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Cluster mission and data analysis for the March 2001 magnetic storm

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RESUMEN

La misión CLUSTER está destinada a estudiar la magnetosfera de la Tierra y las relaciones Sol-Tierra. Los 4 satélites de esta misión vuelan en una formación de tetraedro enviando datos en los que por primera vez pueden separar efectos temporales de efectos espaciales. Esta formación nos dará un mejor entendimiento de las características macroscópicas y microscópicas en la magnetosfera y el viento solar. Como un ejemplo presentamos los datos obtenidos de la espectrometría de iones durante una tormenta magnética intensa.

PALABRAS CLAVE: Misión CLUSTER, tormenta magnética, espectrometría de iones.

ABSTRACT

The CLUSTER mission is intended for the study of the Earth's magnetosphere and Sun-Earth relationships. Four satellites fly in a tetrahedral formation sending data that can separate spatial from temporal effects for the first time. This formation will provide a better understanding of microscopic and macroscopic features in the magnetosphere and the solar wind. As an illustration we discuss the CIS data during a large magnetic storm.

KEY WORDS: CLUSTER mission, magnetic storm, ion spectrometry.

INTRODUCTION

The Cluster mission will bring new light to understand the interaction between the solar wind and the Earth's magnetosphere. This mission consists of four satellites, each with eleven instruments on board. In this paper we use data provided from the Cluster ion spectrometry (CIS) instrument. To illustrate the capabilities of this mission we discuss CIS composition data during a large magnetic storm.

CLUSTER MISSION

The Cluster mission consists of four identical spacecraft with Latin American dance names (Rumba, Salsa, Samba and Tango). The purpose of the mission is the study of different regions of the terrestrial magnetosphere over a period of four years. The regions of principal interest are:

- the solar wind,
- the bow shock,
- the magnetosheath,
- the magnetopause,
- the plasma sheet,
- the polar cusps, and
- the auroral zones.

For the first time three-dimensional measurements of both large and small scale phenomena in the near-Earth environment are being obtained. The satellites are flying in a tetrahedral formation around the Earth and the orbit was designed so that the satellites cover the bow shock in front of the Earth or the plasma sheet in the tail region (see Figure 1). The relative distance between the spacecraft can be adjusted between 200 km in the cusp and 20 000 km in the magnetotail. Each Cluster satellite carries eleven instruments ([E88],

[E93], [E01], [W01]). They are the following:

- ASPOC (Active Spacecraft Potential Control)
Measurements of the ambient plasma distribution functions.
- CIS (Cluster Ion Spectrometry)
Analysis of composition and dynamics of magnetospheric ions in the energy range from 0 - 40 keV. It consists of two different instruments: CODIF (Composition and Distribution Function Analyzer) and HIA (Hot Ion Analyzer).
- DWP (Digital Wave Processor)
Control of the wave consortium experiments (EFW, STAFF, WHISPER and WDB) and performance of particle and wave-particle correlations.
- EFW (Electric Field and Waves)
Measurements of the electric field and density fluctuations.
- EDI (Electronic Drift Instrument)
Measurements of the drift of an electron beam caused by the plasma electric field.
- FGM (Fluxgate Magnetometer)
Magnetic measurements inside the magnetosphere and in the interplanetary medium.
- PEACE (Plasma Electron and Current Analyzer)
Measurements of the three dimensional velocity distribution and flow plus energy distribution of electrons from 0.67 eV to 30 keV.
- RAPID (Research with Adaptive Particle Imaging Detectors)
Advanced spectrometer for analyzing electrons and composition with energies from ~ 20 keV to a few MeV.
- STAFF (Spatio-Temporal Analysis of Field Fluctuations)
Measurements of the rapid electromagnetic fluctuations in the regions of interaction between the solar wind and the magnetosphere.
- WHISPER (Waves of High Frequency and Sounder for Probing of Density by Relaxation)
Measurements of the density of the plasma in the magnetosphere.
- WBD (Wide Band Data)
Wide band and wave form measurements of plasma waves are provided.

