The Cluster Mission to the Earth's Magnetosphere

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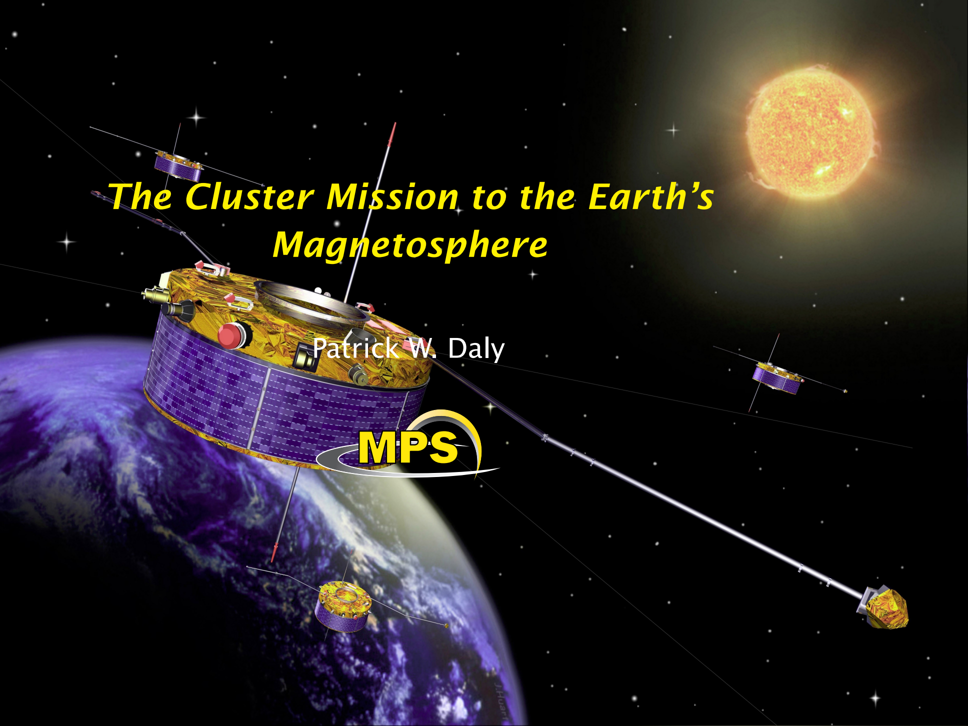

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The Cluster Mission

The Cluster mission is an in-situ investigation of the Earth's magnetosphere using four identical spacecraft simultaneously.

Advantages

- accurate determination of three-dimensional and time-varying phenomena
- distinguishing between spatial and temporal variations

Mission Aims

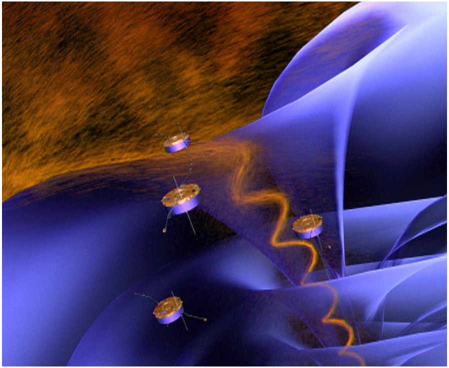
Cluster's main goal is to study the small-scale plasma structures in space and time in the key plasma regions:

- solar wind and bow shock
- magnetopause
- polar cusp
- magnetotail
- auroral zone

Example: Cusp

The interaction between the solar wind and the magnetosphere is a key element in the ISTP program.

Example: direct entry of solar wind particles through the polar cusps, which act as two magnetic funnels, one in each hemisphere, focusing the solar wind particles (rather like a telescope) on photons.



Example: Substorms

Another example: acceleration of plasma in the magnetotail during substorms.

A reversal of the interplanetary magnetic field from north to south can initiate such a substorm, releasing a large quantity of particles towards the Earth.

Both entry mechanisms produce auroras when the precipitating electrons and ions are absorbed in the neutral atmosphere.

These particles can have dramatic effects on, e.g.:

- power transmission and telecommunications,
- satellite operations in geostationary orbit.

Predicting such *space weather* effects is also one of the goals of the Cluster Mission.

