Corrugation of relativistic magnetized shock waves

Journée des Doctorants 2017

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« PIC-MHD simulations of particle acceleration in a magnetized turbulence »
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Outline

Effects of upstream perturbations on a shock?

I. Introduction: Motivations & framework

II. Framework and results

1. Special relativistic ideal MHD (SRIMHD) simulations
2. Results:
   - Relativistic shock
   - Subrelativistic shock

III. Future work and outlook

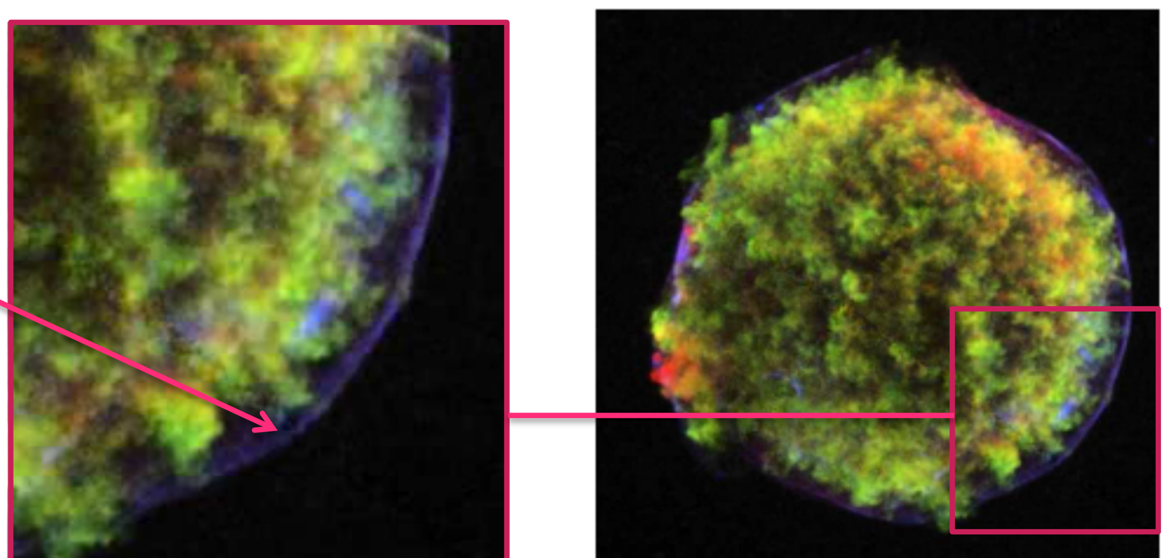
(Collisionless) shocks interacting with perturbations

Motivations:

- Plasma physics: interesting **academic** question
- Astrophysics: **turbulence** = inseparable feature of shocks but
  - How is it generated?
  - How does it influence the shock?

Vink 2012

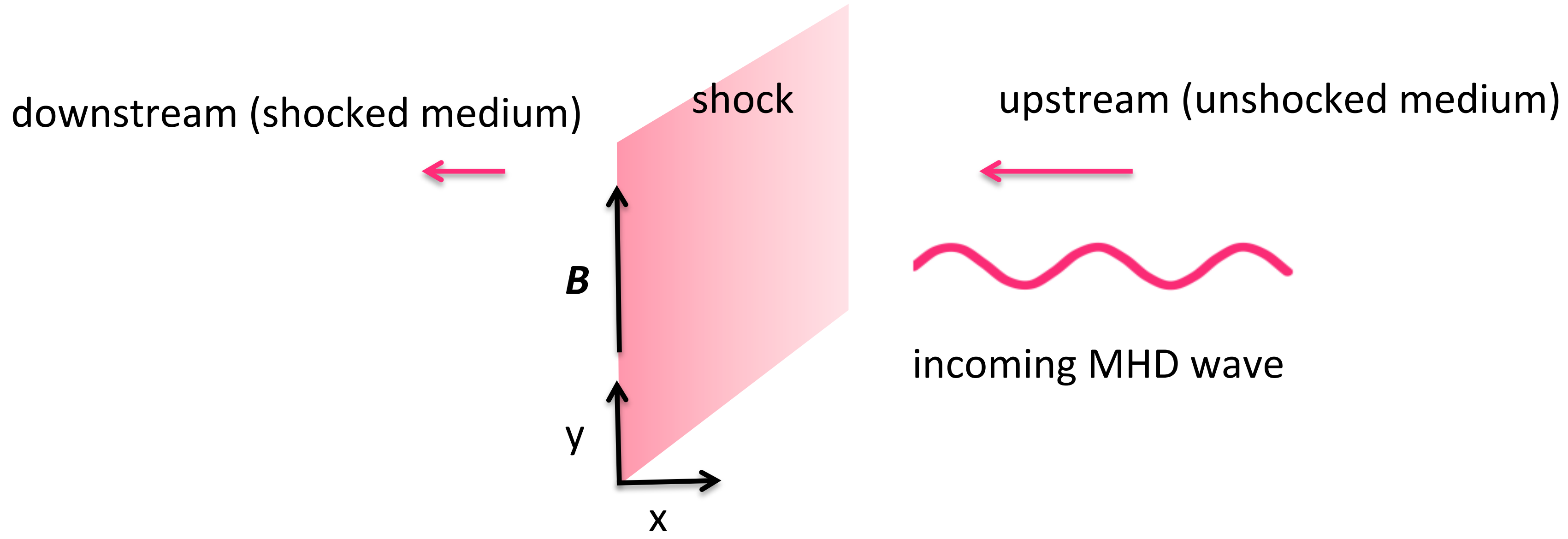
Synchrotron emission from the accelerated e$^-$