In addition to the progress in understanding the Sun-Earth relationship new versatile software has been created to plot the data sent by the Cluster satellites. Most of the

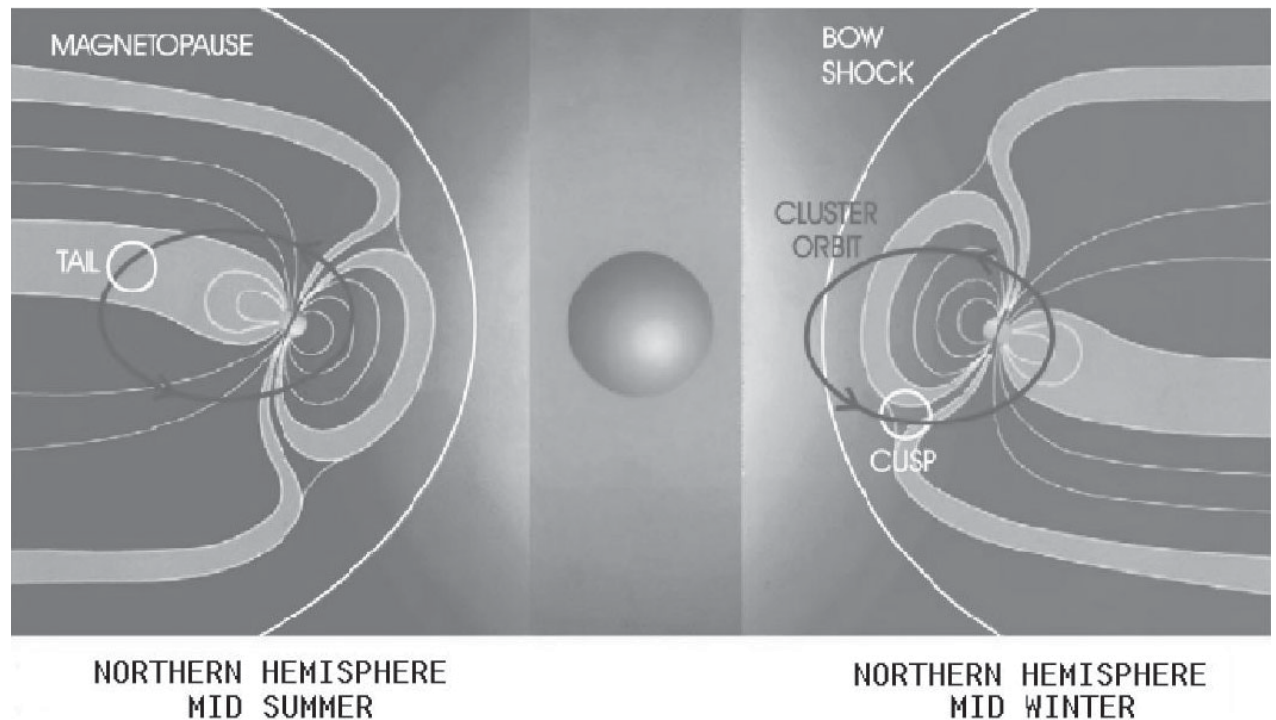


Fig. 1. The Cluster orbit.

programs are based on IDL (Interactive Data Language). Among the programs to visualize the data are the following:

- CL
- CCAT
- OVT (Orbit Visualization Tool)
- PAPCO (Panel Plot Composer)
- QSAS (QMW Science Analysis System)

Information about these programs can be found respectively at:

- <http://cis.cesr.fr:8000/>
- <http://ovt.irfu.se/>
- <http://leadbelly.lanl.gov/ccr/software/>
- http://www.space-plasma.qmw.ac.uk/QSAS/qsas_welcome.html

Overview plots, Cluster locators and further information can be found at:

- http://www.cluster.rl.ac.uk/csdsweb/cgi/csdsweb_pick/
- <http://sci2.estec.esa.nl/cluster/csds/csds.html>
- <http://cl1.plasma.mpe-garching.mpg.de/cdms/>
- <http://sci.esa.int/home/clusterii/index.cfm>

In the next section we will analyze the data provided by the CIS instrument on board of the spacecraft. The program we use to plot the data is CCAT.

THE LARGE MAGNETIC STORM IN MARCH 2001

Figure 2 shows the Dst index between 26 March 2001 and 6 April 2001*. A very strong storm occurred on March 31, 2001 with a minimum Dst of -358 nT at 09:00 UT.

