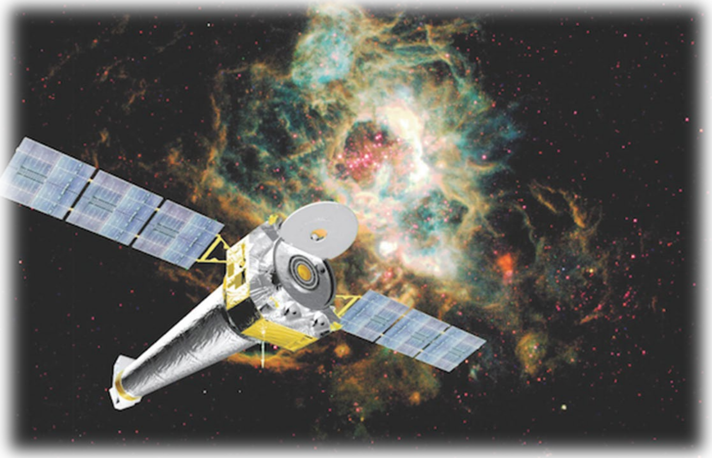
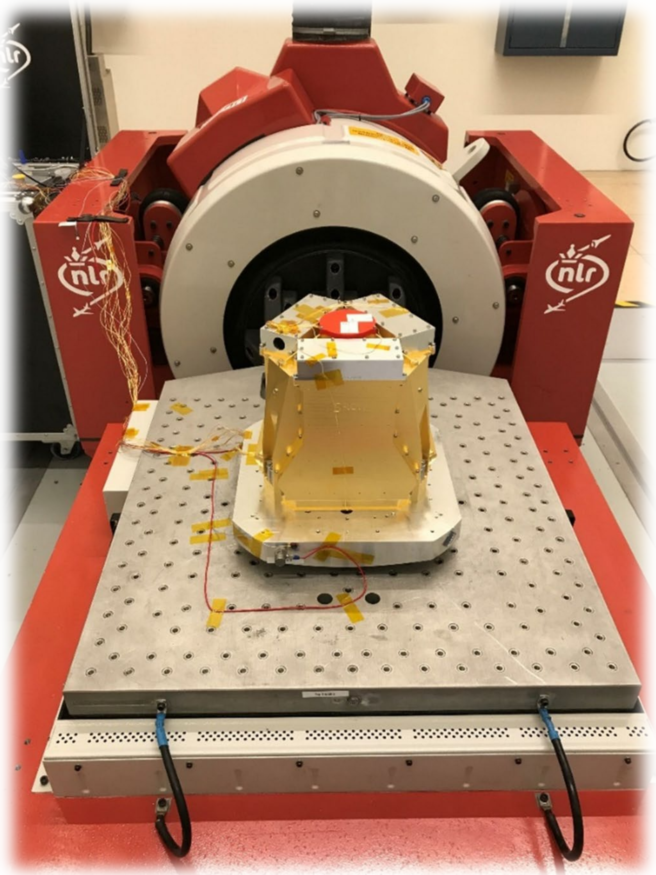
De ontwikkeling van een modulair, shielded, thermisch geïsoleerd, platform voor cryogene detectoren in space

Henk van Weers
Namens het SRON FPA ontwikkel-team
19-04-2023

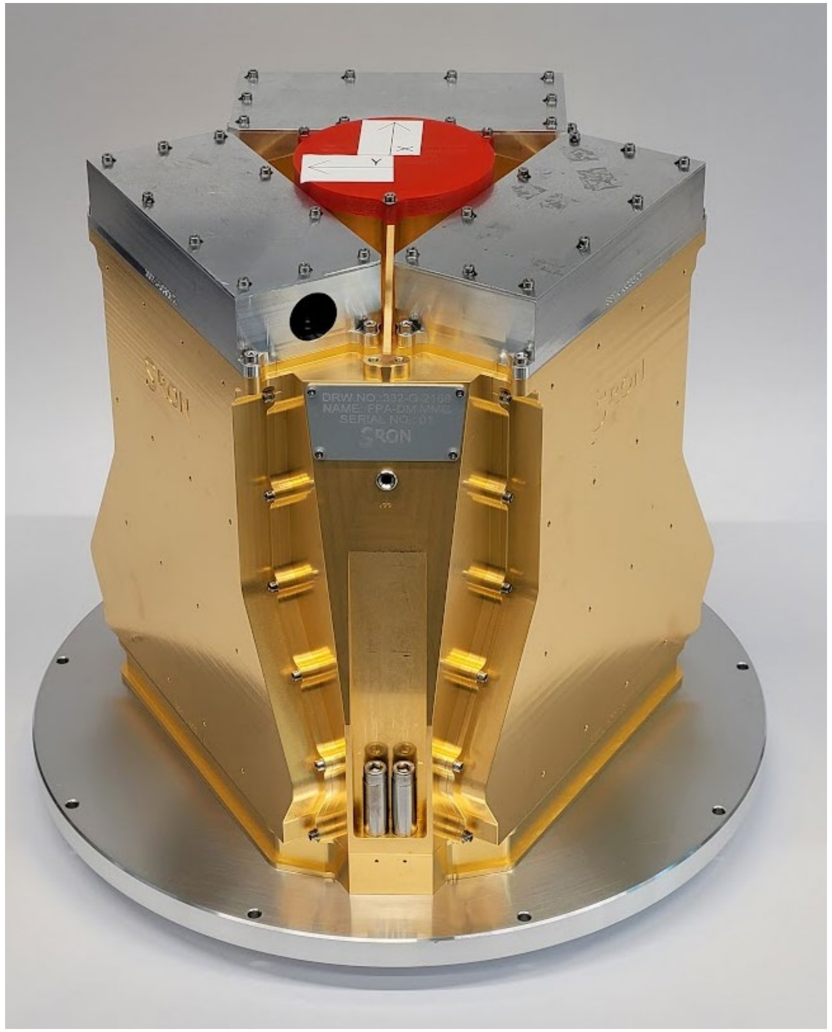




SRON NASA Goddard Space Flight Center INAF Istituto Nazionale di Astrofisica National Institute for Astrophysics VTT

Contents

- Mission example: The X-IFU instrument onboard the Athena observatory
- The Spectral Imaging Focal Plane Assembly (FPA) developed at SRON and its main components
- FPA Thermal Suspension
  - Thermal suspension driving requirements and design approach
  - Vibration induced heating during launch and operation
  - Effect of cooldown on suspension
- Thermal design and characterization
  - Nominal FPA thermal loads
  - Sensitivity of detector stage to temperature fluctuations on higher stages
- Summary and outlook

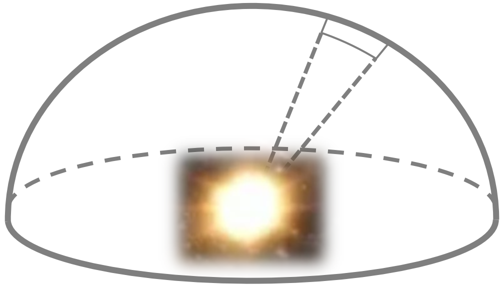


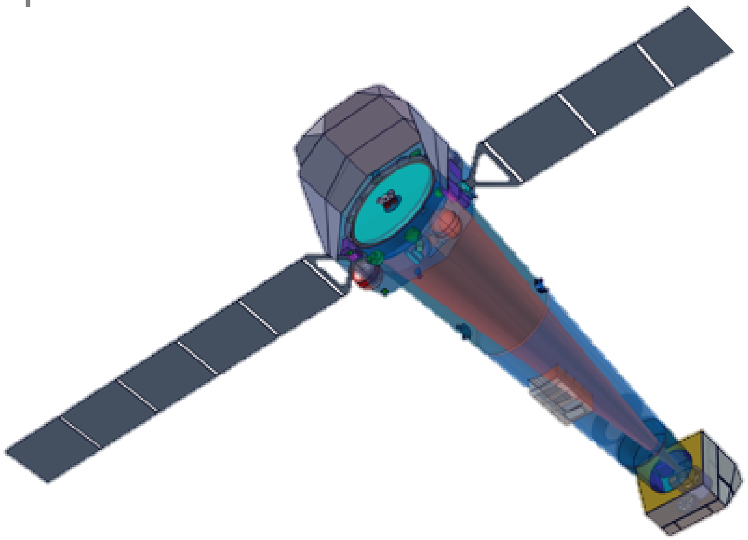
X-IFU FPA
Development Model (FPA-DM)

