Estimating radial diffusion using a hybrid-Vlasov simulation

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Radial diffusion is a radiation belt transport process.

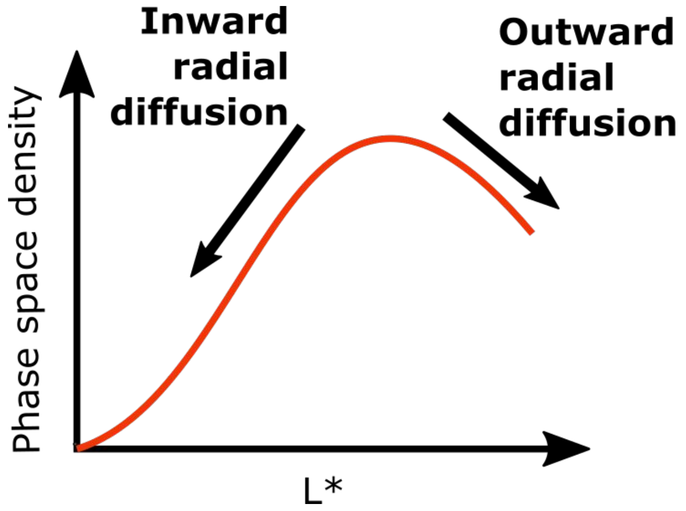
Non-adiabatic transport from violation of L^*.

$L*$ is equivalent to third adiabatic invariant and corresponds to drift motion.

$$L^* = \frac{2\pi B_E R_E^2}{|\phi|}$$

Driven by ULF wave activity.

D_{LL} quantifies effect of radial diffusion.



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Theoretical formalisms for radial diffusion.

Fälthammar (1965)		Fei (2006)	
Electromagnetic (D_{LL}^M)	**Electrostatic (D_{LL}^E)**	**Magnetic (D_{LL}^b)**	**Electric (D_{LL}^e)**
dB/dt ↕ Induced E	Convective E E from charge separation	dB/dt	Induced E Convective E E from charge separation
$D_{LL} = D_{LL}^M + D_{LL}^E$		$D_{LL} = D_{LL}^b + D_{LL}^e$	

↔ = coupling from Faraday's Law

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New theoretical approach to evaluate transport in *L**.

Evaluate directly from driving wave activity with Hamiltonian formalism.

Gives instantaneous, MLT-dependent $L*$ time derivative.

Objective: develop methodology to implement this approach.

$$\frac{dL^*}{dt} = \frac{\mu \tau_D}{q\gamma} \frac{L^{*2}}{2\pi B_E R_E^2} \left(\left\langle \frac{dB}{dt} \right\rangle_\varphi - \frac{dB}{dt} \right)$$

Eq. A.40. Lejosne & Kollmann, 2020

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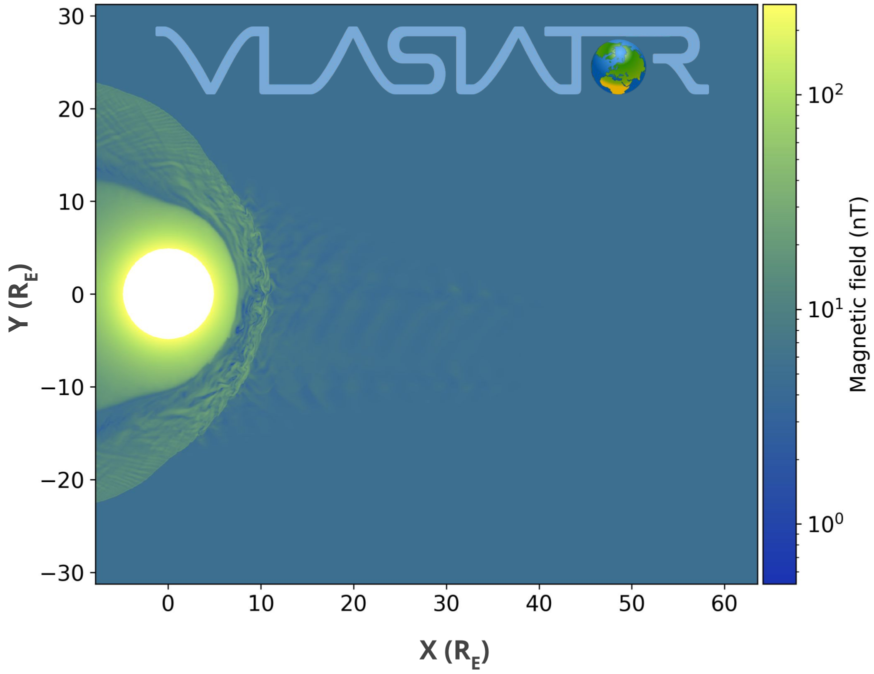
Vlasiator simulation used for methodology development.

