The effect of late giant collisions on the atmospheres of protoplanets

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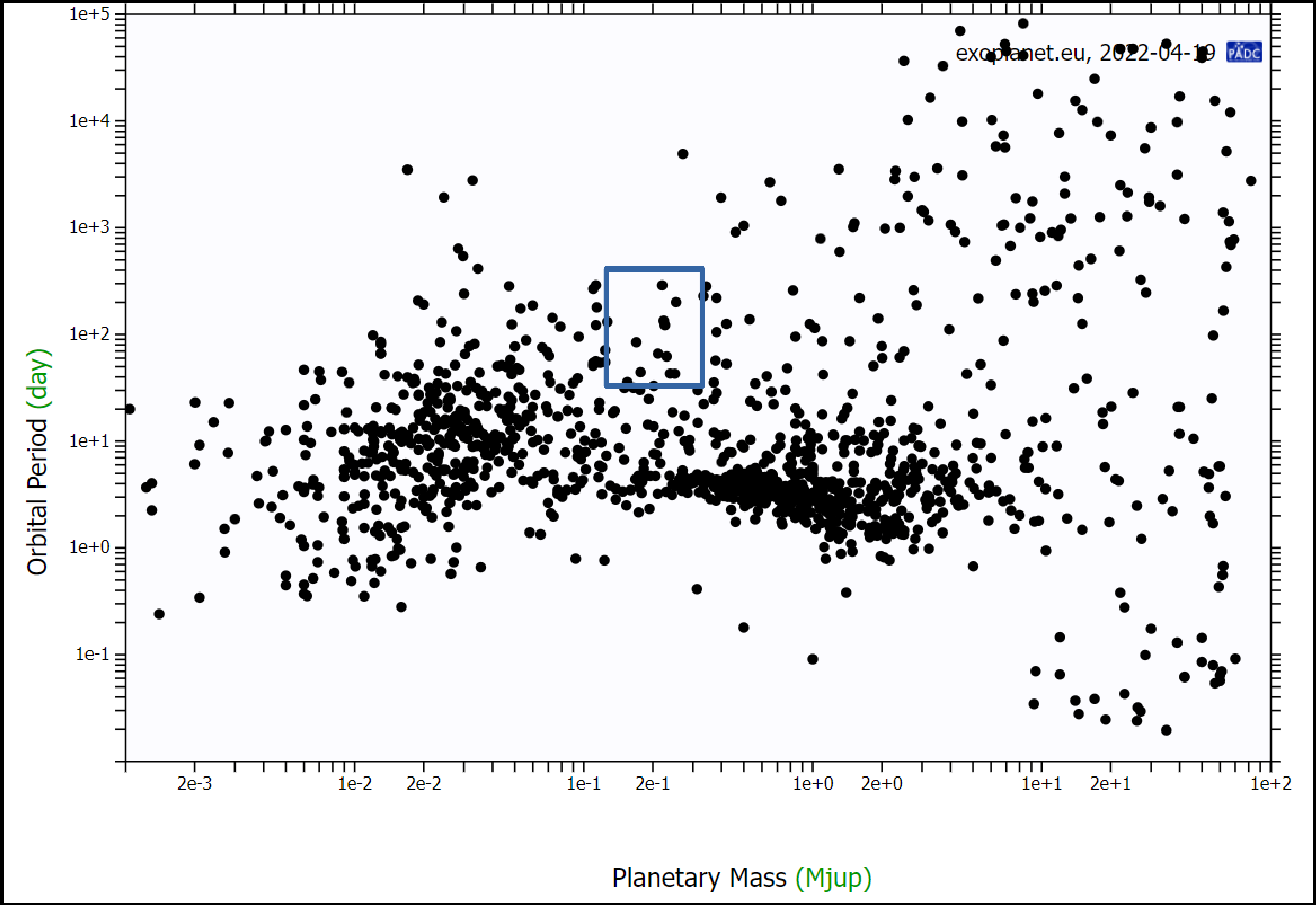
Ali-Dib, M., Cumming A. & Lin, D.N.C. (2022) MNRAS 509, Issue 1, pp.1413-1431

Motivation: how to make cold sub-Saturns ?



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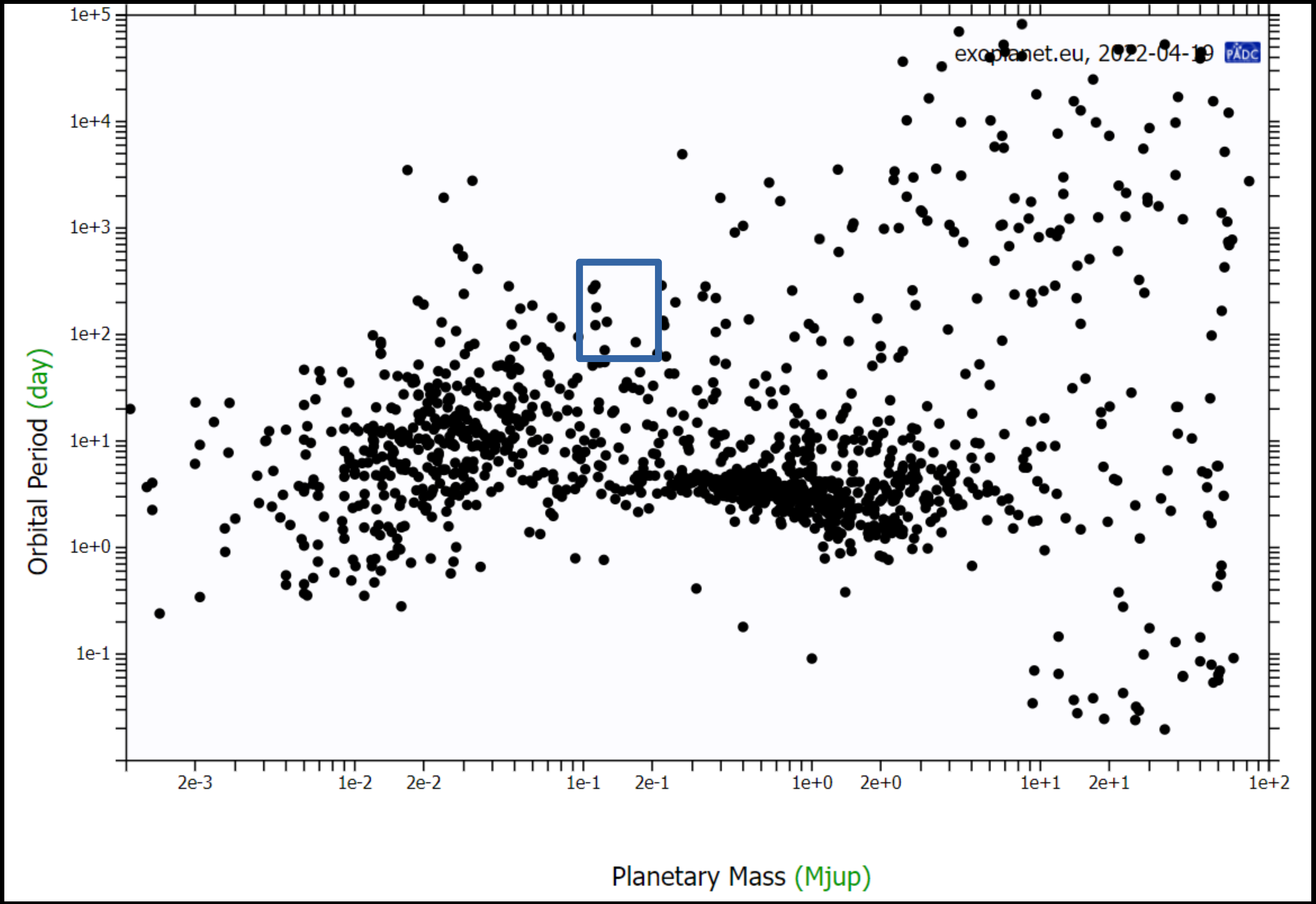

