Primordial Black Hole searches in the Very High Energy gamma-ray band

Rubén López-Coto
Instituto de Astrofísica de Andalucía, Granada, Spain
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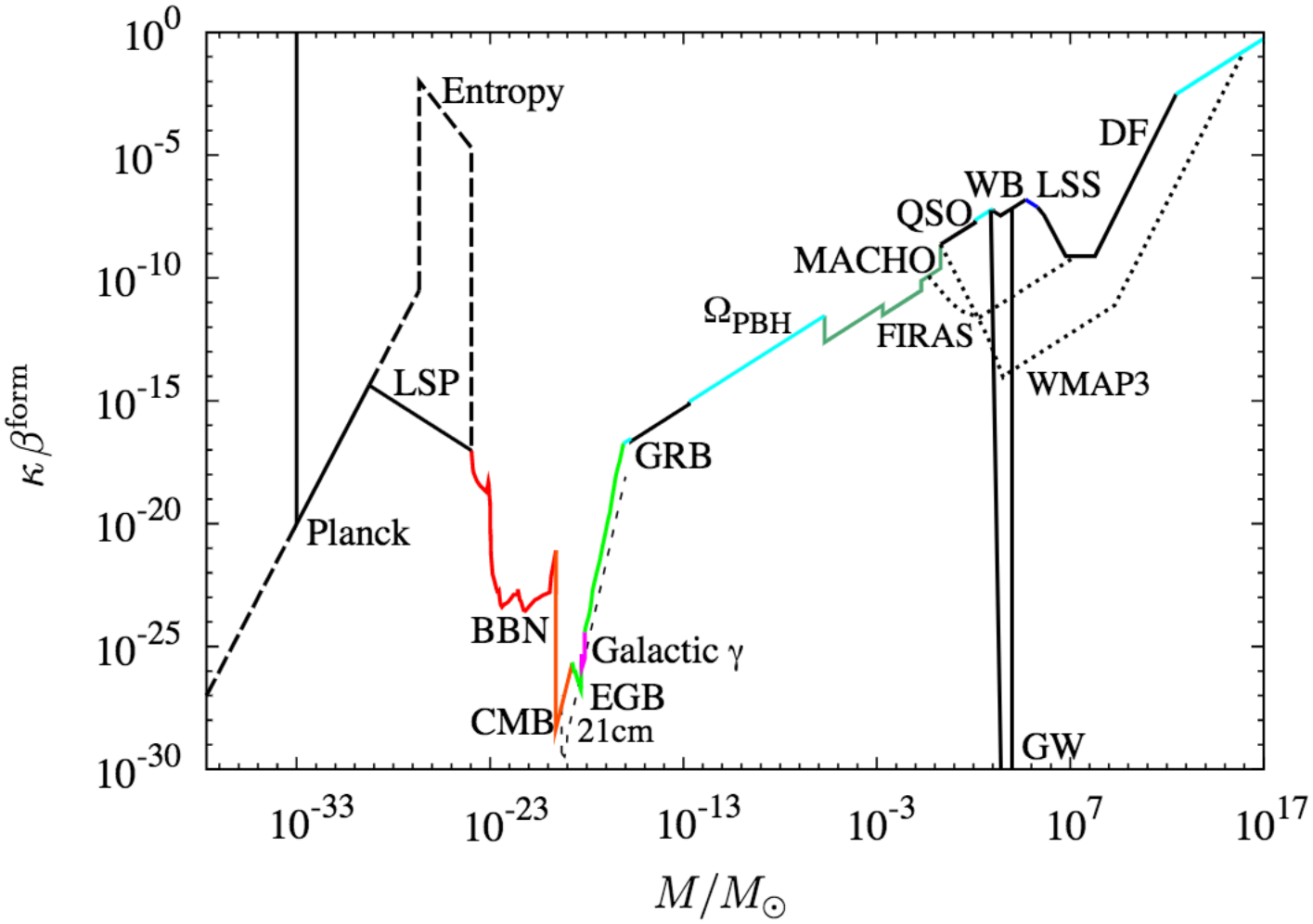
Search for Primordial Black Holes (PBHs) with VHE gamma-ray observatories

- What are Primordial Black Holes (PBHs)?
  - Black Holes that were originated in a radiation dominated era.
  - Predicted by S. Hawking in 1971.
  - Black Holes that were originated in a radiation dominated era.
  - They do not count for the total baryonic mass of the Universe.
  - Their masses can range from the Planck scale up to supermassive BHs.
  - PBH search regained interest after the detection of Gravitational Waves, being proposed as **possible contributors for DM**
- From the experimental point of view, different techniques trying to measure signatures of PBH
- Signatures for evaporation at different stages of the life of PBHs
  - They may have been originated with a wide range of masses
- BH evaporation spectrum is very well known, we need to search for this signature in our data

