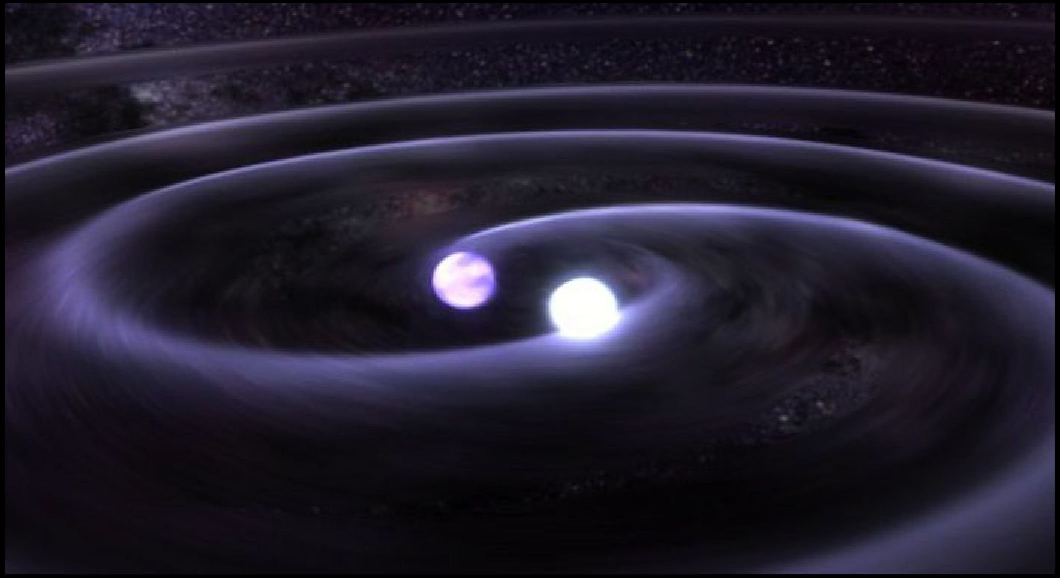
X-Ray Hierarchical Triples

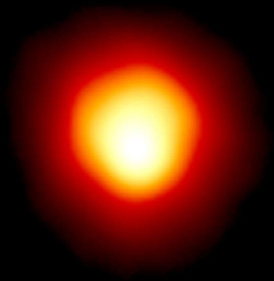
A new channel to gravitational mergers

X-Ray Triple

- **Accretor:** two compact objects in a close orbit

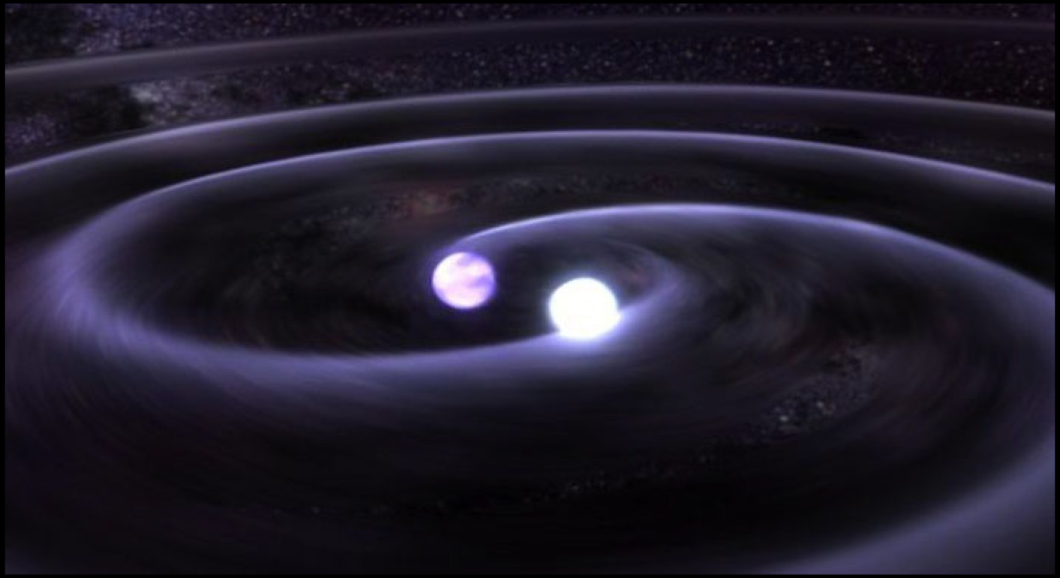


- **Donor:** star in a wide orbit



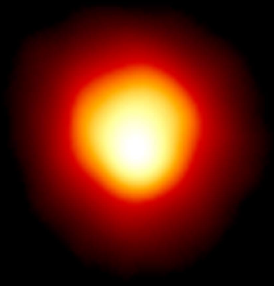
X-Ray Triple

