High-order resonance & the inner disk edge

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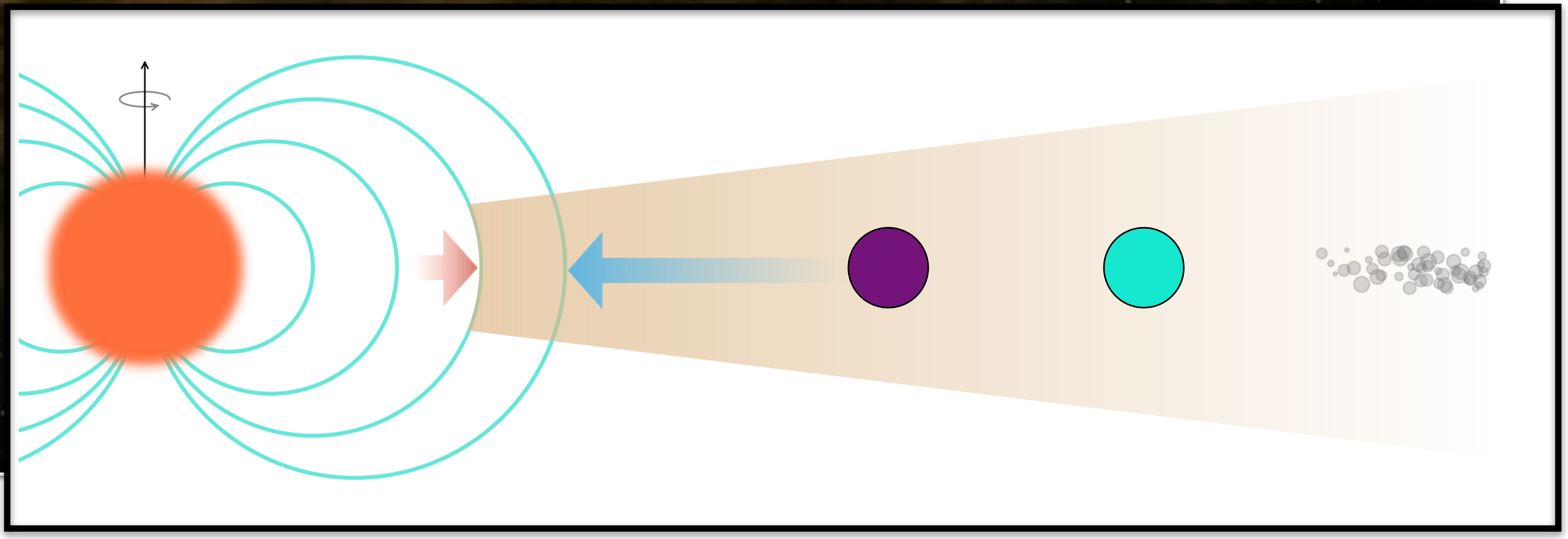
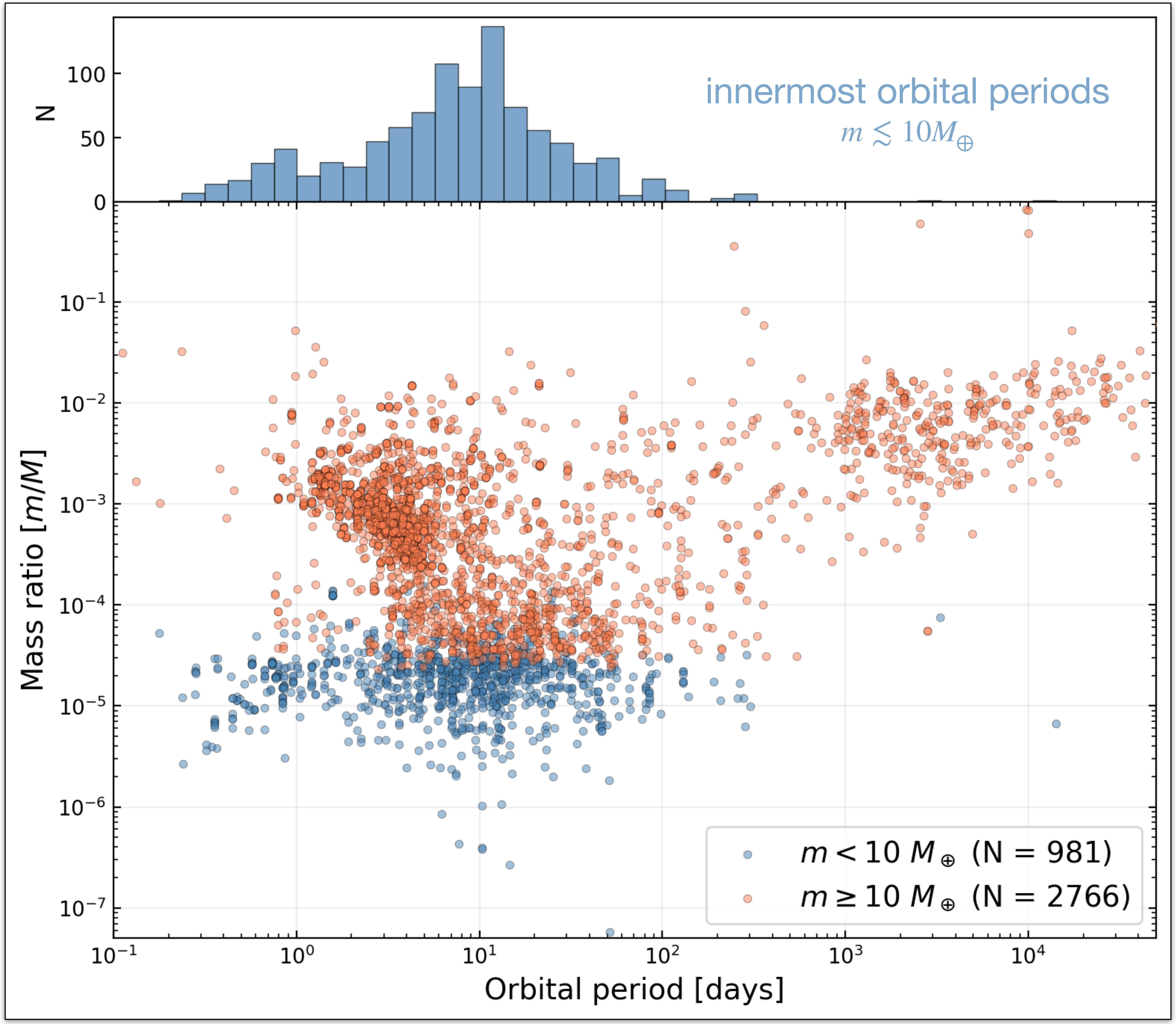
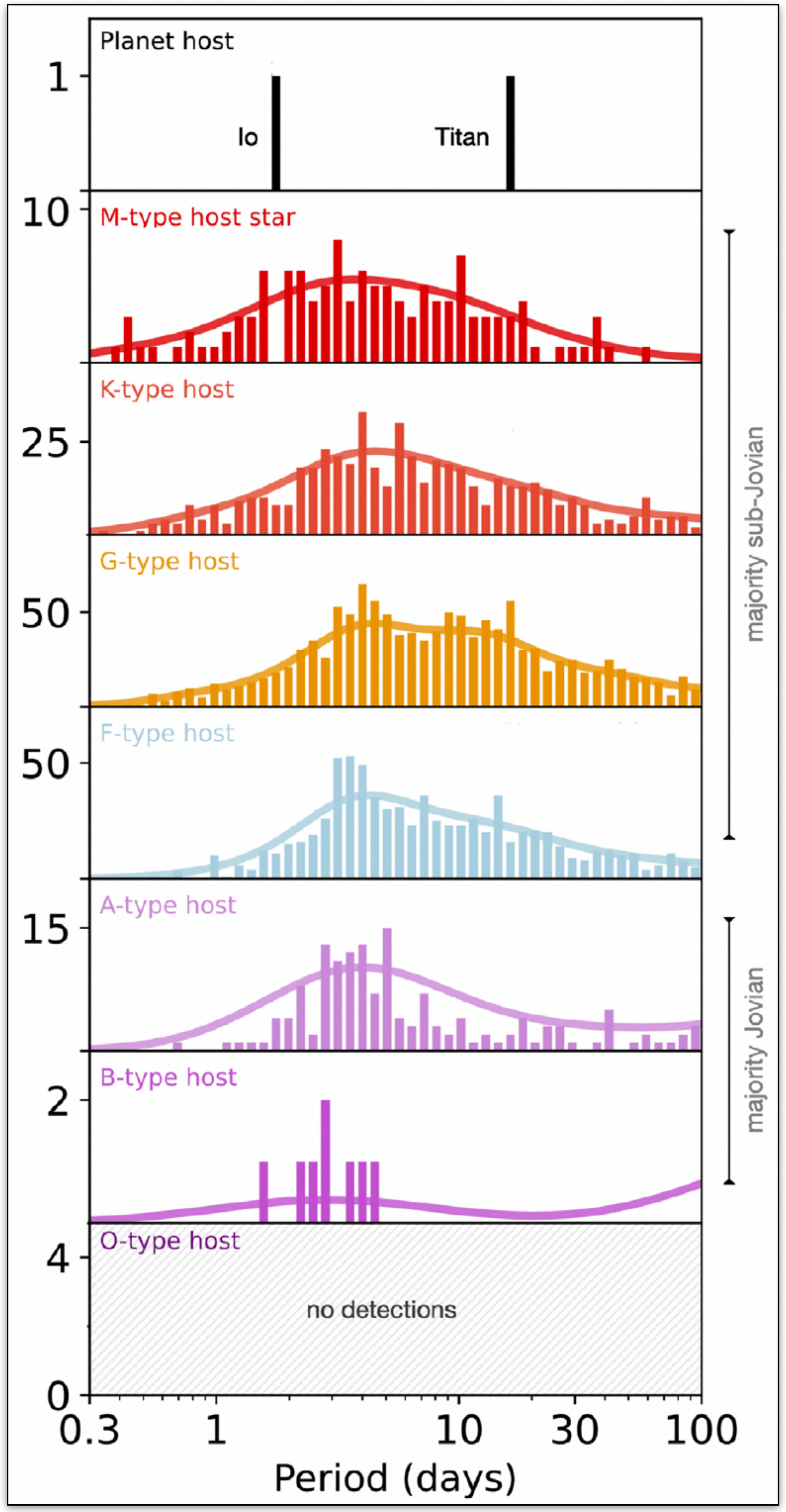


