X-ray Microcalorimeter Spectrometer (XMS)

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on behalf of the XMS team

IXO Science Meeting in Otaru, July 3, 2009

XMS team

All main organizations developing TES μ calorimeters

NASA/GSFC
NIST
MIT
.....

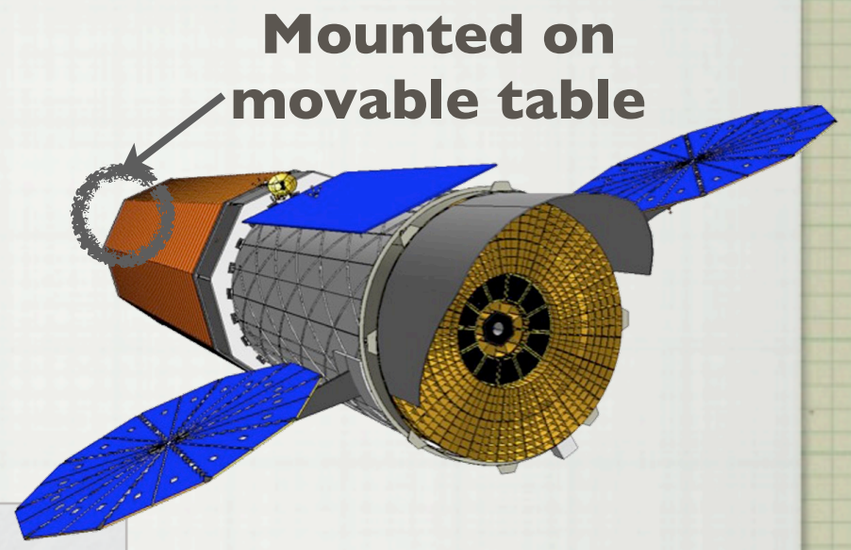
SRON
INAF/IASF
INFN/Genova
.....

JAXA
TMU
Kanazawa
Saitama
.....

Kick-off meeting at NASA/GSFC on January 12-14, 2009

XMS

- **High-energy-resolution imaging spectroscopy with a limited filed of view**

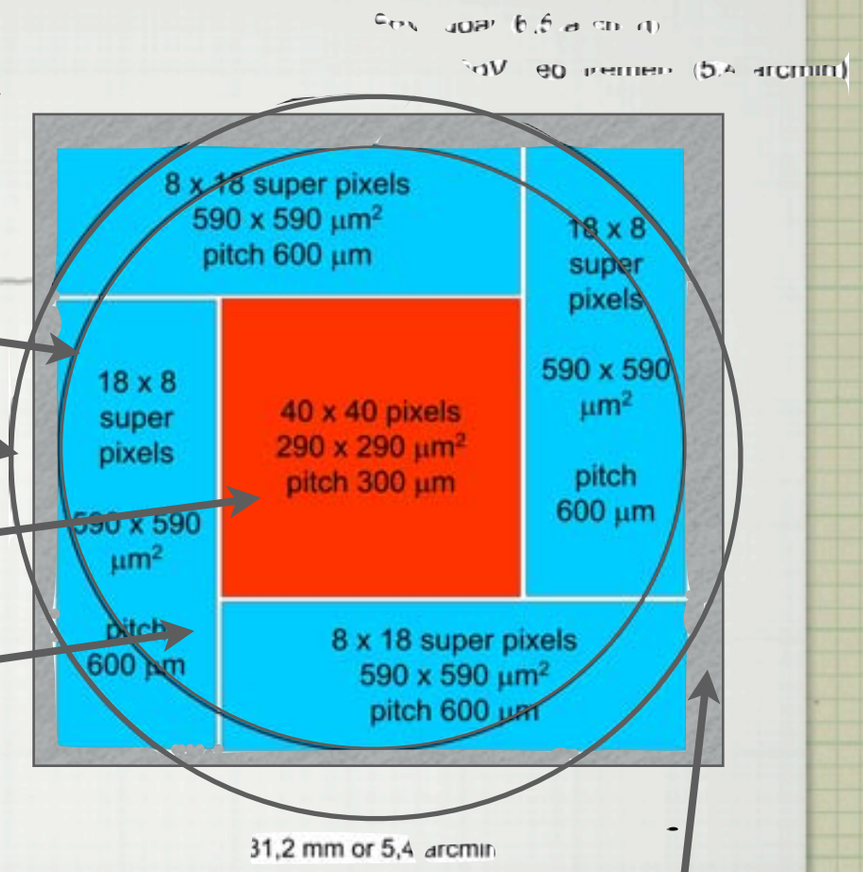


XMS requirements

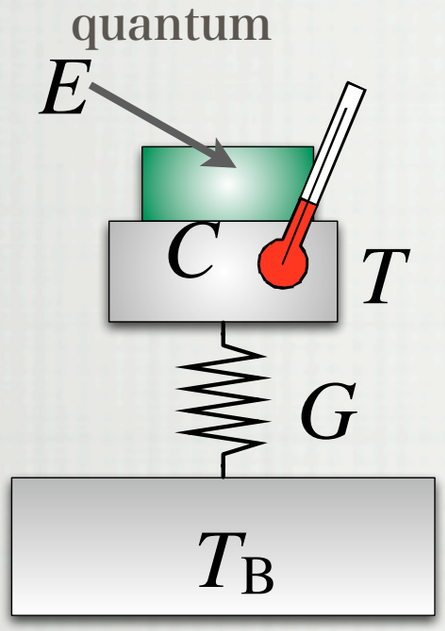
FOV	5’ (29mm)	Full array	
Pixel size	3” (300μm)	Central 2’ pixels	
	6” (600μm)	Outer pixels	
Energy range	0.3 - 10 keV		
Energy resolution	2.5 eV	Central 2’ pixels	
	10 eV	Outer pixels	() for 20 m focal length
Counting rate	2×10^4 c/s	max. good event	500 c/s for 4 mCrab

XMS detector

- TES μ calorimeter arrays
  - 40x40 central core pixels
  - (18x8) x4 outer 'super pixels'
- Signal multiplexing of 2176 pixels(!!) to 70 ch at cryogenic temperature
  - Time Division Multiplexing (TDM),
  - Frequency Division Multiplexing (FDM), or
  - Code Division Multiplexing
- Anti-coincidence fast and large-area TES μ calorimeter, back of the X-ray TES arrays.
- Both X-ray and anti-co detectors will be operated at a cryogenic temperature of 50mK