(Collisionless) shocks interacting with perturbations

- Theoretical study relying on linear perturbation

Ref: Corrugation of Relativistic Magnetized Shock Waves
Lemoine, Martin; Ramos, Oscar; Gremillet, Laurent, ApJ (2016)



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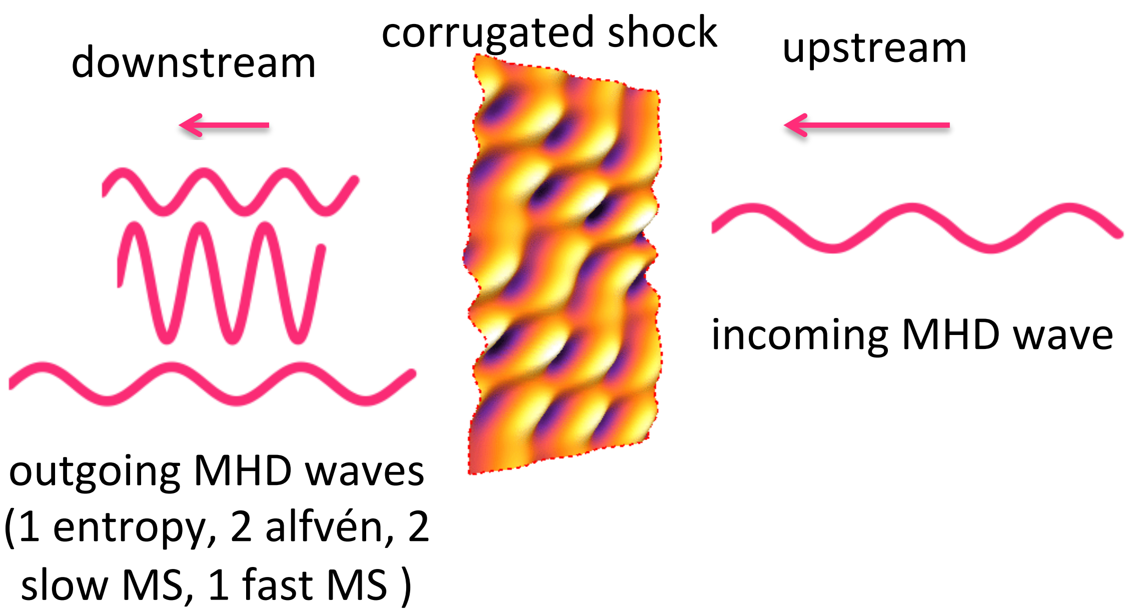


→ resonance for some wave vectors.

SRMIHD simulations

- Defining

$$b^\mu = \left[u^i B_i, \left(\boldsymbol{B} + u^i B_i \boldsymbol{u}\right)/u^0\right],$$

$$T^{\mu\nu} = \left(w + b_\alpha b^\alpha\right) u^\mu u^\nu + \left(p + \frac{b_\alpha b^\alpha}{2}\right)\eta^{\mu\nu} - b^\mu b^\nu,$$

$${}^*F^{\mu\nu} = u^\mu b^\nu - u^\nu b^\mu,$$

the governing equations are:

$$\nabla_\alpha(\rho u^\alpha) = 0,$$

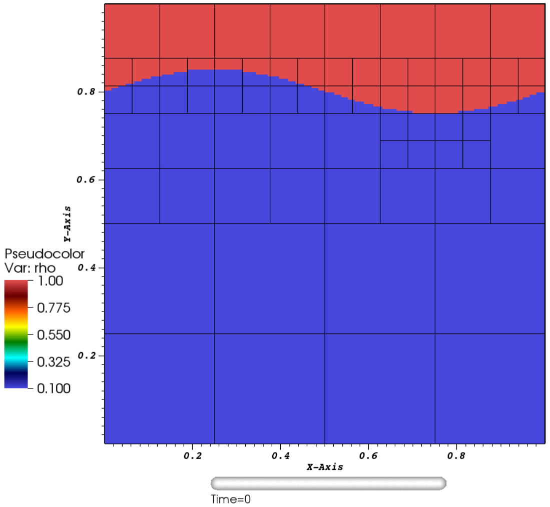
$$\nabla_\alpha T^{\alpha\beta} = 0,$$

$$\nabla_\alpha {}^*F^{\alpha\beta} = 0.$$

c=1, μ_0=1.

u^μ: 4-velocity
$\boldsymbol{B}$: magnetic field
p: thermal pressure
w: enthalpy density
ρ: proper density
$\eta^{\mu\nu}$: Minkowsky metric