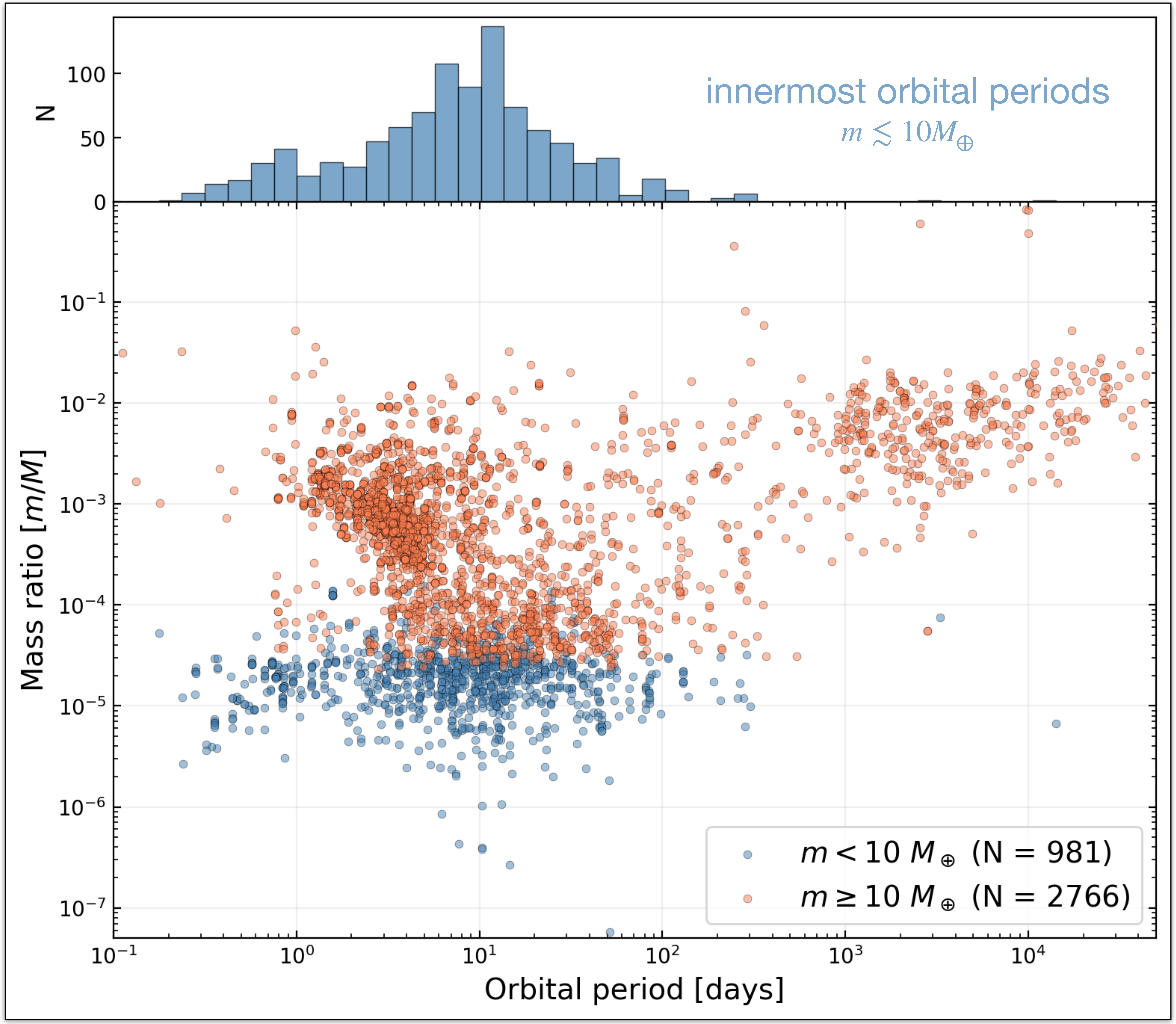


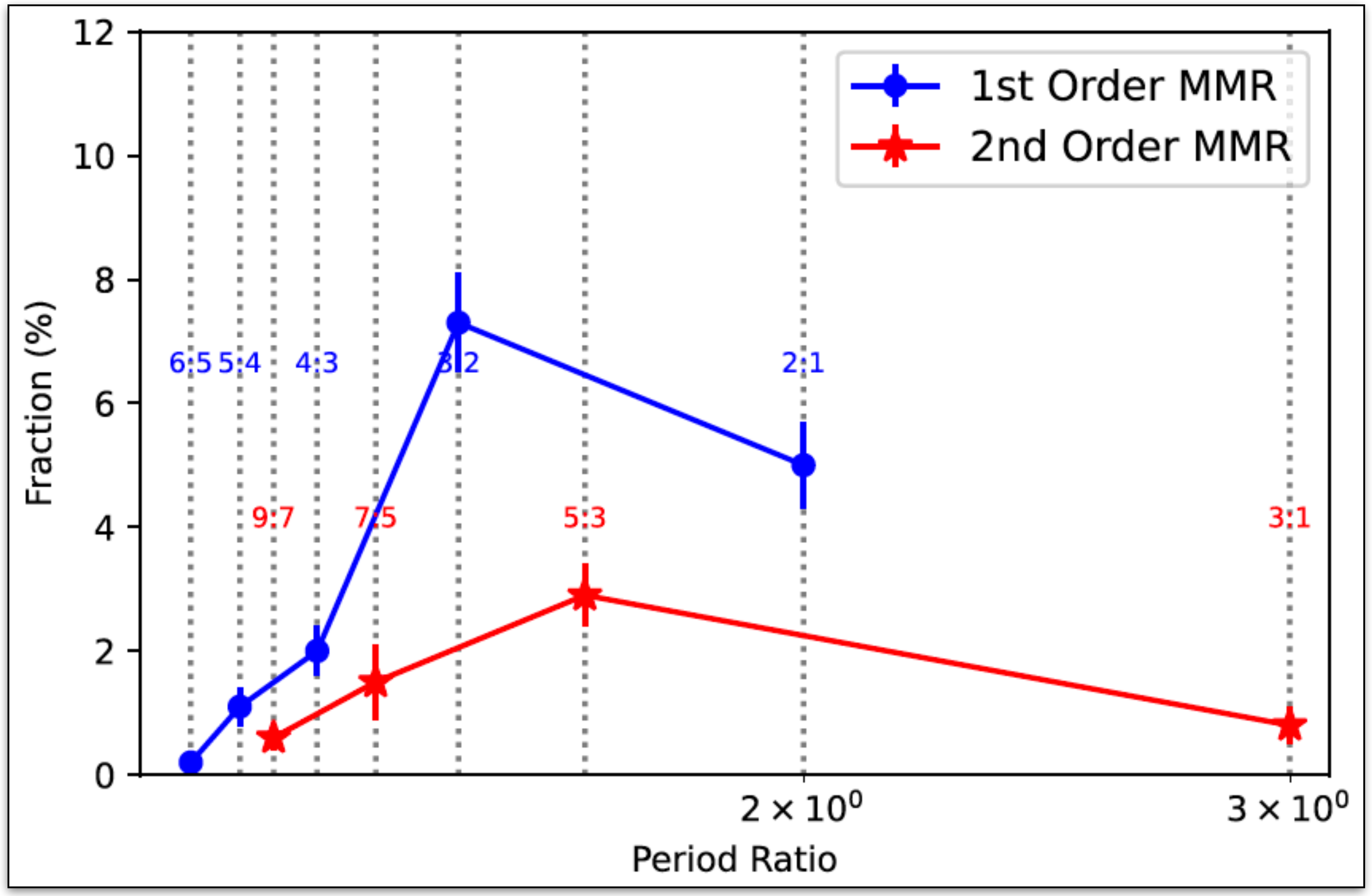
innermost orbital periods
$m \lesssim 10M_\oplus$
N
Mass ratio [m/M]
Orbital period [days]
$m < 10\ M_\oplus$ (N = 981)
$m \geq 10\ M_\oplus$ (N = 2766)



Planet host
Io
Titan
M-type host star
K-type host
G-type host
F-type host
A-type host
B-type host
O-type host
no detections
majority sub-Jovian
majority Jovian
Period (days)

Batygin + (23)





Dai + (24)

1st order MMR
merely reveals planetary migration

2nd order MMR
more complicated…
e.g. Kepler-29 (9:7), Kepler-138 (5:3)

