THE SËISMIC NÖISE DISCOGRAPHY: ATMOSPHERIC HITS WITH THE INSIGHT MISSION.

A. Spiga[1,2], with the InSight Atmospheres Science Team Group [see citations for a faithful rendering of co-authorship], [1]*Laboratoire de Météorologie Dynamique [LMD], Sorbonne Université, Centre National de la Recherche Scientifique, France*, [2]*Institut Universitaire de France*.

InSight is an international, multidisciplinary NASA mission to Mars, which primary goal is to explore the interior of terrestrial planets[1]. A major instrument on board the InSight spacecraft is the ultra-sensitive broad-band seismometer SEIS[2]. The exquisite sensitivity of SEIS lays the foundation for the multi-disciplinary approach of InSight: to be able to measure subtle surface displacements caused by activity at the surface and interior of Mars, seismometers reach a level of sensitivity that makes them vulnerable to sources of background noise, for instance atmospheric motions exciting the surface.

Seismologists are those kind of musicians composing music in silence, seeking for the couple harmonic uplifting notes coming from the interior that speak volumes to the human soul. Atmospheric scientists are those kind of musicians engulfed in a permanently windy world, in love with turbulence and storms, interested by the energy conveyed by music and how it could make the human body move. InSight is an improbable gathering of those two different kinds of musicians. In a nutshell, in the InSight team, poor seismologists are trying to concentrate on their subtle and harmonic music – the *SEISMIC SIGNAL* of the marsquakes – while, on the room just aside, crazy atmospheric scientists are blasting epic heavy metal riffs at stratospheric volumes under the now-legendary moniker `SËISMIC NÖISE`.

InSight is an incredibly successful mission. The goals set up for the mission on Mars' geophysics have all been fulfilled, often better than expectations[3]. Even the impossibility of the HP[3] probe to penetrate the martian subsurface has brought new knowledge on the complex cohesion properties of the Martian regolith[4]. Despite not being within the primary goals of the mission and being included as auxiliary measurements[5,6], atmospheric science with InSight has been integral part of the success of the mission. In other words, as much as anything else, SËISMIC NÖISE is music (Figure 1). Here we propose, at the nadir of the career of SËISMIC NÖISE given the forthcoming death (or zombie status) of InSight, a review of the SËISMIC NÖISE discography a.k.a. the extensive work of the InSight Atmospheres science team group.

InSight works very well as a weather station on Mars. A realization of this occurred early in the InSight mission when a large regional dust storm raged close to the Elysium Planitia location of the mission[7]. The

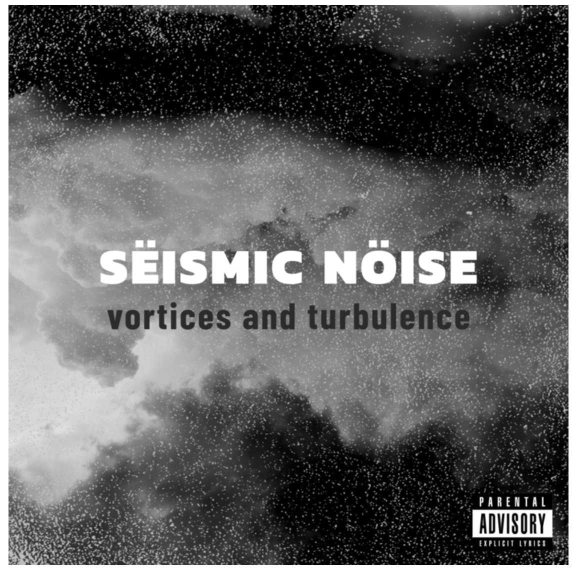

Figure 1: *Cover of the first album of SËISMIC NÖISE. Design modified from a Placeit template.*

wind sensors of InSight also evidence the main global-scale and regional-scale circulation regimes[8] that were predicted by global circulation models[6]. The highly-sensitive pressure sensor at the equatorial site of InSight allows us to monitor over seasonal timescales the prominent modes of midlatitudes planetary waves caused by baroclinic instability[8] [Forget et al. in preparation], a notably difficult task from orbit. InSight also records a rich activity of pressure (and, for the strongest events, wind) fluctuations caused by the propagation of gravity waves; for the first time on Mars, bores and long infrasounds – close to the Brunt-Väisälä frequency limit – are identified in InSight's pressure records[8]. The inclusion of a magnetometer on board InSight can also be used to probe wind-driven fields in the ionosphere and their diurnal and seasonal variability[9].

