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EVOLUTION OF X-RAY BINARIES

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BINARY-BINARY COLLISIONS INVOLVING MAIN-SEQUENCE STARS, WHITE DWARFS AND NEUTRON STARS IN GLOBULAR CLUSTERS

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ABSTRACT

We consider collisions between dynamically-evolved primordial binaries consisting of main-sequence stars, white dwarfs and neutron stars in globular clusters. In our four-body binary-binary scattering experiments, we allow stars to “stick” if they pass close enough to each other, which leads to the formation of a wide variety of exotic objects. Most of these objects have binary companions. Also, relatively clean exchange interactions can produce binaries containing neutron stars that eventually receive material from their companions. Such systems will be observable as X-ray binaries.

1. INTRODUCTION

Collisions between dynamically-evolved primordial binaries consisting of main-sequence stars (MSSs), white dwarfs (WDs) and neutron stars (NSs) must occur in globular clusters, and the purpose of this project is to study such interactions. To reduce the parameter space, we consider only binaries containing at least one MSS. In our scattering experiments, we allow stars to “stick” if they pass close enough to each other. Multiple collisions can take place. The various kinds of stellar mergers that can occur directly or following a common envelope phase and/or the emission of gravitational radiation are 1) MSS-MSS, 2) MSS-WD, 3) MSS-NS, 4) WD-WD, 5) WD-NS, and 6) NS-NS. The exotic phenomena that result from such mergers may include blue stragglers, red giants, Thorne-Żytkow objects, accretion disks around compact objects, spun-up pulsars, ms pulsars formed via AIC, Type Ia supernovae, black holes, and gamma-ray bursts.

2. THE SCATTERING EXPERIMENTS

The scattering experiments were carried out using a modified version of the code originally developed by Alexander (1986). The adopted masses are $M_{MSS} = 0.7 M_{\odot}$, $M_{WD} = 0.7 M_{\odot}$ and $M_{NS} = 1.4 M_{\odot}$. The adopted radii are $R_{MSS} = 0.7 R_{\odot}$, $R_{WD} = 0.01 R_{\odot}$ and $R_{NS} = 0.0 R_{\odot}$. Stars are allowed to “stick” together if they pass close enough. The radius of “stickyness” is $R_{stick} = \Sigma R_{MSS}$ for MSS-MSS encounters, and $R_{stick} = 2 R_{MSS}$ for MSS-WD and MSS-NS encounters. Two MSSs that merge become a $1.4 M_{\odot}$ MSS with a radius of $1.4 R_{\odot}$. For WD-WD encounters, $R_{stick} = \Sigma R_{WD}$. However,

direct collisions between WDs are very rare, since WDs are much more likely to collide with MSSs first. The semi-major axes and eccentricities of both binaries are $a = 50 R_{\odot}$ and $e = 0.6$, respectively. The relative velocity at infinity well before the interaction begins is $V_{rel,\infty} = 10 \text{ km s}^{-1}$. The impact parameter, b , is generated from the distribution $dN/db \propto b$ for $0 \leq b \leq b_{max}$. The values of b_{max} are $36.29a$, $40.46a$ and $44.24a$ for collisions involving zero, one and two NSs, respectively. In all cases, b_{max} corresponds to a pericenter distance of $6a$ for the relative two-body hyperbolic orbit of the binary centers of mass, which is extremely unlikely to lead to a strong interaction.

3. THE RESULTS

The following tables state the number, n , of the various types of mergers that occurred in 1000 examples of various kinds of binary-binary collisions. The corresponding cross section is $(n/1000) \pi b_{max}^2$. The number in brackets is the number of merged stars that have binary companions.

A. (MSS+MSS) (MSS+MSS) Collisions

no merger	673
MSS-MSS merger	236(142)
MSS-MSS-MSS merger	75(35)
two separate MSS-MSS mergers	14(4)
MSS-MSS-MSS-MSS merger	2(0)

B. (MSS+MSS) (MSS+WD) Collisions

no merger	648
MSS-MSS merger	174(87)
MSS-WD merger	96(85)
MSS-MSS-WD merger	47(24)
separate MSS-MSS and MSS-WD mergers	21(11)
MSS-MSS-MSS merger	14(0)

C. (MSS+MSS) (MSS+NS) Collisions

no merger	674
MSS-MSS merger	165(49)
MSS-NS merger	100(91)
MSS-MSS-NS merger	30(15)
separate MSS-MSS and MSS-NS mergers	18(11)
MSS-MSS-MSS merger	11(1)
MSS-MSS-MSS-NS merger	2(0)

D. (MSS+WD) (MSS+WD) Collisions

no merger	658
MSS-WD merger	220(141)
MSS-MSS merger	49(31)
MSS-MSS-WD merger	34(13)
MSS-WD-WD merger	21(11)
two separate MSS-WD mergers	17(7)
MSS-MSS-WD-WD merger	1(0)

E. (MSS+WD) (MSS+NS) Collisions	
no merger	693
MSS-WD merger	124(44)
MSS-NS merger	89(85)
MSS-MSS merger	47(23)
MSS-WD-NS merger	18(13)
MSS-MSS-WD merger	11(0)
separate MSS-WD and MSS-NS mergers	10(3)
MSS-MSS-NS merger	7(6)
MSS-MSS-WD-NS merger	1(0)

F. (MSS+NS) (MSS+NS) Collisions	
no merger	729
MSS-NS merger	193(128)
MSS-MSS merger	31(10)
MSS-MSS-NS merger	22(6)
two separate MSS-NS mergers	12(7)
MSS-NS-NS merger	12(3)
MSS-MSS-NS-NS merger	1(0)

4. MERGED STARS IN BINARIES

Most of the merged stars have binary companions, and a small fraction of them are in triple systems. The binaries tend to have periods that are comparable with or longer than the binaries that originally collided, and the orbits tend to be quite eccentric. These are the same trends as found for the binary properties of blue stragglers produced via physical stellar collisions during strong binary-binary interactions (Leonard & Fahlman 1991).

5. WORK IN PROGRESS

We have just begun this project, which is the binary-binary analog of the binary-single study of Davies, Benz & Hills (1993). To provide better statistics, we will consider 10^4 runs per kind of collision instead of only 10^3 . Point-particle (i.e., zero-radius) experiments corresponding to the cases presented in this paper will be carried out for comparison. We will also carry out hydrodynamical simulations of the most interesting merger cases. Merger rates in real globular clusters will be estimated. Cross sections for non-merger outcomes (e.g., exchanges, triple formation, etc...) will also be calculated.

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