Constraints on the Antistar Fraction in the Solar System neighborhood from the 10-year Fermi-LAT gamma-ray source catalog

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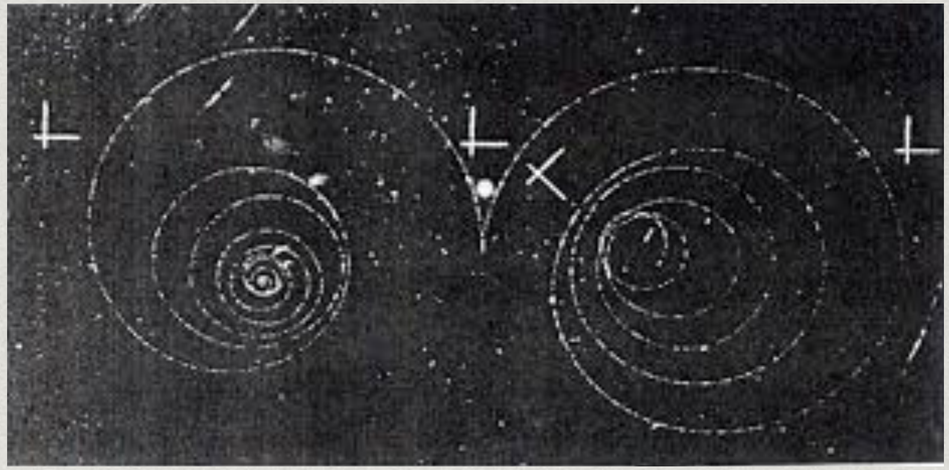
Dupourqué et al. Phys. Rev. D 103, 083016 2021

Outline

- **Matter-antimatter asymmetry**
- Constraining antistars using *Fermi*
- Upper limits
- Summary and perspectives

Matter-antimatter asymmetry

- Laws of physics (almost) symmetric
- Observations show that the Universe is not symmetric
- Major open question in particle physics/ astrophysics/cosmology



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Origin of the asymmetry

- Baryogenesis, cf. Sakharov conditions (BUT no observations of baryon number violation so far and CP violation in quark mixing too small)
- Leptogenesis (evidence for leptonic CP violation in neutrino oscillations from T2K)
- Dirac-Milne Universe: antimatter has a negative gravitational mass (AEgIS experiment)
- CPT-symmetric Universe: Big Bang forms a Universe-antiUniverse pair (upgoing ANITA events)
- …

AMS-02: detection of anti-Helium?

- Candidate anti-He events with rate ~1/year, including a few anti-He-4
- If confirmed
  - Cannot be produced by cosmic-ray spallation
  - Nearby antimatter domain?
  - Dark-matter decay? (seems difficult)

A nearby antimatter domain?

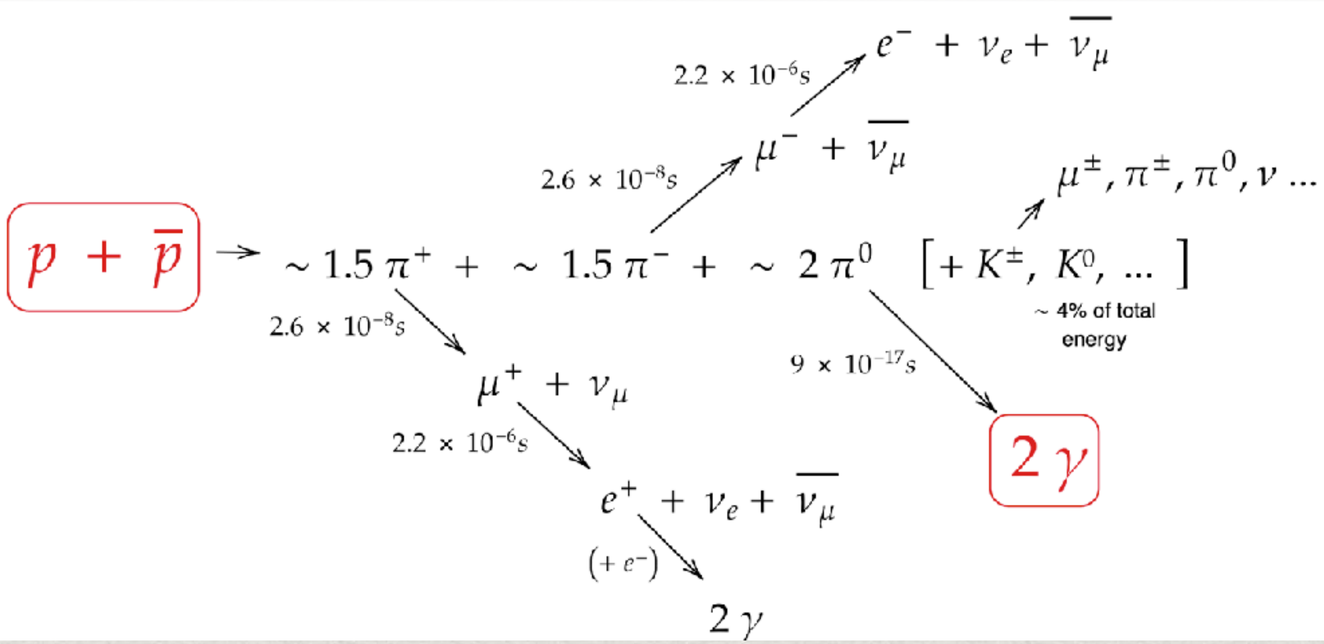
The discovery of a single anti-helium nucleus in the cosmic-ray flux would definitely point toward the existence of stars and even of entire galaxies made of anti-matter

