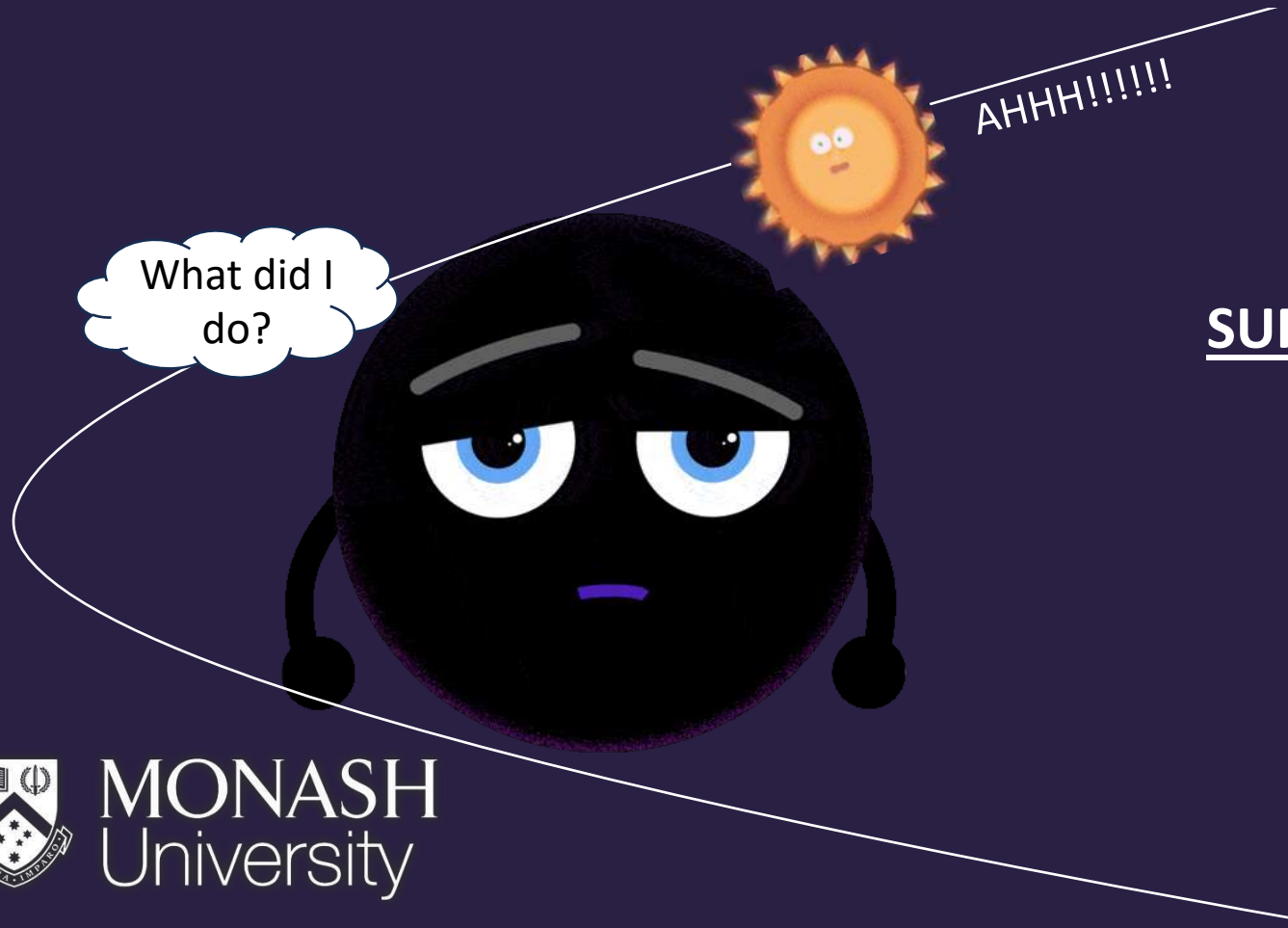
Timmy drinks the Holy Grail!
PARTIAL TIDAL DISRUPTION EVENTS as the ELIXIR OF LIFE



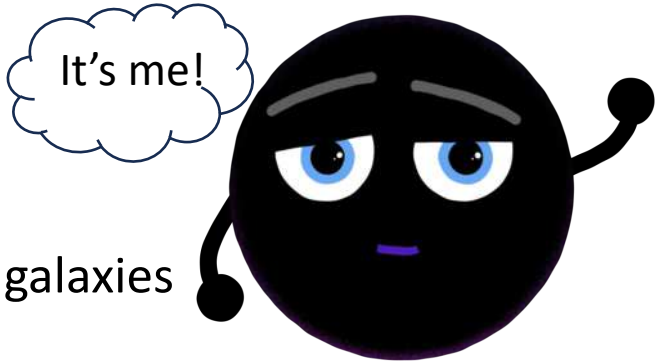
MEGHA SHARMA

SUPERVISORS -> Prof. Alexander Heger
Prof. Daniel Price

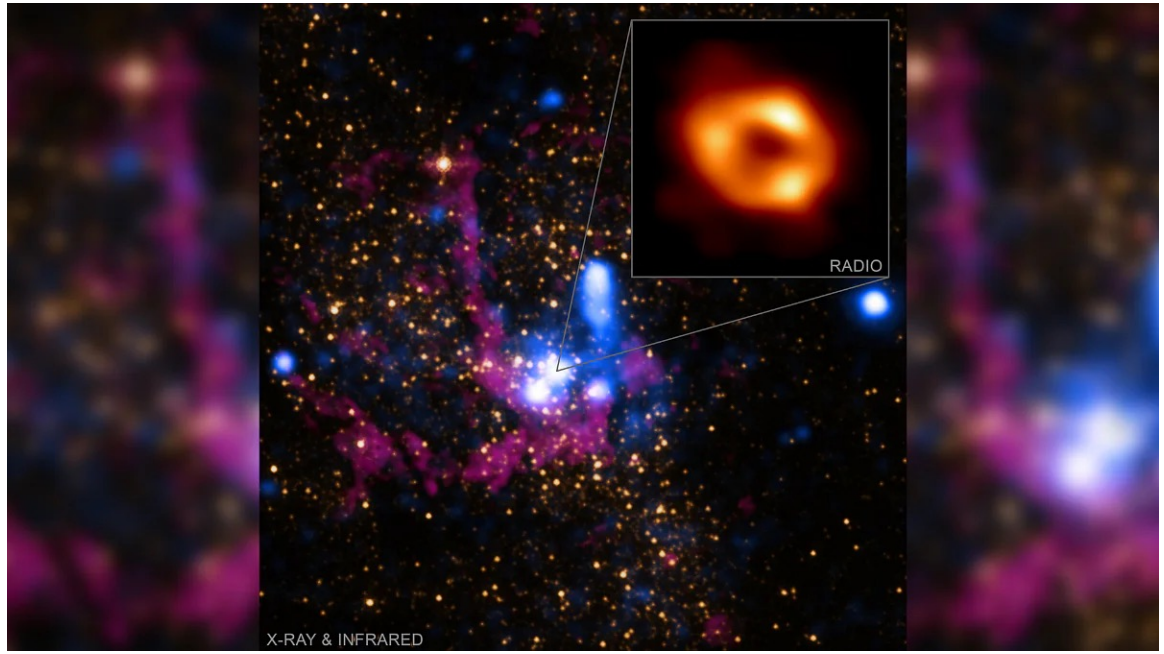
MONASH University

Credit: NASA's Goddard Space Flight Center (https://svs.gsfc.nasa.gov/14099)

Supermassive black holes (SMBH) and Timmy

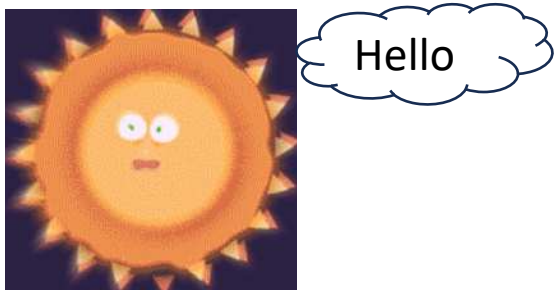


- Mass >= million solar masses
- present in the center of most galaxies
- Nuclear Star Clusters (NSC)



Credit: NASA

Meet Timmy!



Credit: NASA's Goddard Space Flight Center

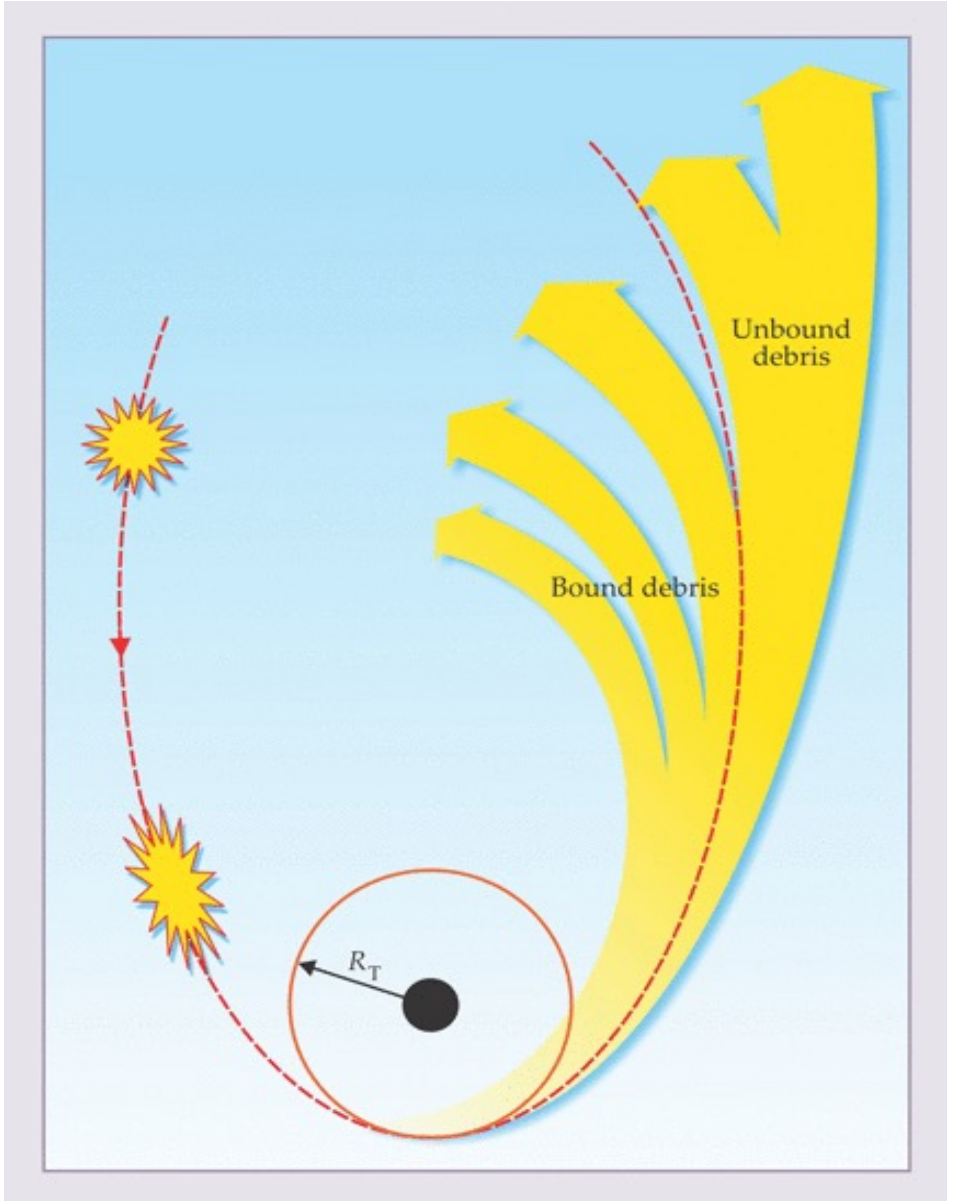
Fate of Timmy -> Tidal Disruption events (TDE)?

- $r_t = R_* \left(\frac{M_*}{M_{BH}}\right)^{1/3}$

where r_t is tidal radius, R_* is radius of star,
M_* is mass of star
and M_{BH} is mass of black hole

- Outcomes -> Partial or full TDE
- First detected by ROSAT all sky survey
- $\beta = \frac{r_t}{r_p}$ -> Penetration factor or strength of encounter

Where r_p is the pericentre distance.



