Development of stable, low resistance solder joints for space-flight HTS lead assemblies

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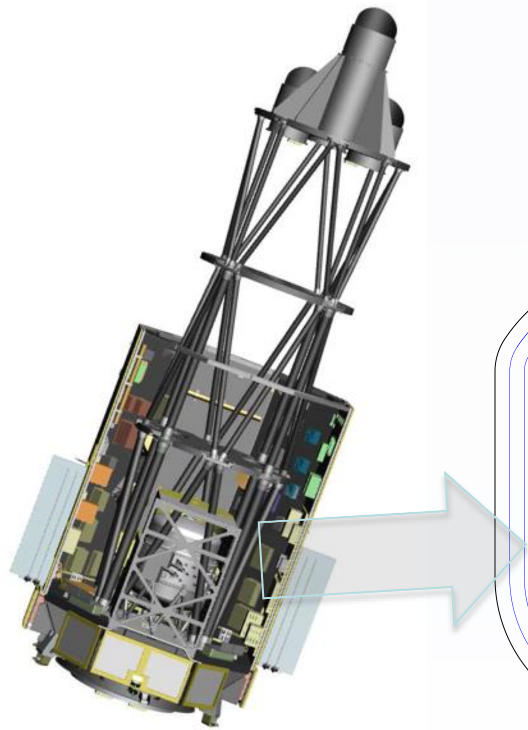
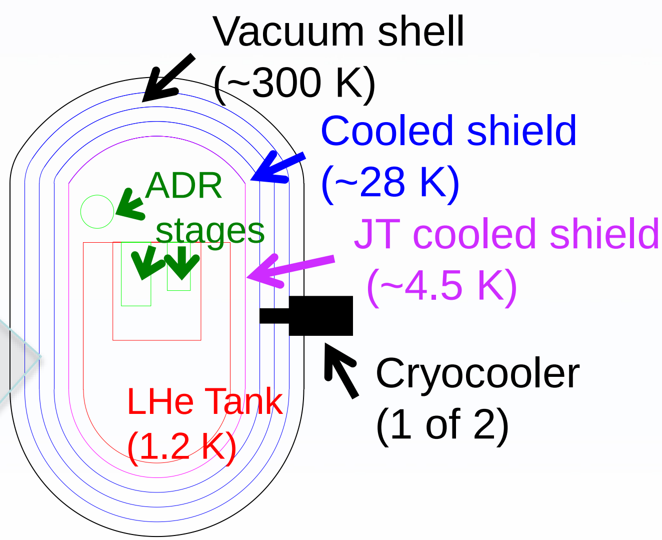
Background: Astro-H (Hitomi)/SXS



Soft X-ray Spectrometer used a microcalorimeter array operating at 50 mK



SXS Thermal System:

- (2x) 2 stage Stirling coolers
- JT cooler (4.5 K)
- 40 l LHe tank (1.2 K)
- 3 stage ADR (50 mK)

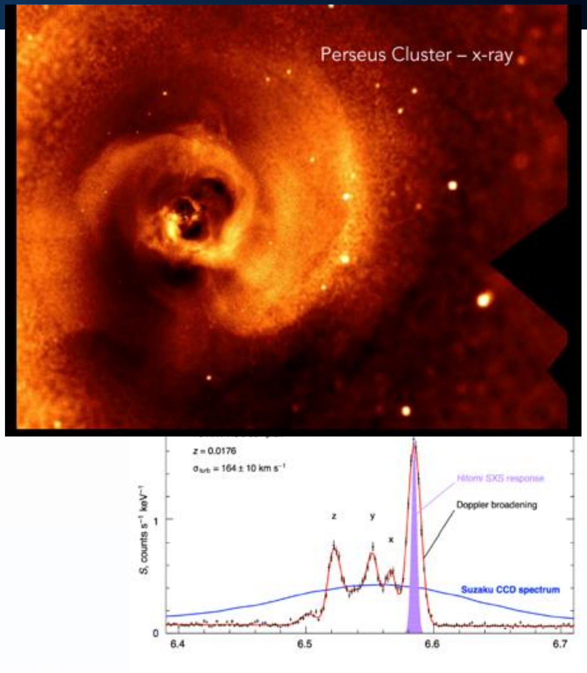
HTS leads for ADR magnet current (2 A) needed to meet stringent parasitic heat load requirements