- Program: **MPI-AMRVAC**
finite volumes solver + constrained transport



Example of simulation of the Rayleigh-Taylor instability

Initial set up: shock in its rest frame

- 2D problem

- **Initial state** = solution of the Rankine-Hugoniot jump relations for given upstream state and $\Gamma_{\rm rel}$

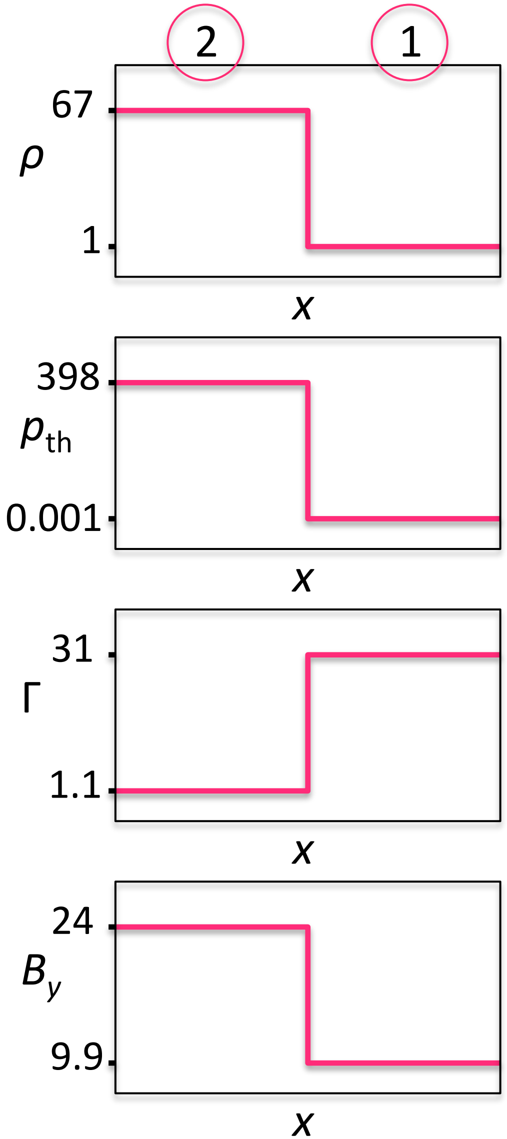
$$\rho_1 \Gamma_1 v_1 = \rho_2 \Gamma_2 v_2$$

$$B_1 v_1 = B_2 v_2$$

$$W_1 {\Gamma_1}^2 {v_1}^2 + P_1 = W_2 {\Gamma_2}^2 {v_2}^2 + P_2$$

$$W_1 {\Gamma_1}^2 v_1 = W_2 {\Gamma_2}^2 v_2$$

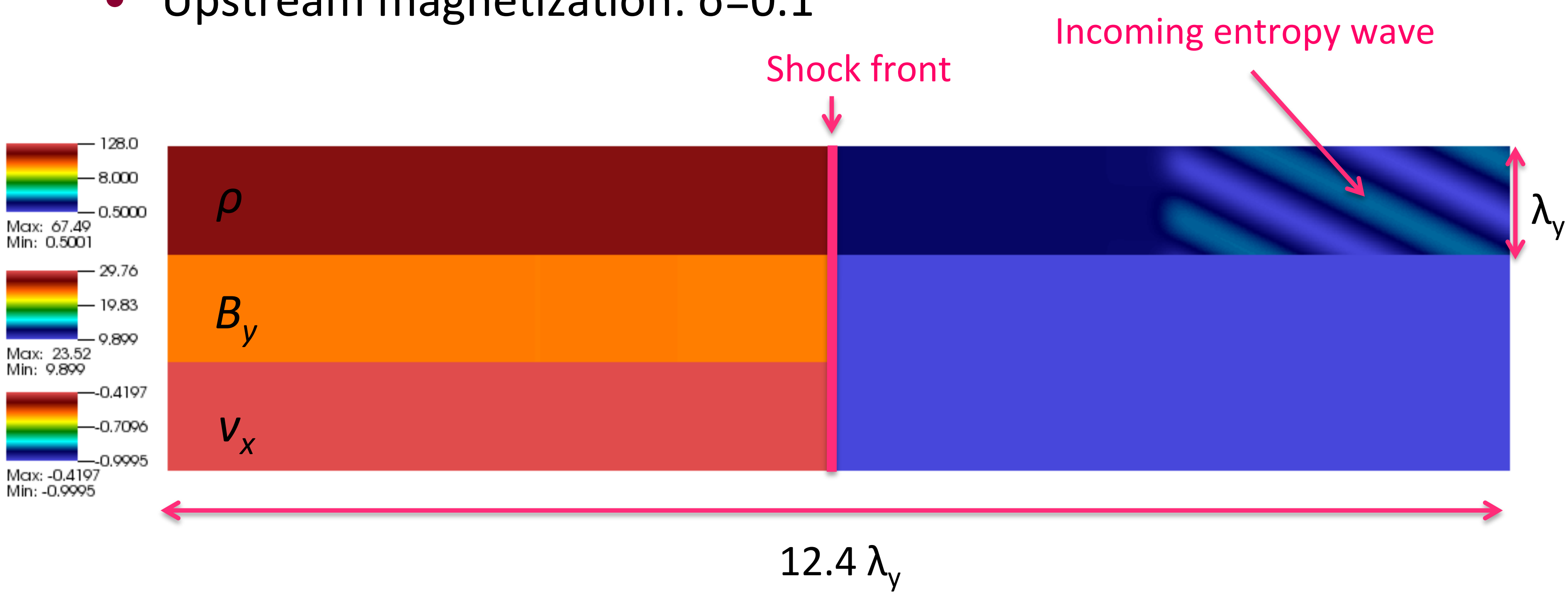
with $P = p_{\rm th} + B^2/\Gamma^2$, the total pressure and $W = w + B^2/\Gamma^2$, the total enthalpy, associated to an adiabatic ideal gas EOS.



