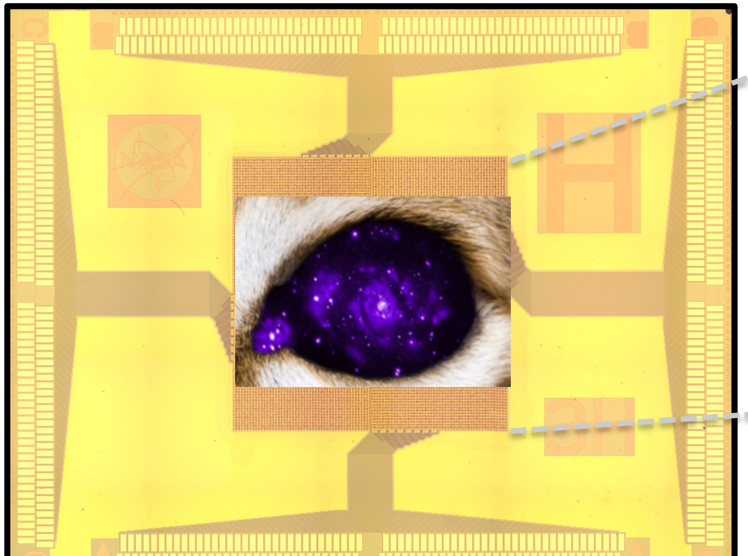
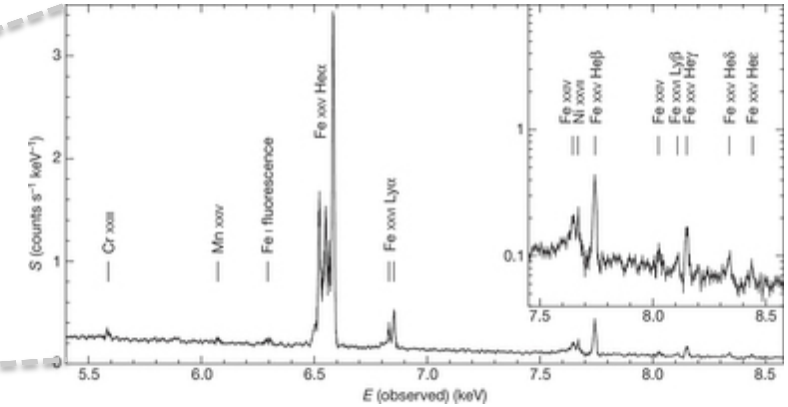
Revealing the Invisible Universe





Options for the Lynx X-ray microcalorimeter "Whiskers"

Lynx Technical Interface Meeting
Huntsville, May 22nd, 2017

Simon Bandler – X-ray microcalorimeter group at NASA/GSFC

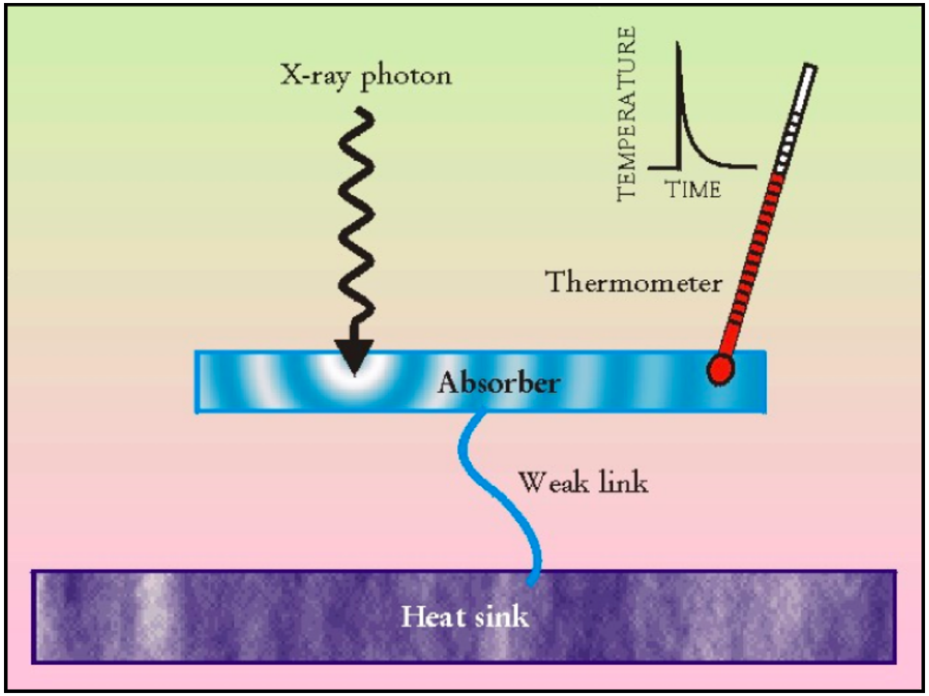
- Microcalorimeter overview
- Preliminary system design
- Tall poles
- Examples of possible CAN development areas.

Suggested Lynx microcalorimeter requirements for initial study

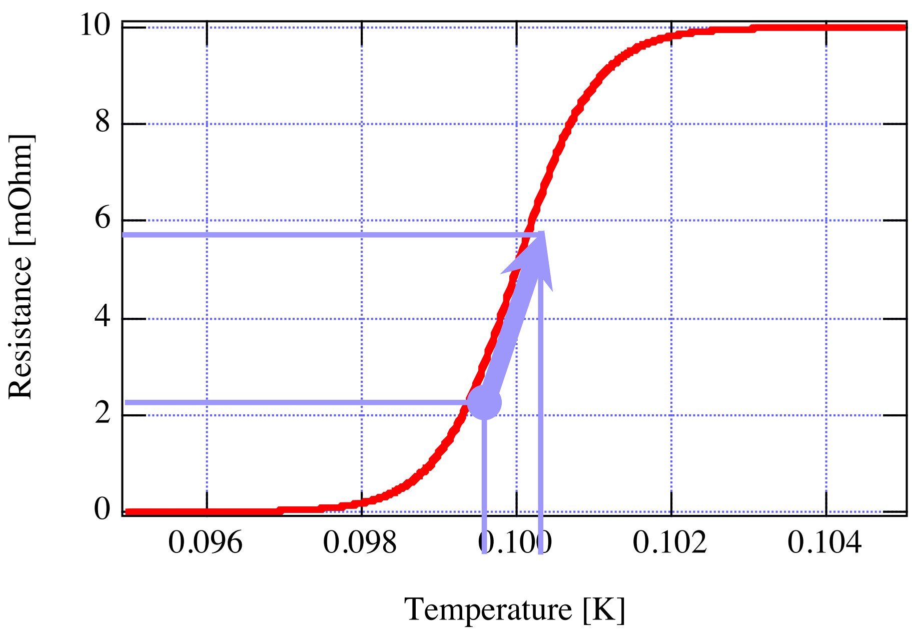
- Pixel size: 1”
- Field-of-View: At least 5’ x 5’
- Energy resolution [FWHM]: < 5 eV
- Count rate capability: < 1 count per second per pixel
- For a focal length of optic of 10 m, 1” corresponds to 50 μm pixels

5’ field-of-view with 1” pixels requires a nominal 300 x 300 array => 90,000 pixels

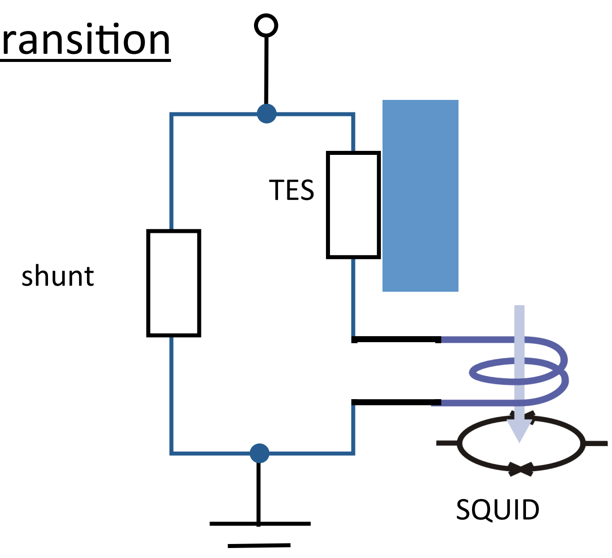
Transition-edge Sensor microcalorimeter basics:



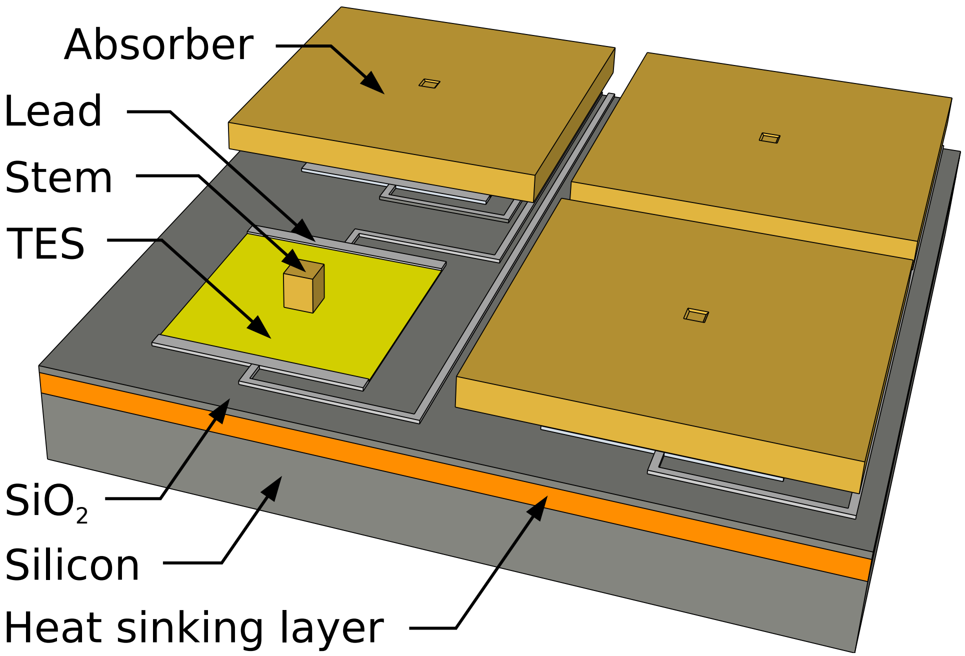
Temperature rise: $\delta T = \frac{E}{C_{\text{tot}}}$



