Gamma ray production resulting from the annihilation of neutrino/antineutrino emitted from the accretion disk surrounding compact objects

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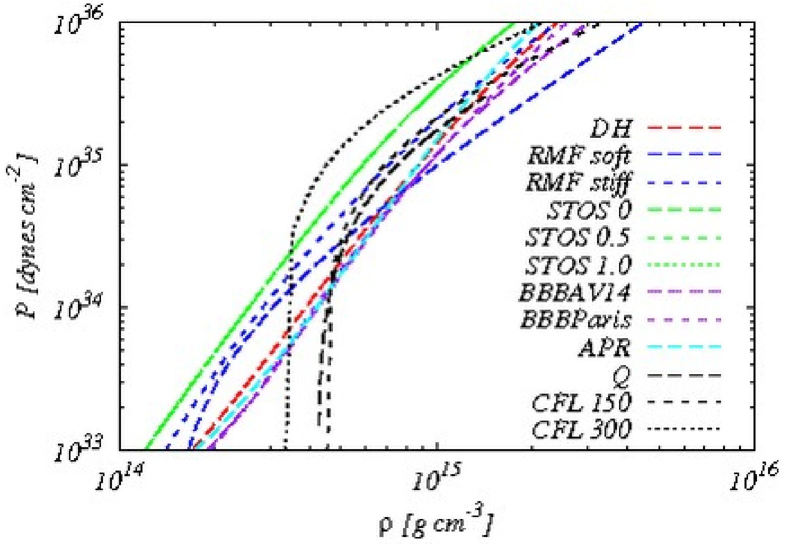
Overview

- Toy model for (anti)neutrino annihilation in accreting systems (disk+central object)
- EOS of the central object (neutron/quark stars)
- Energy production close to the disk
- Energy production along the rotational axis
- Summary & outlook

Toy model for the energy source

- Rotating compact object
  EOS tables for neutron and quark matter
- Standard accretion disk model
  steady state model, geometrically thin and optically thick disk
- Neutrino source: only the disk, star is neglected
- electron/positron pair creation and E liberation via neutrino/antineutrino annihilation
- Considered along the equatorial plane and the rotational axis

EOS



Neutron stars:

DH (Douchin & Hanselm 2001),

RMF soft/stiff (Kubis & Kutchera 1997),

STOS T=0, 0.5, 1 MeV,

(Shen, Toki, Oyamatsu & Sumiyoshi 1998),

BBBAV14 & BBBParis

(Baldo, Bombaci & Burgio 1997),

APR (Akmal, Pandharipande & Ravenhall 1998)

Quark stars:

Q (Witten 1984, Chen et al. 1998),

CFL Δ=150 MeV, … (Alford et al. 1999)

Energy Deposition Rate (EDR)

The EDR per unit volume:

$$\dot{q}(\boldsymbol{r}) = \frac{dE_0}{dtdV} = \int\int f_\nu(\mathbf{p}_\nu, \boldsymbol{r}) f_{\bar{\nu}}(\mathbf{p}_{\bar{\nu}}, \boldsymbol{r}) \{\sigma_{\nu\bar{\nu}} |\boldsymbol{v}_\nu - \boldsymbol{v}_{\bar{\nu}}| \varepsilon_\nu \varepsilon_{\bar{\nu}}\} \frac{\varepsilon_\nu + \varepsilon_{\bar{\nu}}}{\varepsilon_\nu \varepsilon_{\bar{\nu}}} d^3\mathbf{p}_\nu d^3\mathbf{p}_{\bar{\nu}},$$

$$\sigma_{\nu\bar{\nu}} = KG_F^2(\varepsilon_\nu \varepsilon_{\bar{\nu}} - c^2 \mathbf{p}_\nu \cdot \mathbf{p}_{\bar{\nu}}) = -KG_F^2 \boldsymbol{p}_\nu \cdot \boldsymbol{p}_{\bar{\nu}}$$

