X-ray Quantum Calorimeter (XQC)

ESS 490/590 Lecture 22 Feb 2005

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Source:
http://alum.mit.edu/www/jpmorgen/ppt/XQC.ppt

Credits

- University of Wisconsin Space Physics group, Prof. Dan McCammon
- http://wisp.physics.wisc.edu/xray
- McCammon et al. ApJ 576:188 2002

Outline

- Scientific motivation: the history of Diffuse X-ray background research
- Design overview of the X-ray Quantum Calorimeter
  - Two bonus projects
- Project: magnet/temperature controller
- Project: detector readout
- Project: pulse height analyzer

Discovery of the Diffuse X-ray Background

- 1962 sounding rocket with Geiger counters detected X-ray point source Cygnus X-1 and diffuse emission (Giacconi et al. 1962)
- Rocket flights in late 1960s show low-energy X-ray emission coming from plane of the Galaxy
  - Low Energy means <250 eV, a.k.a. “soft”
- Soft X-rays not seen from beyond the Small Magellanic Cloud (just beyond our Galaxy)
- ROSAT (German X-ray satellite) saw the shadow of the moon in soft X-rays
- Soft X-rays observed from comets(!)

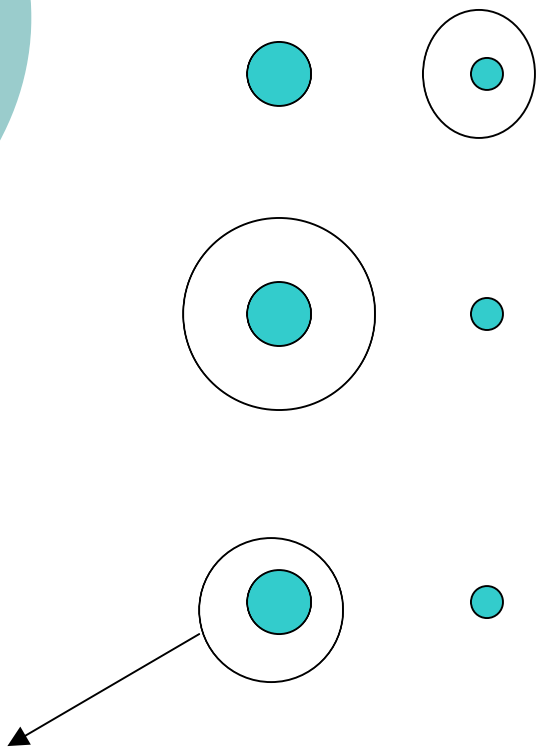
Galactic Source of Soft X-rays

- Supernova explosions create shock waves that heat interstellar gas
- Very hot gas atoms become multiply ionized
  - Species like C, N, O… up to Fe end up with only a few (1-5) electrons
- Valance processes in highly ionize atoms involve inner shell electron energy levels
- Inner shell electron energy levels are “deep” – several 100s to a few 1000s of eV

Heliospheric source of X-rays: Charge exchange

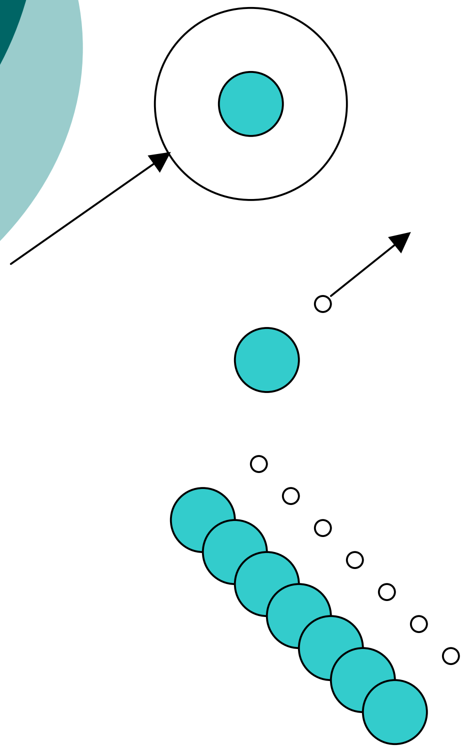
- Solar wind has multiply ionized atoms
- Hydrogen comes from the interstellar medium, planetary or cometary atmospheres
- High ion state atom steals electron from hydrogen
- Ion is likely to be left in an excited state, relaxation emits X-ray

