Minimal Dilatonic Gravity from cosmology to compact massive objects

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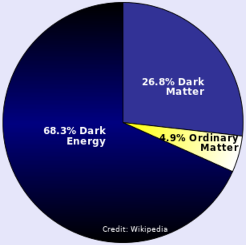
Why MDG?

General relativity – extremely well-tested theory, but only in weak to moderate-field regime ($v/c << 1$ or $GM/c^2R << 1$)

Known *observational* deviations:

- Rotational curves of galaxies and galactic clusters, weak lensing (Dark Matter)
- Cosmology – early inflation and current accelerated expansion of the universe (Dark Energy)
- Over all $\sim$ 95% "Dark", i.e. Uknown Universe

  $\rightarrow$ **there is plenty of space for alternative theories**



Why Minimal Dilatonic Gravity?

1. The inflation and the graceful exit to the present day accelerating de Sitter expansion of the Universe ($U(\Phi)$ can be reconstructed from $a(t)$).
2. Avoids any conflicts with the existing solar system and laboratory gravitational experiments when $m_\Phi \sim 10^{-3} eV/c^2$.
3. The time of inflation as a reciprocal quantity to the mass of dilaton m_Φ.

Minimal Dilatonic Gravity (MDG)

We change the Einstein-Hilbert Action: $A_E = \int \frac{1}{2\kappa}(R - 2\Lambda)\sqrt{-g}\,\mathrm{d}^4x$ to

/ Fiziev, Mod. Phys. Lett. A, 15 1077 (2000) and Fiziev, PRD **87**, 044053 (2013)/

$$A_{g,\phi} = \frac{c}{2\kappa}\int d^4x\sqrt{|g|}(\Phi R - 2\Lambda U(\Phi))$$

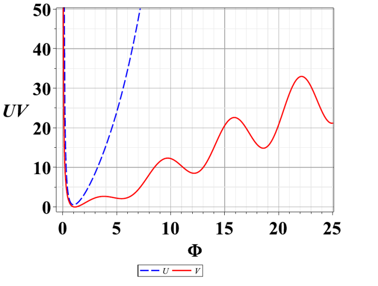
Here $\Phi \in (0, \infty)$, $\Lambda > 0$ is the cosmological constant and $\kappa = 8\pi G_N/c^2$.

The scalar **dilaton** Φ leads to variable gravitational constant $G^{eff}(\Phi) = G_N/\Phi$, while the scalar potential $U(\Phi)$ leads to a variable cosmological factor $\Lambda^{eff}(\Phi) = \Lambda U(\Phi)$.

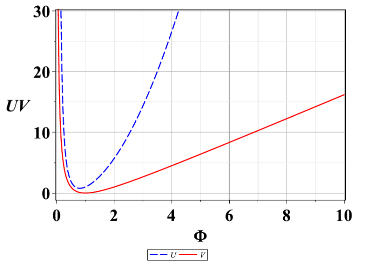
The field equations are:/ $\kappa = c = 1, R = 2\Lambda U_{,\Phi}(\Phi)$, $p = \sqrt{\Lambda}\hbar/cm_\Phi$/:

$$\begin{aligned} &U(\Phi) = \Phi^2 + \frac{3}{16}p^{-2}(\Phi - 1/\Phi)^2 \\ &\Box\Phi + 2/3(\Phi U_{,\Phi}(\Phi) - 2U(\Phi)) = 1/3T \\ &\Phi \hat{R_\alpha^\beta} = -\widehat{\nabla_\alpha\nabla^\beta}\Phi - \hat{T_\alpha^\beta} \end{aligned} \quad (1)$$

Credit: Fiziev, Physical Review D 87, 044053 (2013)



(e) Unique Einstein Vacuum and many deSitter vacuums: $U_{,\Phi\Phi} > 0$



(f) Unique Einstein Vacuum and unique deSitter vacuums: $U_{,\Phi\Phi} > 0$, $V_{,\Phi\Phi} > 0$

$$V(\Phi) = \frac{2}{3}\int_1^{\Phi}(\Phi U_{,\Phi}(\Phi) - 2U)d\Phi$$
$$V_{,\Phi}(\Phi) = 2/3(\Phi U_{,\Phi}(\Phi)$$

