Precise asteroseismic ages from young pulsating stars

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… and many others!

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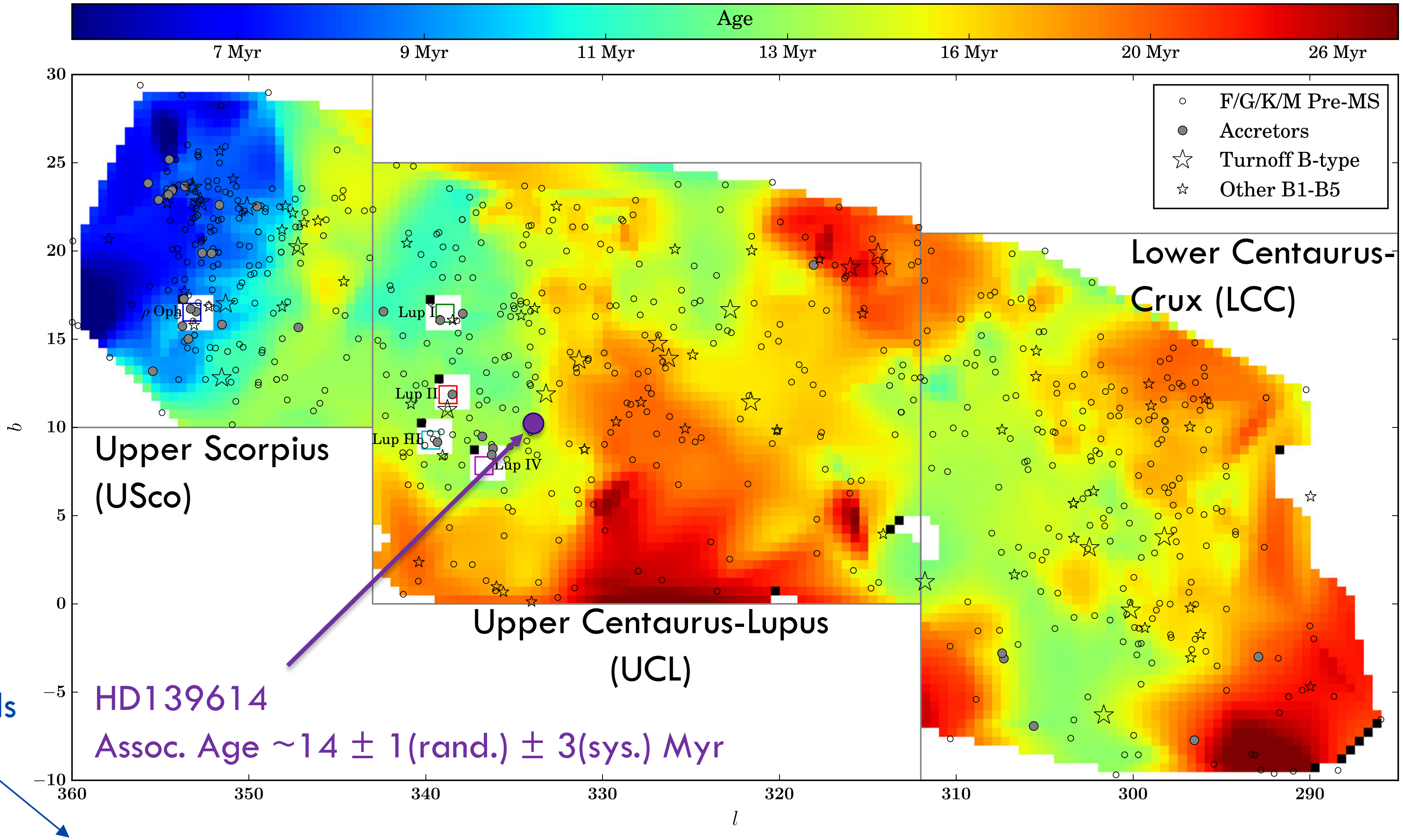
Overview: Young Stars

Age map of Sco-Cen star-forming region (Pecaut & Mamajek 2016)



Asteroseismic models Murphy+2021, MNRAS.502.1633

We model: age = 10.75 ± 0.77 Myr ⟶ pre-main-sequence

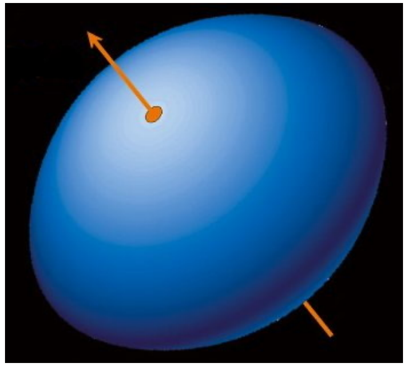
Example: Pleiades ages

– Wide range of isochrone ages. Strong dependence on treatment of rotation

100 Myr	non-rotating isochrones	(Meynet et al. 1993)
100 – 160 Myr	rotating isochrones	(Brandt & Huang 2015b, Gossage et al. 2018)

Two main effects of rotation

1. Star becomes oblate. Gravity darkening: T_{eff} and L depend on observing angle.
   - deformation goes as Ω^2
   - Brighter poles. Cooler, darker equatorial region.
   - Displacement with respect to isochrones.



2. Extra mixing of material
   - fresh hydrogen mixed into the core
   - lengthens the main sequence lifetime

Example: Pleiades ages

- Overly precise Lithium depletion ages. Strong dependence on sample selection, model physics

130 ± 20 Myr	lithium depletion boundary (LBD)	(Meynet et al. 1993)
112 ± 5 Myr	LDB using brown dwarfs	(Dahm 2015)
~ 100 Myr	As above, but accounting for magnetism	(Dahm 2015)

- Large systematic uncertainties with LDB ages (Garret & Pinsonneault 2014, 2015a,b)
  - The effect of differential rotation
  - The effect of starspots
  - Systematic uncertainties of 10-20% for 100-Myr clusters.

- Most ages for the Pleaides are in the range 100 – 160 Myr.
- Only one asteroseismic study so far (Fox-Machado et al. 2006)
  - They used a hard age prior of 70 – 100 Myr :(

Today's message:

Asteroseismology can provide precise stellar ages

- Only weak dependence on typical observables: "ballpark estimates"
- Dust obscuration is not a problem.
- Works for single stars.
- Can measure and properly account for rotation.
- Model physics is always a problem, but we can improve it (e.g. eclipsing binaries)

Project Aim → We can improve cluster age benchmarks and improve the whole age scale

A breakthrough

Bedding et al. Nature (2020)

