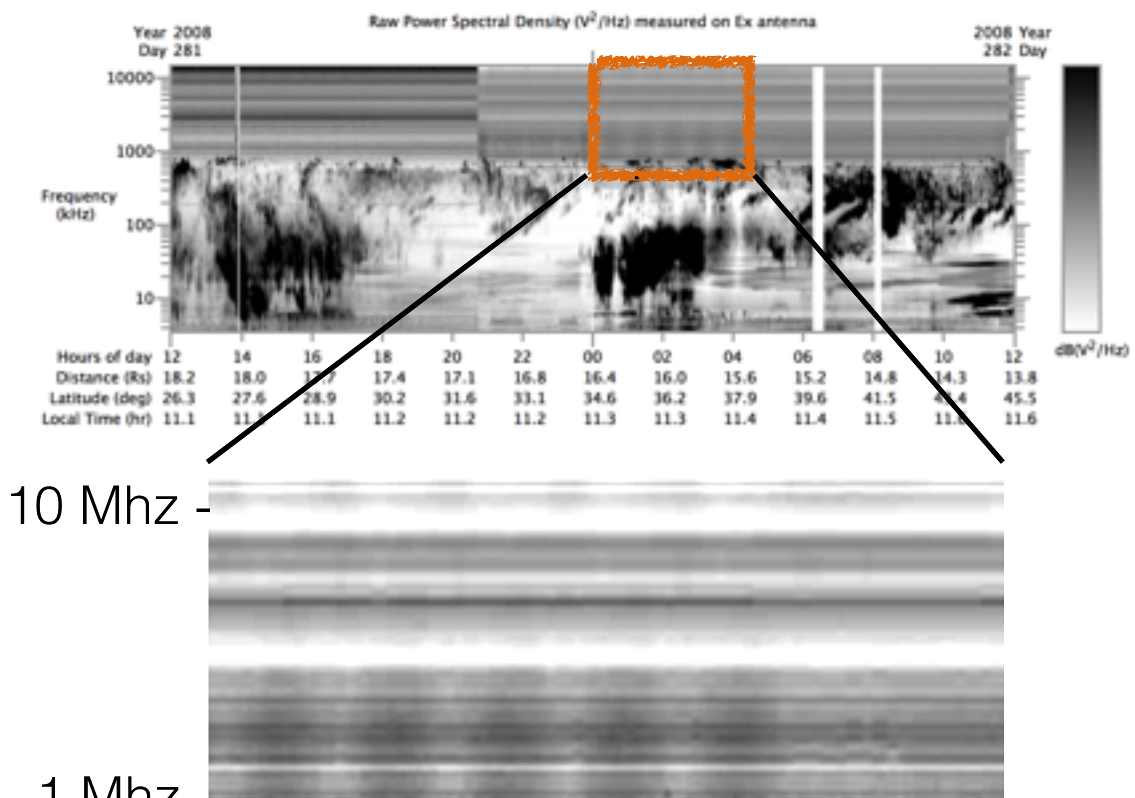
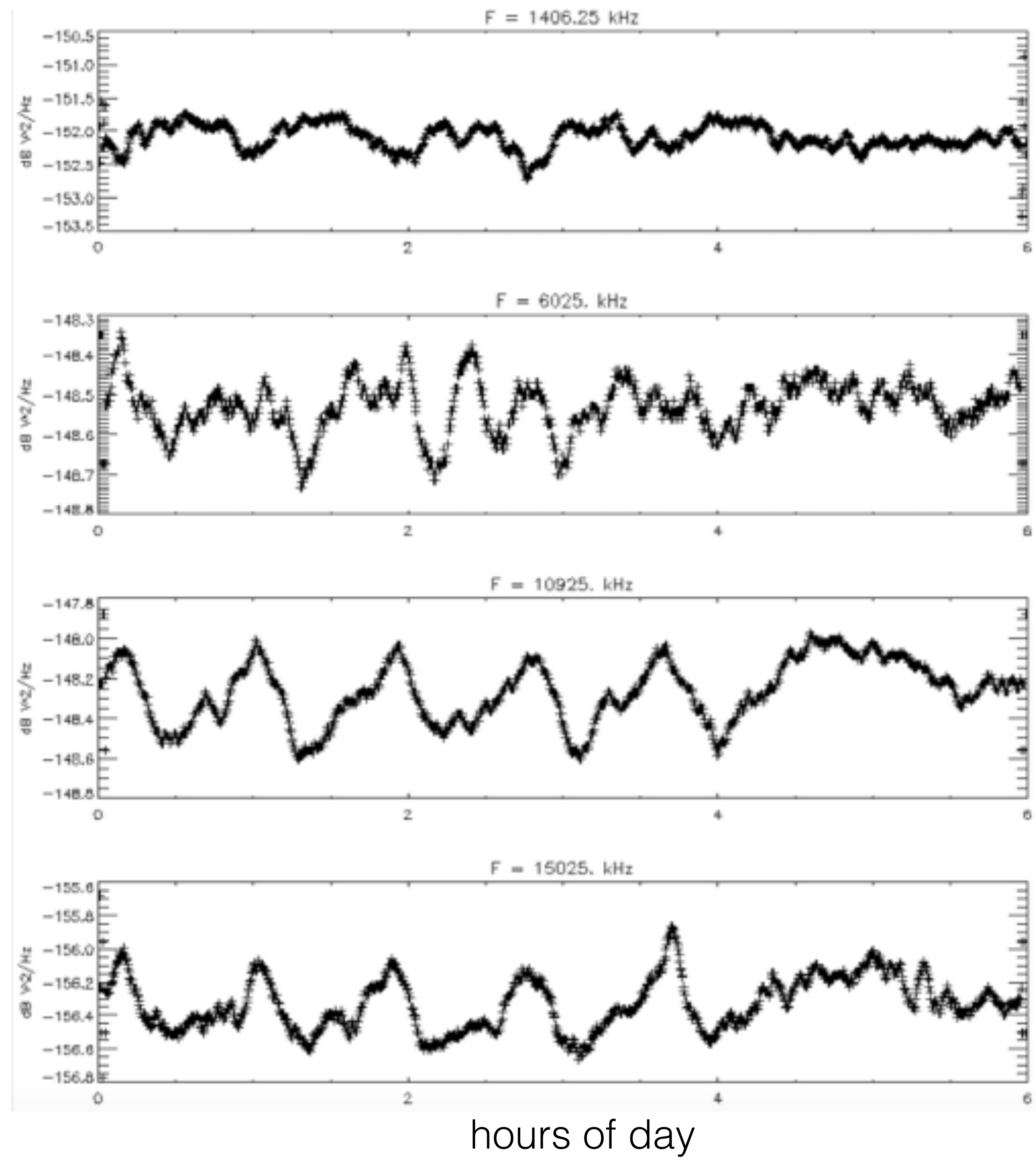
DSL workshop
Solar System Transients

B. Cecconi

Extra slide: Galactic background Data (from Cassini/RPWS)



- 6 hours of data
- S/C rotating around itself
- 4 frequencies:
  - *1.4 MHz,*
  - *6.0 MHz,*
  - *11 MHz,*
  - *15 MHz*
- not in phase
- strong variability !



Solar System Radio Sources

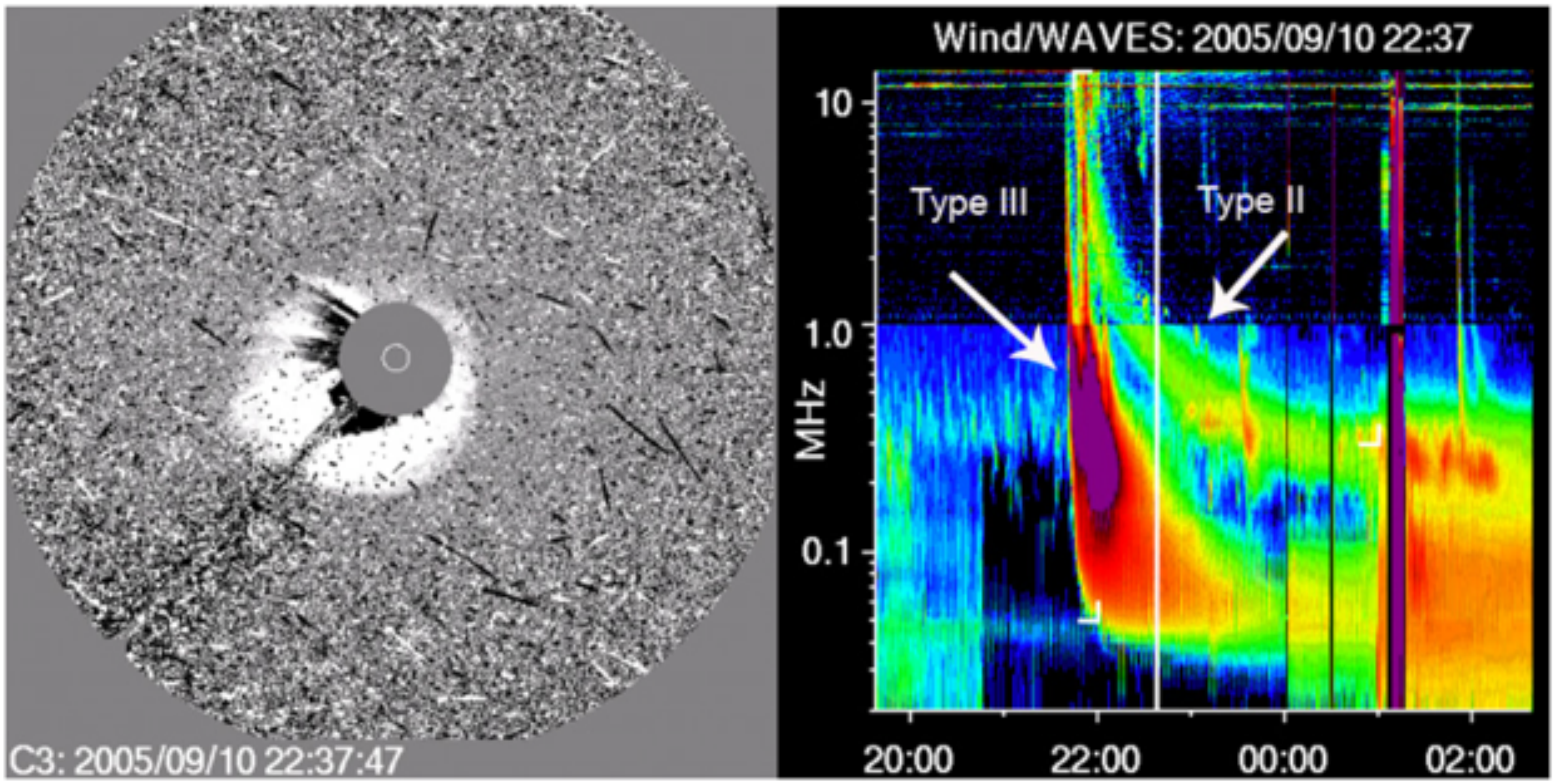
- **Solar Activity**
- **Magnetized planets (aurora)**
- **Magnetized planets (radiation belts)**
- **Lightings**
- **Human Technology**

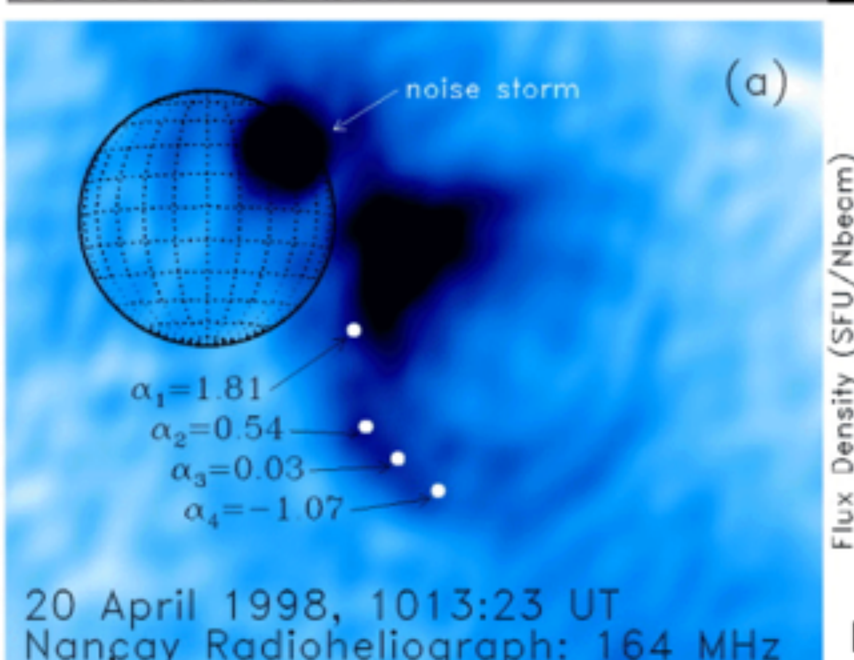
- Preliminary Requirements from past experience on space missions:
  - 3 dipoles needed on each platform.
  - full spectral matrix (auto and cross correlations on 3 antennas)
  - integration order of magnitude: ~10kHz x ~10 ms
  - time-frequency shape is needed with 100 kHz x 1 min resolution

Solar Activity

Low-frequency radio bursts from the Sun, from 1.5 Rs to ~1 AU : Type II & III, CME, ...

