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INFRASOUND DETECTIONS OF THE OSIRIS-REX SAMPLE RETURN CAPSULE RE-ENTRY

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Infrasound Technology Workshop 2024 (ITW2024)

4 – 8 Nov 2024, Vienna International Centre, Vienna, Austria

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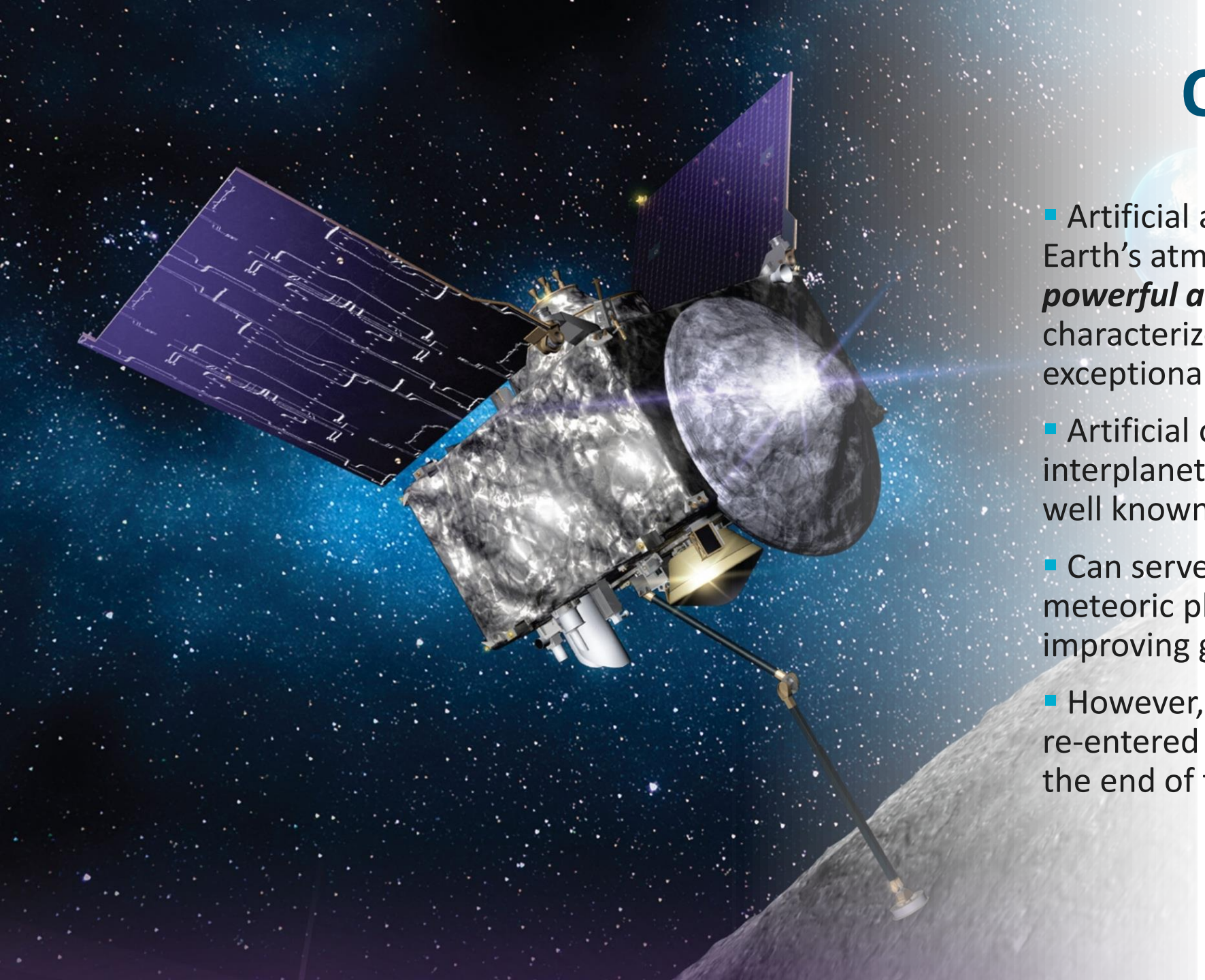
SAND2024-14689C



OVERVIEW

- Artificial and natural objects entering Earth's atmosphere at hypervelocity generate ***powerful acoustic waves***, but well-characterized observations of entries are exceptionally scarce
- Artificial objects arriving from interplanetary space have the parameters well known *a priori*
- Can serve as ideal ***proxies*** for studying meteoric phenomena and are critical for improving global monitoring
- However, only a handful of spacecraft have re-entered from interplanetary space since the end of the Apollo era

NASA’S OSIRIS-REX MISSION

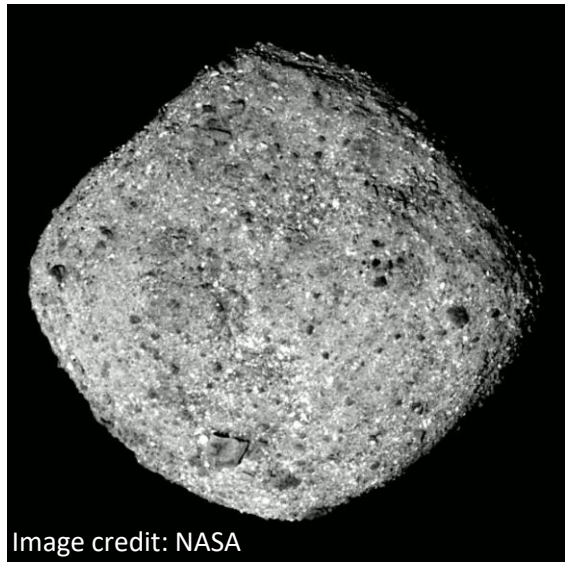


Image credit: NASA

- The re-entry of the OSIRIS-Rex (Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer) Sample Return Capsule (SRC) provided an ***unprecedented and unique opportunity to study a well-known artificial meteor using infrasound and seismic sensors***

- The OSIRIS-REx asteroid sample return mission was launched in 2016 to collect samples of the near-Earth asteroid Bennu
- OSIRIS-REx SRC returned to Earth on 24 September 2023

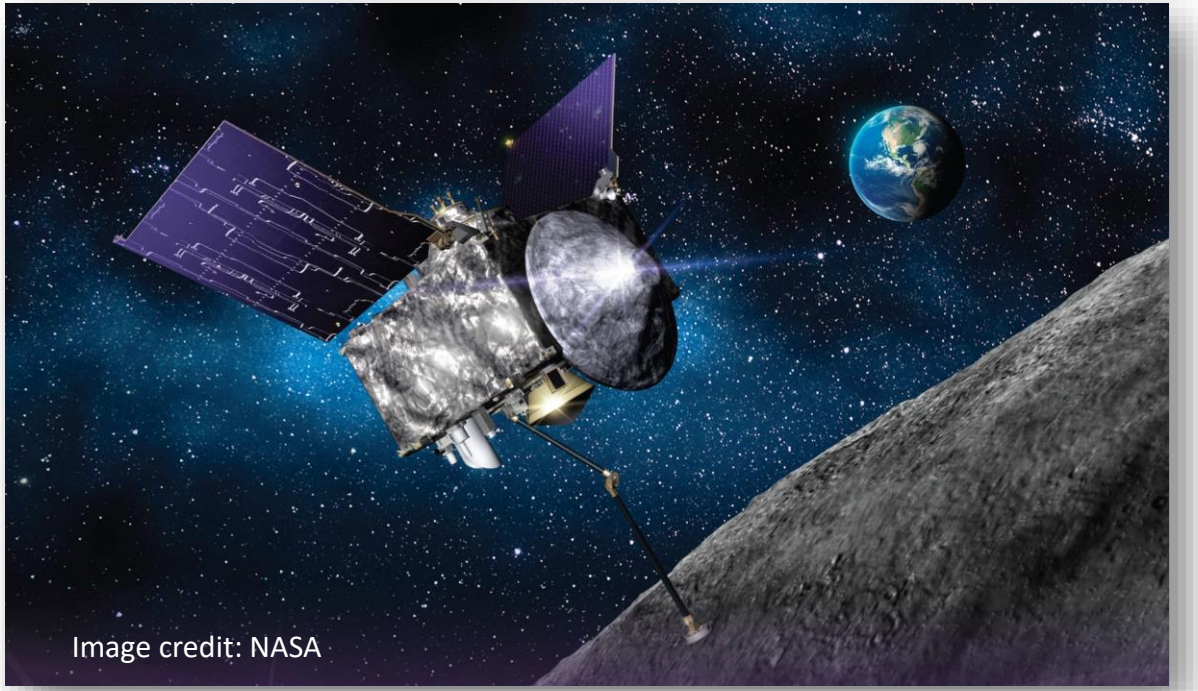


Image credit: NASA

OSIRIS-REX SAMPLE RETURN CAPSULE

- The most recent ‘artificial meteor’ was the re-entry of NASA’s OSIRIS-REx sample return capsule (SRC) on September 24, 2023

