Regularizing cosmological singularities by varying physical constants.

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Type of singularities in Friedmann Cosmology

Type 0 – Big-Bang (BB): $a \to 0, \varrho \to \infty, p \to \infty$ at $t \to 0$.

Type I - Big-Rip (BR): $a \to \infty, \varrho \to \infty, \ p \to \infty$ at $t \to t_s$.

Type II - Sudden Future Singularity (SFS): $a \to const., \varrho \to const.$

$p \to \infty$ at $t \to t_s$.

Type III - Finite Scalar Factor (FSF): $a = a_s = const. \ \varrho \to \infty, p \to \infty$

at $t \to t_s$.

Type IV - Big-Separation (BS): $a = a_s = const., \varrho \to 0, \ p \to 0, \ \dot{p} \to \infty$

$w \to \infty$ at $t \to t_s$.

Type V – w-singularity (w): $\varrho \to 0, p \to 0, \ \dot{p} \to 0, \ w \to \infty,$

at $t \to t_s$.

TYPE II AND III WERE TESTED BY ODSERVATIONS - GOOD FIT

T. Denkiewicz, M. P. Dabrowski, H. Ghodsi, M.A. Hendry, Cosmological tests of sudden future singularities, Physical Review D85 (2012), 083527.

M.P. Dabrowski, K. Marosek, A. Balcerzak, Standard and exotic singularities regularized by varying constants, 1308.5462.

T. Denkiewicz, M.P. Dabrowski, C.J.A.P. Martins, P. Vielzeuf, Redshift drift test of exotic singularity universes, 1402.0520.

Varying Constants Theories

Friedman equation with varying fundamentals constans:

$$\rho(t) = \frac{3}{8\pi G(t)}\left(\frac{\dot{a}^2}{a^2} + \frac{Kc^2(t)}{a^2}\right)$$
$$p(t) = -\frac{c(t)}{8\pi G(t)}\left(2\frac{\dot{a}}{a} + \frac{\dot{a}^2}{a^2} + \frac{Kc^2(t)}{a^2}\right)$$

and the energy-momentum conservation law:

$$\dot{\rho} + 3\frac{\dot{a}}{a}\left(\rho(t) + 3\frac{p(t)}{c^2(t)}\right) = -\rho(t)\frac{\dot{G}(t)}{G(t)} + \frac{3Kc(t)\dot{c}(t)}{4\pi G a^2}$$

Varying G (Brans-Dicke):

$$S = \int d^4x\sqrt{-g}\left[\phi R - \frac{\omega}{\phi}\partial_\mu\phi\partial^\mu\phi + \Lambda + \mathcal{L}_m\right]$$

Where: $\phi \sim \frac{1}{G}$

Varying c (VSL):

$$S = \int \mathrm{d}^4 x\left(\sqrt{-g}\left(\frac{\psi(R+2\Lambda)}{16\pi G} + L_M\right) + L_\psi\right)$$

Where: $\psi \sim c^4$

Andreas Albrecht, Joao Magueijo, A time varying speed of light as a solution to cosmological puzzles, PhysRevD.59.043516

VARYING CONSTANTS MODELS

Our proposal of the scale factor which allows types I-V is:

$$a(t) = a_s \left(\frac{t}{t_s}\right)^m exp\left(1 - \frac{t}{t_s}\right)^n$$

Where a_s, t_s, m, n are constants.

Friedmann equations with zero curvature (for k=0) now is expressed by:

$$\varrho(t) = \frac{3}{8\pi G(t)}\left[\frac{m}{t} - \frac{n}{t_s}\left(1 - \frac{t}{t_s}\right)^{n-1}\right]^2$$

$$p(t) = -\frac{c^2(t)}{8\pi G(t)}\left[\frac{m(3m-2)}{t^2} - 6\frac{mn}{t\,t_s}\left(1 - \frac{t}{t_s}\right)^{n-1} + 3\frac{n^2}{t_s^2}\left(1 - \frac{t}{t_s}\right)^{2(n-1)} + 2\frac{n(n-1)}{t_s^2}\left(1 - \frac{t}{t_s}\right)^{n-2}\right]$$

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REGULARIZING SINGULARITIES

Big-Bang singularity:

To avoid the Big-Bang singularities a gravitational constant could be in this form:

$$G \propto 1/t^2$$

To avoid a future singularities we should assume that gravitational constant change in time in following form:

$$G(t) = G_0 \left(1 - \frac{t}{t_s}\right)^{-r}$$

At the expanse of having $G(t_s) \to 0$ at singularity.

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REGULARIZING SINGULARITIES

Exotic singularities

In order to regularize an SFS singularity by varying speed of light we suggest that the time-dependence of the speed of light is given by:

$$c(t) = c_0 \left(1 - \frac{t}{t_s}\right)^{\frac{p}{2}}$$

which after substituting into pressure equation gives:

$$p(t) = -\frac{c^2(t)}{8\pi G(t)}\left[\frac{m(3m-2)}{t^2}\left(1-\frac{t}{t_s}\right)^p - 6\frac{mn}{t\,t_s}\left(1-\frac{t}{t_s}\right)^{p+n-1} + 3\frac{n^2}{t_s^2}\left(1-\frac{t}{t_s}\right)^{p+2n-2} + 2\frac{n(n-1)}{t_s^2}\left(1-\frac{t}{t_s}\right)^{p+n-2}\right]$$

SFS singularity is regularized by varying speed of light provided that

$$p > n - 2$$

And $c(t_s) \to 0$ at the singularity.

MM. P. Dabrowski, K. Marosek, Regularizing cosmological singularities by varying physical constantsn1207.4038.