Credit: NASA/Brian Brondel (lic. under Creative Commons)

SUPPORTED BY DEUTSCHE FORSCHUNGSGESELLSCHAFT
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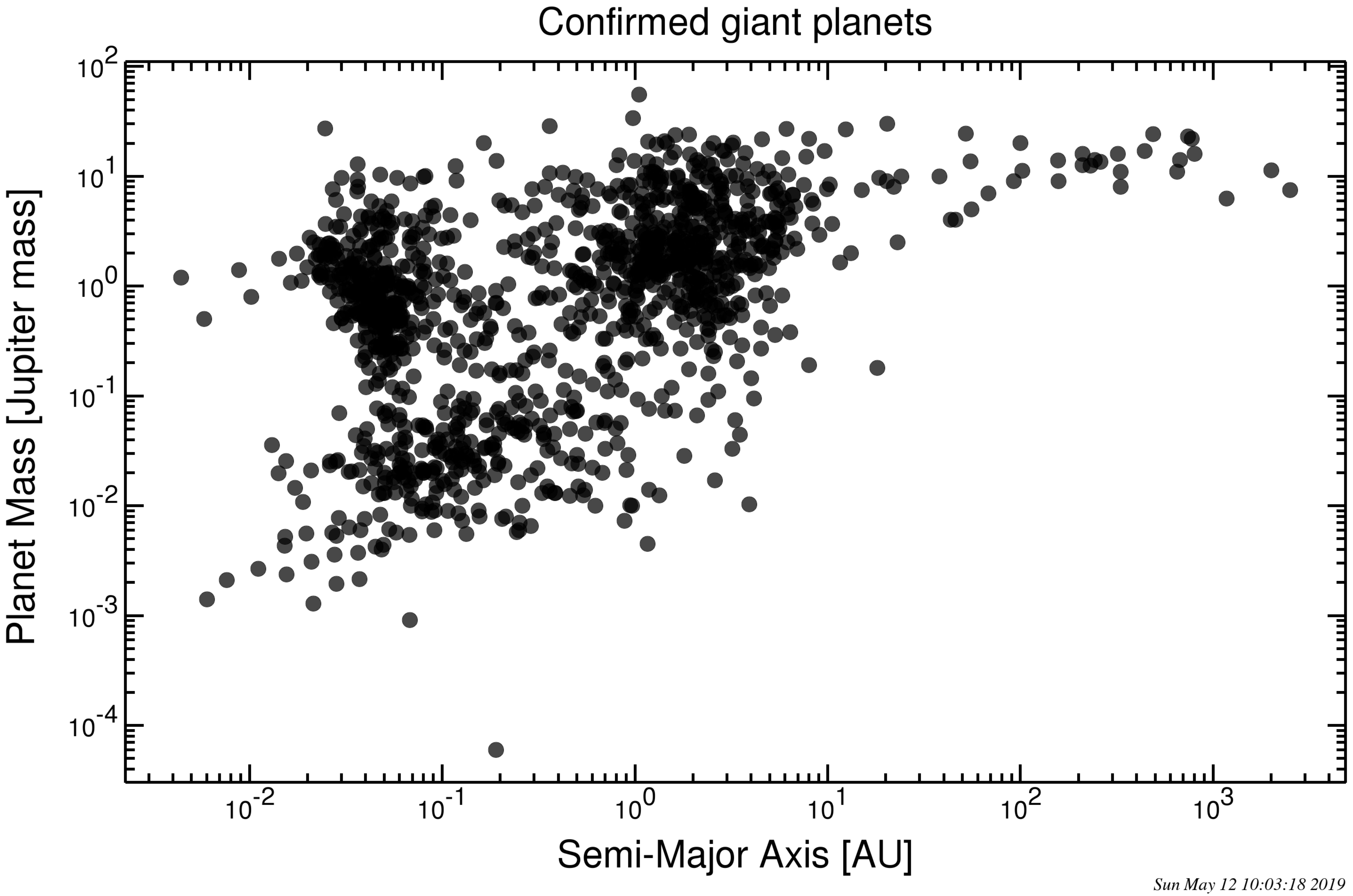
IN COLLABORATION WITH
BARBARA ERCOLANO, GIOVANNI
PICOGNA & THOMAS PREIBISCH

KRISTINA MONSCH · USM-LMU MUNICH

THE IMPRINT OF X-RAY PHOTOEVAPORATION ON THE ORBITAL DISTRIBUTION OF GIANT PLANETS

THE DEMOGRAPHICS OF GIANT PLANETS



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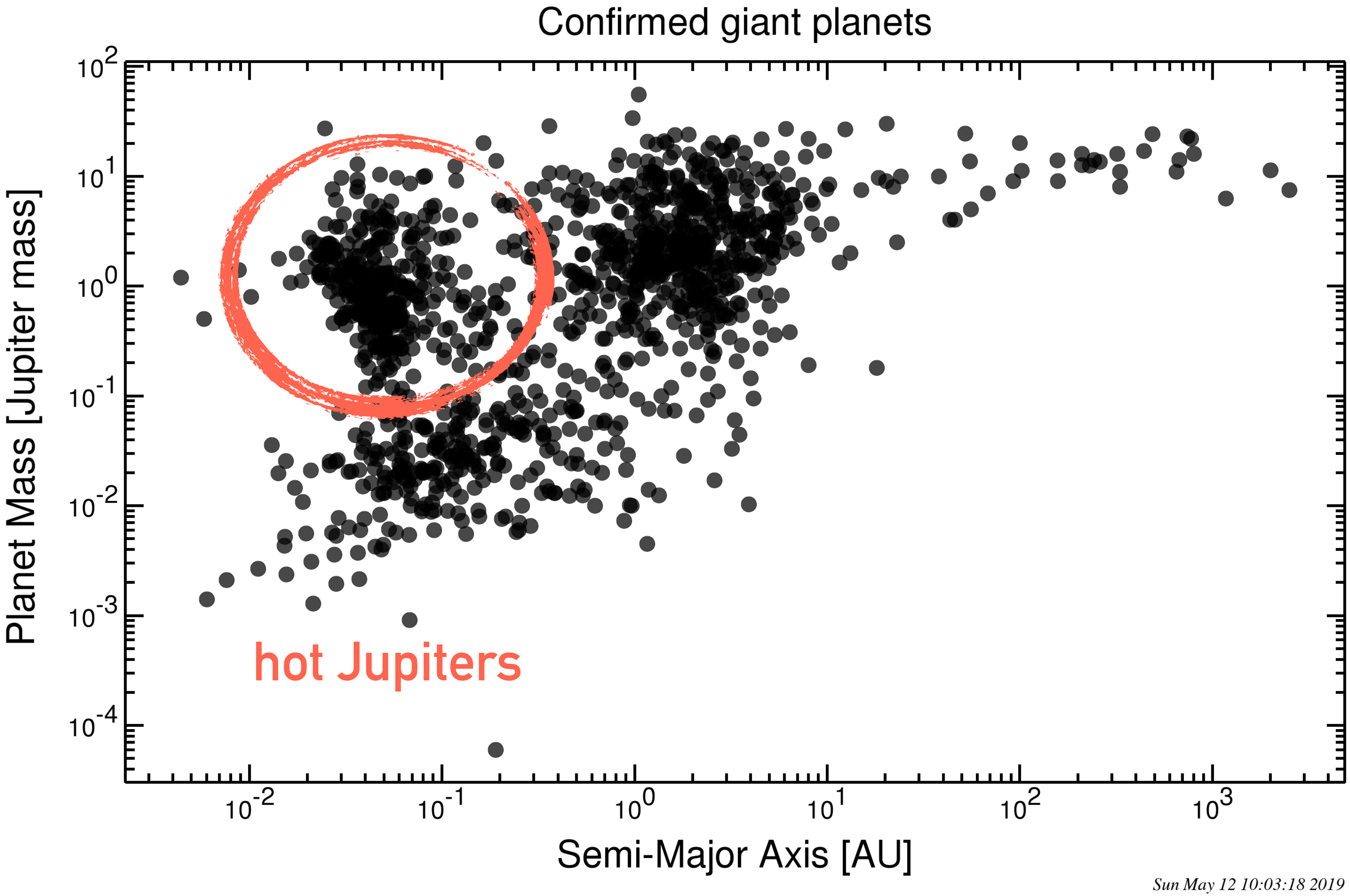

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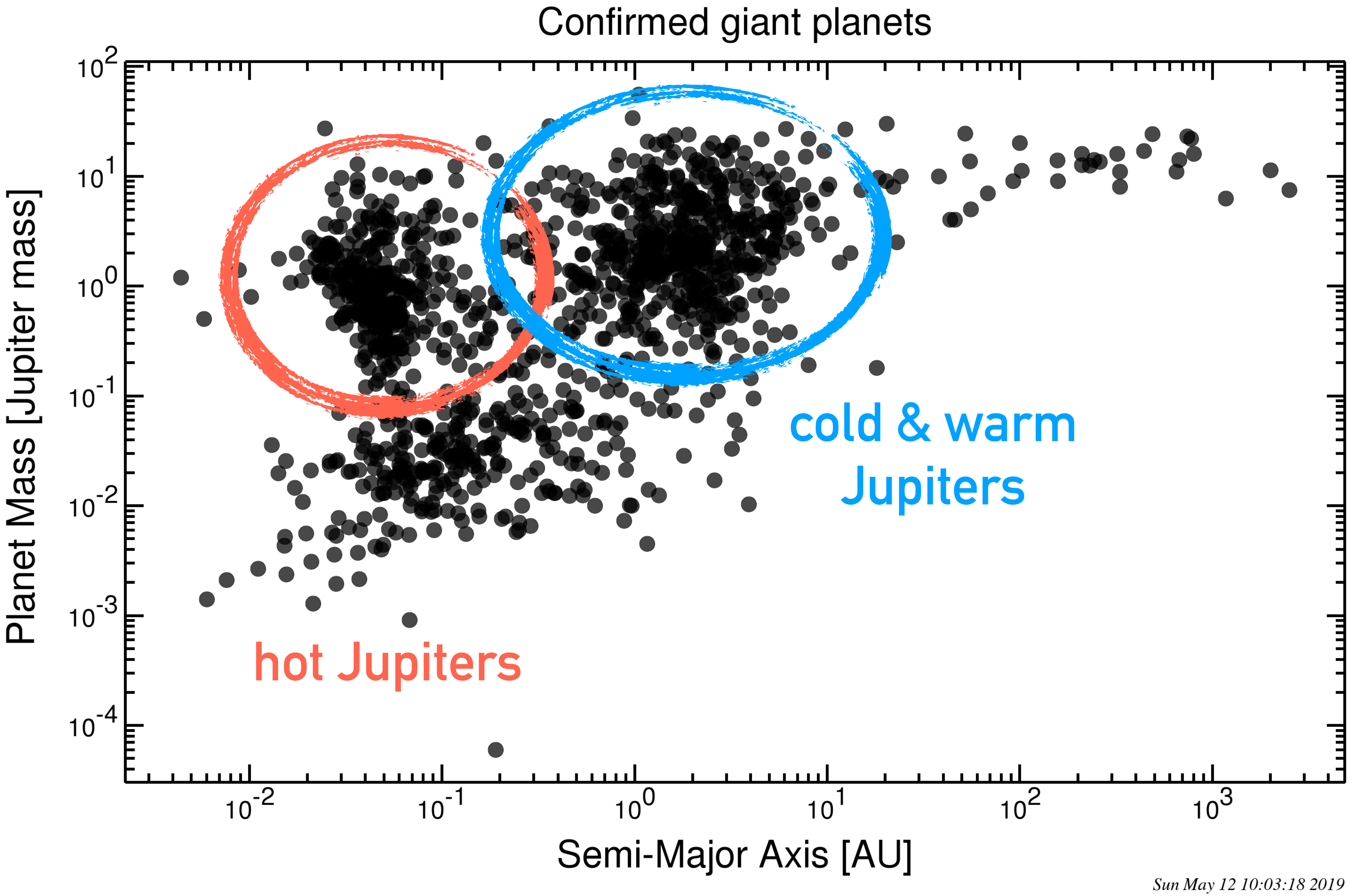

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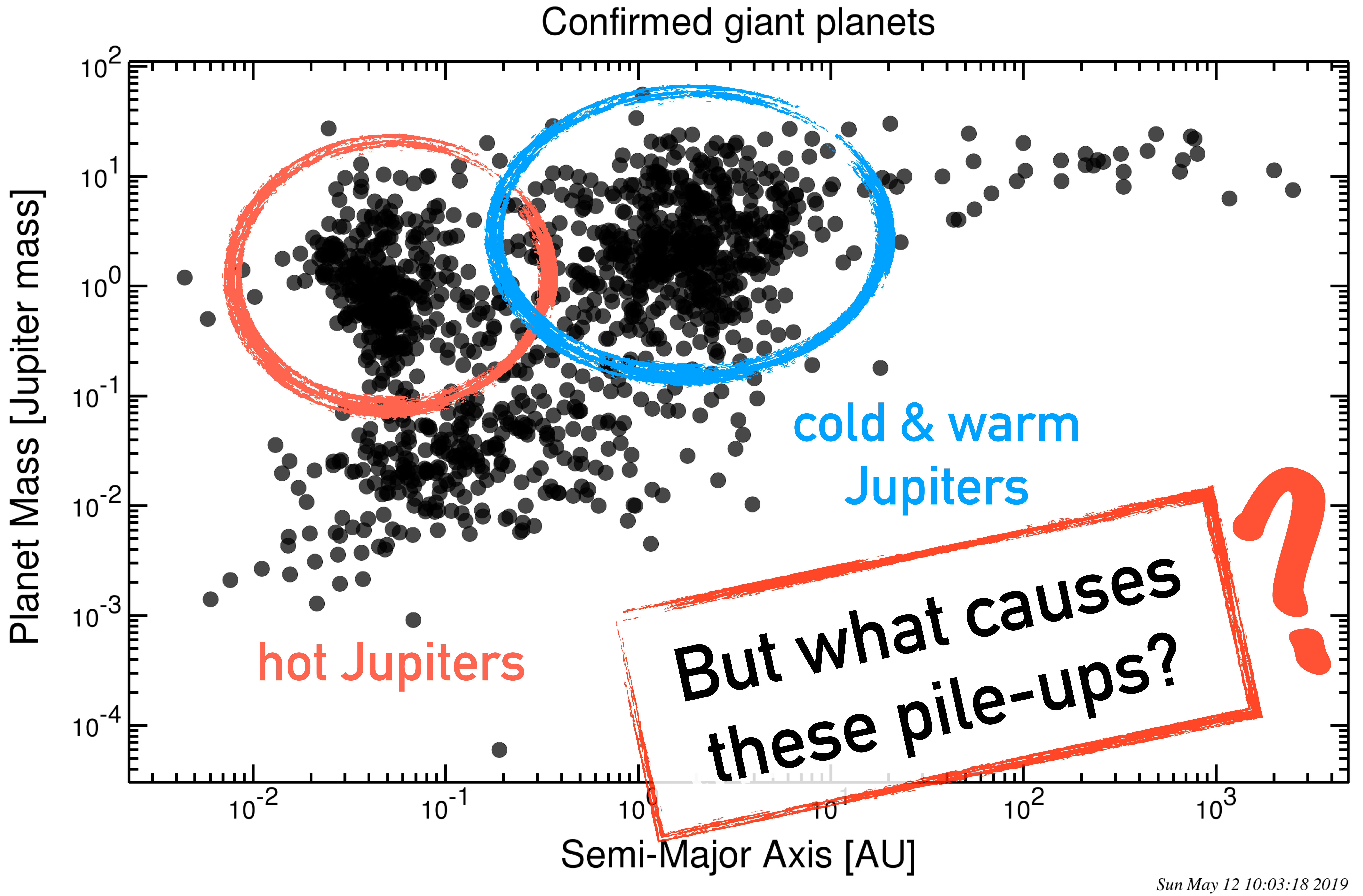
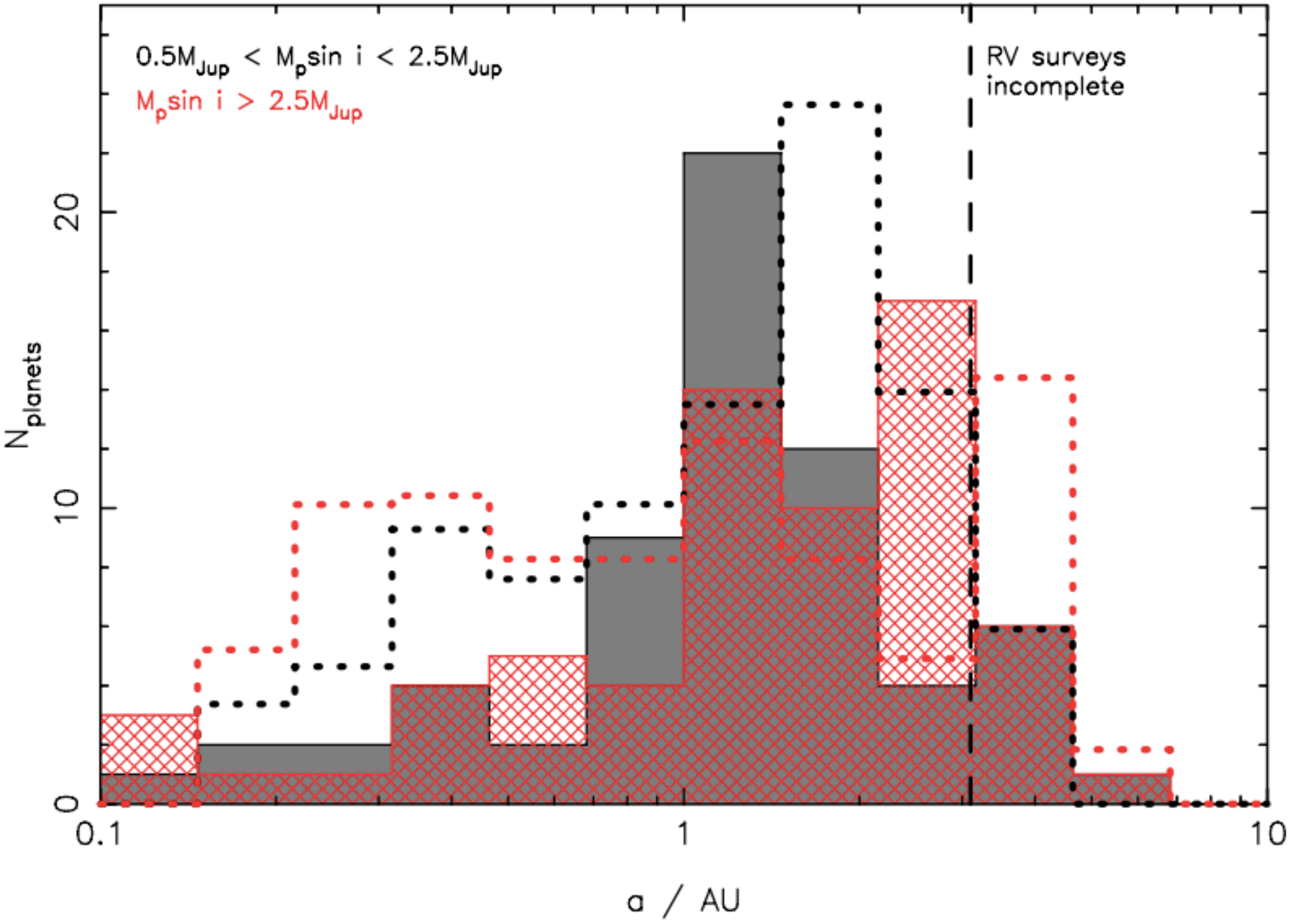