Mass: 40-60 M_{Earth}

Semi-major axis: few AU

Bias corrected occurrence rate: 0.1-0.5 per star

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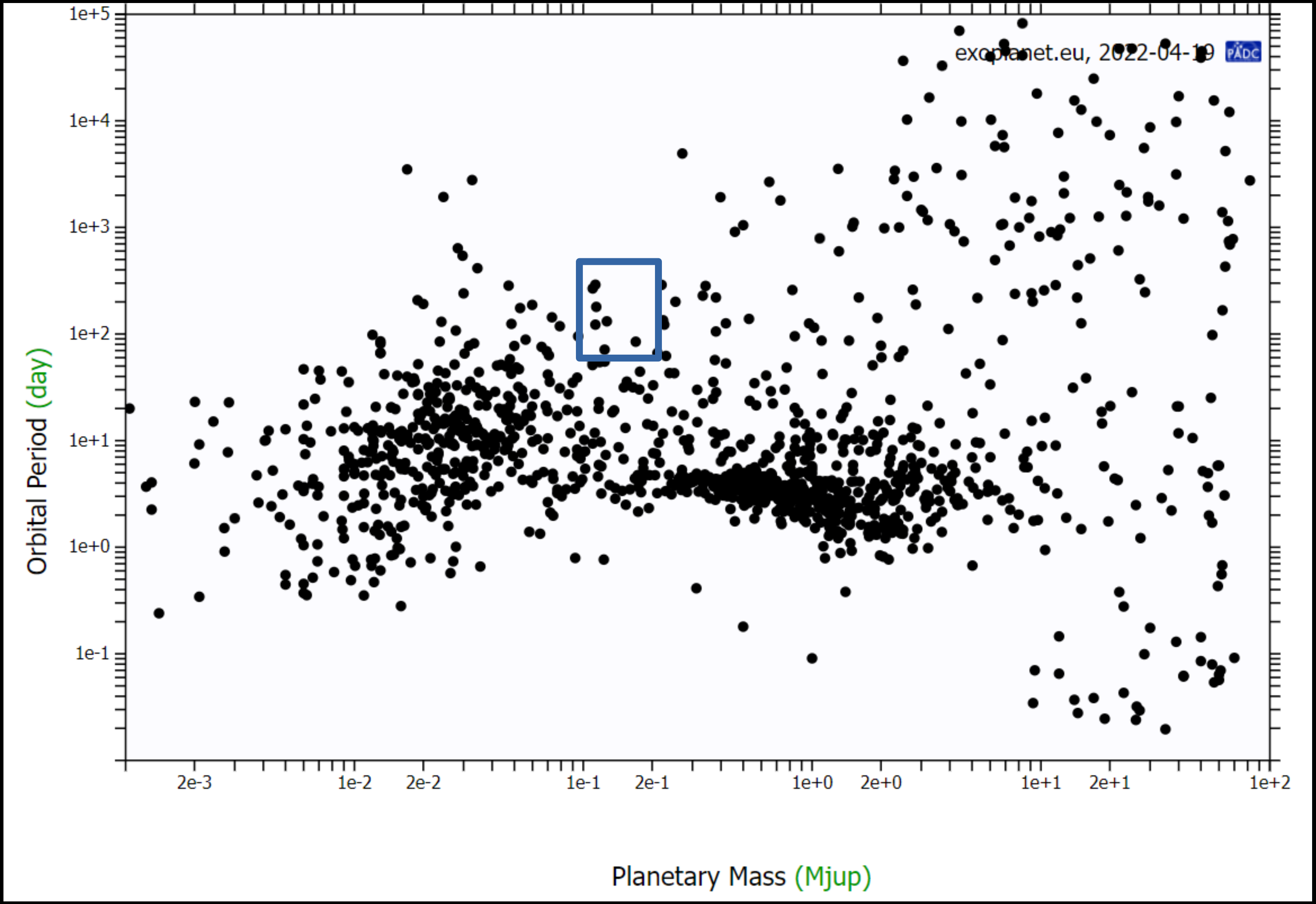
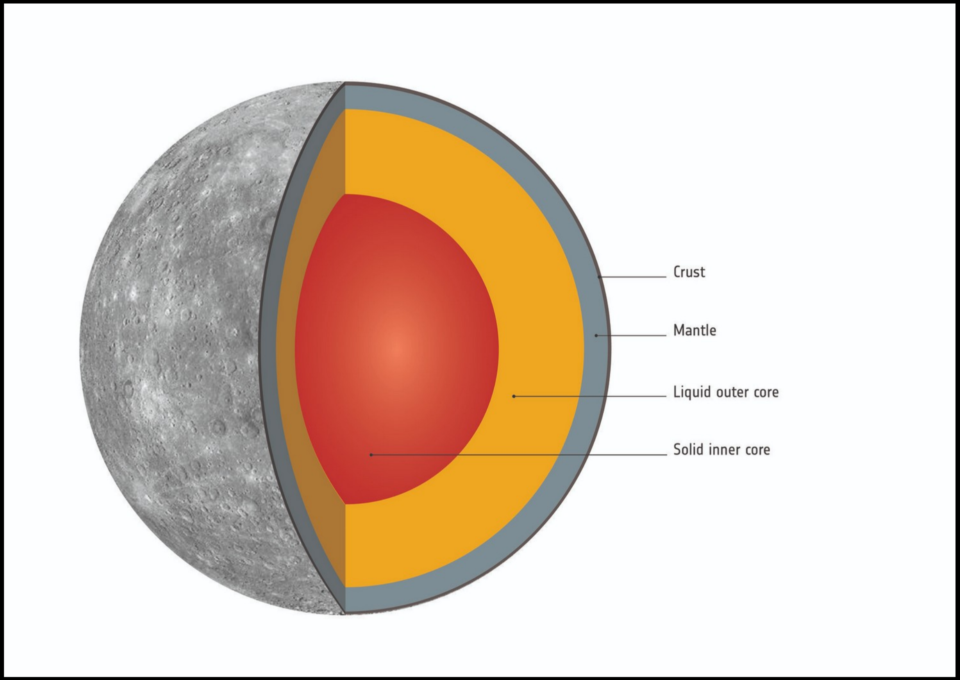
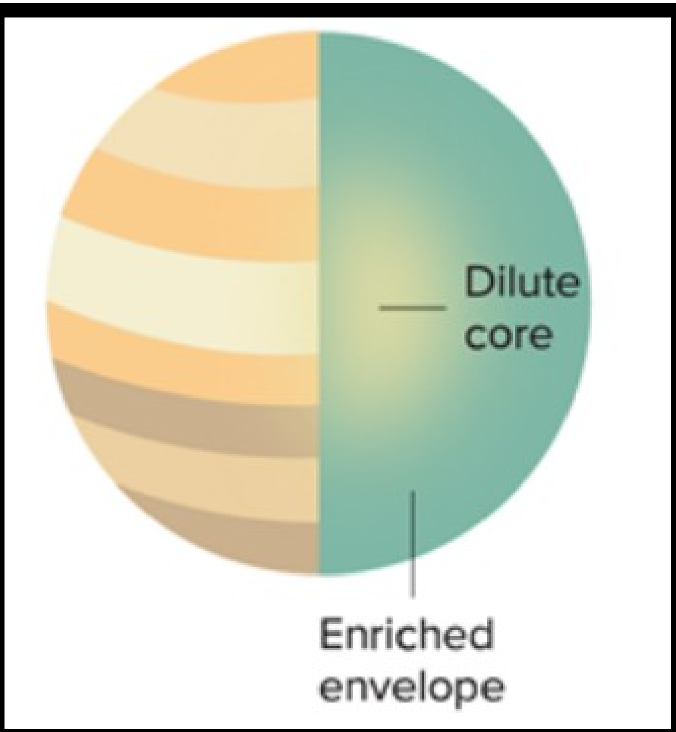
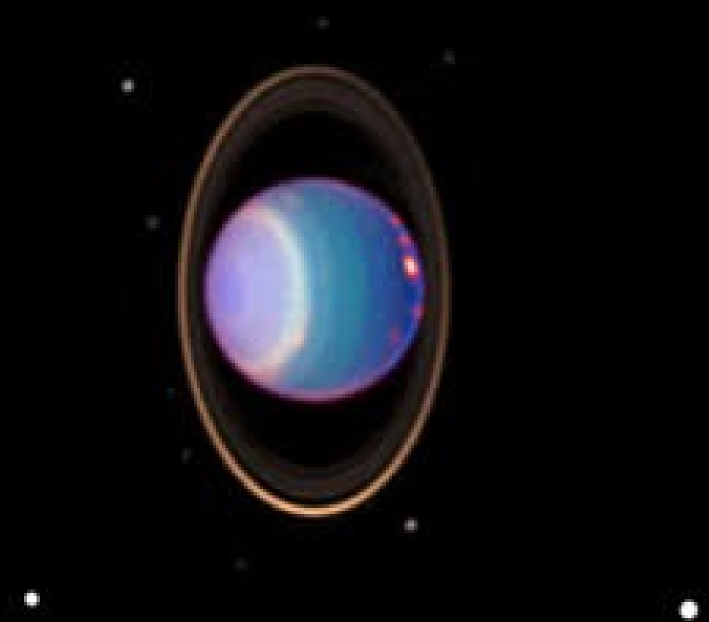


