Limits on Dipole Scalar Radiation

1. Binaries

Yakov,

We can use the expression you derived for the dipole luminosity of a binary,

$$L_\psi = \frac{G^3}{8\pi c^3} A_\psi \frac{M^2\mu^2}{a^4}, \tag{1}$$

to find the coalescence time of the binary due to the emission scalar waves. Here I define, $A_\psi \equiv (l/L_P)^2(\delta\xi)^2$ for brevity. Since the binding energy of the binary is,

$$E = -\frac{1}{2}\frac{GM\mu}{a}, \tag{2}$$

we get,

$$\frac{1}{E}\frac{dE}{dt} = \frac{L_\psi}{E} = \frac{2G^2}{8\pi c^3} A_\psi \frac{M\mu}{a^3}. \tag{3}$$

The period derivative is then,

$$\frac{1}{P}\frac{dP}{dt} = -\left(\frac{3}{2}\right)\frac{1}{E}\frac{dE}{dt}, \tag{4}$$

where $P \propto a^{3/2}$. The coalescence time due to scalar waves is obtained by integrating the dP/dt equation down to $P \to 0$, yielding,

$$t_0 = \frac{4\pi c^3}{3G^2}\frac{a^3}{A_\psi M\mu}. \tag{5}$$

The effect of scalar waves relative to gravitational waves is maximized at the largest possible separation of binaries where the effect is still noticeable. It is therefore useful to find the largest semi-major axis $a_{\rm max}$ for which t_0 equals the age of the Universe, 13.7Gyr. I get,

$$\left(\frac{a_{\rm max}c^2}{GM}\right) = 1.73\times 10^5 \left[\left(\frac{A_\psi}{10^{-6}}\right)\left(\frac{4\mu}{M}\right)\right]^{1/3}\left(\frac{M}{1M_\odot}\right)^{-1/3}. \tag{6}$$

Unfortunately, even at this binary separation, the orbital decay due to gravitational waves dominates over scalar waves for $A_\psi < 10^{-3}$. This implies that in general it would be difficult to find binaries for which one can get an interesting constraint on l/L_P.

2. Free-free Emission of Scalar Waves

The Sun is transparent to scalar waves opaque to photons. It is therefore interesting to check whether cooling by scalar waves is of any significance for the Sun.

Scalar waves will be emitted when a free electron collides with a free proton in a plasma. The process is entirely analogous to the free-free emission of photons in the dipole approximation, albeit with a smaller coupling. To find the coupling conversion, I compare your expression for L_ψ to the electromagnetic luminosity one would get for a charged particle with the same orbit.

The electromagnetic power emitted by a particle of charge e and mass μ which is bound *gravitationally* on a circular orbit to a massive particle of mass M is given by,

$$L_\gamma = \left(\frac{e^2}{3c^3}\right)\left(\frac{GM}{a^2}\right)^2 . \tag{7}$$

Therefore,

$$\frac{L_\psi}{L_\gamma} \equiv \epsilon_\psi = \frac{3}{8\pi}\frac{G\mu^2 A_\psi}{e^2} = 2.6 \times 10^{-44} A_\psi \left(\frac{\mu}{m_e}\right)^2 , \tag{8}$$

where m_e is the electron mass.

We can now find the free-free emissivity in scalar waves by multiplying the standard expression for photons ($1.4 \times 10^{-27} n_e^2 T^{1/2}$ in c.g.s.) by ϵ_ψ. For the Sun this gives a net luminosity,

$$L_{\odot,\psi} \approx 10^{17} A_\psi \ \mathrm{erg\ s^{-1}}, \tag{9}$$

which is negligible compared to the solar luminosity, 4×10^{33} ergs $\mathrm{s^{-1}}$, even if we take the electron mass to be fully electromagnetic. I checked that cooling of white dwarfs and neutron stars by scalar waves is also unimportant.

3. Scalar Wave Background from Astrophysical Sources

Similarly to gravitational waves, scalar waves were probably produced during inflation. Their amplitude peaks on horizon scales because they redshift after entering the horizon. These waves should introduce both temporal and spatial variations of α within the observable Universe. Since the amplitude of inflationary metric perturbations is $\sim 10^{-5}$ on horizon scales and the scalar waves couple more weakly than gravitational waves, it would be very challenging to detect these scalar waves.

There is also a scalar wave background from all astrophysical binaries that spans a wide range of frequencies. In addition, there is a steady flux of scalar waves at high frequencies ($\sim 10^{17}$ Hz) from the Sun, as calculated above. The associated fluctuations in α could in principle affect quantum coherence experiments on Earth, but their amplitude is extremely small.