CONSTRAINTS ON NEUTRON STAR MASS-RADIUS RELATION BY EOS DERIVED FROM REALISTIC INTERACTIONS

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OUTLINE

- Introduction
- EOS and TOV equation
- Statistical methods to constraints of the EOS
- Results and discussion
- Conclusion

INTRODUCTION

- A neutron star is an amazing object with matter of more than 1.4 solar masses compressed into a sphere of radius about 10 km.
- Neutron stars are the densest and tiniest stars known to exist in the universe.
- Mass-radius(M-R) relation is important to determine the EOS in neutron stars. But at present, the observed M-R relation is very limited.
- In this work, we apply a statistical method to obtain the constraints on the EOS.

THE EQUATION OF STATE

- The EOS of nuclear matter is an important ingredient in the study of properties of neutron stars.

- Using realistic baryon-baryon interactions, we determine the EOS based on the Brueckner G-matrix theory

  nsc97e

  nsc97e+three-body force

  FG with QCD-cores(30z01)

TOLMAN-OPPENHEIMER-VOLKOV EQUATIONS

- Tolman-Oppenheimer-Volkov equations

$$\frac{dp}{dr} = -\frac{G}{c^4}\frac{(mc^2 + 4\pi p r^3)(\epsilon + p)}{r\left(r - \frac{2Gm}{c^2}\right)}$$

$$\frac{dm}{dr} = 4\pi \frac{\epsilon}{c^2} r^2$$

- By solving the TOV equation using EOS, masses and radii of neutron stars can be determined as functions of central pressure (or central baryon density).

Statistical methods to constraints of the EOS

Steiner APJ, 722:33-54, 2010

- Bayes theorem:

$$P(\mathcal{M}|D) = \frac{P(D|\mathcal{M})P(\mathcal{M})}{P(D)}$$

- $P(\mathcal{M})$ is the prior probability of the model $\mathcal{M}$ without any information from data D
- $P(D)$ is the prior probability of the data D
- $P(\mathcal{M}|D)$ is the conditional probability of model $\mathcal{M}$ given data D
- $P(D|\mathcal{M})$ is the conditional probability of the data D given the model $\mathcal{M}$

Statistical methods to constraints of the EOS

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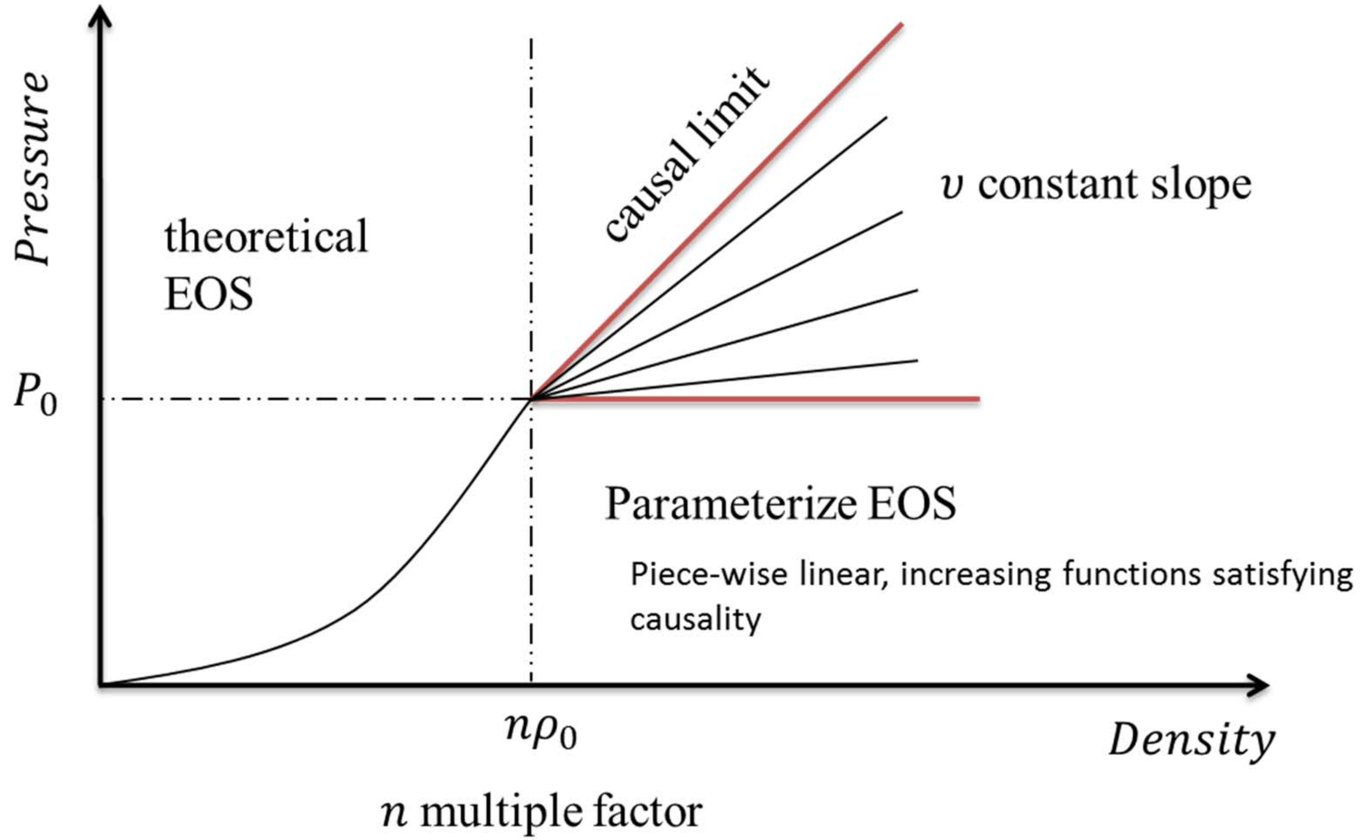
- For our problem, the model space consists of all of the parameters for the EOS, $p_{i=1,\ldots,N_p}$ and values for all of the masses of the neutron stars for which we have data, $M_{i=1,\ldots,N_M}$

