Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

Royal Astronomical Society

MNRAS **532,** 89–111 (2024)
https://doi.org/10.1093/mnras/stae1455
Advance Access publication 2024 June 11

Partial tidal disruption events: the elixir of life（ elixir: 长生不老药 ）

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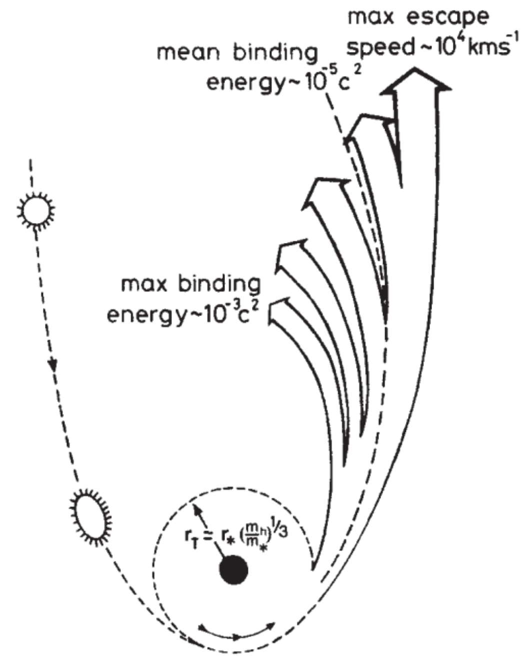
Speaker: Shiyan Zhong

Journal Club, 2024-11-27

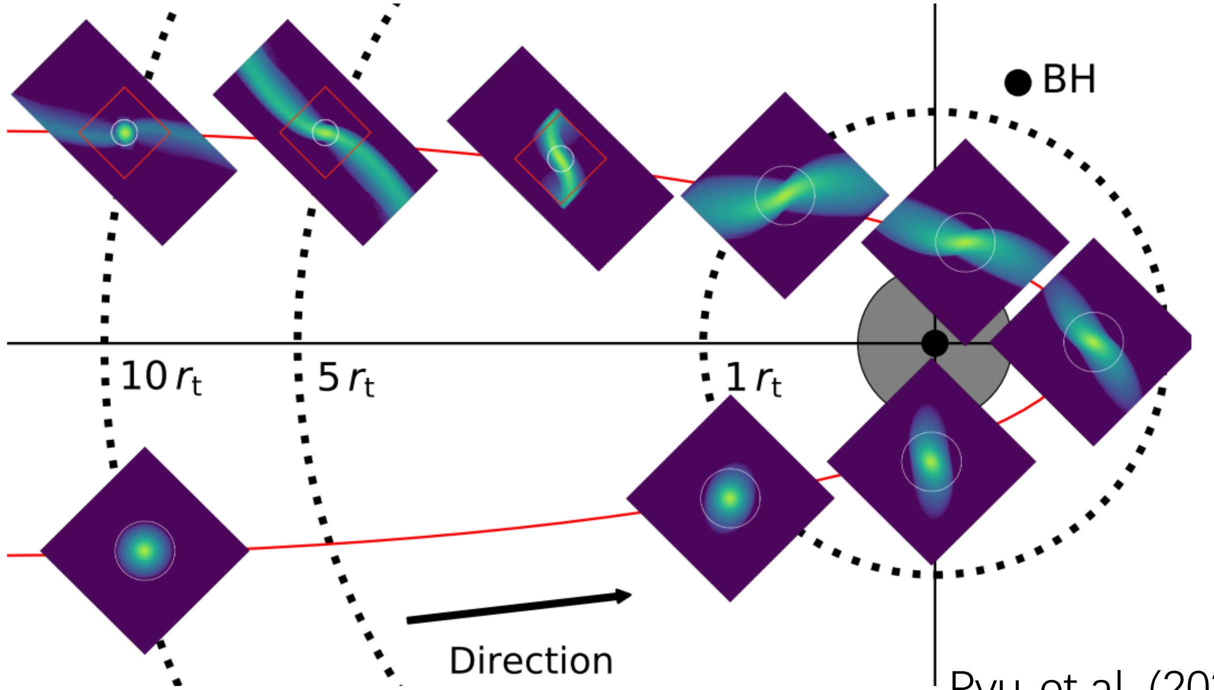
Background: partial tidal disruption event (PTDE)

Full TDE: star is completely destroyed



Rees (1988)

PTDE: a remnant star survives



Ryu et al. (2020)

Capable of producing repeated flares:

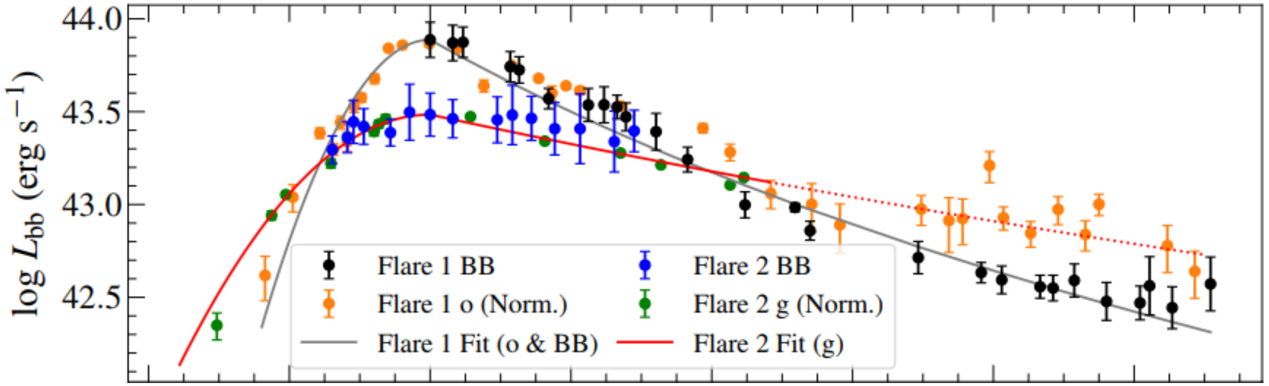
- ASASSN-14ko (Payne et al. 2021)
- AT2018fyk (Wevers+2023; Pasham+2024)
- AT2019aalc (Veres+2024)
- AT2020vdq (Somalwar+2023)
- AT2021aeuk (Bao+2024)
- AT2022dbl (Lin+2024)

