SOLAR ORBITER

RPW Instrument

Definition of the In-Flight Burst Modes Detection Algorithms

RPW-SCI-NTT-000243-LES
Iss. 03, Rev. 00

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Change Record

Issue	Rev.	Date	Authors	Modifications
01	00	15/10/2012	M. Maksimovic	Initial document
01	01	09/12/2013	M. Maksimovic	The SWA & MAG failure modes have been described. A series of minor updates
02	00	09/05/2014	M. Maksimovic	- The SBM2 detection mode has been detailed
02	01	01/10/2014	M. Maksimovic	- A typo error for the shock detection conditions in Step 4 of section 2 has been corrected - The MAG failure mode and the use of LFR search coil spectral data for this purpose has been detailed
03	00	02/06/2015	M. Maksimovic V. Krupar O. Alexandrova	- A section on the SBM1 detection in failure mode has been included - The descriptions of algorithms testing and test data preparation have been included - The SBM2 detection algorithm has been modified following first testing using STEREO data - Most of the TBDs & TBCs have been removed or clarified

Acronym List

Acronym	Definition	Acronym	Definition

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List of figures

Erreur ! Aucune entrée de table d'illustration n'a été trouvée.

1 GENERAL

Scope of the Document

This document defines the detection algorithms to be implemented in the DPU flight software.

Applicable Documents

This document responds to the requirements of the documents listed in the following table:

Mark	Reference/Iss/Rev	Title of the document	Authors	Date
AD1	RPW-SYS-SRD-00040-LES Iss01 Rev03	RPW Science Requirements	M. Maksimovic	09/05/2014
AD2	SOLO-RPW-SB-147-CNES Iss03 Rev03	RPW System Specification	E. Guilhem	09/12/2011
AD3	RPW-SYS-SSS-00013-LES Iss03 Rev00	RPW Instrument Software System Specification	P. Plasson	09/05/2014
AD4				
AD5				

Reference Documents

This document is based on the documents listed in the following table:

Mark	Reference/Iss/Rev	Title of the document	Authors	Date
RD1	O. Kruparova et al., J. of Geophys. Res., Vol. 118, Iss8, pp. 4793, 2013	Automated interplanetary shock detection and its application on WIND observations	O. Kruparova et al.	Oct 2012
RD2	Issue 6	Solar Orbiter in-situ coordination: requirements.	T. Horbury	14/03/2014
RD3	RPW-SYS-MEB-TDS-ICD-00098-LES Iss2Rev2.1	RPW TDS Software ICD	P. Plasson & T. Gadeaud	25/03/2014
RD4		RPW burst trigger algorithms using EPD service 20 data: assessment from STEREO and EPD Simulated Service 20 data for RPW	R. Gomez Herrero	07/2014
RD5	RPW-SYS-MEB-DPS-ICD-001019-LES_Issue_5_RPW_S20_Data_Block_ICD	Description of the RPX service 20 parameters	P. Plasson	

Two “selected burst modes” (SBMs) have been defined for RPW in the document [AD1, AD2, AD3] :

- SBM1 for interplanetary shock measurements
- SBM2 for in-situ type III measurements of radio emission and associated density fluctuations and Langmuir Waves

2 ALGORITHM FOR THE INTERPLANETARY SHOCK MEASUREMENTS (SBM1)

Nominal RPW shock detection mode

Figure 1 gives an example of an interplanetary shock crossing with the WIND S/C. The shock crossing is at about 60.4 minutes after 14:30:00 on 2000-07-19 that is at about 15:30:24 this day. This is a very nice example of a quasi-perpendicular shock that should be detected by the present algorithm.

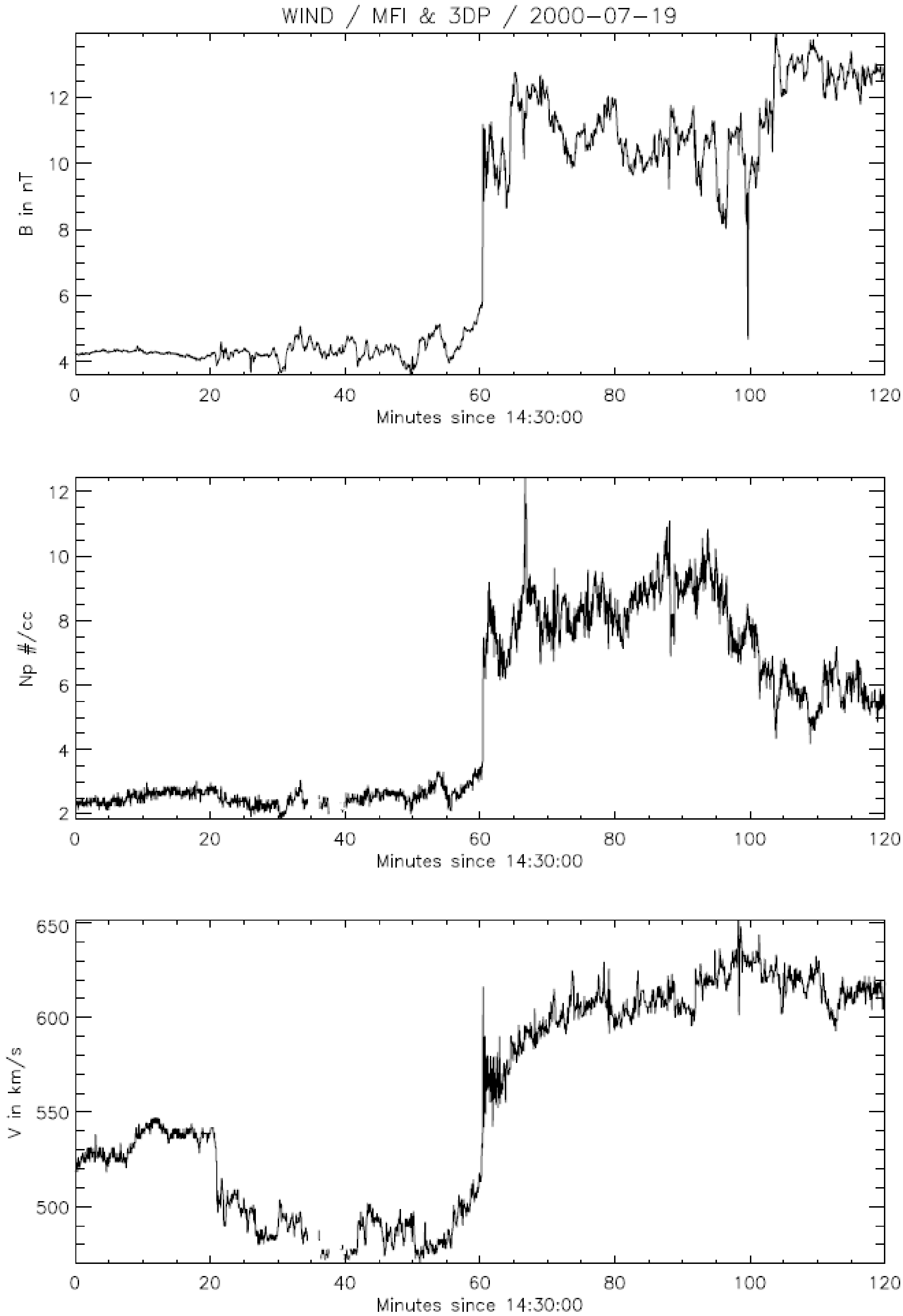

Figure 1 : Example of a quasi-perpendicular shock crossing by the WIND S/C.

The SBM1 algorithm is using data from the MAG and SWA instruments that are transmitted to RPW via Space Wire ("Service 20" TBC). These data are described in [RD2].

The MAG data are: vector magnetic field that is 3 components [*Bx, By, Bz]* per second, at 16 bits per component, 6 octets in total in the spacecraft frame coordinate system The MAG data shall be roughly calibrated and provided in nano tesla (nT) via the service 20. Currently this is still TBC. If this happens not to be the case then a MAG offsets & calibration matrices shall be applied by RPW in order to be able to use calibrated data for the detection.

The SWA data are: the proton number density *Np* (2 octet TBC) and the bulk speed vector [*Vx, Vy, Vz]* (given in the PAS coordinate system, 6 octets TBC) every 4 seconds, that is 4x16 bits (TBC) every 4 sec. The density and speeds shall be provide in physical unit (#/cc for the density and km/s for the speed). This is still TBC.

