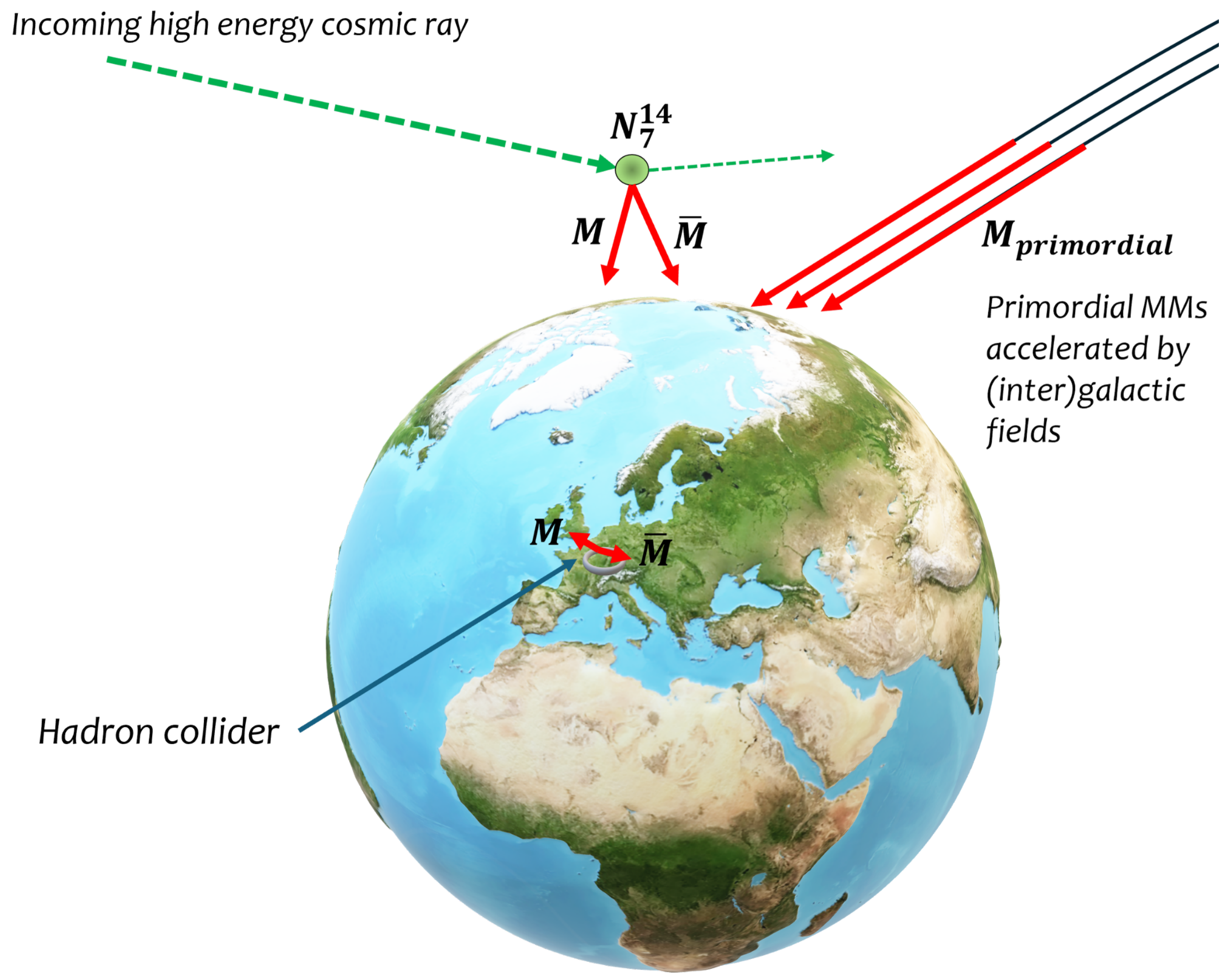
Non-inflationary solution to the Monopole Problem



Speaker:
Daniele Perri

DP, Phys.Rev.D 113 (2026) 2, 023547

and collaborations with
Guillaume Frank (Univ. of Strasbourg),
Keisuke Harigaya (UChicago).

UNIWERSYTET WARSZAWSKI

Next Frontiers in MM Searches - 13/09/26

Contents of the Talk

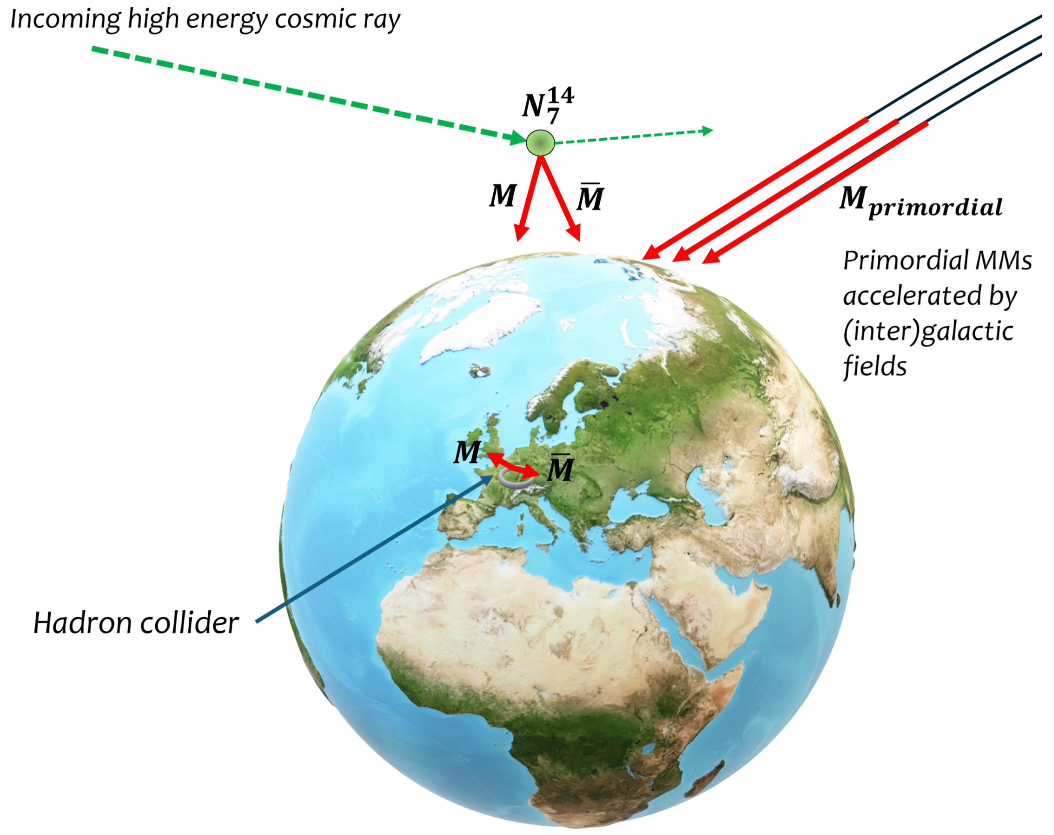
✓ Magnetic monopoles as dark matter.

✓ Model for a global monopole.

✓ Global solution to the monopole problem.

✓ GWs and Dark Matter from global monopoles.

✓ Conclusion.



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’T Hooft-Polyakov Monopoles and Topological Defects

- ’T Hooft and Poliakov monopoles are *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.*

Not necessarily gauge groups!!

Monopoles are *inevitable predictions* of Grand Unified Theories:

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

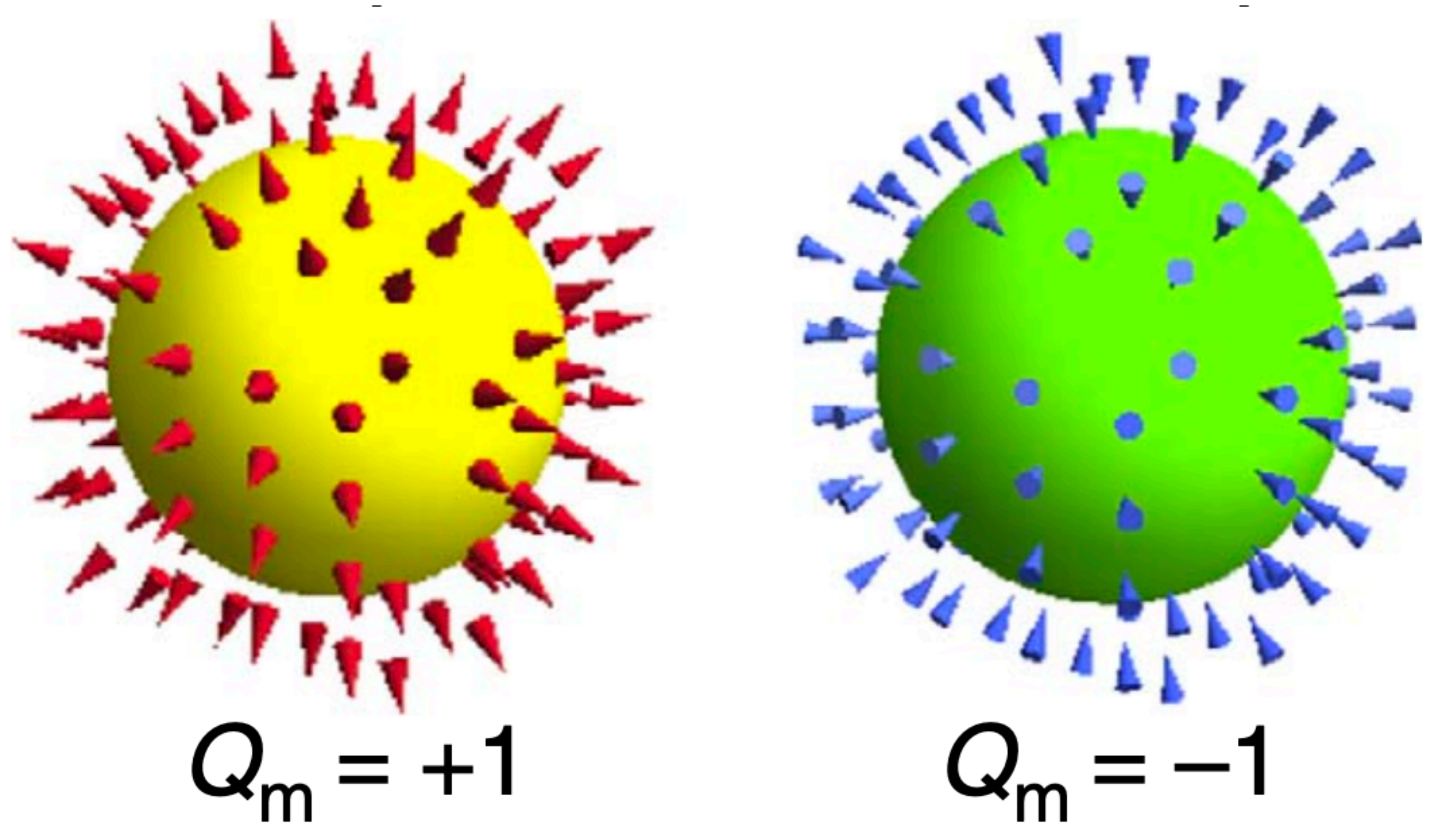
’T Hooft-Polyakov Monopoles and Topological Defects