Why CSS did not grow into Jupiters ?

Giant collisions to the rescue

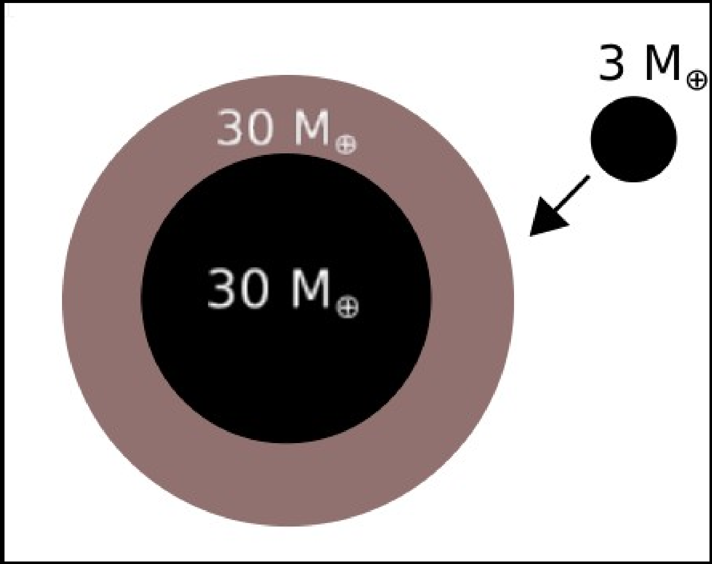






Giant collisions to the rescue

What happens to proto-atmospheres during such events ?



