Fracturas en Distribuciones autogravitantes cargadas

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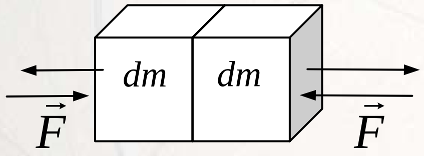
Fractura



$$a^{\alpha} = \left[-R^{\alpha}{}_{\beta\gamma\delta} u^{\beta} u^{\delta} + h^{\alpha}{}_{\beta} \left(\frac{du^{\beta}}{ds} \right)_{;\gamma} - \frac{du^{\beta}}{ds} \frac{du_{\gamma}}{ds} \right] \delta_{\perp} x^{\gamma} \quad (1)$$

La ecuación de Raychaudhuri gobierna la evolución temporal de la expansión

$$\frac{d\Theta}{ds} = -R_{\mu\nu} u^{\mu} u^{\nu} + \left(\frac{du^{\mu}}{ds} \right)_{;\mu} + 2\left(\Omega^{2} - \sigma^{2}\right) - \frac{1}{3}\Theta^{2} \quad (2)$$

Podemos relacionar la fuerza radial con (2) mediante

$$R = -\frac{e^{\lambda}(\rho + P)}{r^{2} e^{\upsilon/2}} \int_{0}^{a} r^{2} e^{\upsilon/2} \frac{d\Theta}{ds} dr \quad (3)$$

es equivalente a observar el signo de la fuerza radial sobre cada elemento de fluido después de la perturbación

$$sign[R] \Leftrightarrow sign[\Theta]$$

Herrera *Phys. Lett A,* **165,** 296 (1992); Di Prisco et al *Phys. Lett A,* **195,** 23 (1994)
Di Prisco, Herrera and Varela *GRG* **29**, 10 (1997)

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Para un fluido anisótropo descrito con la métrica

$$ds^2 = e^{\nu} dt^2 - e^{\lambda} dr^2 - r^2 (d\theta^2 + sen^2\theta d\varphi^2) \qquad (4)$$

La ecuación de equilibrio hidrostático

$$R \equiv \frac{dP}{dr} + (\rho + P)\left(\frac{m + 4\pi r^3 P}{r(r-2m)}\right) - \frac{2}{r}\left(P_T - P\right) \qquad (5)$$

Bajo perturbaciones de densidad y anisotropía

$$\rho + \delta\rho \Rightarrow \begin{cases} P_r(\rho + \delta\rho, r) \approx P_r(\rho, r) + \dfrac{\partial P_r}{\partial \rho}\delta\rho \\ m(\rho + \delta\rho, r) = 4\pi \displaystyle\int_0^r \left(\rho + \delta\rho\right)\bar{r}^2 d\bar{r} \approx m(\rho, r) + \dfrac{4\pi}{3} r^3 \delta\rho \end{cases} \qquad (6)$$

$$\Delta + \delta\Delta$$

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$$R = R(\rho_0 + \delta\rho, P_r, \Delta_0 + \delta\Delta) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0)}_{=0} + \underbrace{\frac{\partial R}{\partial \rho}\delta\rho + \frac{\partial R}{\partial P_r}\delta P_r + \frac{\partial R}{\partial m}\delta m + \frac{\partial R}{\partial \Delta}\delta\Delta}_{\tilde{R}} \qquad (7)$$

$$\tilde{R} = \delta P\left[\left(2\frac{\partial R}{\partial \rho} + \frac{4\pi}{3}r^3\frac{\partial R}{\partial m}\right) - \frac{2}{r}\frac{\delta\Delta}{\delta\rho}\right] \qquad (8)$$

Donde $\frac{\partial R}{\partial \rho} = \frac{m + 4\pi P_r r^3}{r(r-2m)} \geq 0$ y $\frac{\partial R}{\partial m} = \frac{(\rho + P)(1 + 8\pi P_r r^2)}{(r-2m)^2} \geq 0$ (9)

$$\frac{\delta\Delta}{\delta\rho} \approx \frac{\delta(P_T - P_r)}{\delta\rho} \approx \frac{\delta P_T}{\delta\rho} - \frac{\delta P_r}{\delta\rho} \approx v_{sT}^2 - v_{sr}^2 \qquad (10)$$

Donde v_{sT} y v_{sr} representan la velocidad del sonido tangencial y radial respectivamente

Abreu, Hernández y Núñez. *Clacc. Quantum Grav,* **24,** 4631 (2007).