μ calorimeters

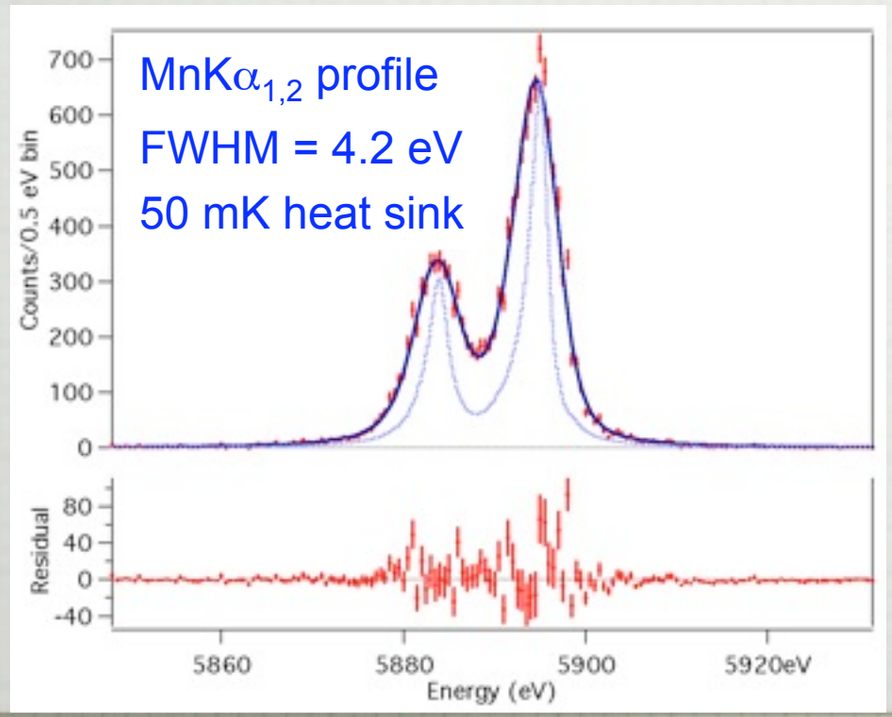


- **High energy resolution when operated at a cryogenic temperature < 100 mK**

$$\Delta E = 2.35\xi\sqrt{k_{\mathrm{B}}T^2C} \qquad \xi \sim 1$$

An X-ray absorber of a few 100μm□ with 10μm thickness → $C \sim 1\mathrm{pJ/K@100mK}$

$$\Rightarrow FWHM = 5.4\xi \ \mathrm{eV}$$



"Proto-type" detector for Astro-H

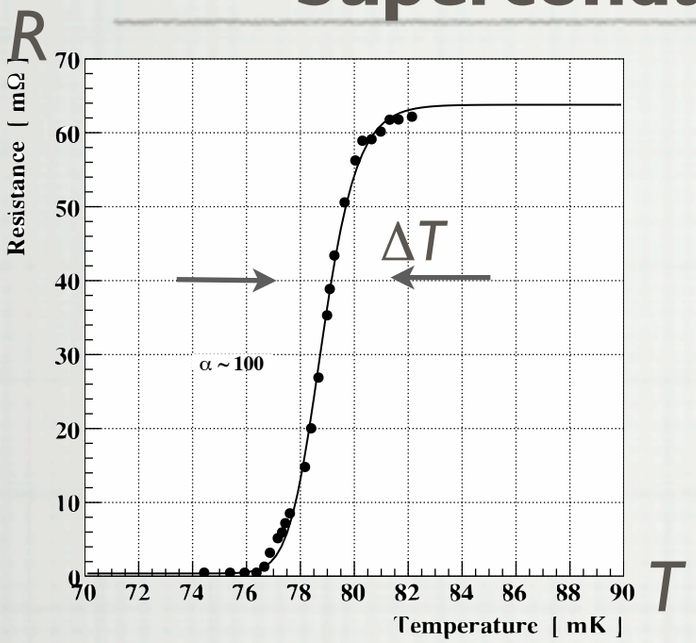
State-of-art semiconductor thermometer μ calorimeter

Doped Si thermometer
Operated at 50 mK
Absorber size 790 × 790 × 6 μm

Kelley+ 2008

TES μ calorimeter

"Superconducting phase transition" as thermometer



$$\alpha \equiv \frac{\mathrm{d}\log R}{\mathrm{d}\log T} \sim 100$$

- **Higher energy resolution (limited by TES saturation)**

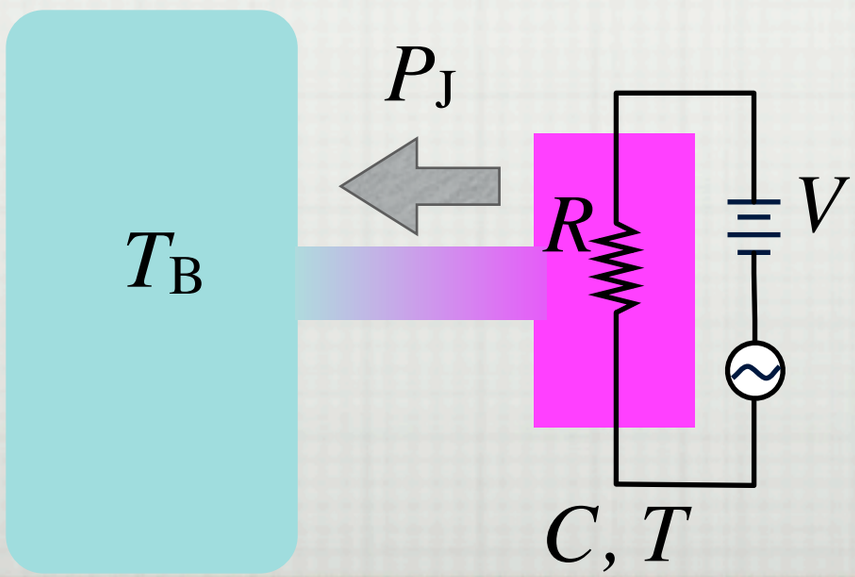
$$\Delta E \sim 2.35\xi\sqrt{k_{\mathrm{B}}T E_{\mathrm{sat}}} \quad \text{where} \quad \frac{CT}{\alpha} \sim C\Delta T \approx E_{\mathrm{sat}}$$

