A “Global” Solution to the Cosmological Monopole Problem

Speaker:
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TeV Particle Astrophysics
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Valencia 2025

Contents of the Talk

- ✓ Models of magnetic monopoles.
- ✓ Global monopole solution.
- ✓ Global solution to the monopole problem.
- ✓ Conclusion.

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Can a Monopole Really Exist?

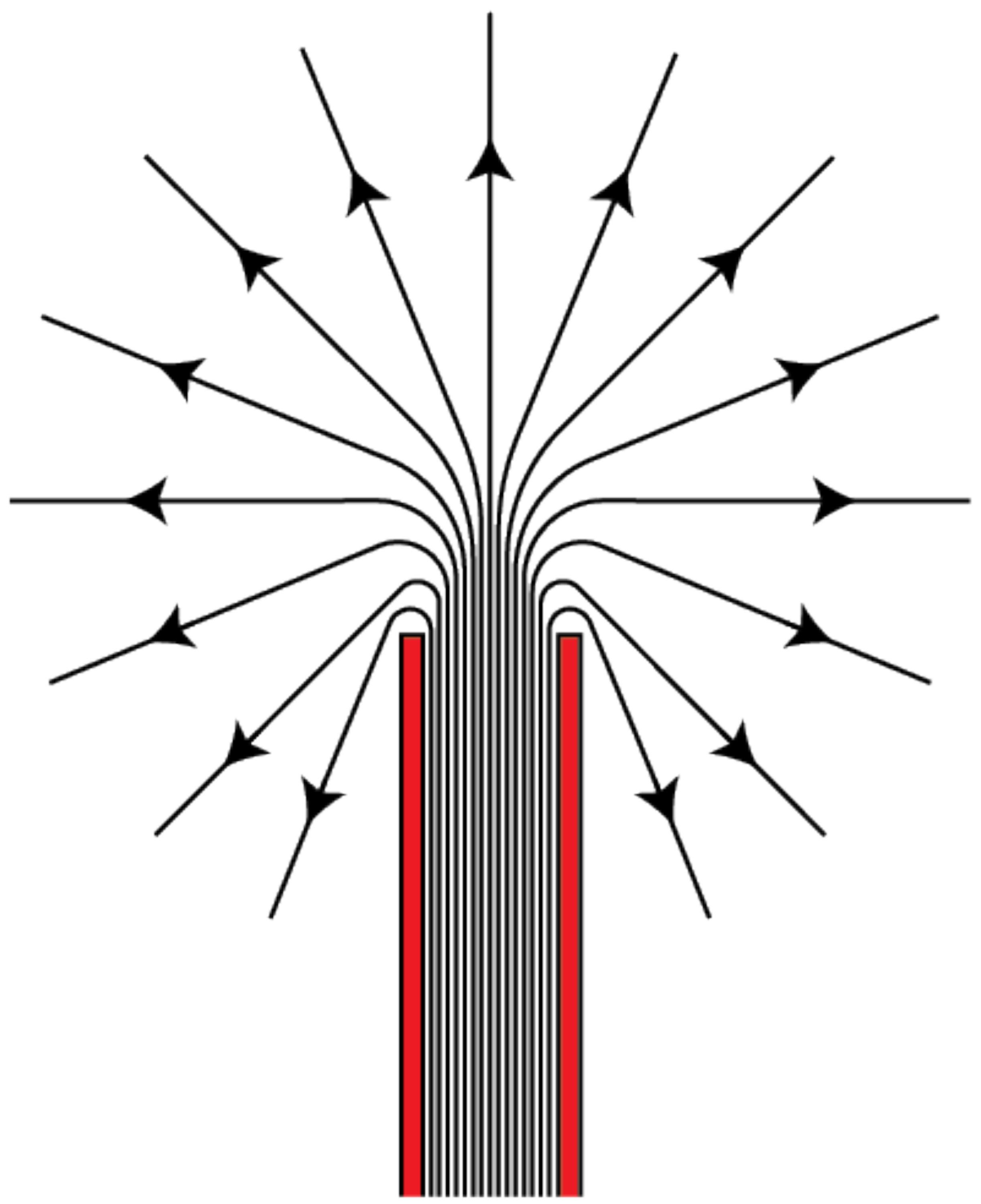
Dirac Monopoles and the Quantization of the Electric Charge

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

- Dirac was the first to suppose the existence of magnetic monopoles.
- In 1948 he proposed the model of 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*:

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

- 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.*

↓

Monopoles are *inevitable predictions* of Grand Unified Theories:

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

Can a Monopole Really Exist?