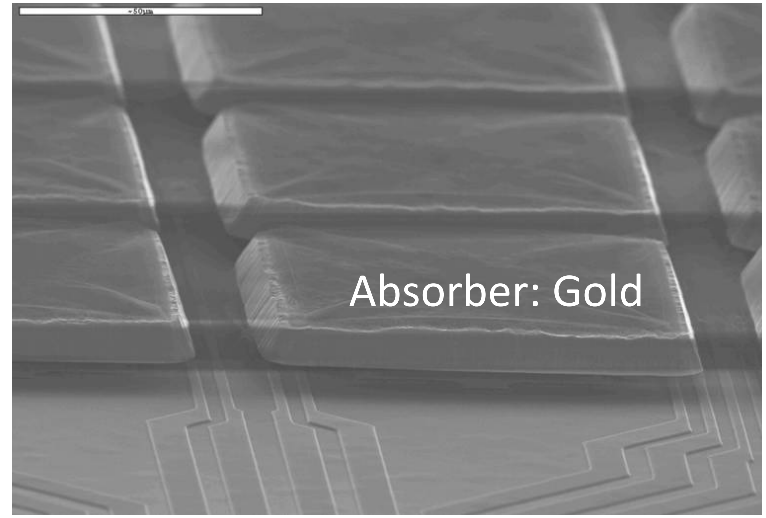
Superconductor voltage-biased in its transition

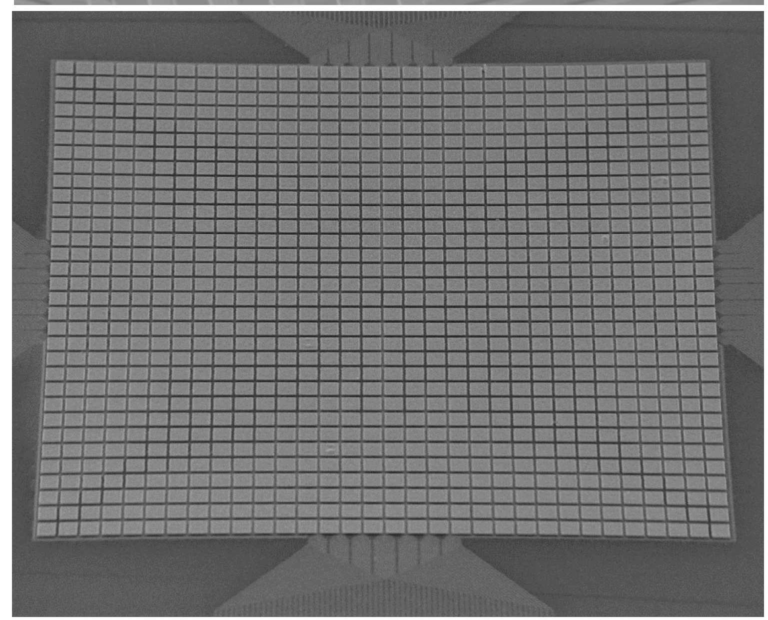


Lynx requires pixels on small pitch



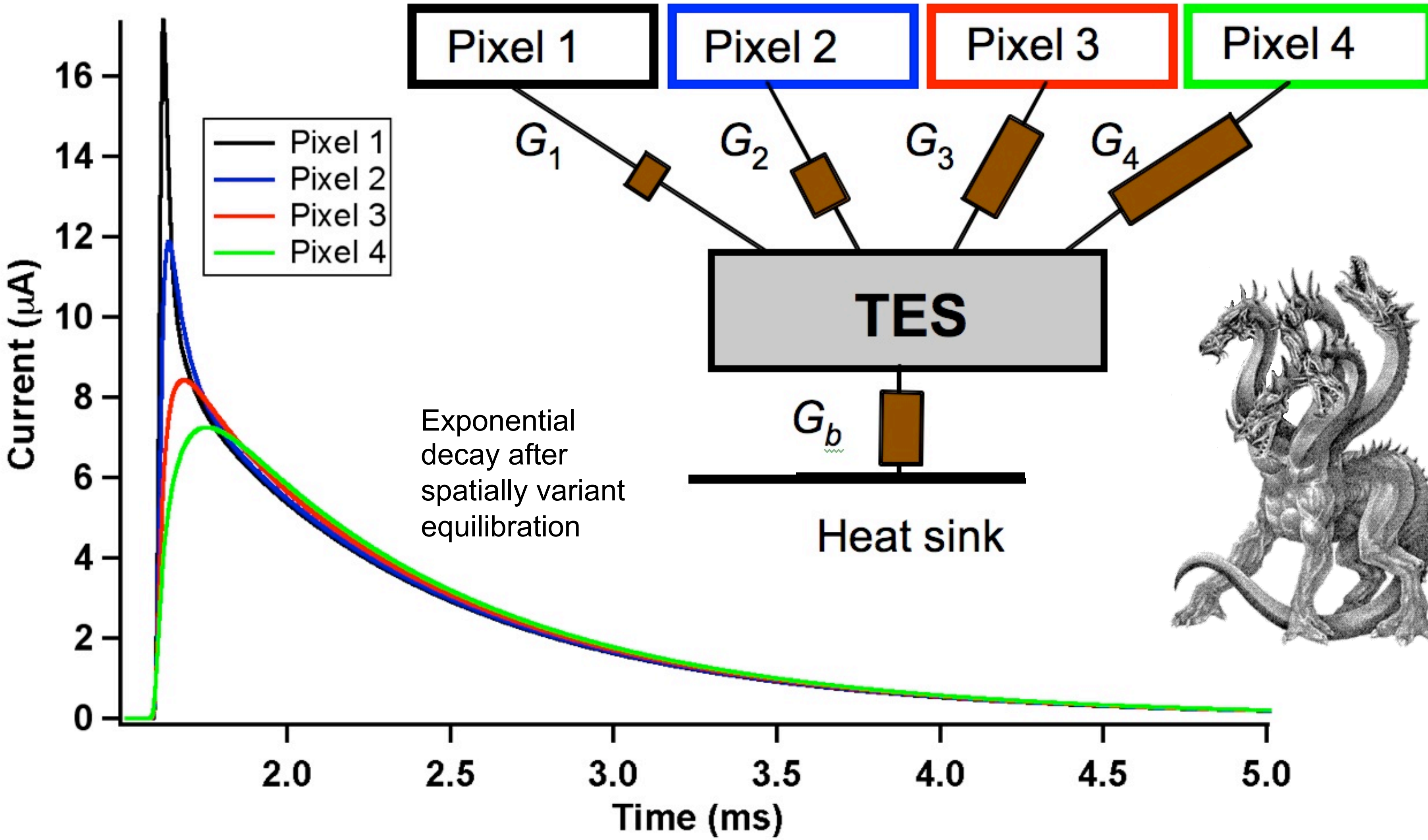
“Small-pixel” TES microcalorimeter design : on solid substrate