Salati et al. Nucl. Phys. B Proc. Supp. 70 1–3 1999

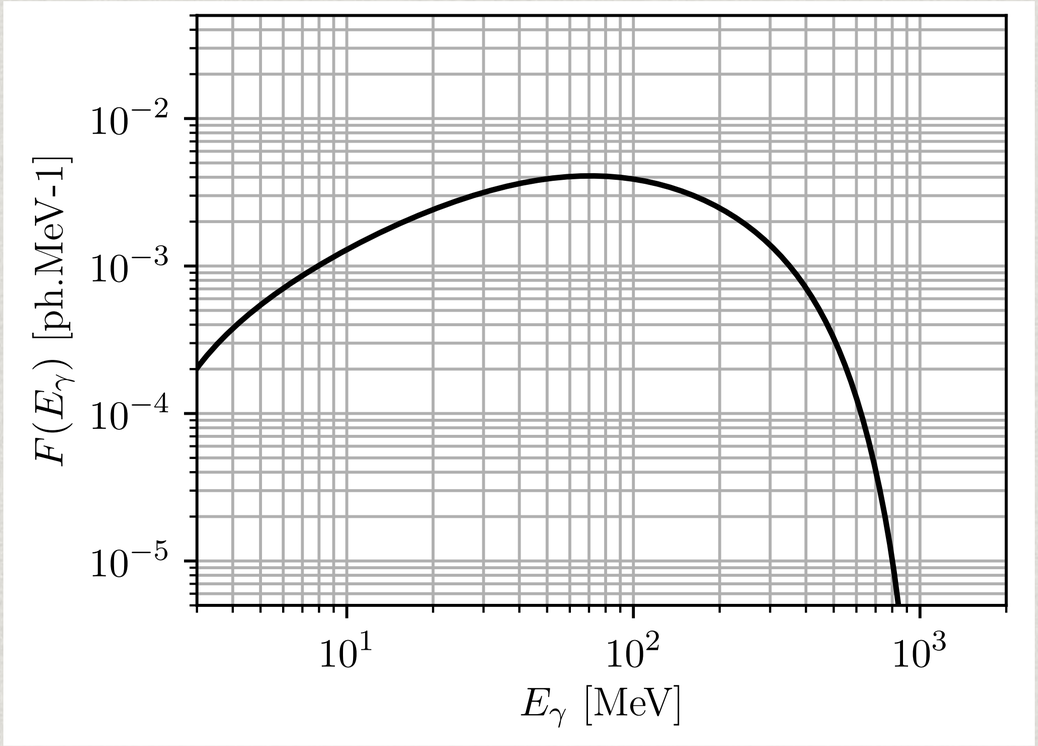
- Anticlouds or antistars
- Challenge #1: how do they form? (e.g., Affleck-Dine mechanism)
- Challenge #2: how do they manage to survive?
  - Antistars in galactic halos accrete matter slowly enough to survive!
- Challenge #3: how are the antinuclei accelerated?

Credit: Sara Michielin/Co.Scienza

Gamma rays as an antimatter tracer



Parametrization of p-antip gamma-ray production spectrum from measurements at CERN PS
Backenstoss et al. Nucl. Phys. B 228 3 424-438 1983