Image credit: NASA

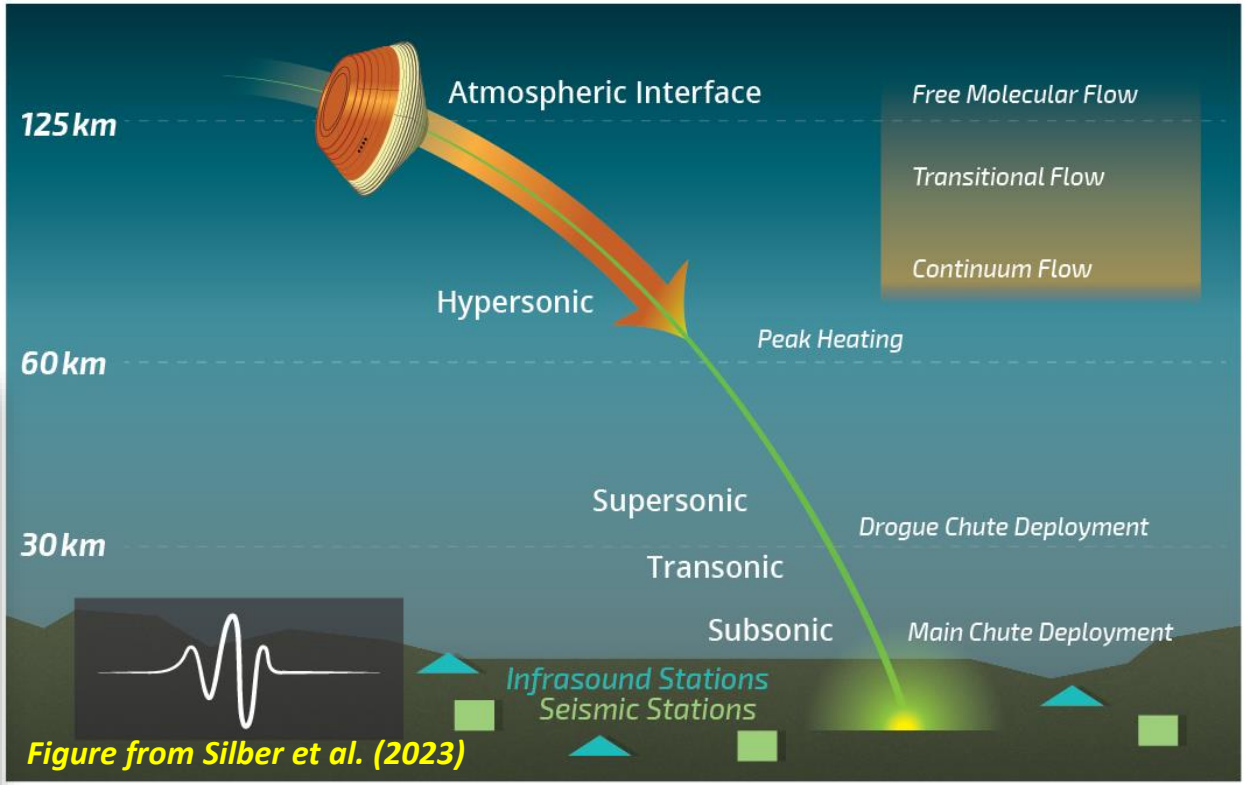


Figure from Silber et al. (2023)

- A multi-institutional effort resulted in the ***largest to-date observational campaign*** to capture ***geophysical signals*** generated by an object as it re-entered the atmosphere from interplanetary space

PAST RE-ENTRIES FROM INTERPLANETARY SPACE

	Genesis[1]	Stardust[2]	Hayabusa 1[3]	Hayabusa 2[4]	OSIRIS-REx[5]
Date	8 Sep 2004	15 Jan 2006	13 Jun 2010	5 Dec 2020	24 Sep 2023
Entry speed* (km/s)	11.0	12.9	12.2	12.0	~12
Entry angle (°)	8.0	8.2	12	12	~8
Landing site	UTTR	UTTR	WPA	WPA	UTTR
Mass (kg)	225	45.8	18	16	46
Diameter (m)	1.52	0.811	0.400	0.400	0.810

List of SRCs. The upcoming OSIRIX-REx SRC re-entry is highlighted. UTTR is the Utah Test and Training Range, Utah, and WPA is the Woomera Prohibited Area, Australia.

*at ~135 km altitude

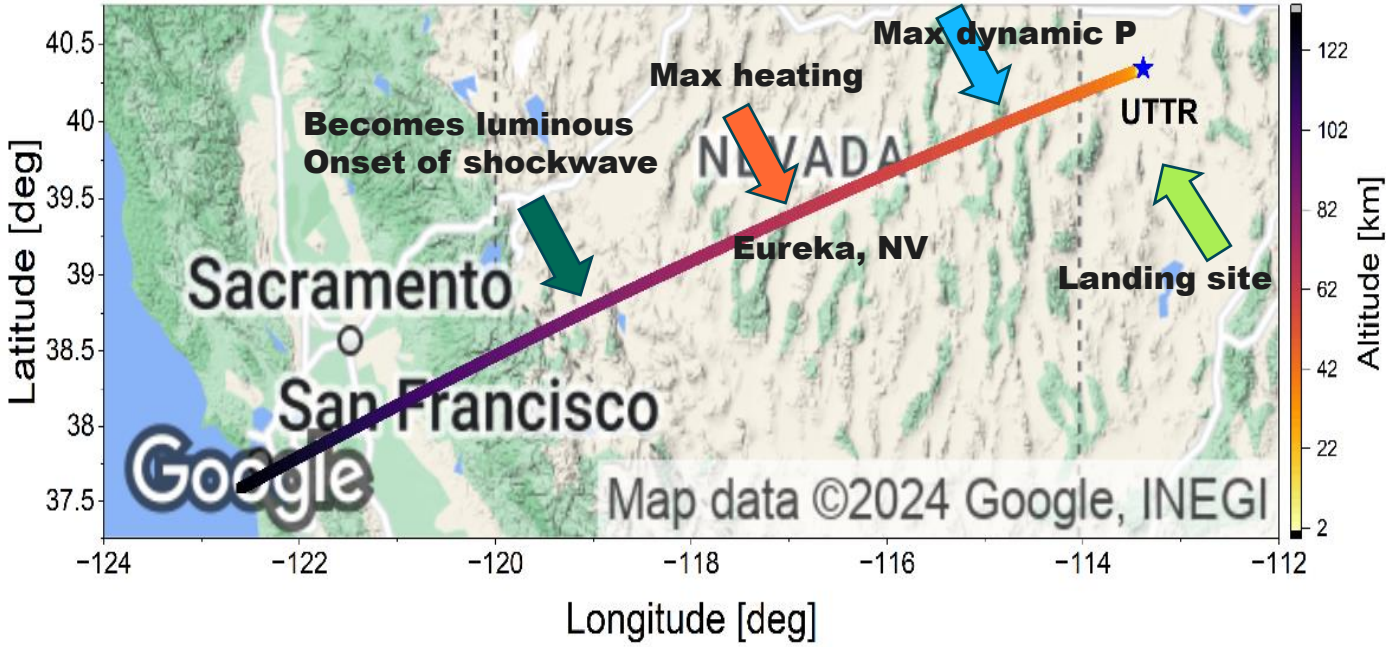
[1]ReVelle, et al., 2005; [2]ReVelle & Edwards, 2007; [3]Yamamoto et al., 2011; [4]Sansom et al., 2022; [5]Lauretta et al., 2017

