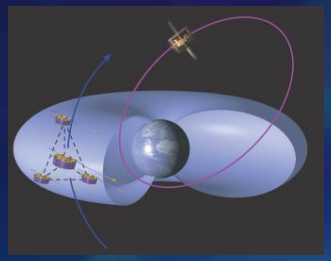

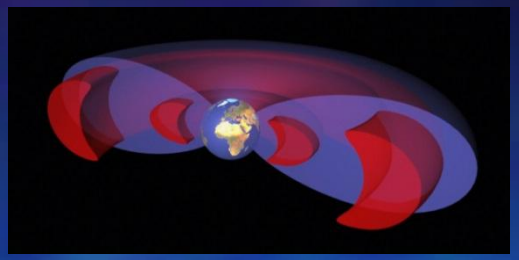

Links between the plasmapause and the radiation belt boundaries as observed by the instruments CIS, RAPID and WHISPER onboard Cluster

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- **Introduction**
  - Motivation
  - Cluster
- Radiation Belt Position
  - CIS
  - RAPID
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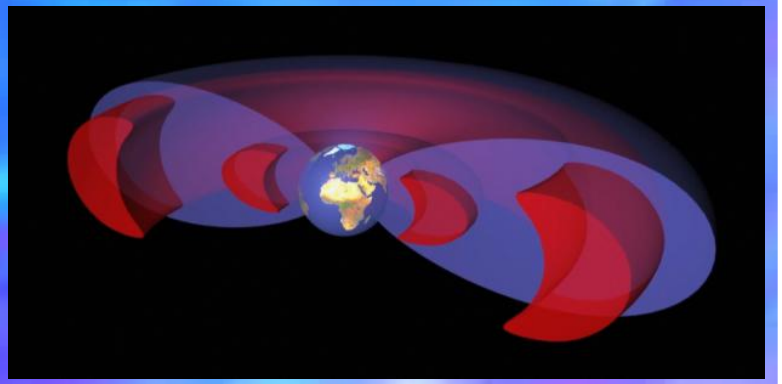
- Comparison + Data during higher activity
- Summary - Conclusion

Introduction: Motivation

- Radiation belt (RB) dynamics is strongly influenced by the core plasmasphere distribution and more specifically, by the position of the plasmapause (PP) and by the plasmaspheric waves that are able to scatter the energetic particles into their loss cones
- Several studies about the relationship between outer RB and PP:
  - SAMPEX for RB + IMAGE for PP: Close correlation between inner extent of outer RB and 3.5-days-averaged PP location ***[Goldstein et al., 2005]***
  - SAMPEX for RB + IMAGE for PP: Close relationship between inner extent of outer belt and PP location during dramatic storms in 2003 ***[Baker et al., 2004]***
  - SAMPEX for RB + CRRES and model for PP: Innermost PP position is the innermost limit of the outer RB penetration ***[Li et al., 2006]***
- All comparative studies between RB boundaries and PP position done with different satellites and/or models…
  - Better if possibility to study both regions with several instruments onboard 1 unique mission !!

    ⇒ Possible with Cluster

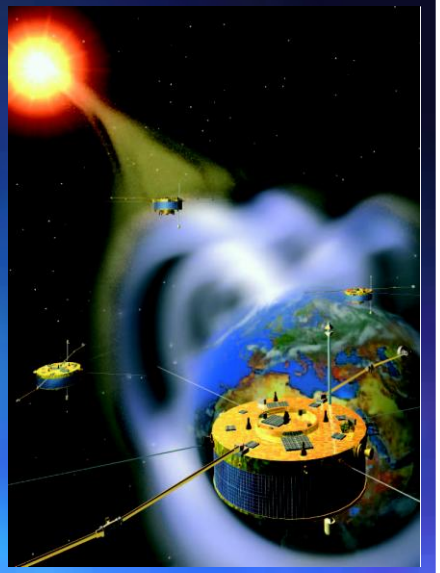


[Courtesy of ESA]

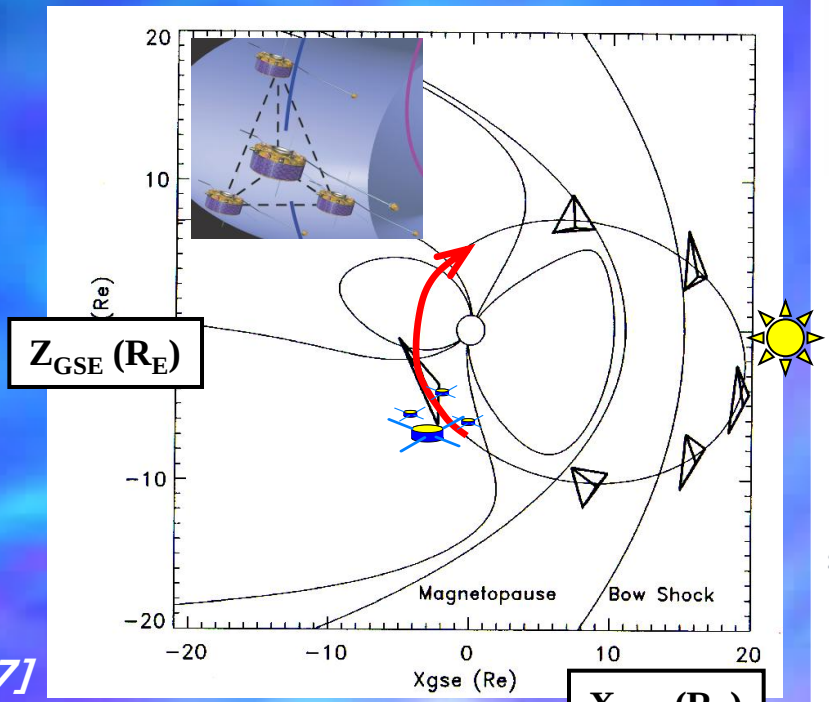
Introduction: Cluster

- Cluster:
  - 4 identical satellites, polar orbit (4x19.6 R_E) with 2 crossings of the inner magnetosphere at perigee in southern then northern hemisphere
  - Inner magnetosphere studies not a primary goal of the mission, but many new results and discoveries
  - New perigee after 2007: down to 1.5 R_E

