Sub-grid modelling of pitch-angle diffusion for ion-scale waves in hybrid-Vlasov simulations with Cartesian velocity space

Dubart, Maxime[1], Battarbee, M.[1], Ganse, U.[1], Spanier, F.[2], Osmane, A.[1], Suni, J.[1], Johlander, A.[1,3], Alho, M.[1], Bussov, M.[1], Cozzani, G.[1], George, H.[1], Grandin, M.[1], Horaites, K.[1], Papadakis, K.[1], Pfau-Kempf, Y.[1], Tarvus, V.[1], Turc, L.[1], Zaitsev, I.[1], Zhou, H.[1], and Palmroth, M.[1,4]

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[2] Center for Astronomy, Institue for Theoretical Astrophysics, Heidelberg University, Heidelberg, Germany
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EGU 2022, 26/05/2022, Vienna, Austria

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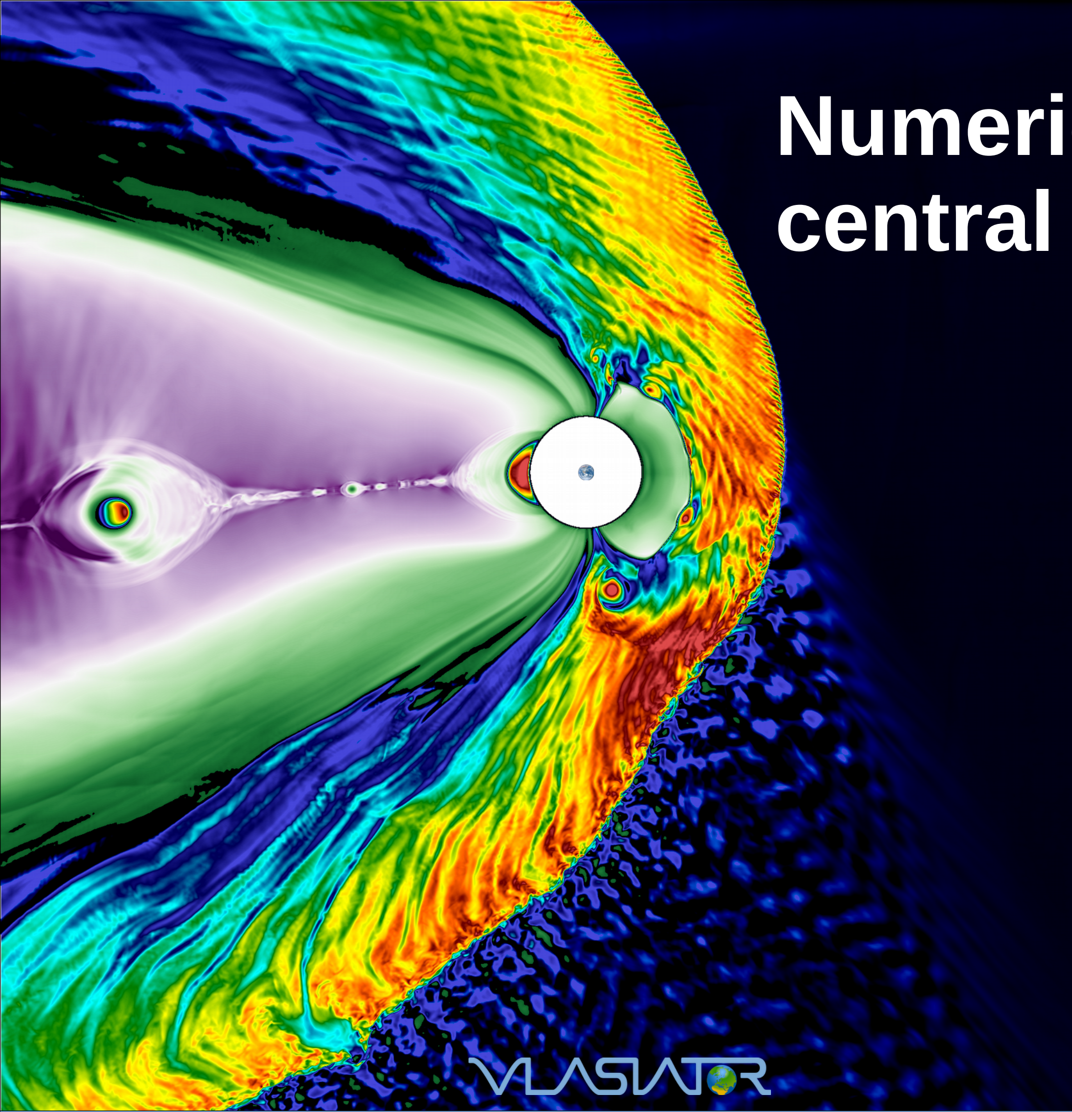
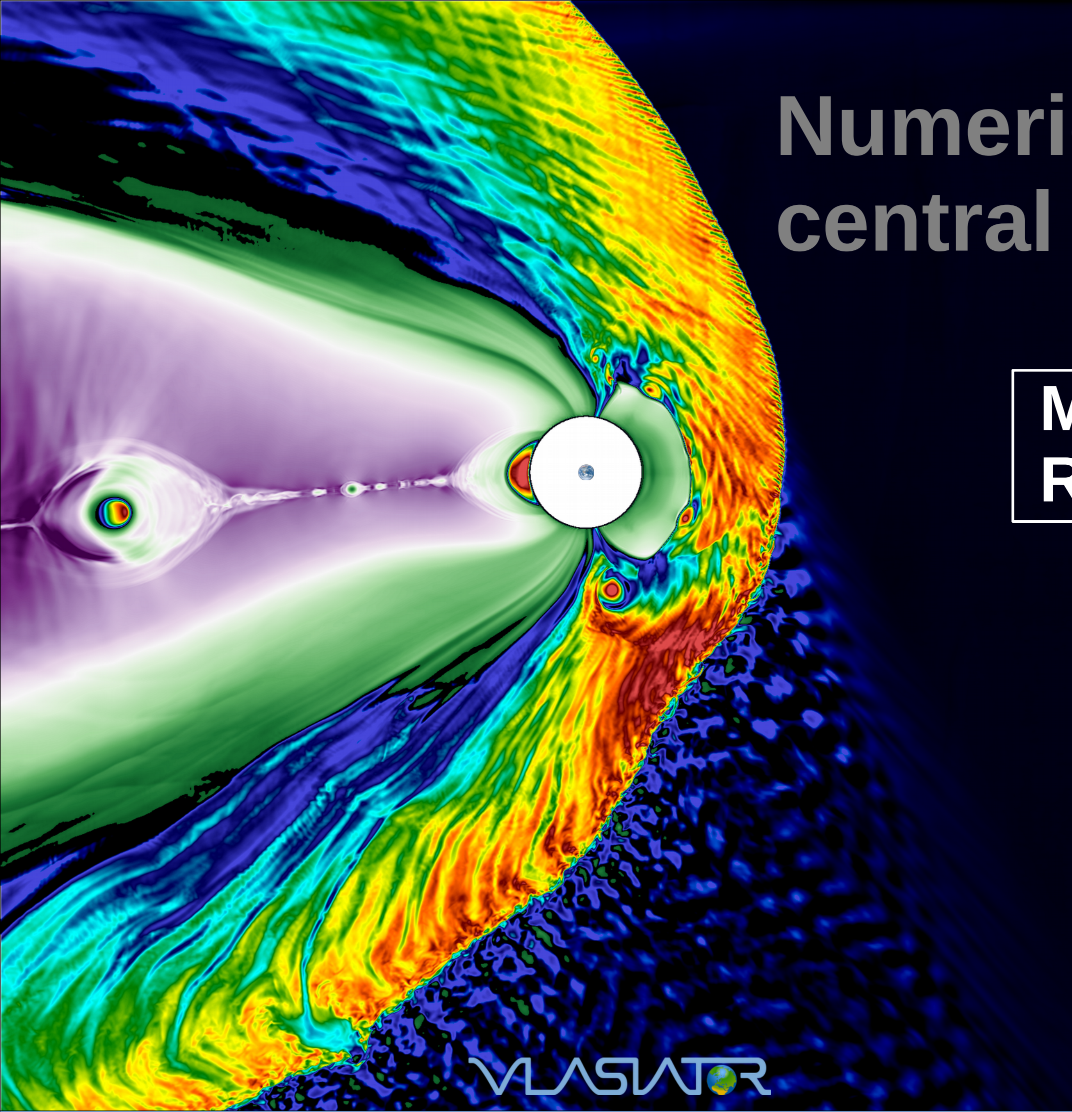
Numerical simulations play a central role in modern sciences





