The RPW Low Frequency Receiver (LFR) on Solar Orbiter: in-situ LF electric and magnetic field measurements of the solar wind expansion

- LFR science objectives
- Instrument description and data products
- Examples of first observations during the commissioning phase (Solar Obiter has been launched successfully February 10, 2020)

Thomas Chust, the LFR team and the RPW instrument consortium, and the MMS team

LFR Science Objectives

- Study the **electromagnetic/electrostatic activity** in the extended corona and the near-Sun solar wind, **from near DC to 10 kHz.**

- Will **cover the electron gyrofrequency** and **most of the Doppler-shifted frequencies** *of the low frequency/small scale plasma waves, structures & turbulence.*

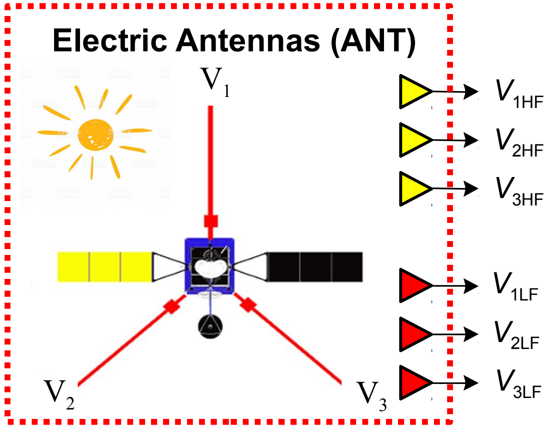
  Kinetic or inertial Alfven waves
  Ion cyclotron waves
  Ion acoustic waves
  Magnetosonic or whistler mode waves
  ...

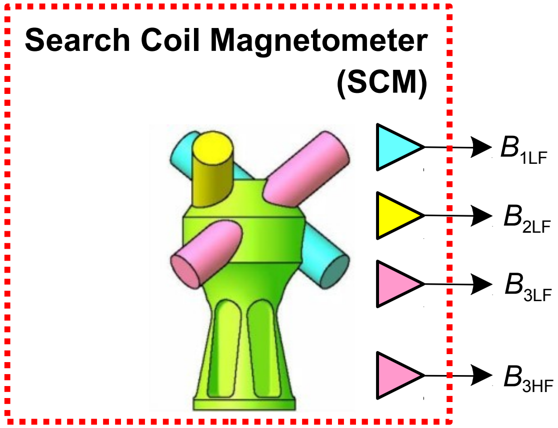
➔ Their characterization and the determination of their respective role **in heating and accelerating the solar wind**, ***<u>during its expansion</u>***, is the main scientific issue addressed by LFR.

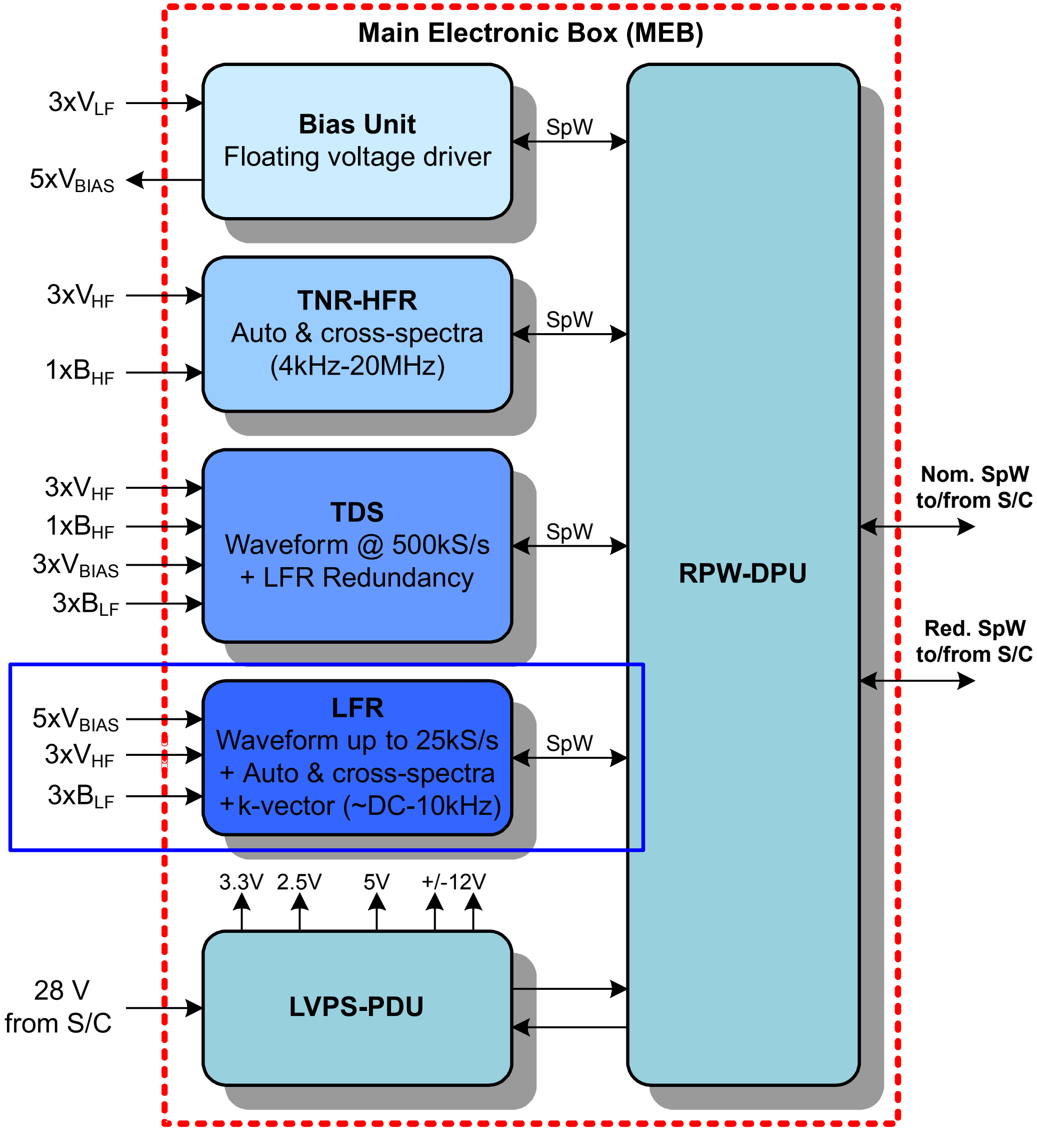
➔ Role of the low frequency/small scale plasma waves & structures associated to solar wind disturbances, **e.g. interplanetary shocks, current sheets...**

RPW Instrument Overview

Will allow the characterization of the electric and magnetic fields associated to the dynamics of the near-Sun heliosphere ***from near DC up to 20 MHz***

