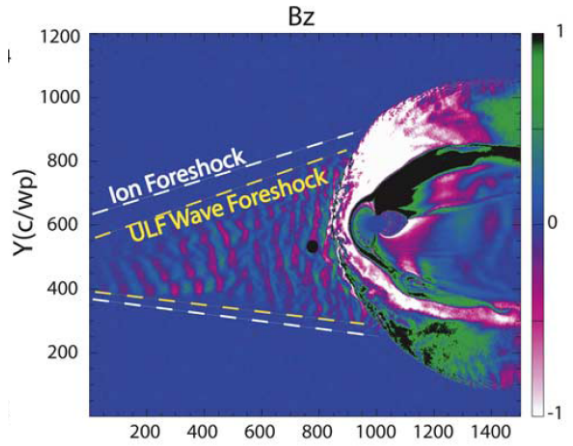
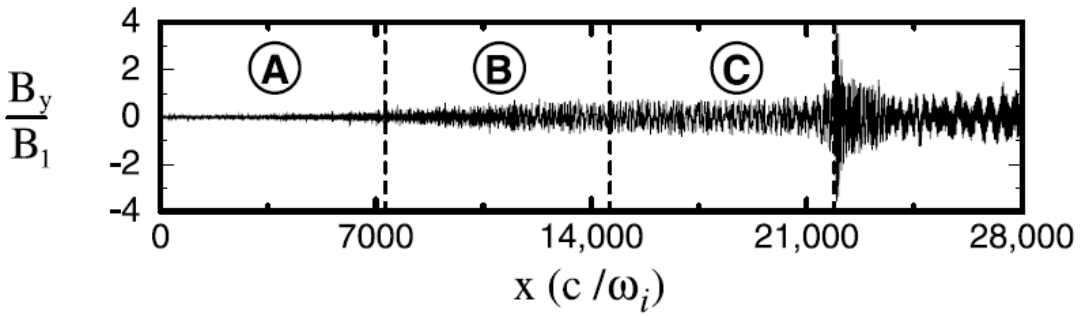
Simulations

Shocks Working Group

Basics



- Shocks are ...
  - Nonlinear
  - Multi-scale
  - Cross-scale



- Simulations have provided key advances:
  - Ion reflection at quasi-perpendicular shock
  - Reformation & particle injection at quasi-parallel shock
  - Et cetera ...

Techniques

Method/ Approach	Good for ...	But ...
MHD (fluid)	Testing the code Global shock propagation	MHD
Hybrid (particle ions + fluid electrons)	Ion scale structure/ instabilities	Effects of electron scales not modelled correctly(?)
Full particle PIC	Apparently gets everything right	Computational cost Use of small me/mi, system size Statistical noise
Vlasov (full particle)	Apparently gets everything right	Low noise Inadequate phase space
PIC explicit	“simpler” algorithms	Courant condition on time step
PIC implicit	“complicated” algorithms	Larger time steps Missing sub timestep/grid physics
Parallel	Can’t be avoided!	Parallel efficiency, scaling
Tera- / Peta-computing	Even more realistic The Future	Data deluge Ask the right questions!

Dimensionality

The easiest way to reduce computational cost

- 1D ... 1000 cells & 1000 ppc = 4×10^6
- 2D ... $(1000)^2$ cells & 1000 ppc = 4×10^9
- 3D ... $(1000)^3$ cells & 1000 ppc = 4×10^{12}

