MARS EXPRESS

PLANETARY FOURIER SPECTROMETER

INSTRUMENT PERFORMANCE BUDGETS

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1 - INTRODUCTION.

A priori the most important scientific objective of PFS is to be able to provide a full global circulation model of Martian atmosphere valid on the time scale of one day to several years. We would like to study the variation of the Martian atmosphere during the day with local time, during the seasonal changes, during annual changes . This would imply 360 x 180 measurements equally spaced on the martian atmosphere taken INSTANTANEOUSLY so that one could monitor the evolution during the day , during the seasons and during the years. It is assumed that one measurement every degree squared of Martian atmosphere is sufficient to give all the needed information.

WORKING BELOW 2000 KM ALTITUDE WE HAVE 53.06MINUTES , IF EACH MEASUREMENT TAKES 6 SEC , WE HAVE 530 MEASUREMENTS PER ORBIT TO WHICH WE HAVE TO ADD 60 CALIBRATION MEASUREMENTS (78 PER ORBIT IN COMMISSIONING PHASE) and two autotest data set.

As it has been said in the PFS – IPDR – 10 , we can have and probably transmit , 590 measurements per orbit , in one hour of data taking, including calibration data and autotests. If we had 180 orbits per day , we could take enough measurements to study the seasonal variations, and assuming the local time variations are decoupled from the seasonal variations, we could select a subset of measurements , so to study the variations during the day. Obviously some limitations are introduced by the limited amount of measurements we can take and transmit.

PFS , however has also scientific objectives concerning the soil of Mars, and in this respect becomes important to know where we point , what we measure and how accurate we measure . We shall compare our measurements with measurements from IRIS Mariner 9, TES from Mars Global Surveyor, and OMEGA from Mars Express.

2.1 – WHAT WE MEASURE.

We measure the radiation intensity coming from Mars and entering the Interferometer within the IFOV (4 deg for the LW channel , and 2 deg for the SW channel). These measurements are repeated during the motion of the double pendulum, so that 18000 measurements are taken equally spaced in terms of optical path difference . Each measurement is taken every 150 nm of displacement of the corner cubes of the interferometer. These measurements are then reduced to 16384 for the SW and 4096 for the LW. The dynamical range of these measurements is tremendous as at least 16 bits are necessary to get the full information. The FFT of these measurements , which we can do on board in real time, will give us the spectrum of the Martian radiation in the wavenumber range 200 – 2000 for the LW and 2000 – 8200 for the SW. The spectral resolution is 2 cm-1 , corresponding to more then 4000 for the ? ?? at 8200 cm-1, and corresponding to 100 at 50 microns. From this point of view we are better than IRIS, much better than TES and extremely better than OMEGA.

2.2 – THE NEEDS FOR OUR SCIENTIFIC OBJECTIVES.

What is needed to achieve our scientific objectives is to have the measured spectrum (1.2 to 5 and 5 to 45 microns) with good Signal to Noise ratio. We aim to have a SNR of >100 over the entire wavenumber interval, but we know this is not always possible, specially in the middle of the CO_2 absorption bands , where the radiation coming from Mars can be very small or vanish complitely. In any case to study minor features we have always the possibility to

average many spectra in order to increase the SNR. This is one reason to try to take as many measurements as possible. Indeed in some cases the absolute radiance in the middle of the absorption bands can be of very crucial importance . It is therefore very important that we will be able to reduce the measurement cycling time from 12-15 seconds (Mars 96 mission) to 6 seconds for Mars Express.

In terms of space resolution , the study of the atmosphere does not require high space resolution, while the study of the soil needs high space resolution. The LW channel has a FWHM of 3 degrees , but has a 4 deg max footprint size. The SW channel , on the contrary has a FWHM of 1.6 degrees and a 2 degrees max footprint size. At pericenter (300 Km) this would correspond to 20 and 10 Km space resolution, while if we start operating +-30 minutes around pericenter, we should get (depending on the final orbit) 100 or 50 Km footprint max size. It is very important to note that this footprint size , which is OK for any atmospheric study , is much smaller than the IRIS footprint size (200 – 400 Km) , but certainly is much bigger than the TES or OMEGA space dimensions of one pixel. But PFS has no imaging requirement. It is very important to add that only PFS , on the basis of the high spectral resolution , will be able to identify the spectral windows in which the atmosphere is completely transparent and , therefore, allows to study the soil mineralogic composition.

3 – SPACE CALIBRATIONS.

PFS needs continuous calibration in space , as the absolute radiance is what we aim to measure.

In order to achieve the calibrated Martian spectrum, we shall take 3 measurements : to Mars, to the deep space and to a warm black body of known temperature :

If we take

$$Ia = Res * (Imars - B(instr)) \qquad Ia - Ib = Res\,(Imars - B(warm))$$

$$Ib = Res * (Bwarm - B(instr))$$

$$Ic = Res * (Bcold - B(instr)) \qquad Ib - Ic = Res\,(B(warm) - B(cold))$$

Then we have :

$$Imars = \frac{(Ia - Ic)}{Ib - Ic} * B(warm)$$

$$Res = (Ib - Ic)/B(warm)$$

Where we have Ia, Ib, Ic respectively the measurement looking at Mars, warm blackbody and deep space. By assuming that there is no radiation from deep space Bcold =0 , we can compute the responsivity of the instrument , and then the Martian radiation, eliminating in this way the responsivity of the instrument, which may be changing at any orbit.

It is for this reason that experiments like PFS will always need a pointing system , a priori. In practice the warm blackbody is the essential part, because soon or later the instrument , during one orbit around Mars, is pointing to deep space, and can take that measurement.