Charge Exchange Schematic



- Ion, Hydrogen atom
- Ion steals electron, possibly in excited state
- Electron transition to ground state, emitting a photon

Conventional X-ray detection



- Photon of energy >100 eV hits atom
- Electron ejected
  - $E_{electron} = E_{photon} - E_{binding}$
  - $E_{binding}$ typically < 10eV
- $E_{electron}$ sufficient to ionize several other atoms (~10)

Conventional X-ray detection limitations

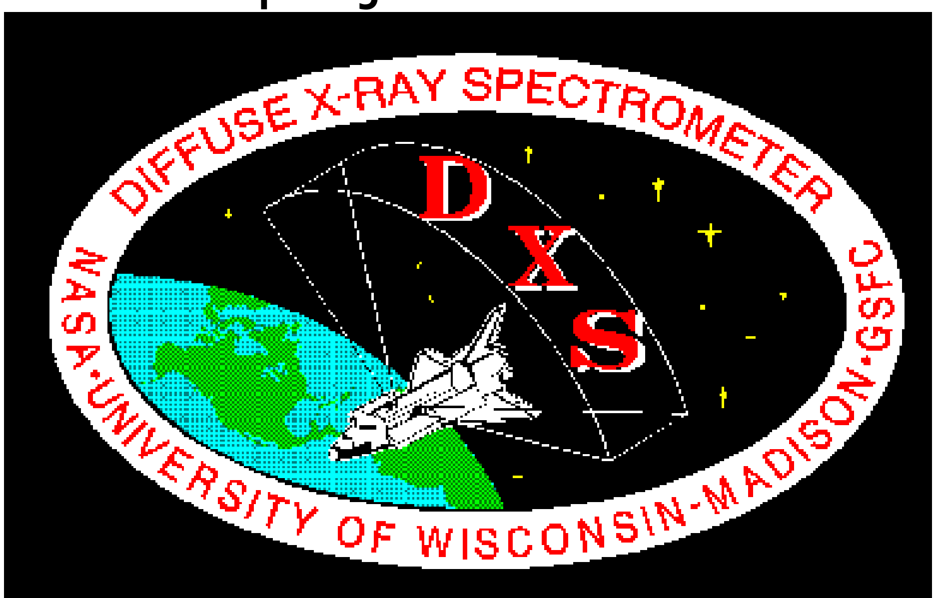
- Amount of charge collected proportional to energy of absorbed photon (i.e. proptional counter)
- Charge is quantized – electrons
- 100 eV photon, 10 eV per electron
  - 10 electrons
- Counting (Poisson) statistics on 10 electrons
  - Sqrt(10) ~ 3
- Resolving power = $E/\Delta E = 10/3 \sim 3$

