Monopole acceleration in intergalactic magnetic fields

Daniele Perri [a b c], Kyrilo Bondarenko [a b c], Michele Doro [d e], Takeshi Kobayashi [a b c f]

PDU 46 (2024) 101704
https://arxiv.org/abs/2401.00560

Recasting experimental constraints on relativistic magnetic monopoles

Daniele Perri [a b c d], Michele Doro [e], Takeshi Kobayashi [a b c f]

PDU 50 (2025) 102134
https://arxiv.org/abs/2507.05136

UNIVERSITÀ DEGLI STUDI DI PADOVA

MAGNETIC MONOPOLE BOUNDS UPDATED BY ACCELERATION IN COSMIC MAGNETIC FIELDS

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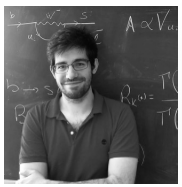

TeVPA Valencia 11/2025

GOAL

For MM, define a coherent acceleration scenario in cosmic magnetic field in order to compute experimental MM limits in terms of MM mass

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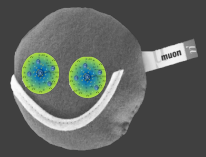
WHAT'S A MAGNETIC MONOPOLE



$$g = 2\pi n/e = ng_D$$

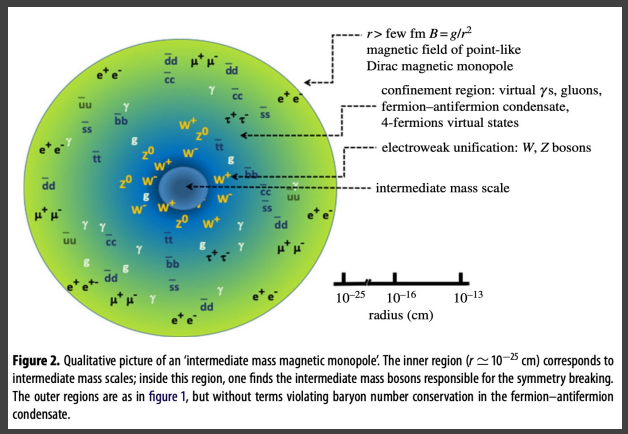


Figure 2. Qualitative picture of an 'intermediate mass magnetic monopole'. The inner region ($r \simeq 10^{-25}$ cm) corresponds to intermediate mass scales; inside this region, one finds the intermediate mass bosons responsible for the symmetry breaking. The outer regions are as in figure 1, but without terms violating baryon number conservation in the fermion–antifermion condensate.

- Theorized new particle (Dirac, '48) that
  - Symmetrize Maxwell equations
  - Motivate electric charge quantization

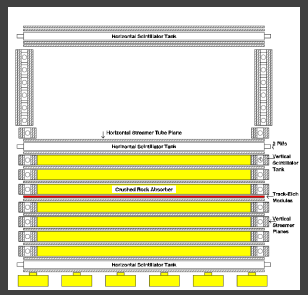
  Now ALWAYS found in GUT
- Have ± 1 magnetic charge g
- Produced in early Universe via topological defects during phase transition, mass up to Planck
- Have equivalent electric charge of $g\beta$. Interact with matter like a super-MIP
  - energy loss is $(g/e)2 \simeq 4{,}700$ times that of a MIP [Frank-Tamn formula].
  - Ionization, Compton, pair-production…the usual

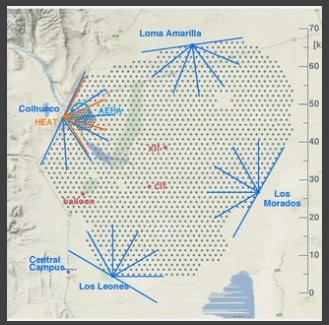
Patrizii+
Ann.Rev.Nucl.Part.Sci.
65 (2015)

EXPERIMENTS

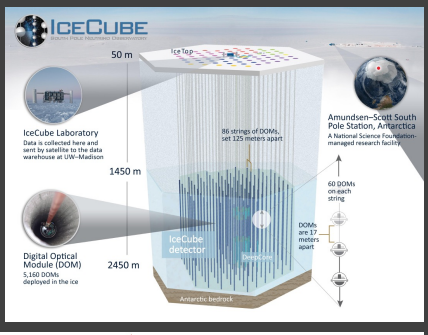
Parker bound + extended Parker bound:
MM should not extract too much magnetic energy for the current /seed GMF to exist

