Quantifying the electron scattering by electrostatic fluctuations in the Earth’s bow shock

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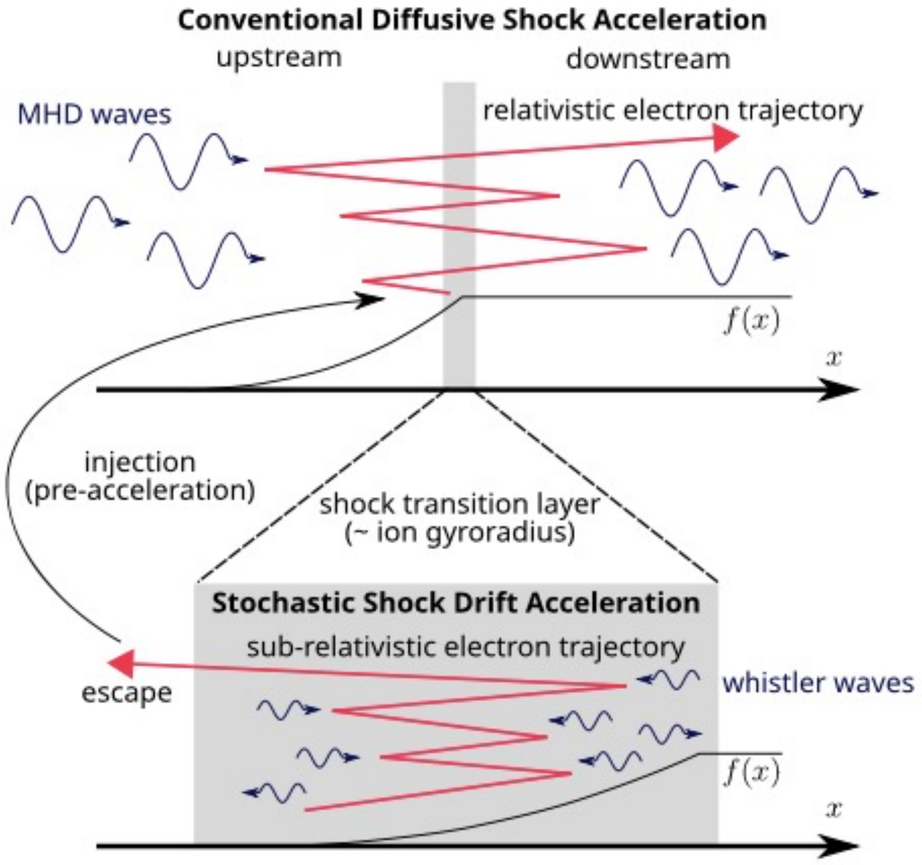
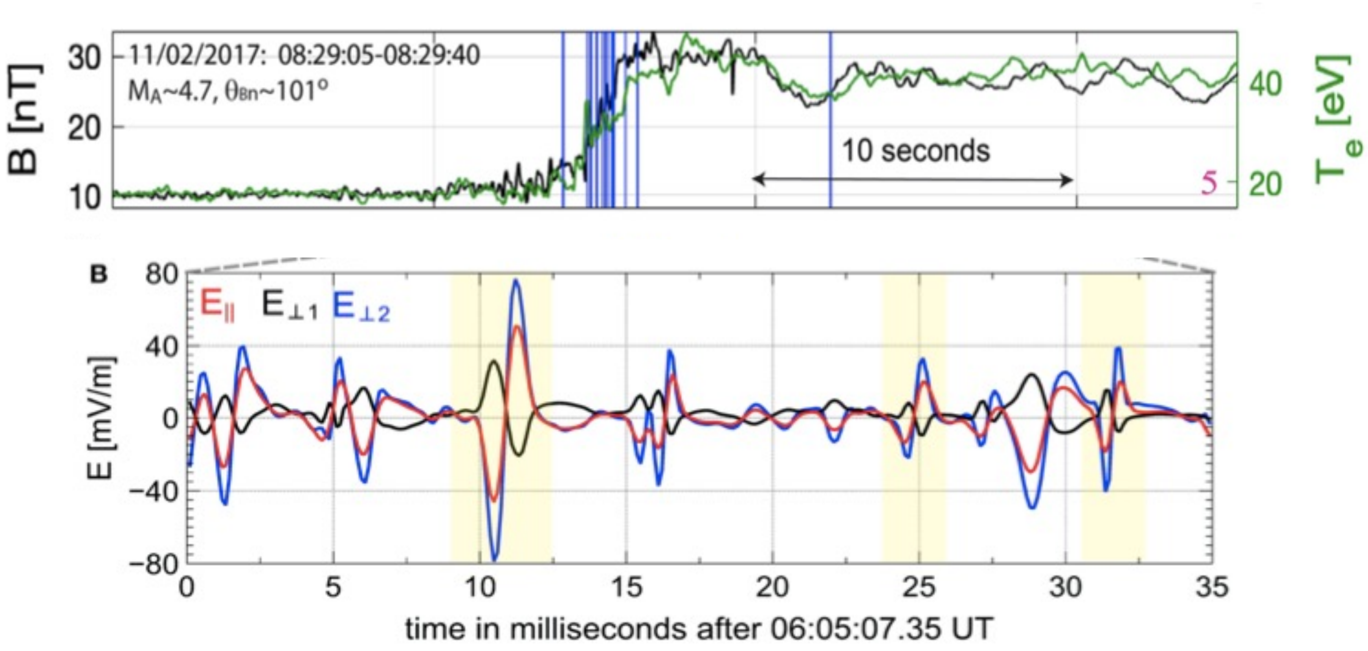
T. Amano et al. 2020



