# Bounds on Monopoles Abundance from Acceleration in Cosmic Magnetic Fields


SISSA

Istituto Nazionale di Fisica Nucleare

**Speaker:**
**Daniele Perri**



**DP**, T. Kobayashi
*Phys.Rev.D* 106 (2022) 6, 063016

**DP**, K. Bondarenko, M. Doro, T. Kobayashi
arXiv:2401.00560

**DP**, M. Doro, T. Kobayashi
arXiv:2409.xxxxx


ICHEP 2024 - 20/07/24

# Contents of the Talk

- ✓ Models of magnetic monopoles and bounds.
- ✓ New bounds from primordial acceleration.
- ✓ Modification of the bounds from late time acceleration.
- ✓ Conclusion.

**DP**, T. Kobayashi (2022)
*Phys.Rev.D* 106 (2022) 6, 063016

**DP**, K. Bondarenko, M. Doro, T. Kobayashi
arXiv:2401.00560

**DP**, M. Doro, T. Kobayashi
arXiv:2409.xxxxx

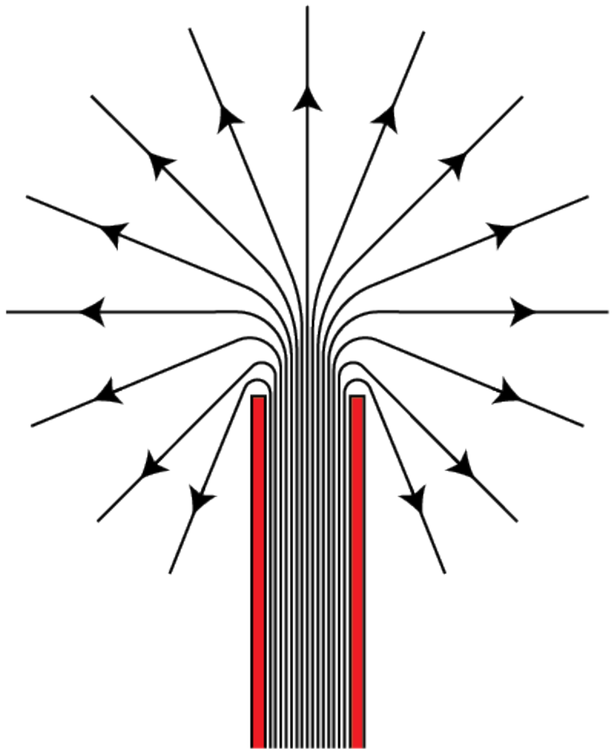
# Can a Monopole Really Exist?

## Dirac Monopoles and the Quantization of the Electric Charge

$$\vec{B}_{\text{mono}} = g\frac{\vec{r}}{r^3}$$

- Dirac was the first to suppose the existence of magnetic monopoles.
- In 1948 he proposed a model for a monopole made of *one semi-infinite string solenoid*.
- The existence of magnetic monopoles is consistent with quantum theory once imposed the *charge quantization condition*:

$$g = 2\pi n/e = n g_{\text{D}}$$



- Monopoles provide a strong theoretical explanation for the quantization of the electric charge.

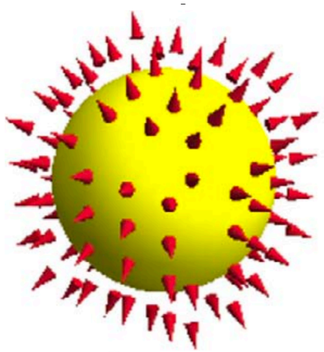
# Can a Monopole Really Exist?

## 'T Hooft-Polyakov Monopoles and Topological Defects

- In 1974 'T Hooft and Poliakov proposed a model of monopoles as *topological defects* linked to non-trivial second homotopy groups of the vacuum manifold:

$$G \to H,\ \pi_2(G/H) \neq \mathrm{I}$$

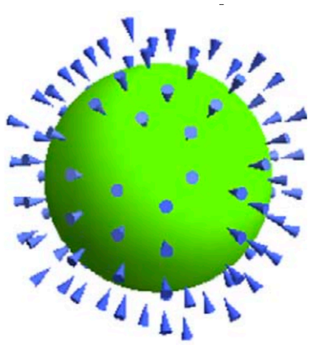
*Each time a simply connected group is broken into a smaller group that contains* U(1) *there is a production of monopoles.*



$Q_m = +1$

Monopoles are *inevitable predictions* of Grand Unified Theories:

