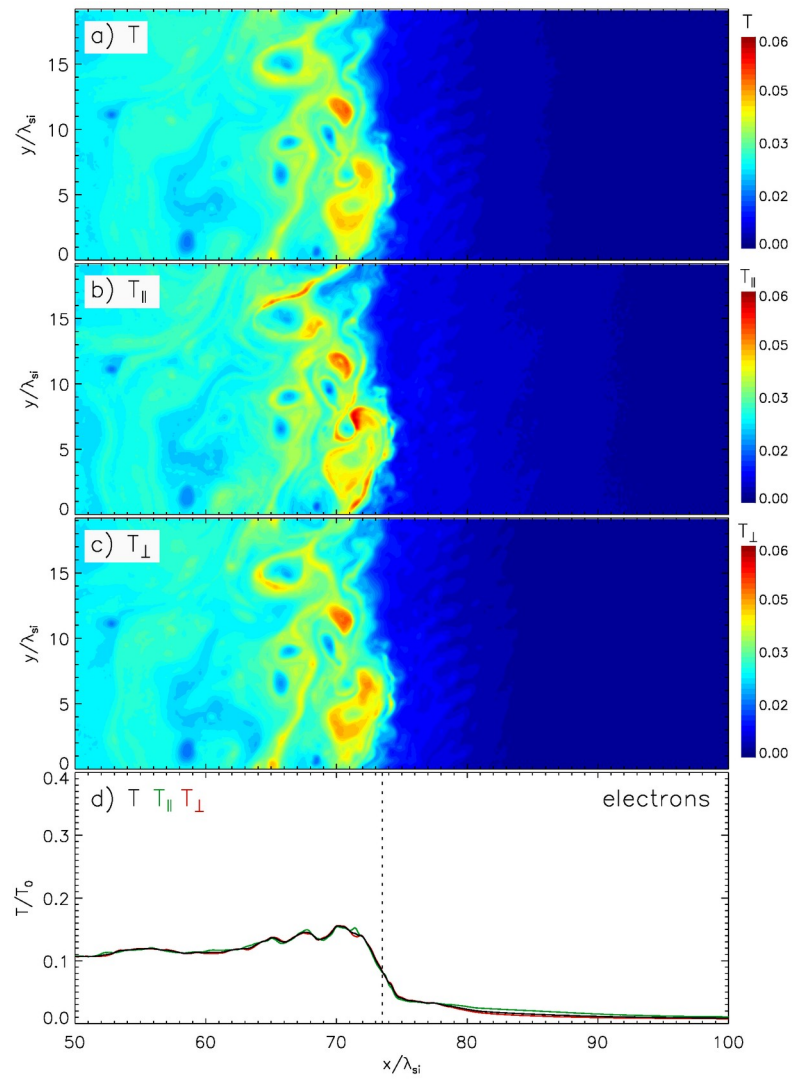




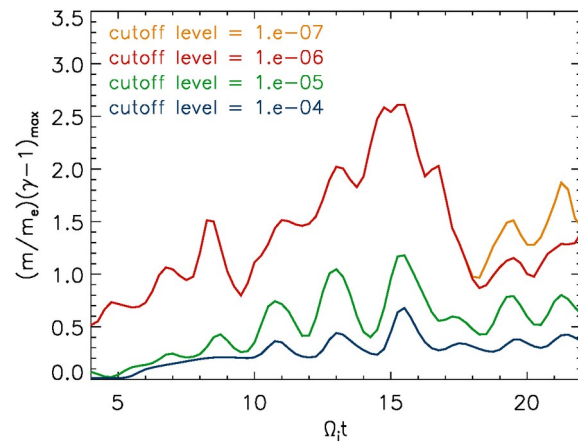
