A thermally-conductive electrical isolator for use at ultra-low temperatures in the Astro-H Adiabatic Demagnetization Refrigerator

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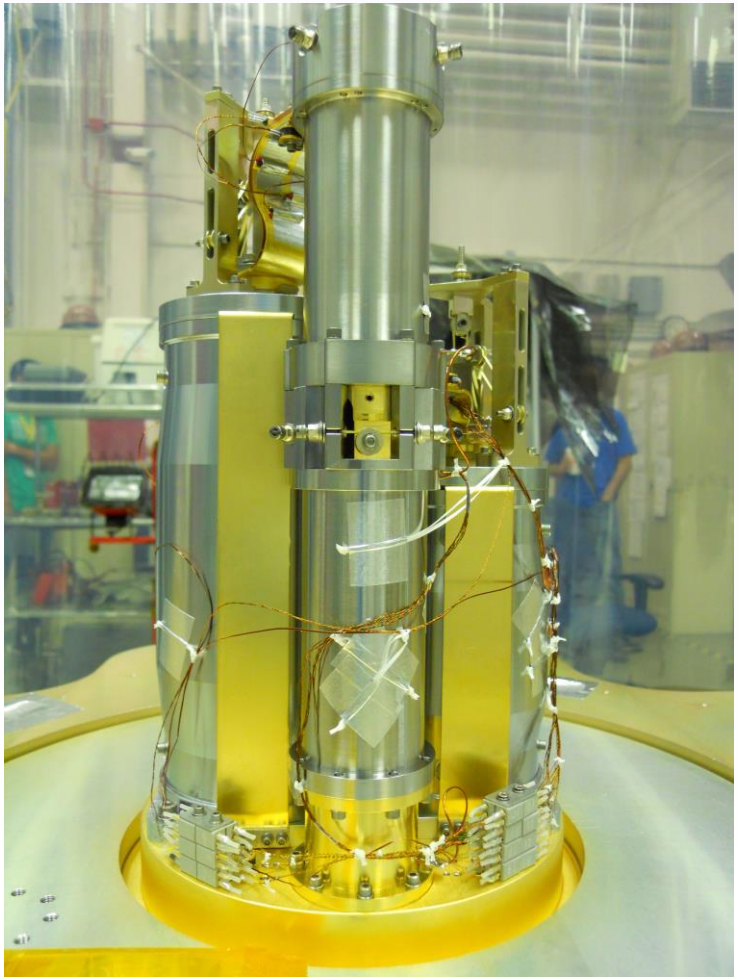
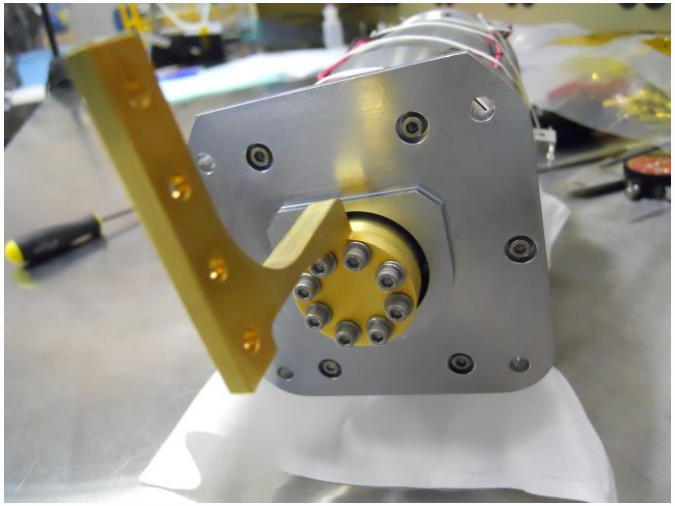
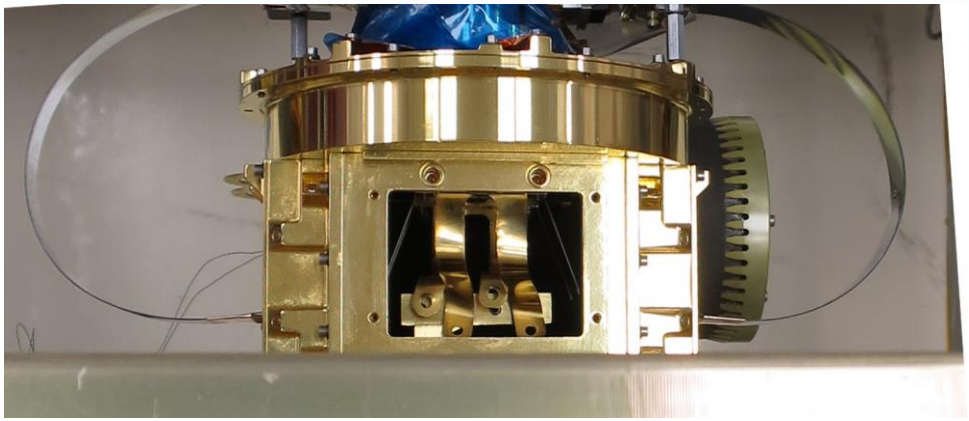
Astro-H Adiabatic Demagnetization Refrigerator (ADR) and Detector Assembly