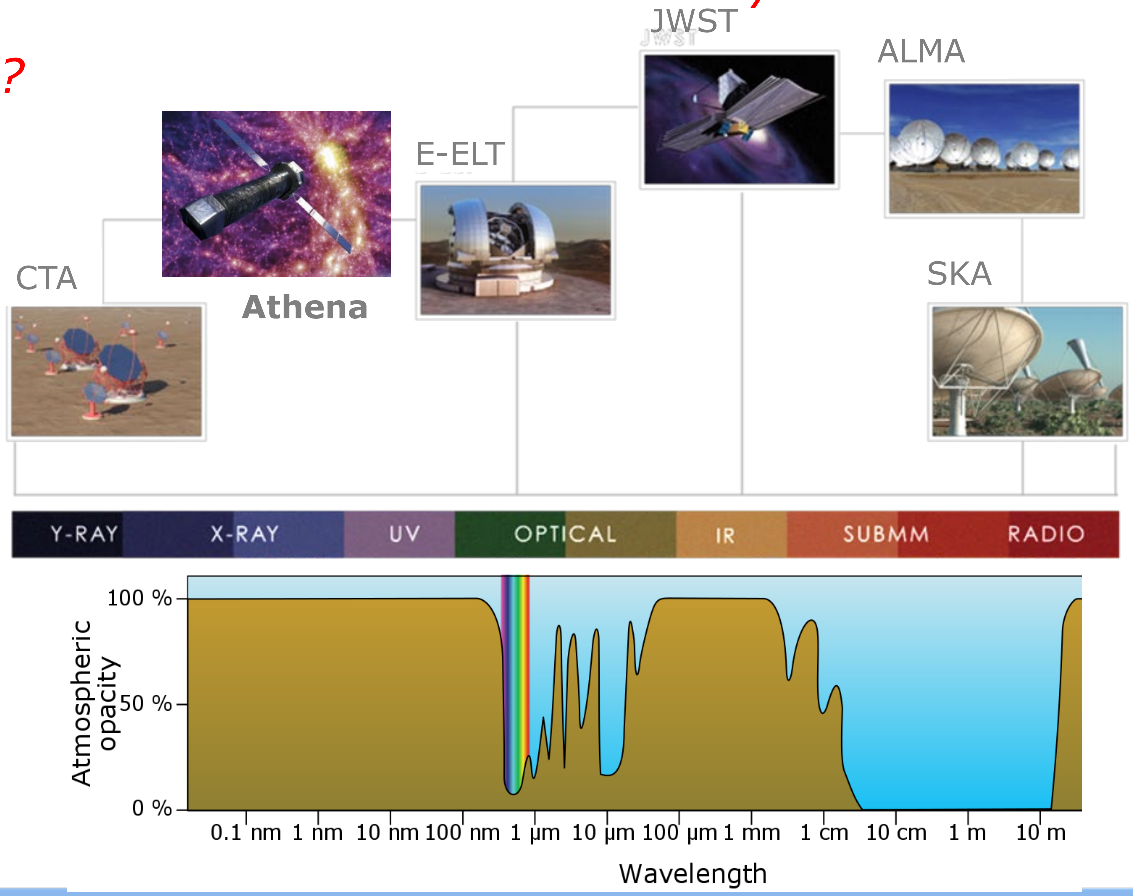
SRON

Mission example: The X-IFU instrument onboard the Athena observatory

- At the June 2014 meeting of ESAs 'Science Program Committee, ***Athena*** was selected as the mission for the 2nd Large mission opportunity, satisfying the Cosmic Vision theme the "Hot and Energetic Universe"
- Athena is an observatory class mission addressing key scientific challenges:
  - *How does ordinary matter assemble into large scale structures that we see today?*
  - *How do black holes grow and shape the Universe?*
- The observatory contains 2 instruments:
  - A Wide Field Imager: WFI
  - An X-ray imaging spectrometer: X-IFU

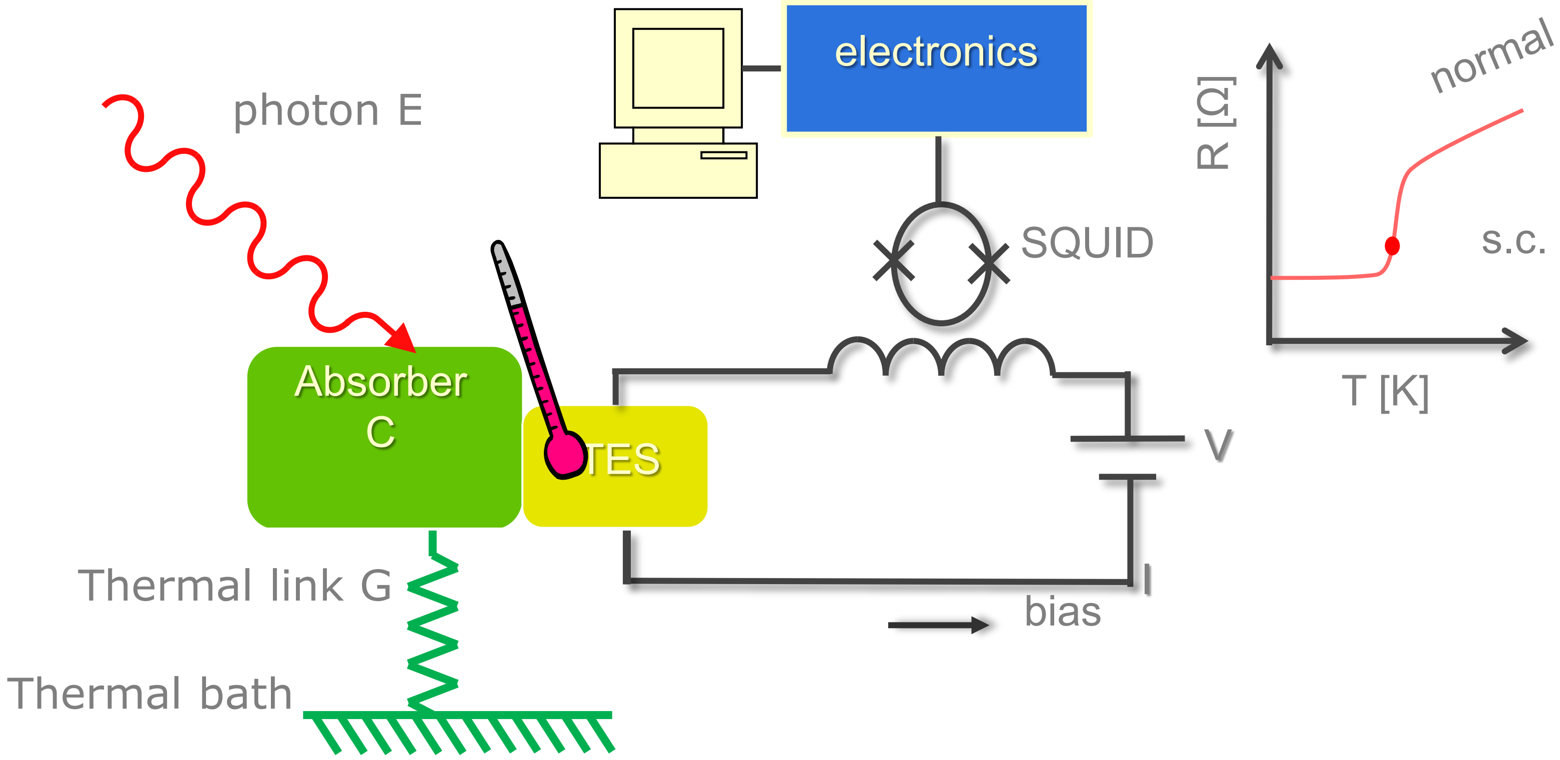




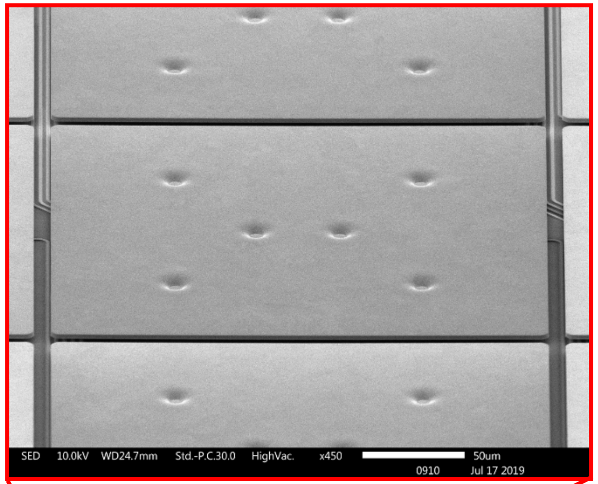


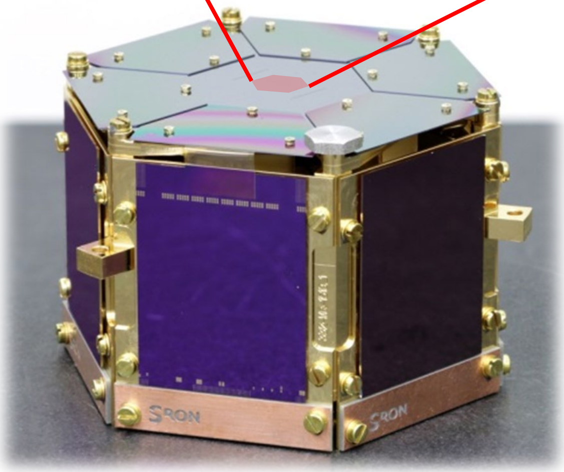
SRON TES X ray detector array sample

- Low Temperature Detector used for X-IFU instrument on Athena: Transition Edge Sensor (TES)
- The FPA contains a 3.6Kpixel array, multiplexed in time domain



