Медленные электронные дыры в Земной магнитосфере

Сергей Камалетдинов[1,2], Иан Хатчинсон[3] , Иван Васько[4,1],

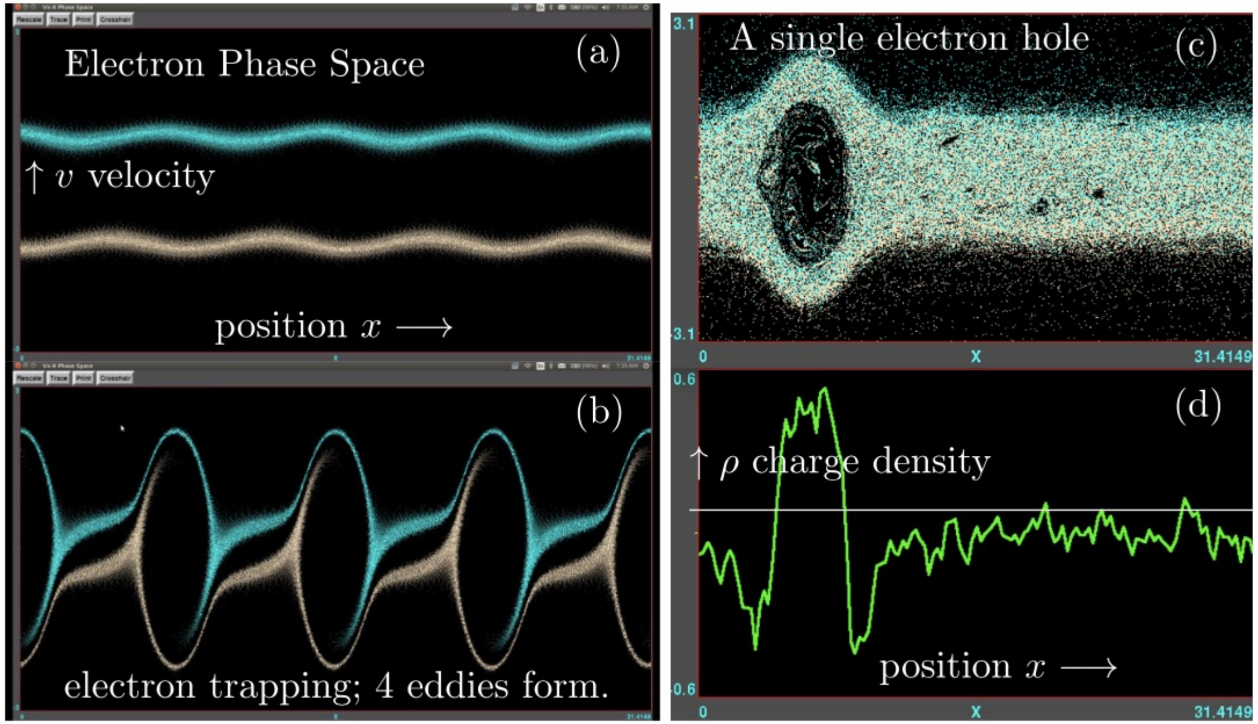
Антон Артемьев[6,1], Эджей Лотекар[7], Форрест Мозер[4]

[1]Институт Космических Исследований РАН, г. Москва (serjesmail@gmail.com)

[2]Факультет Физики, Национальный исследовательский университет "Высшая школа экономики", г. Москва
[3]Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[4]Space Science Laboratory, University of California, Berkeley, California, USA

[5]University of California, Los Angeles, California, USA
[6]Swedish Institute of Space Physics, Uppsala, Sweden
[7]Department of Physics, University of California at Berkeley