Sample size small, but has shown diversity

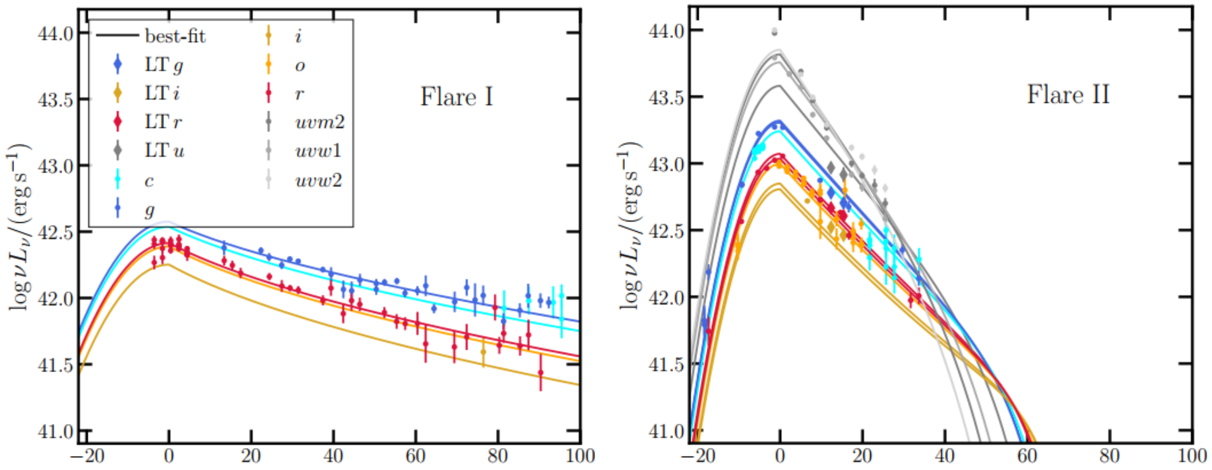
Background: challenge in modeling RPTDE

Sub-types of repeating PTDE flares:

Second flare is dimmer: AT 2022dbl (Lin et al. 2024)



Second flare is brighter: AT 2020vdq (Somalwar et al. 2023)



Background: challenge in modeling RPTDE

Sub-types of repeating PTDE flares:

Strength of disruption is determined by $\beta = \frac{r_t}{r_p}$

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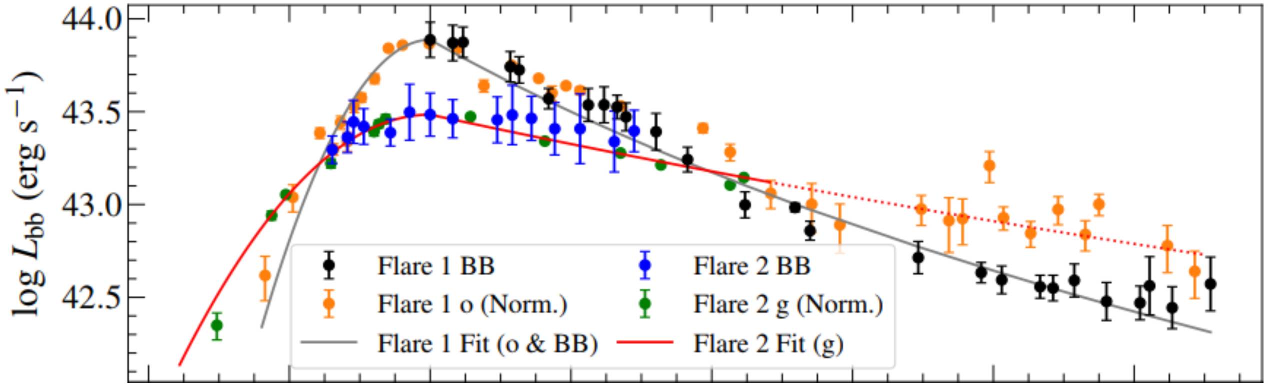

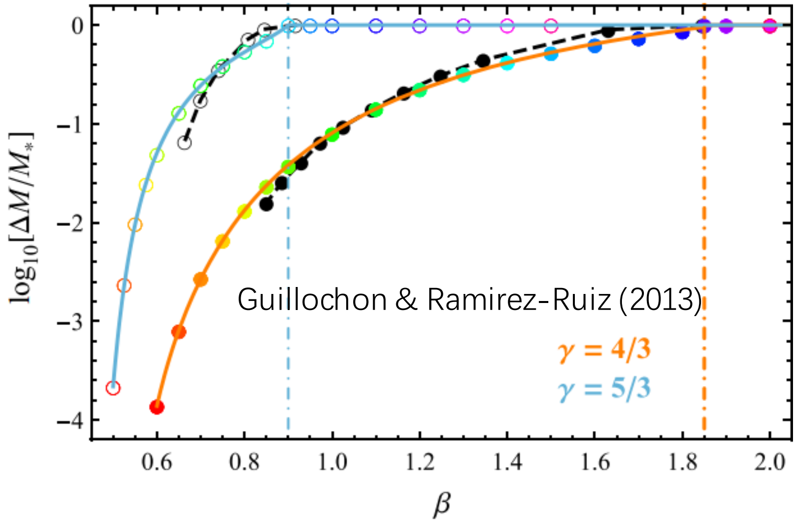

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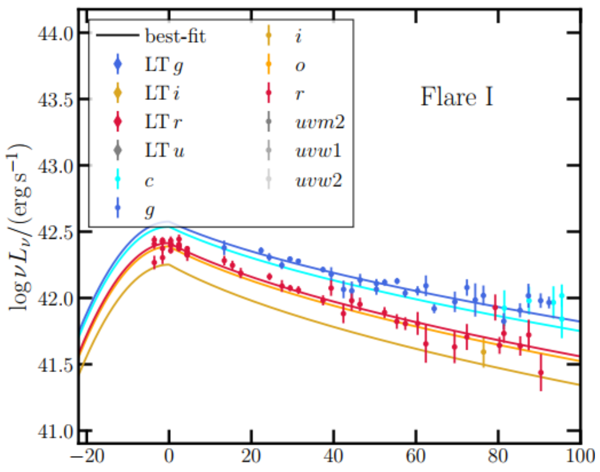

