

Plasmasphere observations with Cluster data supplemented with data from the Dynamics Explorer-1 and Van Allen Probes missions



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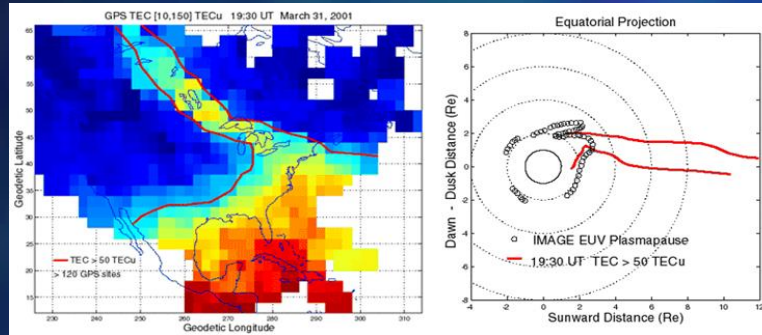
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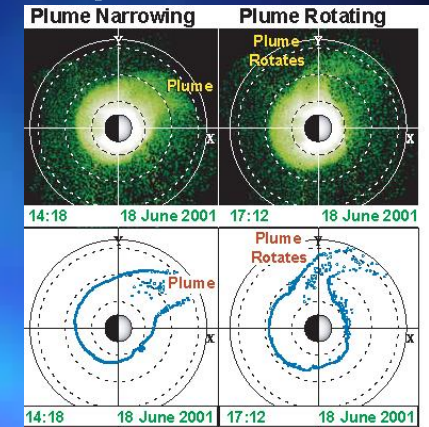
Motivation

- Plasmasphere and plumes studied with single satellites (CRRES), with ground-based data (GPS), with imagers (IMAGE)

⇒ Global and local view



[Foster et al., 2002]



[Goldstein et al., 2004]

- With **Cluster**, constellation of 4 satellites
 - Various perigee altitudes (from 4 to 1.5 Re and now around 5,5 Re)
 - Different configurations (string of pearls, tetrahedron, 2 close satellites, ...) and different spacecraft separations (~10 to 100 000 km)
- But not many ion density and temperature data (except RPA mode by CIS instrument)
 - Old mission **Dynamics Explorer - 1** detects H^+ , He^+ , He^{++} , O^+ , O^{++} ions
- Active mission, **Van Allen Probes (RBSP)**
 - Similar instrument than WHISPER but higher upper density limit (3000 cm^{-3}), shorter orbital period (3 plasmasphere crossings per day), 2 satellites

Outline

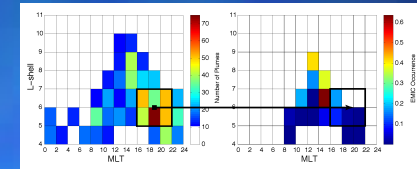
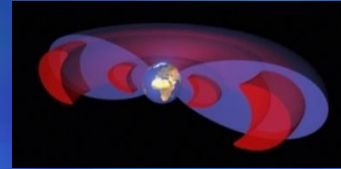


■ Introduction

- Motivation

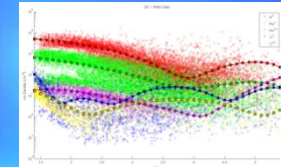
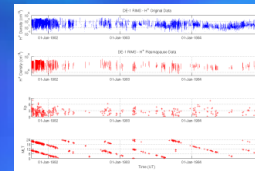
■ Cluster

- Plasmopause study
- Plume study



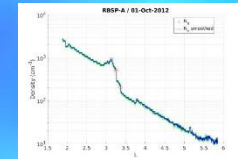
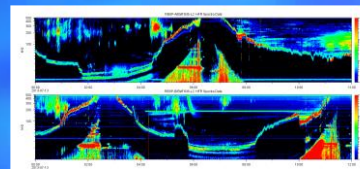
■ Dynamics Explorer - 1