    ⇒ Access to new regions: radiation belts and innermost plasmasphere
- Data used:
  - 11 well-calibrated instruments:
    - WHISPER sounder (electron density)
    - CIS spectrometer (ions)
    - RAPID spectrometer (high energy ions and electrons)
  - Cluster 3, April 2007 – March 2009



[Courtesy of ESA]



[Escoubet et al., 1997]

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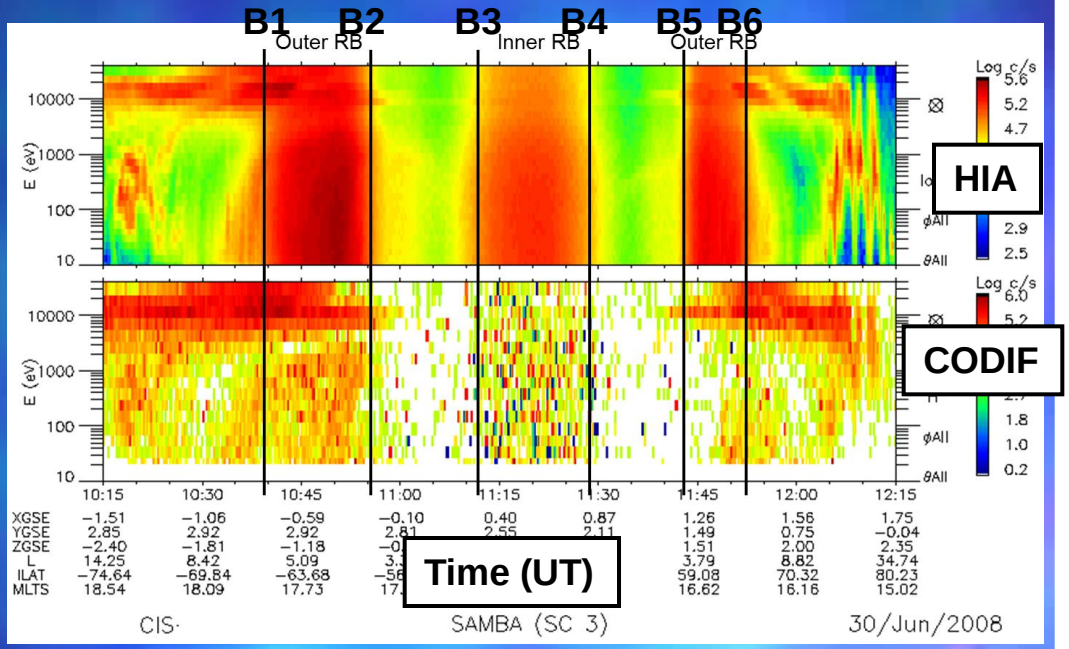
Radiation Belt Position: CIS Data

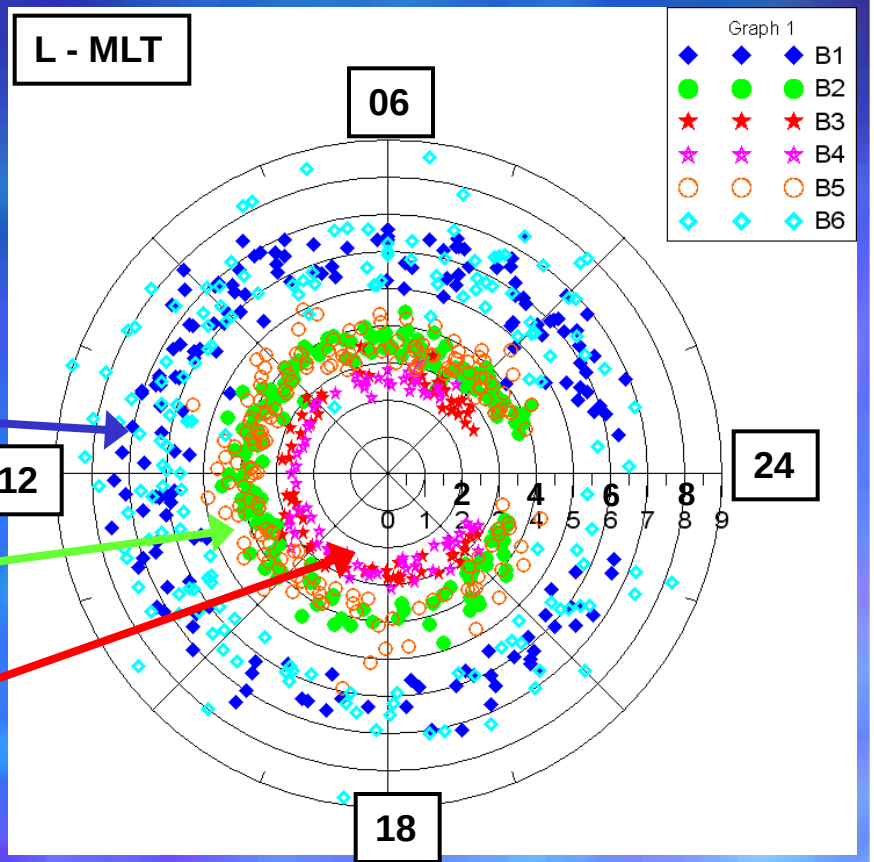
- CIS time-energy spectrograms of ions (in counts/s) for a radiation belt crossing by Cluster 3:
  - 30 June 2008, 10:15-12:15 UT, 16-18 MLT, Kp=1, Dst=-1
  - HIA ions (5 eV - 32 keV) and CODIF H^+ ions (20 eV - 40 keV)
- Method:
  - Careful look at background counts produced by energetic electrons (E>2 MeV)
  - ⇒ Derivation of positions of radiation belt boundaries



[Ganushkina et al., 2011]