Note that in case of failure of the SWA data provision, the RPW spacecraft potential could be used internally as a proxy for *Np* and the information on the bulk speed could be dismissed. In case of failure of the MAG data provision, the RPW SCM data could be used internally as a proxy for [*Bx, By, Bz]*. These degraded modes are described in Annex 1.

The main steps of the SBM1 detection algorithm are as follow:

STEP 1:

From the "service 20" MAG and SWA data the RPW DPU has to build its own database with a time resolution of δt = 4 sec (the time resolution of SWA, TBD). Each δt sec the DPU stores the value of the SWA proton density *Np* and computes $V = \sqrt{V_x^2 + V_y^2 + V_z^2}$ and $B = \sqrt{B_{*x}^2 + B_{*y}^2 + B_{*z}^2}$, where B_{*x}, B_{*y} and B_{*z} are averages over δt of *Bx*, *By* and *Bz* respectively.

STEP 2

Once the DPU has *B, Np & V* in memory it builds a rolling buffer with these quantities over a time interval *ΔT_Buffer*. Figure 2 presents an example of shock detection with a rolling buffer of *ΔT_Buffer* = 10 minutes. With such duration it will be possible to detect and flag a shock *ΔT_Buffer* minutes after it has occurred (see Figure 3). This choice of *ΔT_Buffer* has been implemented successfully in [RD1]. A scheme with a *ΔT_Buffer* = 3 to 4 minutes needs to be investigated in order to be compliant with the SWA own burst data buffer which is of 6 minutes (possibility for RPW to provide a shock flag 3 to 4 minutes after the shock occurrence).

STEP 3

Then every 4 sec the DPU shall compute in real time and for the current time *Tc* the following quantities:

- The average B_1 of *B* on the interval of [*Tc* - *ΔT_Buffer* , *Tc* - *ΔT_Buffer/2*] and the average B_2 of *B* on the interval of [*Tc* - *ΔT_Buffer/2* , *Tc*].

- The average Np_1 of *Np* on the interval of [*Tc* - *ΔT_Buffer* , *Tc* - *ΔT_Buffer/2*] and the average Np_2 of *Np* on the interval of [*Tc* - *ΔT_Buffer/2* , *Tc*].

- The average V_1 of *V* on the interval of [*Tc* - *ΔT_Buffer* , *Tc* - *ΔT_Buffer/2*] and the average V_2 of *V* on the interval of [*Tc* - *ΔT_Buffer/2* , *Tc*].

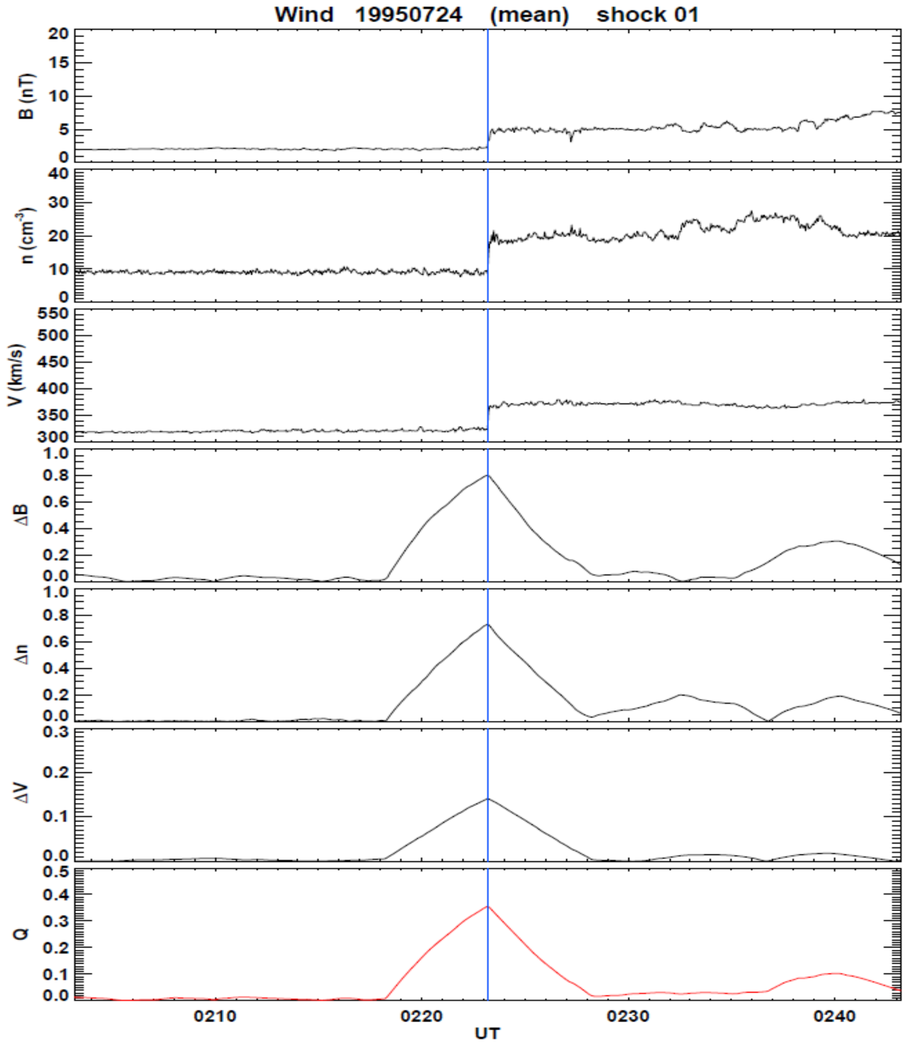

Figure 2 : Example of a shock detection on the WIND spacecraft by [RD1]. The three upper panel display the magnetic field and bulk speed data. The four lower panels display ΔB, ΔNp, ΔV and Q. For this example ΔT_Buffer=10 min.

Then the following quantities have to be computed in real time :

$$\Delta B = \frac{2\times|B_2 - B_1|}{B_1 + B_2} \quad \text{(eqn 1)}$$

$$\Delta Np = \frac{2\times|Np_2 - Np_1|}{Np_1 + Np_2} \quad \text{(eqn 2)}$$

$$\Delta V = \frac{2\times|V_2 - V_1|}{V_1 + V_2} \quad \text{(eqn 3)}$$

And finally a quality factor

$$Q = \alpha\Delta B + \beta\Delta Np + \gamma\Delta V \text{ with } \alpha + \beta + \gamma = 1 \quad \text{(eqn 4)}$$

has to be computed. In [RD1] the following choice has been made: $\alpha = 1/4$, $\beta = 1/12$ and $\gamma = 2/3$. These should be the default values but the [α , β , γ] set of parameters should be upload-able from ground.

STEP 4

Then for a current time *Tc* (with a baseline of 4 sec resolution) the DPU shall have in memory in second rolling buffer [*Tc - ΔT_Buffer* , *Tc*] the following parameters: *Q, ΔB, ΔNp, ΔV* and the time *T*. Let *Tm = Tc - ΔT_Buffer/2* be the time in the middle of the rolling buffer window:

- if the value of Q at *Tm* is the maximum of all the Q values of the rolling buffer and
- if the value of Q at *Tm* is larger than *Qm* and
- if the value of *ΔB* at *Tm* is larger than *ΔBm* and
- if the value of *ΔNp* at *Tm* is larger than *ΔNpm* and
- if the value of *ΔV* at *Tm* is larger than *ΔVm*

then check the following condition

- if the value of $|\Delta B - \Delta n|$ at *Tm* is lesser than CR or if *ΔV* at *Tm* is larger than *ΔVm2*

then there is a shock detected at the time *Tm-ΔT_Buffer/2 = Tc - ΔT_Buffer* and therefore:

- ➢ the rolling buffer containing all the RPW burst data of interest shall be written on the SSMM[1]. This rolling buffer shall have a duration of 13 minutes maximum and shall be centered of the time of the shock *Tm*.
- ➢ a flag shall be sent to the other instruments via the "service 20"[2]
- ➢ the quality factor *Q* shall be sent to the other instruments via the "service 20"[3]

The Figure 3 below describe how the two buffers (one for storing the service 20 data *Bx, By, Bz, vx, Vy, Vz* & *Np* and the second one for storing *Q, ΔB, ΔNp, ΔV*) are implemented. It shows also, since the start time of each buffer are shifted by *ΔT_Buffer*, why a shock detection will be performed only *ΔT_Buffer* minutes after the shock occurred. Note that the while the absolute starting times of the two buffer are shifted by *ΔT_Buffer* their duration is the same, that is *ΔT_Buffer*.