Unlikely, but rich with information…

Mean motion resonance

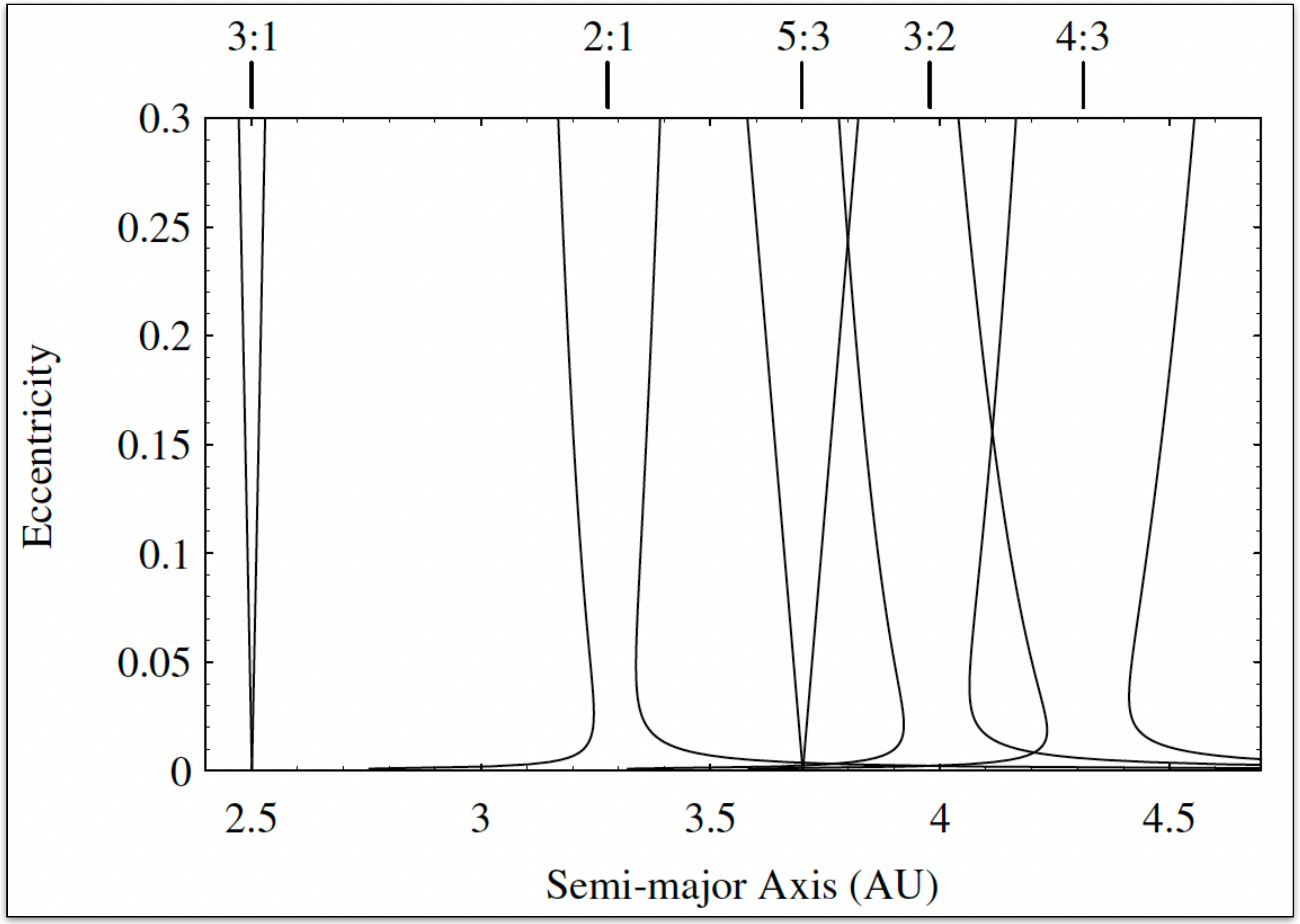
What determines resonance capture?

- Mass ratios
- Disk properties & structure
- Stellar influence

$$\tau_{\mathrm{wav}} = -\frac{1}{\Omega}\frac{M}{m}\frac{M}{\Sigma a^2}\left(\frac{h}{r}\right)^4$$

$$\tau_a \approx \frac{\tau_{\mathrm{wav}}}{2.7 + 1.1s}\left(\frac{h}{r}\right)^{-2}$$

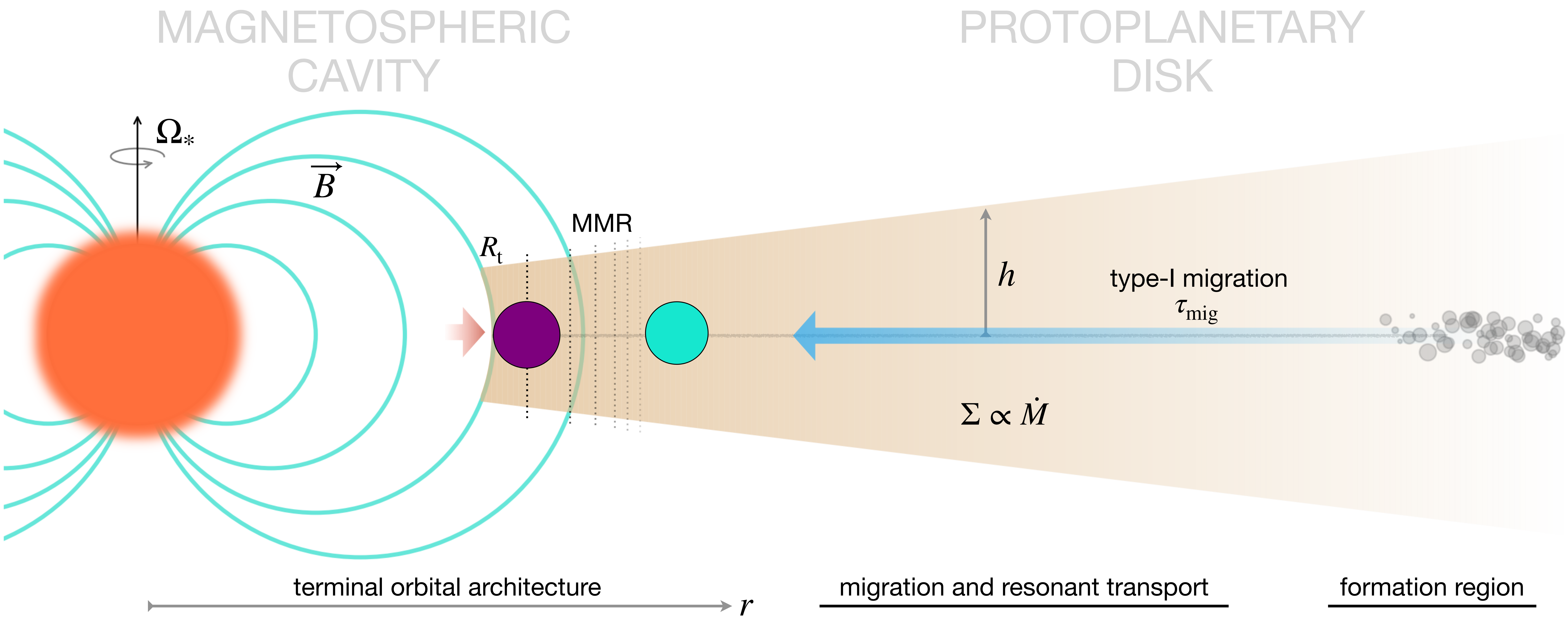
$$\tau_e \approx \frac{\tau_{\mathrm{wav}}}{0.780}$$



Murray & Dermott Ch. 8

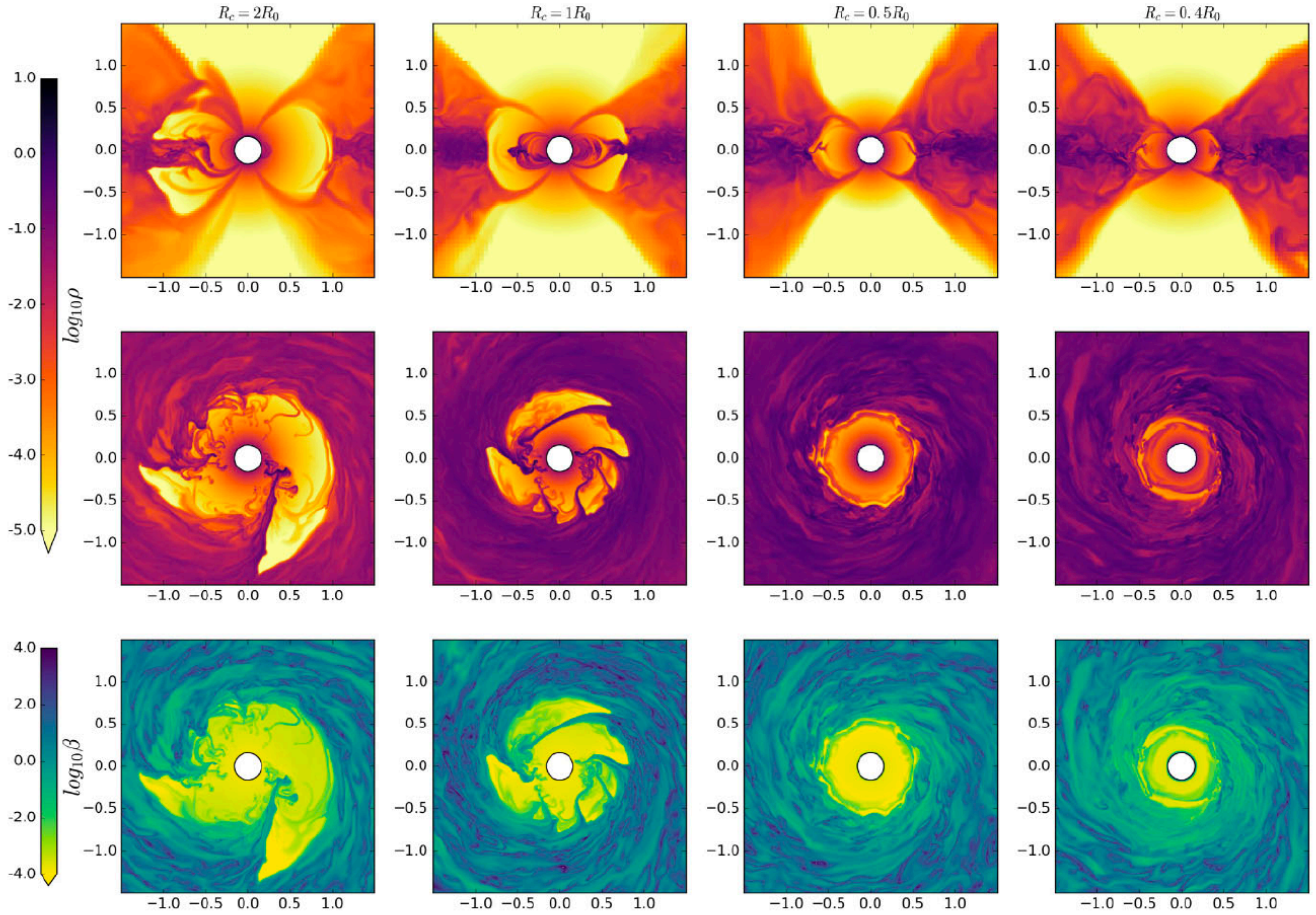
Surviving signatures of early evolution

What determines planetary architectures?

