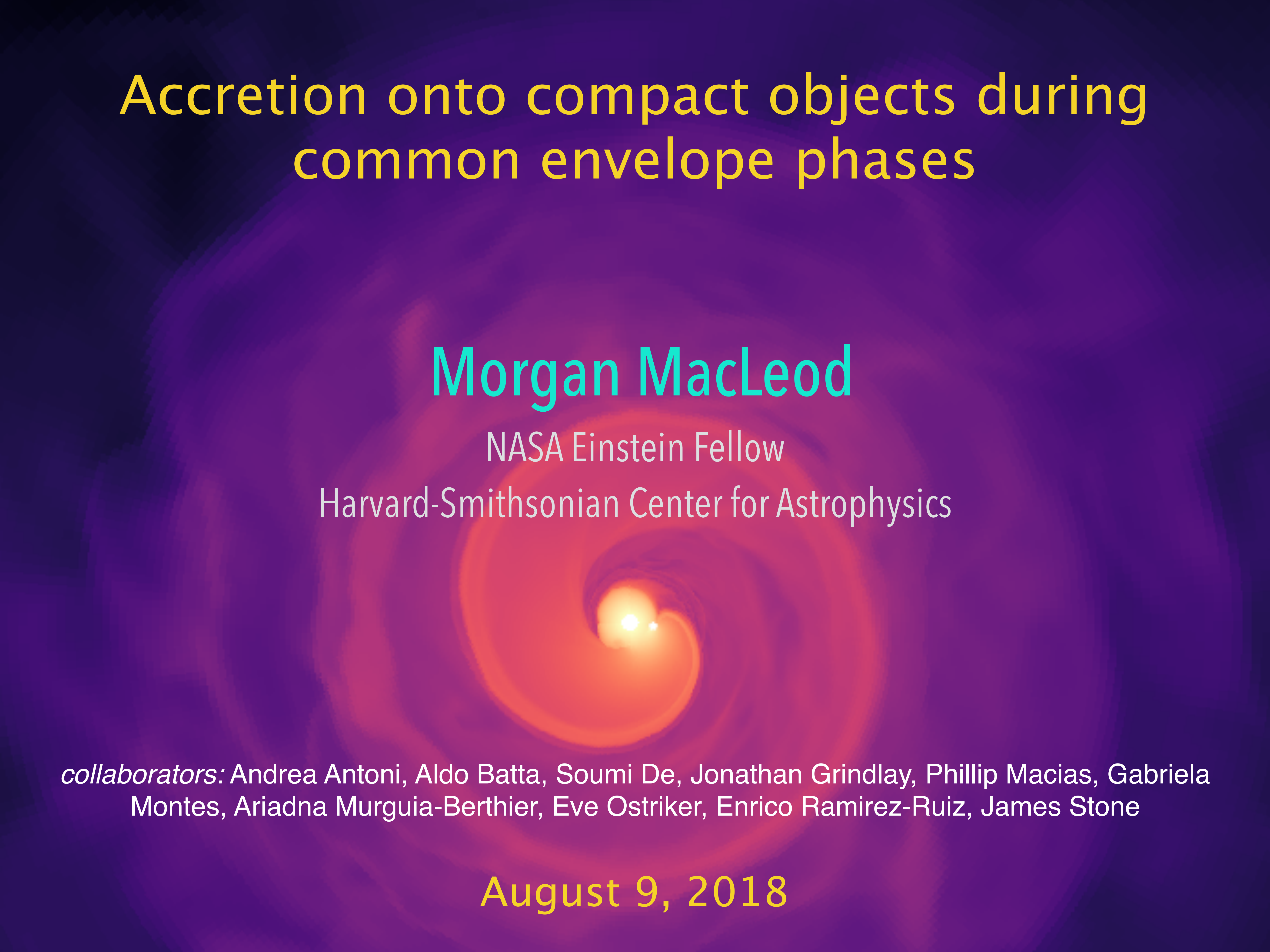
Accretion onto compact objects during common envelope phases



Morgan MacLeod

NASA Einstein Fellow

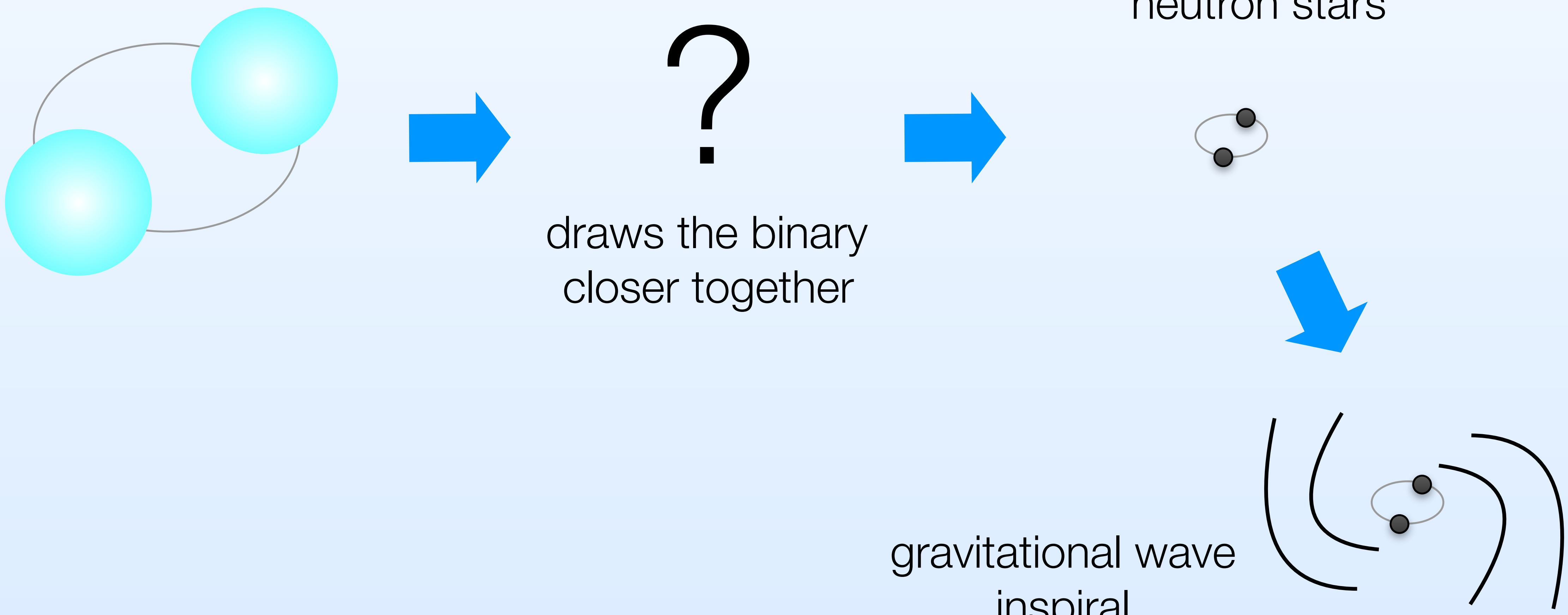
Harvard-Smithsonian Center for Astrophysics