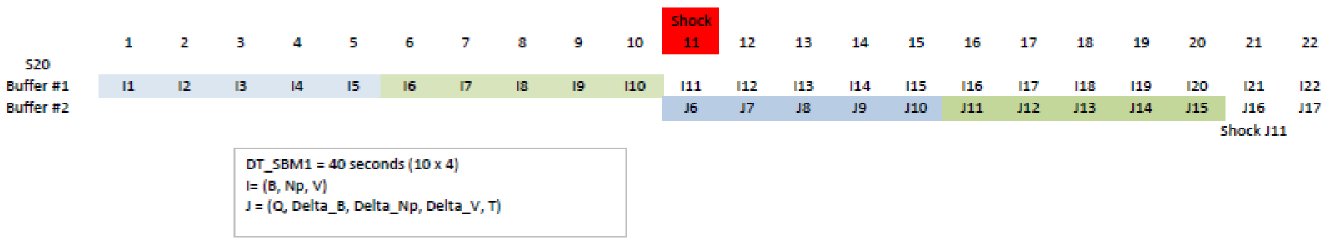

Figure 3 : The two rolling buffers for the SBM1 detection

[1] Note that the duration of this data burst is foreseen to be typically 15 min (see [AD3] but could be decreased if necessary

[2] see [RD2]

[3] see [RD2]

From the study described in [RD1] (efficient shock detection at 1 AU using the WIND data) the baseline values for the parameters *Qm*, *ΔBm*, *ΔNpm* and *ΔVm* are given in Table 1. The Figure 2 displays an example of a shock detection on the WIND spacecraft by [RD1].

Table 1: list of the upload-able parameters for the SBM1 detection

Parameter name	*B* calibration matrix	*Np* & *V* calibration matrixes	*Qm*	*ΔBm*	*ΔNpm*	*ΔVm*	*CR*	*ΔVm2*
Baseline value	TBD	TBD	0.2	0.1	0.1	0.03	0.3	0.1

MAG Shock Detection mode

In the case that, for any given reason, the RPW ground segment decides to disable the RPW shock detection algorithm, the MAG instrument detection shock trigger shall be used. The DPU shall then listen, via the service 20, at the MAG shock trigger flag and retrieve the MAG shock time t_{shock_MAG}. *Tm* shall be then replaced by t_{shock_MAG} in the section above. For this purpose the MAG shock trigger shall be implemented. At the present time this implementation is still TBC by the MAG Team

3 ALGORITHM FOR *IN-SITU* TYPE III MEASUREMENTS (SBM2)

The SBM2 algorithm is using both “service 20” data from the EPD instrument, as described in [RD2, RD4], and data from TDS. The Figure 4 displays an example of an in-situ Type III burst observed by the STEREO spacecraft.

The EPD data of interest are the electron fluxes at several energies in both the sunward direction F^{SW} and in the anti-sunward one F^{ASW} :

Electron flux at 45 keV : F_{45}^{SW} & F_{45}^{ASW}
Electron flux at 55 keV: F_{55}^{SW} & F_{55}^{ASW}
Electron flux at 75 keV: F_{75}^{SW} & F_{75}^{ASW}
Electron flux at 145 keV: F_{145}^{SW} & F_{145}^{ASW}

Note that the four energies above could be change by the EPD instrument if requested by RPW. The SBM2 algorithm will be tested during the cruise phase and we will define then what is the best EPD energy quadruple to be used.

For these energy channels EPD will provide fluxes which will be coded using a 1-byte logarithmic compression (see [RD4]).

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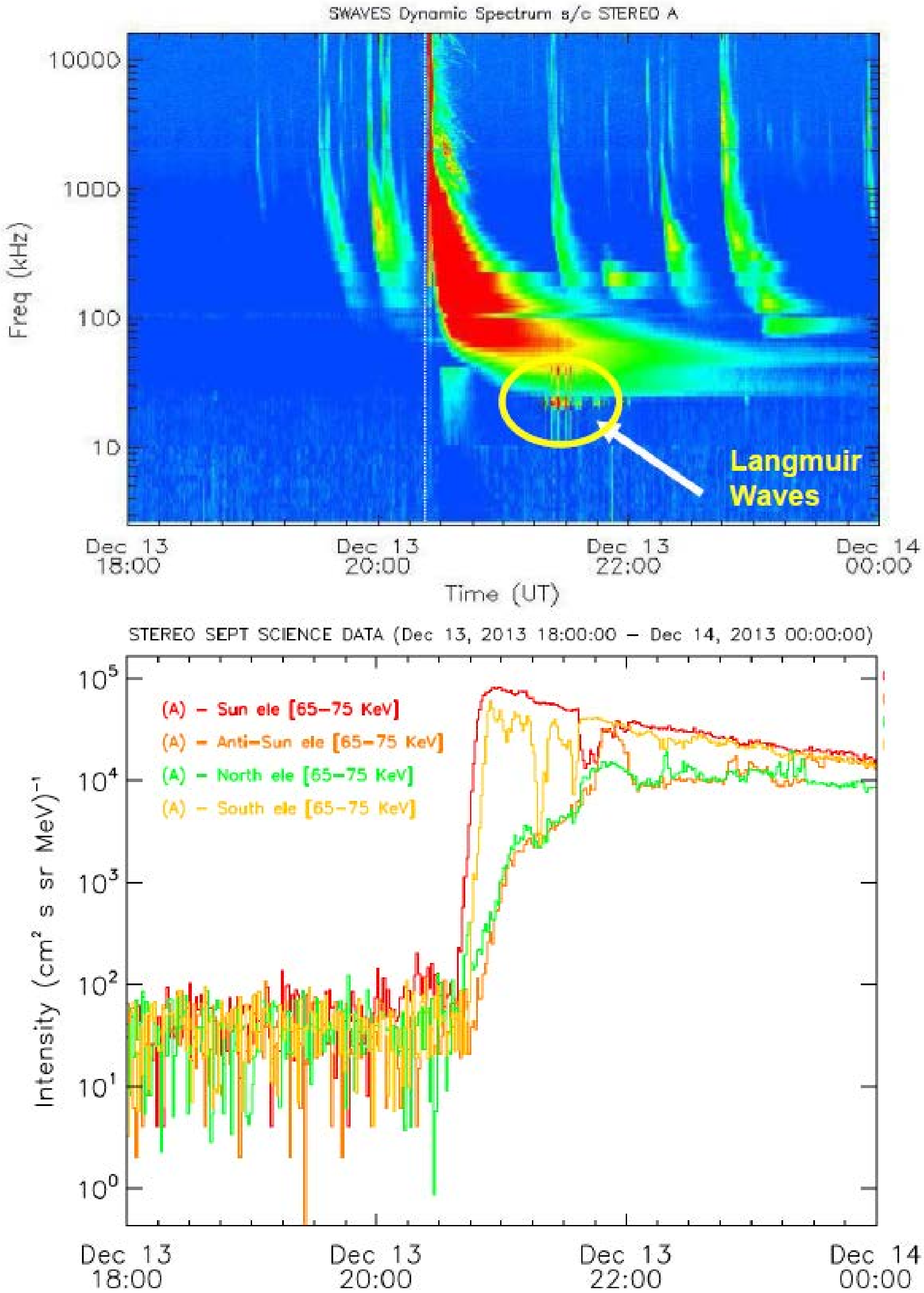

Figure 4 : Example of an in-situ Type III burst observed by the STEREO spacecraft. The upper panel displays the SWAVES TNR-HFR radio observations (equivalent to TNR-HFR on RPW) showing the Type III and the associated in-situ counterpart composed of strong Langmuir waves around the plasma peak. The lower panel displays the solar energetic electrons intensities at in the range 65-75 keV as a function of time and for different flow directions.

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The TDS data of interest are the Low Rate Science (LRS) data that can indicate an intense Langmuir wave activity: typically the electric field peak value *Epeak*, the plasma frequency estimate *Fp* and the number of wave events *Nw*.

The main steps of the SBM2 detection algorithm are as follow:

STEP 1:
From the "service 20" EPD data the RPW DPU has to build its own EPD database with a time resolution of δt_2 =16 sec (time resolution of the TDS LRS data)by averaging over δt_2 sec the EPD fluxes the following way :

$$F_{tot}^{SW} = \left(^{1}/_{N}\right) \sum_{i=1}^{N} F_{45}^{SW}(i) + F_{55}^{SW}(i) + F_{75}^{SW}(i) + F_{145}^{SW}(i)$$

$$F_{tot}^{ASW} = \left(^{1}/_{N}\right) \sum_{i=1}^{N} F_{45}^{ASW}(i) + F_{55}^{ASW}(i) + F_{75}^{ASW}(i) + F_{145}^{ASW}(i)$$

where N=16 is the number of "service 20" EPD 1sec measurements during each TDS measurement period.

