Antimatter signatures from Primordial Black Holes

Based on 2505.04692 - accepted for publication in PRD
in collaboration with V. De Romeri, F. Donato, D. Maurin & L. Stefanuto

Agnese Tolino

IFIC (CSIC-UV)

Dark Tools, Torino

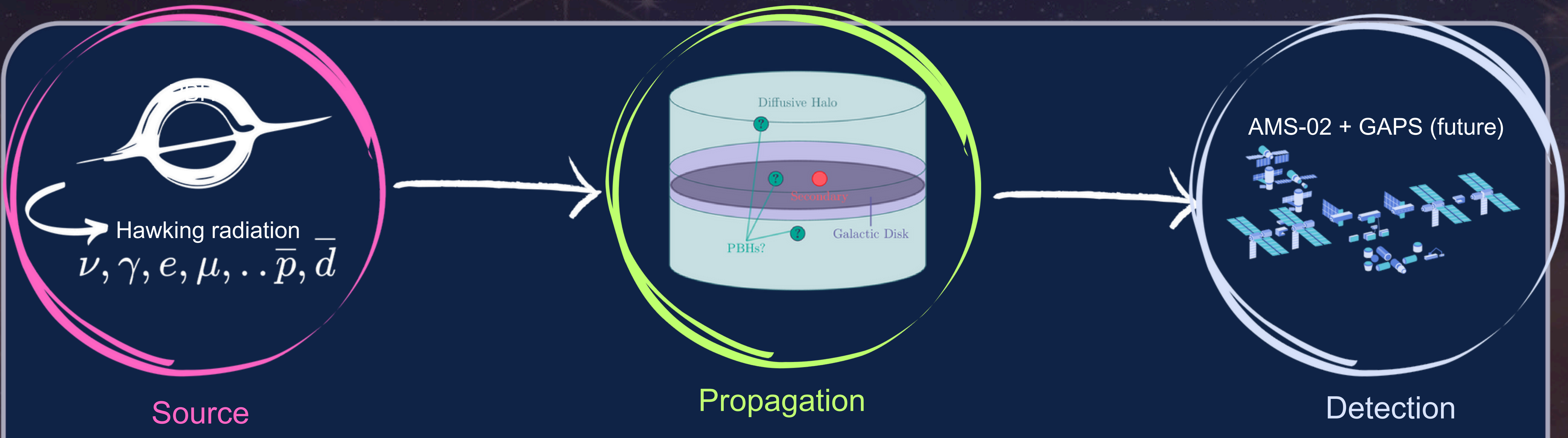
June 18th, 2025

More details here!

arXiV:2505.04692

See talks of
Yoann Génolini
& Andrew Cheek!

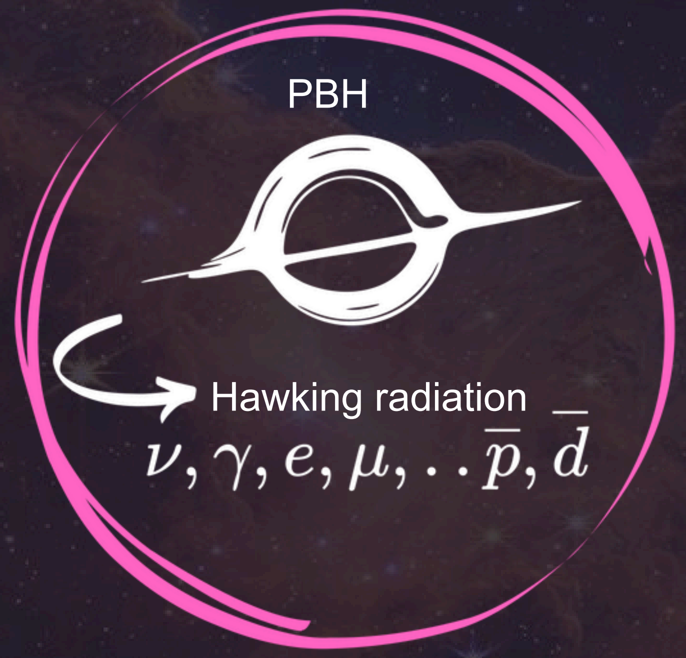
OUR WORK IN A NUTSHELL



We estimated the **antiproton** and **antideuteron signals** from a population of **primordial black holes** (PBHs) following a **lognormal** mass distribution. By comparing with AMS-02 data, we derived competitive **constraints** on the fraction of dark matter that such PBHs could account for and discussed **perspectives** for antideuteron measurements with AMS-02 and GAPS