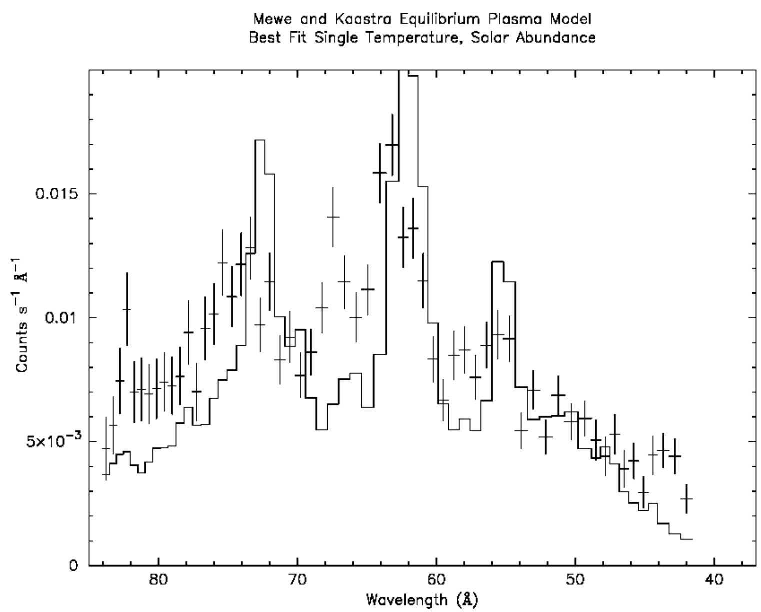
What does a resolving power of 3 mean?

- For optical spectroscopy, red, yellow, blue (~1500 Å chunks)
- Not very scientifically illuminating
  - Can’t even tell the difference between lines and continuum.
- How do you improve on this?

Dispersive Spectroscopy

- Bragg crystal spectrometer
- Resolving power ~30, but low throughput
- http://www.ssec.wisc.edu/dxs/
- Analysis of flight data was my Ph.D. thesis project. We see evidence of lines.