Credit: S. Gazari, Physics Today

Our project

- $10^4 - 10^5$ stars in the Galactic Centre (Alexander and Livio 2001; Manukian 2013)
- Understand Timmy's properties post-disruption (Sharma et al; in prep)

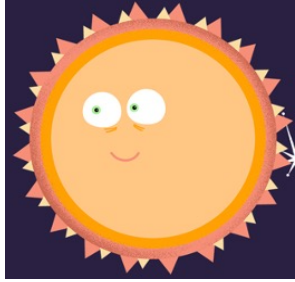
Models from stellar evolution code → Disrupt in 3-D Smoothed Particle Hydrodynamics code → Map back into stellar evolution code

KEPLER

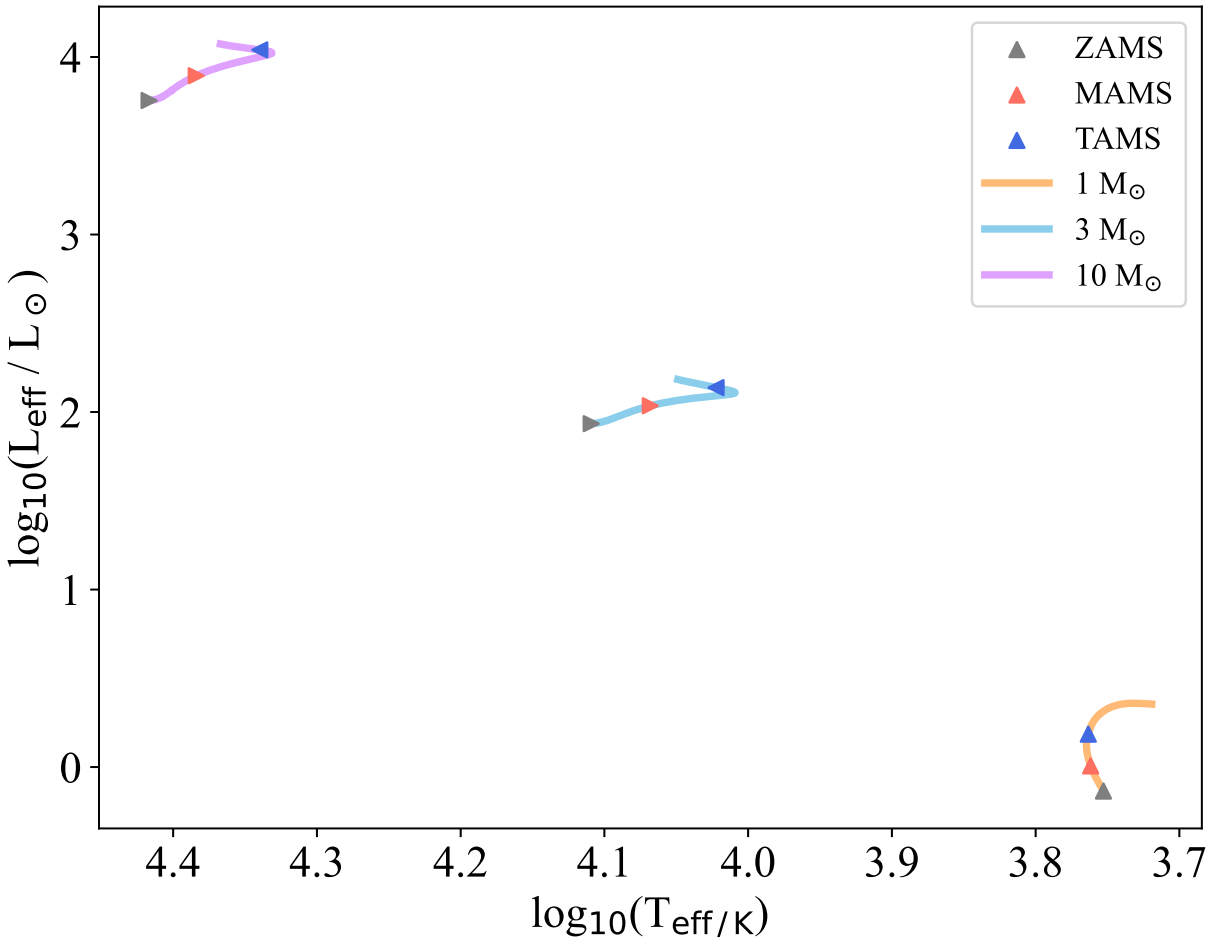
PHANTOM

KEPLER

What kind of star is Timmy in our simulations?



KEPLER models



Hydrogen ignition: Zero-age main sequence (ZAMS)

Hydrogen mid: Middle-age main sequence (MAMS)

Hydrogen depletion: Terminal-age main sequence (TAMS)

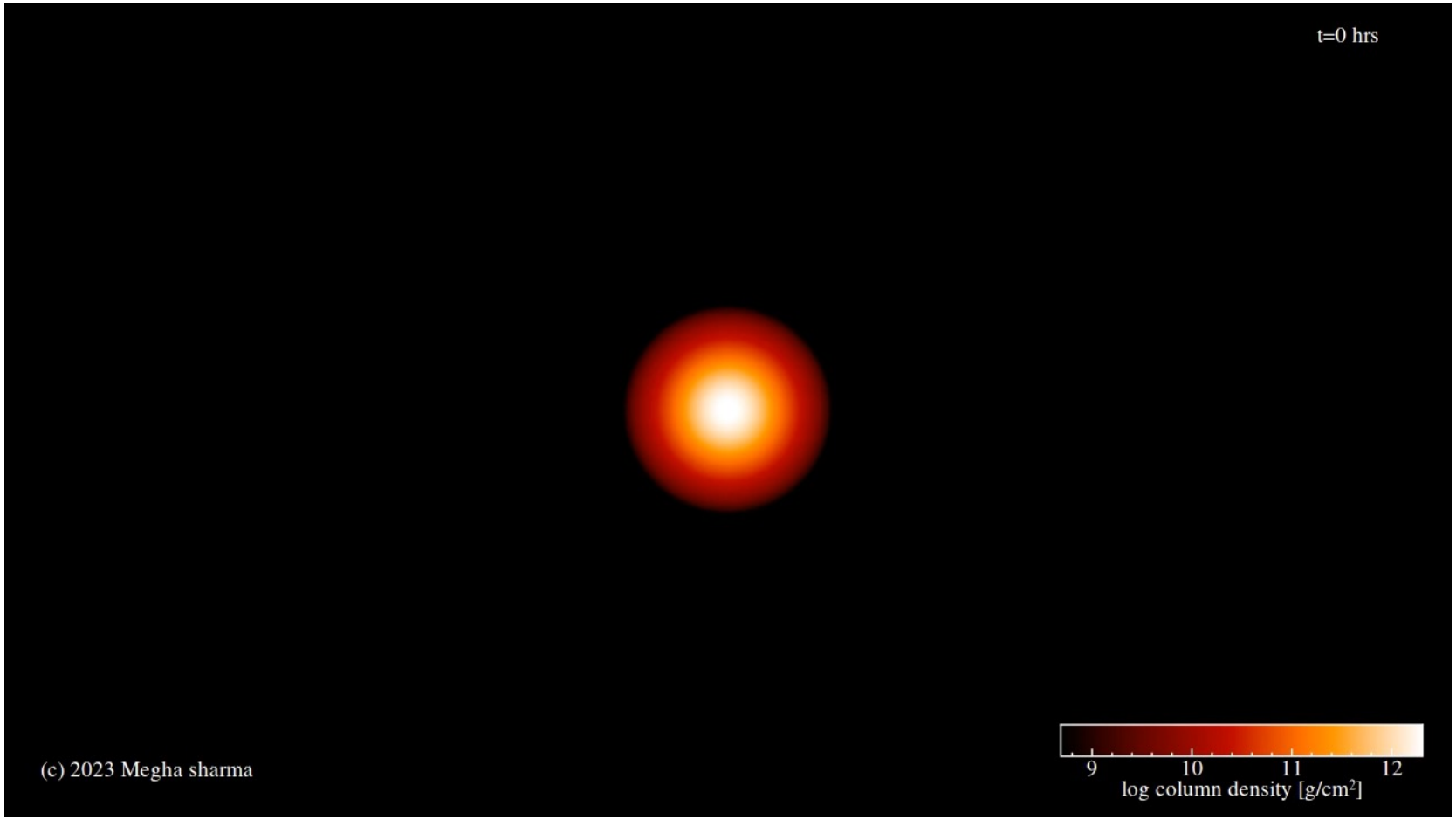
Credit: NASA's Goddard Space Flight Center

Disrupting Timmy in PHANTOM

- 1 million SPH particles
- Consider General relativistic effects
- Black hole with spin = 0
- SMBH of mass $10^6\ \mathrm{M}_\odot$

Credit: NASA's Goddard Space Flight Center

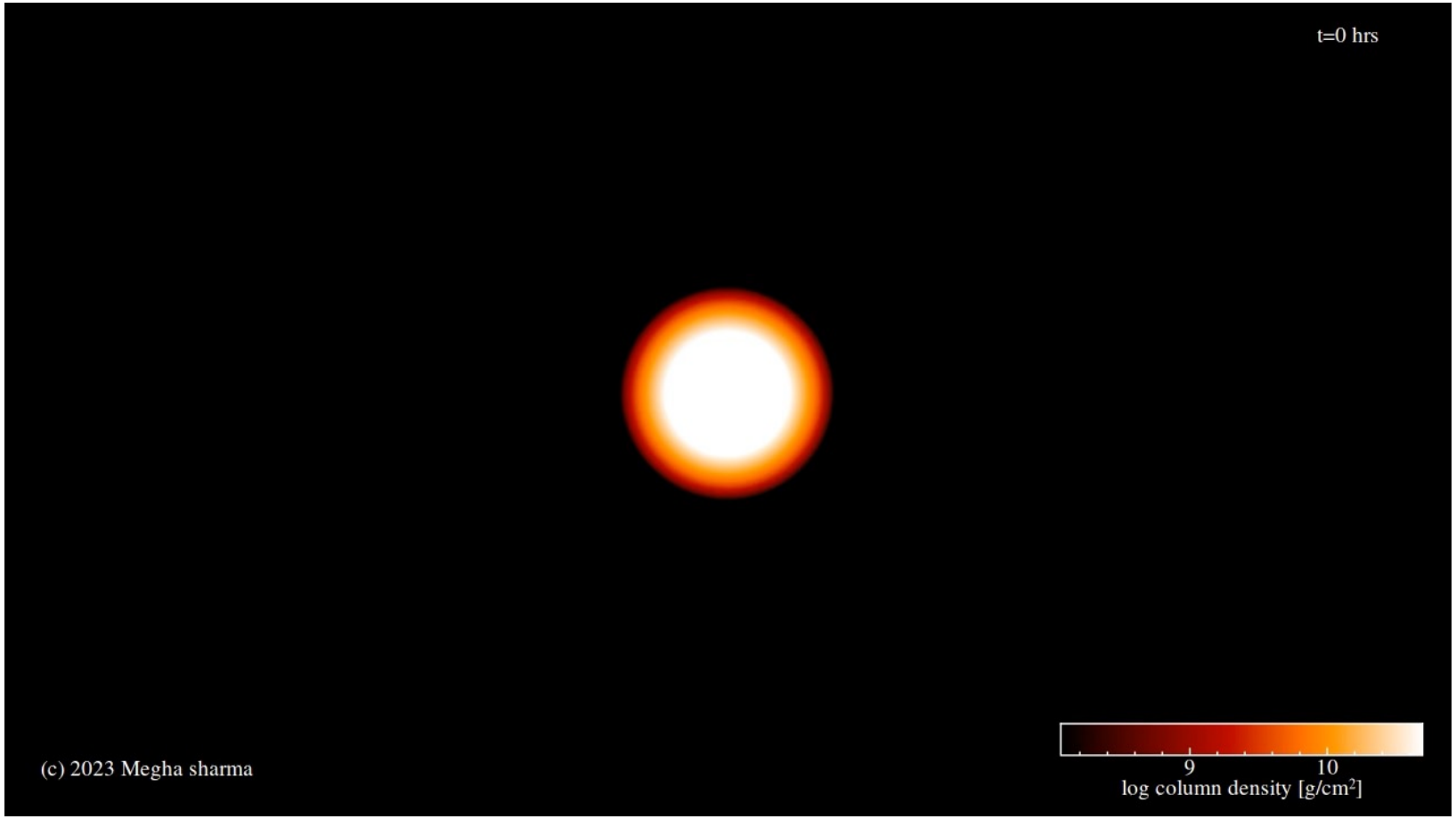
Simulations : Timmy survived!