- Data
- First results



■ Van Allen Probes

- Data
- First results

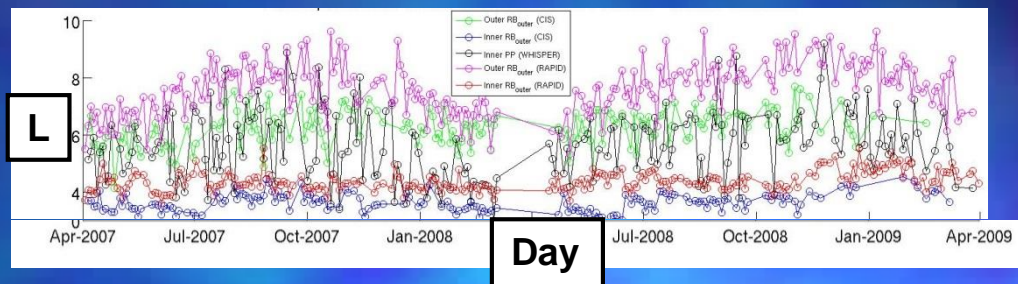


■ Summary - Future

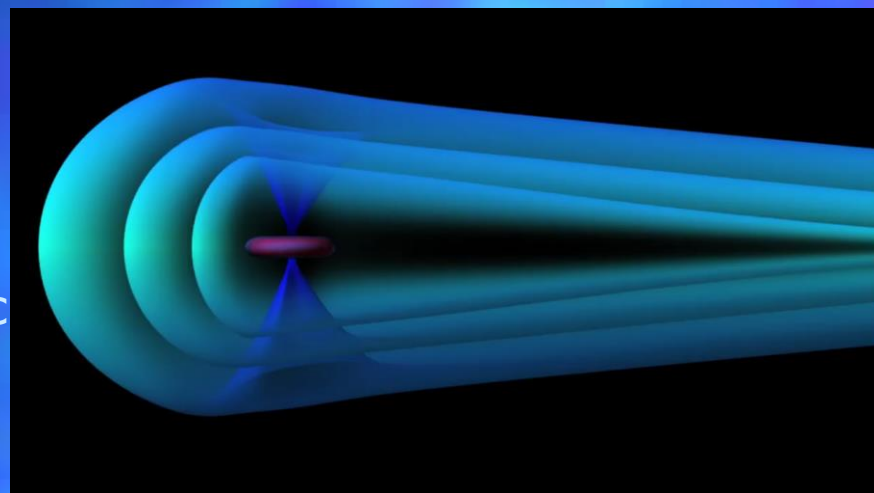
Cluster – Plasmapause / Radiation Belt

04/2007-03/2009: Low perigee ($2 R_E$) for Cluster satellites

- Correlation between PP position obtained from WHISPER (black) and boundary position of the RB obtained from CIS (blue - green) and RAPID (red - magenta) during 2 years (April 2007 – March 2009):



- Quite low activity during those months: plasmasphere very extended at $L > 5 R_E$
- Plasmapause position very variable due to different conditions and strong interaction with geomagnetic activity
- Plasmapause coincides with outer boundary at larger L (low activity) and to inner boundary at smaller L (high activity)