Mass and Frequency Scales

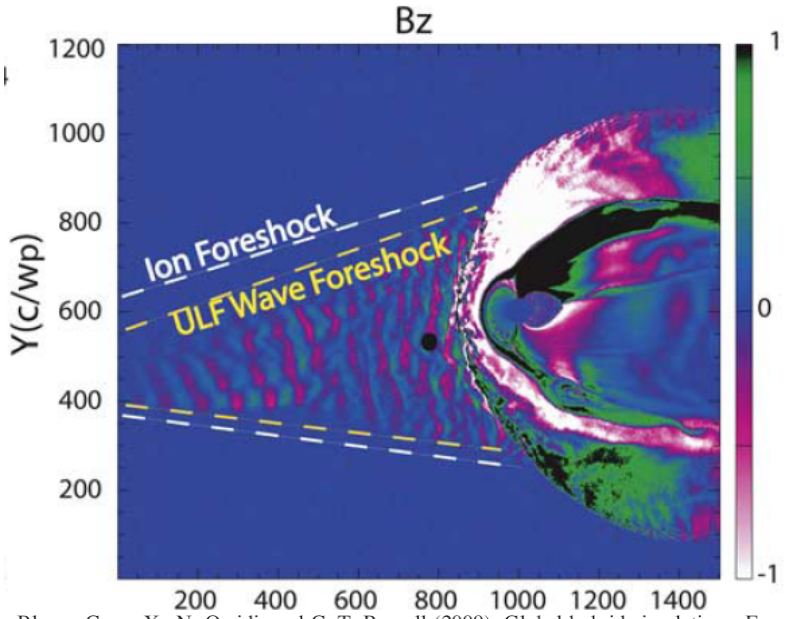
Reduce computational cost by:

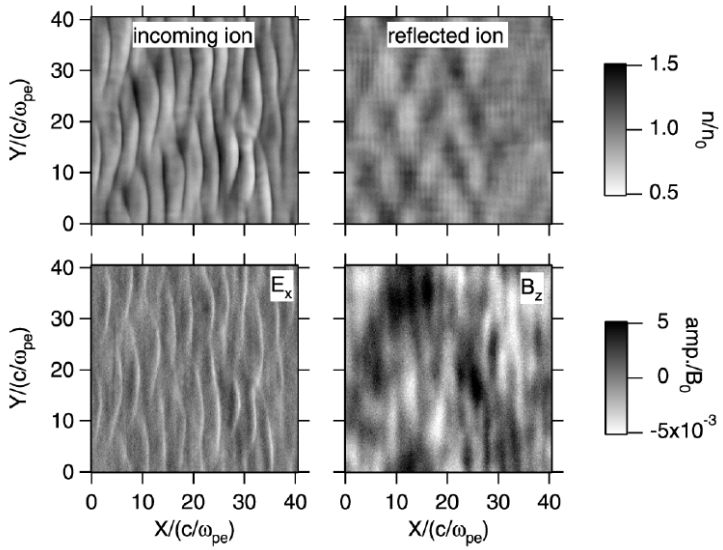
- Lower mass ratio
- Lower ratio plasma to cyclotron frequencies

But compromises:

- coupling between scales
- instability growth rates

Multi-scale and Cross-scale





Citation: Blanco-Cano, X., N. Omidi, and C. T. Russell (2009), Global hybrid simulations: Foreshock waves and cavitons under radial interplanetary magnetic field geometry, *J. Geophys. Res.*, *114*, A01216, doi:10.1029/2008JA013406.

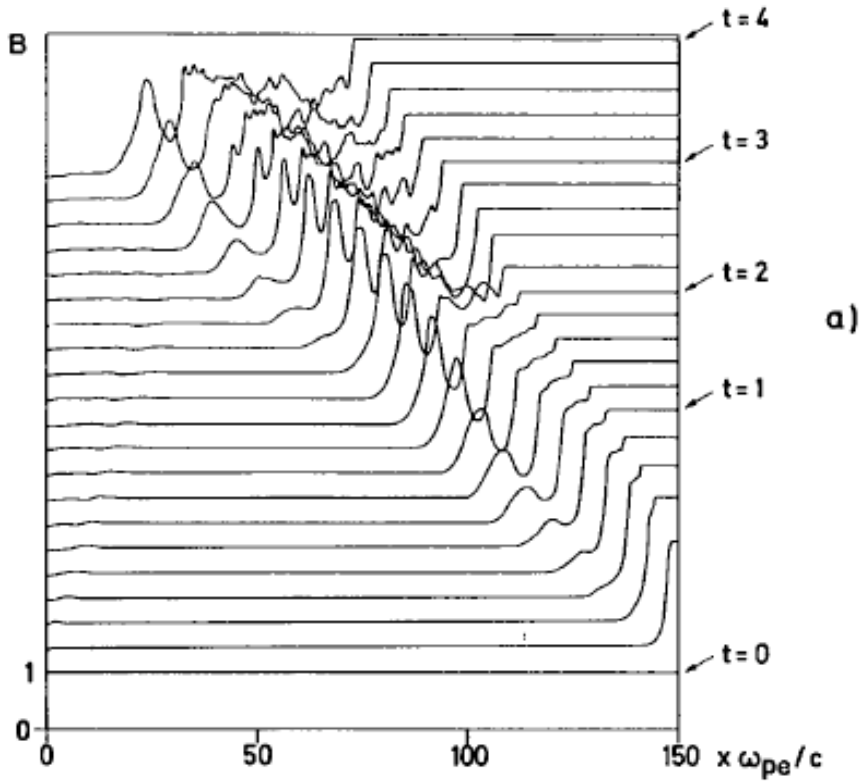
Citation: Matsukiyo, S., and M. Scholer (2006), On microinstabilities in the foot of high Mach number perpendicular shocks, *J. Geophys. Res.*, *111*, A06104, doi:10.1029/2005JA011409.