’T Hooft-Polyakov Monopoles and Topological Defects

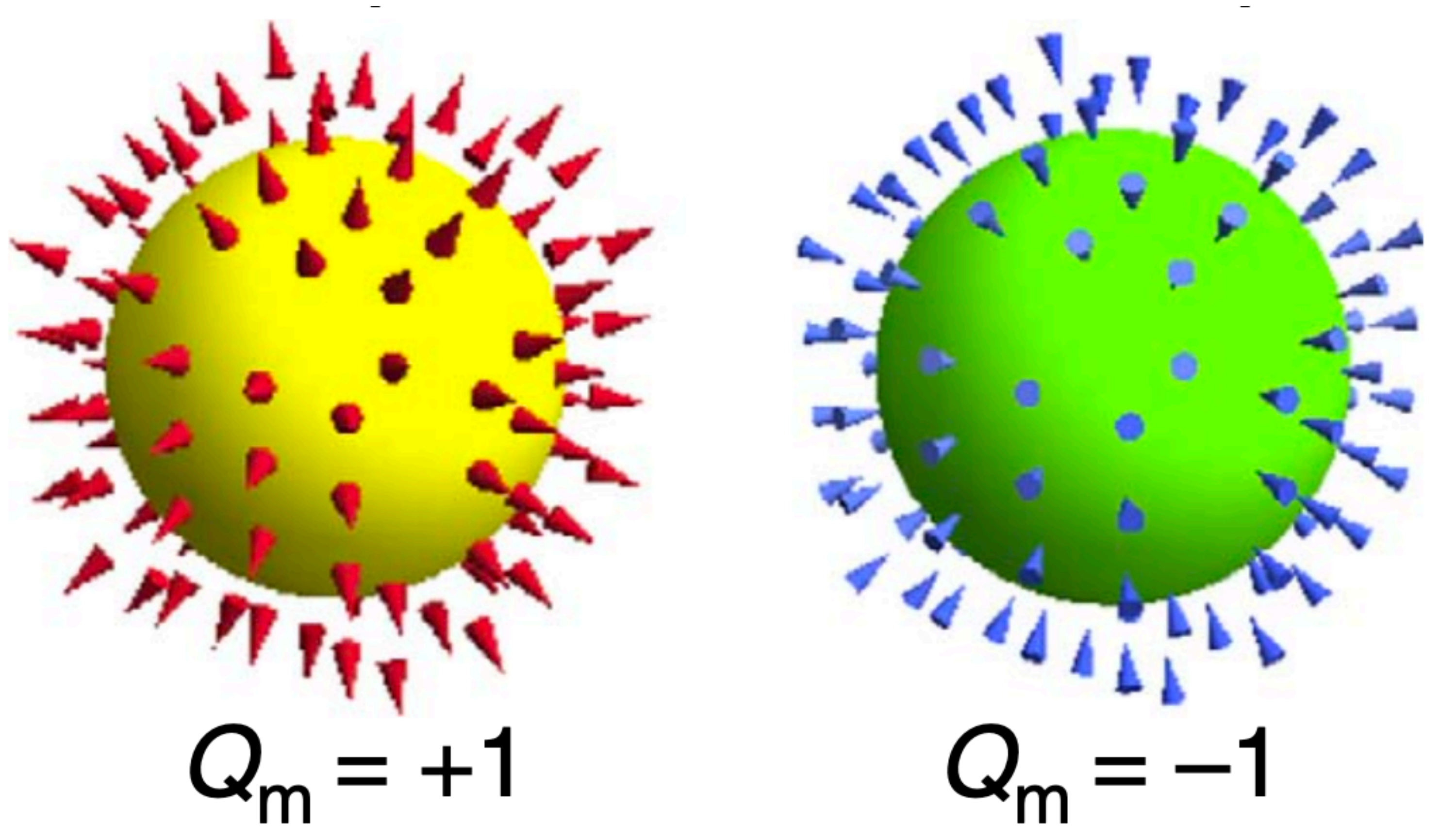
- The ’T Hooft - Poliakov monopole is a zero-dimensional solitonic solution of the vacuum manifold.
- The simplest example is the Georgi-Glashow model: $SU(2) \to U(1)$