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Es claro que debido a $0 \le {v_{sr}}^2 \le 1$ y a $0 \le {v_{sT}}^2 \le 1$ tendremos $\left|{v_{sT}}^2 - {v_{sr}}^2\right| \le 1$, y en consecuencia

$$-1 \le {v_{sT}}^2 - {v_{sr}}^2 \le 1 \Rightarrow \begin{cases} -1 \le {v_{sT}}^2 - {v_{sr}}^2 \le 0 & \text{Potencialmente estable} \\ 0 \le {v_{sT}}^2 - {v_{sr}}^2 \le 1 & \text{Potencialmente inestable} \end{cases} \quad (11)$$

Perturbaciones y fracturas para configuraciones anisótropas

- Stewart no local 1 ⟶ $$\rho = \frac{1}{8\pi r^2}\frac{\left(e^{2Kr}-1\right)\left(e^{4Kr}+8Kre^{2Kr}-1\right)}{(e^{2Kr}+1)^3} \quad (12)$$

(*J Phys. A.* **15**, 2419 (1982))

- Stewart no local 2 ⟶ $$\rho = \frac{1}{8\pi r^2}\left[1-\frac{\sin(2Kr)}{Kr}+\frac{\sin^2(Kr)}{K^2r^2}\right] \quad (13)$$

(*J Phys. A.* **15**, 2419 (1982))

- Gokhroo & Mehra $$\rho = \rho_c\left(1-\frac{Kr^2}{a^2}\right),\; P_r = \frac{\rho_c}{j}\left(1-\frac{2Mr^2}{a^3}\left[\frac{5-\frac{3Kr^2}{a^2}}{5-3K}\right]\right)\left(1-\frac{r^2}{a^2}\right)^n \quad (14)$$

  (*GRG*, ***26***, *75 (1994)*)

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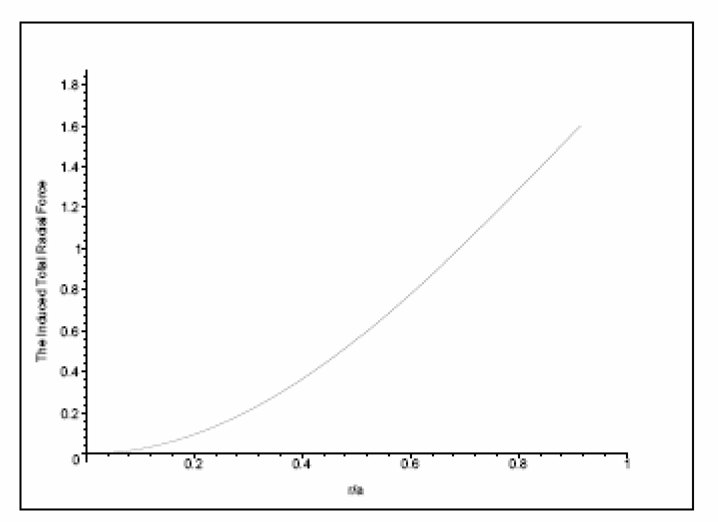
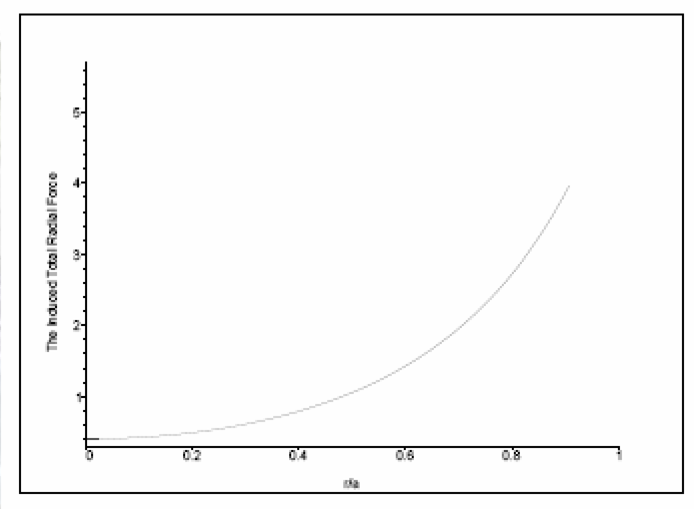