Limits for different masses

PBH fraction of Dark Matter in the Universe



Limits for evaporation now

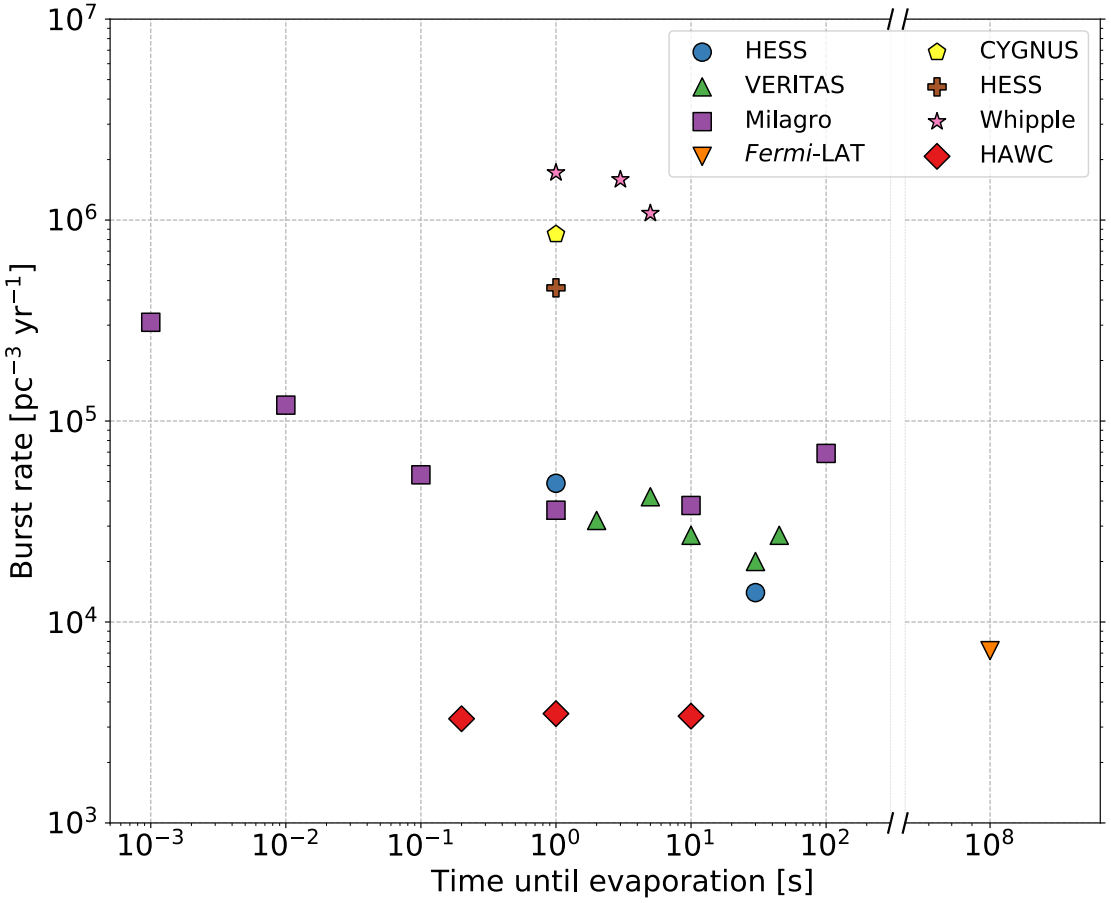
- Focus of this talk: PBHs evaporating **now**
- Current limits:
  - PBHs of mass ~10^{14} g, generated in the Big Bang, should be evaporating ~now
  - The Extragalactic Gamma-ray Background (E~100 MeV) gives very good ***Cosmological*** constrains on PBH evaporation [Burst Density < 10^{-6} pc^{-3} yr^{-1}]
  - On **Galactic** scales, clusters of PBHs should produce an anisotropy in the Gamma-ray measurements (E~100 MeV) [Burst Density < 0.42 pc^{-3} yr^{-1}]
  - On **kiloparsec** scales, the antiproton background can be used to derive limits [Burst Density < 10^{-3} pc^{-3} yr^{-1}]

Search for serendipitous events

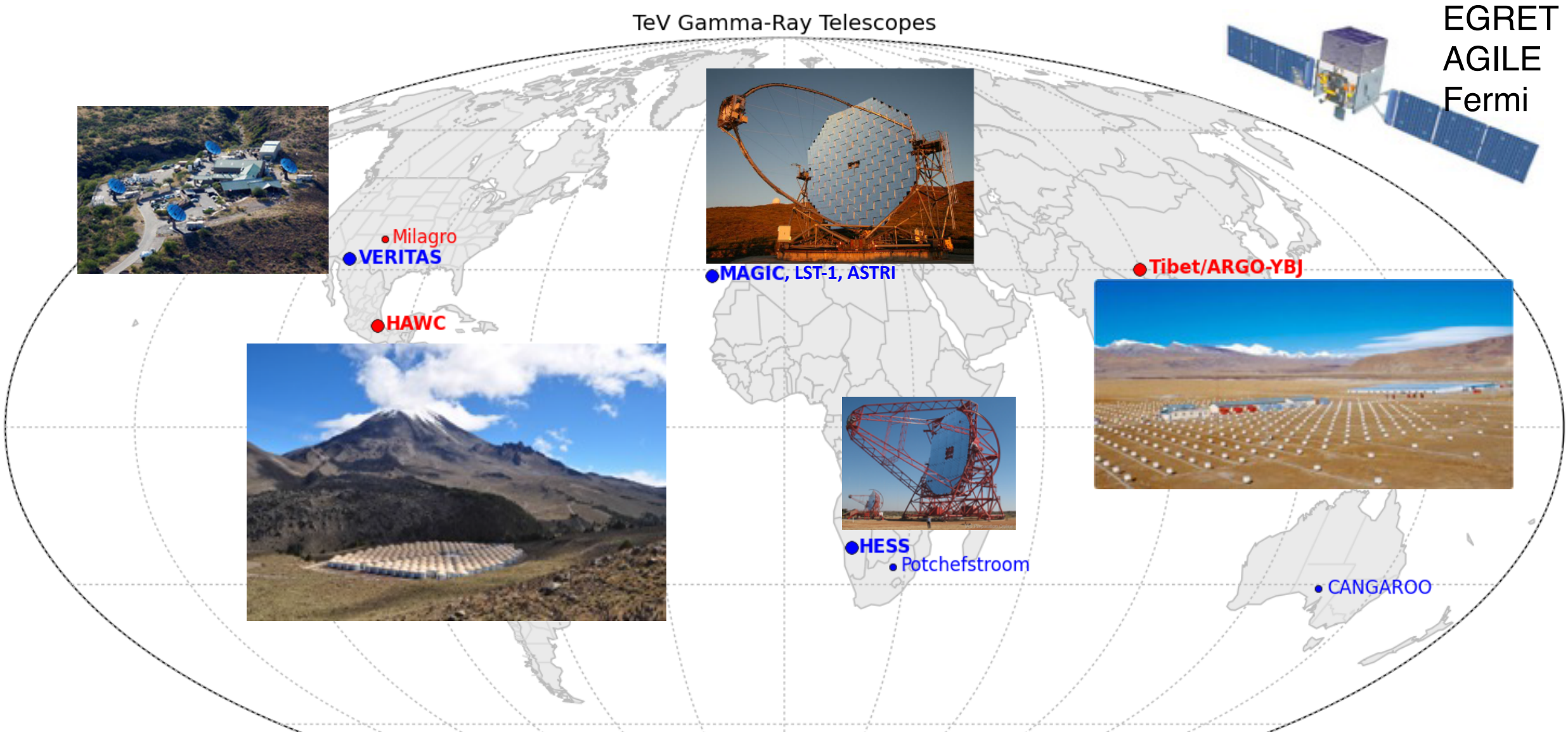
- VHE gamma-ray experiments have sensitivity to detect single events occurring at ~parsec distances

- Wide FoV detectors (Milagro/HAWC/SWGO)
  - Thanks to their large FoV and exposures, cover a large *Volume* and therefore can establish the best limits nowadays

- Imaging Atmospheric Cherenkov Telescopes (IACTs) (MAGIC/HESS/VERITAS/CTAO)
  - Thanks to their very good background rejection and the low expected signal, they are able to have the furthest *reach.*