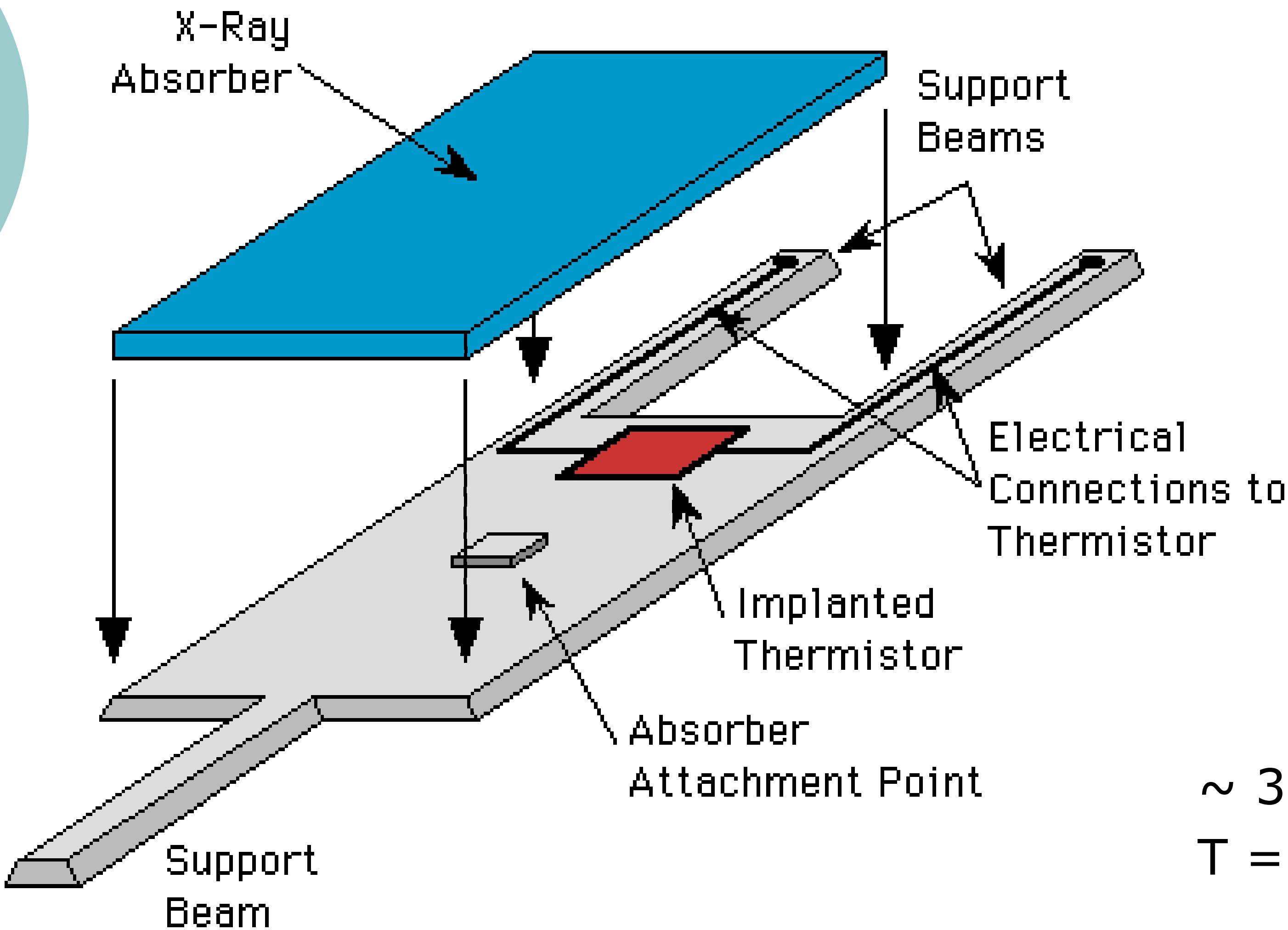




Calorimetry

- Detect the heat deposited by the absorbed photon
- Heat in solids is quantized (phonons), but with much smaller quanta
- Statistical limitations no longer an issue for the photon detection
- Statistical problem transfers to determining the baseline temperature
  - ~3 eV baseline noise is current limit
- Technical problem: photons don’t have a lot of energy