I.Y. Vasko et al. 2020



Electrostatic component of the Bow-shock turbuelnce is dominated by ion-holes (IHs).

Stochastic Shock Drift Acceleration(SSDA) – needs wave turbulence

For what energies can IHs maitain SSDA?

Turbulence of whistlers is sufficient for W > 1 keV

Estimations along unperturbed orbits

Electron equations of motion

$$\dot{p}_{||} = \partial_z \Phi \quad \dot{\boldsymbol{p}}_{\perp} = \nabla_{\perp}\Phi - \omega_{ce}\,(\boldsymbol{p}_{\perp} \times \boldsymbol{z}),$$

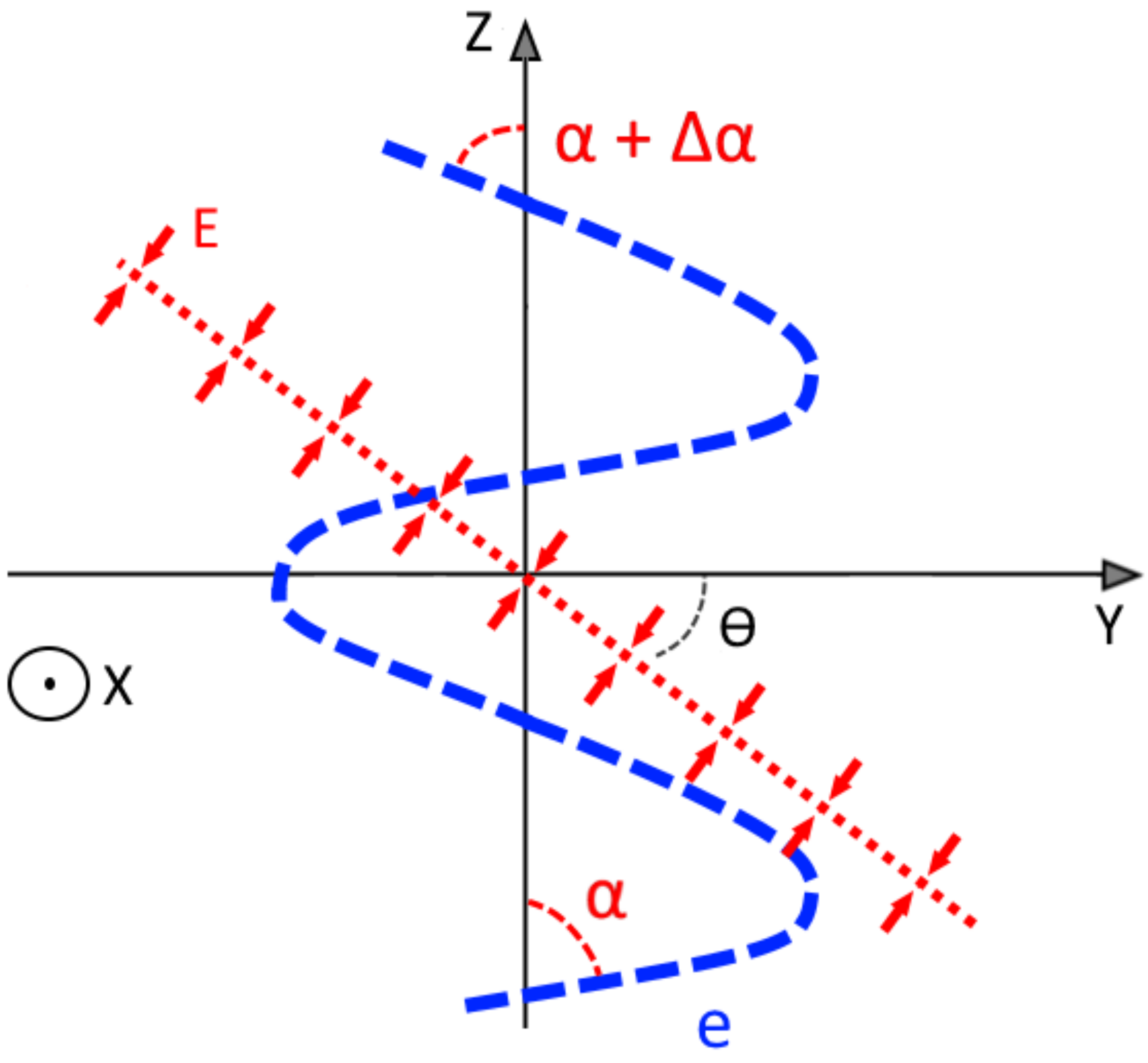
$$\Phi = \Phi_0 exp\left[-(zcos\theta + ysin\theta - V_s t)^2/2l^2\right]$$

