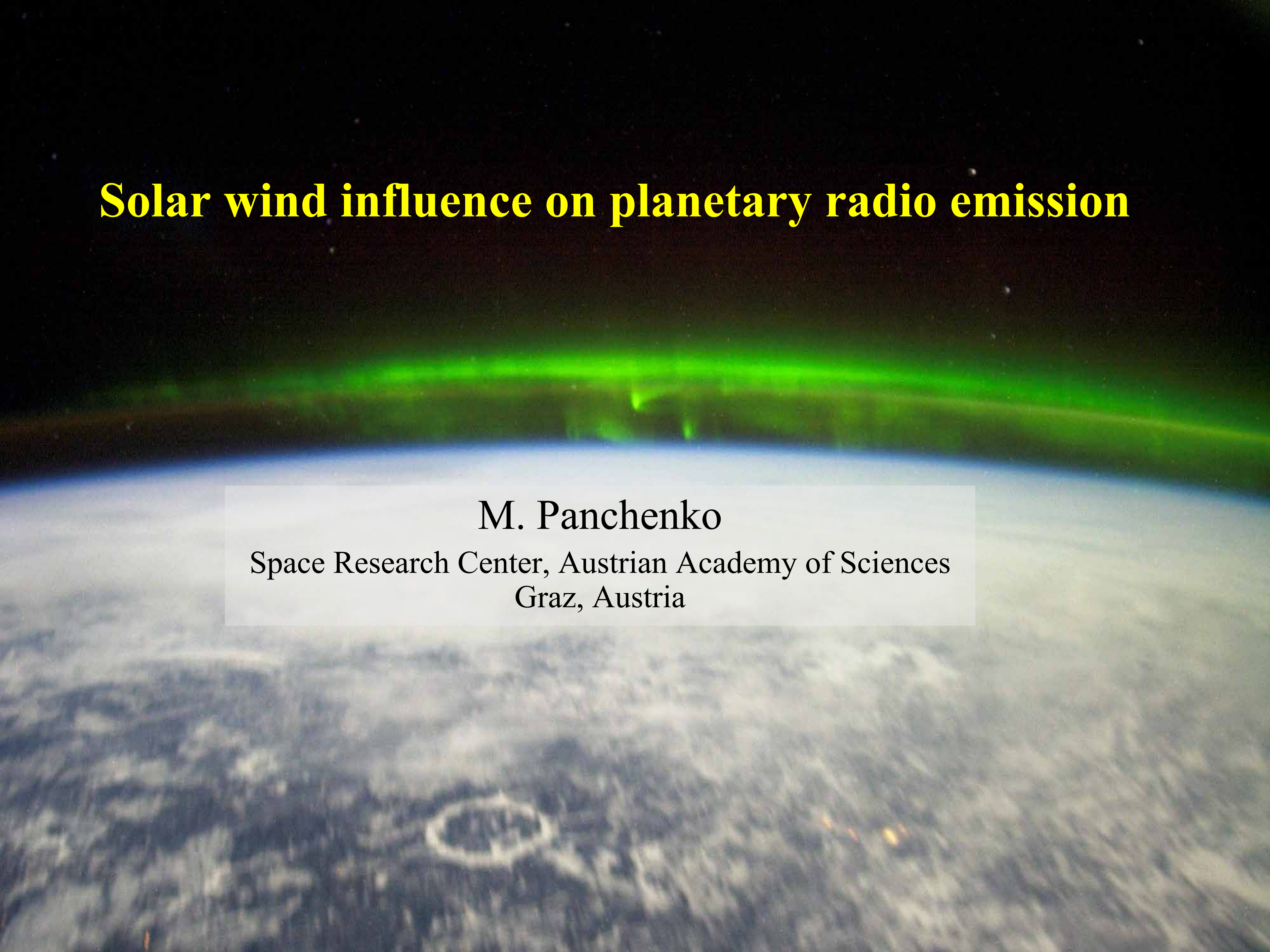

Solar wind influence on planetary radio emission

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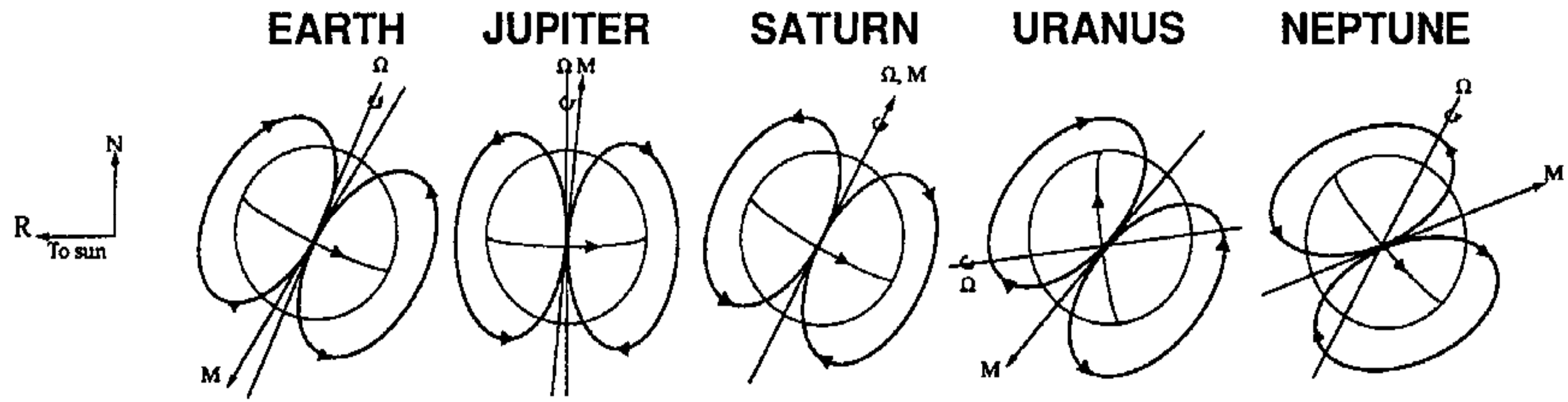
Graz, Austria

Outline

- Planetary magnetospheres; interaction with solar wind;
- Planetary radio emission: Earth, Jupiter and Saturn.
- Radio data analysis.

Planetary magnetospheres

Magnetospheres of solar system planets



	EARTH	JUPITER	SATURN	URANUS	NEPTUNE
Obliquity $\cos^{-1}(\Omega \cdot N)$ =	23.5°	3.1°	26.7°	97.9°	29.6°
Dipole Tilt $\cos^{-1}(\Omega \cdot M)$ =	+11.7°	-9.6°	-0.0°	-59°	-47°
Solar Wind Angle $\cos^{-1}(\Omega \cdot R)$ =	66.5 - 113.5°	86.9 - 93.1°	63.7 - 116.5°	7.9 - 172.1°	60.4 - 119.6°

Figure 2 Orientations of the planets and their magnetic fields.

Bagenal, F., Giant planet magnetospheres, In: Annual review of earth and planetary sciences, 20,289, 1992

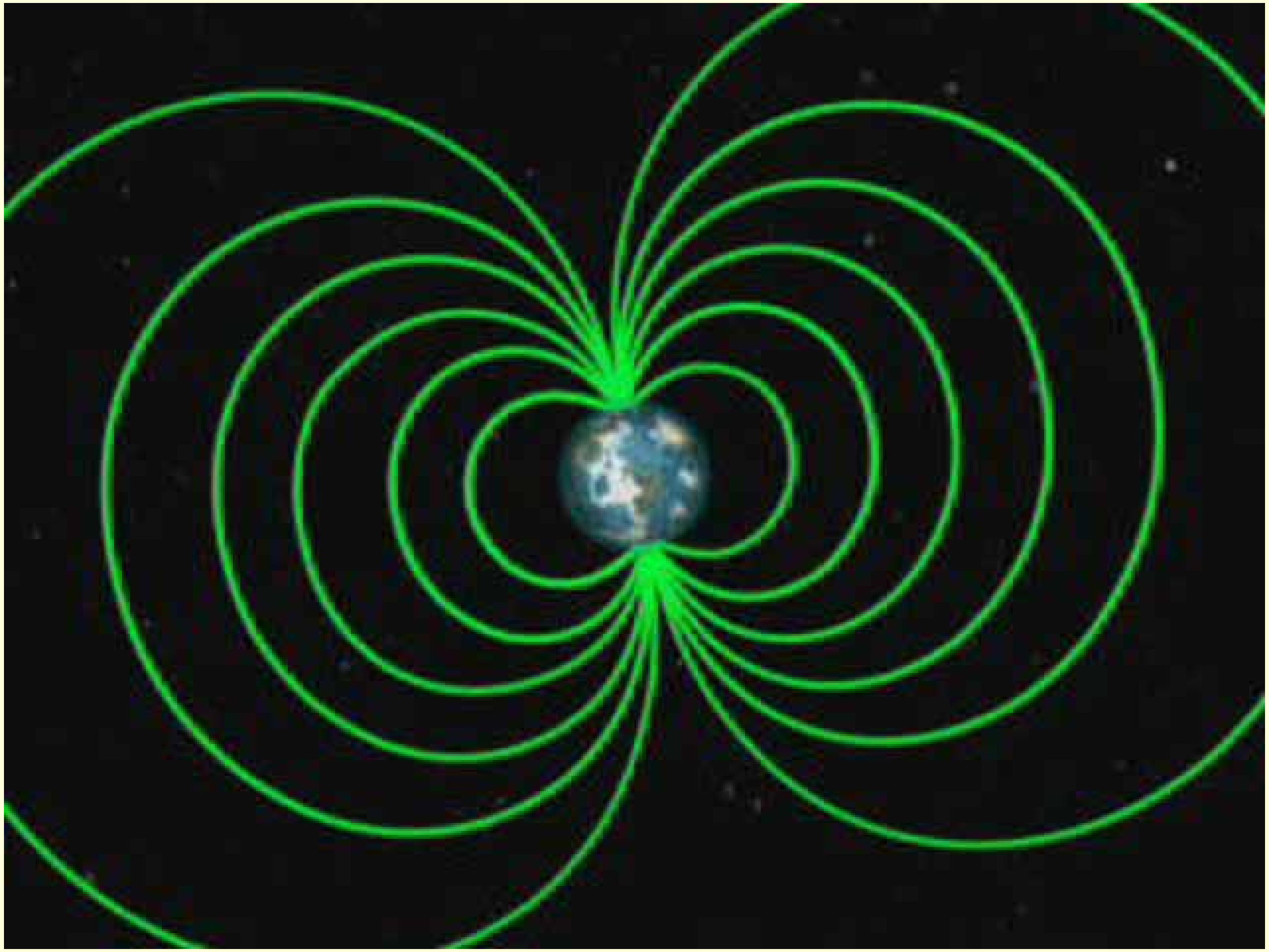
The solar wind plays a main role in a formation of planetary magnetospheres

- **Solar wind (SW)** - stream of charged particles (electrons and protons) ejected from the Sun's hot corona.

