Gravitational instability of planetary gaps and its effect on orbital migration [4.14]

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Introduction

Some theories of giant planet formation invoke self-gravitating protoplanetary disks. This leads to the possibility of gap-opening in massive disks. We show that planetary gaps in self-gravitating disks are potentially unstable to a spiral instability. This gravitational edge instability results in strong co-orbital torques. In our disk models, such torques can cause net outward migration of the planet, on a timescale of a few 10's of orbital periods. The unstable gap outer edge can suddenly trigger outward type III migration, even if there is initially very little net migration. We suggest that gravitational instability of planet gaps is an important issue with regards to the survivability of giant planets or brown dwarfs formed on wide orbits through disk fragmentation.

Disk-planet model

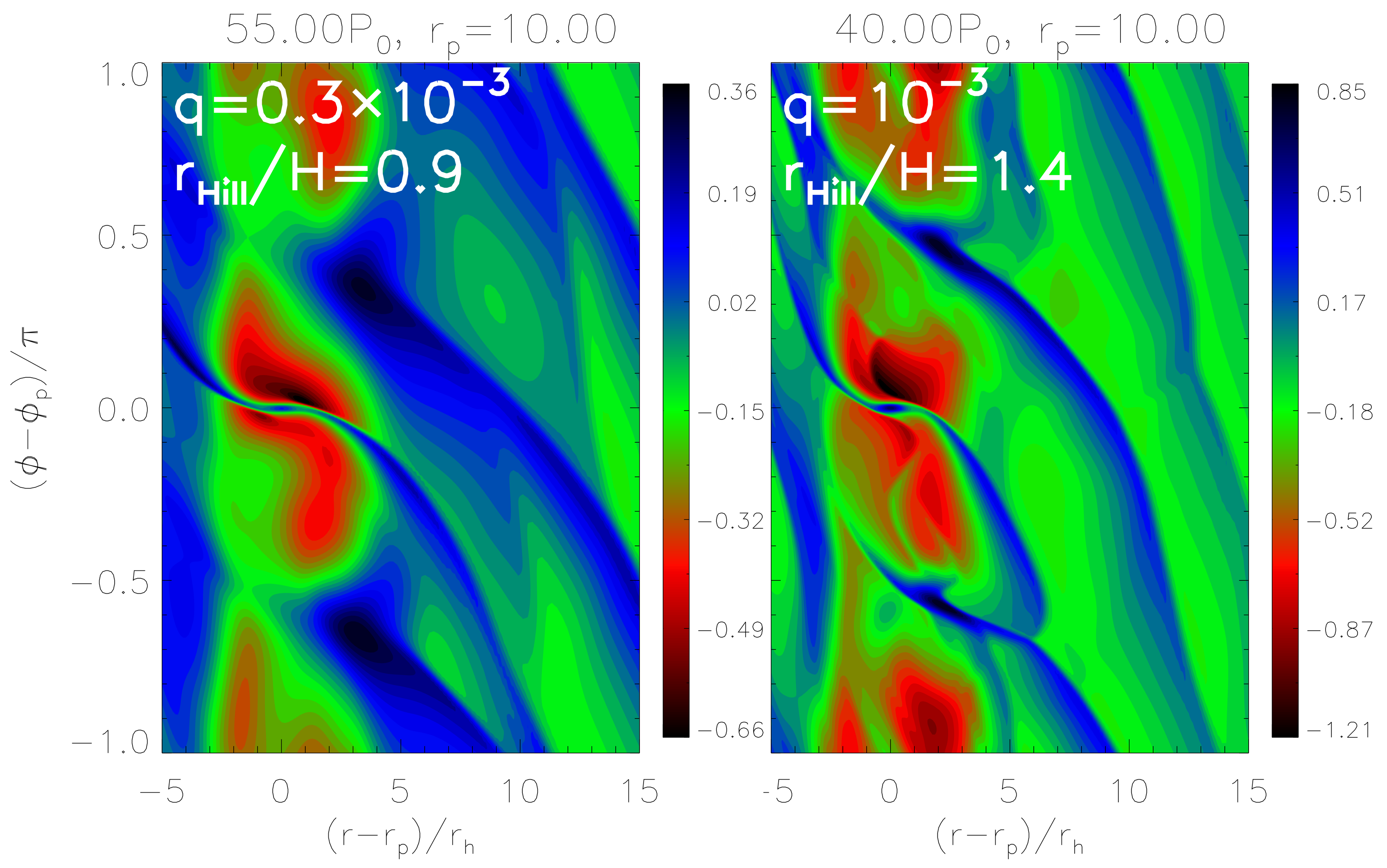
We numerically simulate two-dimensional disk-planet systems using the locally isothermal version of the FARGO hydrodynamic code.