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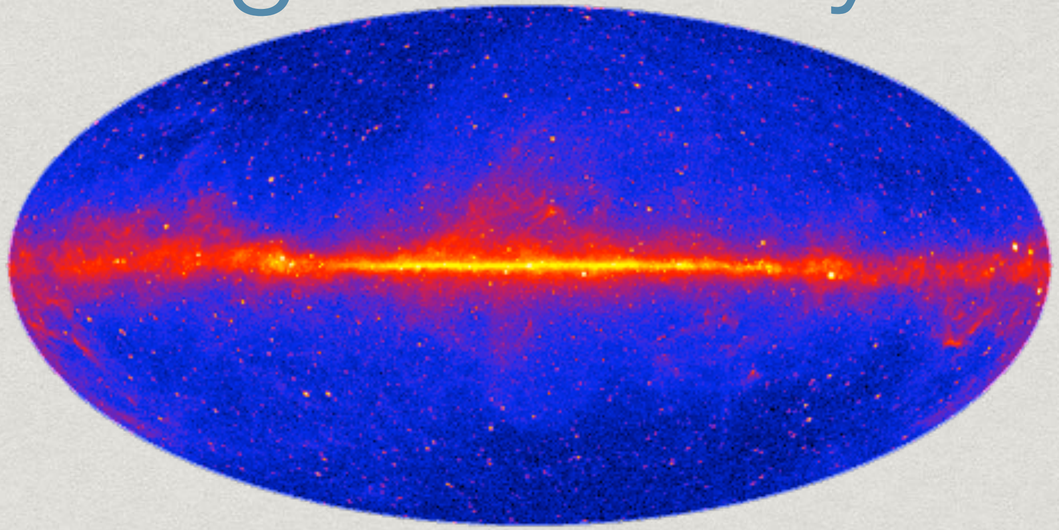
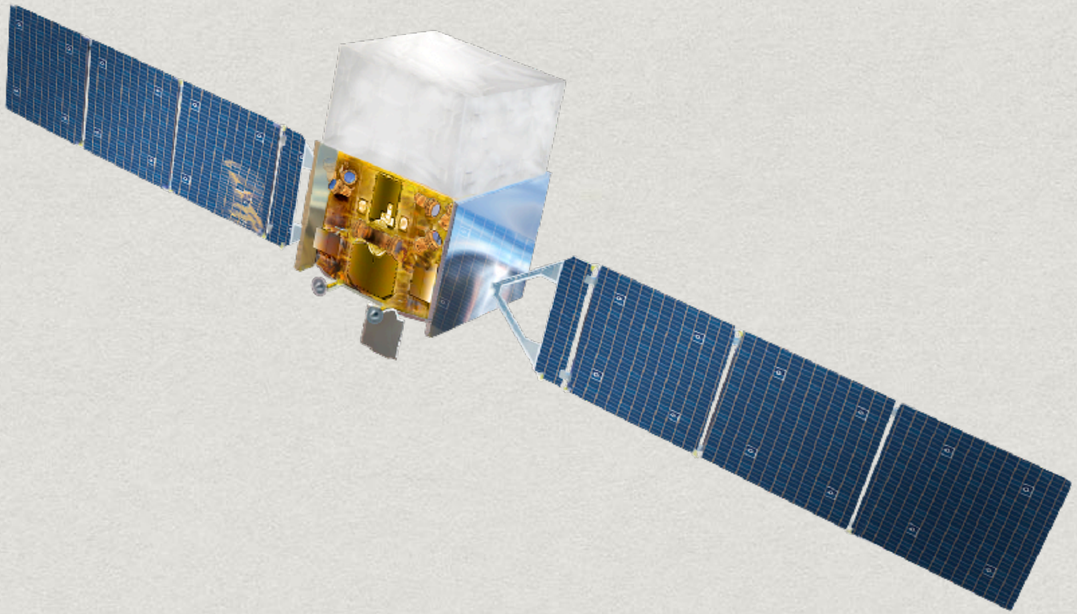
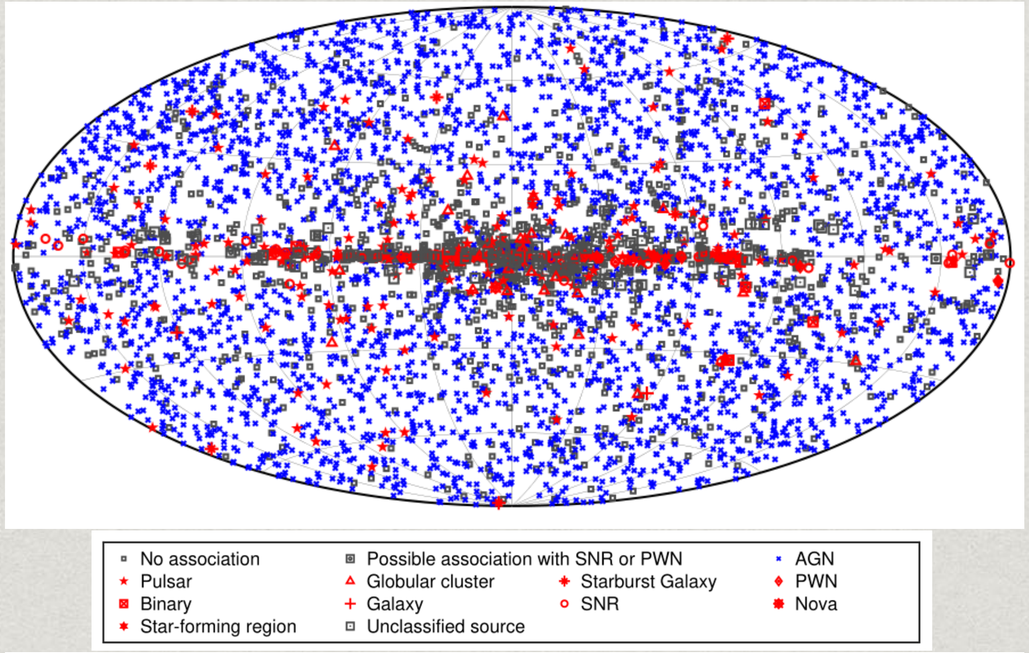
The 10-year *Fermi*-LAT gamma-ray source catalog