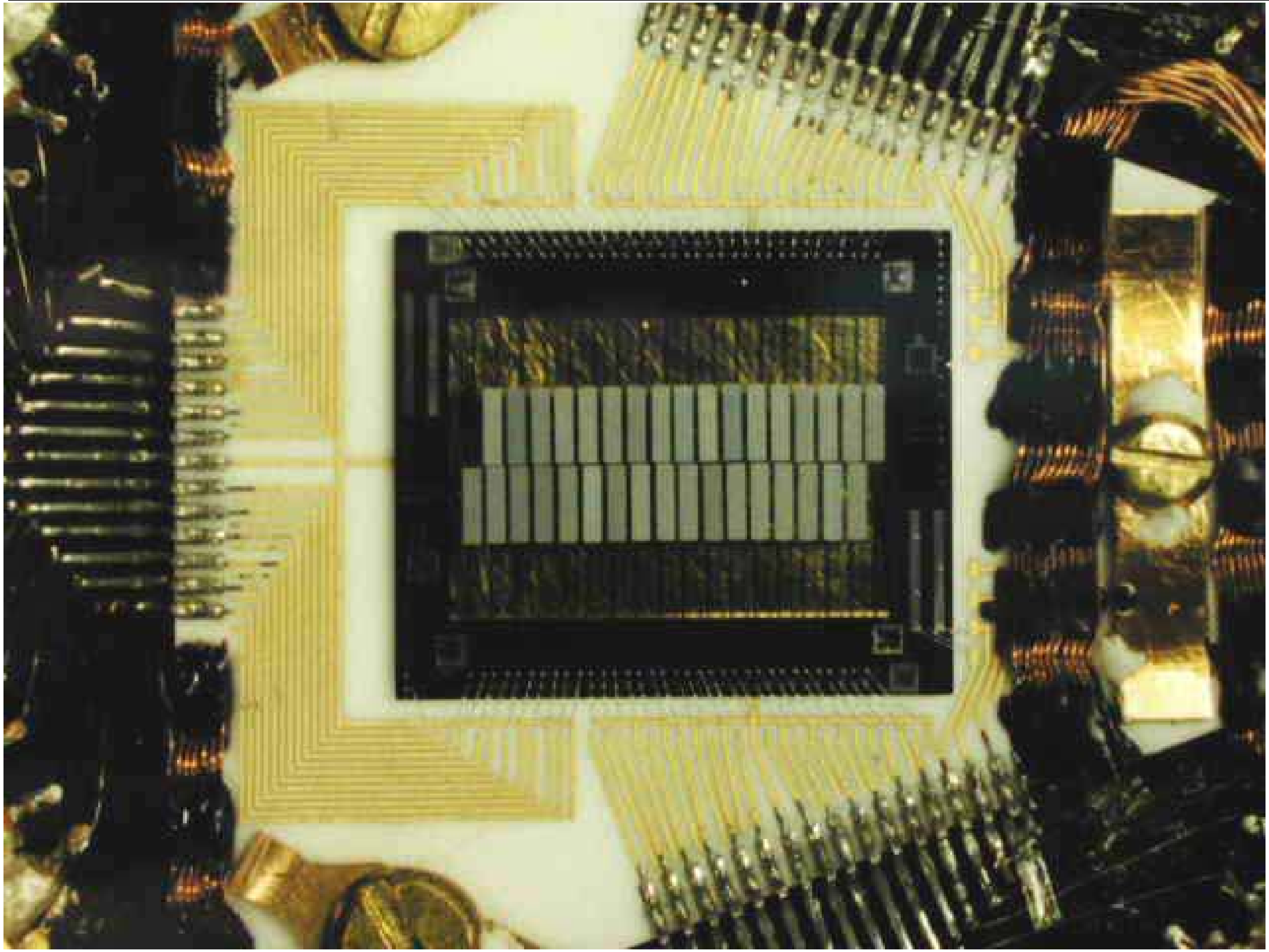
X-ray Microcalorimeter



~ 3mm x 1 mm

T = 60 mK