Setup

- 30 M_{earth} core + 30 M_{earth} atmosphere

- Embedded in the protoplanetary / transition disk

- $M_{impactor} << M_{target}$

Giant collisions to the rescue

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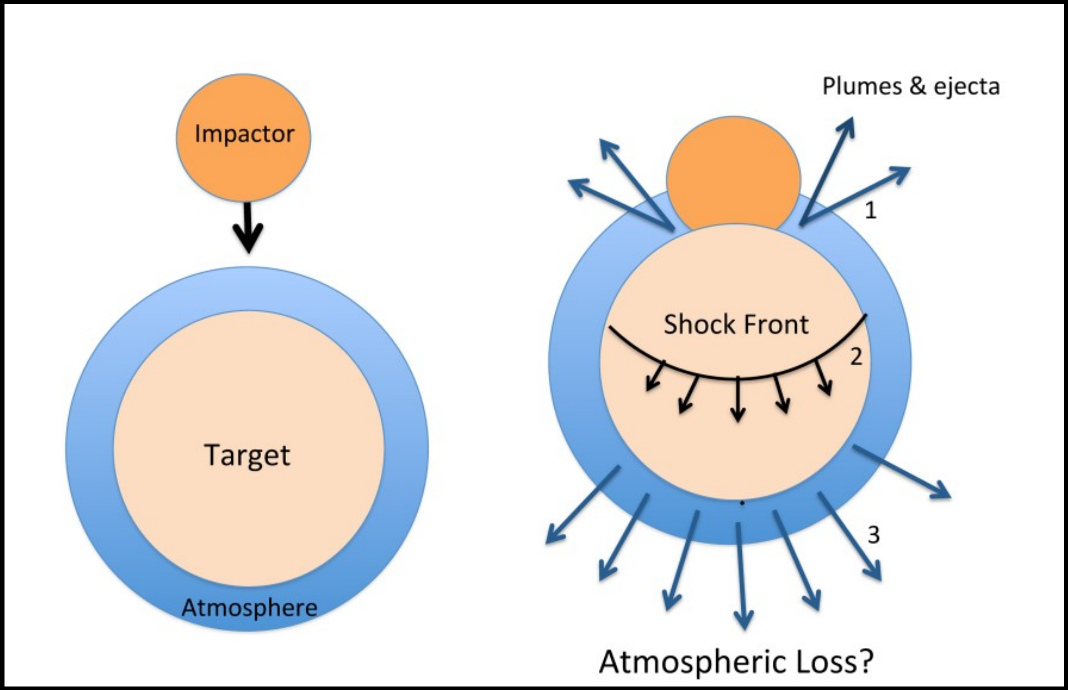

1- Initial atmospheric loss due to global shockwave (Schlichting+2015):

$X_{loss} \sim 0.06$

$$X_{\rm loss} = 0.4\left(\frac{v_{\rm imp}M_{\rm imp}}{v_{\rm esc}M_{\rm tot}}\right) + 1.8\left(\frac{v_{\rm imp}M_{\rm imp}}{v_{\rm esc}M_{\rm tot}}\right)^2 - 1.2\left(\frac{v_{\rm imp}M_{\rm imp}}{v_{\rm esc}M_{\rm tot}}\right)^3,$$

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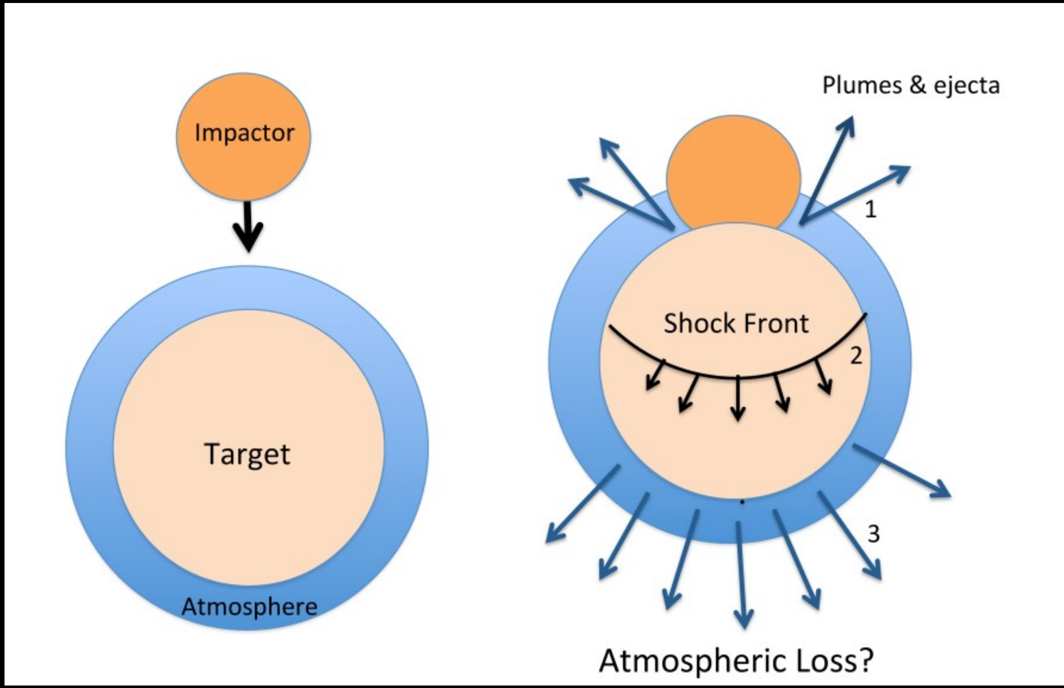

1- Initial atmospheric loss due to global shockwave

2- Inelastic collision: remaining energy deposited in core

$$T_c = T_{c,0} + \frac{(K_{\rm imp} - E_g^L)}{(M_c + M_{\rm imp})C_V}$$

Tc ~ 10^5 K

Giant collisions to the rescue

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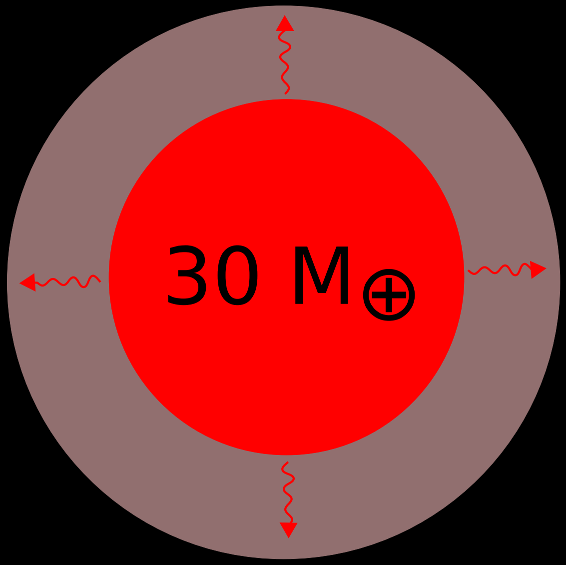

1- Initial atmospheric loss due to global shockwave

2- Inelastic collision: remaining energy deposited in core

3- The core heats up the proto-atmosphere

$$T(r) = T_c - \nabla_{\rm ad} \frac{G M_c \mu}{k_B R_c} \left[1 - \frac{R_c}{r} \right]$$

