Planetary radio emissions in the context of pioneering radio astronomy from the far side of the Moon

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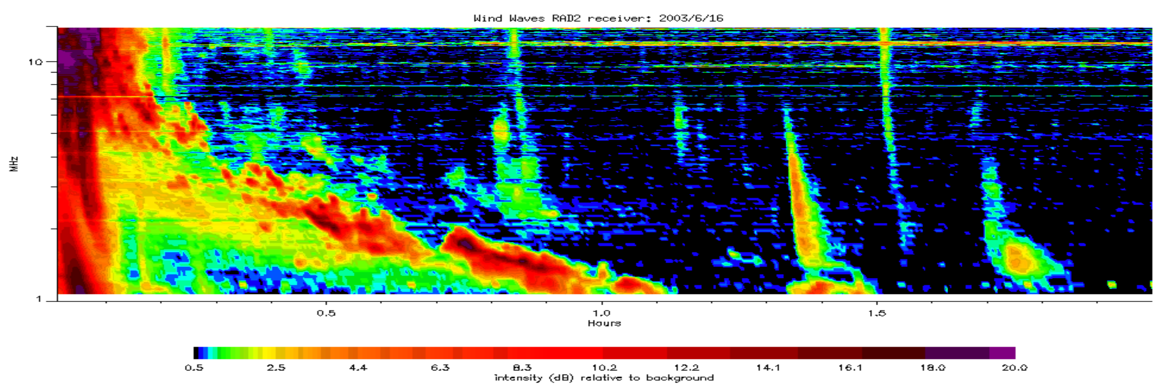
Specificities of LF radio astronomy

- 0-30 MHz
  - antenna arrays (spectro/imagers) on ground
  - simple wire antennas (so far) in space.
- sensitivity limited by (galactic) sky background (from 5 10^4 K to > 10^7 K).
- resolving power limited: 1″ resolution at 10 MHz implies a 2800 km baseline.
- manmade or natural RFI, on the ground;
- careful EC tuning, in case of space experiment.
  - ex: Voyager/PRA/HF, SolO/HFR
  - charged dust and plasma at Moon surface ?

Solar radio emissions

- active Sun: powerful radio emissions from Solar Corona
  - short living (bursts: types I, II, III) emissions produced by non-thermal mechanisms (mainly plasma or gyro synchrotron radiations)
  - partially (circularly) polarized.
  - wideband.
  - only a few percentage of the time (except type III storms)

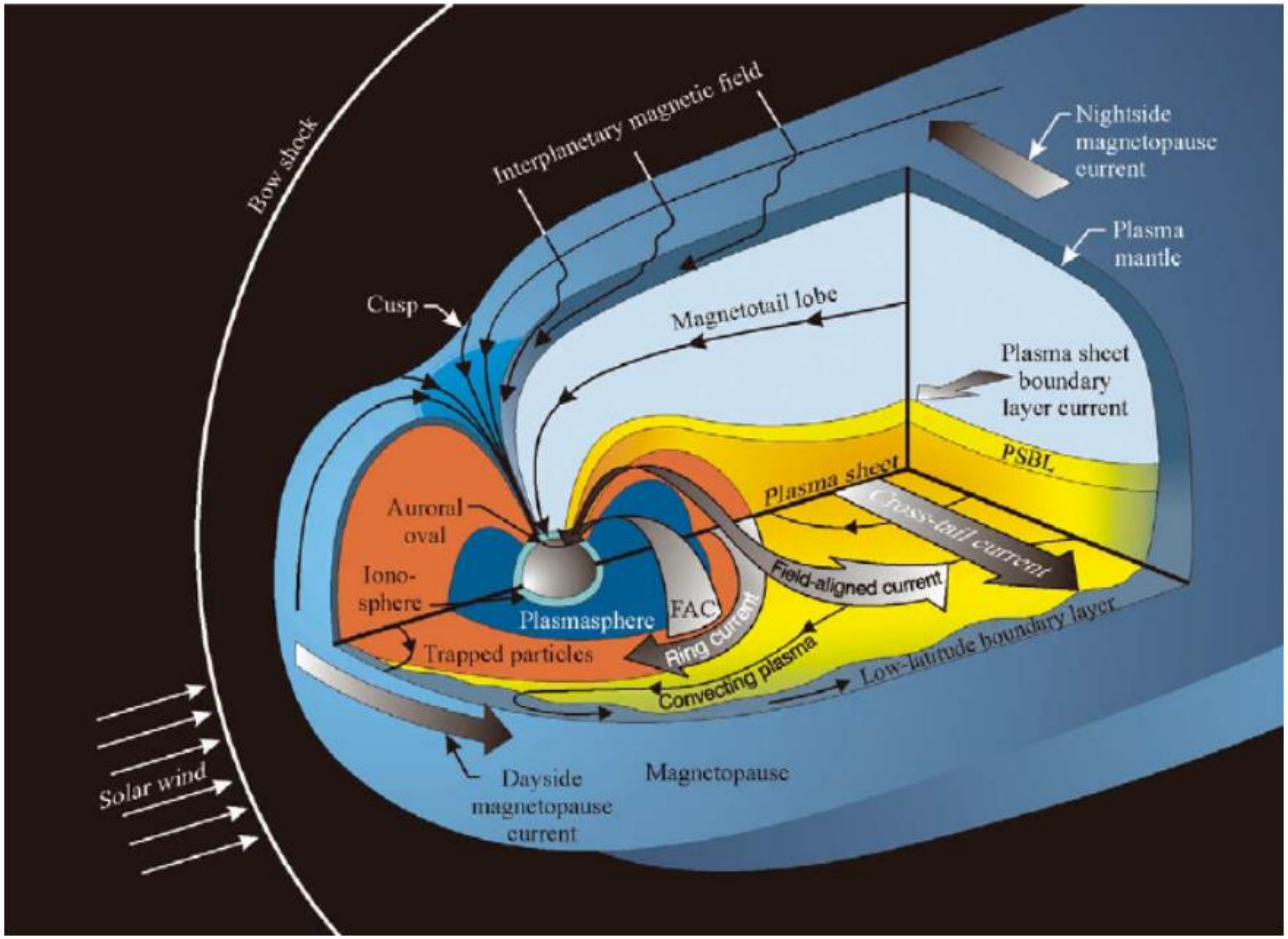
- quiet Sun thermal radiation (bremsstrahlung)
  - much weaker and continuous.



Planetary radio emissions

- all highly magnetized planets (the four giants and the Earth) produce resembling powerful radiations
- result from common processes occurring in their magnetospheres in interaction with the Solar Wind.