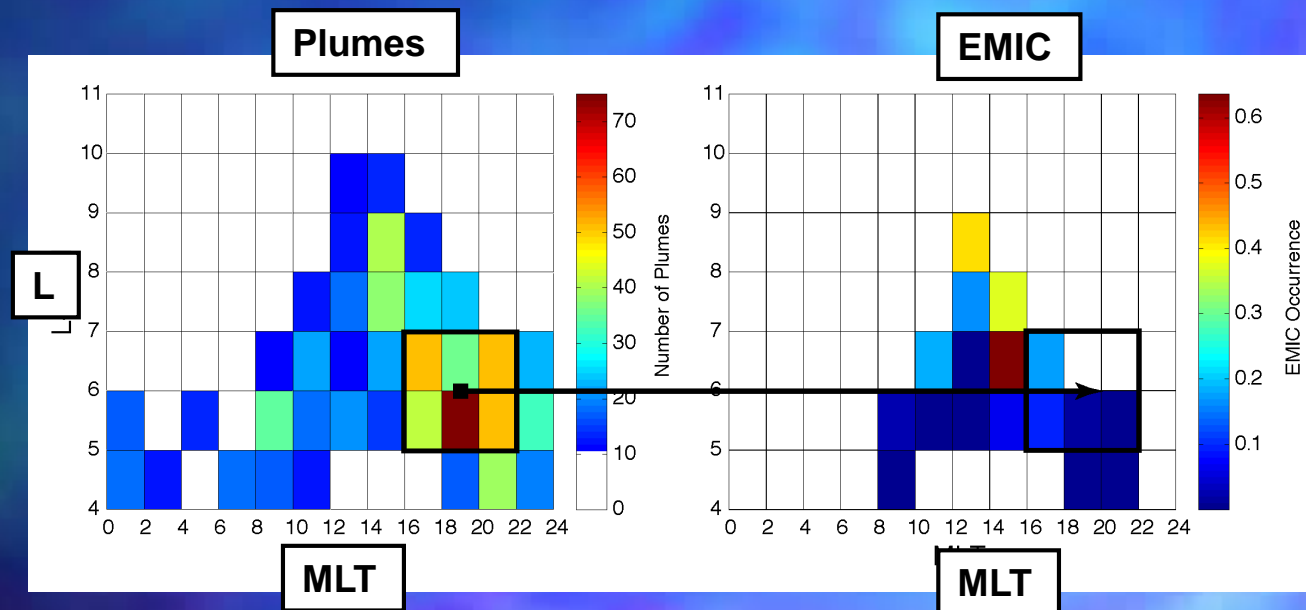


[Darrouzet et al., 2013]

Cluster – Plumes / Waves

2001-2006: Perigee $\sim 4 R_E$ and separation 100 to 10000 km

- Survey of plumes in 2001-2006 identified from WHISPER + search of EMIC waves in magnetic field data from FGM
 - Observation of EMIC waves during only 11% of the time when Cluster observed plumes along its orbit (7% inside the plume and 4% inside and outside the plume)
 - Enhanced EMIC probability observed in the noon sector beyond the GEO orbit (not at plume)
 - EMIC occurrence significantly increases with solar wind dynamic pressure (up to $\sim 40\%$)



[Usanova et al., 2013]

Dynamics Explorer - 1 / RIMS Data



■ DE - 1 launched 3 August 1981

[Chappell et al., 1981]

- Polar orbit: 567 x 23289 km, 409 min, 89° inclination

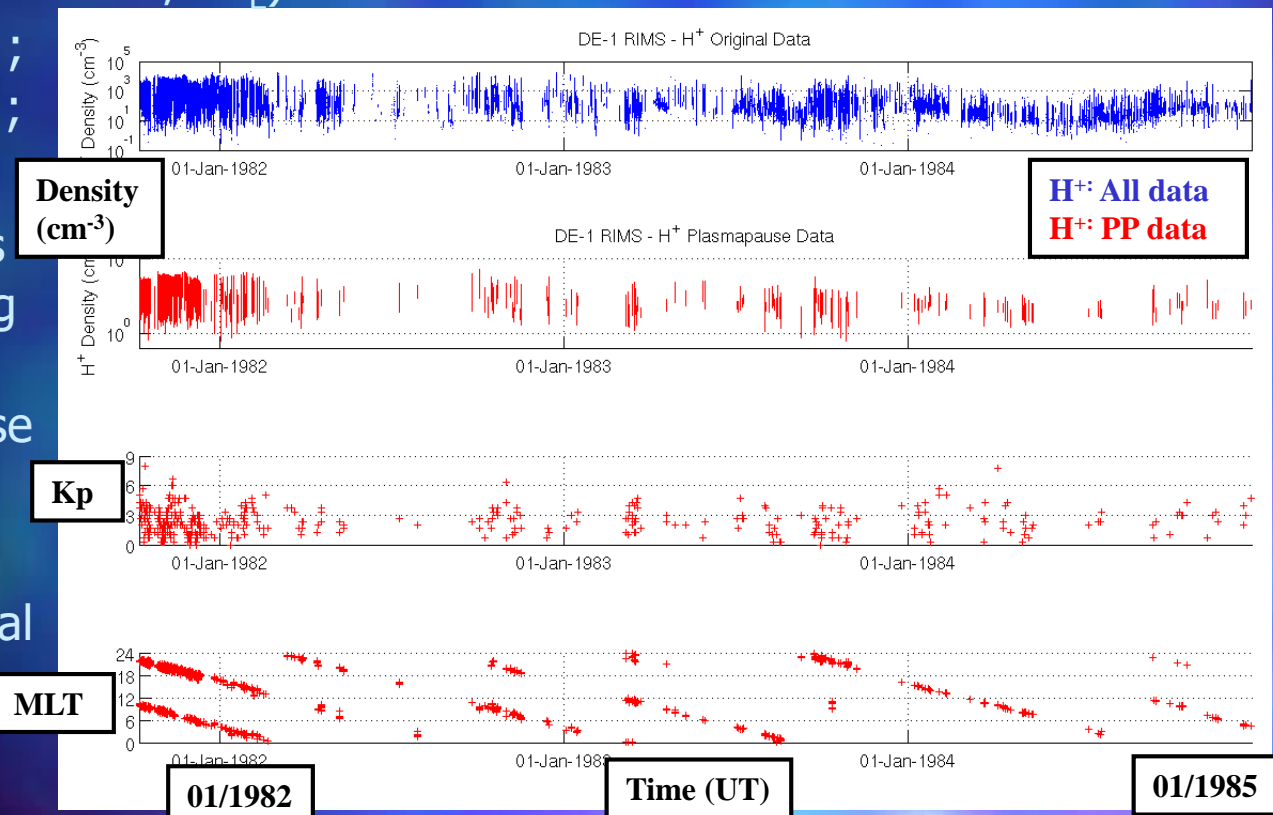
■ RIMS (Retarding Ion Mass Spectrometer) data