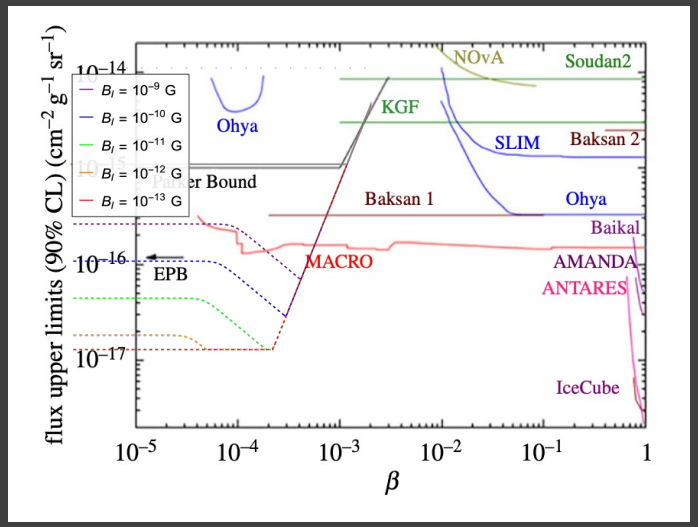
MACRO:
Dedicated direct detection experiment at LNGS until 2010

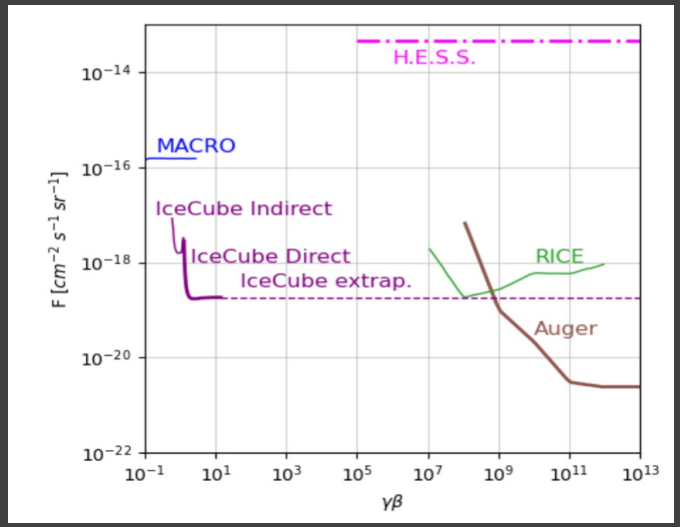


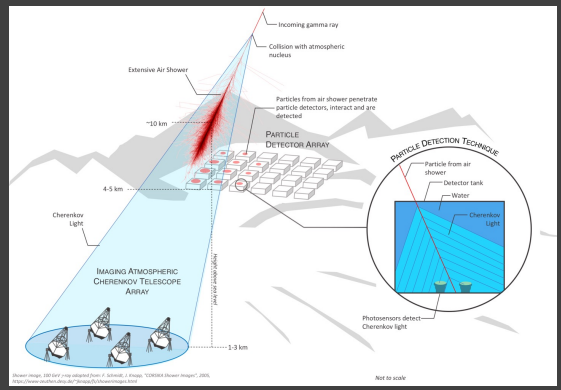


IC/PAO/ IACTs:
Particle shower+ Cherenkov +fluorescence









In all cases, search is made on all-event archival data

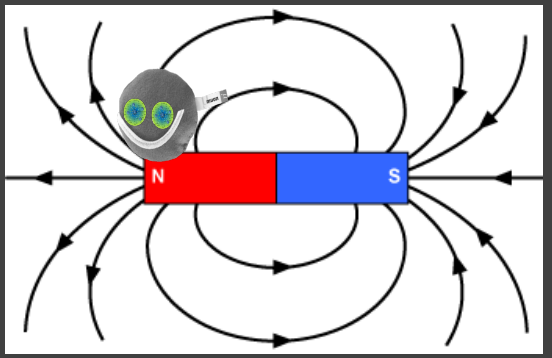
GOAL

For MM, define a coherent acceleration scenario in cosmic magnetic field in order to compute experimental MM limits in terms of MM mass