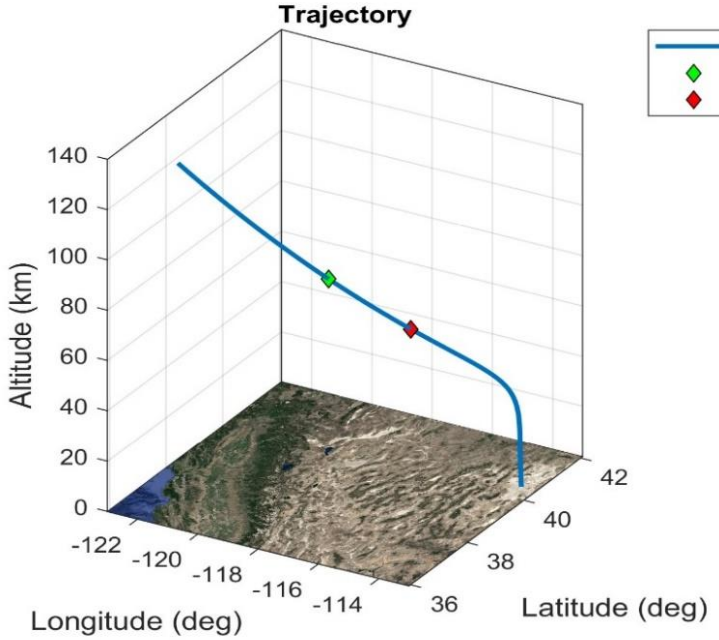
In design and re-entry, the OSIRIS-REx SRC is nearly identical to that of the Stardust SRC

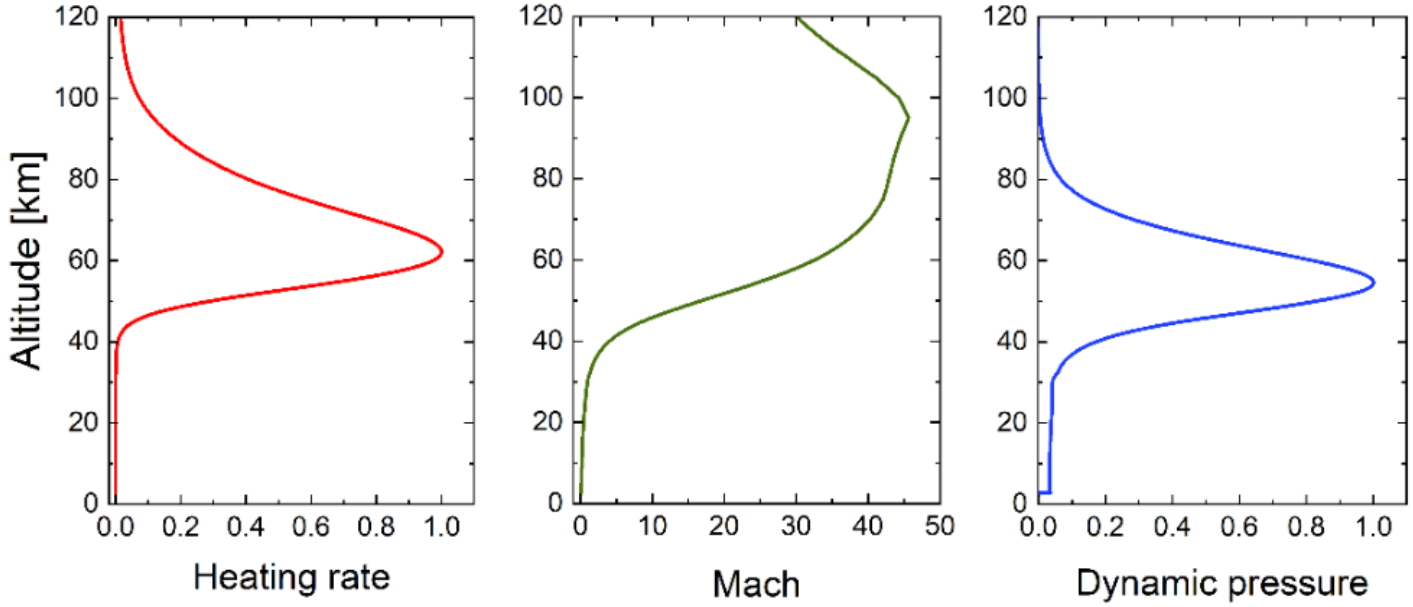
Instrument type	Genesis	Stardust	Hayabusa 1	Hayabusa 2
Seismometers (number)	-	2	20	7
Infrasound array (number)	1	1	1	7
Infrasound array (number of elements)	3	4	3	4
Infrasound (number of stand-alone sensors)	-	-	2	-
Infrasound (total number of sensors)	3	4	5	28

List of dedicated seismo-acoustic instruments used in previous SRC observation campaigns.