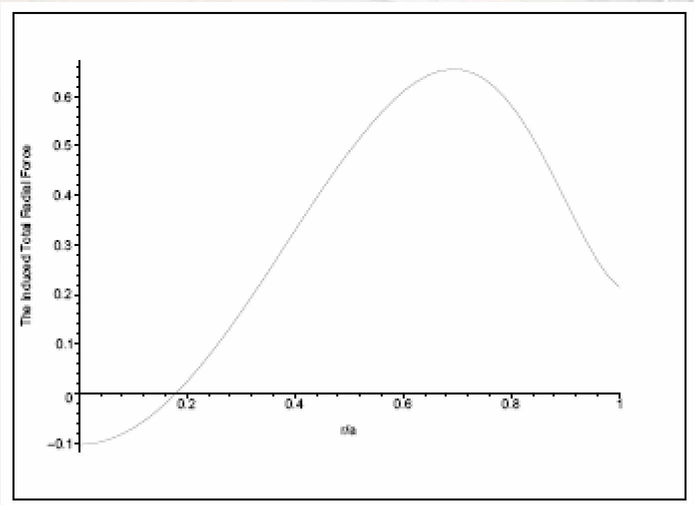
Stewart 1

(*J Phys. A.* ***15****, 2419 (1982))*



Stewart 2

(*J Phys. A.* ***15****, 2419 (1982))*



Gokhroo & Mehra

(GRG, ***26****, 75 (1994))*

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Fracturas cargadas

$$ds^2 = \left(1 - \frac{2m}{r} + \frac{q^2}{r^2}\right)dt^2 - \left(1 - \frac{2m}{r} + \frac{q^2}{r^2}\right)^{-1} dr^2 - r^2\left(d\theta^2 + \sin^2\theta d\phi^2\right) \qquad (15)$$

$$R \equiv \frac{dP_r}{dr} - \boxed{\frac{qq'}{4\pi r^4}} + \left(\rho + P_r\right)\left(4\pi r P_r + \frac{m}{r^2} - \boxed{\frac{q^2}{r^3}}\right)\left(1 - \frac{2m}{r} + \boxed{\frac{q^2}{r^2}}\right)^{-1} - \frac{2}{r}\Delta \qquad (16)$$

Para adimensionalizar R renombramos a los parámetros

$$P = P_c\tilde{P}, \quad m = M\tilde{m}, \quad \tau = a^2 P_c, \quad \Lambda = \frac{M}{a},$$
$$q = Q\tilde{q}, \quad r = a\eta, \quad Z = \frac{\rho_c}{P_c}, \quad \tilde{Q} = \frac{Q}{M}, \qquad (17)$$
$$\rho = \rho_c\tilde{\rho}, \quad \Delta = P_c\tilde{\Delta},$$

Además si sustituimos

$$\chi = \tilde{q}^2$$

$$\chi' = 2qq' \Rightarrow qq' = \frac{\chi'}{2}$$

$$\xi = qq' = \frac{1}{2}\frac{d\chi}{dr}$$

$$\xi + \delta\xi \rightarrow \chi + \delta\chi \qquad (18)$$

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La ecuación de equilibrio hidroestático adimensional es

$$R \equiv \frac{d\tilde{P}_r}{d\eta} - \frac{\xi}{8\pi \mathrm{T} \eta^4} - \left(\mathrm{Z}\tilde{\rho} + \tilde{P}_r \right) \frac{\left(4\pi\eta \mathrm{T} \tilde{P}_r + \frac{\Lambda \tilde{m}}{\eta^2} - \Lambda \tilde{\chi} \right)}{\left(1 - 2\Lambda\tilde{m} + \Lambda^2 \tilde{\chi} \right)} - \frac{2}{\eta} \tilde{\Delta} \tag{19}$$

