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The RACE-OC project: Rotation and ACtivity Evolution in Open Clusters

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Abstract. The RACE-OC (Rotation and ACtivity Evolution in Open Clusters) is a project aimed at studying the evolution of rotation and magnetic activity of the late-type members belonging to open clusters with an age in the range from about 1 to 500 Myr. In late-type stars rotation and solar-like magnetic activity are closely inter-related. In fact, presence and level of stellar magnetic activity depend on rotation. On the other hand, magnetic activity influences the evolution of the angular momentum and determines the atmospheric structure from the PMS to Post-MS evolutionary stages (Dorren & Guinan Dorren (1994); Guinan et al. Guinan (2001)). Studies of the rotation and magnetic activity evolution versus time are particularly relevant to 1) determine the radiative and magnetic properties of the young Sun; 2) study its evolution history to the present; 3) construct irradiance tables to be used to model paleo-planetary atmospheres. Our aim is to describe the evolution versus time of either the stellar angular momentum and magnetic activity, by inferring from observational data accurate empirical relations between global stellar properties, rotation and activity manifestations at different atmospheric levels to be compared to current stellar evolution and hydromagnetic dynamo models. The multiband CCD photometric observations have been so far carried out with the 0.6m REM (Rapid Eye Mount) telescope (La Silla, Chile) of INAF; the 2m HCT (Himalayan Chandra Telescope) of IIA, the 1.3m Cassegrain telescope of Skinakas Observatory (University of Crete) and, finally, the 1.3m RCT (Robotic Controlled Telescope, Arizona) of Villanova University.

Key words. Stars: atmospheres – Stars: magnetic activity – Stars: open clusters – Star: late-type – Stars: rotation

1. Introduction

Open stellar clusters represent privileged astrophysical targets since they provide complete and homogeneous stellar samples to explore a variety of topics of relevant astrophysical impact. The sample homogeneity arises from the fact that all cluster members were formed in the same environment conditions and are characterized by the same age and initial chemical composition. Homogeneous and complete stellar samples are very important, since they allow us to accurately investigate those stellar properties, and their mutual relations, which depend on age and metallicity (such as the luminosity-mass relation, the stellar angular momentum, the element mixing). Indeed, stel-

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lar samples from open clusters of different ages turn out to be best suited to investigate the evolution of the mentioned stellar properties vs. time and their inter-relations (e.g. Messina et al. Messina (2001)).

2. Evolution of angular momentum and activity

As mentioned, one of the basic stellar properties which depend on time is the angular momentum. It undergoes dramatic changes along the whole stellar life. During the pre-main sequence (PMS) phases, notwithstanding the rotation spinning up due to the gravitational contraction, all stars experience significant angular momentum losses due to the interaction with an accretion disk. During the main sequence (MS) life, the interaction of the external convective envelope in lower-mass stars with magnetized winds causes an additional loss of angular momentum and, consequently, a rotation braking (e.g. Skumanich Skumanich (1972)). Finally, during the Post-MS life, either stellar radius variations and stellar winds contribute in varying angular momentum and rotation rate (e.g., Sills et al. Sills (2000)). To date, the number of studied open clusters and of cluster members has not been large enough to fully constrain the models which explain the mechanisms which drive the angular momentum evolution. Specifically, the sequence of ages at which the angular momentum evolution has been studied still has significant gaps, as well the sample of cluster members for a number of clusters is not as complete as needed. The study of angular momentum evolution is very important also to better understand all those phenomena which directly depend on stellar rotation, such as the magnetic activity in late-type stars. The presence of photospheric cool spots and bright faculae, of chromospheric plages and X-ray emission, just to mention a few of numerous activity manifestations, all depend on the action of an hydromagnetic dynamo whose efficiency is related to the rotation rate (e.g. Messina & Guinan Messina (2002), Messina (2003); Randich Randich (2000)). As far as the stellar rotation regime varies, the level of magnetic activity consequently varies. On the other hand, magnetic activity, as mentioned, plays a fundamental role in the angular momentum evolution of late-type stars and represent a powerful tool to probe the stellar internal structure. Magnetic fields are believed to play a key role in the distribution of the mass moment of inertia by coupling the radiative core with the external convection zone (e.g. Barnes Barnes (2003)). Thus, the study of angular momentum and magnetic activity are two complementary approaches to the same problem. Knowledge of the evolution of both rotation and activity, specifically in solar-type stars, is particularly challenging, since it allows us to track the evolution of the radiative and magnetic properties of the young Sun and to construct irradiance tables to be used to model paleo-planetary atmospheres (Ribas et al. Ribas (2005)).

