New Bounds on Monopole from Cosmic Magnetic Fields

Speaker:
Daniele Perri

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

DP, T. Kobayashi
Phys.Rev.D 108 (2023) 8, 083005

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

TAsP Meeting - 18/01/24

Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ New bounds on the monopole abundance.
- ✓ Minicharged monopoles and magnetic black holes.
- ✓ Intergalactic magnetic fields and relativistic monopoles.
- ✓ Conclusion.

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

DP, T. Kobayashi (2023)
Phys.Rev.D 108 (2023) 8, 083005

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

SISSA

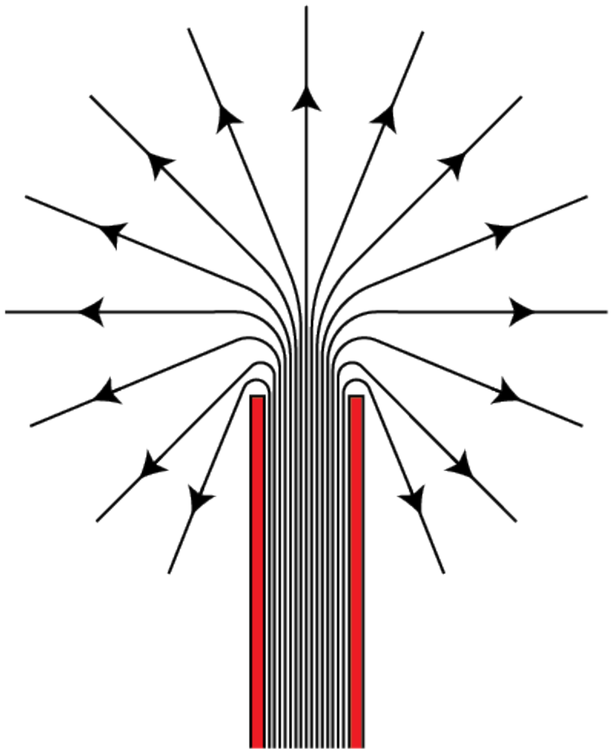
Can a Monopole Really Exist?

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.

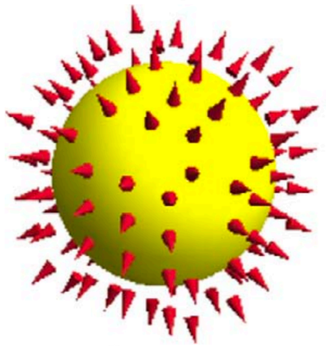
Can a Monopole Really Exist?

'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:

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

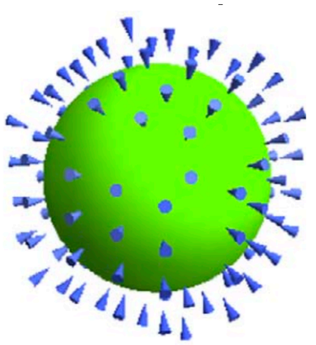
Each time a simply connected group is broken into a smaller group that contains $\mathrm{U}(1)$ *there is a production of monopoles.*



$Q_m = +1$

Monopoles are *inevitable predictions* of Grand Unified Theories:

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



$Q_m = -1$

Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ New bounds on the monopole abundance.
- ✓ Minicharged monopoles and magnetic black holes.
- ✓ Intergalactic magnetic fields and relativistic monopoles.
- ✓ Conclusion.

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

DP, T. Kobayashi (2023)
Phys.Rev.D 108 (2023) 8, 083005

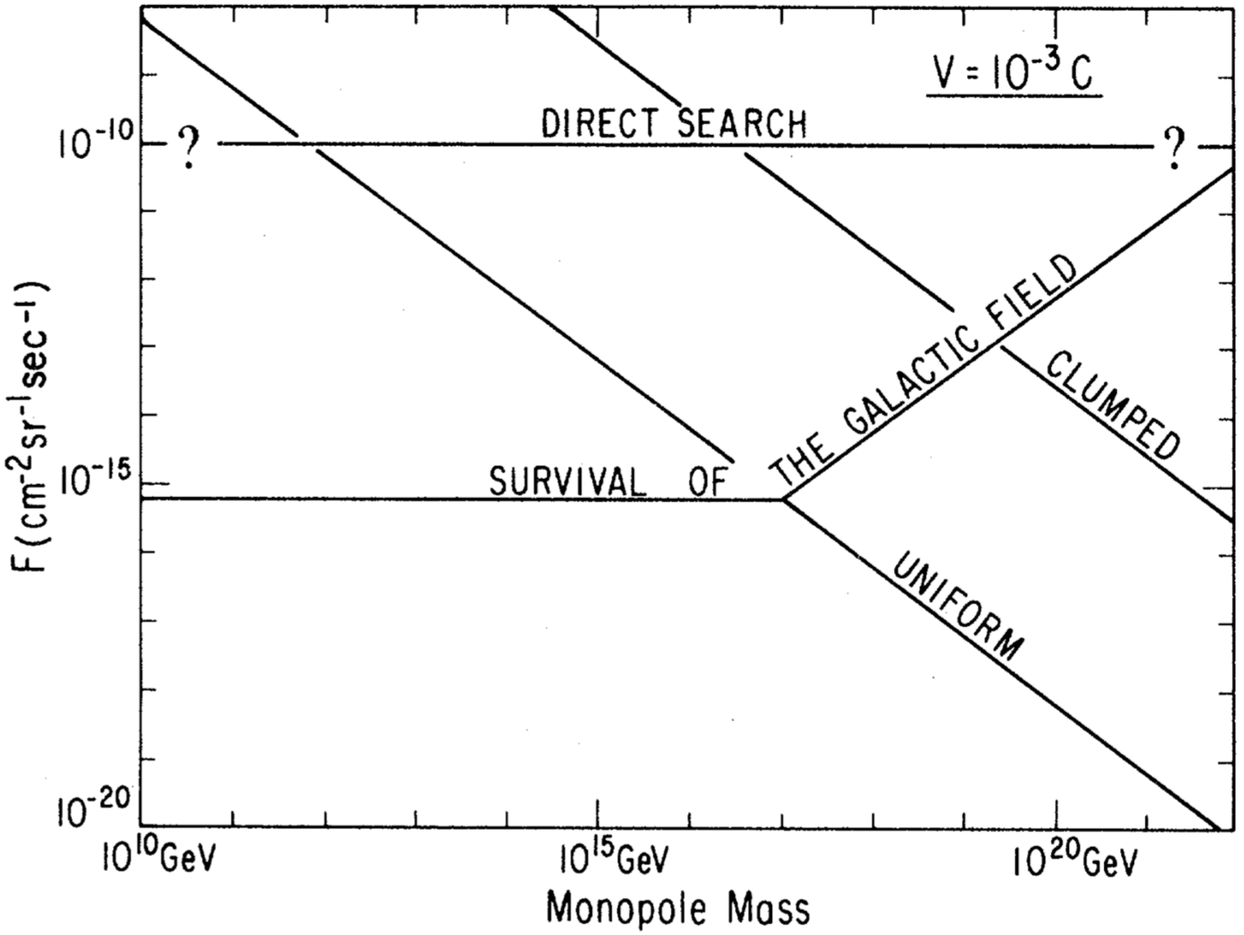
DP, K. Bondarenko,
M. Doro, T. Kobayashi
arXiv:2401.00560

