National Aeronautics and Space Administration

Enceladus Distributed Geophysical Experiment (EDGE)

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Enceladus Surface Sample Acquisition for In Situ Measurements**

Objectives. (1) Document in a peer-reviewed paper models of the interior structure, dynamics, and associated provenance of sampled surface materials: Link tides and ocean dynamics with the surface deposits and ice-ocean exchange to geological activity. (2) Document in a peer-reviewed paper the use of ambient seismic noise and time-reversal and migration seismic imaging at Enceladus

These activities leverage interior structure and seismic modeling developed at JPL in recent years, and build on pioneering geophysical research by collaborators in France and in the Czech Republic. This work advances progress made by JPL's Icy Worlds team, and enhances JPL leadership in geophysical studies of Enceladus.

Background

Objective 1, Interior Activity and Surface Deposits: combined recently developed structural models for Enceladus [1] with inverse techniques that have already been applied to interpreting the tidal response and interior structure of Enceladus from Cassini data [2,3,4]. Global circulation of Enceladus's ocean depends on both the tidal and rotational state [3,5] and on the influence of melting at the ice-ocean interface. As has been shown for Europa [6], the variations in ice thickness imply melting and lateral transport; these effects will be very pronounced for Enceladus, which is predicted to have ice as thin as 5 km at the poles and as thick as ~40 km around the equator.
Objective 2, Ambient Noise Seismic and Time-Reversal Migration Imaging: We developed new data analysis approaches being applied in terrestrial seismology to determine internal structure in the ice shell. The new techniques have the potential to return structure vital to understanding the formation and workings of the tiger stripes features at the south pole of Enceladus.

Approach and Results

Funds for this year were dedicated to completing work already in progress. We made good use of the funds, publishing three peer-reviewed papers and advancing other tasks such that they are likely to continue under their own momentum in FY22.

Milestones and **progress**:

a. Publication of a paper demonstrating separate Ambient Noise Seismic Imaging (ANSI). Demonstration of Time Reversal and Migration Imaging (TRMI)-based simulations) **ANSI paper published in IEEE transactions [A]**

b. Submission of peer-reviewed publications for each of the Objectives 1-3—3D gravity and tilt **responses Paper in Nature Geoscience [B] describing influence of salinity on ocean circulation; Paper in Planetary Science Journal [C] on multi-node geophysics at Enceladus. Paper on 3D seismology of Enceladus still in progress; Paper on transient electromagnetic sounding (TEM) still in progress; Paper on surface tilt for Icarus nearing submission.**

c. Integration of validated ANSI and TRMI approaches into implementable on-board software. **Still in progress.**

Significance/Benefits to JPL and NASA

This work advances networked geophysical exploration that might be deployed on worlds beyond Enceladus. The result of our effort provide the elements to compare the science return of a landed single-station or network architecture versus those of a combined orbiter-lander or orbiter-only mission. Progress made by this project will be helpful feed-forward for the Enceladus geodesy initiative being pursued under the SRTD program, including a KISS workshop happening in October 2021. Members of the team supported by Orbilander concept presented to the Decadal steering committee. The results, including in progress work, have germinated new work that will lead to additional papers, presentations, and funding.

Publications

[A] Wang, S., Li, F., Panning, M., Tharimena, S., Vance, S., and Song, W. (2020). Ambient noise tomography with common receiver clusters in distributed sensor networks. IEEE Transactions on Signal and Information Processing over Networks, 6:656–666.

[B] Lobo, A. H., Thompson, A. F., Vance, S. D., and Tharimena, S. (2021). A pole-to-equator ocean overturning circulation on Enceladus. Nature Geoscience, 14(4):185–189.

[C] Marusiak, A. G., Vance, S., Panning, M. P., Bˇehounkov´a, M., Byrne, P. K., Choblet, G., Daswani, M. M., Hughson, K., Journaux, B., Lobo, A. H., Schmidt, B. E., Sl´adkov´a, K. P., Soderlund, K. M., Song, W., Sou˘cek, O., Steinbru¨gge, G., Thompson, A. F., and Wang, S. (2021). Exploration of icy ocean worlds using geophysical approaches. The Planetary Science Journal, 2(4):150.

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References

[1] Vance, S. D., Panning, M. P., Stähler, S., Cammarano, F., Bills, B. G., Tobie, G., Kamata, S., Kedar, S., Sotin, C., Pike, W. T., and et al. (2018). Geophysical investigations of habitability in ice-covered ocean worlds. Journal of Geophysical Research: Planets. [2] Čadek, O., Souček, O., Běhounková, M., Choblet, G., Tobie, G., and Hron, J. (2019). Long-term stability of Enceladus' uneven ice shell. Icarus, 319:476–484. [3] Choblet, G., Tobie, G., Sotin, C., Běhounková, M., Cadek, O., Postberg, F., and Souček, O. (2017). Powering prolonged hydrothermal activity inside Enceladus. Nature Astronomy, 1(12):841–847. [4] Běhounková, M., Souček, O., Hron, J., and Cadek, O. (2017). Plume activity and tidal deformation on enceladus influenced by faults and variable ice shell thickness. Astrobiology, 17(9):941–954. [5] Soderlund, K., Schmidt, B., Wicht, J., and Blankenship, D. (2014). Ocean-driven heating of Europa's icy shell at low latitudes. Nature Geoscience, 7(1):16–19. [6] Zhu, P., Manucharyan, G. E., Thompson, A. F., Goodman, J. C., and Vance, S. D. (2017). The influence of meridional ice transport on Europa's ocean stratification and heat content. Geophysical Research Letters, 44(12):5969–5977.

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