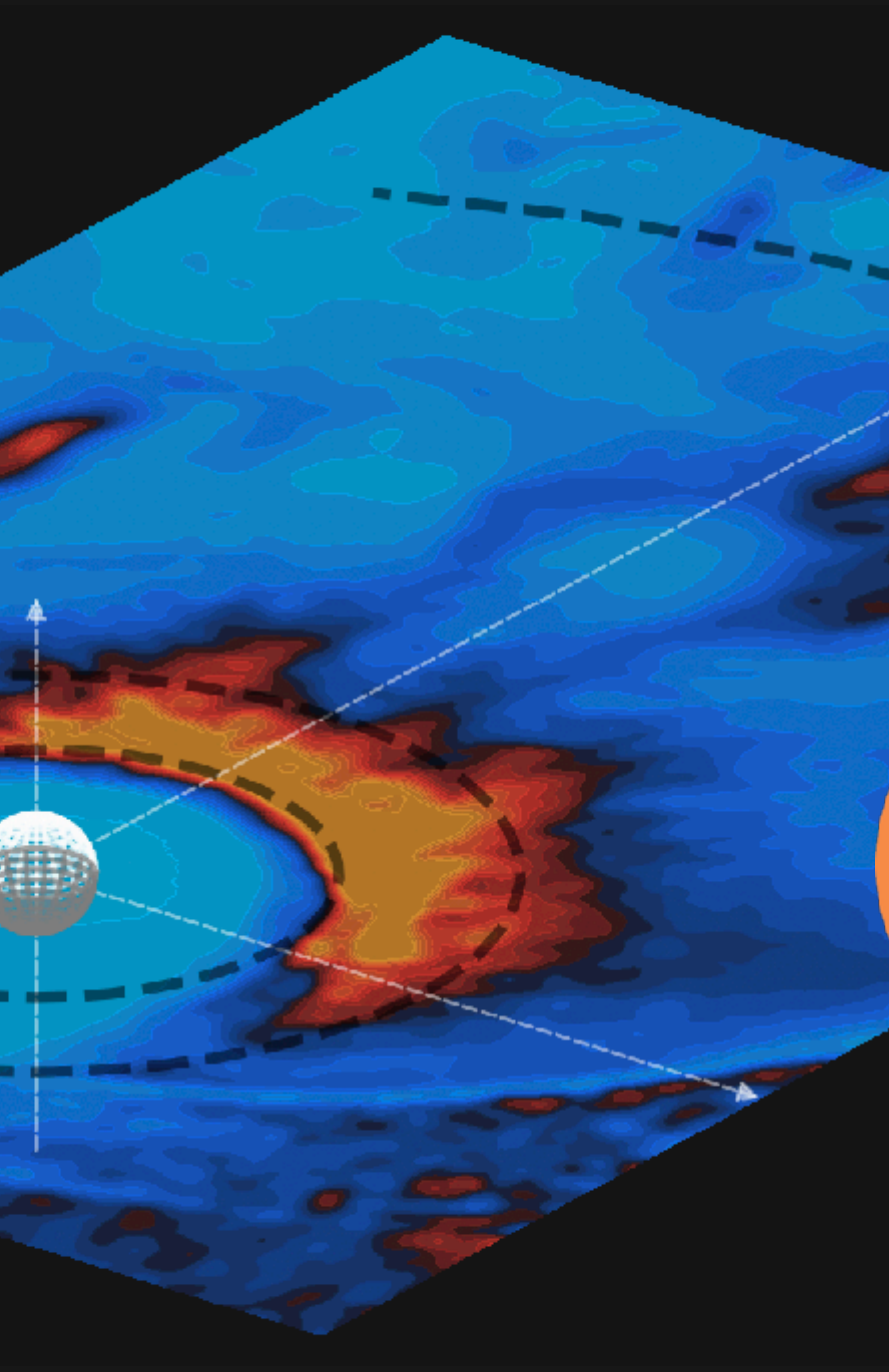
# A Multi-Scale Particle-in-Cell Simulation of Plasma Dynamics from Magnetotail Reconnection to the Inner Magnetosphere



ISSS-15, IPELS-16, IPP Garching

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In collaboration with:

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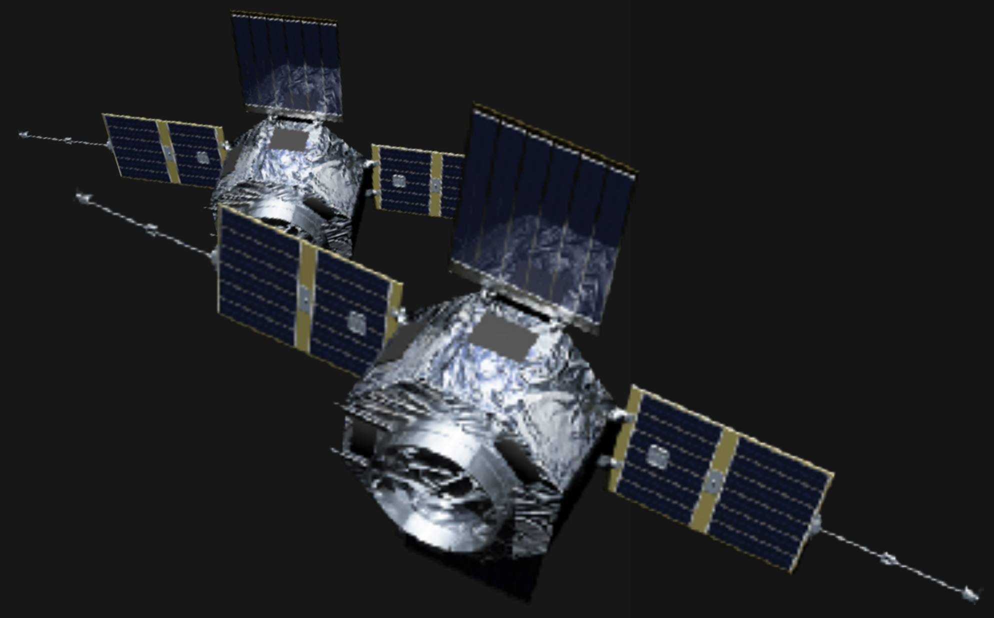
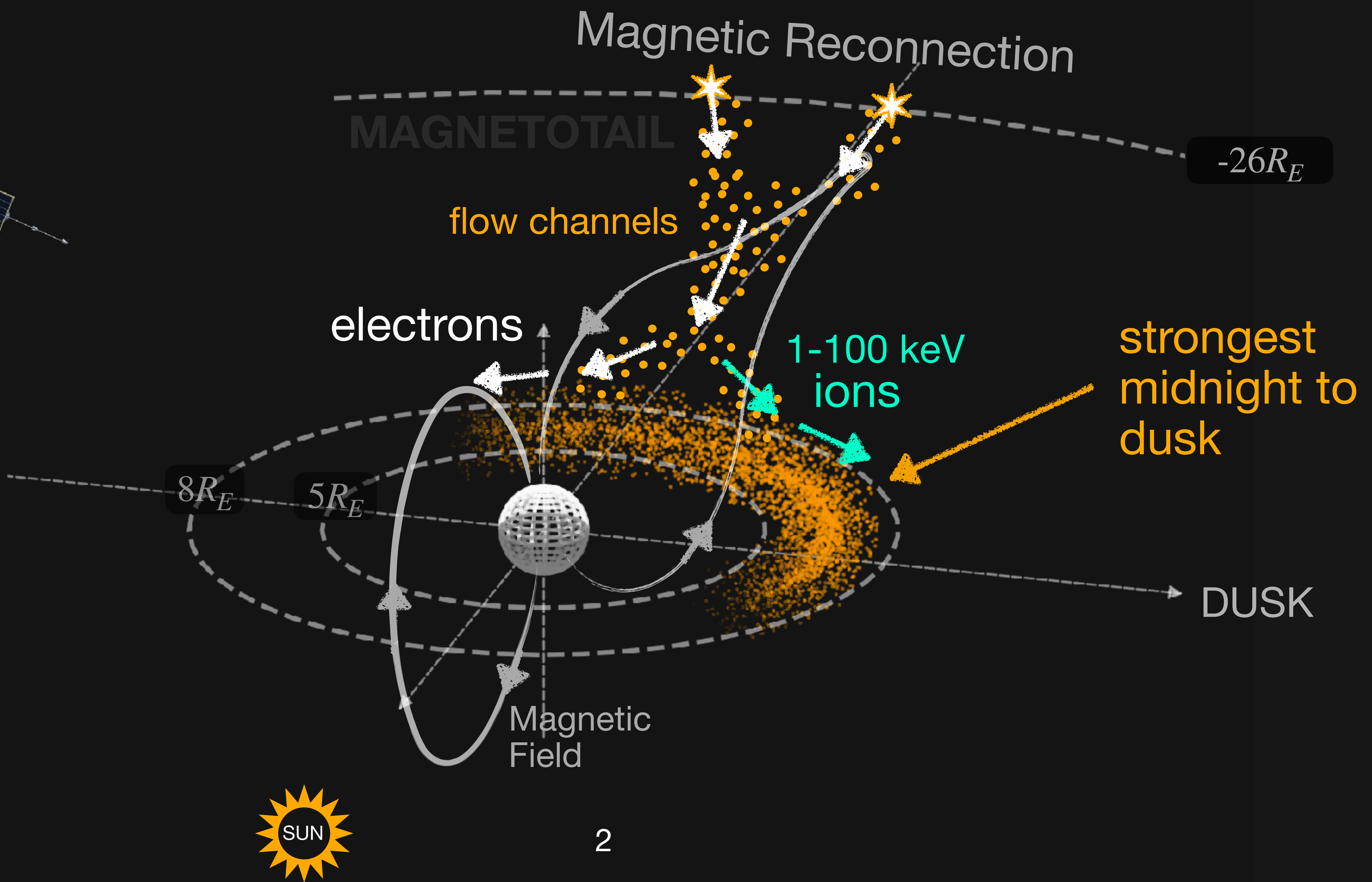
# The ring current is a clockwise electric current in the inner magnetosphere



