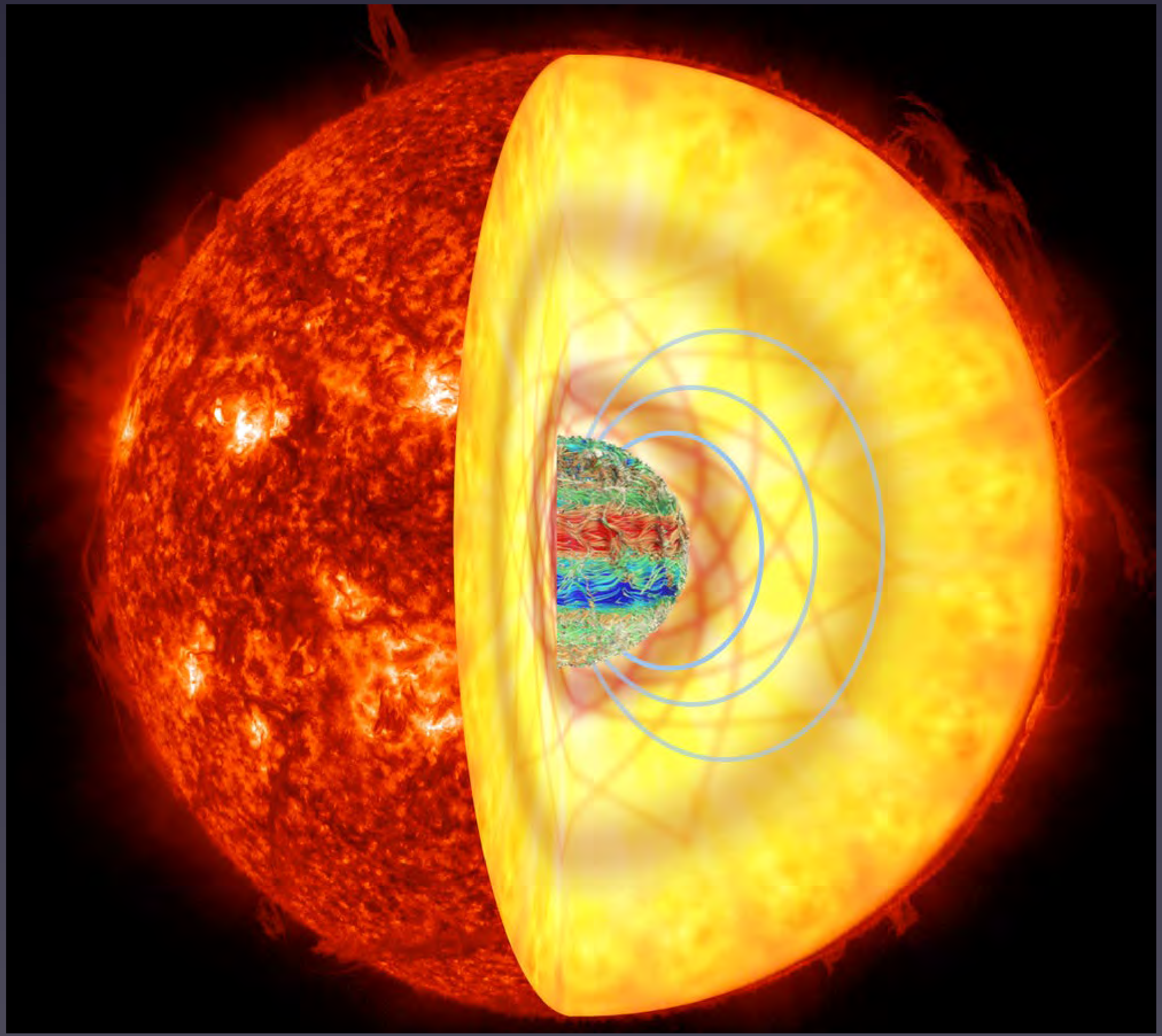
Astrophysics of Stars and Planets

Jim Fuller

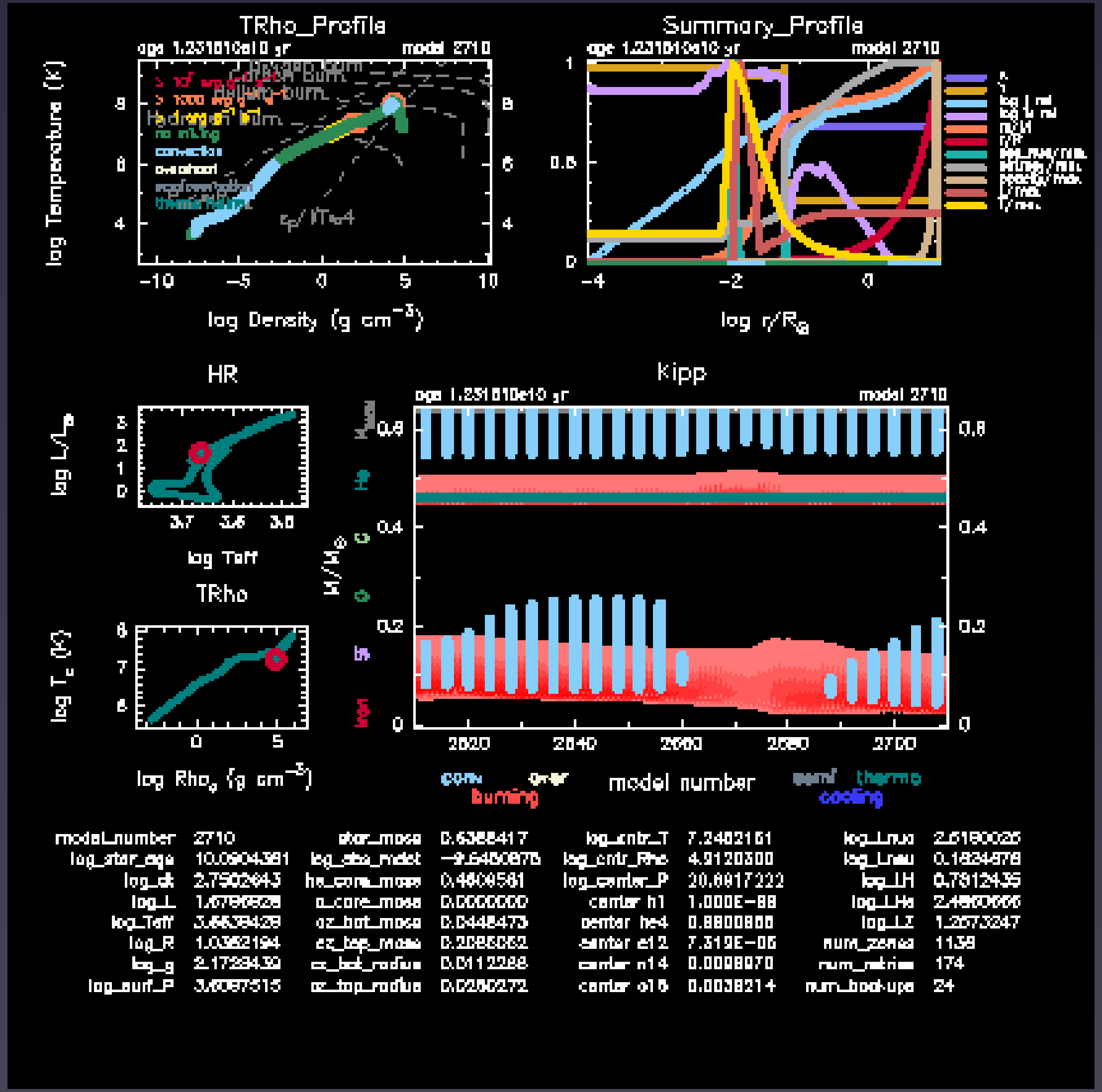
Caltech

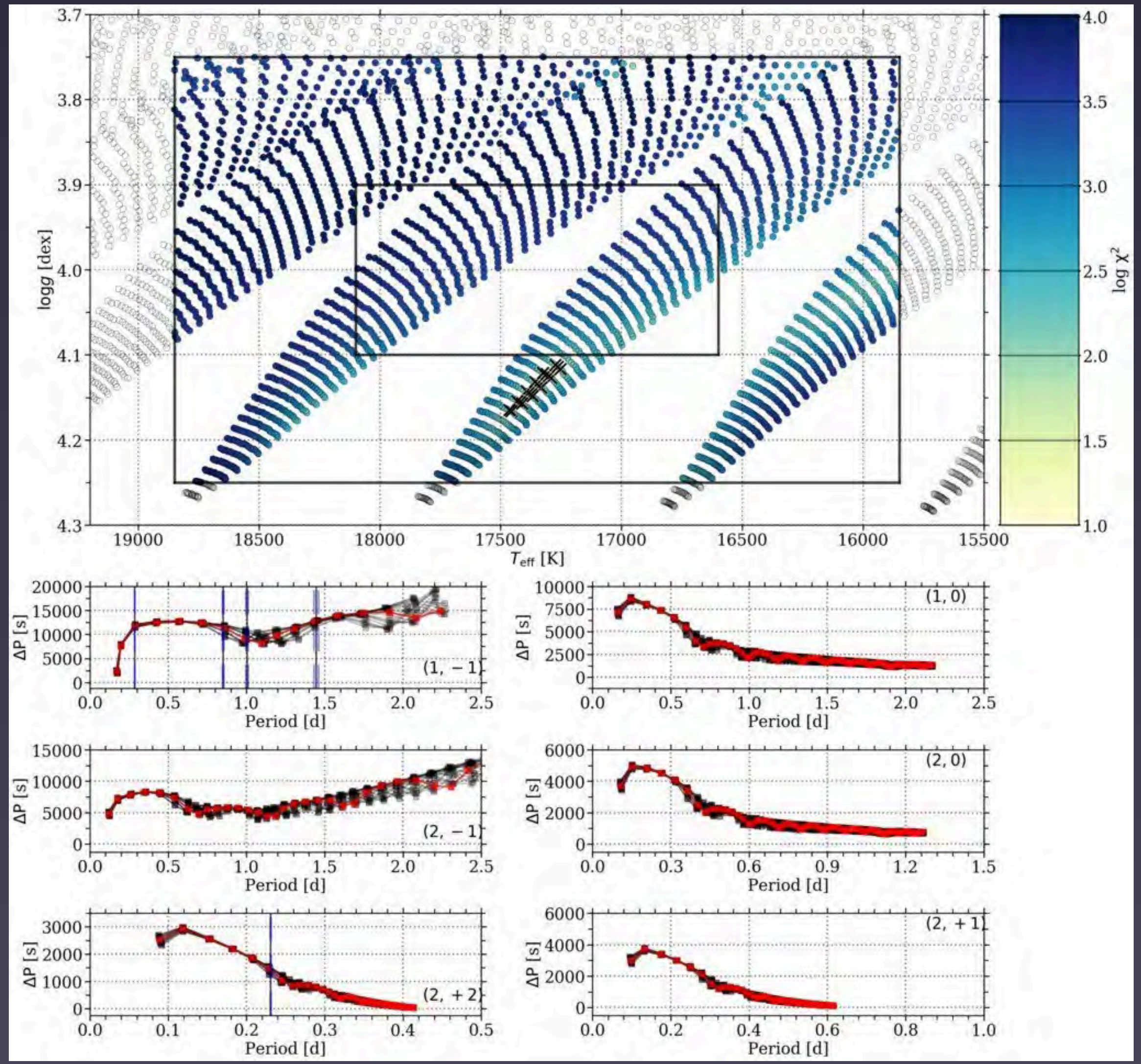


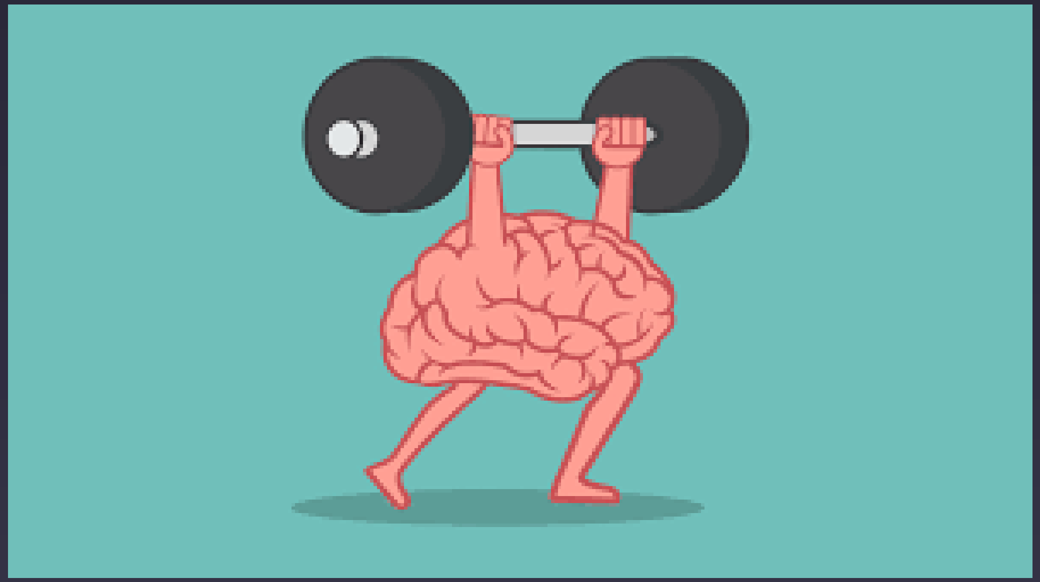
Tools

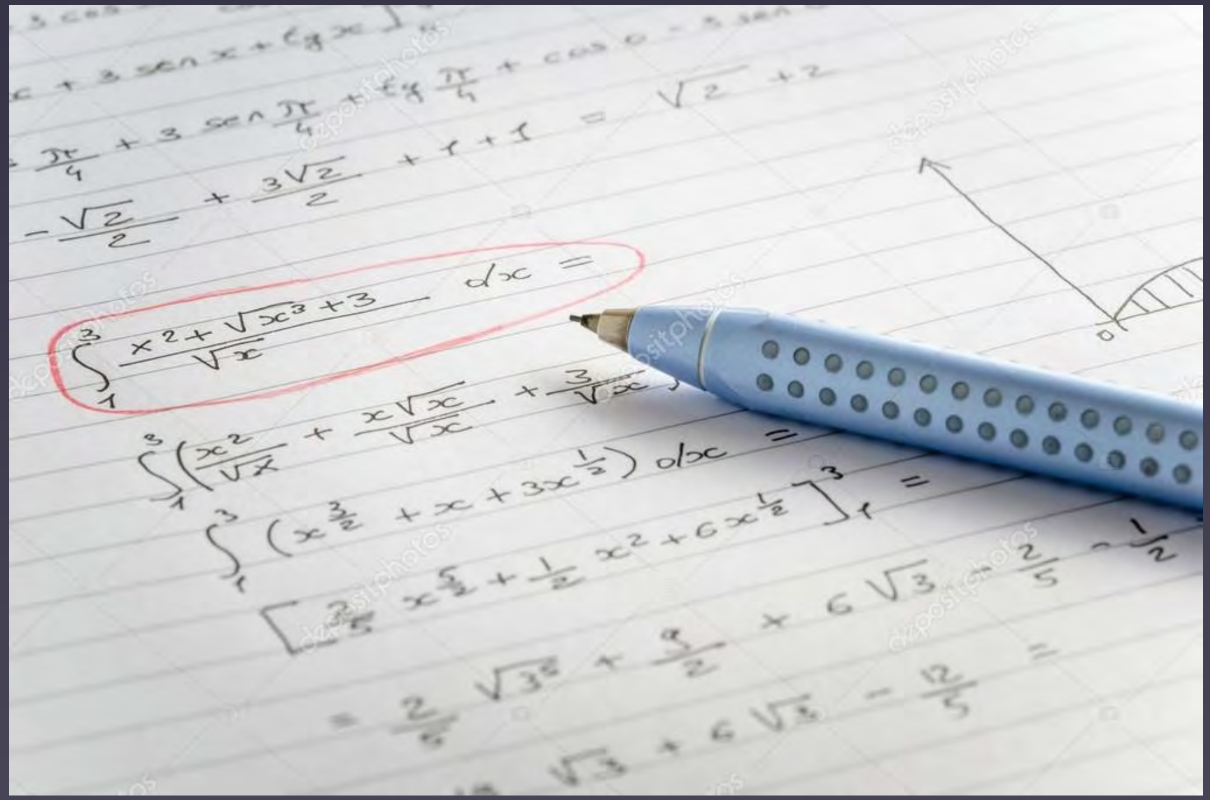
MESA

GYRE

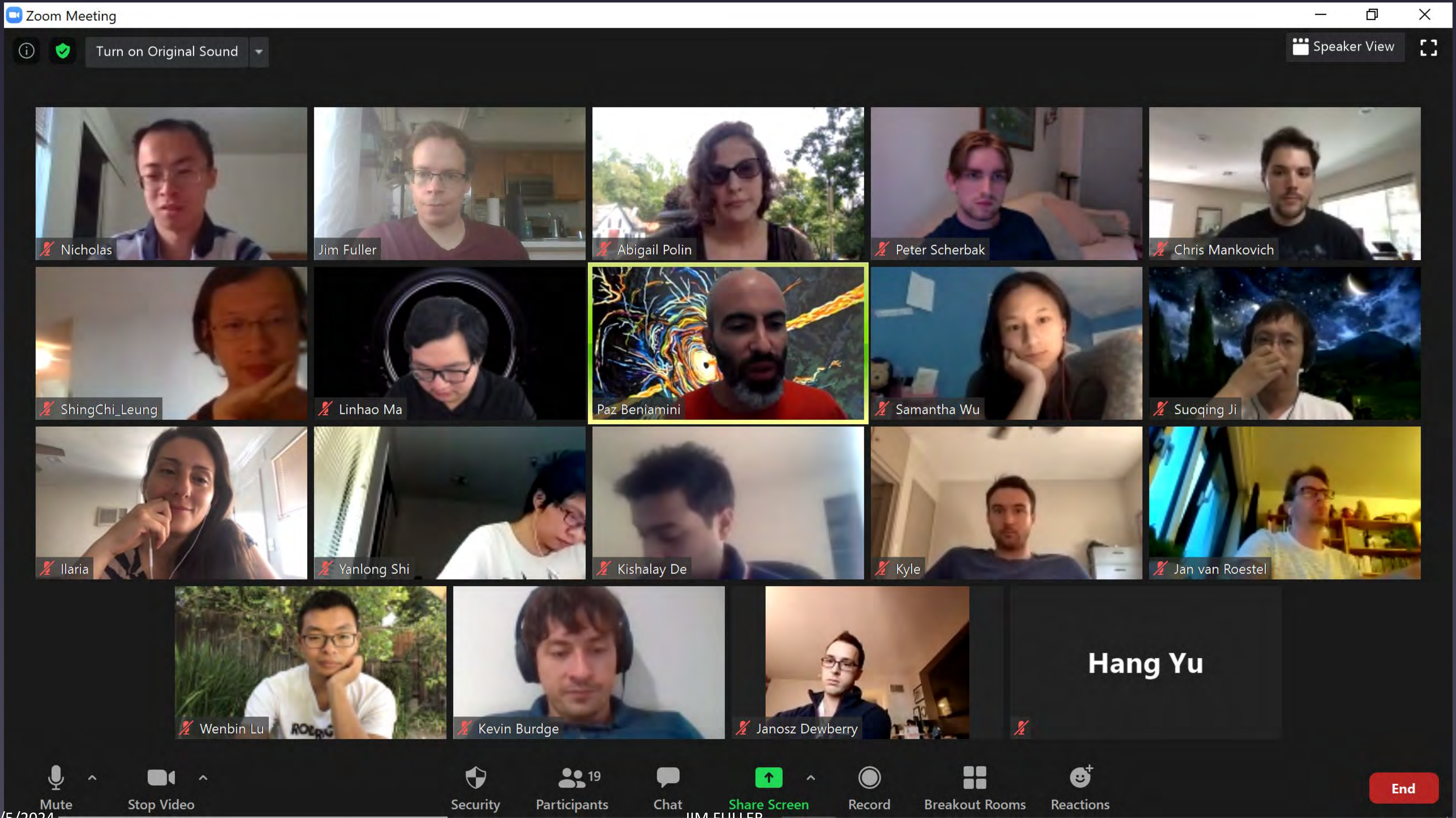








My Group


Zoom Meeting
Turn on Original Sound
Speaker View
Nicholas
Jim Fuller
Abigail Polin
Peter Scherbak
Chris Mankovich
ShingChi_Leung
Linhao Ma
Paz Beniamini
Samantha Wu
Suoqing Ji
Ilaria
Yanlong Shi
Kishalay De
Kyle
Jan van Roestel
Wenbin Lu
Kevin Burdge
Janosz Dewberry
Hang Yu
Mute
Stop Video
Security
Participants
19
Chat
Share Screen
Record
Breakout Rooms
Reactions
End