Radiation Belt Position: CIS Results

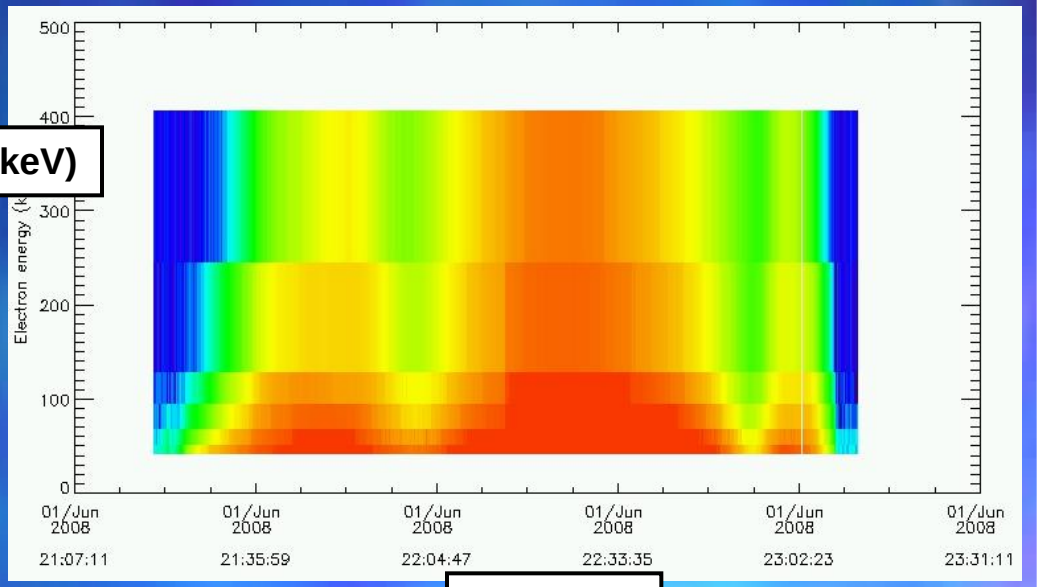
- Statistical analysis of CIS data onboard Cluster 3 from April 2007 to June 2009 (220 crossings):
  - In general determination of inner and outer boundaries of outer RB + many times outer boundary of inner RB
  - Few data around midnight MLT sector (instrument turned off during eclipses)
- L-MLT distribution of boundaries locations:
  - B1 and B6: outer boundary of outer radiation belt (L=5-7)
  - B2 and B5: inner boundary of outer radiation belt (L=3-4)
  - B3 and B4: outer boundary of inner radiation belt (L=2-3)



[Ganushkina et al., 2011]

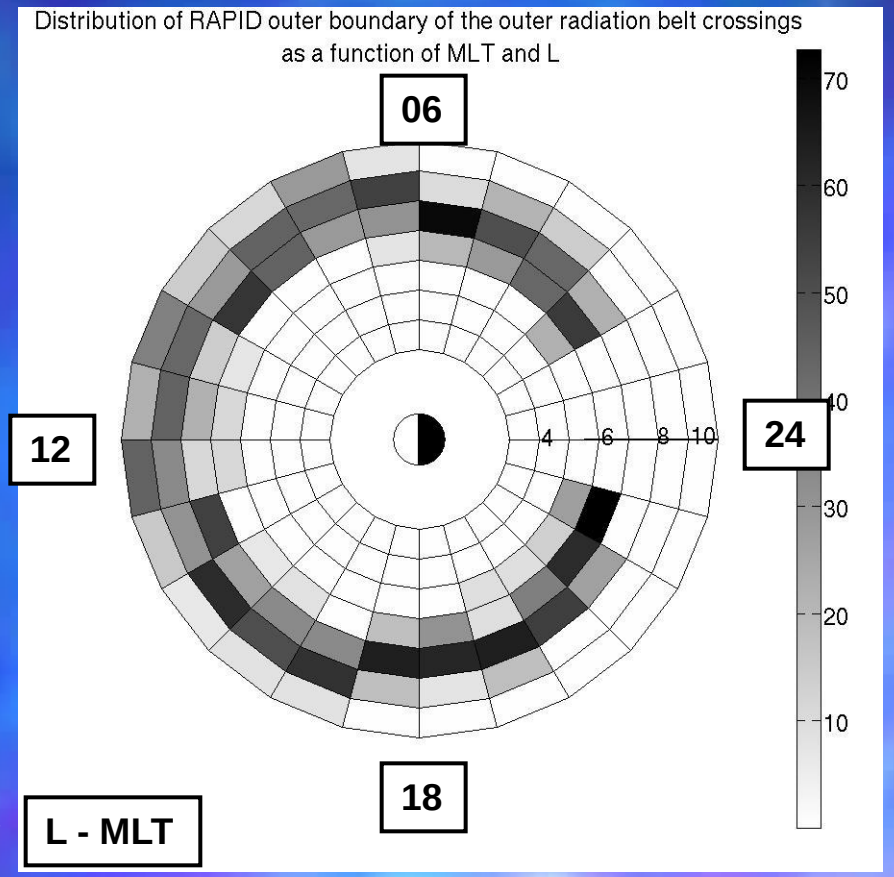
Radiation Belt Position: RAPID Data

- RAPID time-energy spectrogram of high energy electrons for a radiation belt crossing by Cluster 4:
  - 1 June 2008, 21-23 UT, 19-20 MLT, Kp=2$^-$, Dst=-10
  - Analyze of electrons in energy range 244-406 keV
- Method:
  - Careful look at intensity variations
  - ⇒ Derivation of positions of radiation belts boundaries
- Remark:
  - Extension of radiation belts varies for the different electron populations under consideration: The higher the electron energy is, the less extended is the outer radiation belt (observed also in models such as AE-8)



Radiation Belt Position: RAPID Results

- Statistical analysis of RAPID data onboard Cluster 3 from April 2007 to March 2009 (259 crossings)
  - L-MLT distribution of the locations of outer boundary of outer radiation belt (probability of boundary detected inside 1 L-MLT bin)
- Results:
  - All MLT sectors covered, except around midnight, for the same reasons as for CIS (instruments turned off during eclipses)
  - L-position: 5 - 9 R_E, and mainly 6 - 8 R_E
  - Positions at slightly larger L values than deduced from CIS, mainly due to different energy than CIS observations



[Darrouzet et al., 2013]

