Unwrapping the Mystery of Common Envelope Episodes

Morgan MacLeod

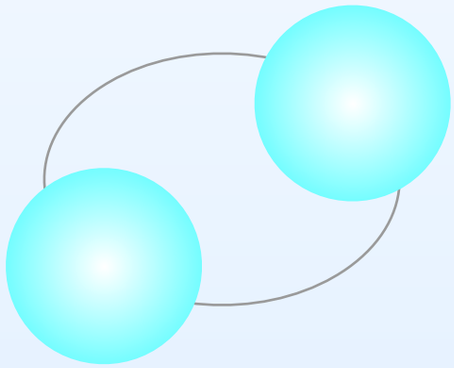
morganmacleod@ias.edu

Einstein Fellows Symposium
Oct 18, 2016

Common envelope interactions transform binary systems

Example: formation of merging pairs of neutron stars

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



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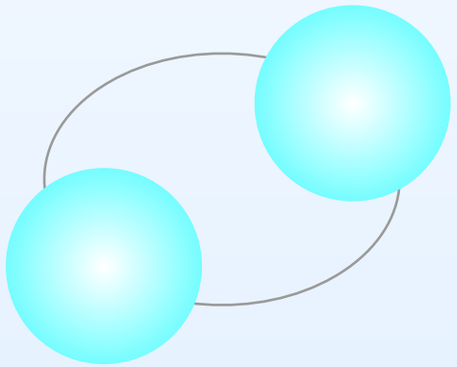
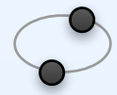


?

draws the binary
closer together

much closer pair of
neutron stars



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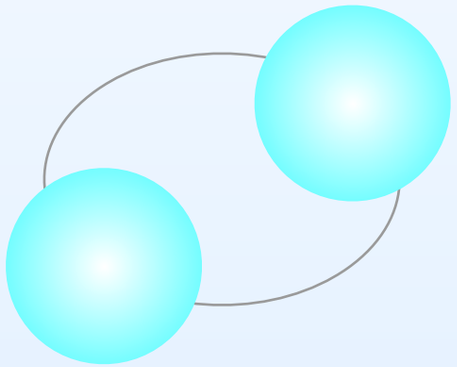

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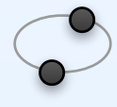

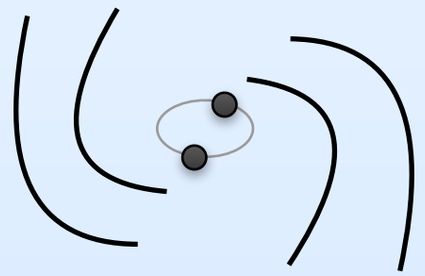

gravitational wave
inspiral

Orbital transformation is key in formation of compact binaries

Common envelope interactions transform binary systems

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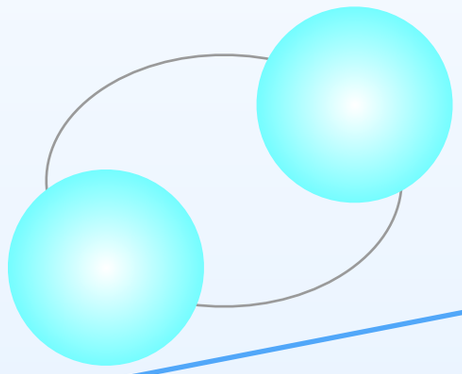
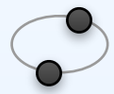
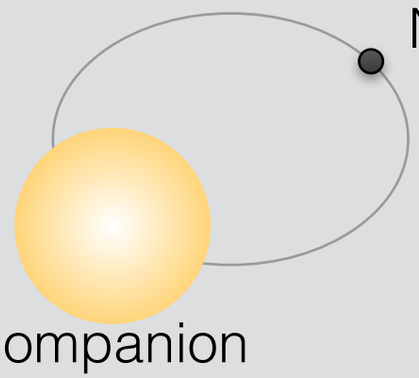


Common Envelope Phase

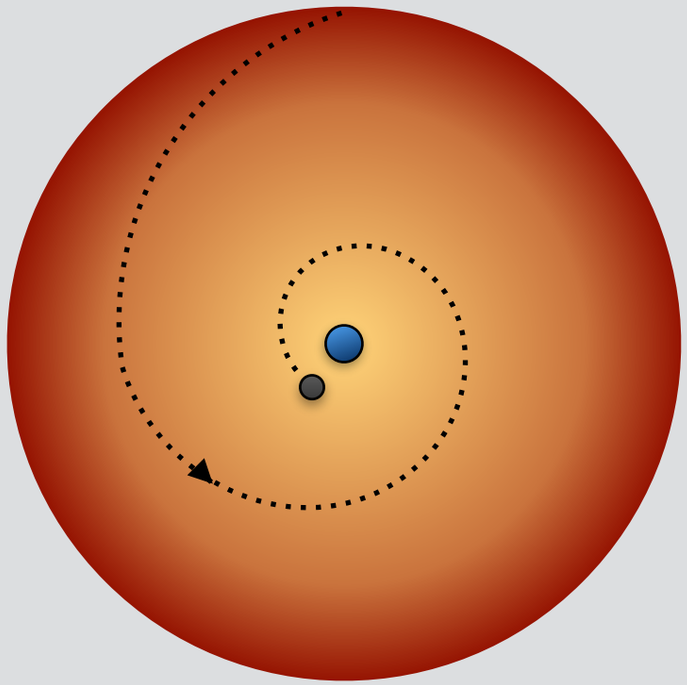
much closer pair of neutron stars



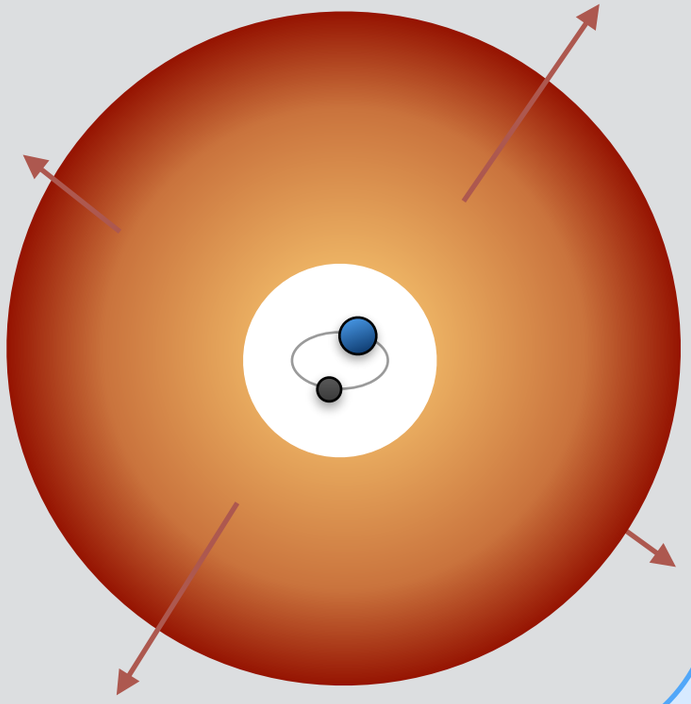
Evolution to contact



Drag on surrounding gas tightens the orbit



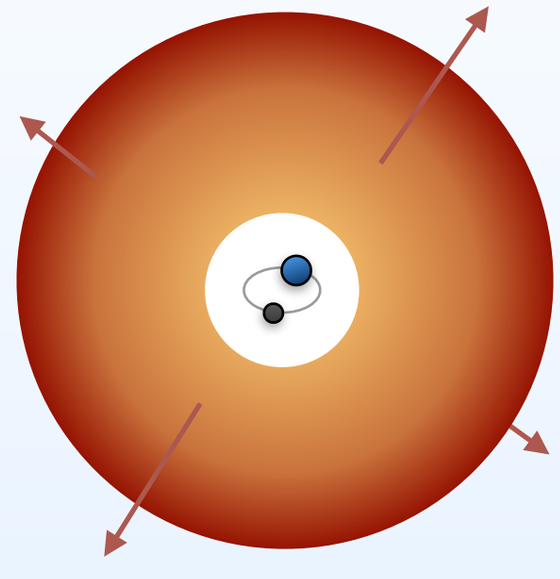
Orbit stabilizes as envelope is ejected



Common envelope interactions transform binary systems

common envelope outcomes:
tightened binary or merger

envelope is ejected
and orbit stabilizes



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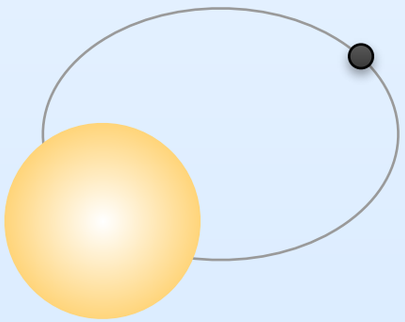
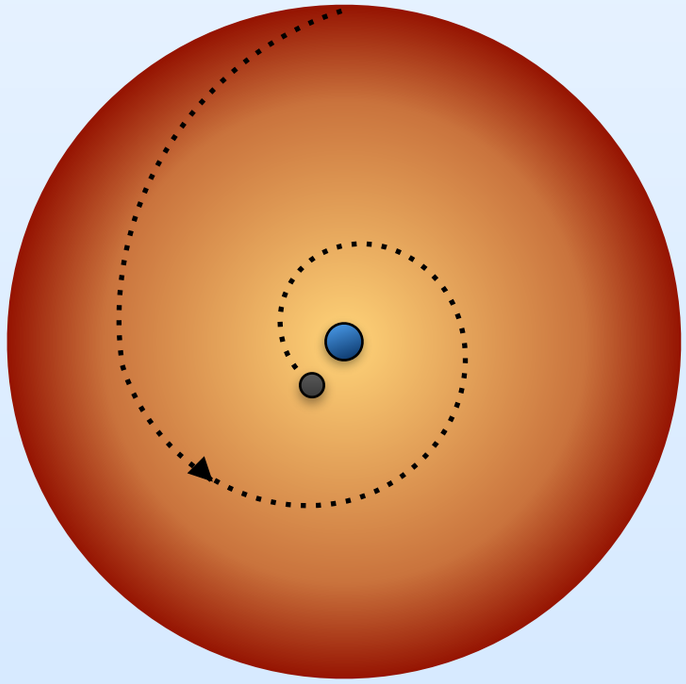
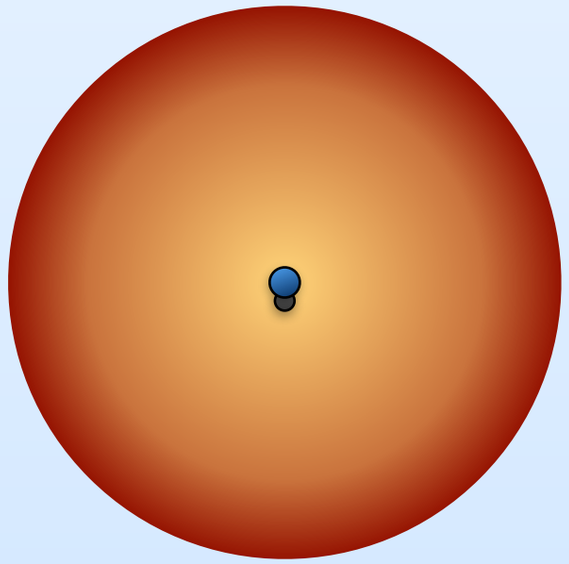
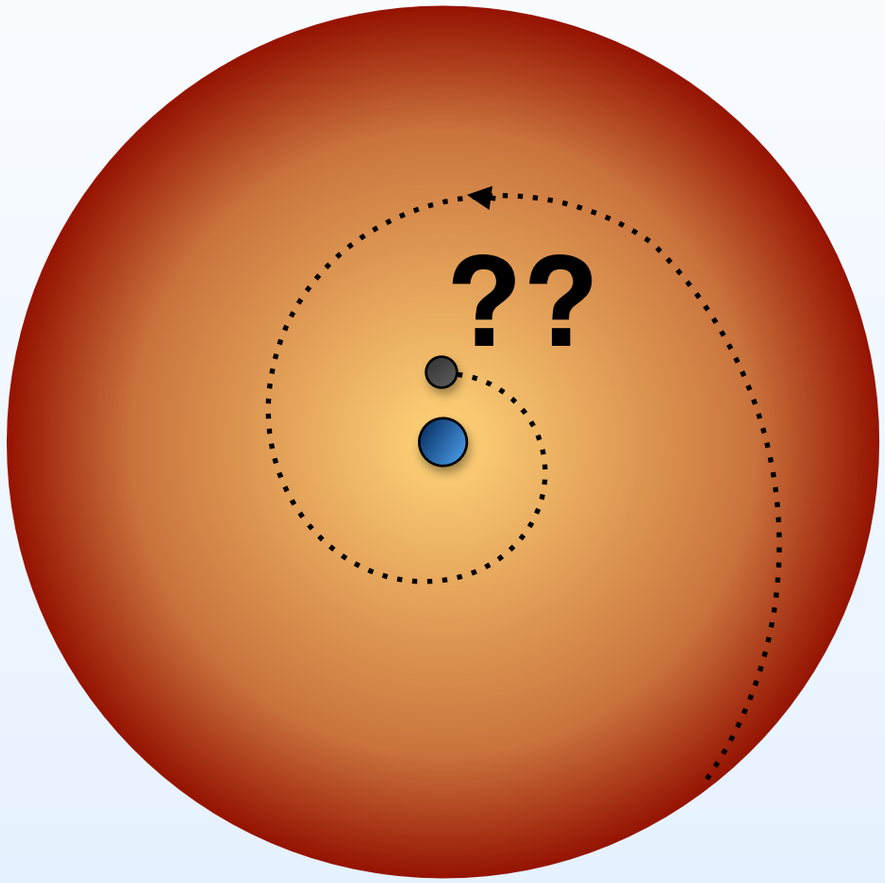




envelope is retained
and binary merges



Many open questions…



Challenging problem for “kitchen sink” numerical approach because of the huge range of relevant spatial and temporal scales.

