Accretion onto compact objects during common envelope phases

Morgan MacLeod
NASA Einstein Fellow
Harvard-Smithsonian Center for Astrophysics

collaborators: Andrea Antoni, Aldo Batta, Soumi De, Jonathan Grindlay, Phillip Macias, Gabriela Montes, Ariadna Murguia-Berthier, Eve Ostriker, Enrico Ramirez-Ruiz, James Stone

October 3, 2018
Common envelope interactions transform binary systems

Example: formation of merging pairs of neutron stars

Pair of massive stars (>8x sun’s mass) draws the binary closer together gravitational wave inspiral much closer pair of neutron stars

Orbital transformation is key in formation of compact binaries
Common envelope interactions transform binary systems

Example: formation of merging pairs of neutron stars

Pair of massive stars (>8x sun’s mass)

Common Envelope Phase

much closer pair of neutron stars

Drag on surrounding gas tightens the orbit

Orbit stabilizes as envelope is ejected

Evolution to contact

Companion

NS
Common envelope interactions transform binary systems

**Today’s topic:** transformation of compact objects during these interactions by accretion

Dense environment implies that accretion is possible.

Accretion and BH spin

LIGO measurements of projected spins

(Farr+ 2017)

(e.g. King & Kolb 1999)
Analytic predictions: inspiral and accretion

Hoyle & Lyttleton (1939), Bondi & Hoyle (1944)

Flow is gravitationally focussed toward the compact object

\[ R_a \sim \frac{2GM}{v_\infty^2} \]

...interacts with a “column” of gas with

\[ \text{Area} = \pi R_a^2 \]
THE EFFECT OF INTERSTELLAR MATTER ON CLIMATIC VARIATION

BY F. HOYLE AND R. A. LYTTLETON

Received 19 April 1939

1. INTRODUCTION

There is direct astronomical evidence for the existence of diffuse clouds of matter in interstellar space. Any section of the Milky Way containing a large number of

within a distance $\sigma$ or less of its centre. It is clear that collisions will occur to the left of the sun because the attraction of the latter will produce two opposing streams of particles and the effect of such collisions is to destroy the angular

momentum of the particles about the sun. If after collision the surviving radial component of the velocity is insufficient to enable the particles to escape, such particles will eventually be swept into the sun. Suppose, for example, that an

How the sun gravitationally captures interstellar gas and how this might affect solar system evolution
Analytic predictions: inspiral and accretion

**In the frame of the orbiting star:**

Flow is gravitationally focussed toward the compact object

\[ R_a \sim \frac{2GM}{v_\infty^2} \]

...interacts with a “column” of gas with

\[ \text{Area} = \pi R_a^2 \]

Hoyle & Lyttleton (1939),
Bondi & Hoyle (1944)

Mass passing through this region is

\[ \dot{M}_{HL} = A \rho v \]

\[ = \pi R_a^2 \rho v \]

(mass per time)

... and kinetic energy is

\[ \dot{E}_{HL} = A \rho v^3 \]

\[ = \pi R_a^2 \rho v^3 \]

\[ = \dot{M}_{HL} v^2 \]

(energy per time)
Inspiral and mass accumulation during common envelope

In the frame of the orbiting star:

\[ \dot{M}_{\text{HL}} = A \rho v \]
\[ = \pi R_a^2 \rho v \]
(mass per time)

Mass passing through this region is **Captured**!

\[ \dot{E}_{\text{HL}} = A \rho v^3 \]
\[ = \pi R_a^2 \rho v^3 \]
\[ = \dot{M}_{\text{HL}} v^2 \]
(energy per time)

... and kinetic energy is **Dissipated**!
Analytic predictions: inspiral and accretion

- **Energy dissipation** drives the orbital inspiral.
- **Mass capture** causes the compact obj. to grow.