- HTS allocation: 10 µW @ 1.2 K; 670 µW @ 4.5 K

17 February 2016: Hitomi launched; SXS performs flawlessly

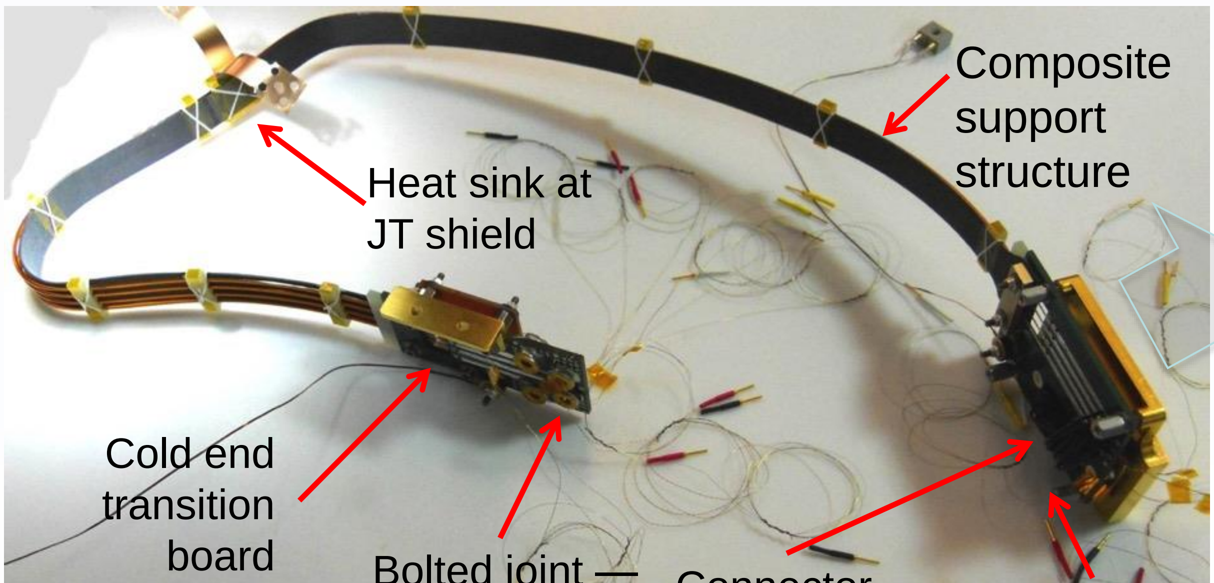
Background: XARM/RESOLVE

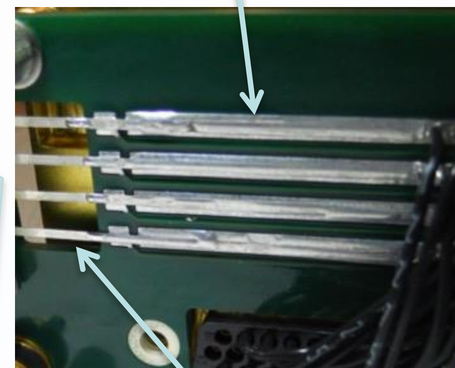
- In first few weeks, SXS demonstrated unprecedented resolution & discovered important new results
- 26 March, 2016: Attitude control system incident disables spacecraft
- 2017 — Start recovery mission
  - RESOLVE instrument – identical to SXS
  - Rapid turn around (2019 delivery to JAXA)
  - “build to print” with very few exceptions