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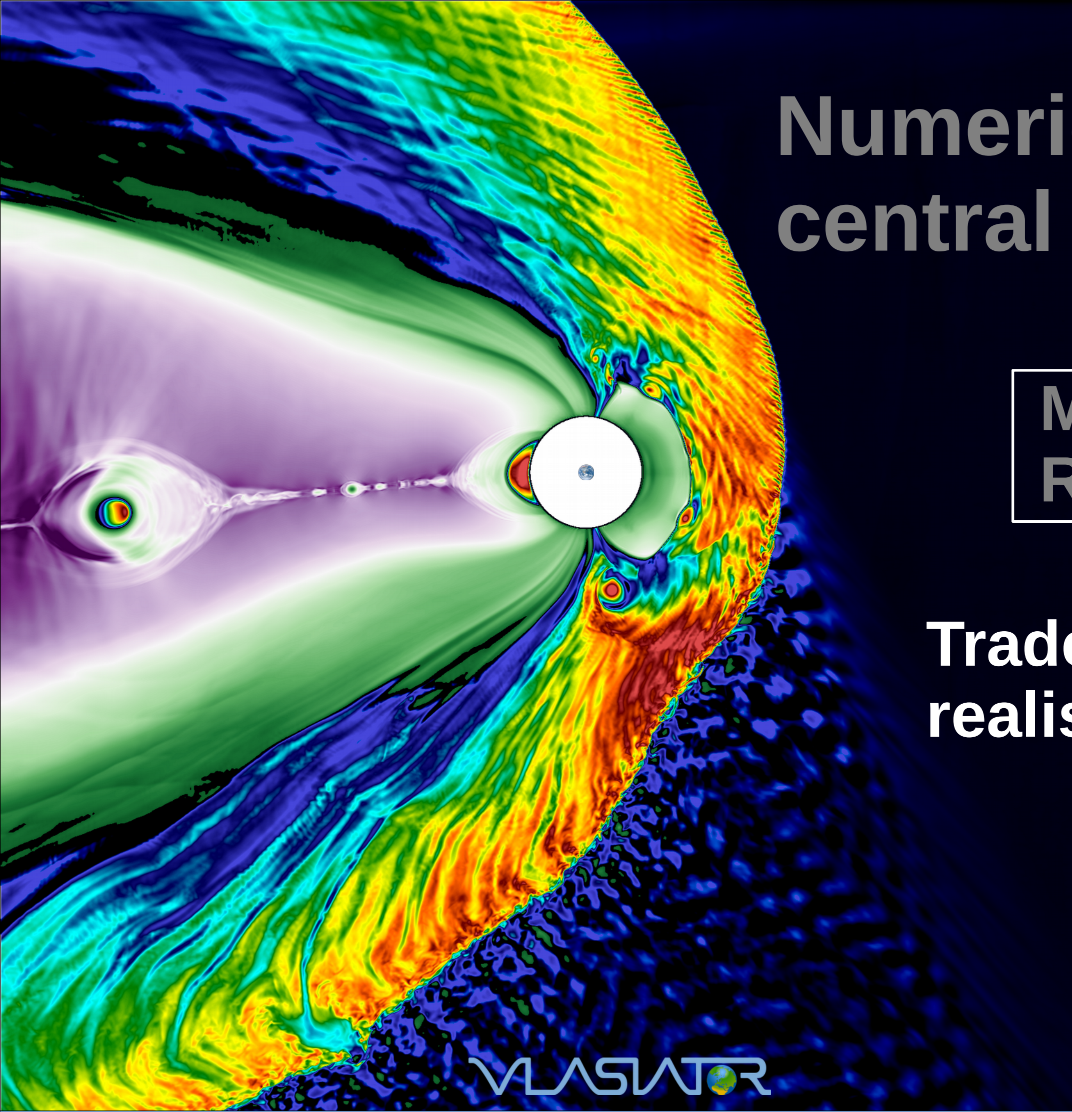
MAIN LIMITING FACTOR: Resolution of the system