- The simplest example is the Georgi-Glashow model: $SU(2) \rightarrow U(1)$

$$\mathscr{L}(t,\vec{x}) = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + \frac{1}{2}(D_\mu\phi^a)(D^\mu\phi^a) - \frac{1}{4}\lambda(\phi^a\phi^a - \eta^2)^2$$

- The monopole configuration is described by the *hedgehog solution* for the scalar field after the symmetry breaking:

$$\phi^a(\vec{x}) = \delta_{ia}\left(\frac{x^i}{r}\right)F(r), \qquad m \sim \frac{4\pi}{e}\eta, \quad r \sim \frac{1}{e\eta}$$



Recipe for a Good Dark Matter Candidates

A magnetic monopole is a *good candidate for Dark Matter* if some conditions are verified:

1. Not excluded by bounds on the flux;

2. Non-relativistic particles clustered with galaxies;

3. Provided with an efficient production mechanism.

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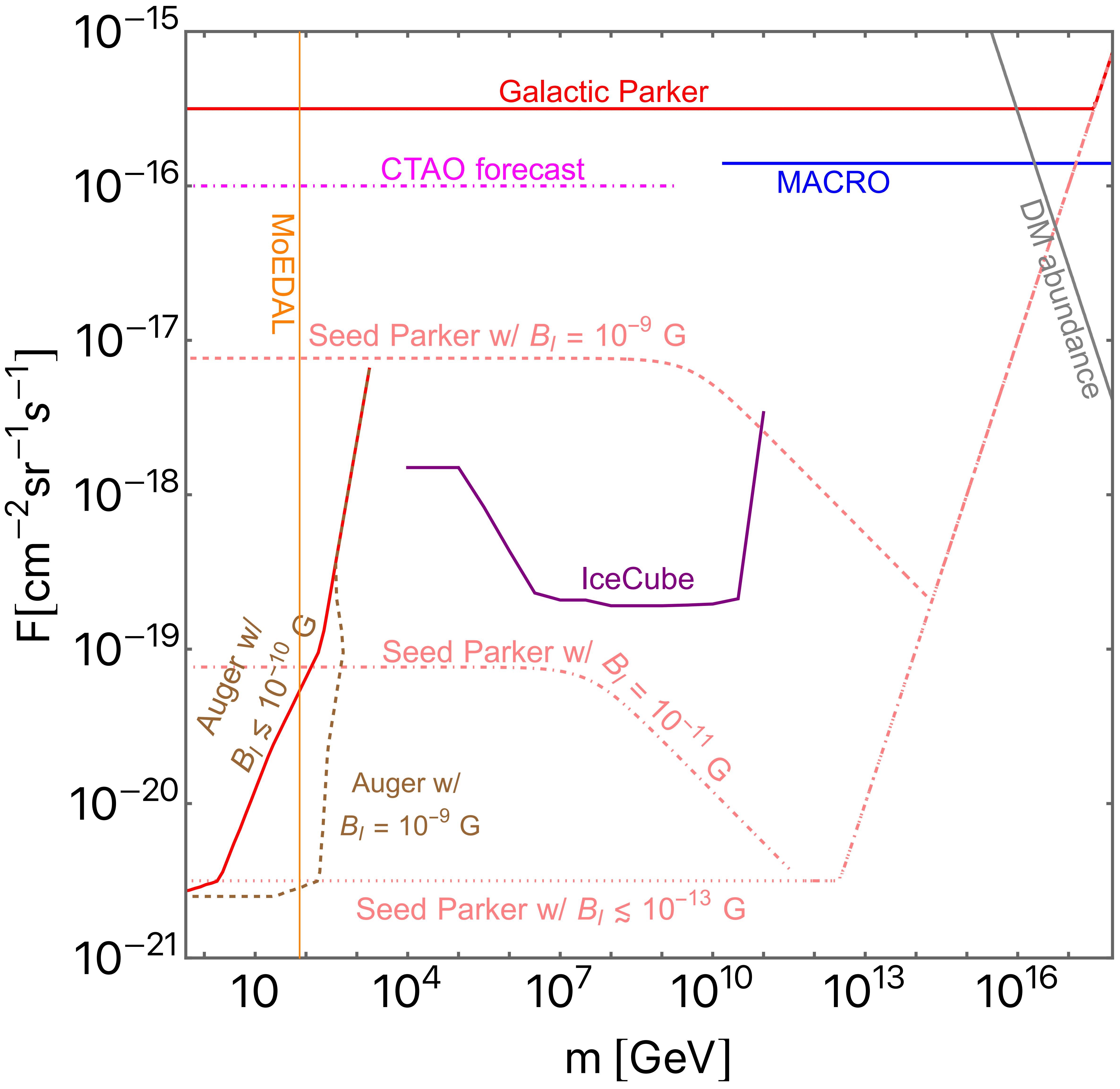
Bounds on the Monopole Flux



1. Low mass excluded by MoEDAL (and ATLAS) via Schwinger pair production;
2. Intermediate mass constrained by UHECR detectors because of the large field of view;
3. Heavy monopoles still difficult to constrain and still compatible with dark matter abundance.

DP, M. Doro, T. Kobayashi
Phys.Dark Univ. 50 (2025), 102134

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See next talk for bounds on “escaped” monopoles!

Production mechanisms

There are three main production mechanisms of magnetic monopoles in the early universe.

- During phase transitions in the early universe:

$$\frac{n_M}{s} \sim 10^2 \left(\frac{T_c}{M_{\rm Pl}}\right)^3$$

(Second or slightly first order PT)

$$\frac{n_M}{s} \sim \left[\left(\frac{T_c}{M_{\rm Pl}}\right) \log\left(\frac{M_{\rm Pl}^4}{T_c^4}\right)\right]^3$$

(Strongly first order PT)

- Thermal production:

$$\frac{n_M}{s} \sim 10^2 \left(\frac{m_M}{T_{\max}}\right)^3 \exp\left(-\frac{2m_M}{T_{\max}}\right)$$

- Production of monopole pairs via the Schwinger effect in strong magnetic fields:

$$\Gamma = \frac{(gB)^2}{(2\pi)^3} \exp\left[-\frac{\pi m^2}{gB} + \frac{g^2}{4}\right]$$

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Cosmological Monopole Problem

Around one monopole per Hubble volume is produced during phase transitions in the early universe (*Kibble mechanism*).

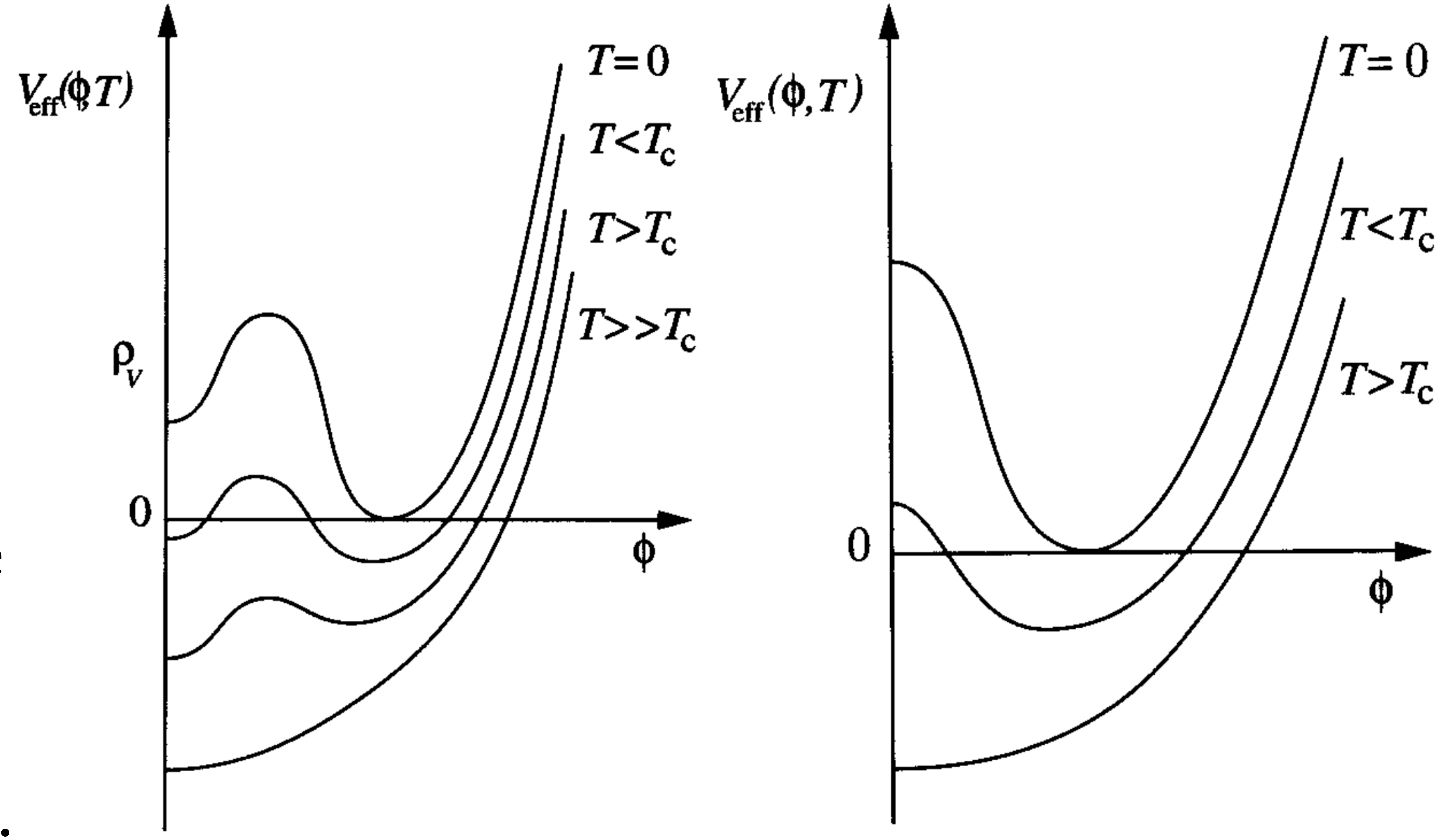
- The abundance of produced monopoles can easily over-dominate the energy density of the universe:

$$\rho_{\mathrm{M,loc}} \sim \rho_{\mathrm{crit}} \left(\frac{v}{10^{11}\ \mathrm{GeV}} \right)^4$$

- Inflation provides a good solution to the problem.

↓

GUT monopoles cannot be produced after inflation.



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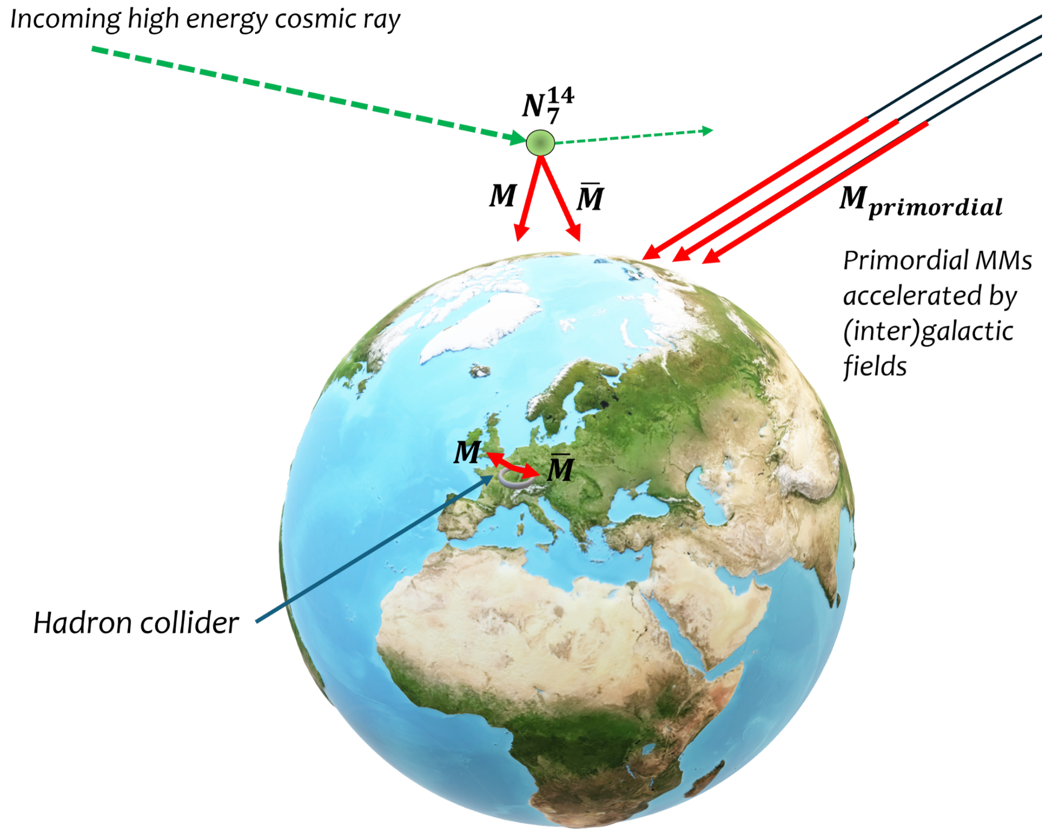

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Can a Global Monopole Really Exist?

Global Monopole Solution

- A monopole solution can still be defined in the case of global symmetry breaking:

$$SO(3) \to SO(2)$$

$$\frac{\mathscr{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial_\mu \phi)^a(\partial_\mu \phi)^a - \frac{\lambda}{4}(\phi^a \phi^a - v^2)^2$$

- The hedgehog solution still describes the monopole configuration, however, the energy of one global monopole is infinite.

$$\phi^a(\vec{x}) = \delta_{ia}\left(\frac{x^i}{r}\right)F(r)$$

$$\downarrow$$

Cut-off R set by the nearest antimonopole.

$$E \sim 4\pi \int_{r_M}^{R} T_t^t r^2 dr \sim 4\pi v^2 R,$$

$$r_M \sim (\sqrt{\lambda} v)^{-1}$$

Can a Global Monopole Really Exist?

Global Monopole Solution

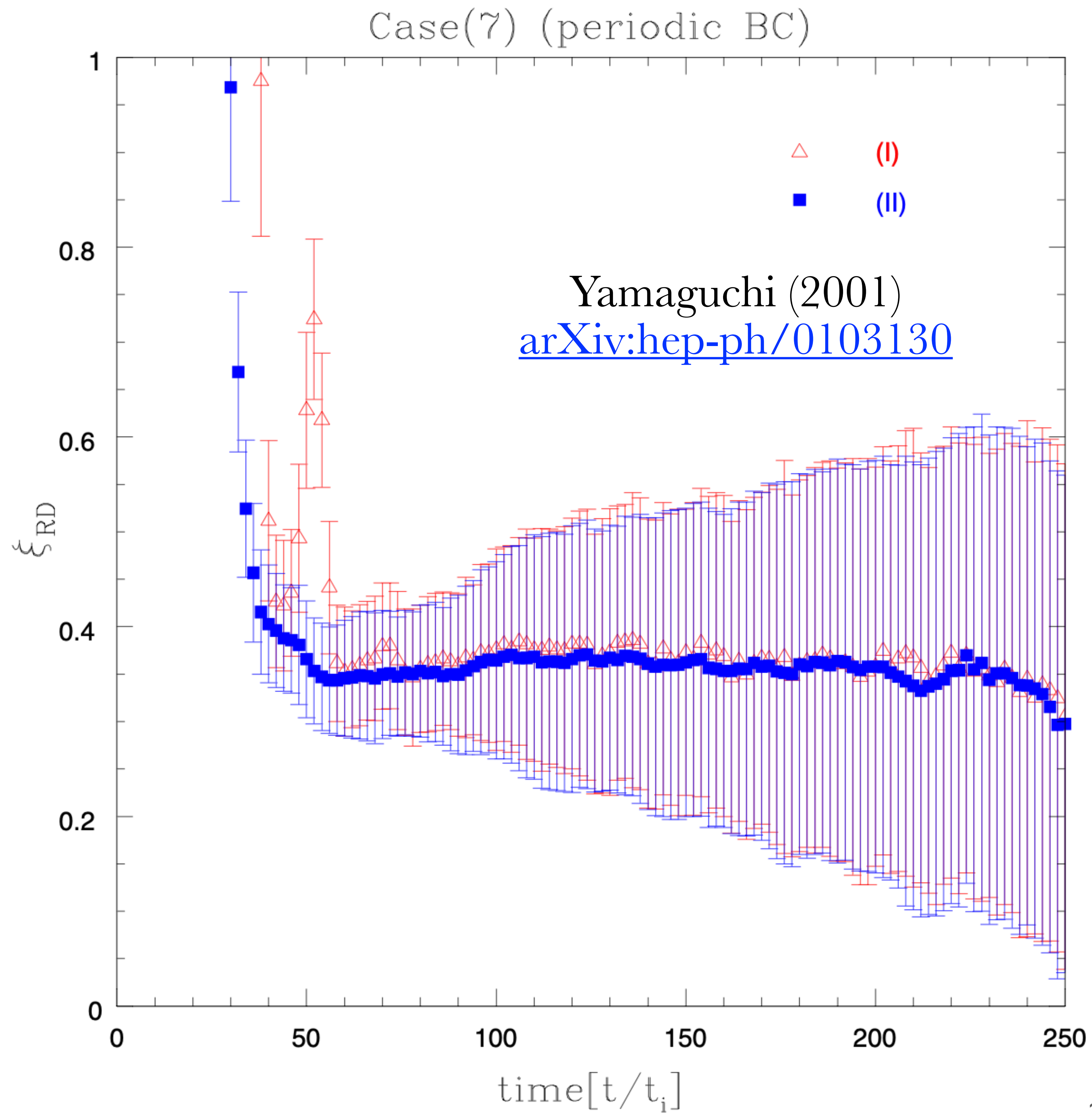
- The attractive force between two global monopoles does not depend on the distance:

$$F = \frac{\partial E}{\partial R} \sim 4\pi v^2$$

- Hence, the annihilation process is very efficient and proceeds until the number density reaches a *scaling regime*:

$$n_{\mathrm{M}} = \left(4 \pm 1.5\right) R_{\mathrm{H}}^{-3}$$

Bennett, Rhie (1990)
Phys. Rev. Lett., 65:1709-1712



Yamaguchi (2001)
arXiv:hep-ph/0103130

No cosmological monopole problem for global monopoles!

