AN OSCILLATING UNIVERSE?

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ABSTRACT

The remarkable feature of the pencil-beam red shift survey recently reported by Broadhurst, Ellis, Koo and Szalay [1] (BEKS) is a periodicity in the galaxy distribution with period 128 h^{-1} Mpc. Might the apparent spatial periodicity really be an observational effect induced by spatially uniform but temporally oscillating physical "constants" of nature?

1. Oscillating Physics

A natural method of inducing oscillations of a fundamental physical "constant" is to suppose that it is really a function of a fundamental scalar field, ϕ. ϕ has an average value $\langle\phi\rangle$, fixed by the minimum of a potential, and oscillates about $\langle\phi\rangle$ [2]. To reproduce the BEKS data, ϕ must be a field with an ultra-low mass (a soft boson) coherently oscillating with a period $L = 128\ h^{-1}$ Mpc corresponding to a mass $m = \mathcal{O}(10^{-31}\ \text{eV})$, where the present Hubble parameter is $H_0 = 100\ h$ km sec^{-1} Mpc^{-1}. Recently, Morikawa [3] has proposed an explanation of the BEKS data wherein the dominant dark matter is an oscillating soft-boson field non-linearly coupled to gravity, which induces oscillations in the Hubble parameter. We [4] have given a more general analysis that considers four separate scenarios: (a) oscillating dark matter fields; (b) oscillating G; (c) oscillating atomic lines (i.e., Rydberg); and (d) oscillating galactic luminosity. We refer the reader to [4] for the references to the constraints described here.

The actual red shift measured by an observer today, z, is related to the red shift observed in the absence of oscillations, z_0, by:

$$\frac{dz}{dz_0} = 1 + \mathcal{A}\cos\left[\frac{2\pi}{L}(t - t_0) + \psi\right], \qquad (1)$$

where $t_0 = 2H_0^{-1}/3$ is the present time and ψ is a phase factor. The number of galaxies dN in a solid angle $d\Omega$ with red shift between z and $z + dz$ is modulated compared to the distribution in the absence of oscillations via

$$\frac{dN}{z^2 dz d\Omega} = \left(\frac{dN}{z_0^2 dz_0 d\Omega}\right)\frac{dz_0}{dz} \qquad (2)$$

where we have used the fact that $z^2 \approx z_0^2$ to lowest order. Owing to the modulation factor, dz/dz_0, even for a spatially uniform galaxy density, an observer would see an apparent variation in the density of galaxies which is isotropic and has peaks lying on concentric spherical shells at periodically spaced radii. An amplitude of at least 0.5 and $\psi \approx 0$ seems to be required to reproduce the BEKS results [4].

2. Oscillating Dark Matter Field

Suppose that the dominant component of dark matter is a massive scalar field, ϕ, which oscillates in a harmonic potential due to its mass, $m^2\phi^2$. This can drive oscillations in H and it is straightforward to show that [4]

$$\frac{dz}{dz_0} = 1 + \frac{3\bar{H}}{4m}\cos\left[2m(t - t_0)\right]; \qquad (3)$$

i.e., $\mathcal{A} = 3\bar{H}/4m$. The ratio $\bar{H}/m$ is fixed, however, by the observed period in the BEKS sample: $L = \pi/m = 128\ h^{-1}$ Mpc $\Rightarrow \mathcal{A} = 0.010$. Since this amplitude is small compared to the required value, $\mathcal{A} \gtrsim .5$, we conclude that it is probably insufficient to introduce a soft-boson field as the dominant source of dark matter to explain the BEKS data.

3. Oscillating Fundamental Constants

The simplest method for implementing oscillations in G is to introduce a scalar field, ϕ, with non-minimal coupling to the scalar curvature $\mathcal{R}$ of the form $[(16\pi G_0)^{-1} + \xi\phi^2]\mathcal{R}$ (see ref.[3, 4]).