OSIRIS-REx was observed with a record number of instruments



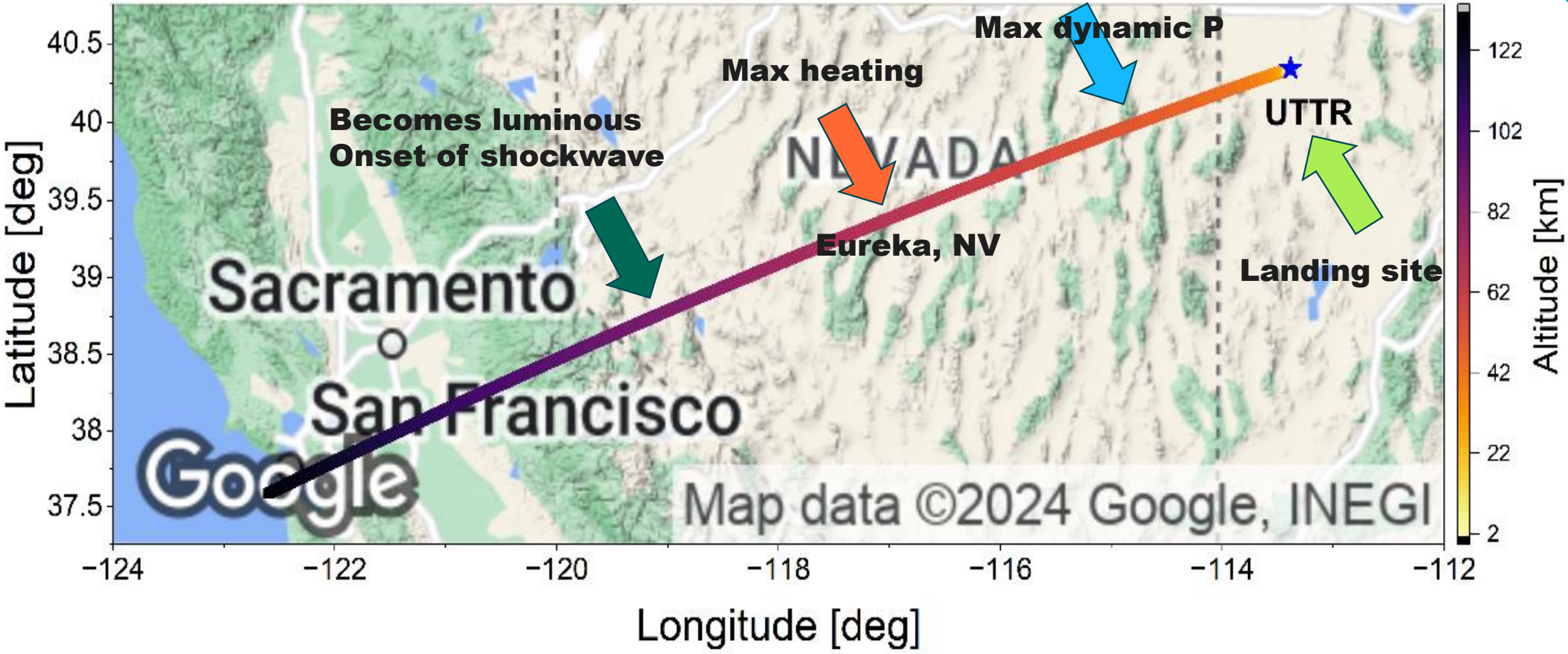




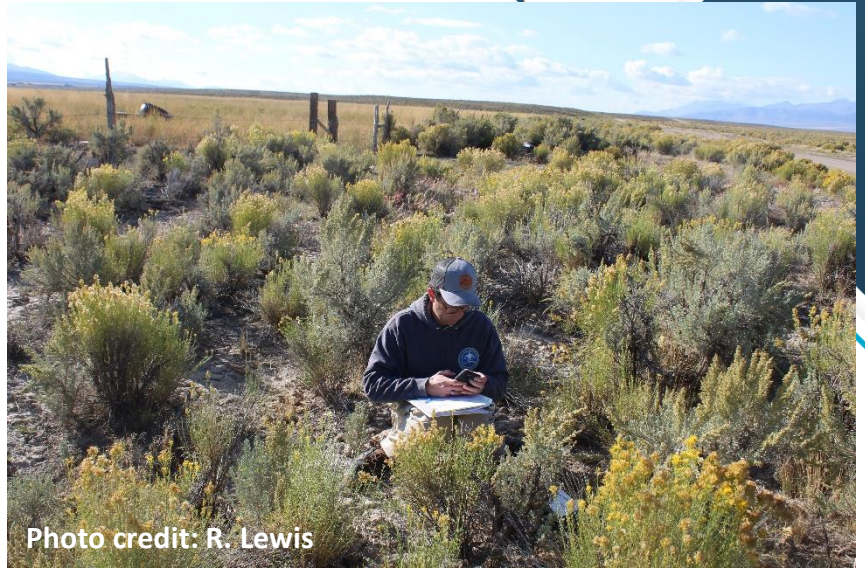
Some considerations

- Signal detection and data collection locations
- Cost considerations
- Instrument synergy and deployment
- Environmental and infrastructure impact
- Personnel allocation
- Timeline and coordination

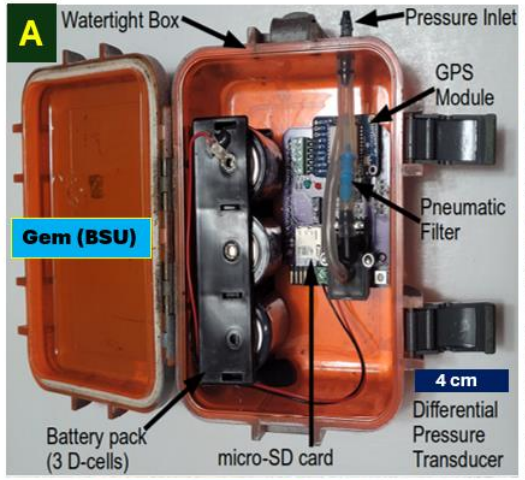
GEOGRAPHICAL CONTEXT

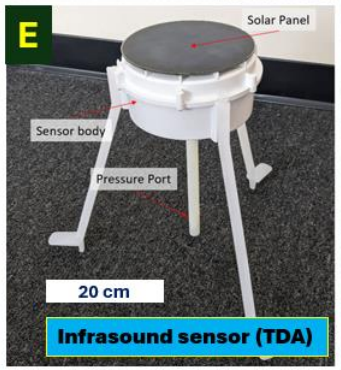


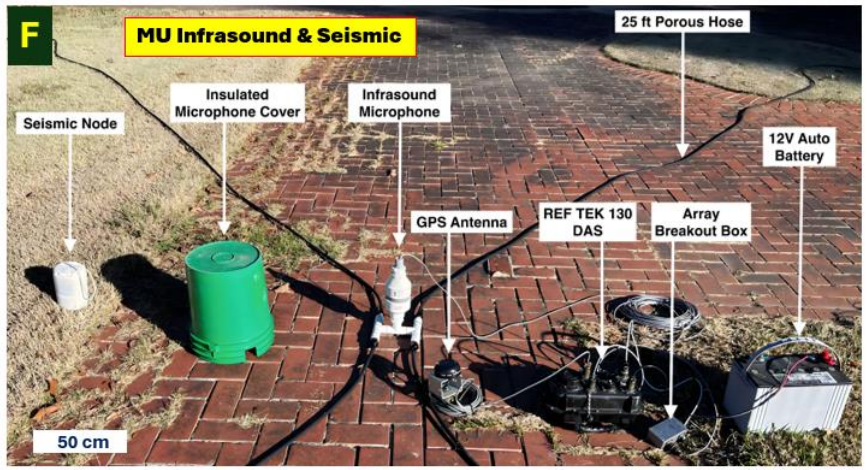
DEPLOYMENT AND DATA COLLECTION



- Approximately 80 investigators from over a dozen institutions participated in this historical observational campaign
- The sensing modalities included infrasound (ground-based and airborne), acoustic (audible), seismic, DAS, and GPS, deployed in several regions







DEPLOYMENT: MULTI-INSTITUTION PARTICIPATION

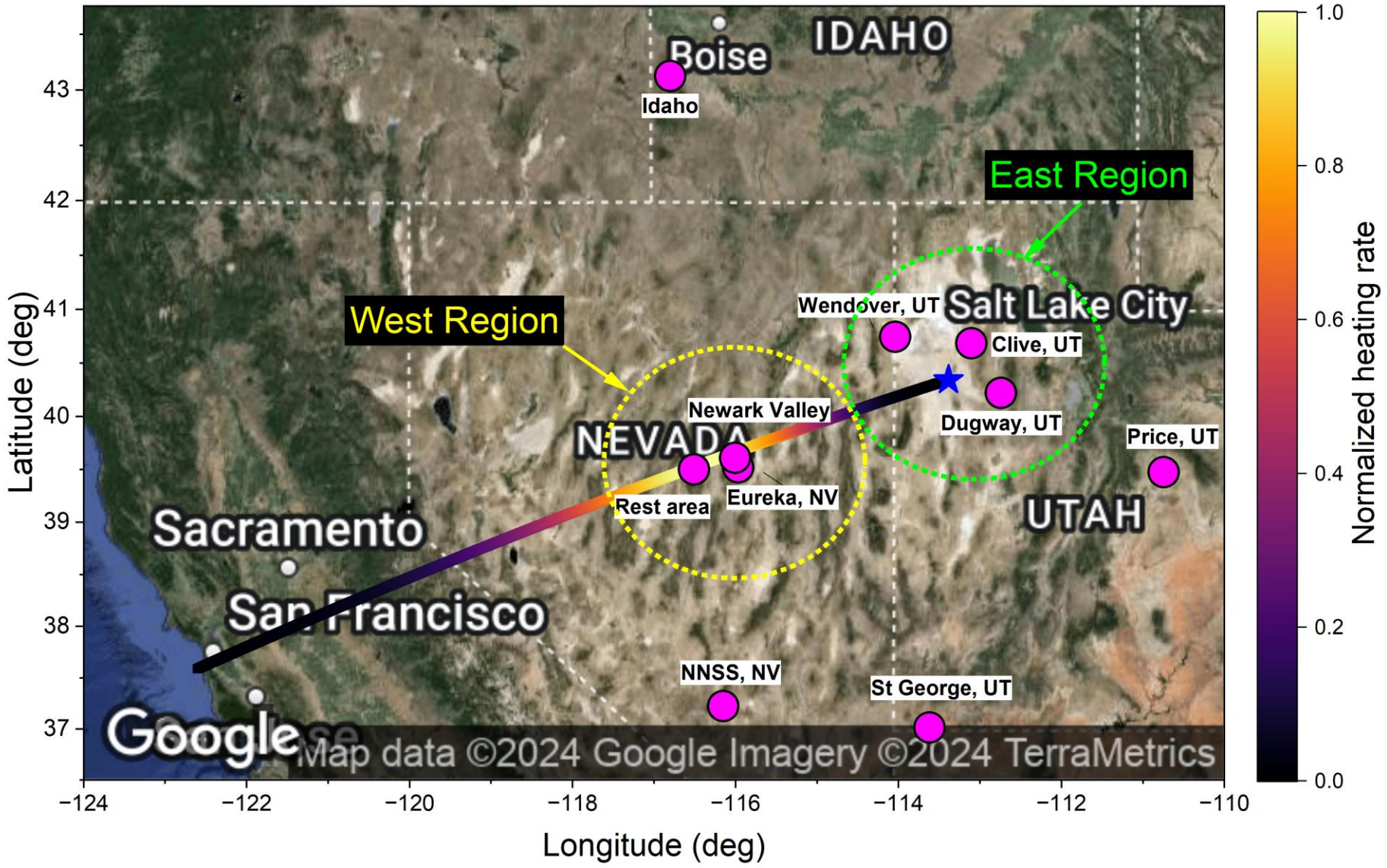
- Sandia National Laboratories (SNL)
- Los Alamos National Laboratory (LANL)
- NASA Jet Propulsion Laboratory (JPL)
- Air Force Research Laboratory (AFRL)
- Atomic Weapons Establishment (AWE) Blacknest
- Boise State University (BSU)
- Defense Threat Reduction Agency (DTRA)
- Idaho National Laboratory (INL)
- Johns Hopkins University (JHU)
- Kochi University of Technology (KUT)
- Nevada National Security Site (NNSS)
- Oklahoma State University (OSU)
- South Methodist University (SMU)
- TDA Research Inc. (TDA)
- University of Hawaii (UH)
- University of Memphis (UM)