ACCELERATION

Cosmic magnetic fields accelerate the monopoles

$$m\frac{d}{dt}(\gamma v) = gB$$



- GMF acceleration:

$$m\,(\gamma_{\rm G}-1) \sim g B_{\rm G}\sqrt{R\lambda_{\rm G}} \sim 10^{11}\ {\rm GeV}\left(\frac{g}{g_{\rm D}}\right).$$

- IGMF acceleration?:

$$(\gamma v)_0 \sim \begin{cases} \frac{gB_{\rm I}\lambda_I}{m}\frac{1}{(\lambda_{\rm I}H_0)^{1/2}} & \text{for } m < \frac{gB_{\rm I}\lambda_{\rm I}^{1/2}}{H_0^{1/2}}, \\ \left(\frac{gB_{\rm I}\lambda_{\rm I}}{m}\right)^{2/3}\frac{1}{(\lambda_I H_0)^{1/3}} & \text{for } \frac{gB_{\rm I}\lambda_{\rm I}^{1/2}}{H_0^{1/2}} < m < \frac{gB_{\rm I}}{\lambda_{\rm I}H_0^2}, \\ \frac{gB_{\rm I}}{mH_0} & \text{for } m > \frac{gB_{\rm I}}{\lambda_{\rm I}H_0^2}. \end{cases}$$

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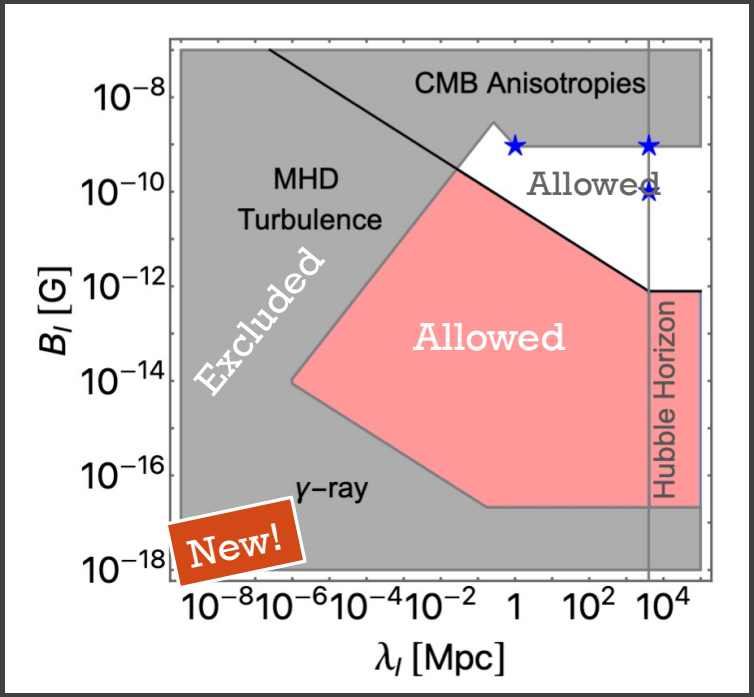
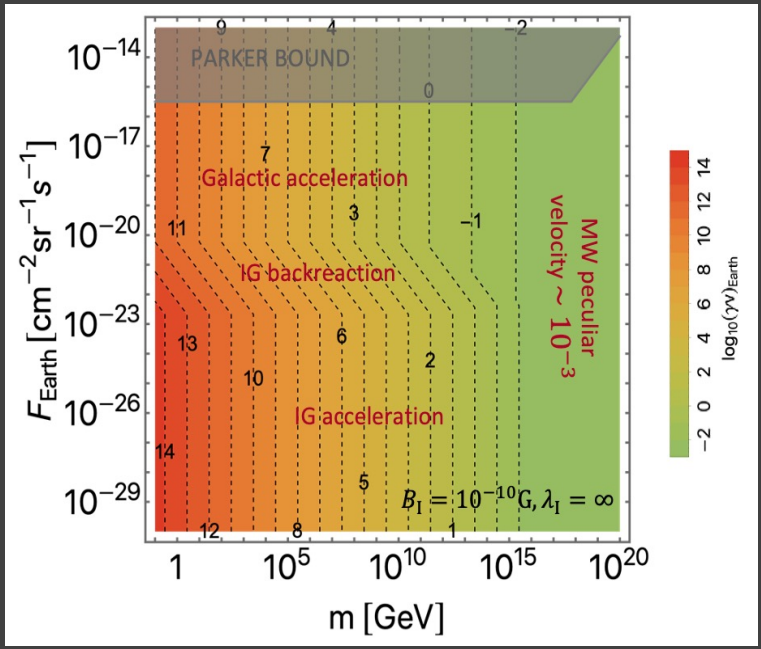
IGMF