- **Accretor:** two compact objects in a close orbit



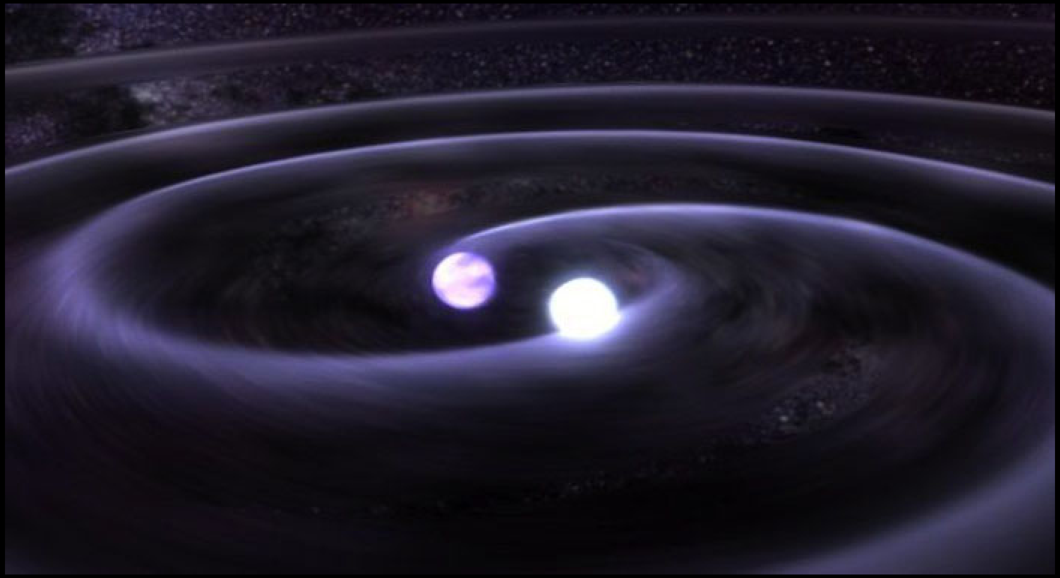
WD-WD
WD-NS
WD-BH
NS-NS
NS-BH
BH-BH

- **Donor:** star in a wide orbit



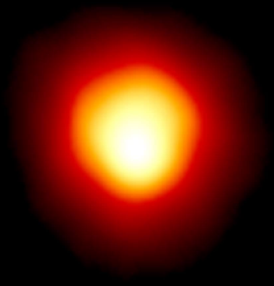
X-Ray Triple

- **Accretor:** two compact objects in a close orbit



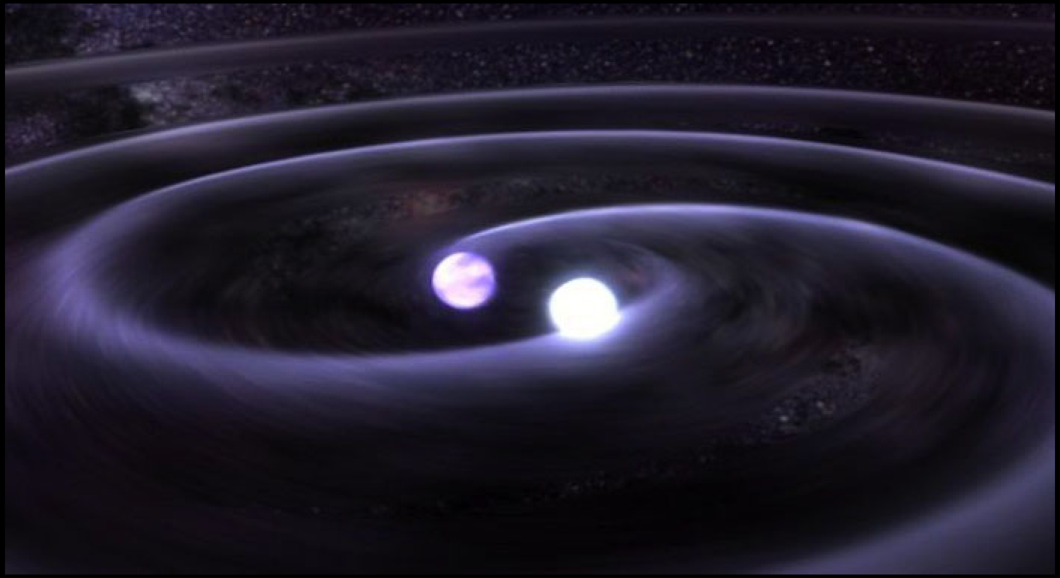
To merge in a Hubble Time…or not!