Podemos perturbar carga

$$R = R(\rho_0, P_r, \Delta_0, \chi_0 + \delta\chi, \xi_0 + \delta\xi) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0, \tilde{\chi}_0 = 0, \xi_0 = 0)}_{=0} +$$

$$\underbrace{\left.\frac{\partial R}{\partial \rho}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\rho + \left.\frac{\partial R}{\partial m}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta m + \left.\frac{\partial R}{\partial \Delta}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\Delta + \boxed{\left.\frac{\partial R}{\partial \xi}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\xi + \left.\frac{\partial R}{\partial \tilde{\chi}}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\tilde{\chi}}}_{\tilde{R}} \tag{20}$$

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$$R \equiv \frac{d\tilde{P}_r}{d\eta} - \frac{\xi}{8\pi \mathrm{T} \eta^4} - \left(\mathrm{Z}\tilde{\rho} + \tilde{P}_r\right) \frac{\left(4\pi\eta \mathrm{T}\tilde{P}_r + \frac{\Lambda\tilde{m}}{\eta^2} - \Lambda\tilde{\chi}\right)}{\left(1 - 2\Lambda\tilde{m} + \Lambda^2\tilde{\chi}\right)} - \frac{2}{\eta}\tilde{\Delta} \qquad (19)$$

Podemos perturbar carga y densidad

$$R = R(\rho_0 + \delta\rho, P_r, \Delta_0, \chi_0 + \delta\chi, \xi_0 + \delta\xi) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0, \tilde{\chi}_0 = 0, \xi_0 = 0)}_{=0} +$$

$$\underbrace{\left.\frac{\partial R}{\partial \rho}\right|_{\substack{\tilde{\chi}=0\\ \xi=0}} \delta\rho + \left.\frac{\partial R}{\partial m}\right|_{\substack{\tilde{\chi}=0\\ \xi=0}} \delta m + \left.\frac{\partial R}{\partial \Delta}\right|_{\substack{\tilde{\chi}=0\\ \xi=0}} \delta\Delta + \left.\frac{\partial R}{\partial \xi}\right|_{\substack{\tilde{\chi}=0\\ \xi=0}} \delta\xi + \left.\frac{\partial R}{\partial \tilde{\chi}}\right|_{\substack{\tilde{\chi}=0\\ \xi=0}} \delta\tilde{\chi}}_{\tilde{R}} \qquad (20)$$

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Podemos perturbar carga y anisotropía

$$R = R(\rho_0 + \delta\rho, P_r, \Delta_0 + \delta\Delta, \chi_0 + \delta\chi, \xi_0 + \delta\xi) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0, \tilde{\chi}_0 = 0, \xi_0 = 0)}_{=0} +$$

$$\underbrace{\left.\frac{\partial R}{\partial \rho}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\rho + \left.\frac{\partial R}{\partial m}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta m + \boxed{\left.\frac{\partial R}{\partial \Delta}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\Delta + \left.\frac{\partial R}{\partial \xi}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\xi + \left.\frac{\partial R}{\partial \tilde{\chi}}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\tilde{\chi}}}_{\tilde{R}} \quad (20)$$

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Podemos perturbar

$$R = R(\rho_0 + \delta\rho, P_r, \Delta_0 + \delta\Delta, \chi_0 + \delta\chi, \xi_0 + \delta\xi) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0, \tilde{\chi}_0 = 0, \xi_0 = 0)}_{=0} +$$

$$\underbrace{\left.\frac{\partial R}{\partial \rho}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\rho + \left.\frac{\partial R}{\partial m}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta m + \left.\frac{\partial R}{\partial \Delta}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\Delta + \left.\frac{\partial R}{\partial \xi}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\xi + \left.\frac{\partial R}{\partial \tilde{\chi}}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\tilde{\chi}}_{\tilde{R}} \quad (20)$$

