Icy Moons Penetrator Organic Analyzer (IMPOA)
An Instrument for Highly Sensitive Organic Detection on a Kinetic Penetrator

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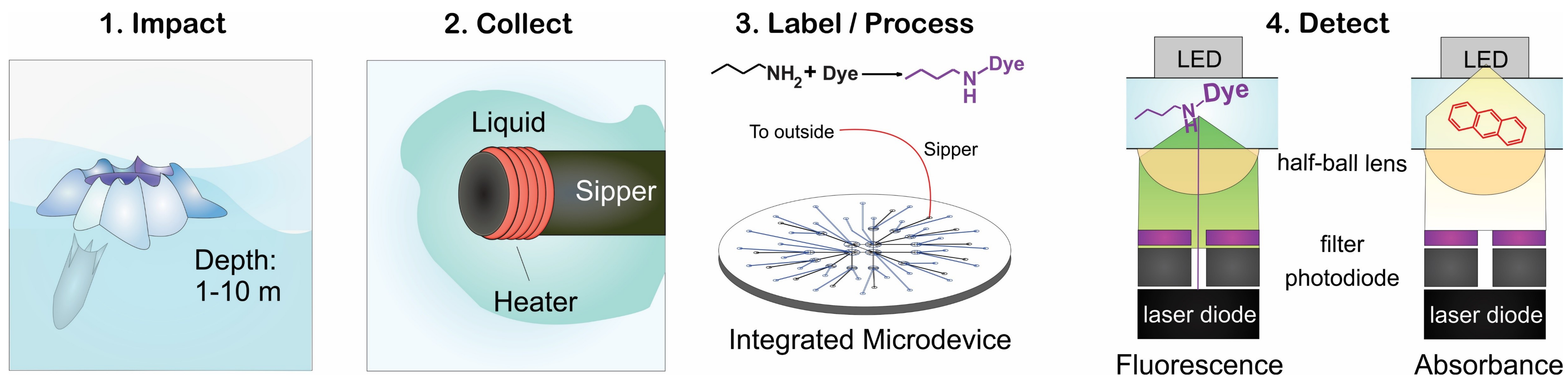
The Ice Shell Impact Penetrator (IceShIP) is a in situ instrument concept that could enable compositional and chiral analysis of organic molecules with superb analytical sensitivity (parts-per-trillion) in addition to analysis of salts at higher concentrations in an instrument platform compatible with a impact penetrator mission platform.

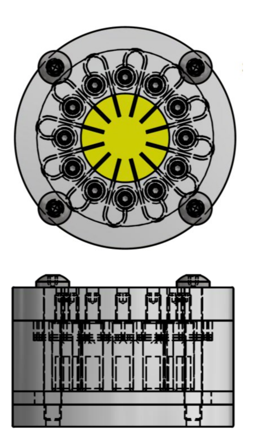
IMPOA Goals:

- **Measure organics:** The IMPOA, with sensitivity ~3 orders of magnitude greater than non-contact systems, would directly analyze subsurface ice for molecules in carbonaceous chondrites including amines, amino acids, and polycyclic aromatic hydrocarbons.
- **Search for biosignatures:** The IMPOA would detect biologically-relevant molecules (including amino acid chirality) in the subsurface ice.
- **Support planetary models:** The IMPOA would provide ground-truth measurements of the subsurface, which combined with other in situ and remote sensing measurements would constrain models on Martian planetary history.



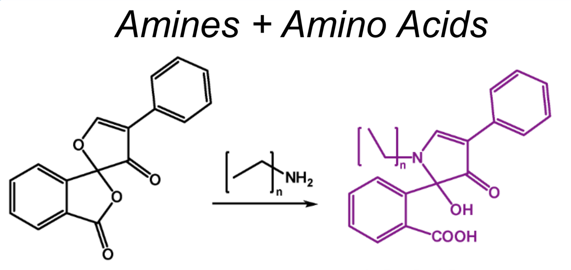
IMPOA Overview

The IMPOA integrates microfluidic sample preparation, miniaturized LIF detection optics, and miniaturized electronics to deliver an instrument that satisfies the low mass, volume, power, and high g accelerations of an impact penetrator platform.

