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Probing muonic forces with neutron star inspirals

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Semi-classical understanding of GW170817

(1) $$\omega^2 = \frac{G_N\,(M_1+M_2)}{\Delta^3}$$

Kepler's law

(2) $$E_{\rm tot} = -\frac{G_N\mu(M_1+M_2)}{\Delta} + \frac{1}{2}\mu\Delta^2\omega^2$$

$E_{\rm tot}$: Total energy of the system

ω: Orbital frequency

(3) $$\frac{dE_{\rm GW}}{dt} = \frac{32}{5}G_N\mu^2\Delta^4\omega^6$$

$\frac{dE_{\rm GW}}{dt}$: Power radiated via gravitational waves

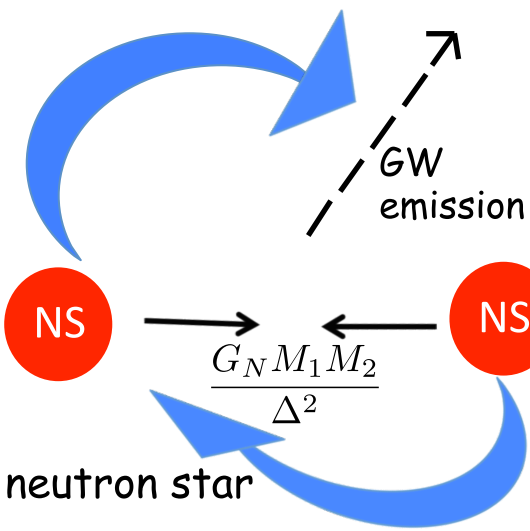
(4) $$\frac{dE_{\rm tot}}{dt} = -\frac{dE_{\rm GW}}{dt}$$: Energy conservation