Students:

Emily Hu

Linhao Ma

Nicholas Rui

Peter Scherbak

Samantha Wu

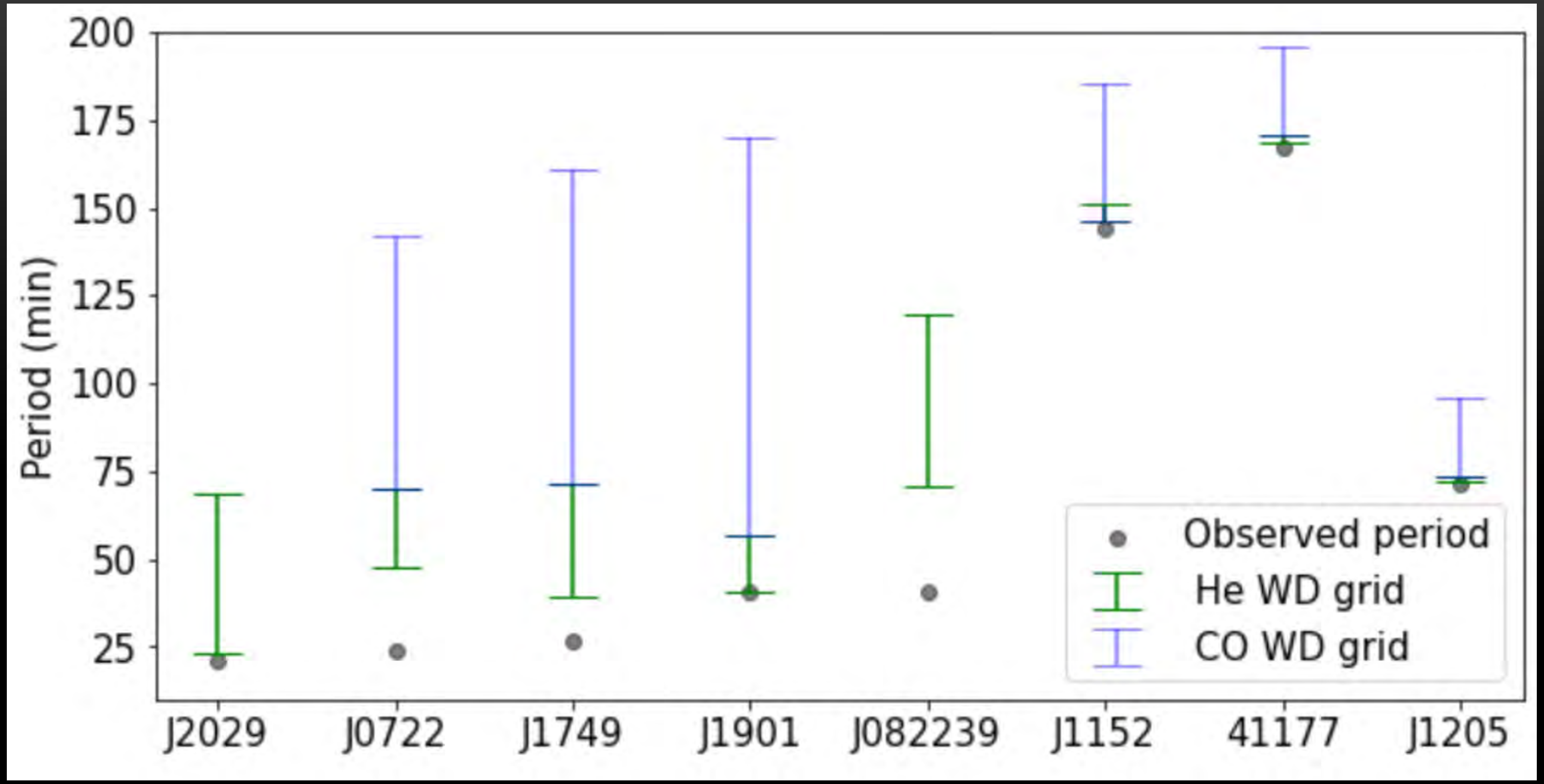
Postdocs:

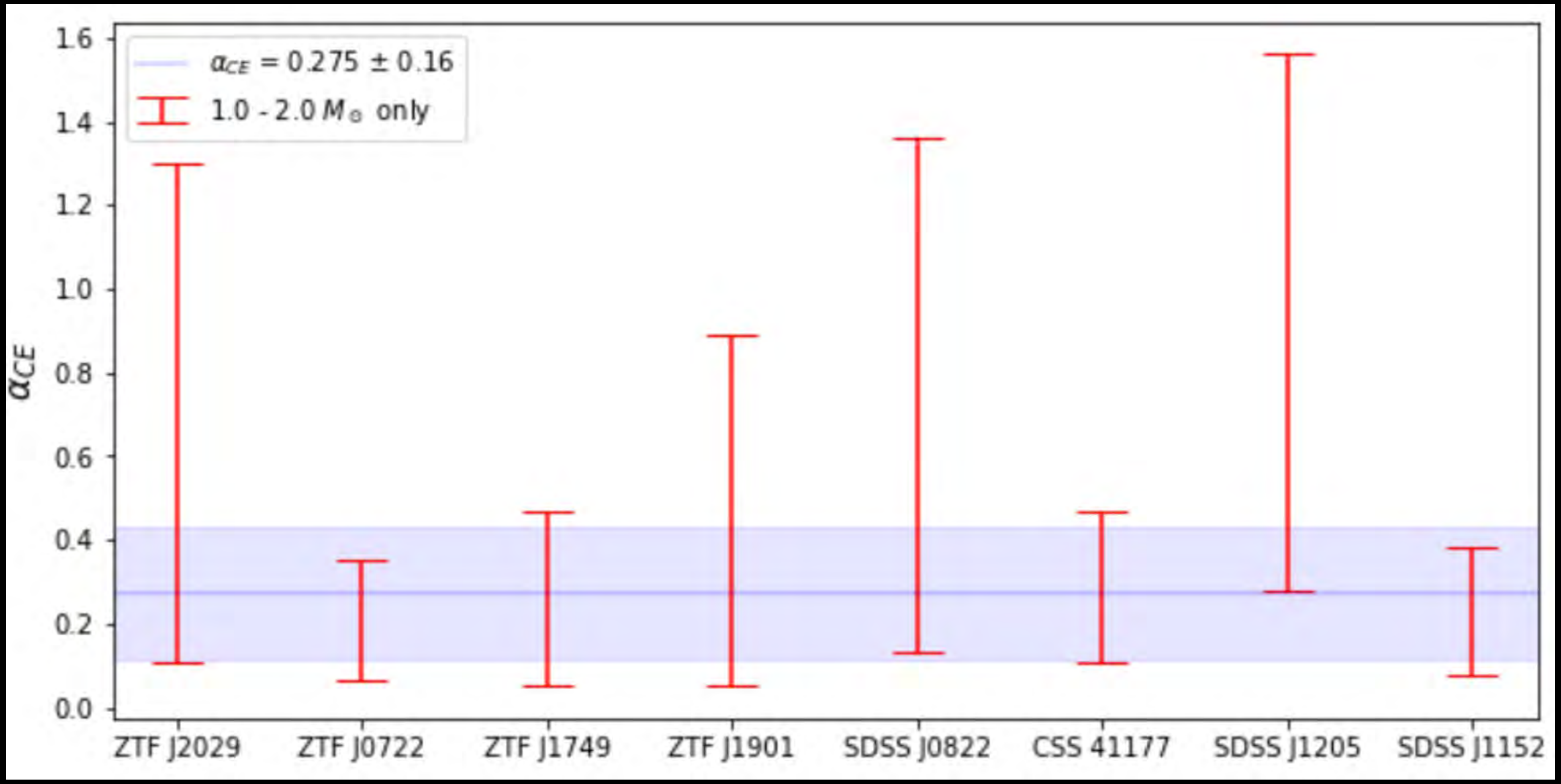
Ilaria Caiazzo

Daichi Tsuna

Models to determine WD birth conditions

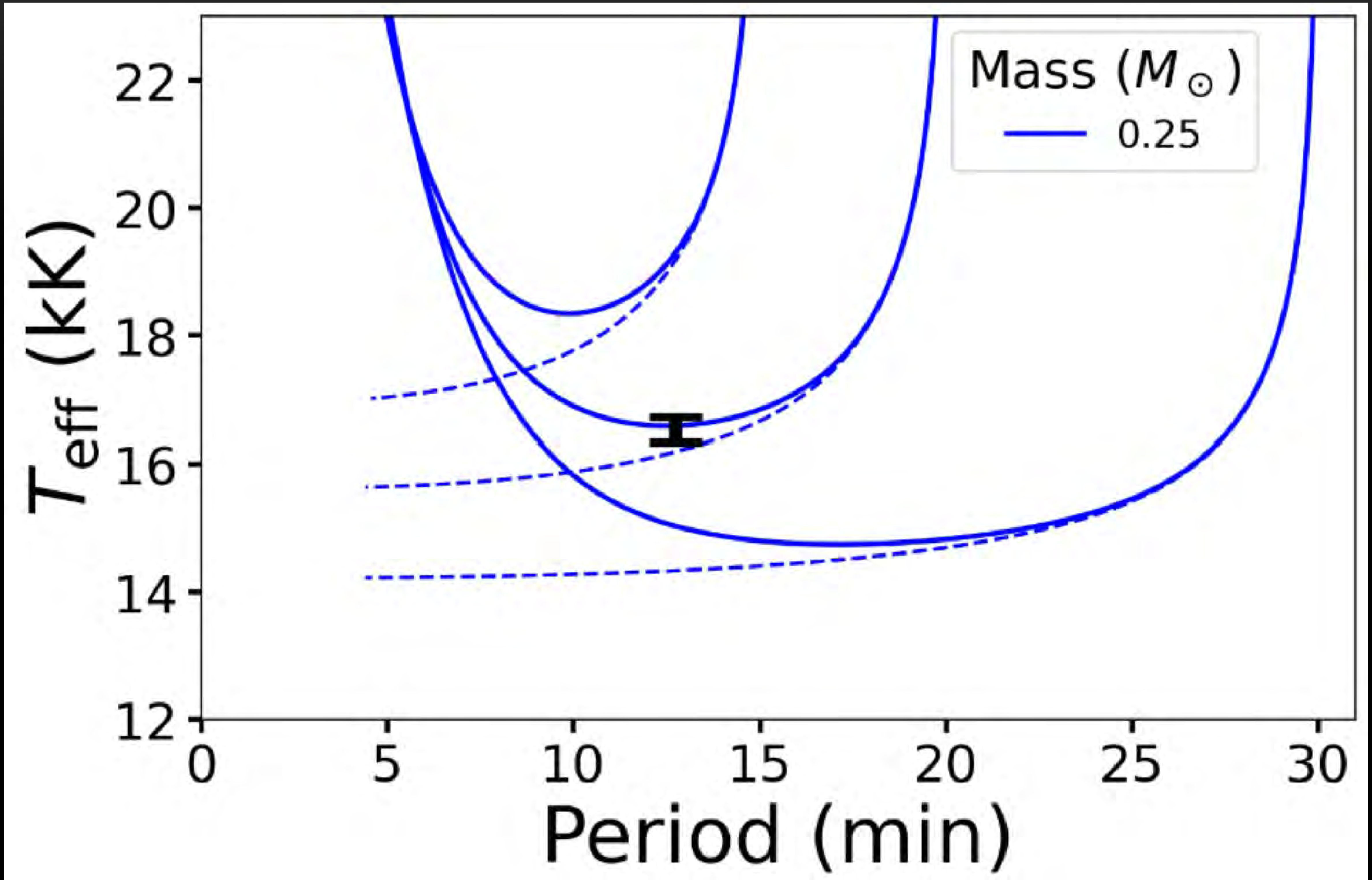
- Model white dwarf cooling
- Determine orbital period at birth
- Constrain common envelope event



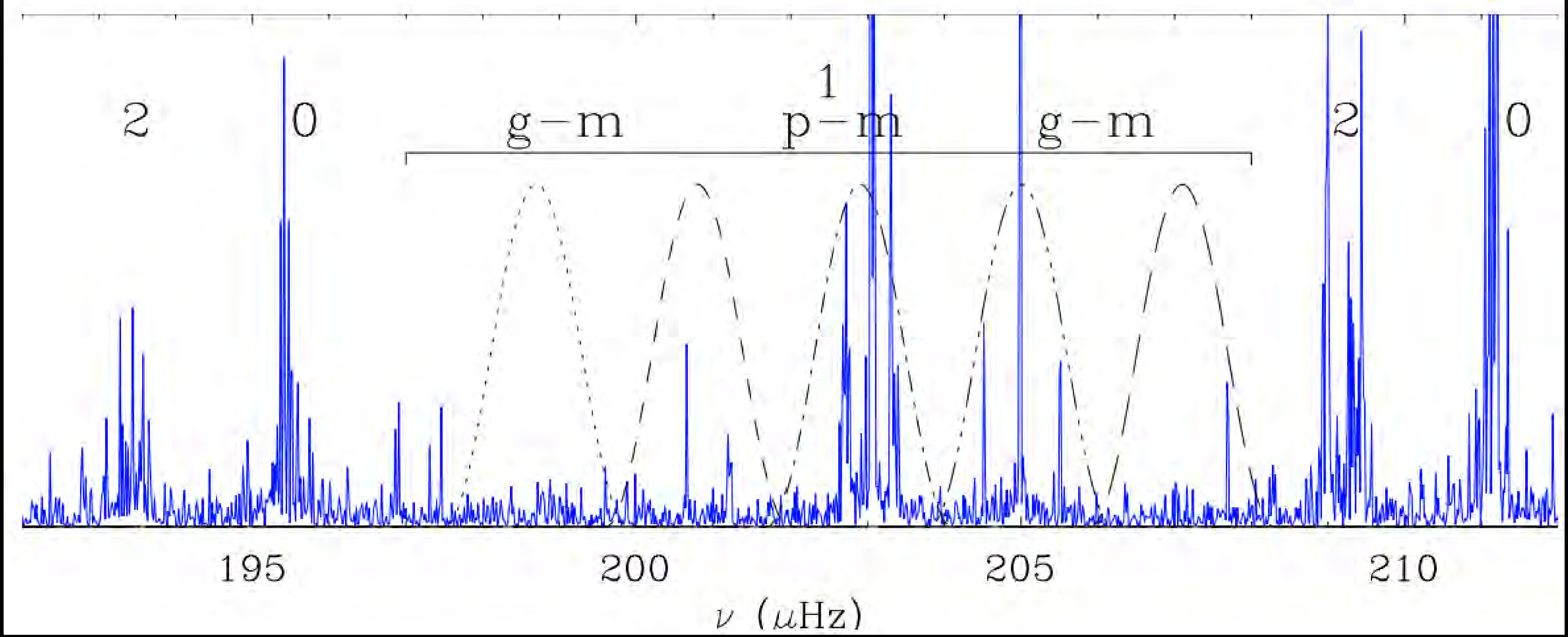


WDs binaries born at short periods

- Tidal heating cannot account for high temperatures
- Systems must be born at orbital periods under an hour