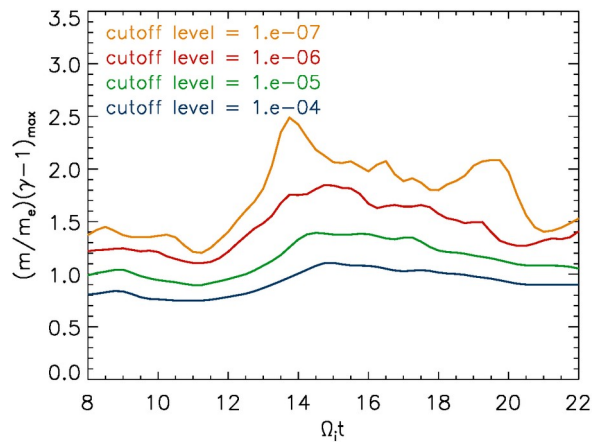
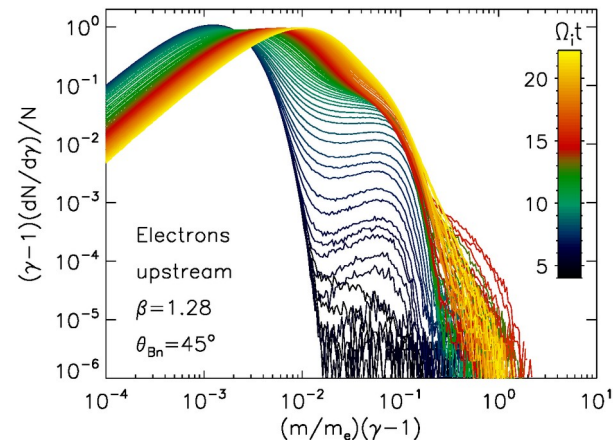
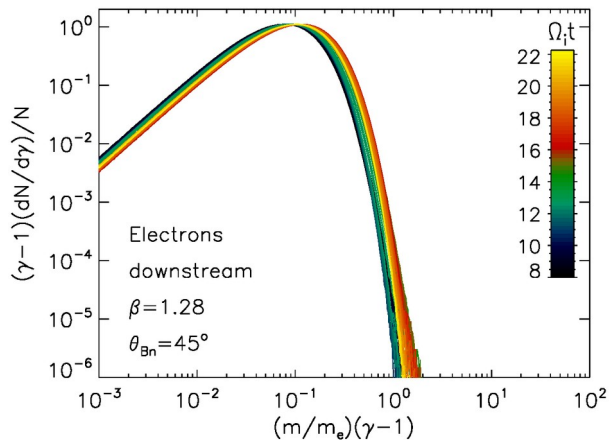