RESOLVE HTS Lead Assemblies — Approach

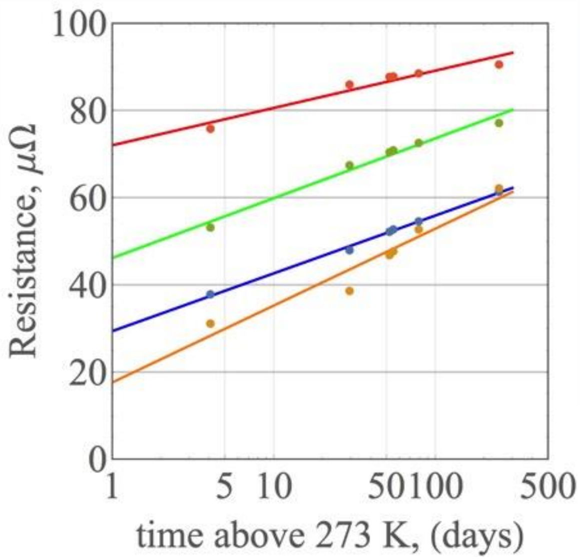
- Physical structure identical to Astro-H





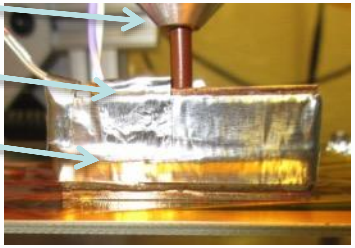
RESOLVE HTS Lead Assemblies – Changes

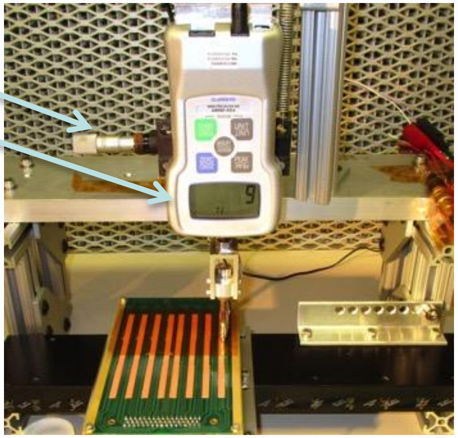
- Changes driven by issues encountered in Astro-H
  - I_c degradation, esp. in humid environment
    - SXS: REBCO 2G conductor, Ag/Au coated, slit to 1 mm after
    - Concern over lateral H2O & CO2 transport from exposed edges
    - RESOLVE: same conductor, coated after slitting
  - Solder joint degradation
    - SXS: measurements showed $R \propto \log(t)$ at ambient T
    - Slow consumption of 2 µm AgAu layer by In3%Ag solder
    - RESOLVE: 20 µm Cu plating over HTS at solder joints
  - Variability of void density & joint R



Updates to HTS/PCB solder process

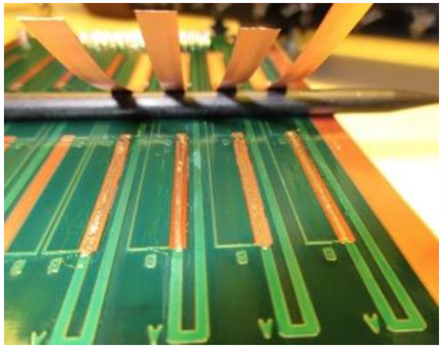
- Prototype solder rig
  - Motivation: tight control of process parameters
  - Ball joint for uniform force
  - Diode for accurate temperature control
  - Wrapped tip heater uniform heating
  - Fine position adjustment
  - Accurate control of force
  - Typical parameters (for In48%Sn):
    - Apply 10 N (80 mm^2 area)
    - Controller on; set point = 150 C
    - Wait 30 s after T = set point; controller off
    - When T < 100 C, remove force
- Production solder rig
  - Miniaturized to fit flight assemblies





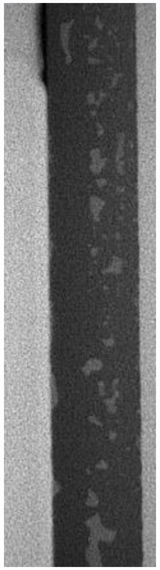
Solder Tests – Materials

- Test boards
  - Solder pads similar to flight boards (2 x 40 mm)
  - Separate voltage tap points
  - 16 joints / board
  - Plating types:
    - Bare copper
    - Immersion tin
    - Electroless Ni/immersion gold
- Solder
  - In48%Sn (m.p.118 C, eutectic)
  - 1 mm preforms



