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Properties of Ion and Electron Kappa Distribution in the Earth's Magnetosphere: THEMIS observations

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Kappa Distribution Function and Plasma beta Relation

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On the Relation between Kappa Distribution Functions and the Plasma Beta Parameter in the Earth's Magnetosphere: THEMIS Observations

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Objective

To investigate the properties of Particle Distribution Function for ion and electron and plasma beta parameters in several magnetopsheric region near the equatorial plane.

Differential Energy Flux

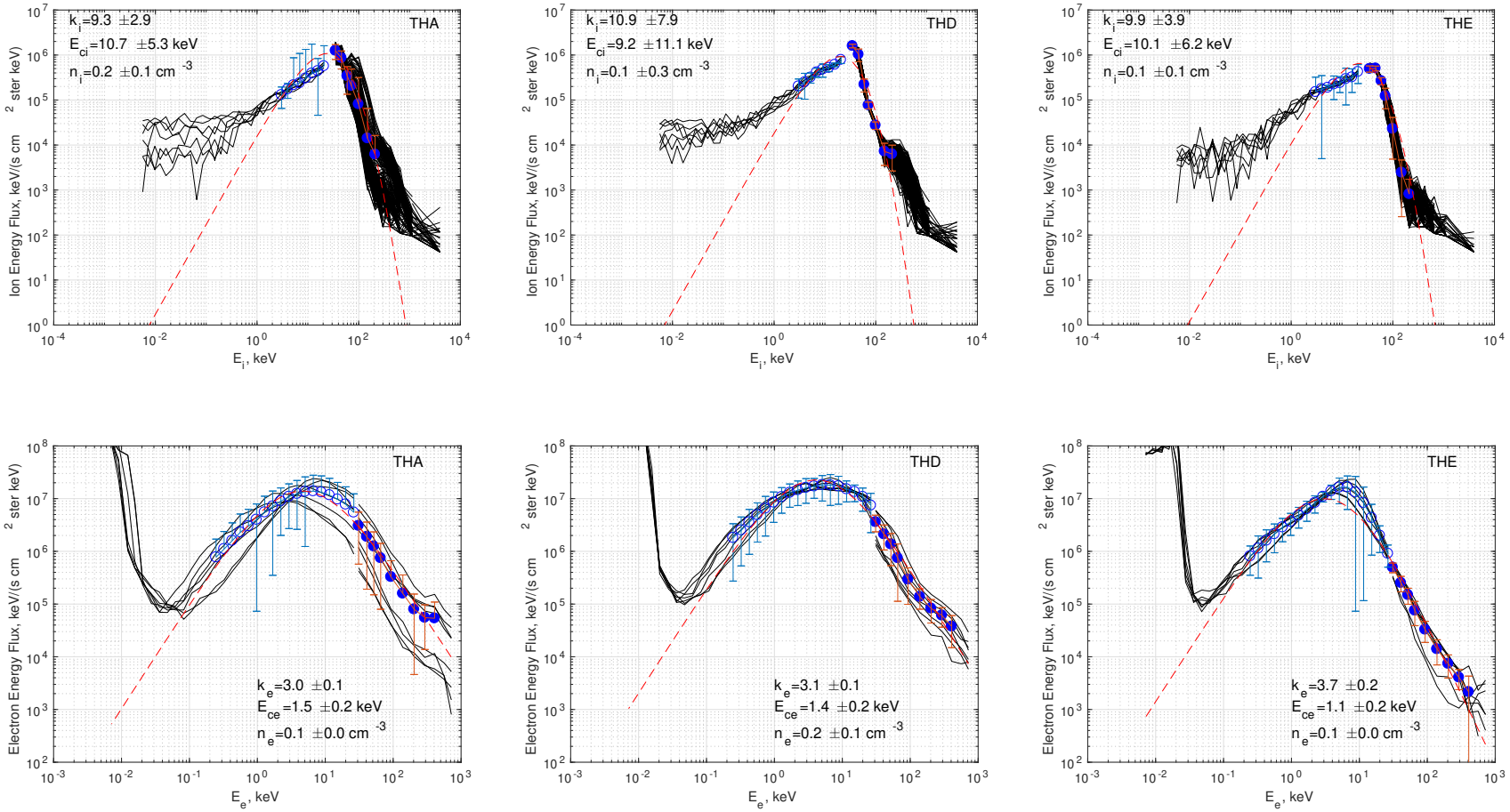
1. The differential energy flux;

$$F_\alpha(E) = \frac{1}{\pi}\frac{n_\alpha}{\sqrt{2\pi m_\alpha}}\frac{E^2}{E_{c_\alpha}^{3/2}}\frac{\Gamma(\kappa_\alpha)}{\Gamma(\kappa_\alpha - \frac{1}{2})\sqrt{\kappa_\alpha}}\left[1 + \frac{E}{\kappa E_{c_\alpha}}\right]^{-\kappa_\alpha - 1} \quad (1)$$

- The differential energy flux $F_E(E)$ is measured in $1/(\mathrm{cm}^2\ \mathrm{s}\ \ \mathrm{ster})$.
- Fitted κ-distributions to thousands of ion and electron energy flux spectra.
- κ_α primarily provides a measure of the departure of the stationary states far from equilibrium.[1]

[1] Burlaga et. al. (2005): "Tsallis distributions of the large-scale magnetic field strength fluctuations in the solar wind from 7 to 87 AU"; JOURNAL OF GEOPHYSICAL RESEARCH; VOL. 110; A07110 .

