FINNISH METEOROLOGICAL INSTITUTE

# Magnetospheric mass and energy transfer: Vlasiator ~~and GUMICS-4~~ simulation results


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# Outline

Objectives

- Solar wind - magnetosheath - magnetopause connection
- Two global models
    - Vlasiator – FMI's new global kinetic model: Foreshock - magnetosheath
    - (GUMICS-4 – FMI's global MHD model: Magnetopause)

Vlasiator

- Foreshock 30-s oblique ULF waves
- Plasma transfer through bowshock and magnetosheath

Results

- Foreshock exhibits 30-second oblique ULF waves in in quantitative agreement with observations
- Bow shock exhibits a 30-s oscillation

# Modelling the magnetosphere

**State of the art in global simulations**

- Global 3-D MHD (FMI: GUMICS-4)

**MHD severely limited in ion physics**

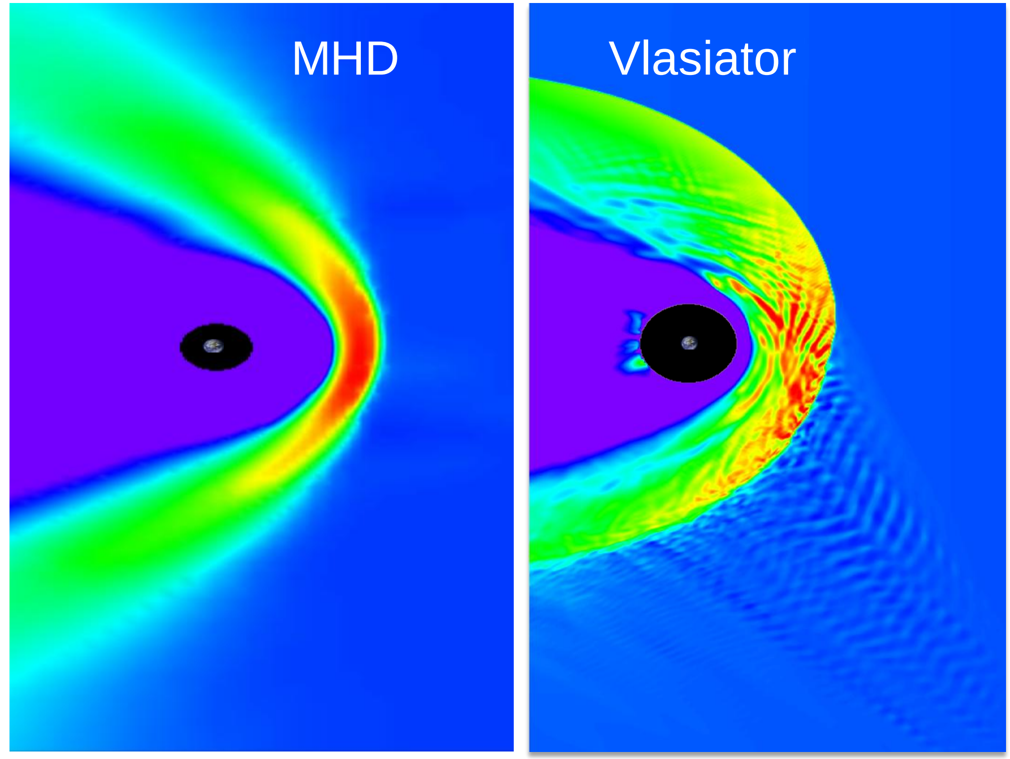
- Accurate foreshock – magnetopause modelling requires ion physics

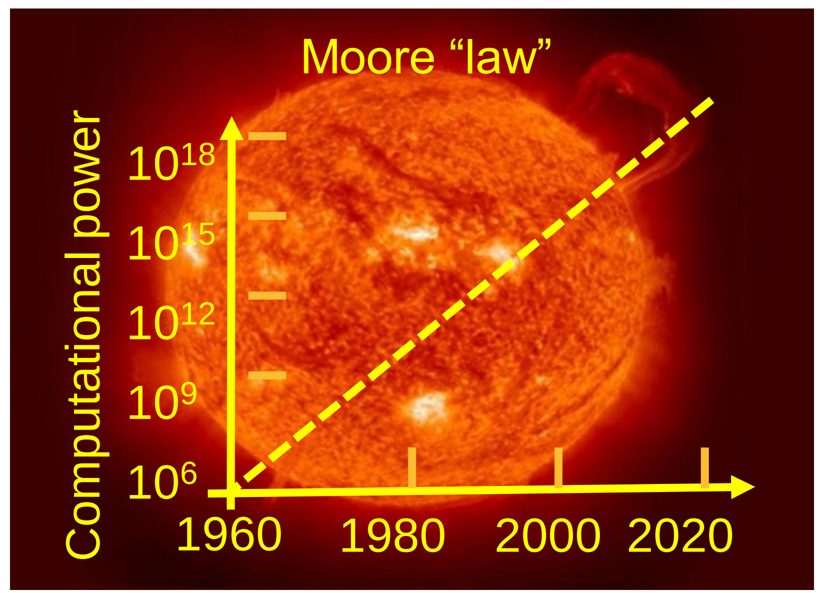
**Improve modelling**: Code coupling or better physical description

- Fluid → hybrid-particle → kinetic

**FMI's Vlasiator**

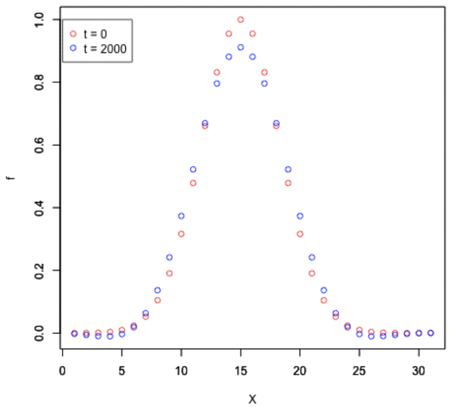
- Global **hybrid-Vlasov** simulation
- **Electrons**: MHD fluid
  **Protons**: distribution functions
- Includes multi-temperature ion kinetics
- No noise (as in hybrid-particle simulations)



