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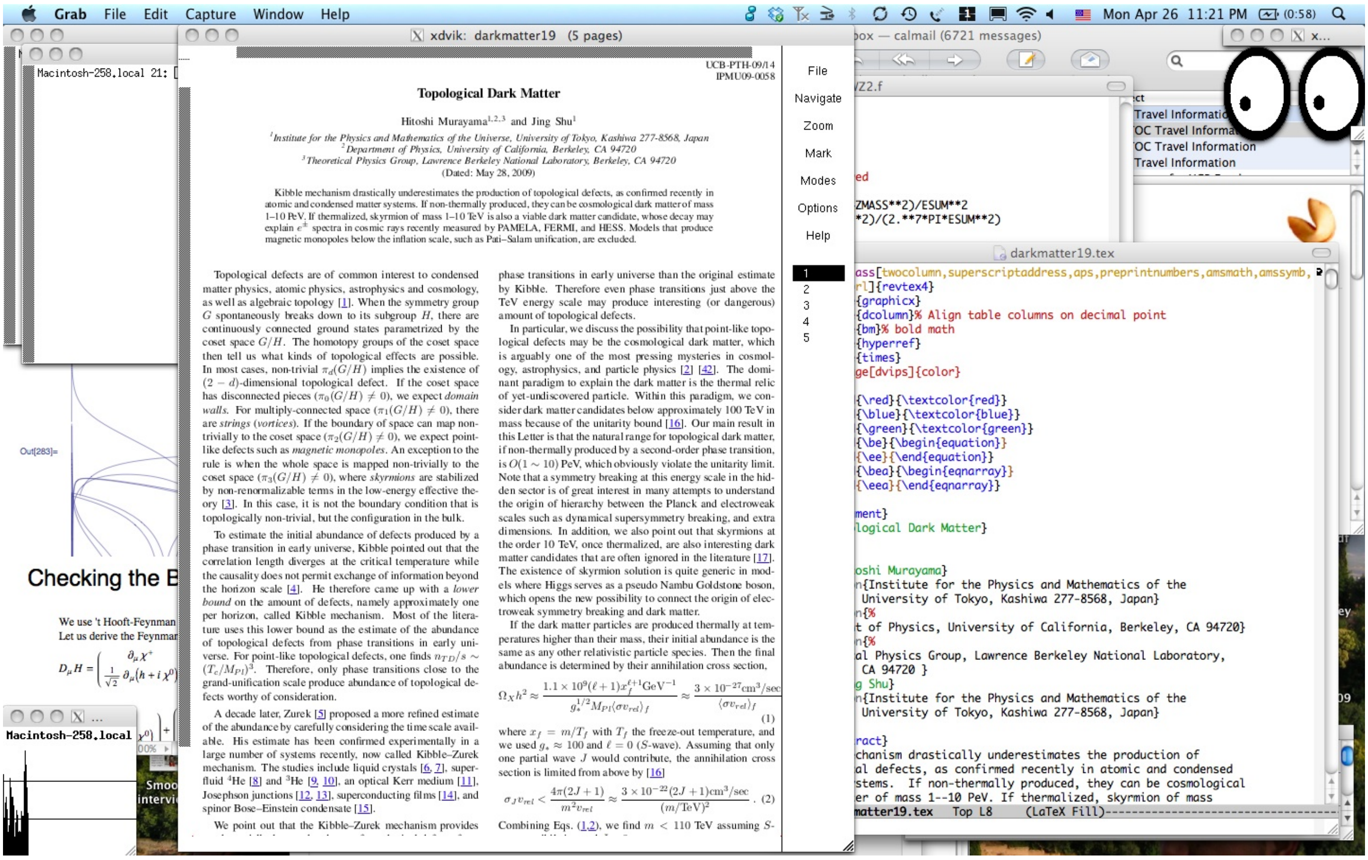

UCB-PTH-09/14
IPMU09-0058

Topological Dark Matter

Hitoshi Murayama[1,2,3] and Jing Shu[1]

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(Dated: May 28, 2009)

Kibble mechanism drastically underestimates the production of topological defects, as confirmed recently in atomic and condensed matter systems. If non-thermally produced, they can be cosmological dark matter of mass 1–10 PeV. If thermalized, skyrmion of mass 1–10 TeV is also a viable dark matter candidate, whose decay may explain $e^{\pm}$ spectra in cosmic rays recently measured by PAMELA, FERMI, and HESS. Models that produce magnetic monopoles below the inflation scale, such as Pati–Salam unification, are excluded.

