Eccentricity growth of planetesimals in a self-gravitating protoplanetary disc

M. Britsch[1,2,*], G. Lodato[1] and C. J. Clarke[1]

[1]Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0HA; UK

[2]Zentrum für Astronomie Heidelberg, ITA, University of Heidelberg, Albert-Ueberle-Str. 2, 69120 Heidelberg; GERMANY

* markward@ita.uni-heidelberg.de

Abstract

We simulate the dynamics of small plants in the transient spiral structure of self-gravitating protoplanetary accretion disks of 0.1 M_* *and 0.5* M_* *(where* M_* *is the mass of the central star* $M_* = \mathrm{M}_\odot$*). We are using a Smoothed Particle Hydrodynamics (SPH) code. Our simulations are done in the test particle regime where the planets don't change the disc structure and valid for a size range of planetesimal of 100 metre to earth sized planets. They show that due to the gravitational interaction with the spiral structure the mean eccentricities of the planets grow within 4000 yr to 0.17 in the 0.1* M_* *disc and within 1600 yr to 0.3 in the 0.5* M_**. At the same time the planets undergo a violent random walk like radial motion.*

Introduction

It has been inferred from observations that there are massive (up to 0.4 $\mathrm{M}_\odot$) gas discs around stars in star forming regions of an age of about 1 Myr (see, e.g., [1]). In a model that combines the core accretion model (see, e.g., [2]) with the gravitational instability model (see, e.g., [3]) of planet formation, Rice et al. (2004) [4] showed in a simulation of metre sized planetesimals in a self-regulated self-gravitating disc that the spiral structure of such a disc can help reducing the time-scale of the core accretion model. The work presented here, addresses the subsequent evolution of such planetesimals, once they are grown larger than about 100 metres in radius.

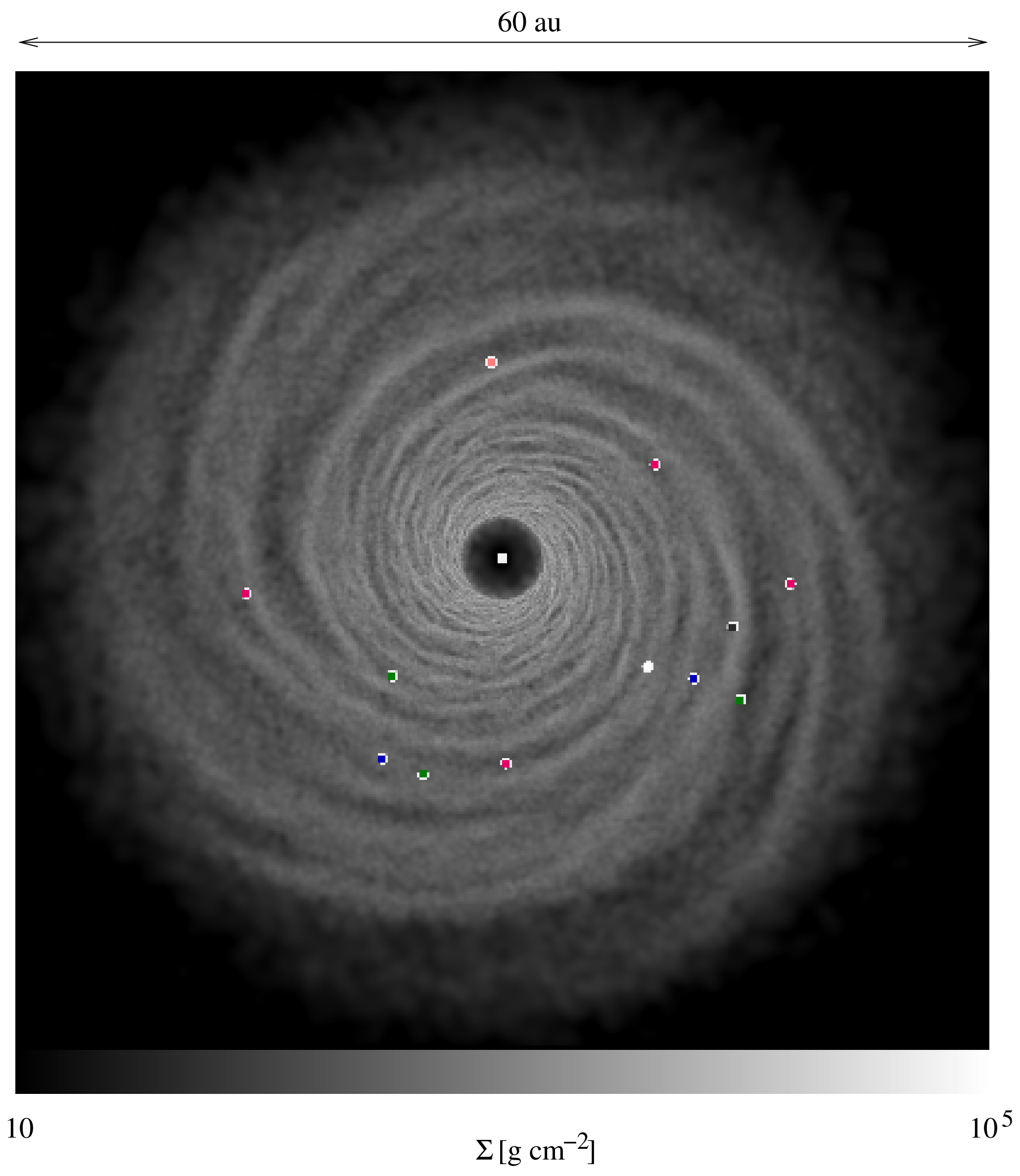
Self-regulated self-gravitating accretion disks

