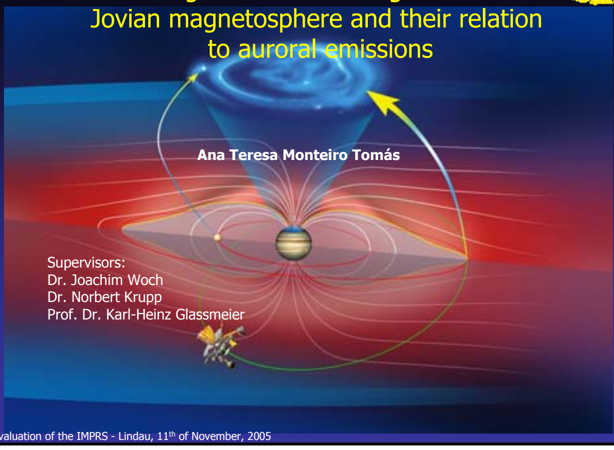
Energetic Particle changes in the Jovian magnetosphere and their relation to auroral emissions



Ana Teresa Monteiro Tomás

Supervisors:
Dr. Joachim Woch
Dr. Norbert Krupp
Prof. Dr. Karl-Heinz Glassmeier

Evaluation of the IMPRS - Lindau, 11th of November, 2005

Outline

- **Aim of the work**
- **Introduction**
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  - Pitch angle diffusion
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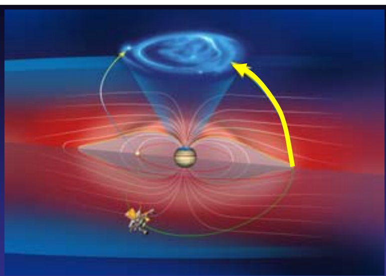
- **Energetic Particle and Magnetic field measurements**
- **Relation of particle boundaries to auroral emissions**
- **Physical processes at the origin of the particle boundaries**
- **Conclusions**

Aim of the work

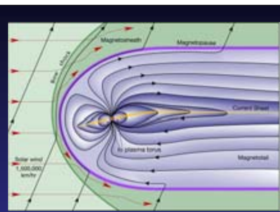


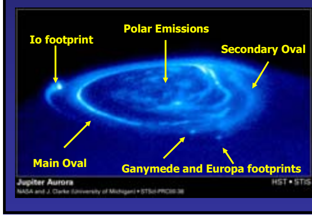
1. Studying the characteristics of the energetic particle population in the inner to middle magnetosphere.
2. Identifying the source region for auroral features (at the transition from the current sheet to the dipolar region).
3. Explaining the formation of the auroral features by studying the physical processes occurring in this region.

The Jovian magnetosphere

Internally driven system

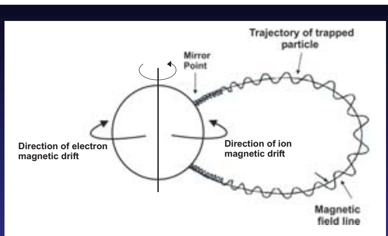
- Io Volcanic activity → 1 ton/sec of neutral atoms
- Fast rotation of the planet → plasma corotation up to large radial distances → formation of current sheet.





Main auroral oval	Breakdown of corotation on the middle magnetosphere
Satellite Footprints	Current circuits connecting the moons to the ionosphere
Polar emissions	Magnetospheric processes occurring in the far tail region of the magnetosphere
Secondary oval	?

Adiabatic Invariants



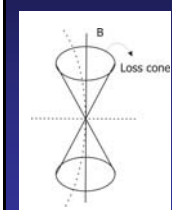
1. First adiabatic invariant — Gyro motion ⇩ $\mu = \frac{p^2 \sin^2\alpha}{B}$

2. Second adiabatic invariant — Bounce motion ⇩ $k = \int_{s_m}^{s'_m} \sqrt{1 - \frac{B(s)}{B_m}}\, ds$

3. Third adiabatic invariant — Drift motion ⇩ $J_3 = q\Phi$

Pitch angle diffusion

- Diffusion is one of the processes by which particles are transported in the magnetosphere. It can lead to loss of particles into the loss cone and consequent precipitation.
- Dominant mechanism for electron pitch angle diffusion – whistler waves.