Integrate it over unperturbed trajectories

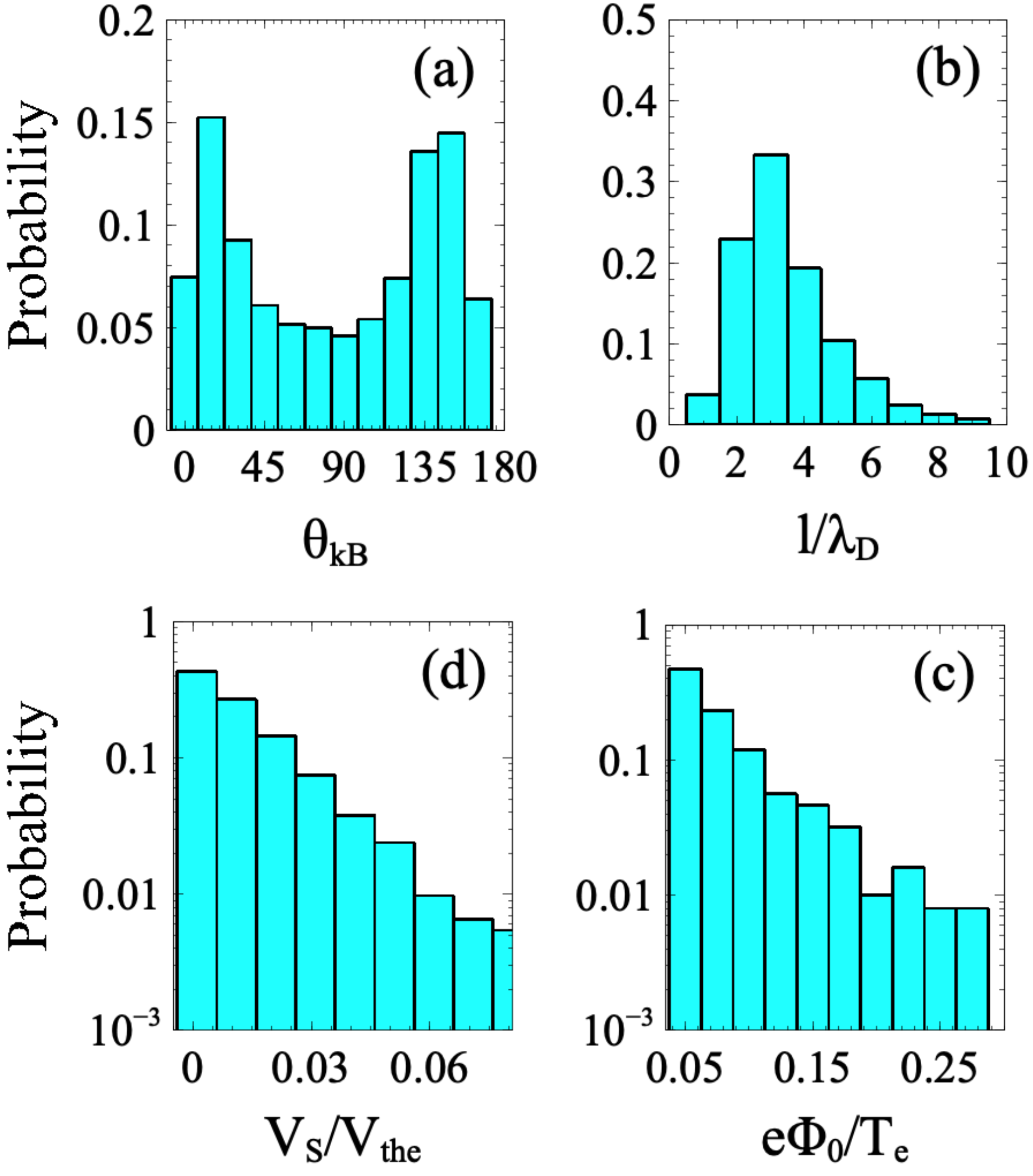
$$z = z_0 + V_{||}t,$$
$$y = y_0 + \rho_L \cos(\omega_{ce}t - \varphi),$$
$$x = x_0 - \rho_L \sin(\omega_{ce}t - \varphi)$$