Schematic of Earth's magnetosphere



Planetary radio emissions

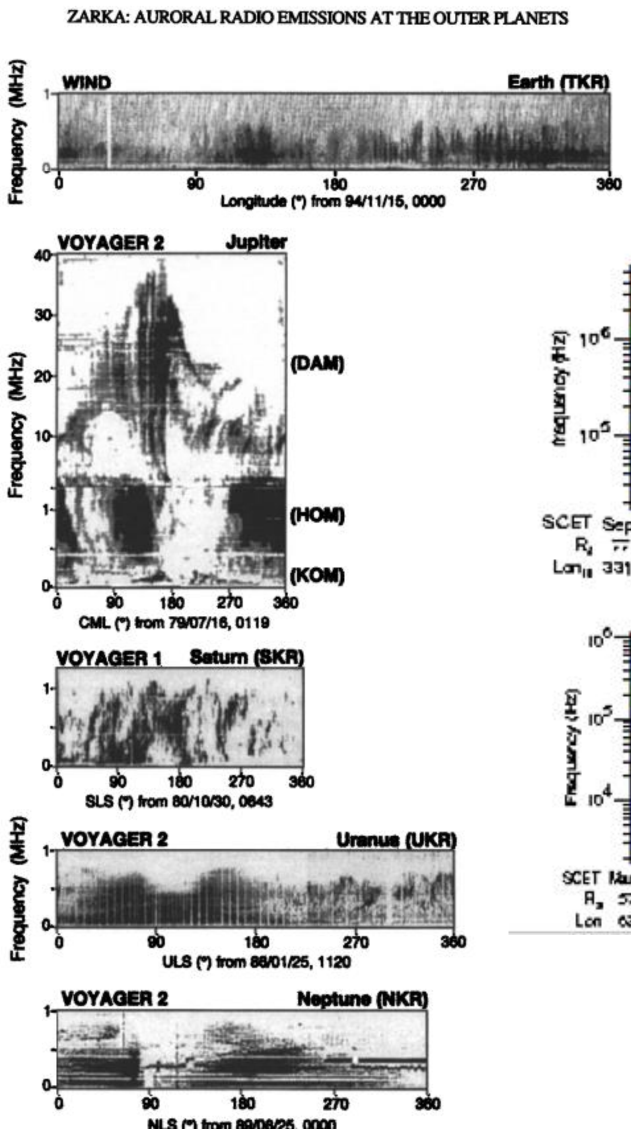
- all highly magnetized planets (the four giants and the Earth) produce resembling powerful radiations
- result from common processes occurring in their magnetospheres in interaction with the Solar Wind.
- two kinds of (escaping) planetary radio emissions:
  - less or not relevant in case of a low sensitivity radio telescope:
    - "non-thermal continuum" radiations (VLF range only)
    - synchrotron radiation (Van Allen belts)
    - atmospheric lightnings (when escaping)
    - …
  - mainly: non-thermal auroral radio emissions

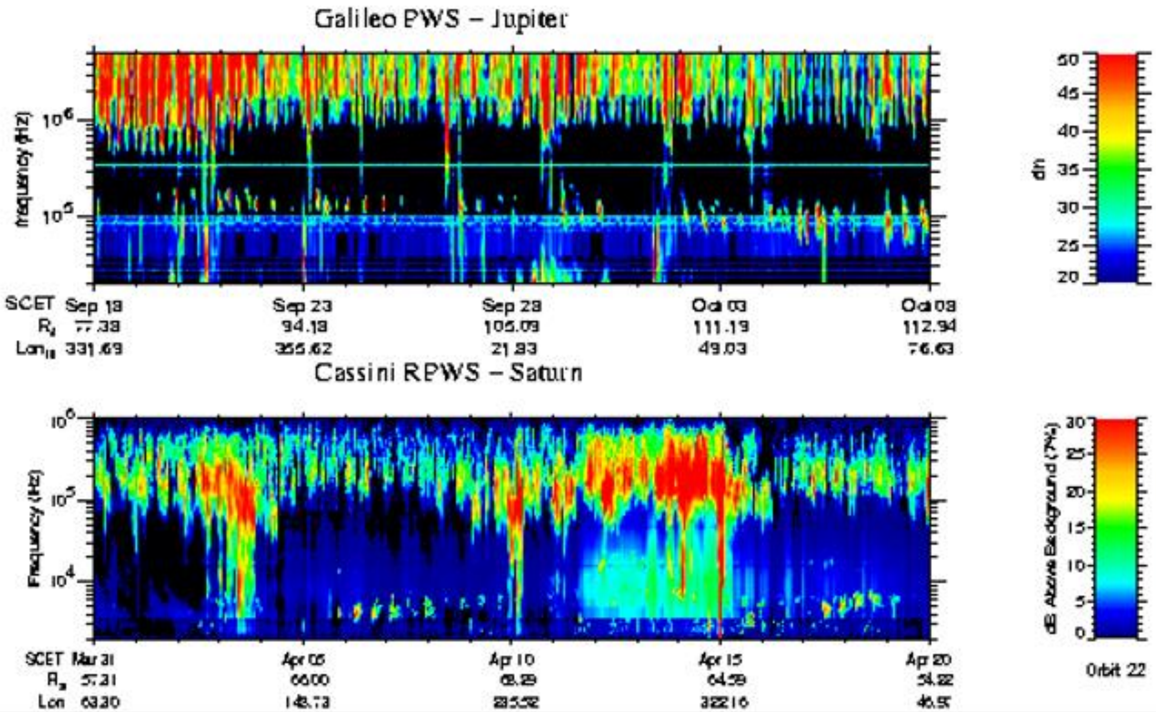
Non thermal continuum radiation

- < 50 kHz, but powerful enough, in case of Jupiter, to be observed throughout the outer Solar System.

- believed to be produced at steep density gradients (plasmapause for the Earth, magnetopause for giant planets) by mode conversion from upper hybrid resonance waves.

- observed in most of the radio planets (ITKR or "LF bursts" at the Earth, NTC at Jupiter and Saturn).