- speeds of about 300 - 800 km/s; density at 1 AU ~3-20 cm^{-3}

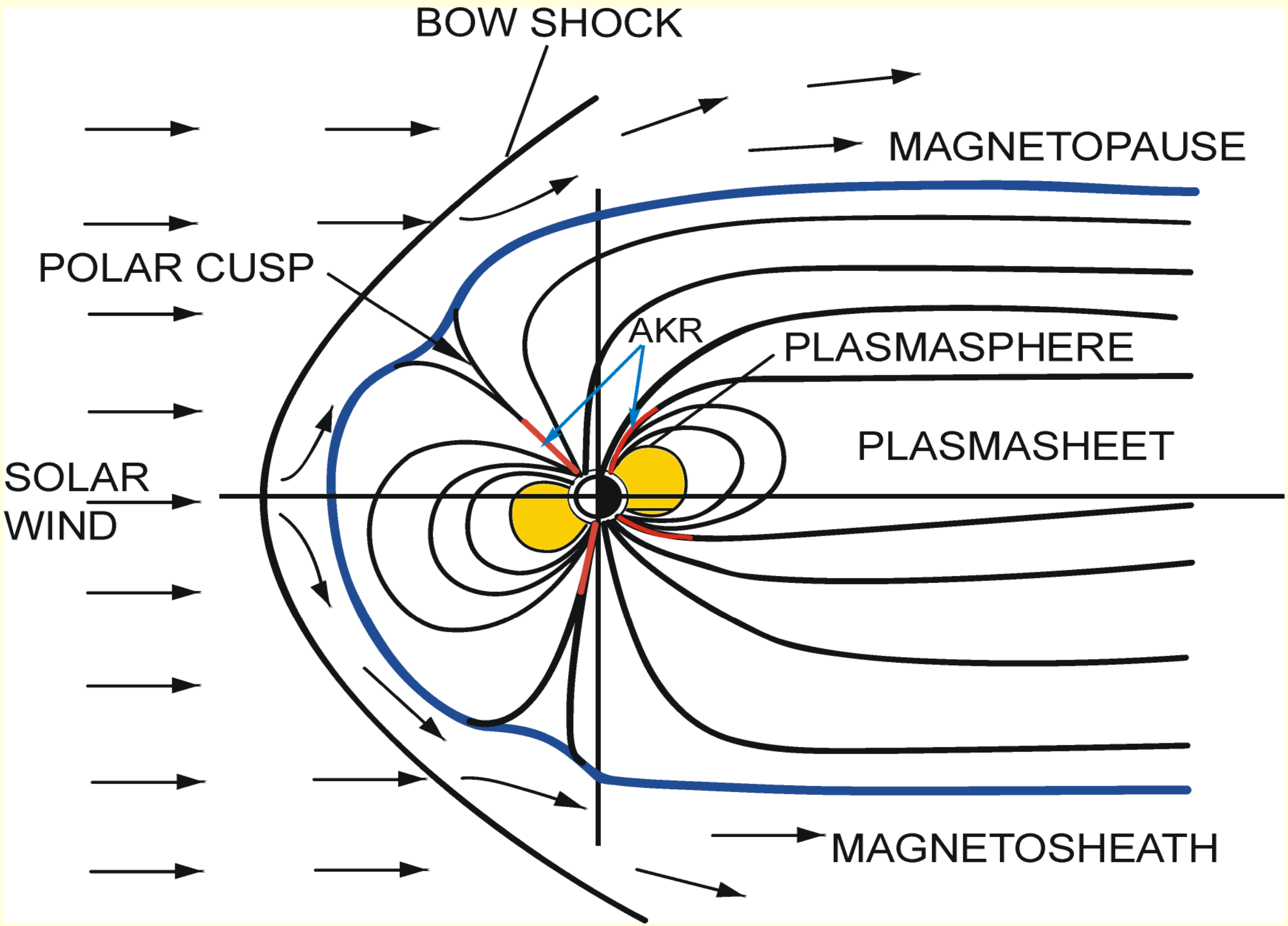
- conductivity of the solar wind plasma is high -> the solar magnetic field is “frozen into” the solar wind -> Solar wind carries magnetic field from the Sun to the interplanetary space

Planetary Magnetosphere

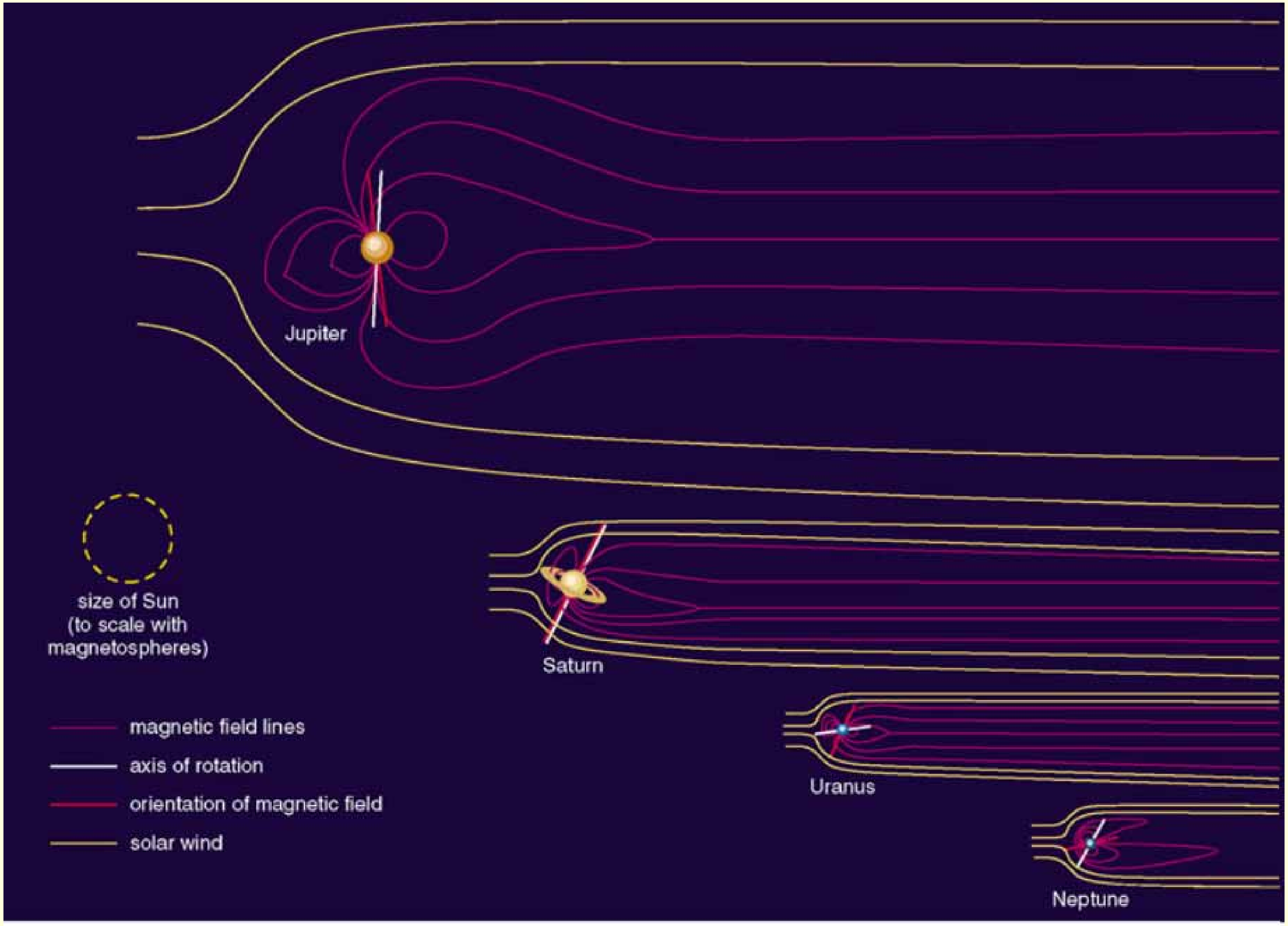


Solar wind modifies the form of the magnetosphere, by pushing it in in the dayside and creating a long magnetotail in the nightside

Earth's magnetosphere

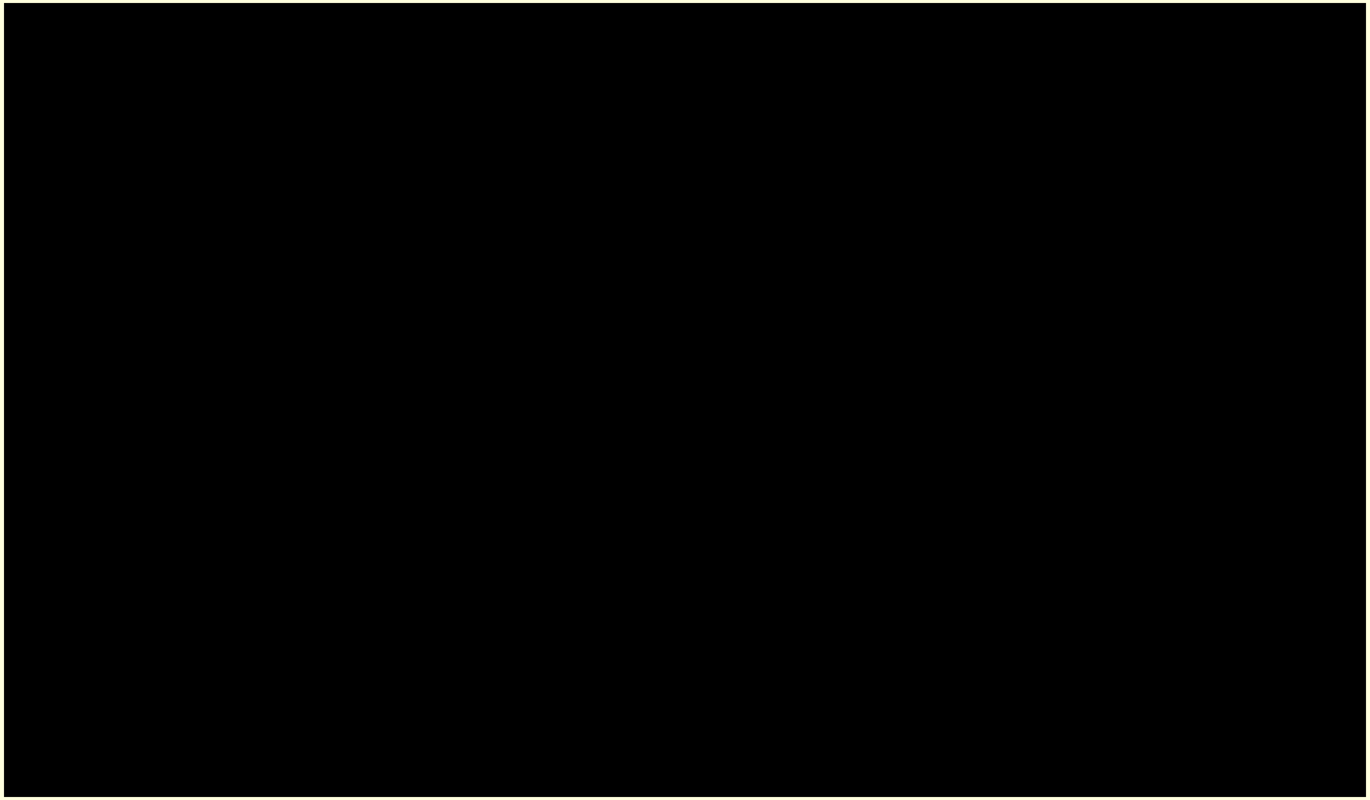


Magnetospheres of solar system planets



Solar wind interaction with magnetospheres.
Substorms and auroras.