- Self-gravitating disk: $\mathbf{M_d = 0.08M_*}$, $\mathbf{Q_{out} = 1.5}$, $\mathbf{H/r = 0.05}$
- Giant planets with mass $\mathbf{q \in [0.3, 2.0] \times 10^{-3}M_*}$

These planets satisfies the gap-opening criteria $\mathbf{r_{Hill} \gtrsim H}$.

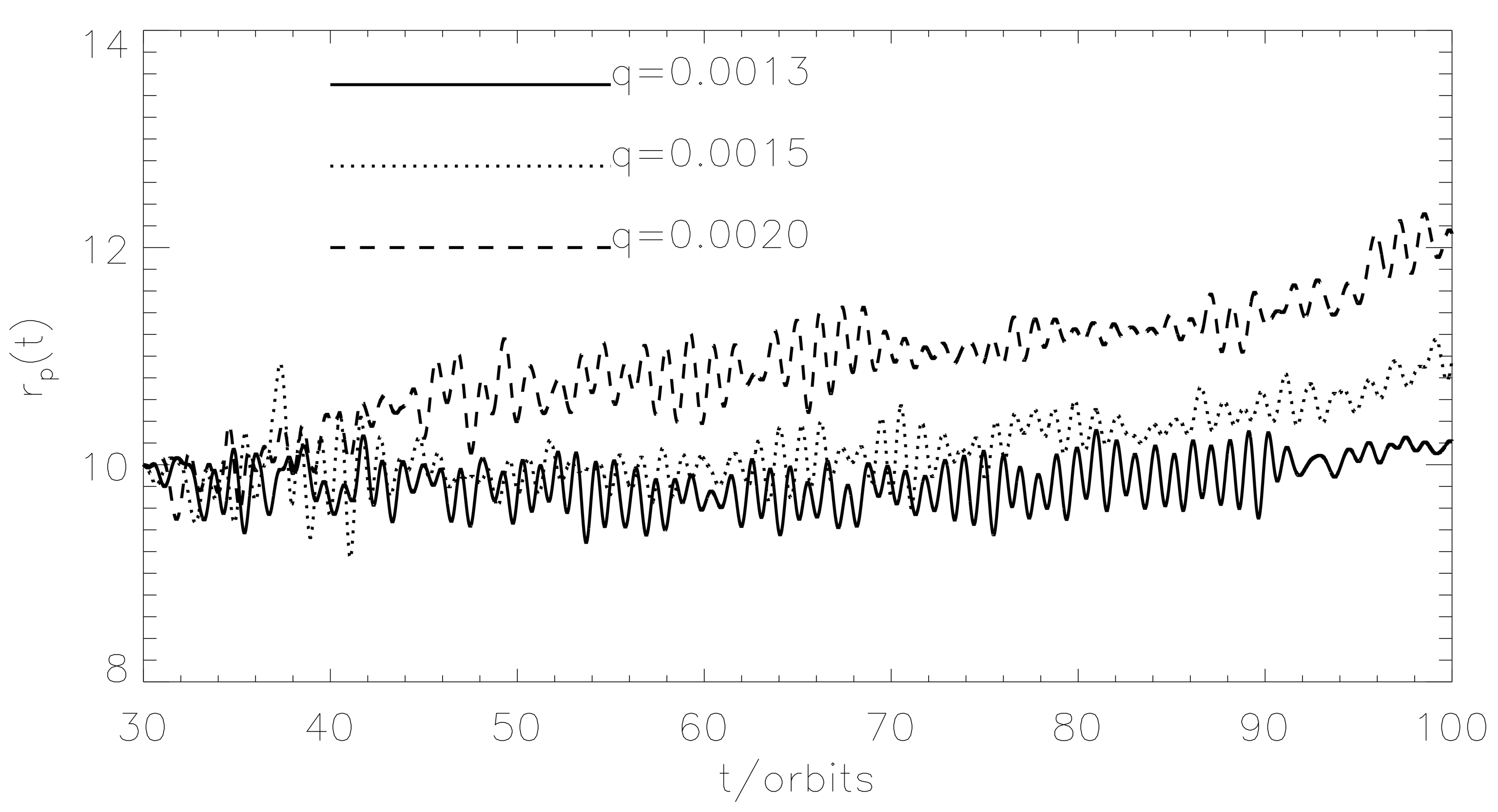
The gravitational edge instability

Fixed-orbit simulations $[\log(\Sigma/\Sigma_{t=0})]$:



- Global GI associated with potential vorticity *maximum* at the gap edge
- Increasing **q** ⟶ sharper gap edge ⟶ stronger instability
- *'Reload'* horseshoe orbits with material ⟶ co-orbital torques