- **Donor:** star in a wide orbit

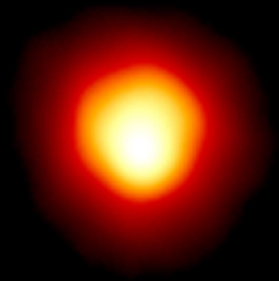


X-Ray Triple

- **Accretor:** two compact objects in a close orbit



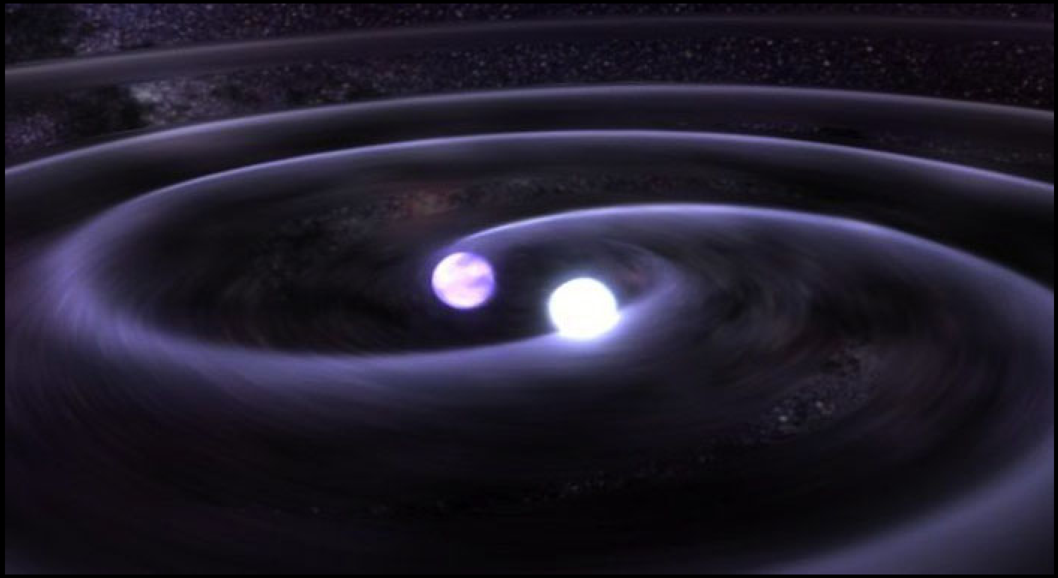
- **Donor:** star in a wide orbit



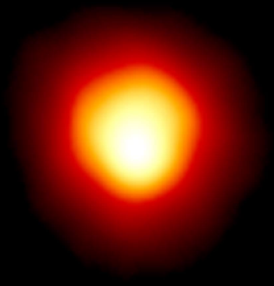
Giant or main-sequence

X-Ray Triple

- **Accretor:** two compact objects in a close orbit



- **Donor:** star in a wide orbit



In a wide-enough orbit.

Why consider them?

Because they ***may be*** there!

Why consider them?

- Most young high-mass stars are in binaries, hierarchical triples, or quadruples.

  (Moe & Di Stefano 2018)

- The “multiplicity factor” is > 2. (e.g., Sana et al 2014)

- There are scenarios in which the third star survives.

Why consider them?

- Accretion by one or both members of the inner binary makes the system detectable pre-merger. For example, via binary self-lensing;

  D’Orazio & Di Stefano 2018a, 2018b.

- Angular momentum can be drained from the inner orbit, decreasing the time to merger.

- The compact objects can gain mass and may become transformed.

How to consider them *cautiously*

- Craft the inner binary.
- Select a donor mass.
- Select an initial orbital separation such that the donor does not fill its Roche lobe as a subgiant.
- Start with a core mass of 0.2 solar masses.
- Evolve the core, changing the radius, mass-loss rate, and total mass with each time step.

How to consider them?

