Properties of rotating protoneutron star within the extended field theoretical model

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The bulk properties of rotating relativistic star constrain the proposed equations of state in the high density region. Accreted matter in their gravitational fields undergoes high frequency oscillations that could become a sensitive probe for general relativistic effects. The keplerian configurations of rapidly rotating protoneutron stars have been computed in framework of general relativity by solving the Einstein field equations for stationary axisymmetric space time (e.g. see Ref.[1] and references therein). The numerical calculations have been performed by employing the Rotating Neutron Star (RNS) code [2]. In the present work we have employed a set of parameterizations of the ERMF model as BSR1 - BSR21 [3, 4], generated by varying the ω meson self-coupling ζ and neutron skin thickness Δr for the ^{208}Pb nucleus. These parametrizations have been obtained so as to reproduce the properties of many finite nuclei, and bulk properties of nuclear matter at nuclear saturation density [3]. The parameter set BSR1 and BSR7 correspond to the value of ω meson self-coupling $\zeta = 0.0$, set BSR8 and BSR14 correspond to $\zeta = 0.3$, set BSR15 and BSR21 correspond to $\zeta = 0.6$, and for each of set parametrization the value of neutron skin thickness of ^{208}Pb is 0.16fm and 0.28fm.

The structural properties such as central energy density (ϵ_c), maximum gravitational mass (M_{max}), radius (R_{max}), keplerian frequency (f_k), moment of inertia (I), ratio of rotational kinetic energy to gravitational kinetic energy (T/$|W|$), ratio of equatorial radius at pole to the equatorial radius at the equator (r_{pole}/r_{eq}) of rotating protoneutron star, with keplerian frequency are presented in Table I. These properties have been calculated by employing various parametrizations of extended FTRMF model [3, 4] obtained by varying neutron skin thickness Δr for the ^{208}Pb nucleus and ω-meson self coupling parameter ζ at 0, 3, 5 and 10 MeV temperature of nuclear dense matter. In Table. I we present the results of rotating protoneutron star constructed without hyperons in upper panel, and with inclusion of hyperons in lower panel. It is observed from the table I that the central energy density of keplerian frequency decreases with increase in temperature and increases with increase in the values of ζ parameter. The increase in the value of Δr has negligible effect on the values of central energy density. In Table I the values of rotational kinetic energy to gravitational kinetic energy T/$|W|$ is also presented. The value of T/$|W|$ decreases with increase in temperature and its value also decreases on increasing ζ parameter. If we include hyperons in the calculation, the value of T/$|W|$ decreases further. The T/$|W|$ is maximum = 0.1348 for BSR1 parametrization (without hyperons) and minimum = 0.0929 for BSR21 parametrization (with inclusion of hyperons). Similarly the ratio of equitorial radius at pole to the equitorial radius at the equator r_{pole}/r_{eq} is also presented. The ratio has small variation $\sim$ 0.55-0.58. The equitorial radius at pole increases as compared to equitorial radius at the equator on increasing temperature, ζ parameter and Δr. It also increases further on inclusion of hyperons in the calculations.

References

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TABLE I: The properties of rotating PNS, rotating with keplerian frequency at a temperature of 0, 3, 5 and 10 MeV. The uppper panel contains EOS without hyperons, whereas the lower panel contain EOS having hyperons in its composition. The values of central energy density (ϵ_c), maximum gravitational mass (M_{max}), radius (R_{max}), keplerian frequency (f_k), moment of inertia (I), ratio of rotational kinetic energy to gravitational kinetic energy ($T/|W|$), ratio of equatorial radius at pole to the equatorial radius at the equator (r_{pole}/r_{eq}) is presented for BSR1, BSR7, BSR8, BSR14, BSR15 and BSR21 parametrization of ERMF model.