Need for an Electrical Break

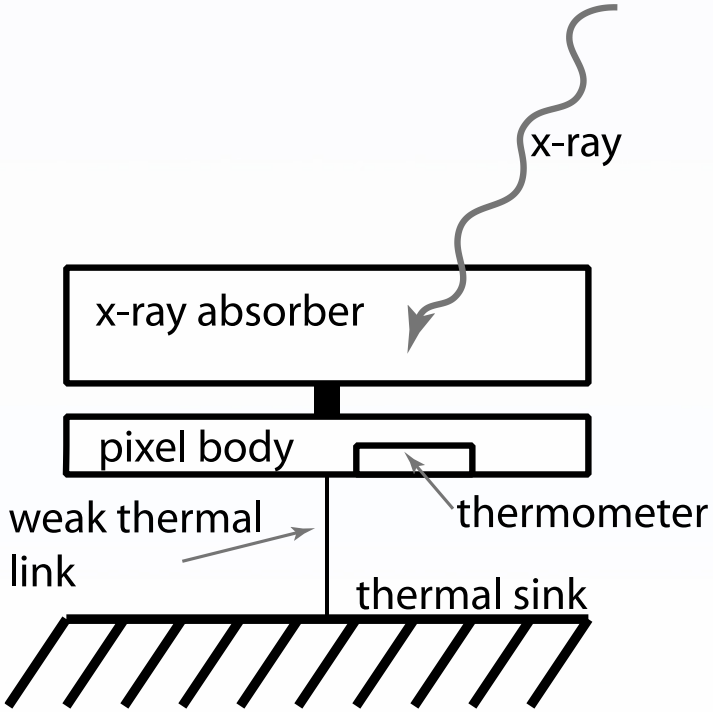
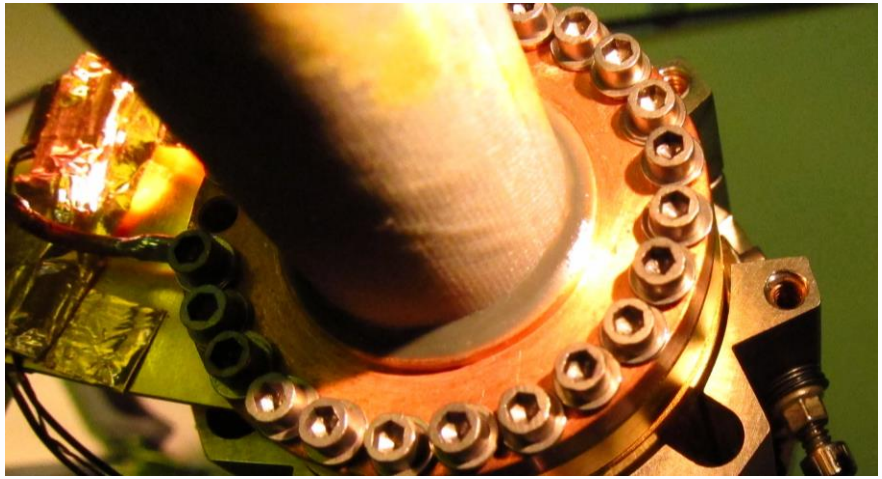


