Gravitational instability of planetary gaps and its effect on orbital migration

Min-Kai Lin, Ryan Cloutier

Canadian Institute for Theoretical Astrophysics

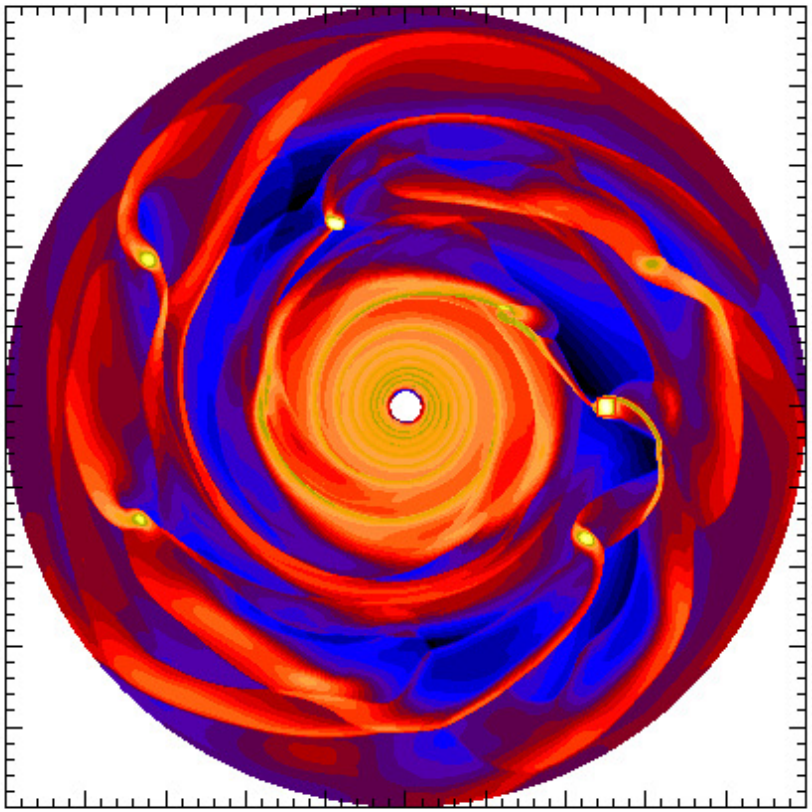
May 8 2013

Long-period giant planets/brown dwarfs

Star	M_p/M_J	r_p/AU
Oph 11	21 ± 3	243 ± 55
CHXR 73	15^{+8}_{-5}	210
DH Tau	11^{+3}_{-10}	330
CD-35 2722	31 ± 8	67
GSC 06214-00210	17 ± 3	320
Ross 458(AB)	8.5 ± 2.5	1170
GQ Lup	21.5 ± 20.5	103
1RXS J1609	≈ 8	330
CT Cha	17	440
AB Pic	13.5 ± 0.5	260
HN Peg	16 ± 9	795 ± 15
HR 8799	5–10	15–68
Fomalhaut	$3^{+1.2}_{-0.5}$	119

(Adapted from Vorobyov, 2013)

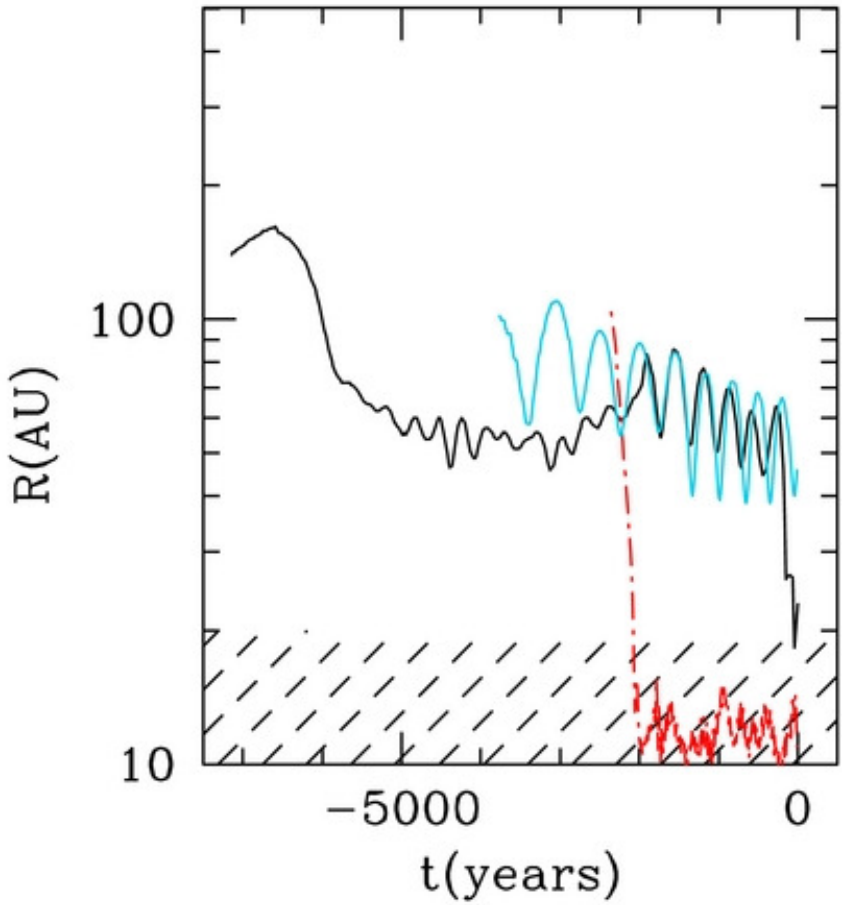
Disk fragmentation model



Recent works: Zhu et al. (2012), Vorobyov (2013)