SISSA

Parker Bound 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.



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

- Strong evidences for intergalactic magnetic fields $\gtrsim 10^{-15}$ G with *primordial origin*.

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

$$\frac{\dot{\rho}_B}{\rho_B} = -\Pi_{red} - \Pi_{acc}$$

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

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

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

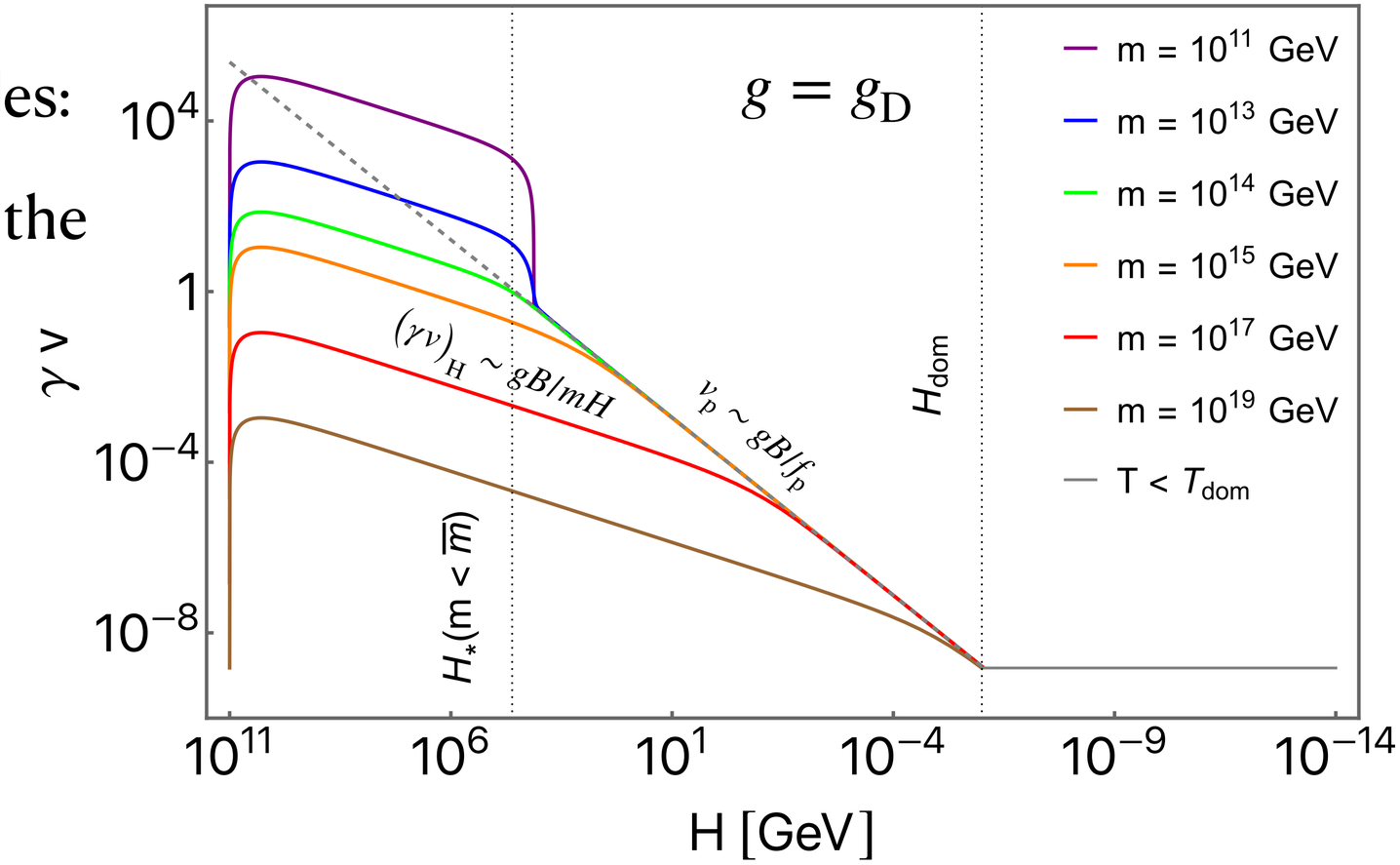
The Equation of Motion of the Monopoles

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

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.