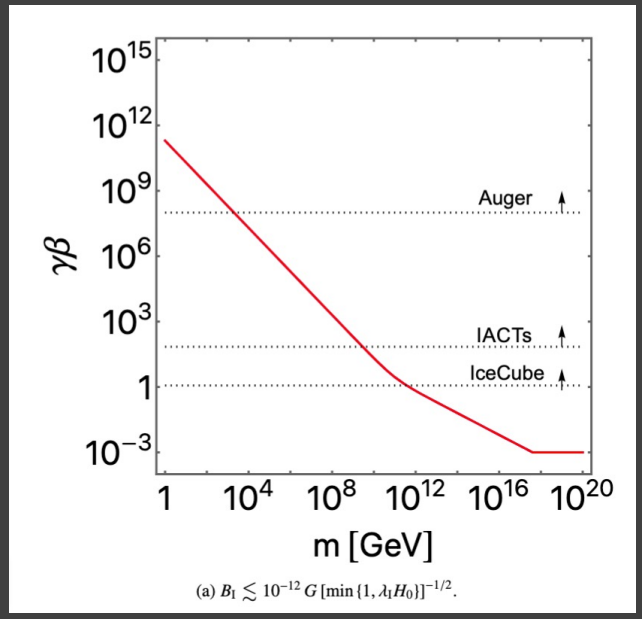


Note:

- Backreaction (MM extract energy from B) depends on MM number density

ALL CONSIDERERED

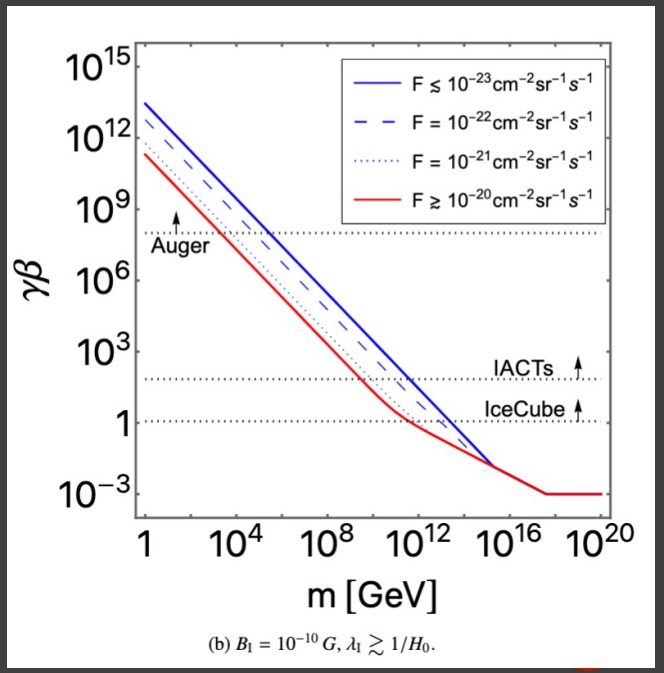




(a) $B_I \lesssim 10^{-12}\, G\, [\min\{1, \lambda_I H_0\}]^{-1/2}$.