NASA's Van Allen Probes
A and B (2012-2019)



# METHOD: Types of Particle-in-Cell Codes

## EXPLICIT

- simple
- breaks the link between particles and fields for the duration of one time step
- does not conserve energy

## SEMI-IMPLICIT

- does not require non-linear iteration
- conserves energy exactly
- particle mover has a complexity identical to explicit PIC, only the field solver has an increased computational cost

ECSim *(Lapenta, 2017, 2023)*

## IMPLICIT

- energy conserved
- particle and field equations have to be solved together, coupled via a non-linear Newton or Picard iteration

Model Developer

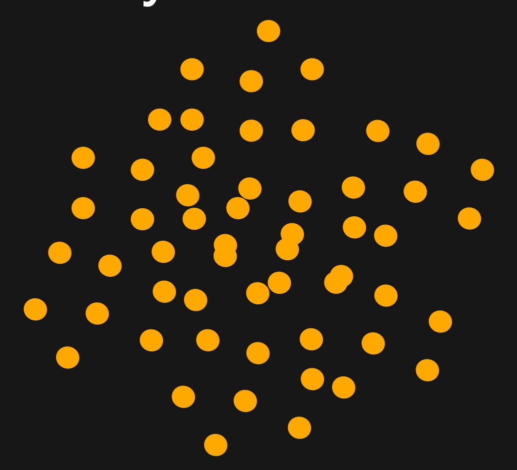
*Giovanni Lapenta*

KU Leuven

# METHOD

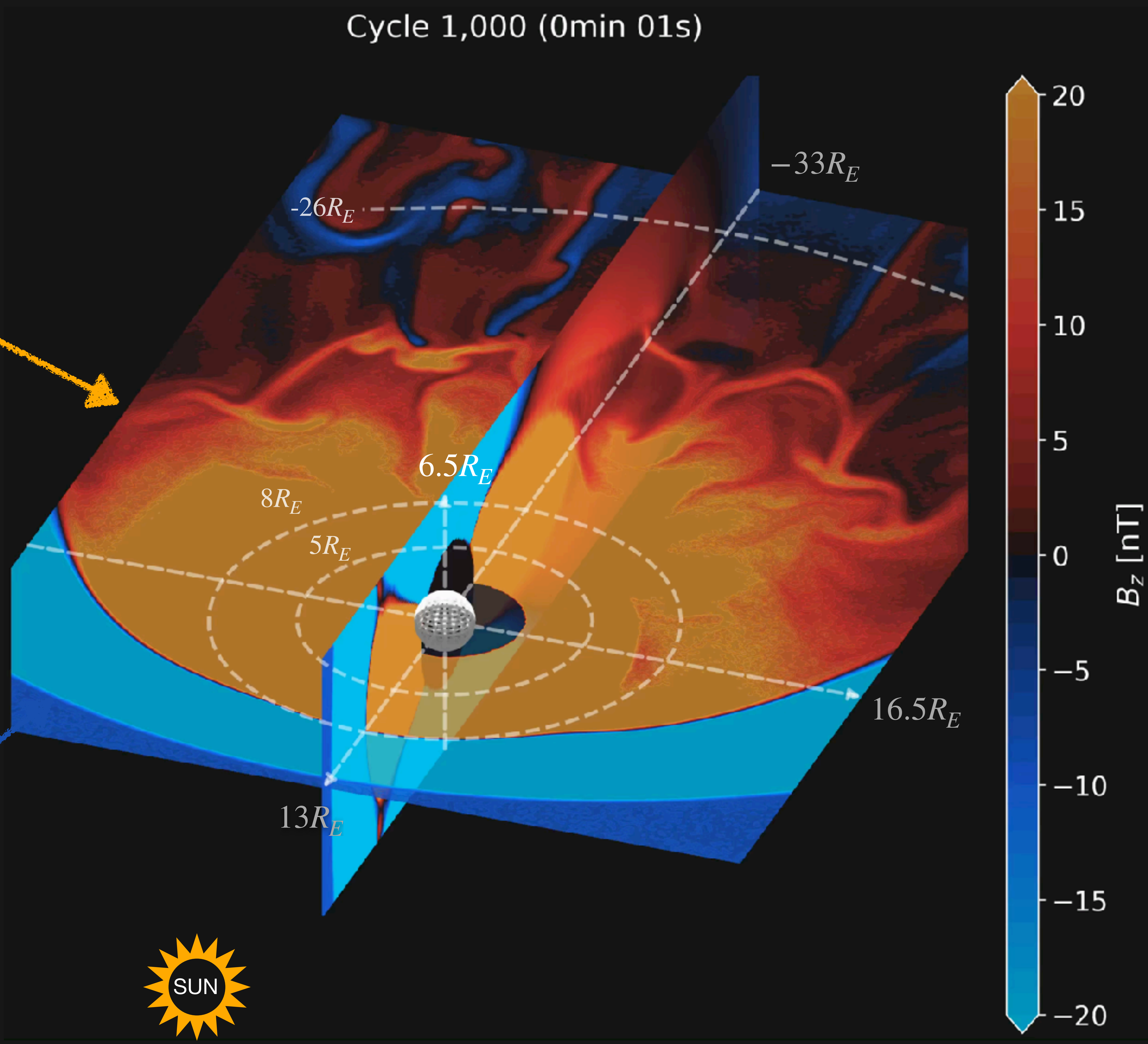
Global MHD fields as boundary conditions

