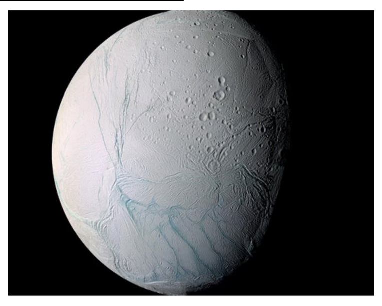
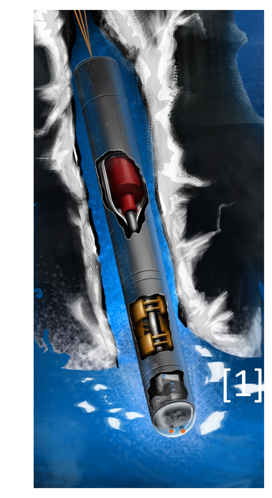


Updates on the Sending Signals Through the Ice (STI) Project for an Ice-Ocean Probe at Europa and Ocean Worlds

K. L. Craft[1], C. R. German[2], M. V. Jakuba[2], R. R. Lien[1], R. D. Lorenz[1], C. McCarthy[3], G. W. Patterson[1], A. R. Rhoden[4], M. Silvia[2], V. Singh[3], M. Walker[5], N. Farr[2], L. Freitag[2], C. McRaven[2], J. Partan[2], R. Coker[1], E. Asenath-Smith[6], and J. Lever[6]

[1]Johns Hopkins Univ. Applied Physics Laboratory, Laurel, MD, (Kate.Craft@jhuapl.edu), [2]Woods Hole Oceanographic Institution (Woods Hole, MA), [3]Lamont-Doherty Earth Observatory (Palisades, NY), [4]Southwest Research Institute (Boulder, CO), [5]Planetary Science Institute, [6]US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (Hanover, NH)



Introduction

Future missions to icy ocean worlds will not be satisfied by remote, plume, or shallow surface analyses. In order to follow up on detections of habitable environments and potential life signals obtained by previous missions (e.g. Europa Clipper, Europa Lander, Enceladus mission concepts), deep subsurface exploration, or reaching the moons' oceans or perched water pockets (e.g. [1]), will reveal and/or confirm, as well as characterize in detail, any life that may exist there. However, in order to sample an ocean world's ocean, significant technical challenges would need to be overcome.

Europa and Enceladus' elliptical orbits around their parent planets, cause their ice shell to flex and distort, **triggering surface cracks and shear motion [e.g. 2 & Lien poster this meeting]**. **A successful mission to the ocean will require penetrating the ice shell with instrumentation robust to these forces, down to possibly 10s of kms depth, *while maintaining communication with the surface.***

The Signals Through the Ice (STI) project is working to develop a robust communication architecture for transmitting data collected by the descending ice probe up to the surface lander for transmission back to Earth. Progress to date is shared here and future '21- '24 COLDTech efforts are outlined.

Fig. 1: Artist impression of Tunnelbot reaching the ocean, after deploying communication repeaters and the anchor [1].

