The rotation of low mass stars at 30 Myr in the cluster NGC 3766

Julia Roquette[1] [ORCID]**, Jerome Bouvier[2], Estelle Moraux[2], Herve Bouy[3], Jonathan Irwin[4], Suzanne Aigrain[5] and Régis Lachaume[6,7]**

[1]Department of Physics and Astronomy, University of Exeter, Physics Building, Stocker Road, Exeter, EX4 4QL, United Kingdom
email: jt574@exeter.ac.uk

[2]Univ. Grenoble Alpes, CNRS IPAG, F-38000 Grenoble, France

[3]Laboratoire d'astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy Saint-Hilaire, 33615 Pessac, France.

[4]Smithsonian Astrophysical Observatory 60 Garden Street Cambridge, MA 02138 USA

[5]Department of Physics, University of Oxford, Keble Road, OX3 1RH, UK

[6]Instituto de Astronomía, Facultad de Física, PUC-Chile, casilla 306, Santiago 22, Chile

[7]Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

Abstract. Together with the stellar rotation, the spotted surfaces of low-mass magnetically active stars produce modulations in their brightness. These modulations can be resolved by photometric variability surveys, allowing direct measurements of stellar spin rates. In this proceedings, we present results of a multisite photometric survey dedicated to the measurement of spin rates in the 30 Myr cluster NGC 3766. Inside the framework of the Monitor Project, the cluster was monitored during 2014 in the i-band by the Wide Field Imager at the MPG/ESO 2.2-m telescope. Data from Gaia-DR2 and *grizY* photometry from DECam/CTIO were used to identify cluster members. We present spin rates measured for ∼200 cluster members.

**Keywords.** stars: low-mass, brown dwarfs, stars: pre–main-sequence, stars: rotation, stars: spots

1. Introduction

Along with the mass and initial composition, angular momentum is a fundamental stellar property, and it has a direct influence in the stellar structure, close environment, magnetic field, and their evolution with time. Inside the context of the angular momentum evolution of low mass stars, it is relatively well understood, from both models and observations, that once pre-main-sequence (PMS) stars lose their disks, they follow a spin-up phase, which is later followed by a decrease of their spin rates with age. Even though tenths of thousands of rotational periods for stars of all ages have been measured in the past decades, very few data is available for stars with ages around 20−40 Myr. Filling this age gap may help us better understand the end of the PMS spin-up phase.

In this ongoing study, we are working on measuring spin rates for low mass stars in the 30 Myrs old open cluster NGC 3766. With a higher mass population of more than 200 B-type stars, NGC 3766 is at a distance of ∼2kpc (dM = 11.8 in our estimation with Gaia DR2 data) and has a moderate extinction of E(B-V) = 0.22 (Aidelman *et al.* 2012).
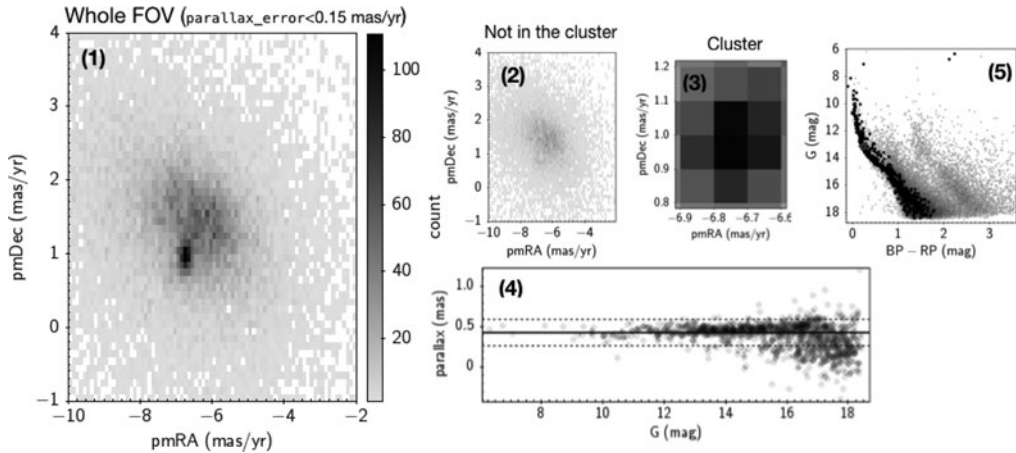
Figure 1. Panels **(1)** to **(3)** show Gaia DR2 proper motion diagrams with: **(1)** data for the whole field of view observed by WFI@ESO; **(2)** non-cluster members, and **(3)** selection of cluster members done using a squared-box. The sources selected inside the squared-box in **(3)** had their parallaxes values plotted as a function of G magnitude and are shown in panel **(4)**. Continuous and dashed black lines show median and 1σ values, which were used as a cut to clean member selection in **(3)**. Panel **(5)** shows a Gaia colour-magnitude diagram (CMD) with selected cluster members (black dots).The Gaia DR2 data used include the same cuts for high-quality astrometric data as in CG18, but we did not make any cut for the magnitude of fainter stars.