ZARKA: AURORAL RADIO EMISSIONS AT THE OUTER PLANETS
WIND
Earth (TKR)
Longitude (°) from 94/11/15, 0000
VOYAGER 2
Jupiter
(DAM)
(HOM)
(KOM)
CML (°) from 79/07/16, 0119
VOYAGER 1
Saturn (SKR)
SLS (°) from 80/10/30, 0643
VOYAGER 2
Uranus (UKR)
ULS (°) from 86/01/25, 1120
VOYAGER 2
Neptune (NKR)
Frequency (MHz)


Galileo PWS – Jupiter
frequency (Hz)
SCET Sep 18 Sep 23 Sep 28 Oct 03 Oct 08
Cassini RPWS – Saturn
Frequency (Hz)
SCET Mar 31 Apr 05 Apr 10 Apr 15 Apr 20
Orbit 22

Auroral radio emissions

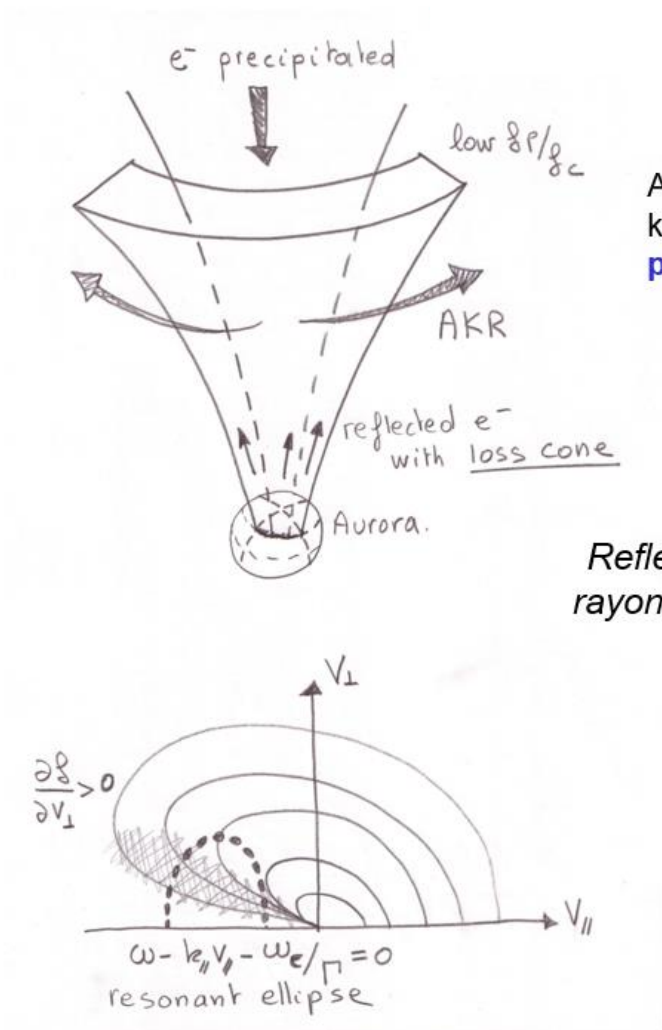
- well documented: RAE, IMP, Voyager, ISEE, Ulysses, Galileo, Wind, Cassini,…
- $T_B > 10^{14}$ K, up to 10^{21} K (short bursts from Jupiter) implying non- thermal coherent mechanism .
- average power ranging from 0.1 (Neptune NKR) to 1000 times (Jupiter DAM) the one of the Earth AKR (10^8 W).
- emitted close to electron gyro-frequency, the spectral range scaling to the planetary magnetic field intensity.
- extreme variability at short time and frequency scales.
- at longer time scale:
  - strong control by the planetary rotation (pulsar like).
  - steady mean intensity (by averaging over many planetary rotations)
- 100 % polarised (mainly circular, the sense depending on magnetic field orientation at the source).

Auroral radio emissions

- explained as CMI radiation (X mode) from unstable electron populations (a few keV energy) in depleted (high latitude) auroral regions located in both N and S hemispheres of the planet.
- wideband emissions along planetary magnetic field lines
- close relationship with Solar Wind variations:
  - *sub-storm activity at Earth*
  - *SW velocity variations at Jupiter*
  - *SW ram pressure at Saturn*
  - *unclear at Uranus and Neptune*
- another version (at Jupiter) involving "internal" auroras located at the footprints of Galilean satellites magnetic flux tubes.

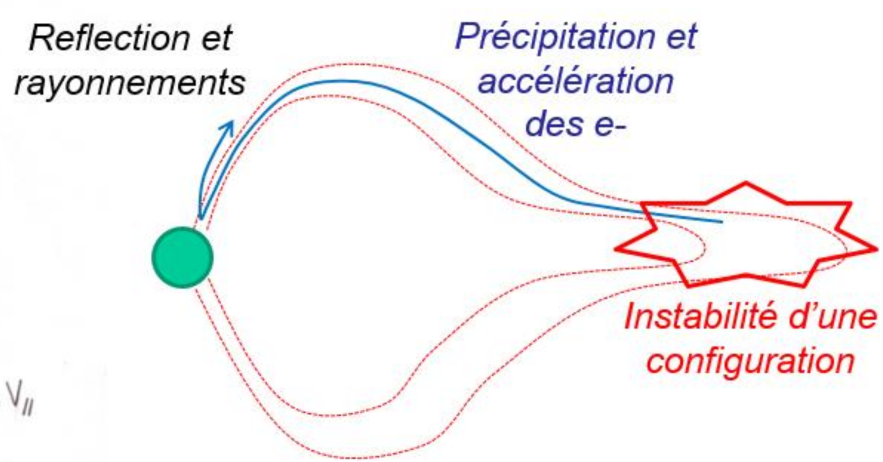
Cyclotron Maser Instability

(Louarn, 2002)



Amplification par des électrons énergétiques (qq 10 keV) qui sont réfléchis et **présentent un 'cone de perte'** (**df/dv⊥ positif**). (Wu et Lee, 1979)