Gamma-ray astronomy



EGRET
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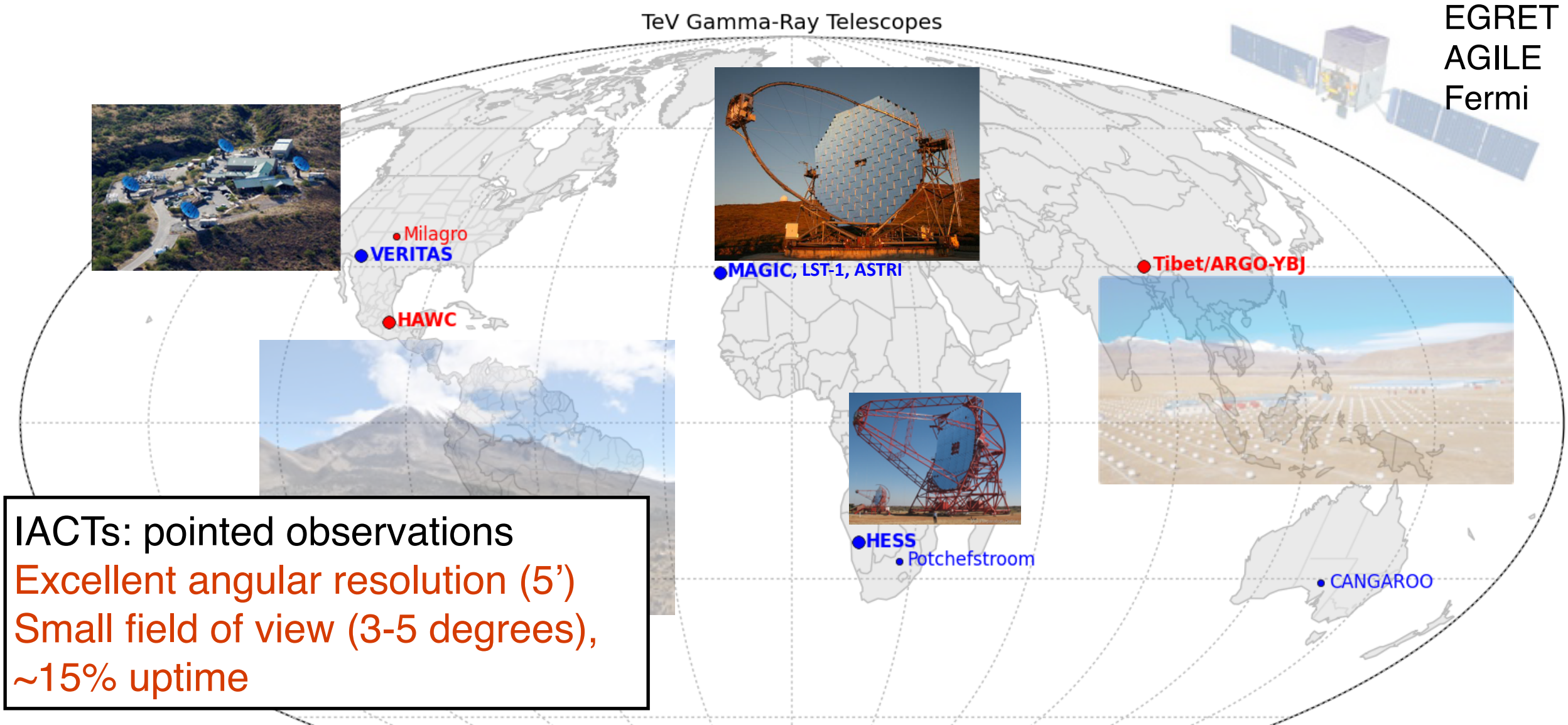
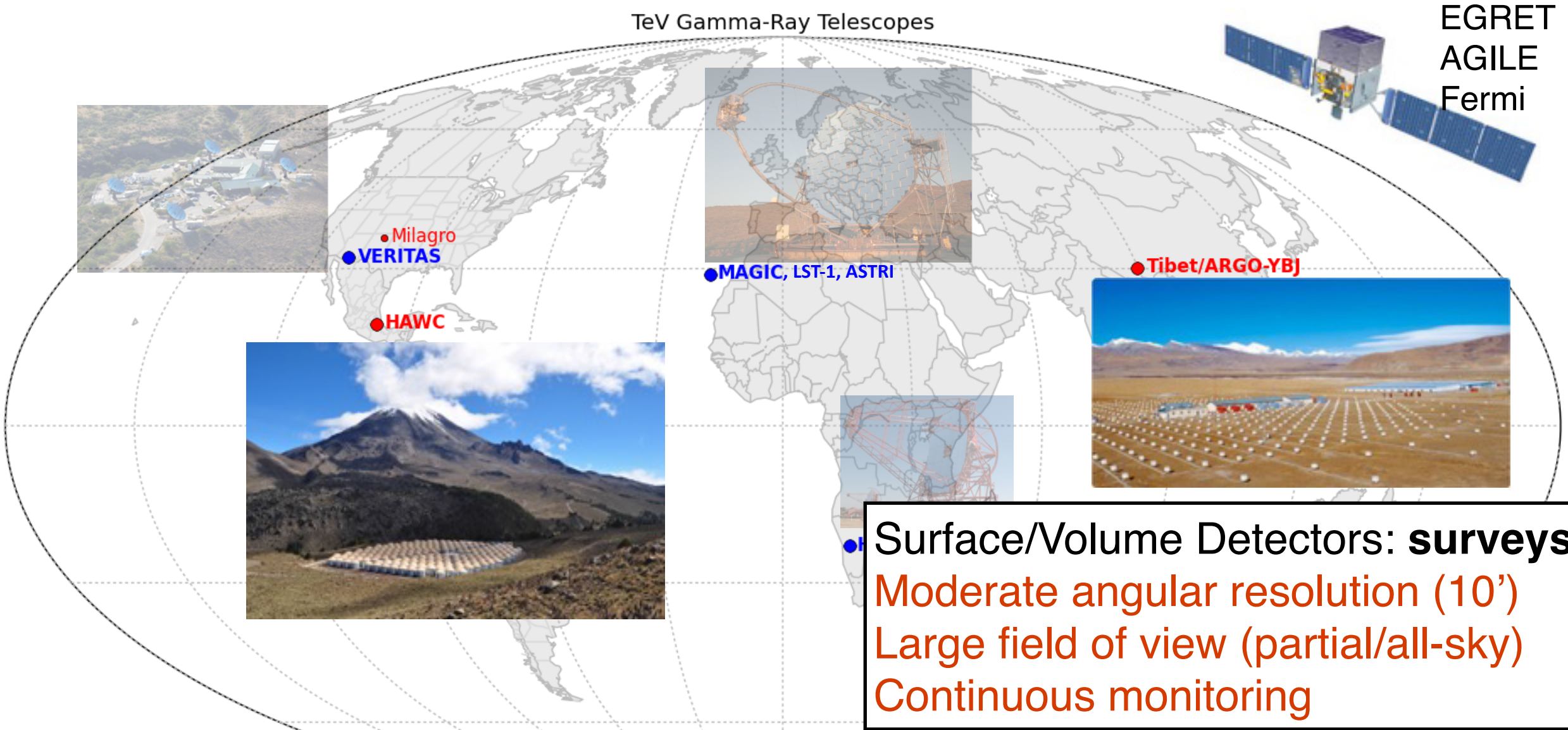
Fermi