Once F_{tot}^{SW} and F_{tot}^{ASW} are defined, the parameter ΔF_{EPD} has to be computed using the following formula :

$$\Delta F_{EPD} = \left| \frac{F_{tot}^{ASW} - F_{tot}^{SW}}{F_{tot}^{ASW} + F_{tot}^{SW}} \right|$$

When both F_{tot}^{SW} and F_{tot}^{ASW} are equal to zero then ΔF_{EPD} has to be set to -1.

Then the DPU has to retrieve the value of the heliospheric distance RUA. Since RUA will not be transmitted via the "service 20", it is necessary to upload it by a telecommand on a weekly basis

STEP 2:
The Figure 4 illustrates the main time management scheme for the SBM2 detection.

Figure 4 : Main time management scheme for the SBM2 detection.

For the current time *Tc*,with a baseline of δt_2 =16 sec resolution, the DPU shall have in memory in a rolling buffer [$Tc - \Delta T_{EPD}$, Tc] the following parameters: ΔF_{EPD} , and the time *T*.

- let N_{EPD} be the number of time occurrences, within the rolling buffer, for which the following condition is verified :

$$\Delta F_{EPD}^{tresh\ 1} \leq \Delta F_{EPD} \leq \Delta F_{EPD}^{tresh\ 2}$$

- if $N_{EPD} > N_{EPD\text{-}tresh.}$ then :

The DPU shall be put into SBM2 mode for a duration ΔT_{SBM2} and the Step 3 below shall be activated. The SBM2 trigger flag 1 is sent to the “service 20” (see RD5).

The following baseline values shall be used :

- ΔT_{EPD} = *20 min.*
- $\Delta F_{EPD}^{tresh\ 1} = 0.2$ and $\Delta F_{EPD}^{tresh\ 2} = 0.99$
- $N_{EPD\text{-}tresh}$ = *25* for RUA > 0.5 and $N_{EPD\text{-}tresh}$ = *60* for RUA > 0.5
- ΔT_{SBM2} = *120 min.*

but these parameters should be upload-able.

STEP 3:
Once in SBM2 the DPU has to quantify the Langmuir Waves activity by using the following TDS data (see RD3 for more details):

- *Nw*, which is the number (between 0 & 16) of strong wave activity occurences during 16 sec
- *Epeak*, is the median value of the amplitudes (in mV/m) of the *Nw* occurences.
- *Fp*, which is the median value of the characteristic frequencies (in kHz) of the *Nw* occurences.
-

The DPU has to set a counter N_{LW} in order to measure how many time occurrences exist during ΔT_{LW} for which there are intense Langmuir waves. More precisely how many time occurrences of the following conditions are satisfied:

- $Epeak > Epeak_{tresh}$
- and $Fp_{min} / R_{UA} < Fp < Fp_{max} / R_{UA}$
- and $Nw > Nw_{tresh}$

Finally if $N_{LW} > N_{LW\text{-}tresh}$ then

- the N_{LW} counter shall be stopped and the SBM2 mode shall run normally until $Tc + \Delta T_{SBM2}$.
- The SBM2 trigger flag 2 shall be sent to the “service 20” (see RD5), confirming that RPW has detected Langmuir waves and is remaining in “in-situ Type III” mode with a quality factor of detection Q_{SBM2} defined as follows:

$$Q_{SBM2} = \frac{N_{LW} - N_{LW-tresh}}{N_{LW}}$$

On the contrary if $N_{LW} < N_{LW\text{-}tresh}$ then both the N_{LW} counter and the SBM2 data mode acquisition shall be stopped.

The baseline values for ΔT_{LW}, $Epeak_{tresh}$, Fp_{min}, Fp_{max}, Nw_{tresh}, and $N_{LW\text{-}tresh}$ shall be discussed with the TDS team but these parameters shall be also upload-able. The table 2 provides the list of the upload-able parameters for the SBM2 detection.

Table 2: List of the upload-able parameters for the SBM2 detection with their baseline values. These latter come from testing of the SBM2 algorithm, described in chapter 5.

Parameter name	***Baseline value***
R_{UA}	
δt_2	16 sec.
ΔT_{EPD}	20 min.
ΔT_{LW}	40 min.
$\Delta F_{EPD}^{tresh\ 1}$ $\Delta F_{EPD}^{tresh\ 2}$	0.2 0.99
ΔT_{SBM2}	120 min.
$N_{EPD\text{-}tresh}$	25 for RUA > 0.5 60 for RUA > 0.5
$Epeak_{tresh}$	4 mV/m
Fp_{min}	5 kHz
Fp_{max}	60 kHz
Nw_{tresh}	3
$N_{LW\text{-}tresh}$	20

If EPD fails in providing any of the F_{45}^{SW} , F_{45}^{ASW} , F_{55}^{SW} , F_{55}^{ASW}, F_{75}^{SW} , F_{75}^{ASW} , F_{145}^{SW} , F_{145}^{ASW} data then the EPD failure mode described in the following chapter shall be applied.

Note finally that, SWA & EPD could go into special in-situ Type III modes for some durations during the [Tc, $Tc + \Delta T_{SBM2}$] time interval. For instance SWA could try to measure the fastest possible the proton density and EPD could put their emphasis on the measurement of the electron fluxes with energies lower than 50 keV. This link between special SWA & EPD modes and enhanced Langmuir Wave activity requires RPW to send the following flags over the service 20 :

- A first flag (HK_RPW_S20_SBM2_FLAG1) is set to 1 when RPW has detected a SBM2 event from the EPD data, i.e when RPW enters in SBM2_ACQUISTION mode. The flag is set to 1 while RPW is in SBM2_ACQUISTION mode.
- A second flag (HK_RPW_S20_SBM2_FLAG2) is set to 1 when RPW has confirmed the SBM2 event by the presence of Langmuir wave. The flag is set to 1 until the end of the SBM2_ACQUISTION mode. This second flag is therefore set ΔT_{LW} minutes after having entered in the SBM2_ACQUISTION mode.

4 MANAGEMENT OF THE "SERVICE 20 DATA" FAILURE MODES

SWA failures modes

If SWA fails in providing the proton density *Np*, then this latter value should be replace by a 4 seconds average of

$$N_{\Phi_{SC}} = a_0 10^{\Phi sc/a_1} + a_2 10^{\Phi sc/a_3} + a_4 10^{\Phi sc/a_5} \qquad \text{(eqn 5)}$$

where Φ_{sc} is the spacecraft potential computed and provided by RPW through the "service 20". The parameters [a_0, a_1, a_2, a_3 a_4, a_5] shall be determined on ground and sent to RPW by telecommand. These parameters may be updated typically every 6 months. First guesses of these parameters are provided in Chapter 5.

note that in equation (5) Φ_{SC} is expressed in Volts and the density in cm^{-3}.

Actually as demonstrated in Chapter 5, when SWA fails in providing the proton density in equation (2) shall be replaced by the following quantity

$$\Delta\Phi = \frac{2|\Phi_2 - \Phi_1|}{|\Phi_2 + \Phi_1|}$$

If SWA fails in providing the proton bulk speed [V_x, V_y, V_z], then the parameter γ shall be set to zero in equation (4) and new parameters α and β shall be sent to RPW by telecommand. Lets call them then α_2 and β_2. One should use as a first guess α_2 =3/4 & β_2=1/4.

MAG failure mode

If MAG fails in providing the magnetic field [*Bx*, *By*, *Bz]*, then these latter value should be replace by the Search Coil Magnetometer low frequency spectral data. More precisely the quantity $B = \sqrt{B_{*x}^2 + B_{*y}^2 + B_{*z}^2}$ defined in step 1 in section 2 above shall be replaced by

$$B_{LFR} = \left(\sum_{i=1}^{i=12} \delta B_{xLFR}^2\,(f_i) + \delta B_{yLFR}^2(f_i) + \delta B_{zLFR}^2(f_i) \right)^{1/2}$$

where the $\delta B_{xyzLFR}^2(f_i)$ are the LFR basic Parameters power spectral densities measured with the F2 LFR filter. More precisely the 12 frequencies involved in the summing above are :

$$f_i(Hz) \in [10.5, 18.5, 26.5, 34.5, 42.5, 50.5, 58.5, 66.5, 74.5, 82.5, 90.5, 98.5]$$

The $\delta B_{xyzLFR}^2(f_i)$ values above shall be used in physical units (nT^2/Hz). The calibration shall involve the multiplication of the telemetry values of $\delta B_{xyzLFR}^2(f_i)$ by a 12 elements calibration vector composed of xx bits numbers (TBD).