$$SU(5) \to SU(3) \times SU(2) \times U(1) \to SU(3) \times U(1)$$

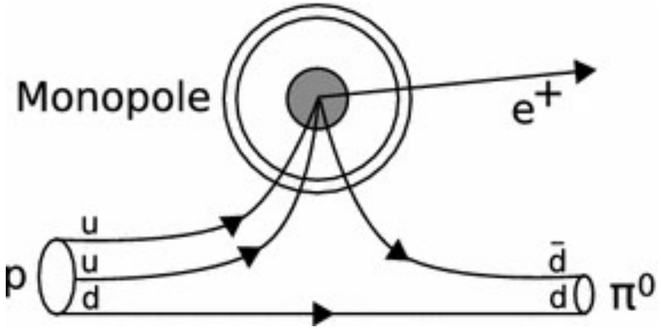


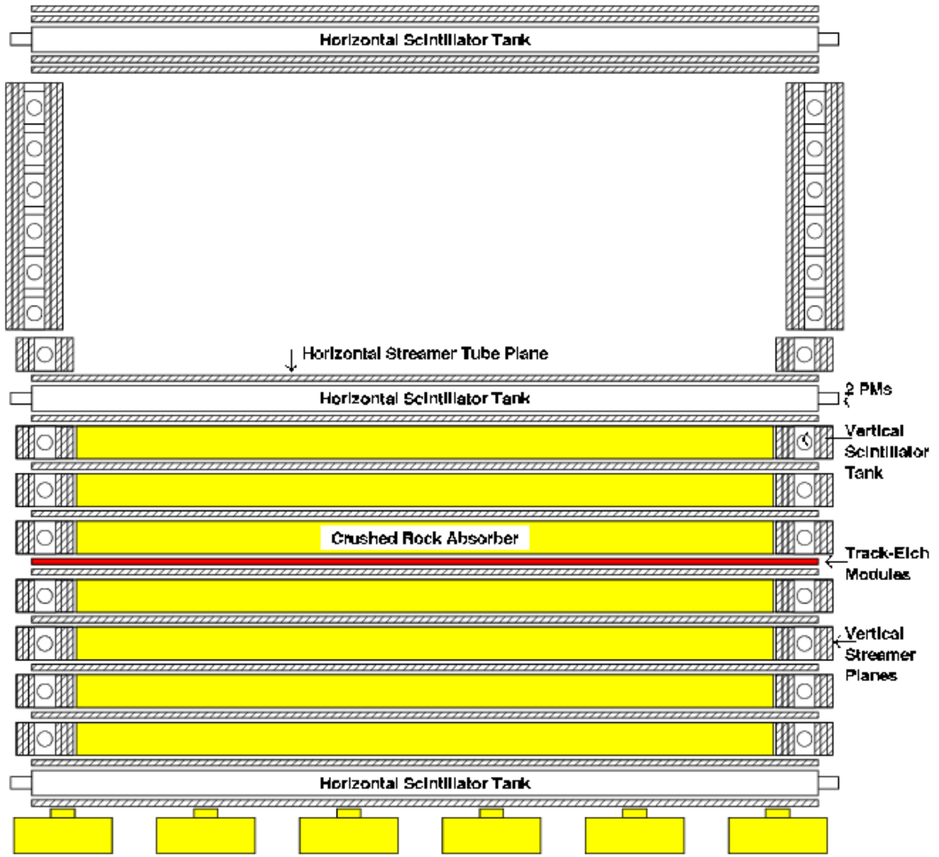
$Q_m = -1$

# Direct Observations of Monopoles

There are different strategies for the direct observation of magnetic monopoles:

- Induction of electric currents into a coil;
- Energy loss in the medium (Ex. MACRO, IceCube);
- Catalysis of nucleon decays (only for GUT monopoles).

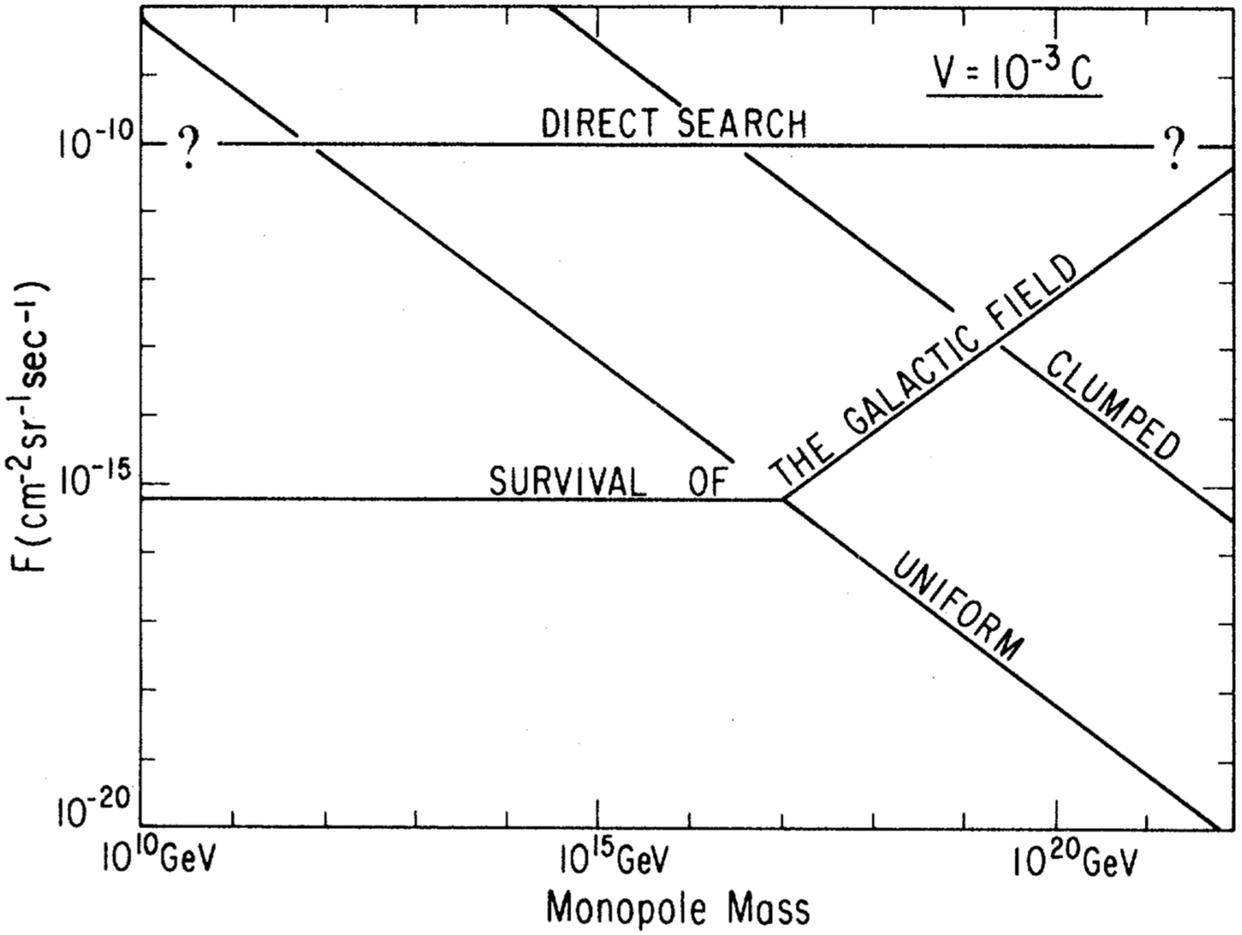


# Parker Bounds on the Monopole Flux

In 1970 Parker proposed a bound on the monopole flux today inside our Galaxy:

- The Galaxy presents a magnetic field of $\sim 2 \times 10^{-6}$ G;
- The Galactic magnetic field accelerates the monopoles losing its energy;
- The survival of the field provides a bound on the monopole flux today.