Relativistic shocks: incoming entropy wave

- Entropy wave: pertubations in ρ
- Perturbation amplitude: $\delta\rho/\rho$ = 45%
- Relative Lorentz factor: 20
- Upstream magnetization: σ=0.1

$$\sigma \equiv \frac{\text{magn. energy}}{\text{enthalpy}}$$



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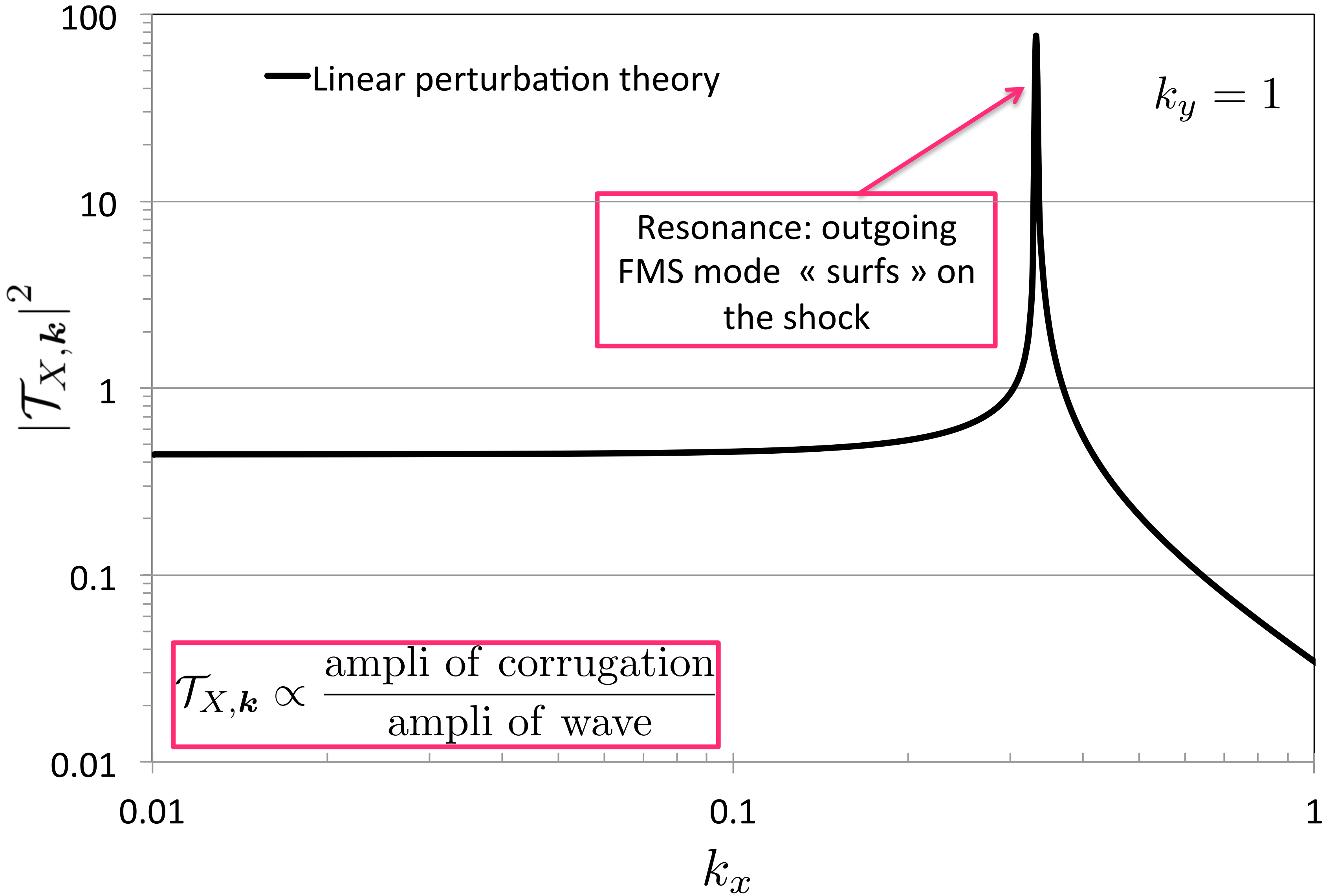
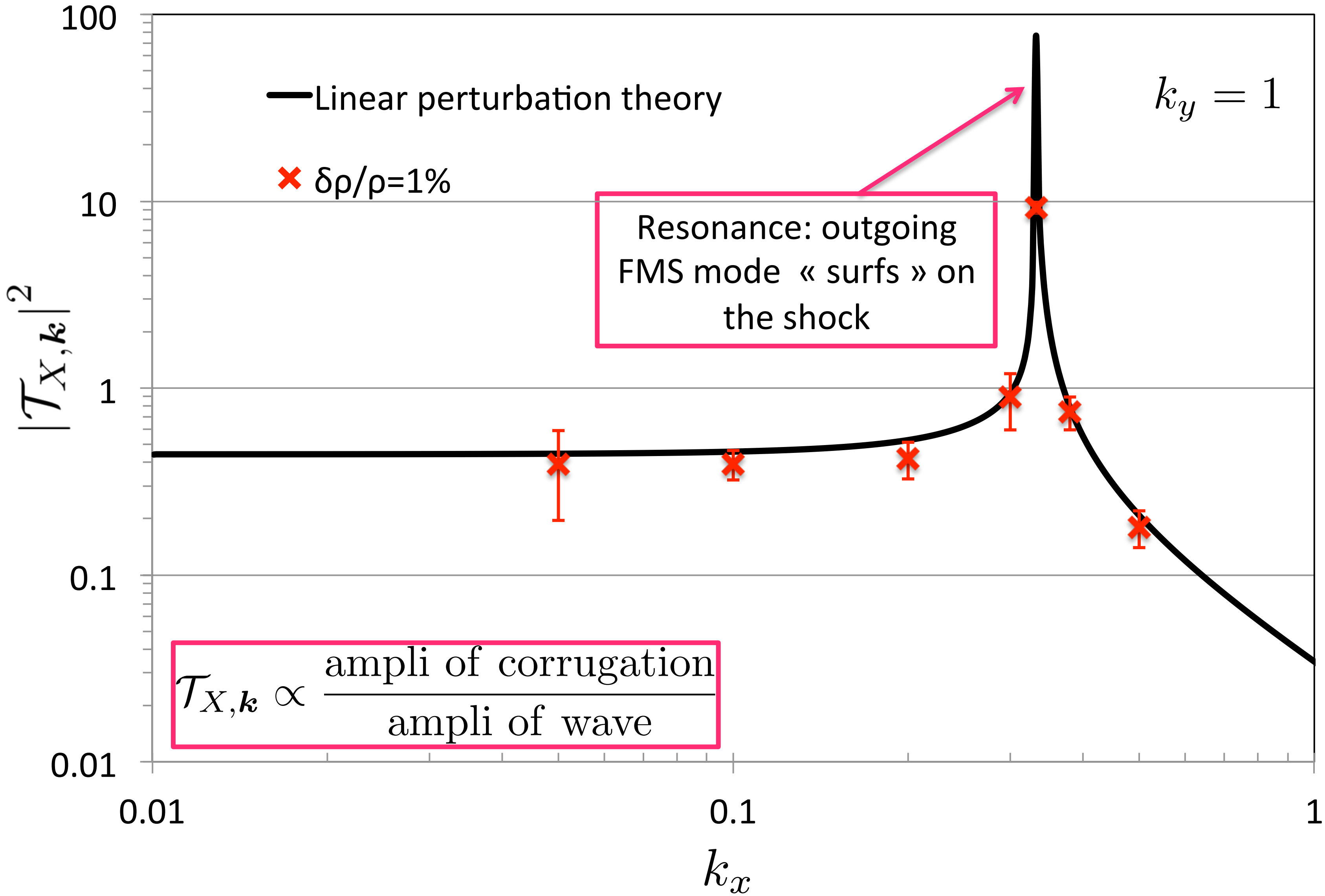
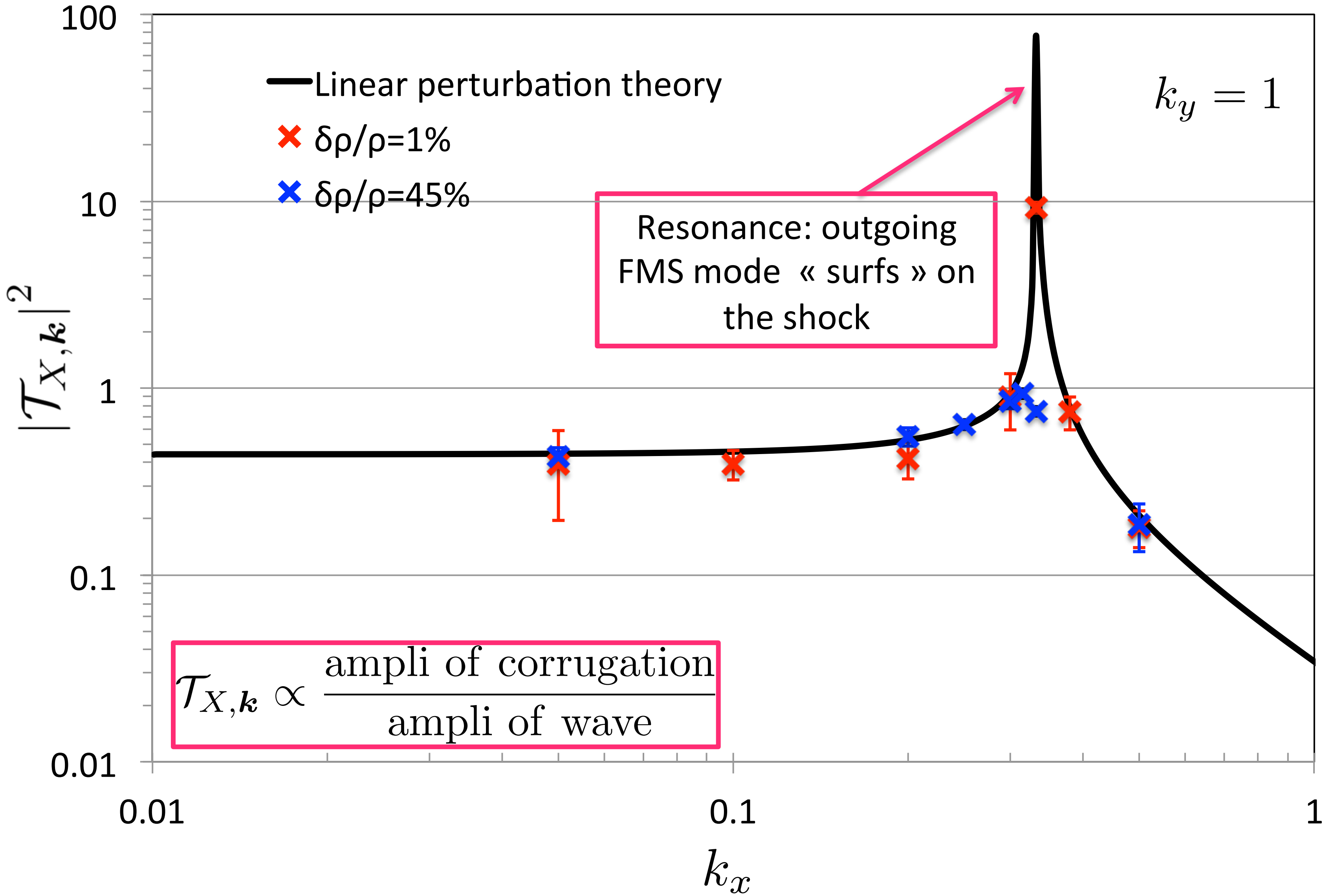


