Gamma-rays from ultracompact primordial dark matter minihalos

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Ultracompact primordial dark matter minihalos can be produced in phase transitions in the early Universe. We show that if they contain WIMPs, minihalos produced in the electron-positron annihilation epoch will be found by Fermi. Minihalos from the QCD phase transition may also be detectable.

Based on Scott & Sivertsson, arXiv:0908.4082 (*Phys Rev Letters,* in press)

Abstract

Ultracompact primordial dark matter minihalos have recently been proposed as a new class of dark matter structure. Ultracompact minihalos would be produced by phase transitions in the early Universe, and constitute non-baryonic massive compact halo objects (MACHOs) today. Here we examine the prospects for detecting ultracompact minihalos in gamma-rays if dark matter consists of self-annihilating particles. We show present-day fluxes from ultracompact minihalos produced in the electroweak and QCD phase transitions in the early universe, and from the electron-positron annihilation epoch. Ultracompact minihalos produced during the electron-positron epoch should be eminently detectable today, either by Fermi, current Air Cherenkov telescopes, or even in archival data from EGRET. If they exist within 2 kpc of Earth, ultracompact minihalos from the electron-positron epoch should also appear as extended sources to Fermi. Ultracompact minihalos formed in the QCD phase transition have similar predicted fluxes to the dwarf spheroidal galaxies targeted by Fermi, and might be detectable by future instruments.

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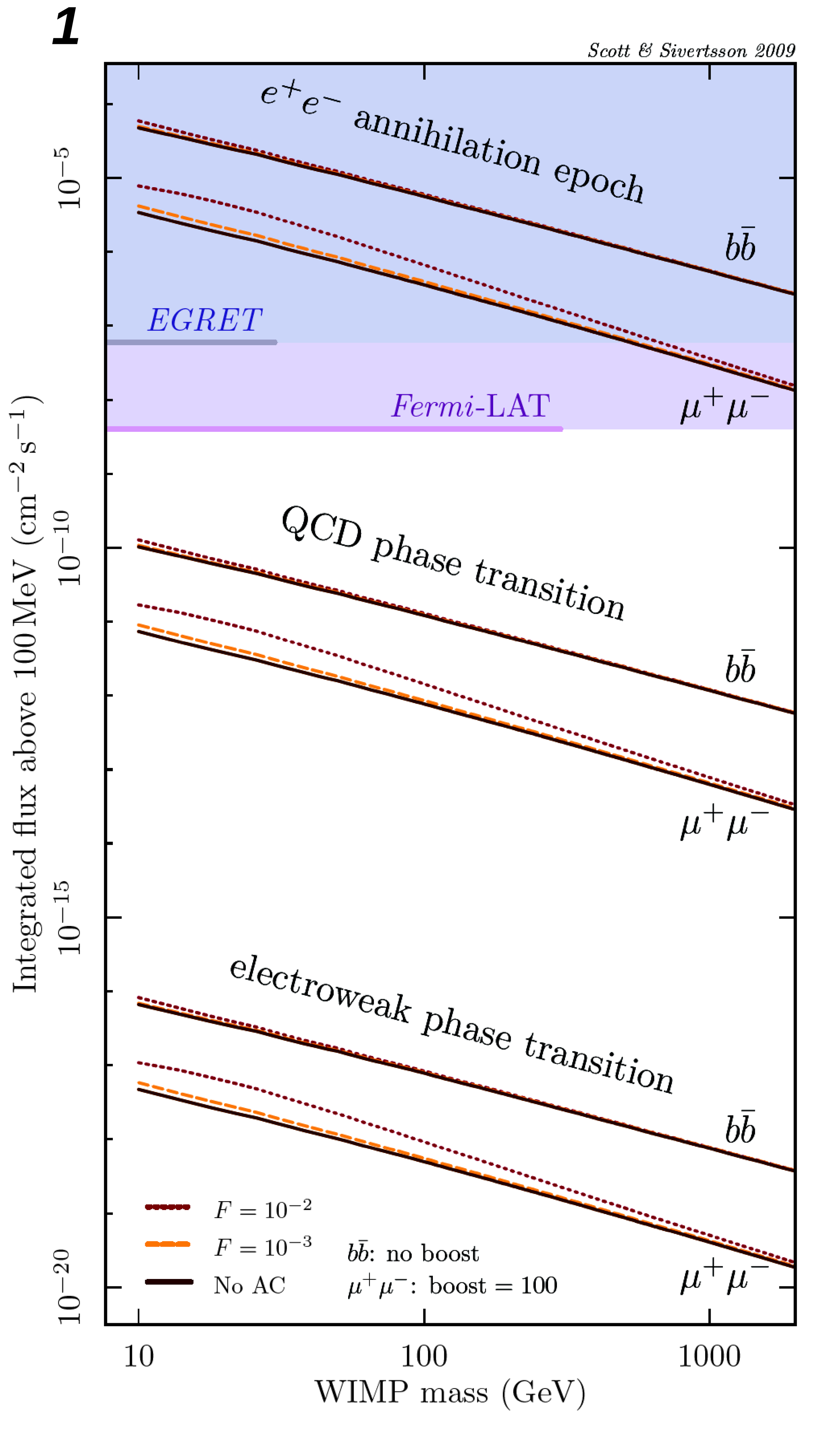