Microcalorimeter Array



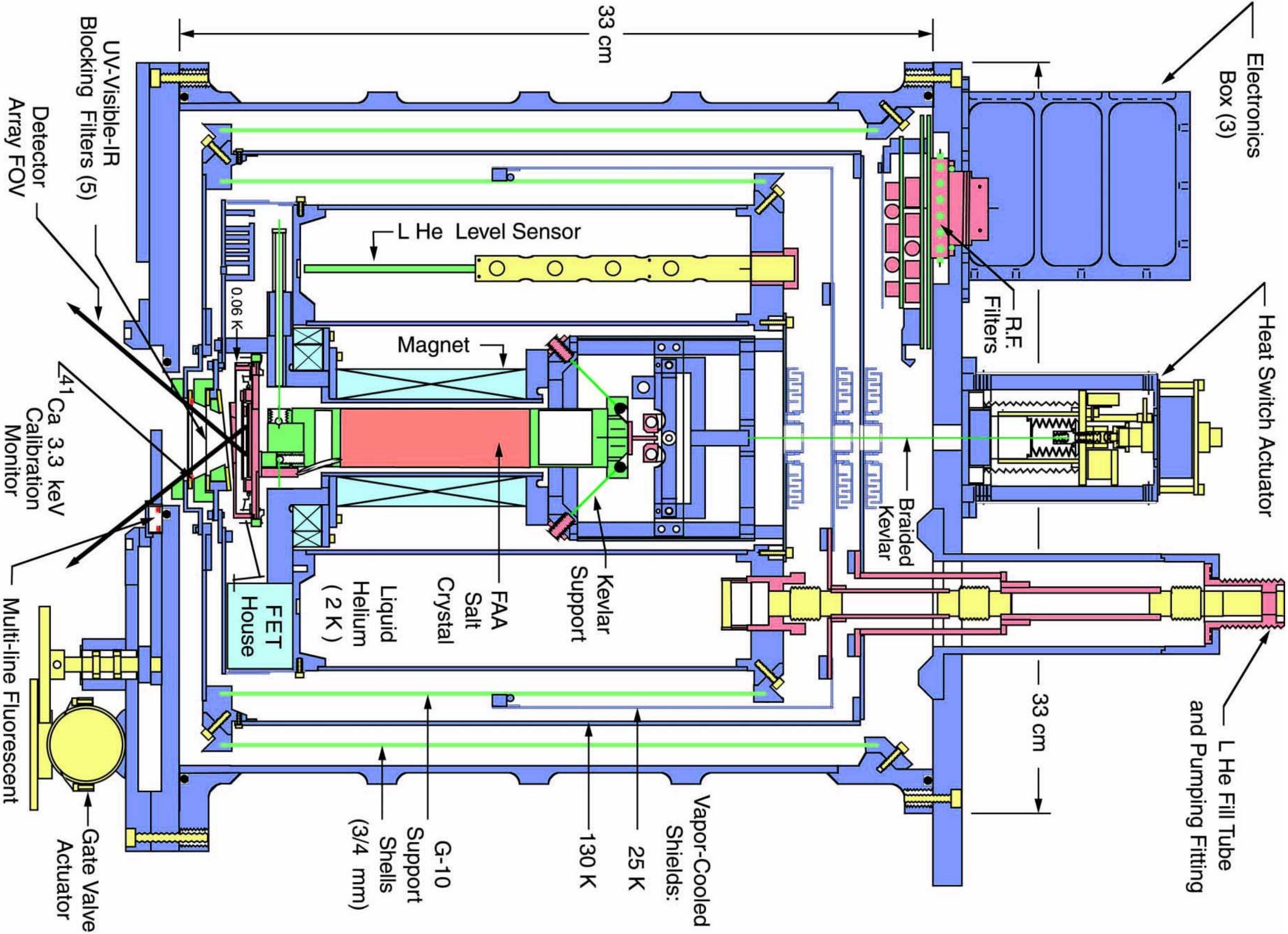
Did you say 60 mK (0.060 K)?