# Magnetic Monopoles and Cosmic Magnetic Fields

*The evolution of magnetic monopoles and cosmic magnetic fields is strictly coupled throughout the universe's history.*

Cosmic magnetic fields accelerate the monopoles

Accelerated monopoles extract energy from cosmic magnetic fields

Monopole bounds are affected by the acceleration

The survival of cosmic magnetic fields might lead to new bounds

# Contents of the Talk

- ✓ Models of magnetic monopoles and bounds.
- ✓ New bounds from primordial acceleration.
- ✓ Modification of the bounds from late time acceleration.
- ✓ Conclusion.

**DP**, T. Kobayashi (2022)
*Phys.Rev.D* 106 (2022) 6, 063016

**DP**, K. Bondarenko, M. Doro, T. Kobayashi
arXiv:2401.00560

**DP**, M. Doro, T. Kobayashi
arXiv:2409.xxxxx

# Acceleration in Primordial Magnetic Fields

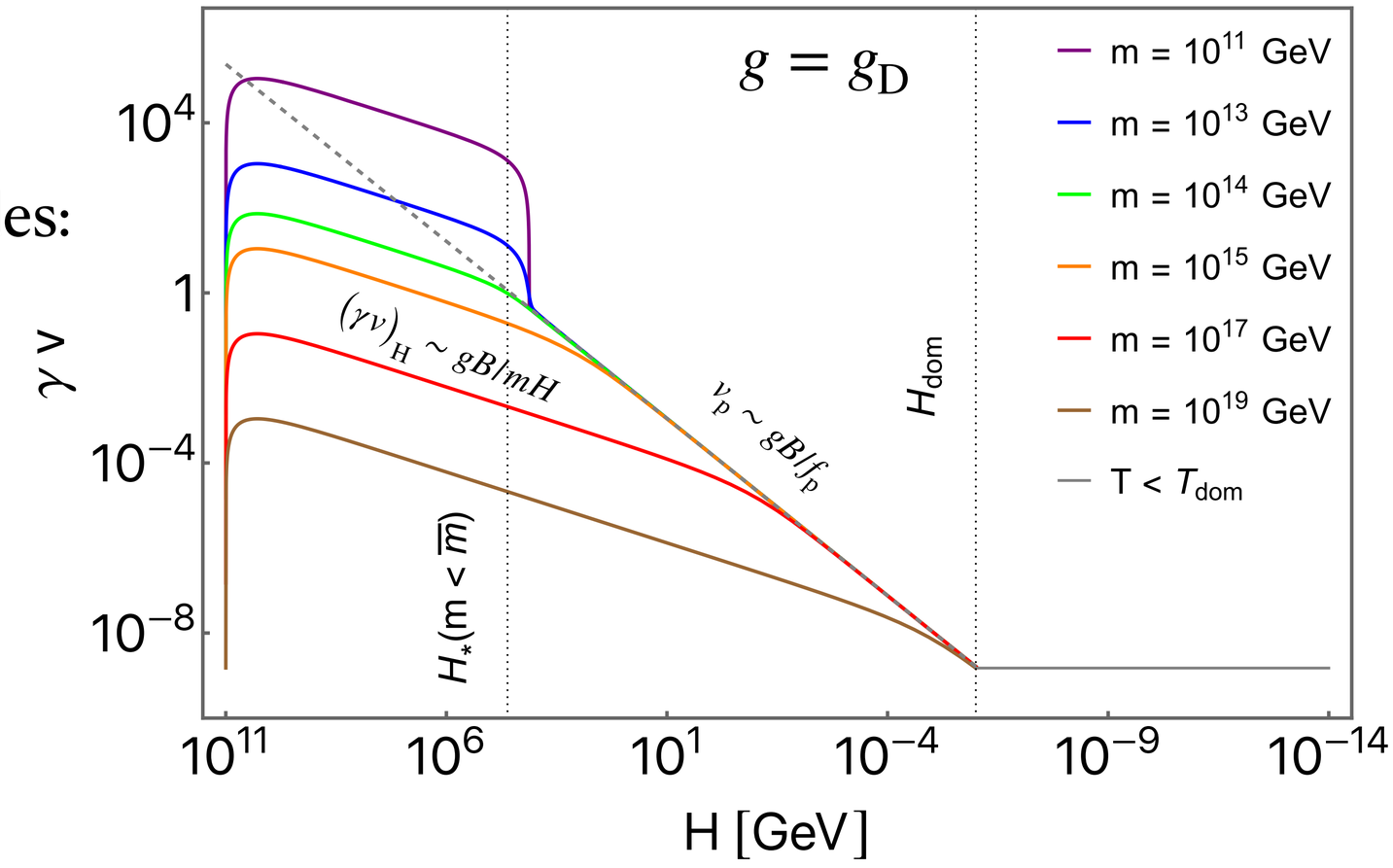
We now have strong evidence for intergalactic magnetic fields $\gtrsim 10^{-15}$ G with *primordial origin*.

$$m\frac{d}{dt}(\gamma v) = gB - \left(f_{\rm p} + mH\gamma\right) v$$

Two external forces act on the monopoles:

- $gB$, the *magnetic force* that accelerates the monopoles;
- $-f_{\rm p} v$, the *frictional force* due to the interaction with the particles of the primordial plasma.

$$f_{\rm p} \sim \frac{e^2 g^2 \mathcal{N}_c}{16\pi^2} T^2$$



# New Bounds from Primordial Magnetic Fields

*An analogous of the Parker bound can be derived from primordial magnetic fields.*

Long, Vachaspati (2015)
arXiv:1504.03319

- The evolution of the *magnetic field energy density* in the presence of monopoles is described by the equation:

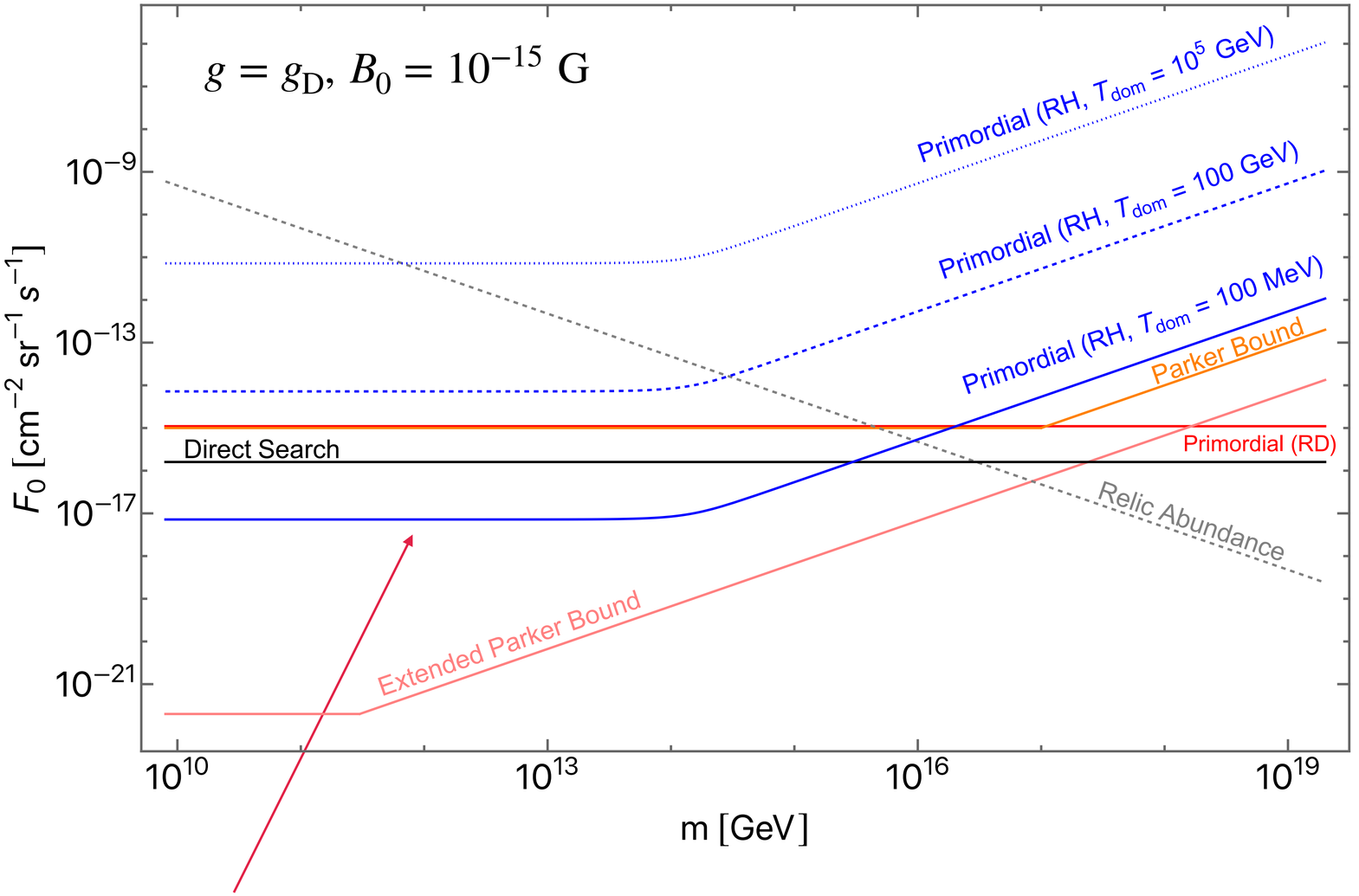
$$\frac{\dot{\rho}_{\rm B}}{\rho_{\rm B}} = -\,\Pi_{\rm red} - \Pi_{\rm acc}$$

$$\Pi_{\rm red}(t) = 4H(t) \qquad\qquad \Pi_{\rm acc}(t) = \frac{4g}{B(t)} v(t) n(t)$$

- The magnetic fields survive under the condition $\Pi_{\rm acc}/\Pi_{\rm red} \lesssim 1$ .

*Necessary to study the equation of motion of the monopoles!!*

# New Bounds from Primordial Magnetic Fields




1) During radiation domination:

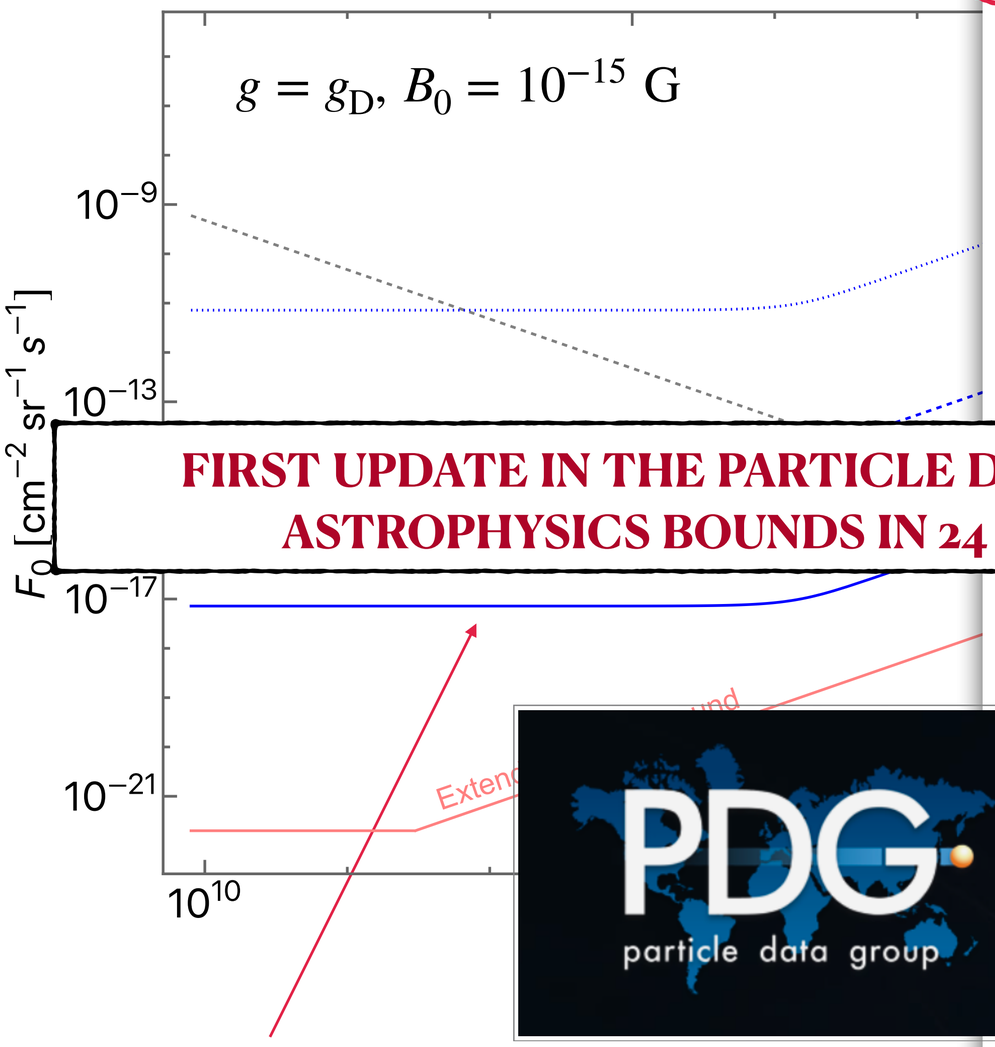
$$n_0 \lesssim \max\left\{ 10^{-21}\ \mathrm{cm}^{-3},\ 10^{-21}\ \mathrm{cm}^{-3} \left(\frac{m}{10^{19}\ \mathrm{GeV}}\right) \left(\frac{g_D}{g}\right)^2 \right\}$$