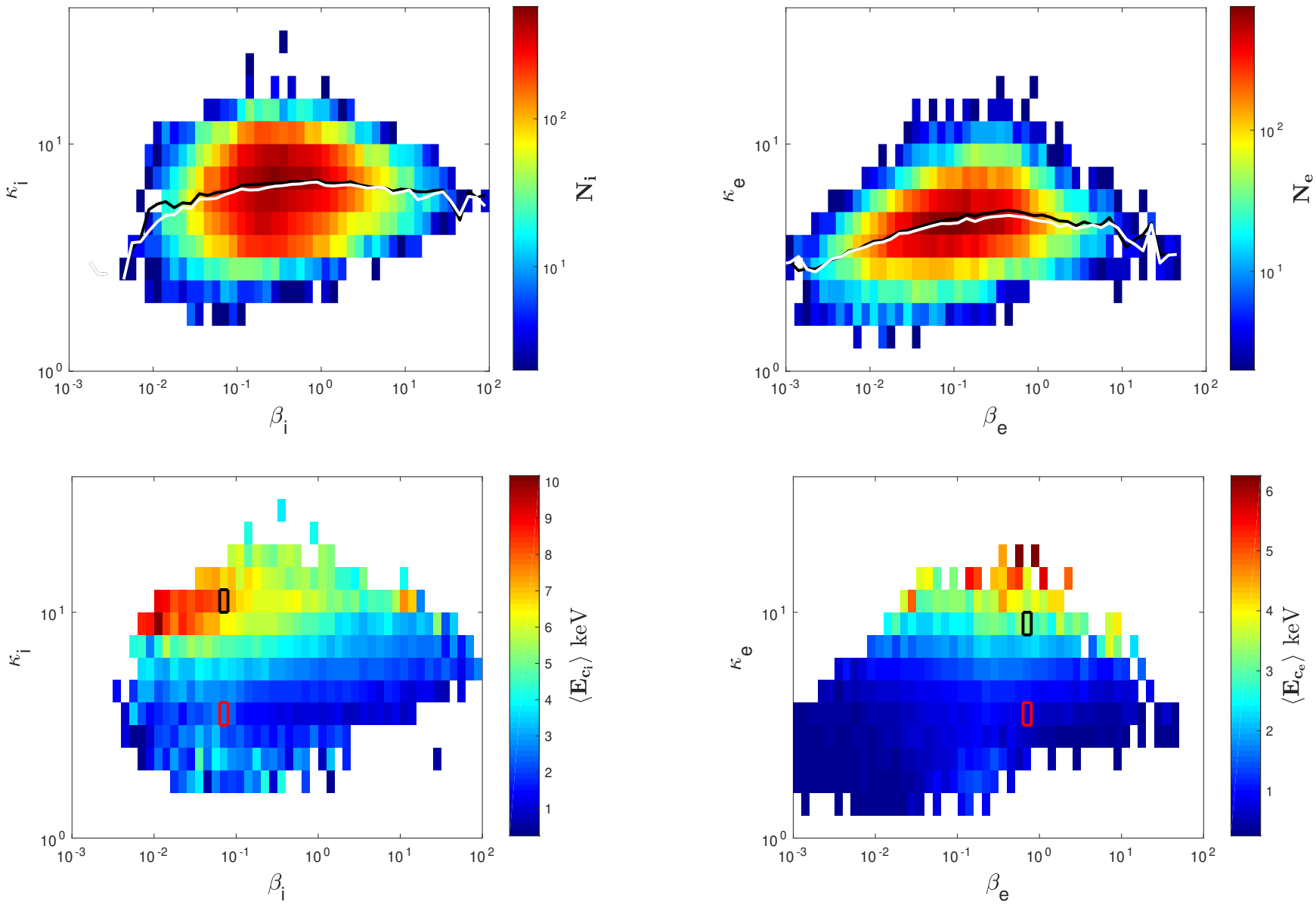
Examples of κ-distributions fits



ESA+SST energy range

- ion fluxes 1.75-210 keV
- electron fluxes 0.36-203.5 keV
- Data collected are averaged over 12 minute long intervals