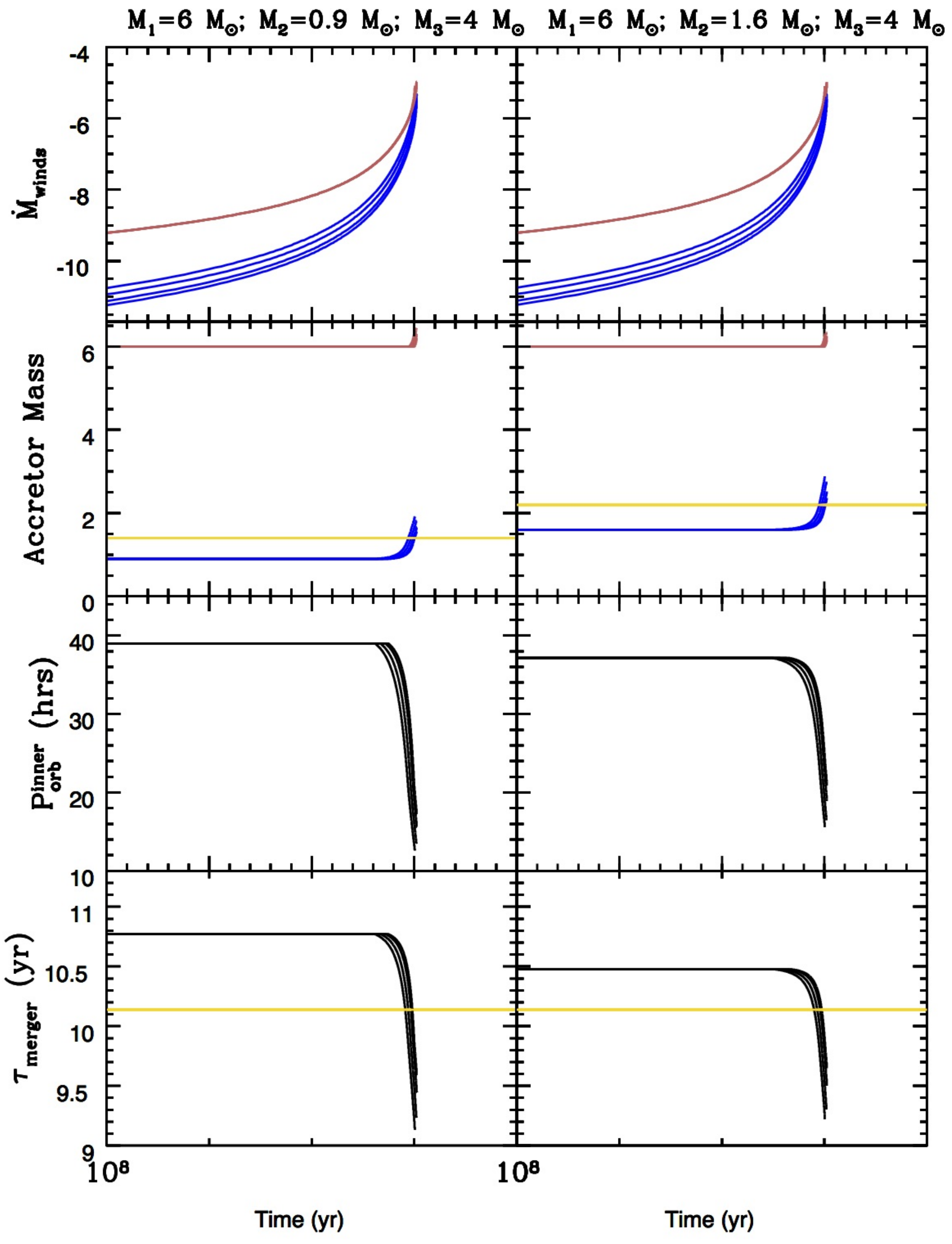
- ϒ of winds is channelled toward inner binary.
- (1 - ϒ) escapes system, carrying specififc angular momentum of outer orbit.
- β_2 of incoming mass is retained by M_2.
- β_1 $(1-\beta_2)$ is retained by M_1
- The rest of the mass exits the system carrying the specific angular momentum of the inner binary.

How to consider them?