~ 400 instruments deployed

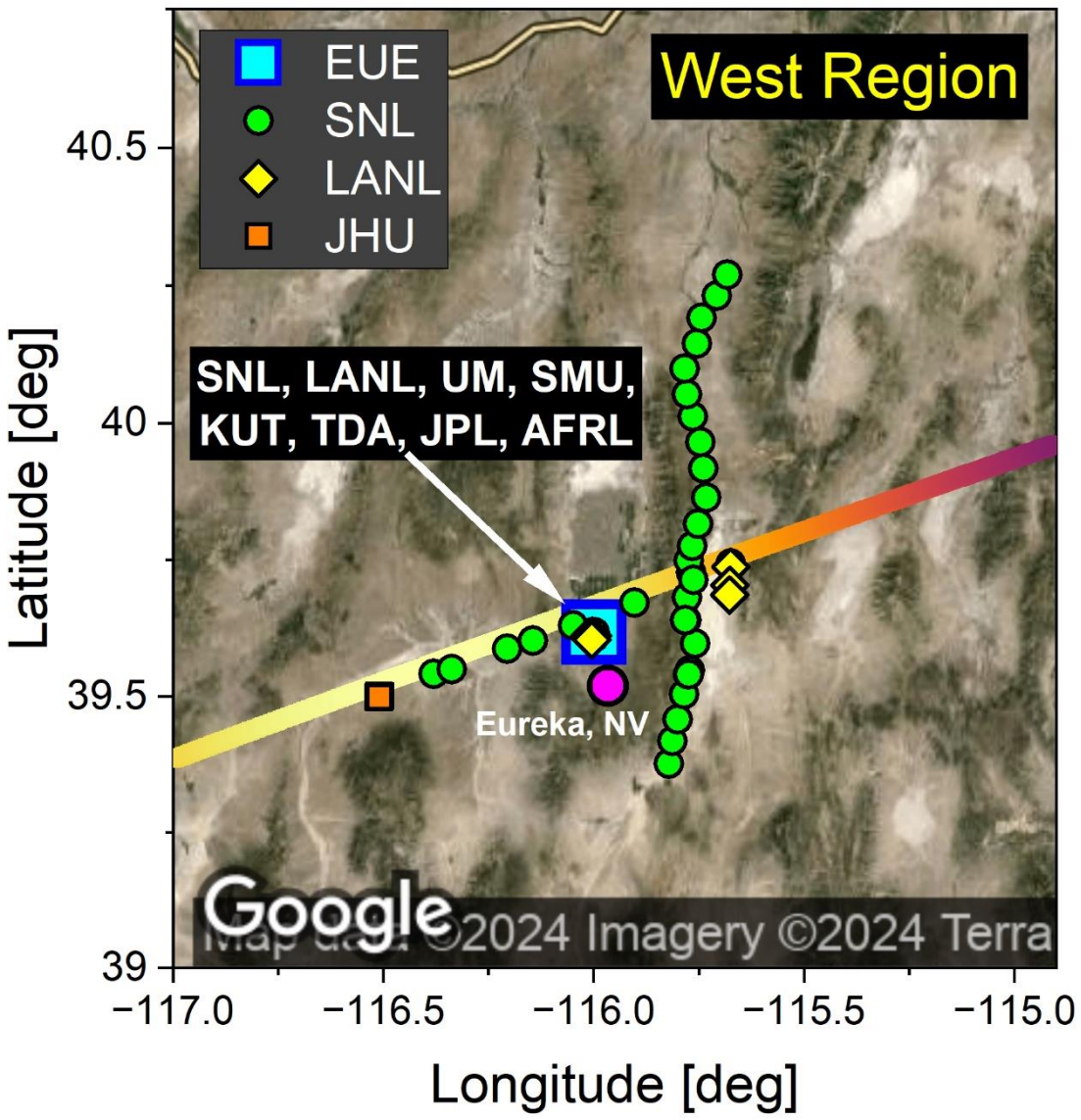
Institution	Infrasound (single sensor station)	Infrasound (array)	Total number of sensors in arrays	Large N-array (number of sensors)	Audible microphone	Smart phone	Seismic	DAS	GPS	Balloons
SNL	47	3 (x4)	12	-	-	2	19	-	-	8
LANL	6	2 (x4) + 1 (x6)	14	-	1	-	6	2	5	
AWE	-	1 (x4)	4	-	-	-	-	-	-	
BSU	-	3 (x4), 1 (x44)	56	-	-	-	-	-	-	
JHU	-	-	-	-	-	-	11	-	-	
JPL	-	-	-	-	-	-	-	-	-	1
KUT	-	1 (x4)	4	-	5	-	-	-	-	
OSU	12	1 (x4)	4	-	-	-	-	-	-	
SMU	-	1 (x4)	4	-	-	-	-	-	-	
TDA	-			115	-	-	-	-	-	
UofH, AFRL, INL	-	-	-	-	-	33	-	-	-	
UofM	-	2 (x4)	8	-	-	-	76	-	-	
	65	**13**	**106**	**115**	**6**	**35**	**112**	**2**	**5**	**9**

