Advanced Energetic Pair Telescope for Medium-Energy Gamma-Ray Polarimetry

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Future Space-based Gamma-ray Obs.
GSFC, Feb. 6, 2015

Hunter, et al., Astroparticle Physics, 59, 18-28 (2014)
AdEPT Science, 5-200 MeV

• **AdEPT will reveal the configuration of the most energetic accelerators in the Universe**

• Explore fundamental processes of particle acceleration in active astrophysical objects
  – Pulsars, pulsar nebulae, supernova remnants, active galactic nuclei, magnetars, accreting binaries, gamma-ray bursts, ...

• Map the transition from electronic to hadronic processes in the Galactic diffuse emission

• Probe the universe for exotic processes
AdEPT Design Philosophy

- Optimize for angular resolution

Angular resolution of pair telescope limited by nuclear recoil, “Kinematic Limit”

![Graphs showing screening for gamma rays with different energies](image1)

![Graphs showing screening for gamma rays with different energies](image2)

Jost, Luttinger, & Slotnick, Phys. Rev. 80, 189-196 (1950)
AdEPT Angular Resolution

Achieving angular resolution near the Kinematic Limit

Continuous medium track imager density must be < ~5 mg/cm³, i.e. a Gaseous medium.

Hunter et al., Astroparticle Physics 59, 18-28 (2014)
• Optimizing for angular resolution → polarization sensitivity

- Modulation factor, $\lambda$,

$$\sigma(\varphi) = \frac{\sigma_0}{2\pi} \left[ 1 + P\lambda \cos^2(\varphi) \right]$$

decreases exponentially with thickness of tracking medium above $\sim 1$ mRL

- Measure $e^-$ and $e^+$ directions in $\lesssim 1$ mRL
  - $\sim 100$ $\mu$m of Si
  - $\sim 8$ cm of Ar at 1.5 atm

AdEPT is a Viable Gaseous G-ray Polarimeter!

- **Baseline design studied in IDL/MDL**
  - $2 \times 2 \times 2$ array of $1 \text{ m}^3$ 3-DTI modules
    - $A_{\text{geom}}$: 4 $\text{ m}^2$, ~40,000 channels
  - Ar (1100 torr) + $\text{CS}_2$ (40 torr), 25° C
  - Pressure vessel: Al, 4 mm thick, ~300 cm diameter, ~530 kg
  - Instrument power: ~500 W,
    - mass: ~320 kg w/o s/c, pv
  - Spacecraft: zenith pointed,
    - 3-axis stabilized, scanning mode
  - Orbit: near equatorial, ~550 km altitude
  - Athena launch vehicle
  - Fits within Explorer mission constraints: Mass, Power, & Cost

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3-Dimensional Track Imager (3-DTI)

**AdEPT Enabling Technology**

- Large-volume gas *time projection chamber (TPC)*
  - Low density, homogenous, 100% active particle tracking
  - Thermal diffusion achieved with negative ion drift
- **2-D readout**, 2-D micro-well detector (MWD) + GEM
  - Active detector, 0.4 mm pitch
  - GEM provides additional gain lost to negative ion drift
- Isotropic medium, scalable to large sensitive volume
Electron Tracking in 3-DTI

X-Z, & Y-Z projections of single electrons from $^{90}\text{Sr}$ in Ar + $\text{CS}_2$ with 0.4 mm resolution

X-Z projection of 6.129 MeV gamma interaction in 80% P-10 + 20% CS$_2$
TPC Memory and Data Processing

• Ionization charge from all charged particles traversing TPC volume drifts to MWD and is “read out”
  • Total drift time is ~50 ms
  • Expect ~175 CR protons per m$^3$ in TPC volume
  • Gb/s raw data rate
  • Developing simulated data and multi-core on-board processing to discriminate gamma-rays from CRs, low-energy gamma interactions, & noise

6 February 2015
AdEPT Gamma Ray Polarimeter
Fermi-LAT front, P7SOURCE_V6 (FSSC)

EGRET, Thompson et al. (1993)

AdEPT, 8 m$^3$ vol Ar+CS$_2$ at 1.5 atm

3σ significance,
$T_{\text{obs}}=10^6$ s, and $\Delta E=E,$
$F_{\text{egb}}=2.7\times10^{-3} (E/1 \text{ MeV})^{-2.1}$

No correction for inefficiencies in track recognition

$\lambda = 0.15$
AdEPT Instrument Development

• **2015-18 ROSES-APRA**
  – 50 x 50 x 100 cm³ AdEPT prototype
    • Multi-core processor to discriminate gamma-rays from background
      – Determine gamma-ray direction, energy, polarization, and time of arrival
    • Large area MWD integration
    • FEE ASIC
  – Calibrate at accelerator with polarized gamma rays, 5 - ~90 MeV
    • Determine electron energy from Coulomb scattering
    • Measure angular resolution and Polarization sensitivity

• Future NASA mission!