

# Extraterestrial Seismology: The perspective after nearly 1 year of InSight on Mars

Mark Panning<sup>1</sup>, W.B. Banerdt<sup>1</sup>, P. Lognonné<sup>2</sup>, W.T. Pike<sup>3</sup>, D. Giardini<sup>4</sup>, R. Lorenz<sup>5</sup>, E. Bozdag<sup>6</sup>, J. Clinton<sup>4</sup>, R. Garcia<sup>7</sup>, J. Irving<sup>8</sup>, T. Kawamura<sup>2</sup>, S. Kedar<sup>1</sup>, B. Knapmeyer-Endrun<sup>9</sup>, L. Margerin<sup>10</sup>, D. Mimoun<sup>7</sup>, N. Schmerr<sup>11</sup>, N. Teanby<sup>12</sup>, R. Weber<sup>13</sup>, K. Hurst<sup>1</sup>, M. Drilleau<sup>2</sup>, M. Böse<sup>4</sup>, S. Ceylan<sup>4</sup>, C. Charalambous<sup>3</sup>, M. van Driel<sup>4</sup>, A. Horleston<sup>12</sup>, A. Khan<sup>4</sup>, M. Knapmeyer<sup>14</sup>, G. Orhand-Mainsant<sup>7</sup>, S. Stähler<sup>4</sup>, A. E. Stott<sup>3</sup>, A. Spiga<sup>15</sup>, L. Fayon<sup>2</sup>, B. Kenda<sup>2</sup>, N. Brinkman<sup>4</sup>, V. Lekic<sup>11</sup>, N. Murdoch<sup>7</sup>, C. Nunn<sup>1</sup>, C. Schmelzbach<sup>4</sup>, M. Schimmel<sup>16</sup>, E. Stutzmann<sup>2</sup>, B. Tauzin<sup>17</sup>, S. Tharimena<sup>1</sup>

1. Jet Propulsion Laboratory, California Institute of Technology, 2. Institut de Physique du Globe de Paris, 3. Imperial College, London, 4. ETH Zürich, 5. Applied Physics Laboratory, Johns Hopkins University, 6. Colorado School of Mines, 7. Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), 8. Princeton University, 9. University of Cologne, 10. Institut de Recherche en Astrophysique et Planétologie (IRAP), 11. University of Maryland, 12. University of Bristol, 13. NASA Marshall Space Flight Center, 14. DLR Berlin, 15. Laboratoire de Météorologie Dynamique, 16. Instituto de Ciencias de la Tierra Jaume Almera, 17. Australian National University