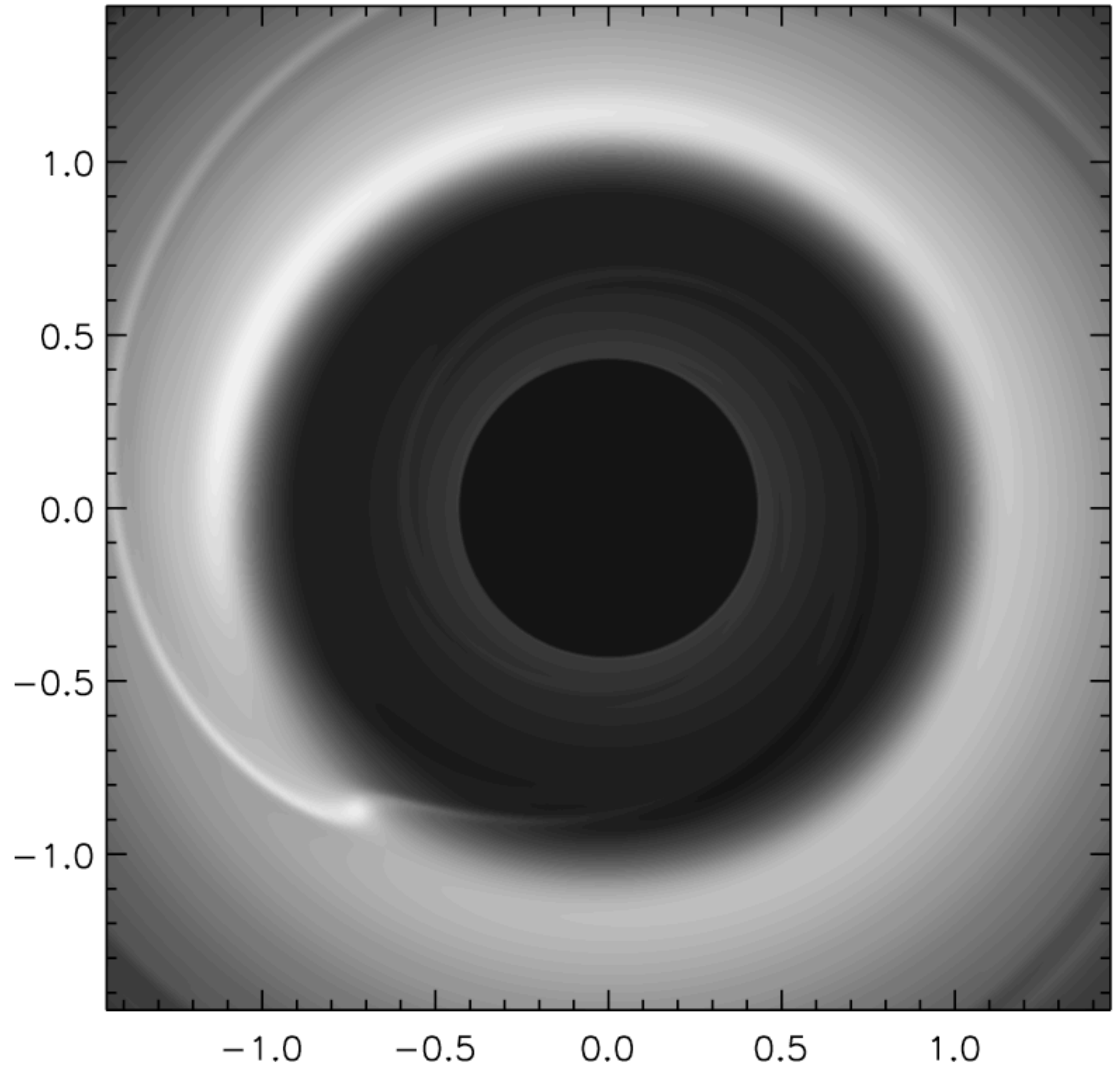


Inner disk edge

A natural zone for convergent migration



Zhu (25)



Masset + (06)

$$\tau_a \approx \frac{\tau_{\rm wav}}{2.7 + 1.1s}\left(\frac{h}{r}\right)^{-2} \qquad \tau_e \approx \frac{\tau_{\rm wav}}{0.780} \qquad \tau_{\rm wav} = -\frac{1}{\Omega}\frac{M}{m}\frac{M}{\Sigma a^2}\left(\frac{h}{r}\right)^4$$

Inner disk edge

Most common way to model the physics of the inner disk edge [for example, as in `REBOUND`]:

$$\tau_a \longrightarrow f_{\rm red}\tau_a = \begin{cases} \tau_a & a \geq d_e(1+h_e) \\ \left[5.5\ \cos\left(2\pi\frac{d_e(1+h_e)-a}{4d_eh_e}\right) - 4.5\right]\tau_a & d_e(1-h_e) \leq a \leq d_e(1+h_e) \\ 10\ \tau_a & 0 \leq a \leq d_e(1-h_e) \end{cases}$$

Pichierri, Morbidelli, & Crida (18)

$$\tau_a \approx \frac{\tau_{\rm wav}}{2.7+1.1s}\left(\frac{h}{r}\right)^{-2} \qquad \tau_e \approx \frac{\tau_{\rm wav}}{0.780} \qquad \tau_{\rm wav} = -\frac{1}{\Omega}\frac{M}{m}\frac{M}{\Sigma a^2}\left(\frac{h}{r}\right)^4$$

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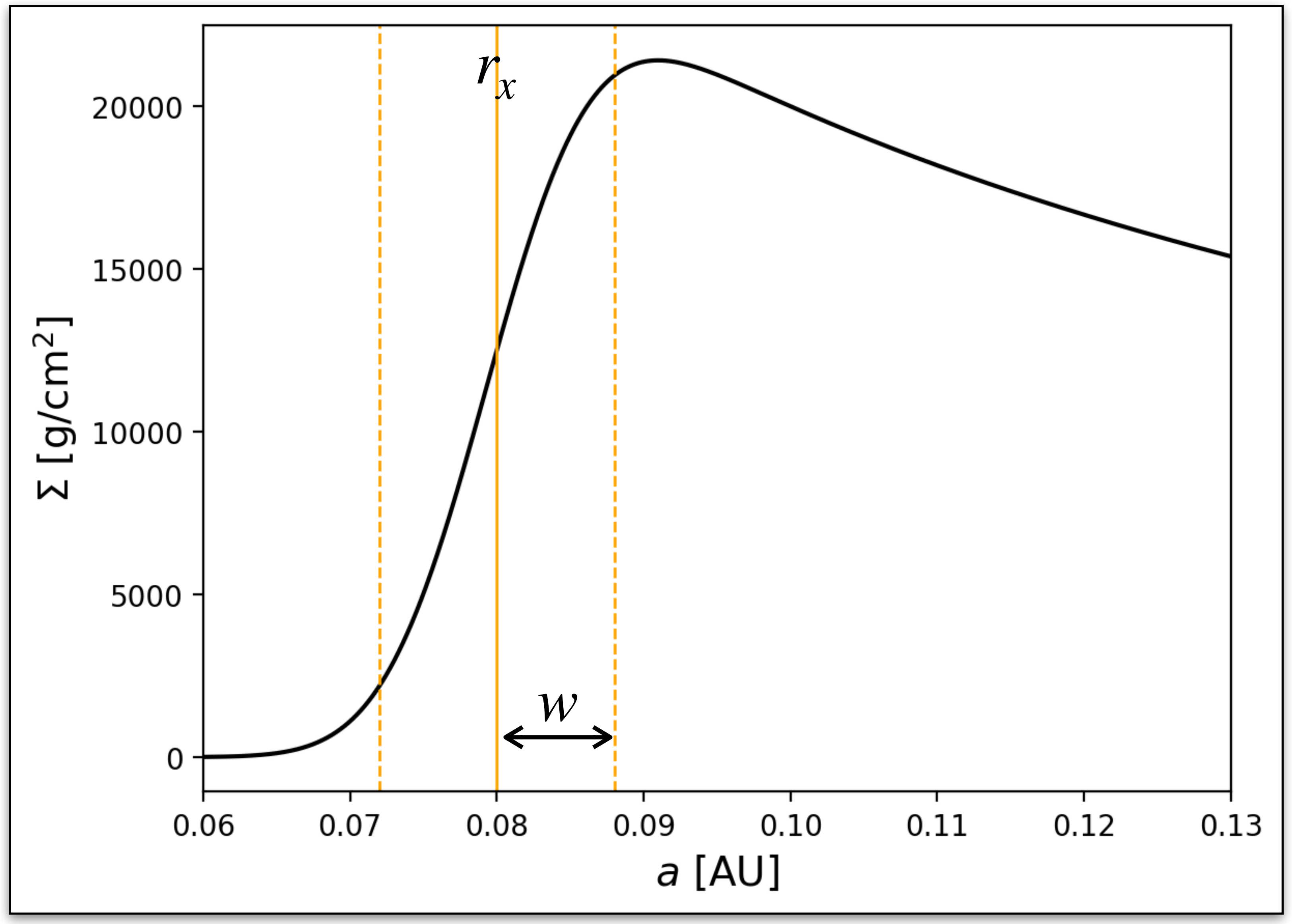
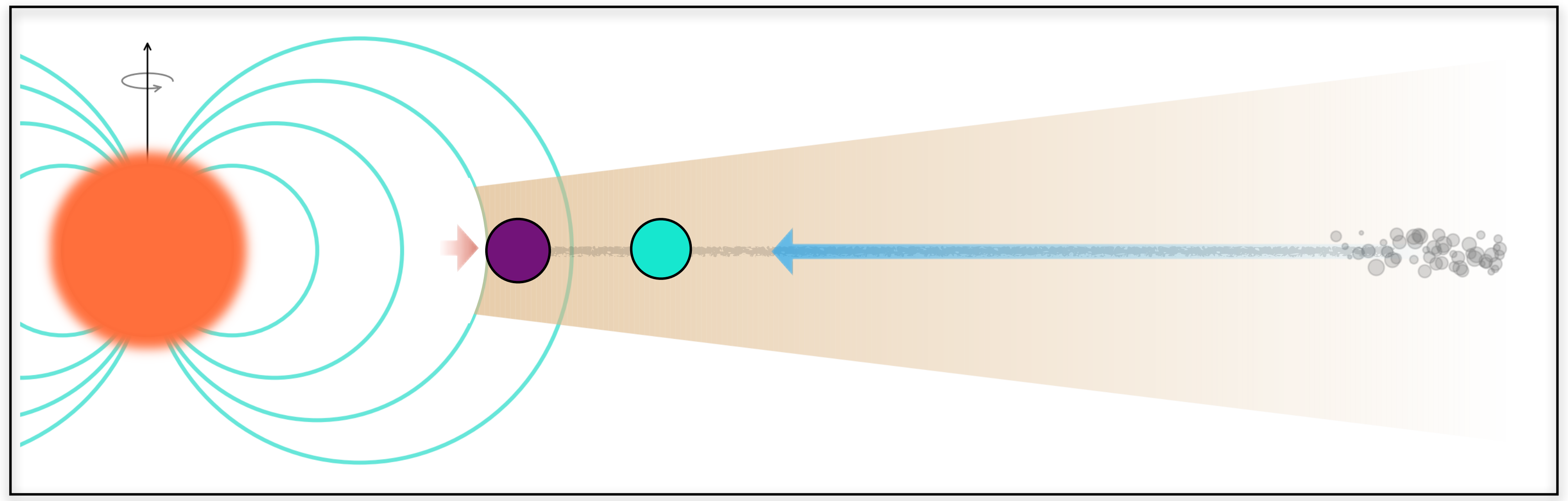
Pichierri, Morbidelli, & Crida (18)