Giant collisions to the rescue

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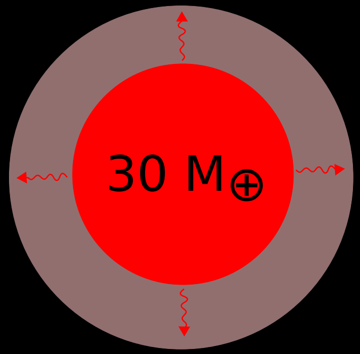

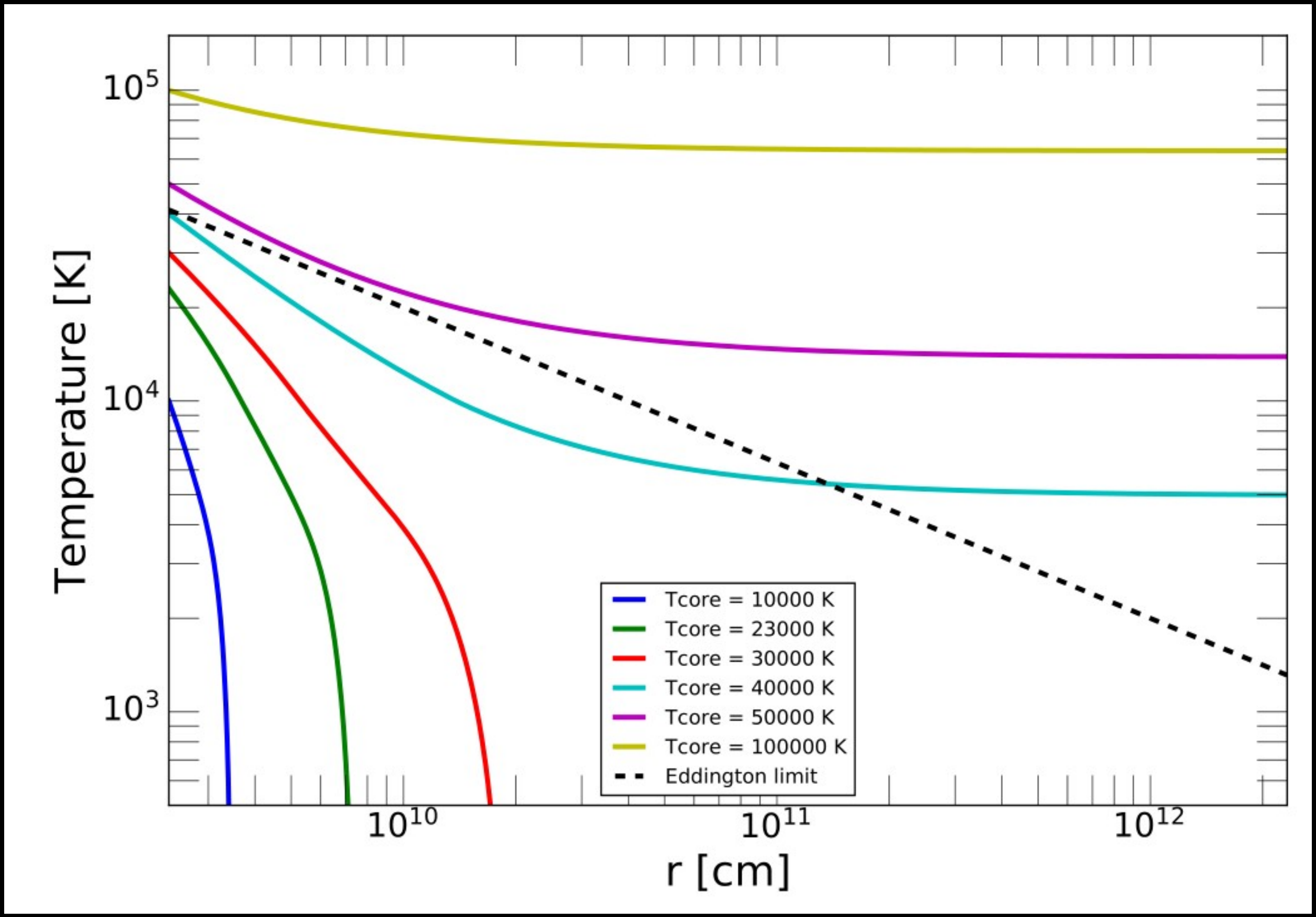

Giant collisions to the rescue

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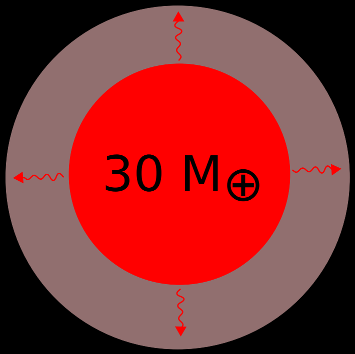