Magnetospheric substorm



Animation that explains the magnetospheric substorm

Aurora (polar light) observed in polar regions

Credit: Joshua Strang, USAF, Wikipedia

Credit & Copyright: D. Hutchinson

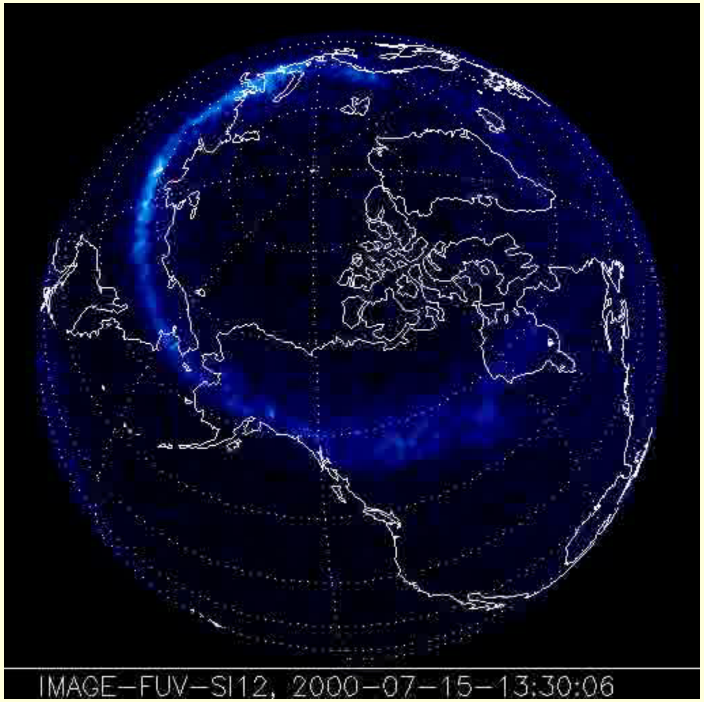
Northen and southern polar lights (auroras) typically are observed in polar regions between 65 to 75 deg north and south latitudes.

Aurora (polar light) observed in polar regions

Credit & Copyright: Terje Sorgjerd, Norway

Aurora observed from space

A view of the Auroras as seen from the International Space Station, Sep. 2011.

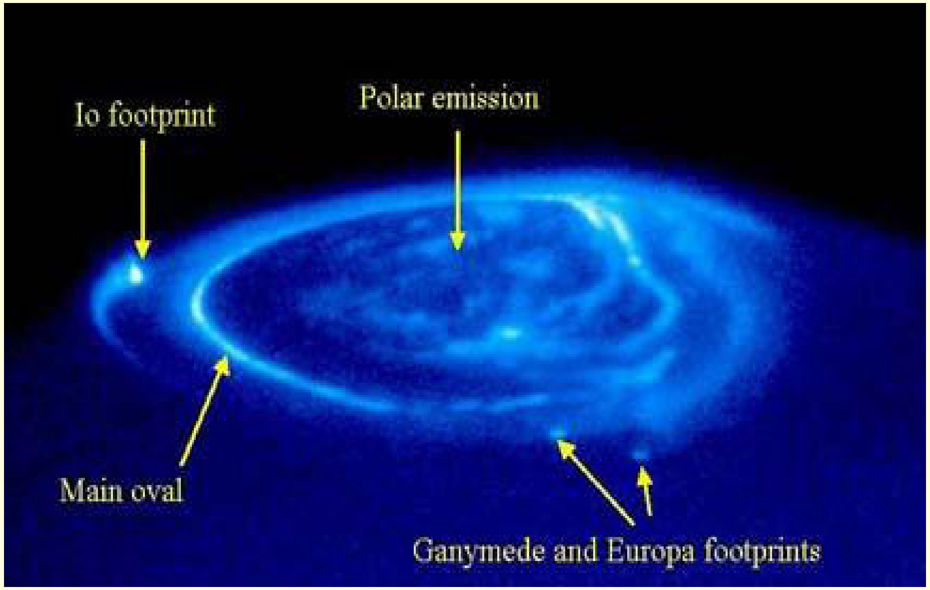


Animation of aurora in ultraviolet

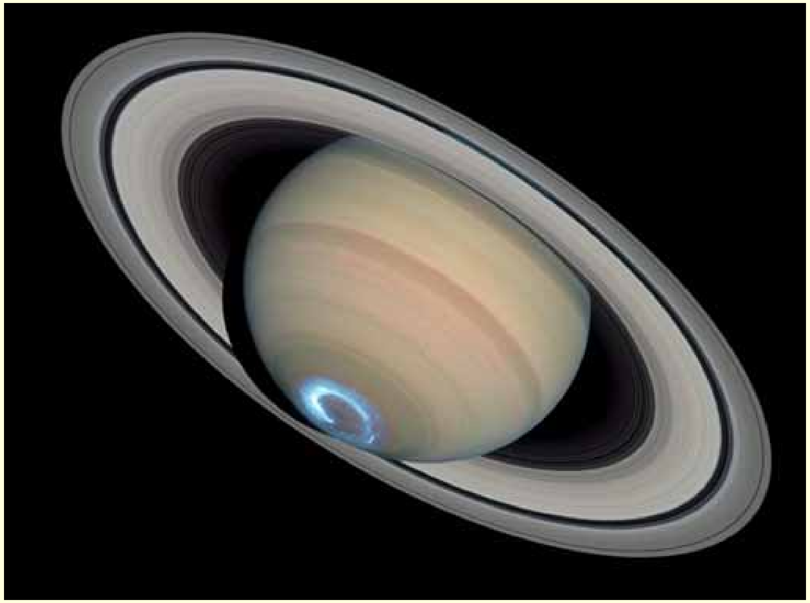
UV aurora observed by IMAGE spacecraft

Auroras are a visible manifestation of an interaction between magnetized planet and solar wind.

Jovian and Saturn’s aurorae



The ultraviolet image of the Jovian aurora taken by Hubble Space Telescope's Photo credit: John T. Clarke (U. Michigan), ESA, NASA



The ultraviolet image of the southern Saturn’s aurora taken on January 28, 2004 by the Hubble Space Telescope's Photo credit: NASA, ESA, J. Clarke (Boston University), and Z. Levay (STScI).

Planetary radio emissions

Five planets, Earth, Jupiter, Saturn, Uranus, and Neptune produce powerful radio emissions

Non-thermal radio waves in the Earth's magnetosphere

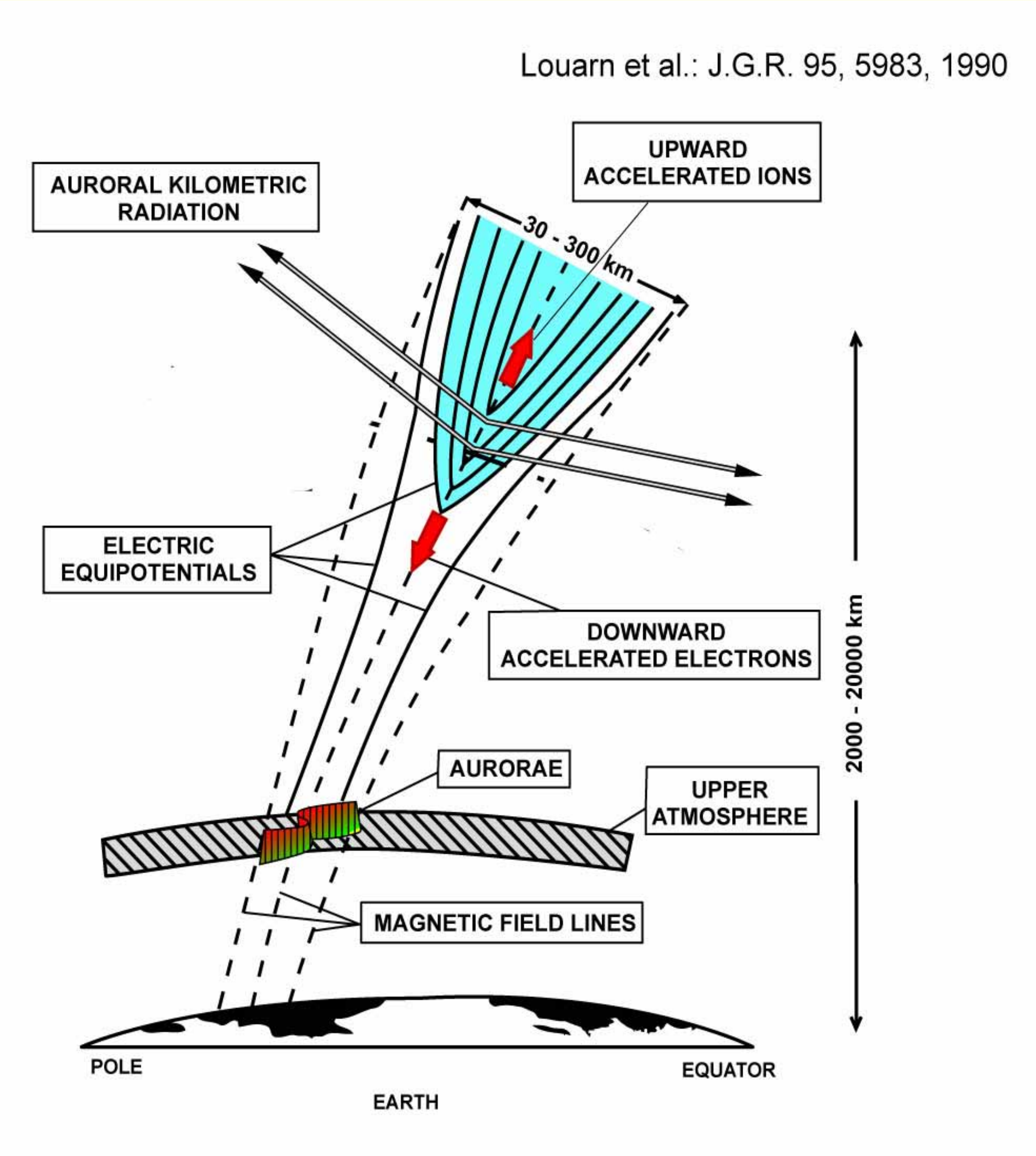
The Earth's magnetosphere - wide variety of wave phenomena:

• **Electrostatic waves** (Langmuir Waves, ion-acoustic, ion-cyclotron, electron-cyclotron)

• **MHD waves** (Alfvén, Magnetosonic waves) - coupling forces between the magnetic field and highly conductive plasma.