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Caso 1: Perturbando carga

- $\xi + \delta\xi \rightarrow \int (\xi + \delta\xi) dr \approx \tilde{\chi}(\xi, r) + \frac{M}{a\eta}\delta\tilde{\chi}$

$$R = R(\rho, P_r, \Delta, \chi_0 + \delta\chi, \xi_0 + \delta\xi) \equiv \underbrace{R_0(\rho_0, P_r, \Delta_0, \tilde{\chi}_0 = 0, \xi_0 = 0)}_{=0} + \underbrace{+ \left.\frac{\partial R}{\partial \xi}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\xi + \left.\frac{\partial R}{\partial \tilde{\chi}}\right|_{\substack{\tilde{\chi}=0 \\ \xi=0}} \delta\tilde{\chi}}_{\tilde{R}} \quad (21)$$

R perturbada:

$$\tilde{R} = \left(\frac{\left(Z\tilde{\rho} + \tilde{P}\right)\Lambda^2}{1 - 2\Lambda\tilde{m}} + \frac{\left(Z\tilde{\rho} + \tilde{P}\right)\left(4\pi T \eta \tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)\Lambda^2}{(1 - 2\Lambda\tilde{m})^2} - \frac{1}{8}\frac{\Lambda}{T\eta^5} \right)\delta\tilde{\chi} \quad (22)$$

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Caso 2: Perturbando carga y densidad

- $\xi + \delta\xi \rightarrow \int (\xi + \delta\xi) dr \approx \tilde{\chi}(\xi, r) + \frac{M}{a\eta}\delta\tilde{\chi}$ (22)
- $\rho + \delta\rho \Rightarrow m(\rho + \delta\rho, r) = 4\pi\int_0^r \left(\rho + \delta\rho\right)\bar{r}^{-2} d\bar{r} \approx m(\rho, r) + \frac{4\pi}{3} r^3 \delta\rho$

R perturbada:

$$\tilde{R} = \frac{(Z\tilde{\rho} + \tilde{P})\Lambda}{1 - 2\Lambda\tilde{m}}\left[\Lambda\left(1 + \frac{\left(4\pi T \eta \tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{(1 - 2\Lambda\tilde{m})} - \frac{1}{8}\frac{(1 - 2\Lambda\tilde{m})}{T\eta^5\Lambda(Z\tilde{\rho} + \tilde{P})}\right)\delta\tilde{\chi} - \right.$$

$$\left.\frac{1}{\eta^2}\left(1 + \frac{3}{4}\frac{Z\left(4\pi T\eta\tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{\pi\eta T^2\left(Z\tilde{\rho} + \tilde{P}\right)} + \frac{2\eta^2\left(4\pi T\eta\tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{(1 - 2\Lambda\tilde{m})}\right)\delta\tilde{m}\right] \quad (23)$$

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Caso 3: Perturbando carga y anisotropía

- $\xi + \delta\xi \rightarrow \int (\xi + \delta\xi) dr \approx \tilde{\chi}(\xi, r) + \frac{M}{a\eta} \delta\tilde{\chi}$ (24)
- $\tilde{\Delta} + \delta\tilde{\Delta}$

R perturbada:

$$\tilde{R} = \frac{(Z\tilde{\rho} + \tilde{P})\Lambda}{1 - 2\Lambda\tilde{m}} \left(1 + \frac{\left(4\pi T \eta \tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2} \right)}{(1 - 2\Lambda\tilde{m})} - \frac{1}{8} \frac{(1 - 2\Lambda\tilde{m})}{T\eta^5\Lambda(Z\tilde{\rho} + \tilde{P})} \right) \delta\tilde{\chi} - \frac{2\delta\tilde{\Delta}}{\eta} \Lambda \quad (25)$$