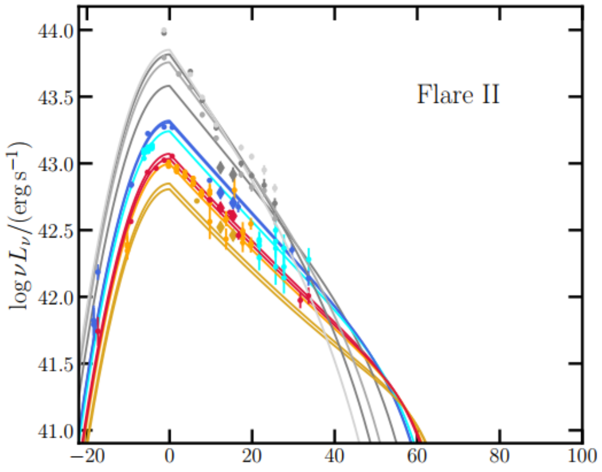

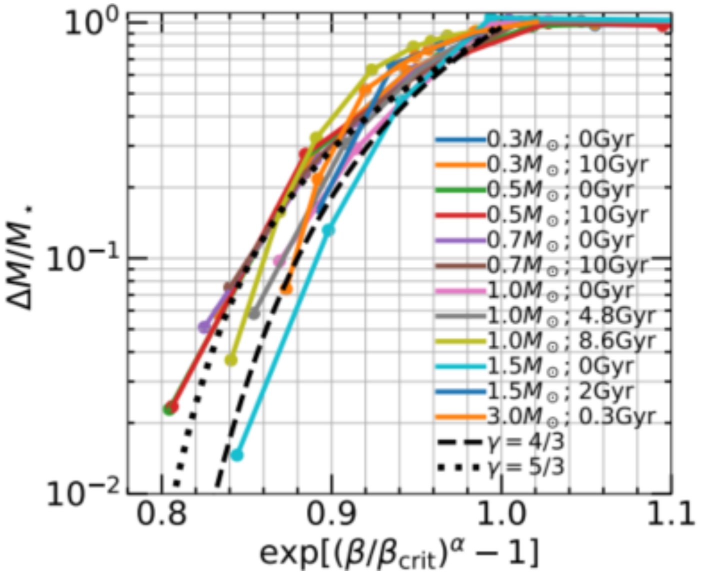

Law-Smith et al. 2020

Background: challenge in modeling RPTDE

Penetration factor $\beta = \frac{r_t}{r_p}$

- Variation in r_p : orbital angular momentum J

$$r_{\mathrm{p}} = \frac{J^2}{2GM_{\mathrm{BH}}}, \qquad (e \to 1)$$

- Driven by two-body relaxation process

Mean variation of J^2 per orbit

$$\langle \Delta J^2 \rangle \approx J_{\mathrm{c}}(r_{\mathrm{a}})^2 \left(\frac{t_{\mathrm{dyn}}}{t_{\mathrm{relax}}} \right),$$

$$t_{\mathrm{dyn}} \ll t_{\mathrm{relax}}$$

(order of years) (order of Gyr)

Unlikely responsible for notable variation in β

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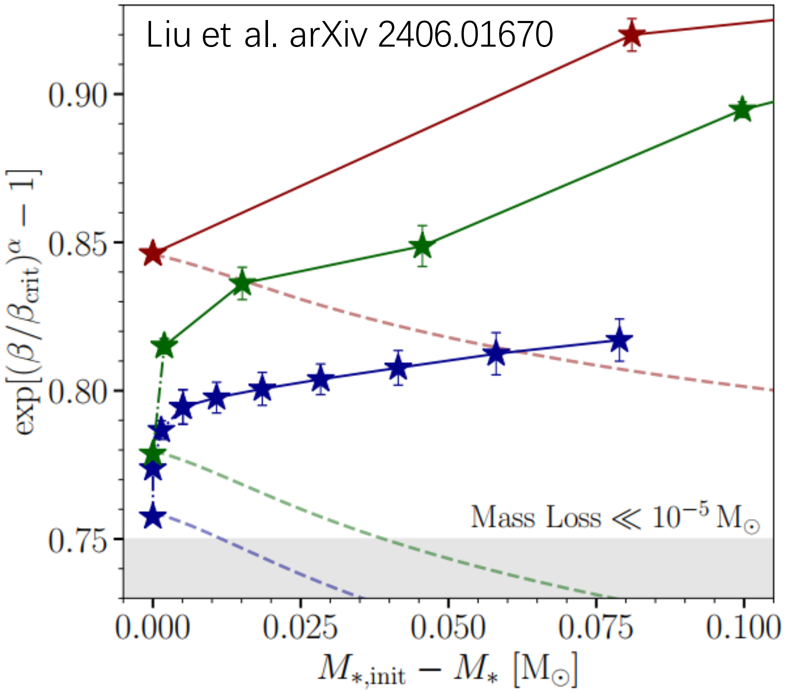
- Variation in r_t after PTDE :
  - shrinks (Hjellming & Webbink 1987; Dai+2013)
  - expands (Ryu+2020; Liu+2024)



Solid line: hydrodynamic simulation
Dashed line: adiabatic mass stripping

This work: methodology

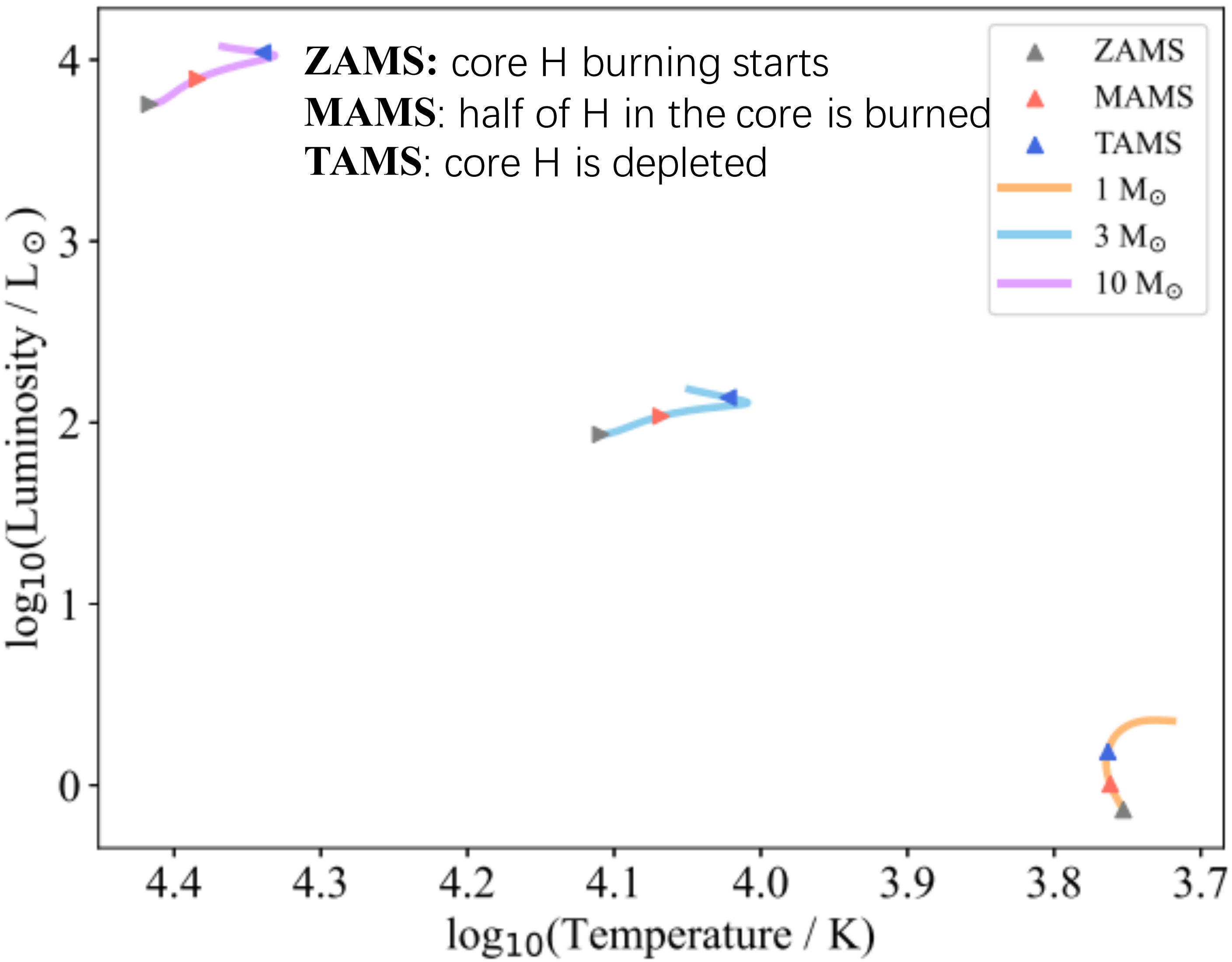
Using KEPLER (Weaver et al. 1978) to generate 1D stellar model

