A new Population Synthesis Code for NS/BH Binaries

StarBurst

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Outline

1. The Code
2. Parameter Studies
3. Gravitational Wave Mergers
4. Outlook
Aim

- predict event rates of NS/BH binaries
Aim

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  - gravitational merger rates
  - SN rates
Aim

- predict event rates of NS/BH binaries
  - gravitational merger rates
  - SN rates
- get distributions of binaries in mass, semi-major axis, eccentricity, ... at various points in the evolution
Flowchart

initialize and read in parameters
Flowchart

1. Initialize and read in parameters
2. Read in tables
3. Check for next evolutionary phase
4. Apply current evolutionary phase
5. Analyze system, save/print data and delete system
6. Next phase
7. System is merged/disrupted or all components are compact remnants
8. Print population synthesis output
9. Next system
10. All systems calculated
11. Delete values and free space
Flowchart

initialize and read in parameters

read in tables

initialize system
The Code

Structure

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apply current evolutionary phase

analyze system, save/print data and delete system

print population synthesis output

delete values and free space

next system

next phase
Differences to Other Binary Population Synthesis Codes

- very fast
  - ⇒ low statistical errors
  - ⇒ allow to estimate systematic errors caused by the input parameters

credits: T. Tauris
Differences to Other Binary Population Synthesis Codes

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  ⇒ allow to estimate systematic errors caused by the input parameters

• interpolate stellar evolutionary tables
  ⇒ possibility to easily use other or update stellar evolutionary tables
  ⇒ can account for structure of the star without detailed integration, e.g. via pre calculated $\lambda$-values
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- case BB RLO according to Tauris et al. 2015
  - changes number of surviving systems by $>1$ dex
Stable RLO vs. CE Case A-C: $q_{\text{limit}}$

- Larger $q_{\text{limit}}$ ⇒ More stable RLO, less CE

Graph showing counts of stable RLO and CE events for cases A, B/C, and BB as a function of $q_{\text{limit}}$. The graph indicates that as $q_{\text{limit}}$ increases, the number of stable RLO events increases and the number of CE events decreases.
Interpolate $\lambda$-values for CE: $\alpha_{\text{TH}}$

\[
\lambda = -G \cdot \frac{M \cdot M_{\text{env}}}{R \cdot E_{\text{bind}}} \\
E_{\text{bind}} = E_{\text{grav}} + \alpha_{\text{TH}} \cdot E_{\text{int}}
\]
Interpolate $\lambda$-values for CE: $\alpha_{\text{TH}}$

- Larger $\lambda$ implies less systems merge in CE.

**Graph:**
- **$\lambda_G$** and **$\lambda_B$** versus $\alpha_{\text{TH}}$.
- Formation rate per yr in MW.
- Different colors and markers for NS-NS, NS-BH, BH-NS, BH-BH.

**Legend:**
- Larger $\lambda$.
- Less systems merge in CE.

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Counts of systems

Counts

- NS-NS
- NS-BH
- BH-NS
- BH-BH

Time until gravitational wave merger in yr

Counts of systems

- $10^0$ to $10^3$
- $10^6$ to $10^9$
- $10^{12}$ to $10^{15}$
- $10^{18}$ to $10^{21}$
- $10^{24}$
Counts

<table>
<thead>
<tr>
<th>system</th>
<th>count</th>
<th>fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSNS</td>
<td>57051</td>
<td>25.73%</td>
</tr>
<tr>
<td>NSBH</td>
<td>771</td>
<td>0.35%</td>
</tr>
<tr>
<td>BHNS</td>
<td>55071</td>
<td>24.84%</td>
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<tr>
<td>BHBH</td>
<td>108839</td>
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Normalised

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Counts of systems/total number of systems

Time until gravitational wave merger in yr

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Merger Rate in the MW

Gravitational wave merger rate per year in MW vs. IMF index $\alpha$. The plot shows four types of binary mergers: NS-NS, NS-BH, BH-NS, and BH-BH. The rates are given in the range $10^{-8}$ to $10^{-4}$ gravitational wave merger rate per year in MW for IMF indices $\alpha$ ranging from -3 to -2.

Merger Rate in the MW

- less steep IMF
  ⇒ more NS or BH progenitors

gravitational wave merger rate per yr in MW vs. $\alpha_{IMF}$

- NS-NS
- NS-BH
- BH-NS
- BH-BH
Outlook

Goals

• get reliable merger rates in MW like galaxy
  ⇒ detections rate for LIGO
  • distance to host galaxy at merger
  • most probable formation channel
  • most important parameters on rates

• calibration using earlier evolutionary phases, like HMXBs

• predictions for characteristics of NS-NS Binaries ($P_{\text{orb}}, e, P_{\text{spin}}, \ldots$)