Subject offered for a contract starting October 2019

SUBJECT TITTLE: Multiwavelength characterization of the SEIS recorded Mars seismic noise and associated constraints on the crustal structure and atmosphere dynamics.

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IPGP- Planetology and Space Science Team – UMR7154

(collaboration with IPGP Seismology Team and Laboratoire de Meteorologie Dynamique)

Financing: Doctoral contract with or without teaching assignment

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The InSight mission landed on Mars on November, 26th, 2018 and deployed successfully the SEIS experiment, a 6 axis seismometer composed with a three axis Very Broad Band sensor and a three axis Short Period instrument. It detected its first marquake in March/April 2019, but also noise not related to the sensors which will be the major focus of this PhD. See http://seis-insight.eu for more info.
As observed in the early times of seismology by Bertelli (1872), the Earth's surface is permanently oscillating due to microseismic, non-coherent Rayleigh surface waves between 3 and 10 seconds which were first explained by Longuet-Higgins (1950). One century after Bertelli, the Apollo seismometer did not record any natural microseism on the Moon. This noise is indeed only possibly related to continuous micro-impacts and might be several orders of magnitude below the Apollo resolution (Lognonné et al., 1998). 50 years after Apollo, InSight is therefore monitoring seismically the third terrestrial planetary body of the history of seismology. Extremely low noise levels are measured, demonstrating the high performances and installation quality of SEIS. The preliminary analysis of the VBB noise suggest that this noise is a combination of lander and local wind generated noise but also of an elliptical polarized noise which is likely associated to micro-seismic waves, either acoustic or seismic.
Contrary to Earth, where most of the microseisms are related to the non-linear interaction of oceanic waves with the sea floor and with coast lines, such a micro-seismic noise of Mars in only related to the coupling of the atmosphere with the Martian surface. Preliminary explanations suggest that this microseismic noise might be related to acoustic emissions related to the local and remote turbulent circulations in the atmosphere (e.g. *Posmentier*, 1974 and *Cuxart et al*., 2016 for Earth observation) which either hit the station surface or are remotely converted into Rayleigh waves and then guided by low-velocity subsurface layers.
The first goal of this PhD will be to couple observations, analysis and modeling of the SEIS data together with observation, analysis and modeling of the APSS (*Banfield et al*., 2019) data in order to remove from the signal most of the noise related to direct wind and pressure effects on either the lander, the WTS and/or the ground, in order to better estimate the amplitude of the micro-seismic noise. This task will of course be used for better analysis of all detected quakes and will therefore associate the PhD candidate to these quakes analysis.
The second goal of the PhD will be to determine the amplitude and variability of the micro-seismic noise for different wavelength and frequencies covering the complete bandwidth of the VBB, e.g. from 0.005 Hz to 10 Hz. These wavelengths will first be those of the landing site are, possibly associated to locally trapped high frequency surface waves and therefore above 1 Hz. They will then be those of the 0.1-1 Hz Rayleigh waves