Space weather - Passive: through scintillation and Faraday rotation
- Active: through radar scattering

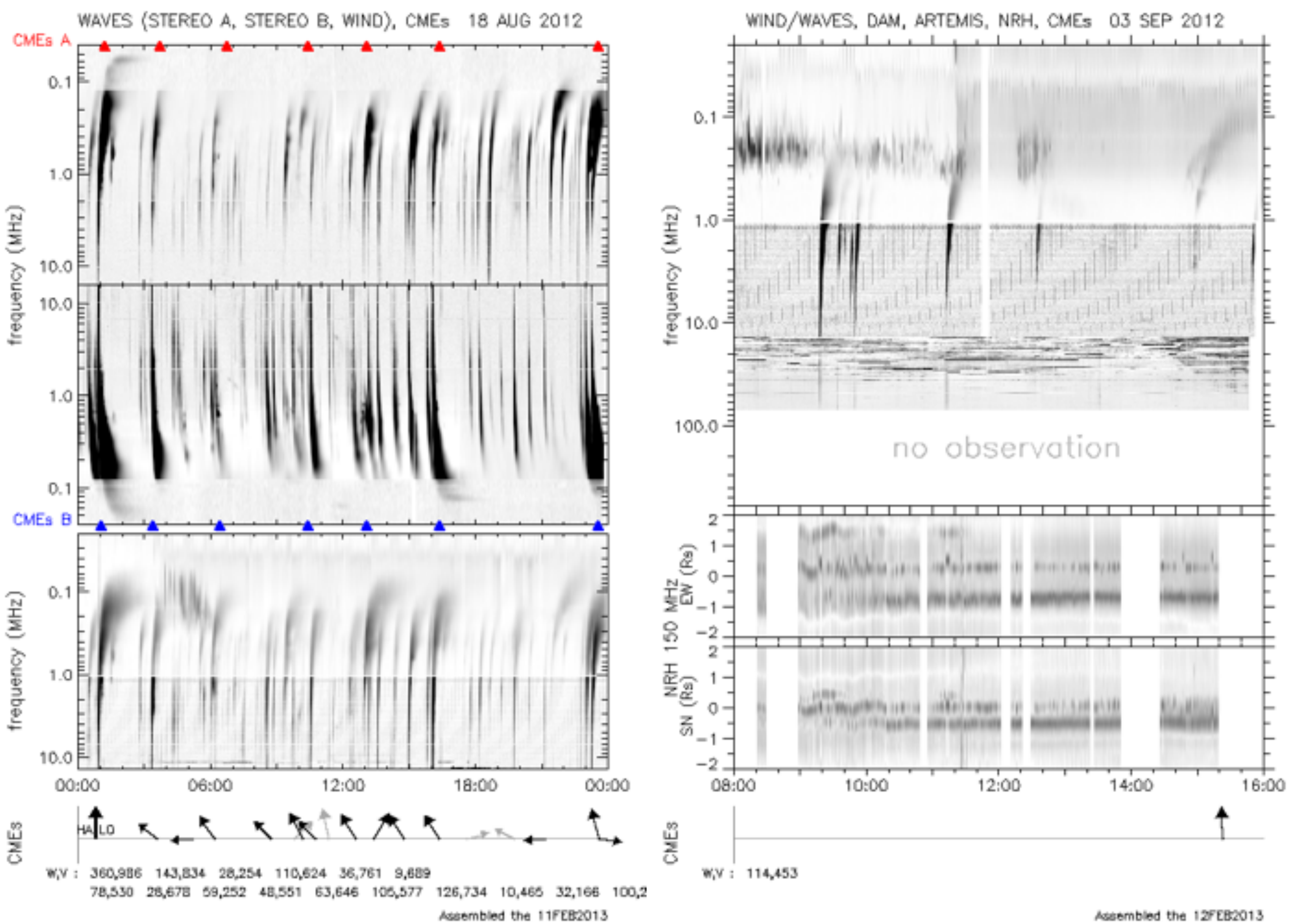




Bastian et al., 2001

Solar Activity

extracted from Solar Radio Monitoring service in Obs Paris
(http://secchirh.obspm.fr)

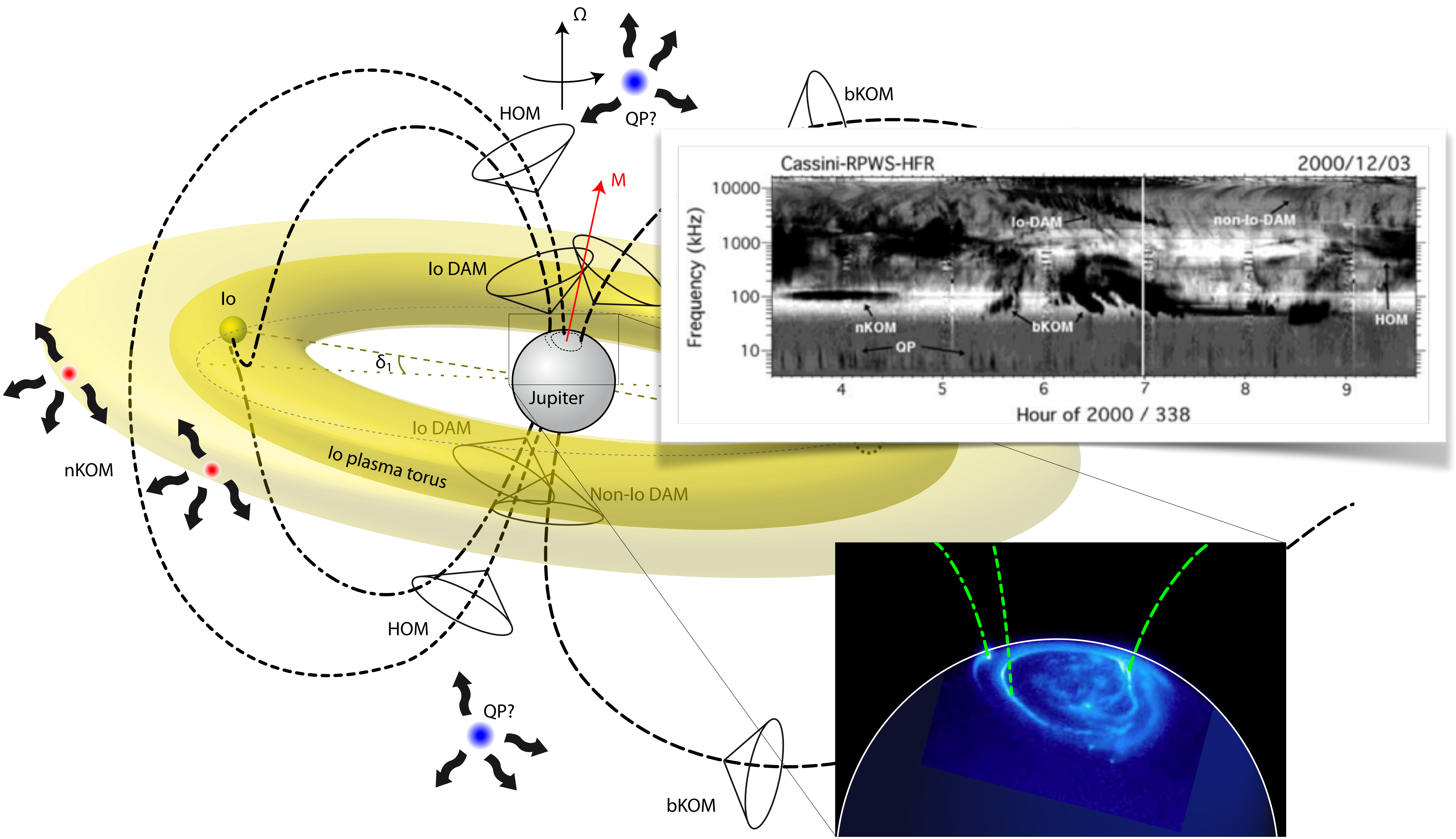


Single dipole measurement

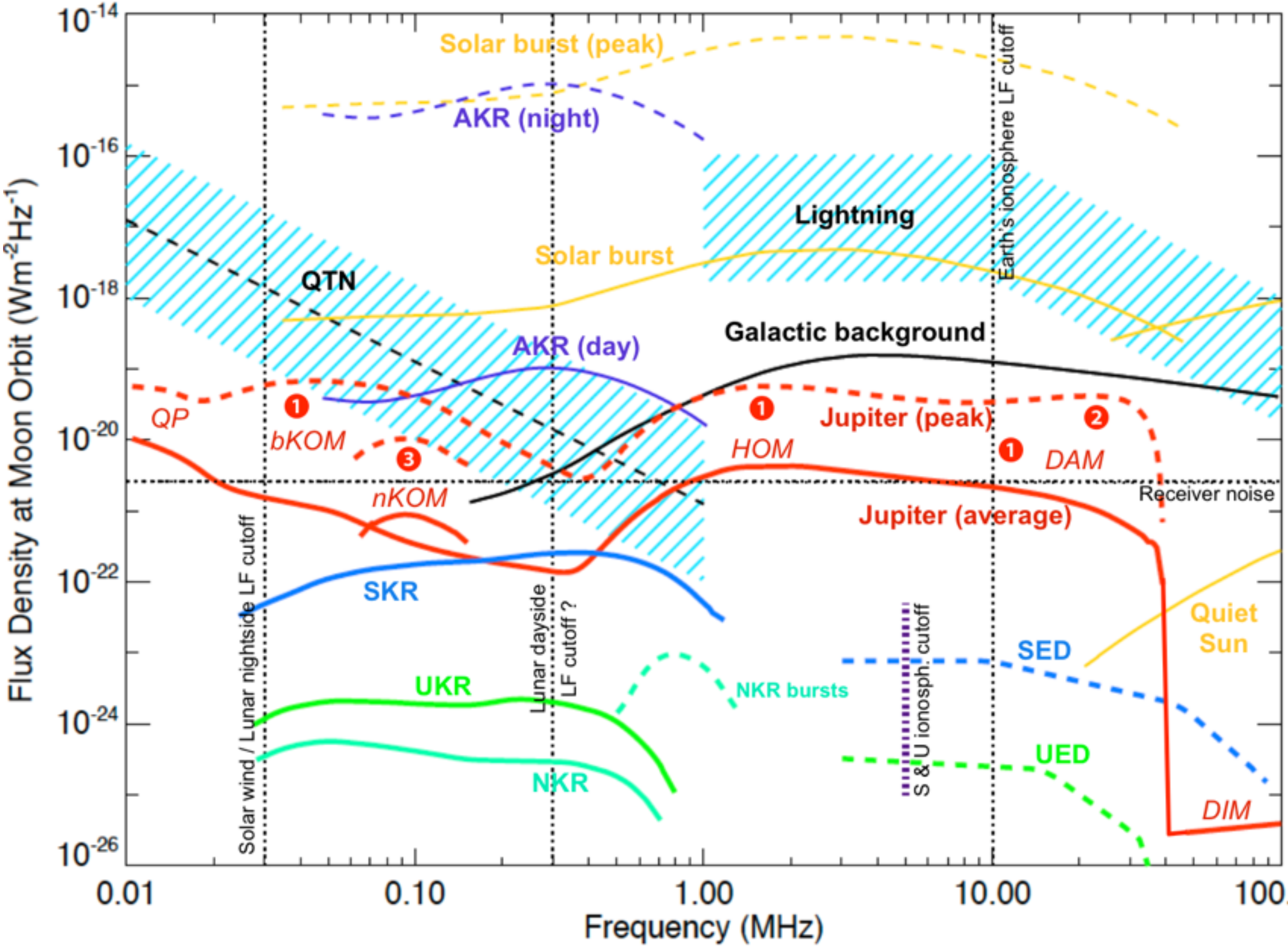
Summary
Solar Activity

Name	solar type II bursts	solar type III bursts
Source	electron beams from active regions	electrons accelerated in front of interplanetary shocks
Emission process	ES to EM mode conversion	
Time-frequency shape	Drifting feature LF temporal broadening	Drifting feature
Frequency Range	a few 10 kHz to 100 MHz	1 to 10 MHz
Duration	a few minutes (HF) to few hours (LF)	a few 10 minutes for each frequency
Recurrence	correlated to solar cycle	
Flux Density	10^9 to 10^{12} Jy	~10^{10} Jy
Source Size	a few degrees (HF) ~40° (LF) [interplanetary medium scatering]	unkown
System Parameters	Time-Frequency sampling (required for event identification): ~10 kHz / ~1 sec Instantaneous imaging => new insight on inner solar system IP scattering	

Planetary Aurora



Planetary Aurora



Planetary Aurora
Fine Structures

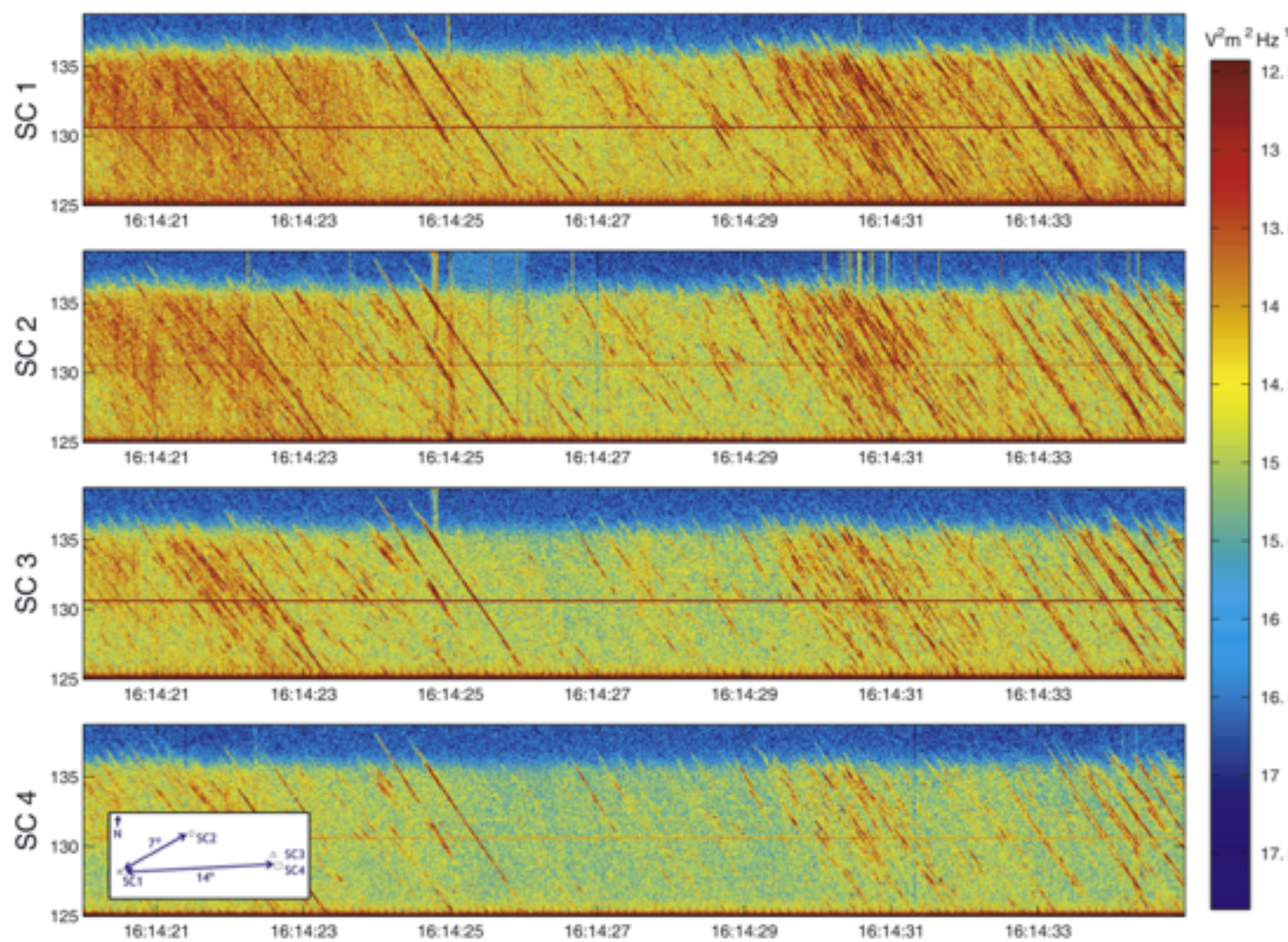


Figure 1. Frequency-time spectra of striated AKR bursts observed on 4 Cluster spacecraft on 31 August 2002 from 1614:20 to 1614:35 UT. The inset shows the projected angular separations of the spacecraft as seen from the source.

