Pulsation in pre-main sequence stars: TESS observations & models from accreting protostars

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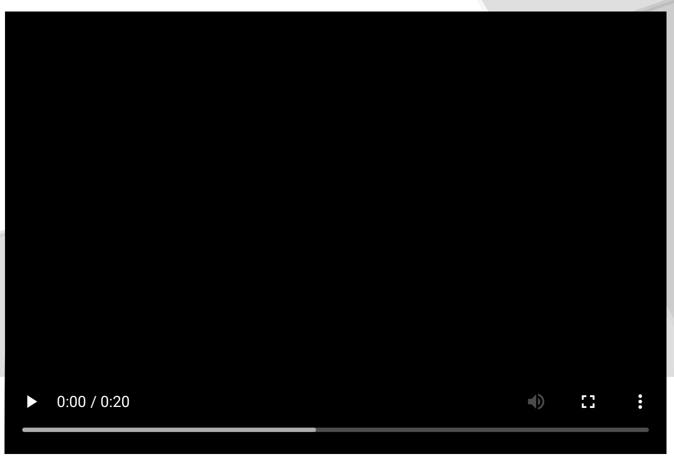
In context of stellar modelling, the pre-main sequence phase of evolution is often substantially simplified. Initial models are created with huge radii and uniform contraction to make them fully convective. These then follow the classical pre-main sequence evolution starting with a fully convective contraction along the Hayashi track. Only after the onset of thermal reaction slows the contraction will the star develope a radiative core that will continue to grow while the star evolves along the Henyey track. Before arriving at the main sequence, a first episode of hydrogen burning leads to a convective core and pauses the contraction, resulting in the well known hook in the evolutionary track.



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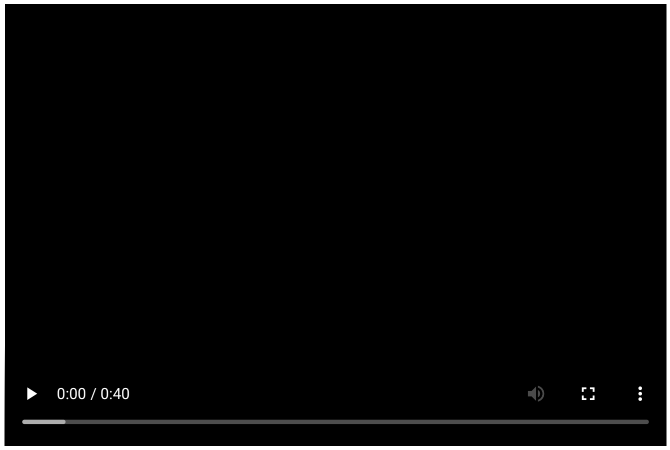
This however is far from the real processes that happen in and around newly born stars. Born in the collapse of a molecular cloud, protostellar seeds typically have a few Jupiter masses at a few solar radii. A main difference to the classical pre-main sequence evolution is that these protostellar seeds need to accrete material from their surrounding cloud/disk to obtain the same mass at the zero age main sequence. Such accreting protostars never obtain the huge radii adopted for the classical initial models. As a consequence, the evolutionary track is completely altered. The model starts at significantly lower temperatures and accretes material at a constant rate. The initially fully convective star quickly obtains a radiative part between the convective core and the convective envelope. Only during the short phase of deuterium burning will (almost) the whole star be convective again. After the model has accreted all its mass, it converges to the classical model.



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Asteroseismic studies of pre-main sequence stars have so far relied on these (unrealistic) classic models of the pre-main sequence evolution. This poster presents the first study of the pulsational instability of pre-main sequence models originating from accreting protostellar seeds (Steindl et al. 2021). This is done by calculating evolutionary models and comparing the resutling instability regions with the position of known pre-main sequence pulsators. To do so, we first aim to constrain some free parameters in the input physics with spectroscopic parameters of pre-main sequence stars including pulsating variables. We searched the literature for samples of young ZAMS and pre-main sequence stars with spectroscopic parameters and compiled a sample of pulsating variables in their pre-main sequence phase. The latter is expandend by searching for new pulsating variable stars in the TESS observations of the stellar sample. We used the short cadence pipeline data if available. Otherwise, we downloaded the Full Frame images and extracted the long cadence light curve.