Gamma-ray astronomy



IACTs: pointed observations
Excellent angular resolution (5')
Small field of view (3-5 degrees),
~15% uptime

Gamma-ray astronomy



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Surface/Volume Detectors: **surveys**
Moderate angular resolution (10')
Large field of view (partial/all-sky)
Continuous monitoring

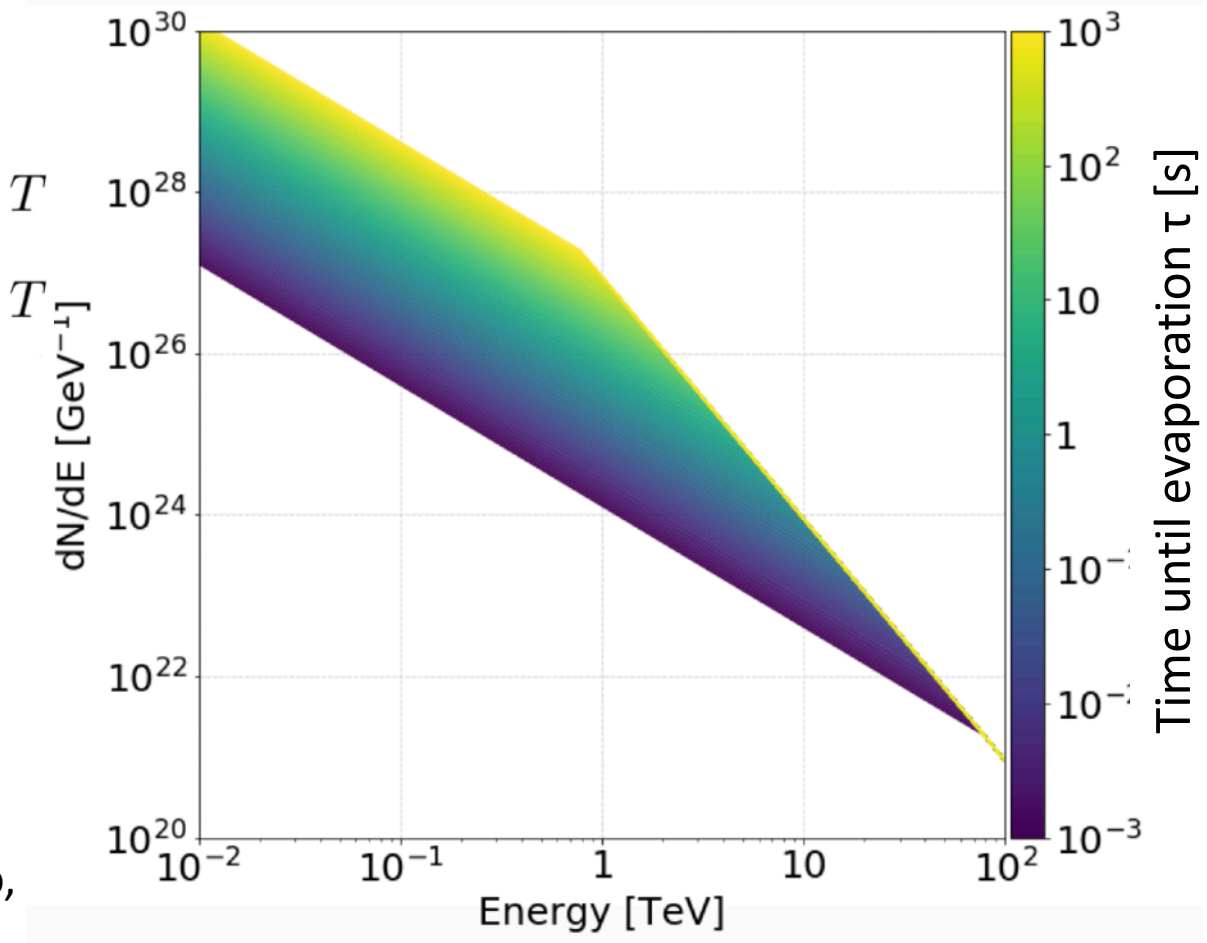
Evaporation models

- If we assume the evaporation model from Ukwatta, D. et al. (2016)

$$\frac{dN}{dE} \approx 9\times10^{35} \begin{cases} \left(\frac{1\ \mathrm{GeV}}{T}\right)^{\frac{3}{2}} \left(\frac{1\ \mathrm{GeV}}{E}\right)^{\frac{3}{2}} \ \mathrm{GeV}^{-1} & E < T \\ \left(\frac{1\ \mathrm{GeV}}{E}\right)^{3} \ \mathrm{GeV}^{-1} & E \geq T \end{cases}$$

