Rotating neutron stars and mass estimates of QPO sources

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Motivation

- Quasiperiodic oscillations are observed in X-ray spectrum coming from Low Mass X-ray Binaries with Neutron Star.
- QPO frequencies are comparable with frequencies connected to orbital motion (Keplerian, radial epicyclic, vertical epicyclic).
- Our selection of QPO models is based on Török, Kotrlová, Šrámková, Stuchlík (2011).

	RP	TD	WD	RP1	RP2	ER
ν_U	ν_K	$\nu_K + \nu_{rad}$	$2\nu_K - \nu_{rad}$	ν_θ	$2\nu_K - \nu_\theta$	ν_θ
ν_L	$\nu_K - \nu_{rad}$	ν_K	$2(\nu_K - \nu_{rad})$	$\nu_K - \nu_{rad}$	$\nu_K - \nu_{rad}$	ν_{rad}

- Frequency - frequency plots for various sources shows ratio ν_U/ν_L 3:2 for frequencies $\simeq$ (900 : 600) Hz.

Non-rotating Neutron Stars

- For non-rotating NS we used Schwarzschild spacetime.
- Observed ratio of frequencies $\nu_{\mathrm{U}}/\nu_{\mathrm{L}}$ is identified with the place, where QPOs are excitated - resonant radius
  - For RP, RP1 a RP2 models on $r = 6.75\ M$,
  - For WD and TD models on $r = 8\ M$,
  - For ER model on $r = 10.8\ M$.
- By using our presumption $\nu_{\mathrm{U}} = 900\ \mathrm{Hz} = 3\nu_{\mathrm{L}}/2$ we get these predictions of masses for non-rotating NS

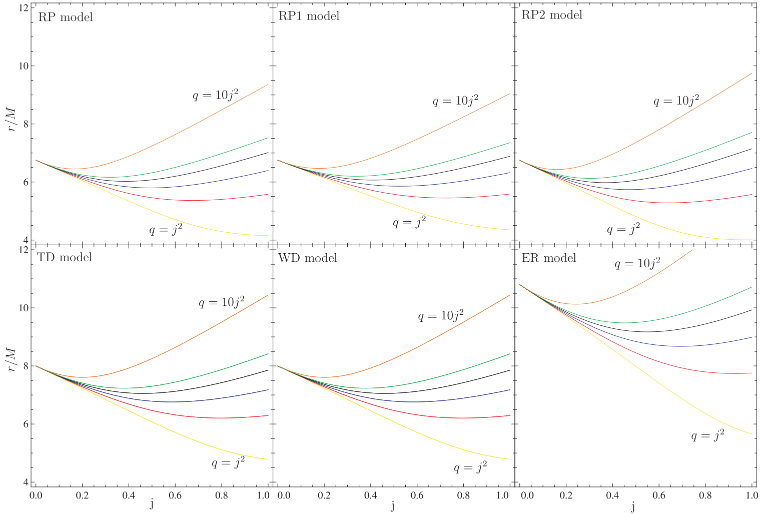
$$M^0_{\mathrm{RP}} = M^0_{\mathrm{RP1}} = M^0_{\mathrm{RP2}} = 2.05\ M_{\odot},$$
$$M^0_{\mathrm{TD}} = M^0_{\mathrm{WD}} = 2.38\ M_{\odot},$$
$$M^0_{\mathrm{ER}} = 1.01\ M_{\odot}.$$

- These mass estimates do not fit observed masses of neutron stars ($M \simeq 1.4 M_{\odot}$).
- Since neutron stars are rotating it is important to investigate, whether inclusion of rotational effect could lead to more reasonable mass predictions.

Rotating Neutron Stars

- For rotating NS we used Hartle-Thorne spacetime.
- These spacetimes are given by three parameters
  M ... mass of the rotating object,
  J ... angular momentum of the rotating object,
  Q ... quadrupole moment of rotating object.
- It is usefull to use dimensionless quantities $j = J/M^2$ and $q = Q/M^3$.
- All important functions were taken from Abramowicz, Almergren, Kluzniak & Thampan 2003 gr-qc/0312070.
- We have used for our investigations $j = 0.1,\ 0.2,\ 0.3,\ 0.5$ and for all these we used $q = (1,\ 2,\ 3,\ 4,\ 5,\ 10) \times j^2$.

QPO models - resonant radius



Masses implicated for rotating Neutron Stars

Table: Table of masses calculated for RP model.