Challenging Ice Shell Environments

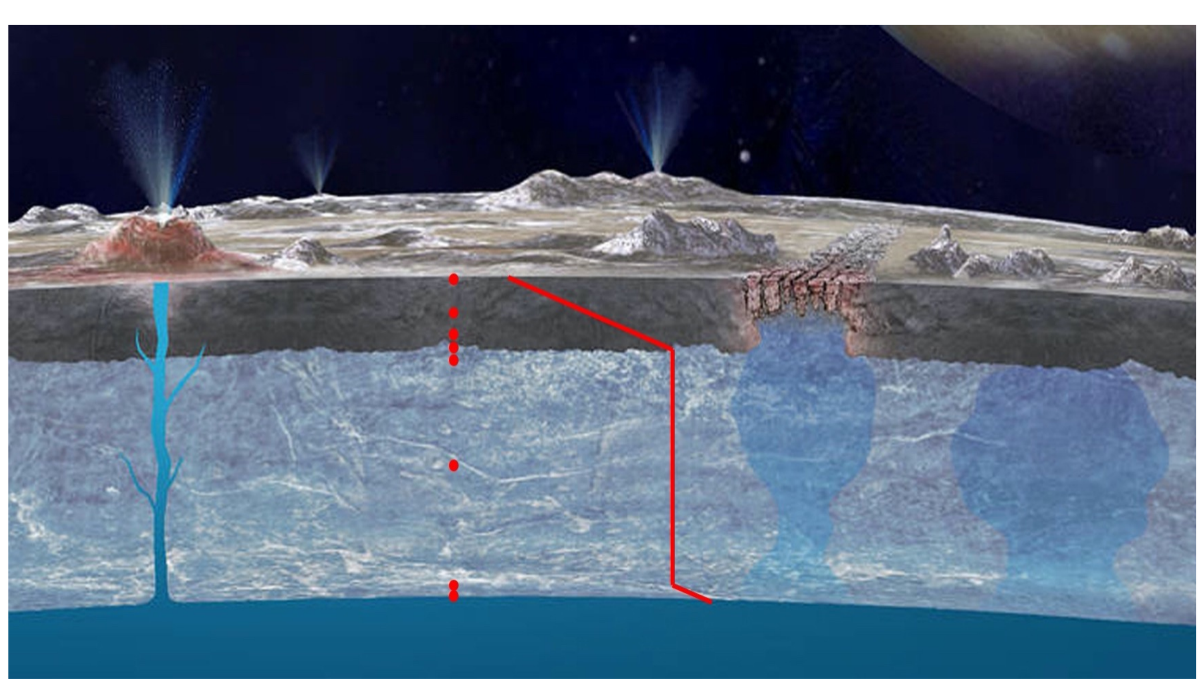


Fig. 2. Artist's conception of the ice shell of Europa. Modified from image courtesy NASA/JPL-Caltech.

- Ice shell thickness of Europa, Enceladus: Estimates range from 5 - 30+ km
- Brittle, fractured (and fracturing) uppermost few hundreds of meters to km present potential hazards for traverse
- Tidal cycles that can activate fractures/faults
- Potential for various porosities, high salt content, water pockets, sulfur, sulfuric acid, clathrates
- ~90-100 K, vacuum at surface; ~270 K, 20 MPa at ice-ocean interface

Communication Development - Tether Laboratory Testing

Tethers working in ice-water environments

- Rated for tensile and compressive strength, but not shear.
- Europa, Enceladus ice shell temperatures?

Tether types being evaluated:

Tether	Diameter (mm)	Max Tensile Load (N)	Max Shear Load	Mass (kg/km)	Mass (kg/20km)
Linden STFOC	0.965	220	unknown	0.9	18
Linden HS-STFOC	1.9	1100	unknown	3.6	72

Testing in a laboratory setting that simulates a relevant ocean world environment. Shear testing is performed by freezing a **section of tether into ice and applying forcing loads to simulate shear** (see procedure described in [3], Fig. 3) **while measuring data transmission performance.**