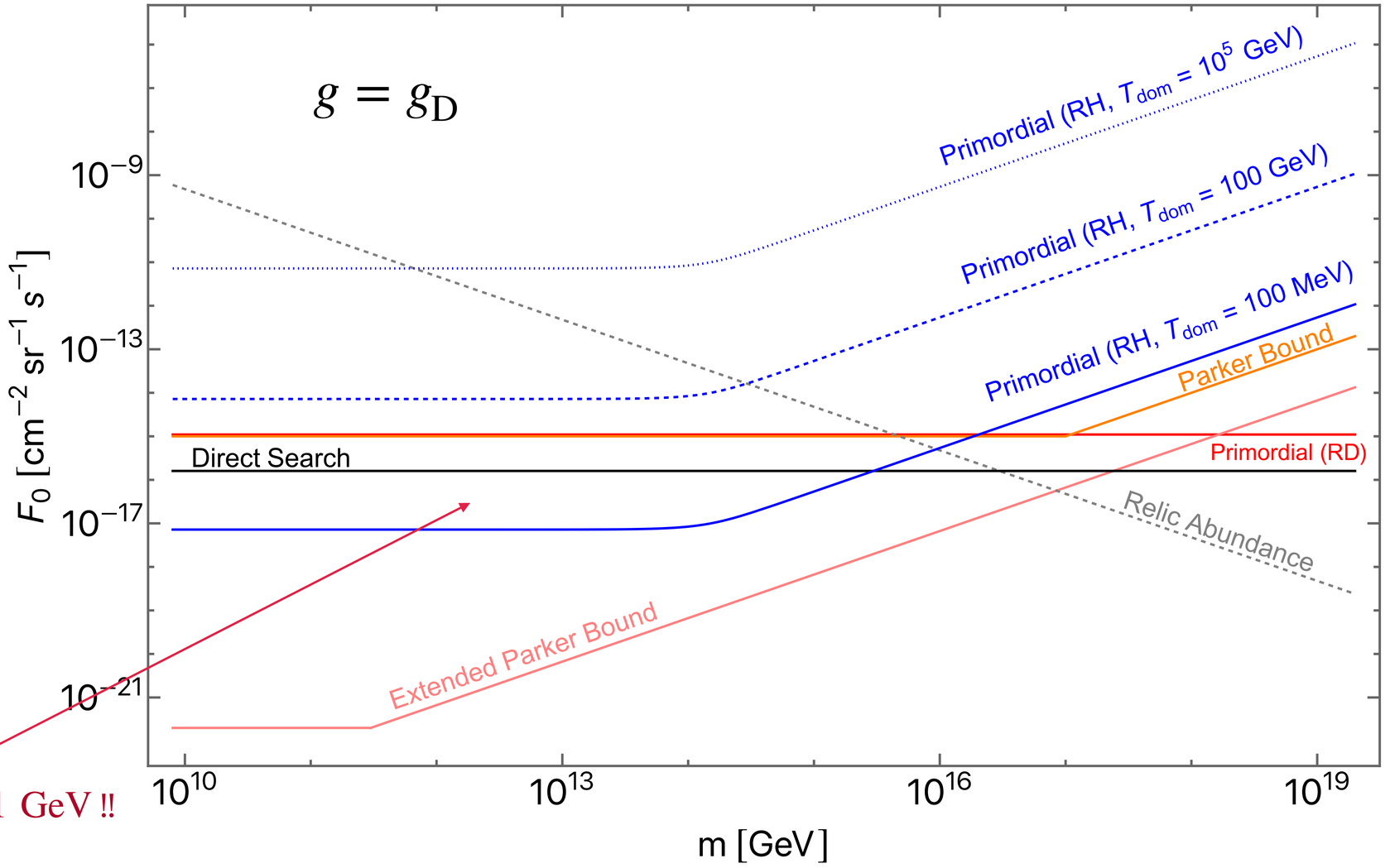
$$f_{\rm p} \sim \frac{e^2 g^2 \mathcal{N}_c}{16\pi^2} T^2$$



The *expansion of the universe* acts as an effective additional frictional force.

Bounds on the Monopole Flux

- We compare the new bounds with previous bounds on the monopole abundance:



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

Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ New bounds on the monopole abundance.
- ✓ Minicharged monopoles and magnetic black holes.
- ✓ Intergalactic magnetic fields and relativistic monopoles.
- ✓ Conclusion.

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

DP, T. Kobayashi (2023)
Phys.Rev.D 108 (2023) 8, 083005

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

SISSA

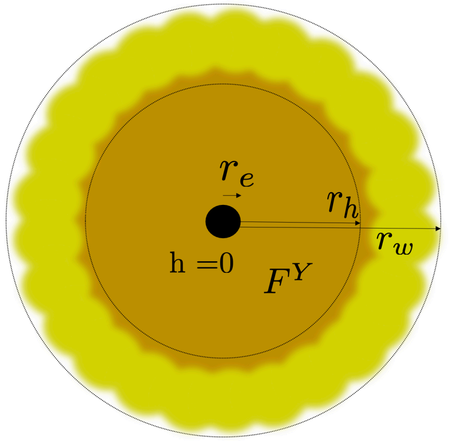
Could Monopoles be Dark Matter?

Monopoles are sometimes suggested as possible candidates for Dark Matter.

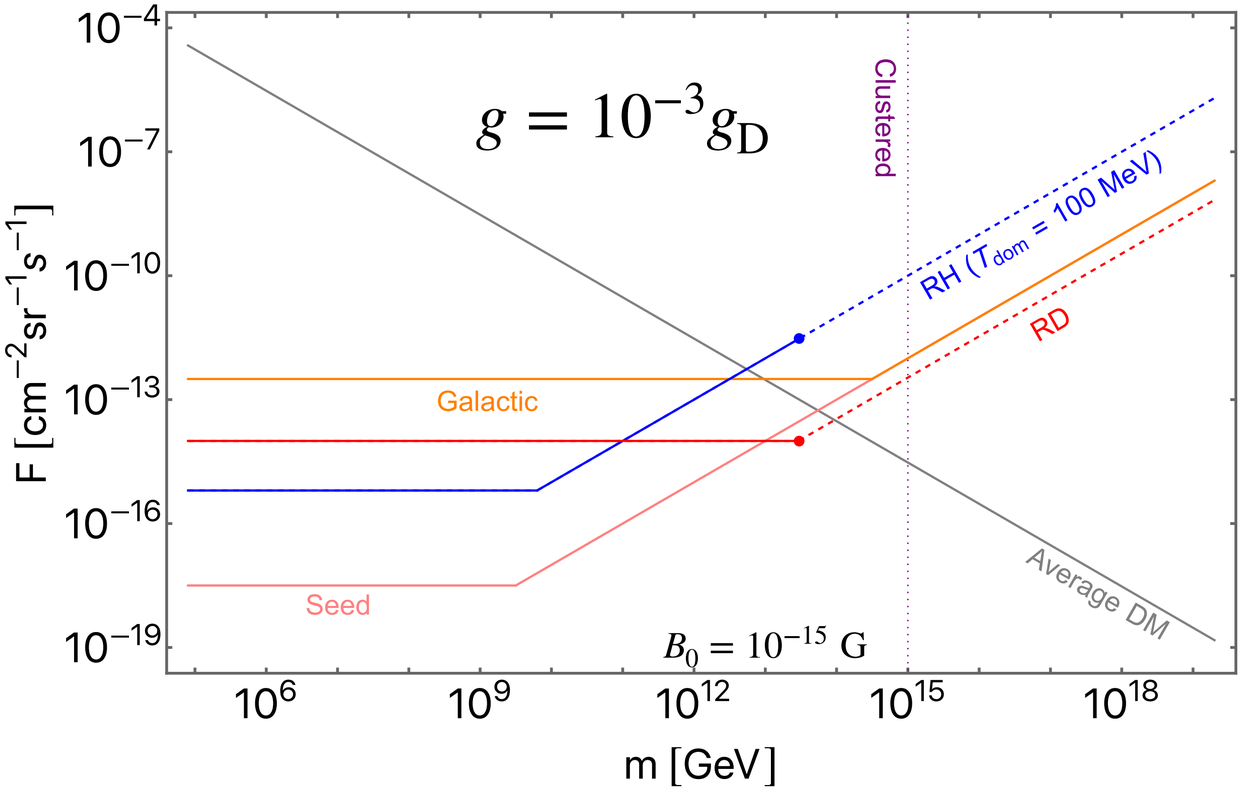
Standard magnetic monopoles must be very heavy to cover all the Dark Matter of the universe ($m \gtrsim 10^{17}$ GeV).