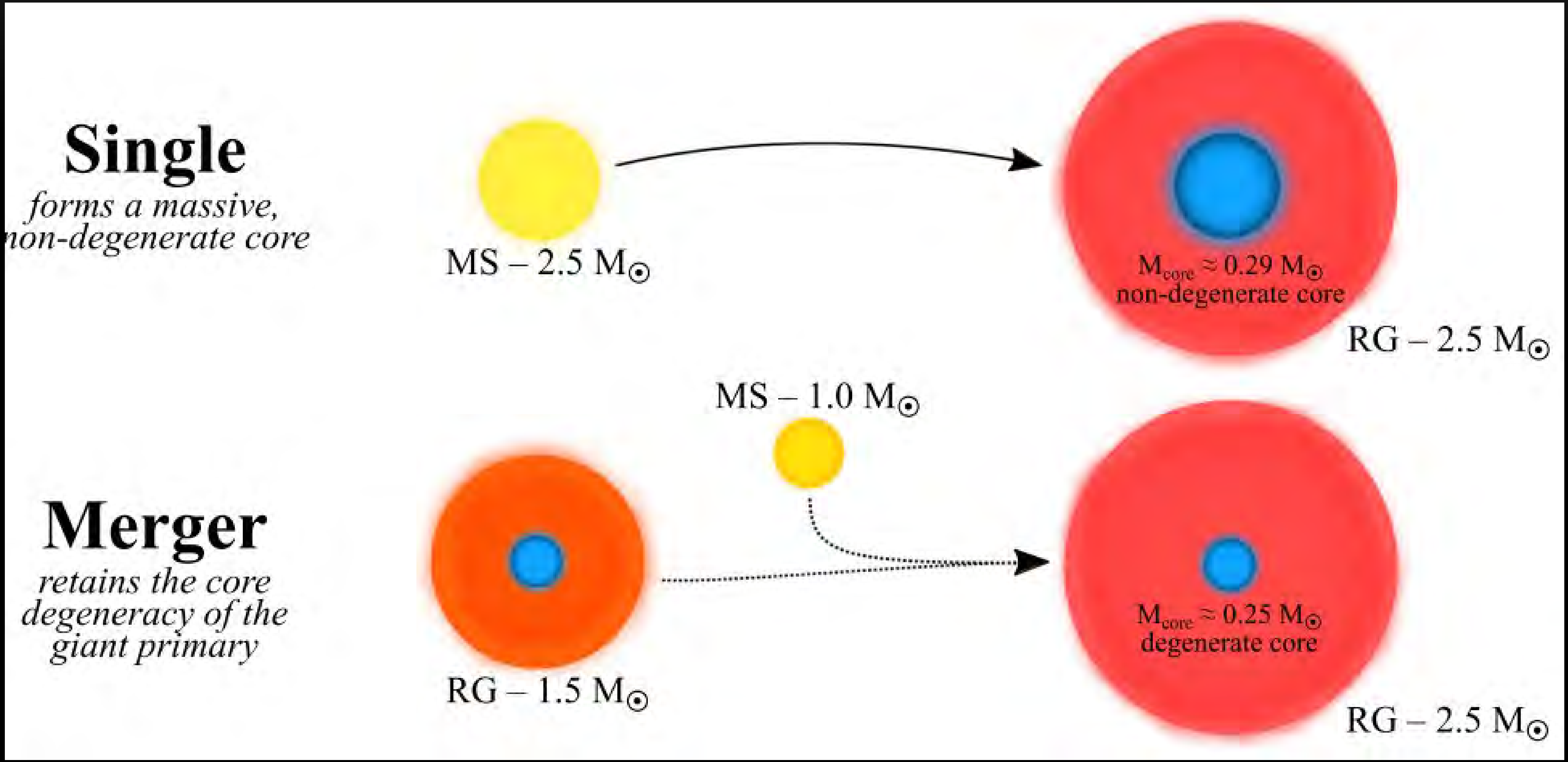
ASTEROSEISMOLOGY



INTERNAL STRUCTURE

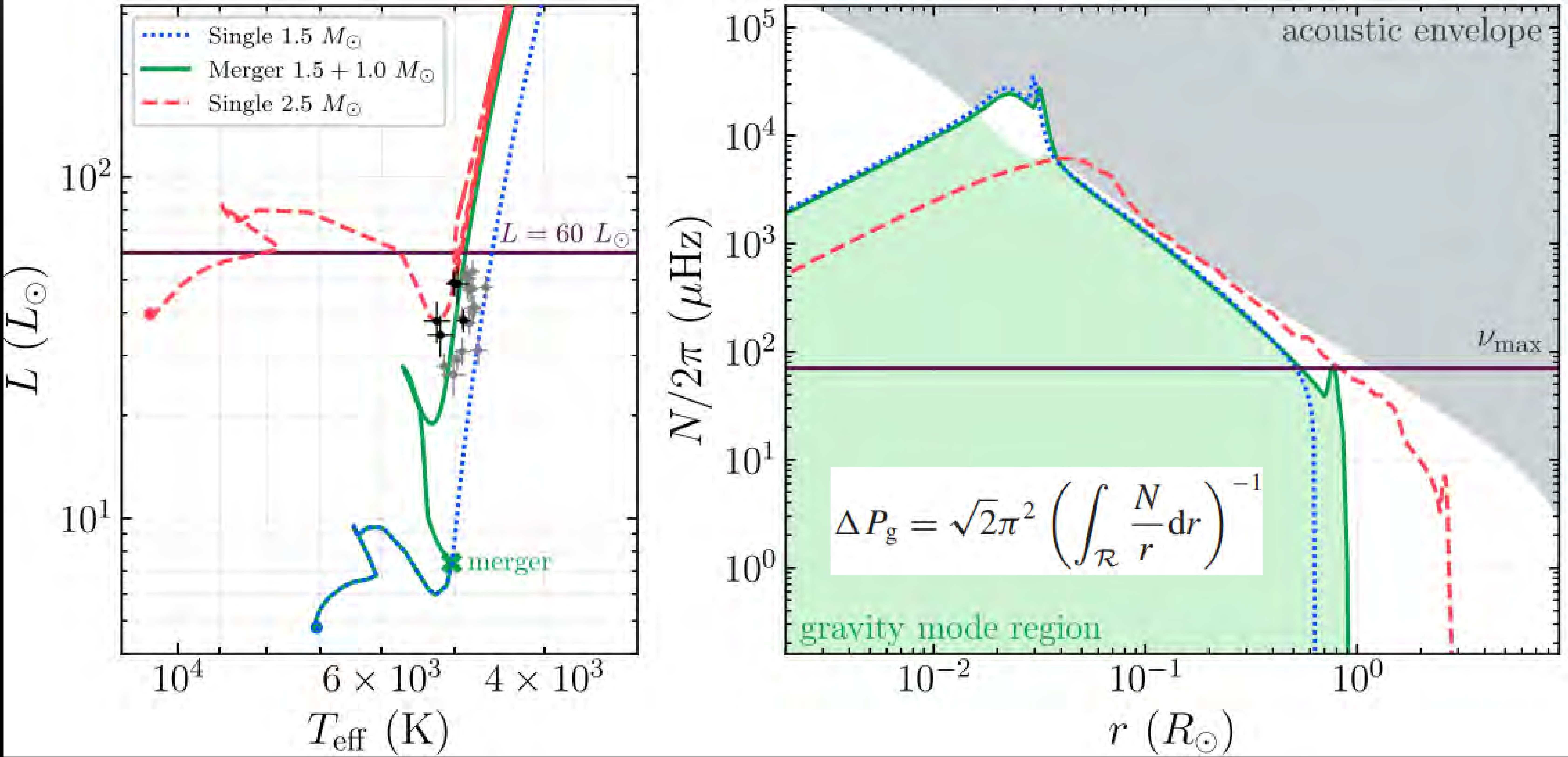
Merger remnants have unique core/envelope structure

Nicholas Rui



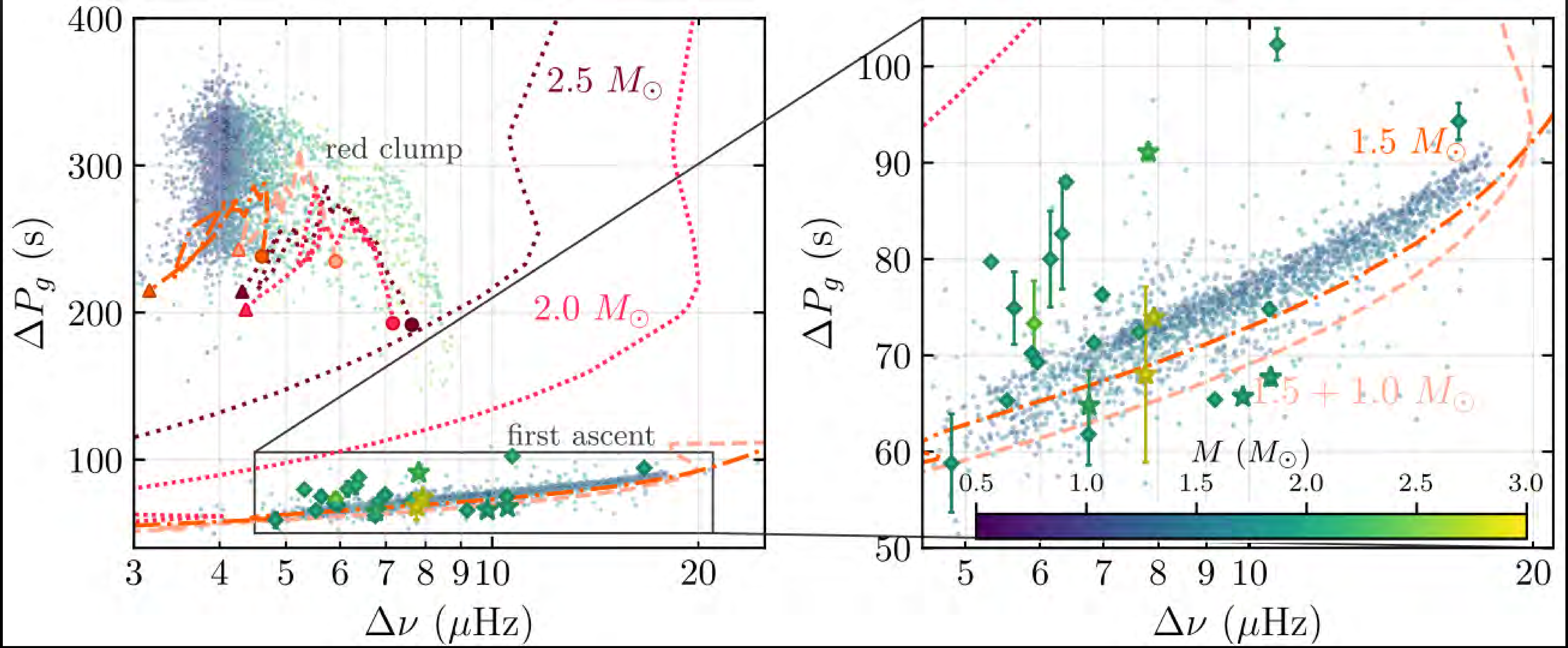
Rui & Fuller 2021

MODE PROPAGATION



Rui & Fuller 2021

IDENTIFYING MERGER CANDIDATES

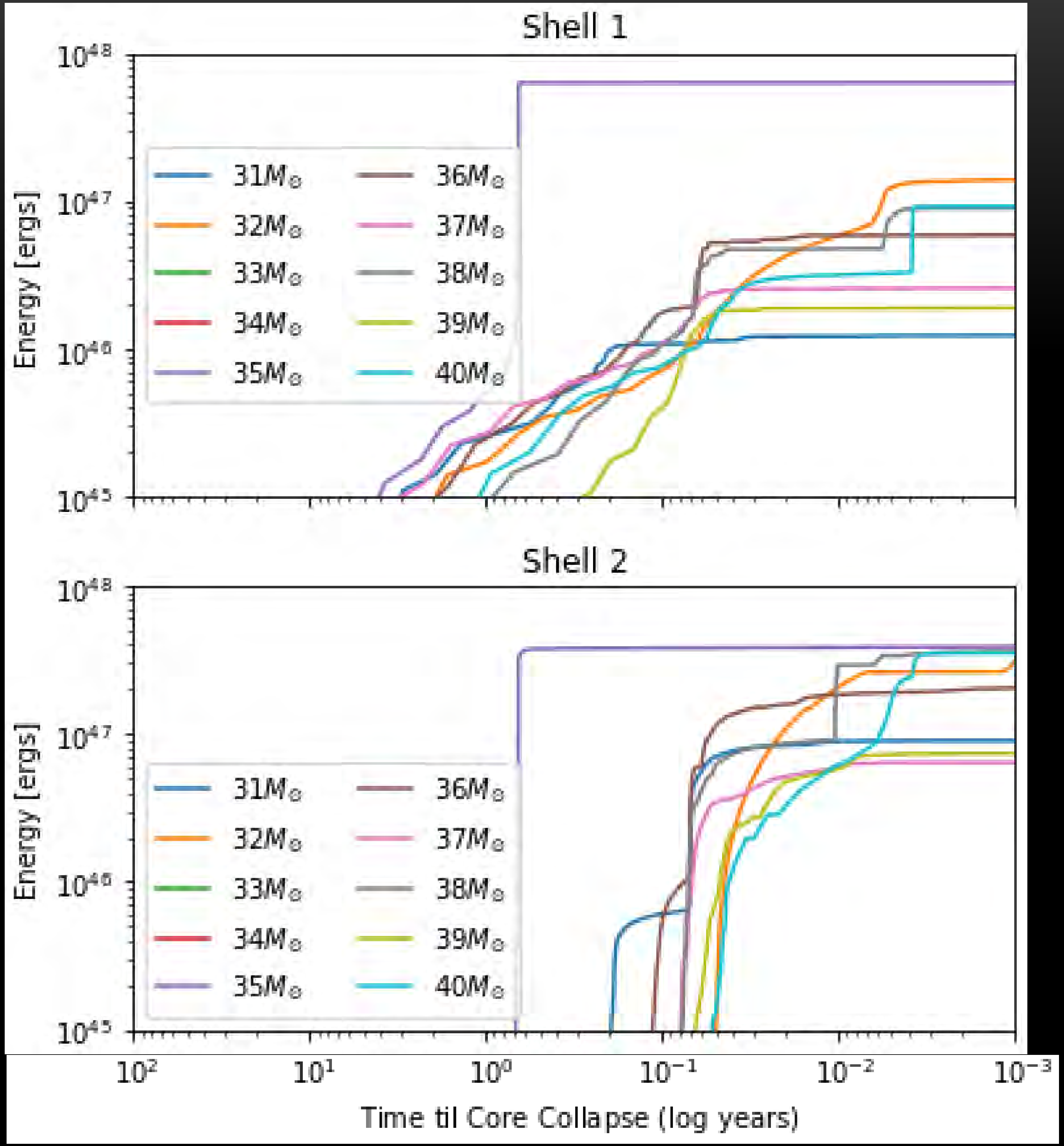


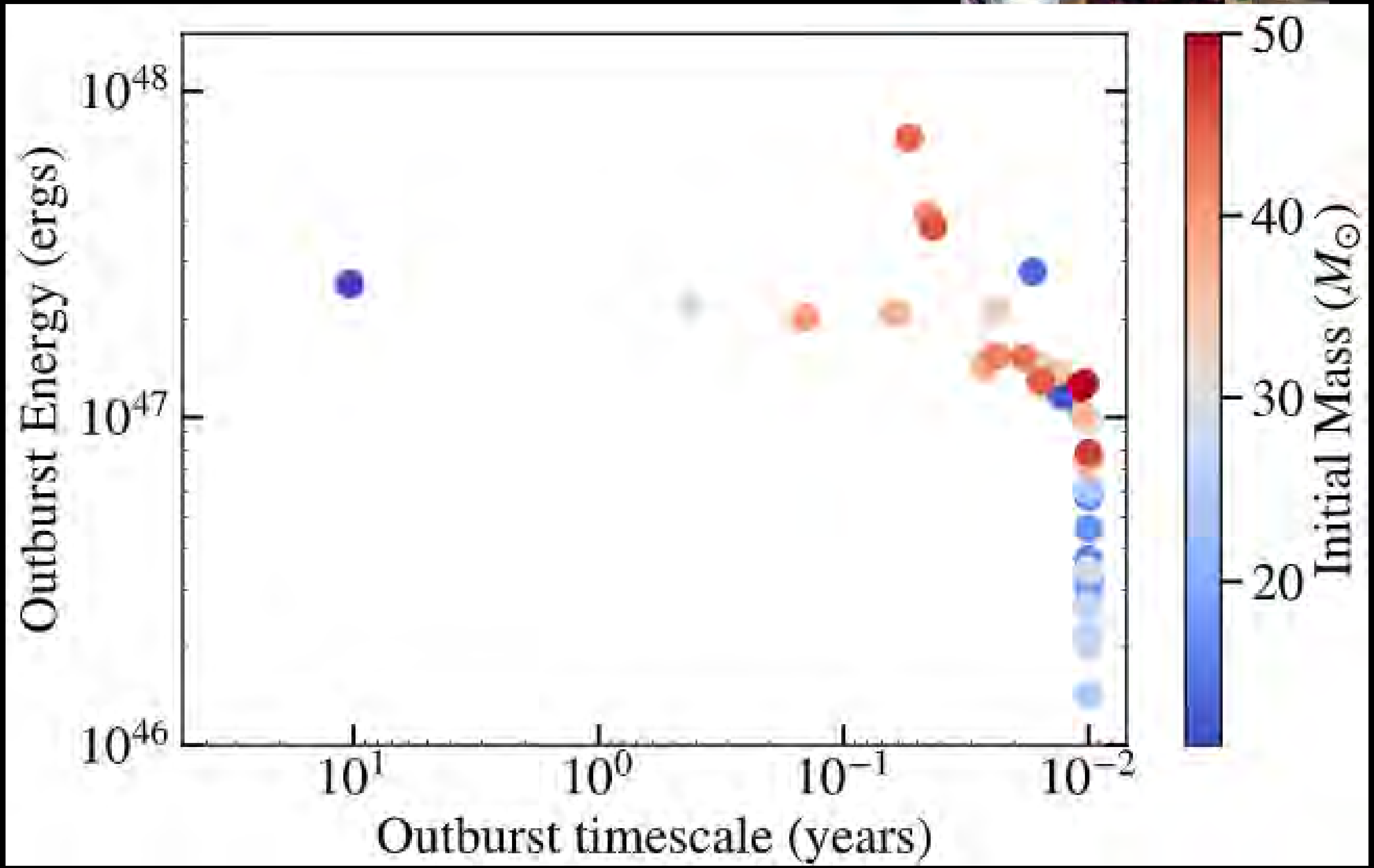
Data from Vrard et al. (2016)