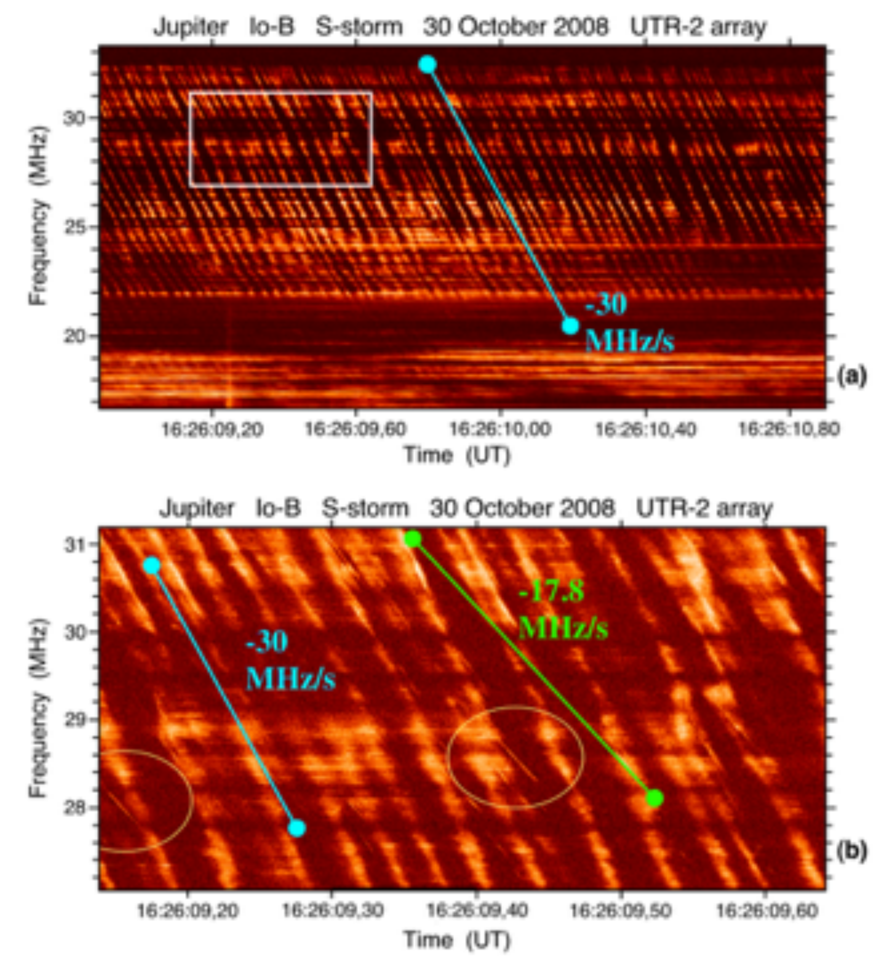


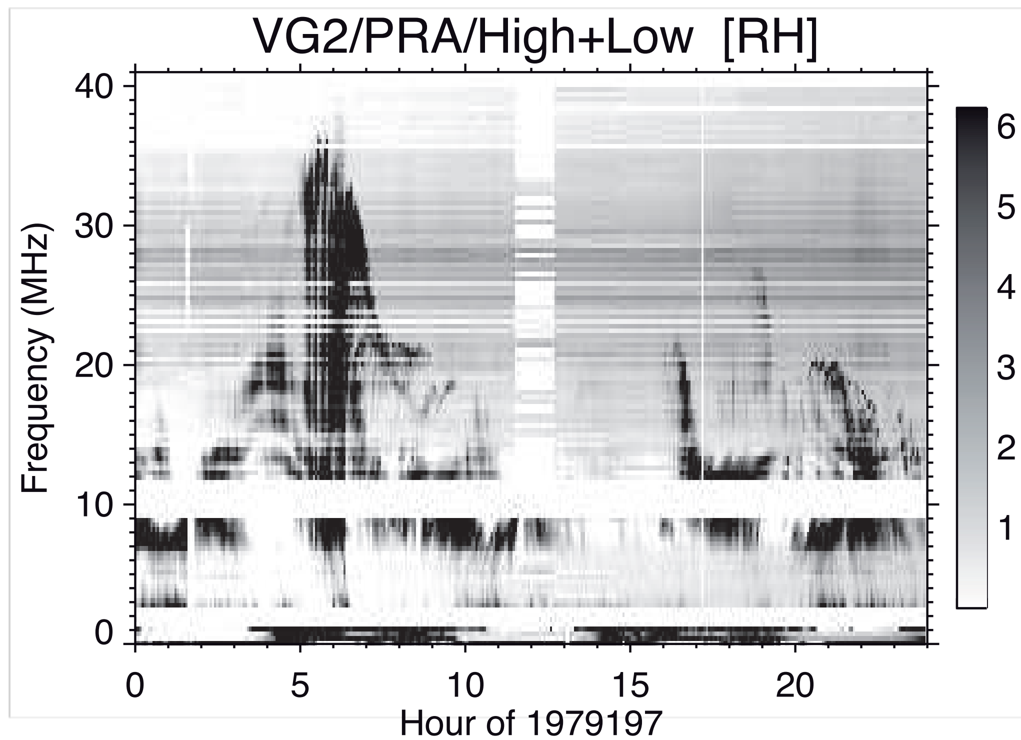
Fig. 7. a) Fast drifting quasi-periodic "fat" S events (FS) with a negative drift rate ∼−30 MHz/s. The rectangular area is zoomed in **b)**. The high resolution image in **b)** reveals superimposed or forking QS bursts (encircled) with their usual drift rate ∼−17 MHz/s and bandwidth ∼10 kHz. Resolution: 1 pixel = 32 kHz × 2 ms **a)**, 8 kHz × 0.5 ms **b)**. Blue and green segments illustrate drift rates.

Mutel et al, 2003 [Earth]

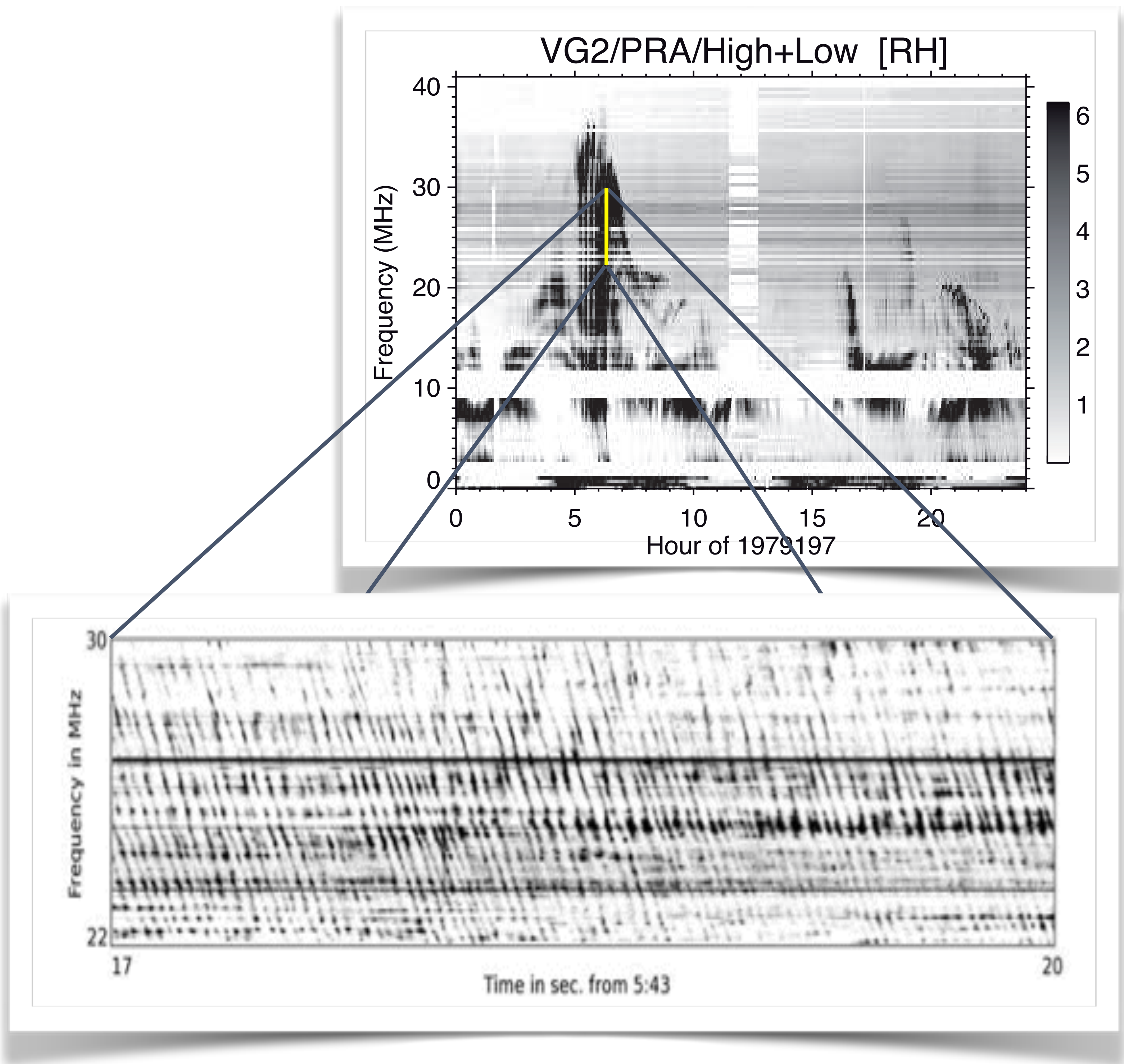
Ryabov et al, 2014 [Jupiter]