Electron phase space holes – solitary structures we are interested in

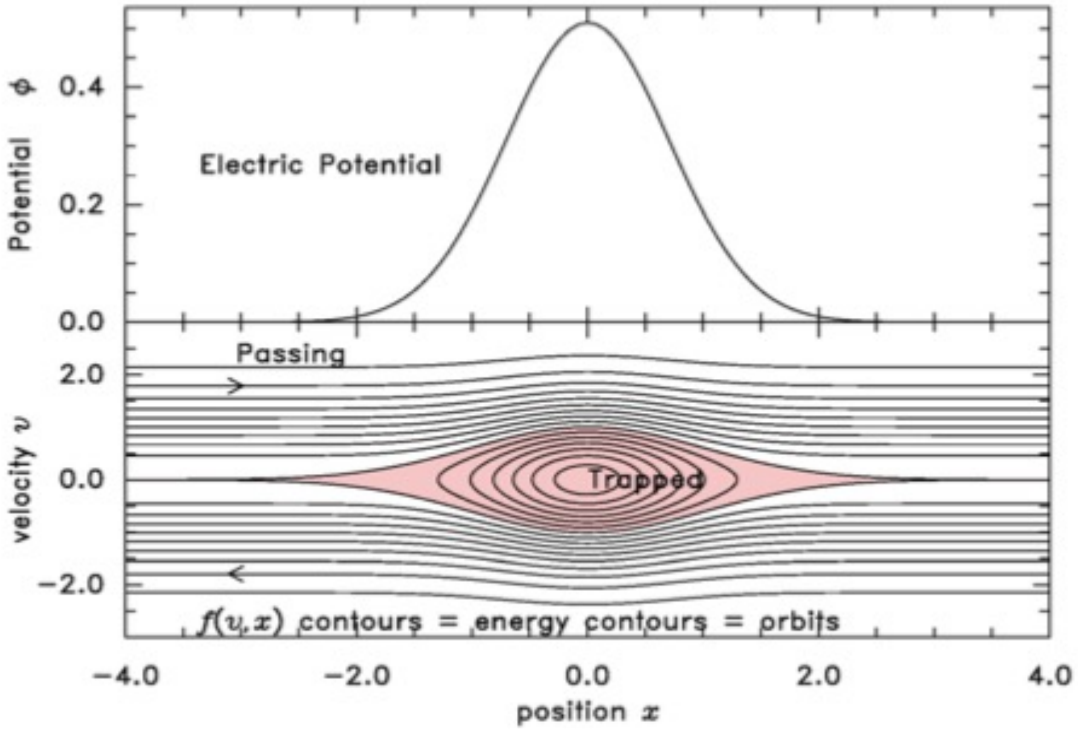


Electron-phase-space holes are formed in a nonlinear stage of various electron streaming instabilities (bump-on-tail, two-stream, Buneman)

see, e.g., Omura+, jgr, 1996; Drake+, Nat., 2003

In spacecraft measurements they are observed as solitary waves with positive potentials

these solitary waves are kinetic modes existing due to a depletion of the phase space density of trapped electrons

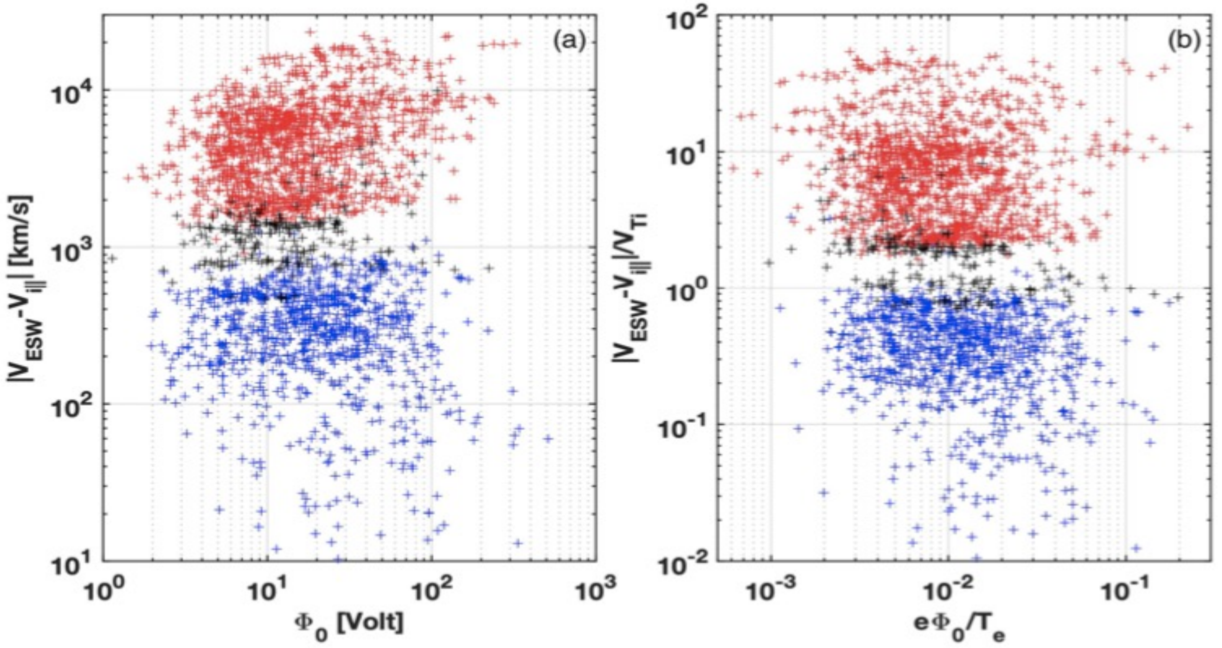


see, e.g., Hutchinson, Phys.Plasmas, 2017

JGR Space Physics

Multisatellite MMS Analysis of Electron Holes in the Earth's Magnetotail: Origin, Properties, Velocity Gap, and Transverse Instability

A. Lotekar[1], I. Y. Vasko[2], F. S. Mozer[2], I. Hutchinson[3], A. V. Artemyev[4,5], S. D. Bale[2], J. W. Bonnell[2], R. Ergun[6], B. Giles[7], Yu. V. Khotyaintsev[8], P.-A. Lindqvist[9], C. T. Russell[5], and R. Strangeway[5]



