X-ray Quantum Calorimeter (XQC)

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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](http://wisp.physics.wisc.edu/xray)
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
  - $E_{\text{electron}} = E_{\text{photon}} - E_{\text{binding}}$
  - $E_{\text{binding}}$ typically $< 10$eV
- $E_{\text{electron}}$ sufficient to ionize several other atoms ($\sim 10$)
Conventional X-ray detection limitations

- Amount of charge collected proportional to energy of absorbed photon (i.e. proportional counter)
- Charge is quantized – electrons
- 100 eV photon, 10 eV per electron
  - 10 electrons
- Counting (Poisson) statistics on 10 electrons
  - $\sqrt{10} \sim 3$
- Resolving power $= \frac{E}{\Delta E} = \frac{10}{3} \sim 3$
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 \( \sim 30 \), but low throughput
- http://www.ssec.wisc.edu/dxs/
- Analysis of flight data was my Ph.D. thesis project. We see evidence of lines.

![Diffuse X-ray Spectrometer](image)
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
  - $\sim 3$ 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 $\sim 2$ K
- Adiabatic Demagnetization Refrigeration (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
Magnet subsystem

- 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*