Multi Absorber TES “Hydras” - 1 TES, 4 absorbers

– increase field of view for a fixed number of read-out channels

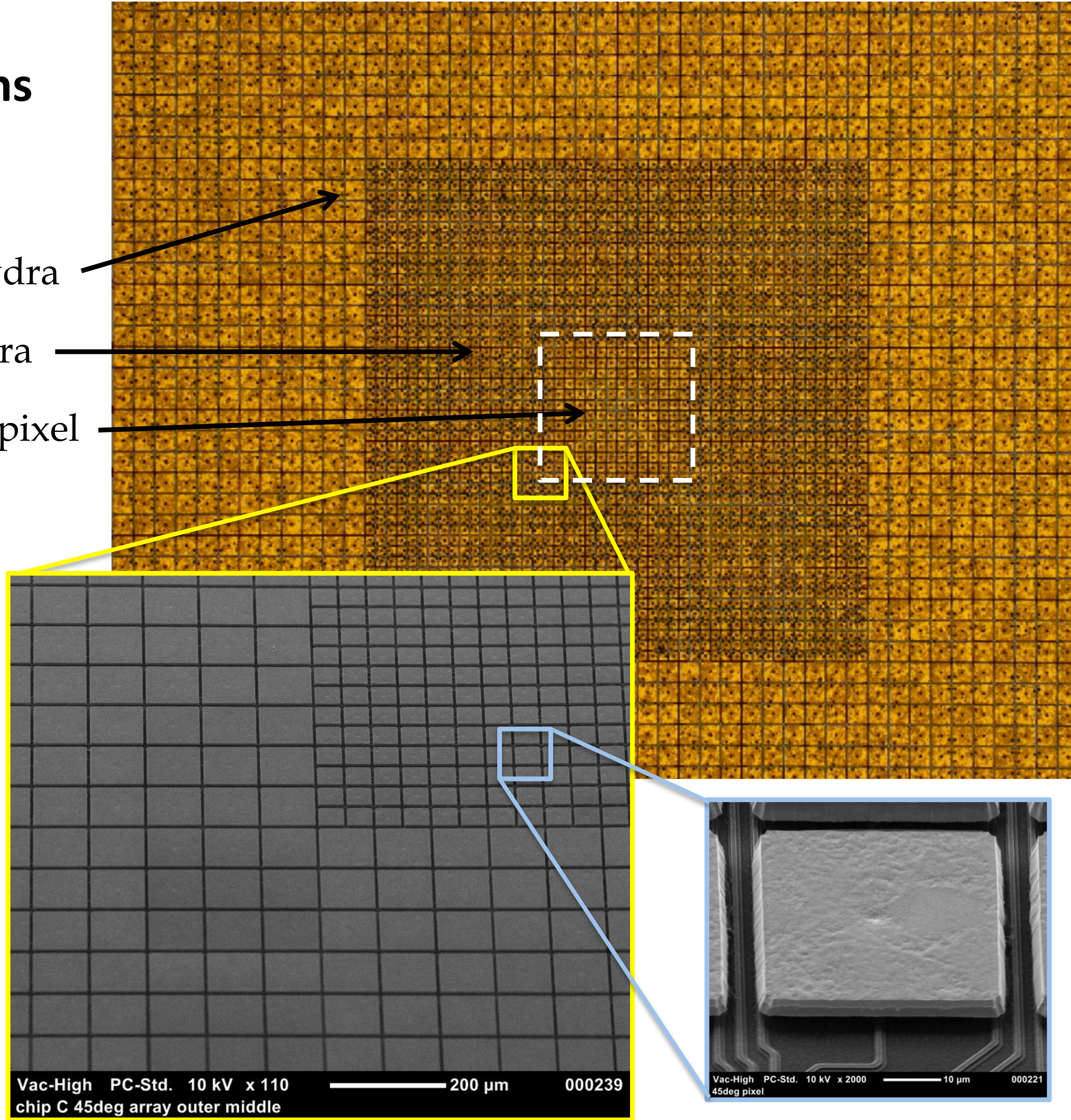


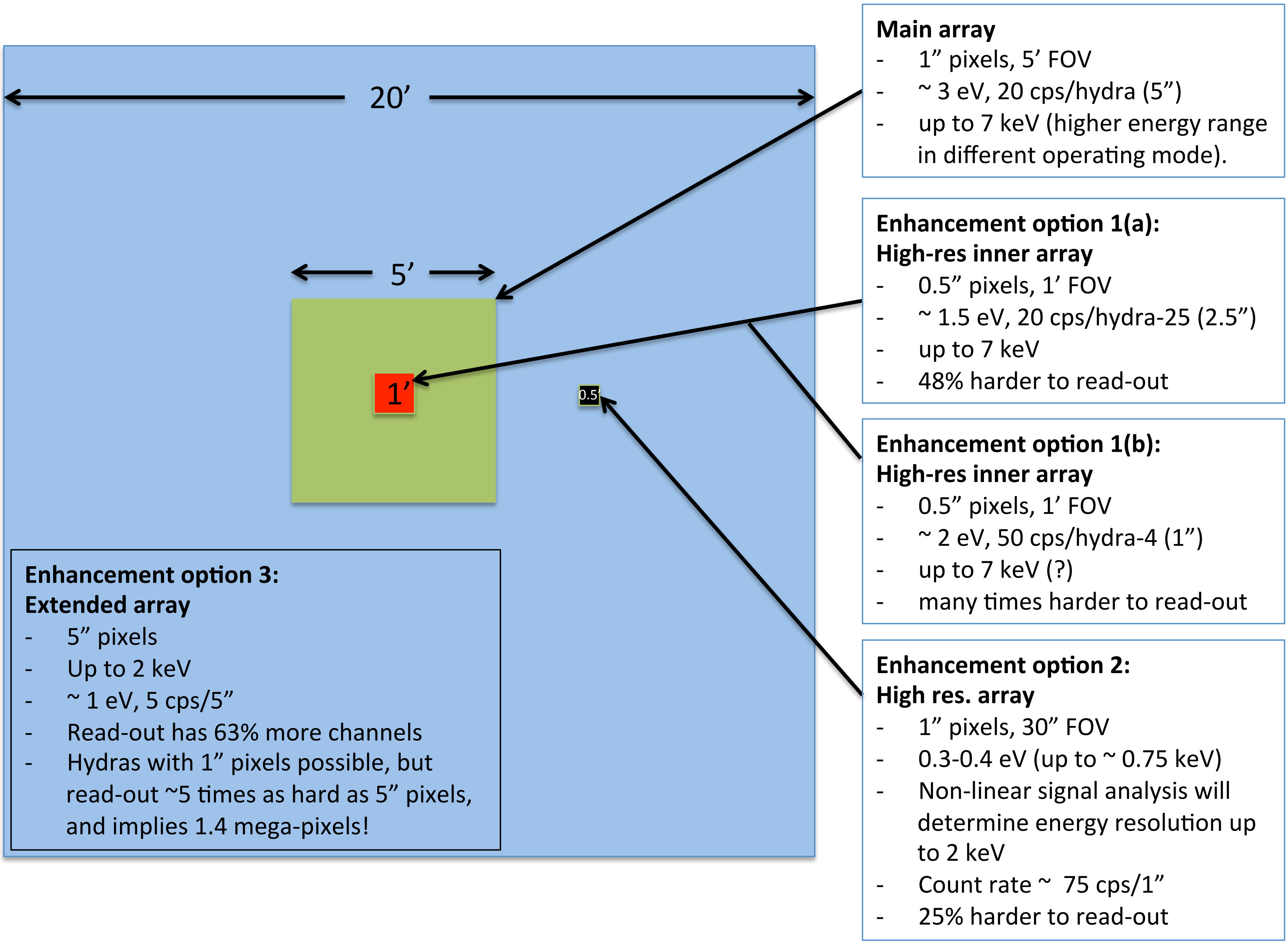
Hybrid array designs with small pixels:

Outer tier 100 μm 3x3 hydra

Inner tier 50 μm 3x3 hydra

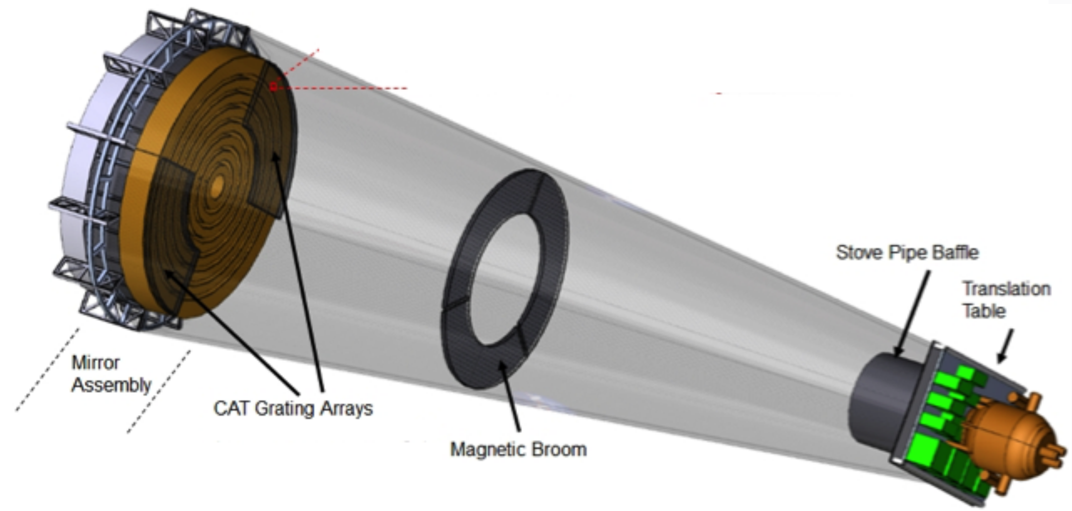
Core array 50 μm single pixel

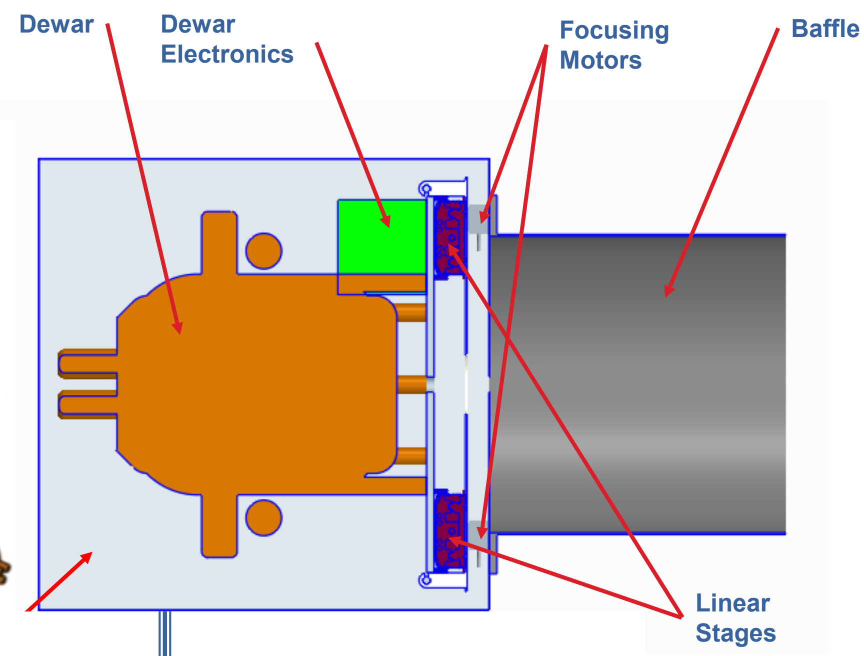


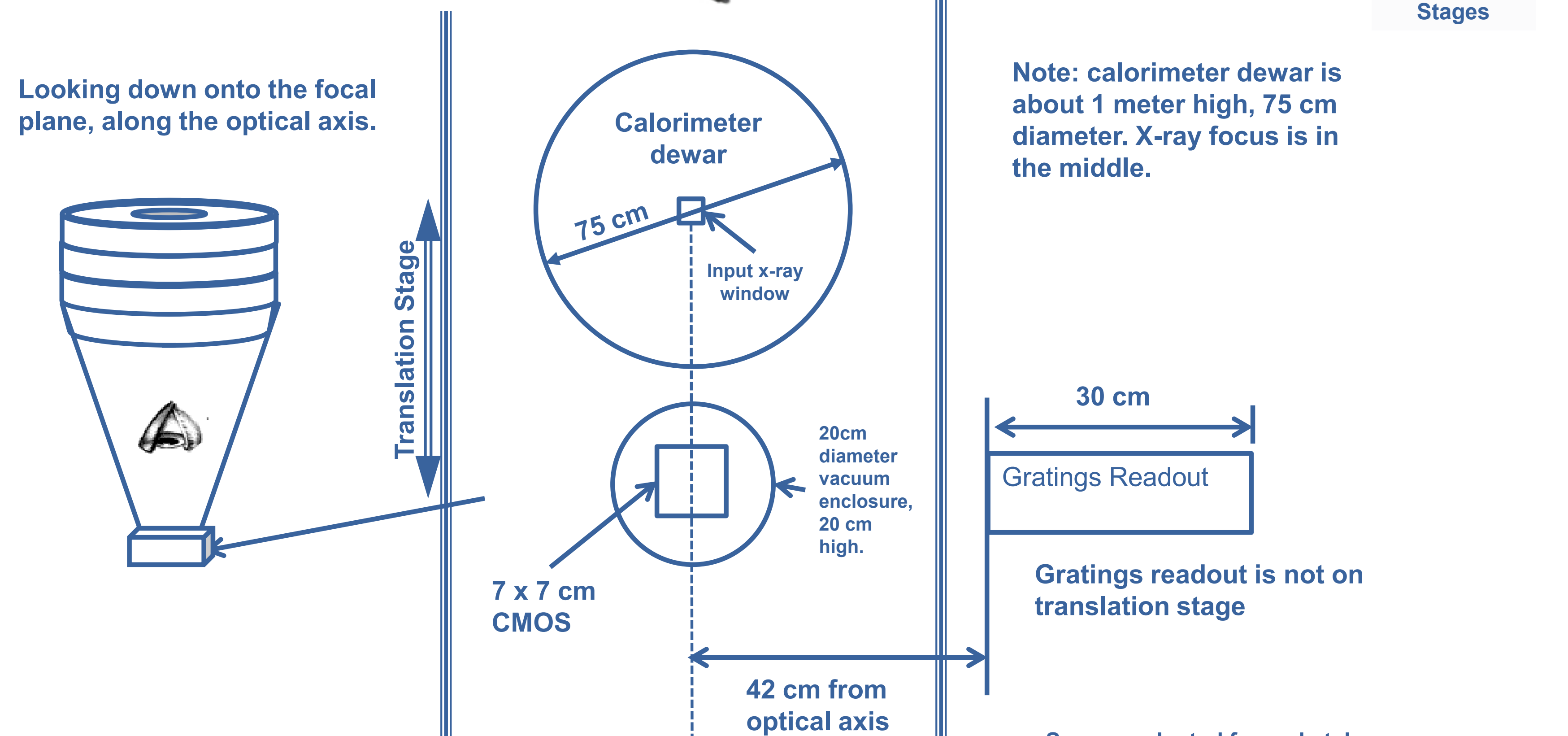


20’
5’
1’
0.5’
Main array
- 1” pixels, 5’ FOV
- ~ 3 eV, 20 cps/hydra (5”)
- up to 7 keV (higher energy range in different operating mode).
Enhancement option 1(a):
High-res inner array
- 0.5” pixels, 1’ FOV
- ~ 1.5 eV, 20 cps/hydra-25 (2.5”)
- up to 7 keV
- 48% harder to read-out
Enhancement option 1(b):
High-res inner array
- 0.5” pixels, 1’ FOV
- ~ 2 eV, 50 cps/hydra-4 (1”)
- up to 7 keV (?)
- many times harder to read-out
Enhancement option 2:
High res. array
- 1” pixels, 30” FOV
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Non-linear signal analysis will determine energy resolution up to 2 keV
- Count rate ~ 75 cps/1”
- 25% harder to read-out
Enhancement option 3:
Extended array
- 5” pixels
- Up to 2 keV
- ~ 1 eV, 5 cps/5”
- Read-out has 63% more channels
- Hydras with 1” pixels possible, but read-out ~5 times as hard as 5” pixels, and implies 1.4 mega-pixels!

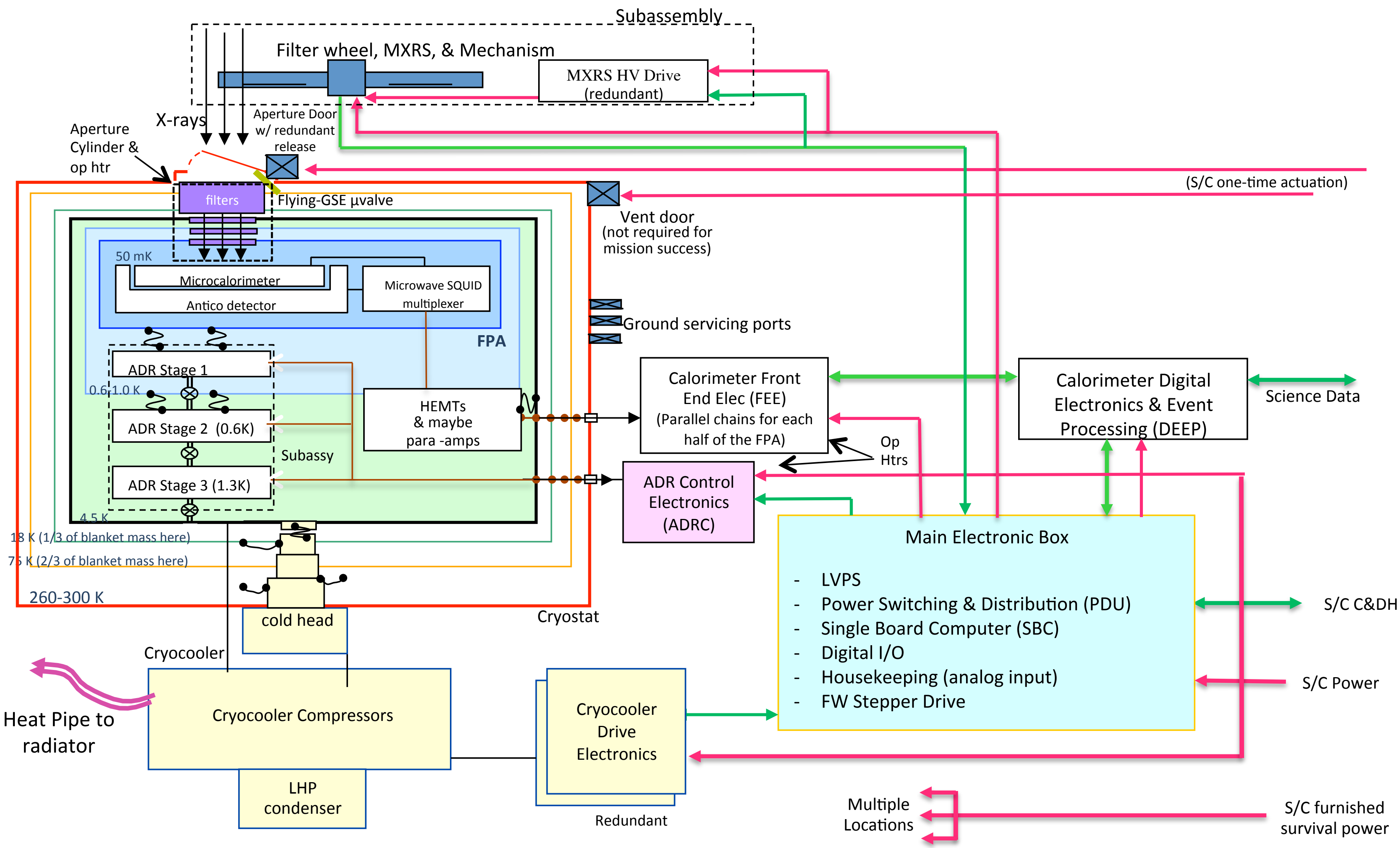
Schematic of focal plane layout:



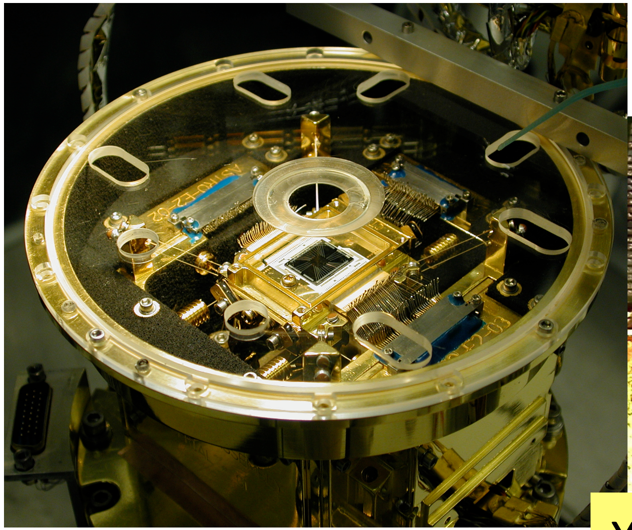


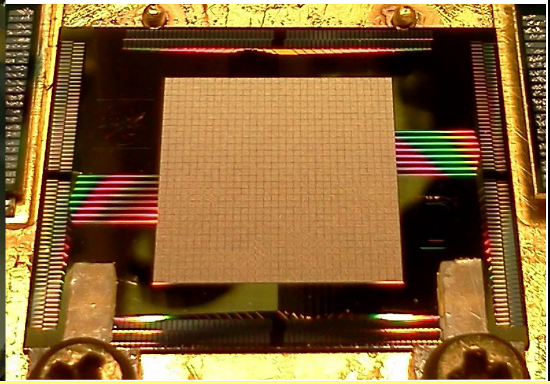


Lynx Block Diagram:

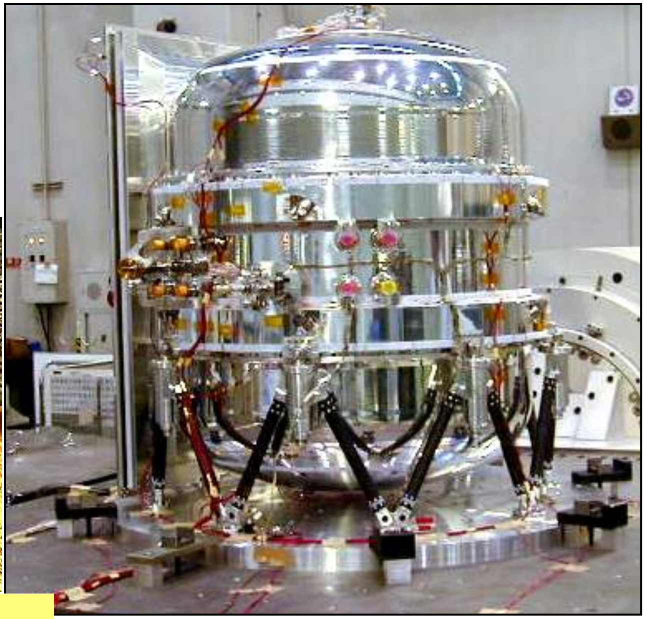


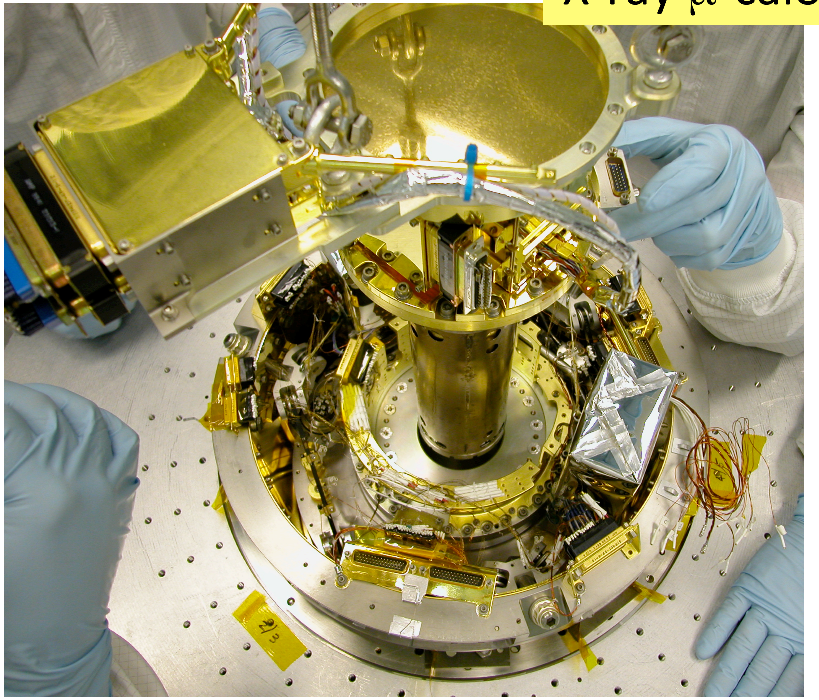
Typical X-ray Microcalorimeter Instrumentation

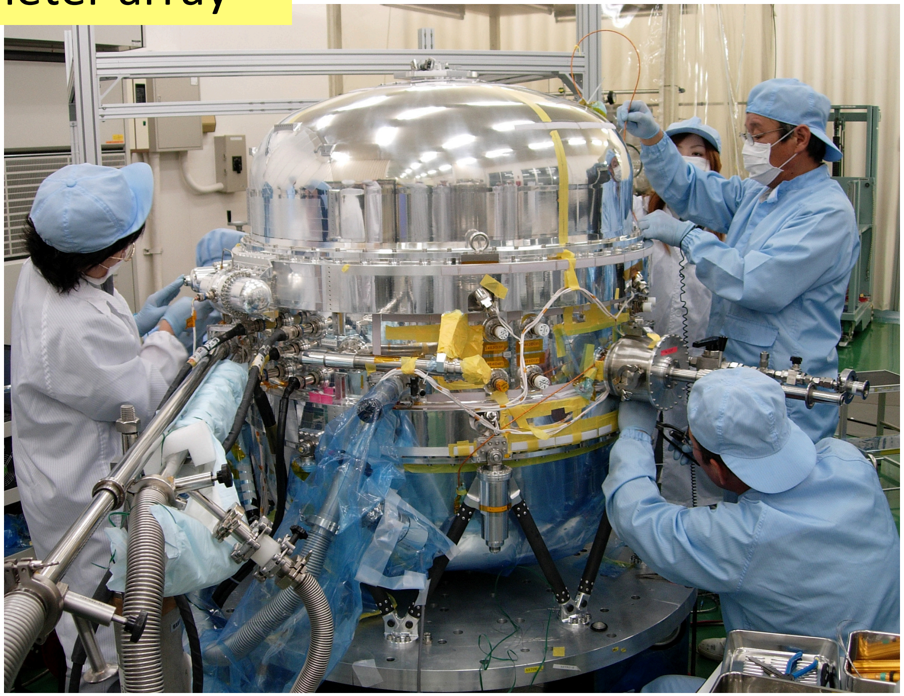




X-ray μ-calorimeter array







What are the tallest poles for making larger microcalorimeter instruments such as are desired for Lynx?

1. Development and fabrication of *read-out*

- Large number of TESs to read out within the system constraints

2. **Fabrication of arrays**

- Complexity of fabricating arrays with sufficient number of pixels, good enough energy resolution, small enough pitch, sufficient heat-sinking, and reliable wiring to amplifiers.

3. **Cryogenics**

- Accommodating heat loads from low temp. read-out & wiring – SQUIDs and HEMTs.

4. **Hydra design**

- Discrimination between pixels of X-ray events Hydras down to very low energies.

5. High throughput filters

- Many X-rays < 1 keV, where IR blocking filter transmission affected by filters.

5**. Ease of calibration.**

6. **Adequate high-yield contacts**

- Bump bonding between detector chip & low-temperature read-out.

7. **Flight qualified room temperature electronics**

- Power load/cost from large number of electronics channels - ASICs

8. **Complexity of FPA design, and integration of GHz technologies.**

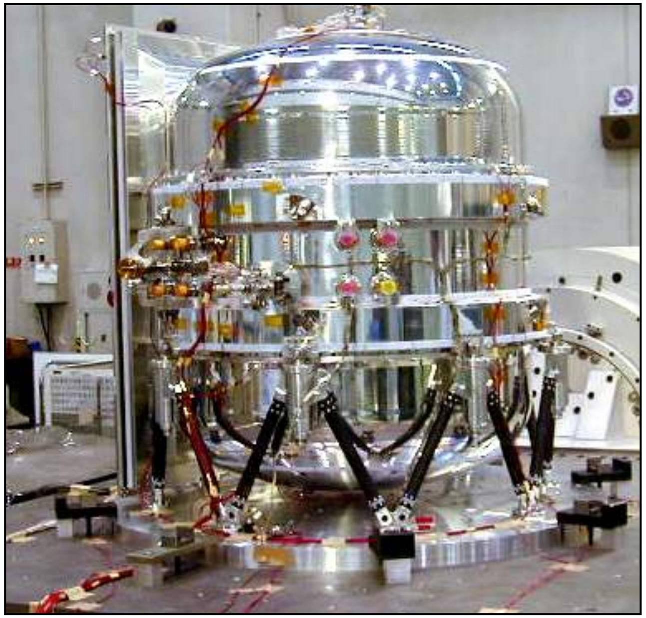
- Flex designs, coax designs, packaging, connectors

Possible Lynx CAN topics:

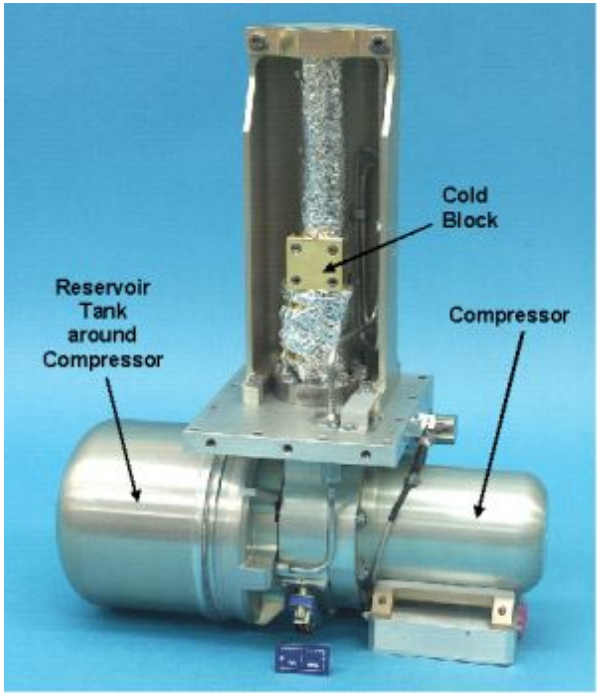
- Cryostats & Cryocoolers
- Adiabatic demagnetization refrigerators
- Technology for efficient IR/optical/UV blocking filters with maximum soft (E ~ 0.2 keV) X-ray transmission
- Low-noise, low-power High Electron Mobility Transistors
- Parametric amplifiers
- Multi-channel GHz cabling and packaging
- Application-specific integrated circuits (ASICs)

Cryostats & Cryocoolers

- Cryostats need to minimize of mass/power/cost & have high reliability.
  - Feasibility of putting gratings detector as close to on-axis as possible.
  - Could the edge of gratings read-out be ~ 42 cm from central optical axis?