#### InSight JPL NASA Cnes DLR 0 0 × 2 m m 0 BBSI 3 Þ RTI Imperial College London 2

#### The InSight Science Team

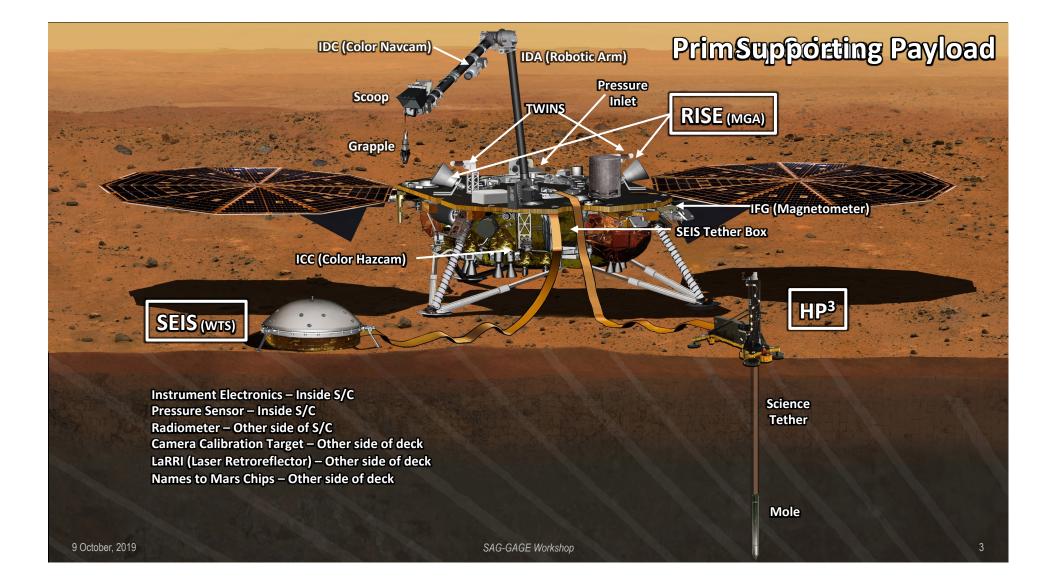
Bruce Banerdt, Sue Smrekar, Daniele Antonangeli, Sami Asmar, Don Banfield, Caroline Beghein, Neil Bowles, Ebru Bozdag, Peter Chi, Ulrich Christensen, John Clinton, Gareth Collins, Ingrid Daubar, Véronique Dehant, Matthew Fillingim, Bill Folkner, Raphael Garcia, Jim Garvin, Domenico Giardini, Matt Golombek, John Grant, Matthias Grott, Jurek Grygorczuk, Troy Hudson, Jessica Irving, Catherine Johnson, Günter Kargl, Taichi Kawamura, Sharon Kedar, Scott King, Brigitte Knapmeyer-Endrun, Mark Lemmon, Philippe Lognonné, Ralph Lorenz, Justin Maki, Ludovic Margerin, Scott McLennan, Chloë Michaut, David Mimoun, Antoine Mocquet, Paul Morgan, Nils Mueller, Seiichi Nagihara, Claire Newman, Francis Nimmo, Mark Panning, Tom Pike, Ana-Catalina Plesa, Jose-Antonio Rodriguez-Manfredi, Chris Russell, Nick Schmerr, Matt Siegler, Aymeric Spiga, Tilman Spohn, Sabine Stanley, Nick Teanby, Jeroen Tromp, Nicholas Warner, Renee Weber, Mark Wieczorek, James Badro, Silvia Boccato, Pierre Delage, Guillaume Morard, Julien Siebert, Fang Xu, Elizabeth Barrett, Tammy Bravo, Paul Davis, Simone Dell'Agnello, Ken Hurst, Mike Malin, Liliya Posiolova, Haotian Xu, Peter Grindrod, Stephen Lewis, Manish Patel, Meng Jia, Paul Sava, Laurent Gizon, Walter Goetz, John-Robert Scholz, Rudolf Widmer-Schnidrig, Conny Hammer, Natalia Wojcicka, Eleanor Sanson, Ozgur Karatekin, Valery Lainey, Sébastien Le Maistre, Jean-Charles Marty, Marie-Julie Péters, Attilio Rivoldini, Tim Van Hoolst, Marie Yseboodt, Dustin Buccino, Danny Kahan, Ryan Park, Nicolas Compaire, Guénolé Mainsant, Léo Martire, Ryan Dotson, Fredrik Andersson, Amir Bagheri, Felix Bissig, Maren Böse, Nienke Brinkman, Savas Ceylan, Fabian Euchner, Johannes Kemper, Amir Khan, Johan Robertsson, Cedric Schmelzbach, Simon Stähler, David Sollberger, Martin Van Driel, Fred Calef, Eloise Marteau, Tim Parker, Sylvain Piqueux, Nathan Williams, Sharon Purdy, Cathy Weitz, Nicholas Attree, Doris Breuer, Christian Krause, Achim Morschhauser, Bartosz Kedziora, Ewelina Ryszawa, Lukasz Wisniewski, Anna Mittelholz, Lydia Philpott, Benoit Langlais, Norbert Kömle, Joshua Poganski, Keisuke Onodera, Victor Tsai, Josh Murphy, Alejandro Sebastian Carrasco Mo, Rakshit Joshi, Charissa Campbell, John Moores, Salma Barkaoui, Alexey Batov, Eric Clévédé, Françoise Courboulex, Melanie Drilleau, Nobuaki Fuji, Jeannine Gagnepain-Beyneix, Lucile Fayon, Marouchka Froment, Tamara Gudkova, Alice Jacob, Foivos Karakostas, Balthazar Kenda, Antoine Lucas, Milena Marjanovic, Sabrina Menina, Jean-Paul Montagner, Yasuhiro Nishikawa, Clement Perrin, Sébastien Rodriguez, Lucie Rolland, Maria Saade, Henri Samuel, Martin Schimmel, Eléonore Stutzmann, Martin Vallée, Frédéric Béijna, Micha Bystricky, Marie Calvet, Marc Monnereau, Denis Savoie, Lu Pan, Cathy Quantin-Nataf, Benoit Tauzin, Damian Walwer, Baptiste Pinot, Naomi Murdoch, Laurent Pou, Véronique Ansan-Mangold, Eric Beucler, Mickaël Bonnin, Yann Capdeville, Olivier Verhoeven, Mariah Baker, Kevin Lewis, Vedran Lekic, Ceri Nunn, Saikiran Tharimena, Simon Calcutt, Constantinos Charalambous, Jane Hurley, John McClean, Gerald Roberts, Zachary Slingsby-Smith, Alex Stott, Tris Warren, Sebastiano Padovan, Nicola Tosi, Antonio Molina Jurado, Jorge Pla-Garcia, Daniel Viúdez-Moreiras, Steve Joy, Yanan Yu, Quancheng Huang, Foivos Karakostas, Doyeon Kim, Ross Maguire, Angela Marusiak, Norbert Schorghofer, Mackenzie White, Jean-Pierre Williams, Jose Andrade, Daniel Nunes, Lujendra Ojha, Audran Borella, François Forget, Anni Määttänen, Ehouran Millour, François Ravetta, Axel Hagermann, Ernst Hauber, Ralf Jaumann, Jörg Knollenberg, Christos Vrettos, Benjamin Fernando, Anna Horleston, Kuangdai Leng, Bob Myhill, Tarje Nissen-Meyer, Jennifer Stevanović, James Wookey, Carène Larmat, Youyi Ruan, Maria Banks, Jesse Dimech, Heidi Haviland, Martin Knapmeyer, Brian Shiro, Adrien Broquet, Katarina Miljkovic, Tanja Neidhart, Andrea Rajsic, Mélanie Thiriet, Jeremie Vaubaillon,

#### Mars is Only the Third Planetary Interior to be Investigated in Detail



- InSight follows in the footsteps of terrestrial geophysics at the dawn of the 20<sup>th</sup> century, attempting to answer basic questions about the planet:
  - What is the thickness of the crust?
  - What is the structure of the mantle?
  - What is the size and density of the core?
  - What is the distribution of seismicity?
  - What is the planetary heat flow?
- It also follows a similar path taken a half-century ago on the Moon, when Apollo put in place a lunar seismic/heat flow/laser retroreflector network.
  - The overarching goal motivating this mission is to better understand the processes of planetary differentiation that formed the terrestrial planets, and the global processes that subsequently modify them.