Fig 1: Integrated fluxes above 100 MeV for single ultracompact minihalos consisting of WIMPs annihilating into either *b*-quarks or $\mu^+\mu^-$ pairs at a distance *d* = 4 kpc. Curves are shown for different phase transitions and degrees of adiabatic contraction. Adiabatically-contracted ultracompact minihalos are assumed to have a fraction *F* of their mass collapsed into a constant-density baryonic core of radius 10^{-3} times the radius of the minihalo itself. Also shown are approximate 5σ, power-law, high-latitude, point-source sensitivities for 2 weeks of pointed EGRET and one year of all-sky Fermi Large Area Telescope (LAT) observations. Solid limits indicate instruments' nominal energy ranges.

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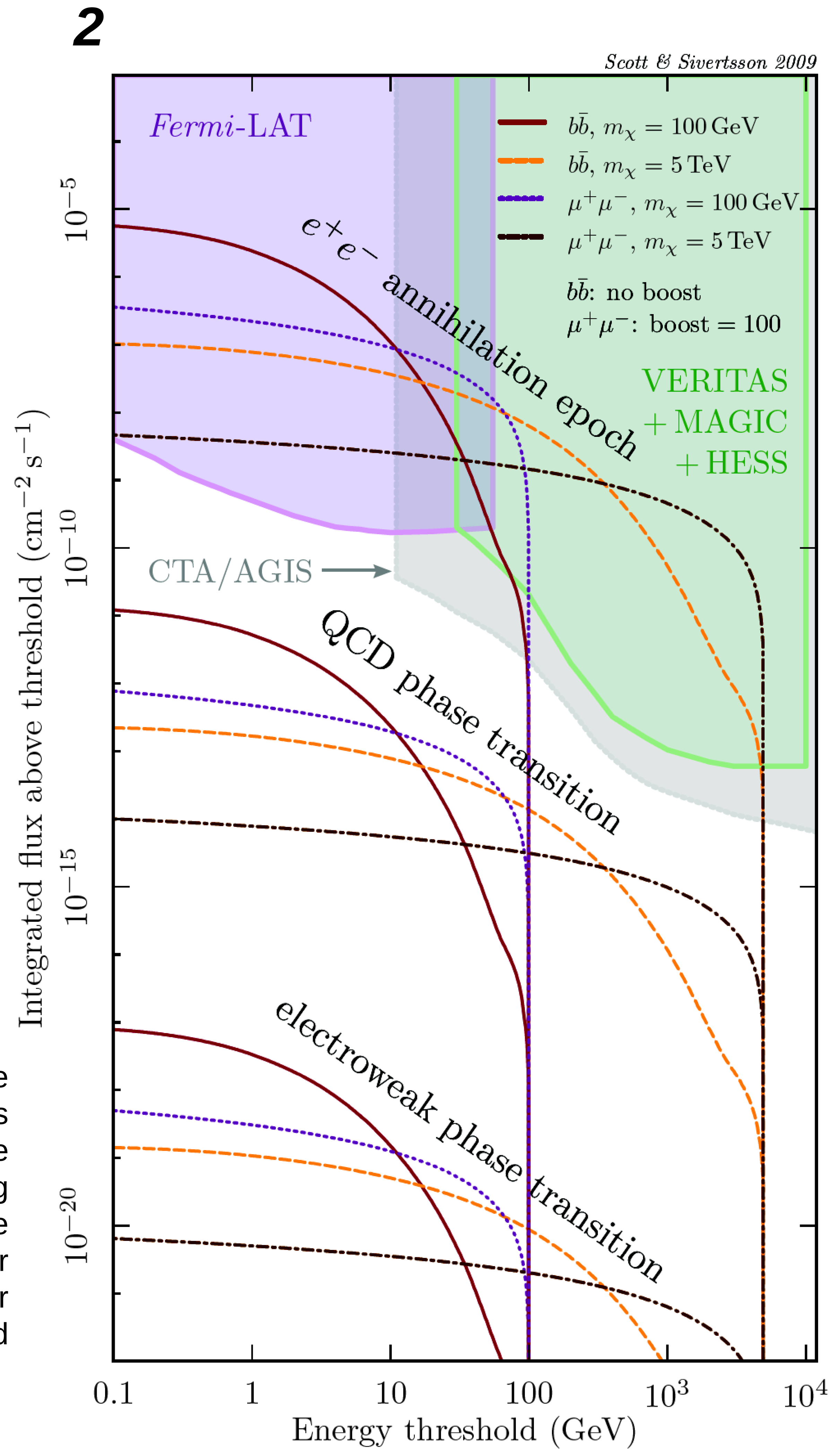