Rui & Fuller 2021

See also Deheuvels+ 2021

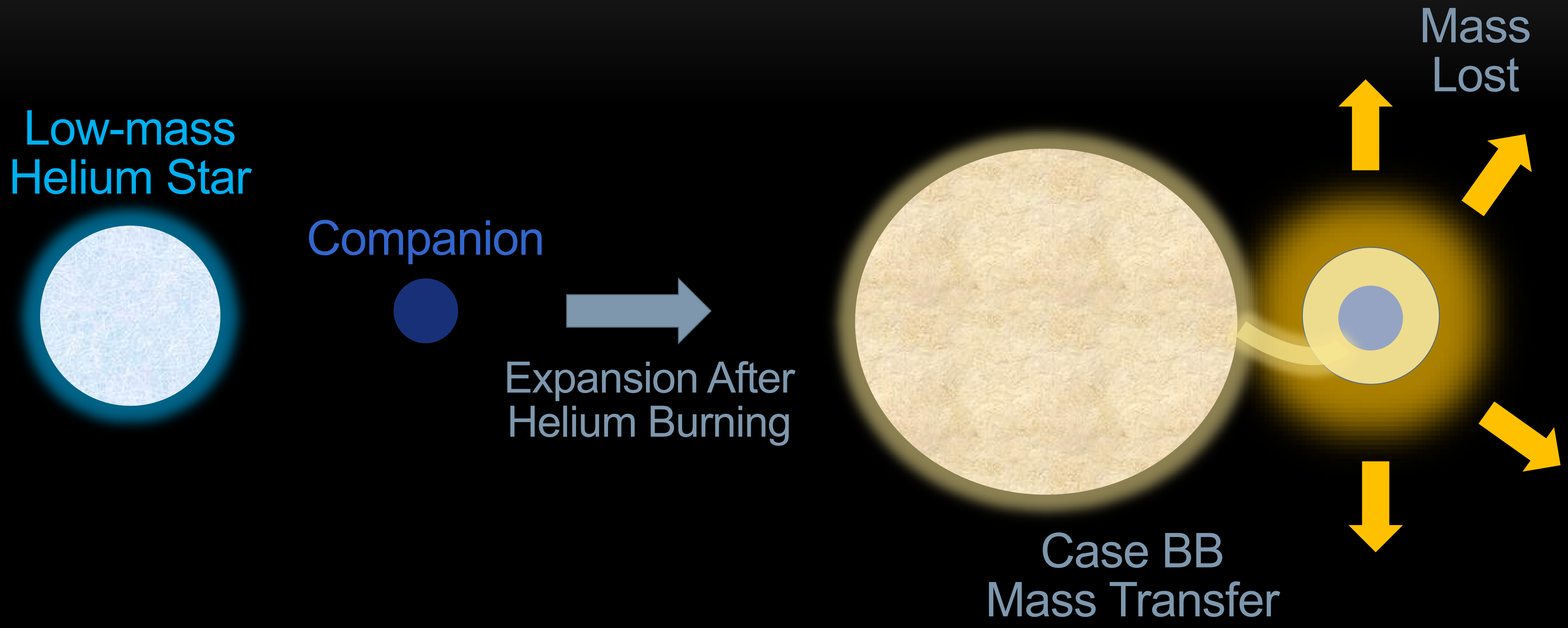
PRE-SUPERNOVA OUTBURSTS





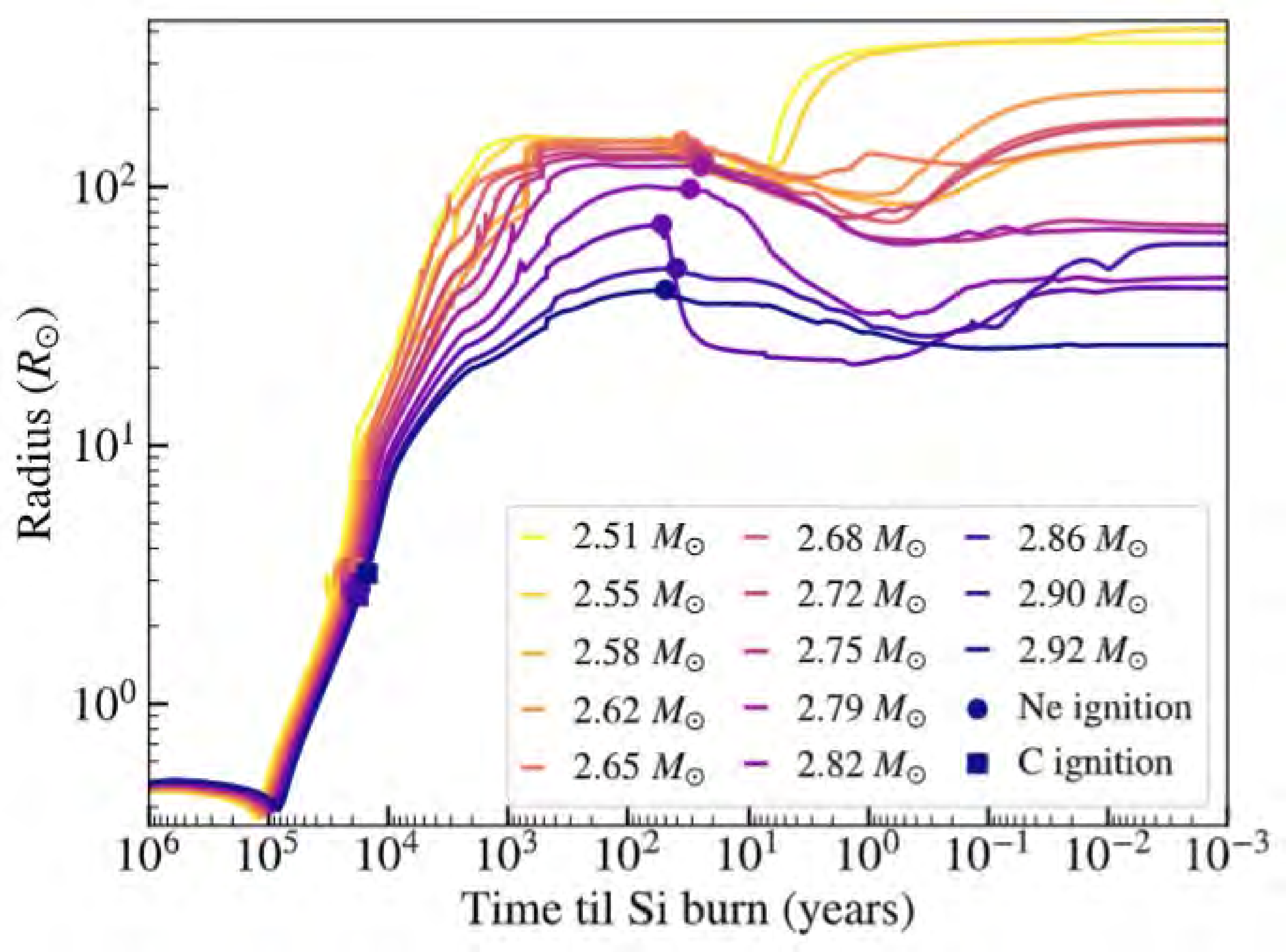
Wu & Fuller, submitted

Late Stage Stellar Expansion

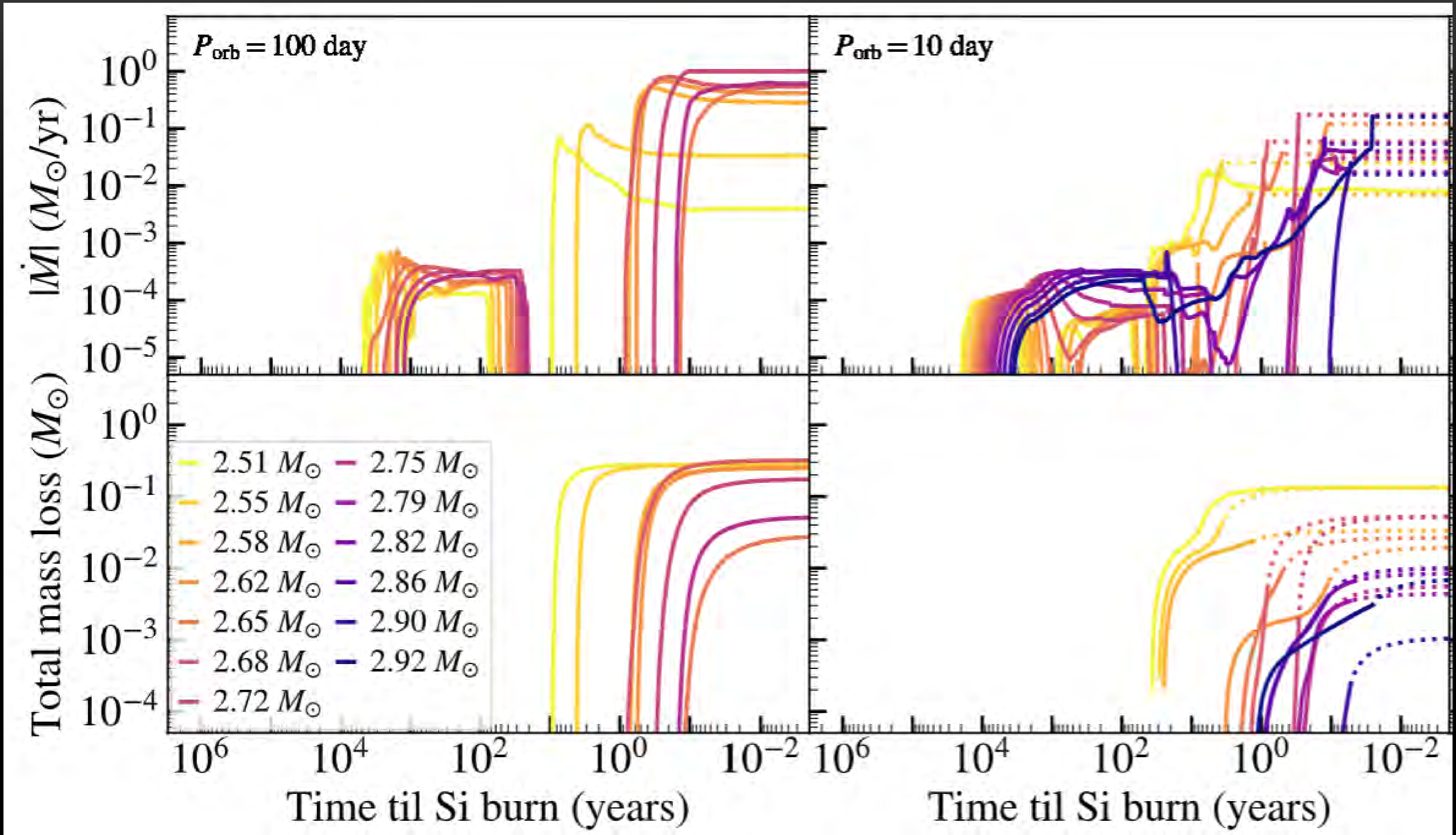


Extreme Pre-SN Expansion

- Low-mass Helium stars shrink and re-expand on ~1 yr time scale during Ne/O Burning

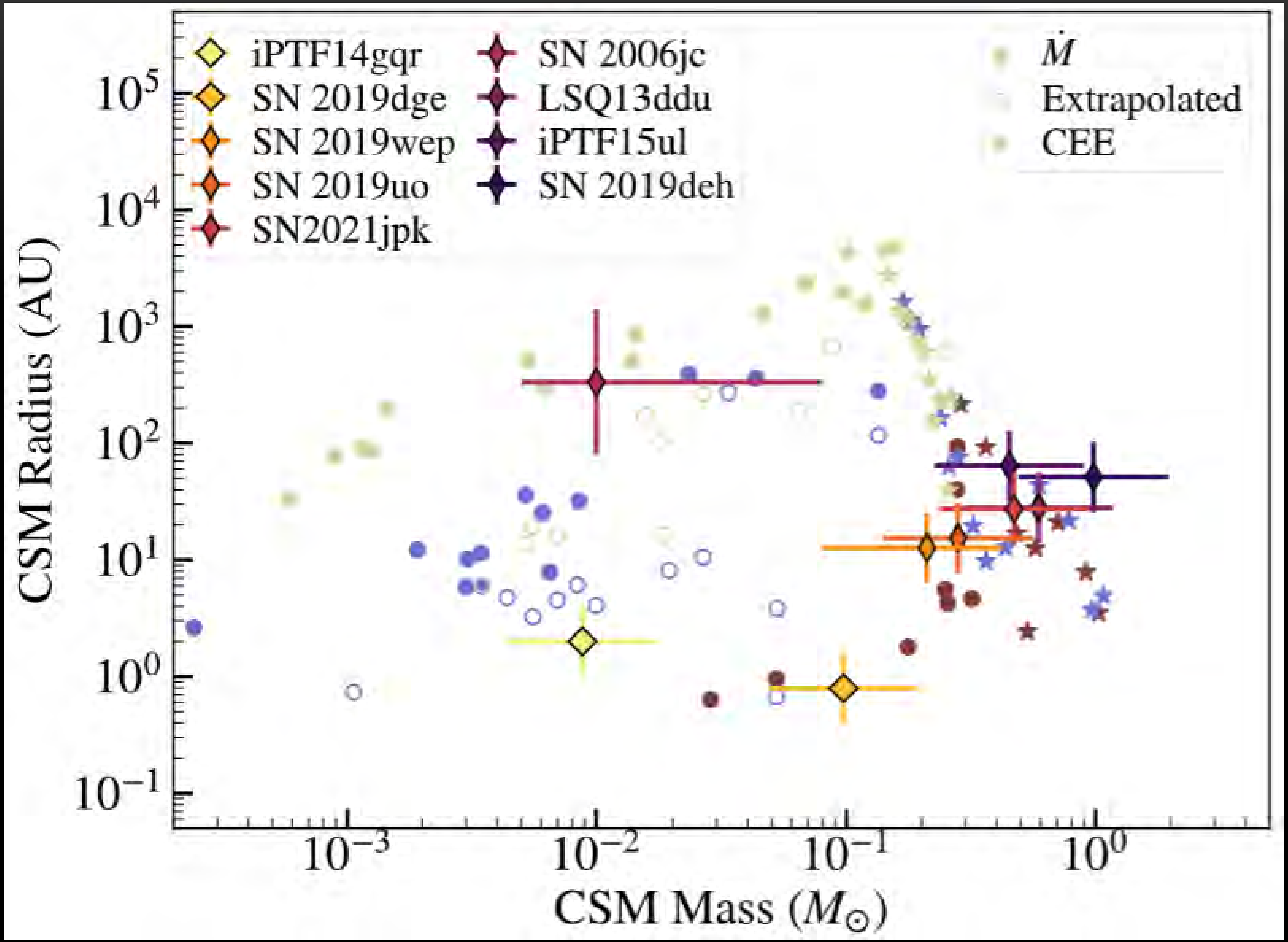


Wu & Fuller 2023



Wu & Fuller 2023

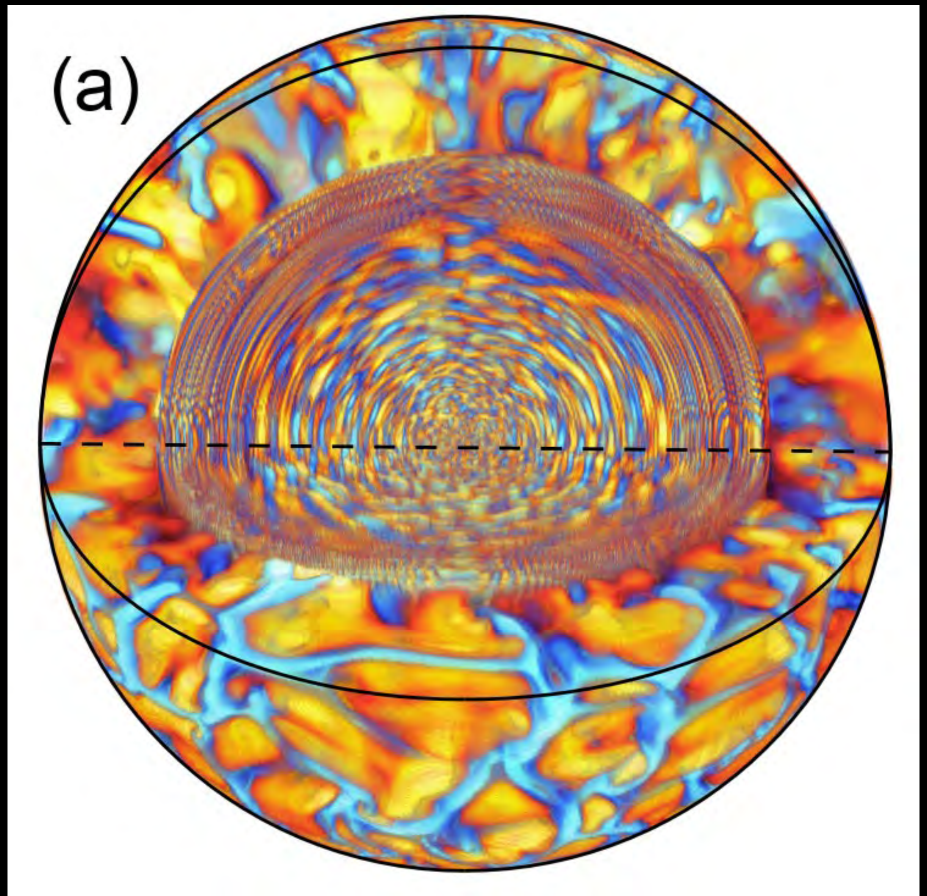
- Promising scenario to produce type Ibn supernovae and CSM in ultra-stripped supernovae

