Electron Acceleration and Loss in the Radiation Belts

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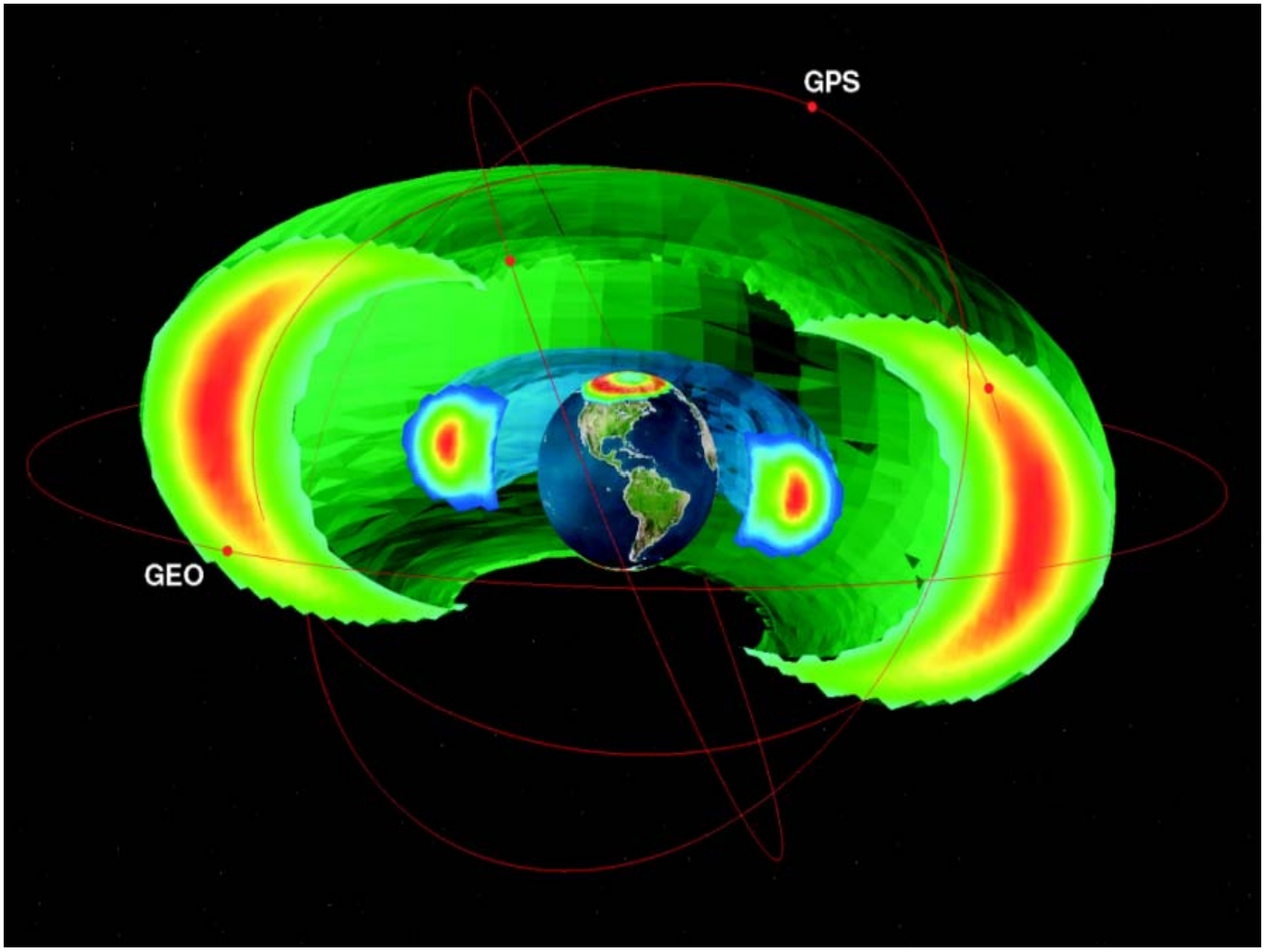