# Vlasiator version history

ERC grant 2007
Literature
- Prototypes




Two prototypes
- Semi-Lagrangian
- Finite volume

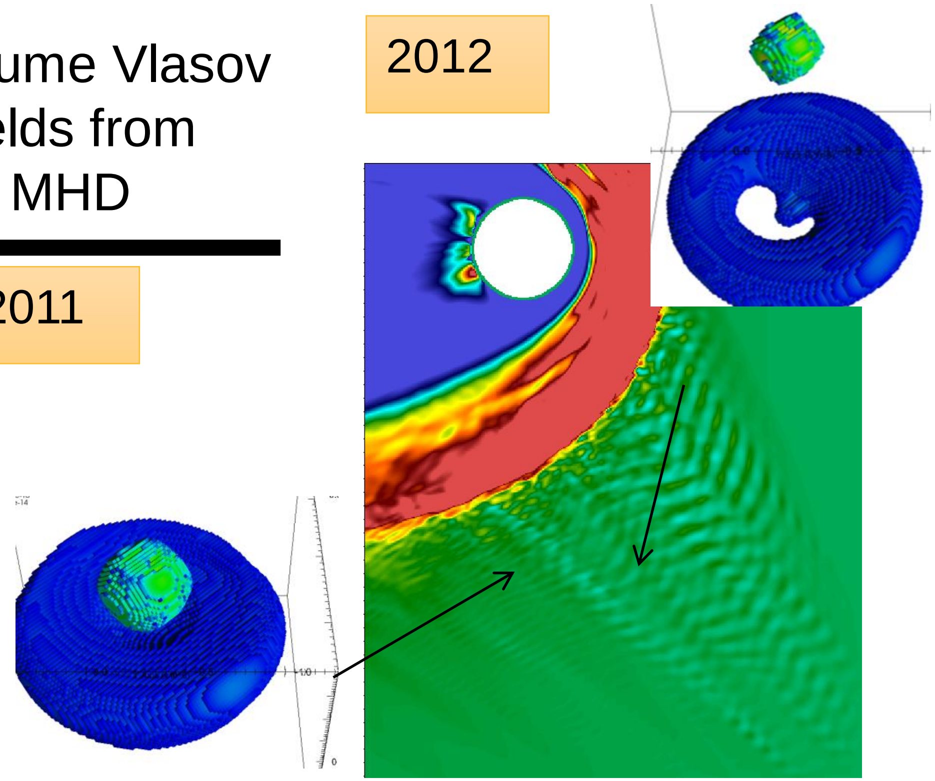
2010

Finite volume Vlasov
- EM-fields from global MHD

2011

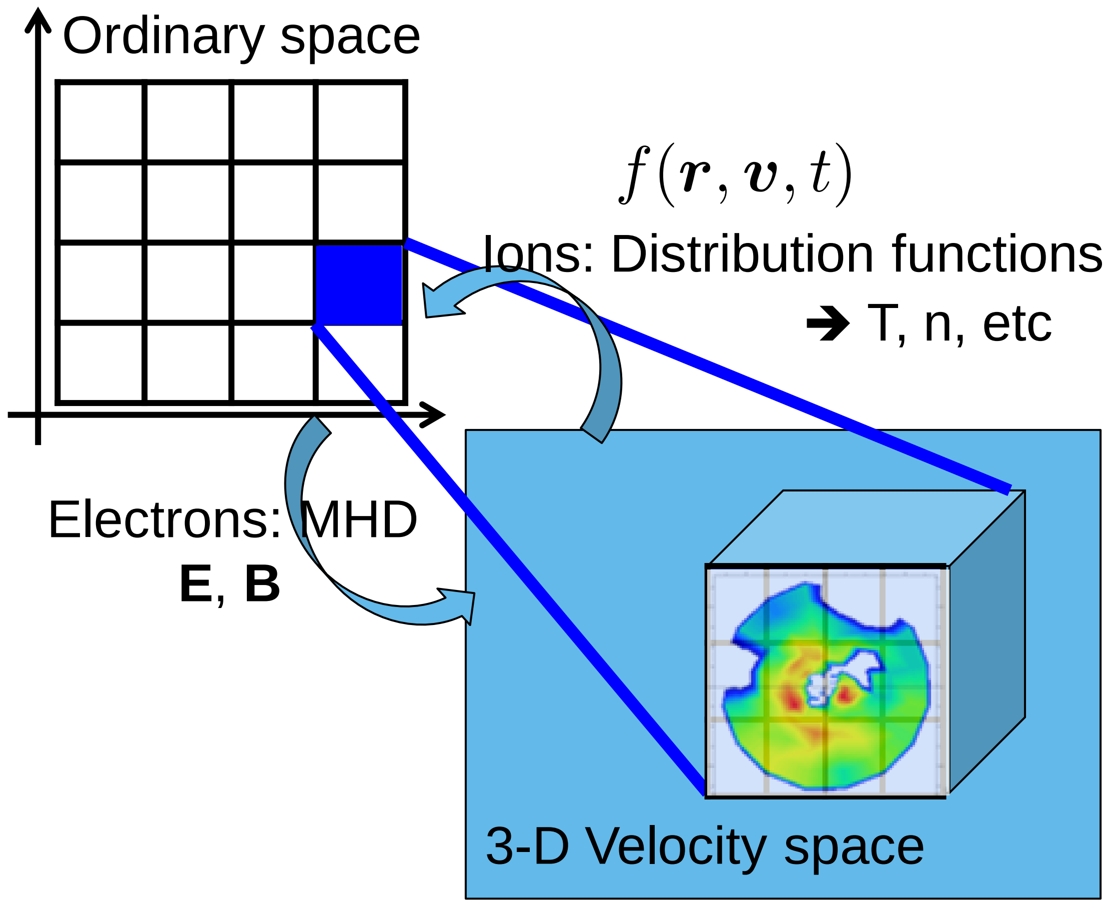
Coupled hybrid-Vlasov
- New field solver
- Access to Europe's largest machines
- First global test runs

2012



# Vlasiator scheme in a nutshell

- Divide ordinary space into grid cells
- Compute EM-fields in ordinary space
- Each ordinary space cell contains a 3D velocity space
- In velocity space, propagate distribution function with Vlasov equation
    - Couple back to ordinary space to compute EM-fields