Anisotropic pitch angle distribution – unstable particle distribution

⇩

Free energy - Whistler wave instability

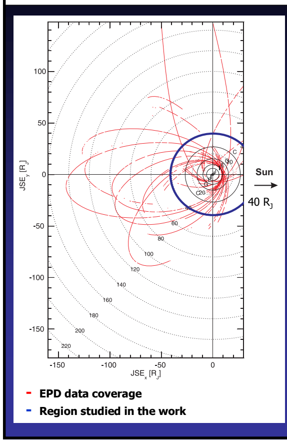
⇩

Whistler waves interact with electrons – Pitch angle diffusion

⇩

Precipitation into the ionosphere – Auroral emissions

EPD instrument on Galileo - the data used



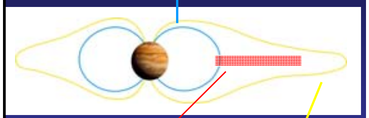
- Analyzing 33 Galileo Orbits
- Region of interest : r < 40 RJ
- Energy range :

Ions		Electrons	
Channel	Energy (keV)	Channel	Energy (keV)
A0	22 - 42	E0	15 - 29
A1	42 - 65	E1	29 – 42
A2	65 – 120	E2	42 – 55
A3	120 – 280	E3	55 – 93
A4	280 – 515	F0	93 - 188
A5	515 – 825	F1	174 - 304
A6	825 – 1680	F2	304 – 527
A7	1680 - 3200	F3	527 - 884

- Time Resolution : 3 – 11 min

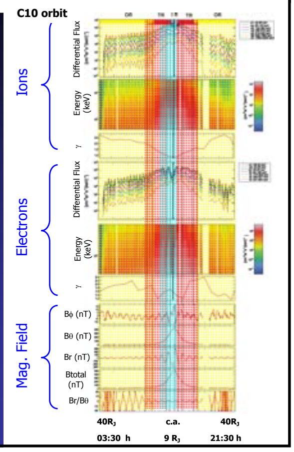
Observations – Energetic particle and magnetic field

- Inner regime : < 10 R_J
Dipolar region



Transition Region

- Outer regime : > 20 R_J
Core plasma sheet region



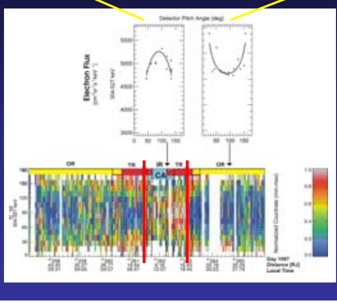
Observations - Electron pitch angle distribution

- Inner regime – dipolar region

Pancake distribution with maximum of flux at 90°

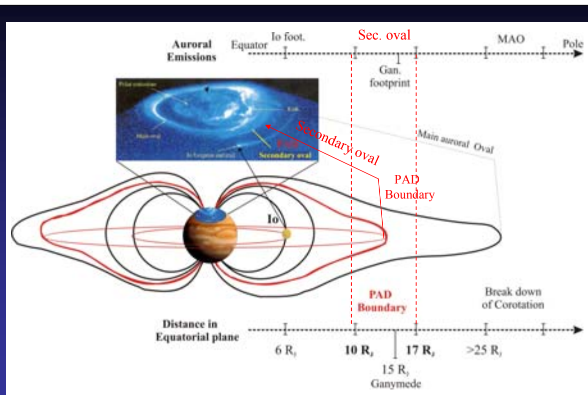
- Outer regime – core plasma sheet region

Bi-directional distribution with maximum of flux at 0° or 180°



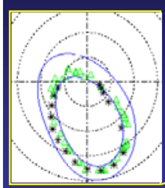
- Most prominent and well defined boundary – Located from 10 R_J to 17 R_J