Maxwellian + Kappa
velocity distortions



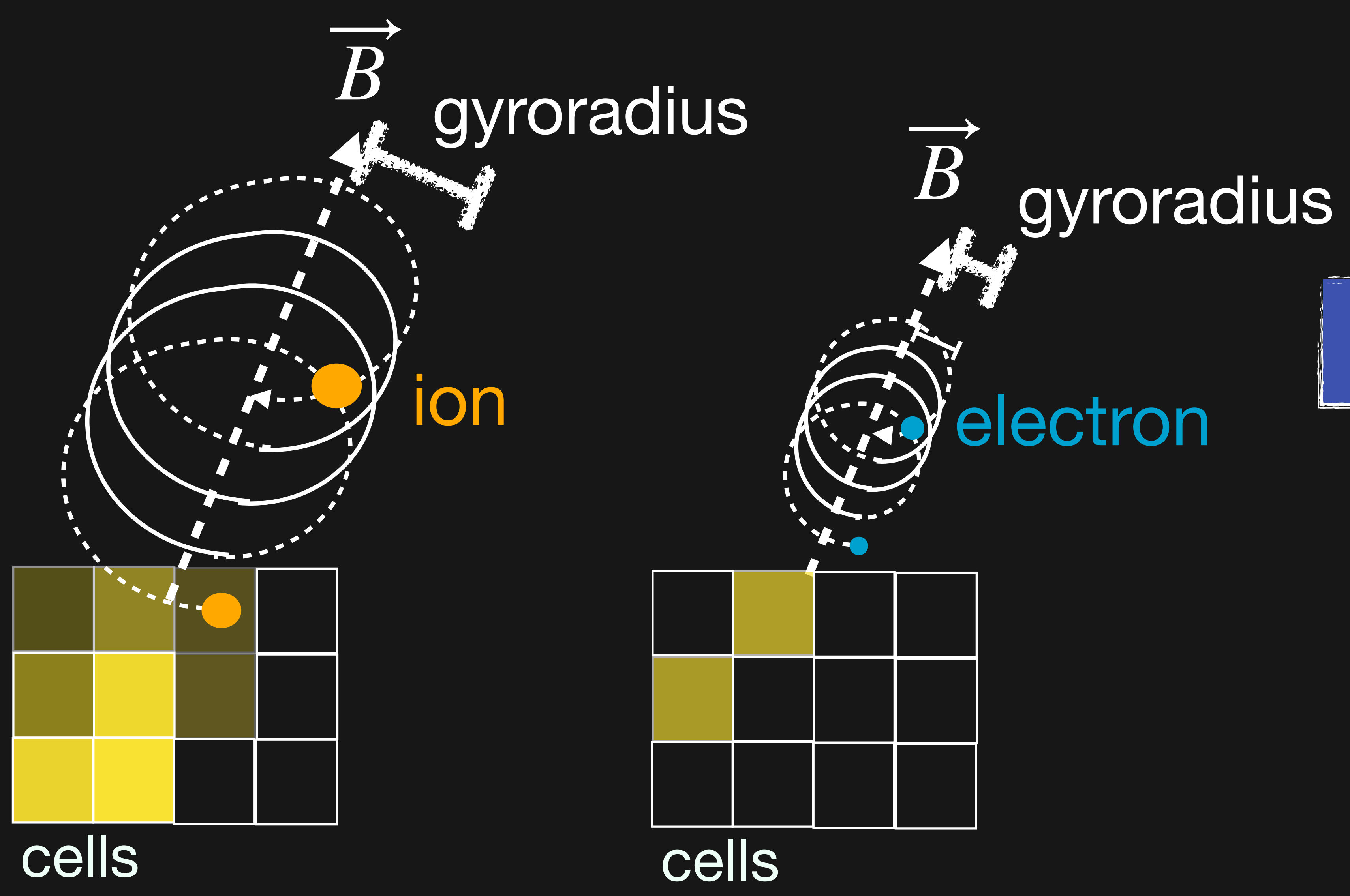
2 billion electrons and ions

ECSim *(Lapenta, 2017, 2023)*

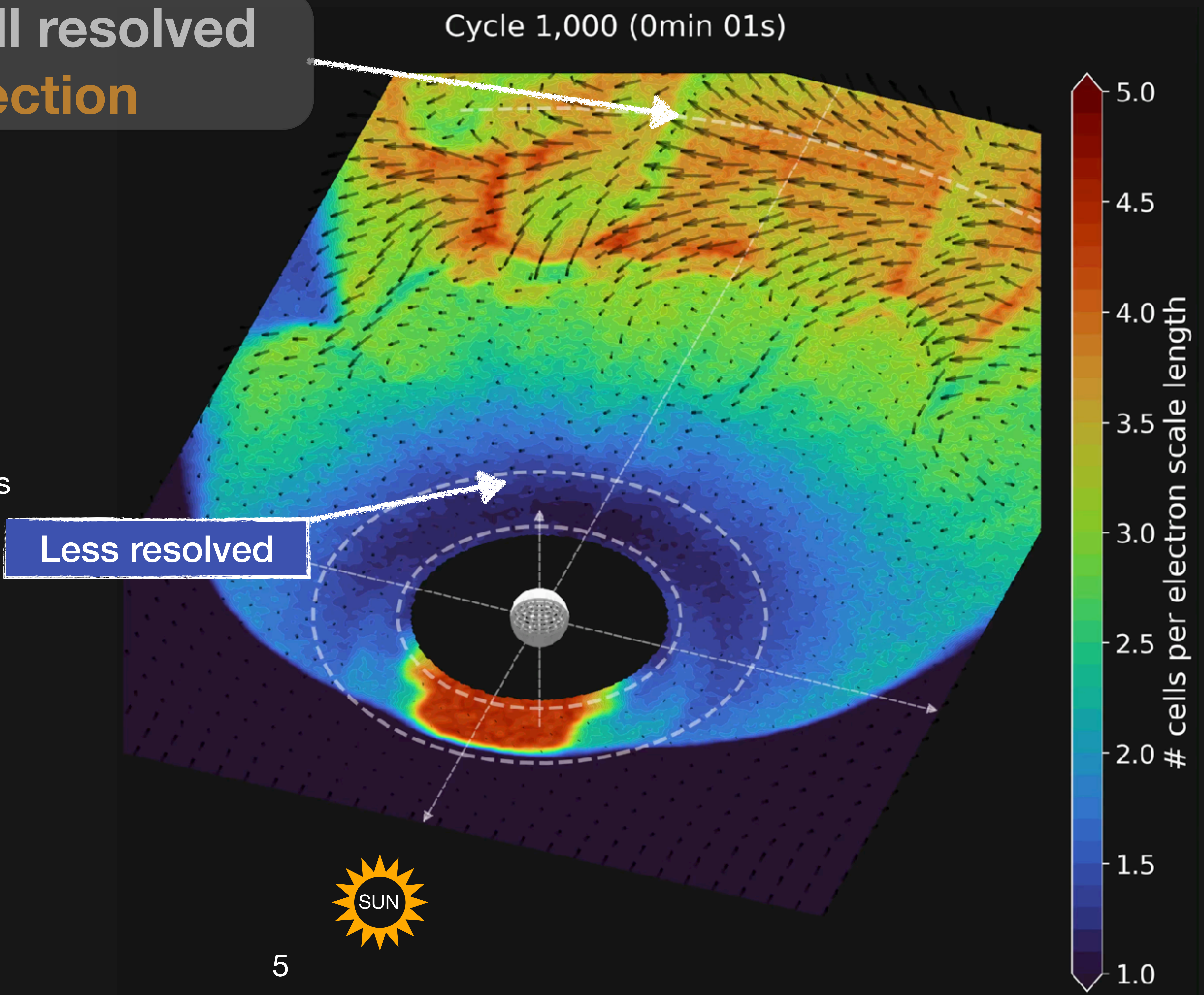



**SOLAR WIND**
$B_z = -8$nT
$V_x = -530$kms$^{-1}$
$n = 6$ cm$^{-3}$

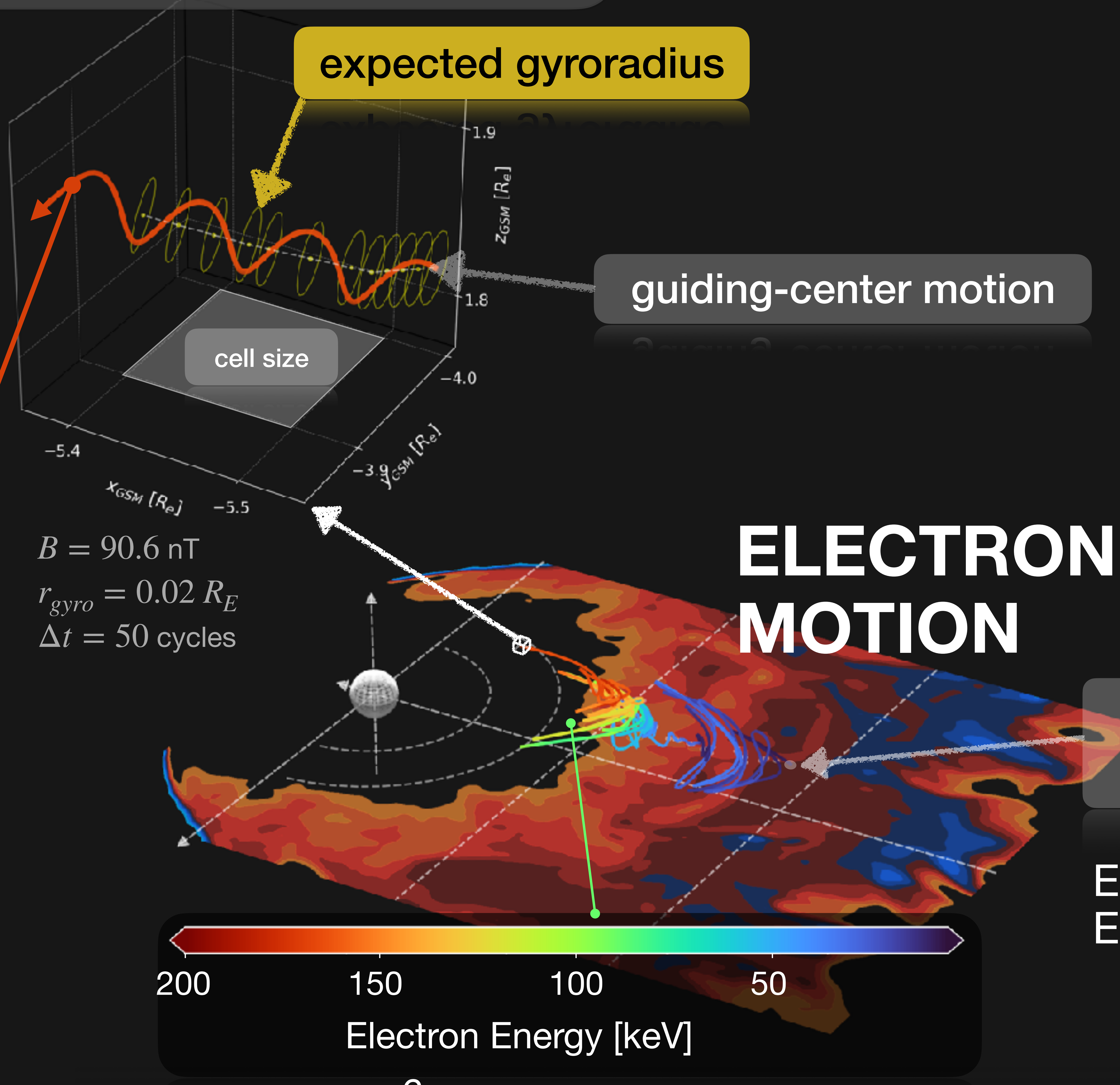
# Kinetic physics is well resolved near the reconnection




Electrons are harder to resolve.