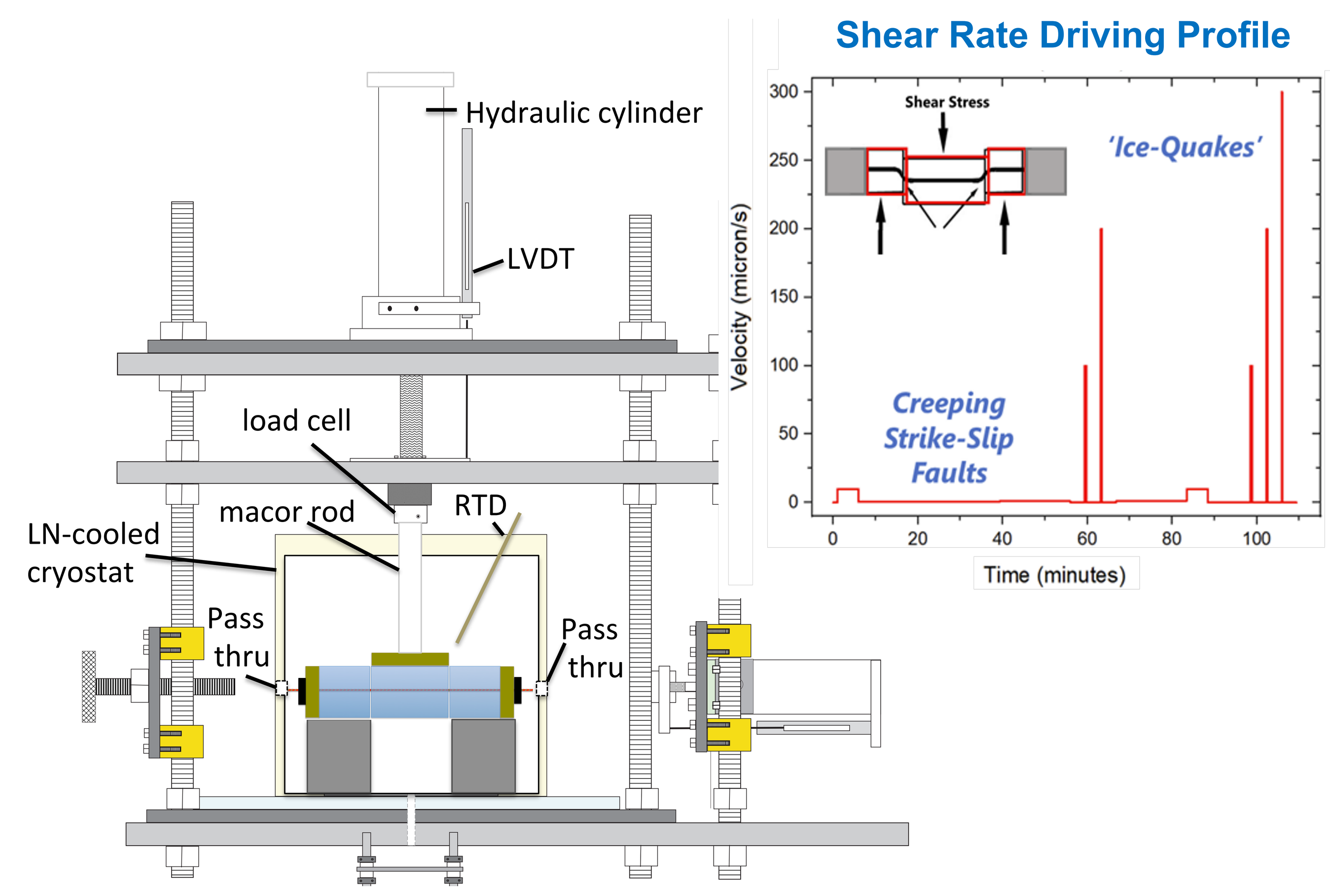