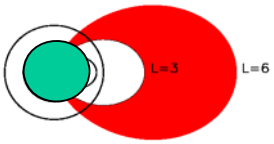
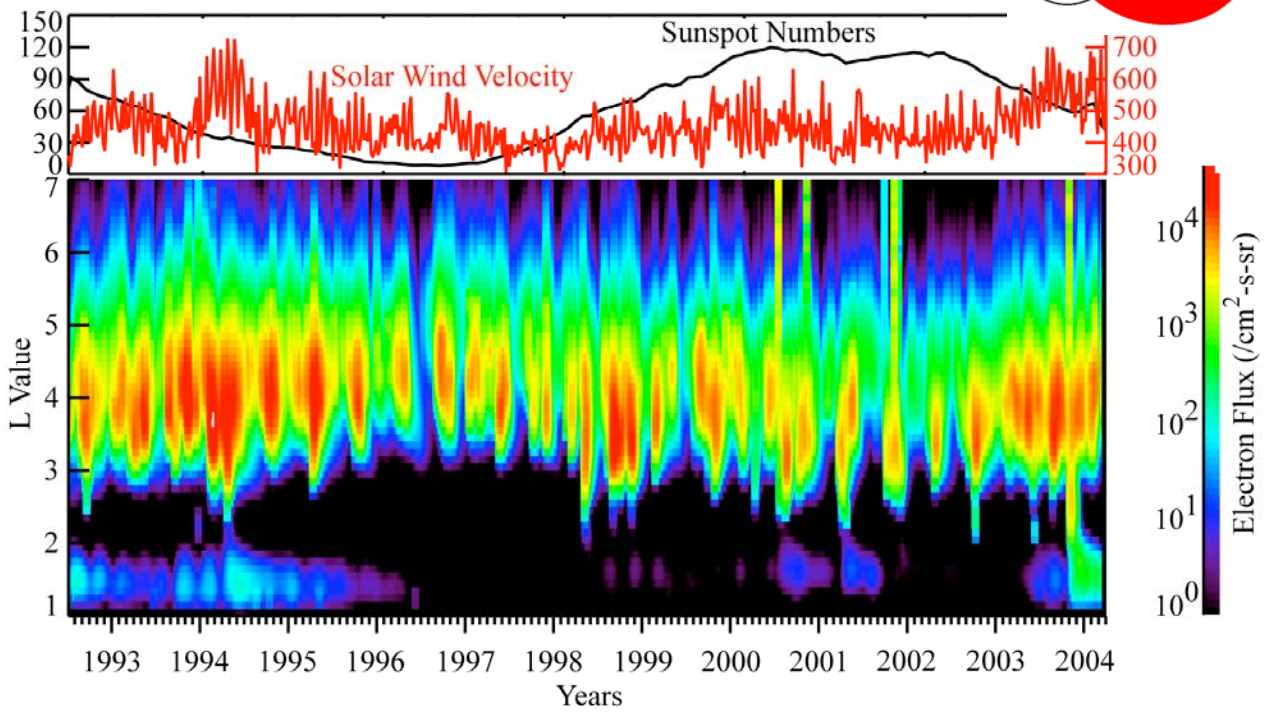
Invited plenary, JENAM, U. of Hertfordshire, 20th April 2009