Etablit un lien avec l'activité de la magnétosphère



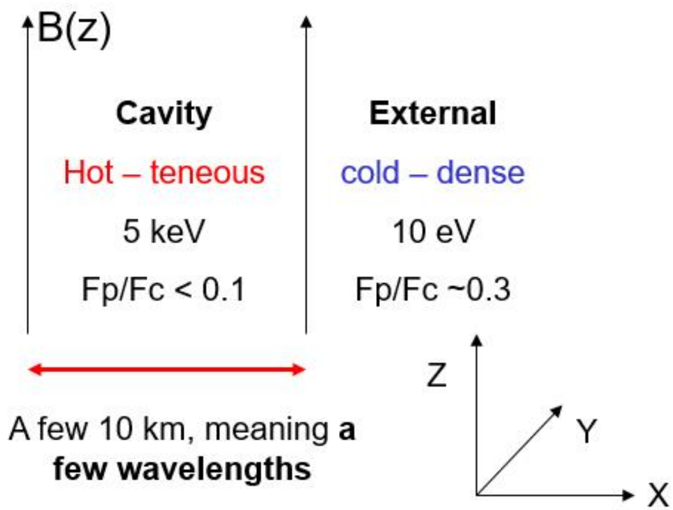
Cyclotron Maser Instability

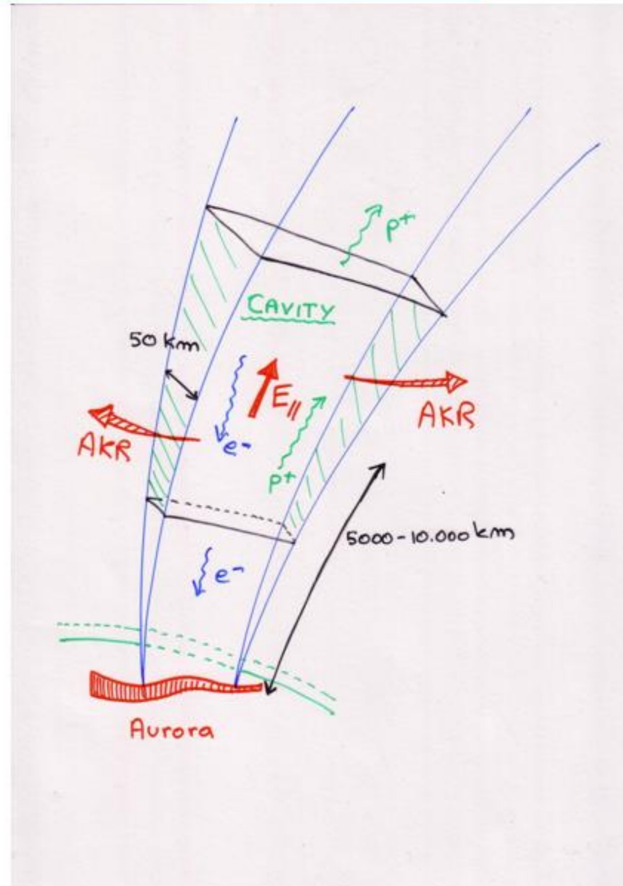
Modèle de génération dans des cavités

Sources de l'AKR:

- Régions de faible densité
(Fp/Fc < 0.1 interne, Fp/Fc ~0.3 externe)
-Régions dominées par une population chaude.
(~ 5 keV)
-Petite dimension perpendiculaire à B (~ 10 km)

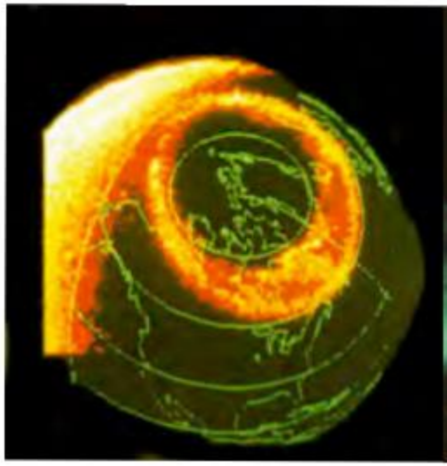
Un modèle de 'couche' pour la source:

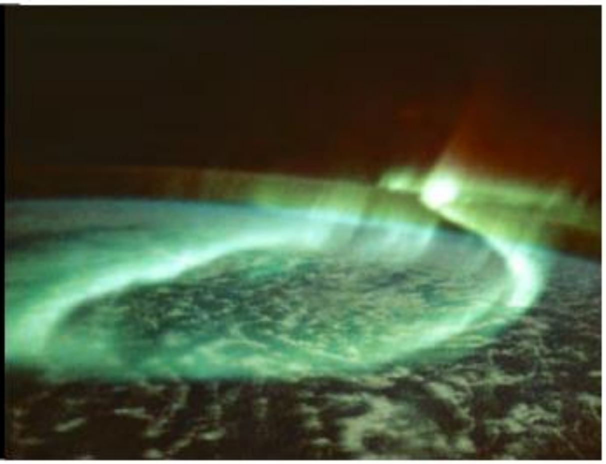




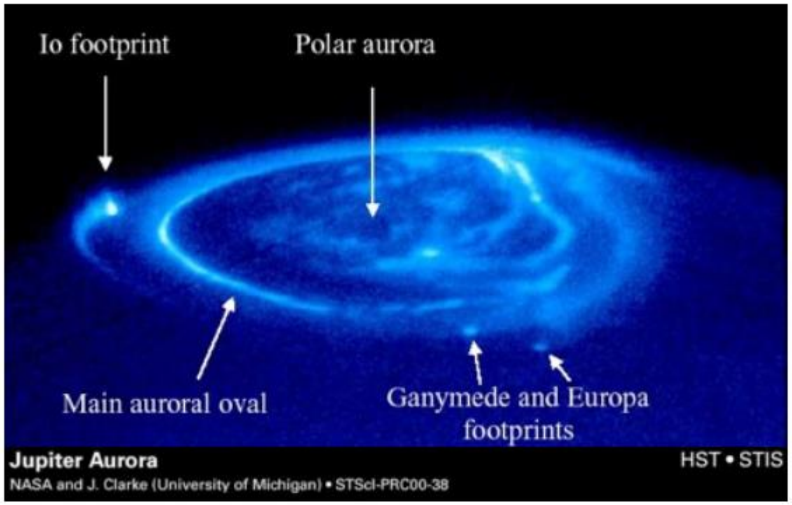
(Louarn, 2002)

Earth auroras

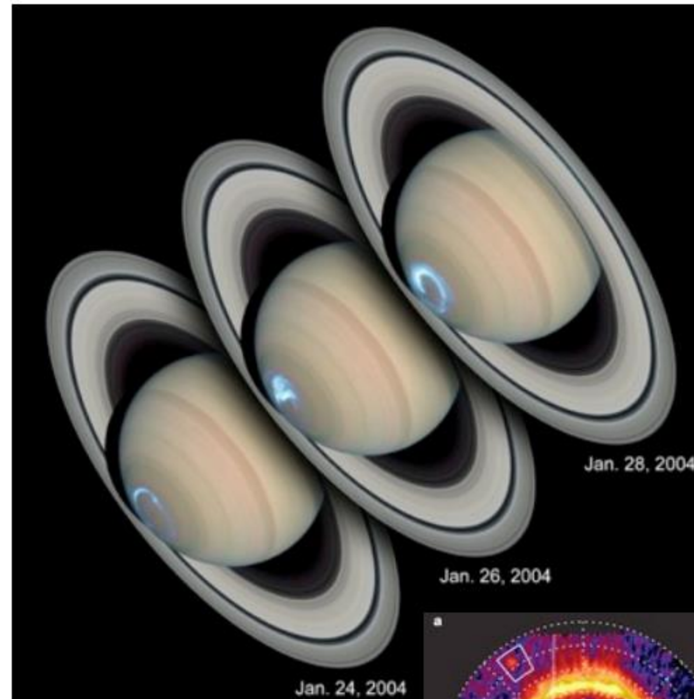




Jupiter and Saturn auroras

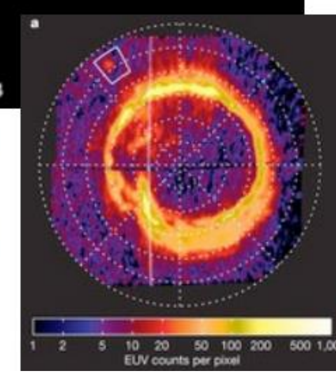


- Main oval
- Polar aurora
- Moon footprints
- Low latitude diffuse aurora



Clarke et al. [2005]