- More than 3 years of data (Oct 1981-Dec 1984 ; 218 692 times of data)
- Valid plasmopause crossings ($N_{\max} > 20 \text{ cm}^{-3}$, increase of N of min factor 3 in a distance of min $L=0,5 R_E$):

H⁺: 414 ; He⁺: 475 ;
He⁺⁺: 94 ; O⁺: 149 ;
O⁺⁺: 87

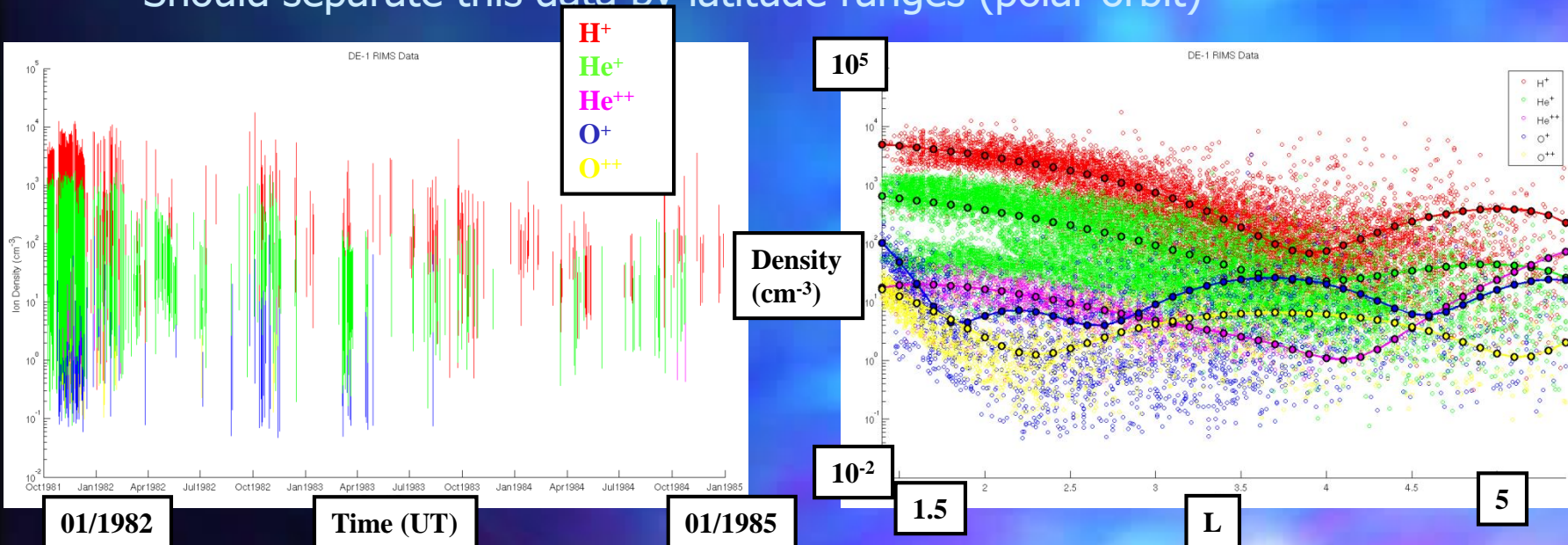
- Not many events with $K_p > 5$ during this time period (decreasing phase of solar cycle)

