Constraining neutron-star matter with microscopic and macroscopic collisions
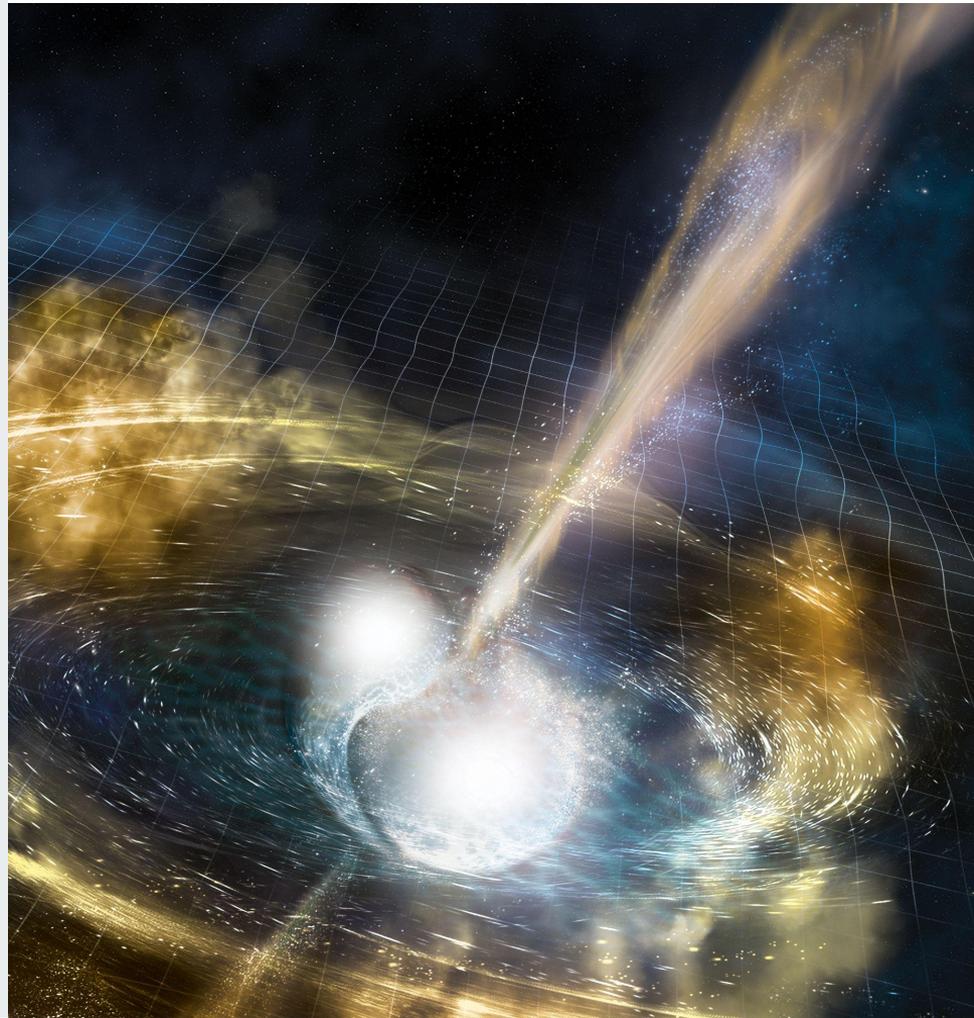
Arxiv: 2107.06229