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

August 9, 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

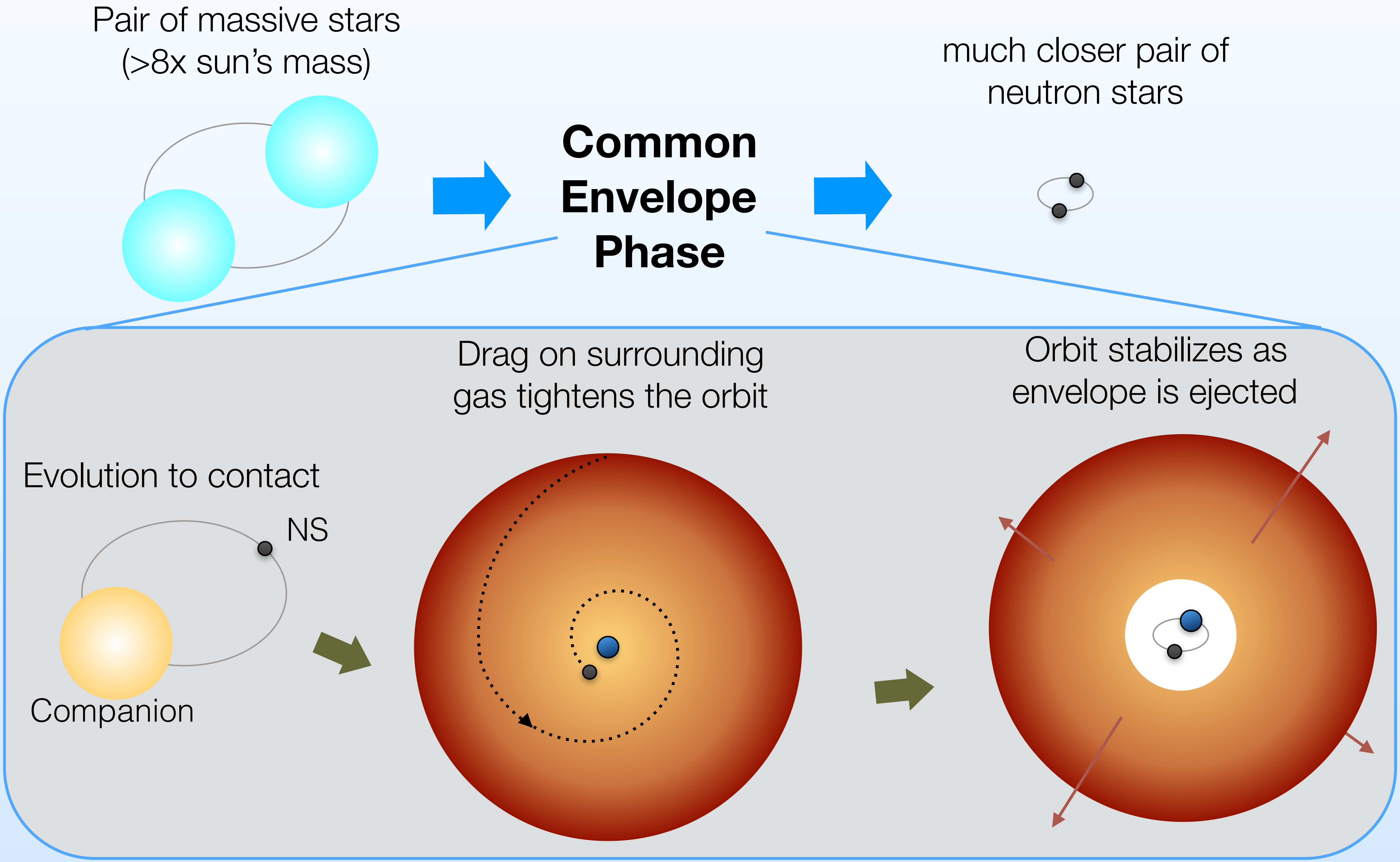
much closer pair of
neutron stars

gravitational wave
inspiral

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

Evolution to contact

NS

Companion

Drag on surrounding
gas tightens the orbit

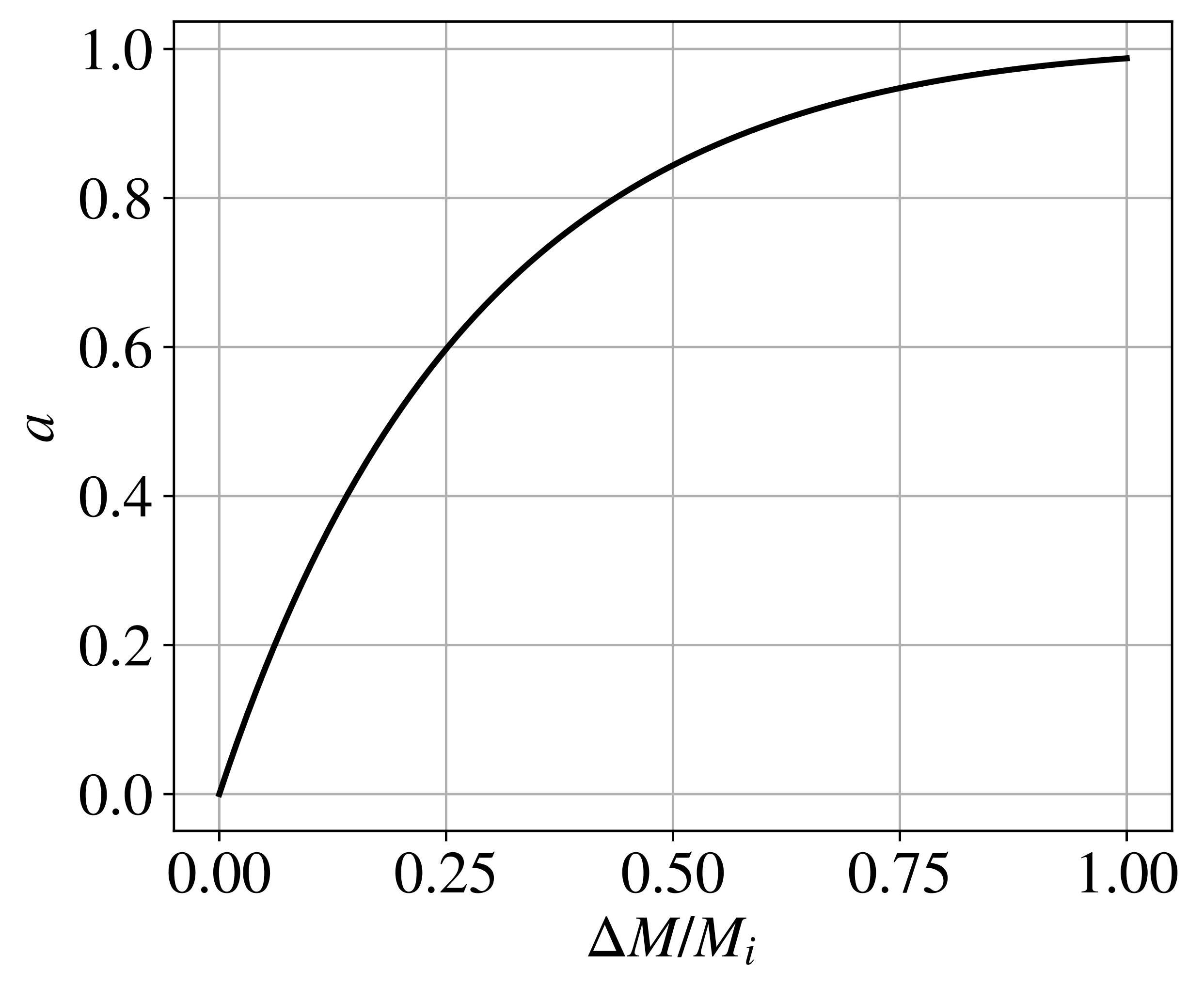
Orbit stabilizes as
envelope is ejected

Common envelope interactions transform binary systems

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

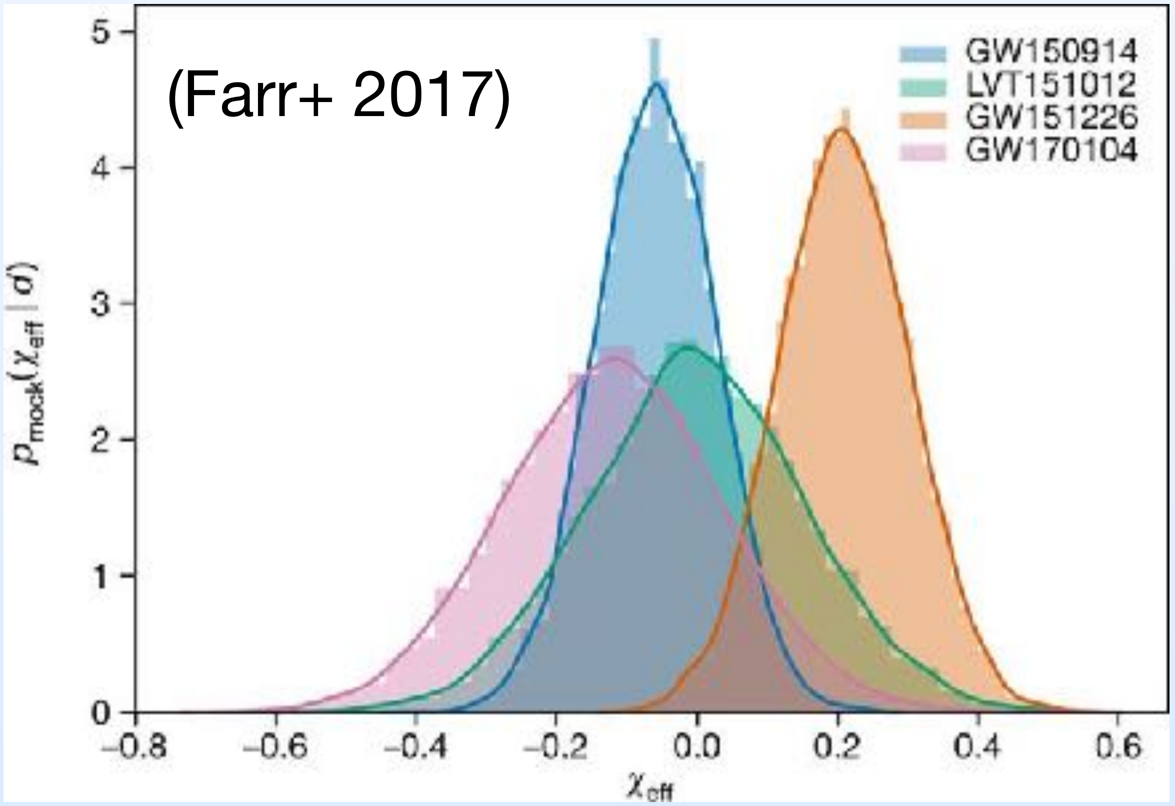
Dense environment implies that accretion is possible.

Accretion and BH spin



(e.g. King & Kolb 1999)

