# Dark matter from "strong gravity" - consistent with CRESST, CoGeNT and DAMA/LIBRA

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#### Abstract

Kelso, Hooper and Buckley [\[arXiv:1110.5338\]](http://arxiv.org/abs/1110.5338) found CRESST, Co-GeNT and DAMA/LIBRA results are consistent with 10 - 15 GeV dark matter particles. Hennawi and Ostriker [\[arXiv:astro-ph/0108203\]](http://arxiv.org/abs/astro-ph/0108203) analyzed supermassive black hole formation in the centers of galaxies, finding a best fit for dark matter (self-interaction cross-section)/mass ratio =  $0.02 \text{ cm}^2/\text{g}$ , with round-off error  $\pm 25\%$ . Combining the Hennawi/Ostriker result with the "strong gravity" model for dark matter [\[arXiv:0706.3050\]](http://arxiv.org/abs/0706.3050) requires dark matter particles with mass between 10.5 GeV and 17.5 GeV, overlapping the Kelso/Hooper/Buckley dark matter particle mass range.

## Introduction

The Kelso, Hooper and Buckley [\[1\]](#page-4-0) analysis of CRESST, CoGeNT and DAMA/LIBRA results indicates a dark matter particle mass of 10 - 15 GeV. Based on the Kelso/Hooper/Buckley work, the following analysis shows CRESST, CoGeNT and DAMA/LIBRA results and the Hennawi/Ostriker [\[2\]](#page-4-1) estimate of (self-interaction cross-section)/mass ratio of dark matter particles, are consistent with dark matter from "strong gravity" [\[3\]](#page-4-2)

Hennawi and Ostriker's [\[2\]](#page-4-1) best fit of  $\frac{\sigma}{M} = 0.02 \text{ cm}^2/\text{g}$  for the (self-interaction cross-section)/mass ratio of dark matter particles is based on growth of black

holes in the center of galaxies. The Hennawi/Ostriker estimate for  $\frac{\sigma}{M}$  is consistent with upper bounds on  $\frac{\sigma}{M}$  based on evaporation of galactic halos [\[4\]](#page-4-3), optical and X-ray observations of the colliding "Bullet Cluster" galaxies 1E0657-56 [\[5\]](#page-4-4) [\[6\]](#page-4-5), and X-ray observations of the merging galaxy cluster MACSJ0025.4-1222 [\[7\]](#page-4-6).

## Dark Matter

Many cosmological models assume all four forces governing the universe were unified very early in the history of the universe. After the initial force symmetry broke, the gravitational structure constant  $\frac{Gm_p^2}{\hbar c} = 5.9 \times 10^{-39}$ , with  $\hbar = 1.05 \times 10^{-27}$  g cm<sup>2</sup>/sec,  $c = 3 \times 10^{10}$ cm/sec and  $m_p = 1.67 \times 10^{-24}$ g, is the ratio of the strength of gravity and the strong force after inflation. In the flat homogeneous and isotropic space of the post-inflationary universe with matter energy density  $\rho$ , the "strong gravity" model for dark matter [\[3\]](#page-4-2) approximates the strong force as an effective "strong gravity" (acting only on matter) with strength  $G_S = \left(\frac{M_P}{m_p}\right)^2 G = 1.7 \times 10^{38} G$ , where the gravitational constant  $G = 6.67 \times 10^{-8} \text{cm}^3/\text{g sec}^2$  and the Planck mass  $M_P = \sqrt{\frac{\hbar c}{G}} = 2.18 \times 10^{-5}$  g. Then, the strong gravity Friedmann equation  $\left(\frac{dR}{dt}\right)^2$  –  $rac{8\pi G_S \rho R^2}{3} = -c^2$  describes the local curvature of spaces defining closed massive systems bound by the effective strong gravity. Because a strong force at short distances is involved, a quantum mechanical analysis of such systems is necessary. The Schrodinger equation resulting from Elbaz-Novello quantization of the Friedmann equation [\[8\]](#page-4-7) for a closed massive system bound by the effective strong gravity is  $-\frac{\hbar^2}{2\mu}$  $rac{\hbar^2}{2\mu} \frac{d^2}{dr^2} \psi - \frac{2G_S\mu M}{3\pi r} \psi = -\frac{\mu c^2}{2}$  $\frac{c^2}{2}\psi$ , where  $M = 2\pi^2 \rho r^3$  is the conserved mass of the closed system with radius  $r$  and  $\mu$  is an effective mass. This Schrodinger equation is identical in mathematical form to the Schrodinger equation for the hydrogen atom and can be solved immediately. The ground state curvature energy  $-\frac{\mu}{2\hbar^2}\left(\frac{2G_S\mu M}{3\pi}\right)^2$  of this Schrodinger equation must equal  $-\frac{\mu c^2}{2}$  $\frac{c}{2}$  for consistency with the corresponding Friedmann equation, so the effective mass  $\mu = \frac{3\pi\hbar c}{2G_S M}$ . The ground state solution of this Schrodinger equation describes a stable closed system bound by the effective strong gravity, with zero orbital angular momentum and radius  $\langle r \rangle = \frac{G_S M}{\pi c^2} = \frac{\hbar M}{\pi c m_p^2}$ . Geodesic paths inside the stable ground state closed systems created by the effective strong gravity are all circles with radius  $\langle r \rangle = \frac{\hbar M}{\pi c m_p^2}$ , so matter within these closed systems is permanently confined within a sphere of radius  $\langle r \rangle$ . No particle can enter or leave these small closed systems after they form, to increase or decrease the amount of matter in those closed systems. These small closed systems act like rigid impenetrable spheres interacting only gravitationally and constituting the majority of dark matter.