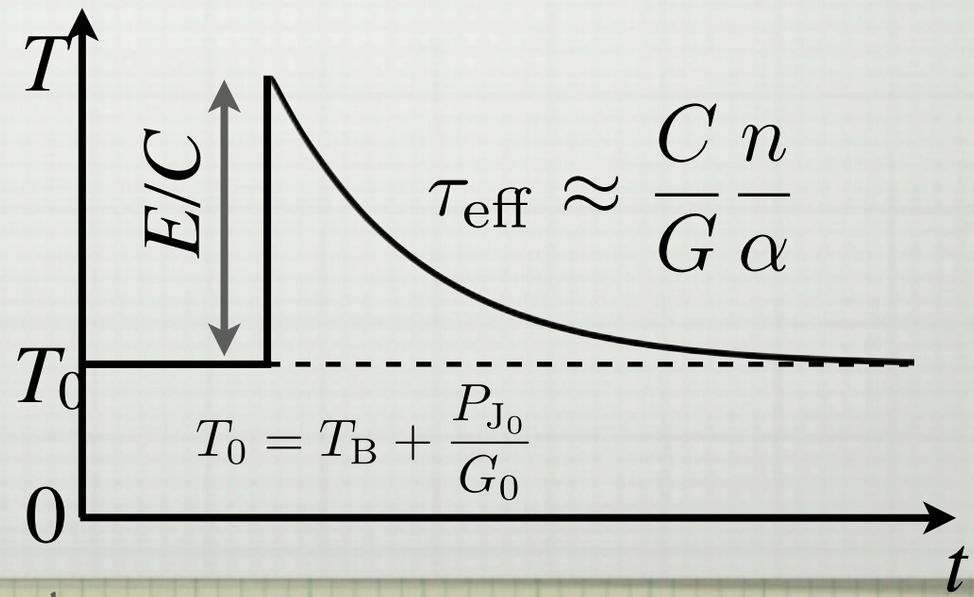
- **Fast response of ~ 100 μs** → Higher counting rate
- **Possibility of signal multiplexing**

$$\Delta f_{\mathrm{signal}} << \Delta f_{\mathrm{readout}}$$

a few kHz **SQUID > MHz**

Strong electro-thermal feedback





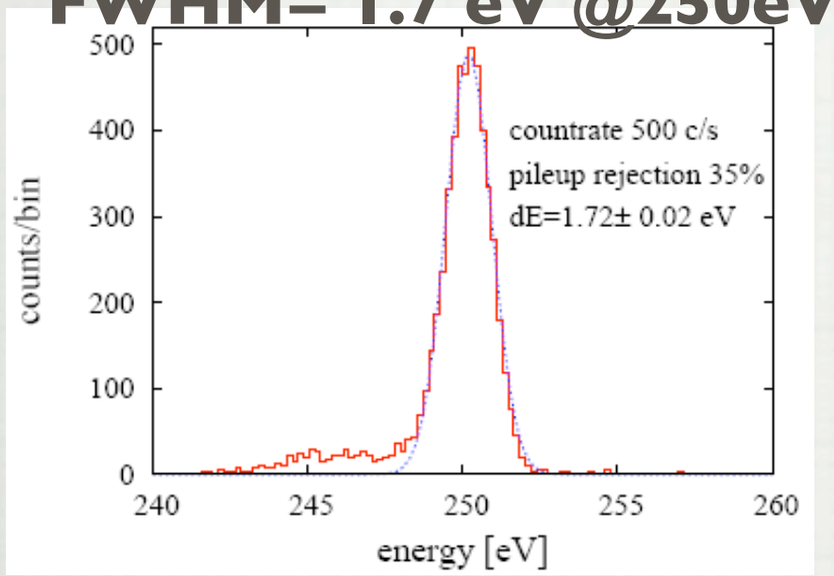
State-of-art TES μ calorimeters

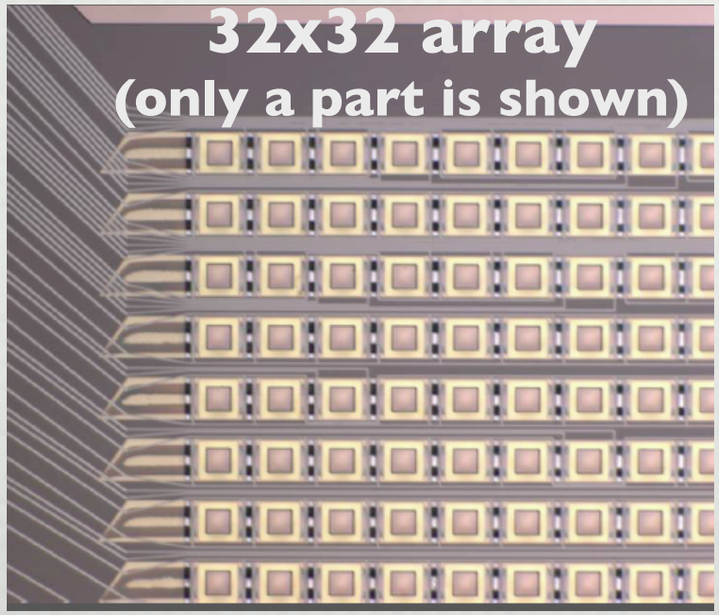
	NASA	NIST	SRON	JAXA-TMU
FWHM @5.9keV	1.8 eV	2.4 eV	2.5 eV	2.8 eV
TES	Mo/Au	Mo/Cu	Ti/Au	Ti/Au
Absorber	6μm(Bi) +0.7μm(Au)	1.5μm (Bi)	2.7μm(Bi) +0.3μm(Cu)	1.5μm (Au)
	240μm	240μm	100μm	120μm

