Large grains can grow in circumstellar discs

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~ Introduction ~

We perform coagulation and fragmentation simulations to understand the growth of grains in T Tauri and brown dwarf discs. We present a new physically motivated approach to determining the collision velocities of dust particles by combining analytical and numerical techniques. This approach uses a probability distribution function (PDF) for the collision velocities (also adopted earlier by Okuzumi et al., 2011; Galvagni, Garaud, Meru & Olczak, 2011; Windmark et al., 2012b) but crucially, the key development is that it separates the deterministic (i.e. directional) and stochastic (i.e. non-directional) velocities. The particle velocity in any one direction is given by the deterministic velocities (radial drift, azimuthal drift and vertical settling) while the spread in the distribution function is determined by the stochastic components (turbulence and Brownian motion).

By applying this technique to T Tauri disc conditions, growth to larger sizes is possible compared to previous studies. Furthermore, we study the growth in brown dwarf discs and find that grains are also able to reach large sizes. In particular, if brown dwarf discs are scaled down versions of T Tauri discs (in terms of stellar mass, disc mass and disc radius) growth at an equivalent location with respect to the disc outer edge can occur to the same size in both discs. This is because the collisional timescales in the two discs are comparable.

~ Principles behind the new physically motivated model ~

Two key features:

- Velocity of a dust aggregate takes on a distribution of values and is *not* single-valued
- Particle velocity is driven by the deterministic velocities and the spread in the distribution is given by stochastic processes

These features are used to produce:

1D Gaussian probability distribution function (PDF) of velocities in the radial direction for a single particle - mean given by the radial drift velocity and spread given by the non-directional velocities (i.e. turbulence and Brownian motion)

Repeat for the azimuthal and vertical directions using the azimuthal drift and vertical settling velocities as the directional velocities

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1D distribution of *relative velocities* in the radial direction for a pair of particles

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Combine 1D PDFs of relative velocities into a 3D PDF for the collision velocity for a pair of particles

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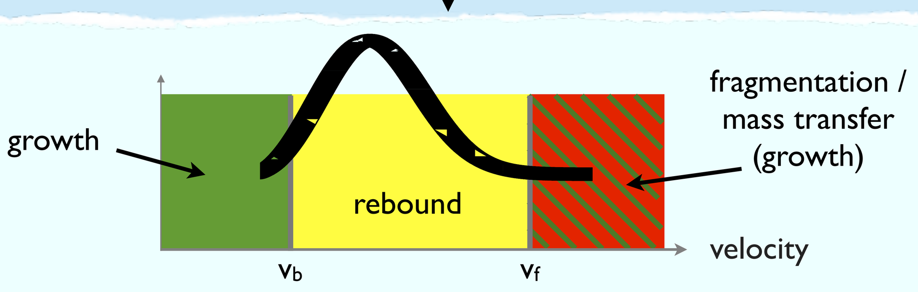

The final PDF may cover regions where particles can grow, rebound or fragment. These determine the collisional outcomes.

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Use these collisional outcomes to simulate the time evolution of an ensemble of particles locally in a disc