$$\mathcal{M}(p_1, p_2, \ldots, p_{N_p}, M_1, M_2, \ldots, M_{N_m}) \stackrel{\text{def}}{=} \mathcal{M}(p_{i=1,\ldots,N_p}, M_{i=1,\ldots,N_M})$$

- From the parameters p_i we can construct the EOS and solve the TOV equations to get a R_i for each of neutron star masses M_i

STATISTICAL METHODS TO CONSTRAINTS OF THE EOS

At the first step, we introduce a very simple model (two parameters model)



Statistical methods to constraints of the EOS

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- We construct our data D as a set of $N_M = 6$ probability distributions, $\mathcal{D}_i(M,R)$ in the (M,R) plane, which are all normalized to unity, i.e.,

$$\int_{M_{low}}^{M_{high}} dM \int_{M_{low}}^{R_{high}} dR\mathcal{D}_i(M,R) = 1\ \forall i$$

- Choose

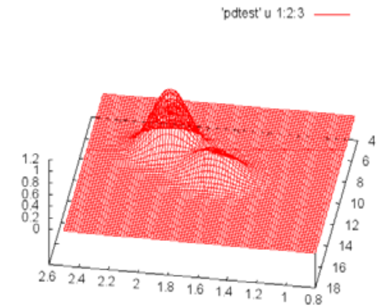
$$M_{low} = 0.8M_{\odot};\ M_{high} = 2.5M_{\odot}$$

$$R_{low} = 5\ km;\ R_{high} = 18\ km$$

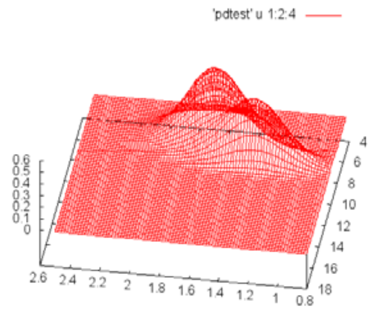
Statistical methods to constraints of the EOS

N_M	**Name**	**Mass (center)**	**Reference**
1	4U 1608-52	1.74	APJ, 712:964-973, 2010
2	EXO 1745-248	1.4	APJ, 693:1775-1779, 2009
3	4U 1820-30	1.58	APJ, 719:1807-1812, 2010
4	M13	1.3	APJ, 671:727-733, 2007
5	X7	2.2	APJ, 644:1090-1103, 2006
6	ω Cen	1.66	APJ, 671:727-733, 2007