A massive disc can become gravitational unstable when

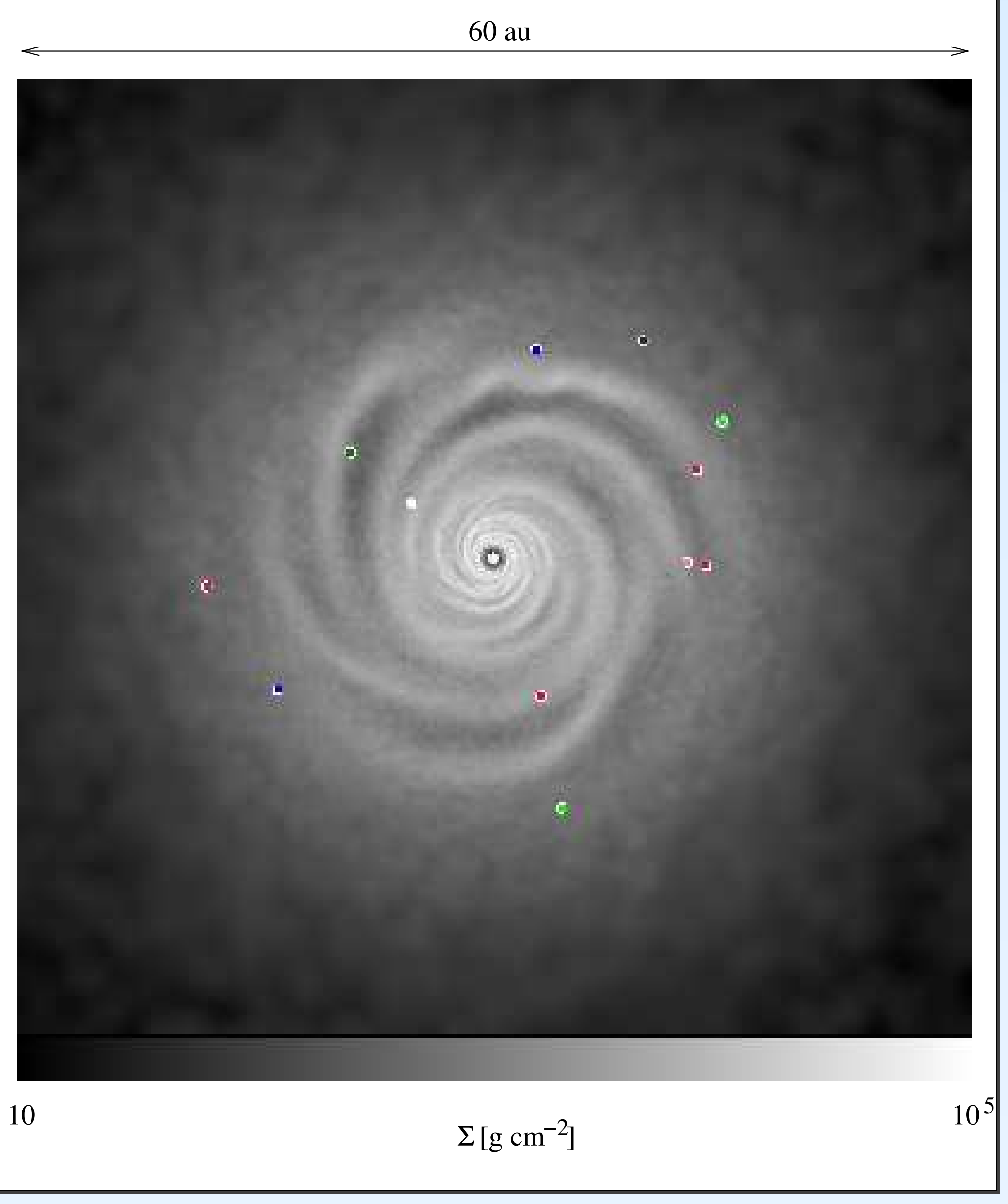
$$Q := \frac{c_s \kappa}{\pi G \Sigma} < 1 \qquad (1)$$

