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Magnetospheric Response to a Pressure Pulse in a Three-dimensional Hybrid-Vlasov Simulation

Konstantinos Horaites
and the Vlasiator Team, presented by
Yann Pfau-Kempf
University of Helsinki

Vlasiator Simulations

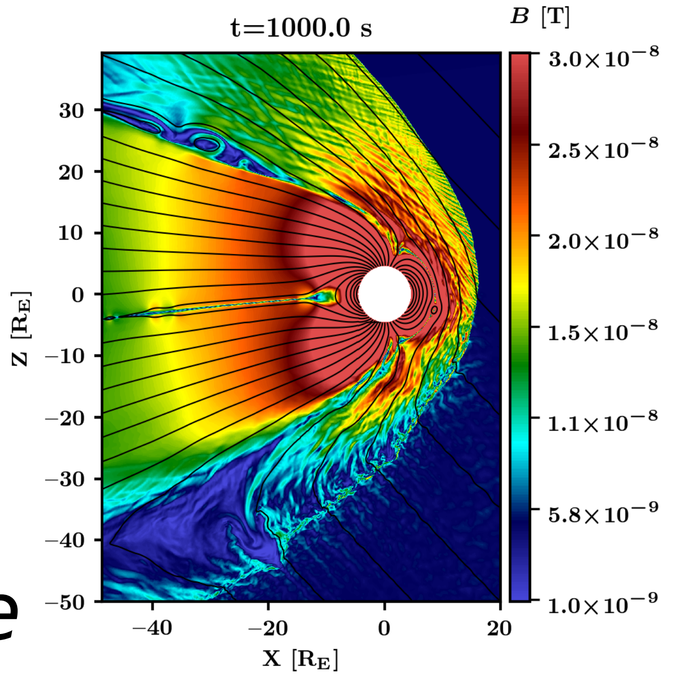
- hybrid-Vlasov (kinetic p+, fluid e-)
- 3D box (side length ~100 R_E)
- Inner boundary: r=4.7 R_E
- Adaptive mesh

For details:

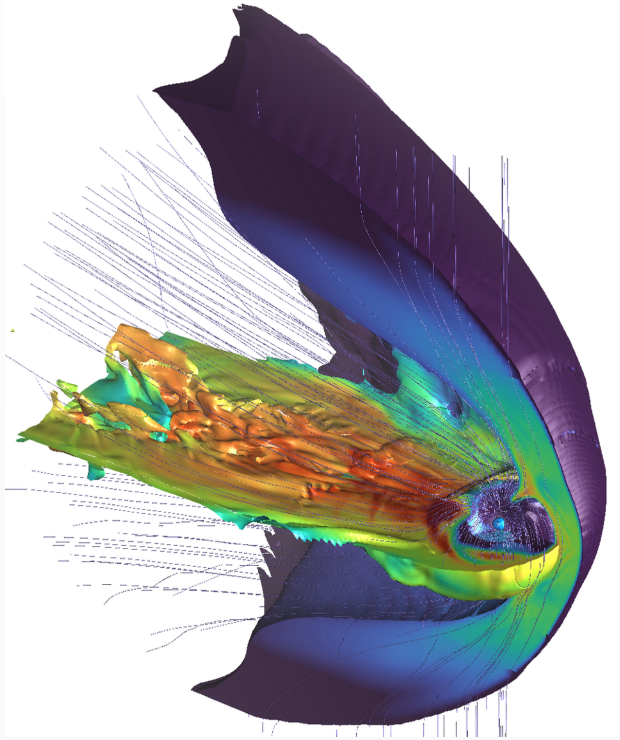
M. Palmroth et al., 2018

“Vlasov methods in space physics and astrophysics”