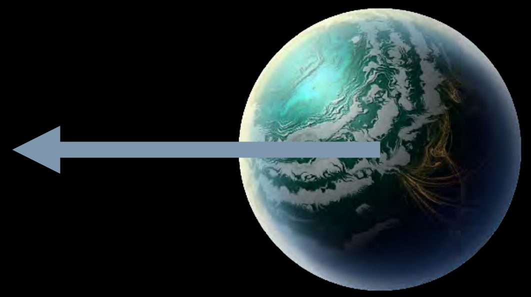


Wu & Fuller 2023

EXOPLANET MIGRATION

- Most exoplanets orbit faster than star spins, so tides cause orbital decay

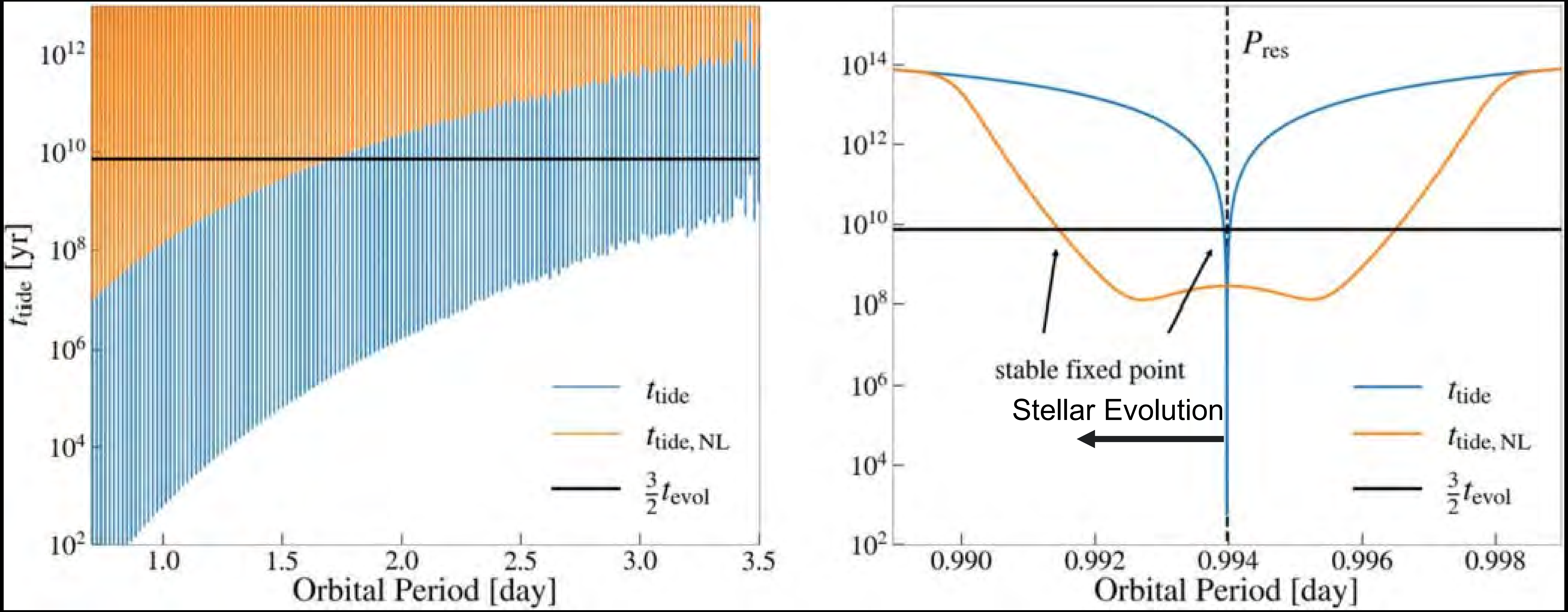




Exoplanets migrate inwards via tides

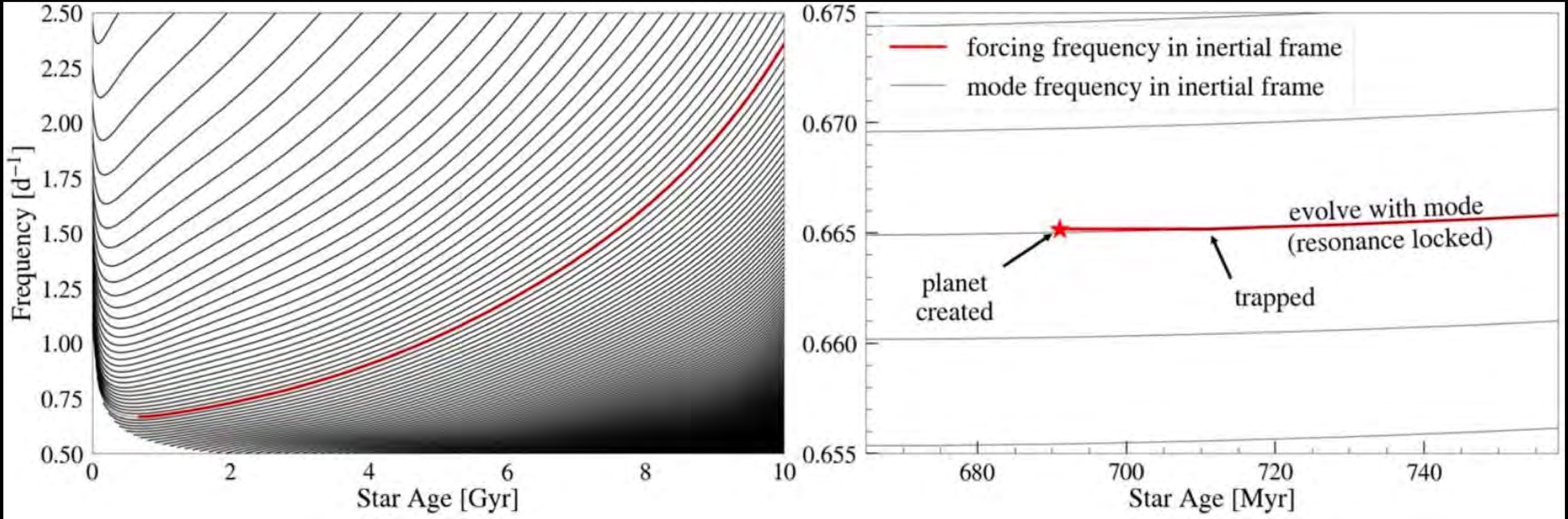
Linhao Ma

STARS HAVE DENSE MODE SPECTRA



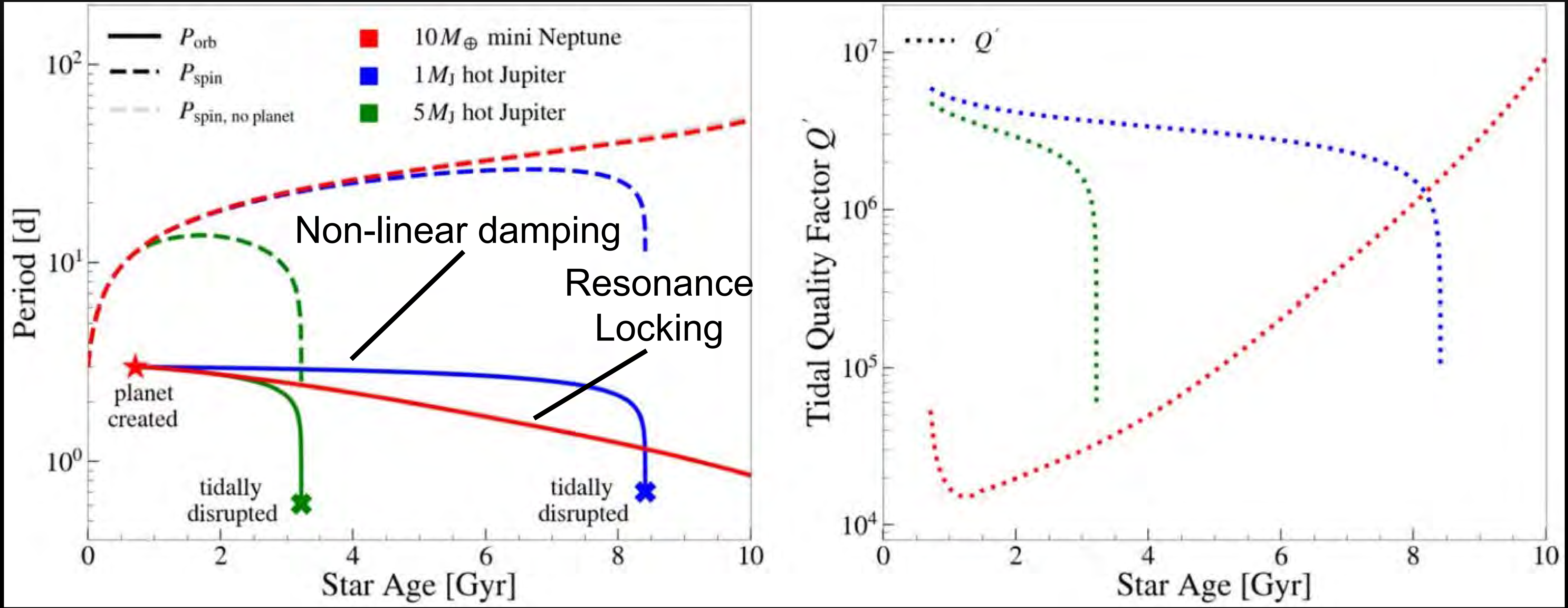
Fuller & Ma, 2021

INWARD MIGRATION VIA RESONANCE LOCKING



Fuller & Ma, 2021

PLANETARY MIGRATION HISTORY



Fuller & Ma, 2021

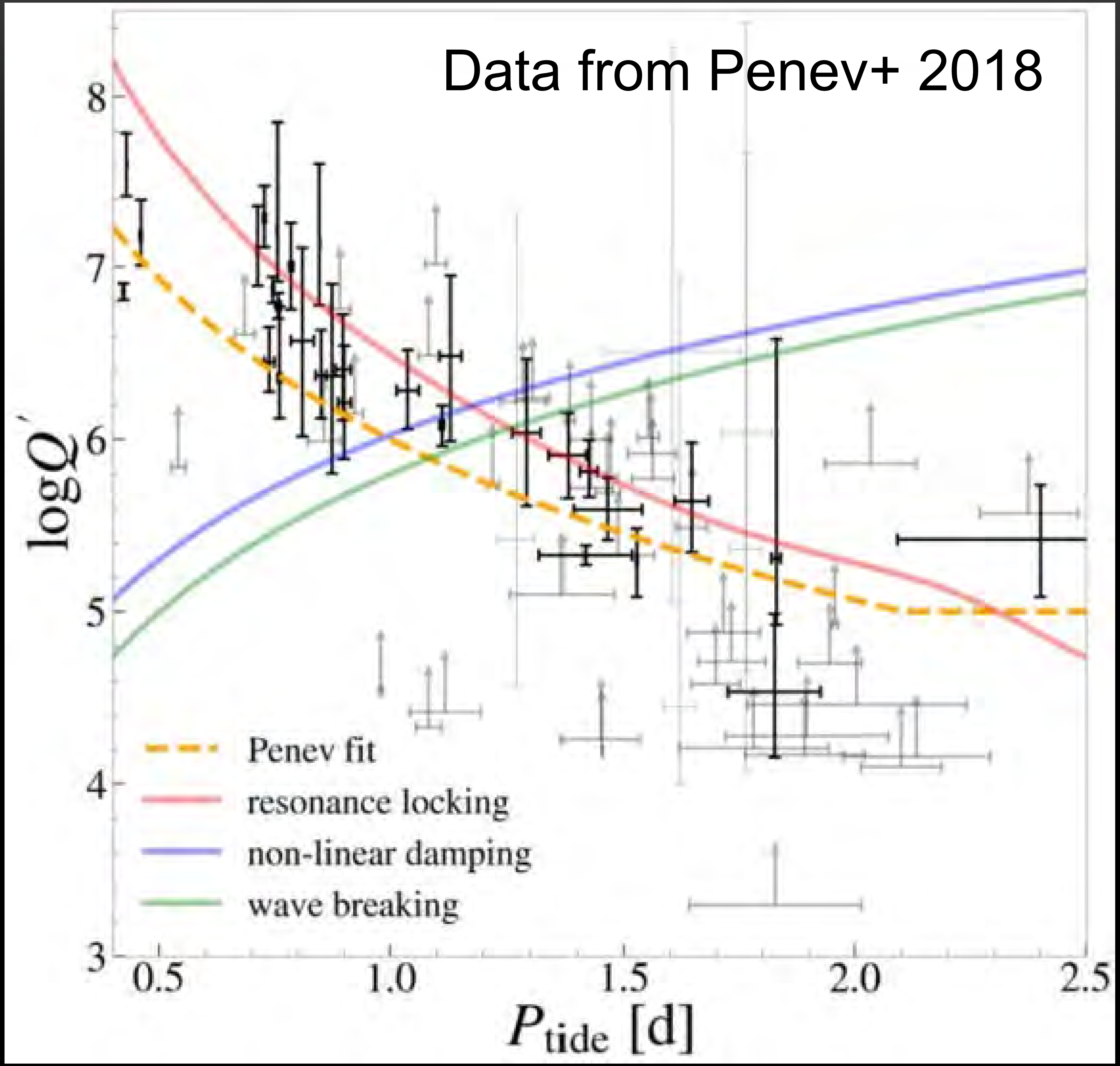
CONSISTENT WITH EMPIRICAL CONSTRAINTS?

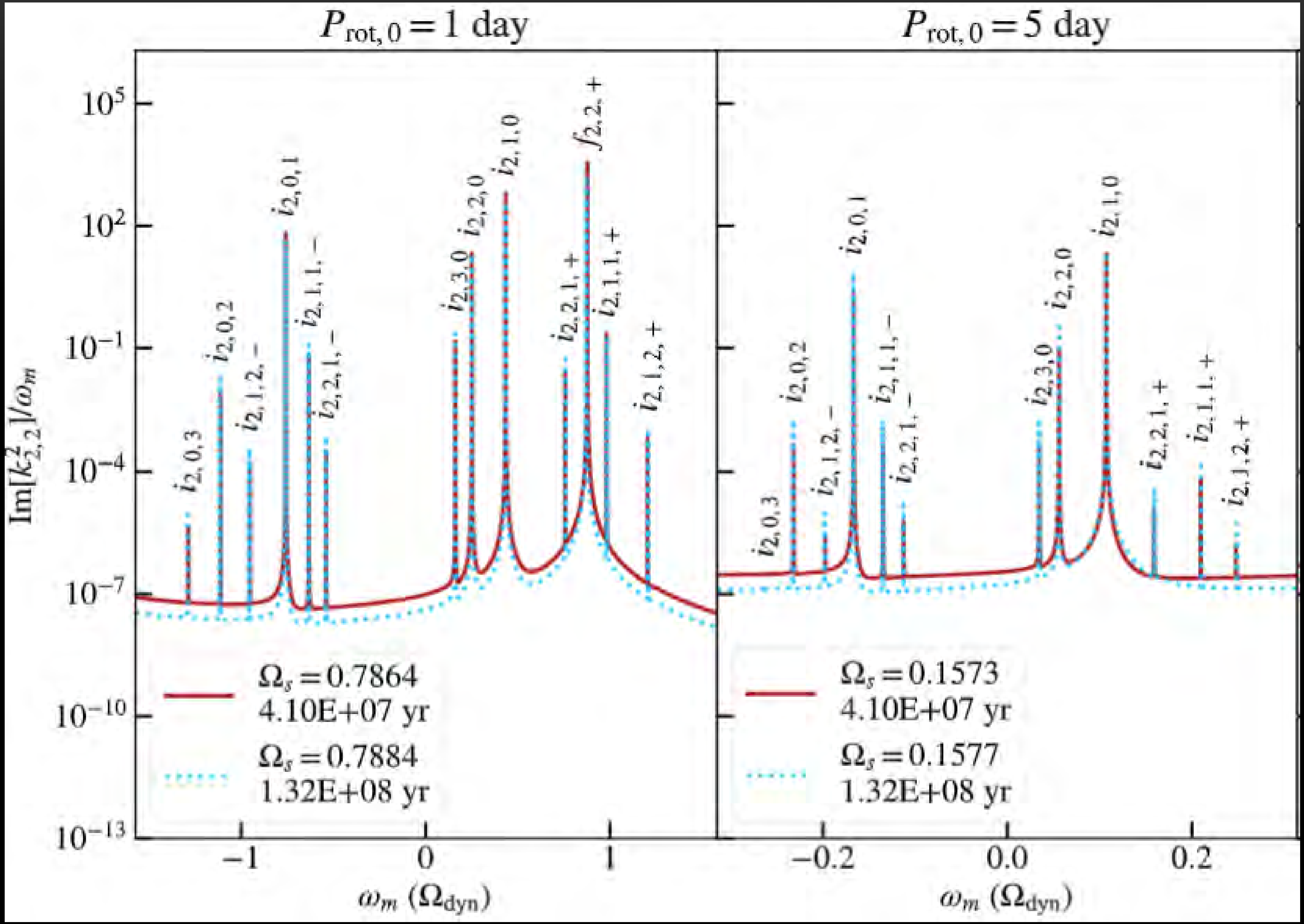
- Resonance locking predicts

$$Q'_{\rm RL} \simeq 2 \times 10^6 \times \left(\frac{M_{\rm p}}{M_{\rm J}}\right)\left(\frac{M_*}{M_\odot}\right)^{-8/3}\left(\frac{R_*}{R_\odot}\right)^5\left(\frac{t_\alpha}{5\ {\rm Gyr}}\right)\left(\frac{P_{\rm orb}}{2\ {\rm days}}\right)^{-13/3}$$

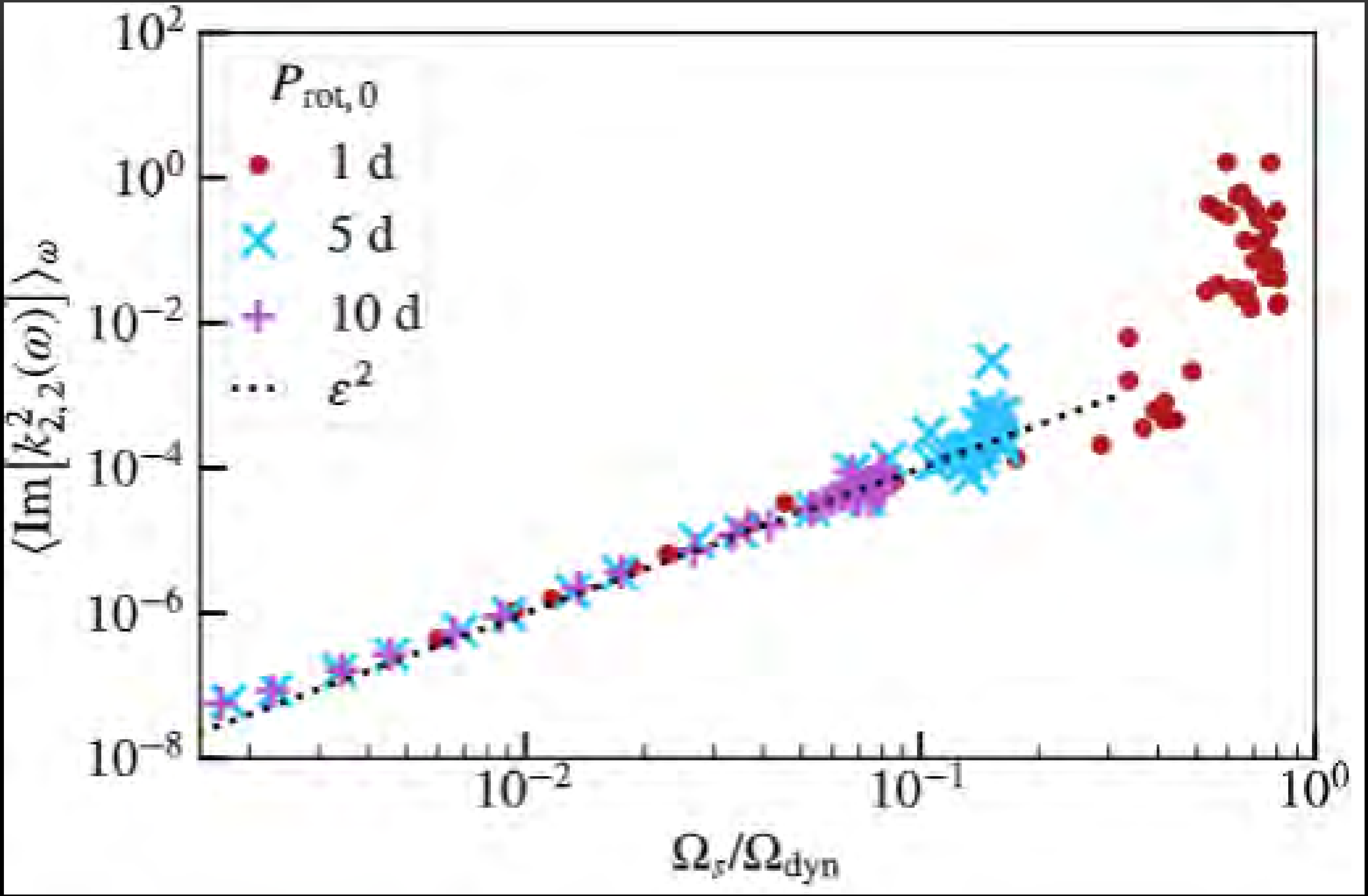
- Similar trend expected if host star age estimates are incorrect

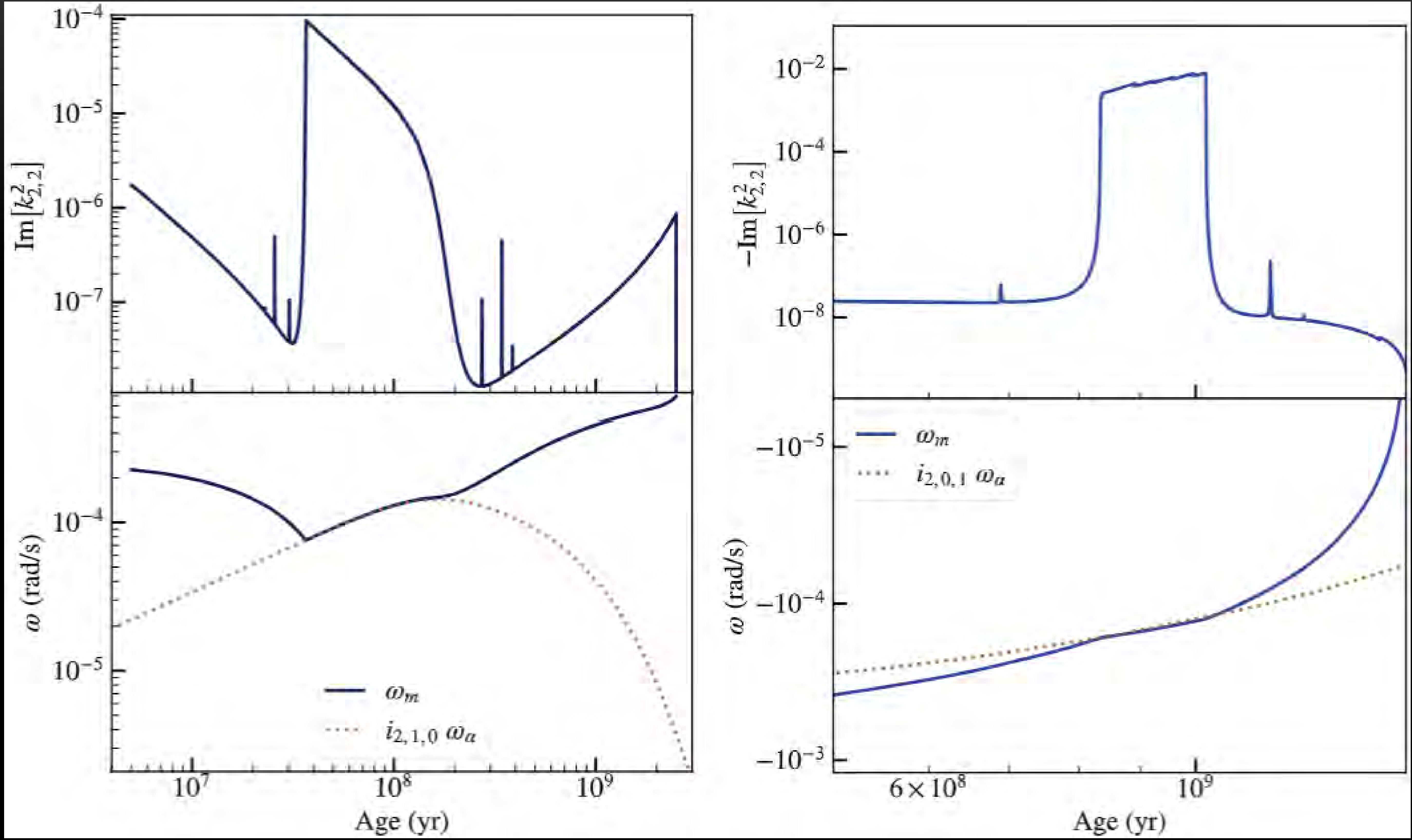
Fuller & Ma, 2021



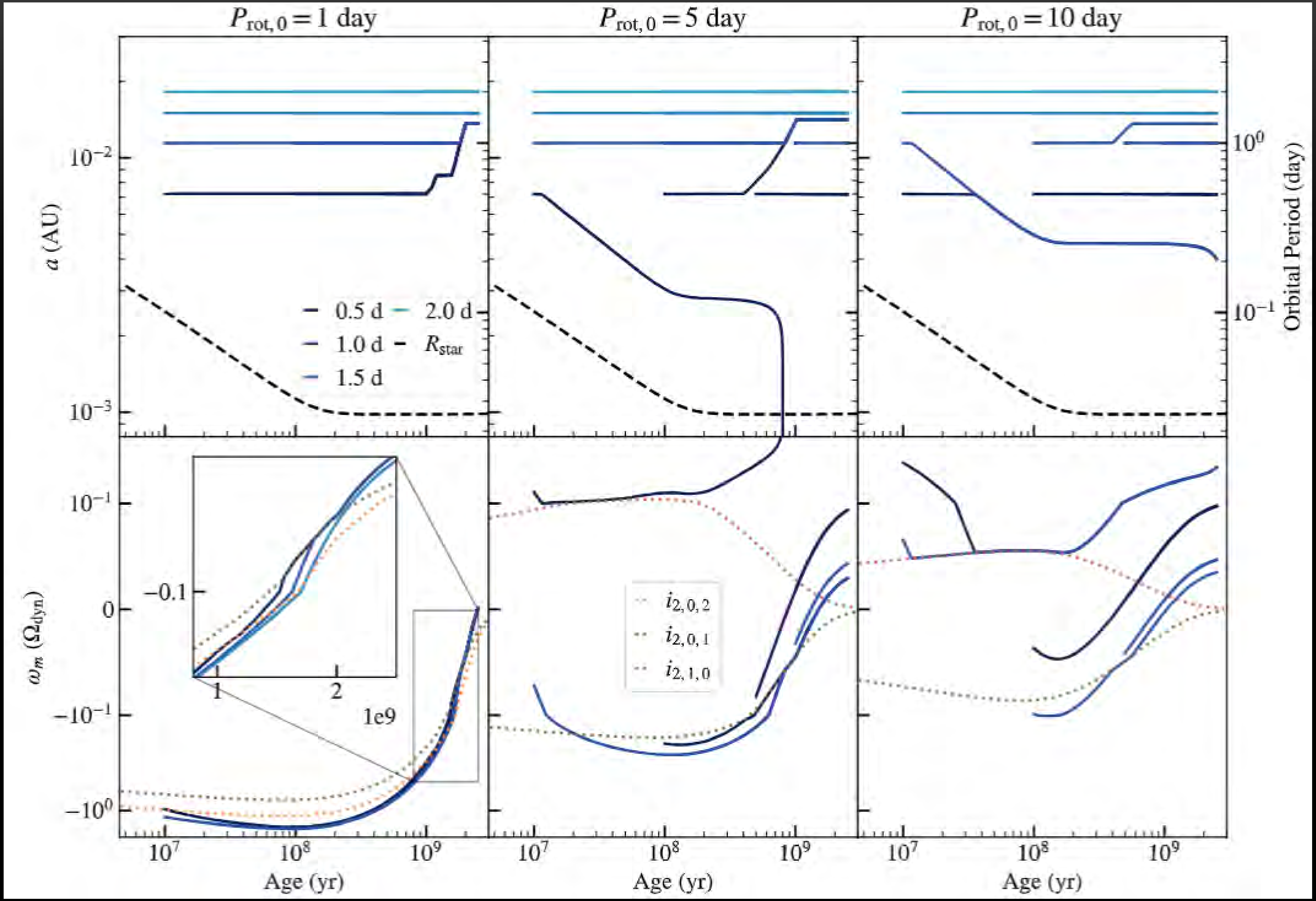


Wu & Fuller, 2024


$P_{\rm rot,0}$
1 d
5 d
10 d
ε^2
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
$\langle \mathrm{Im}[k^2_{2,2}(\omega)] \rangle_\omega$
10^{-2}
10^{-1}
10^0
$\Omega_s/\Omega_{\rm dyn}$