See also:
J. Herms et al., JCAP 02 (2017)
A. Barrau et al., Astron. Astrophys. 388 (2002) 676
A. Barrau et al. Astron. Astrophys. 398 (2003) 403

PRIMORDIAL BLACK HOLES

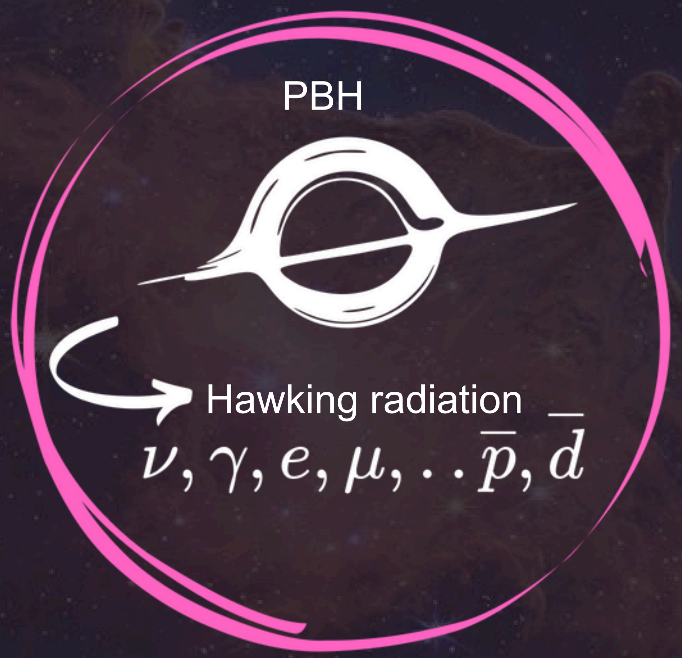


Source

- Might have formed in the **Early Universe** by the collapse of large density fluctuations
- Masses span from 10^{-5} g to $10^{5} M_{\odot}$
- Predicted to **evaporate,** i.e. lose mass and emit particles with a semi-blackbody spectrum
- PBHs above 5x10^{14} g could be **viable DM candidates**, as they would have not completely evaporated yet

Hawking, Nature 248 (1974) 30-31
Carr et al., Ann. Rev. Nucl. Part. Sci. 70 (2020)
Carr et al., Rept. Prog. Phys. 84 (2021) 11, 116902
Arbey et al., Eur. Phys. J. C 79 no. 8, (2019) 693
Barrau, et al., Astron. Astrophys. 388 (2002) 676
Herms et al.l, JCAP 02 (2017) 018