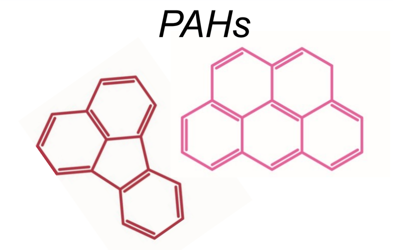


The individual subsystems of the IMPOA are the ***LIF optical stack***, the ***microdevice***, and the ***external housing***. The external housing must maintain alignment of linear actuators with the microvalve actuation pads on the microdevice, must provide electronics for read-off and control, and must be low mass. The 300 g test articles we have built are made of aluminum, as shown on the right.

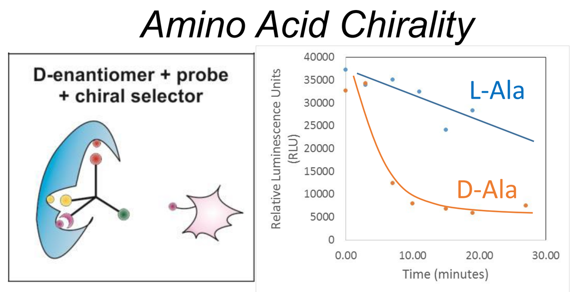
Optical Detection Chemistry

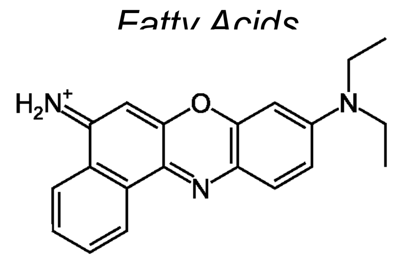


Fluorescamine[1-3, 6-12]



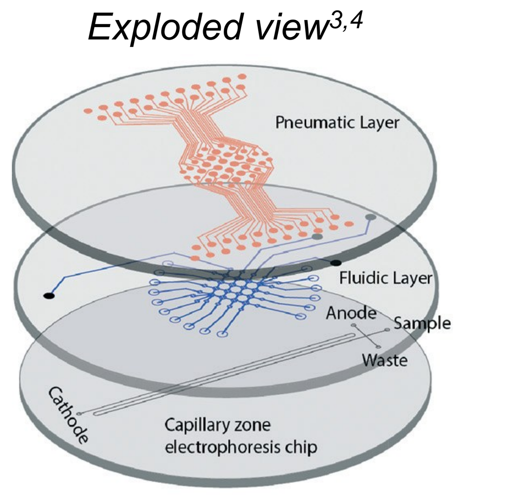
Native fluorescence[7]