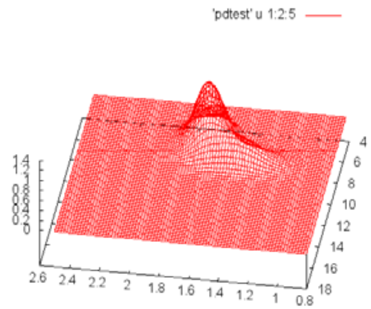
PROBABILITY DISTRIBUTIONS $\mathcal{D}_i(M, R)$ FOR 6 NEUTRON-STARS



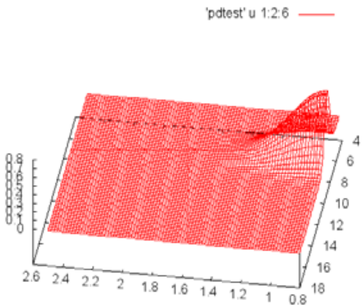
4U 1608-52



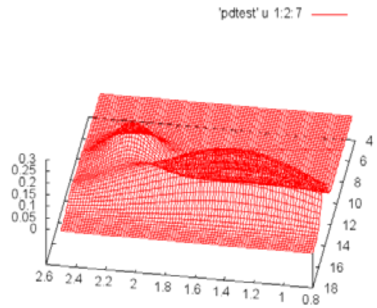
EXO 1745-248



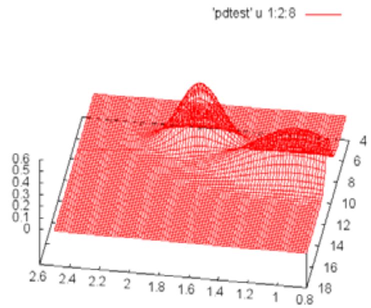
4U 1820-30



M13



X7



ω Cen

STATISTICAL METHODS TO CONSTRAINTS OF THE EOS

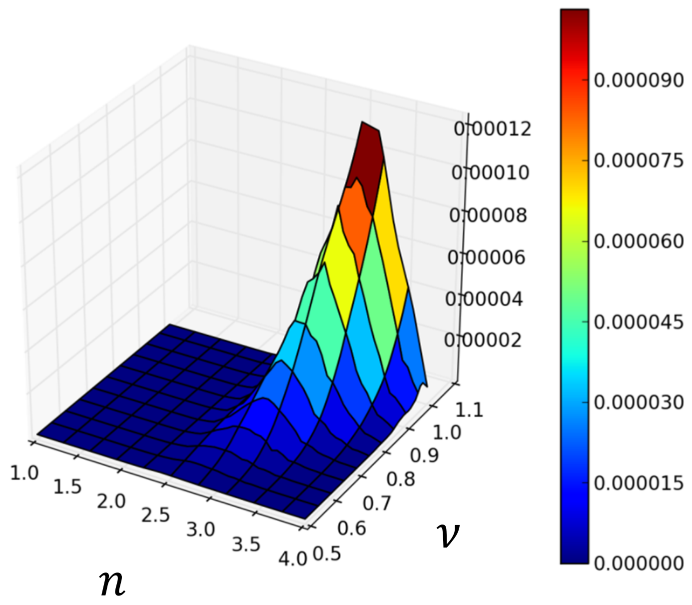
Steiner APJ, 722:33-54, 2010

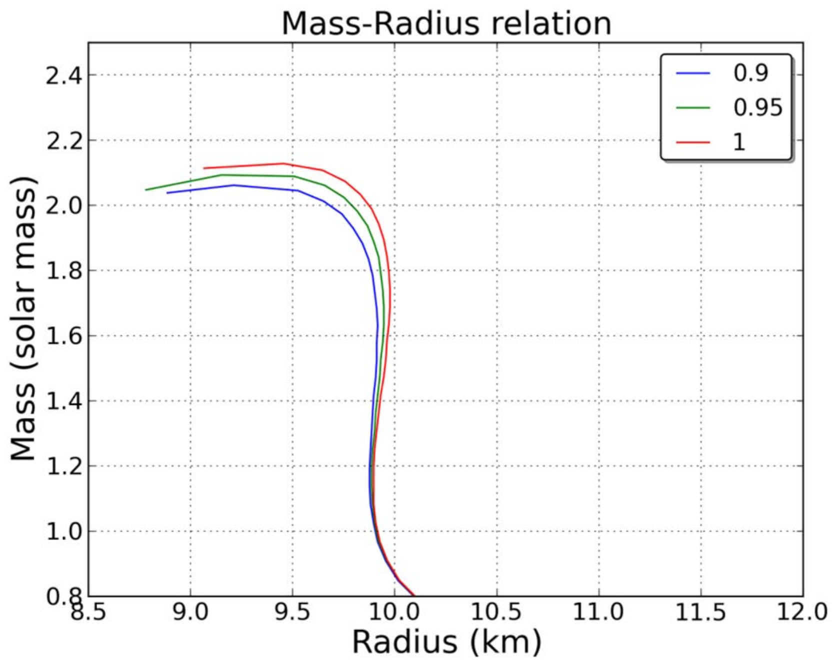
- Assume that

$$P[D|\mathcal{M}(p_{1\ldots N_p}, M_{1\ldots N_M})] \propto \prod_{i=1\ldots N_M} \mathcal{D}_i(M,R)|_{M=M_i, R=R(M_i)}$$

- This implicitly assumes that all of the data distributions $\mathcal{D}_i$ are independent of each other and also independent of the model assumptions and prior distribution