LIGO measurements of projected spins

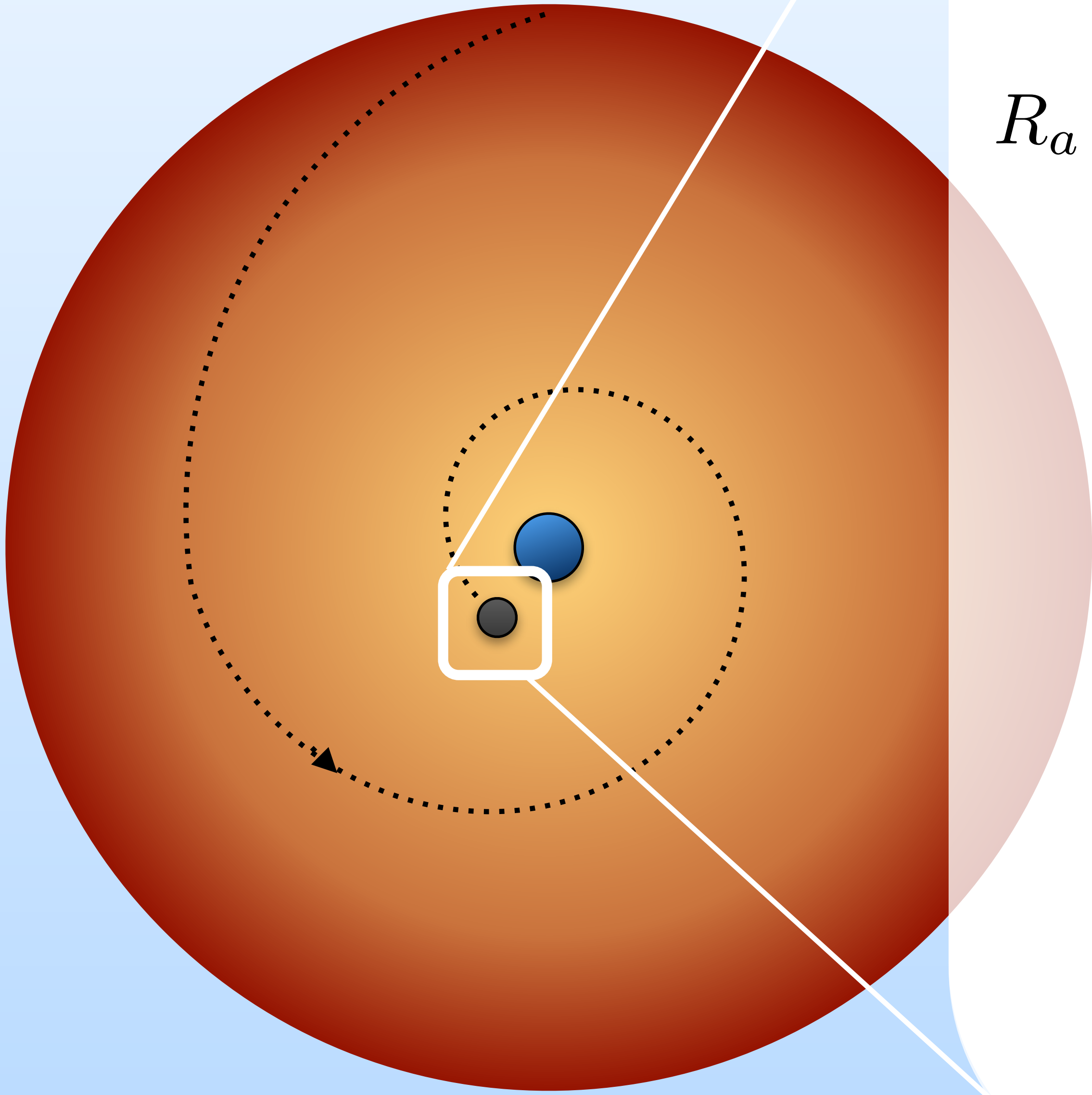


(Farr+ 2017)

χ_{eff}

Analytic predictions: inspiral and accretion

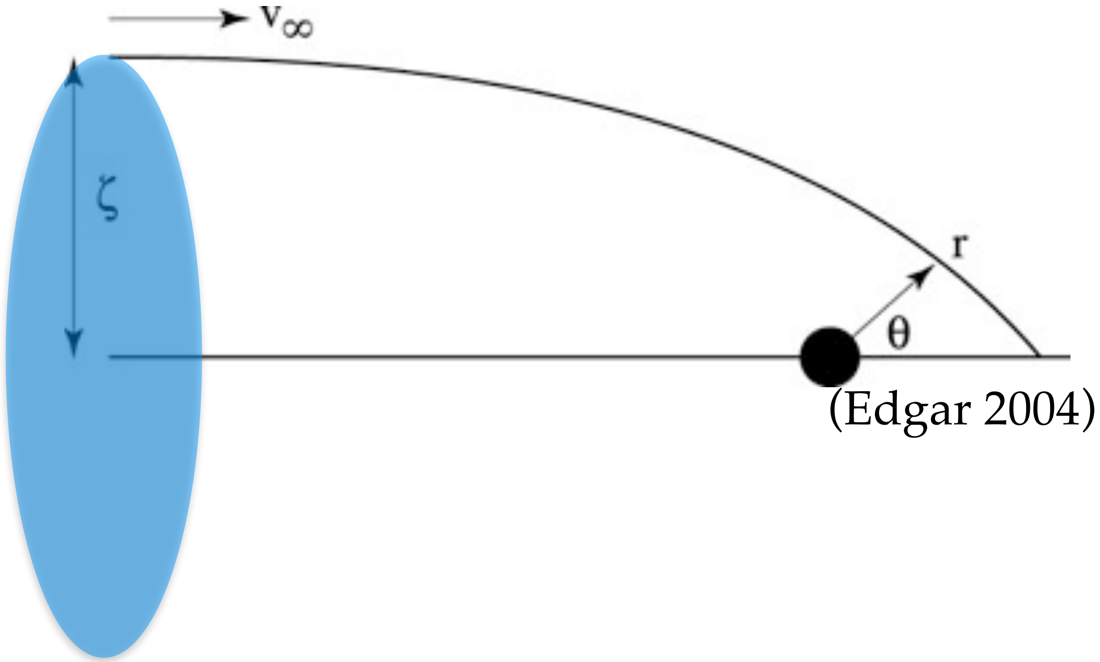
Hoyle & Lyttleton (1939),
Bondi & Hoyle (1944)



In the frame of the orbiting object:

Flow is gravitationally focussed
toward the compact object

$$R_a \sim \frac{2GM}{v_\infty^2}$$

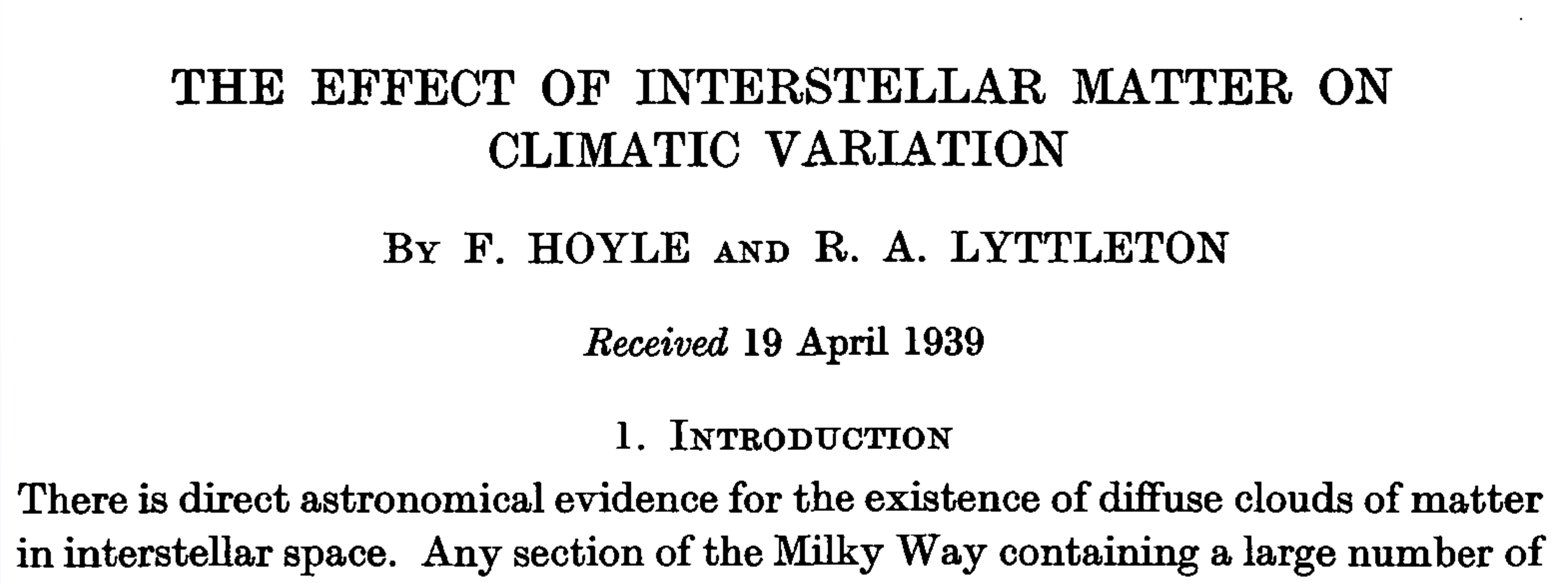


(Edgar 2004)