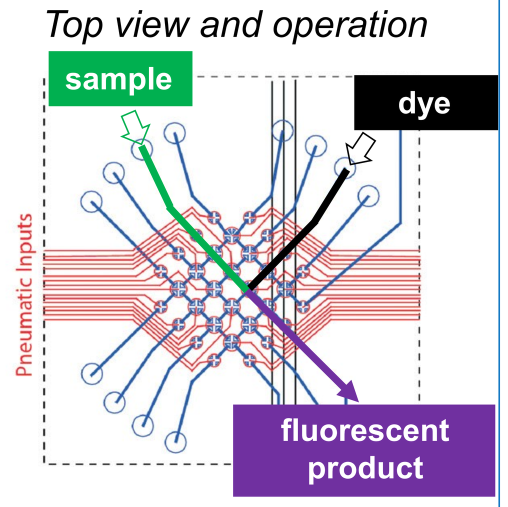


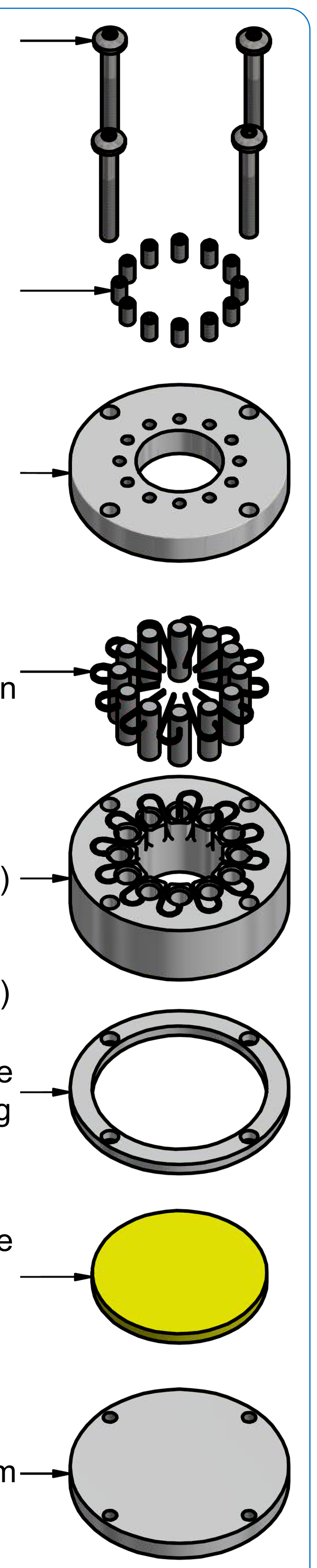


Nile Blue

Microfluidic Operations





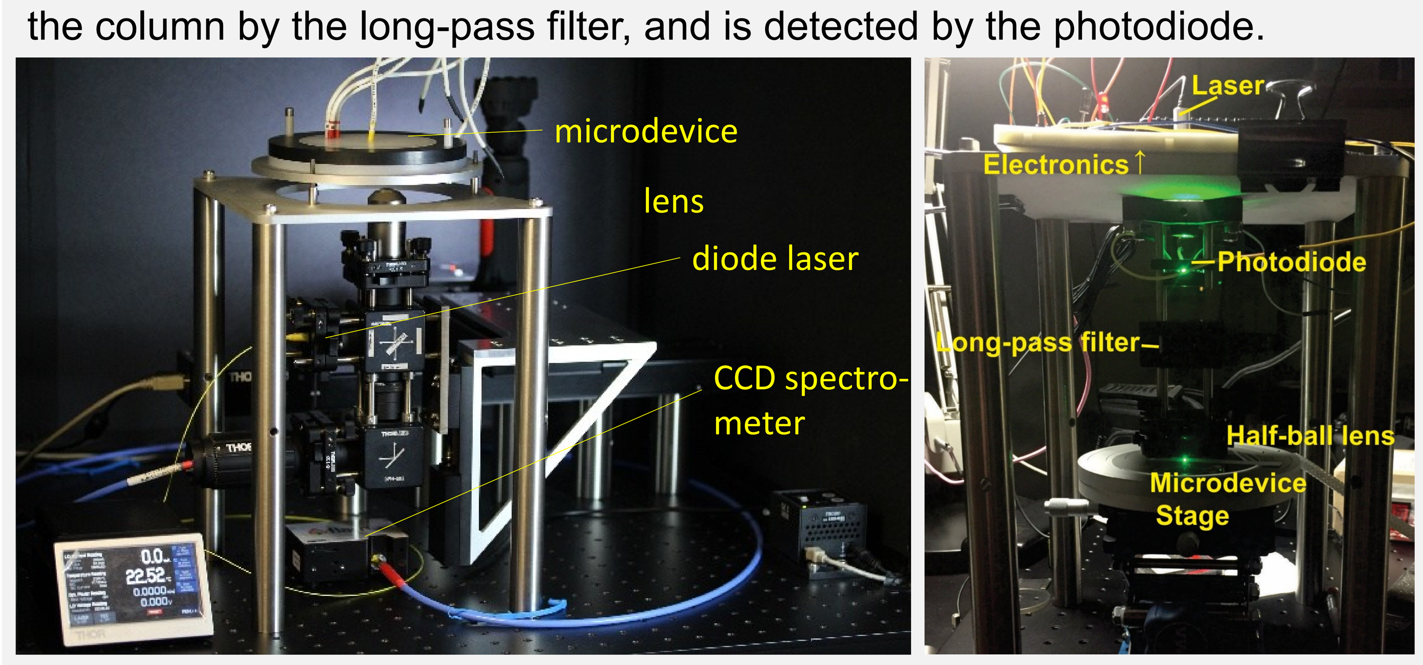


Exploded view of components of an IMPOA impact test article. This is a prototype system that will be impact tested to inform design.

IMPOA Subsystems

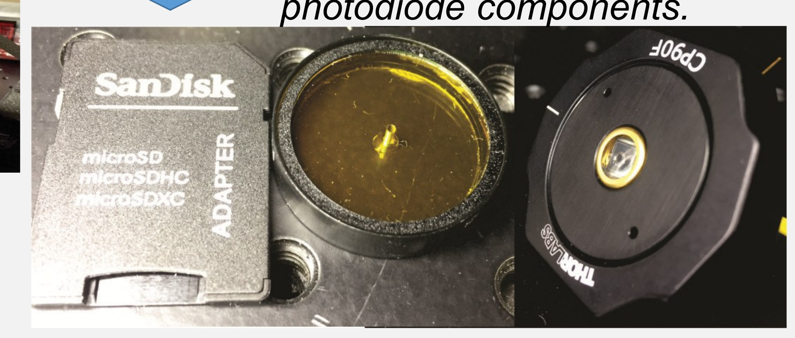
IMPOA LIF Detection Optics

The IMPOA optical stack is based on that by Kamei, *et al*, and requires that a laser diode pass through a hole in a photodiode and a long-pass filter before it is focused to a 20 µm spot at the center of the microfluidic channel by the half-ball lens. Excited fluorescence is collected and