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MAGNETIC MONOPOLE BOUNDS UPDATED BY ACCELERATION IN COSMIC MAGNETIC FIELDS

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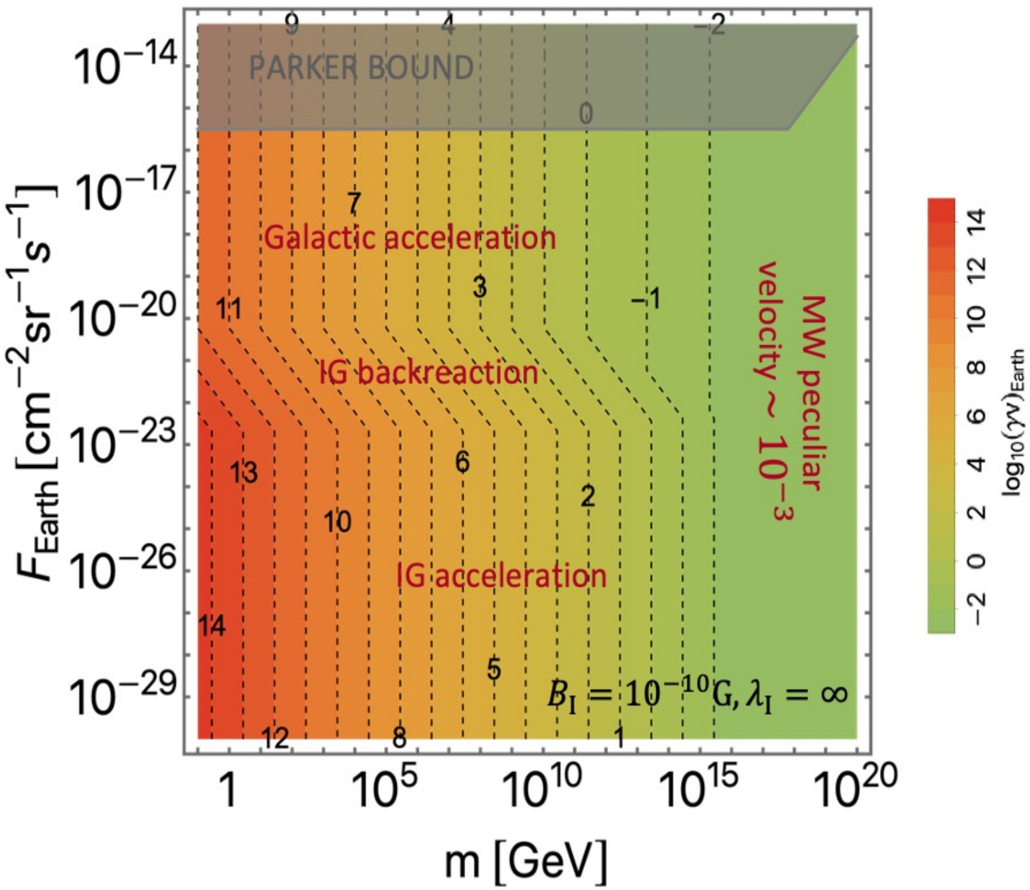
UNIVERSITÀ DEGLI STUDI DI PADOVA

Experiments: MAGIC, CTAO/LST1, SWGO, Trinity
← ask me if curious

STRAIGHT TO THE POINTS

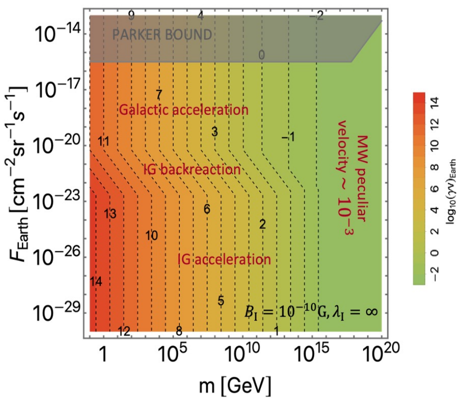


1/

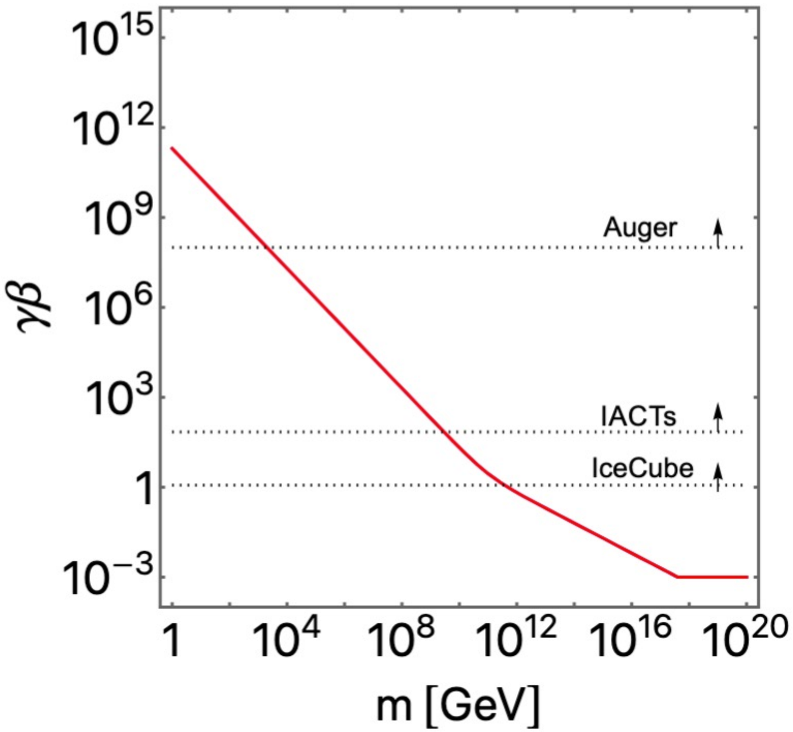
We have developed a framework to compute MM acceleration (according to MM mass) in

- GMF and IGMF
- Including backreaction

STRAIGHT TO THE POINTS



1/ MM Acceleration

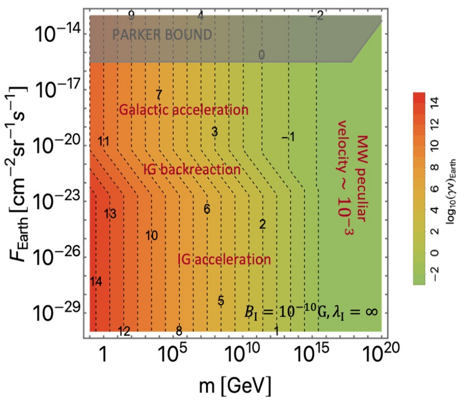


(a) $B_I \lesssim 10^{-12}\, G\, [\min\{1, \lambda_I H_0\}]^{-1/2}$.

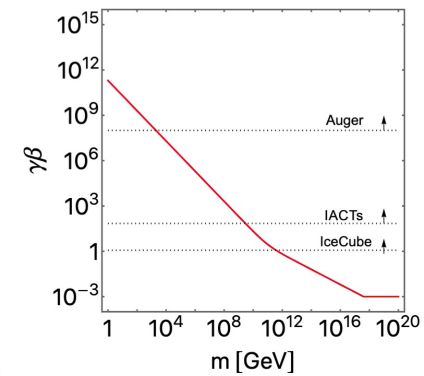
2/

Generated MM mass-speed relation within this framework (for a given IGMF scenario)