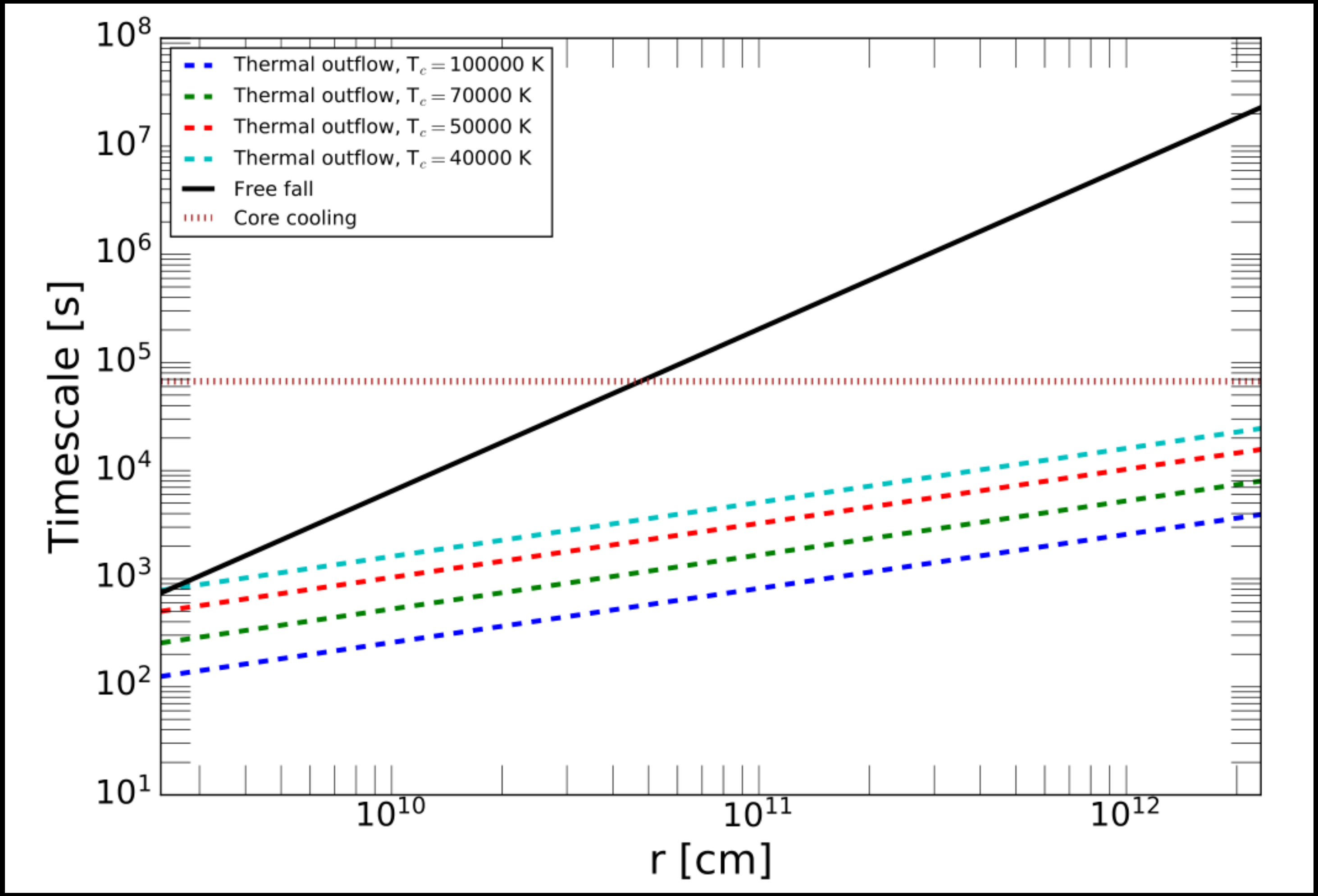

Giant collisions to the rescue

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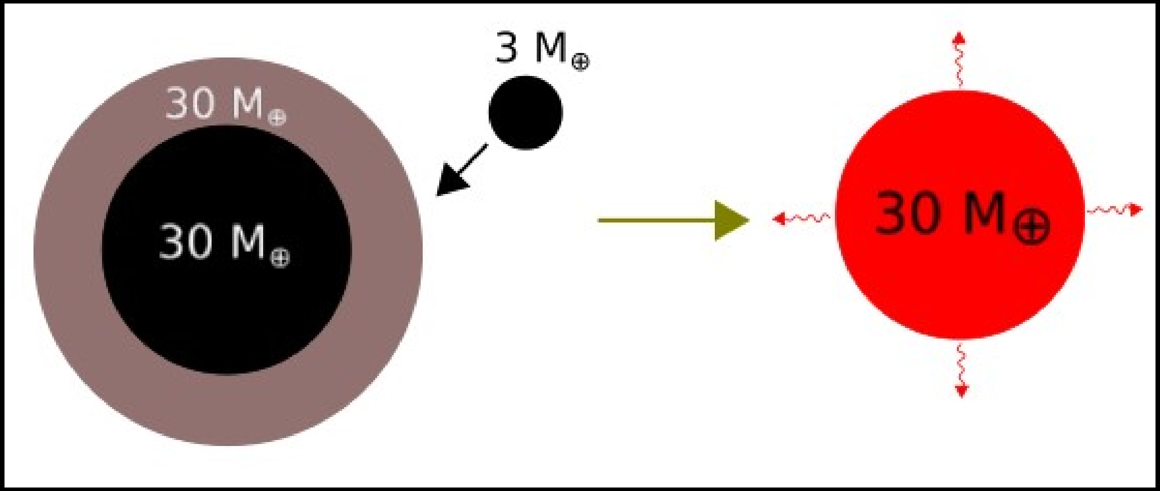
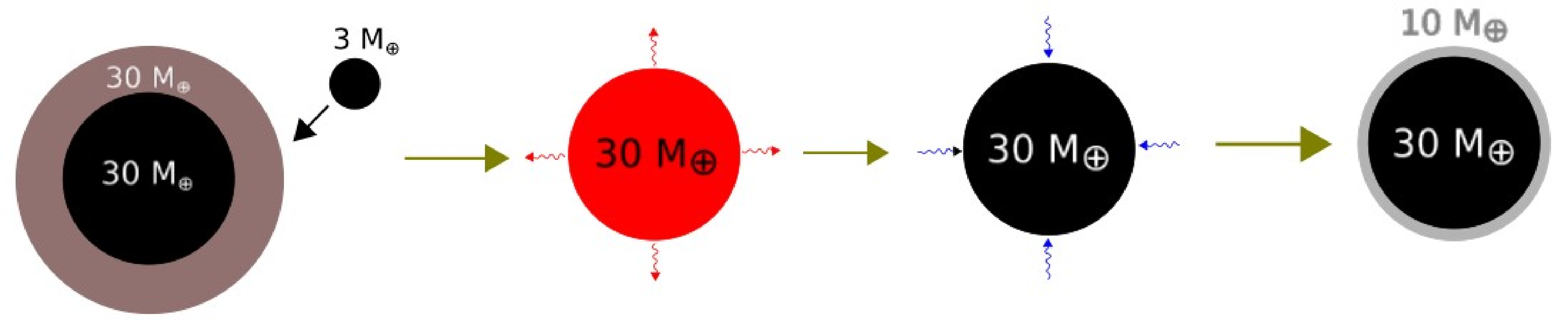


1- Initial atmospheric loss due to global shockwave
2- Inelastic collision: remaining energy deposited in core
3- The core heats up the proto-atmosphere
4- The envelope is stripped thermally