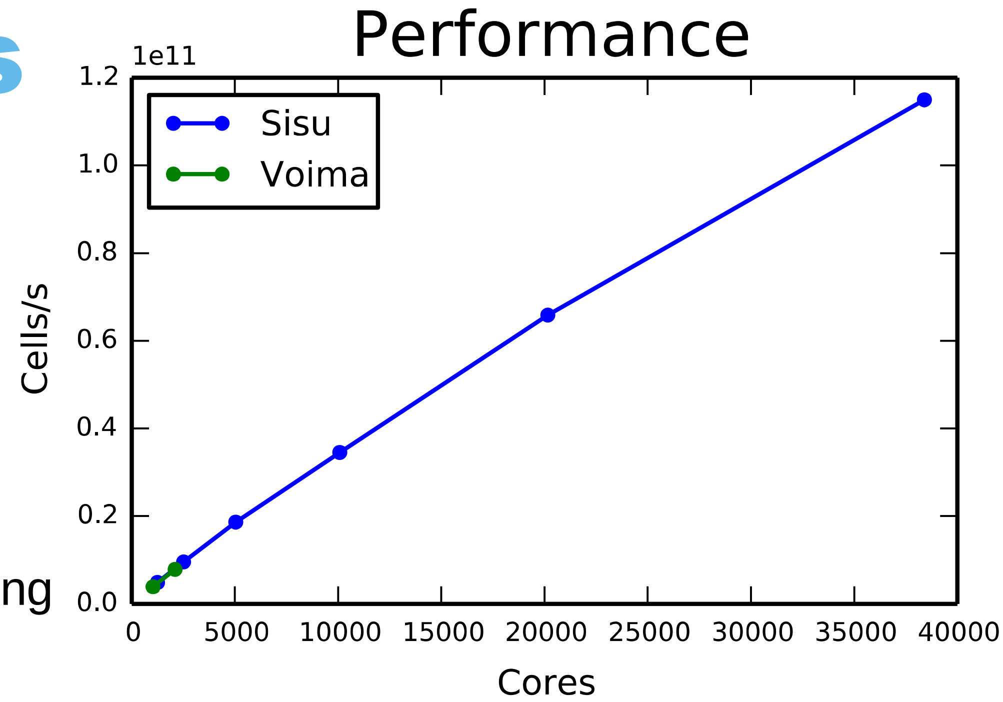
# Vlasiator requires supercomputers

- A modern code in C++…
    - Extendable with latest HPC techniques (Cuda, ADIOS, Hybrid OpenMP-MPI)

… with extreme scalability …

Efficient on 40k cores, target 100k cores

Collaboration with top-end EU supercomputing infrastructure (PRACE, CSC)