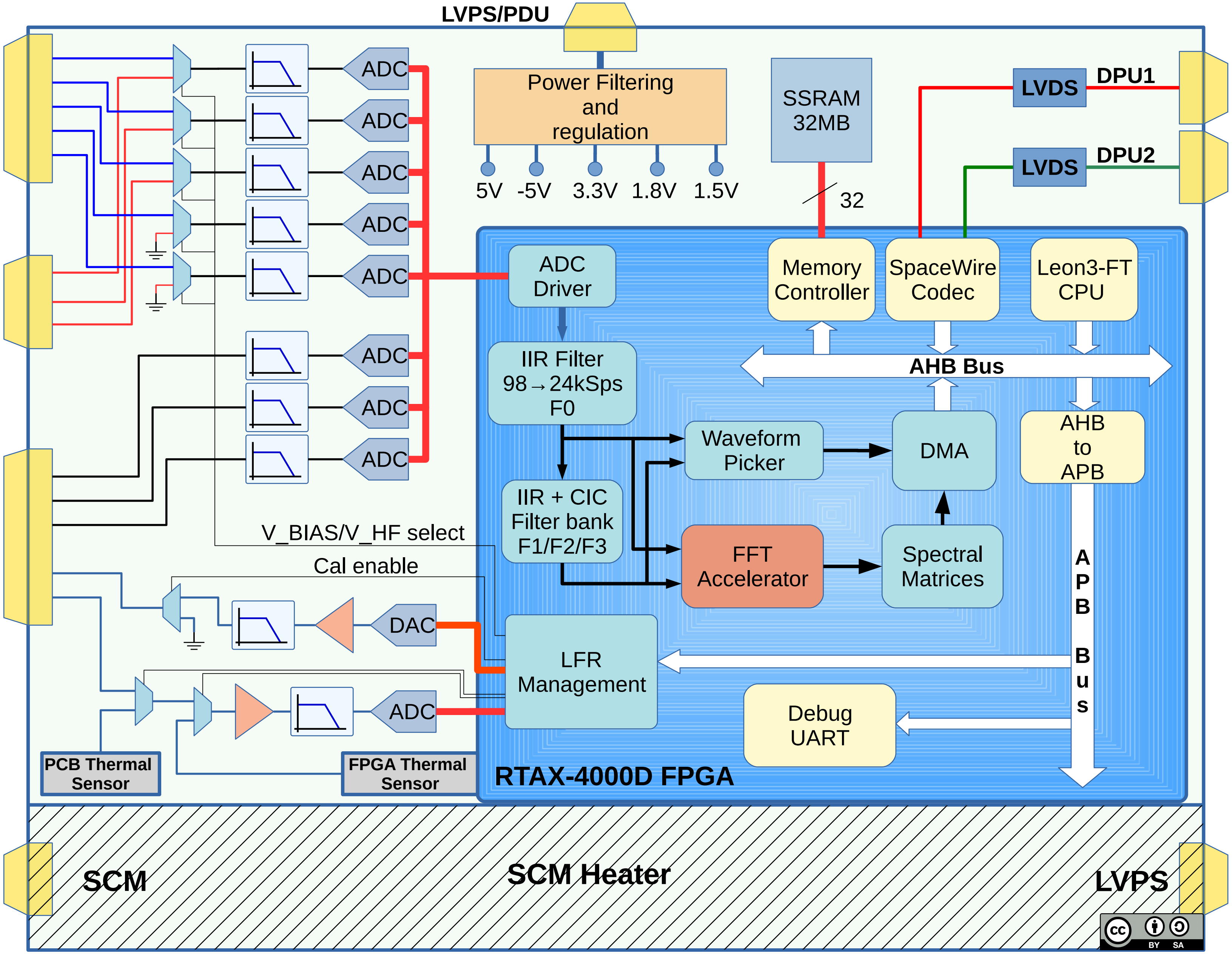




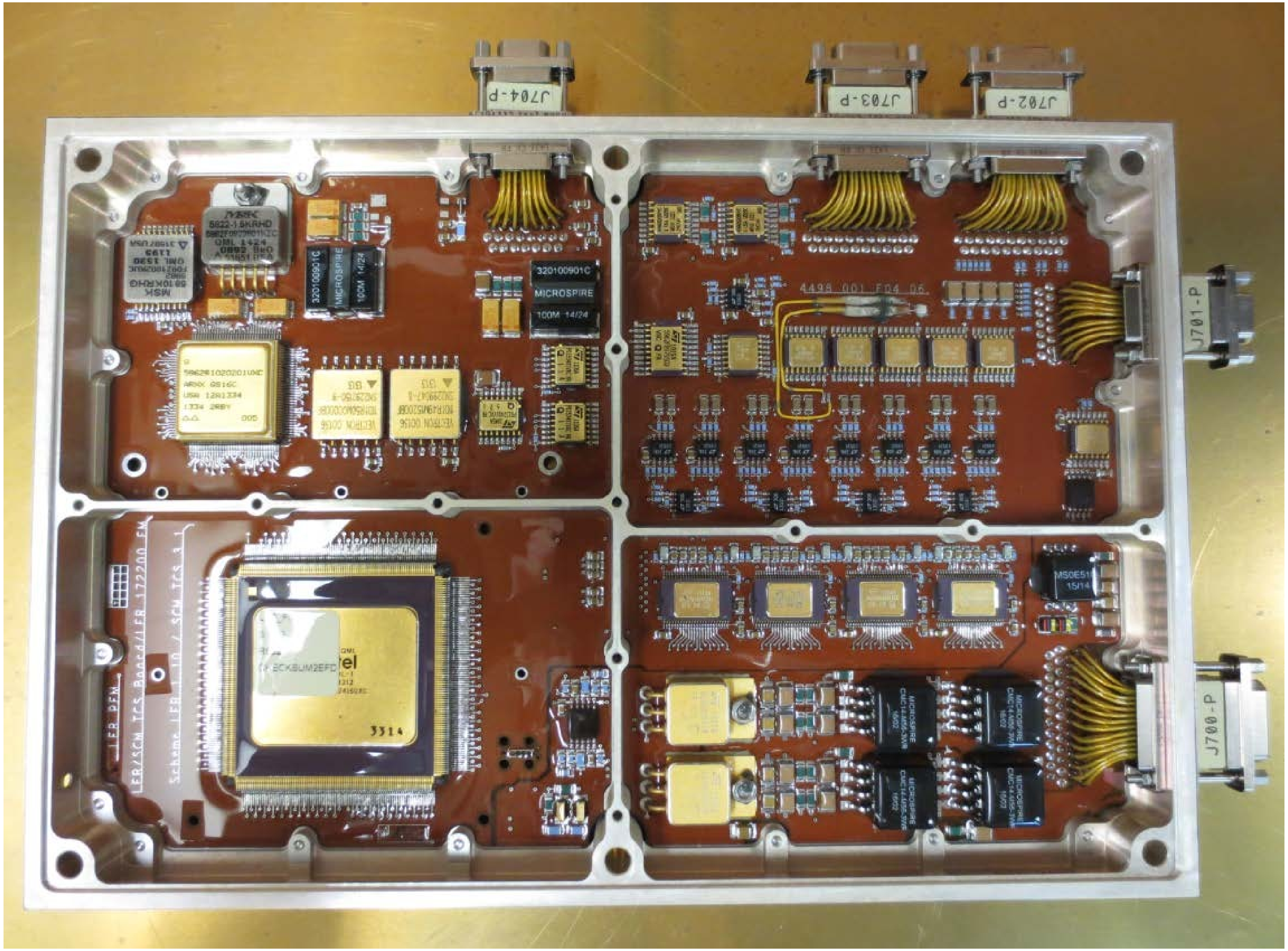


Low Frequency Receiver

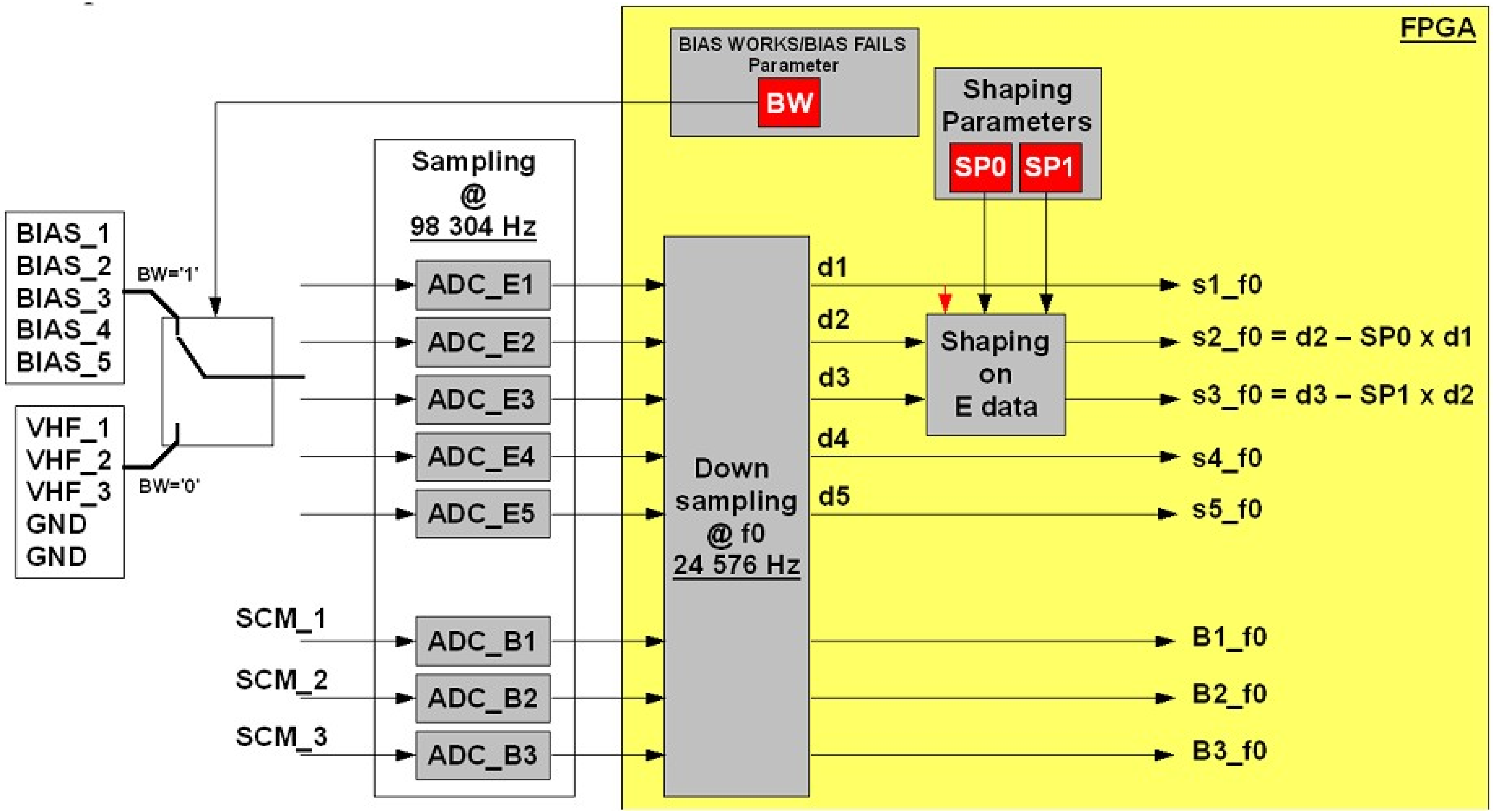
LFR block diagram



LFR FM board at LESIA

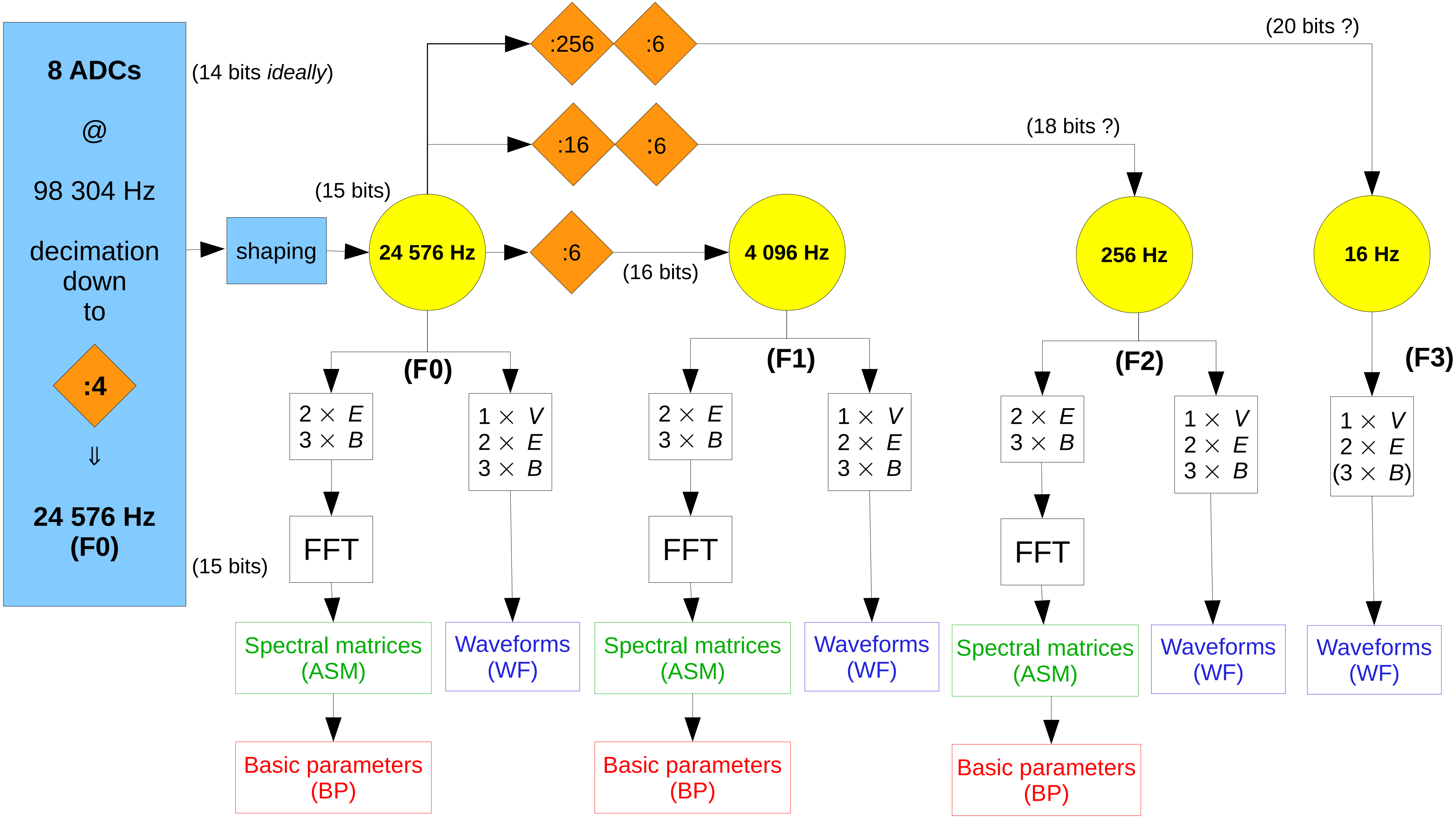


LFR 11 analogue inputs



When BIAS is off LFR electric field measurements can be performed from the ANT HF preamps

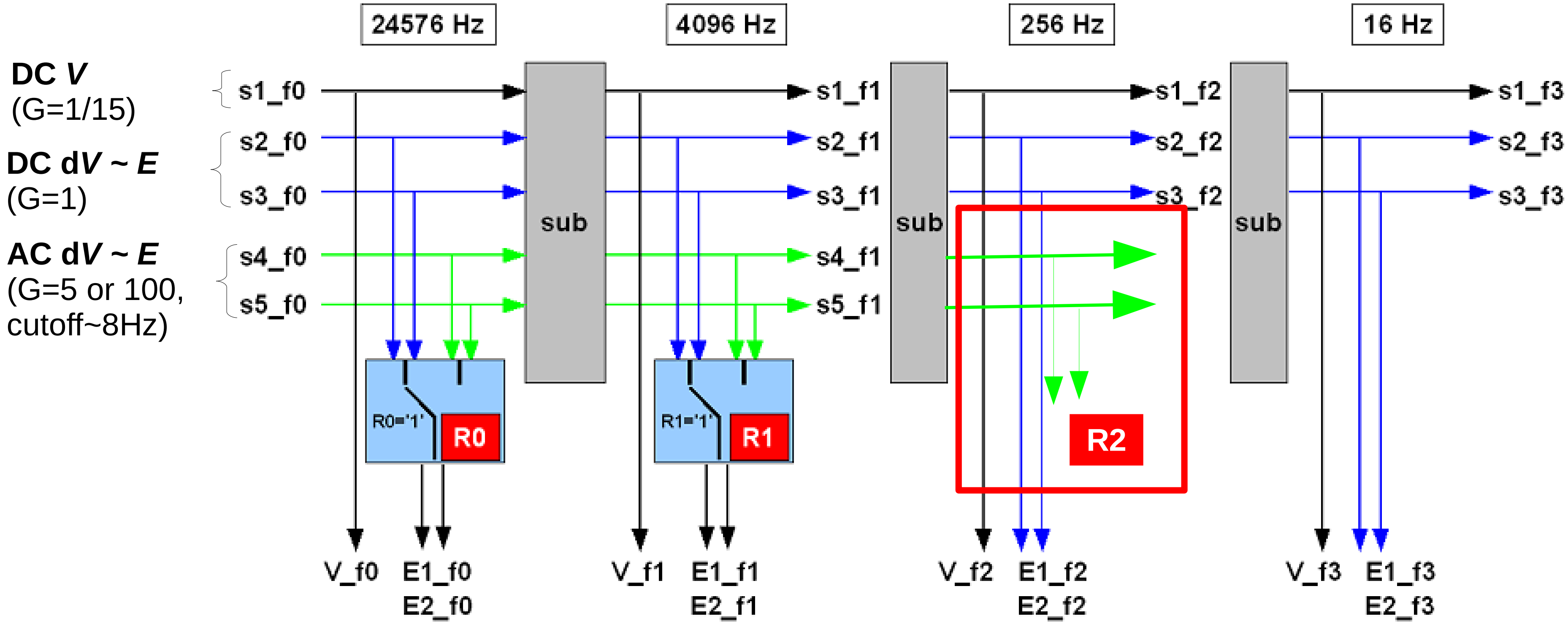
LFR Decimation and Processing Strategy



BIAS 5 outputs in the different modes

	BIAS output signals					
MODE	**V1**$_{BIAS}$	**V2**$_{BIAS}$	**V3**$_{BIAS}$	**V4**$_{BIAS}$	**V5**$_{BIAS}$	**Operation**
0	$V1_{DC}$	$V12_{DC}$/ $V13_{DC}$	$V23_{DC}$	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Standard operation
1	$V2_{DC}$	$V3_{DC}$	$V23_{DC}$	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Operation if antenna 1 fails
2	$V1_{DC}$	$V3_{DC}$	$V13_{DC}$/$V12_{DC}$	$V13_{AC}$/ $V12_{AC}$	$V23_{AC}$	Operation if antenna 2 fails
3	$V1_{DC}$	$V2_{DC}$	$V12_{DC}$/ $V13_{DC}$	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Operation if antenna 3 fails
4	$V1_{DC}$	$V2_{DC}$	$V3_{DC}$	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Calibration mode 0
5	2.5V Ref	2.5V Ref	2.5V Ref	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Calibration mode 1
6	GND	GND	GND	$V12_{AC}$/$V13_{AC}$	$V23_{AC}$	Calibration mode 2

BIAS 5 outputs and the LFR R-parameters



LFR current set of Basic Parameters

"Instantaneous" 5 x 5 spectral matrix (256-point FFT)

