Image credit: Carl Knox OzGrav-Swinburne University

# An alternative formation scenario for radio-quiet neutron star - light black hole binary systems

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## Abstract

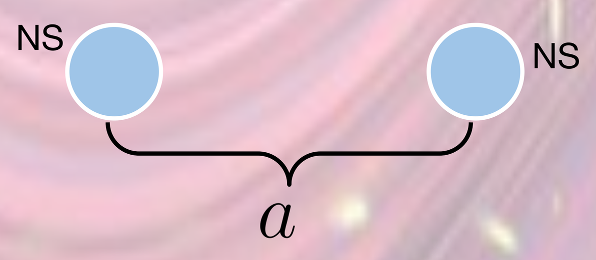
Two collisions between a neutron star (NS) and a black hole (BH) have been recently detected. Collisions of such compact objects create ripples in the fabric of spacetime that travel across the universe. These ripples, also known as gravitational waves (GWs), can be detected on Earth using GW observatories. These observations of NS-BH binaries, which have not been detected in the Milky Way yet, could mean that our ideas of how such systems are assembled might need to be revised.

Here, we propose a novel formation channel for NS - light BH binary systems wherein massive helium stars, formed after a common envelope (CE) phase, remain compact and avoid mass transfer onto the NS companion, thereby evading pulsar recycling.

We present three-dimensional Smoothed-Particle Hydrodynamics (SPH) simulations of the supernova (SN) explosion of the massive stripped helium star and follow the mass fallback evolution and the subsequent accretion onto the central NS.

We find that fallback leads to significant mass growth in the newly formed compact object and that the newly born NS can accrete sufficient mass to become a light BH.