$$\Downarrow$$

$$\frac{d\omega}{dt} = \frac{96}{5}(G_N\mathcal{M}_c)^{5/3}\omega^{11/3}$$

GW frequency

$$f_{\rm GW} = \frac{\omega}{\pi}$$

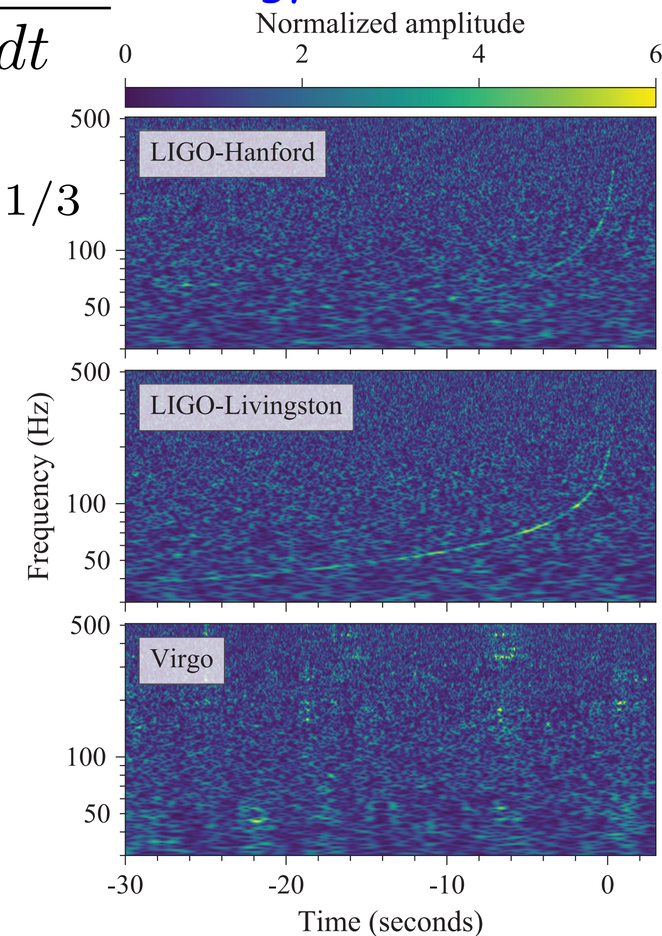


Kopp, **Laha**, Opferkuch, and Shepherd 1807.02527 JHEP

Cartoon of neutron star inspiral

$M_{1,2}$ = neutron star

Δ = distance between two neutron stars



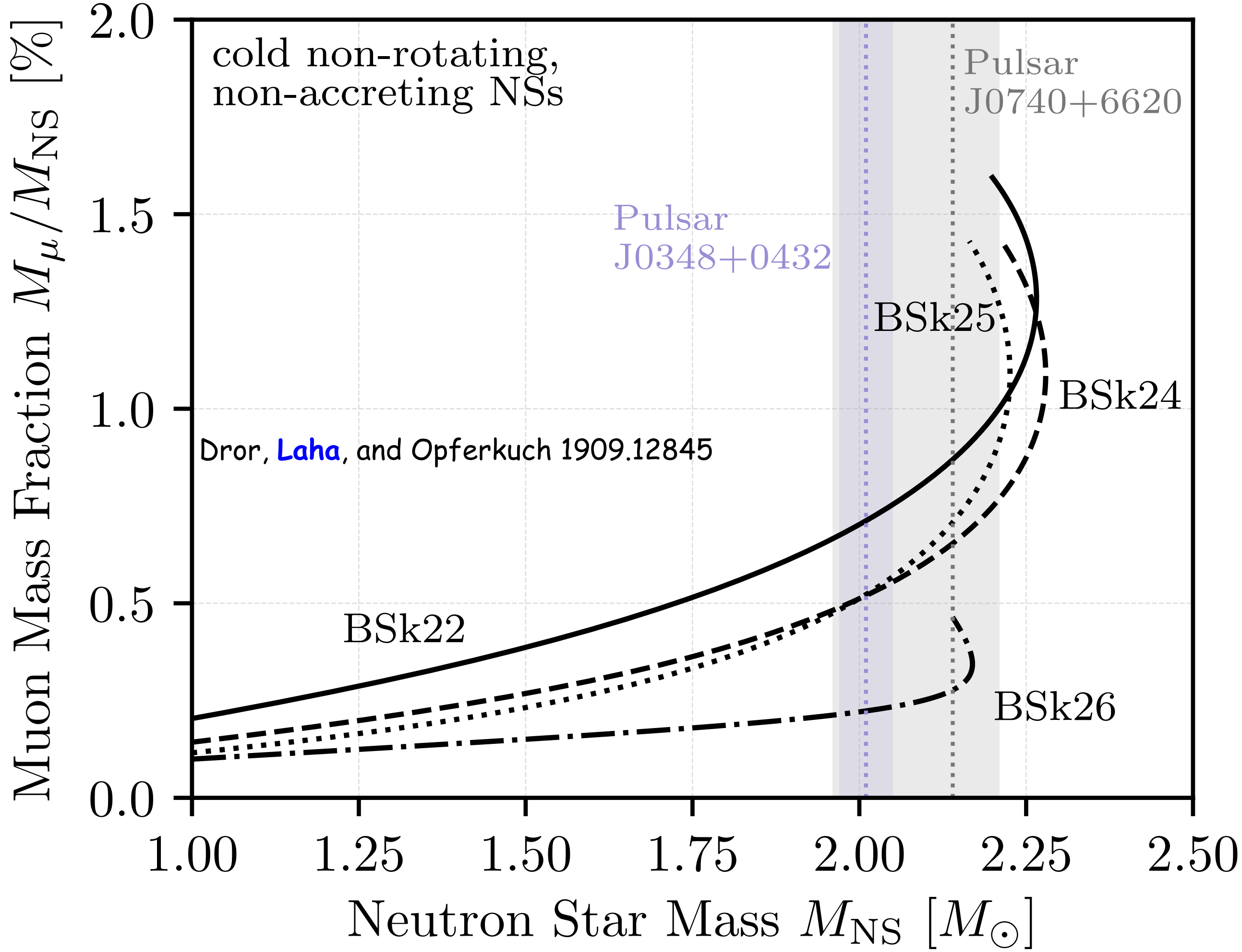
Muons inside neutron stars

Neutron stars host a large population of muons

Muon population arises from chemical equilibrium, charge neutrality, and a typical Fermi energy of ~ 100 MeV