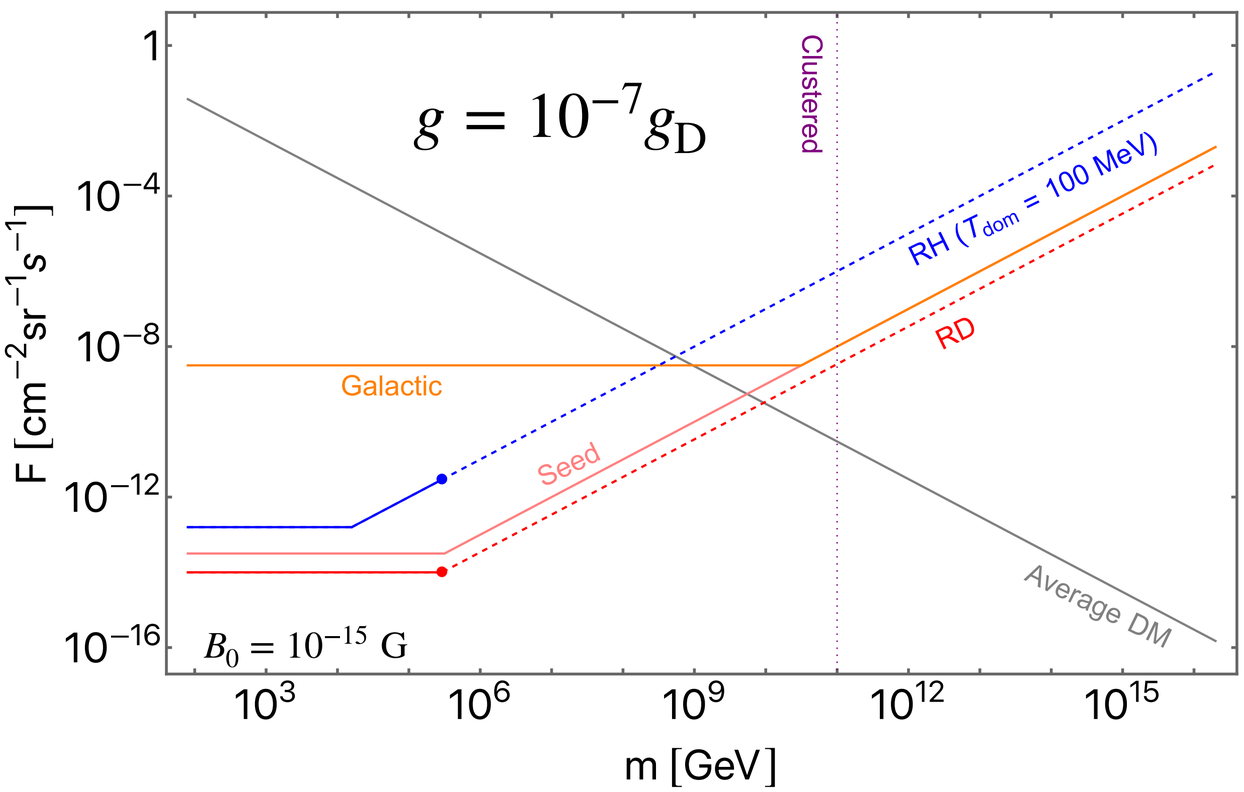
- *Minicharged monopoles* relax the bounds opening the possibility of lighter monopoles as Dark Matter.
- *Magnetically charged black holes* act as very heavy magnetic monopoles.

Maldacena (2020)
arXiv:2004.06084



Bounds on Minicharged Monopoles





- The primordial bounds are less dependent on the monopole charge and they are the **strongest** for small charges.