Assuming velocity-independent rigid sphere scattering [\[9\]](#page-4-8), the (self-interaction collision cross-section)/mass ratio for the dark matter particles is  $\frac{\sigma}{M} = \frac{4\pi(2r)^2}{M}$ . Consider values of  $\frac{\sigma}{M}$  between 0.015 cm<sup>2</sup>/g and 0.025 cm<sup>2</sup>/g, that round off to the Hennawi/Ostriker estimate of  $\frac{\sigma}{M} = 0.02 \text{ cm}^2/\text{g}$ . Inserting the dark matter particle radius/mass relation  $r = \frac{\hbar M}{\pi c m_p^2}$  into the rigid sphere (self-interaction colp lision cross-section)/mass relation  $\frac{\sigma}{M} = \frac{4\pi(2r)^2}{M}$  yields  $M = \left[ \left( \frac{\sigma}{M} \right) \frac{\pi}{16} \left( \frac{c}{\hbar} \right)^2 m_p^3 \right] m_p$ . Therefore, values of  $\frac{\sigma}{M}$  between 0.015 cm<sup>2</sup>/g and 0.025 cm<sup>2</sup>/g indicate a dark matter particle mass between 10.5 GeV and 17.5 GeV, overlapping the 10 - 15 GeV dark matter particle mass range determined by the Kelso/Hooper/Buckley [\[1\]](#page-4-0) analysis of CRESST, CoGeNT and DAMA/LIBRA results. The nucleon mass equivalent  $A = \left(\frac{\sigma}{M}\right) \frac{\pi}{16} \left(\frac{c}{\hbar}\right)^2 m_p^3$  of the dark matter particles ranges from 11.2 to 18.7, and the radius of the dark matter particles  $r = \left(\frac{A}{\pi}\right) \left(\frac{\hbar}{m_i}\right)$  $\frac{\hbar}{m_pc}$  ranges from 0.75 fm to 1.25 fm.

The radius of the dark matter particles, estimated from the Hennawi/Ostriker  $\frac{\sigma}{M}$  result, relates to the finite range of the strong force. The distance  $\pi r$ , halfway around a geodesic path inside the small closed systems constituting most dark matter, is a characteristic length for the collective strong gravity effective force binding A nucleon mass equivalents into dark matter particles. It's roughly analogous to the radius of an atomic nucleus containing A nucleons, bound by collective effects of the strong interaction. The characteristic length for dark matter particles  $\pi r = A \left(\frac{\hbar}{m}\right)$  $\frac{\hbar}{m_pc}$ , ranging from 2.4 fm to 3.9 fm, is similar to the 2.4 fm to 2.9 fm range of root mean square charge radii [\[10\]](#page-4-9) for nuclei containing 10 (boron) to 19 (fluorine) nucleons.