Article

Very regular high-frequency pulsation modes in young intermediate-mass stars

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Check for updates

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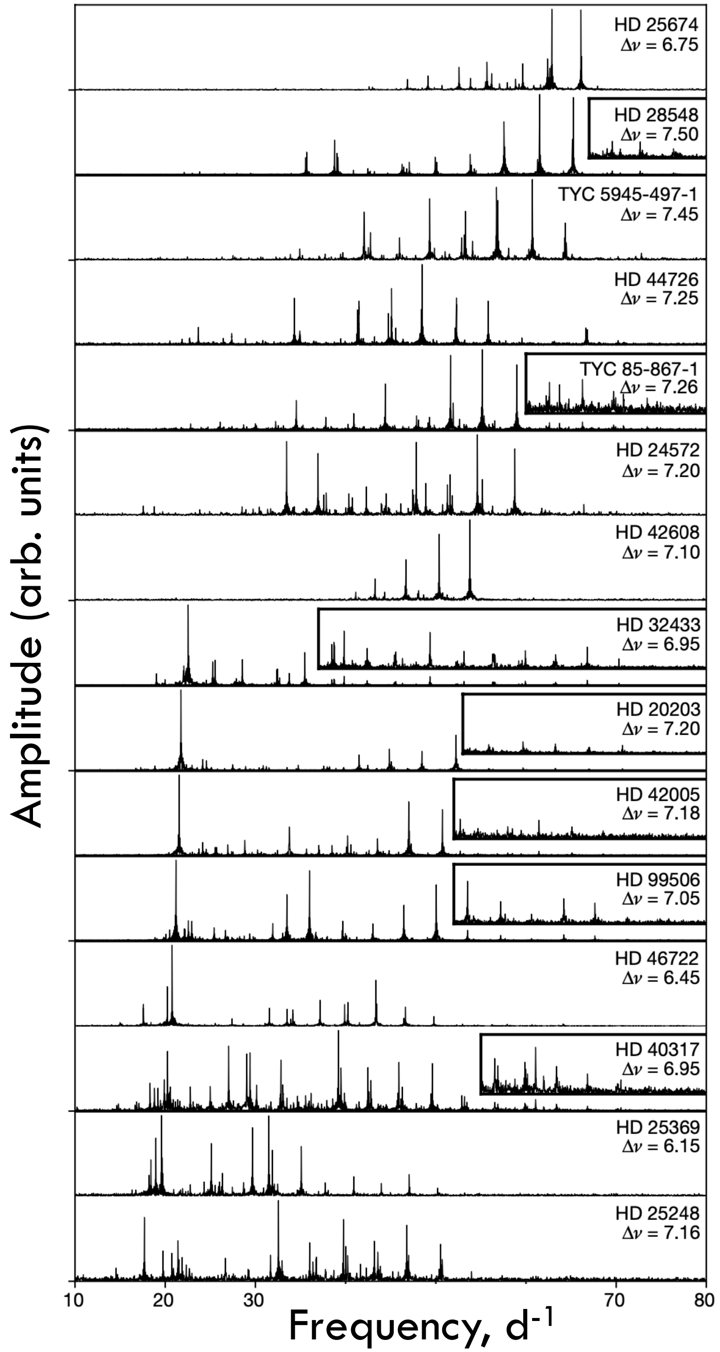
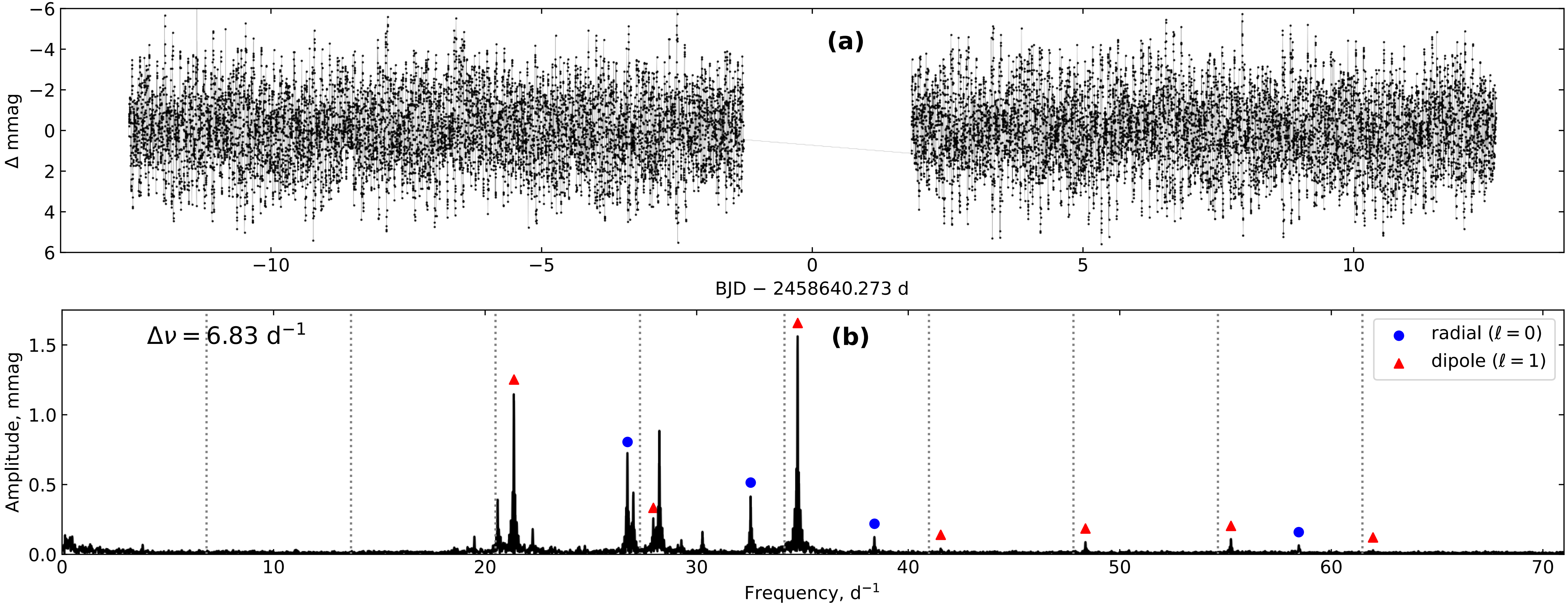
Asteroseismic large spacing, $\boldsymbol{\Delta\upsilon}$, as a new observable for dSct stars.



Young delta Scuti pulsators

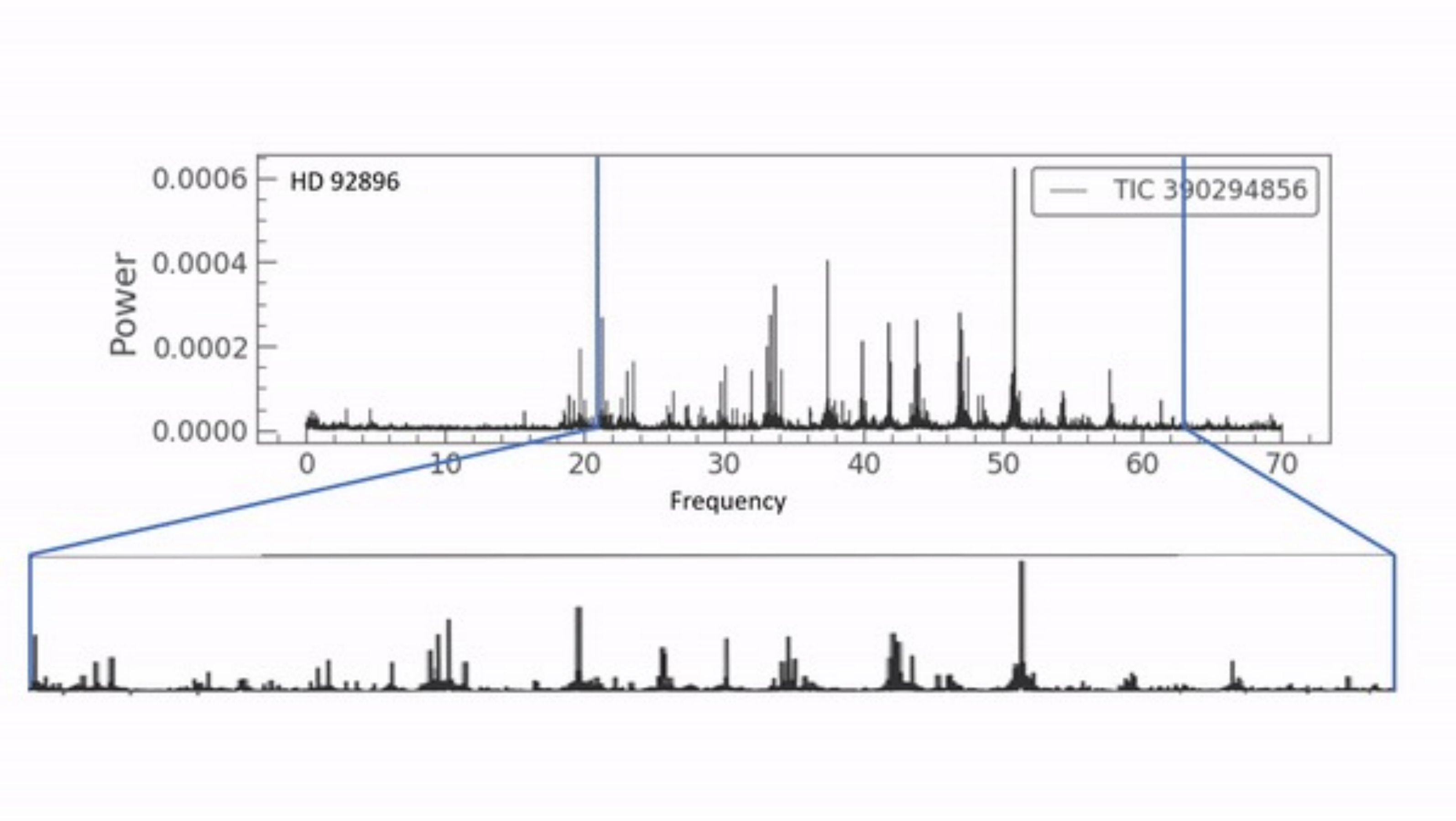
TESS data: HD139614 is a dSct star



$\Delta\upsilon$ = 6.83 c/d is quite large. Goes as $\rho^{0.5}$. Star is very dense, hence young.

