Compact binaries as probes of dense matter and dark matter

Dense matter *LOI #441 Read+*

"CF7 covers cosmic probes of fundamental physics topics [e.g.] equation of state of dense nuclear matter and hadron-quark gluon phase transitions"

Gravitational waves from merging neutron stars encode information about their internal structure, probing the QCD phase diagram at high densities and constraining fundamental nuclear many-body interactions.

Dark matter *LOIs #441 Read+, #1785 Sinha+*

"CF3 covers uniquely astrophysical probes of dark matter [e.g.] through its interactions with astrophysical objects"

Population-scale observations of compact binaries can reveal evidence for dark matter accumulation inside neutron stars, informing the nature of dark matter and constraining its nucleon scattering cross-section.

Studying dense matter with gravitational waves

Cold, ultra-dense matter inside NSs. Phase of inspiral GWs is sensitive to zero-temperature equation of state up to several times nuclear saturation density.

- Important synergy with EM observations of pulsars, nuclear theory/experiment
- Full NS mass spectrum unlocked by LIGO+Virgo+Kagra sensitivity gains, later 3G detectors
- Transport properties from dynamical processes, e.g. GWs from stellar oscillations?

Warm postmerger remnant matter. Postmerger GWs directly probe remnant matter, revealing thermal corrections to equation of state and threshold mass for collapse to a black hole.

- First postmerger GW detection possible with LIGO A+, fully realized with 3G detectors
- Exotic states of matter, strong phase transitions?

Kilonovae. EM observations of GW-localized kilonovae shed light on heavy-element nucleosynthesis, help predict matter outflows in NS mergers.

- More localizations with LVK sensitivity gains, LIGO-India addition, new EM facilities, 3G detectors
- Tidal disruption in NSBH merger?

Searching for dark matter in compact objects

DM capture in NSs. DM accumulates inside NSs by gravitational capture after nucleon scattering, leaving imprint on internal structure that depends on NS age/environment.

- Admixed DM or DM in stable core produces diversity in mass-radius, -tidal deformability relations
- Unstable core DM reduces maximum NS mass relative to hadronic-matter prediction
- Requires many binary NS observations, good knowledge of hadronic equation of state

DM produced in NS mergers. DM modifies temperature profile/evolution of postmerger remnant.

- Axion-like DM particles free-stream out of remnant, cooling it on millisecond timescale
- Other dark-sector particles may be trapped in remnant, leading to heat conduction
- Confront postmerger EM and GW observations with merger simulations

Exotic compact objects made of DM. DM agglomerates into compact objects on its own.

- Self-gravitating ultra-light scalar field DM forms NS/BH mimickers
- Distinguish exotic compact objects via tidal deformabilities