where Q is the Toomre parameter, c_s the speed of sound, κ the epicyclic frequency which is equal to the angular velocity Ω since we deal with Keplerian discs. Σ is the surface density and G the gravitational constant. If the cooling is not efficient enough and thus the disc does not fragment, it gets into a self-regulated state with $Q \approx 1$. Here this is ensured by a cooling law that keeps the cooling time $t_{\mathrm{cool}} = \beta\Omega$ with $\beta = \text{const.} > 3$ for the self-regulated state [5].

The simulations

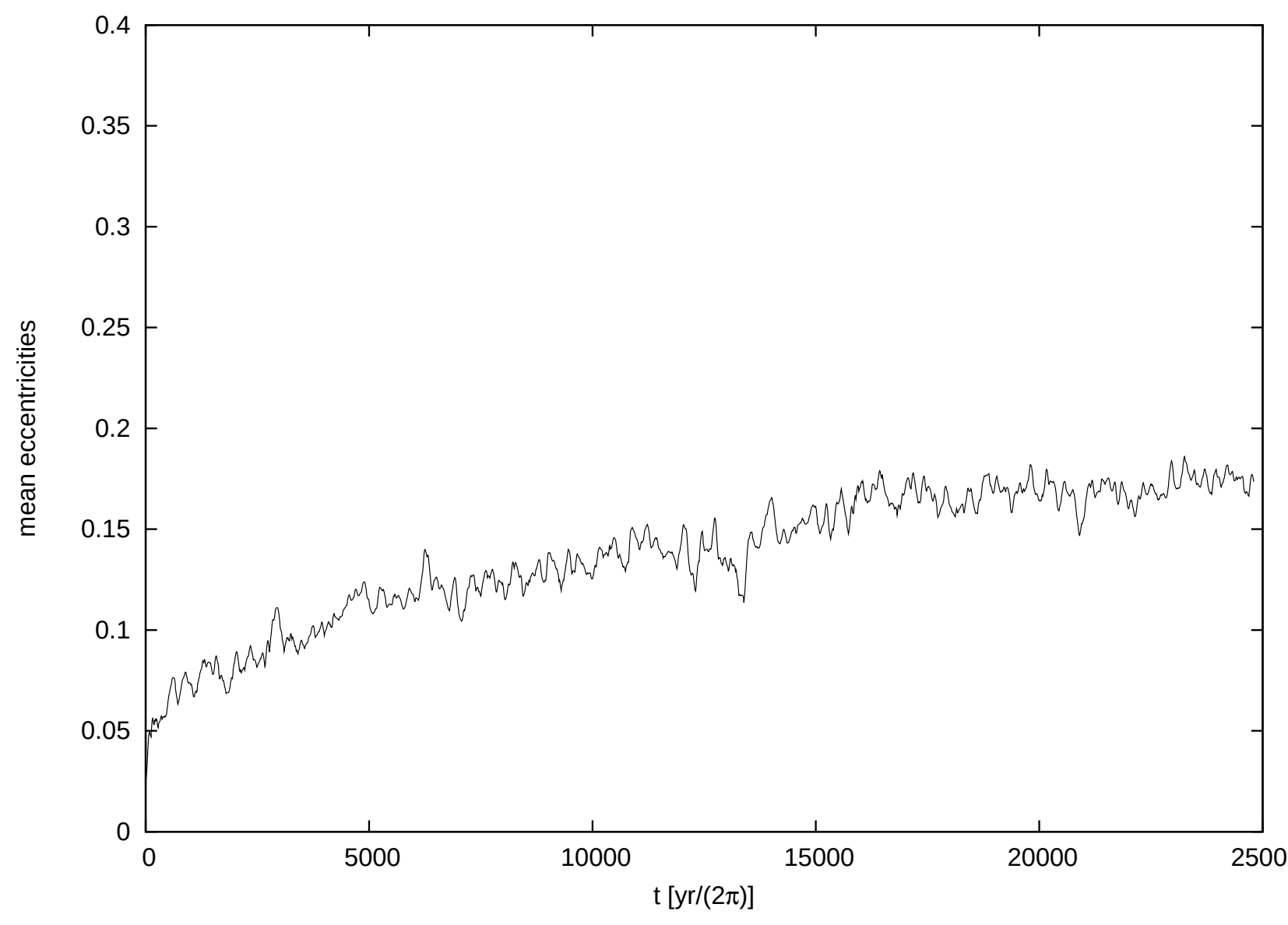


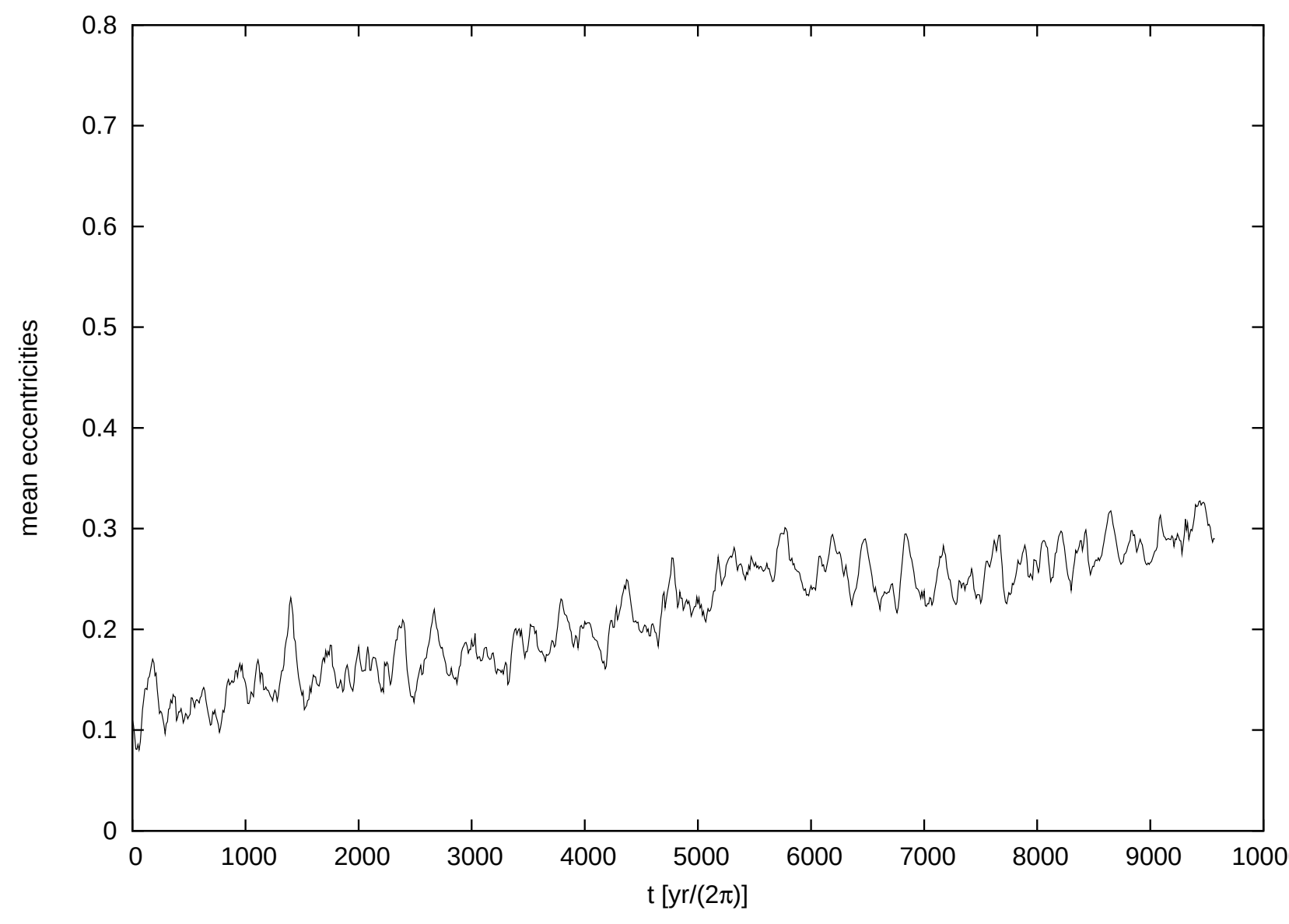
In the two simulations a 0.1 M_* disc and a 0.5 M_* disc were simulated with $M_* = \mathrm{M}_\odot$. Both had been run for more than 45 outer dynamical times to get to a self-regulated state before the planets were put in. The discs stretched originally from 0.25 au to 25 au radially. The two images are snapshots of the twelve non-accreting planets in the spiral structure (the surface density in a logarithmic scale) of the discs, the 0.1 M_* disc on the left and the 0.5 M_* disc on the right hand side. The planets, which have the same mass as the gas particles (i.e., $4.0 \cdot 10^{-7}\,\mathrm{M}_\odot$ and $2.0 \cdot 10^{-6}\,\mathrm{M}_\odot$), are point masses and only enlarged for clarity. The motion of the planets is significantly different from the usual migration mechanism where the planet excites a spiral wave in the disc. Here the disc structure is not influenced by the planets and they are influenced only by the spiral structure that comes about due to the self-gravity of the disk. It was also checked that the planets don't influence each other. The size interval where we stay in this test particle regime starts at about 100 meters planetesimal radius below which the gas drag plays a non-negligible role. And it ends at about earth sized objects where the planets start to influence the structure of the gas disk significantly.