An aside: Echelle Diagrams

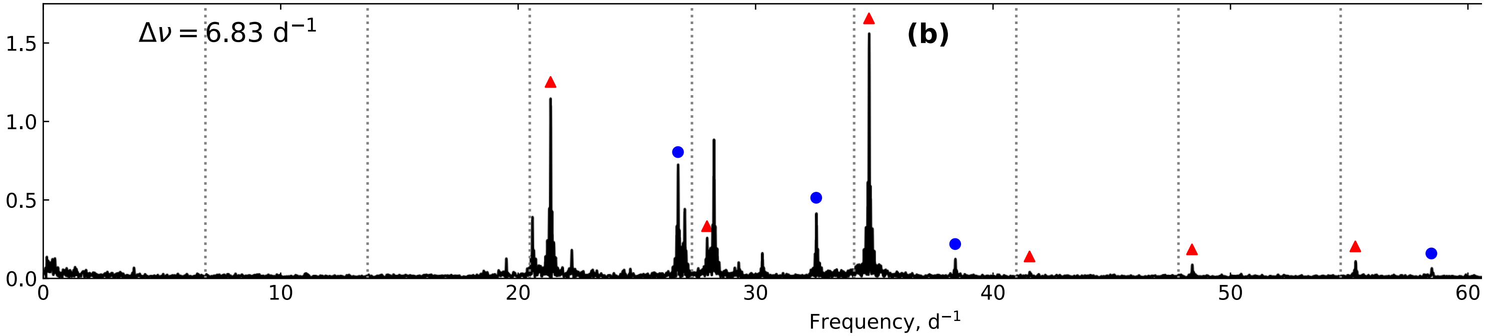
échelle is the French word for “ladder”

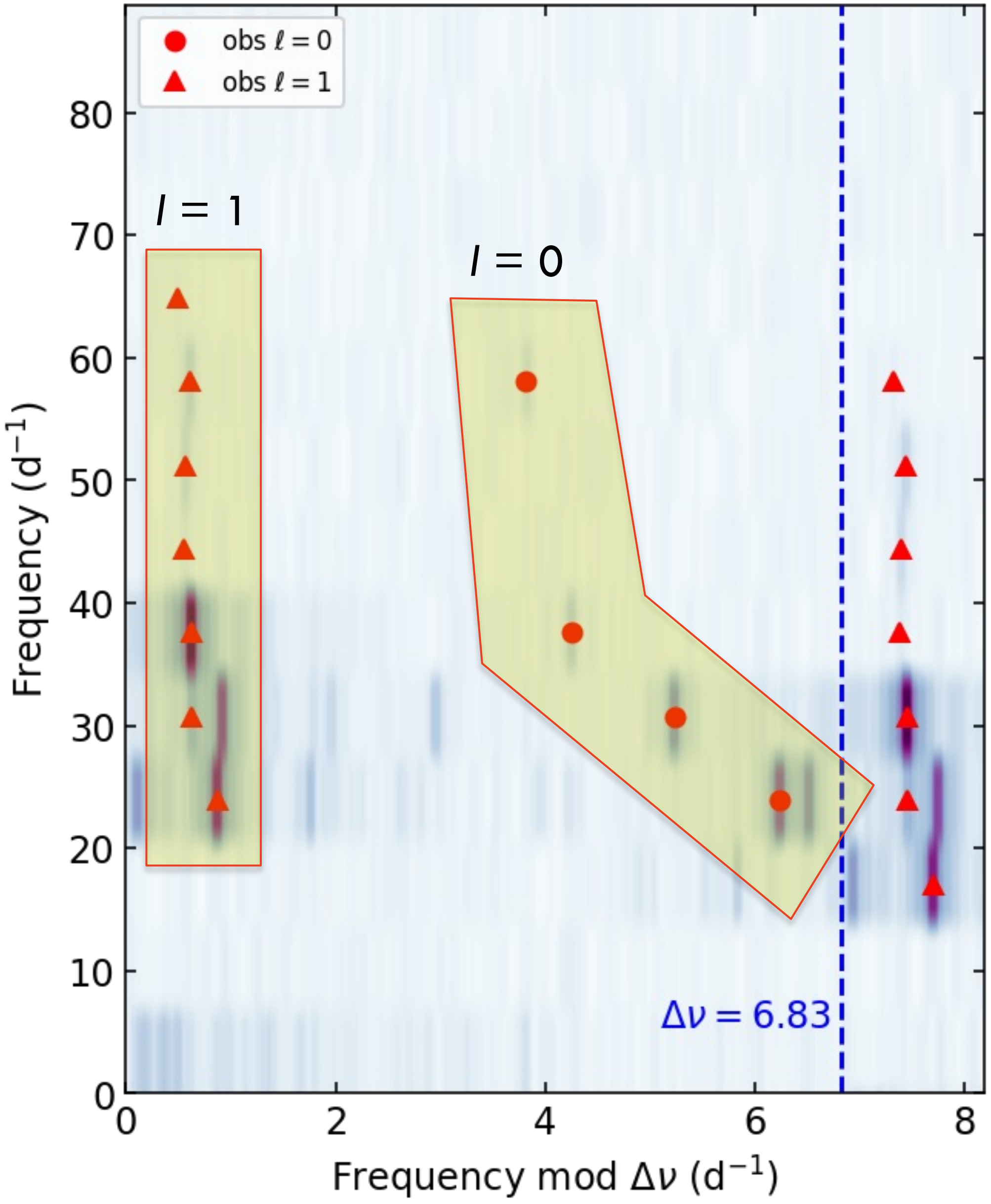


gif credit: Daniel Hey & Adam Hamilton

https://github.com/danhey/echelle

Echelle for HD139614, mode ID.



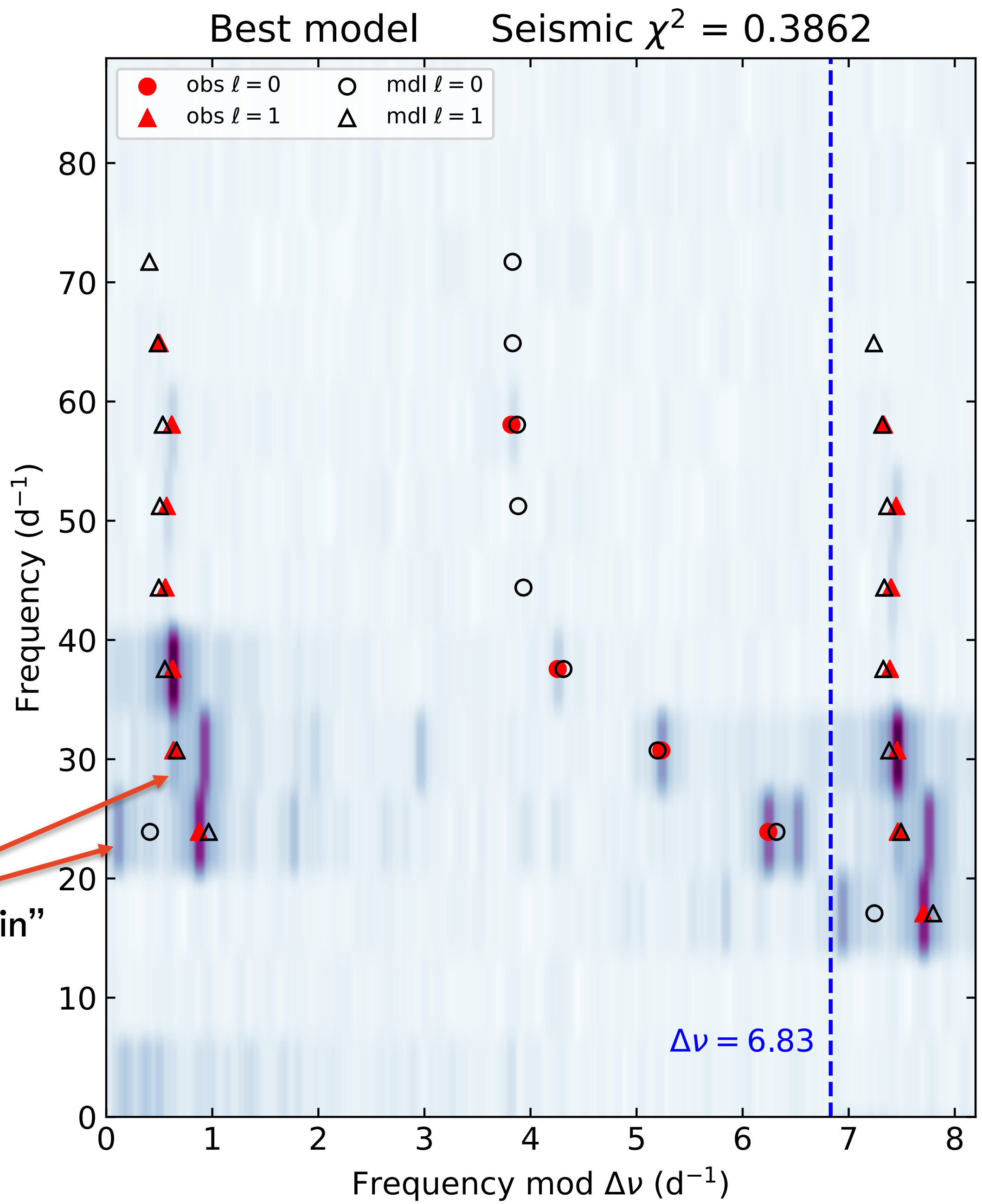


New development for this type of star:
Bedding, Murphy, et al. Nature (2020)

Mode identification was previously intractable.

We identify 7 dipole modes, and 4 radial modes.