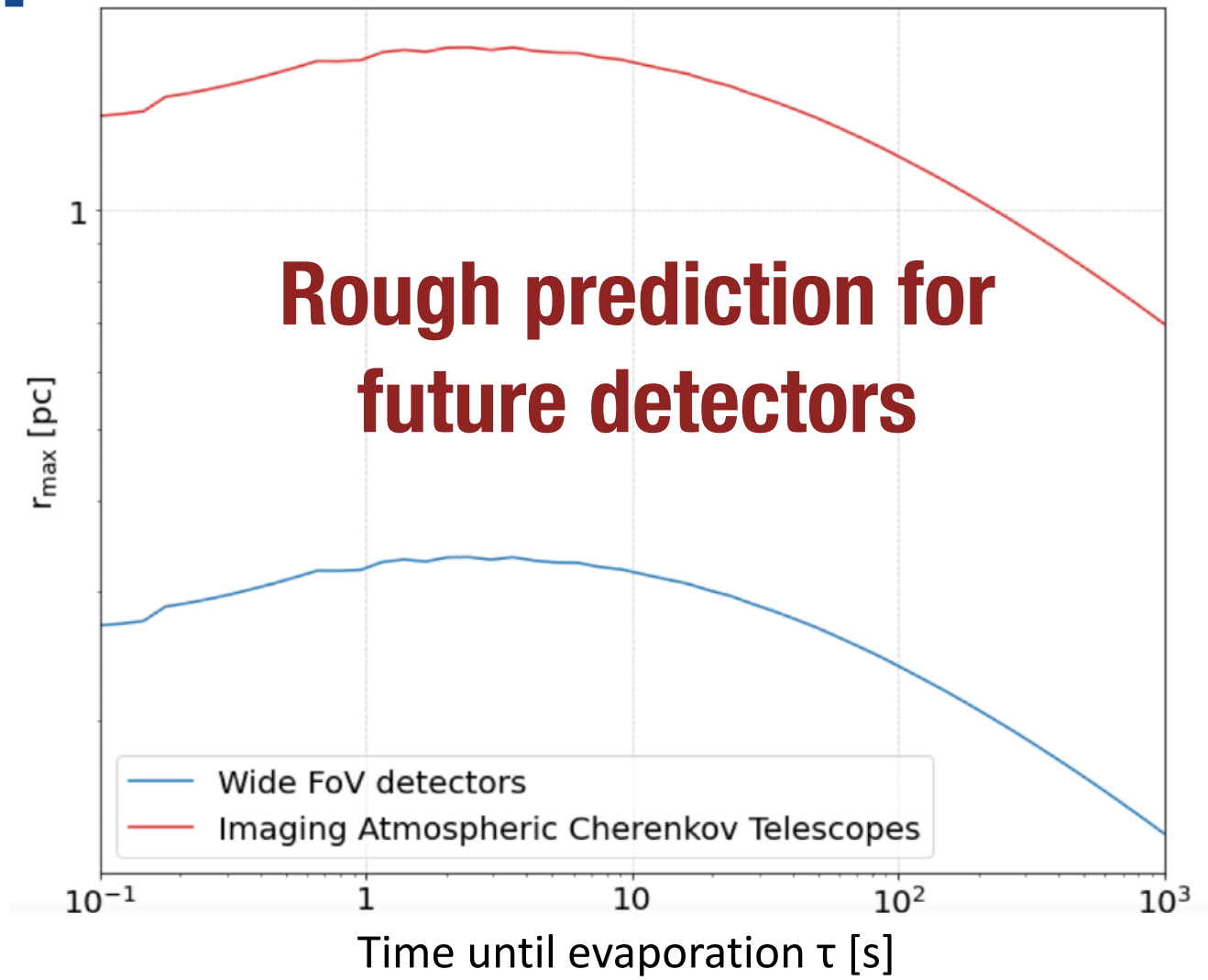
with $kT^* = 7.8\ (\tau/1s)^{-1/3}$ TeV

$$T_{BH} \sim \left(\frac{\hbar^2 c^5}{8^3 \pi^3 G k^3} \frac{1}{\tau}\right)^{1/3}$$

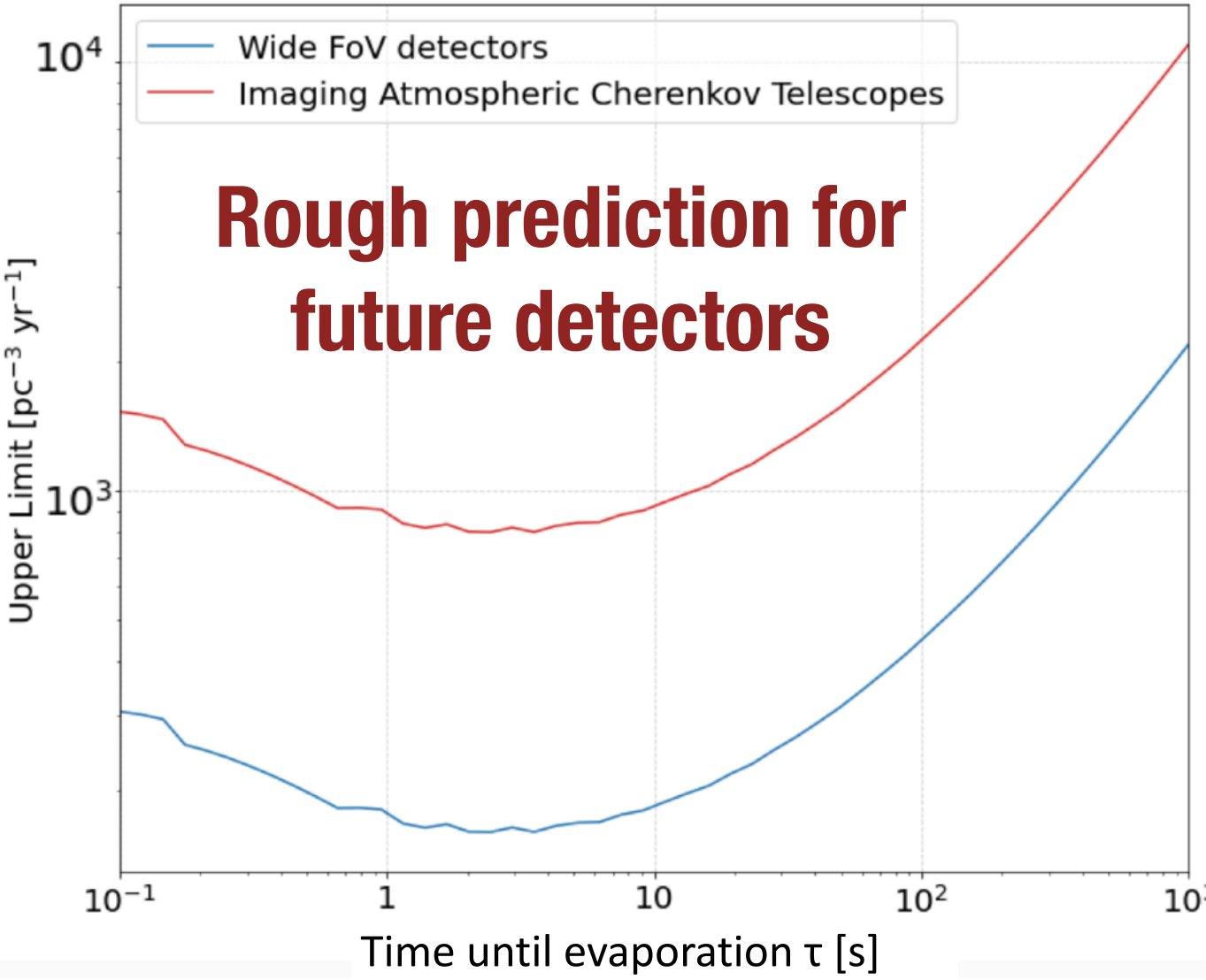


Maximum reach

- One needs to evaluate the expected number of events selecting a given duration for the search window.
  - The result is the maximum reach of your observation
  - Closest star located at ~1 pc
  - Goal: maximum possible distance