EPD failures modes

If EPD fails in providing any of the F_{45}^{SW} , F_{45}^{ASW} , F_{55}^{SW} , F_{55}^{ASW}, F_{75}^{SW} , F_{75}^{ASW} , F_{145}^{SW} , F_{145}^{ASW} data then the EPD data shall be dismissed and the following procedure shall be used as a failure case.

For the current time Tc (with a baseline of δt_2 sec resolution) the DPU shall have in memory in a rolling buffer [Tc - ΔT_{LW}^F, Tc] the number N_{LW}^F of the time occurrences for which the following conditions are satisfied:

- $Epeak > Epeak_{tresh}^F$
- and $Fp_{min} / R_{UA} < Fp < Fp_{max} / R_{UA}$
- and $Nw > Nw_{tresh}^F$

If $N_{LW}^F > N_{LW\text{-}tresh}^F$ then RPW shall go into SBM2 mode for a time duration of ΔT_{SBM2}^F, a flag shall be sent to the other instruments via the "service 20"[4], stating that RPW is in "in-situ Type III" mode. Note that in this case quality factor as defined previously shall be set equal to 1 by defaut since there is no way of measuring a quality factor in this case ($N_{LW} = N_{LW-tresh}^F$).

The baseline values for ΔT_{LW}^F, $Epeak_{tresh}^F$, Nw_{tresh}^F, and $N_{LW\text{-}tresh}^F$ shall be discussed with the TDS team but these parameters shall be also upload-able. The table 3 provides the list of the upload-able parameters for the SBM2 detection in failure mode.

Table 3: List of the upload-able parameters for the SBM2 detection on failure mode, with their baseline values

Parameter name	R_{UA}	δt_2	ΔT_{LW}^F	ΔT_{SBM2}^F	$Epeak_{tresh}^F$	Nw_{tresh}^F	$N_{LW\text{-}tresh}^F$
Baseline value	0.5	16 sec.	20 min.	120 min.	4 mV/m	3	20

5 TESTING OF THE SBM1 & SBM2 ALGORITHMS

SBM1 testing

The SBM1 algorithm has actually been built using real data from the WIND spacecraft. It does not require therefore to be tested. In the following sections we test only the SBM1 algorithm in failure modes.

Testing the SWA failure mode

If SWA fail in providing the proton density n, then this value can be replaced by the proton density n_φ calculated from the spacecraft potential Φ as:

$$n_\Phi = a_0 10^{\Phi/a_1} + a_2 10^{\Phi/a_3} + a_4 10^{\Phi/a_5}, \quad \text{(eqn 6)}$$

[4] see [RD2]

where parameters a_i shall be determined on ground and sent to RPW by telecommand [RD1]. We performed tests using the Cluster data. We present analysis of two IP shocks observed by Cluster-1 (Figures 5 & 6). The parameters a_i for equation (6) obtained by polynomial fitting with the Cluster/Whisper data are given in Table 1.

Table 1: Parameters a_i for equation (6) for Cluster-1 for 2004-01-22 and 2003-02-27

	2004-01-22	2003-02-27
a_0	236	123
a_1	-5.88	200
a_2	-87	-109
a_3	50	100
a_4	43	0.43
a_5	16.7	250

Figures 5 and 6 show the fast forward (FF) and fast reverse (FR) IP shock passages at Cluster-1, respectively. Panels a) – c) display the magnetic field B (Cluster-1/FGM), proton density n (Cluster-1/CIS), and proton flow velocity V (Cluster-1/CIS). Panel d) shows results of the IP shock detection in the nominal mode (ΔB in red, Δn in green, ΔV in blue, and Q in purple). Vertical dashed line indicates the IP shock detection time. Panel e) displays n_Φ calculated from equation (6) using parameters a_i from the table 1. Discrepancies between panels b) and e) are negligible. Panel f) shows results of the IP shock detection using n_Φ instead of n (ΔB in red, Δn_Φ in orange, ΔV in blue, and Q in purple). Obtained IP shock crossing is consistent with panel d). Since the parameters a_i from the table 1 are very different for the two days and the IP shock detection algorithm evaluates relative changes of input parameters, we suggest to use directly the spacecraft potential Φ (panel g) in order to detect the shock. Practically Δnp in eq (2) shall be replaced by .

$$\Delta\Phi = \frac{2|\Phi_2 - \Phi_1|}{|\Phi_2 + \Phi_1|}$$

Panel f) displays results of the IP shock detection using Φ instead of n (ΔB in red, $\Delta\Phi$ in orange, ΔV in blue, and Q in purple). We conclude that proton density n should be substituted directly by the spacecraft potential Φ, if SWA fail in providing the proton density n_p.

In case that SWA fails in providing both the proton density n_p and the proton bulk speed V, then the parameter γ shall be set to 0 in equation (1) and new parameters α and β shall be sent to RPW by telecommand. Let's call them then α_2 and β_2. One should us as a first guess α_2=0.75 and β_2=0.25 [RD2]. We have performed the same analysis as above but omitting the proton bulk speed V (Figures 7 and 8). We obtain good results for both events.

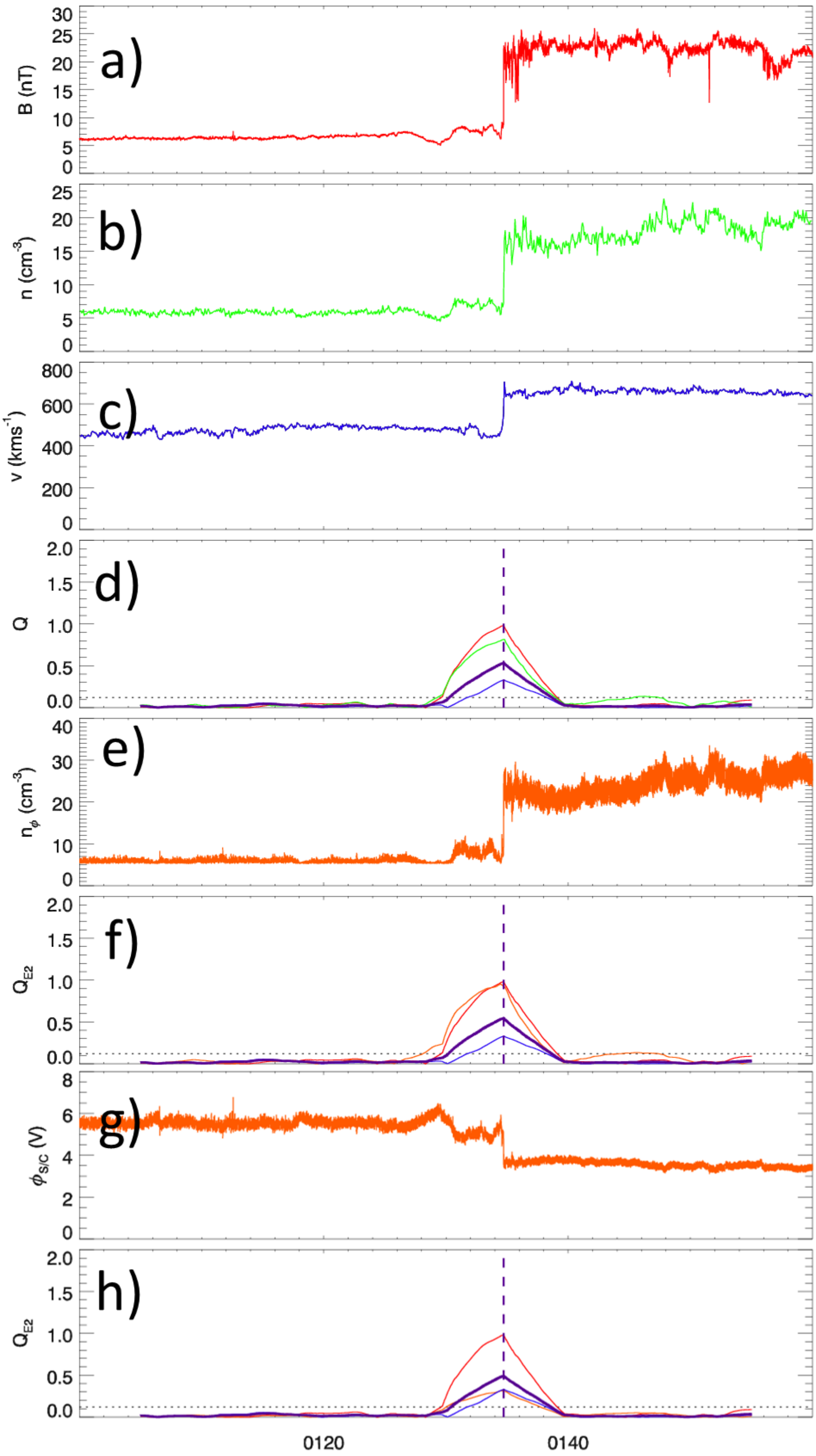

Figure 5: Analysis of FF IP shock detected by the Cluster 1 spacecraft from 2004-01-22