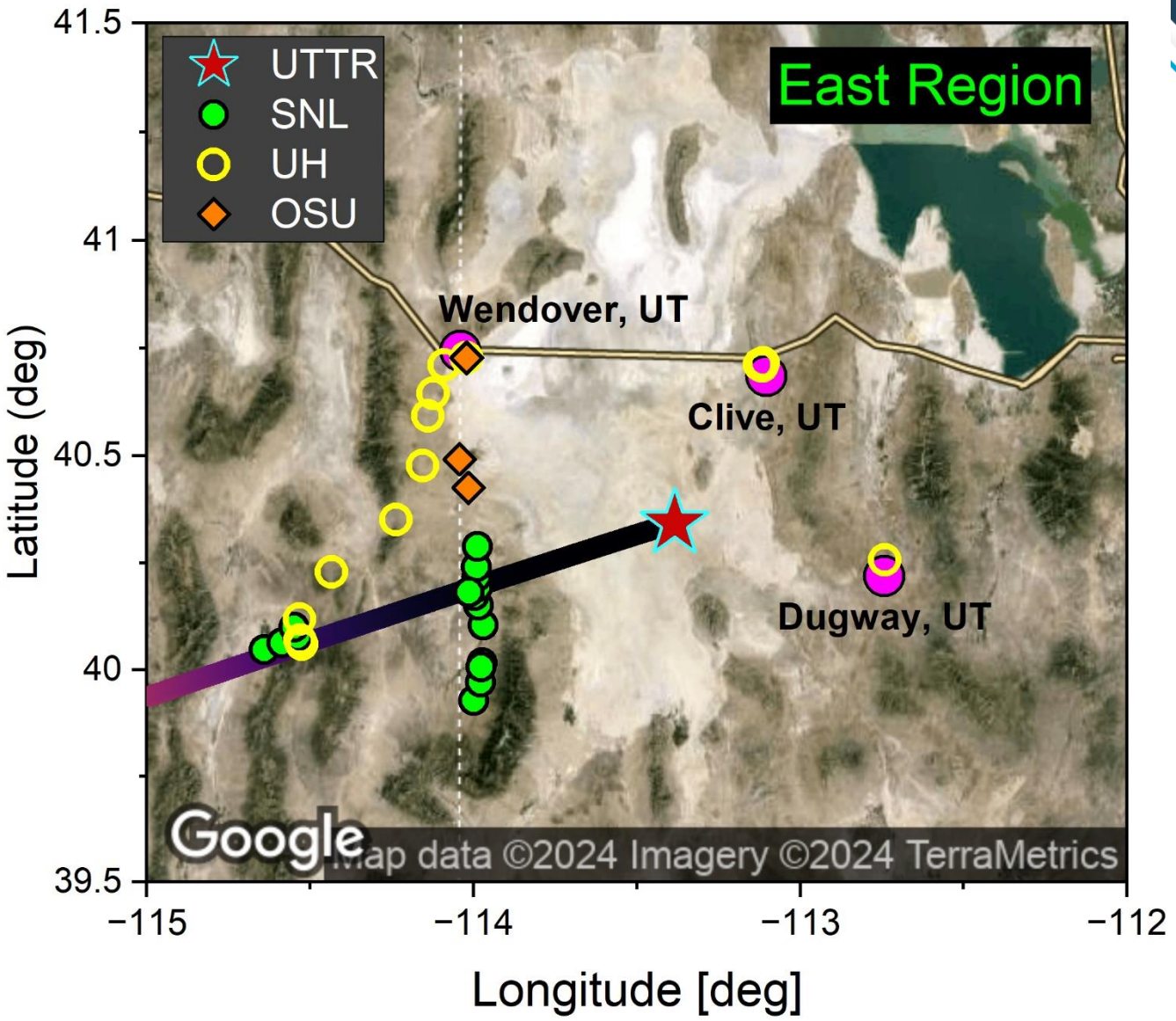
GEOGRAPHICAL CONTEXT

West Region			East Region		Distal stations
Eureka Airport	Newark Valley	Bean Flat Rest Area	West Wendover Airport	NV/UT	
SNL, LANL, UM, SMU, KUT, TDA, JPL, AFRL	SNL, LANL	JHU	OSU, UH	UH, AFRL, INL	LANL, AWE, BSU, NNSS



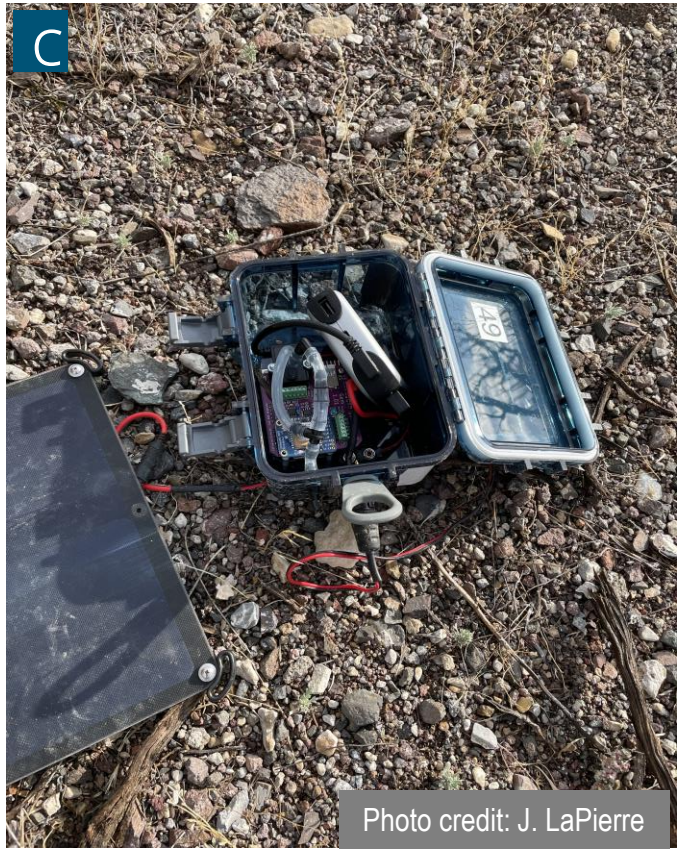
GEOGRAPHICAL CONTEXT CONT'D

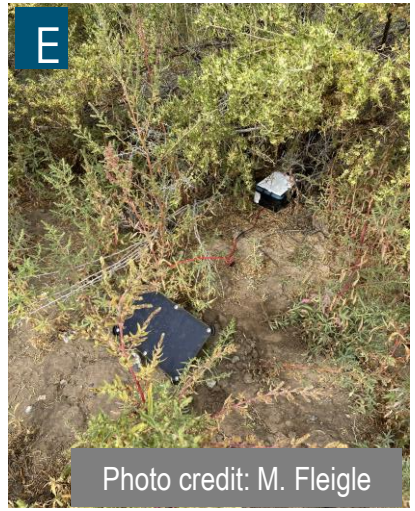




SNL DEPLOYMENT

- We deployed infrasound and seismic sensors in Nevada and Utah to capture the signals as a function of distance from the trajectory and from different parts of the trail.
- 47 single sensor stations (30 in West Region, and 17 in East Region), three 4-element arrays, and 19 seismic nodes were installed in total. Figure shows the map with deployment areas.





