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Inferring Rotation Periods of Young Stars from Synoptic Observations

Patrick Hartigan[1], **Christopher M. Johns-Krull**[1], **and Paul Scowen**[2]

[1]Dept. of Physics and Astronomy, Rice University, Houston, TX, USA
emails: `hartigan@sparky.rice.edu; cmj@rice.edu`

[2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA
email: `paul.scowen@asu.edu`

Abstract. Using known distributions for the periods, amplitudes and light-curve shapes of young stars, we examine how well one could measure periods of these objects in the upcoming era of large synoptic surveys. Surveys like the LSST should be able to recover accurate rotation periods for over 90% of targets of interest in regions near to massive-star formation. That information will usher in a new era in our understanding of how the angular momentum of a young star/disk system evolves with time.

Keywords. stars: pre-main-sequence, stars: rotation

1. Introduction

One of the main goals of star-formation research is to learn how individual stars, binaries and clusters of various masses form, evolve and disperse within a cloud. To accomplish those goals, one must first find all the young stars within a given region, including any that may have drifted away from their birthplaces, and determine their spectral types and luminosities in order to place them in an H–R diagram and to infer masses and ages of each source from a set of pre-main-sequence models. With that information one can begin to recover the history of star formation within a given region, to assess whether or not winds from the most massive stars trigger collapse within molecular cores, to observe clustering behaviour, and to understand the degree to which massive stars affect initial mass functions in star-forming regions. The addition of rotational periods for each of the objects opens up a wealth of research related to the changes in the angular momentum of the objects as they contract towards the main sequence—an area of great importance for studies of young solar systems and early stellar winds. The photometric databases required to measure rotation periods also support other areas of research, such as testing pre-main-sequence evolutionary tracks through newly-discovered eclipsing binaries, and correlating observed accretion events with the ejection of knots in stellar jets.

Unfortunately it can be quite difficult to identify all the young stars within a given area. Low-mass ($\lesssim 1.2$ M$_\odot$) young stars are classified either as classical T Tauri stars (cTTs), or as weak-lined T Tauri stars (wTTs), according to the strength of their Hα emission lines. Although cTTs are surrounded by dense accretion disks that produce strong infrared excesses, and readily stand out in near-IR colour–colour diagrams and in Hα emission surveys (Guieu *et al.* 2009), the wTTs, which dominate for clusters older than about 5 Myr (Fedele *et al.* 2010), resemble field stars in those surveys. One can identify both wTTs and cTTs via their active chromospheres and large starspots, which give rise respectively to X-ray emission and a low-amplitude quasi-periodic variability in the optical. X-ray surveys uncover many wTTs, but those efforts are limited in both areal coverage and depth.

Optical synoptic surveys such as LSST will usher in a new era in which variability should become the new standard for discovering young stars. That has the important benefit of determining periods as well, provided that the sensitivities and cadence are sufficiently high to detect the variables and to recover their periods accurately. Optical surveys are particularly attractive because the amplitudes of the optical light curves are higher than they are in the near-IR. The light curves of both wTTs and cTTs have non-periodic components, but the phases of the periodic parts of the light curves generally remain stable over the course of a year.

In this contribution we create an ensemble of typical T-Tauri light curves, and assess how well one can extract periods of those systems from a survey that has a cadence of once every three days, with an uncertainty of 0.02 mag. The parameters approximate those of LSST for $V < 19$–20 mag. Since a typical T Tauri star in a nearby star-forming region such as Orion has $V \sim 17$ mag, the parameter range is critical for studies of nearby star-forming regions as well as for more massive clusters such as Carina that are four times more distant (3 magnitudes fainter).

2. Model Parameters

To determine how well a synoptic survey will recover periods for a given class of variable stars, we must first define the period and amplitude distribution of the variables and the shapes of the light curves. For the survey we adopt a cadence of once every three days, with a standard deviation of 0.2 days, in order to mimic typical observing variations (and to help eliminate artificial aliases). We adopt a Gaussian noise of 0.02 mag in each data point, and use a Scargle method to recover periods with some false-alarm probability (FAP) (Horne & Baliunas 1986).