PHOTOEVAPORATIVE DISC-CLEARING AS A POSSIBLE EXPLANATION

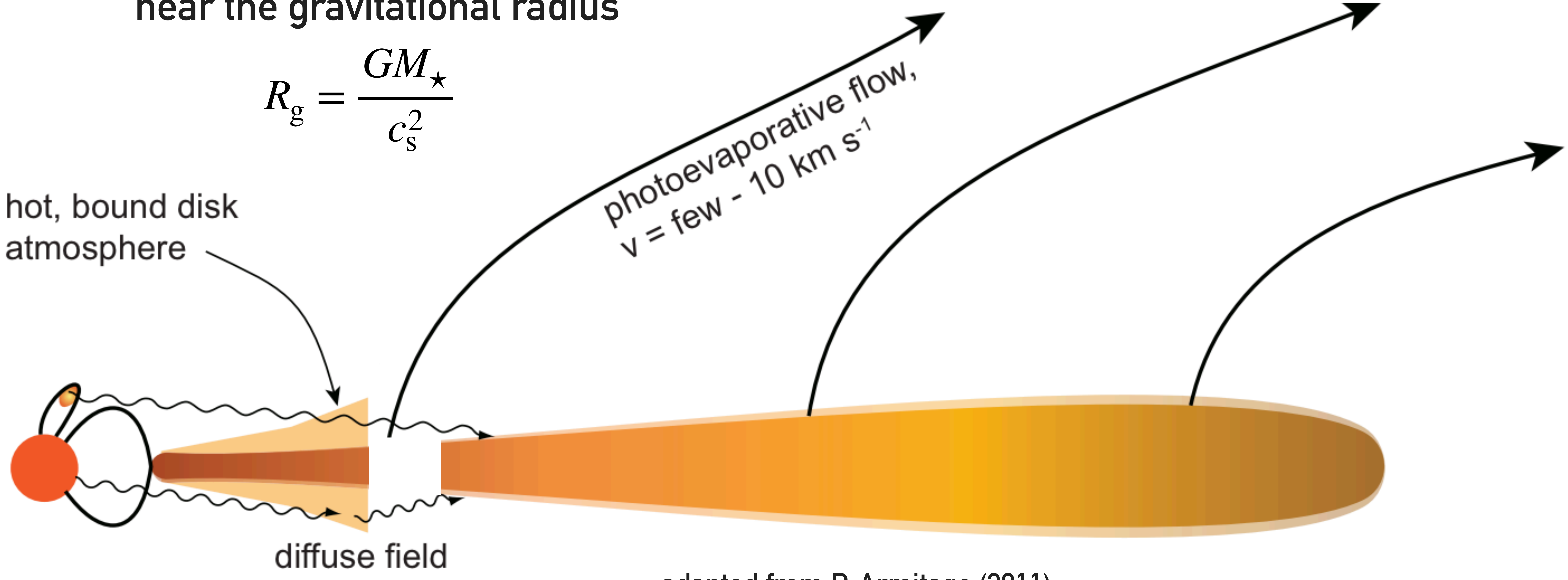
Alexander & Pascucci (2012):



Alexander & Pascucci (2012): disc clearing due to EUV photoevaporation results in a pile-up of ~Jupiter-mass planets at ~1-2 au

photoevaporation opens a gap
near the gravitational radius

$$R_g = \frac{GM_\star}{c_s^2}$$



adapted from P. Armitage (2011)

THE DISPERSAL OF PLANET-FORMING DISCS BY X-RAY PHOTOEVAPORATION

photoevaporation opens a gap
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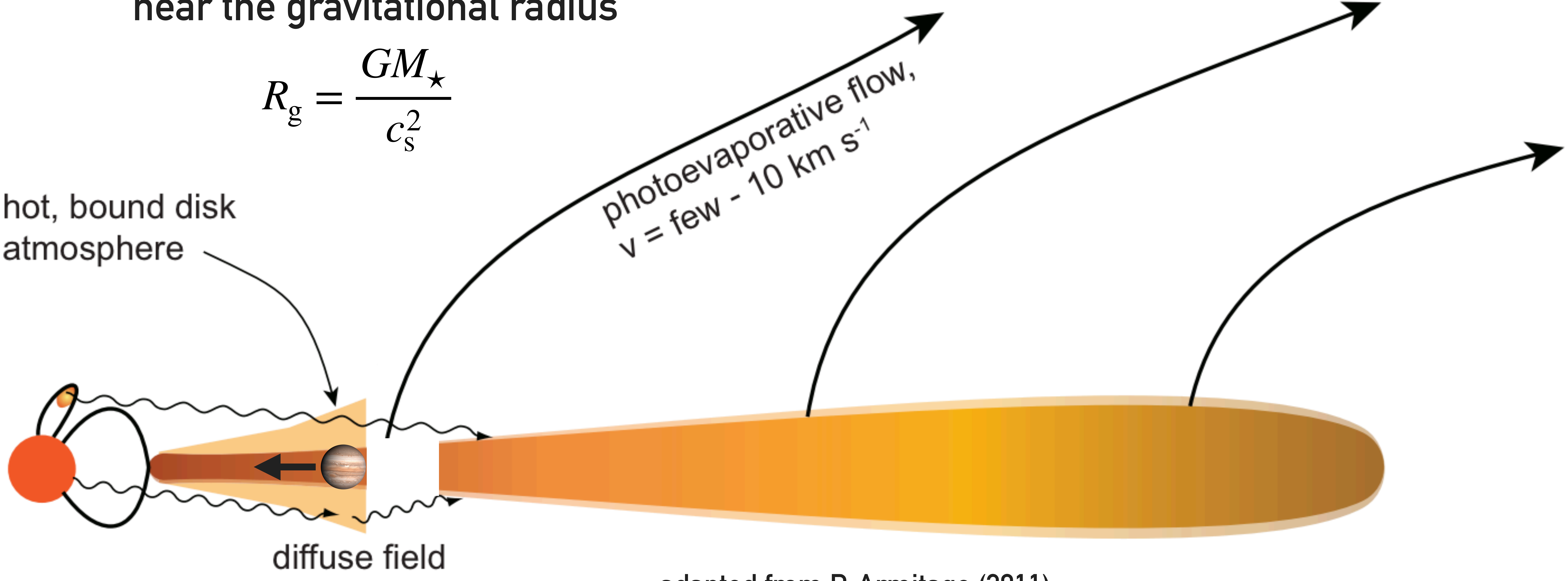
$$R_g = \frac{GM_\star}{c_s^2}$$



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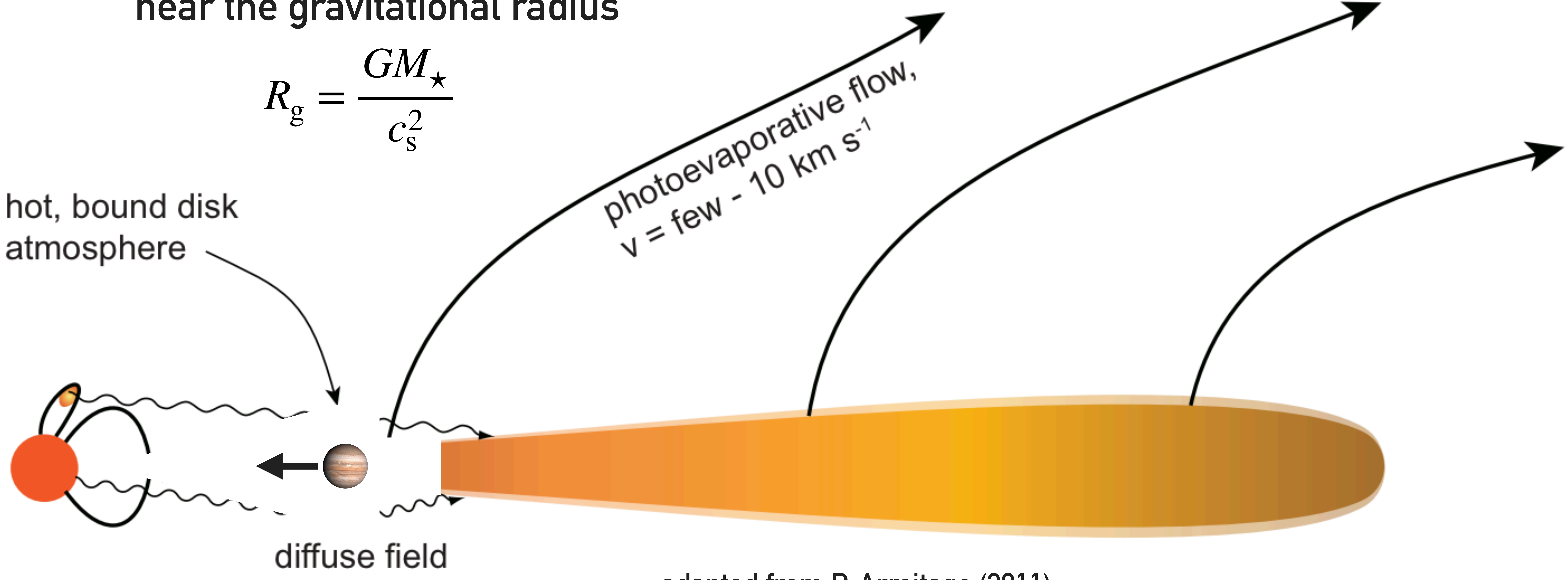