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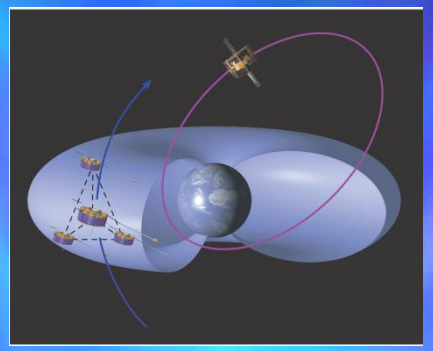
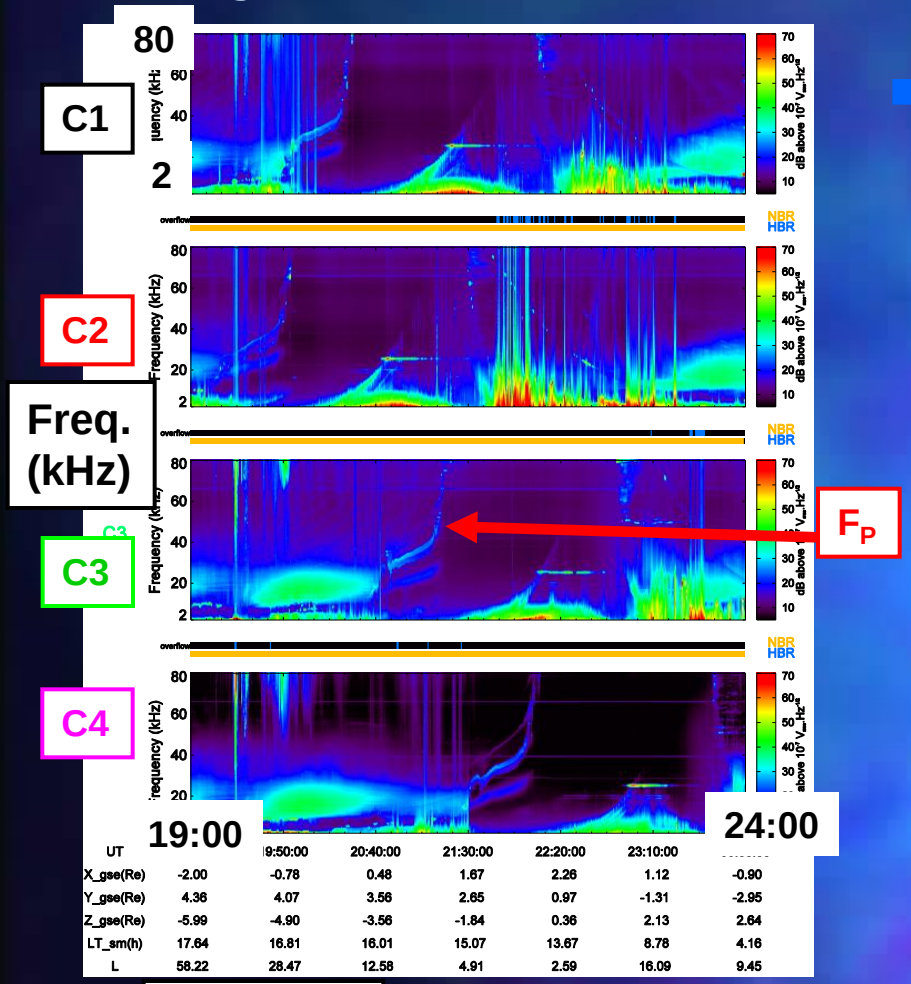


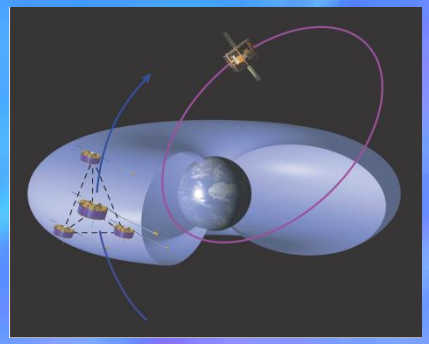
Plasmapause Position: WHISPER Data

- WHISPER time-frequency electric field spectrograms for a plasmasphere crossing:

  28 August 2008, 19-24 UT, 15 MLT, Kp=1, Dst=-5

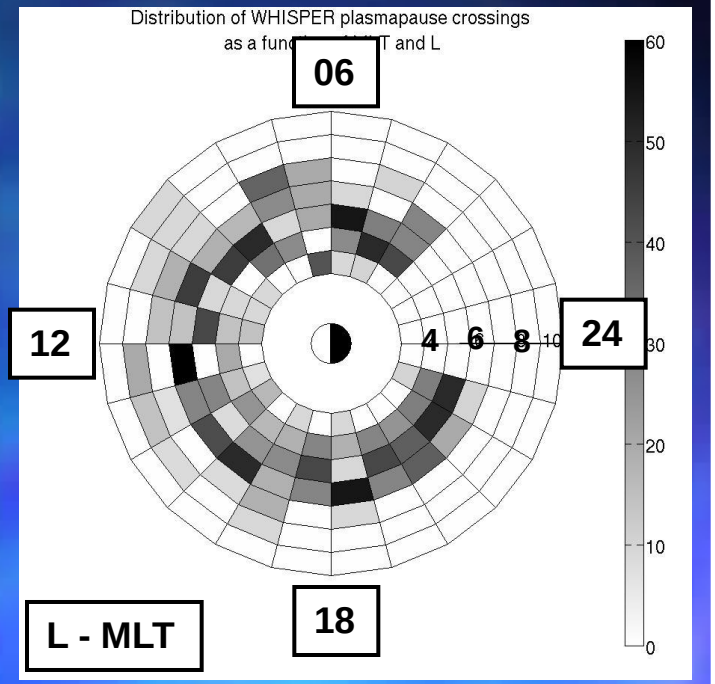


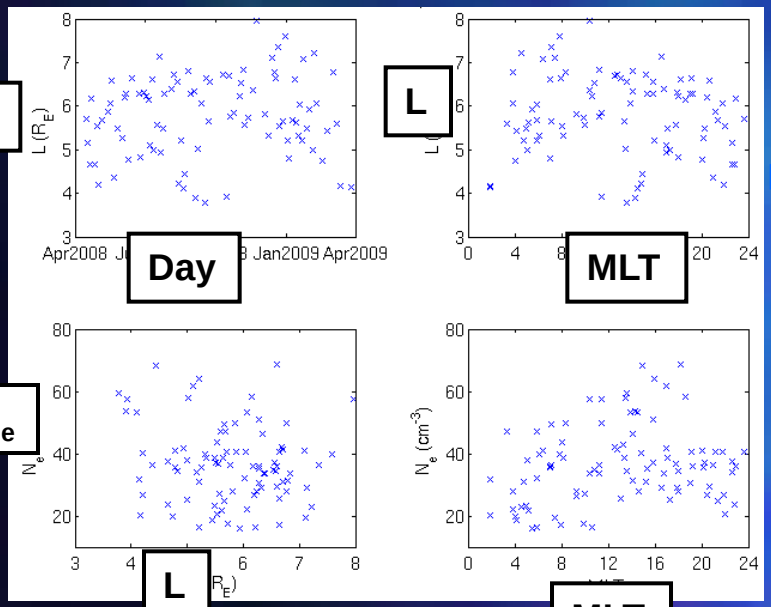
- Method:
  - Determination of F_p, then N_e during the plasmasphere inbound crossing (for Cluster 3)
  - Search of largest jump of N_e
  - Derivation of average innermost position of plasmapause