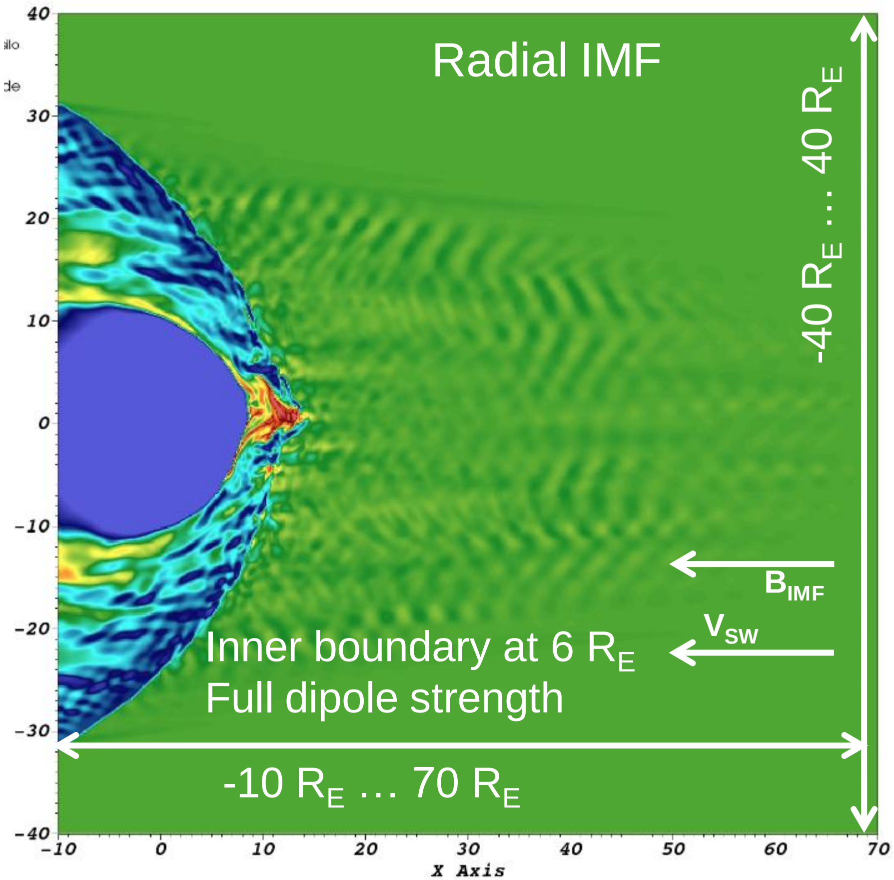


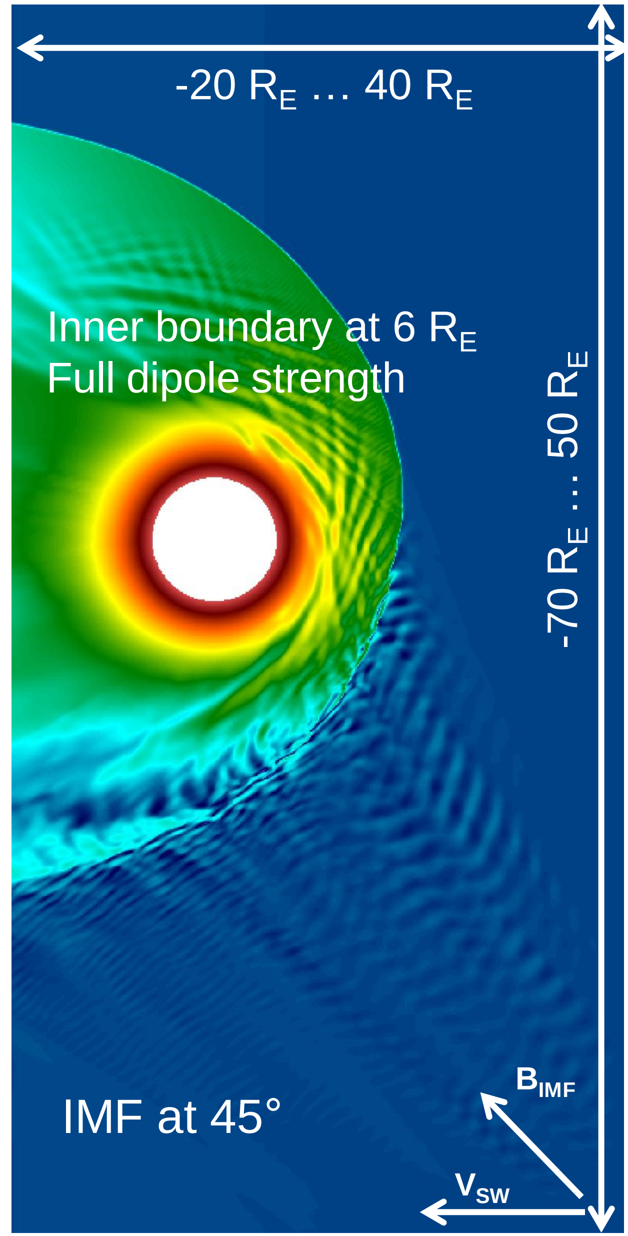
Center for Scientific Computing Finland

# Run setup

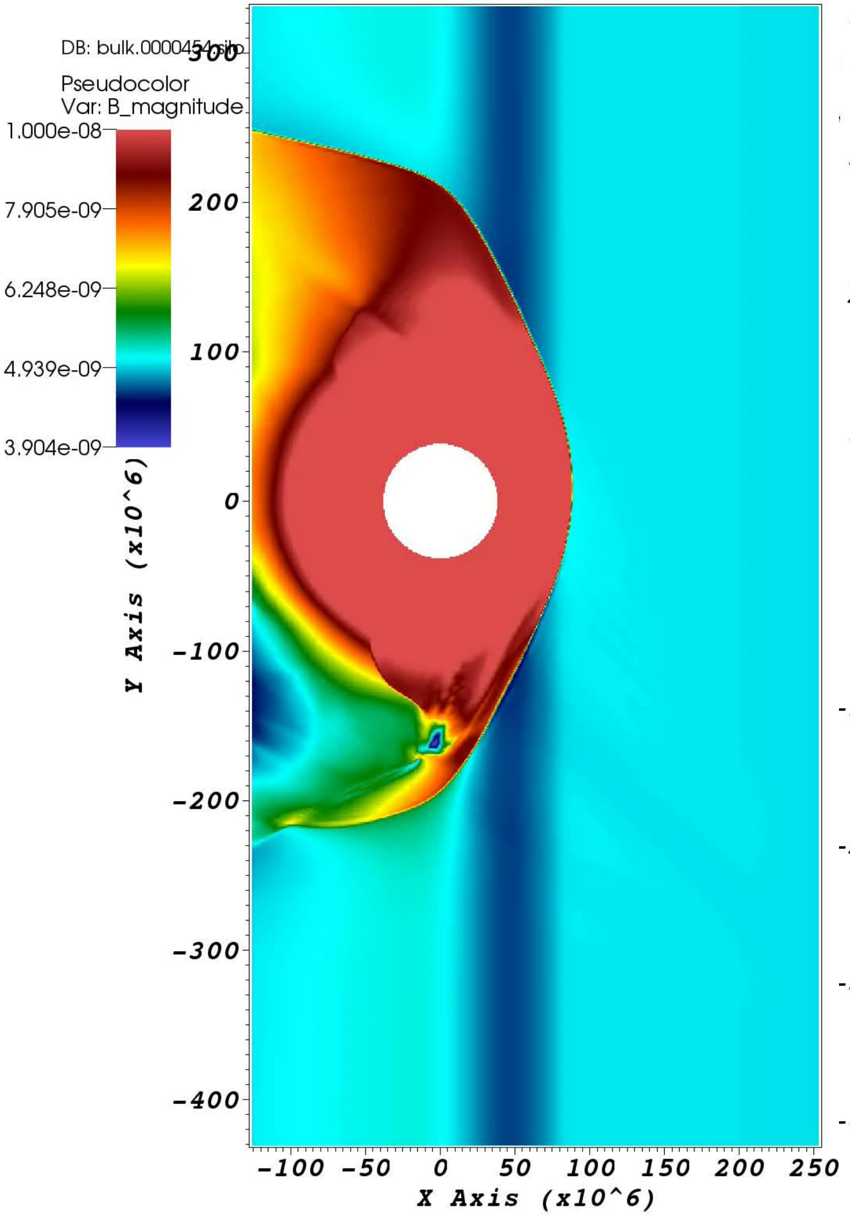