- gamma-ray data
  from 50 MeV to 1 TeV
- 5788 sources

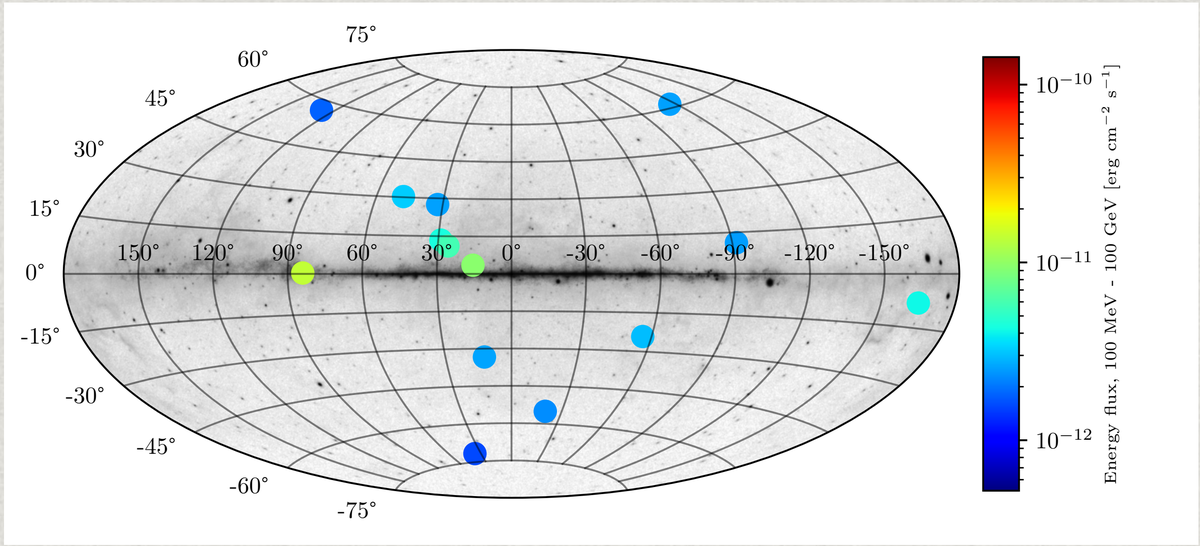






Antistar candidates: selection

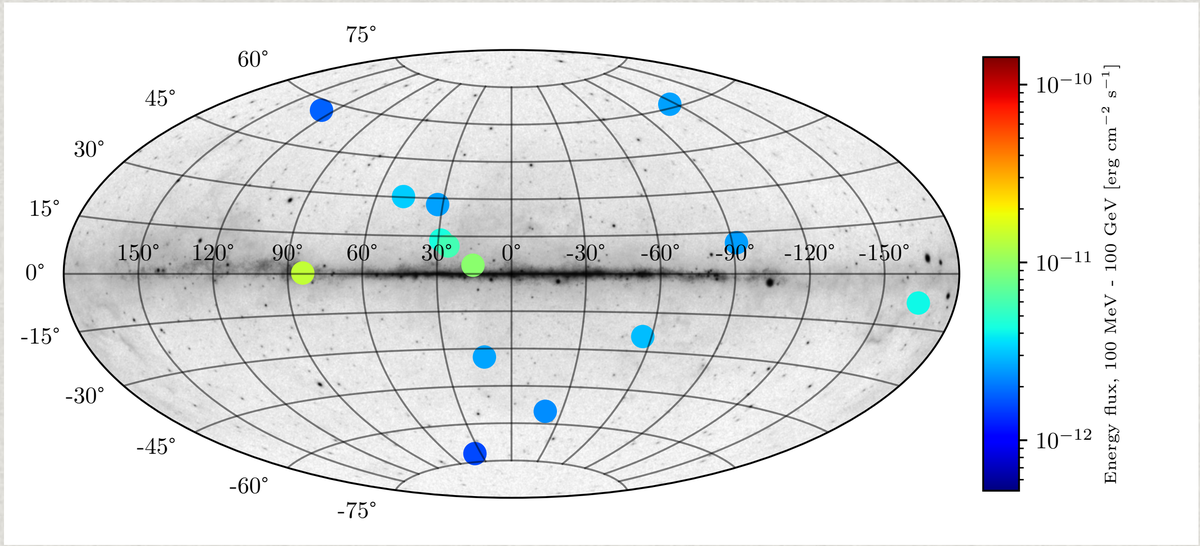
- Exclusion criteria
  - associated to known object via multiwavelength observations
  - extended
  - significant (> 3σ) emission above 1 GeV
  - flagged for analysis problems
- **14 candidates**



Antistar candidates: what are they?

