A bound on the unparticle-photon cross section from the CMB temperature

Maryam Aghaei Abchouyeh[1,2], Maurice H.P.M. van Putten[1]

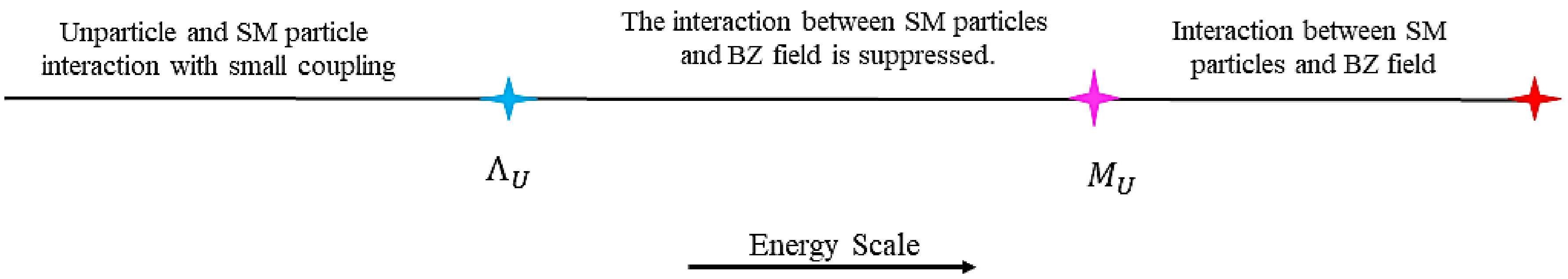
[1]Sejong University, Seoul, South Korea

[2]Center for High Energy Astrophysics, UNIST, Ulsan, South Korea

M. H.P.M. van Putten, M. Aghaei, arXiv:2203.16076 [astro-ph.CO]

Unparticles

Unparticles are the low energy phase of Banks-Zaks field.



- ► They belong to energy scales below Λ_U.
- ► They can interact with standard model particles.
- ► They have scale invariant feature at low energies.
- ► They have a non-trivial IR fixed point.

Georgi, H. 2007, `Unparticle Physics', Phys.Rev.Lett.98(221601).

Unparticles Field Equation

For a gauge theory and in a situation that all renormalaized masses disappear, the trace anomaly for energy-momentum tensor is

$$\theta_\mu^\mu = \frac{\beta}{2g} N\left[F_a^{\mu\nu} F_{a_{\mu\nu}}\right]$$

$$\begin{cases} \beta = a(g - g_*) \\ \left\langle N\left[F_a^{\mu\nu} F_{a_{\mu\nu}}\right]\right\rangle = bT^{4+\gamma} \\ \langle\theta_\mu^\mu\rangle = \rho_U - 3\mathcal{P}_U \end{cases}$$

$$\Rightarrow$$

$$\rho_U - 3\mathcal{P}_U = AT^{4+\delta}$$

$$\delta = a + \gamma$$

$$\delta = 2(d_u - 1)$$

Grzadkowski, B. and Wudka, J. [2009], Phys. Rev. D 80(103518), 189.

