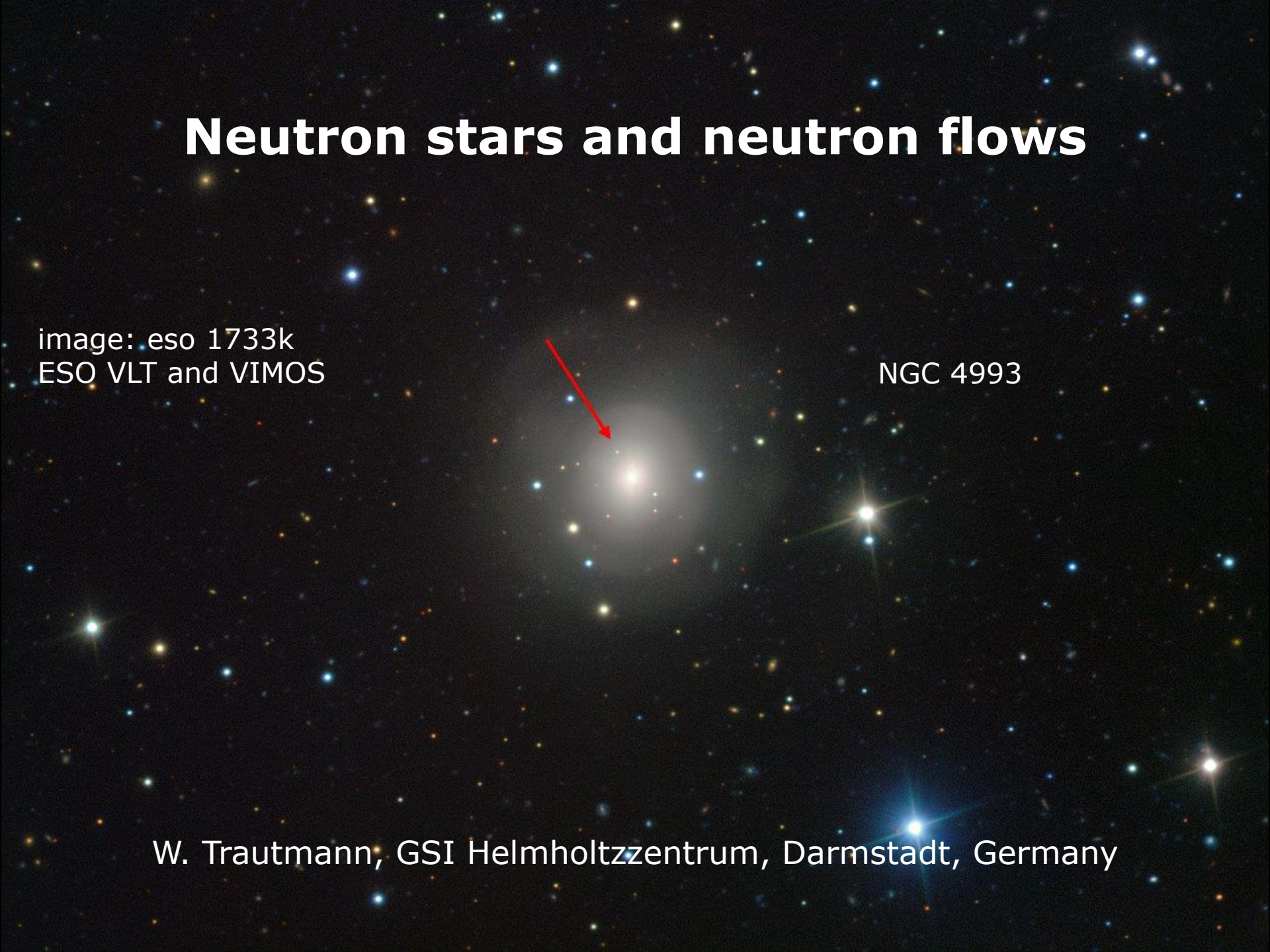
Neutron stars and neutron flows



W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany

GW170817 and ASY-EOS

image: eso 1733d
ESO VLT and MUSE

NGC 4993

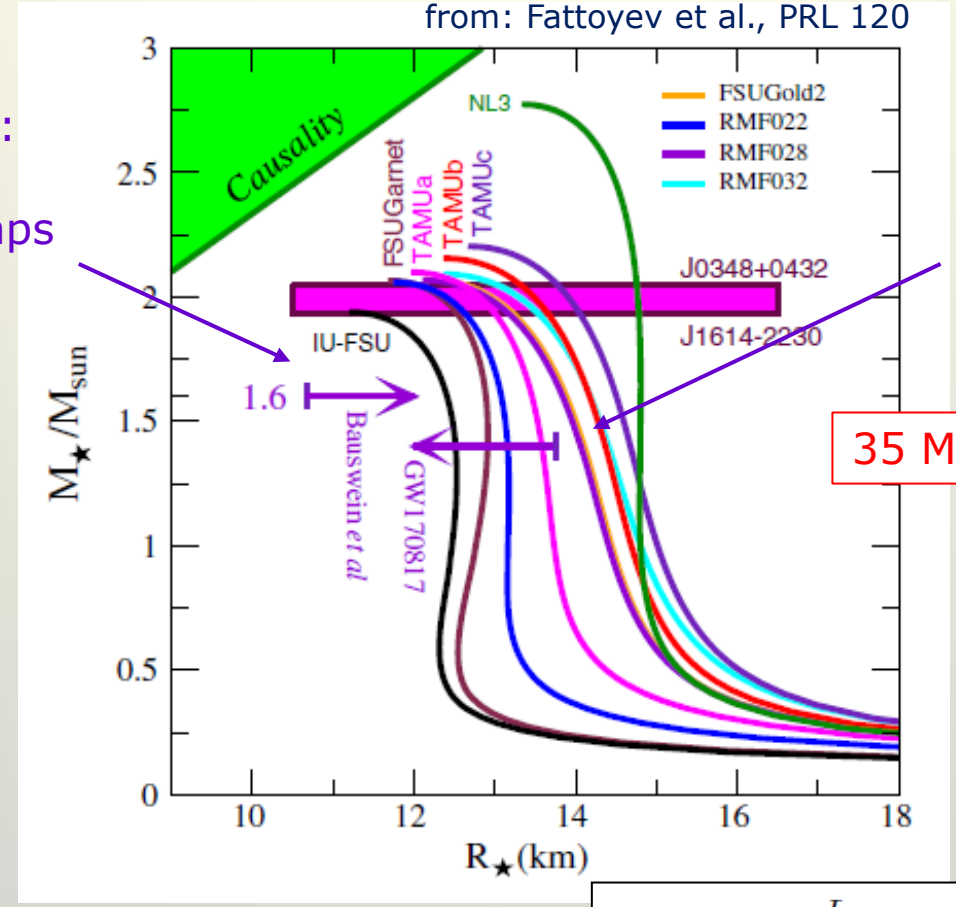
W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany

pre- and post-merger dynamics

Bauswein et al.:
max mass +
no prompt collaps

ApJL 850 (2017)

from: Fattoyev et al., PRL 120



Fattoyev et al.:
max mass +
tidal deformability

PRL 120 (2018)

35 MeV < L < 90 MeV

cf.
20 < L < 70 from
^{48}Ca neutron skin
Zenihiro+ arxiv(2018)