Topological defects are of common interest to condensed matter physics, atomic physics, astrophysics and cosmology, as well as algebraic topology [1]. When the symmetry group G spontaneously breaks down to its subgroup H, there are continuously connected ground states parametrized by the coset space G/H. The homotopy groups of the coset space then tell us what kinds of topological effects are possible. In most cases, non-trivial $\pi_d(G/H)$ implies the existence of $(2-d)$-dimensional topological defect. If the coset space has disconnected pieces ($\pi_0(G/H) \neq 0$), we expect *domain walls*. For multiply-connected space ($\pi_1(G/H) \neq 0$), there are *strings* (*vortices*). If the boundary of space can map non-trivially to the coset space ($\pi_2(G/H) \neq 0$), we expect point-like defects such as *magnetic monopoles*. An exception to the rule is when the whole space is mapped non-trivially to the coset space ($\pi_3(G/H) \neq 0$), where *skyrmions* are stabilized by non-renormalizable terms in the low-energy effective theory [3]. In this case, it is not the boundary condition that is topologically non-trivial, but the configuration in the bulk.

To estimate the initial abundance of defects produced by a phase transition in early universe, Kibble pointed out that the correlation length diverges at the critical temperature while the causality does not permit exchange of information beyond the horizon scale [4]. He therefore came up with a *lower bound* on the amount of defects, namely approximately one per horizon, called Kibble mechanism. Most of the literature uses this lower bound as the estimate of the abundance of topological defects from phase transitions in early universe. For point-like topological defects, one finds $n_{TD}/s \sim (T_c/M_{Pl})^3$. Therefore, only phase transitions close to the grand-unification scale produce abundance of topological defects worthy of consideration.

A decade later, Zurek [5] proposed a more refined estimate of the abundance by carefully considering the time scale available. His estimate has been confirmed experimentally in a large number of systems recently, now called Kibble–Zurek mechanism. The studies include liquid crystals [6, 7], superfluid ^{4}He [8] and ^{3}He [9, 10], an optical Kerr medium [11], Josephson junctions [12, 13], superconducting films [14], and spinor Bose–Einstein condensate [15].

We point out that the Kibble–Zurek mechanism provides

phase transitions in early universe than the original estimate by Kibble. Therefore even phase transitions just above the TeV energy scale may produce interesting (or dangerous) amount of topological defects.

In particular, we discuss the possibility that point-like topological defects may be the cosmological dark matter, which is arguably one of the most pressing mysteries in cosmology, astrophysics, and particle physics [2] [42]. The dominant paradigm to explain the dark matter is the thermal relic of yet-undiscovered particle. Within this paradigm, we consider dark matter candidates below approximately 100 TeV in mass because of the unitarity bound [16]. Our main result in this Letter is that the natural range for topological dark matter, if non-thermally produced by a second-order phase transition, is $O(1 \sim 10)$ PeV, which obviously violate the unitarity limit. Note that a symmetry breaking at this energy scale in the hidden sector is of great interest in many attempts to understand the origin of hierarchy between the Planck and electroweak scales such as dynamical supersymmetry breaking, and extra dimensions. In addition, we also point out that skyrmions at the order 10 TeV, once thermalized, are also interesting dark matter candidates that are often ignored in the literature [17]. The existence of skyrmion solution is quite generic in models where Higgs serves as a pseudo Nambu Goldstone boson, which opens the new possibility to connect the origin of electroweak symmetry breaking and dark matter.

If the dark matter particles are produced thermally at temperatures higher than their mass, their initial abundance is the same as any other relativistic particle species. Then the final abundance is determined by their annihilation cross section,

$$\Omega_X h^2 \approx \frac{1.1\times 10^9(\ell+1)x_f^{\ell+1}\mathrm{GeV}^{-1}}{g_*^{1/2}M_{Pl}\langle\sigma v_{rel}\rangle_f} \approx \frac{3\times 10^{-27}\mathrm{cm}^3/\mathrm{sec}}{\langle\sigma v_{rel}\rangle_f} \qquad (1)$$

where $x_f = m/T_f$ with T_f the freeze-out temperature, and we used $g_* \approx 100$ and $\ell = 0$ (S-wave). Assuming that only one partial wave J would contribute, the annihilation cross section is limited from above by [16]

$$\sigma_J v_{rel} < \frac{4\pi(2J+1)}{m^2 v_{rel}} \approx \frac{3\times 10^{-22}(2J+1)\mathrm{cm}^3/\mathrm{sec}}{(m/\mathrm{TeV})^2}\,. \qquad (2)$$