2) During reheating:

$$n_0 \lesssim \max\left\{ 10^{-16}\ \mathrm{cm}^{-3} \left(\frac{B_0}{10^{-15}\ \mathrm{G}}\right)^{3/5} \left(\frac{T_{dom}}{10^6\ \mathrm{GeV}}\right) \left(\frac{g_D}{g}\right)^{3/5},\right.$$
$$\left. 10^{-16}\ \mathrm{cm}^{-3} \left(\frac{m}{10^{14}\ \mathrm{GeV}}\right) \left(\frac{T_{dom}}{10^6\ \mathrm{GeV}}\right) \left(\frac{g_D}{g}\right)^2 \right\}$$

Stronger than direct search for $T_{dom} \lesssim 1$ GeV !!

# New Bounds fro




**FIRST UPDATE IN THE PARTICLE DATA GROUP**
**ASTROPHYSICS BOUNDS IN 24 YEARS!!**

## Monopole Flux — Astrophysics

| FLUX ($cm^{-2}sr^{-1}s^{-1}$) | MASS (GeV) | CHG ($g$) | COMMENTS ($\beta = v/c$) | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|
| $< 1.2 \times 10^{-21}$ | $> 10^4$ | 1 | Parker | [1] KOBAYASHI | 23A | COSM |
| $< 1.3 \times 10^{-20}$ | | | faint white dwarf | [2] FREESE | 99 | ASTR |
| $< 1 \times 10^{-16}$ | $10^{17}$ | 1 | galactic field | [3] ADAMS | 93 | COSM |
| $< 1 \times 10^{-23}$ | | | Jovian planets | [2] ARAFUNE | 85 | ASTR |
| $< 1 \times 10^{-16}$ | $10^{15}$ | | solar trapping | BRACCI | 85B | ASTR |
| $< 1 \times 10^{-18}$ | | 1 | | [2] HARVEY | 84 | COSM |
| $< 3 \times 10^{-23}$ | | | neutron stars | KOLB | 84 | ASTR |
| $< 7 \times 10^{-22}$ | | | pulsars | [2] FREESE | 83B | ASTR |
| $< 1 \times 10^{-18}$ | $< 10^{18}$ | 1 | intergalactic field | [2] REPHAELI | 83 | COSM |
| $< 1 \times 10^{-23}$ | | | neutron stars | [2] DIMOPOUL... | 82 | COSM |
| | | | neutron stars | [2] KOLB | 82 | COSM |
| | | | galactic halo | SALPETER | 82 | COSM |
| | | 1 | $\beta = 3 \times 10^{-3}$ | [4] TURNER | 82 | COSM |
| | | 1 | galactic field | PARKER | 70 | COSM |

[1] KOBAYASHI 23A found Parker-type bounds on magnetic monopoles with arbitrary magnetic charge based on the survival of galactic, seed, and primordial magnetic fields. Bounds are between $10^{-21}$ and $10^{-5}$ $cm^{-2}sr^{-1}s^{-1}$ for masses between $10^4$ and $10^{18}$ GeV. Reported bound is the most stringent one.

[2] Catalysis of nucleon decay.

[3] ADAMS 93 limit based on "survival and growth of a small galactic seed field" is $10^{-16}$ $(m/10^{17}$ GeV$)$ $cm^{-2}$ $s^{-1}$ $sr^{-1}$. Above $10^{17}$ GeV, limit $10^{-16}$ $(10^{17}$ GeV$/m)$ $cm^{-2}$ $s^{-1}$ $sr^{-1}$ (from requirement that monopole density does not overclose the universe) is more stringent.

[4] Re-evaluates PARKER 70 limit for GUT monopoles.

$$\left\{ \left( \frac{g_D}{g} \right)^2 \right\}$$

$$\left( \frac{g_D}{g} \right)^{3/5},$$

$$\left\{ \left( \frac{g_D}{g} \right)^2 \right\}$$

Stronger than direct search for $T_{dom} \lesssim 1$ GeV !!

# Contents of the Talk

- ✓ Models of magnetic monopoles and bounds.
- ✓ New bounds from primordial acceleration.
- ✓ Modification of the bounds from late time acceleration.
- ✓ Conclusion.