- most fragments lost from system (inward migration, ejection)
- only a small fraction of runs ($\sim$ 10%) show a clump survive on large orbits — by opening a gap

Clump survival by gap opening



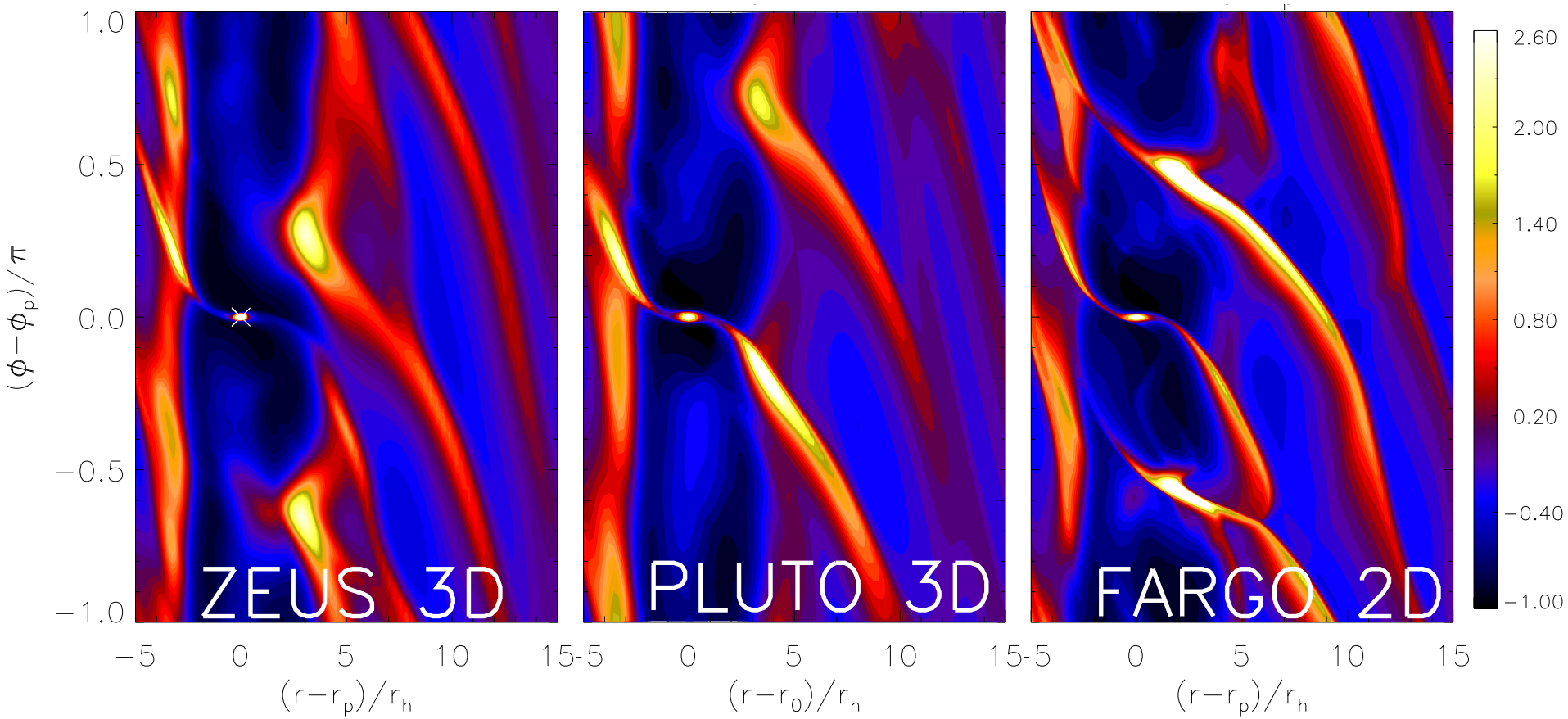
(solid line, Zhu et al., 2012)

- Gaps in massive disks: a stable fluid configuration?