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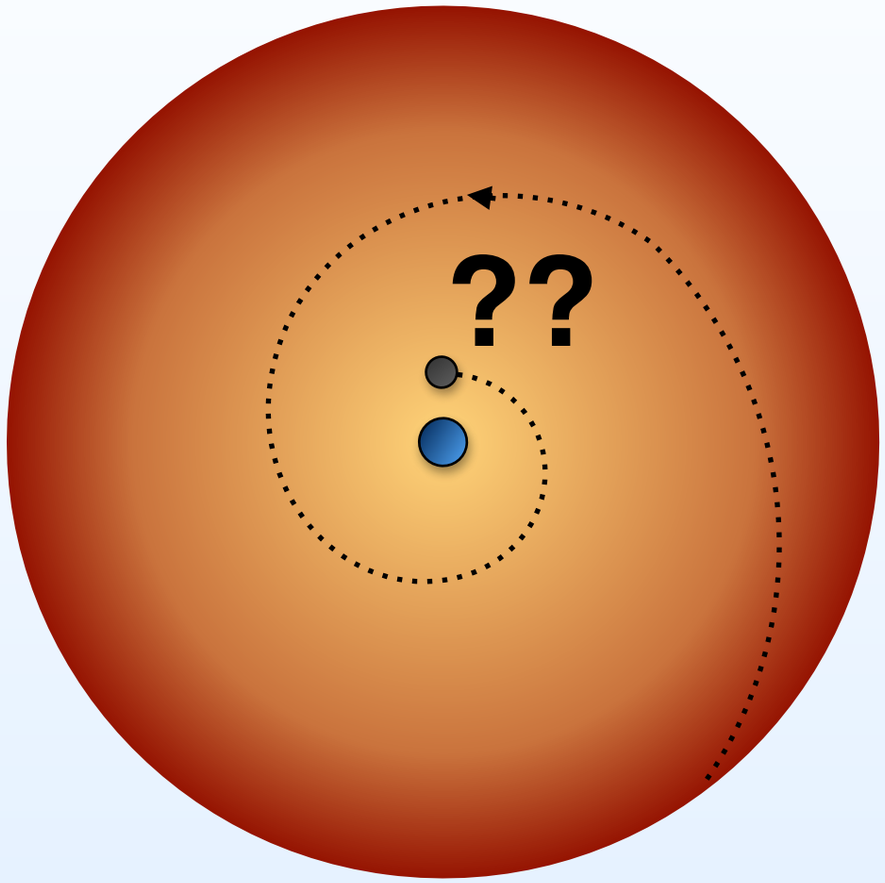

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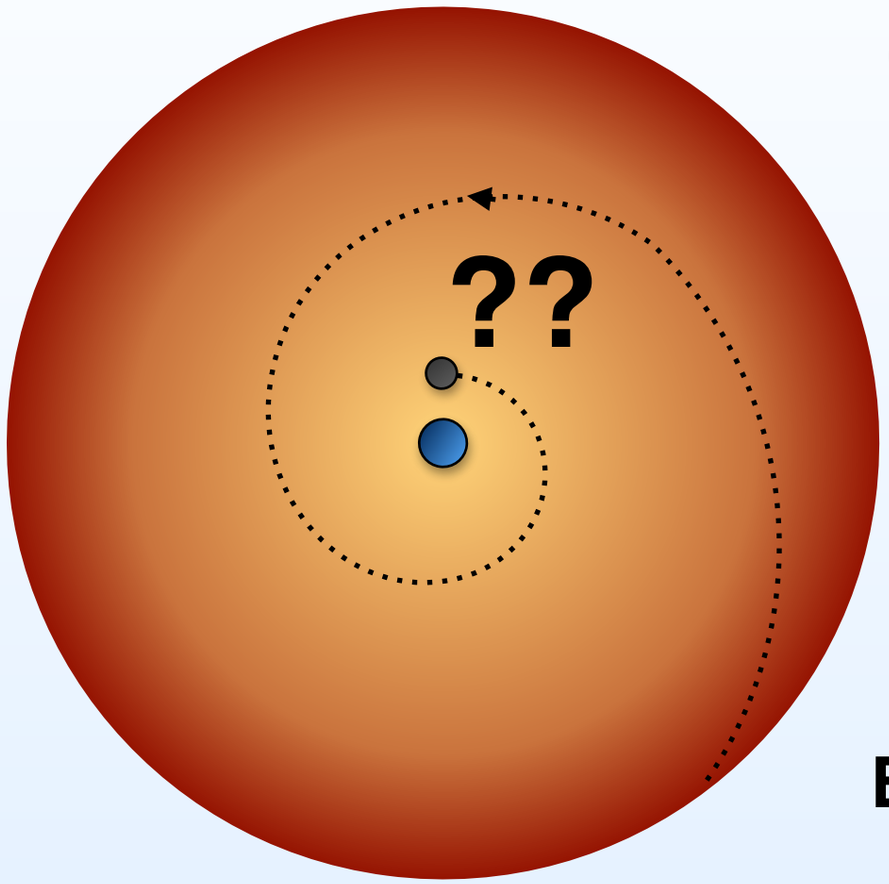

Challenging problem for “kitchen sink” numerical approach because of the huge range of relevant spatial and temporal scales.

… and infinite combinations of binary properties!

But, there are some general questions:

- ***What*** *are the initial conditions of CE episodes?*
- ***How*** *is energy/momentum transfer between embedded object and the gas mediated?*
- ***What*** *is the timescale of envelope ejection?*
- ***How*** *do initial binary parameters map to outcomes?*

Two strategies for progress

- ***Gas dynamics of common envelope:***
  - *goal:* isolate and understand aspects of the physics of CE flows

- ***Catching common envelope in action:***
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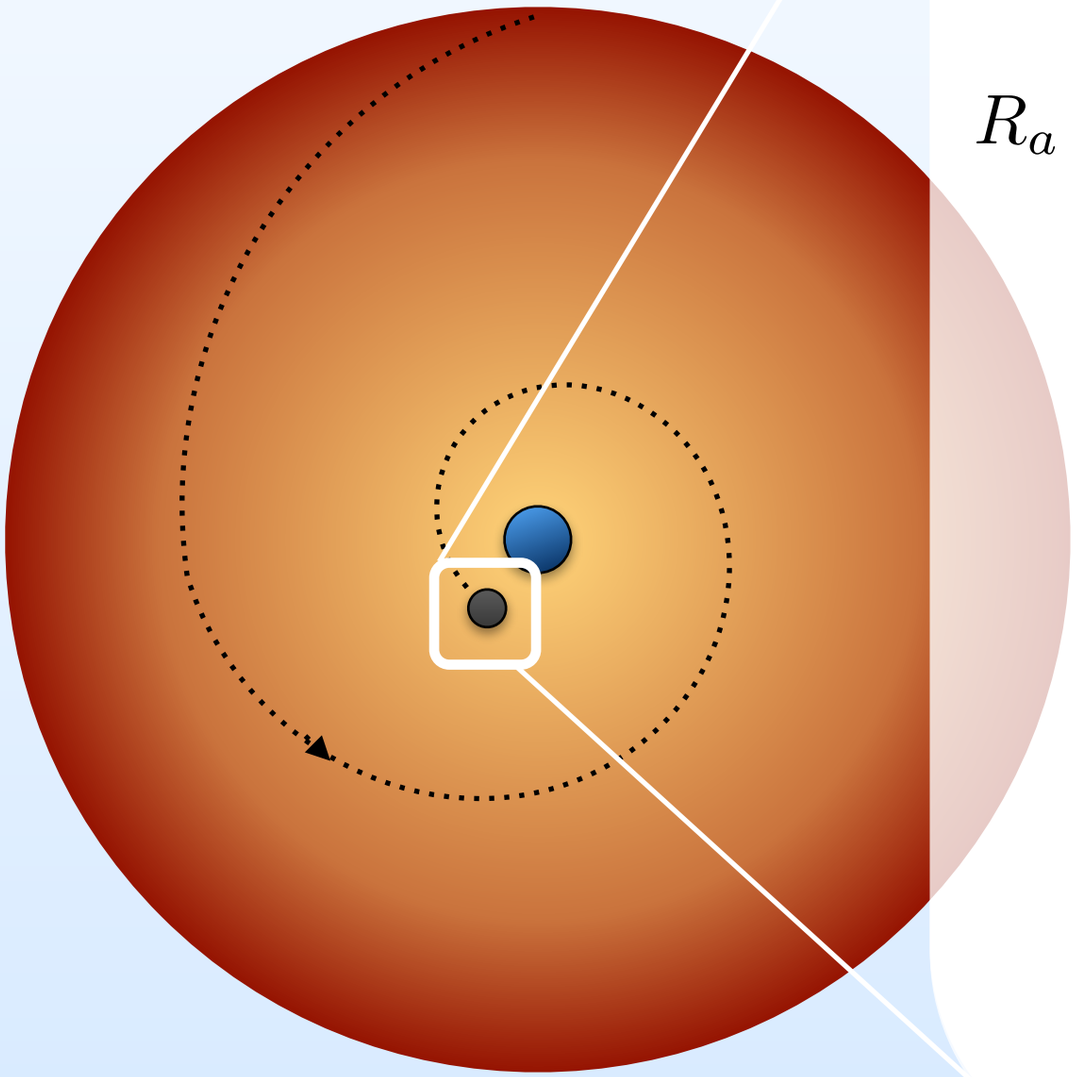
Gas dynamics of common envelope

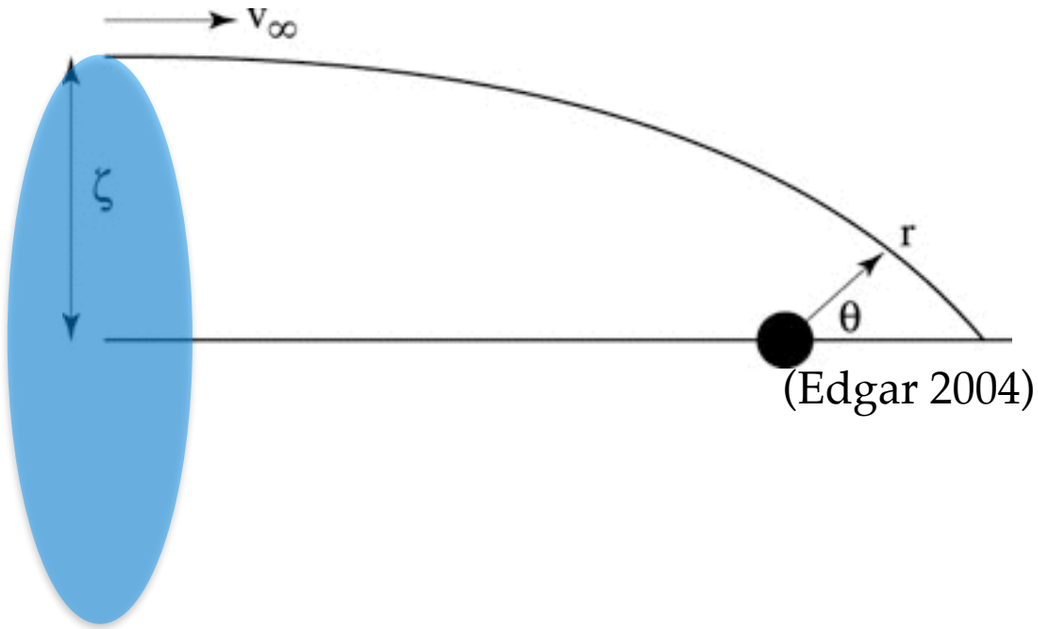
Hoyle & Lyttleton (1939),
Bondi & Hoyle (1944)



In the frame of the orbiting star:

Flow is gravitationally focussed
toward the embedded star

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



(Edgar 2004)