GPS
GEO

Radiation Belts - The Problem





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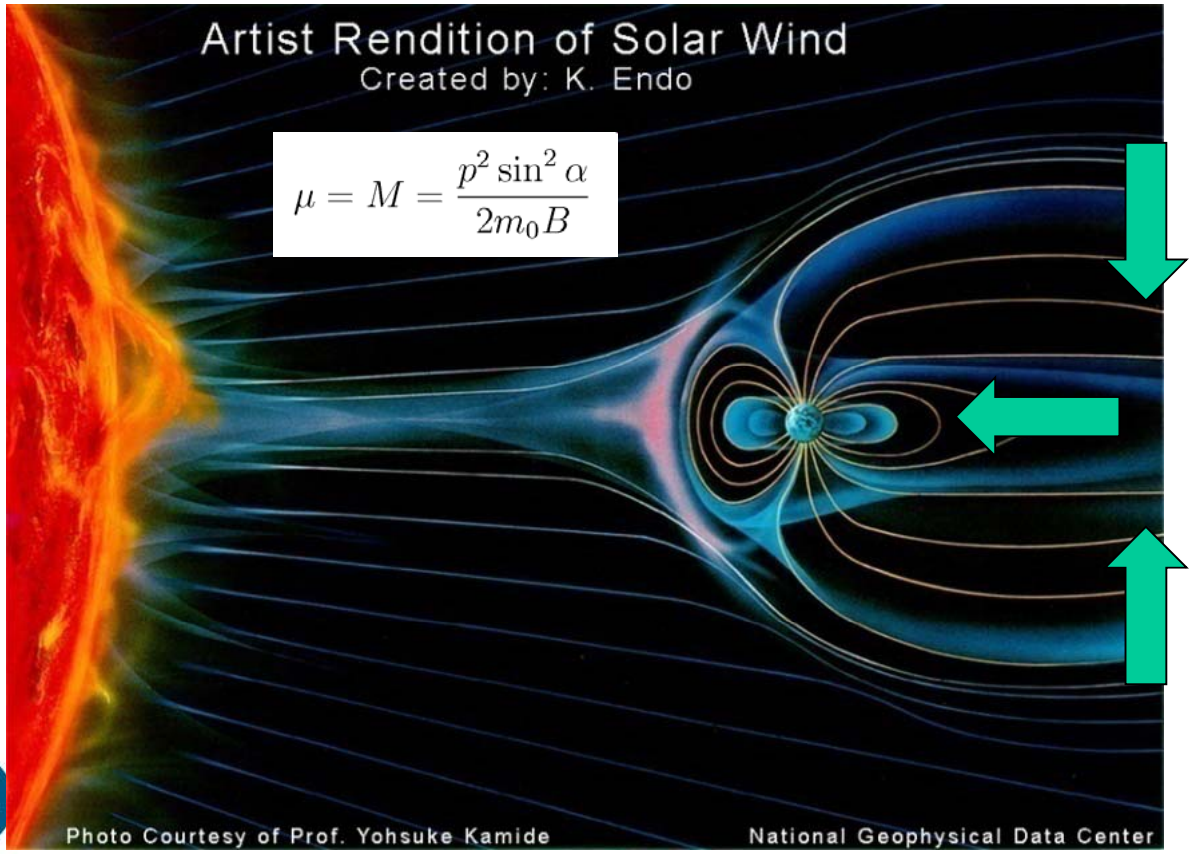
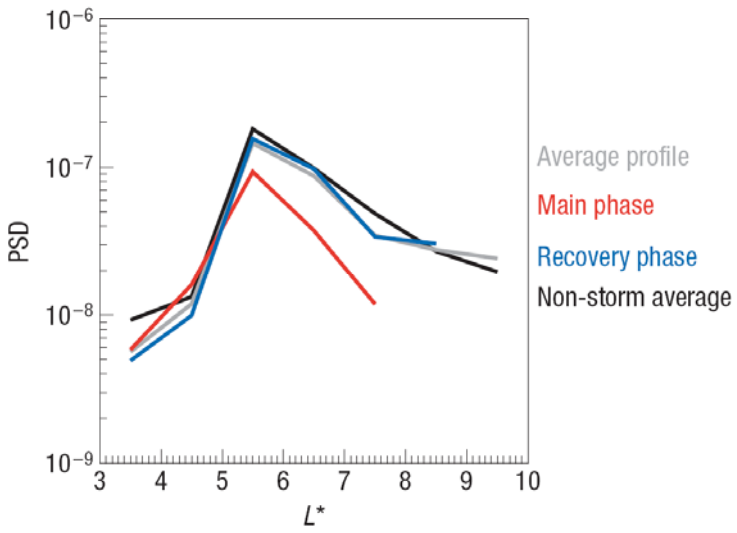
How do you produce >1 MeV electrons?
What causes the variations?

Radiation Belt Formation – Original Idea



Electron Phase Space Density

M = 2083 MeV/Gauss



- BUT
- Peak does not support radial diffusion from a source in the outer magnetosphere
- Suggests a new "local" acceleration mechanism

Chen et al., *Nature Physics,* [2007]