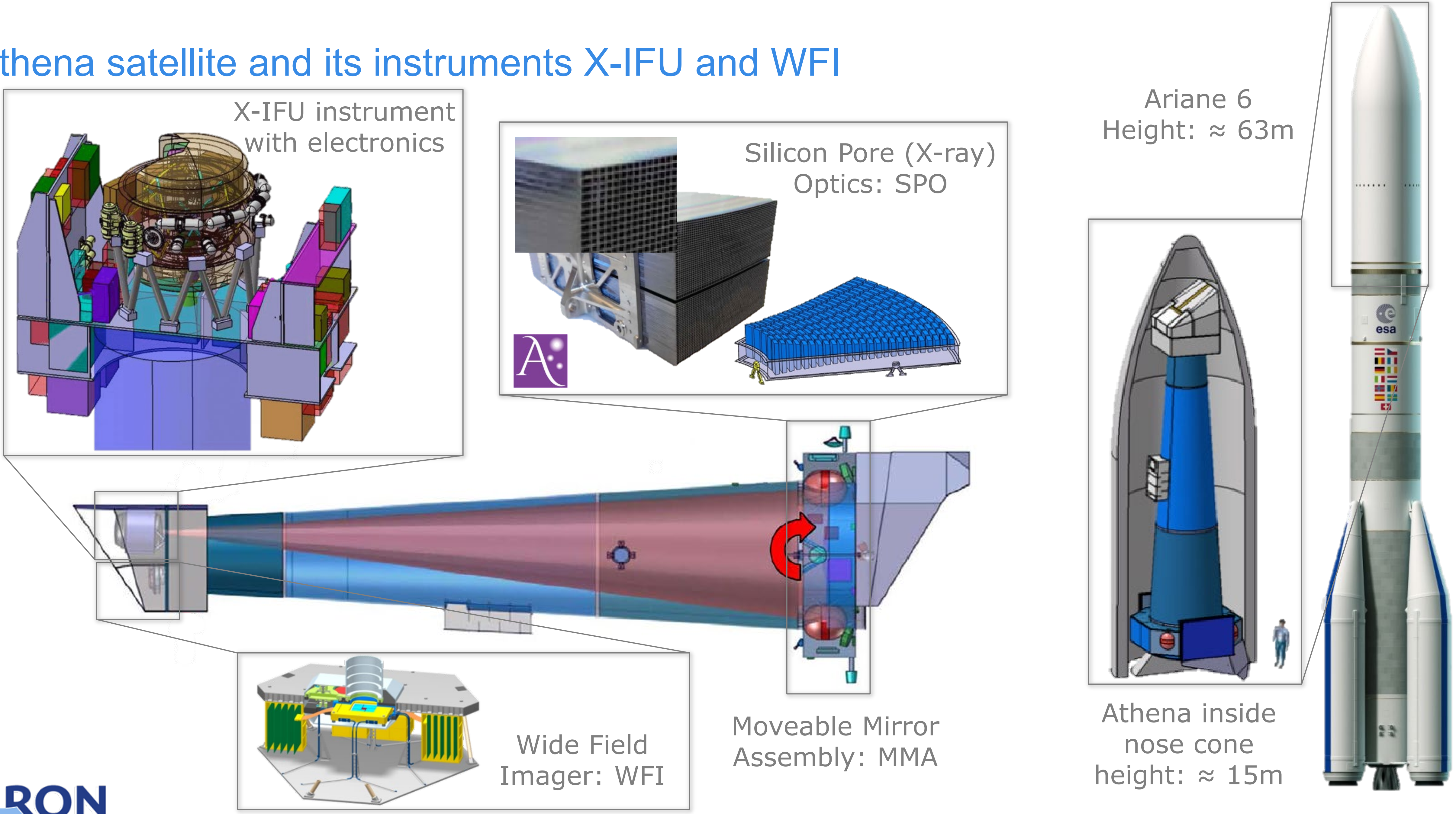
X-ray TES pixel close up





SRON

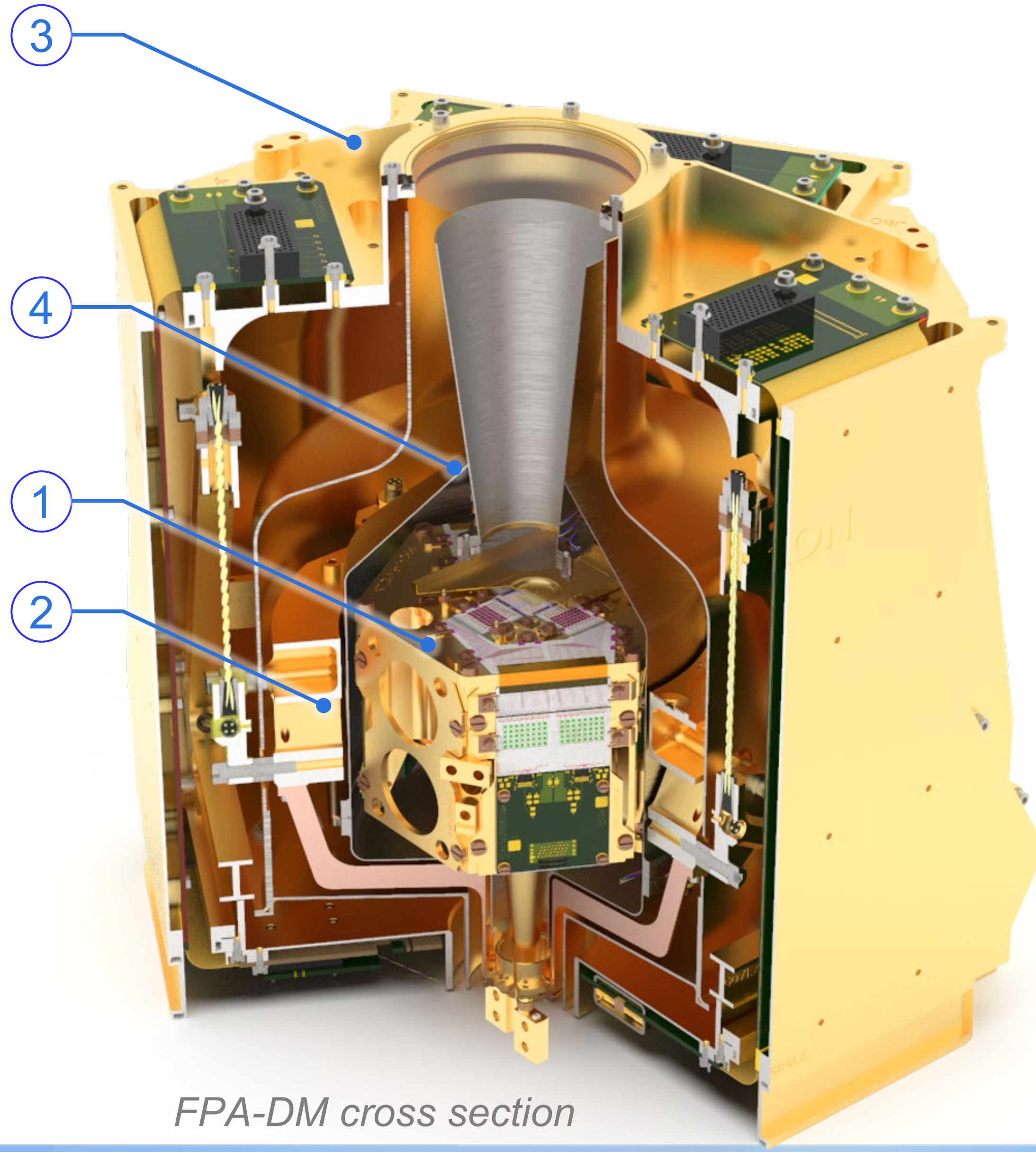
Athena satellite and its instruments X-IFU and WFI