Relationship between beta, kappa and core energy

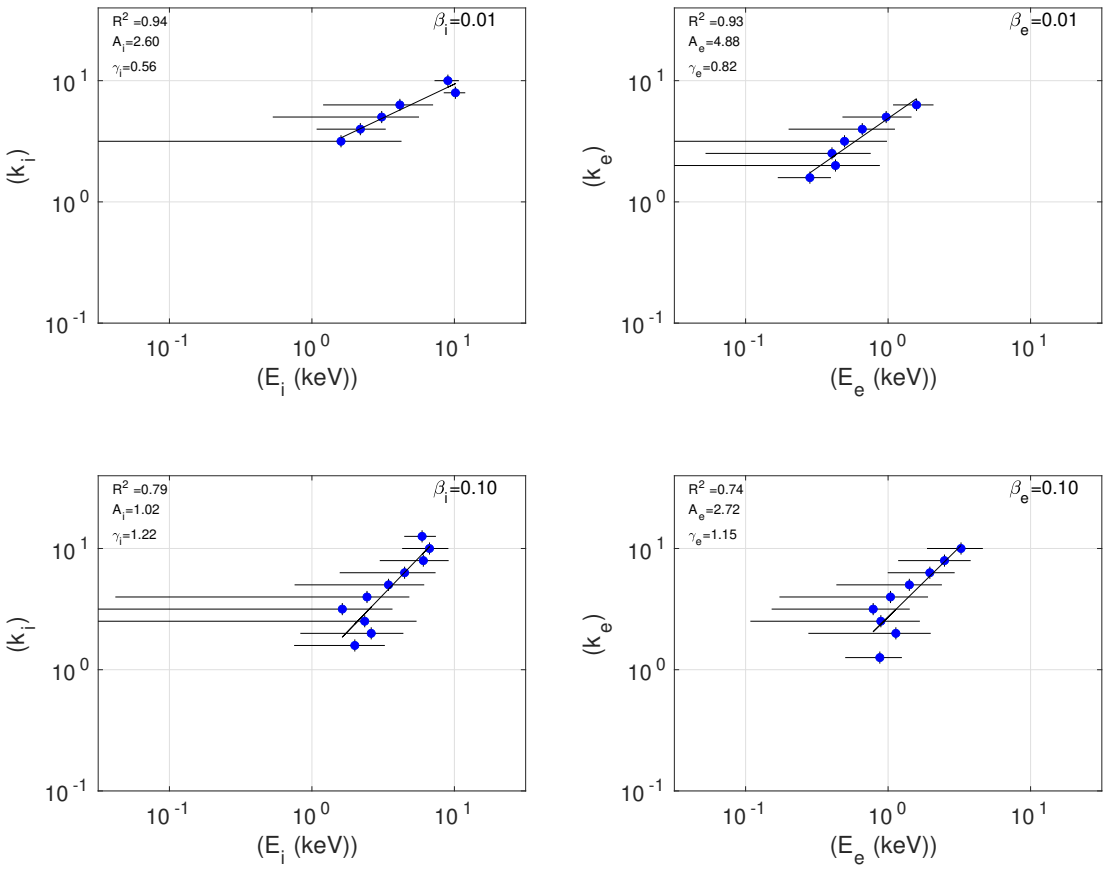


[Eyelade et al., 2021a, ApJSS]

Dependence of kappa on core energy for different constant Plasma Beta

- non-linear relationship between κ and energy
- Fit to power-law model

$$\boxed{\kappa = f(E) = AE^{\gamma}}$$



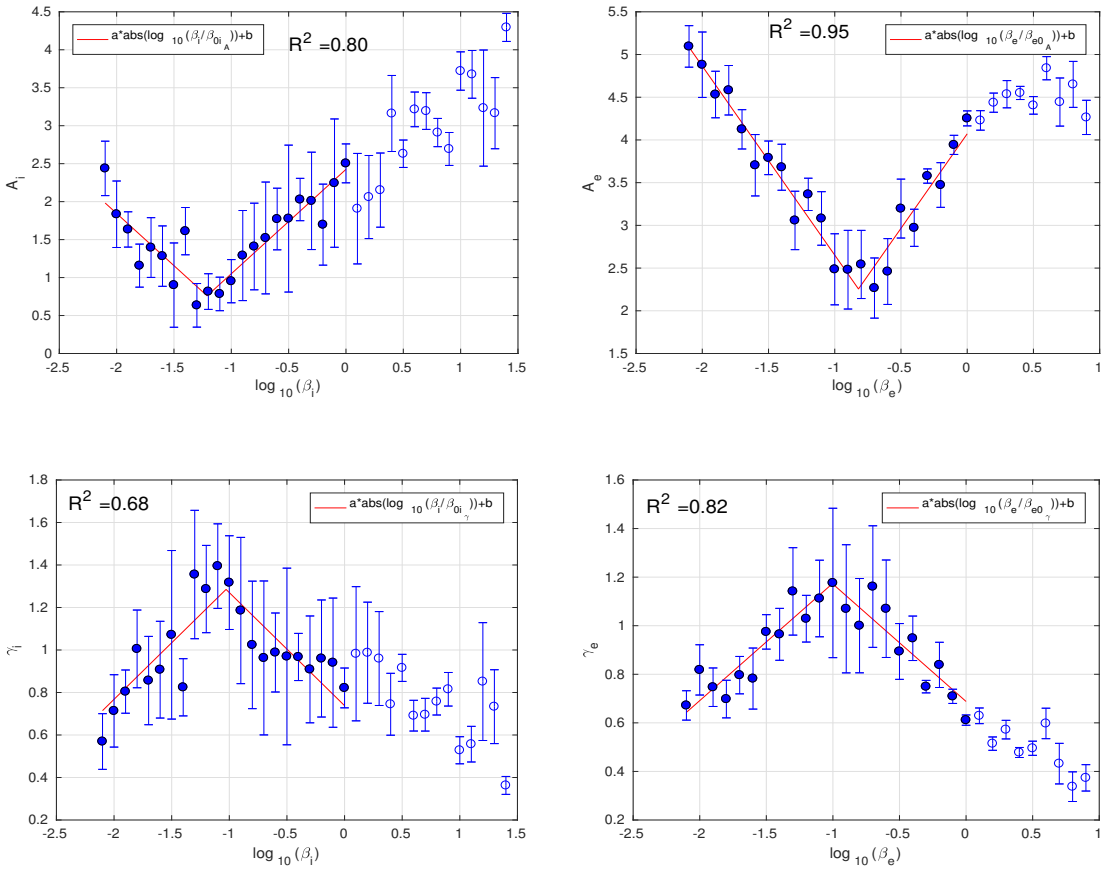
[Eyelade et al., 2021a, ApJSS]

Power-law coefficients Relationship with Plasma Beta

$$a|\log_{10}(\beta/\beta_0)| + b$$

$$\kappa = f(E) = AE^{\gamma}$$

- Presence of extremums near $\beta_0 \sim 0.1$
- Magnetic field controls the dynamics $\beta < 0.1$
- Kinetic instabilities dominate in $\beta > 1$
- Saturation of power-law coefficients $\beta > 1$



[Eyelade et al., 2021a, ApJSS]

Summary I

- The observations of **ion and electron energy fluxes** made by the THEMIS mission instruments allowed us to study the behavior of the Kappa distribution parameters for 47,058 cases, in which we **successfully modeled** the spectra of both species **with *kappa*-functions which gives three free parameters (density (n), kappa-index (κ), and core energy (E_c))**.