Lucky Example: Short Cadence Data | A bit more work: Extracting the light curves from Full Frame Images

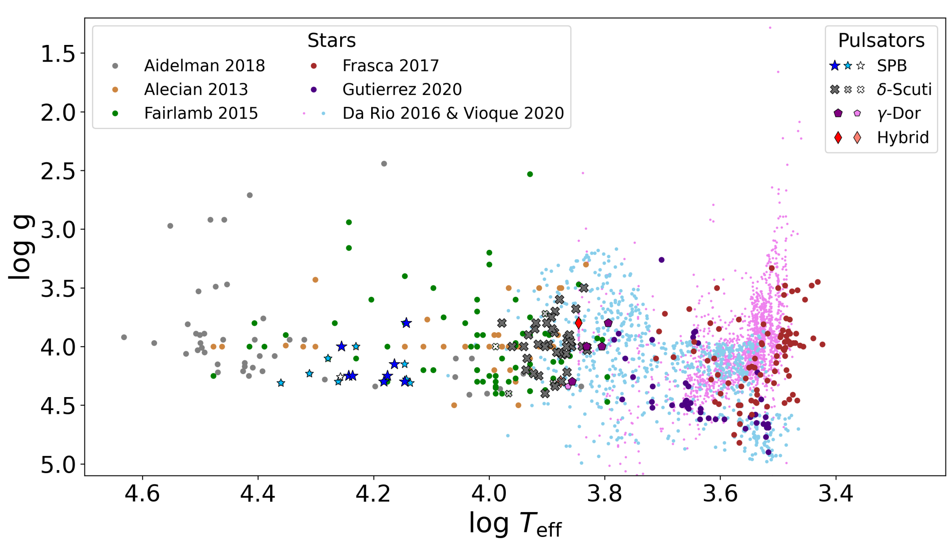
In total we found six formerly unknown pre-main sequence Slowly Pulsating B stars/candidates, six δ Scuti stars/candidates and one γ Doradus star.

Slowly Pulsating B stars | δ Scuti stars | γ Doradus star

Once the stellar sample was fixed, we calculated accreting protostellar evolution models with different input physics. In our approach, we first found a set of input physics that envelopes most of the stellar sample within the accreting evolutionary track and the zero age main sequence. We subsequently changed one of six free parameters and compared the resulting tracks.

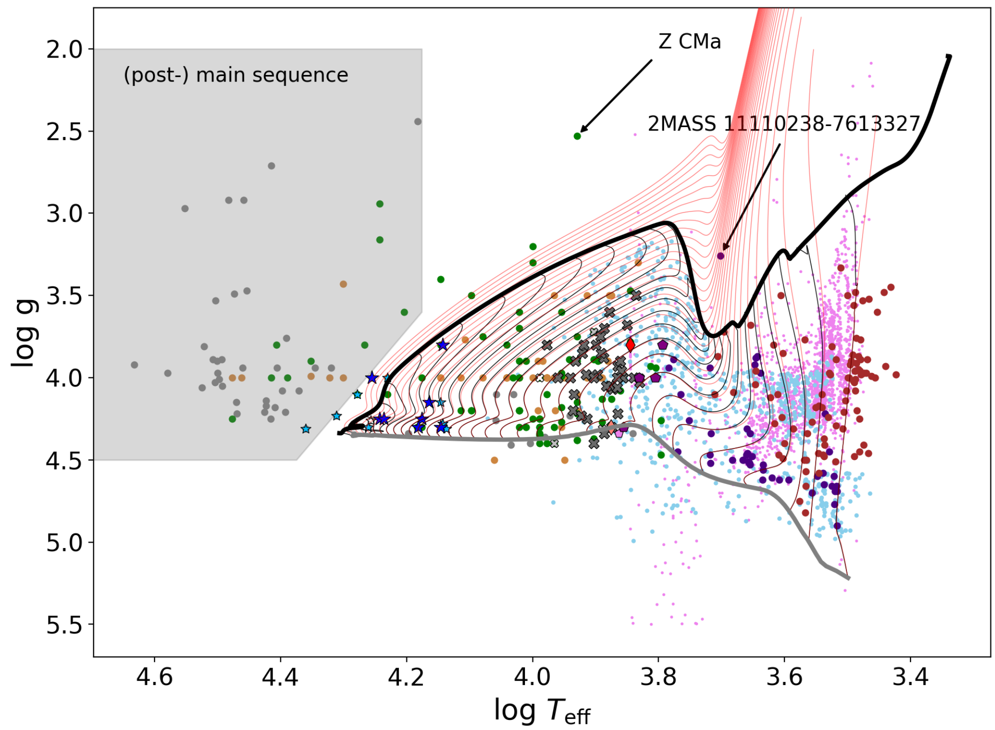
Stellar Sample | Atmospheres | Accretion Rate | Mixing Length | Deuterium | Injected Energy | Position of Injection