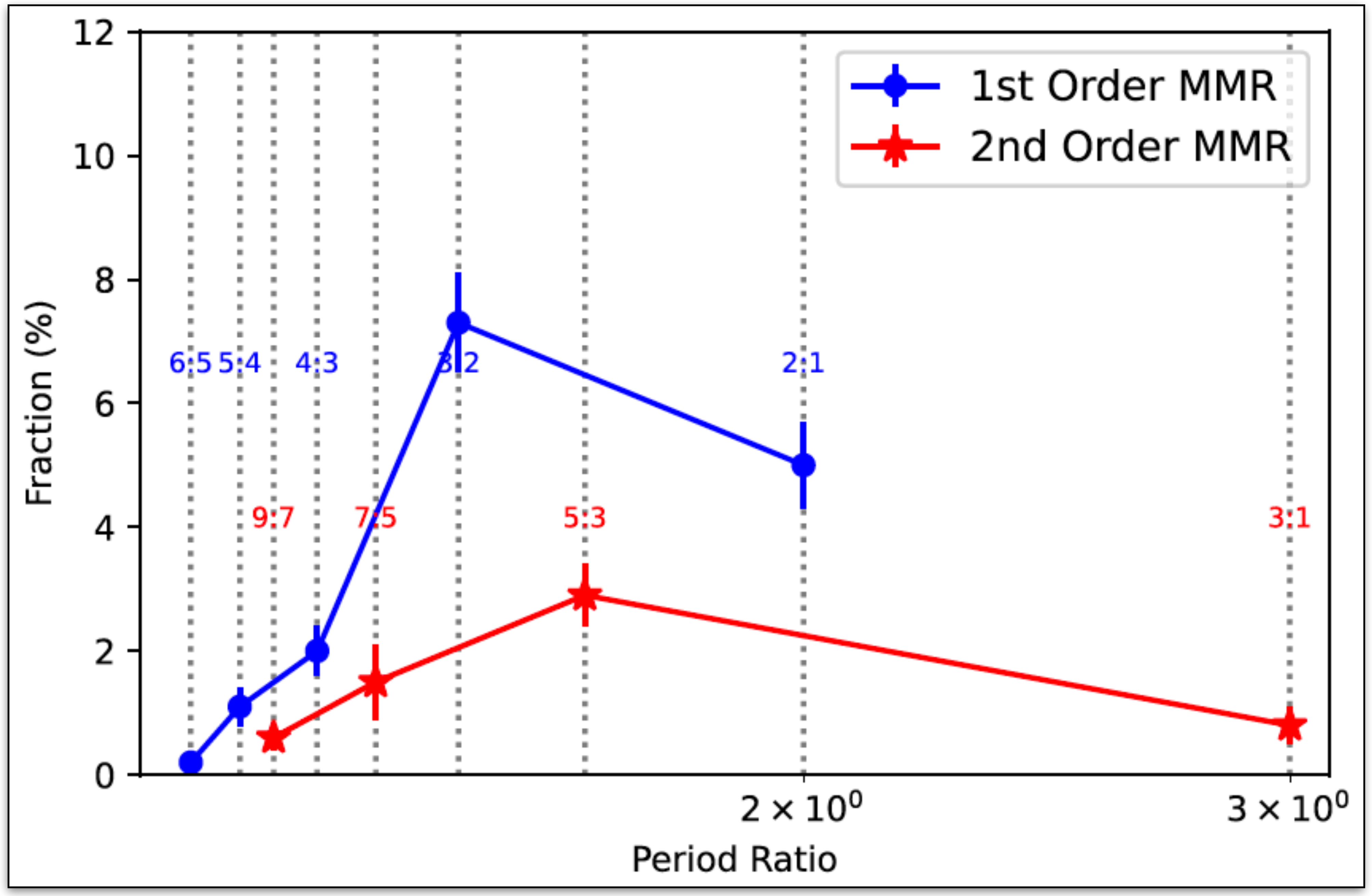
$$\Sigma = \Sigma_0\left(\frac{r}{r_0}\right)^{-s} \longrightarrow \Sigma = \Sigma_0\left(\frac{r}{r_0}\right)^{-s(r)}\frac{1}{2}\left(1+\mathrm{erf}\left[\frac{\mathrm{r}-\mathrm{r_x}}{\mathrm{w}}\right]\right)$$

$$s(r) = \frac{1}{2}\left(\frac{1}{2}+\mathrm{erf}\left[\frac{\mathrm{r}-(\mathrm{r_x}+\mathrm{w})}{\mathrm{w}}\right]\right)-\frac{r}{\sqrt{\pi}w}\exp\left[-\left(\frac{r-r_x}{w}\right)^2\right]$$