- A more detailed study for both species revealed a robust correlation of the power-law form $\kappa = AE_c^{\gamma}$ for fixed plasma beta conditions. This **power-law form exhibits a non-linear relation between kappa and core energy**.

- Evidence suggests that **the power-law coefficients** (A and γ) **depend on** β, the values of A **are found to exhibit a minimum near** $\beta \sim 0.1$; while the power-law indices γ exhibit a **maximum** at around the same value of β. **The presence of extremums near** $\beta \sim 0.1$ **indicate the existence of two plasma regimes**.

- **Some combinations of κ and β are absent in the studied plasmas. More in depth studies using theoretical models and simulations might help us to understand the dynamics responsible for such behaviour.**

Kappa Distribution Function and MHD Turbulence

frontiers in Astronomy and Space Sciences

ORIGINAL RESEARCH
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Influence of MHD Turbulence on Ion Kappa Distributions in the Earth's Plasma Sheet as a Function of Plasma β Parameter

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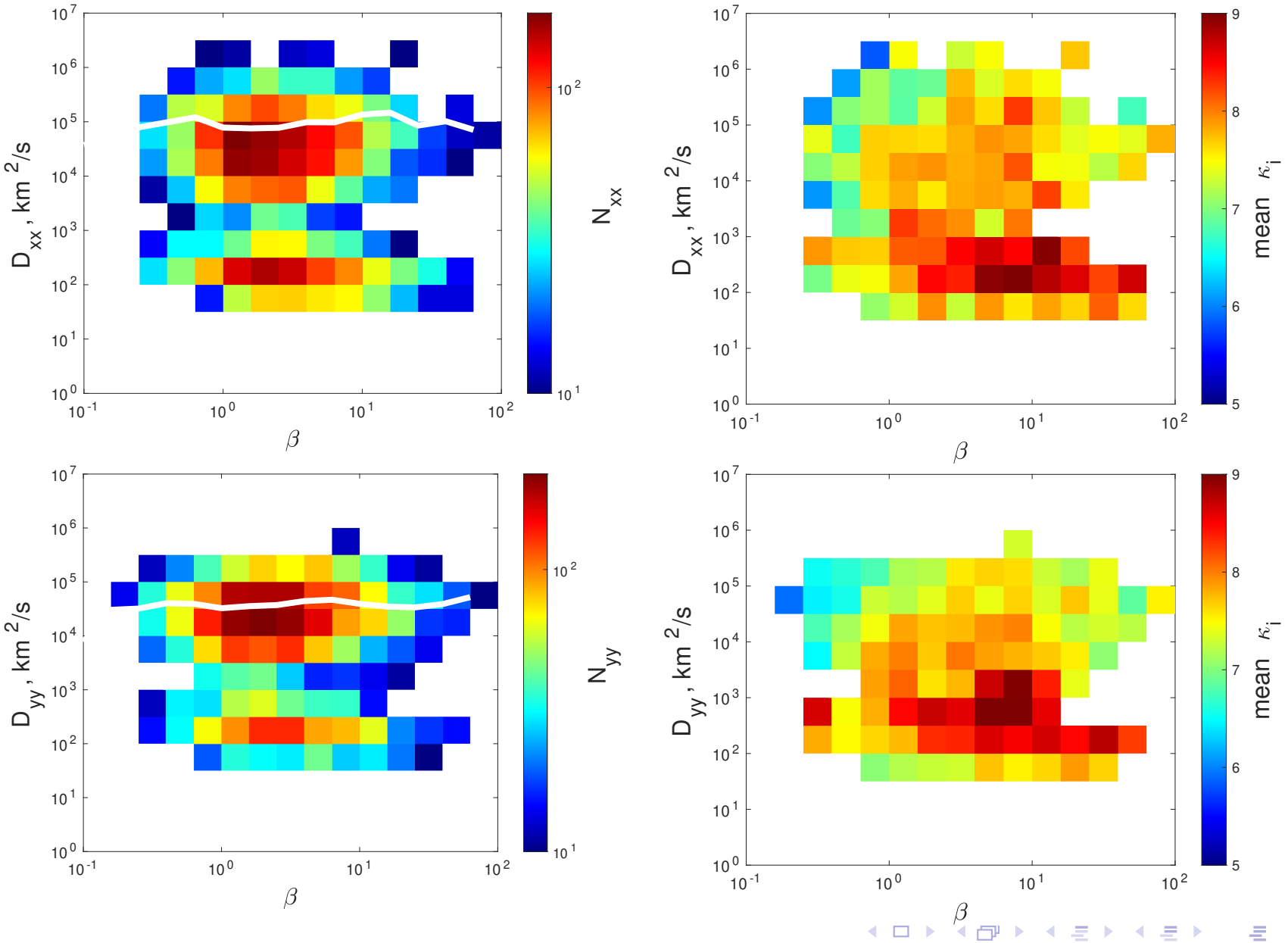
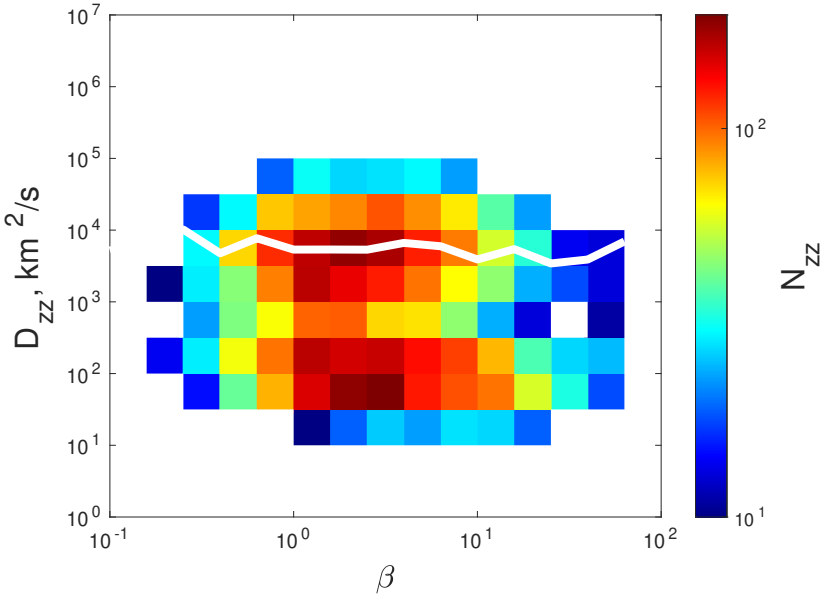
Motivation II