Assuming uniformly distributed phases $0 < \phi < 2\pi$

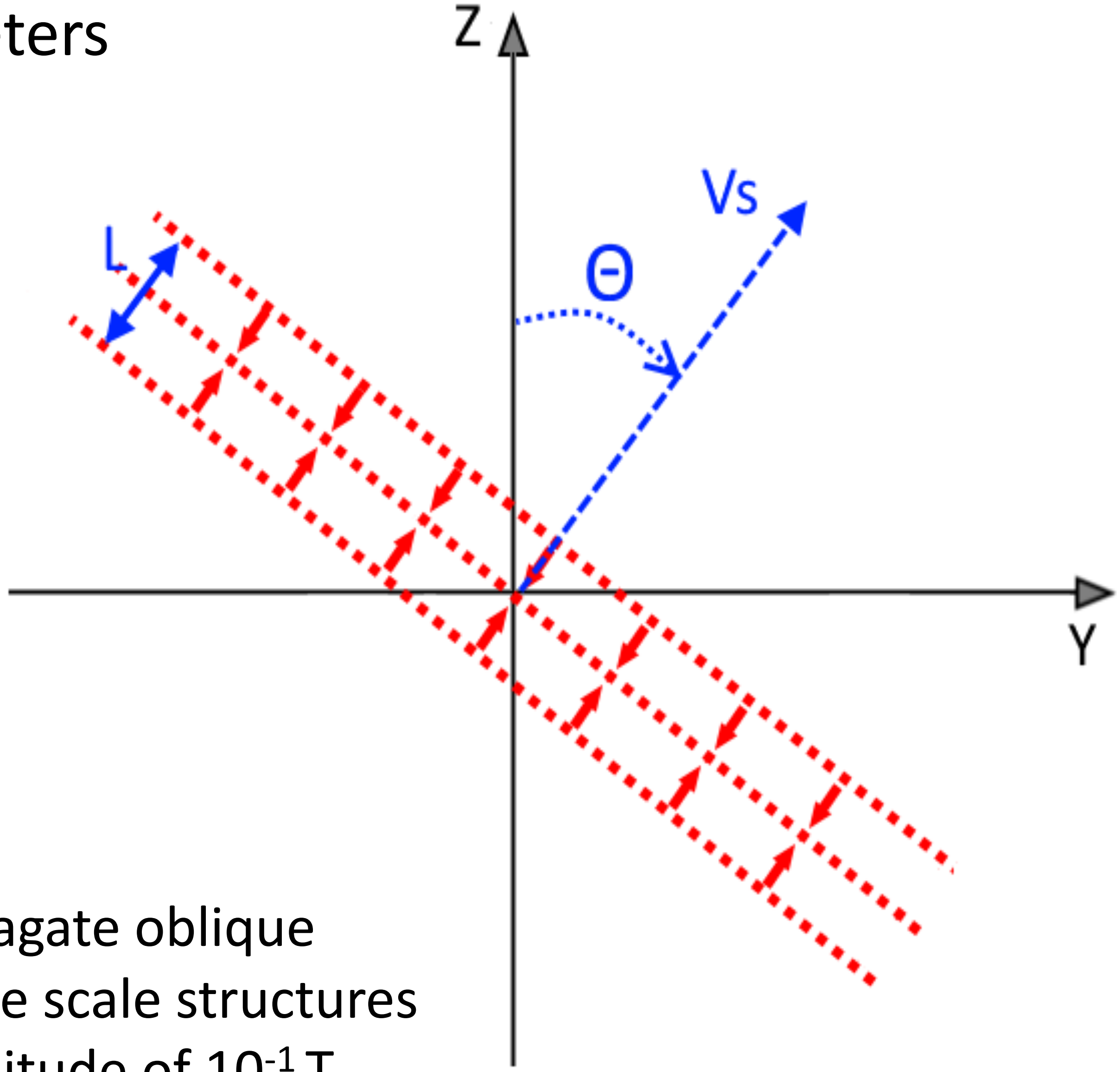
$$\langle\Delta\alpha^2\rangle_\varphi = \frac{4\pi\Phi_0^2}{W^2\sin^2(2\alpha)}\frac{\omega_{ce}^2\, l^2\,(V_s\cos^2\alpha - V_{||}\cos\theta)^2}{(V_s - V_{||}\cos\theta)^4}\times$$
$$\times\sum_{n=1}^{\infty} n^2 J_n^2\left(\frac{nV_\perp\sin\theta}{V_s - V_{||}\cos\theta}\right)\exp\left[-\frac{n^2\omega_{ce}^2\, l^2}{(V_s - V_{||}\cos\theta)^2}\right]$$