Fig 2: Fluxes from single uncontracted ultracompact minihalos at *d* = 4 kpc, as a function of the energy threshold of the observing experiment. Shaded areas show the regions accessible after a 1 year survey by the Fermi-LAT, and 50 hr of observation by existing and planned Air Cherenkov Telescopes.

Estimating the relic abundance of ultracompact minihalos

To estimate the cosmological abundance of ultracompact minihalos, one integrates the probability distribution of primordial density perturbations between the ultracompact minihalo formation threshold ($\delta \sim 10^{-3}$) and the primordial black hole (PBH) threshold ($\delta \sim 0.3$). We approximate the distribution as Gaussian [1], giving a relic density at matter-radiation equality of

$$\Omega_{\rm mini}(M_{\rm H}) = \int_{10^{-3}}^{0.3} \frac{\delta}{\sqrt{2\pi}\sigma(M_{\rm H})} \exp\left(-\frac{\delta^2}{2\sigma(M_{\rm H})^2}\right) \mathrm{d}\delta. \quad (7)$$

Here $\sigma(M_{\rm H})^2$ is the variance of perturbations at $M_{\rm H}$. Assuming a scale-independent perturbation spectrum of index n, and normalising to the perturbations observed in the CMB, σ can be approximated as [1]

$$\sigma(M_{\rm H}) = 9.5 \times 10^{-5} \left(M_{\rm H}/10^{56} g\right)^{(1-n)/4}. \quad (8)$$

On CMB scales, $n \sim 1$ [2]. However, the CMB probes only a limited number of modes. A different power law could plausibly dominate at the small scales relevant to ultracompact minihalo formation; indeed, many inflationary models give a running spectral index [3], and phase transitions could produce scale-dependent features in the power spectrum. The present limit at the scale of PBH/ultracompact minihalo formation is $n \lesssim 1.25$ [1]. As they grow by a further factor of 290 between equality and $z = 10$, ultracompact minihalos formed in the e^+e^- annihilation epoch could account for e.g. ∼1% of today's dark matter if $n = 1.15$. For the QCD and electroweak phase transitions, similar abundances could be obtained for $n = 1.09$–1.11.