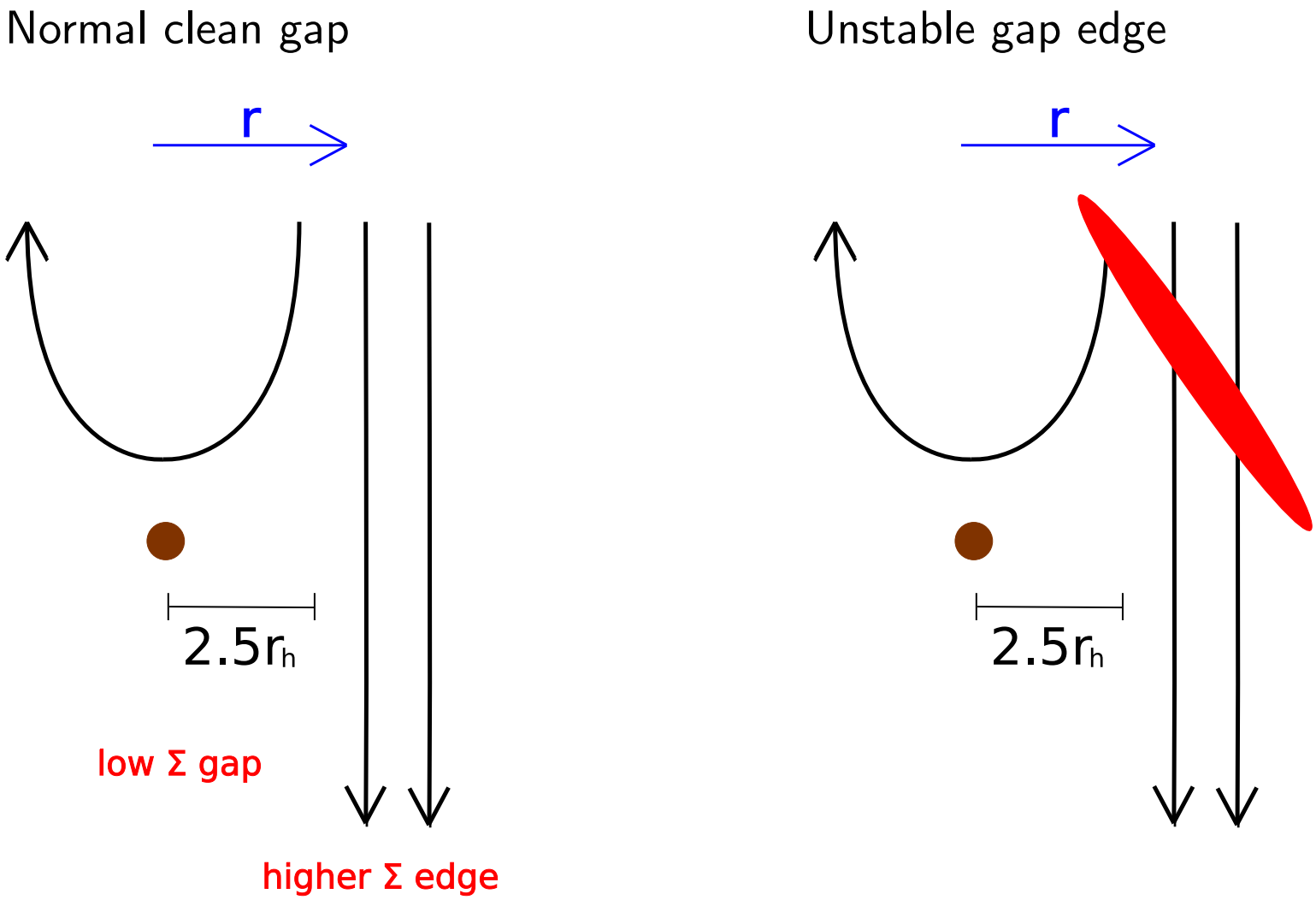
Gravitational edge instabilities

GI associated with gaps or edges even when Toomre stability criterion satisfied ($Q_T > 1$ everywhere)

- Lovelace & Hohlfeld (1978); Sellwood & Kahn (1991): galactic/stellar disks
- Meschiari & Laughlin (2008): gaps in gaseous protoplanetary disks
- Lin & Papaloizou (2011): confirmation of GEI for planet gaps