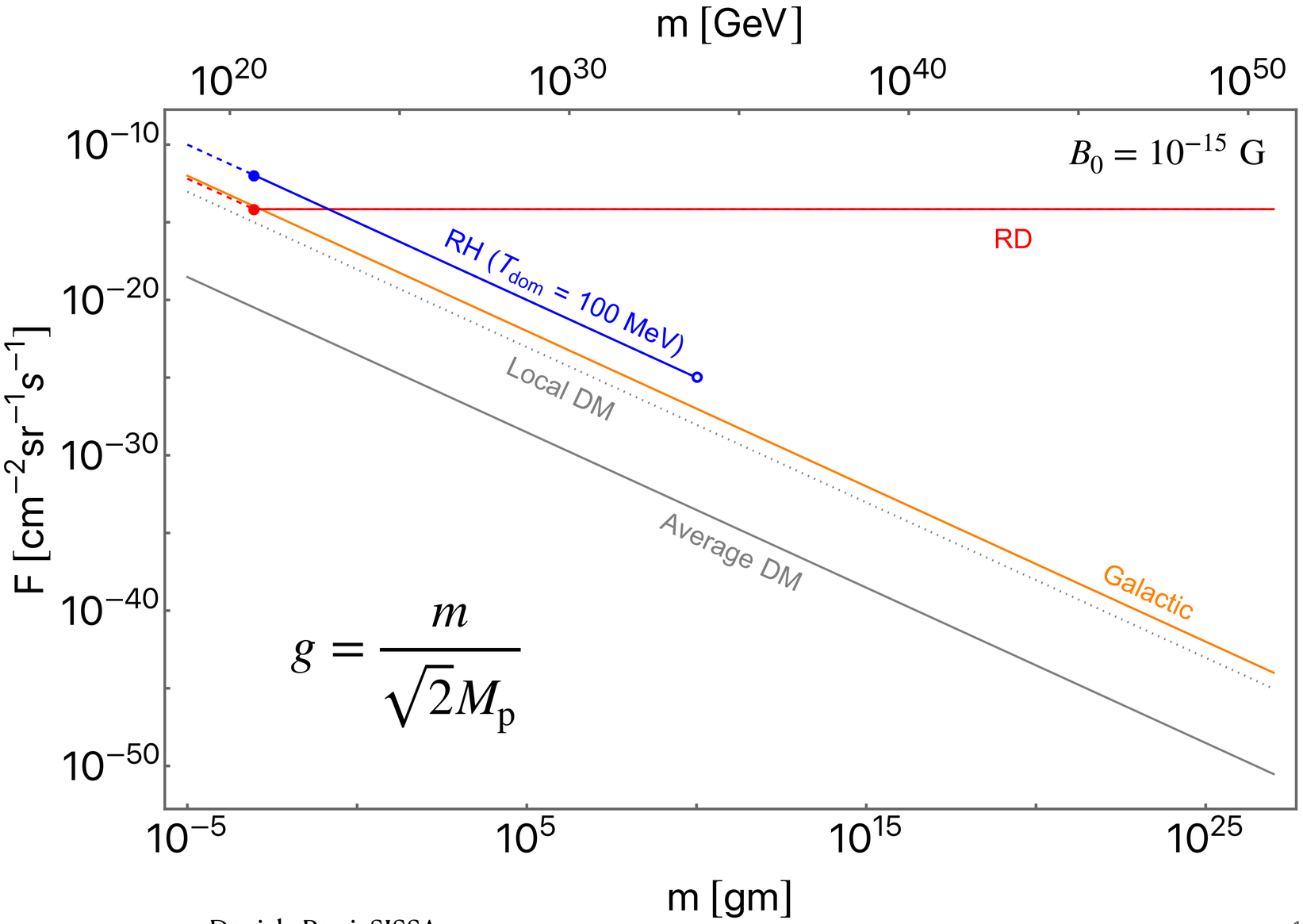
- Minicharged monopoles can cluster with the Galaxy and be DM for masses **much smaller than** $M_{\rm Pl}$.

Bounds on Magnetic Black Holes

- Extremal magnetic BHs have a *fixed mass-to-charge ratio.*

- Cosmological bounds are the strongest (caveat: **Parker bound from M31** seems **stronger**)