• **Electromagnetic waves** (whistlers, chorus, auroral hiss, Auroral Kilometric radiation)

Structure of AKR sources



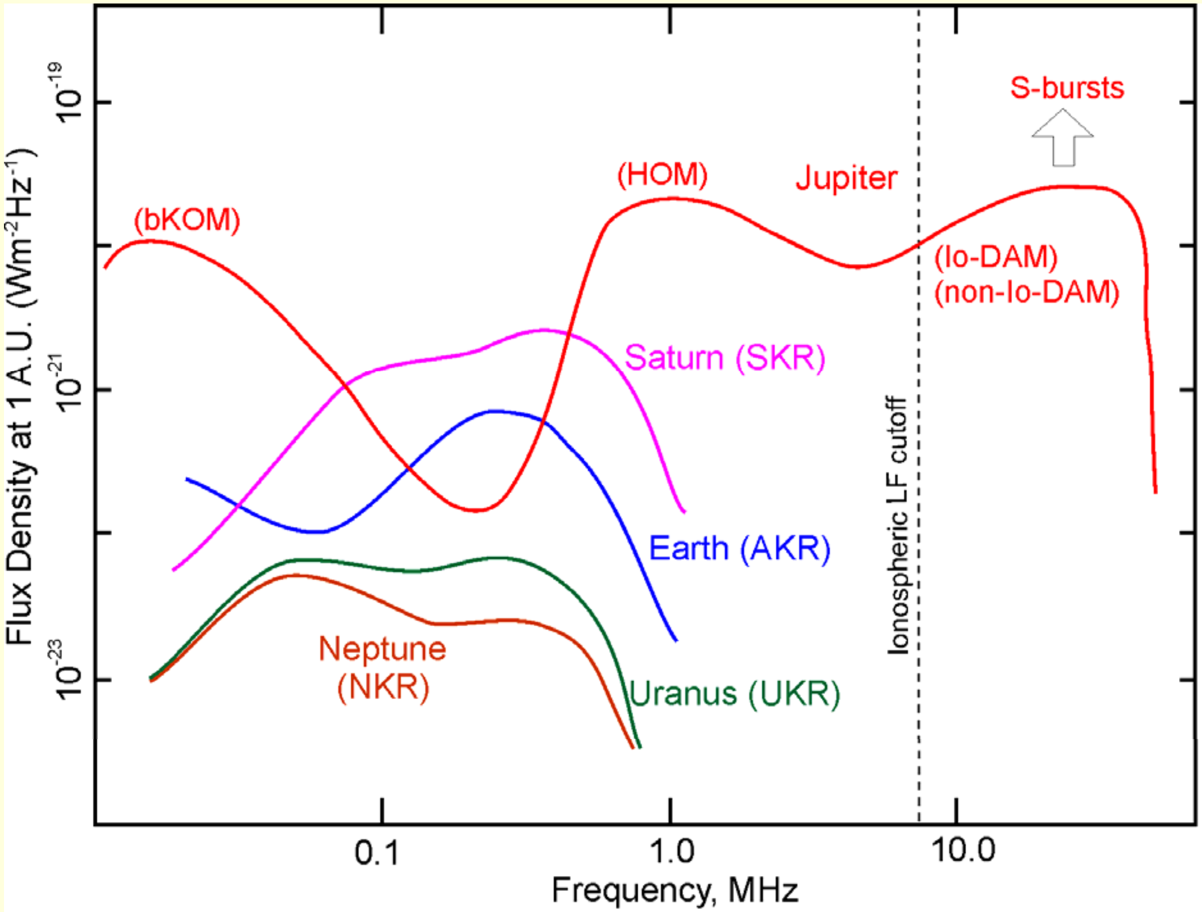
General scenario auroral emission generation:

•Energetic particles stream into polar regions of magnetosphere

•Energy of the particle is converted into electromagnetic waves via Cyclotron Maser Instability

•CMI is a wave-particle interaction process which based on stimulation of cyclotron emission involving energetic electrons gyrating in a magnetic field..

Comparative spectra of auroral planetary radio emissions

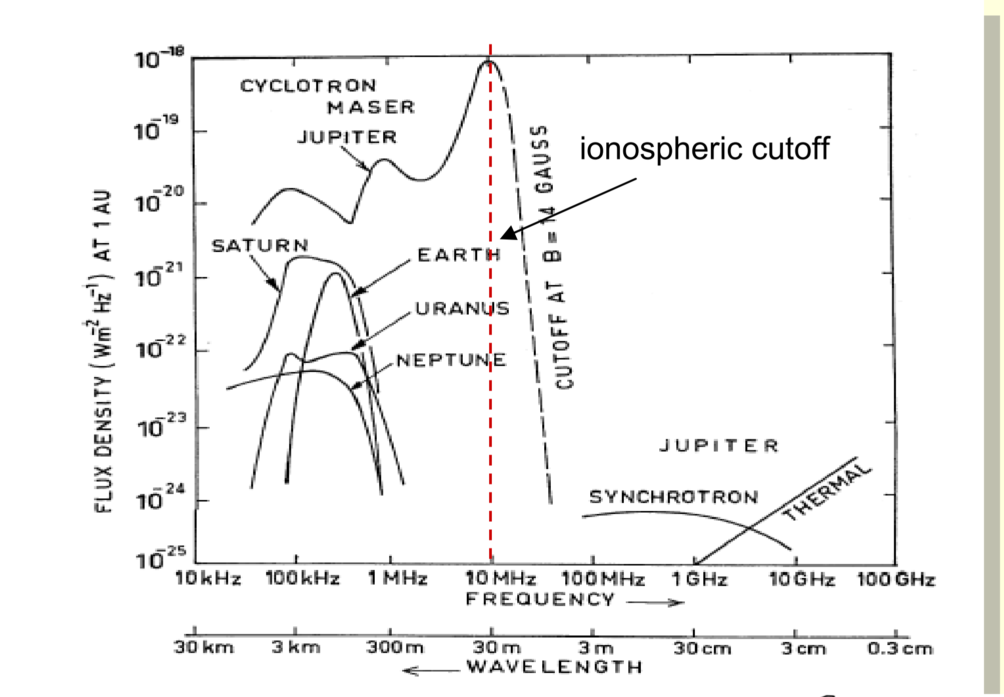


Comparative spectra of auroral radio emissions normalized to a distance of 1 AU from the source. Adapted from *Zarka 1998, JGR, 103(E9), 20159*

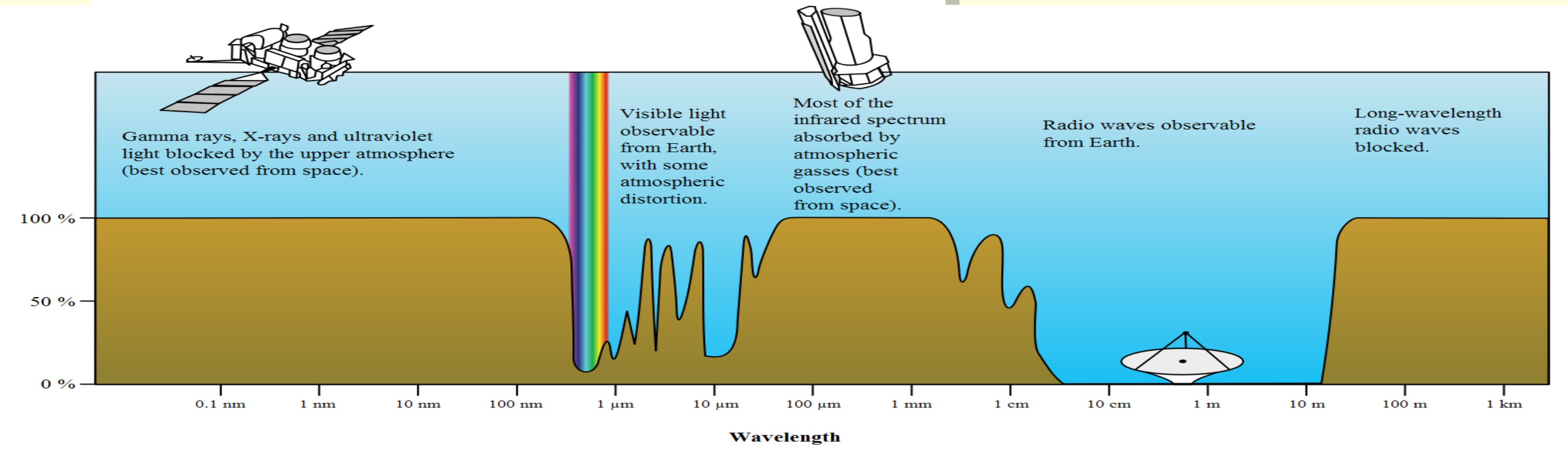
Radio palnets:

- Earth
- Saturn
- Jupiter
- Uranus
- Neptun

Planetary radio emissions



Only Jovian decametric radiation > 10 MHz can be observed from Earth's surface.

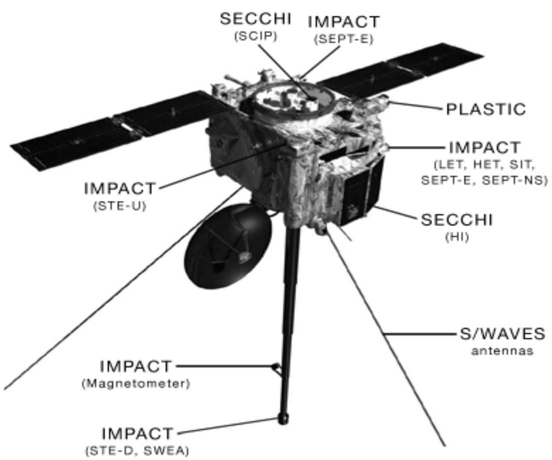


Ground-based radio telescopes

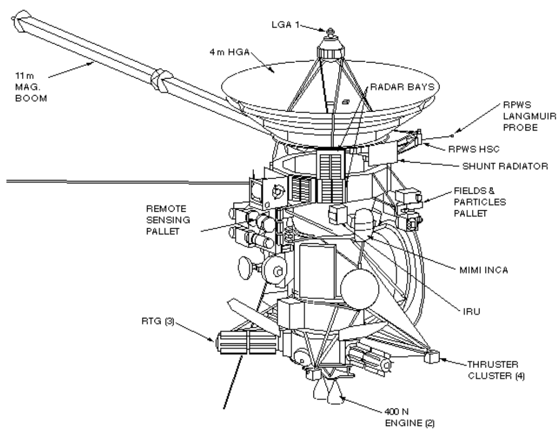
Nançay Decametric Array

UTR-2 radio telescope

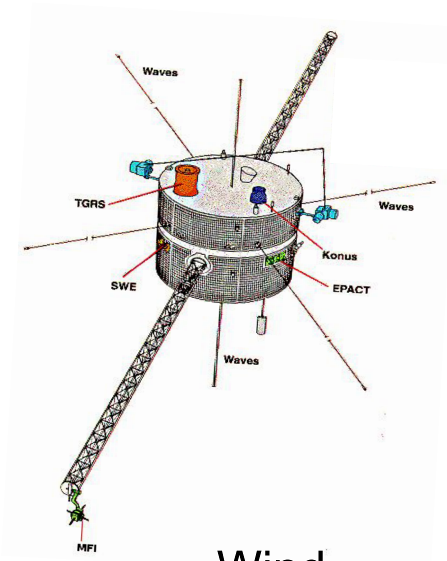
Spaceborn observations of planetary radio emission