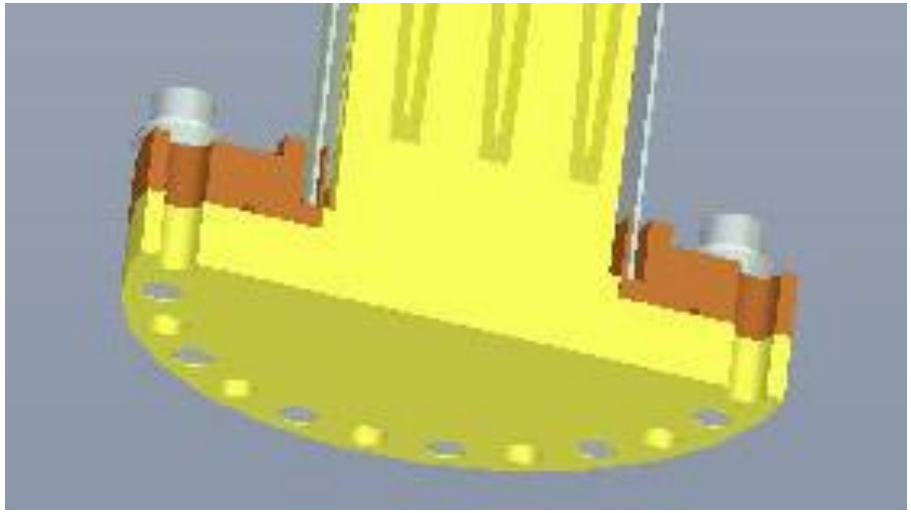
Image courtesy of Dr. F. Scott Porter
NASA / GSFC

Sensitive thermometer embedded in each pixel of detector array

- Highest sensitivity achieved when JFET amplifiers are placed close to thermometer
- Any electrical input from sources other than JFET readout is noise on the signal
- Thermal sink is the coldest ADR stage
- Electrical isolation must occur between helium tank and detector array
  - Many places this may occur, need to balance thermal impact to ease of assembly and number of thermal breaks