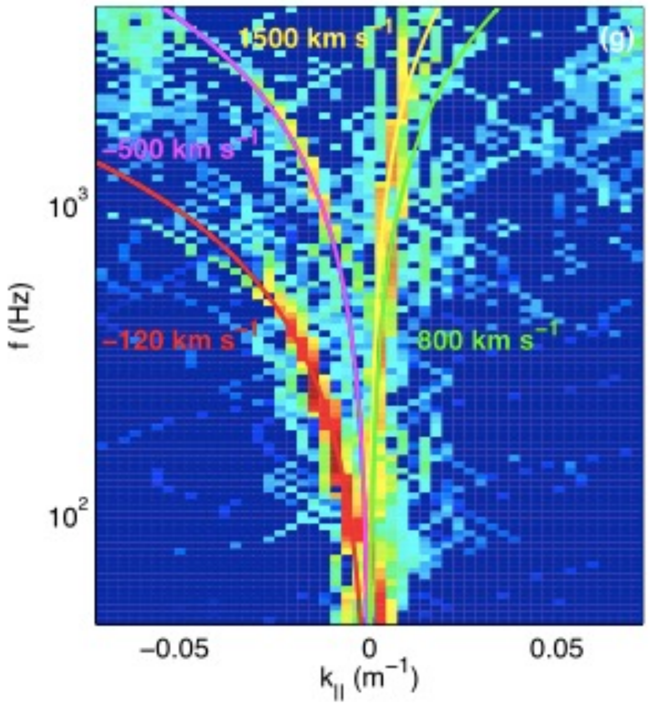
1. Electron holes have distinctly different velocities in the plasma rest frame, $|V_{ESW}-V_{i||}|$ is in the range from just a few km/s up to 20,000 km/s, electrostatic potential amplitudes Φ_0 are from a few up to a few hundred volts and parallel spatial scales $d_{||}$ are from 0.5 up to 30 km. In normalized units the spatial scales and amplitudes are typically $\lambda_D \lesssim d_{||} \lesssim 10\ \lambda_D$ and $10^{-3}\ T_e \lesssim e\Phi_0 \lesssim 0.1\ T_e$. The parallel spatial scales are shown to be correlated with a local Debye length λ_D.

6. The statistical analysis of time intervals between sequentially observed fast and slow electron holes showed that electron holes of the different types are not associated with each other and produced by instabilities, which operate independently.

Geophysical Research Letters

Electrostatic solitary waves with distinct speeds associated with asymmetric reconnection

D. B. Graham[1], Yu. V. Khotyaintsev[1], A. Vaivads[1], and M. André[1]



1. ESWs with distinct time scales, corresponding to ESWs with distinct speeds and length scales, are observed at the dayside magnetopause.
2. The ESWs were observed near the separatrices of asymmetric reconnection where magnetospheric and magnetosheath electrons were observed. When the ESWs are observed, the magnetosheath electron population dominates, suggesting that magnetosheath electrons are responsible for ESW generation.
3. The observation of ESWs with distinct speeds suggests that multiple instabilities are active at the magnetopause when magnetic reconnection is occurring.

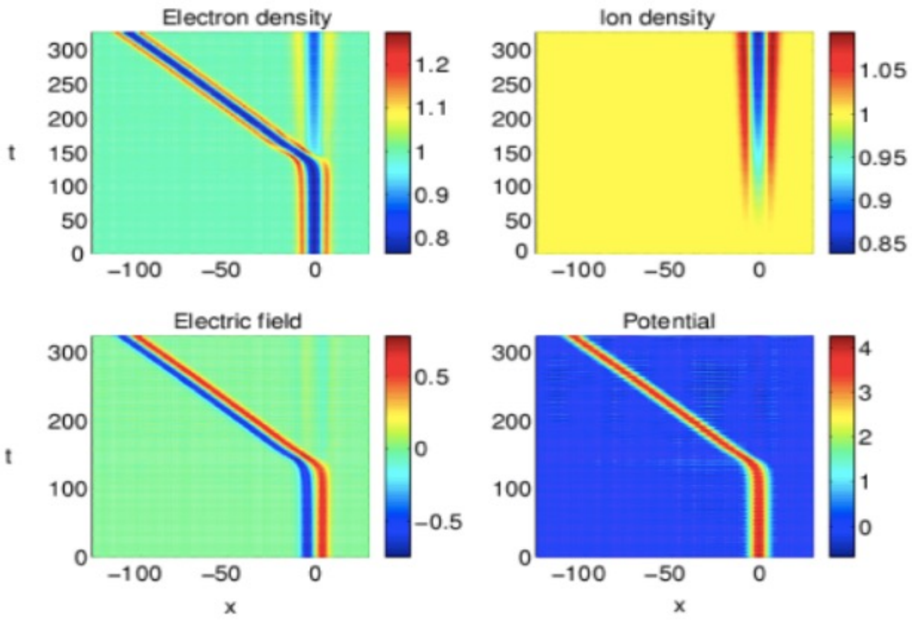
The problem of slow electron holes acceleration

Dynamics of Electron Holes in an Electron–Oxygen-Ion Plasma

B. Eliasson and P. K. Shukla
Institut für Theoretische Physik IV, Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, D-44780 Bochum, Germany
(Received 12 March 2004; published 19 July 2004)

The dynamics of electron holes (EHs) in an electron–oxygen-ion plasma is studied by means of Vlasov simulations. It is found that EHs are attracted by ion density maxima but repelled by ion density minima. Standing EHs repel ions owing to the positive EH potential, creating an ion density cavity which ejects the EH, which propagates away from the cavity with a constant speed. On the other hand, propagating EHs can be trapped at ion density maxima. The results of our simulations will help in understanding the nonlinear dynamics of EHs in space and laboratory plasmas.

