CONSTRAINING THEORY AND MODELLING OF PROTOPLANETARY DISCS

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Abstract Circumstellar discs around Young Stellar Objects (YSO) are of great scientific interest, since one expects there to find the precursors of planets. Most of the material on the disc is at cold temperatures and mm observations can be used to infer disc properties. The project ALMA (Atacama Large Milimeter Array) will count with the highest ever sensitivity spatial and spectral resolution in the mm constituting the key project for astronomy of cold objects on the next decades. Here we discuss on how present observational facilities allow to obtain disc properties and how this can be related with theory and models of disc formation and evolution. We explore how ALMA will help us to reduce current incertitudes in our understanding of these systems.

Keywords: Accretion, protoplanetary discs

1. Introduction

Discs are formed in early phases of stellar formation when a molecular cloud collapses to a protostar. Conservation of angular momentum does not allow the material to fall directly into the protostar but to fall into a plan perpendicular to the rotation of the cloud forming a circumstellar disc. The star and disc system are formed in a typical timescale of 10^5 yr. The evolution of protoplanetary discs is governed by the mechanisms able to transport the angular momentum. The very first stage of disc evolution ($10^4 - 10^5$ yr) is strongly affected by gravitational global instabilities producing irregular accretion and spiral patterns. When the star has accreted enough material, its gravity and its radiated heat break the gravitational instabilities of the disc. Further evolution is produced by turbulent exchange of angular momentum caused by some kind of fluid instability. This takes a much longer time ($10^6 - 10^7$ yr) and is probably the phase where planets are built.

Two different mechanisms for producing global turbulence in a disc have been proposed (and strongly defended by their advocates against the other). The classical, and widely accepted, mechanism is magneto-rotational linear instability, proposed on theoretical grounds (Balbus and Hawley 1991). The other possibility is non-linear instability, produced by differential rotation on the disc. This was proposed on view of laboratory experiments over differential rotation on fluid tanks (Richard and Zahn 1999) and on theoretical considerations over turbulence in discs (Dubrulle 1993).

The final evolution of the disc is governed by dissipative mechanisms such as solar wind, photoevaporation of the disc, mass lost by planetary formation and gravitational perturbations by nearby stars.

2. Observations of protoplanetary discs

With present state of art observational facilities, like the *Plateau the Bure*, it is possible to obtain maps of mass and temperature distribution, rotational velocity, disk extension and other parameters for close-in systems like those situated on the Taurus-Auriga region (Dutrey et al 98, Guilloteau et al 98). These observations were used by our team to compare the present state of two well known systems, DM Tau and GM Aur, with parameterized models of disc formation and evolution (Hueso and Guillot 2002). We considered gravitational collapse of molecular clouds following the classical solution of Shu (1977) and integrated the star-disc formation equation by angular momentum conservation (Cassen and Moosman 1981) and the disc evolution by viscous diffusion following and α prescription for viscosity, supposed to be representative of magnetorotational instabilities (Shakura and Sunyaev 1973, Pringle 1981). We also tested a β prescription representative of non-linear fluid instabilities (Dubrulle 1993). Results for DM Tau in the α prescription are summarized on Figure 1. This case behaves as a typical accretion disc with typical values of $\alpha \sim 0.01$ and reasonable values of the initial conditions of the molecular clouds. Similarly, solutions with the β prescription were also found.

Details of the models made Hueso and Guillot (2002) suggest the presence of a forming protoplanet on GM Aur (mainly the low accretion rate of the disc and its high mass content). Other authors have recently informed of the detection of an inner gap on the GM Aur disc (Sargent 2001), which should be caused by an inner forming protoplanet.

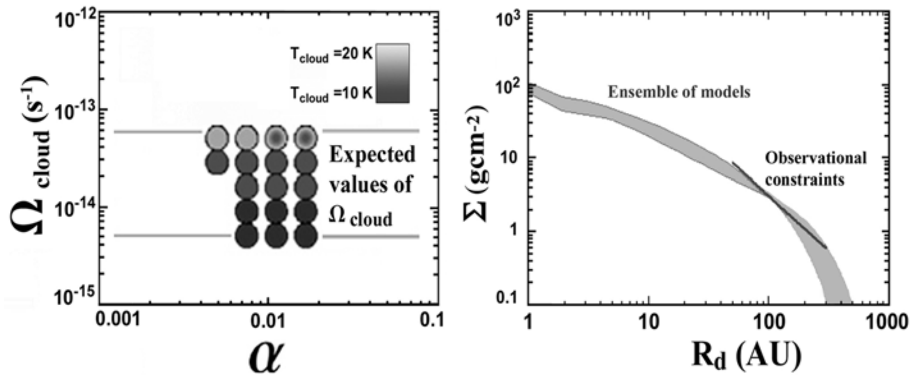

Figure 1. Fitting models for DM Tau with an α prescription for turbulence. Ω_{cloud} is the rotational frequency of the initial molecular cloud, which determines disk size, and T_{cloud} is the cloud temperature, governing the accretion rate over the disc on the collapse models. On the right we present a comparison of density surface from the models and the observations.

Statistics over the number of discs present at different star formation regions with different ages and covering several spectral types begin to be available (Haisch et al 2001) but still lack information over the more evolved and cool discs.

3. The role of ALMA

ALMA will provide the first images of the mass distribution inside protosolar-like nebulae. Relevant properties that could be examined include size, temperature, dust density and chemistry. If we think on terms of spatial resolution of its observations it will achieve 0.01" resolution at 1 mm wavelength. For nearby discs such as DM Tau and GM Aur, both at distances of 150 pc, it will obtain spatial resolution on the order of 2 AU. For the first time, direct images of the inner accreting region, where planetary formation is expected to occur, will be obtained.

The highest sensitivity of ALMA will also allow to study the distant parts of the disc. This is very interesting because it is there where the Σ surface density profile is most sensitive to the particular mechanism feeding the turbulence. For instance, present observations can be explained by scenarios where magnetorotational instabilities and non-linear fluid shear instabilities are the cause of the turbulence. This two scenarios produce different disc properties at large radius (Rd > 300 AU). ALMA will be able to discriminate between both possibilities and will teach us about the details of the turbulence.

ALMA will also provide strong constraints on the dust distribution over the disc and the dust size distribution. We will also be able to "see" most of the gaps on the nearby protoplanetary discs making statistics of giant planets appearance possible.

4. Conclusions

ALMA will resolve fine details on small scales on nearby accretion disks. It will help to understand how these discs are created from collapsing molecular clouds and which mechanisms make the discs evolve. We will have images of the planet formation regions in the disc together with particle size information for discs of different ages. For the more distant and numerous discs ALMA will be of great help in detecting the discs on more evolved objects making good statistics of evolved discs and teaching us about disc dissipation mechanisms. Other nearby projects, like the planned European Space Agency Herschel mission, will also provide more details of the initial conditions of protostar and disk formation helping to answer open questions on this subject.

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