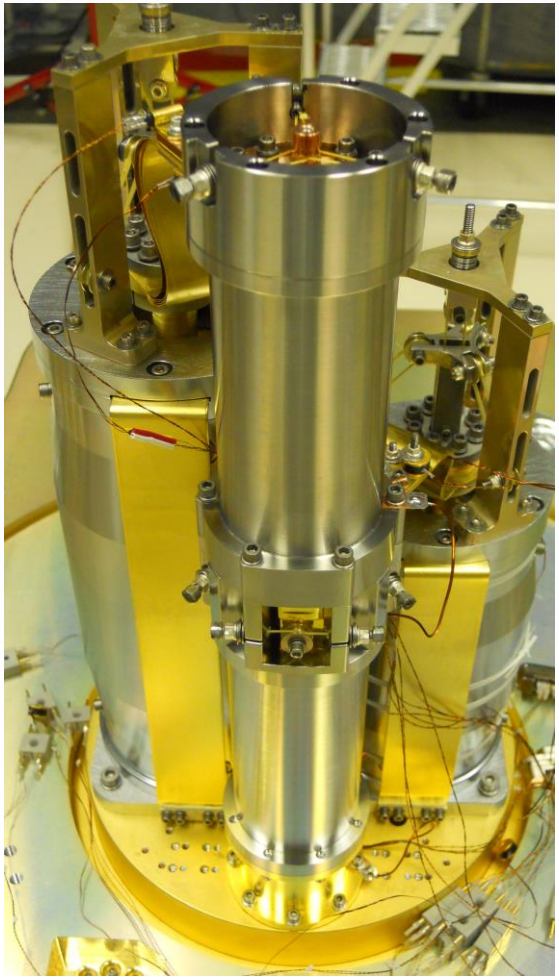
Engineering Model Electrical Break

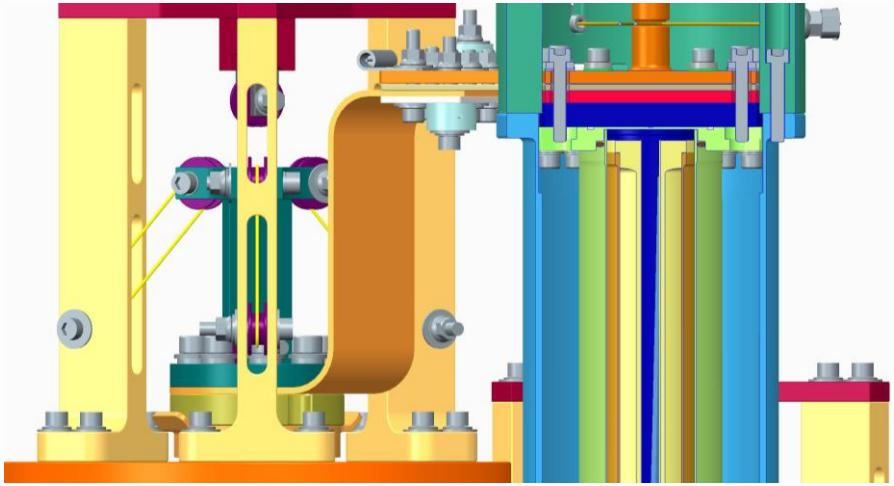




- Electrical isolation intrinsic to design
- Heat switches with composite tubes for the hermetic outer shell and epoxy joints provided electrical isolation
- Compromised shell led to a redesign using all metal shells and flanges
  - No intrinsic electrical break

Proposed Solution for Flight Model

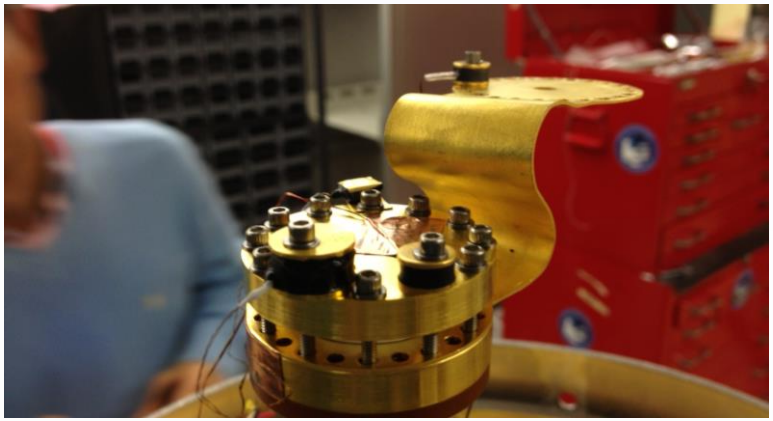


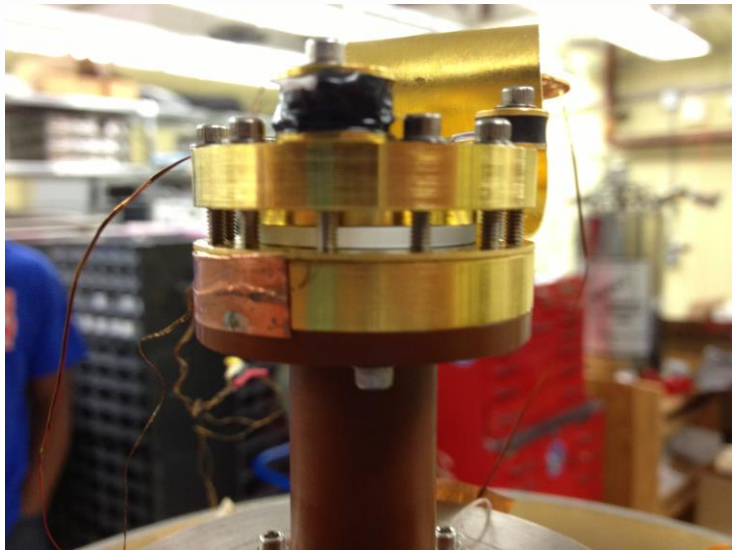


Use sapphire for an electrical break

- High thermal conductivity even at low temp
- If inserted close to coldest ADR stage, only one break needed
- If properly designed, capacitance requirement of ≤ 100 pF can be met