Plasmapause Position: WHISPER Results

- Statistical analysis of WHISPER data onboard Cluster 3 from April 2007 to March 2009 (205 crossings):
  - Use of average innermost position of plasmapause

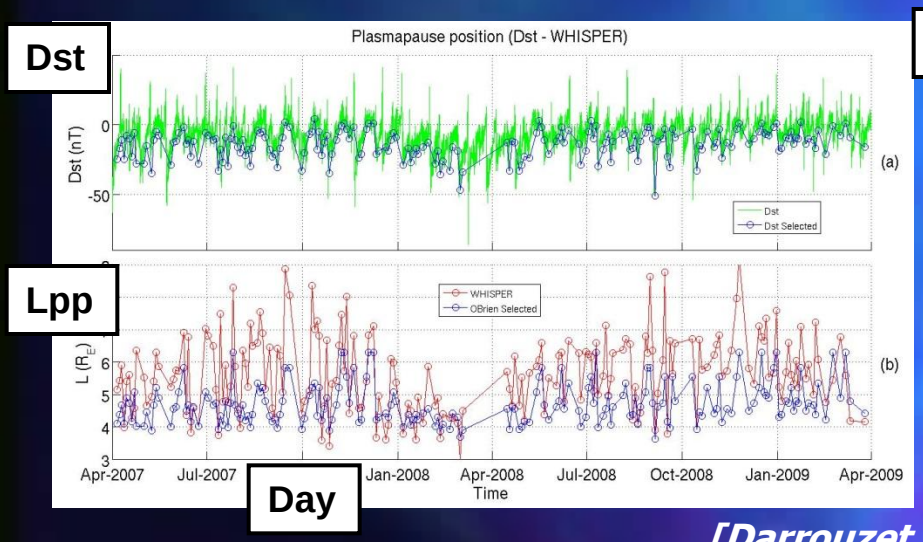


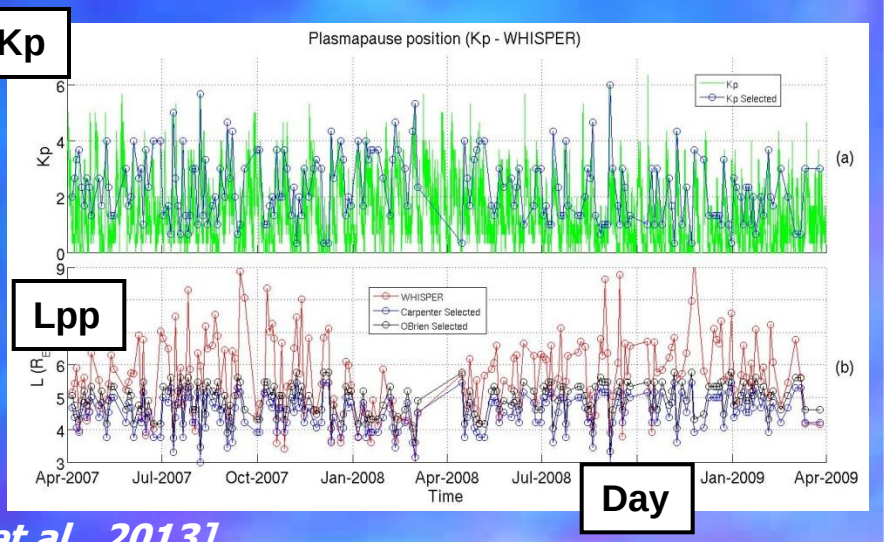


- Results:
  - L-position: 4-7 R_E (low geomagnetic activity time period)
  - Higher N_e in afternoon MLT sector
  - Low density values (due to WHISPER instrumental limits) ⇒ WHISPER gives an outer position of the plasmapause

Plasmapause Position: WHISPER Results

- Analysis as a function of geomagnetic activity, and comparison with 3 models (April 2007 – March 2009):
  - Lpp = 6.3-1.57 log10|Dstmin| (O'Brien & Moldwin model, blue left)
  - Lpp = 5.9-0.43 Kpmax (O'Brien & Moldwin model, black right)
  - Lpp = 5.6-0.46 Kpmax (Carpenter & Anderson model, blue right)
- Results:
  - Plasmapause derived from WHISPER (red) at higher L than models
  - Variations with Dst and Kp well recovered





[Darrouzet et al., 2013]

