ECCENTRIC PLANETS IN DISCS

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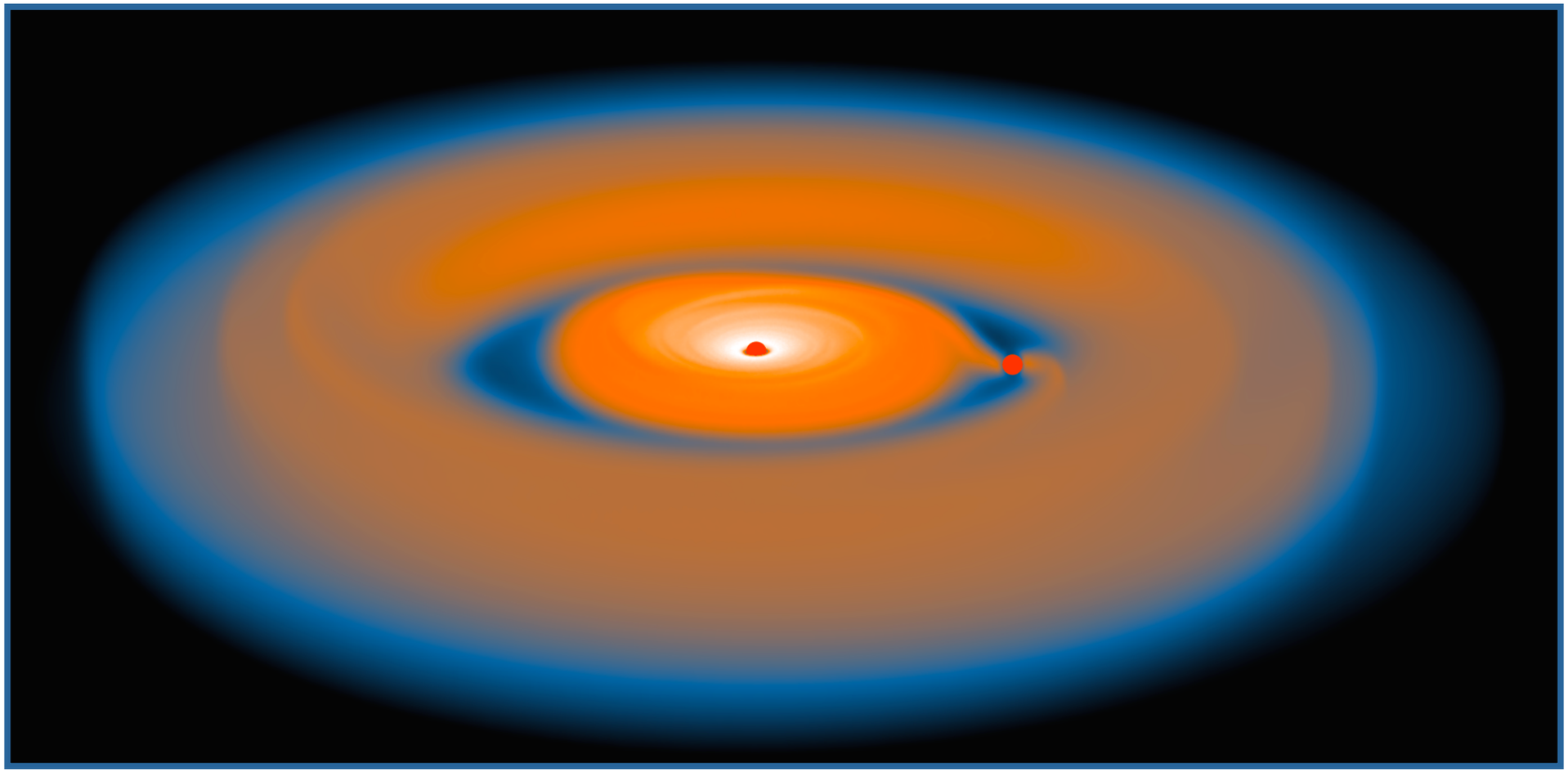
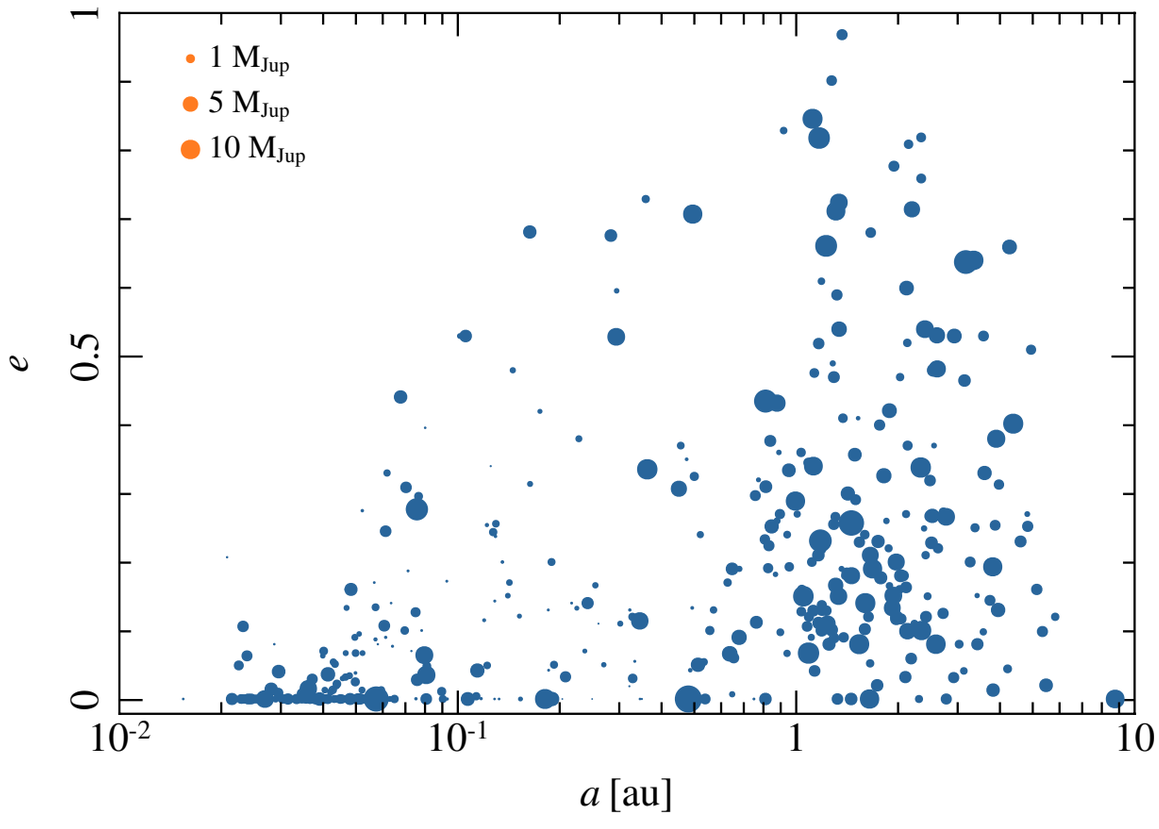