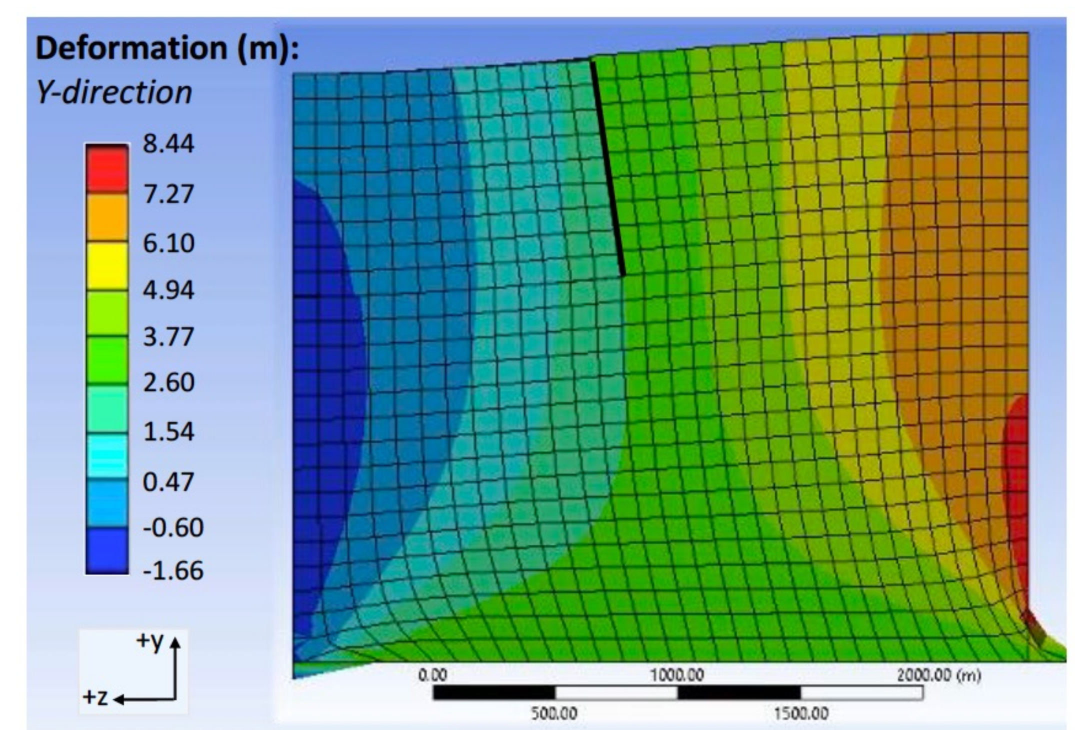