Planetary Aurora

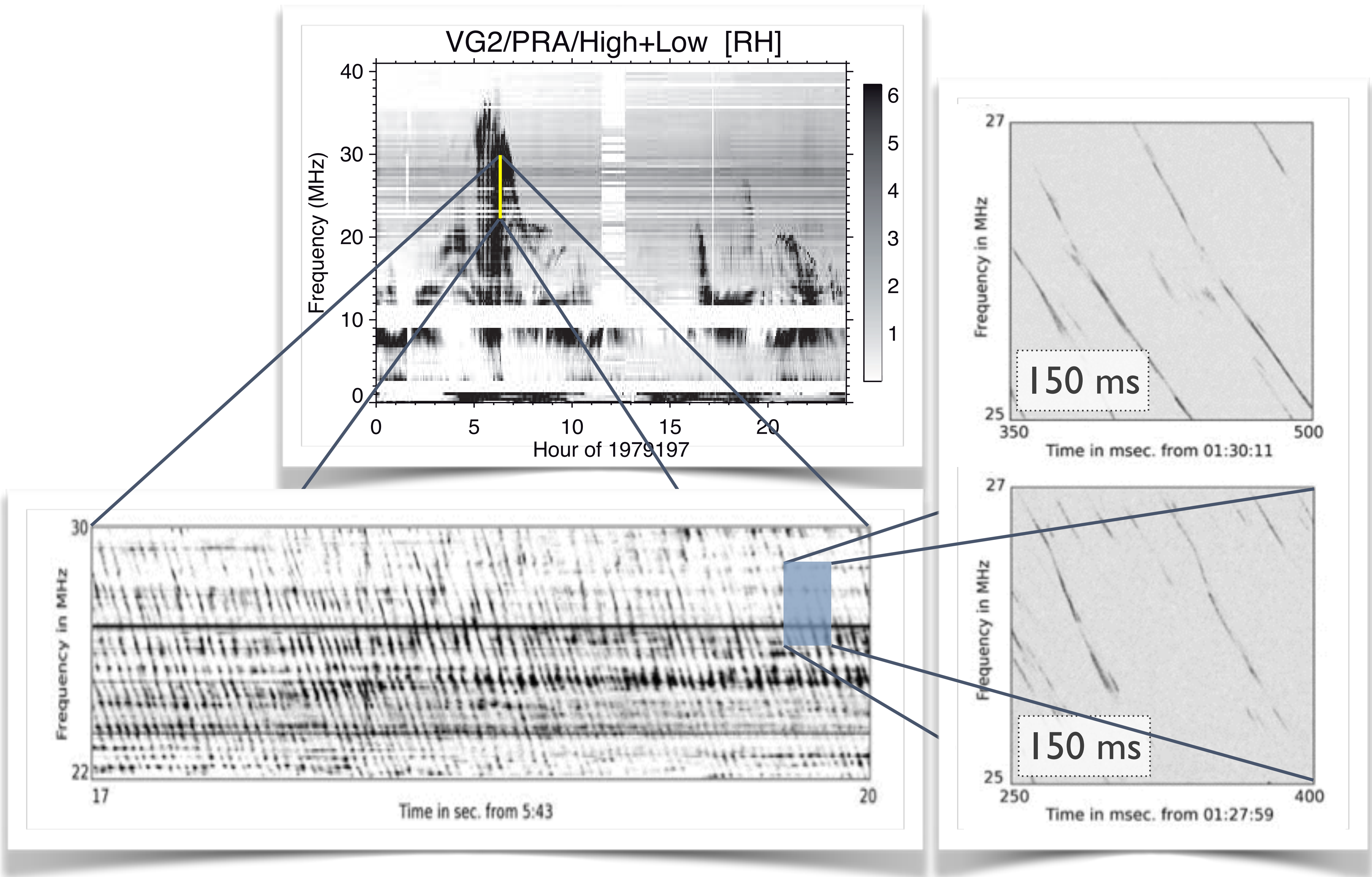
Time scales



Planetary Aurora
Time scales

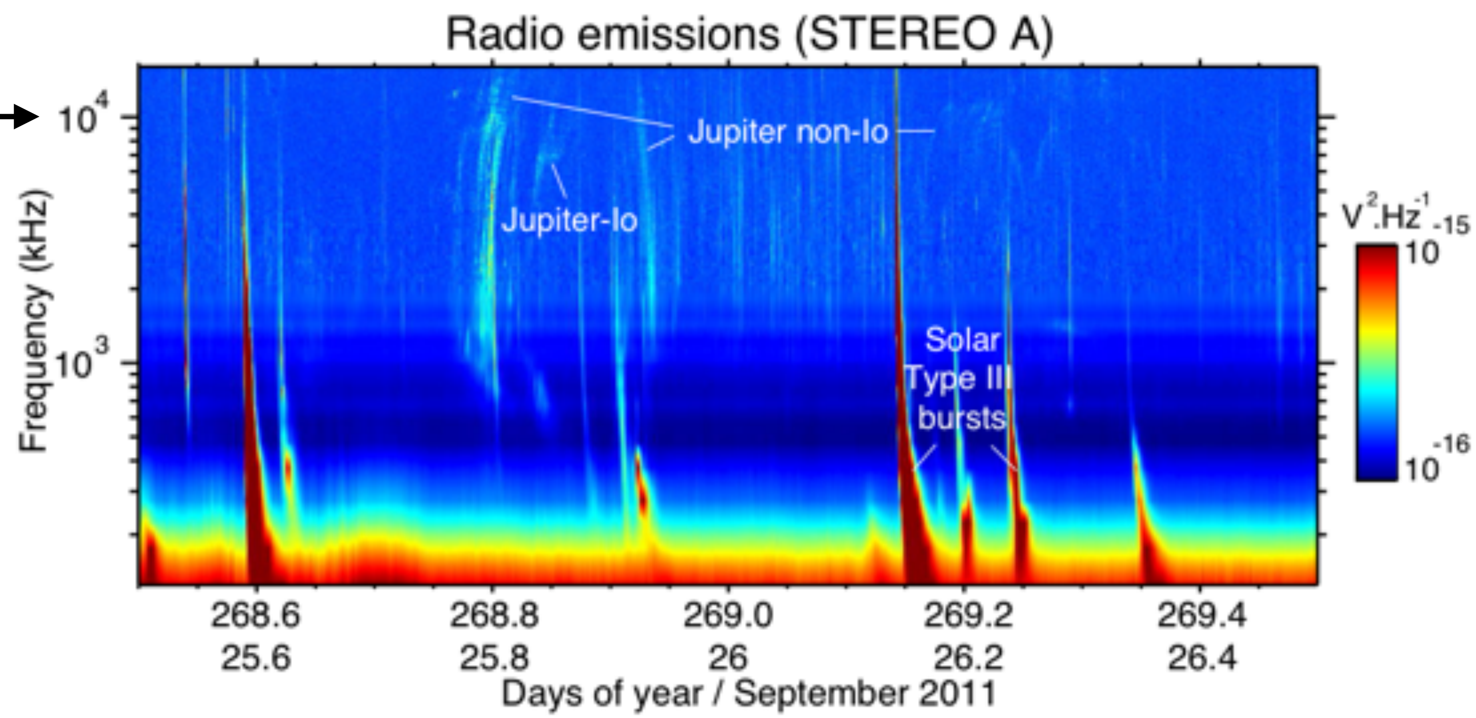


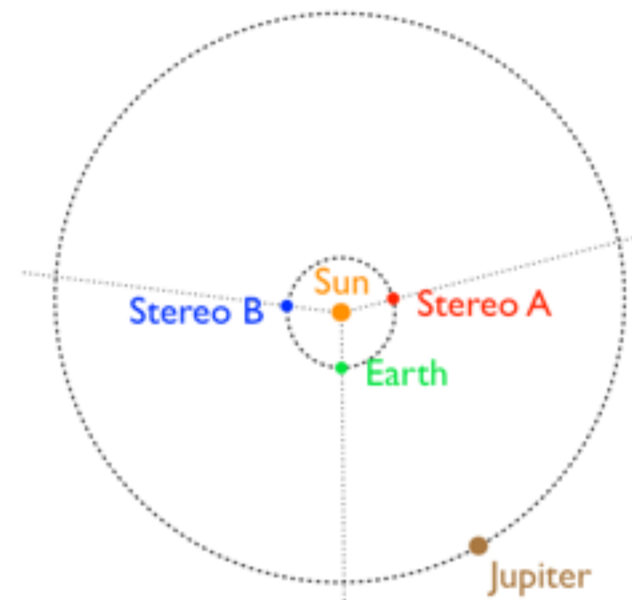
Planetary Aurora
Time scales



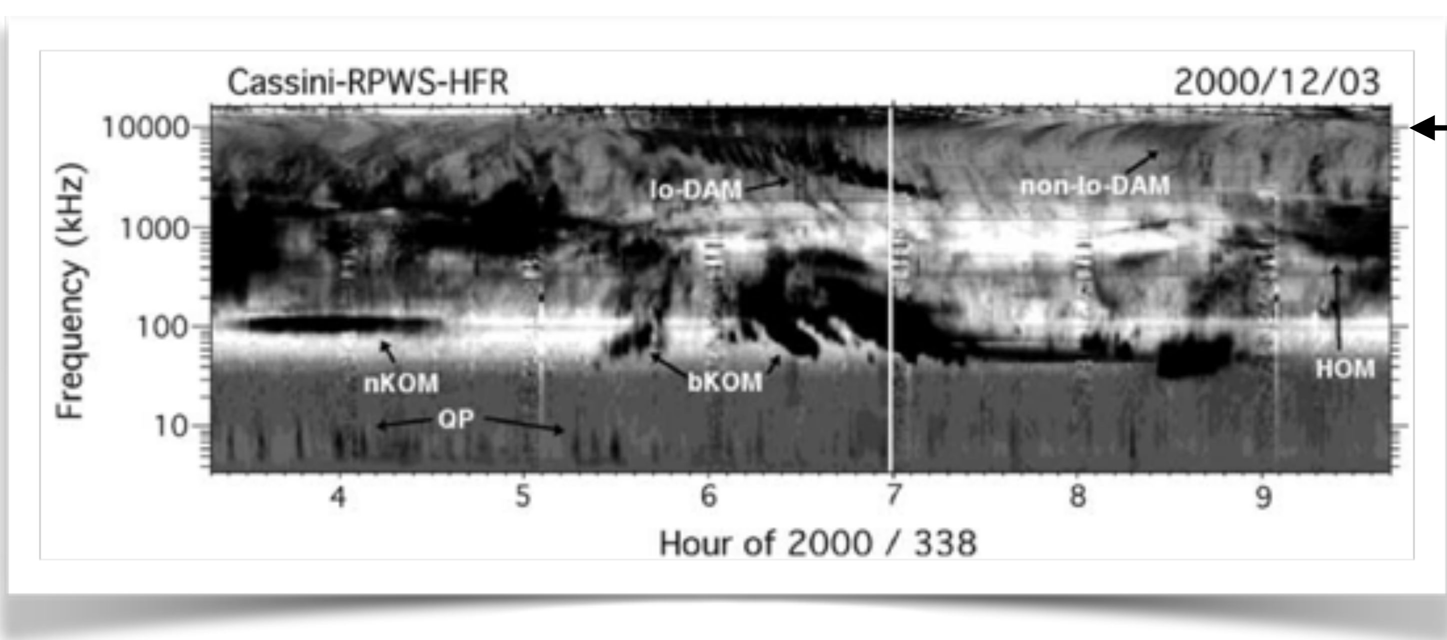
Planetary Aurora

10 MHz





Easy detection of Jovian radio emissions with a single dipole from Earth orbit

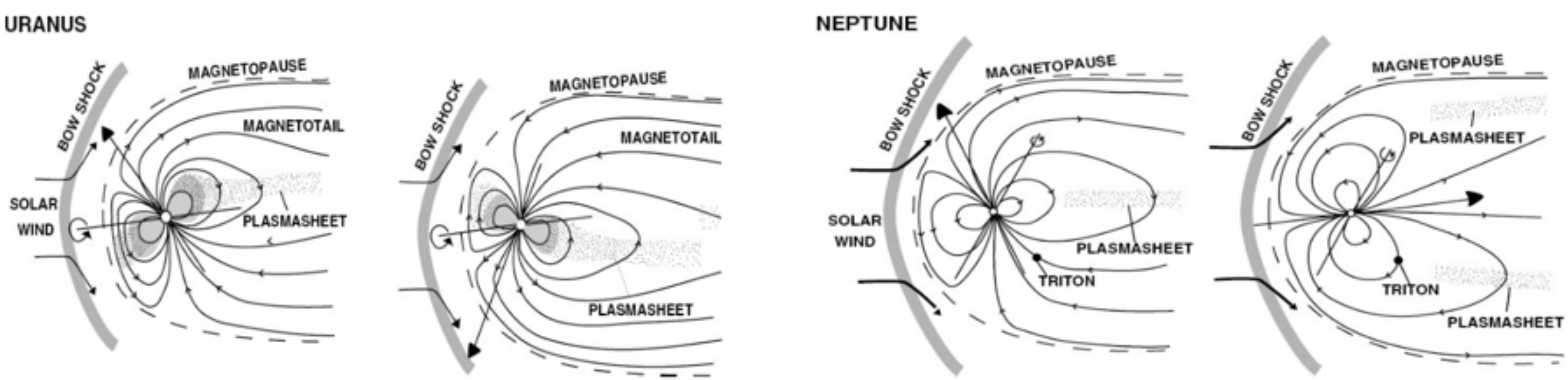


10 MHz

Very sensitive instrument =>
we will always see Jupiter
below 10 MHz !!

Planetary Aurora

Radio emission	C	N (dipoles)	b (kHz)	τ
Jovian radio components	10^1–10^2	1	10	1 s
			100	10 ms
SKR	10^2–10^3	1	100	1–10 s
UKR and NKR	10^4–10^5	1	200–500	10–60 min
		10^1–10^2	100	10 s
SED	10^5	10^2	10^4	300 ms
UED	10^6	10^3	10^4	300 ms
Radio-exoplanet	10^7	100–500	10^3–10^4	10–60 min
		~ 10	2×10^4	1 day



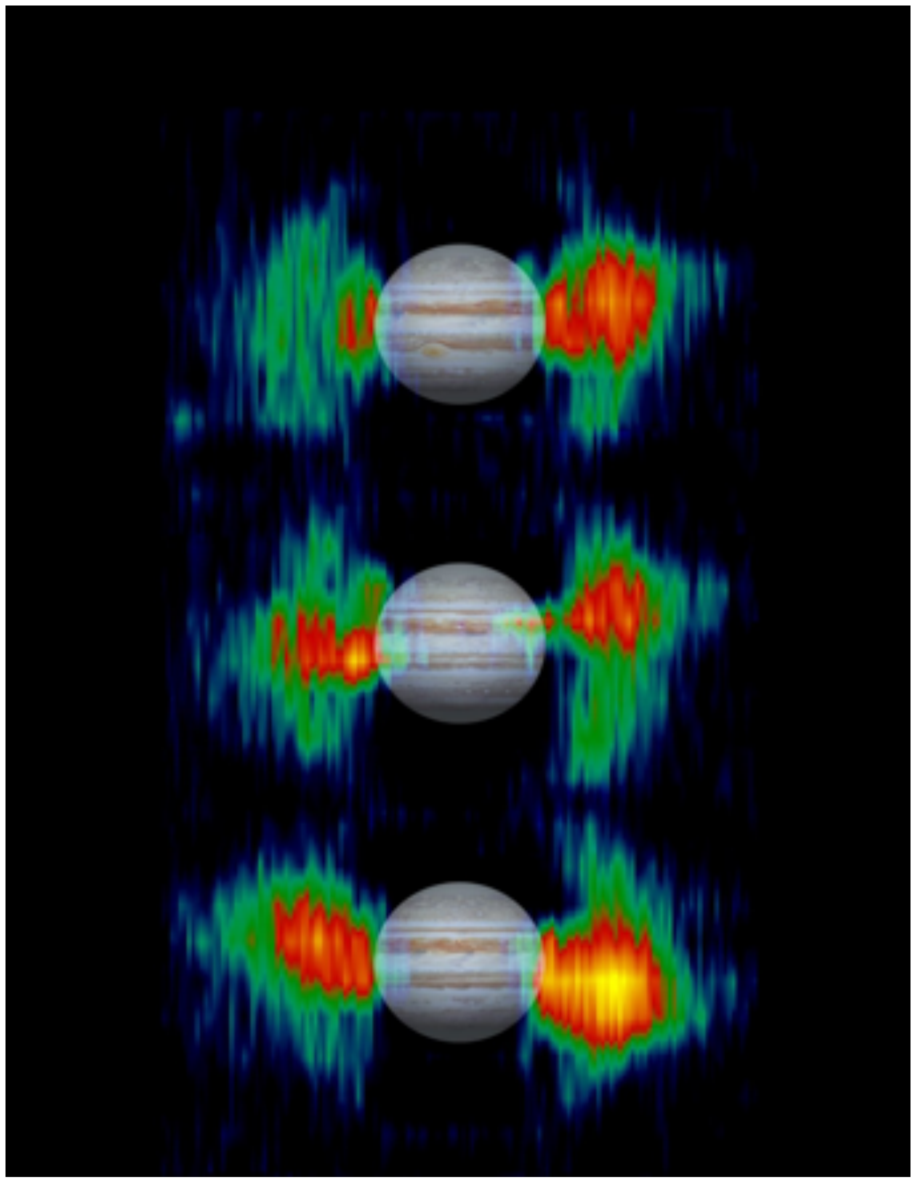
First opportunity in decades to study Uranus and Neptune

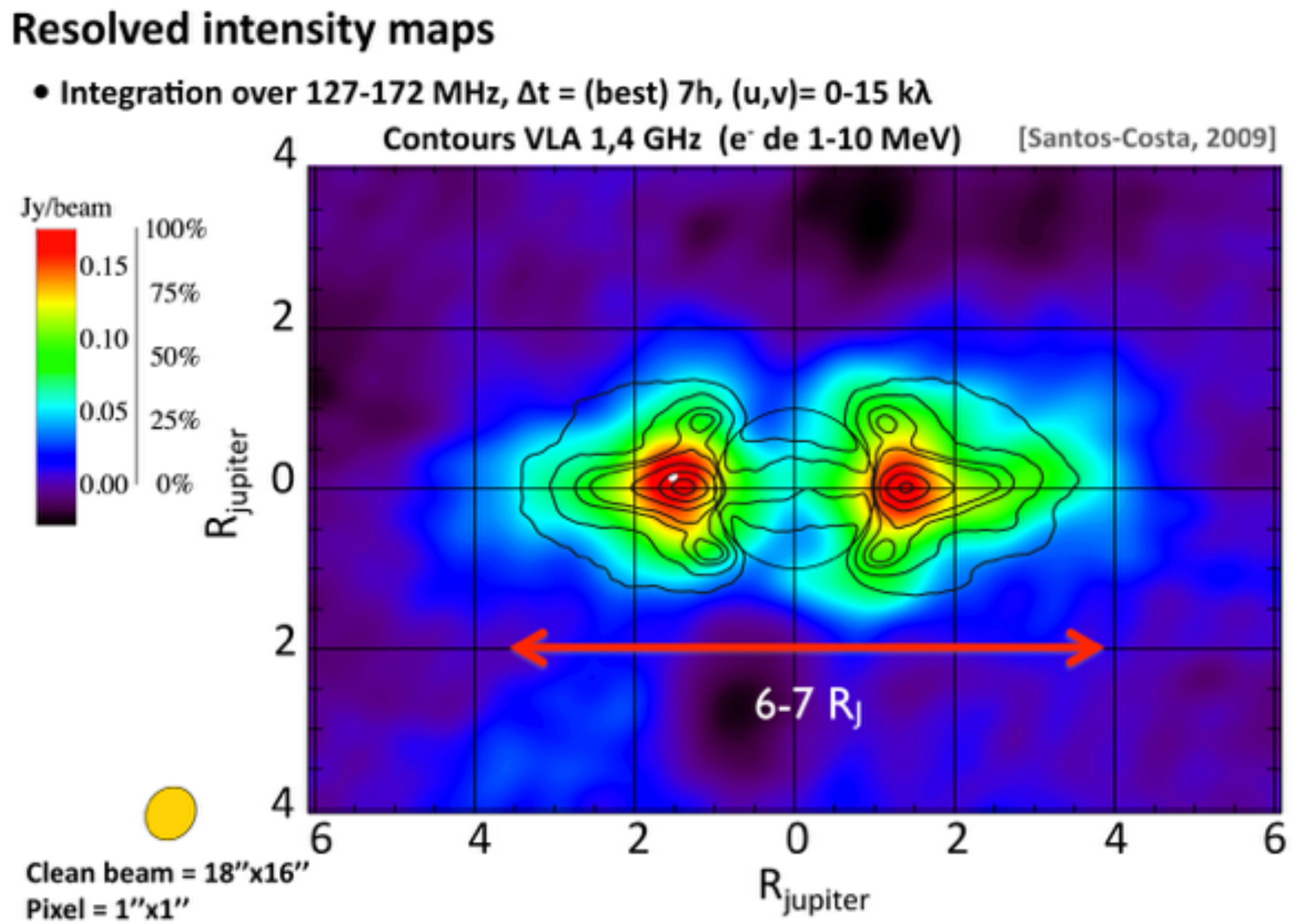
Summary
Planetary Aurora

Planet	Jupiter	Earth, Saturn, Uranus Neptune
Source	Io-Jupiter magnetic flux tube; magnetospheric dynamic; Solar Wind interaction.	magnetospheric dynamic; Solar Wind interaction.
Emission process	Cyclotron Maser Instability	
Time-frequency shape	Arc-shaped (anisotropic source, shape defined by source/observer geometry)	
Frequency Range	a few 10 kHz to 45 MHz	1 kHz to 1 MHz
Duration	a few millisecond for fine structure; a few minutes per bursts; a few hours per episode	
Recurrence	Io rotation period around Jupiter; Jupiter rotation period	Planetary rotation period
Flux Density	10^5 Jy (average) to 10^7 Jy (peak)	Earth =10^7 Jy; Saturn = 10^4 Jy; Uranus, Neptune = ~10^2 Jy
Source size	point source	
System Parameters	Time-Frequency sampling (required for event identification): ~10 kHz / ~10 ms Beam forming/imaging of Jupiter. First observation opportunity since Voyager for Uranus and Neptune	