↓

Map the 1D stellar model to 3D: model star made up of 10^6 SPH particles

↓

Simulate the PTDE process with PHANTOM (Price et al. 2018)



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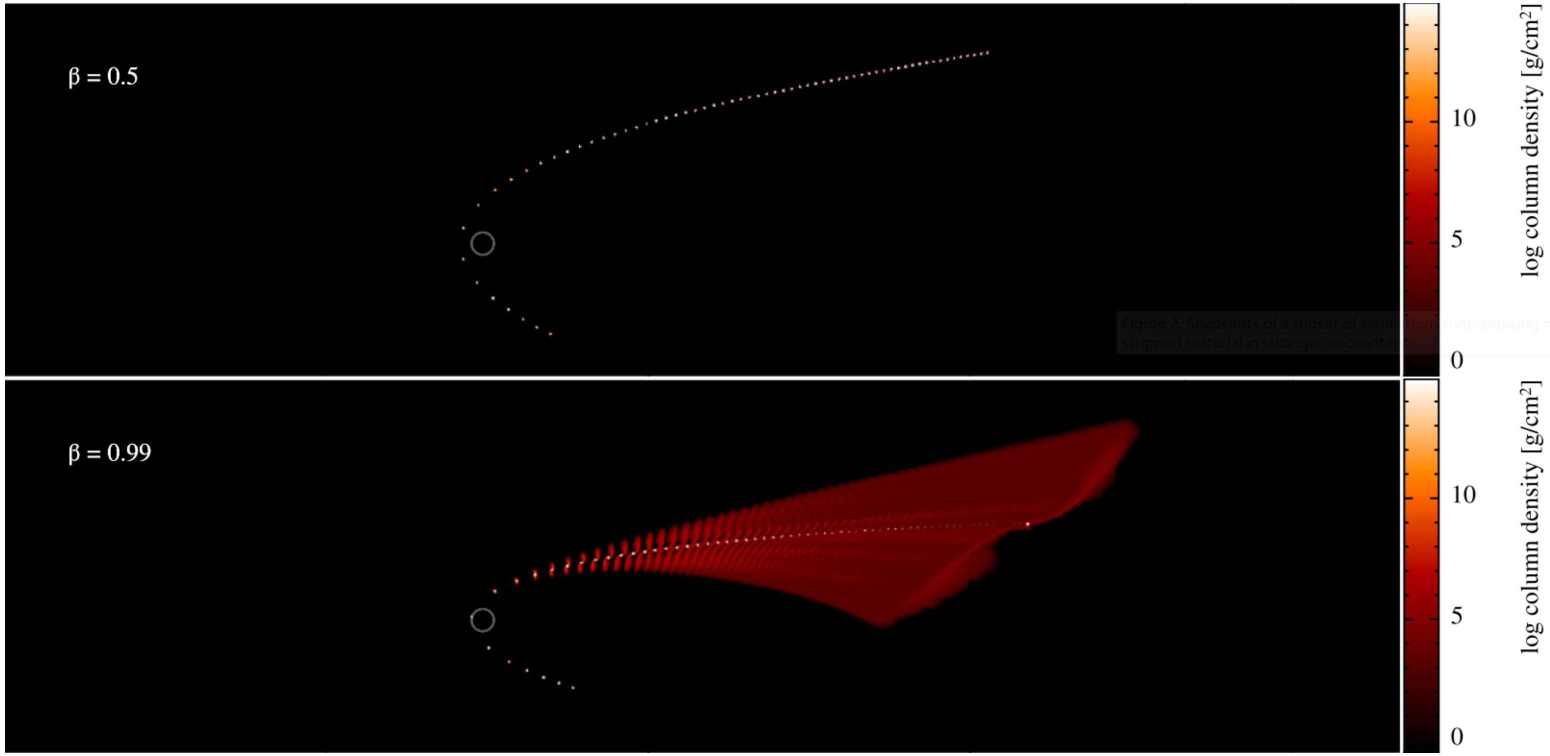


The above procedures have been adopted by other studies (with different codes):
Goicovic+2019, Ryu+2020, Law-Smith+2020, Liu+2024

This work: methodology, one step further

Using KEPLER (Weaver et al. 1978) to generate 1D stellar model

⇩

Map the 1D stellar model to 3D: model star made up of 10^6 SPH particles

⇩

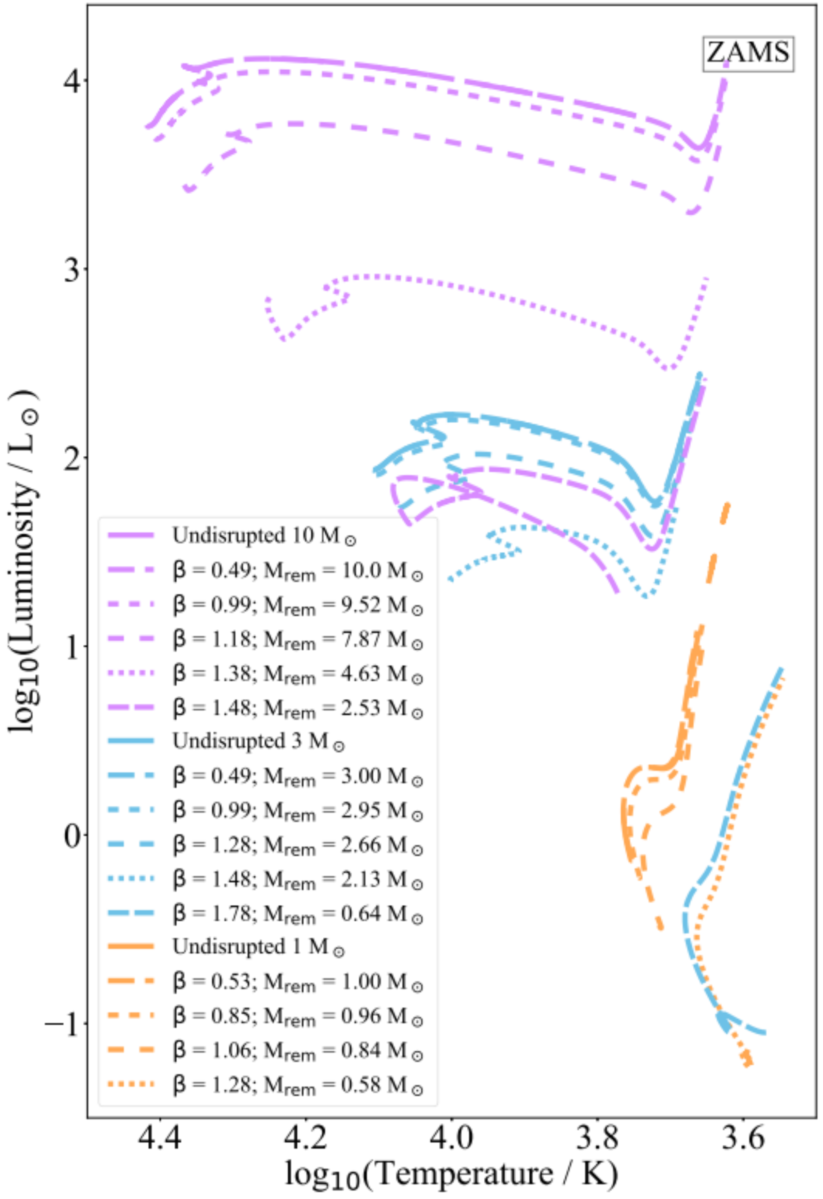
Simulate the PTDE process with PHANTOM (Price et al. 2018)