Thanks to: Richard Alexander, Phil Armitage, Jorge Cuadra, Sebastian Perez, Matías Gárate

PLANET-DISC INTERACTIONS

- Young giant planets interact resonantly with disc (Goldreich & Tremaine 1979, 1980)
- Angular momentum exchange changes semimajor axis, also eccentricity
- This mechanism could be responsible for (part of) the observed distribution of exoplanet eccentricities



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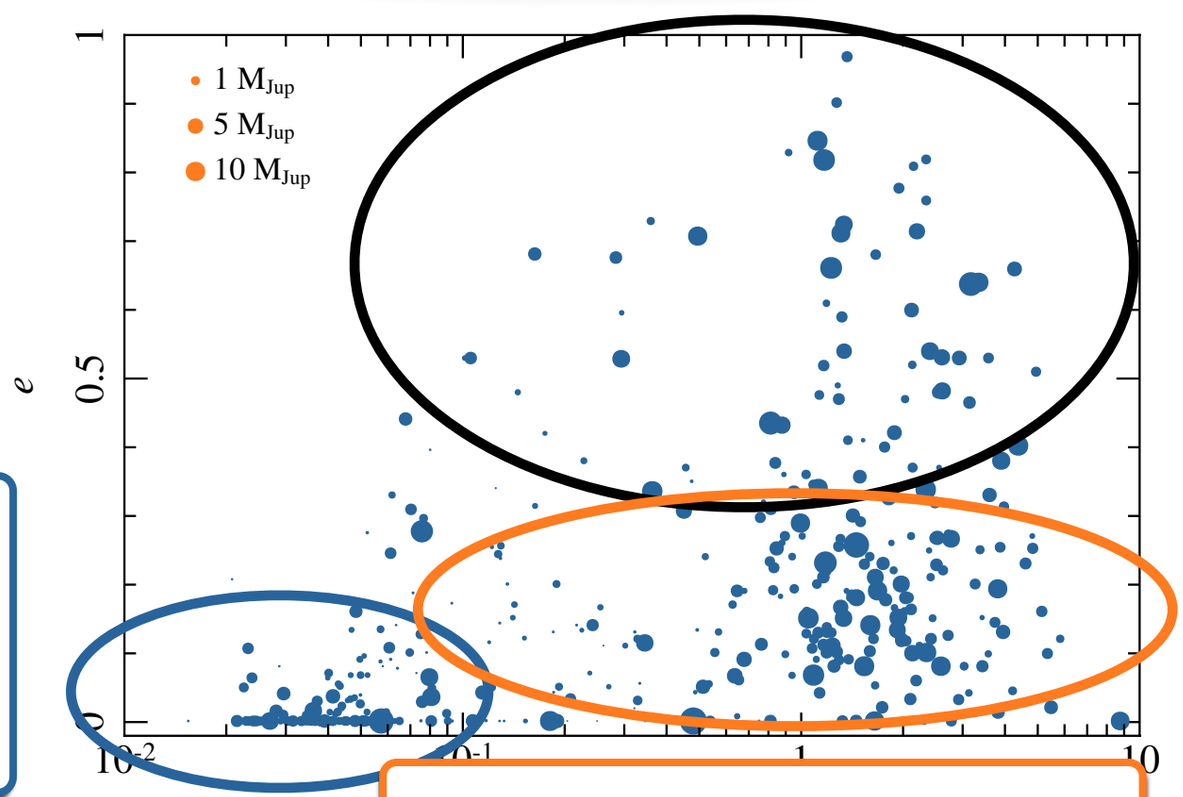
Planet-planet scattering

(e.g. Juric & Tremaine 2008)