STRAIGHT TO THE POINTS

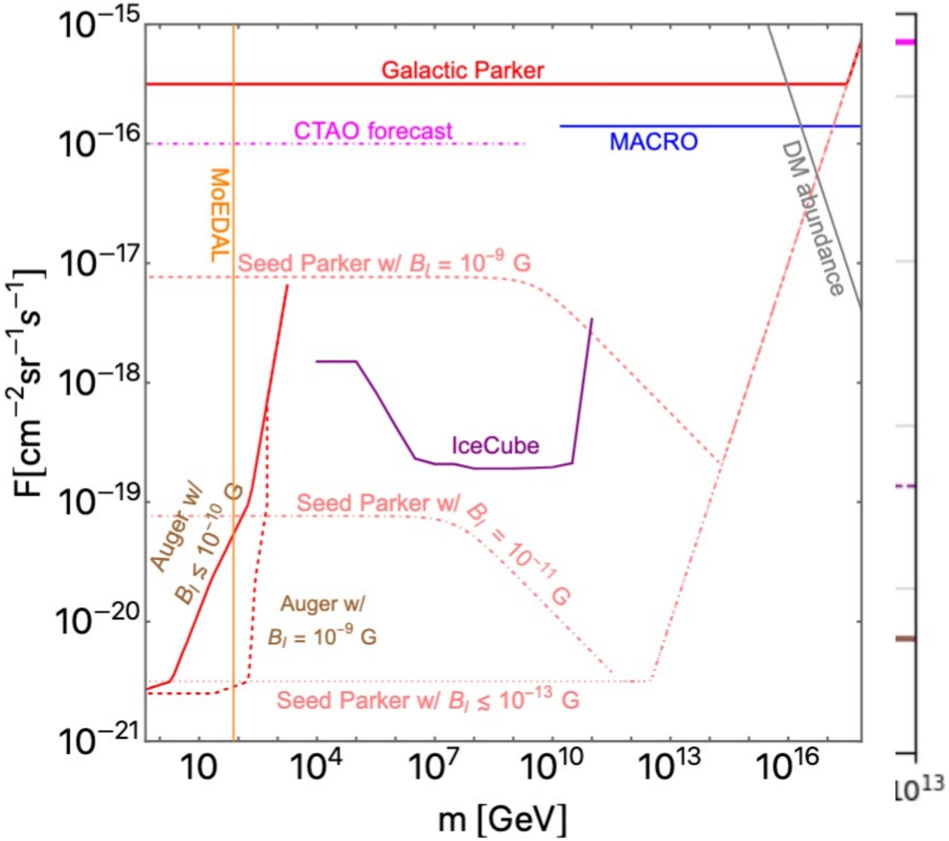


1/ MM Acceleration



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

2/ MM mass-speed rel.

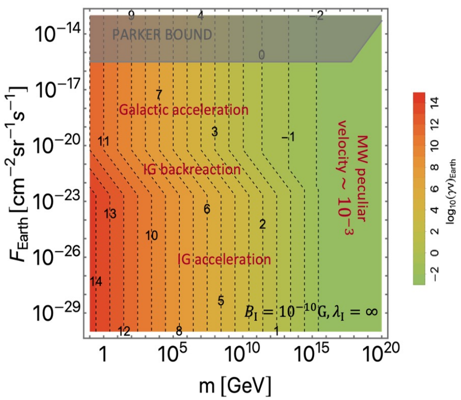


3/

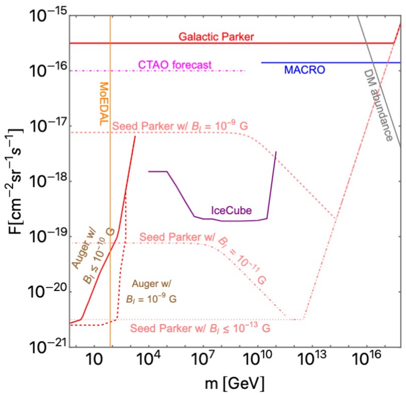
Taken current experimental bounds (in function of speed)

And recast them into more physical MM mass limits

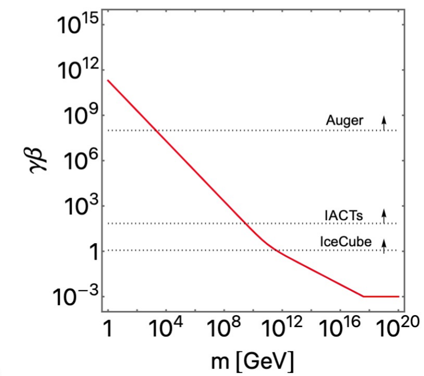
STRAIGHT TO THE POINTS



1/ MM Acceleration



3/ Recast exp. limits



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

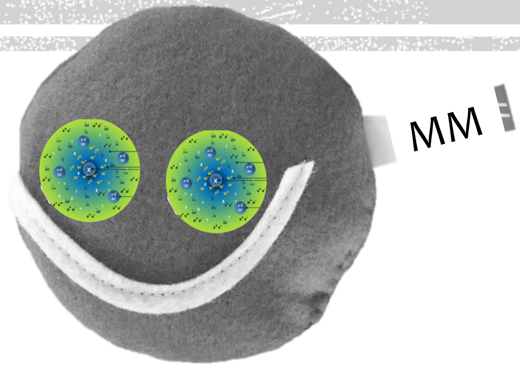
2/ MM mass-speed rel.

In the following
- A little more explanation
- Some implications

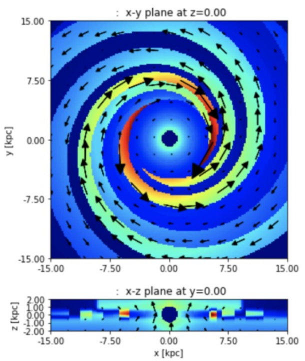
14:20 **Monopoles and Cosmological Magnetic Fields**

Speaker: Takeshi Kobayashi (SISSA)

#1 MM ACCELERATION THROUGH GMF AND IGMF



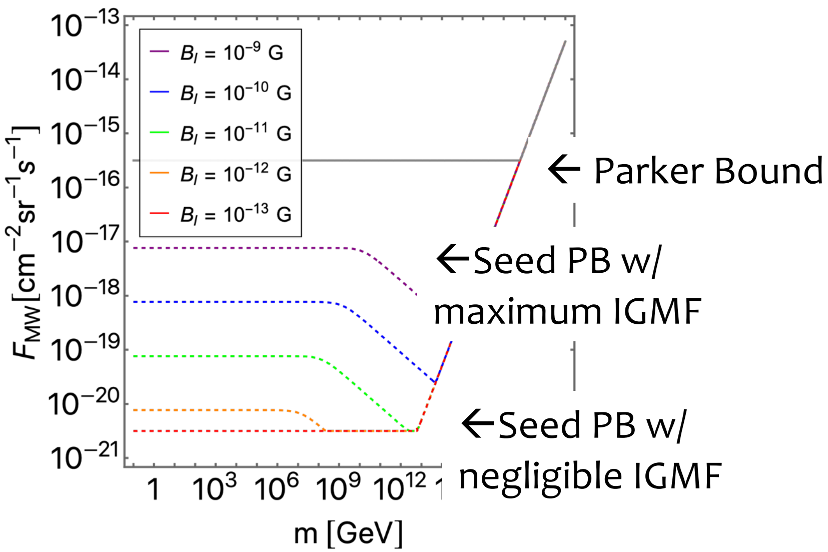
MM THROUGH GMF AND IGMF



- Galactic Magnetic Fields (GMFs) are well modeled, see e.g. Farrar+ works
  - More clear picture of GMF now, less clear picture of GMF history: were there MF seeds that grew?

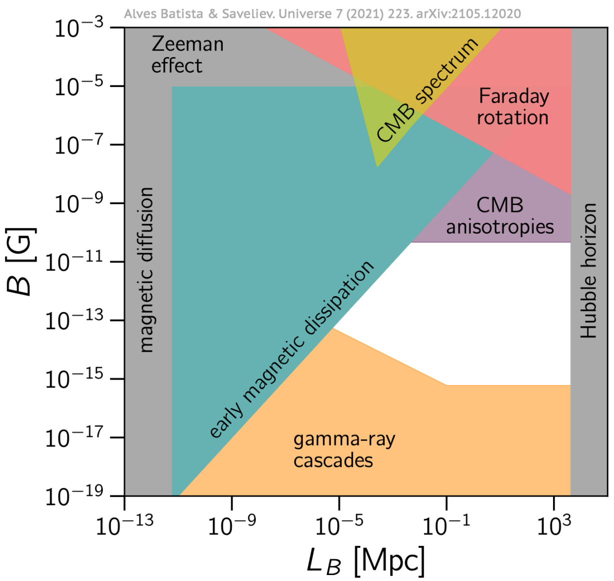
Energy gain of MMs in the GMF can be computed in a single-cell model (for this purpose)

$$m\,(\gamma_G - 1) \sim g B_G \sqrt{R \lambda_G} \sim 10^{11}\,\mathrm{GeV} \left(\frac{g}{g_D}\right).$$



← We found that seed Parker bounds are weakened by acceleration into IGMF. Accelerated MMs extract less energy from GMF.

