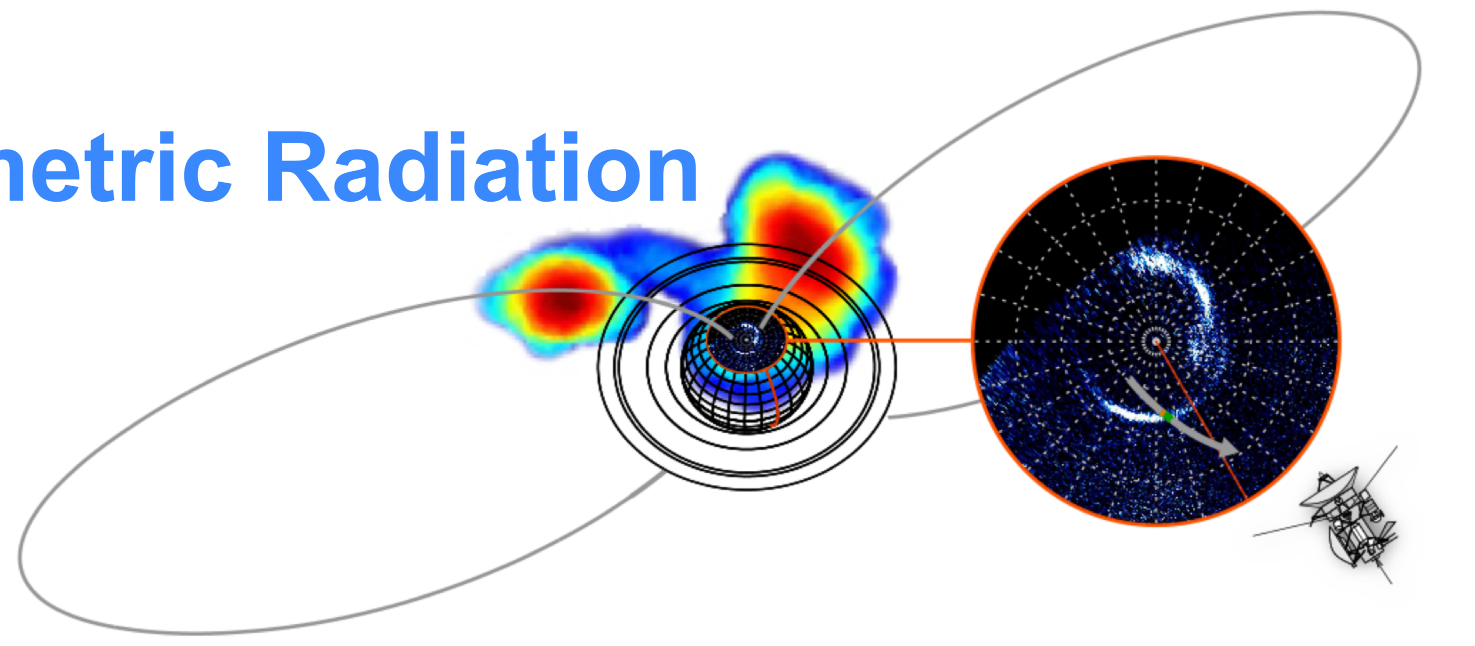
The peak frequency source of Saturn's Kilometric Radiation



