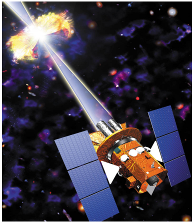
Compact Object Mergers as Short-hard Gamma-ray Burst Progenitors



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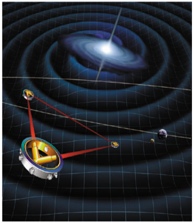
[2]LIGO Scientific Collaboration



GRB mini-Workshop, Warsaw: October 4-6, 2006

Galactic NS-NS Binaries

Phone No.	P_{orb}/hr	e	t_{mrg}/Gyr	Comment
1) B1913+16	7.75	0.617	0.33	field
2) B1534+12	10.1	0.274	2.7	filed
3) J0737-3039	2.45	0.088	0.09	field
4) J1756-2251	7.67	0.181	1.7	field
5) B2127+11C	8.04	0.681	0.22	cluster
6) (J1906+0746)	3.98	0.085	0.30	??? (field)
7) J1811-1736	451	0.828	—-	field
8) J1518+4904	207	0.25	—-	field
9) J1829+2456	28	0.139	—-	field

– relatively short merger times: $\sim$ 0.1 – 3 Gyr
– young pulsars in close NS-NS: 0.1-0.4 Gyr

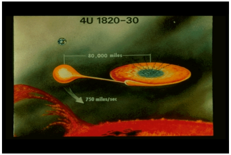
Population Synthesis: The Method

Population synthesis is a Monte Carlo method which allows to evolve large stellar ensembles (both single and binary stars):

- start with initial conditions
- follow single and binary evolution
- calibrate results
- extract given population

In the end synthetic populations are generated:

- statistical analysis
- comparisons with observations
- finally, specific predictions

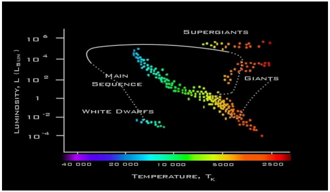


StarTrack: Single Star Evolution

Stars are evolved from the onset of nuclear burning.

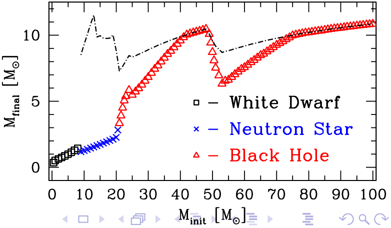
Evolution depends on:

- initial mass ($M_{\rm init}$)
- chemical composition
- mixing (overshooting)
- stellar winds



... and in the end stars form compact remnants:

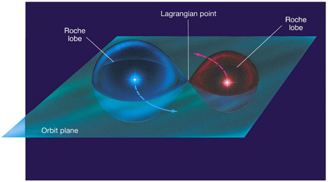
- white dwarfs ($M_{\rm init} \lesssim 8 M_\odot$)
- neutron stars ($8 \lesssim M_{\rm init} \lesssim 20 M_\odot$)
- black holes ($M_{\rm init} \gtrsim 20 M_\odot$)

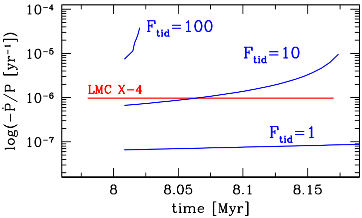


StarTrack: Binary Evolution

Evolution of binary systems is complex and some processes are still not fully understood. The input physics key ingredients are:

- tidal interactions
- mass transfer phases
  - rejuvenation
  - orbit evolution
  - common envelope
- supernova explosions
  - mass loss/natal kicks
  - full orbital solution
- ang. momentum losses
  - systemic mass loss
  - magnetic braking
  - gravitational radiation





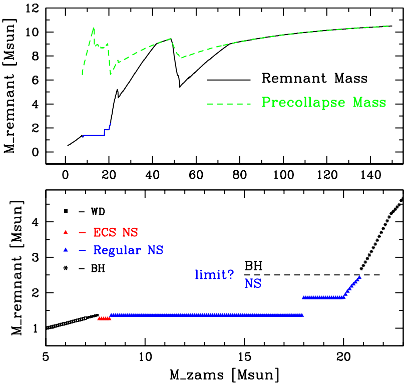
NS Star Masses

Modeling:

- $\sim 1.35 M_\odot$: $M_{\rm zams} < 18 M_\odot$
- $\sim 1.8 M_\odot$: $M_{\rm zams} > 18 M_\odot$
- $\sim 1.26 M_\odot$: ECS NS ($M_{\rm zams} \sim 8 M_\odot$)

Observations:

- $\sim 1.2 - 1.4 M_\odot$: double pulsars
- $\sim 1.9 M_\odot$: Vela X-1 pulsar
- $\sim 2.1 M_\odot$: PSR J0751+1807



What is maximum NS mass? (accretion, collapse to BH?)