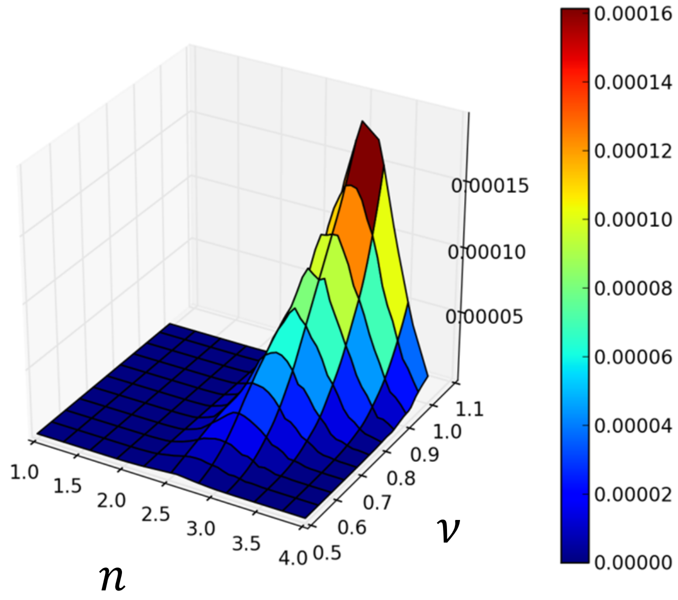
Fermi Gas N-only model

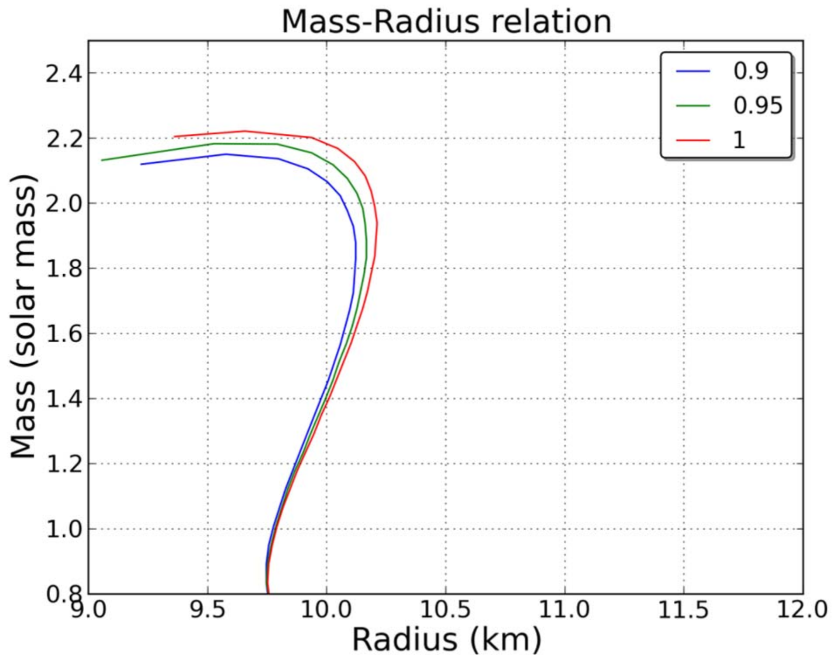




$n = 3.4$

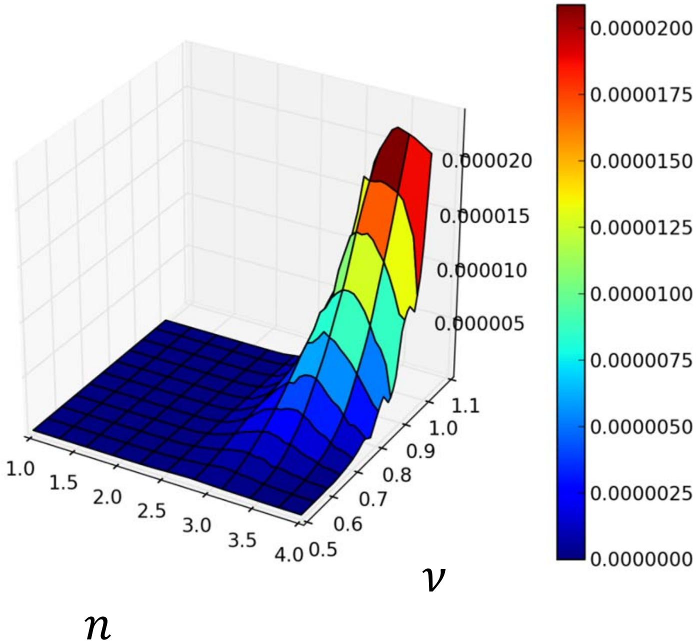
NSC97e WITH OCTET BARYONS

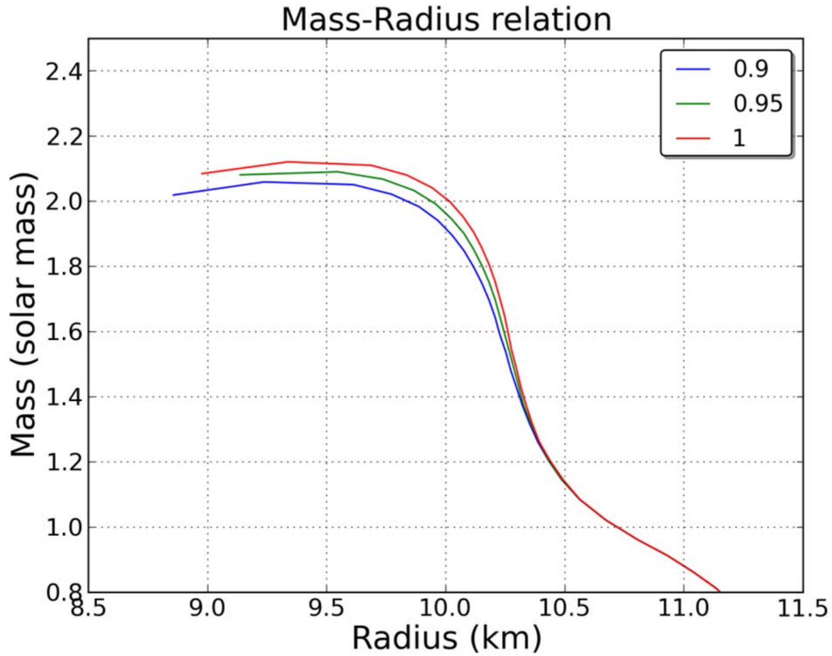




$n = 3.2$

NSC97E WITH OCTET BARYONS + 3BF





$n = 3.6$

CONCLUSION

- Using realistic baryon-baryon interactions, we determine the EOS of high-density beta-stable baryonic matter and calculate the mass-radius relation of neutron stars by solving the TOV equation.
- Our aim is to impose constraints on the mass-radius relation of neutron stars.
- Based on probability, we can decide which is the most suitable $n - \upsilon$ (parameters in EOS).
- If observations improve, our calculation will be more effective.

Thank you very much!