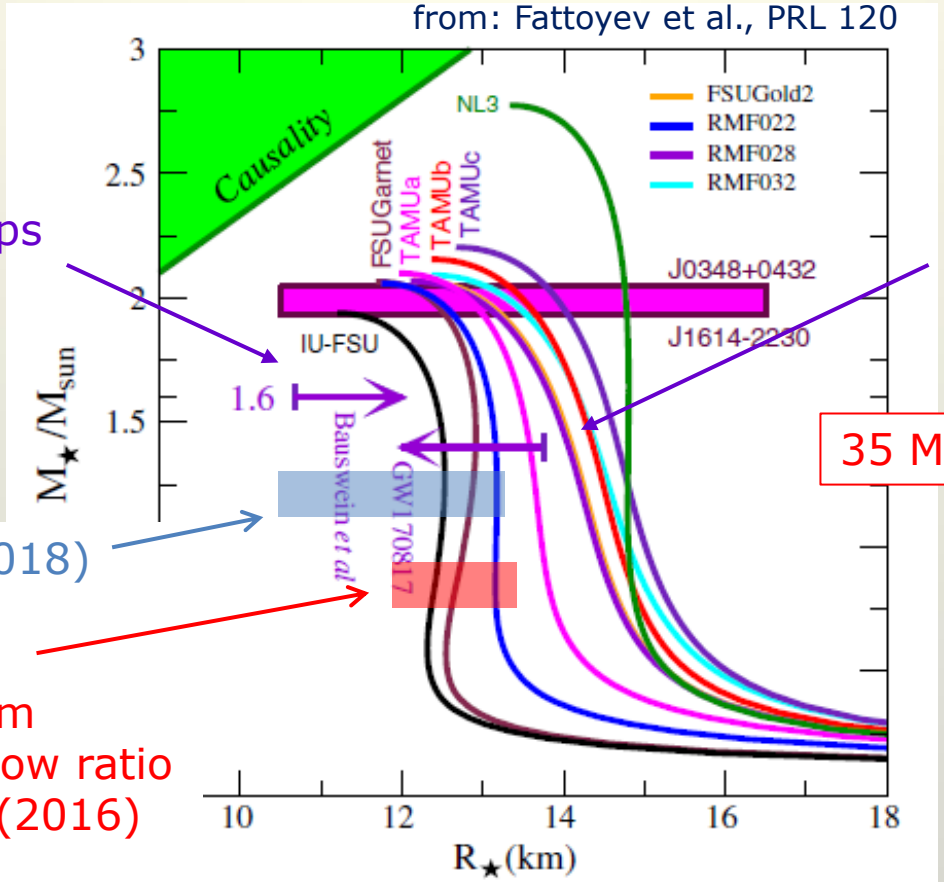
$$S(\rho) = S_0 + \frac{L}{3}\frac{\rho-\rho_0}{\rho} + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho}\right)^2 + \cdots$$

ASY-EOS: elliptic flow ratio ⟶ L ⟶ p_0 ⟶ $R_{1.4}$

Bauswein et al.:
max mass +
no prompt collaps

ApJL 850 (2017)

from: Fattoyev et al., PRL 120



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LIGO-VIRGO (2018)

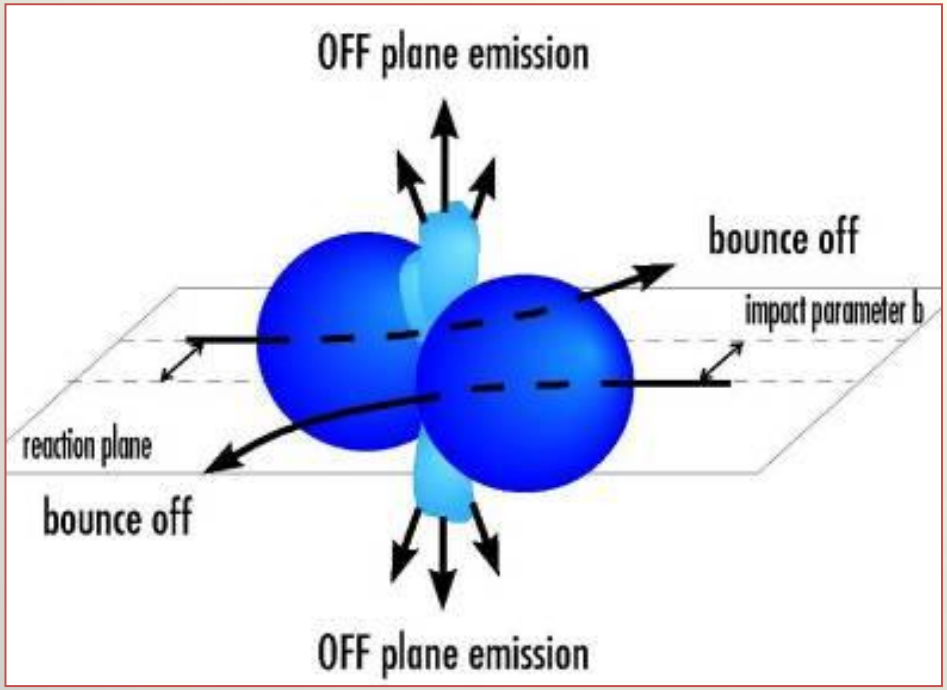
ASY-EOS:
59 < L < 85 from
Au+Au elliptic flow ratio
Russotto+ PRC (2016)

p_0 vs $R_{1.4}$: Lattimer & Prakash,
Phys. Rep. (2016), Fig. 8

$$S(\rho) = S_0 + \frac{L}{3}\frac{\rho-\rho_0}{\rho} + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho}\right)^2 + \cdots$$

pressure gauge for neutron-star matter

Buchwald/Frankfurt



tested with existing **FOPI-LAND** data

^{197}Au + ^{197}Au @ 400 A MeV

Russotto et al. PLB 697 (2011)

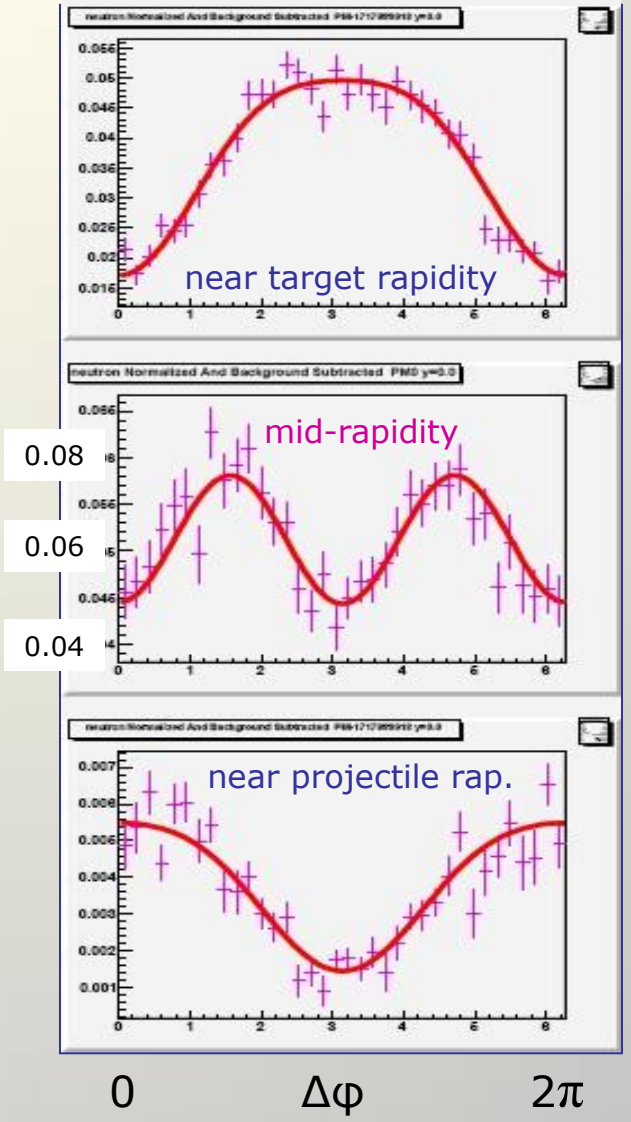
ASY-EOS experiment in 2011

Russotto et al., PRC 94 (2016)