Cluster Concept

The fundamental idea behind Cluster:

- Four identical satellites in a tetrahedron formation
- with identical payloads designed for magnetospheric plasma studies:
  - electromagnetic waves
  - electric and magnetic fields
  - electron and ion measurements over broad energy spectrum
- on elliptical polar orbit to cover all the regions magnetosphere in course of one year (4–19 R_E)

History I

Cluster has a long story behind it, going back to the early 1980's.

- Cluster was proposed as an official ESA Mission in 1984, and model payloads and technical/financial feasibilities were worked out.
- Announcement of Opportunity for experimenters came out in 1987.
- Proposals accepted, begin building experiments in 1989.
- Integration, tests in 1994-1996.
- Launch with first Ariane 5 rocket on June 4, 1996.
- End of Cluster (I) Mission, June 4, 1996.

History II

In spite of great financial and technical difficulties, ESA and the participating institutes decided that Cluster should be rebuilt.

- Final decision to go ahead in November 1996.
- Spacecraft and experiments rebuilt exactly as before, as far as that was possible.
- New start for Cluster II on two Soyuz rockets, July, August 2000.
- This time, successful.

Current Status

- After one extension to the end of 2005, the mission has now been extended to the end of 2009. (Reentry will occur during 2010.)
- Most of the experiments are still working satisfactorily, although some degradation and failures have occurred.
- The spacecraft are still functioning well, fuel is sufficient, solar cells acceptable, but the batteries will likely not last much longer. (This means reduced operations during eclipses.)
- Spacecraft separations have been varied from 200 to 5000 km.
- As of July 2005, permanent large separation of 10 000 km between 3 spacecraft; 4th one can vary 100 to 10 000 km. This is called multi-scaling.

The Payload

The Cluster satellites each contain 11 different experiments.

Wave Instruments

DWP coordinates the other wave instruments and performs particle/wave correlations.

EFW measures the electric field in the plane $\perp$ spin axis and it power density up to 180 Hz.

STAFF measures magnetic field fluctuations $<$ 4 kHz.

WHISPER measures electron density with a relaxation sounder, and electric fields in frequency range 2–80 kHz.

WBD provides electric or magnetic waveforms up to 577 kHz.

The Payload. . .

Fields

ASPOC controls the spacecraft potential by emitting indium ions, preventing charging which would hamper the electron instruments.

FGM fluxgate magnetometer, measures the magnetic field in 3 dimensions.

EDI measures electric fields by shooting keV electrons into space and detecting their return to the spacecraft via gyromotion.

The Payload. . .

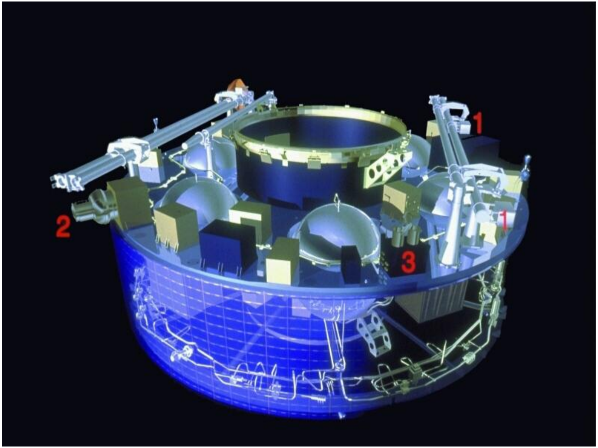
Particles

CIS hemispherical electrostatic ion spectrometer, in 4π directions, up to 32 keV/e, for H^+, He^+, He^{++}, and O^+.

PEACE two hemispherical electrostatic electron spectrometers, for 4π coverage up to $\sim$26 keV.

RAPID measures energetic electrons and ions with imaging techniques and time-of-flight methods, from $\sim$30–400 keV, with 4π coverage.

Payload: The Movie



RAPID Overview

RAPID stands for

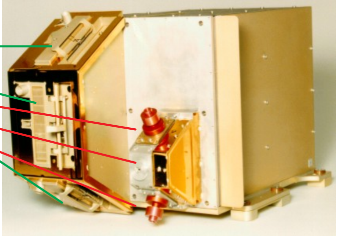
Research with Adaptive Particle Imaging Detectors

and is an energetic ion and electron (E$>$30 keV) imaging spectrometer.