As a turbulence explorator, InSight is a particularly rich experiment. The exploration of turbulent fluctuations of pressure down to a couple of hertz for multiple complete sols is unprecedented on Mars. InSight pressure measurements show that, akin to Earth measurements, the daytime turbulent spectra of pressure is not following the Kolmogorov scaling[8] which is a concrete example as to how Mars' atmosphere could serve as

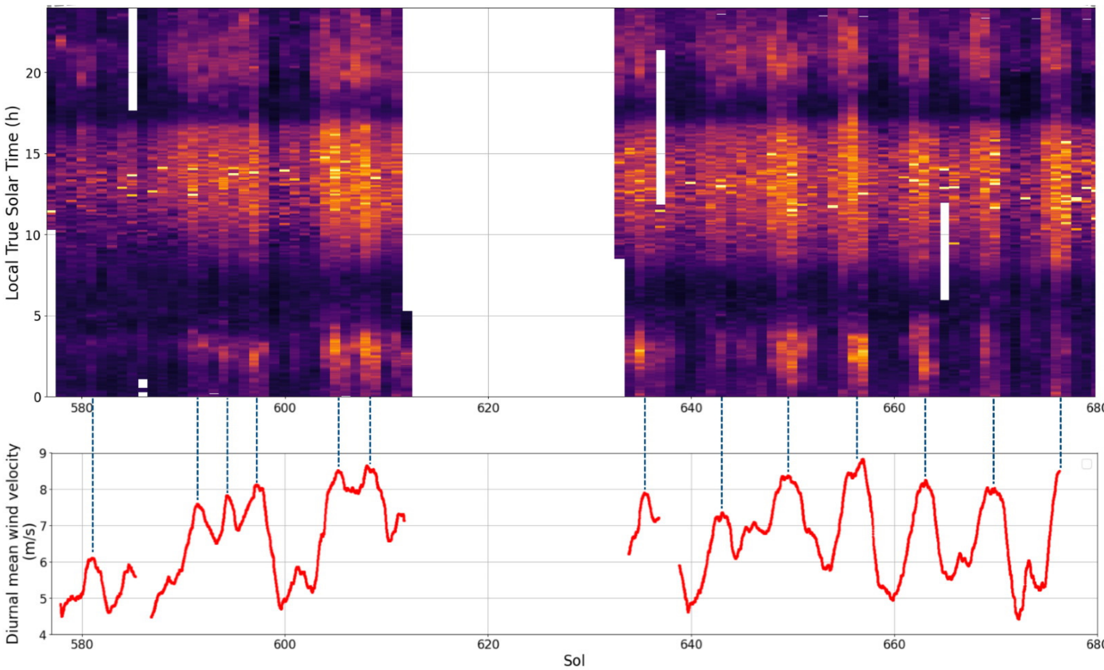

Figure 2: *Standard deviation of InSight pressure measurements (yellow 0.12 Pa, black 0 Pa) in the range L_s 240-290°demonstrating that, at this season, the nighttime Martian atmosphere is as turbulent as the daytime one*[10]*. This surprising high level of nocturnal turbulence in the dusty season results from the subtle combination of a stronger low-level jet, producing shear-driven turbulence, and a weaker stability. As a matter of fact, the level of nocturnal turbulence undergoes modulation by sol-to-sol variability of large-scale wind speed (measured by InSight) caused by planetary waves associated with baroclinic instability. This figure demonstrates how the InSight weather station is capable to probe many spatial and temporal scales relevant to Martian weather.*

an excellent additional laboratory to Earth's for fluid dynamics studies. The seasonal variability of high-frequency fluctuations of pressure probed by InSight also revealed the high level of turbulence in the dusty season of Mars[10] (even featuring nighttime putatively vortex-induced pressure drops) with a subtle combination of increased background wind and reduced stability that gives rise to an active shear-driven convective regime (Figure 2). Daytime and nighttime spectra are also particularly distinct, with many implications [Temel et al. in revision] A particularly interesting perspective of InSight is how complementary it has been to the exploration of ultra-high-frequency dissipation-regime fluctuations by Perseverance's microphone [Murdoch et al. this issue].