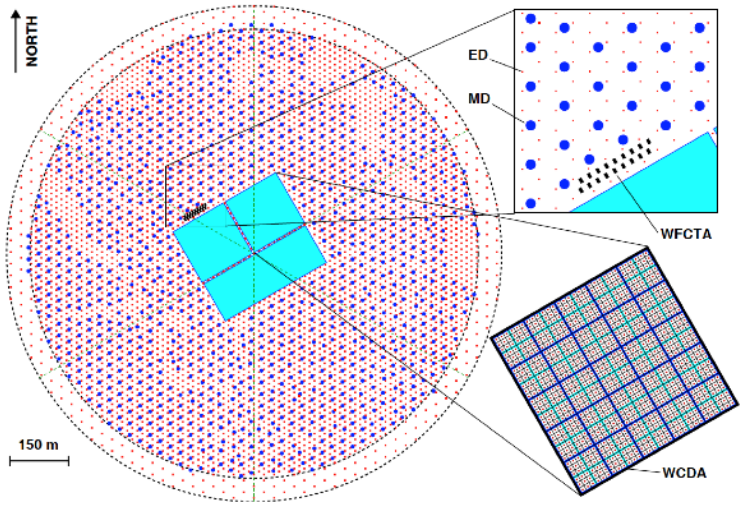
Upper limits

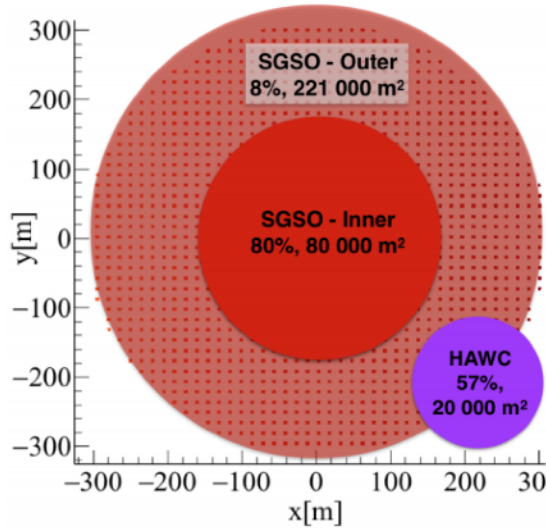


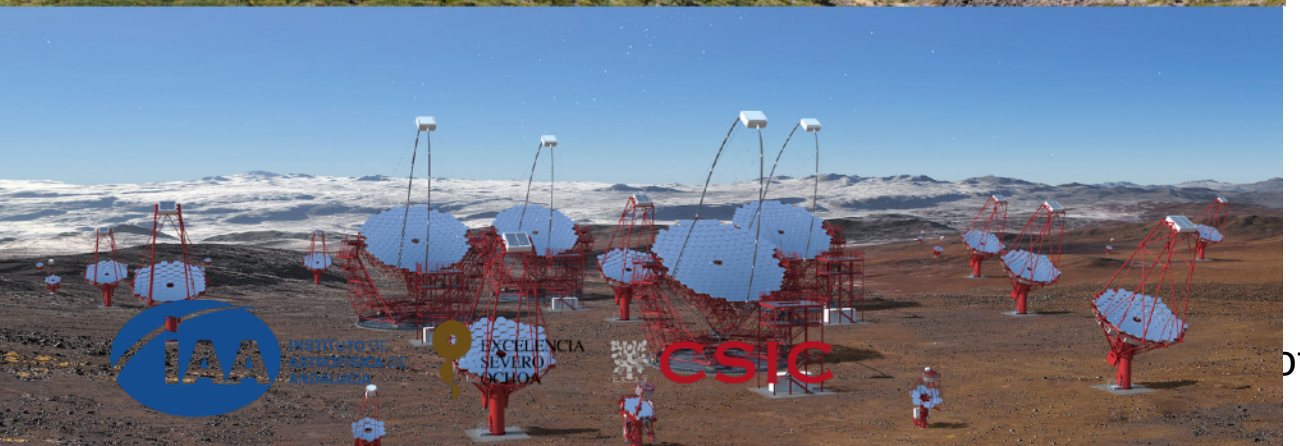
- Limits are put on the volume covered by the Field of View (FoV) of the detector.