TES μ development at SRON and in the US

SRON

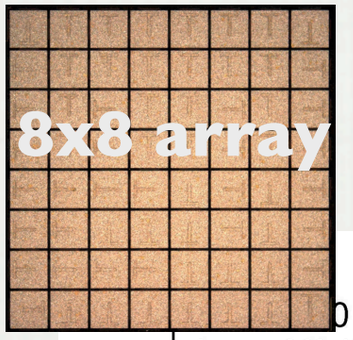
FWHM= 1.7 eV @250eV





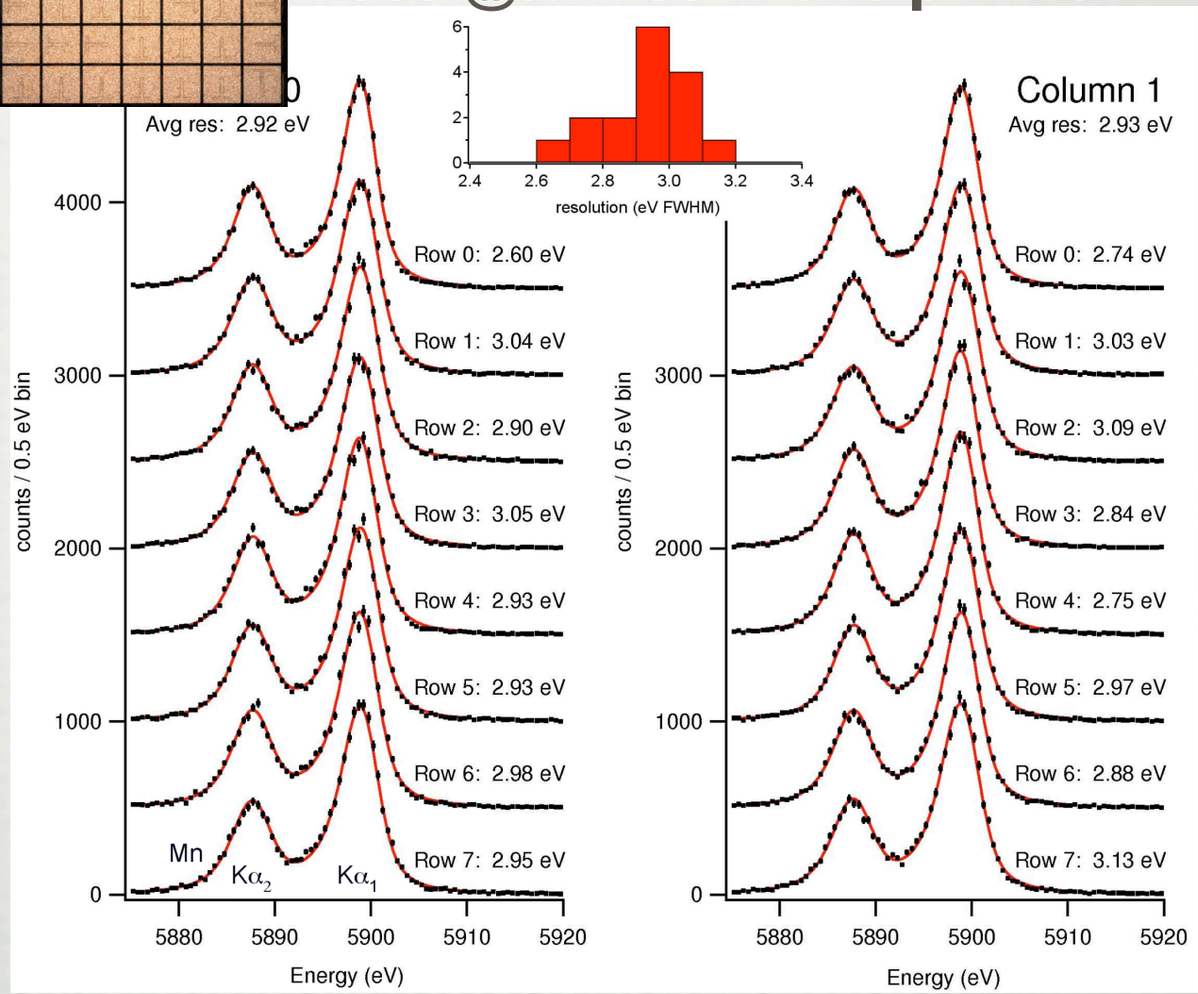
de Korte+2009

NASA/GSFC + NIST



2x8 TDM MUX

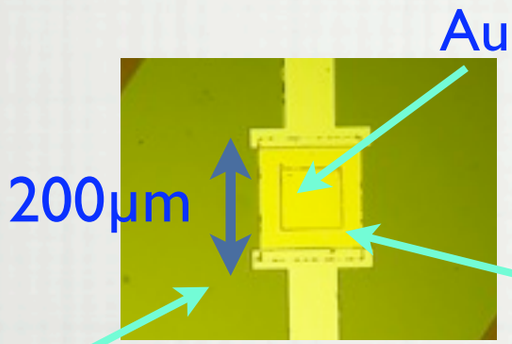
3eV @5.9 keV with 8 pix MUX

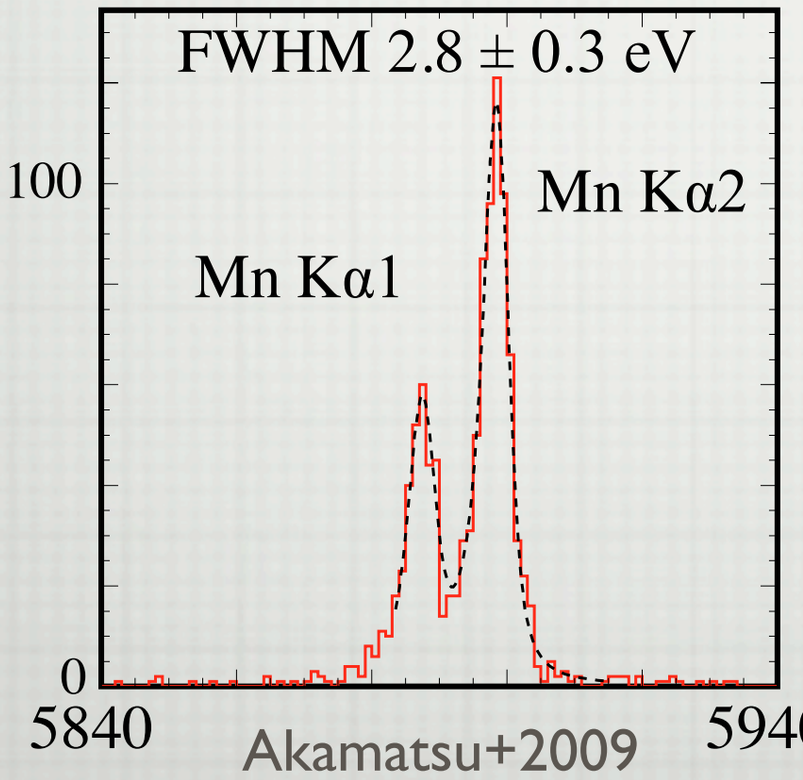


Kilbourne+2009

TES μ calorimeter development in Japan (1)