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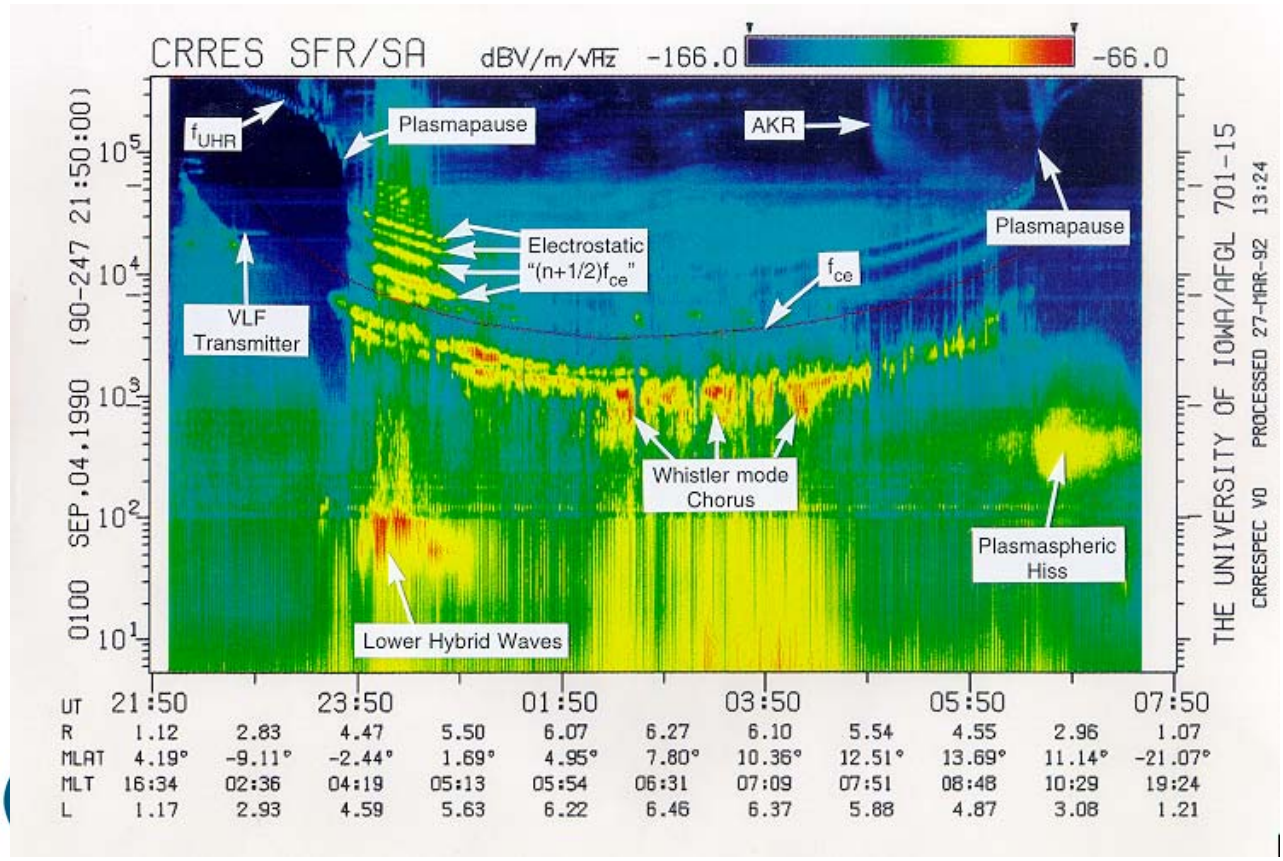
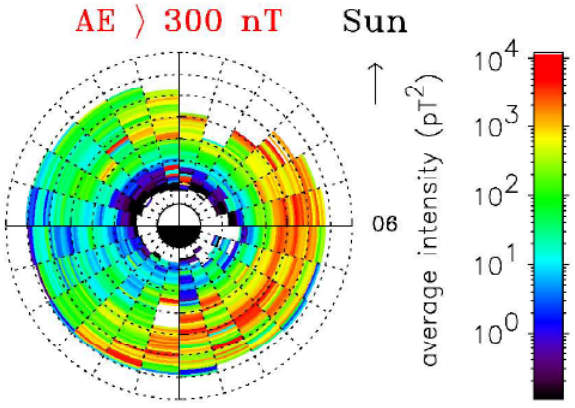
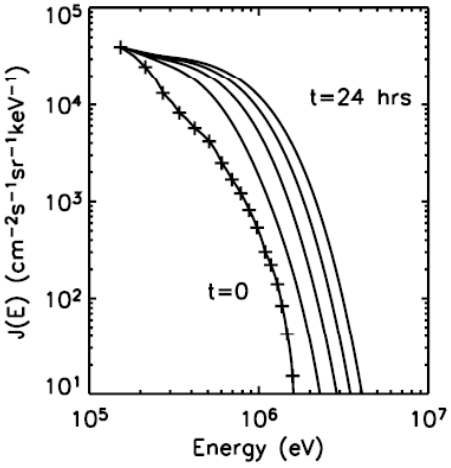
Acceleration by Whistler Mode Waves