Vlasiator fully 6-D, here 5-D runs (XY plane, 3D velocity space)

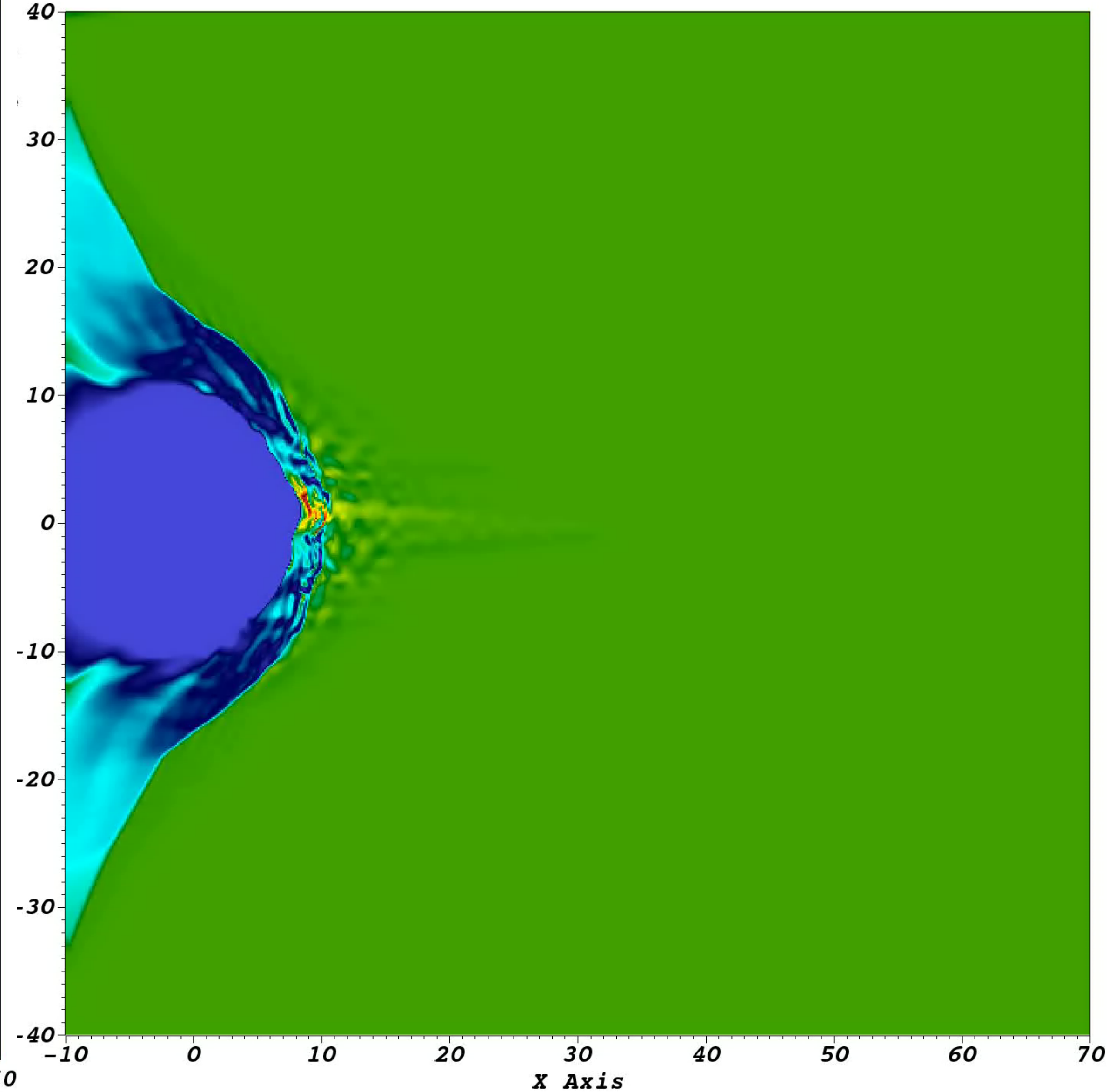
- Resolution: $0.13R_E$ (ordinary), 20 $kms^{-1}$ (velocity)
- Run time: 15 min physical time