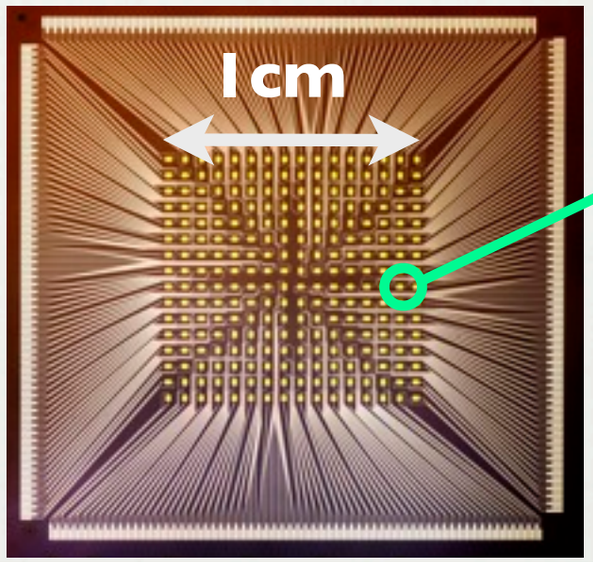
single pixel device

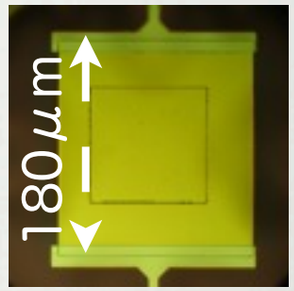


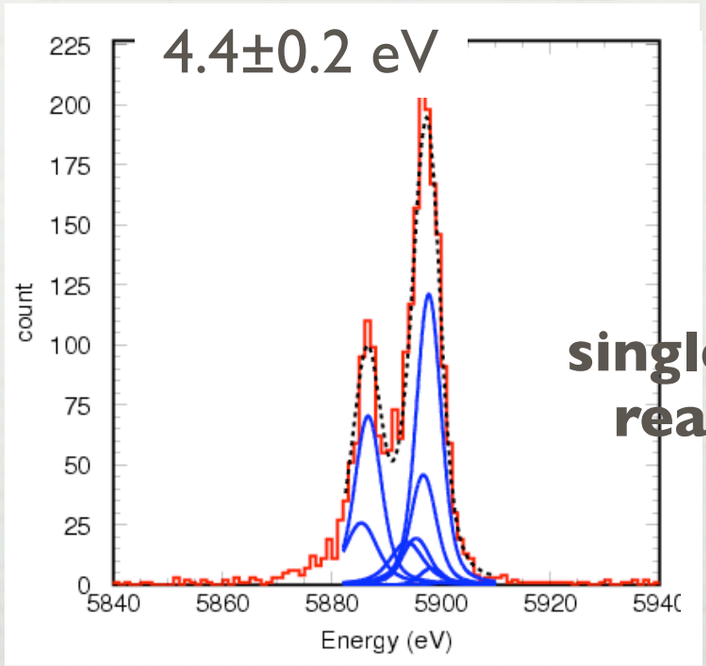


Akamatsu+2009

array device



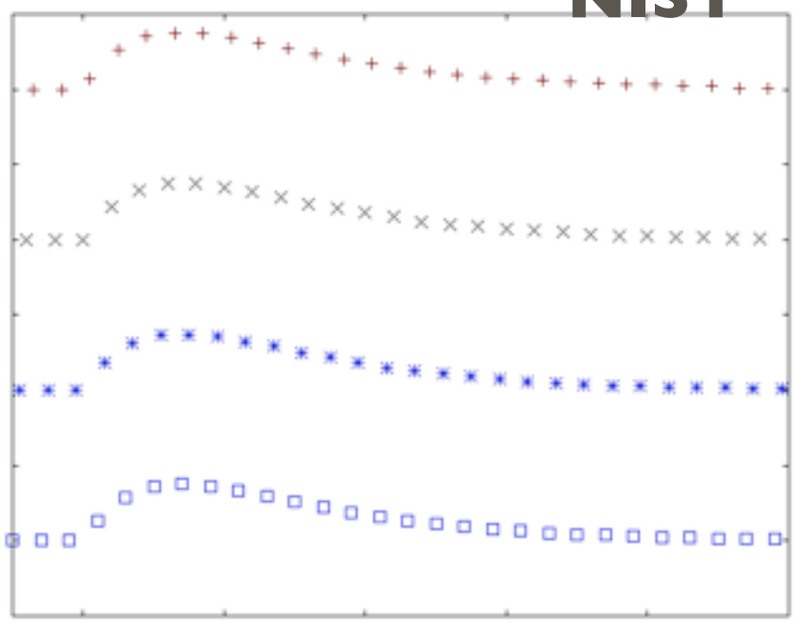
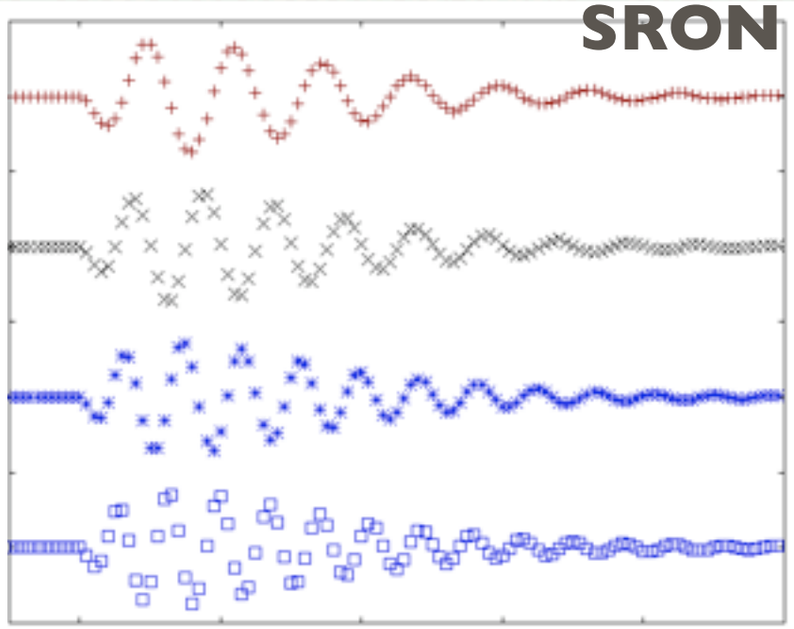
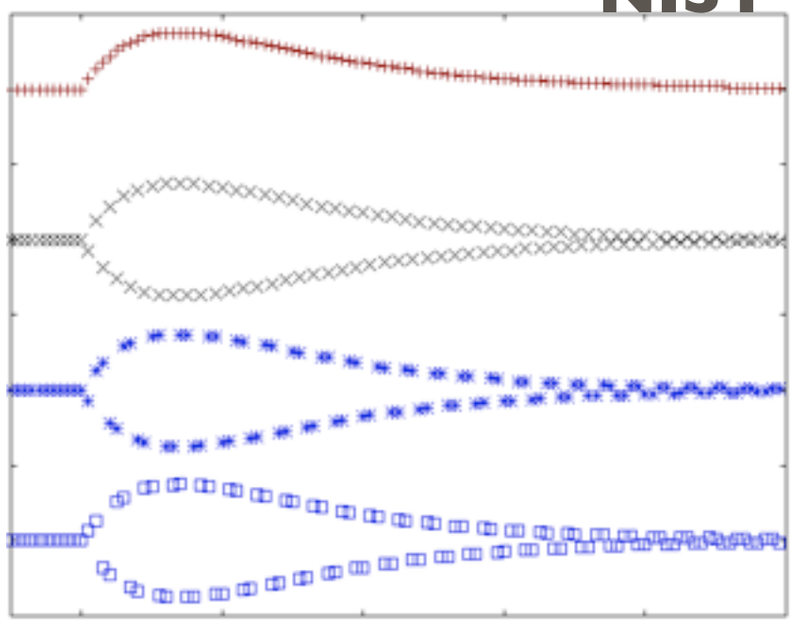