2. Data Analysis

2.1. *Dataset*

NGC 3766 was observed during 2014 inside the framework of the Monitor Project. *WFI-dataset*: It was monitored in the i-band by the Wide Field Imager at the MPG/ESO 2.2-m telescope at La Silla in Chile, with a total of 402 exposures of 300 s in the i Sloan band, carried out in 20 nights between May 6 and Jun. 29, and spanning 54 nights. Light-curves were created as in Irwin *et al.* (2007). *CTIO-dataset:* Additional single-epoch *grizY* data were obtained from DECam/CTIO archive. We also used Gaia DR2 astrometric data.

2.2. *Membership evaluation*

Brighter members down to $\sim$1 M$\odot$ were previously identified in proper motion studies by Yadav *et al.* (2013, hereafter Y13) and Cantat-Gaudin *et al.* (2018, Gaia DR2 study, hereafter CG18). Y13 gives 274 members with $P_{\mathrm{memb}} > 70\%$ and *WFI-data*, and CG18 gives 57 members with $P_{\mathrm{memb}} > 70\%$ and *WFI-data*. The two combined give a list of 327 good member candidates with valid light-curve in the *WFI-dataset*.

We used Gaia DR2 data to complement the list of members, identify likely background and foreground stars and eliminate those from the posterior analysis. Figure 1 shows the steps followed to distinguish possible members from non-members. The procedure selects 231 member candidates shown in Figure 1 **(5)**: 51 of which were also identified by CG18 or Y13, 60 were new member candidates with $G > 16$ mag, but 120 member-candidates from Y13 and CG18 that had P_{memb} in the range $10-70\%$ were reintroduced to the list. Those were flagged but kept in the member-candidate list. The combination of the selection of members in Figure 1 with previously identified members accounts for a list of 507 member candidates. In the remaining text, we refer to this sample as *Proper Motion Members*. The selection of background and foreground sources in Figure 1 **(2)** accounts for 14,402 sources eliminated from the *WFI-dataset*.
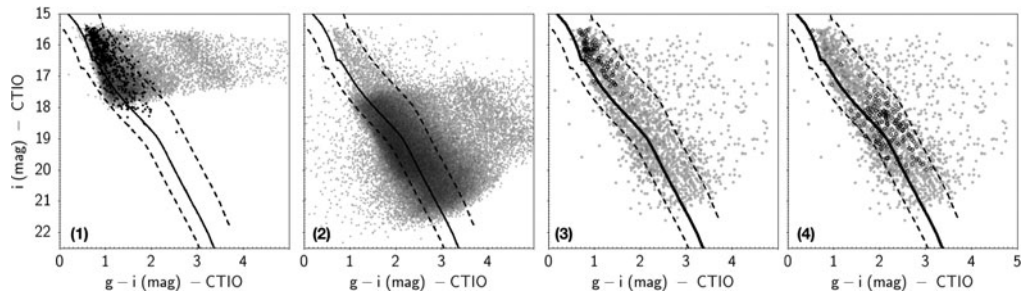
Figure 2. Example of *gi*-CMD built with the *CTIO-dataset* and used for identifying cluster members. Panel **(1)**: all sources with WFI light-curve and with good quality Gaia DR2 data are shown as grey dots, dark dots show the position of the *Proper Motion Members* including literature members and also those Figure 1. Panel **(2)**: sources with WFI light-curve and without Gaia DR2 data are shown as grey dots; Panel **(3)**: Gray dots show sources from (1) that showed periodic variability in their WFI-light-curves. *Proper Motion Members* that were also periodic are shown as black circles. Panel **(4)**: Gray dots show sources from (2) that showed periodic variability in their WFI-light-curves. Black circles show *Photometry member candidates* that were also periodic. The bold line shows a MESA 30 Myrs isochrone at cluster distance and median reddening. The dashed lines show the shifted isochrones used for selecting member-candidates. *Photometry member candidates* were selected based on their position between the dashed line in multiple colour-diagrams.