…interacts with a "column" of gas with

$$\mathrm{Area} = \pi R_{\mathrm{a}}^2$$

Hoyle-Lyttleton Accretion



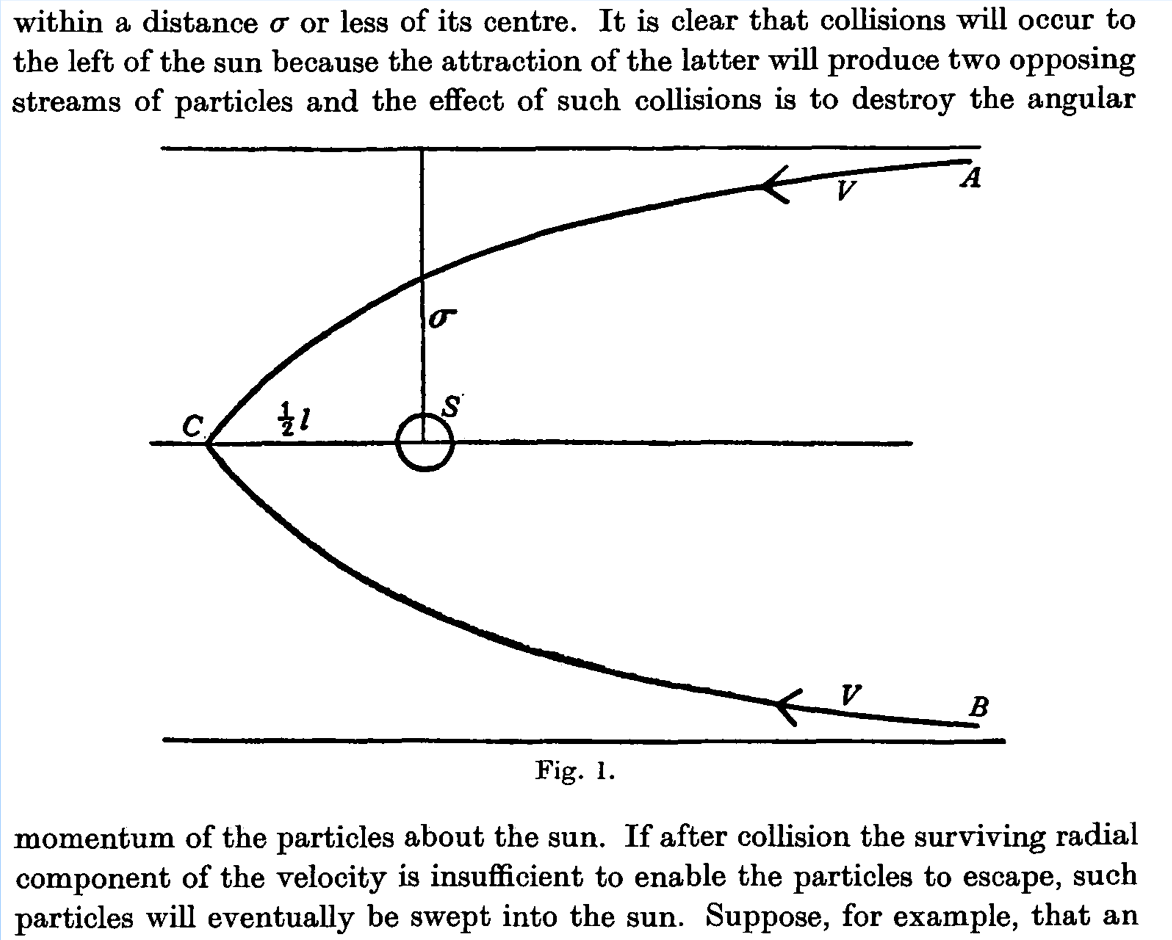
THE EFFECT OF INTERSTELLAR MATTER ON CLIMATIC VARIATION

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 σ 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

Fig. 1.

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

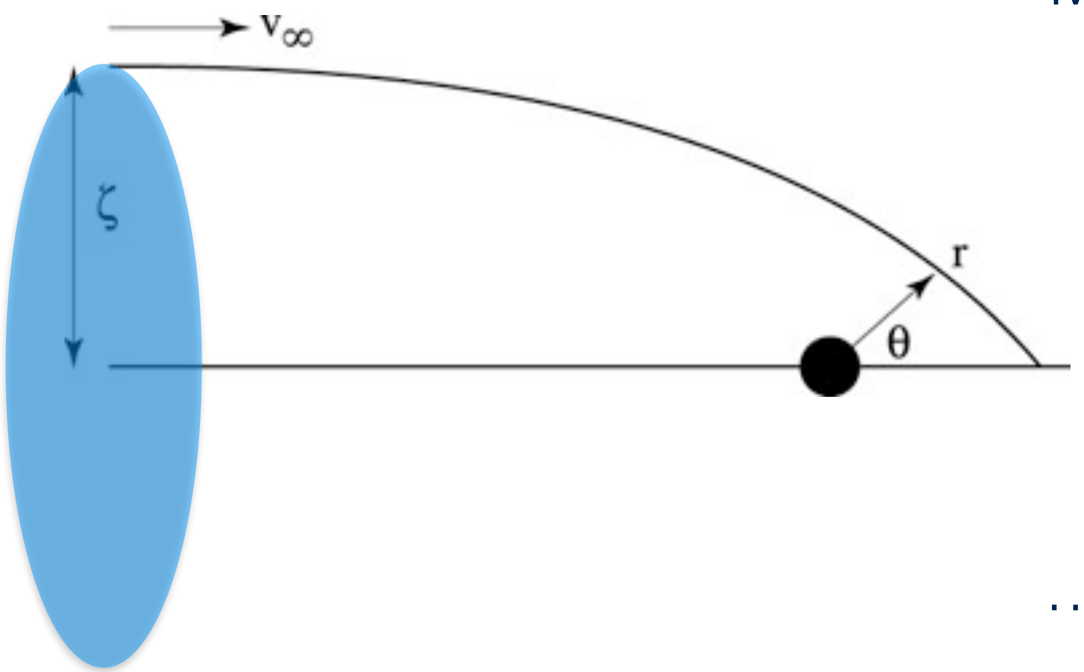
How the sun gravitationally captures interstellar gas and how this might affect solar system evolution

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

$$\mathrm{Area} = \pi R_\mathrm{a}^2$$

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

Mass passing through this region is

$$\dot{M}_\mathrm{HL} = A\rho v$$
$$= \pi R_\mathrm{a}^2 \rho v$$

(mass per time)

… and kinetic energy is

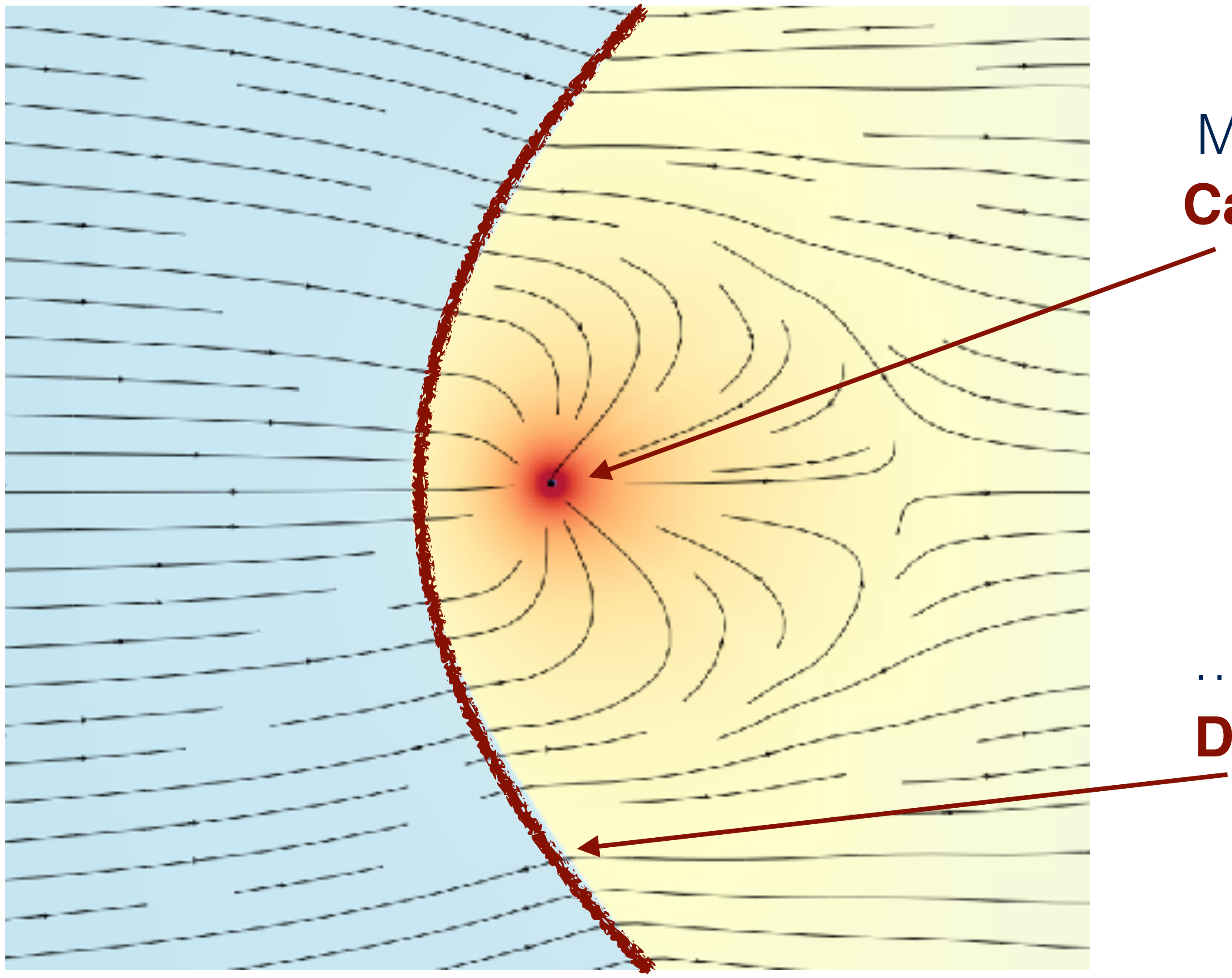
$$\dot{E}_\mathrm{HL} = A\rho v^3$$
$$= \pi R_\mathrm{a}^2 \rho v^3$$
$$= \dot{M}_\mathrm{HL} v^2$$

(energy per time)

Inspiral and mass accumulation during common envelope

In the frame of the orbiting star:

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



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

$$\dot{M}_{\rm HL} = A\rho v$$
$$= \pi R_{\rm a}^2 \rho v$$

(mass per time)

… and kinetic energy is **Dissipated!**

$$\dot{E}_{\rm HL} = A\rho v^3$$
$$= \pi R_{\rm a}^2 \rho v^3$$
$$= \dot{M}_{\rm HL} v^2$$

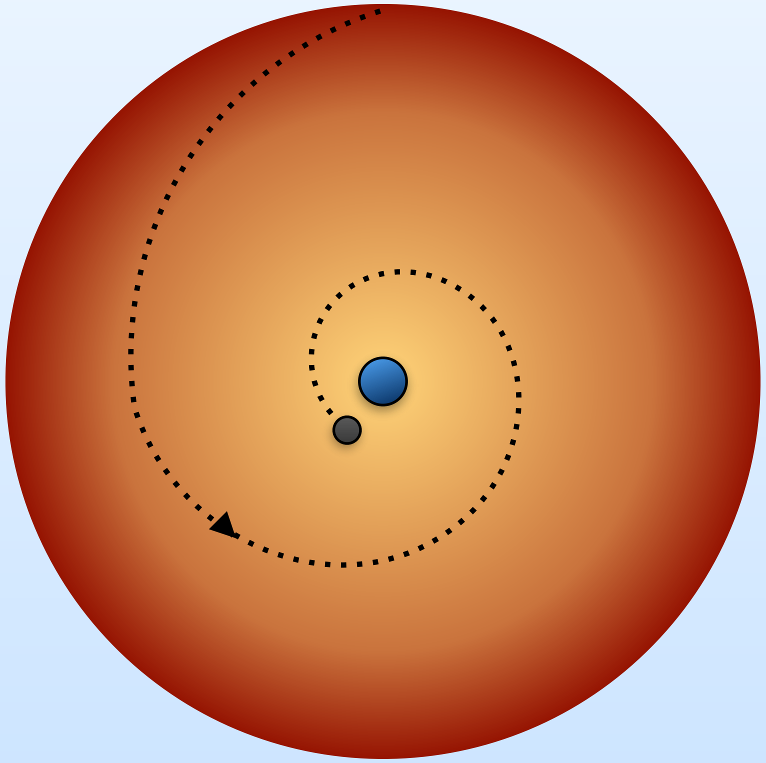
(energy per time)

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:

$$\dot{E}_{\rm HL} = \dot{M}_{\rm HL} v^2$$



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

$$\Delta M_{\rm NS} \approx \dot{M}\frac{E}{\dot{E}} = \frac{E}{v^2}$$

$$\approx \frac{M_{\rm NS} M_{\rm comp}}{M_{\rm NS} + M_{\rm comp}}$$

$$\gtrsim 1 M_\odot$$

This is enough mass to cause a neutron star to collapse to a black hole!