single pixel readout

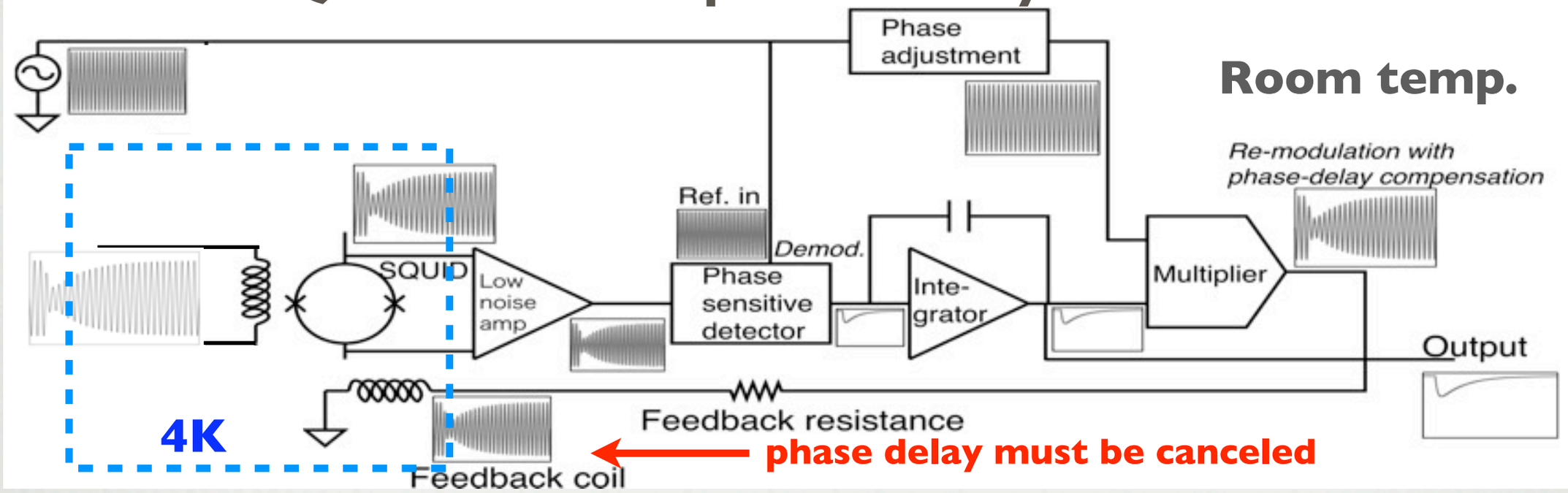
Ezoe+2009

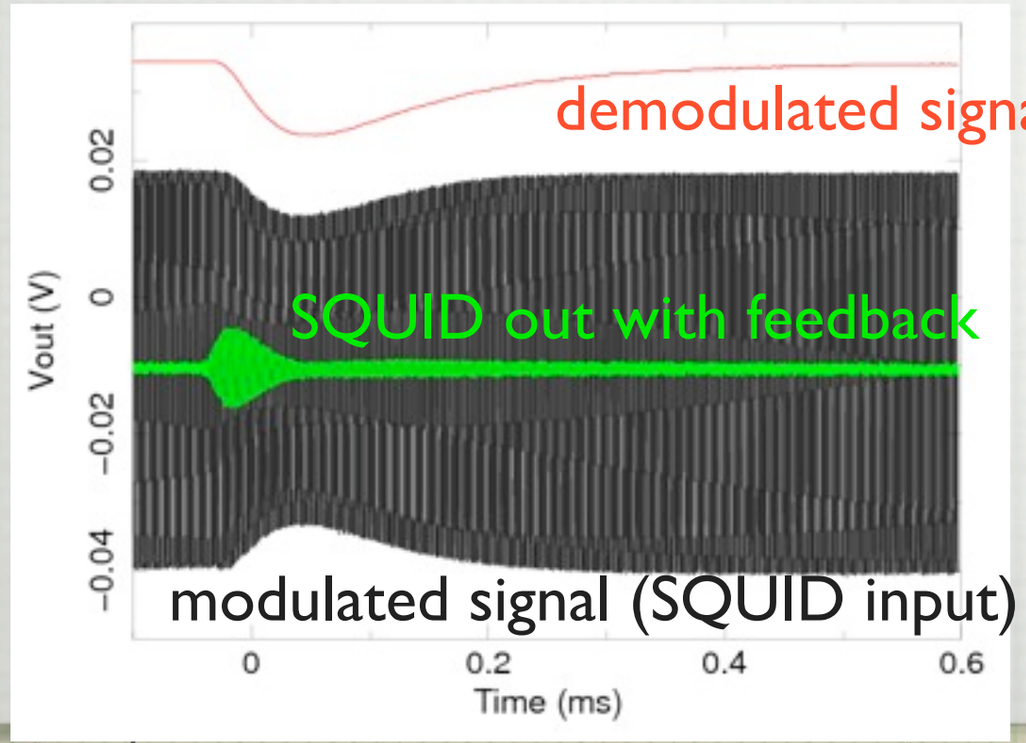
Signal multiplexing

Time Division MUX (TDM)	Frequency Division MUX (FDM)	Code Division MUX (CDM)
NIST	JAXA SRON	NIST
		
Pros • 8 MUX demonstrated • TES bias not modulated	• 1 SQUID/column • No SQUID noise aliasing	• No SQUID noise aliasing • TES bias not modulated • 1 SQUID/column
Cons • *N* SQUID/column • $\sqrt{N}$ SQUID noise aliasing	• TES bias modulated • LC-filter necessary • A few MUX at present	• New • Possible code / pulse-shape mixing

TES μ calorimeter development in Japan (2)

SQUID fluxed-loop feedback system for FDM





- ☑ Carrier frequency up to 5MHz
- ☑ Signal bandwidth of 10 kHz
- ☑ Low noise level of < 30 pA/√Hz

In principle, signals from 50 TES pixels can be multiplexed to a single channel.