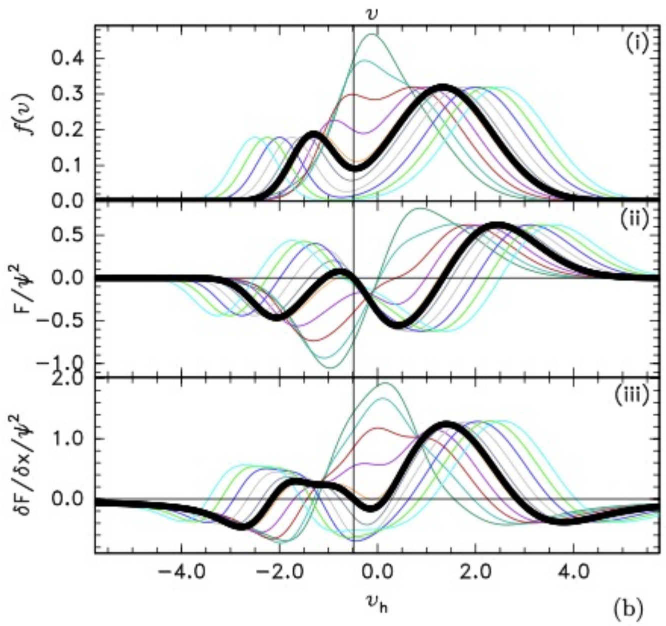
DOI: 10.1103/PhysRevLett.93.045001 PACS numbers: 52.35.Mw, 52.35.Ra, 52.35.Sb, 94.30.Tz



How can slow plasma electron holes exist?

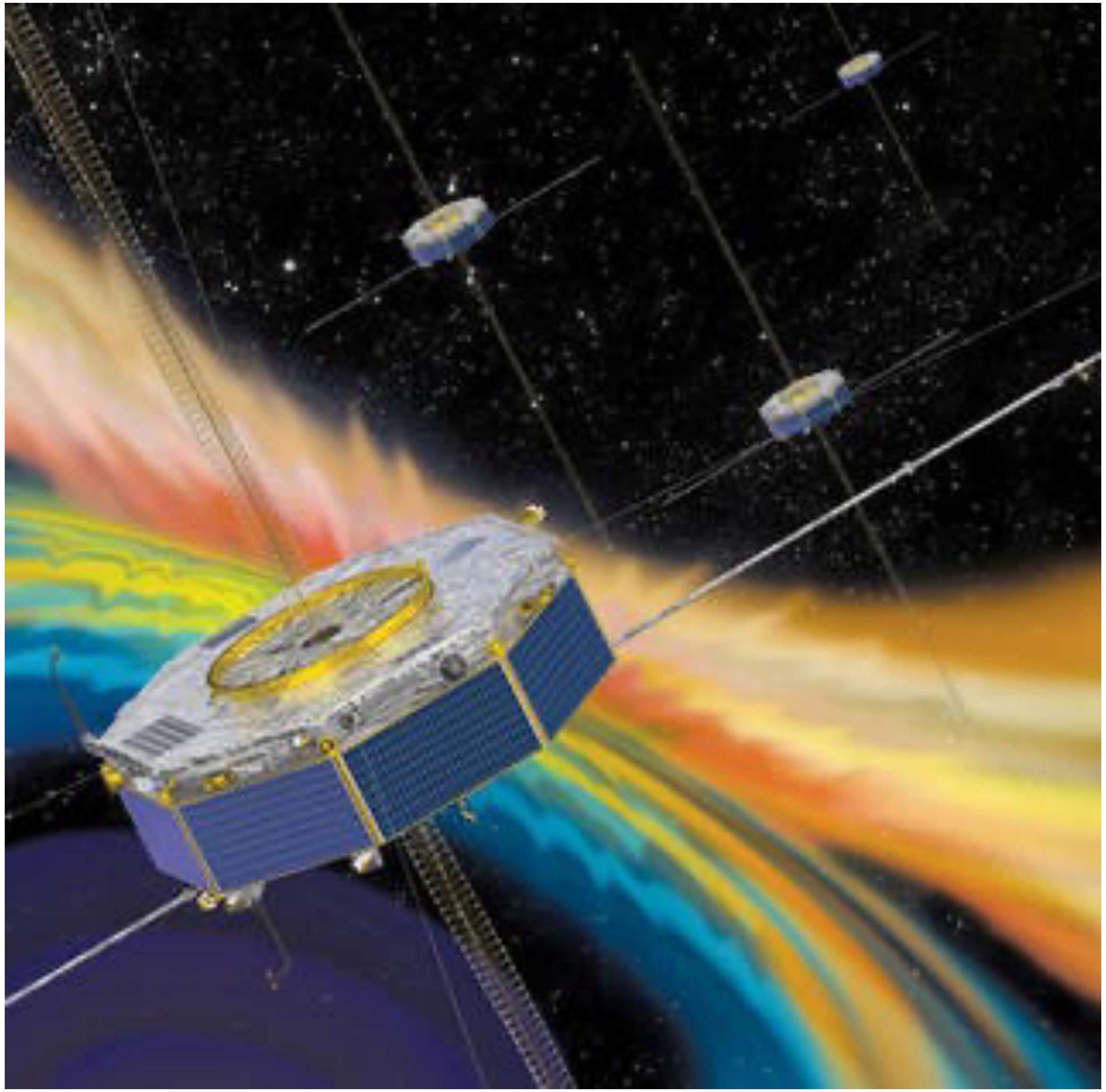
I H Hutchinson
Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA, USA

One dimensional analysis is presented of solitary positive potential plasma structures whose velocity lies within the range of ion distribution velocities that are strongly populated: so called "slow" electron holes. It is shown that to avoid the self-acceleration of the hole velocity away from ion velocities it must lie within a local minimum in the ion velocity distribution. Quantitative criteria for the existence of stable equilibria are obtained. The background ion distributions required are generally stable to ion-ion modes unless the electron temperature is much higher than the ion temperature. Since slow positive potential solitons are shown not to be possible without a significant contribution from trapped electrons, it seems highly likely that such observed slow potential structures are indeed electron holes.