$$\mathbf{SM}\left(\omega_j^{(m)}\right)=\begin{bmatrix} B_1B_1^* & B_1B_2^* & B_1B_3^* & B_1E_1^* & B_1E_2^* \\ cc & B_2B_2^* & B_2B_3^* & B_2E_1^* & B_2E_2^* \\ cc & cc & B_3B_3^* & B_3E_1^* & B_3E_2^* \\ cc & cc & cc & E_1E_1^* & E_1E_2^* \\ cc & cc & cc & cc & E_2E_2^* \end{bmatrix}$$

Time Averaged Spectral Matrix (ASM)

$$\mathbf{ASM}\left(\omega_j^{(m)}\right)=\frac{1}{N_{SM}^{(m)}}\sum_{k=1}^{N_{SM}^{(m)}}\mathbf{SM}_k\left(\omega_j^{(m)}\right)=\langle\mathbf{SM}\rangle_{time}$$

***Frequency* average ...**

$$\mathbf{S}\left(\omega_j^{(m)}\right)=\langle\mathbf{ASM}\rangle_{frequency}$$

... before computations of the BPs (i.e. wave parameters)

Mono-**k** assumption :

	BP1 set 1:	Power spectrum of the magnetic field (***B***)
	BP1 set 2:	Power spectrum of the electric field (***E***)
(Means, JGR, 1972) {	BP1 set 3:	Wave normal vector (from ***B***)
	BP1 set 4:	Wave ellipticity estimator (from ***B***)
(Samson & Olson, GJRA, 1980) {	BP1 set 5:	Wave planarity estimator (from ***B***)
	BP1 set 6:	X_{SO}(radial)-component of the Poynting vector
$\mathbf{n}\times\mathbf{E}=\frac{\omega}{k}\mathbf{B}$ →	BP1 set 7:	Phase velocity estimator
$\frac{S_{ij}}{\sqrt{S_{ii}S_{jj}}}$ →	**BP2** set 1:	Autocorrelations
	BP2 set 2:	Normalized cross correlations

LFR spectral frequencies

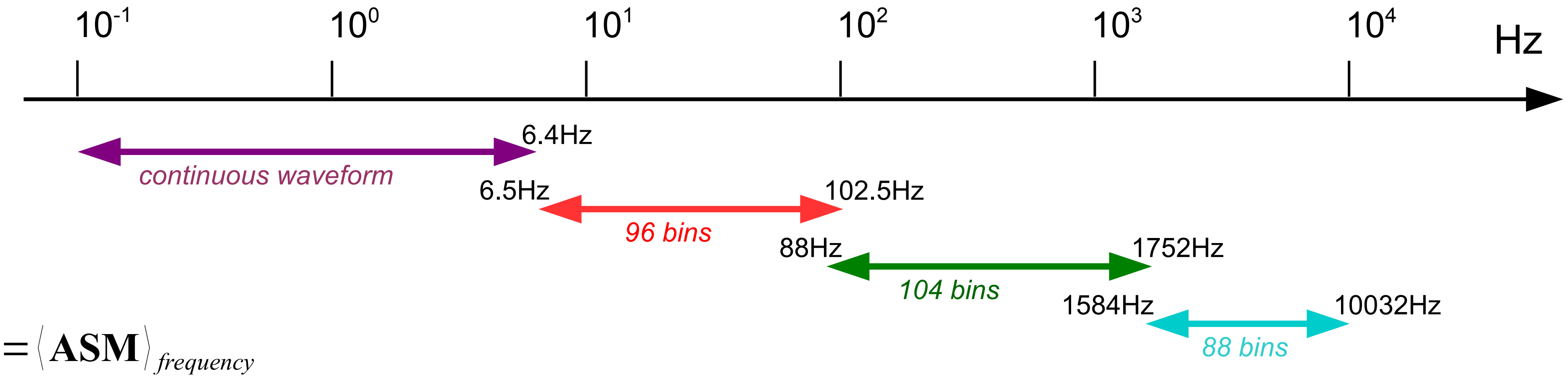
(1) Depending on the frequency channel, **selection** of 96, 104 or 88 consecutive **frequency bins** among 128 (N_{FFT} = 256) of the *time* averaged spectral matrices.