- Absolute zero anyone?
- On a sounding rocket?
- Dewar with liquid helium 4.2 K
- Pump on helium ~2 K
- Adiabatic Demagnitization Refridgeration (ADR)
  - Entropy trick with a ferromagnetic salt in a high magnetic field
  - gets to 50 mK

XQC ADR ingredients

- Vacuum jacket
- Tank for liquid helium
  - liquid helium level sensor*
- Magnet
- Salt crystal for entropy cooling
- Kevlar strands and G10 fiberglass tubes for mechanical strength and thermal isolation
- Heat switch (adiabatic)
- Aluminized parylene IR blocking filters
- Lots of diodes for temperature detection*

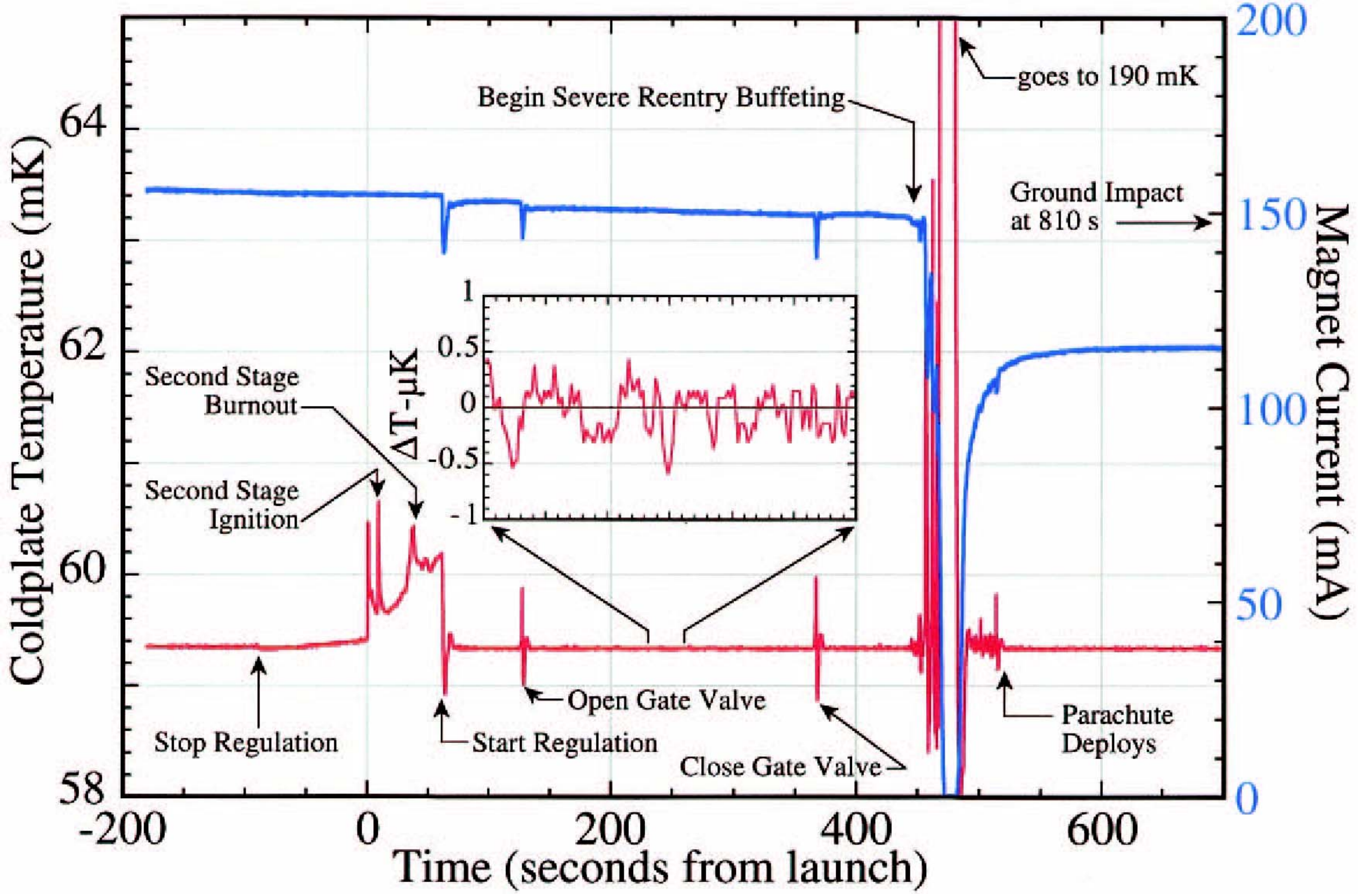
*bonus projects


33 cm
Electronics Box (3)
UV-Visible-IR Blocking Filters (5)
Detector Array FOV
L He Level Sensor
0.06 K
R.F. Filters
Magnet
Heat Switch Actuator
^{41}Ca 3.3 keV Calibration Monitor
Braided Kevlar
Kevlar Support
FAA Salt Crystal
Liquid Helium (2 K)
FET House
Multi-line Fluorescent Calibration Source
Gate Valve Actuator
G-10 Support Shells (3/4 mm)
130 K
25 K
Vapor-Cooled Shields:
33 cm
L He Fill Tube and Pumping Fitting