Fig. 3. Custom, servo-controlled, biaxial deformation apparatus with LN-controlled cryostat (LDEO, [4]). Inset is the shear rate driving profile for velocity over time.

Numerical Modeling

We are also **numerically modeling the tidally induced stress and displacements** that Europa's ice shell likely undergoes [5], that can drive fault motion [2 & Lien poster this meeting].

Fig. 4 (at right). Vertical (Y) deformation result for a 5-degree off vertical fracture model at Thera Macula at perijove. Bold black line highlights the location of the fracture in the ice block. The +X-direction is east, Y-direction is vertical, and +Z-direction is south.



See R. Lien Poster (this meeting)!

Laboratory Testing Results

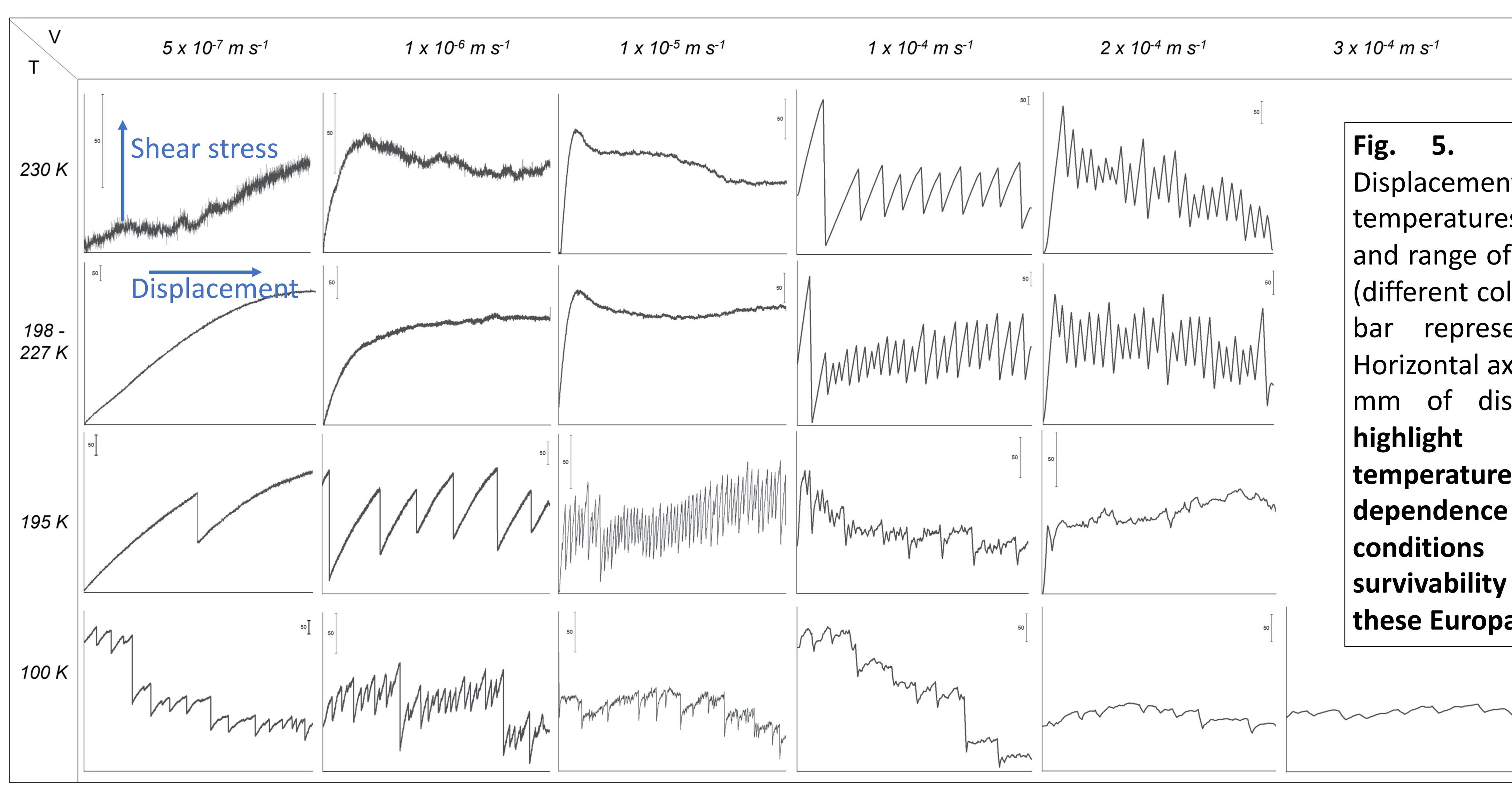


Fig. 5. Shear stress vs. Displacement for a range of temperatures (different rows), and range of test shear velocities (different columns). Vertical scale bar represents 50kPa stress. Horizontal axis ranges from 0 to 1 mm of displacement. **Results highlight the distinct temperature and velocity dependence of friction in ice for conditions tested and the survivability of tethers under these Europa-like conditions.**