Statistical distribution of ion hole parameters



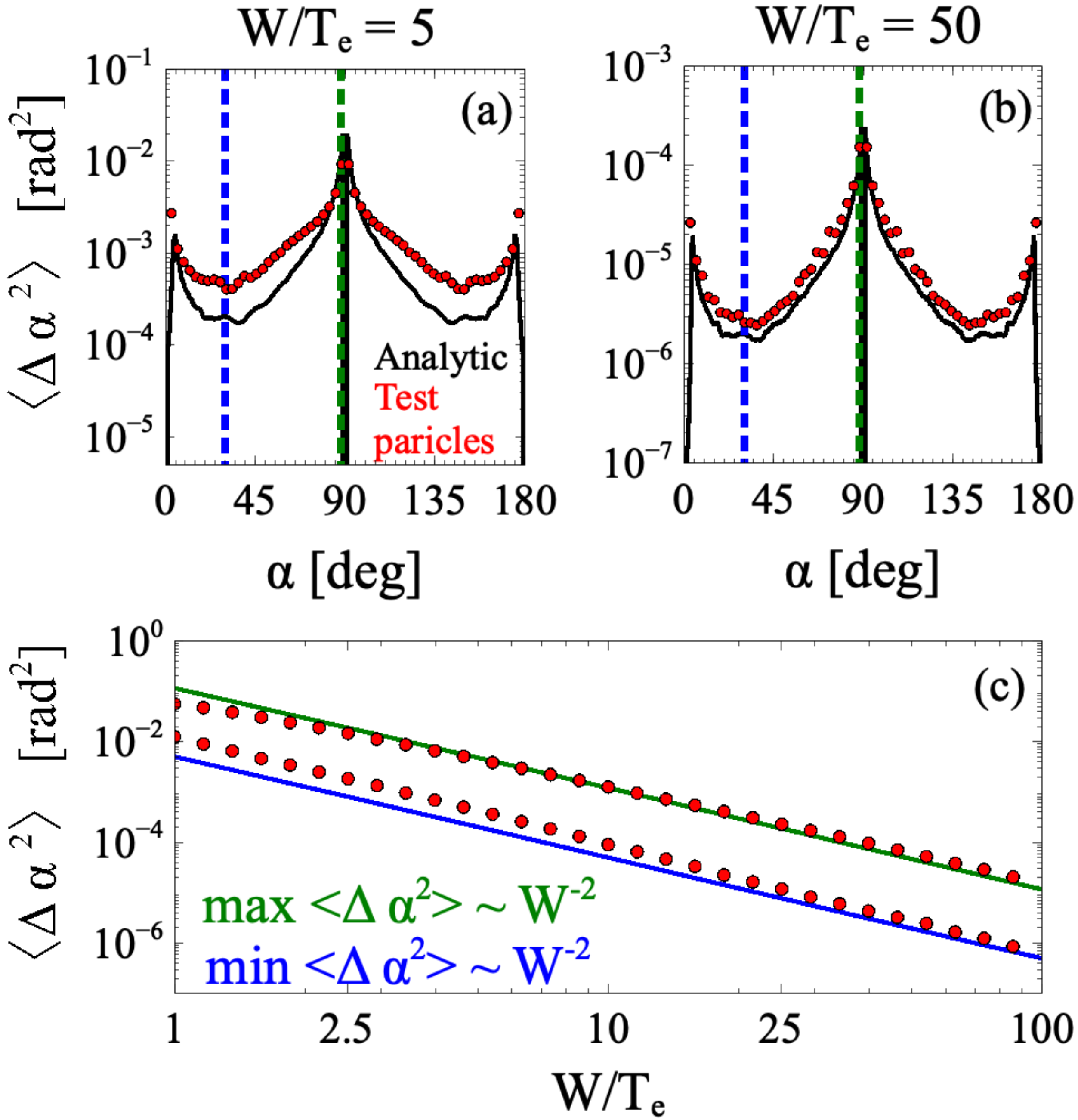
Wang, R., et al. 2021



Results

- Propagate oblique
- Debye scale structures
- Amplitude of 10^{-1} T_e
