Diagnosis of Gravitational Instability in Models of Star-Forming Galaxies

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Introduction

Gravitational instability appears to plays a dominant role in determining the star formation properties of galaxies (Li, Mac Low, & Klessen 2005ab, 2006). Models of galactic disks including isothermal gas (with sound-speed of order 10 km/s), collisionless stars, and dark matter, were evolved with the smoothed particle hydrodynamics code GADGET. A strong correlation was found between the initial strength of gravitational instability in the galaxies, as measured by the minimum value of the Toomre (1964) Q parameter in the disk, and the timescale for the gas to collapse gravitationally to form stars. This relationship between disk instability and collapse timescale was derived using the initial value of the instability parameter in the disks. However, that is not an observable quantity, as observers can only measure the instantaneous instability parameter of the disks for comparison to their star formation rates. The measurement of the instantaneous instability parameter has been done, for example, by Martin & Kennicutt (2001), who measured the gas instability parameter, or by Dalcanton et al. (2004) who measured the combined instability parameter for stars and gas following Rafikov (2001). It is therefore important to extend the study of the correlation in the models to a study of the current collapse rate compared to the observable value of the instantaneous instability parameter. We perform this study on the ensemble of models described in Li, Mac Low, & Klessen (2005b).

Instability

$$\frac{1}{Q_{sg}} = \frac{2}{Q_s}\frac{1}{q}\left[1 - e^{-q^2} I_0(q^2)\right] + \frac{2}{Q_g}\xi\frac{q}{1+q^2\xi^2},\ \text{where}$$

$$Q_s = \frac{\kappa\sigma_s}{\pi G\Sigma_s}\ \text{and}\ Q_g = \frac{\kappa c_g}{\pi G\Sigma_g},$$

$q = k\sigma_s/\kappa$, $\xi = c_g/\sigma_s$, is the radial velocity dispersion of stars,

cg is the sound speed of the gas, ∑s and ∑g are the surface densities for stars and gas, I_0 is the Bessel function of order 0, and k is the dimensionless wave number of the perturbation.

Rafikov (2001) showed that $\mathbf{Q_{sg} > 1}$ yields **gravitational stability** against local axisymmetric perturbations in a thin, rotating disk of collisionless stars and collisional gas.

Models

As outlined in Li, Mac Low & Klessen (2005b), our models follow collisionless stars and dark matter with a tree-based N-body algorithm, and collisional, dissipative gas dynamics with smoothed particle hydrodynamics (SPH). The Lagrangian SPH algorithm follows the local mass density (Monaghan 1992). These models are computed with a modified version of the publicly available, three-dimensional, parallel, N-body/SPH code GADGET v1.1 (Springel, Yoshida, & White 2001) that contains an implementation of ink particles to follow gravitational collapse

Table 1 provides a summary of physical components outlined in the models of Li, Mac Low & Klessen (2005b).

Table 1: Summary of Galaxy Models

Model by Rot. Vel. at Virial rad. in km/s	**Virial Mass** in 10^{10} M$_\odot$	**Disk Mass Fraction** in gas	**Rad. Disk scale** length in kpc
G50 - 1 to 4	4.15	0.2 to 0.9	1.41 to 1.07
G100 - 1 to 4	33.22	0.2 to 0.9	2.81 to 2.14
G120 - 3 to 4	57.4	0.5 to 0.9	3.38 to 2.57
G160 - 1 to 4	136.0	0.2 to 0.9	4.51 to 3.42
G220 - 1 to 4	353.7	0.2 to 0.9	6.20 to 4.71

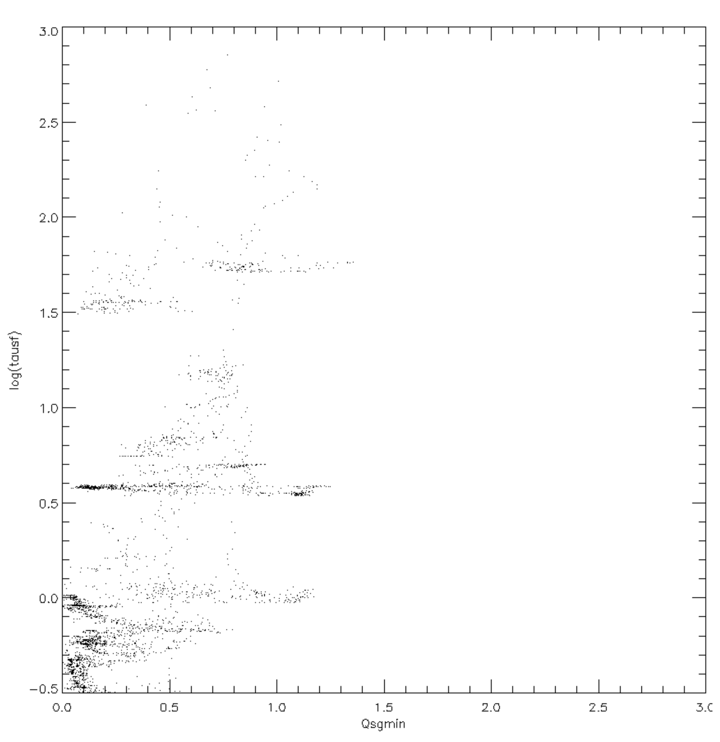
Results

The minimum Q_{sg} value was calculated over time using azimuthally averaged profiles. It is plotted as a function of the star formation rate time scale $\tau_{sf} = M_{gas}/\dot{M}_*$, calculated by dividing the total mass of gas in the galaxy by the accretion rate.