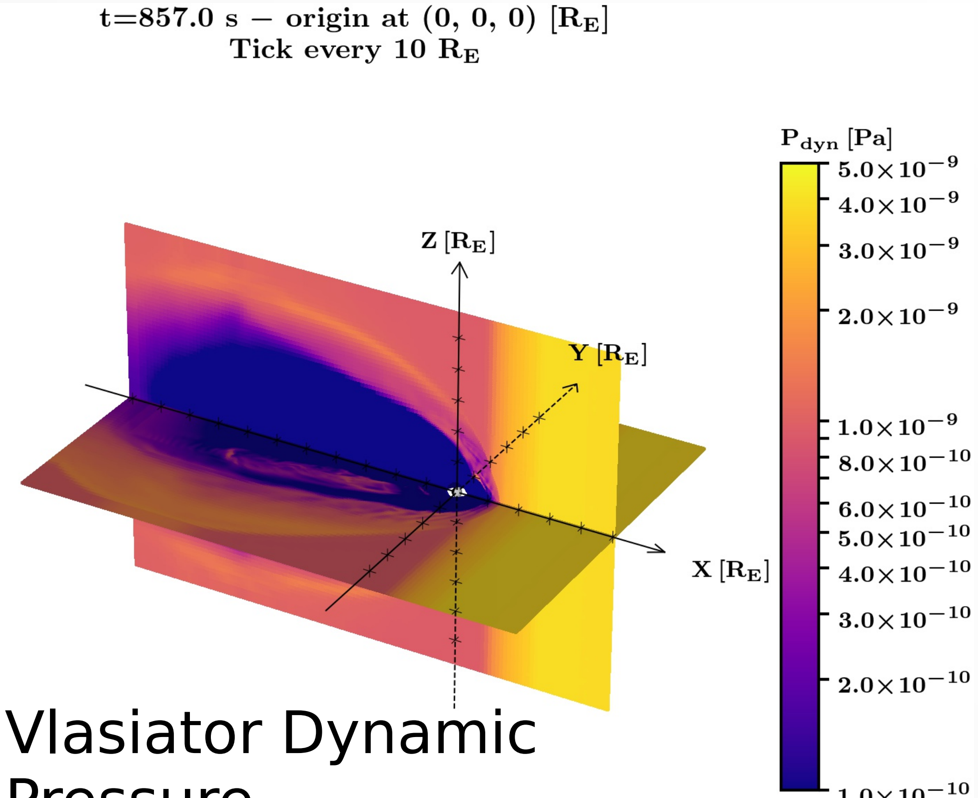
2D3V



3D3V



Pressure Pulse



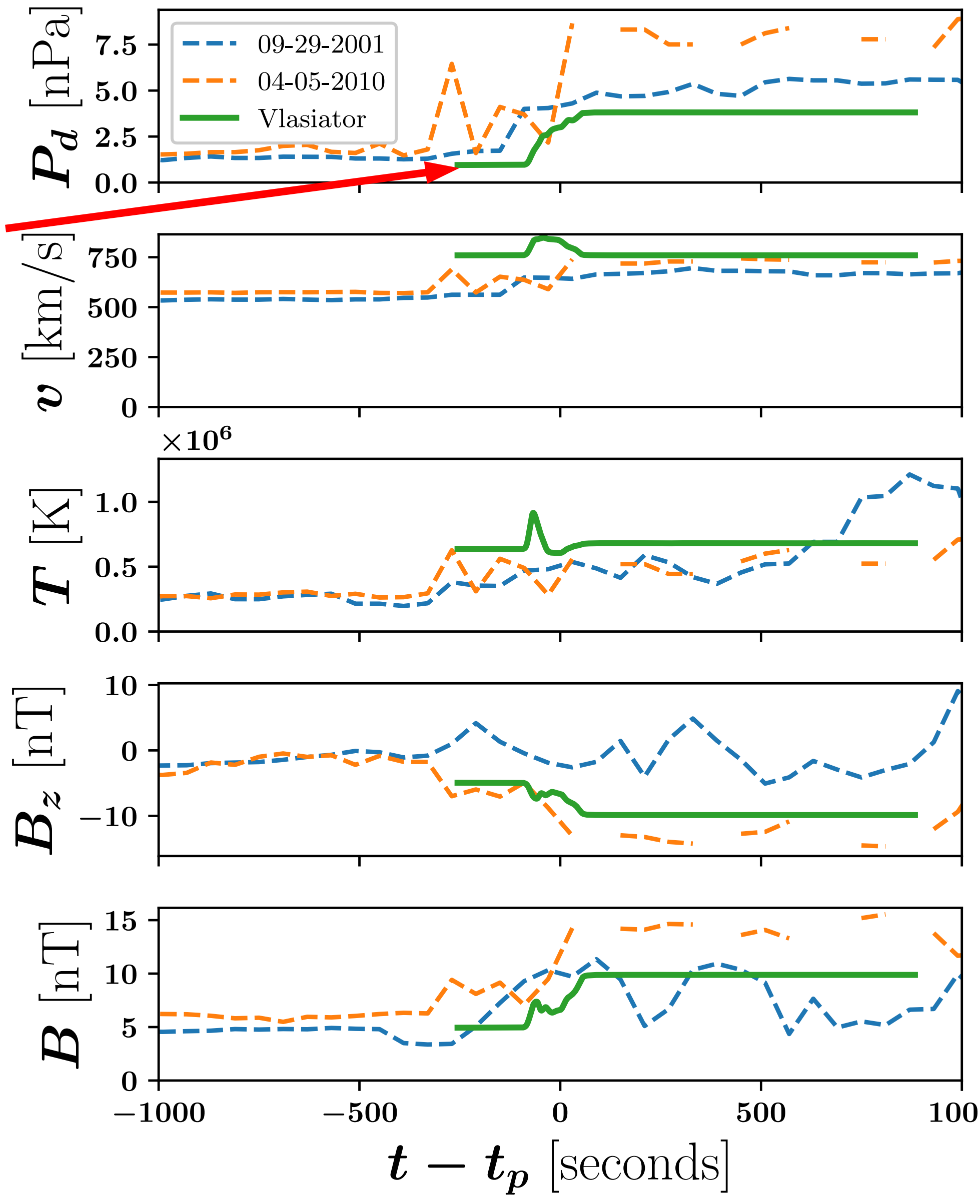
Vlasiator Dynamic Pressure

Pressure is **step function** at boundary, but **smooths out** in transit to Earth.