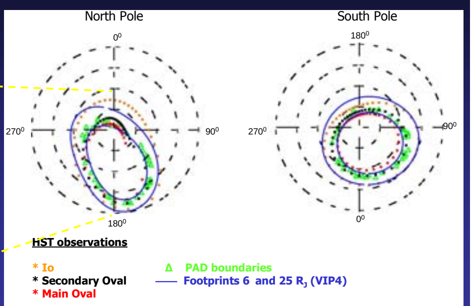
PAD boundary and auroral emissions



PAD boundary and auroral emissions – tracing of magnetic field lines

- Comparing the footprints of the PAD boundary (VIP4 model) with the HST observations





- Good conjugation between the PAD boundary and the secondary oval

Simulation of electron PAD changes

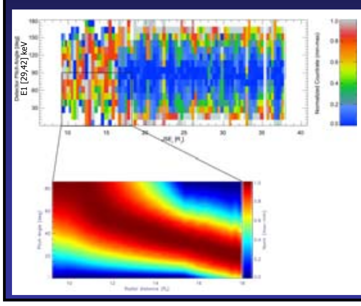
- Initial distribution :

$j(E,\alpha) = f(E)*(\sin(\alpha)^{b(E)} + c(E))$

- **E ∈ [29, 527]** keV and **α ∈ [1, 90]** deg

- Final distribution :
  - Conservation of **1st** and **2nd** adiab. inv. - retrieves final **E** and **α**.
  - Conservation of Phase space density - retrieves final j.

- Variation of the pitch angle distribution with radial distance – Observations and simulation

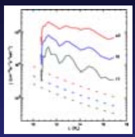


- Adiabatic processes lead the distribution from a pancake to a bi-directional distribution within the same radial range as observed by measurements.

Wave-particle interaction and pitch angle diffusion

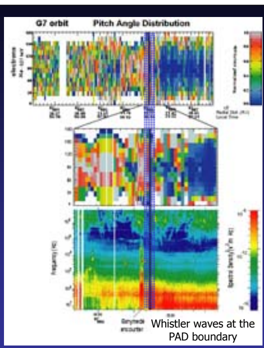
• Critical flux – Minimum flux needed for whistler wave instability.

$$Jc \propto 8\times10^{10}\left(\frac{L^{-4}}{E}\right)$$



• Verified that measured flux is bigger than critical flux.

• Whistler waves – Presence confirmed by wave frequency-time spectrograms.



Whistler waves at the PAD boundary

• Estimation of the ratio : Dαα/Dsd

$$D_{\alpha\alpha}=\frac{2\pi f_c}{\gamma}\left(\frac{B'}{B}\right)^2\cdot\varepsilon \qquad D_{sd}=\left(\frac{v}{4R_J}\right)\frac{1}{L^4}$$

⇨ • $D_{\alpha\alpha}$ well above D_{sd} → The conditions for strong pitch angle diffusion are satisfied.

Precipitation energy flux

• Considering:

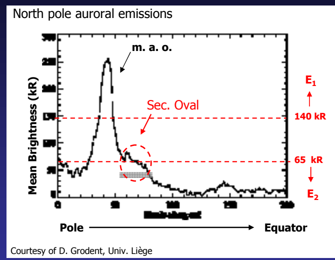
• The precipitation energy flux given by :

$$\varepsilon=4\pi\int_{E_{min}}^{E_{max}} E\cdot j(E,\gamma)\cdot dE$$

• Measured electron spectra at the PAD boundary.

• Strong pitch-angle scattering.

• Electron's energy : $E_1 \in [55, 304]$ keV.
$E_2 \in [55, 188]$ keV.



Courtesy of D. Grodent, Univ. Liège

• Sufficient to directly produce the observed auroral emissions of the secondary oval without the need of a field aligned potential drop.

Conclusions

1. Energetic particle characteristics on 33 of Galileo orbits (from 10 R_J to 30 R_J) ⇨ • Electron pitch angle distributions pancake to bi-directional : 10 R_J < r < 17 R_J

2. Relation to the secondary auroral oval ⇨ • Tracing of magnetic field lines and comparison with the HST observations.

3. Physical processes occurring at the pitch angle boundary ⇨
• Bi-directional distribution in the outer current sheet region evolves to a pancake in the dipolar inner region.
• Whistler waves in the PAD boundary lead to pitch angle scattering and strong diffusion
• Calculated precipitation energy flux gives brightness values in the range of the secondary oval brightness.