ANTIPARTICLES FROM PBHs

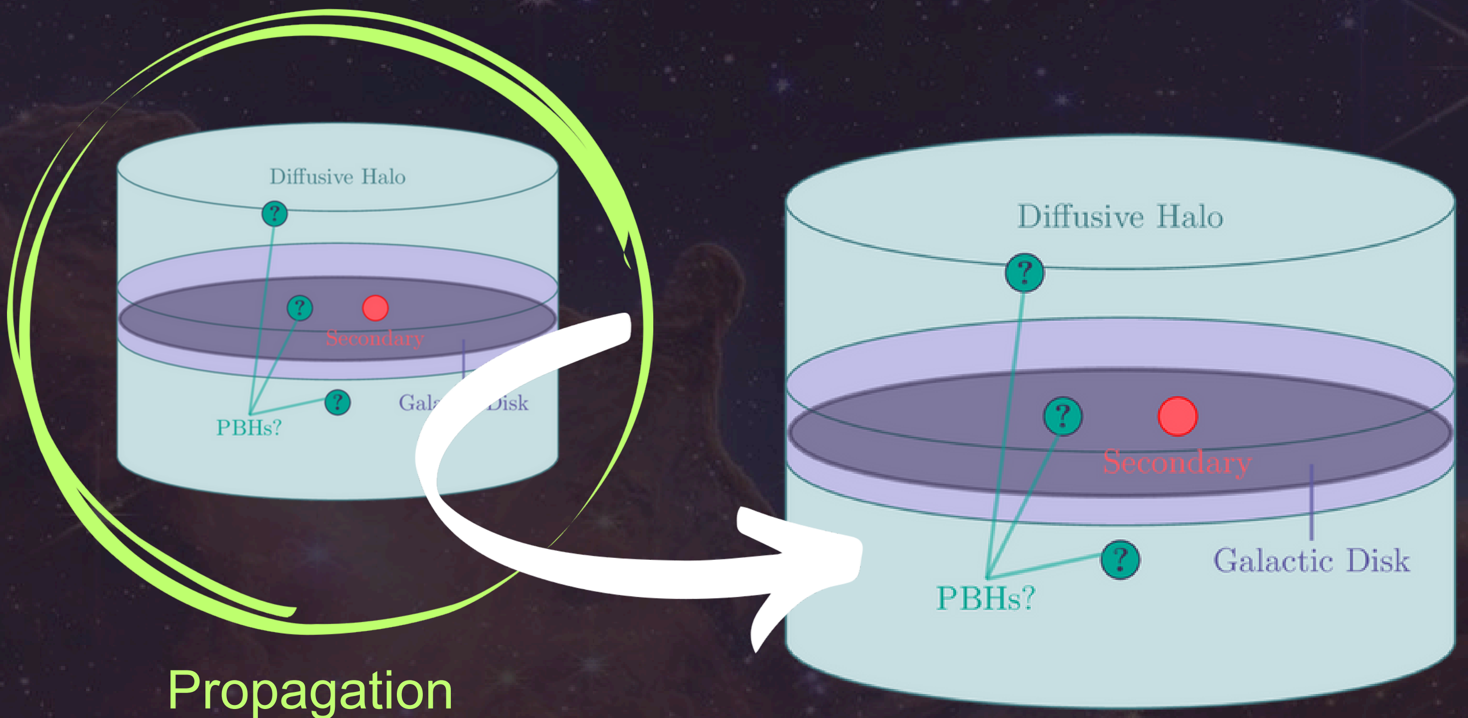


Source

- **Antinuclei** result from the **hadronization** of **quarks** and **bosons** directly emitted through the evaporation time
- PBHs can follow **extended mass distributions** (EMD); in our work, lognormal EMD at the formation time with critical mass μ_c and width σ
- EMDs **evolve over time** due to evaporation, but during the typical antinuclei propagation period, they stay **nearly constant: static cosmic-ray sources**

M.R. Mosbech et al., SciPost Phys. 13 (2022) 100
Herms et al.l, JCAP 02 (2017) 018