Not a shock (v_{sw}=constant, M_A=constant)

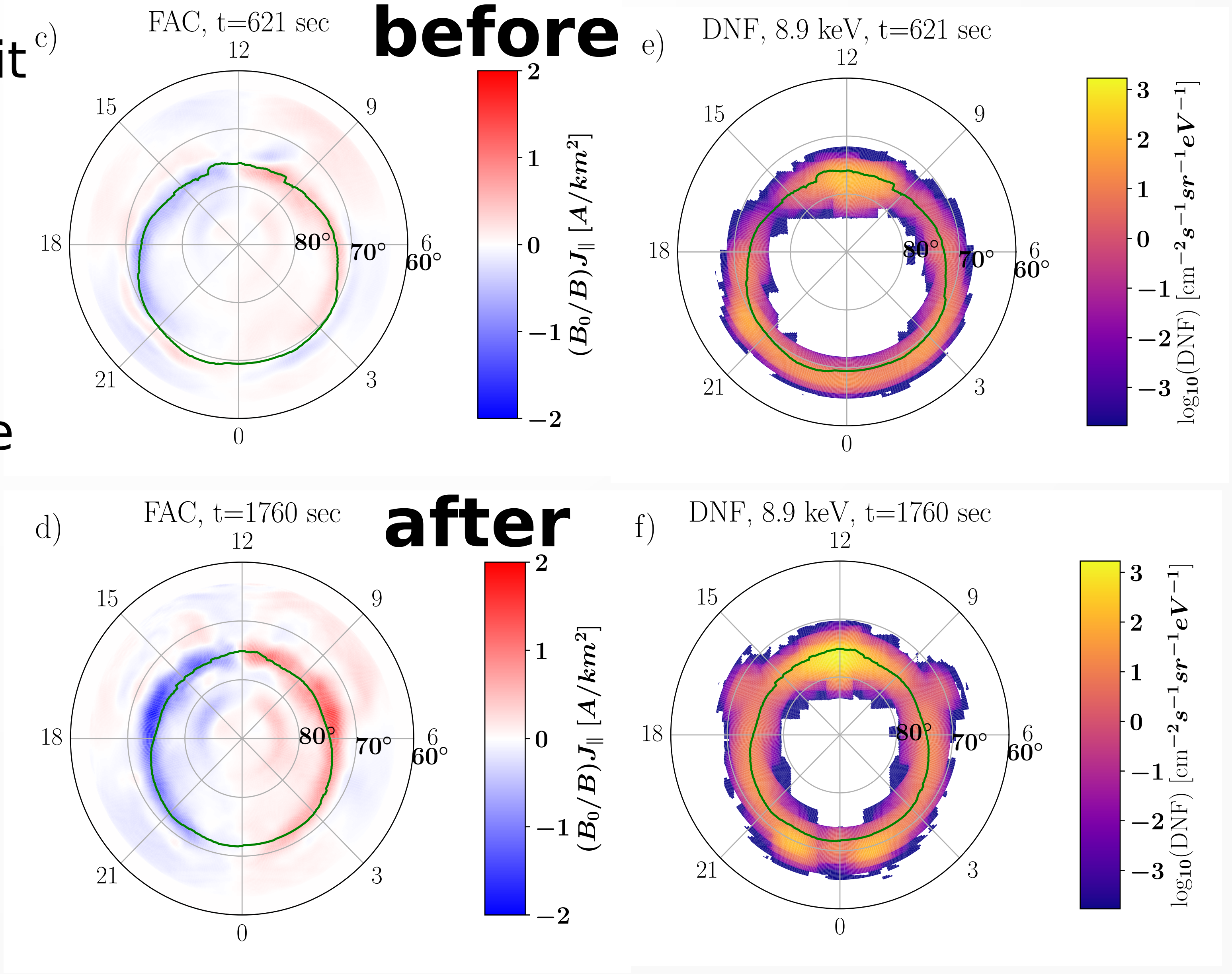
Driving	B [nT]	v_{sw} [km/s]	n [cm^{-3}]
Initial	[0, 0, -5]	750	1
Pulse	[0, 0, -10]	750	4

Virtual spacecraft near bow shock, compared with OMNI pulse events.