Wu & Fuller, 2024



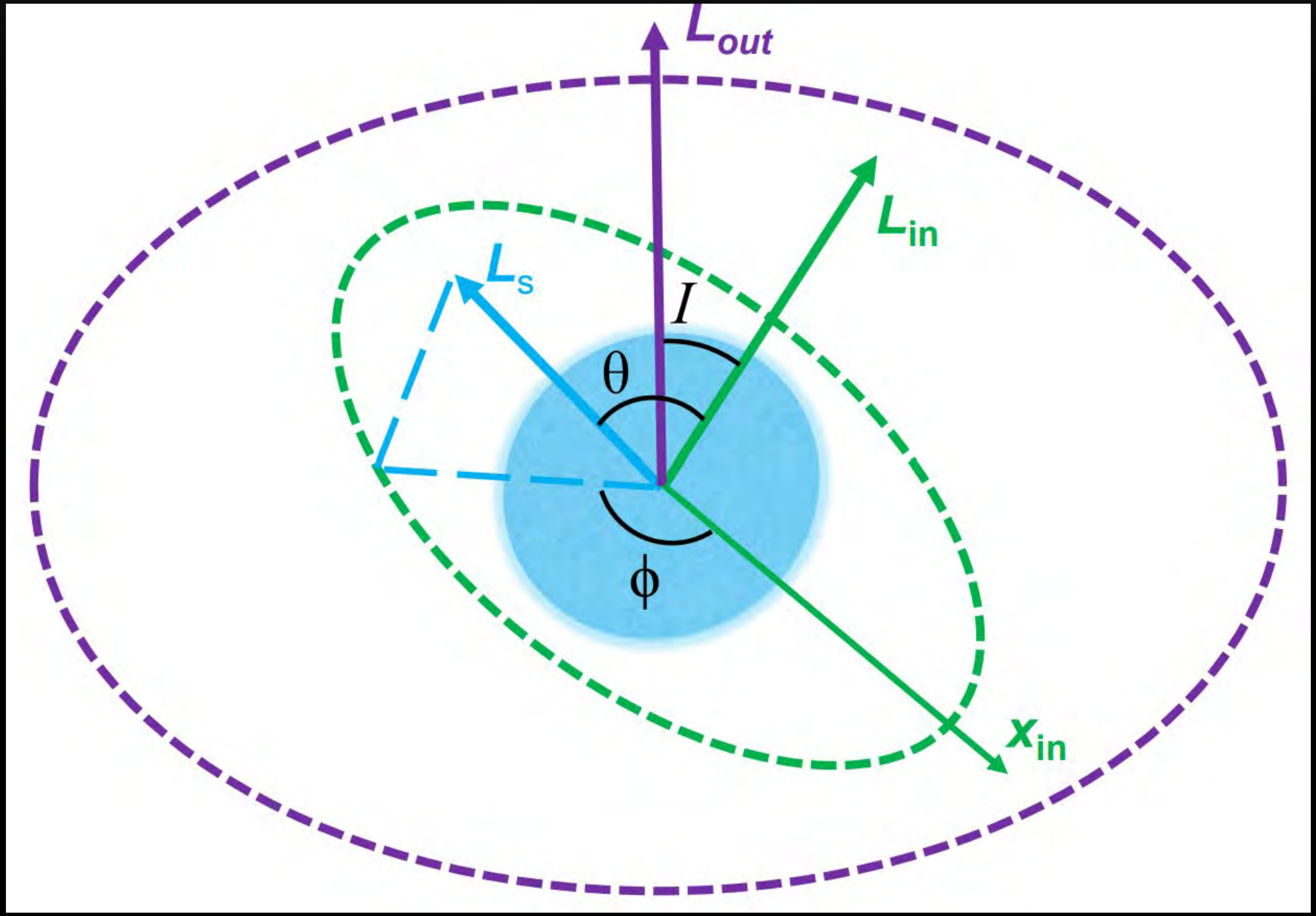
Wu & Fuller, 2024

SUPER SLOWLY SPINNING STARS

Name	M_1 ($M_\odot$)	M_2 ($M_\odot$)	R ($R_\odot$)	P_{orb} (d)	P_{rot} (d)
KIC 4480321	$1.5^{+0.3}_{-0.2}$	$1.5^{+0.3}_{-0.2}$	$1.9^{+0.5}_{-0.5}$	9.166^{+6e-05}_{-6e-05}	$121.0^{+4.0}_{-4.0}$
KIC 8197761	$1.384^{+0.281}_{-0.276}$	0.28^{+7e-01}_{-0e+00}	$1.717^{+0.858}_{-0.41}$	9.869^{+3e-07}_{-3e-07}	$301.0^{+3.0}_{-3.0}$
·KIC 4142768	$2.05^{+0.03}_{-0.03}$	$2.05^{+0.03}_{-0.03}$	$2.96^{+0.04}_{-0.04}$	13.996^{+6e-05}_{-6e-05}	$2702.7^{+1300.0}_{-662.0}$
KIC 8429450	$1.68^{+0.2}_{-0.13}$	$1.462^{+0.174}_{-0.113}$	$2.438^{+0.083}_{-0.081}$	2.705^{+2e-07}_{-2e-07}	$38.0^{+128.0}_{-17.0}$
HD 201433	$3.05^{+0.025}_{-0.025}$	$0.7^{+0.3}_{-0.3}$	$2.6^{+0.2}_{-0.2}$	3.313^{+5e-04}_{-5e-04}	$292.0^{+76.0}_{-76.0}$
KIC 9850387	$1.47^{+0.14}_{-0.14}$	$0.79^{+0.08}_{-0.08}$	$2.04^{+0.06}_{-0.06}$	2.749^{+5e-06}_{-5e-06}	$188.68^{+74.5}_{-41.6}$
HD 126516	$1.34^{+0.2}_{-0.2}$	$0.28^{+0.03}_{-0.03}$	$1.66^{+0.08}_{-0.08}$	2.124^{+1e-07}_{-1e-07}	$18.3^{+2.8}_{-7.7}$

CASSINI STATES

- Complex spin-orbit dynamics induced by tertiary companion
- Spin axis precession due to centrifugal distortion
- Orbital precession induced by tertiary
- Tidal alignment and synchronization



CASSINI STATE 1

- Nearly aligned and synchronous rotation

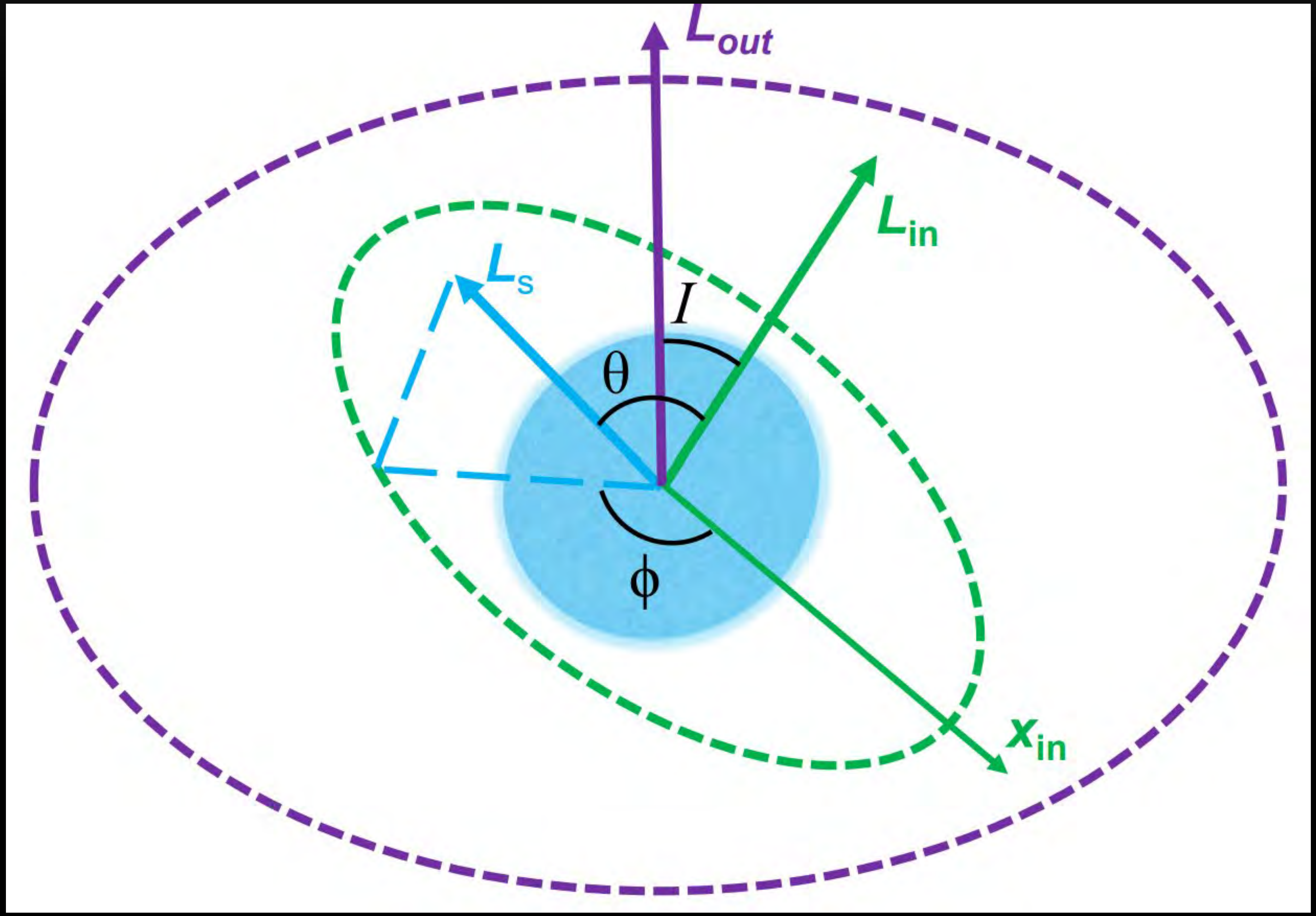
Cassini State 2

- Nearly orthogonal and very slow rotation

$$\cos\theta_{\rm eq} \simeq \sqrt{\eta_{\rm sync}\cos I/2}$$

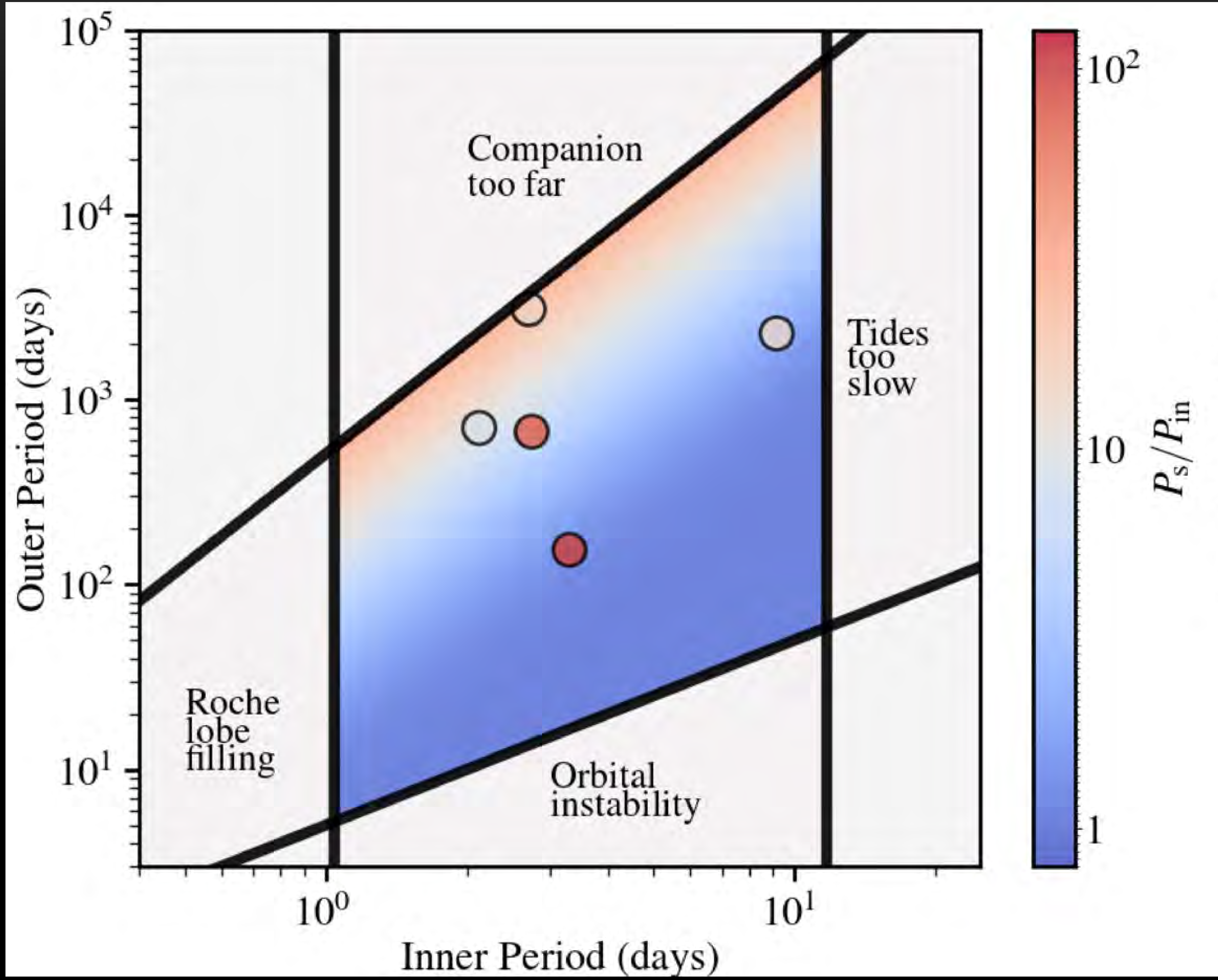
$$\Omega_{s,\rm eq} \simeq \sqrt{2\eta_{\rm sync}\cos I}$$

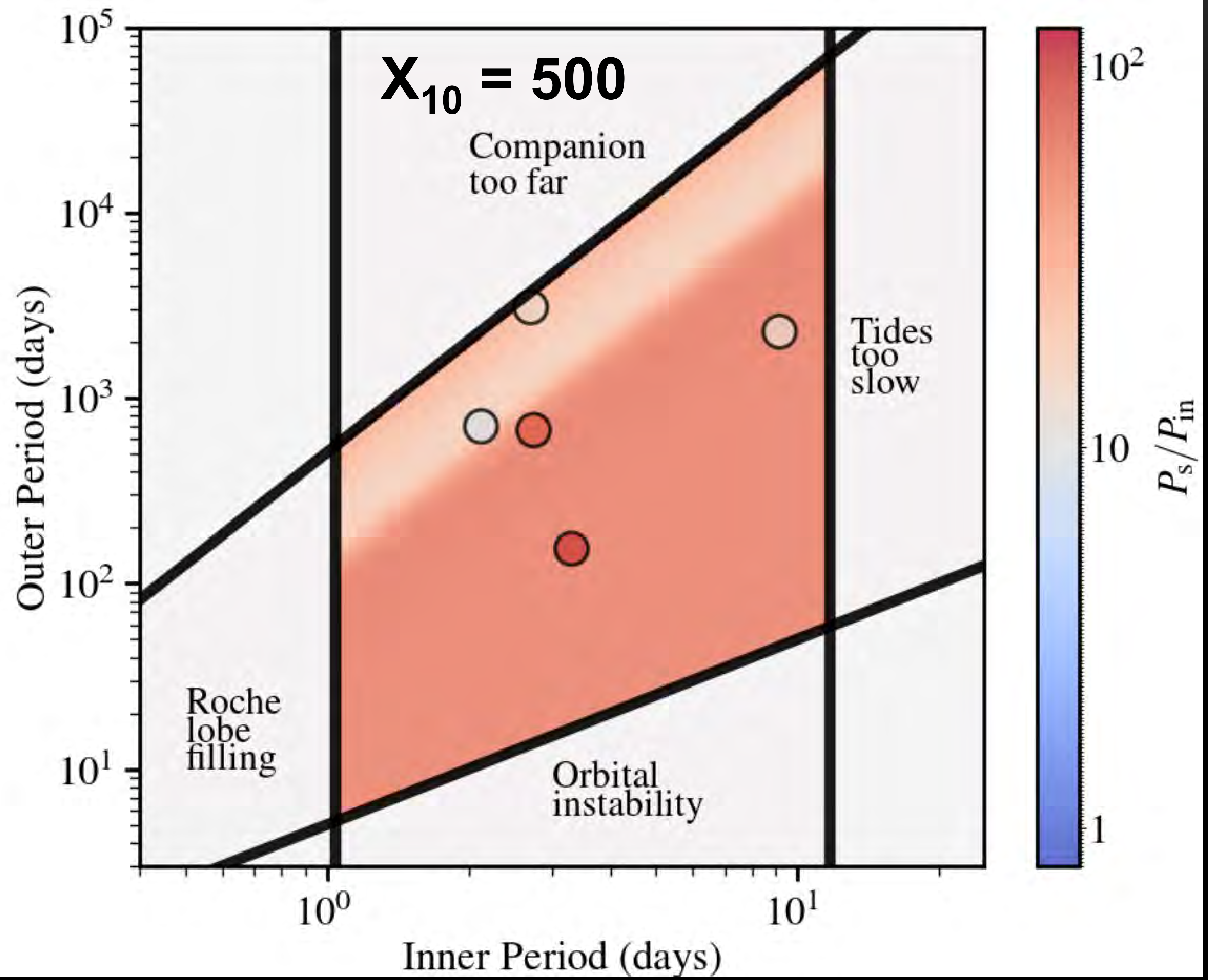
$$\eta_{\rm sync} = \frac{3k}{k_2}\frac{M_{\rm out}M_1}{M_2(M_1+M_2)}\left(\frac{a_{\rm in}}{R}\right)^3\left(\frac{a_{\rm in}}{a_{\rm out}}\right)^3\cos I$$