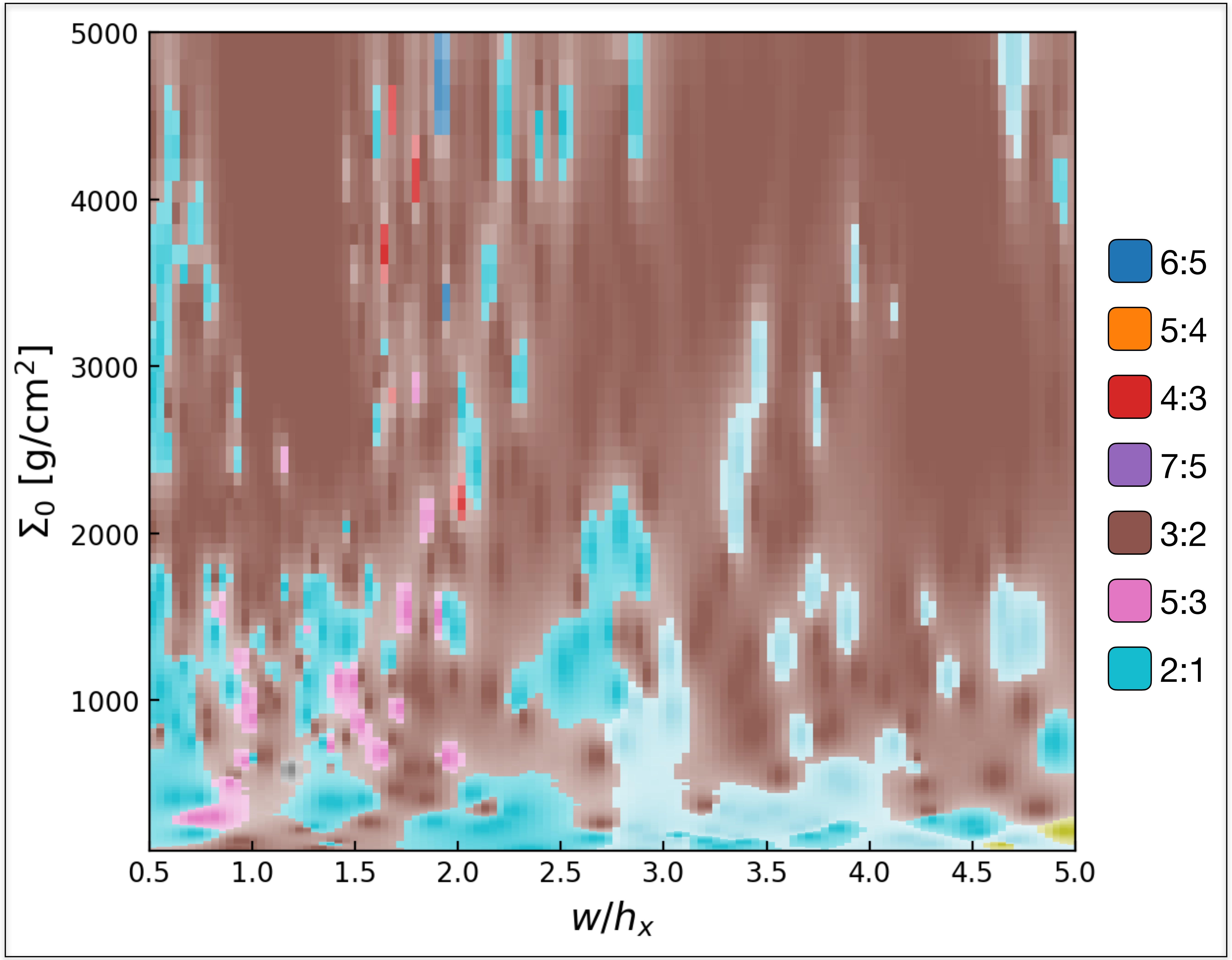


Results

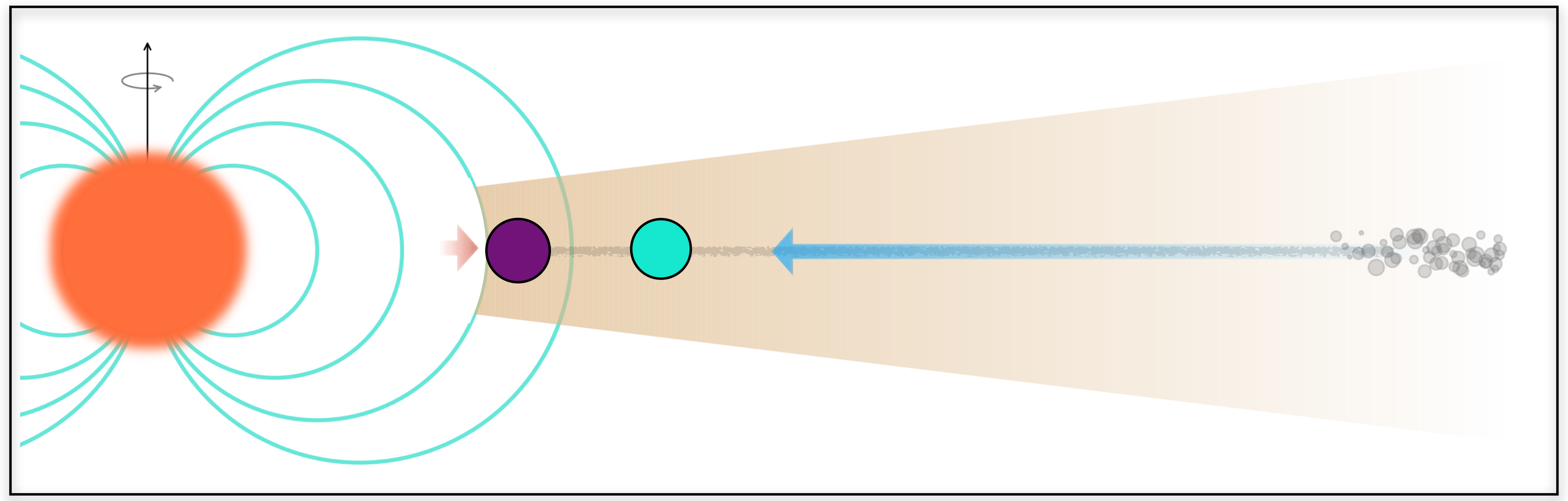


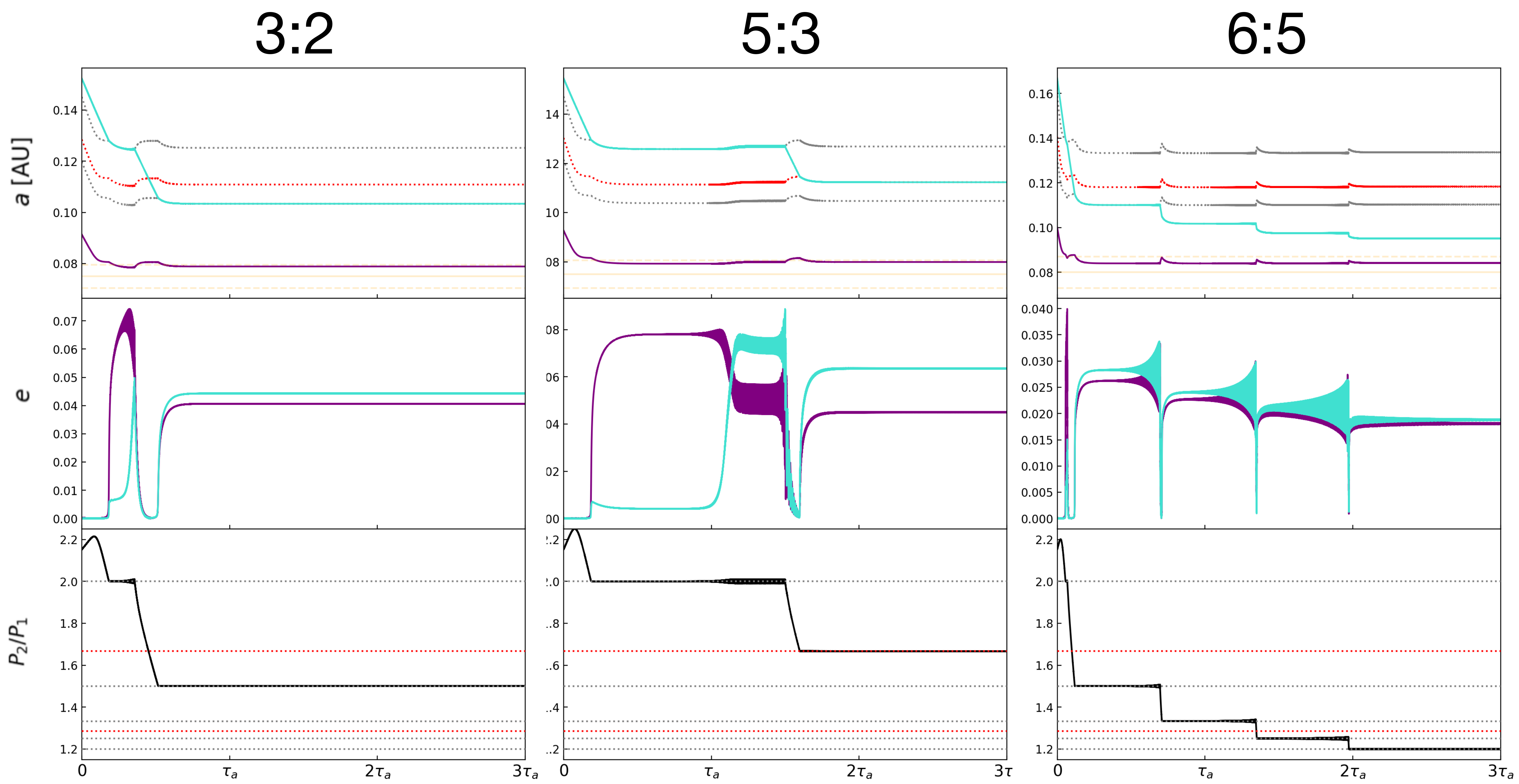


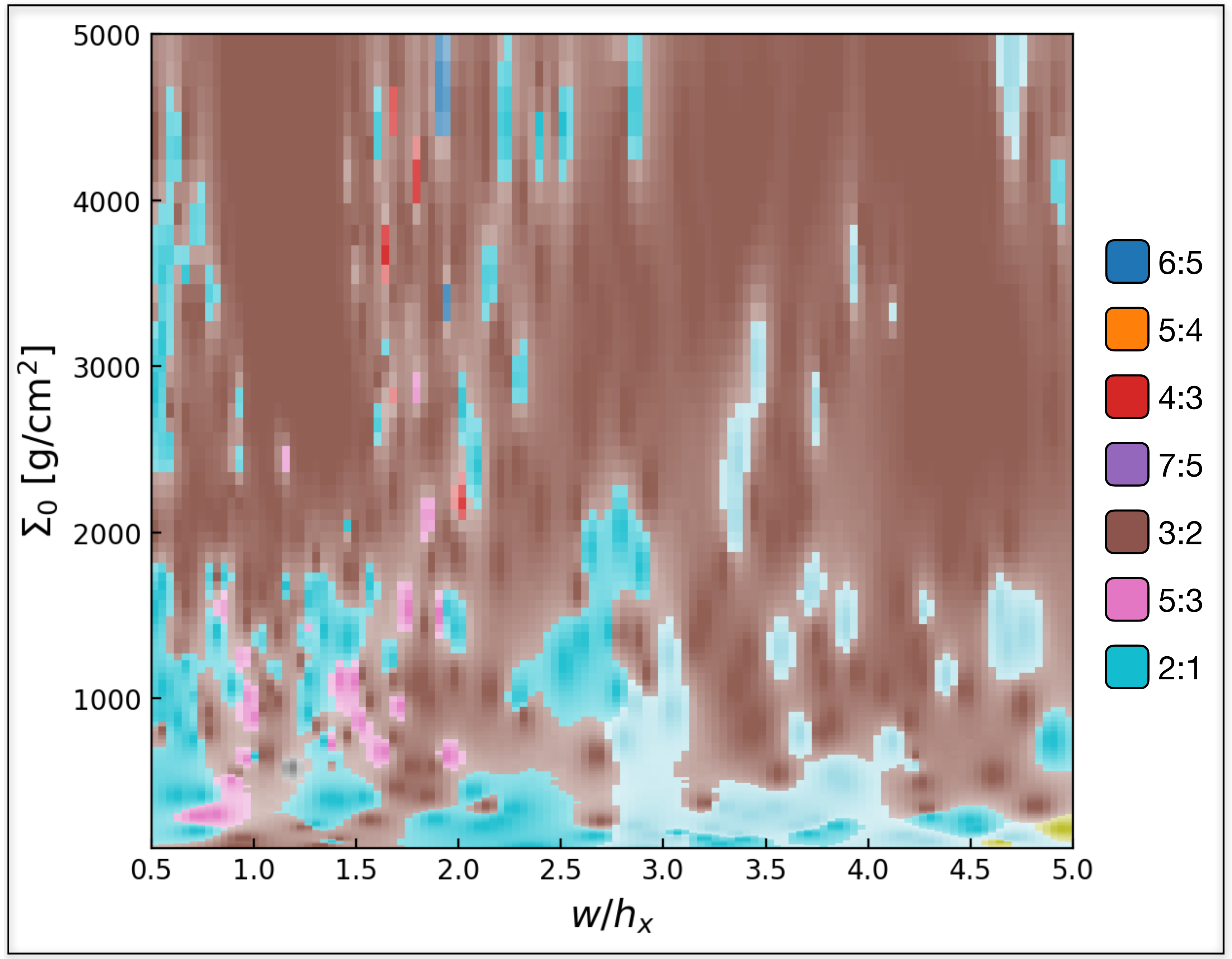
Dai + (24)