The topic of dust devils pertains to turbulence, but InSight encounters with dust devils deserve particular mention. To form a dust devil on Mars, you need a) small, turbulent, whirlwinds named convective vortices; b) dust particles being lifted and transported in those whirlwinds. As it is obvious in the very first acquisitions of InSight's pressure sensors, daytime convective vortices are very abundant at InSight's landing site[8,11,12], even reaching an impressive burst of activity in northern fall and winter[10]. Aeolian activity is also strong at InSight in Elysium Planitia, particularly related to vortex activity[13,14] giving rise to tracks visible from orbit[15]. Despite those elements, and a good imaging coverage by InSight's cameras, not a single dust devil has been detected thus far at the InSight landing site, making an anomaly with respect to other sites visited by in situ spacecraft on Mars (Figure 3).

Inasmuch as heavy metal can be considered music or noise depending on the subjective point of view of the considered operator, seismic signatures caused by atmospheric features could be considered as either signal or noise depending on whether or not you are a hardcore fan of the SËISMIC NÖISE band. At any event, seismic acquisitions by InSight gives to this mission a very original and interesting twist for atmospheric science. A first example is how the distinctive seismic signatures of convective vortices[16,17] can be used as seismic sources to probe the first meters below InSight[18] (see also Onodera et al. accepted 2022), to the point of revealing subsurface spatial heterogeneity in the vicinity of InSight[19]. A second example is how wind noise on seismic records can be explored with methods enlightening areas of improvements for both quake detection and the use of SEIS as a wind sensor[20,21]. A third example is how pressure and seismic measurements can be combined to search for

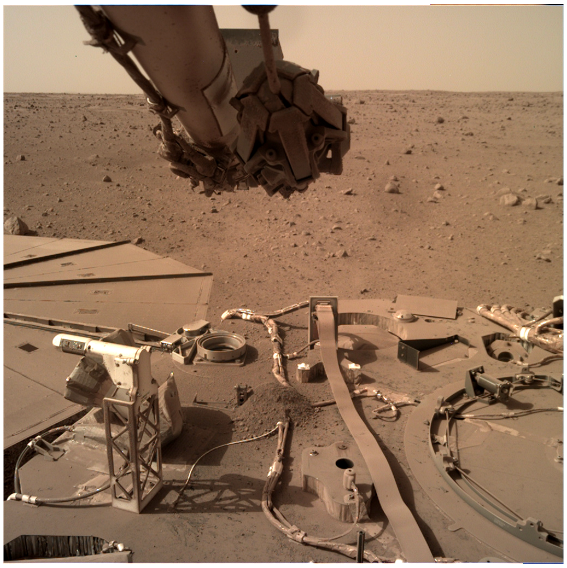

Figure 3: *InSight on Mars. Dust everywhere Loads of dust particles on the deck and solar panels. Nevertheless, not any dust devil spotted in the whole mission. IDC image on sol 1211, April 24, 2022 at local time 2PM. NASA/JPL-Caltech.*

infrasound signals – which has actually resulted difficult to detect [22,23] – as well as, possibly, gravity waves [24].

At the time of writing, InSight has almost two complete martian years of observing time. The energy situation is, however, difficult since the beginning of the second martian year of InSight operations. Both dust accumulation over solar panels [25] and the seasonal evolution of column dust optical depth is putting strong constraints on energy available at InSight's solar panels [26]. Additional energy was obtained, however, by an original approach to dump dust particles with InSight's arm and scoop over the InSight's platform (see the dust pile in Figure 3) and use the wind-induced kinetic energy of the largest dust particles to clean the solar panels from the deposited smaller dust particles, in an active saltation experiment [Golombek et al. in preparation]. Despite this, the atmospheric sensors are switched off most of the time in the second martian year of InSight operations; interannual studies can still be carried out with the atmospheric data acquired in this second year of operation. Once corrected from a long-term drift of the sensor temperature, interannual pressure measurements indicate that the permanent CO2 ice cap mass do not seem to undergo multiannual change (Lange et al. 2022 in revision). Wind measurements on board InSight over two distinct martian years are compliant with the known strong repeatability of the martian weather, but subtle interannual differences are noticed with interesting perspectives for comparison with models [Newman et al. in preparation].

References

[1] William Bruce Banerdt, et al. Initial results from the InSight mission on mars. *Nature Geoscience*, 13(3):183–189, 2020.

[2] P. Lognonné, et al. Seis: Insight's seismic experiment for internal structure of mars. *Space Science Reviews*, 215(1):12, 2019. ISSN 1572-9672.

[3] Simon C. Stähler, et al. Seismic detection of the martian core. *Science*, 373(6553):443–448, 2021.

[4] Tilman Spohn, et al. The InSight-HP^3 mole on Mars: Lessons learned from attempts to penetrate to depth in the Martian soil. *Advances in Space Research*, 69(8):3140–3163, 2022.