- Cryocoolers:
  - How much redundancy is required?
  - How much does redundancy add to reliability?
  - If more than one, how many required in to continue operation if one fails?
  - Cooling power likely needed ~ 10-40 mW at ~ 4K (TBR)



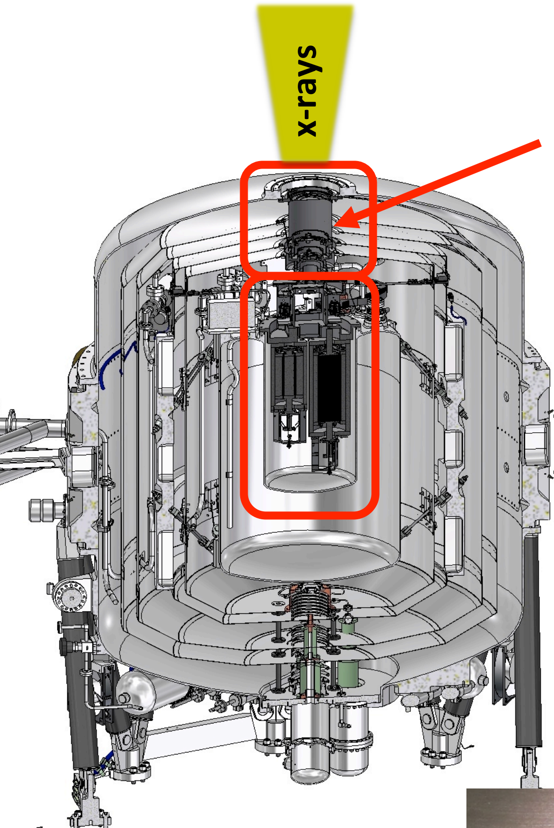
Adiabatic Demagnetization Refrigerators - ADR's

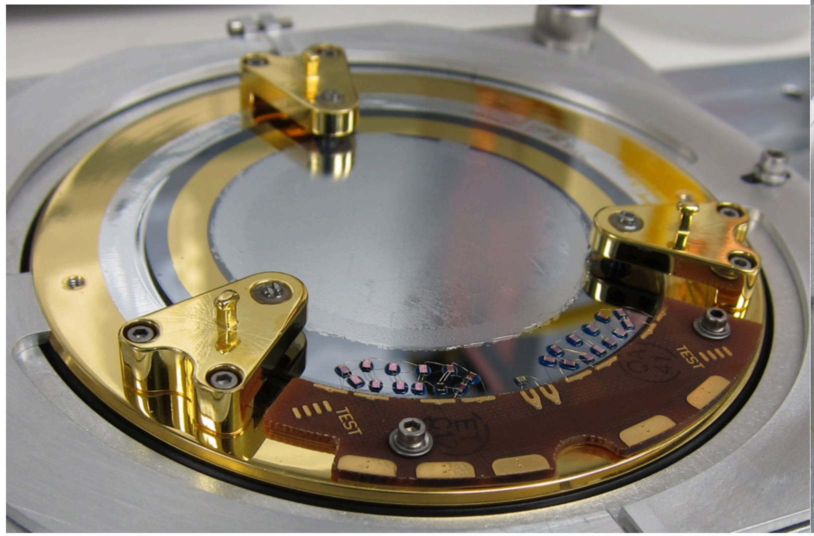
- Continuous ADRs needed capable of ~ 5 uW of cooling at 50 mK, with next heat-sink at 300 mK-2K.

  => 2.5 uW available of cooling power at 50 mK

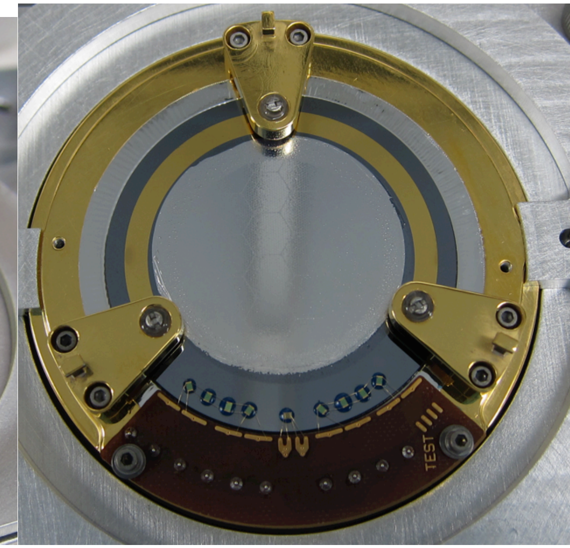
IR/UV/Optical blocking Filters – would like much better than Astro-H!