COSMIC RAYS PROPAGATION

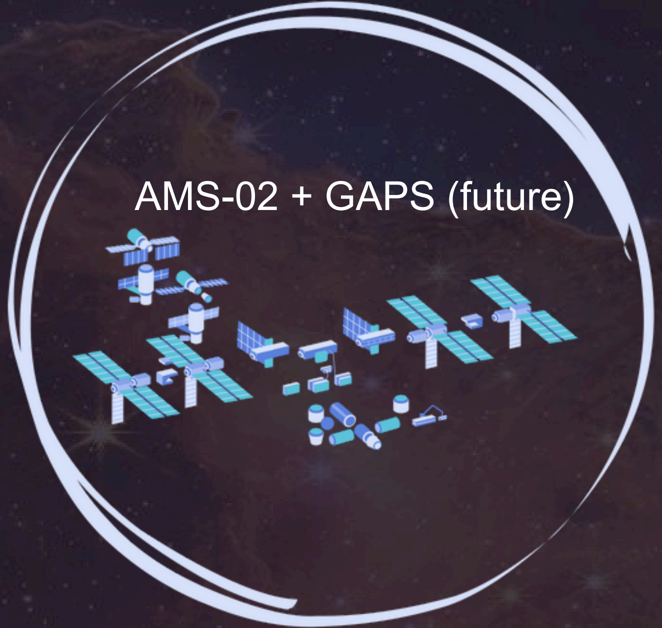


Propagation

- The Galaxy is a thin disk surrounded by inhomogeneous magnetic fields, that cause **cosmic rays** (**CRs**) to diffuse in the so called diffusive halo
- PBHs could be **located** anywhere **in the diffusive halo**
- Once produced by PBHs, the antinuclei **propagate** and arrive to the Earth
- In addition to this, **secondary antinuclei** are produced by the **spallation of primary** (mainly from supernovae shock waves) CRs over the H and He in the Galactic disk

V.S. Berezinskii, et al., *Astrophysics of cosmic rays*, Elsevier Science and Technology (1990)
Y. Genolini et al., Phys. Rev. D 99 (2019) 123028,

AMS-02 & GAPS



- The **Alpha Magnetic Spectrometer** (**AMS-02**) on the International Space Station has **measured cosmic-ray antiprotons** (latest data: 2021), which are still **well fitted by secondary production** models

- **No** confirmed detection of **antideuterons** to date

- The **General AntiParticle Spectrometer** (**GAPS**) is a balloon-borne future experiment in Antarctica that will search for **low-energy cosmic antinuclei** (< 0.25 GeV/n), where primordial black hole (PBH) signals could be most **visible**

AMS collaboration, Phys. Rev. Lett. 117 (2016) 091103.
AMS collaboration, Phys. Rept. 894 (2021)
T. Aramaki et al., GAPS, Appl. Phys. 74 (2016) 6.
GAPS collaboration, Astropart. Phys. 145 (2023) 102791

COMPUTATIONAL ASPECTS AND STATYSTICAL ANALYSIS

1

Through **BlackHawk**, we compute the Hawking radiation from a population of **PBHs** with a **lognormal mass distribution**,
for different μ_c and σ