- All MLT covered but MLT-statistical analysis possible only for H⁺ and He⁺



DE-1 / RIMS – First Results

- Analysis of density during plasmopause (and/or PBL) crossings
 - Not very often plasmopause crossings data for all 5 ions (mostly only before Feb 1982)
 - Higher density for H^+ and lower density for O^+ (not O^{++} !!)
 - Higher density ratio with respect to H^+ at low L
 - $L \sim 2$: 90% H^+ - 9% He^+ - 0.2% He^{++} - 0.1% O^+ - 0.1% O^{++}
 - Similar distribution for H^+ , He^+ and He^{++}
 - Higher O^+ and O^{++} density at $L = 3 - 4.5$
 - Should separate this data by latitude ranges (polar orbit)



Van Allen Probes / EMFISIS



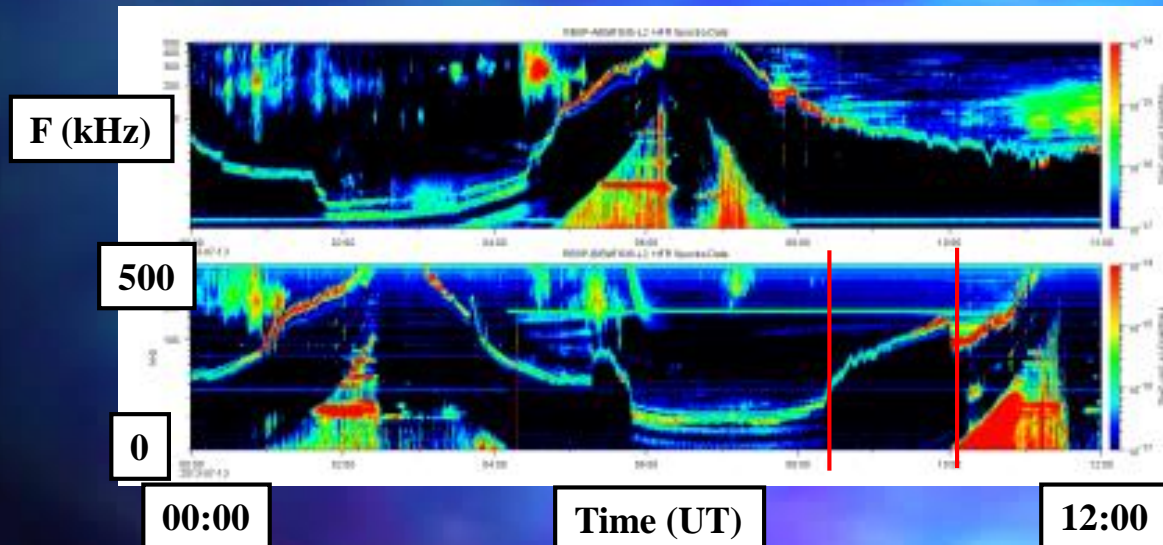
■ Van Allen Probes (RBSP)

- NASA, 2 satellites (A and B), launch in August 2012
- 600 x 32 000 km, inclination 10°, period 9h
- 5 instrument suites dedicated to study the radiation belts
- 19 July 2019: end of satellite RBSP-B

■ EMFISIS/Waves onboard Van Allen Probes

[Kletzing et al., 2013]

- Single electric field component of waves (10-500 kHz) → upper hybrid resonance frequency F_{uh} → electron plasma frequency F_{pe} → electron density N_e (similar as WHISPER); N_e up to 3000 cm^{-3} , resolution of 6 s, precision ultimately 3% after density smoothing