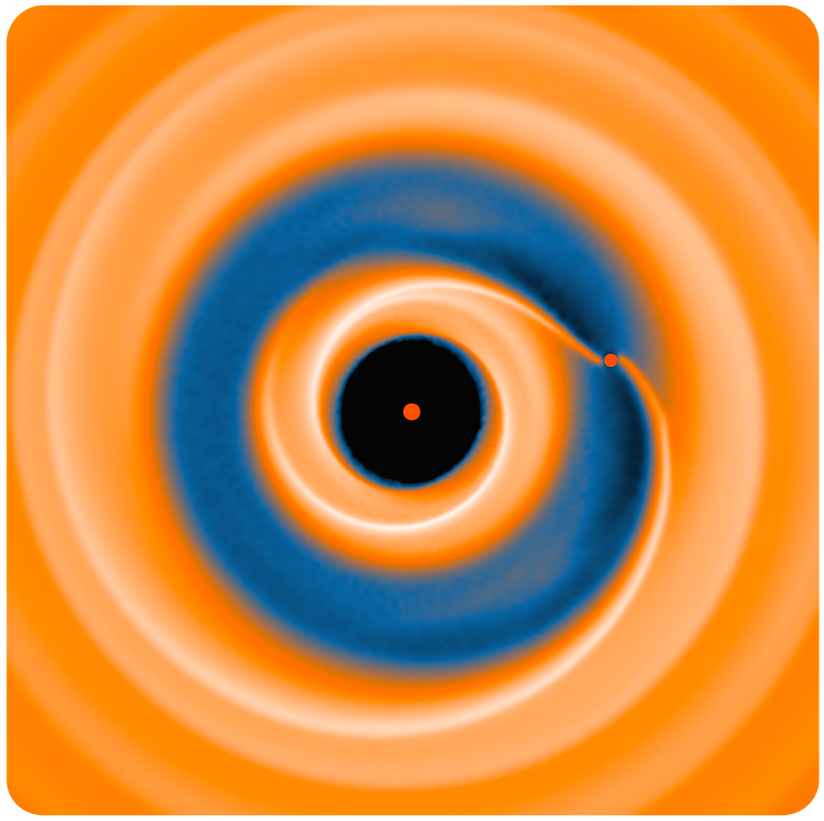
Tidal circularisation

(e.g. Rasio et al. 1996)

Disc interactions?

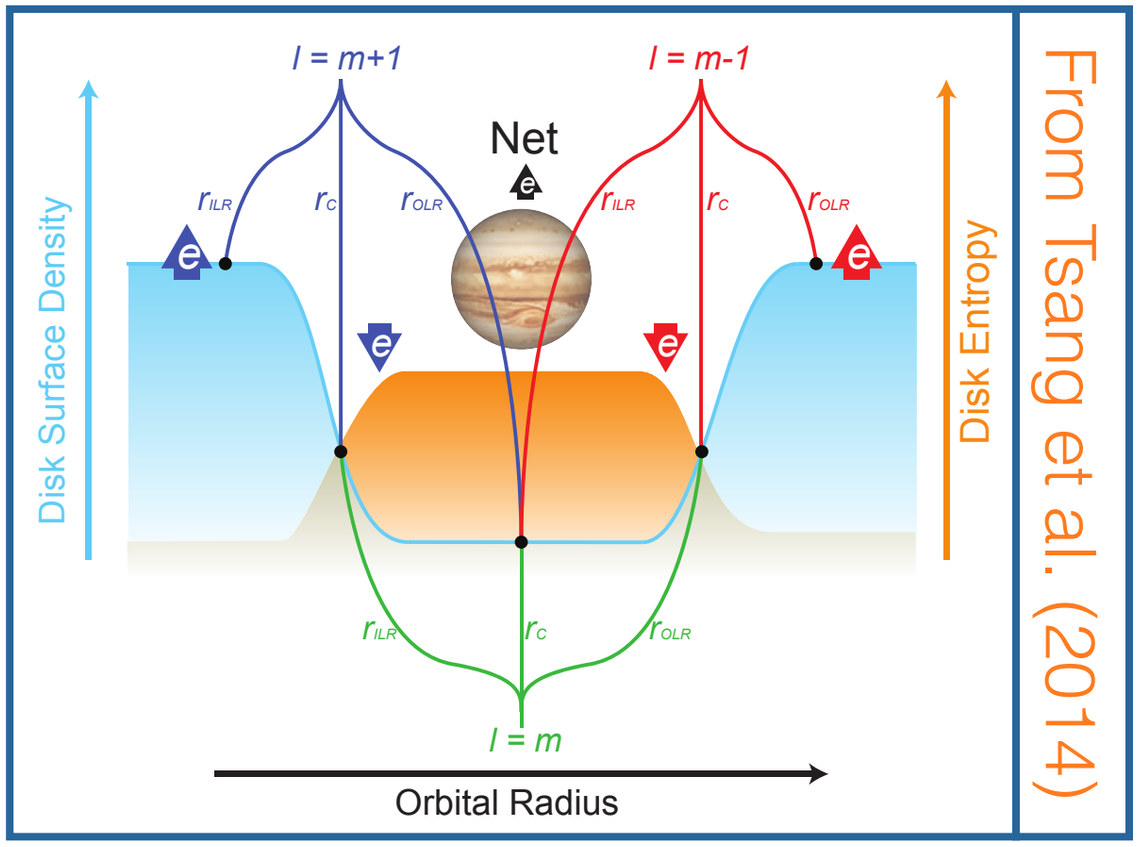
SIMULATIONS

- Problem is extremely non-linear — numerical simulations!
- Does not work for sub-Jovian masses — but when planet opens a clean gap, answer is unclear
  - e growth found in simulations (2D: Papalouizou et al. 2001, D'Angelo et al. 2006. 3D: Dunhill et al. 2013, Bitsch et al. 2013)
  - Requires massive disc, massive planet (Dunhill, Alexander & Armitage, 2013, MNRAS, 428, 3072)



