Dark Astronomical Compact Objects in Inflationary Dark Matter Model

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Outline

1. Model of Luminogenesis from Inflationary Dark Matter
2. Radius and mass scales of Dark Astronomical Compact Objects (DACOs)
3. Critical mass and radius of χ compact objects
4. A mechanism for energy dissipation
5. Detection of DACOs in nearby galaxies

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- Dark matter in this model, χ_l and $\bar{\chi}_l$, transform under $SU(4)_{DM} \times SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{DM}$ as $(4,1,1,0)_3$ and $(4^*,1,1,0)_{-3}$, respectively.

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$$\frac{g^2}{M^2_{\gamma DM}} \left(\bar{\chi}\gamma_\mu \chi\right) \left(\bar{f}\gamma^\mu f\right). \tag{4}$$

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- A species of dark pion is formed as bound state of one χ_l and one $\bar{\chi}_l$.
- From [2], the CHIMP's mass, m_B, can be from 1 to 100 TeV or so and the dark pion mass, $m_{\pi DM}$, is of several MeV.

Radius and mass scales of Dark Astronomical Compact Objects (DACOs)

- Follow Jean's analysis, let ρ, ρ_1, v_s, G be average density, density fluctuation, sound velocity and gravitational constant, respectively. The DM density evolution is governed by:

$$\frac{\partial^2 \rho_1}{\partial^2 t} = v_s^2 \nabla^2 \rho_1 + 4\pi G \rho \rho_1, \tag{5}$$

which has solution $\rho_1 \propto exp(i\vec{k}\vec{x} - i\omega t)$, where
$\omega^2 = \vec{k}^2 v_s^2 - 4\pi G\rho = v_s^2 \left[\vec{k}^2 - (4\pi G\rho/v_s^2)\right]$, $v_s^2 = \partial p/\partial \rho$.

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- Equations of states: $\rho = nm_B + 3nkT/2$, $p = nkT$.

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- Number density scales as $n = n_i(T/T_i)^{3/2}$. Sound speed is $v_s^2 = 5kT/3m_B$.
- Jean mass is then:

$$M_J = \frac{4}{3}\pi\lambda_J^3 n m_B = (\pi/3)^{5/2}(5k/G)^{3/2}T_i^{3/4}T^{3/4}n_i^{-1/2}m_B^{-2}. \quad (7)$$

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- For comparison, $M_\odot = 2 \times 10^{33}$ (g), $M_{Earth} = 5.9 \times 10^{27}$ (g).

Critical mass and radius of χ compact objects

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$$E = E_F + E_G = k_F c - \frac{GNm_\chi^2}{R} = \left(\frac{9\pi}{2}\right)^{\frac{1}{3}} \frac{\hbar c}{R} N^{\frac{1}{3}} - \frac{GNm_\chi^2}{R} \quad (8)$$

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- If $E < 0$, gravitational energy is negatively larger than Fermi energy. χ sphere would collapse and might result in a black hole. If this is the case, then

$$N > N_{\text{crit}} = (9\pi/2)^{1/2}(\hbar c/Gm_\chi^2)^{3/2}, \text{or} \qquad (9)$$

$$M > M_{\text{crit}} = N_{\text{crit}} m_\chi = (9\pi/2)^{1/2}(\hbar c)^{3/2} m\chi^{-2}. \qquad (10)$$

$$R > R_{\text{crit}} = (9\pi/2)^{1/3}(\hbar c/m_\chi c^2) N_{\text{crit}}^{1/3} \qquad (11)$$

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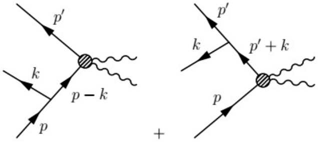
- For $m_\chi = m_B/4$, $M_{\text{crit}} = 1.97 \times 10^{29}$ (g), $R_{\text{crit}} = 36.4$ (m).

A mechanism for energy dissipation

- An energy dissipation mechanism is required for gravitationally bounded astronomical object to be formed. We suggest a Bremsstrahlung process:



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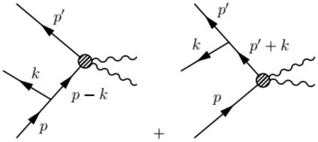

- The total probability for a Bremmstrahlung radiation is

$$\text{total prob } P = \frac{\alpha_{DM} m_B^2}{\pi} \ln\left(\frac{-q^2}{m_{\pi^2_{DM}}}\right)\left(\frac{2}{m_B^2} + \int_0^1 dx \frac{-2}{m_B^2 - x(1-x)q^2}\right) \tag{12}$$

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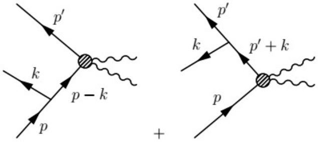

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- On Dwarf scale, Milky Way scale, and cluster scale, speeds of DM are $10^4, 10^5, 10^6$ m/s, respectively [2]. The energy loss of DM due to Bremssstrahlung while travelling is:

$$\frac{dE}{dx} = 10^{-8} - 10^{-4} \frac{\text{MeV}}{\text{cm}} \tag{13}$$

Detection of DACOs in nearby galaxies

- From [3], if a MACHO in Galatic halo of mass $> 10^{-8} M_\odot$, it can be detected by gravitational microlensing with the average time scale of microlensing event given by:

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- MACHO and EROS collaborations has published the upper limit on the planetary-mass dark matter object in Large Magellanic Cloud and Small Magellanic Cloud. Specifically, objects with masses $10^{-7} M_\odot \lesssim m \lesssim 10^{-3} M_\odot$ contribute less than 25% of the halo dark matter.

- [1] Paul H. Framton, Pham. Q. Hung, arXiv:1309.1723v4
- [2] Pham Q. Hung, Kevin J. Ludwick, arXiv:1508.01228v1
- [3] EROS Collaboration, MACHO Collaboration, arXiv:astro-ph/9803082