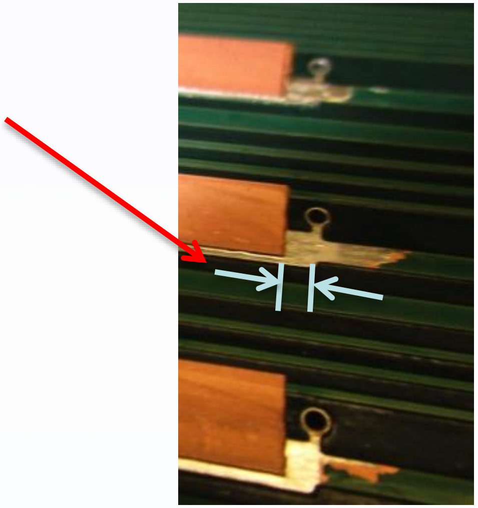
Measurements and Early Results

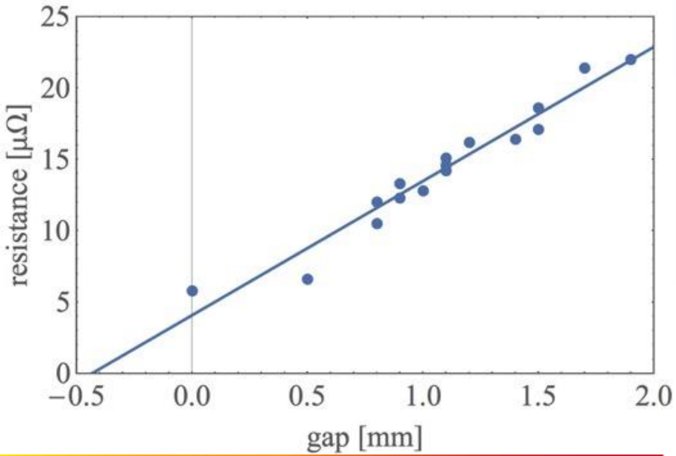
- X-ray images to determine void fraction, wetting
- Joint resistances at 77 K
- Joint R vs T (3 K – 300 K)
- Early development test
  - Varied T_{solder} 150 – 165 K, Force 5 – 20 N, hold time 30 – 90 s
  - no obvious patterns in x-ray images or R(77 K)
- Cycled 20 x (300 K → 77 K); no change in any R(77 K)
- Comparison of surface treatment in process
  - Best results so far with manual pre-tinning of solder pads



Current Transfer Length

- Serendipitous measurement:
  - x = HTS end to voltage tap distance
  - In early boards, x varied
  - Measure joint R at 77K
  - dR/dx = trace resistivity = 9.4 μΩ/mm
  - AstroH samples: trace resistivity = 8 μΩ/mm
  - Intercept = average current transfer length, λ = 0.43 mm
  - In Astro-H samples, $\lambda = 2 - 4$ mm
- For subsequent boards, $x = 0$