Equilibrium Tides

Inertial Waves

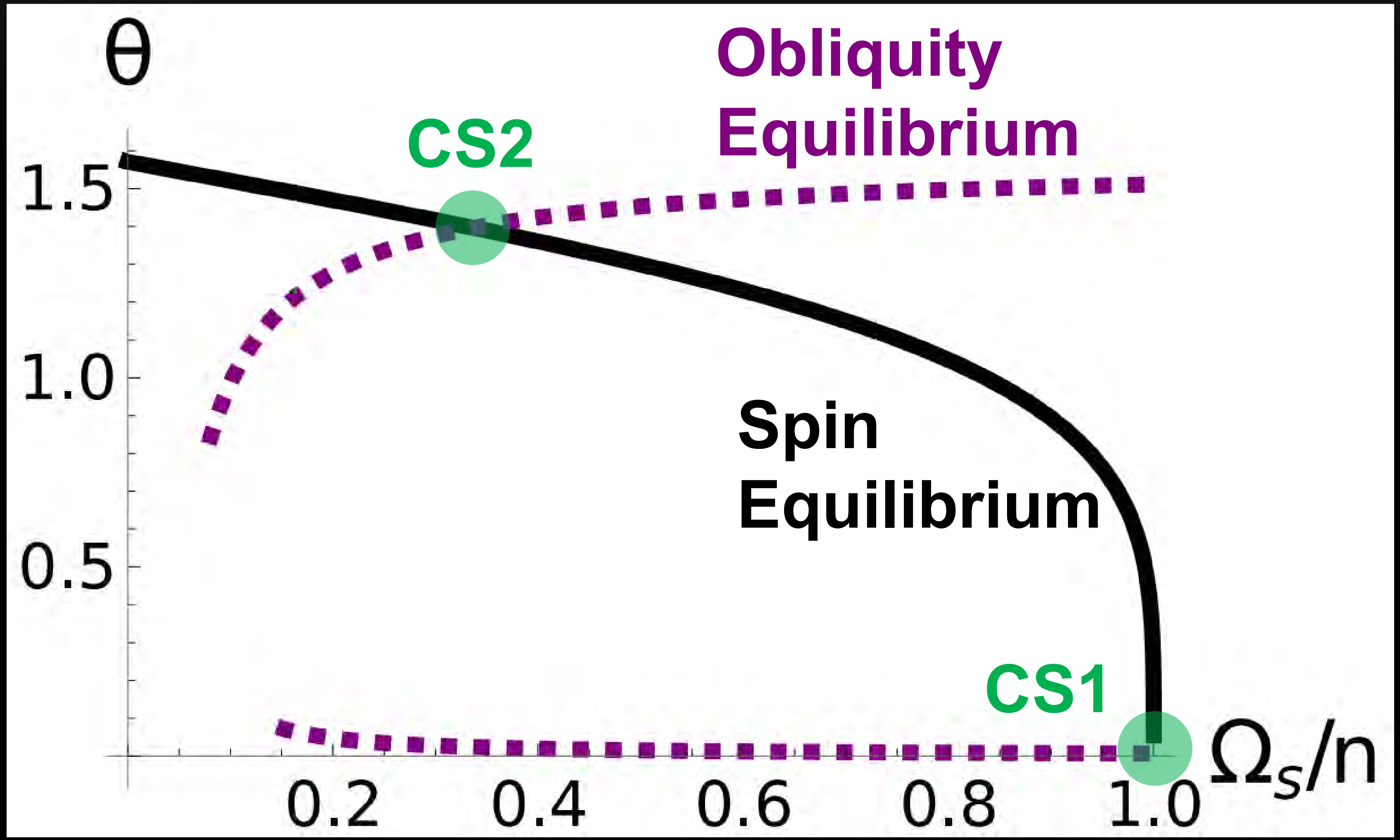




$$\Omega_{s,\mathrm{eq}} \simeq \sqrt{2\eta_{\mathrm{sync}} \cos I}$$

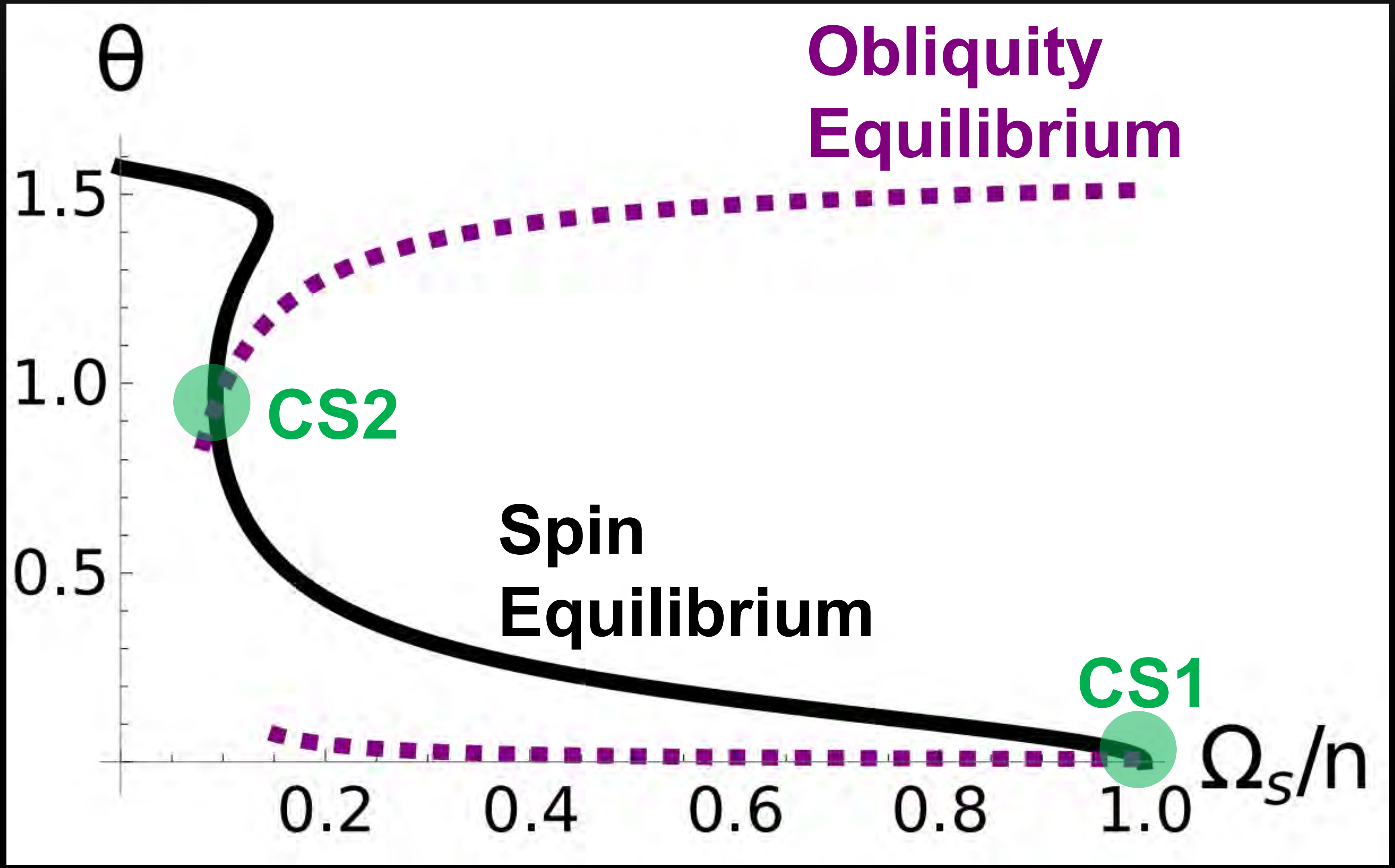
$$\Omega_{s,\mathrm{eq}} \simeq \mp \frac{4n}{X_{10} \sin^2 I \cos I}$$

Equilibrium Tides



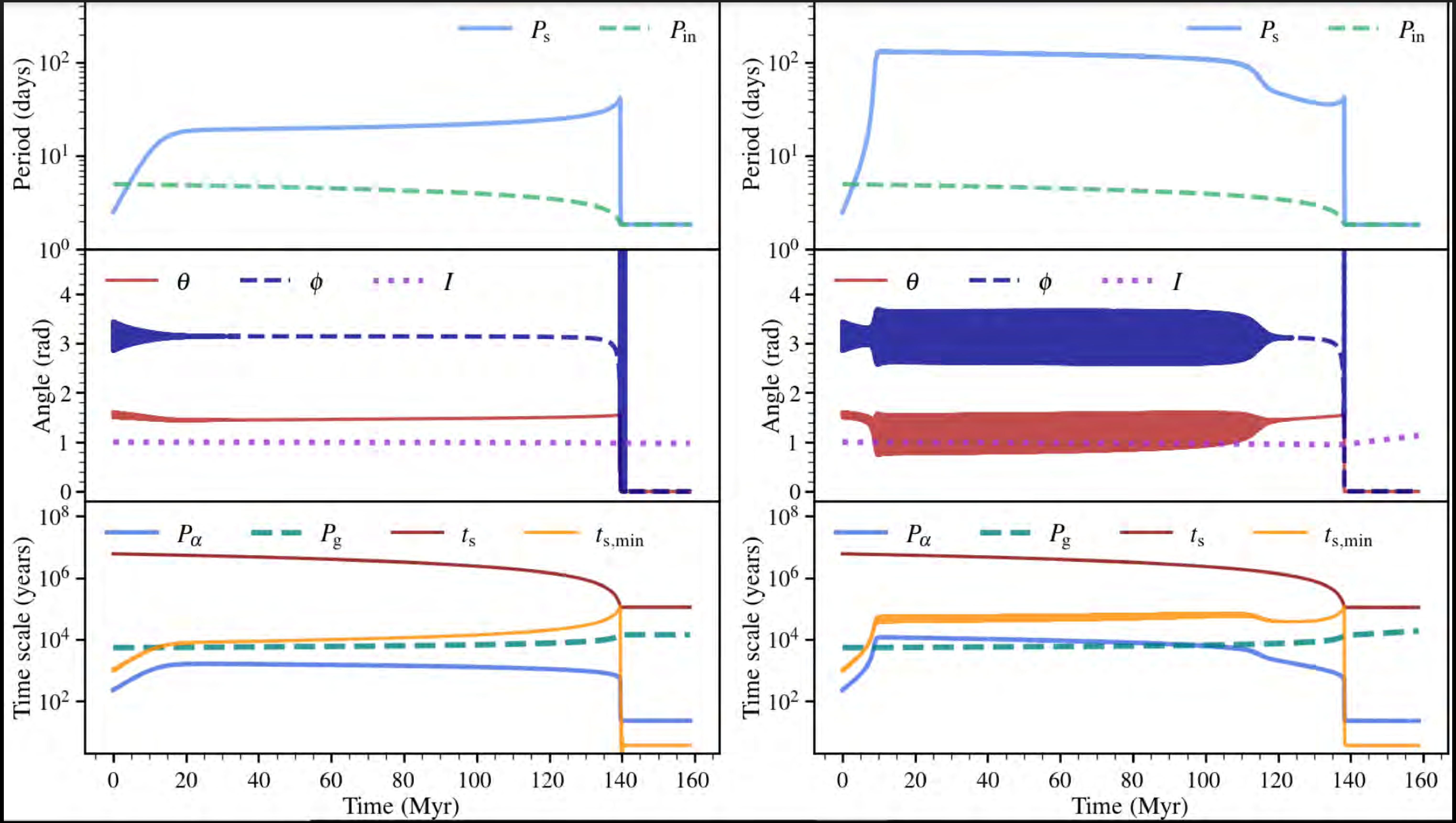
$$\Omega_{s,\mathrm{eq}} \simeq \sqrt{2\eta_{\mathrm{sync}} \cos I}$$

