Neutron Star Mass Distribution in Binaries

Chang-Hwan Lee

Sabbatical Year @ Stony Brook (2013.8~2014.8)
Life of THB inspired by Drs. Brown & Bethe (My Life in HR Diagram)

95.4.21 (Fri) : Star Trek - First Contact

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Gerry’s Three Questions

The Future

The Life

The Science
20 years with Gerry since 1992

1996~2000@Stony Brook

34 papers with Gerry

1st paper: Kaon condensation in `nuclear star` matter
Lee, Brown, Rho (PLB 335, 266, 1994)

... ...

14th paper: Discovery of Black Hole Mass-Period Correlation in Soft X-ray Transients and its implication for GRB and Hypernova mechanisms

... ...

34th paper: Kerr parameters for stellar mass black holes and their consequences for GRBs and hypernovae
All well measured NS masses in NS-NS binaries are < 1.5 Msun

Gerry’s favorite

Prakash (2013)
Our open questions

- 1.97 & 2.01 Msun NS were observed in NS-WD binaries
- Why all well-measured NS masses in NS-NS binaries are less than 1.5 Msun?

→ NS mass may/should depend on the evolution process

High-mass neutron stars in NS-White Dwarf binaries
1.97 solar mass NS: Nature 467 (2010) 1081
2.01 solar mass NS: Science 340 (2013) 6131
In 2007
✓ we discussed that NS masses in NS-NS binaries may be the result of evolution, not an indication of maximum NS mass.
✓ Gerry accepted the possibility that the maximum mass of NS can be significantly higher than 1.5 solar mass.
Contents

Part I : What we discovered in BH binaries

Part II : What if we apply the same evolution process to neutron star binaries?
Main Sequence companion $\leftrightarrow$ Evolved companion

![Graph showing orbital period vs. black hole mass for various systems (J1118+480, J0422+32, Veil 93, A0568+32, V1216+10, H1705-290, 4U1543-47, J1557+57, Nova Sco 94, V4641 Sgr, V496 Cyg, 1915+105).]
Q) How can we understand the population of SXTs?

Q1) Evolution of BH/NS Progenitor

Q2) What happens at birth?

Q3) Evolution of Donor Star

Progenitors

Current Observation
Tidal interaction just before BH formation

Fe

Synchronization of BH-Progenitor Spin & Binary Orbital Period

rapidly spinning BH
Reconstructed BH Binaries at Birth

\[ M_{\text{He}} = 11 \, M_{\text{Sun}} \]

\[ M_{\text{He}} = 7 \, M_{\text{Sun}} \]

\[ M_{\text{BH}} \]

Orbital Period [days]
Rapidly spinning black holes at birth

![Graph showing the relationship between pre-explosion orbital period and Kerr parameter for different masses.](image)

- **Graph Title:** Pre-explosion orbital period (days) vs. Kerr parameter (a)
- **Graph Description:** The graph illustrates the decrease in Kerr parameter with respect to the pre-explosion orbital period for different masses.

Legend:
- **7 M_{\odot}**
- **11 M_{\odot}**
- **Woosley’s**
Rapidly spinning black holes at birth

4U 1543-47
GRO J1655-40

Shafee et al. (2006)
Evolution after BH formation
GRS 1915+105

Spin-up due to conservative accretion

Low-spin black holes at birth
McClintock et al. (2006)

GRS 1915+105

$a^* > 0.98$
Gerry’s last paper


submitted 2009 May 11, accepted 2010 Nov 8, published 2011 Jan

KERR PARAMETERS FOR STELLAR MASS BLACK HOLES AND THEIR CONSEQUENCES FOR GAMMA-RAY BURSTS AND HYPERNOVAE

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ABSTRACT

Recent measurements of the Kerr parameters $a_*$ for two black hole binaries in our Galaxy, GRO J1655−40 and 4U 1543−47, of $a_*=0.65–0.75$ and $a_* = 0.75–0.85$, respectively, fit the predictions of Lee et al. of $a_* \lesssim 0.8$. They predicted $a_* > 0.5$ for 80% of the soft X-ray transient (SXT) sources. The maximum available energy in the Blandford–Znajek formalism for $a_* > 0.5$ gives $E > 3 \times 10^{53}$ erg, orders of magnitude larger than the energy needed for the gamma-ray burst (GRB) and hypernova explosion. We interpret the SXTs to be relics of GRBs and hypernovae. We find that most galactic SXTs were subluminous given that they could use only a small part of the available rotational energy.

Key words: binaries: close – black hole physics – gamma-ray burst: general – supernovae: general – X-rays: binaries
Part II

What if we apply the same evolution process to neutron star binaries?

- Supercritical accretion in NS binaries
- Possibilities of `NS + high-mass NS/BH` binaries
Supercritical Accretion onto first-born NS

- Eddington Accretion Rate: photon pressure balances the gravitation attraction.
- If this limit holds, neutron star cannot be formed from the beginning (e.g. SN1987A; $10^8$ Eddington Limit).
- Neutrinos can take the pressure out of the system allowing the supercritical accretion when accretion rate is bigger than $10^4$ Eddington limit! ($T > 1$ MeV: Thermal neutrinos dominates!)

Q) What is the implications of supercritical accretion, if it works?
Fresh NS mass from Fe core collapse

In close binaries (evolution without H envelope)

Low Fe core mass $\rightarrow$ NS mass = 1.3 - 1.5 M$_{\odot}$

This value is independent of NS equation of state.

Q) What is the fate of primary (first-born) NS in binaries?
Final fate of first-born NS

1\textsuperscript{st}-born NS

Accretion

NS + accretion

2\textsuperscript{nd} NS/WD

Evolution of Companion

Accretion of Fe and He

Graph showing evolutionary stages with labels for H core, H shell, and He core burning.
Case 1

No accretion: nearly equal mass NS-NS binary!
First born NS should accrete only < 0.2 M⊙!
Case 3

Supercritical Accretion: First born NS can accrete up to 0.9 $M_\odot$!
Possibilities of `NS + high-mass NS/BH` binaries
Final mass of first-born NS with supercritical accretion

Q) maximum NS mass?

Final mass of 1st-born NS

Original mass of 2nd star

NS + WD

NS/BH+NS

NS + NS

without accretion

seen
Can we see BH-NS binaries as pulsars even if they exist?

Pulsar life time: \(1/B\)

Fresh pulsar: \(B \sim 10^{12}\) G

- **NS-NS**
  - if first-born NS is recycled by accretion
  - longer pulsar life time (\(B \sim 10^8\) G)
  - larger beaming angle
  - bigger chances to be observed

- **BH-NS**
  - no recycled pulsar
  - much smaller chances to be observed
GW sources with NS

- **NS-NS**
  - already seen

- **NS-BH**
  - no evidence yet
  - can contribute to GW if exist
Consequences of supercritical accretion, if it works

- different class of NS binaries may exist
  high mass NS/BH ( > 2 solar mass) + typical NS
- could be hidden GW sources
Fly with Eagles
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Gerry’s contribution to my HR diagram?
Well, I'll go to heaven!
I really enjoyed working with Gerry