EQUATION OF STATE

- These simulations used locally isothermal EoS
- Tsang et al. (2014) showed that discs with a less idealised EoS and a heated gap have weakened non-coorbital corotation torques — could allow e to grow



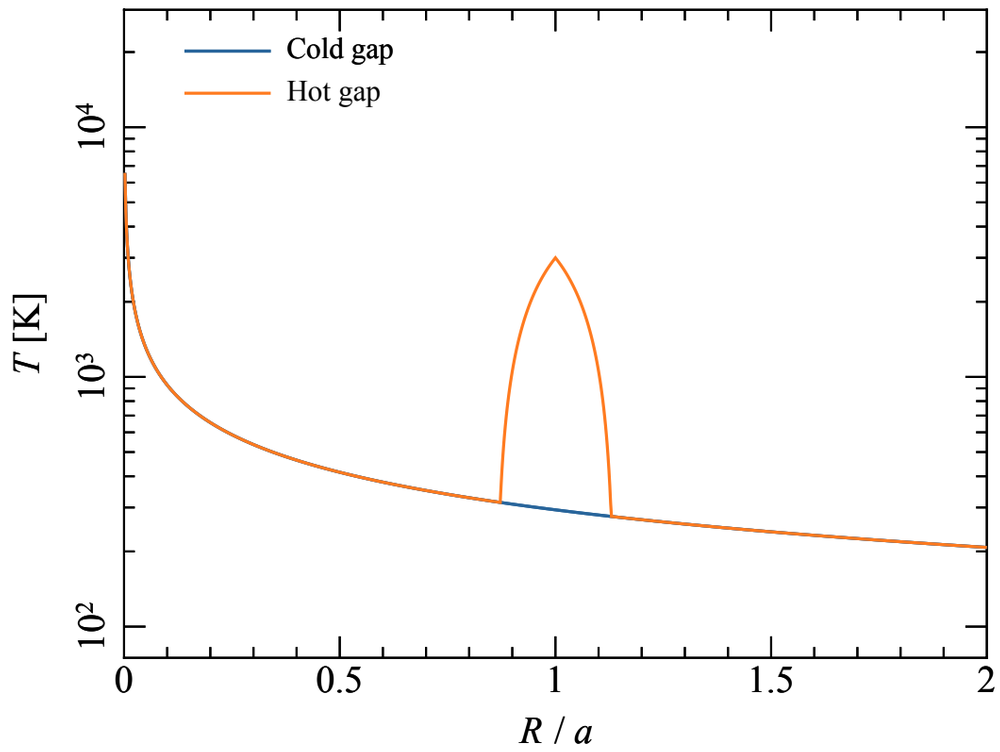
- Criteria required: $$\frac{\left(\frac{\partial \ln T}{\partial R}\right)}{\left(\frac{\partial \ln \Sigma}{\partial R}\right)} < \gamma\,\chi_{\rm crit} - 1$$

TESTING TSANG CRITERIA

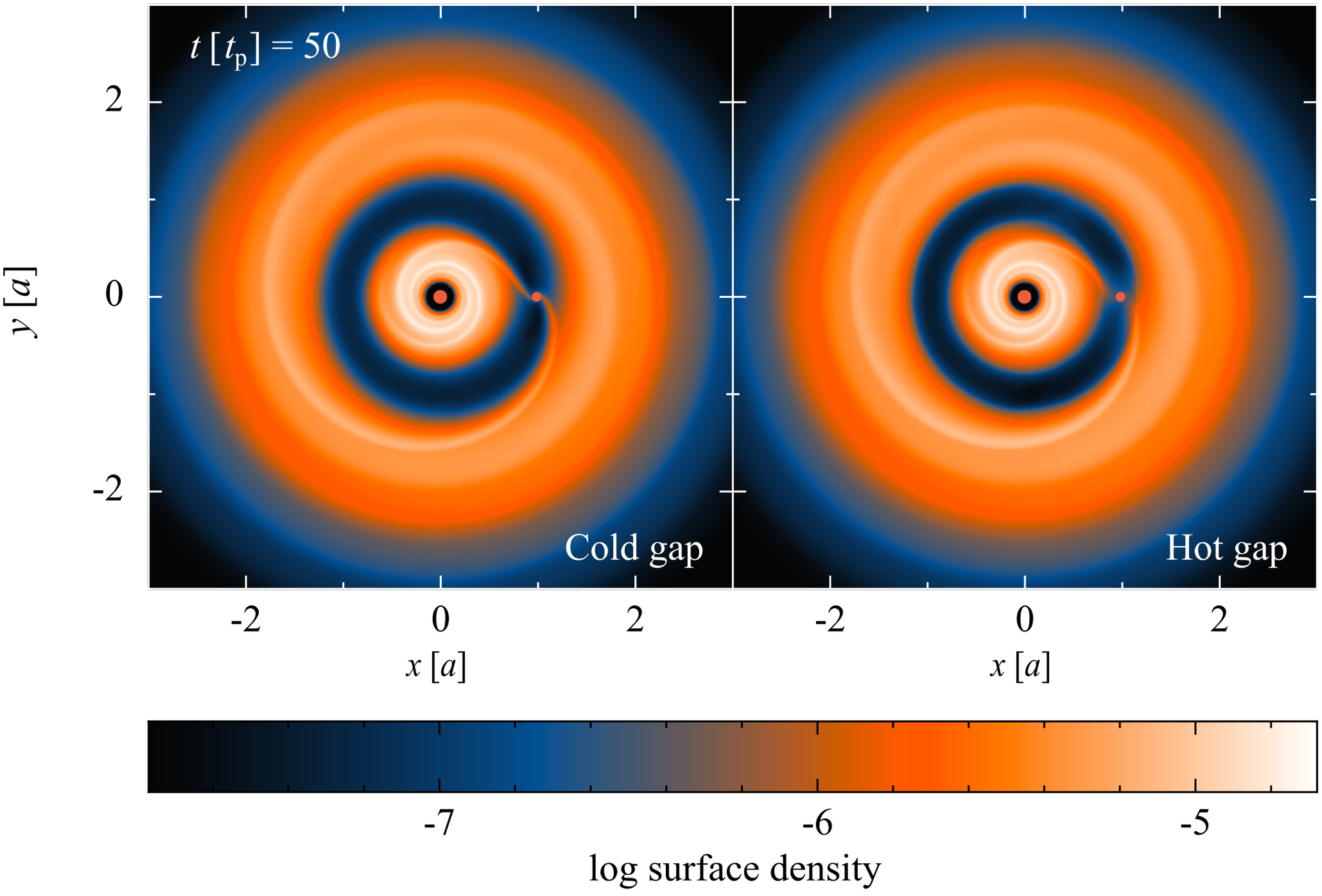
- We set out to numerically test this result, using high resolution 3D SPH simulations of a 5 $M_{\rm Jup}$ planet embedded in a disc

