

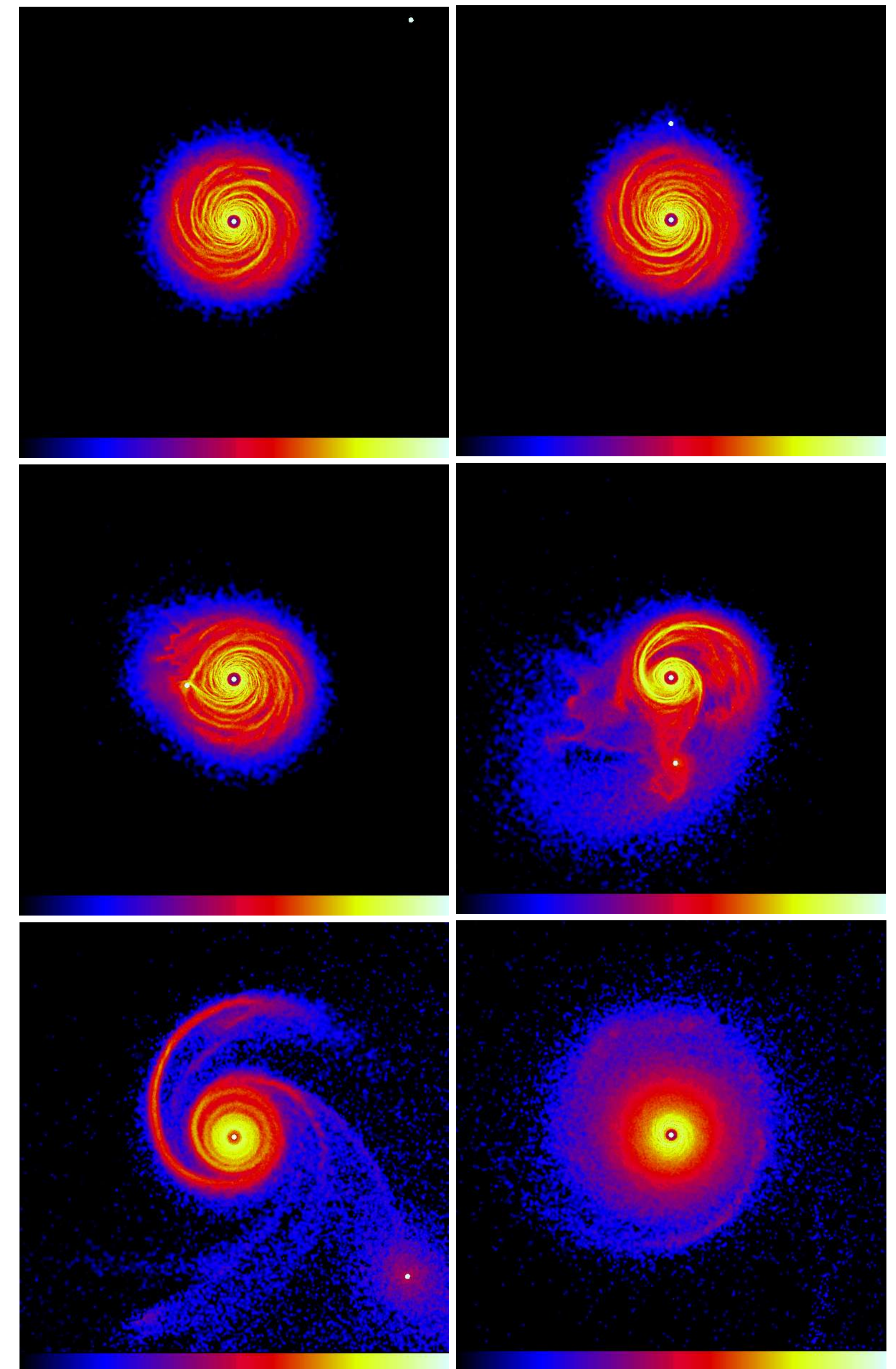
# ENVIRONMENTAL EFFECTS ON PLANET FORMATION VIA FRAGMENTATION



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We present the results of a series of smoothed particle hydrodynamics (SPH) simulations to investigate the response of a marginally stable self-gravitating protostellar disc to a close parabolic encounter with a companion discless star. Our main aim is to test whether close brown dwarfs or massive planets can form out of the fragmentation of such discs at close distances from the primary star (c.f. the results of Boffin et al. (1998) at large distances). The gas disc is allowed to heat up through compression and shocks and to cool down slowly, so that in isolation the disc does not fragment but attains a marginally stable, self-regulated state (Gammie 2001, Lodato & Rice 2004, Lodato & Rice 2005). We widely explore the parameter space by varying the orbital properties of the stars, their mass ratio, and the mass ratio between the star and the disc. **We find that in all of our simulations, the interaction inhibits fragmentation, as a result of tidal heating, leaving behind a highly stable disc.** As in the case of isolated discs, it appears that the condition for fragmentation ultimately depends on the cooling rate.