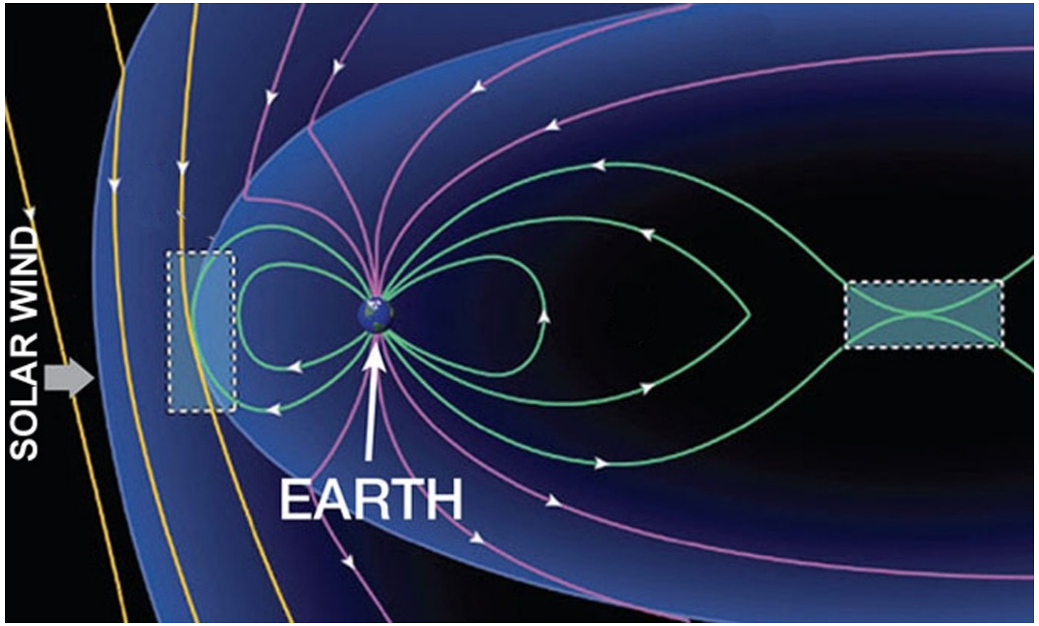


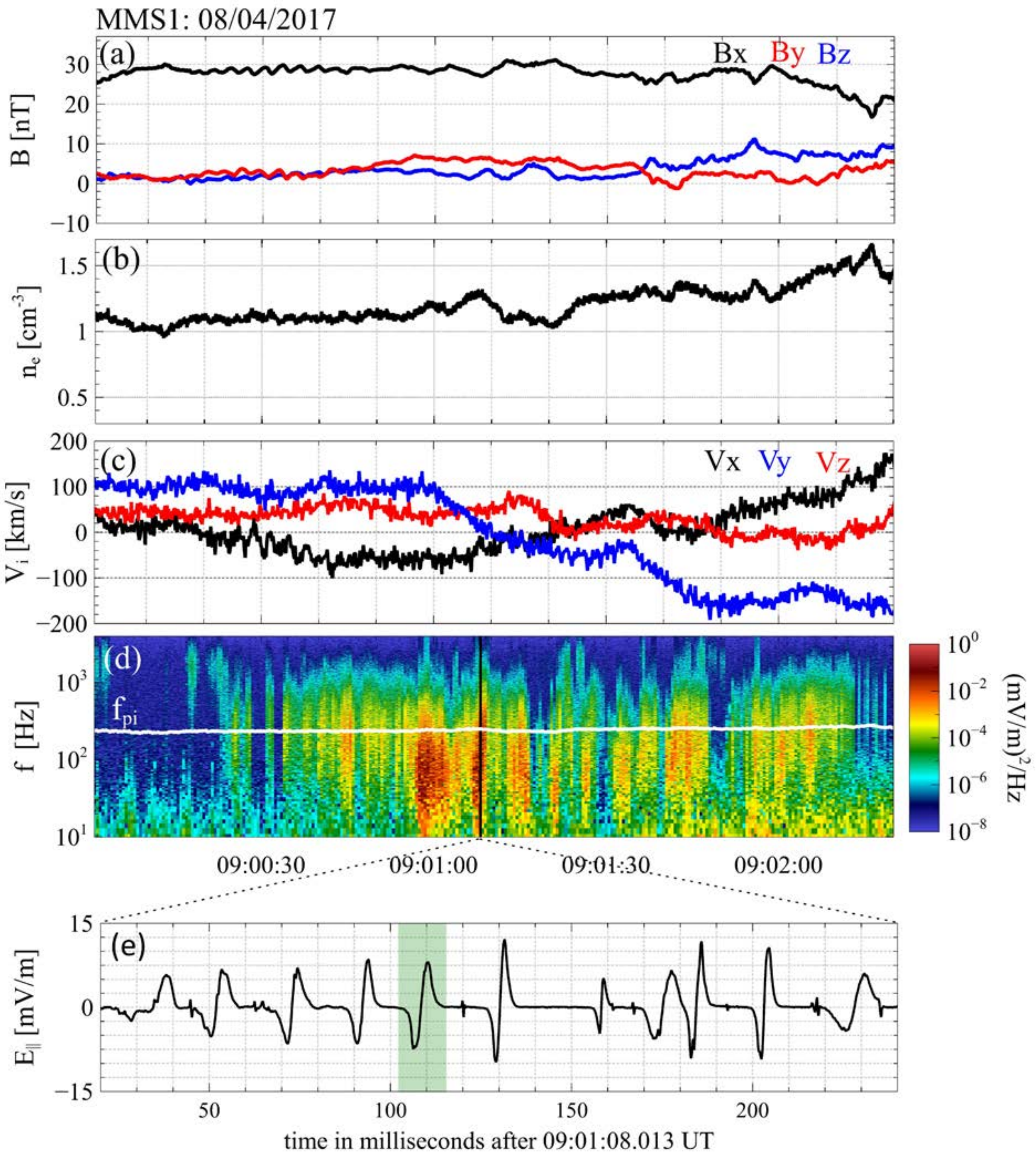
Summary: Slow electron holes certainty cannot be stable in Maxwellian plasmas. But their stability can be achieved in plasmas with non-Maxwellian Ions.