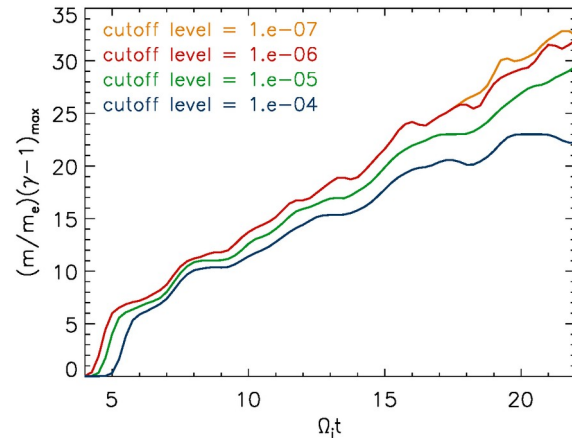
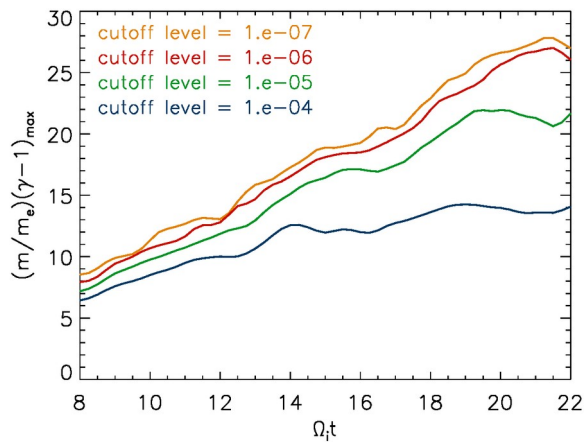
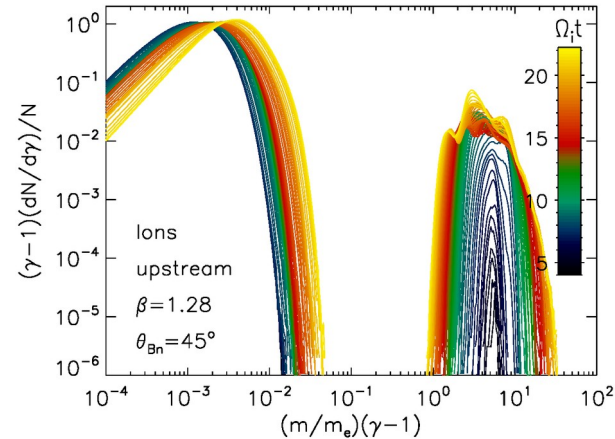
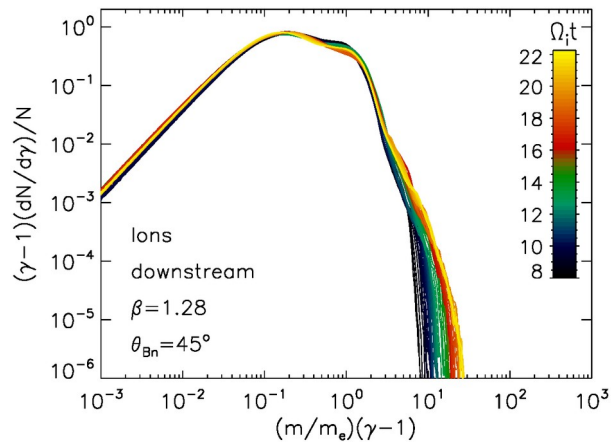