Garaud, Meru, Galvagni & Olczak, 2013

~ Grain growth in T Tauri and brown dwarf discs ~

T Tauri discs

1 AU

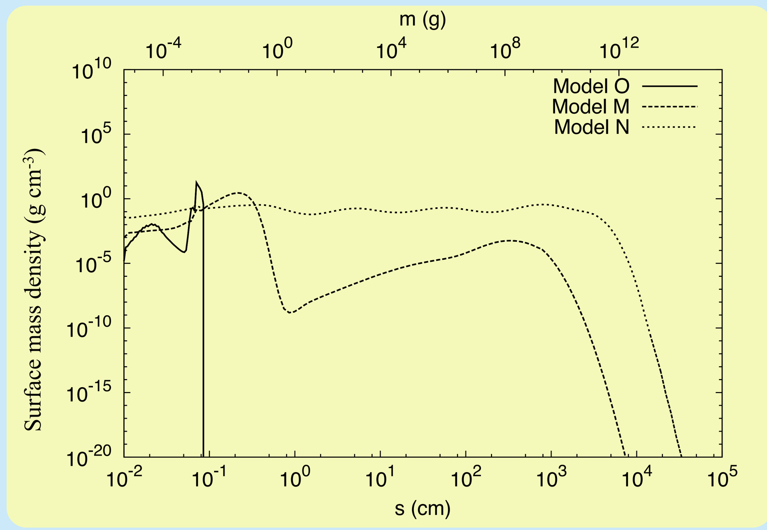


Figure (a) Comparing the new model to others
Model O: without velocity PDF
Model M: assumes stochastic velocities dominates over deterministic velocities
Model N: the new model

The new model shows growth to larger sizes than other models

30 AU

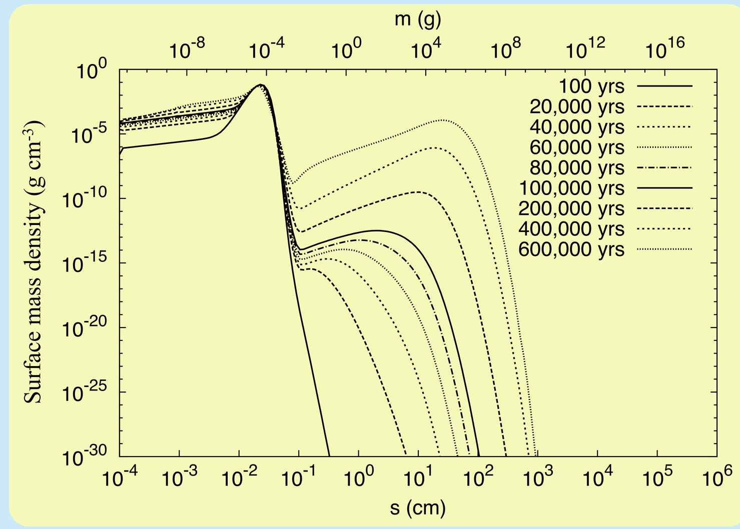


Figure (b) Time evolution of surface density distribution using the new model (Model N)