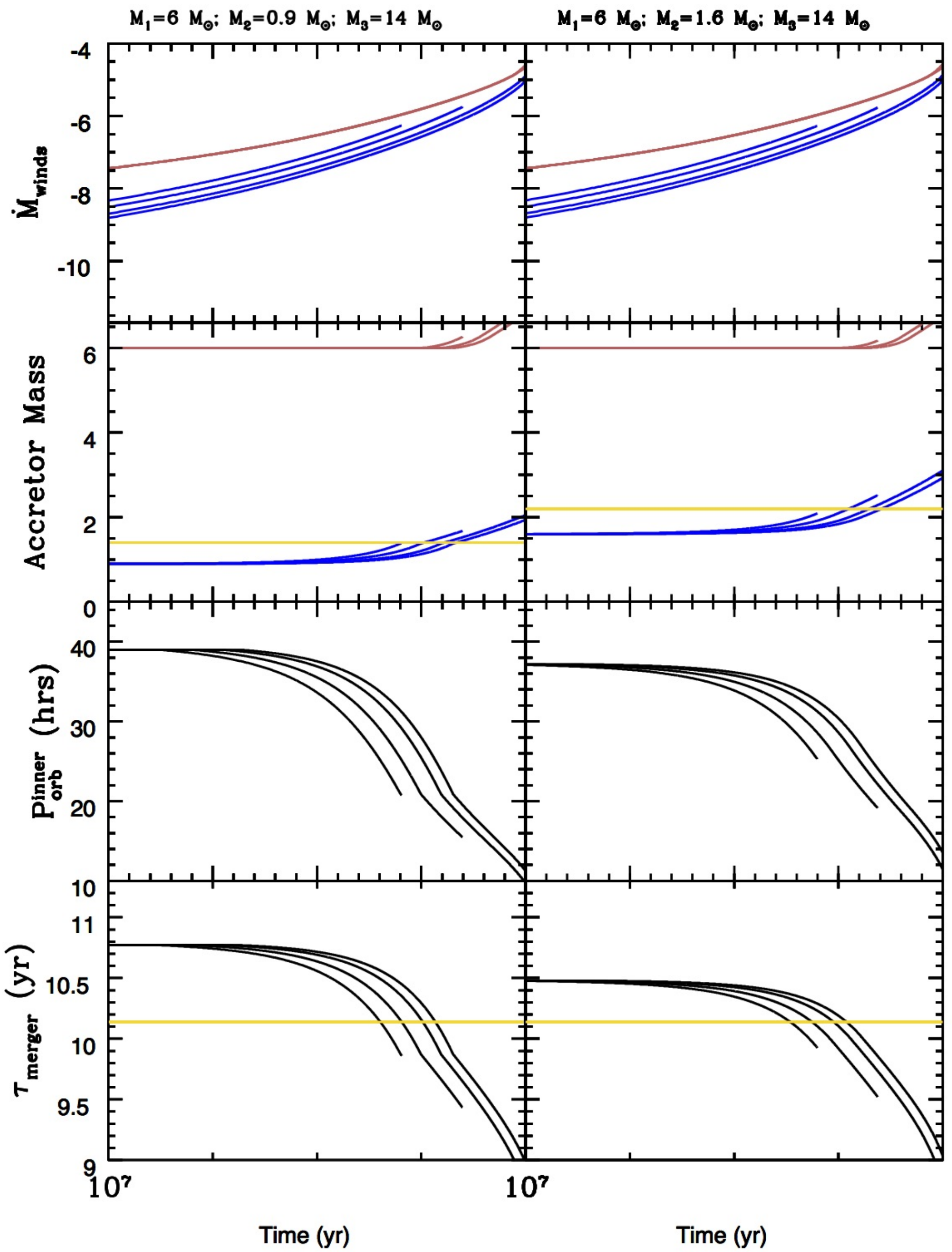
- If the donor fills its Roche lobe, determine whether a common envelope will ensue. If so, angular momentum is drained from both orbits. We do not permit mergers, even though Nature might.
- If mass transfer is stable, evolve the system until the donor exhausts its envelope.

How to consider them?

- Run many simulations, altering key parameters.