Modelling method: χ^2 minimization *

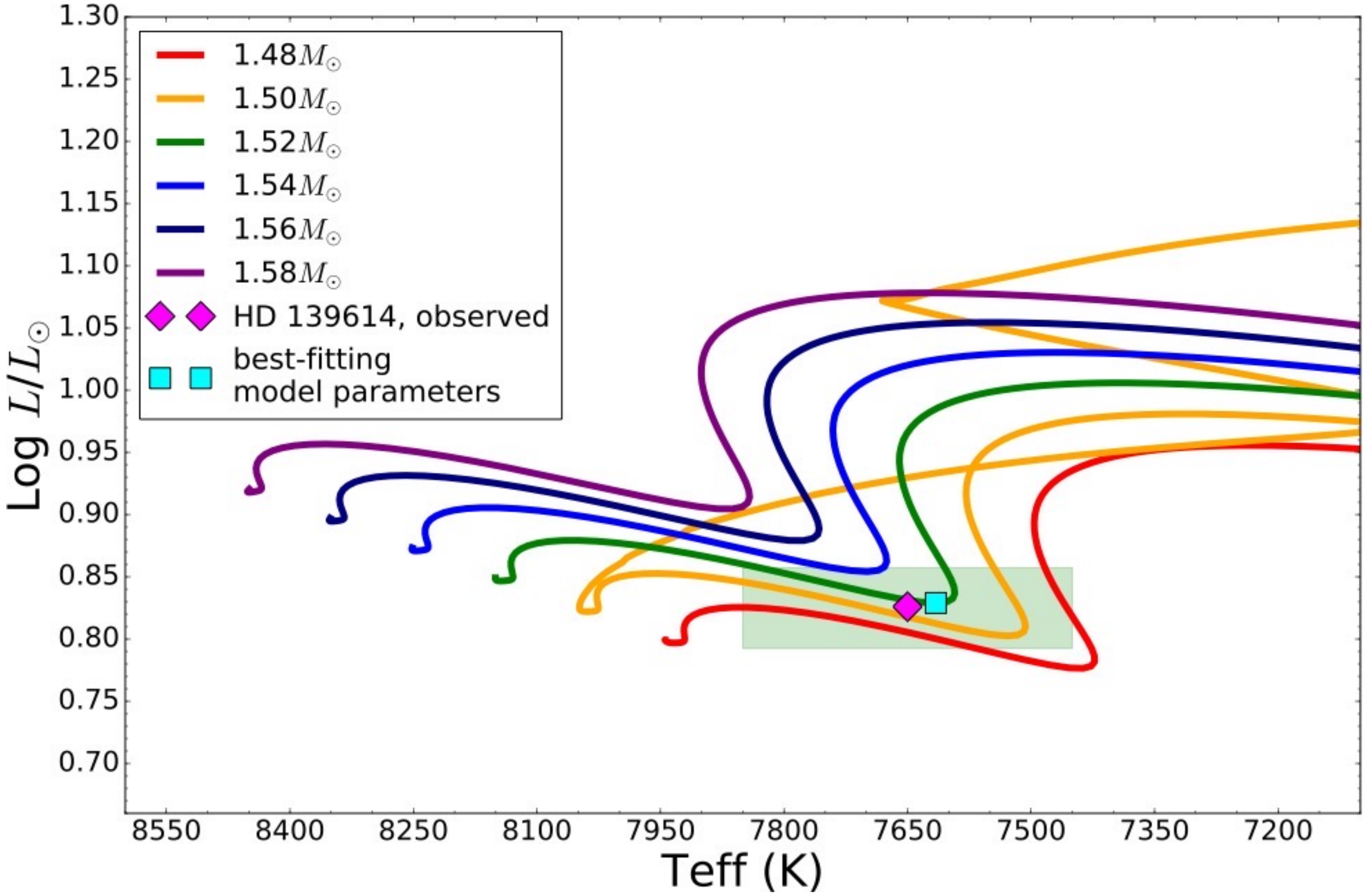


- Careful mode ID
- 10 mode ID scenarios
- Strong peaks not necessarily "in"

*Technically not a true χ^2 distribution.
"s_score" or "seismic χ^2"

Grid exploration. MESA + GYRE

stellar models — pulsation calculations



starting point:

Classical error box (Teff, L)

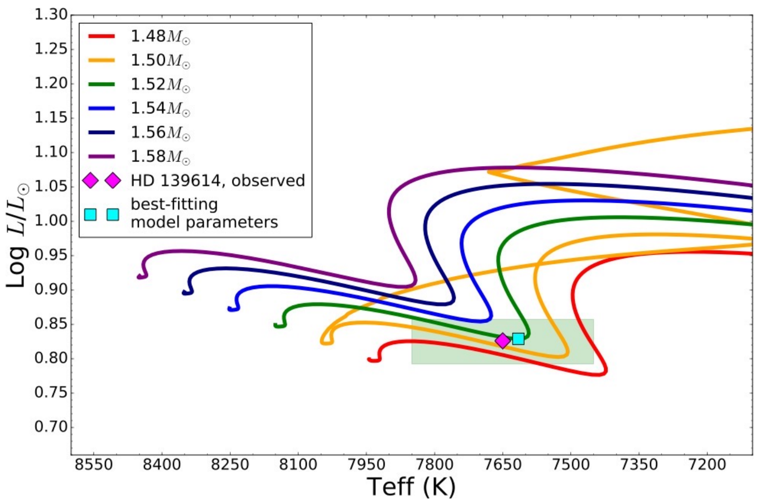
"roughly solar" Z

Age < 30 Myr

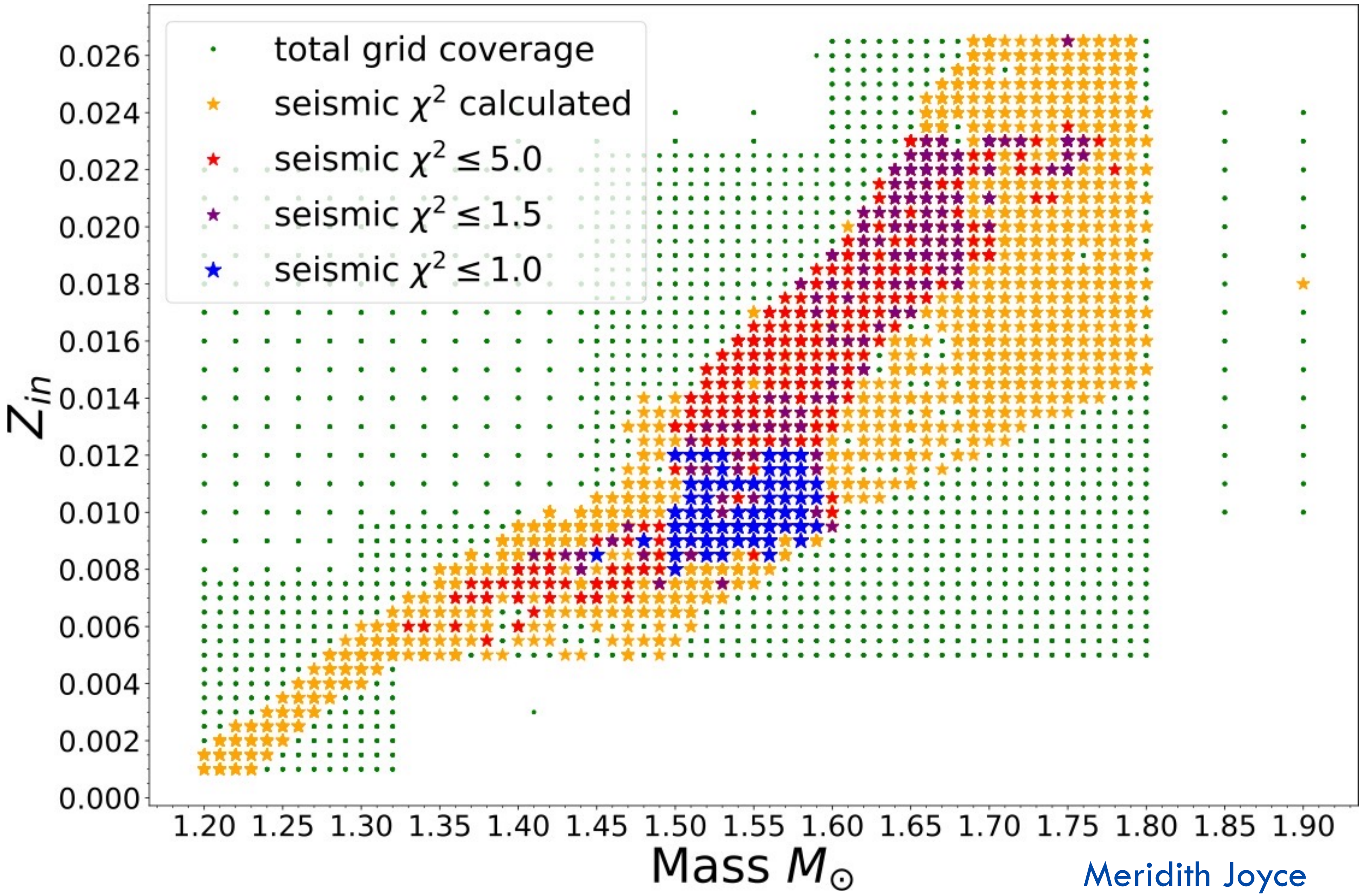
Meridith Joyce

Grid exploration. MESA + GYRE

stellar models — pulsation calculations



Meridith Joyce



Meridith Joyce

starting point:

Classical error box (Teff, L)

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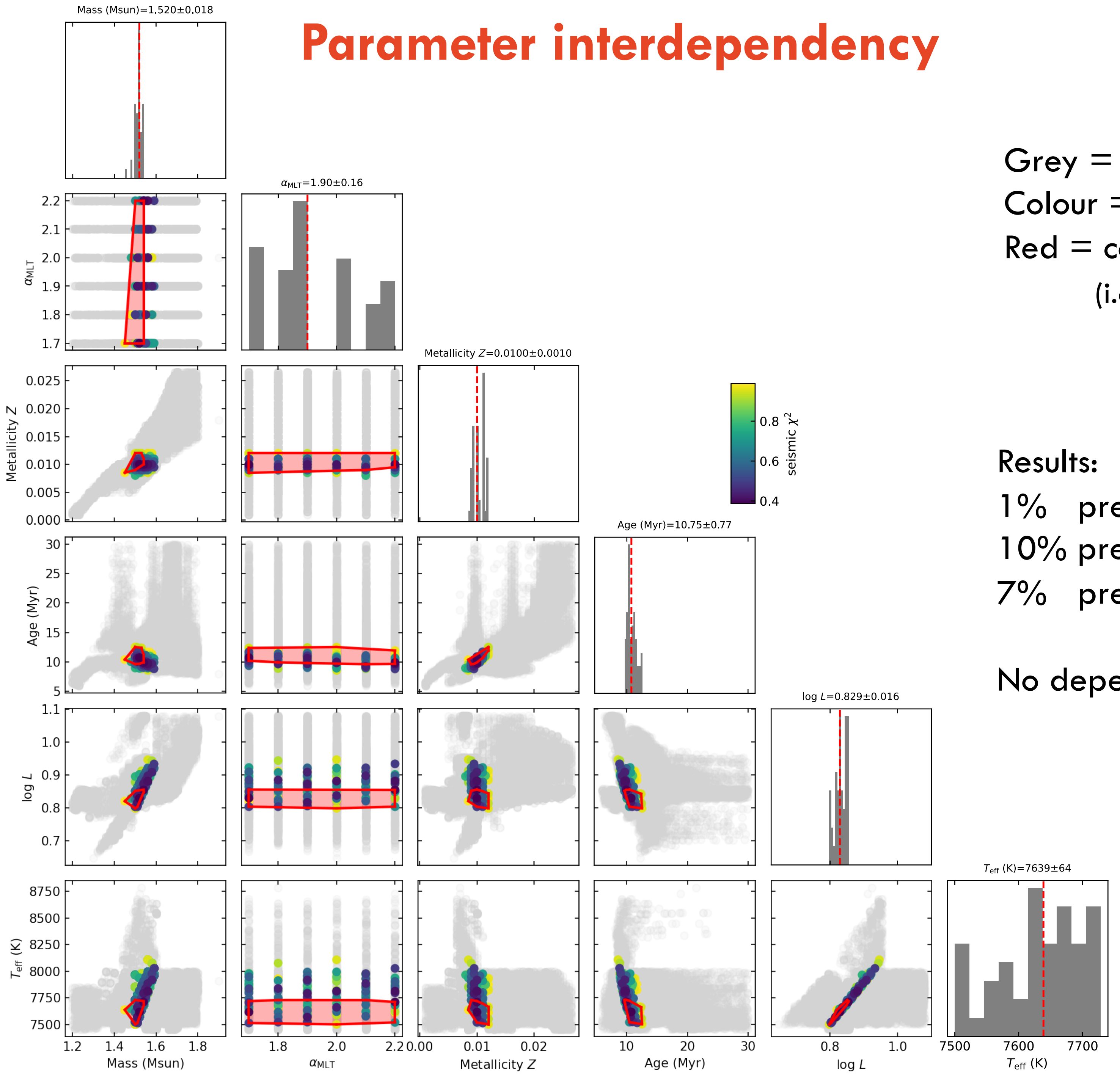
Age < 30 Myr

Parameter interdependency



Grey = all (10^5) evaluated models

Colour = all points at $\chi^2 < 1$

Red = convex hull for classical box

(i.e. agrees with known Teff, logL)

Results:

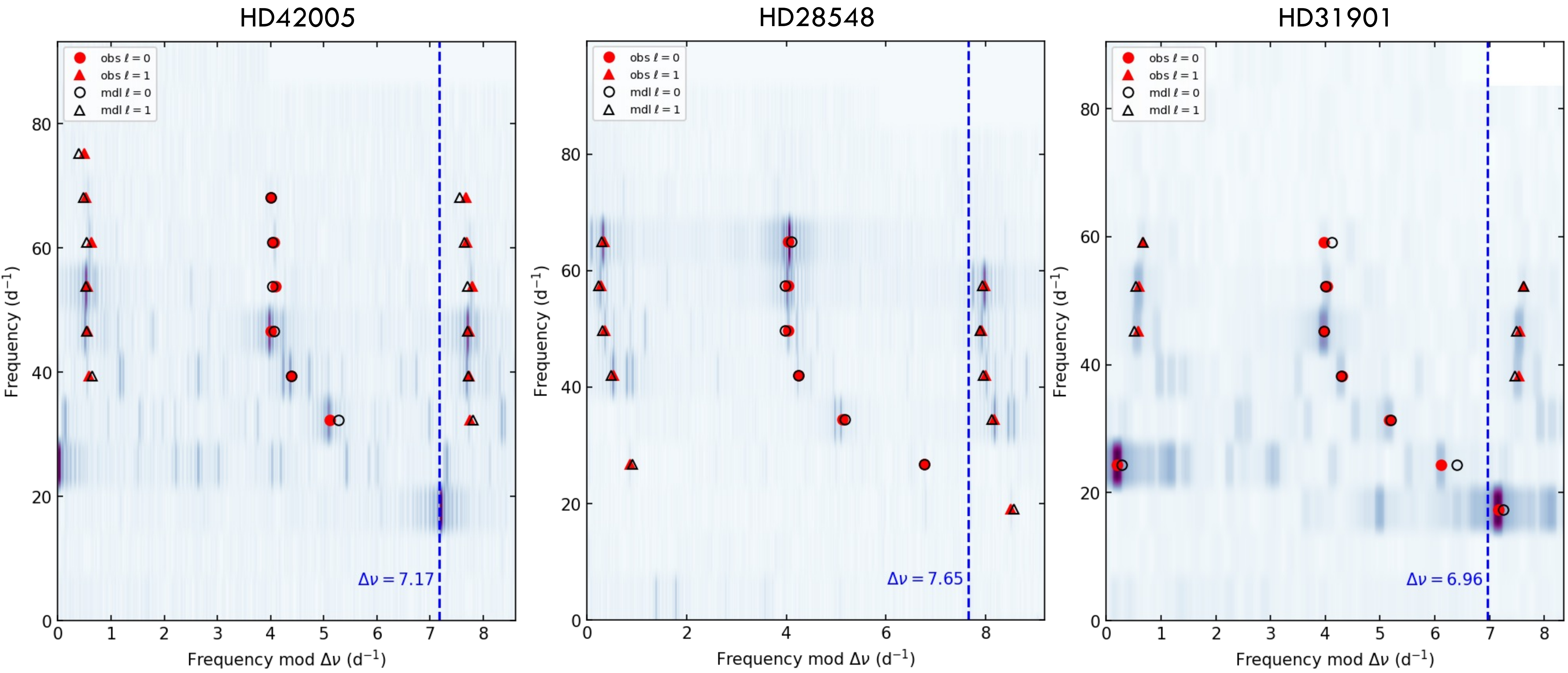
1% precision on mass

10% precision on metallicity

7% precision on age.