MM THROUGH GMF AND IGMF



- IGMF constrained with several instruments to be below 10^{-9} G with preferred large coherence lengths
- Recently, LOWER limits from gamma-ray telescopes

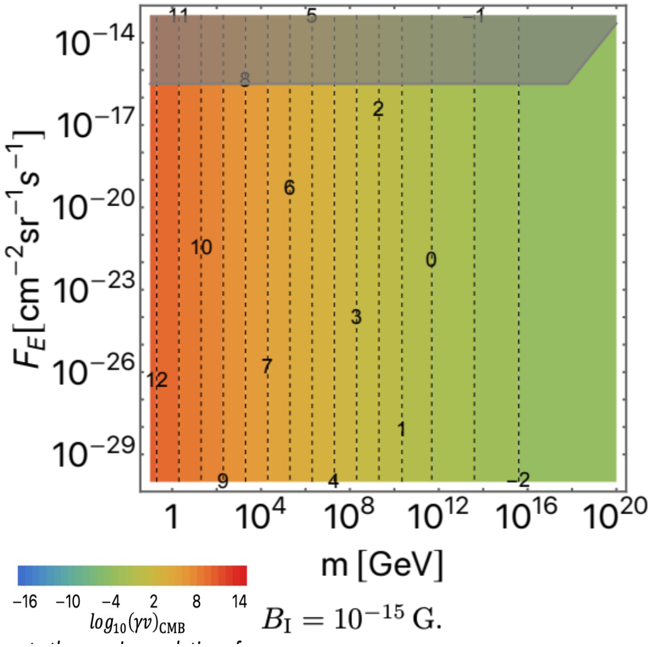
- What is the effect on MM acceleration?
  - Set B strengths and coherence length
  - Compute acceleration in function of MM mass
  - Consider back-reaction on B field (flux dependent)
  - Compare GMF and IGMF

14:20 **Monopoles and Cosmological Magnetic Fields**
Speaker: Takeshi Kobayashi (SISSA)

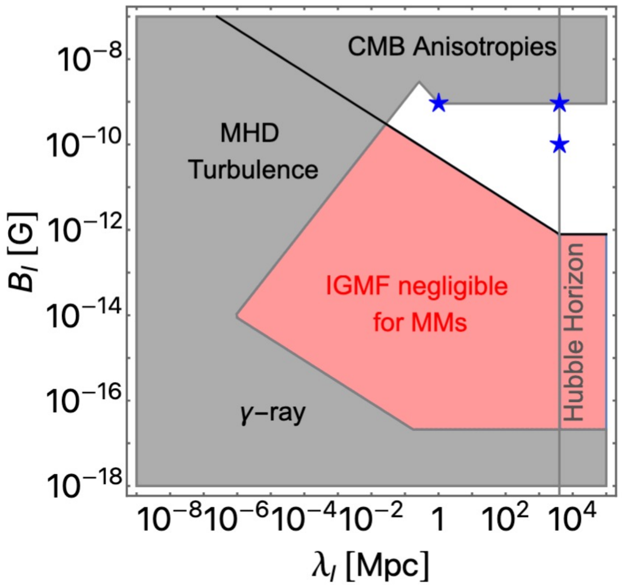
$$(\gamma v)_0 \sim \begin{cases} \dfrac{gB_I\lambda_I}{m}\dfrac{1}{(\lambda_I H_0)^{1/2}} & \text{for } m < \dfrac{gB_I\lambda_I^{1/2}}{H_0^{1/2}}, \\ \left(\dfrac{gB_I\lambda_I}{m}\right)^{2/3}\dfrac{1}{(\lambda_I H_0)^{1/3}} & \text{for } \dfrac{gB_I\lambda_I^{1/2}}{H_0^{1/2}} < m < \dfrac{gB_I}{\lambda_I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

CONCLUSIONS

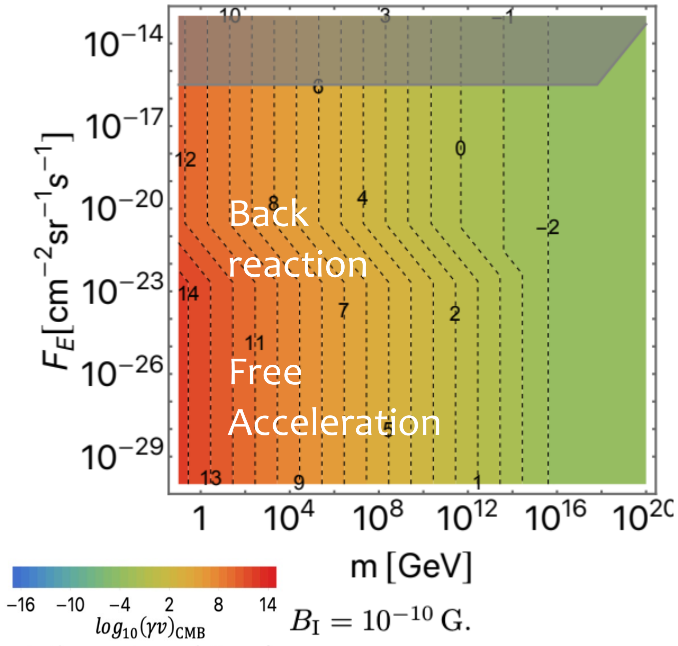
The maximum speed depends on flux: $max(v_{MW}, v_{IGMF}, v_{GMF})$



IGMF below some strength to not contribute to acceleration

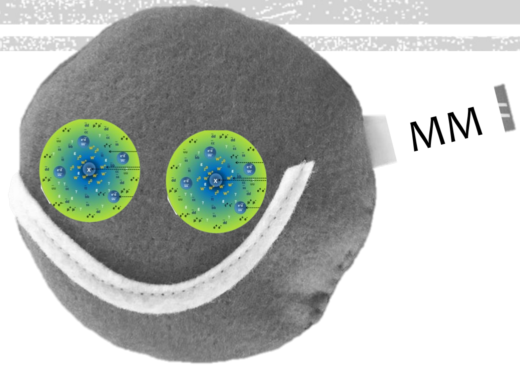


IGMFs contribute only if in at the largest strengths allowed



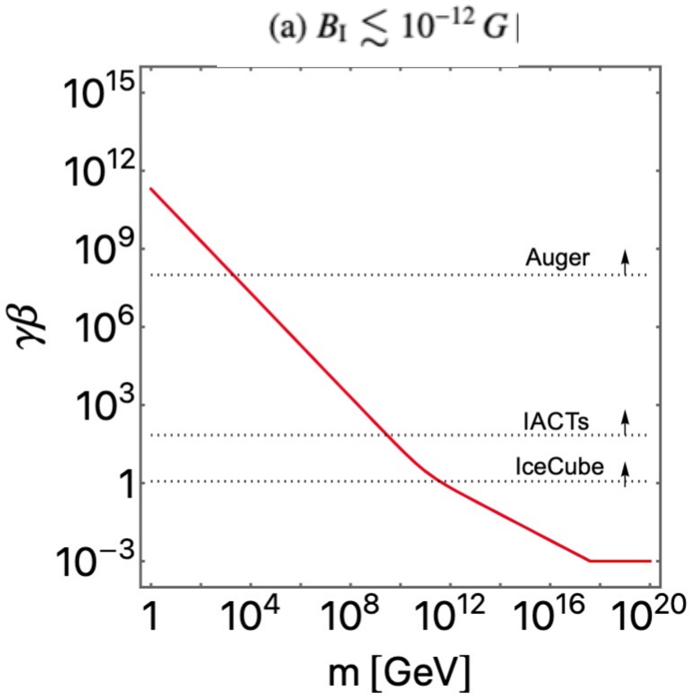
IGMFs can boost MM acceleration

#2 MM SPEED-MASS RELATION



A SPEED-MASS RELATION (DEP. FLUX)

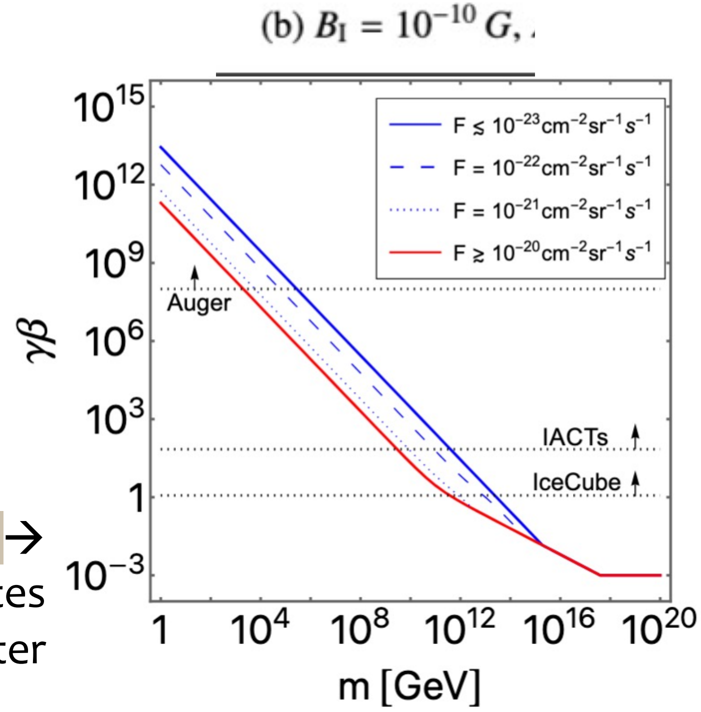
- One can compute the speed-mass relation for different scenarios of IGMF (and flux)