collimated by the same lens. Scattered laser light is filtered from the column by the long-pass filter, and is detected by the photodiode.



Second, higher-fidelity IMPOA breadboard: LIF system with a 405 (or 488 nm) laser diode, a photodiode detector, a half-ball lens, and a long-pass filter.

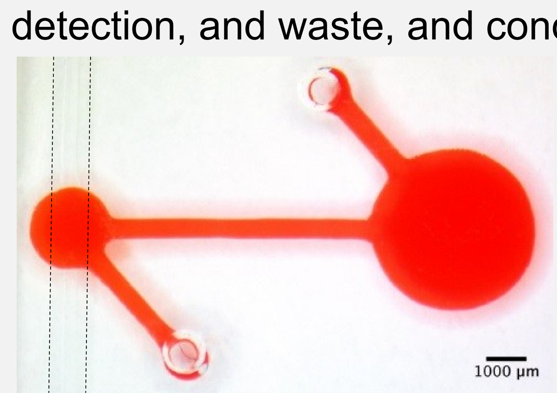
The system requires precision holes drilled directly in the center of miniature filter and photodiode components.

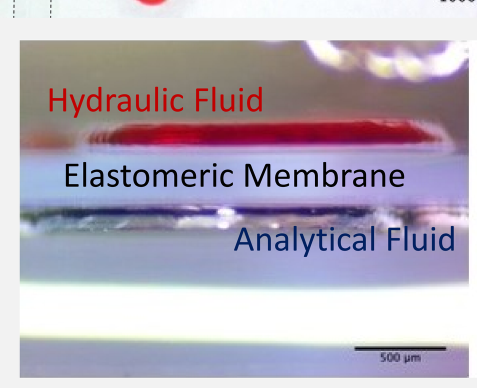


First IMPOA breadboard: benchtop LIF system for in-lab testing and comparison of the microfabricated system with 405 nm excitation and a CCD spectrometer. LOD = 3.1 nM Pacific Blue dye.