…interacts with a “column” of gas with

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

Gas dynamics of common envelope

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

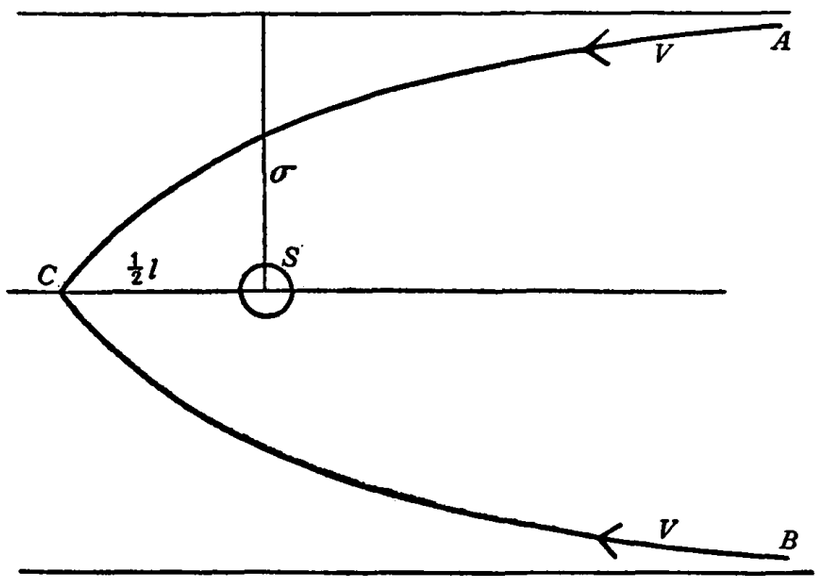


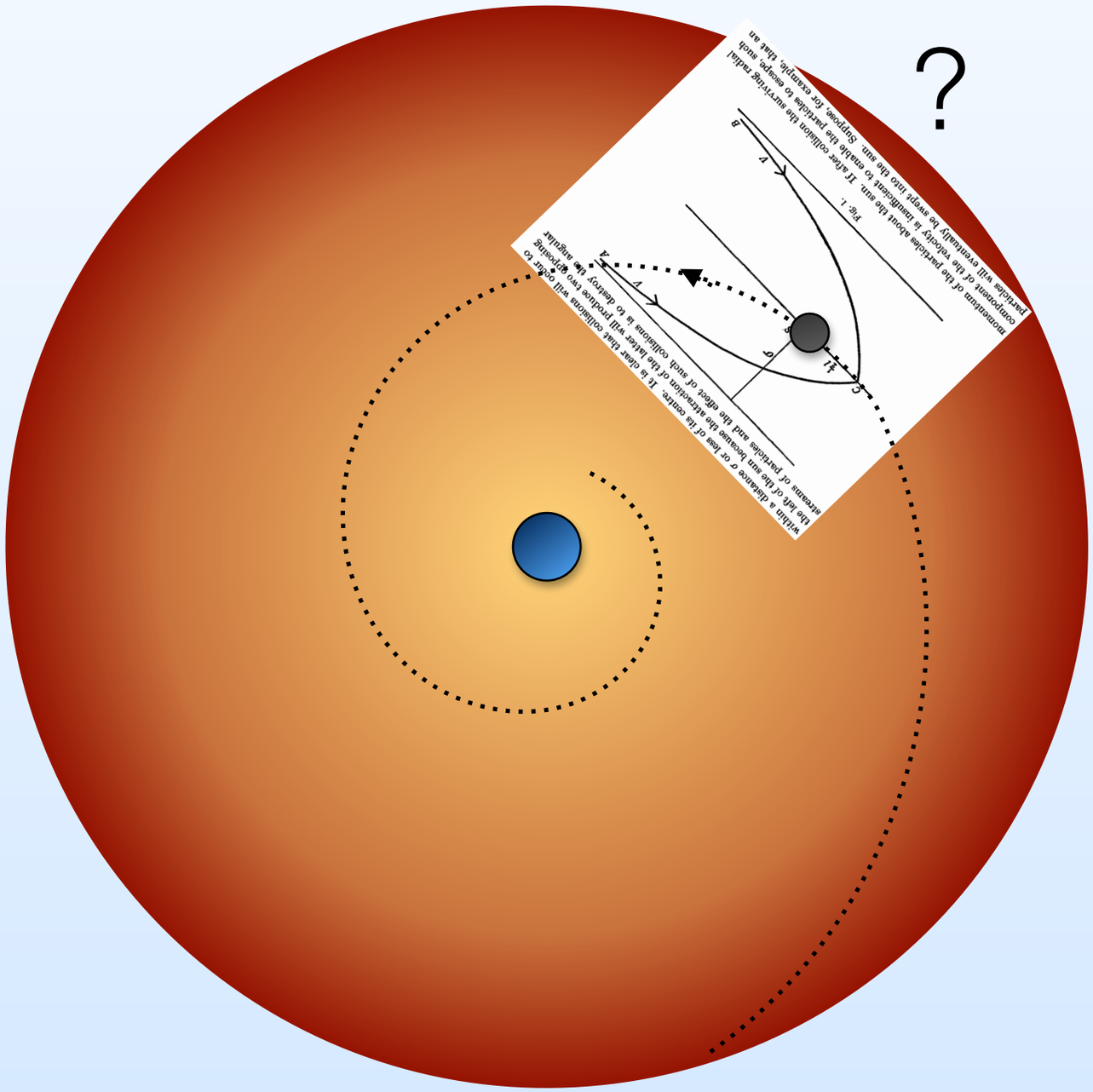
Fig. 1.

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

Gas dynamics of common envelope

Express typical flow properties in terms of the dimensionless scales of Hoyle-Lyttleton theory



Then simulation results can be applied to any stellar pair:

Length: $R_{\rm a} = 2GM/v^2$

Time: $R_{\rm a}/v$

Mach number: $\mathcal{M} = v/c_{\rm s}$

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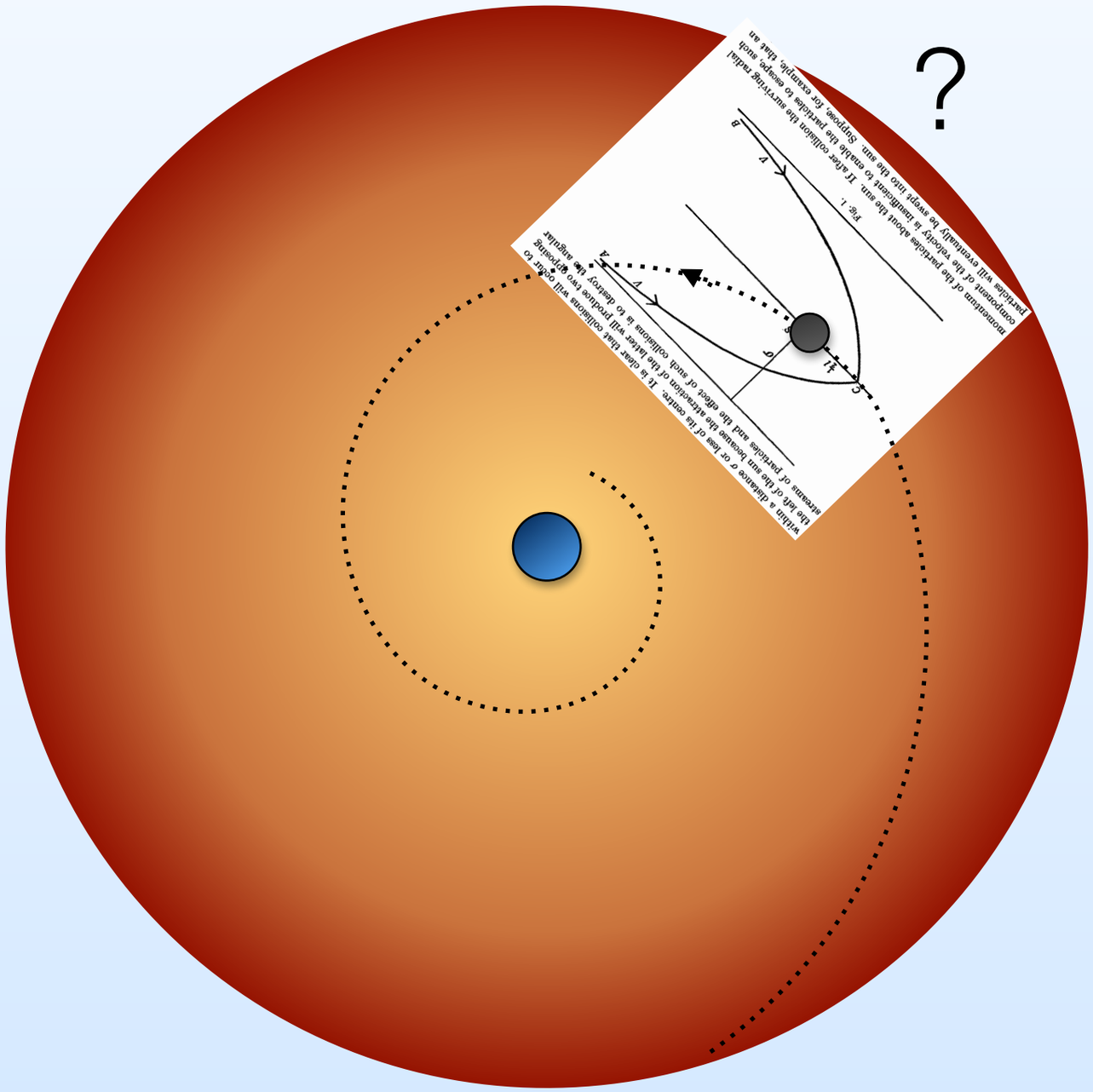

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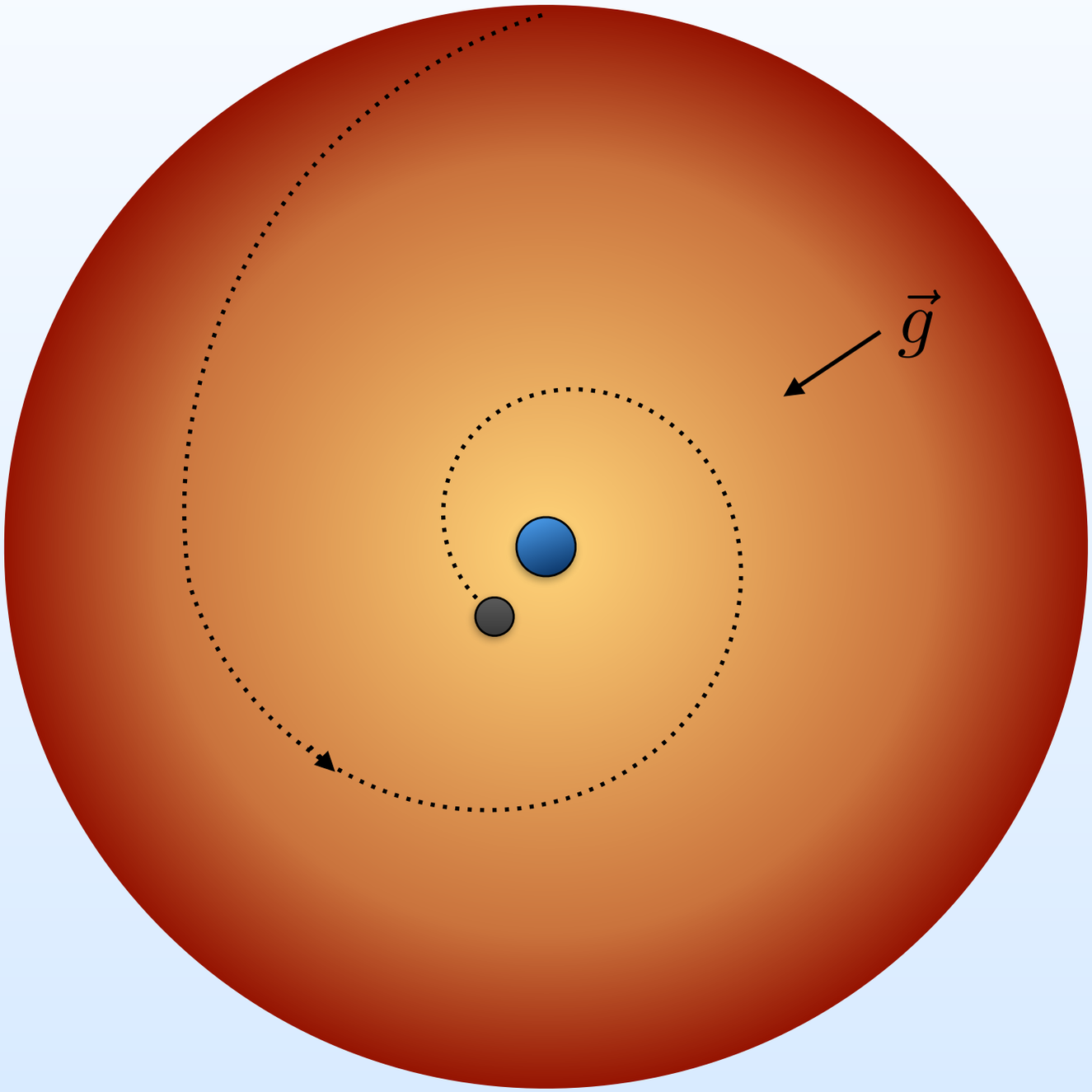
Density gradient: $\epsilon_\rho = R_{\rm a}/H_\rho$

Flow parameters for common envelope inspiral



Relations between flow parameters:

The stellar envelope is in HSE with the same gravity that drives the orbital motion!