SRON

FPA main components

1) ***"T0 stage"* at nominally 50 mK:**
   1.4 kg detector stage at 50 mK including superconducting 0.43 kg Nb magnetic shield and Cu structural parts
   FPA-DM: 120 Pixel, FDM; FM: 3.6 kPixel
2) ***"T1 stage"* at nominally 300 mK:**
   0.65 kg Intermediate heat intercept at 300 mK; Aluminum ring structure + Cu strap
3) ***"T2 stage"* at nominally 2K:**
   3.5 kg Main mechanical structure in Al6061 (FM: 5.3 kg)
4) Cryogenic Mu Metal (CMM) and Niobium superconductive magnetic shields

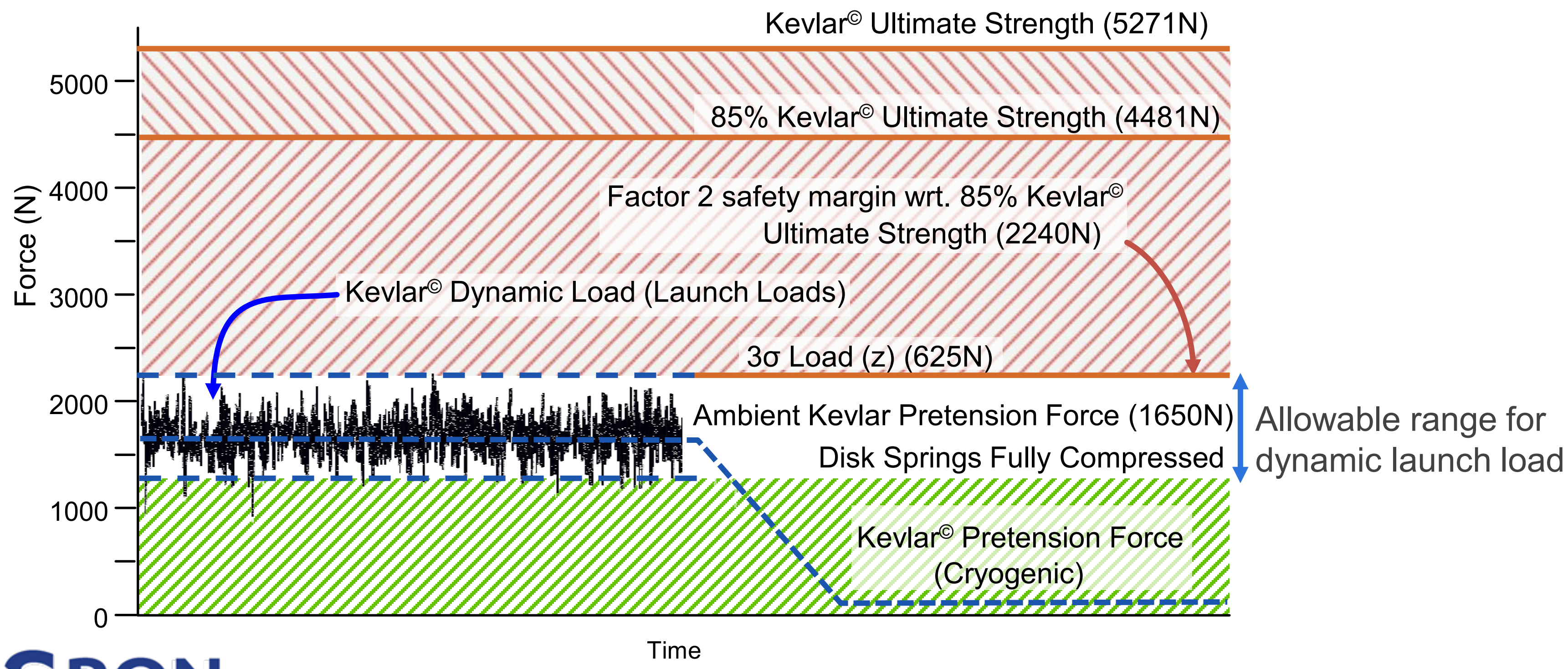


FPA-DM cross section

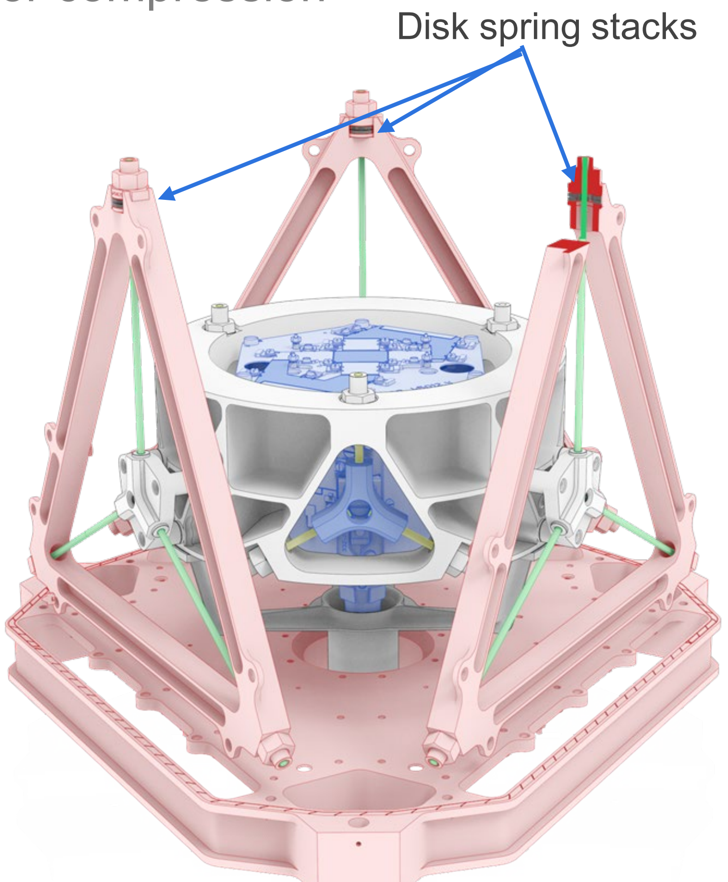
SRON

Thermal suspension driving requirements

- The FPA suspension is designed to minimum heat load, while maintaining a first resonance of $f_1 > 250$ Hz.
- Kevlar© (4 strand, 35572 Dtex) cord selected as material due to its very high strength and stiffness vs. cryogenic thermal conductivity ratio.
- Construction is under pre-tension to avoid need for additional buckling factor for compression to allow large cord lengths combined with minimal cross sections.
- Disk spring stacks are added to compensate for thermal expansion of Kevlar©