Astro-H SXS Dewar optical blocking filters

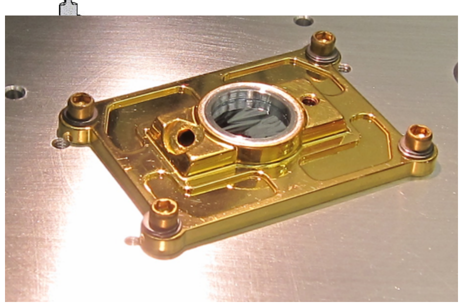




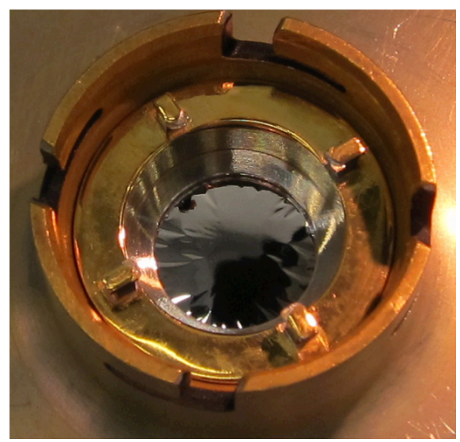
DMS filter



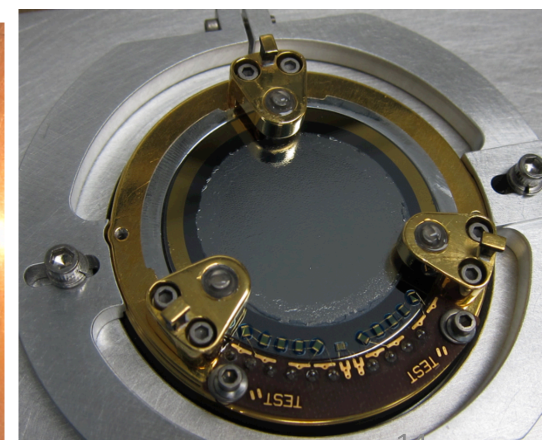
OVCS filter



CTS filter

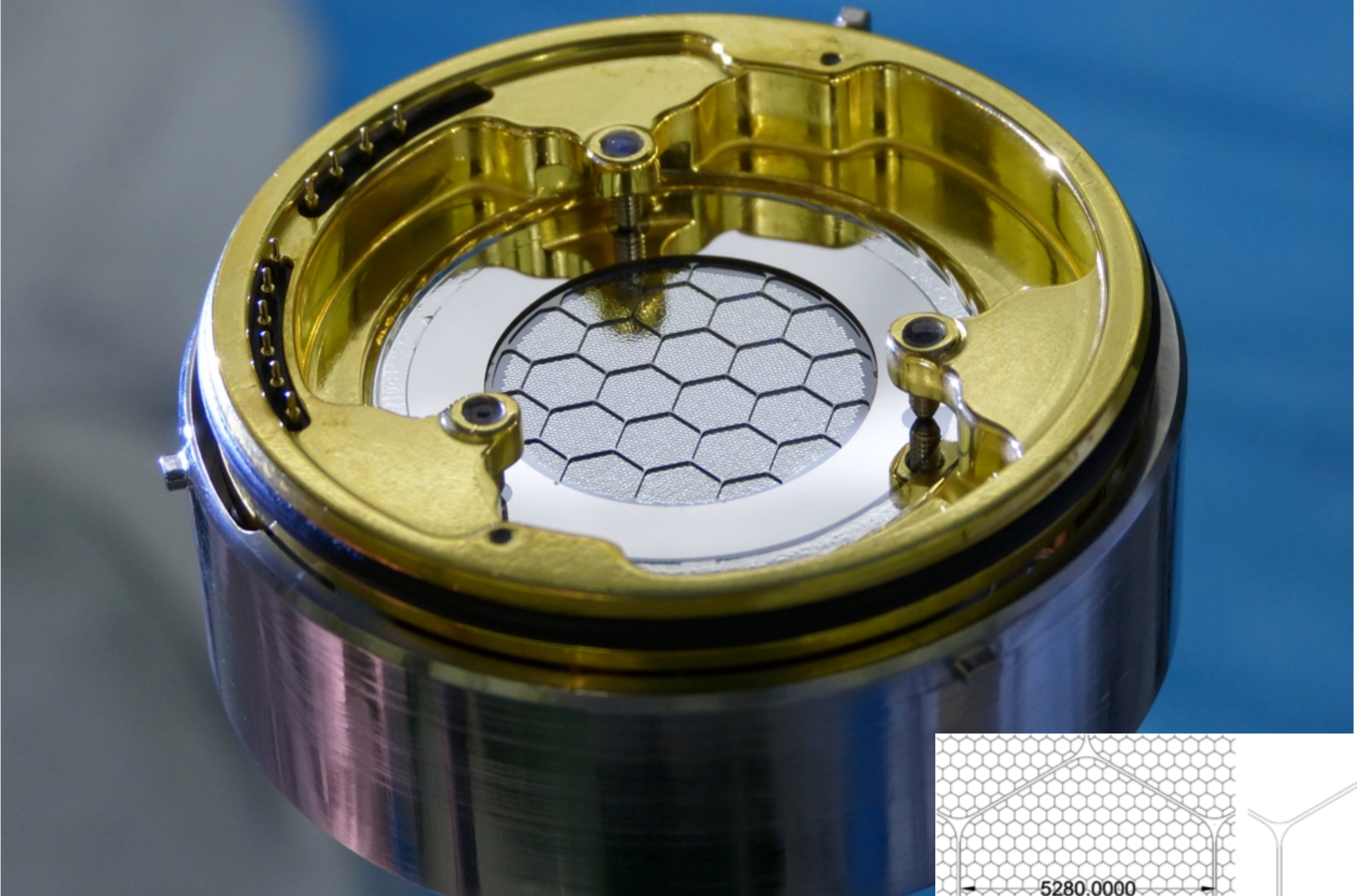


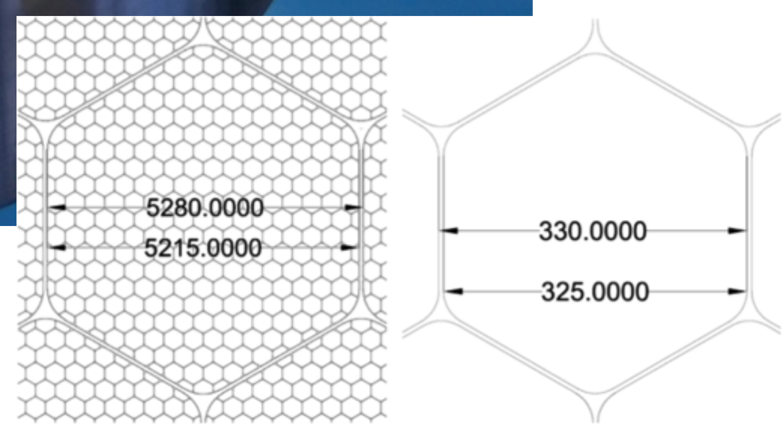
DA Lid filter



IVCS filter

Si filter mesh filters needed





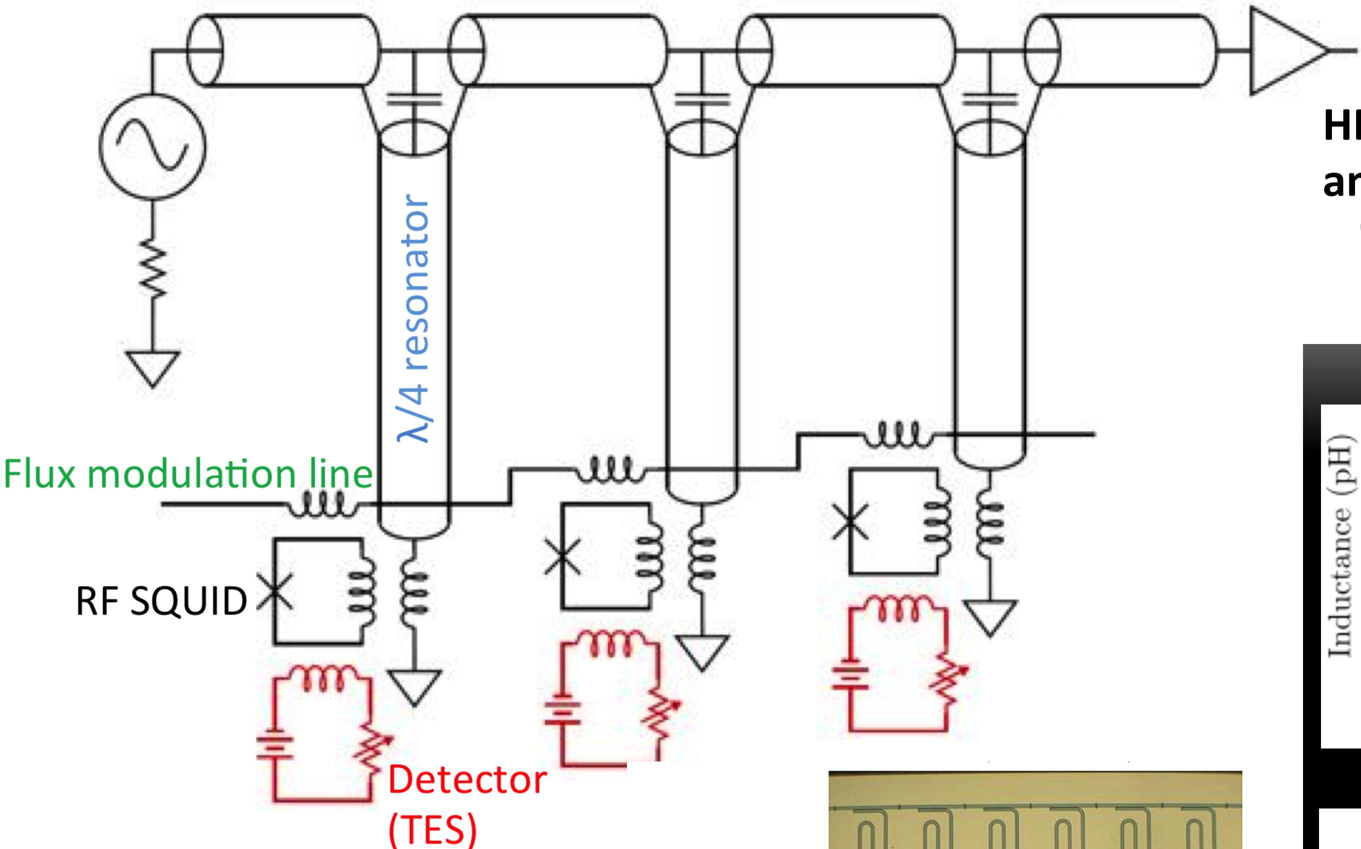
Need to try to develop thinner filters to increase soft-band x-ray transmission

- Astro-H SXS:
  - 5 filters, 385 Al / 488 poly, 3 Si meshes
- XQC Sounding Rocket:
  - 6 filters, 120 Al / 270 poly, 4 meshes
- Athena XIFU (baseline):
  - 5 filters, 150 Al / 225 poly, 5 meshes

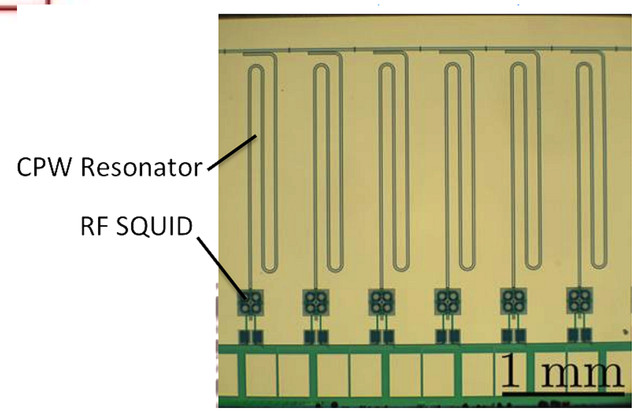
- Lynx?
  - Large diameter – arrays could be 6 cm x 6 cm!
  - Each filter ~10nm Al / 20 nm poly. Limited by ~few nm-thick oxide on filters; challenge fabrication experts to inhibit oxidation so we can use thinner Al.
  - 5 or more filters, 50nm Al / 100 nm poly
  - Use Al meshes ?
  - Waveguide Cutoff Filters
    - 3-to-1 ratio explored at GSFC
    - ½-to-1 ratio explored at U Wisconsin
    - Easier for low T, but 300K radiation is difficult

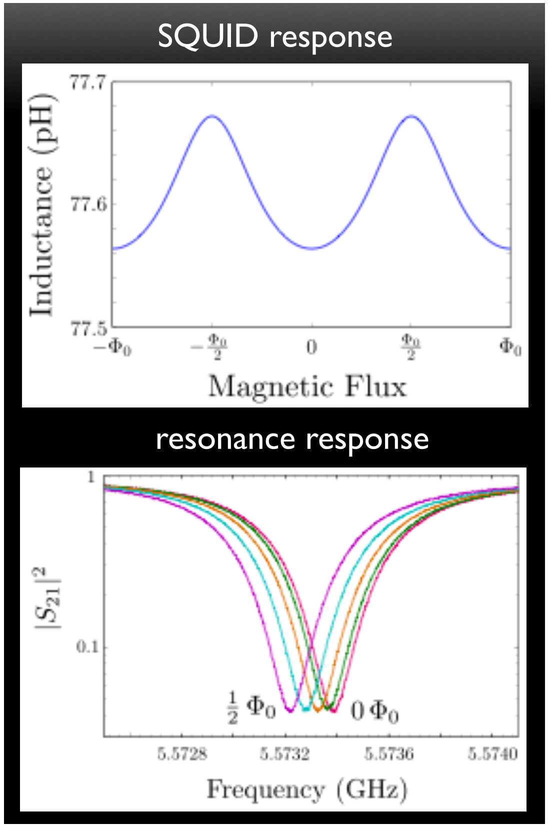
- Low-Temperature FW with baffling?
  - At 1–4K stage, use stepper motor with superconducting leads
  - Would need >15cm diameter clearance for FW, since filter diameter would need to be ~6 cm diameter