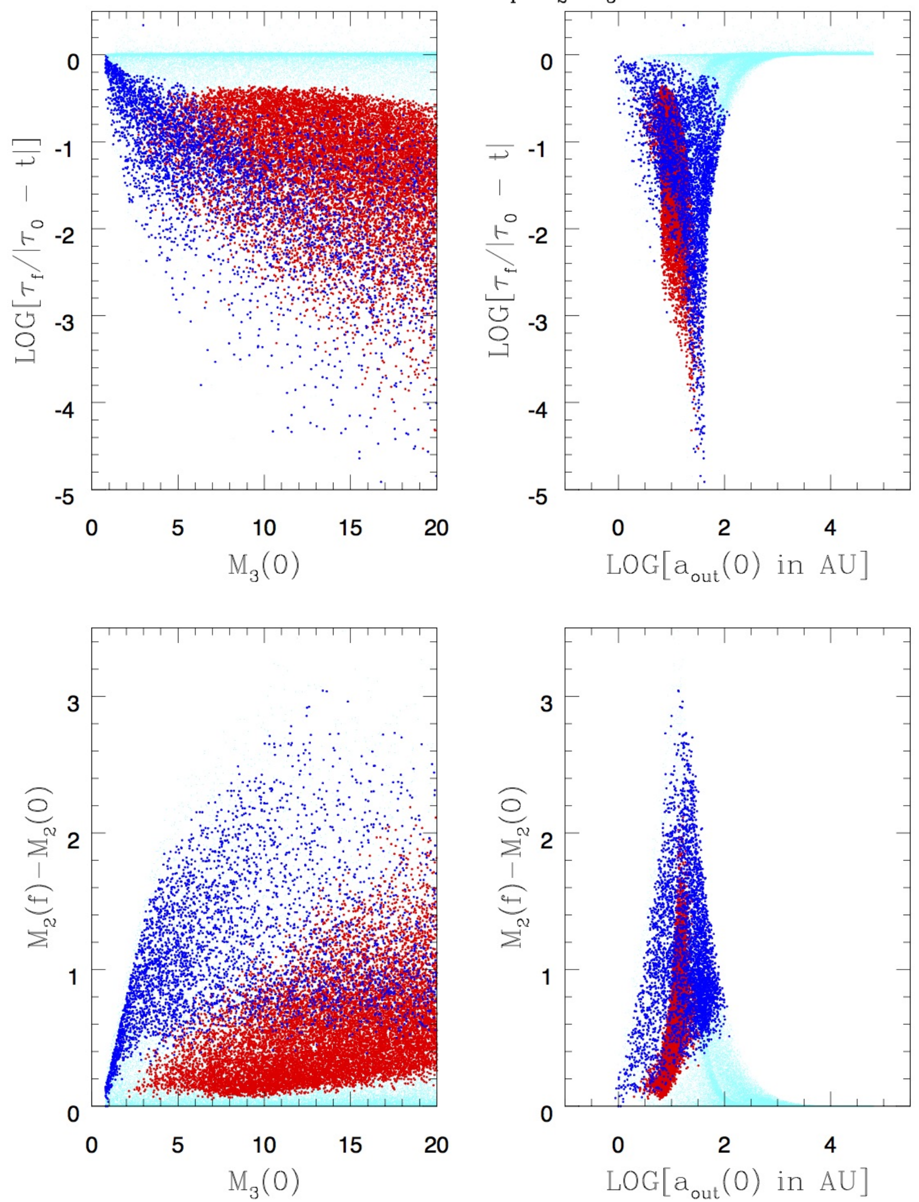


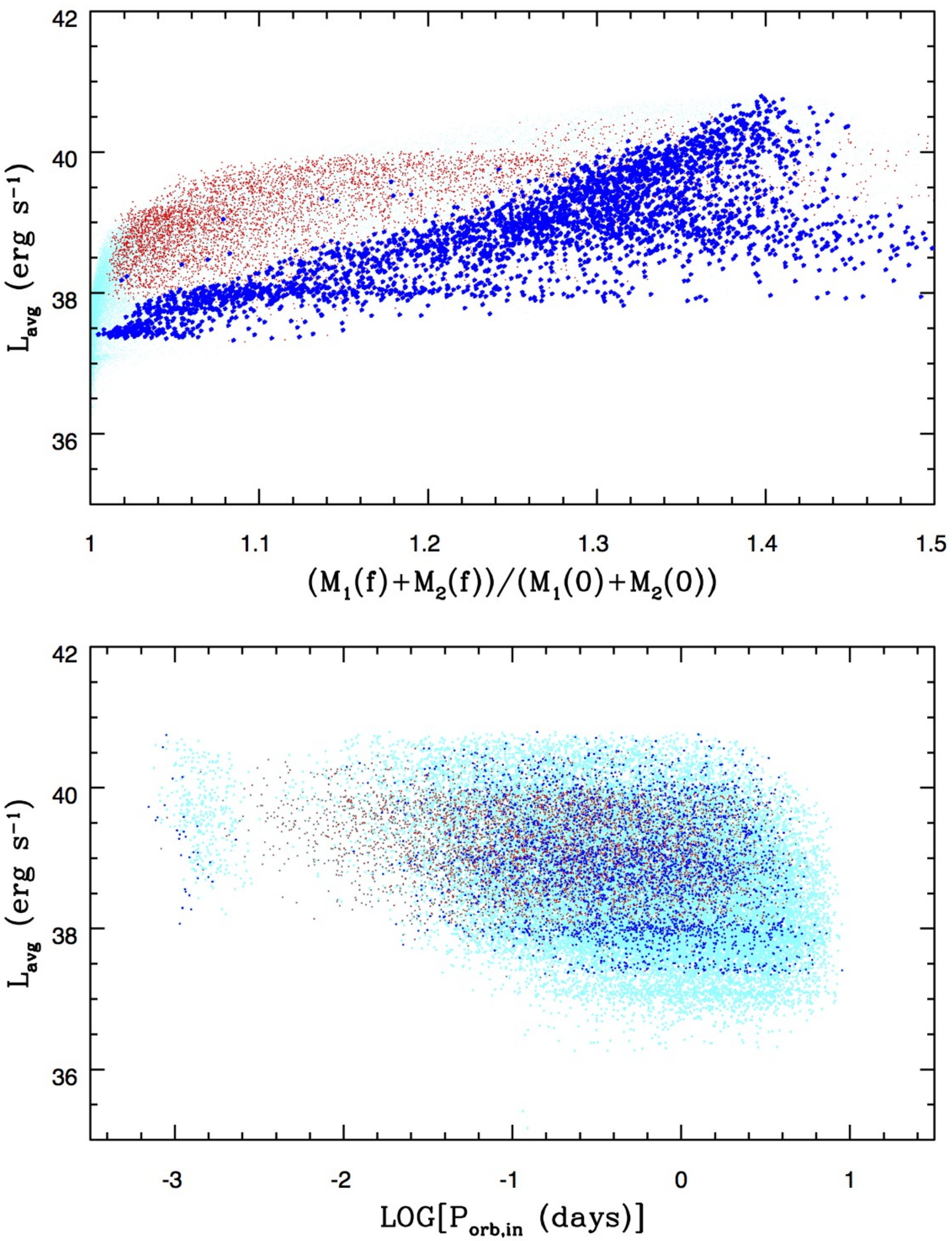
M_1=6 $M_\odot$; M_2=0.9 $M_\odot$; M_3=4 $M_\odot$
M_1=6 $M_\odot$; M_2=1.6 $M_\odot$; M_3=4 $M_\odot$
$\dot{M}_{winds}$
-4
-6
-8
-10
Accretor Mass
6
4
2
0
P_{orb}^{inner} (hrs)
40
30
20
10
τ_{merger} (yr)
11
10.5
10
9.5
9
10^8
10^8
Time (yr)
Time (yr)