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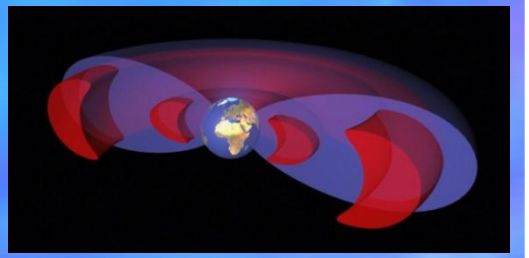
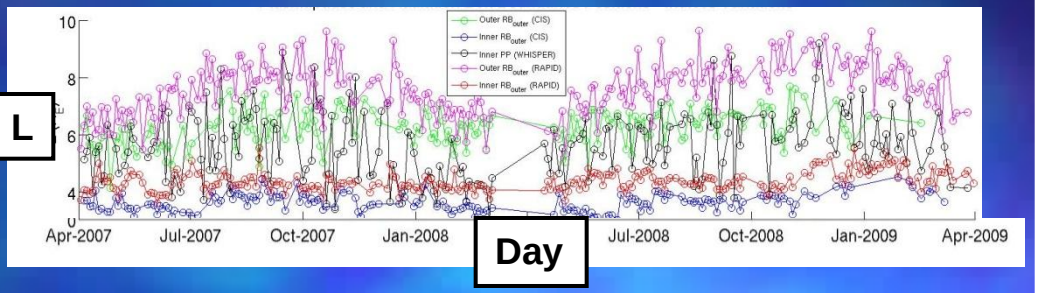
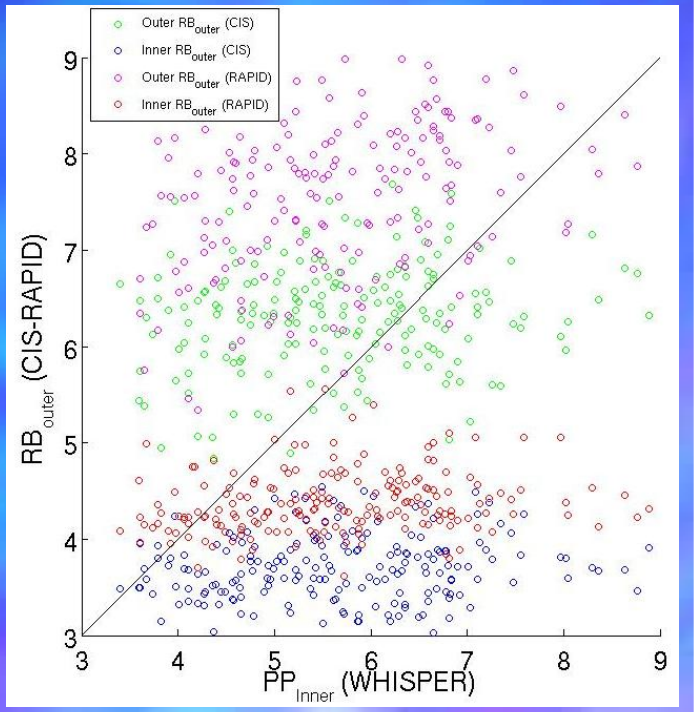


Plasmapause / Radiation Belt (1)

- Correlation between PP position obtained from WHISPER (black) and boundary location of the outer RB obtained from CIS (blue-green) and RAPID (red-magenta) from April 2007 to March 2009:
  - Many daily variations are similar, but some differences between CIS and RAPID
  - Quite low activity during those years: plasmasphere very extended at L>4
  - Plasmapause position very variable due to different conditions and strong interaction with small variations in geomagnetic activity
  - Plasmapause coincides to outer boundary at larger L (low activity) and to inner boundary at smaller L (high activity)

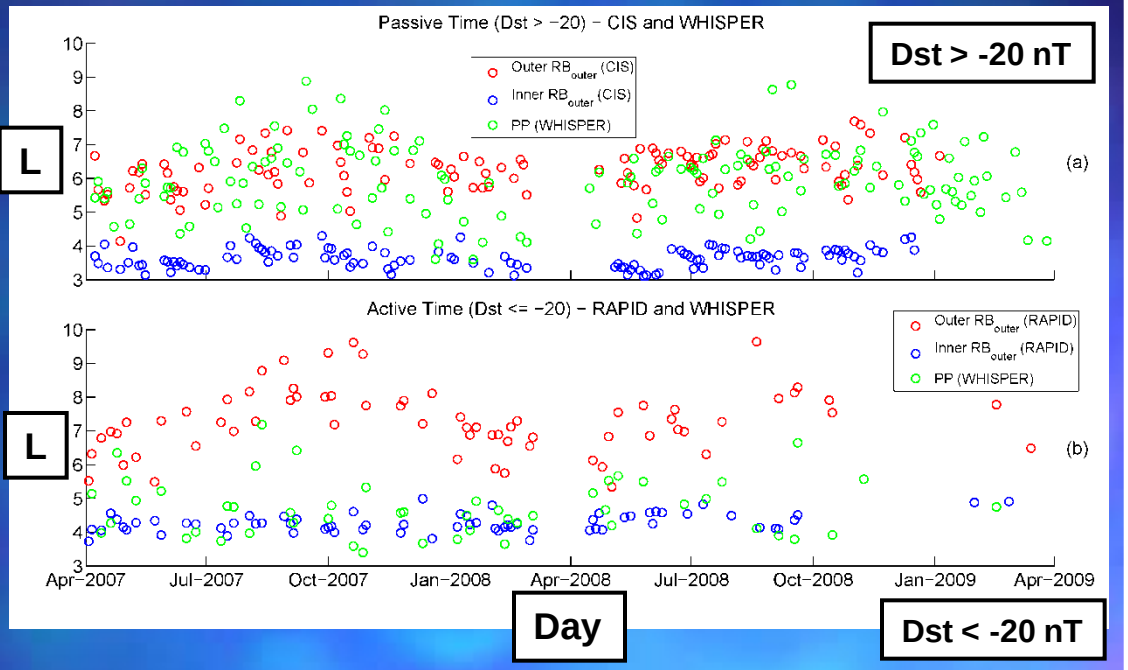




[Darrouzet et al., 2013]

Plasmapause / Radiation Belt (2)

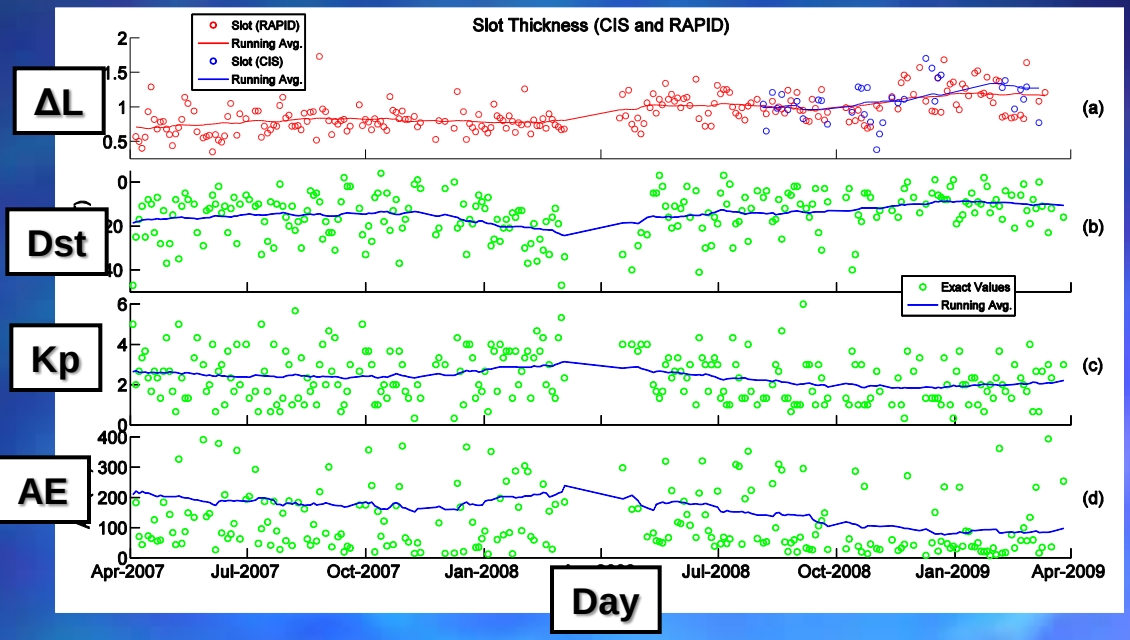
- Dataset divided in 2 by analyzing the minimum Dst index in the 24 hours preceding an event and by selecting the data with Dst > and < -20 nT
  - Passive period: plasmapause located at L ~ 6 R_E and globally closer to the outer boundary of outer belt
  - More active period: plasmapause located closer to the Earth (L ~ 4-5 R_E) and very close to the inner boundary of outer belt