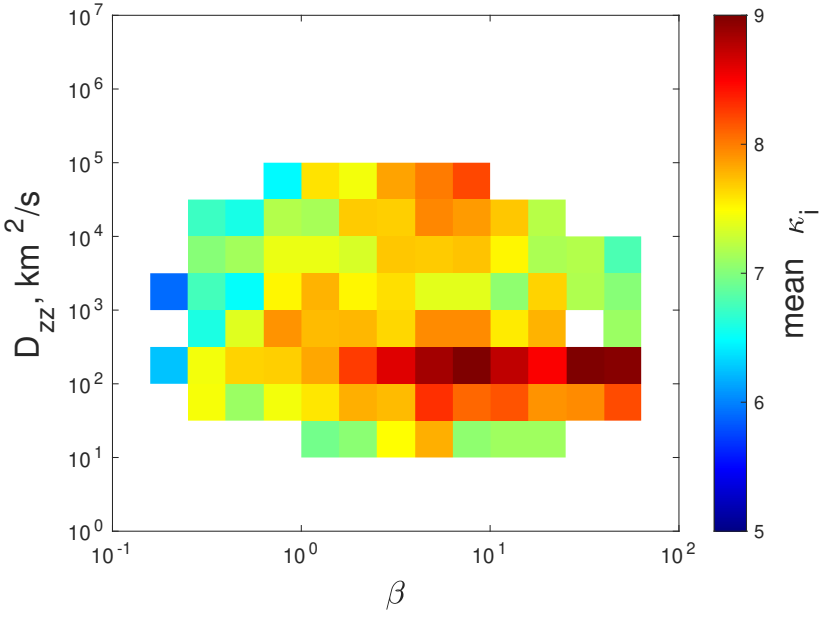
In the previous presentation, we saw that the behavior of the Kappa distribution function is sensitive to the plasma beta parameter in the Earth's magnetosphere. The presence of turbulence is another plasma property related to plasma beta. It will be interesting to see if both phenomena are related in terms of turbulent particle acceleration and turbulent plasma mixing.