A pure Standard Model phenomenon

Muon fraction depends on the equation of state



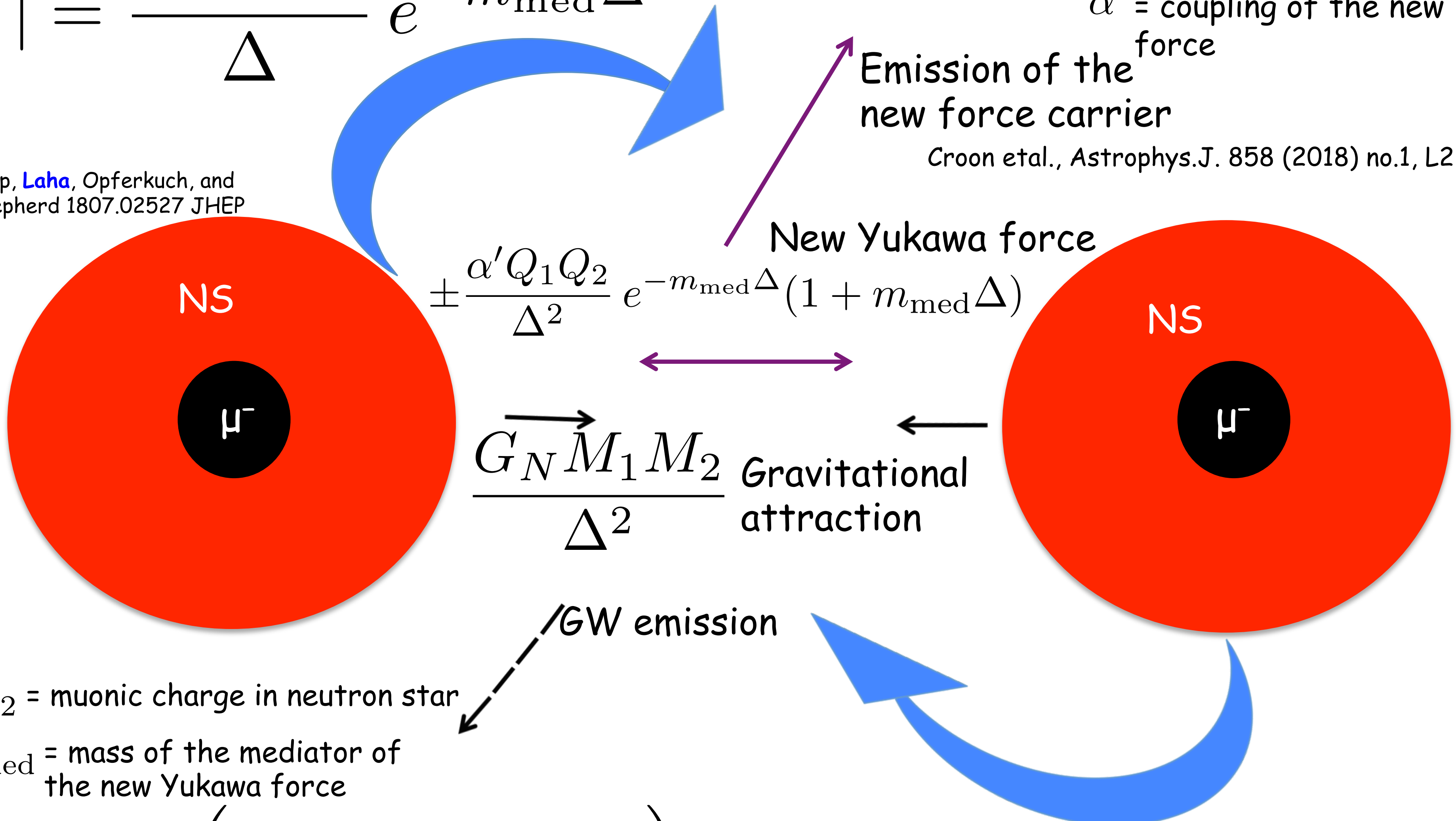
Bell etal. 1904.09803, Garani and Heeck 1906.101445, Poddar etal. 1908.09732, Pearson etal. 1903.04981

