Binary models for short GRBs

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Goals of talk

• Why a merger model?
  [=Lamb’s plenary talk Friday]

• Does a merger model work?
  – Do we make enough mergers?
  – Are the right galaxies hosts?
  – Do the binaries last long enough to escape?
    [=Chris Belczynski’s talk today]
  – Are the redshifts consistent with expectations?
Earlier work

• For long GRBs:
  – Bromm and Loeb (2002), …

• For short GRBs:
  – Ando (2004), Guetta and Piran (2005)
    Nakar, Gal-Yan, Fox (2005), …
Outline

• Population synthesis for the universe
  – Star formation history
  – Heterogeneity: Ellipticals and spirals
  – NS-NS and BH-NS population synthesis
    • Mass efficiencies
    • Merger times

• Implications for mergers and GRBs
  – Long-lived progenitors
  – Merger rates
  – Relative frequency in ellipticals/spirals
  – Redshift distribution
    [intractable w/o luminosity function]
Star formation history

- Peaks near $z \sim 1$

Porciani and Madau’s SFR 1
[cf. Heavens; XXX]
Heterogeneity

- **Idealized model:**

<table>
<thead>
<tr>
<th></th>
<th>Fraction</th>
<th>(Z)</th>
<th>IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spirals</td>
<td>80%</td>
<td>(Z_\odot = 0.02)</td>
<td>Kroupa</td>
</tr>
<tr>
<td>Ellipticals</td>
<td>20%</td>
<td>0.5-2x (Z_\odot)</td>
<td>(~\text{Salpeter})</td>
</tr>
</tbody>
</table>
Population synthesis

- BH-NS (elliptical conditions)

Mass efficiency

$$\lambda_{e, \text{BH-NS}} \sim 1.3 \times 10^{-2}/M_\odot$$

Merger time distribution

[Graphs showing distribution of merger times]
Population synthesis

- BH-NS (spiral conditions)

Mass efficiency

\[ \lambda_{s,\text{BH-NS}} \sim 3.7 \times 10^{-4}/M_{\odot} \]

Merger time distribution

\[ \log(\lambda) \]

\[ \log(t/\text{Myr}) \]
Population synthesis

- NS-NS (elliptical conditions)

Mass efficiency

\[ \lambda_{e,\text{NS-NS}} \sim 1.5 \times 10^{-2}/M_\odot \]

Merger time distribution
Population synthesis

- NS-NS (spiral conditions)

Mass efficiency

\[ \lambda_{s, \text{NS-NS}} \sim 10^{-3}/M_\odot \]
• Key points:
  – Elliptical conditions =
    flatter IMF =
    higher mass efficiency (10x - 50 x)
  – Many progenitors **long-lived**
    Fraction of merging systems with $t_{mgr} > 100$ Myr
    dominates
    Fairly independent of popsyn assumptions
    ….except **NS-NS** (under spiral conditions)
Implications: Long-lived progenitors?

- **Many** long-lived progenitors

\[
1 - P(0.1 \text{ Gyr})/P(10 \text{ Gyr})
\]

<table>
<thead>
<tr>
<th></th>
<th>elliptical</th>
<th>spiral</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS-NS</td>
<td>75%</td>
<td>43%</td>
</tr>
<tr>
<td>BH-NS</td>
<td>89%</td>
<td>75%</td>
</tr>
</tbody>
</table>

- **Useful** for explaining…
  - Distance from host galaxy
  - Presence in host galaxy with old stellar population
Implications:
Merger & intrinsic GRB rates at present?

• **Model 0**: Reference model (estimate)
  
  – **Method**
    
    • ~ 35% merge
    • Spirals only:
      
      – density $n_s=0.01$/Mpc$^{-3}$
      – SFR: $dM/dt$/galaxy = 3.5 $M_\odot$/yr
    
  – **Result:**
    
    ~ confirmed by more detailed calculations
    

  – **Problems:**
    
    • Spirals only (“blue light” normalization)
    • Ignores time dependent SFR & merger delays

<table>
<thead>
<tr>
<th>Method 0</th>
<th>NS-NS</th>
<th>BH-NS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$4 \times 10^{-7}$ -- $4 \times 10^{-4}$</td>
<td>$4 \times 10^{-7}$ -- $4 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Implications:
Merger & intrinsic GRB rates at present?

- **Model 1**: Use SFR of universe
  - **Method**
    - Fix elliptical:spiral ratio
    - Convolve each with SFR
  - **Result**: ...slightly higher
  - **Problems**:
    - Dominated by recent ‘elliptical’ star formation
    - Needs continuous elliptical SF at present

<table>
<thead>
<tr>
<th></th>
<th>Method 1</th>
<th>Method 0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mpc$^{-3}$ yr$^{-1}$</td>
<td>Mpc$^{-3}$ yr$^{-1}$</td>
</tr>
<tr>
<td>NS-NS</td>
<td>10$^{-5.5}$-10$^{-2.5}$</td>
<td>10$^{-6.5}$-10$^{-3.5}$</td>
</tr>
<tr>
<td>BH-NS</td>
<td>10$^{-6}$-10$^{-3}$</td>
<td>10$^{-6.5}$-10$^{-3.5}$</td>
</tr>
</tbody>
</table>
Implications: Merger & intrinsic GRB rates at present?

- **Model 1**: Use SFR of universe
  - Elliptical, spiral merger rate history: (BH-NS)
**Implications:**
Merger & intrinsic GRB rates at present?

- **Model 2**: Ellipticals only form *early*

  - **Method**
    - Ellipticals for $z>1$, spirals for $z<1$
    - Convolve each with SFR

  - **Result**:

### Method 2 | Method 0
---|---
NS-NS  | $10^{-6.5} - 10^{-3.5}$ | $10^{-6.5} - 10^{-3.5}$
BH-NS  | $10^{-6.5} - 10^{-3.5}$ | $10^{-6.5} - 10^{-3.5}$

...ends up same as by naïve approach
Implications: Merger & intrinsic GRB rates at present?

• **Model 2**: Use SFR of universe
  - Elliptical, spiral merger rate history: (BH-NS)

![Graphs showing transition at z=1 and z=2](image)
Implications: Relative frequency of hosts?

- Competing factors
  - Ellipticals form more massive stars
  - Spirals form stars now; + more spirals

<table>
<thead>
<tr>
<th>$R_{\text{sp}}/R_{\text{ell}}$</th>
<th>Estimate</th>
<th>$\frac{\lambda_{sp}f_{sp}}{\lambda_{el}f_{el}}$</th>
<th>Calculation (Method 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS-NS</td>
<td>0.2</td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>BH-NS</td>
<td>0.1</td>
<td></td>
<td>0.1</td>
</tr>
</tbody>
</table>
Implications:
GRB detection rate and Redshift distribution?

• Tricky!
  – Need good detection model
    (i.e. luminosity function)
  
  – Received flux depends on
    • Viewing geometry (beaming)
    • BH spin (BH-NS cases)
      → **no** a priori method
      → not enough data from experiment

Summary

• Bias towards early-type galaxies can be explained
  – Higher mass efficiency via IMF
  – Long progenitor lifetimes permissible
• Predictive? Not yet…
  – IMFs and elliptical:spiral ratio critical!
  – LF needed!
• Questions:
  – Where are non-escaping mergers?
  – Stellar interactions?