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

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

$$m \sim \frac{4\pi}{g}\eta, \quad r \sim \frac{1}{e\eta}$$

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



Cosmological Monopole Problem

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

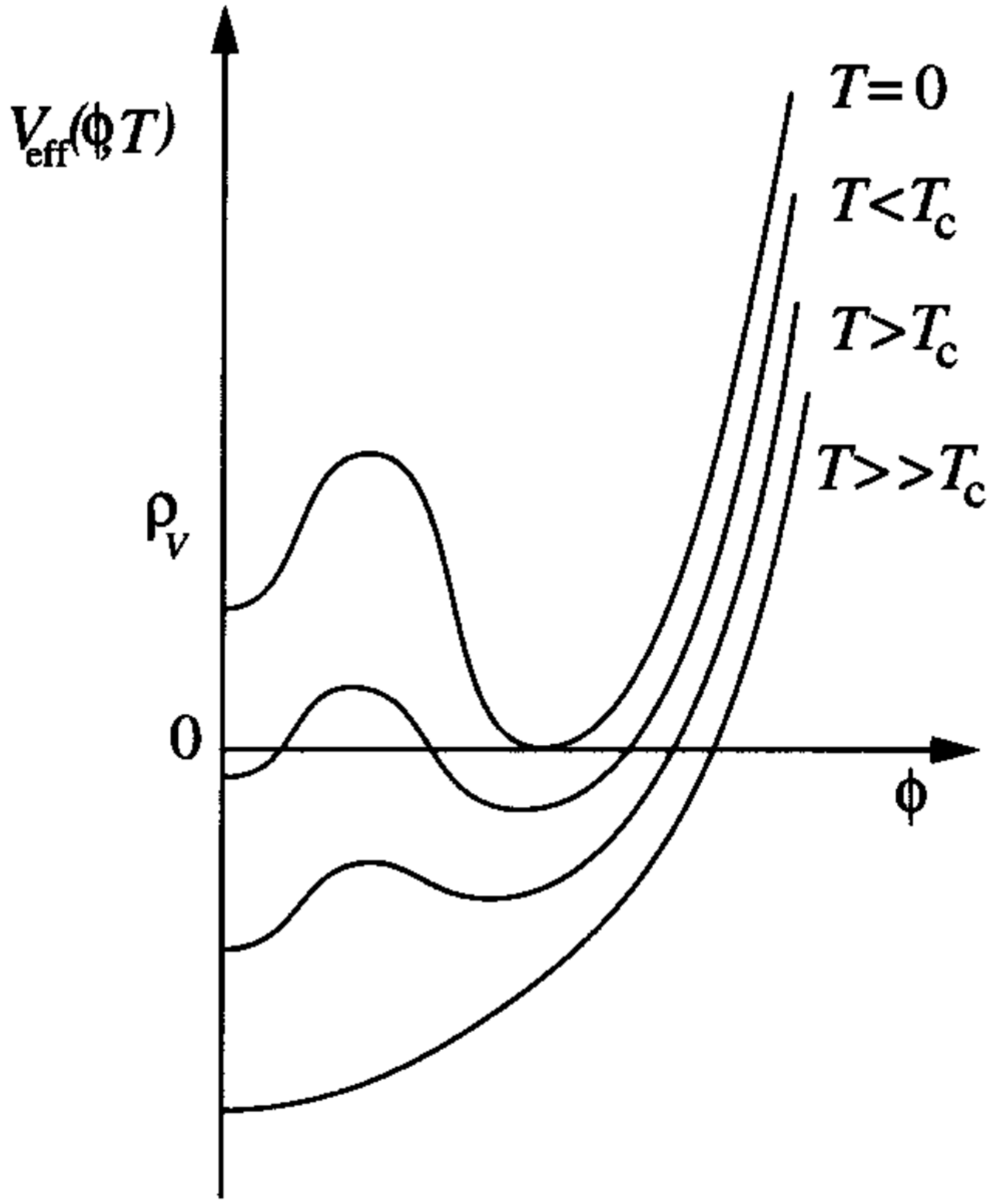
- The abundance of produced monopoles can easily over-dominate the energy density of the universe:

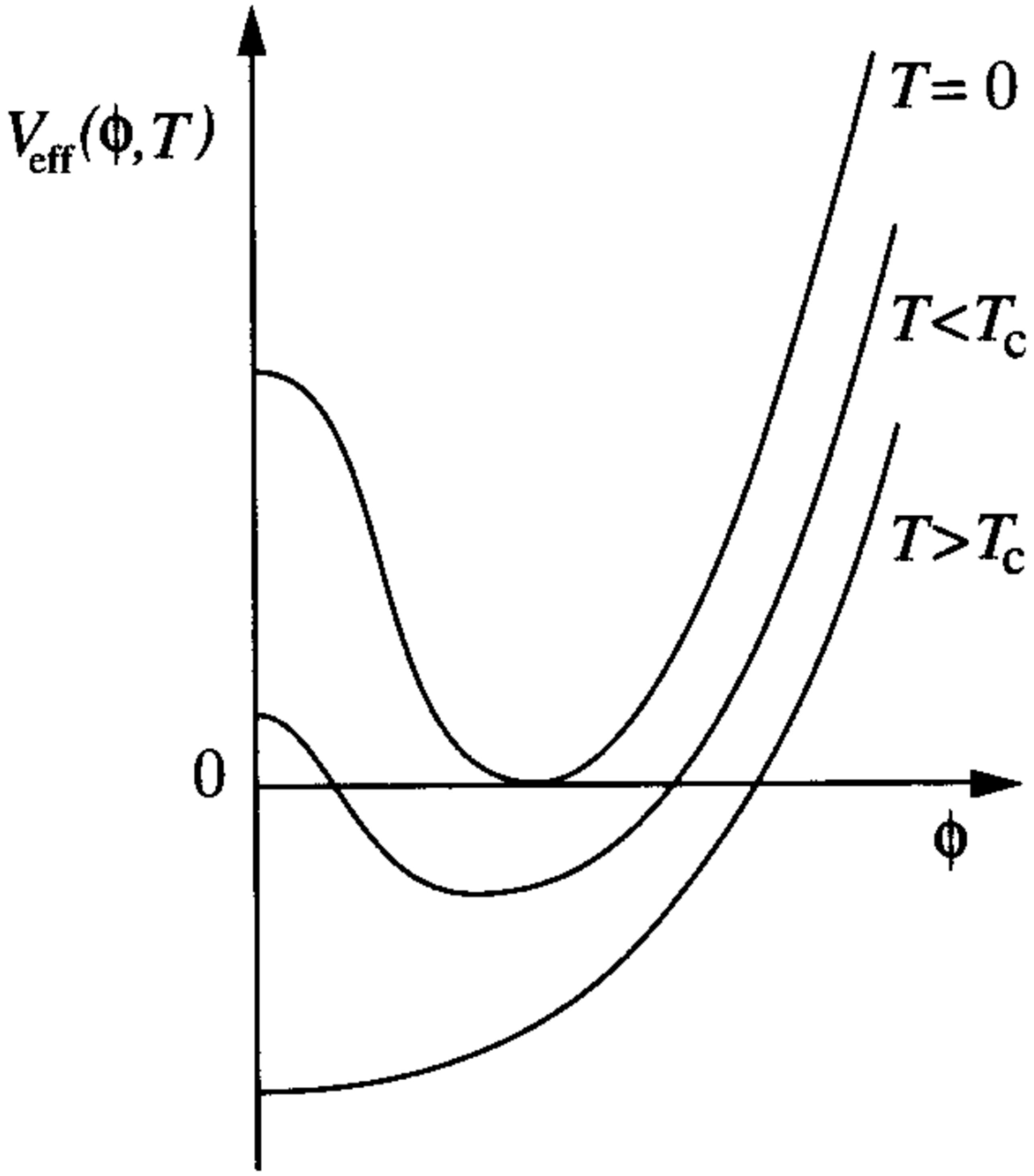
$$\rho_{\mathrm{M,loc}} \sim \rho_{\mathrm{crit}} \left(\frac{v}{10^{11}\ \mathrm{GeV}} \right)^4$$

- Inflation provides a good solution to the problem.

↓

GUT monopoles cannot be produced after inflation.





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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.

↓

Cut-off R set by the nearest anti-monopole.

$$E \sim 4\pi \int_r^R T_t^t r^2 dr \sim 4\pi v^2 R,$$

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

Can a Global Monopole Really Exist?