They are directly related in **Hoyle-Lyttleton** theory:

\[ \dot{E}_{HL} = \dot{M}_{HL} v^2 \]

**NS Example**: Common envelope orbital inspiral implies an accumulated mass:

\[ \Delta M_{NS} \approx \dot{M} \frac{E}{\dot{E}} = \frac{E}{v^2} \]

\[ \approx \frac{M_{NS} M_{\text{comp}}}{M_{NS} + M_{\text{comp}}} \]

\[ \geq 1M_\odot \]

(Chevalier 1993)

This is enough mass to cause a neutron star to collapse to a black hole!
Common Envelope Wind Tunnel

3D (AMR) calculation in FLASH

- inject flow with polytropic (HSE) profile
- specified by \((\epsilon_{\rho}, \mathcal{M}, q)\)

Cartesian geometry

- \(\vec{g}\)
- \(-y\) boundary enforces HSE
Common Envelope Wind Tunnel

mass accretion

\[ \dot{M} \left[ \pi R_a^2 \rho_\infty v_\infty \right] \]

density gradient

\[ \epsilon_\rho \]

\[ \gamma = 5/3 \]
\[ \gamma = 4/3 \]
\[ \cdots \text{M2015} \]
Common Envelope Wind Tunnel

![Graph showing drag force vs. density gradient]

- Drag force $F_{df} \propto \pi R_a^2 \rho_\infty v_\infty^2$
- Density gradient $\epsilon_\rho$

- $\gamma = 5/3$, $r < 1.06R_a$
- $\gamma = 4/3$, $r < 1.06R_a$
- $\gamma = 5/3$, $r < 1.6R_a$
- $\gamma = 4/3$, $r < 1.6R_a$

**IMPLICATIONS FOR COMMON ENVELOPE**

- Drag forces plotted versus density gradient break the symmetry of the inertial force.
- Recalling the profiles of Figure 3, we see a nested shock outside of an accretion wake.

- We note the coefficients of drag and their dependence.

- Our ability to correctly assess the dynamical friction acting on the embedded object, and the difference of our new results reflect these changes.

- The drag should behave differently in the more compressible flow.

- Our simulations because a higher density wake trails the embedded object.

- Drag forces plotted versus density gradients provide less resistance to flow convergence and accretion in the more compressible flow.

- We note here our dependence on the flow Mach number, thus broadens as the focused material deviates through a large angle then expelled toward the secondary star's gravity.

- This gravitational force leads some material to rise and fall in a "tidal" effect.

- Drag forces are corrected due to low flow Mach number, thus broadens as the focused material deviates through a large angle then expelled toward the secondary star's gravity.

- We note that the sink could become large.

- In all cases, the secondary's gravitational focus lifts some material.

- In higher densities in the immediate wake of the embedded object because the pressure does not build up as rapidly upon displacements.

- Recalling the profiles of Figure 3, we see a nested shock outside of an accretion wake.

- We note that this sink could become large.

- In all cases, the secondary's gravitational focus lifts some material.

- In higher densities in the immediate wake of the embedded object because the pressure does not build up as rapidly upon displacements.

- Recalling the profiles of Figure 3, we see a nested shock outside of an accretion wake.

- We note that this sink could become large.
on the size of the sink boundary compared to the accretion rat-
tron star, or black hole. Here we study rates and properties of

\[ \frac{dM}{dt} = C_m \dot{M}_{HL} \]
\[ \frac{dE_{orb}}{dt} = C_d \dot{F}_{HL} v \]

\((C_d, C_m)\) are coefficients of
drag and mass accretion

with simulation coefficients:
< few % mass
increase

(MacLeod+, 2015ab,2017, De+ in prep)
Common envelope interactions transform binary systems

**Today’s topic:** transformation of compact objects during these interactions by accretion

Dense environment implies that accretion is possible.

**Accretion and BH spin**

- Graph showing the relationship between $\Delta M/M_i$ and $a$.
  - $\Delta M/M_i$ ranges from 0.00 to 1.00.
  - $a$ ranges from 0.0 to 1.0.

- (e.g. King & Kolb 1999)

**LIGO measurements of projected spins**

- Graph showing the distribution of projected spins ($\chi_{\text{eff}}$).
  - Color-coding for different events (e.g., GW150914).

- (Farr+ 2017)
Open question: feedback from accretion?

Any accretion that occurs is highly super-Eddington and may be accompanied by mechanical feedback

Murguia-Bertier+ 2017: Under what conditions do disks form around objects during CE?

Lopez-Camara+ 2018: If the accretion flow launches jets, how do these impinge upon the surroundings.

(See also Chamandy+ 2018)
Common envelope interactions transform binary systems

**Common envelope interactions** play a key role in the assembly of compact binaries. In the dense, gaseous environment objects can grow via accretion while dynamical friction tightens the orbit.

**Strong density gradients** provide an angular momentum barrier, making accretion inefficient relative to predictions of Bondi-Hoyle-Lyttleton accretion rates.

potentially-**low accreted mass** implies low accreted spin, with implications for the observable properties of merging GW sources.