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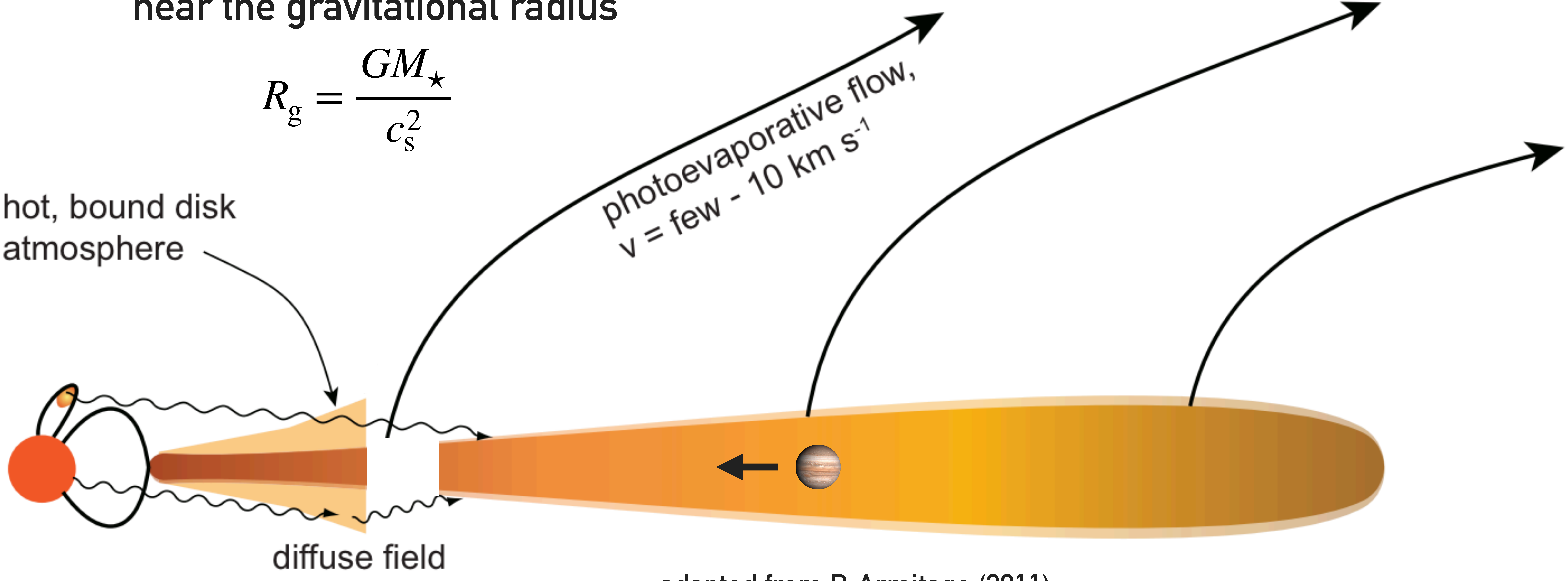
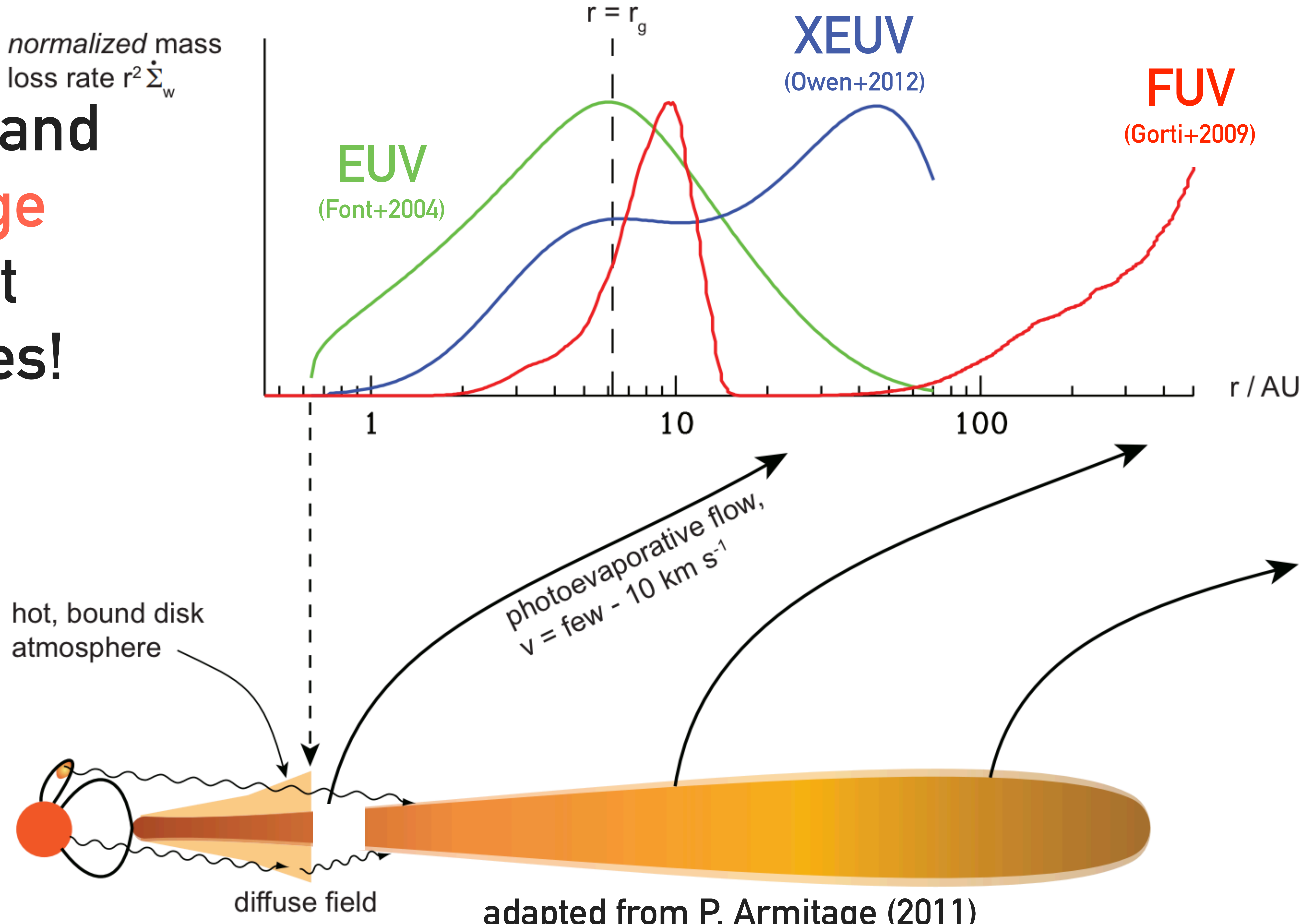


adapted from P. Armitage (2011)

The total mass-loss rate and the location of R_g change drastically for different photoevaporation profiles!

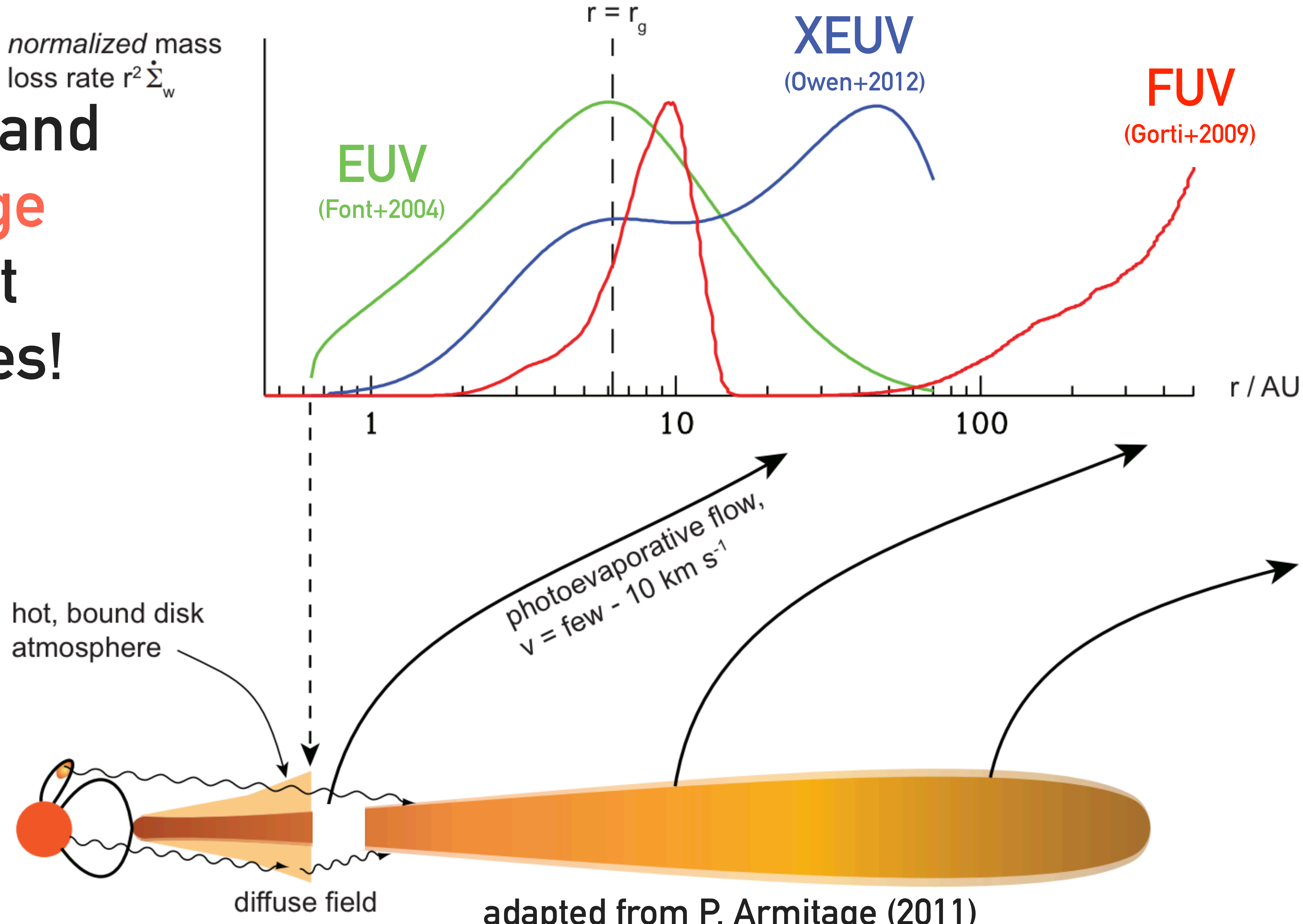


adapted from P. Armitage (2011)

THE DISPERSAL OF PLANET-FORMING DISCS BY X-RAY PHOTOEVAPORATION

The total **mass-loss rate** and the **location of R_g change** drastically for different photoevaporation profiles!

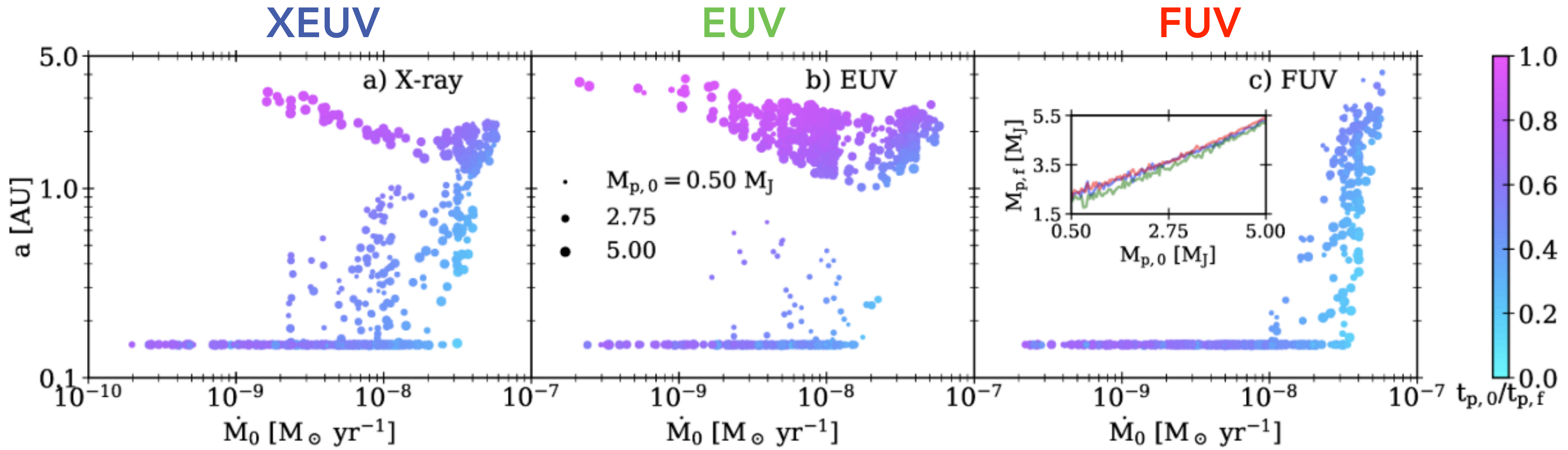
This should leave an imprint in today's giant planet distribution!



adapted from P. Armitage (2011)

JENNINGS ET AL. (2018): A COMPARATIVE STUDY BETWEEN XEUV, EUV & FUV

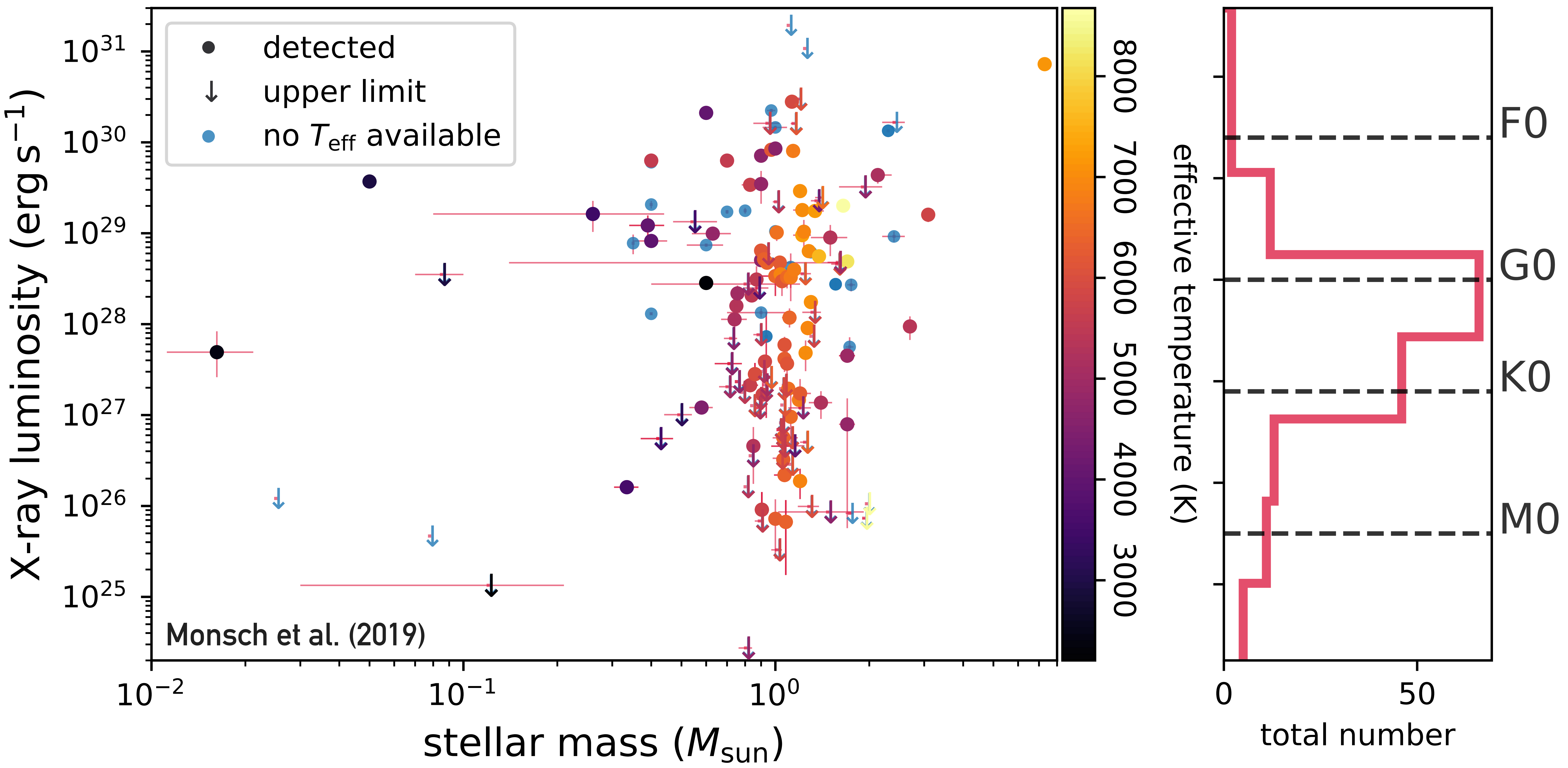
A comparative study on the effect of FUV, EUV and X-ray photoevaporation on gas giant separations



Theoretically, different photoevaporation profiles lead to different orbital configurations of giant planets!