Peter T. H. Pang

What is neutron star made of ?
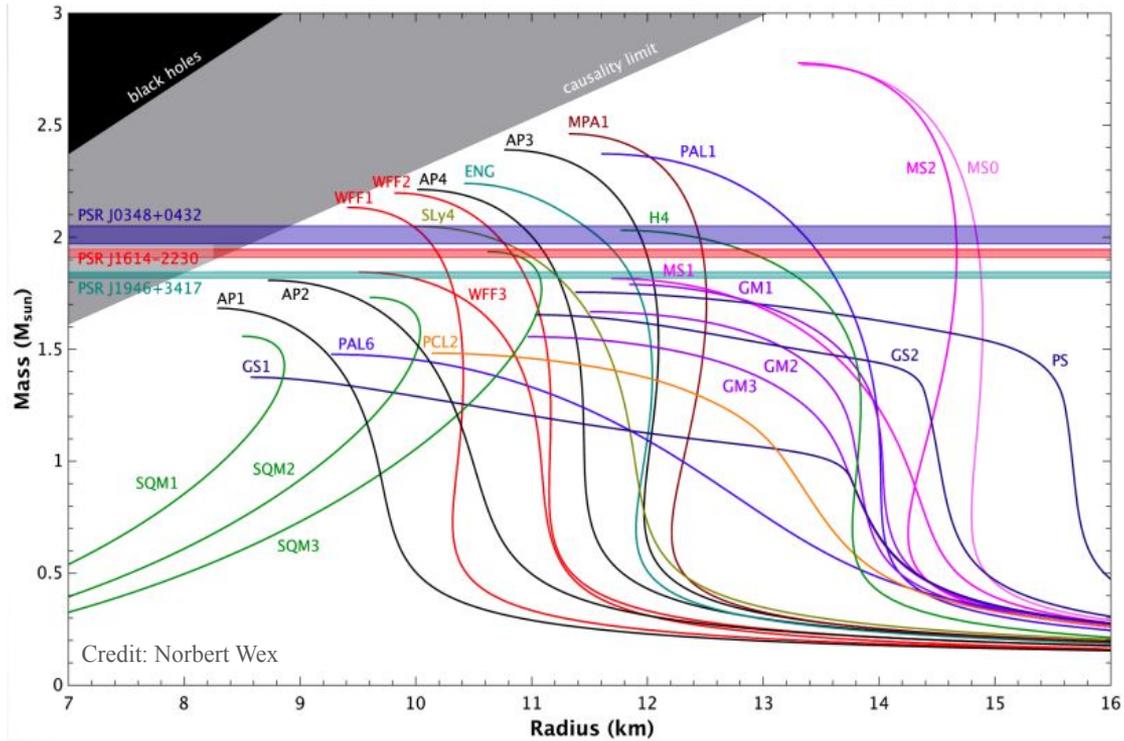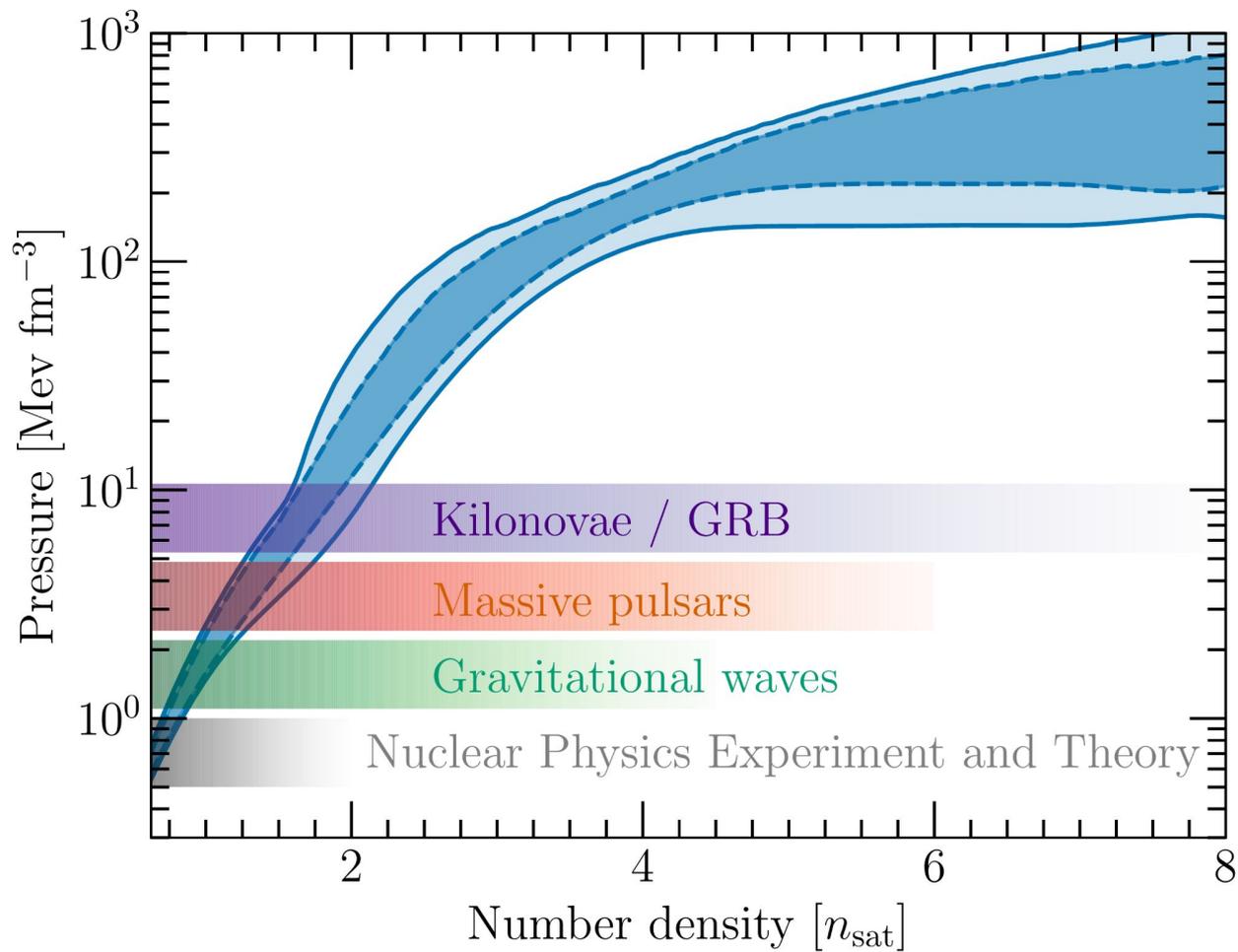
What is the radius of a neutron star ?