Global Monopole Solution

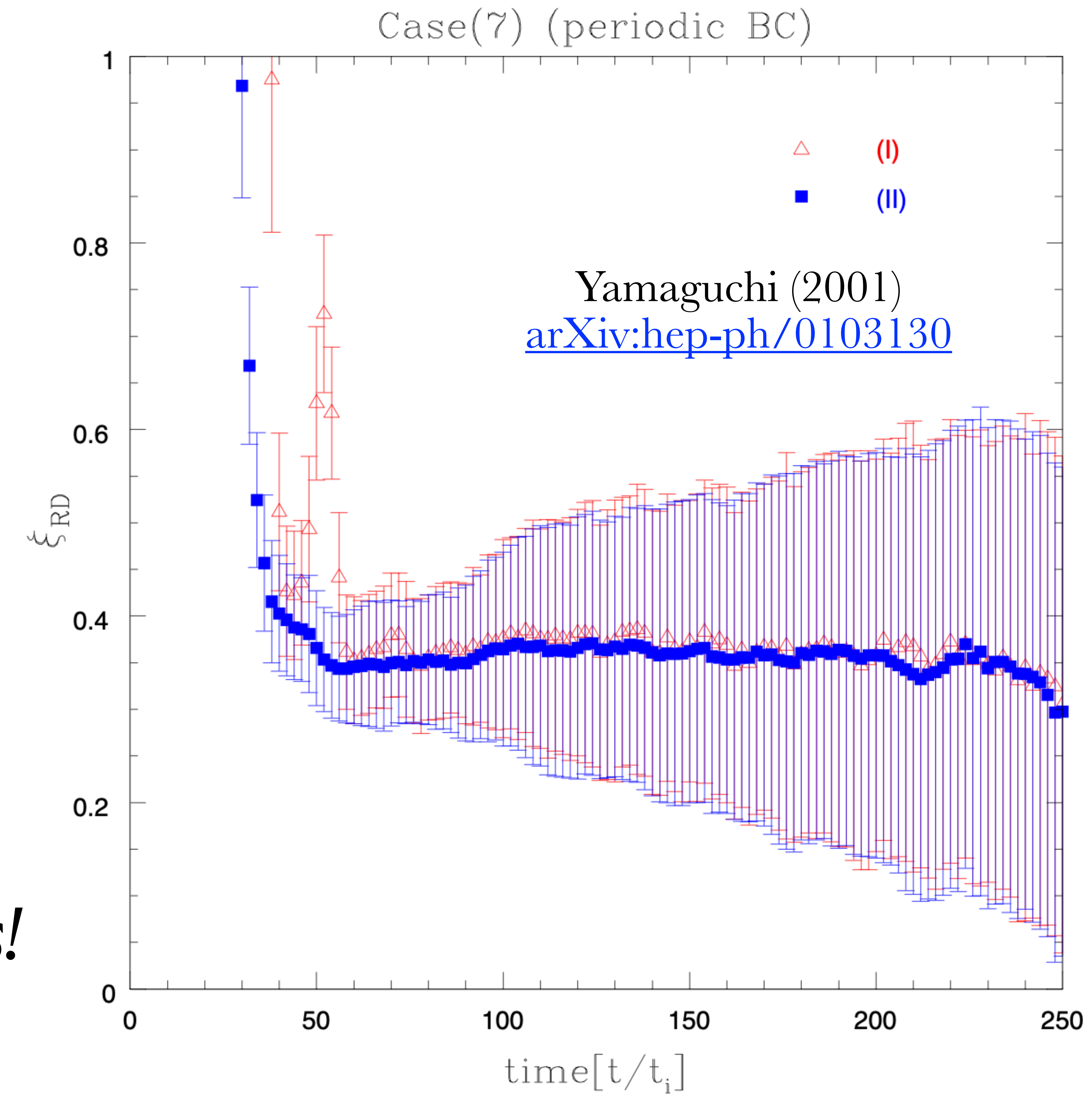
- The attractive force between two global monopoles does not depend on the distance:

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

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

$$n_M = \left(4 \pm 1.5\right) R_H^{-3}$$

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



No cosmological monopole problem exists for global monopoles!

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“Global” Solution to the Monopole Problem

We propose a modification of the Lagrangian that breaks the conformal 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.

