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

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Hunter, et al., Astroparticle Physics, 59, 18-28 (2014)
Gamma-Ray Workshop

• Future Space-Based Gamma-Ray Observatories
  – NASA/GSFC, Feb 5-7, 2015

• Main themes for future gamma-ray missions
  – Nuclear Lines and Polarization

• AdEPT instrument and mission
  – Optimized for angular resolution and polarization
  – Mature mission and instrument concept
    • GSFC IDL/MDL runs
    • Viable Explorer mission
AdEPT Science, 5-200 MeV

- AdEPT will reveal the geometry 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 electron to hadronic processes in the Galactic diffuse emission
- Probe the universe for exotic processes
  - Dark matter
  - Lorentz invariance violation
AdEPT Design Philosophy

• Optimize for angular resolution
  - Angular resolution of pair telescope limited by nuclear recoil, "Kinematic Limit"

• Optimize for polarization sensitivity
  - Modulation factor, $\lambda$, decreases exponentially with thickness of tracking medium above $\sim 1$ mRL
    $$\sigma(\Psi_+) = \frac{\sigma_0}{2\pi} [1 + P\lambda \cos^2(\Psi_+ - \Psi_0)]$$
  - 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 Angular Resolution

- Continuous, low density, conversion and tracking medium
  - \(~5 \text{ mg/cm}^3\) \textit{i.e. a Gaseous medium}
- Angular resolution better than twice the Kinematic Limit up to \(~200 \text{ MeV}\)
- Low density enables detection of Triplet interactions
  - Low-energy angular resolution limited by spatial resolution, better than kinematic limit
  - Enhanced polarization sensitivity

AdEPT is a Viable Gaseous G-ray Polarimeter!

- Baseline design studied in GSFC 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) + CS$_2$ (40 torr), 25$^\circ$ 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 mission constraints: Mass, power, & cost
AdEPT Baseline Performance

Fermi-LAT front, P7SOURCE_V6 (FSSC)

EGRET, Thompson, et al. (1993)

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

Effective Area (cm$^2$)

Continuum Sensitivity (MeV cm$^2$ s$^{-1}$)

Minimum Detectable Polarization (%)

$F_{egb} = 2.7 \times 10^{-3} (E/1 \text{ MeV})^{-2.1}$

3σ significance, $T_{obs} = 10^6$ s, and $\Delta E = E$.

No correction for inefficiencies in track recognition

$\lambda = 0.35$
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
    • Polarization sensitivity

• Future NASA mission!
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
  - Scalable to large area

19 June 2014  AdEPT Gamma Ray Polarimeter
Electron Tracking in 3-DTI

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

X-Z projection of 6.129 MeV gamma interaction in 80% P-10 + 20% CS$_2$