Stellar sample



Besides the mass accretion rate and the amount of injected heat, no parameters influence the accreting tracks enough to constrain the values with our current sample. However, the accreting evolutionary track does a fantastic job explaing the position of the pre-main sequence star in the low temperature regime.

(Steindl et al. 2021)



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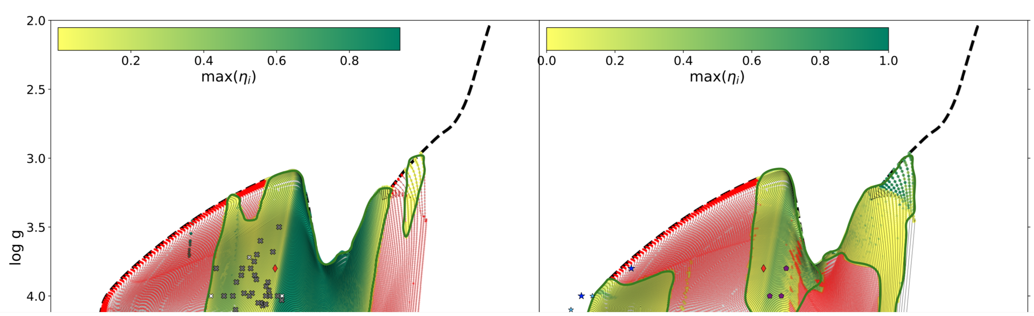
We used our best fitting model to calculate the subsequent pre-main sequence evolution and performed linear non-adiabatic stellar pulsation analysis for pressure and gravity modes with the stellar oscillation code (Townsend & Teitler 2013, Townsend et al. 2018). The resulting theoretical pulsation modes allow the determination of instability regions for pre-main sequence stars. The pressure mode instability region (left panel) contains all δ Scuti stars and candidates, but places the red edge of the instability strip too far lower effective temperatures than our sample suggests (more later). The gravity mode instability region (right panel) reproduces the instabilty region for SPB and γ Doradus stars and candidates. An additional instability region for very low effectice temperature stars (K- and M-type stars) is also present.

(Steindl et al. 2021)



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We further investigate the red edge of the pressure mode instability strip. Including the information about the work performed by one pulsation cycle, we can find a better estimate of the real red edge.

Including the latter, our resulting instability regions compare very well with the observational sample of pre-main sequence pulsators and improve upon earlier calculations using classical initial models.

Even more, we investigate radial order dependent instability regions. These can represent additional constraints once mode identification on multiple pre-main sequence stars are more common.

The theory of stellar structure and evolution expects K- and M-type stars to be unstable for certain kinds of oscillations (see e.g. Rodríguez-López 2019). However, to this day no such pulsating stars has been detected. We present a candidate star of spectral type M5.5 showing possible g-mode pulsation frequencies consistent with models in our calculated grid.

About the red edge of pressure mode pulsations | Radial dependent instability regions | candidate for g-mode pulsation in M-type stars

Read the publication

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