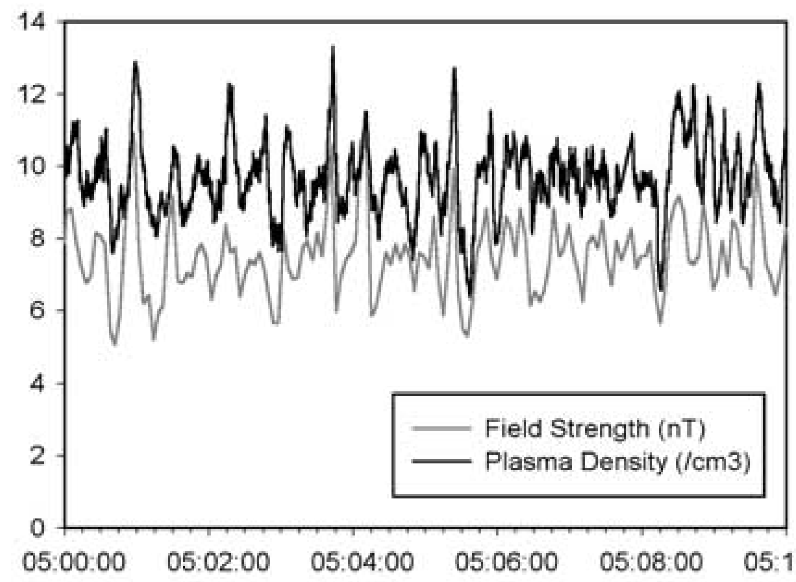
# Overview of runs



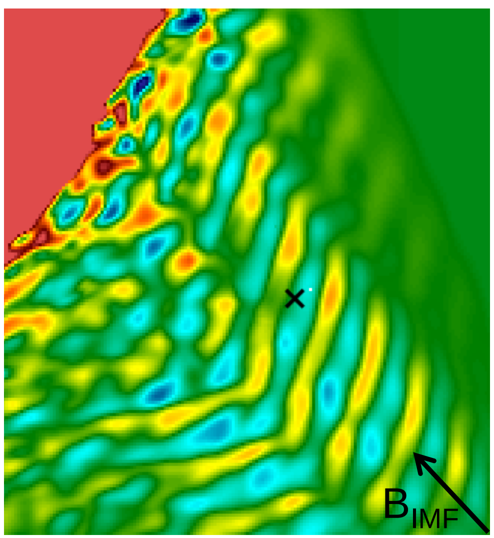
# Properties of the foreshock waves

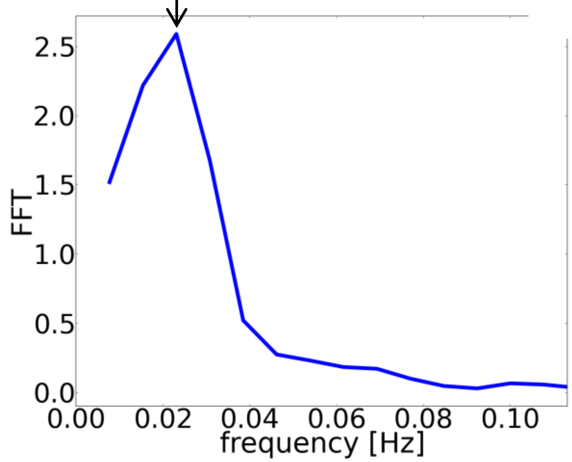
Eastwood et al. 2002

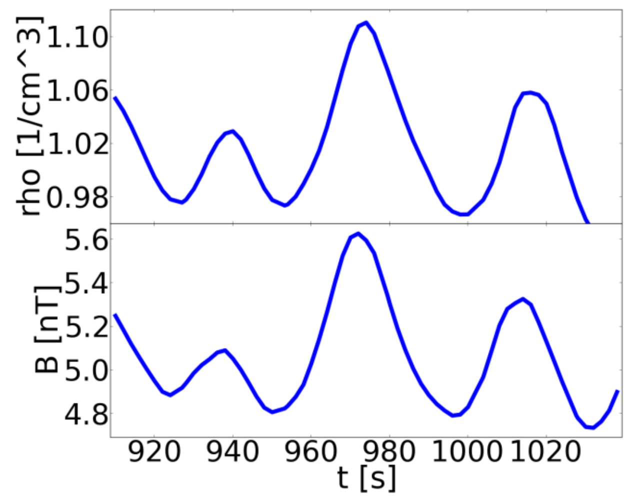



Parker spiral run

- Quasi-monochromatic, 30-s period waves
- Angle of propagation close to what is observed
- Compressive, δn/n ~ δB/B ~ 0.13