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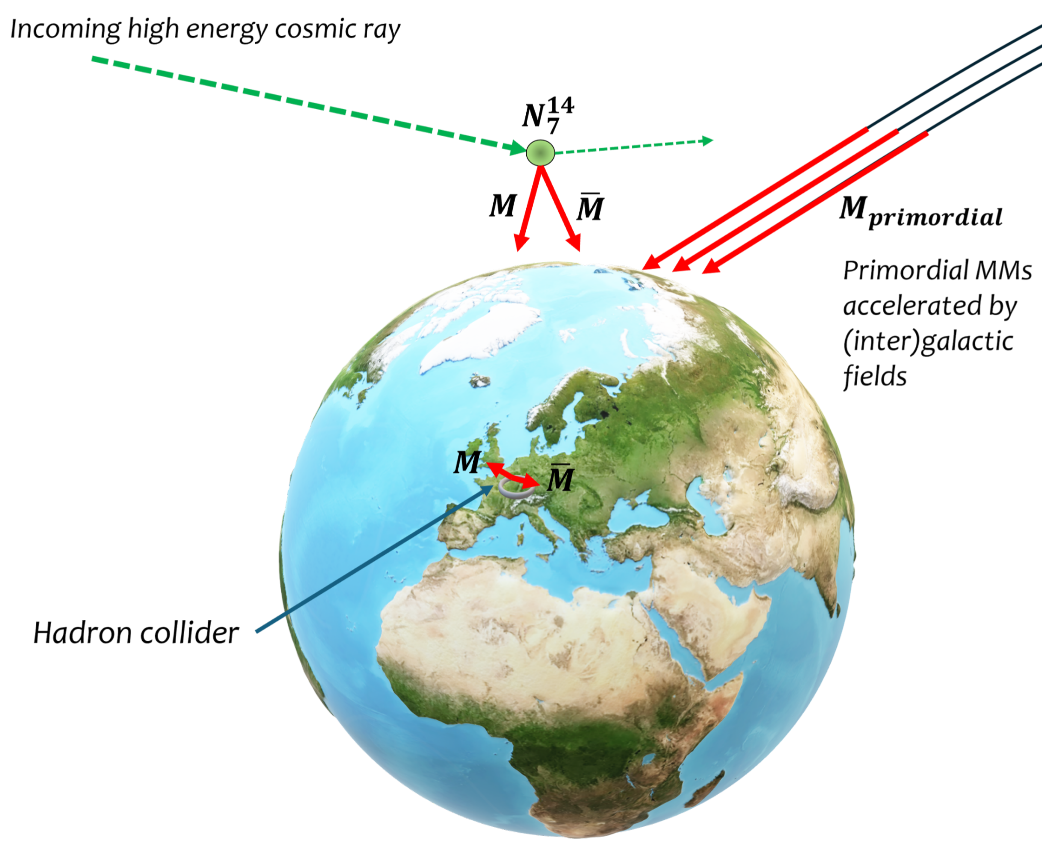

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"Global" Solution to the Monopole Problem

We propose a modification of the Lagrangian that breaks the Weyl symmetry of the gauge kinetic sector as a solution to the monopole problem without inflation.

$$\frac{\mathscr{L}}{\sqrt{-g}} = -\frac{I(t)^2}{4}F^a_{\mu\nu}F^{a\mu\nu} - \frac{1}{2}(D_\mu\phi)^a(D_\mu\phi)^a - \frac{\lambda}{8}(\phi^a\phi^a - v^2)^2$$

- The Lagrangian can be canonically normalized by redefining the vector field and the gauge coupling:

$$\tilde{A}^a_\mu = IA^a_\mu, \quad \tilde{e} = e/I, \quad \tilde{g} = gI$$

To large value of the function $I(t)$ corresponds small electric charge and large magnetic charge.

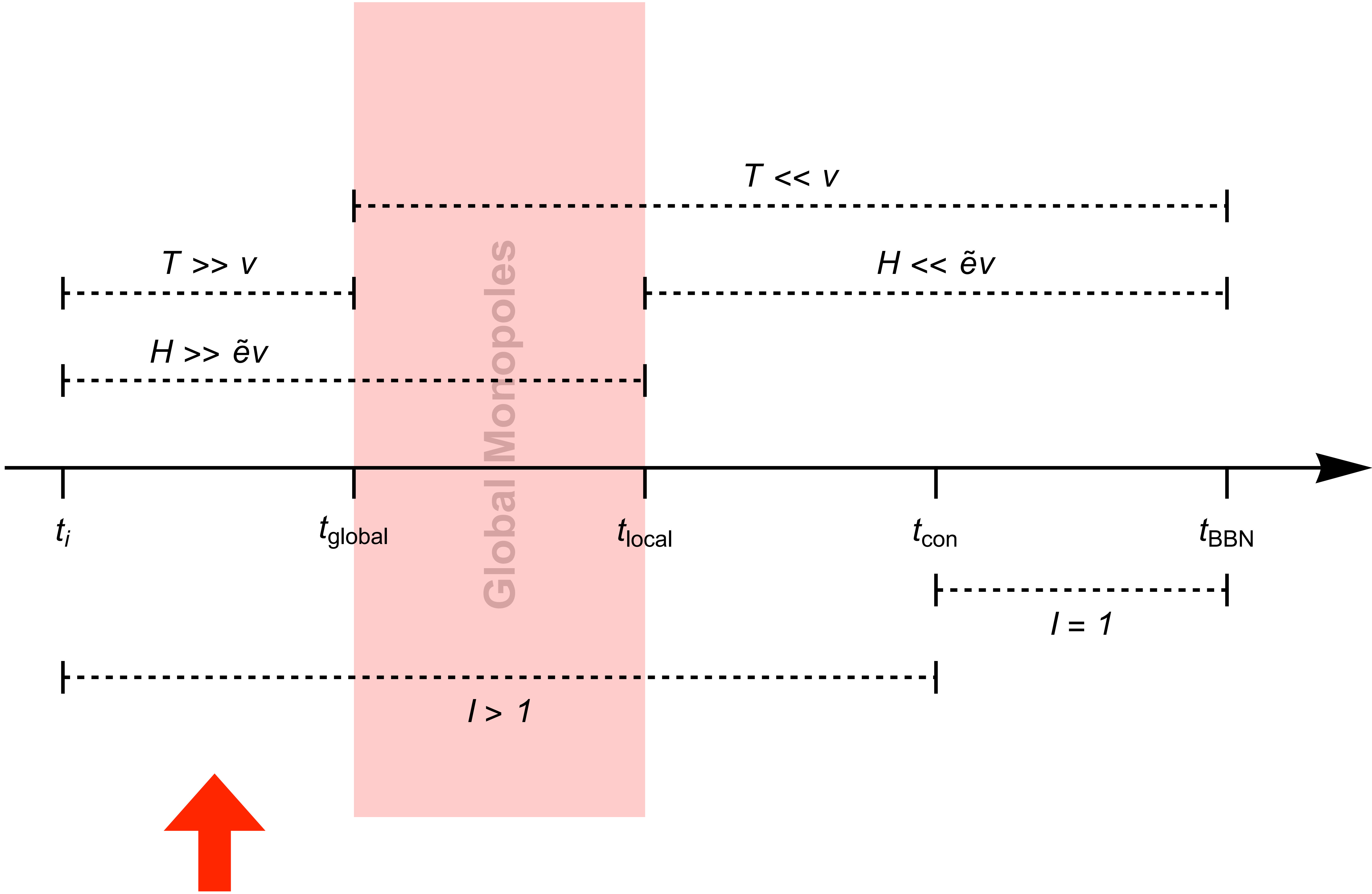
"Global" Solution to the Monopole Problem

1. Symmetric phase:

$$H \gg \tilde{e}v,\ T \gg v$$

- The universe becomes radiation-dominated at T_i .

- The vector field is effectively massless and no monopole solution exists.



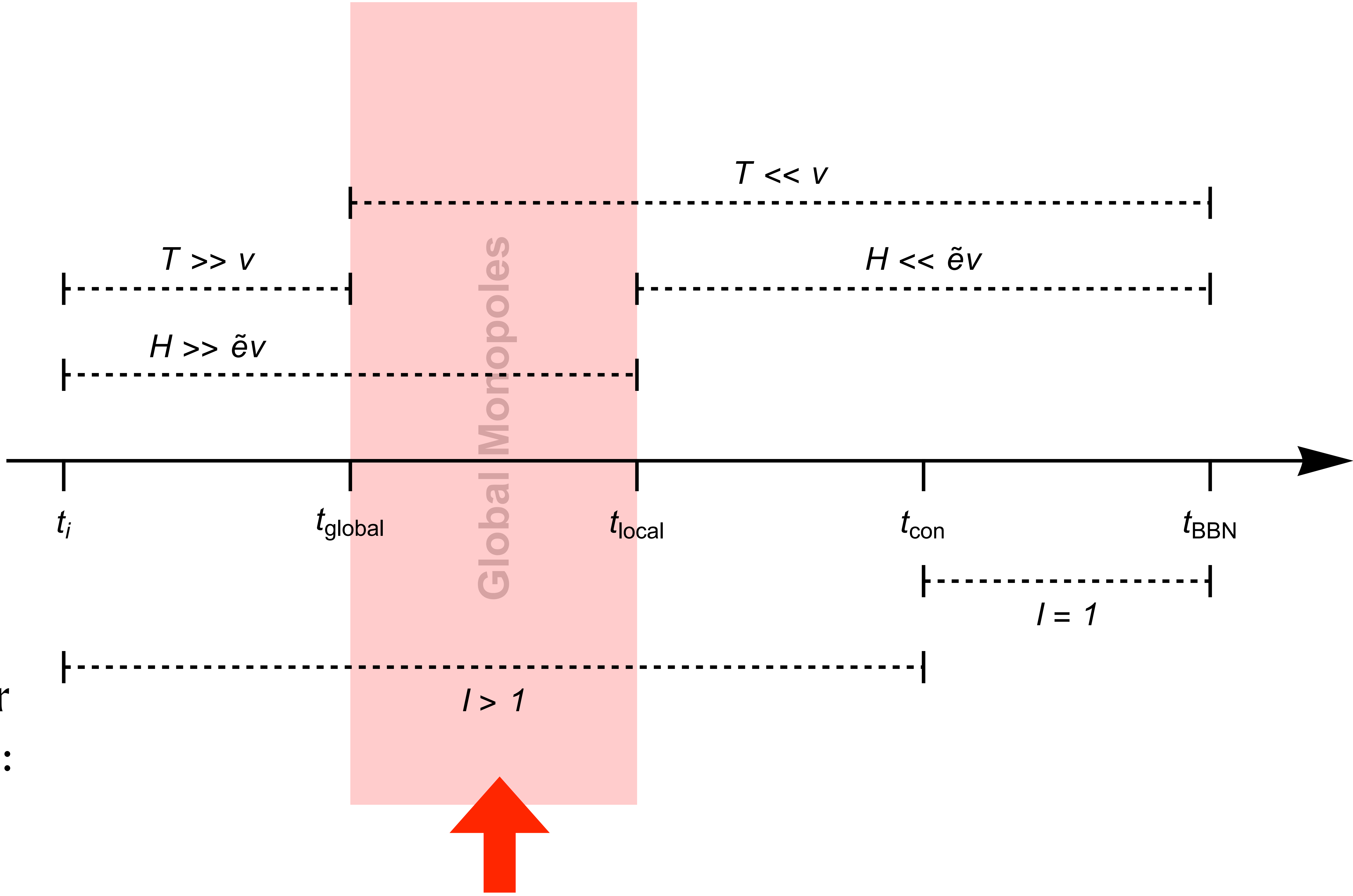
"Global" Solution to the Monopole Problem