Credit: Norbert Wex

Which one is the correct one ?

Kilonovae / GRB

Massive pulsars

Gravitational waves

Nuclear Physics Experiment and Theory
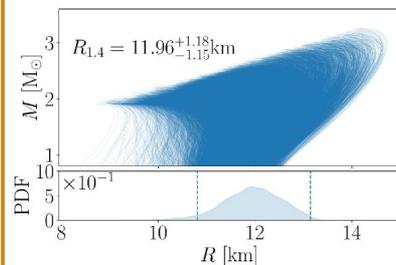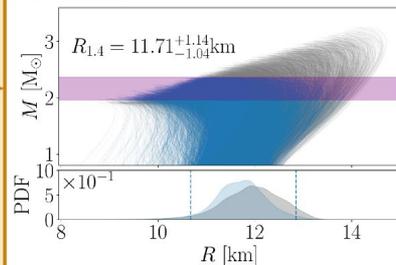
Prior construction

(A) Chiral effective field theory:
EOS derived with the chiral EFT result and $M_{\max} \geq 1.9 M_\odot$

$R_{1.4} = 11.96^{+1.18}_{-1.15}\text{km}$

(B) Maximum Mass Constraints:
PSR J0348+4032/PSR J1614-2230 and GW170817/AT2017gfo remnant classification