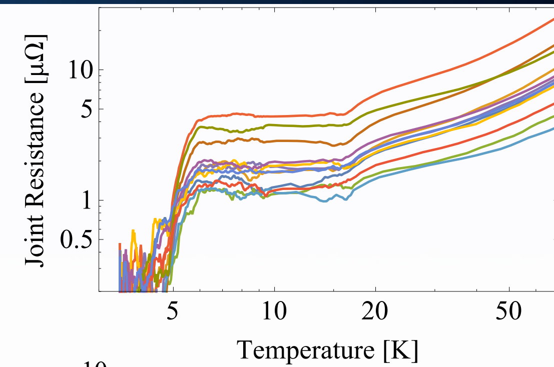


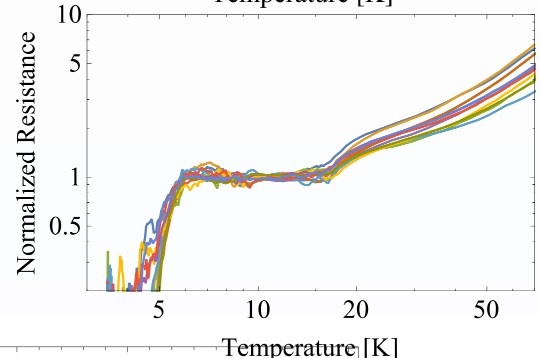
Low Temperature Resistance

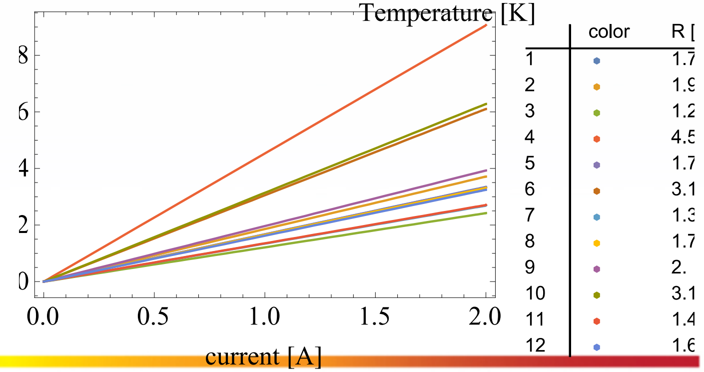
- Measured R vs T (3 – 300 K)
  - Plateau 5 K < T < 16 K
  - $R \approx 0$ for $T \lesssim 5$ K (T_c InSn 7.1 – 7.5 K)

- Normalized by mean (8 – 16 K)
  - Still ~ 2 x variation at 70 K ➔ not a simple geometric effect

- Measure I-V at 10 K
  - I up to full operating current (2A)
  - Linear ➔ ohmic behavior
  - Derived R matches those measured at low I

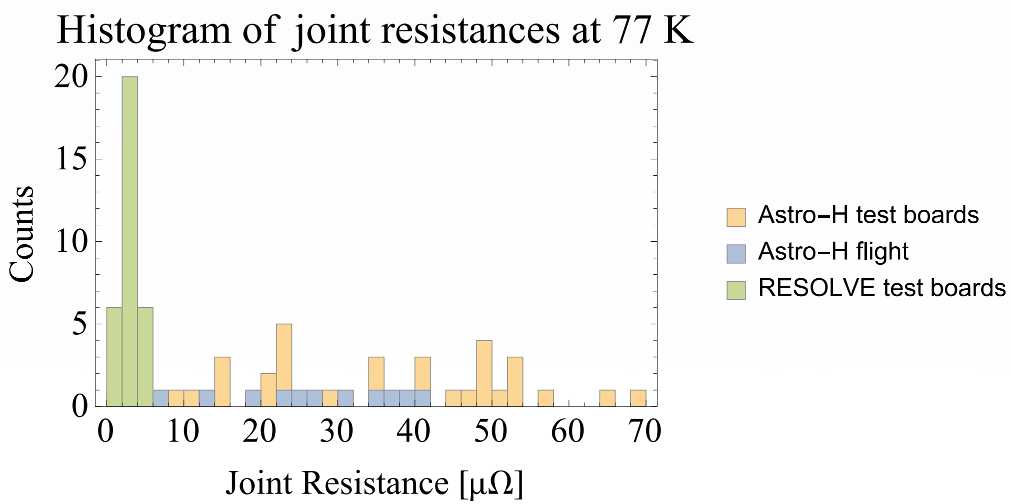






Distribution of Joint Resistances at 77 K

- Allows convenient comparison
- Astro-H
  - Test board & prototype measurements
  - Flight units (from post-vibe functional cool-down)
- 4 recent boards produced with same prototcol