What has been described above about calibration , concerns only the LW channel. For the SW channel thhe situation is that only between 3.5 and 5 microns there is thermal radiation , so that only in this range we will have some radiative calibration from Mars . These calibrations will be valid for studying the night measurements, in which we shall have only

thermal radiation and no solar radiation. A relative global radiative calibration will be achieved by using on board a known calibration lamp.
It should be noted that in space the spectral calibration may be provided from the martian measurements themselves, as thin spectral features like the CO2 Q brenches should appear at the same wavenumber always.

4 – THE GROUND CALIBRATION EXERCISE.

The ground calibration exercise will aim to perform the following studies :
--Measure the responsivity of the instrument in different conditions (gain factors , temperatures , different conditions for the speed control loop , different sample/ hold and A/D converter , etc).
--Measure the actual spectral resolution for the 2 channels. Perform also the actual spectral calibration , by studying the dependence of the laser diode wavenumber from the instrument temperature.
--Model possible thermal behaviour of the LW channel when thermal sources with rapidly changing temperature are observed. This can be called memory effect, tipical of all IR detectors.
-- Control the overall optical performance before and after environmental tests , in order to identify the actions needed, if any , to keep the experiment still performing well in space.

The list of calibration tools includes: (1) Vacuum chamber. (2) Source system A = a standard (certified) lamp with a certified scattering screen. (3) Source system B = narrow aperture high temperature SW BBS (black body source) with a scattering screen. (4) Source system C = two wide aperture low temperature LW BBS , one of them to imitate the planet, other the cosmic space.
Vacuum chamber. It has internal diameter 1.1 m, PFS itself and also calibration systems B and C are placed inside the chamber during calibration. It has an optical window. Light from the source A which is placed outside the camera comes through this window to PFS posed inside of camera. The chamber was produced in Italy specially for PFS calibration and installed in IFSI, Frascati .

In the past the ground calibration exercise has allowed us to conclude that :
1. For the SW channel the reference wavelenght varies between 1.2067 and 1.2142 ?m as the reference channel temperature rises from 6.5 to 25 øC; similarly, for the LW channel the reference wavelenght varies in the range 1.2120 - 1.2150 ?m as the reference channel temperature rises from 15.5 to 25 øC.
2. All the major features of testing gases and liquids are well detected, both in relative intensities and in wavelength position.
3. The LW reference laser can be used to record the SW spectrum, and viceversa. In this case only the wavenumber scale has to be properly determined. This adds an element of redundancy to the PFS.
4.The spectral resolution derived by looking either at the closest resolved features or at the full width at half maximum of sharp features is consistent with the nominal value of 2 cm-1.

4.1 – POINTING AND SPATIAL PERFORMANCE.

PFS is not an imaging instrument, in the sense that the end result is not necessarely an image. In this sense space resolution is not appropriate term for our experiment. It is not excluded, however , that at the end the results may be shown as images.
PFS has two channels with different FOV : the LW channel has a FOV of 4 degrees, while the SW channel has a FOV of 2 degrees. Note that at a pericenter distance of 300 Km the footprint size is 10 Km for the SW and 20 for the LW. If the pericenter is going to be as low as 250 Km , then we shall have 8.5 Km footprint for the SW and 17 Km for the LW. As we shall start taking measurements 30 minutes before pericenter, we shall have the worst resolution of the order of 47 Km for the SW and 94 Km for the LW.
We can see from the numbers given above , that , if the orbit spacing will be of the order of 50 Km, working at distances of the order of 2000 Km will allow PFS to cover completely the Martian surface, and therefore to built images of the soil and of the atmosphere, after some tens of orbits.
Finally , as PFS has pointing capability, we can state that the accuracy of the pointing system , being 0.5 deg, is smaller than the FOV of both channels, therefore will allow us to locate the footprint on the martian surface with enough accuracy.

5 – SUMMARY

We shall summarize here the performance budgets of PFS :

		LW	SW	
Spectral coverage cm-1		**200 – 2000**	**2000 – 8200**	
	Microns	**5 – 50**	**1.2 – 5**	
Spectral resolution cm-1		**2**	**2**	
	? ?? ?? ?	?????? ???? ?	????? ?? ????	
Footprint size Km		**100 –20**	**50 – 10**	
Number of points :				
Interferogram		**4096**	**16384**	
Spectrum		**2048**	**8196**	
Acquisition time sec.		**5**	**5**	
Repetition time sec.		**6**	**6**	
SNR		**>100**	**>100**	
Working time minutes below Km 2000				
Around pericentre		**53.06 m**	**53.06 m**	**(*)**
Number of measurements				
Per orbit		**530**	**530**	
Per day		**1590**	**1590**	
Calibrations Meas. orbit				
	Space	**10,13**		
	BlcBd	**10,13**	**10, 13**	
	In total	**10+10+10 before and 10+10+10 after pericenter**		
In commissioning phase		**13+13+13 before and 13+13+13 after pericenter**		
Number of bits				
Per orbit	**Megabits**	**530 measurements + 60 calib.**		
Per orbit	**Megabits**	**530 measurements + 60 calib.**		
Per day	**measurements**	**1590 +60 interferograms**		
Per day	**measurements**	**1590 +60 spectra**		

See document MEX-CNR-IPDR-10.01 for detailed bit budget.

Which includes 1590 martian measurements SW and LW , +
+ 60 calibration measurements interfer.+ all housekeeping.

(*) It is assumed here and in all the documents that will be possible to work for 53 minutes around pericenter, i.e. below 2000 Km altitude . Deep space and calibration black body measurements will be taken before and after this observation period, as they do not need the nadir pointing platform.

It should be noted that the number of Mbits per day that we want to transmit to ground are very flexible as we have possibility to reduce the amount of data by cutting either the interferograms or the spectra. The numbers given above shall be rather considered our baseline.