Cyclotron Resonant Electron Acceleration





- Whistler mode waves excited by ~1-50 keV electrons
- Waves accelerate a fraction of the population up to MeV energies

- Fokker-Planck calculations
- Timescale ~ 1-2 days

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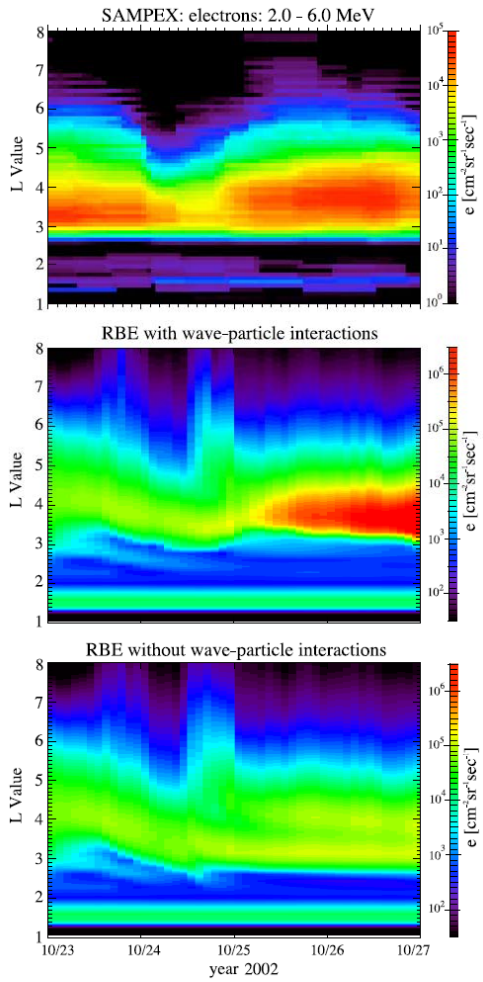
- Horne et al., *Nature* [2005]



Global Modelling

- Data
- 2-6 MeV electrons

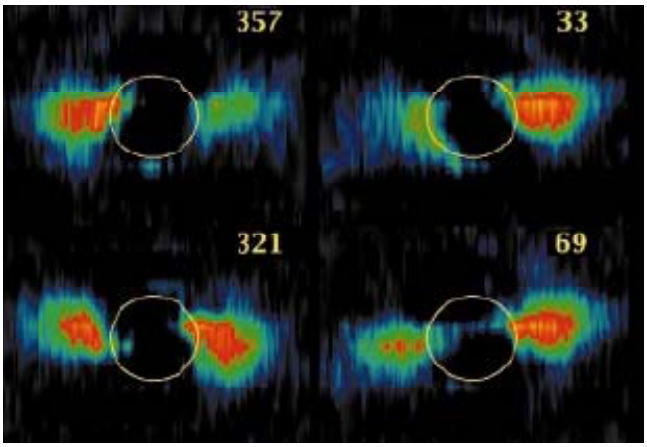
Varotsou et al., 2005, 2008
Fok et al., 2008

- Model
- Transport and cyclotron resonant wave-particle interactions

- Model
- Transport only

- Wave-particle interactions are essential to explain dynamics

Jupiter



[Bolton et al., *Nature*, 2002]

- Synchrotron radiation indicates intense radiation belt:
  - 50 MeV electrons at L=1.4
- Could cyclotron-resonant electron acceleration apply to Jupiter?