2. Global monopole phase:

$$H \gg \tilde{e}v,\ T \ll v$$

- The vector field is effectively massless, and the monopole radius larger than the horizon. NG bosons are asymptotic states, and monopoles are produced as **global**.
  - The global SB occurs at $T_{\text{global}} = v$.
- Global monopoles annihilate, and their number density is in the scaling regime:

$$n_{\text{M}} = \left(4 \pm 1.5\right) R_{\text{H}}^{-3}$$



"Global" Solution to the Monopole Problem

3. Gauge monopole phase:

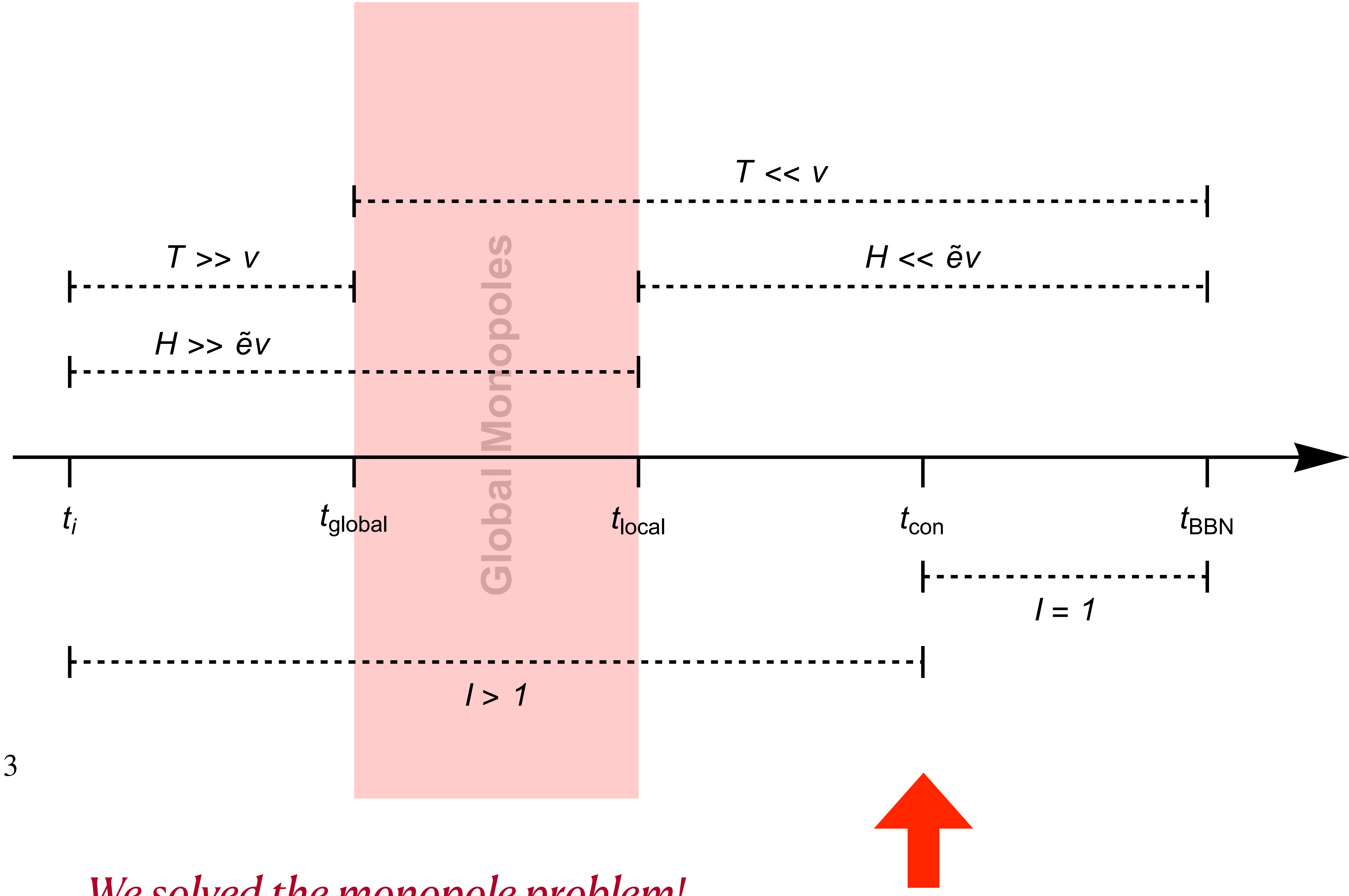
$$H \ll \tilde{e}v, \; T \ll v$$

- The local SB occurs at $H_{\rm local} = \tilde{e}v$.

- Vector bosons become massive and monopoles magnetically charged.

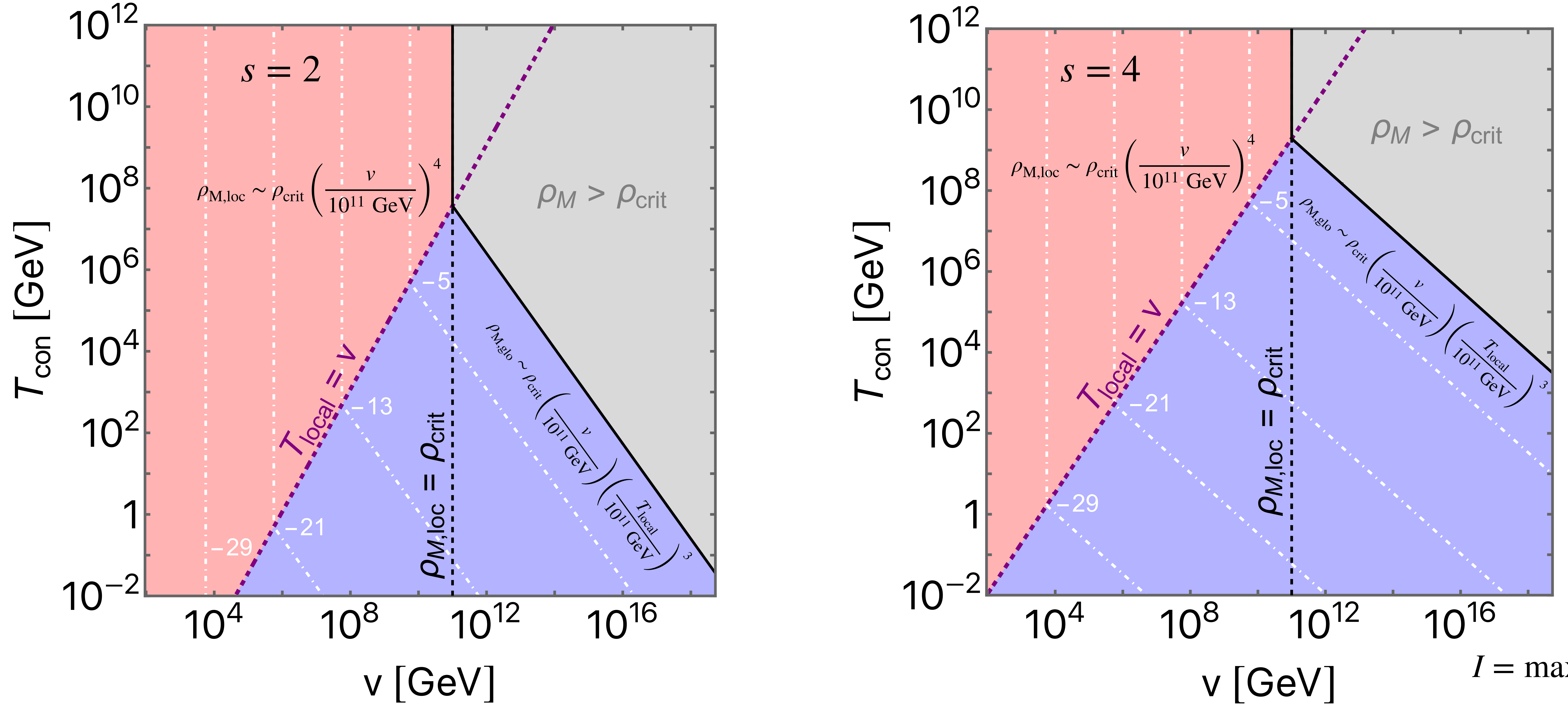
- Monopoles redshift following standard cosmology:

$$\rho_{\rm M,glo} \sim \rho_{\rm crit} \left(\frac{v}{10^{11}\ \rm GeV}\right)\left(\frac{T_{\rm local}}{10^{11}\ \rm GeV}\right)^3$$



We solved the monopole problem!