Shocks “in the wild” are not ideal.

- How do scales in system and upstream flow couple to shock?
- Is there ever, really, an ideal shock?

Non-stationarity at Qperp Shocks

- 1972:
  1D PIC: overturning via over-reflection of ions

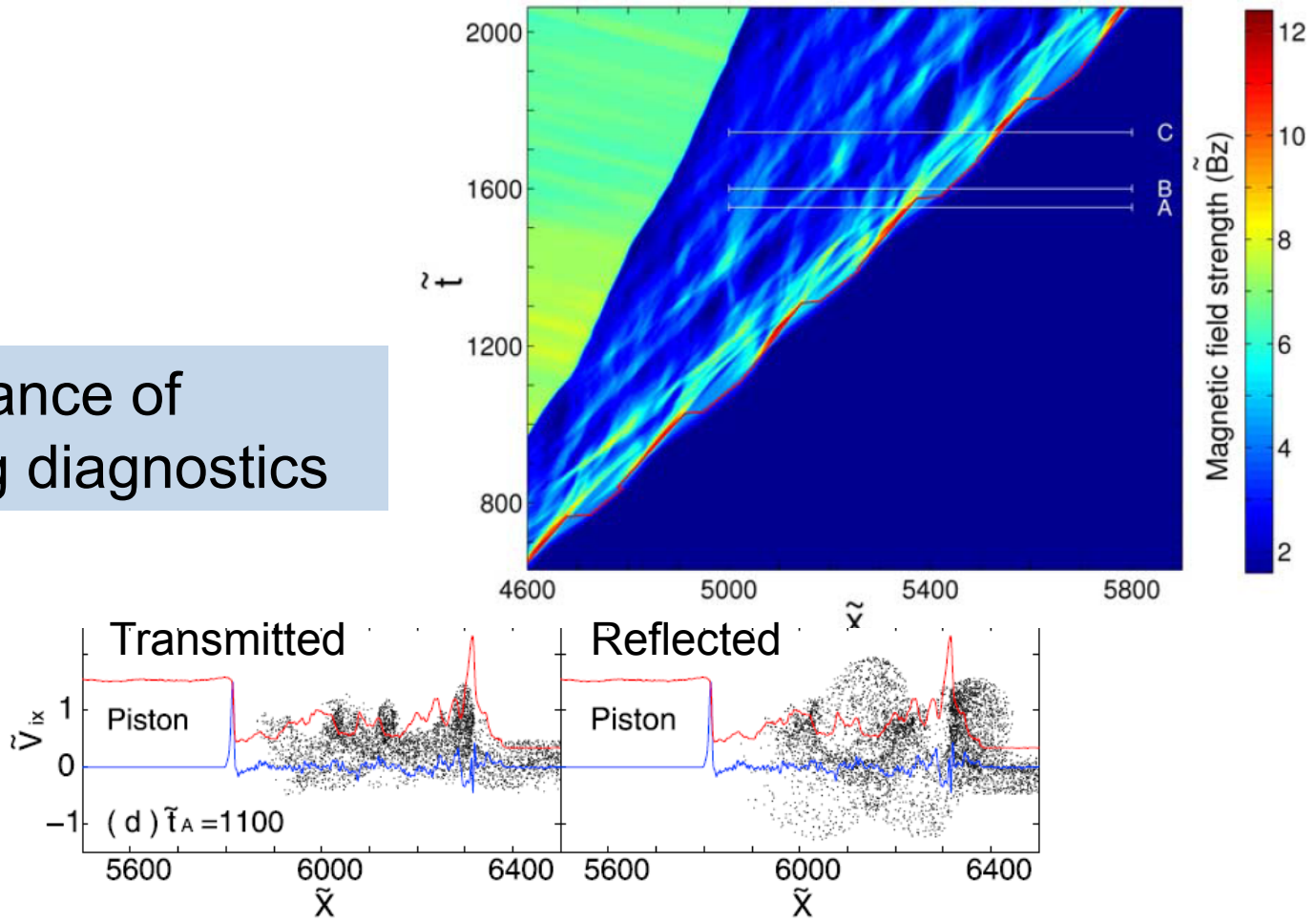


D. BISKAMP, H. WELTER

- Will history repeat itself?

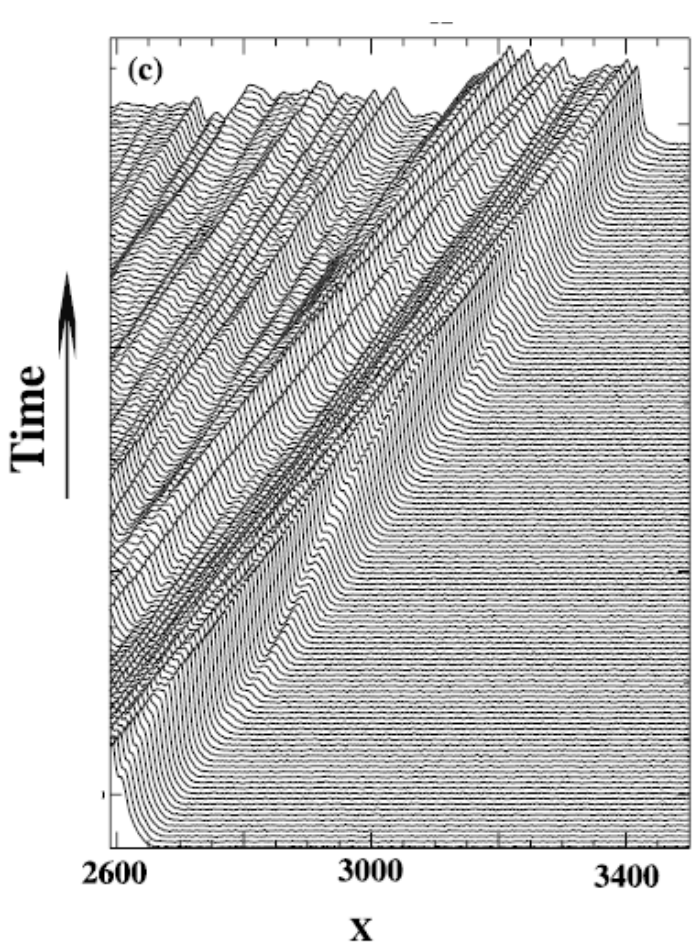
And repeat ...