3. The RACE-OC project

3.1. Participants

The project is leaded by the Catania Astrophysical Observatory of the Italian National Institute for Astrophysics (INAF-OACt). To this project also participate the Indian Institute for Astrophysics (IIA, India), the Villanova University (PA, USA) and the University of Crete (Greece). The multiband CCD photometric observations have been so far carried out with the 0.6m REM (Rapid Eye Mount) telescope (La Silla, Chile) of INAF, which is used to observe the southern clusters; the 2m HCT (Himalayan Chandra Telescope) of IIA, the 1.3m Cassegrain telescope of Skinakas Observatory (Crete) and, finally, the 1.3m RCT (Robotic Controlled Telescope, Arizona) of Villanova University. Starting from 2008, we plan to use also the new robotic 0.8m APT80/2 telescope of INAF-OACt. This telescope, which is currently in commissioning phase, is located in the mountain station "M.G. Fracastoro" (Etna, 1725m a.s.l.) of INAF-OACt. Two research groups at the University of Victoria (Canada) and the Korea Astronomy & Space Science Institute (Korea) also joined to this project contributing with

Table 1. List of open clusters studied by the RACE-OC project

Cluster	RA(2000.0)	DEC (2000.0)	Age (Myr)
ONC	05 35	−05 29	1
NGC 3572	11 10	−60 15	7
NGC 1893	05 22	+33 25	10
NGC 1502	04 07	+62 20	11
NGC 3766	11 36	−61 36	14
NGC 6716	18 55	−22 42	90
NGC 2516	07 58	−60 45	112
NGC 7243	22 15	+49 54	114
Pleiades	03 47	+24 07	130
NGC 7086	21 30	+51 35	140
NGC 2374	07 23	−13 16	290
NGC 2099	05 52	+32 33	350
NGC 6633	18 27	+06 34	425

data on the open clusters NGC 7086 and NGC 2099, respectively.

3.2. The cluster sample

The cluster sample currently consists of 13 open clusters. We selected clusters with an age in the range from about 1 to 500 Myr and for which neither rotation nor activity investigation has been so far carried out. That was done to fill the age gaps in the current empirical description of the age-activity-rotation relationship. Nonetheless, we have also included well-studied clusters, such as the Pleiades or NGC6633. In fact, one of our aims is to study the magnetic activity on a long-term time scales (years) in order to investigate the existence of starspot cycles and evidence from photometry of Surface Differential Rotation (SDR) at different evolutionary stages. Thus, even for the well studied clusters, we plan to extend the currently available photometric databases to cover several observing seasons. We selected clusters with an angular size smaller than 10 arcmin, which is the FoV of all mentioned telescopes. However, there are a few clusters of larger size for which we observe a mosaic of FoVs, notwithstanding a much larger amount of observation time is needed. We have selected a number of clusters of similar age also to investigate whether, apart from age, also different environment conditions influence the rotational and activity properties and their evolution.

3.3. Scientific objectives

The main motivation of the RACE-OC project is to accurately study the evolution of angular momentum and magnetic activity in stars of late spectral type (Rotation and ACtivity in Open Clusters – Messina et al. Messina (2006); Distefano et al. Distefano (2006)). This project is presently based on long-term multiband CCD photometric observations of a sample of open stellar clusters of different ages ranging from about 1 to 500 Myr.

The primary objectives of the project are:

- the determination of the cluster members. As a first step, multicolor photometry of the target clusters is being obtained to get a sample of candidate members complete down to main-sequence late M-type stars. The candidate members are selected from color-magnitude diagrams. Then, follow-up spectroscopic observations will be carried out to confirm their membership.

- the determination of the distribution of rotational periods of the cluster late-type members. The rotation period is determined from the periodic light variation induced by the presence of uneven spotted regions on the stellar photosphere. Scargle-Press periodograms as well the CLEAN algorithm are used to infer the rotation period (Scargle Scargle (1982); Horne & Baliunas Horne (1986); Roberts et al. Roberts (1987)).
- the characterization of the magnetic activity from the photosphere to the upper atmospheric layers. The properties of photospheric spotted regions are inferred by using spot models (e.g. Lanza et al. **?**)). The magnetic structures in chromosphere and corona will be investigated by carrying out possibly simultaneous optical spectroscopy and satellite observation in the X-ray band.
- the determination of accurate empirical inter-relationships among period, magnetic activity indicators, age and global stellar parameters to be compared to current models of internal stellar structures, evolution and hydro-magnetic dynamos.

3.4. Data reduction

The huge amount of photometric data collected by the CCD imager at the HCT telescope during the present project of monitoring required a fully automated approach to the reduction and analysis procedures. To this end, we are developing a pipeline, making use of IRAF, DAOPHOT II and tasks build up by us, which will enable to: (1) automatically correct for bias and flat field; (2) automatically generate a stellar object list and transform all frames to a common reference frame; (3) extract differential magnitude time series of any object in the object list. Both aperture and PSF photometry methods are used to build a proper sample of comparison stars, with the best method between the two being automatically selected as the one that provides the highest photometric accuracy.

3.5. The current status

The project has started at the beginning of 2005 and so far has been carried out with the use of the REM telescope to observe the southern clusters NGC2374, NGC3572, NGC3766 and NGC2516 (currently under observation); of HCT to observe ONC and the Pleiades. For these clusters the multicolor photometric observations have allowed us to: a) select a list of candidate members from magnitude-color and color-color diagrams; b) derive their rotational period and level of magnetic activity in photosphere. The next step will be to confirm cluster membership for selected candidates and to extend the study of magnetic activity to the atmospheric upper layers.

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