Eddy diffusion coefficients and κ indices as a function of β



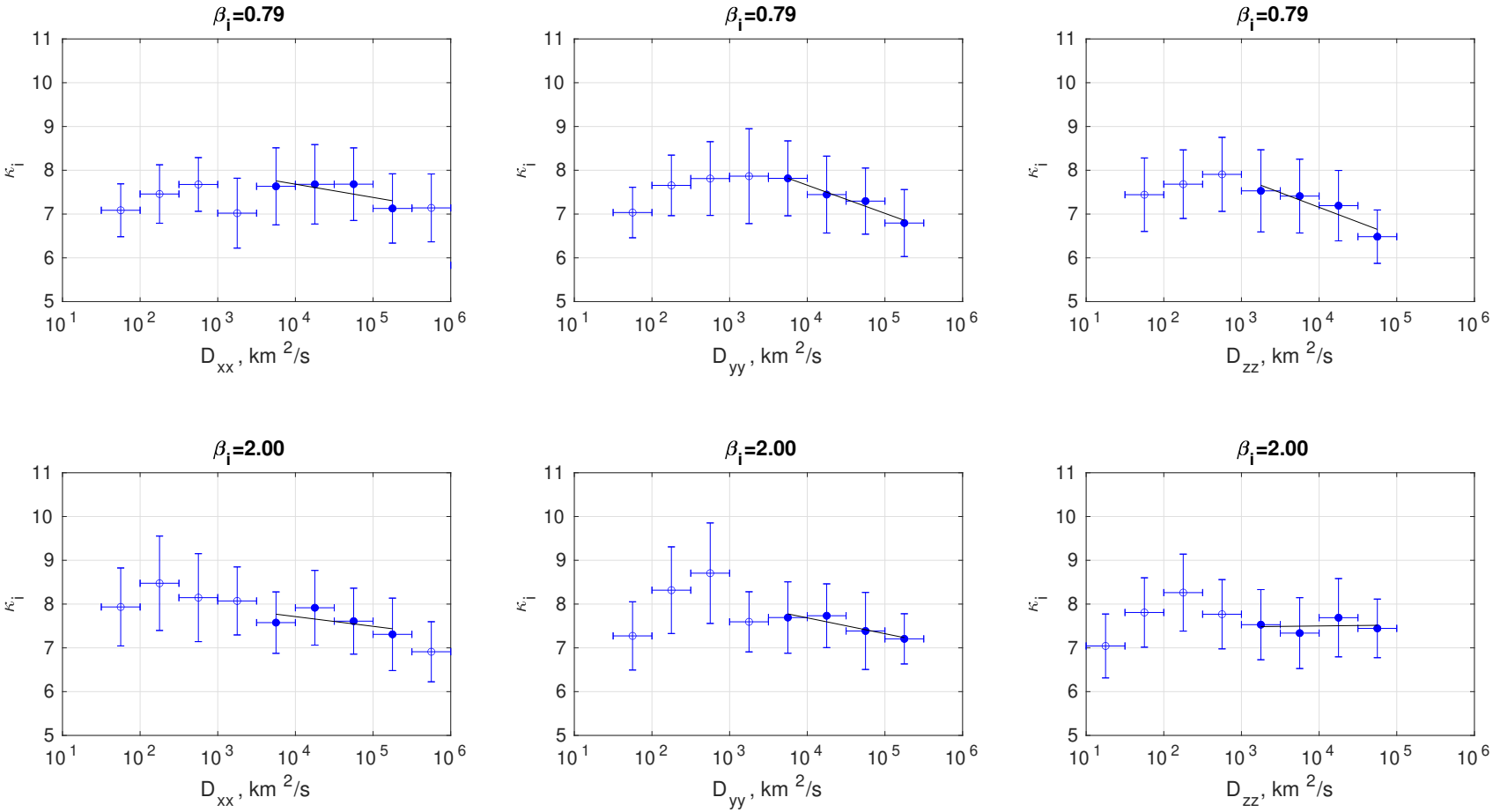
Eddy diffusion coefficients and κ indices as a function of β