←Weak IGFM
GMF dominates
No back-reaction

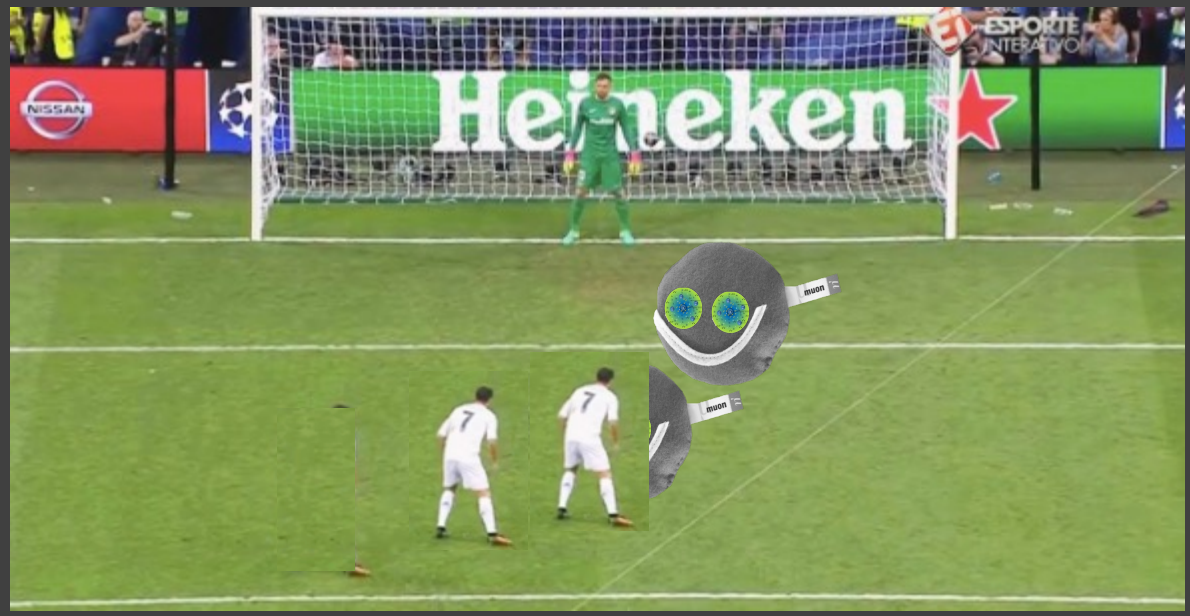
Strong IGMF →
IGMF contributes
Back-reaction matter



(b) $B_I = 10^{-10}\, G$, $\lambda_I \gtrsim 1/H_0$.

Mass+speed = MM kinetic energy at Earth for a given acceleration scenario

GOAL



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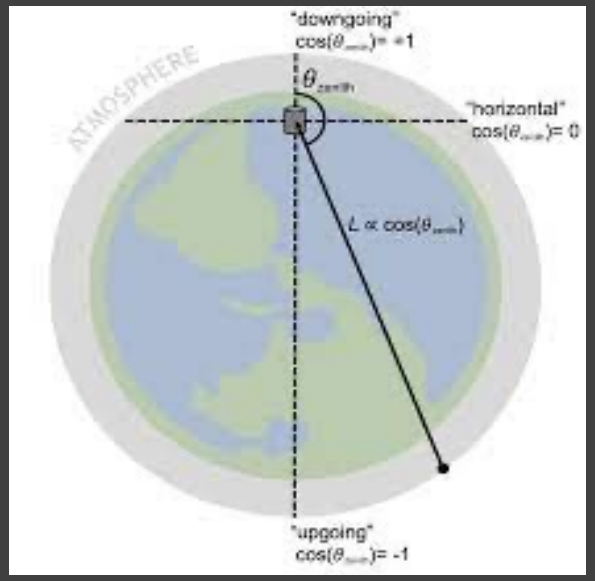
INSTRUMENT ACCEPTANCE #1



- Icecube and Macro [underground]
  - Kinetic energy at the detector depends on direction [earth crossed] → re-computed directional acceptance
- Pierre Auger Observatory
  - Energy loss in atmosphere is negligible

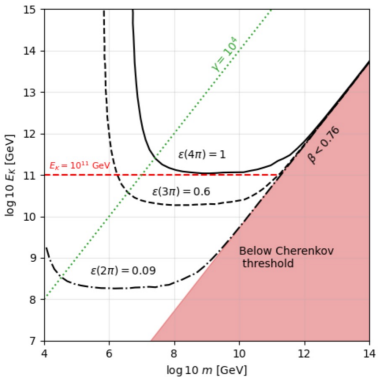


Figure B.7: Detection efficiency of IceCube in terms of the MM mass and kinetic energy at the Earth's surface. The mass-energy combinations along the red dashed lines are actually constrained by IceCube. This figure is based on Tab. F.2 of [56] and Fig. 11 of [17]. See the text for details.