Inertial Waves

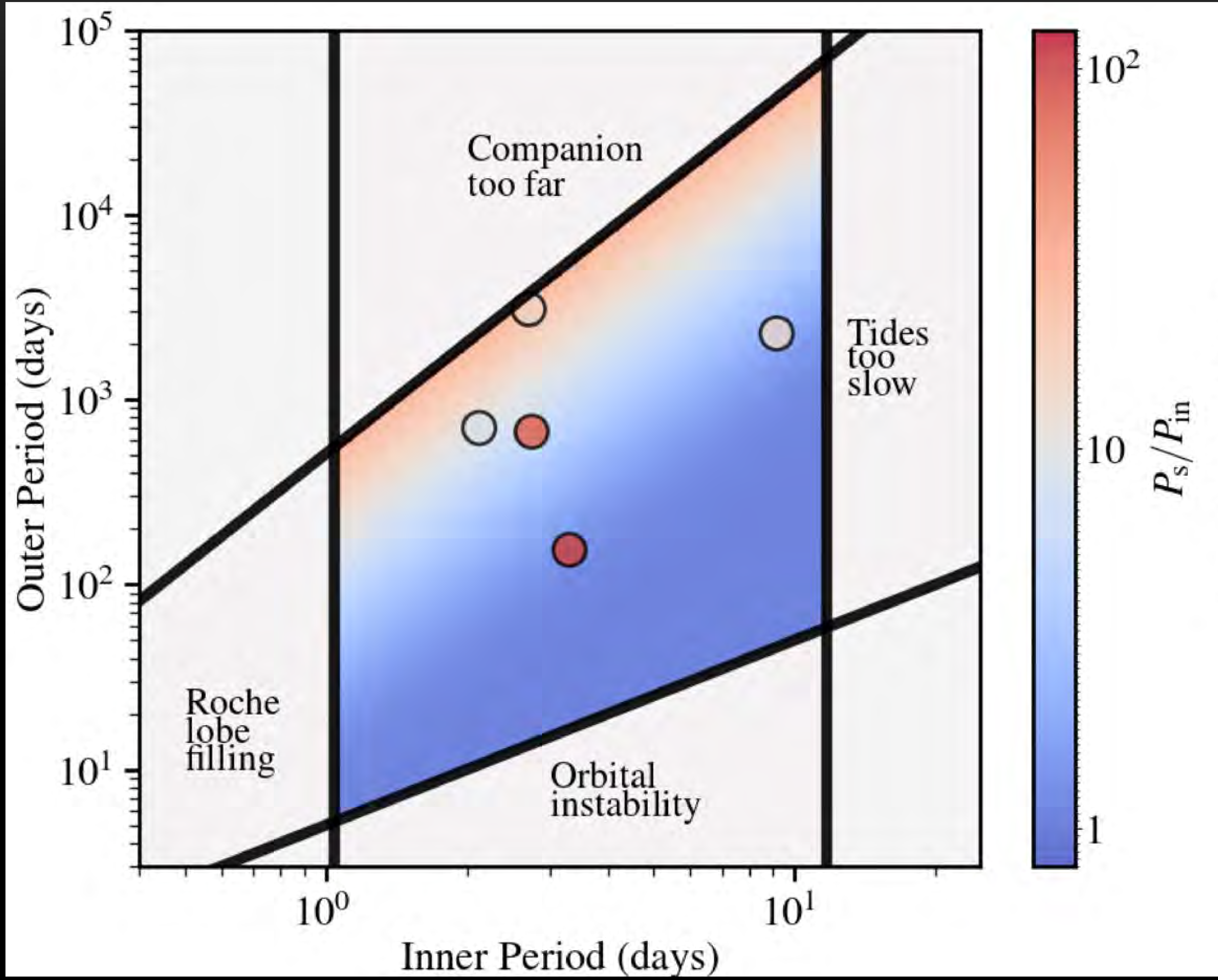


$$\Omega_{s,\mathrm{eq}} \simeq \mp \frac{4n}{X_{10} \sin^2 I \cos I}$$

Equilibrium Tides   Inertial Waves

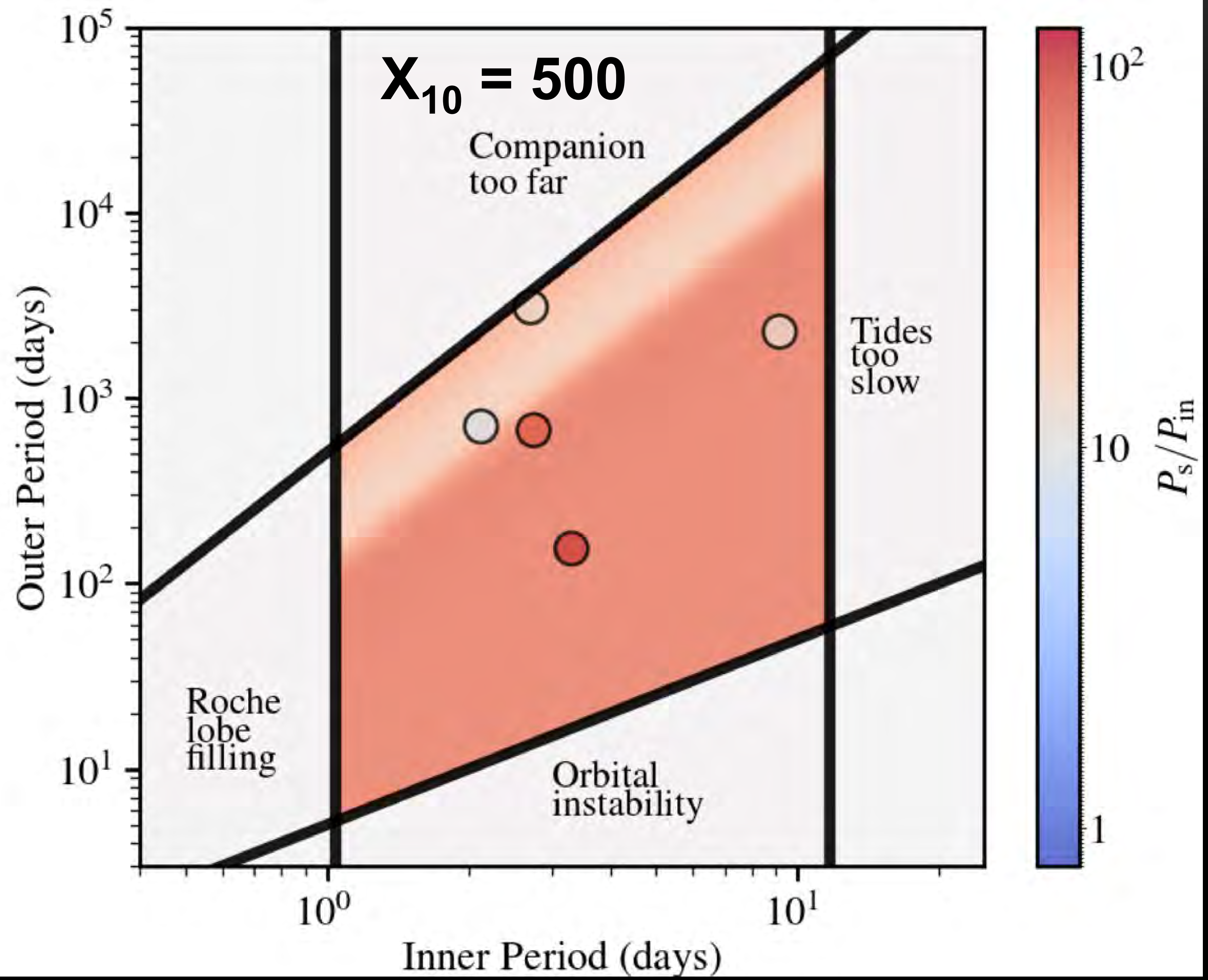


Equilibrium Tides



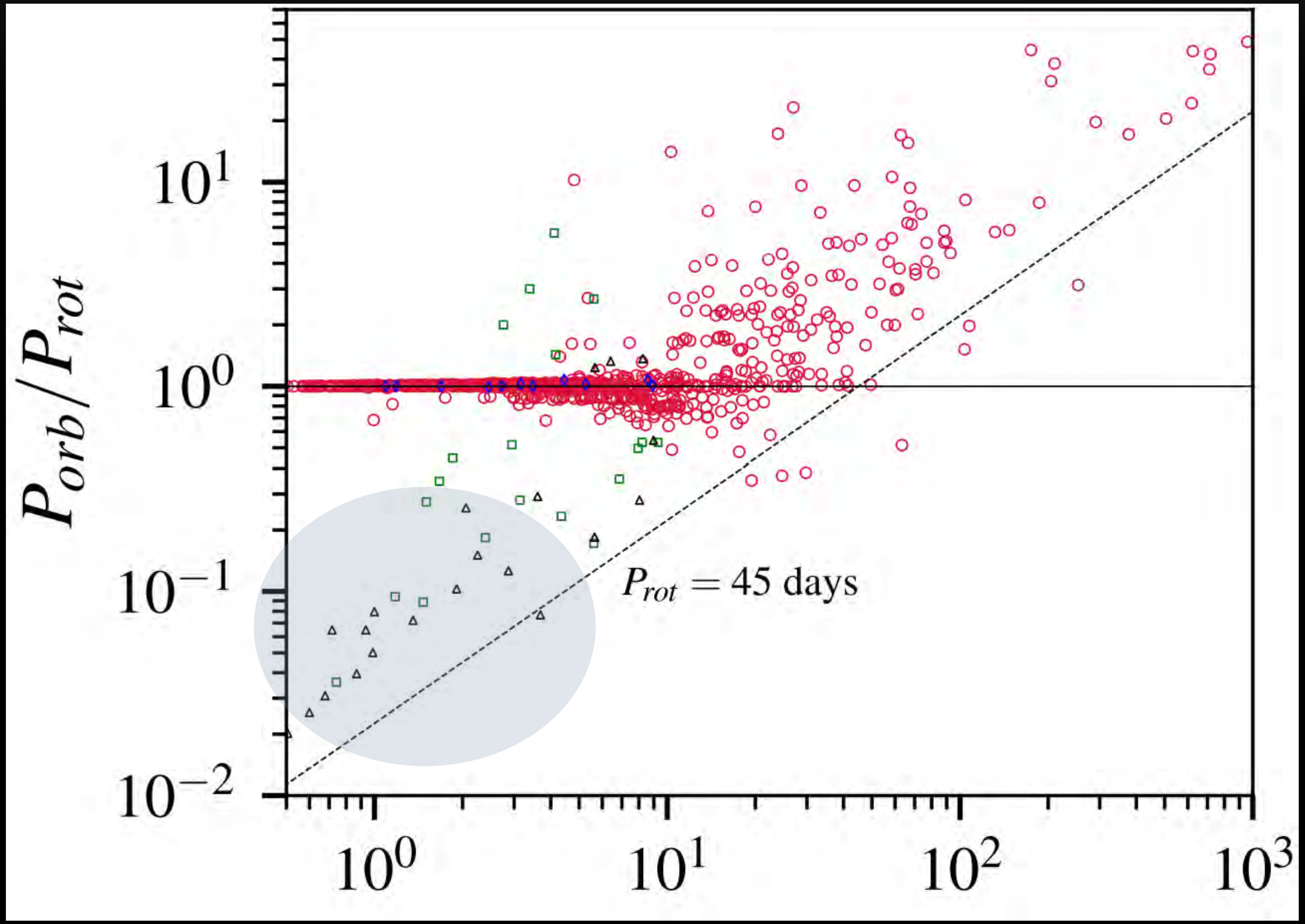
$$\Omega_{s,\mathrm{eq}} \simeq \sqrt{2\eta_{\mathrm{sync}} \cos I}$$

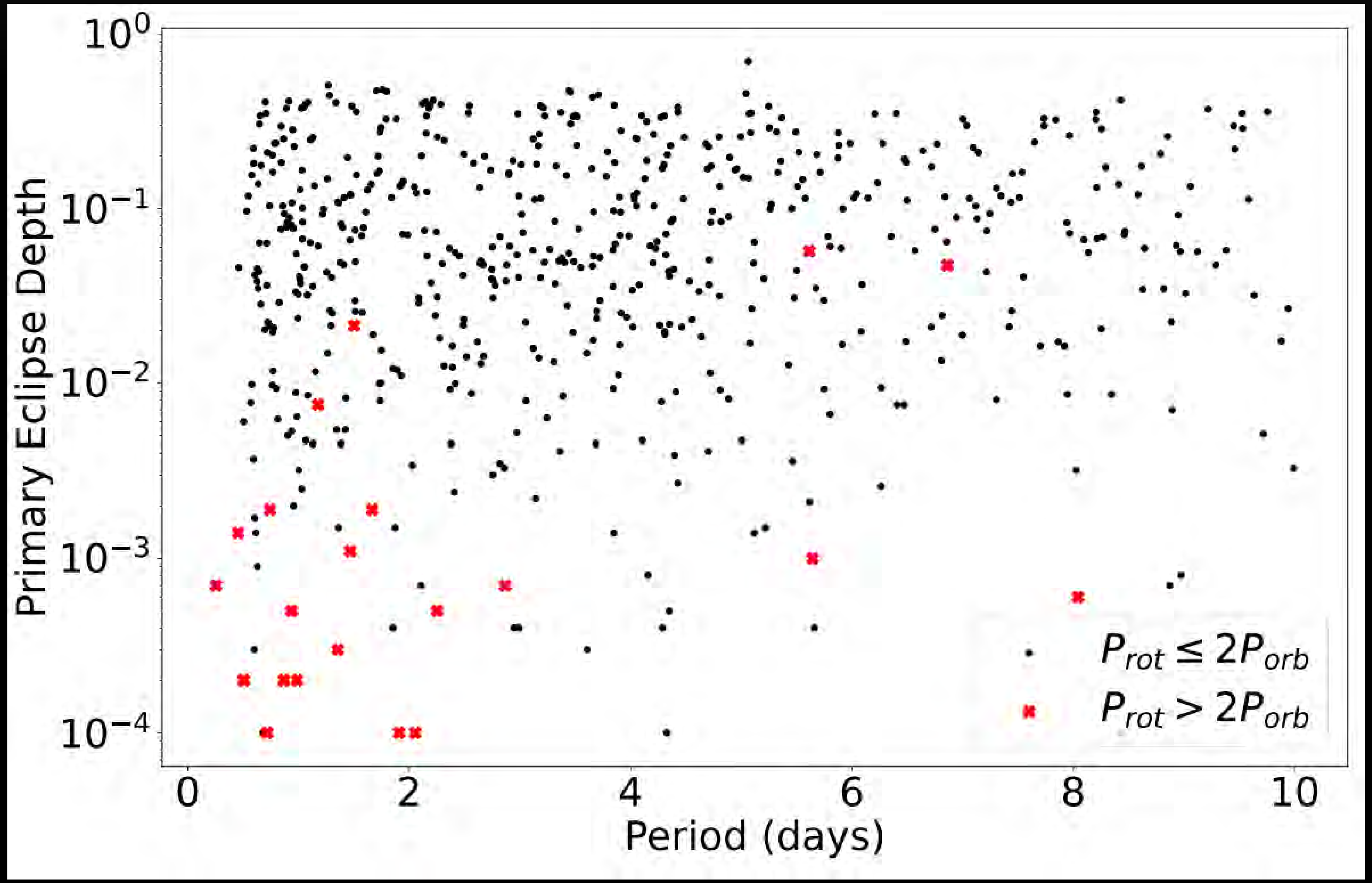
Inertial Waves



$$\Omega_{s,\mathrm{eq}} \simeq \mp \frac{4n}{X_{10} \sin^2 I \cos I}$$

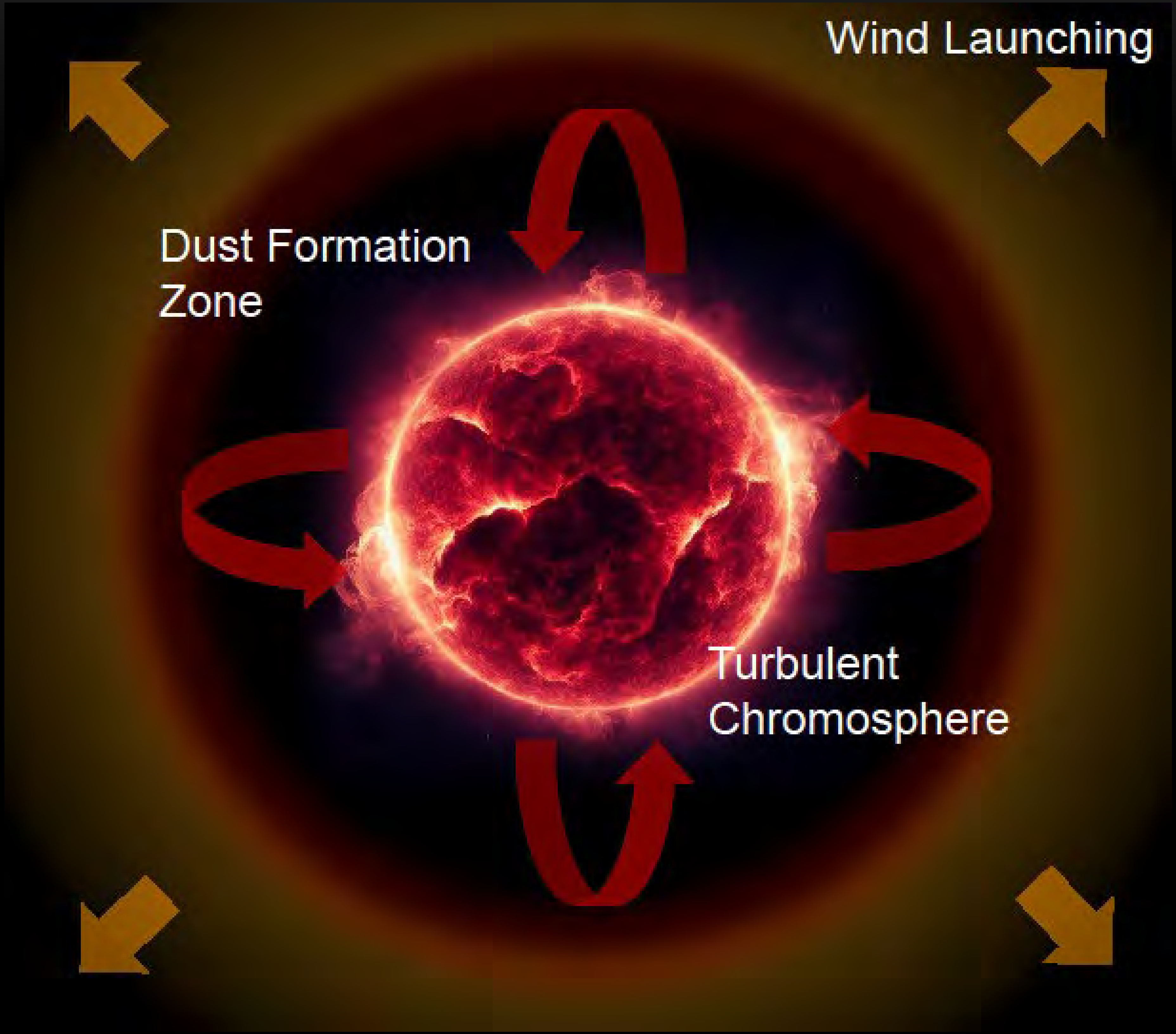
THE SEARCH FOR STARS IN CS2

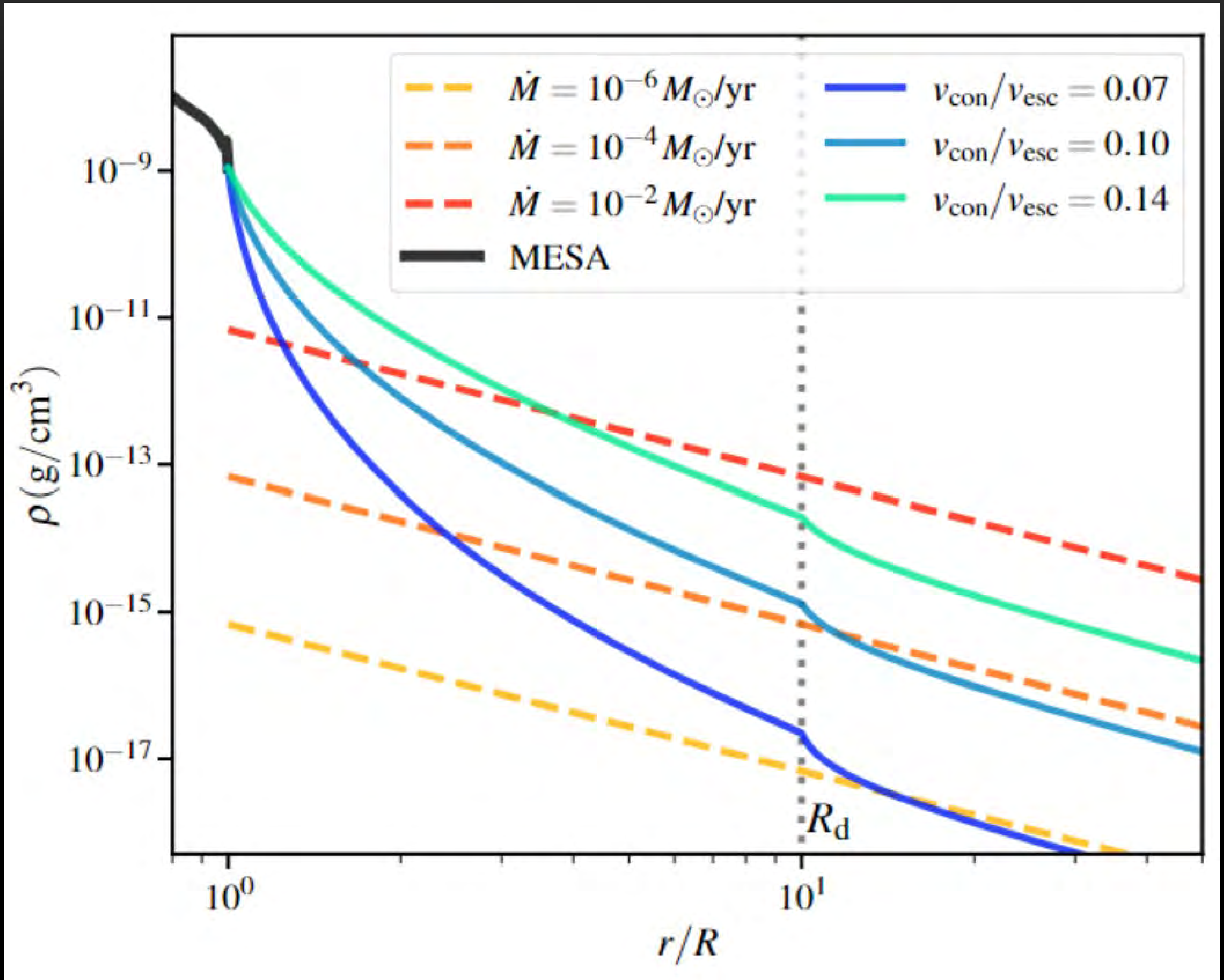




Lurie+ 2017

CSM AND MASS LOSS FROM RED SUPERGIANTS





$\dot{M} = 10^{-6} M_\odot/\mathrm{yr}$
$\dot{M} = 10^{-4} M_\odot/\mathrm{yr}$
$\dot{M} = 10^{-2} M_\odot/\mathrm{yr}$
MESA
$v_{\mathrm{con}}/v_{\mathrm{esc}} = 0.07$
$v_{\mathrm{con}}/v_{\mathrm{esc}} = 0.10$
$v_{\mathrm{con}}/v_{\mathrm{esc}} = 0.14$
10^{-9}
10^{-11}
10^{-13}
10^{-15}
10^{-17}
$\rho\,(\mathrm{g/cm^3})$
R_d
10^0
10^1
r/R

PROJECTS!

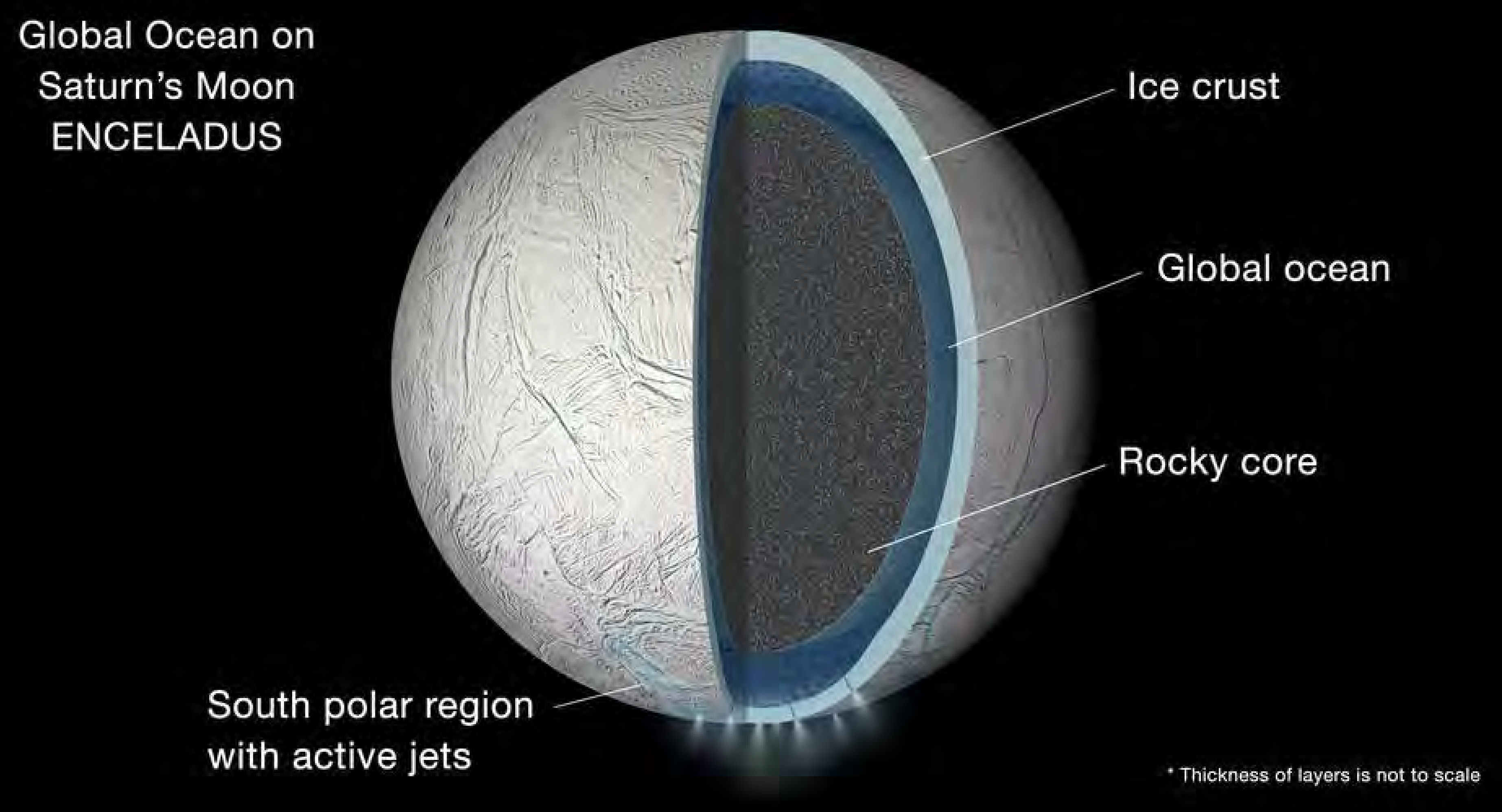
- Chromospheres and mass loss of red supergiants
  - Perform Athena++ sims of red supergiants
  - Very computational

Projects!

- Giant planet seismology and moon migration
  - Make evolving planetary models
  - Calculate evolving oscillation mode frequencies
  - Compute moon migration rates
  - Computational/analytical

Projects!

- Asymmetry of crusts in moons subject to tidal heating
  - Thinner part of crust flexed more, heated more, melts and gets thinner
  - May explain why the thickness of crust varies in Moon, Enceladus, etc.
  - Analytical



Projects!

- Constrain structure of exoplanets
  - Tidal Qs disappation appears to be very small in super-Earths
  - May require liquid silicate cores/crusts
  - Analytical