In addition to the initial time steps, this study evaluated the minimum Qsg value at various time points throughout the evolution of several models.

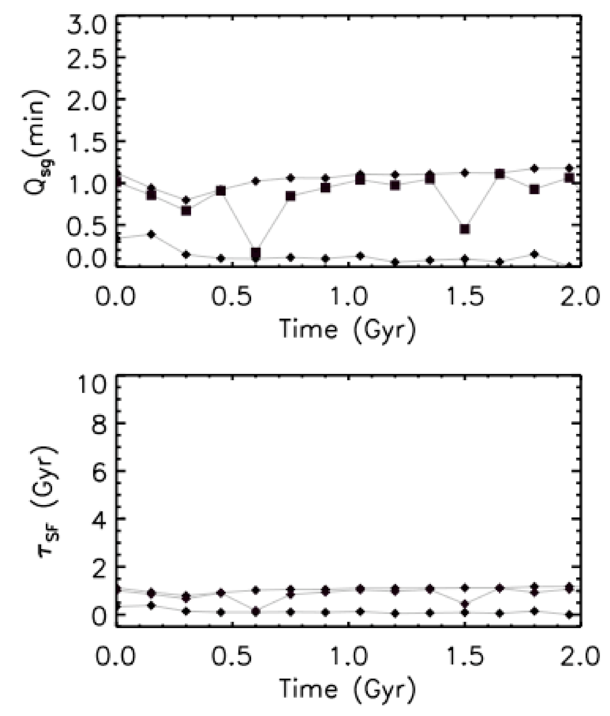
In marked contrast to the results of Li, Mac Low, & Klessen (2005b) for *initial* gravitational instability, we find that the *current* strength of gravitational instability correlates only weakly with the current star formation time scale

Figure 1: All Times



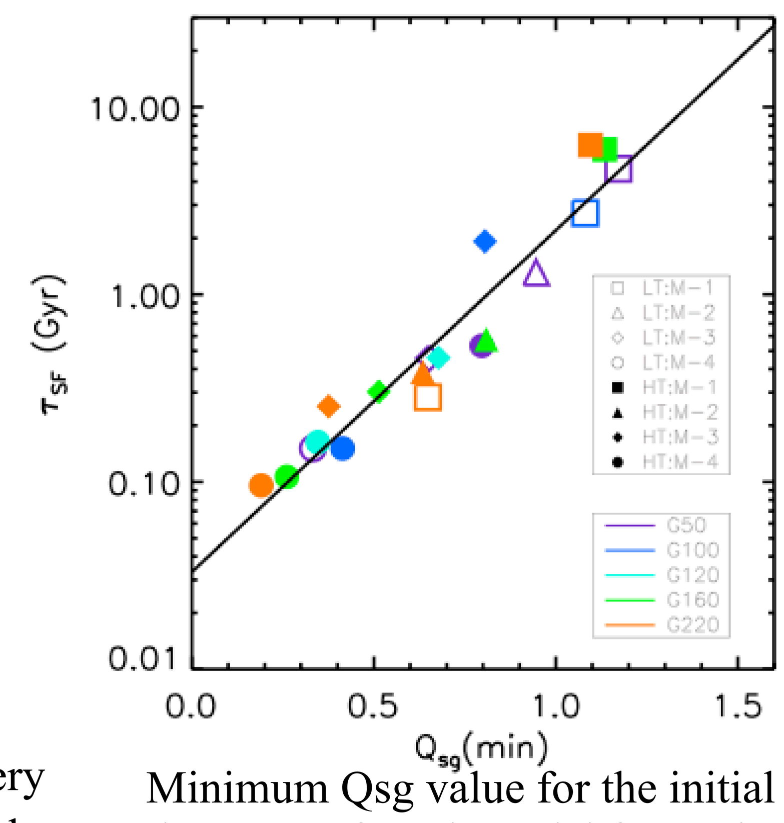
Minimum Q_{sg} values against τ_{sf} for all models. Each point corresponds to a new time in a galaxy model.

Figure 2: By Galaxy



Minimum Qsg values against τ_{sf} for every fifteenth time point to demonstrate trends associated with hdg120-6, hdg50-6, hdg100-6

Figure 3: Initial Snapshot



Minimum Qsg value for the initial time step of each model from Li, Mac Low & Klessen (2005b).

Conclusion

Preliminary results suggested that the currently observed disc stability does not seem to determine current star formation rate. Rather, the initial stability criteria determines the star formation rate as opposed to the observable quantity.

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Current Work

This study evaluates the minimum Q_{sg} statistic on radial bins rather than on a Cartesian grid as was done, for example, by Yang et al. (2007) for the LMC. Thus, it is necessary to reformat the Q_{sg} calculation. Once a grid of Q_{sg} values is setup, it will be possible to find putative young stellar objects (YSOs) based on changes in the masses of sink particles over time. With this information we can compare directly to the results of Yang et al. (2007).

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