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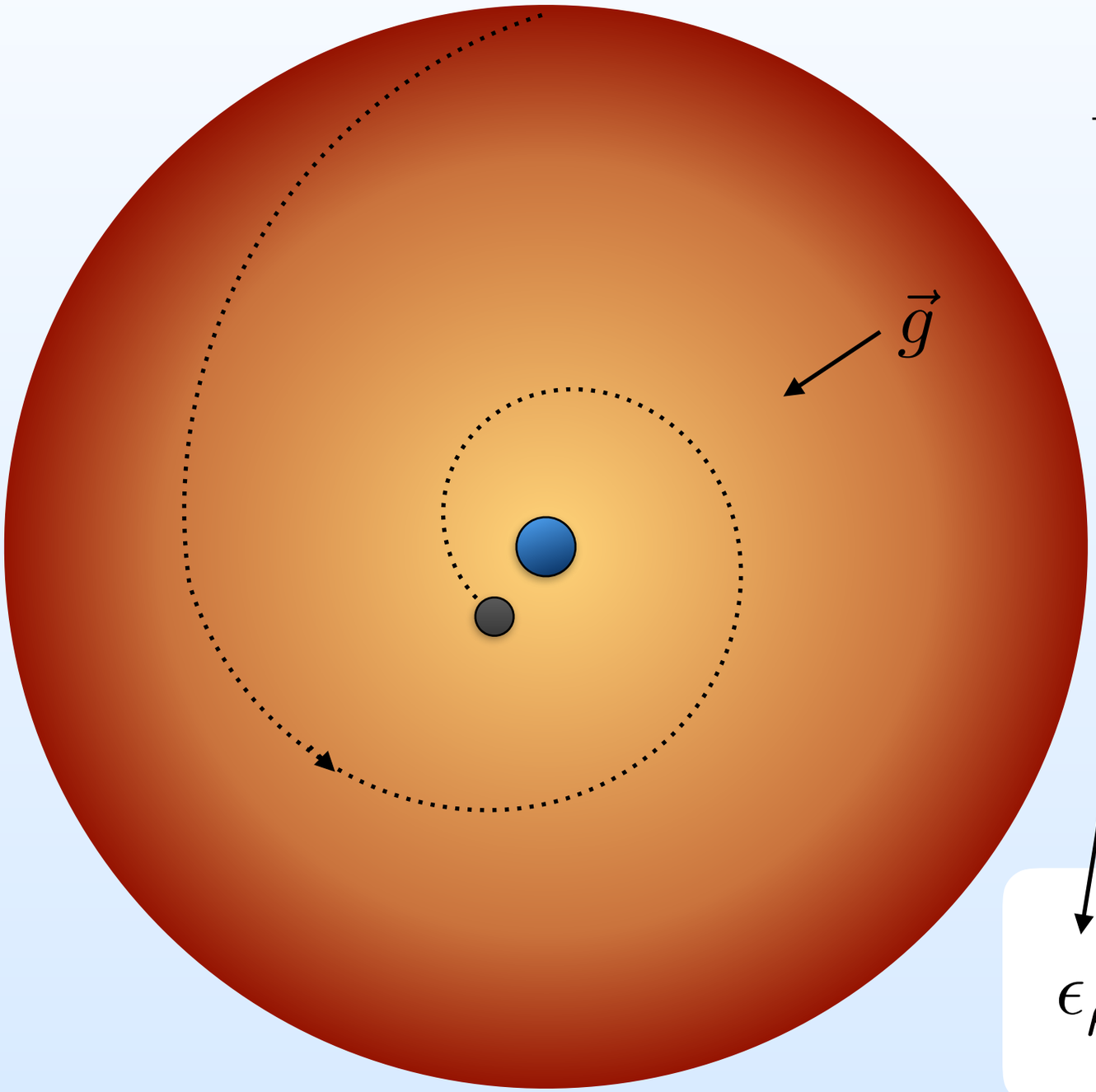

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Density gradient

Envelope structure vs gas compressibility

relative velocity: fraction of Keplerian

Mass ratio

$$\epsilon_\rho = \frac{2q}{(1+q)^2}\mathcal{M}^2 f_{\rm k}^{-4}\left(\frac{\Gamma_{\rm s}}{\gamma}\right)^{-1}$$

Mach Num

Common Envelope Wind Tunnel

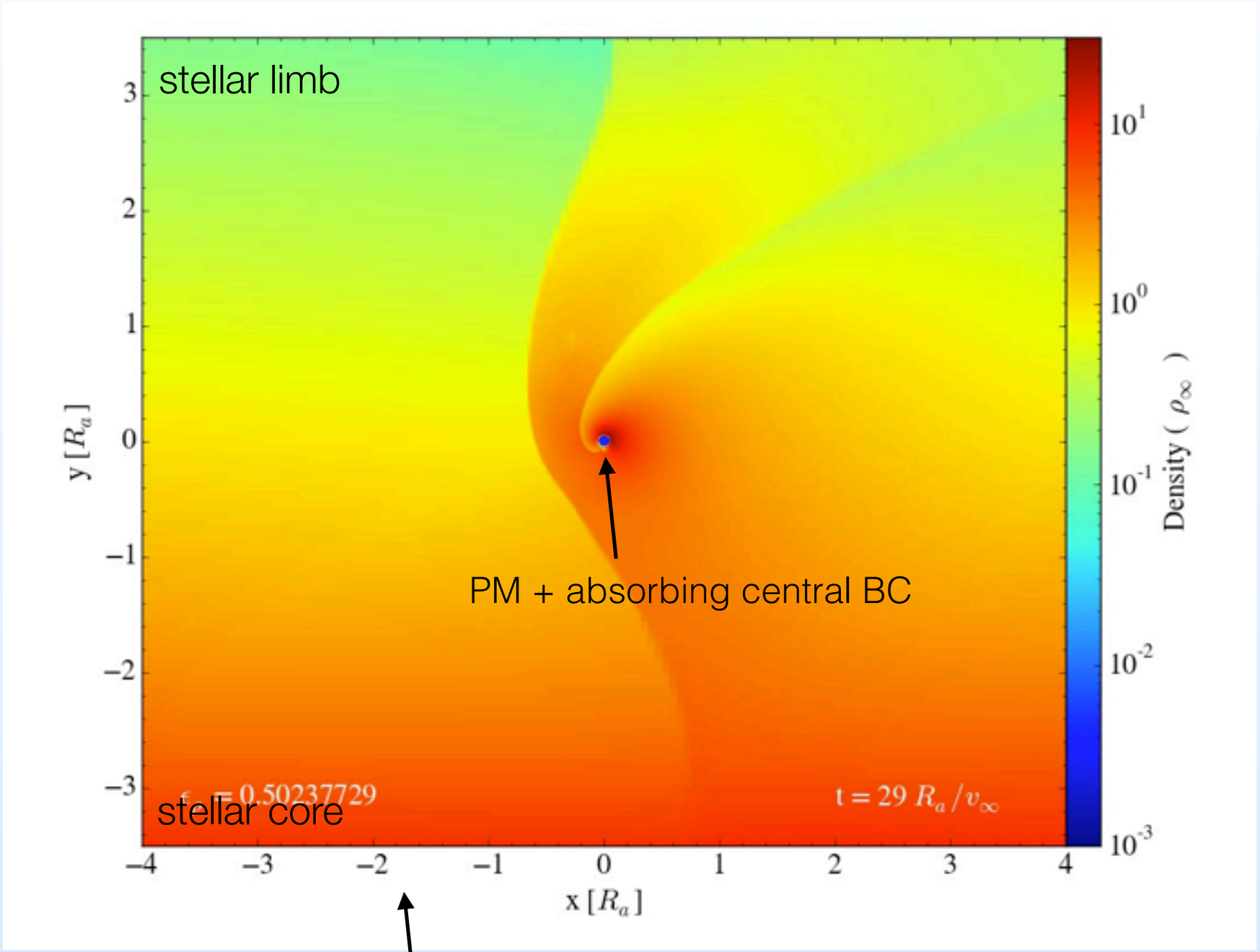
3D (AMR) calculation in FLASH

Cartesian geometry: “unwrapped” star

inject flow with polytropic (HSE) profile

specified by

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



-y boundary enforces HSE

Common Envelope Wind Tunnel

3D (AMR) calculation in FLASH

Cartesian geometry: “unwrapped” star

inject flow with polytropic (HSE) profile

specified by

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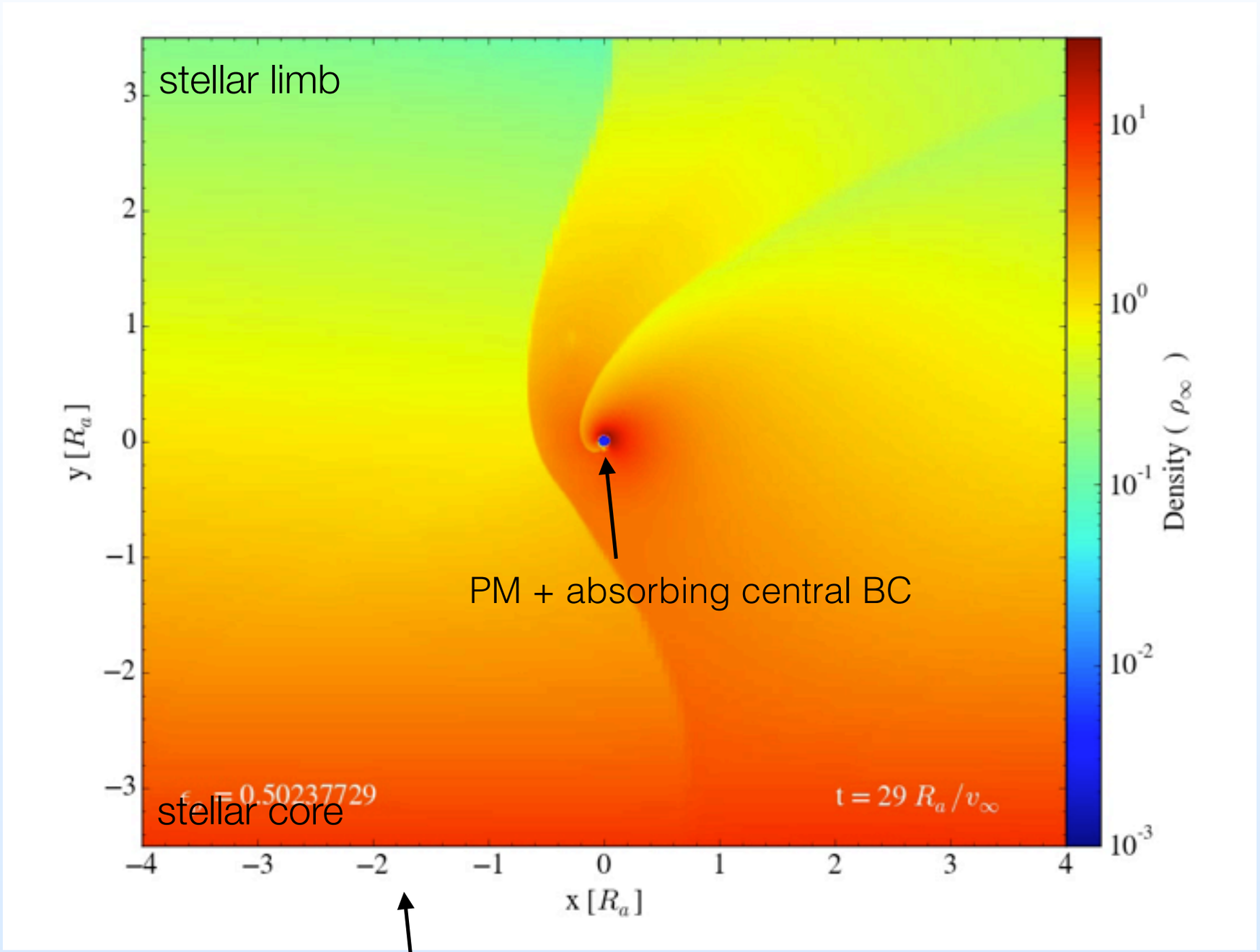
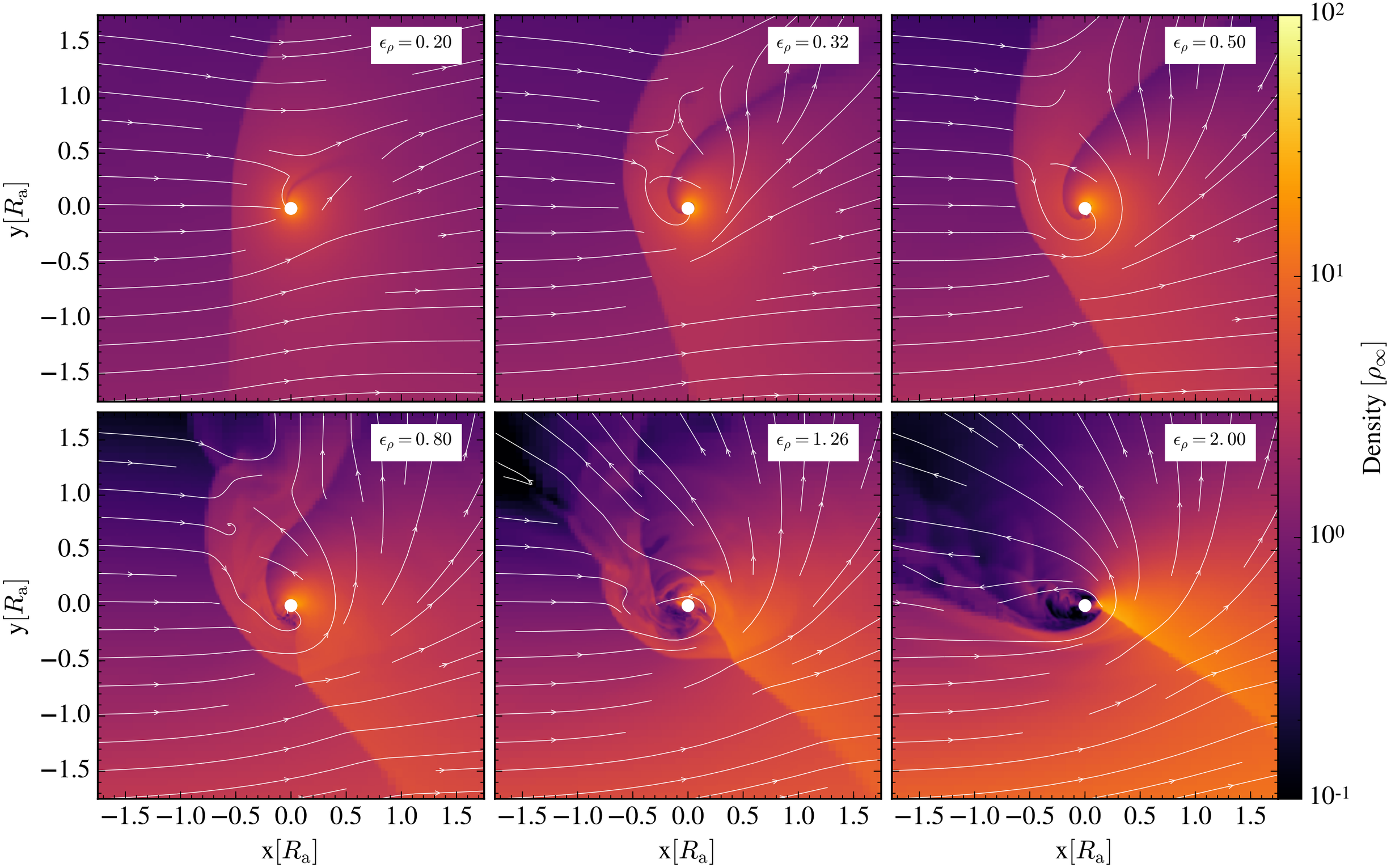