Read-out - Microwave (GHz) SQUID Resonators



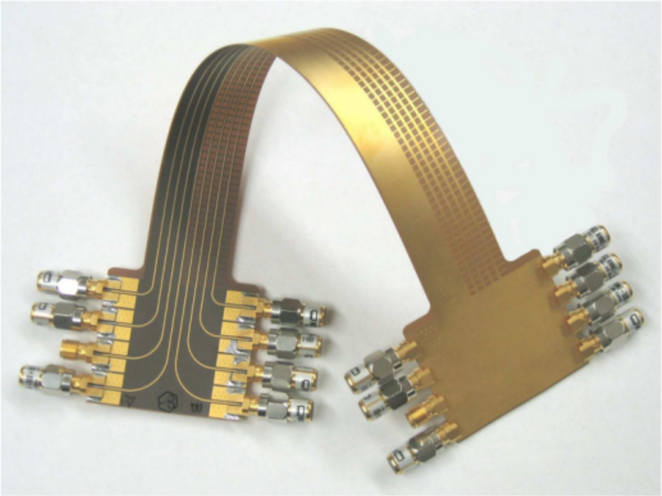
HEMT amplifier
(High-electron-mobility transistor)





RF flex circuit cabling for Lynx

<u>Goal:</u> **High-density, low-loss, low thermal conductivity RF lines**



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Superconducting flex circuits offer path to density and thermal requirements

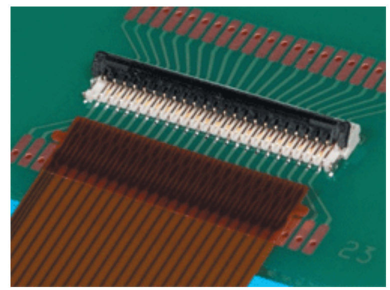
High-frequency connectorized transmission flex

- Goal: Flexible 4-8 GHz transmission lines that connects 50 mK TES to 2-4 K HEMTs
- Typically use semi-rigid miniature superconducting coax cables with SMA connectors → limits number of read-out channels
- Must limit heat inflow into the 50 mK detector to a few microwatts

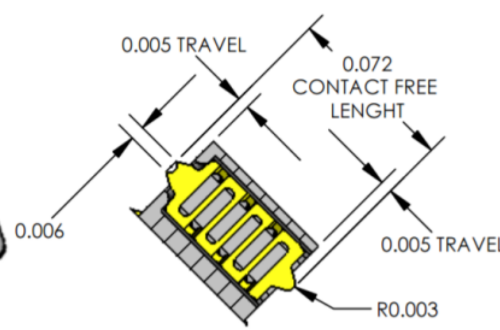
Technology	Heat load per conductor (nW)		
	4 K to .6 K	2 K to .6 K	.6 K to .05 K
.085 NbTi coax	7600	950	30
.047 NbTi coax	2100	270	8.5
PhBr microstrip	630	150	15
SnPb-plated PhBr microstrip	≤6000	≤500	≤30
NbTi microstrip	180	28	1.8
Ti6Al4V microstrip	140	38	2.0

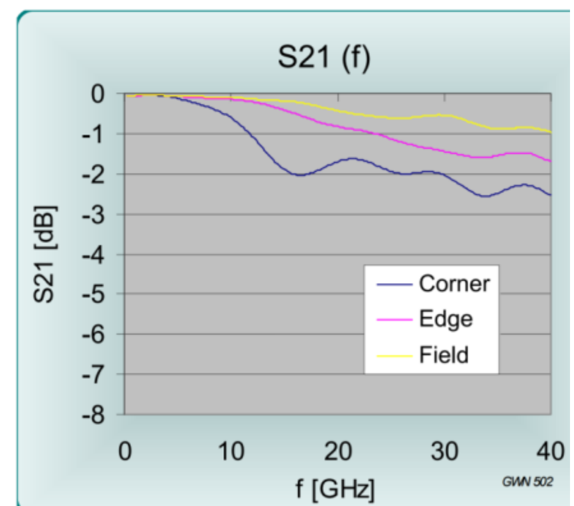
RF connectorization

- Low temperature operation needed
- High density needed
- Rugged
- Integrated with multiple coaxial wwires/flex

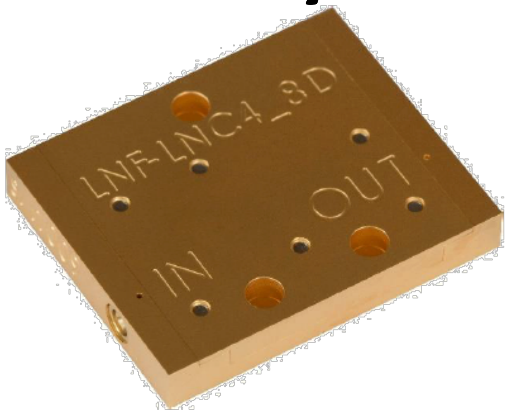


- Spring contacts?
- Integrated with flexes?





HEMTs for Lynx



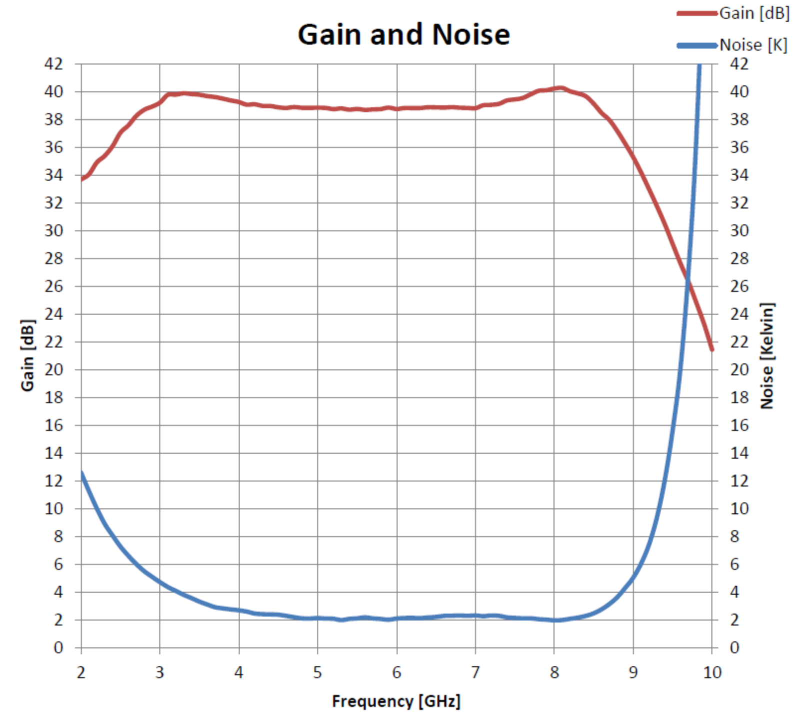
Commercial HEMTs sufficient for many applications

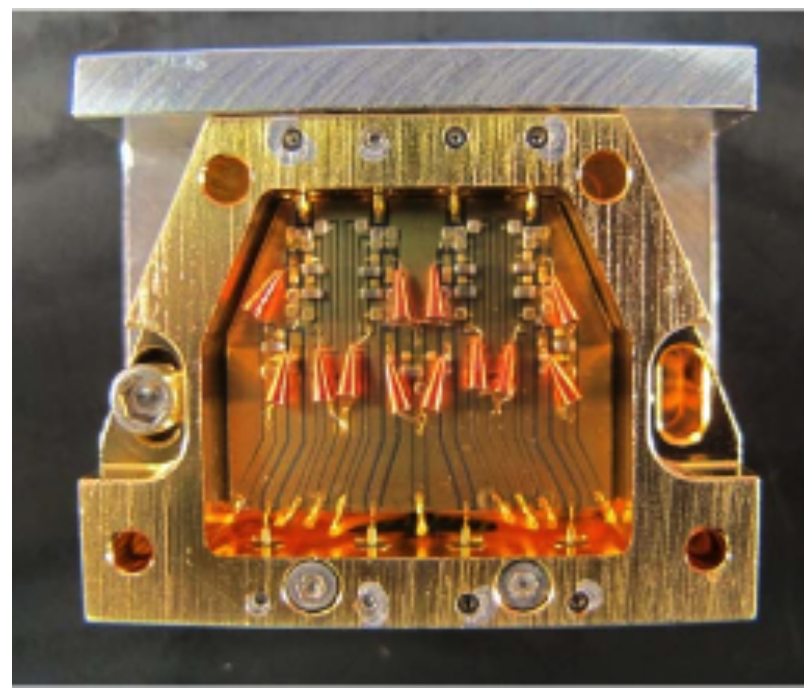
Example: Low Noise Factory HEMT

- Compact (25 x 21 x 3.5 mm) and stackable
- Noise temperature < 2 K
- 40 dB gain over 4-8 GHz
- 4 mW power dissipation
- 3 stages at 4 K
- Can make lower power HEMTs?
- Different stages at different temps?

Packages is multiple HEMTs desirable

- Example of 4 K module with multiple HEMTs shown right.
- Very low power **Parametric Amplifiers** suitable for typical microwave SQUID powers also an option.





ASICs for Lynx

- Need rad-hard, high-performance, low-power ASICs to read out large array of GHz HEMTs
- Including DACs, ADCs, FPGAs
- What will be available 10 years from now?
- Need to estimate performance/cost/power etc.