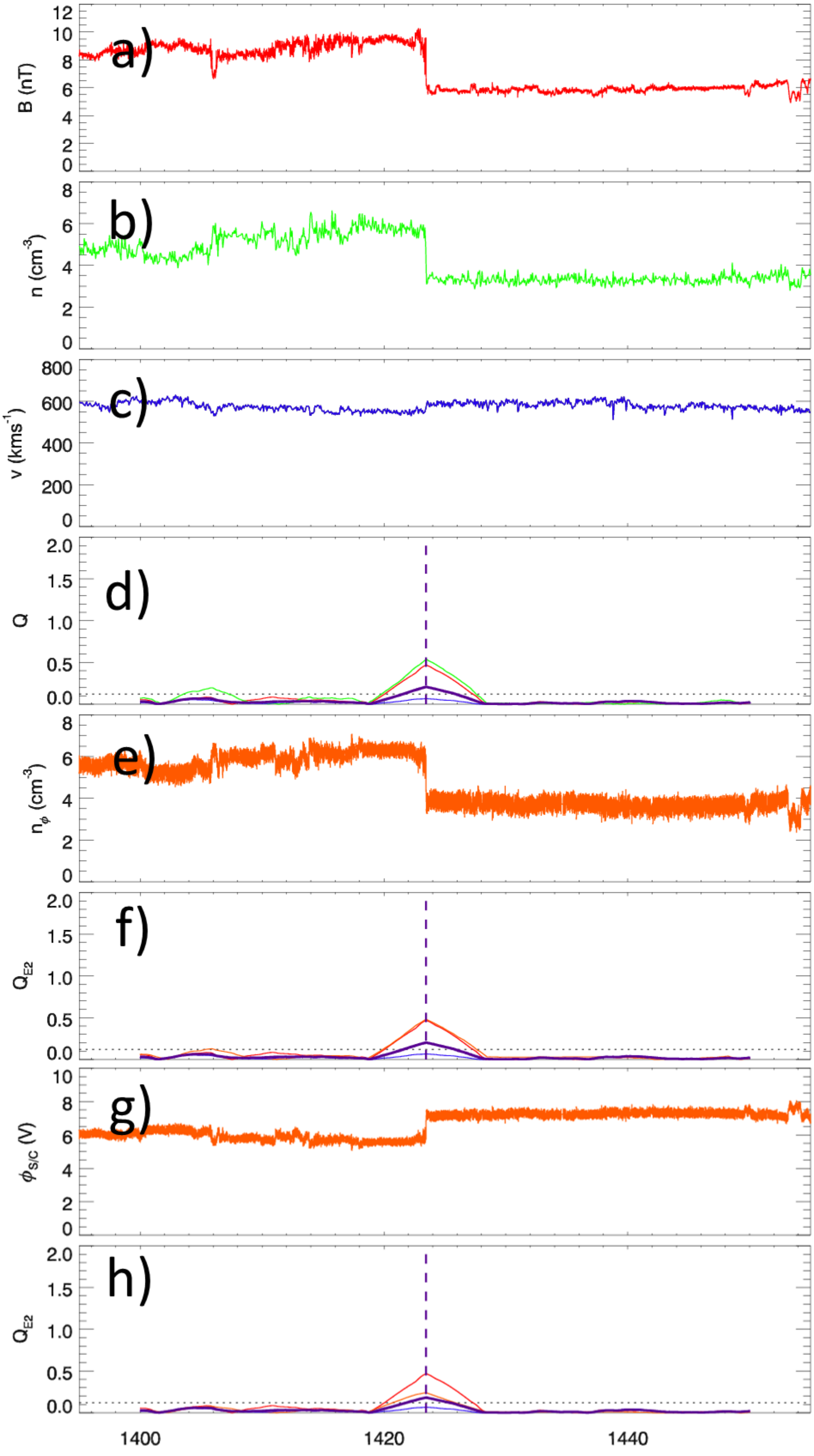

Figure 6: Analysis of FR IP shock detected by the Cluster 1 spacecraft from 2003-02-27

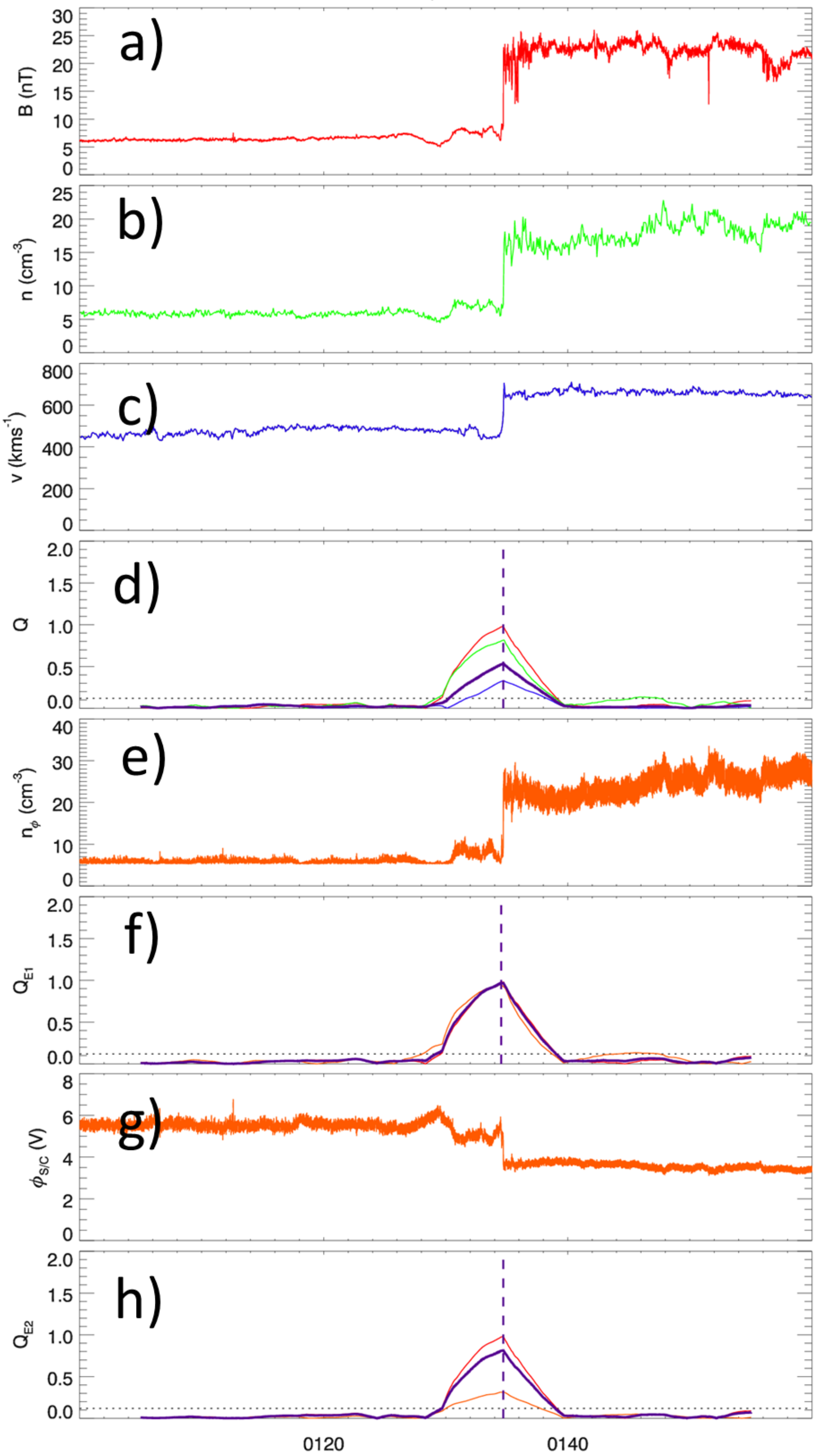

Figure 7: Analysis of FF IP shock detected by the Cluster 1 spacecraft from 2004-01-22