Planetary Radiation Belts

Girard et al. LOFAR-HBA





Temporal variation
(flux + planetary rocking + movement in sky)

Summary
Planetary Radiation Belts

Planet	Jupiter	Earth
Source	Radiation Belt	Radiation Belt (Van Allen Belt)
Emission process	synchrotron emission	
Time-frequency shape	wide band continuum	
Frequency Range	<30 MHz to >1 GHz	?
Duration	continuum	
Recurrence	planetary rotation	
Flux Density	a few Jy	?
Source size	7x2 R_Jupiter, rocking and moving in sky	?
System Parameters	Time-Frequency sampling (required for event identification): ~10 kHz / ~10 ms Beam forming/imaging of Jupiter	

Planetary Lightnings

Earth

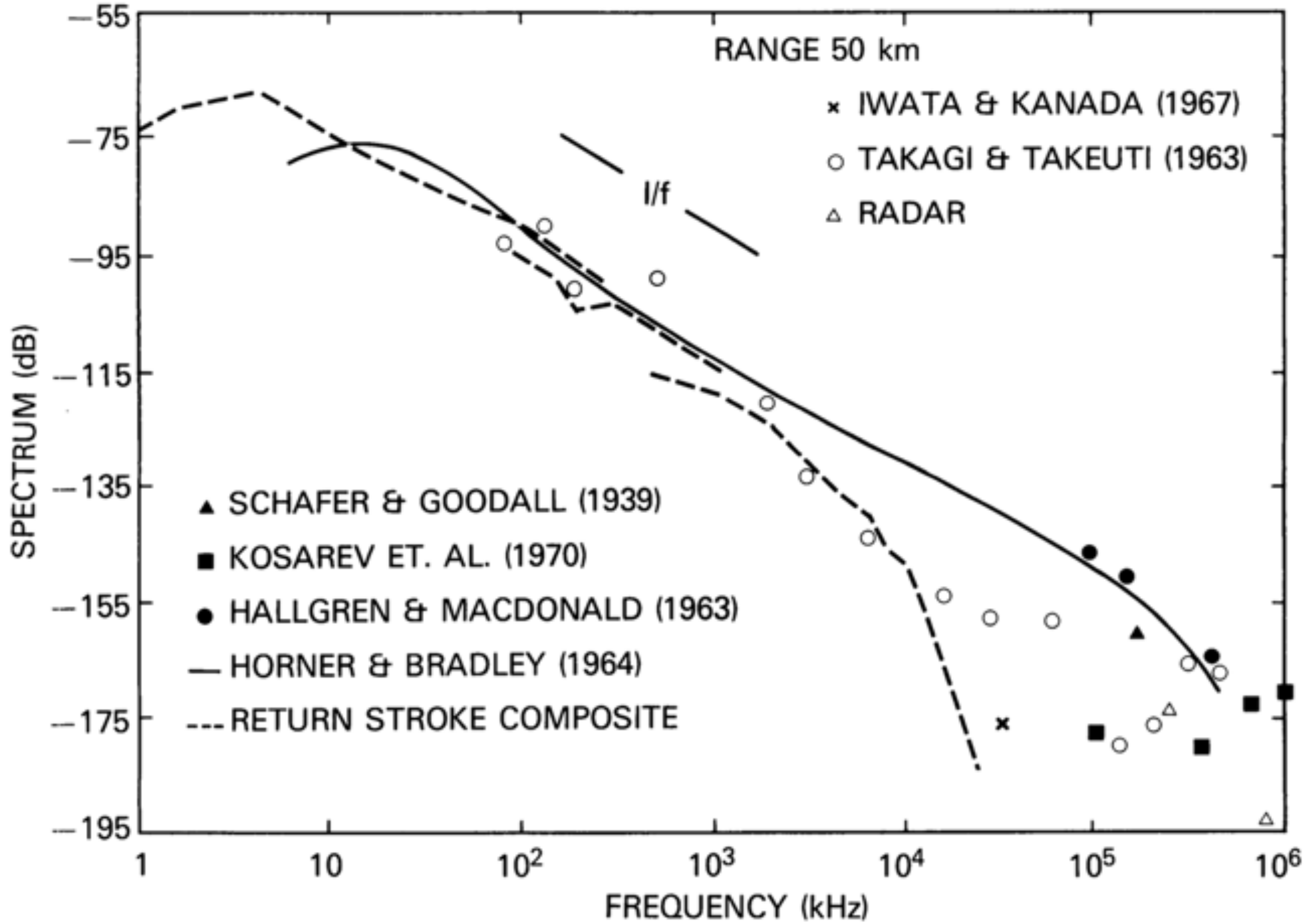


Figure 9. Composite spectrum of radiation from lightning normalized to 50 km. (Figures 3 and 6 combined).

Planetary Lightnings

Saturn

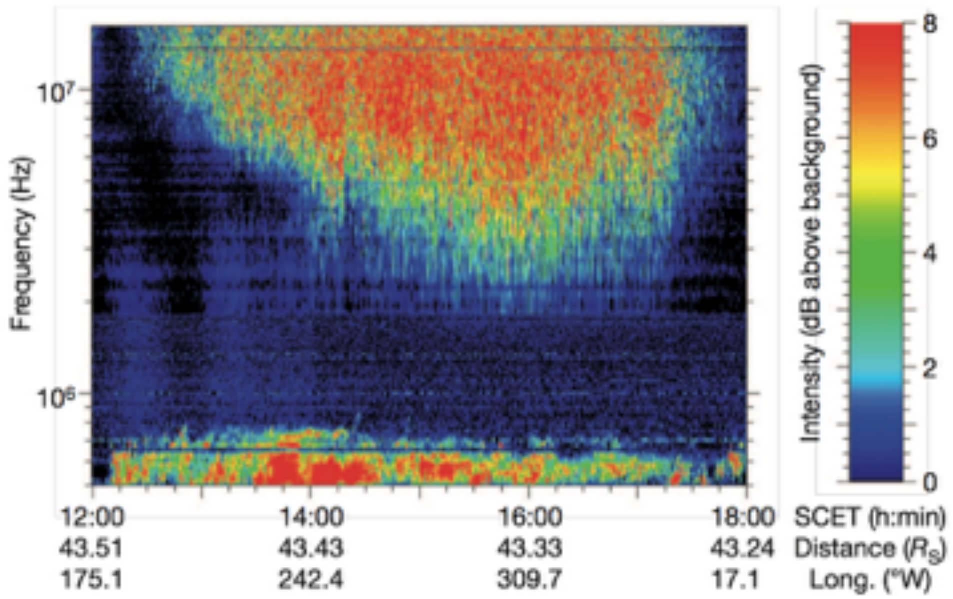


Figure 1 | Time-frequency spectrogram of the SED episode on 12 December 2010. The colour-coded intensity (with 30% background division) of the radio emissions is plotted as a function of spacecraft event time (SCET) over 6 h and frequency from 500 kHz to 16 MHz on a logarithmic scale. Cassini coordinates (distance to Saturn's centre in units of Saturn's radius, R_S, and SLS west longitude in degrees, 'Long.') are indicated on the abscissa. Cassini was in the equatorial plane at a local time of ~18.6 h. The RPWS instrument sweeps in frequency, and it detects the broadband SEDs at whatever frequency (above the ionospheric cut-off) it happens to be tuned to at the time of the flash. This SED episode shows such a high flash rate that the receiver sweep rate of ~28 frequency channels per second (35.2 ms per channel) can no longer resolve the single SEDs. Flash rates of 5–10 SEDs per second can lead to a temporal superposition of SEDs that normally extend over several frequency channels. At the edges of the episode, where the rate is lower, one can see the individual SED bursts. The continuous emission below 800 kHz is Saturn kilometric radiation.

Fischer et al, 2011 [SED@Cassini]

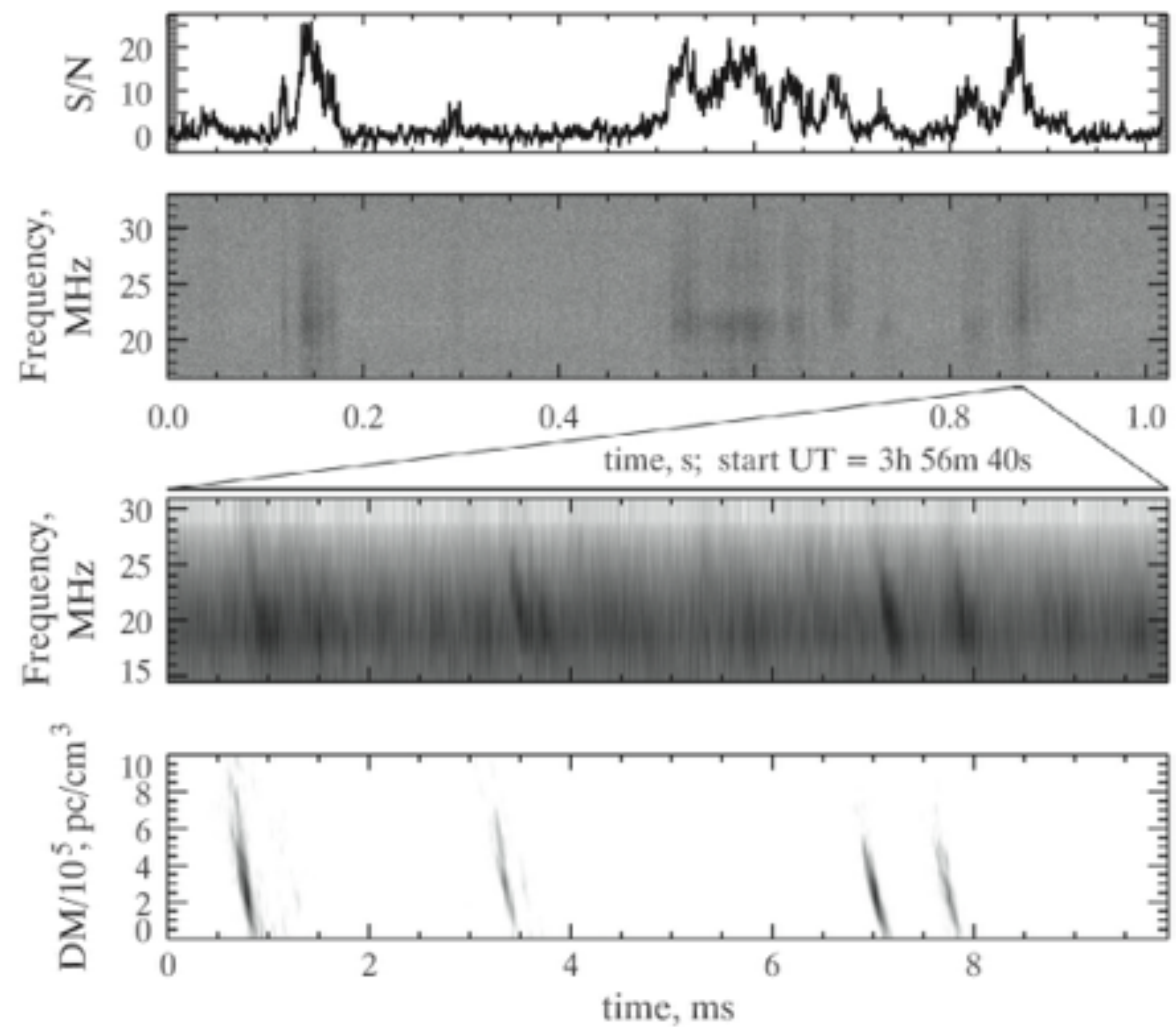


Fig. 12. Relative intensity S/N and dynamic spectra at frequencies 15–33 MHz. Dispersion time delay of the short pulses between 15 and 30 MHz at the level of few tens of microseconds. It corresponds to the dispersion measure of $\approx 2.6 \times 10^{-5}$ pc cm^{-3}. These data are from the UTR-2 SED detection as reported in Zakharenko et al. (2012).

Konovaleko et al, 2013 [SED@UTR-2]

Planetary Lightnings

Radio emission	C	N (dipoles)	b (kHz)	τ
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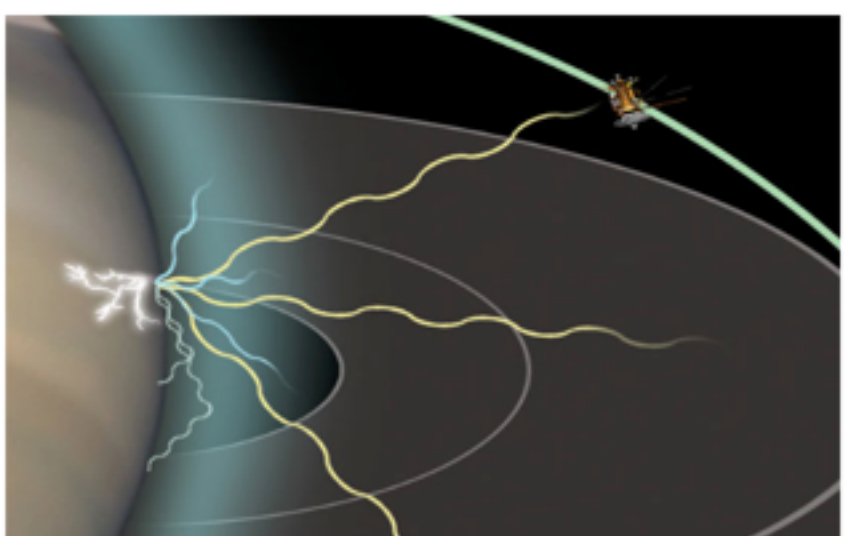

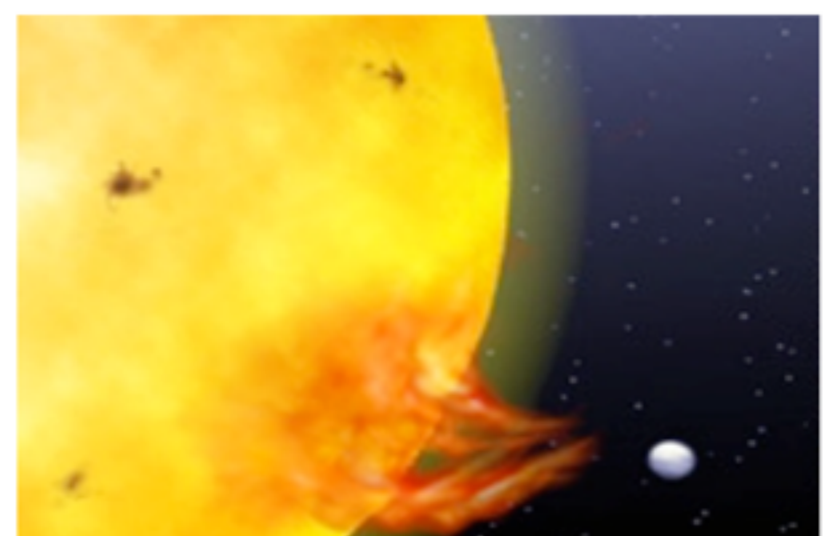

Lightning from Saturn, Uranus, Mars ?