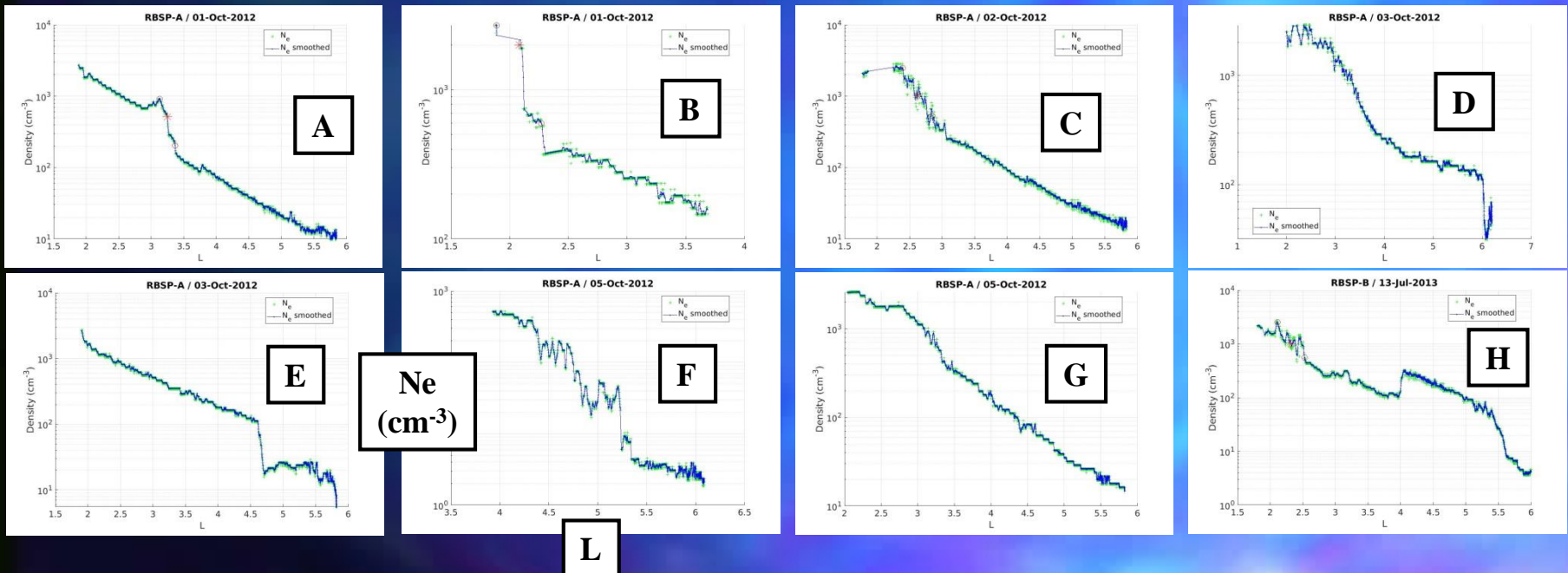


RBSP / EMFISIS – First Results

■ Plasmopause (or plasmasphere boundary layer, PBL) not easy to determine automatically

- Very different density profiles, large or short PBL in terms of L-scale (E-F)
- Many density irregularities and plumes observed (C-H)
- Density values outside the plasmopause (plasmatrough) variable (B-D)
- Simply no plasmopause boundary (G)

⇒ The usual condition “Location closest to the Earth where Ne increases by a factor of 5 within 0,5 L” does not work !!



Summary - Future

- 19 years of plasmasphere crossings by Cluster with different configurations, perigee altitudes and spacecraft separations
 - Low perigee: Comparison of plasmopause with radiation belts positions
 - Close and similar spacecraft separation: Wave analysis between all s/c
 - Very close distance between 2 satellites: Event analysis of plume crossing (+ data from other mission and numerical simulation)
 - And many more studies not presented here...
- And new data from old mission: Dynamics Explorer - 1 / RIMS
 - Many possibilities of new analysis with data of 5 different ions
- And data from actual mission: Van Allen Probes / EMFISIS
 - Full crossing of plasmopause (PBL) with various structures of boundary

■ Future

- Analyse plasmasphere by Cluster with higher perigee altitude (5-6 R_E now)
- Multi-mission study of the plasmasphere (ERG satellite, BARREL balloons, VLF whistlers ground-based instruments, ...)
- Continue analysis of old DE-1/RIMS data and actual RBSP/EMFISIS data

Some References



- Dynamics Explorer – 1
 - Chappell et al., *Space Sci. Instrum.*, **1981**
- Van Allen Probes - RBSP
 - Kletzing et al., *SSR*, **2013**; Kurth et al., *JGR*, **2015**
- Plasmopause
 - Darrouzet et al., *JGR*, **2013**
- Plumes
 - Darrouzet et al., *Ann. Geophys.*, **2006**; Darrouzet et al., *Ann. Geophys.*, **2008**;
Foster et al., *GRL*, **2002**; Goldstein et al., *JGR*, **2004**
- Waves
 - Grison et al., *GRL*, **2016**; Usanova et al., *JGR*, **2013**
- Numerical simulations
 - Goldstein et al., *JGR*, **2014**