Some common examples







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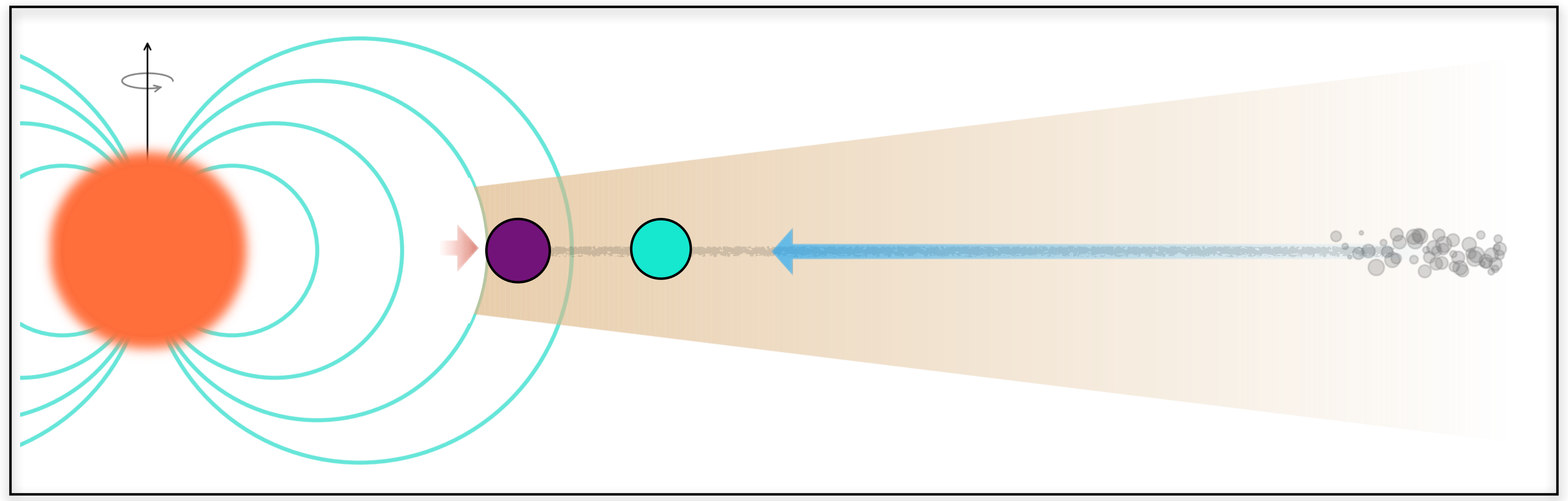
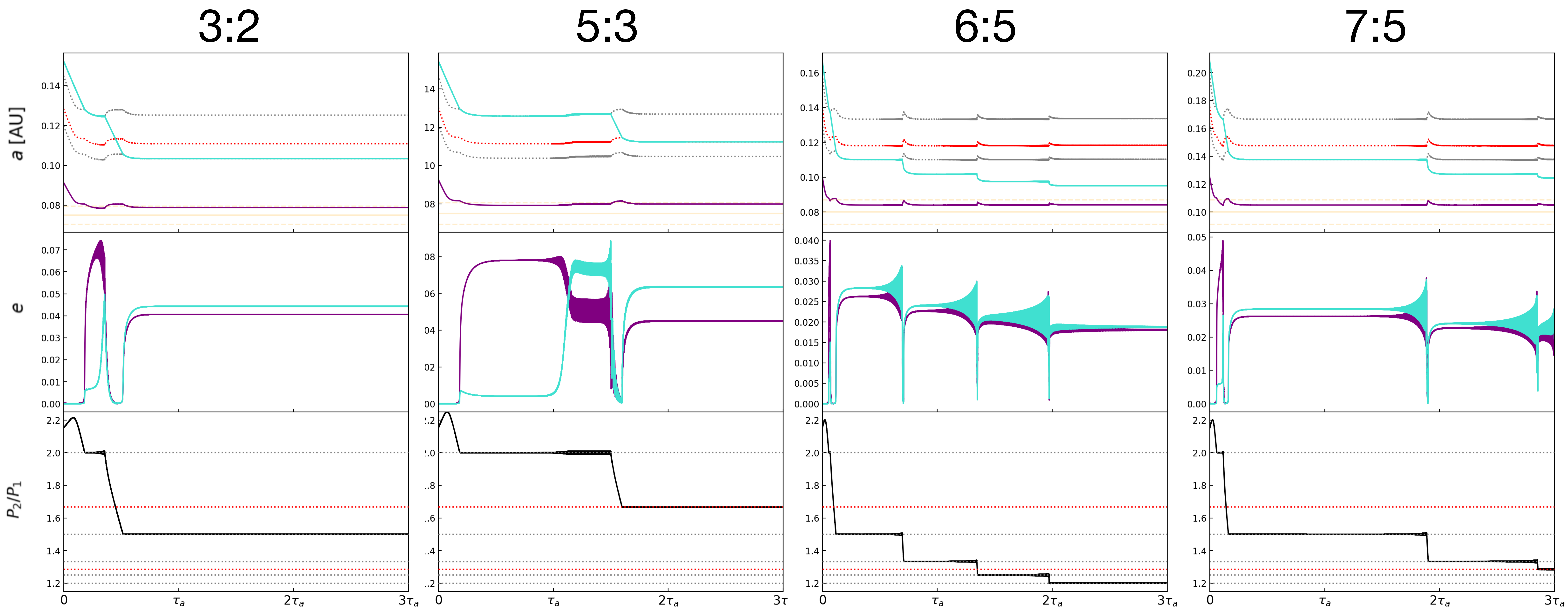
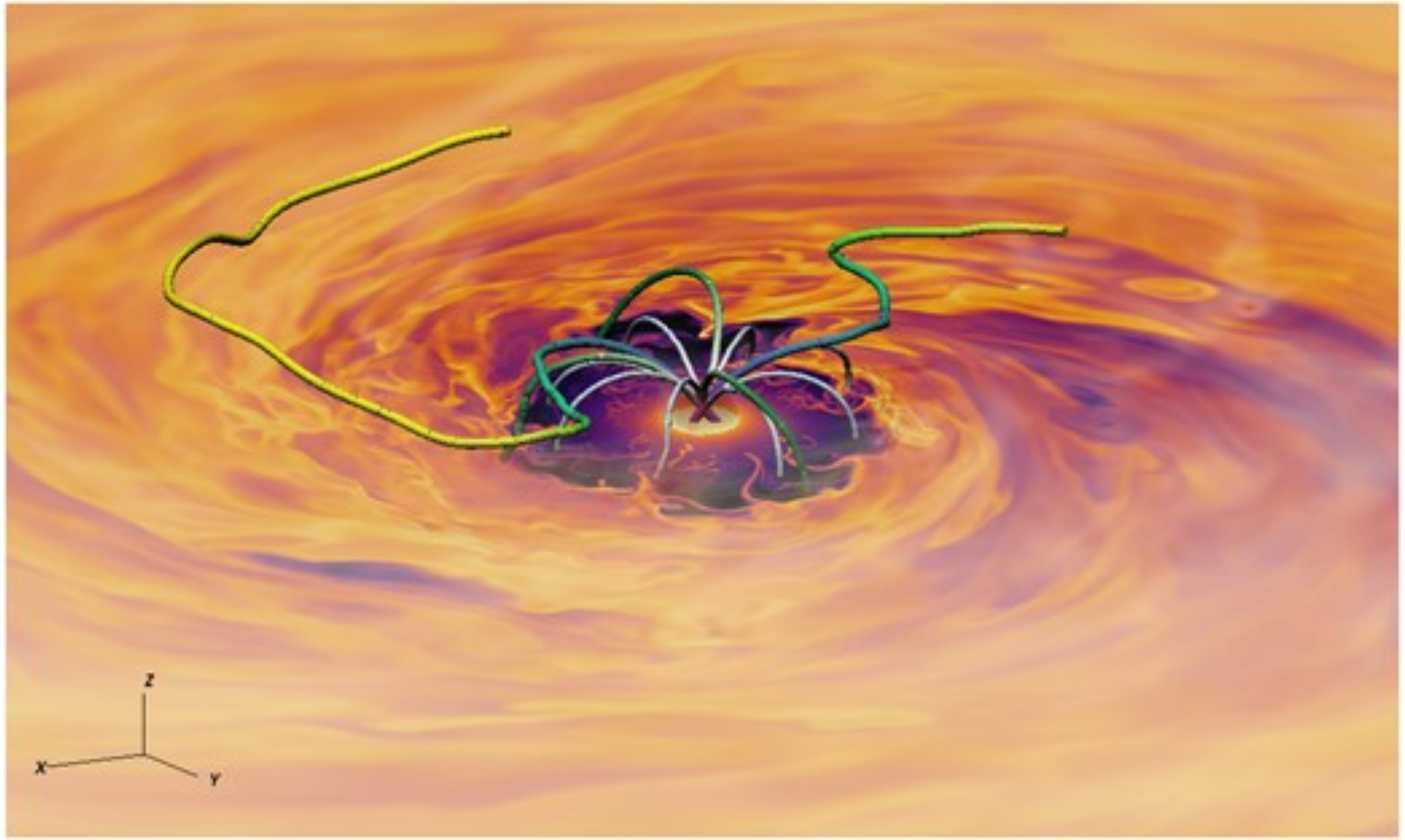




Inferring stellar/disk properties

What these say for the planetary formation environment

- Strength of the magnetic field
- Thermodynamic properties of the disk
- Stellar-planetary interactions