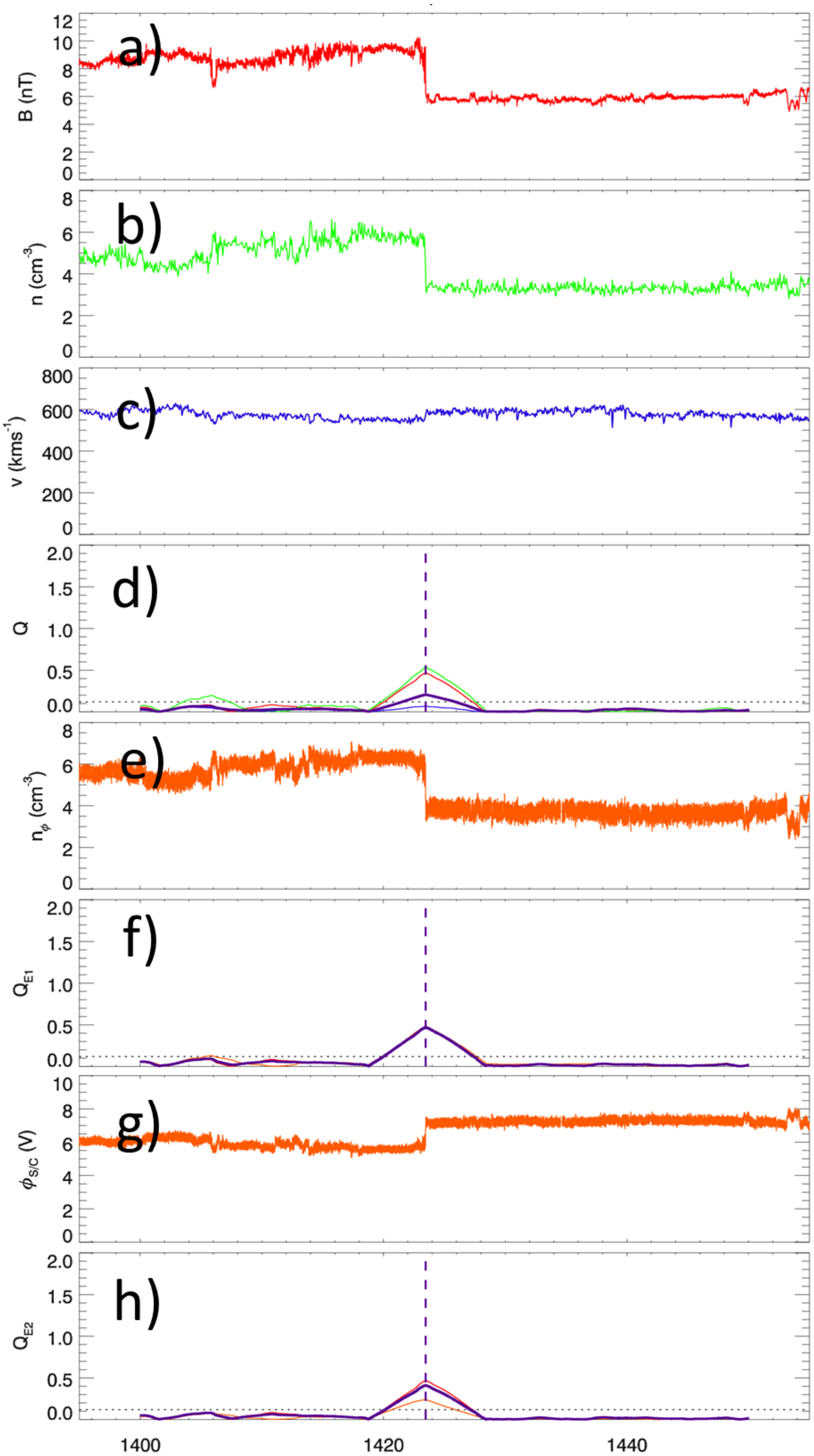

Figure 8: Analysis of FR IP shock detected by the Cluster 1 spacecraft from 2003-02-27

Testing the MAG failure mode

If MAG fails in providing the magnetic field, then these value should be replaced by the SCM low frequency data B_{LFR} [RD1]:

$$B_{LFR} = (\sum_{i=1}^{i=12} \delta B_{xLFR}^2(f_i) + \delta B_{yLFR}^2(f_i) + \delta B_{zLFR}^2(f_i))^{1/2},$$

where $\delta B_{xLFR}^2(f_i)$ are the LFR basic Parameters power spectral densities measured with the F2 LFR filter with following frequency channels f_i(Hz): [10.5, 18.5, 26.5, 34.5, 42.5, 50.5, 58.5, 66.5, 74.5, 82.5, 90.5, 98.5]

We perform tests using the Cluster data to validate this substitution. We used power spectral densities measured by the STAFF-SA instrument onboard Cluster-1. Our results are shown in Figure 9. Panels a) – d) are identical as in Figures 1 – 4. Panel e) displays B_{LFR} calculated as in equation (7). The only difference is in used frequency channels. RPW will have frequency channels separated linearly, whereas STAFF-SA has a logarithmic scale. For our analysis we used following frequency channels f_i(Hz): [11.0, 13.9, 17.5, 22.1, 27.8, 35.1, 44.2, 56.7, 70.2, 88.4]. Panel f) shows results of the IP shock detection using B_{LFR} instead of B (ΔB_{LFR} in orange, Δn in green, ΔV in blue, and Q in purple). Obtained IP shock crossing is consistent with panel d).