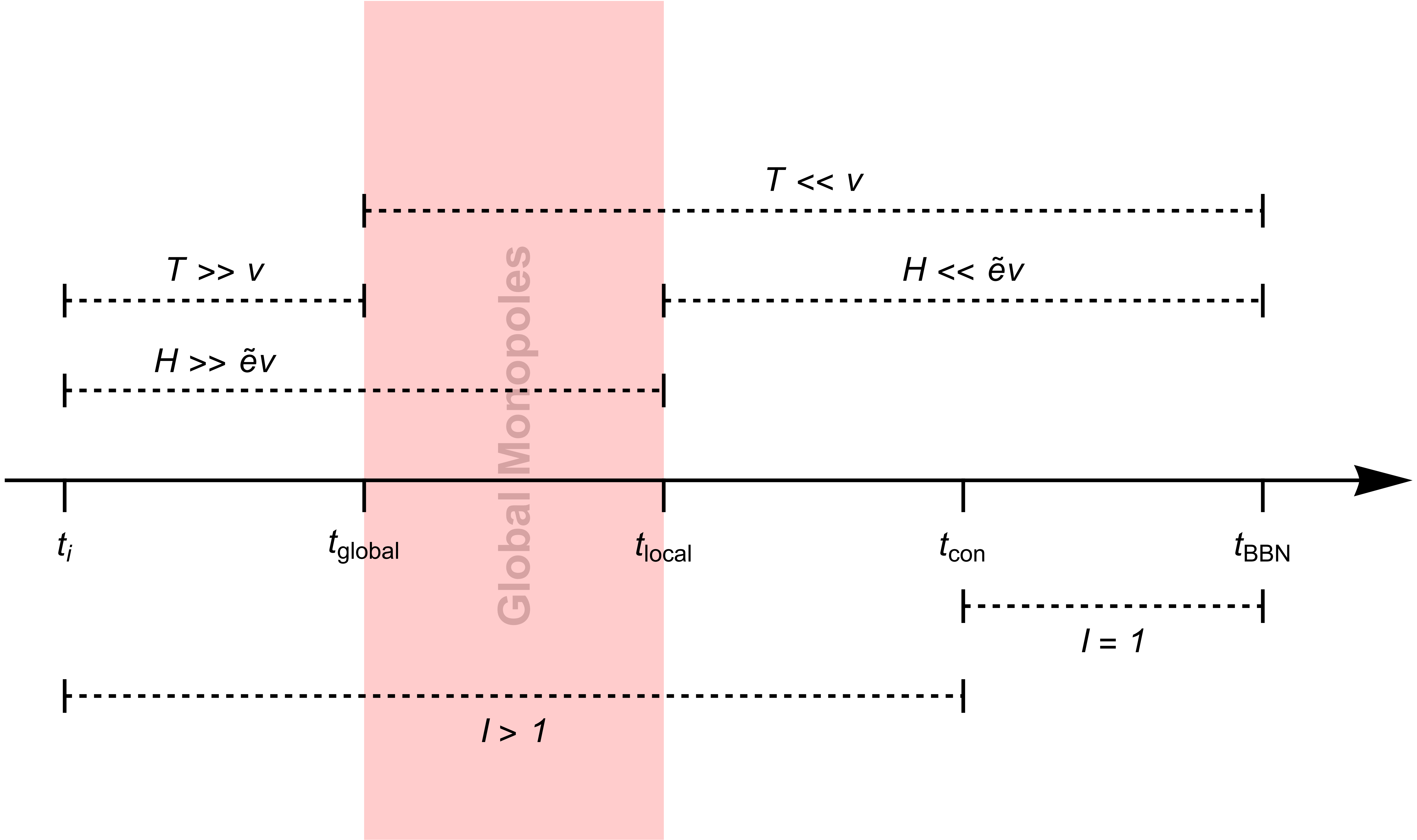
$$I = \max\left\{\left(\frac{a_{\rm con}}{a}\right)^s, 1\right\}$$

"Global" Solution to the Monopole Problem

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

- The vector field is effectively massless, and the monopole radius larger than the horizon. Only the global symmetry is broken and monopoles are produced as global.
- Global monopoles annihilate solving the monopole problem:

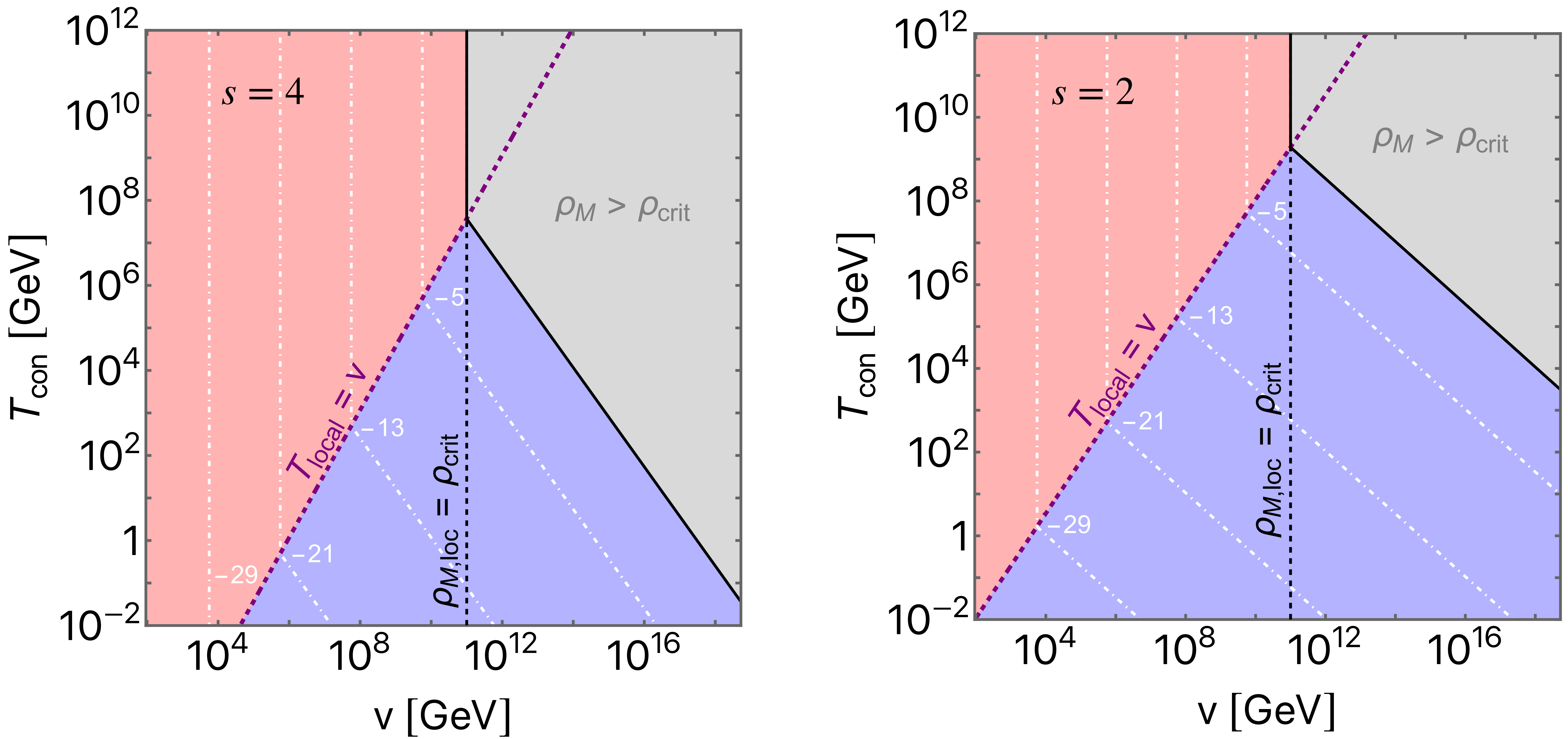
$$\rho_{\mathrm{M,glo}} \sim \rho_{\mathrm{crit}} \left(\frac{v}{10^{11}\ \mathrm{GeV}}\right)\left(\frac{T_{\mathrm{local}}}{10^{11}\ \mathrm{GeV}}\right)^3$$



2. $H \ll \tilde{e}v,\ T \ll v$

- The local part of the symmetry is broken and the monopoles become magnetically charged.

“Global” Solution to the Monopole Problem



With the conformal-breaking term, we have access to parameters compatible with the GUT scale even without inflation. GUT monopole dark matter is still not excluded!

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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.

Magnetic monopoles (even GUT's) are still good candidates for dark matter!

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Thank You!!

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