2

We derive the antiproton emission with **CosmiXs** from quarks and bosons

3

We propagate the $\bar{p}$ flux with **USINE** in the **BIG** configuration

4

By comparing with AMS-02 2021 data, we derived **UL PBH densities** at 95% CL

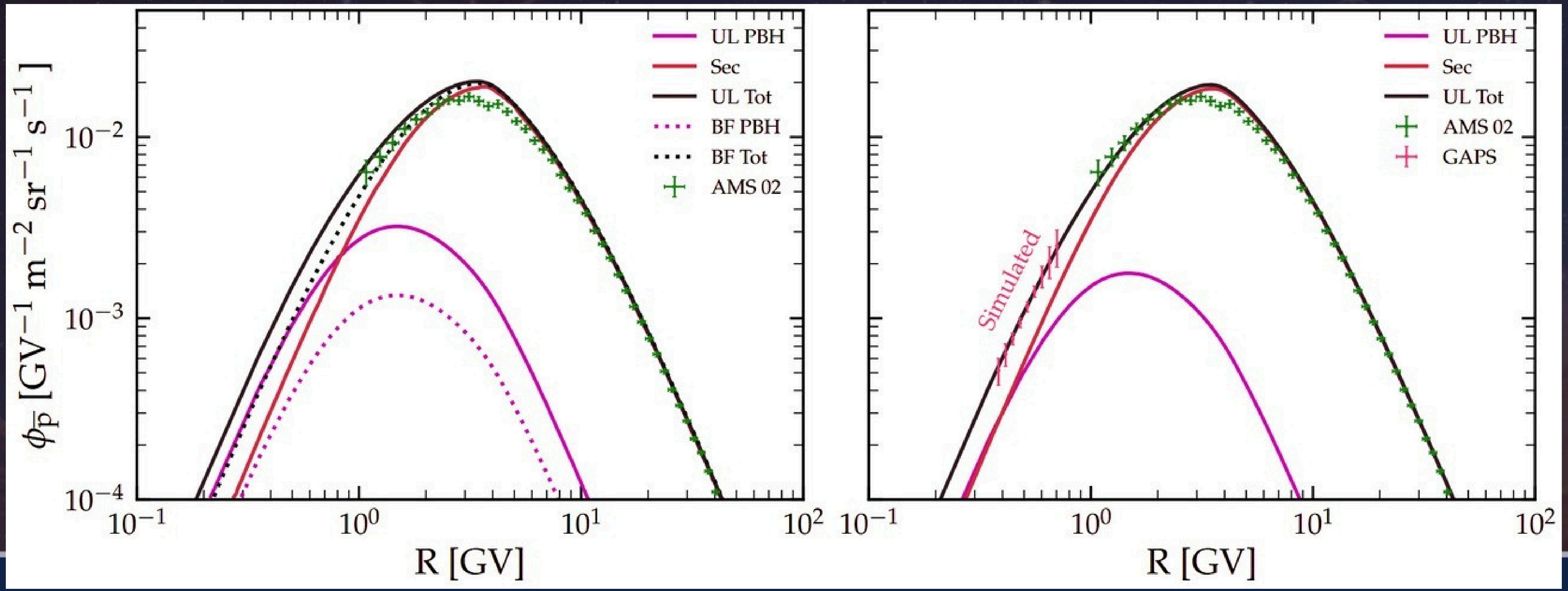
5

We evaluate the antideuteron primary fluxes using the **Argon-Wigner coalescence of CosmiXs**, and applying the **antiproton density bounds**.

Y. Genolini et al., PRD 99 (2019) 123028
M. Boudaud et al., Phys. Rev. Res. 2 (2020) 02302
F. Calore et al., SciPost Phys. 12 (2022) 16
A. Arbey et al., Eur. Phys. J. C 79 (2019) 693
C. Arina et al., JCAP 03 (2024) 035
M. Di Mauro et al., 2411.04815
D. Maurin, Communications 247 (2020) 106942