(Chevalier 1993)

Common Envelope Wind Tunnel

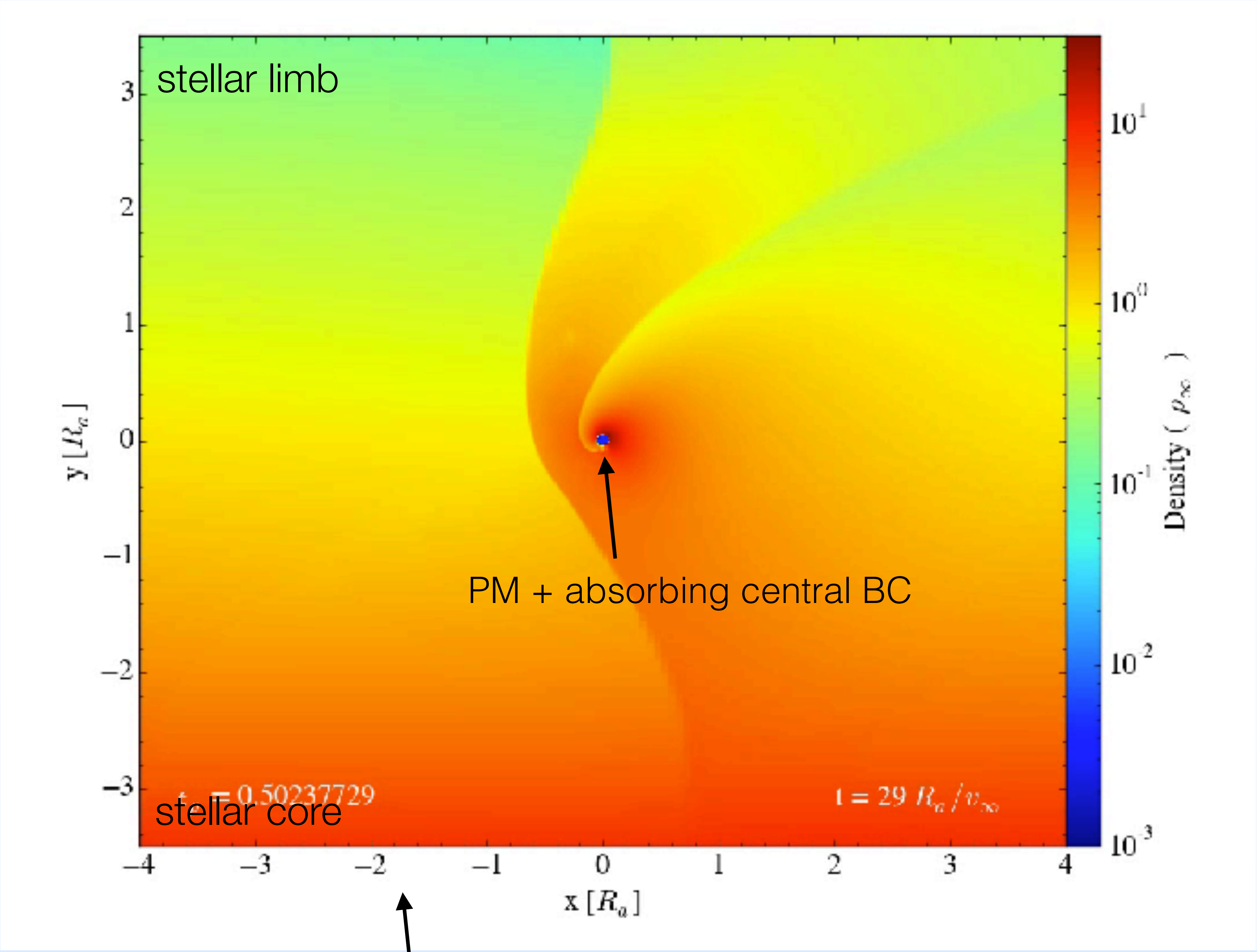
3D (AMR) calculation in FLASH

Cartesian geometry

inject flow with polytropic (HSE) profile

specified by

$$(\epsilon_\rho, \mathcal{M}, q)$$



stellar limb

PM + absorbing central BC

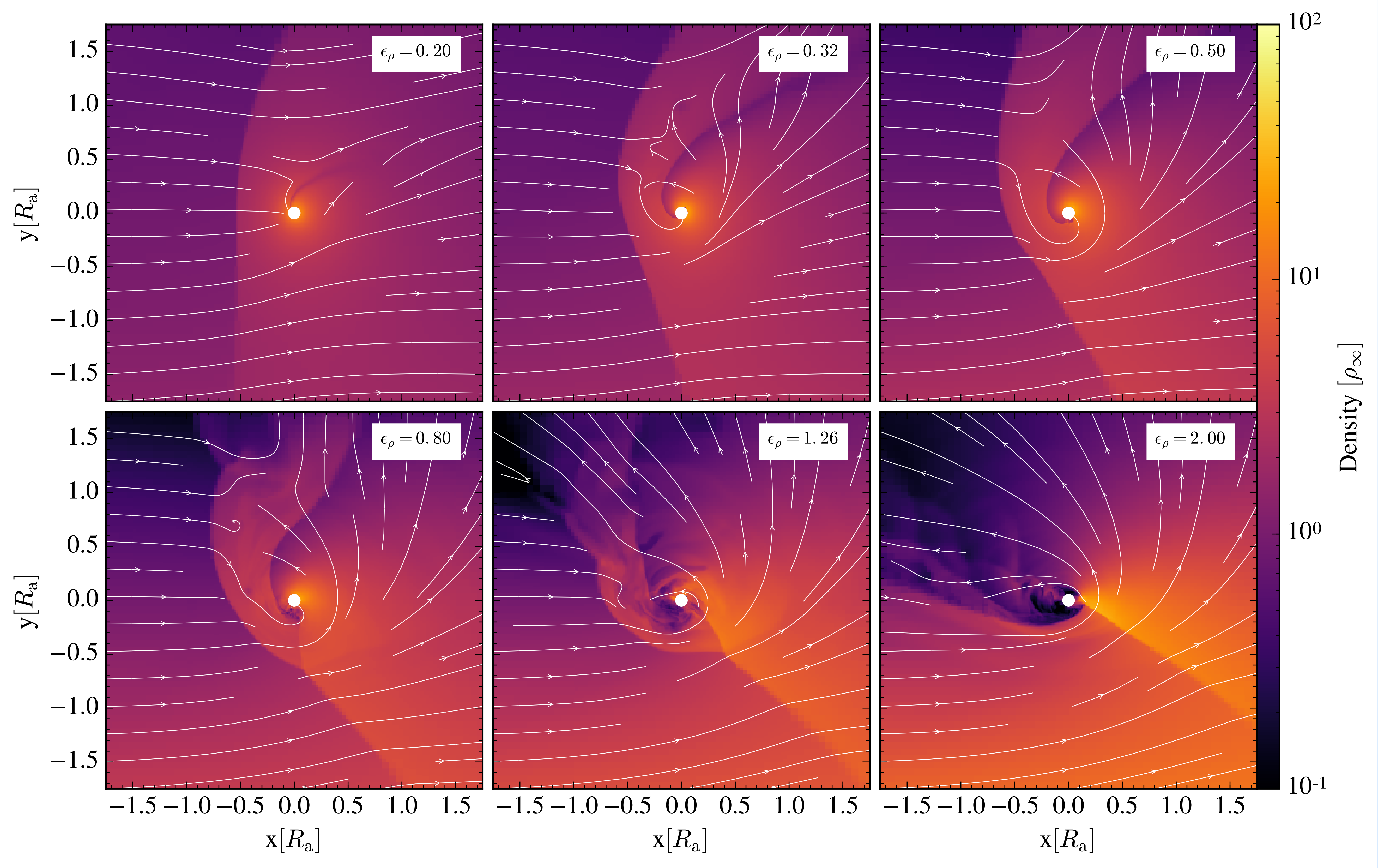
stellar core

$\vec{g}$

-y boundary enforces HSE

Common Envelope Wind Tunnel

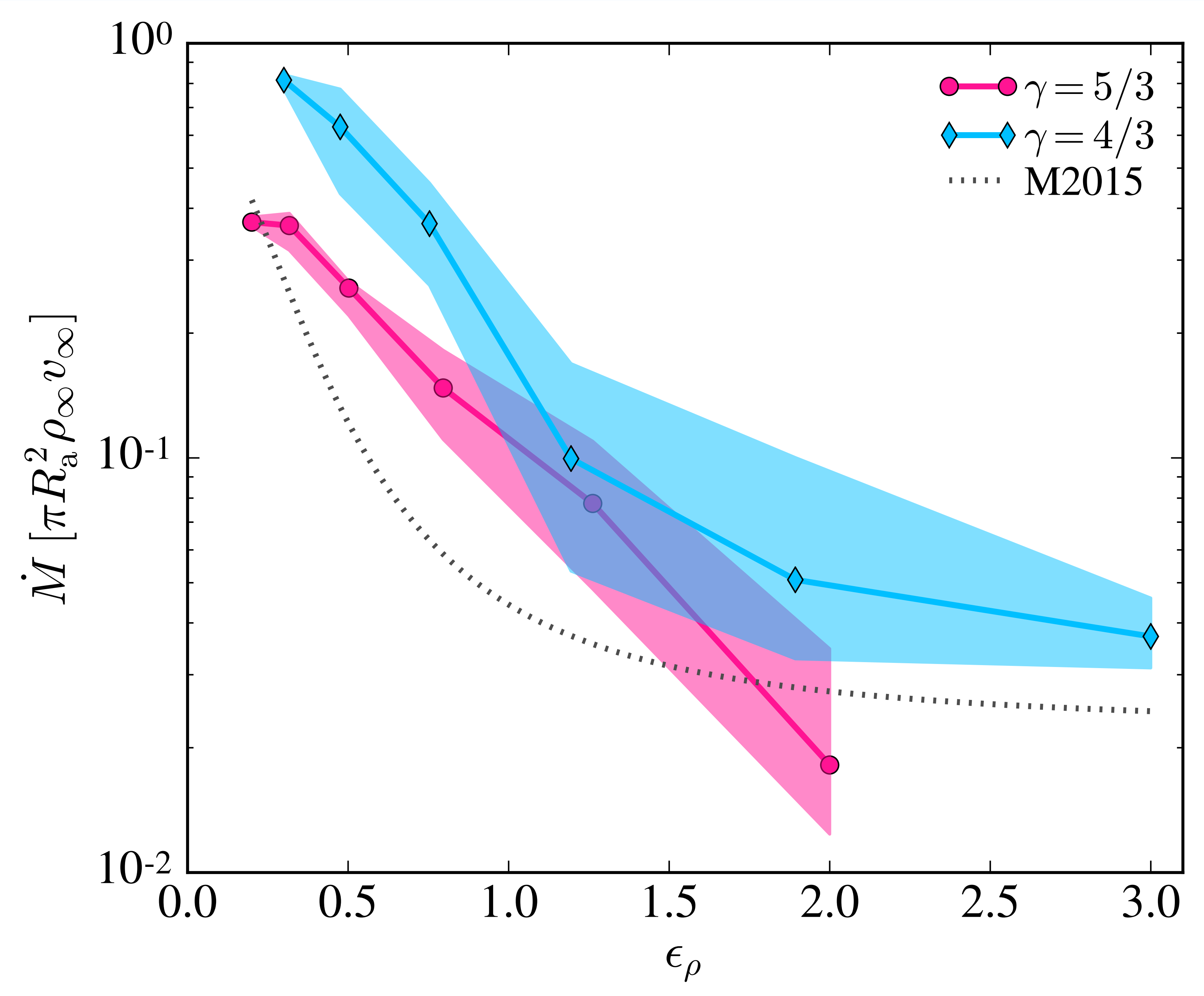
$\gamma = \Gamma_s = 5/3$



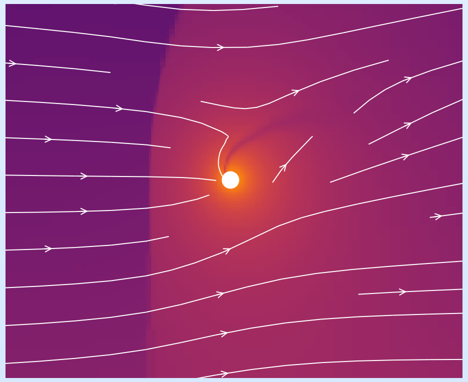
(MacLeod+, 2017)