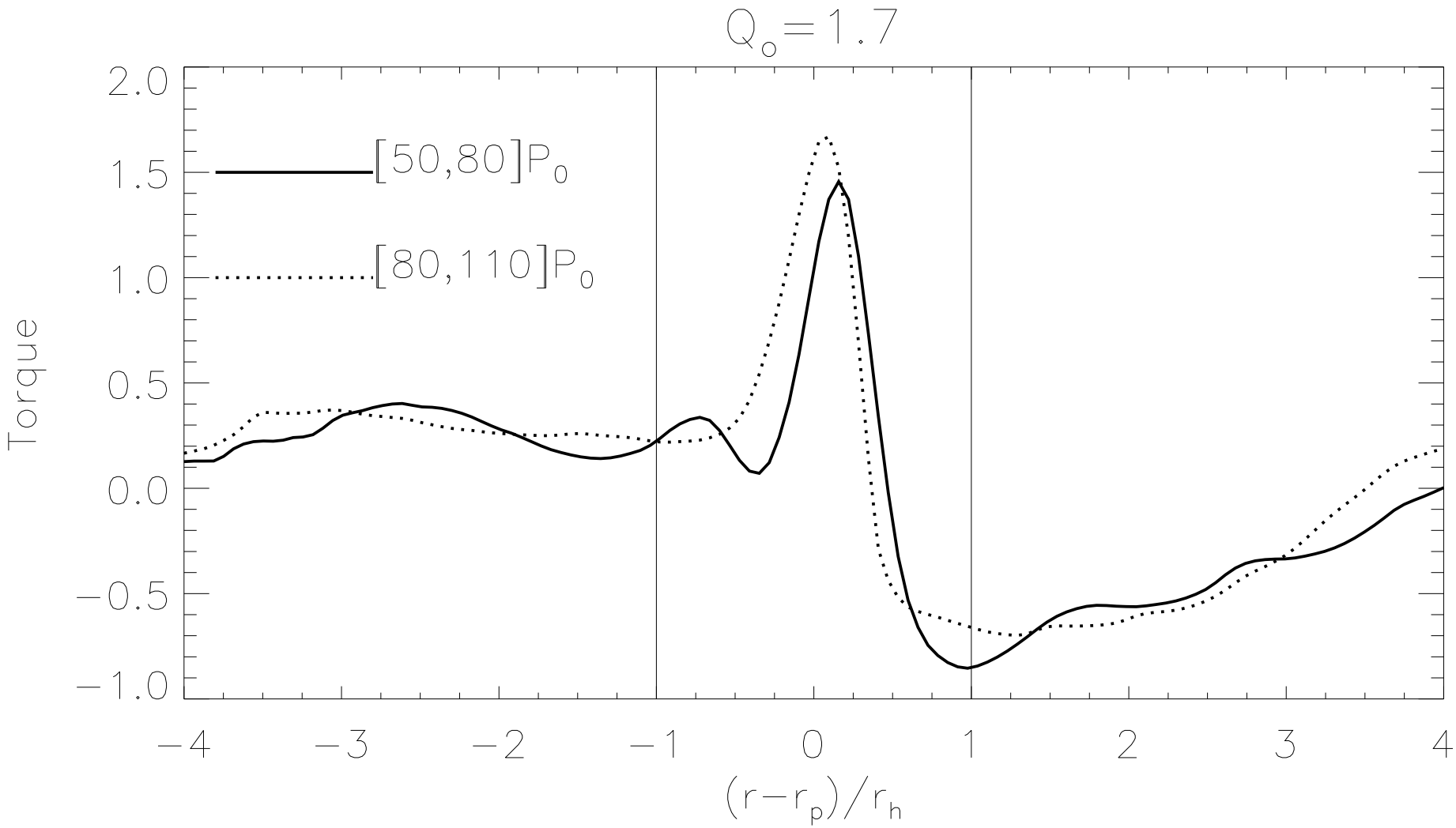


Co-rotation torques due to GEI



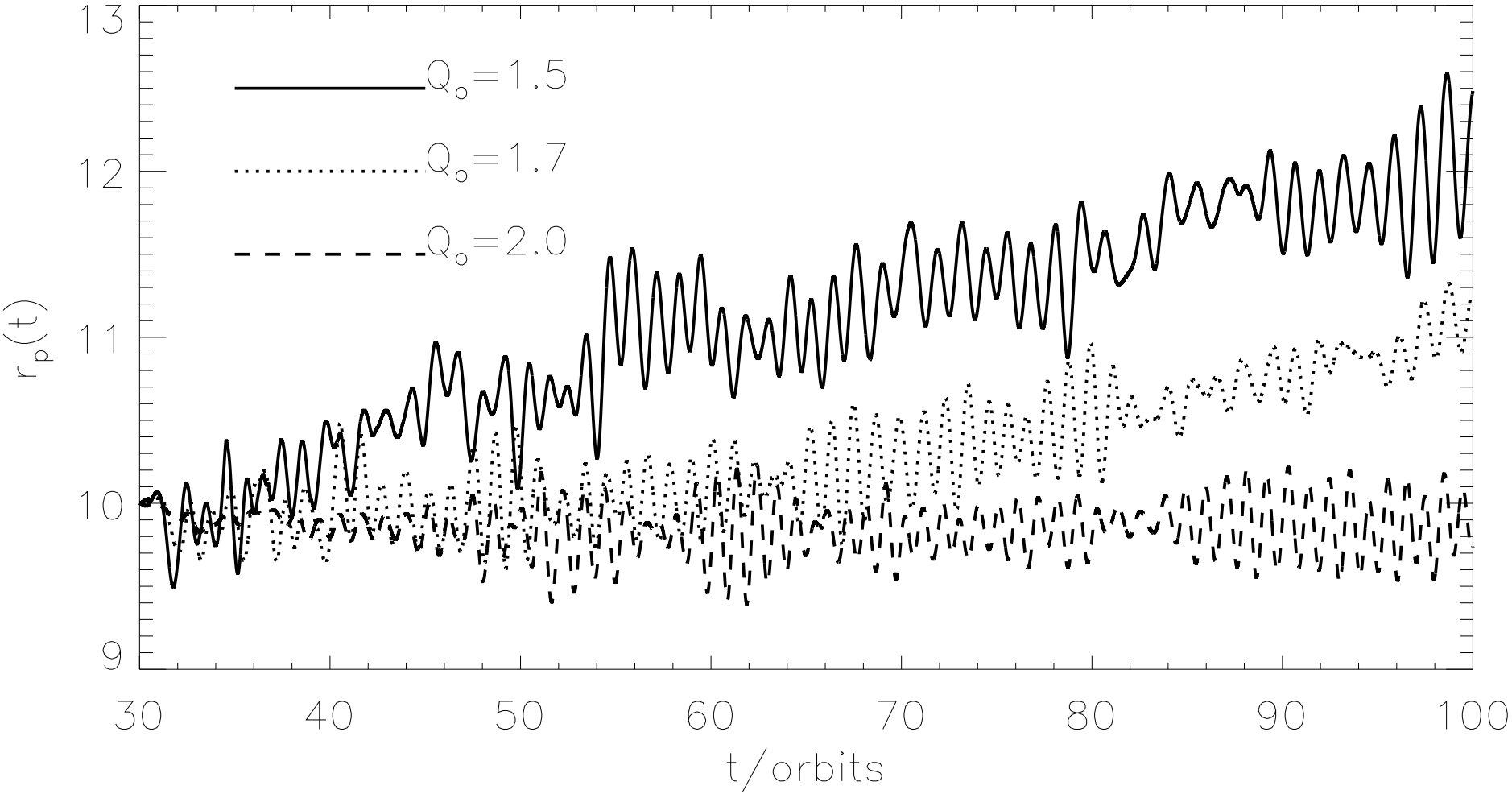
Reload horseshoe orbits with material $\longrightarrow$ positive co-orbital torques