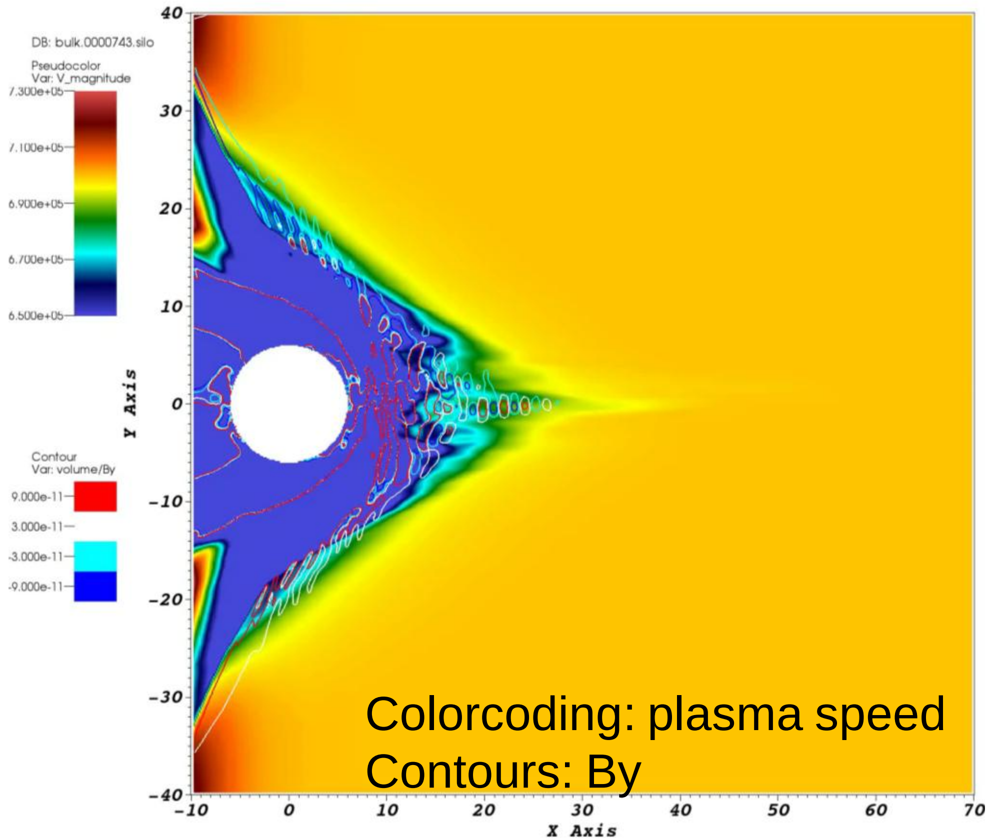


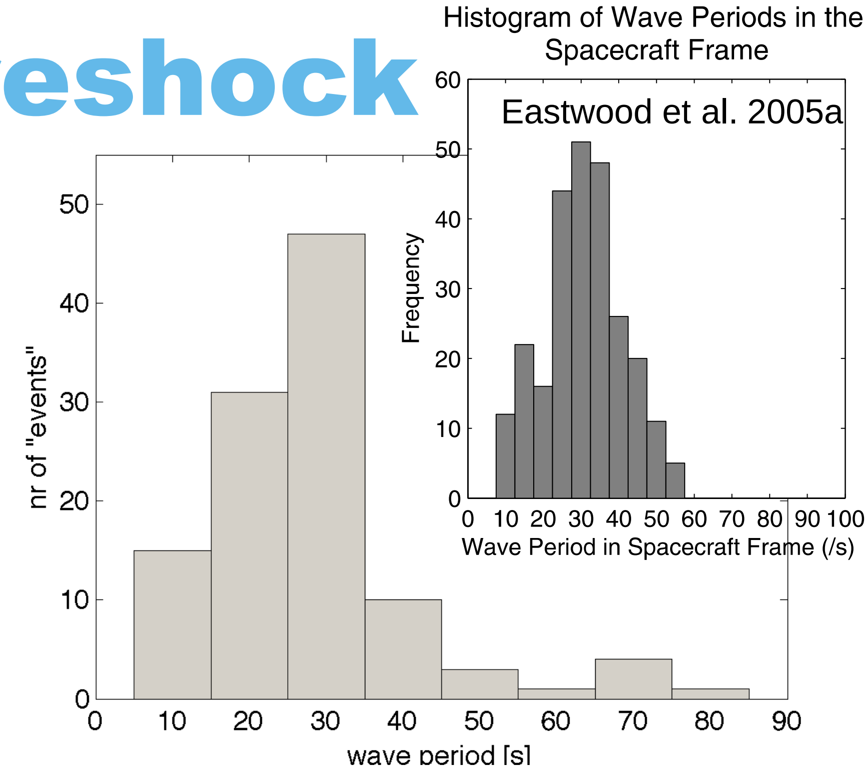



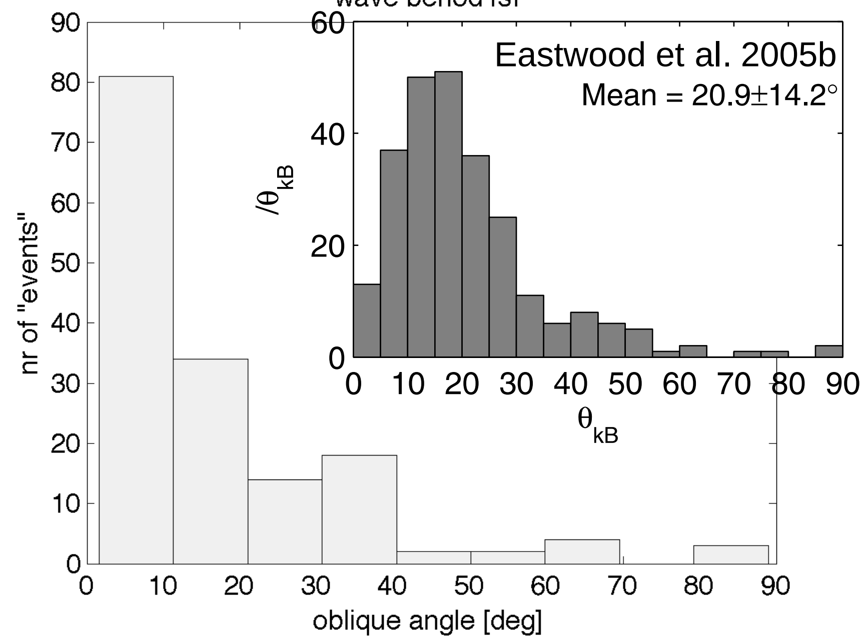



# Properties of the foreshock waves (0°)

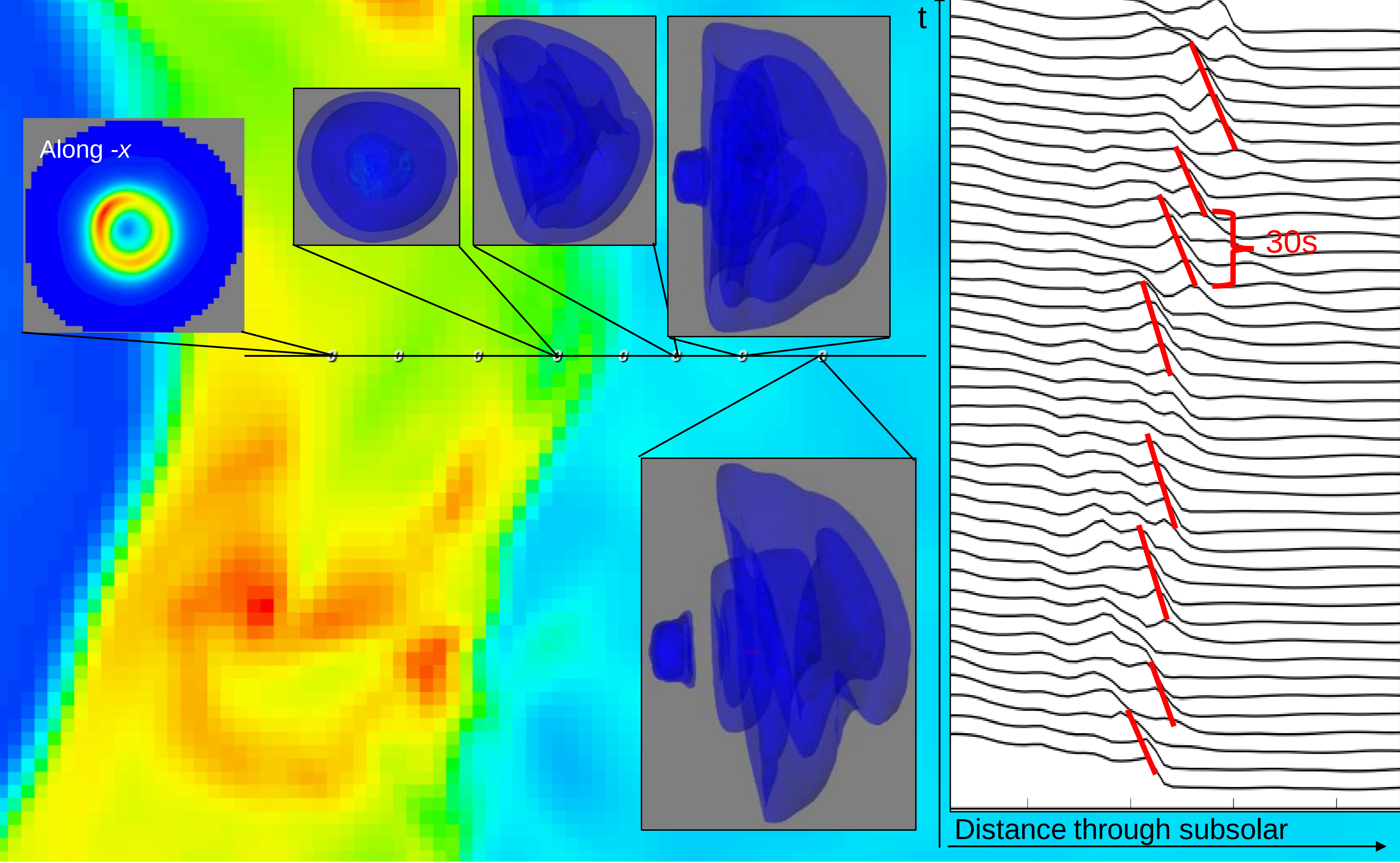
- Time series of 48 foreshock virtual spacecraft
- Wavelengths 2.1 – 3.4$R_E$ parallel to ***k***
- Wave "size" perpendicular to ***k***: ~9-16$R_E$
    - In agreement with Archer et al., 2005