Combining Eqs. (1,2), we find $m < 110$ TeV assuming S-

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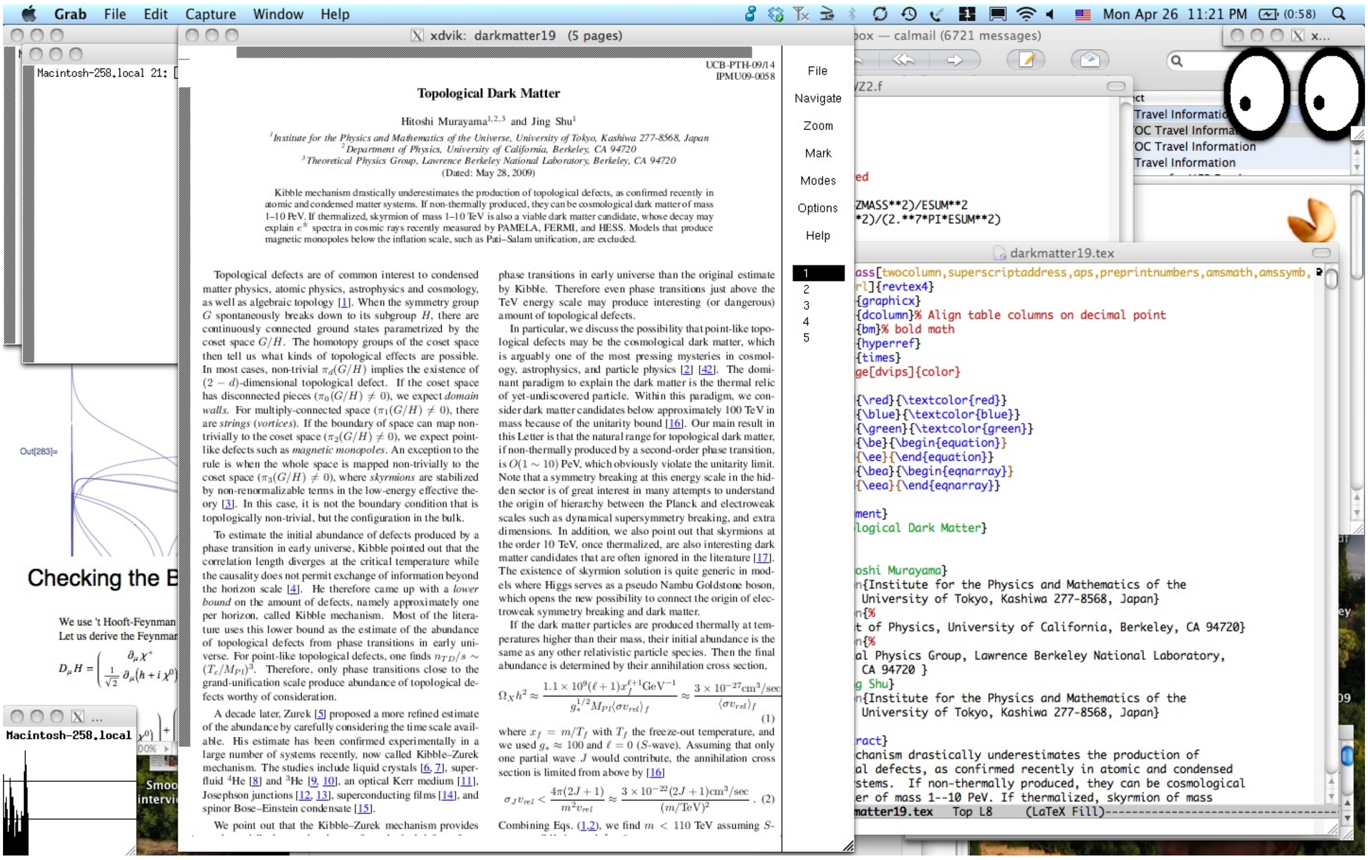

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Después de instalar, usted no se aburrirá después de un día de trabajo en él y esto cómo se convierte en uno de los mejores editores de látex.. En la arena de Linux, LaTeX es considerado como un lenguaje de marcado estándar.. MathType para Mac es un potente editor de fórmulas matemáticas y científicas De enseñanza virtual y para documentos basados en Tex, LaTeX o MathML.. Nota: para aclarar, estas aplicaciones no se enumeran en ningún orden específico, y las características mencionadas aquí no son todo incluido.. Si usted es un gran fan de la edición de látex o acaba de empezar a aprender, esta lista le guiará para obtener el mejor editor de látex para su sistema Linux.. Tal vez sea el editor; que había estado buscando durante años Puede personalizar cualquier cosa y muy fácil de usar.. Ayuda a los usuarios a editar los documentos a nivel de marcado Hay un montón de mejor editor de látex disponible para Linux, pero parece difícil elegir el mejor editor de látex para principiantes y avanzados.. TeXStudio es un tenedor de Texmaker que viene con características multiplataforma y una gran cantidad de personalización.. Si usted es un principiante, sin duda Kile le enseñará muy bien y profesionalmente. 34bbb28f04 Dell Monitor Drivers For Mac Os X

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