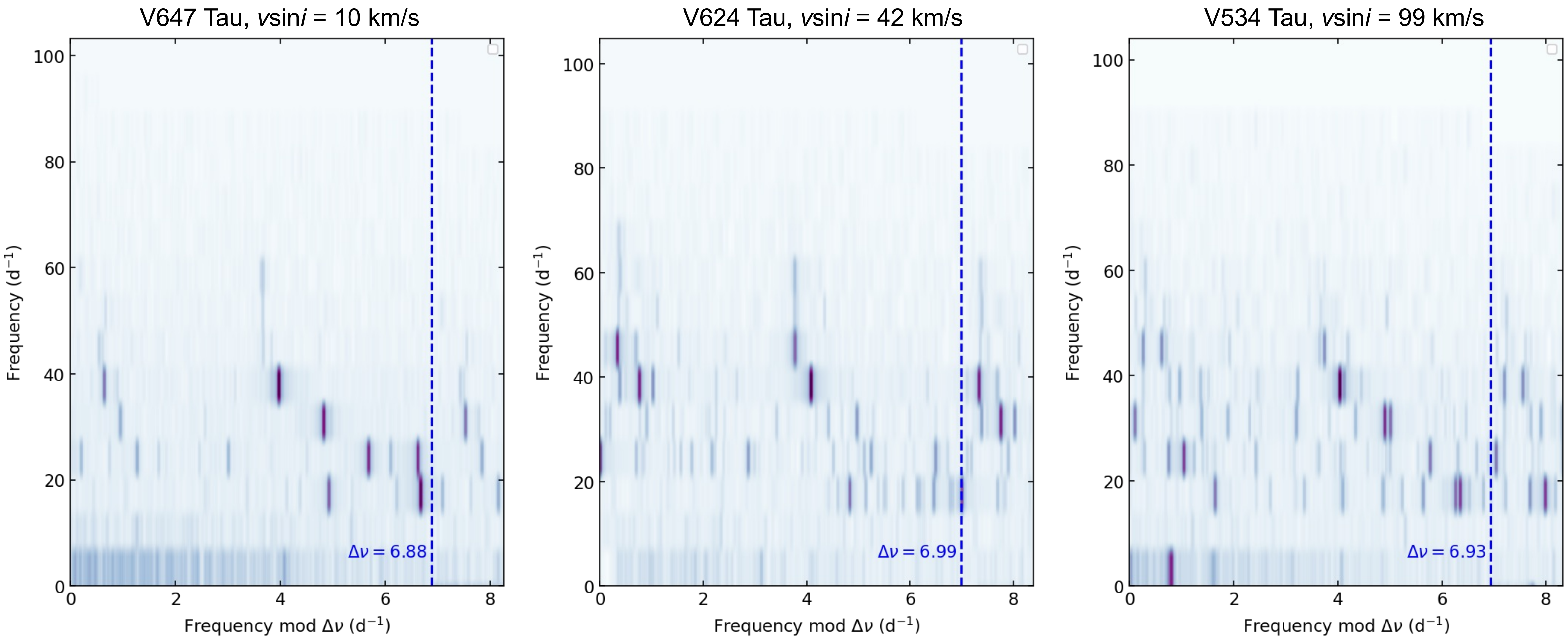
No dependence on α_{MLT}

Works for many young stars / associations



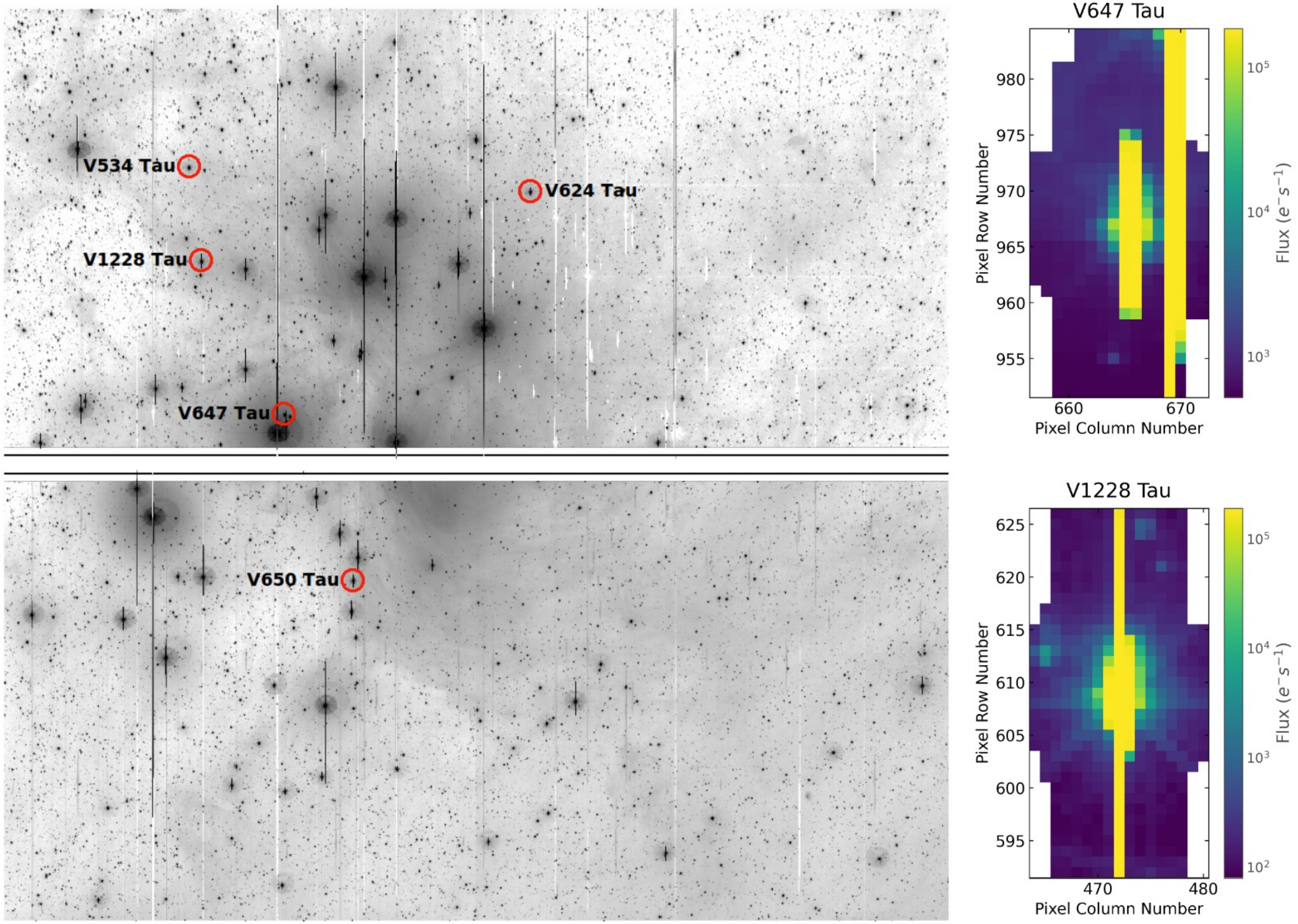
Remodelled stars from Bedding et al. (2020)

Back to the Pleiades



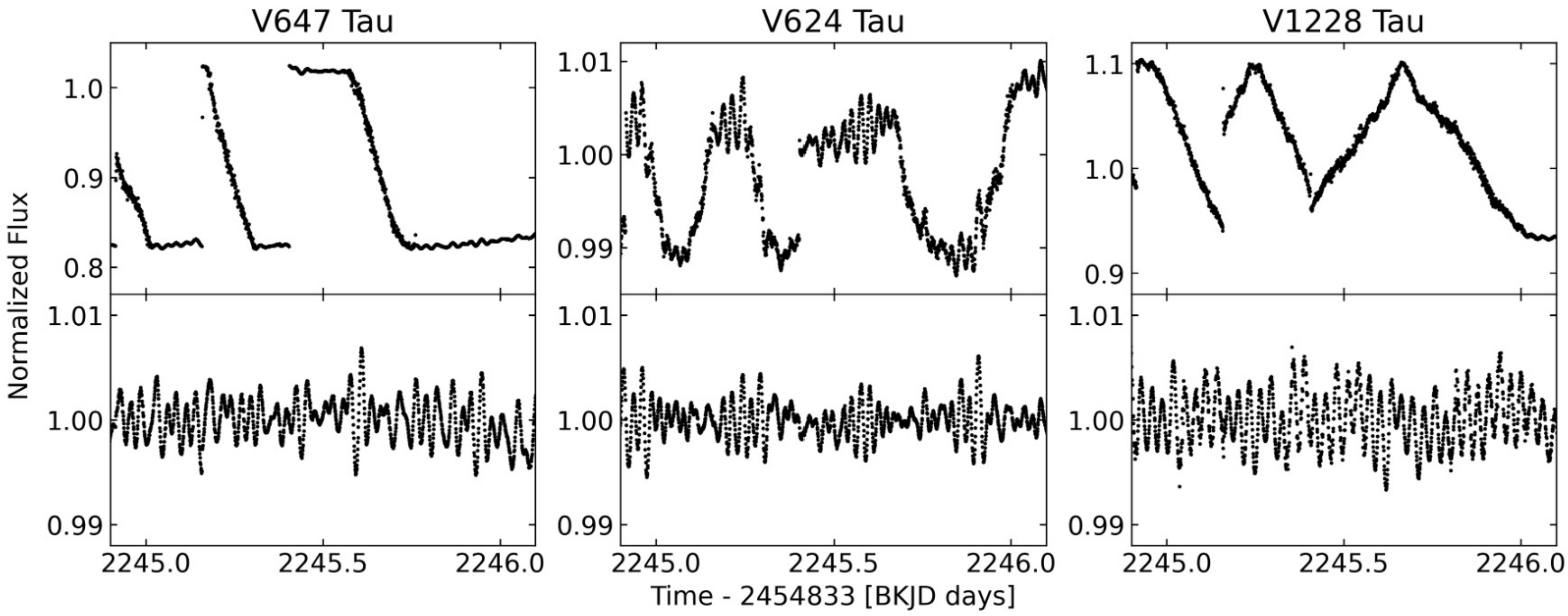
Using custom light curves from K2 data, made by Tim White

