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Stellar Rotation and Disks in the Orion Nebula Cluster

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Abstract.

The new Wide Field Imager attached to the MPG/ESO 2.2 m telescope on La Silla, Chile, has been used to monitor ~2000 stars in the Orion Nebula Cluster (ONC) at 815 nm on 45 nights between 25 Dec 1998 and 28 Feb 1999. Over 400 periodic variables have been found, most or all of which are rotating, spotted T Tauri stars (TTS), more than doubling the number of known rotation periods for cluster members. Masses and ages are available for 335 of these from the literature. We confirm the existence of a bimodal period distribution for stars with M > 0.25 $M_\odot$. A surprising new result is that stars of lower mass tend to rotate faster than higher mass stars, perhaps indicating that their disks have dissipated more rapidly in the harsh cluster environment. In the mass range 0.1 - 1 $M_\odot$ between 40% and 80% of the stars have the variability characteristics of weak-line TTS (WTTS), suggesting that the half-life for accretion disks is ~1 Myr in this cluster and probaby even smaller for the lower mass stars.

1. Introduction and Observations

The Orion Nebula Cluster (ONC) is an excellent target for star formation studies since it contains thousands of pre-main sequence (PMS) stars within ~2 pc of the central Trapezium stars (Herbig & Terndrup 1986; Hillenbrand & Hartmann 1998). The age of the cluster is ~1 My and it has a range of masses from ~25 $M_\odot$ (for Θ^1 C Ori) down to well below the Hydrogen-burning limit (0.075 $M_\odot$) and perhaps even below the Deuterium-burning limit of ~0.01 $M_\odot$ (Hillenbrand 1997, Lucas and Roche 1999). Being relatively nearby, its PMS stars are still relatively bright and not heavily embedded since much of the dust within the cluster has been cleared by radiation pressure and winds from the massive stars. Photometric rotation studies have been on-going since the pioneering work of Mandel & Herbst (1991) and recently culminated in two extensive studies (Stassun et al. 1999 and Herbst et al. 2000). An important issue of relevance to this Symposium is whether the rotation period distribution in the ONC is bimodal.

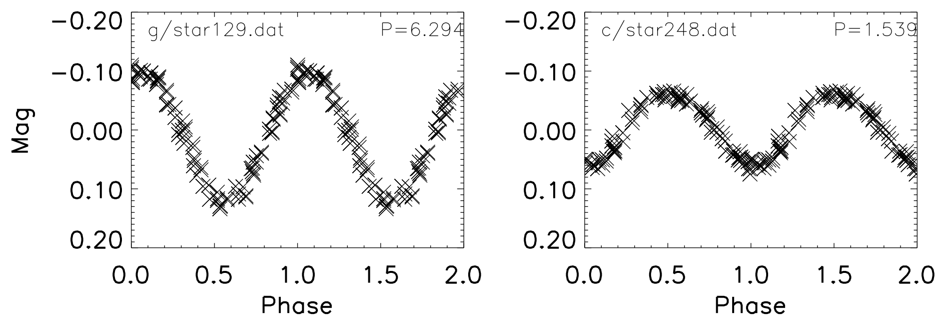

Figure 1. Two examples of periodic variables. Two cycles are shown for clarity. The period (in days) is given on each.

By more than doubling the sample of known rotation periods, the present study strongly supports the bimodal distribution providing new evidence for a disk-rotation link. Variability can further be used as an indicator of the presence of an accretion disk allowing us to assess disk frequency and survival times in the ONC. If most stars form in dense clusters then these survival times may have relevance to planet formation scenarios, setting limits on the time available for the formation of gas giants.

The WFI consists of 8 CCD's, each 2048x4096, mounted in two rows so as to produce an approximately 8Kx8K array with only small gaps. The pixel scale is 0.238″/pixel and the size of the field is 33′x 34′with only about 4% lost to the gaps. The average seeing for these observations was 0.92″(FWHM). Altogether we performed photometry on 2,294 objects. The average external deviations of comparison stars was 0.007 mag or less in all cases; this is a reasonable estimate of the precision of the photometry for stars brighter than about I = 16.5.

2. Rotation Period Versus Mass

A periodogram analysis based on the method of Scargle (1982) was used to search for periodicity in all of the monitored stars. Details are given by Herbst et al. (2001). 403 stars fulfilled our criterion to be regarded as periodic. Two examples of our light curves are shown in Fig. 1. There were 111 stars in our sample which were also reported to be periodic by either Stassun et al. (1999) or Herbst et al. (2000) or both and in all but one case our periods are consistent with one another when aliasing and period doubling are accounted for.

Herbst et al. (2000) showed that the frequency distribution of rotation periods was bimodal for stars more massive than $\sim$0.25 $M_\odot$ and unimodal for lower mass stars. This result is clearly confirmed and strengthened by this study as illustrated in Fig. 2. We interpret the long period peak among the higher mass stars as an effect of rotational breaking by their disks. A weak but significant (at the 99.3% level according to a Spearman rank-order test) correlation between rotation period and infrared excess, Δ(I-K), as computed by Hillenbrand et al. (1998), supports this view. We note, however, that most of the stars with long periods appear to be WTTS suggesting that they have

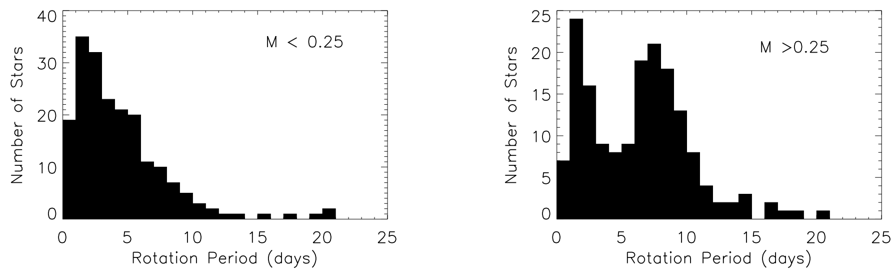

Figure 2. Histogram of periods for the lower mass stars on the left and higher mass stars on the right.

only recently lost their disks. This is consistent with the short disk lifetimes indicated by current evaporation rates from proplyds (Henney & O'Dell 1999).

3. Accretion Disk Frequencies Based on Photometric Properties

We find, based on their small variability range, periodic behavior, and lack of significant IR excess emission that no more than 60% of the stars in the mass range 0.1 - 1 $M_{\odot}$ currently have accretion disks. Since the mean age for the low mass stars is about 0.8 My (Hillenbrand 1997) this means that the half-life for accretion disks in the ONC is only ~1 My. Since reasonably substantial disks are required for the formation of gas giant planets, the timescale for forming such objects must be comparable (or less) if they are common in the Galaxy, assuming most stars form in clusters similar to the ONC. It will be interesting to see how the rotational properties of low mass stars vary with environment as other clusters and associations are studied in comparable detail.

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