- Extremal magnetic BH cluster with Milky Way, **but not all galaxies.**

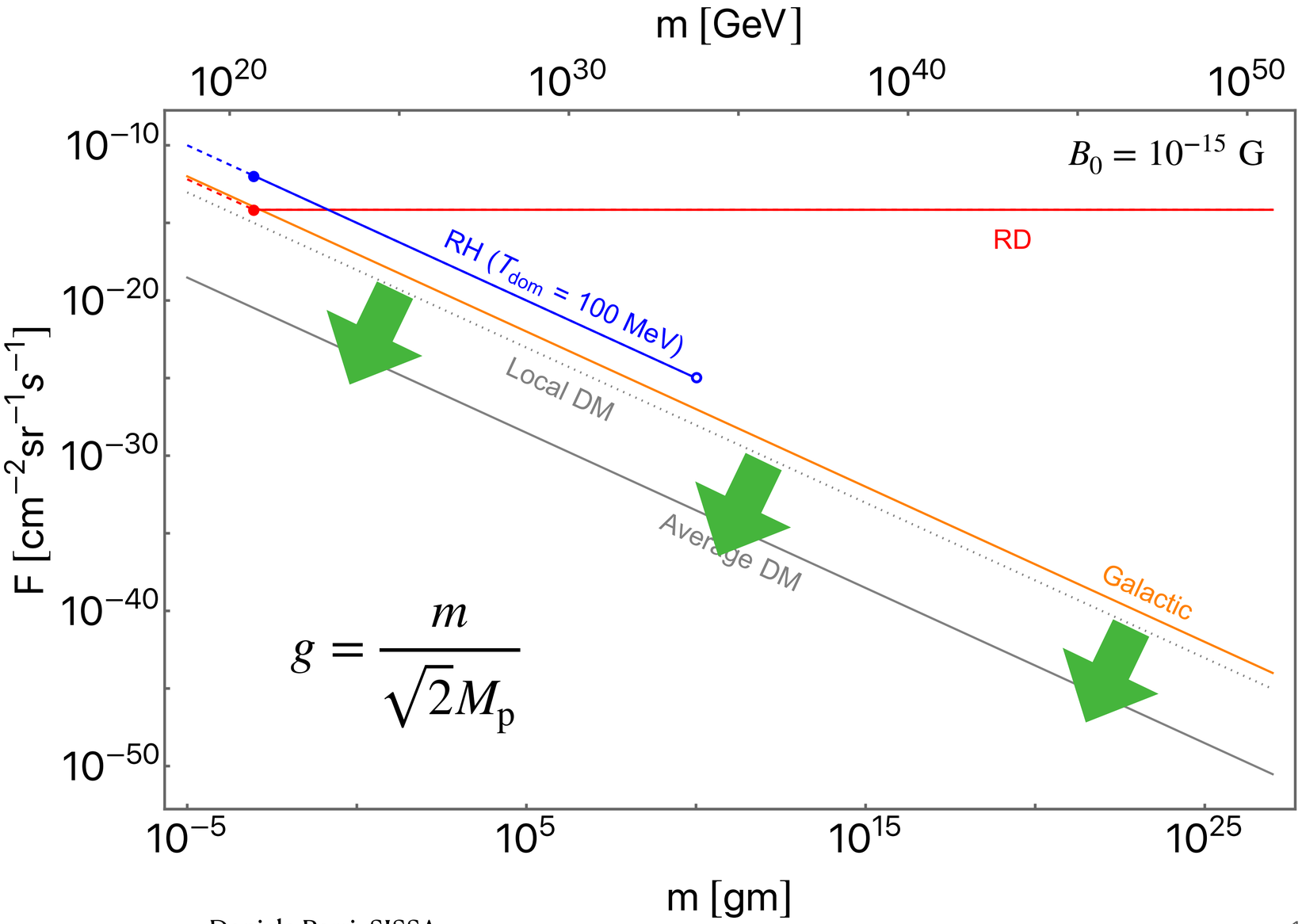


Bounds on Magnetic Black Holes

- Extremal magnetic BHs have a *fixed mass-to-charge ratio.*

- Cosmological bounds are the strongest (caveat: **Parker bound from M31** seems **stronger**)

- Extremal magnetic BH cluster with Milky Way, **but not all galaxies.**



Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ New bounds on the monopole abundance.
- ✓ Minicharged monopoles and magnetic black holes.
- ✓ Intergalactic magnetic fields and relativistic monopoles.
- ✓ Conclusion.

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

DP, T. Kobayashi (2023)
Phys.Rev.D 108 (2023) 8, 083005

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

SISSA

Relativistic monopoles in the universe?

- Depending on the amplitude and coherence length, intergalactic magnetic fields accelerate monopoles in voids.

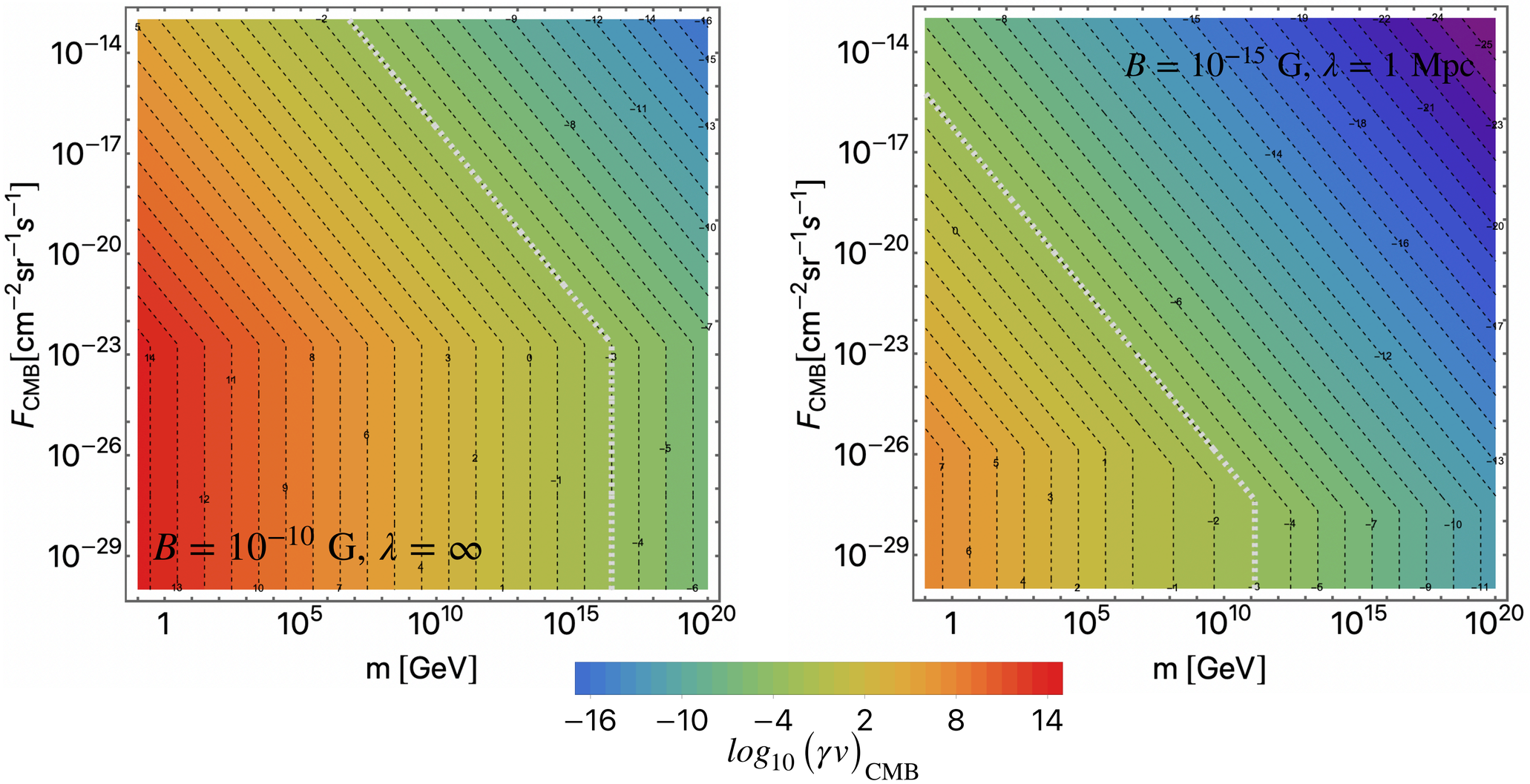
- In the presence of enough monopoles, this causes backreaction on the intergalactic fields that oscillate on cosmological scales.

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

homogeneous fields

In the presence of backreaction, the velocity shows a flux dependence.