SAGE/GAGE workshop



## HP3 status

- The HP<sup>3</sup> was deployed to the surface in mid-February and immediately began penetration.
- A depth of 35 cm was reached relatively rapidly (within a few hundred strokes); repeated subsequent hammering (~9000 strokes) resulted in no measurable further progress.
- Our conclusion is that the mole has either encountered an obstacle (e.g., a rock) or, more likely, has lost sufficient hull friction to maintain downward progress.
- As of today, we have new images down which appear to show progress of the mole

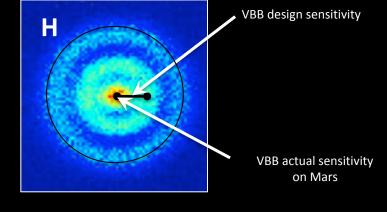


#### The Albadength of Napsetating a Seismometer on Mars

- Need extremely high sensitivity expect fewer and smaller quakes than on the Earth
  - Sensitivity target: 2.5x10<sup>-9</sup>m/sec<sup>2</sup>/Hz<sup>1/2</sup>
  - This is equivalent to displacement amplitudes smaller than a hydrogen atom

#### • Therefore one must minimize/compensate for all noise sources:

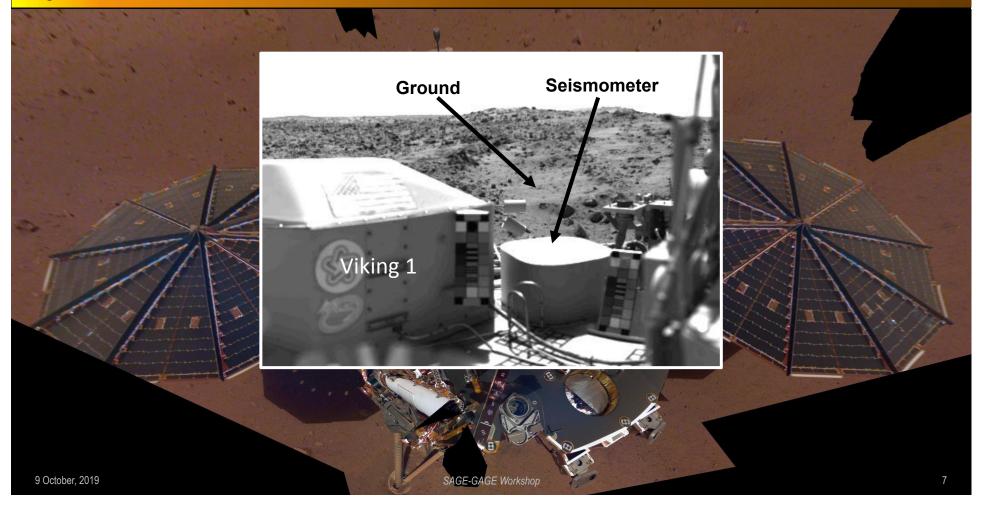
- Instrument intrinsic noise
- Temperature variations
- -Wind
- Atmospheric pressure variations
- Magnetic field variations
- Lander vibrations



SAGE-GAGE Workshop

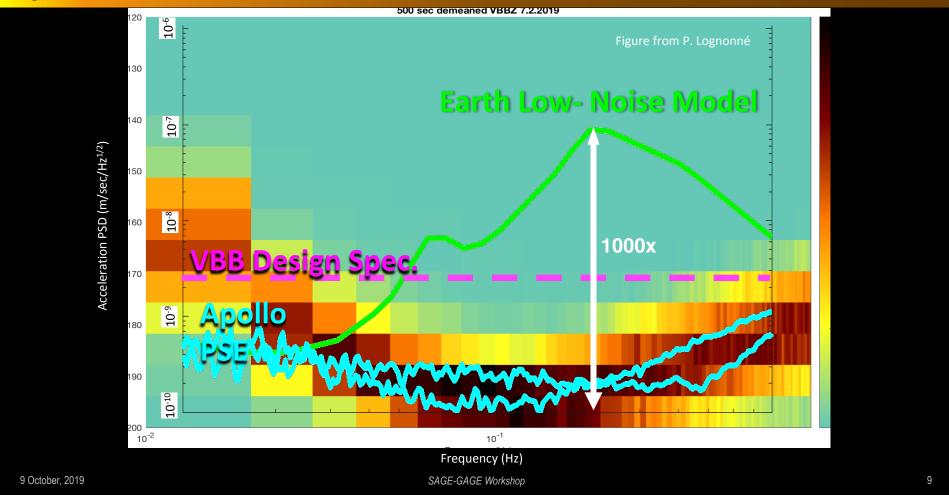


# SEIS on Mars – Almost

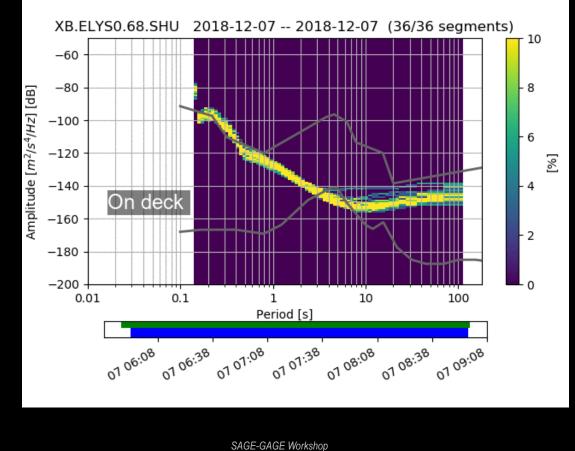




# VBB Acceleration Noise Statistics



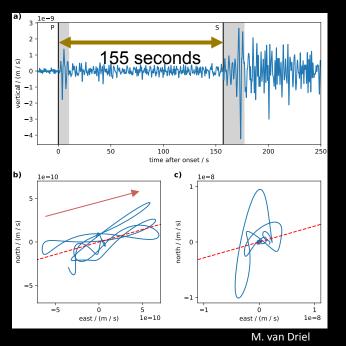


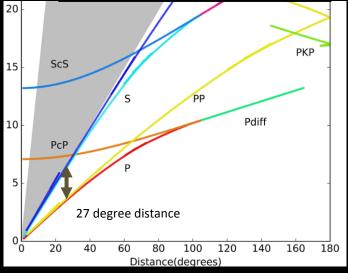


9 October, 2019



# Locating marsquakes with a single station





Ceylan et al. (2017)