(2) Then, the ASMs are averaged over packets of N_{freq} (8 or 4) consecutive bins :

$$\Delta f^{(m)} = \frac{f_m}{N_{FFT}} \times N_{freq}$$

$$N_{freq} = 8$$

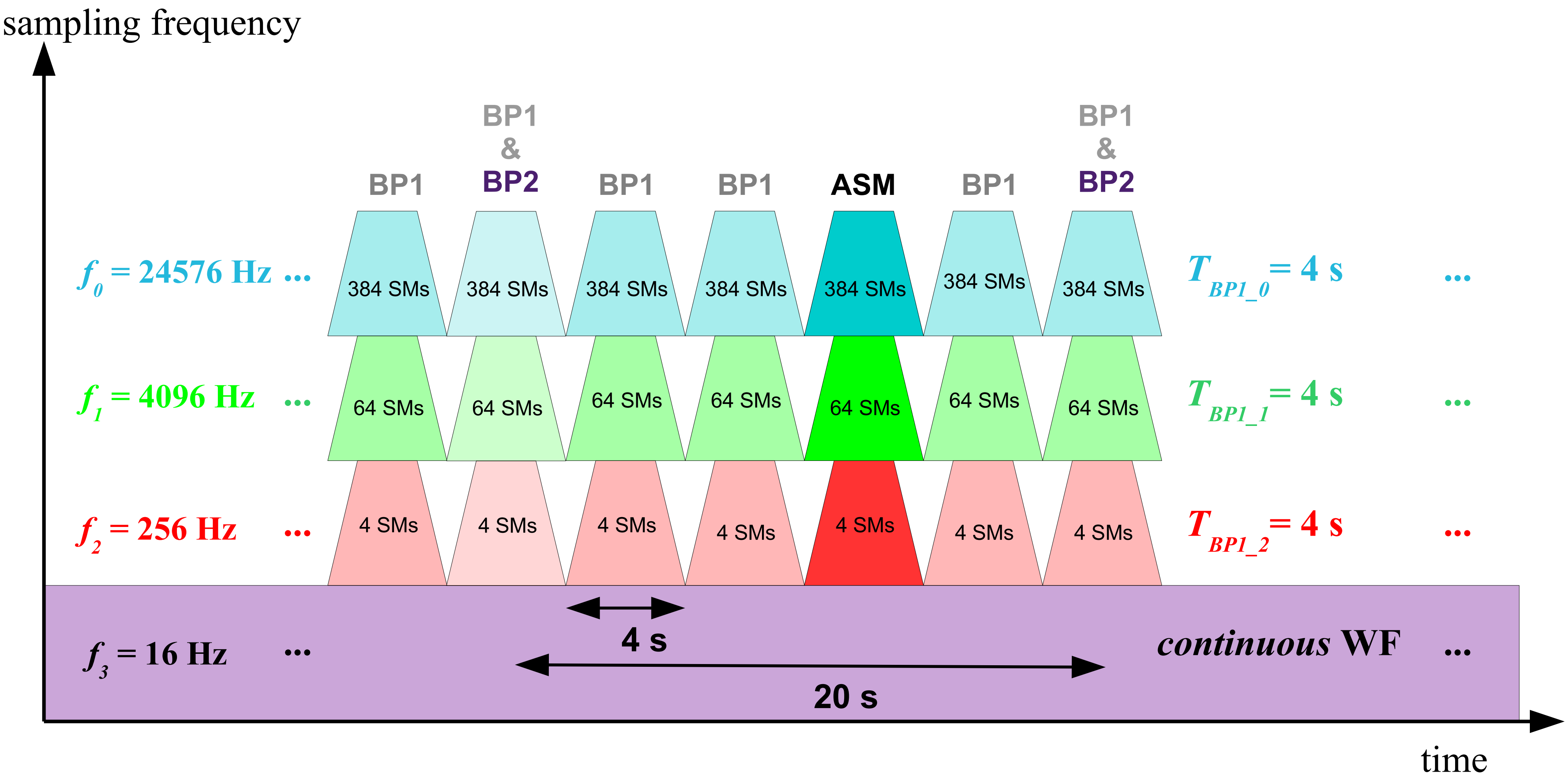
f_3 = **16 Hz**	=>	waveform	[DC, 8Hz]		f_3 / 2.5 = 6.4 Hz
f_2 = **256 Hz**	=>	12 frequencies	[6.5Hz, 102.5Hz]	$\Delta f^{(2)}$ = 8 Hz	f_2 / 2.5 = 102.4 Hz
f_1 = **4096 Hz**	=>	13 frequencies	[88Hz, 1752Hz]	$\Delta f^{(1)}$ = 128 Hz	f_1 / 2.5 = 1638.4 Hz
f_0 = **24576 Hz**	=>	11 frequencies	[1584Hz, 10032Hz]	$\Delta f^{(0)}$ = 768 Hz	f_0 / 2.5 = 9830.4 Hz



$$\mathbf{S} = \langle \mathbf{ASM} \rangle_{frequency}$$

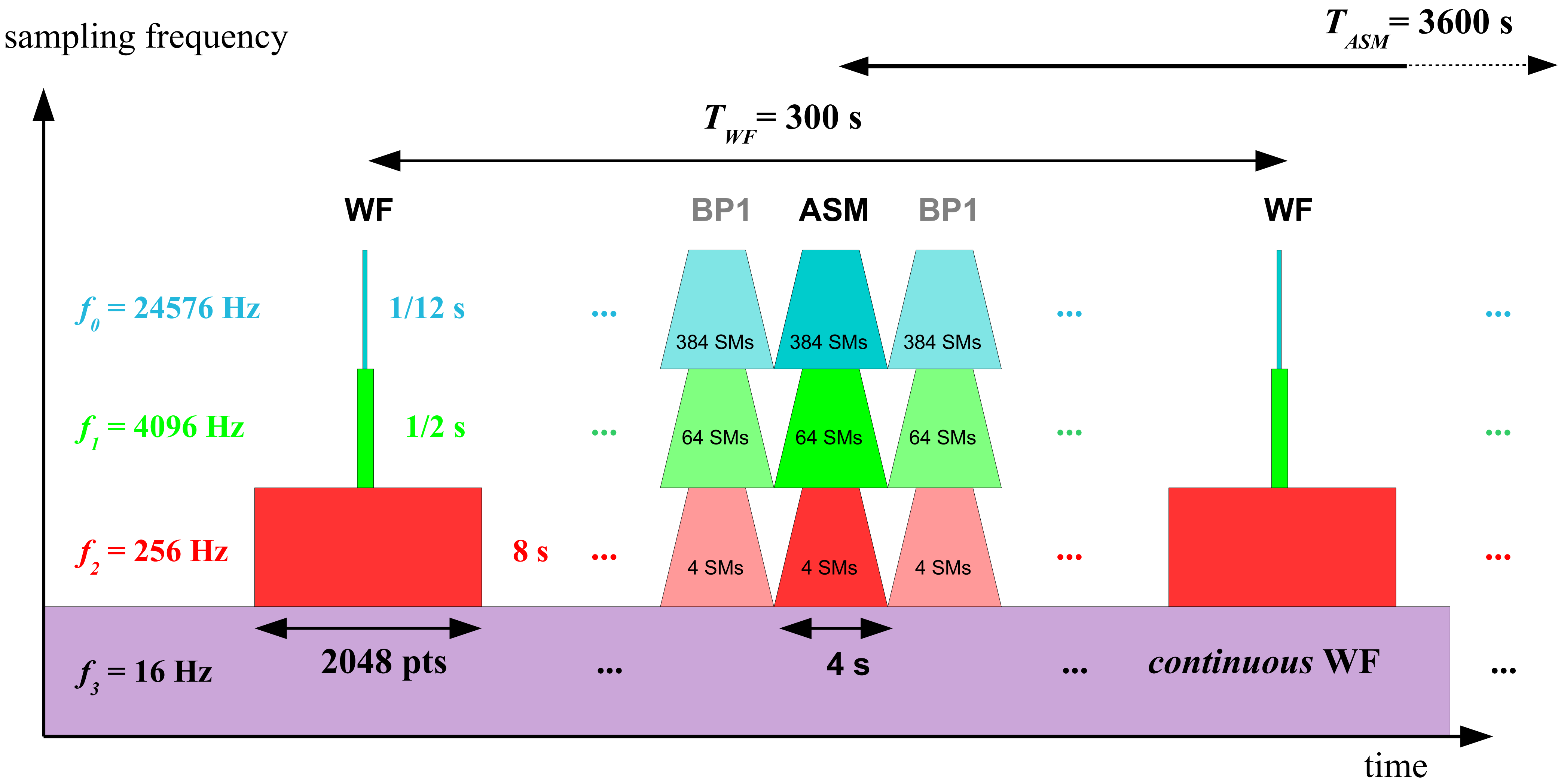
LFR Normal Mode (1)