Exoplanets with a large array

Summary
Planetary Lightnings

Planet	Earth	Saturn
Source	Atmospheric lightnings	Atmospheric lightnings
Emission process	Current pulse	Current pulse
Time-frequency shape	impulsion (wide band, short time)	impulsion (wide band, short time)
Frequency Range	up to 100 MHz	1 MHz to > 20 MHz
Duration	a few 10 μs	?
Recurrence	—	—
Flux Density	10^8 to 10^{10} Jy	~100 Jy
Source size	point source	point source

Different kind of transient radio detection in the time domain

<<1ms 1s 10s 1m 10 m H Days Weeks M Y

Variability timescale

Time series $V(t)$

Dynamic spectroscopy $V(f,t)$

Imaging $I_t(x,y)$

Light curves

data mining

Different kind of transient radio detection in the time domain

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Light curves
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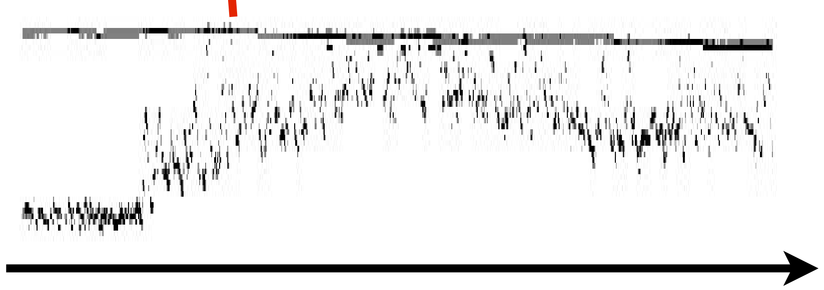

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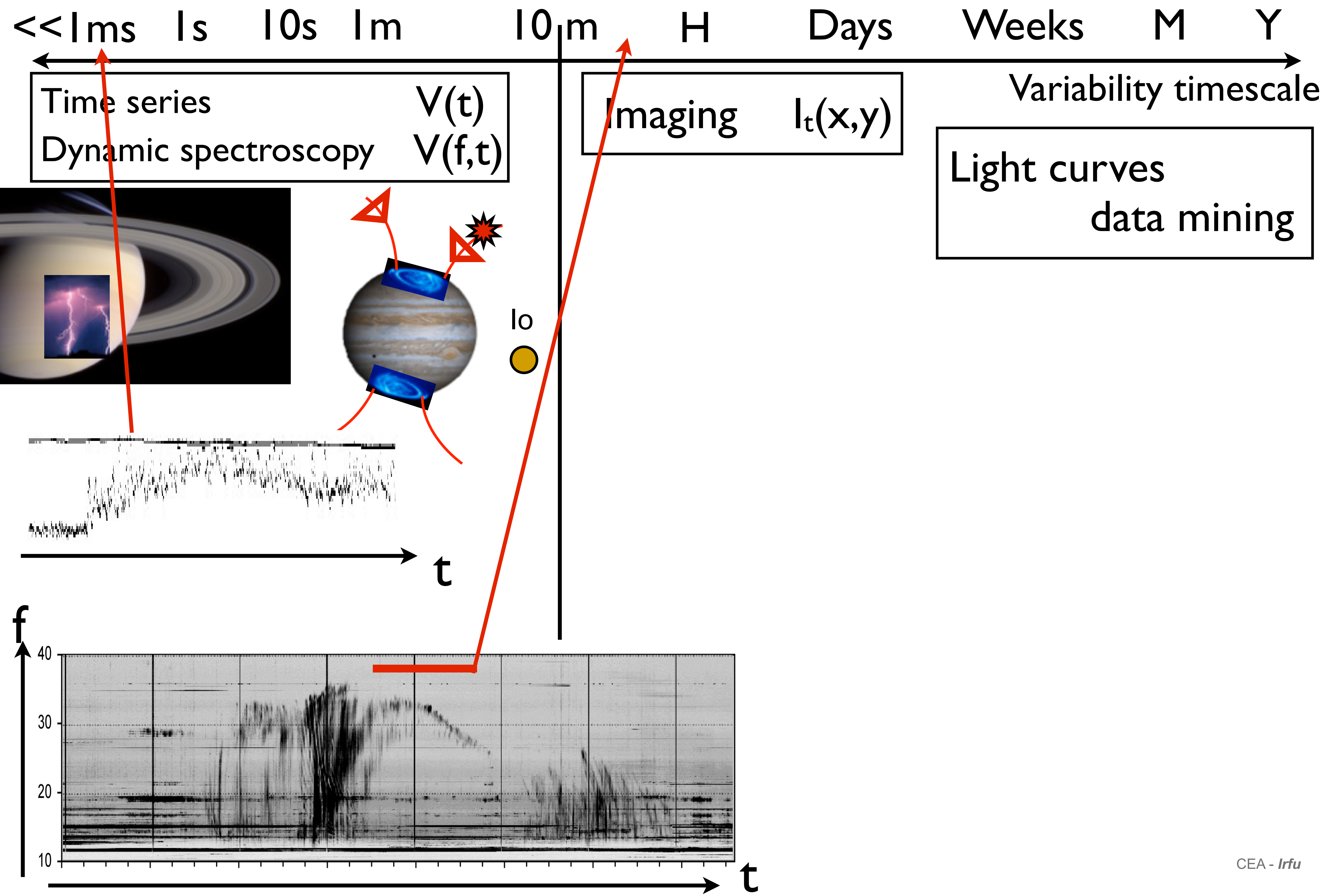
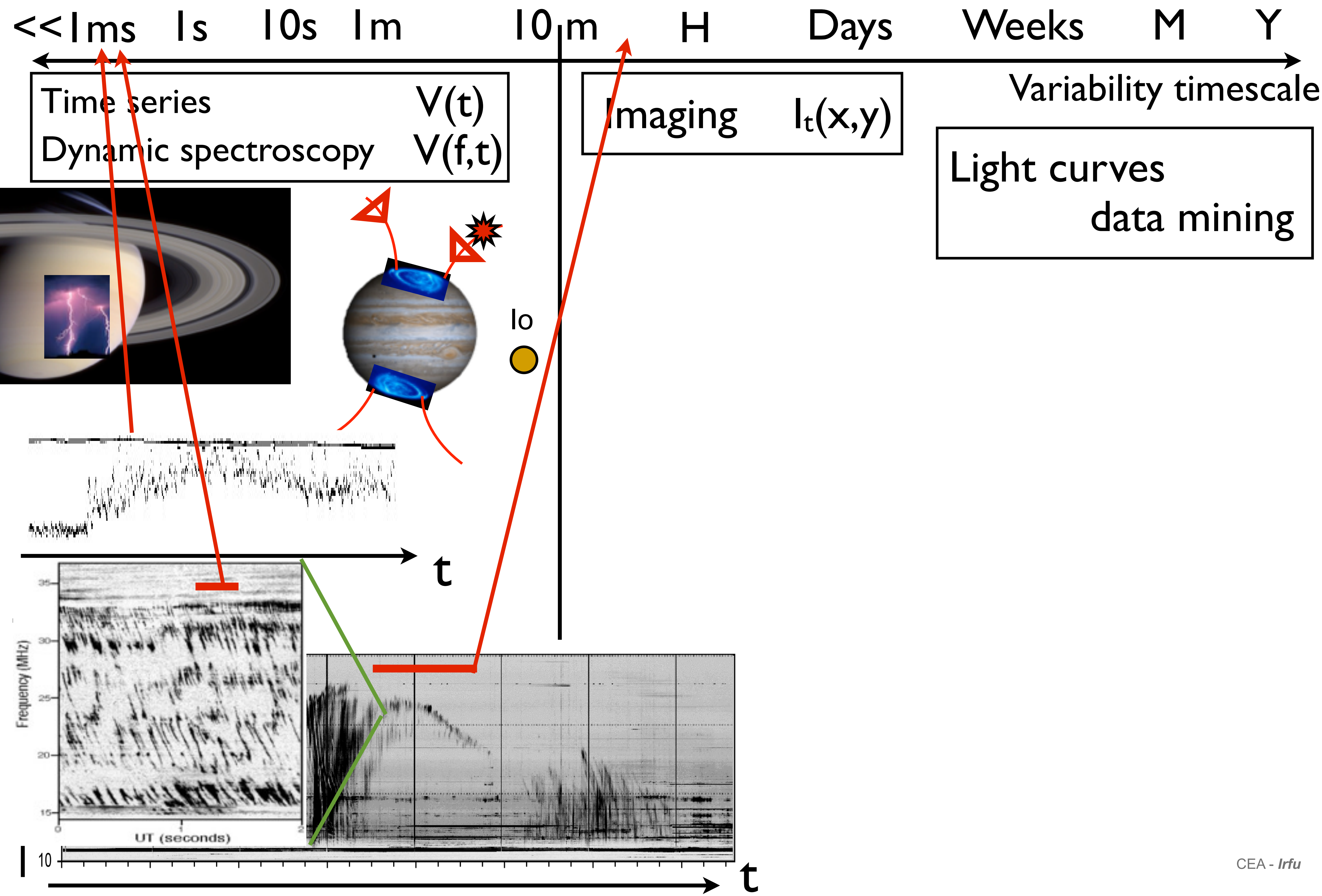
Different kind of transient radio detection in the time domain



Different kind of transient radio detection in the time domain



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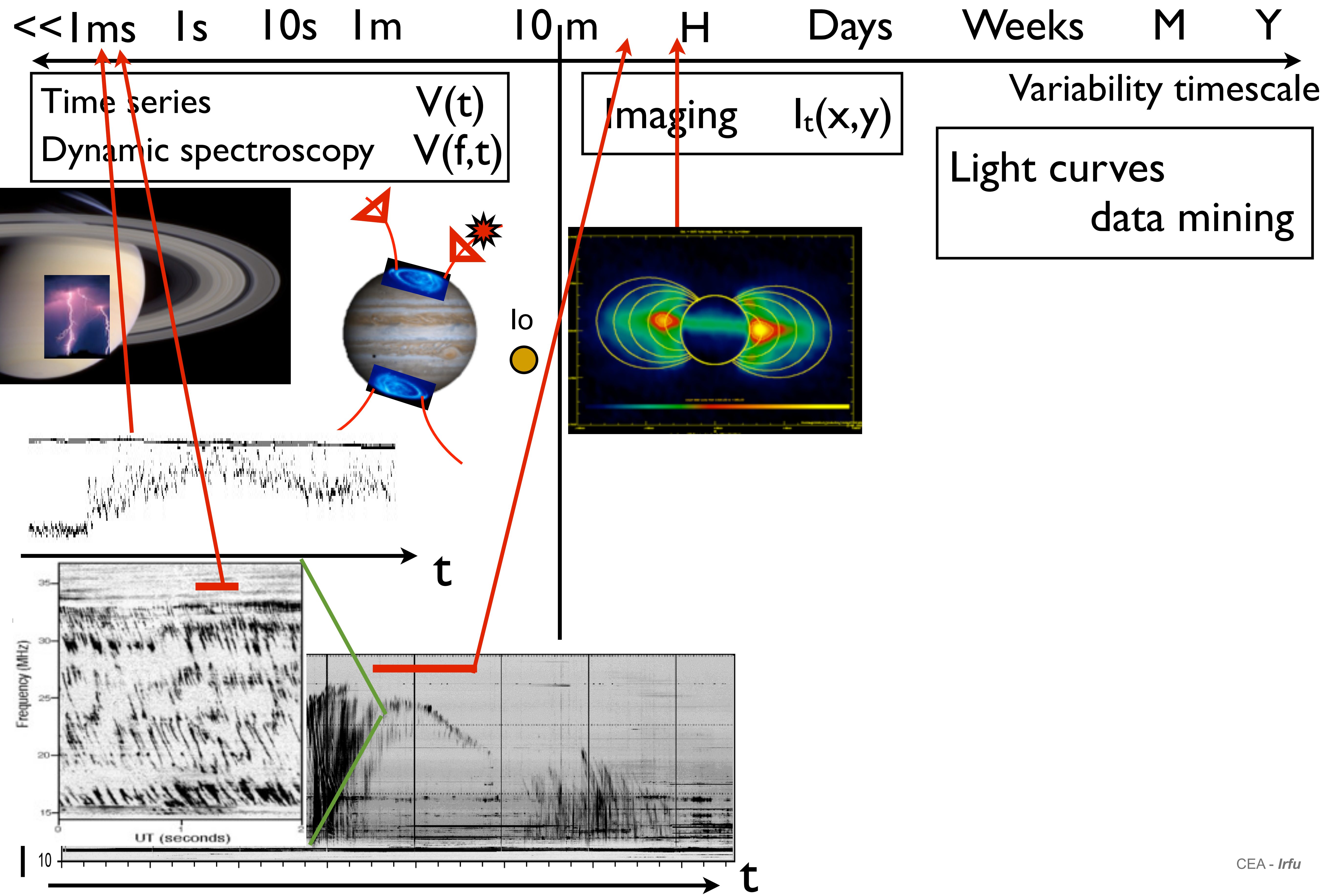