RESULTS

ANTIPROTON FLUXES



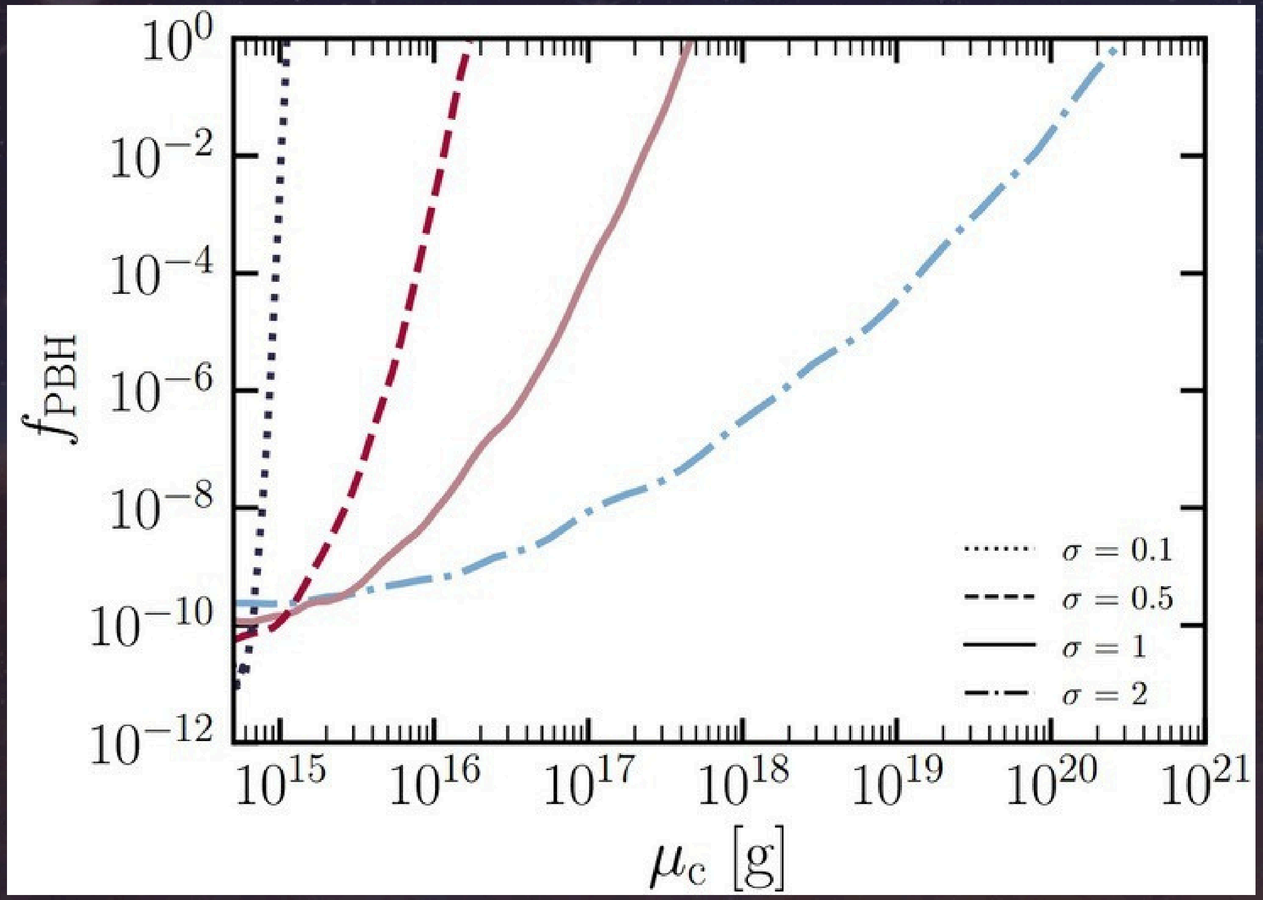
- The **Upper Limit** (**UL**) is evaluated at 95% C.L. with **AMS-02 2021 data only** (left) and adding **GAPS simulated** data (right) - Best Fit (BL) only illustrative
- AMS-02 2021 data are well fitted by the secondary contribution → **suppressed PBH contribution**
- GAPS data would help to investigate the **low energy tail** where the PBH contribution is significant

AMS collaboration, Phys. Rept. 894 (2021) GAPS collaboration, Astropart. Phys. 145 (2023) 102791
F. Calore et al., SciPost Phys. 12 (2022) 163

P. De la Torre Luque et al. PRD 110 (2024) 123022
M. Boudaud et al., PRL 122 (2019) 041104
A. Arbey et al., PRD 101 (2020) 023010