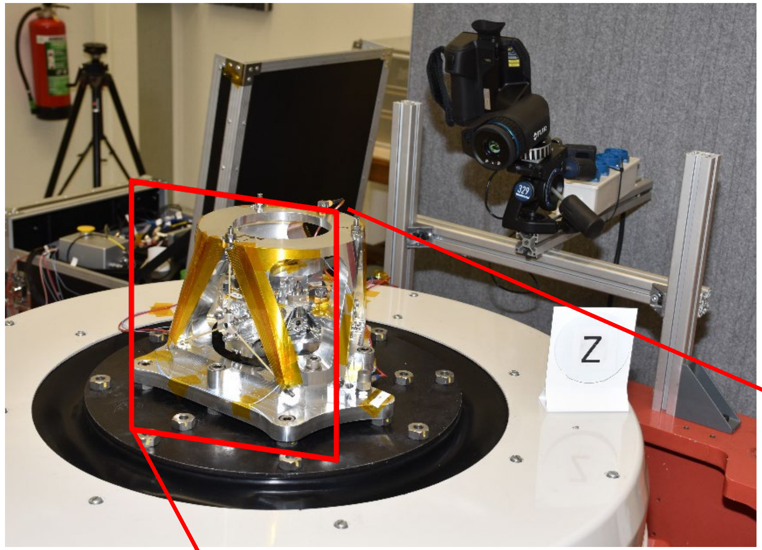
Pretension during life cycles

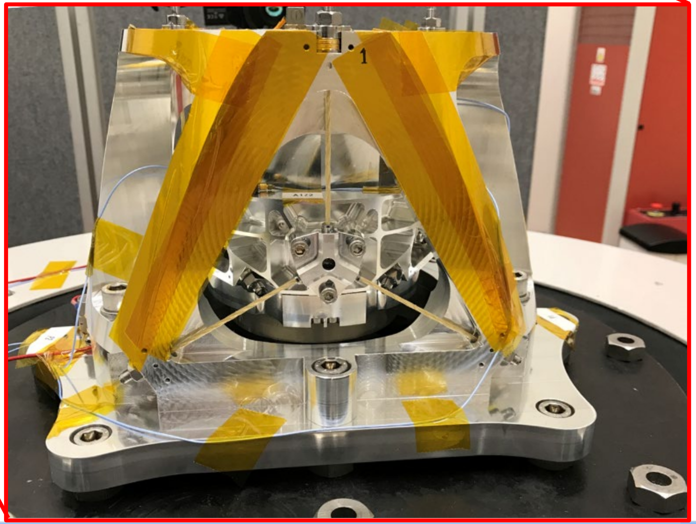


FPA thermal suspension and disk springs

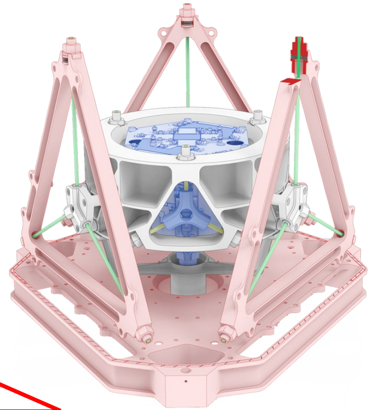
FPA Kevlar suspension: launch vibration tests

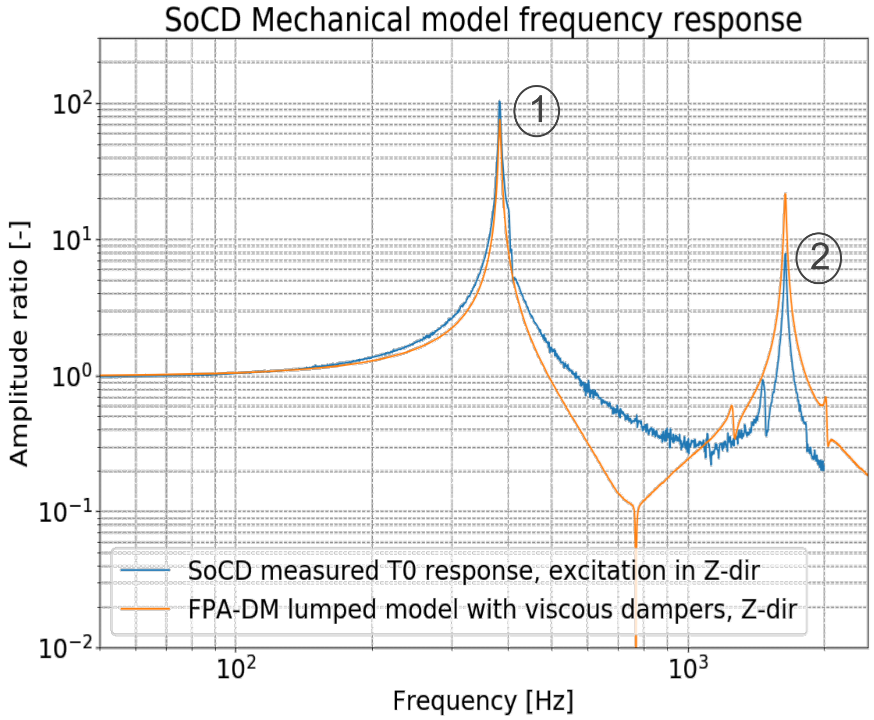
- High load Random vibration tests on mechanical model



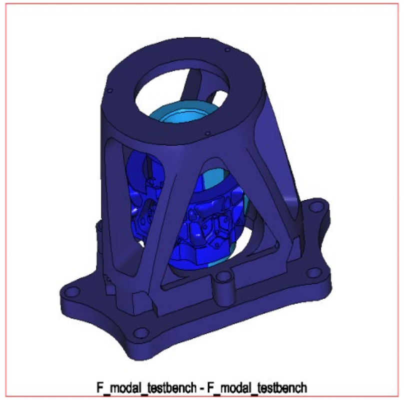


Suspension modes measured and modelled using viscous damper elements

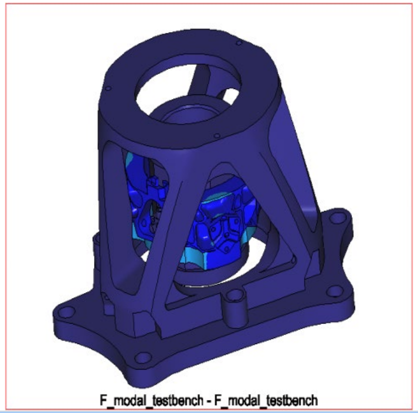




① *First mode in Z:*
T0 and T1 move in phase



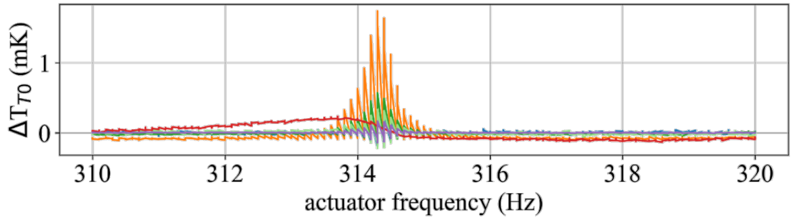
② *Second mode in Z:*
T0 and T1 move out of phase

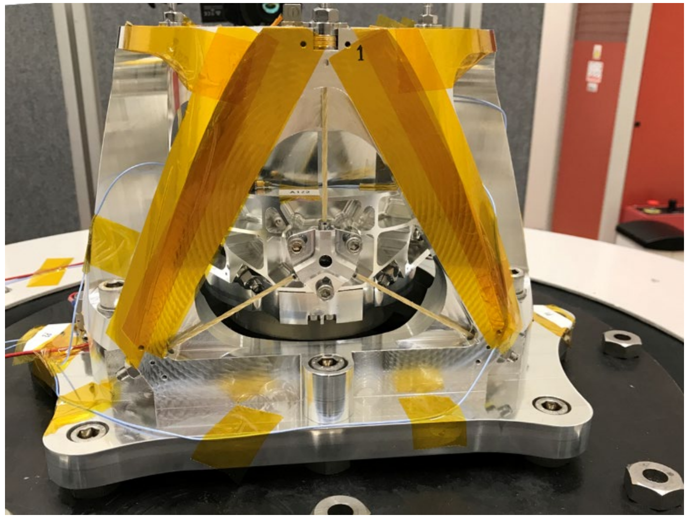


Vibration induced heating during launch vibration tests

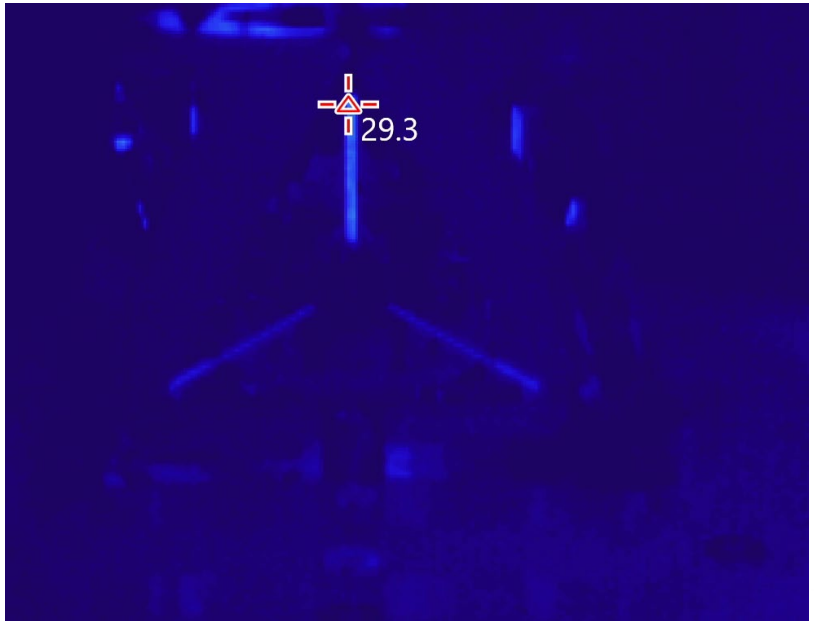
- By matching both 1st and 2nd mode resonances an estimation could be performed on the viscous damping contribution for each T1T0 and T2T1 cord:
  - Value found for the T1T0 cords is around 2 N·s/m
  - Value found for the T2T1 cords is around 10 N·s/m
- Using the thermal test data, a thermal model has been created including (orthotropic) thermal conduction, convection and radiation.
- This model is used to predict the suspension behavior in absence of air (instrument is in vacuum during actual launch)