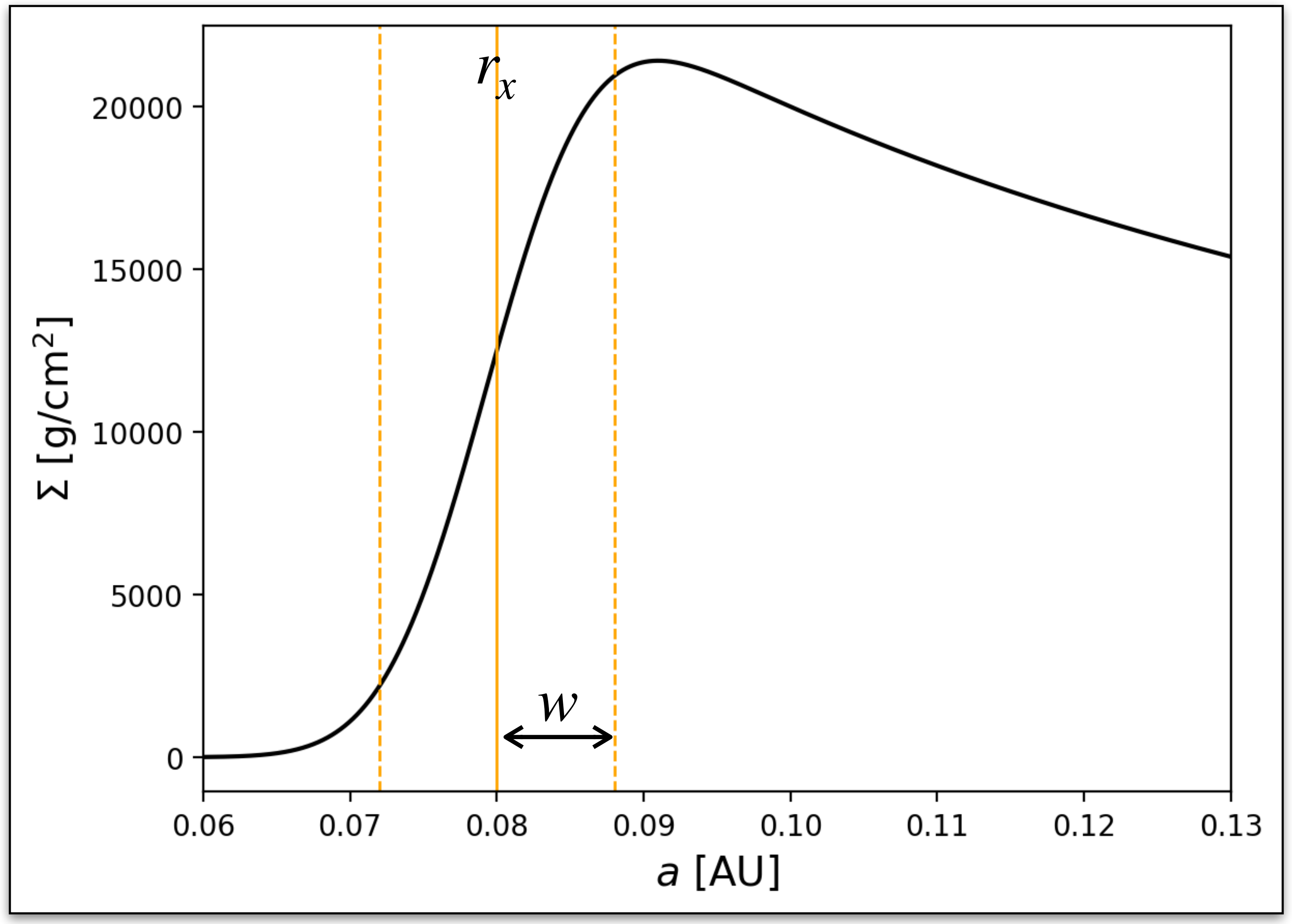


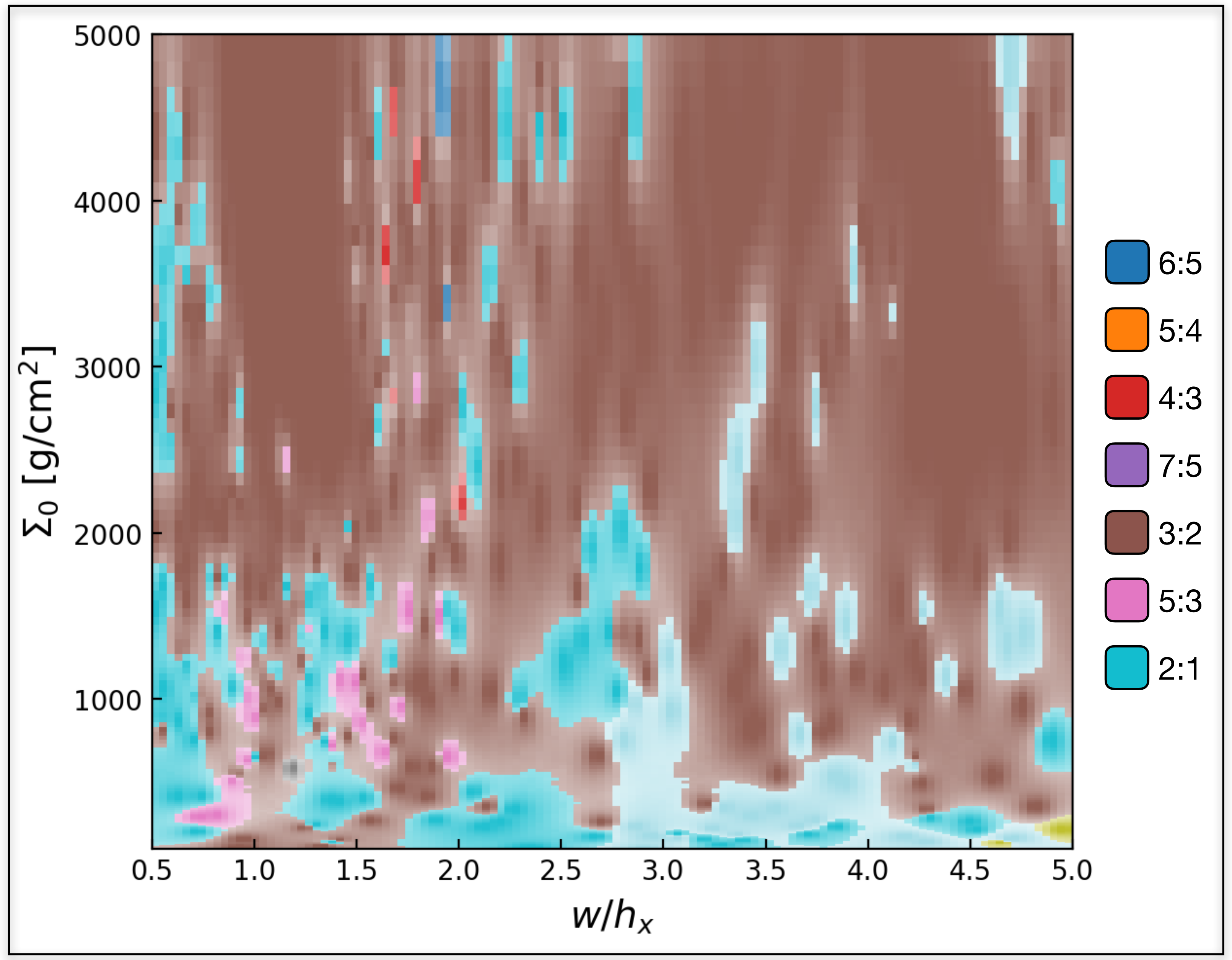
Zhu + (24)

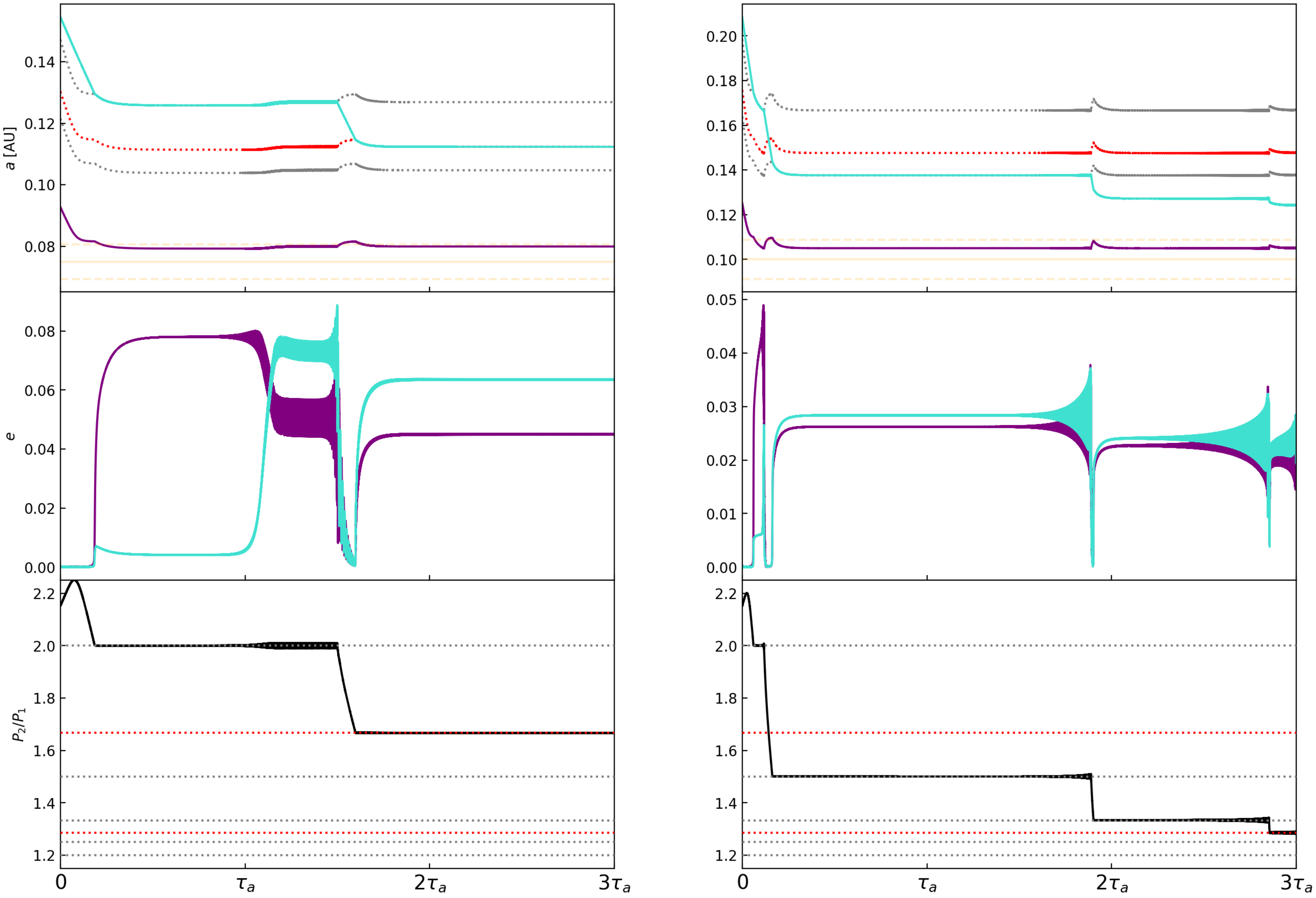
Summary

Unlikely resonances are rich with information about the early epoch of planetary evolution:

- Protoplanetary disk environment
- Structure of the inner disk edge
- Stellar properties







a [AU]
e
P_2/P_1
0
τ_a
$2\tau_a$
$3\tau_a$