1 $M_{\odot}$ ZAMS

β=0.85

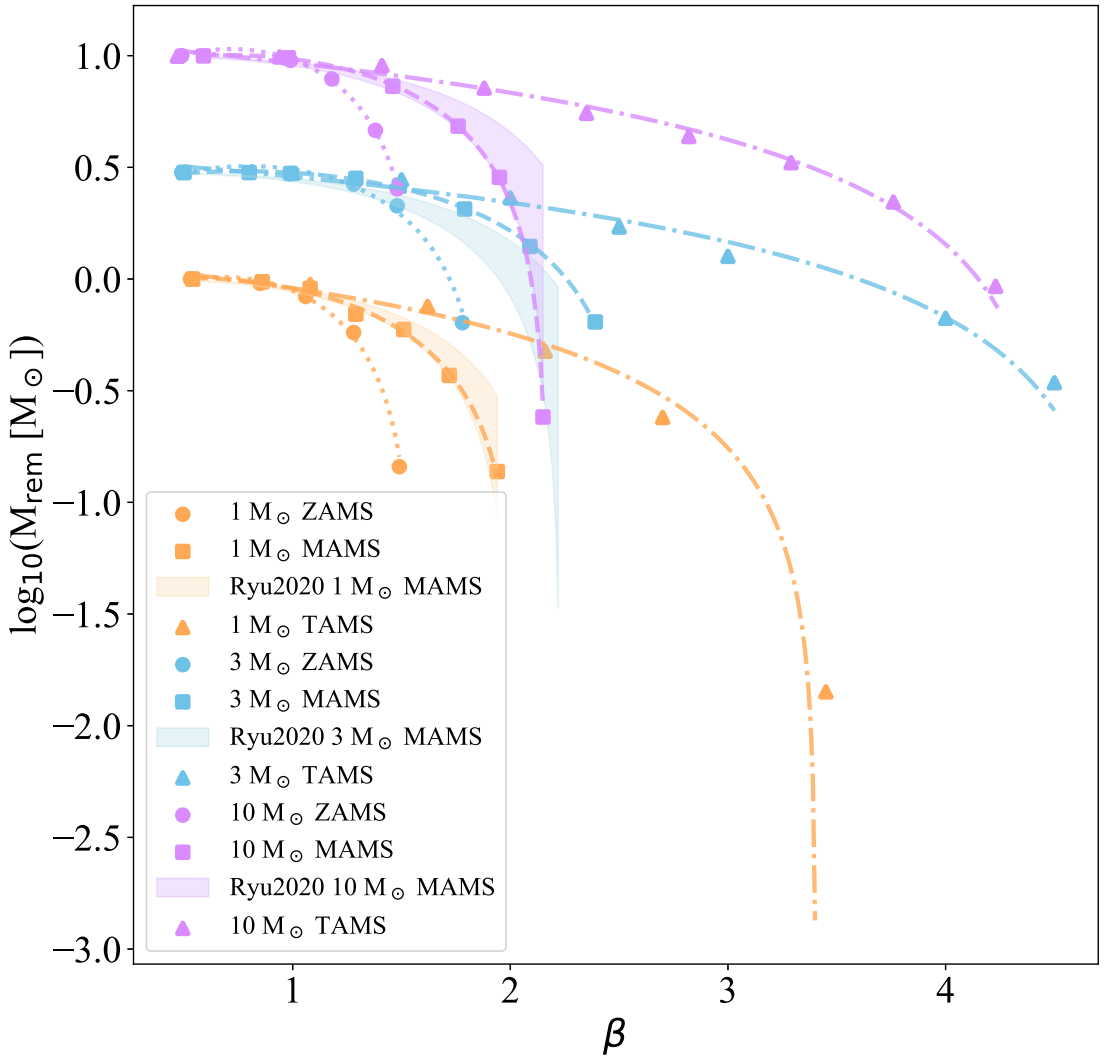
Strength of encounter



1 $M_{\odot}$ ZAMS

β=1.49

Timmy's mass as they pass closer to the SMBH



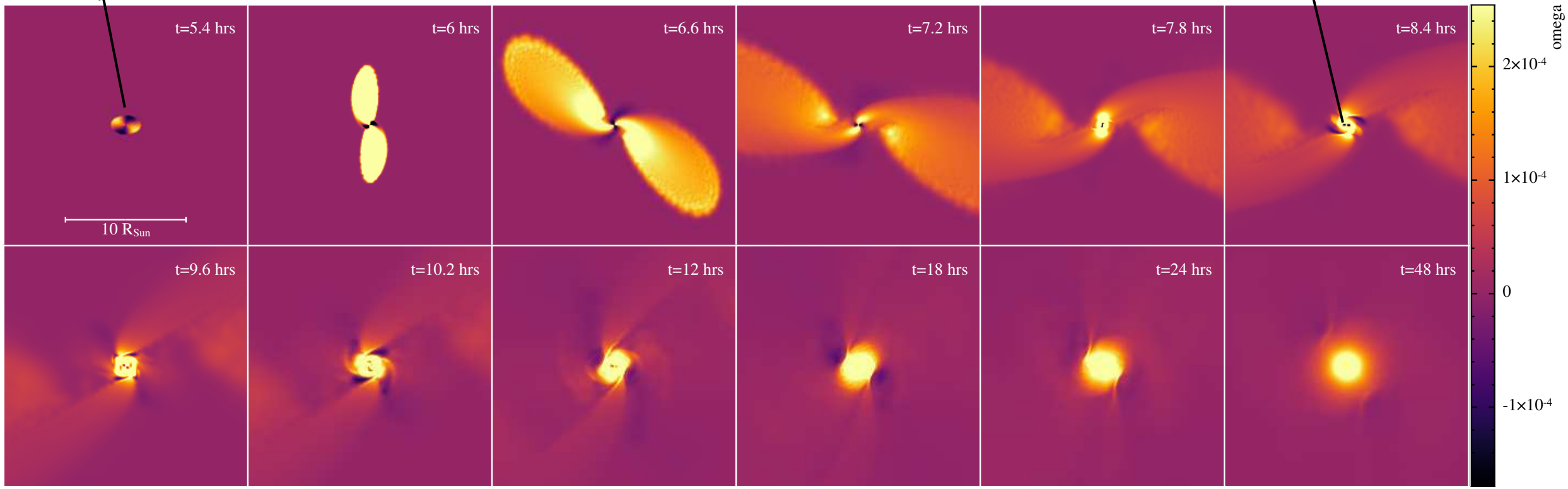
Higher β -> Closer to the SMBH/ stronger encounter

Credit: NASA's Goddard Space Flight Center

Timmy spins!

Star near Pericentre

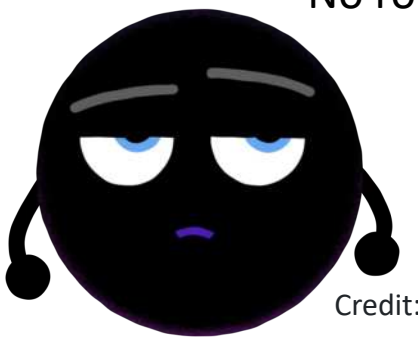
Vortices



No rotation in the initial model

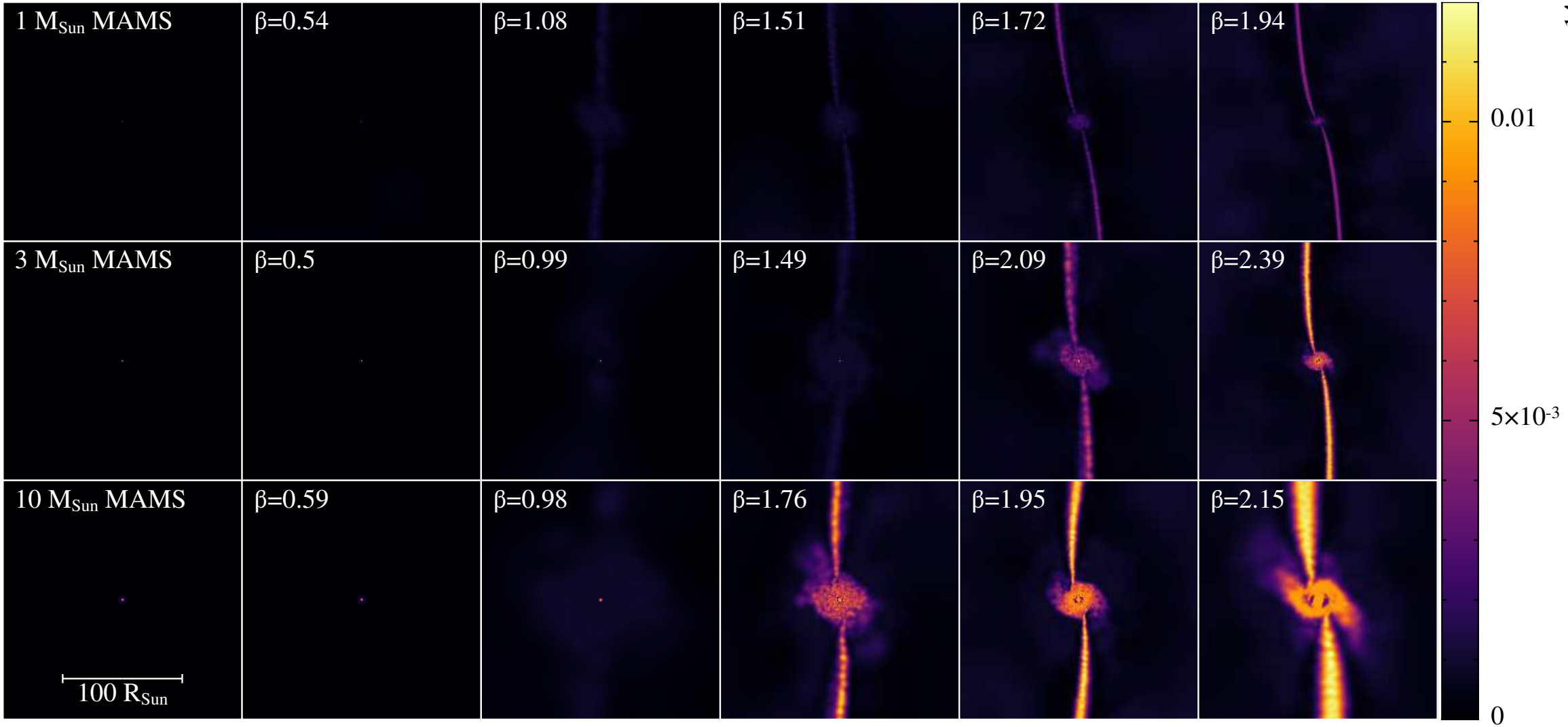
1 $M_\odot$ ZAMS, β = 1.28

Mass of remnant = 0.58 $M_\odot$



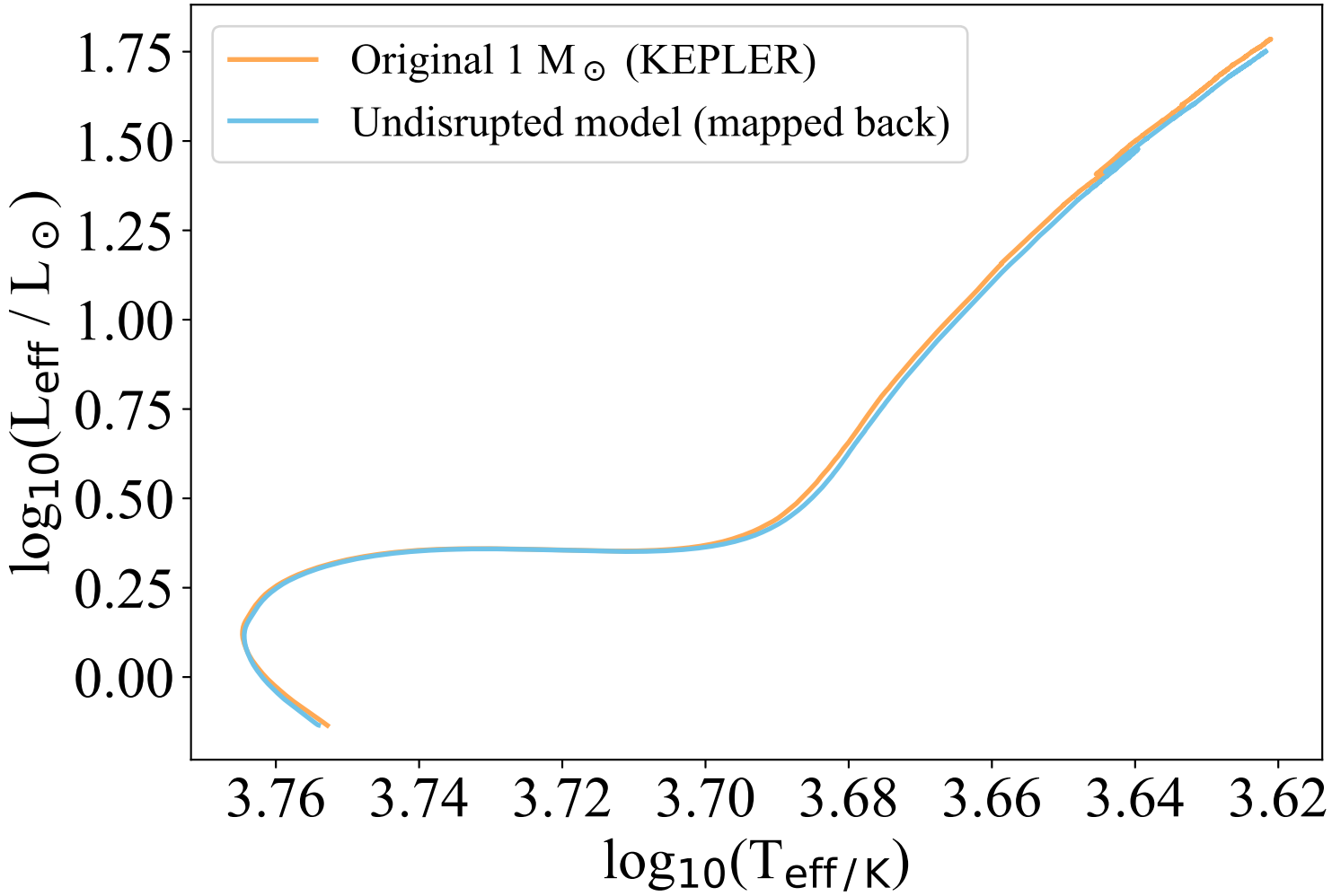
Credit: NASA's Goddard Space Flight Center