$R_{1.4} = 11.71^{+1.14}_{-1.04}\text{km}$

(C) NICER:
PSR J0030+0451 and PSR J0740+6620

$R_{1.4} = 12.05^{+0.78}_{-0.81}\text{km}$

Parameter estimation

(D) GW170817:
reanalysis with
IMRPhenomPv2_NRTidalv2

$R_{1.4} = 12.02^{+0.76}_{-0.75}\text{km}$

(E) AT2017gfo:
analysis of the observed lightcurves

$R_{1.4} = 11.98^{+0.76}_{-0.73}\text{km}$

(F) GW190425:
reanalysis with
IMRPhenomPv2_NRTidalv2

$R_{1.4} = 11.93^{+0.80}_{-0.75}\text{km}$

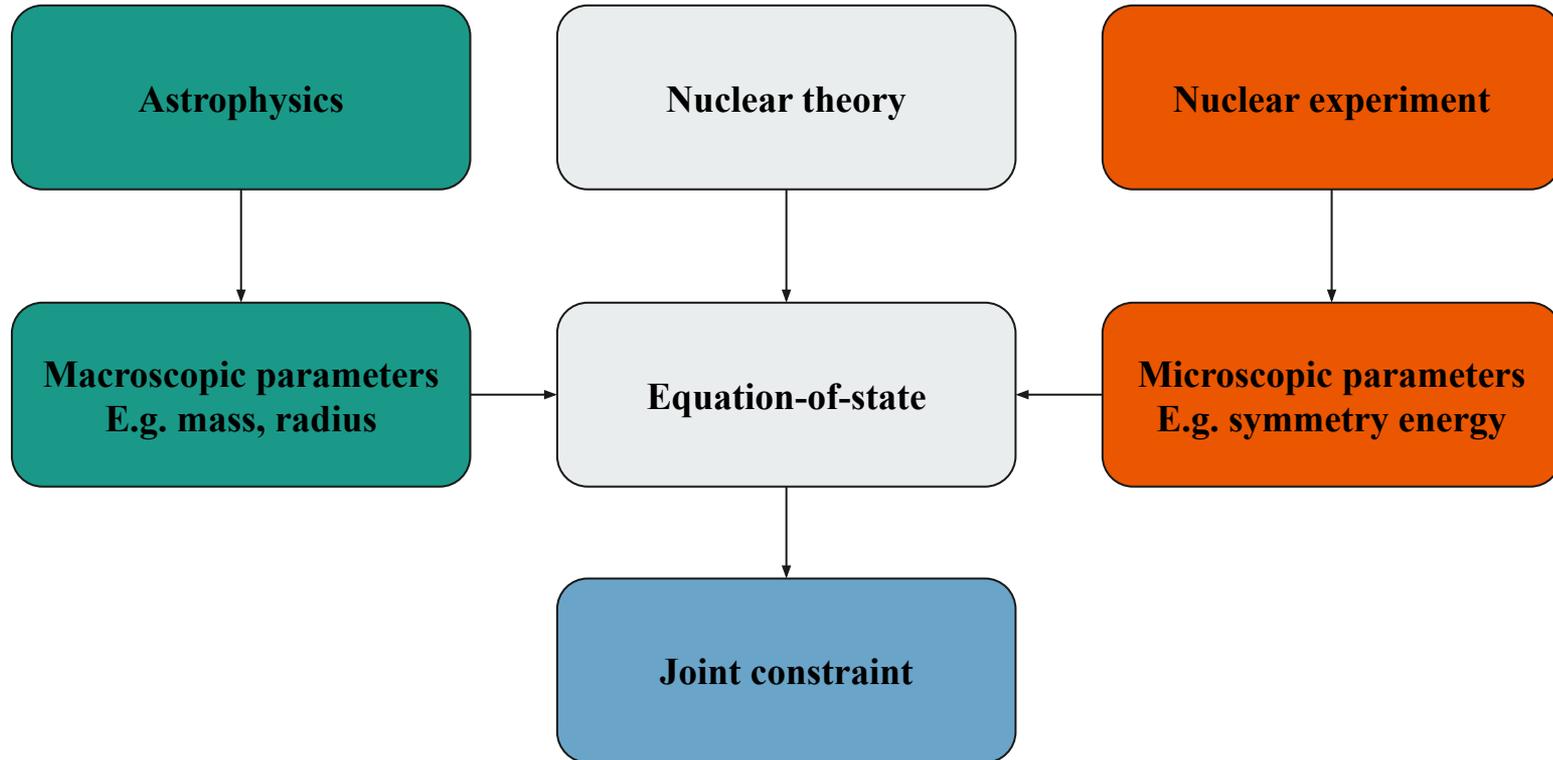# What about terrestrial experiments?