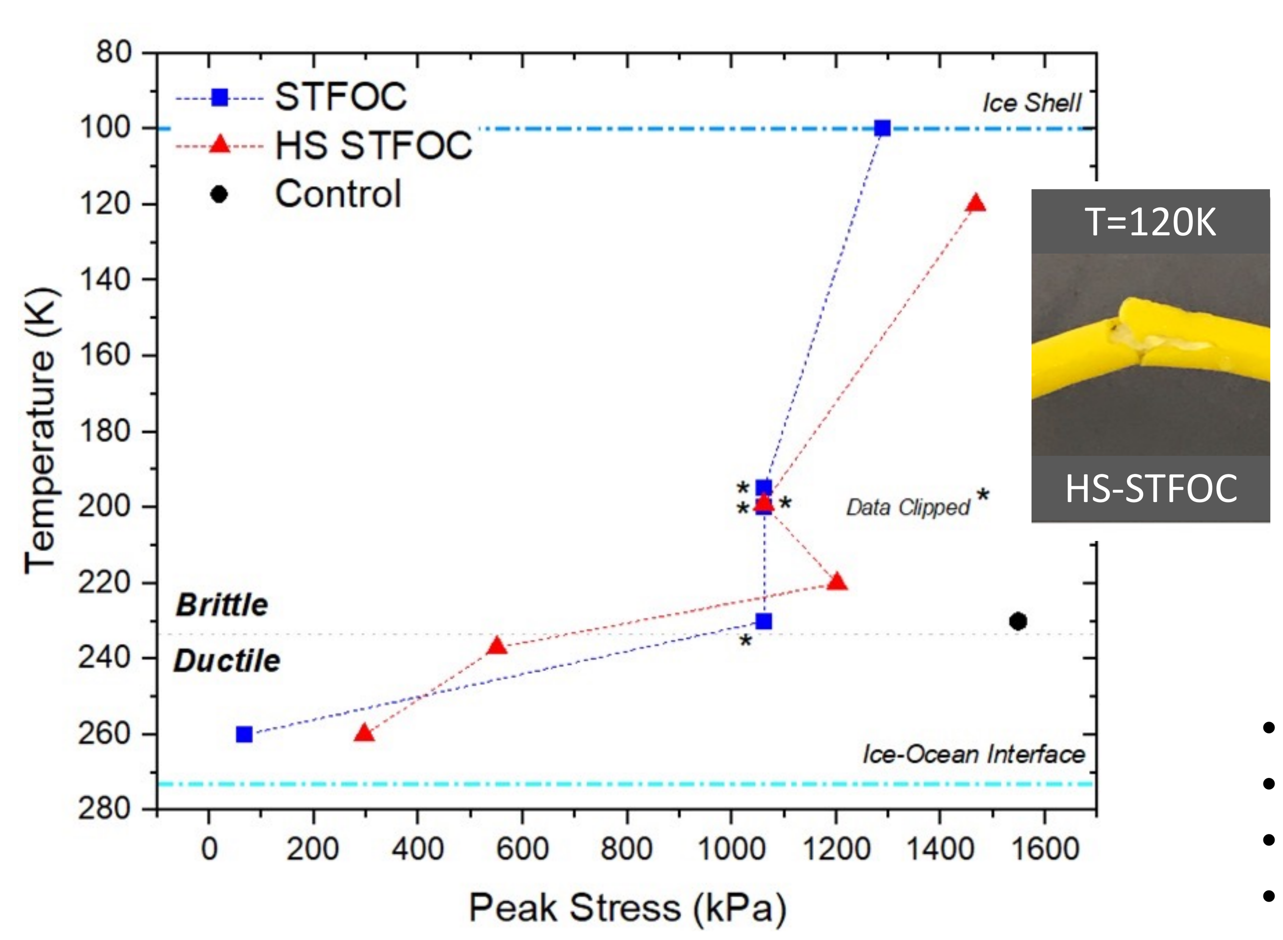


Fig. 6 (at left). Peak stress survived by Linden tethers and control ice samples over the range of ice shell temperatures. **Pictures of HS-STFOC tether shows damage to outer jacket but signal connectivity was maintained.**

Results show:

- **Tethers are more robust than originally expected! Yet more tests are needed to complete range of expected conditions and further improve tether robustness**
- **Numerical modeling show faults in certain locations could be very hazardous**

Future COLDTech Work

- Thorough environmental evaluations on tethers and RF modules
- Specific tether design for Europa and Enceladus conditions
- Evaluation of tether for shear, tension, and adhesion robustness
- Design, build, and test RF module structure for thermal and mechanical survival

Acknowledgements

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References

[1] Oleson et al., 2019, NASA/TP–2019-220054; [2] Lien et al., 2021, *LPSC*, Abs. 1005; [3] Singh et al., 2021, *LPSC*, Abs. 2403; [4] McCarthy et al, 2016, *Review of Scientific Instruments, 87*, 055112; [5] Walker et al., 2020, *LPSC*, Abs. 2448.