Direction



# All Seismic Data Through Sol 289 (about 3 weeks ago)

Sols: 72-289 58.BZC,02.BHZ,03.BHZ,17.BLZ Sol 080 --140  $\nabla$ --150 **[8p]** <sub>ZH/<sub>b</sub></sub> Sol 090 -Sol 100 -Sol 110 -C Sol 120 -Sol 130 -Г -200 Sol 140 -▼ Sol 150 -0 Sol 160 -VV Sol 170 -Broadband Sol 180 -▼ Low freq. 0 A High freq. Sol 190 -2.4Hz **∆**₀ 0 0 Sol 200 -0 Sol 210 -0 0.0 0 Quality Δ Sol 220 -C 0 Ă B C D 00 Sol 230 -Sol 240 -0 Ono Sol 250 -Sol 260 -0 Sol 270 -Sol 280 -01:00:00 07:00:00 16:00:00 19:00:00 22:00:00 04:00:00 10:00:00 13:00:00 Credit: InSight MQS LMST 9 October, 2019 SAGE-GAGE Workshop

#### InSight

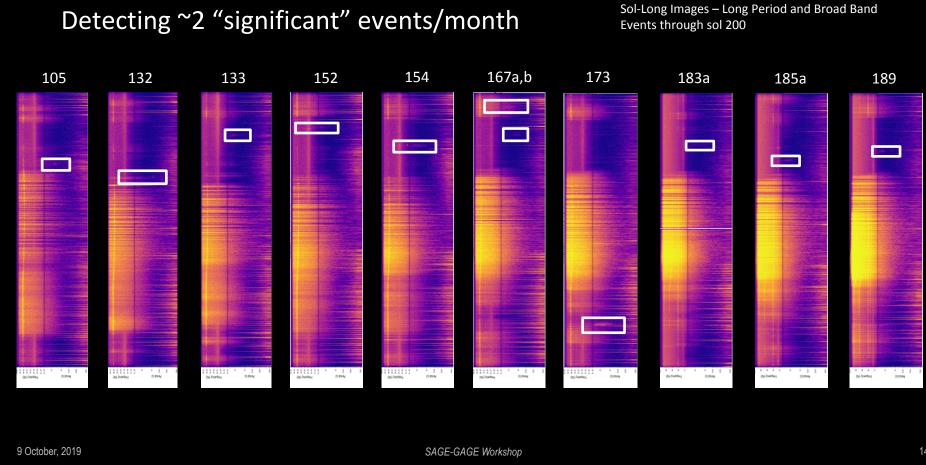
#### InSight Seismic Event Catalog (10/9/2019)

- Currently there are 162 events in the InSight catalog.
  - 3 Quality A
    - » Clear seismic phases and polarization, or SNR>10
  - 5 Quality B
    - » Signal clearly observed, clear seismic phases, but no polarization
  - 94 Quality C
    - » Signal clearly observed, but no clear phases
  - 60 Quality D
    - » Signal only weakly observed
    - » OR likely not a seismic event
    - » OR signal possibly contaminated by environmental conditions
- Preliminary classification scheme:
  - Low frequency (energy only below 1 Hz) 17 events
  - High frequency (energy only above 1 Hz) 22 events
  - Broad-Band 9 events
  - 2.4 Hz 114 events