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ABSTRACT

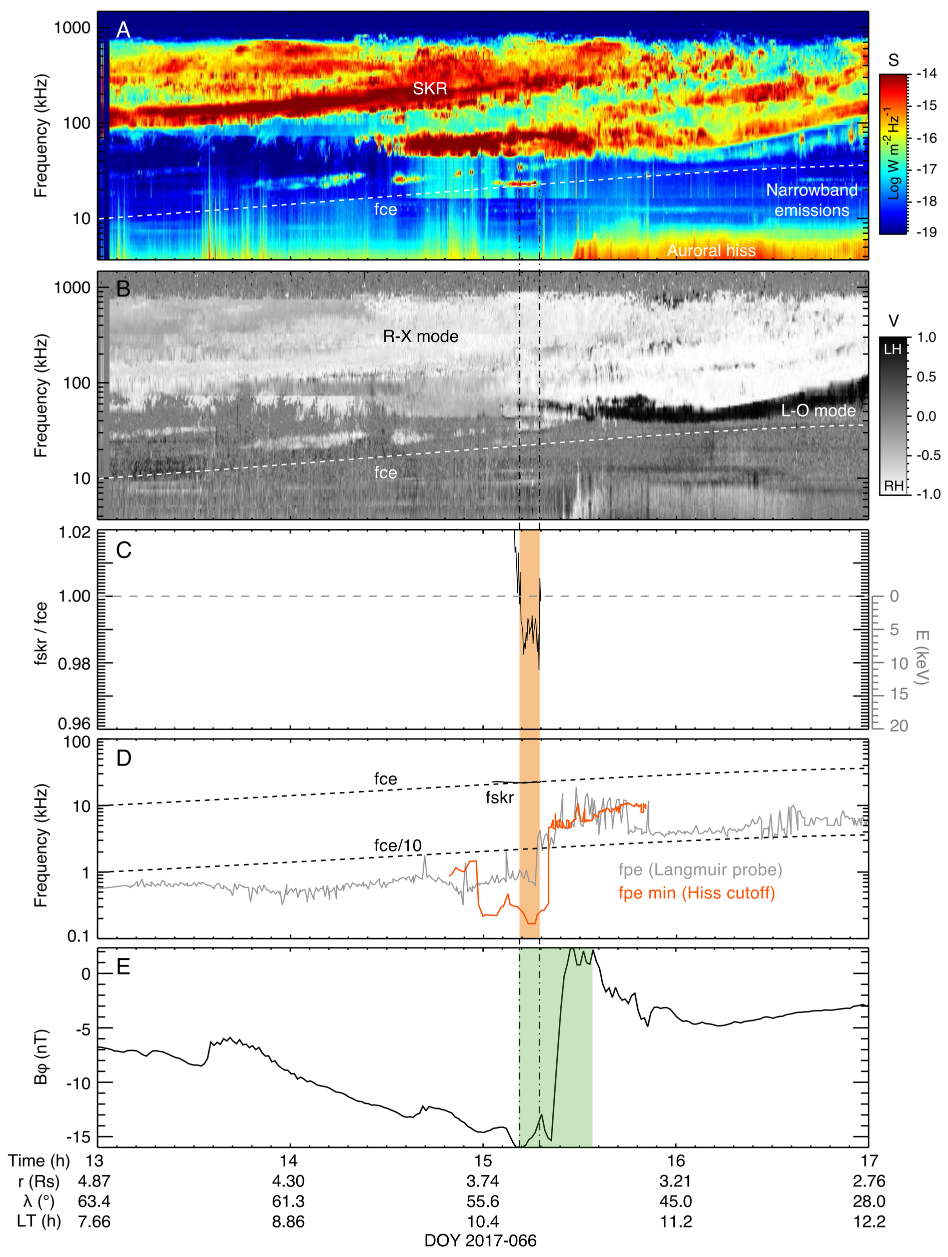
Before to ultimately plunge into Saturn's atmosphere, the Cassini spacecraft explored between 2016 and 2017 the auroral regions of Saturn's magnetosphere, where rises the Saturn's Kilometric Radiation (SKR). This powerful, nonthermal, radio emission analog to Earth's Auroral Kilometric Radiation, is radiated through the Cyclotron Maser Instability (CMI) by mildly relativistic electrons at frequencies close to the local electron gyrofrequency. The typical SKR spectrum, which ranges from a few kHz to ~1MHz, thus corresponds to auroral magnetic flux tubes populated by radiosources at altitudes ranging from ~4 kronian radii (R_S) down to the planetary ionosphere. During the F-ring orbital sequence, Cassini probed the outer part of both northern and southern auroral regions, ranging from ~2.5 to ~4 R_S altitudes, and crossed several SKR low frequency sources (~10-30 kHz). Their analysis showed that the radiosources strongly vary with time and local time, with the lowest frequencies reached on the dawn sector. They were additionally colocated with the UV auroral oval and controlled by local time-variable magnetospheric electron densities, with importants consequences for the use SKR low frequency extensions as a proxy of magnetospheric dynamics. Along the proximal orbits, Cassini then explored auroral altitudes below ~2.5 R_S and crossed numerous, deeper, SKR sources at frequencies close to, or within the emission peak frequency (~80-200 kHz). Here, we present preliminary results of their survey analysis, taking advantage of HST remote UV observations coordinated with Cassini in situ radio and magnetic measurements. Understanding how the CMI operates in the widely different environments of solar system magnetized planets has direct implications for the ongoing search of radio emissions from exoplanets, ultracool dwarves or stars.