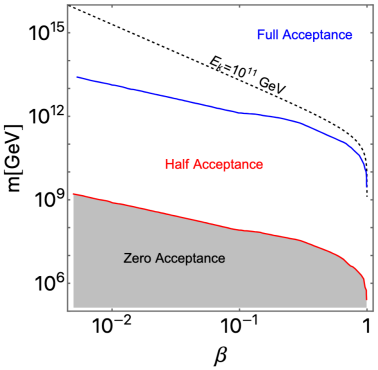


Figure A.6: The acceptance of MACRO in the plane of the MM mass and velocity at the Earth surface. MMs reach the detector from all directions in the parameter region above the blue line, MMs reach only from above in the region between the blue and red lines, and no MMs reach the detector in the gray shaded region. The dashed black line shows the velocity-mass reation for MMs accelerated in GMFs. This figure is based on Fig. 6.18 of [76].

← Pretty technical, see publication

THE IACTS CASE

Signatures of Ultrarelativistic Magnetic Monopoles in Imaging Cherenkov Telescopes

Diplomarbeit

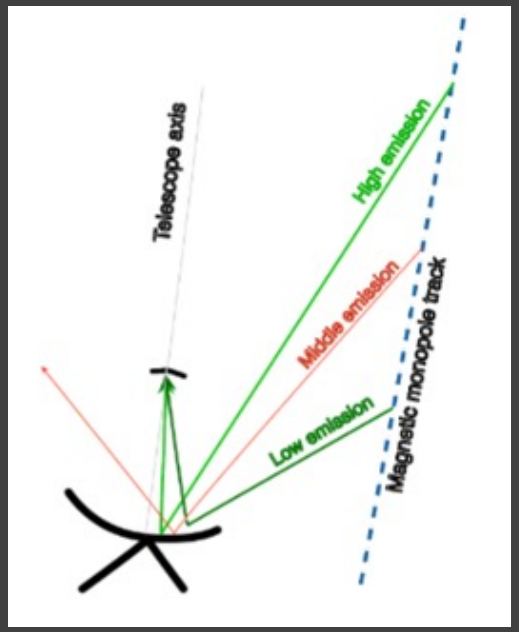
zur Erlangung des akademischen Grades
Dipl.-Phys.
im Fach Physik

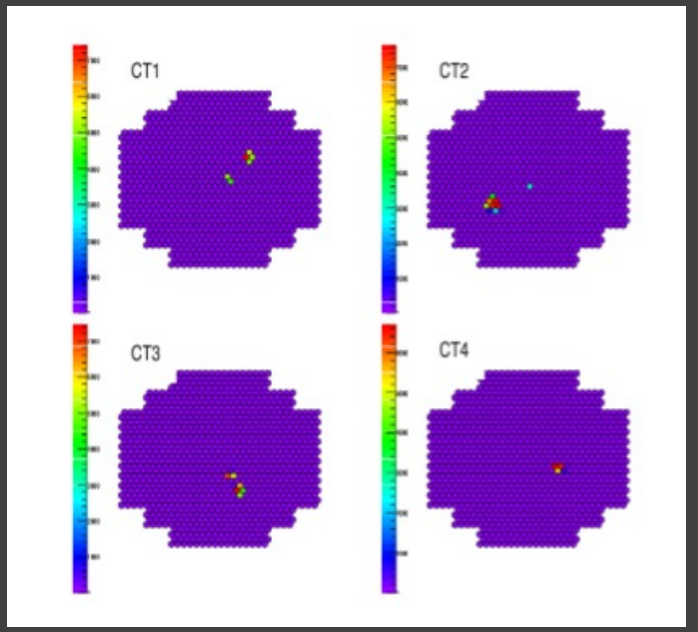
eingereicht an der
Mathematisch-Naturwissenschaftlichen Fakultät I
Humboldt-Universität zu Berlin

von
Gerrit-Christian Spengler
geboren am 25.09.1983 in Darmstadt

Gerrit Spengler (MSc 2009) performed the first and unique (to my knowledge) search for MMs in 5y/3000h of HESS data