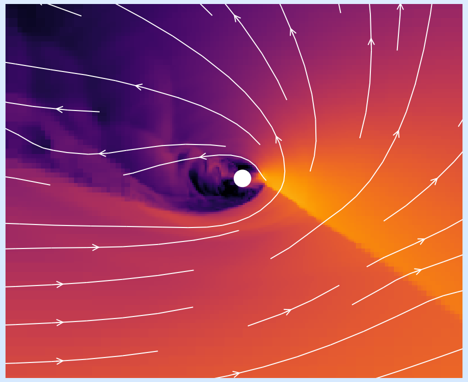
Common Envelope Wind Tunnel

mass accretion



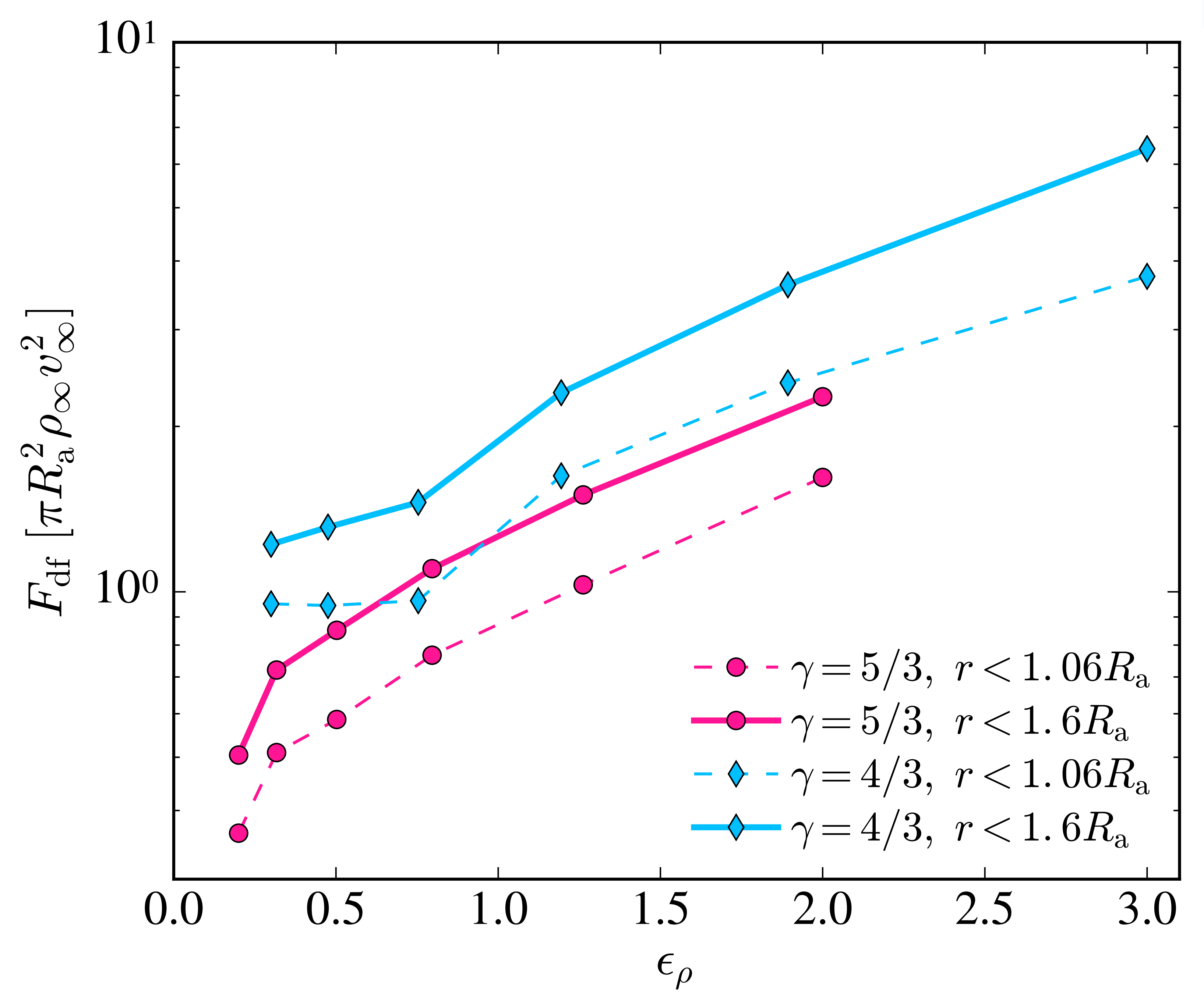
density gradient



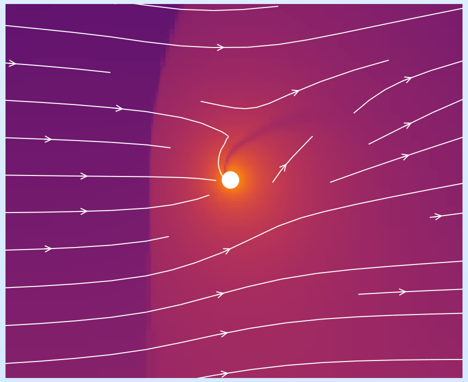


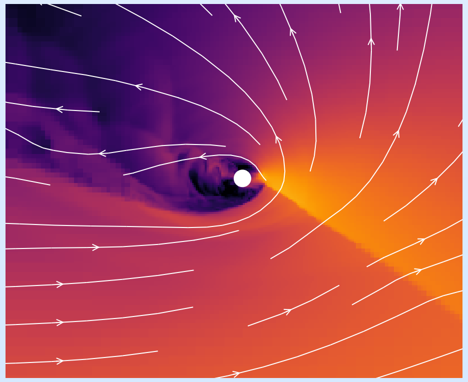
Common Envelope Wind Tunnel

drag force

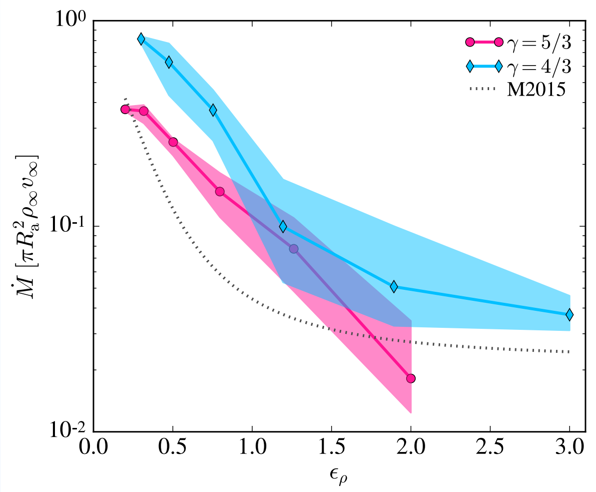


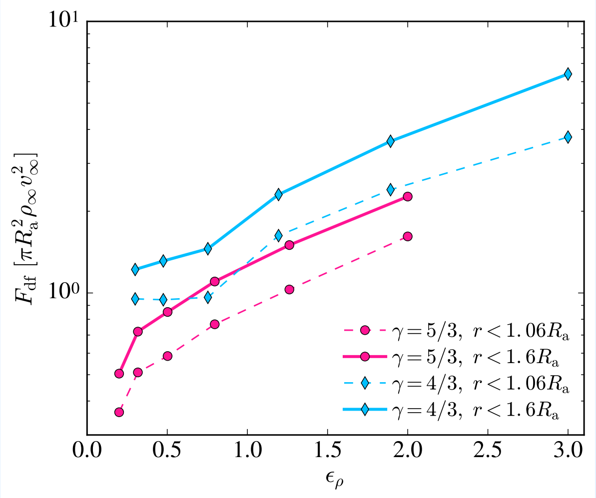
density gradient