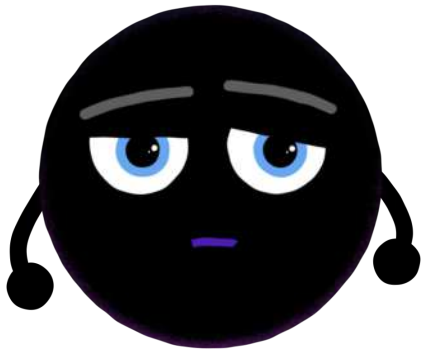
Timmy undergoes composition mixing!



Credit: NASA's Goddard Space Flight Center

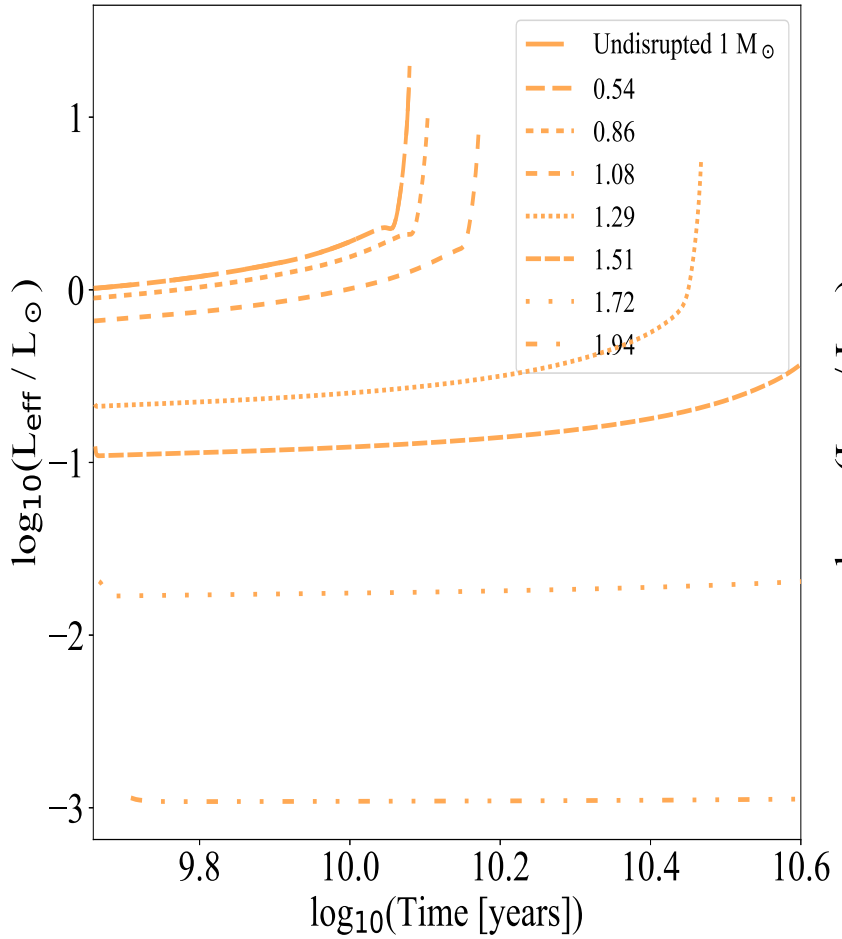
Stellar Evolution

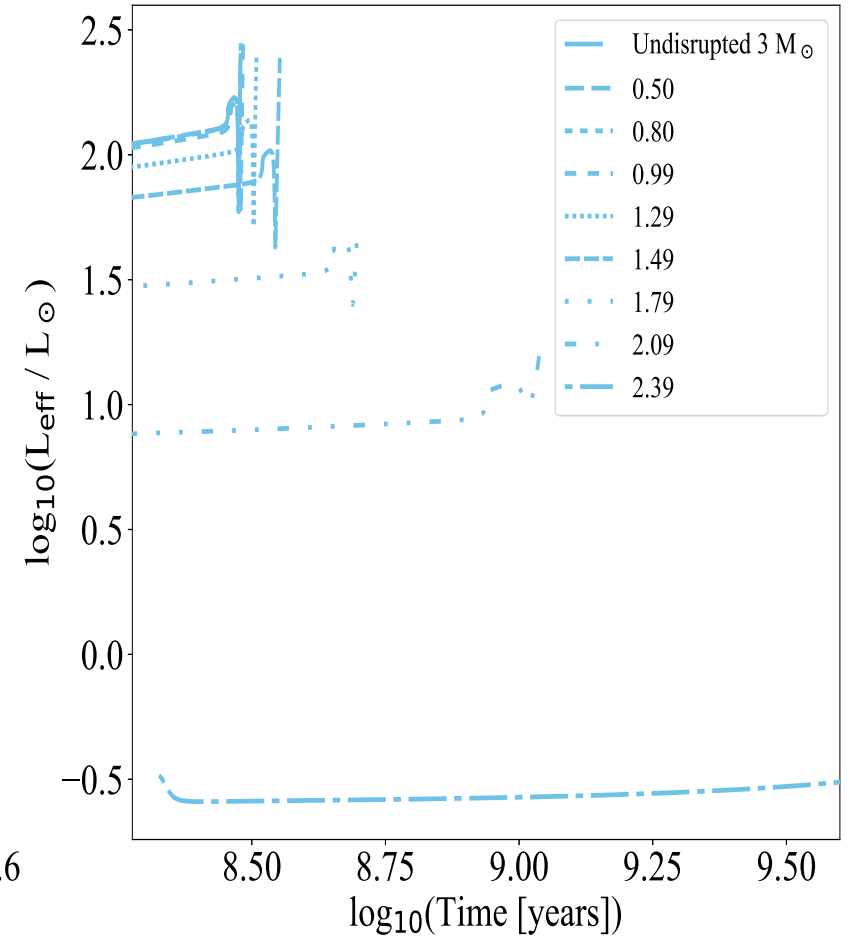


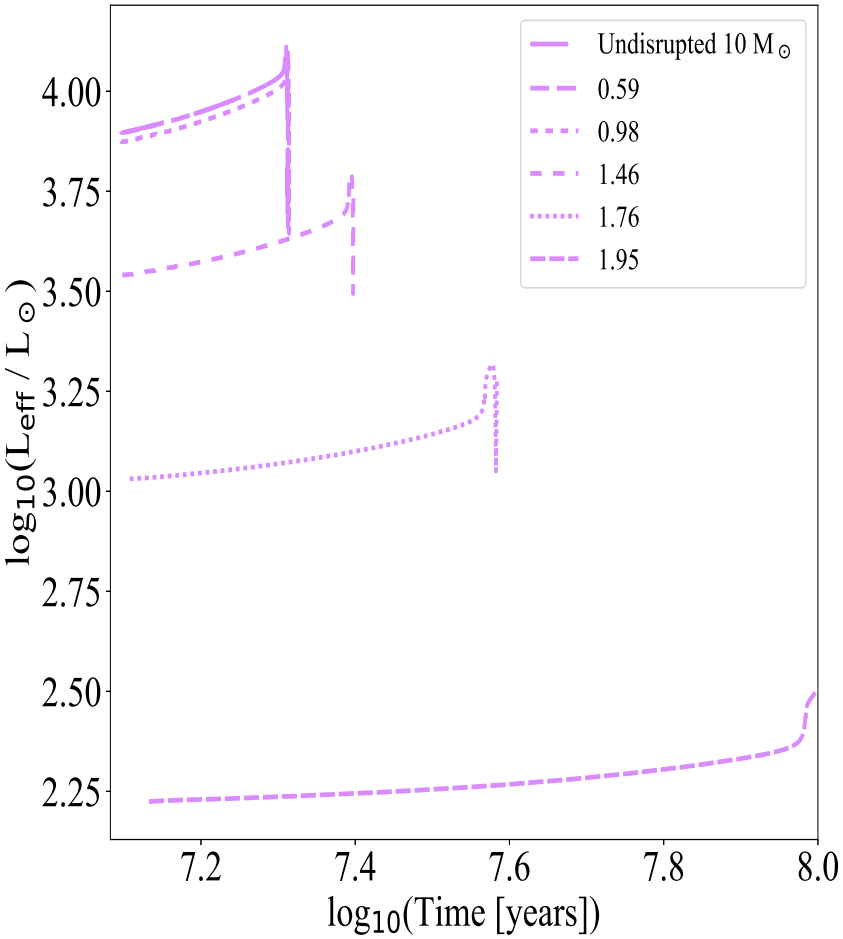


Credit: NASA's Goddard Space Flight Center

Timmy found Elixir of Life!