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Caso 4: Perturbando carga, densidad y anisotropía

- $\xi + \delta\xi \rightarrow \int (\xi + \delta\xi) dr \approx \tilde{\chi}(\xi, r) + \frac{M}{a\eta}\delta\tilde{\chi}$ (26)
- $\rho + \delta\rho \Rightarrow m(\rho + \delta\rho, r) = 4\pi \int_0^r (\rho + \delta\rho)\bar{r}^2 d\bar{r} \approx m(\rho, r) + \frac{4\pi}{3} r^3 \delta\rho$
- $\tilde{\Delta} + \delta\tilde{\Delta}$

R perturbada:

$$\tilde{R} = \frac{(Z\tilde{\rho} + \tilde{P})\Lambda}{1 - 2\Lambda\tilde{m}} \left[\Lambda \left(1 + \frac{\left(4\pi \mathrm{T}\eta\tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{(1 - 2\Lambda\tilde{m})} - \frac{1}{8}\frac{(1 - 2\Lambda\tilde{m})}{\mathrm{T}\eta^5\Lambda(Z\tilde{\rho} + \tilde{P})} \right) \delta\tilde{\chi} - \frac{1}{\eta^2}\left(1 + \frac{3}{4}\frac{Z\left(4\pi \mathrm{T}\eta\tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{\pi\eta T^2 \left(Z\tilde{\rho} + \tilde{P}\right)} + \frac{2\eta^2\left(4\pi \mathrm{T}\eta\tilde{P} + \frac{\Lambda\tilde{m}}{\eta^2}\right)}{(1 - 2\Lambda\tilde{m})} \right)\delta\tilde{m} \right] - \frac{2\delta\tilde{\Delta}}{\eta} \quad (27)$$

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Resultados

Caso 1: Perturbando carga $\delta\tilde{\chi} = 1.10^{-8}$

- Stewart no local 1

(J Phys. A. **15**, 2419 (1982))

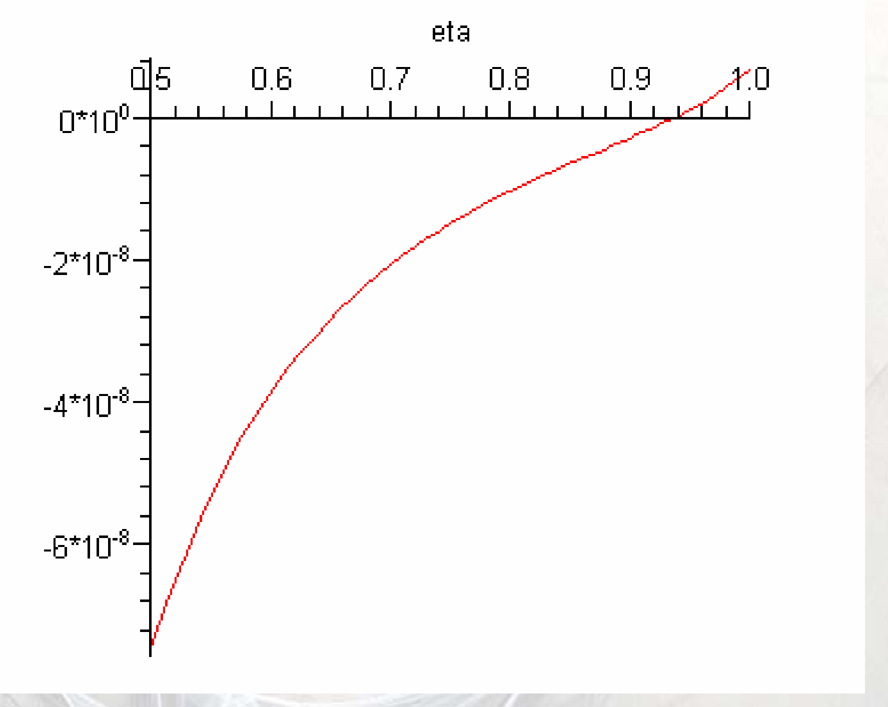
$$\rho = \frac{1}{8\pi r^2}\frac{\left(e^{2Kr}-1\right)\left(e^{4Kr}+8Kre^{2Kr}-1\right)}{(e^{2Kr}+1)^3} \quad (28)$$