FACs and precipitation

- Vlasiator simulations exhibit **field-aligned currents (FACs)** and **proton precipitation** at proton aurora energies (~10 keV).
- Both signatures are enhanced minutes after the pressure pulse arrival, and are comparable to observations.
- Region 2 FACs not seen in this run because of simplified ionosphere boundary conditions.



Magnetopause Identification

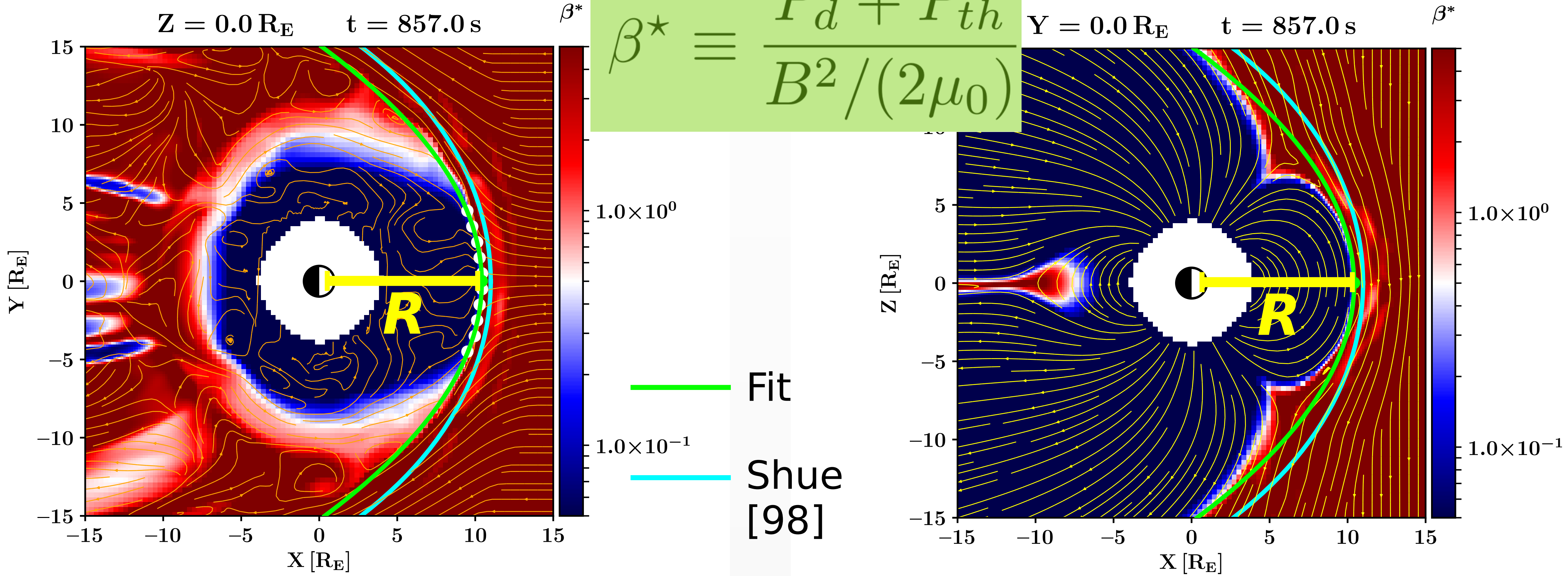
- Magnetopause is identified as an **isocontour** of the ***β**** parameter (A. Brenner et al. 2021).
- Subsolar magnetopause standoff distance ***R*** is found by fitting a parabola to the ***β*=0.5*** **isocontour**.