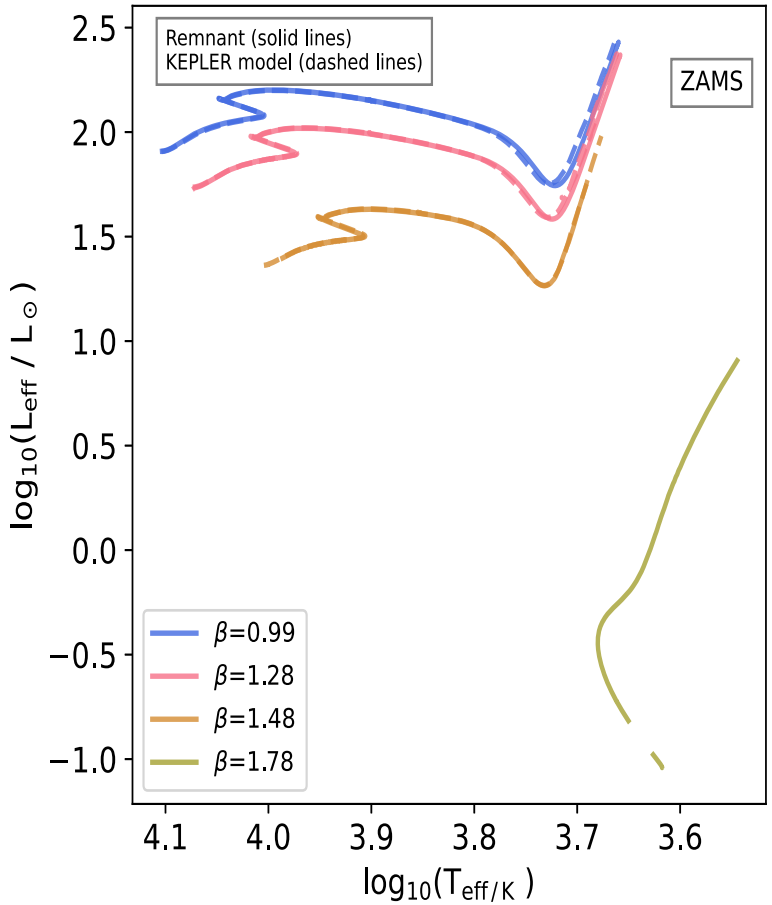


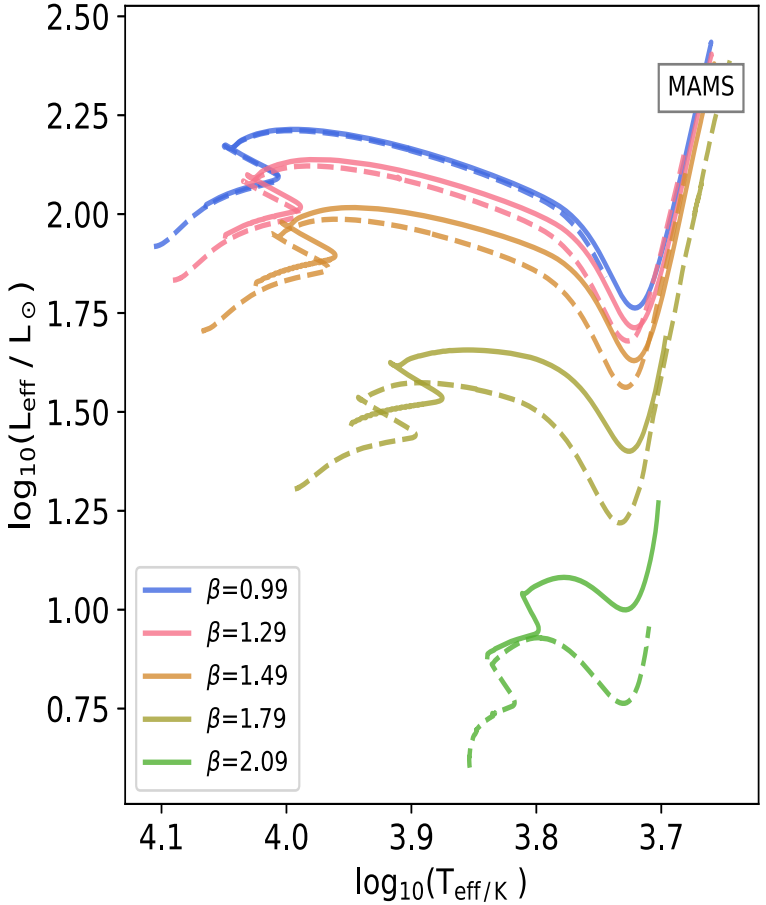


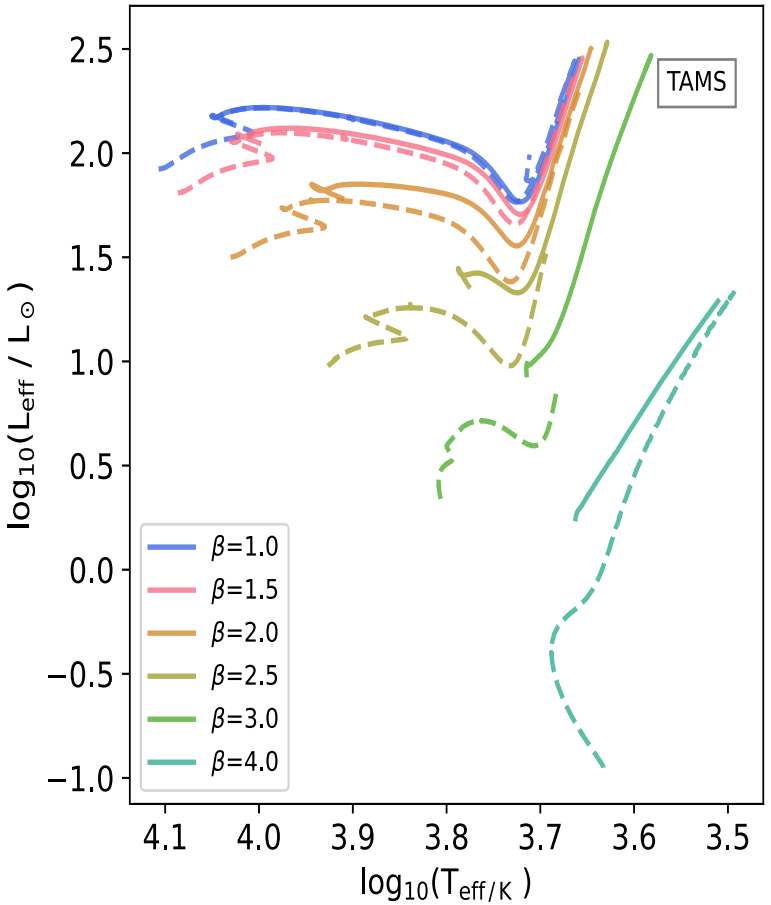


Credit: NASA's Goddard Space Flight Center

How different is Timmy after disruption?







Credit: NASA's Goddard Space Flight Center

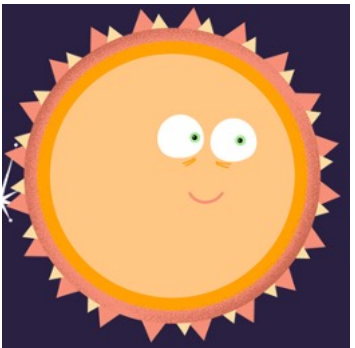
- Stars can lose a lot of mass and still survive
- The core rotates faster than the outer layers (Inversion of rotation profile due to Vortices)
- Stars encountering black holes found ‘Elixir of Life’!

Conclusions

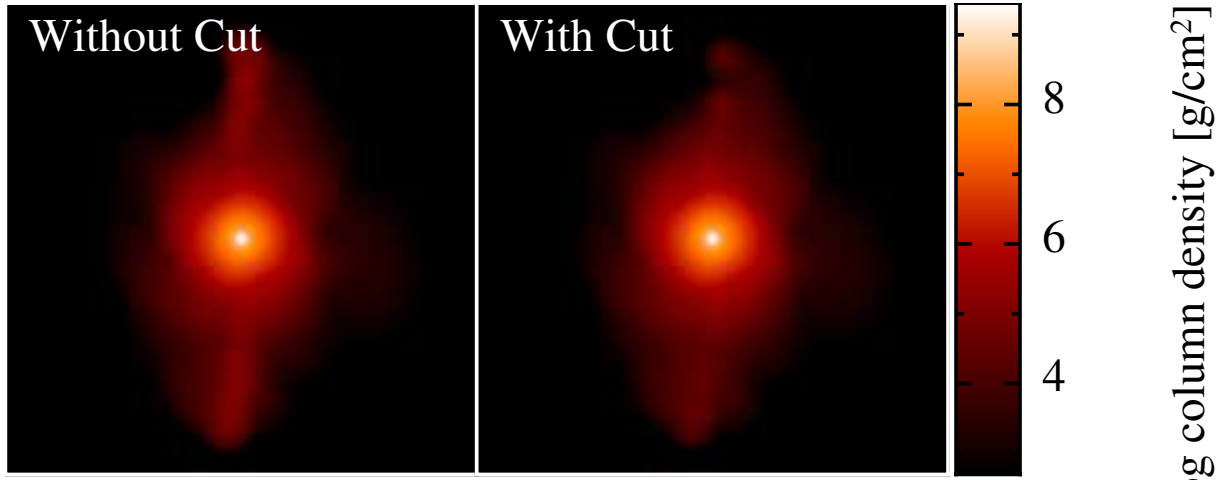
Credit: NASA's Goddard Space Flight Center

What do we consider as a remnant?

1. Maximum density particle is considered as centre of the star.
2. Potential energy + kinetic energy + internal energy < 0 and kinetic energy< 0.5*potential energy
3. Remove streams