- Properties
  - no obvious pattern on the sky
  - weak sources close to detection threshold
- Alternative explanations
  - pulsars, active galactic nuclei
  - defects of interstellar emission model

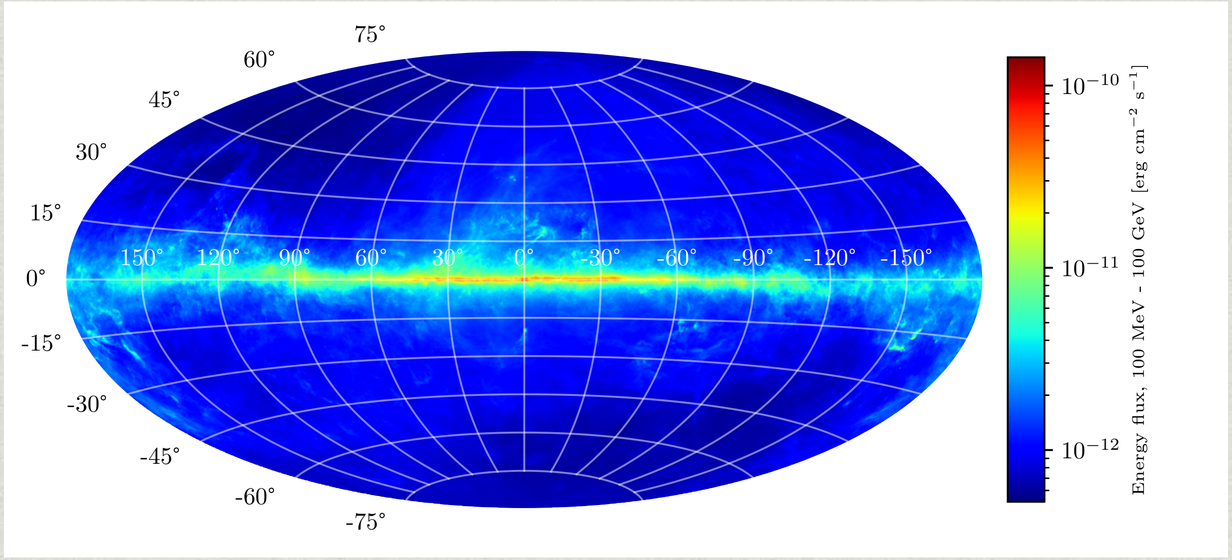
➡ Upper limits on antistar fraction/density



LAT sensitivity to antistars

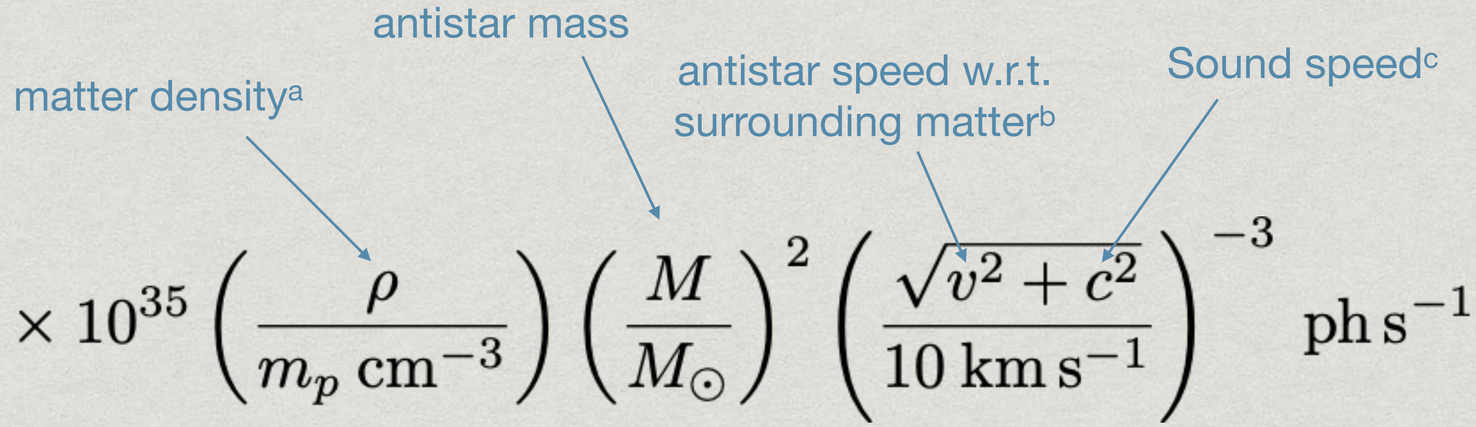
- Input
  - instrument response
  - background model
  - matter-antimatter annihilation spectrum