Takei+2009

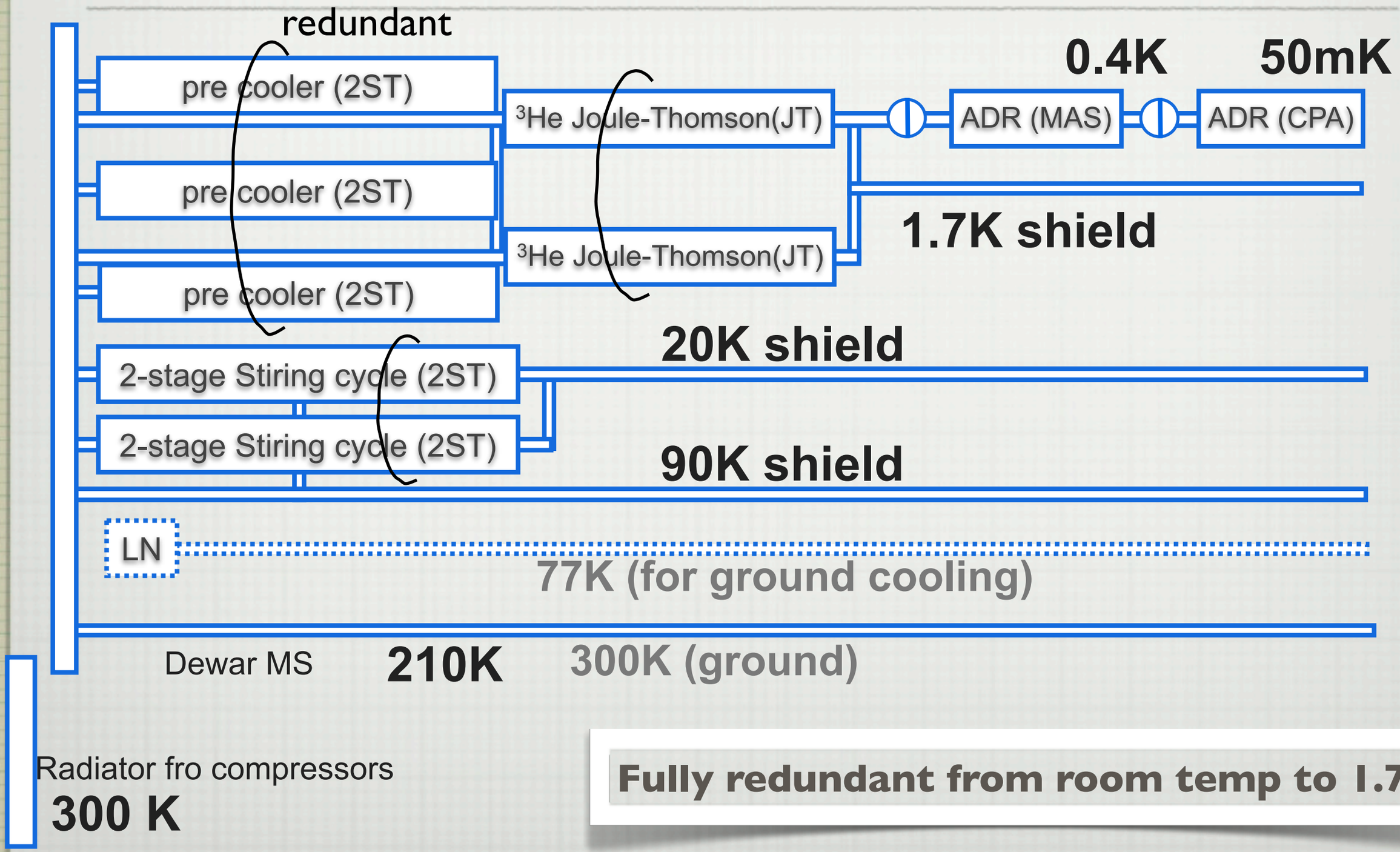
Cooling system

- **Interface temperature to detector: 45 mK**
- **Lifetime: 5 years (requirement), 10 years (goal)**
- **Four different cryogen-free cooling systems are understudy by JAXA, ESA, and NASA**

	JAXA	ESA		NASA
Based on	Astro-H	Planck+Hershel		JWST
Last stage cooler (LSC)	dADR	Sorption + ADR	dADR	5-stage cADR
LST heat sink temperature	1.7 K	2.5 K	4K	6K
Pre-coolers	^{3}He JT+2ST	^{3}He JT +2ST	^{4}He JT+ +2ST	^{4}He JT+2PT