P_d: dynamic pressure

P_{th}: thermal pressure

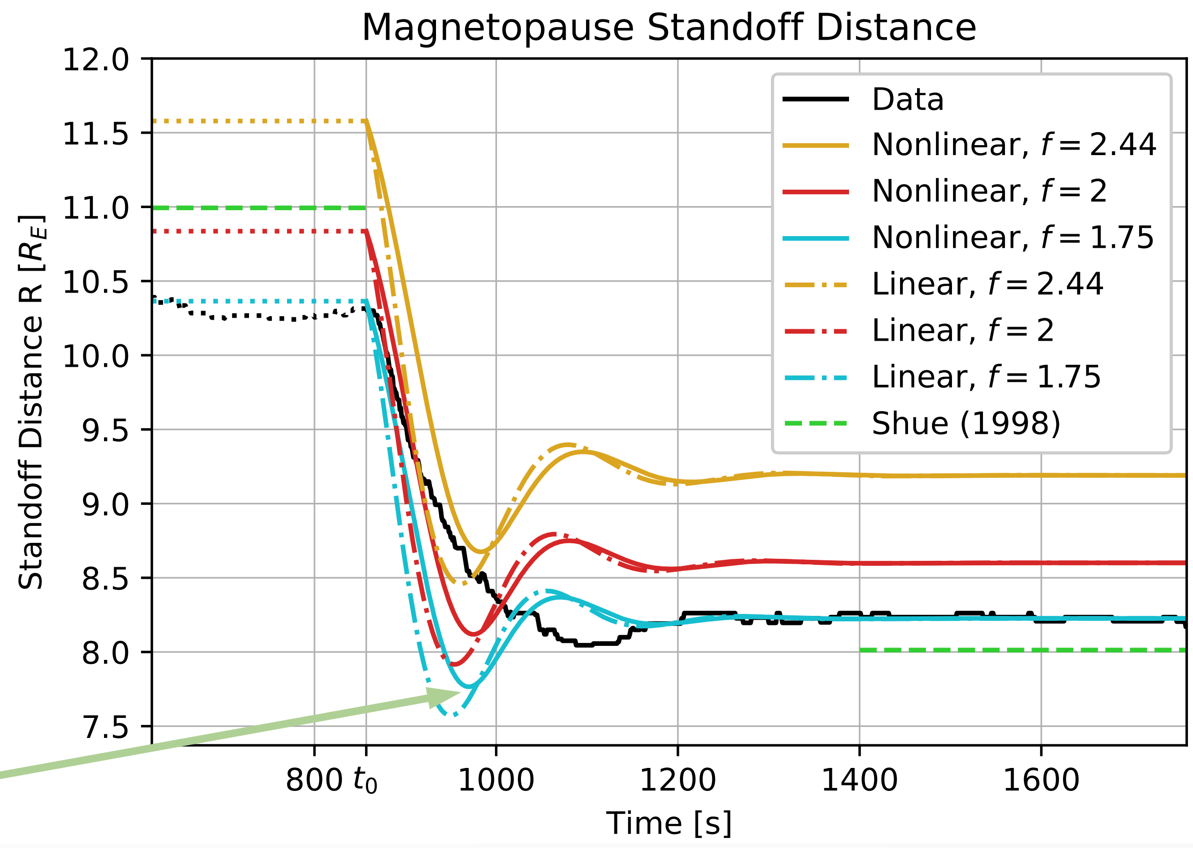
B: Magnetic field

$$\beta^\star \equiv \frac{P_d + P_{th}}{B^2/(2\mu_0)}$$

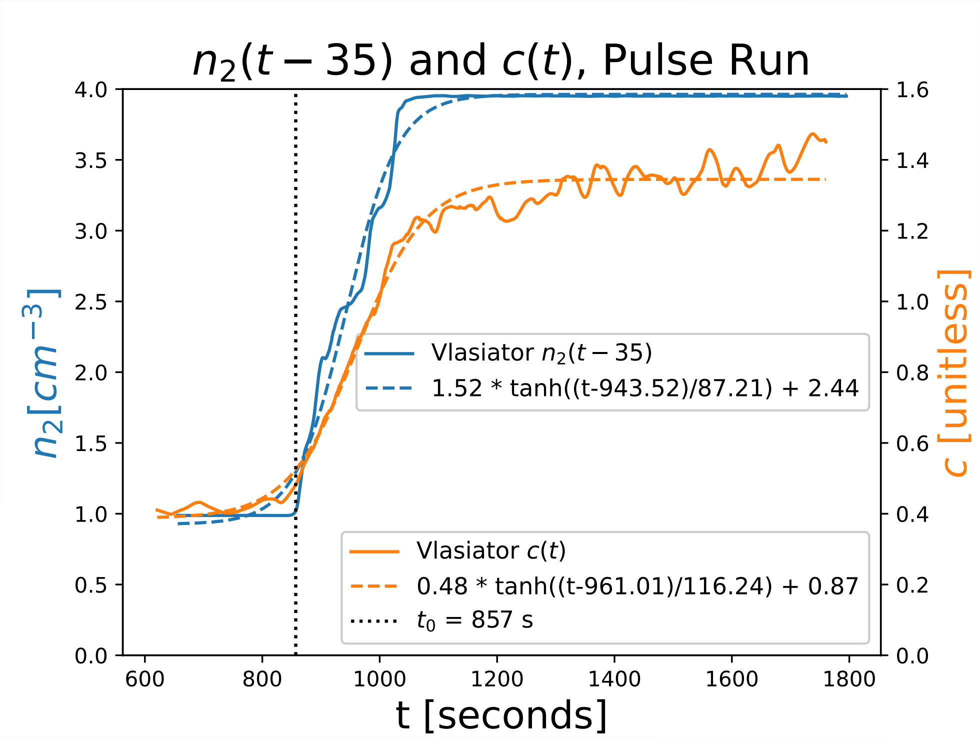


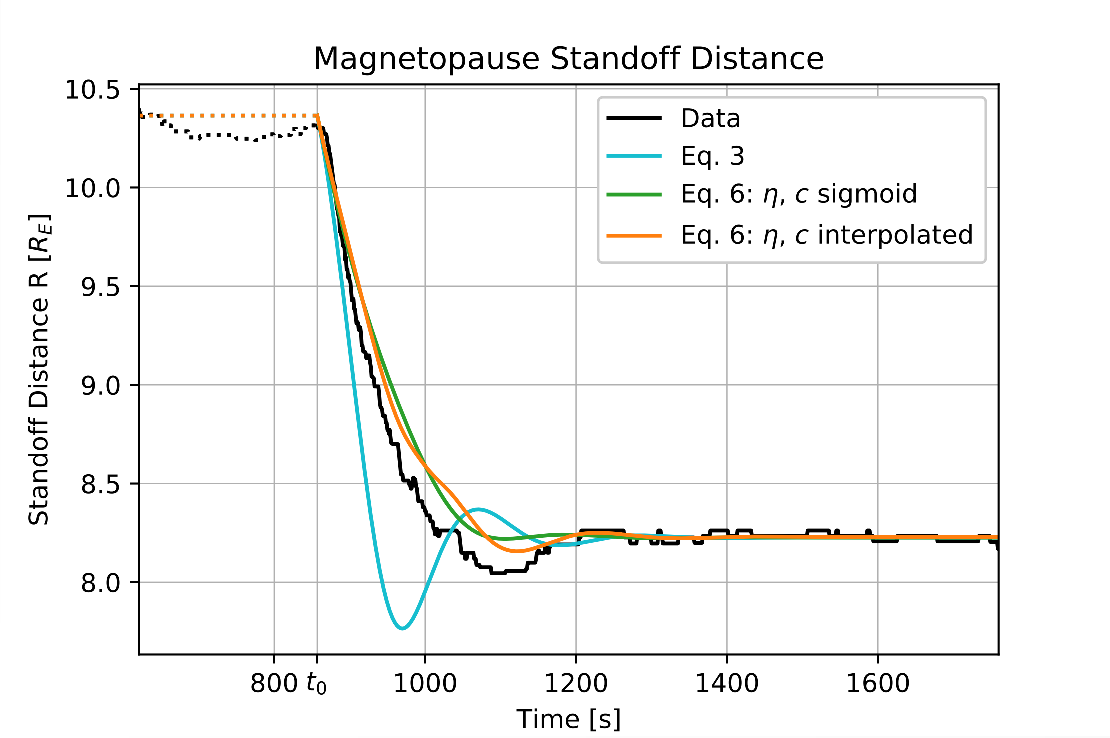
Magnetopause Oscillations

- The subsolar magnetopause standoff distance ***R*** is modeled following ***Freeman et al., 1998.***
- ***R(t)*** oscillates around an equilibrium set by incoming SW dynamic pressure and magnetic pressure.
- Dipole compression factor *f*=1.75 gives the best match to pre- and post-pulse equilibria.
- Both nonlinear and linearized solutions *R(t)* reaches the global minimum value **too early**.



$$\frac{d^2R}{dt^2} + \frac{1}{cR_F}\left\{\left(v_F + \frac{dR}{dt}\right)^2 - v_F^2\left(\frac{R_F}{R(t)}\right)^6\right\} = 0$$