Custom light curves

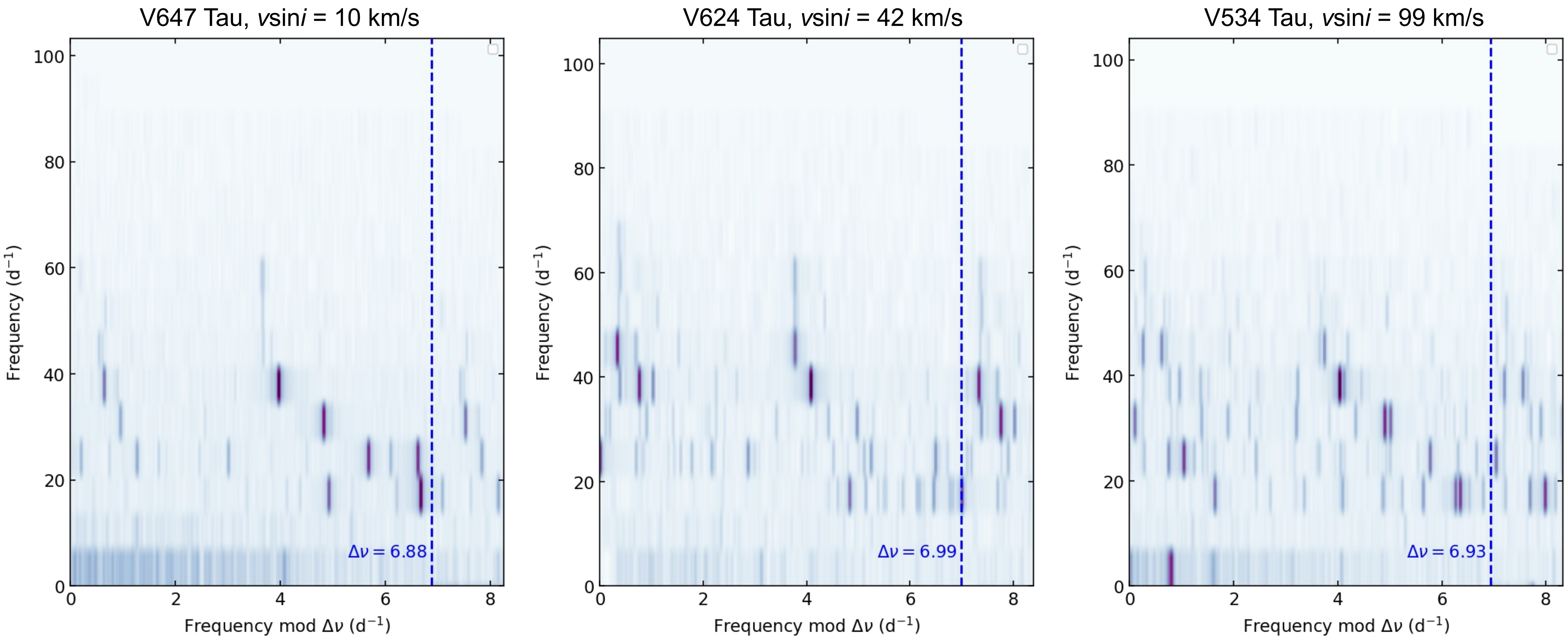


Back to the Pleiades

Before and after, for three of the five stars

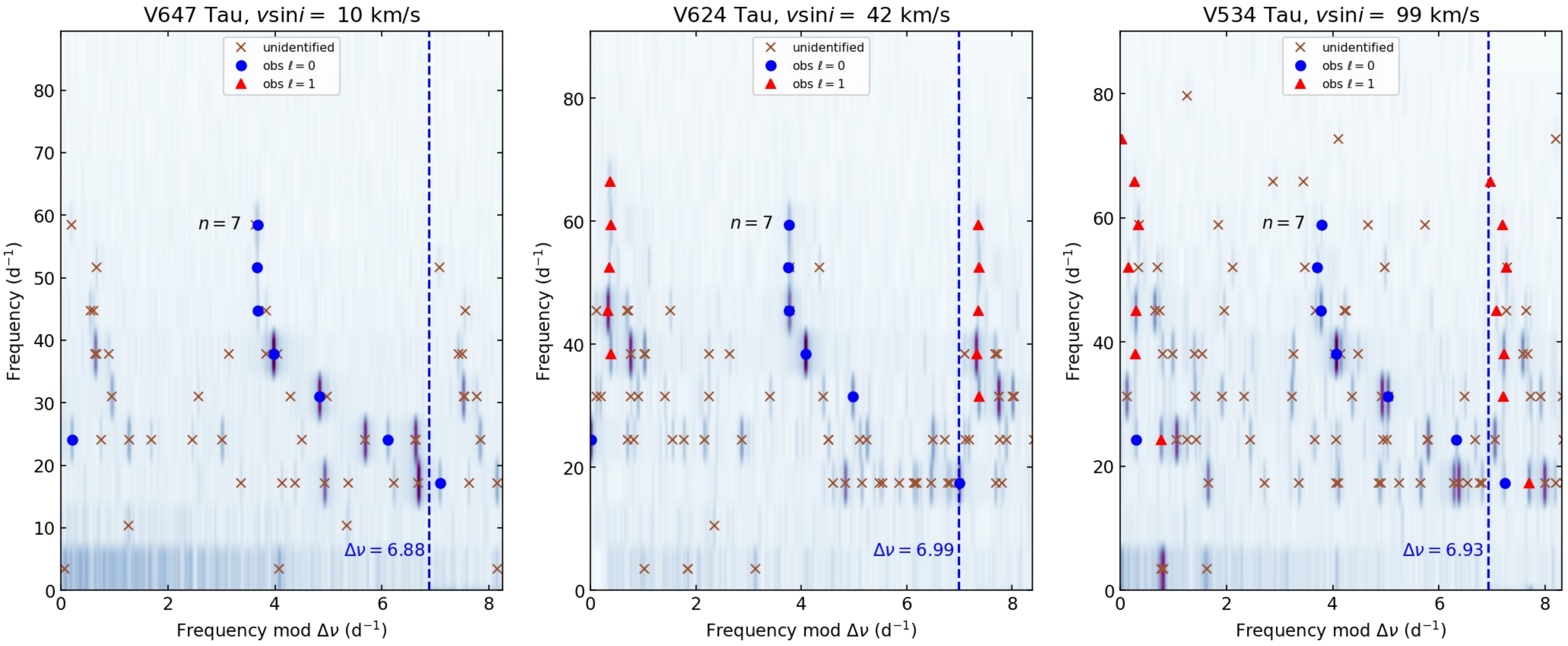


Back to the Pleiades



Using custom light curves from K2 data, made by Tim White

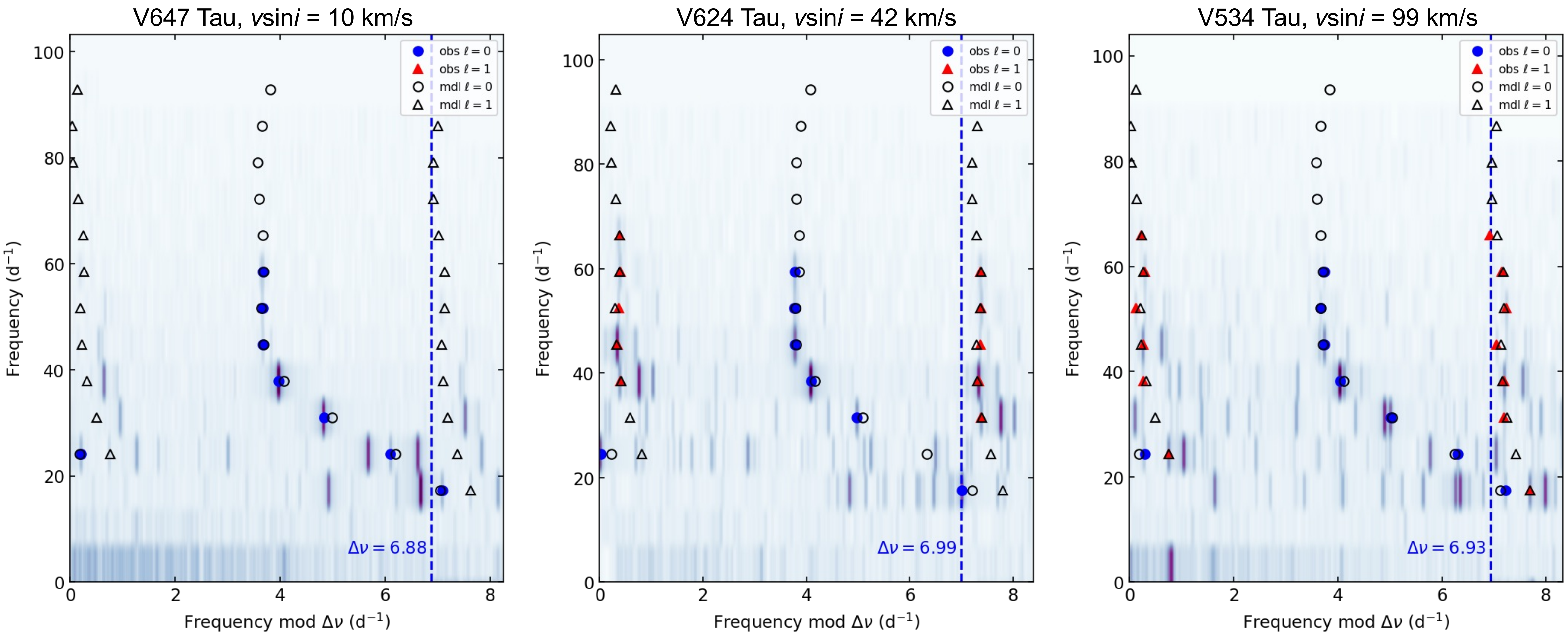
Mode identification



$$\nu_{nlm} = \nu_{nl0} + m\,(1 - C_{nl})\,\Omega/2\pi$$

Murphy et al. 2022 (MNRAS)