- We use an EoS based on β-cooling, but cooling towards a defined profile on some timescale

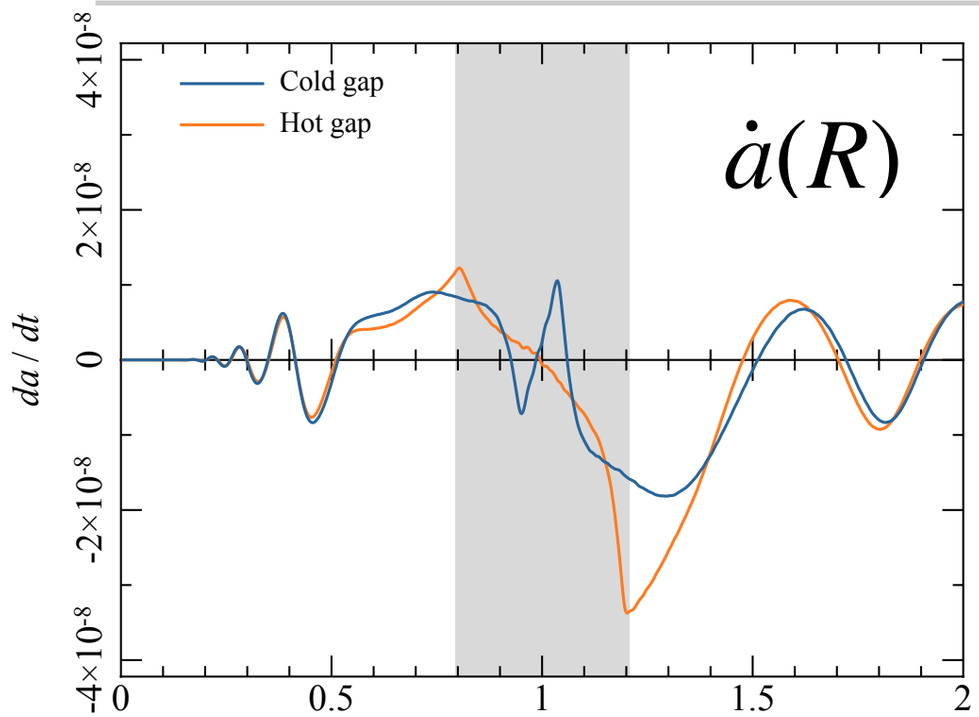
- Defined profile is locally isothermal, plus large spike in T across the gap

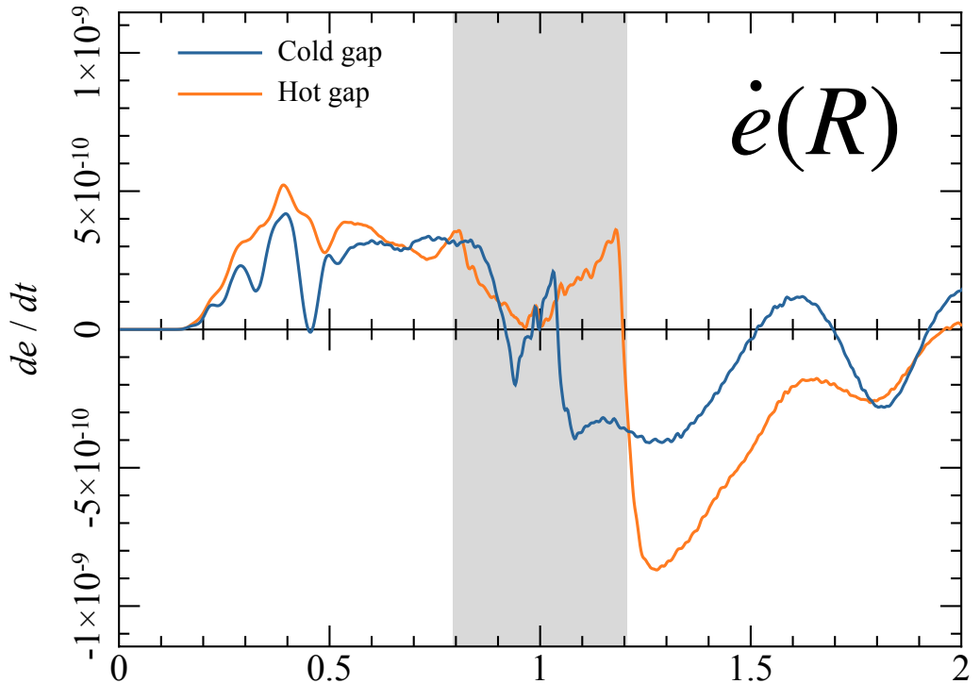


EFFECT OF GAP HEATING



DA/DT AND DE/DT





- *da/dt* dominates torque, faster migration with a heated gap
- But *de/dt* is indeed positive across the hot gap
- Little dependance upon cooling time
- Early days (only 50 orbits) but indications are good

IMPLICATIONS?

