# *Anisotropic Spherically Symmetric Collapsing Star From Higher Order Derivative Gravity Theory*

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## *ABSTRACT:*

**We add linear combinations $R^2, R^{\mu\alpha}R_{\mu\alpha}$ and $R^{\alpha\mu\beta\sigma}R_{\alpha\mu\beta\sigma}$ with Einstein-Hilbert action and obtain interior metric of an anisotropic spherically symmetric collapsing stellar cloud. We solved linearized metric equation via perturbation method and obtained 12 different kinds of metric solutions called as $P_1, P_2, \ldots\ldots P_{12}$. Calculated Ricci and Kretschmann scalars of our metric solutions are non-singular at beginning of the collapse for 2 kinds of them only. Event and apparent horizons are formed at finite times for two kinds of singular metric solutions while 3 metric solutions exhibit with event horizon only with no formed apparent horizon. There are obtained 3 other kinds of the metric solutions which exhibit with apparent horizon with no formed event horizon. Furthermore 3 kinds of our metric solutions do not exhibit with horizons. Our solutions satisfy different regimes such as domain walls (6 kinds), cosmic string (2 kinds), dark matter (2 kinds), anti-matter (namely negative energy density) (1 kind) and stiff matter (1 kind). Calculated time dependent radial null geodesics expansion parameter $\Theta_i^*(T)$; i=1,2,3…12 takes positive, (negative) values for 4 (8) kinds of our solutions which means the collapse ended to a naked (covered) singularity at end of the collapse.**

## *Effective gravity and spherically symmetric anisotropic collapsing cloud*

$$G_{\mu\nu} = 8\pi T_{\mu\nu} = -\left(\alpha H^1_{\mu\nu} + \beta H^2_{\mu\nu}\right)$$

$$H^1_{\mu\nu} = 2\nabla_\mu\nabla_\mu R + RR_{\mu\nu} - g_{\mu\nu}(2\nabla^\mu\nabla_\mu R + R^2/2)$$

$$H^2_{\mu\nu} = \nabla_\mu\nabla_\nu R - \nabla^\gamma\nabla_\gamma R_{\mu\nu} + 2R^{\alpha\beta}R_{\alpha\beta\mu\nu} - g_{\mu\nu}[\nabla^\gamma\nabla_\gamma R + R^{\alpha\beta}R_{\alpha\beta}]/2$$

$$ds^2 \approx \left[1 + AT^{\mu(\omega)}/B\right]dt^2 + \left[1 + T^{\mu(\omega)}\right]dr^2 + t^2[1 + ET^{\mu(\omega)}/B](d\theta^2 + \sin^2\theta d\varphi^2) \qquad T = \frac{t}{\sqrt{\alpha}}$$

$$\frac{\rho(T)}{\rho(\sqrt{\alpha})} = T^{\mu-2} = \frac{p_t(T)}{p_t(\sqrt{\alpha})} = \frac{p_r(T)}{p_r(\sqrt{\alpha})} = \frac{p(T)}{p(\sqrt{\alpha})} = \frac{R^\lambda_\lambda(T)}{R^\lambda_\lambda(\sqrt{\alpha})} = \sqrt{\frac{K(T)}{K(\sqrt{\alpha})}}$$

Table 1. Characteristics of metric parameters for 12 kinds of solutions

| $P_i$ | $\mu_i$ | $\omega_i$ | $(A/B)_i$ | $(E/B)_i$ | $R_i^*$ | $K_i^*$ |
|---|---|---|---|---|---|---|
| $P_1$ | +2.433 | +2.433 | +2.433 | +2.433 | +2.433 | +2.433 |
| $P_2$ | +2.057 | +0.968 | +0.029 | -0.015 | +6.392 | +13.345 |
| $P_3$ | +1.888 | -0.607 | -0.174 | -0.188 | +9.583 | +14.424 |
| $P_4$ | +1.616 | -1.648 | +1.633 | +1.568 | -25.774 | +199.272 |
| $P_5$ | +0.644 | -0.086 | -0.001 | +0.295 | 0.531 | +6.690 |
| $P_6$ | +0.521 | +1.883 | +1.478 | -4.782 | +18.432 | +1875.170 |
| $P_7$ | +0.508 | -1.713 | -0.304 | +1.086 | -3.257 | +92.697 |
| $P_8$ | -0.041 | +3.285 | -0.028 | -0.009 | -0.002 | +0.039 |
| $P_9$ | -0.201 | +0.850 | +0.389 | -0.672 | +0.076 | +20.787 |
| $P_{10}$ | -0.270 | -1.986 | -0.044 | -0.047 | -0.083 | +0.269 |
| $P_{11}$ | -3.284 | -2.013 | +3.467 | -1.339 | +37.305 | +456.394 |
| $P_{12}$ | -6.206 | +0.645 | -9.146 | -2.433 | +68.973 | +21412.731 |

Table 2. Fluid characteristics of stellar cloud

| $P_i$ | $\rho_i$ | $(p^*_r)_i$ | $(p^*_t)_i$ | $p_i^*$ | $\Delta_i^*$ |
|---|---|---|---|---|---|
| $P_1$ | +3.049 | -7.033 | -5.452 | -7.298 | +1.069 |
| $P_2$ | +0.925 | +0.230 | -2.038 | -1.317 | -0.616 |
| $P_3$ | +0.633 | +1.061 | -1.435 | -0.498 | -1.198 |
| $P_4$ | +3.468 | -6.456 | -3.300 | -5.253 | +1.081 |
| $P_5$ | +1.486& | -0.799 | -0.364 | -0.410 | +0.207 |
| $P_6$ | -7.755 | +13.316 | +2.145 | +3.525 | +1.117 |
| $P_7$ | +2.942 | -2.928 | -0.622 | -0.876 | +0.695 |
| $P_8$ | +1.037 | -0.036 | -0.0001 | +0.0002 | -8.917 |
| $P_9$ | +0.074 | +0.740 | -0.113 | -0.157 | +0.157 |
| $P_{10}$ | +1.010 | -0.007 | -0.035 | -0.031 | -0.527 |
| $P_{11}$ | +0.590 | -0.936 | -6.065 | -2.162 | -0.753 |
| $P_{12}$ | +22.814 | +113.561 | +48.430 | +53.458 | -7.776 |