$$\Downarrow$$

$$P_r = \frac{1}{8\pi r^2}\frac{(1-e^{2Kr})(e^{4Kr}-8Kre^{2Kr}-1)}{(e^{2Kr}+1)^3} \quad (29)$$

$$\Downarrow$$

$$P_T = \frac{2K^2 e^{4Kr}}{\pi(e^{2Kr}+1)^4} \quad (30)$$



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Resultados

Caso 2: Perturbando carga y densidad

- Stewart no local 1

(J Phys. A. **15**, 2419 (1982))

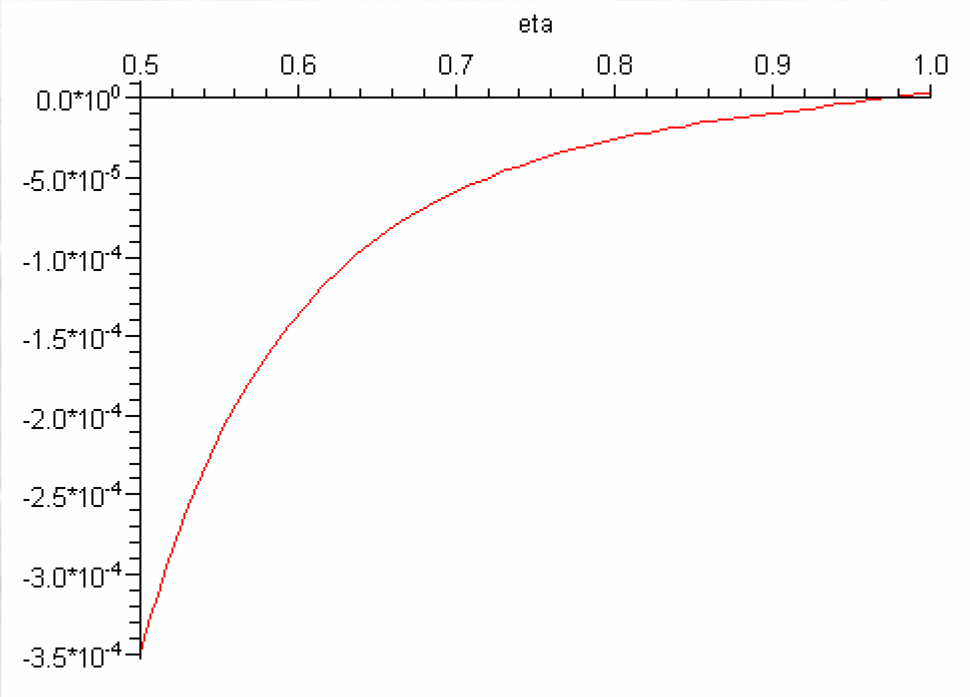
$$\rho = \frac{1}{8\pi r^2}\frac{\left(e^{2Kr}-1\right)\left(e^{4Kr}+8Kre^{2Kr}-1\right)}{(e^{2Kr}+1)^3} \quad (28)$$

$$\Downarrow$$

$$P_r = \frac{1}{8\pi r^2}\frac{(1-e^{2Kr})(e^{4Kr}-8Kre^{2Kr}-1)}{(e^{2Kr}+1)^3} \quad (29)$$

$$\Downarrow$$

$$P_T = \frac{2K^2 e^{4Kr}}{\pi(e^{2Kr}+1)^4} \quad (30)$$



$$\delta\tilde{m} = 1.10^{-8}, \quad \delta\tilde{\chi} = 1.10^{-5}, \frac{\delta q}{\delta m} = 3{,}16.10^{5}$$