⇩

Re-map the remnant star (3D) back into 1D stellar model

⇩

Evolving the remnant star with KEPLER



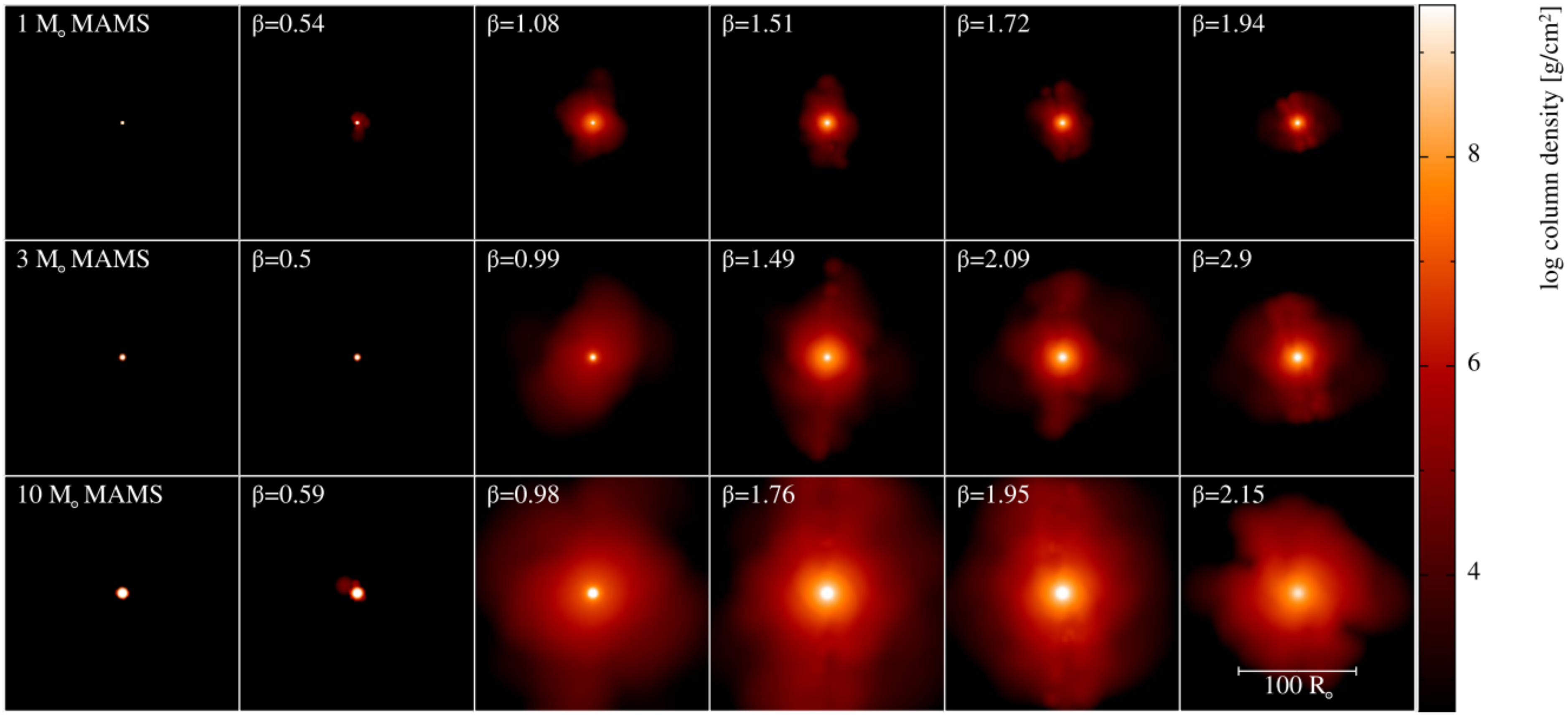
This work: the properties of the remnant star