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

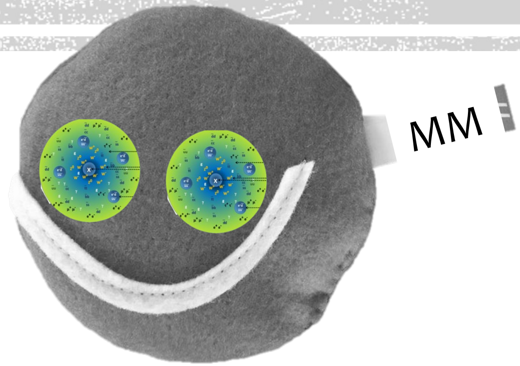
← Weak IGFM
GMF dominates
No back-reaction

Strong IGMF →
IGMF contributes
Back-reaction matter

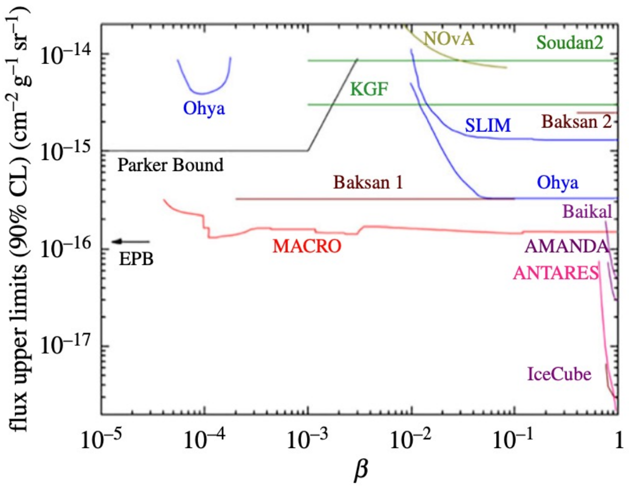


(b) $B_I = 10^{-10}\,G$, $\lambda_I \gtrsim 1/H_0$.

#3 EXPERIMENTAL LIMITS



CURRENT LIMITS



A lot of direction detection experiments and indirect detectors (over the years), see PDG

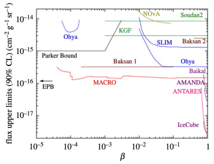
Here after we report just the strongest limits

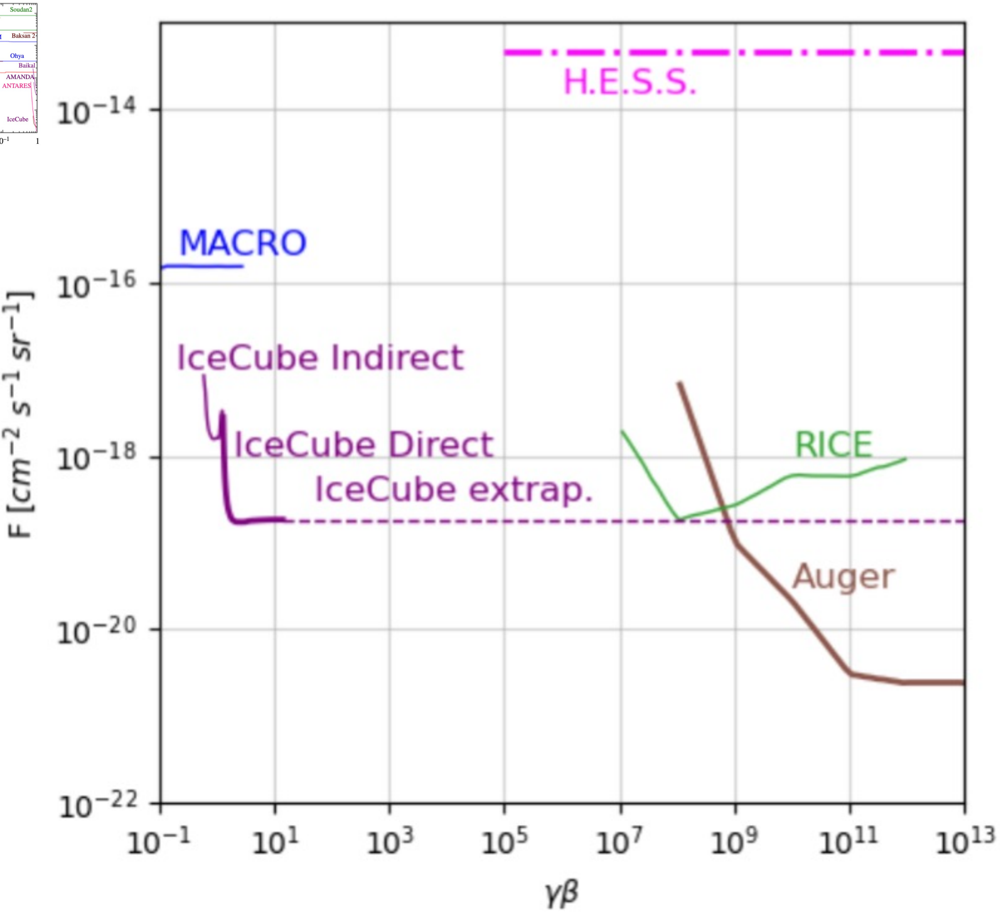
Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022) and 2023 update

Magnetic Monopole Searches

See the related review(s):
Magnetic Monopoles

CURRENT LIMITS





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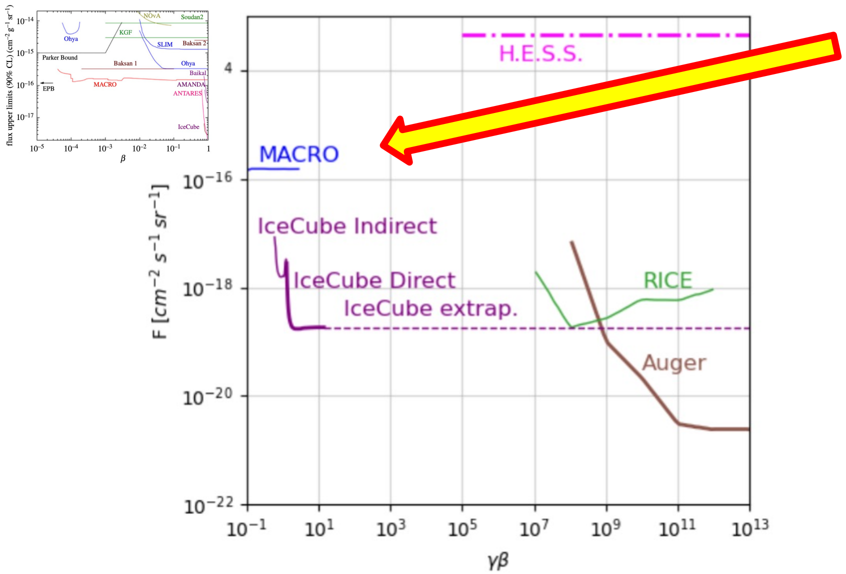
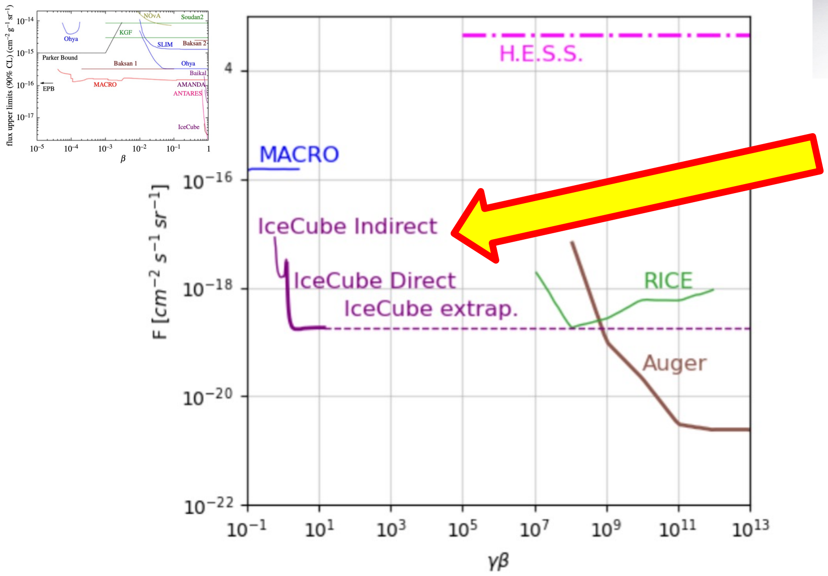
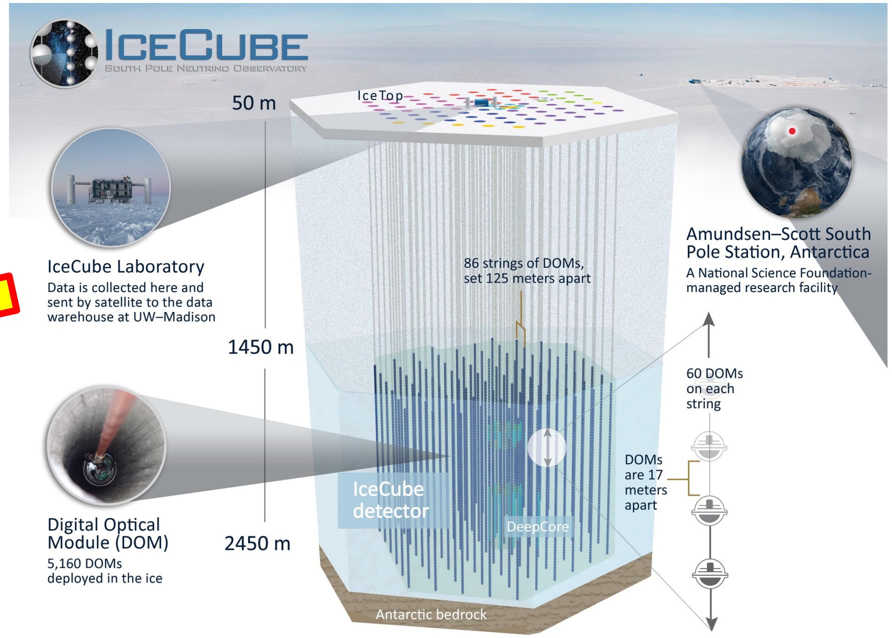
CURRENT LIMITS