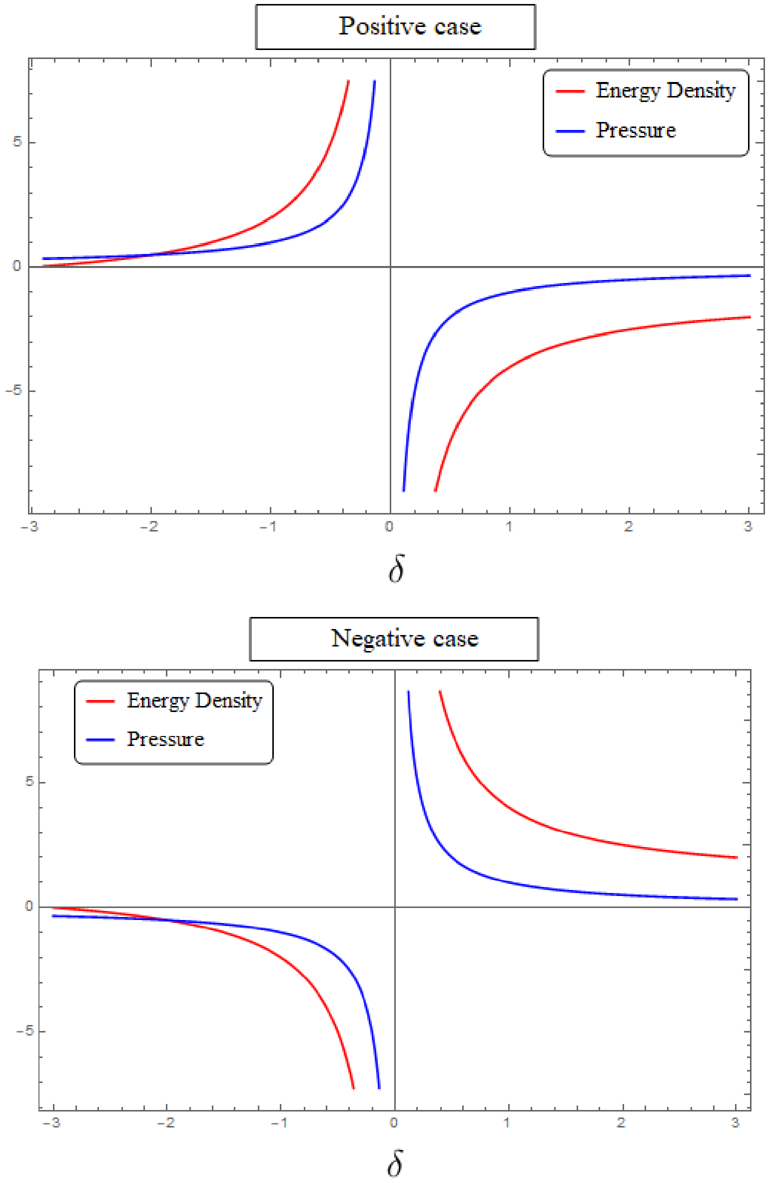
Unparticle Cosmology (UC)

$$\rho_U = \sigma T^4 + A\left(1 + \frac{3}{\delta}\right) T^{4+\delta}$$

$$\mathcal{P}_U = \frac{1}{3}\sigma T^4 + \frac{A}{\delta} T^{4+\delta}$$

CH^{α}

If $B = A\left(1 + \frac{3}{\delta}\right)$ ➡



Maryam Aghaei Abchouyeh and Maurice H. P. M. van Putten Phys. Rev. D ***104****, 083511*

Grzadkowski, B. and Wudka, J. [2009], Phys. Rev. D 80(103518), 189.

Unparticles with negative coefficient

$$\rho_U = \sigma T^4 + A\left(1 + \frac{3}{\delta}\right)T^{4+\delta}$$

$$\mathcal{P}_U = \frac{1}{3}\sigma T^4 + \frac{A}{\delta}T^{4+\delta}$$

$$T_c = \left[\frac{4}{3}\left(\frac{-\sigma}{B}\right)\left(\frac{\delta+3}{\delta+4}\right)\right]^{1/\delta}$$

$$T_0 = \left(\frac{-\sigma}{B}\right)^{\frac{1}{\delta}}$$

$$T_{w=0} = \left(\frac{4}{4+\delta}\right)^{-1/\delta} T_c$$

M. Artymowski et. al,
JCAP 015, 410

$$T_{w=0} > T_c > T_0$$

Note: It prevents Unparticles to have purely non-relativistic behavior.

Cosmic opacity of Unparticles

$$w = -1 \Rightarrow \rho_{r,\mathcal{U}} = -\frac{3}{4}\left(\frac{\delta+4}{\delta+3}\right)\rho_{nr,\mathcal{U}}$$

$$\begin{cases} \rho_{r,\mathcal{U}} = \sigma T^4 \\ \rho_{nr,\mathcal{U}} = B T^{4+\delta} \end{cases}$$

These equations show an approximate equipartition in unparticles energy density.

$$\rho_{BZ} = \frac{3}{\pi^2} g_{BZ} T^4 \qquad g_{BZ} = 100$$

$$\rho_{EM} = \left(\frac{\pi^2}{15}\right) T^4 \simeq 0.658 T^4$$

$$\eta = \frac{\Omega_{\mathcal{U}}}{\Omega_{CMB}} \simeq 10^4 \Leftarrow \begin{cases} \Omega_{\mathcal{U}} \simeq 1 \\ w = -1 \end{cases}$$

$$T_c \simeq \left(\frac{10^4 \pi^4}{45 g_{\mathcal{U}}}\right)^{1/4} T_{CMB} \simeq 4\, T_{CMB}$$

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Grzadkowski, B. and Wudka, J. (2009), Phys. Rev. D 80(103518), 189.