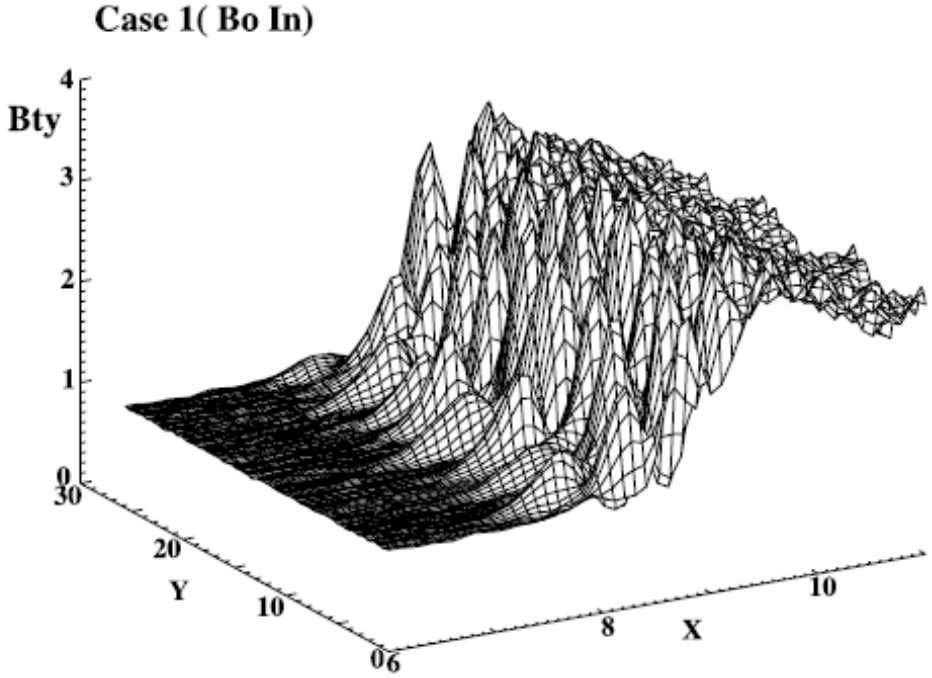
Importance of refining diagnostics



YANG ET AL.: ION ACCELERATION IN NONSTATIONARY SHOCKS
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, A03111, doi:10.1029/2008JA013785, 2009

And repeat ... In 2D

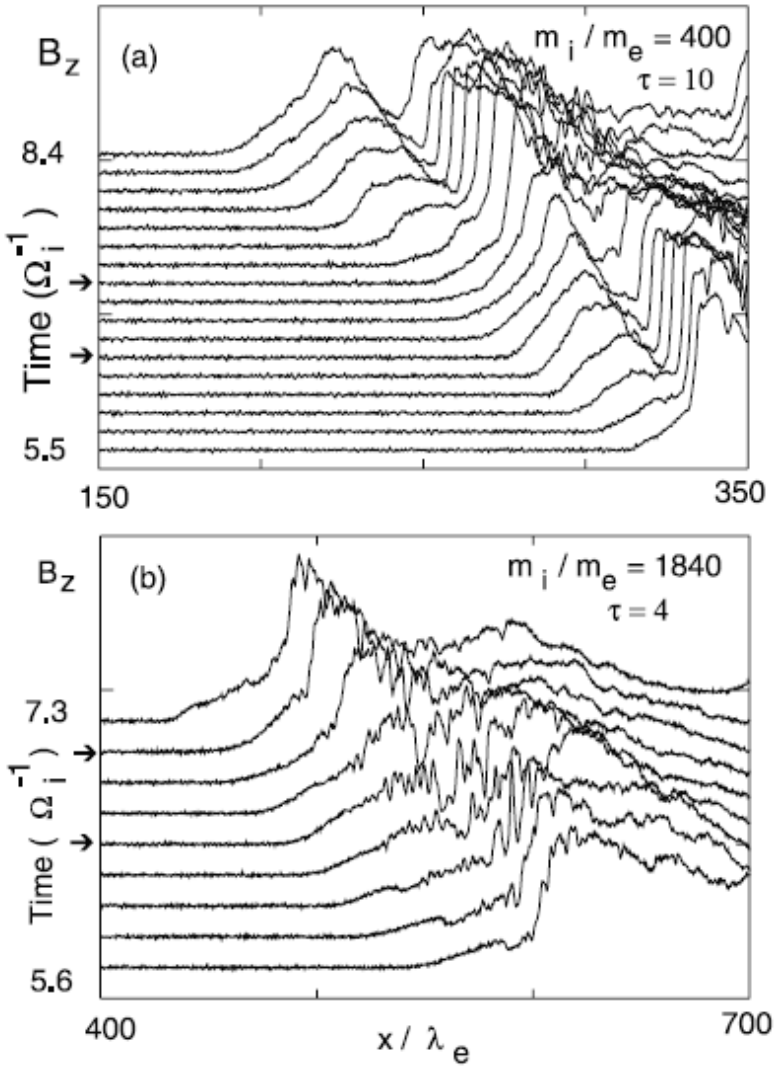




Importance of parameter regime, and dimensionality for behaviour of shock structure

Citation: Lembège, B., P. Savoini, P. Hellinger, and P. M. Trávníček (2009), Nonstationarity of a two-dimensional perpendicular shock: Competing mechanisms, *J. Geophys. Res.*, *114*, A03217, doi:10.1029/2008JA013618.