- Speed is small – we will neglect it

Where unperturbed orbits are valid ?



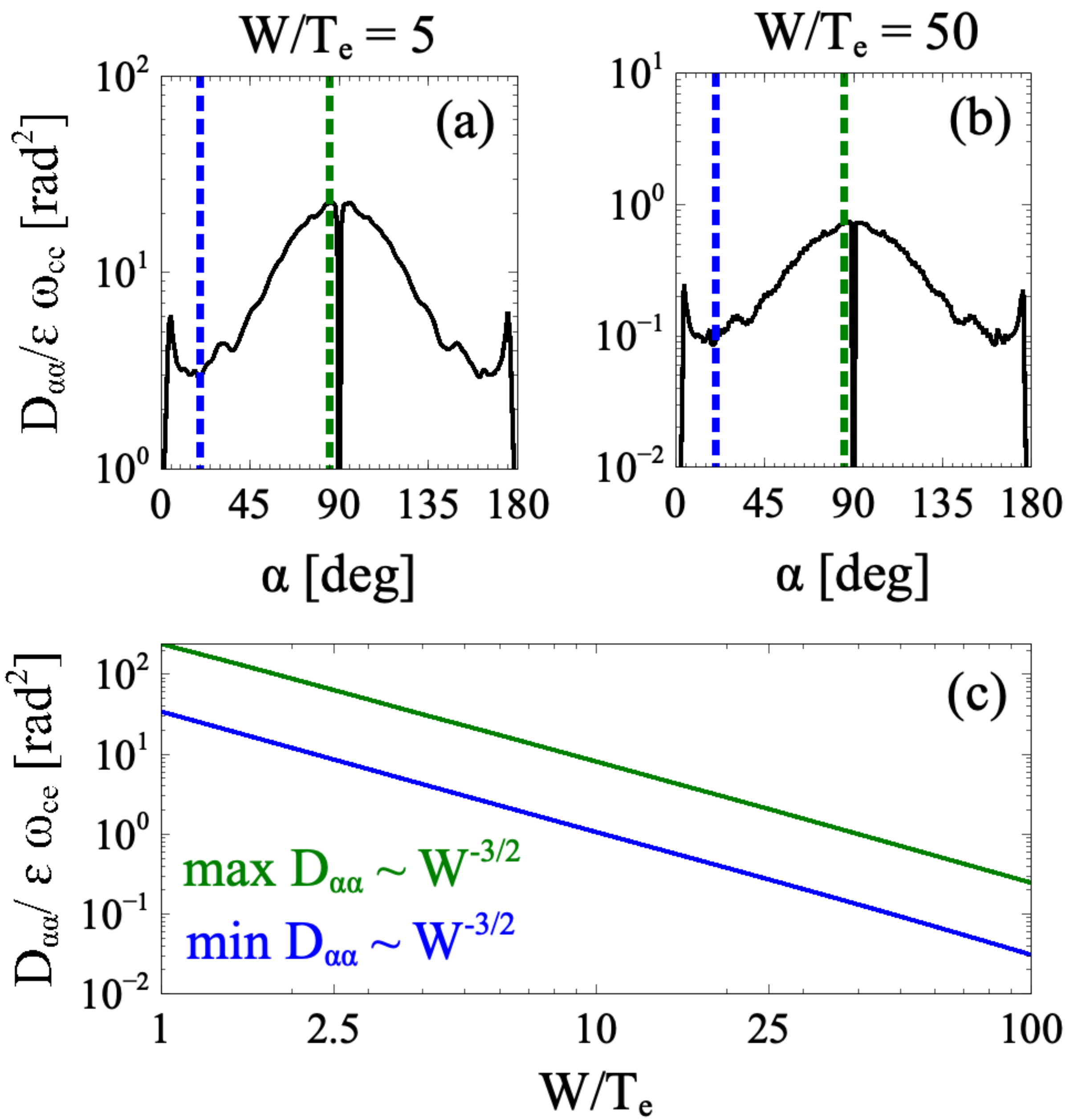
$$< (\Delta\alpha)^2 >= \int f(x) < (\Delta\alpha)^2 >^{(x)} dx$$