FOPI-LAND data

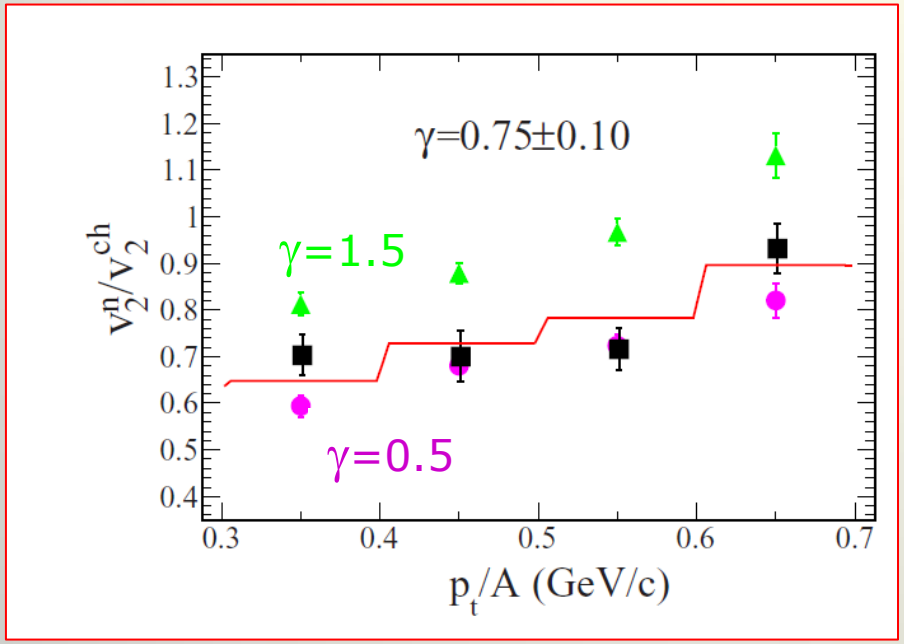
neutrons, b ≈ 5-7 fm

fit with Fourier expansion



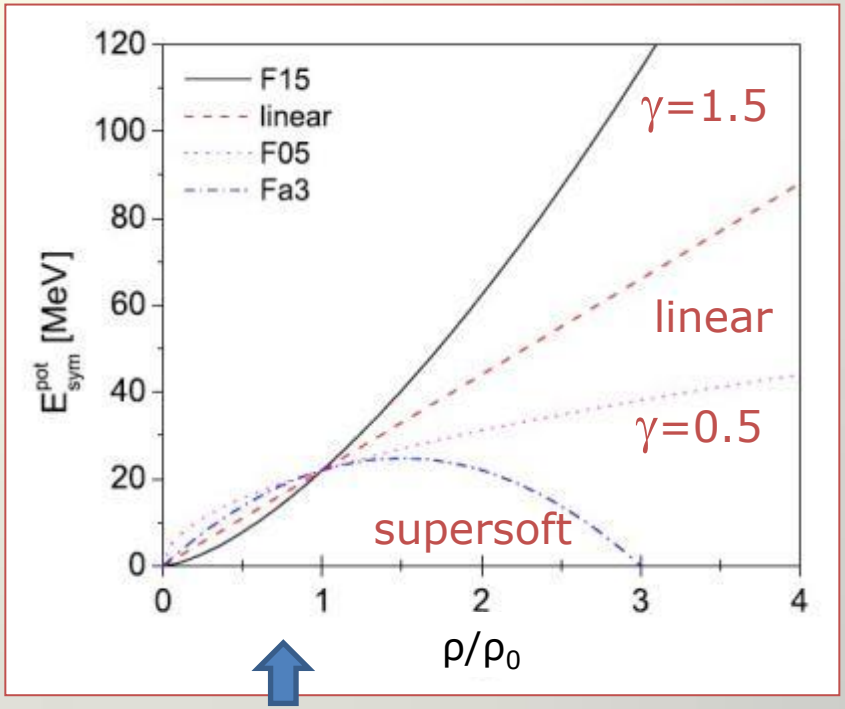
ASY-EOS: flow ratio vs transverse momentum

data
Au + Au 400 MeV/nucleon



P. Russotto et al., PRC 94, 034608 (2016)

parametrization
in transport theory: UrQMD, Q.F. Li et al.



$\mathbf{E_{sym}(\rho)} = 22\ \text{MeV}\cdot(\rho/\rho_0)^{\gamma} + 12\ \text{MeV}\cdot(\rho/\rho_0)^{2/3}$

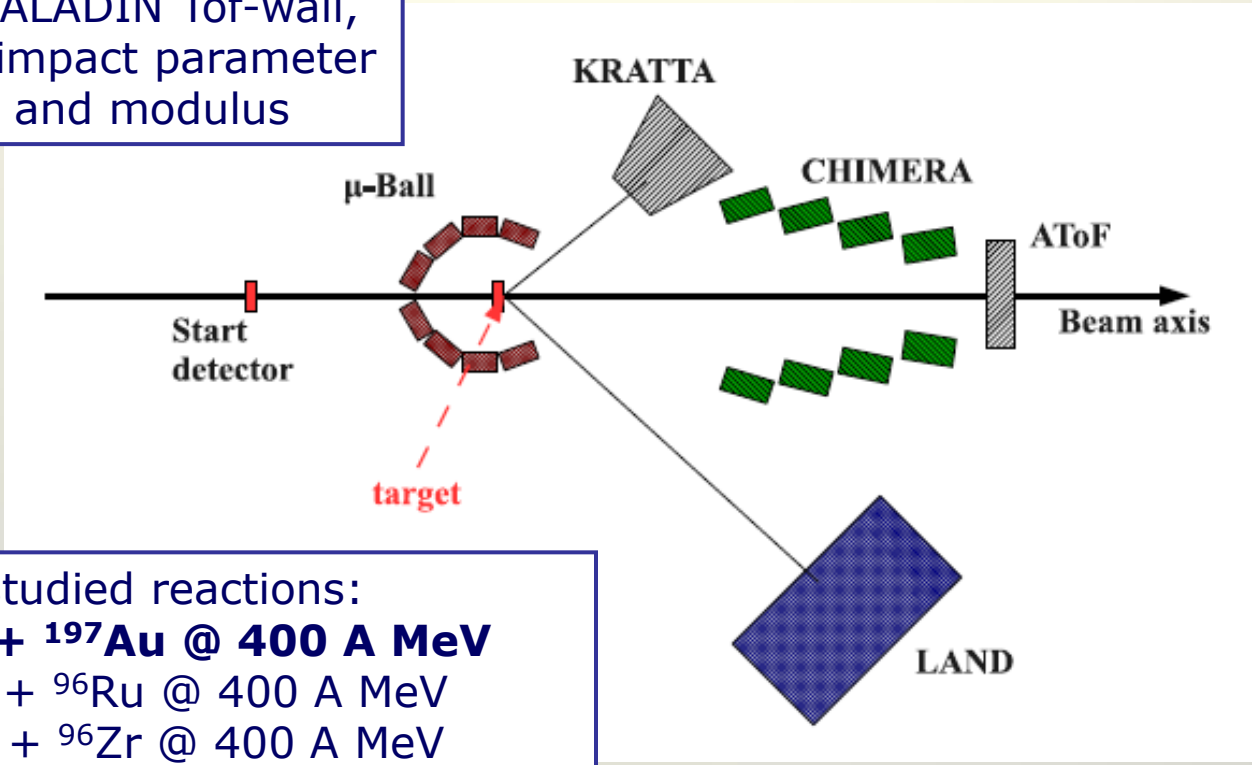
final: $\gamma = 0.72 \pm 0.19$ (incl. syst. error)

$E_A(\rho,\delta) = E_A(\rho,0) + \mathbf{E_{sym}(\rho)} \cdot \delta^2 + O(\delta^4)$

asymmetry parameter $\delta = (\rho_n - \rho_p)/\rho$

ASY-EOS experiment S394 in May 2011

CHIMERA, ALADIN Tof-wall, μ-ball, for impact parameter orientation and modulus



studied reactions:

^{197}Au + ^{197}Au @ 400 A MeV

^{96}Ru + ^{96}Ru @ 400 A MeV

^{96}Zr + ^{96}Zr @ 400 A MeV

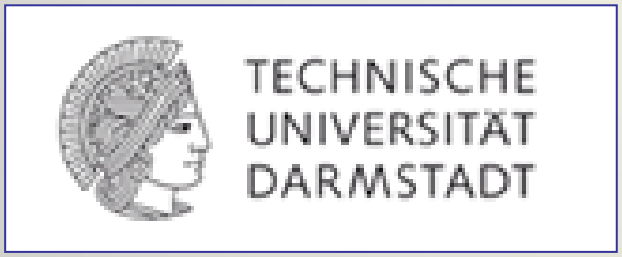
Constraining the Symmetry Energy at Supra-Saturation Densities with Measurements of Neutron and Proton Elliptic Flows