Relativistic shocks: incoming entropy wave

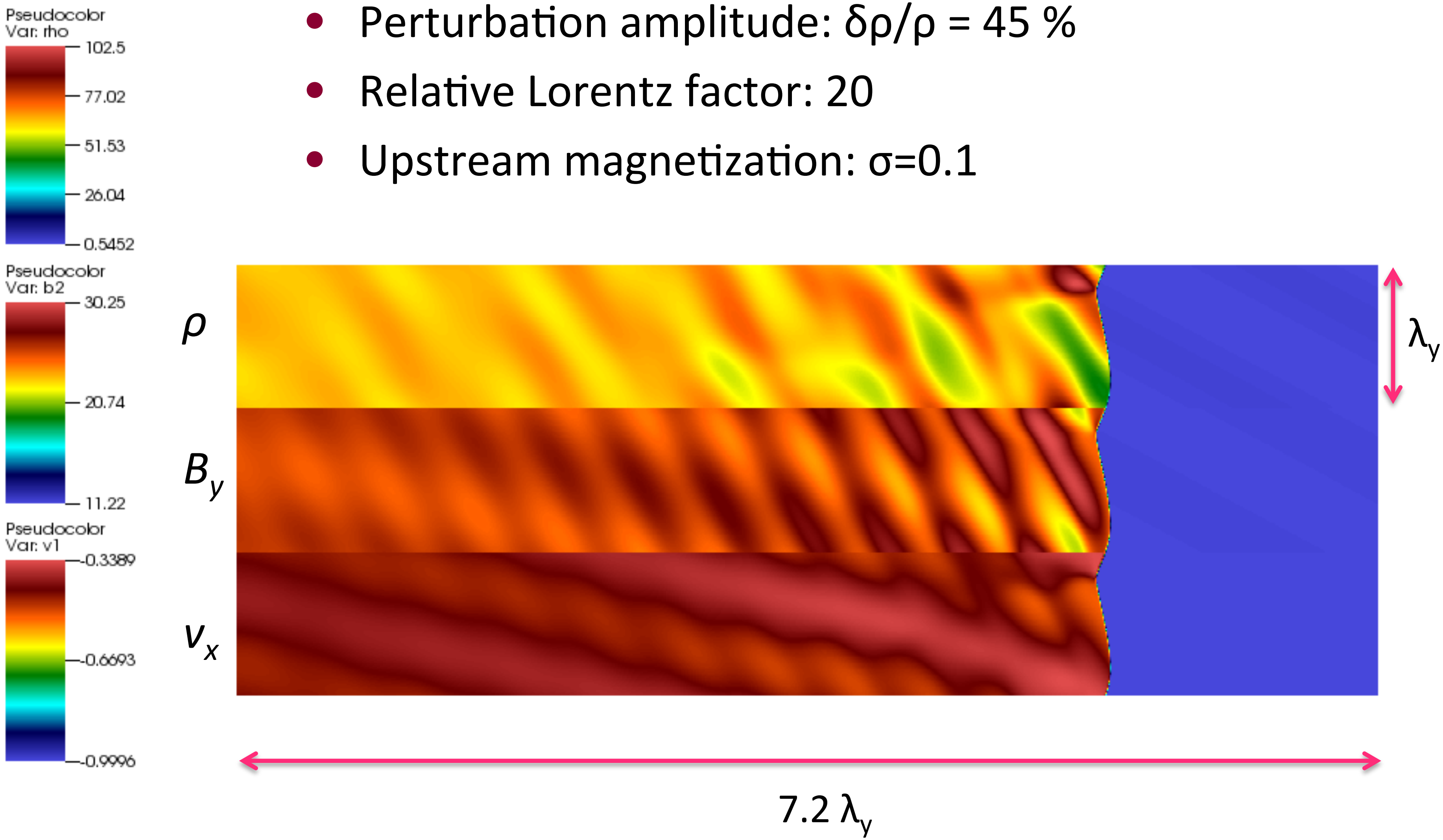


Relativistic shocks: incoming entropy wave

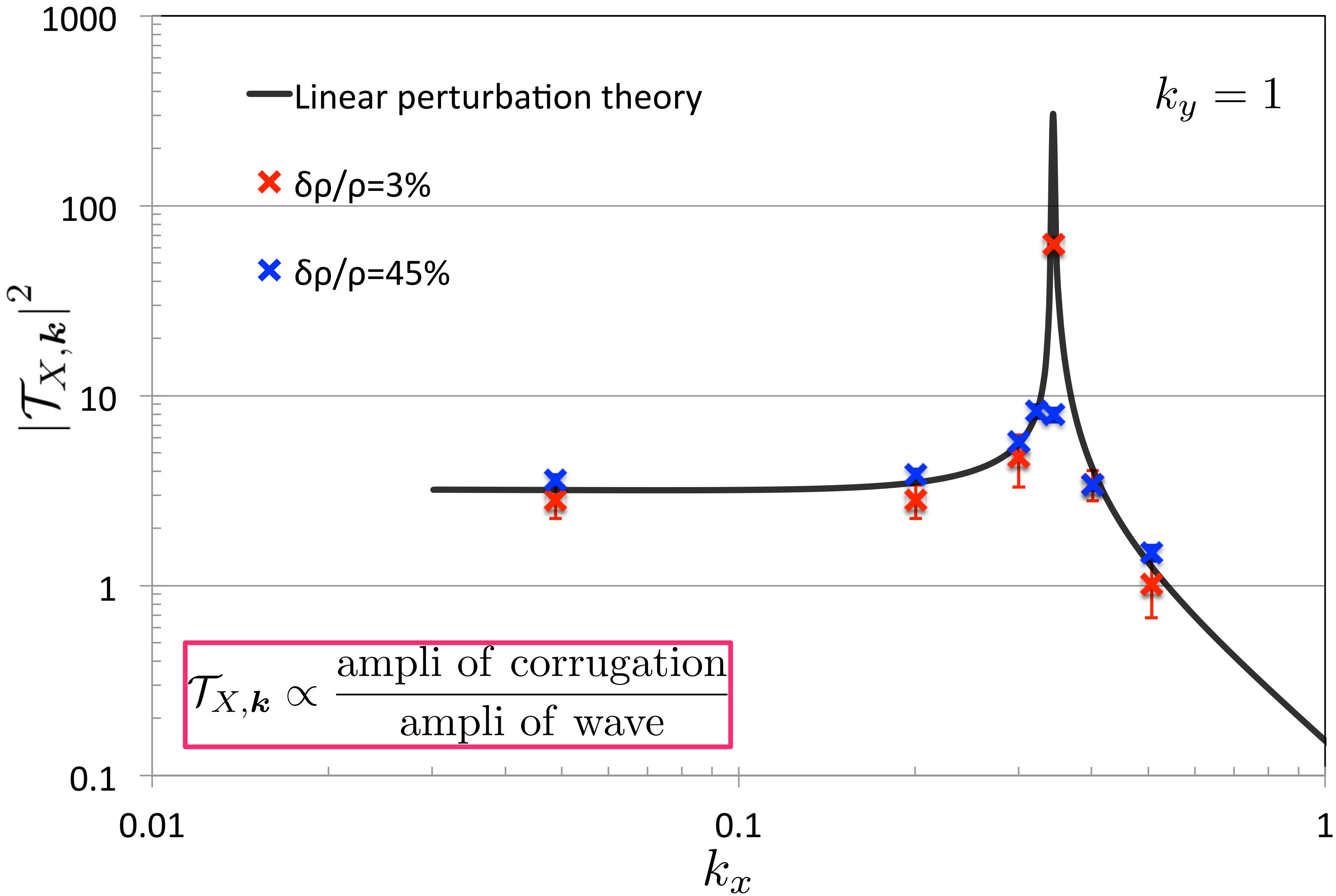


Relativistic shocks: incoming FMS wave

- Perturbation amplitude: $\delta\rho/\rho$ = 45 %
- Relative Lorentz factor: 20
- Upstream magnetization: σ=0.1