Co-rotation torques due to GEI



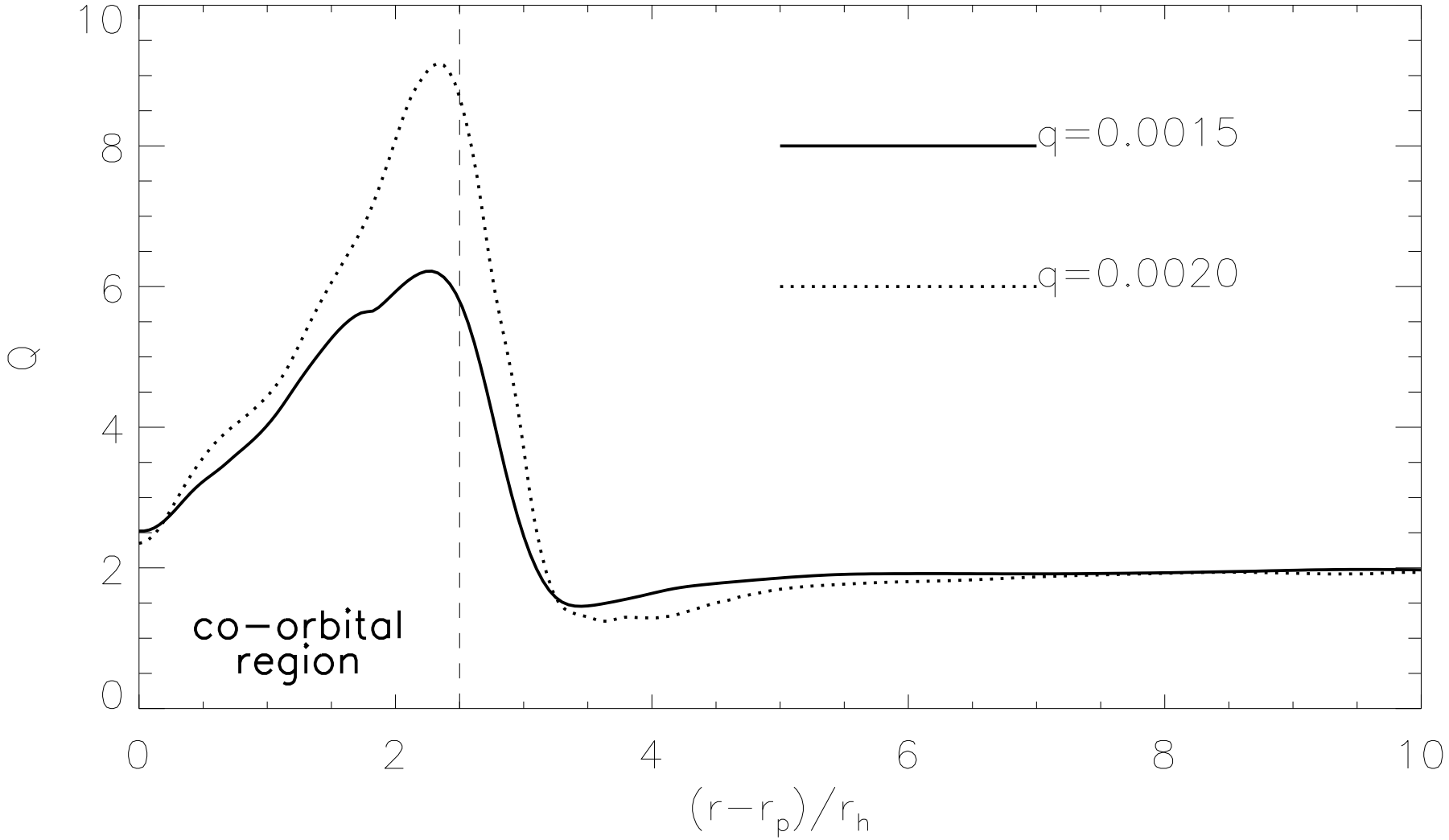
(Lin & Papaloizou, 2012)

Outward migration induced by GEI



Dependency on planet mass

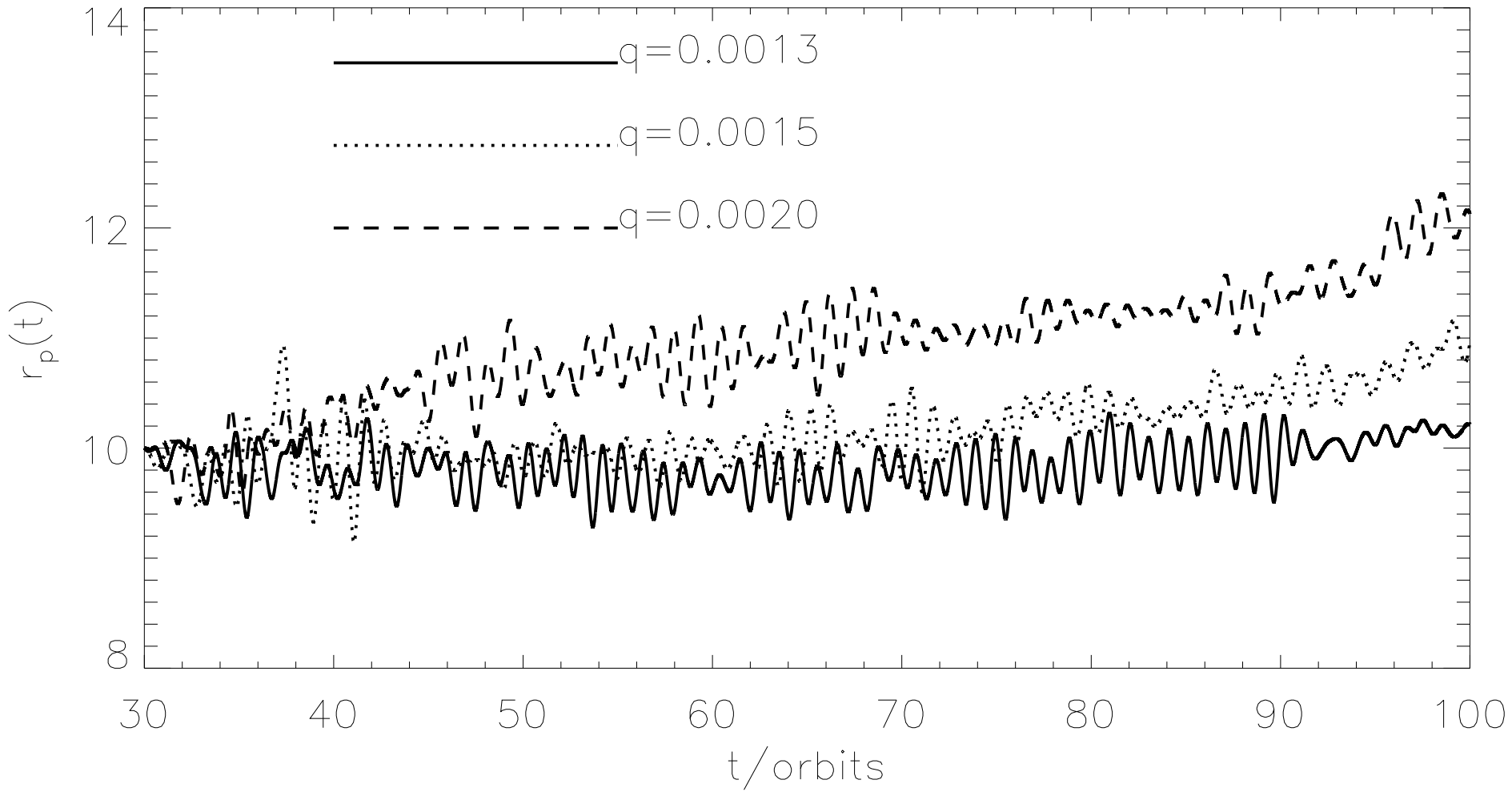
Instability $\leftrightarrow$ gap structure $\leftrightarrow$ planet mass $\leftrightarrow$ orbital migration