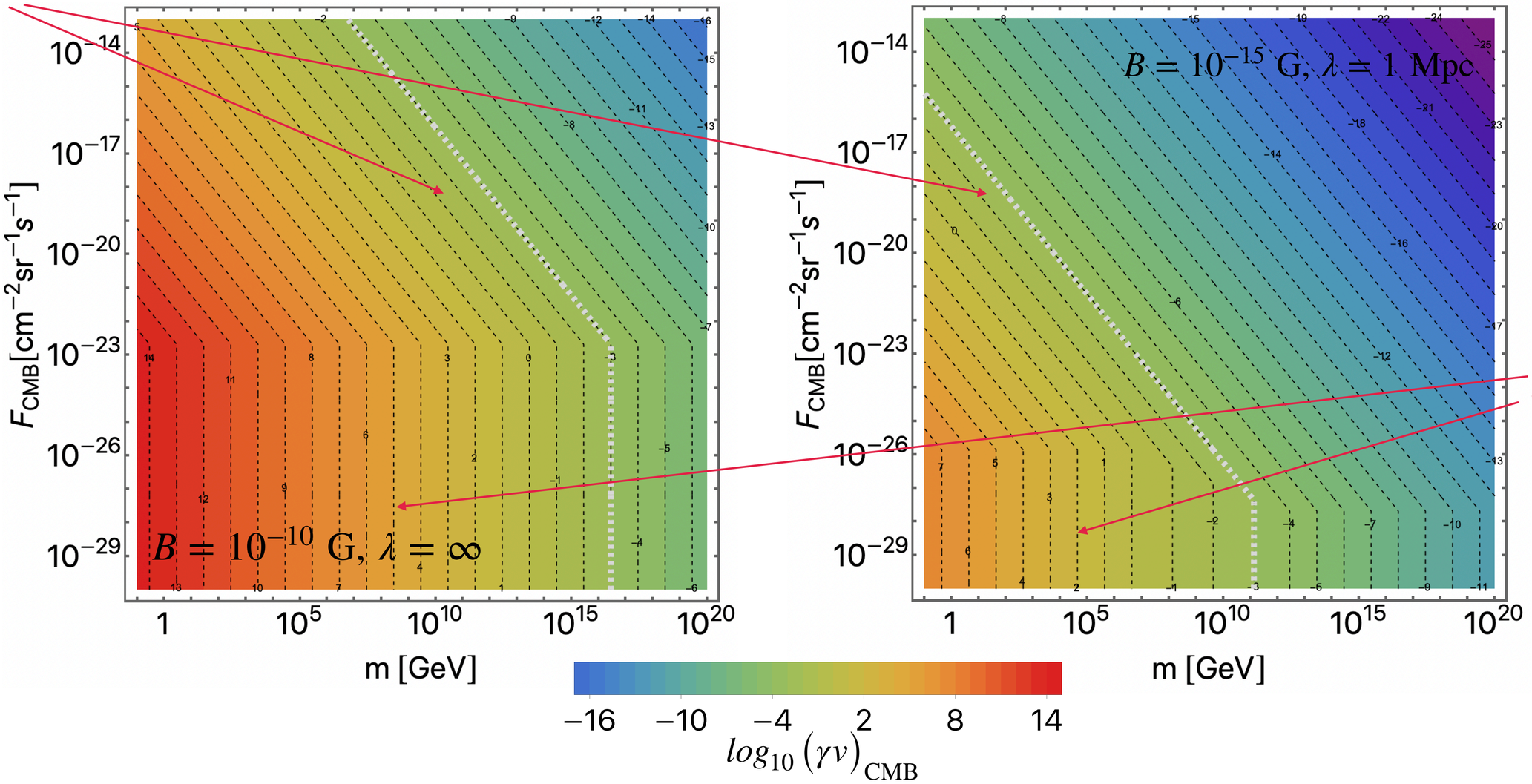
Relativistic monopoles in the universe?



Intergalactic magnetic fields can accelerate monopoles to relativistic velocities.

Relativistic monopoles in the universe?

Backreaction!!