Combing information

(A) Chiral effective field theory:
Prior

(B) Multi-messenger astrophysics:
Astro
Prior

(C) HIC experiments:
HIC
Prior

(D) HIC and Astro combined:
Astro+HIC
Prior

(E) $1.4M_\odot$

(F) $2M_\odot$

(A) Chiral effective field theory:

(B) Multi-messenger astrophysics:

(C) HIC experiments:

(D) HIC and Astro combined:

(E) $1.5n_{\rm sat}$

(F) $2.5n_{\rm sat}$

Result

	Prior (CEFT)	Astro	HIC	Combined
$P_{1.5n_{\text{sat}}}$ $[\text{MeVfm}^{-3}]$	$5.59^{+2.04}_{-1.97}$	$5.84^{+1.95}_{-2.26}$	$6.06^{+1.85}_{-2.04}$	$6.25^{+1.90}_{-2.26}$
$R_{1.4}$ $[\text{km}]$	$11.96^{+1.18}_{-1.15}$	$11.93^{+0.80}_{-0.75}$	$12.06^{+1.13}_{-1.18}$	$12.01^{+0.78}_{-0.77}$

What is neutron star made of ?

What is the radius of a neutron star ?

$$R_{1.4} = 9{-}15\mathrm{km} \rightarrow 12.01^{+0.78}_{-0.77}\mathrm{km}$$

Combing information

$$\mathcal{L}_{\text{HIC}}\left(\text{EOS}\right) = \int dn\, dP\, p(\text{HIC}|n, P)p(n, P|\text{EOS})$$

$$\propto \int dn\, dP\, p(n, P|\text{HIC})p(n, P|\text{EOS})$$

$$\propto \int dn\, dP\, p(n, P|\text{HIC})\delta(P - P(n, \mathbf{EOS}))$$

$$= \int dn\, P(n, P = P(n; \mathbf{EOS})|\text{HIC})\,,$$

Result

Density	Astro-only	HIC-only	Combined
1.0 n_{sat}	$2.00^{+0.52}_{-0.49}$	$2.05^{+0.49}_{-0.45}$	$2.11^{+0.49}_{-0.52}$
1.5 n_{sat}	$5.84^{+1.96}_{-2.26}$	$6.06^{+1.85}_{-2.04}$	$6.25^{+1.90}_{-2.26}$
2.0 n_{sat}	$18.44^{+16.24}_{-9.69}$	$19.47^{+33.63}_{-11.67}$	$19.07^{+15.27}_{-10.53}$
2.5 n_{sat}	$45.05^{+39.80}_{-19.62}$	$47.78^{+75.96}_{-32.96}$	$45.43^{+40.41}_{-19.11}$

Result

Mass	Astro-only	HIC-only	Combined
$1.0 M_{\odot}$	$11.76^{+0.65}_{-0.71}$	$11.89^{+0.79}_{-0.98}$	$11.88^{+0.57}_{-0.76}$
$1.4 M_{\odot}$	$11.94^{+0.79}_{-0.78}$	$12.06^{+1.13}_{-1.18}$	$12.01^{+0.78}_{-0.77}$
$1.6 M_{\odot}$	$11.97^{+0.87}_{-0.78}$	$12.11^{+1.33}_{-1.33}$	$12.03^{+0.98}_{-0.75}$
$2.0 M_{\odot}$	$11.88^{+1.23}_{-1.10}$	$12.19^{+1.71}_{-1.59}$	$11.91^{+1.24}_{-1.11}$