NS Mergers White Paper

Summary

E Burns. on behalf of

Co-authors:
The Future of GW-EM Observations

<table>
<thead>
<tr>
<th>Interferometer Generation</th>
<th>Start Year (approx.)</th>
<th>Range (Mpc)</th>
<th>BNS Rates (1/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced LIGO</td>
<td>2020</td>
<td>175</td>
<td>2-50</td>
</tr>
<tr>
<td>LIGO A+</td>
<td>2024</td>
<td>325</td>
<td>10-300</td>
</tr>
<tr>
<td>LIGO Voyager</td>
<td>~2030</td>
<td>~1,050</td>
<td>&gt;1,000</td>
</tr>
<tr>
<td>3rd Generation</td>
<td>~late 2030s</td>
<td>~4,200</td>
<td>~100,000</td>
</tr>
</tbody>
</table>

![Graph showing observed SGRB CDF with different generations of interferometers]
Astrophysics

Short Gamma-ray Bursts
• What is the prompt emission mechanism of SGRBs?
• What are the progenitors of GRBs?

Kilonovae
• What is the diversity of kilonova?
• The distribution of heavy element production

Both
• How do their intrinsic properties affect EM observables?
• How do BNS and NSBH mergers differ?
• When do NSBH mergers cause SGRBs or kilonovae?
Fundamental Physics

The seconds variability over cosmological baselines enables unique tests of fundamental physics

Measure:
• Speed of gravity
• Relative violations of
  • The Weak Equivalence Principle
  • Lorentz Invariance Violation
• (Absolute Lorentz Invariance Violation)

Largest Discovery Space / Tightest Constraints on:
• The Special Theory of Relativity
• (Non)-Metric Theories of Gravity
• The General Theory of Relativity
• Quantum Gravity
Astrophysical Jets

• What is the structure of ultrarelativistic jets?
  • The effect of their environments?

• How do jets form?
  • Blandford-Znajek, neutrino-antineutrino annihilation?

• Do relativistic jets require an event horizon to form?
  • Can they form around magnetars? Other central engines?

• How is energy carried in relativistic jets?
  • Through baryons or Poynting flux? Both? What’s the fraction?
  • Also informed through joint neutrino detections
Heavy Element Enrichment through Cosmic Time

• R-process nucleosynthesis occurs in NS mergers and core-collapse Sne.
• Both should track the stellar formation rate, modulo inspiral time for NS mergers
• Uncovering the redshift distribution of NS mergers determines their source evolution, and the lanthanide/actinide enrichment history of the universe
The EOS of Supranuclear Matter

- Neutron stars achieve densities and temperatures entirely unobtainable on Earth.

- Understanding the NS EOS can constrain the phase diagram of quantum chromodynamics and enable more accurate QCD predictions

- MMA studies of NS Mergers measures:
  - The radii and mass of NS
  - Constrain metastable NS masses and lifetimes
Cosmology

Standard sirens have luminosities predicted by GR. They will:

• Resolve the $H_0$ controversy
• Calibrate the cosmological ladder
• When combined with CMB+BAO:
  • Resolve the neutrino mass hierarchy (determine the neutrino mass eigenstates?)
  • Constrain/measure the number of effective neutrino species
  • Constrain the equation of state of dark energy
• With CMB+BAO and WFIRST/LSST/EUCLID:
  • Enable sub-percent precision cosmology throughout the universe
  • Measure multi-parameter extensions to $\Lambda$CDM

Riess et al. 2018
Type Ia measure
NS Merger Science

• The physics of SGRBs
• Astrophysical Jets
• Fundamental Physics

• Origin of the Elements
• Cosmology
• Identification and classification of GW sources
NS Merger Recommendations
General: Upgraded GW interferometers

Next 5-10 years
• Extension of the Fermi and Swift missions
• Develop suitable replacements with small-scale missions
• IceCube Gen-2 upgrade
• Allocation of observing time and ToO programs on all necessary telescopes
• Greater NSF-NASA collaboration

10+ years
• Design large-scale missions for this era
• A large-scale gamma-ray observatory with ~keV-MeV sensitivity and a wide field of view
• Appropriately matched X-ray/UVOIR/radio telescopes

B.S. Sathyaprakash “Multimessenger Universe with Gravitational Waves from Binary Systems” Astro2020 WP (no arXiv link)