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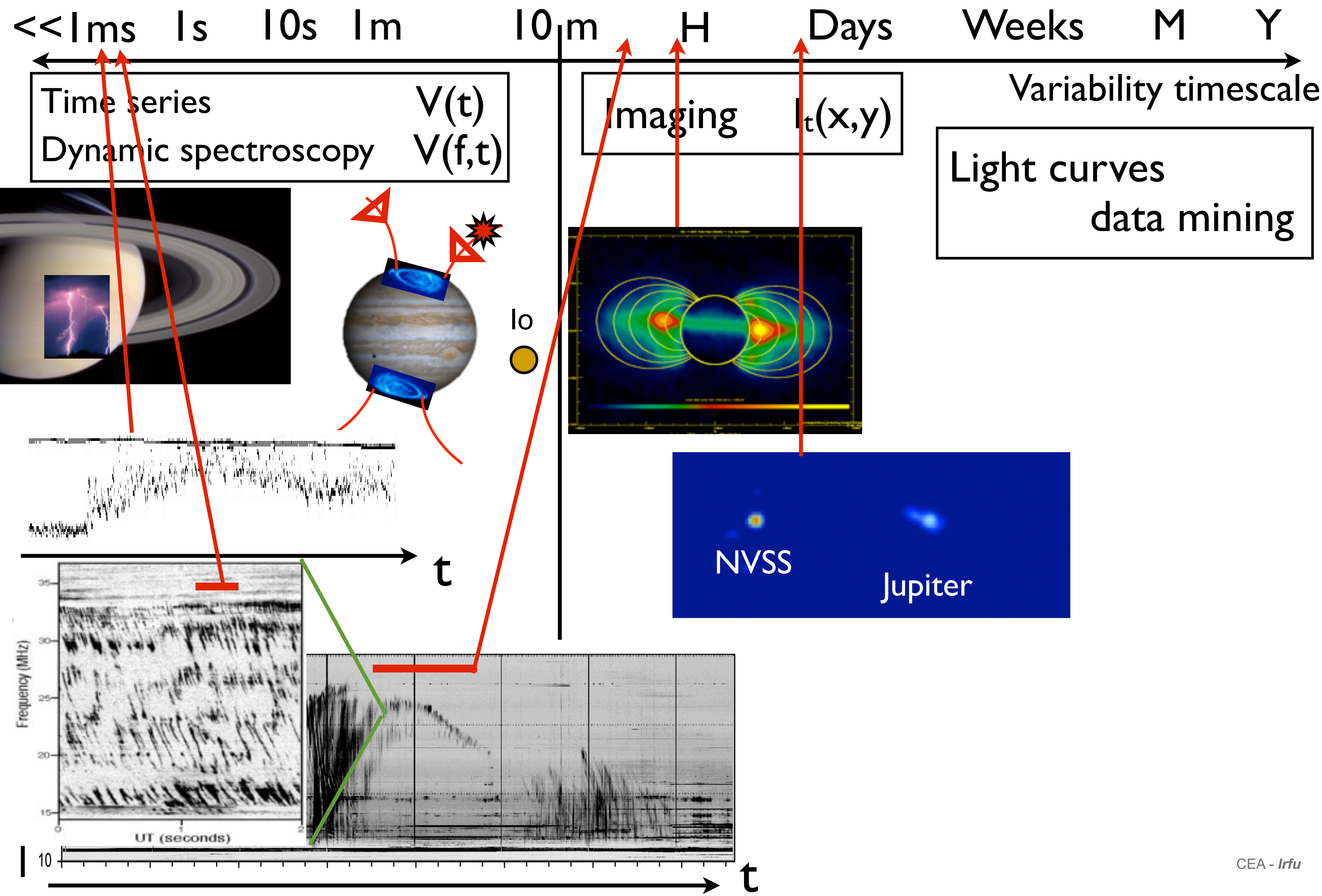

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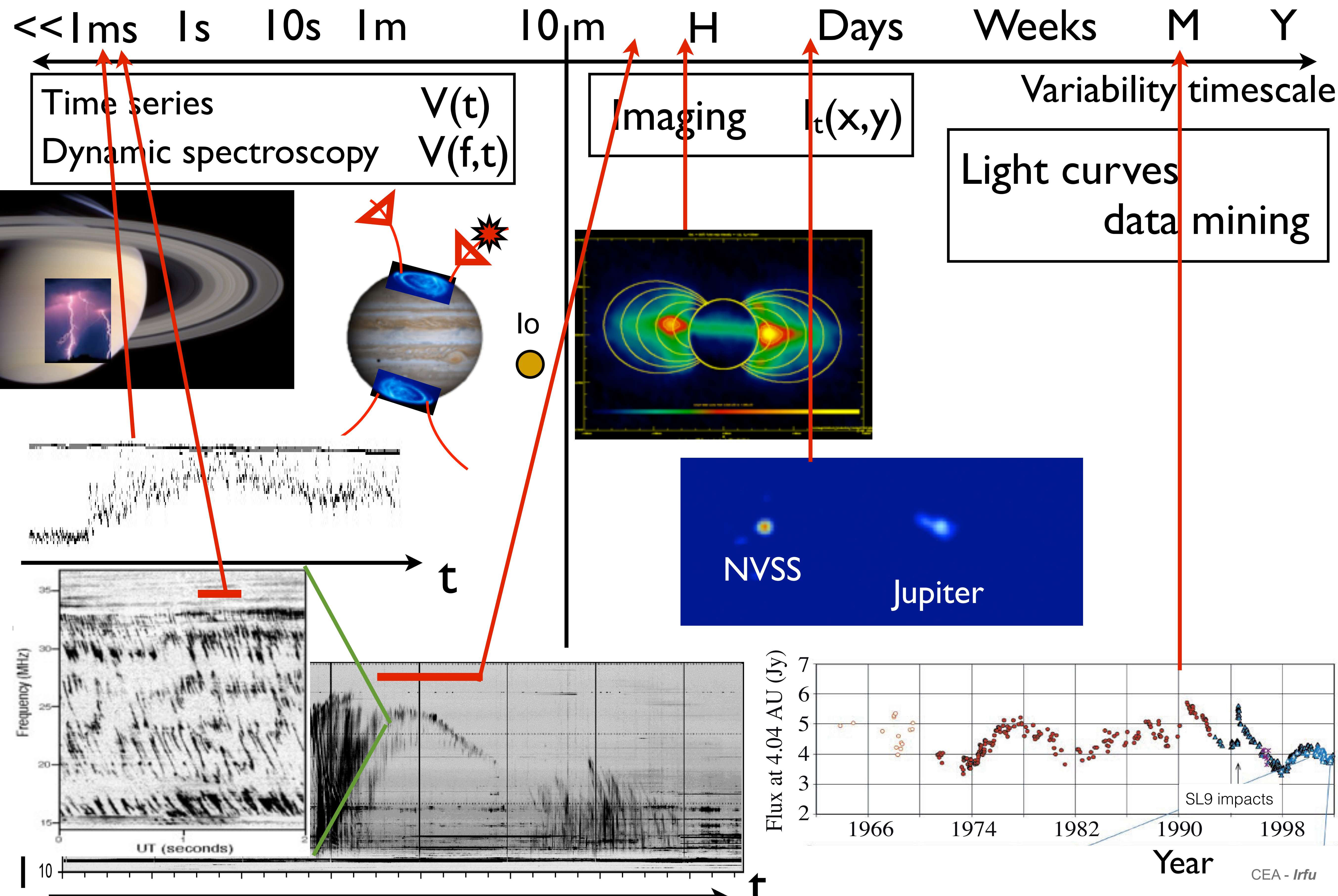
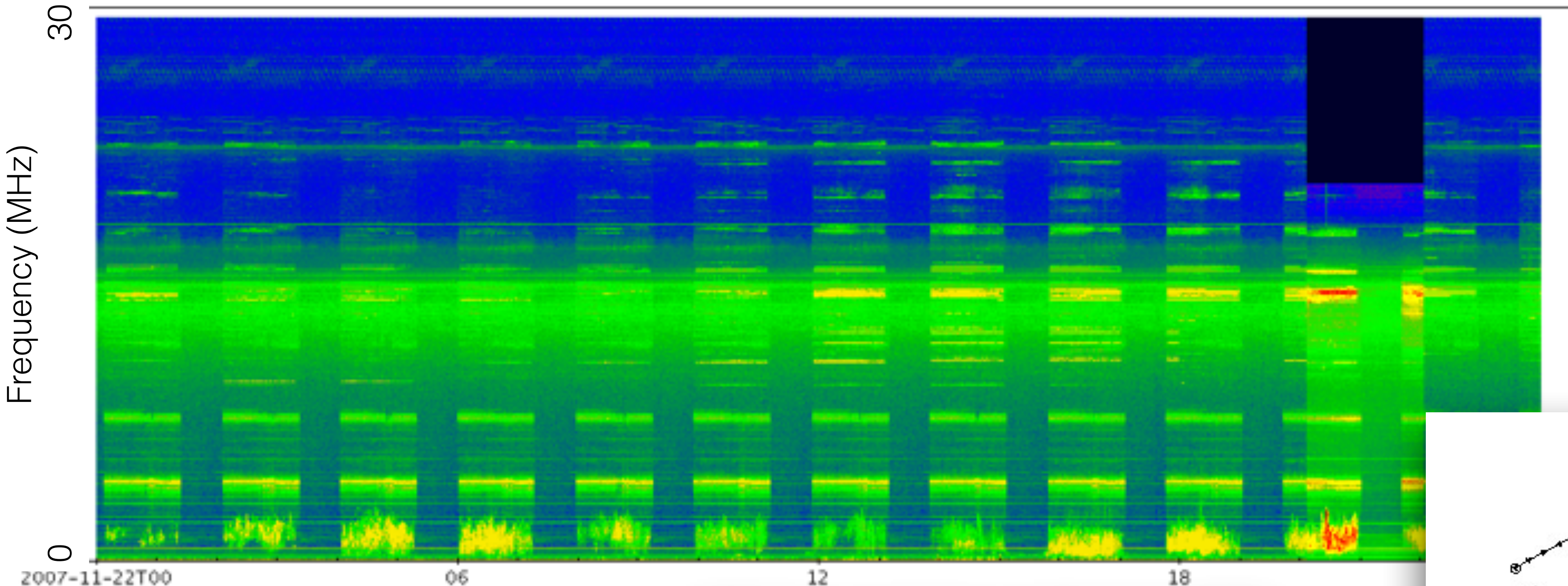


CEA - *Irfu*

Technology RFI

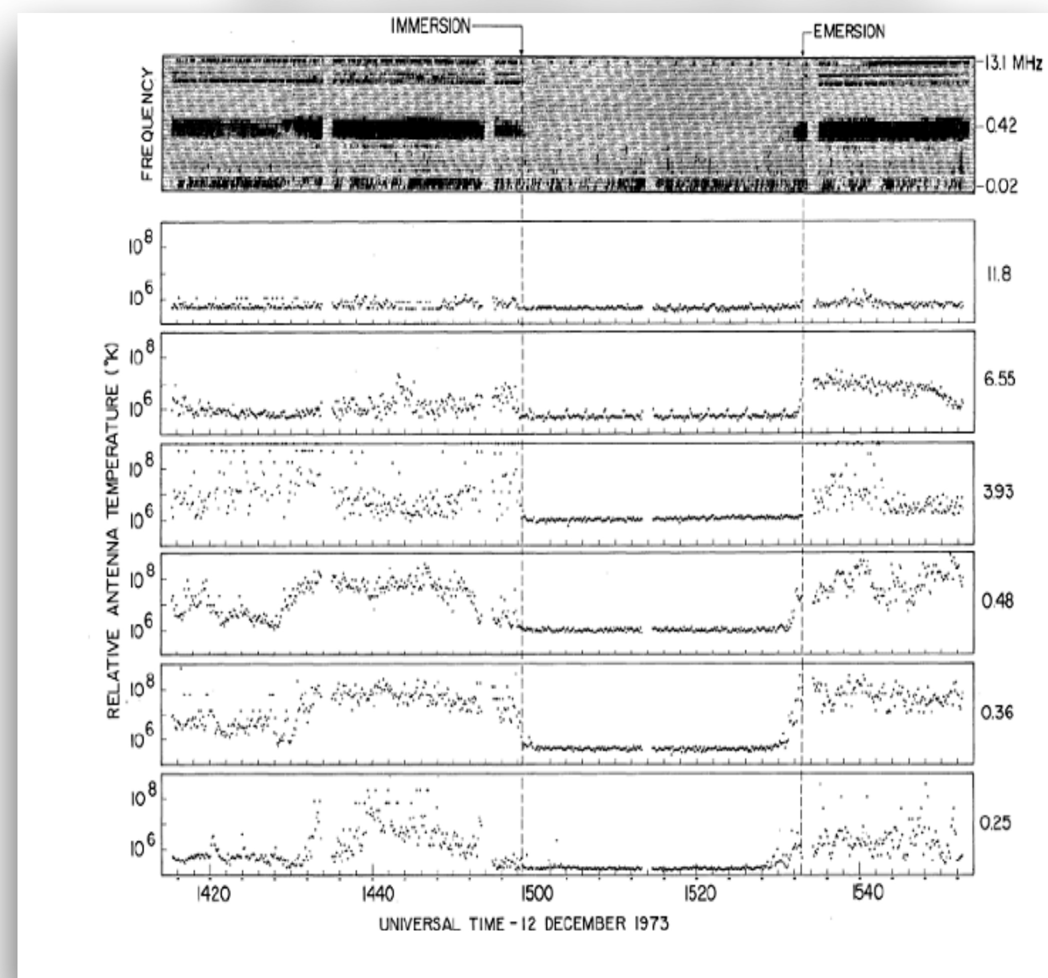


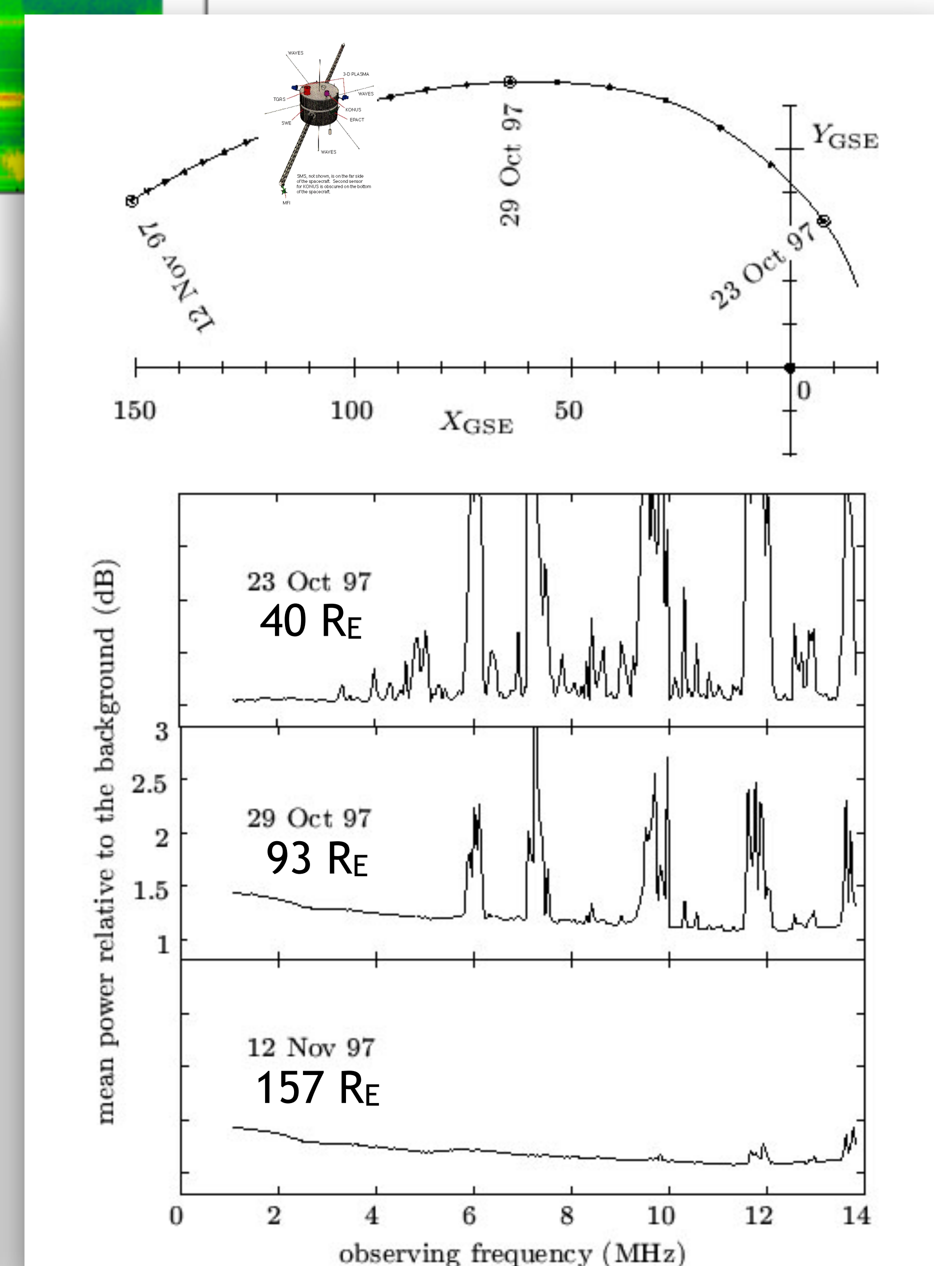
SELENE Mission (Japan)
LRS: RF receiver
data acquired in 2007

Human RFI
The near-Earth environment is dominated by the "radio-smog", which is a combination of natural radio emissions of the Earth's magnetosphere (AKR) and atmosphere (lightnings), together with the man-made radio frequency interferences (RFI). The only quiet place near Ether is the far side of the Moon.