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If $G = G_0 + G_1 \cos[2m(t-t_0)+\psi]$, the leading correction to the Hubble parameter is $H \approx \bar{H}[1 - \frac{1}{2}(\dot{G}/G\bar{H})]$ and

$$\frac{dz}{dz_0} = 1 - \frac{\dot{G}}{2G\bar{H}} = 1 - \frac{mG_1}{\bar{H}G_0}\cos[2m(t-t_0)+\psi]. \tag{4}$$

and thus $\mathcal{A} = -\frac{mG_1}{\bar{H}G_0}$. The chief constraint comes from limits on $\dot{G}/G$ based upon the Viking radar-echo experiments: $\dot{G}/GH_0 \leq .3h^{-1}$, which implies $\mathcal{A} \lesssim .15h^{-1}$. We have included only the lowest order (i.e., linear) effects of $\dot{G}/G$ on H and we have not allowed for possible time-variation of the amplitude $\mathcal{A}$. Also, the systematic errors in the Viking experiment and/or more accurate experiments merit renewed consideration.

An oscillation in the Rydberg constant, $Ry = \alpha^2 m_e c/2h$, produces a periodic variation in the wavelength of the radiation emitted by galaxies (and all systems). Such an effect could arise from oscillations in α or m_e induced by coupling a soft-boson field to $F_{\mu\nu}F^{\mu\nu}$ or $\bar{\psi}_e\psi_e$ [2]. The frequency of emitted radiation varies as $\nu_E = \nu_*[1+\varepsilon\sin(m(t-t_0)+\psi)]$, where ε is the amplitude of the oscillation in Ry and m is the mass of the soft-boson. The measured red shift (z) is related to the real Hubble contribution (z_0) by:

$$\frac{dz}{dz_0} = 1 - \frac{m\varepsilon}{H_0}\cos[m(t-t_0)+\psi]. \tag{5}$$

To obtain an amplitude $\mathcal{A} = m\varepsilon/H_0 \gtrsim 0.5$, we require only

$$\varepsilon \equiv \frac{\delta Ry}{Ry} = \frac{\delta m_e}{m_e} + 2\frac{\delta\alpha}{\alpha} \gtrsim 3\times 10^{-3}. \tag{6}$$

The restrictions are severe [4]. The Oklo natural reactor gives $\delta\alpha/\alpha < 10^{-8}$. Comparison of the lifetime of the rhenium isotope, Re^{187} in the laboratory, and geologic and meteoritic samples, gives $\delta\alpha/\alpha < 2\times 10^{-5}$. Moreover, since m_e enters the decay energy of rhenium directly, $\delta m_e/m_e \lesssim 6\times 10^{-4}$. An astronomical limit arises from the coincidence of red shifts deduced from 21 cm (hyperfine, $\sim \alpha^4 m_e^2/m_N$) and ordinary ($\sim Ry$) transitions in aborbing gas clouds in front of seven quasi-stellar objects ($.4 < z < 2.1$): $2\delta\alpha/\alpha \sim \delta m_e/m_e < 3\times 10^{-4}$. The oscillating Rydberg scenario is ruled out.

4. Oscillating Luminosity

An apparent periodicity could be induced by variations in galactic luminosity (with no alteration in redshift) in a survey of the BEKS type. A periodic variation in brightness by a factor of two or so could produce the observed periodic variation in galaxy count.

One approach for varying luminosity is to increase the stellar luminosities of the brightest galaxies through small oscillations in fundamental constants or, for example, weakly interacting particles (e.g., axion) whose masses and/or couplings oscillate coherently with time. An alternative, intriguing approach is to consider variations in couplings that might periodically cause the matter in the dark halos (or centers) of galaxies to "glow" so that their total luminosity increases. For example, a neutrino halo might glow if optical photons are produced in a reaction $\nu' \to \gamma + \nu' + X$ which turns on due to mass oscillations in ν or ν' (or X). The glowing of dark matter would have dramatic cosmological implications without affecting our present understanding of stellar evolution.

References

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