Outward migration induced by an unstable gap

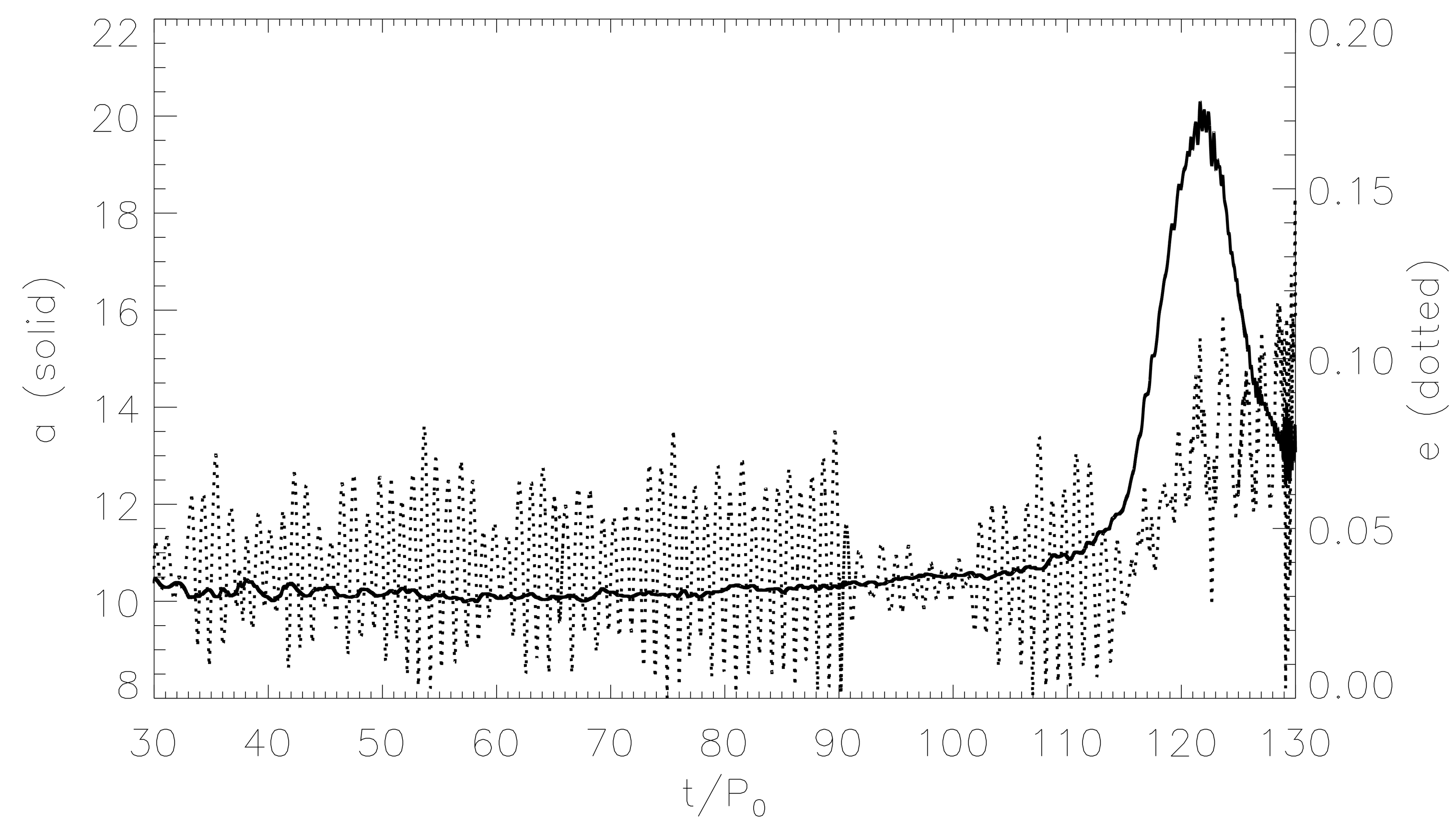


- Increasing planet mass ⟶ *stronger* co-orbital torques despite deeper gap
- Faster outward migration with increasing **q**

(Immediate rapid inward migration if planet is unable to open a gap quickly, e.g. $\mathbf{q = 0.3 \times 10^{-3}}$.)