Pryor et al. [2011]



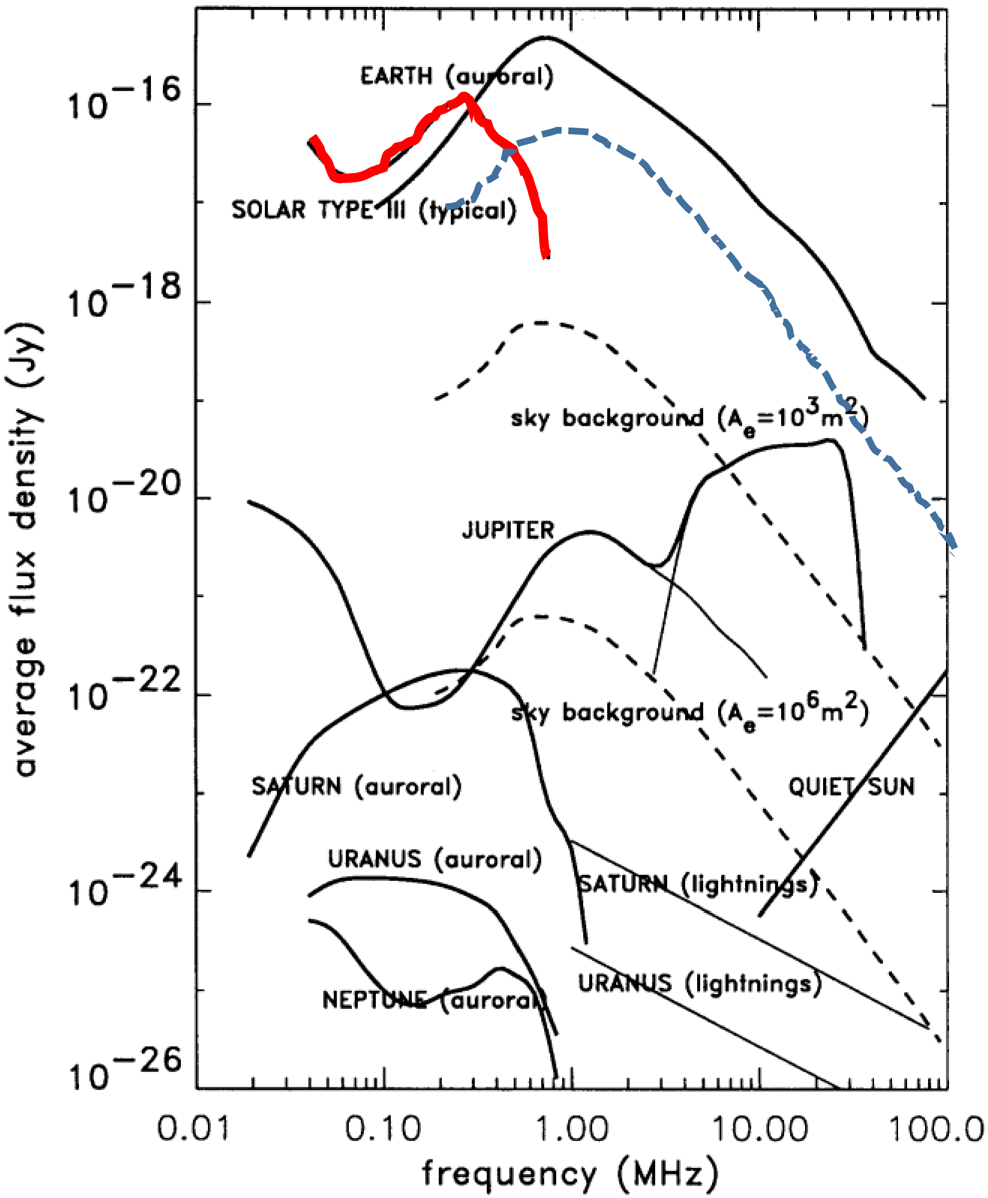
Auroral radiations for an observer located at the Moon

Simplified, averaged spectra (over 10 mn) of freely propagating radio emissions in the Solar System.

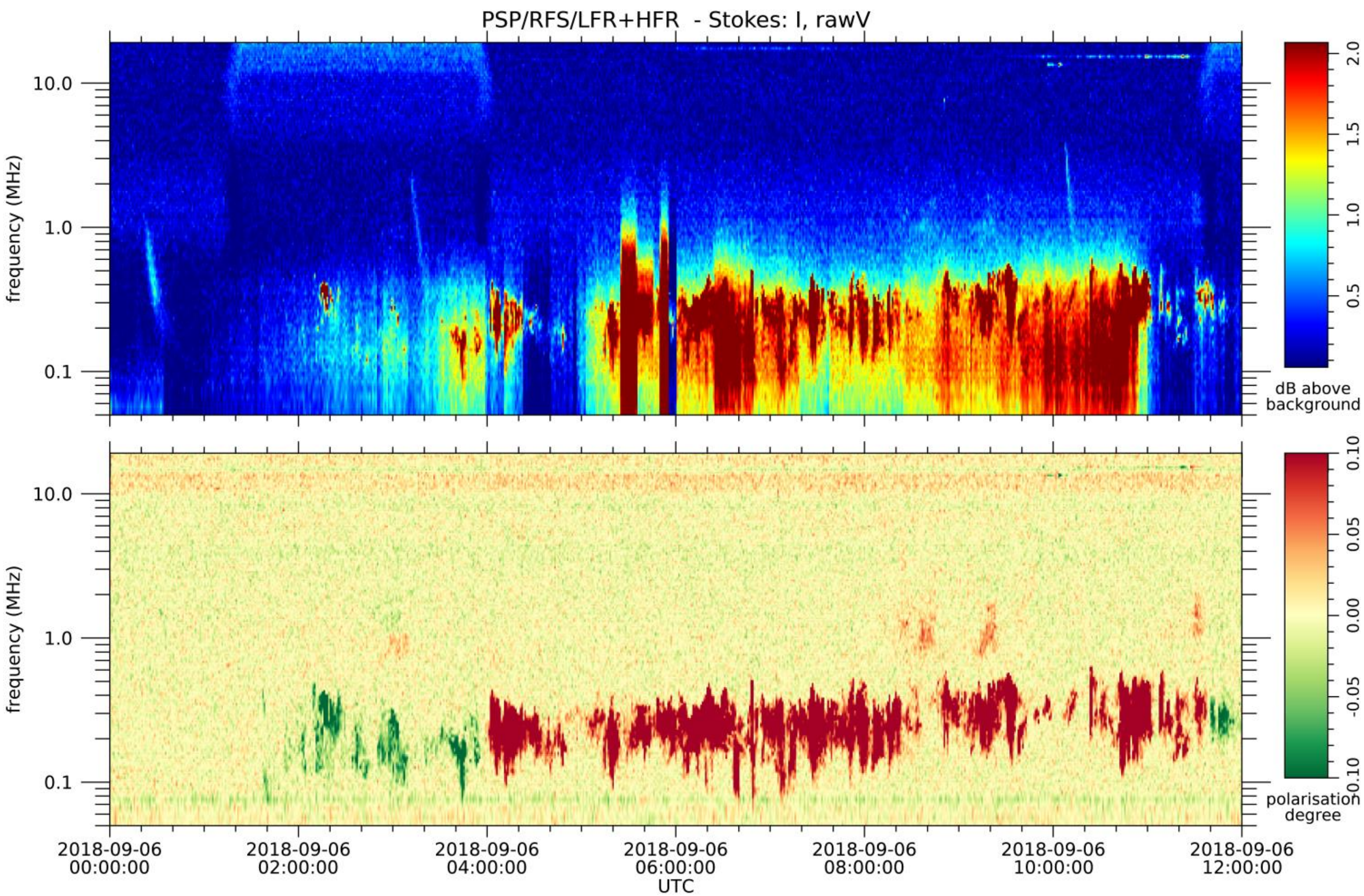
The observable flux density levels are compared to the sky background level (dashed lines) for an observer located at the Moon and using small (10^3 m^2) or large (10^6 m^2) antenna effective areas.