We apply the field equations on a static, spherically symmetric metric: $ds^2 = e^{\nu(r)}dt^2 - e^{\lambda(r)}dr^2 - r^2 d\Omega^2$ for $T^{\mu\nu} = diag(\epsilon, p, p, p)$, (perfect-fluid)

$\rightarrow$ a system of 4 coupled 1st order ODEs + EOS

White Dwarfs and Neutron Stars

In the case of GR, the white dwarfs are described well even in the polytropic approximation

$p_{nonrel} = K_{nonrel}\epsilon^{\frac{5}{3}}, p_{rel} = K_{rel}\epsilon^{\frac{4}{3}}$,

1. We use it to test the limit $\Phi = 1, U(\Phi) = 1$ in which MDG $\rightarrow$ GR:

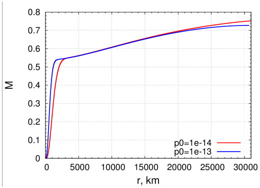
$M_{WD} = 0.17 - 1.3 M_\odot$
$R_{WD} = 0.008 - 0.02 R_\odot$
$\rho_{WD} = 10^5 - 10^9 gr/cm^3$

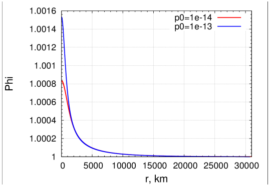
$M_{NS} = 1.4 - 2 M_\odot$
$R_{NS} = 12 - 13 km$
$\rho_{NS} = 10^9 - 10^{17} kg/m^3$

Model	r_{MDG}	r_{GR}	Δr	m_{MDG}	m_{GR}	Δm
Relativistic WD ($p0 = 10^{-14}$)	4 947	4840	1.07%	1.2406	1.2431	0.2%
Relativistic WD ($p0 = 10^{-15}$)	8 799	8600	1.99%	1.2419	1.2432	0.1%
Relativistic WD ($p0 = 10^{-16}$)	15 648	15 080	5.6%	1.2427	1.2430	0.02%
Non-Relativistic ($p0 = 10^{-15}$)	10 603	10 620	0.17%	0.3929	0.3941	0.3%
Non-Relativistic ($p0 = 10^{-16}$)	13 349	13 360	0.11%	0.1969	0.1974	0.25%

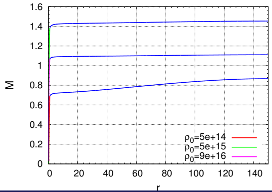
Some plots: WD with Maple and NS with COCAL /Compact Object CALculator (Tsokaros et al. (2014))

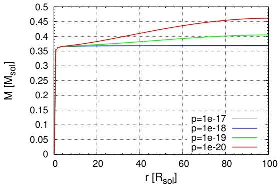
White Dwarfs /p=1e-19, $\rho 0 = 10^7 - 10^8$ CGS/:

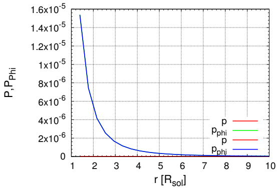




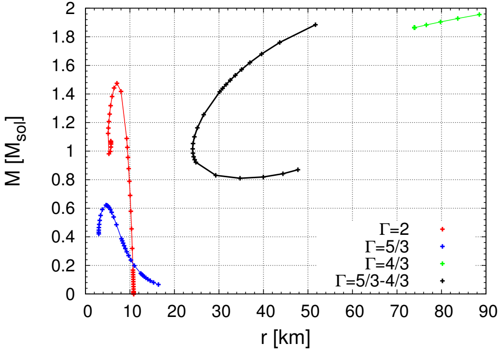
Neutron stars $/\gamma = 4/3$, p0=1e+15 /:

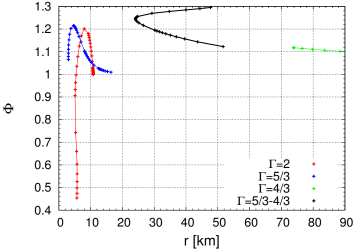






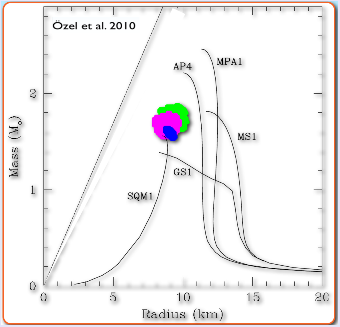
The complete picture for NS for different EOS





The connection with cosmology

1. We get get masses/radii in the expected ranges and reproduce GR in the limit
2. In both cases, the total mass is $\sim 30\%$ the mass of the compact star
3. The less massive the dilaton, the higher the total mass (for the moment, we are at ($d \sim 10^{-20}$), the goal is $\sim 10^{-30}$.
4. The total mass of WD is critical to their consideration as standard candles – essential to cosmology
5. The maximal neutron star mass is important for both particle physics, astrophysics and cosmology (GRBs as standard candles)



Good perspectives in front of MDG in both stellar physics and cosmology!

