The Advanced Scintillator Compton Telescope (ASCOT) Balloon Project


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Philosophy

- The ASCOT project is motivated by the theory that the most cost-effective, low-risk way to implement an advanced, *general-purpose* Compton telescope is to build directly on the experience of COMPTEL.

- A advanced, scintillator-based Compton telescope would use *modern detector materials* to improve efficiency, energy resolution, and time-of-flight (ToF) resolution for background rejection.

- It would also use *advanced light readout devices*, such as silicon photomultipliers (SiPMs), to reduce passive mass, volume, and power.
COMPTEL Background

COMPTEL suffered intense background from particle interactions:

ToF was critical to COMPTEL's sensitivity:

Improved ToF resolution will greatly reduce background in straightforward manner

Balloon Flight Demonstrations

UNH has conducted two successful balloon flight tests of available technology that would enable an advanced scintillator Compton telescope:

- The **FAst Compton TELescope (FACTEL)** experiment (September 2011): new scintillators (collaboration with LANL)
- The **Solar Compton Telescope (SolCompT)** experiment (August 2014): SiPM readouts
FACTEL Experiment

- Compton telescope consisting of three 1-inch liquid organic D1 scintillators and three 1-inch LaBr$_3$ D2 scintillators, all read out by fast PMTs
- D1-D2 separation of ~30 cm
- D1 surrounded by plastic ACS
- Pressure vessel, PC-104 flight computer
FACTEL Flight Results (2011)

Flight Corrected ToF

- ToF spectrum fully described by two Gaussians
- “Down” and “Up” gammas cleanly separated
- FWHM ~ 1.2 ns

Flight vs Sum of Sims

- Downward moving gamma spectrum agrees with Geant4 simulations

Julien, M., et al., 2012 IEEE NSS Conference Record, 1893
The Silicon Photomultiplier (SiPM)

- Scintillator detectors limited by size, mass, and power of readout
- A SiPM (aka SSPM, MPPC) is a summed array of tiny (~50 μm) silicon APDs reverse-biased slightly above breakdown voltage in *limited Geiger mode*; recovers in 10s of ns
- SiPMs are compact, light, robust, low power, LV (30 - 70 V), and have gain ($10^5 - 10^6$), timing (~1 ns rise time), and effective quantum efficiency (20% - 30%) equivalent to PMTs
- *Replacing PMTs with SiPMs in a Compton telescope would eliminate passive material, reduce mass, and allow closer packing*

(Stapels et al. 2005)
SolCompT Experiment

- 2-element Compton telescope: D1 is 1-inch stilbene, D2 is 26 mm × 26 mm × 26 mm LaBr$_3$
- Both read out using 2 × 2 array of Hamamatsu S11828-3344 MPPCs with transformer FEE for low input impedance
- Payload used hardware (pressure vessel, heaters, readout electronics, and PC-104 computer) flown in 2011 as part of the FACTEL payload
- Tagged $^{60}$Co source (~240 nCi) to monitor gain and energy resolution
SolCompT Flight Results (2014)

Although only had 3.75 hours at float, tagged events $^{60}$Co show good ToF and energy spectra:

Untagged events harder to interpret due to small spacing and surrounding material – but still see up vs. down on top of broad continuum:

Bloser, P. F., et al., 2016, NIM-A, 812, 92
The ASCOT Balloon Project

- We are conducting a program to fly a larger scintillator-based Compton telescope with SiPM readouts on a balloon and observe the Crab in a 1-day flight.
- D1 will be p-terphenyl organic scintillator; D2 will be CeBr$_3$ (due to difficulties with Saint-Gobain, also lower internal background).
- Will use the SensL MicroFC-60035-SMT 6 mm × 6 mm SiPM – has “fast” output, good for ToF.
ASCOT Balloon Instrument

- Instrument concept: basic “module” with 8 × 8 scintillator array optically coupled to a 8 × 8 SiPM array
- Each scintillator 15 × 15 × 25 mm³
- Each scintillator read out by 2 × 2 SiPM array (same as lab tests)
- Detector layers each 2 × 2 array of modules
- Two D1 layers, one D2 layer (cost)
- Estimate ~4σ Crab detection
ASCOT D1: P-terphenyl

- 142 p-terphenyl crystals have been delivered
- Show good uniformity, light output
- Will be assembled into 8 × 8 array with Delrin housing

Test data with test SiPM array
Project SMART Balloon Flight

- A prototype D1 detector was flown as a weather balloon payload by high school students participating in UNH’s Project SMART
- Reached altitude of ~31 km, counting rate shows expected behavior (Pfotzer Maximum)
- “Poor man’s thermal/vac test”
ASCOT D2: CeBr$_3$ Array

- 8 × 8 vacuum-rated array made by Scionix
- Initial testing shows slightly reduced energy resolution compared to 13 × 13 × 13 mm$^3$ LaBr$_3$ crystal
- Due to light loss via entrance window (i.e., cross talk):

\[ \Delta E/E = 6.2\% @ 662 \text{ keV} \]
Time of Flight

- Measured ToF resolution between one p-terphenyl and one CeBr$_3$ pixel using custom CFD/TAC board
- We see very little PH-dependent walk in timing
- For coincident $^{60}$Co events with large PH, get:

$$527 \pm 34 \text{ ps (FWHM)}$$
ASCOT Instrument

- Mechanical design is underway
- Electronics design as well
- SiPMs will be mounted on 8-pixel “strip” boards, plugged into motherboard
Initial Simulations

- Preliminary simulations done with MGGPOD indicate ~4σ Crab detection
- Have begun using MEGAlib for more detailed work
Simulation of Potential Explorer Mission

- Explorer-sized instrument concept: $7 \times 7$ array of modules forms a “layer”
- Three D1 layers and three D2 layers, 50 cm separation
- Assume FRP frame (as in FACTEL), plastic ACS
- Estimate $120 \times 120 \times 100$ cm$^3$ instrument, ~1000 kg payload
- Simulate response and background with MGGPOD – assume radiation inputs from Advanced Compton Telescope Concept Study for 5º inclination, 550 km LEO
- Use measured detector response
Simulated Compton Telescope Performance

Simulations indicate that an Explorer-sized Compton telescope using this technology would greatly improve on the performance of COMPTEL:

- Much greater effective area than COMPTEL, especially below 1 MeV
- ~8 times better on-axis continuum sensitivity around 1 MeV for 2-week observation (compare to COMPTEL Cyg X-1 spectrum)
- Instrument could study MeV spectra of multiple Galactic black holes (spectra from OSSE)