In case of planetary radiations, peak values may be larger by several orders of magnitude.

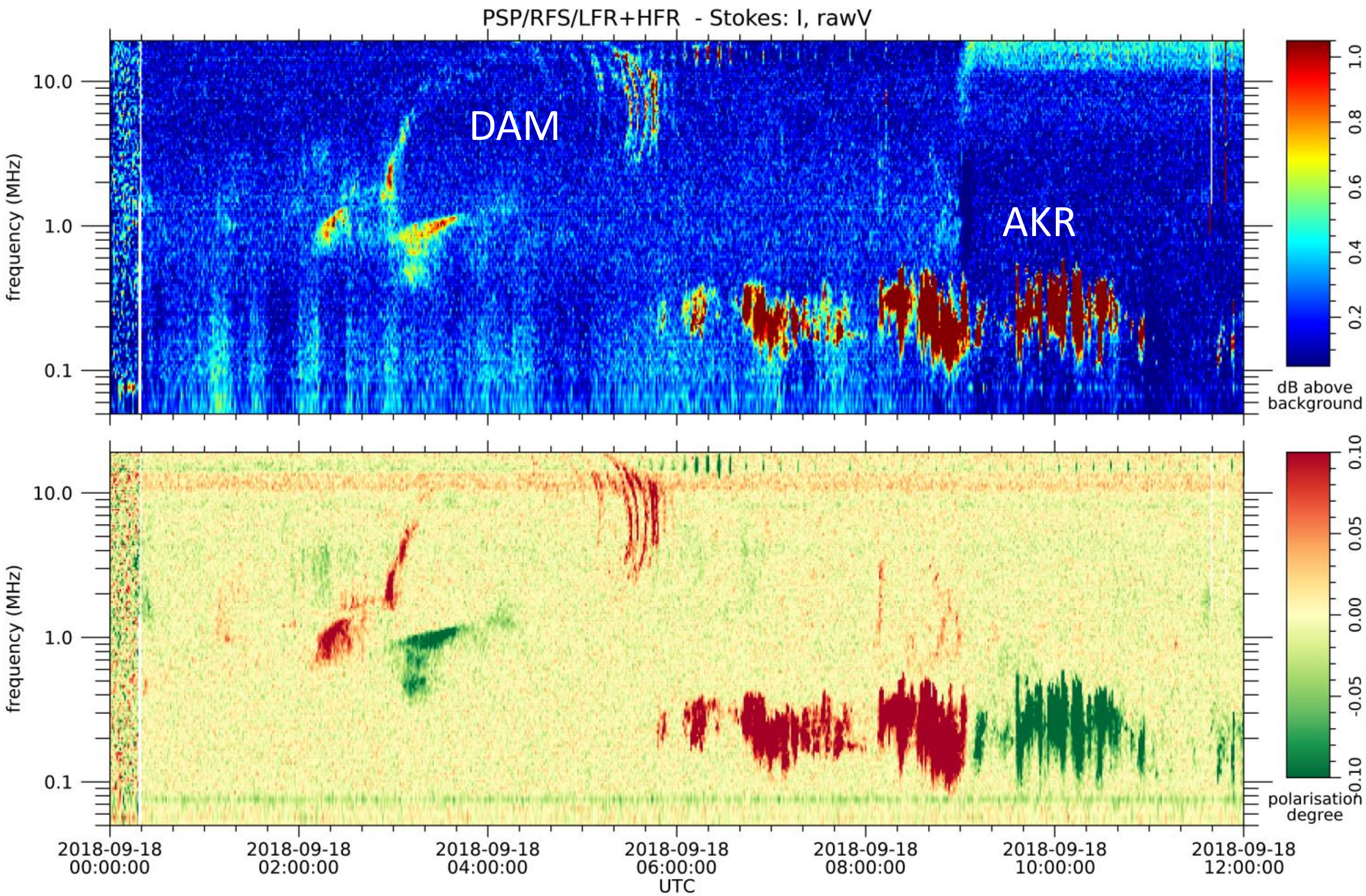
(Lecacheux, 1994)



