ANALYTICAL MODEL AND SPECTRAL CORRECTION OF VIBRATION EFFECTS ON PFS FOURIER TRANSFORM SPECTROMETER. F. Schmidt[1], I. Shatalina[2], B. Saggin[2], N. Gac[3], M. Kowalski[3] and M. Giuranna[4], [1]Univ Paris-Sud/CNRS, IDES, UMR8148, Orsay, F-91405, France (frederic.schmidt@u-psud fr), [2]Dipartimento di Meccanica, Politecnico di Milano, Campus of Lecco, via Gaetano Previati 1/c, 23900, Lecco, Italy, [3]Laboratoire des Signaux et Systèmes (L2S), UMR8506 Univ Paris-Sud - CNRS – SUPELEC, SUPELEC, 3 rue Joliot Curie, Gif sur Yvette, F-91192, France; [4]IFSI, via del Fosso del Cavaliere 100, 00133, Roma, Italy

Introduction: Since January 2004, the Planetary Fourier Spectrometer (PFS) [1] onboard Mars Express (MEx) is the instrument with the highest spectral resolution observing Mars from orbit. It permits studying the atmospheric structure, major and minor compounds. The present time version of the calibration [2,3] is limited by the effects of mechanical vibration [4], currently not corrected. We proposed here a new approach to correct for the vibrations based on semi-blind deconvolution of the measurements. This new approach shows that a correction can be done efficiently with 85% reduction of the artifacts, in an equivalent manner to the stacking of 10 spectra. It may be applied on the complete PFS dataset, correcting the large-scale perturbation due to microvibrations for each spectrum independently. This approach is validated on actual PFS data of Short Wavelength Channel (SWC), perturbed by microvibrations. More generally, this work may apply to numerically "deshake" Fourier Transform Spectrometer (FTS), widely used in space experiments or in the laboratory.

Method: Using some mathematical reorganization and simplification, the analytical expression of mechanical vibration due to periodic misalignment and optical path errors can be written as a convolution products in complex form [5,6]:

$$I_{PFS}(\sigma) = I_{Mars}(\sigma) \star K_{PFS}(\sigma)$$

To estimate the signal from Mars I_{Mars}, from the observed spectra I_{PFS} , without knowing the kernel K_{PFS} due to microvibration, we need to perform a blind deconvolution. Our approach is based on cost function that must be minimized [7]:

$$\frac{1}{2}\|I_{PFS} - K_{PFS} \star I_{Mars}\|_2^2 + \lambda_K \|K_{PFS}\|_1 + \frac{\lambda_{Mars}}{2}\|D \star I_{Mars}\|_2^2$$

The first terms represent the data fit, the second the sparsity regularization and the third a smooth regularization. We proposed to minimize the function iteratively by estimating I_{Mars}, and K_{PFS}. We use an initial guess of the Martian spectra as the first step and estimate K_{PFS} with the sparsity regularization only. We then estimate I_{Mars} with smooth regularization only. The iterative loops between those two steps are performed until to reach convergence (see figure 1).

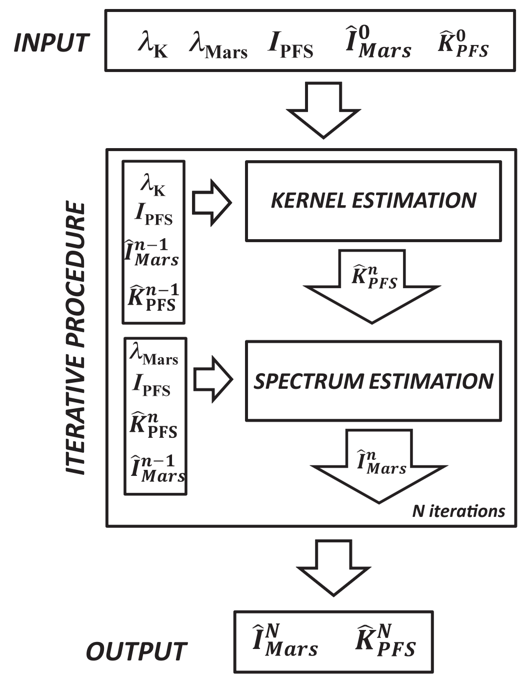

Figure 1: Scheme of the proposed iterative deconvolution algorithm

Results: Figure 2 represents the results for the PFS spectra ORB0032 # 106 in the useful domain, not perturbed by the laser line (0 to 5000 cm^{-1}). This spectrum is taken as an example due to its high level of perturbation. The artifacts, called "ghosts", are pointed by arrows in the raw spectra (at the top). Ghosts features are significantly removed by 85% and the noise standard deviation is reduced from 0.17 to 0.07. To reach the same level of ghosts removal, a stacking of 10 spectra raw is required.

Figure 3 represents the results in the laser line domain (5000 to 8330 cm^{-1}), where the microvibrations artifact of the reference laser line occur. The laser line modulated through filter, aliasing and vibration kernel is compatible with the observation. The L_2 distance is relatively small (~ 0.013).