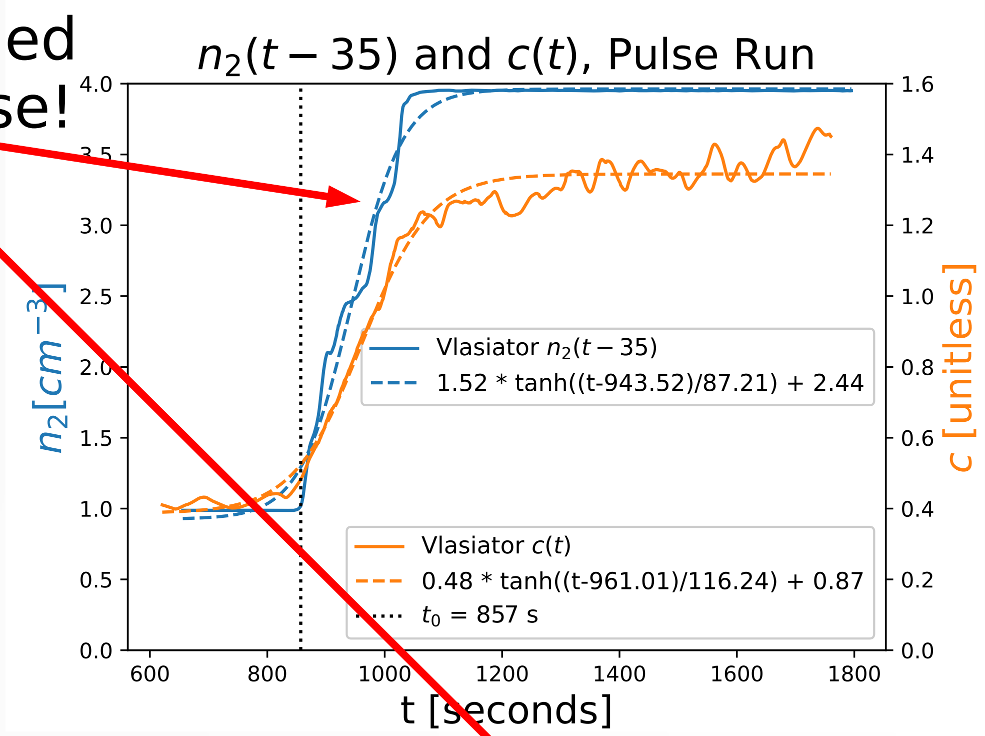


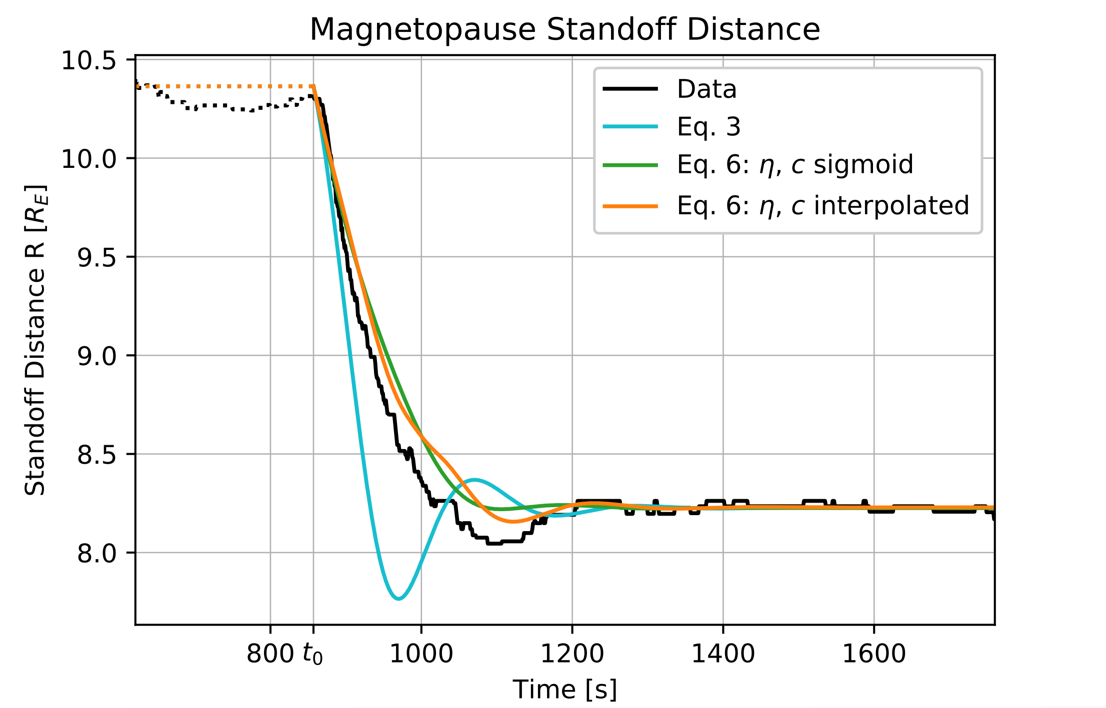


$$\frac{d^2R}{dt^2} + \frac{1}{c(t)R_F}\left\{\eta(t)\left(v_F + \frac{dR}{dt}\right)^2 - v_F^2\left(\frac{R_F}{R(t)}\right)^6\right\} = 0$$

- **GENERALIZE** Freeman et al. (1998): allow time-dependent mass loading ***c(t)*** and solar wind density ***η(t)***, evaluated directly from Pulse run.

Smoothed out pulse!





$$\frac{d^2R}{dt^2} + \frac{1}{c(t)R_F}\left\{\eta(t)\left(v_F+\frac{dR}{dt}\right)^2 - v_F^2\left(\frac{R_F}{R(t)}\right)^6\right\} = 0$$

- Smoothed out pulse leads magnetopause standoff ***R(t)*** to decrease more slowly.