A new Yukawa force (attractive/ repulsive)

$$|V| = \frac{\alpha' Q_1 Q_2}{\Delta} e^{-m_{\rm med}\Delta}$$

α' = coupling of the new force

Kopp, Laha, Opferkuch, and Shepherd 1807.02527 JHEP



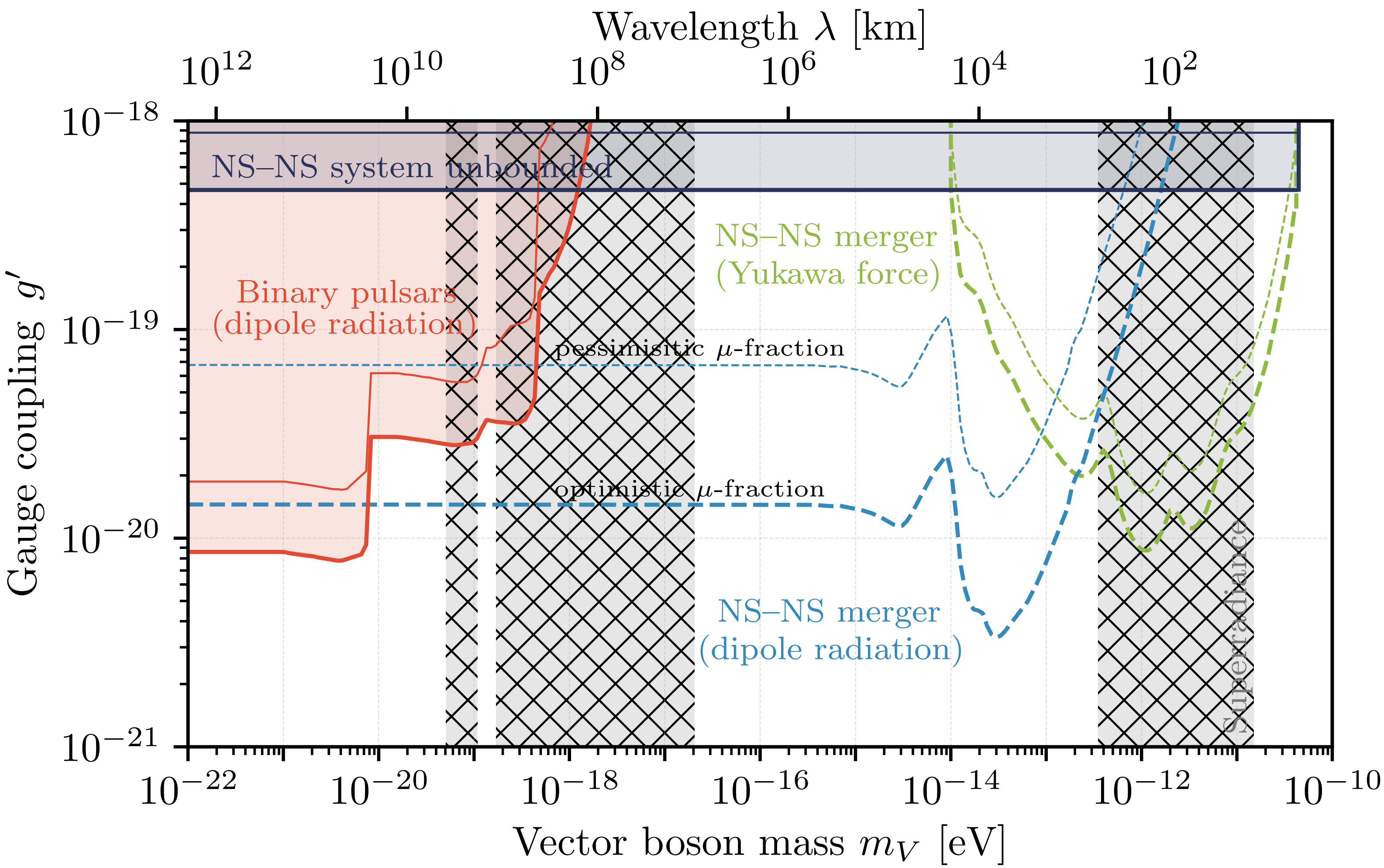
$Q_{1,2}$ = muonic charge in neutron star

$m_{\rm med}$ = mass of the mediator of the new Yukawa force

$$\frac{dE_{\rm tot}}{dt} = -\left(\frac{dE_{\rm GW}}{dt} + \frac{dE_{\rm dipole}}{dt}\right)$$