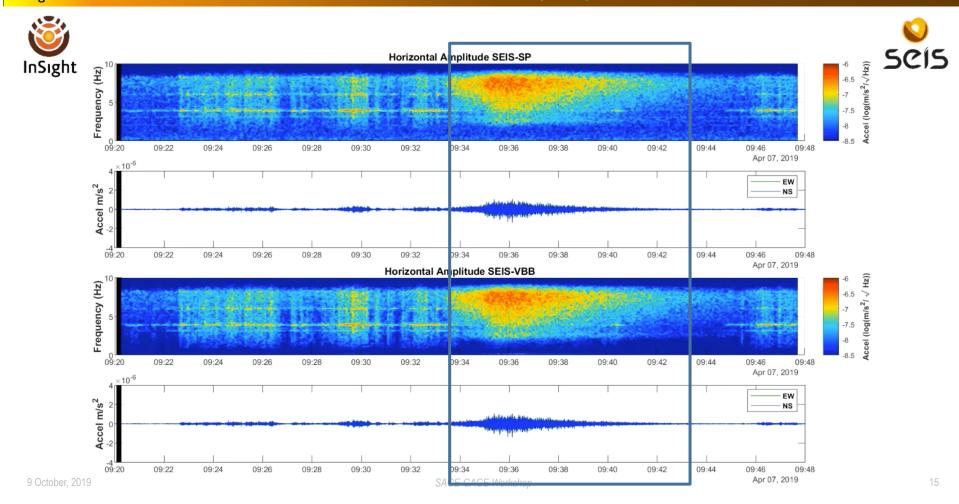
|--|

Respire to							burn.	
Dates -	Rate 1	Dest Spin	unue :	Longitude -	Dem 1	Degrant.	Every and	w -
		1.04				2010/07/11/12	2010-08-2171-28-68	0 Dat
	1000	108				2010/1784248	2010/2708-032	6 0 0 0
2010/06/2712/21/20	1000	108				211017020	2010/07/07/0444	0 04 0 04
1010-08-0710-0316	20204	LOR LOR LOR				TRANSPORT OF TAXABLE		
2010-08-00708/34/51	5004	14.02				2010-06-05708-0815	2010/08/2010 10	8 6m
	Service Service	14.92				101-10-0708-0214	10040301010	
100825025	5076 5076	A.M.				200-24-25 (2012) 200-24-25 (2012) 200-24-25 (2012)	2008-2009-2018 2009-2018-2019 2009-2018-2019	1 14
2010/06/201102101	NOTE:	BROKEBINE 24.92				2010/07/02 10	2010/08/2011 04:02	C Dut
2010-06-20707-07-04	1000					2010/06/2017 2014	2010/07/22/10	0 Get
2010/06/2010/16/20	-	108				2010/06/2010/2010	2010/08/2010/04 14	0 Det
1008070414	1004a					211-2072-04	DOMOTORIA DI	1 Dat
10-14-0419-02.55 10-14-0419-02.55 10-14-0419-02.55	NOW	HOL/HED/DOY				201-06-070700.11 2016-06-070700.11 2016-06-077071041	20-0-0707.024 20-0-0705.024 20-0-0705.024	0 Dat
111-18-1738-1839	NOUN	LOI INCOMPANY				2010/07/01104	2010/07/08/24	0 Dat
2110-08-21710-18 2110-08-21700-18-15	NOUN NOUN	14,12 BROOMER				219-06-25708-44-12 2019-06-25708-44-12	1010-06-00708-0112	
1010-06-02708-0244	5055	810405446				219-24-278-2234	1010-06-0706-0451	8 6m
11-10-08-027-01-02	-	24,92				2010/02/02/02 01	2010/08/02/10/10:00	· •
2010-08-20104-19-28 2010-08-21104-08-57 2010-08-10104-004	HOTA HOTA HOTA	AUN BROOBING AUNI				2010-06-2010-24-01 2010-06-2010-24-01 2010-06-0010-24-01	2019-28-2018-24-14 2019-28-2018-24-14 2019-28-2018-24-24	6 0.0
2010-08-10703-004	HOUN .	24,92				2010-0618702-04-01	2010-08-1010-00.24	8 Des
100-08-0738.34.57 100-08-0738.34.57	BOD'S	104 104				20-0-170223	2010/07/02 10	0 Def
22 - 08 - 1732,223,23	10794	24.92				2110110	2010/01/2012 14	0 04
10.00.00.00.00.00.00	1000	14.92				201-04-07023028	2010-08-10102-0112	1 Dat
119-36 OFEREN	5054 5054 5054	LONUMBOURNON ALAR				279-08-1703004 279-08-1702044	10-10-10-1010-1010 10-10-10-1010-1010 10-10-10-1010-1010	8 84
11-12-16 S-F-16-16-15	SICCR.	108				100-06-0700-0640 2010-06-0700-0640	2010-06-14700-0144	· •
1010-08-12121-025	1010	108				1010-08-0703-04	1010-08-0700-04-08	
2010-08-010008-24 2010-08-010-00-24	-	LON/MEQUENCY				2010/01/02/11	2010-08-1703-08.34 2010-08-09721-02.34	C Due
2010/06/07 10:00	10.08	24.92				2010/06/07 2020	2010/08/07214238	
2010/00/2012/00/2012 2010/00/2012/00/2012 2010/00/22/00/2012	10.00 10.00 10.00	108				2010/00/2010/2010/2010/2010/2010/2010/2	20-3-372-323 20-36-372-323 20-36-3722-323	
0.01110-01-010	1045	14.02				2010/07/21082	2010-01120821 2010-01120-021	
10-0-072-4147 10-0-07213144	1015	108				201-01-0727-4120 2010-08-0872033-41	279-28-2872-2020	0 Dat
1010-08-08710-1110	512-65 512-65						2010-08-087 00.00.41	1 Dat
1010-06-04739-0459	Stores.	LOR LOR LOR				219-06-047 00104 219-06-047 00104 219-06-047 0 4430	2014-01/1251 2014-01/1254 2014-01/1254	
00000000000000	50.44 50.44	14.98				2010-06-047-C-44-34	101010-001	
	-	24,92					2010/04/04/08/04	· •
2010-06-0711-02-00 2010-06-0711-03-16	10.04	ANR ANR ANR				2010/0710/01	2010/08/07 10:0042	0 Dat
	10144						2010/07/100113	0 Gen
2010-07-0710-4001	NUTS NUTS	HOL/HEQUINCY 14,98				2040-2710-1648 2040-28710-1648 2040-28740-710	2002/0710000 2002/0710000 2002/0710000	C Des
100-01010-000	10.74	1-OE 1-OE BROOMD BROOMD				2010/07/04/21	2010/07/08128	8 D.0
	NEN	108				2010/07/0101	2012/07/02/04	0 04
1010-07-0210-10-10	51270	BRINGSING	11.00	16.05	-61	2010/07/2211	2010-07-0210	
0.01/01/03/0494	54004						2010/07/05/04	1 64 1 64
1000-07-0010000 1000-07-000-00 1000-07-000-00 2000-07-000-00	5004 5004 5004 5004	Increased				2002/27/22/2 2002/27/22/2	2002/3702/3 2002/3702/3	* 64
2010/07/07 02:00	10210					2010/07/02/02	2010/2012/12/12	
2010/07/2017 02:00:21	10114	34,NE HOL/NEQUENCY				2010/27/02/28	2010/2011 02:00	0 0a
2010/07/2012/08/08/08	NOT N					2010-01-02102-04-02	2010-01-02108-0644	0 04
10.000	1074	108 108 108				2040-078383 2040-078383 2040-07823738 2040-07823738	2010-01-0202-0012 2010-01-0202-0012 2010-01-0202-0012	0 Def
10-0-0703434	10.00	14.00				NAME AND ADDRESS OF	2010/01/07/01/01/01	5 Da
10110-01-02700-02-04	1000	LOR LOR				2010/07/07/08		a
2010-01-10708-01-05 2010-01-10707-08-10	SHITY SHITY	14.02				2010-01-0710-0234 2010-07-0710-0234 2010-07-0710-0214	2010-01-070819834	1 Det
						2010-07-0706-04-17	2010-07-0707-04-06	
10 0 0 10 00 00 00 00 00 00 00 00 00 00	1075 1076	24.08 24.08				2010-01-0138-06-08 2010-01-0138-06-08 2010-01-0138-06-08	2012 100 100 100 100 100 100 100 100 100	8 64 8 64
2010/01/0728-20-20	10.00	LON /HEQUENCY				2010-01-0708-0034	2010-01-0106-0104	C Dut
		Market Distance of the						C 04
2010-07-10708-1028	NO.	104 108				2010-07-1070620-04	2010-01-0708-0110 2010-01-0708-0110	0 Del
		24.92						0 04
109-0-0700234 109-0-0700234 109-0-07003450	NUTS NUTS NUTS	108				2044-1200420 2044-1200420 2044-1200420	219-01-0202303 219-01-0202303 219-01-0202303	0 04
2010-07-1738-0030	MOTO N	108 108				2010-01-11708-0224	2010-01-1708-0140 2010-01-1708-0140	1 Dat
2010-21-0702-21-29	512.00 512.00	108				2010-01-010-010 2010-01-0100-010	2010-07-070236-04	
1001 05104	502.0%	ALCR. HOL/HEALENCY				2010-01-0100,00.00	2010/01/01/02/02 12	* 64
NUMBER OF STREET, STREET,	1000	100 0000000				NUMBER OF TAXABLE PARTY.	2010-07-08700.4431	
2010-01-047031-24 2010-01-04706-0310	NU VA	14,98 14,98				2010-01-08/5019-09 2010-01-02/08-44-02	2010-01-00700-04-01 2010-01-0710-02-14 2010-01-02700-041	C Dat 8 Dat 8 Dat
NUMBER OF STREET, ST. M.	80.04	14.92				2010/07/07/02 49		0 04
10-1-0782838	NO.	108				NUMBER OF TAXABLE	2010/07/07/06/02	0 Dat
10.0010-02210-0027	NUTS.						2010/07/07/08/10	1 04
109-06-0717-10-10	5076	LON PROJECT INSUPERATOR				21-0-07120-0	Row Witness	
10-36-2717-1210 20-36-2717-1210 20-36-2715-8219 20-36-271-20-00	5051	INSUMBATION AND A				219-36-227-558-25	2010-06-227 10:02:15	· •
	SUDA SUDA SUDA SUDA	14.92				219-06-027-028-03 219-06-027-028-03 219-06-027-028-03 219-06-027-028-03 219-06-027-028-03	2014-0-0712-014 2014-0-0712-014 2014-0-0712-014 2014-0-0712-014	8 548
		108 108				2010/06/27 16:020	2010/01/02/02	8 0.0 8 0.0
000010000	BIDD's	LON/MEQUINCH				хонистехни	201-MOTORIA 201-MOTORIA	
2010-26-107122427	10.000	14,92				2010/07/0802	2010/10/10	0 000 0 000
2008 (1020) 2008 (1020) 2008 (1020)	11794 11794 11794	108 108 108				2014 (1000) 2014 (1000) 2014 (1000) 2014 (1000)	2010/07/08/01	0 Det
10.000 MILLION	10.04	108				2048-02243	2010/06/07/21/08	1 Dat
10 m m m m m m m m m m m m m m m m m m m	NTER ACTES	LOR HIP/PROMOV				2010-08-0708-0230	2214-06-1258-0412	0 0.0
						219-04-1707-02-0	274-06-1752-1028	0 0.0
01-0-070.210	acom acom acom	LON/HEILENCY HEIL/HEILENCY BROKERIE				211-0-0702-000 211-0-0702/020 211-0-0702/020	271-0-0702202 271-0-0702202	· 0.0
0101010	10104	BIOADSHID				211010-0112-020	271-0-0712,2020	
211-0-0702-0	50.000 50.004	LANE LINUTERATION				273-0-075235-0 273-0-075235-0		0 0.0
1014-05-25762-0-03	50174	BROAD64ND	-	-	-	2018-05-21702121-08	271-0-07023054	
	40174	Line residency					222.05.217.0404.07	
2010/1710/00	scurs Acura	LIN/WEARCY LIN/WEARCY				2710-1703094 2710-170-220	2710-1710-02 2710-1711-02	
2010/01/01 01:00	10104	870406490				2710.0107071710	2010/01/07/27:00	8 0.0
2010/07/2111	ACC24	and sold share				2110-0212729-0	2710-0707-020	6 Q.M
2010-01-01-02-02 2010-01-02-02-02	8010a	14,90 LDN/WEARCY				2010/01/2010 02:00	271002120221	0 0.0
STRACT STR	NO OR	RECORDERS.				TRACK STREAM	272-04127-028-0	
3094411702720	10.00	BROADBAND				279-04-177-02027	279-04172-620	0 0.0
2010/01/2012 02	NOTE:	HOLPHOLENCY 24,92				271-0-07082028	273-01-0728-028	A 0.0
1011-101-101-10-10-10-10-10-10-10-10-10-								
1014-03-00 <sup>-00</sup>	50104	LIN/WEILINCY						