bandwidth, excited regionally by atmospheric processes. They will finally be also those associated to longer periods, up to a few hundred seconds, associated to Mars Hum, as proposed by *Nishikawa et al* (2019).
The third goal of the PhD will be to constrain and model the source of these observed seismic waves. We will test the hypothesis that this noise is associated to shear wind in the atmosphere and will therefore estimate the possible altitude of the seismic sources and their local or remote location with respect to the InSight station. We expect with this technics to provide unique constrain on the activity of the Planetary Boundary layer through the seismic monitoring of the Martian microseism, in way similar to what has been done recently on Earth for the tracking of cyclones (e.g. *Davy et al*., 2014, 2015) and with an approach complementing the analysis to be made with the more classical APSS pressure, temperature and wind sensors of InSight (*Spiga et al.,* 2018). This will request efforts towards higher frequency modeling of the Planetary Boundary Layer (PBL) turbulent activity by Large Eddy Simulations (*Spiga et al.* 2016) in order to approach the upper frequency of both SEIS and infrasound pressure measurements (1Hz) on board InSight, and better modeling of the mesoscale (regional) atmospheric circulation that modulates the turbulent circulations in the PBL. This effort will be made in collaboration with A.Spiga, from Laboratoire de Météorologie Dynamique, in Paris. Both models suitable for Large-Eddy Simulations and mesoscale simulations on Mars are used for a decade at LMD by A.Spiga and colleagues and were already used as a basis for prospective studies before InSight landing (*Kenda et al.* 2017, *Murdoch et al*. 2017). From these temporal models of high frequency pressure and Reynold stresses fields, we will then will model both the generated micro-seismic noise, the acoustic infra-sound noise and will compare it to observation in order to quantify the source and the amplitude of shear stresses associated to the acoustic emission.
The last goal of the project will be to constrain, with these seismic waves generated by the atmosphere, the subsurface and possibly the crustal structure of the planet, independently of quakes and impacts. This will complete already used internal sounding techniques, such as the static loading of pressure variations associated to dust devils (*Kenda et al*. 2017) and Planetary boundary layer turbulence (*Murdoch et al*. 2017). If well identified and stacked over long period, the mars micro-seismic noise will open the possibility to image, through autocorrelation of the seismic signals, the landing site upper crustal structure with these Rayleigh waves (e.g. *Knapmeyer et al.,* 2019) and the deeper crust and upper mantle for the long period Hum (Nishikawa et al., 2019). This upper crust imaging will complete the deeper structure imaging, expected to be performed from quakes and impacts, as detailed by *Panning et al.* (2017) and *Daubar et al.* (2018) respectively and will provide the first seismic imaging of the landing site of a Mars mission. To study the impact of the global hum, Global Climate Modeling studies of large-scale atmospheric circulations on Mars will be necessary; the PhD candidate at IPGP will have access to the latest high-resolution LMD global simulations performed (*Forget et al*. 1999, *Pottier et al*. 2017), already used in *Nishikawa et al*. 2019 to obtain a proof-of-concept for the use of Global Climate Modeling for the estimates of seismic signatures caused by global atmospheric circulations. In this last goal of the PhD project, feedback on atmospheric science will also be made, by performing improved global atmospheric circulations validated against actual InSight measurements and covering seasonal variations, and eventually applying those simulations to interpret the seismic signals witnessed by InSight.

PhD conditions and schedule: The PhD candidate will have a collaborator status for InSight, giving her/him access to the data during the proprietary phase.
Both seismic and atmospheric data collected by InSight will therefore be immediately available about 90 days priori their public distribution, and typical global, regional, and turbulent simulations from the LMD group are already available. While the scientific analysis is being carried out, working on new, improved, atmospheric simulations will be possible to prepare the detailed analysis that will form the core of the PhD project. The PhD candidate will also be familiarized with InSight SEIS data analysis, investigations and event requests to be operational within the IPGP team for seismic analysis.
The PhD candidate will present his/her work at the Science Team Meeting of InSight, expected to be made at a rate of two per year, one being in USA and the second one in Europe. In addition, the work will be presented to international conferences. The PhD advancement will be performed in standard ways, with yearly reports to a nominated PhD committee, in addition to 6-months written reports made to the two PhD supervisors, in order to push for a steady flow in the PhD manuscript redaction.
The InSight project is operational on Mars and fully funded on the NASA side for its nominal mission of one Mars year plus 6 months. A very likely extension of the mission will be made starting in 2021. CNES already funded this extended mission for one additional Martian year. This will therefore ensure CNES funding for travels, meeting and mission activities until the end of the PhD.
In Summary, the overall schedule of the PhD will be the following:

- Year 1: InSight data analysis. Systematic characterization of the microseism as function of Local Time, Season, wind amplitude. Development of the Lander/Linear/Wind noise removal algorithms. Seismic, GCM and other tools appropriation. Contribution to InSight papers. Presentation of Results to InSight Science Team meeting
- Year 2: redaction and submission of a first scientific paper as lead author with joint analysis and modeling for daily and weekly signals. Analysis of the micro-seismic noise and search for storms related signals and hum.

- Year 3: redaction of a second scientific paper as lead author with joint analysis/modeling of storms signals and hum. Writing of the PhD manuscript and defense.