**DP**, T. Kobayashi (2022)
*Phys.Rev.D* 106 (2022) 6, 063016

**DP**, K. Bondarenko, M. Doro, T. Kobayashi
arXiv:2401.00560

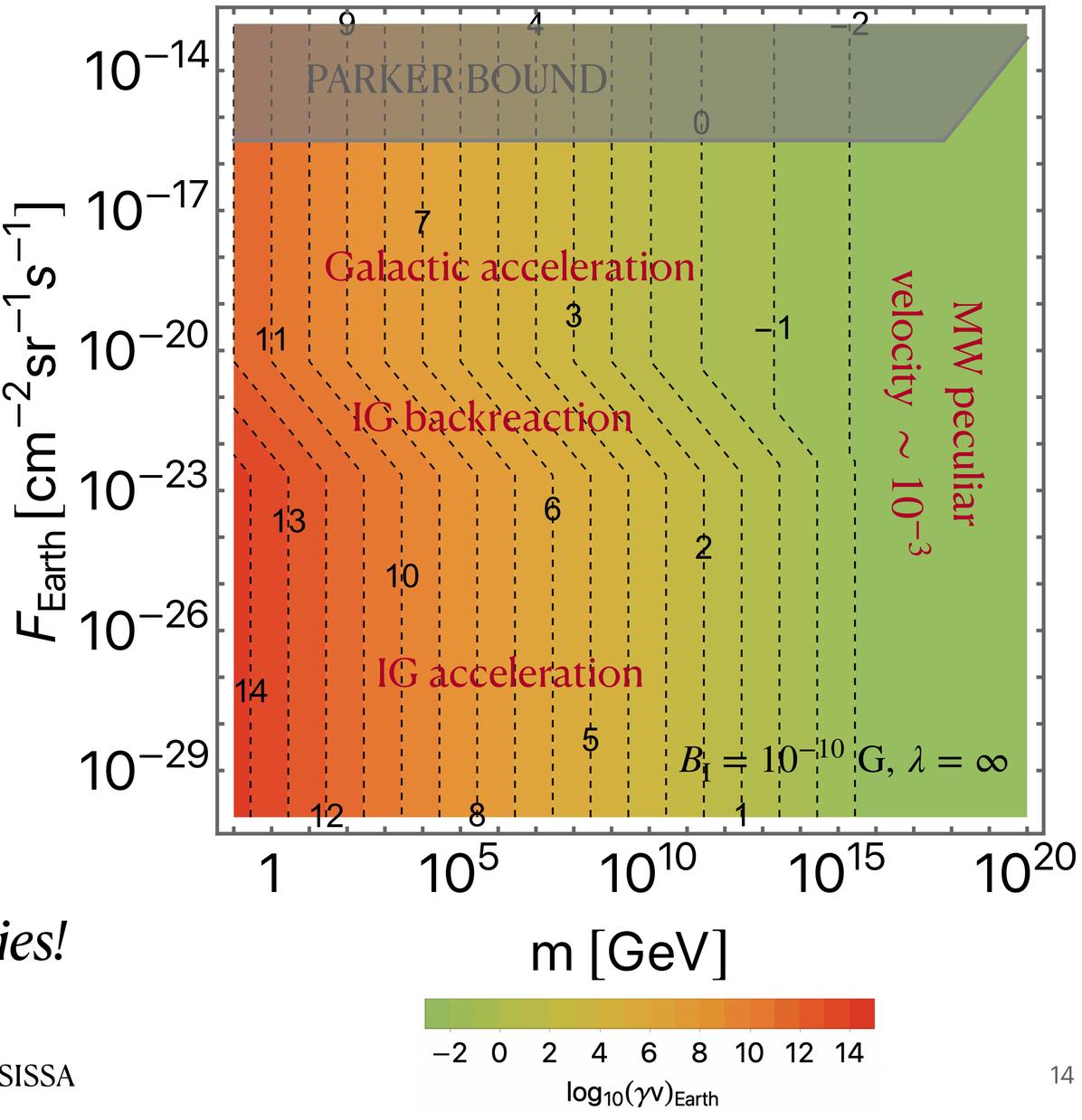
**DP**, M. Doro, T. Kobayashi
arXiv:2409.xxxxx

# Acceleration in Late Universe Magnetic Fields

In literature, monopole velocity on Earth is usually assumed to be comparable to the MW peculiar velocity $\sim 10^{-3}\ c$.

However intergalactic and Galactic magnetic fields free accelerate the monopoles:

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




*Monopoles can be accelerated to relativistic velocities!*

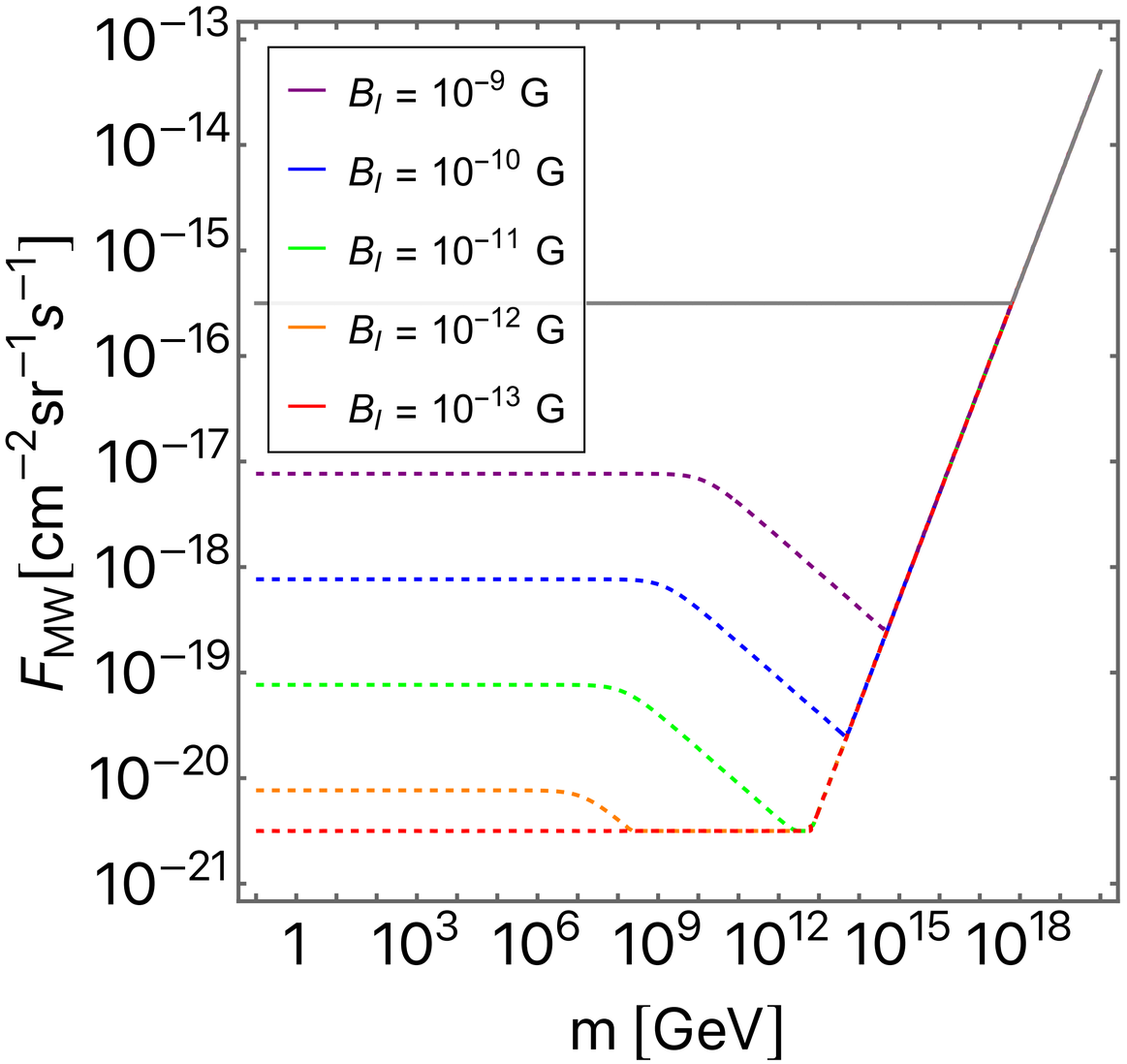
# Modification of Galactic Parker bounds

Galactic Parker bounds depend on the monopole incident velocity on the Milky Way (intergalactic acceleration).

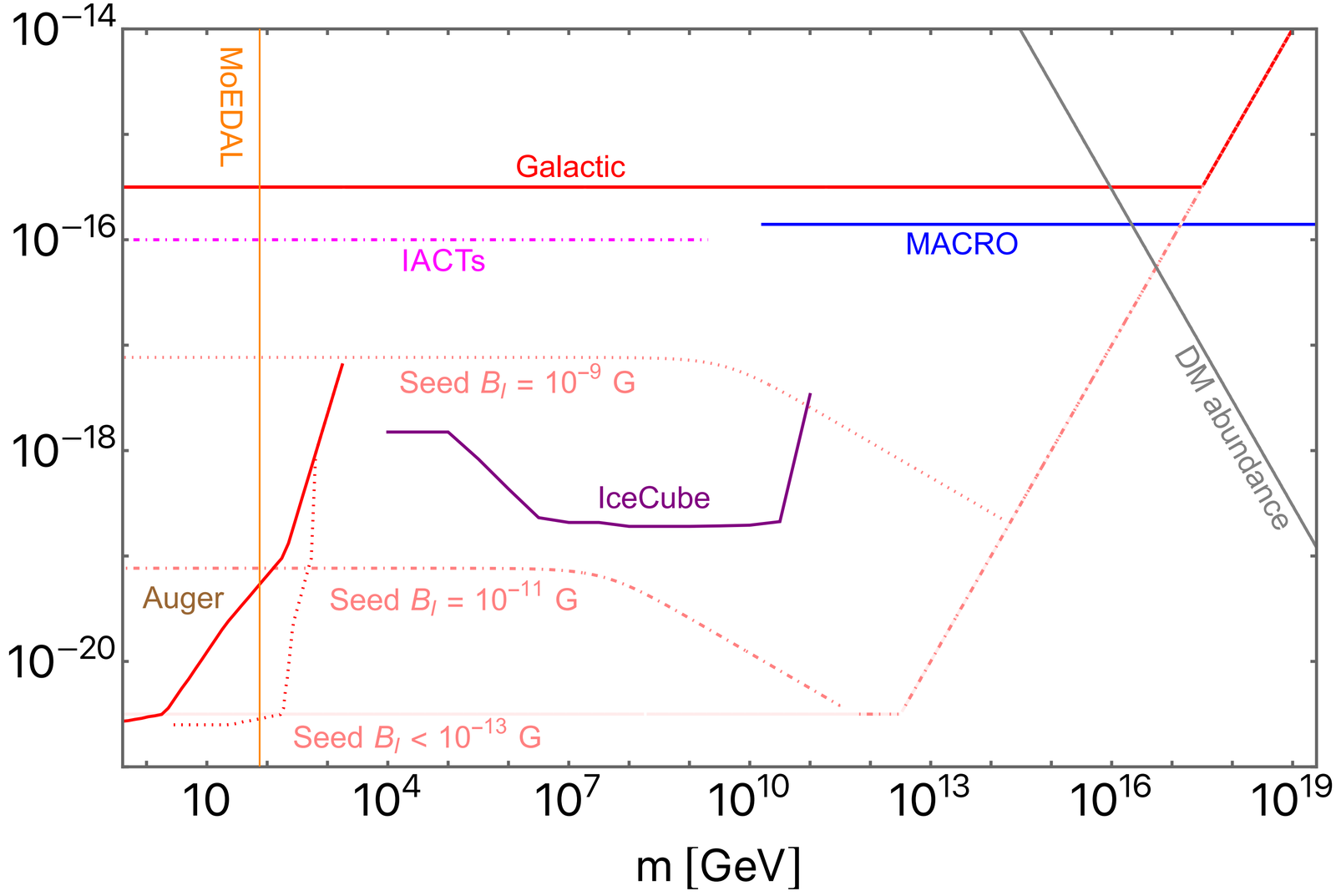
The bounds are weakened for large values of the monopole velocity:

1. *The Galactic bound is not affected by acceleration in intergalactic magnetic fields.*

2. *The seed Galactic bound is strongly affected by the acceleration.*



# Modification of Direct Search Bounds




- Many experiments (ex. IceCube, Auger) put bounds in terms of the velocity at the detector.
- The bounds can be recasted in terms of the mass once an acceleration mechanism is fixed.

