PRE-MAIN SEQUENCE ROTATING STELLAR MODELS SIMULATING THE DISK-LOCKING MECHANISM.

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Abstract In this work we present our recent rotating models including a regulation mechanism for the stellar angular velocity during the early stages of pre-main sequence evolution. We assume that the disk-locking mechanism is the responsible for the very characteristic distribution of observed rotational periods of T Tauri stars. We consider a range of disk lifetimes and use our theoretical predictions to analyze the rotational properties of the Orion Nebula Cluster (ONC) stars, which were found to vary considerably with mass.

keywords stars: evolution, stars: low-mass, stars: pre–main-sequence, stars: rotation, accretion disks

1 Introduction

It is well known that rotational periods of T Tauri stars show a very characteristic distribution. Classical T Tauri stars (CTTS) have a narrow period distribution, peaked at about 8 days. Weak T Tauri stars (WTTS) have a much broader distribution, with some stars showing lower rotational periods by a factor of 4 relative to those presented by CTTS. These observations suggest that T Tauri stars in accretion disk systems are subjected to a regulation of their angular velocities, countering the tendency to spin up both from accretion of disk material of high specific angular momentum and from readjustments in momentum of inertia as they contract toward the main sequence.

The introduction of rotation in the ATON 2.3 stellar evolutionary code makes possible to explore the physical mechanism which apparently maintain the stellar angular velocity constant.

As an example of such explorations, we present our new rotating evolutionary tracks, including the disk-locking mechanism as a plausible explanation for the rotational evolution of pre-main sequence stars. We consider a range of disk lifetimes and use our theoretical predictions to analyze the rotational properties of the Orion Nebula Cluster (ONC) stars, which were found to vary considerably with mass. Stars with masses larger than a threshold value, have a clear bimodal period distribution (which peaks $\sim$ 2 and 8 days), while the less massive sample contains only a tail of slow rotators. Assuming that disk-locking is responsible for the peak at 8 days, we investigate the role of disk lifetimes on the rotational evolution of ONC stars.

2 Models

In this section we breafly present the version of the ATON code used in this work and show how we introduced the effect of the presence of an accretion disk in CTTS. The evolutionary tracks was computed in the mass range of 0.085-0.8 $M_\odot$. The solar chemical composition was adopted (Y=0.27 and Z=0.0175). We used Allard & Hauschildt (1997) and Allard et al. (2000) boundary conditions. Convection was treated by using the classical Mixing Length Theory (MLT), with α=2.0. As the most of ONC stars are low-mass pre-main sequence stars, we assumed rigid body rotation. We used Iglesias & Rogers (1993) and Alexander & Ferguson (1994) opacities and Rogers et al. (1996) and Mihalas et al. (1988) equations of state. For more details see Landin et al. (2006).

The version of ATON code presented above, was used to include the possibility of evolving the stars simulating the presence of a disk by keeping constant their angular velocity during the early stages of pre-main sequence. We consider three different disk lifetimes: 0.5, 1 e 3 Myr. Based on these disk lifetimes, we generated three sets of evolutionary tracks taking into account the disk-locking mechanism. These sets of models is compared with that considering constant angular momentum evolution since the beginning.

3 ONC STARS

In order to study the angular momentum evolution in pre-MS phase, we compare our sets of evolutionary tracks with observational data of the ONC stars.

Fig. (1) shows the mass distribution of the observed stars, obtained by using three sets of models. The resulting mass distribution of the bulk of the ONC population is in the range 0.2-0.4 $M_\odot$.

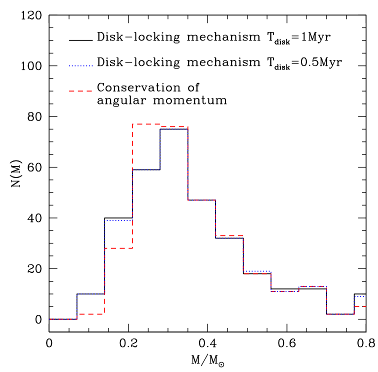

Figure 1: Mass histogram of ONC.

