Constraints on the nuclear symmetry energy

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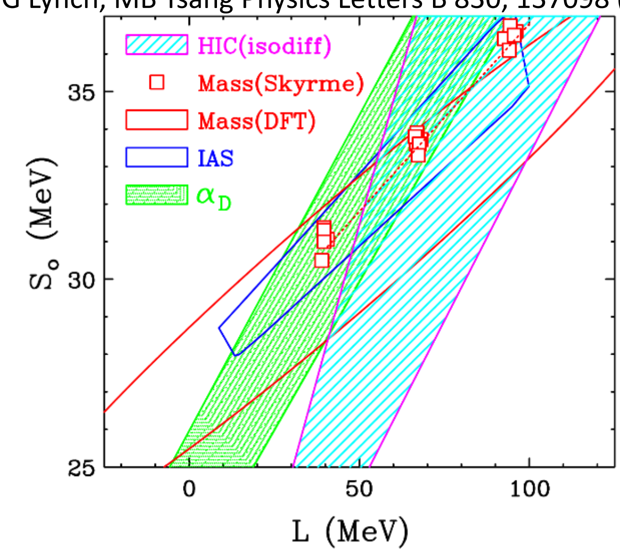
Methods for EoS Constraints

- Find observables sensitive to Symmetry Energy (SE)
- Determine what each observable constrains such as $S(\rho_s)$, $L(\rho_s)$, $P_{sym}(\rho_s)$ … and at what density or range of densities ρ_s the SE is constrained.
- Choose a technique, such as Pearson correlations, Bayesian inference, crossover technique, analysis of the correlations of fit parameters along curves of constant χ^2.
- Find the "sensitive" density ρ_s that is most accurately probed by that observable and the SE at that density

WG Lynch, MB Tsang Physics Letters B 830, 137098 (2022)



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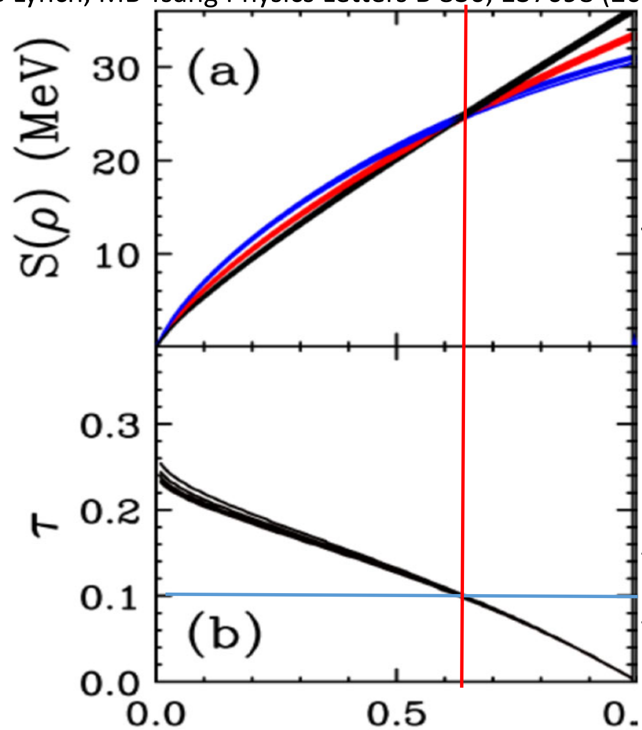

B.A. Brown, Phys. Rev. Lett. 111, 232502 (2013)

Comparison of Crossover and inclination analyses techniques.

$$\tau = \Delta S_0 / \Delta L = -\partial\left(\partial S(\rho_s)/\partial L\right)/\left(\partial S(\rho_s)/\partial S_0\right);$$

τ depends monotonically on ρ_s

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Bayesian determination of SE

$$S(\rho) = S_{kin}(\rho) + S_{int}(\rho)$$

$$S_{int}(\rho) = S_{int}(\rho_{01}) + S'_{int}(\rho - \rho_{01}) + \frac{1}{2}S''_{int}(\rho - \rho_{01})^2 + \frac{1}{6}S'''_{int}(\rho - \rho_{01})^3$$

Where $S_{int}(0) \equiv 0$

$$S_{kin}(\rho) = S_{kin}(\rho_0)(\rho/\rho_0)^{2/3}\,\mathrm{MeV}$$

And “fit” is insensitive to $S_{kin}(\rho_0)$ for $12\mathrm{MeV} < S_{kin}(\rho_0) < 13\mathrm{MeV}$