***j* = 0.1**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.40	6.41	6.42	6.43	6.44	6.49
$M/M_\odot$	2.20	2.19	2.19	2.18	2.18	2.15
***j* = 0.2**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.04	6.09	6.14	6.19	6.24	6.46
$M/M_\odot$	2.38	2.35	2.33	2.30	2.28	2.18
***j* = 0.3**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.69	5.82	5.95	6.06	6.16	6.61
$M/M_\odot$	2.59	2.51	2.45	2.38	2.33	2.12
***j* = 0.5**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.01	5.46	5.80	6.08	6.32	7.24
$M/M_\odot$	3.09	2.76	2.54	2.39	2.26	1.88

Masses implicated for rotating Neutron Stars

Table: Table of masses calculated for RP1 model.

***j* = 0.1**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.44	6.45	6.46	6.47	6.48	6.52
$M/M_\odot$	2.16	2.16	2.15	2.15	2.15	2.13
***j* = 0.2**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.13	6.17	6.21	6.25	6.29	6.47
$M/M_\odot$	2.28	2.27	2.25	2.24	2.22	2.17
***j* = 0.3**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.82	5.93	6.02	6.12	6.20	6.59
$M/M_\odot$	2.41	2.38	2.34	2.31	2.28	2.15
***j* = 0.5**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.23	5.58	5.86	6.10	6.31	7.12
$M/M_\odot$	2.71	2.56	2.45	2.36	2.28	2.02

Masses implicated for rotating Neutron Stars

Table: Table of masses calculated for RP2 model.

j = 0.1						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.36	6.37	6.39	6.40	6.41	6.48
$M/M_\odot$	2.25	2.24	2.24	2.23	2.22	2.19
j = 0.2						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.97	6.03	6.09	6.14	6.20	6.45
$M/M_\odot$	2.50	2.45	2.42	2.38	2.34	2.20
j = 0.3						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	5.57	5.73	5.87	6.00	6.13	6.64
$M/M_\odot$	2.79	2.66	2.56	2.46	2.38	2.09
j = 0.5						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	4.81	5.35	5.74	6.06	6.33	7.36
$M/M_\odot$	3.53	2.96	2.64	2.41	2.24	1.76

Masses implicated for rotating Neutron Stars

Table: Table of masses calculated for TD and WD models.

***j* = 0.1**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	7.62	7.63	7.64	7.65	7.66	7.71
$M/M_\odot$	2.55	2.55	2.54	2.54	2.53	2.51
***j* = 0.2**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	7.23	7.28	7.32	7.37	7.41	7.61
$M/M_\odot$	2.74	2.72	2.70	2.68	2.65	2.56
***j* = 0.3**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.84	6.96	7.07	7.17	7.27	7.69
$M/M_\odot$	2.96	2.90	2.84	2.78	2.73	2.53
***j* = 0.5**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	6.07	6.47	6.78	7.06	7.30	8.25
$M/M_\odot$	3.50	3.22	3.01	2.85	2.72	2.30

Masses implicated for rotating Neutron Stars

Table: Table of masses calculated for ER model.

***j* = 0.1**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	10.26	10.27	10.28	10.29	10.31	10.36
$M/M_\odot$	1.08	1.08	1.08	1.08	1.08	1.07
***j* = 0.2**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	9.71	9.76	9.81	9.86	9.91	10.15
$M/M_\odot$	1.17	1.16	1.15	1.14	1.14	1.10
***j* = 0.3**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	9.14	9.27	9.40	9.52	9.64	10.16
$M/M_\odot$	1.26	1.24	1.22	1.20	1.18	1.10
***j* = 0.5**						
q	j^2	$2j^2$	$3j^2$	$4j^2$	$5j^2$	$10j^2$
r/M	7.99	8.45	8.84	9.19	9.50	10.75
$M/M_\odot$	1.50	1.40	1.33	1.26	1.21	1.04

Conclusions

- We have used that 3:2 ratio of QPO frequencies is observed for (900:600) Hz to make a very simple mass estimate for rotating neutron stars.
- We have shown that the only model that predicts mass $M = 1.4M_{\odot}$ is ER model. Unfortunately this happens for large spin $j = 0.5$ and for $q/j^2 = 2$ that is too small for such mass.

THANK YOU FOR YOUR ATTENTION
PLEASE POSTPONE YOUR QUESTIONS TO GABO OR PAVEL