M1=6 M⊙; M2=0.9 M⊙; M3=14 M⊙
M1=6 M⊙; M2=1.6 M⊙; M3=14 M⊙
$\dot{M}_{winds}$
-4
-6
-8
-10
Accretor Mass
6
4
2
0
P_{orb}^{inner} (hrs)
40
30
20
10
τ_{merger} (yr)
11
10.5
10
9.5
9
10^7
10^7
Time (yr)
Time (yr)

$\kappa=0.5;\ v_1=v_2=v_3=2$




42
40
38
36
L_{avg} (erg s^{-1})
1
1.1
1.2
1.3
1.4
1.5
$(M_1(f)+M_2(f))/(M_1(0)+M_2(0))$
42
40
38
36
L_{avg} (erg s^{-1})
-3
-2
-1
0
1
LOG[$P_{orb,in}$ (days)]

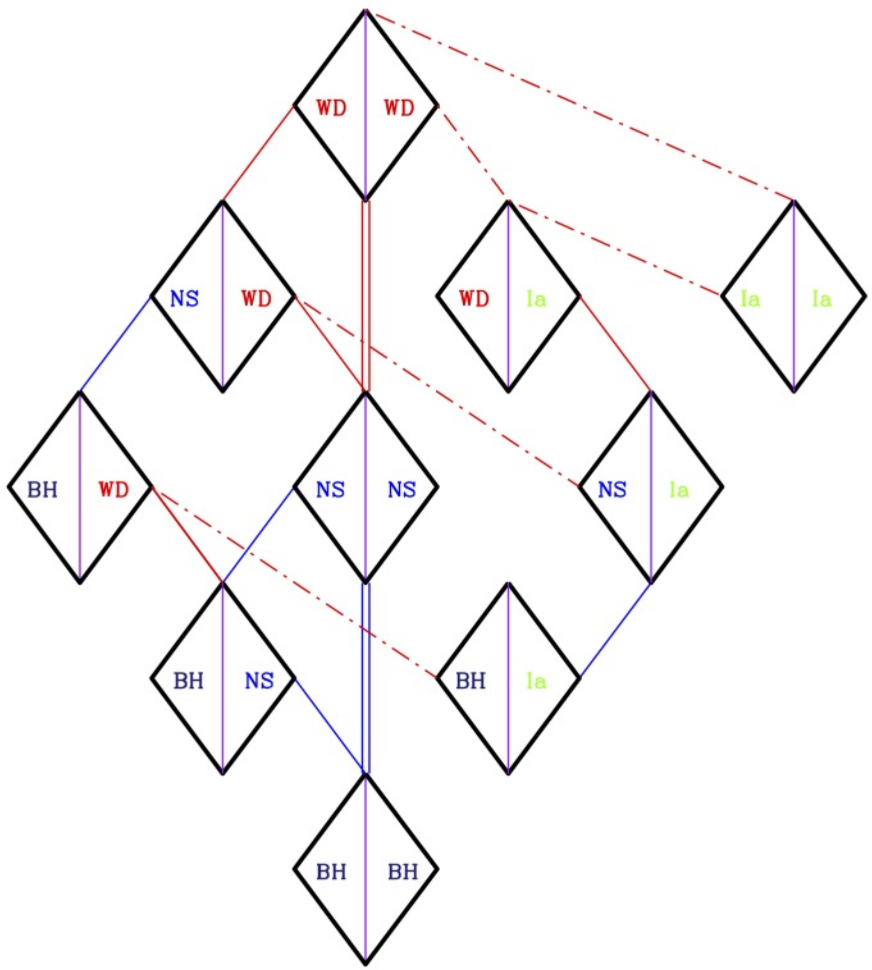

WD WD
NS WD
WD Ia
Ia Ia
BH WD
NS NS
NS Ia
BH NS
BH Ia
BH BH

Table 1. Numbers of events per 33,333 triples

v_1	v_3	κ	$N_{<0.5\,\tau(0)}$	$N_{<0.1\,\tau(0)}$	X-WD ⇓ X-Ia	X-WD ⇓ X-NS	X-WD ⇓ X-BH	X-NS ⇓ X-BH	NS-NS ⇓ BH-BH	WD-WD ⇓ NS-NS	WD-WD ⇓ Ia-Ia
0.00	0.00	0.50	5282	2790	618	361	93	889	98	18	36
0.50	0.50	0.50	5911	3090	721	400	82	1000	102	21	36
1.00	1.00	0.35	6321	2742	709	475	52	1033	82	22	27
1.00	1.00	0.50	6853	3538	801	498	101	1217	109	16	37
1.00	1.00	0.75	7408	4368	929	490	108	1287	137	25	43
2.00	2.00	0.50	9024	4469	912	718	68	1419	110	30	20
2.00	0.00	0.50	5369	2798	662	389	77	930	82	22	28
0.00	2.00	0.50	8923	4344	873	693	91	1430	123	35	35

Special conditions are not needed.