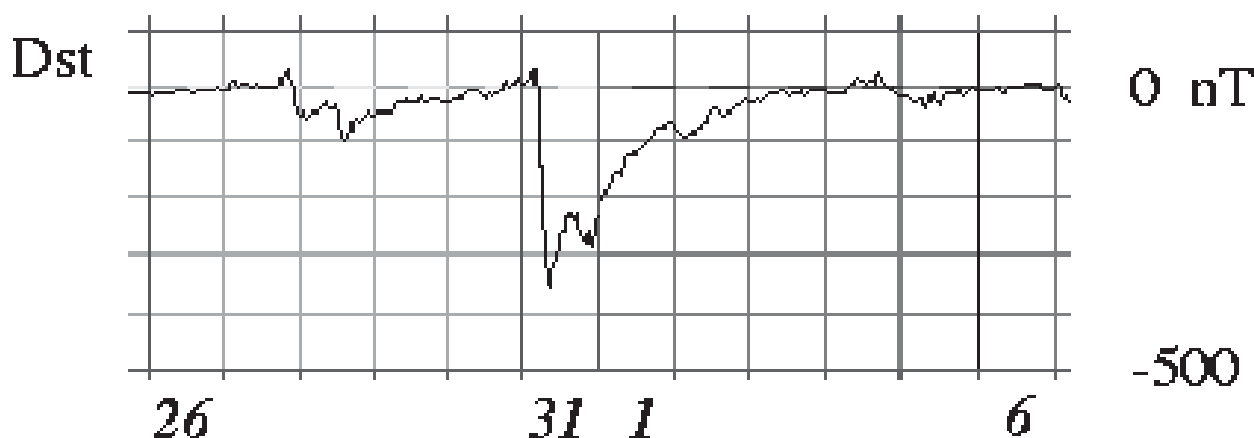


Fig. 2. The provisional Dst index between March 26 and April 6 2001*.

* <http://swdcd.b.kugi.kyoto-u.ac.jp/dstdir/>

The Cluster spacecraft, Rumba, traverses for the time period 07:00 to 12:00 UT through the outer radiation belt into the northern auroral zone and from there via the northern polar cap and cusp into the magnetosheath (see Figure 3).

Figure 4 presents spectrograms for the major magnetospheric ions as H^+ , He^+ , He^{++} , and O^+ during this time period. The period of interest is the auroral zone between 08:00 and 10:00 UT which extends during the storm far to the north. During this period we happened to be in the main phase and beginning of the recovery of the storm.

The global plots in Figure 5 show as an example during a 5 minutes period the flow direction with respect to the magnetic field for H^+ and O^+ ions for various energy channels. The cross means that the ions are moving with a pitch angle of 180° with respect to the magnetic field and the star means that the ions are moving along the field line. The global plots tell us that the low energy ions (H^+ and O^+) < 1 keV in the northern hemisphere are moving antiparallel to the magnetic field and therefore emerging from the auroral region. In addition we observe high energy ions (H^+ and O^+) above 1 keV which are moving parallel and opposite to the field line. These are interpreted as ions injected from the tail. They are connected with a large substorm which happened around 8:00 UT. Besides the direct injection we identify two more dispersion curves at higher energies which could be explained by an injection to the southern hemisphere plus one bounce and to the northern hemisphere plus two bounces [Kob].

The O^+ fluxes exceed the H^+ fluxes by more than one order of magnitude. It means that storm-time substorms are more effective in transporting O^+ than H^+ [Koa].