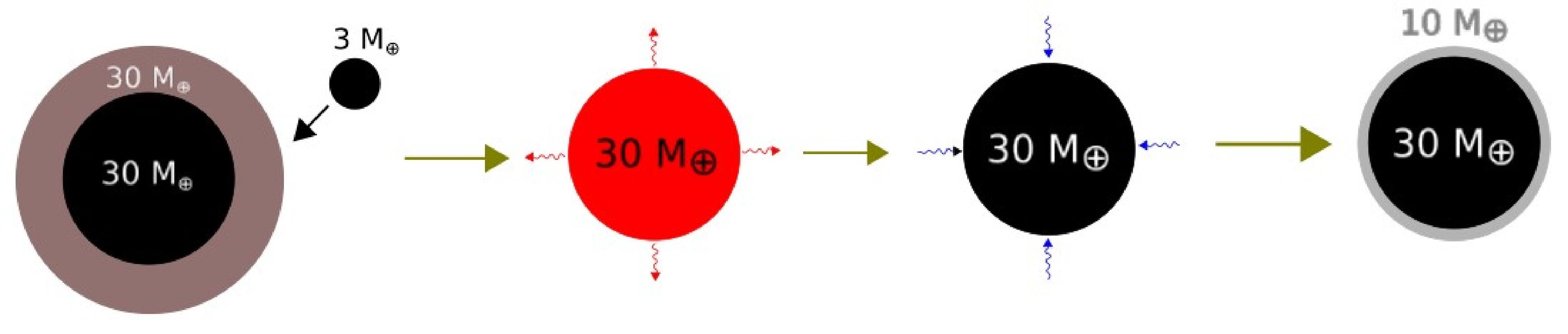
Giant collisions to the rescue

What happens to proto-atmospheres during such events ?



Model parameters	E_G [erg]	U [erg]	$\|E_G+U\|$	E_G^{a1}	E_G^{a2}	$m_{\rm imp}^{\rm min,3}$ [$M_\oplus$]	$m_{\rm imp}^{\rm min}$ [$M_\oplus$]
M_c=30 $M_\oplus$, γ=1.40	-3.04 $\times 10^{41}$	2.12 $\times 10^{41}$	9.14 $\times 10^{40}$	-7.74 $\times 10^{40}$	-8.3 $\times 10^{41}$	1.50	1.50
M_c=30 $M_\oplus$, γ=1.25	-4.94 $\times 10^{41}$	4.72 $\times 10^{41}$	2.22 $\times 10^{40}$	-5.76 $\times 10^{40}$	-8.3 $\times 10^{41}$	0.43	0.55
M_c=20 $M_\oplus$, γ=1.40	-1.71 $\times 10^{41}$	1.18 $\times 10^{41}$	5.31 $\times 10^{40}$	-5.01 $\times 10^{40}$	-4.22 $\times 10^{41}$	1.15	1.15
M_c=20 $M_\oplus$, γ=1.25	-2.68 $\times 10^{41}$	2.51 $\times 10^{41}$	1.78 $\times 10^{40}$	-4.10 $\times 10^{40}$	-4.22 $\times 10^{41}$	0.38	0.53

Giant collisions to the rescue
What happens to proto-atmospheres during such events ?

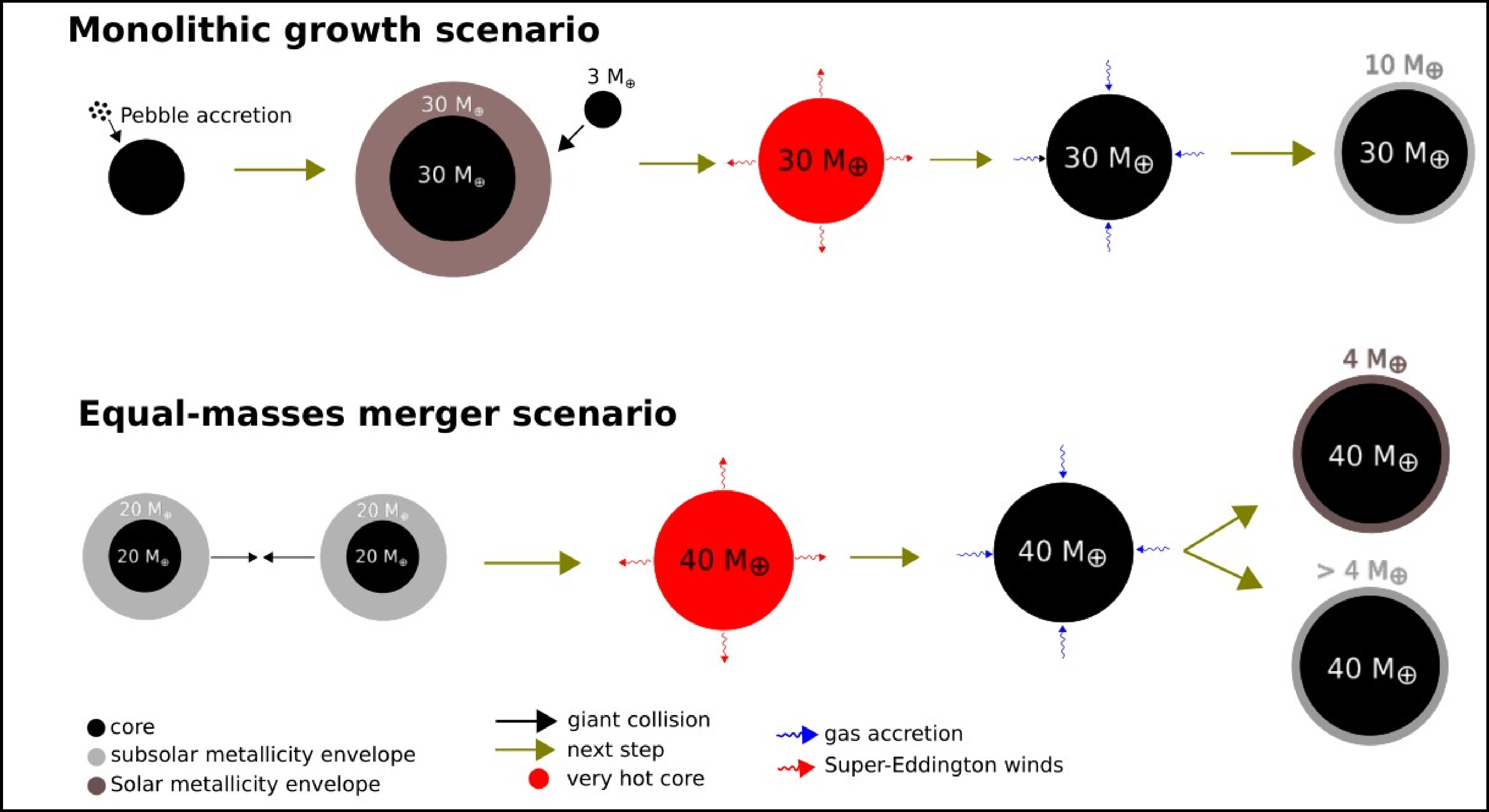


1- Initial atmospheric loss due to global shockwave
2- Inelastic collision: remaining energy deposited in core
3- The core heats up the proto-atmosphere
4- The envelope is stripped thermally
5- A new envelope can be re-accreted

Take-home conclusion 1

Impactors ~ 5% the mass of protoplanets can completely strip their primordial atmospheres

How do cold sub-Saturns form ?