Outer RB
Inner RB
PP

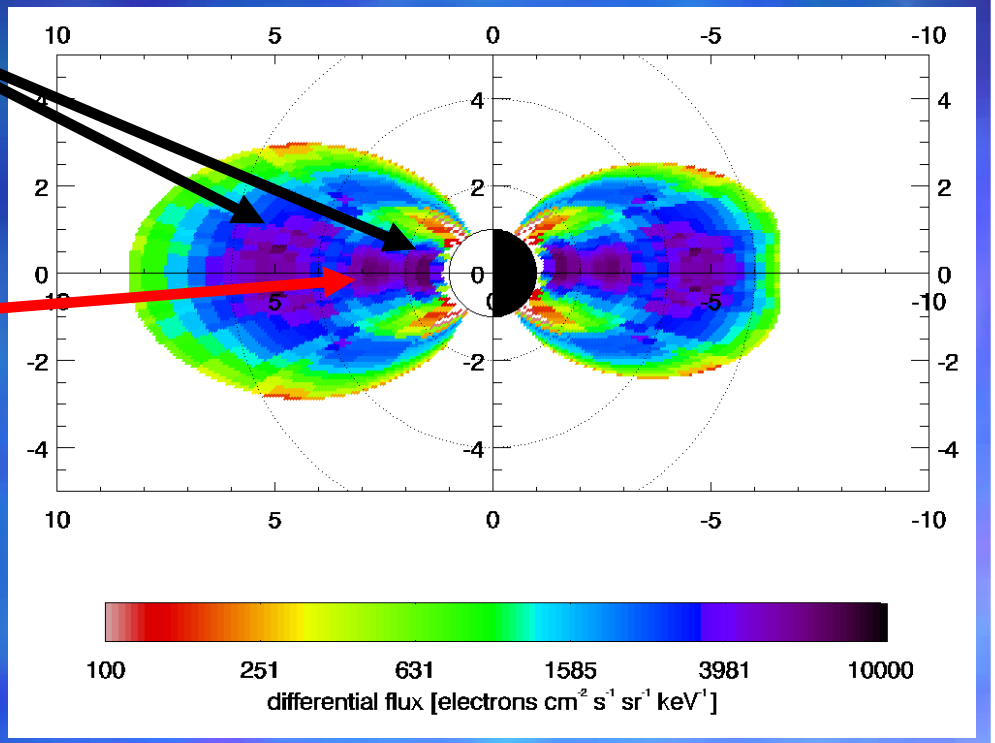
Plasmapause / Radiation Belt (3)

- Evolution of slot thickness ΔL as a function of time (RAPID data in red and CIS data in blue only after August 2008) and variations of geomagnetic indices:
  - Very similar slot thickness values and variation
  - For RAPID data, there are clearly two different time periods:
    - Before March 2008: ΔL quite constant, with geomagnetic activity quite low and constant.
    - After May 2008: ΔL slowly increasing from 1.0 to 1.2 R_E, related to regular decrease of the geomagnetic activity.
      Mainly due to increase of inner boundary location of outer belt (outer boundary of inner belt not varying much).



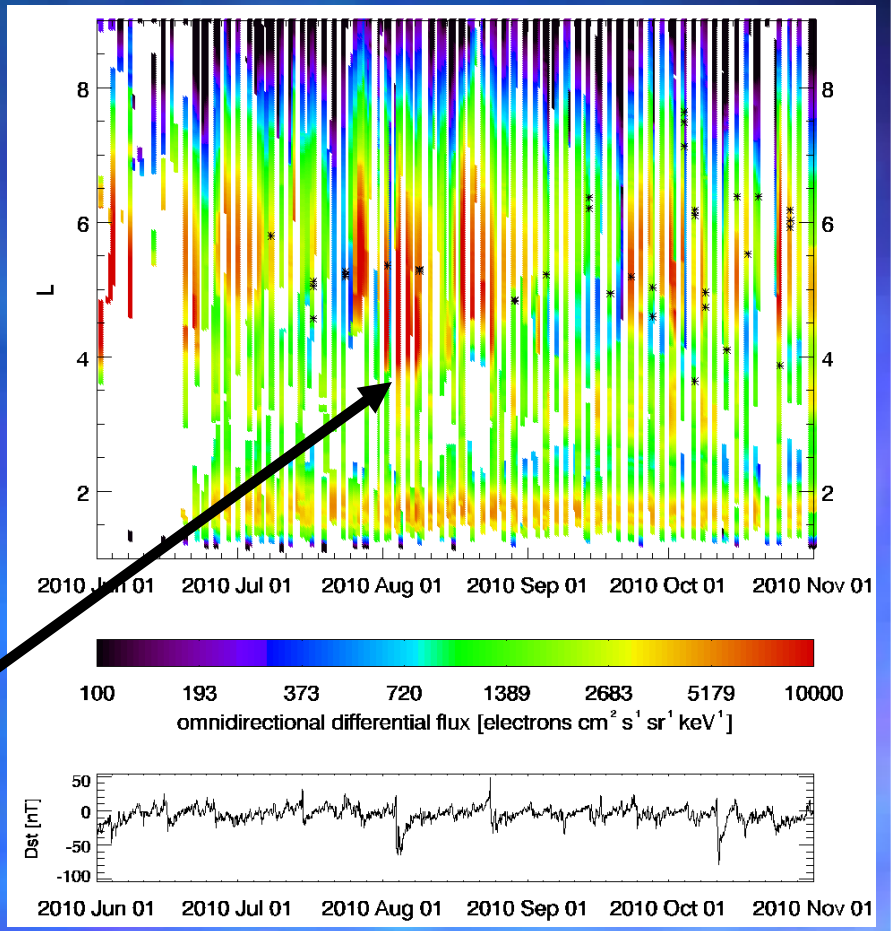
Radiation Belt / Higher Activity (1)