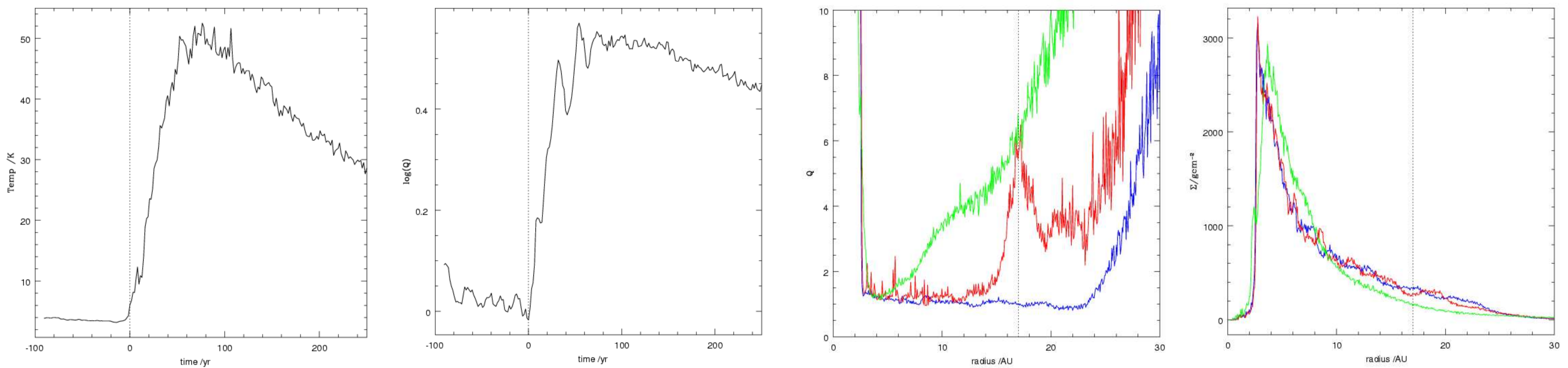


## Summary of simulations

$M_{disc} / M_{Sun}$	No of particles	$M_{pert} / M_{Sun}$	Angle	Retrograde/Prograde	Eccentricity	$R_{peri} / AU$
0.1	250,000	0.1	coplanar	prograde	1	17
0.1	250,000	1.0	coplanar	prograde	1	17
0.1	250,000	0.1	90°	N/A	1	17
0.1	250,000	0.1	coplanar	retrograde	1	17
0.1	250,000	0.1	coplanar	prograde	7	17
0.2	250,000	0.1	coplanar	prograde	1	17
0.1	500,000	0.1	coplanar	prograde	1	17
0.05	250,000	0.1	coplanar	prograde	1	17
0.1	250,000	0.1	coplanar	prograde	1	30
0.1	250,000	0.1	coplanar	prograde	1	40

Images of the reference simulation (from top left to bottom right) (a)  $t \approx -90.7$  yrs (b)  $t \approx -22.3$  yrs (c)  $t = 0$  yrs (d)  $t \approx 19.1$  yrs (e)  $t \approx 81.2$  yrs (f)  $t \approx 302.4$  yrs. The disc orbits in an anti-clockwise motion. The result of the disc that starts off in a marginally stable state is that the spiral structure disappears leaving a very stable disc.

## The Reference Simulation



Figures (a) and (b): Average (a) temperature and (b) Toomre parameter over time. The values are taken from a radius of 8.5 AU from the central star (radius of disc = 25 AU). Figure (c) & (d): Radial profile of (c) Q and (d) sigma at  $t \approx -90.7$  yrs (blue),  $t \approx 0$  yrs (red) and  $t \approx 302.4$  yrs (green). The dotted line in all the figures shows the pericentre distance.

**Overall Conclusions:** In all of our simulations, the interaction inhibits fragmentation rather than promotes it (see also Mayer et al, 2005), as a result of the **overwhelming effect of tidal heating**. The result is that a **highly stable disc is left behind**. Therefore, the detailed modelling of the heating and cooling processes in the disc is essential rather than simply using an isothermal assumption (cf. Boffin et al, 1998). Note: analysis of surface mass density and accretion rates of the discs are currently underway.