➡ minimum antistar flux detectable by the LAT



Antistar luminosity

Bondi-Hoyle accretion + proton-antiproton annihilation



a. interstellar medium density

b. Galactic rotation curve

c. ≃ 1 km/s

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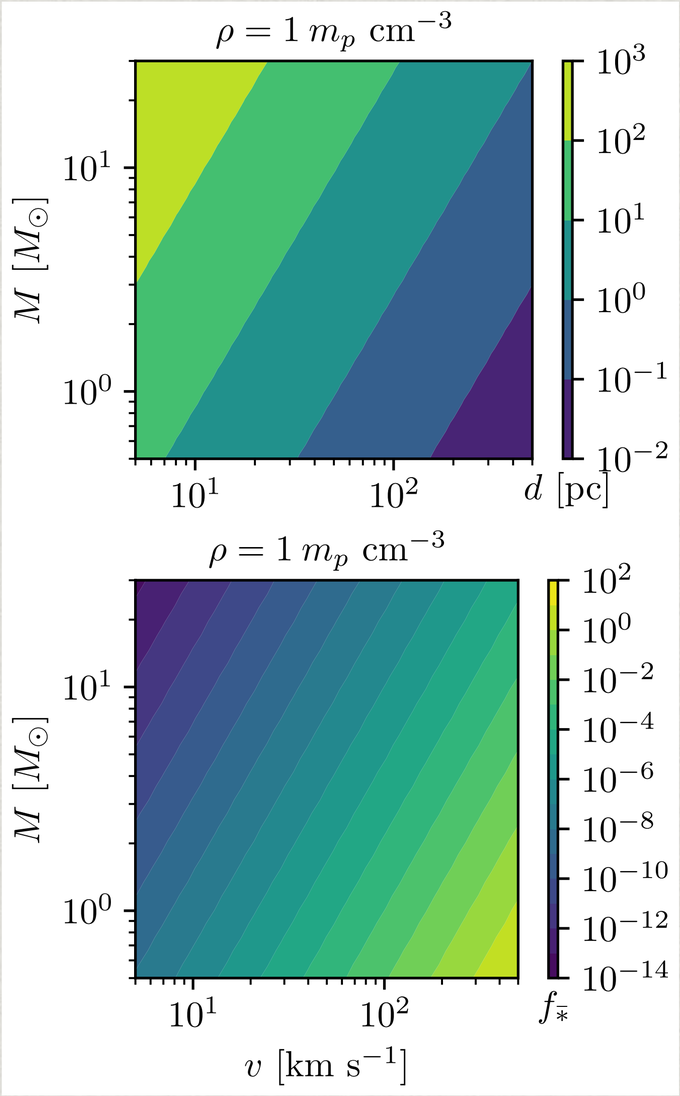
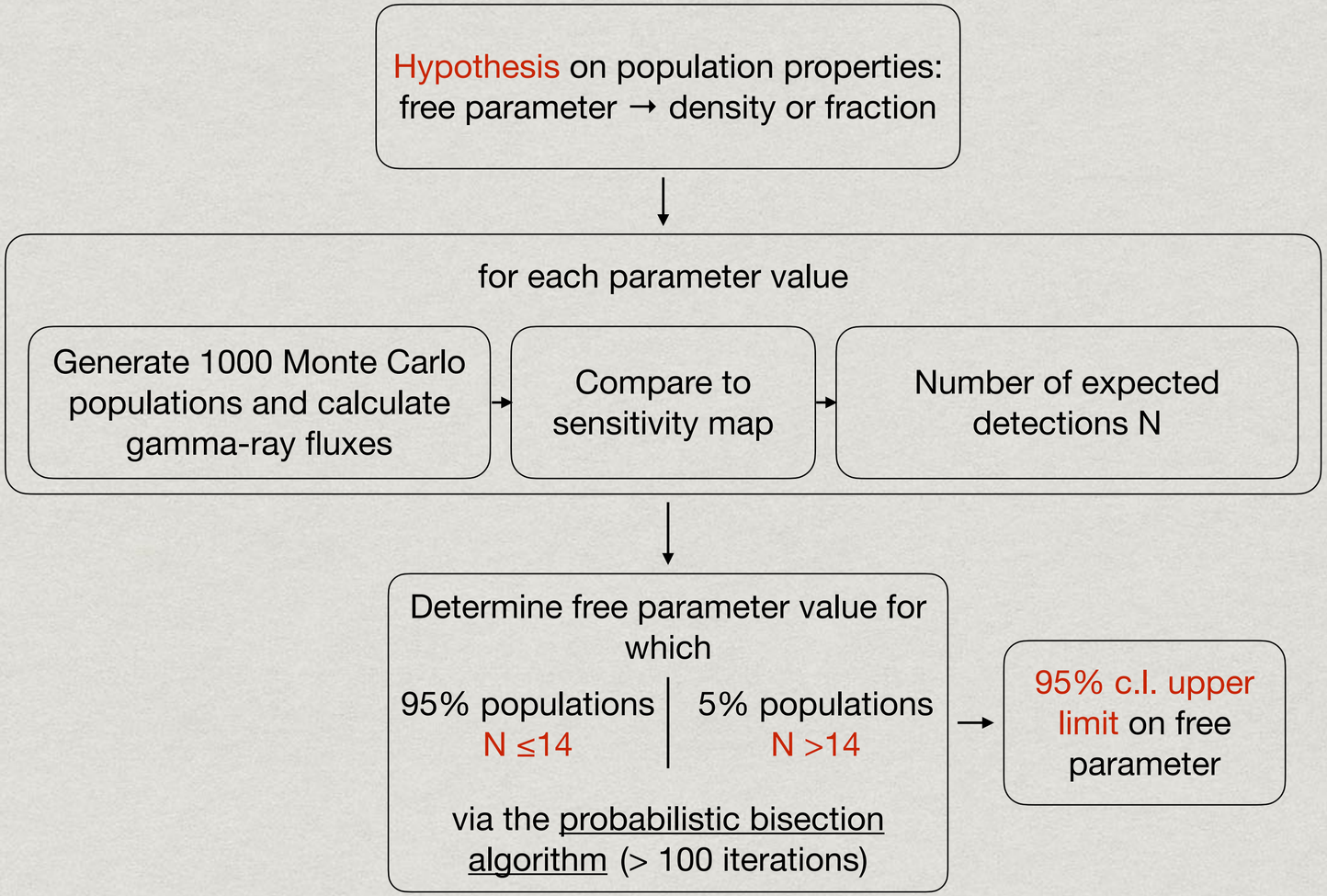
Parametric method