THE SKR LOW FREQUENCY SOURCE REGION (< 40 kHz)

Prior to the proximal orbits, Cassini traversed **5 low frequency SKR sources**, which have been analyzed exhaustively in [1-8]. The two events of 2008 benefited from CAPS-ELS electron measurements which enabled us to **definitely validate the CMI as the SKR generation mechanism**, as AKR at Earth [1-2]. SKR source properties (Fig. 1-2) are strongly similar to those of AKR with two main differences :

(1) They are driven by 6-12 keV electron beams consistent with shell-type distribution functions at 2.8 to 3.7 R_s above the atmosphere, so that part of the acceleration by upward currents **takes place farther along the field lines** [10].
(2) SKR LF sources are only partially colocated with the main UV auroral oval, the CMI is indeed **quenched for too large magnetospheric plasma densities.**

FIGURE 1



Similarities (=) and Differences (≠) with AKR :
= Isolated X-mode source with f < fce
= Perpendicular emission [5,8]

= Source size ~ 6000km
= Accurate tracking of f_{cutoff} + perp. emission :
$$f = f_{ce}/\Gamma$$
$$\Gamma = 1/\sqrt{1-v^2/c^2}$$
=> E(e-) = 3-10 keV

= $f_{pe}/f_{ce} < 0.1$ (CMI condition 1)
≠ no Earth-like auroral cavity

= and ≠ Strong upward current (CMI condition 2) larger than the radio source

Figure 1 : Cassini/RPWS and MAG data on 2017-066 [8]. (A-B) SKR dynamic spectra of flux and circular polarization. (C) Ratio of SKR low frequency cutoff / f_{ce}. (D) Characteristic frequencies f_{ce}, $f_{ce}/10$ (dashed) and f_{pe} (gray and red). (E) Azimuthal magnetic field.