Integrating in spherically symmetric geometry of the ST:

$$\begin{aligned} \dot{q}(r) &= \frac{dE_0}{dtdV} = 2cKG_F^2 \Theta(r) \int\int f_\nu f_{\bar{\nu}} (\varepsilon_\nu + \varepsilon_{\bar{\nu}}) \varepsilon_\nu^3 \varepsilon_{\bar{\nu}}^3 d\varepsilon_\nu d\varepsilon_{\bar{\nu}} \\ &= \frac{21\pi^4}{4} \zeta(5) \frac{KG_F^2}{h^6 c^5} k^9 T_{eff}^9 (3r_g) \Theta(r) \end{aligned}$$

EDR along the disk

Integrated over the 3-volume (Salmonson & Wilson 1999):

$$\dot{Q}(R) = 2\int_0^{2\pi}\int_0^{\pi/2}\int_R^{\infty} \dot{q}(r,R,\theta)\sqrt{g_{rr}g_{\theta\theta}g_{\phi\phi}}\,dr\,d\theta\,d\phi.$$

Restricted into the equatorial plane:

$$\left.\frac{d\dot{Q}}{d\theta}\right|_{\theta=\pi/2} = 2\int_0^{2\pi}\int_R^{\infty} \dot{q}(r,R,\theta)\sqrt{g_{rr}g_{\theta\theta}g_{\phi\phi}}\,dr\,d\phi\Big|_{\theta=\pi/2}$$

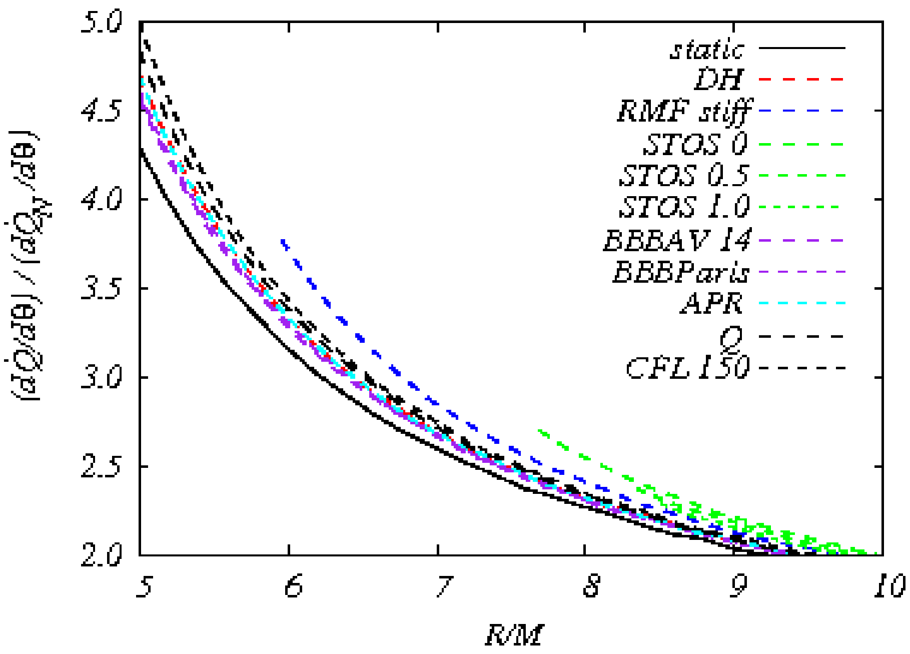
$$= 4\pi\int_R^{\infty} \dot{q}(r,R,\theta)\sqrt{g_{rr}g_{\theta\theta}g_{\phi\phi}}\,dr\Big|_{\theta=\pi/2}.$$

Compared with the Newtonian model:

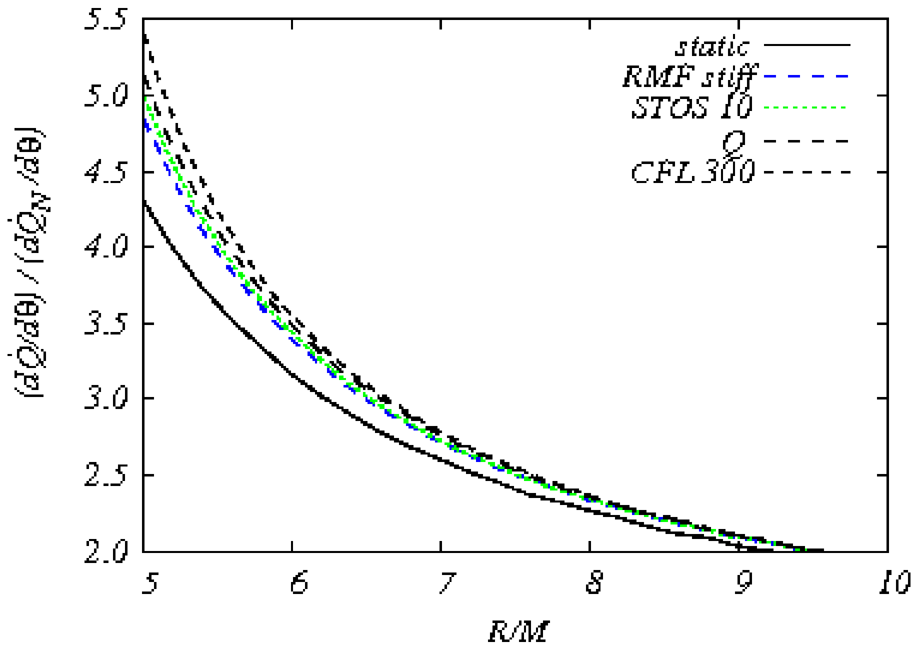
$$\left.\frac{d\dot{Q}/d\theta}{d\dot{Q}_N/d\theta}\right|_{\theta=\pi/2} = \frac{\int_R^{\infty} \dot{q}(r,R,\theta)\sqrt{g_{rr}(r,\theta)g_{\theta\theta}(r,\theta)g_{\phi\phi}(r,\theta)}\,dr\Big|_{\theta=\pi/2}}{\int_R^{\infty} \dot{q}_N(r,R)r^2dr},$$

EDR along the disk

The radial distribution of EDR restricted into the equatorial plane (Kovács, Cheng & Harko 2009)