Preliminary Tests of the Sapphire Isolator



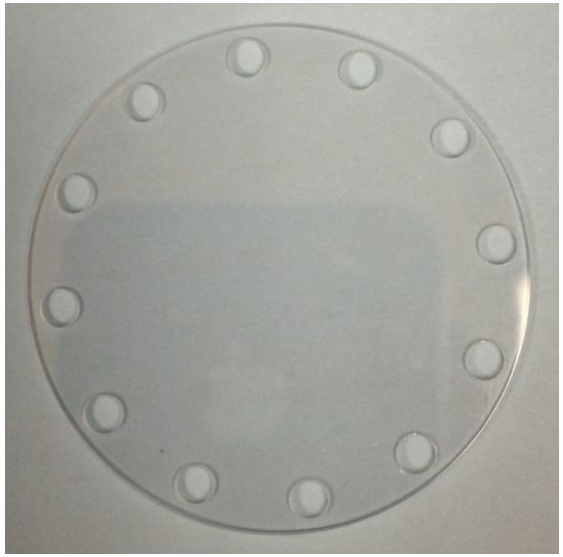


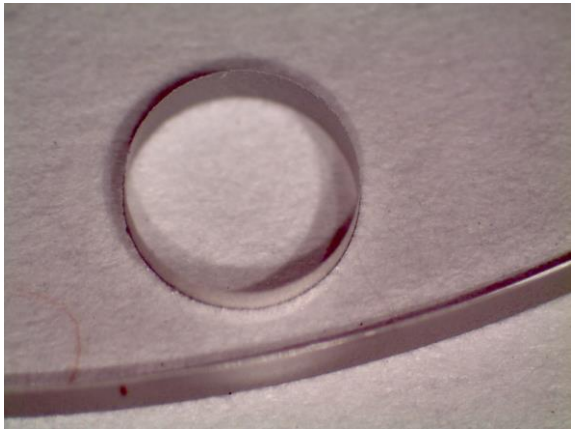
- Use commercial off-the-shelf sapphire discs
- Choose a metal coating to lower the interface boundary resistance
  - Presume a metal with a Debye temperature close to sapphire will better match phonon spectrum
  - Choose candidates that are commonly evaporated onto sapphire surfaces
  - Apply final layer of gold to cap surface

Materials	Debye Temperature (K)
Sapphire	1074
Chromium	630
Aluminum (needs Ti layer)	428

- Surprising result: Al / Ti / Au showed slightly higher conductivity

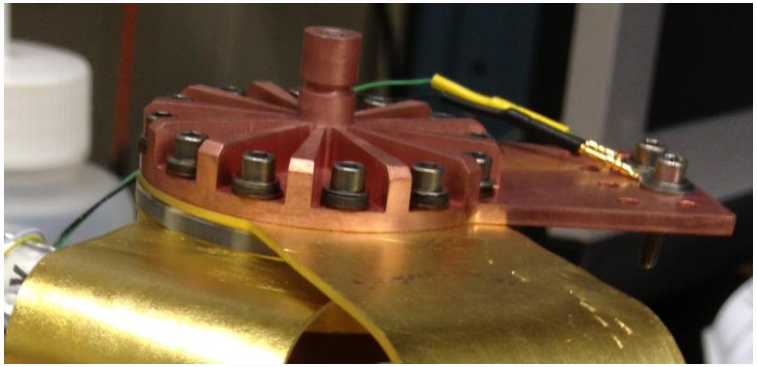
Holes for screws in sapphire wafers

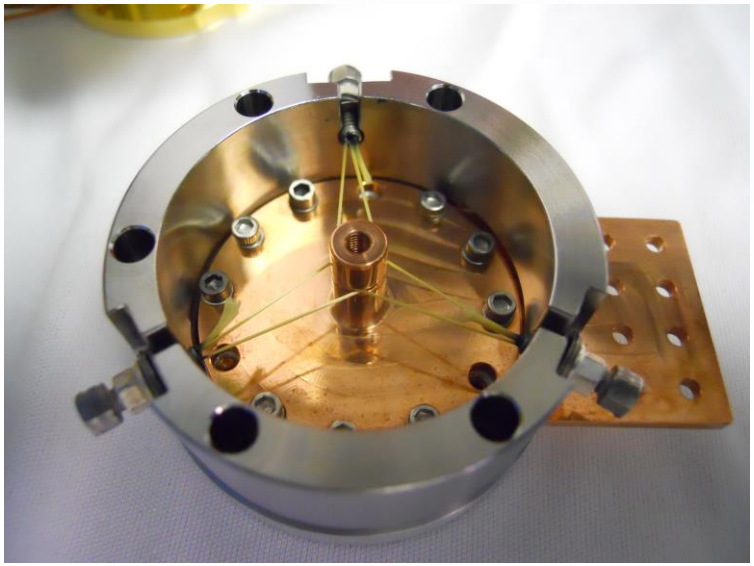




- If possible, holes through sapphire allow a bolted interface without a bending moment applied via the clamp
- Purchased high quality sapphire discs in both 1 and 2 mm thicknesses with a matching diameter to our heat switch: *Guild Optical Associates, Amherst NH*
- Found a company who regularly micromachines sapphire using ultrasonic motion and abrasive powder: *Bullen Ultrasonics, Eaton OH, USA*
- Put a bolt circle pattern into a variety of discs to test various coatings and effect of thickness