# Electron physics is (mostly) resolved




Electron gyrates around the local magnetic field

guiding-center motion

Electron trace starts at 20,000 cycles near the reconnection

Electron Gets Energized to 150 keV

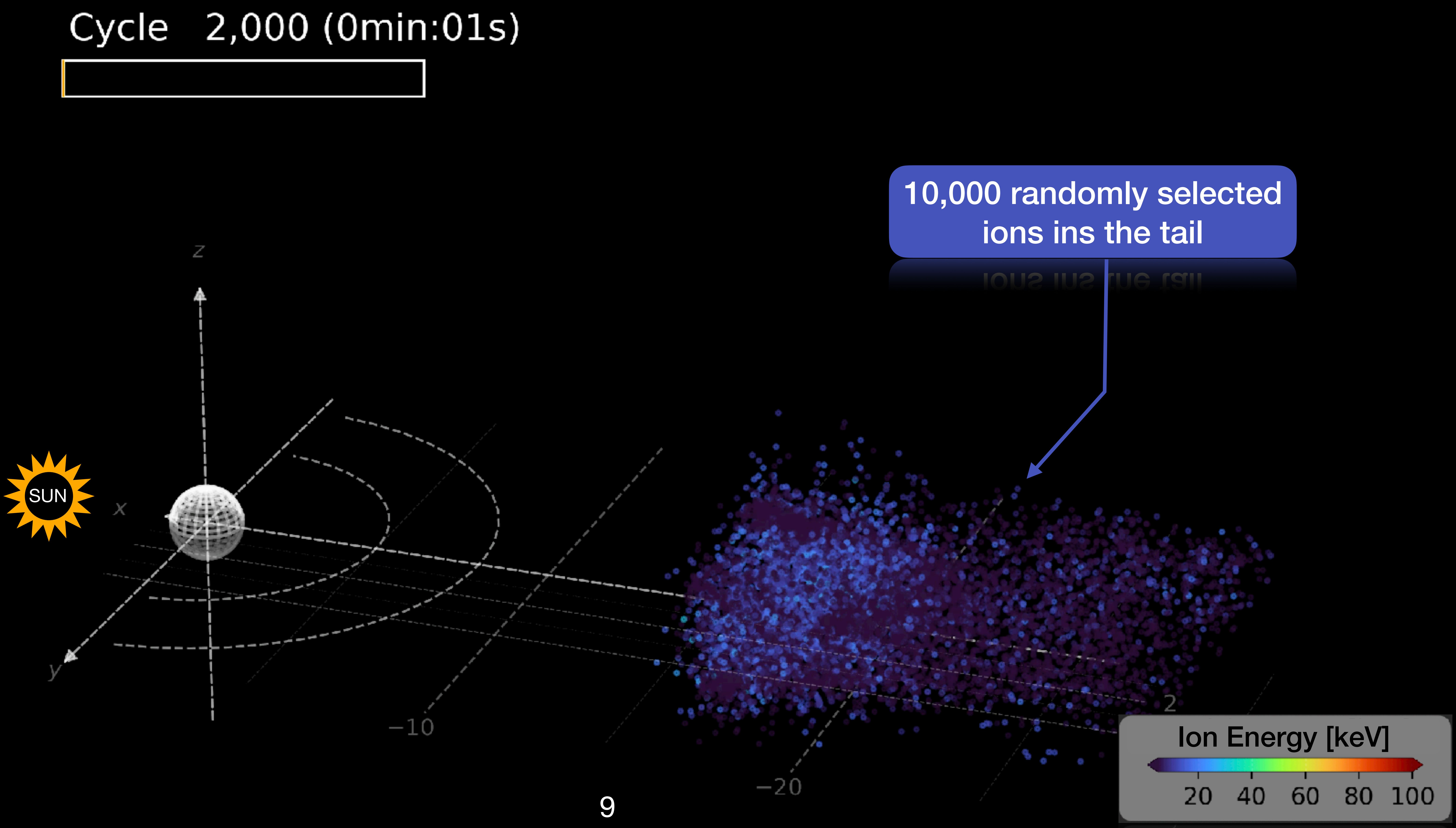
# Multiple Dipolarization Fronts near the Reconnections