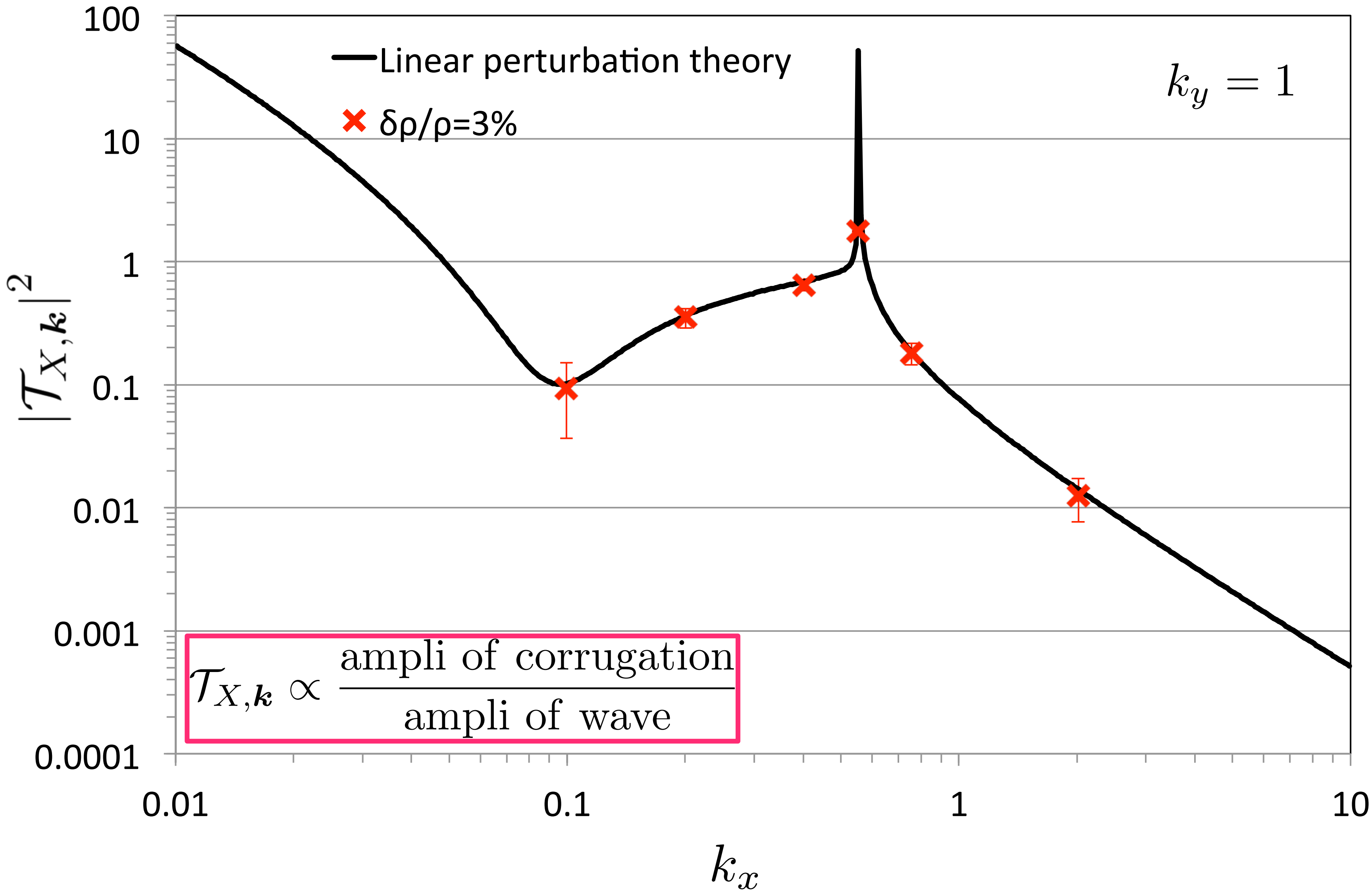


Relativistic shocks: incoming FMS wave



$$\mathcal{T}_{X,\boldsymbol{k}} \propto \frac{\text{ampli of corrugation}}{\text{ampli of wave}}$$

Sub-relativistic shocks: incoming FMS wave



$$\mathcal{T}_{X,\boldsymbol{k}} \propto \frac{\text{ampli of corrugation}}{\text{ampli of wave}}$$

Conclusion

Summary:

- Performed **SRMHD simulations** of interaction of upstream monoλ MHD mode with shock.
- Proved existence of **resonant response of shock** to perturbations **in linear regime** in agreement with analytical study.

Outlook: Effects of corrugation on particle acceleration?

→test particle simulations,

→PI[SRMHD]C simulations.

References

- Camilia Demidem, Martin Lemoine, and Fabien Casse (submitted to MNRAS, arXiv:1710.08127)
- Martin Lemoine, Oscar Ramos, and Laurent Gremillet (2016), ApJ 827
- Vink (2012) , arXiv:1206.2363v1