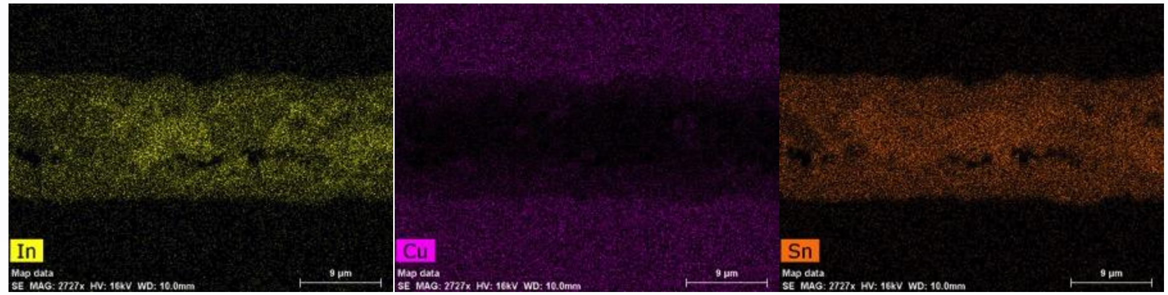
- Results
  - Values not directly comparable, but distributions are
  - Astro-H measurements all had wide distribution
  - Boards produced under new protocol show much tighter distribution

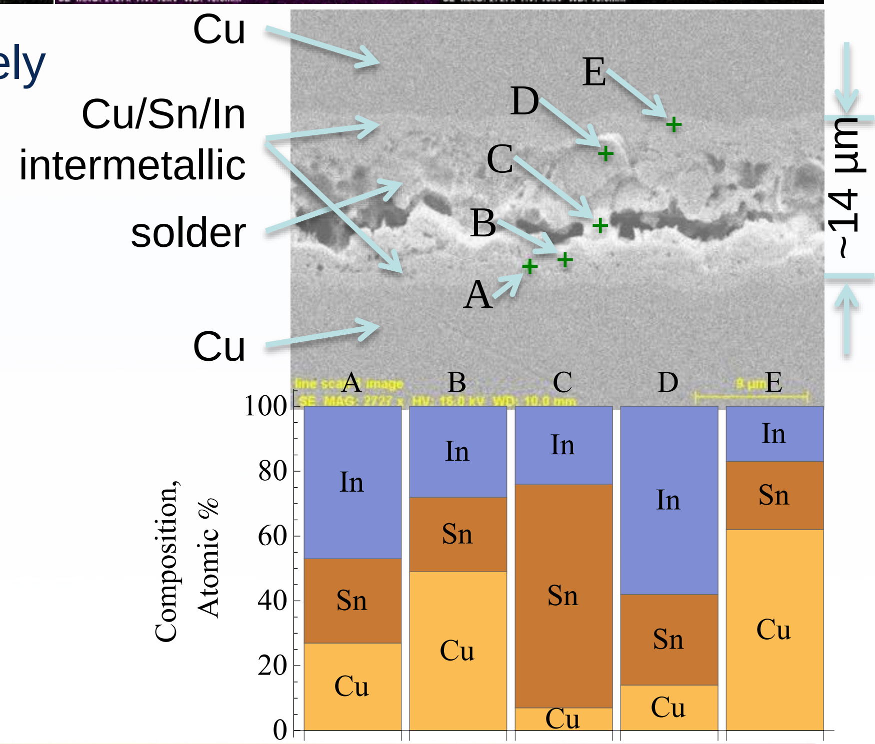
SEM/EDS of Cross-Sections

- EDS
  - Provides map of joint composition
  - Shows formation of inter-metallics at boundaries, largely unreacted solder in center
- Vianco, et al.:
  - CuIn growth rate follows

$$\Delta y = A t^n e^{-Q/RT}$$

  - Predicts $\Delta y \approx 2.5$ µm in 4 yr
    ➔will maintain compliant InSn layer





Conclusions

- RESOLVE: Rapid rebuild of Soft X-ray Spectrometer
- RESOLVE HTS lead assemblies to "build to print" except
  - Improved HTS material
  - New solder joint material & process
    - Plating protects Au layer from slow consumption by solder
    - New rig gives tight control of process parameters
- Solder process qualification tests
  - Good wetting and void levels (x-ray image)
  - Acceptable intermetallic layers at boundary
  - Ohmic behavior to full operating current
  - Excellent sample-to-sample variation in 77 K resistance
- Path forward
  - I-V testing to 5 A in prototype
  - Environmental degradation testing of joints an HTS tape