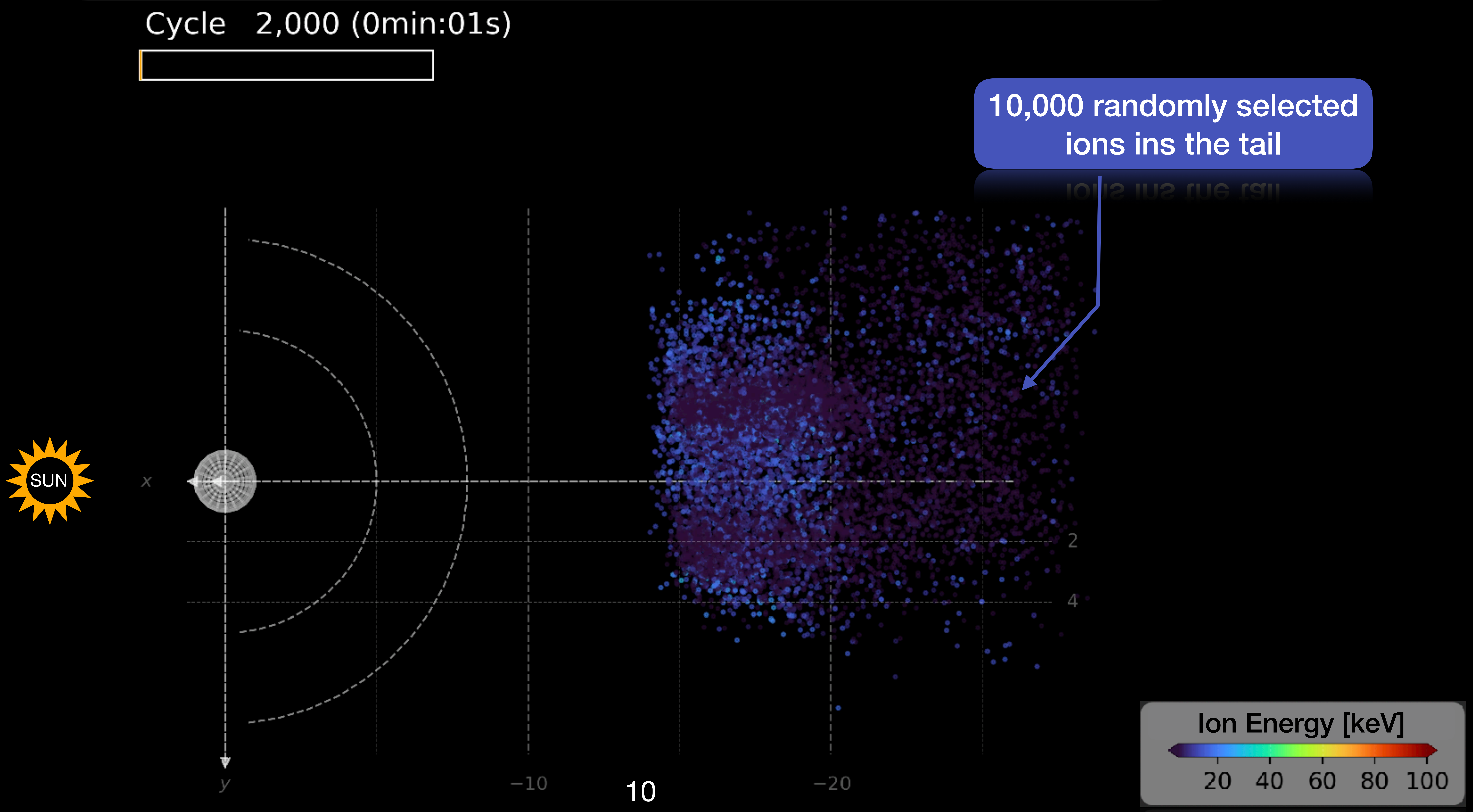

*See Angelopoulos et al. (1992) for description of BBFs*

# Electron and Ion Bulk Velocities

# Particles organize into prominent bulk flows

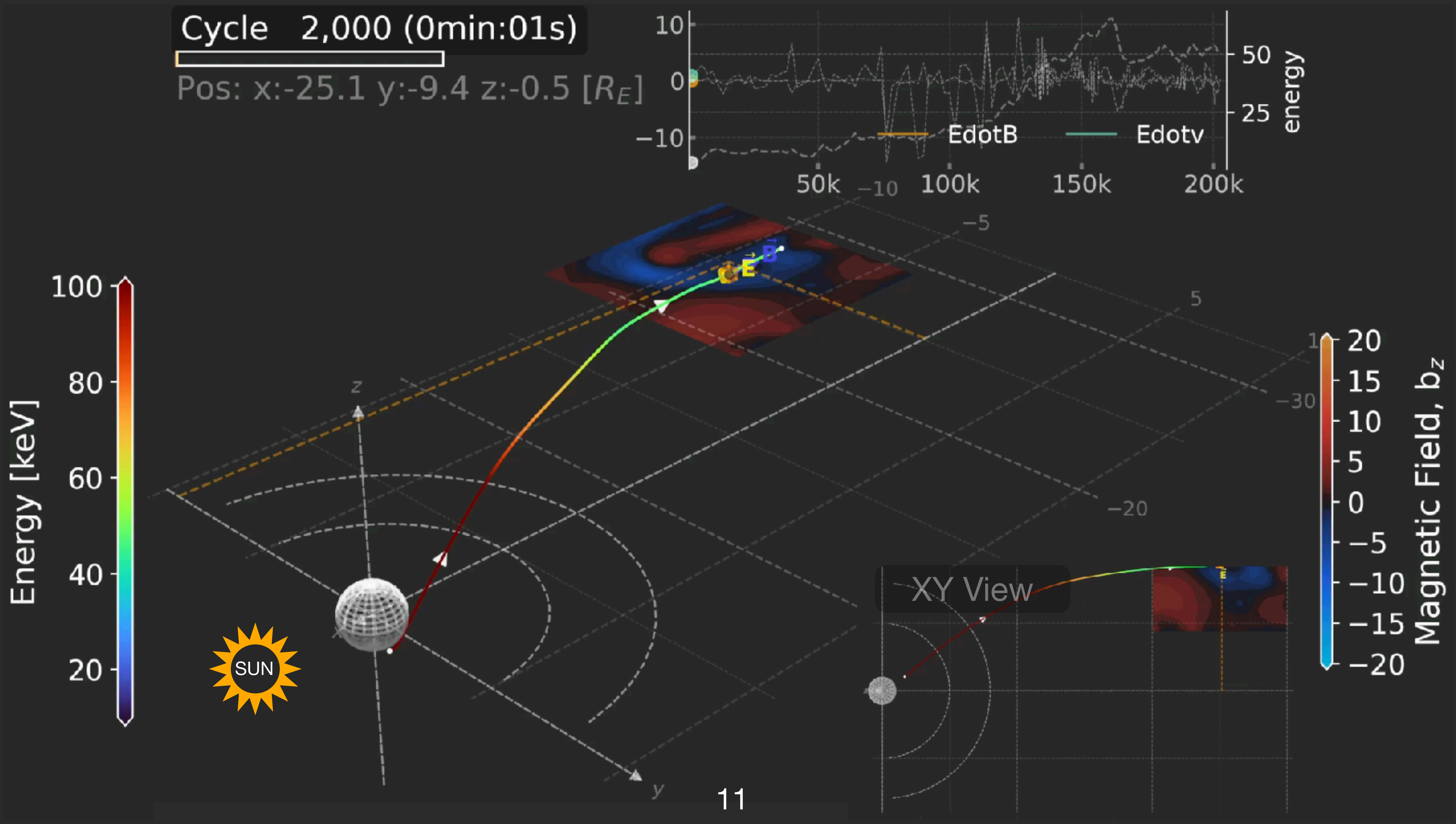


# Particles organize into prominent bulk flows



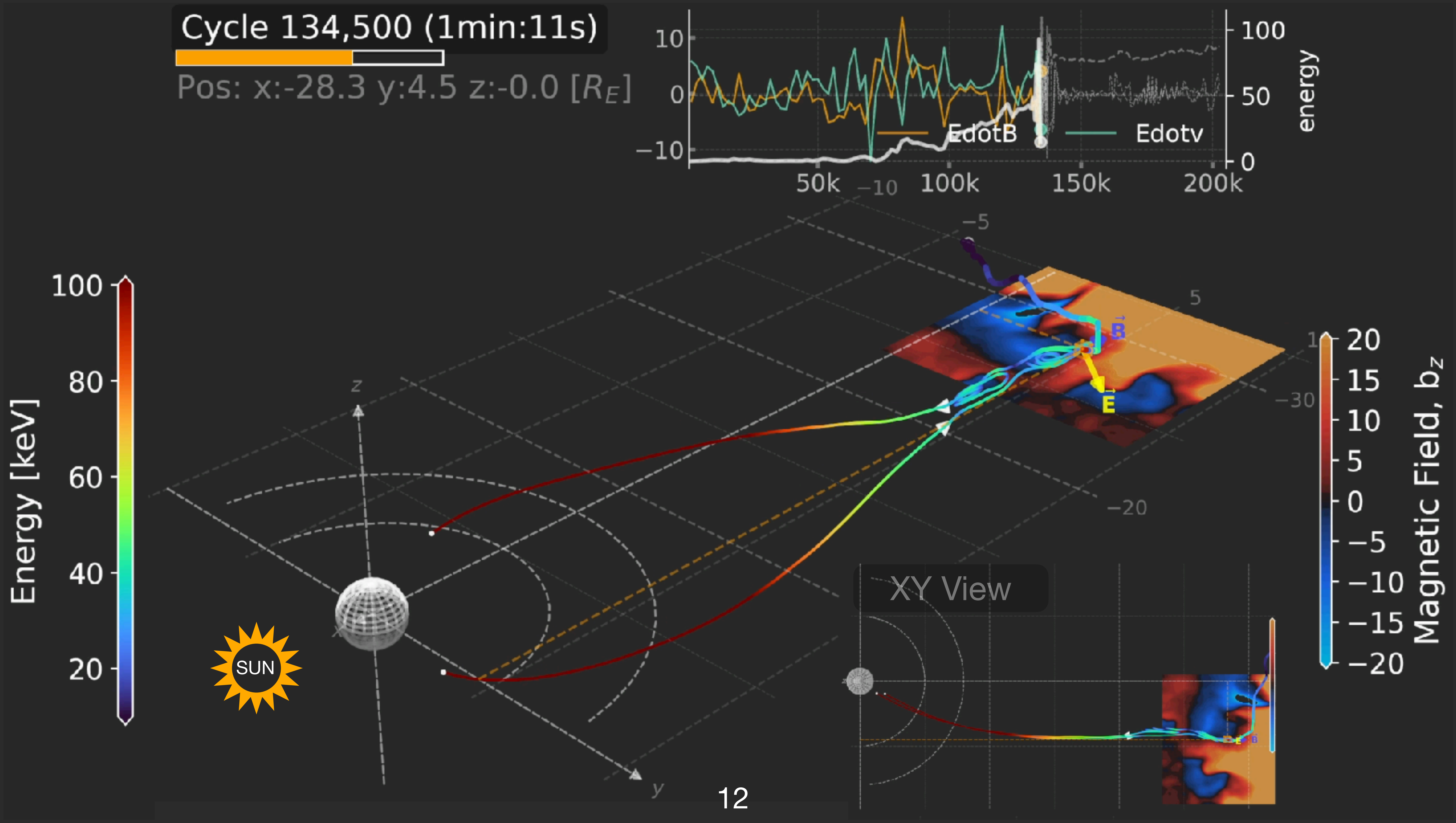
# Example 1. Speiser Ion

Non-adiabatic
SPEISER ORBIT



# Example 2. High-energy Ion

Non-adiabatic SPEISER ORBIT + Adiabatic FERMI + Turbulent E FIELDS ?