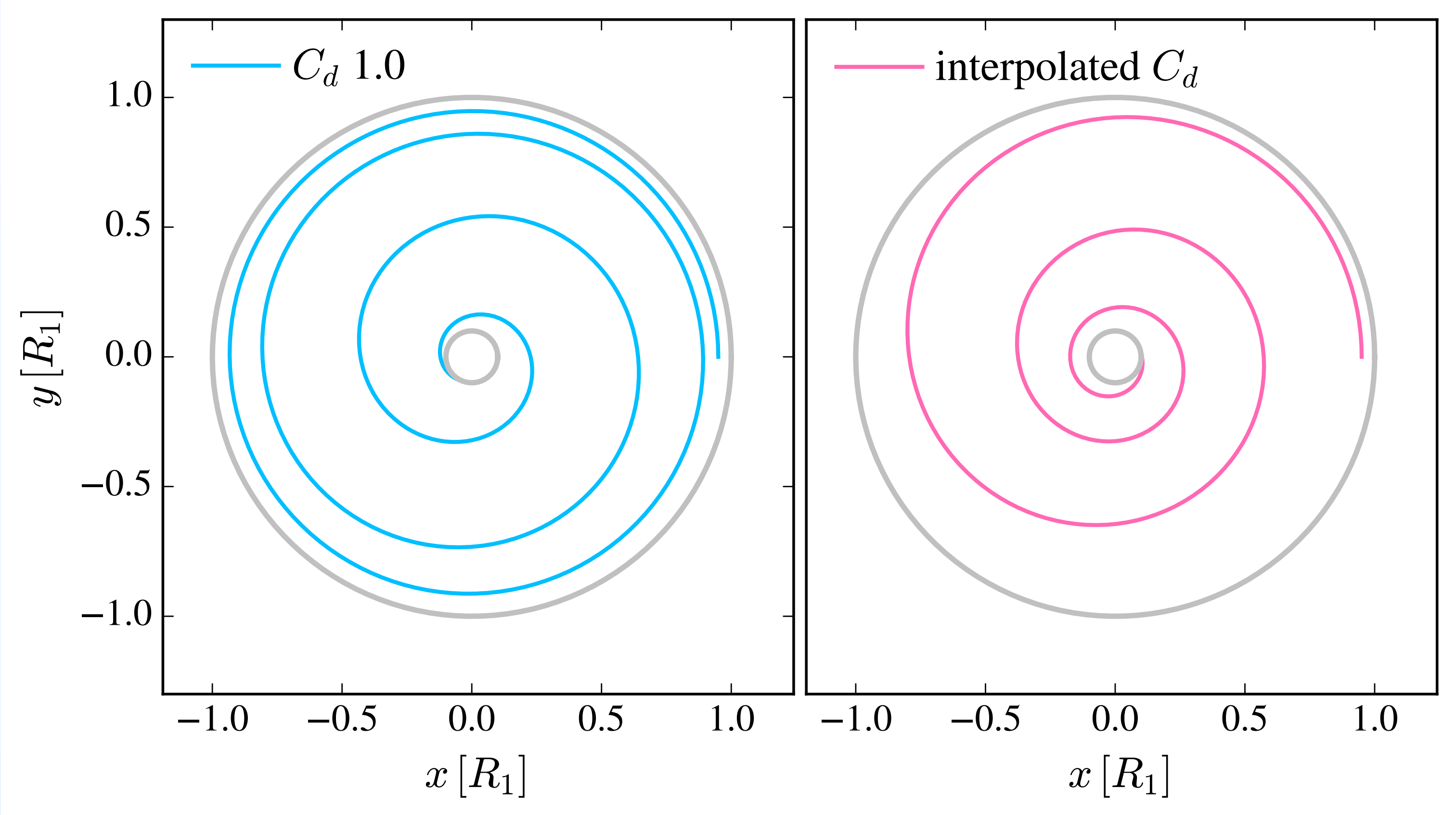
Common Envelope Wind Tunnel





$$\frac{dM}{dt} = C_m \dot{M}_{\rm HL} \qquad \frac{dE_{\rm orb}}{dt} = C_d \dot{F}_{\rm HL} v$$

$(C_{\rm d}, C_{\rm m})$ are coefficients of drag and mass accretion



with simulation coefficients:

< few % mass increase

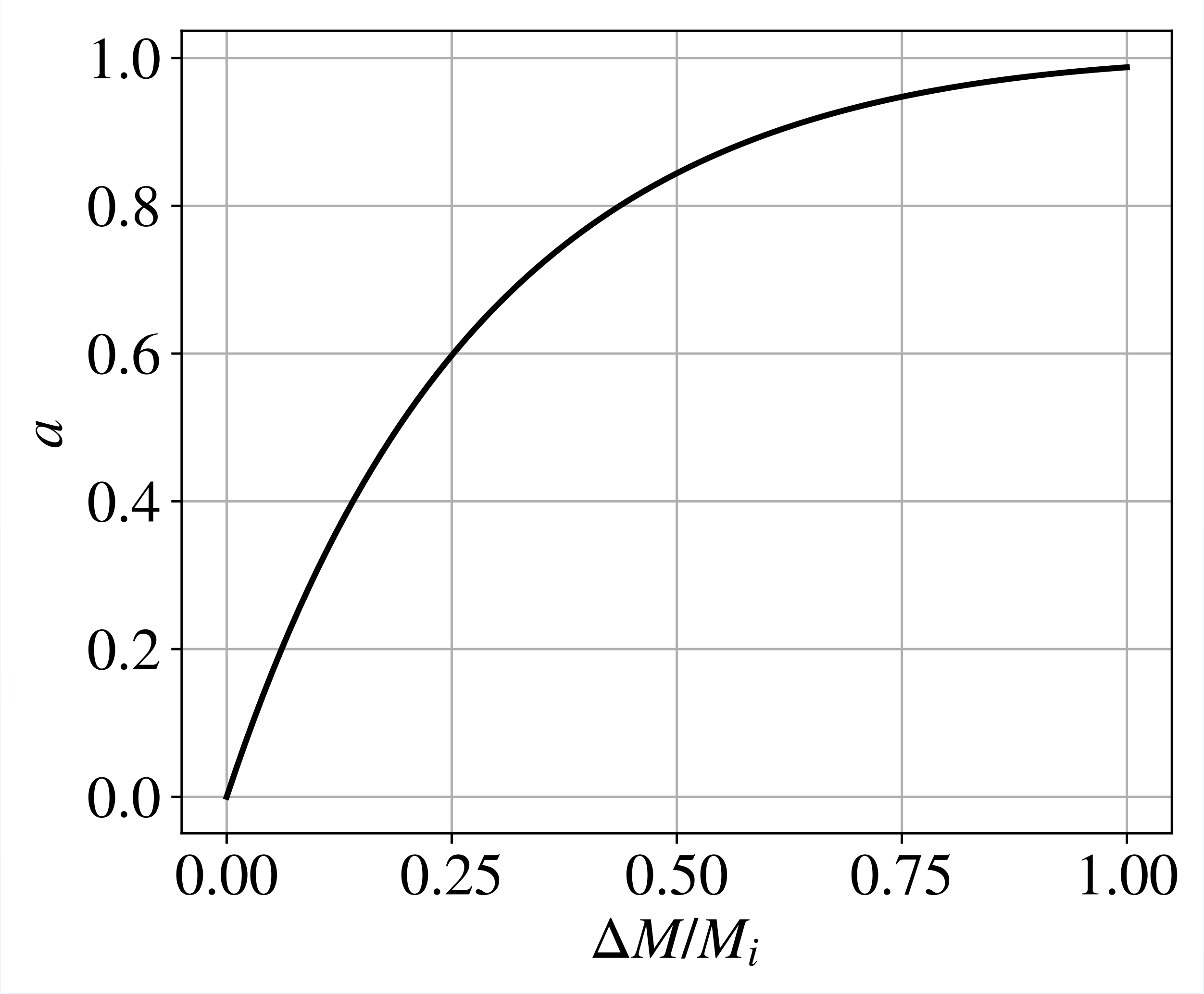
(MacLeod+, 2015ab,2017, De+ in prep)