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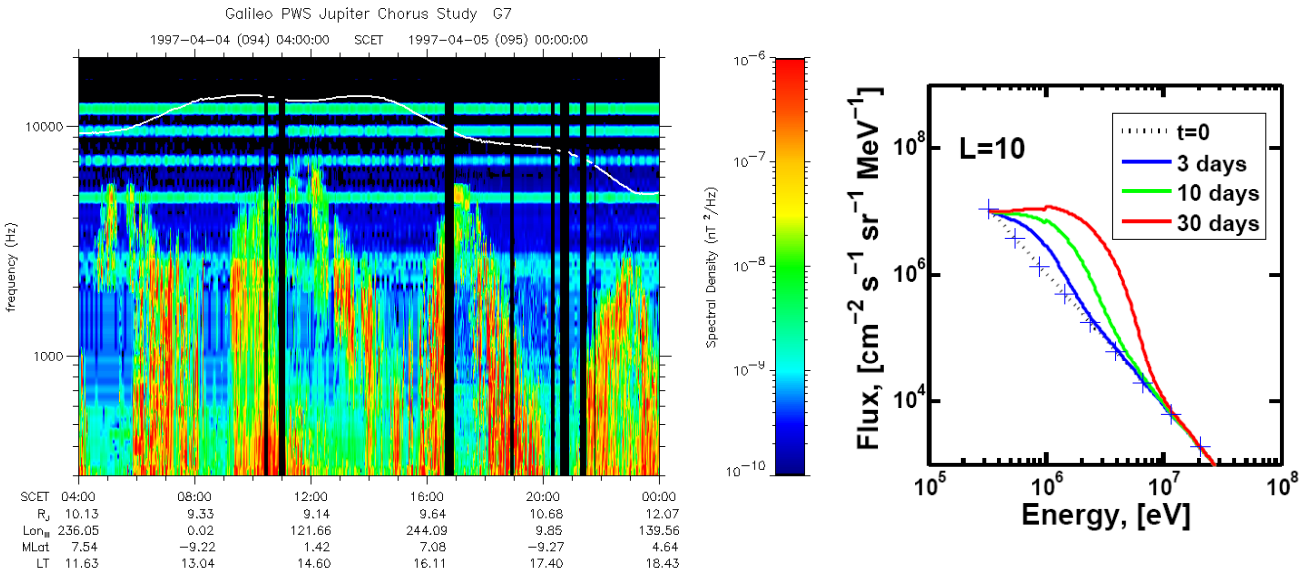
Cyclotron Resonant Acceleration at Jupiter



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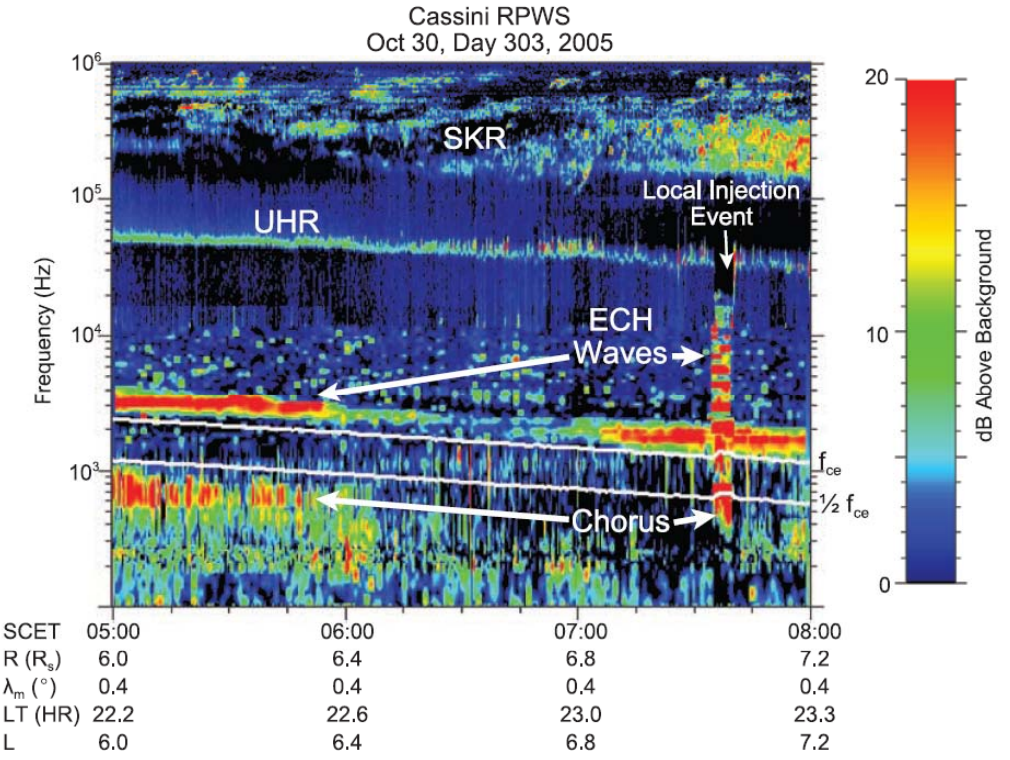
Horne et al., *Nature Phys*, [2008]

Saturn



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- Hospodarsky et al. [2008]