## Results of the change in parameters

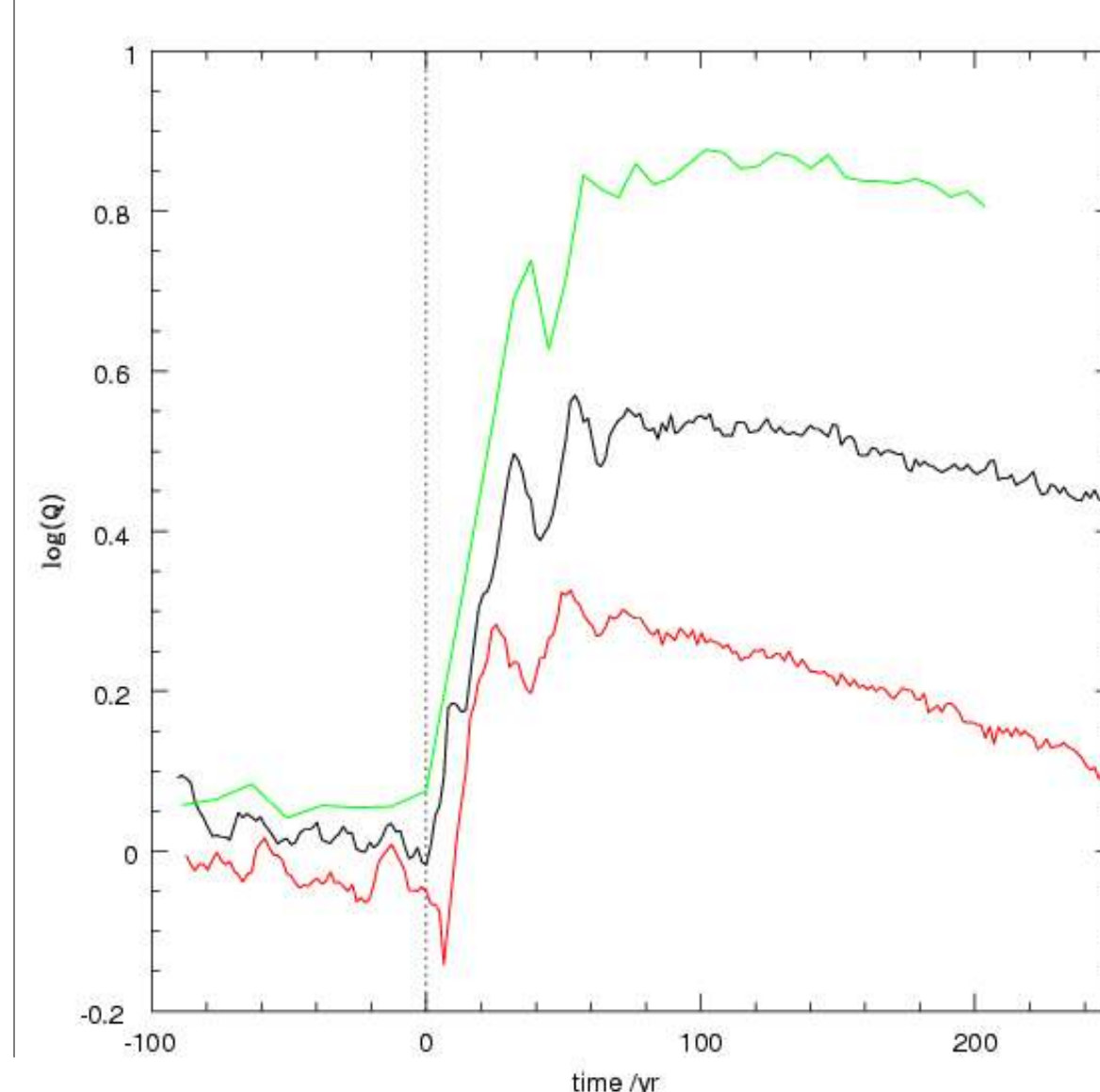
**DIRECTION OF PERTURBING STAR:** comparing prograde, retrograde and non-coplanar orbits

**ECCENTRICITY:** comparing a hyperbolic and parabolic encounter

**RESULT**  
Greater interaction = Greater disc disruption = More stable disc

**PERICENTRE DISTANCE:** comparing orbits with  $r_{peri} < r_{disc}$ ,  $r_{peri} = r_{disc}$  and  $r_{peri} > r_{disc}$