				Without hyperons					
Force	Δr (fm)	T (MeV)	ϵ_c ($10^{15} gm cm^{-3}$)	M_{max} ($M_\odot$)	R_{max} (Km)	f_k (Hz)	I ($10^{45} gm cm^{-2}$)	$T/\|W\|$	r_{pole}/r_{eq}
BSR1	0.16	0	1.5761	2.9933	16.2702	1487.82	5.9040	0.1348	0.5576
		3	1.2814	3.2517	18.2275	1309.64	7.8083	0.1306	0.5588
		5	1.2814	3.2648	18.3126	1302.80	7.8924	0.1292	0.5594
		10	1.1400	3.3917	19.6709	1194.45	9.1286	0.1246	0.5615
BSR7	0.28	0	1.5534	3.0130	16.4893	1461.41	6.0050	0.1307	0.5606
		3	1.1421	3.4262	19.4872	1217.20	9.2740	0.1286	0.5593
		5	1.1421	3.4252	19.5037	1215.45	9.2707	0.1283	0.5596
		10	1.1073	3.4347	20.0487	1168.52	9.5290	0.1233	0.5621
BSR8	0.16	0	1.7818	2.3699	15.8920	1385.52	3.7167	0.1159	0.5634
		3	1.4143	2.6632	18.0465	1214.98	5.3480	0.1152	0.5633
		5	1.3609	2.6677	18.2582	1195.57	5.4490	0.1149	0.5633
		10	1.2124	2.7635	19.6751	1089.61	6.3127	0.1102	0.5658
BSR14	0.28	0	1.8540	2.3386	15.9710	1365.16	3.5752	0.1094	0.5683
		3	1.1950	2.8067	19.4658	1115.70	6.4949	0.1155	0.5621
		5	1.1950	2.8059	19.4896	1113.48	6.4937	0.1151	0.5624
		10	1.1506	2.8218	20.1701	1061.30	6.7674	0.1103	0.5655
BSR15	0.16	0	2.0002	2.0858	15.3455	1374.07	2.7901	0.1056	0.5697
		3	1.4889	2.3847	17.6871	1189.36	4.2696	0.1079	0.5672
		5	1.4889	2.3862	17.7592	1182.52	4.2834	0.1070	0.5679
		10	1.3277	2.4519	19.1037	1076.09	4.8808	0.1020	0.5709
BSR21	0.28	0	2.0003	2.0910	15.6456	1336.05	2.8217	0.1008	0.5732
		3	1.2473	2.5448	19.2005	1088.34	5.3630	0.1092	0.5654
		5	1.2938	2.5440	19.0897	1096.93	5.2898	0.1082	0.5664
		10	1.2026	2.5599	19.9364	1032.34	5.6055	0.1040	0.5690
				With hyperons					
BSR1	0.16	0	1.4350	2.2080	17.3409	1185.70	3.8152	0.1148	0.5598
		3	1.3927	2.5626	18.3264	1167.25	5.0534	0.1094	0.5663
		5	1.3381	2.6048	18.6506	1146.57	5.3344	0.1102	0.5656
		10	1.0776	2.2462	20.6622	1013.41	6.7563	0.1104	0.5640
BSR7	0.28	0	1.5371	2.1690	17.2879	1178.07	3.5555	0.1057	0.5678
		3	1.2037	2.6337	19.6192	1071.48	5.8439	0.1095	0.5651
		5	1.2037	2.6377	19.6643	1068.61	5.8705	0.1092	0.5653
		10	1.0332	2.7217	21.1472	976.18	6.8786	0.1092	0.5643
BSR8	0.16	0	1.4183	1.8787	17.2356	1109.66	2.9017	0.1065	0.5653
		3	1.3653	2.2071	18.5589	1070.84	4.0096	0.1019	0.5700
		5	1.3172	2.2230	18.8248	1052.55	4.1482	0.1021	0.5697
		10	1.0621	2.3763	20.8572	935.77	5.4203	0.1039	0.55672
BSR14	0.28	0	1.5280	1.8421	17.3023	1090.73	2.7226	0.0977	0.5731
		3	1.2707	2.2698	19.3037	1024.55	4.4397	0.1017	0.5698
		5	1.2260	2.2667	19.5128	1008.00	4.5125	0.1019	0.5695
		10	1.0246	2.3552	21.1500	913.19	5.4471	0.1028	0.5679
BSR15	0.16	0	1.5859	1.7057	16.7056	1108.39	2.3219	0.0984	0.5723
		3	1.6335	1.9768	17.4187	1114.27	2.9793	0.0939	0.5765
		5	1.5759	1.9933	17.6797	1094.70	3.0904	0.0941	0.5763
		10	1.2260	2.1008	19.8371	949.14	4.0239	0.947	0.5749
BSR21	0.28	0	1.5534	1.7004	17.1506	1063.52	2.3441	0.0929	0.5772
		3	1.3381	2.0804	18.8595	1017.22	3.6870	0.0964	0.5739
		5	1.3382	2.0825	18.9108	1013.57	3.7010	0.0960	0.5742
		10	1.12246	2.1528	20.5559	911.91	4.4485	0.0963	0.5732