X-RAY OBSERVATIONS OF GIANT-PLANET HOST STARS

Monsch et al. (2019): The imprint of X-ray photoevaporation of planet-forming discs on the orbital distribution of giant planets *(arXiv: 1812.02173)*



We constructed a catalog containing the X-ray luminosities as well as basic properties of more than 200 giant planets and their host stars

X-RAY OBSERVATIONS OF GIANT-PLANET HOST STARS

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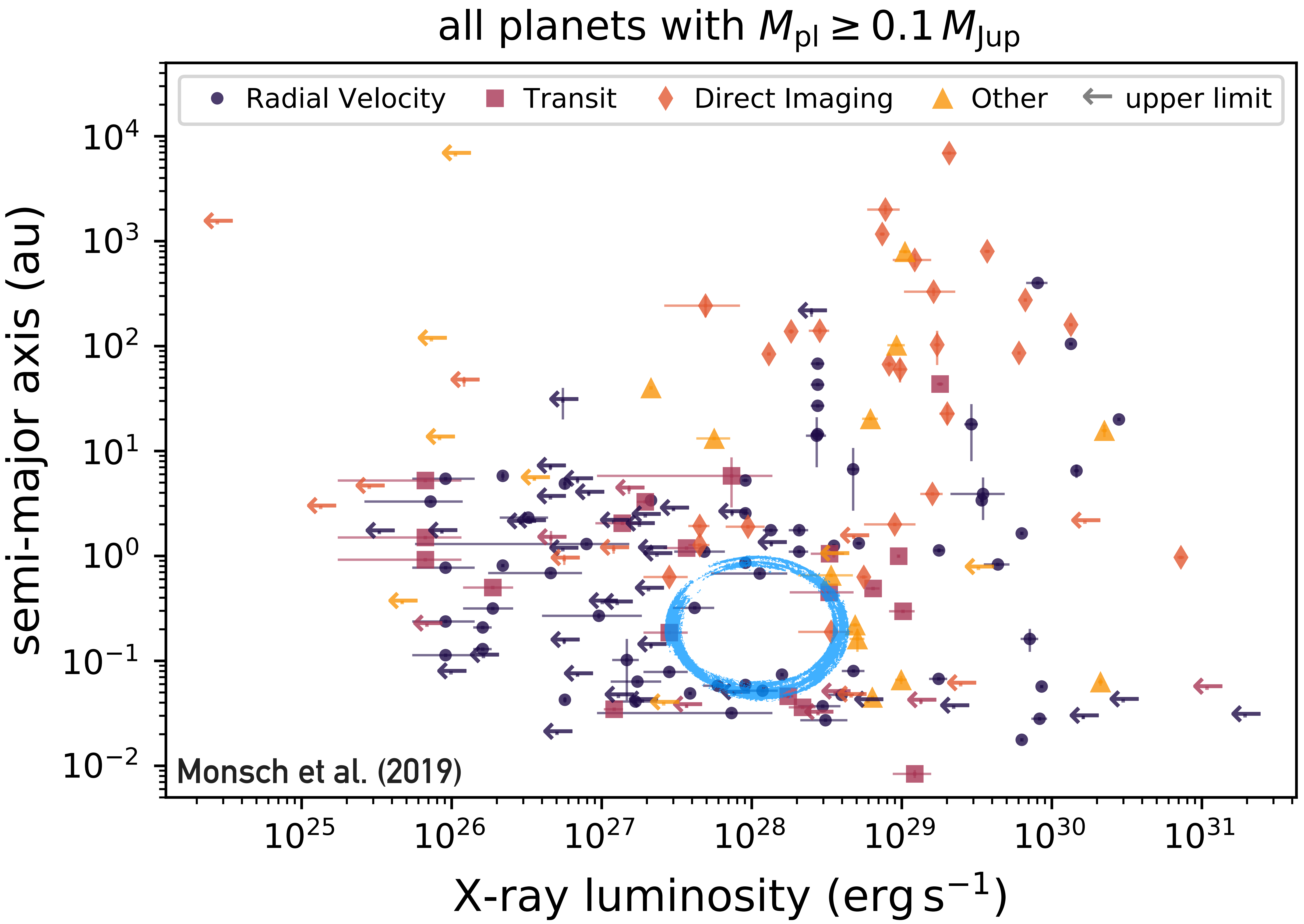


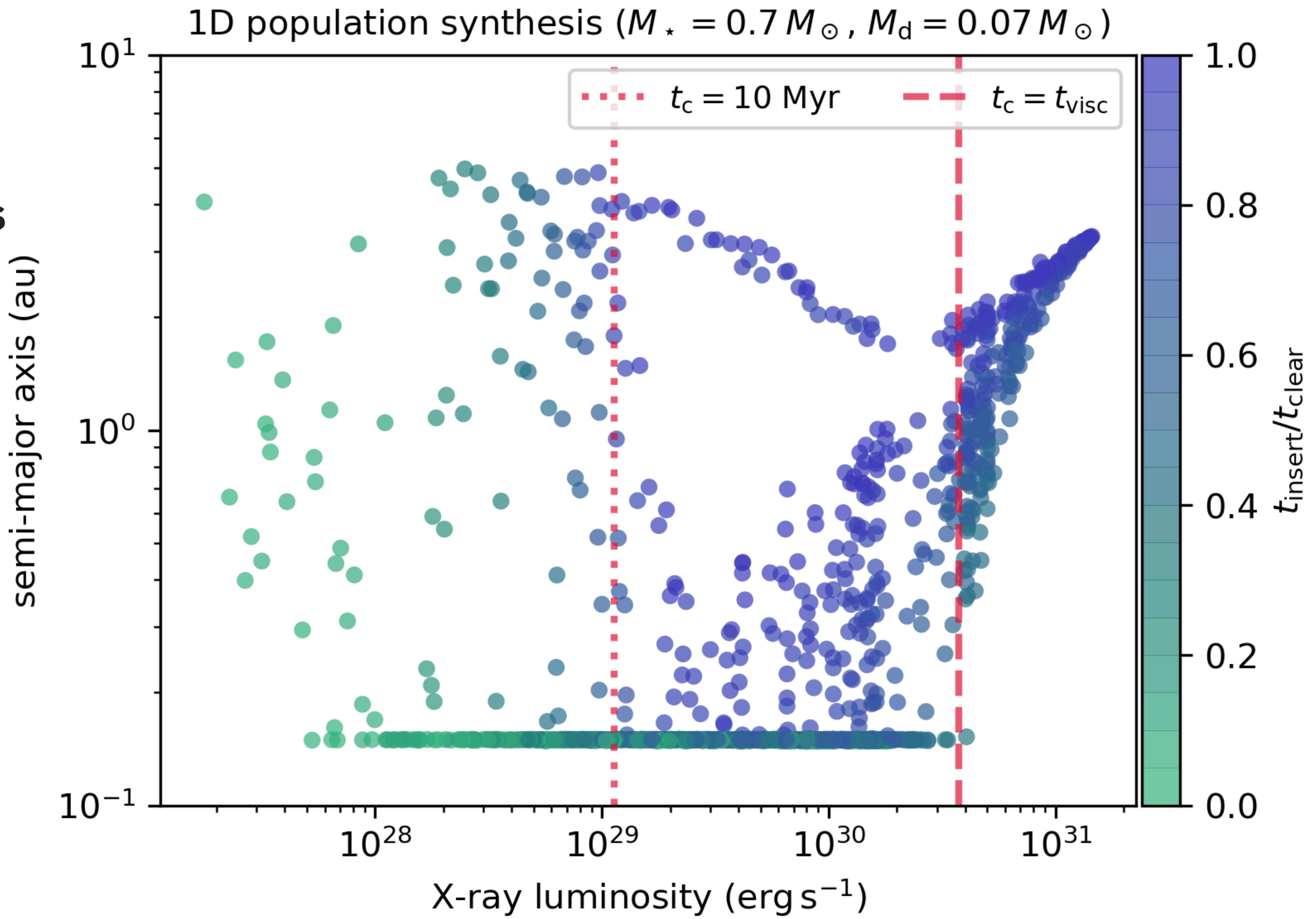
We have used archival Chandra, XMM-Newton and ROSAT data to calculate source fluxes and luminosities

the catalog is publicly available and can be downloaded from Harvard Dataverse (doi: 10.7910/DVN/FPXFA5)

NUMERICAL RESULTS

1D planet population synthesis using the viscous evolution code SPOCK
(Ercolano & Rosotti, 2015)

numerical setup:
$M_\star = 0.7\ M_\odot$
$M_{disc} = 0.07\ M_\odot$
$M_{pl} = 0.5 - 5\ M_{jup}$
$a_{initial} = 5$ au
$H/R = 0.1$
XEUV-PE



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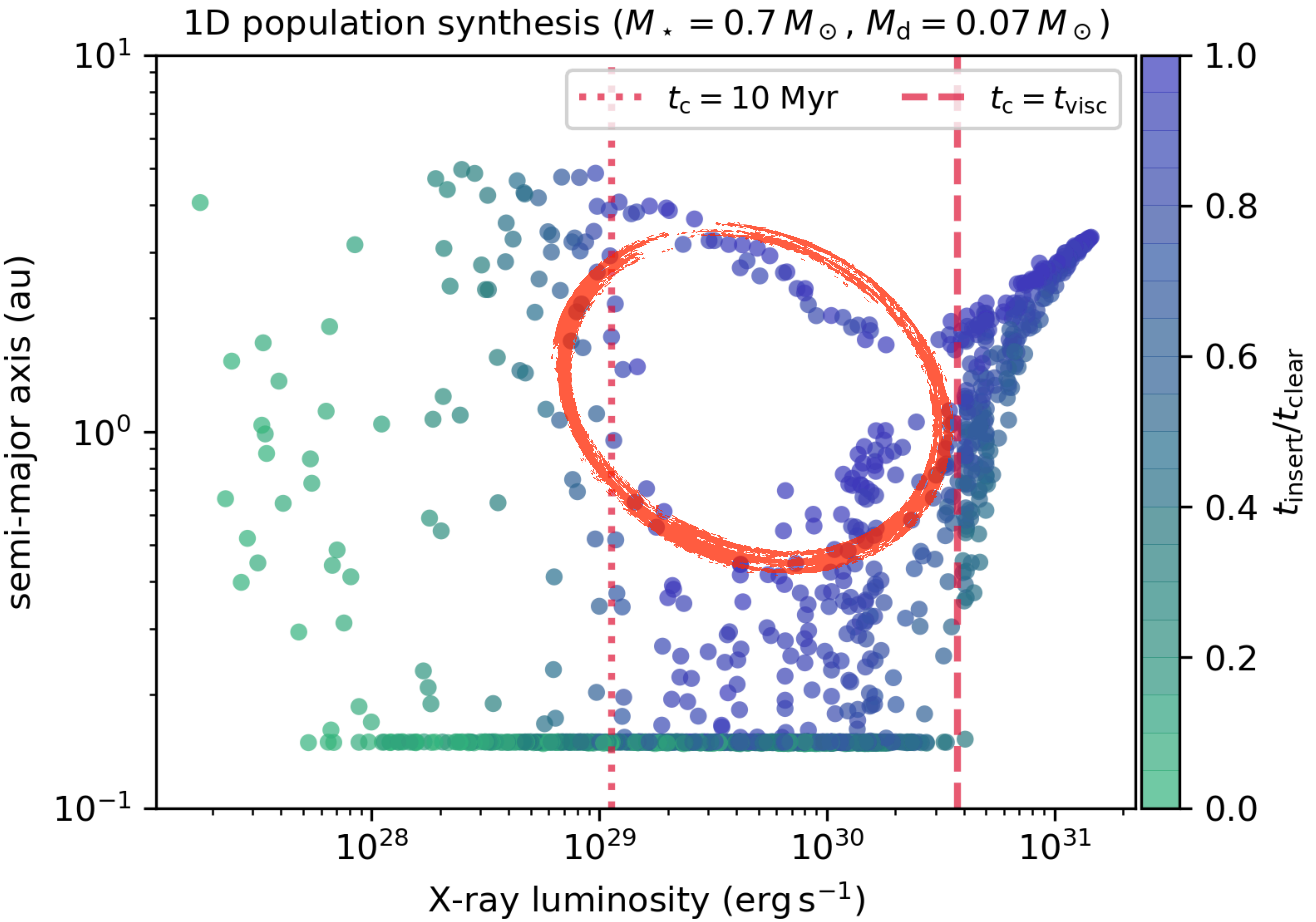

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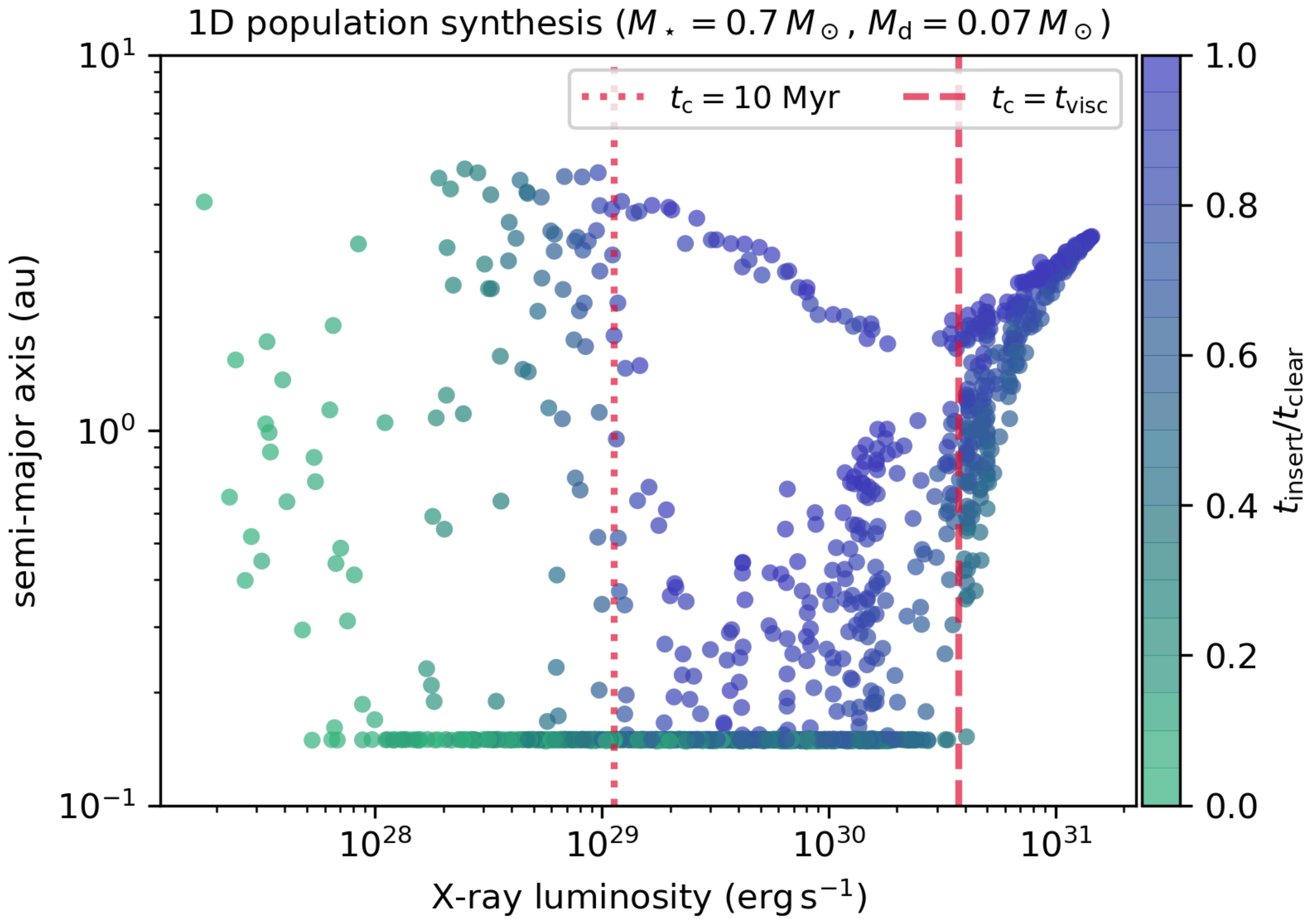


Caution!