-y boundary enforces HSE

Common Envelope Wind Tunnel

$$\gamma = \Gamma_{\rm s} = 5/3$$



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Catching common envelope in action

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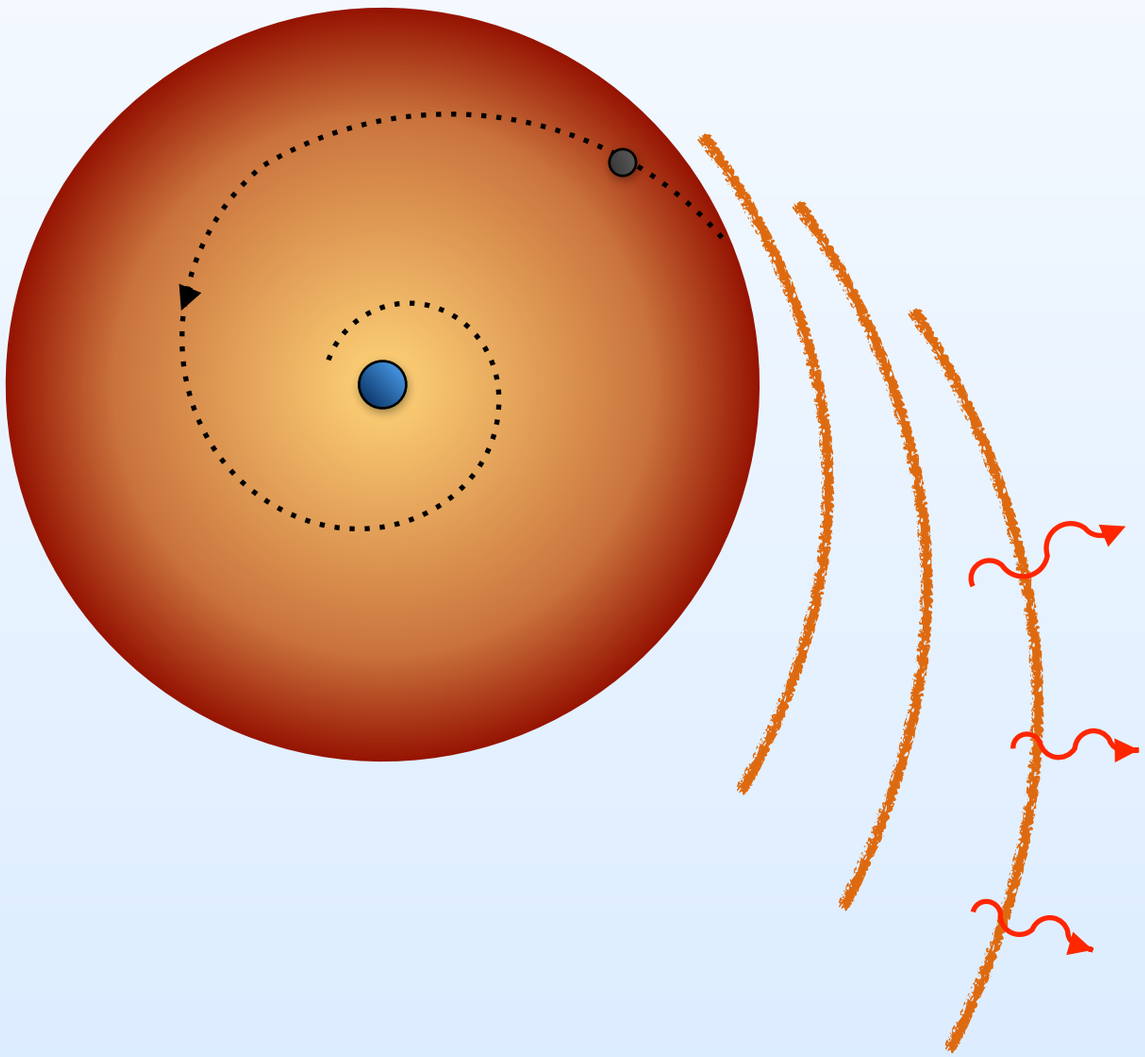

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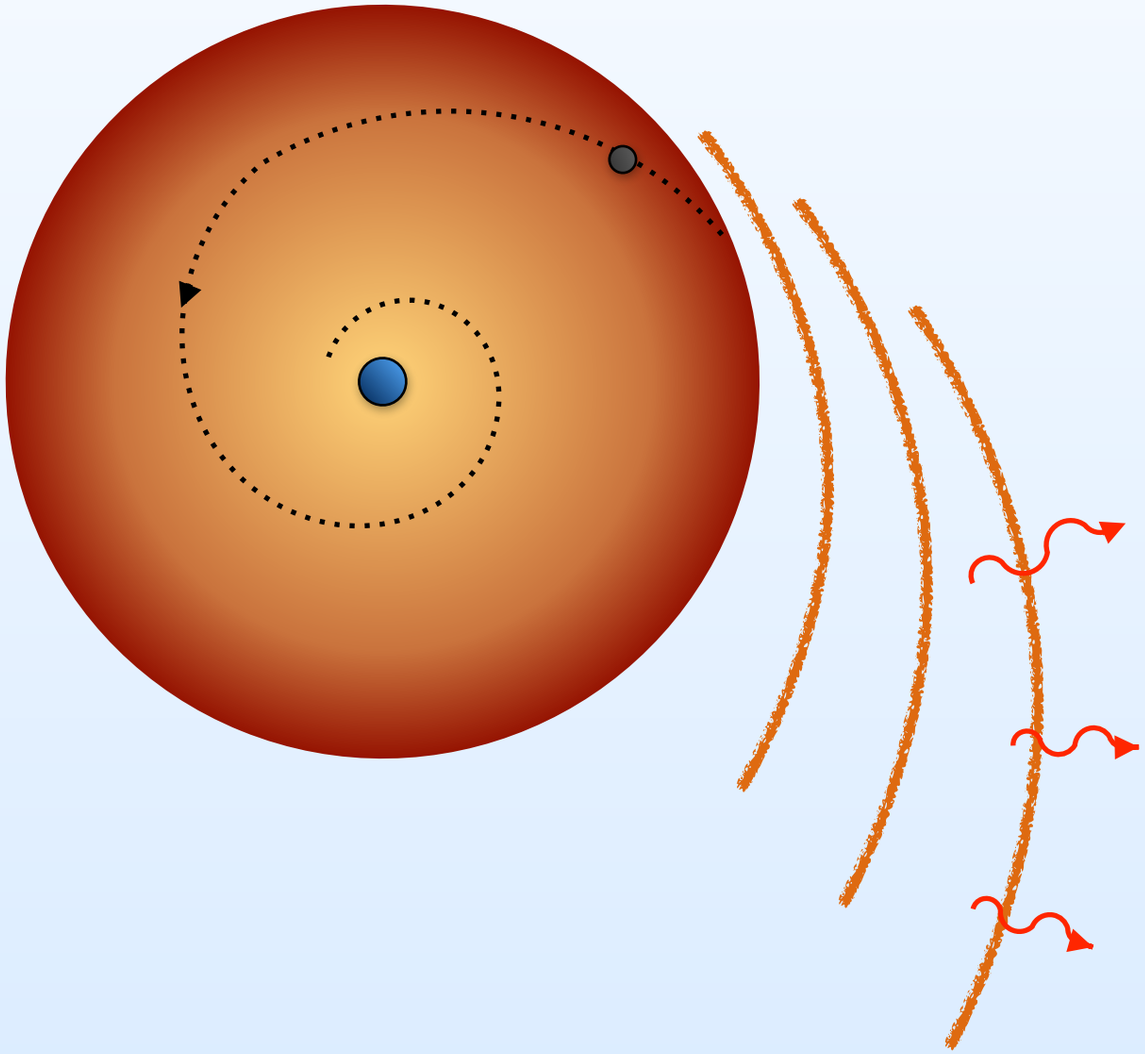
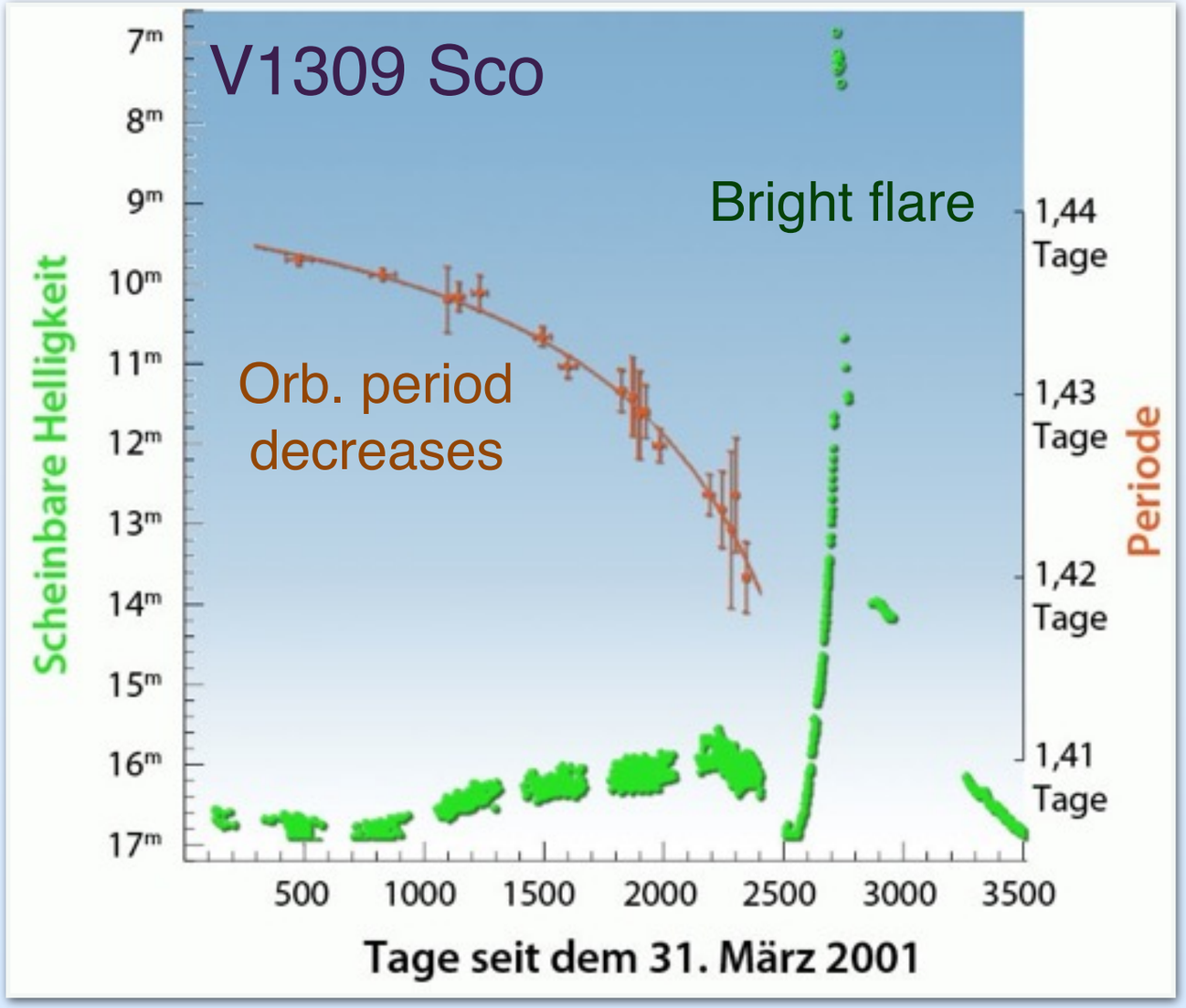
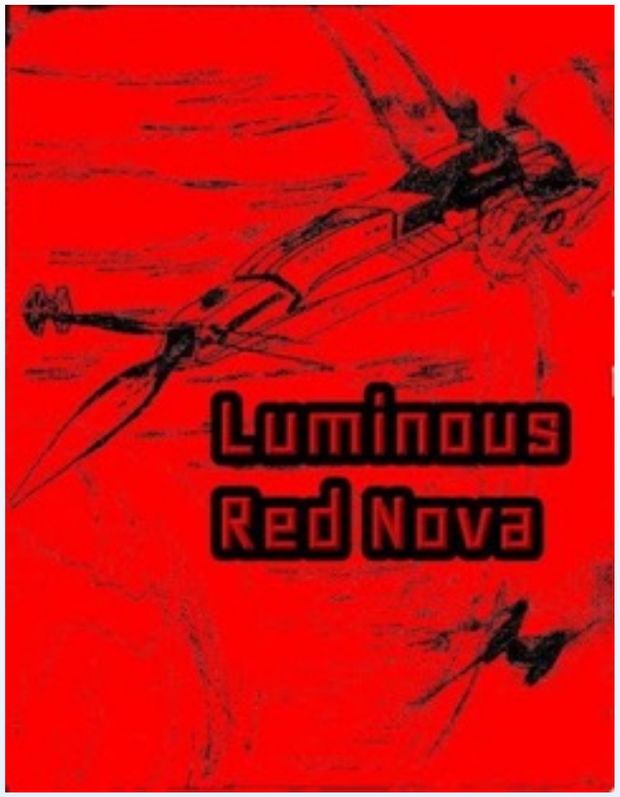