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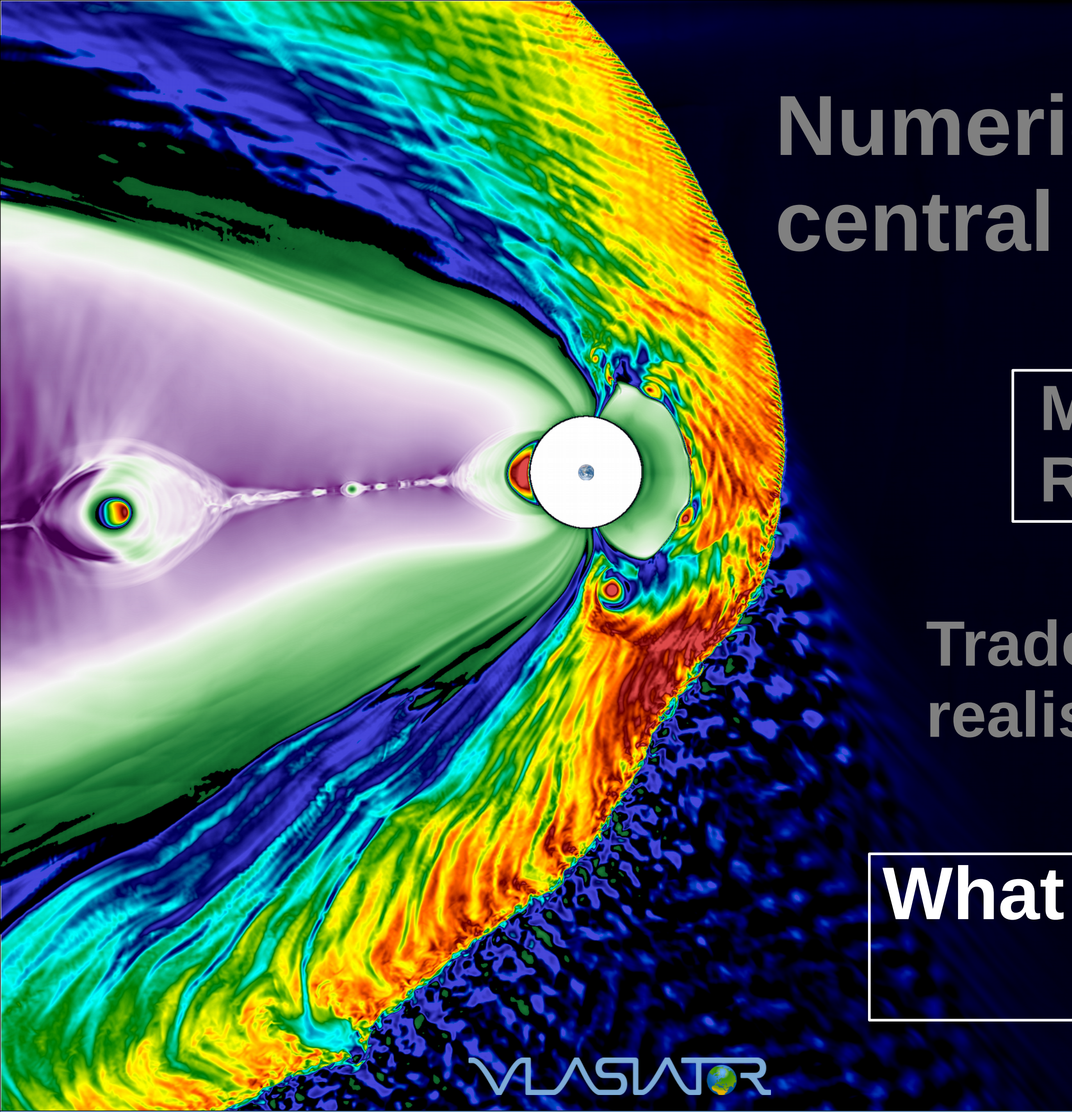
MAIN LIMITING FACTOR:
Resolution of the system

Trade-off between precision and realistic computational resources



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MAIN LIMITING FACTOR: Resolution of the system

Trade-off between precision and realistic computational resources

What do we do when we cannot meet this trade-off?