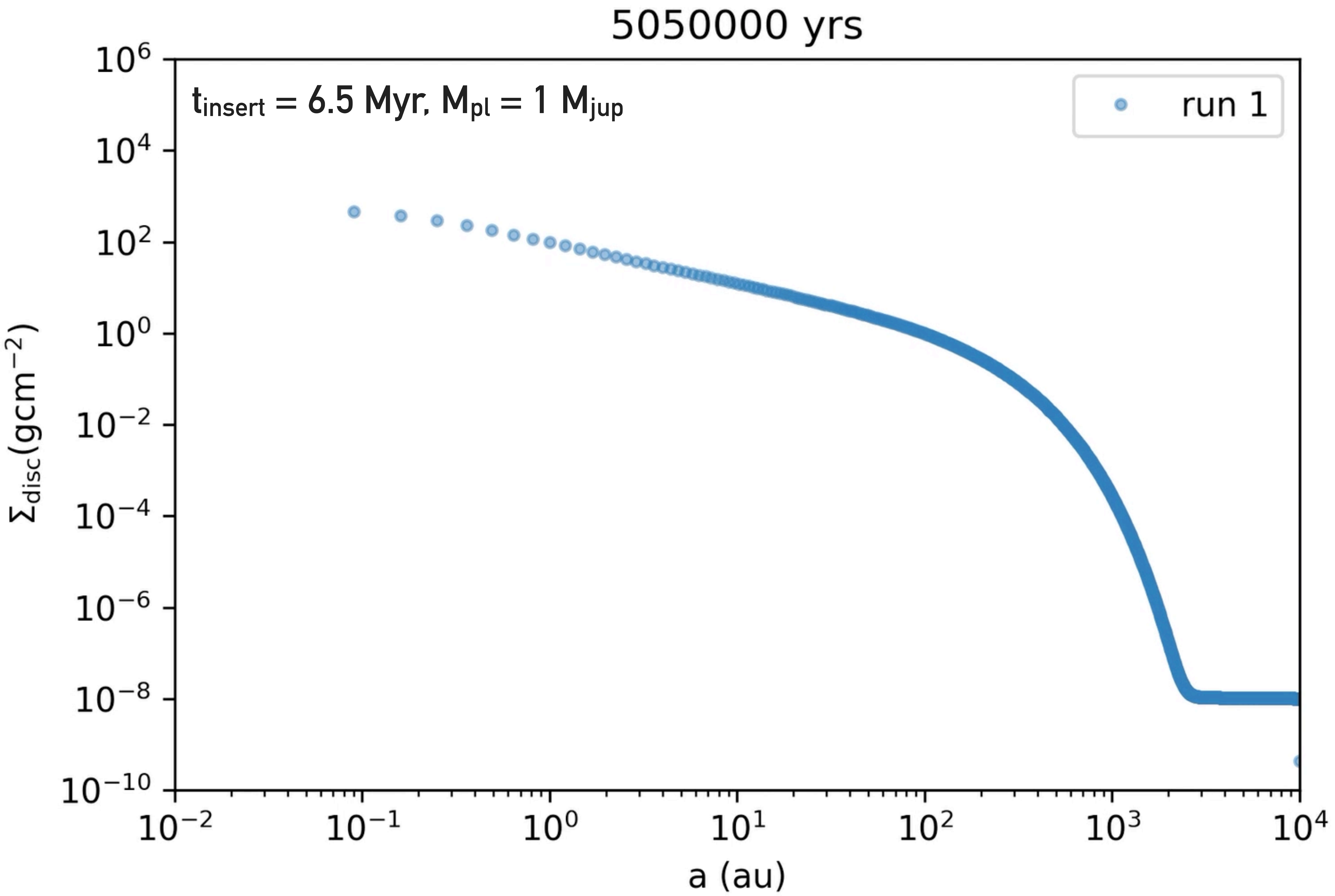
This plot is the result of very specific initial conditions!

Little changes in the initial setup can have drastic effects on the outcome!

OUR 1D MODEL SHOWS INWARD MIGRATION FOR ONE-SIDED TORQUE

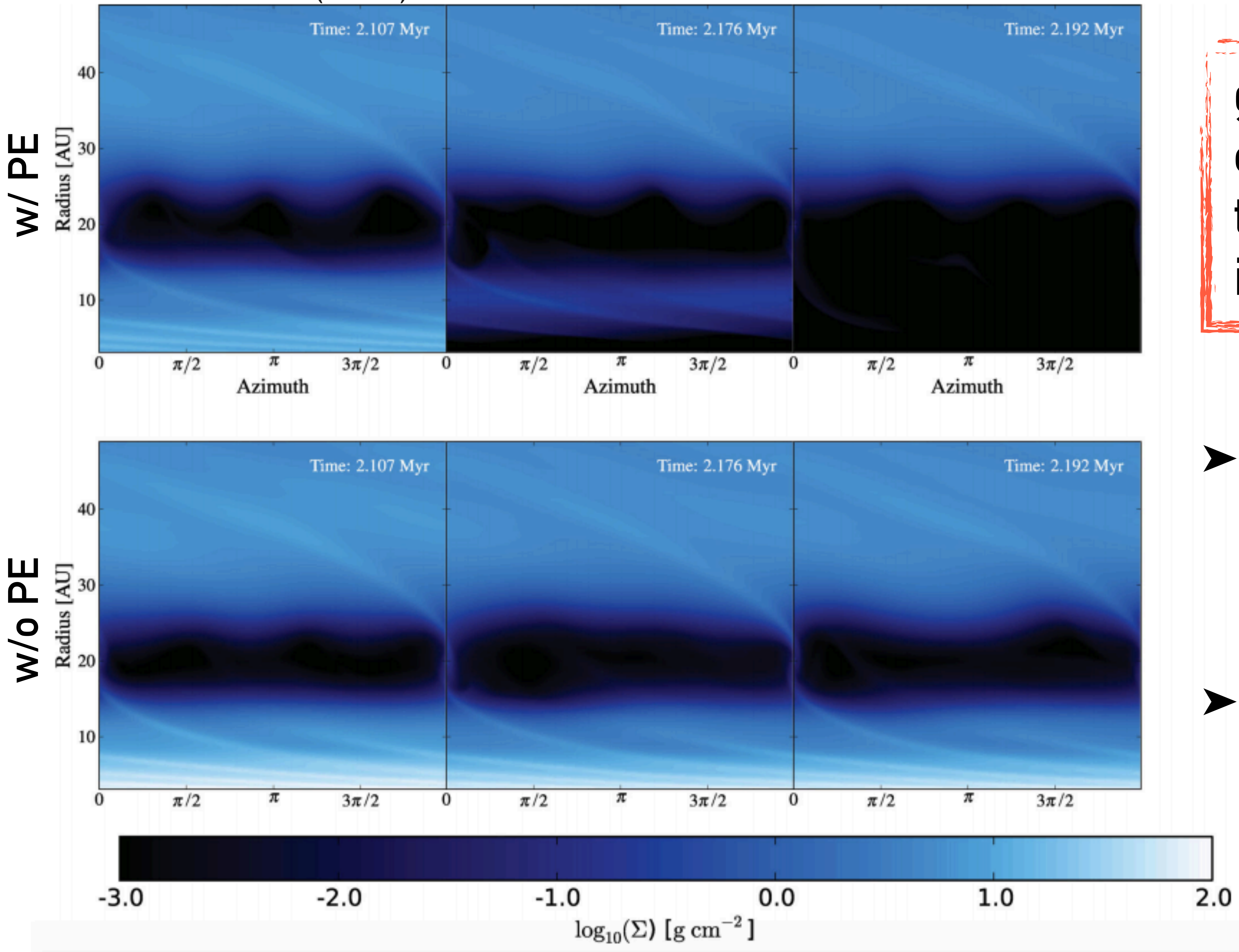
migration rate is calculated using the impulse approximation (Lin & Papaloizou 1986, Armitage et al. 2002)

$$\frac{\mathrm{d}a}{\mathrm{d}t} = -\left(\frac{a}{GM_*}\right)^{1/2}\left(\frac{4\pi}{M_p}\right)\int_{r_{\mathrm{in}}}^{r_{\mathrm{out}}} r\Lambda\Sigma dr$$



PIPE: PLANET-INDUCED PHOTOEVAPORATION

Rosotti et al. (2013)



giant planets reduce the inflow of mass into the inner disc, so that photoevaporation can kick in earlier (cf. Rosotti et al., 2013)

- due to PE, the disc inside the planet's orbit is removed quickly, so that only a massive outer disc remains
- the mass-flow across the gap can strongly affect the migration rate of the planet

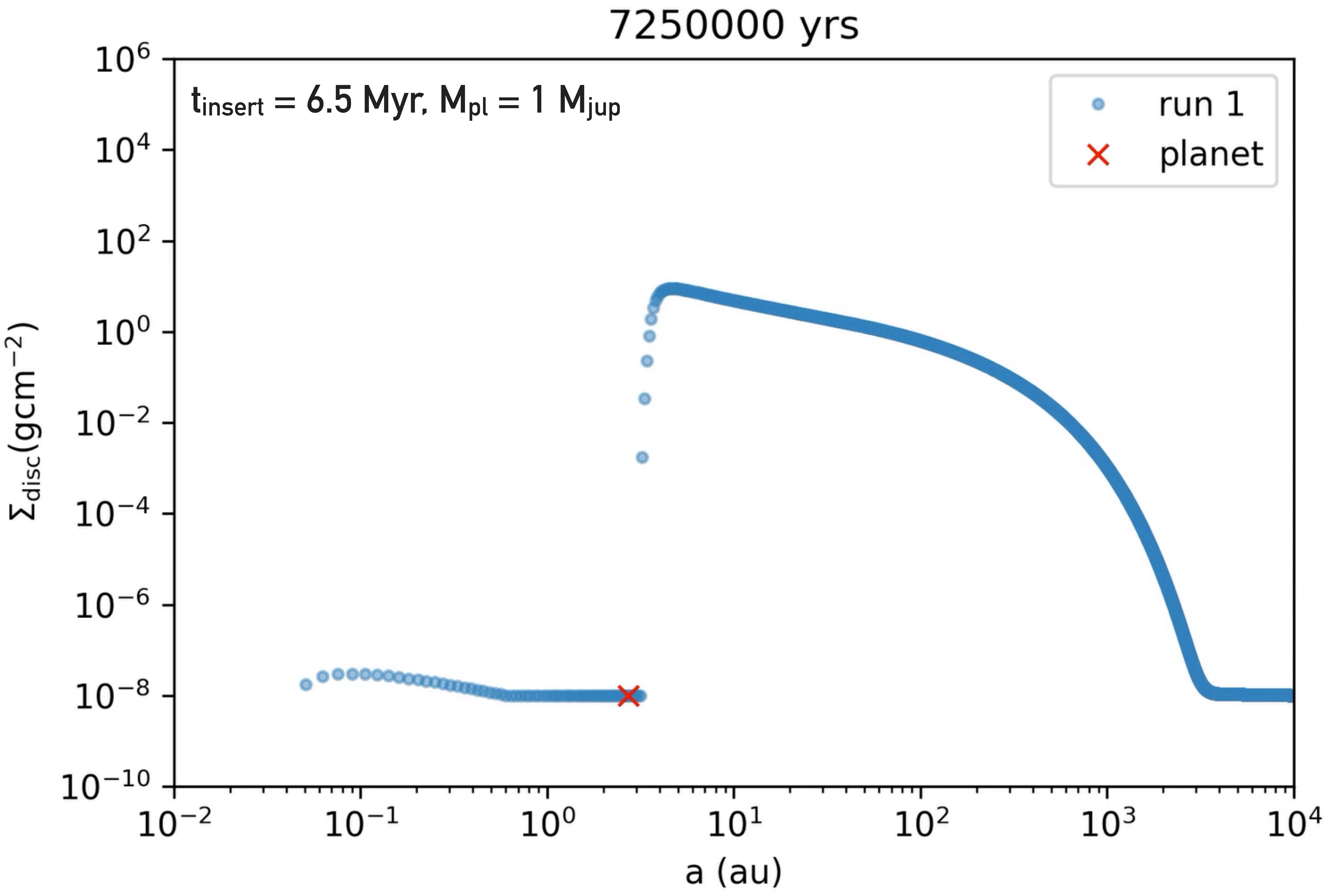
OUR 1D MODEL SHOWS STRONG INWARD MIGRATION DUE TO A MASSIVE OUTER DISC

migration rate is calculated using the impulse approximation (Lin & Papaloizou 1986, Armitage et al. 2002)

$$\frac{\mathrm{d}a}{\mathrm{d}t} = -\left(\frac{a}{GM_*}\right)^{1/2}\left(\frac{4\pi}{M_p}\right)\int_{r_{\rm in}}^{r_{\rm out}} r\Lambda\Sigma dr$$

in 1D, the planet is 'pushed' inwards by the massive outer disc with an increased migration speed.

Is this realistic?



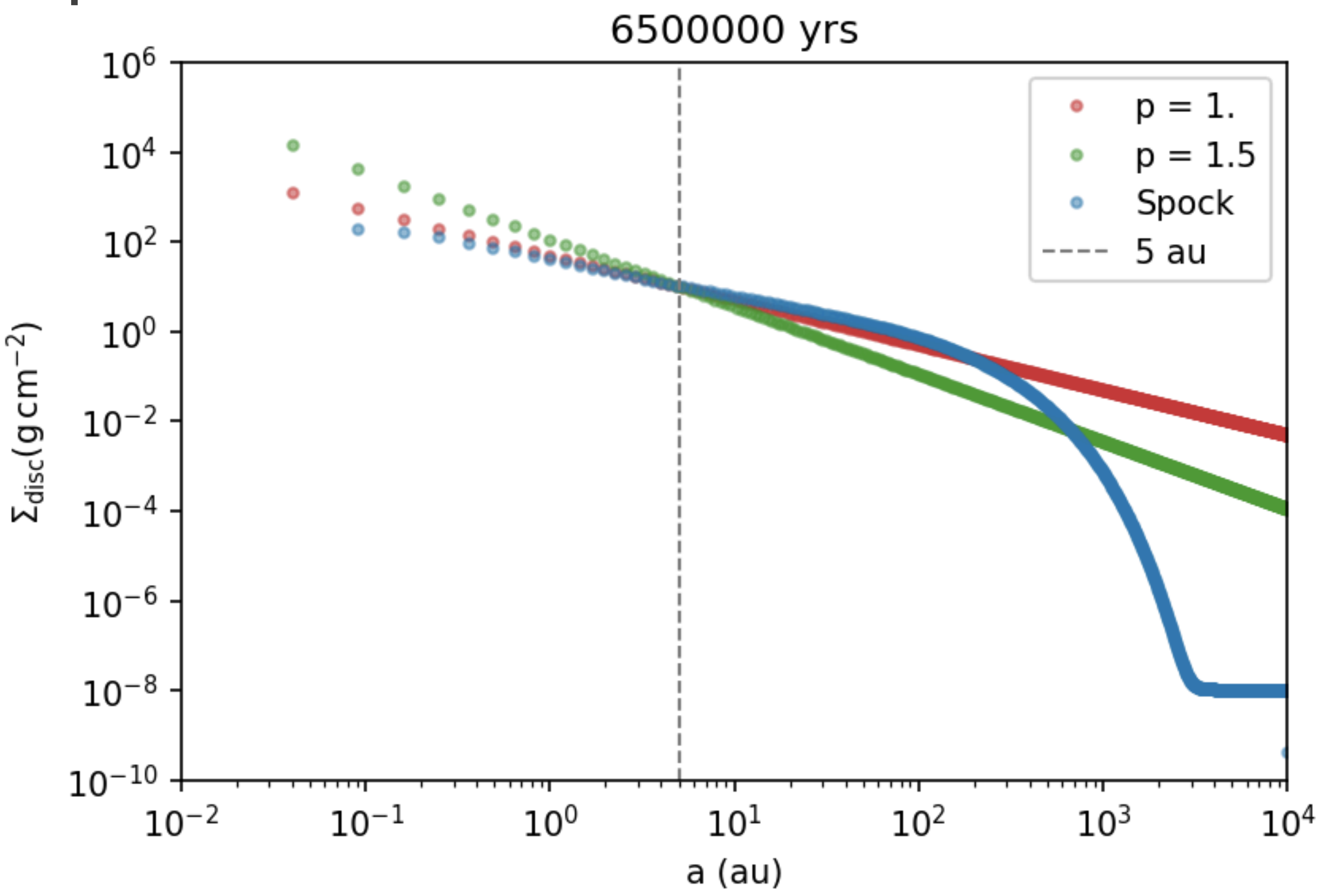
MODELLING A PIPE-PLANET IN FARGO WITH PHOTOEVAPORATION

- includes XEUV photoevaporation (Owen+2010, 2011, 2012)
- following Rosotti+2013, we model the disc in 1D until the planet is inserted
- then we get a fit of the disc profile and put it into FARGO

$$\Sigma(r) = \Sigma_0 \left(\frac{R}{R_0}\right)^{-p}$$

For this specific run, this yields at $l_0 = 5$ au:

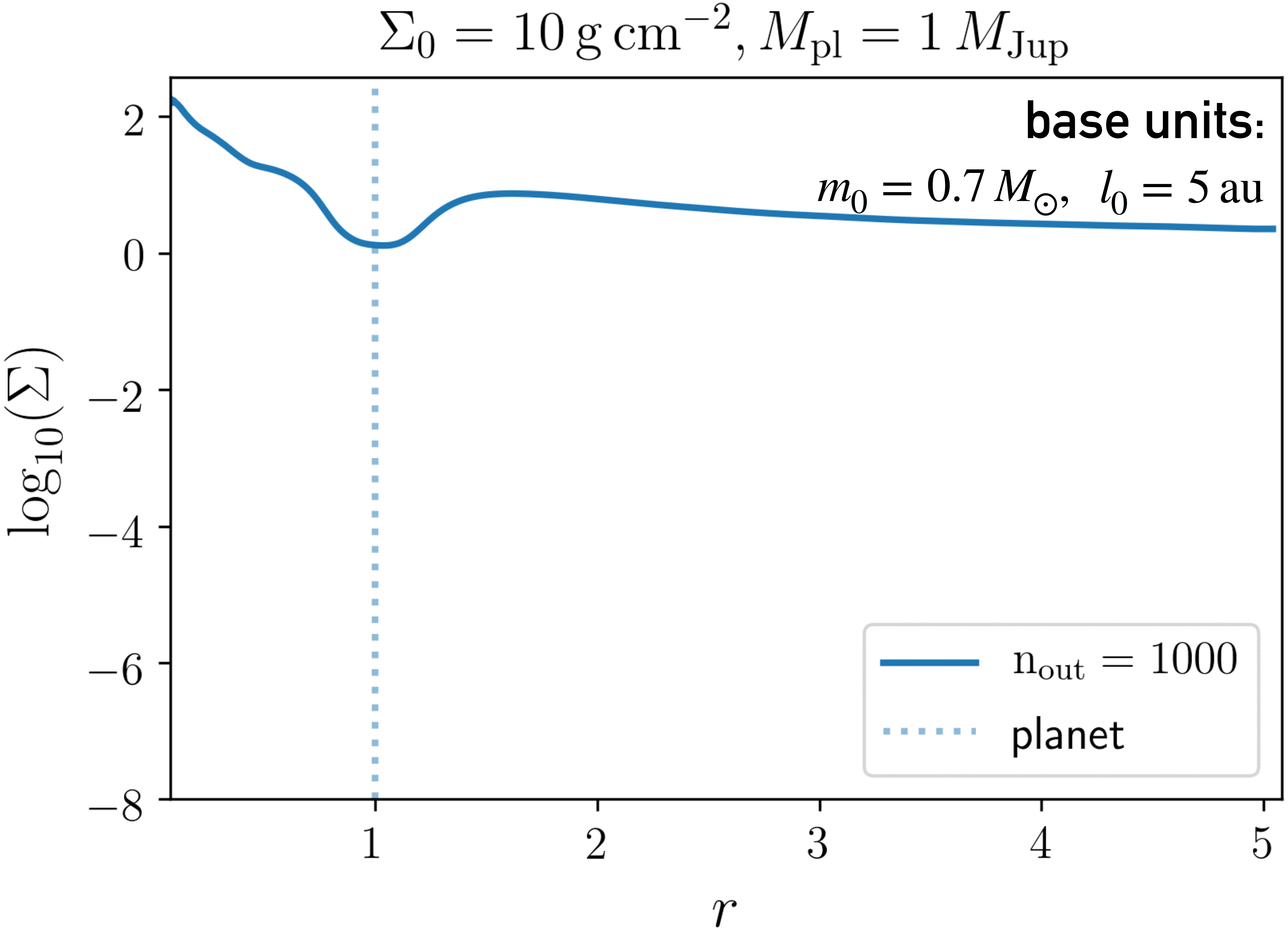
$$\Sigma_0 \approx 10\,\mathrm{g\,cm^{-2}}$$
$$p = 1$$



FARGO RESULTS:

approach:

- keep the planet position fixed for 1000 orbits and let the disc reach a stable state (w/o PE)
- then switch on PE and let the planet migrate

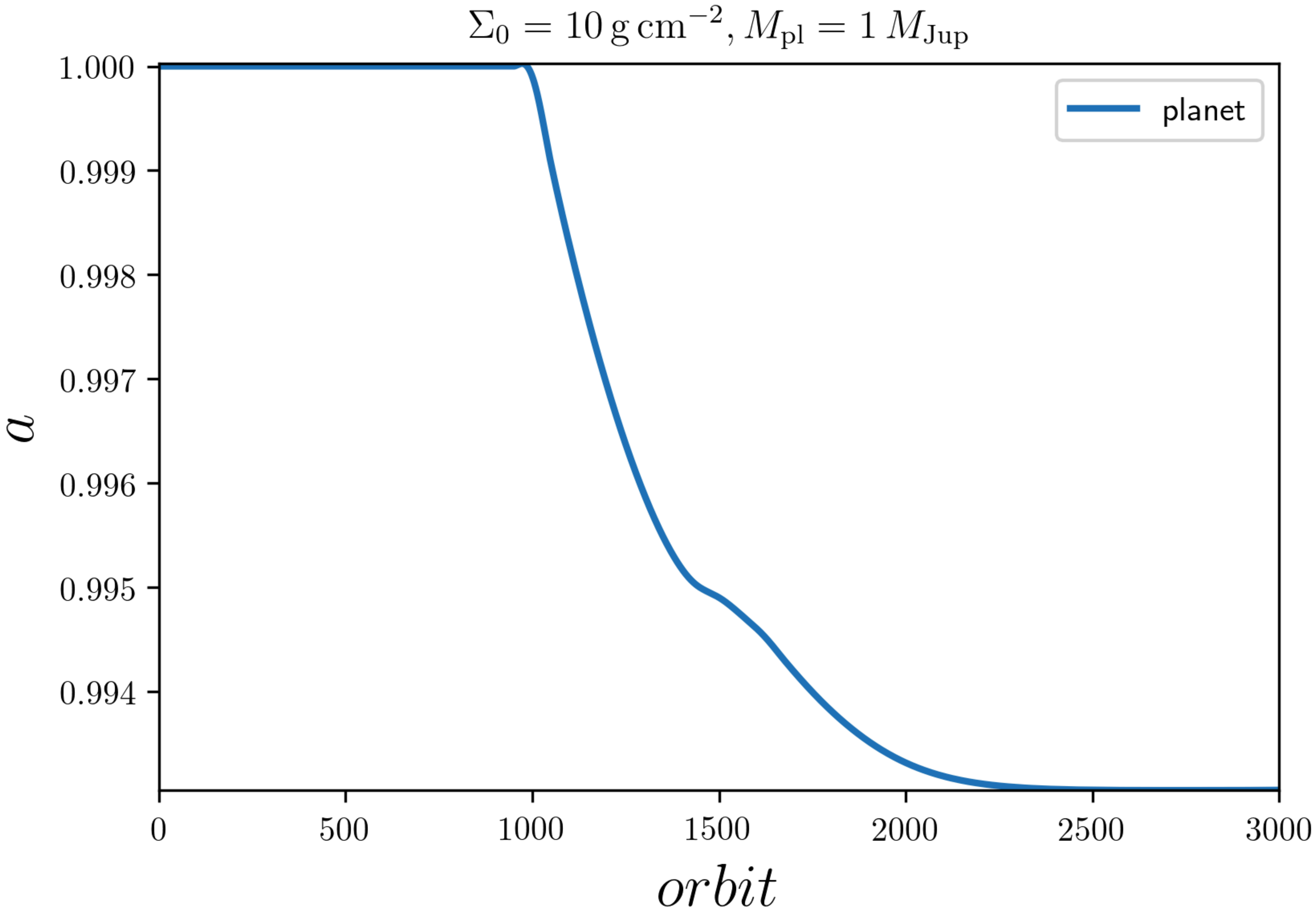


FARGO RESULTS:

approach:

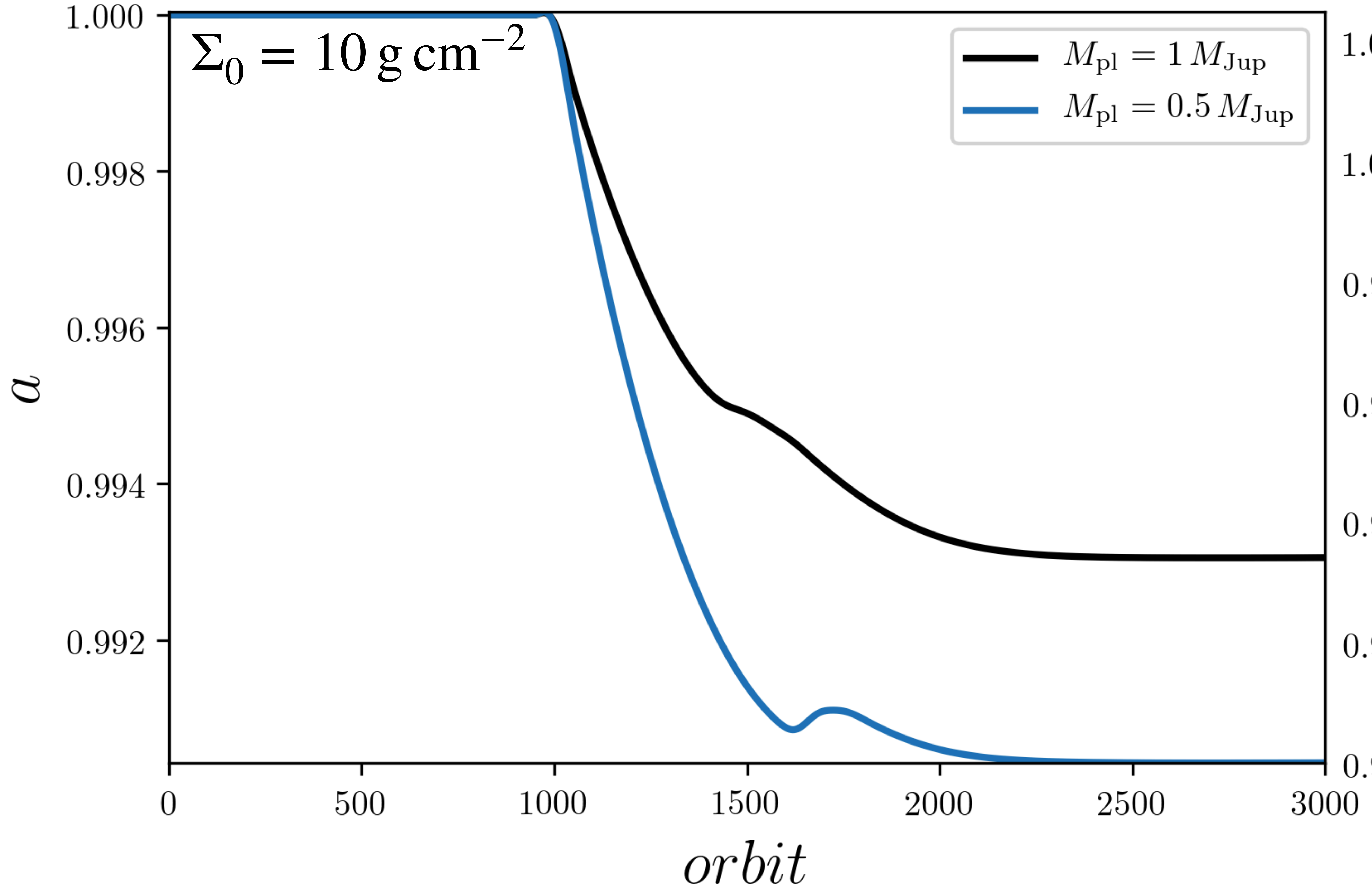
- ➤ keep the planet position fixed for 1000 orbits and let the disc reach a stable state (w/o PE)
- ➤ then switch on PE and let the planet migrate

The planet barely migrates in FARGO!

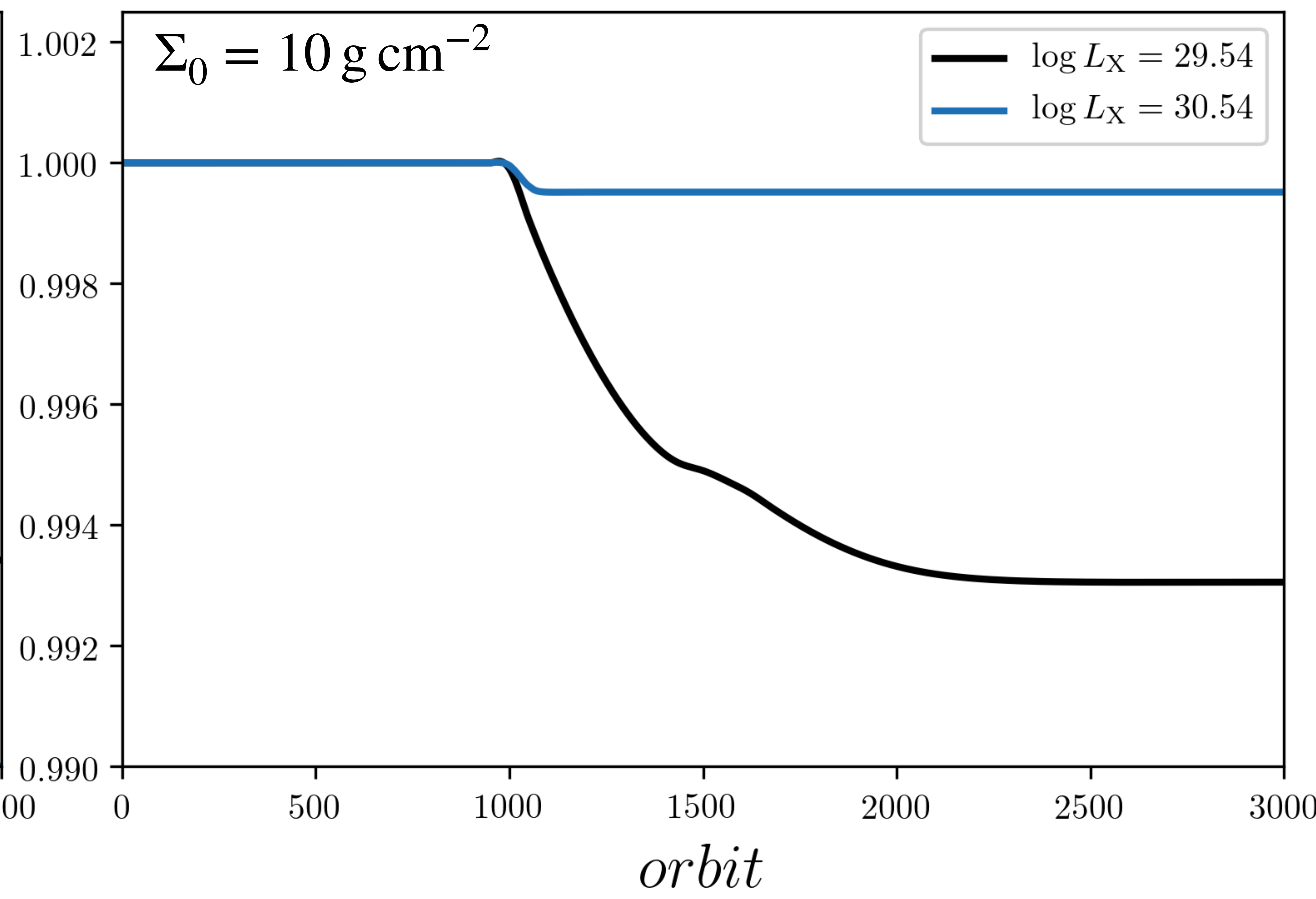


EXTENDING THE PARAMETER SPACE ...