Future

- Wide FoV experiments
  - LHAASO
  - SWGO

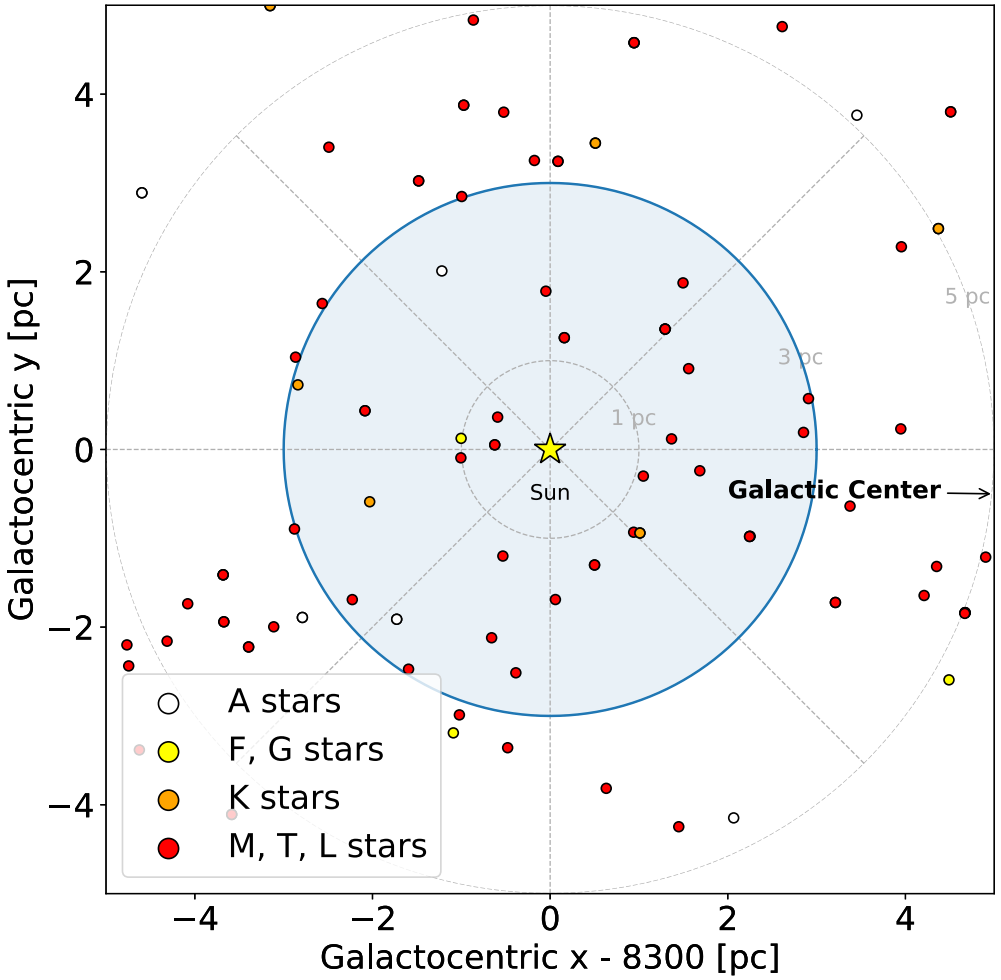


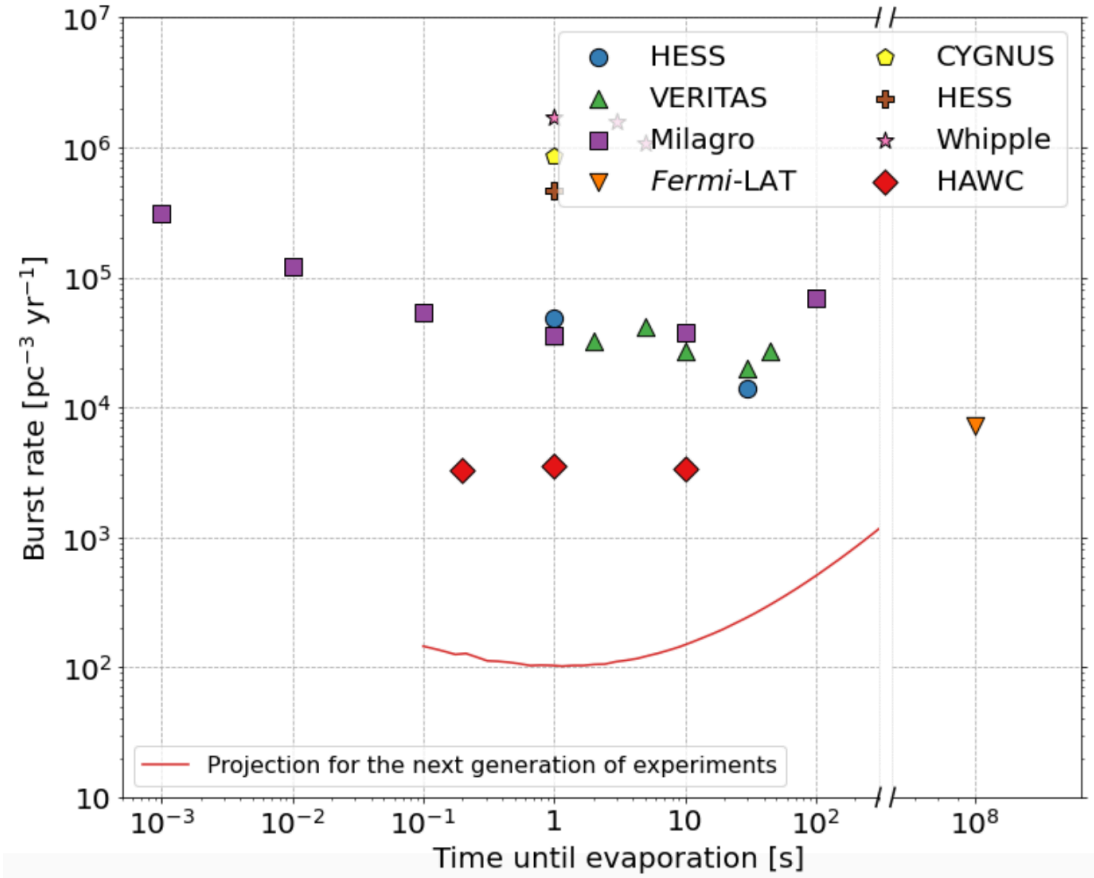




- Imaging Atmospheric Cherenkov Telescopes
  - The Cherenkov Telescope Array Observatory (CTAO)

Projections for reach and limits



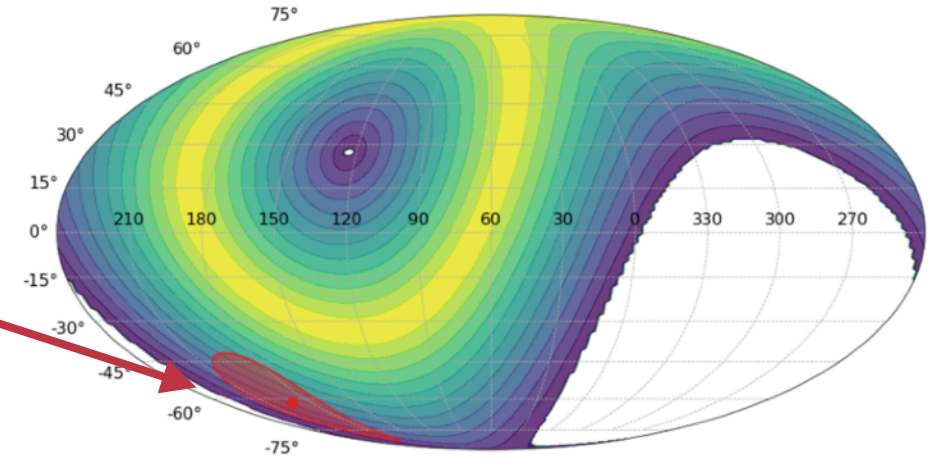


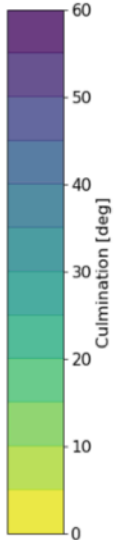
RLC, Doro, de Angelis, Mariotti & Harding, JCAP, 2022

Bonus track: what if Planet 9 is a PBH?

- Hypothetical planet suggested to explain some anomalies in the orbits of trans-Neptunian objects.
  - To learn more: https://en.wikipedia.org/wiki/Planet_Nine
- Most likely sky location already pinpointed:
  - Right Ascension ~ 40 deg; Declination ~ -15 deg.
  - Although too large uncertainty (radius ~ 20 deg) to perform a direct search for it.