BOUNDS ON PBHs AS DM

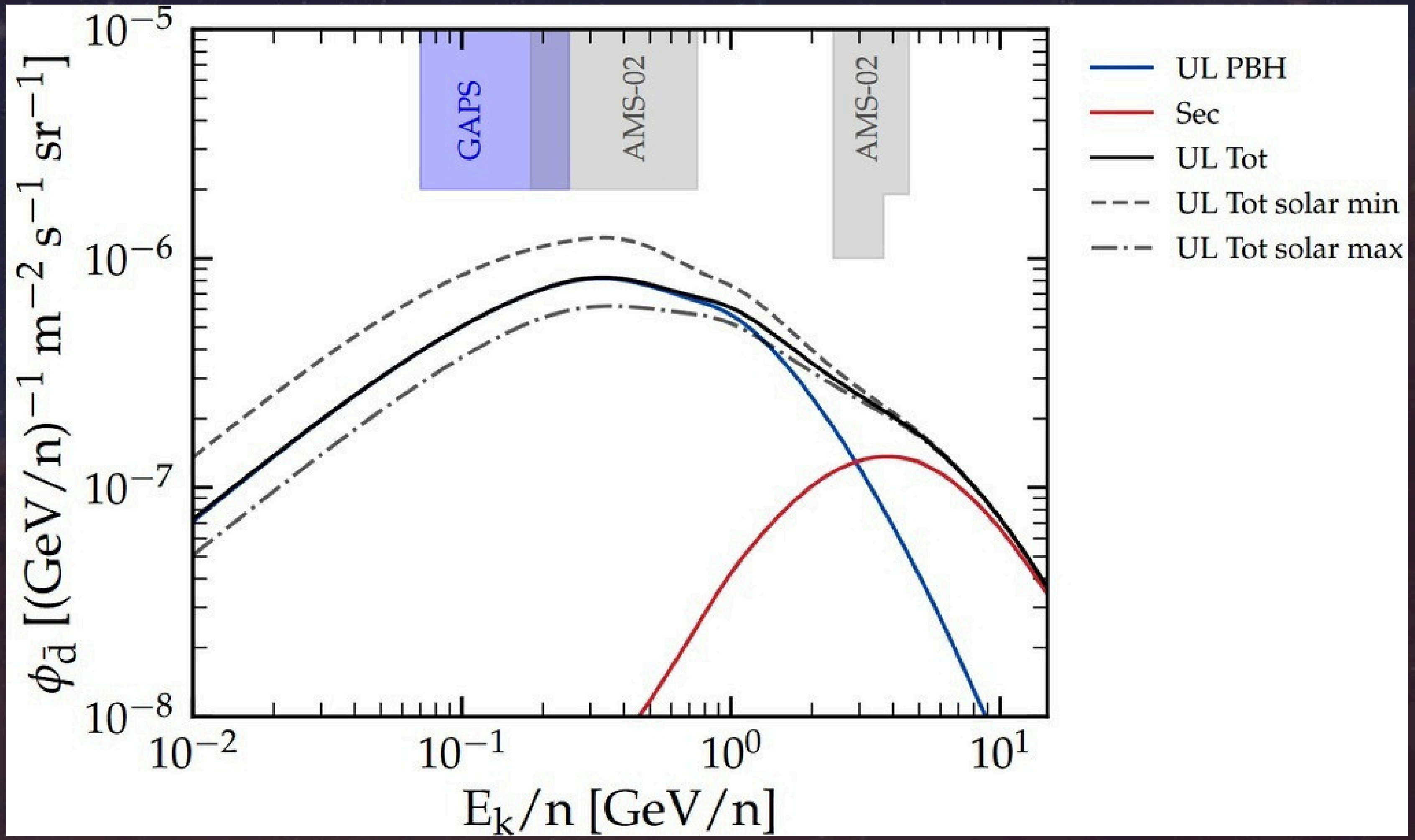
$$f_{\mathrm{PBH}} = \frac{\rho_{\mathrm{PBH}}}{\rho_{DM}}$$



- 95% CL UL on ρ_{PBH} and f_{PBH} with **AMS-02 2021** data
- Higher widths imply that a bigger portion of the asteroid mass range is constrained, although the **constraining power gets reduced** with increasing mass

ESTIMATED ANTIDEUTERON FLUX

- We applied the **UL densities from antiprotons**
- The PBH contribution is more relevant than the secondary one below 3 GeV/n, but it is **far from GAPS** and **AMS-02** sensitivities, even accounting for solar modulation effects
- If antideuterons were to be detected, they **could not be explainable by PBHs only** as BSM physics



$$\mu_c = 10^{15} g$$
$$\sigma = 1$$
$$\rho_{\rm PBH} = 5.2 \times 10^{-11}\ {\rm GeV\ cm^{-3}}$$

M. Di Mauro, et al., 2411.04815
T. Aramaki et al., Appl. Phys. 74 (2016) 6
T. Aramaki, et al., Physics Reports 618 (2016) 1

arXiV:2505.04692

CONCLUSIONS

- We **revisited** the **CR antiproton and antideuterons signatures from PBH** evaporation in the Galaxy
- We **improved previous calculations** by assuming a lognormal PBH mass distribution, using updated Galactic propagation parameters and the most recent AMS-02 antiproton data within a sophisticated statistical analysis
- We cast **competitive bounds** with antiprotons on f_{PBH} in the asteroid mass range
- We estimated that if one or more **antideuterons** were to be measured by AMS-02 or by GAPS, they would clearly be a signal of new physics, but **not completely expainable with PBH emission**

Thanks! Questions?