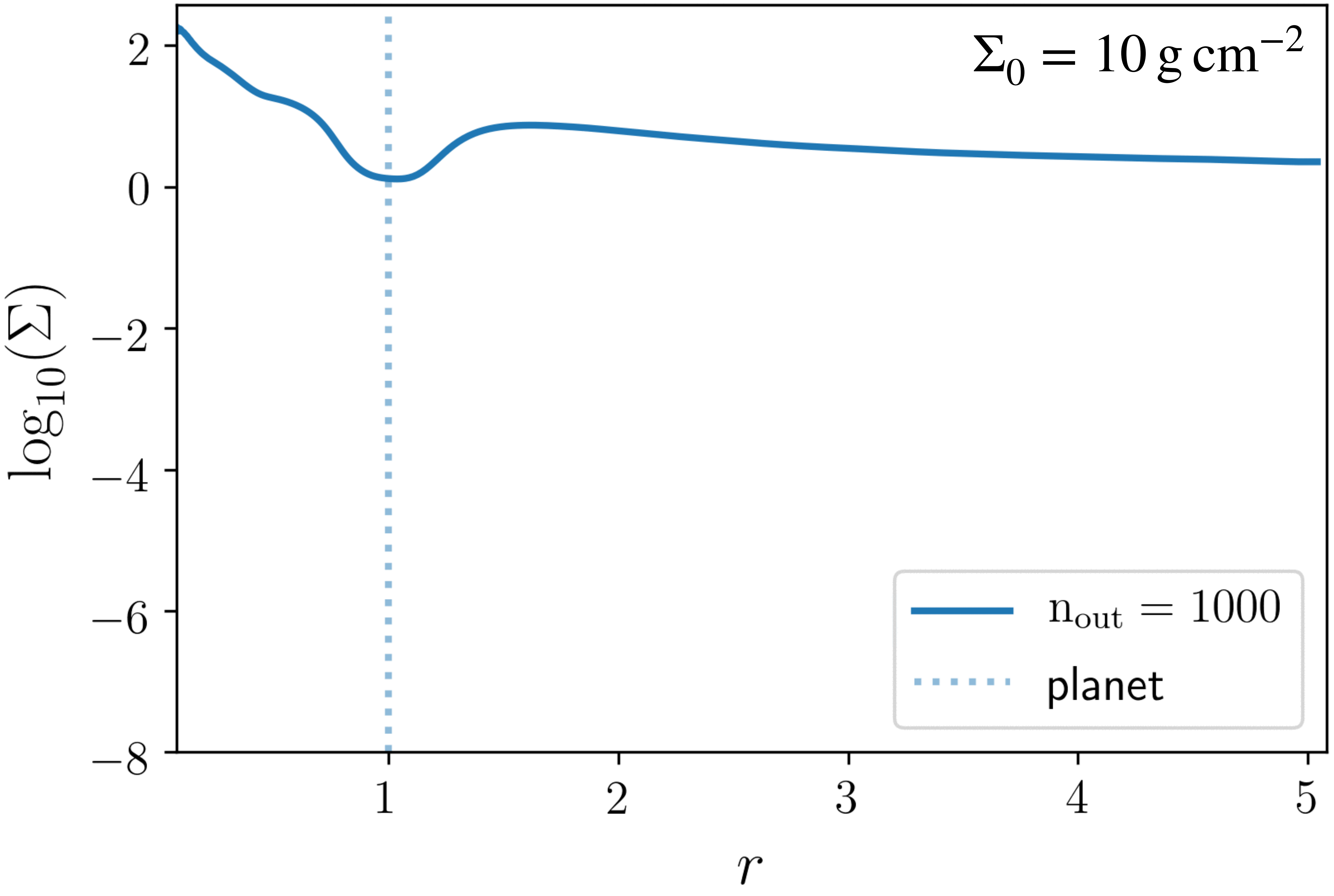
lower vs. higher planet mass:



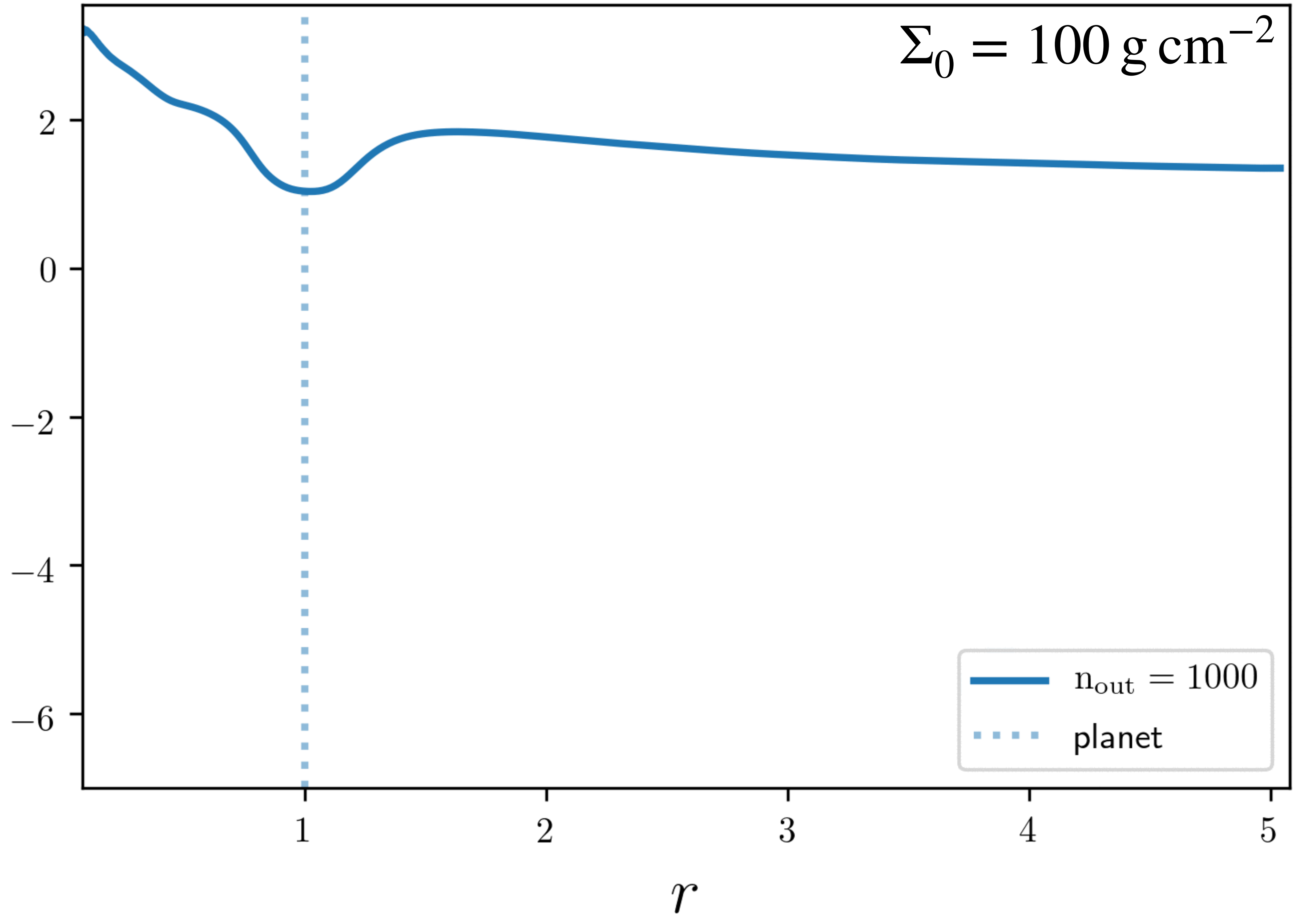
lower vs. higher X-ray luminosity:



lower-mass disc:



higher-mass disc:



EXTENDING THE PARAMETER SPACE ...