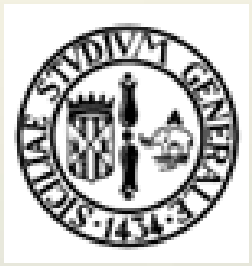
Co-Spokespersons: R.C. Lemmon and P. Russotto

very international

spokespersons: P. Russotto (Catania)
R.C. Lemmon (Daresbury)

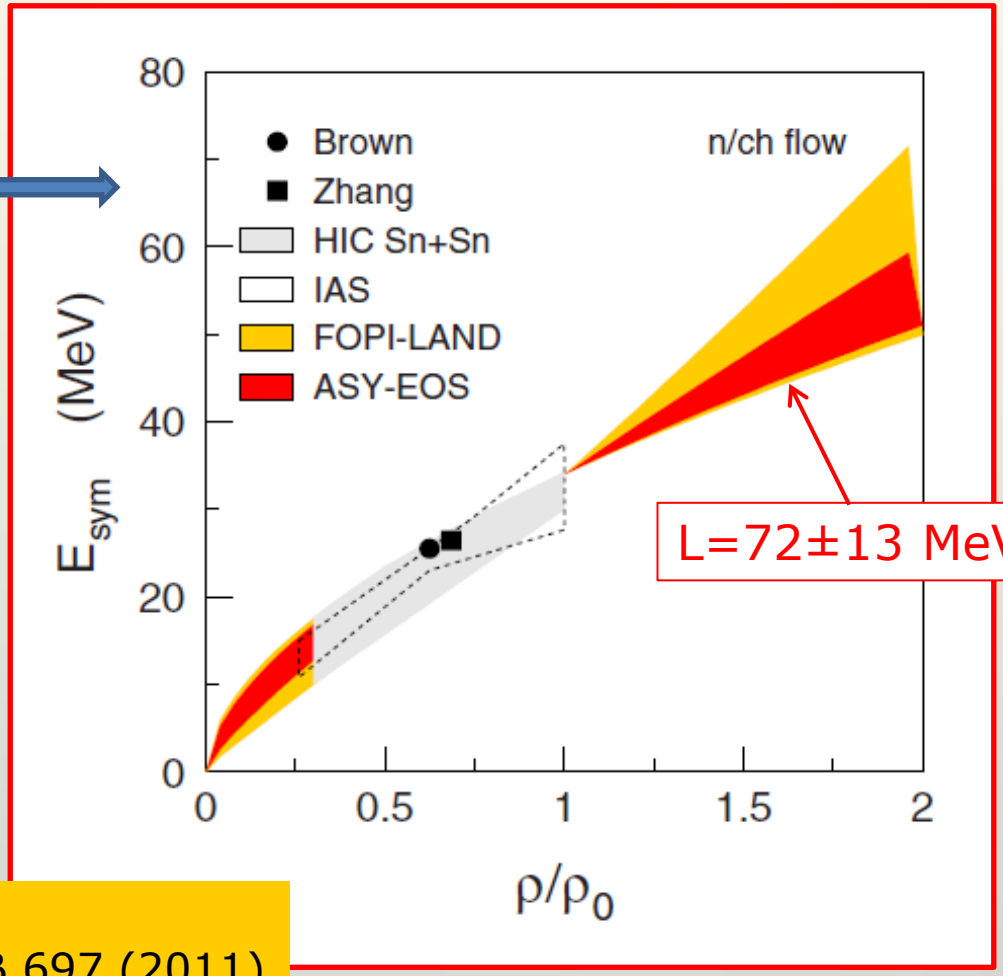
P. Russotto, PRC 94, 034608 (2016)
93 authors from 14 countries





neutron vs charged-particle elliptic flow ratios

compiled by
Horowitz et al.,
JPhysG (2014)

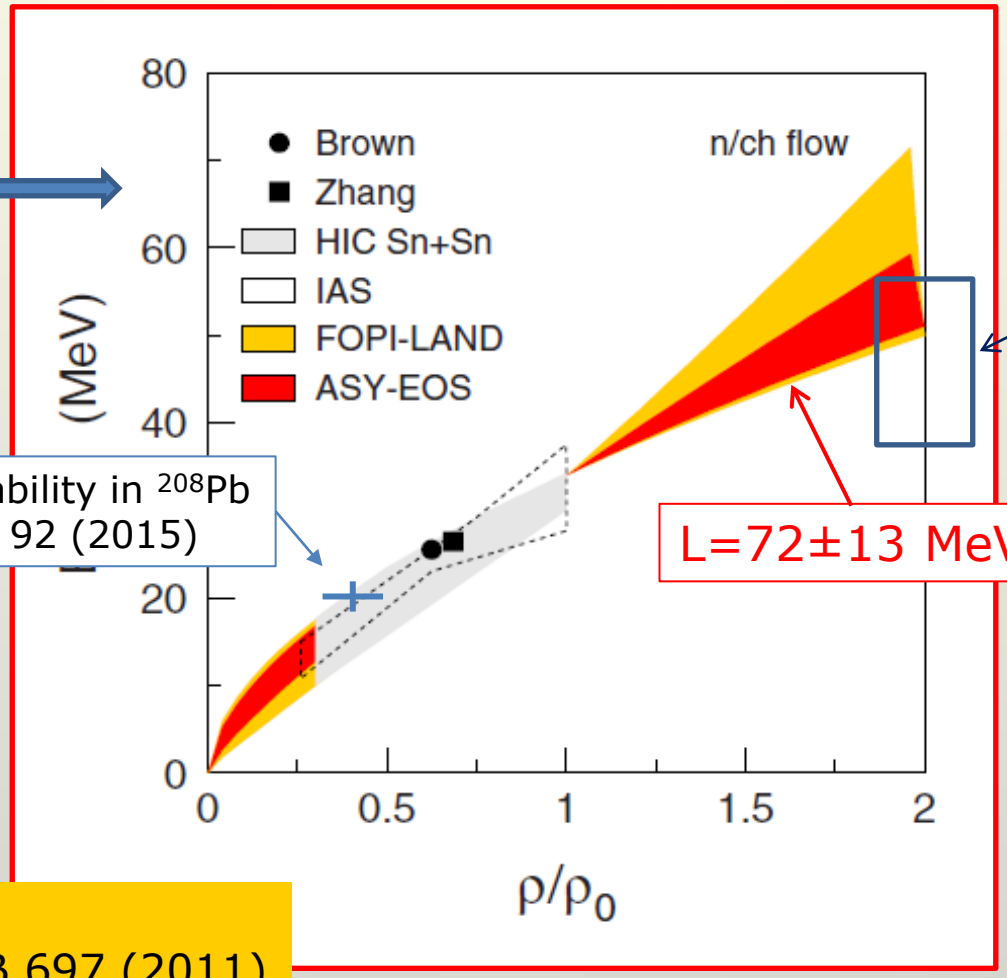


FOPI-LAND:
Russotto+ PLB 697 (2011)

ASY-EOS:
Russotto+ PRC 94 (2016)

consistency at sub- and supra-saturation density

compiled by
Horowitz et al.,
JPhysG (2014)



neutron star
X-ray observations
Zhang & Li
arXiv:1807.07698
E_{sym} ($2\rho_0$) =
47 ± 10 MeV

electric dipole polarizability in ^{208}Pb
Zhang and Chen, PRC 92 (2015)