[2012 CITA summer student project (Cloutier and Lin, 2013, submitted)]

Dependency on planet mass

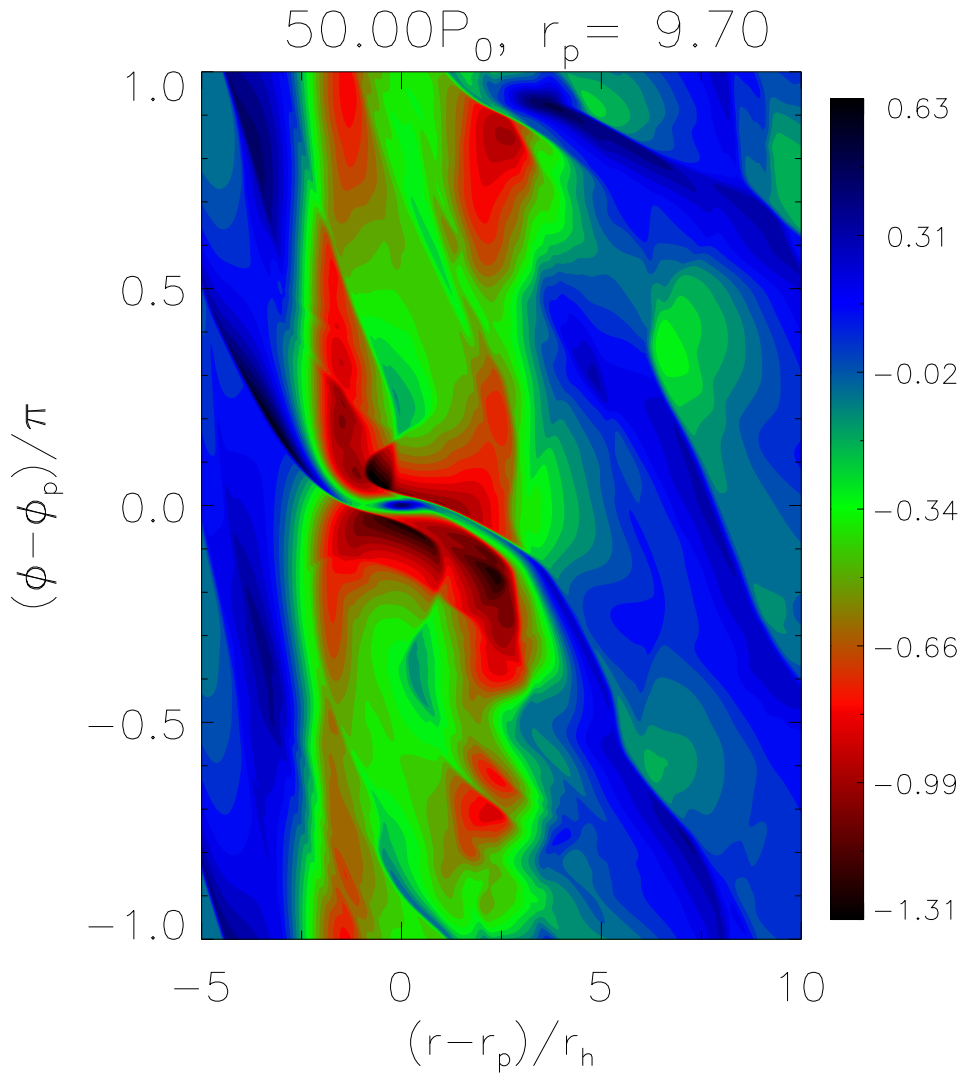
Instability $\leftrightarrow$ gap structure $\leftrightarrow$ planet mass $\leftrightarrow$ orbital migration



[2012 CITA summer student project (Cloutier and Lin, 2013, submitted)]

Torque balance?