- Dedicated instrument for MMs at LNGS operating until 2000.
- MACRO was composed of three sub-detectors, sensitive to different MM speeds, operated in combination:
  - scintillation counters,
  - limited streamer tubes,
  - nuclear track detectors
- M. Spurio, (this conference) was member

CURRENT LIMITS





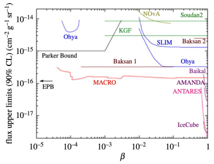
IceCube. An array of thousands of optical sensors in the South Pole. They detect Cherenkov light from passage of charged leptons, in search of cosmic neutrinos.

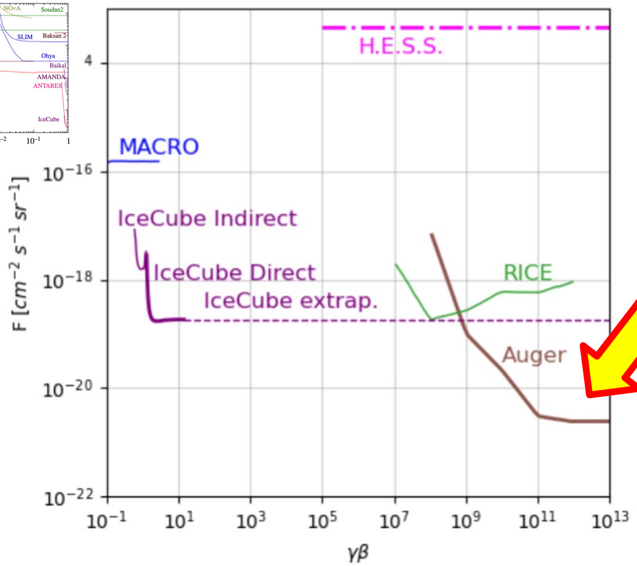
$$\frac{d^2N}{dx d\lambda}_{\text{Monopole}} \approx 4700 \frac{d^2N}{dx d\lambda}_{\text{Electric}} .$$

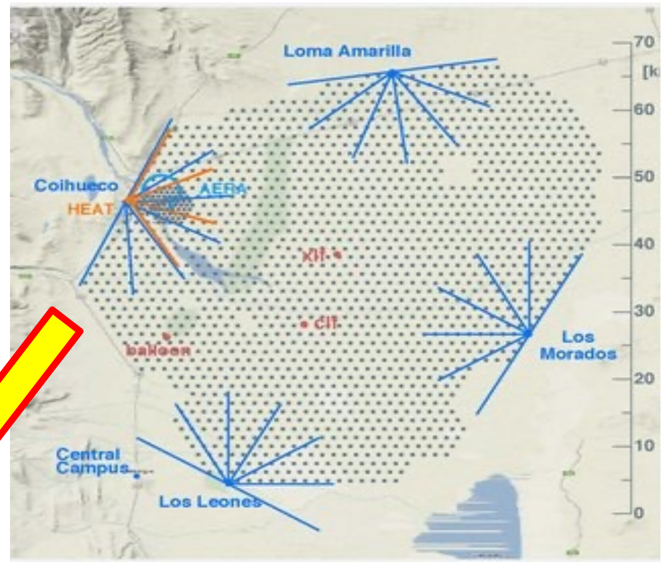
MMs give similar signals (actually, much brighter than an average muon) and can be detected.

Three curves: Indirect (beta <0.7, Cherenkov threshold), Direct (beta> 0.7, with MC simulations) Extrapolated (without MC)

CURRENT LIMITS

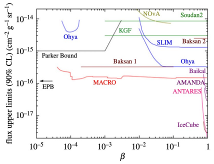


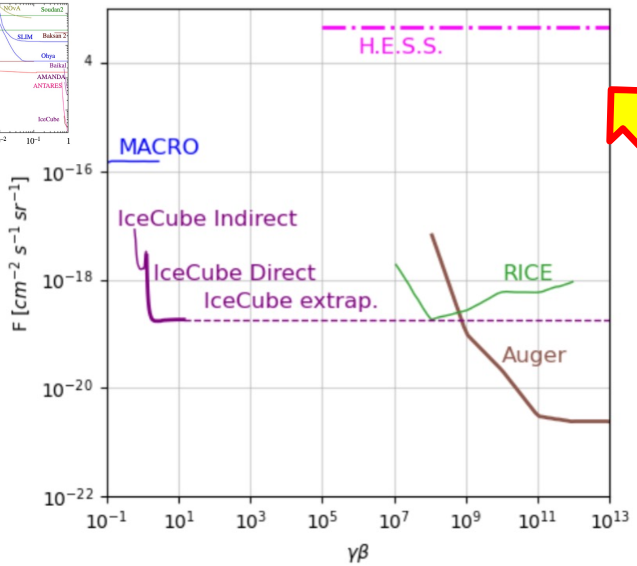


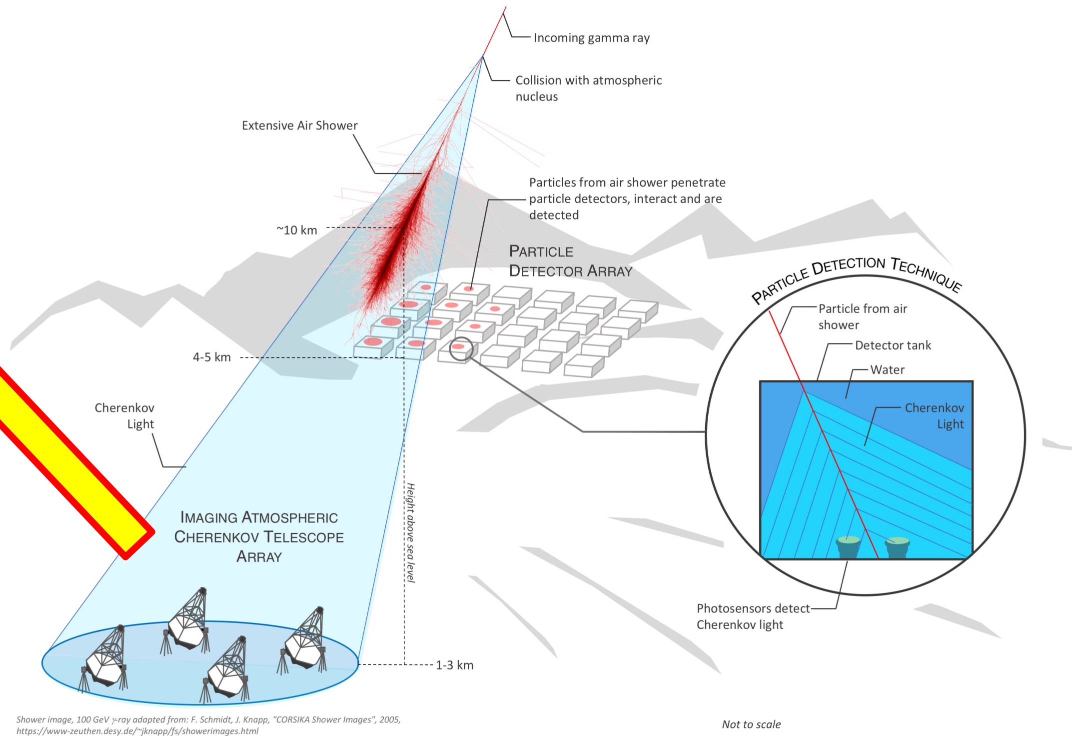


- Pierre Auger Observatory (PAO) is the largest (3, 000 km2, Argentina) ultra-high-energy cosmic-ray detector currently in operation.
- It detects fluorescence lights (telescopes), and particles from atmospheric showers (with water tanks)
- MM crossing the atmosphere produce fluorescence, Cherenkov, secondary e.m showers
- Require ultra-relativistic MMs