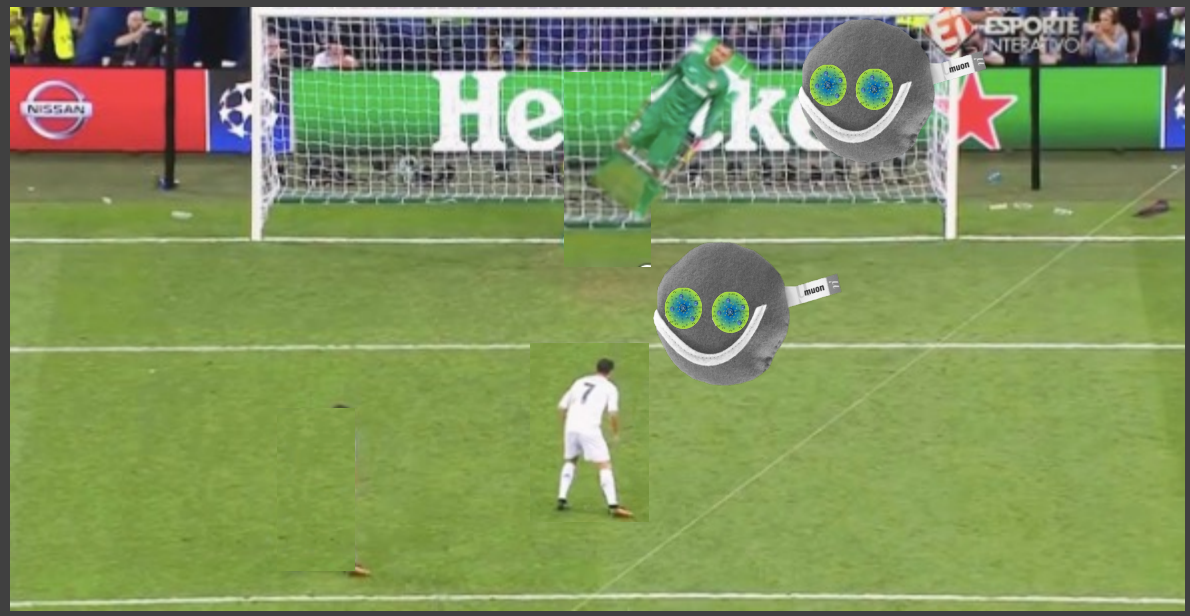
Relativistic MMs are never absorbed in the atmosphere and emit Cherenkov light through the entire path, differently than cosmic rays





We took HESS limits and made an educated guess for CTAO: 600x better

GOAL!