Absence of proton cyclotron instability at low spatial resolution

VLASIATOR

- Global hybrid-Vlasov simulation of near-Earth space
- 1D, 2D, 3D Cartesian spatial grid
- 3D Cartesian Velocity grid
- Protons described as Velocity Distribution Functions
- Electrons cold, massless, charge-neutralising fluid

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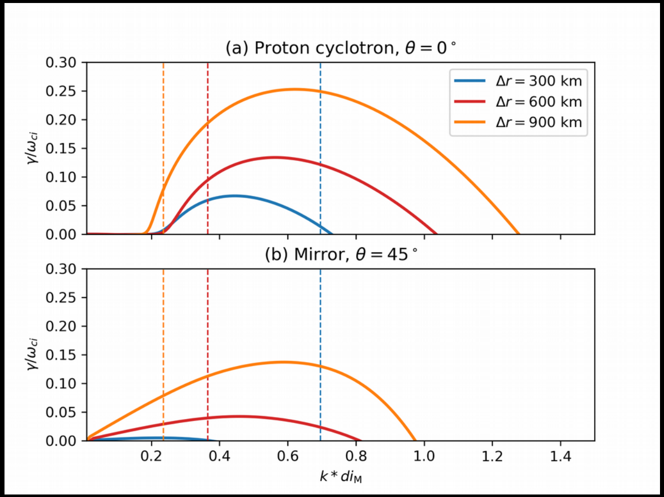

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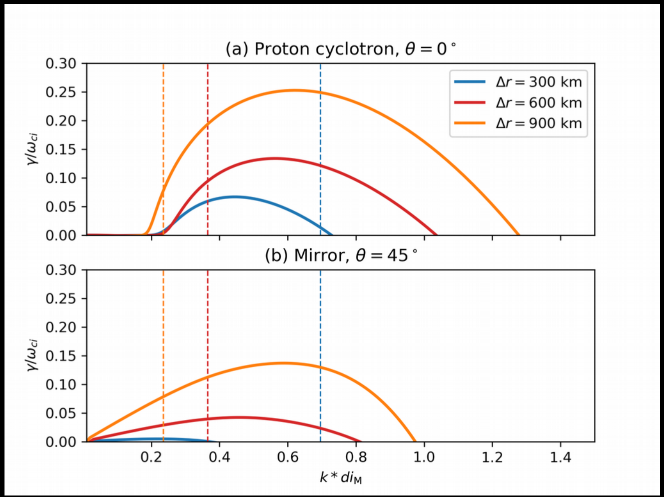
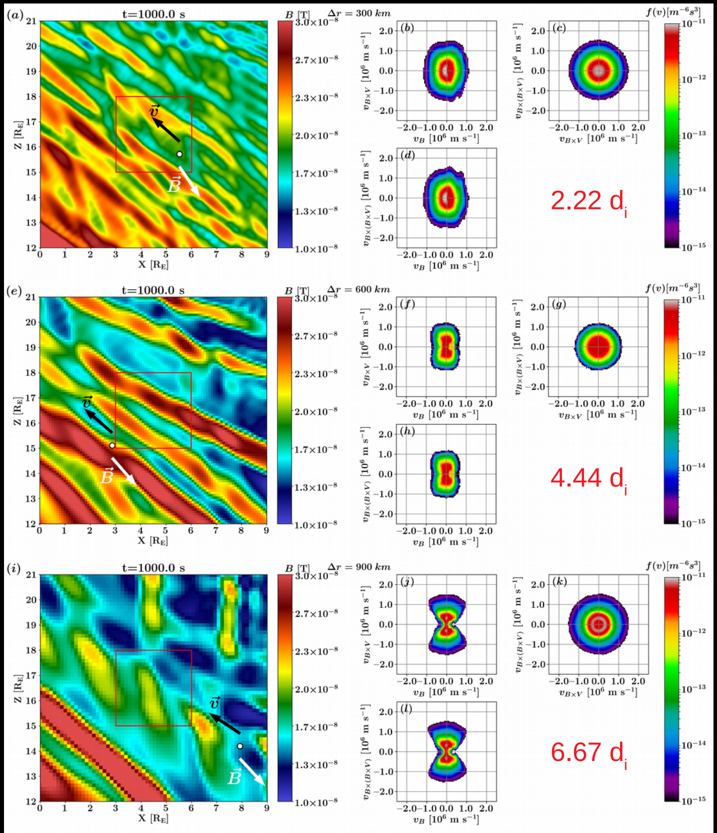


- Leads to lack of isotropisation in VDFs
- Leads to higher than expected temperature anisotropy