Basic Parameters

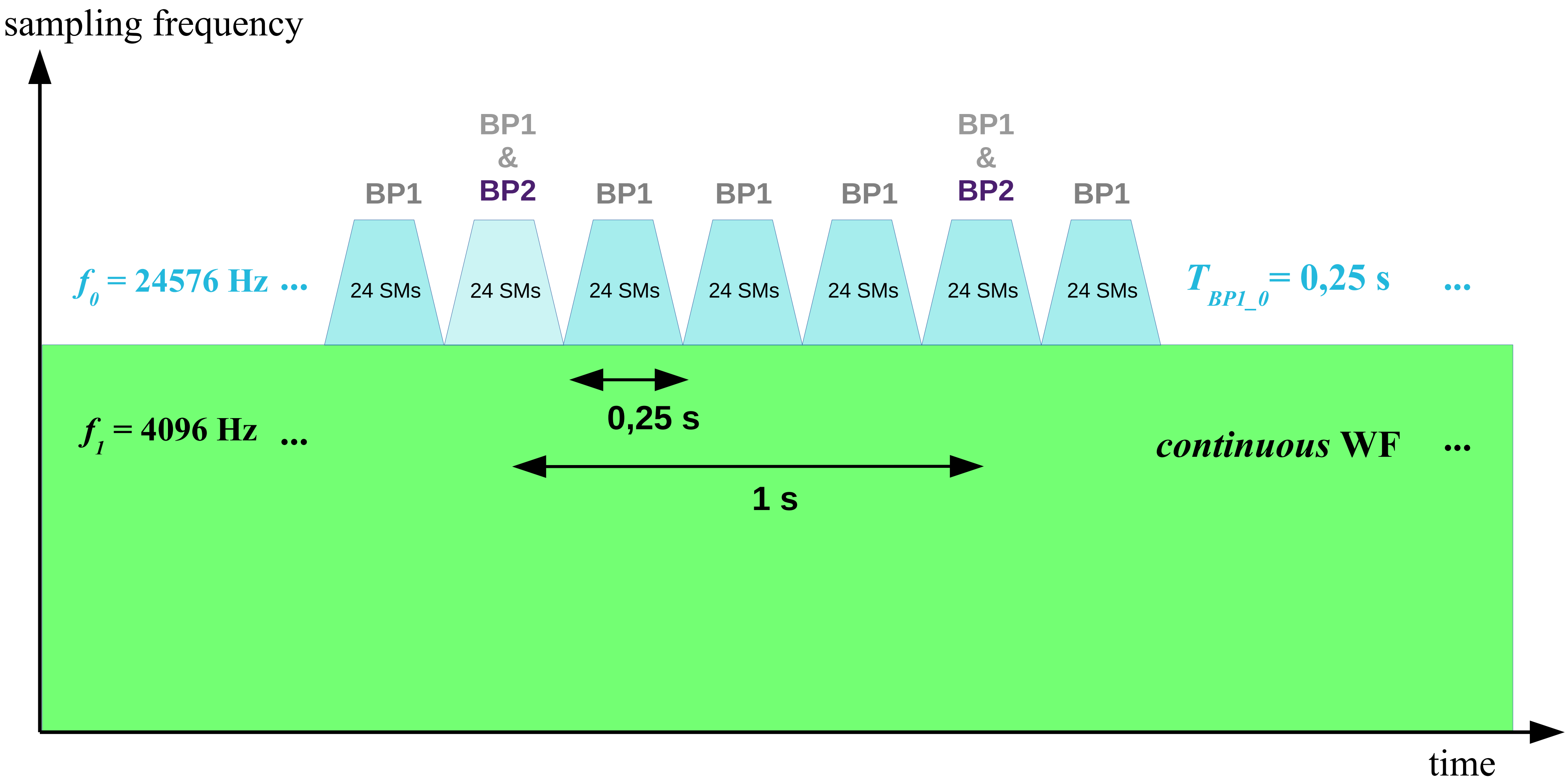


LFR Normal Mode (2)