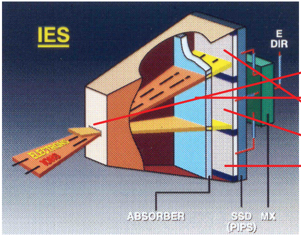
RAPID actually consists of two sets of spectrometers:

- one for ions
- one for electrons.

Each set contains three units, each covering 60°, for a total of 180° in one plane.



The IES electron heads

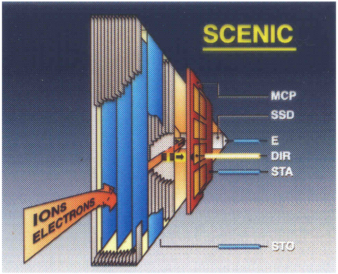


Each of the electron heads consists of

- a “pin-hole” aperature
- an absorber for ions (E<350 keV)
- 3 solid state detectors.

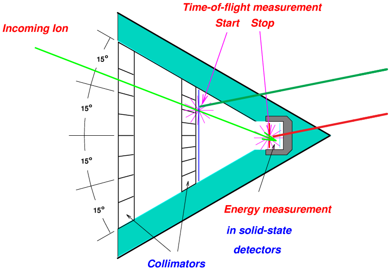
The 3 detectors determine the electron incidence angle to within 20°.

The IIMS/SCENIC ion heads



Particles entering the ion heads must first pass through the collimating plates before encountering the time-of-flight arrangement.

The Time-of-Flight Measurement



One of 3 IIMS (Ions) Sensors

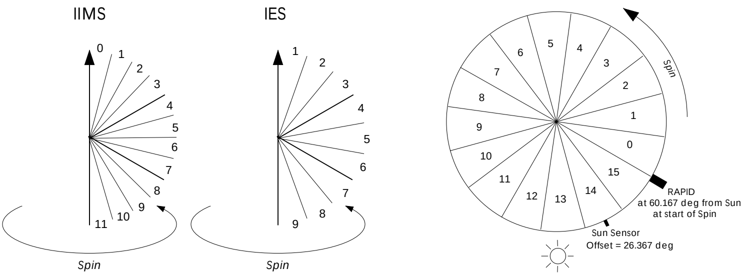
The collimated ions encounter a thin foil, emitting electrons that serve as the START signal.
The STOP signal is the absorption in the solid state detector that determines the ion's energy.
The START signal also serves to localize the incident direction within 15°.

The combination of energy (SSD) and velocity (TOF) determine the ion mass and thus identify its species.

RAPID Specifications

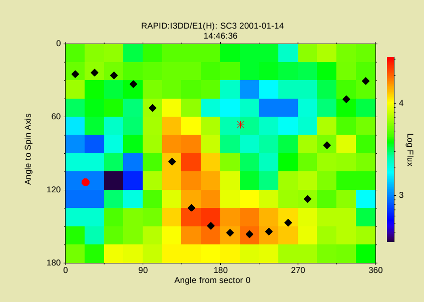
Energy ranges:	Hydrogen	28–1500 keV
	Helium	29–1500
	CNO	92–1500
	Electrons	26–400
Mass range:		1, 4, 12–16, 28–56
Resolution (A/dA):	Oxygen	4
Field-of-view:	IIMS (Ions)	$\pm$ 3°$\times$ 180°
	IES (Elec.)	$\pm$ 17.5°$\times$ 180°
Geometry factor:	IIMS	2.6×10^{-2} cm$^2 \cdot$ sr
(for 180°)	IES	2.0×10^{-2}

Angular Coverage in 3-D



Note: the spin axis is directed towards the *southern* ecliptic pole!