IMPOA Microdevice

The IMPOA microdevice uses normally open microvalves[2,3] with a hydraulic working fluid rather than pneumatic actuation to mitigate membrane damage during impact. The device can intake samples from 4 independent lines and has 4 independent on-chip storage / reaction reservoirs. The 2x2 programmable microfluidic array (PMA) core is capable of multiple fluidic operations, including intaking sample and dye, combining them, transferring them to storage, detection, and waste, and conducting self-cleaning steps.[3,5]





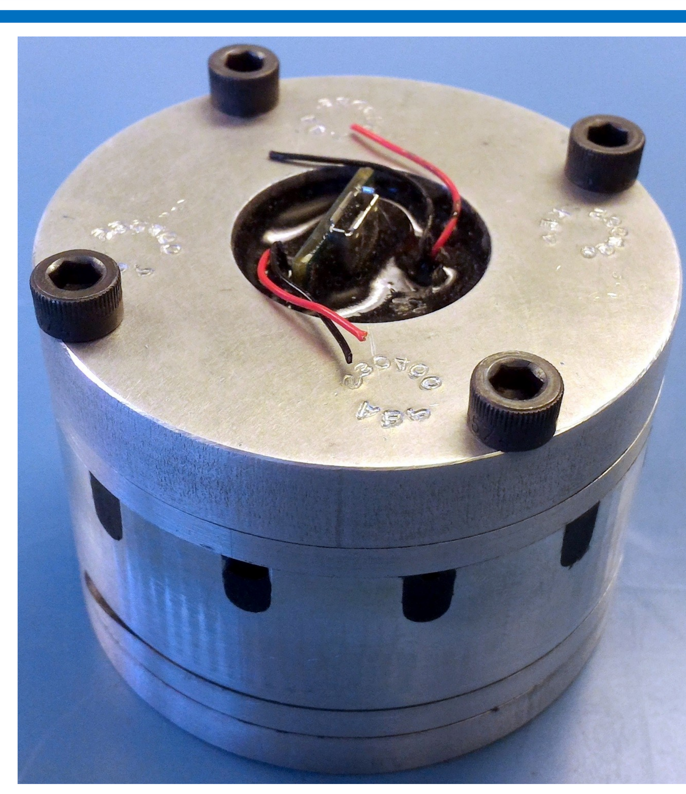
The modified valves (left top) require a large actuation pad that is depressed by the linear actuators external to the microdevice. When this pad is depressed, the fluid is forced to deflect into the channel at the valve's intersection with the channel. A cross-section view (bottom left) indicated that deflections > 200 µm could be achieved with this method. Hig-fidelity devices are now in fabrication (right).

IMPOA Impact Testing

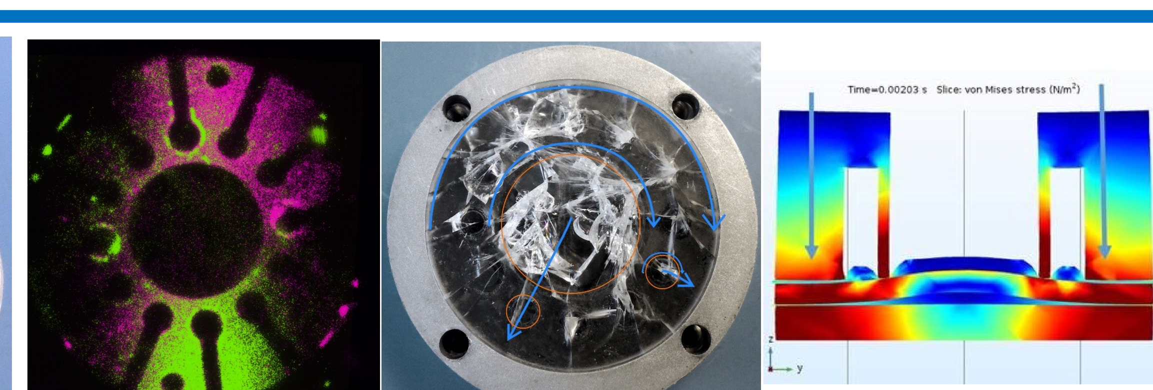
The IMPOA is impact tested at decelerations up to 50,000 g with the M100 at Sierra Lobo in Milan, OH.