Difficulty in achieving torque balance

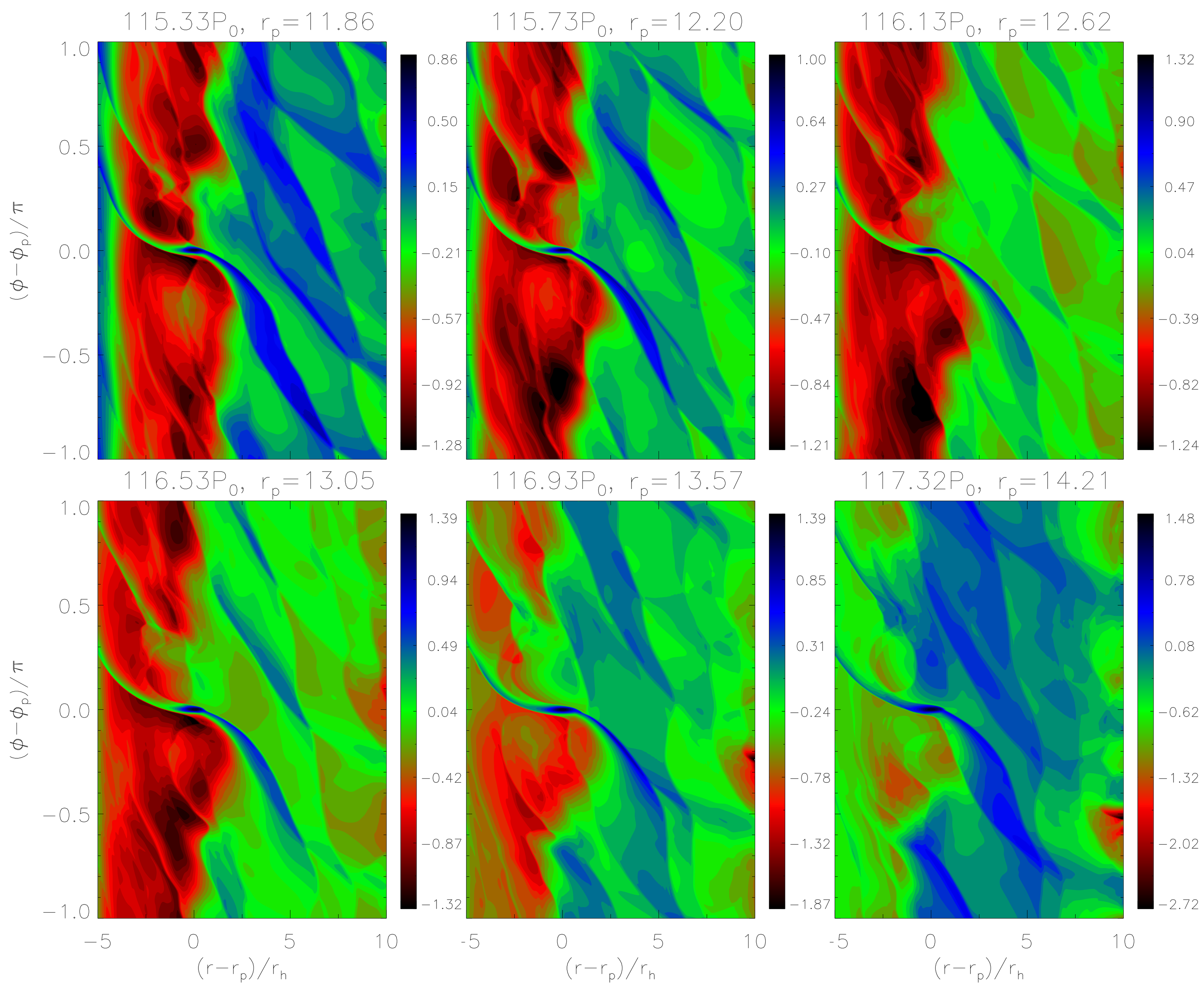
$\mathbf{q = 1.3 \times 10^{-3}}$



- $\mathbf{t \lesssim 100P_0}$: inward Lindblad torques ∼ outward co-orbital torques ⟶ little net migration
- $\mathbf{t \sim 110P_0}$: spiral-planet scattering event

Spontaneous outward type III migration

$\mathbf{q = 1.3 \times 10^{-3}}$, $\mathbf{\log[\Sigma/\Sigma_{t=0}]}$



- Regular passage of large-scale spiral arms by the planet provide positive torques ⟶ planet moves closer to the outer gap edge
- Outer gap edge eventually comes within the planet's co-orbital region ($\mathbf{r_{edge} \lesssim 2r_{Hill}}$) ⟶ bulk scattering of edge material
- Front-back surface density asymmetry ⟶ type III migration
- Effective planet mass increases rapidly ($\mathbf{M_{Hill} = 1.3M_p}$ at $\mathbf{t = 120P_0}$) ⟶ circumplanetary disk?

Implications: planet-formation in massive disks

- **Disk fragmentation has been proposed as a mechanism to form long-period giant planets or brown dwarfs. Numerical simulations show this requires the perturber to open a gap to avoid rapid inward migration. Our results indicate the gravitational edge instability may help to further avoid inward migration. However, if it persists, the instability may scatter the planet. Gap instability a potential threat to the survival of gap-opening perturbers on wide orbits.**
- **On the other hand, the gap instability can act as a trigger for outward type III migration, thereby moving planets from small to large orbital radii on dynamical time-scales.**
- **Cloutier, R., Lin, M.-K., MNRAS, 2013, submitted**

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