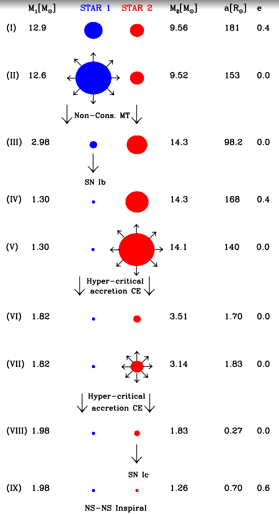
NS-NS Formation Channels

Reanalysis of compact object formation led to
a prediction of new NS-NS population:

- late evolutionary stages ->
- helium star expansion ->
- extra mass transfer episode ->
- if stable RLOF: Classical || if CE: New

New (versus Classical) NS-NS binaries:

- orbital periods: < 2 hr ($\sim 2 - 100$ hr)
- merger times: < 1 Myr (~ 1 Gyr)
- merger sites: birth place (further out)



Belczynski & Kalogera 2001
Belczynski, Bulik & Kalogera 2002
Belczynski, Bulik & Rudak 2002
Perna & Belczynski 2002
Ivanova, Belczynski, Kalogera, Rasio & Taam 2003
Belczynski, Perna, Bulik, Kalogera, Ivanova & Lamb 2006

NS-NS: Formation -> Present

Systems evolve only due to emission of gravitational radiation:

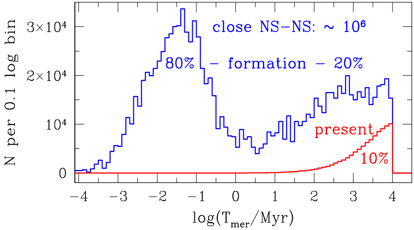
- orbital decay
- circularization

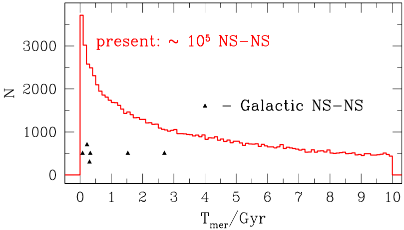
Present population contains only:

- $\sim$ 10% of systems that have formed
- the long-lived systems (short-lived systems have merged)

Models are consistent with observations:

- observed merger rates: $3 - 300 Myr^{-1}$
- modeling: $30 - 50 Myr^{-1}$

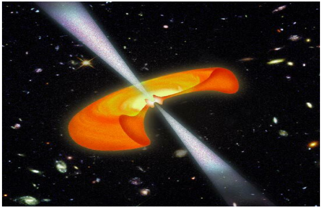




Short Gamma-ray Bursts: Observations

Short-hard GRBs:

- several found within z<0.5-1 (?)
- in old ellipticals
- in young (star-forming) galaxies
- both low- and high-mass hosts



Localized within and outside hosts
Long delay times estimated $\sim 3 - 6$ Gyr

What are their progenitors?

- NS-NS/BH-NS mergers
- NS/quark star transition
- accretion induced collapse

homogeneous progenitor population?

if NS-NS progenitor then ->

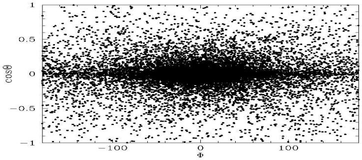
Short Gamma-ray Bursts: Modeling I

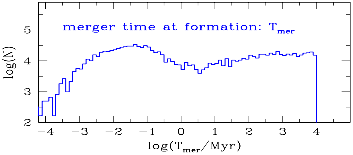
GRB locations:

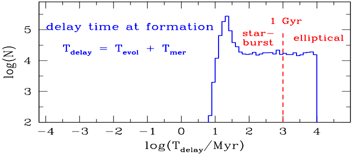
- start with NS-NS population
- put them in GRB host galaxies
- follow their trajectories (birth SNe kicks)
- calculate NS-NS merger locations

Depending on a host:

- old galaxies (ellipticals) -> long-lived (old) NS-NS
- young hosts (star-forming) -> short-lived (young) NS-NS



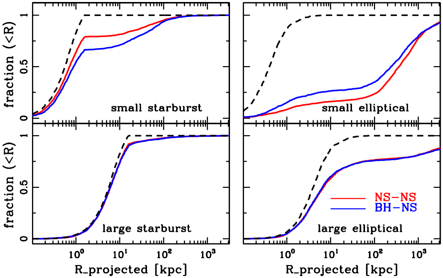




Short Gamma-ray Bursts: Modeling II

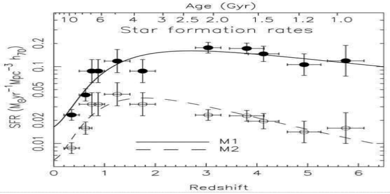
New NS-NS || Classical NS-NS:

- in starbursts || in ellipticals
- inside/outskirt || outskirt/outside
- all redshifts || low-intermediate



Open questions:

- if more GRB found in small ellipt.
  lower natal kicks in binaries?
- if no GRB found at $z \sim 3-5$
  no New NS-NS: no CE survival?
- if no GRB found at $z \sim 1-2$
  how do we explain Galactic NS-NS?!



Summary

- Compact object mergers can explain
  - presence of GRBs in both: old and young galaxies
  - their locations with respect to hosts (lower kicks?)
- Potential problem with the lack of higher redshift GRBs
  - unless some are already observed (e.g., GRB 060121 , $z \sim 1.7 - 4.6$)
  - any bias against detecting them at higher z?
  - or some process preventing NS-NS formation at high z?

or if nothing of the above works, NS-NS is not a GRB progenitor.....

- Currently, we work on
  - formation at high z
  - redshift distribution