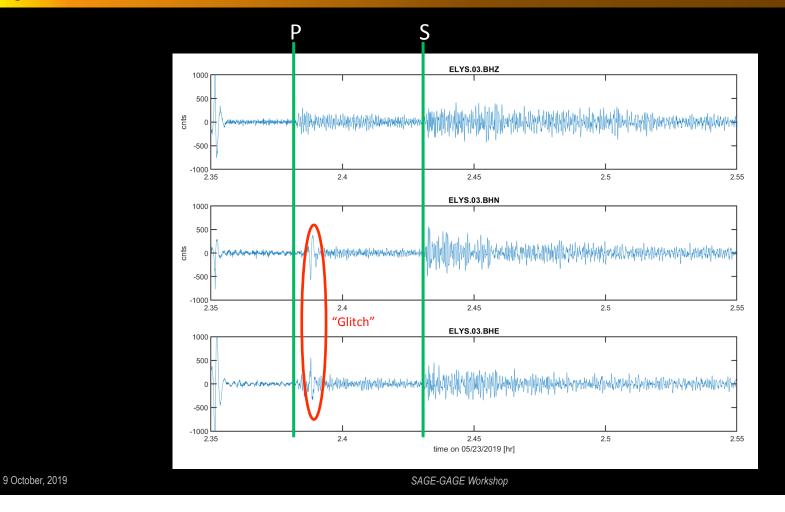
### SEIS Continues to Detect Several New Events/Week