JT=Joule-Thomson, 2ST=double stage Stirling-cycle, 2PT=double-stage pulse tube

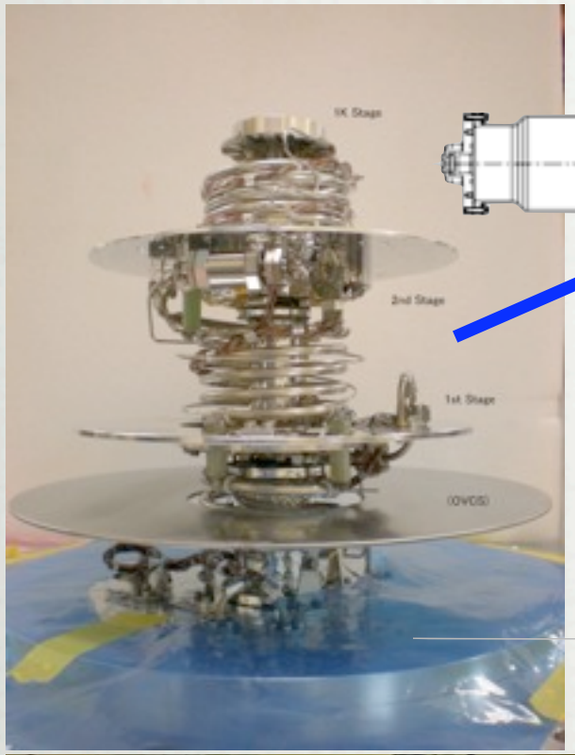
Cooling Chain of JAXA design



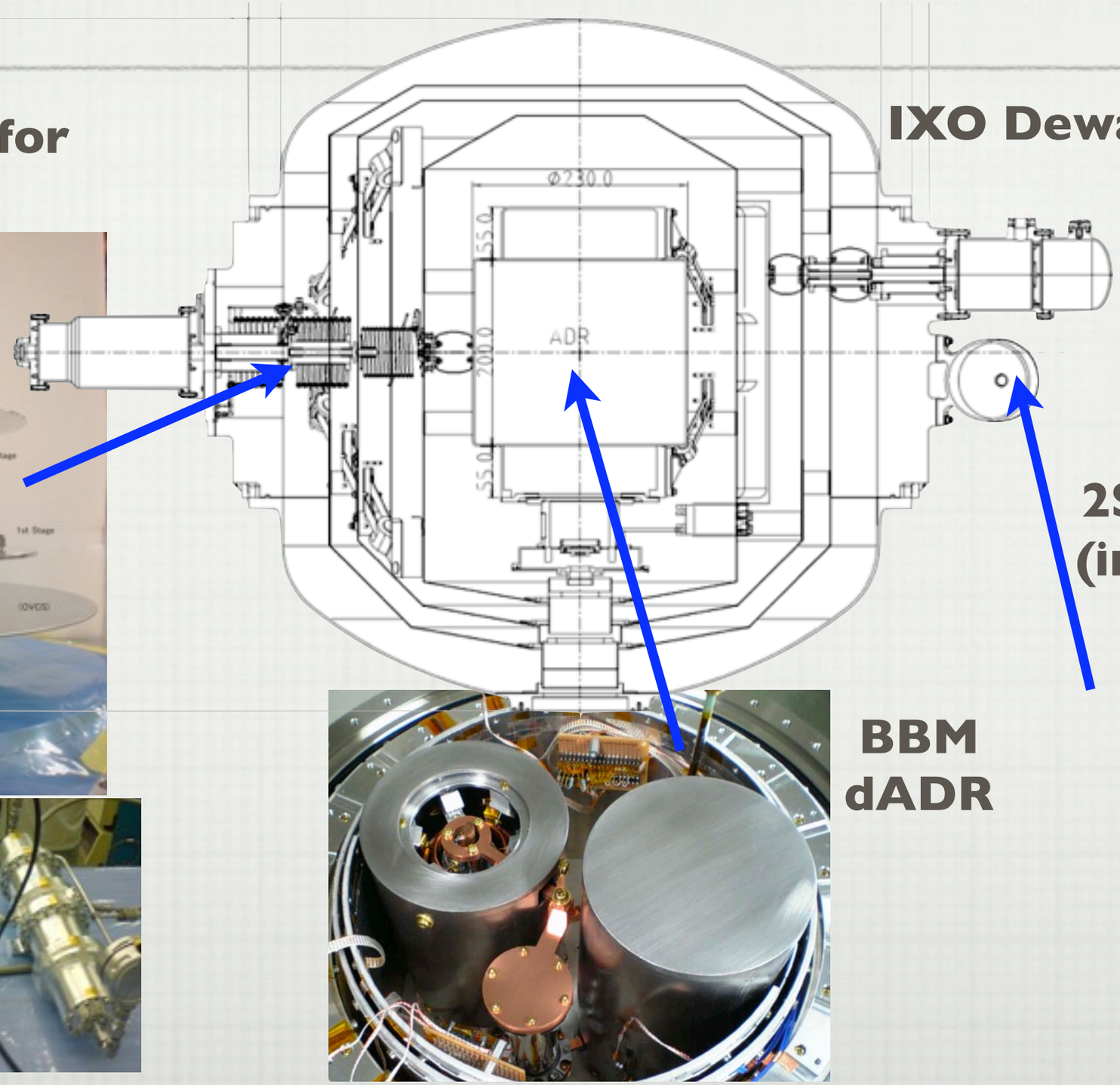
Fully redundant from room temp to 1.7K

Cooler development at JAXA

EM ^{3}He JT for Astro-H



Sato+ 2009



IXO Dewar

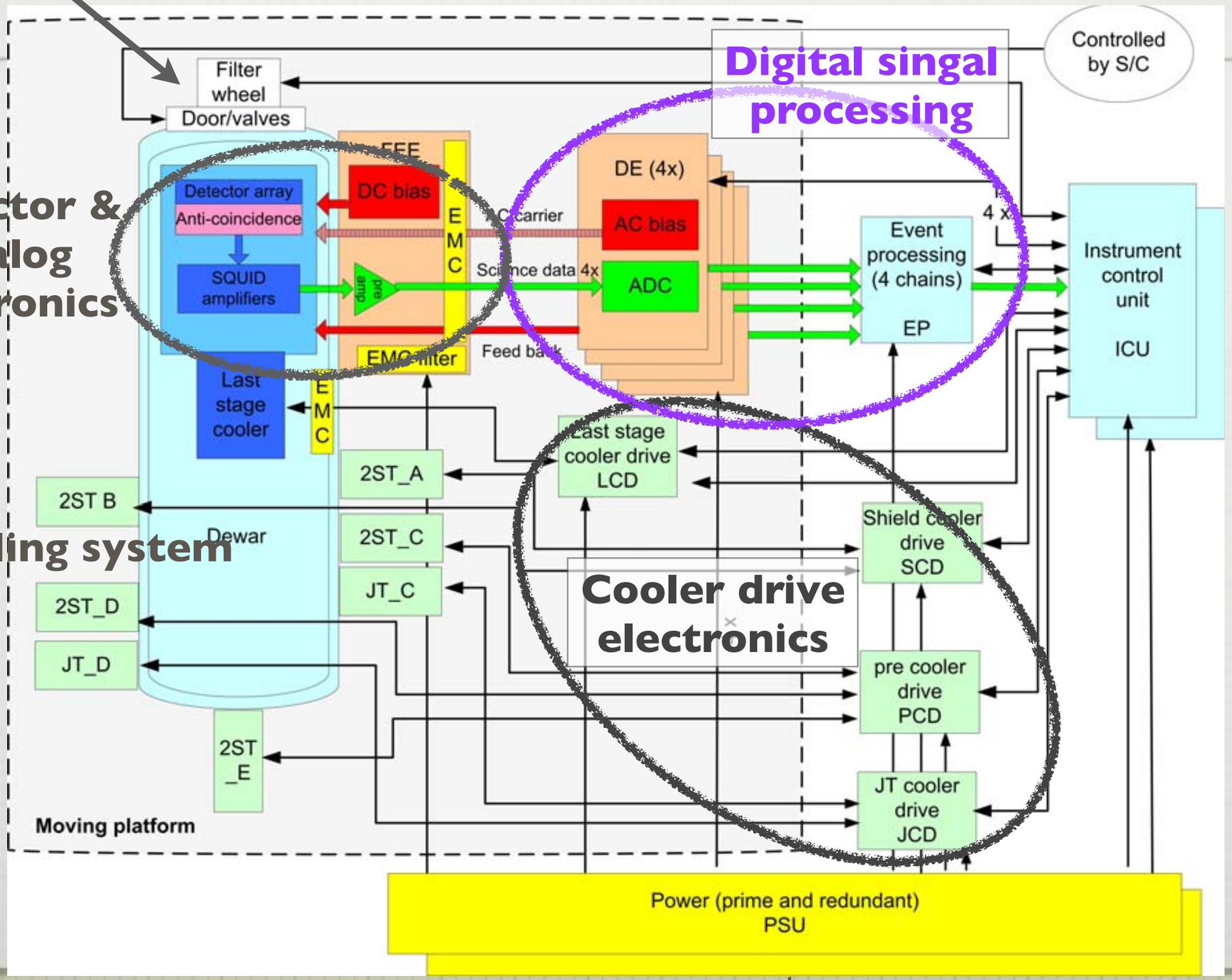
2ST for Akari (in orbit ≥ 3y)

BBM dADR

Shinozaki+ 2009

Nakagawa+ 2008

XMS system diagram



Assessment study

- **Purposes**
  - **To narrow down options of some key components:**
    - **TES read-out schemes: TDM or FDM (or CDM)**
    - **Cooling solutions from room temperature to 50mK**
  - **To demonstrate the technical readiness of the baseline design**
  - **Goal is to define the technically most promising instrument.**
- **Activities**
  - **33 (19 Europe, 7 Japan, 7 US) technology development activities identified**
  - **16 trade-off study activities identified**
- **Final report by the end of July, 2010.**

Summary

- **XMS will provide high-energy-resolution imaging spectroscopy with an energy resolution of 2.5 eV (FOV of 2') and 10 eV (FOV of 5.6').**
- **XMS will consist of a core TES μ calorimeter array, outer μ calorimeter arrays, an anti-co detector, cooling system, electronics, and a filter wheel.**
- **Basic functionality has been demonstrated for key components.**
- **Several different options are possible to fulfill the requirements; readout, cooling system.**
- **In assessment-study phase, we will narrow down the options, and demonstrate technical readiness.**