FIGURE 2

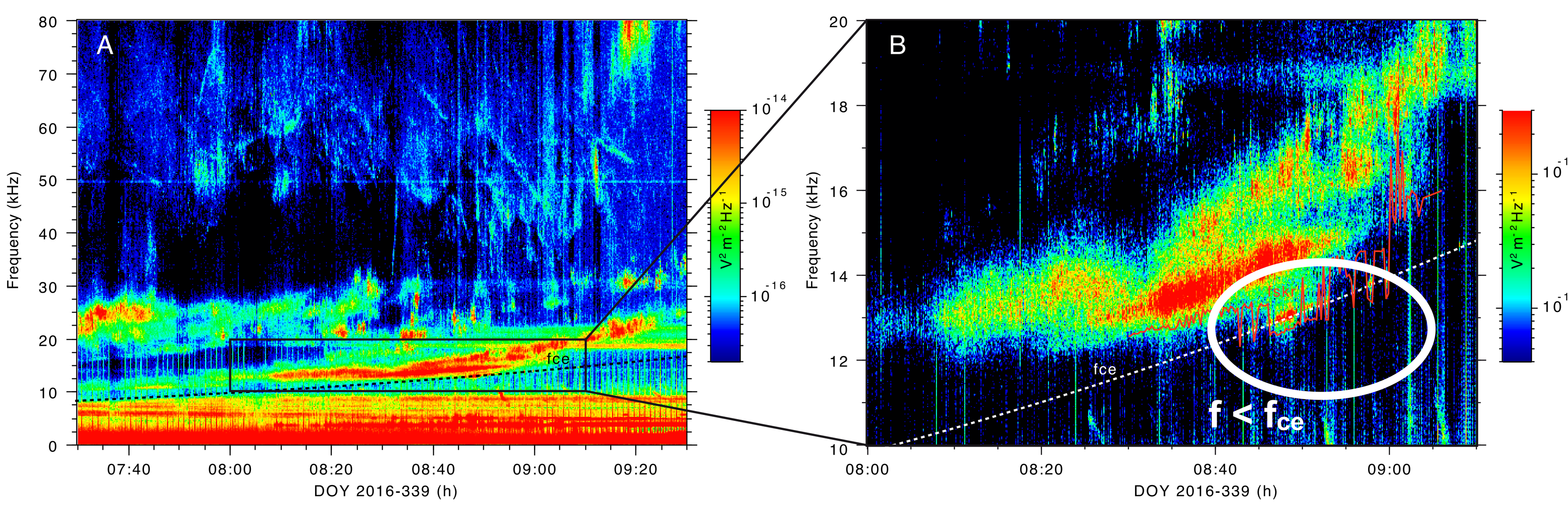


Figure 2 : Cassini/RPWS/WBR waveform measurements for the SKR source on 2016-339. The red curve (SKR low frequency cutoff derived from RPWS/HFR survey data) coincides with the SKR low frequency cutoff shown by waveform data.

THE SKR PEAK FREQUENCY SOURCE REGION (100-400 kHz)

In this work (see also [9]), we surveyed the 22 proximal orbits to search for SKR sources at higher frequencies, matching the 100-400 kHz peak range, **paying attention to simultaneous radio/UV observations** (Fig. 3).

Importantly, intense emissions and subsequent RPWS/HFR saturation effects (such as in Fig. 5) rendered **difficult the identification of the SKR low frequency cutoff** from usual RPWS/HFR survey (swept-frequency) measurements.

Meanwhile, in the absence of electron measurements, **we can only reliably track radiosources at $f < f_{ce}$ consistent with shell-type electron distributions**. Loss-cone electron distribution function remain a possible/plausible source of free energy for SKR (such distributions are observed to power most of auroral radio emissions of Jupiter) but, as **they imply $f > f_{ce}$ they cannot be unmabiguously disentangled from distant sources**, as illustrated in Fig. 3.