- Torques never exactly balance
- If e does not grow, it is damped (Dunhill et al. 2013)
- Eccentric planets in discs likely grew e by disc interactions (damping timescale is short)
  - ➡ e distribution of embedded (proto-)planets can be an important diagnostic of gap physics
- Obvious question: can we characterise e of embedded planets observationally?

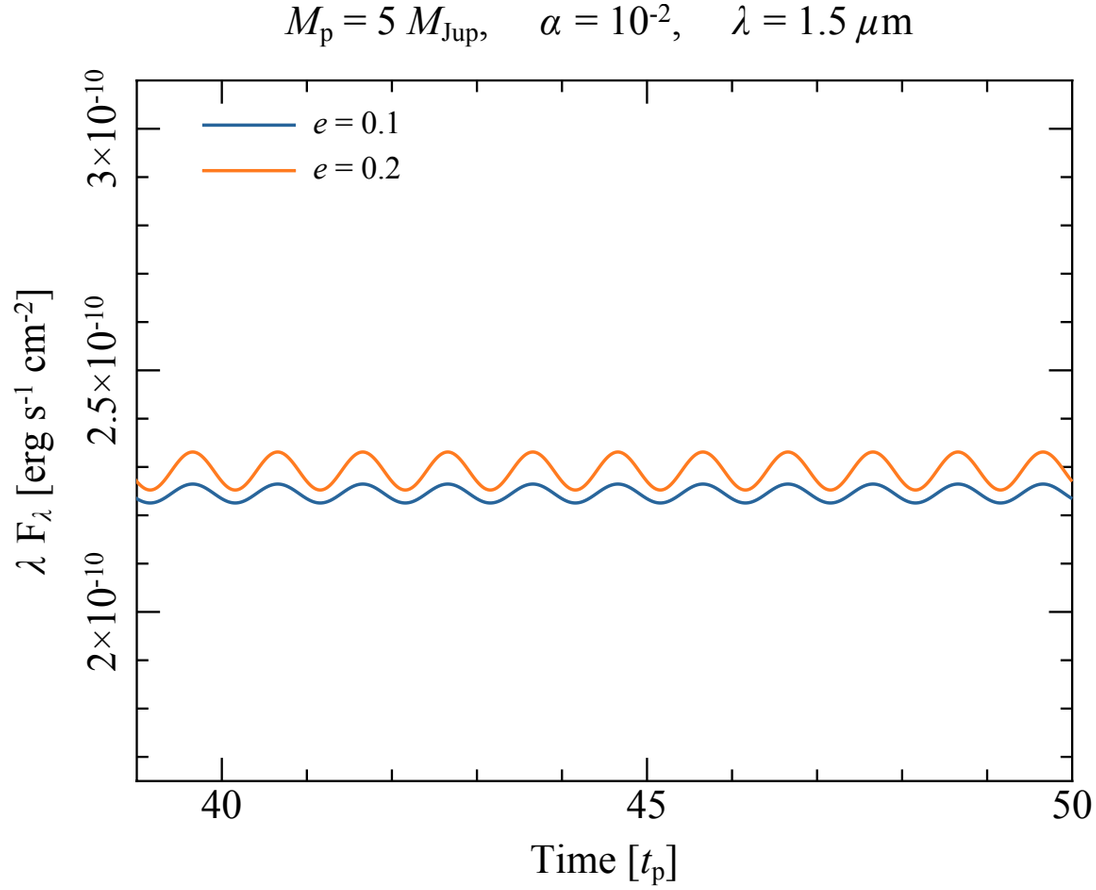
VARIABLE L_{ACC}

- Simple 1D viscous diffusion model of circumplanetary disc (CPD; from Martin & Lubow 2011)

- Vary cutoff torque (function of stellocentric distance) and mass injection (calibrated from SPH sink accretion)