"Global" Solution to the Monopole Problem



$$I = \max\left\{\left(\frac{a_{\mathrm{con}}}{a}\right)^s, 1\right\}$$

With the conformal-breaking term, we have access to parameters compatible with the GUT scale even without inflation. GUT monopole dark matter can be produced!

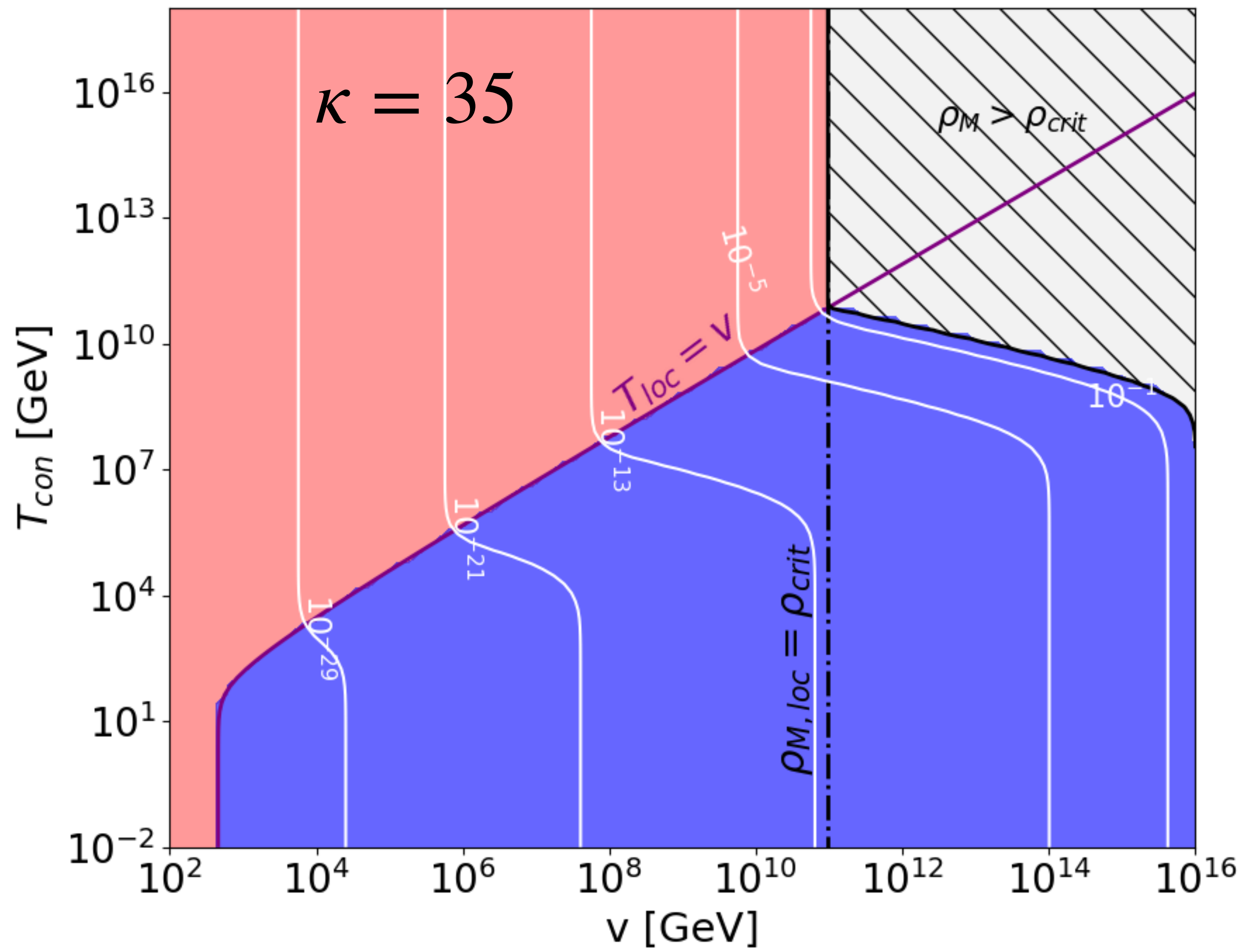
Weyl symmetry breaking in UV theories

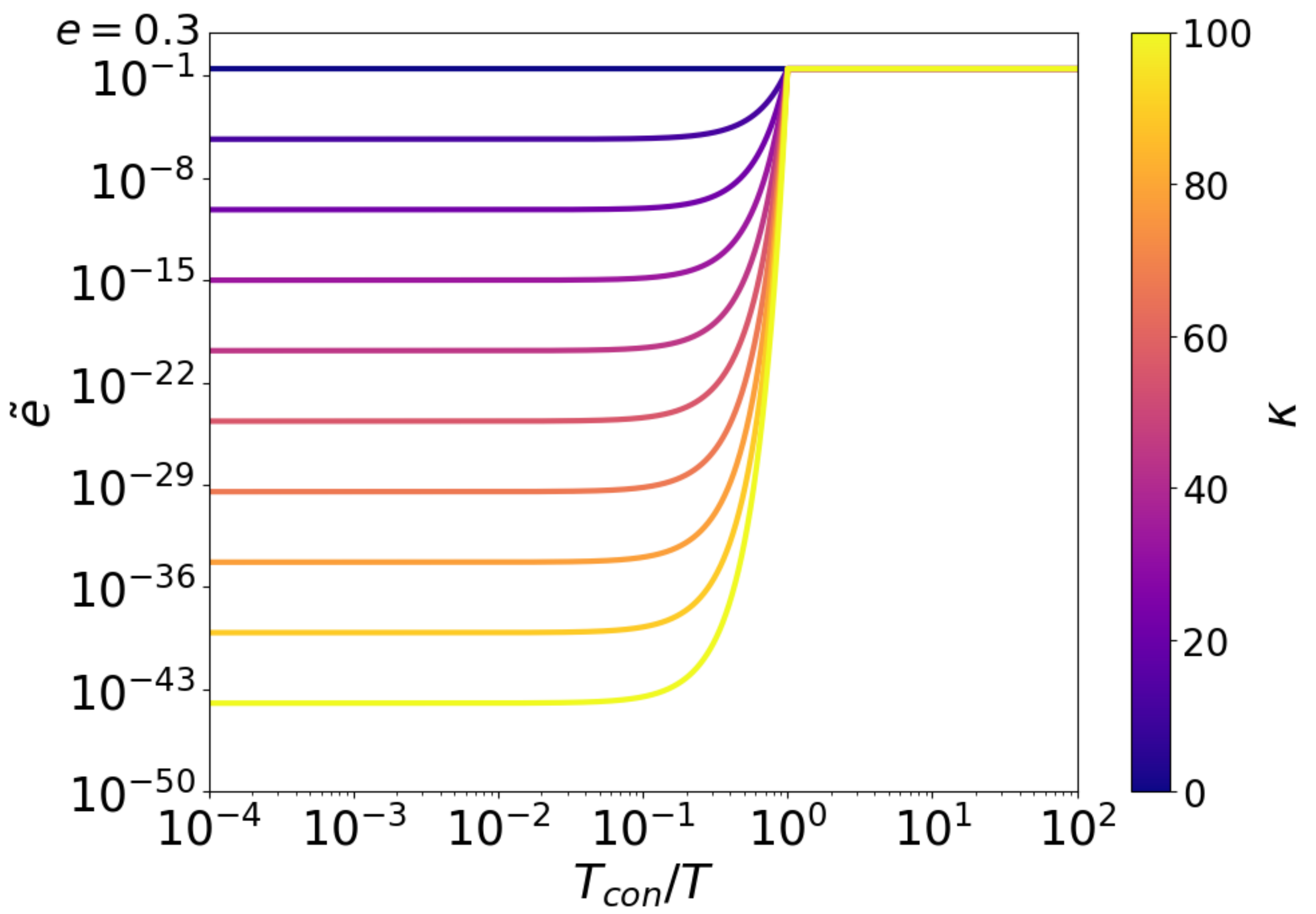
Possible UV completions of the Weyl-breaking model are: non-minimal coupling with gravity, supergravity, string theory, etc.

- **Ex:** Dilatonic coupling from string theory models where the scalar dilaton energy is dominated by the field kinetic energy ($\dot\xi$ = constant):

$$\frac{\mathscr{L}}{\sqrt{-g}} = -\frac{1}{4}e^{\alpha\xi}F^{\mu\nu}F_{\mu\nu} + R - (\partial\xi)^2 \longrightarrow I = e^{\alpha\xi} = e^{\alpha(\xi_0+\dot\xi t)}$$

$$\tilde e = e\exp\left[-\frac{\alpha}{\Lambda}\xi_0\left(1-\left(\frac{T_{con}}{T}\right)^2\right)\right] = e\exp\left[-\kappa\left(1-\left(\frac{T_{con}}{T}\right)^2\right)\right]$$





Master's thesis of Guillaume Frank
(University of Strasbourg)