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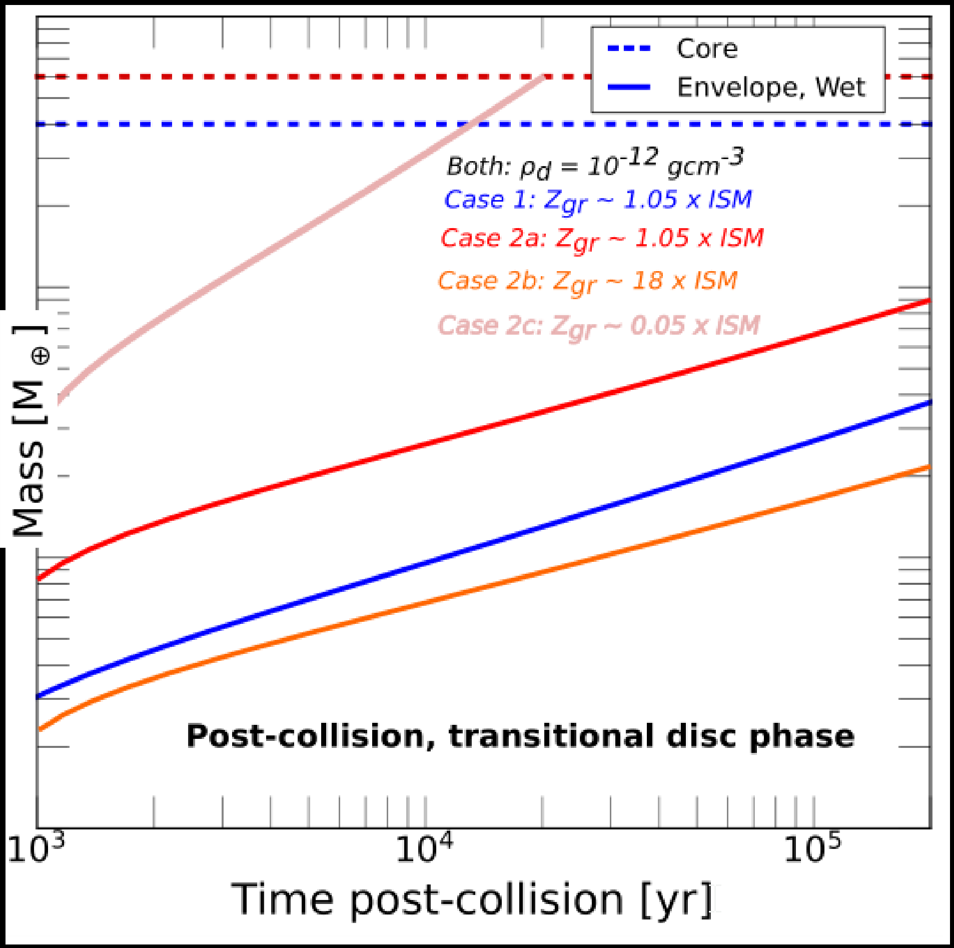

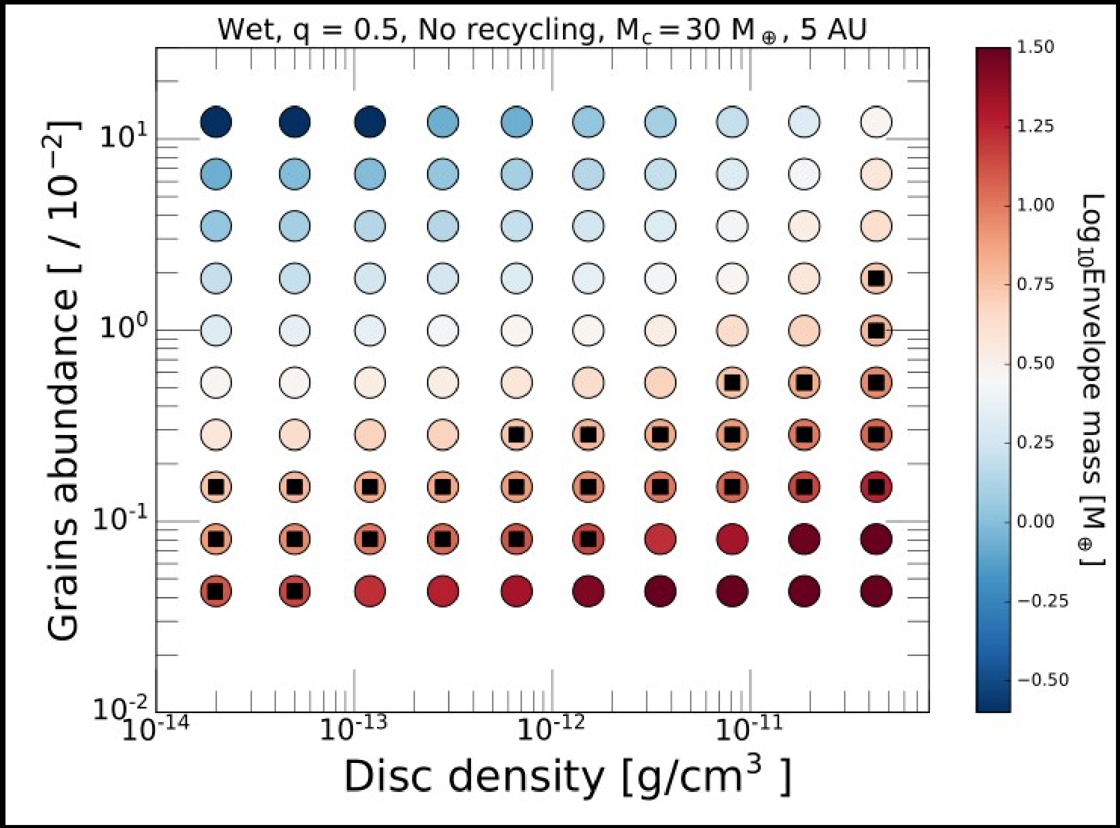

Take-home conclusion 2

Giant impacts in a transition disk can explain sub-Saturns

Summary

- **Giant impacts can heat up the core and launch super-Eddington winds**
- **These winds can completely strip the atmosphere**
- **Impactors only have to be ~ 5% of the target's mass**
- **In some cases, these cores can re-accrete and become CSS**

Thank you

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