[5] D. Banfield, et al. Insight auxiliary payload sensor suite (apss). *Space Science Reviews*, 215(1):4, 2018. ISSN 1572-9672.

[6] A. Spiga, et al. Atmospheric Science with InSight. *Space Science Reviews*, 214:109, 2018.

[7] D. Viúdez-Moreiras, et al. Gale surface wind characterization based on the Mars Science Laboratory REMS dataset. Part I: Wind retrieval and Gale's wind speeds and directions. *Icarus*, 319:909–925, 2019.

[8] Don Banfield, et al. The atmosphere of Mars as observed by InSight. *Nature Geoscience*, 13(3):190–198, 2020.

[9] A. Mittelholz, et al. The Origin of Observed Magnetic Variability for a Sol on Mars From InSight. *Journal of Geophysical Research (Planets)*, 125(9):e06505, 2020.

[10] Audrey Chatain, et al. Seasonal Variability of the Daytime and Nighttime Atmospheric Turbulence Experienced by InSight on Mars. *arXiv e-prints*, arXiv:2110.06113, 2021.

[11] Ralph D. Lorenz, et al. The whirlwinds of Elysium: A catalog and meteorological characteristics of "dust devil" vortices observed by InSight on Mars. *Icarus*, 355:114119, 2021.

[12] A. Spiga, et al. A study of daytime convective vortices and turbulence in the martian planetary boundary layer based on half-a-year of InSight atmospheric measurements and large-eddy simulations. *Journal of Geophysical Research: Planets*, 126(1):e2020JE006511, 2021.

[13] C. Charalambous, et al. Vortex-Dominated Aeolian Activity at InSight's Landing Site, Part 1: Multi-Instrument Observations, Analysis, and Implications. *Journal of Geophysical Research (Planets)*, 126(6):e06757, 2021.

[14] M. Baker, et al. Vortex Dominated Aeolian Activity at InSight's Landing Site, Part 2: Local Meteorology, Transport Dynamics, and Model Analysis. *Journal of Geophysical Research (Planets)*, 126(4):e06514, 2021.

[15] C. Perrin, et al. Monitoring of dust-devil tracks around the insight landing site, mars, and comparison with in-situ atmospheric data. *Geophysical Research Letters*, 2020.

[16] Savas Ceylan, et al. Companion guide to the marsquake catalog from InSight, Sols 0-478: Data content and non-seismic events. *Physics of the Earth and Planetary Interiors*, 310:106597, 2021.

[17] Salma Barkaoui, et al. Anatomy of Continuous Mars SEIS and Pressure Data from Unsupervised Learning. *The Bulletin of the Seismological Society of America*, 111(6):2964–2981, 2021.

[18] B. Kenda, et al. Subsurface Structure at the InSight Landing Site From Compliance Measurements by Seismic and Meteorological Experiments. *Journal of Geophysical Research (Planets)*, 125(6):e06387, 2020.

[19] N. Murdoch, et al. Constraining Martian Regolith and Vortex Parameters From Combined Seismic and Meteorological Measurements. *Journal of Geophysical Research (Planets)*, 126(2):e06410, 2021.

[20] C. Charalambous, et al. A Comodulation Analysis of Atmospheric Energy Injection Into the Ground Motion at InSight, Mars. *Journal of Geophysical Research (Planets)*, 126(4):e06538, 2021.

[21] Martin Schimmel, et al. Seismic Noise Autocorrelations on Mars. *Earth and Space Science*, 8(6):e01755, 2021.

[22] Léo. Martire, et al. Martian Infrasound: Numerical Modeling and Analysis of InSight's Data. *Journal of Geophysical Research (Planets)*, 125(6):e06376, 2020.

[23] Raphael F. Garcia, et al. Search for Infrasound Signals in InSight Data Using Coupled Pressure/Ground Deformation Methods. *The Bulletin of the Seismological Society of America*, 111(6):3055–3064, 2021.

[24] Raphael F. Garcia, et al. Pressure Effects on the SEIS-InSight Instrument, Improvement of Seismic Records, and Characterization of Long Period Atmospheric Waves From Ground Displacements. *Journal of Geophysical Research (Planets)*, 125(7):e06278, 2020.

[25] Ralph D. Lorenz, et al. Lander and rover histories of dust accumulation on and removal from solar arrays on Mars. *Planetary and Space Science*, 207:105337, 2021.

[26] R. Lorenz, et al. Scientific observations with the insight solar arrays: Dust, clouds and eclipses on mars. *Earth and Space Science*, 2020.