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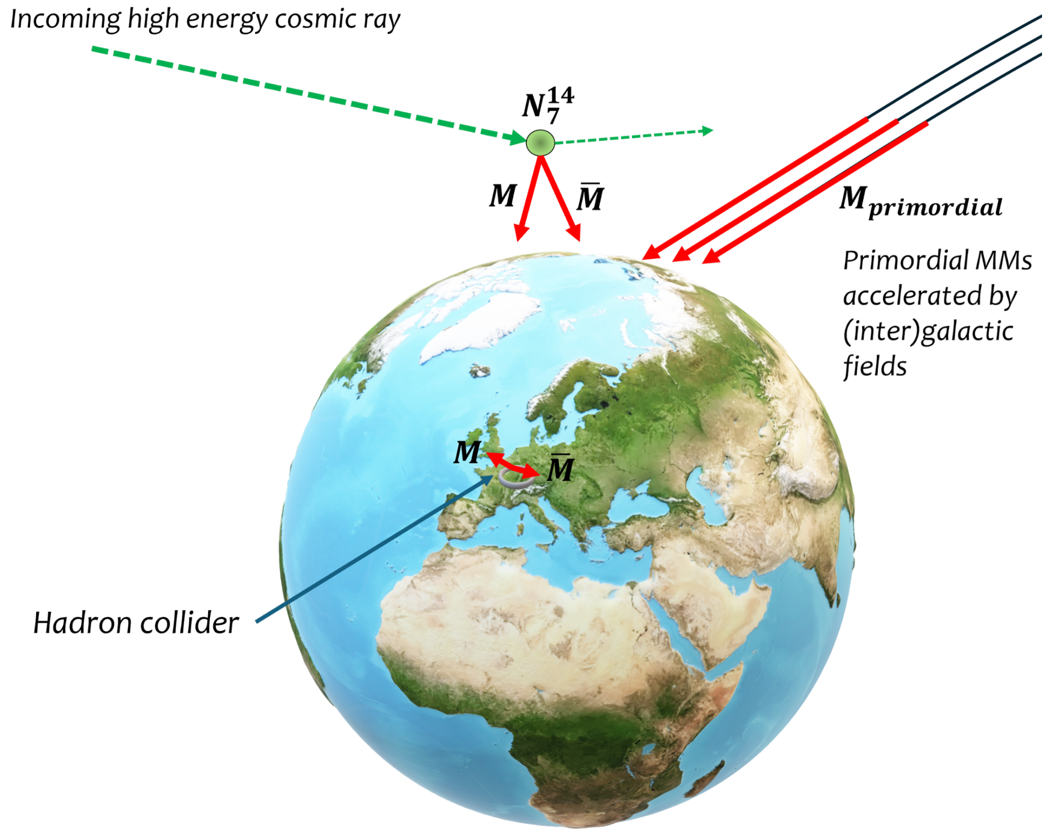

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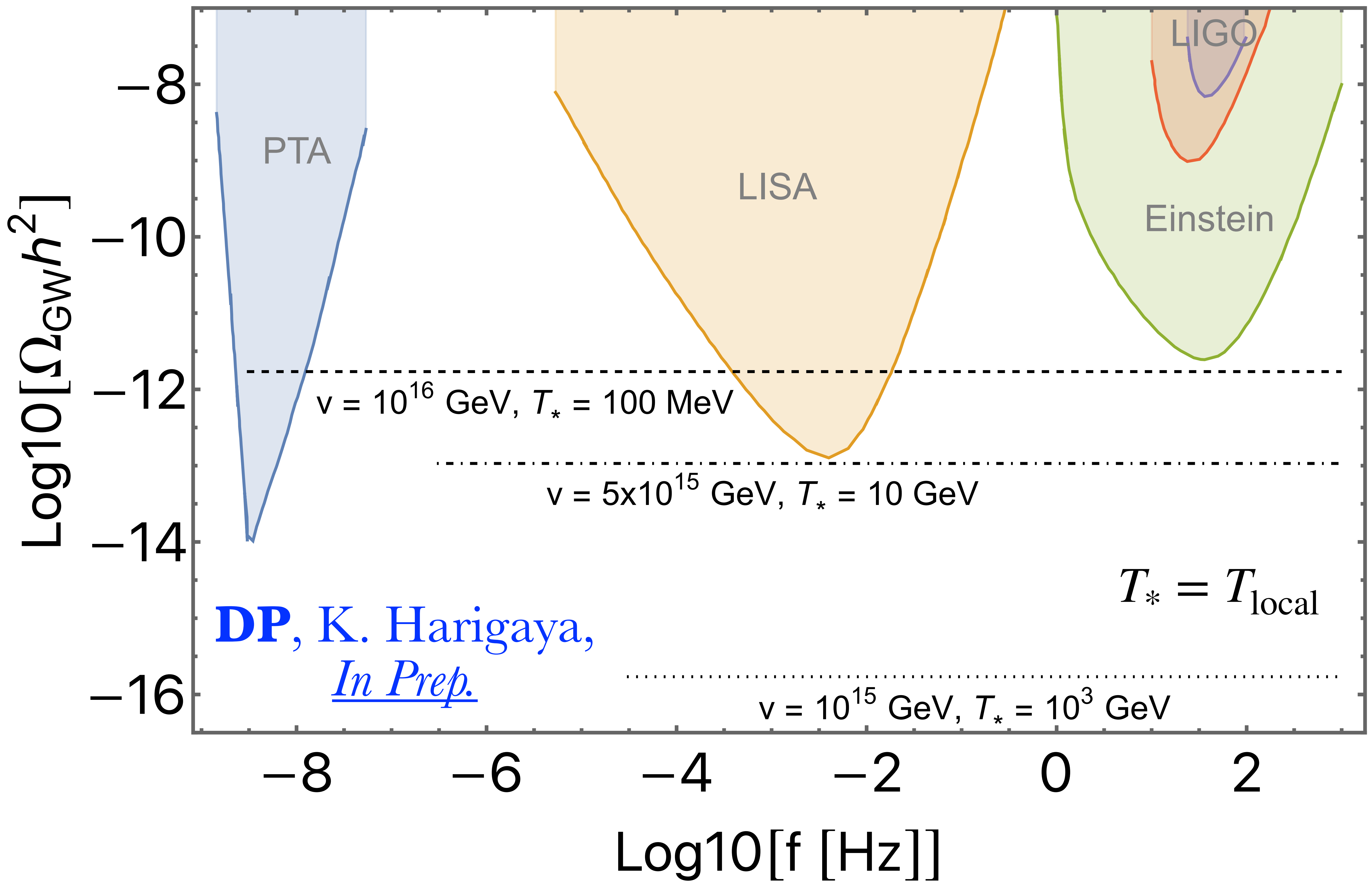
GW spectrum from the global monopole phase

Annihilation of monopoles during the global phase produces a GW signal possibly detectable by next gen detectors.

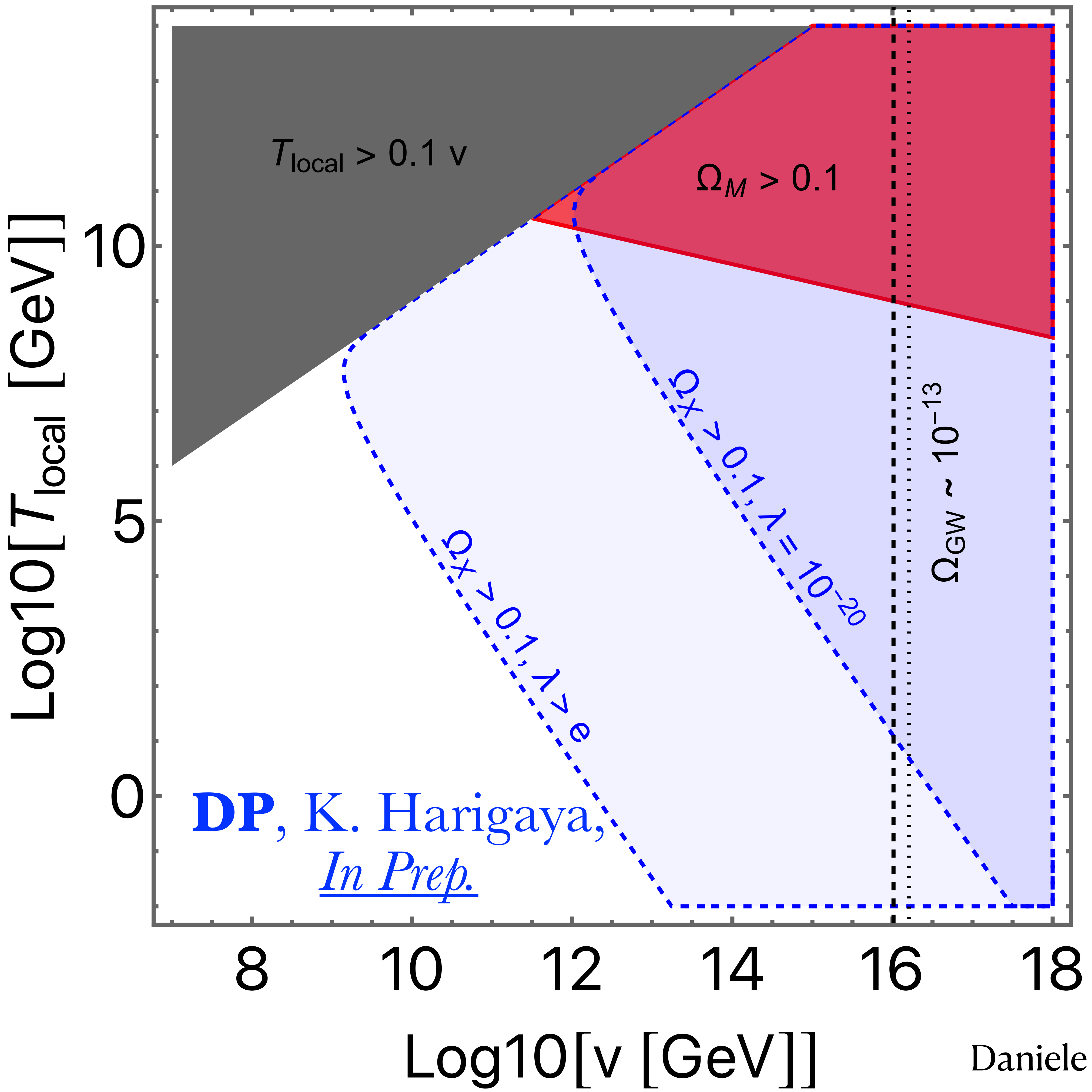


$$\Omega_{\rm GW}h^2 \sim 3 \times 10^{-4} \left(\frac{v}{M_{\rm Pl}}\right)^4 \left(\frac{100}{g_*}\right)^{1/3}$$

$$f_* \sim 3 \times 10^{-8}\ {\rm Hz} \left(\frac{T_*}{1\ {\rm GeV}}\right) \left(\frac{g_*}{100}\right)^{1/2} \left(\frac{100}{g_{*s}}\right)^{1/3}$$

Dark matter prodution from Global-to-Local Phase Transition

- The annihilation of monopoles produces a significant amount of NG bosons which are later converted into massive vector bosons.