That's it!

Thank you for the attention!

Earlier works on MDG

Some of the works where details on the MDG model have been worked out.

A theory in development

Fiziev, arXiv:1402.2813 [gr-qc], "Frontiers of Fundamental Physics 14", Marseille, France, July, 15-18, 2014, PoS(FFP14)080
P.P. Fiziev, Physical Review D 87, 044053 (2013)
P. Fiziev, Georgieva D., Phys. Rev. D 67 064016 (2003).
Plamen P. Fiziev, arXiv:gr-qc/0202074
Fiziev P. P., Yazadjiev S., Boyadjiev T., Todorov M., Phys. Rev. D 61 124018 (2000).
P. P. Fiziev, Mod. Phys. Lett. A, 15 1077 (2000)

The pioneering work on the MDG model is by O'Hanlon, Phys. Rev. Lett. 29 137 (1972).

The equations

1. For the inner domain $r \in [0, r_*]$:

$$\frac{dm}{dr} = 4\pi r^2 \epsilon_{eff}/\Phi \quad (2)$$

$$\frac{dp}{dr} = -\frac{p+\epsilon}{r}\frac{m + 4\pi r^3 p_{eff}/\Phi}{\Delta - 2\pi r^3 p_\Phi/\Phi} \quad (3)$$

$$\frac{d\Phi}{dr} = -4\pi r^2 p_{eff}/\Delta \quad (4)$$

$$\frac{dp_\Phi}{dr} = -\frac{p_\Phi}{r\Delta}\left(3r - 7m - \frac{2}{3}\Lambda r^3 + 4\pi r^3 \epsilon_{eff}/\Phi\right) - \frac{2}{r}\epsilon_\Phi \quad (5)$$

Additionally, we have:

$$\epsilon_\Lambda = -p_\Lambda - \frac{\Lambda}{12\pi}\Phi,$$

$$\epsilon_\Phi = p - \frac{1}{3}\epsilon + \frac{\Lambda}{8\pi}V'(\Phi) + \frac{p_\Phi}{2}\Pi$$

$$\epsilon = \epsilon(p)$$

where

$\Delta = r - 2m - \frac{1}{3}\Lambda r^3, \epsilon_{eff} = \epsilon + \epsilon_\Phi + \epsilon_\Lambda, p_{eff} = p + p_\Phi + p_\Lambda, \Pi = \frac{m + 4\pi r^3 p_{eff}/\Phi}{\Delta - 2\pi r^3 p_\Phi/\Phi}$

and

$\epsilon_\Lambda = \frac{\Lambda}{8\pi}(U(\Phi) - \Phi), p_\Lambda = \frac{\Lambda}{8\pi}(U(\Phi) - \frac{1}{3}\Phi)$

...

The 4 unknown functions are $m(r), p(r), \Phi(r), p_\Phi(r)$.

Initial and boundary conditions:

$$m(0) = m_c = 0, \Phi(0) = \Phi_c, p(0) = p_c$$

$$p_\Phi(0) = p_{\Phi c} = \frac{2}{3}\left(\frac{\epsilon(p)}{3} - p_c\right) - \frac{\Lambda}{12\pi} V'(\Phi_c)$$

On the star's edge ($p(r^*) = 0$) we have

$$m^* = m(r^*; p_c, \Phi_c), \Phi^* = \Phi(r^*, p_c, \Phi_c), p_\Phi^* = p_{\Phi c}(r^*, p_c, \Phi_c)$$

2. For the outer domain: a boundary value problem for Φ:

$$p = 0, \epsilon = 0, \Phi_\Delta = 1$$

After introducing the EOS, we solve the ODE system + the initial and boundary conditions for the unknown functions $m(r), p(r), \Phi(r), p_\Phi(r)$.