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Sub-grid modelling of pitch-angle diffusion

$$\frac{\partial}{\partial \mu}\left[(1-\mu^2)D_{\mu\mu}\frac{\partial f^{2D}_{\mu v}(\mu,v,t)}{\partial \mu}\right] = \frac{\partial f^{2D}_{\mu v}(\mu,v,t)}{\partial t}$$

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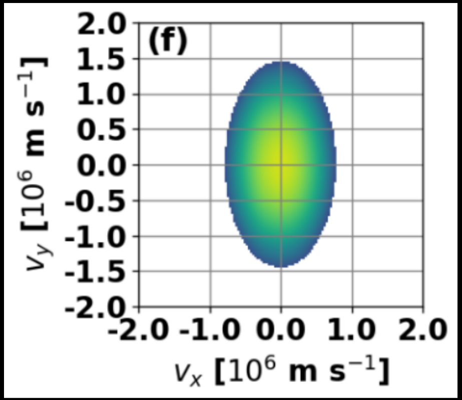
VLASIATOR

3D Cartesian velocity space



$$f^{3D}_{cart}(v_x, v_y, v_z)$$

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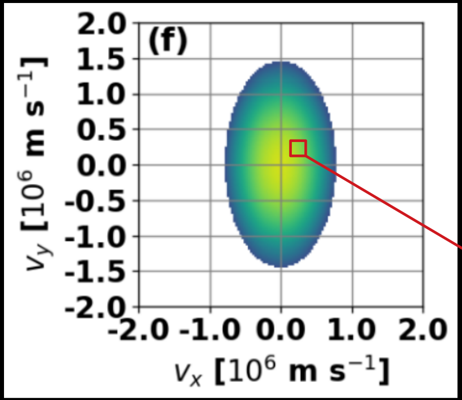
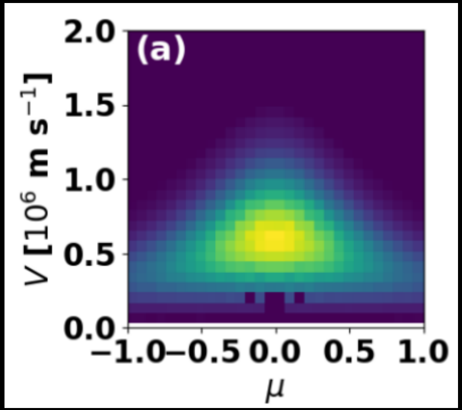


$f^{3D}_{cart}(v_x, v_y, v_z)$



$$f^{3D}_{cart}(v\mu, v\sqrt{1-\mu^2}) = \frac{f^{2D}_{\mu v}(\mu, v)}{2\pi v^2}$$

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VLASIATOR

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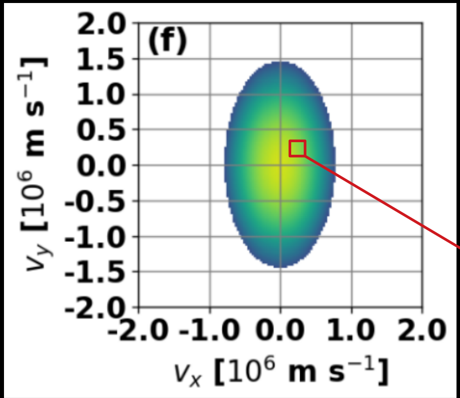

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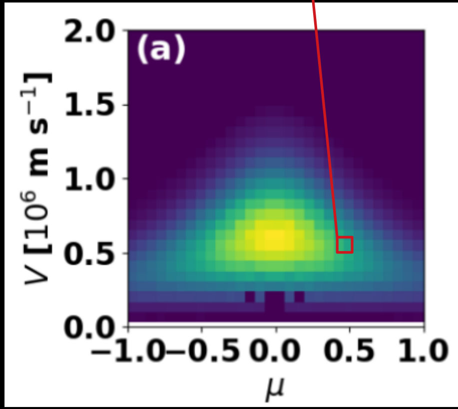