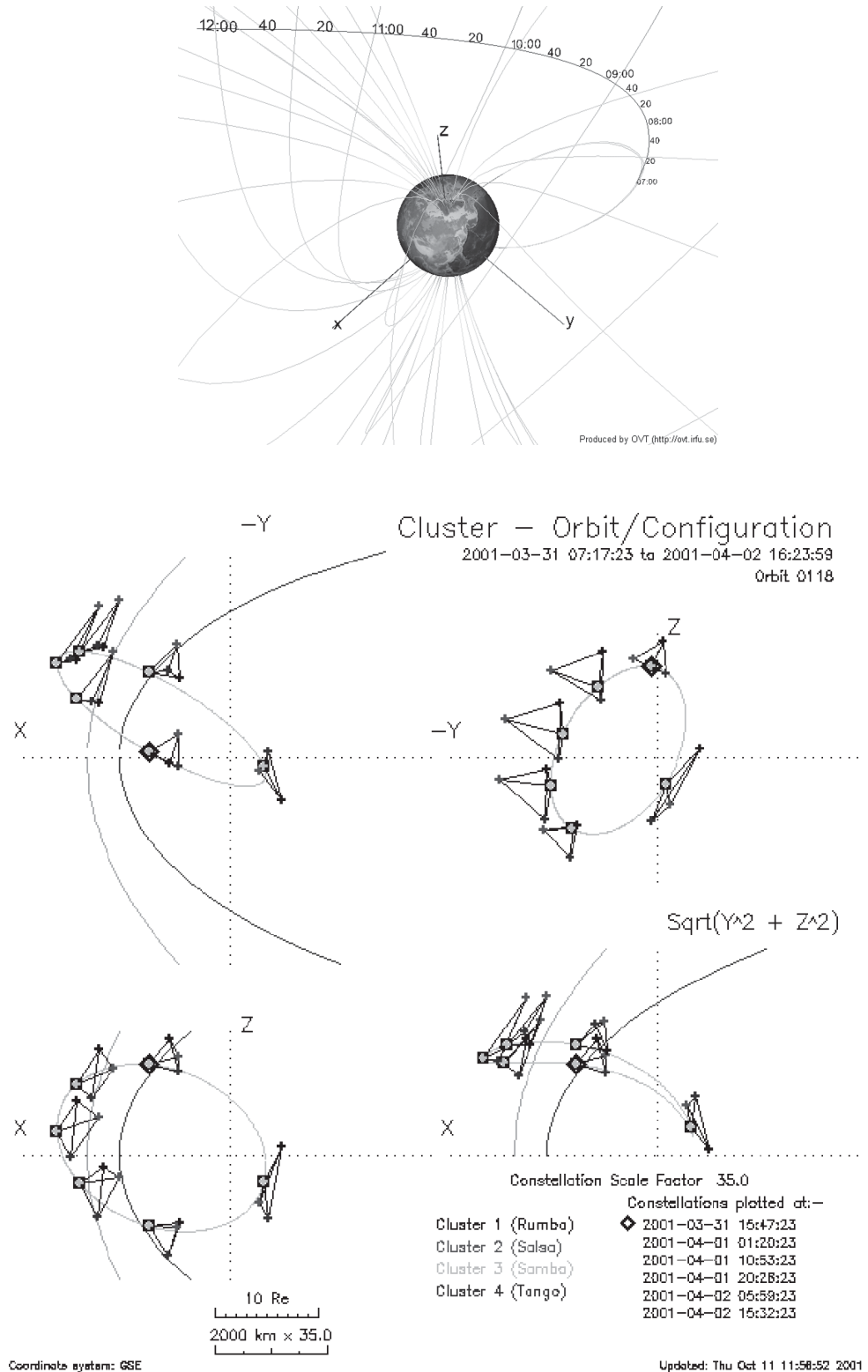


Fig. 3. Top Part of the orbit of Rumba on March 31, 2001 from 07:00 to 12:00 UT. The magnetic field is also depicted. It was produced by the OVT program. Bottom: Orbit of the Cluster satellites from March 31 to April 2, 2001. The nominal bow shock and magnetopause are also shown. We used the CSDS locator from the Internet.