Fig. (2) presents the age distribution of our ONC star sample. The age function peaks at the same age ($\sim$ 1 Myr) for all models and they have roughly the same age distribution.

ONC period distribution presents two main features: bimodality and dichotomy. Bimodality is characterized by the presence of two peaks in the period distribution. Dichotomy, which is related to bimodality, is the dependence on mass of the

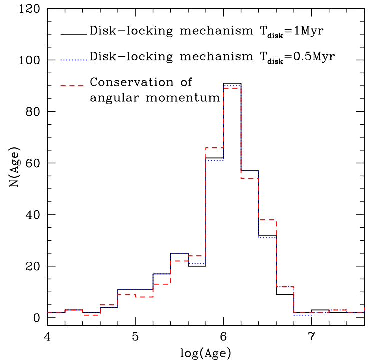

Figure 2: Age histogram of ONC.

rotational properties, i.e., the different behavior of the period distribution exhibited by lower and higher mass objects. Stars with masses greater than a given threshold (that we called transition mass - M_{tr}) present a bimodal distribution. Stars with masses smaller than M_{tr} have only a tail of slow rotators. For the models presented here M_{tr}=0.3 $M_{\odot}$ (Fig. 3). Landin et al. (2006) used the observed rotational periods of the ONC stars to establish a criterion of presence of disk. Stars with $P > P_{thresh}$ (=8 days) are still locked (Herbst et al., 2002). For stars with $P < P_{thresh}$ (unlocked) they determined the epoch at which their period were equal to 8 days. This would be the time at which the stars would have lost their disks.

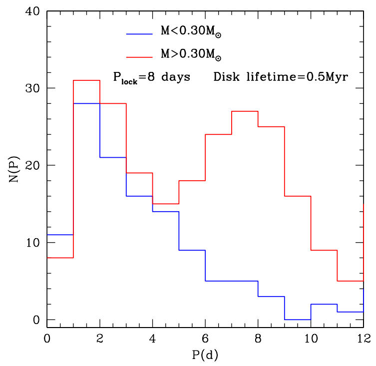

Figure 3: Period histograms of the ONC stars for lower and higher mass stars.

In this way, they identified three distinct populations:
i) early fast rotators – stars locked only for ages $<10^5$ yr;
ii) slow rotators – stars probably still disk embedded;
iii) moderate rotators.

This criterion of presence of disk is in agreement with observed infrared excesses. According to Landin et al. (2006), the evolution of the early fast rotators is consistent with an evolution conserving angular momentum from the beginning. To fully bracket the observed periods it is necessary to assume a distribution of initial angular momenta $J_{\rm in}$, at least, in the range $J_{\rm kaw} < J_{\rm in} < 3J_{\rm kaw}$ ($J_{\rm kaw}$ is described by the prescription of Kawaler, 1987).

4 Results

In this work we test the hypothesis that there exist a mechanism preventing the stellar spinning up. To accomplish this goal, we used the objects that Landin et al. (2006) classified as moderate rotators. In Fig. (4) we show them in the P vs. inferred age plane. We assumed that these objects had a disk during an earlier evolutionary stage. In a given epoch they lose their disk and, after that, began a constant angular momentum evolution.

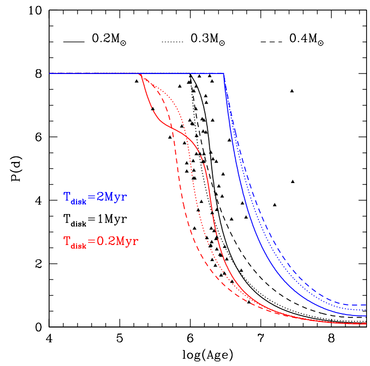

Figure 4: Temporal evolution of the periods of our models. We show also the stars classified as "moderate rotators".

We present only three mass models in Fig. (4) because they represent the bulk of ONC population (0.2-0.4 $M_{\odot}$). We can note from this figure that our theoretical curves reproduce the observed loci of our slow rotators sample. The full distribution is reproduced by using a range of disk lifetimes (0.2–3 Myr).

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