$M=1.8\ M_{\odot},\ \Omega=5\ 10^3\ s^{-1}$

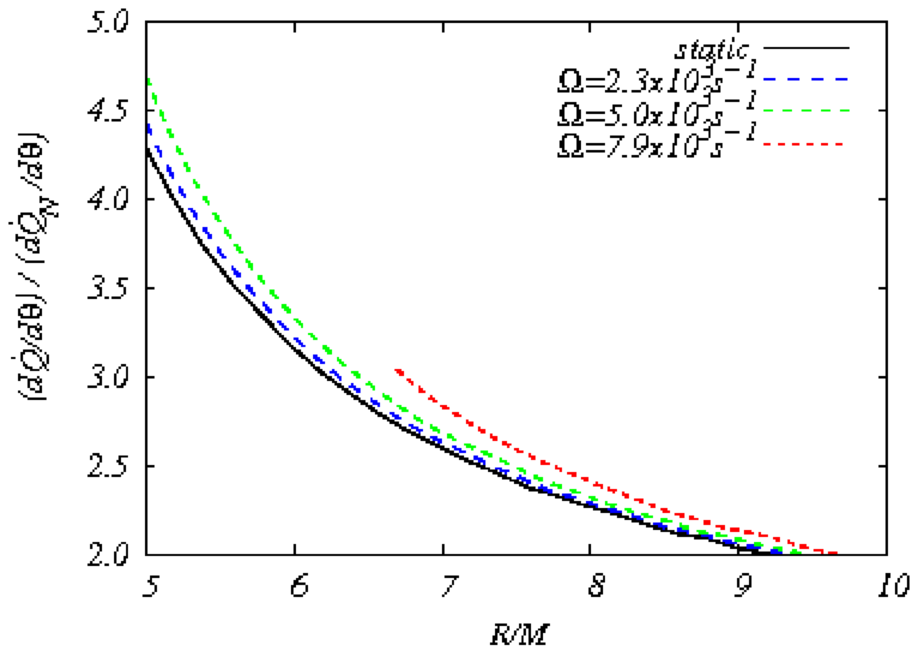


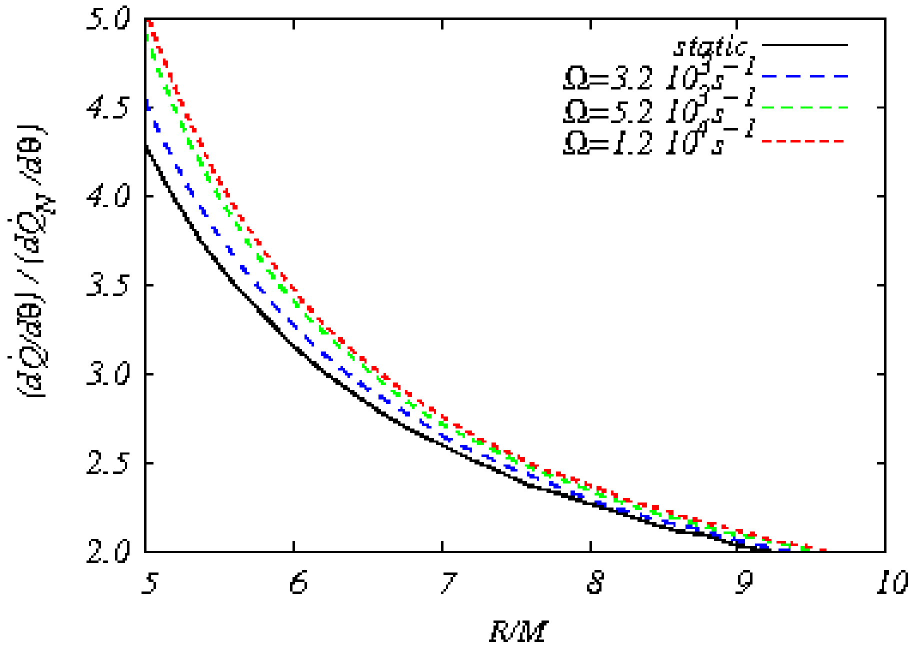
$M=2.8\ M_{\odot},\ \Omega=5\ 10^3\ s^{-1}$

RMF stiff & STOS: high EDR but small disk surface.
Quark stars produce higher EDR.

EDR along the disk

Dependence of the EDR on Ω for APR and Q type EOS
(Kovács, Cheng & Harko 2009)





$M=1.8\ M_\odot$, APR

$M=1.8\ M_\odot$, Q

The EDR is proportional to the rotational frequency.