Fainter members of NGC 3766 were identified based on their position in the cluster loci in the colour-space. Figure 2 shows some of the steps followed: We built CMDs for various sets of colours ($grizY$) from our *CTIO-dataset*. We split each CMD diagram into two samples: 1- a sample of sources that had good quality data in Gaia DR2 (Figure 2 **(1)**), and 2- a sample of sources without counterpart in Gaia (Figure 2 **(2)**). In 1- we only consider as members those sources that were *Proper Motion Members*, and we ruled out the sample of stars that were not in the cluster according to their proper motion and parallax. For the data in 2-, we used a MESA 30 Myrs isochrone to identify the position of the Cluster sequence in the CMD, at the distance and median reddening of NGC3766: we then shifted this isochrone by ± 0.25mag in each axis, plus 0.75 mag in the y-axis, and we selected member candidates sources that fell in between the shifted isochrones. A source was considered as a good photometric member candidate if this procedure selected it in several of the CMD for the $grizY$ colours.

2.3. *Time-series analysis*

To select periodic stars, we initially used a combination of Lomb-Scargle Periodogram (Lomb 1976; Scargle 1982), String-Length statistics Clarke (2002) and Saunder-Statistics (Saunders *et al.* 2006) and visual inspection of light-curves and periodograms. The left panel in Figure 3 shows a distribution of the power of maximum peak in the Lomb-Scargle periodogram as a function of period.

3. A first glimpse of the rotational scenario in NGC 3766

Among cluster members, we measured possible spin rates for 289: 221 of which are associated with member candidates identified with photometry only and 68 are associated with member candidates identified by proper motion studies. Figure 3 shows the current period distribution and period-colour diagram for our sample. The period distributions seem to have intermediate characteristics between those in the period distribution for the 13 Myr old hPer (Moraux *et al.* 2013) and the 40 Myr old NGC 2547 (Irwin *et al.* 2008).
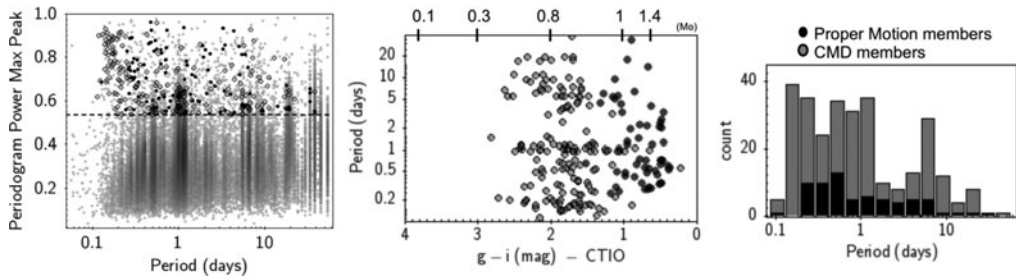
Figure 3. *Left:* Distribution of the power of the highest peak in the periodogram shown as a function of the highest peak period for each source with valid light-curve in the *WFI-dataset*. The dashed line shows the power for a False Alarm Probability of 0.01. Members from astrometry selected as periodic are shown as full black circles and member candidates selected in the CMD of Figure 2 that were periodic are shown as black circles with a grey filling. Period-colour (mass) diagram (*middle*) and Period distribution (*left*) are shown for the 68 proper motion members and for the 221 CMD members.

3.1. *Conclusions and Future work*

The period distributions in Figure 3 still show an excess of stars with periods around 1 day, which are likely aliases. Ongoing analysis of the light-curves with the fast-χ^2 method Palmer (2009) will help to improve the contamination due to the 1 day aliases. Ongoing completeness analysis and mass derivation will complement the results. A comparison with other well studied young clusters will help to contextualise the results inside the observational and theoretical scenario for the rotational evolution of young stars.

References

Aidelman, Y., Cidale, L. S., Zorec, J., *et al.* 2012, *A&A*, 544, A6
Cantat-Gaudin, T., Jordi, C., Vallenari, A., *et al.* 2018, *A&A*, 618, A93
Clarke, D. 2002, *A&A*, 386, 763
Irwin, J., Irwin, M., Aigrain, S., *et al.* 2007, *MNRAS*, 375, 1449
Irwin, J., Hodgkin, S., Aigrain, S., *et al.* 2008, *MNRAS*, 383, 1588
Lomb, N. R. 1976, *Ap&SS*, 39, 447
Moraux, E., Artemenko, S., Bouvier, J., *et al.* 2013, *A&A*, 560, A13
Palmer, D. M. 2009, *ApJ*, 695, 496
Saunders, E. S., Naylor, T., & Allan, A. 2006, *Astronomische Nachrichten*, 327, 783
Scargle, J. D. 1982, *ApJ*, 263, 835
Yadav, R. K. S., Sariya, D. P., & Sagar, R. 2013, *MNRAS*, 430, 3350