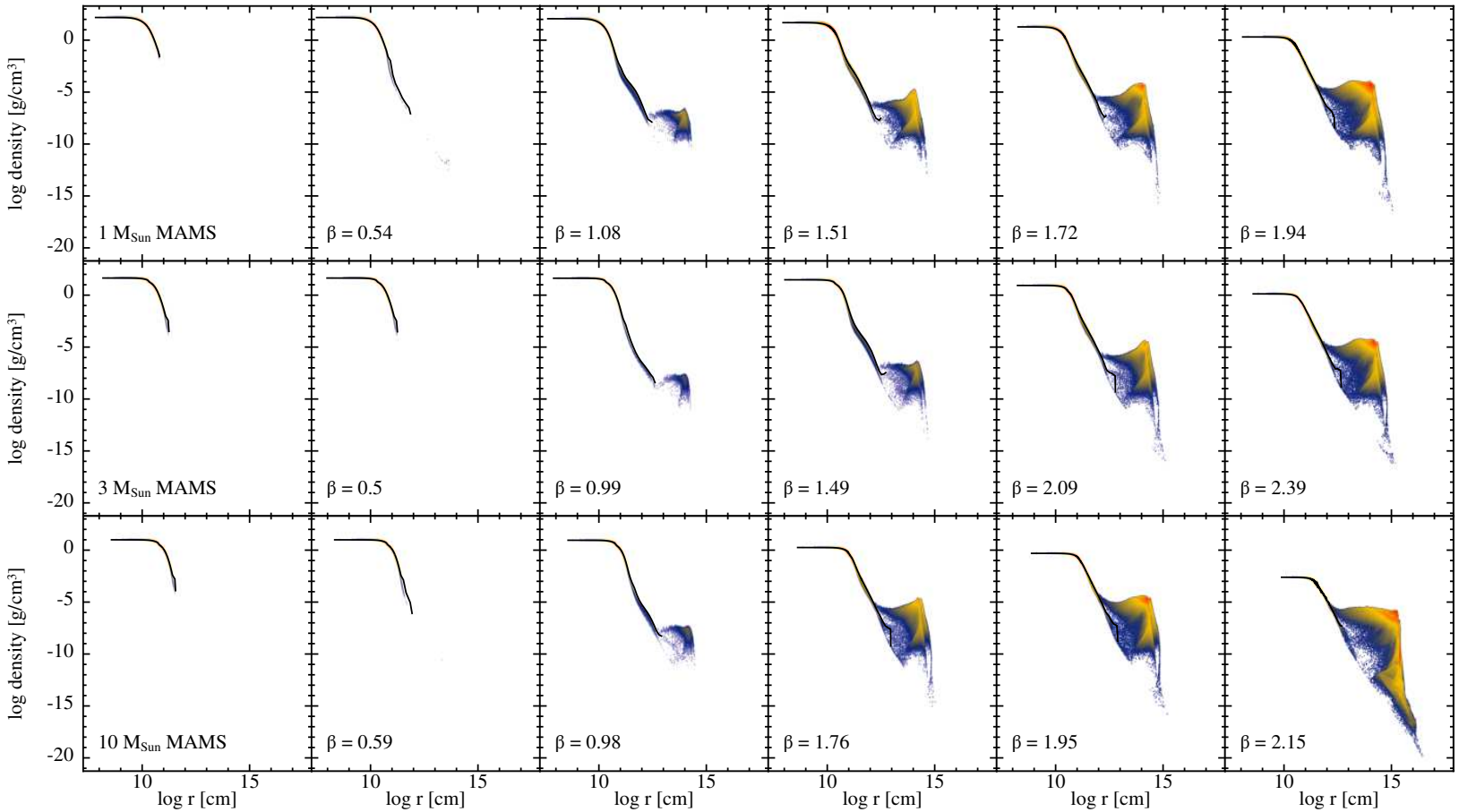


Credit: NASA's Goddard Space Flight Center



β=1.48, 3 $M_\odot$ ZAMS at 8 days
Mass of remnant = 2.13 $M_\odot$

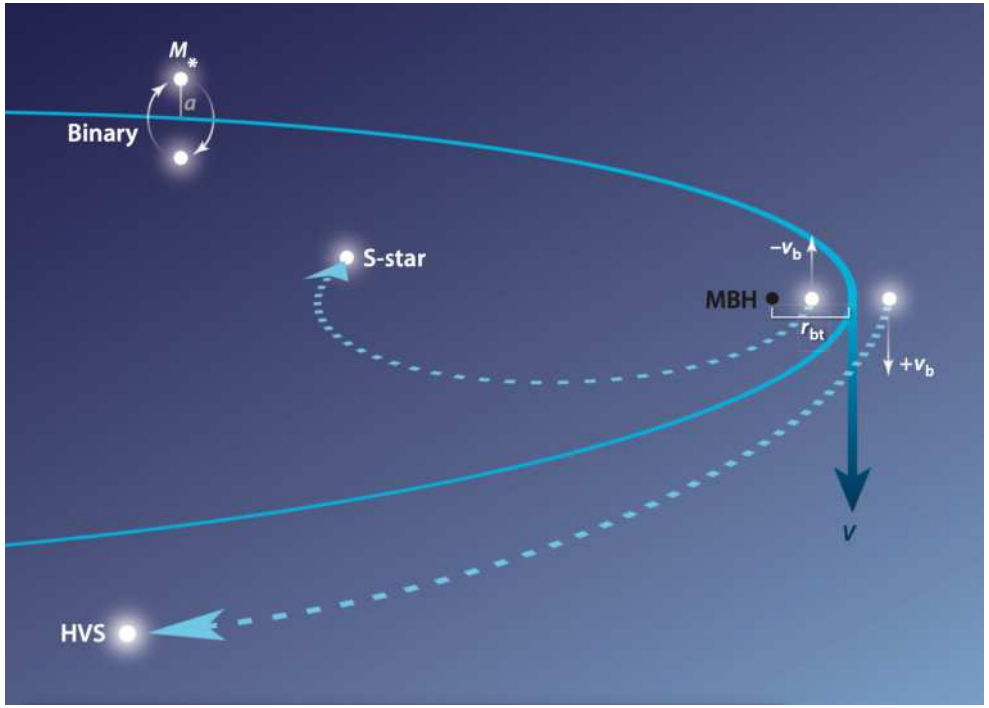
Density of remnants



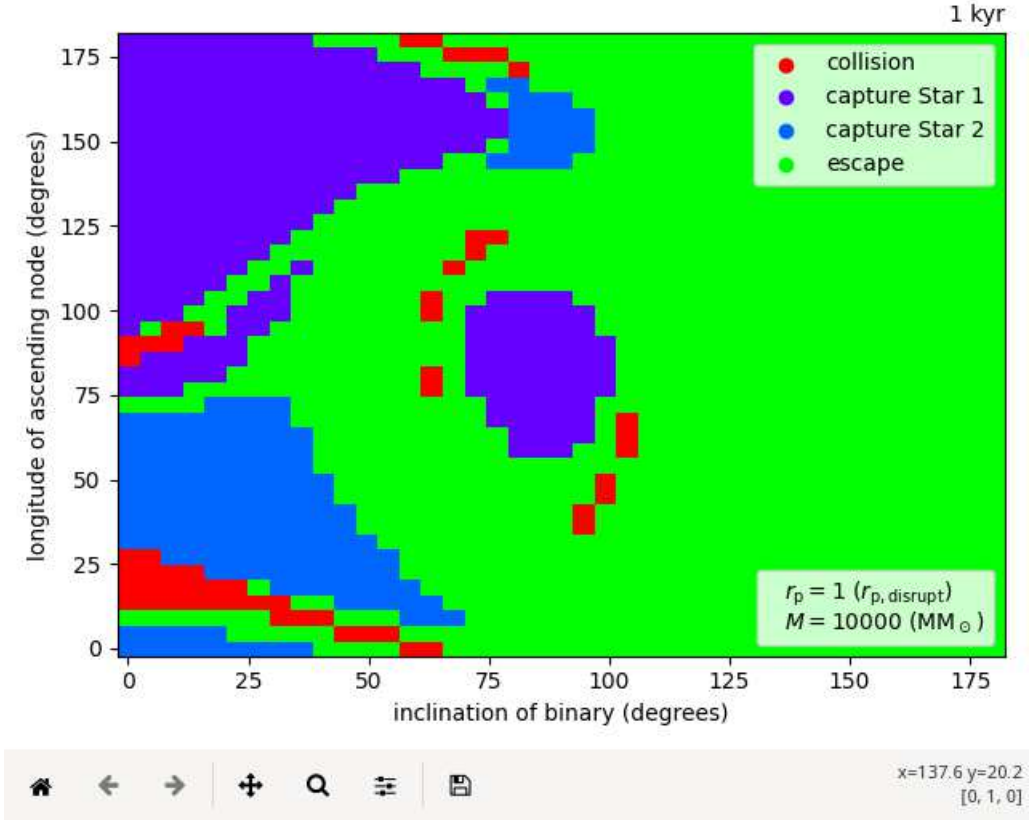
Credit: NASA's Goddard Space Flight Center

What next?

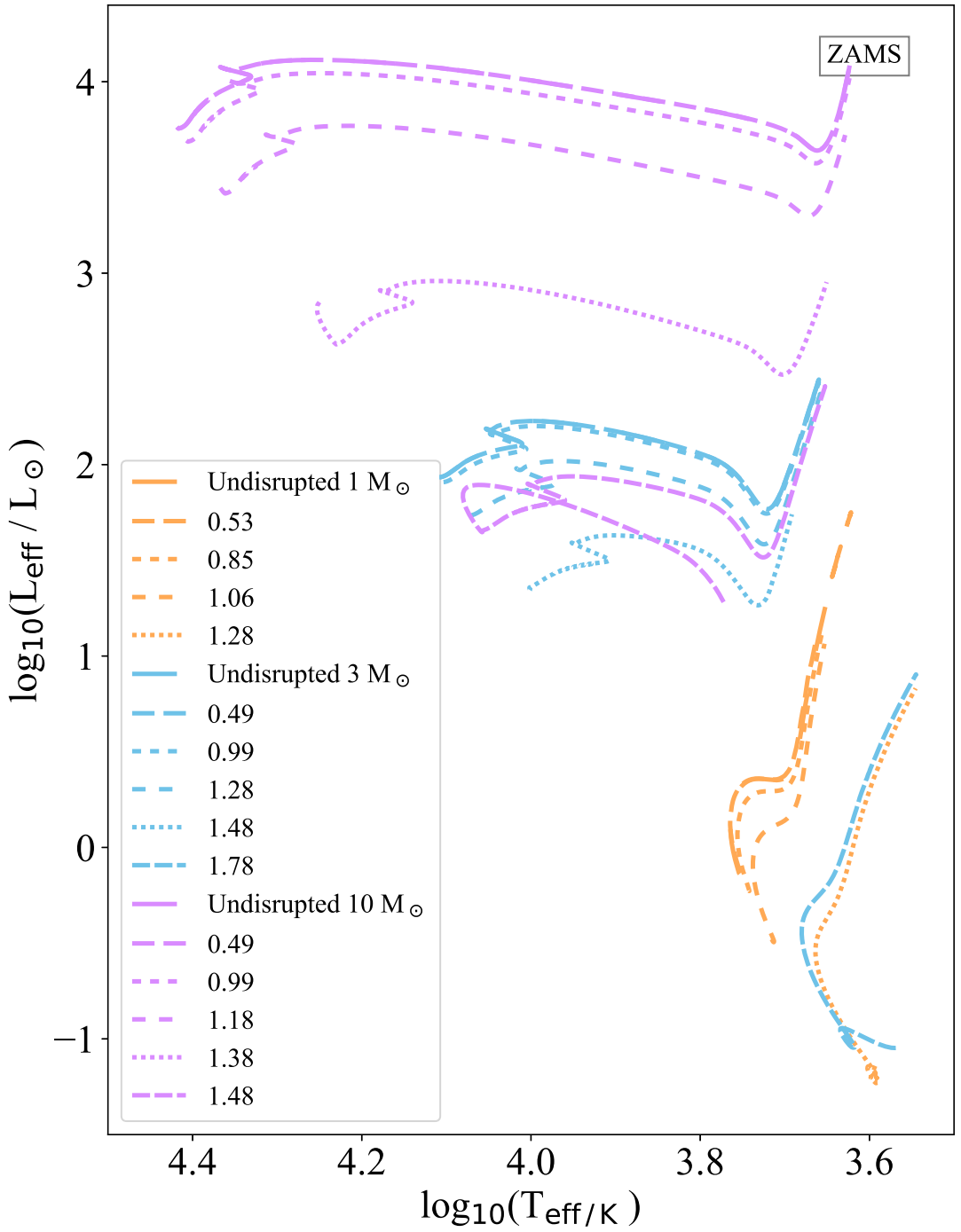
1. Map stellar rotation into KEPLER from disrupted models.
2. Binary TDEs!

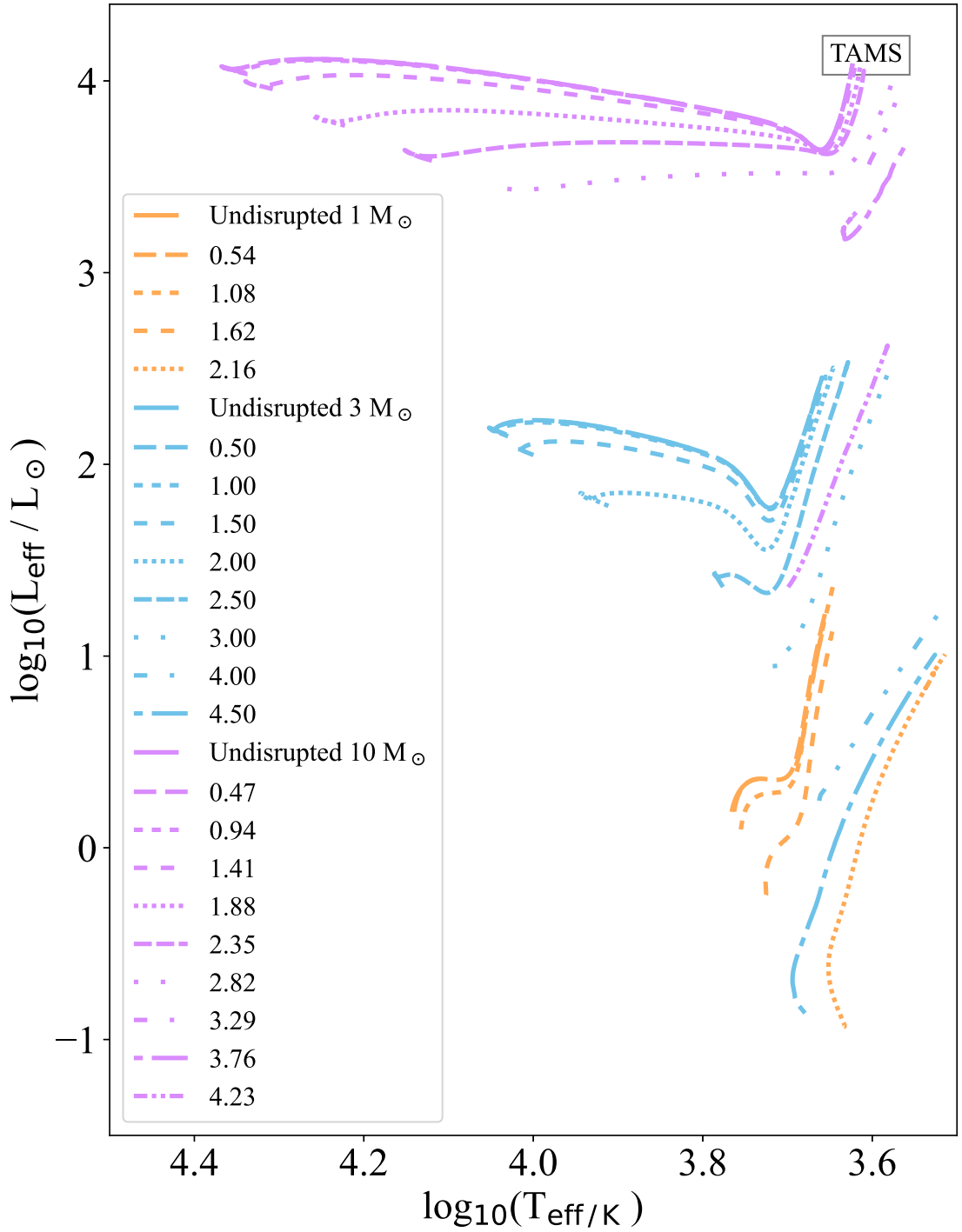


Credit: Brown 2015

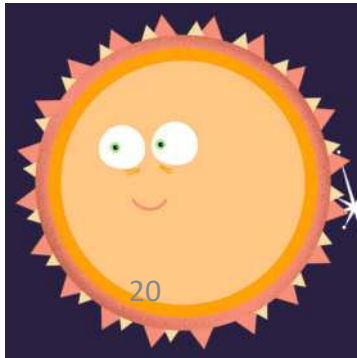


Credit: Prof. Alexander Heger


ZAMS
Undisrupted 1 M⊙
0.53
0.85
1.06
1.28
Undisrupted 3 M⊙
0.49
0.99
1.28
1.48
1.78
Undisrupted 10 M⊙
0.49
0.99
1.18
1.38
1.48
log10(Leff / L⊙)
log10(Teff/K)
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6