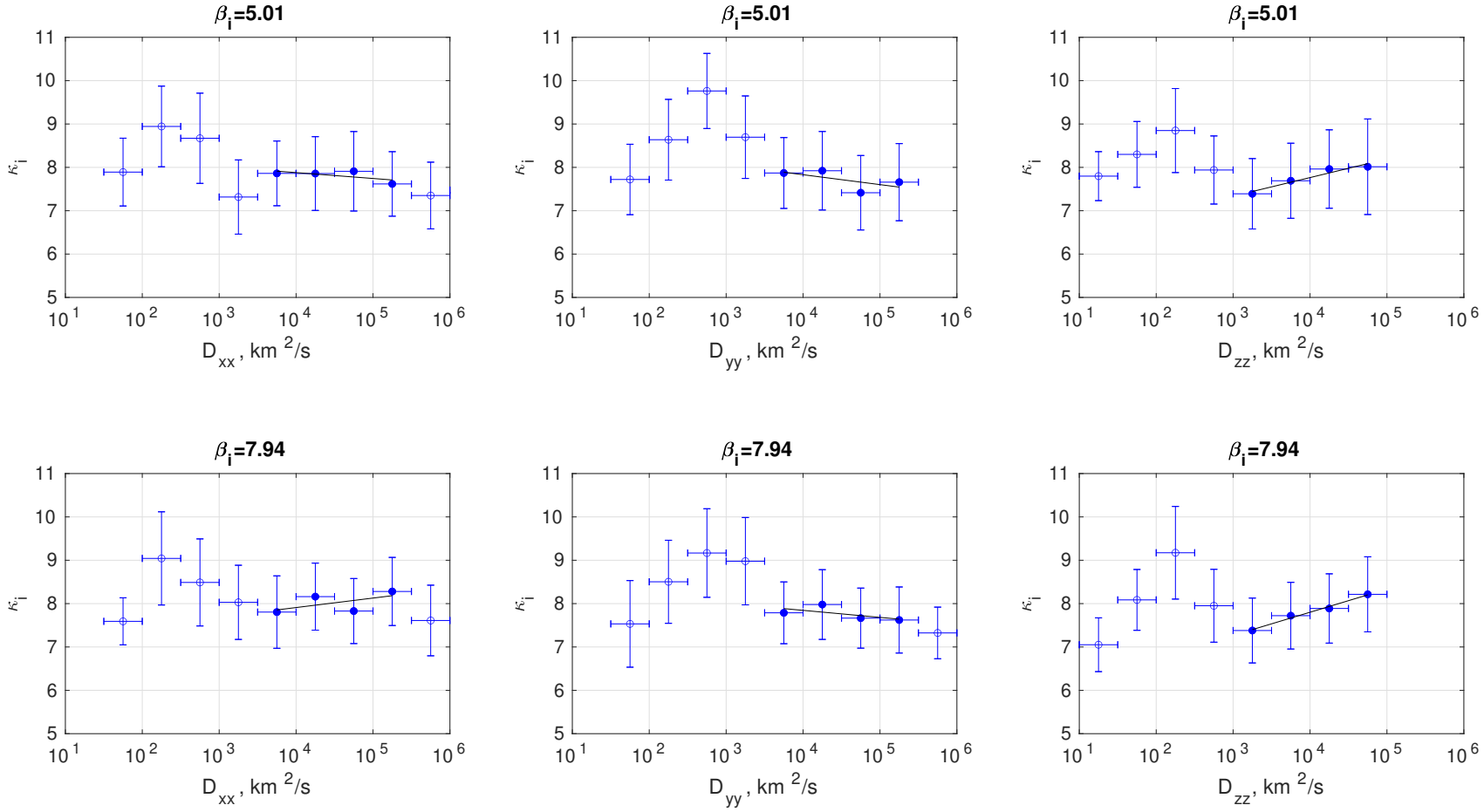


Dependence of kappa on Eddy diffusion for a fixed plasma beta

$$\kappa = A \log_{10} D + B$$

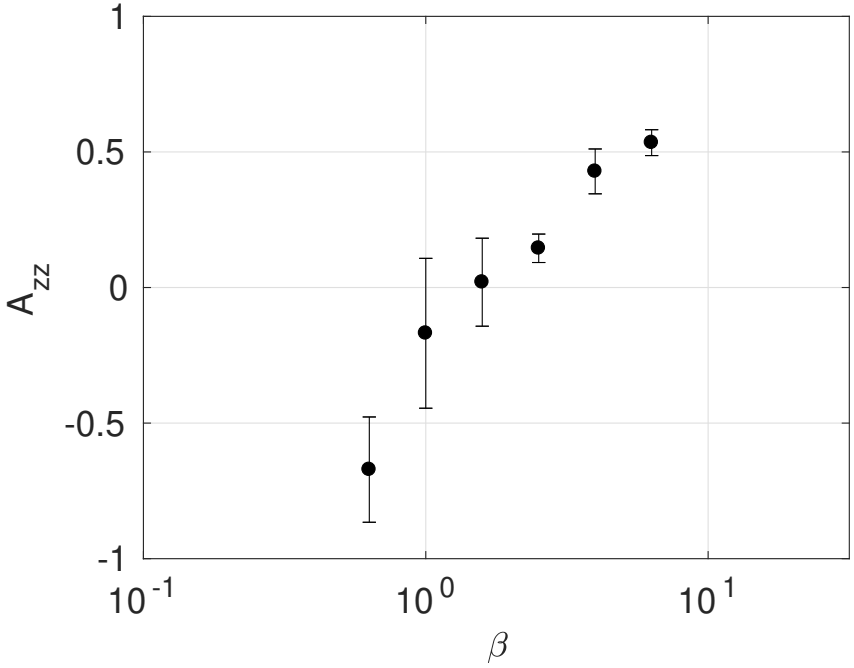


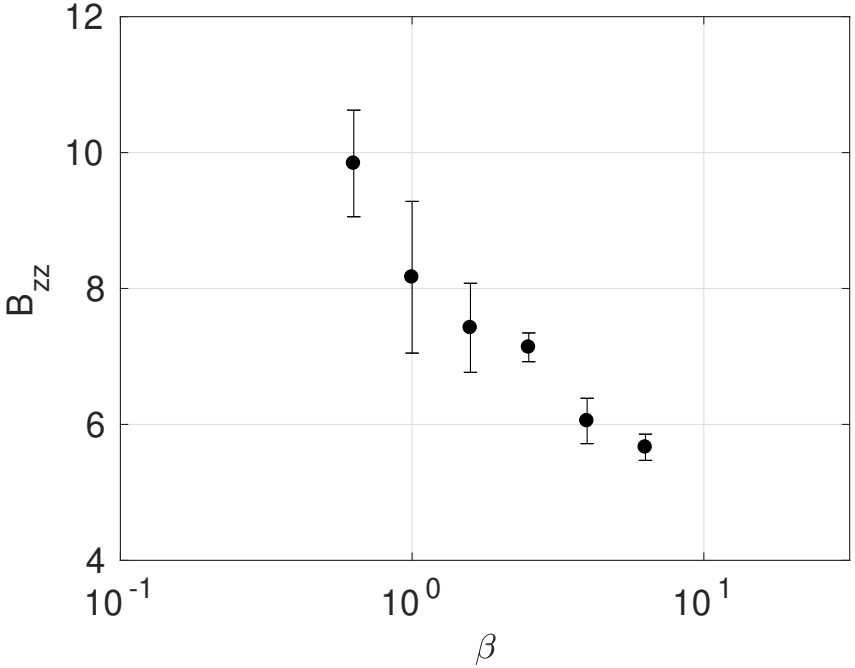
Dependence of kappa on Eddy diffusion for a fixed plasma beta



Behavior of measured slopes (A) and intercepts (B) contd

$$\kappa = \mathrm{A}\log_{10}\mathrm{D} + \mathrm{B}$$





- EDC in $\beta > 2$ plasmas might stabilize the distribution function to Maxwellian in zz-component
- Turbulent mixing start to predominate and thermalize plasma at $\beta > 2$

Summary II

- **We established a functional form to relate the eddy diffusion coefficients and the kappa-indices for a given beta value, and found how the functional form varies with plasma beta.**

- The **MHD turbulence might have an intermittent character as most** β **values of the eddy diffusion coefficients vary over a wide range (** 10^1-10^6 **km**^{2}**/s)**. Nonetheless, the majority of **the coefficients concentrate around** 10^4-10^5 **km**^{2}**/s, which correspond to medium scale vortices** with scales of $\sim 10,000$ km **that contribute to turbulent transport**.

- At the same time, **turbulent flows alternated with quasi-laminar flows (**$D \sim 10^2$ **km**^{2}**/s), which might belong to large vortexes that are beyond the detection limits of our method**.

- For turbulent plasmas, **several processes related to MHD turbulence lead to either an increase or decrease of the** κ **index, depending on the value of** β **and the direction of the turbulent transport with respect to the plasma sheet**.