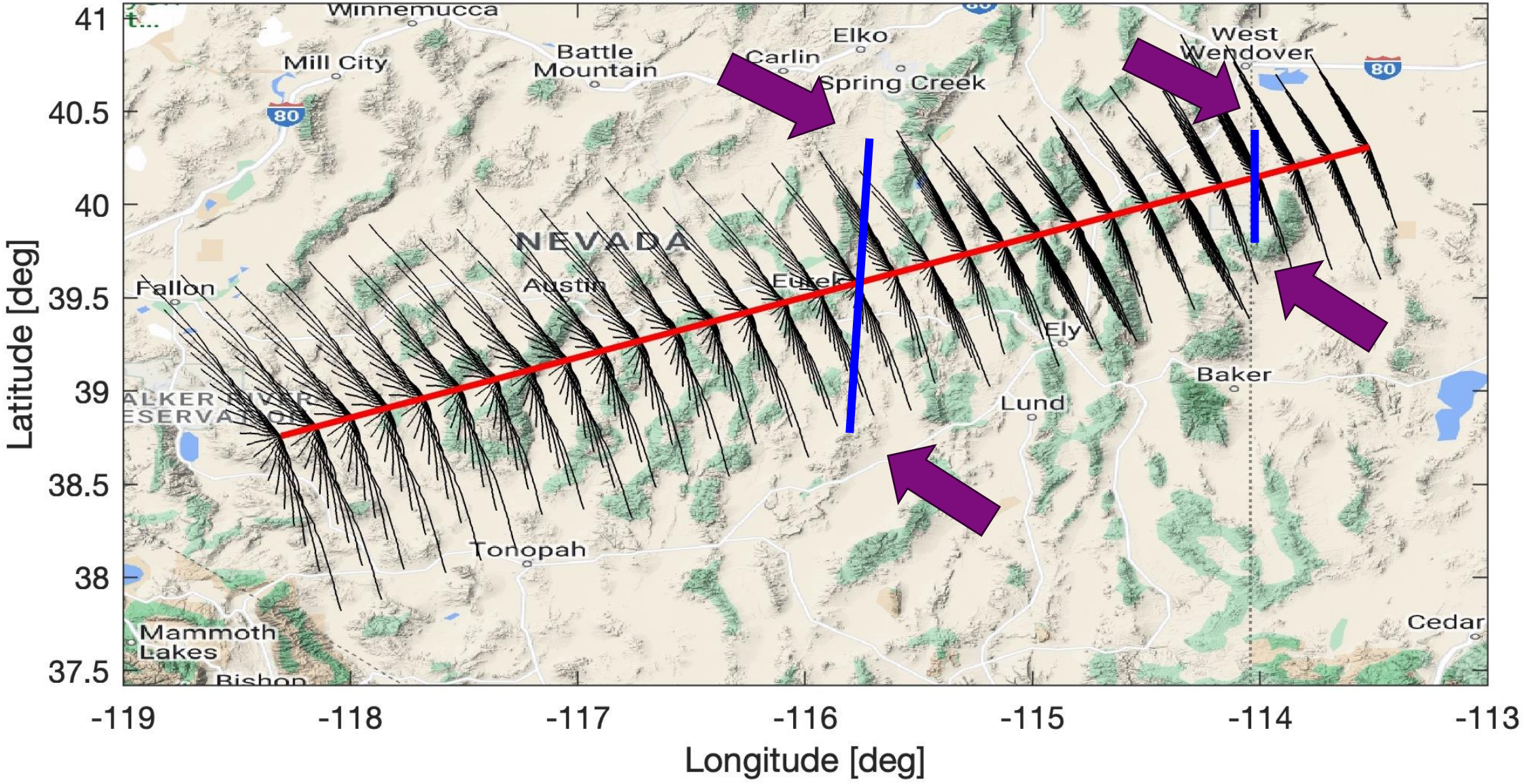
A, B and D show the Hyperion sensor array and seismic node installations. C and E shows the single sensor Gem.

OSIRIS-REX RE-ENTRY

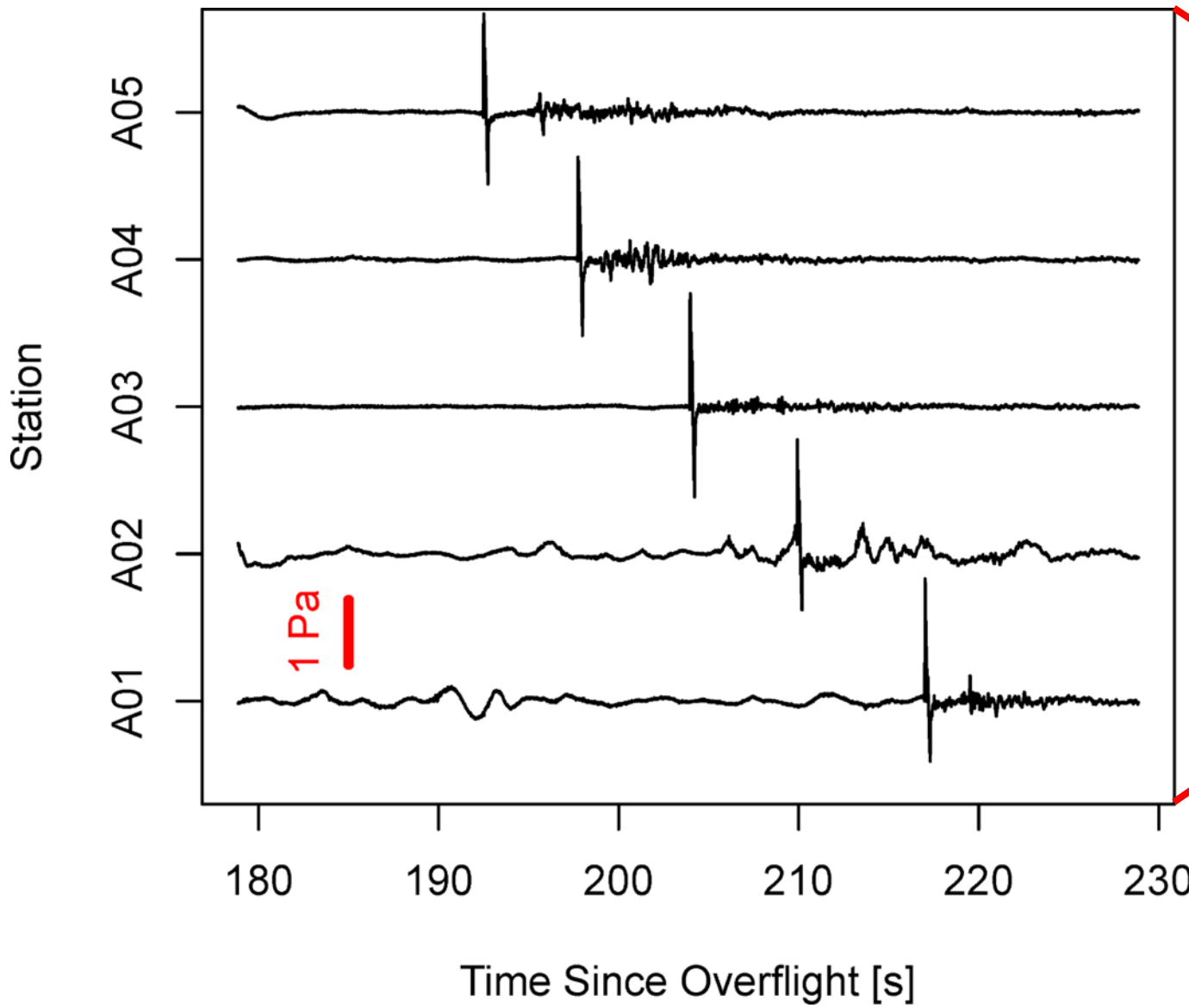
- Overflight was at 07:42 am local time
- Calm day, clear skies
- Teams in all regions heard audible sounds (single and double “thud”)
- All operational instruments detected signals