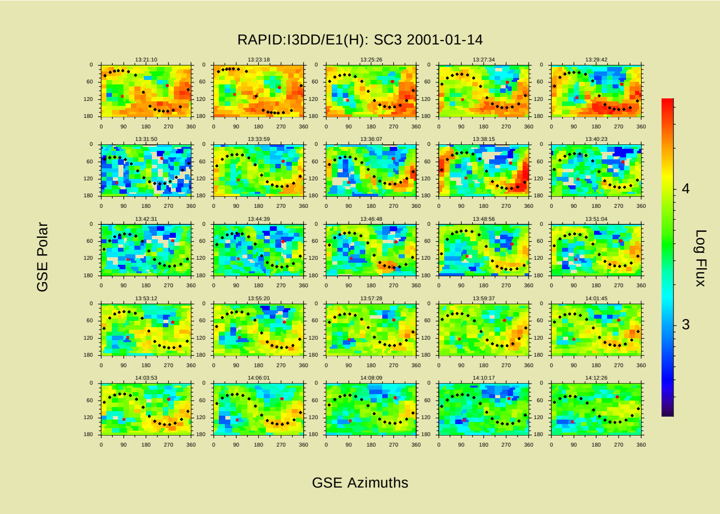
The 3-D plots



RAPID protons (30 keV)

Possible formats:

1. Spacecraft
2. GSE coordinates
3. Bi-spherical GSE
4. Smoothed


RAPID:I3DD/E1(H): SC3 2001-01-14
13:21:10
13:23:18
13:25:26
13:27:34
13:29:42
13:31:50
13:33:59
13:36:07
13:38:15
13:40:23
13:42:31
13:44:39
13:46:48
13:48:56
13:51:04
13:53:12
13:55:20
13:57:28
13:59:37
14:01:45
14:03:53
14:06:01
14:08:09
14:10:17
14:12:26
GSE Polar
GSE Azimuths
Log Flux
4
3

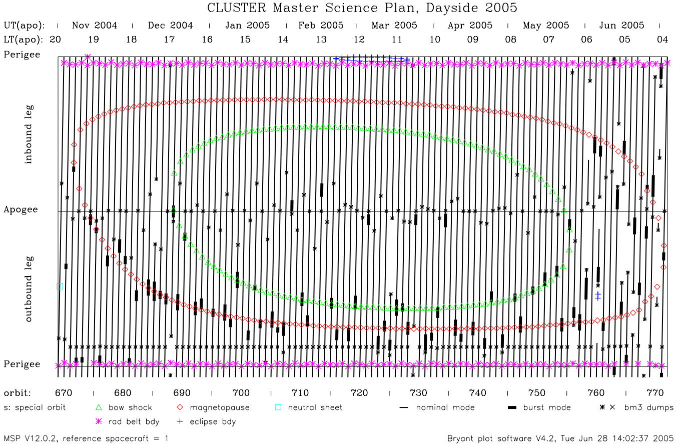
Long Term Overview

The plots on the following slides were produced by

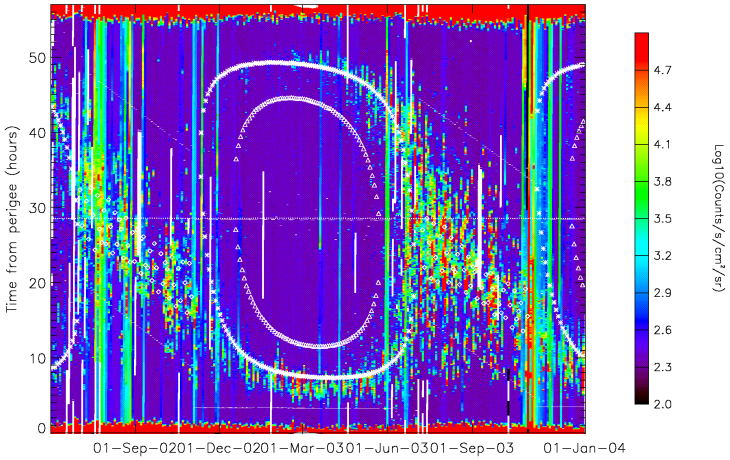
Jackie Davies
Rutherford Appleton Laboratory

They show RAPID electron and proton flux intensities from June 2002 to January 2004, against location in the magnetosphere.
(These are so-called *Bryant* plots.)