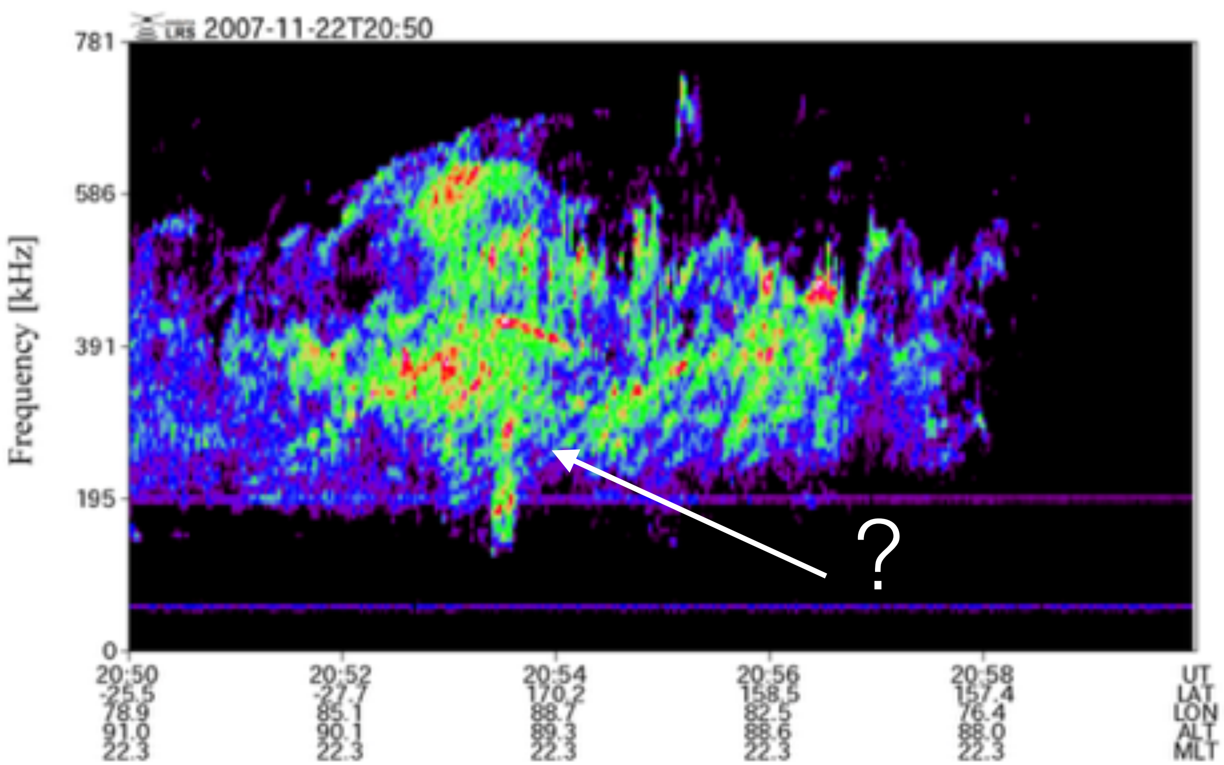
S/C induced RFI
All subsystem are producing RFI. EMC (electromagnetic cleanliness) is a key driver for system design !

RAE-2 occultation of Earth (1973)



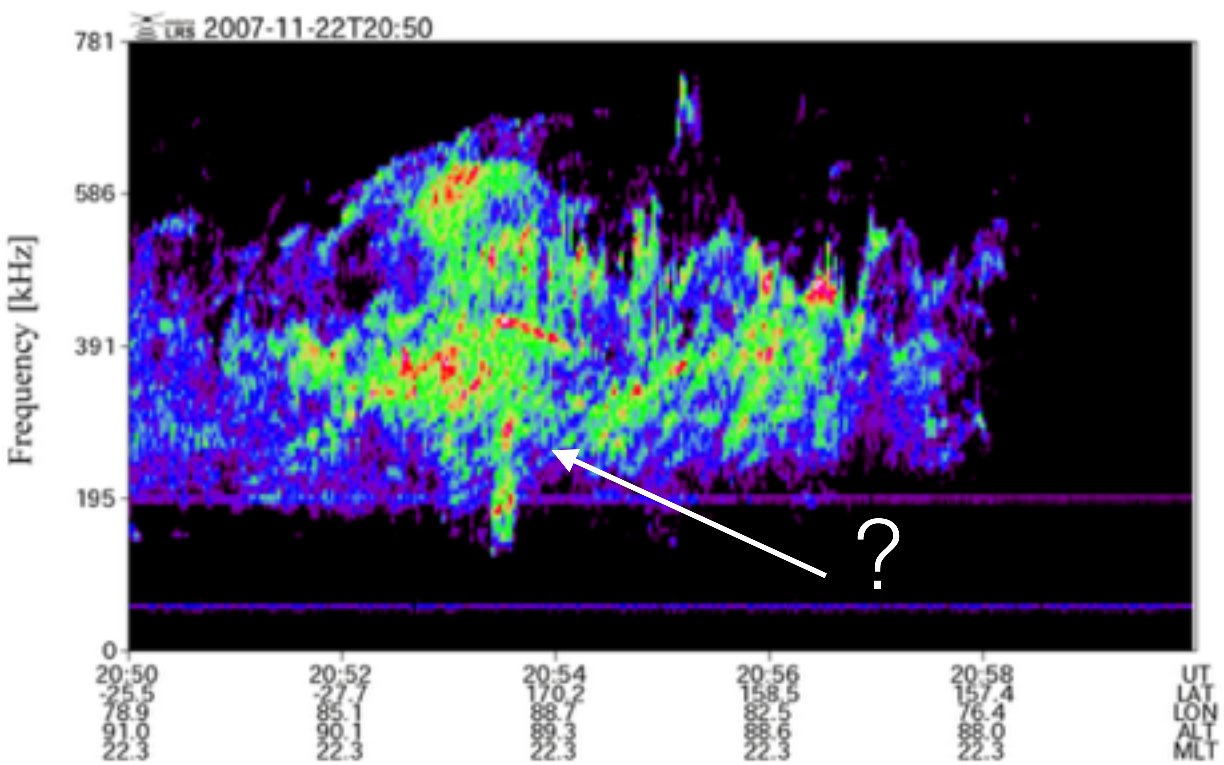


Lunar Surface effect

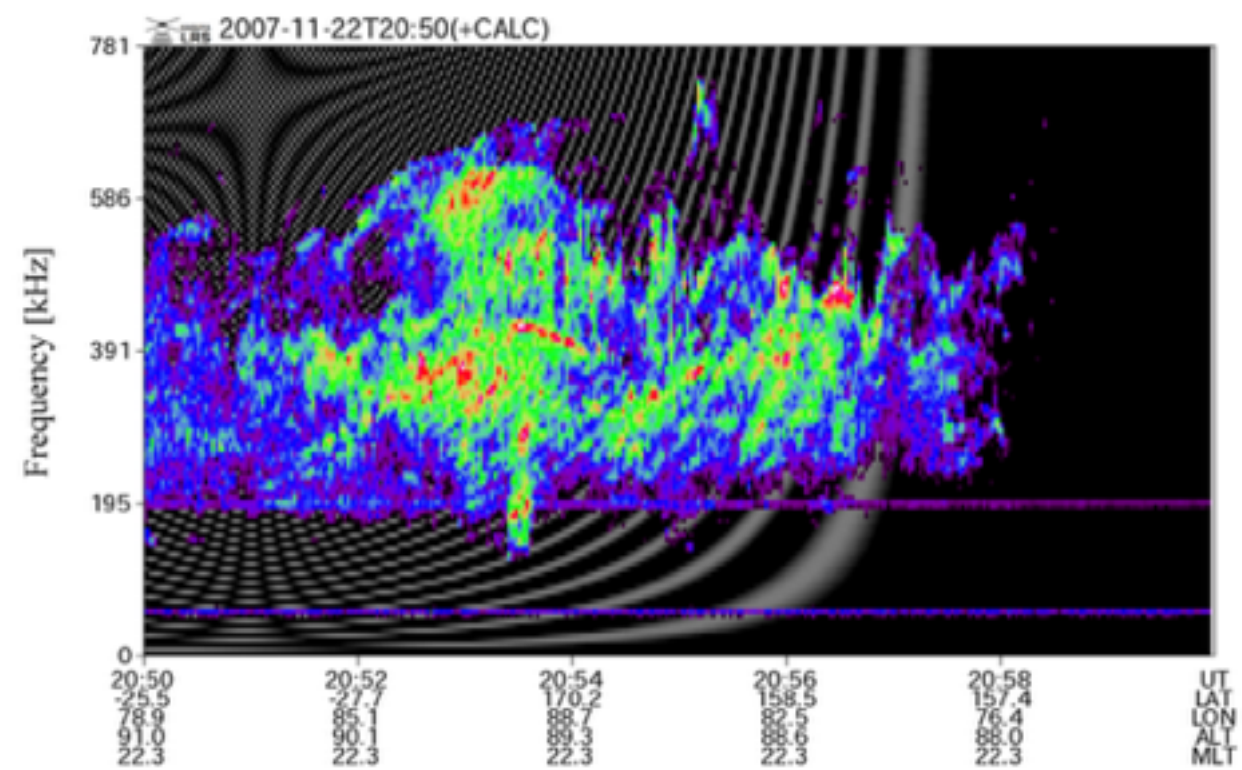


LRS/SELENE observations of AKR
Observations close to surface.
Interference pattern ?

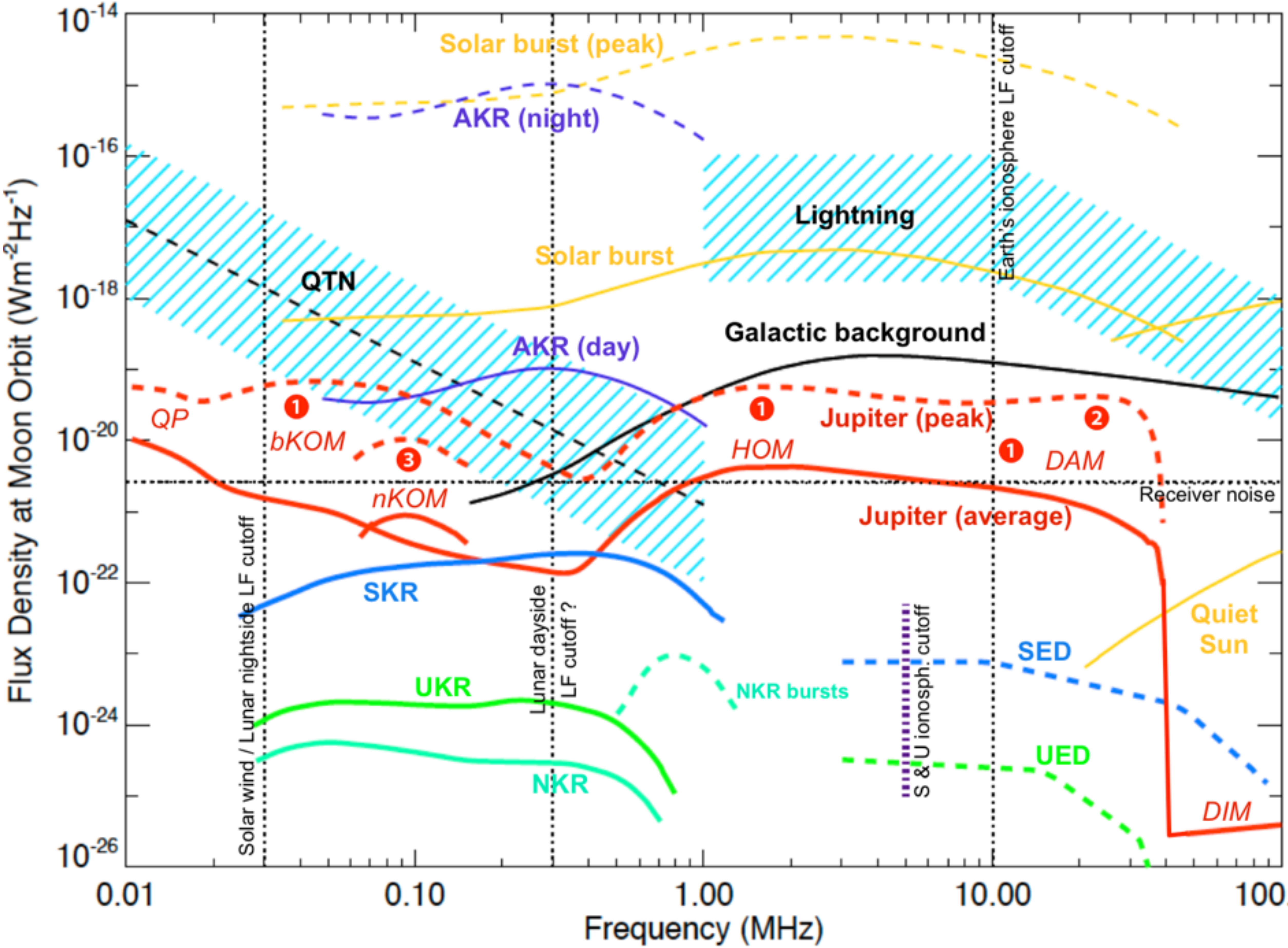
Lunar Surface effect



LRS/SELENE observations of AKR
Observations close to surface.
Interference pattern ?



LRS/SELENE observations of AKR
theoretical interference pattern superimposed for reflexion on lunar surface.



Solar burst (peak)
AKR (night)
Lightning
Solar burst
QTN
Galactic background
AKR (day)
Earth's ionosphere LF cutoff
QP
bKOM
Jupiter (peak)
HOM
DAM
nKOM
Receiver noise
Jupiter (average)
SKR
Quiet Sun
SED
UKR
NKR bursts
UED
NKR
DIM
Solar wind / Lunar nightside LF cutoff
Lunar dayside LF cutoff ?
S & U ionosph. cutoff
Flux Density at Moon Orbit (Wm⁻²Hz⁻¹)
Frequency (MHz)