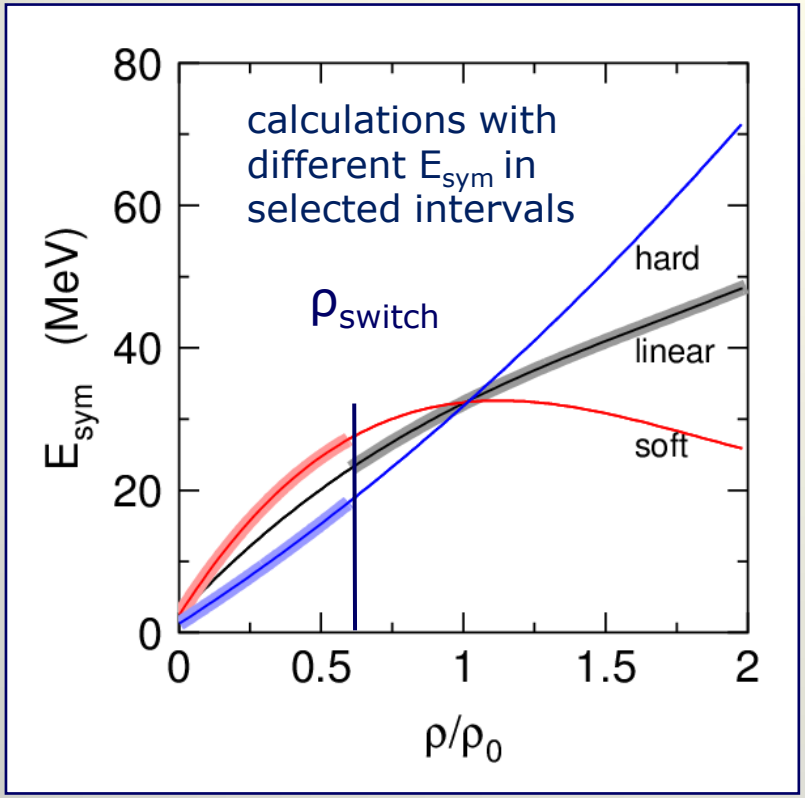
L=72±13 MeV

FOPI-LAND:
Russotto+ PLB 697 (2011)

ASY-EOS:
Russotto+ PRC 94 (2016)

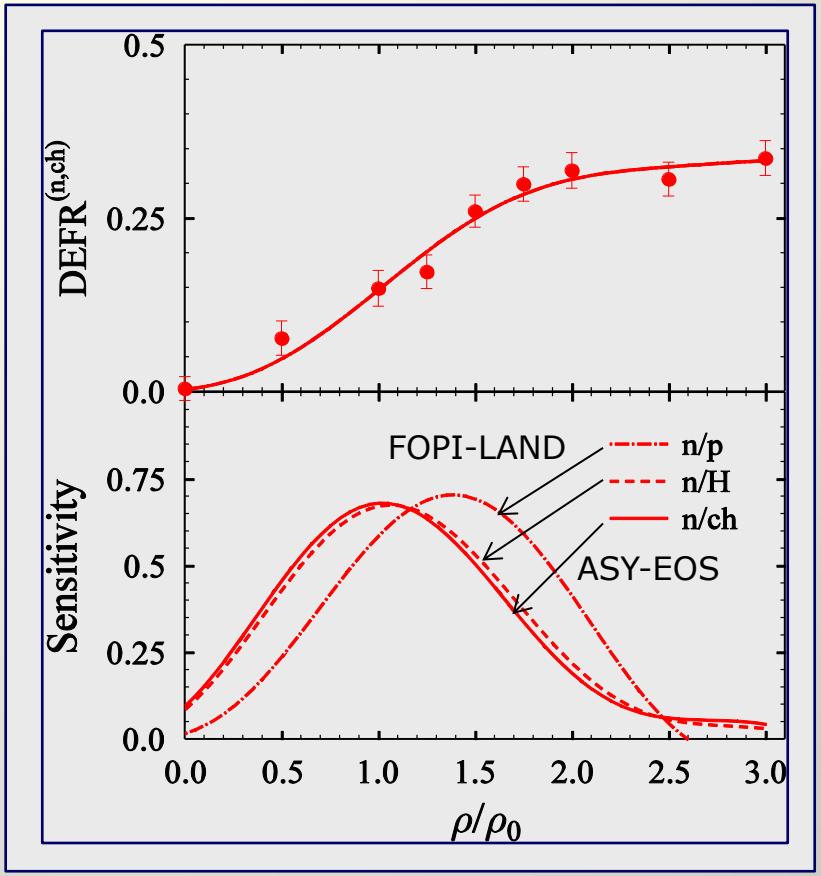
sensitivity to density

Dan Cozma using Tübingen QMD



graphics by Y. Leifels

Difference of **E**lliptic-**F**low **R**atio

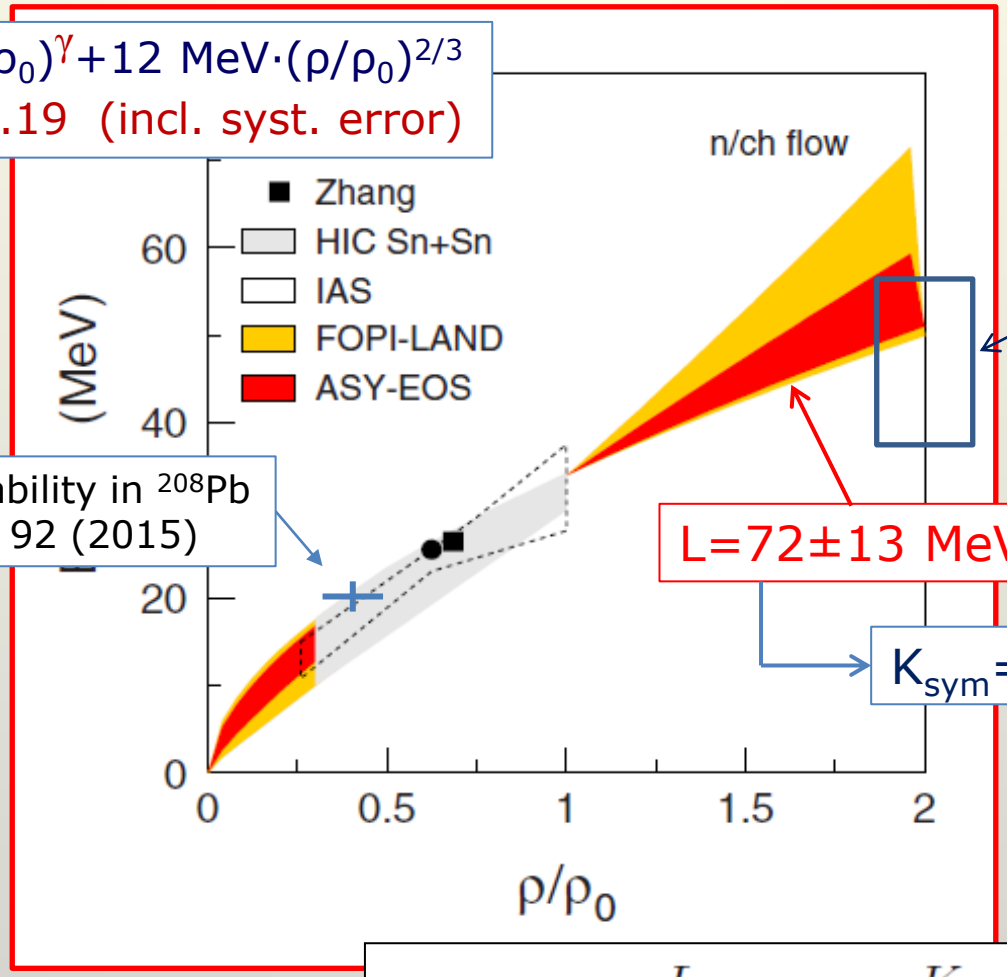


Russotto+ PRC 94, 034608 (2016)

lifting the model dependence

E_{sym} = 22 MeV·$(\rho/\rho_0)^{\gamma}$+12 MeV·$(\rho/\rho_0)^{2/3}$

final: γ = 0.72 ± 0.19 (incl. syst. error)



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electric dipole polarizability in ^{208}Pb
Zhang and Chen, PRC 92 (2015)