FIGURE 3

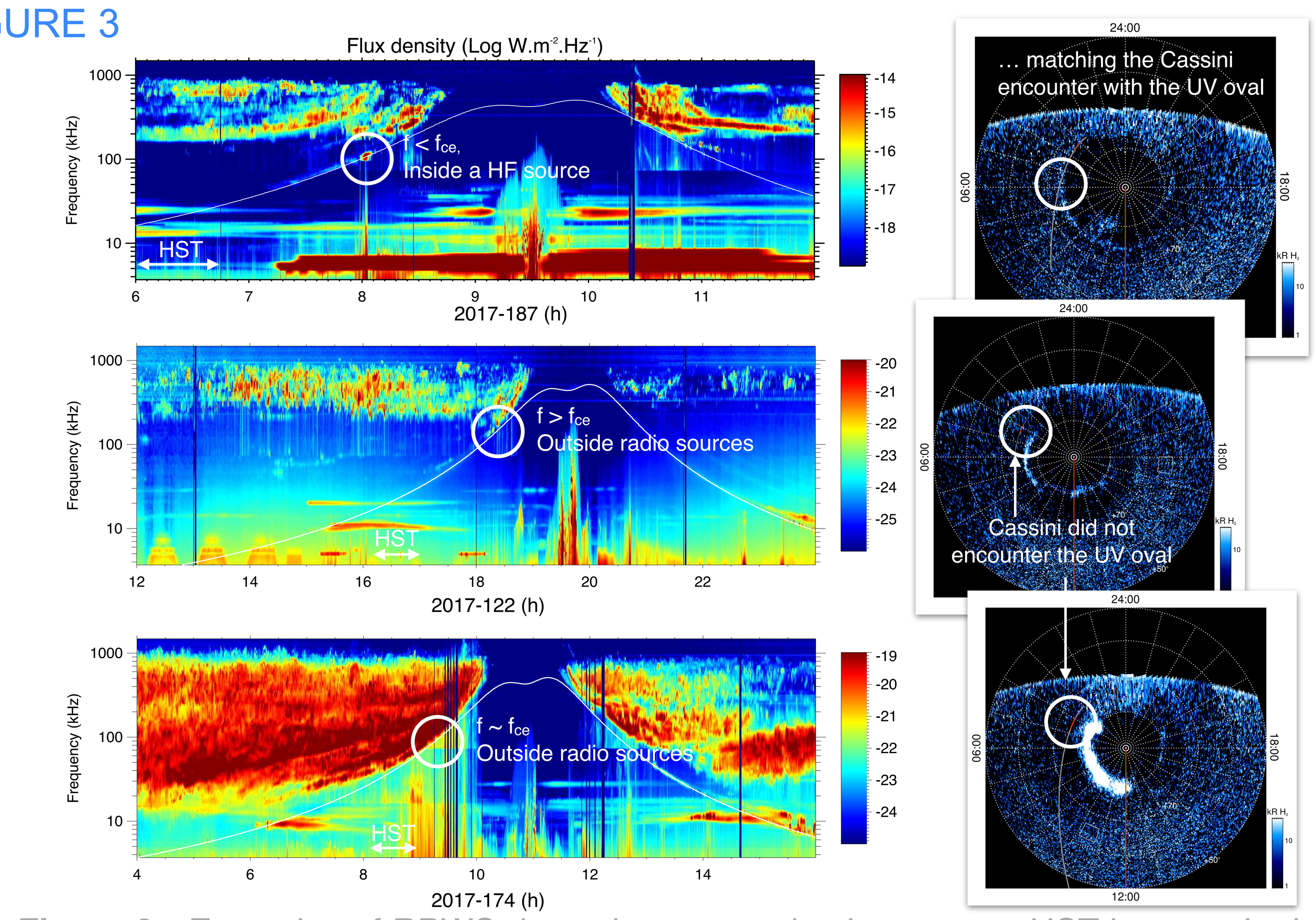