Ion-Electron Mass Ratio



Importance of moving to realistic parameters

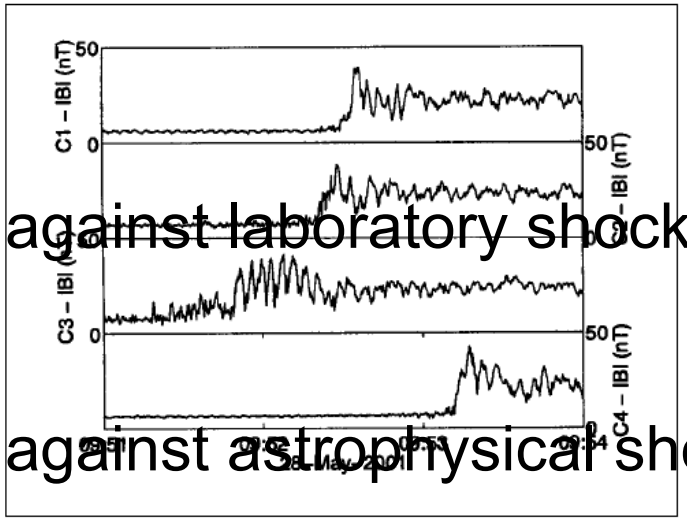
Citation: Scholer, M., I. Shinohara, and S. Matsukiyo, Quasi-perpendicular shocks: Length scale of the cross-shock potential, shock reformation, and implication for shock surfing, *J. Geophys. Res.*, *108*(A1), 1014, doi:10.1029/2002JA009515, 2003.

Validation - How do we know a simulation is right?

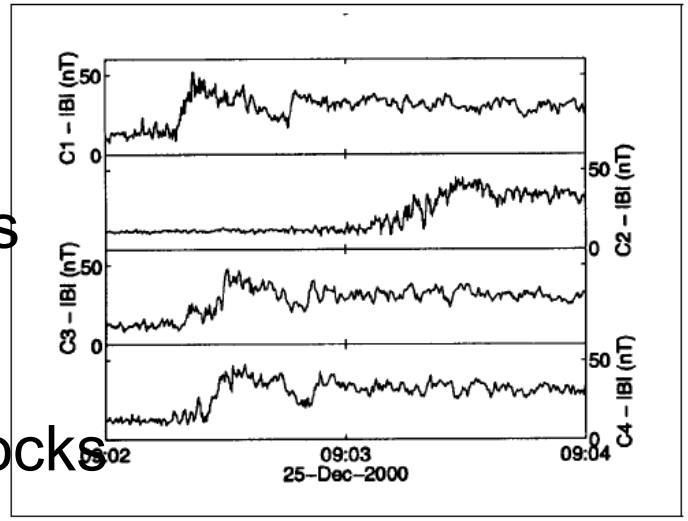
Validation against heliospheric shocks

- spacecraft observations
- only over a limited parameter range
- incomplete spatial information