Common envelope interactions transform binary systems

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

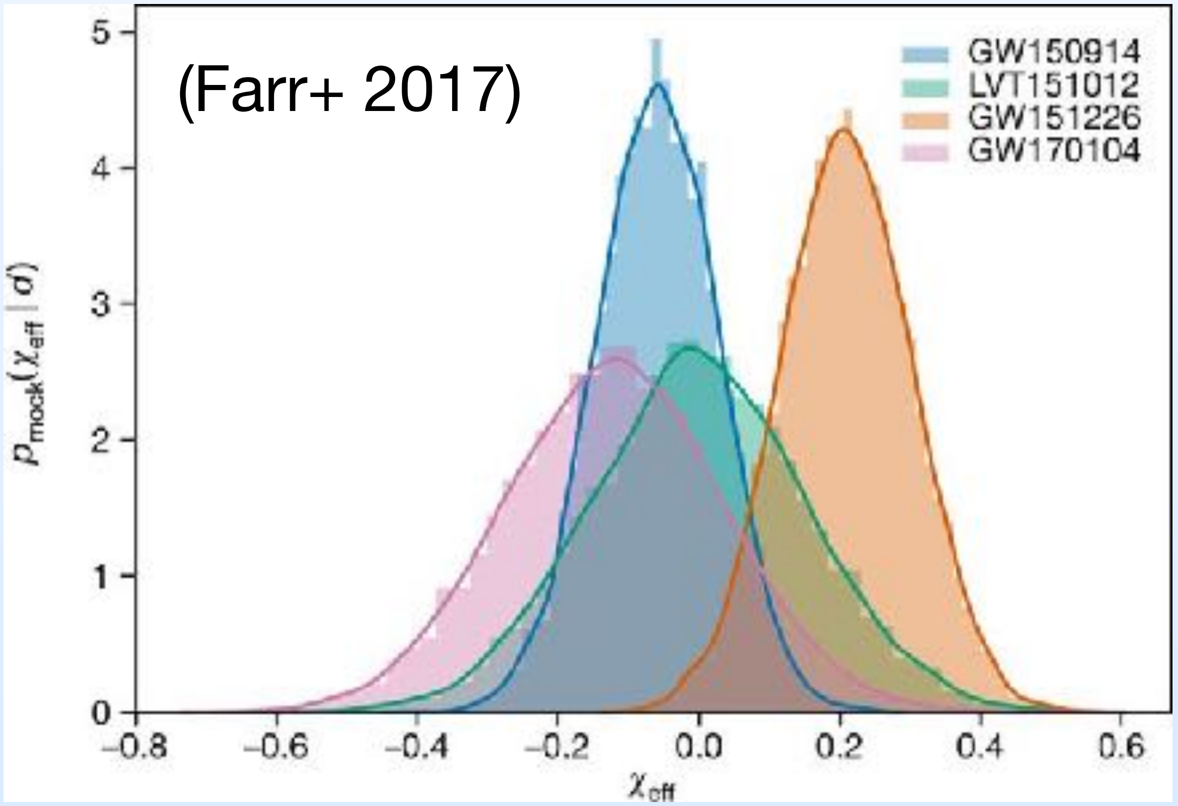
Dense environment implies that accretion is possible.

Accretion and BH spin



(e.g. King & Kolb 1999)

LIGO measurements of projected spins

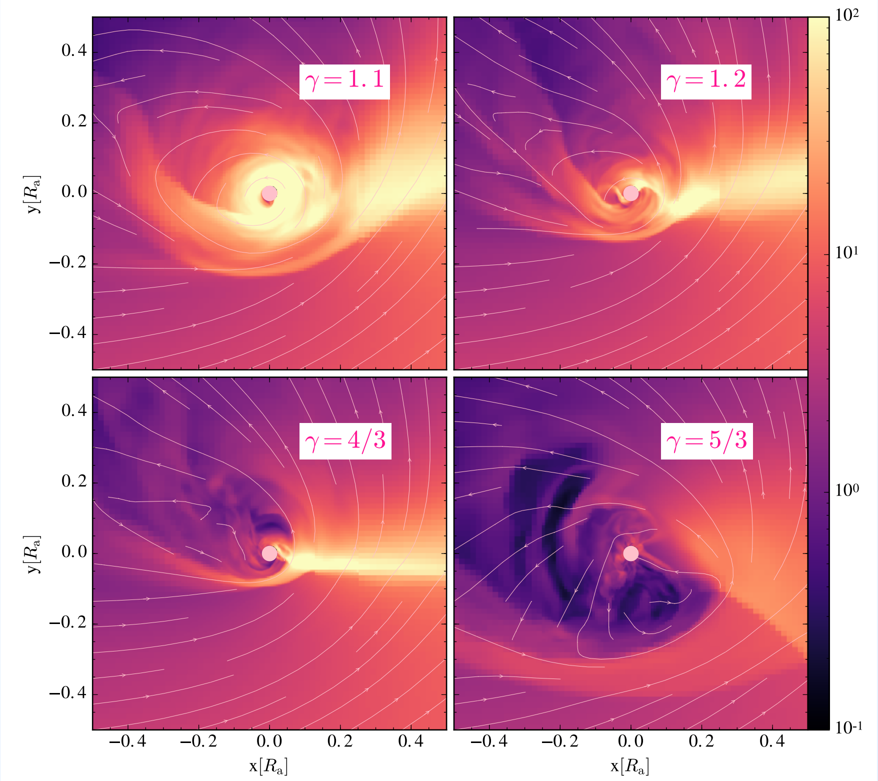


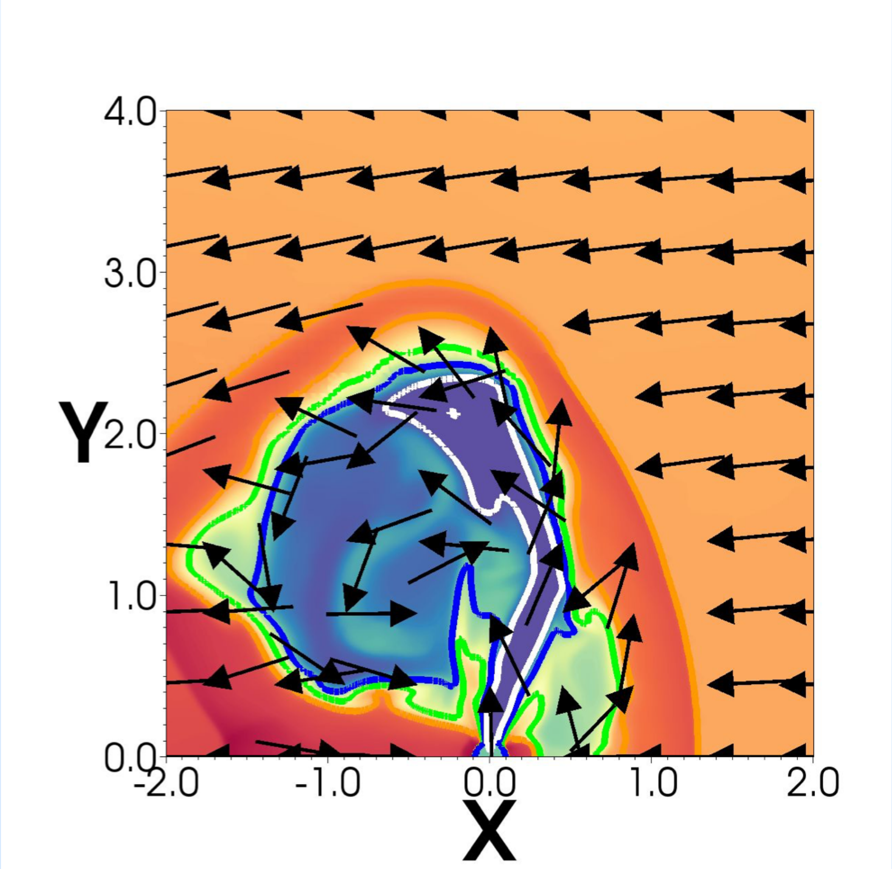
χ_{eff}

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?



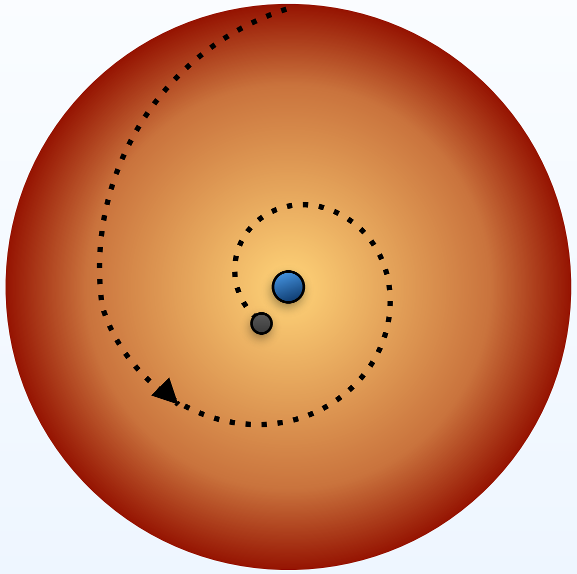


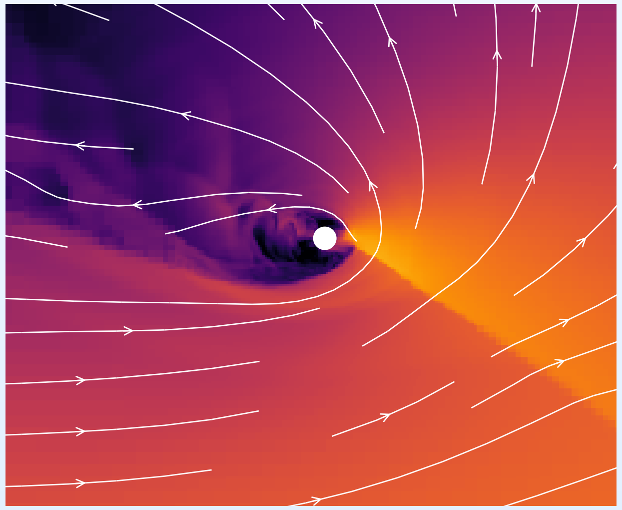
Lopez-Camara+ 2018: If the accretion flow launches jets, how do these impinge upon the surroundings.

(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.