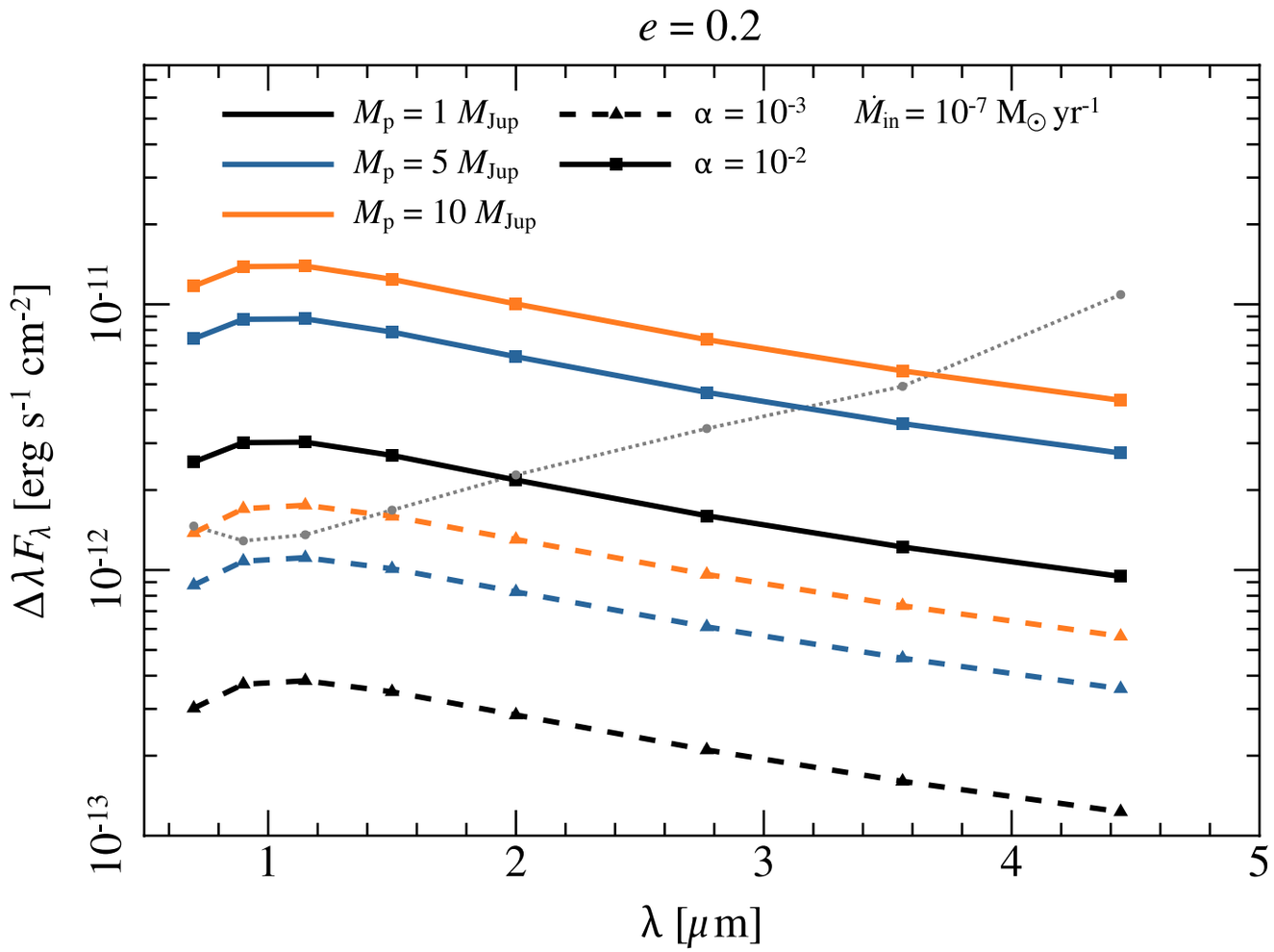
- Simple model, but fluxes are similar to more complex SED models by Zhu (2015)

- Periodic variability due to orbital modulation



NIR EMISSION

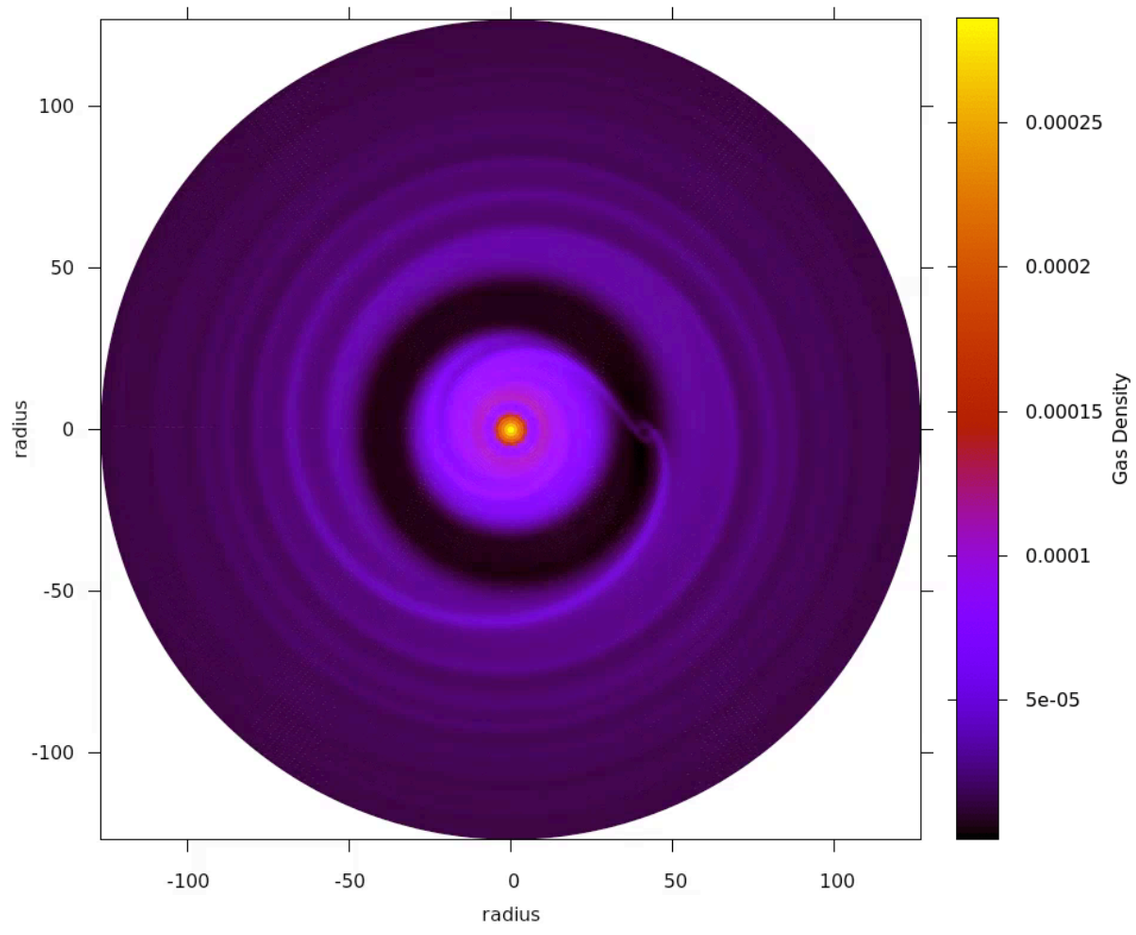
- Variability in emission due to viscous heating for a variety of orbit and CPD assumptions:



- (Very) optimistic interpretation — *may* be detectable with JWST (Dunhill, 2015, MNRAS, 448, L67)

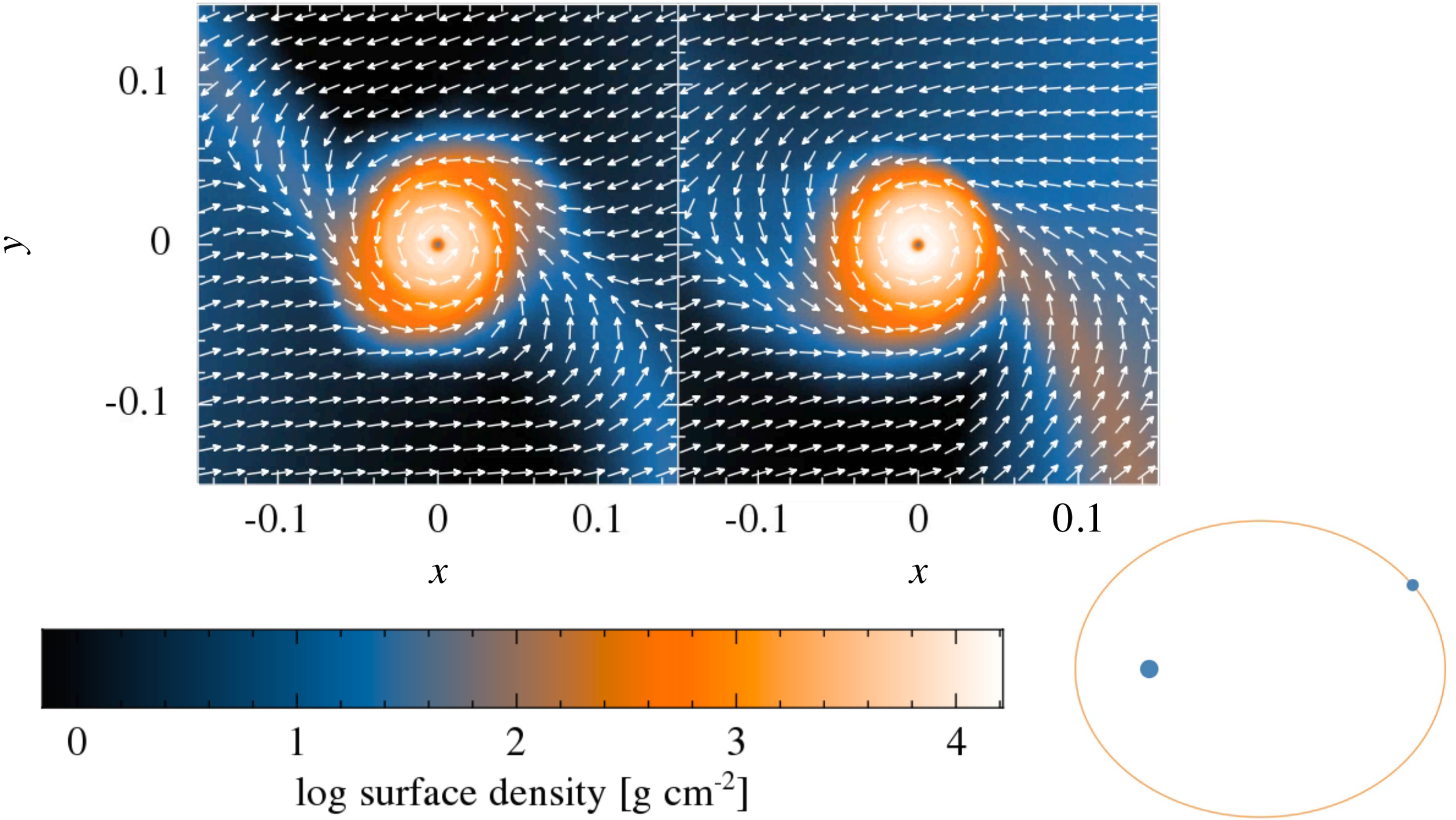
NIR EMISSION

- Could accretion feedback from the planet heat the gap? (Montesinos et al. 2015; see poster)



- Related work: in 2D with FARGO: disc structure, heating (by graduate student Matías Garáte)

(3D) KINEMATIC SIGNATURE?



SUMMARY

- Testing Tsang et al. result that heated gaps promote eccentricity growth
  - Work in progress, but signs are positive
- Implication is that e distribution of embedded exoplanets can probe disc structure
  - Accreting eccentric protoplanet has variable $L_{\rm acc}$, *may* be detectable with JWST (though unlikely)
  - Kinematic signature may be key to identifying eccentricities (See also talk by Sebastian Perez)