- Vector bosons may (or may not) decay into CHAMPs:

$$\mathscr{L} \supset y_X \bar{L} H l_R, \qquad \Gamma_X \sim \frac{\tilde{e}^2}{16\pi} M_W \sim \frac{\tilde{e}^3}{16\pi} v$$

- The produced CHAMPs may ba a good candidate of dark matter while still predicting a detectable GW signal:

$$\Omega_X \sim \left(\frac{16\pi I_X^3 y_X}{e^3}\right)^{1/2} \left(\frac{v}{10^{11}\ \mathrm{GeV}}\right)^2 \left(\frac{T_{\rm local}}{10^4\ \mathrm{GeV}}\right) \left(\frac{g_{*,\rm local}}{g_{*s,\rm local}}\right)$$

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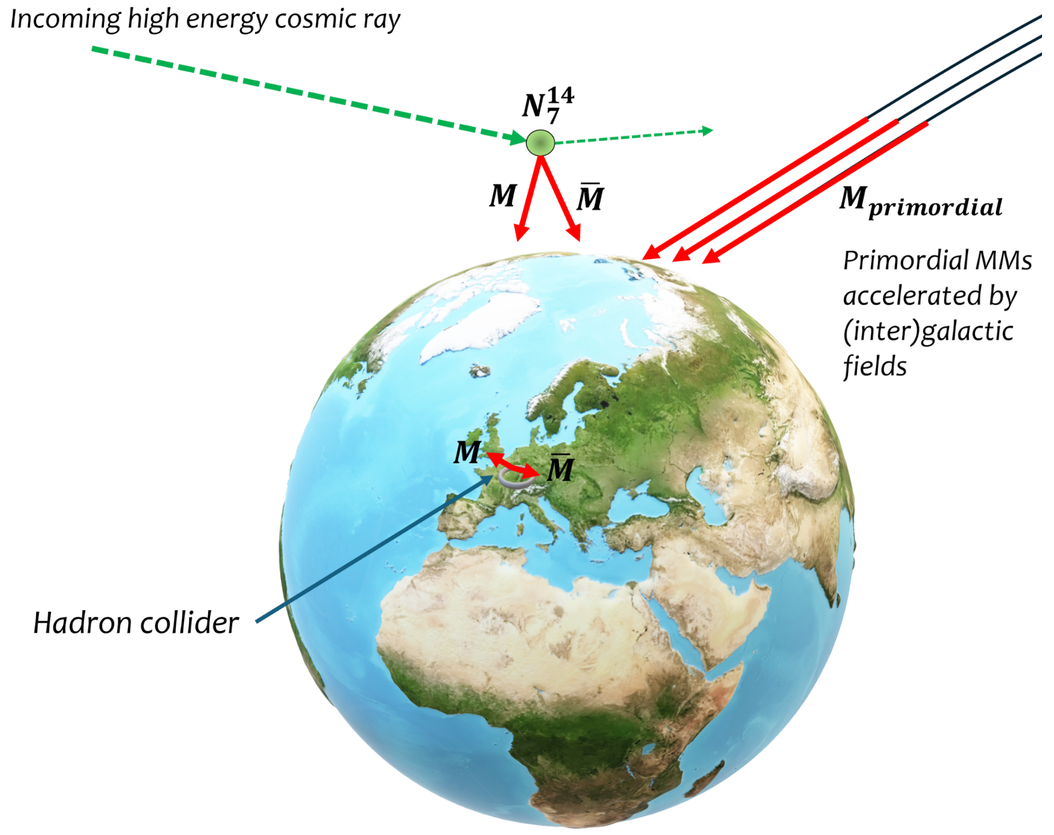

Conclusion

- Phase transitions in the early universe generate monopoles *too efficiently*, so a period of inflation is required afterward to dilute their abundance to acceptable levels.

- In contrast, inflation is unnecessary for *global monopoles*, since their high annihilation rate drives the system rapidly toward a *scaling regime* for the number density.

    - Modifying the *kinetic term of the gauge sector*, monopoles can be first produced as global, solving the monopole problem without inflation.

    - The model provides a possibly observable *GW signal* and include an additional good candidate for *CHAMP dark matter*.

Conclusion

GUT monopoles are still alive, please do not forget about them!!

Many solutions to the cosmological monopole problem even without inflation
(Global-to-Local early universe phase transition,
superconductive phase in the early universe, enhancing annihilation via BHs, via topological defects, etc.)

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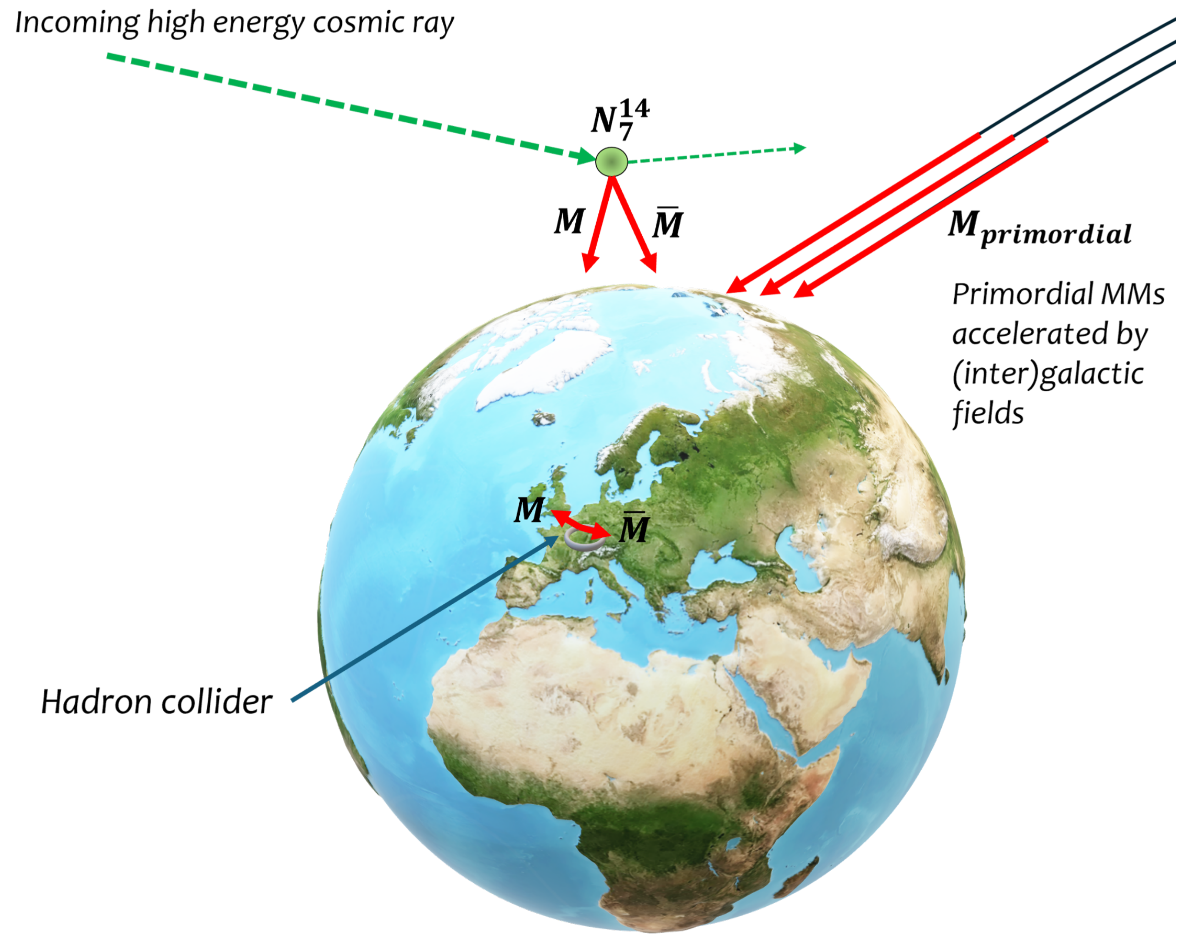
Thank You!!



Clustering condition

Monopoles are accelerated in cosmic magnetic fields and might not cluster with galaxies today!

1. From the simple requirement that monopoles do not acquire from the galactic magnetic field a kinetic energy larger than that for virialized particles (simplest condition):

$$m v_{\mathrm{vir}}^2/2 \gtrsim g B l_{\mathrm{c}}$$

2. By comparing the monopole escape time with the magnetic field generation timescale (stronger condition):

$$m \gtrsim 10^{18}\,\mathrm{GeV}\left(\frac{g}{g_{\mathrm{D}}}\right)\left(\frac{B_0}{10^{-6}\,\mathrm{G}}\right)\left(\frac{l_{\mathrm{c}}}{1\,\mathrm{kpc}}\right)^{1/2}\left(\frac{\tau_{\mathrm{sat}}}{10^{10}\,\mathrm{yr}}\right)^{1/2}\left(\frac{v_{\mathrm{vir}}}{10^{-3}}\right)^{-3/2}.$$

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

Schwinger Effects and Monopole Pair Production

Primordial magnetic fields are strong enough to produce significant amount of monopole-antimonopole pairs through the Schwinger Effect:

$$\Gamma = \frac{(gB)^2}{(2\pi)^3} \exp\left[-\frac{\pi m^2}{gB} + \frac{g^2}{4}\right]$$

The instanton computation is valid under the ***weak field condition***:

$$B \lesssim \frac{4\pi m^2}{g^3}$$

The survival of the fields after pair production and the acceleration of the produced monopoles provides the most conservative bound on the primordial magnetic field amplitude.