Validation against laboratory shocks



Validation against astrophysical shocks

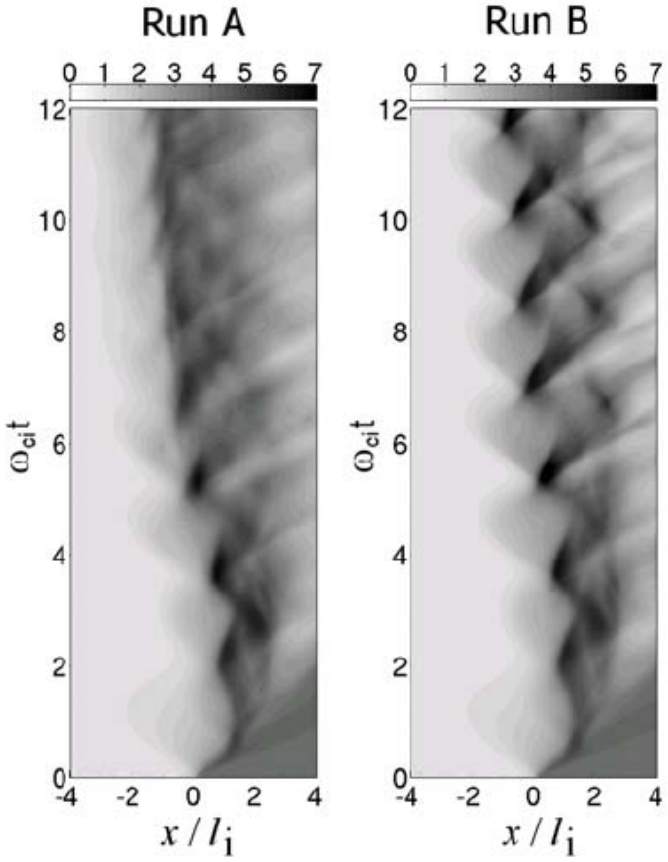


Dimensionality & System Size

Run A: system size large enough to include ion scale ripples on shock

Run B too small for ion scale ripples to develop

Run B shows coherent overturning throughout

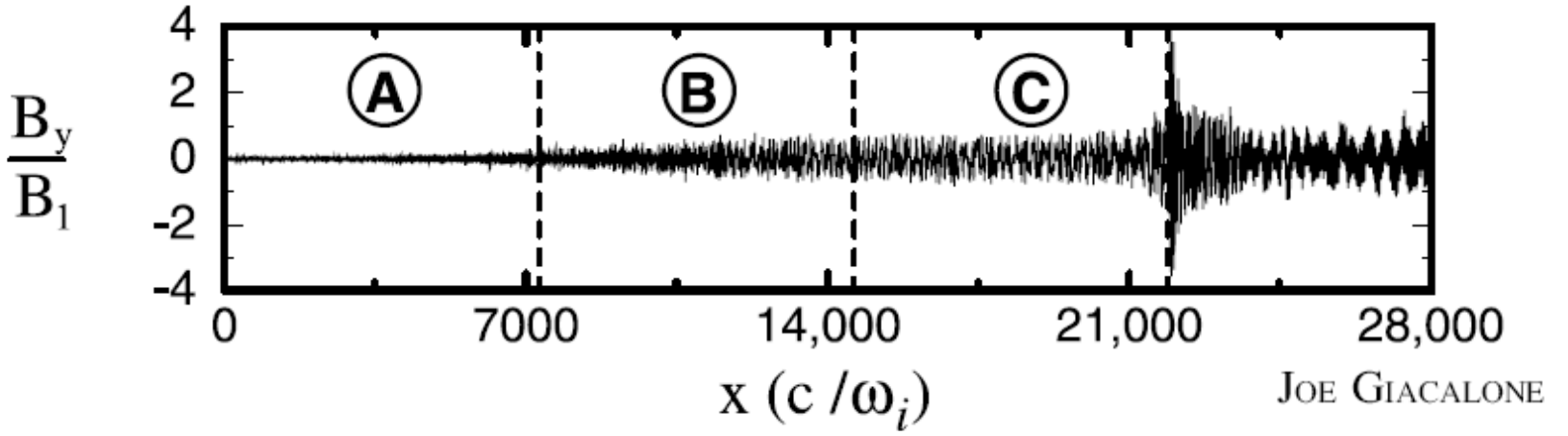


Umeda et al. PSS 2009

2D Full particle PIC

Dimensionality & System Size

1D hybrid parallel shock simulation



Going to 3D:

- Is it computationally possible?
- Is the computational cost appropriate?

Challenges

Move towards ...

- using more realistic mass ratio
- understanding effects of reduced dimensionality
- understanding the nature of shocks “in the wild” (turbulence, global morphology, etc.)
- bridge the gap between heliospheric shocks and “astrophysical” and laboratory shocks

And try to answer the right questions ...