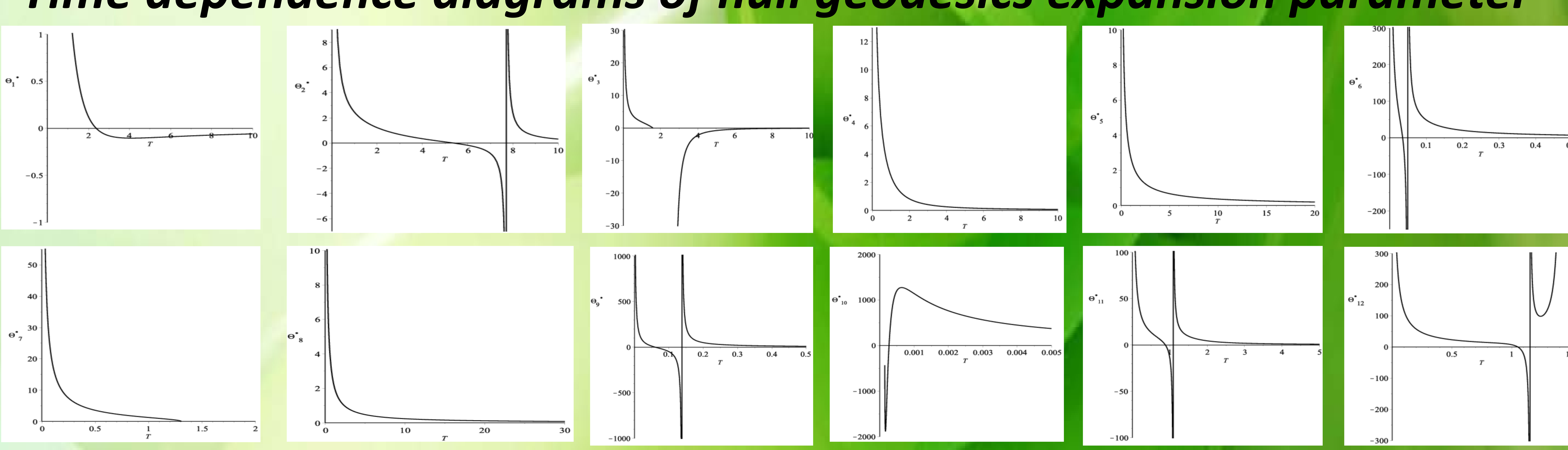
Table 3. Formation Times and radiuses for event and apparent horizons

| $P_i$ | $T_{EH}/\sqrt{\alpha}$ | $T_{AH}/\sqrt{\alpha}$ | $R_{EH}/\sqrt{\alpha}$ | $R_{AH}/\sqrt{\alpha}$ |
|---|---|---|---|---|
| $P_1$ | - | - | - | - |
| $P_2$ | - | +5.453 | - | +3.889 |
| $P_3$ | +2.526 | +1.707 | +2.752 | +1.188 |
| $P_4$ | - | - | - | - |
| $P_5$ | 36692.907 | - | +38236.634 | - |
| $P_6$ | - | +0.032 | - | +0.015 |
| $P_7$ | +10.427 | - | +3.054 | - |
| $P_8$ | $1.372 \times 10^{-38}$ | - | $1.342 \times 10^{-38}$ | - |
| $P_9$ | - | 0.082 | - | - |
| $P_{10}$ | $9.473 \times 10^{-6}$ | $7.099 \times 10^{-6}$ | $9.677 \times 10^{-6}$ | - |
| $P_{11}$ | - | - | - | - |
| $P_{12}$ | +1.429 | - | +2.647 | - |

Table 4. Trapped surfaces, Phase of fluid and Nakedness

| $P_i$ | $\gamma_i$ | Trapped surfaces | Phase of fluid | Nakedness |
|---|---|---|---|---|
| $P_1$ | -0.669 | Full | Domain walls | Covered |
| $P_2$ | -0.323 | Quasi | Cosmic sting | Naked |
| $P_3$ | -0.174 | Full | Dark matter | Covered |
| $P_4$ | -0.796 | No | Domain walls | Naked |
| $P_5$ | -0.563 | No | Domain walls | Naked |
| $P_6$ | -0.822 | Quasi | Anti-matter | Covered |
| $P_7$ | -0.704 | No | Domain walls | Naked |
| $P_8$ | +1.092 | No | Stiff matter | Naked |
| $P_9$ | -0.691 | Quasi | Domain walls | Covered |
| $P_{10}$ | -0.438 | Quasi | Quasi-cosmic string | Covered |
| $P_{11}$ | -0.178 | Quasi | Dark matter | Covered |
| $P_{12}$ | -0.552 | Quasi | Quasi-domain walls | Covered |

## *Time dependence diagrams of null geodesics expansion parameter*



## $\Theta_i^*(T) < 0$: *trapped surface;* $\Theta_i^*(T) = 0$: *apparent horizon regions*