CURRENT LIMITS







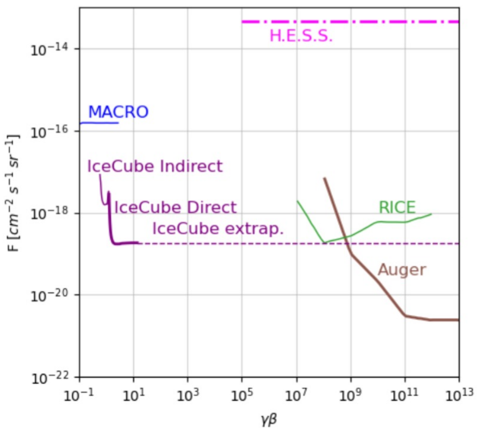
Imaging Atmospheric Cherenkov Telescopes (IACTs) probe VHE gamma-rays through atmospheric showers. They detect Cherenkov light in the atmosphere

MM can make strong Cherenkov light in the atmosphere (bright signals), however, IACTs are pointed instrument with ~5x5 deg^2 field of view.

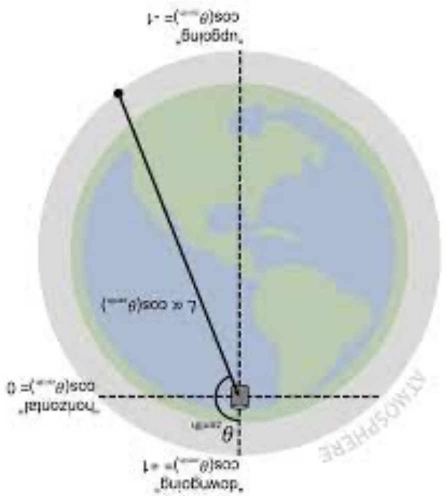
Require ultra-relativistic MMs

$$\frac{d^2N}{dx\,d\lambda}^{\text{Air}}_{\text{Monopole}} \approx 4700 \frac{d^2N}{dx\,d\lambda}_{\text{Electric}} .$$

INSTRUMENT ACCEPTANCE

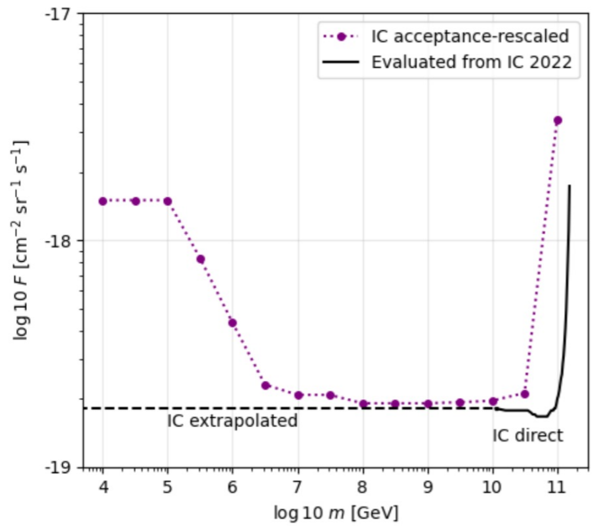


- Terrestrial experiments require relativistic and ultra-relativistic speeds
- One should then consider 'kinetic energy at the detector'
  - Compute energy loss in matter (if required)
  - Acceptance direction depedent

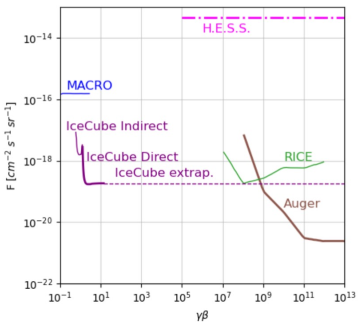


- We carefully checked detectors differential acceptance and rescaled limits

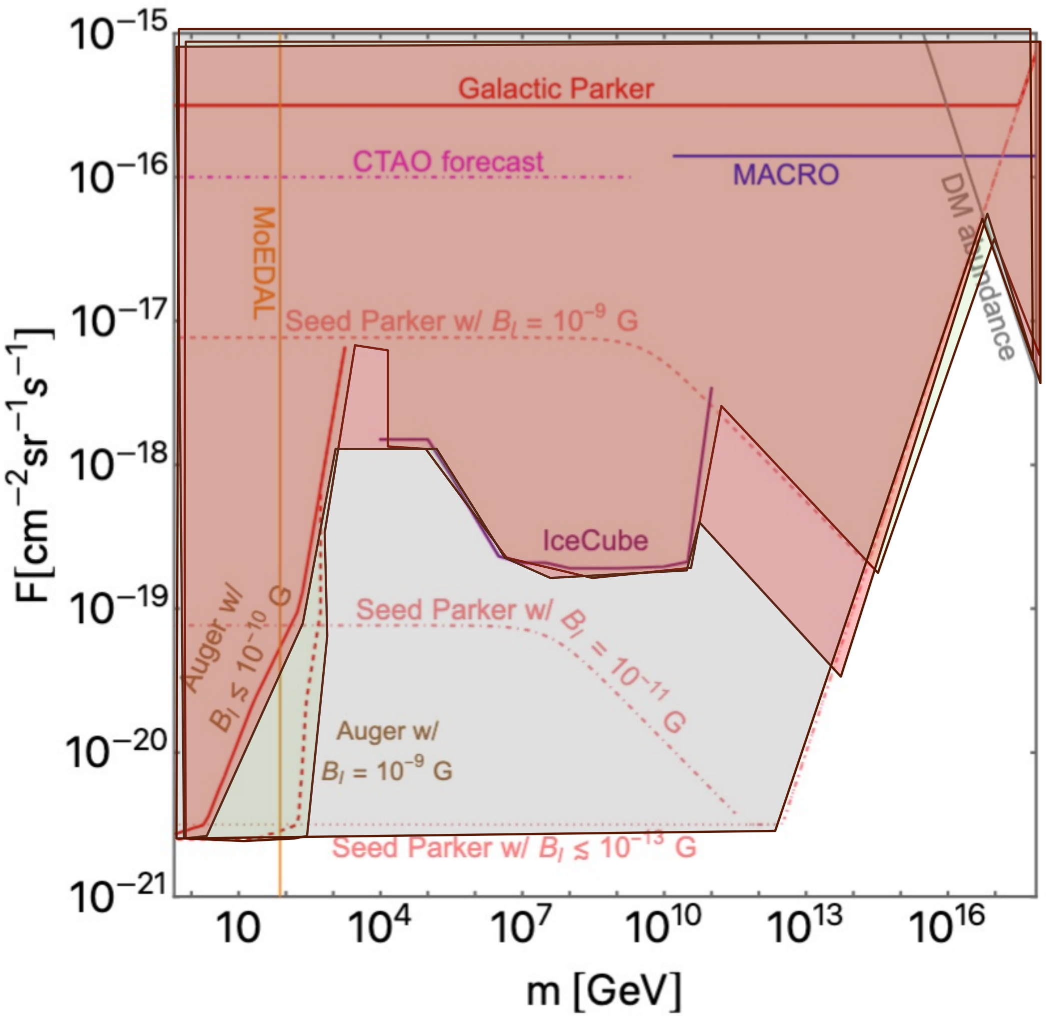
e.g.: IC limits rescaled.
Also done for MACRO