2.1. *Period distribution*

Classical T Tauri stars rotate somewhat more slowly than weak-lined T Tauri stars do, probably owing to the influence of the surrounding circumstellar disk. A recent survey of rotational properties of both types of T Tauri stars by Affer *et al.* (2011) shows that the combined sample of the objects exhibits a period distribution analogous to a Poisson one, with a mean of roughly 4 days. We therefore adopt a Poisson distribution with a mean of 3.5 days, and then add 0.5 days to the distribution to ensure that all stars have periods longer than 0.5 days, as defined by the observations.

2.2. *Amplitude distribution*

Amplitudes of T Tauri light curves calculated by the ROTOR programme (Grankin *et al.* 2008) peak at around 0.1 magnitude, with an extended tail to higher variability. Because the limit of the ROTOR survey was ~ 0.1 mag, we anticipate that lower-amplitude variables also exist. For the purposes of this study we adopt for the amplitudes a Poisson distribution that has a mean of 0.05 mag, and then add 0.05 mag to ensure that the mean variability is 0.1 mag, with a minimum variability of 0.05 mag.

2.3. *Light-curve shapes*

Photometric variations in weak-lined T Tauri stars are caused by starspots, with the additional complication of accretion variability present in classical T Tauri stars. By observing sources continuously from space-based platforms over the course of several weeks, the MOST (Siwak *et al.* 2011) and CoRoT satellites (Alencar *et al.* 2010) have collected dozens of high-precision light curves of T Tauri stars. The shapes tend to be either sinusoidal, or flat with a positive or negative bowl-like feature that extends over

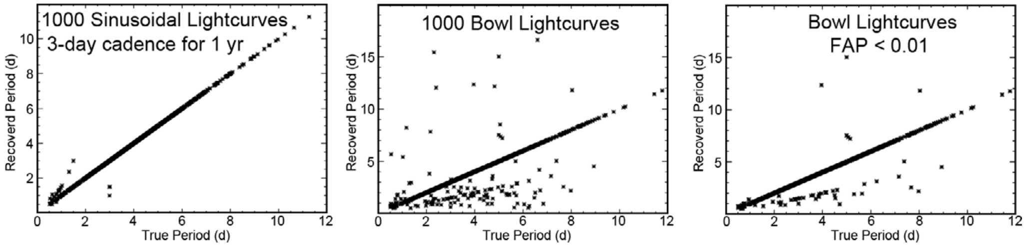

Figure 1. Recovered period vs. true period for a sample of sinusoidal (left), bowl-shaped (middle) and bowl-shaped with False Alarm Probability < 0.01 (right), assuming a 3-day cadence and one year of observing. The bowl-shaped curves are more difficult to recover than the sinusoids, but the method is highly successful in both cases.