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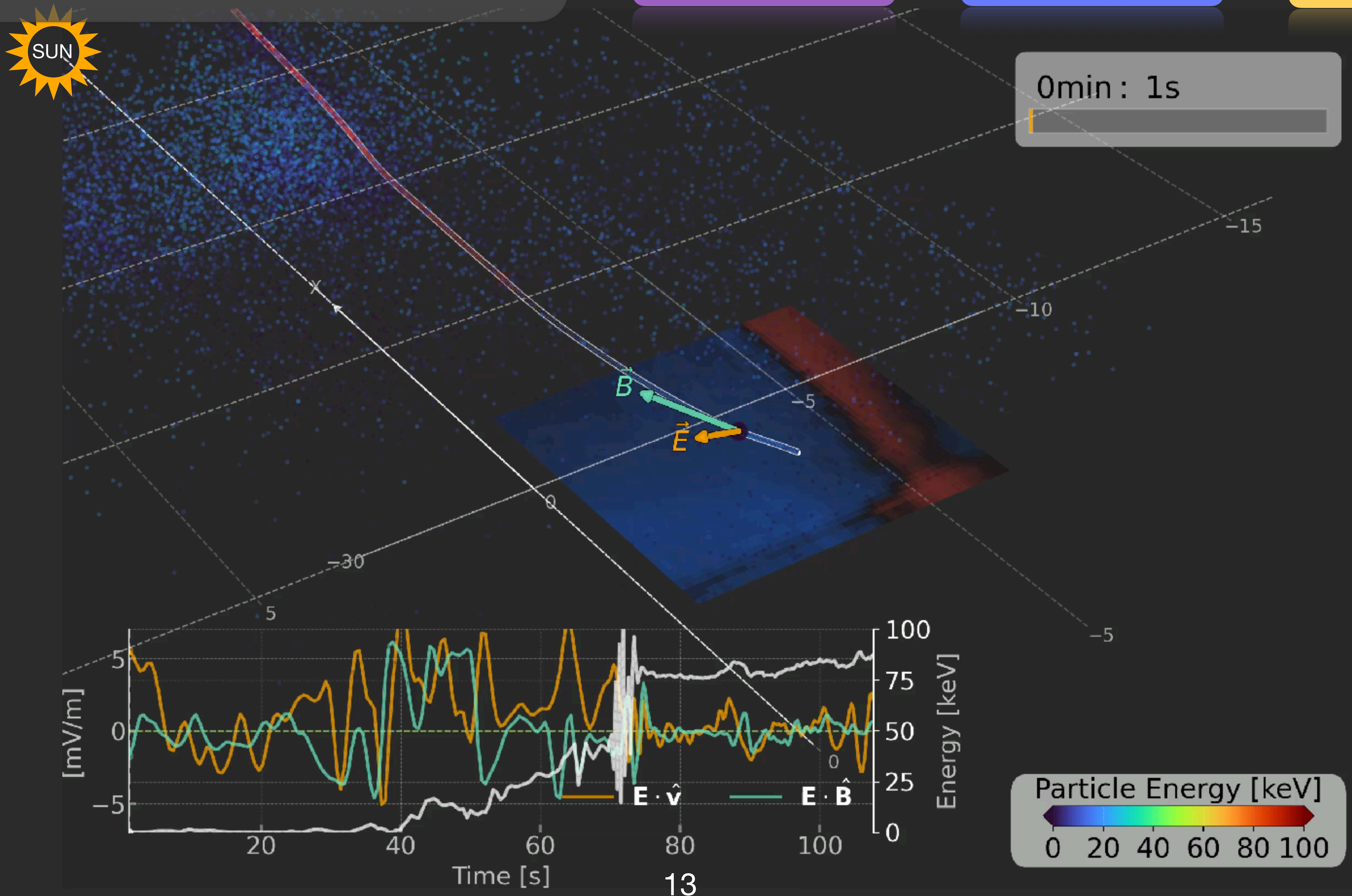
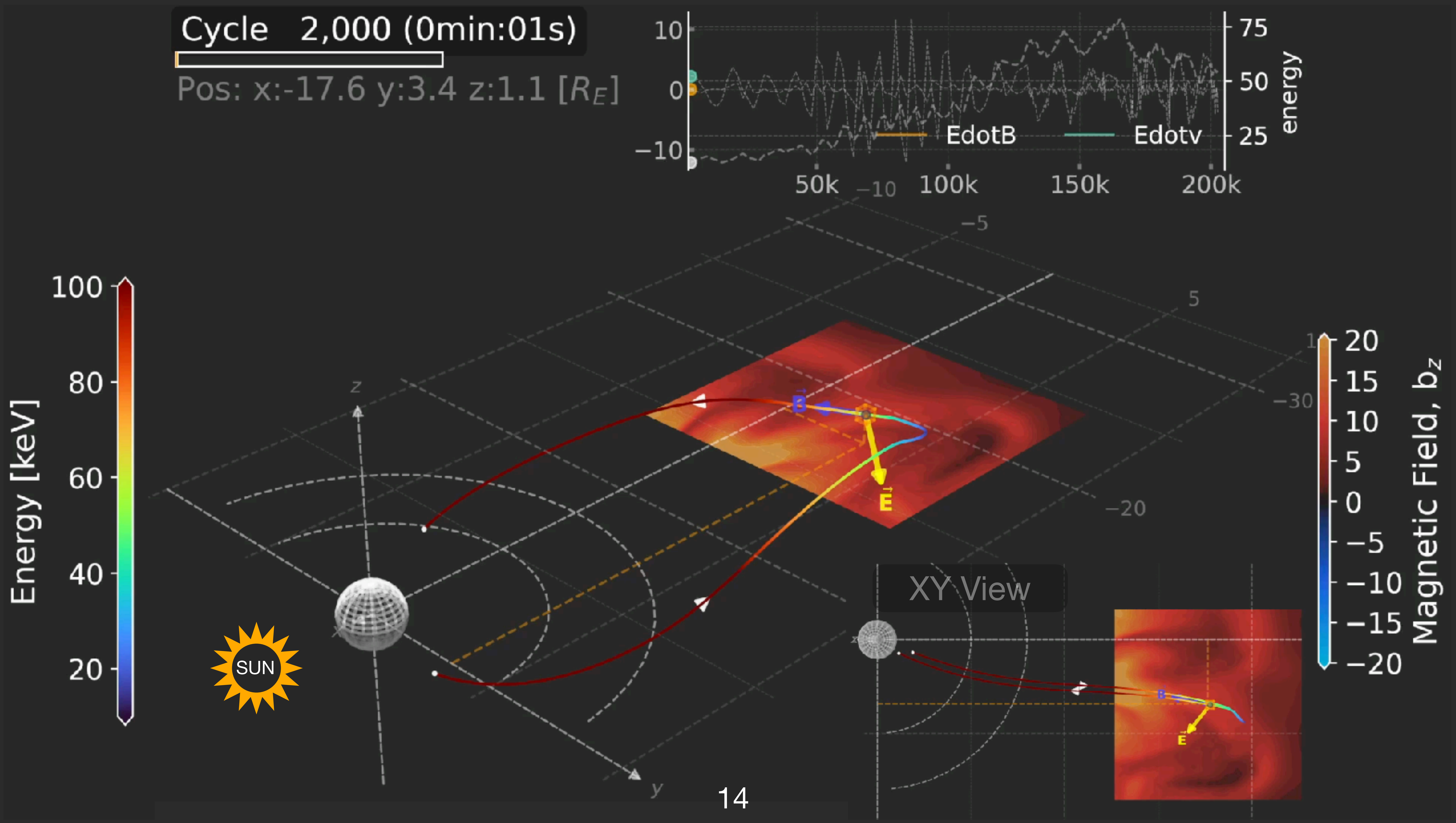
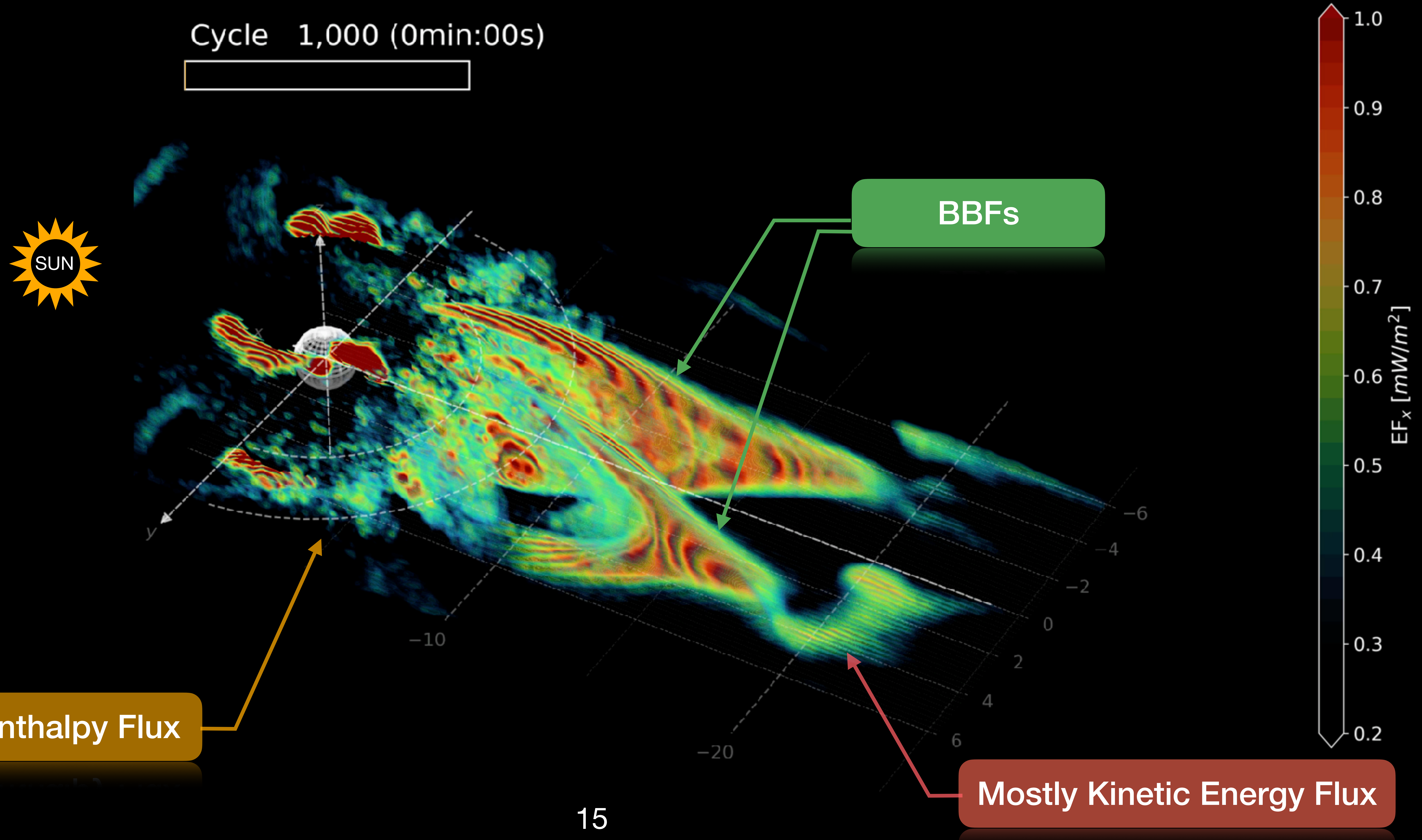