- Radiation belt fluxes from RAPID (E=244-406 keV), onboard all 4 Cluster satellites, during higher geomagnetic period (2011), averaged in B/L* bins, plotted in a meridian plane (Sun towards left, color scale inversed)
  - Inner and outer belts observed, as well as slot region
  - Third belt observed in equatorial plane at about L*=3 (but due to instrument contamination)
  - Slight asymmetry due to orbits of satellites
  - Preliminary radiation belt model during quiet and active time derived from RAPID data and Dst variations (talk by Pierrard et al. on Wednesday)



Radiation Belt / Higher Activity (2)

- Radiation belt fluxes from RAPID (E=244-406 keV), onboard all 4 Cluster satellites, during higher geomagnetic activity (June-October 2010)
  - Low variability of inner belt even after Dst=-70 nT
  - Variation of plasmapause position (black star)
  - Third belt from contamination of RAPID instrument
  - Increase of flux in outer belt after storm
  - Penetration of particles at lower L-shells after August 2010 storm



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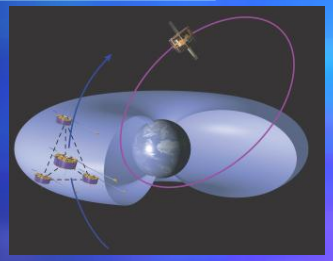
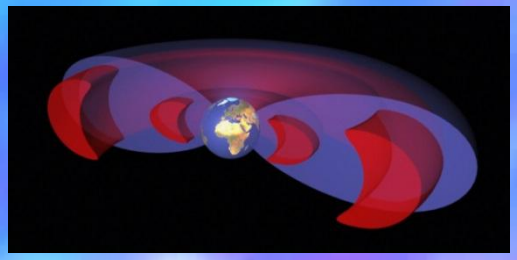




Summary – Conclusion (1)

- April 2007 – March 2009, Cluster deeper in inner magnetosphere at their low perigee (1.5 R_E):
  - Boundaries of outer and inner radiation belts determined from background measurements of CIS instrument but also from RAPID measurements + Plasmapause position determined from WHISPER ⇒ Comparison between all boundary locations
    - Plasmapause closer to outer boundary of outer belt during this low geomagnetic activity time period
    - During small geomagnetic activity enhancements, plasmapause closer to inner boundary of outer belt
    - Plasmapause position very dependent on small-scale geomagnetic activity variations, not so the case for radiation belts boundary positions
  - Important to know the plasmapause location for radiation belt studies (wave-particle interaction), but also electron density…

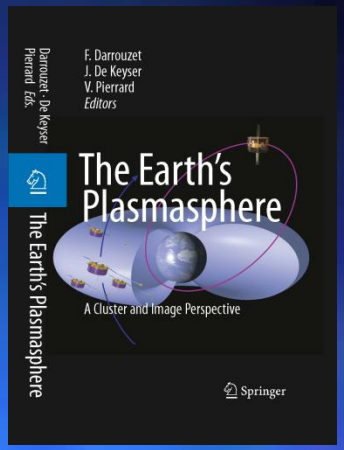
- Future:
  - Check waves occurrence (hiss, EMIC, chorus) during those events
  - Compare radiation belt and plasmapause datasets at a daily level
  - Expend the study and compare with Van Allen Probes data

Summary – Conclusion (2)

- Short animation on plasmapause/radiation belts made by ESA :

- See also an ESA web story at http://sci.esa.int/cluster/52802

Some References



- CLUSTER AND PLASMASPHERE BOOKS/REVIEWS:
  - Darrouzet, De Keyser, Pierrard (eds.), *Springer*, **2009**
  - Escoubet, Russell, Schmidt (eds.), *Kluwer*, **1997**

- PLASMAPAUSE-RADIATION BELTS STUDIES:
  - Baker et al., *Nature*, 432, 878, **2004**
  - Darrouzet et al., *JGR*, 118, **2013** (http://sci.esa.int/cluster/52802)
  - Ganushkina et al., *JGR*, 116, **2011**
  - Goldstein et al., *GRL*, 32, **2005**
  - Li et al., *GRL*, 33, L14107, **2006**

Thank you for your attention !

Abstract

- With its lower perigee, the Cluster mission offered the exceptional opportunity to analyze the positions of the plasmasphere and radiation belt boundaries with identical sensors on multiple spacecraft. We compare the positions of the radiation belt edges deduced from CIS observations (electrons with energy > 2 MeV) with the positions of the plasmapause derived from WHISPER data (electron plasma frequency). In addition, we compare those results with the boundaries positions determined from RAPID observations (electrons with energy between 244.1 and 406.5 keV).
- The period of 1 April 2007 to 31 March 2009 has been chosen for the analysis because at that time Cluster's perigee was located at lower radial distances than during the earlier part of the mission (as close as 2 RE, deep inside the plasmasphere and the radiation belts). This time period corresponds to a long solar activity minimum.
- Differences are observed between the radiation belt boundary positions obtained from the two different instruments: The radiation belt positions are related to the energy bands. The plasmapause position is more variable than the radiation belt boundary positions, especially during small geomagnetic activity enhancements. A correspondence is observed between the plasmapause position determined by WHISPER and the outer edge of the outer radiation belt of energetic electrons (> 2MeV) observed by CIS. This result is unexpected since previous studies based on other spacecraft observations indicated a correlation between the inner edge of the outer belt and the plasmapause. However, during higher geomagnetic activity time periods, the plasmapause is located closer to the inner boundary of the outer radiation belt.
- We have pursued the analysis of radiation belt boundaries positions during time period with higher geomagnetic activity, showing different characteristics. We present also some first conclusions from a comparison of those data with a global plasmasphere model and a radiation belt model.