## How can NS-BH binaries assemble?

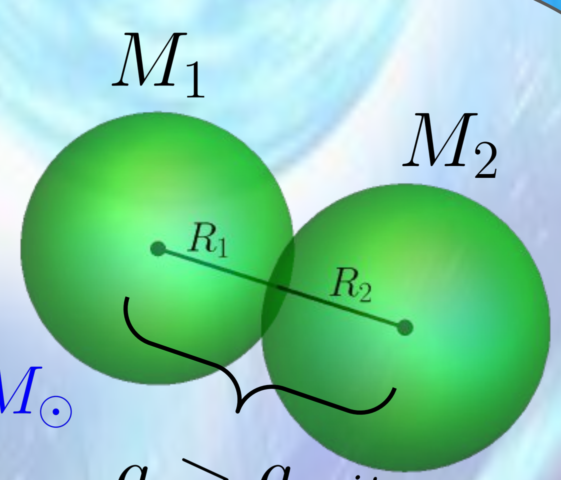



$t < t_H$

$a < a_{crit}$

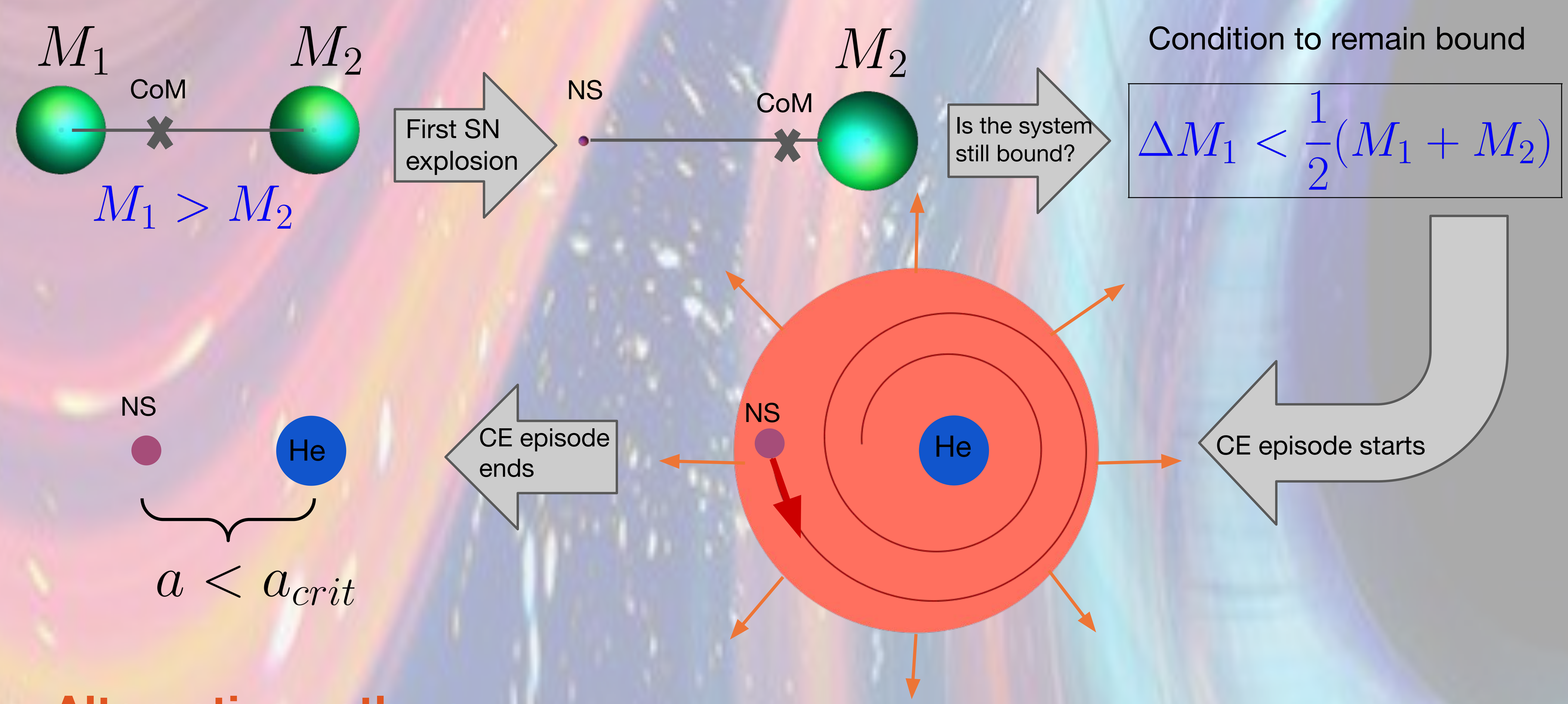
Problem:

$M_1, M_2 > 10 M_\odot$




$a > a_{crit}$

## Formation channel



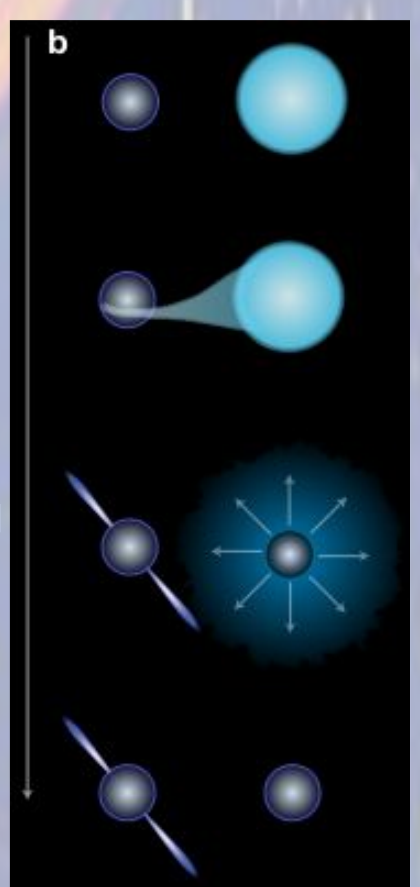

## Alternative pathway

Low mass He core

Mass transfer

NS is recycled & SN explosion

Pulsar & NS



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Massive He core

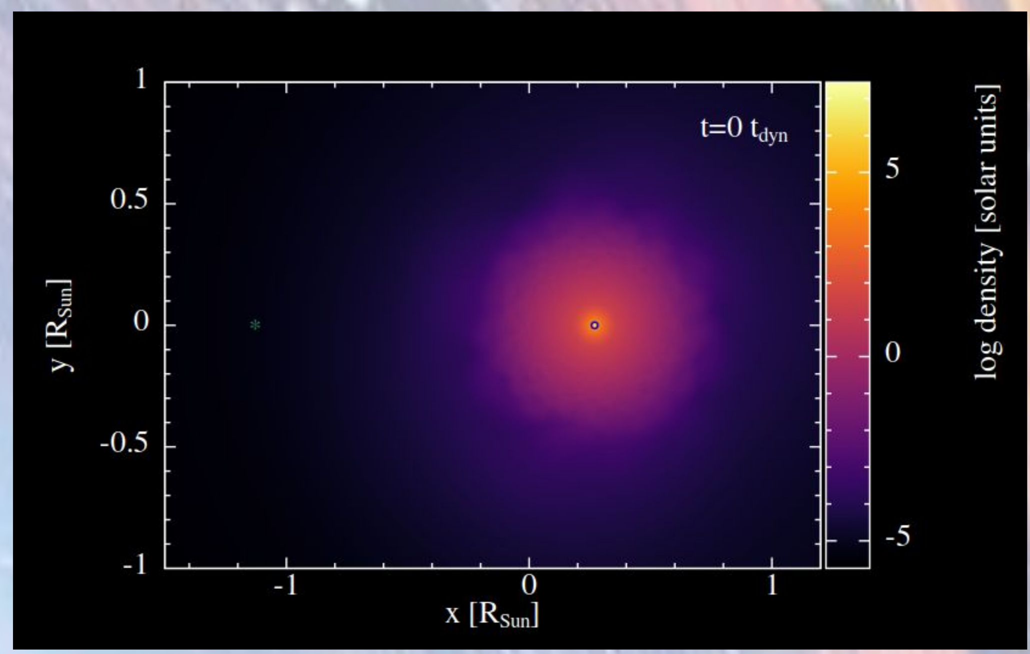
SN explosion & mass fallback

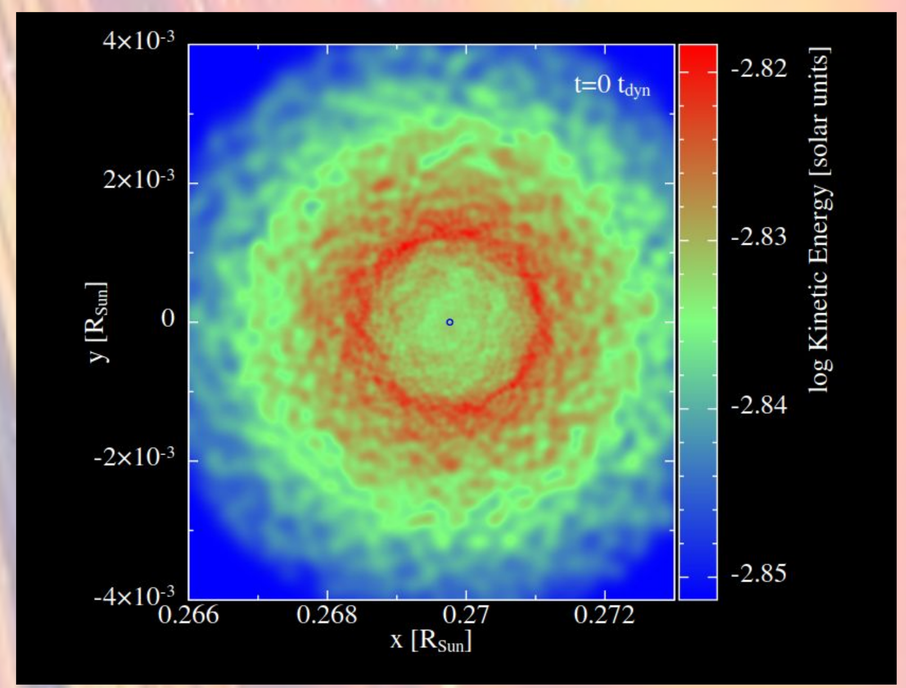
High mass accretion & accretion disk

NS & BH

## Simulations

3D SPH simulations of the SN explosion of a massive He star with GADGET-2

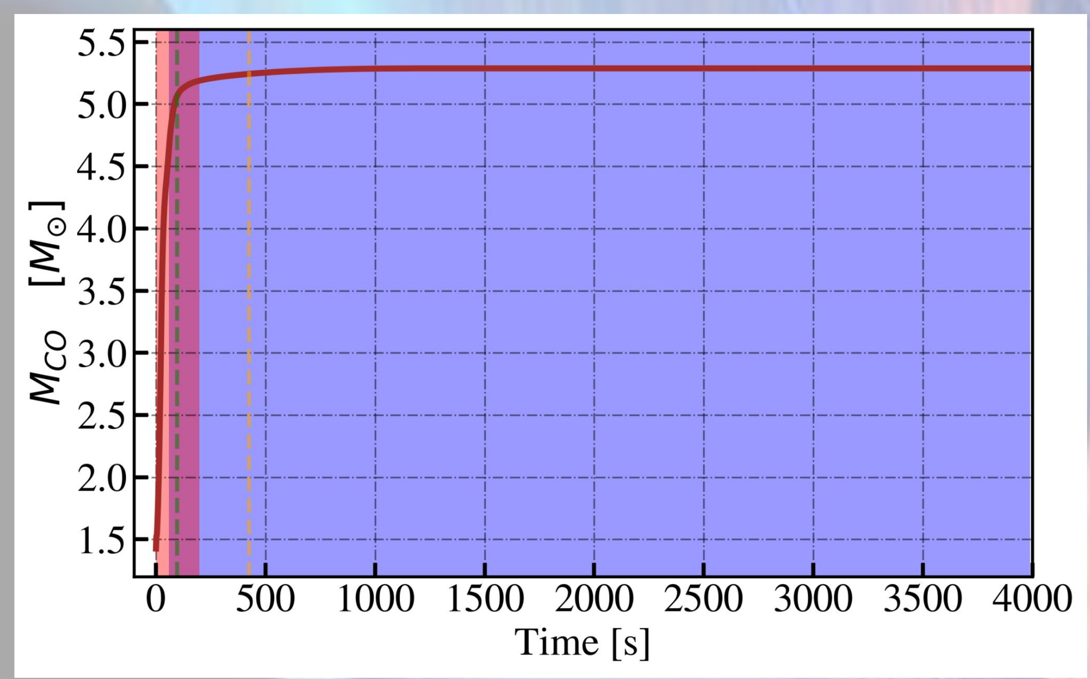


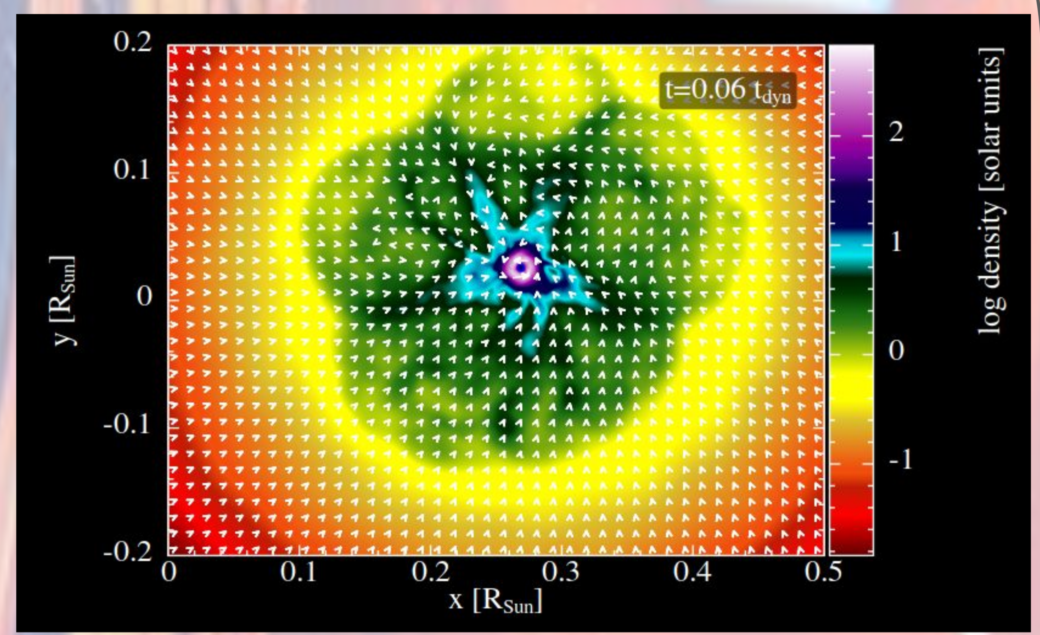