# Example 3. Betatron Ion

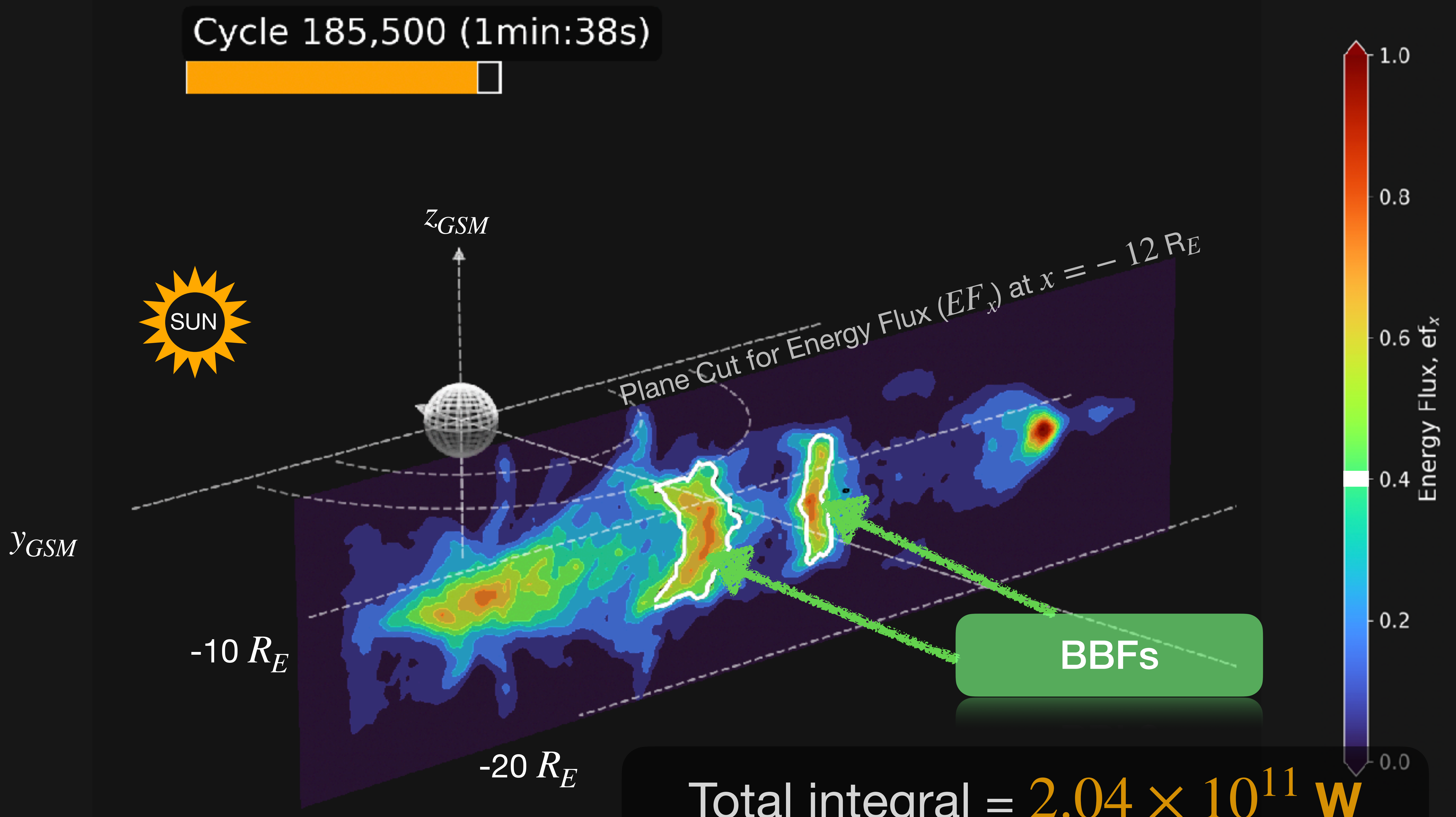
Adiabatic BETATRON + Non-adiabatic SPEISER ORBIT



# Energy Flux Increases in Ring Current and BBFs



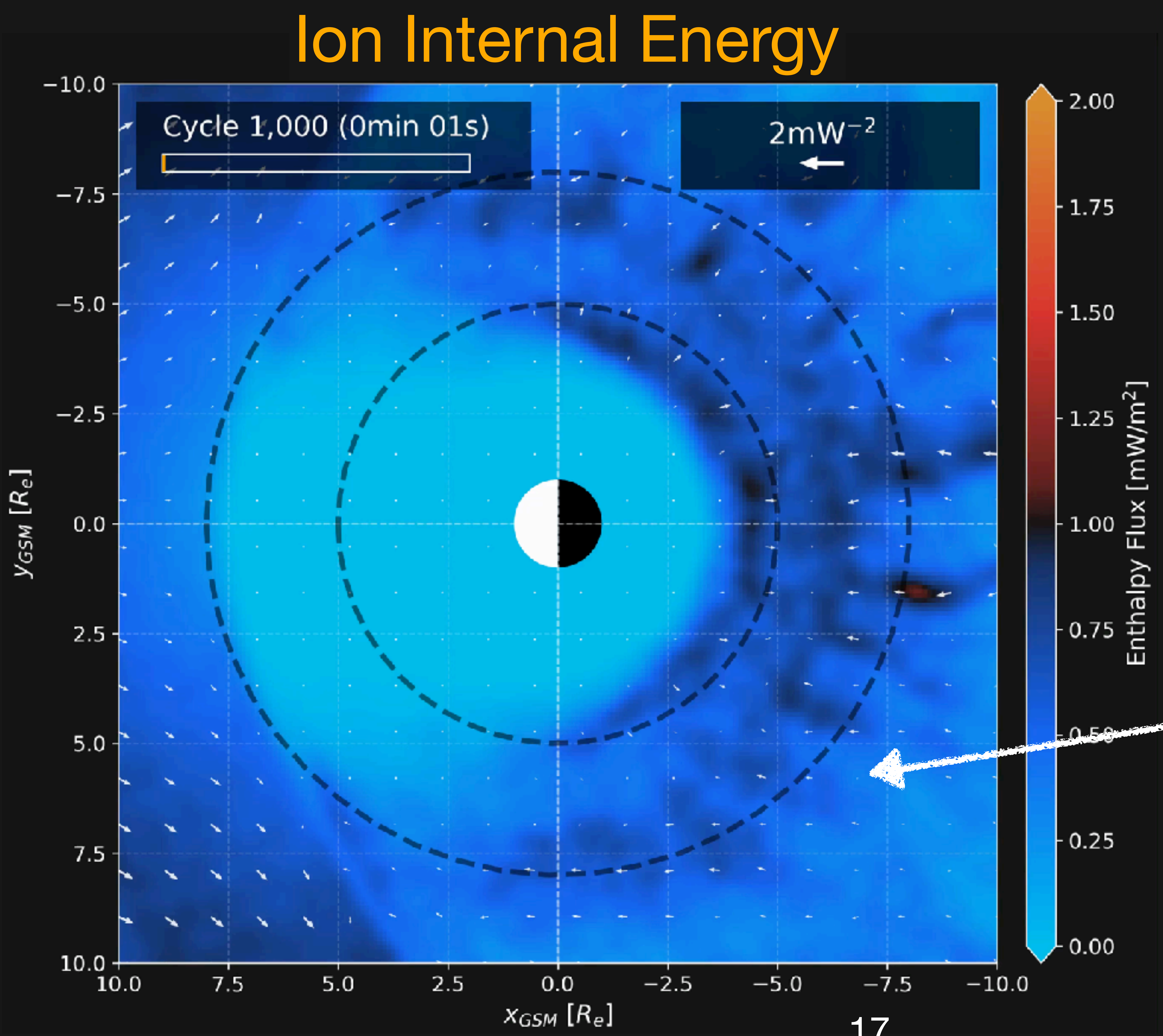
# Energy Flux in the BBFs is Consistent with Observations




Total integral = $2.04 \times 10^{11}$ W

Similar to estimates from the observations (~$3 \times 10^{11}$W, Angelopoulos et al., 1997).