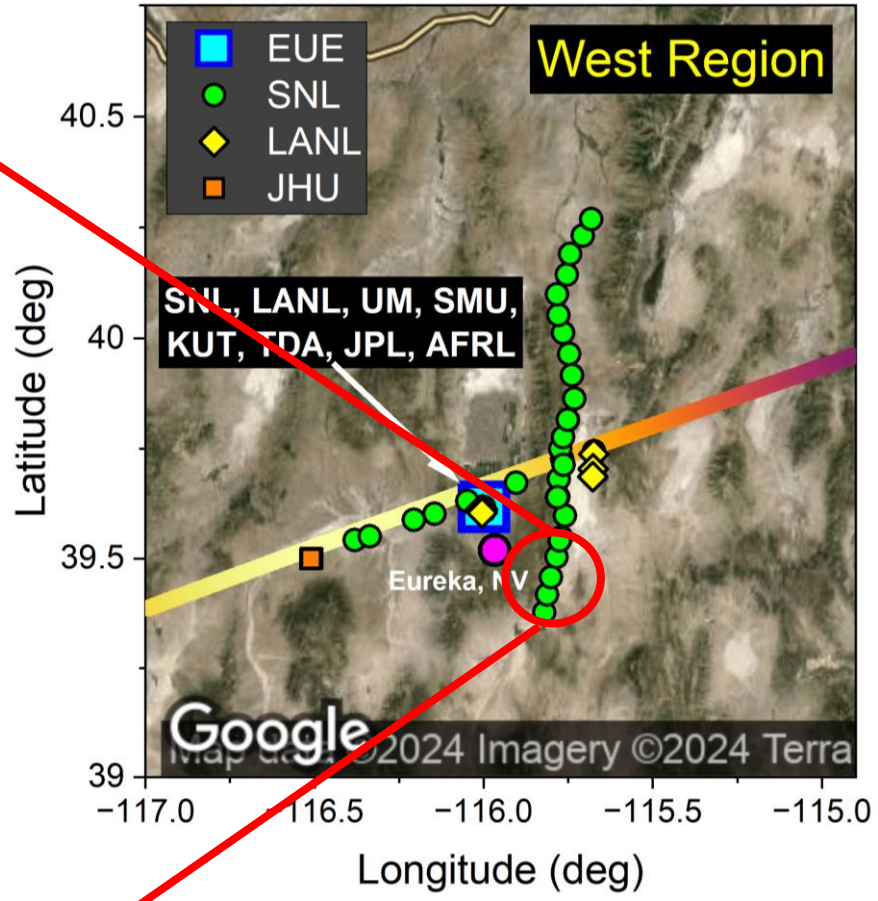
Photos credit: R. Lewis

HYPERSONIC CORRIDOR



INFRASOUND DETECTIONS

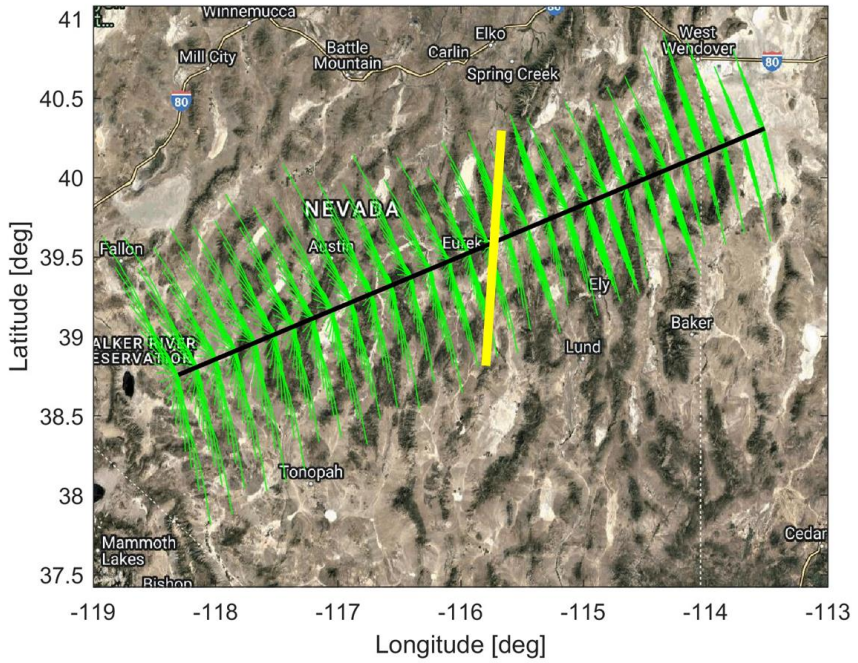


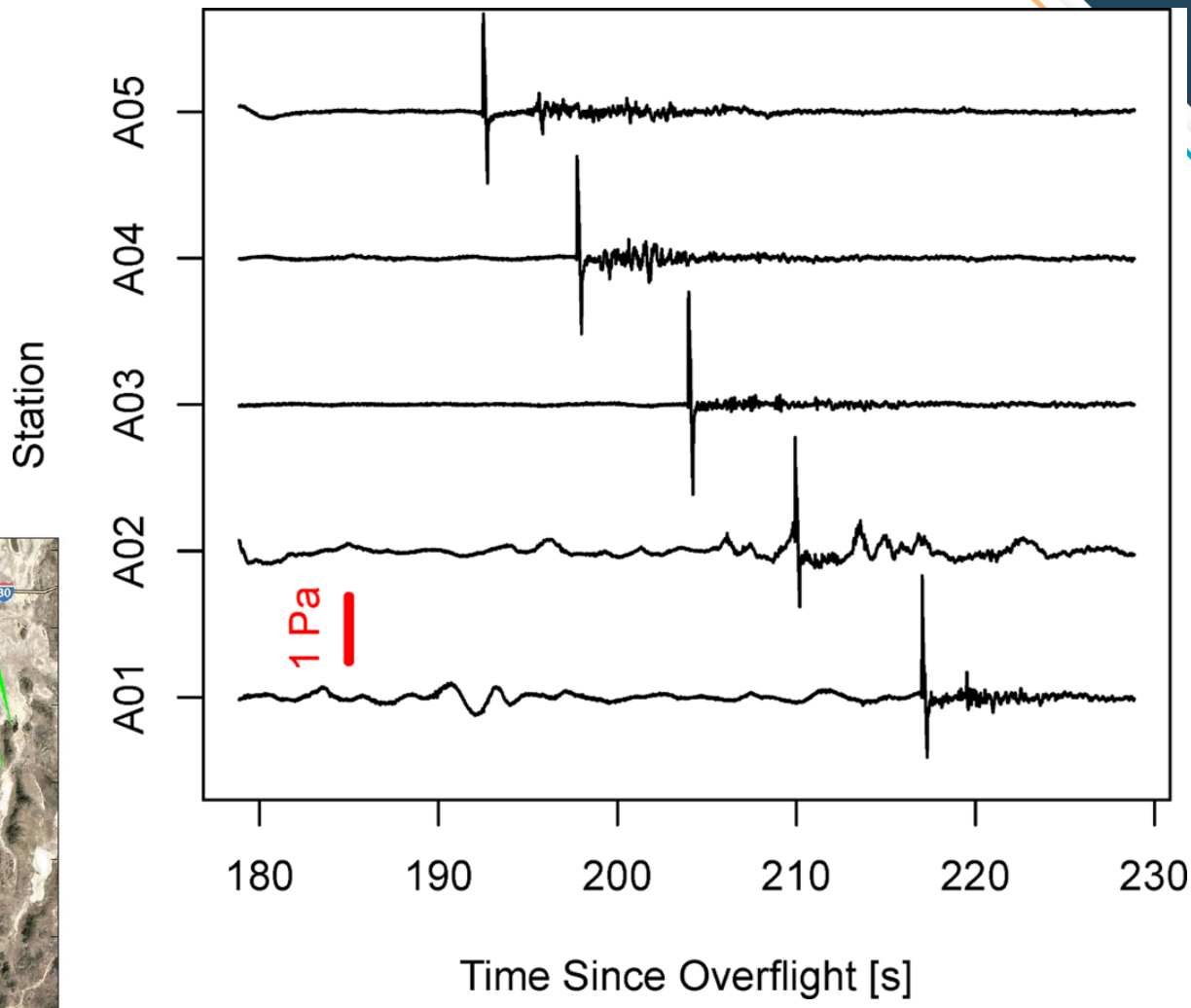


- An N-wave with some coda was detected at all operational single sensor stations

INFRASOUND DETECTIONS

- An N-wave with some coda was detected at all operational single sensor stations
- Figure shows the signals from the south end of the transect in the West Region
- We detected strong infrasound signals generated by the OSIRIS-REx SRC at nearly all sensors in NV and UT
- Early analysis indicate that some signals come from a common point and some from different points along the trail





CONCLUSIONS

- The observational campaign was very successful
- We detected strong infrasound signals at nearly all sensors in NV and UT
- The results have implications for future observational efforts on Earth as well as capturing shockwave signatures on other planetary bodies with atmospheres (e.g., Mars, Titan, Venus)

Photos credit: R. Lewis

SPECIAL THANKS

The authors gratefully acknowledge the Board of Eureka County Commissioners and the Eureka Municipal Airport personnel. The authors thank Nevada Highway Patrol and Eureka County Deputies for their assistance during the OSIRIS-REx SRC re-entry. The authors also thank people of Town of Eureka for their hospitality. We are grateful for the Bureau of Land Management Ely District Office for granting us permission to deploy sensors in eastern Nevada as well as assisting us with coordination.

Acknowledgements: Sandia National Laboratories is a multimission laboratory operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. Cleared for release.

RELEVANT PUBLICATIONS

Silber, E.A., Bowman, D.C., & Albert, S. (2023). Atmosphere, 14(10), 1473, doi: 10.3390/atmos14101473

Silber, E.A. et al. (2024) PSJ, doi: 10.3847/PSJ/ad5b5e

Silber, E. A. (2024) Remote Sensing, doi: 10.3390/rs16193628

EXTRA SLIDES