Luminous Red Novae:



Catching common envelope in action

Luminous Red Novae?



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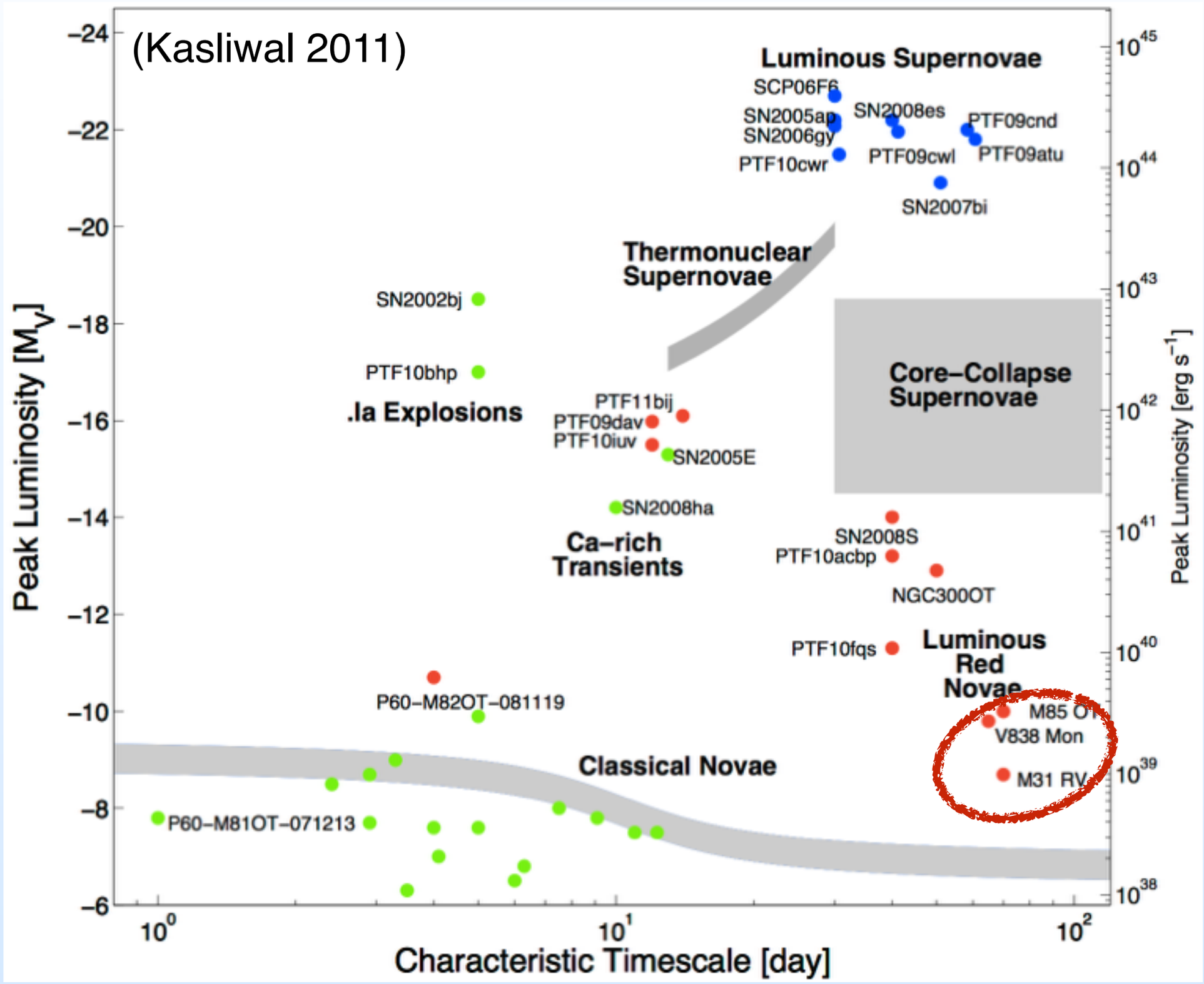

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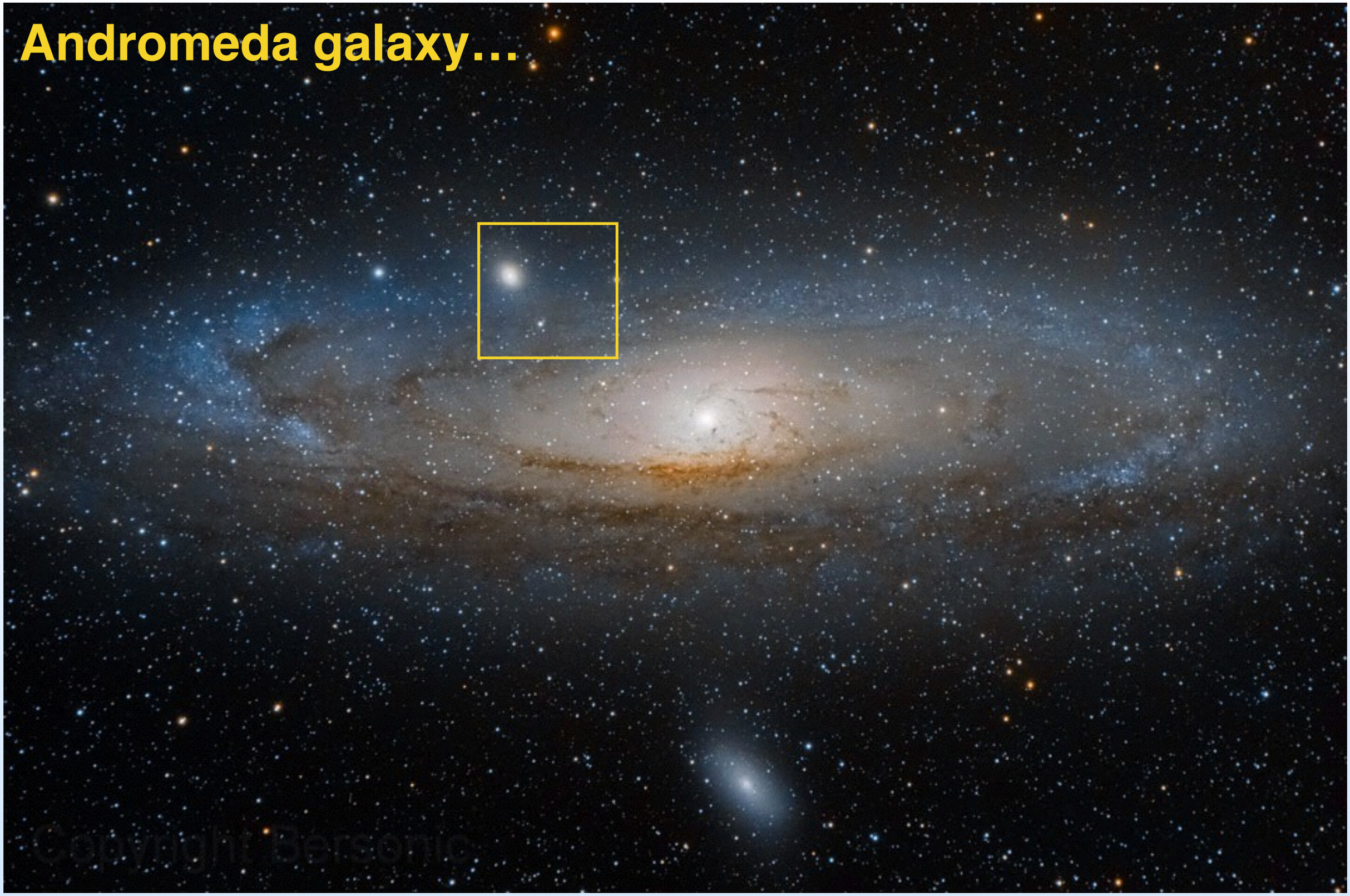
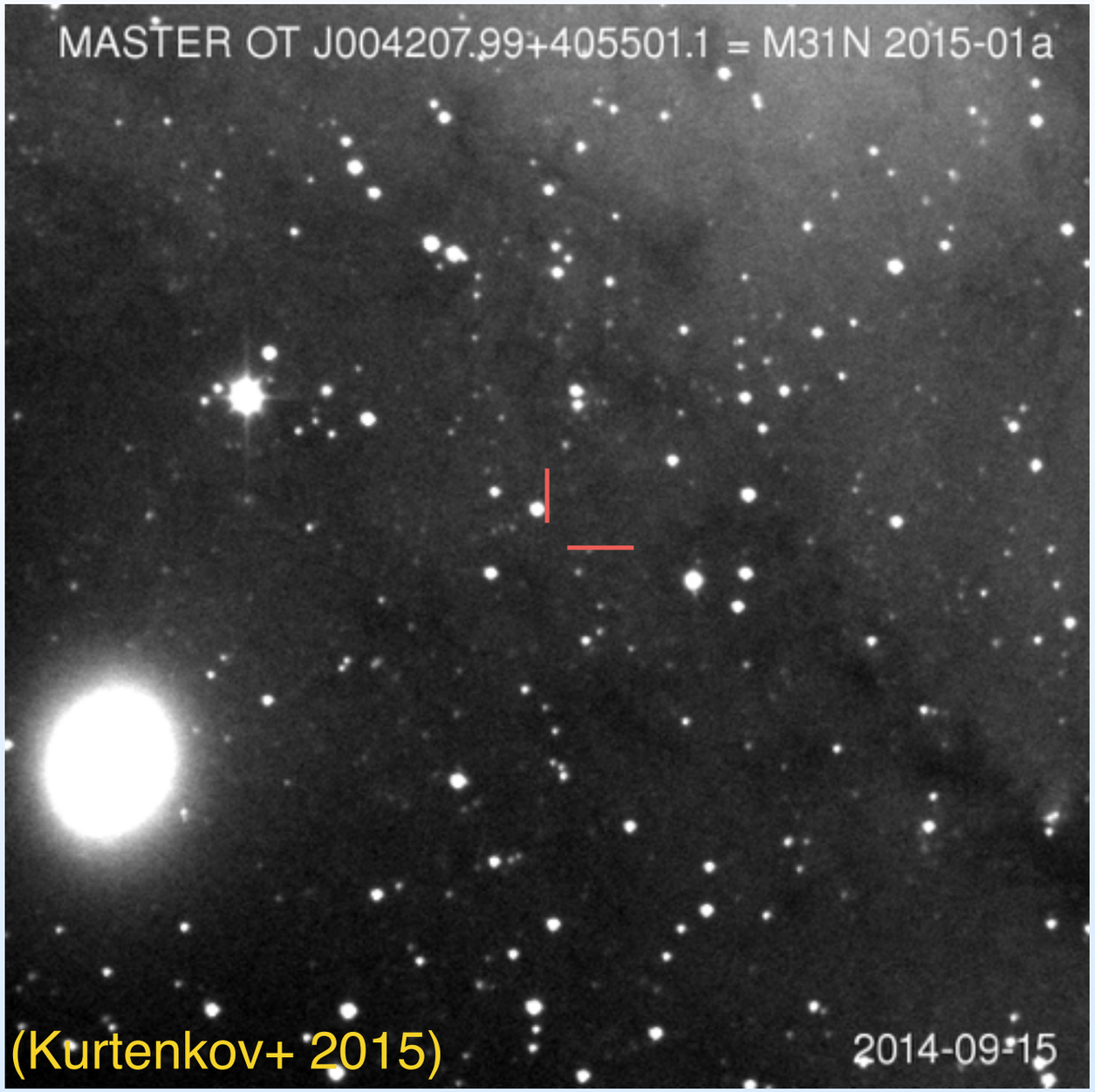