# The Ring Current is carried mostly by the ions





The partial ring current is strongest midnight to dusk.

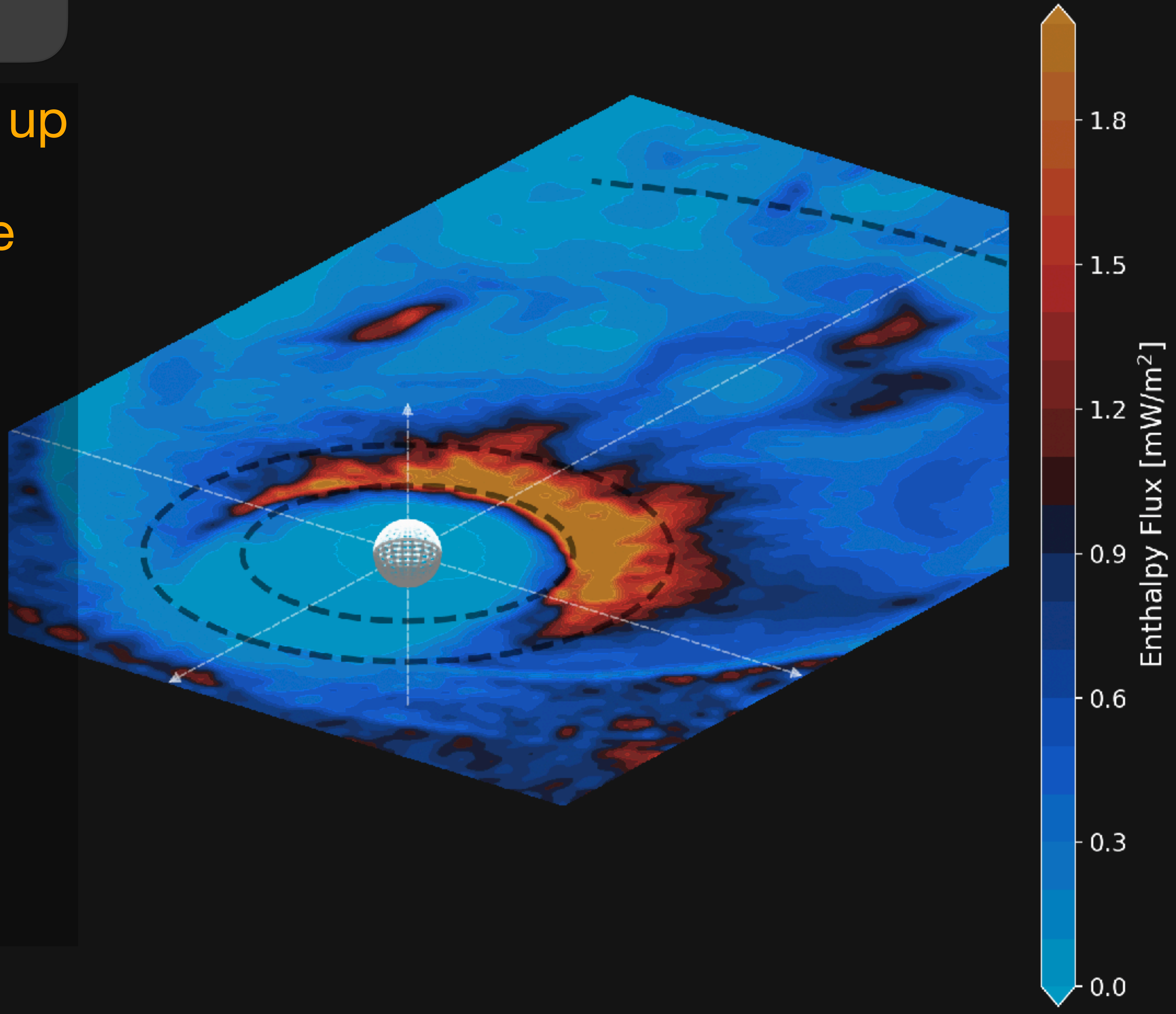
# What did we learn?

- Electrons and ions get accelerated up to ~100keV in the tail reconnection and reach the inner magnetosphere

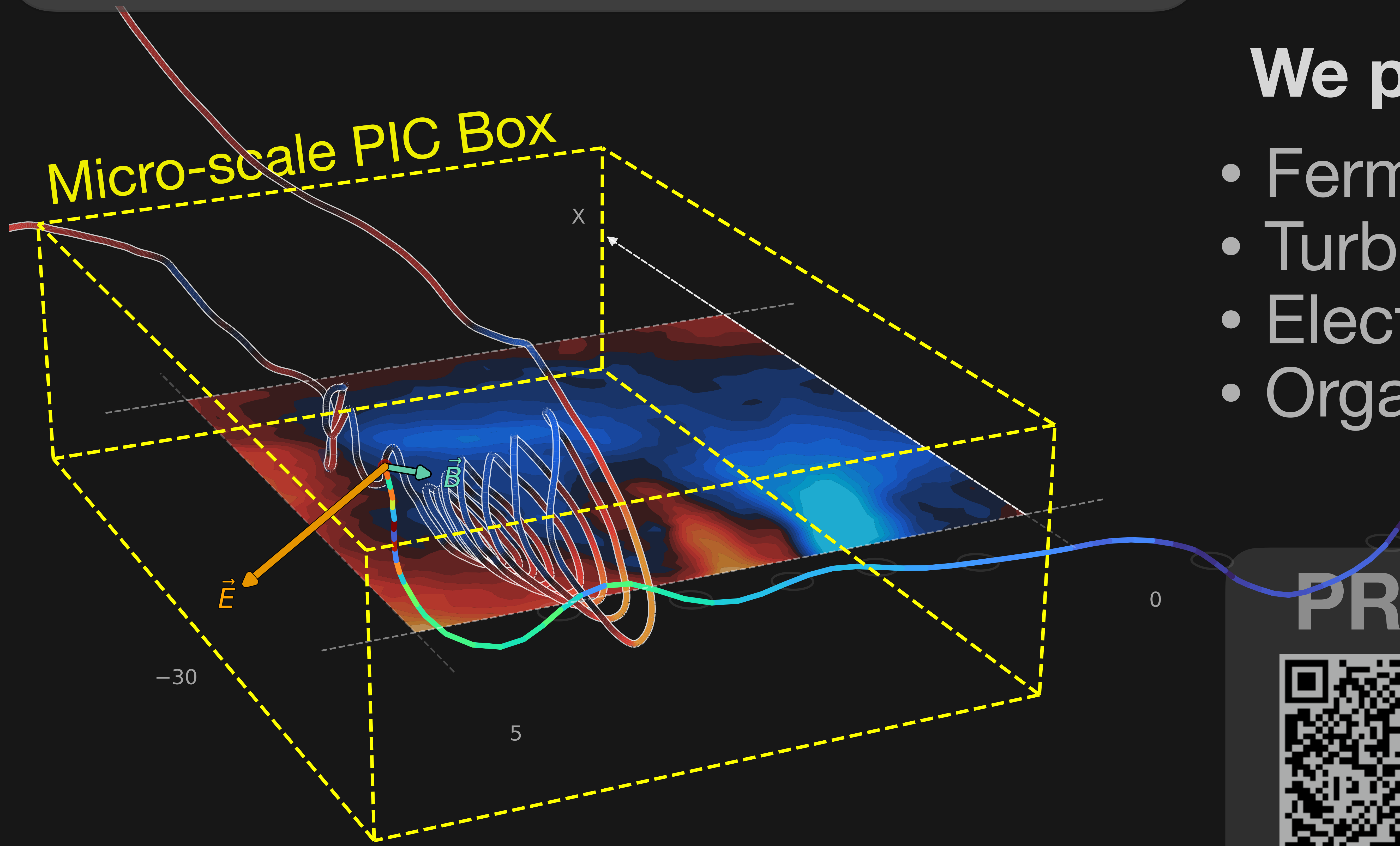
- We see a development of a partial ring current

- We have observed a few different acceleration mechanisms

- Energy fluxes in the fast flow channels are consistent with observations



# Next Steps




**We plan to investigate:**

- Fermi/Betatron Acceleration
- Turbulence
- Electron physics
- Organization into BBFs

**PREPRINT**

JGR (submitted)

Model Developer

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