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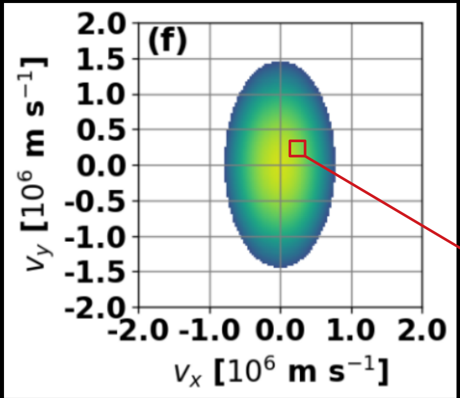

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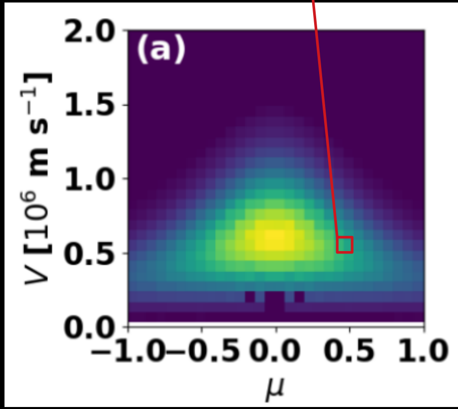
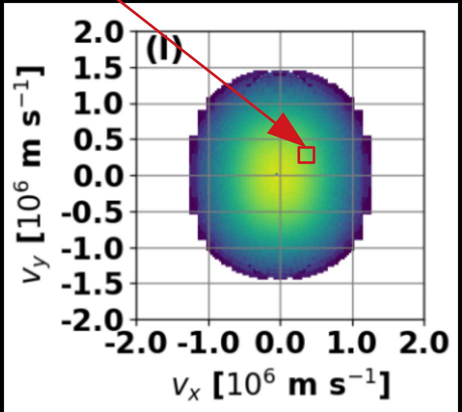


$$\frac{\partial f^{3D}_{cart}(\mathbf{v},t)}{\partial t} = \frac{1}{2\pi v^2}\frac{\partial f^{2D}_{\mu v}(\mu,v,t)}{\partial t}$$



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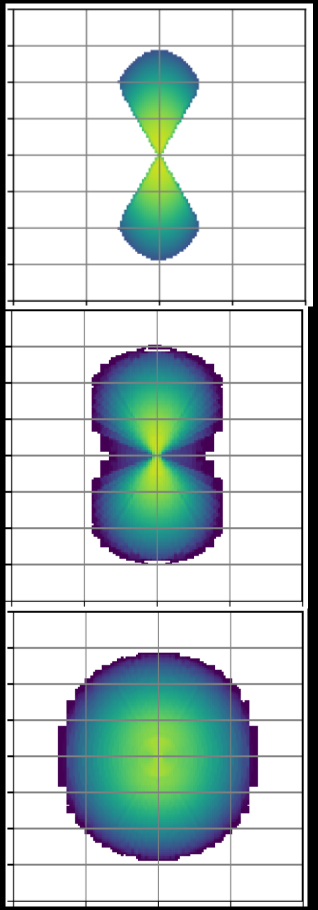
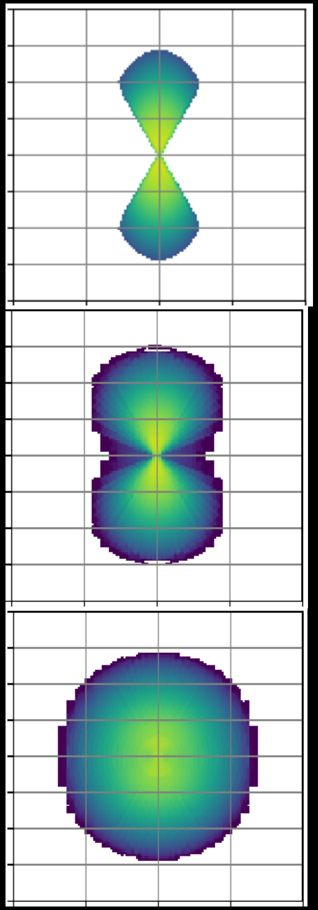


- Can be ran with small time sub-steps to maintain numerical stability
- Can be ran with any magnetic field direction
- Isotropises VDFs, reduces temperature anisotropy in the system
- Can be enabled in a small part of the system
- Allows lower resolution runs whilst still modelling accurately pitch-angle diffusion
- **TO BE** extended to large global simulations

Sub-grid modelling of pitch-angle diffusion



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