Dror, Laha, and Opferkuch 1909.12845

Probing long-range muonic interactions



Huge discovery potential on exotic long-range forces due to muons

LIGO - VIRGO can probe large parts of the unexplored parameter space

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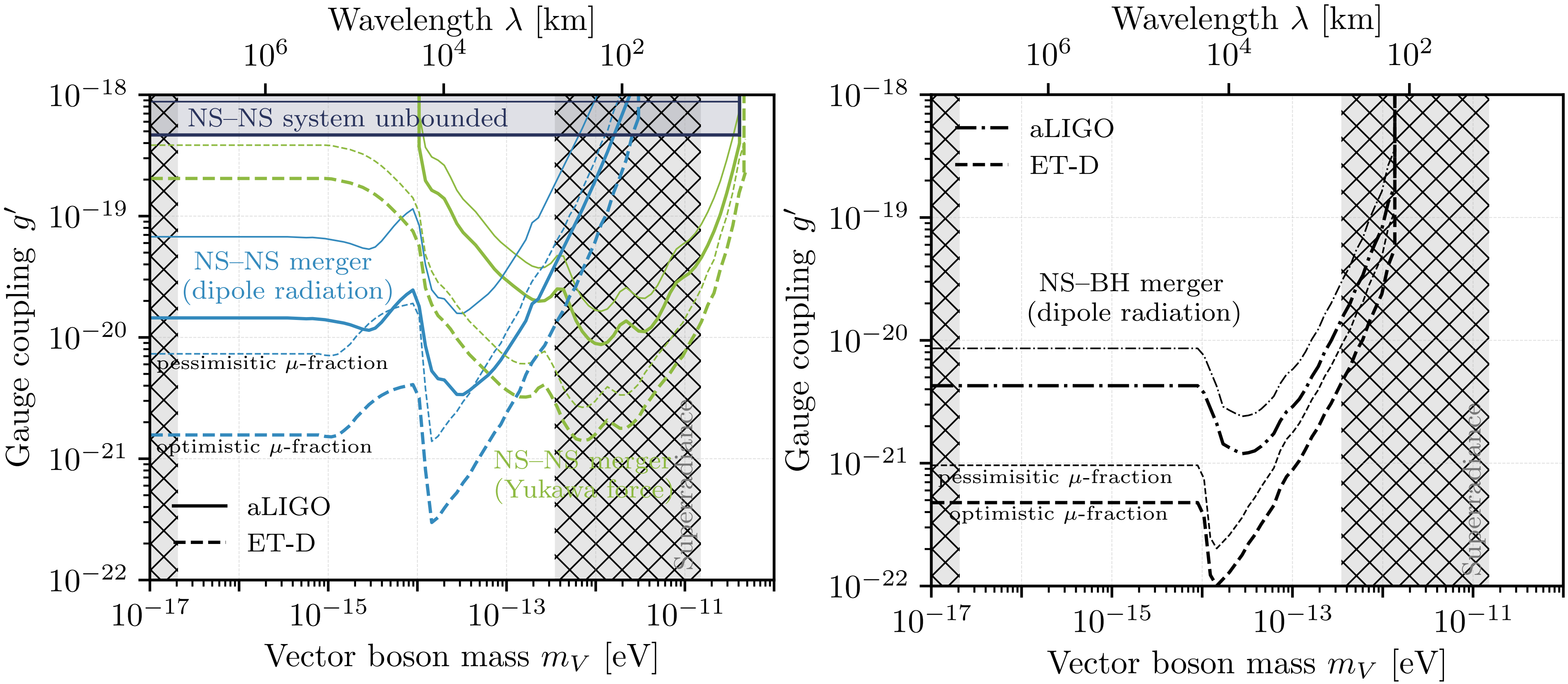
Probing long-range muonic interactions



Einstein Telescope and Cosmic Explorer have great potential to discover new parts of the parameter space

Neutron star – black hole mergers hold promising avenues for discovery

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Conclusions

- Neutron star inspirals are a great laboratory to discover new long-range forces
- We showed that LIGO - VIRGO observations can discover new long-range interactions of muons
- Great discovery potential for Einstein Telescope and Cosmic Explorer