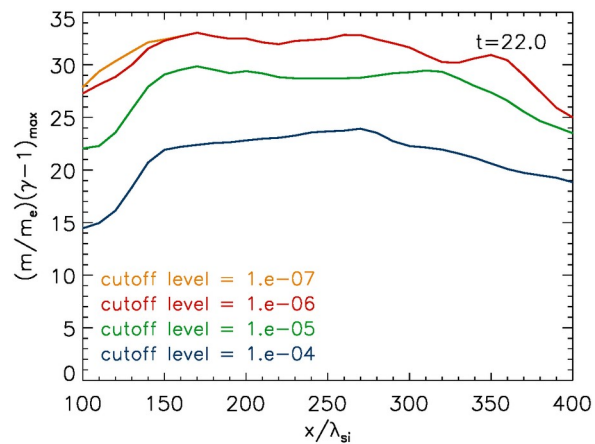
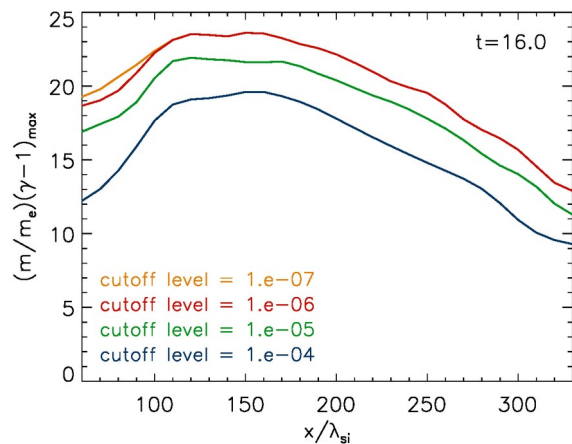
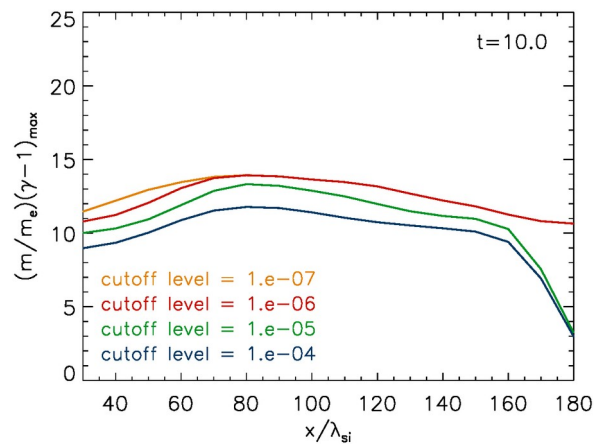
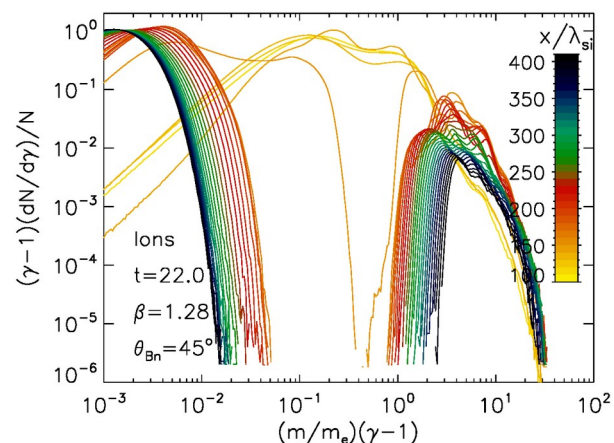
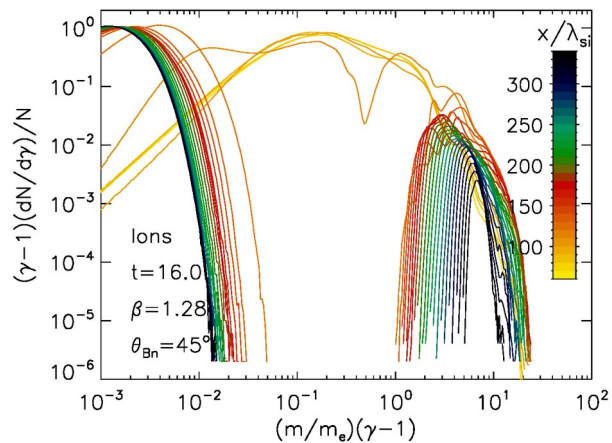
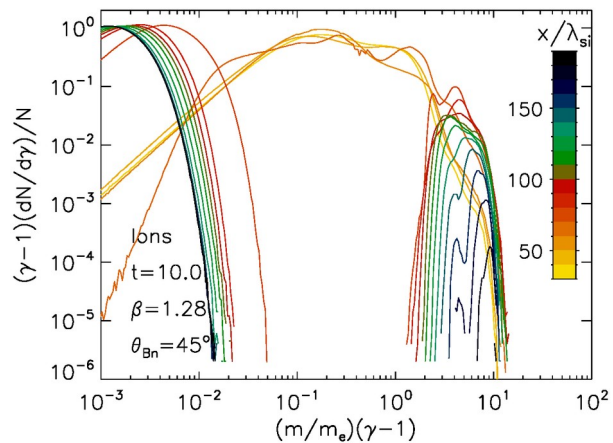
PIC simulation of nova shock



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PIC simulation of nova shock



Summary

- The obtained results are very preliminary.
- Indication of particle acceleration – how efficient???
- The properties of shocks at novae vary in a wide range.
- TO DO – series of simulations with range of parameters:
 - Mach numbers, especilly high, $M > 100$;
 - plasma beta, $0.1 < \beta < 100$;
 - shock obliquity, $\theta_{Bn} > 45^\circ$.

Thank You!