STEREO



Cassini



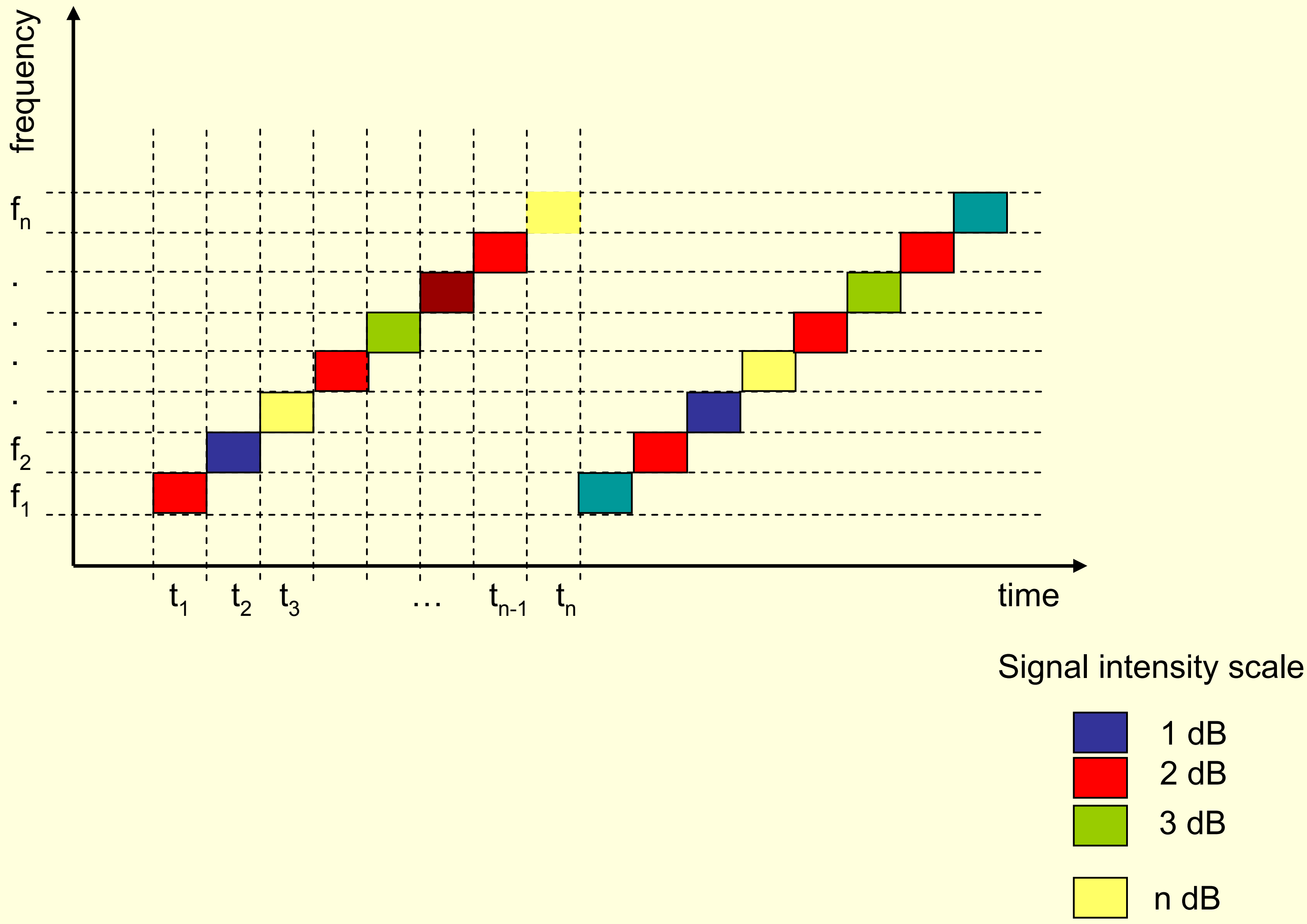
Wind

STEREO (Solar TErrestrial RElations Observatory) consists of two spacecraft (A and B), launched on Oct. 25, 2006. **STEREO/WAVES** covers the frequency range up to16 MHz.

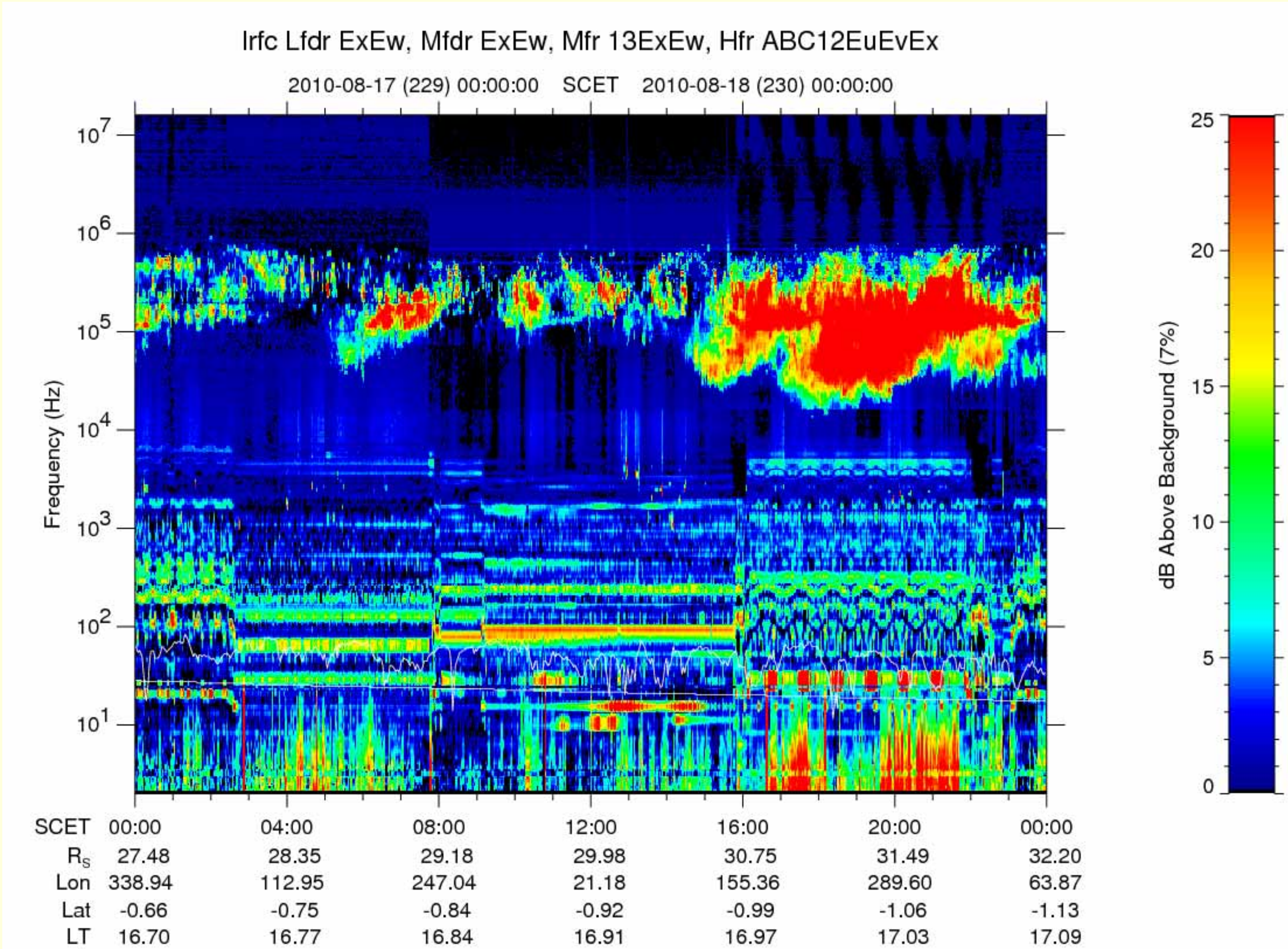
Cassini, launched in Oct. 1997; in July 2004 it reached Saturn. **RPWS** (Radio and Plasma Wave Science) - is designed to measure the radio signals coming from Saturnian planetary system (1 Hz - 16MHz).

Wind spacecraft – a mission launched on Nov. 1,1994 as part of the International Solar-Terrestrial Physics (ISTP) program. **WAVES** experiment onboard Wind covers the frequency range from a few Hz up to 14 MHz.

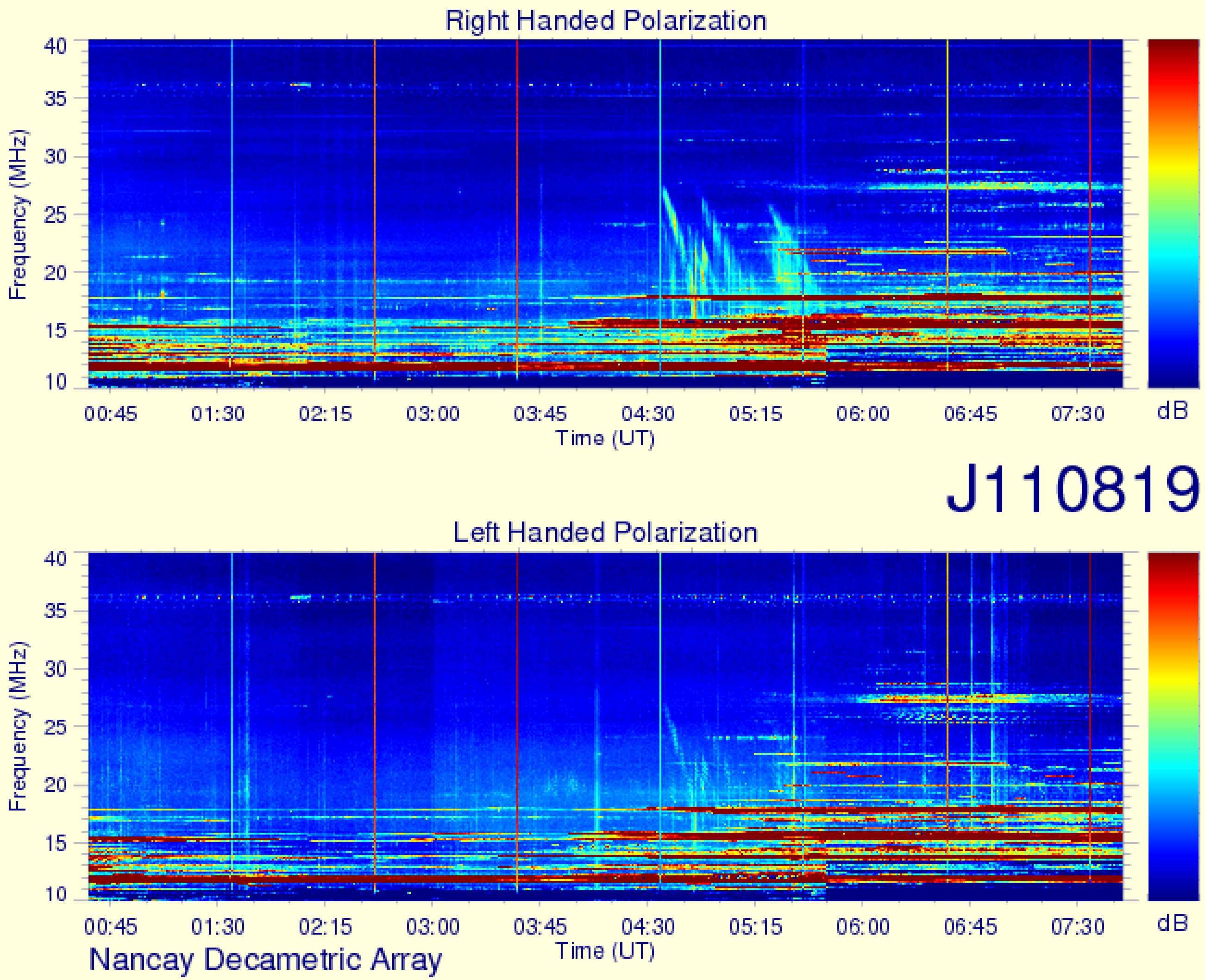
Concept of a sweep-frequency radio receiver