*Monopole acceleration drastically changes the scenario of the bounds (search with cosmic rays detectors!)*

# Contents of the Talk

- ✓ Models of magnetic monopoles and bounds.
- ✓ New bounds from primordial acceleration.
- ✓ Modification of the bounds from late time acceleration.
- ✓ Conclusion.

**DP**, T. Kobayashi (2022)
*Phys.Rev.D* 106 (2022) 6, 063016

**DP**, K. Bondarenko, M. Doro, T. Kobayashi
arXiv:2401.00560

**DP**, M. Doro, T. Kobayashi
arXiv:2409.xxxxx

# Conclusion

- The evolution of magnetic monopoles and cosmic magnetic fields is *strictly coupled* throughout the universe's history.
- We derived *new competitive bounds on the magnetic monopole abundance* by generalizing the Parker bound to the survival of primordial magnetic fields.
- Cosmic magnetic fields can accelerate the cosmic population of monopoles to *relativistic velocities*.
- Considering monopole acceleration in cosmic magnetic fields drastically affects the bounds on the abundance (*direct search with cosmic rays detectors!*).

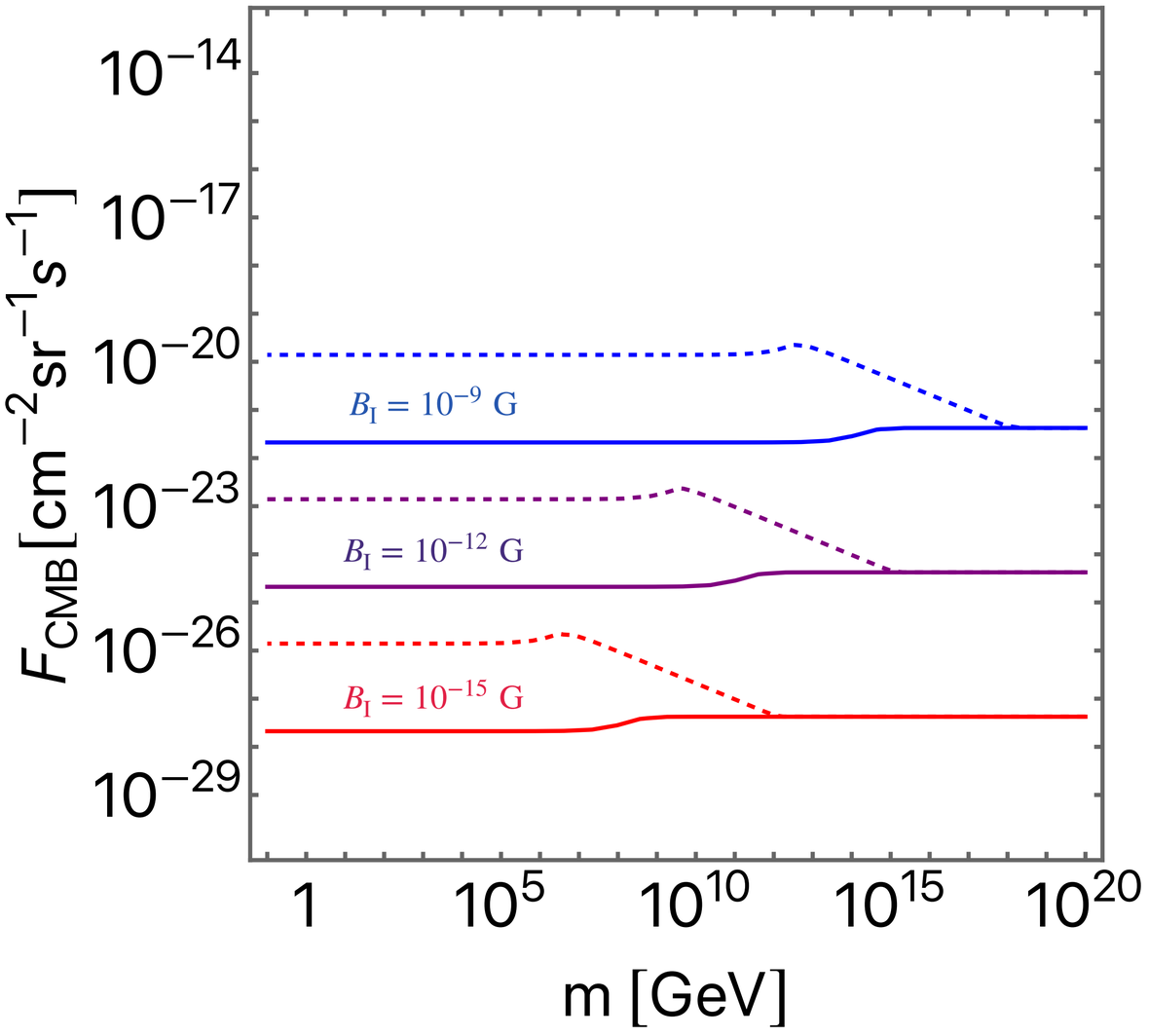
# Thank You!!


INFN
Istituto Nazionale di Fisica Nucleare


ICHEP 2024
PRAGUE


MA PER SEGUIR VIRTUTE E CANOSCENZA
SISSA

# Acceleration in Intergalactic Magnetic Fields




In the presence of enough monopoles, the acceleration can cause backreaction on the intergalactic fields which oscillate on cosmological scales.

$$\gamma_{\rm max} - 1 = \frac{B_{\rm I}^2 v_{\rm max}}{8\pi m F_{\rm CMB}}$$

*In the presence of backreaction, the velocity shows a flux dependence:*

$$(\gamma v)_{\rm CMB} \sim \min\left(\frac{gB}{mH_0}, \frac{B^2}{4\pi m F_{\rm CMB}}\right)$$

(homogeneous fields)