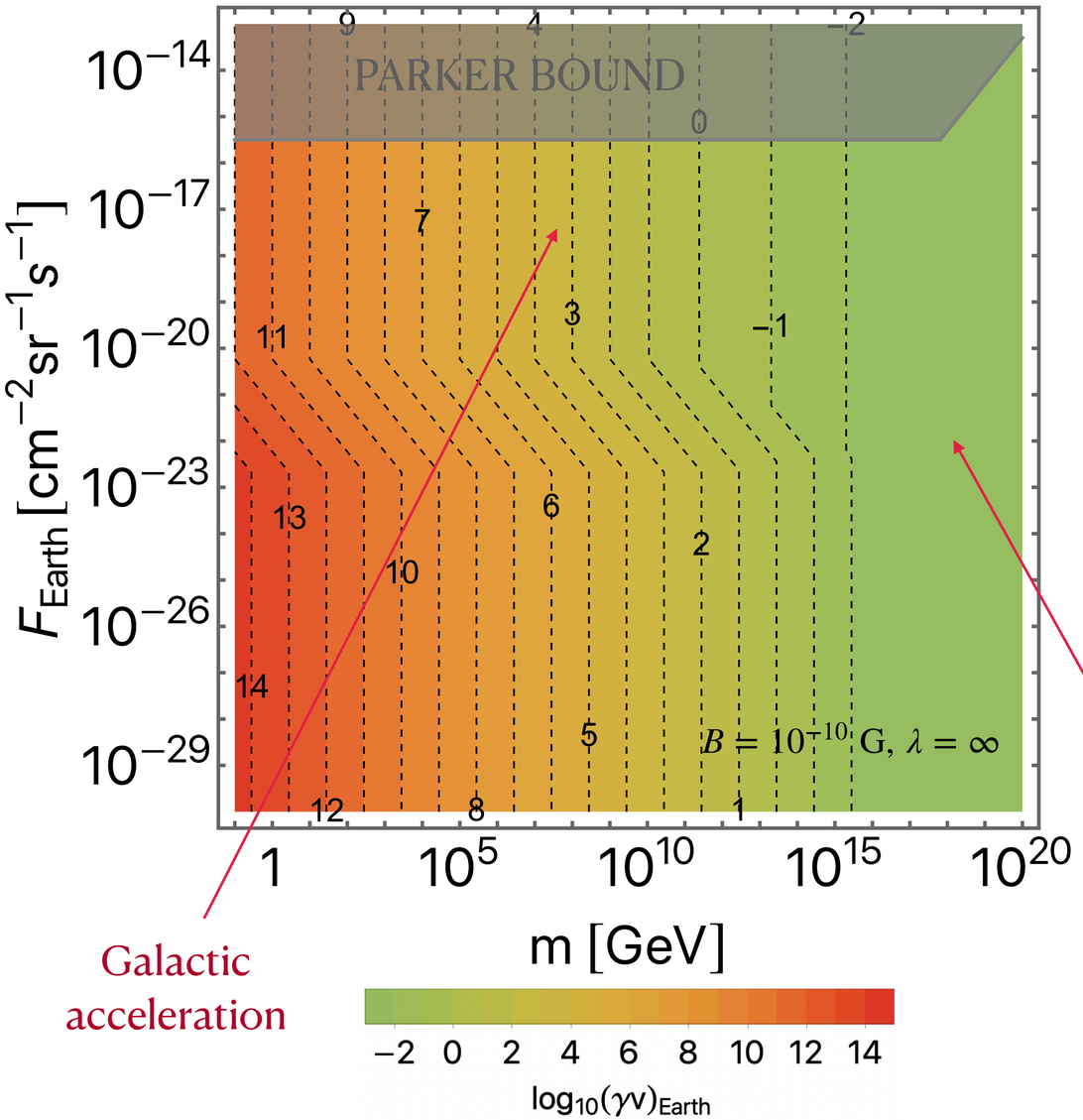


Free acceleration!!

Intergalactic magnetic fields can accelerate monopoles to relativistic velocities.

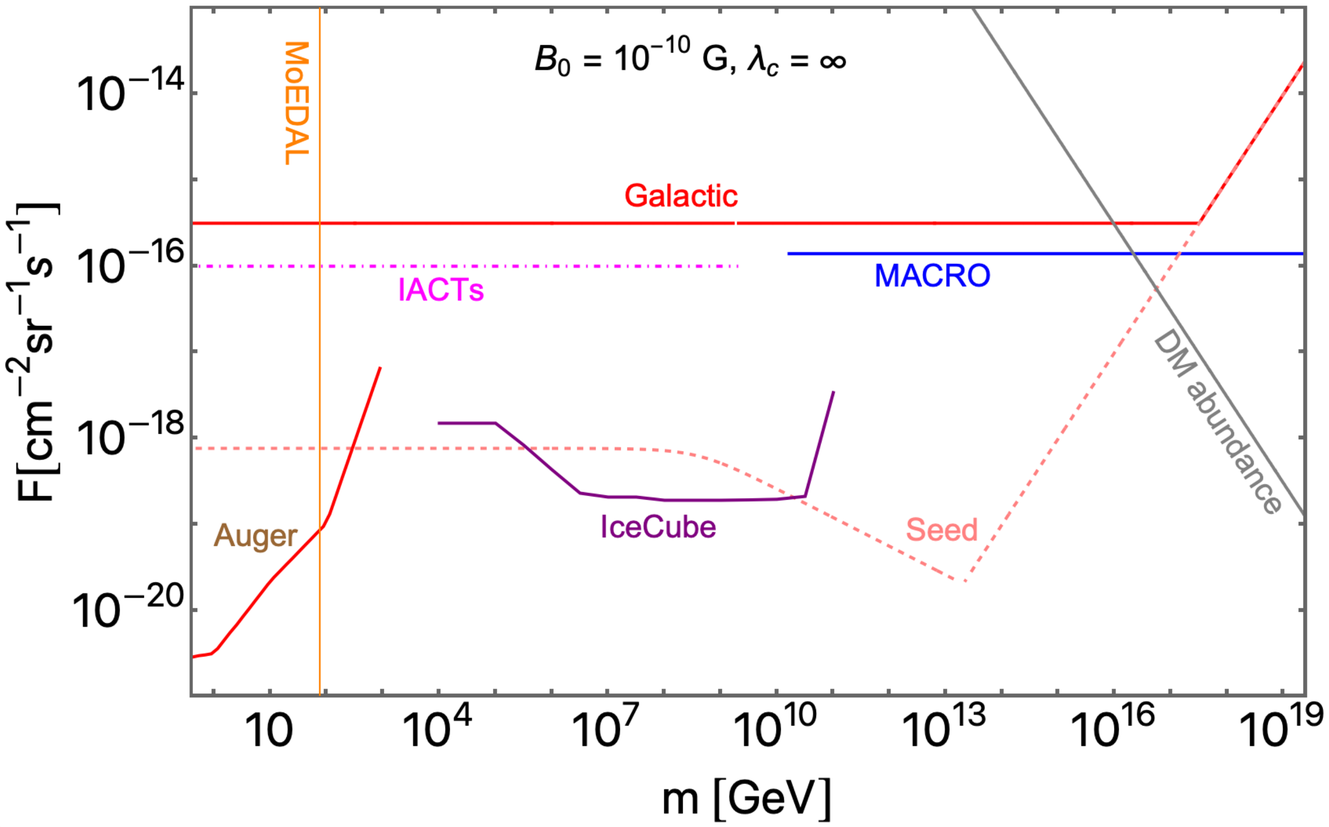
Monopole velocity at the Earth

The velocity at the Earth takes contribution from both intergalactic and galactic fields.



Galactic acceleration

MW peculiar velocity $\sim 10^{-3}$



Knowing the acceleration mechanism, we know how the bounds are modified by the velocity!

Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ New bounds on the monopole abundance.
- ✓ Minicharged monopoles and magnetic black holes.
- ✓ Schwinger effect and monopole pair production.
- ✓ Conclusion.

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

DP, T. Kobayashi (2023)
Phys.Rev.D 108 (2023) 8, 083005

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

SISSA

Conclusion

- We derived *new competitive bounds on the abundance of magnetic monopoles* by generalizing the Parker bound to the survival of primordial magnetic fields.

- We studied under which condition magnetic monopoles are *possible Dark Matter candidates*.

  1. For $g = g_{\rm D}$ they can be DM only for masses comparable to or larger than $M_{\rm Pl}$.
  2. Minicharged monopoles can be DM for much smaller masses.
  3. Extremal magnetic BH are excluded as DM candidates.

- Cosmic magnetic fields affect all the bounds through monopole acceleration to relativistic velocities (*search with Cherenkov detectors!*).

Thank You!!

Istituto Nazionale di Fisica Nucleare

SISSA