Thermal response on sine swept disturbance during cryogenic test

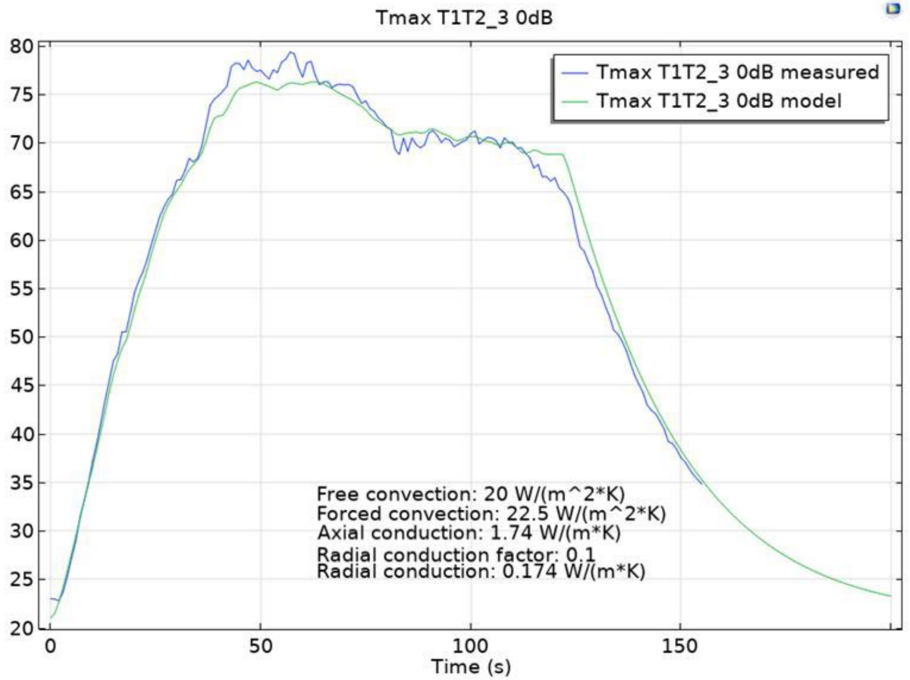




View of the thermal camera on test setup



Thermal image during 0dB random test



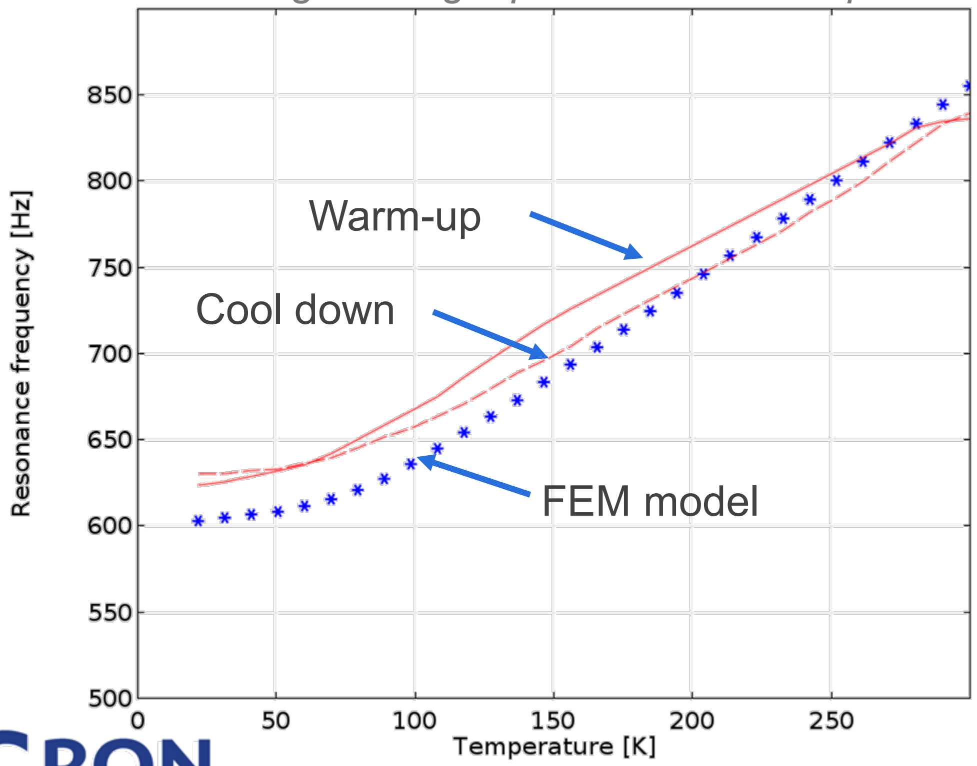
Thermal response of Kevlar cord And thermal model result

SRON

Effect of cooldown on suspension: Kevlar elongation

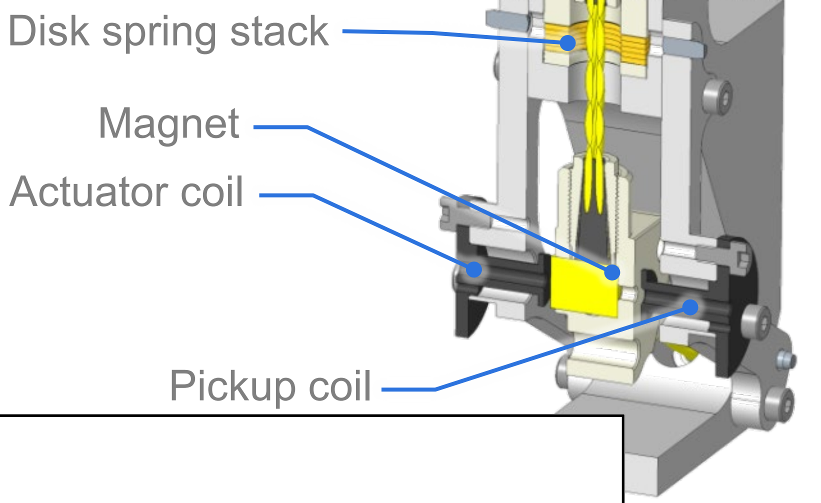
- ***Single suspension setups show that disk spring stack indeed retains pretension during cool down.***
- 40% reduction in stiffness of vertical cords in line with model predictions
- Result shown for T1-T0 triangle, results for T2-T1 triangle available as well