Radial expansion

4.7 days post-pericenter

7.3 days post-pericenter

8.9 days post-pericenter



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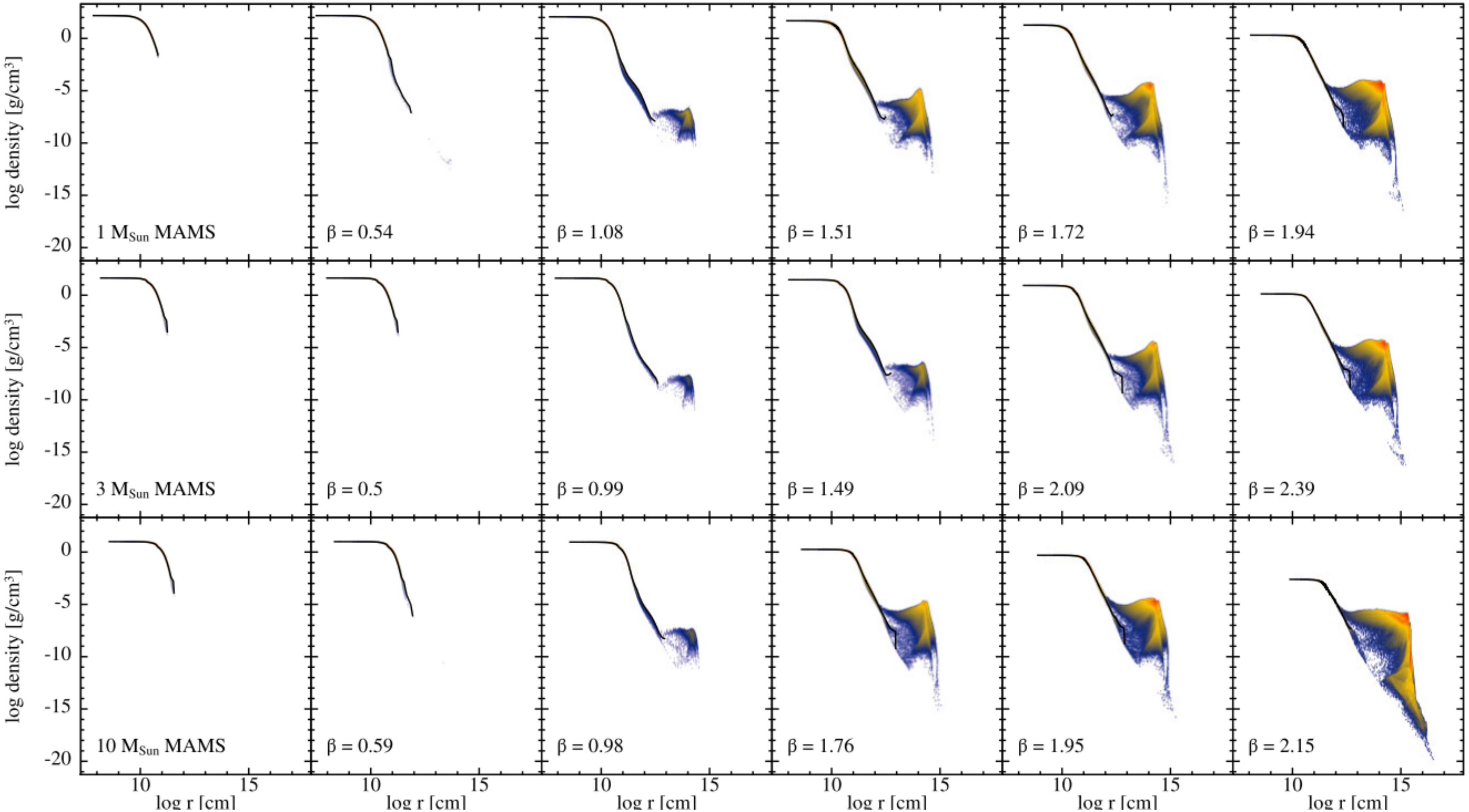


This work: the properties of the remnant star

Rotation

Rigid rotating core + differential rotating envelope

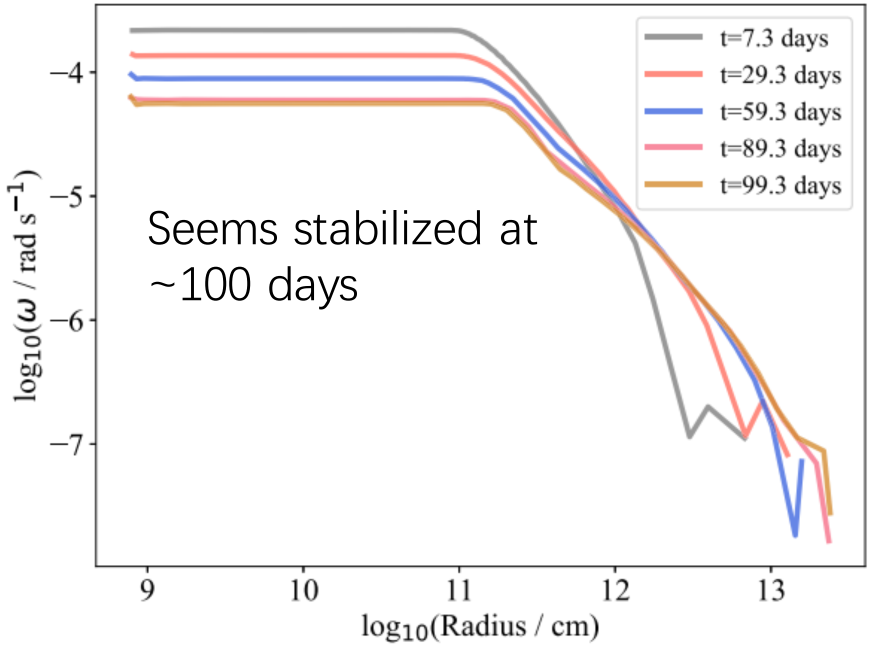
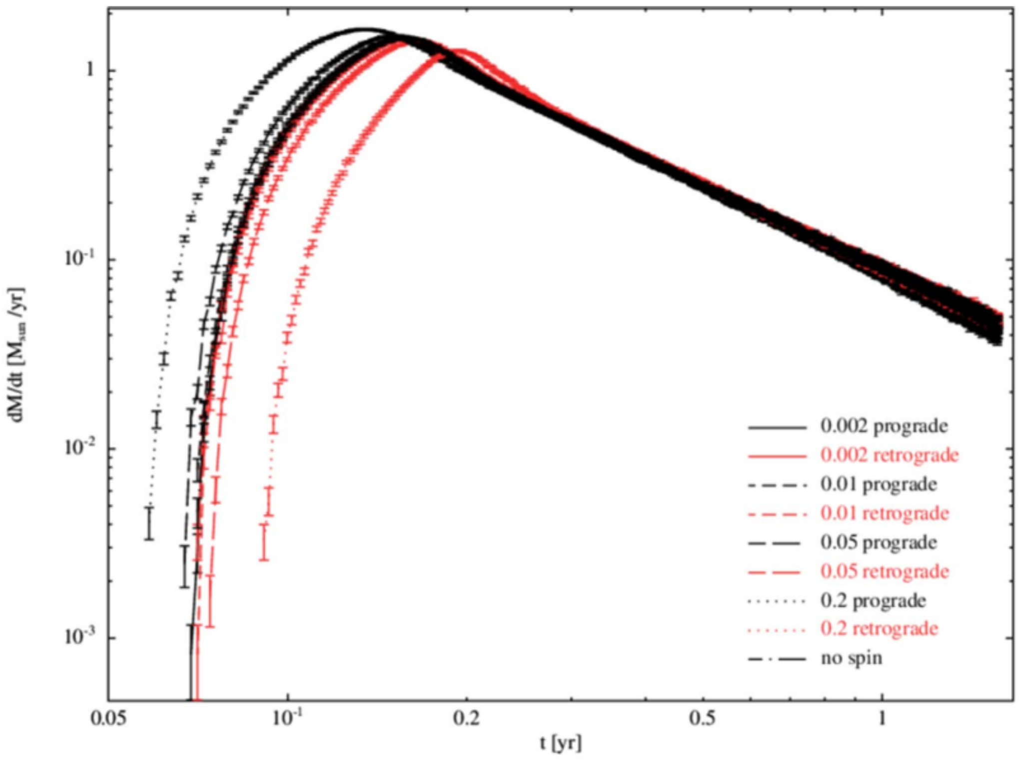


Figure 13. Binned angular velocity of remnant of 3 $M_\odot$, $\beta = 1.79$ at different times since pericentre passage. As time increases, the rigid rotating layers rotate slower, while the differentially rotating region rotates faster. This could be the result of angular momentum redistribution in the star.