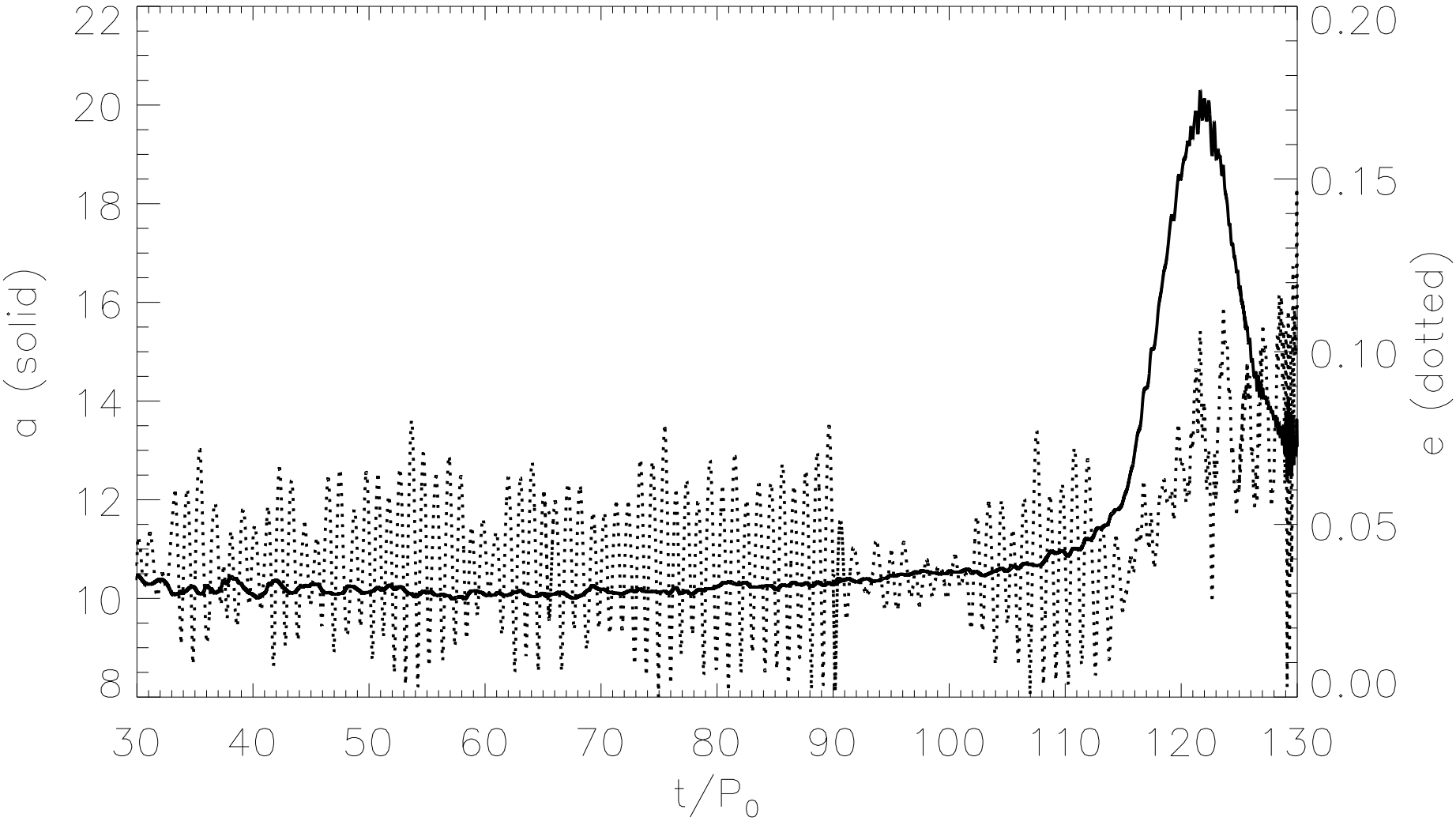
Can positive torques counter-act inward type II migration $\longrightarrow$ no migration?



Cloutier and Lin (2013, submitted)

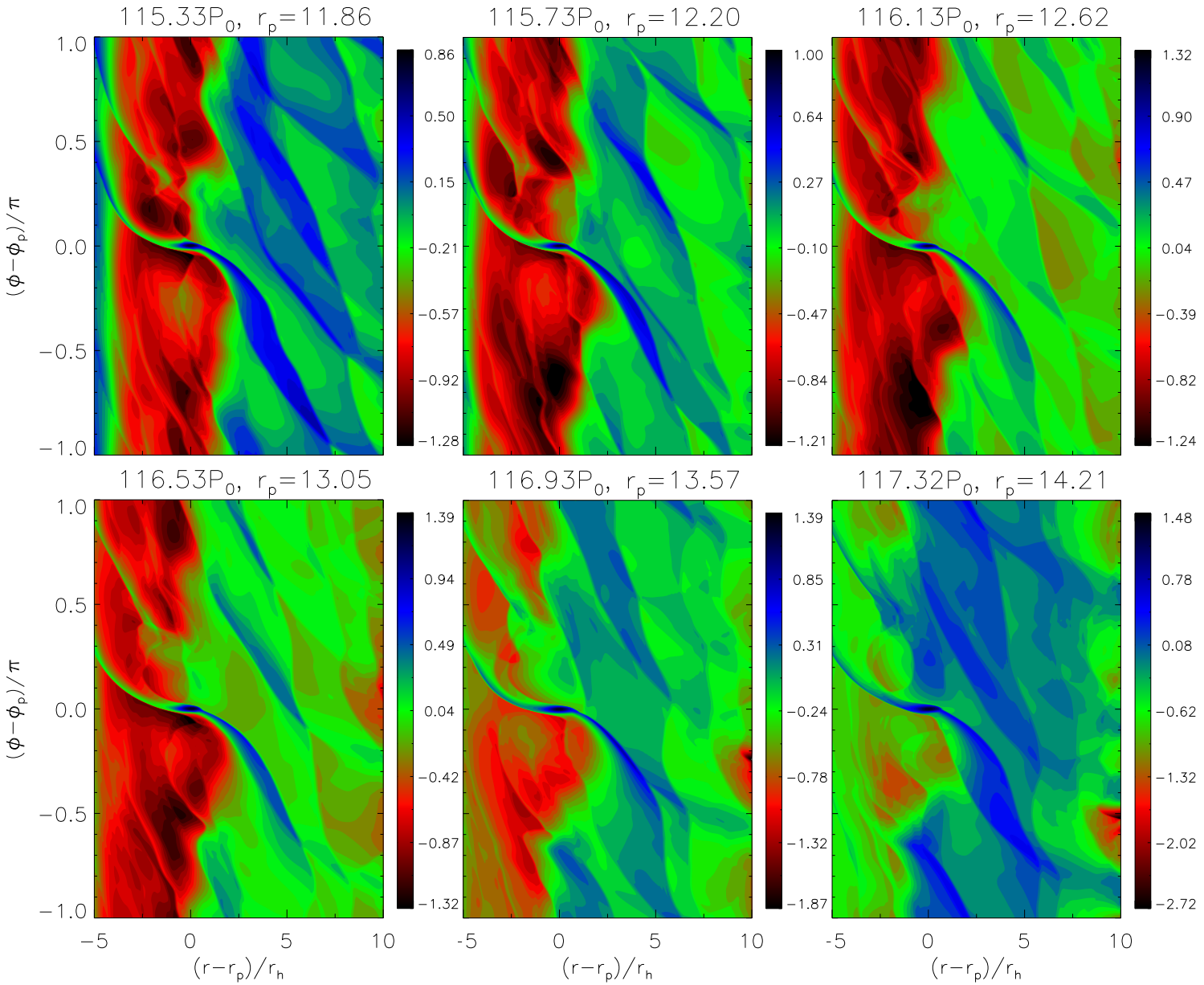
Torque balance?