Magnet susbsystem

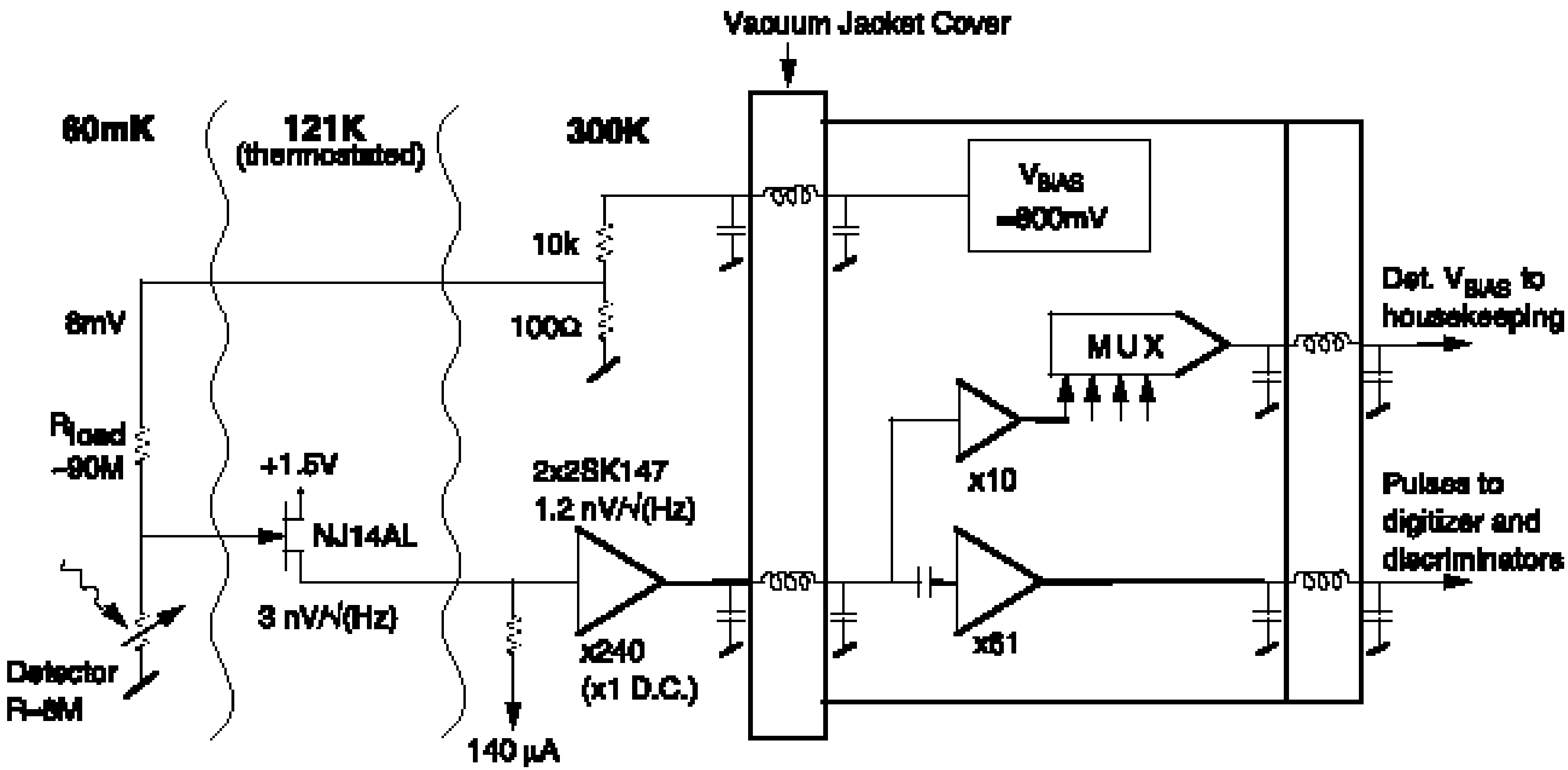
- Magnetic field aligns quantum mechanical spins of ferromagnetic salt
- 4 Amp DC current, no heat dissipation
  - Superconducting solenoid
  - High temperature superconducting segment of lead wires
- $\Delta H_{out} = T\Delta S$
- PID temperature controller regulates magnet terminal voltage (proportional to rate of current change)*
  - NOT buck and boost

Magnet current/temperature performance



Detector electronics

- Thermister, voltage divider, FET readout*



Detector pulses

- Pulses digitized for later analysis
- Basic pulse height extraction done in analog electronics*