THE ASTROPHYSICAL JOURNAL, 872:163 (11pp), 2019 February 20 https://doi.org/10.3847/1538-4357/aafd2f

Tidal Disruption Events: The Role of Stellar Spin

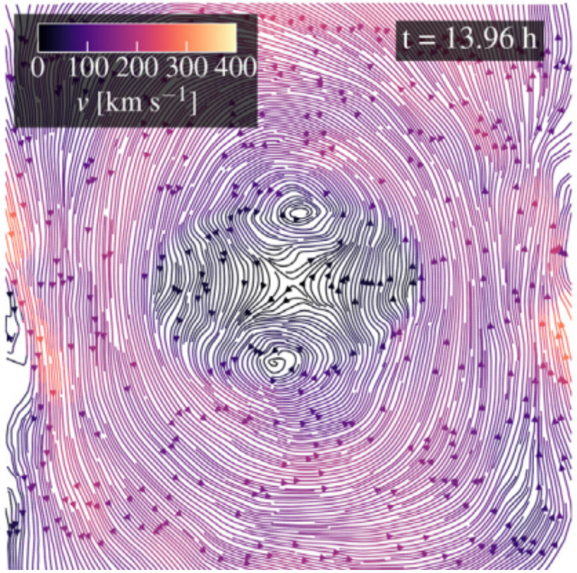
Elen C. A. Golightly[1], Eric R. Coughlin[2,3], and C. J. Nixon[1]



This work: the properties of the remnant star

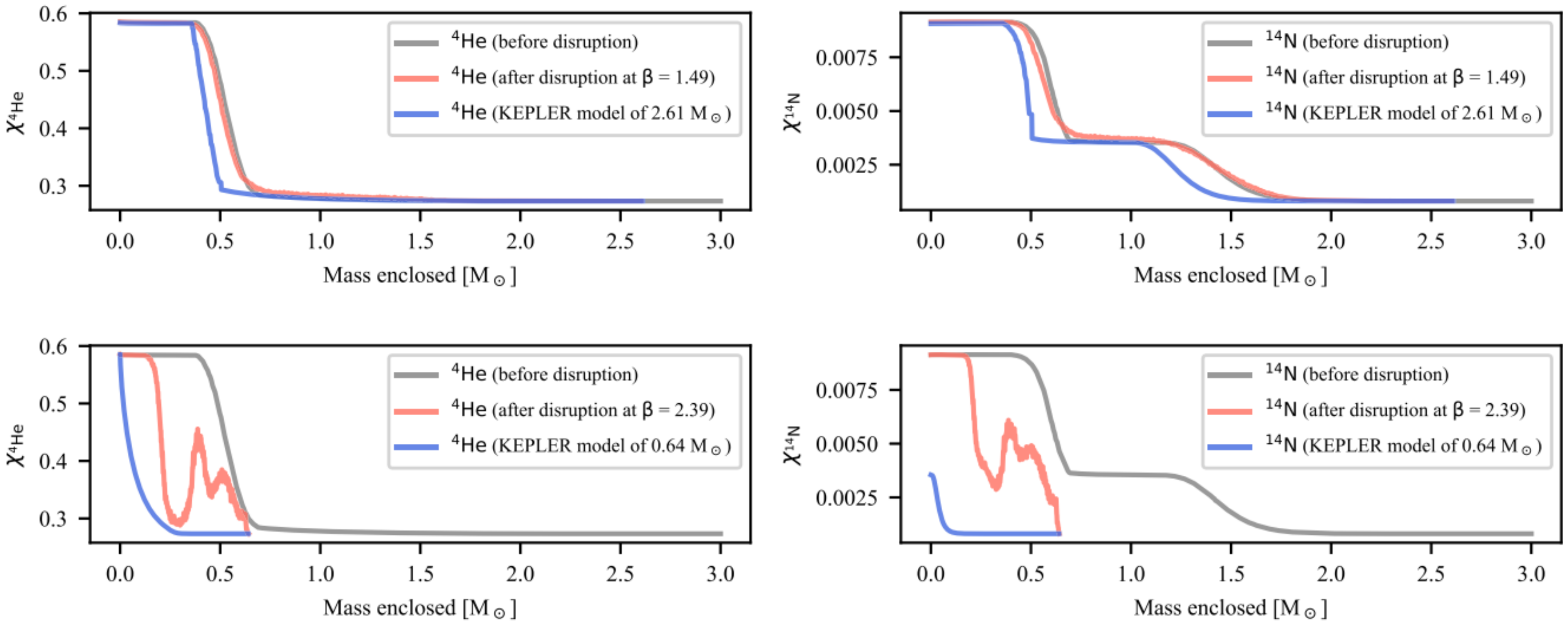
Chemical composition mixing inside the remnant star emerged from disruption of **MAMS, TAMS** star

In the case of ZAMS disruption, the composition is unchanged.



Goicovic et al. (2019)

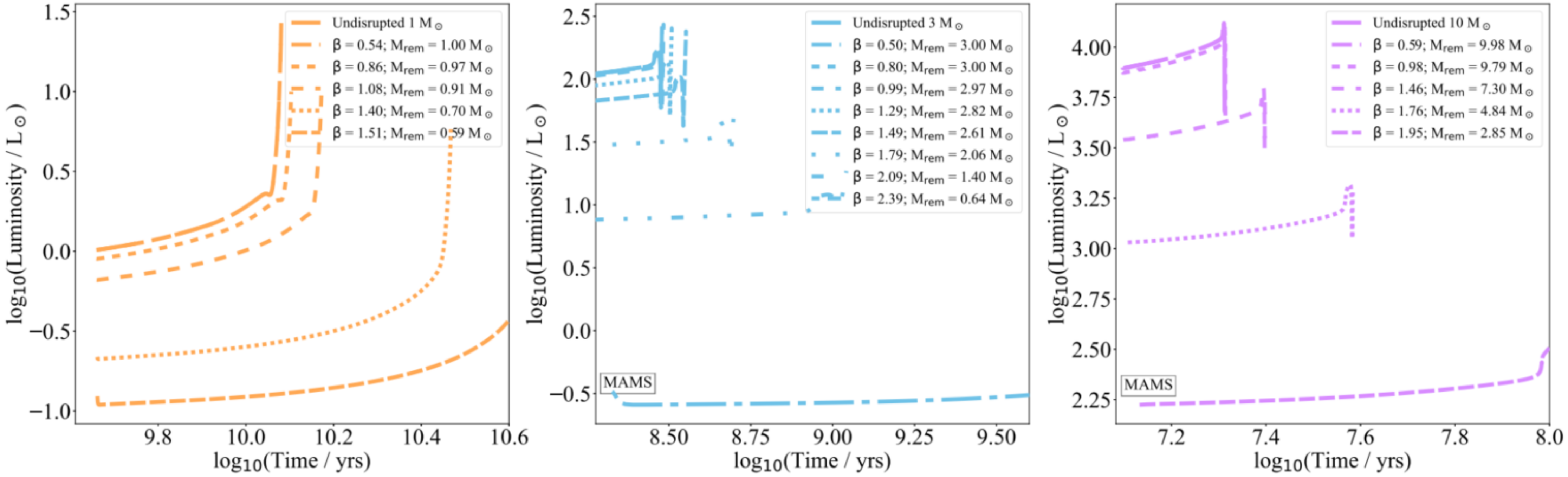
He and N enriched in the outer layer of remnant star (initially 3 Msun MAMS), compared to normal star with the same mass



This work: the properties of the remnant star

For partial disruption of MAMS, TAMS star: remnant star can live longer on main-sequence, as the mass of remnant decreases.