L=72±13 MeV

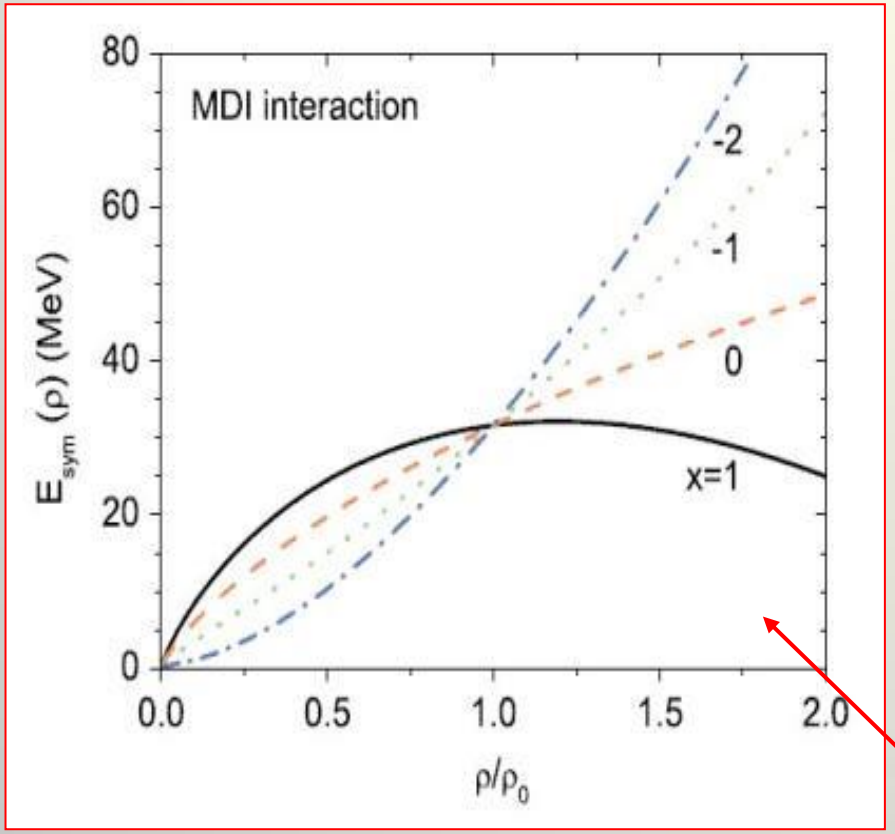
K_{sym}=-70 to -40 MeV

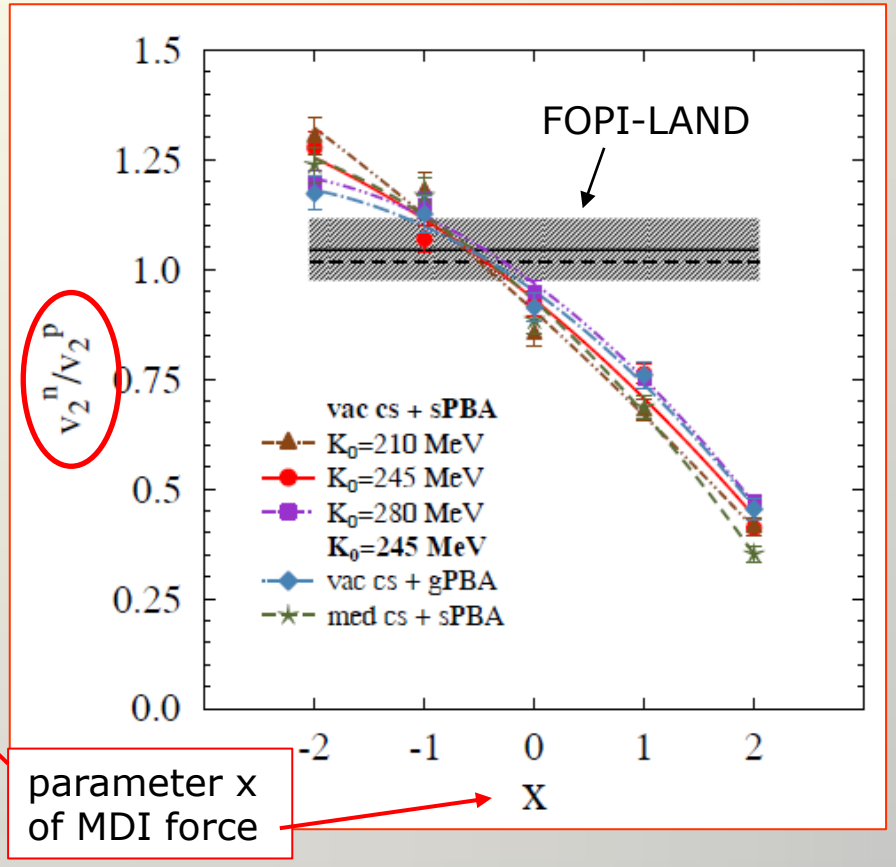
$$S(\rho) = S_0 + \frac{L}{3}\frac{\rho-\rho_0}{\rho} + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho}\right)^2 + \cdots$$

perspectives for the curvature K_{sym}

M.D. Cozma, EPJA 54:40 (2018)
MDI force as starting point: param x
new density depend. term: param y

independence of model assumptions
npEFR important but has large error
➞ new data with isotopic resolution!



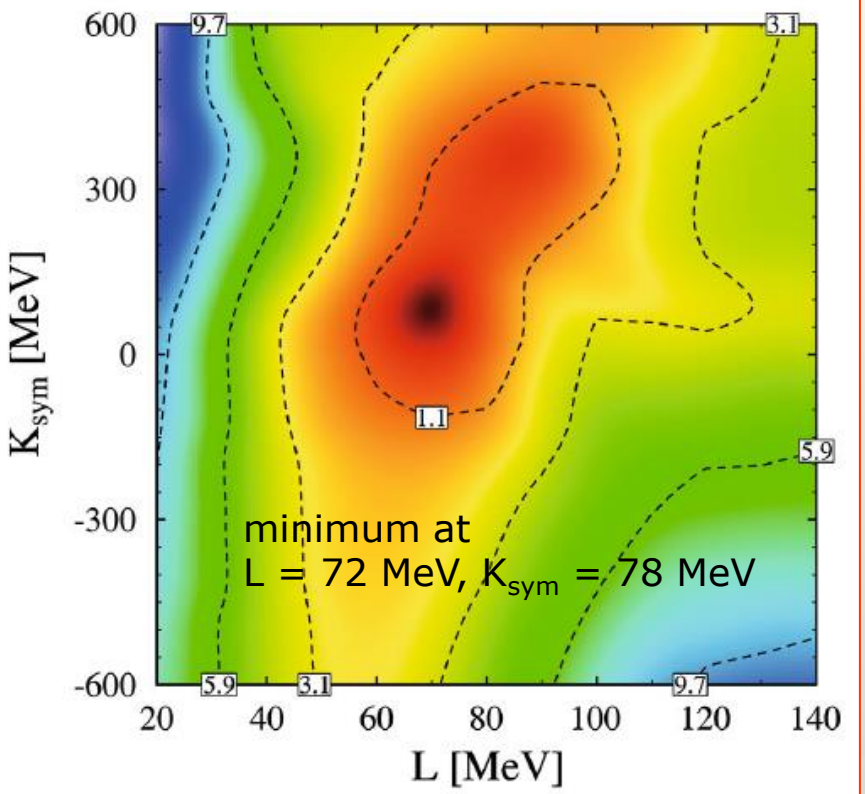


parameter x
of MDI force

perspectives for the curvature K_{sym}

continued with **MDI2**:
FOPI-LAND, ASY-EOS, FOPI data
and E_{sym}=25.5 MeV at ρ=0.1 fm^{-3}

M.D. Cozma, EPJA 54:40 (2018)



with additional corrections:
e.g., energy conservation
proton to cluster yield ratios