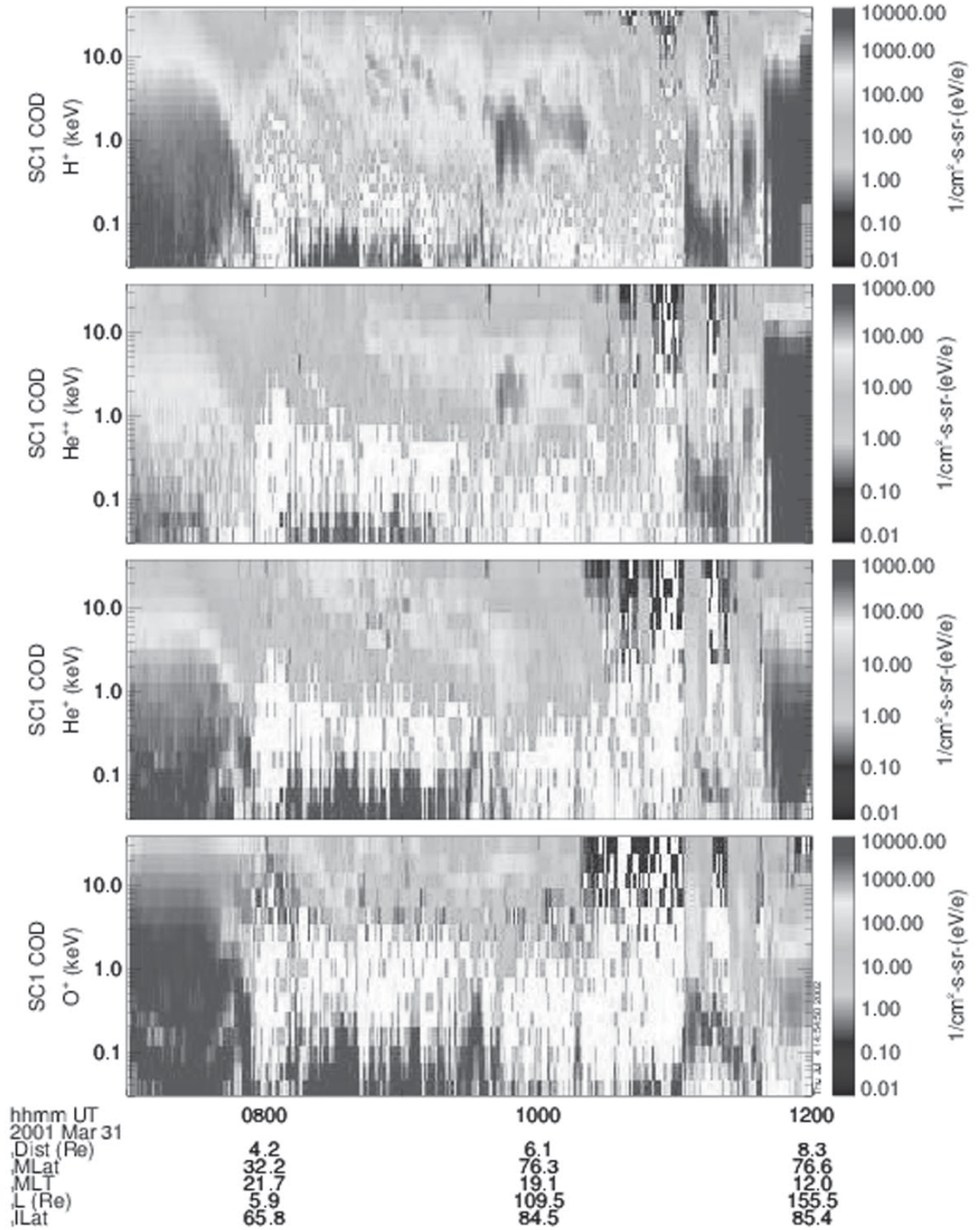


Fig. 4. Spectrograms of four species measured by Rumba on March 31, 2001 from 7-12 UT.