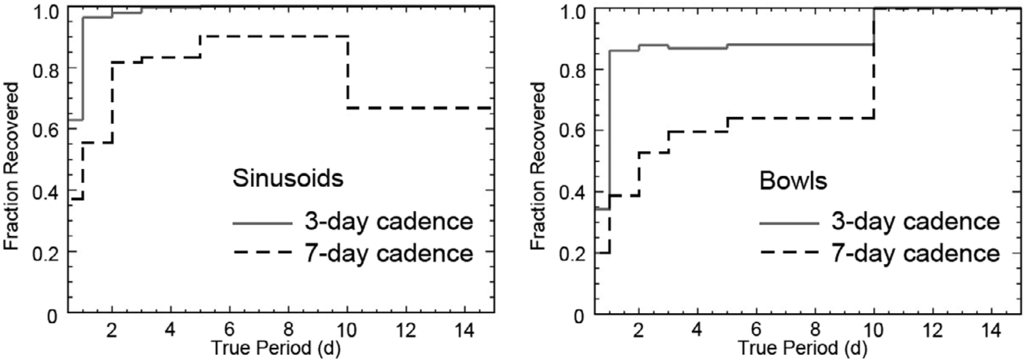

Figure 2. Fraction of periods recovered correctly for sinusoidal (left) and bowl light curves (right) for 3-day (solid line) and 7-day (dashed line) cadences over an observing period of one year. A 3-day cadence is significantly better than a 7-day one. Over 98% of sinusoidal, and 86% of bowl, light curve periods are recovered successfully with the 3-day cadence. The percentages drop to about 82% and 59% respectively, for the 7-day cadence.

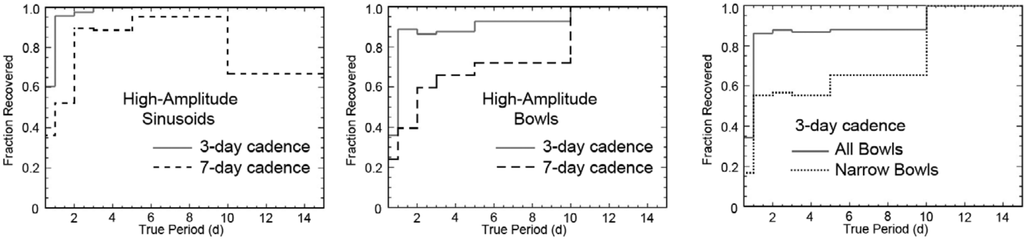

Figure 3. Left and centre: Same as Fig. 2 but restricting the sample to amplitudes greater than 0.1 mag. The method is only marginally more successful with the larger amplitude objects than it is with the entire sample. Right: The narrowest 278 bowls have a significantly higher error rate than the entire sample does.

some range of phase. We consider both sinusoids and bowl-shapes in our models. For the latter shape we use a Gaussian distribution with a FWHM chosen uniformly within the interval of 0–0.75 units of period for the bowl.

3. Results

The results of our simulations are shown in Figs. 1–3. We define a period to be recovered correctly if it is less than 1% in error. Using the parameters described above, the method recovers over 98% of the sinusoidal periods (Fig. 1, left), and 86% of the bowl curves (Fig. 1, centre). The few sinusoids which are missed tend to have periods less than about a day. The bowl light curves are somewhat more difficult to extract, although restricting the sample to those with FAP < 0.01 eliminates over half the outliers (Fig. 1, right). The erroneous bowl periods tend to be an alias that is twice the true period.

Fig. 2 shows that reducing the cadence to once every seven days significantly reduces the success rate to about 82% for the sinusoids and to about 59% for the bowls. For both types of light curve the shorter periods are more difficult to extract correctly. Comparing the large-amplitude (> 0.1 mag) curves in Fig. 3 with the entire sample in Fig. 2 shows little difference, implying that reduced amplitude is not the main source of error. However, when comparing the 278 narrowest bowls with the entire bowl sample (Fig. 3, right) we see a marked reduction in the success rate of the method at all periods. A narrow bowl resembles a shorter period, and those bowls are the most difficult to interpret correctly because the number of points with useful period information is reduced compared with sinusoids or wider bowls.

4. Summary

A survey like LSST should be extremely successful in recovering accurate periods of young stars. Using a sampling rate of about 3 days and uncertainties of 0.02 mag (easily within reach for $V \lesssim 19$ with LSST), we were able to recover the correct periods for over 90% of T-Tauri-like variable stars. The most difficult targets will be the few that have periods less than about a day, or light curves that are largely flat over a large phase interval, so the time-scale of variability is correspondingly shorter than it would be for more smoothly varying systems. A limit of $V \sim 20$ mag would reach most young stars in nearby star-forming regions like the Orion Nebula, and the all-sky nature of the survey will ensure that the distributed populations of young objects are included. The resulting dataset should revolutionize our understanding of how stellar angular momentum evolves in young clusters and associations.

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