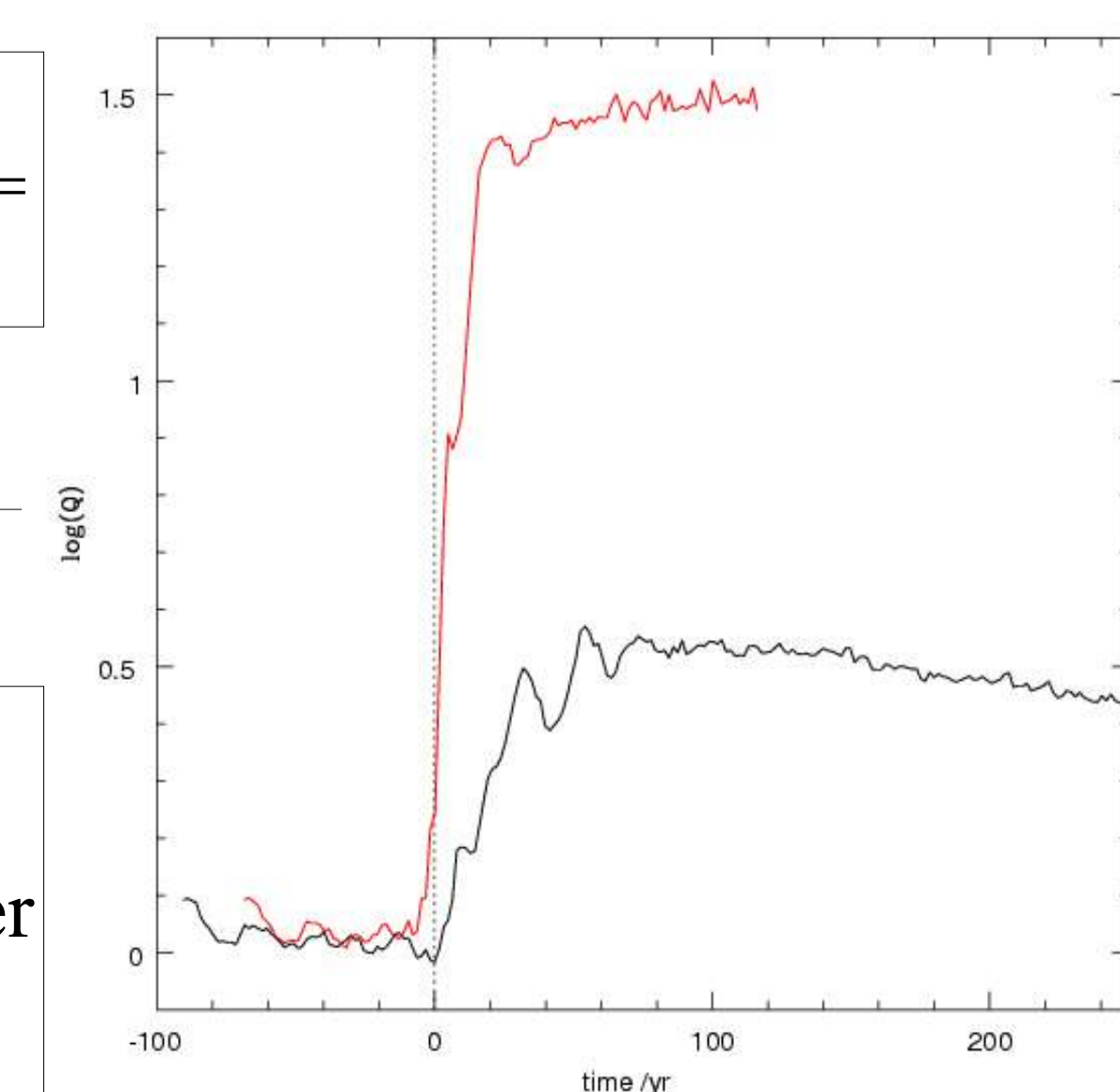
**DISC MASS:** comparing 0.05  $M_{\odot}$  (green), 0.1  $M_{\odot}$  (black) and 0.2  $M_{\odot}$  (red) discs



**RESULT**  
Lower mass disc = More stable

**RESULT**  
Higher mass perturber = Greater tidal heating = More stable disc

**PERTURBER MASS:** comparing 0.1  $M_{\odot}$  (black) and 1.0  $M_{\odot}$  (red) perturbing stars



**CONVERGENCE TEST:** comparing 250,000 particle and 500,000 particle discs

**RESULT**  
No difference between the two simulations

**References**  
• Boffin H.M.J., Watkins S.J., Bhattal A.S., Francis N., Whitworth A.P., 1998, MNRAS, 300, 1189  
• Gammie C.F., 2001, ApJ, 553, 174  
• Lodato G., Rice W.K.M., 2004, MNRAS, 351, 630  
• Lodato G., Rice W.K.M., 2005, MNRAS, 358, 1489  
• Mayer L., Wadsley J., Quinn T., Stadel J., 2005, MNRAS, 363, 641