Validation: Time-dependence

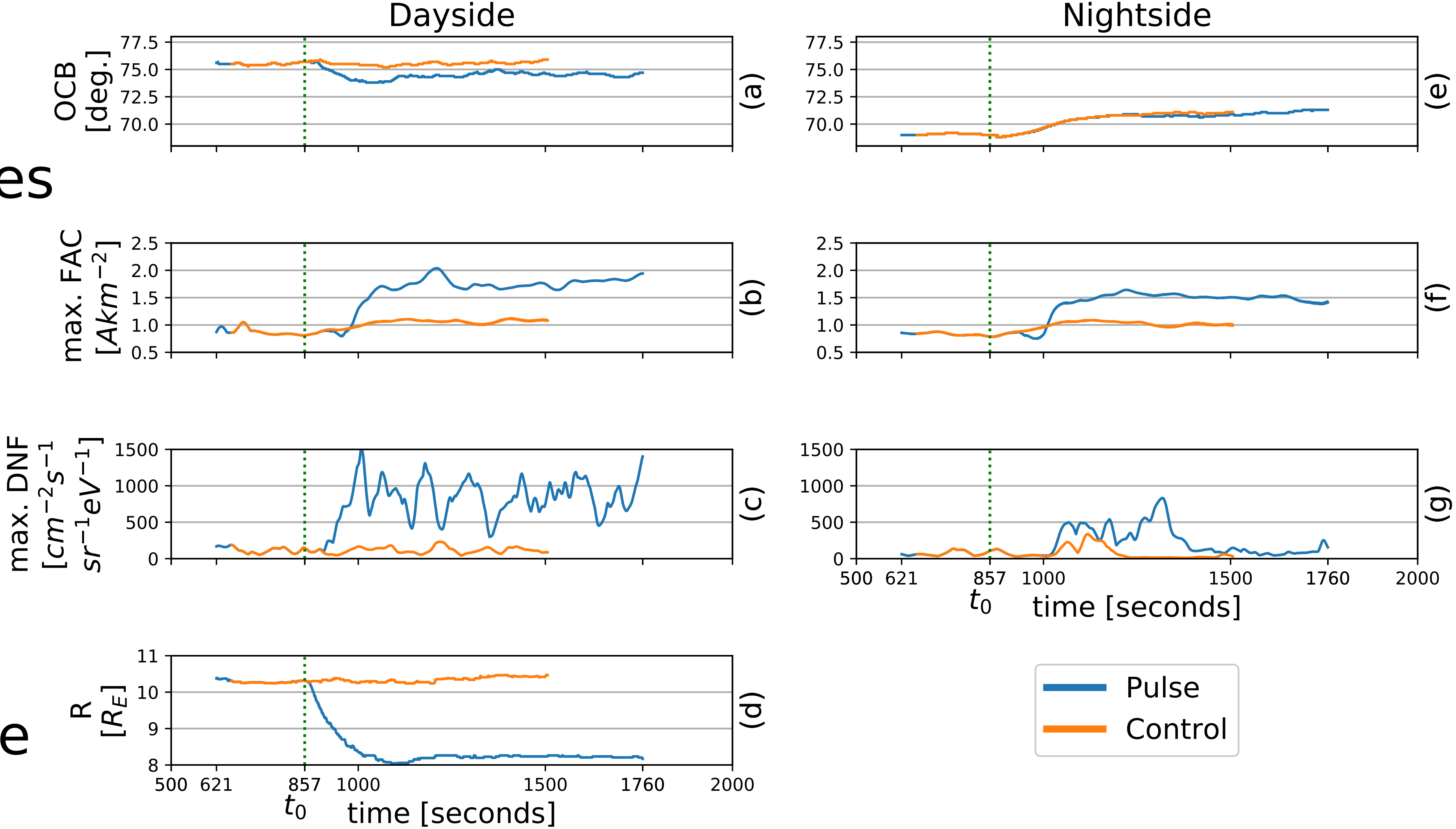
Comparison between the “Pulse” and “Control” runs allows us to isolate effects due to pressure pulse.

Only dayside OCB moves

FAC x2

10 keV **DNF x8**

Magnetopause compression (see previous slides)



- **Vlasiator's 3D hybrid-kinetic model** of the global magnetosphere **produces expected behavior** for a pressure pulse arriving at Earth.
- The **finite transition time** of the pressure pulse causes **magnetopause oscillations to be weak and elongated** relative to established models.
- The **magnetopause oscillations are explained with a generalized model** that accounts for the finite transition time of the pressure pulse.

Horaites et al. (JGR, under review)

Email: konstantinos.horaites@helsinki.fi

www.physics.helsinki.fi/vlasiator

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