Credit: NASA's Goddard Space Flight Center

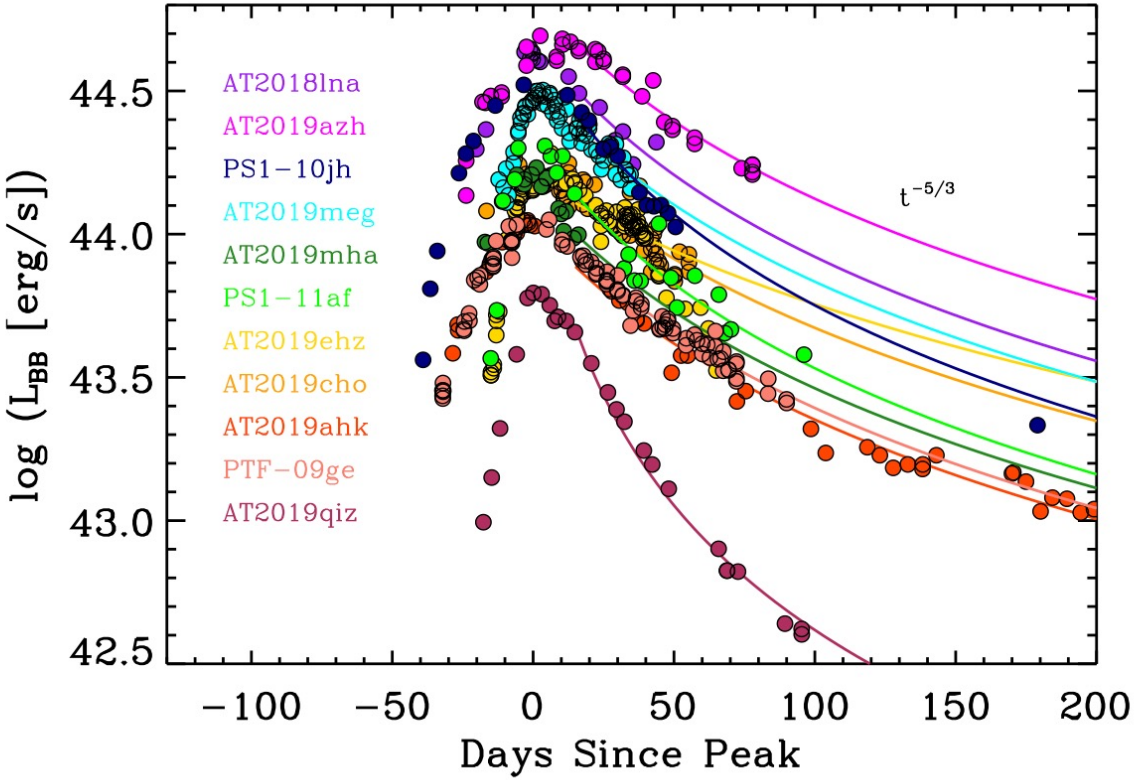


Have we detected TDEs?

- First detected by ROSAT all sky survey
- 10^{-4} to 10^{-5} per galaxy per year

(Magorrian and Tremaine, 1999; Wang and Merritt, 2004)

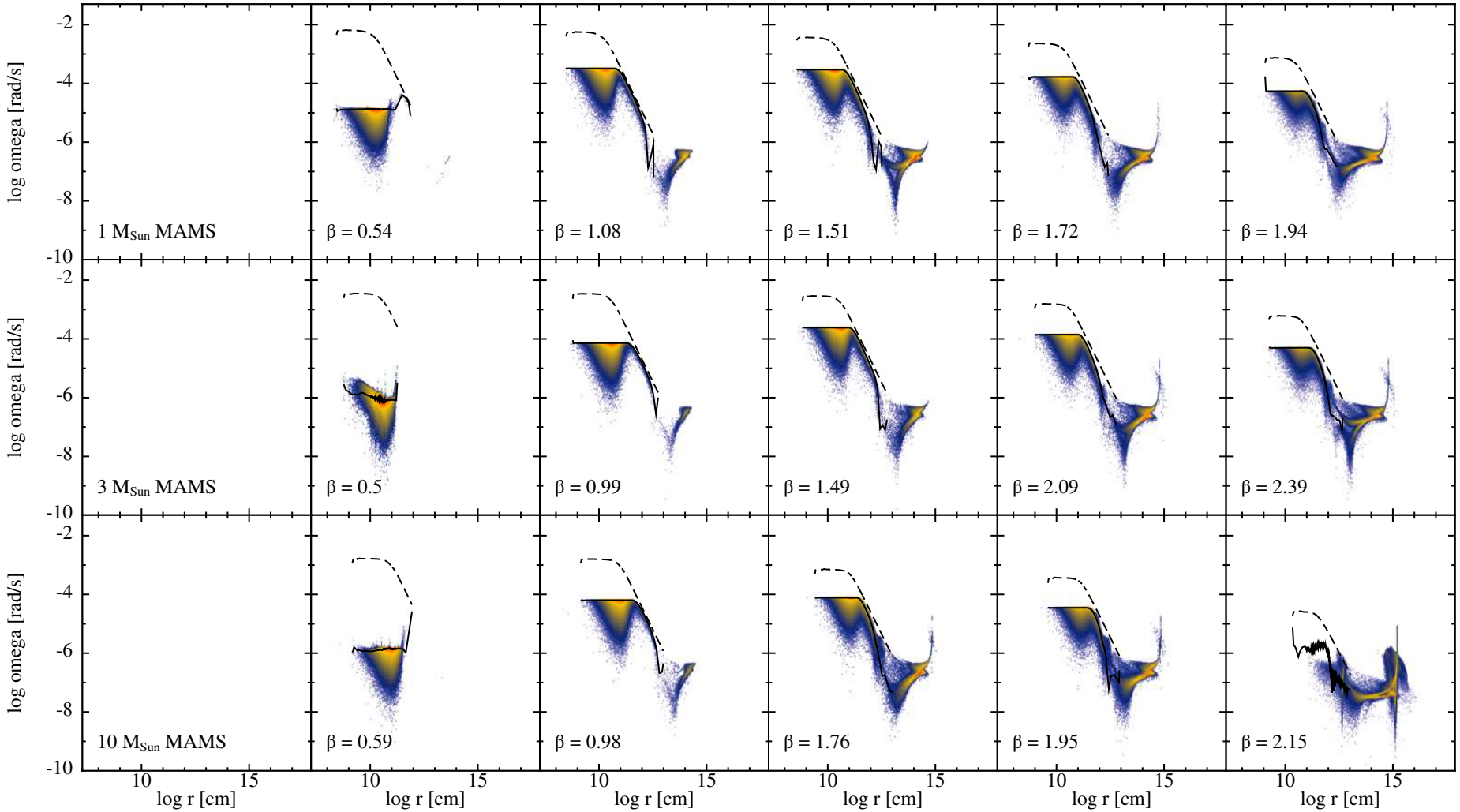
- Have detected a few Partial TDEs (PS1-1af, AT2018hyz,AT2019qiz)



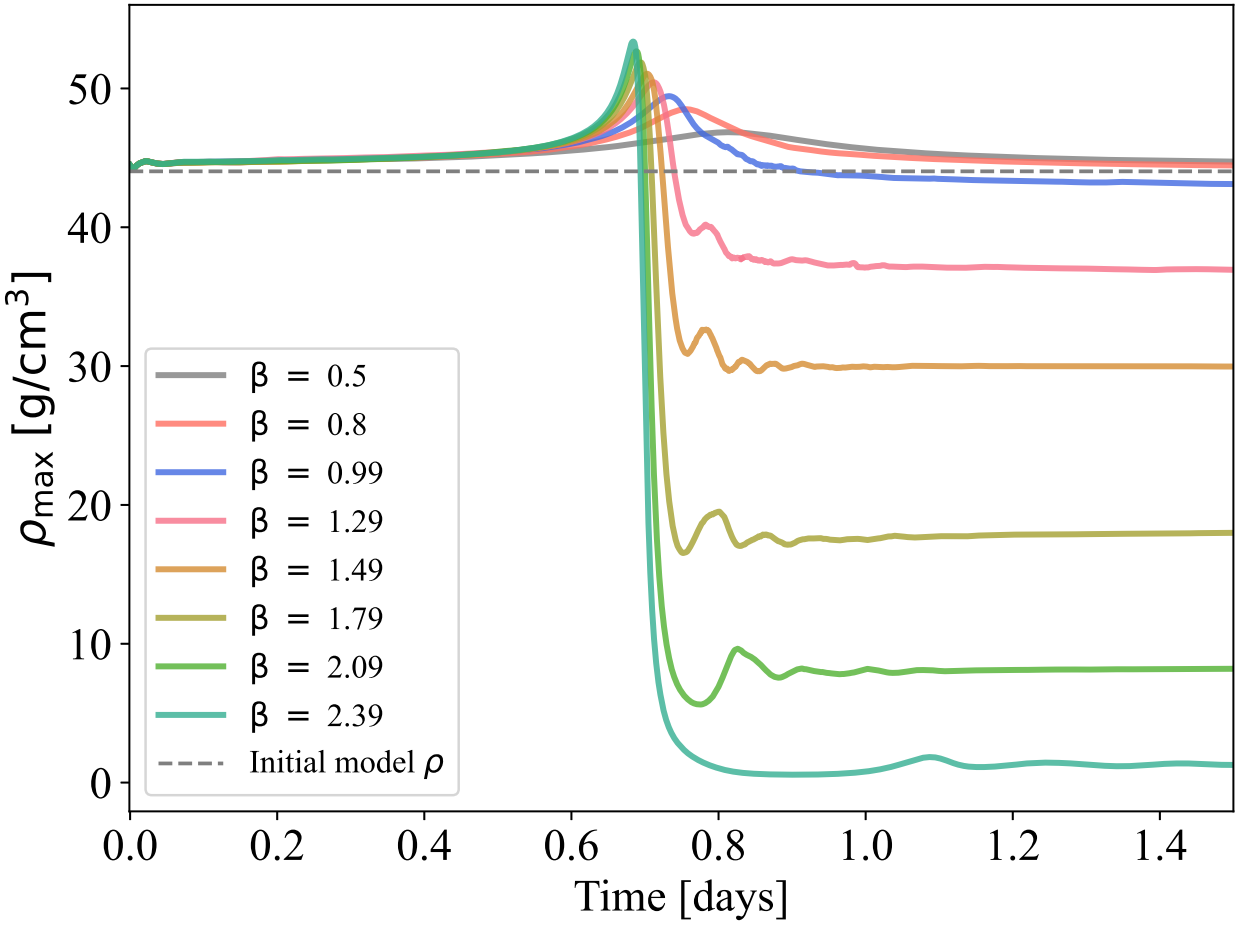
Credit: Gezari 2021

Credit: NASA's Goddard Space Flight Center

Rotation profiles

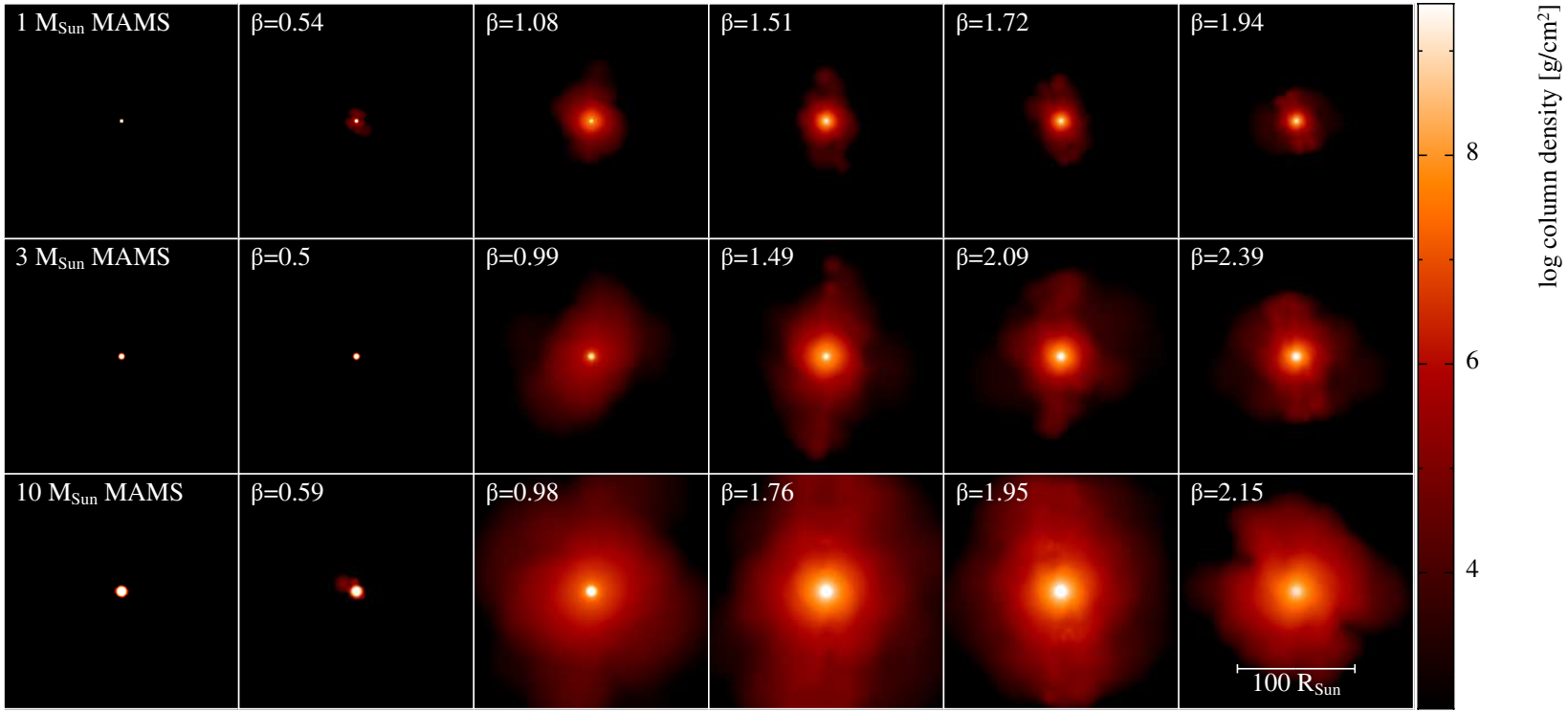


Timmy undergoes compression!