- Brightest candidate = closest antistar
- Hypothesis on mass and speed → distance
- At most one antistar in the defined volume

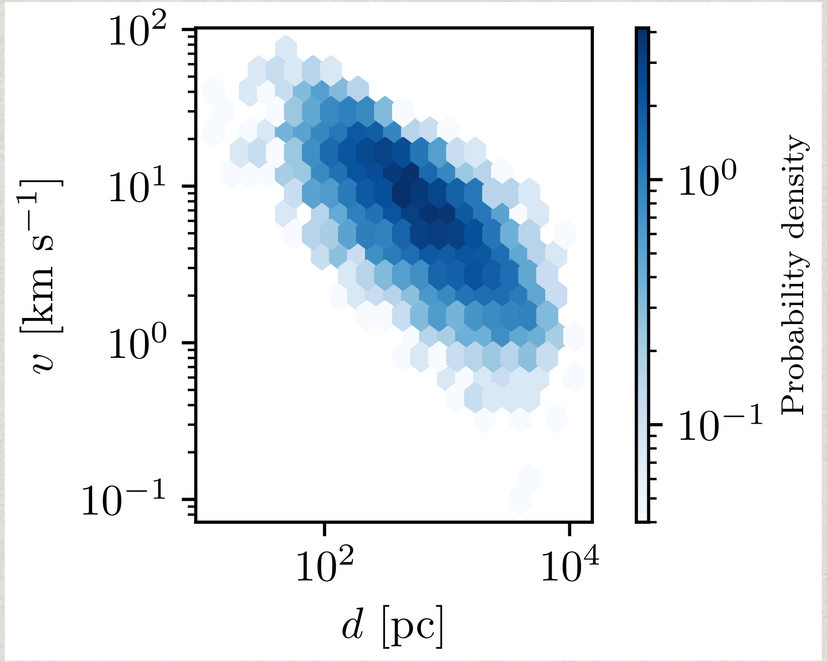


Monte Carlo method



Hypothesis I: star-like distribution

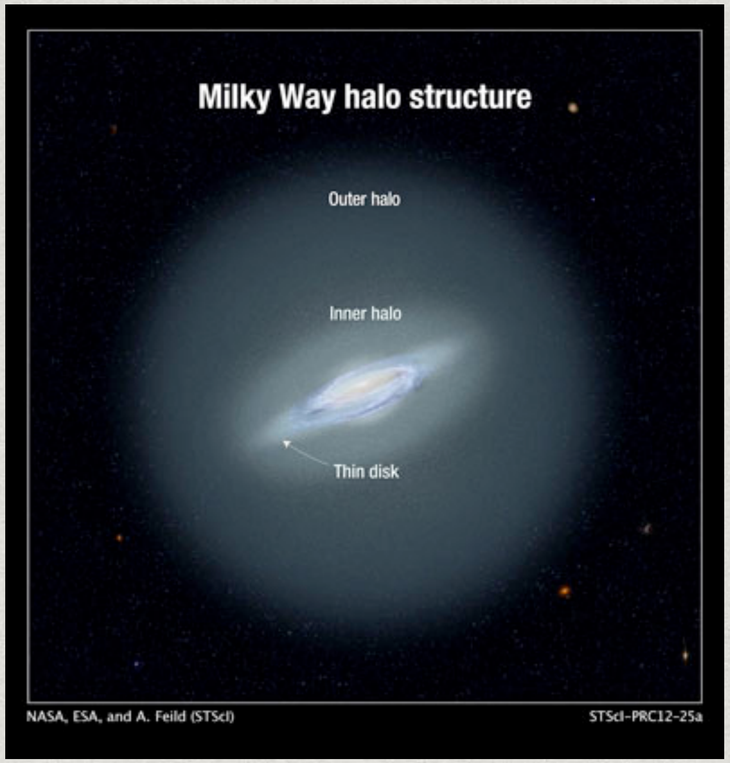
- Same spatial, mass, and velocity distribution as stars
  - no physical justification
  - compare with early results
- Galaxya stellar population synthesis code
- $f_{\bigstar} < 2.5 \times 10^{-6}$
  - Steigmann 1976 $< 10^{-4}$
  - von Ballmoos 2014 $< 4 \times 10^{-5}$



