Dark Matter Indirect Detection with the GAPS Experiment

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(On behalf of the GAPS Collaboration)
The GAPS Experiment

- **GAPS** = General Antiparticle Spectrometer, a balloon flight experiment.
  - Instruments size: ~3.7m x 3.7m x 3.7m
  - Flight from Antarctica.

- Use uniquely characterized atomic X-rays and charged particles from the decay of exotic atoms to identify cosmic anti-nuclei.

- Search for low energy (<0.25 GeV/n) antideuteron.
  - Probe various dark matter models.

- High statistics measurement of low energy antiproton and antihelium search.

- The first of a series of flight is expected for **late 2021**
Why Antideuteron as DM probe?

- **Primary flux**: DM annihilation/decay
  - Example: (decay) $m = 50$ GeV gravitino
  - $m_{\chi} = 40$ GeV astrophys. background

- **Secondary flux**: Cosmic ray interaction
  - Example: $p (CR) + H (ISM) \rightarrow p + H + p + n + \bar{p} + \bar{n}$
  - $CR =$ cosmic ray
  - $ISM =$ interstellar medium

- **Background free for DM searches at low energy range!**

Perez et al., Astro 2020 Decadal White Paper
GAPS Detection Principle

- **Time-of-Flight** system measures velocity, direction and dE/dx.
- Loses energy in layers of semiconducting silicon targets/detectors.
- Stops, forming *exotic excited atom*.
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➢ **Time-of-Flight** system measures velocity, direction and dE/dx.
➢ Loses energy in layers of semiconducting silicon targets/detectors.
➢ Stops, forming *exotic excited atom*.
➢ Atom de-excites, emitting *X-rays*.
➢ Remaining nucleus annihilates, emitting *pions* and *protons*.

*Aramaki et al., Astroparticle Physics 74 (2016)*
GAPS “Background” Rejection

- $\bar{p}$ and $\bar{d}$ selected by TOF system
- Antiparticle ($\bar{p} / \bar{d}$) identification:
  - Stopping range, $dE/dx$
  - Pion & proton multiplicity
  - Unique atomic X-rays

“Background” for antideuteron searches ($\bar{p}$ mis-identification) rejection $>10^6$ !

Aramaki et al., Astroparticle Physics 74 (2016)
GAPS Collaboration
GAPS Instrument Design

- **Time of Flight (TOF)**
  - High-speed trigger and veto.

- **Si(Li) Tracker**
  - X-ray identification
  - Stopping depth, $dE/dx$
  - Particle multiplicity
  - Vertex reconstruction

- **Thermal System**
  - Radiator
  - Oscillating heat pipe (OHP)

- **Series of long-duration (~30 days) balloon flights from Antarctica.**
  - Initial flight is scheduled in late 2021.
GAPS Instrument-TOF

1.6~1.8m

196 plastic scintillator

SiPMs x6

1.8m SiPM paddles

Item | Value | Comments
--- | --- | ---
TOF resolution | \( \sigma_T < 400 \text{ ps} \) | Laboratory
Velocity resolution | \( \Delta \beta / \beta < 0.12 \) | 
Charge resolution | \( (\sigma_q)_{68\%} < 0.20e \) | Initial study
Position resolution | \( \sigma_x = 3.0 \text{ cm} \) (length)\( \sigma_y = 4.6 \text{ cm} \) (width) | Laboratory
Angular resolution | \( \sigma_\theta < 3^\circ \) (typical) | Simulations

Trigger principle:
- **Beta**: select slow particles.
- **Charge**: reject high Z particles.
- **Hit**: number of fired paddles.

Accept ~80% of anti-nuclei and suppress rate <500 Hz!

S. Quinn’s ICRC proceedings
GAPS Instrument-\textbf{Si(Li) Tracker}

- Large acceptance, total active area $>10 \ m^2$.
  - 10-cm diameter detectors
  - 10 layers, >1000 detectors.

- High operation temperature: resolution $<4 \ keV$ @ -35 to -43 C.

- Huge dynamic range:
  - $\sim keV \rightarrow 100 \ MeV$

- Low-cost and high-yield fabrication process.
GAPS Instrument—**Si(Li) Tracker**

**Custom Si(Li) detectors**: *(See F. Rogers contribution to particle detector session)*

- 10-cm diameter and 2.5 mm thickness
  - Absorption efficiency to capture $\bar{d}$ up to 0.25 GeV/n
  - Escape fraction and efficiency for X-rays.

- 8 strips per detector
  - Tracking efficiency for incoming anti-nuclei and outgoing annihilation products.

- Achieved energy resolution <4 keV @ -35 C!

- Batch production by Shimadzu Corp. (Japan) ongoing.

- Readout via custom ASIC (pSLIDER-32), wire bonded with Si(Li) strips:
  - Integrated low-noise preamplifier.
  - 32 channels and 11-bit ADC.
  - Dynamic range: 20 keV to 50 MeV.

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Rogers et al., arXiv:1906.00054
Kozai et al., arXiv:1906.05577
Perez et al., NIM A 905 12-21 (2018)
GAPS Instrument - **Thermal System**

- Design: Low power, low mass, semi-passive.
- Radiator + oscillating heating pipe (OHP)
  - Si(Li) detector cooling: local heating (≈100 W) + infra-red (IR) heat from surroundings (≈200 W) transferred to a radiator then to the space.
  - TOF system are insulated from Si(Li) and kept at moderate Temp by radiation-based thermal design.
- Scaled radiator model is validated on engineering flight (NASA SIFT), next flight test this Aug.-Oct.

**References**

Light WIMPs annihilating into $u\bar{u}$ for **MED** and **MAX** Galactic propagation scenarios

- Probes a variety of dark matter models that evade or complement collider, direct, or other cosmic-ray searches

TeV-scale WIMPs annihilating into $b\bar{b}$ and 500 GeV pure-Wino dark matter.
GAPS will measure >1000 antiprotons (E<0.25 GeV) in each long duration balloon flight.

- BESS: 29 at ~0.2 GeV
- PAMELA: 7 at ~0.25 GeV
- AMS-02: E>0.25 GeV

- Reduces systematic uncertainties for antideuteron search, both experimental and theoretical.

- Can probe light dark matter (e.g. decaying gravitino, LZP from extra-dimensional theories, primordial black holes).

- Optimizing for antihelium searches.

Aramaki et al., Astroparticle Physics 59 (2014) 12-17
Summary & Conclusions

- Comic-ray anti-nuclei provide a clean and complementary channel for dark matter detection.

- GAPS will sensitively search for low energy anti-nuclei using the novel exotic atomic technique.

- GAPS has made a good progress toward a first flight in late 2021, including a successful CDR in January 2019.

- Stay tuned!

DPF 2019, Jul. 29- Aug. 2, NEU MA
Thank you!
X-ray Yields of Antiprotonic Exotic Atom

Aramaki et al., Astroparticle Physics 49 (2013) 52-62

- X-ray yields for the antiprotonic exotic atom with Al and S targets were measured at KEK, Japan in 2005.

- Measurements are consistent with the calculations.