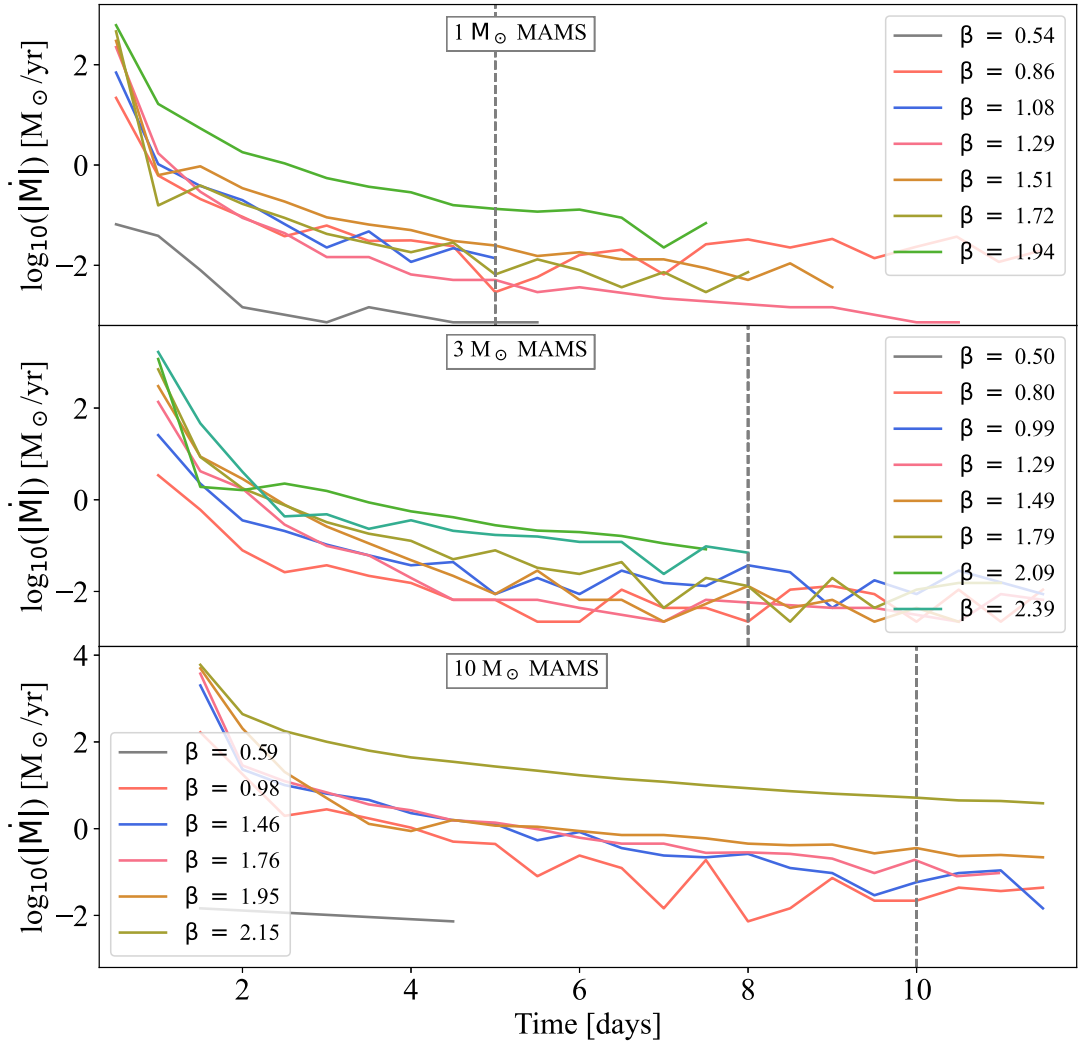


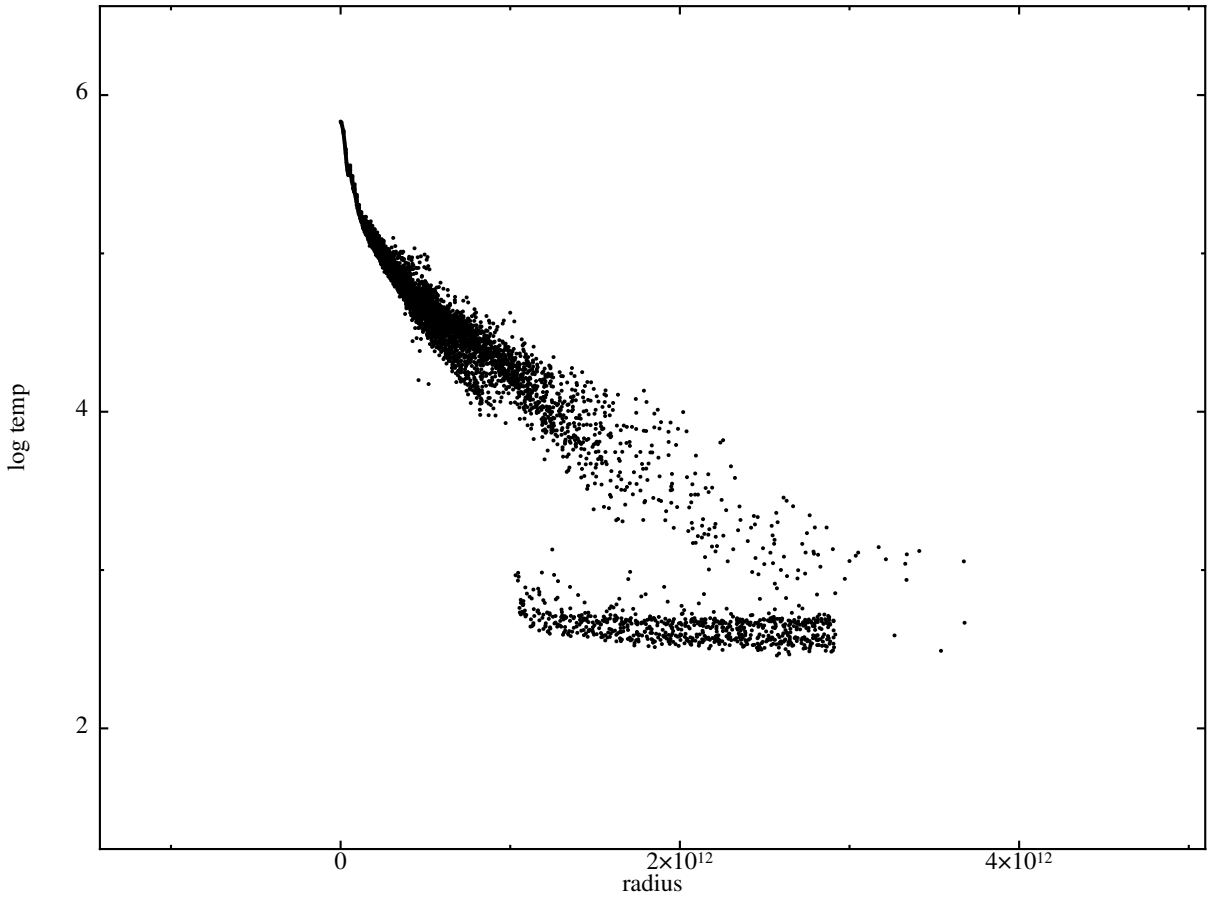
Credit: NASA's Goddard Space Flight Center

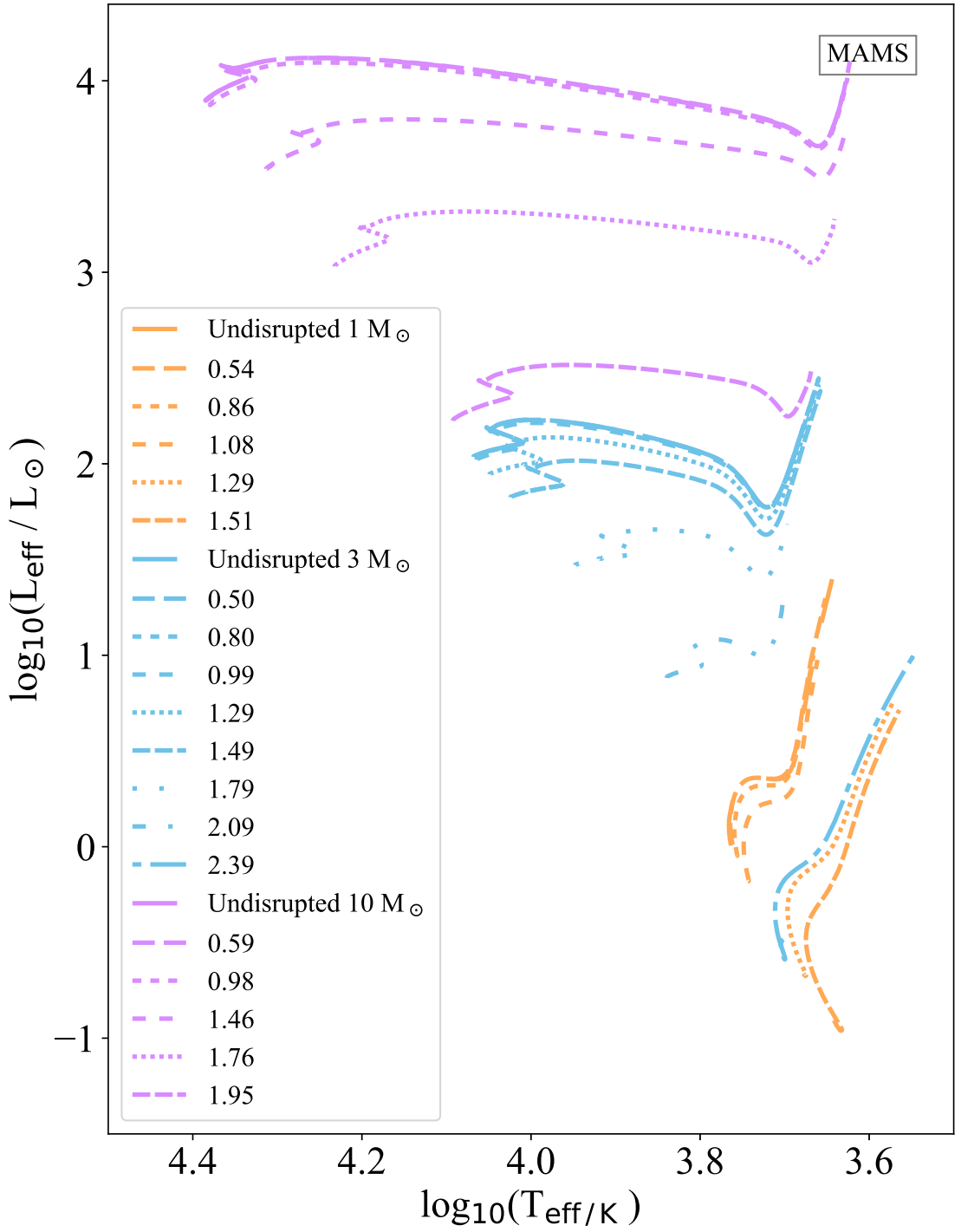
What do remnants (Timmy) look like?



Accretion rate




6
4
2
log temp
0
2×10^12
4×10^12
radius


MAMS
Undisrupted 1 M⊙
0.54
0.86
1.08
1.29
1.51
Undisrupted 3 M⊙
0.50
0.80
0.99
1.29
1.49
1.79
2.09
2.39
Undisrupted 10 M⊙
0.59
0.98
1.46
1.76
1.95
log10(Leff / L⊙)
log10(Teff/K)
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6