The radius of a nucleus comprised of A nucleons is often approximated as  $r_n = 1.25A^{\frac{1}{3}}$  fm. Considering only nuclei comprised of 10 to 19 nucleons, a least squares fit to ten tabulated values [\[10\]](#page-4-9) of root mean square charge radii gives  $r_n = 1.04 A^{0.34}$  fm  $[R^2 = 0.91, p = 2 \times 10^{-5}]$ . If these relations adequately approximate the effective length  $\pi r = A\left(\frac{\hbar}{m_e}\right)$  $\left(\frac{\hbar}{m_p c}\right)$  characterizing A nucleon mass equivalents bound into a dark matter particle, they suggest a dark matter particle mass of 13.6 GeV or 10.7 GeV, respectively.

The Kelso/Hooper/Buckley [\[1\]](#page-4-0) estimate of dark matter elastic scattering cross section with nucleons  $(10^{-41}$ to  $10^{-40}$  cm<sup>2</sup>) estimates the cross section for scattering of rigid spheres of dark matter on quark partons in nucleons boumd into atomic nuclei, as the spheres of dark matter plow through ordinary matter in detectors. Detectable nuclear recoils only occur in low probability events when an incoming dark matter particle collides almost head-on with a quark parton carrying most of the center-of-mass momentum of the struck nucleus.

### Dark matter formation

If  $\frac{\sigma}{M} = 0.02 \text{ cm}^2/\text{g}$ , dark matter particle have mass = 14.9 $m_p = 14.0 \text{ GeV}$ , radius = 1.00 fm and density  $6 \times 10^{15}$  g/cm<sup>3</sup>. As the universe expanded after inflation, the matter density of the universe steadily dropped. When the matter density in the early universe fell to  $6 \times 10^{15}$  g/cm<sup>3</sup>, most matter in the universe coalesced into dark matter - small closed spherically symmetric systems with zero orbital angular momentum. This resulted in a universe packed with small invisible and impenetrable systems interacting only gravitationally. Assuming uniform matter density in the universe and instantaneous coalescence with maximum packing fraction, 74% of the matter in the universe is small closed impenetrable systems constituting the bulk of dark matter. With non-uniform density, coalescence would occur first in lower density volumes, and expansion of the universe might allow slightly more than 74% of matter to coalesce into small closed systems.

The matter fraction of the energy density in the universe today is about 0.3. If the hadronic matter fraction is about 0.05, dark matter is about (0.25/0.3)  $= 83\%$  of all matter. If 74% of all matter is small closed systems, those small bound systems account for  $0.74 \times 0.3 = 0.22$  of the energy density in the universe today, or about  $(0.22/0.25) = 88\%$  of the dark matter. Using today's scale factor of the universe  $R_0 \approx 10^{28}$  cm and today's matter density  $2.4 \times 10^{-30}$  g/cm<sup>3</sup>, the matter density  $6 \times 10^{15}$  g/cm<sup>3</sup> required for coalescence into small closed systems with mass 14.0 GeV occurred when the scale factor of the universe was  $R_c \approx 7 \times 10^{12}$  cm.

## Minimum black hole mass

The impenetrable spheres of dark matter are the ultimate defense against gravitational collapse. The radius of a close-packed sphere of  $n$  dark matter particles is  $R_n = \sqrt[3]{n} \frac{\hbar M}{\pi c m_p^2} = \sqrt[3]{n}$  fm. The Schwarzschild radius of that sphere,  $R_S = \frac{29.9Gnm_p}{c^2} = 3.7n \times 10^{-51}$ cm, is smaller than the physical radius of the sphere until  $\sqrt[3]{n}(1\times10^{-13} \text{cm}) = 3.7n \times 10^{-51} \text{cm}$ , or  $n = 1.4 \times 10^{56}$ . This indicates a minimum mass for accretionary black holes of  $2.1 \times 10^{57} m_p = 3.5 \times 10^{33}$  g, or about 1.5 times the solar mass, and a minimum Schwarzschild radius of 5.2 km. The limit prohibits black holes with mass around  $10^{20}$  g proposed as "antimatter factories" by Bambi et al [\[11\]](#page-4-10).

## Accelerator production

The impenetrable spheres of dark matter will not be created in particle accelerators because of Lorentz contraction of the accelerated particles. In the colliding particle center of mass system, the energy of colliding particles is dumped into a thin Lorentz-contracted disk. This does not create the uniform matter distribution in a sphere of radius 1 fm necessary to reproduce early universe conditions resulting in coalescence of impenetrable spheres of dark matter.

## <span id="page-4-0"></span>References

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