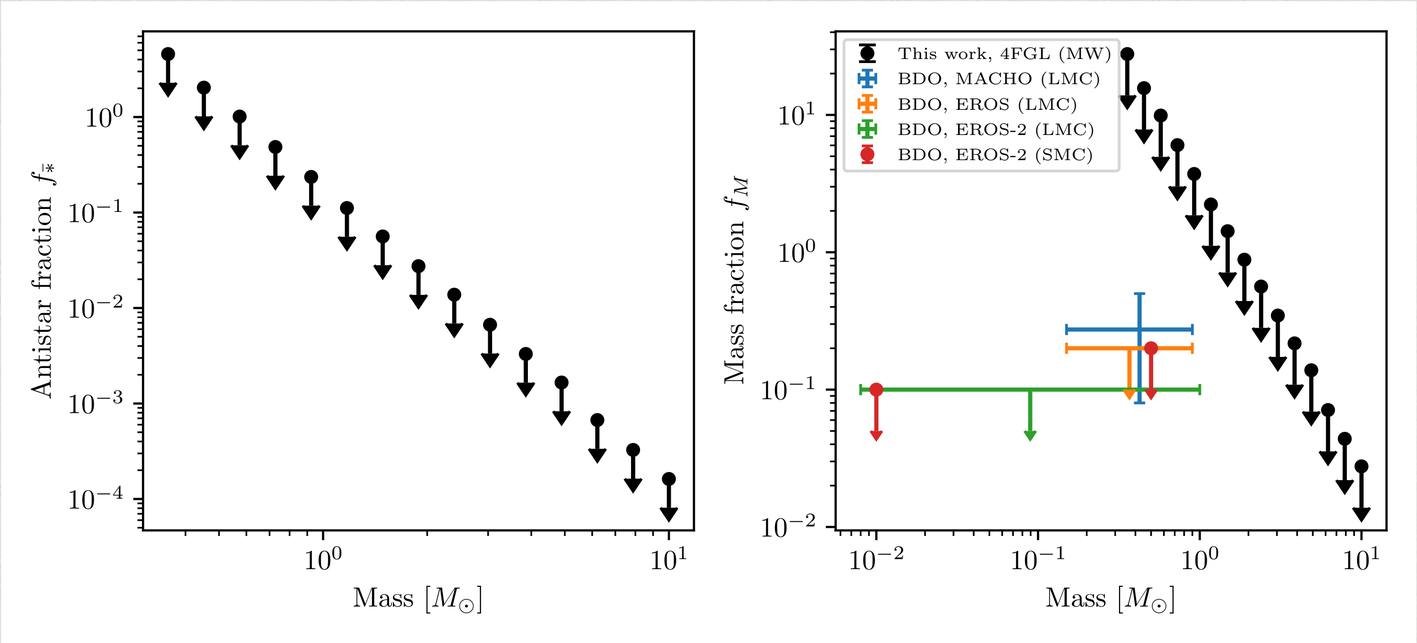
Most likely LAT detection
1 $M_\odot$, 10 km/s, 500 pc

Hypthesis II: primordial antistars

- Expected in some baryogengesis scenarii
- Subclass of baryo-dense objects (BDOs) aka MACHOs studied as dark-matter candidates
- Properties
  - uniform spatial distribution
  - high velocities (typical value 500 km/s)
  - unknown mass



Results: primordial antistars



- Mass fraction to compare with microlensing results: new results in the unexplored mass range > 2 $M_\odot$
- Only detectable by LAT < 60 pc: cannot exclude large numbers in the halo

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What's next?

- Use multiwavelength data to rule out antistar nature of candidates
  - 4FGL J1721.4+2529 identified as active galactic nucleus via optical spectroscopy
  - 4FGL J1806.2-1347 has a bright radio counterpart
  - more optical and radio observations on the way
- Deeper *Fermi*-LAT catalogs: 12-year catalog upcoming
- Develop acceleration/propagation models to jointly exploit gamma-ray and charged-particle measurements

Summary and conclusions

- Antistars get renewed attention due to the possible detection of anti-Helium
- Upper limits on fraction/density of nearby antistars improved by an order of magnitude
- The limits can be further improved by deeper *Fermi* LAT catalogs and multiwavelength observations …
- … or even more with a new telescope optimized in the MeV-GeV energy range (Astrogam, AMEGO)