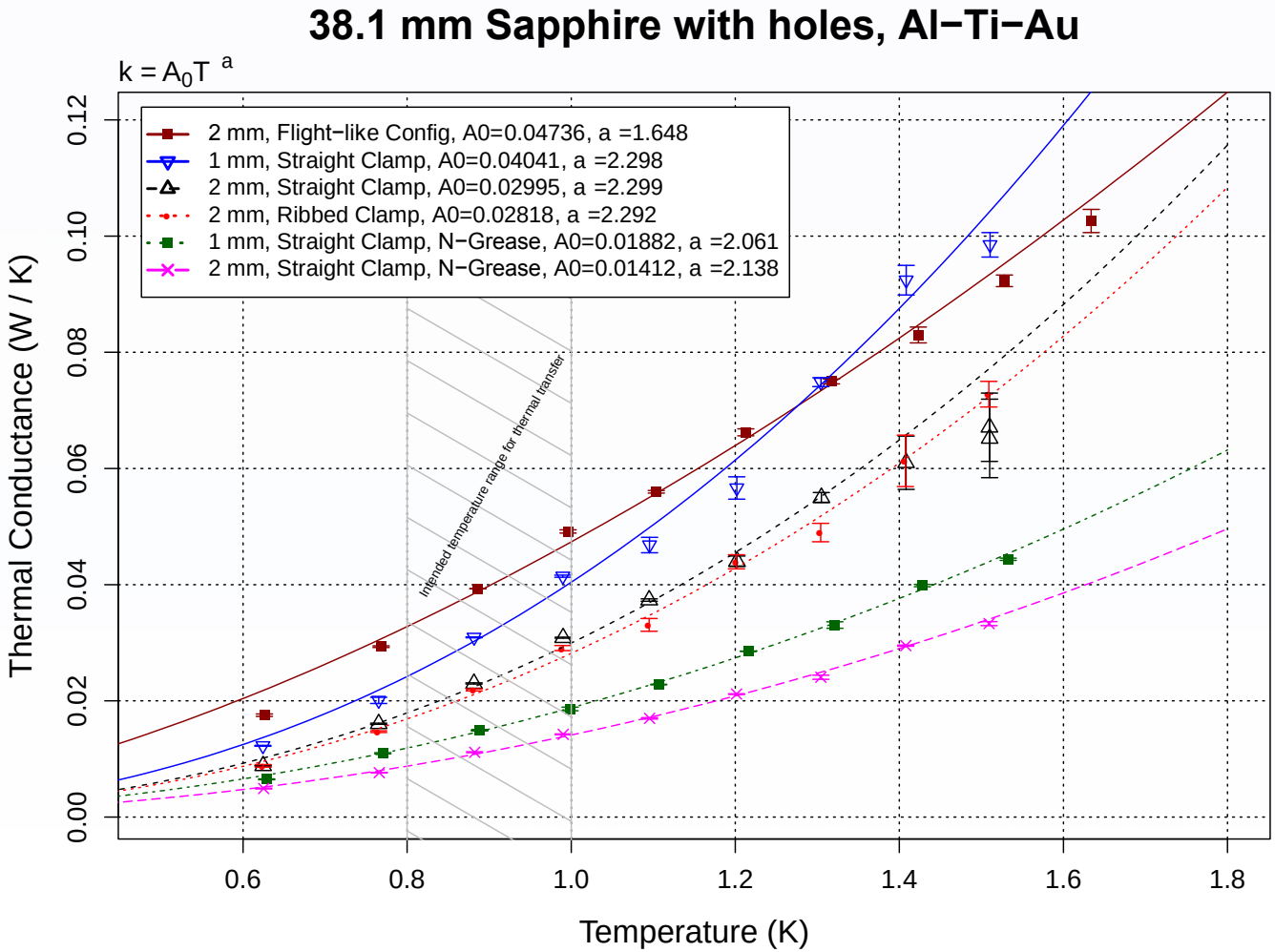
Sapphire Clamp Design



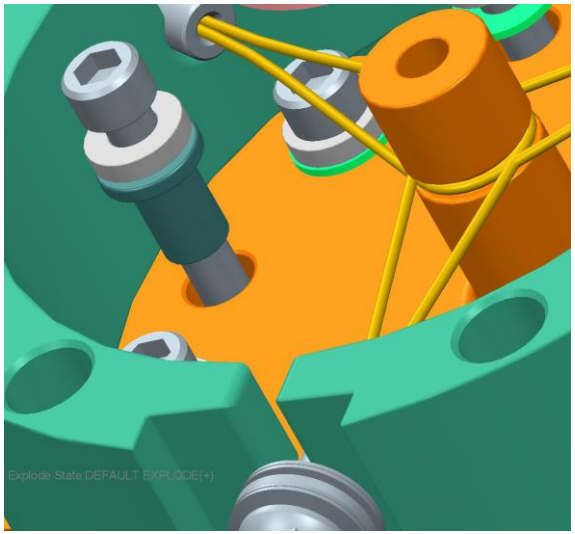


- Clamp has many functions
  - Sandwiches the sapphire disc between a thermal strap and heat switch
  - Tabbed section aligns two sections of a disjointed thermal strap
  - Acts as a suspension pickup point
- Concern regarding flexing or cupping of the clamp led to two clamp designs
  - Ribbed
  - Straight
- Structural analysis showed either works
- Thermal testing confirms this so clamp with less mass used for flight project

Coating Test with Holes in Sapphire



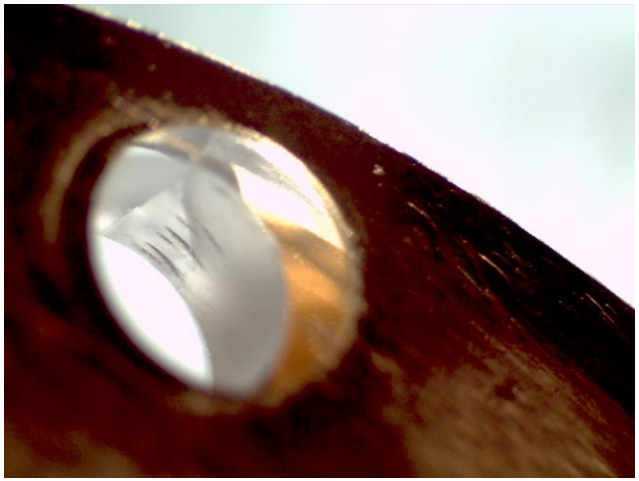
Final Solution



- Sandwich gold-plated copper gasket on both faces of sapphire disc
  - Protects metallized surfaces
  - Allows easier removal of disc from assembly (if necessary)

- Bushing made from Vespel prevents screws from making electrical contact between heat switch and clamp

Concerns with Cracking of Sapphire

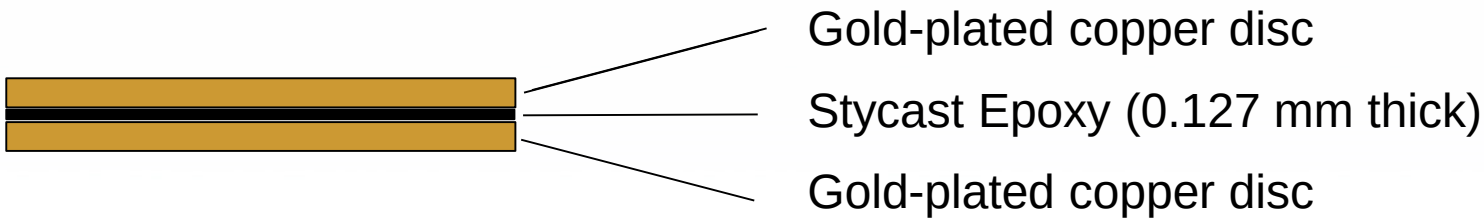


- Found cracks in some samples after cycling to cryogenic temperatures
- No loose sapphire witnessed
- Astro-H debris requirement states no particular larger than 50 microns may exist
- No way to verify we meet this requirement
- Proceed with ideas on encapsulation

Final Final Solution

Thin bond of stycast epoxy sandwiched between two copper discs

- Meets thermal requirements
- Needed to relax capacitance requirement
  - Estimated capacitance > 130 pF



Summary

- ✓ Identified a solution to the need for a low-temperature electrical isolator that is thermally conductive
- ✓ Identified a metallic coating to lessen the boundary resistance between the isolating sapphire and the metallic thermal interfaces it separates
- ✓ Identified a means to put precise holes in sapphire without breakage
- ✧ Cracking lead to concerns regarding violating debris requirement
- ✓ Final solution was a robust copper-epoxy-copper sandwich that required a relaxation of the original capacitance requirement