L = 85 ± 32 MeV
K_{sym} = 96 ± 395 MeV

315 (exp)±170(th)±166(sys)

errors contain all individual uncertainties

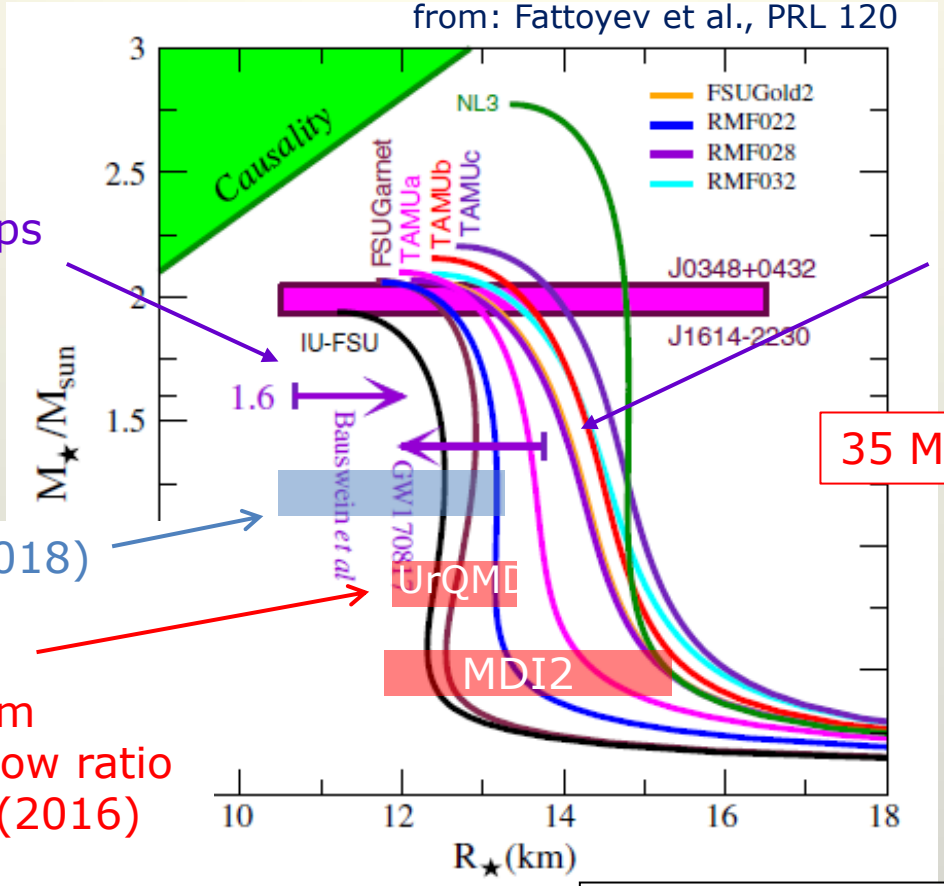
large contribution
to the errors from **npEFR**

ASY-EOS and MDI2 ⟹ $R_{1.4}$ > 11.6 km

Bauswein et al.:
max mass +
no prompt collaps

ApJL 850 (2017)

from: Fattoyev et al., PRL 120



Fattoyev et al.:
max mass +
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PRL 120 (2018)

35 MeV < L < 90 MeV

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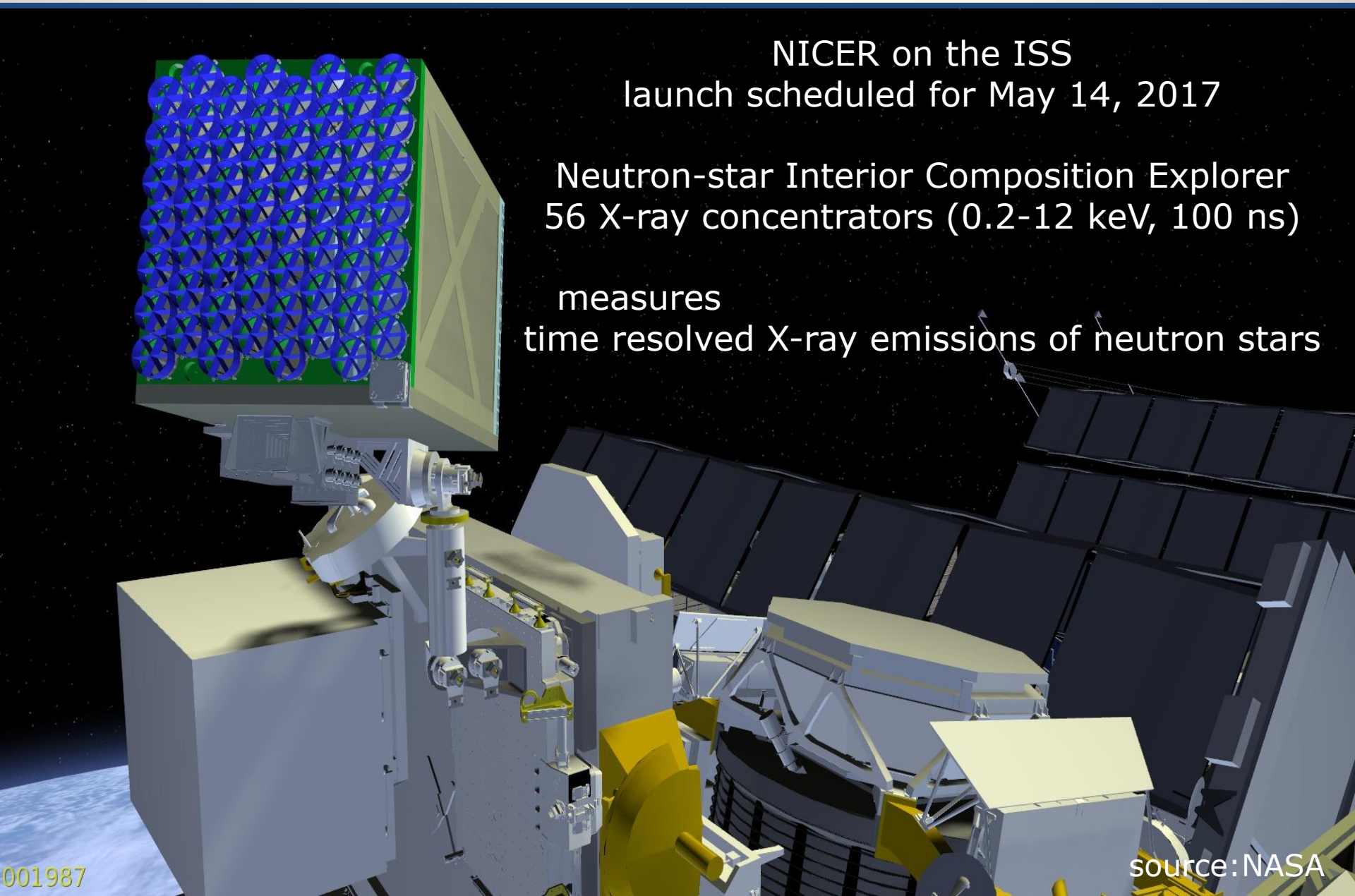
ASY-EOS:
59 < L < 85 from
Au+Au elliptic flow ratio
Russotto+ PRC (2016)

cf.
20 < L < 70 from
^{48}Ca neutron skin
Zenihiro+ arxiv(2018)
$R_{1.4}$ < 12.6 km

$R_{1.4}$ from Lattimer & Prakash, Phys. Rep. (2016), Fig. 8

$$S(\rho) = S_0 + \frac{L}{3}\frac{\rho-\rho_0}{\rho} + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho}\right)^2 + \cdots$$

first radii expected in 2019



NICER on the ISS
launch scheduled for May 14, 2017

Neutron-star Interior Composition Explorer
56 X-ray concentrators (0.2-12 keV, 100 ns)

measures
time resolved X-ray emissions of neutron stars

source:NASA

001987

summary and perspectives

special thanks to
Dan Cozma, Bucharest
Arnaud Le Fèvre, Darmstadt
Yvonne Leifels, Darmstadt
Jerzy Łukasik, Kraków
Angelo Pagano, Catania
Paolo Russotto, Catania
Hermann Wolter, München

- differential elliptic flow presently unique regarding high density
- model-independent lower limit L ≈ 55 MeV and $R_{1.4}$ ≈ 11.6 km

- **ways to higher precision:**

- more neutron star merger events
- first radii from **NICER** soon to be expected (ΔR ± 0.5 km ?)