T1T0 single triangle pretension vs temperature



T1T0 single suspension

Pretension test setup



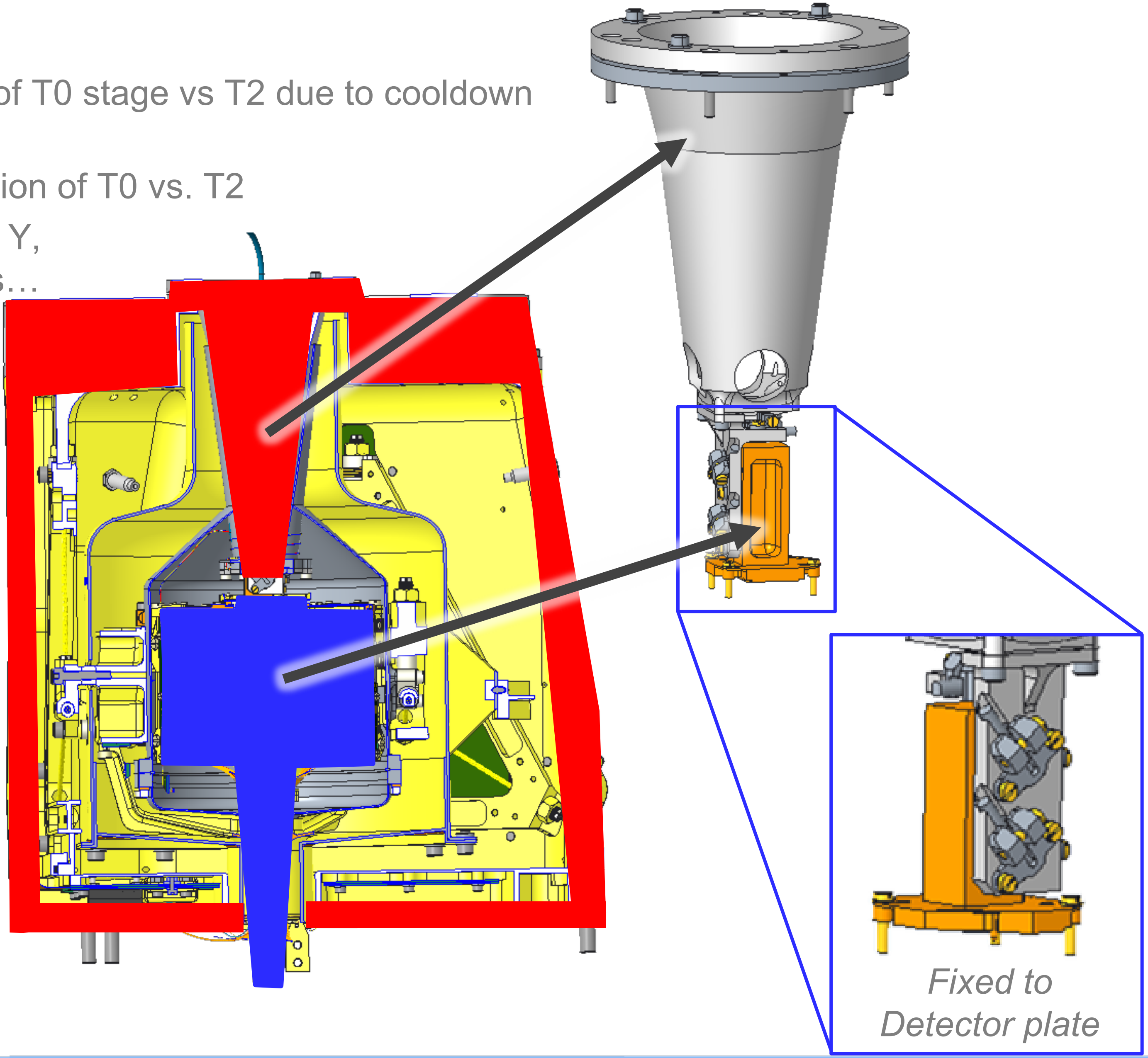
SRON

Effect of cooldown on suspension

- Preparing experiment to measure <u>change</u> in alignment of T0 stage vs T2 due to cooldown
  - Differential CTE of Kevlar vs Aluminum structure
    → disk springs "activate" during cooldown → Z motion of T0 vs. T2
  - Symmetry of suspension → ideally, no motion in X, Y, θ_x, θ_y. However, real systems contain asymmetries…

- Goal
  - Show that changes in T0 vs T2 alignment (X, Y, θ_x, θ_y) due to cooldown are small
  - Justify measurement of as-built alignment of future FPA models at room-T only

T2 insert
with 5 distance sensors



Capacitive distance sensor
(1mm range, 0.5 µm resolution)

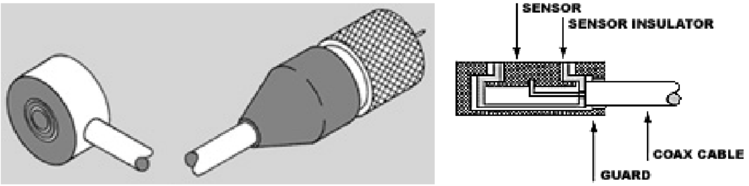
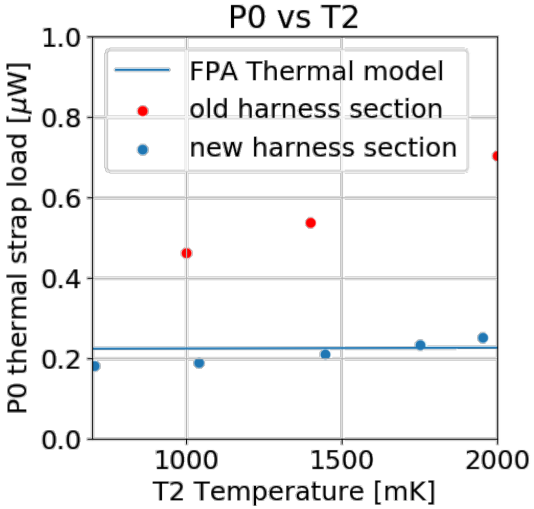


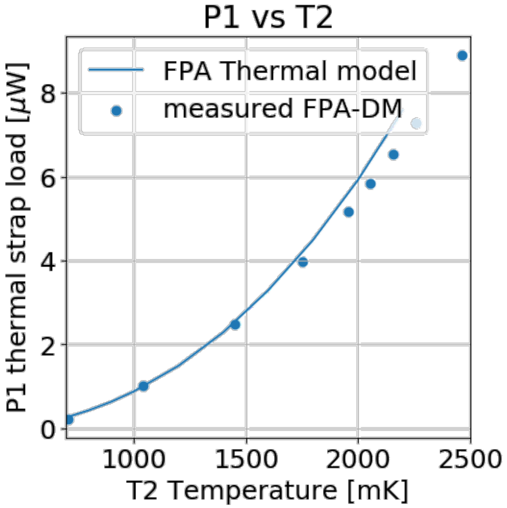
Figure 2.29. Capacitec HPB button probe (with microdot connector) [CapW].

SRON

Nominal passive FPA thermal loads without readout activated

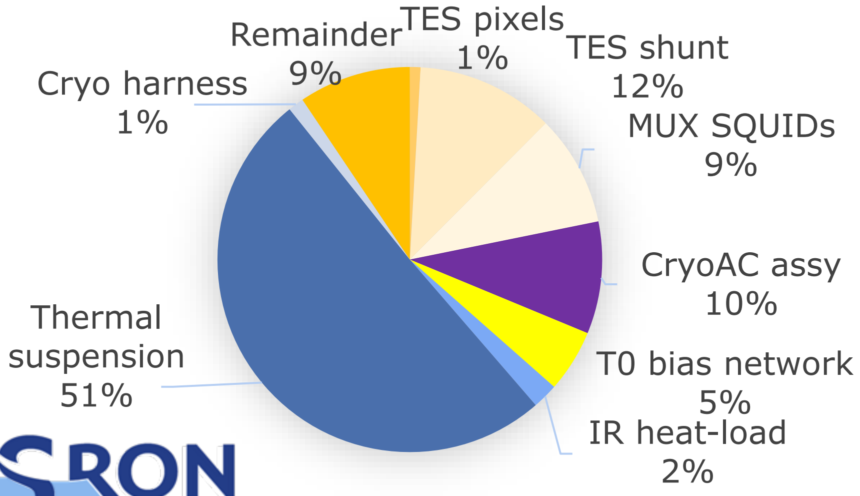
- FPA suspension is biggest heat load on T0 (51%) and highly dominating on T1 (90%). Therefore, experimental verification in FPA-DM was set to 1st priority.
- ***After initial issue related to a faulty T2-T0 harness section this suspension heat load was confirmed on both T0 and T1.***
- Thermal model static heat load predictions coincide well, no major updates needed.