Global and Spatial Ion Kappa Distribution Parameters

JGR Space Physics

RESEARCH ARTICLE
10.1029/2021JA029409

Key Points:

- Ion spectra obtained from the Time History of Events and Macroscale Interactions during Substorms satellite mission near the equatorial plane are fitted by a kappa distribution function
- Distribution of three fitting parameters (density, core energy, value of k characterizing the spectra slope at high energies) are obtained
- Region of increased k index at geocentric distances 8–10 R_E is selected

Ion Kappa Distribution Parameters in the Magnetosphere of the Earth at Geocentric Distances Smaller Than 20 R_E During Quiet Geomagnetic Conditions

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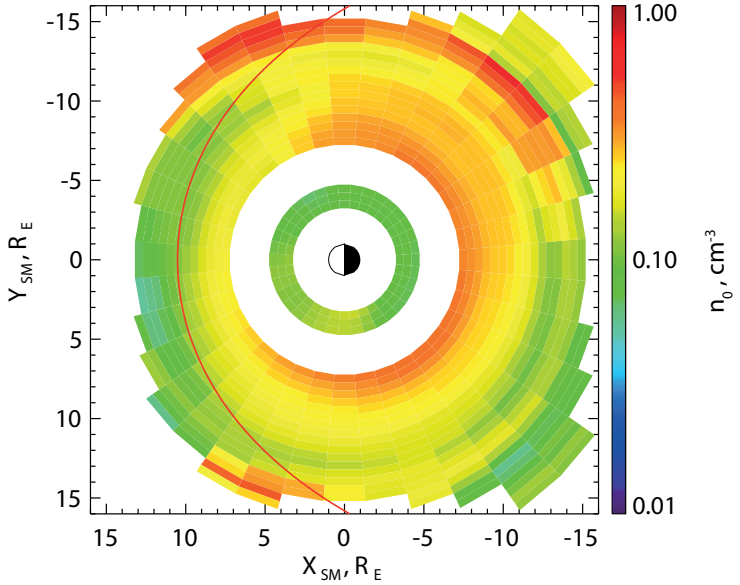
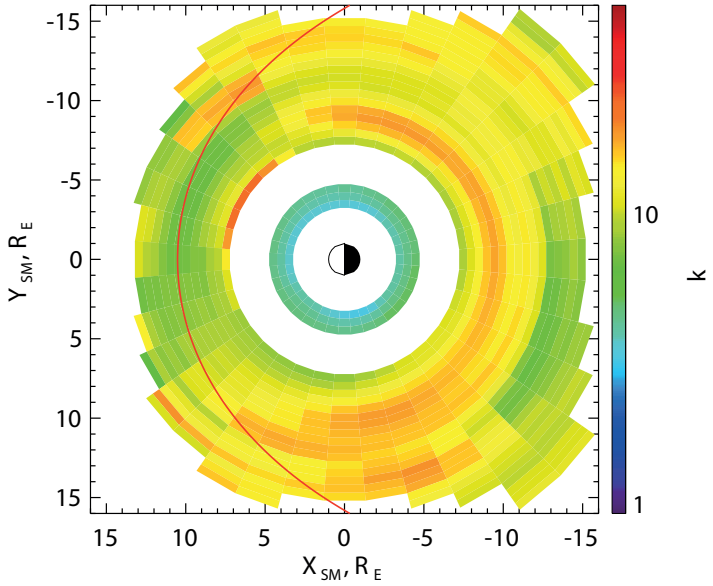
Abstract The Earth's magnetosphere is mainly a collisionless plasma system with non-Maxwellian particle distributions, which are often fitted by the kappa function. While the Maxwell distribution

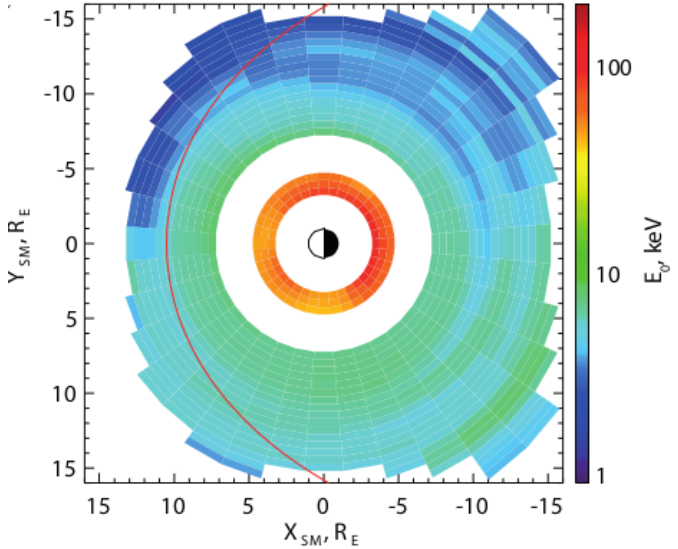
Motivation III

Despite having the same plasma beta parameter values ($\beta \sim 0.1$) in both the inner magnetosphere near the earth and the tail lobes, the geomagnetic field values are of different order, resulting in different plasma processes. Instead of looking at the plasma beta parameter, we will look at the spatial distribution of kappa parameters in the magnetosphere near the equatorial plane in order to identify the region of particle acceleration.

Distribution of the n_0, E_0, and κ-index parameter at the equatorial plane







- Observed decrease of n_0 in the dayside
- observed crescent-like kappa maximum ($\kappa > 10$) between 7 and 10R_E


THANK YOU
FOR YOUR ATTENTION