In addition, a complete ab initio approach allows us to estimate the vibration frequencies from different sources: reaction wheels, Inertia Measurement Units and PFS eigenmodes. Thanks to telemetry data from ESA, it is possible to estimate the frequencies of reaction wheels for ORB0032, spectra No 106 at 56.7 Hz, 33.3 Hz, 40.6 Hz and 30.3 Hz. Astrium technical specification of MEx states that the IMU dithering onboard MEx are at 513.9 Hz, 564.3 Hz and 617.4 Hz. The PFS eigenmodes are around 135 Hz and 160 Hz. Not all of these micro-vibration frequencies are expected to be active, depending on the relative phase.

Figure 3 represents the ab initio expectation of the micro-vibration effect on the laser line in gray color. The four main picks are compatible with ab initio informations, but also smaller picks.

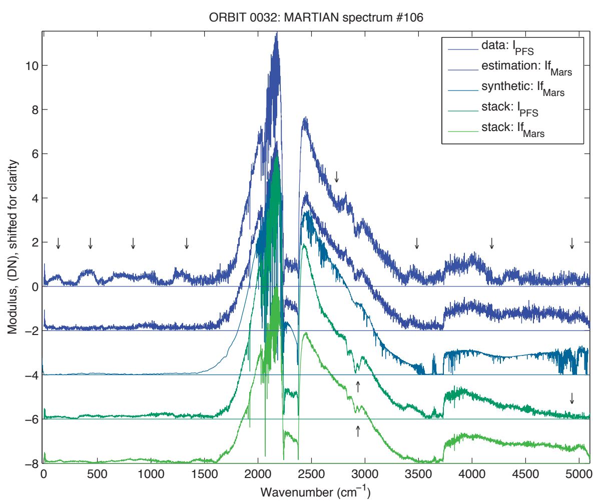

Figure 2: Final results of the spectra ORB0032 #106 as compared with stacking and synthetic measurements, from top to bottom: (i) raw PFS measurements, all arrows represents ghosts artifacts, (ii) estimated spectra from our algorithm, (iii) synthetic measurement of PFS, (iv) stack of 11 PFS spectra, (v) stack of 11 estimated spectra from our algorithm. The arrow at 2900 cm−1 represents the mirror contamination by hydrocarbons, the arrow at 4900 cm−1 represents an artifact of abnormal small signal, probably due to ghosts.

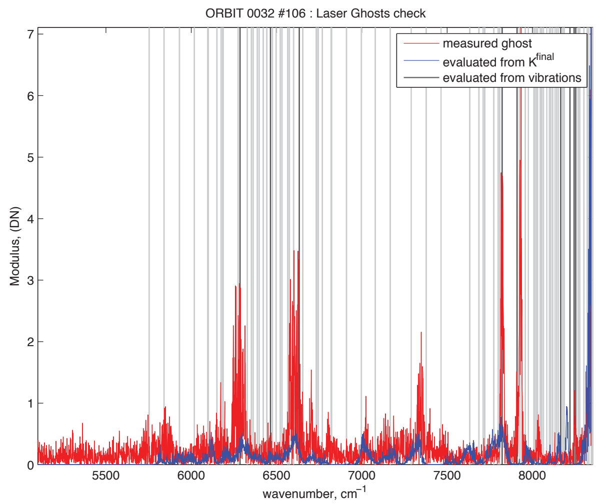

Figure 3: Modulus of the simulated laser line modulated I^{final} through filter, aliasing and vibration kernel K^{final} (blue), the observation I (red). The lack of fit is 0.0270. The microvibrations effect on the laser line computed ab initio using telemetry is in gray.

Discussion and conclusion: We described the approximated direct problem and an algorithm able to correct for the mechanical vibration of the PFS instrument. For the first time, we show that it is possible to reduce significantly the ghosts from the observed signal from 3-5 % of the total energy to 0.4-0.7 %. Our estimation is coherent using three quantities: ghosts in the signal domain, laser line ghosts, distance to approximated kernel. Thus the global shape of PFS SWC spectra can be corrected with our algorithm, allowing to better estimate temperature, and thermal profile on each PFS measurement, improving the few % of spectra with high $\chi 2$ that could not be processed with current calibration. Also, our correction may avoid the continuum removal step in the minor species retrieval. When the signal to noise ratio is high enough, our correction will also reduce the stacking procedure.

In the future, we would like to propose an algorithm to correct the complete archive that would require: efficient algorithm, timesaving implementation, and fully automatic procedure. Also, new correction procedure must be developed to treat the whole orbits currently available (>6400 at the date of writing).

Reference: [1] Formisano, V., et al. (2005) PSS 53 (10), 963–974. [2] Giuranna, M., et al. (2005) PSS 53 (10), 993–1007. [3] Giuranna, M., et al. (2005) PSS 53 (10), 975–991. [4] Comolli, L. et al. (2010) PSS 58 (5), 864-874 [5] Shatalina, I. et al. (2013) Aerospace Science and Technology submitted. [6] Schmidt, F. et al. (2014) PSS accepted [7] Idier, J. (2008) Bayesian Approach to Inverse Problems