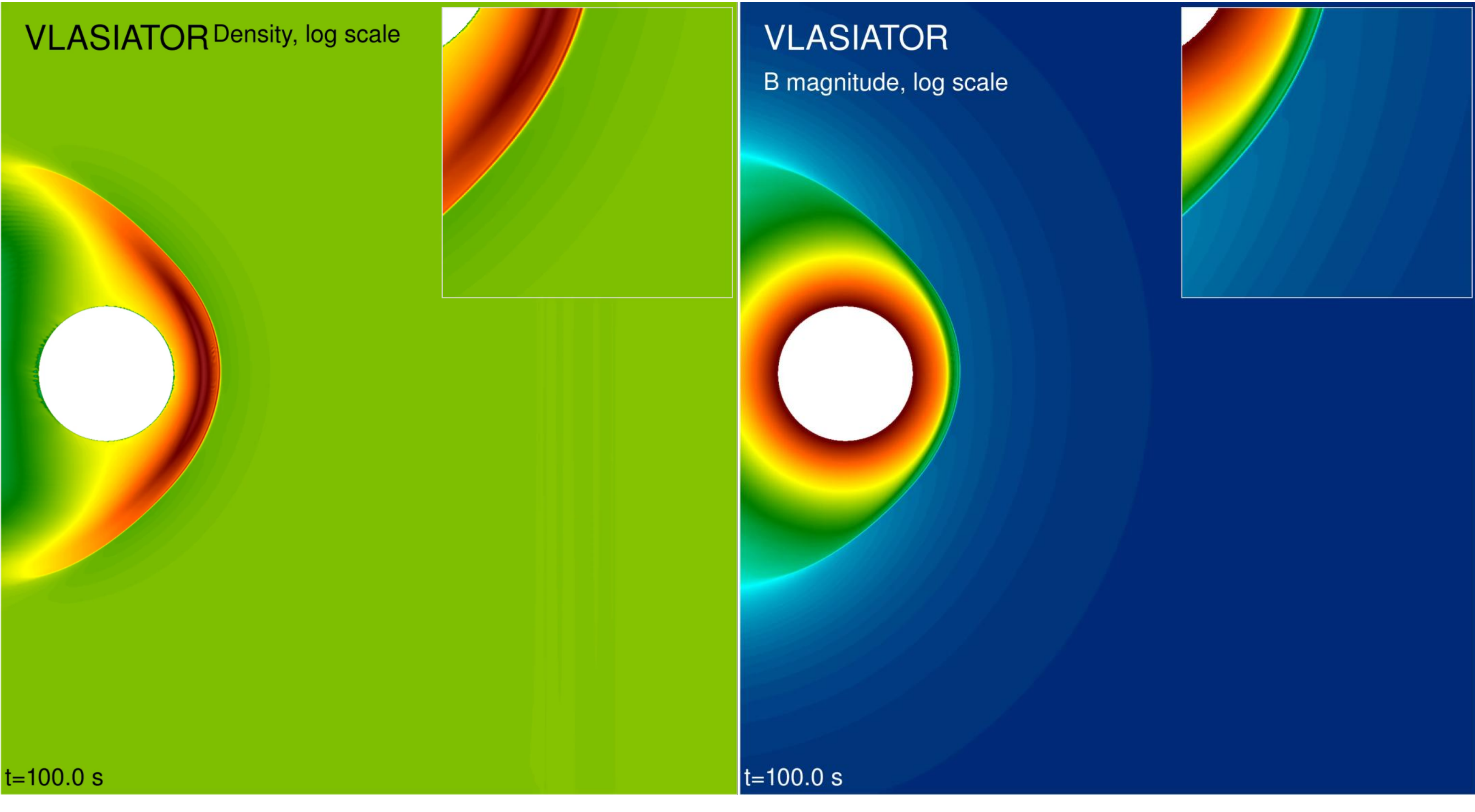



# Bow shock evolution



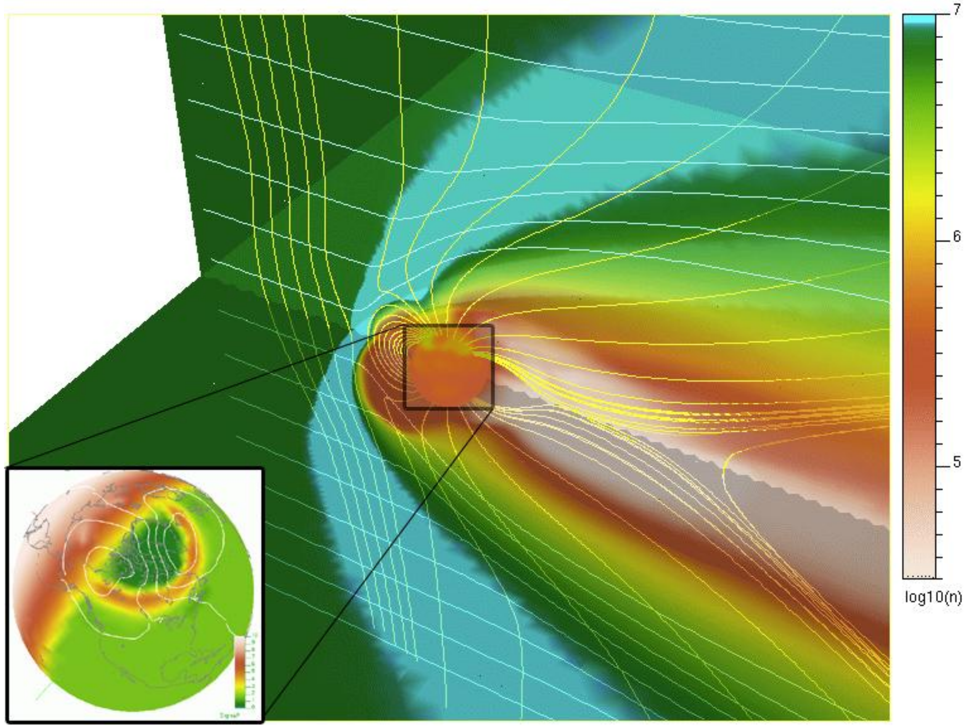
# New runs with CSC’s new sisu

Resolution 227km in ordinary space, Hall term added, 5D

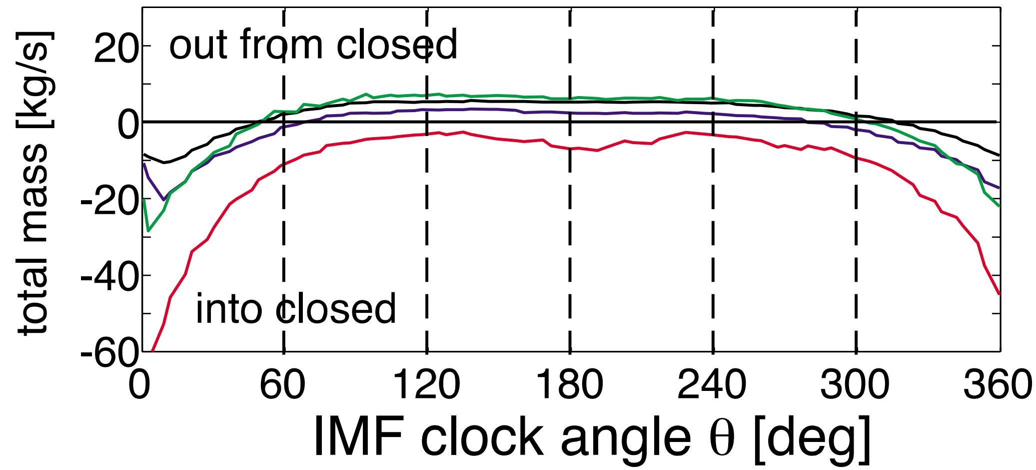


# Global MHD: Magnetopause mass transfer

**Palmroth et al., 2006 *Ann. Geophys.***




| | Small p | High p |
|---|---|---|
| Small IMF | \|IMF\| = 5 nT<br>Pdyn = 2 nPa | \|IMF\| = 5 nT<br>Pdyn = 8 nPa |
| High IMF | \|IMF\| = 10 nT<br>Pdyn = 2 nPa | \|IMF\| = 10 nT<br>Pdyn = 8 nPa |



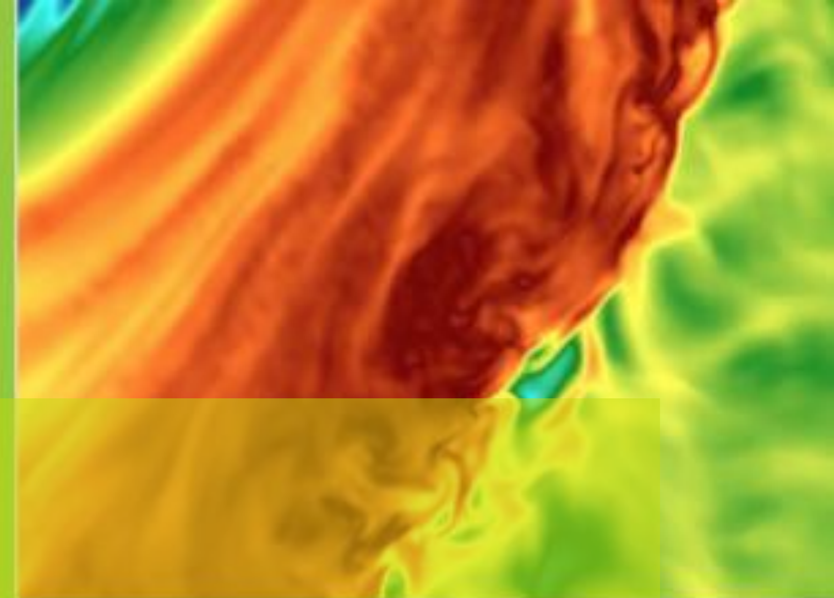

FMI's GUMICS-4 simulation

- Ideal conservative MHD
- Adaptive (cell-by-cell) Cart. Grid
- Spherical electrostatic ionosphere

Mass transfer to dayside closed field

- Identify surface formed by last closed field line
- Take mass perpendicular to surface
- Integrate net mass into and out from closed

# Conclusions



Vlasiator: New global hybrid-Vlasov simulation

- Kinetic physics in a global setup

5-D run with realistic dipole

- Quasi-parallel foreshock develops
- Foreshock exhibits 30-second oblique ULF waves
    - in quantitative agreement with observations

Vlasiator shows that foreshock oblique waves are observed both for 45° IMF and for radial IMF, and bend in many directions

Bow shock exhibits a 30-s oscillation in the radial run

http://vlasiator.fmi.fi

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