Sierra Lobo M100 and airgun.

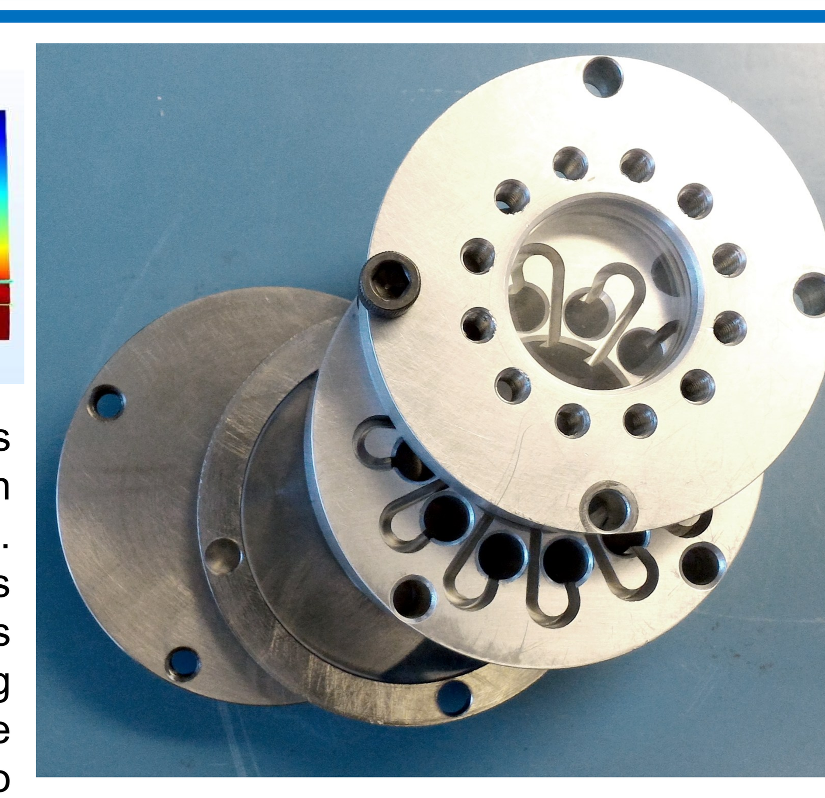
Finite-element modeling was done before the first test, and it became clear that we needed data to inform our models. We tested our first payload in January 2017. The payload was the external housing with a blank wafer, two linear actuators, and a test electronics board. Thin (200 µm) nitrile was used as a gasket, and the entire system was potted in a polyurethane encapsulent.



IMPOA Test Article #1



The primary structures showed no measurable differences after testing – a pressure-sensitive paper imprint was taken before and after with no observable differences (above left). However, the microchip shattered with the fracture patterns indicated (above middle). This informed the FEA models (above right), and has led to improved design for upcoming tests. The next text planned for March 2017 will include mock-up LIF optical stacks with multiple modes of bonding to test potential welding / adhesive options.



IMPOA Test Article #2

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References: 1. Skelley, *et al*, *J. Geophys. Res.*, 2006. 2. Kim, *et al.*, *Anal. Chem.*, 2012. 3. Kim, *et al.*, *Anal. Chem.*, 2013. 4. Kim, *et al.*, *Lab Chip*, 2016. 5. Duca, *et al.*, *Astrobio.*, 2017 in prep. 6. Skelley, *et al.*, *Proc. Natl. Acad. Sci.*, 2005. 7. Stockton, *et al.*, *Anal. Chem.*, 2009. 8. Kamei, et al., *Anal. Chem.*, 2003. 9. Stockton, *et al.*, *Astrobio.*, 2009. 10. Stockton, *et al.*, *Electrophoresis*, 2010. 11. Stockton, *et al.*, *Astrobio.*, 2011. 12. Stockton, *et al.*, *Sensors Actuat. B*, 2013.