# First Identified Marsquake: S0128a (HA)



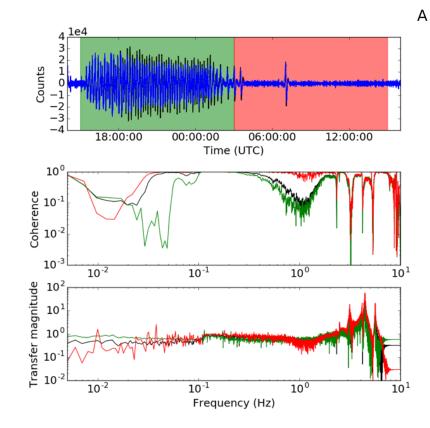
# Largest Marsquake to Date: S0173a (BA), Magnitude 3.7

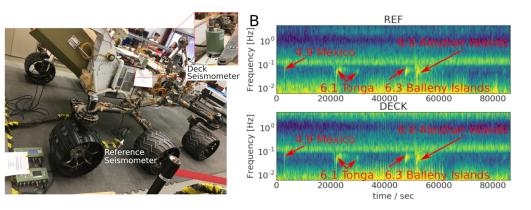


#### Future deployments on deck?

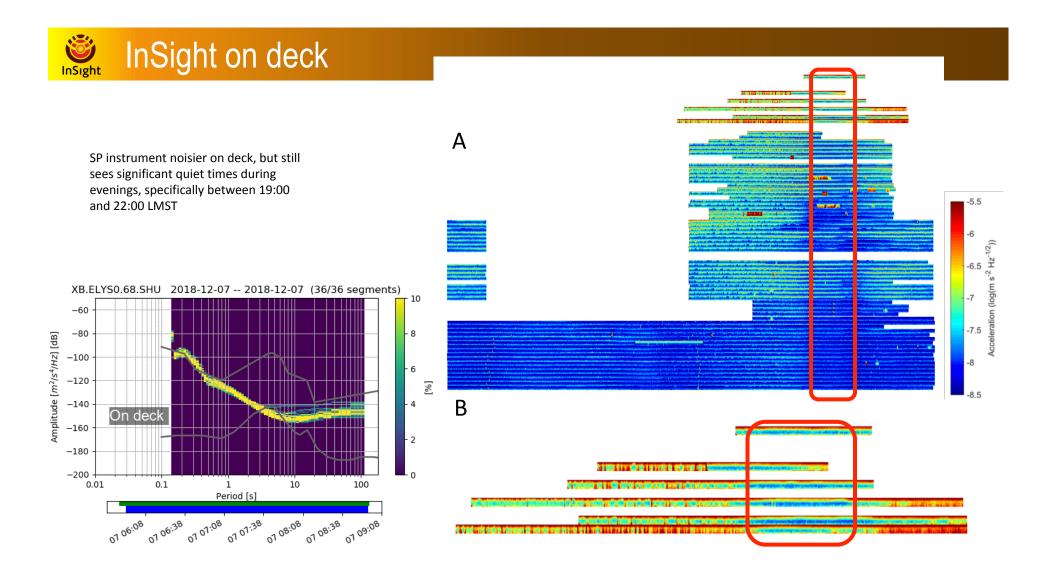
- The deployment process was critical for achieving target noise levels
- It was also the most expensive part of the mission (building a robotic arm and staffing people to work it for deployment for months!)
  Can we do things on future missions more cheaply if not as high perormance?



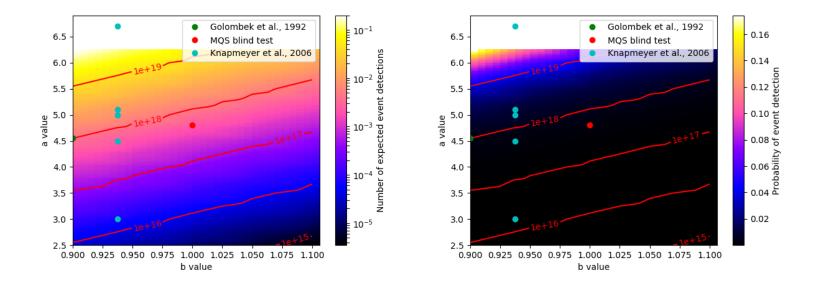




On deck operation on MSL engineering model shows clean recording of teleseismic events and simple transfer function from ground motion. Air motion causes decoherence. Lander activity not considered here (measurements were taken over a weekend, and engineering model does not require active thermal management used on Mars).