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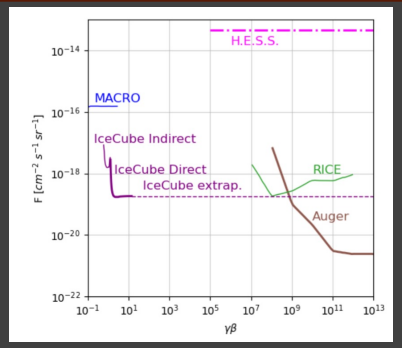
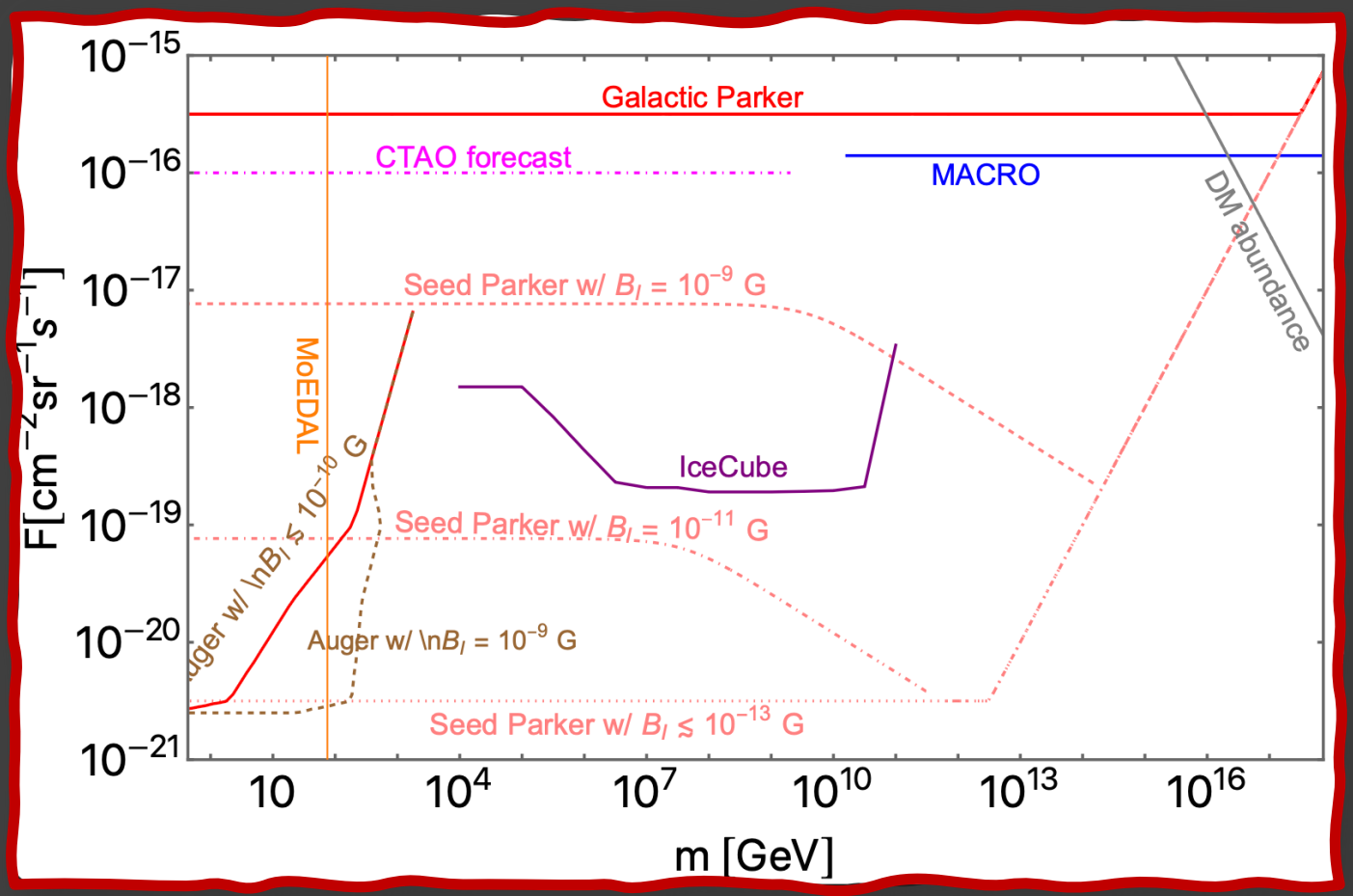
FINAL RESULT



From speed limits to

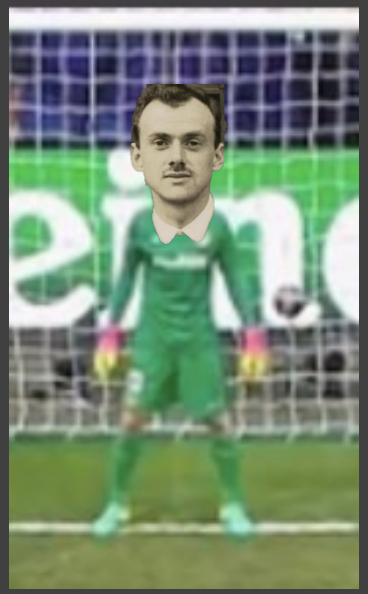
MM mass limits →



1. Limits with physical parameter: mass
2. PAO: light MM, but can probe IGMF acceleration
3. Seed Parker: strong but depends on IGMF
4. CTAO: intermediate mass range [science case for ASTRI]

CONCLUSIONS

- MMs are fun! Dirac himself said of MM *"One would be surprised if Nature had made no use of it"*
- MMs in the past studied according to their speed
- With a coherent cosmic B scenario, MM 'kinetic energy' can be computed
- We recast limits following this recipe. Limits now on physical parameter: MM mass
- Strong signatures at experiments: let's not forget to look for them in the archives



THANKS!