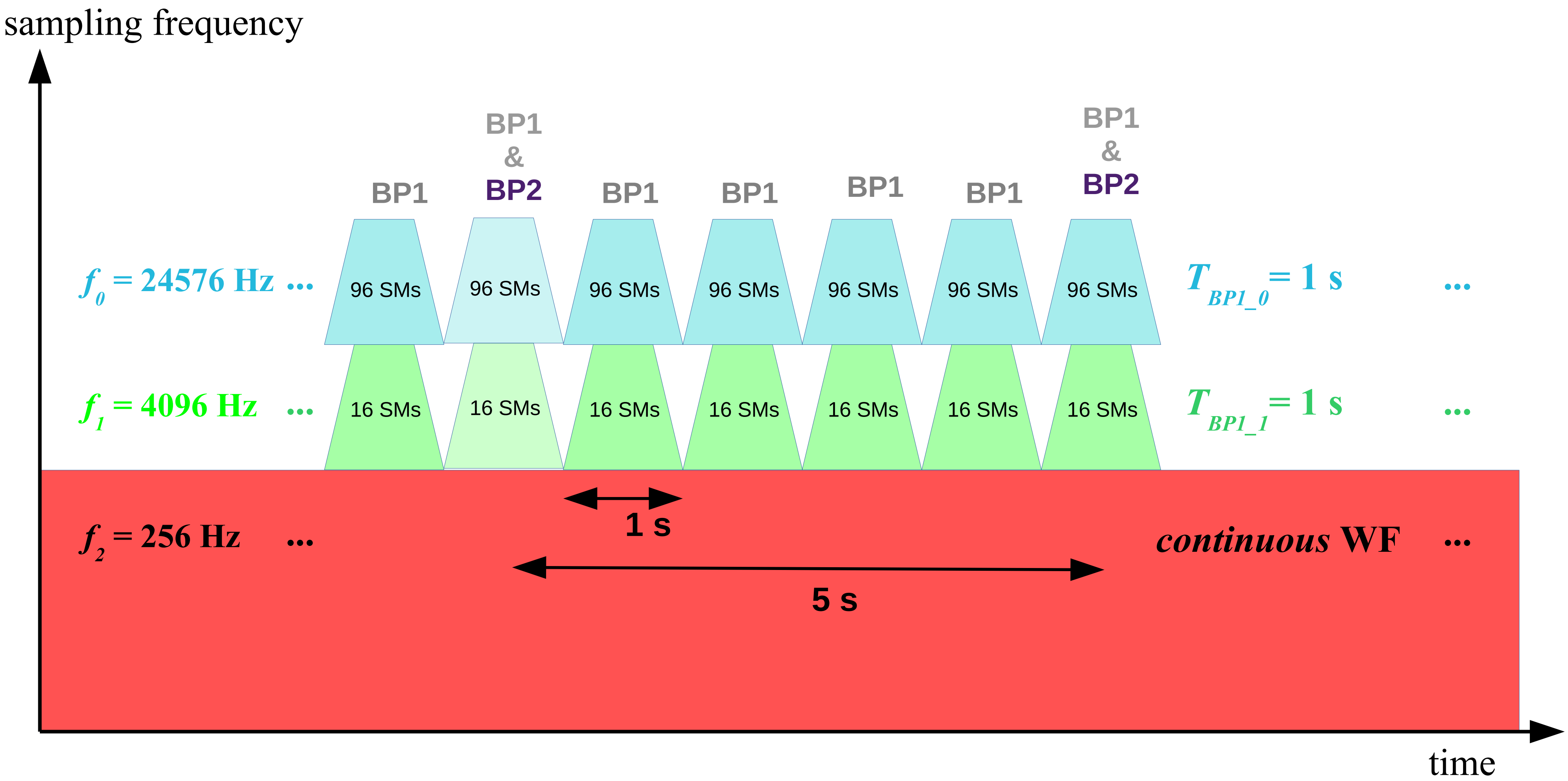
Wave Forms & Averaged Spectral Matrices



LFR Selected Burst Mode 1



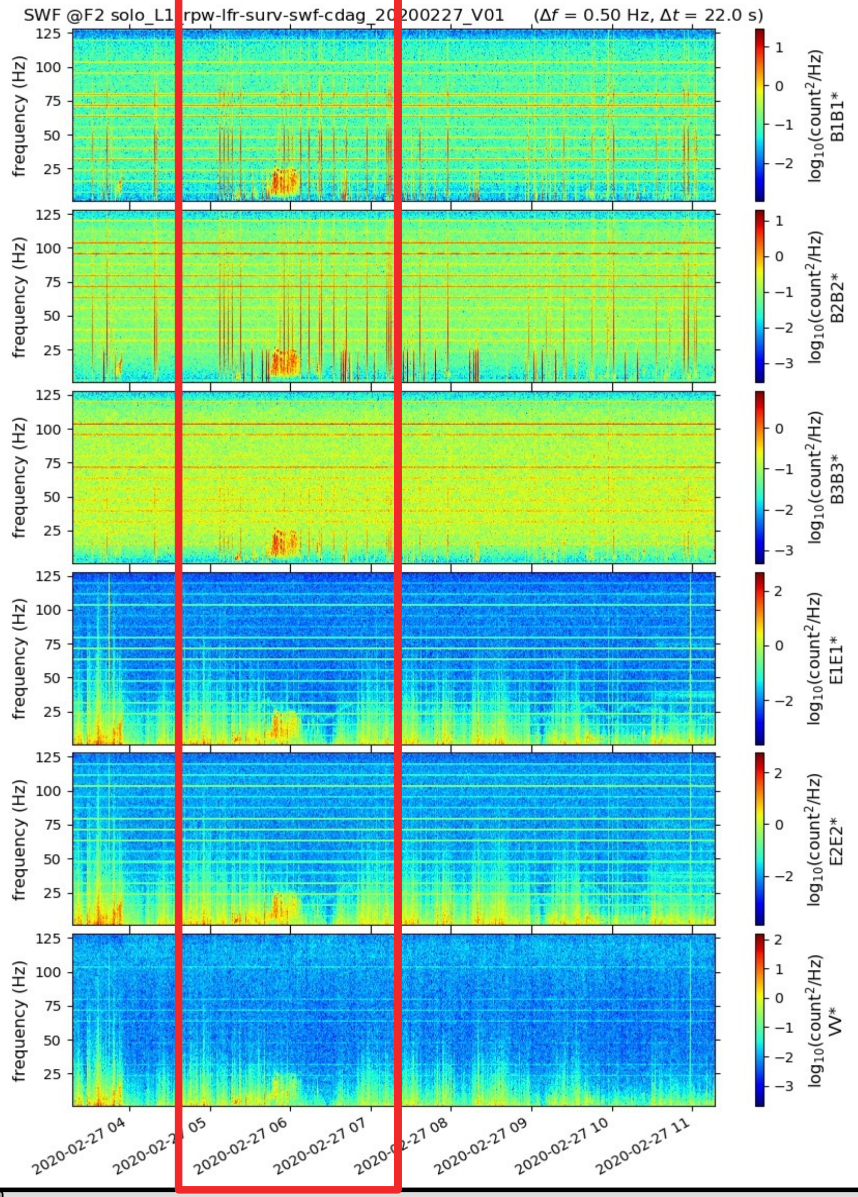
LFR Selected Burst Mode 2 & BURST mode



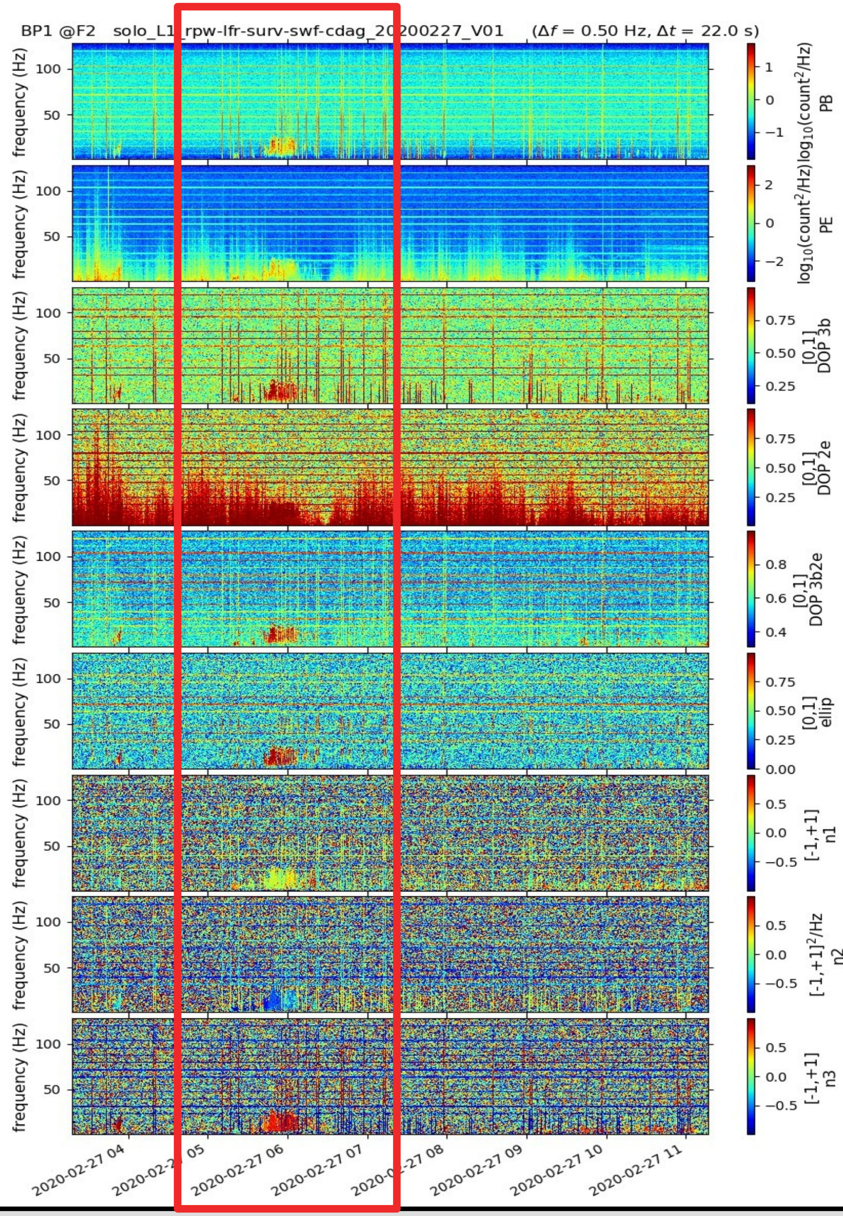
Electromagnetic wave event at frequencies ~ 5-25Hz: Whistler waves?

27/02 full day **2020**

ASM from SWF @F2



BP1 from SWF @F2

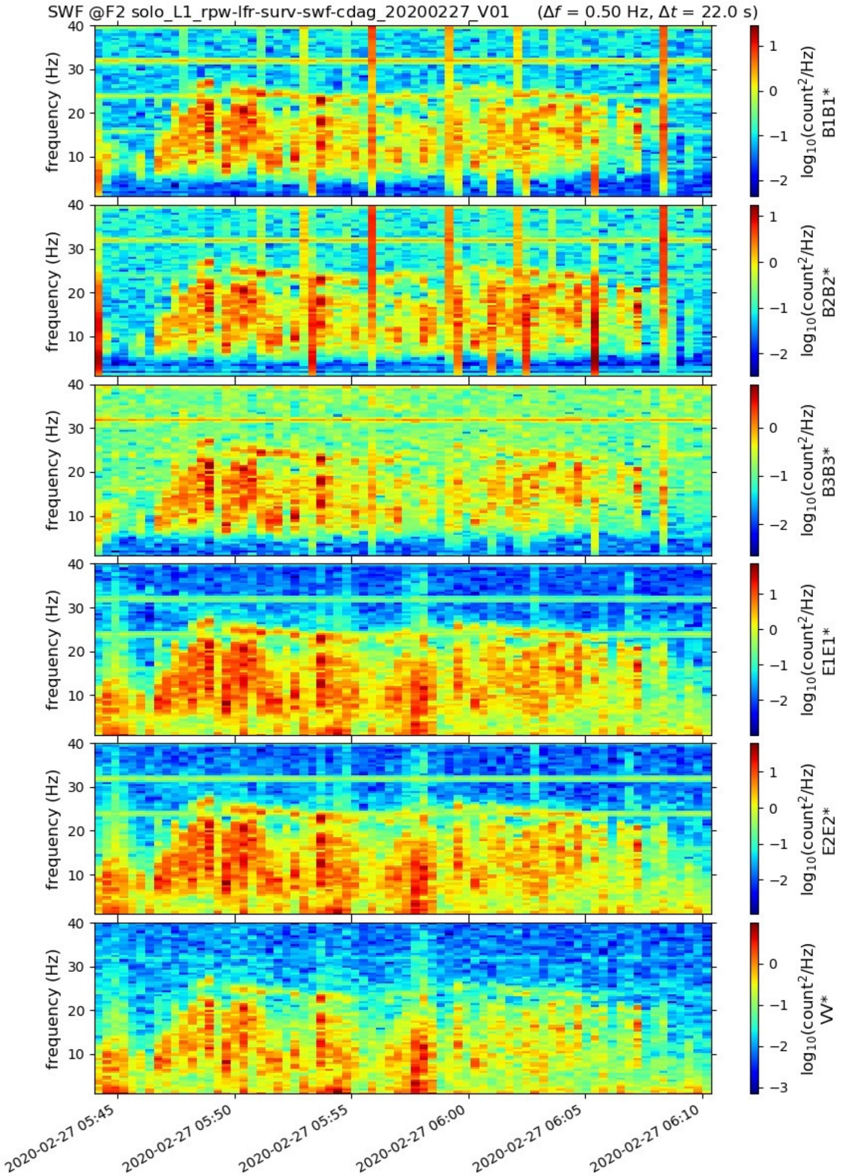


Electromagnetic wave event at frequencies ~ 5-25Hz: Whistler waves?