FINAL RESULT



From speed limit to



$B_{IGMF} = 10^{-9} G$

$B_{IGMF} = 10^{-11} G$

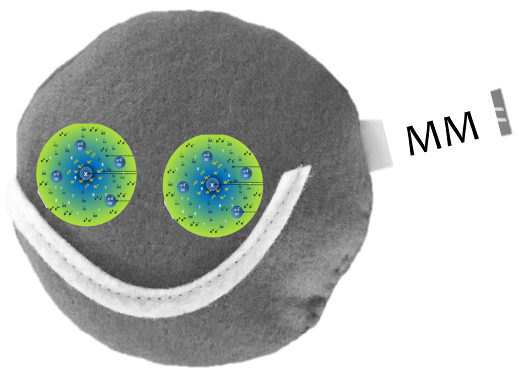
$B_{IGMF} = 10^{-13} G$

MM mass limits →

CONCLUSIONS

TAKE-HOME

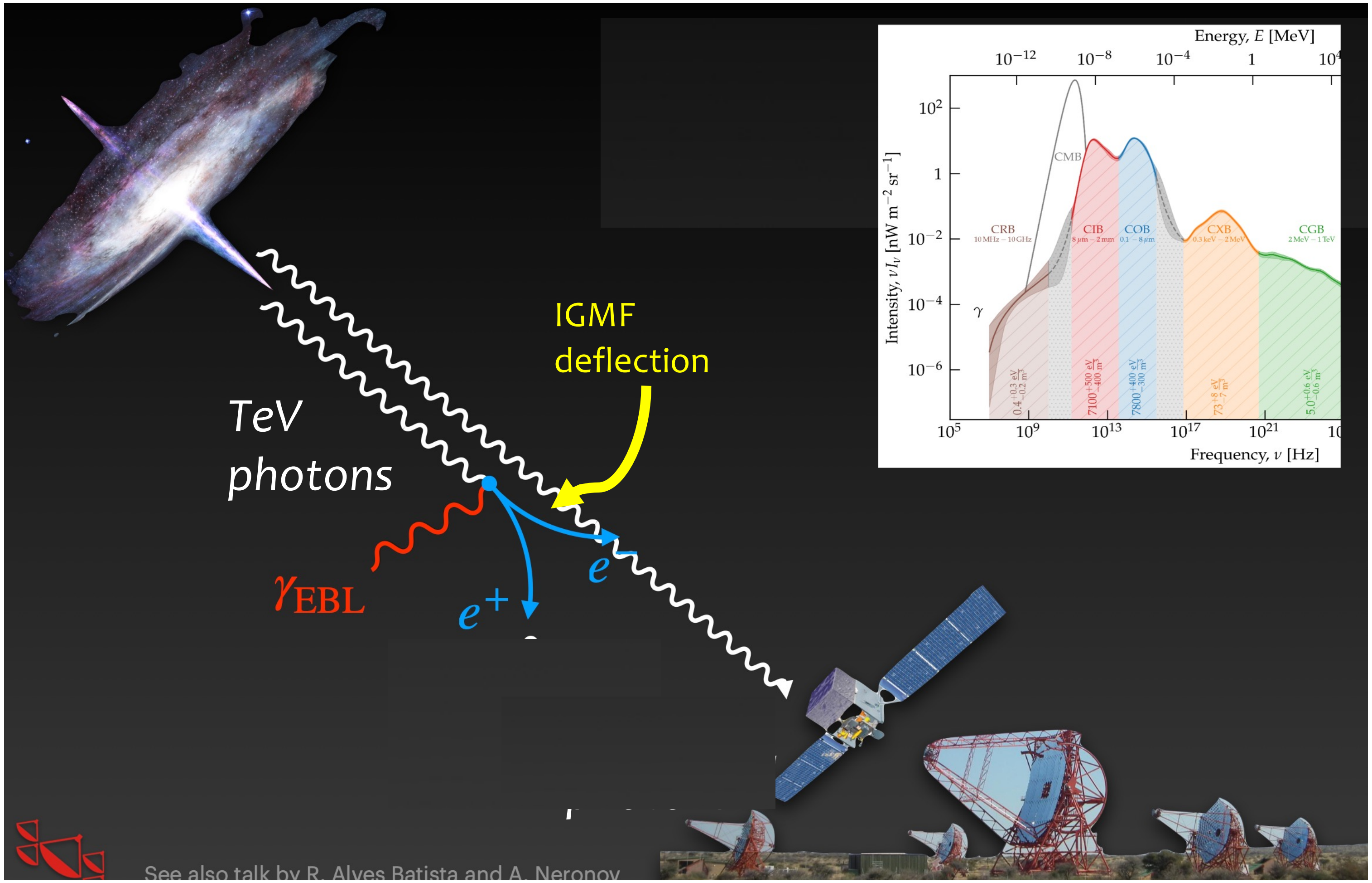
- We have developed a framework that computes the relation MM mass-speed in cosmic MFs (that includes back-reaction)
- We have made assumptions on MFs, if better models come out, more accurate estimations can be made
- Strong IGMFs impact MM acceleration (could contribute, could dominate)
- Terrestrial instruments are sensitive to different MM mass (related to their formation mechanisms)



Thanks!