Planet 9 location in Galactic coordinates





Culmination in La Palma

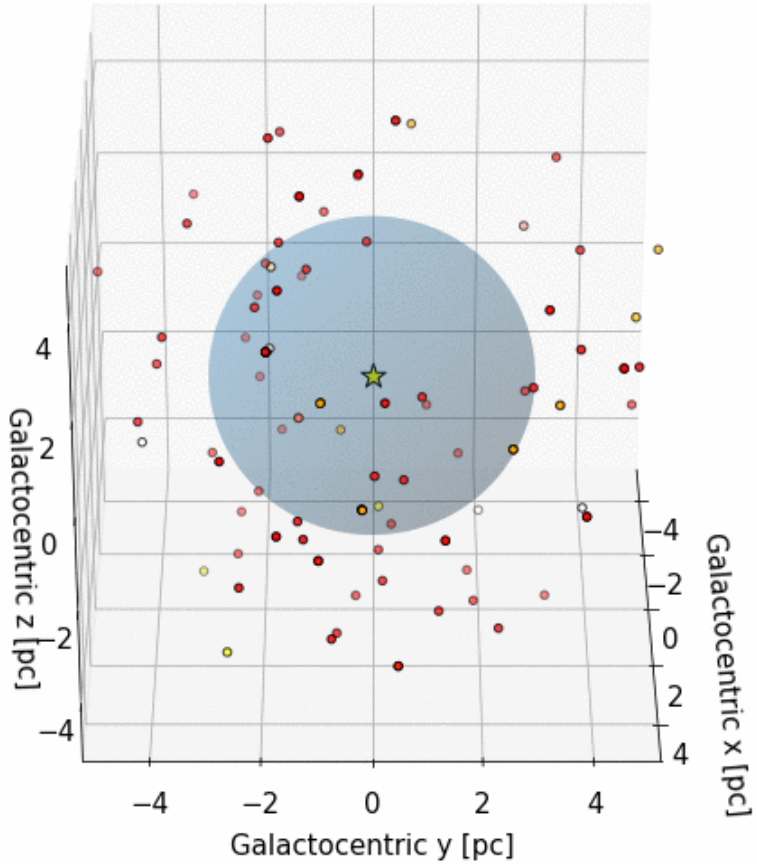
y, 04/10/23

Hypothesis: Planet 9 is a PBH

- Proposal: **Planet 9 is a Primordial Black Hole:**
  - https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.125.051103
- You cannot detect its direct emission because it has a very low temperature:
  - "On its own, a PBH of mass $5M_{\oplus}$ has a Hawking temperature of 0.004 K, making it colder than the cosmic microwave background, and since its radius is $r_{BH} \sim 5$ cm, the power radiated by the PBH alone is minuscule."
- But you can detect the gamma-ray emission from its interaction with Dark Matter:
  - "However, the DM halo around this PBH can, if annihilating, provide a powerful signal. Annihilations in the PBH halo at the position of P9 would make for a potential *Fermi*-LAT source"
- Bachelor thesis searching for the amount of MAGIC data taken in the region (~50 hours) and making predictions on the flux limits that can be detected using those data.
  - S. Fogliacco, "A Primordial Black Hole origin of Planet 9 and its observability through dark matter indirect observations with the MAGIC telescopes", 2021

Summary

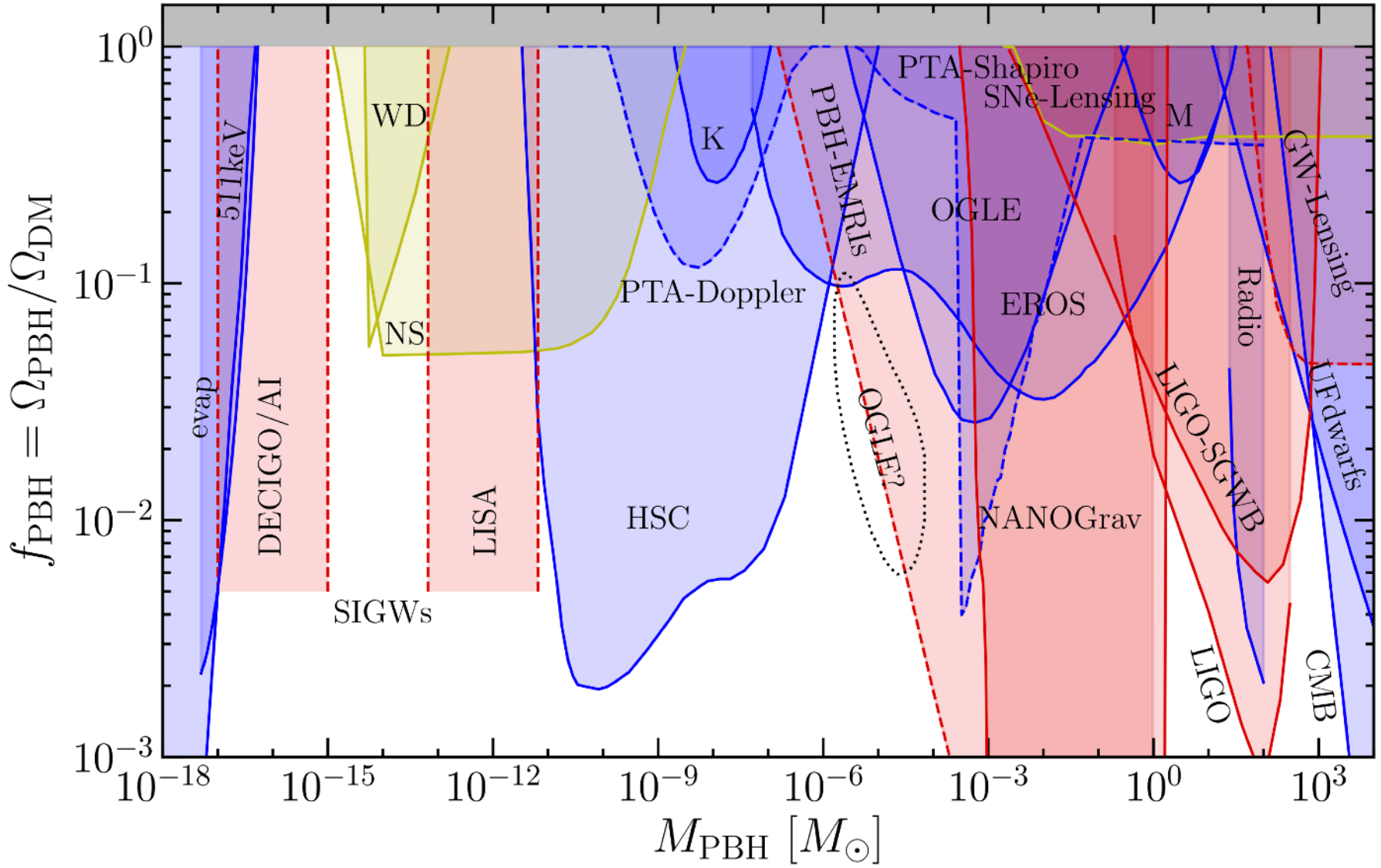
- PBH evaporation can be studied with VHE gamma-ray detectors
  - Current limits of the order of ~10^3 bursts yr^{-1} pc^{-3}
  - r_{max} limit of less than 1 pc
  - Reach and limits expected to improve one order of magnitude with the next generation of experiments.
  - Let's hope for one interesting event!



THANKS

BACKUP

Current limits



Serendipitous events

- V
  - T

Serendipitous events

- V
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- V
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