S_{01}	24.0±0.5 MeV
L_{01}	53.9±0.9 MeV
K_{01}	-42±31 MeV

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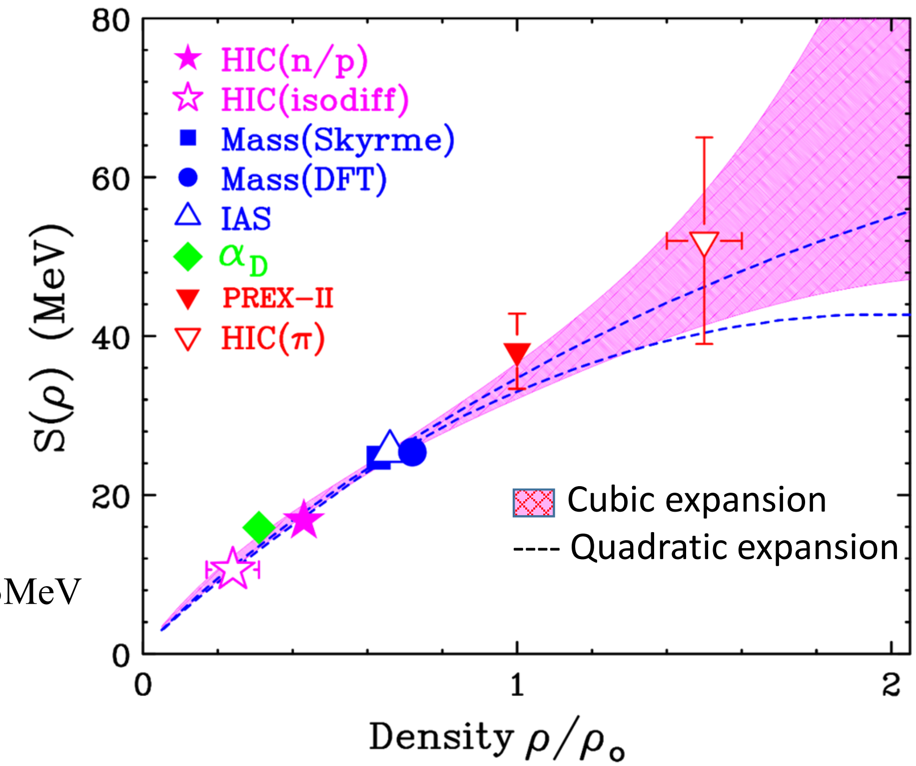

Bayesian Determination of pressure

Extrapolation to Neutron Stars

- Experimental data appear more consistent with stiffer NICER EoS.
- Low density data and quadratic EOS leads to underprediction of NS EoS
- With the cubic EoS, the overall trend of existing data extrapolates to the NICER constraints, while extrapolations of the quadratic EoS appear to provide too little pressure at high density.
- This might be less evident in a more constrained density functional.

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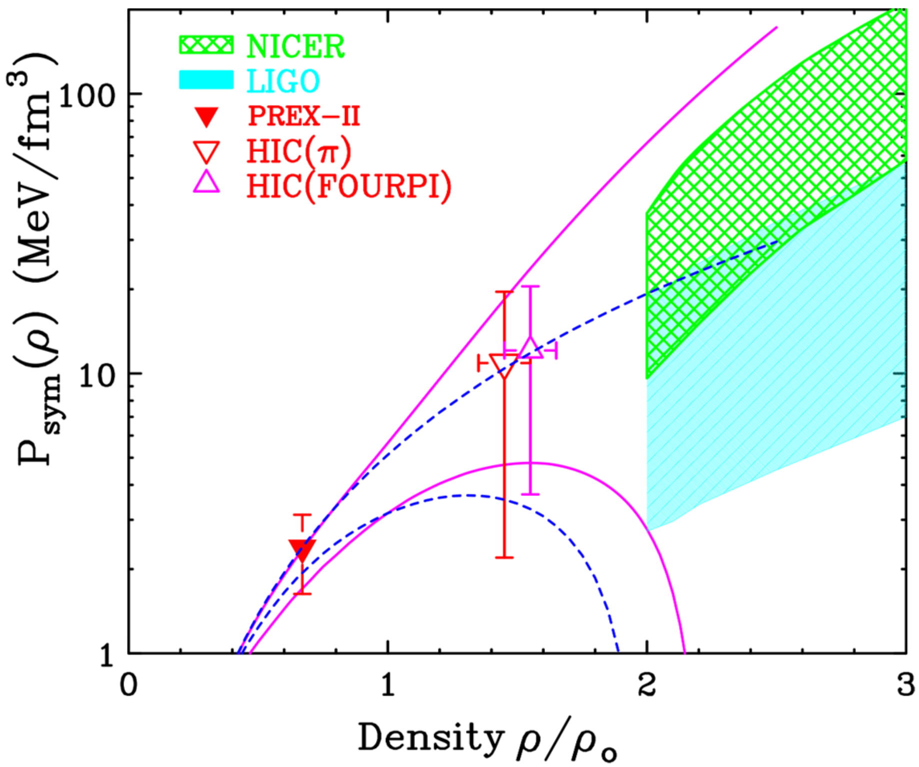