Dynamic radio spectrum



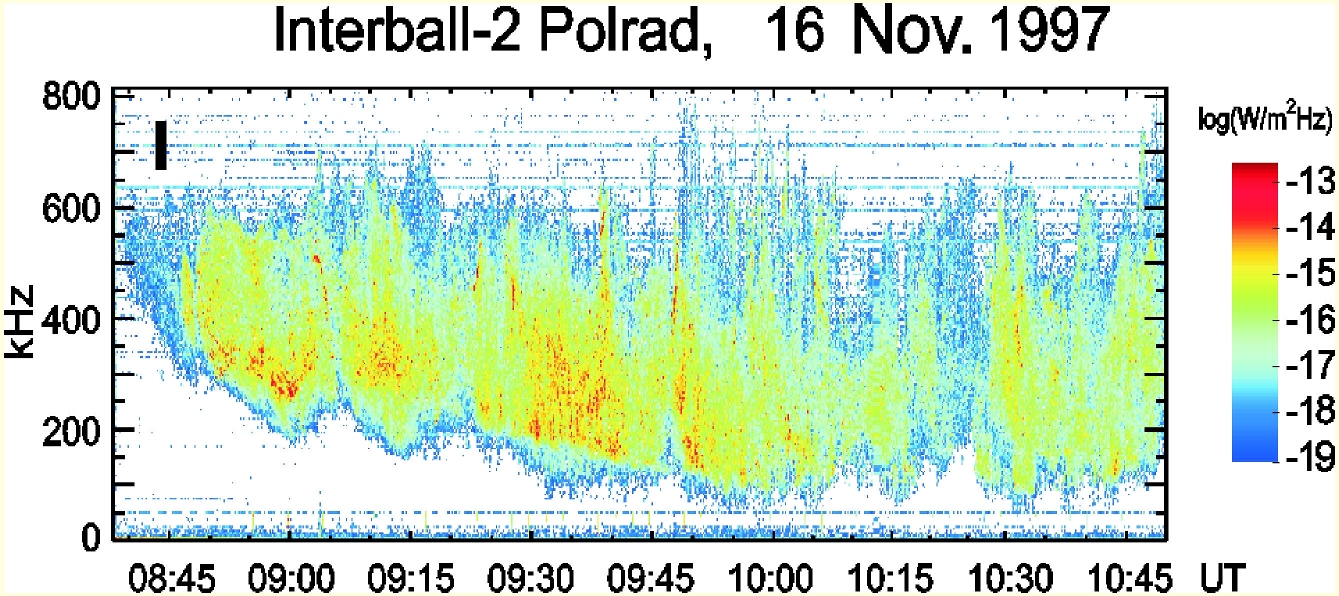
Nancay decametric radio telescope



Terrestrial Auroral Kilometric radiation (AKR)

AKR

- Most powerful Earth's radio emission;
- Frequency ~ 20 KHz – 900 kHz (300 kHz -> λ = 1 km);
- Emitted near the local gyro-frequency of electrons in low density source cavities;
- Strong correlation with the development of magnetospheric substorms and discrete arcs in the auroral oval;



Jovian radio emission

- The most powerful radio source in the Solar system
- First emission detected from the Earth in 1955
- <u>Two types of non-thermal radio emission :</u>

  a) driven by solar wind-magnetosphere interaction

  b) driven by interaction with Io satellite

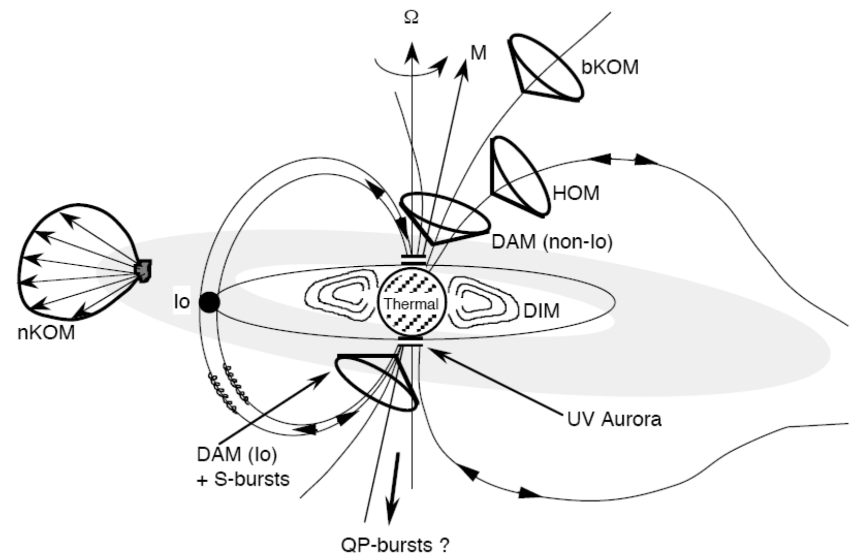
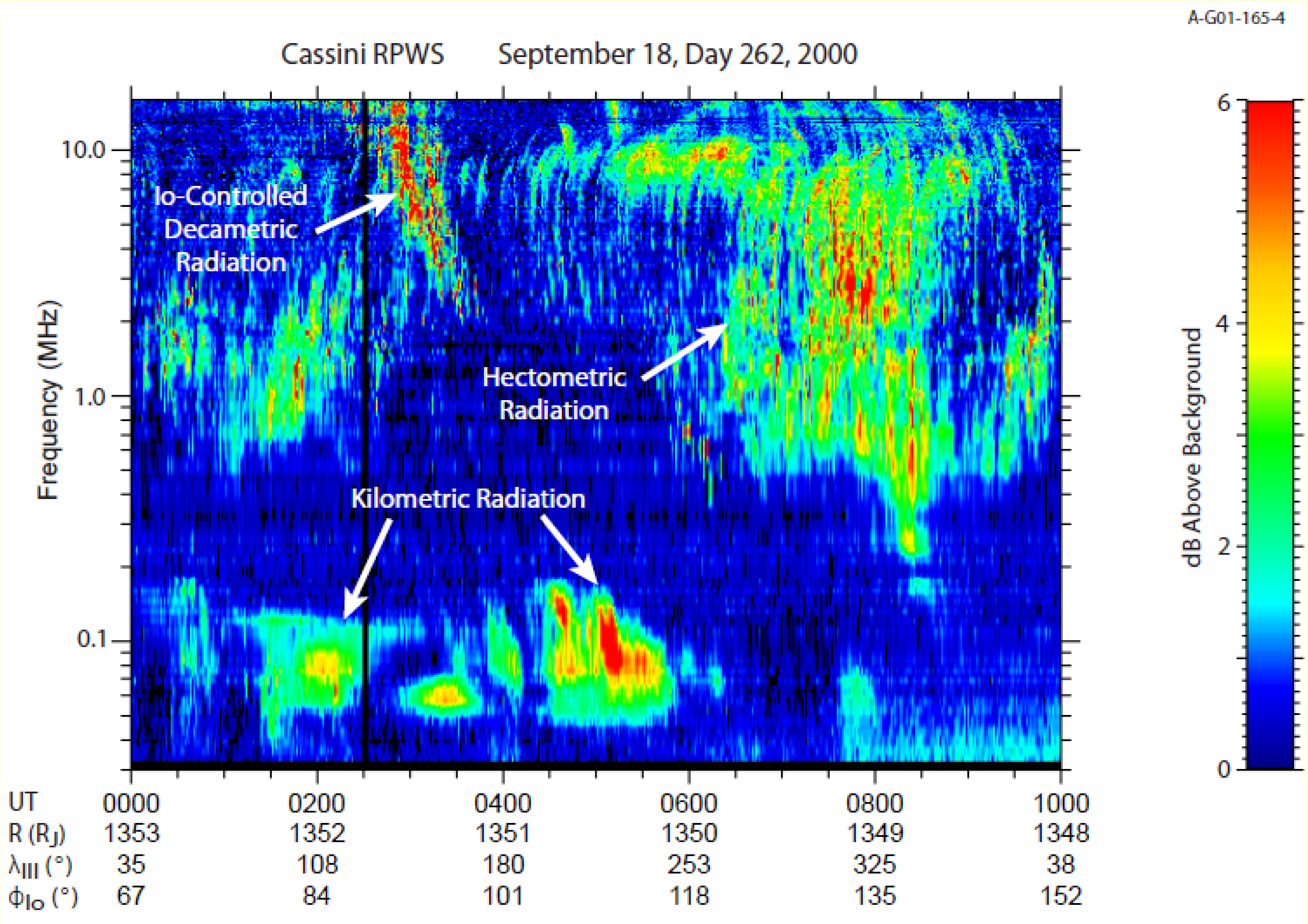


TABLE 1. Characteristics of Jovian Radio Components

Component Name	Frequency Range	Radiated Power	Source Location	Comments
DIM	~80 MHz - 300 GHz	2 GW	radiation belts	
DAM	2 - 40 MHz	400 GW	Io torus field lines	
HOM	0.2 - 2 MHz	1 GW*	auroral field lines	
bKOM	10 - 1000 kHz	500 MW	Io torus or auroral	
nKOM	40 - 200 kHz	100 MW	Io torus	
Continuum	0.1 - 30 kHz	100 GW	outer magnetosphere	steep (f^{-4}) spectrum
Fast drift	1 - 500 kHz	large	?	

* From *Desch and Kaiser* [1984]. All other table values after *Carr et al.* [1983].