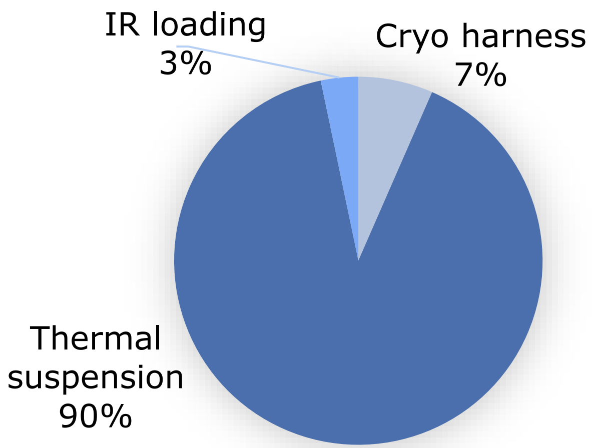
FPA-DM T0 predicted heat-loads

FM CBE: 670 nW



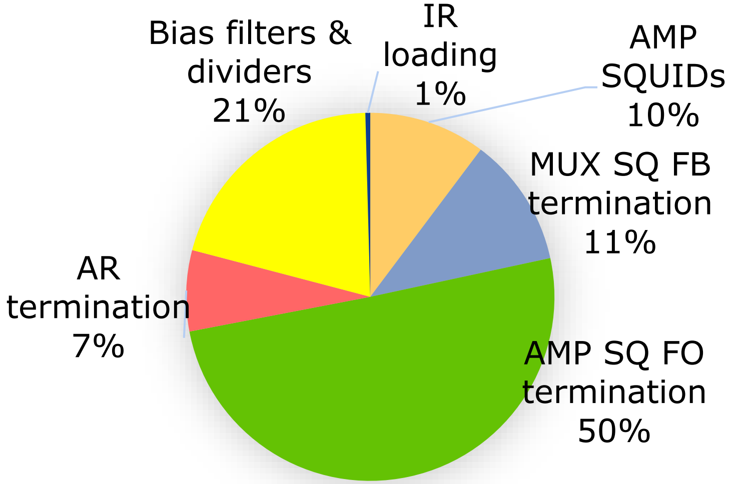
FPA-DM T1 predicted heat-loads

FM CBE: 9 μW



FPA-DM T2 predicted heat-loads

FM CBE: 2.4 mW



Sensitivity of detector stage to fluctuations on T1 and T2

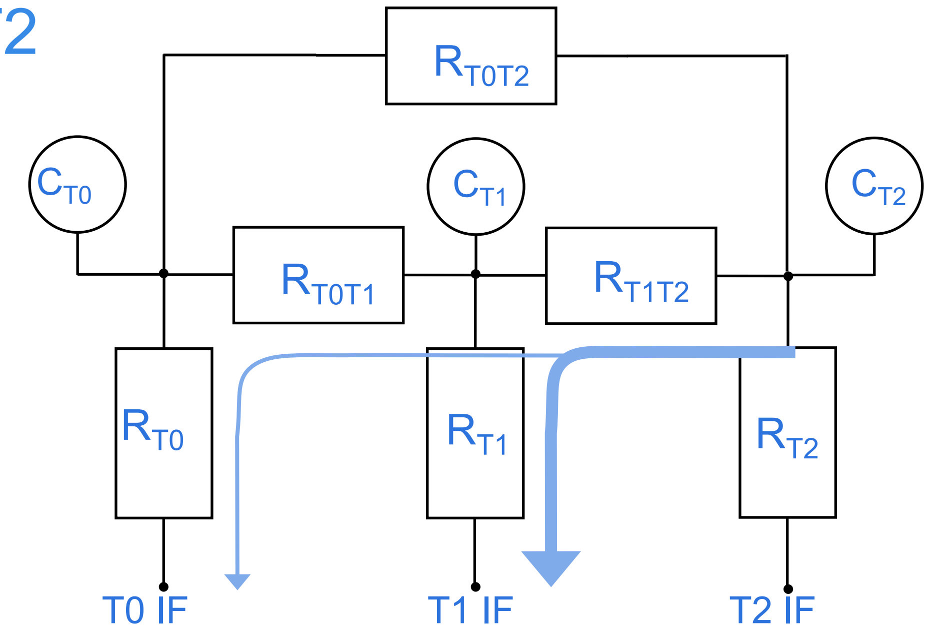
- The ratio between the isolation of the T0 stage and the conductance of the T0 strap (+ conductive path to cooler) determine the ratio at which low frequency variations on T1 translate into temperature fluctuations on T0.
- Predicted ratio of between R_{T0T1} and $R_{T0strap}$ within thermal model:

$$\frac{G_{T1T0model}}{G_{T0model}} = 1.4 \cdot 10^{-3}$$

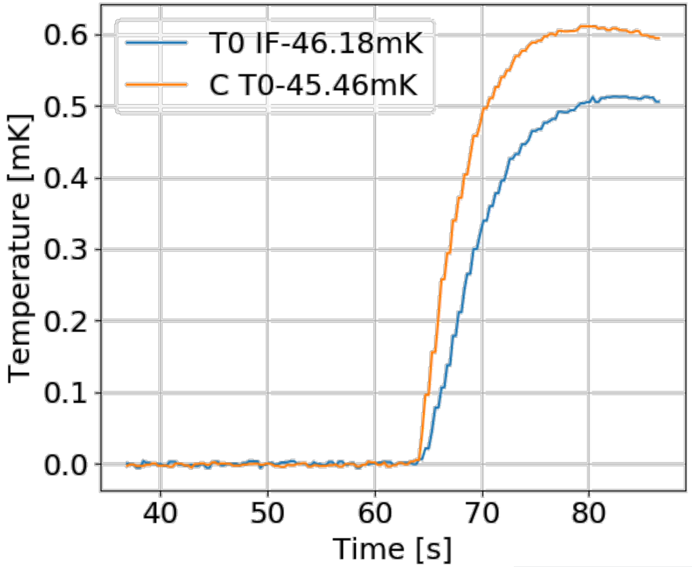
- Thermal measurements show a ratio between R_{T0T1} and $R_{T0strap}$ of:

$$\frac{G_{T1T0exp}}{G_{T0exp}} = 1.2 \cdot 10^{-3}$$

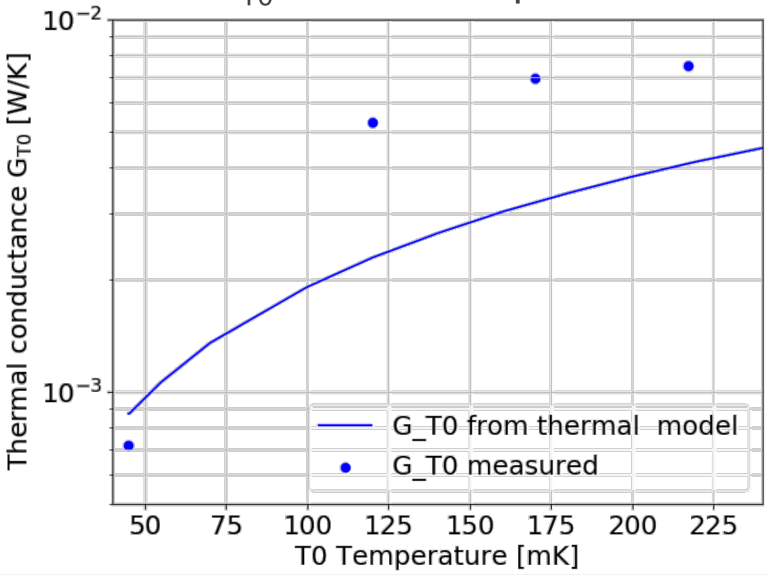
FPA simplified thermal schematic



Example: 80 nW step on T0



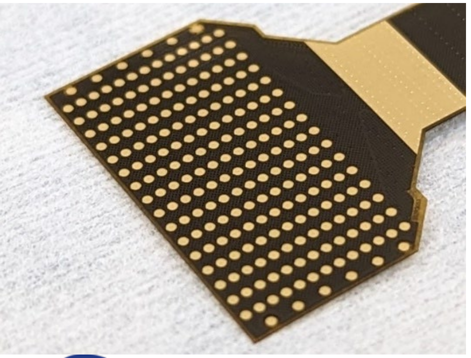
G_{T0} model vs experiment



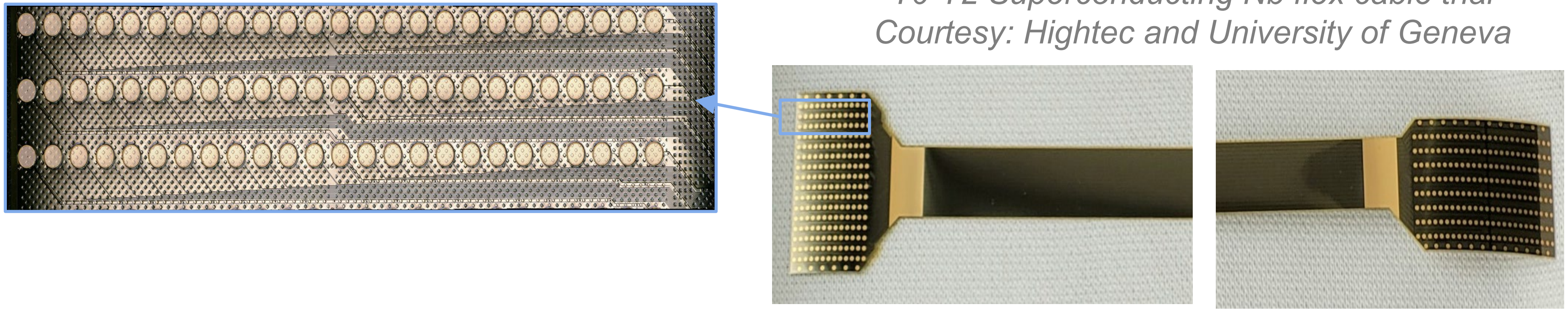
Summary and outlook

Kevlar© cord assembly from latest fabrication batch

- SRON realized a first FPA model including all relevant subsystems. For the first time we adapted our engineering models. These can be used for the next FPA model iterations.
- New data is gathered which raises our understanding of this complex subsystem of the X-IFU instrument.
- The detector thermal insulating suspension is a crucial element of the FPA, with challenging requirements on stiffness, strength, stability and thermal behaviour.
- Low temperature thermal models of the FPA, combined with viscous dissipation models of the Kevlar suspensions are used to predict the detector thermal response.
- New FPA model iterations are planned to verify the design and engineering implementation. An example is the use of multi-layer superconducting Nb in PI flex cables.



T0-T2 Superconducting Nb flex cable trial
Courtesy: Hightec and University of Geneva




Thank you!