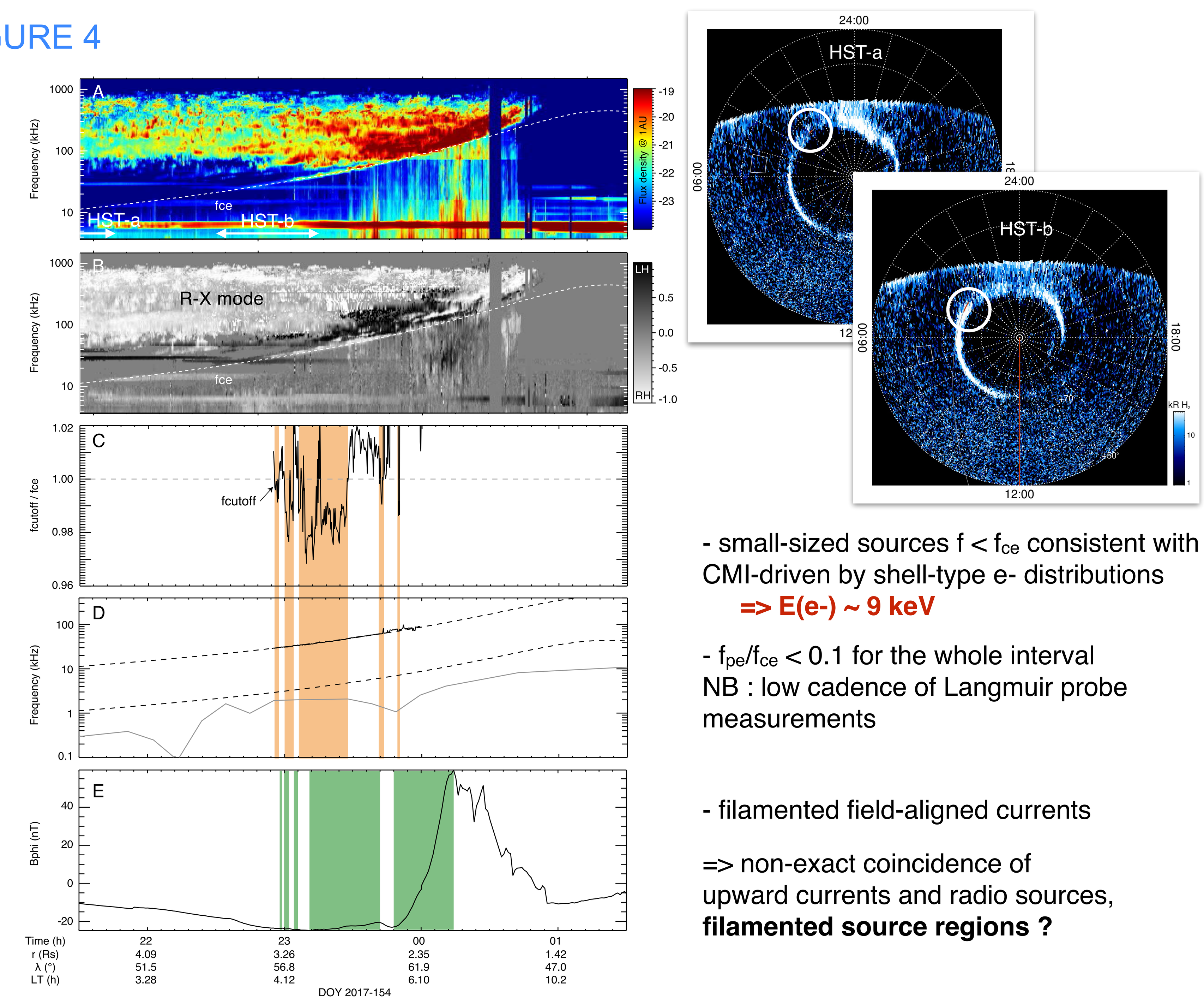