- Circular binary: exploding star & NS companion
- 1D MESA progenitor star models at core collapse
- 3D SPH particle distribution
- Innermost $1.3M_{sun}$ replaced by sink particle with same mass
- Deposit energy in between outermost layer of Fe core and above sink particle

## What did we find?

### Mass accretion of the newly born compact object



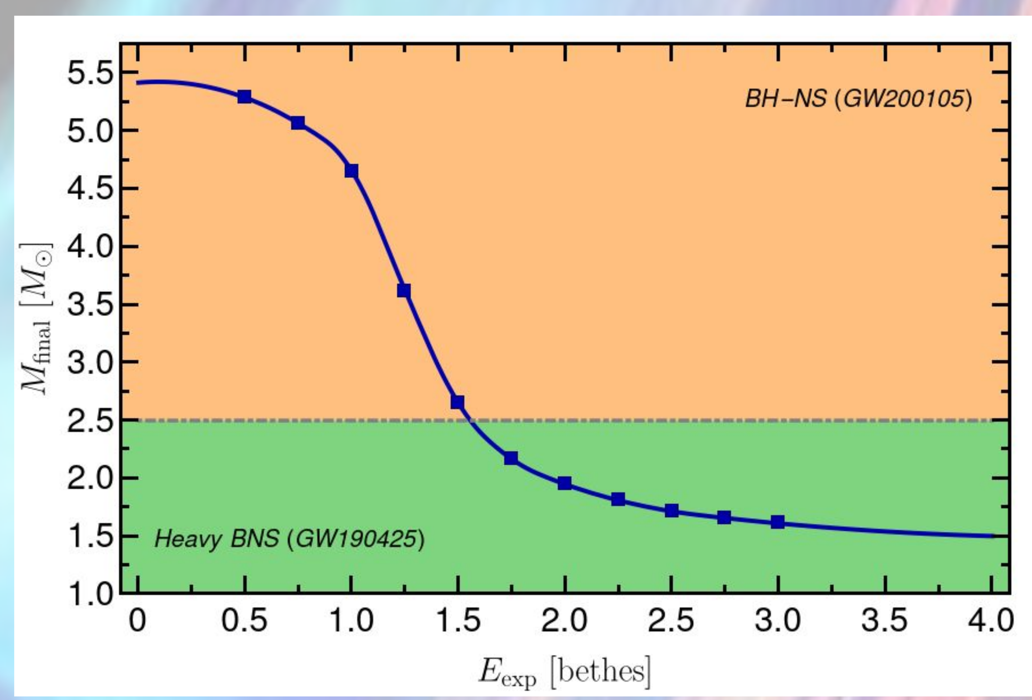




- Direct accretion
- Disk accretion
- Transition region
- t=0.06 $t_{dyn}$
- Dynamical timescale exploding star

$10M_\odot$ Z=0.02

E=0.5 Bethes

### Distribution of double compact object systems




- As we increase the explosion energy, the remnant mass of the exploding star decreases: less fallback as we move to higher explosion energies because the gas particles' velocities are greater than escape velocity.
- Boundary between BH & NS

## References

1. Vigna-Gómez, *et al.* ApJ Letters (2021)

## Acknowledgements

We would like to thank the National Science Foundation for supporting this work through the NSF-Lamat REU program under Grant No. AST-1852393. This research would have not been possible without the guidance and incredible support of my mentors Alejandro, Enrico, and Sophie.