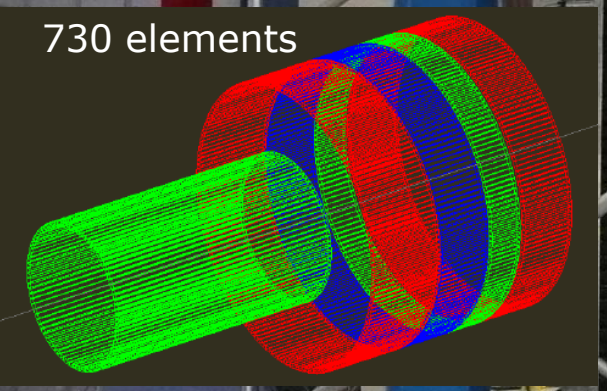
- precise data for **neutron-proton elliptic-flow ratio**
- $<\rho> \simeq 2\ \rho_0$ within reach with SIS18 beams and new instrumentation prepared for FAIR (proposal to FAIR-0 (2017))

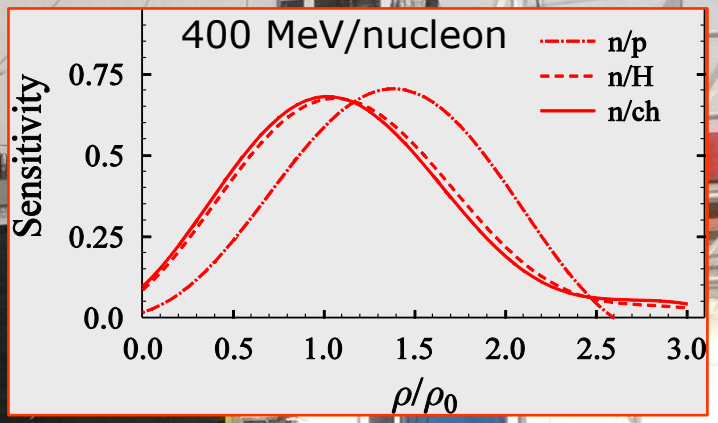
- **further reading:**
  M.D. Cozma, EPJA 54:40 (2018)
  W.T. and H.H. Wolter, Greiner Memorial Volume, arXiv (2017)

NeuLAND
August 2018

KRAB

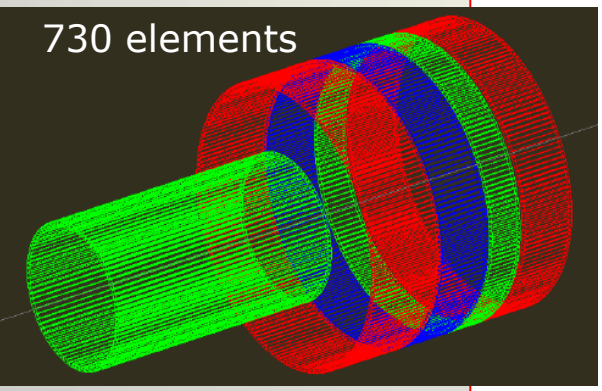
730 elements

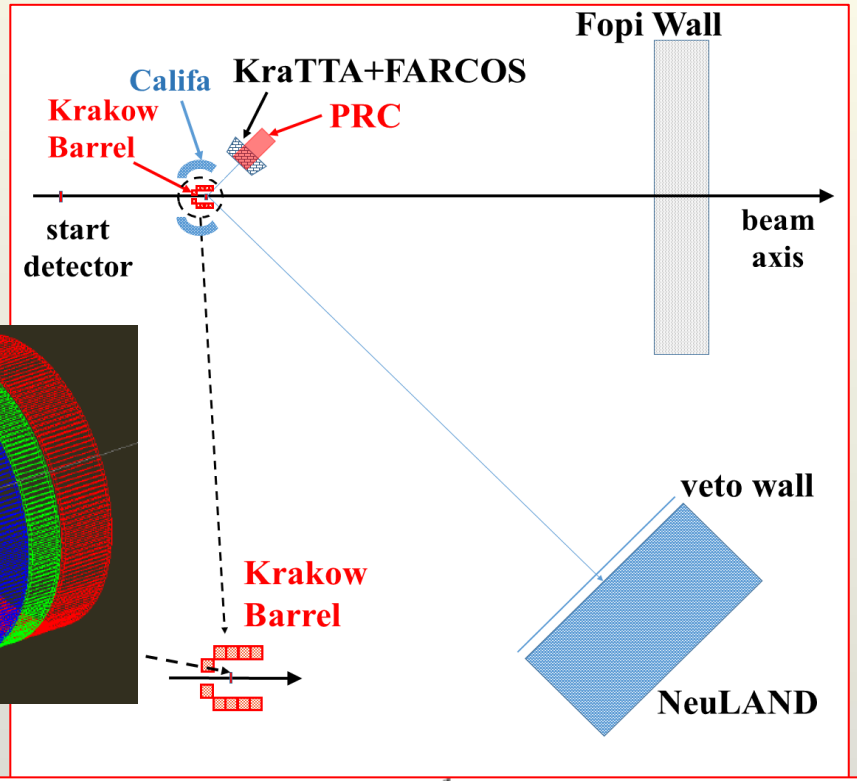


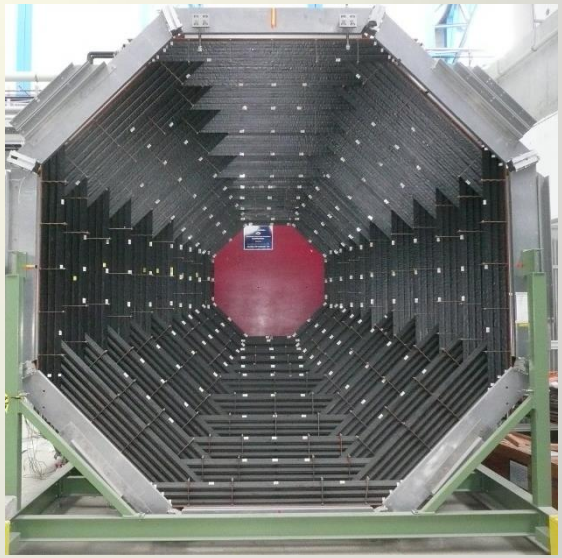


possible setup for ASY-EOS II with NeuLAND at FAIR

KRAB







FOPI Wall

SPOKESPERSON: P. Russotto[1]

PRINCIPAL INVESTIGATORS: A. Le Fèvre[2], Y. Leifels[2], J. Łukasik[3],

INSTITUTIONS: [1]INFN-LNS, Catania, Italy; [2]GSI, Darmstadt, Germany; [3]IFJ PAN, Kraków, Poland; [4]Jagiellonian University, Kraków, Poland; [5]Universidade de Santiago de Compostela, Spain; [6]SUBATECH, Nantes, France; [7]Texas A&M University Cyclotron Institute, College Station, USA; [8]NSCL/MSU, East Lansing, USA; [9]GANIL, Caen, France; [10]IFIN-HH, B[illegible]one di Catania, Italy; [12]Western Michigan University, Kalamazoo, MI, USA; [1][illegible], Wako-shi, Japan; [15]King Saud University, Riyadh, Saudi Arabia; [16]Institute for Nuclear Research, Debrecen, Hungary; [17]School of Science, Huzhou University, P.R. China; [18]CEA, DAM, DIF, Arpajon, France; [19]Kyoto University, Japan; [20]Università di Catania, Italy; [20] Politecnico di Milano and INFN-Sezione di Milano, Italy; [22]CEA, Saclay, France; [23]Dipartimento di Scienze MIFT, Univ. di Messina, Italy.

(23 institutions)