Heat Transfer

Optical depth

$$\tau = \int_{s_0}^{s} \sigma n \; ds$$

Fractional change in energy

$$|\Delta E| \simeq E_0 \tau$$

Optical depth for CMB photons

$$\tau \cong \sigma n R_H$$

Therefore, Unparticles pose a potentially enormous heat exchange with the CMB upon retaining finite interactions with the CMB photons.

Age of the Universe

CMB

$$H_{\Lambda CDM}(z) = H_0\sqrt{(1-\Omega_m) + \Omega_m(1+z)^3} = H_0 h(z)$$

$$T_{u,0} = \frac{1}{H_0}\int_0^\infty \frac{dz}{h(z)(1+z)} = \frac{1}{H_0}(1-\epsilon) \simeq \boxed{13.8 \pm 0.02 \text{ Gyr.}}$$

&

2.73 K

378000 yr

$$\frac{T_{CMB,0}}{T_{CMB}(1100)} = \frac{a(1100)}{a_0} \simeq \left(\frac{T_u(1100)}{T_{u,0}}\right)^{2/3} \Rightarrow T_{u,0} \simeq 13.7 \text{ Gyr}$$

3000 K

Globular Clusters

$$\boxed{T_{u,GC} = 13.5^{+0.16}_{-0.14}(stat.) \pm 0.5(sys.) \text{ Gyr.}}$$

Take care!

In the presence of any additional particle, the consistency between the age of universe derived from CMB and globular cluster must be preserved.

Globular Clusters

$$T_{u,GC} = 13.5^{+0.16}_{-0.14}(stat.) \pm 0.5(sys.)\ \text{Gyr.}$$

Raising the CMB temperature by warm unparticles in excess of a few percent would lower the age of the Universe below this independent astronomical age estimate

$$0.04 \gtrsim n_{\mathcal{U}} \sigma_{\gamma\mathcal{U}} R_H .$$

M. H.P.M. van Putten, M. Aghaei arXiv:2203.16076,
D. Valcin, et. al.JCAP 2020 (12), 002.

Unparticles cross section: Relativistic case

$$k_B T \gg m_{\mathcal{U}} c^2 \quad \Rightarrow \quad n_{\mathcal{U}}^{eq} = \frac{\zeta(3)}{\pi^2} g_{\mathcal{U}} T^3$$

$$\frac{n_\gamma}{n_{\mathcal{U}}} = \frac{g_\gamma T_{CMB}^3}{g_{\mathcal{U}} T_c^3}$$

$$g_\gamma = 2$$

$$g_{\mathcal{U}} = 100$$

$$n_\gamma = 420\ cm^{-3}$$

$$n_{\mathcal{U}} \simeq 1.3 \times 10^{12}\ \mathrm{m}^{-3}$$

$$\sigma_{\gamma\mathcal{U}} \lesssim 10^{-40}\ \mathrm{m}^2 = 10^{-3}\ \mathrm{nb}$$

$$\sigma_{\gamma\gamma} \simeq 10^{-35}\ \mathrm{m}^2 = 100$$

$$\sigma_{\gamma\nu} \sim 10^{-43}\ \mathrm{m}^2 = 10^{-6}\ \mathrm{nb}$$

Unparticles cross section: Mildly non-Relativistic

$$k_B T \sim m_{\mathcal{U}} c^2 \quad \Rightarrow \quad n_{\mathcal{U}} = \frac{\rho_{\mathcal{U}}}{E_{\mathcal{U}}} \sim \frac{\rho_{\mathcal{U}}}{k_B T_c}$$

$$E_{\mathcal{U}} \sim k_B T_{\mathcal{U}}$$

$$n_{\mathcal{U}} = \frac{\rho_{\mathcal{U}}}{E_{\mathcal{U}}} \simeq 10^4 \, \frac{\rho_{CMB}}{k_B T_c} \simeq 2.5 \times 10^3 \; n_\gamma$$

$$\sigma_{\gamma \mathcal{U}} \lesssim 10^{-40} \; \mathrm{m}^2 = 10^{-3} \; \mathrm{nb}$$

Take Home messages

Combining $T_c \backsimeq 4T_{CMB}$ and $\Omega_U \backsimeq 10^4\Omega_{CMB}$, the model prediction is that the CMB is exposed to an enormous heat bath. This exposure is suppressed only by the small cross section of Unparticles, $\sigma_{U\gamma} \lesssim 10^{-3}nb$.

In conclusion, preserving weak interactions with SM particles, we find unparticles to be a potential candidate for warm Dark Matter and/or interacting Dark energy. Their minuscule cross section puts unparticle cosmology to the edge of the standard model interactions with the CMB photons.


Thank You