Implications
(examples)

- ***Additions to the merger rates.*** Theoretical work (including population synthesis starting with the correct distributions of primordial-multiple's properties) and observations will determine the relative contributions.

- ***New models for Type Ia supernovae.***

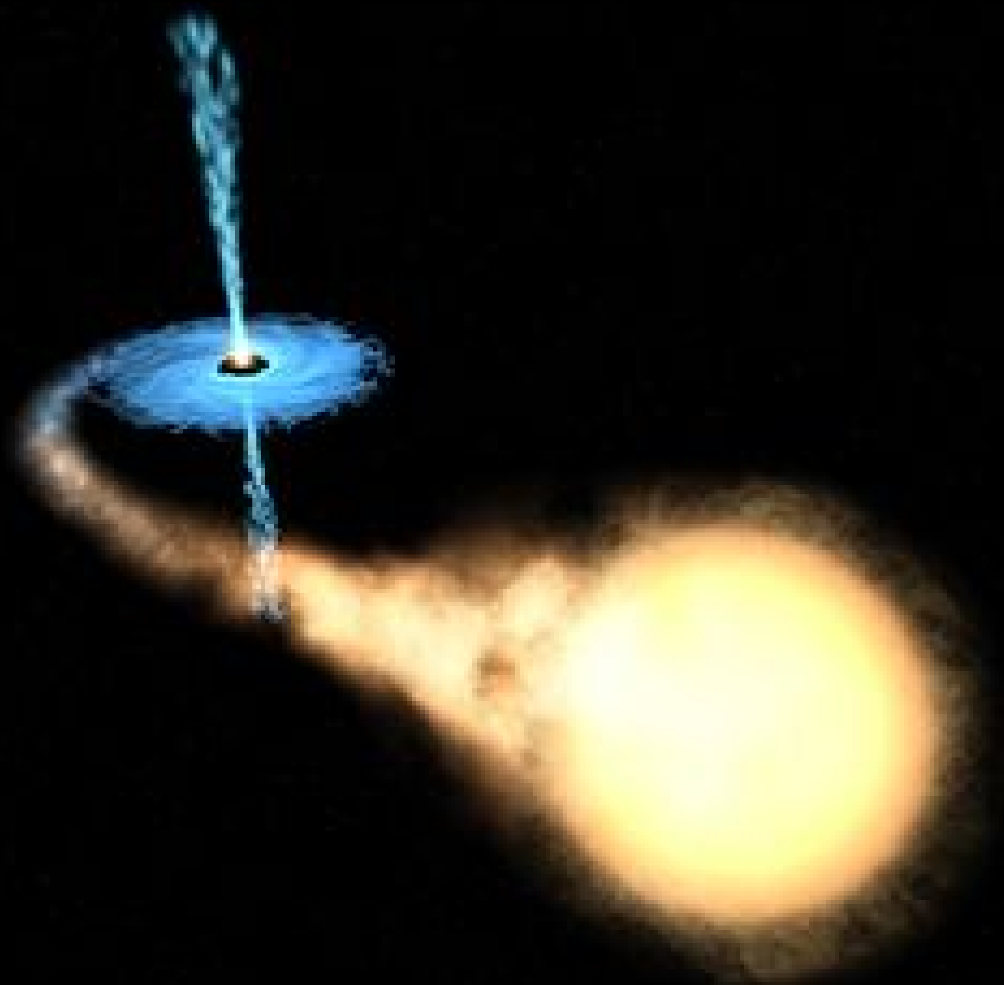
Tests
(examples)

- HMXBs with wide-orbit companions.
- X-ray triples.
- Binary self-lensing.
- Low-mass BH mergers.
- Electromagnetic signatures accompanying mergers.

Hierarchical X-ray Triples

- An important addition to our study of accretion processes.
- Disk studies can extend to circumbinary disks and minidisks. (analogy with double AGN candidtaes).
- May enhance gravitational merger rates. This removes pressure from binary-only models.
- Provide new models for Sne Ia.
- Accretion and dynamics must be combined.

Is the accretor in this X-ray binary itself a compact binary?



How do compact binaries form and merge?