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Bayesian determination of SE Compared to Pawel's IAS+skins

$$S(\rho) = S_{kin}(\rho) + S_{int}(\rho)$$

$$S_{int}(\rho) = S_{int}(\rho_{01}) + S'_{int}(\rho - \rho_{01}) + \frac{1}{2}S''_{int}(\rho - \rho_{01})^2 + \frac{1}{6}S'''_{int}(\rho - \rho_{01})^3$$

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S_{01}	24.0±0.5 MeV
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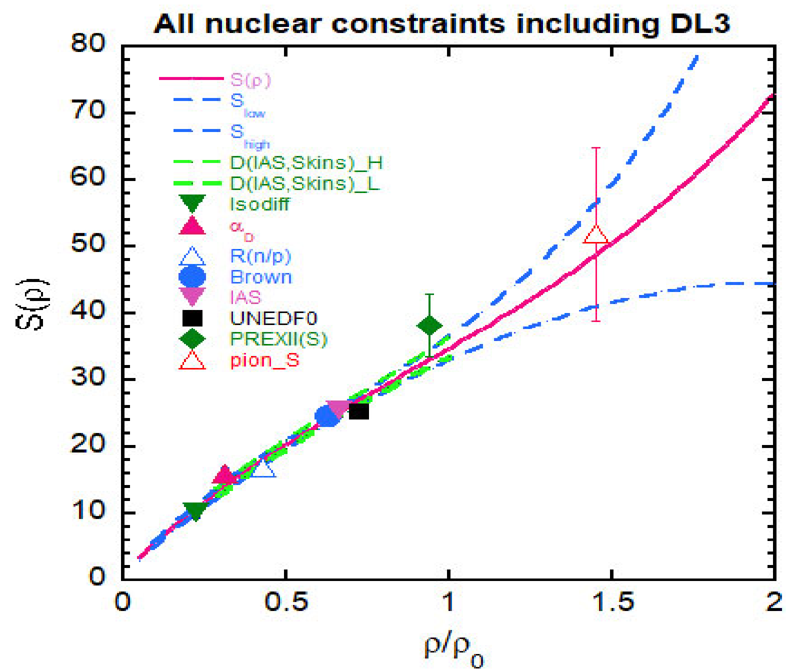
$\Rightarrow$

ρ_{cc}	.069±0.006 fm^{-3}
P_{cc}	0.33±0.07 MeV/fm^3



List of constraints on the SE used (not used) in the fits:

Constraint	ρ/ρ_0	$S(\rho)$ (MeV)	L_{01} (MeV)	L (Mev)	K_{sym} (Mev)	P_{sym} (MeV/fm^3)
Masses	0.63	24.7±0.8				
Masses	0.72	25.4±1.1				
IAS	0.66	25.5±1.1				
HIC (I_{diff})	0.22	10.3±1.0				
α_D	0.31	15.9±1.0				
HIC(n/p)	0.43	16.8±1.2				
PREXII	0.67		71.5±22.6			
HIC(π)	1.45	52±13		79.5±38	47±256	10.9±8.7
HIC(n/p flow)	1.5	24.7±0.8		85±0.8	96±390	12.1±8.4
NICER-P_{SM}	2	24.7±0.8				24±14
NICER-P_{SM}	2	24.7±0.8				72±41
LIGO-P_{SM}	2.5	24.7±0.8				10±7
LIGO-P_{SM}	2.5	24.7±0.8				22±15