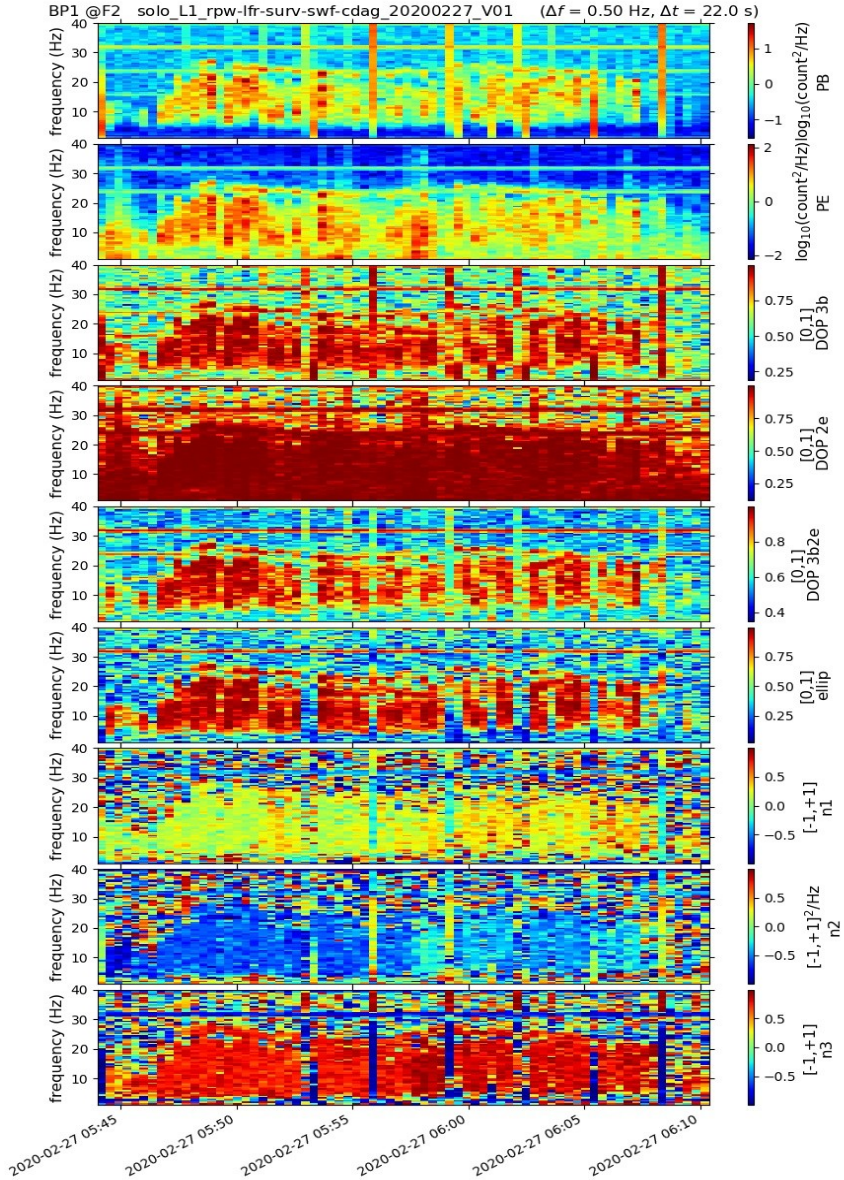
27/02 **2020**

ASM from SWF @F2

zoom



BP1 from SWF @F2



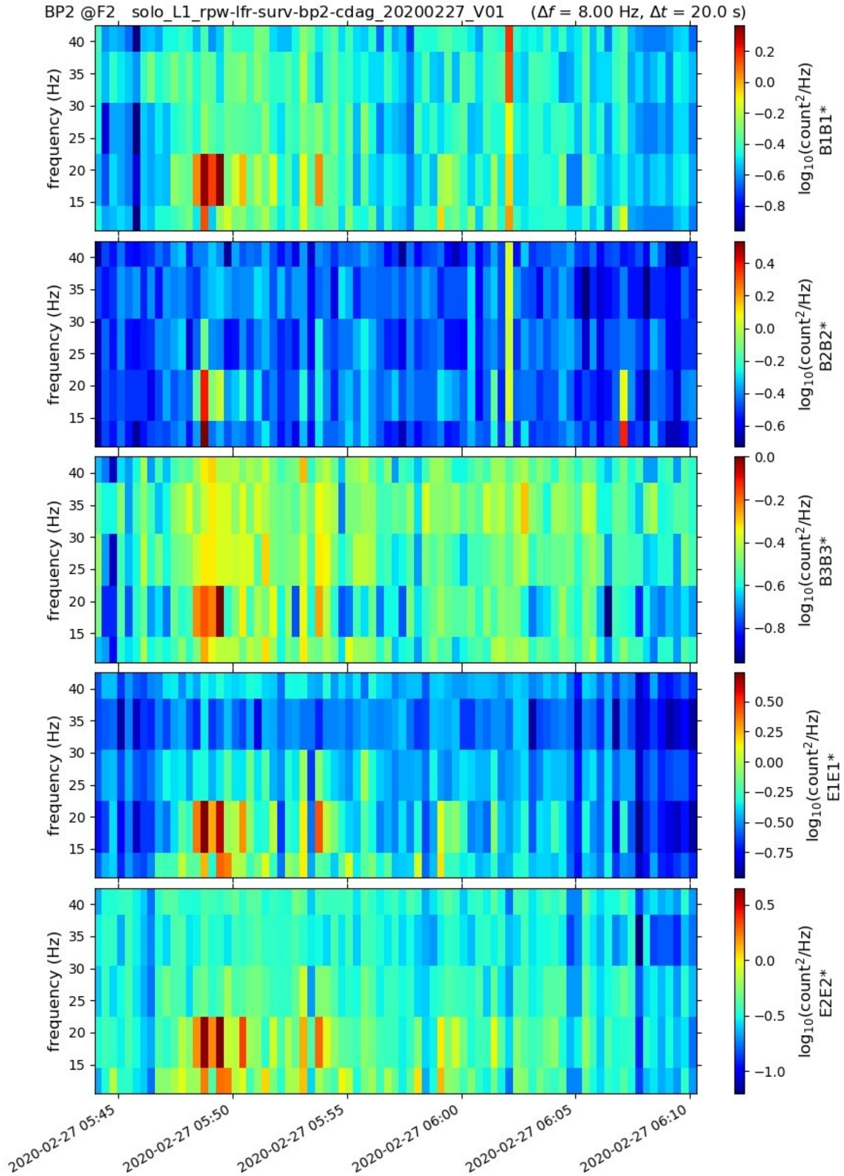
Electromagnetic wave event at frequencies ~ 5-25Hz: Whistler waves?

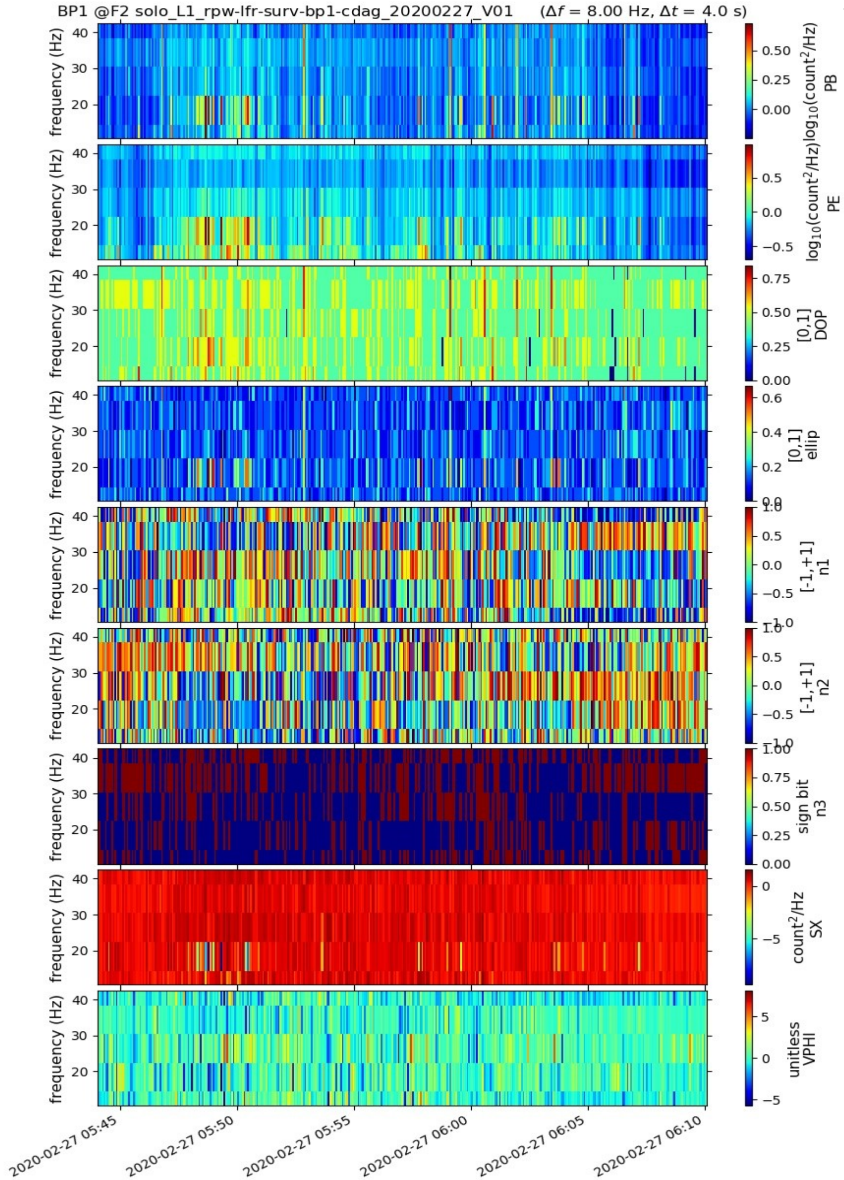
27/02 **2020**

onboard BP2 @F2

zoom

onboard BP1 @F2





Electromagnetic wave event at frequencies ~ 5-25Hz: Whistler waves?

27/02 **2020**

- Looking at time **(2020, 2, 27, 5, 50, 0)** and frequency of **18 Hz**

- One observes a normal wave vector expressed in the SCM reference frame :

  n = [0.10533082, -0.57960344, 0.80806266]_SCM

- Which expressed in the Spacecraft Reference Frame gives :

  n = [0.82970735, 0.55613863, 0.04791182]_SRF

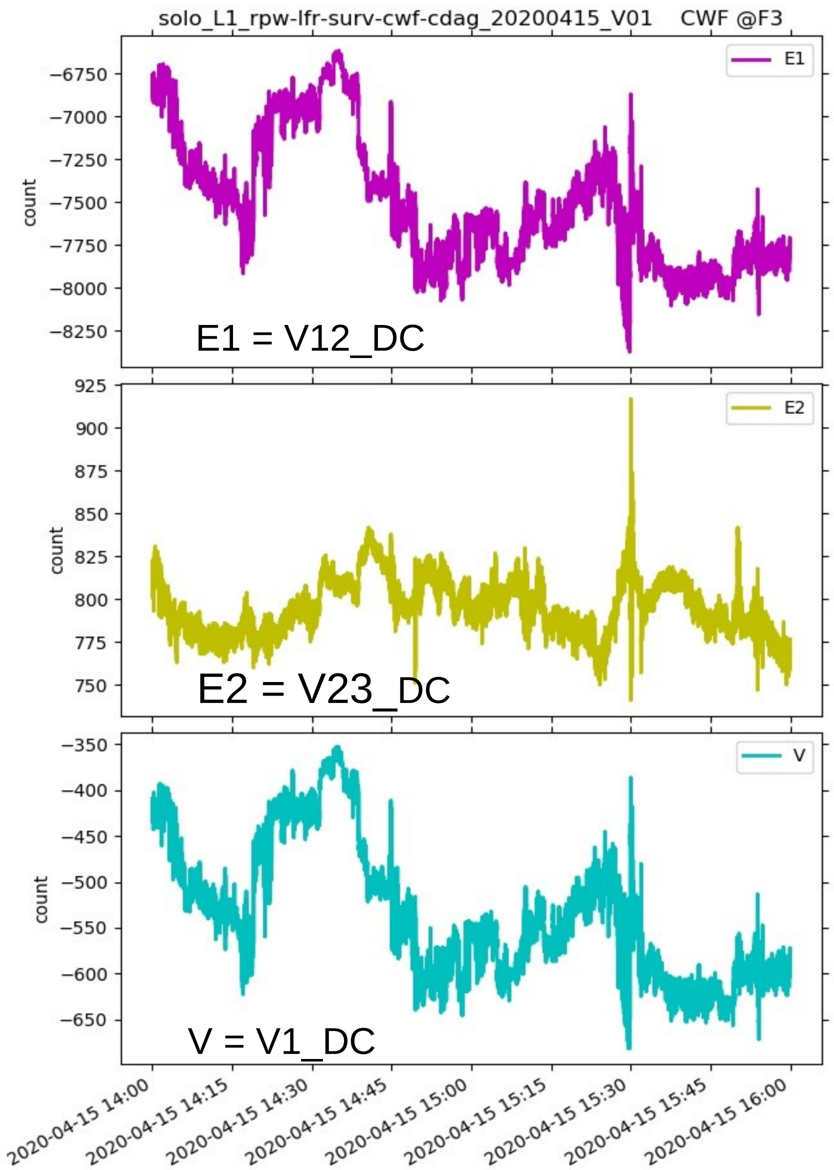
- From first exchange with the MAG team this vector would make an angle of ~1-2° with the DC magnetic field