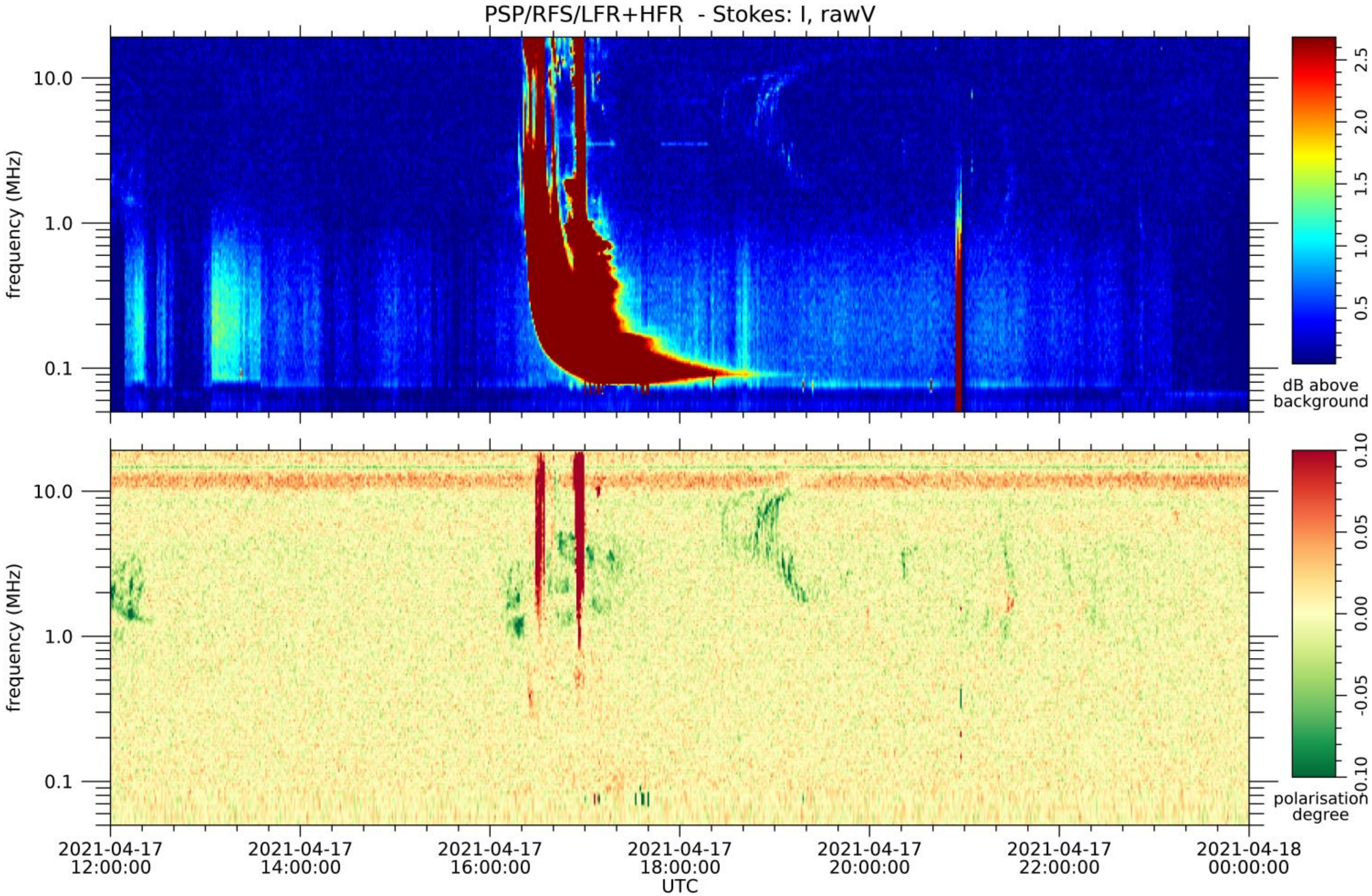
AKR seen by PSP (when located at 68 times the Moon distance to the Earth)



AKR and Jovian DAM mixed on PSP (when located at 98 times the Moon distance to the Earth)



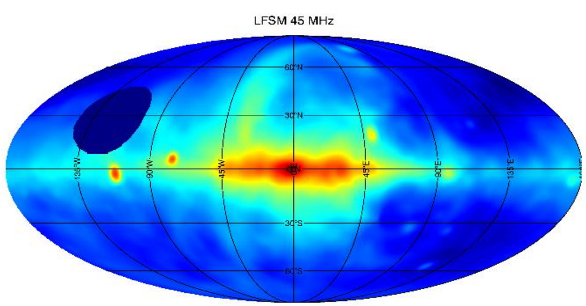
Efficiency of source discrimination by using polarisation



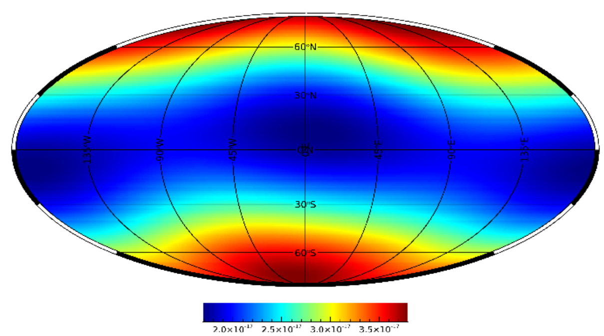
Any other astrophysical objects ?

- nothing else, by using simple wire antennas, excepted <u>the Galaxy</u> itself.
- i.e. study its brightness spatial distribution (mapping) in function of the frequency.

LFSM 45 MHz



Cassini/RPWS **1.6 MHz**
(reconstructed from 2014-09-03 roll data)



(Lecacheux and Maksimovic, 2019)

(a few) instrumental recommendations for evaluating planetary radiations when observing from the Moon

- simple autocorrelation (detection) of antenna voltages is not sufficient (because of low directivity and intrinsic linear polarisation of dipolar antennas(*))
- a correlator is likely needed :
  - 2-axis antenna system (crossed dipoles) in correlation allows in principle DOA and circular polarisation of a single point source to be estimated.
  - but problematic in case of simultaneous, multiple or extended sources (the actual case !)
- 3-axis antenna scheme in full correlation would be ideal (but has never be used so far in space radioastronomy):
  - allows to get the coherence matrix of the incident electric field (Born & Wolf) by analyzing the full correlation matrix of antenna voltages (both matrices are indeed proportional)
  - will maximize assessment capabilities of the experiment (for instance by using a combination of three, no coplanar monopoles).