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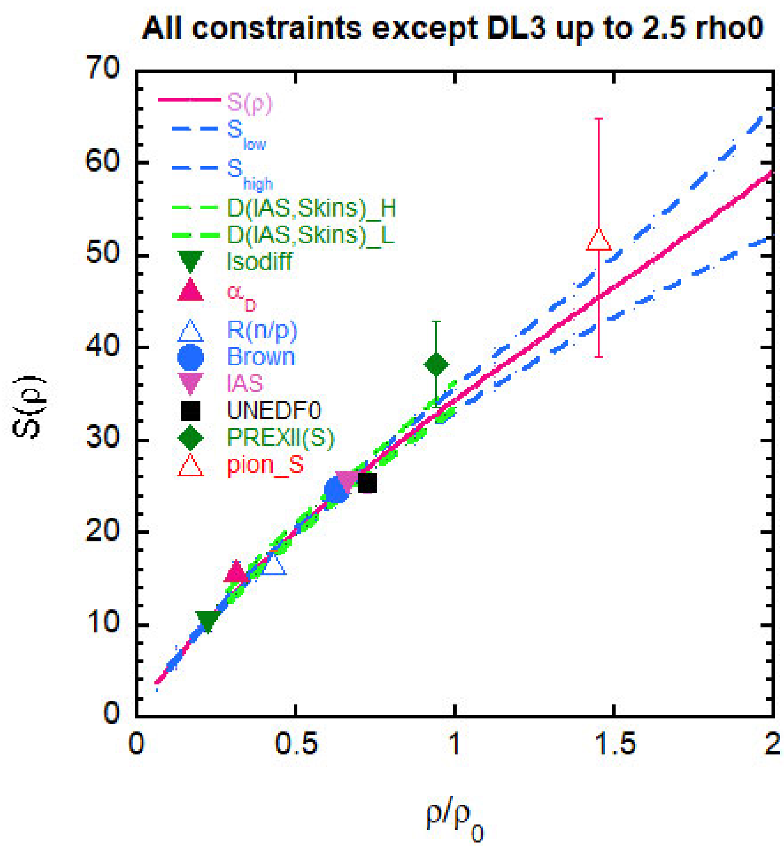
Symmetry Energy with constraints from NS

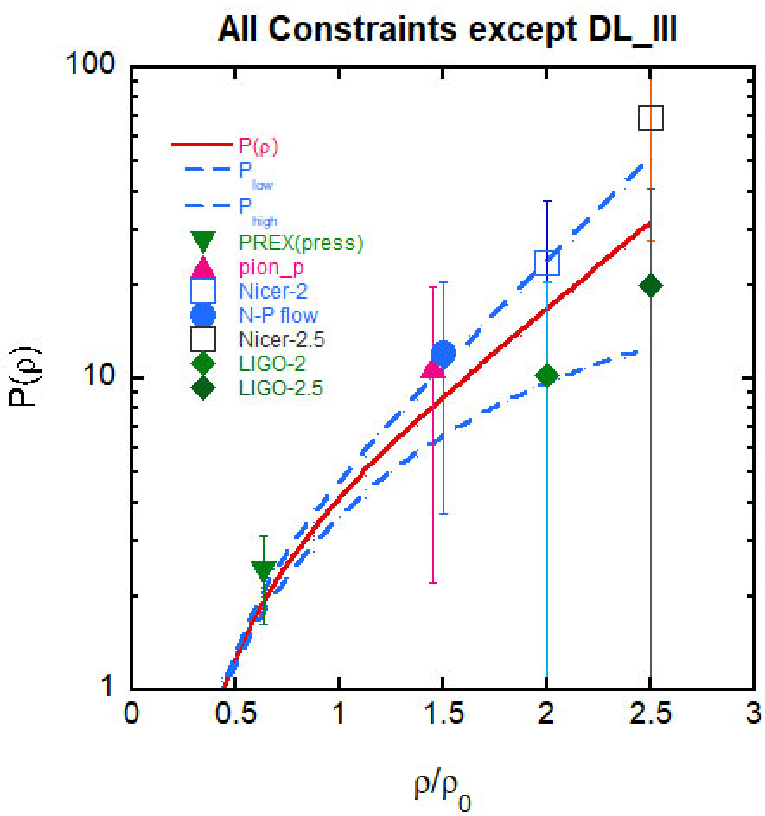
- Assuming the NS EoS is close to that of neutron matter, one may extrapolate the symmetry to the NS interior by assuming $P_{sym} \simeq P_{ns} - P_{sm}$ for matter in the NS interiors.

- Within that approximation, we can extend the constraint contours to 2.5 ρ_0. A better extrapolation obtained by solving the TOV equation will be presented next Tuesday by Betty Tsang.



Symmetry Pressure with constraints from NS

- Assuming the NS EoS is close to that of neutron matter, one may extrapolate the symmetry to the NS interior by assuming $P_{sym} \simeq P_{ns} - P_{sm}$ for matter in the NS interiors.
- Within that approximation, we can extend the constraint contours to 2.5 ρ_0. A better extrapolation obtained by solving the TOV equation will be presented next Tuesday by Betty Tsang.
- Addition of the LIGO constraint pulls the pressure down at higher densities.



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