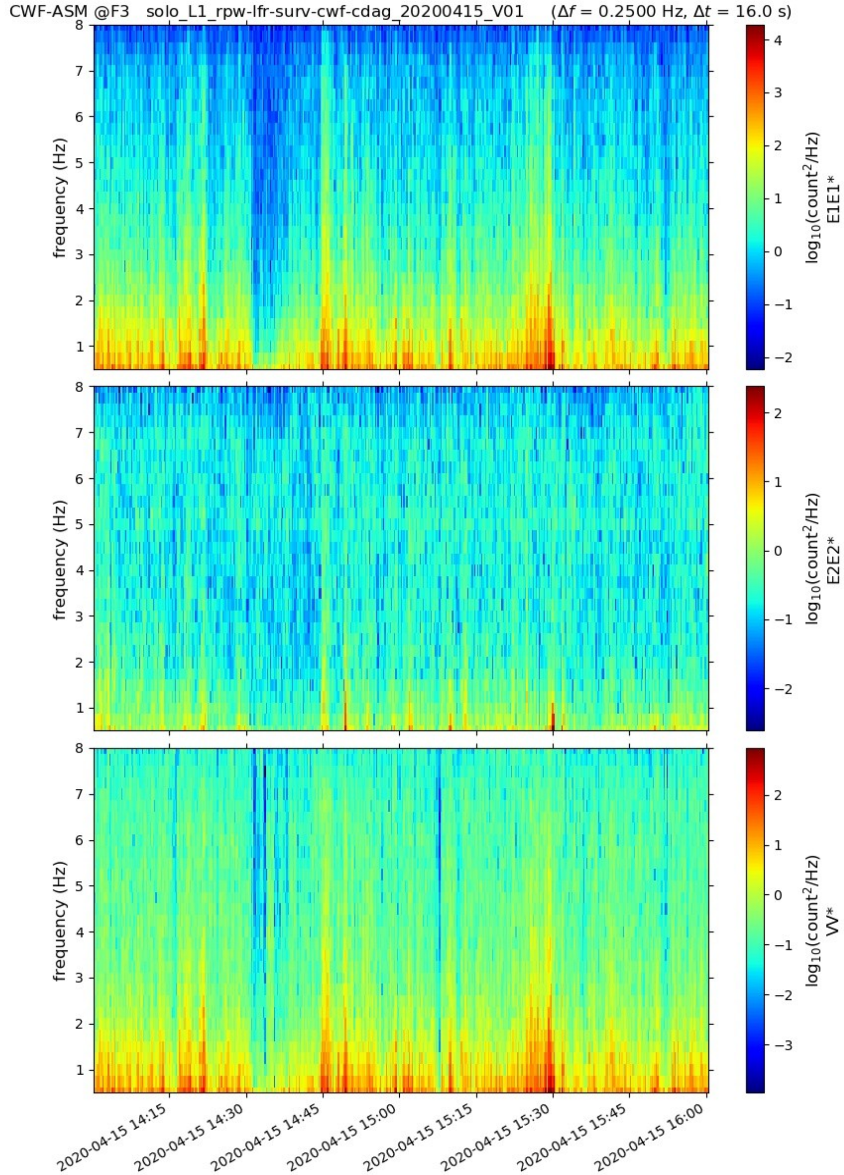
- Together with the fact that the local electron gyrofrequency would be ~100 Hz, it is likely that the observed waves are whistler waves

Short plasma perturbation possibly seen by PAS at ~15:30 (Continuous WF)

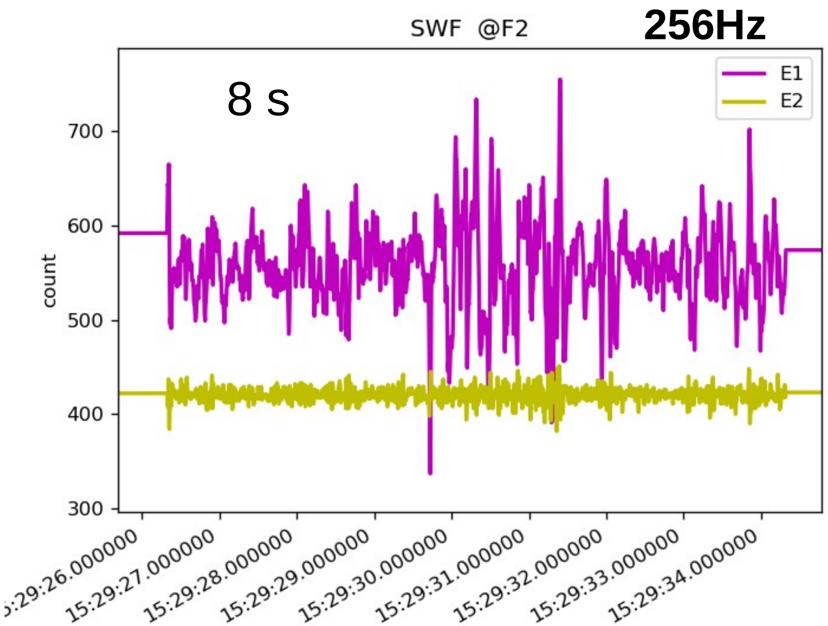
15/04 **2020**

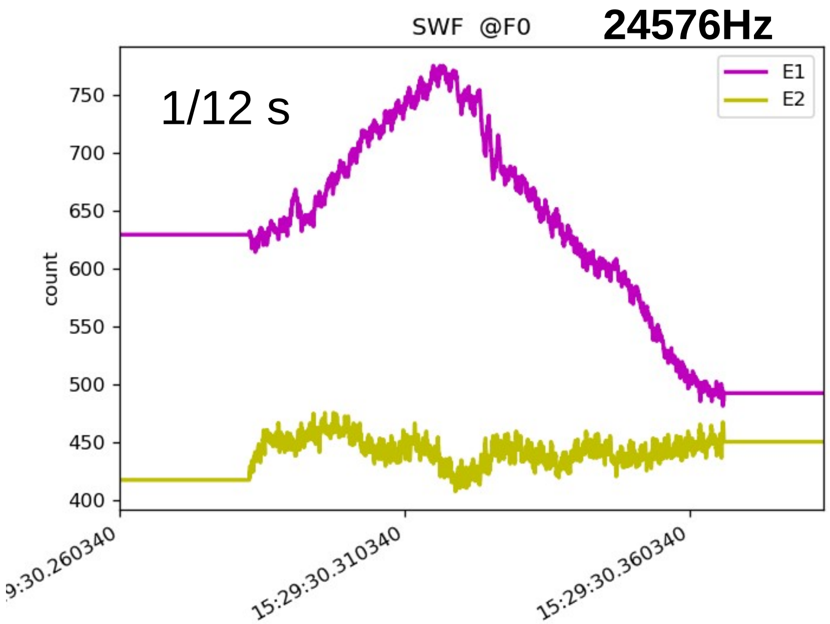
CWF @F3 = 16Hz => **PSD**





Short plasma perturbation possibly seen by PAS at ~15:30 (Snapshot WF)

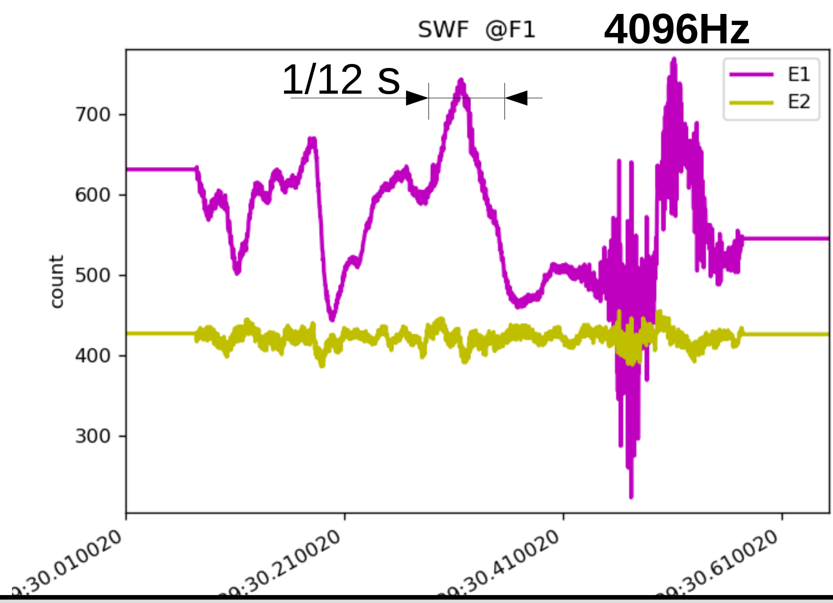




For all SWFs one has AC channels:

E1 = V12_AC
E2 = V23_AC

0.5 s



15/04/2020

Conclusion / Summary

- ✔ LFR is one of the subsystems of the Solar Orbiter **Radio and Plasma Waves (RPW)** instrument**.**
- ✔ Performs the **on-board digital processing** of the low frequency electromagnetic field & wave data (1*V*, 2*E*, 3*B*), measured **in the extended corona and the near-Sun solar wind.**
- ✔ Frequency range of investigation: **~0.1 Hz < *f* < 10 kHz.**

  [**microphysics of the SW** (heating, turbulence, VDF, …)]
- ✔ Combines different output data: from low-level (WF) to high-level (ASM & BP) processed data.

  [assessment of **k** => **dedopplerization possible**]
- ✔ Allows to **increase the scientific return** *for a given telemetry* by ***implementing different strategies* for analyzing and transmitting the data**.
- ✔ These first observations during the near-Earth commissioning phase are encouraging and show **a good consistency of the data**.