Vlasiator is a hybrid-Vlasov simulation of near-Earth space.

Equatorial 2D simulation with steady solar wind and duration of 335 s.

Methodology directly applicable to other simulations.



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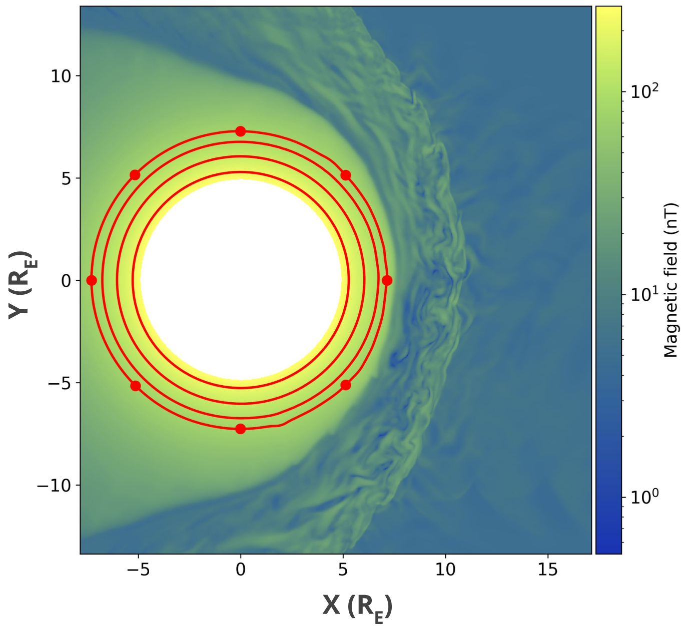
Methodology to calculate *dL*/dt* from global EM data:

1. Determine initial L^*.
2. Calculate local wave activity (dB/dt) along drift path.
3. Find drift-averaged wave activity, $\langle dB/dt \rangle$
4. Compute μ, τ_D and γ from particle energy.
5. Calculate dL^*/dt.

$$\frac{dL^*}{dt} = \frac{\mu\tau_D}{q\gamma}\frac{L^{*2}}{2\pi B_E R_E^2}\left(\left\langle\frac{dB}{dt}\right\rangle_\varphi - \frac{dB}{dt}\right)$$



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Key application: Calculating D_{LL}

New technique to calculate D_{LL} from simulations.

$$D_{LL} = \frac{1}{2}\frac{\Delta L^{*2}}{\Delta t} \approx \frac{1}{2\Delta t}\left\langle \left(\frac{dL^*}{dt}\Delta t\right)^2 \right\rangle$$

Initial L^*	**D_{LL} (day^{-1})**
5.21	1.25×10^{-6}
5.97	2.01×10^{-6}
6.67	1.01×10^{-5}
7.18	5.68×10^{-5}

Enables evaluation of radial diffusion beyond quasilinear theory.

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New method now available to evaluate radial diffusion.

Estimating Inner Magnetospheric Radial Diffusion Using a Hybrid-Vlasov Simulation

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