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LIMITING FLUX VERSUS REDSHIFT AS A FLAG OF NEW PHYSICS

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ABSTRACT

I show that General Relativity sets an absolute upper limit on the energy flux observed from a cosmological source as a function of its redshift. Detecting a brighter source in gravitational waves, neutrinos or light, would flag new physics. The derived flux limit can also be used to determine the maximum redshift possible for any source with an unknown origin.

According to General Relativity, the maximum possible luminosity of a source which is bound by its own gravity, equals to its total rest-mass energy, Mc^2, divided by the light crossing-time of its gravitational radius, GM/c^2. This limit applies to all possible carriers of energy, including gravitational waves, elementary particles such as neutrinos, or electromagnetic radiation. Packing the energy to a smaller scale would result in an implosion to a black hole according to the hoop conjecture (Peng 2021), and a shorter emission time would require faster than light travel (Schiller 2021; Jowsey & Visser 2021; Cardoso et al. 2018; Hogan 1999). These considerations are purely classical and do not involve quantum mechanics.

The ratio between the maximum emission energy and the minimum emission time is independent of mass M, implying that the maximum luminosity is a universal constant, combining the speed of light c and Newton's constant G,

$$L_{\max} = \frac{c^5}{G} = 3.64 \times 10^{59} \text{ erg s}^{-1}. \tag{1}$$

A similar argument can be applied to any self-gravitating system of size r, where the characteristic velocity v is dictated by the virial theorem, $v^2 \sim GM/r$, and the characteristic energy release time is limited by the crossing-time, $\sim r/v$, so that the limiting output power is $\sim v^5/G$, smaller by a factor of $\sim (v/c)^5$ than the universal limit in equation (1).

Given the luminosity distance as a function of redshift, $d_L(z)$, the above limit gives a maximum energy flux that can be observed from a cosmological source which emits isotropically any form of radiation or relativistic particles,

$$f_{\max}(z) = \frac{L_{\max}}{4\pi d_L^2(z)}. \tag{2}$$

To quantify this universal flux limit, we use an analytic approximation to $d_L(z)$ which is accurate to a sub-percent level (Adachi & Kasai 2012) for the standard flat cosmology with a matter density parameter $\Omega_m = 0.32$ and a Hubble constant of 70 km s^{-1} Mpc^{-1} (Planck Collaboration et al. 2020). This gives,

$$f_{\max}(z) = \frac{13.26 \text{ erg s}^{-1} \text{ cm}^{-2}}{(1+z)^2 \left\{\phi(2.13) - (1+z)^{-1/2}\phi[2.13(1+z)^{-3}]\right\}^2}, \tag{3}$$

where,

$$\phi(x) \equiv \frac{1 + 1.32x + 0.4415x^2 + 0.02656x^3}{1 + 1.392x + 0.5121x^2 + 0.03944x^3}, \tag{4}$$

and $\phi(2.13) = 0.91$.

In the high-redshift limit, $z \gg 1$, we get the simple result,

$$f_{\max}(z) = \frac{15.93 \text{ erg s}^{-1} \text{ cm}^{-2}}{(1+z)^2[1 - \sqrt{1.21/(1+z)}]^2}. \tag{5}$$

This flux limit can be used to set an upper limit on the redshift of a source with an unknown origin.

For comparison, a flux of ~ 15 erg s^{-1} cm^{-2} is generated by local blackbody radiation at a temperature of 23 K, about ten times hotter than the cosmic microwave background today.

The highest luminosities for astrophysical sources are expected to occur during the formation of compact objects, in the form of gravitational waves or a γ-ray burst for a black hole or neutrinos for a neutron star. A violation of the limit in equation(4) for an isotropic, self-gravitating source with a known redshift z, would flag new physics.

The redshift of a cosmological source can be inferred from the spectral lines of its host galaxy or the Lyα absorption imprinted by the intergalactic medium.

The limit in equation (4) should be multiplied by a correction factor, $f_\Omega = (4\pi/\Delta\Omega)$, for a source radiating its energy into a limited solid angle $\Delta\Omega$.

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