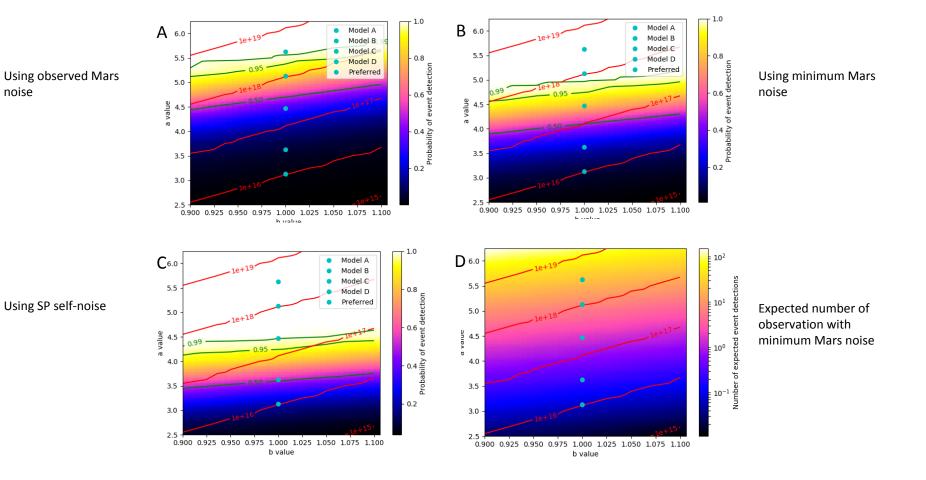
# Detection probability on Mars for 48 hours of on-deck observation



Using synthetic martian seismograms to model detection threshold, it looks like likely years of on-deck operation would be required on Mars.

#### Simulated 48 hour detection probabilities on Europa!

InSight



#### Summary

- Deploying a seismometer on Mars is a long, slow process.
- The data, though, is quieter than anywhere on Earth in some frequency bands
- We have detected many events and located several of them
- Future deployment on airless bodies may be able to be done without deployment with more modeling of the specific mission design

#### Sunset over Elysium, sol 145

Raw images are available at mars.nasa.gov/insight essentially as soon as they hit the ground.

All InSight science data through the end of June (sol 210) is currently available in the PDS.

GSA Annual Meeting — Phoenix, AZ

## HP3 status

9 October. 2019

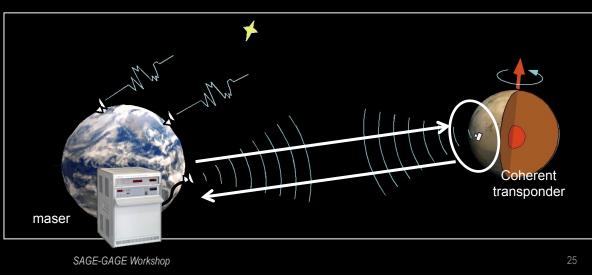
- The HP<sup>3</sup> was deployed to the surface in mid-February and immediately began penetration.
- A depth of 35 cm was reached relatively rapidly (within a few hundred strokes); repeated subsequent hammering (~9000 strokes) resulted in no measurable further progress.
- Our conclusion is that the mole has either encountered an obstacle (e.g., a rock) or, more likely, has lost sufficient hull friction to maintain downward progress.
- We have been developing and testing a recovery plan and are preparing to use the robotic arm to increase the hull friction.



#### RISE Status

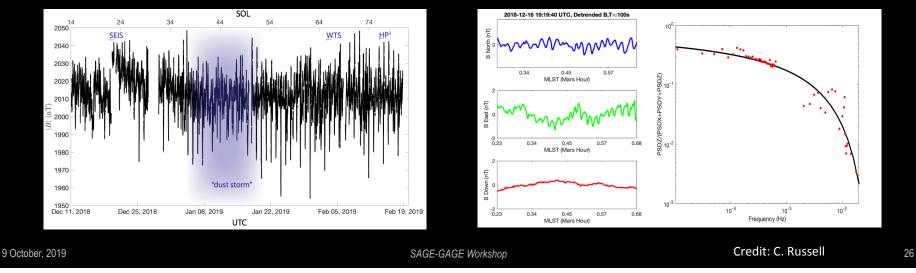
9 October. 2019

- Measurement of the timing and Doppler shift of the X-band radio signal between the Earth and InSight allow us to track the location and motion of the lander to an accuracy of better than 10 cm in inertial space.
- We are tracking the lander location for about an hour, several sols/week, allowing us to measure the motion of the rotation vector of Mars.
- We expect to have an improved precession measurement, yielding an improved Mars MOI, within a few months.
- Measurement of the nutation to a precision that will allow the separation of core radius and density is expected to require an additional year.



#### Magnetometer (IFG)

- InSight is providing the first magnetic measurements from the surface of Mars. Notable early results include:
  - The DC field at the landing site is roughly an order of magnitude stronger than measured from orbit, evidence of significant crustal field variations at spatial scales less than ~150 km.
  - Vertical field oscillations are observed to be attenuated at higher frequencies relative to horizontal components, possibly suggesting high conductivity at depth.



#### InSight Meteorology

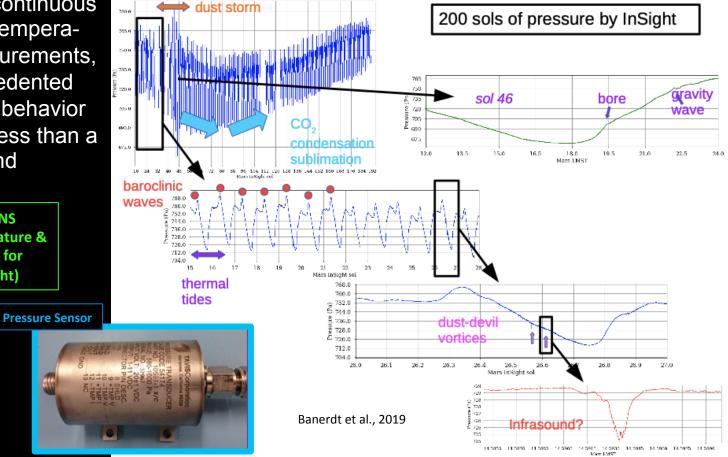
InSight is returning continuous high-rate pressure, temperature, and wind measurements, providing an unprecedented view of atmospheric behavior at time scales from less than a second to months and seasons.

TWINS

(Temperature &

Wind for

InSight)



### InSight Cameras (2967 Images as of Sol 293, 9/23/2019)