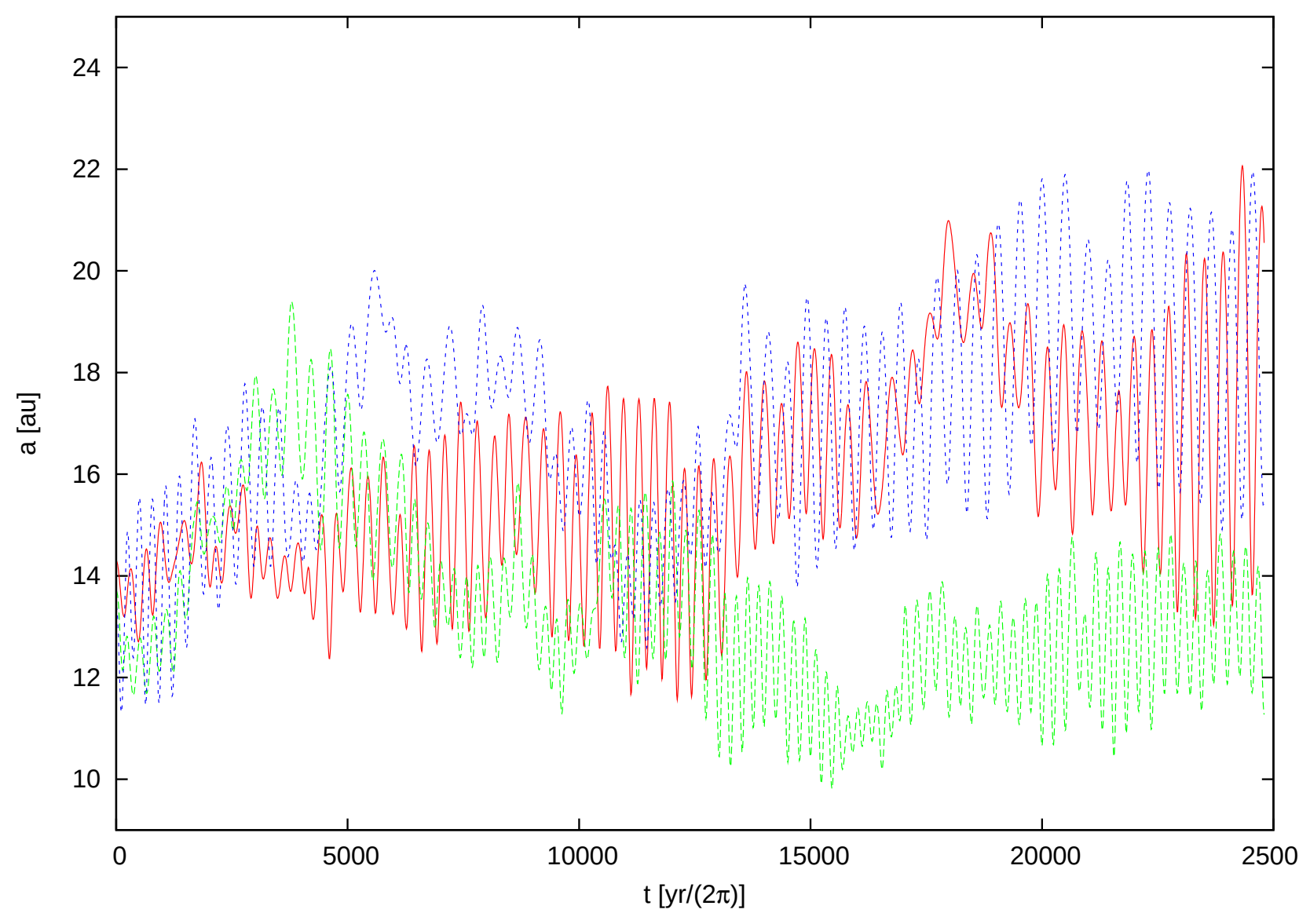
Results

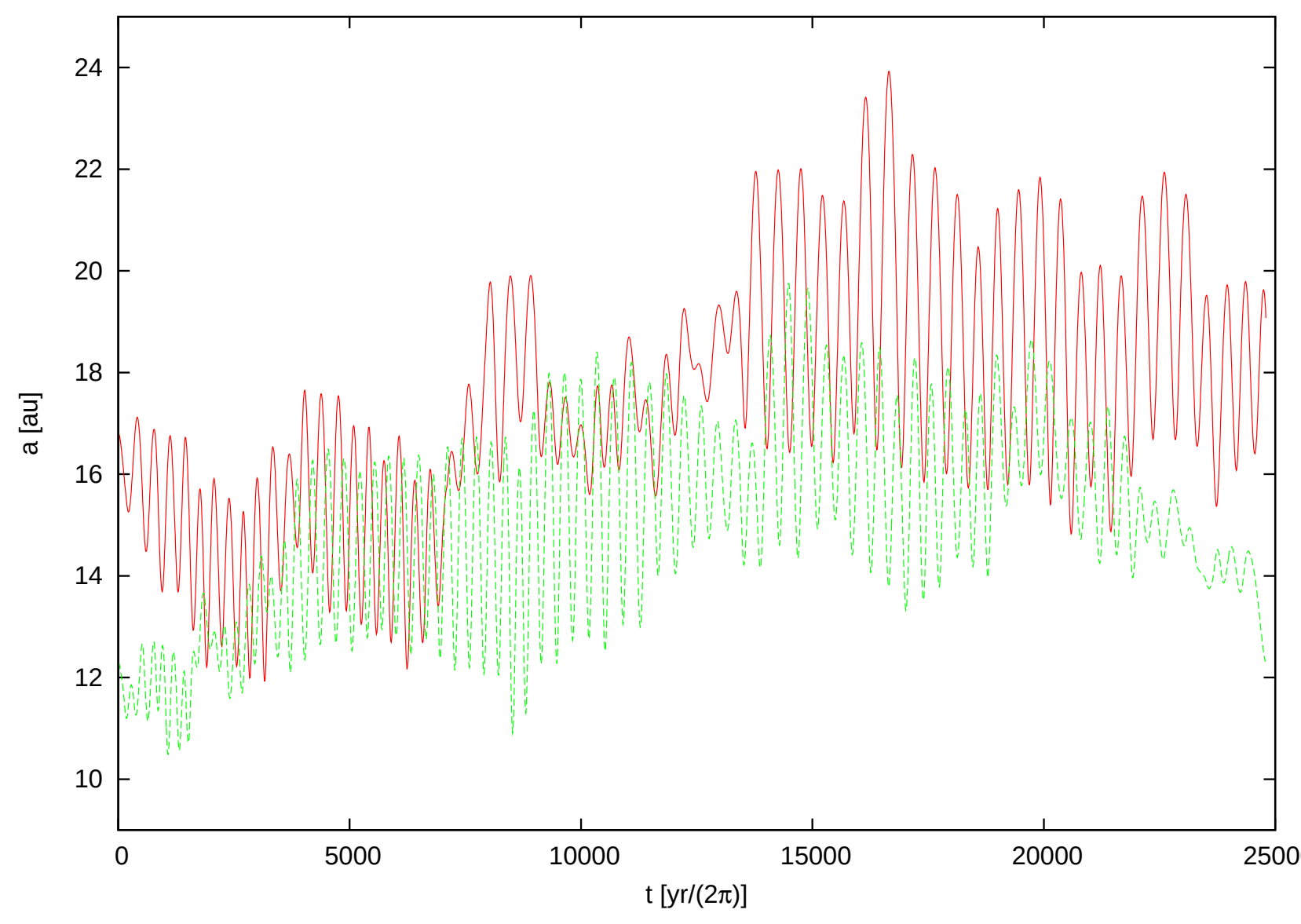
Here the mean eccentricities over all planets are plotted against time for the 0.1 M_* disc (left panel) and the 0.5 M_* disc (right panel). The mean eccentricity rises to 0.17 and 0.3 respectively.





In the two panels below the radial coordinate for some sample planets are plotted against time for the 0.1 M_* disc which show rather random movements apart from the nearly Keplerian oscillations.





Conclusions and outlook

- Eccentricity growth ⇒ more close encounters (good for growth) but also higher encounter velocities (less gravitational focusing, bad for growth)
- Compare with the work of [6] about random walks and eccentricity growth of planetesimals in turbulent MHD discs
- Can the large eccentricities save the planetesimals from migrating into the star (see e.g. [7] or [8])?
- Understand the orbits of the planets in detail

References

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