Figure 3 : Examples of RPWS dynamic spectra simultaneous to HST images. In the latest two examples, $f \sim f_{ce}$ (or slightly above) while Cassini did not intercept auroral field lines.

RADIO, UV AND MAGNETIC MEASUREMENTS

On 2017-154, HST images (Fig. 4) revealed a bright co-rotating auroral region, attributed to a rotationally-driven nightside injection [10]. Meanwhile, Cassini was moving slowly enough during this interval so that **the S/C was intercepted at dawn by these active auroral flux tubes.**

FIGURE 4



- small-sized sources $f < f_{ce}$ consistent with CMI-driven by shell-type e- distributions
=> E(e-) ~ 9 keV

- $f_{pe}/f_{ce} < 0.1$ for the whole interval
NB : low cadence of Langmuir probe measurements

- filamented field-aligned currents

=> non-exact coincidence of upward currents and radio sources, **filamented source regions ?**

Figure 4 : Same as Fig. 1 on 2017-154. The HST images on the right were acquired during intervals shown by white double arrows on panel A.

The SKR source identified on of 2017-187 (Fig. 3) displays properties very similar to that on 2017-154. When UV observations are lacking, polar maps of SKR footprints (derived from HFR goniopolarimetric results) also indicates whether Cassini intercepted auroral flux tubes. Fig. 5 shows an example of this together RPWS/WBR waveform measurements. While Cassini crossed auroral field lines, $f \lesssim f_{ce}$ rather than clearly below.

FIGURE 5

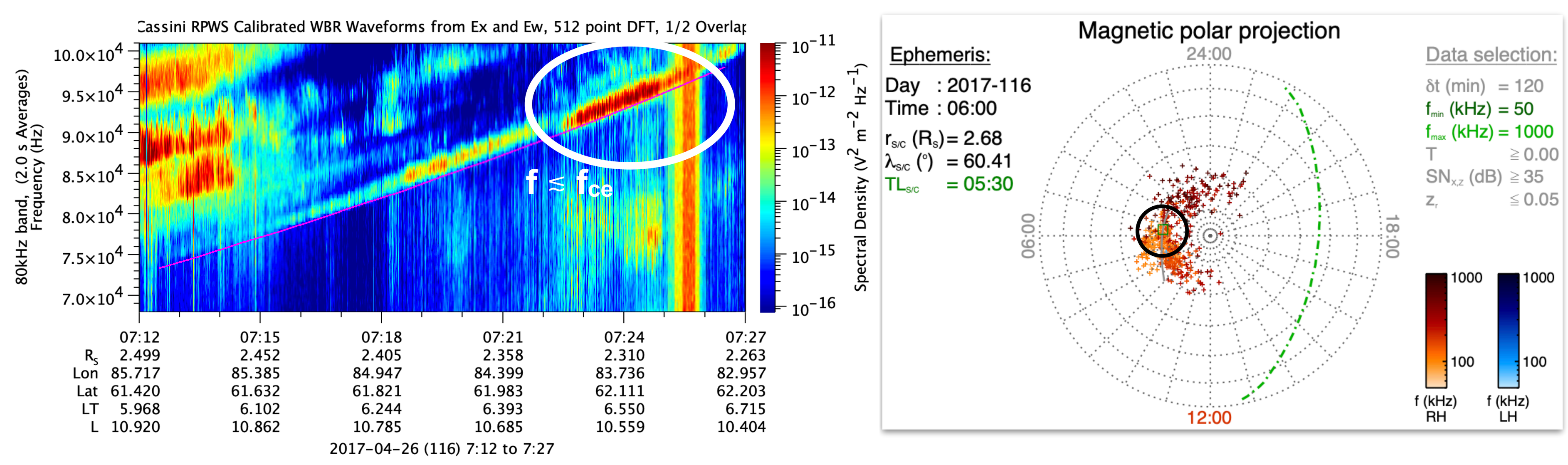


Figure 5 : (Left) RPWS/WBR measurements on 2017-116, with f only slightly below f_{ce} and (Right) RPWS/HFR-derived SKR « radio oval » (SKR footprint) crossed by the Cassini footpath.

REFERENCES

[1] Lamy et al., Geophys. Res. Let., 2010. [2] Mutel et al., Geophys. Res. Let., 2010. [3] Bunce et al., Geophys. Res. Let., 2010. [4] Kurth et al., PRE7, 2011. [5] Lamy et al., Journal of Gephys. Res., 2011. [6] Schippers et al., J. of Gephys. Res, 2011. [7] Menietti et al., J. of Gephys. Res., 2011. [8] Lamy et al., Science, 2018. [9] Lamy et al., EPSC, 2020. [9] Lamy et al., Geophys. Res. Let., 2018.