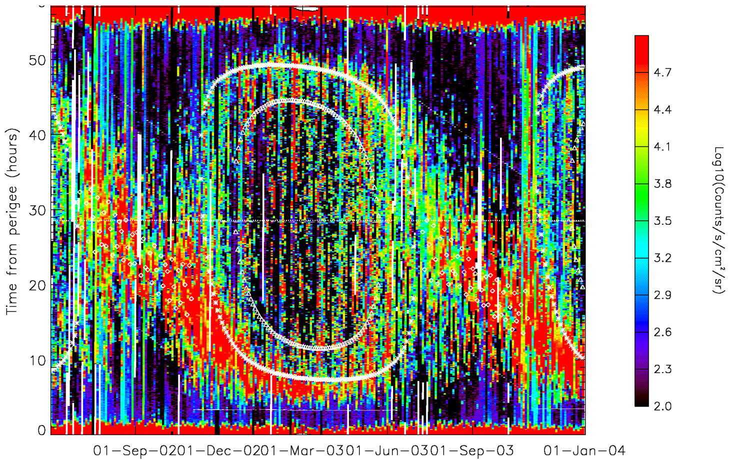
Bryant Plot


CLUSTER Master Science Plan, Dayside 2005
UT(apo): Nov 2004 Dec 2004 Jan 2005 Feb 2005 Mar 2005 Apr 2005 May 2005 Jun 2005
LT(apo): 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04
Perigee
inbound leg
Apogee
outbound leg
Perigee
orbit: 670 680 690 700 710 720 730 740 750 760 770
s: special orbit
bow shock
magnetopause
neutral sheet
nominal mode
burst mode
bm3 dumps
rad belt bdy
eclipse bdy
MSP V12.0.2, reference spacecraft = 1
Bryant plot software V4.2, Tue Jun 28 14:02:37 2005

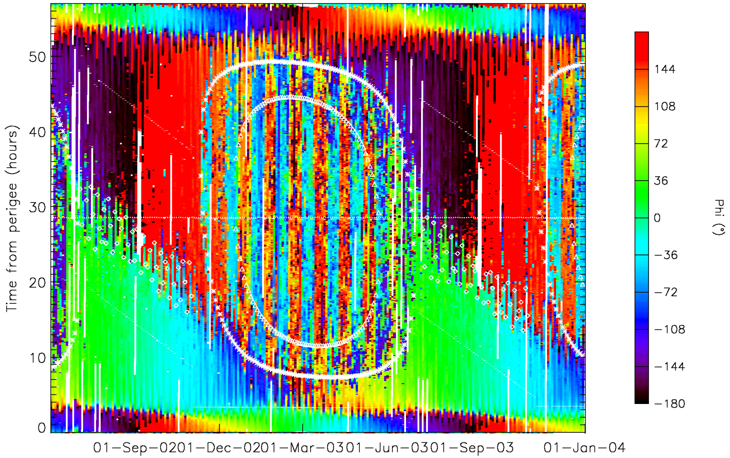
RAPID Electrons



RAPID Protons



Cluster Magnetic Azimuth



Data Transmission

On board

- Once per spin ($\sim$4 s), the RAPID DPU stores the accumulated counts into an Experiment Data Block, EDB. This contains 512 bytes (or 2304 bytes in high rate mode).
- The counts are compressed: one byte encodes numbers from 0 to 734000.
- Once per spacecraft cycle of 5.1522 s, a block of 660 bytes (2976 in high rate) is shifted to the output stream.
- The data are stored on board until contact with the receiving stations, when they are downloaded.
- Accurate planning is needed to avoid storage overflow and data loss.

On the Ground

- Data received by ground station.
- Transmitted to ESOC in Darmstadt.
- Reconstructed time tags added.
- Data are put online for Experiment Teams to retrieve.

Data Disposition

- Data available 20 days at ESOC.
- PI Teams order the data that they wish.
- Ordered data transferred per FTP to the recipient.
- Data are recorded to CDs on daily basis (2–3 CDs per day).
- Sets of CDs are mailed to PIs, Data Centres, Co-I institutes.

Data Processing

Raw Data

- Raw data are repackaged, merging filtered science and HK data to form Merged Science Files, MSF.
- The MSF files, available to Co-Is and CAA, are primary input for further processing.

Science Data

- Science data generated with a program `msf2sci`.
- It reads the raw data, locates the EDBs within the transmission packages, reconstructs the original accumulation time stamp,. . .
- applies calibration parameters, determines energy levels, accumulation time intervals, etc,. . .
- and writes flux values to SCI file in an ascii format.
- The SCI files are inputs to further plotting and analysis programs.