Catching common envelope in action (M31 LRN2015)

M31 LRN 2015



Outburst in Andromeda galaxy in Jan 2015

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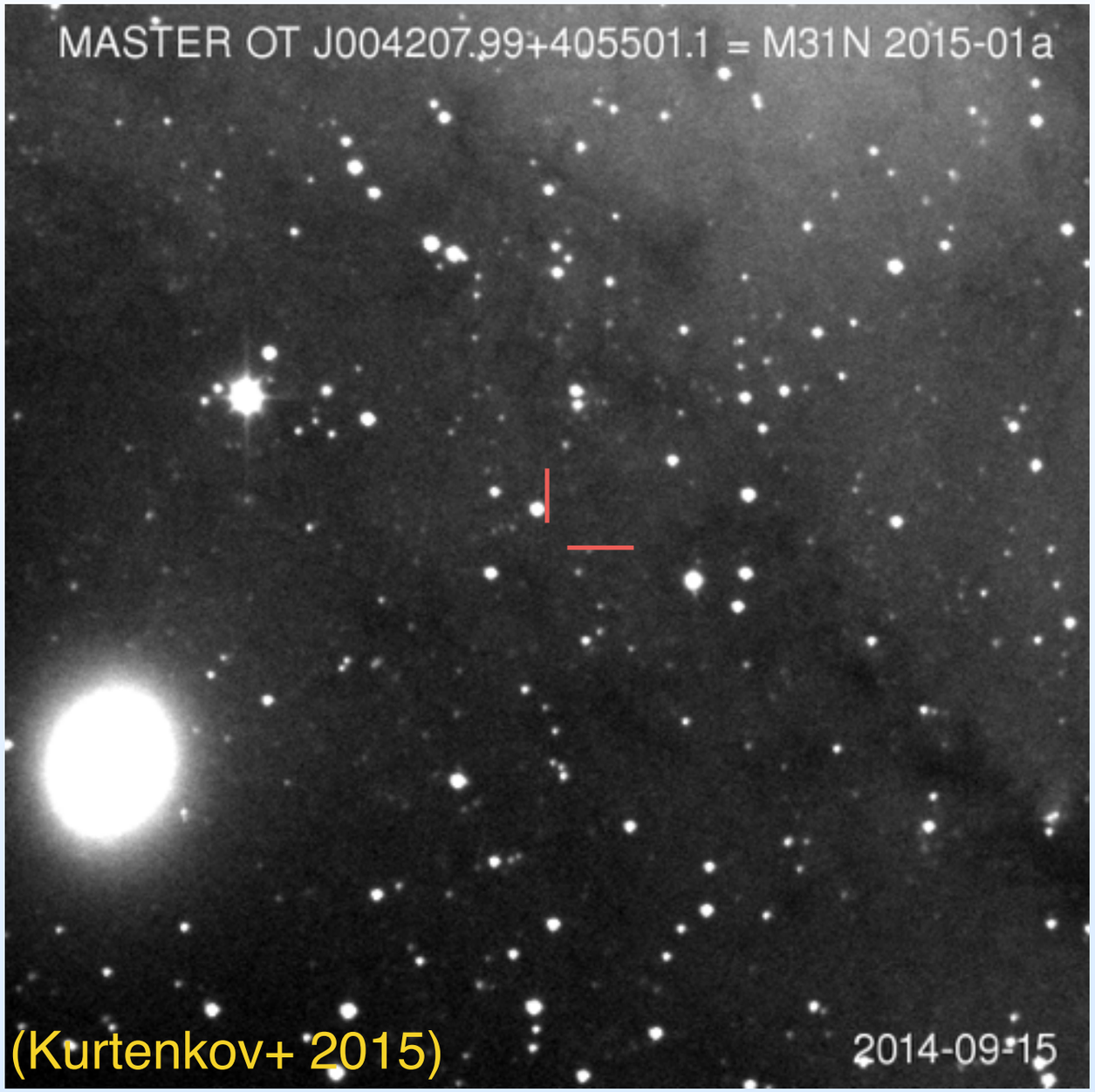

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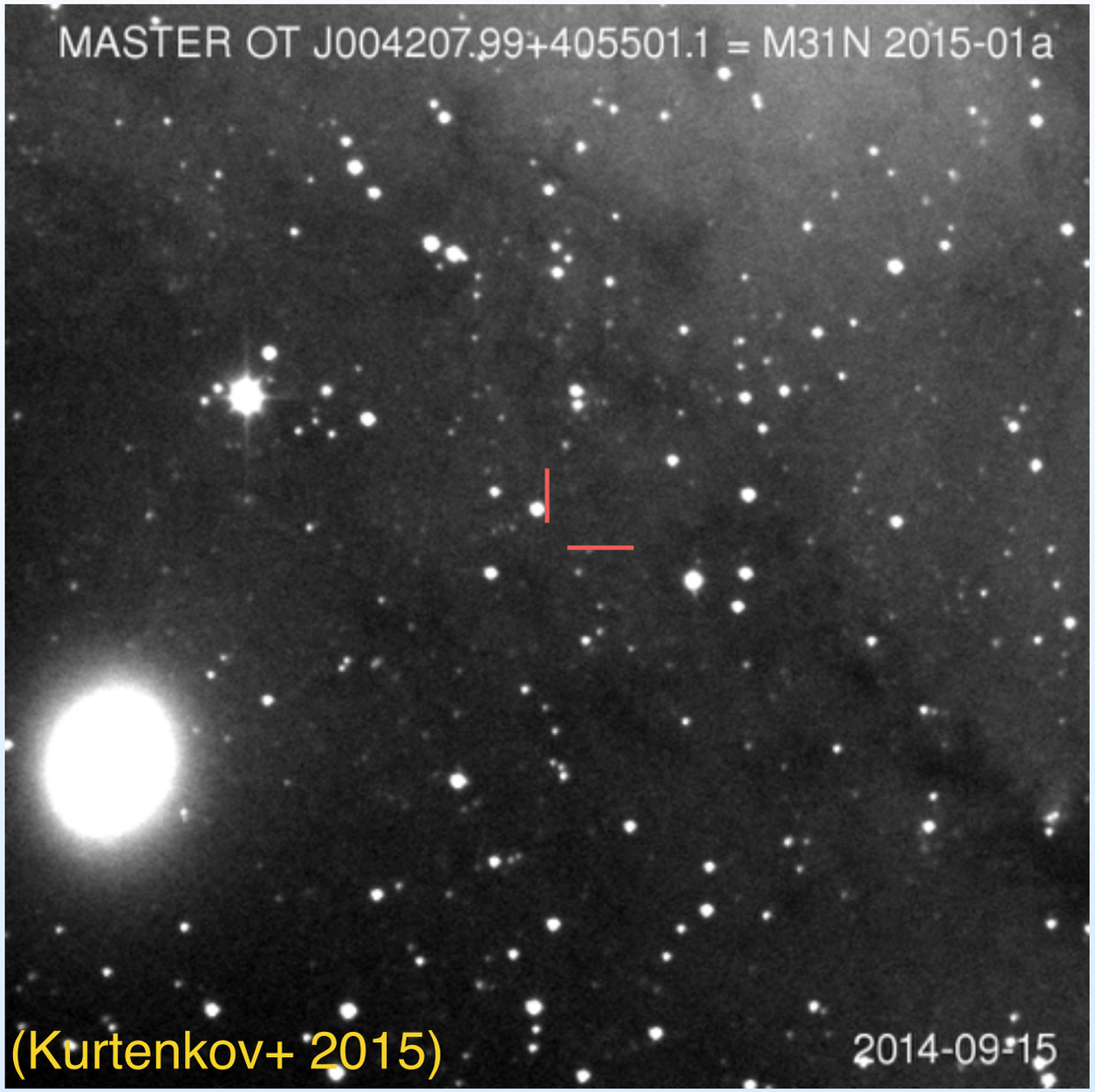

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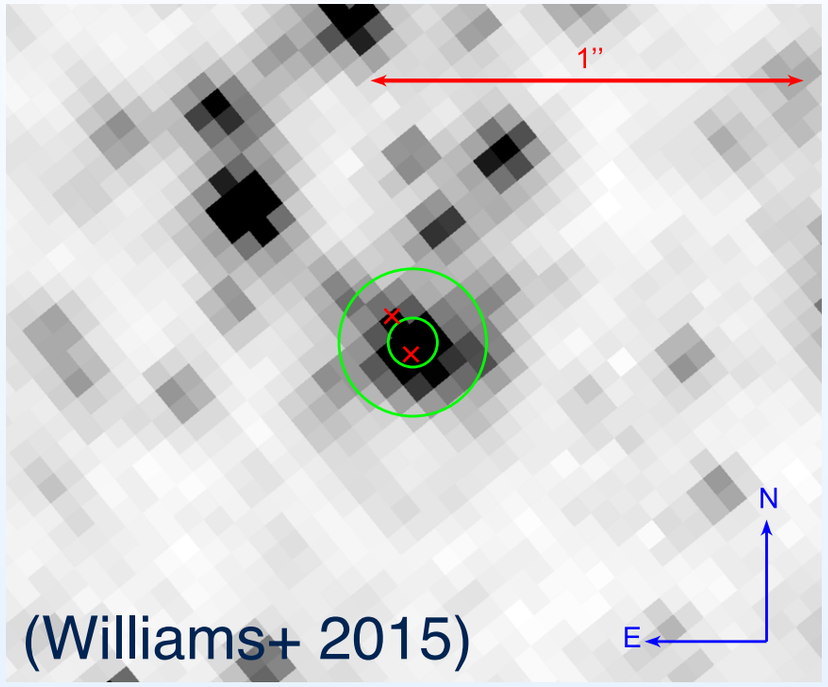

Pre-outburst source in *HST* imaging

Catching common envelope in action (M31 LRN2015)