Can be taken from
- Analytic expression
- Test-particles

Integration variable is x = (L, ϕ, Θ), probability function f(x) is chosen according to the data-driven distribturions

Results
- Underestimates for W < 10 T_e
- Works well for W > 10 T_e
- Although generally yields a correct estimations on all energies

Quasi-linear Diffusion coefficient



Quasi-linear results

$$D_{\alpha\alpha} = \varepsilon\omega_{ce} \frac{l^3}{w^2 sin^2(\alpha)} \frac{\sqrt{\pi}}{2} \frac{\omega_{ce}}{\omega_{pe}} \frac{[v_s cos(\alpha) - \sqrt{w} cos(\theta)]^2}{[v_s - \sqrt{w} cos(\alpha) cos(\theta)]^3} \times$$

$$\times \sum_{n=1}^{n=+\infty} n^2 J_n^2 \left(\frac{n\sqrt{w} sin(\alpha) sin(\theta)}{v_s - \sqrt{w} cos(\alpha) cos(\theta)} \right) \times$$

$$\times exp\left(-\frac{\omega_{ce}^2}{2\omega_{pe}^2} \frac{n^2 l^2}{[v_s - \sqrt{w} cos(\alpha) cos(\theta)]^2} \right)$$

$$\varepsilon = \frac{E_w^2}{4\pi N_e T_e} \approx 10^{-3}$$

$$\frac{\omega_{ce}}{\omega_{pe}} \approx \frac{1}{100}$$

Dimensionless of turbulence intensity

Results

- Diffusion coefficient depends on two main parameters Turbulence Intensity, Freq. ratio
- $D_{\alpha\alpha}$ decreases with energy as $D_{\alpha\alpha} \propto W^{-3/2}$

Estimations of the maximum energy gain

Accoring to *Amano et al.* the maximum energy gain is given as follows

$$W_{max} \approx 6\eta \cdot \frac{m_e V_n^2}{2\cos^2\theta_{Bn}} \frac{D_{\mu\mu}}{\omega_{ci}},$$

V_n - the upstream plasma flow velocity
θ_{Bn} - the angle between the upstream magnetic field and shock normal

This equation should be resolved with respect to W_{max} , in our particular case

$$D_{\alpha\alpha} \approx K \cdot \varepsilon\omega_{ce} \cdot (W/T_e)^{-3/2},$$

where $K \approx 100$ and $\langle \varepsilon\omega_{ce} \rangle \approx 10^{-2}$

It yields the following estimation of the maximum energy gain provided by ion-holes turbulence

$$\frac{W_{\max}}{T_e} \approx \frac{2}{|\cos\theta_{Bn}|^{4/5}}, \quad W_{max} \approx 0.1 - 0.5 keV$$

Results

- Scattering by ion holes has been considered in the framework of the QLT.
- Test particle simulations were employed in order to verify the applicability of the QLT
- We provide quasi-linear diffusion coefficients averaged over the statistical ensemble of ion holes with data-driven parameters
- Effectiveness of pitch-angle scattering in application to SSDA mechanism is estimated