Radiation Belts - Relevance

- Satellite industries
- Climate links

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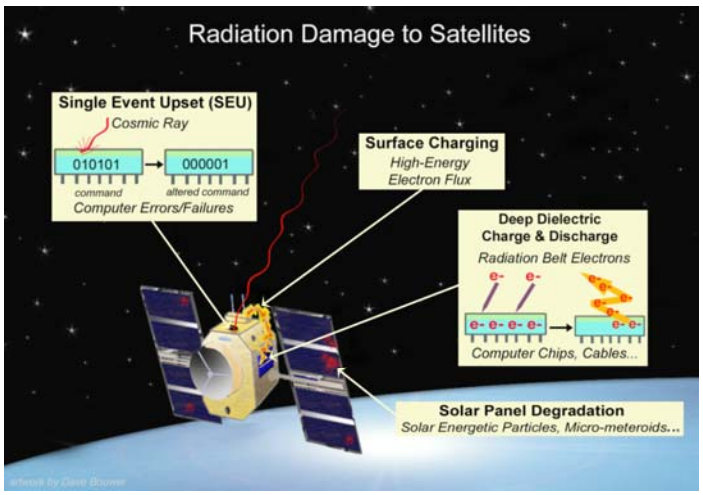
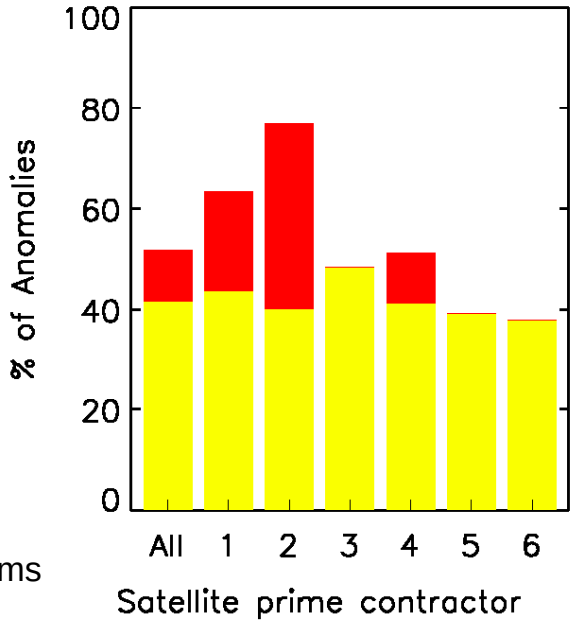
Relevance – Satellite Insurance





- 5 day risk period during geomagnetic storms
- Red - anomalies directly related to storms
- Yellow – anomalies that can occur by chance

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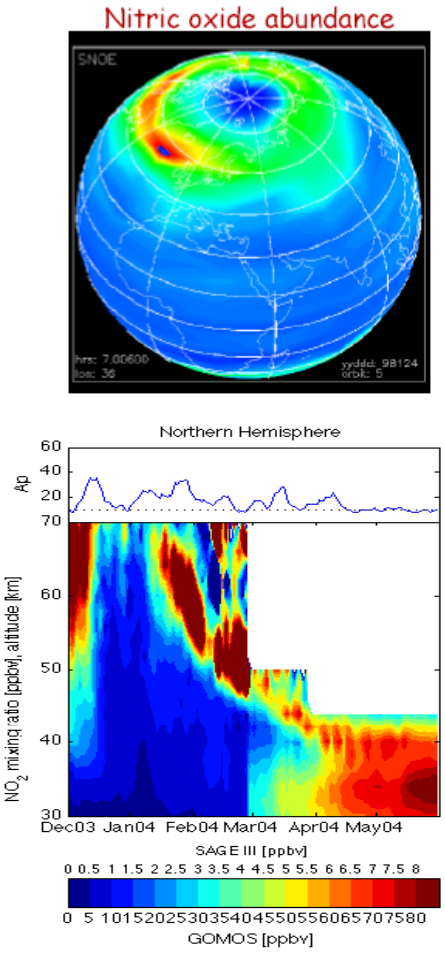

Radiation Belt - Climate Link

- Electron precipitation creates odd nitrogen NOx
- Polar winds enable downward descent and accumulation in the polar regions
  - Clilverd et al., JGR [2007, 2009]
- Depletes ozone
- Climate models show cooling effect:
  - $\Delta T \sim 2$ K in polar stratosphere
  - $\Delta T \sim 0.5$ K outside polar latitudes
  - Rozanov et al., GRL, [2005]
- Solar variations may affect climate via electron precipitation from the radiation belts which cause chemical reactions affecting temperatures and winds