MMS



- **Magnetospheric Multiscale mission**
- **Launched in 2015**
- **Studies Earth's magnetosphere**
- **Four identical spacecrafts flying in a tetrahedron**
- **3D electric field measurements; fast particle measurements**



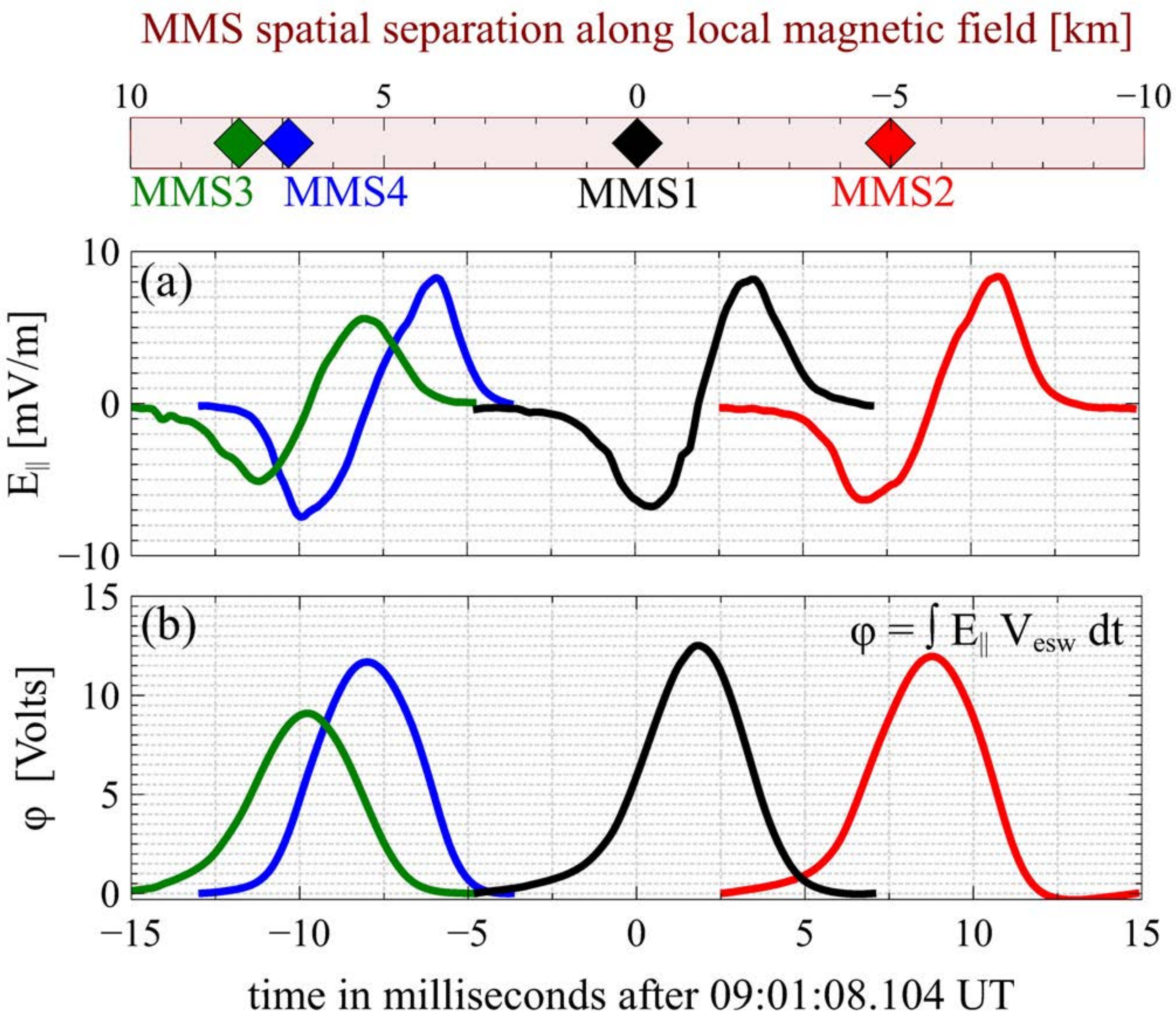


We consider a particular 3 minute long interval of MMS data

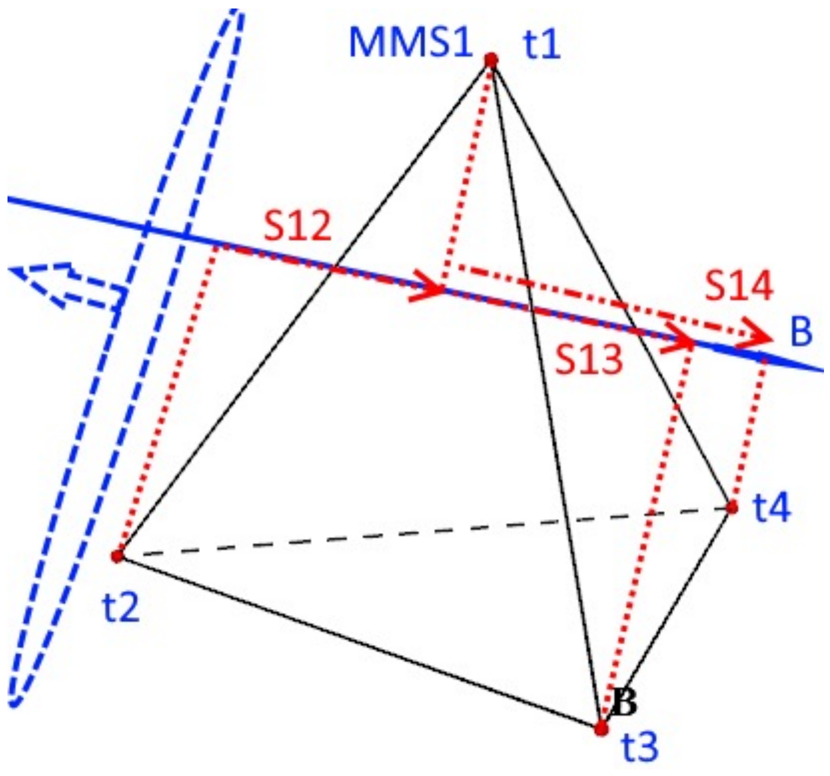
- MMS spacecraft were located at about 20 R_E from the Earth, in the plasma sheet boundary layer
- Quiet conditions with magnetic field was around 30 nT in magnitude and was pointed earthward(along the x-axis in the GSE)
- Electron density remained stationary at the level of 1.3cm^{-3}
- Ion bulk velocity was within 200 km/s
- Broad band electrostatic noise is persistent around the ion plasma frequency f_{pi}

A cluster of of 751 Bi-polar structures with ($\phi > 0$)