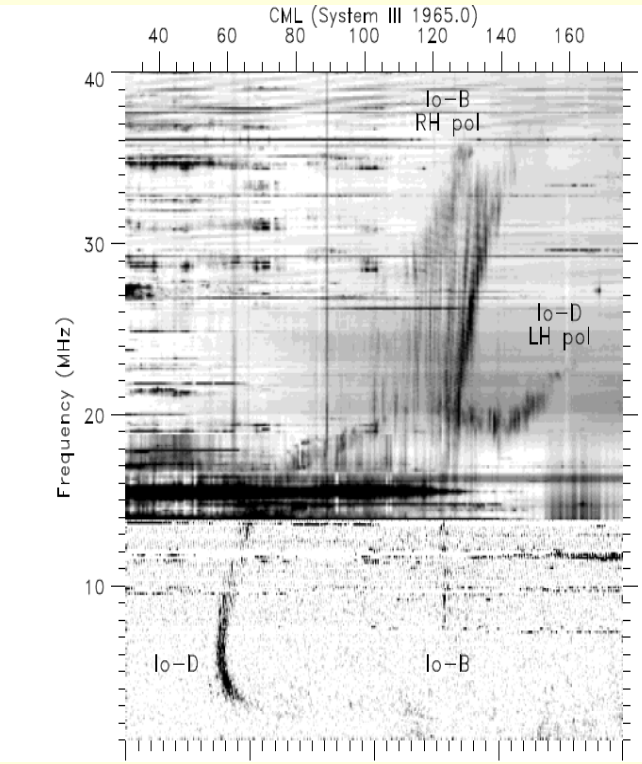
Jovian non-thermal radiation



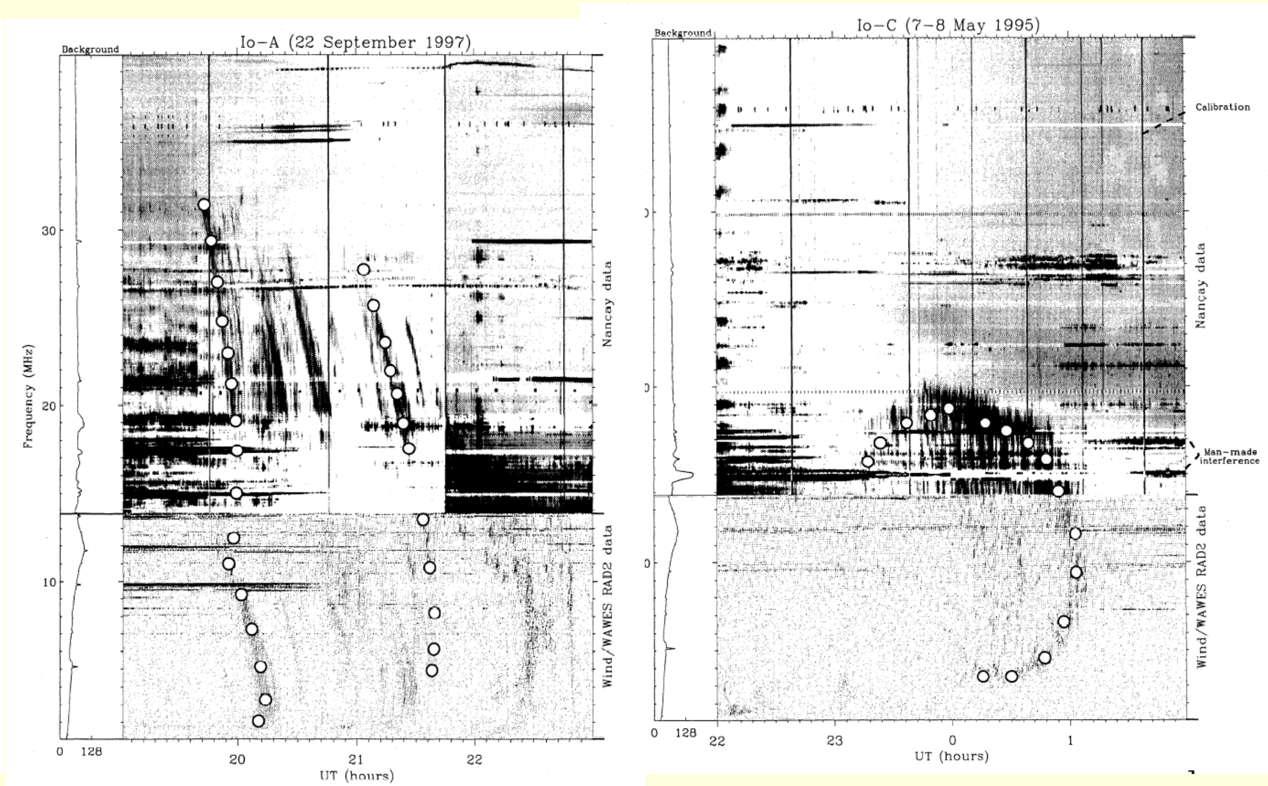
Gurnett et al., Control of Jupiter's radio emission and aurorae by the solar wind, Nature 415, 985, 2002

Time-freq. spectrum of the Jovian radio emission recorded by Cassini/RPWS

Io controlled DAM



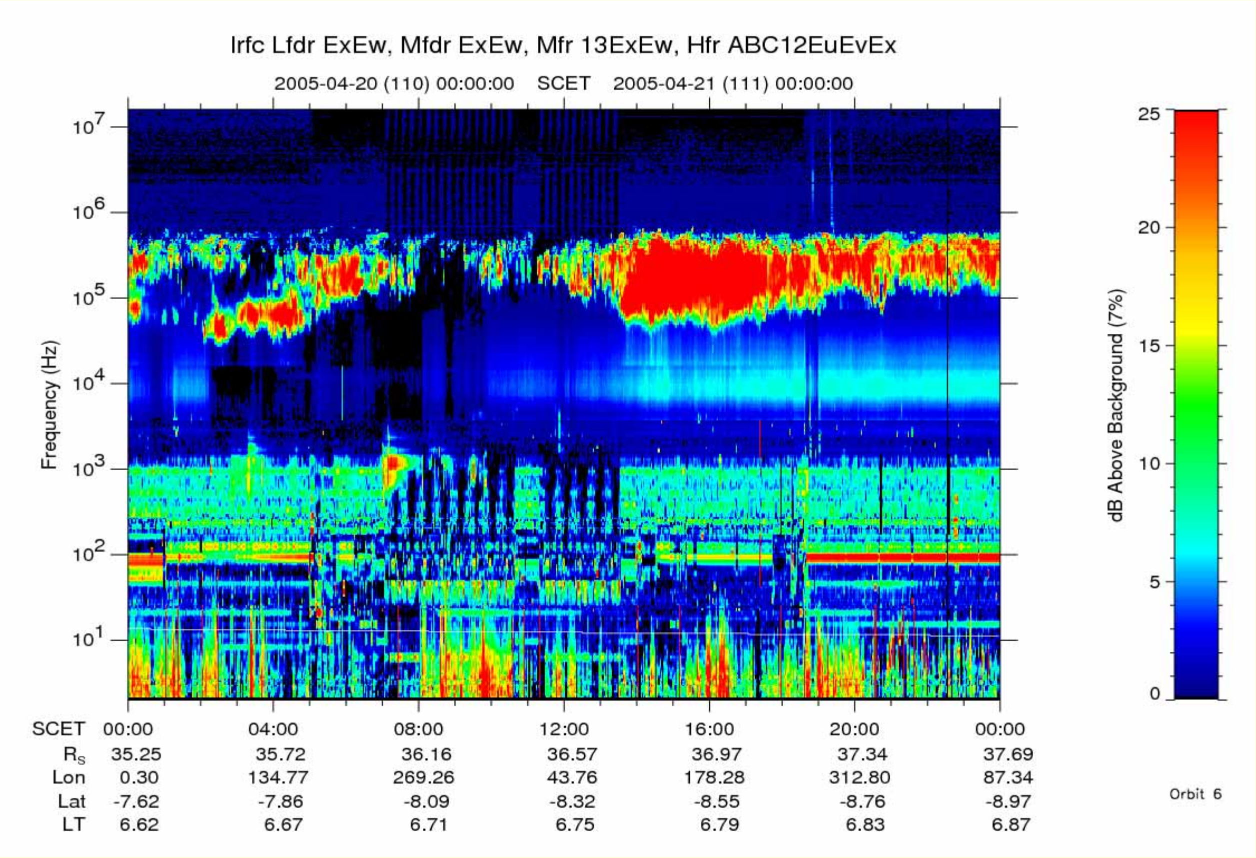
Lecacheux et al., Astron.Astrophys. 329, 776 1998



Queinnec, J., and P. Zarka , JGR., 103, 26649, 1998

Saturn non-thermal radiation

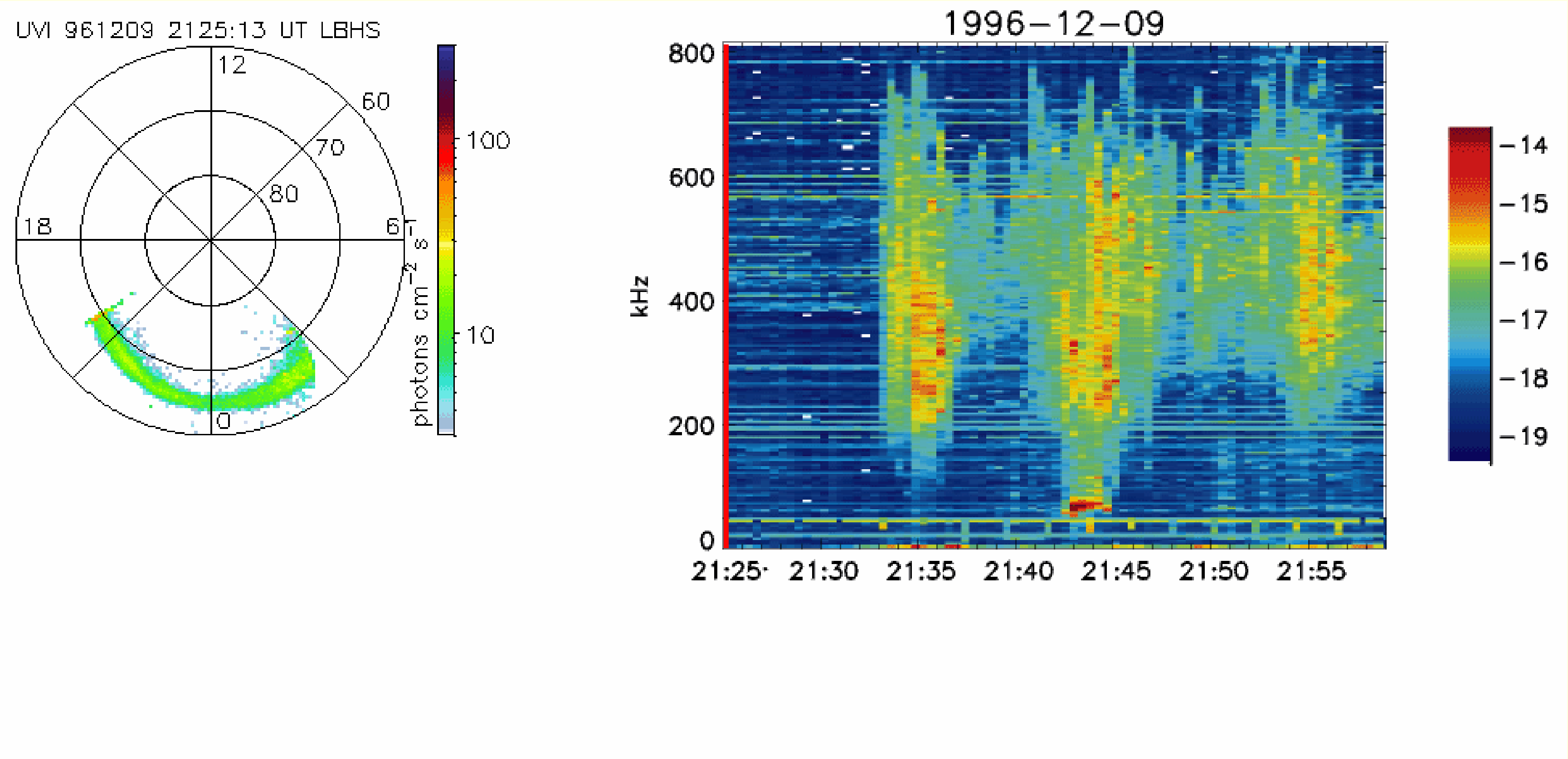
- Detected by Voyager
- Frequency range - several kHz - 1.2 MHz with a peak between 100 kHz and 400 kHz.
- Strongly modulated by the planet rotation, T~ 10 h 45 m
- Sources at local morning region of the magnetosphere



Solar wind and planetary radio emission

SW and terrestrial auroral kilometric radiation (AKR)

- The AKR intensity is correlated with the development of magnetospheric substorms (*Huff et al., 1988, Kurth and Gurnett, 1998, Hanasz et al., 2001*), which play an important role in transferring energy of the solar wind into the magnetosphere (*McPherron et al., 2005*).