EDR along the rotational axis

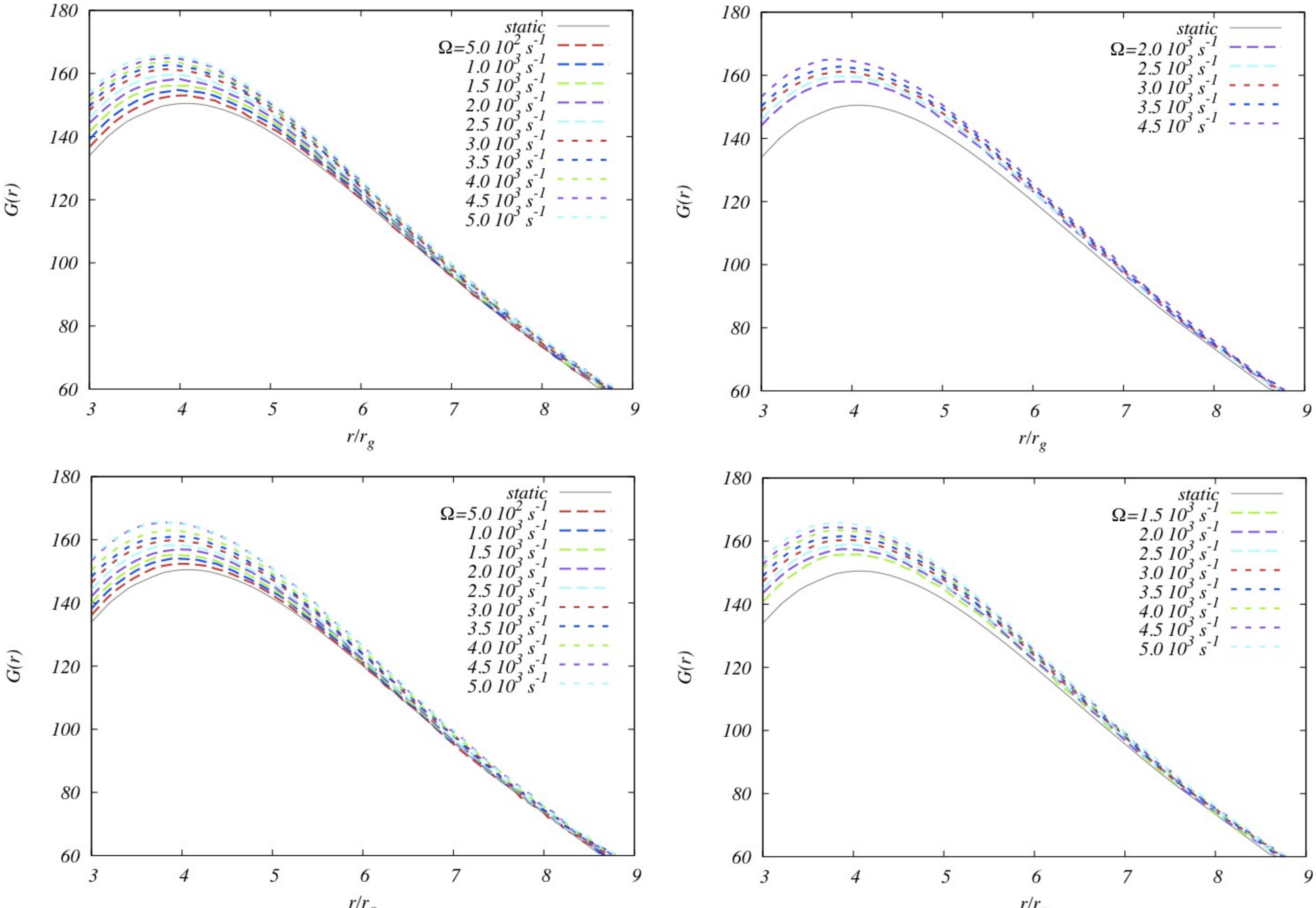
Integrated over the 4-volume (Asano & Fukuyama 2001) but restricted along the axis of rotation:

$$\left.\frac{dE_0}{dt}\right|_{\theta=0} \simeq 2\frac{d}{d\theta}\int_0^{2\pi}\int_0^{\pi/2}\int_{r_{min}}^{r_{max}} \frac{dE_0}{dtdV}\sqrt{-g}dr\,d\theta d\phi\Big|_{\theta=0}$$
$$= 21\pi^5\zeta(5)\frac{KG_F^2}{h^6c^5}k^9T_{eff}^9(3r_g)r_g^2\int_{r_{min}}^{r_{max}} G(r)dr\ ,$$

