Multi-messenger astronomy and neutrinos

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CAP
Neutrino Symposium
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Multi-messengers

Hubble Space Telescope

Swift: Gamma-rays

SuperK: Neutrinos

LIGO: Gravitational Waves
Neutrinos determine the evolution of mergers and supernova, AND the synthesis of elements

Neutrino emission is influenced by the properties of nuclear matter

Neutrino spectra is affected by strong gravitational fields

Neutrino signals combined with other observations will lead to better understanding of several phenomena
Neutrinos and Gravitational waves in Neutron star mergers

$q < 1$

$q = m_1 / m_2$
Merger of unequal mass magnetized NSs
(CQG 2016, L. Lehner et al)
Effect of the mass ratio

$q = m_1 / m_2$
$q = 0.85$

Tidal effects are more pronounced with stiffer EoS
Hotter matter for softer EoS
Neutrinos in SK: NS-NS merger at 10 kpc

<table>
<thead>
<tr>
<th>EoS</th>
<th>q</th>
<th>$t$ [ms]</th>
<th>$\langle E_{\bar{\nu}_e} \rangle$ [MeV]</th>
<th>$\langle E_{\nu_e} \rangle$ [MeV]</th>
<th>$L_{\bar{\nu}_e}$ [$10^{53}$ erg/s]</th>
<th>$R_\nu$ [#/ms]</th>
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</thead>
<tbody>
<tr>
<td>NL3</td>
<td>1.0</td>
<td>3.4</td>
<td>18.5 (22.4)</td>
<td>15.2 (18.3)</td>
<td>0.7</td>
<td>18</td>
</tr>
<tr>
<td>NL3</td>
<td>0.85</td>
<td>3.0</td>
<td>15.6 (18.7)</td>
<td>12.6 (15.1)</td>
<td>0.8</td>
<td>18</td>
</tr>
<tr>
<td>DD2</td>
<td>1.0</td>
<td>3.3</td>
<td>18.3 (22.1)</td>
<td>14.6 (17.4)</td>
<td>1.1</td>
<td>28</td>
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<tr>
<td>DD2</td>
<td>0.85</td>
<td>2.8</td>
<td>18.1 (21.7)</td>
<td>15.1 (18.0)</td>
<td>1.0</td>
<td>25</td>
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<tr>
<td>DD2</td>
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<td>2.4</td>
<td>19.7 (23.9)</td>
<td>14.8 (17.9)</td>
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<tr>
<td>SFHo</td>
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<td>3.5</td>
<td>24.6 (29.7)</td>
<td>23.5 (28.3)</td>
<td>3.5</td>
<td>121</td>
</tr>
<tr>
<td>SFHo</td>
<td>0.85</td>
<td>3.9</td>
<td>17.8 (21.3)</td>
<td>15.3 (17.9)</td>
<td>2.0</td>
<td>50</td>
</tr>
</tbody>
</table>

Larger changes with soft EoS when $q$ decreases

Supernova: $R = 1/\text{ms}$, $L = 10^{52}$ erg/s, $E \sim 11$ MeV, $t = 10$ sec
Merger of unequal mass magnetized NSs

(CQG 2016, L. Lehner et al)

Effect of the mass ratio

$q = m_1 / m_2 \quad q = 0.85$

As the mass ratio decreases, the tidal effects become stronger.

Tidal effects are more pronounced with stiffer EoS

Reduction of the mass ratio disrupts the star earlier

As $q$ decreases, the stronger are the tidal effects.
Neutrino luminosity evolution

Luminosity oscillates for $q=1$
Neutrino luminosity evolution

Luminosity oscillates for $q=1$
Electron fraction decreases as \( q \) decreases, compatible with \( r \)-process nucleosynthesis and kilonova.
Remarks

• Neutrinos from mergers will not be mistaken for Supernova neutrinos

• We could detect neutrinos from:
  • Milky way and satellite galaxies in SuperK
  • Andromeda (780 kpc) in HyperK

• Note that 2017 NS-NS merger observation lead to a source distance of 40 Mpc.
Remarks

• Soft EOS would produce a stronger (more energetic and more counts) neutrino signal compared to a stiff EOS.

• Neutrino average energies are more sensitive to the mass ratio in the case of a soft EOS.

• Ejecta with Ye < 0.2 could be produced regardless of the EoS

• Given several observations of q and GW neutrinos we could decipher the EoS
Relic neutrinos

Cosmic Epochs

Galaxy A1689-zD1: ~700 million years after the Big Bang

Big Bang
Radiation era

~300,000 years: "Dark ages" begin

~400 million years: Stars and nascent galaxies form

~1 billion years: Dark ages end

~9.2 billion years: Sun, Earth, and solar system have formed

~13.7 billion years: Present
Relic Neutrinos

\[ \frac{dF}{dE_o} = c \int (1 + z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} \, dz_c \]

- Cosmological redshift
- Neutrino spectrum
- Event rates
- Universe expansion
Relic Neutrinos

\[ \frac{dF}{dE_0} = c \int (1+z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} dz_c \]
Accretion disk relic neutrinos

Mergers:
- Neutron star - Neutron star
- Neutron star - Black Hole

Collapsars:
- rotating massive star collapsing to black hole
Neutrino Spectra from accretion disks

Observed at 10 kpc from the source

T. Schilbach*, O. L. Caballlero, McLaughlin (PRD, 2018)
Accretion disk relic neutrinos

Collapsar relic neutrinos at SuperK and HyperK

T. Schilbach*, O. L. Caballero, McLaughlin (PRD, 2018)

SuperK in 5 years: 0.2-25 neutrinos from Collapsars
HyperK in 10 years: ~900 from collapsars, 6 from NS-NS
Merger relic neutrinos at SuperK and HyperK


SuperK in 5 years: 0.1-25 neutrinos from Collapsars

HiperK in 10 years: ~900 from collapsars, 2 from NS-NS
Conclusions

This is a new era in Astronomy: neutrino physics expertise is integral to the success of multi-messenger studies.

Experimental facilities around the world will bring insights on nuclear properties at an unprecedented scale.

Neutrinos provide information about the explosive stellar mechanisms by direct detection and by their influence on their by-products (e.g. heavy element synthesis).

Neutrinos from the past can tell us about the star formation rate, mergers and collapsar rates, and cosmic metallicity.
Collaborators

- Tyson Schilbach* (U. Of Guelph), G. McLaughlin (North Carolina State University)

- Luis Lehner (Perimeter Institute), Carlos Palenzuela (University of the Balearic Islands), David Neilsen (Brigham Young U.), Steve Liebling (Long Island U.), Evan O’Connor (North Carolina State University)