(*) circular polarisation can be obtained by detection of two linear antenna voltages after summation in quadrature

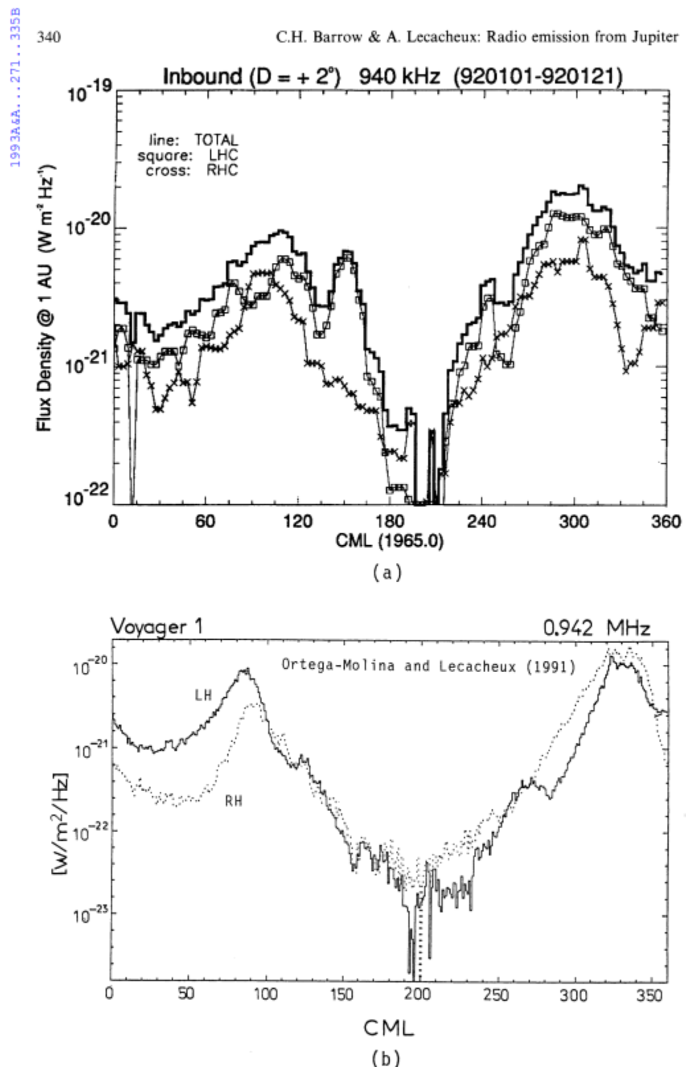
Summary

LuSee-Night radio experiment, on Moon's far side, will likely be able to detect some radio planets and the Sun.

+ Jupiter (in the whole band) may serve as an absolute calibrator (point source of known direction, polarisation and (average) intensity).

- Some part of Earth's emissions (below 1 MHz) might be a nuisance, in spite of the blocking by Moon's body, depending on the Moon's geometry with respect to the magnetospheric tail (anomalous propagations).

Observed Jupiter’s emission intensity profile at 1 MHz



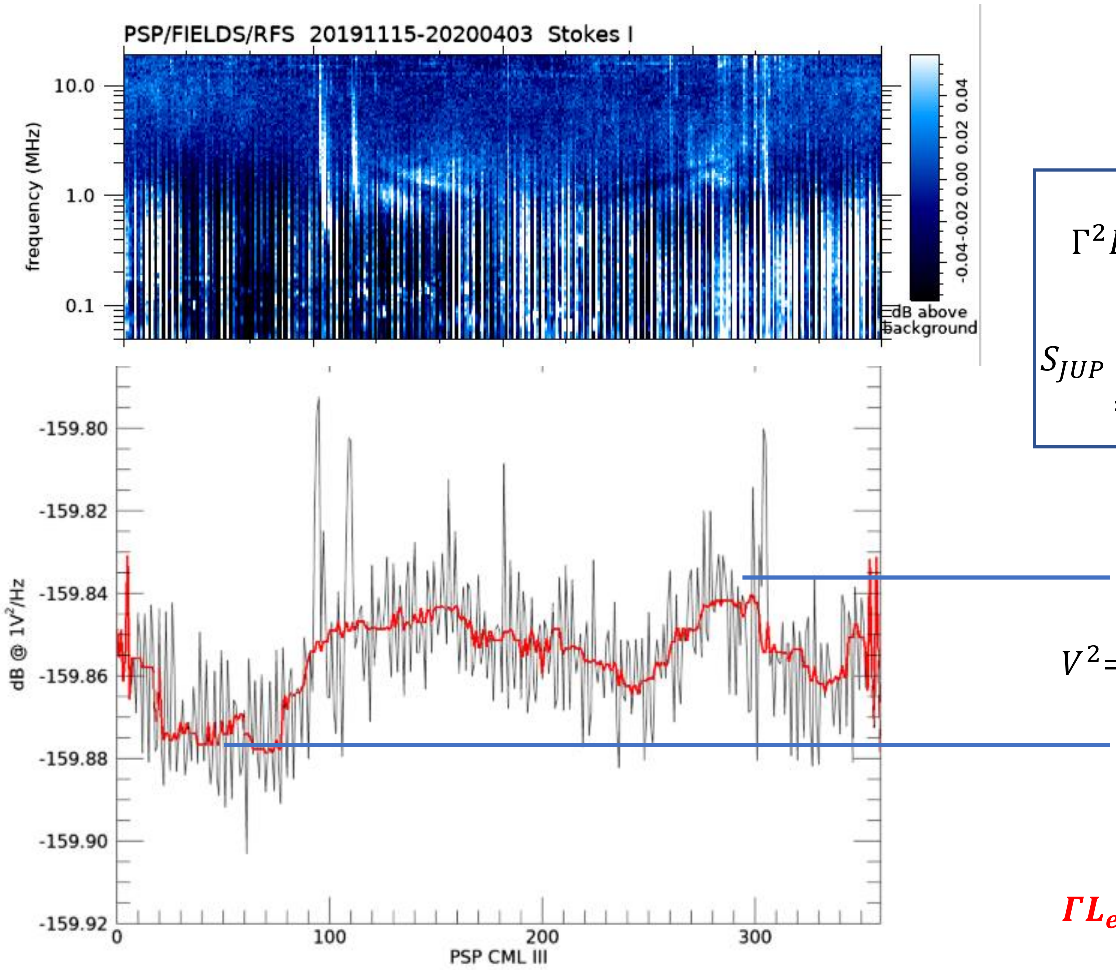
Ulysses/URAP

Voyager/PRA

Fig. 5a and b. Average LH and RH flux densities normalised to 1 AU from the planet. **a** Observed by Ulysses at 940 kHz for 48 jovian rotations before encounter. **b** Observed by Voyager 1 at 942 kHz 61 jovian rotations before encounter (Ortega-Molina & Lecacheux 1991)

(Also checked
by using Galileo/PWS)

Calibrating PSP radio experiment



$$\Gamma^2 L_{eff}^2 = \frac{V^2}{2 Z_0 S}$$

$$S_{JUP} = 2\ 10^{-20}\ Wm^{-2}Hz^{-1}\ @\ 1\ AU$$
$$= 7.4\ 10^{-22}\ @\ 5.2\ AU$$

$$V^2 = 10^{-15.984} - 10^{-15.988} = 9.5\ 10^{-19}$$

$$\boldsymbol{\Gamma L_{eff}} = \sqrt{\frac{9.5\ 10^{-19}}{240\pi\ \ 7.4\ 10^{-22}}} = \mathbf{1.3\ m}$$

CODALEMA **tri-axial** antenna for UHECR (cosmic rays) study