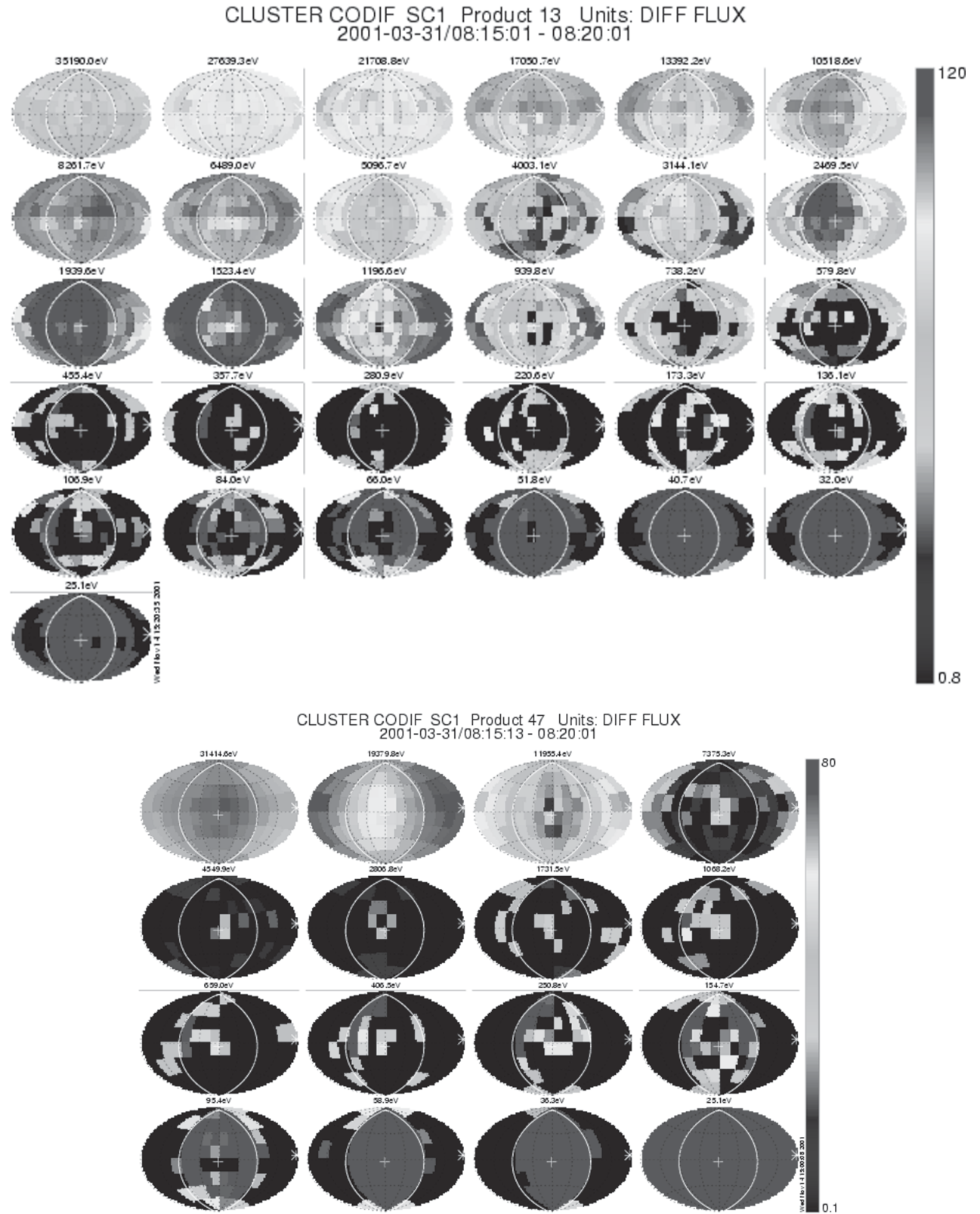


Fig. 5. Global distributions of H⁺ and O⁺ measured by Rumba on March 31, 2001 from 8:15-8:20 UT.

CONCLUSIONS

The main goal of this mission is the accurate study of the dynamics of the terrestrial magnetosphere. This is possible due to the tetrahedral fly formation. Three-dimensional measurements of both large and small scale phenomena in the Earth's magnetosphere are being obtained for the first time.

It is a misfortune that the CIS instruments on Salsa and the HIA instrument on Tango are not operating properly, but nevertheless the analysis of the data sent by the Cluster satellites will increase our knowledge on the Sun-Earth relationship.

Moreover this project is bringing an important development in versatile software to analyze the Cluster data. An organized data system to distribute the data around the world is also operating.

We showed some features that can be deduced from the data of March 31, 2001 event as an example of the capabilities of the Cluster mission. Specifically with the CIS instrument it is possible to separate spatial and temporal variations of ion fluxes (H⁺, He⁺, He⁺⁺, and O⁺) in magnetospheric substorms.

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To plot the orbit of the Cluster spacecraft we have used OVT program (K. Stasiewicz, M. Khotyaintsev and Y. Khotyaintsev, Orbit Visualization Tool (<http://ovt.irfu.se>)) and CSDS locator (http://www.cluster.rl.ac.uk/csdsweb-cgi/csdsweb_pick/).

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