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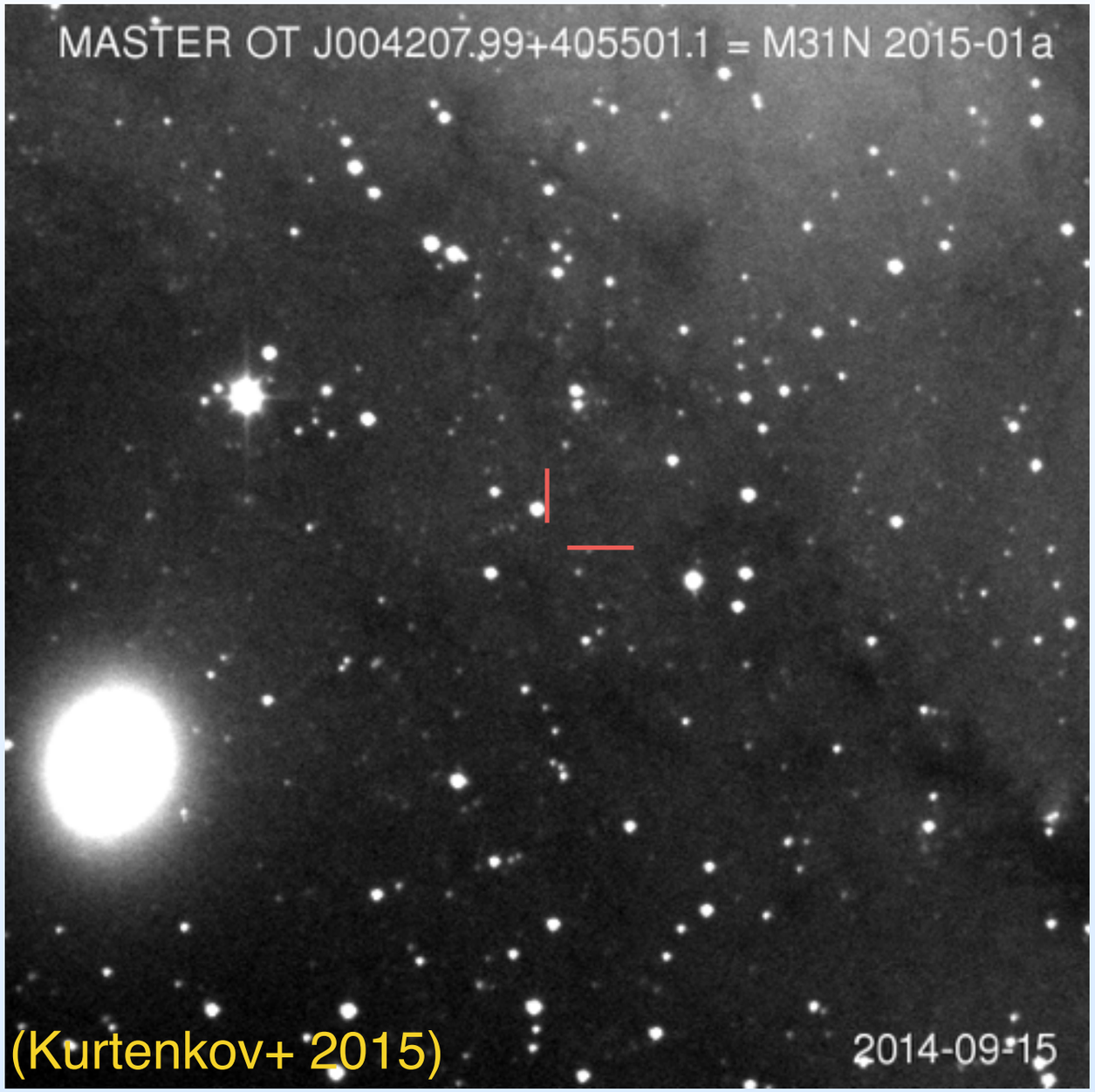

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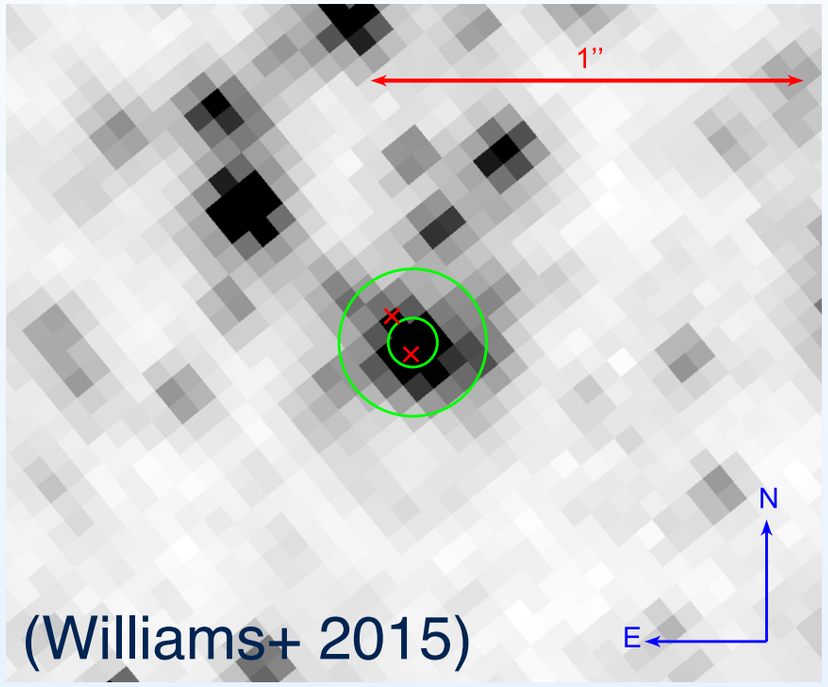

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Binary System

Transient Outburst

Taken together: a binary merger outburst

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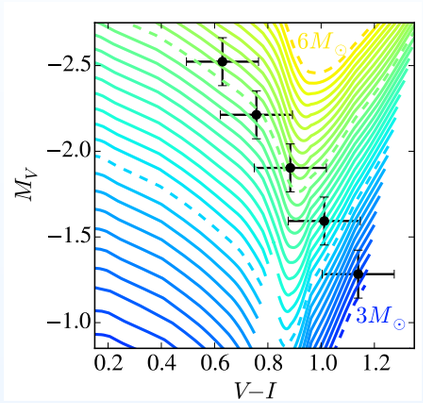

sub-giant primary star
growing to point of interaction

$$M_1 \approx 4 - 5M_\odot; \quad R_1 \approx 30R_\odot$$

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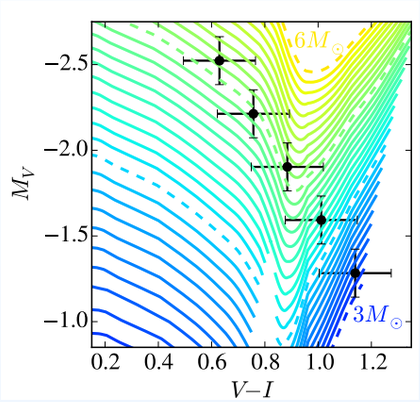

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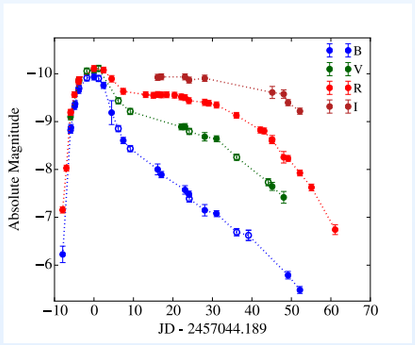

transient rise time similar
to orbital period

$$\Delta t_{\rm peak} \sim t_{\rm orb}$$

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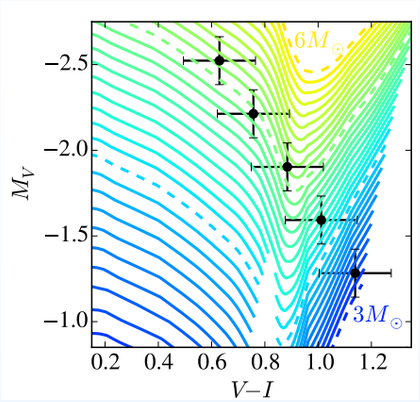

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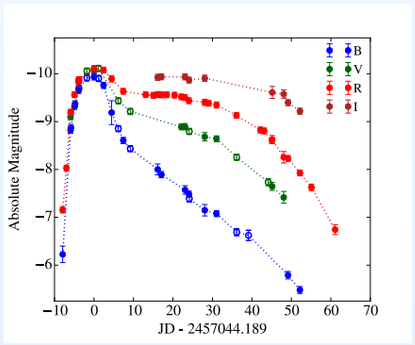

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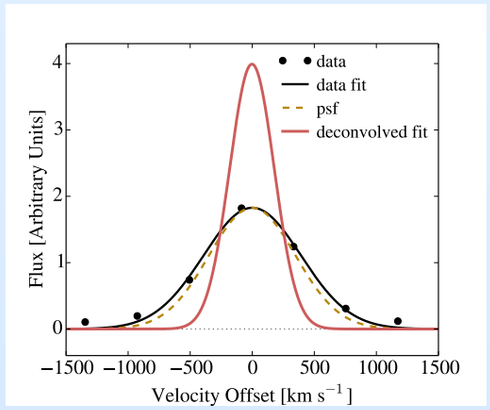
$$\Delta t_{\rm peak} \sim t_{\rm orb}$$

fast ejecta relative to escape velocity

$$v_{\rm ej} > v_{\rm esc}$$



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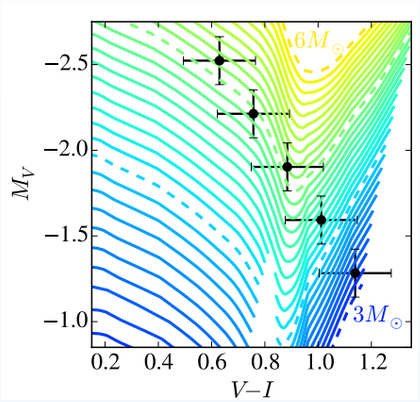
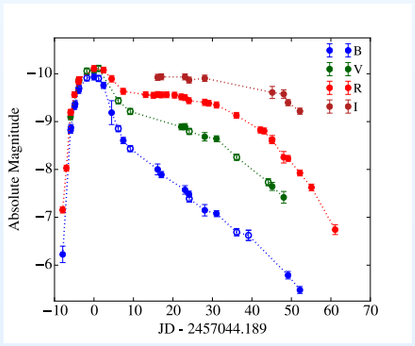


sub-giant primary star growing to point of interaction

$$M_1 \approx 4 - 5M_\odot; \quad R_1 \approx 30R_\odot$$



transient rise time similar to orbital period

$$\Delta t_{\rm peak} \sim t_{\rm orb}$$

merger transient:

$$E_{\rm rad} \sim 10^{46}\ {\rm erg}$$

$$v_{\rm ej} \sim 400\ {\rm km\ s^{-1}}$$

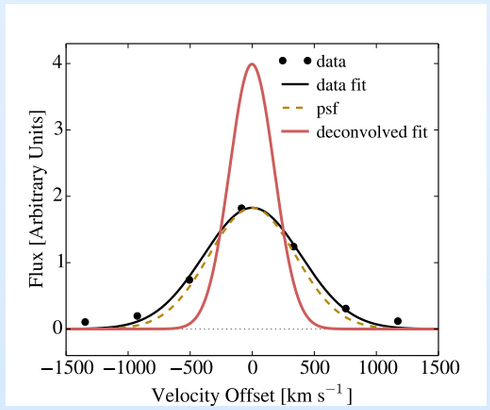
$$\Delta t_{\rm peak} \sim 8\ {\rm d}$$

$$\Delta m_{\rm ej} \sim 10^{-2} M_\odot$$

small fraction of system mass ejected dynamically

fast ejecta relative to escape velocity

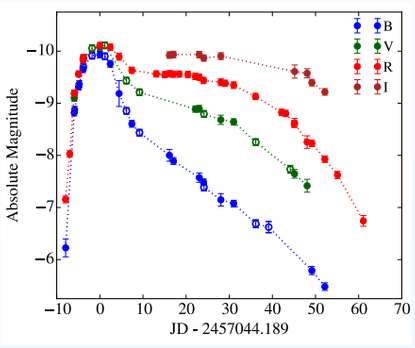
$$v_{\rm ej} > v_{\rm esc}$$



What can we learn about common envelope?

- Stars sometimes swallow other stars: this can make new (tighter) binaries, or cause a complete merger.

- We still have NO IDEA how the details work!!



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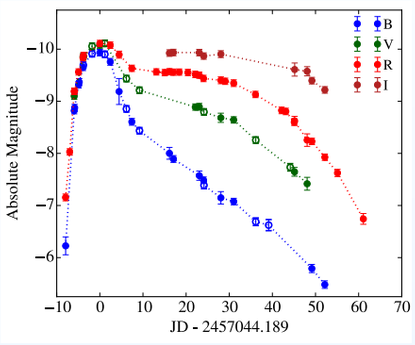

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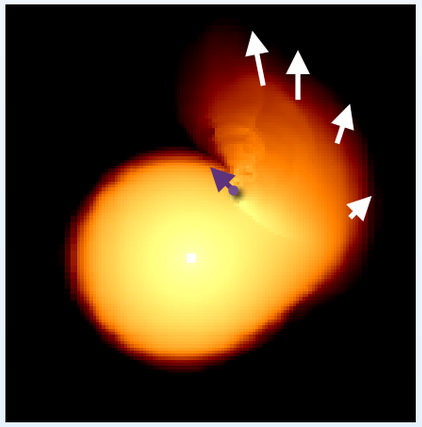

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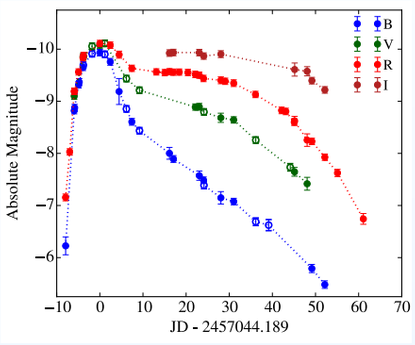

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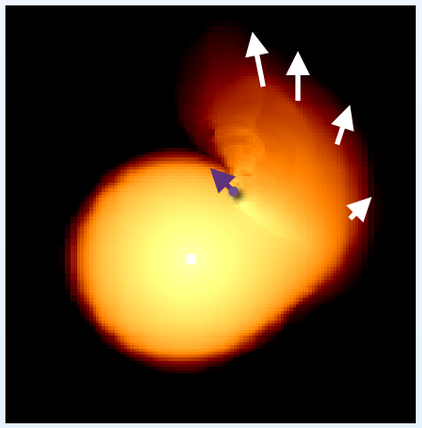

- As we start to discover binaries merging through the emission of gravitational waves, it's extremely important to understand the **assembly** of these close systems through common envelope phases.