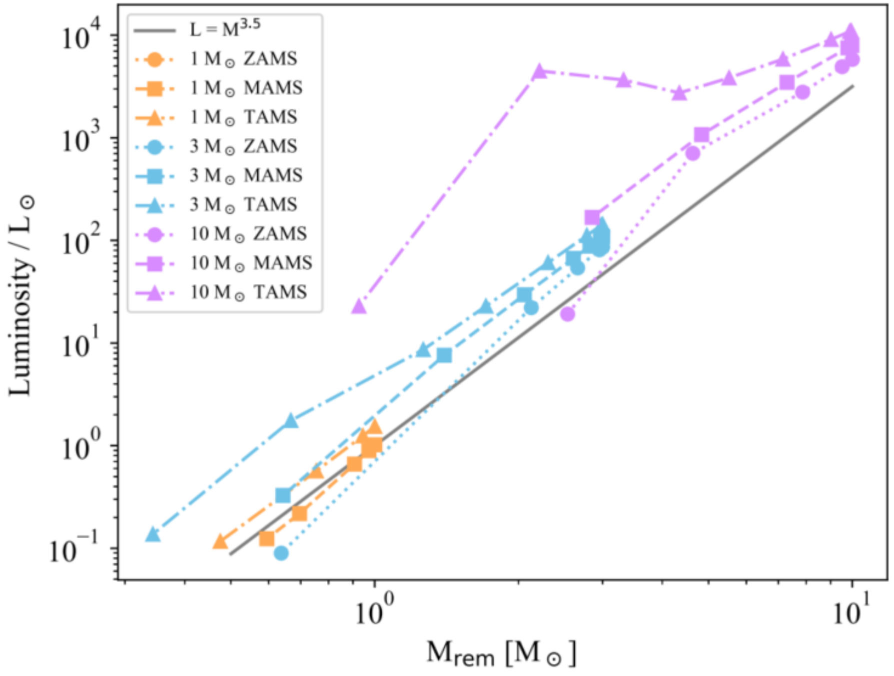
For ZAMS star, the evolution track is not affected.



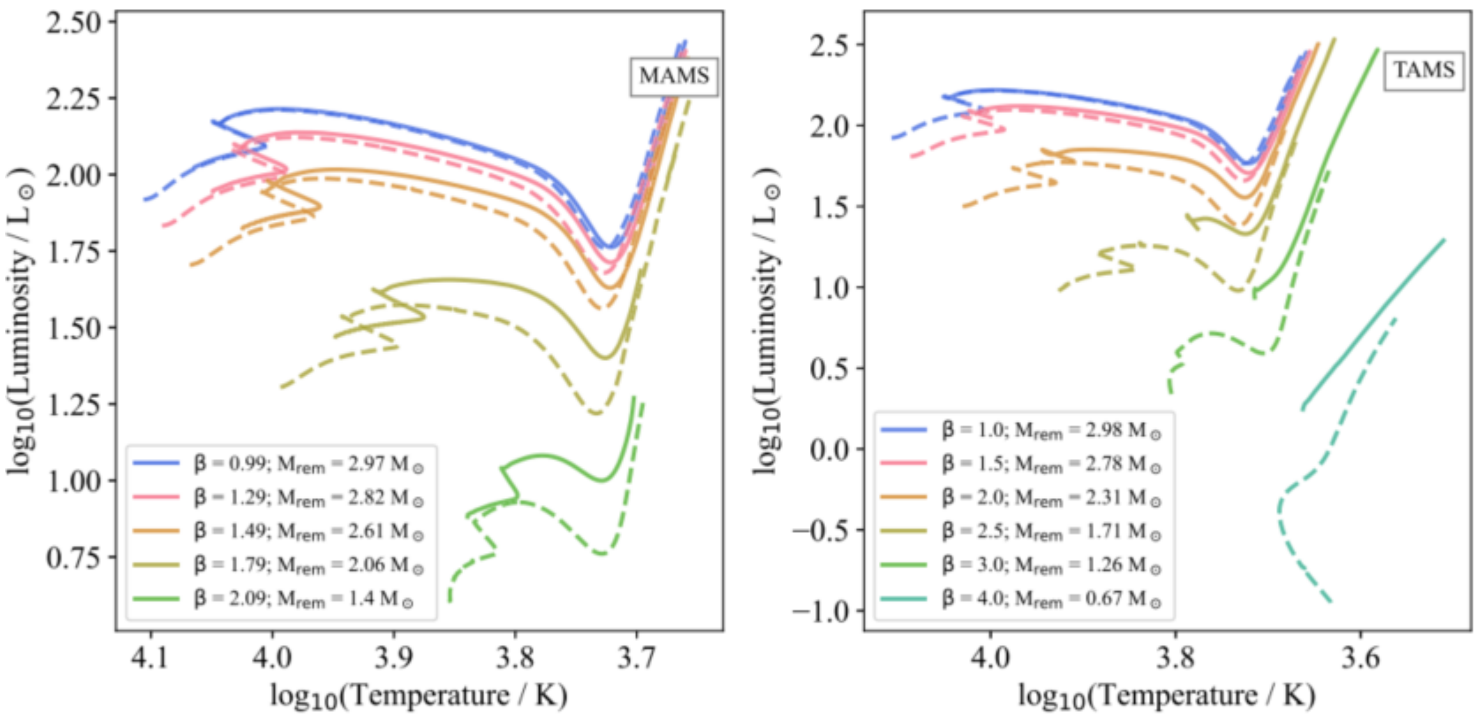
These curves stop at the time when core Helium burning starts.

This work: the properties of the remnant star

For partial disruption of MAMS, TAMS star: remnant has larger luminosity and effective temperature than the star with the same mass but has not experienced PTDE.



The grey straight line: luminosity-mass relation for main-sequence stars at the Kelvin-Helmholtz time.



Dashed line: post-hydrogen-ignition evolution of stars having the same mass as the remnant

Final thought: future prospect on modeling the repeating PTDEs

- This paper alone is not enough to address the diverse features in repeating PTDE flares.
- The method used in this paper can help us to achieve the goal.