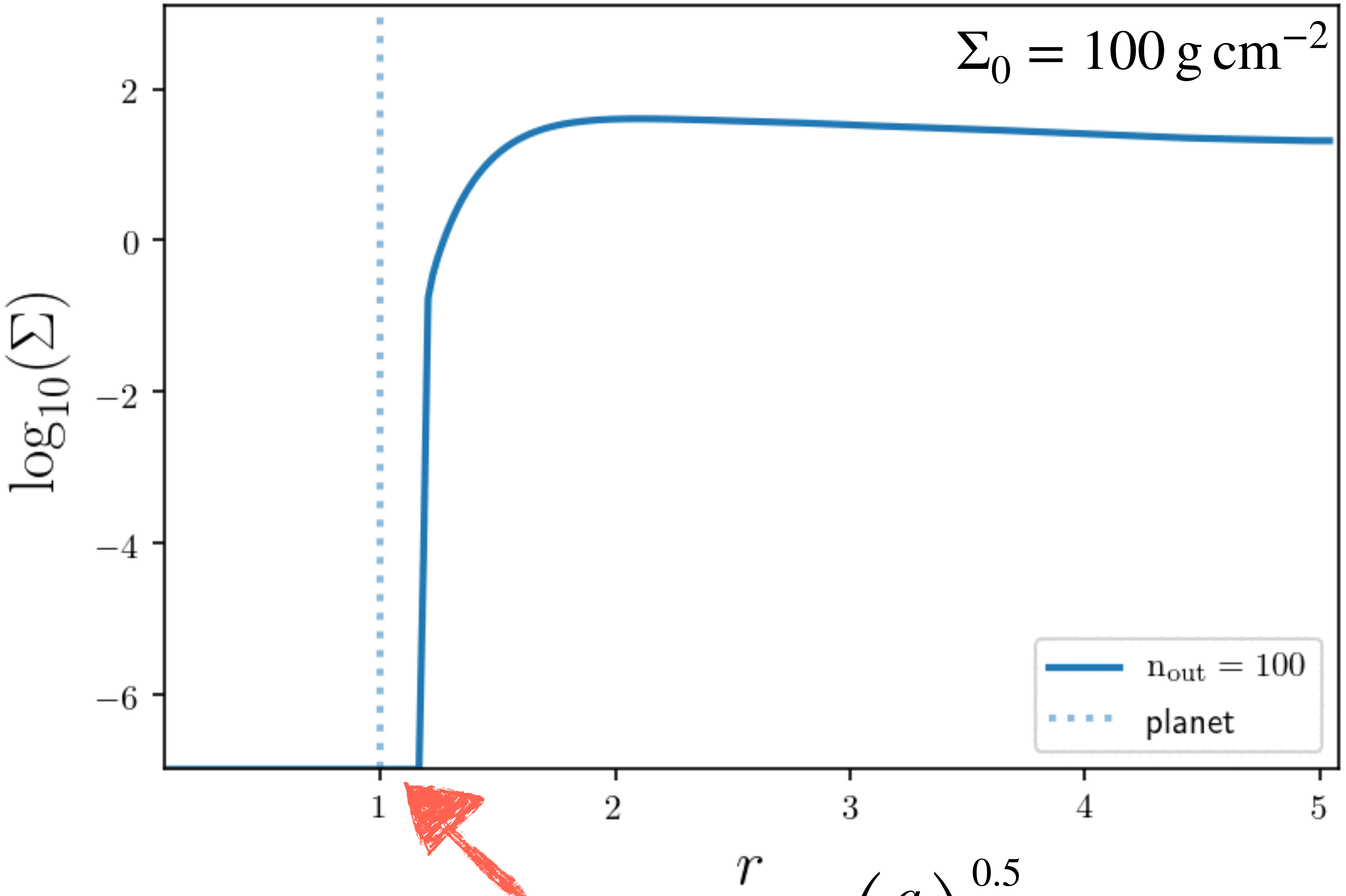
lower-mass d

ONE-SIDED TORQUES IN THE MASSIVE-DISC CASE

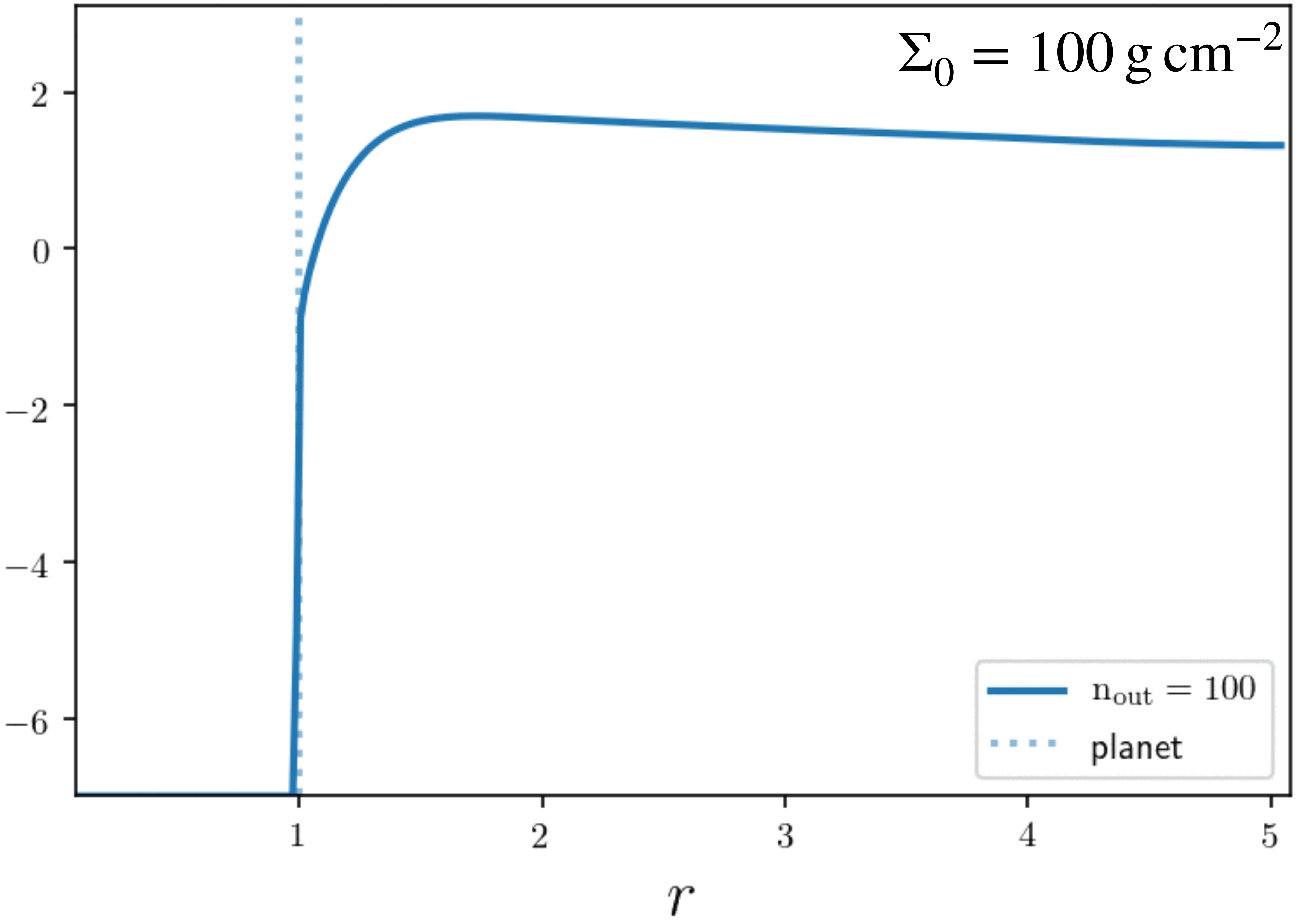
PRELIMINARY

test #1: without photoevaporation

only outer Lindblad torques



outer Lindblad+corotation torques



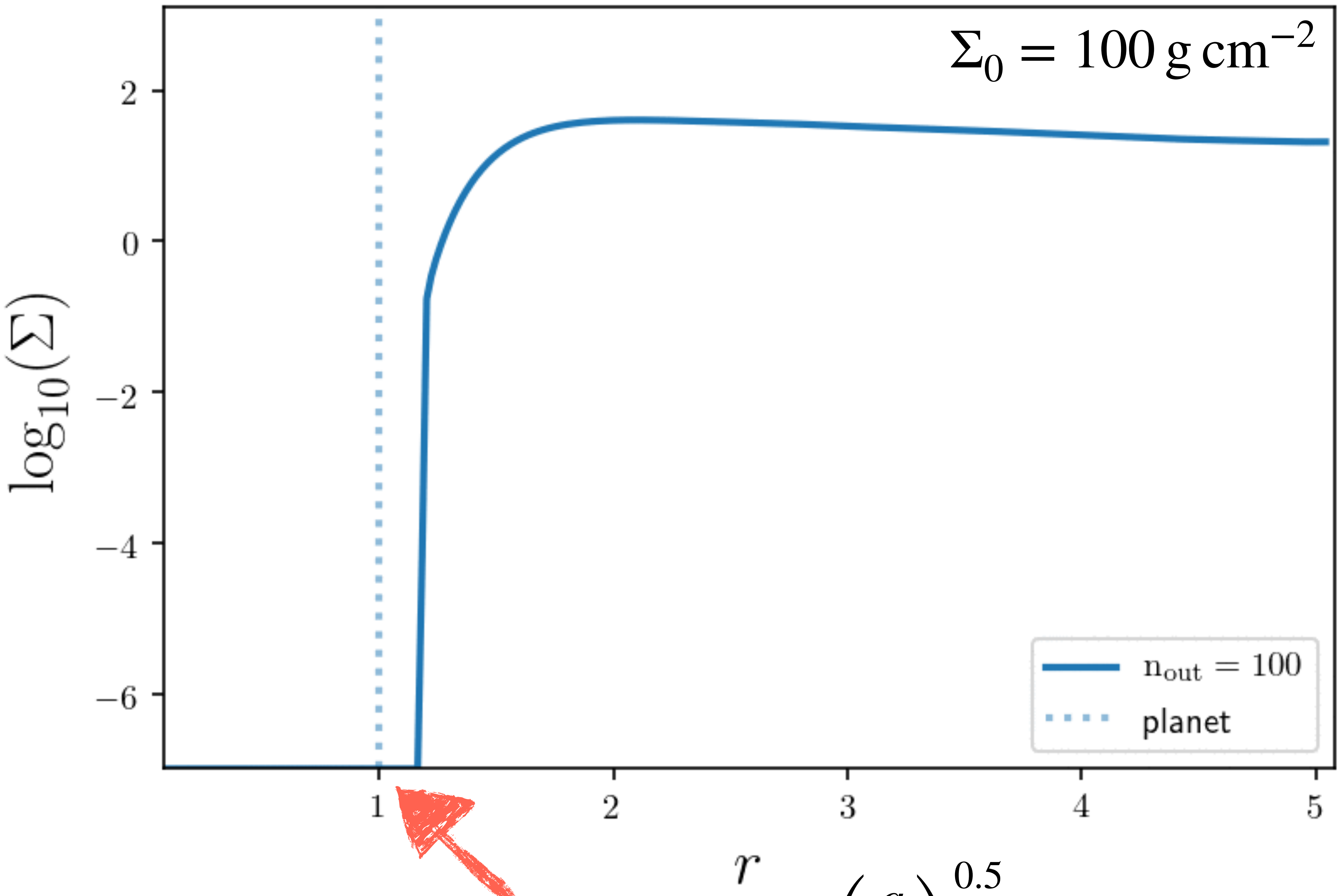
$x_s = 1.68 R_P \left(\frac{q}{h}\right)^{0.5}$ (horseshoe half-width, cf. Paardekooper & Papaloizou (2009))

ONE-SIDED TORQUES IN THE MASSIVE-DISC CASE

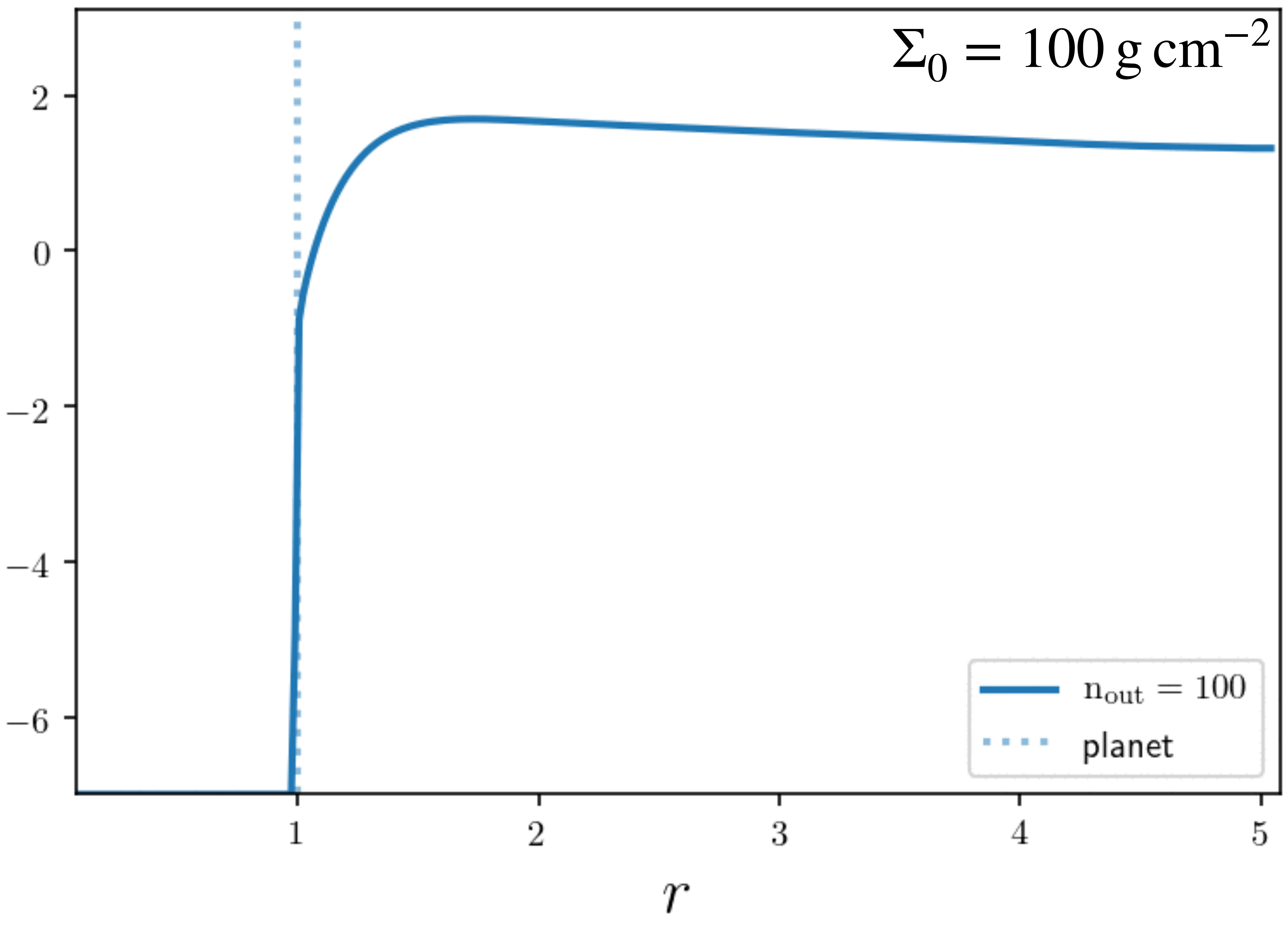
PRELIMINARY

test #2: with photoevaporation

only outer Lindblad torques



outer Lindblad+corotation torques



$$x_s = 1.68 R_P \left(\frac{q}{h}\right)^{0.5}$$ (horseshoe half-width, cf. Paardekooper & Papaloizou (2009))

CONCLUSIONS

1. Observations:

- We searched for a possible imprint of XPE of planet-forming discs onto the present-day semi-major axis distribution of the observed giant planets (Monsch et al., 2019)

2. Population Synthesis with Photoevaporation:

- our simplified 1D population synthesis model shows that disc dispersal via X-ray driven photoevaporation can affect the semi-major axis distribution of giant planets, however: <u>it is plagued by a number of uncertainties!</u> Therefore, we need 2D simulations!!

3. FARGO with Photoevaporation:

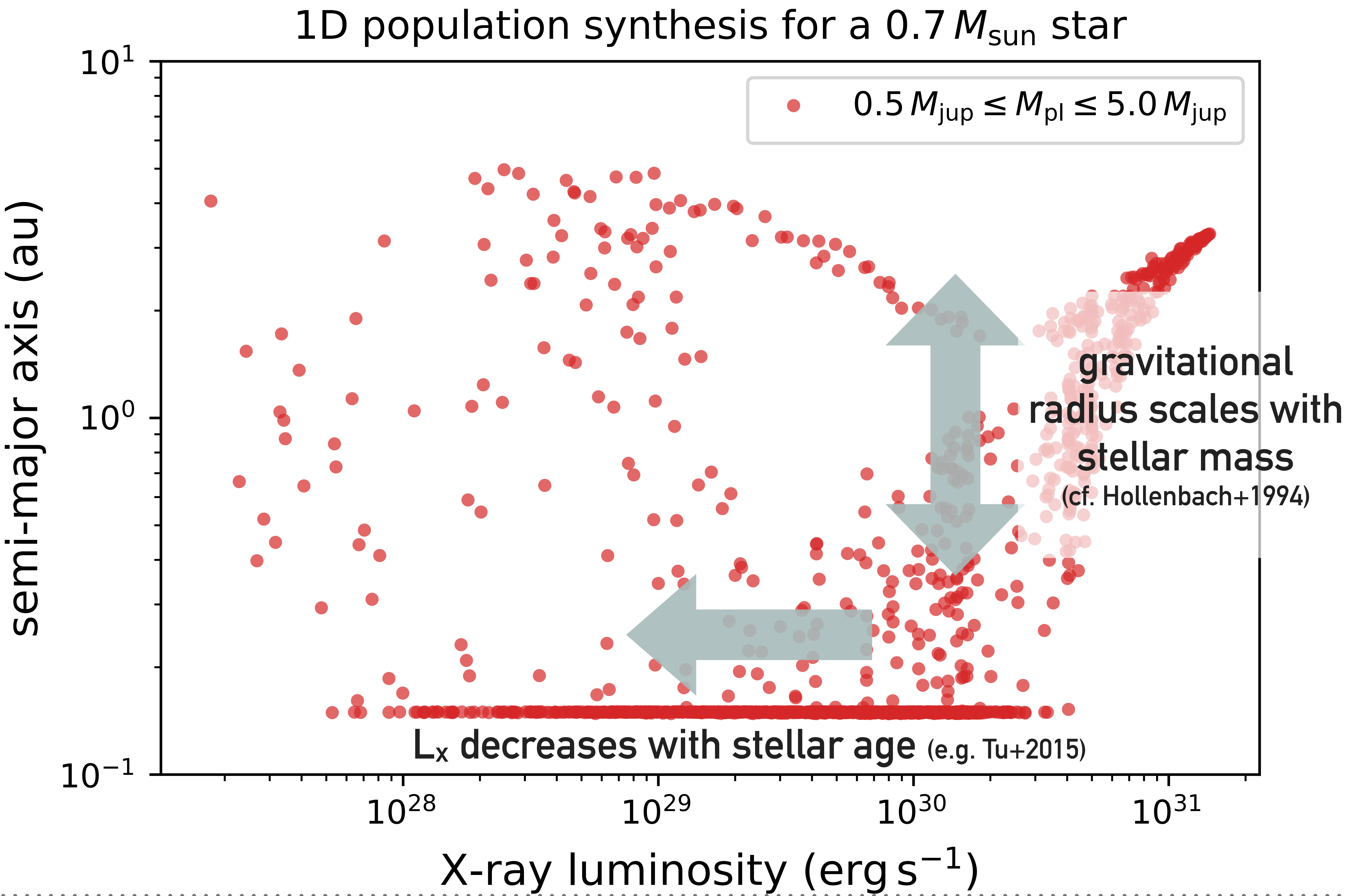
- seems like standard impulse approximation does not treat one-sided torques correctly, so we are currently working on a better prescription of type II migration from our 2D models

4. Next steps:

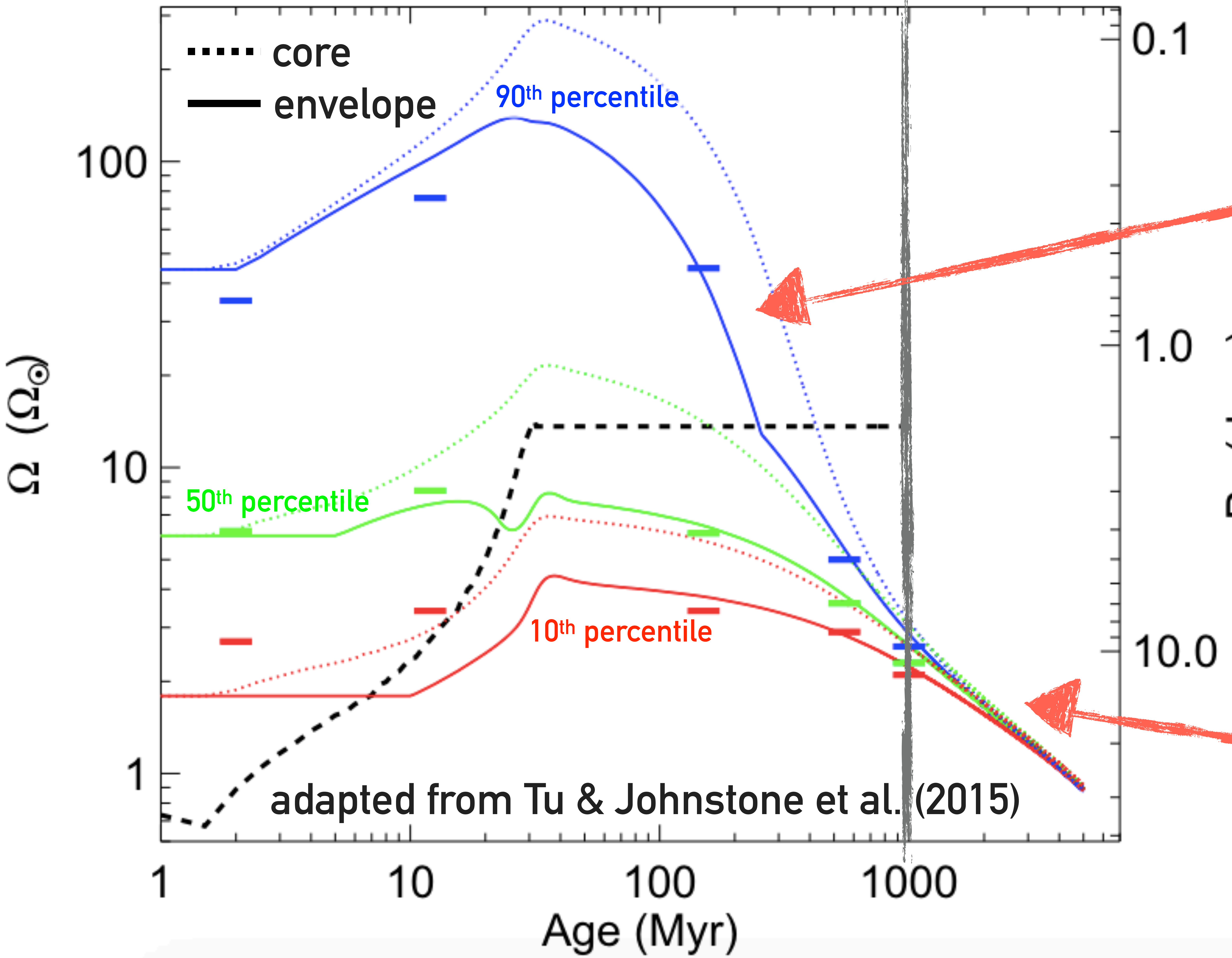
- make 1D model more realistic (e.g., planet insertion location, ...) & include planet formation (in collaboration with Bern-group: Remo Burn, C. Mordasini & Y. Alibert)

BACKUP SLIDES

THEORETICAL PREDICTIONS OF OBSERVATIONAL FEATURES



TIME EVOLUTION OF STELLAR X-RAY LUMINOSITY



The order of different evolutionary tracks for Lx remains the same for t ~ 5-1000 Myr

$L_X \propto t_\star^{-1.5}$ (Skumanich, 1972)