[1] A. M. Green and A. R. Liddle, Phys. Rev. D **56**, 6166 (1997), arXiv:astro-ph/9704251.
[2] E. Komatsu et al., ApJS **180**, 330 (2009), arXiv:0803.0547.
[3] A. S. Josan, A. M. Green, and K. A. Malik, Phys. Rev. D **79**, 103520 (2009), arXiv:0903.3184.

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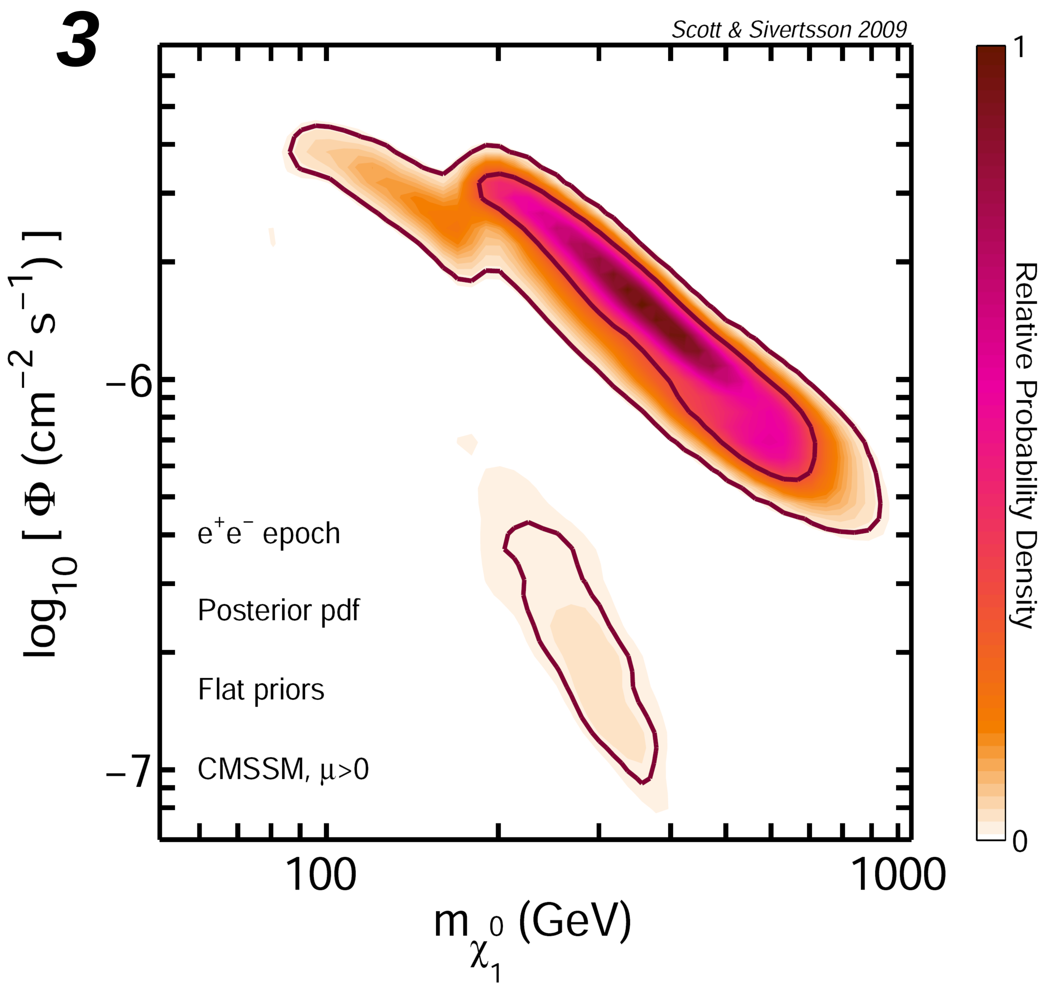

Fig 3: Expected fluxes in the context of the CMSSM, for ultracompact minihalos formed in the e^+e^- annihilation epoch, integrated above 100 MeV. Contours indicate 1 and 2σ credible regions. Fits included a range of experimental data, and required that the neutralino is the only component of dark matter. Predictions from the QCD and electroweak transitions look similar, but are ∼5.5 and ∼12 orders smaller, respectively.