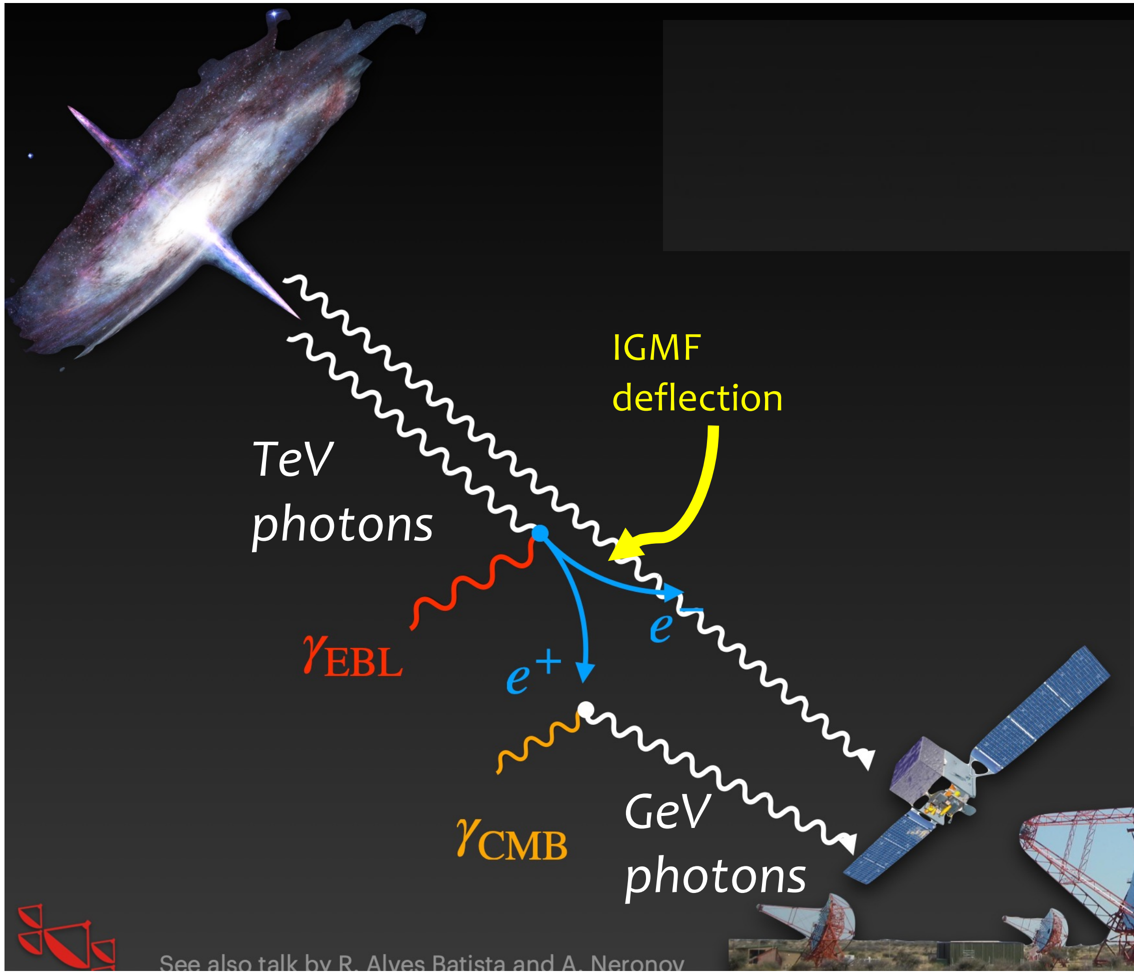
BACKUPS

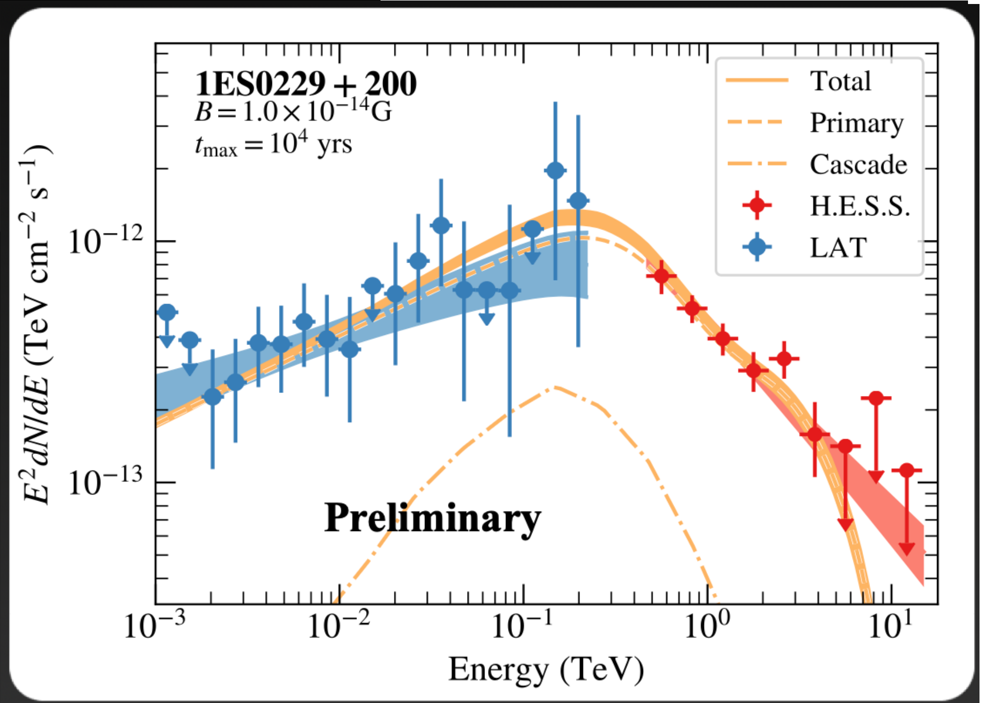
4/ INTERGALACTIC MAGNETIC FIELDS



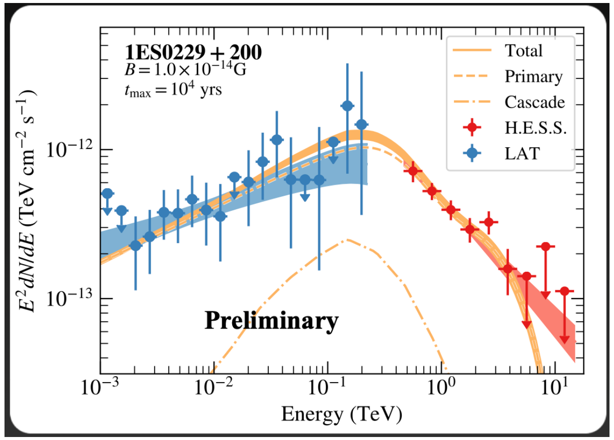
EBL light reprocess TeV gamma-rays to GeV gamma-rays

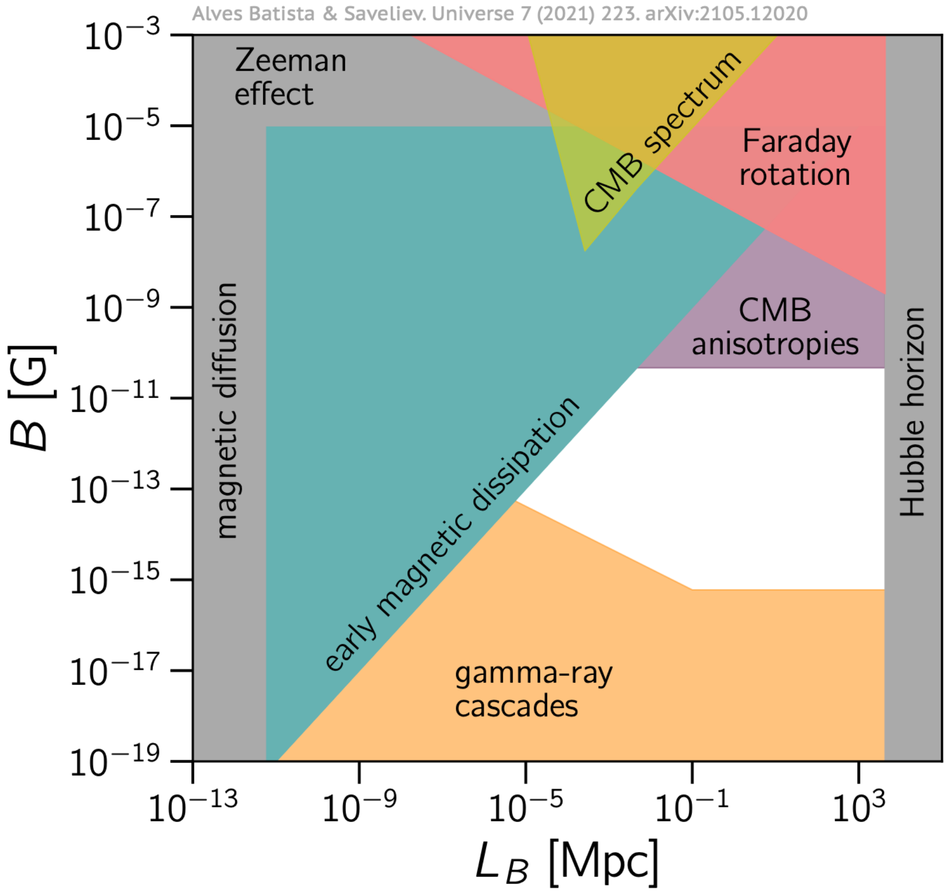
4/ INTERGALACTIC MAGNETIC FIELDS



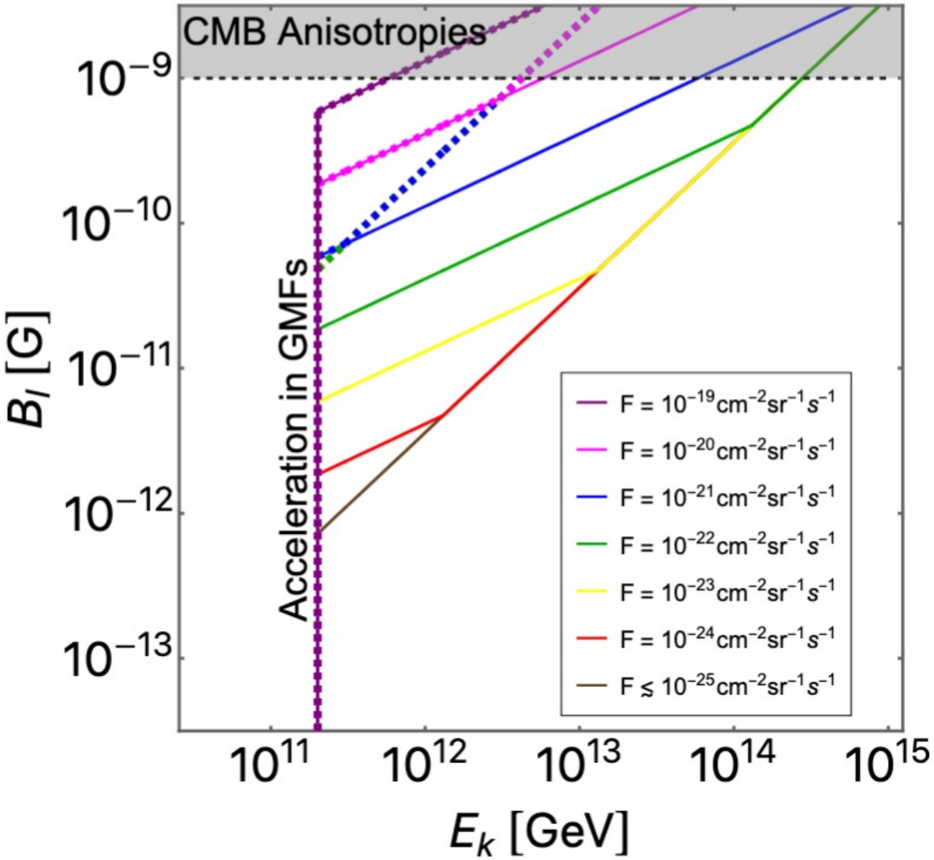


4/ INTERGALACTIC MAGNETIC FIELDS





REVERSE BONUS: MM CAN LIMIT IGMF



- The argument can be reversed
- A MM flux limit, assuming a certain kinetic energy, could be translated into an IGMF limit