~~Can positive torque counter-act inward type II migration $\longrightarrow$ no migration?~~



Cloutier and Lin (2013, submitted)

Type III migration triggered by the unstable gap



Cloutier and Lin (2013, submitted)

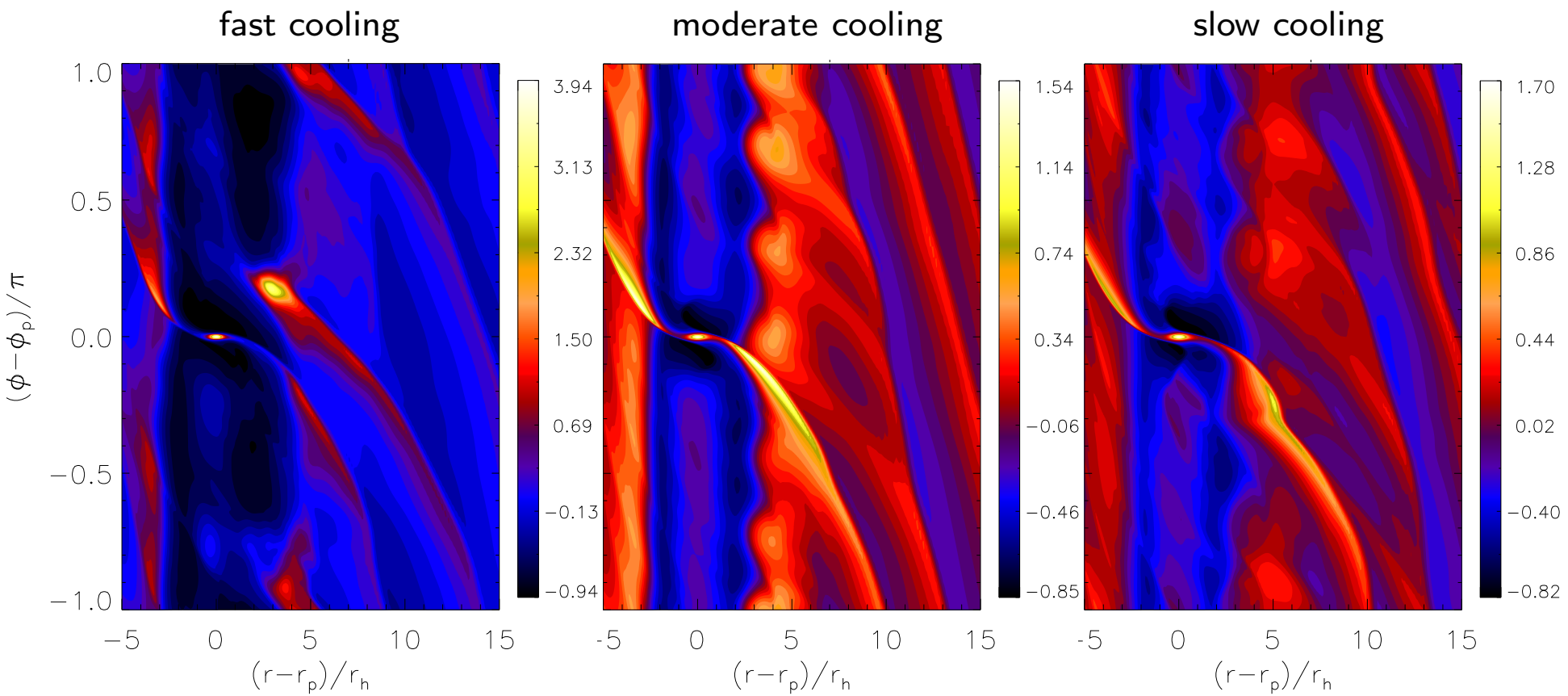
Implications and future/current work

- Gap instability is a potential threat to keep massive planets in massive disks on fixed wide orbits

Implications and future/current work

- Gap instability is a potential threat to keep massive planets in massive disks on fixed wide orbits

Including an energy equation:



References

Lin M.-K., Papaloizou J. C. B., 2011, MNRAS, 415, 1445

Lin M.-K., Papaloizou J. C. B., 2012, MNRAS, 421, 780

Lovelace R. V. E., Hohlfeld R. G., 1978, ApJ, 221, 51

Meschiari S., Laughlin G., 2008, ApJL, 679, L135

Sellwood J. A., Kahn F. D., 1991, MNRAS, 250, 278

Vorobyov E. I., 2013, A&A, 552, A129

Zhu Z., Hartmann L., Nelson R. P., Gammie C. F., 2012, ApJ, 746, 110