Two particle populations emerge over time

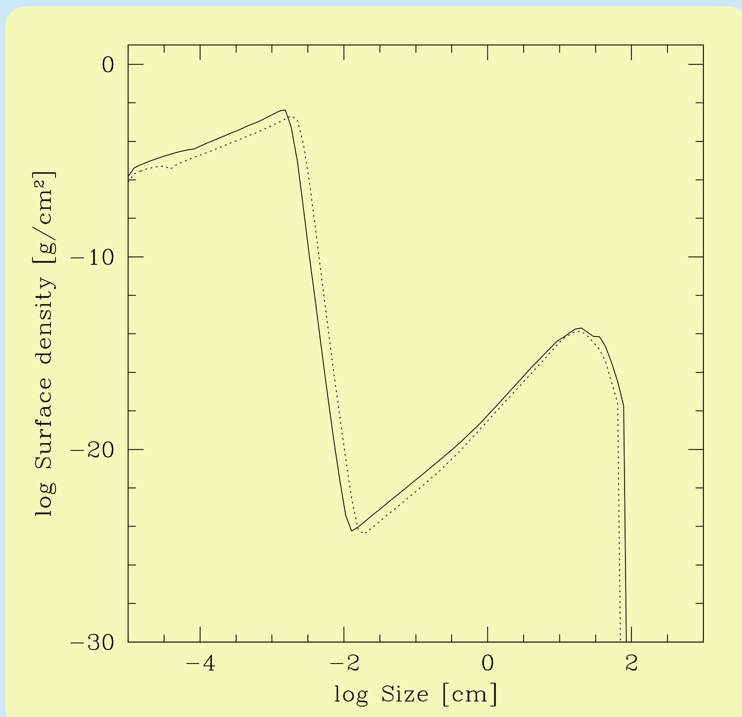
Garaud, Meru, Galvagni & Olczak, 2013

Brown dwarf discs

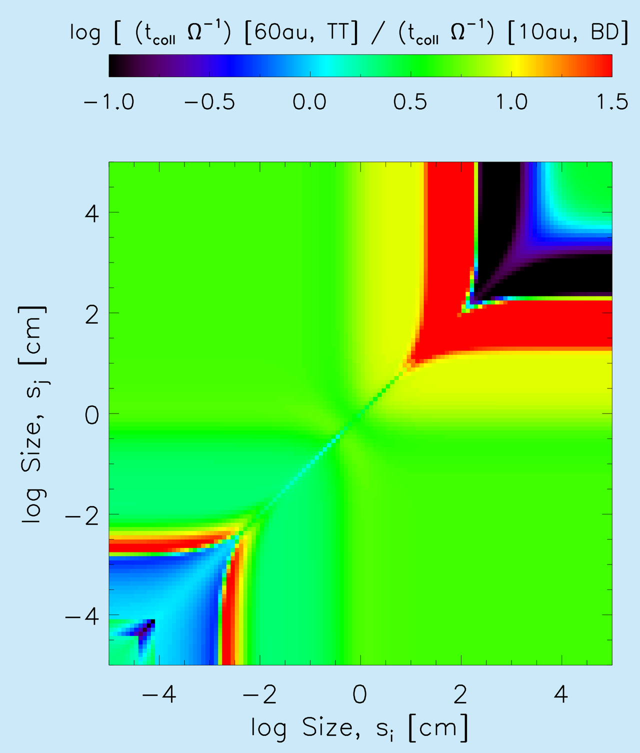
Parameter	Brown dwarf	T Tauri
M_{star}	0.06 $M_\odot$ [60 M_{Jup}]	1 $M_\odot$
M_{disc}	4 x 10^{-4} $M_\odot$	7 x 10^{-3} $M_\odot$
Disc outer radius	15 au	90 au
Simulated radius	10 au	60 au

Ricci et al (2012) used as a guide for the brown dwarf disc parameters

We simulate grain growth in brown dwarf and T Tauri discs whereby the latter is a scaled-up version (in terms of disc mass, star mass and radius) of the former - i.e. with the same disc to star mass ratio, and simulated at a location which is the same distance to the outer radius as that in the brown dwarf disc.



Surface density distribution against particle size in the brown dwarf (solid line) and T Tauri (dotted line) discs at the same time in units of the local orbital time. Growth occurs to similar sizes in both discs.



Estimate of the ratio of the collisional timescale (in units of the orbital timescale) of the T Tauri disc to that in the brown dwarf disc, for collisions between particles of sizes s_i and s_j. Growth occurs to similar sizes because the collisional timescales for most of the particle collisions are comparable (i.e. the ratio is close to unity).

Meru et al, submitted

~ Conclusions ~

We present a new model for coagulation and fragmentation that separates out the deterministic and stochastic velocities in a physically-motivated way.

With this model, growth to larger sizes is possible compared to previous studies. A robust result of our model is the existence of two particle populations: one at small and one at large sizes (also noted by Windmark et al 2012a).

Our results also suggest that if brown dwarf discs are scaled-down versions of T Tauri discs, the long-term growth is expected to occur to similar sizes. Therefore, our model has the potential to explain the large (≈ millimetre-sized) grains recently observed in brown dwarf discs (Ricci et al 2012, 2013).

These results potentially explain a long-standing problem of grain growth in T Tauri as well as brown dwarf discs: growing dust aggregates while still maintaining a population of smaller-sized aggregates that are also detected using infrared wavelength observations.

Garaud, Meru, Galvagni & Olczak, 2013; Meru et al, submitted