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HOW LIGHT IS DARK?

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It has been proposed that photomultipler tubes in the sea are a very sensitive way to search for the class of **dark matter** candidates in the mass range $10^{-10} < \mathcal{M} < 10$ g which have nuclear density and are no smaller than atoms.[1] Here some details are given on the light production mechanism and the luminous efficiency of seawater is calculated.

Following De Rujula and Glashow,[2] it is assumed that the particle emits a cylindrical shock wave as it travels through the water with a speed v. The rate of expansion of the shock is given by

$$\dot{R}(t) = (2nT/m)^{1/2} \tag{1}$$

where m is the molecular mass, n is the number of degreees of freedom (taken as 3), and the temperature T of the shock at the time t is given by

$$T(t) = T_o(t_o/t) \tag{2}$$

where $T_o = mv^2/n$ is the intitial temperature (natural units are used). The radius of the shock at a time t is then given by

$$R(t) = R_o(t/t_o)^{1/2} \tag{3}$$

where R_o is the radius of the particle and $t_o = R_o/\sqrt{8}v$ is an integration constant which specifies that time at which the shock starts.

Light is assumed to be emitted with the black-body spectrum,

$$\frac{dp}{d\omega\, da} = \frac{\omega^3}{(2\pi)^2} \frac{1}{e^{\omega/T} - 1} \tag{4}$$

and the optical energy emitted in the band $(\omega_{min}, \omega_{max})$ is

$$\frac{dE_\gamma}{dx} = \int_{\omega_{min}}^{\omega_{max}} d\omega \int_{t_o}^{\infty} dt\, 2\pi\, R(t) \frac{dp}{d\omega da} \tag{5}$$

In all the cases here, the radius R of the shock exceeds the mean free path of the particle in the water.

The luminous efficiency then is defined as

$$\eta = (dE_\gamma/dx)/(dE/dx) \tag{6}$$

where $dE/dx = \rho v^2 A$, $A = \pi R_o^2$.

De Rujula and Glashow assume that the medium is highly transparent and integrate (5) analytically, assuming also that $T >> \omega_{max}$. Since seawater is not transparent, and in fact has a sharp spectral acceptance, this may not be a good assumption for our purposes. Thus I have integrated (5) numerically. I find that η depends on both the assumed spectral band $(\lambda_{min}, \lambda_{max})$ and the dark particle mass $\mathcal{M}$, with a peak at $\mathcal{M} = 5 \times 10^{-11}$ g. The results are shown in Fig. 1. For the whole visible band (350,650) nm, I obtain $\eta = 2 \times 10^{-5}$ at the peak, in agreement with De Rujula and Glashow. To conservatively approximate the response of seawater I assume a smaller band, (400,500) nm, and this is also shown in Fig. 1.

Since the attenuation of light in water depends sharply on wavelength, a more precise calculation would compute a luminous efficiency as a function of ω and propagate each ω separately to the array. However, this should be an adequate approximation for most purposes..

REFERENCES

1. V.J. Stenger, HDC-3-87
2. A. De Rujula and S.L. Glashow, *Nature* **312**, 734 (1984).

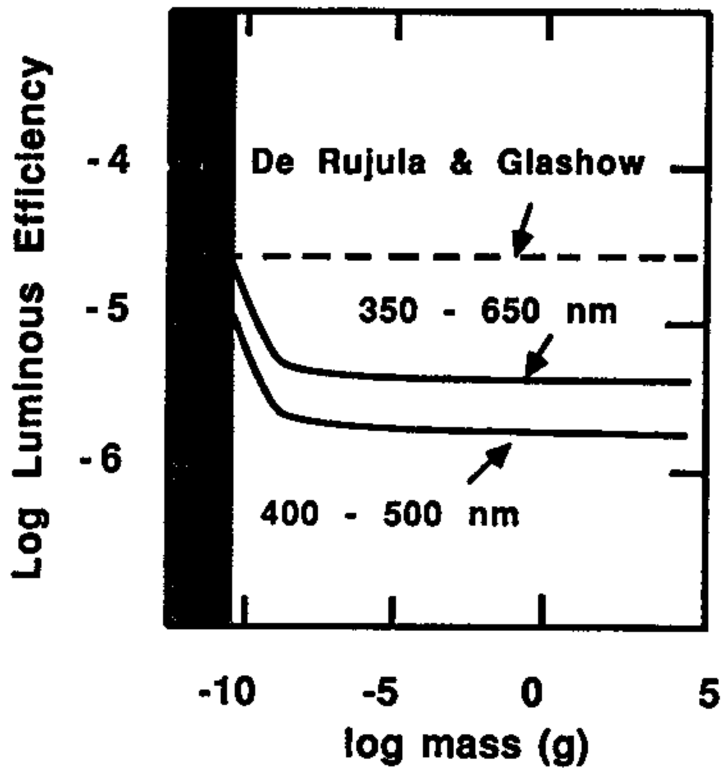

Fig. 1. The luminous efficiency as a function of dark particle mass, for two spectral bands. The 400 - 500 nm band was used in this report. The calculation of De Rujula and Glashow gives $2x10^{-5}$ independent of mass, for highly transparent water.