Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310009415

Thermodynamics in Variable Speed of Light Theories

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Variable speed of light theories (VSL) are interesting because they could solve several cosmological puzzles. In this work we study the thermodynamics and Newtonian limit of the varying speed of light theory developed by J. Magueijo (Magueijo 2000). In the covariant and locally Lorentz invariant VSL proposed by Magueijo c is a dimensionless dynamical scalar field $c = c_0 e^{\psi}$, where c_0 is a constant. The matter and gravitational lagrangians are multiplied by the factors $e^{b\psi}$ and $e^{a\psi}$ respectively.

Among other phenomena the energy density and the total energy of a body in hydrostatic equilibrium may vary if c is not constant. We obtain a lagrangian for the perfect fluid following Schutz 1970. After obtaining a modified first law of thermodynamics we derive a general prescription on how to modify any equation of state up to first order in ψ.

In the Newtonian limit of this VSL theory, we show that the hydrostatic equilibrium equation is equivalent to a Newton's constant G varying equation. This equation plus an equation of state and boundary conditions determine the radius of a planet. The presence of ψ in these equations causes time variations of planetary radii. For Mercury its radius R hasn't changed more than 1 kilometer in the last 3.9×10^9 years. We find that $\left(\frac{11}{3}q - b - \frac{10}{3}\right)\dot{\psi}(t) = -\frac{1}{\delta}\frac{\dot{R}}{R} \simeq 0 \pm 5 \times 10^{-12}\mathrm{y}^{-1}$ for $\frac{\Delta R}{R} = 0 \pm 0.0004$, where ΔR corresponds to a time interval approximately equal to 3.5×10^9 years. This result can be combined with bounds for $\dot{\alpha}/\alpha$ that have been obtained using atomic clocks $\frac{\dot{\alpha}}{\alpha} = (4.2 \pm 6.9) \times 10^{-15}\mathrm{y}^{-1}$. Assuming $b = 0$ we obtain $\frac{\dot{c}}{c} = \dot{\psi} = 0 \pm 2 \times 10^{-12}\mathrm{y}^{-1}$.

White dwarfs are excellent objects to test any energy injection from a scalar field given their low luminosity and their extremely high heat conductivity. Most of them are adequately described by Newtonian physics and a polytrope type equation of state (EOS). We obtain for the dependence of the stellar internal energy $E \propto \exp\psi f(q, b, \gamma)$ where $f(q, b, \gamma) = \frac{13}{3}q - \frac{13}{3}b - \frac{14}{3}$ for white dwarfs with $\gamma = 5/3$. We assume that all the energy injected by the field ψ is radiated away, so the luminosity induced by the ψ field is $L_{\psi} = -\dot{E} = -f(\gamma, q, b)E\dot{\psi}$.

Using again the upper bound for the present time variation of α, bounding L_{ψ} by the observed luminosity of the white dwarf and assuming $b = 0$, Stein 2015B provides the strongest bound. We obtain $\frac{\dot{c}}{c} = \dot{\psi} = 0 \pm 1.4 \times 10^{-13}$. Comparing our results we see that white dwarf physics provides the strongest constraints on the VSL theory near the present epoch. Combining both bounds we obtain the b independent bound $\dot{\psi} = 0 \pm 2.2 \times 10^{-12} y^{-1}$.

References

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