Pulsating Pre–Main-Sequence stars in the Upper Scorpius Association

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A complete understanding of the star formation process requires the ability to predict how the properties of young stars depend on their initial conditions. Despite significant observational efforts, a key observational problem remains: that is, the reliable determination of the mass and age of the youngest pre-main-sequence (PMS) stars once they become optically visible after the main accretion phase. Among other things, stellar masses are needed to investigate the shape of the initial mass function (IMF) and its possible variations with the parent cloud properties. However, obtaining reliable stellar masses is a very difficult task. The only direct method to obtain the mass of a star is in the case of eclipsing binary systems where the solution yields individual masses of the components with great accuracy. However, these systems are rare. Lacking such a direct determination, a common procedure is to place young stars in the HR diagram and compare their position to theoretical evolutionary tracks (e.g., Hillenbrand & White 2004, ApJ 604, 741). Recently, considerable theoretical work has been done that has advanced our understanding of PMS evolution (e.g. Palla & Stahler, 1999, ApJ 525, 772; Siess et al. 2000, A&A 358, 593; Baraffe et al. 2002, A&A 382, 563). Yet, there remain differences in the tracks owing to alternative treatments of convection, opacities and the zero-point of the calculated ages, making the mass estimate of single stars still quite uncertain (at best). Without adequate observational constraints, it is nearly impossible to establish which are the correct assumptions of the different evolutionary models. Therefore, obtaining independent determinations of PMS masses and ages to constrain the corresponding evolutionary tracks is of critical importance.
In this context, intermediate-mass PMS stars (with mass in the range 1-8 $M_\odot$; also called Herbig Ae/Be stars) are particularly useful. After the seminal work by Marconi & Palla (1998, ApJ 507, L141) who established the locus of the theoretical instability strip in the HR diagram, it has become clear that these stars pulsate as δ Sct, γ Dor or hybrid δ Sct/γ Dor variables with characteristic periods of a few hours and small amplitudes (Ripepi et al. 2011, MNRAS, 416, 1535; Zwintz et al. 2014, IAU Symposium, 301, 149 and references therein). Detailed models of the varying internal structure of these stars as they contract toward the main sequence can then be compared to the pulsation frequencies detected especially through observations from satellites (Ripepi et al. 2011, Casey et al. 2013, MNRAS 428, 2596). Thus, the main goal of the study of pulsational instabilities is to obtain unique constraints on the stellar mass (and other parameters) and to test evolutionary models by deriving the internal structure using asteroseismological techniques.

Here we propose to observe 20 objects belonging to the young Upper Scorpius Association. This association has been studied in detail by de Bruijne (1999, MNRAS, 310, 585) who published photometry, distances and spectral types for the low, intermediate, and high-mass members (B to K spectral types). At a mean distance of about 145 pc, Upper Scorpius is the ideal target to investigate the whole extension of the PMS instability strip. Indeed, its member stars are sufficiently bright to acquire extremely precise Kepler photometry. They also share approximately the same distance (as inferred from the Hipparcos parallaxes), chemical composition and interstellar absorption, greatly simplifying the comparison between theory and observations. We have identified 20 PMS stars in Upper Scorpius from de Bruijne sample (all of them falling on silicon) with magnitudes 7.2–10.0 mag and spectral types between F7 to A2 which are ideal candidates for pulsation studies. We propose to observe 5 of them in short cadence as their spectral types A8-F0 locate them in the middle of the instability strip, while the remaining 15 targets should be observed in the long cadence mode. *We stress that Upper Scorpius has the largest number of pulsating candidates of all the young associations studied so far.* The superior Kepler photometry precision will allow us to reach the following goals:

- To derive the mass (as well other stellar parameters) and the internal structure for all the pulsating objects by means of asteroseismical techniques;
- To put empirical constraints on the extension of the instability strip of the young δ Sct, γ Dor or hybrid δ Sct/γ Dor variables;
- To put new and tight constraints on stellar evolutionary models of PMS stars.