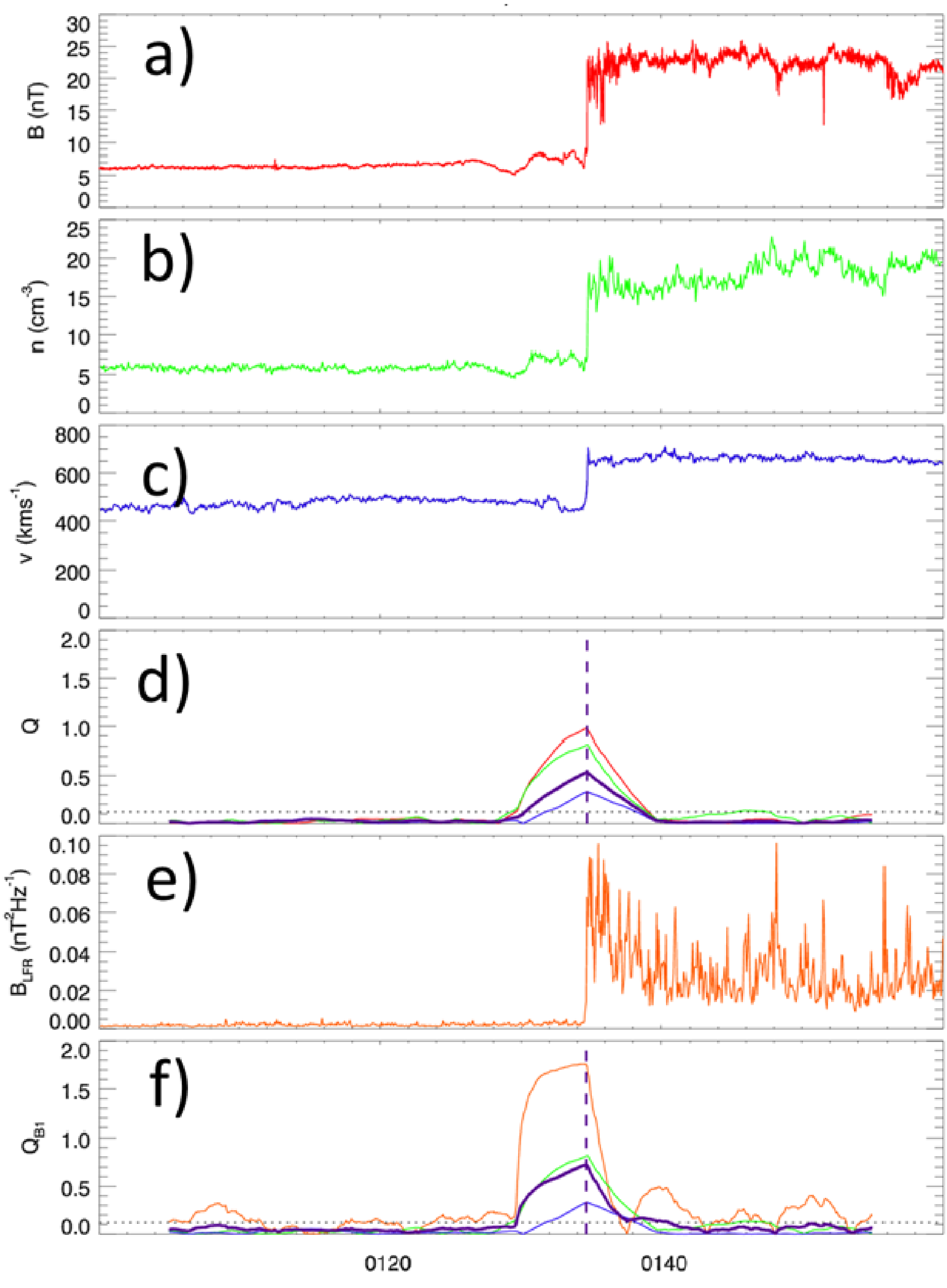

Figure 9: Analysis of FR IP shock detected by the Cluster 1 spacecraft from 2003-02-27

SBM2 testing

For the purpose of the SBM2 testing, we have used

- STEREO data of energetic electron to mimic the EPD data
- STEREO/WAVES LFR data to mimic the TDS data

For the energetic electrons data we have received from the Spanish EPD team STEREO energetic particle data which are close to those that will be produced by EPD on Solar Orbiter [see RD4]

For the TDS data, we have used the S/WAVES LFR data. For each of the events, we have integrated the LFR Power Spectral Densities ($V^{\wedge 2}$/Hz) around the plasma peak, multiply it by the frequency bandwidth of integration and then divided it by L^2, where L is the Stereo Antenna length.

We end up then with a quantity that we call E^2_{radio} which square root we assume to be proportional to the product of the two TDS data products $N_W \times E_{peak}$., where N_W is the number (between 0 & 16) of strong wave activity occurences during 16 second and E_{peak} is the median value of the amplitudes (in mV/m) of the N_W occurences.

Then for the time interval for which we have activity we sort a value of N_W from 0 to 16 using a half normal distribution having a maximum at 16. Then E_{peak} is simply proportional to E_{radio}/N_W. For N_W =0 we assume that E_{peak} = 0.

Figure 10 displays a typical SBM2 event observed by STEREO and used for our testing. This is actually the same event as the one displayed on Figure 4. The first and second panels displays the value of E_{peak} and N_W respectively, as retrieved from the S/WAVES LFR data. The third panel represents the total EPD electron fluxes F_{tot}^{SW} (solid line) and F_{tot}^{ASW} (dots) as defined in chapter 3. The last panel represent the number N_{EPD} of time occurrences, within a rolling buffer of 20 minutes, for which the condition $\Delta F_{EPD}^{tresh\,1} \leq \Delta F_{EPD} \leq \Delta F_{EPD}^{tresh\,2}$ is satisfied (see chapter 3).

The two vertical lines on Figure 10 represent the time of Langmuir Waves activity. The dotted line represent the start of the SBM2 mode defined from $N_{EPD} > 25$. The dashed vertical line represents the start of the SBM2 mode plus ΔT_{LW} =40 minutes. The choices, $N_{EPD} > 25$ and ΔT_{LW} =40 minutes comes from the testing of six STEREO events for which the EPD-like data have been provided by the EPD team. The value of ΔT_{LW} =40 minutes comes from the fact that on average the time between the start of the SBM2 event and the start of the Langmuir waves is on the average 15 minutes. There is therefore a need to use a ΔT_{LW} large enough so that we capture enough Langmuir waves. Using the parameters as defined in chapter 3 we have been able to detect 5 of the 6 SBM2 provided by the EPD team.

Testing the EPD failure mode

If EPD fails in providing the electron data, we shall use only the TDS data, applying the procedure as define in chapter 3.

If we test this procedure on the six STEREO test candidates, we are able to detect all of them with a time delay (delay between the actual start of the Langmuir waves event and the entering into SBM2 mode) of 15 minutes.

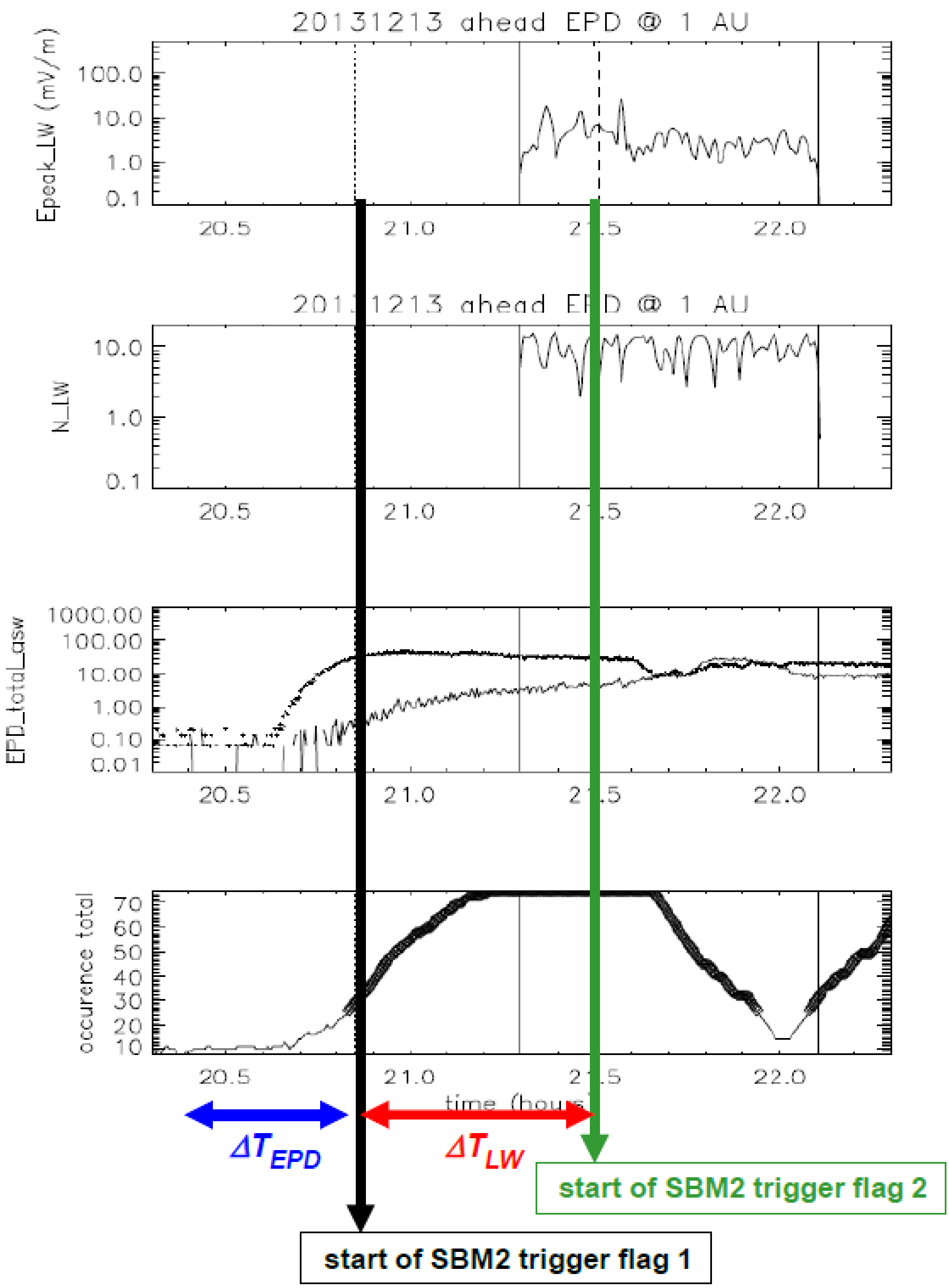

Figure 10: Exemple of SBM2 detection

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