ASTROPHYSICAL CONSTRAINTS ON THE GRAVITATIONAL CONSTANT

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Abstract. We study the astrophysical bounds on the change of the gravitational constant with time. We found that $|\dot{G}/G| < 10^{-12} \text{ yr}^{-1}$ is the condition that has to be satisfied in order not to cause a conflict with the observations. We find the condition to be in accord with the lower limits, the superstring theory predicts.

The variation of the gravitational (fundamental coupling) constant with time may give a good understanding of cosmology and particle physics (Salam and Wigner, 1972). Dirac (1937) first proposed this idea, but it seems not to be supported by the observations. Lately, superstring theories (Green et al., 1987) have appeared as likely correct unification theories, because they provide a consistent theory of quantum gravity. The consistency of the superstring theory fixes the space-time dimensions to be 10, 6 of which are the small compact manifold $K (10^{-32} \text{ cm})$ (Candelas et al., 1985). The coupling constants are related to those in 10 dimensions by a factor of the inverse volume of $K$.

The Einstein equations determine not only the evolution of the usual 3-dimensional space but also that of $K$ and, therefore, determine dynamically the time variation of the fundamental coupling constants in four dimensions. In the multidimension point field theory (Chodos and Detweiler, 1982), quantum effects in $K$ (Appeliquist and Chodos, 1983) may give rise to an effective potential which may determine the size of internal space in vacuum and influence its cosmological evolution. The non-perturbative supersymmetric breaking effects (Rohm, 1984) including worldsheet instantons have not produced a potential with a minimum at the finite size of the internal space.

It was calculated by Wu and Wang (1986) that the time variation of the coupling constants critically depends on the shape of this potential, in the case that potential is flat: i.e.,

$$\dot{G}/G \sim -1 \times 10^{-11} \pm 1 \text{ yr}^{-1}$$

which overlaps the present observational bound $|\dot{G}/G| \leq 1 \times 10^{-11} \text{ yr}^{-1}$ (Salam and Wigner, 1972). However, if the potential has actually a minimum at a finite size of the internal space, then $|\dot{G}/G|$ will be suppressed and become unobservably small.

In this paper we will show that the astrophysical bounds derived from stellar evolution models seem to prefer a potential model with a minimum at a finite size of the internal space.

We start with a standard stellar evolution code developed by Iben (1963) with updated reaction rates, equation of states and analytic fits for the opacities. We start with a one solar mass initial model with uniformly distributed chemical elements $\text{H}^1$, $\text{He}^4$, $\text{He}^3$, $\text{C}^{12}$.
Fig. 1a. Standard model of time evolution of luminosity and radius of the Sun. A represents luminosity in units of solar luminosity. C represents radius in unit of solar radius. Time is in terms of seconds.

Fig. 1b. Standard model of structure variables as function of mass of the Sun at solar age. A represents pressure in units of $10^{17}$ dyns. B represents temperature in units of $10^6$ K. C represents luminosity in units of solar luminosity. D represents radius in units of solar radius. E represents density in units of g cc$^{-1}$. $M$ is the mass in terms of solar mass.