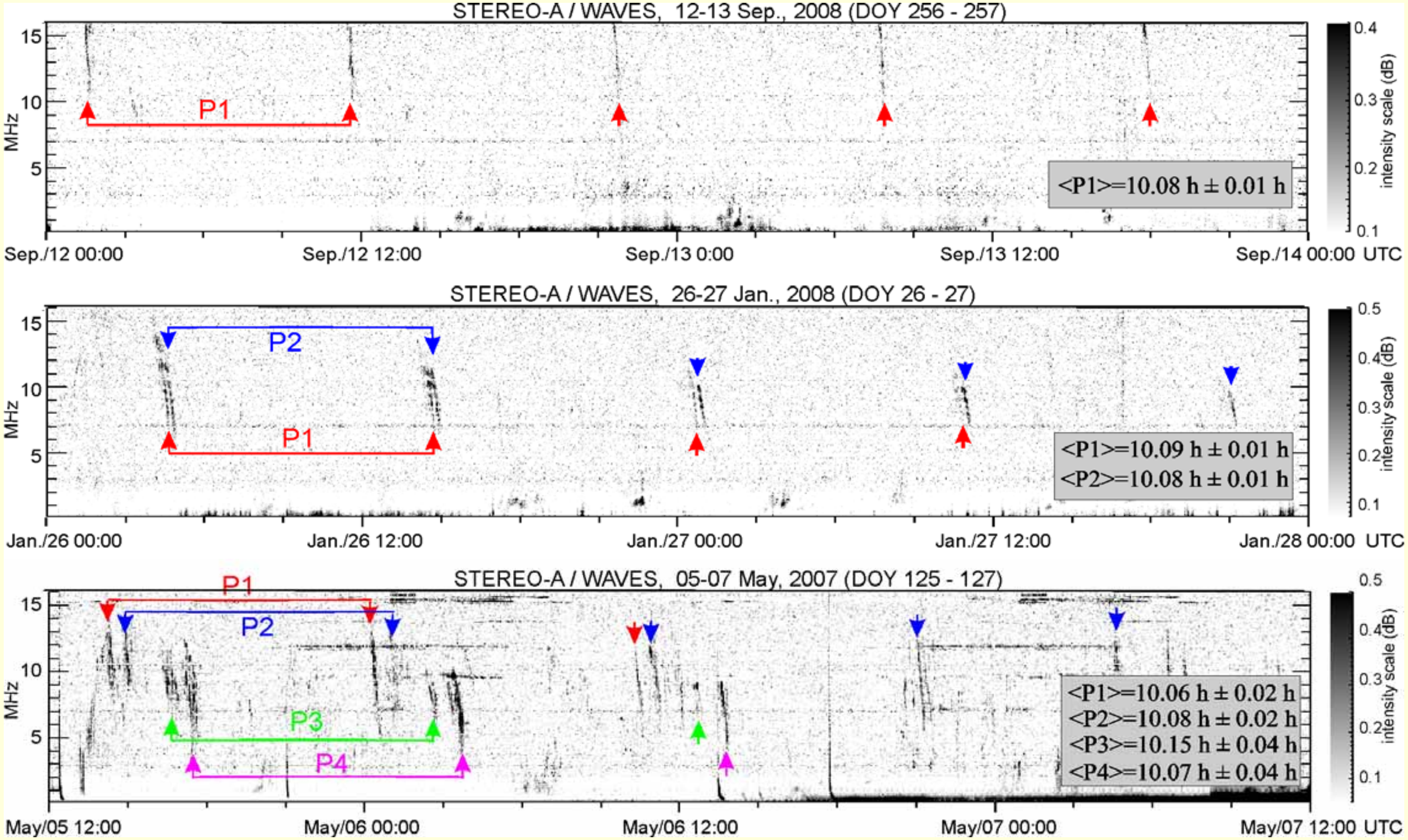


The AKR is strongly linked with discrete aurora-arcs in the aurora-oval

SW influence on Jovian radio emission

- close relationship between Jupiter’s decametric radio emissions (DAM) and solar activity (Gallet, 1957, Carr et al., 1958, Barrow, 1972, Carr and Desch,1976, Genova et al. ,1989)
- part of the non Io-DAM and strong UV auroral emission are triggered by interplanetary shocks [*Gurnett et al.*, 2002; *Echer et al.*, 2010],
- correlation between variations in the HOM energy and the solar wind density; Desch and Barrow (1984) , Galopeau and Boudjada (2005)

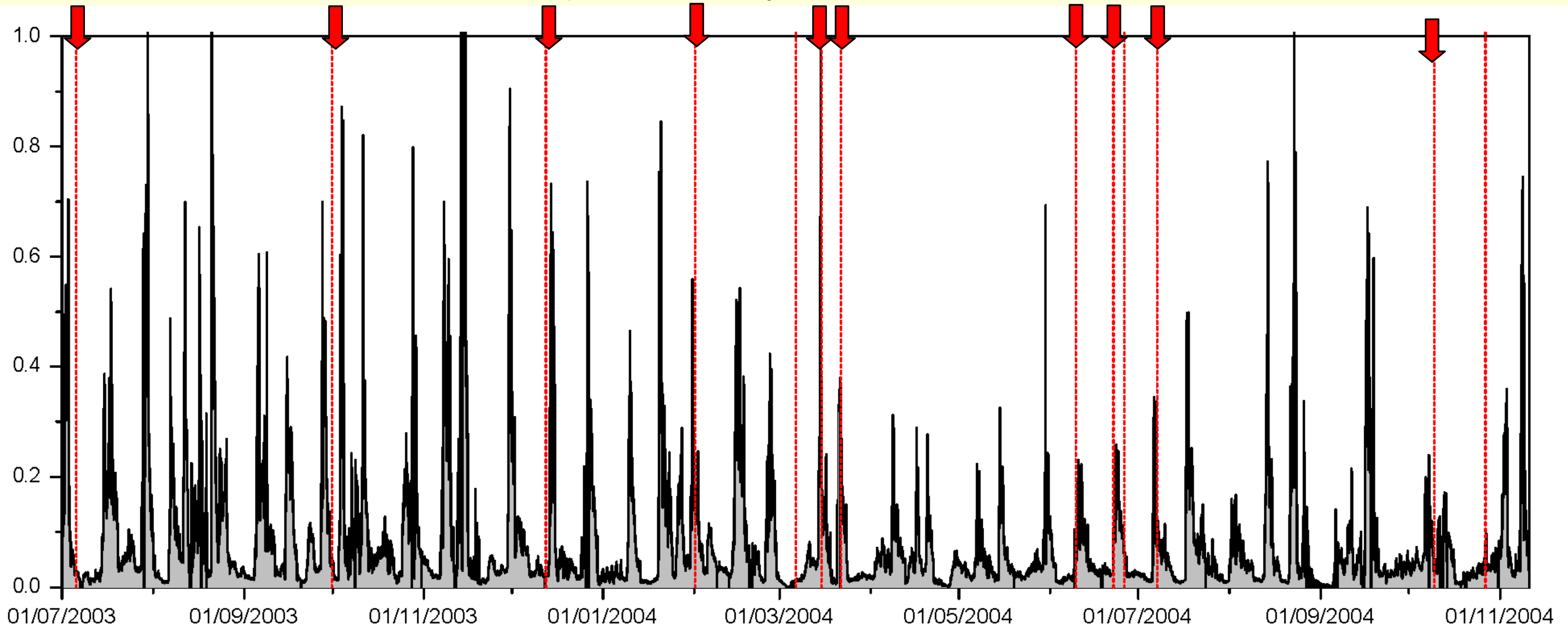
Periodic bursts of non-Io DAM



- The source of the periodic bursts sub-corotates with Jupiter and it may be active during longer periods of time.
- The averaged period of the burst recurrence is ~1.5 longer than System III (9.925 h)

Correlation with SW ram pressure

SW ram pressure - Ulysses measurements



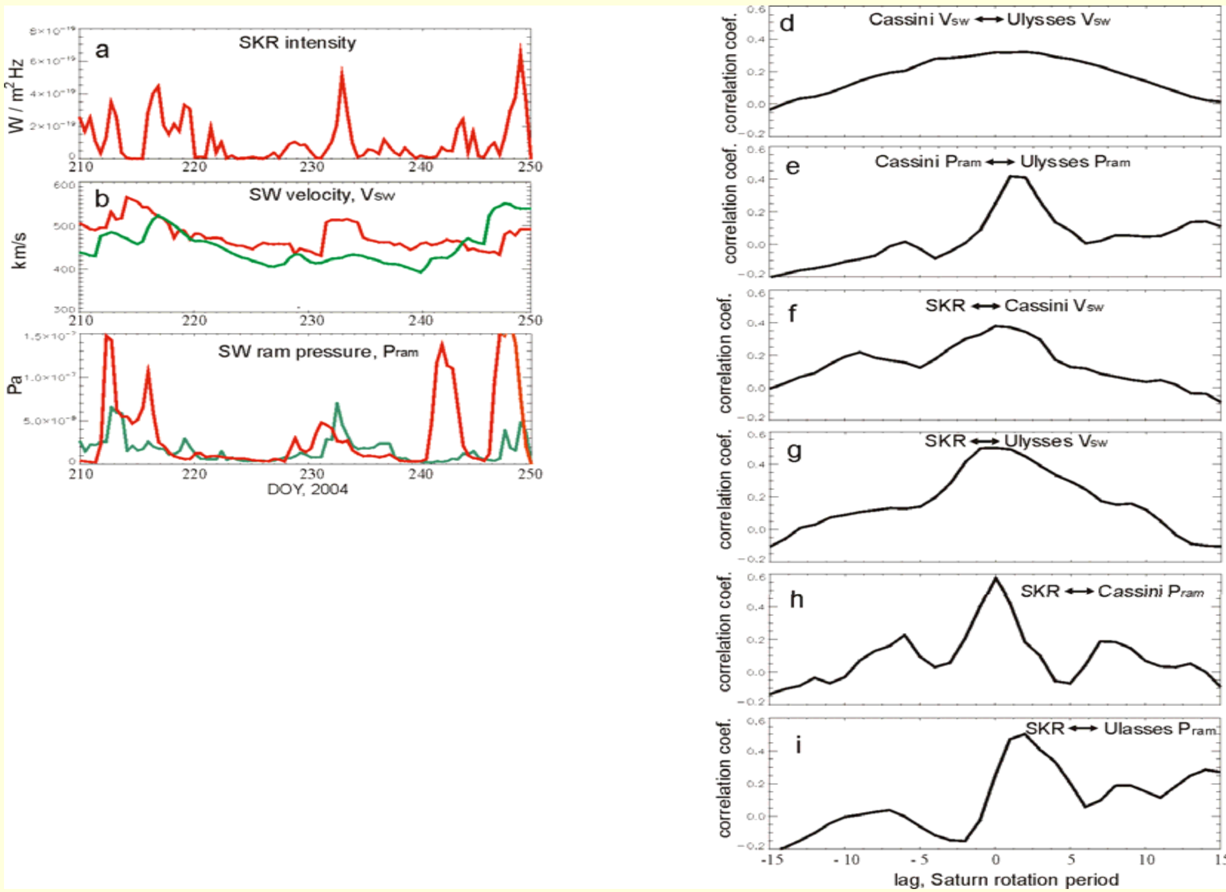
<u>Occurrence of periodic bursts of non-Io DAM is correlated with solar wind conditions around Jupiter</u>

---- Ulysses: SW $P_{ram} = \rho V^2$
---- onsets of episodes with periodic DAM

Panchenko, M., et al., Periodic bursts of Jovian non-Io decametric radio emission. Planetary and Space Science (2012),

The strong correlation between SKR intensity and solar wind parameters

Since the Voyager mission it is known that the SKR is strongly affected by the solar wind, in particular by the solar wind ram pressure (e.g. *Desch and Rucker, 1983, 1985; Taubenschuss et al., 2006, Rucker et al., 2007*).



$C_{max}=0.32$

$C_{max}=0.42$

$C_{max}=0.38$

$C_{max}=0.49$

$C_{max}=0.57$

$C_{max}=0.42$

correlation coefficients are "statistically significant" with probability of 95%.

Rucker et al., "Saturn Kilometric Radiation as monitor for the solar wind?", *Advances in Space Research,* 2007.

Conclusions

- Five planets, Earth, Jupiter, Saturn as well as Uranus and Neptune, produce powerful radio emissions.

- The characteristics of the planetary radio emission are merely depending on the dynamics and topology of the magnetosphere as well as the solar wind environment.

- Planetary radio emission is strongly controlled by the solar wind. This makes planetary radiation to be an important information source for remote diagnostics of planetary magnetospheres as well as for monitoring of the solar wind activity.

Thank You for Your Attention