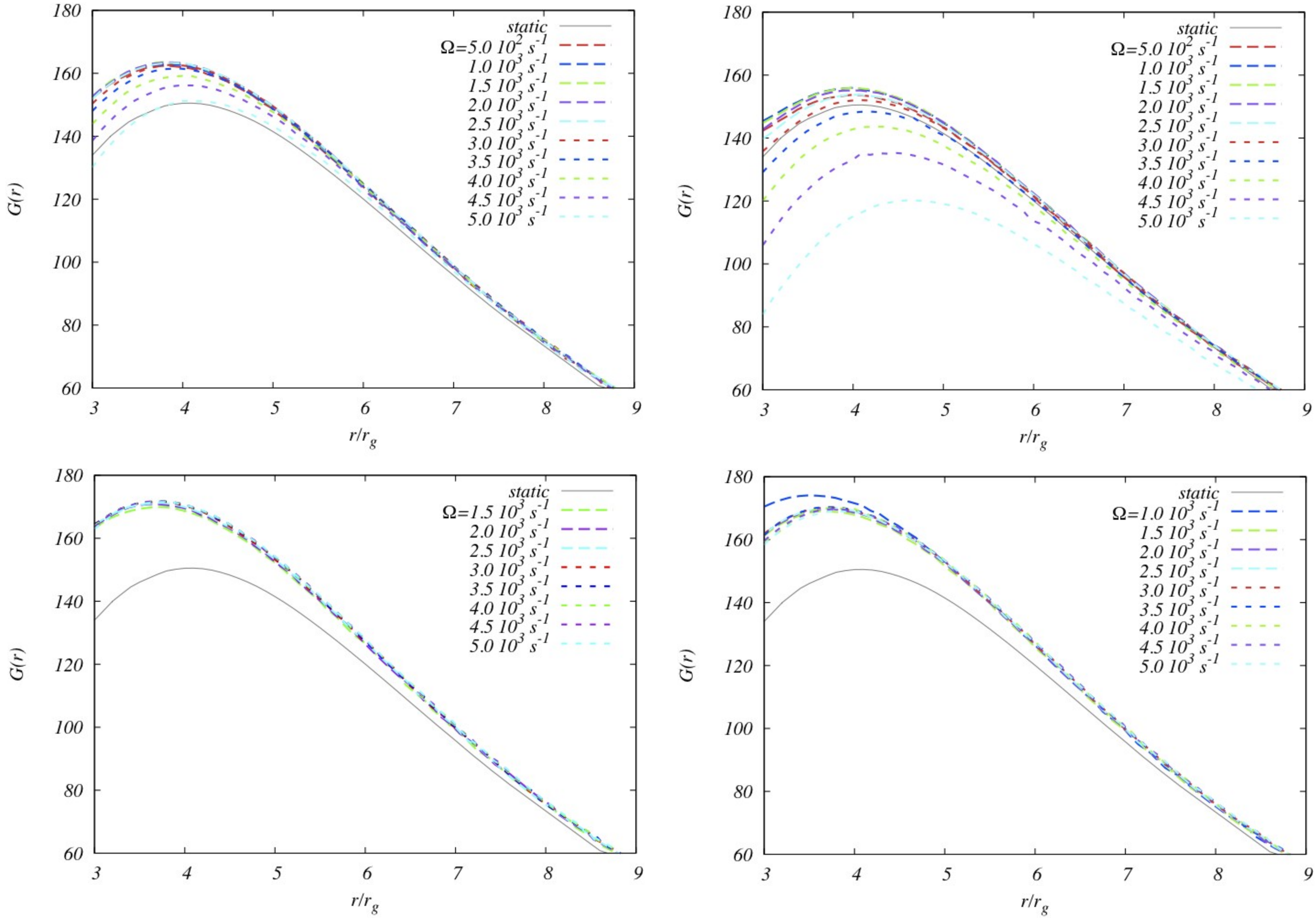
$$G(r) \equiv r_g^{-2}\left.\frac{\sqrt{-g(r,\theta)}}{\sin\theta}\right|_{\theta=0}\Theta(r)\ .$$

G describes the effects of the geometry on the EDR.

Dependence of the EDR on Ω: DH, APR, BBBAV14 & BBBParis



Dependence of the EDR on Ω: RMF stiff, STOS, Q & CFL



Summary & Outlook

- Studied simple models for energy production due to antineutrino/neutrino annihilation in accreting systems with rotating central objects
- Considered a broad variation of EOS for the central neutron and quark stars
- Presented the radial distribution of EDR along the equatorial plane and the rotational axis
- Considerable dependence on the EOS: quark stars produce higher rates
- Possible reconstruction of 3D maps for EDR