Conclusions

- Revolution in how radiation belts are formed
  - Wave-particle interactions essential
  - Overturned a theory lasting 40 years
- New applications to the planets, solar physics, astrophysics,…
  - Space as a natural laboratory
- Relevant to industry:
  - Satellite design, Satellite operators, Satellite insurance
- New climate links:
  - Solar variations may affect climate via electron precipitation from the radiation belts which cause chemical reactions affecting temperatures and winds

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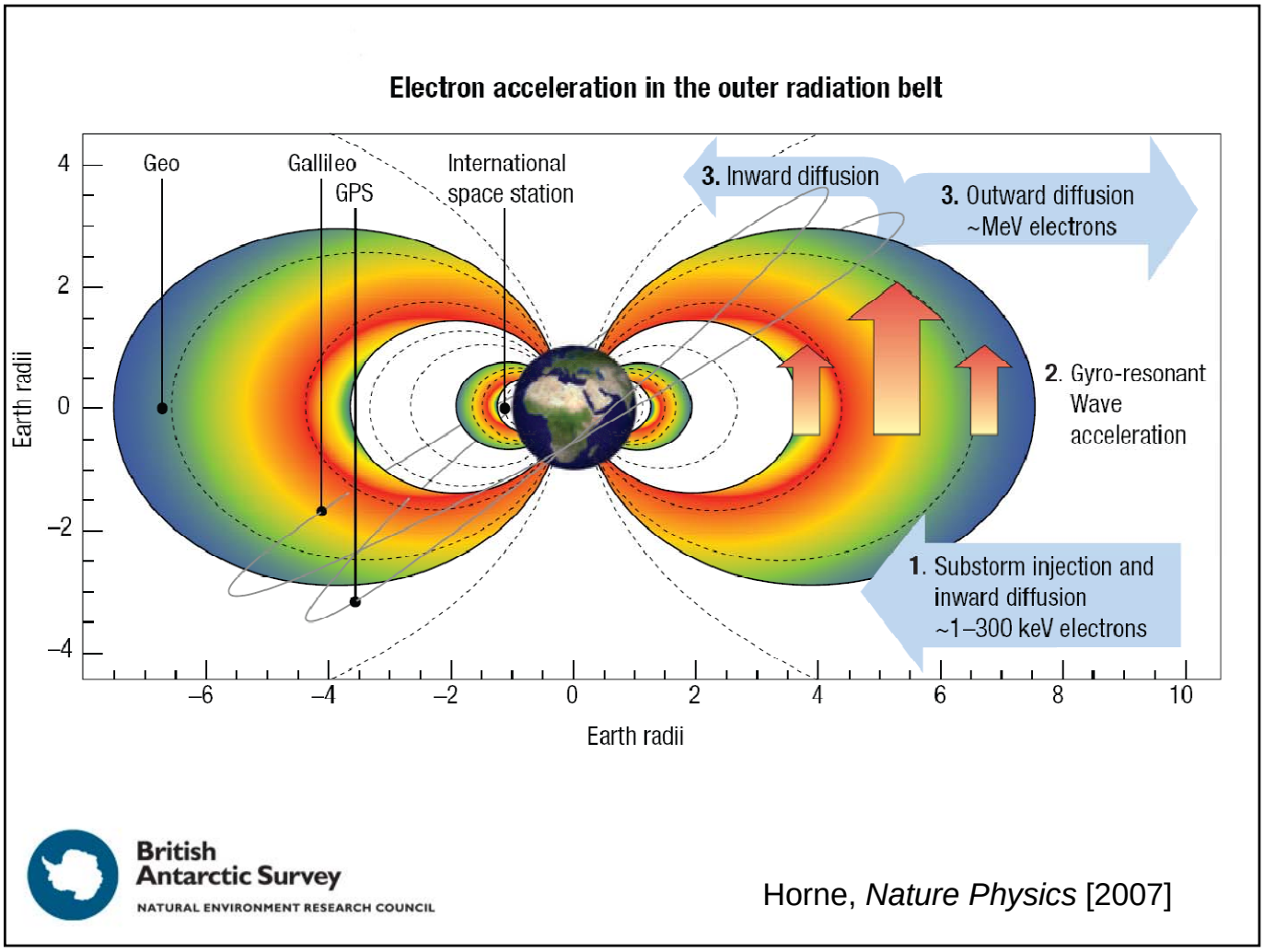

Horne, *Nature Physics* [2007]