Planetesimal formation by gravitational collapse

Over the last twenty years, it has become increasingly apparent that planetesimals form by gravitational collapse of a dust cloud. Gravitational collapse is common in astrophysics, but the collapsing object is usually made of gas, so the leading-order force balance is usually between gravity and pressure. For planetesimals, however, most of the mass is in the form of small solids that are insensitive to pressure. The dynamics should therefore be different. For instance, we expect non-conservative effects such as drag, collisions and solid friction to play a central role.

This ‘solid-driven' regime is almost entirely unexplored, even though it is at the origin of every asteroid, comet, planet and moon in the Solar System. In particular, all papers to date rely on heavy numerical simulations. To complement those works, we are building an analytical toy model of solid-driven collapse. We have already been able to show that:

- As soon as the cloud reaches the Hill density, it cannot be eroded by the disc’s Keplerian shear or by the disc’s turbulence anymore. Indeed, it costs too much energy to lift dust out of the cloud’s potential well.
- Despite the virial theorem, the system is nearly isothermal. Indeed, heat exchanges between the gas and the solids are fast and the heat capacity of the solids is high.
- Thanks to mass loading, the turbulent cascade of the disc cannot penetrate into the cloud.

We have also been able to determine how the presence of dust modifies Jeans’ collapse criterion. Our new criterion indicates that the gas in the outer layers of the cloud is initially incompressible.

We are now trying to add rotation and collisions to the model. Once this is done, our toy model will be highly valuable. Indeed, it will provide sanity checks for the simulations, give order-of-magnitude estimates for key observables such as the initial size or porosity of planetesimals, and highlight the main differences between planetesimals formed by different mechanisms (streaming instability / turbulent concentration / dusty gravitational instability / …). This will open a new way to use the meteoritic, asteroid and cometary records to determine which planetesimal formation mechanisms were active in the early Solar system.