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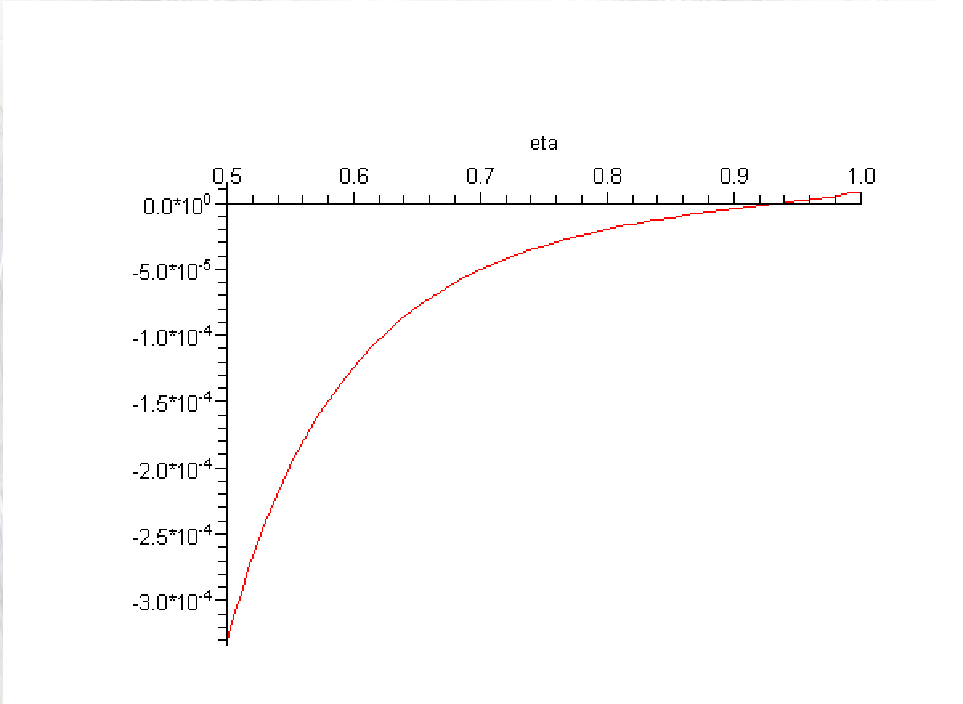
$$\rho = \frac{1}{8\pi r^2}\frac{\left(e^{2Kr}-1\right)\left(e^{4Kr}+8Kre^{2Kr}-1\right)}{(e^{2Kr}+1)^3} \quad (28)$$

$$\Downarrow$$

$$P_r = \frac{1}{8\pi r^2}\frac{(1-e^{2Kr})(e^{4Kr}-8Kre^{2Kr}-1)}{(e^{2Kr}+1)^3} \quad (29)$$

$$\Downarrow$$

$$P_T = \frac{2K^2 e^{4Kr}}{\pi(e^{2Kr}+1)^4} \quad (30)$$



$$\delta\tilde{m} = -1.10^{-8}, \quad \delta\tilde{\chi} = 1.10^{-5}, \quad \frac{\delta q}{\delta m} = 3{,}16.10^{5}$$

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Conclusiones

• Se encontró que las perturbaciones en la carga inducen fractura en modelos de esferas anisótropas autogravitantes.

• Las perturbaciones de carga que inducen fracturas pueden ser:

$$\delta\xi \neq 0, \quad \delta\tilde{\chi} \neq 0, \quad \delta\rho = 0, \quad \delta m = 0, \quad \delta\Delta = 0$$

y $\delta\xi \neq 0, \quad \delta\tilde{\chi} \neq 0, \quad \delta\rho \neq 0, \quad \delta m \neq 0, \quad \delta\Delta = 0$

• Todas las perturbaciones de carga se hicieron sobre modelos neutros anisótropos

• Se encontró que todas las perturbaciones

$$\delta\xi \neq 0, \quad \delta\tilde{\chi} \neq 0, \quad \delta\rho = 0, \quad \delta m = 0, \quad \delta\Delta = 0$$

fracturaron para $\dfrac{\sqrt{\delta\tilde{\chi}}}{\delta m} = \dfrac{\delta q}{\delta m} = 1.10^{5}$

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