Multispacecraft interferometry technique



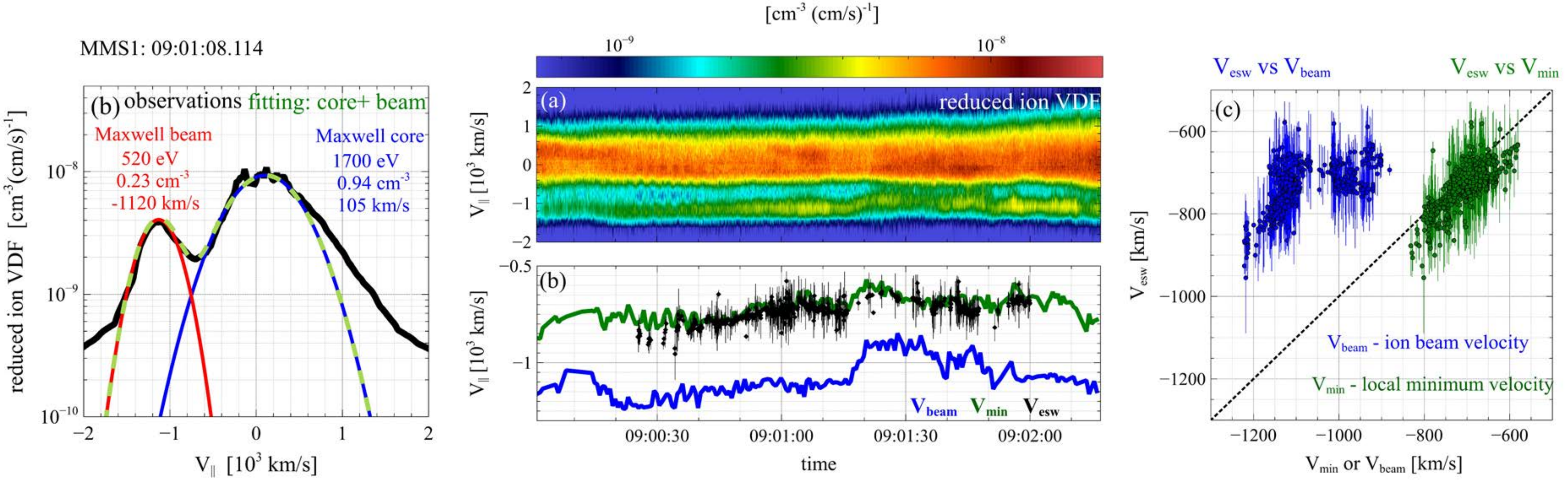
$V_{1i} = S_{1i} /(t_i – t_1)$ i = 2:4



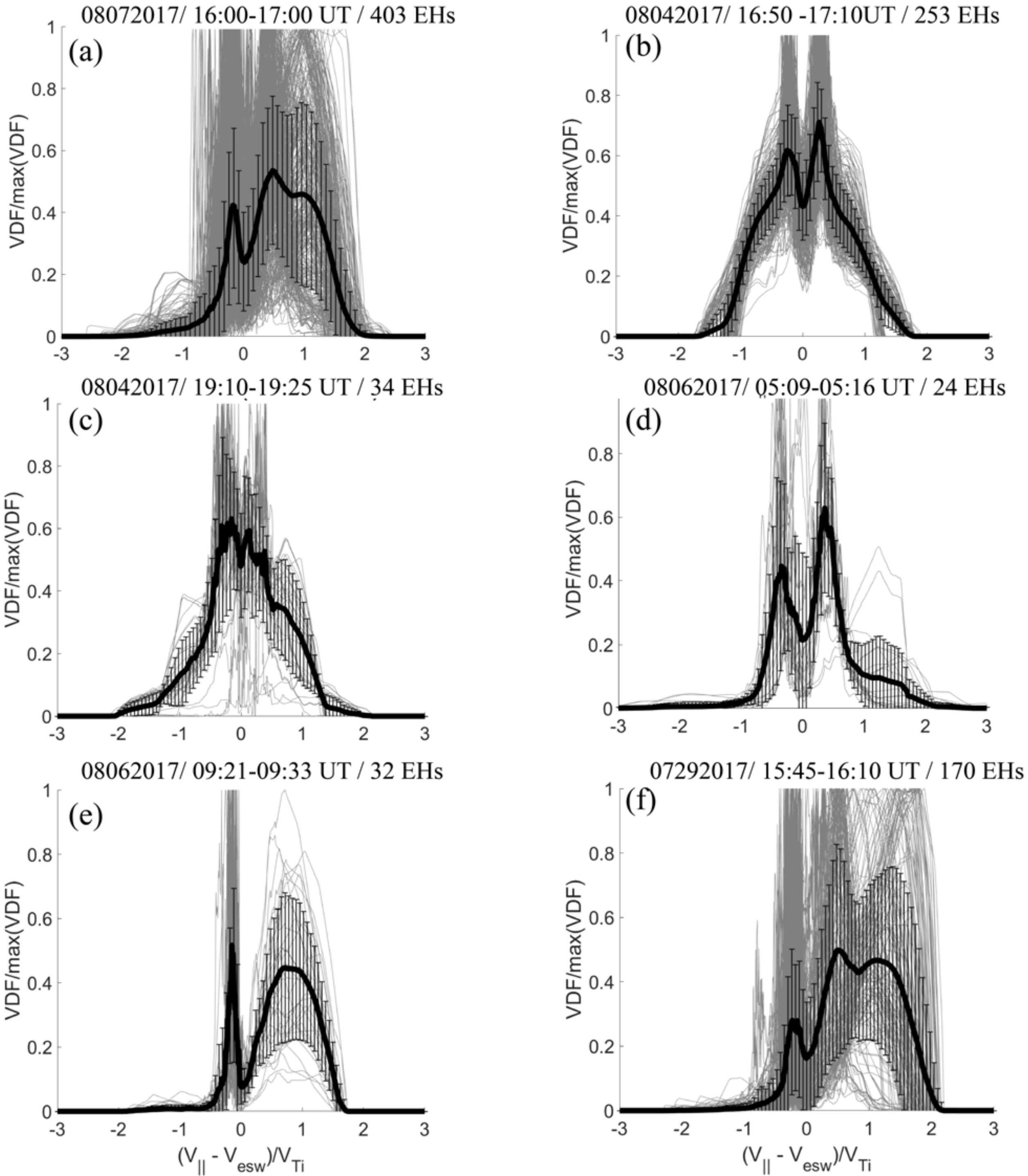
Speed from 1 to 2| -759 km/s
Speed from 1 to 3| -690 km/s
Speed from 1 to 4| -705 km/s

Mean| -719 km/s
Deviation| +- 36 km/s

Background ion velocity Distribution



- Reduced ion velocity distribution function $f(v_{||})$ was computed at 150 ms cadence using ion distribution functions measured aboard MMS1
- Ion population consists of a core population and a beam propagating antiparallel to the local magnetic field, i.e. in the same direction as the solitary waves
- Velocities of detected solitary waves cluster close to the local minimum between the core and beam populations
- Double-hump structure is well preserved through out the whole time interval and velocities of structures strongly correlate with the position of the local minimum



- We have perfomed the same analyse for another 1000 slow electron holes collected by Lotekar et.al 2020
- The results indicate that the considered interval is not exceptional
- Slow electron holes occurrence is correlated with double hump ion velocity distribtuions

Conlusions

- We considered a particular event in the Earth’s plasma sheet boundary layer, where significant turbulence of electron holes has been detected
- Using multispacecraft interferometry we were able to determine velocities of electron holes, which happened to be of order of ion thermal velocity.
- We made use of local measurements of ion velocity distribution. It was shown, that slow electron holes are accompanied by double-hump ion distributions, with speeds of slow electron holes clustered in the local minimum.
- By employing the new theory of electron hole stability, we prove that observed double-hump ion distributions allow avoiding self-acceleration otherwise prevents electron holes from remaining slow
- Additional analysis of the previously observed slow electrons holes confirms that the considered event was not exceptional