Modelling with MESA & Gyre



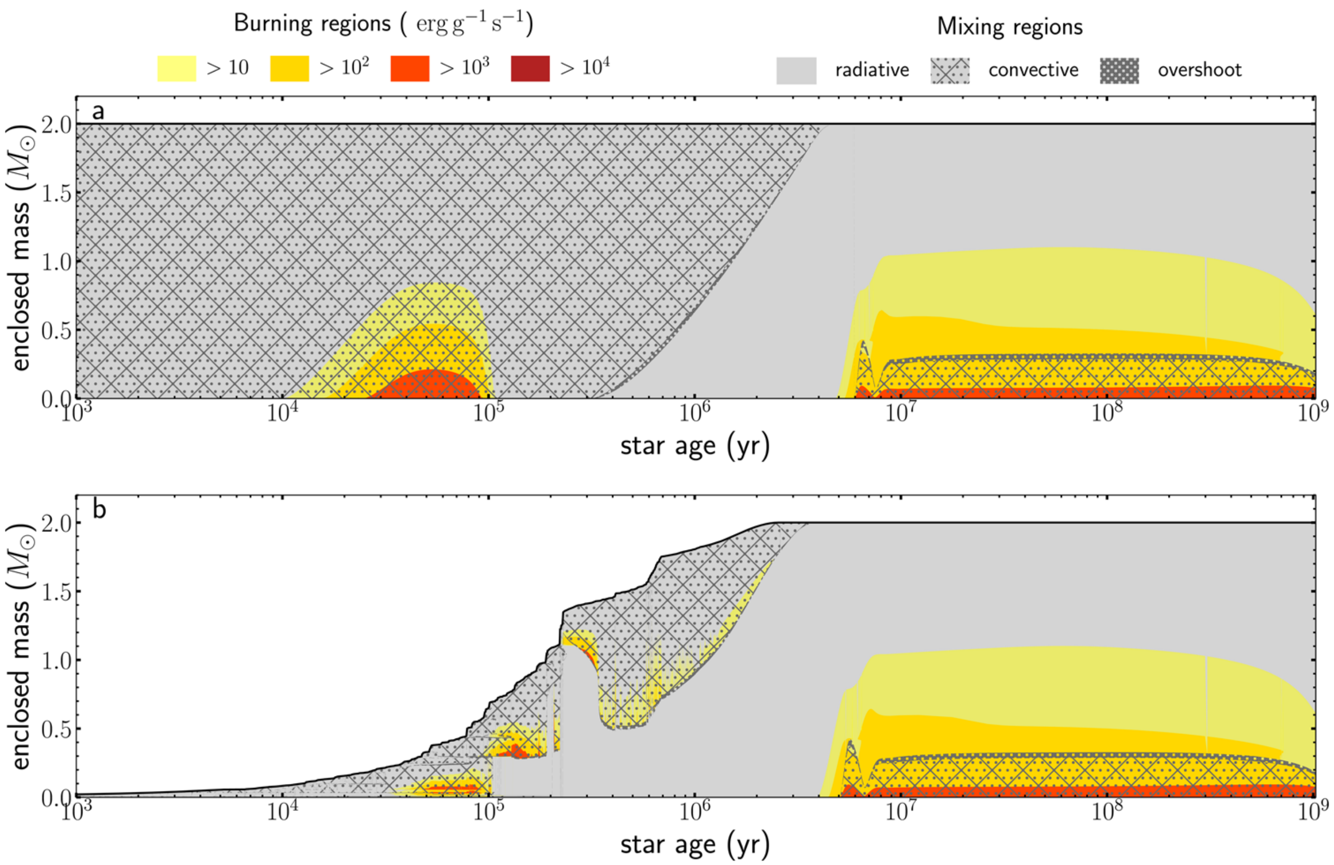
Good matches! BUT best-fitting model is always the oldest, most massive, most metal rich.

= LEAST DENSE model

What about accretion histories?

Disk-mediated accretion alters the pre-main-sequence burning; evolutionary history.

This leaves an imprint on the stellar pulsations, but is it superseded by rotation?



Steindl et al. 2022 (Nature Communications)

Pleiades, one more time…

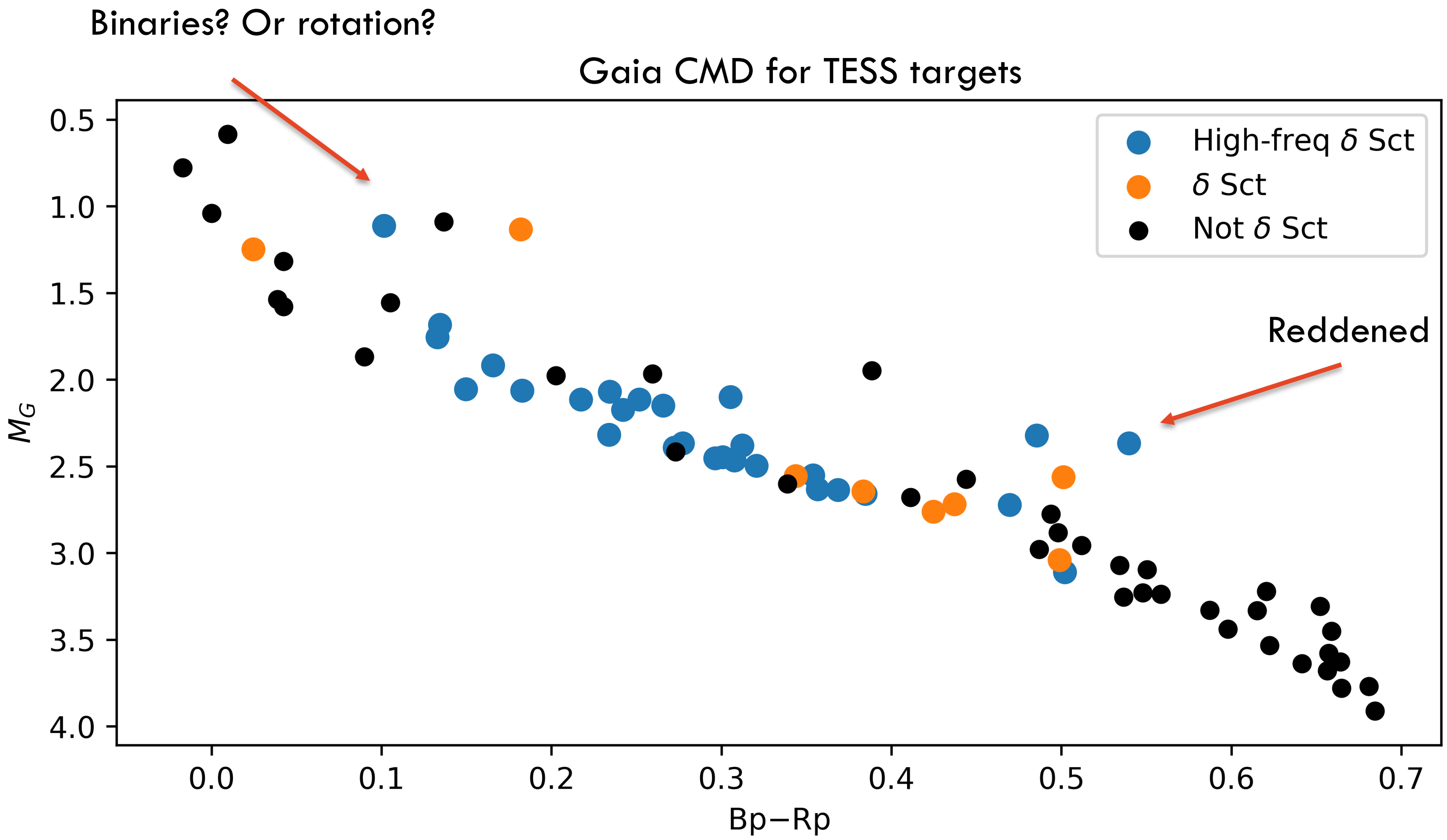


Fig: Tim Bedding

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Summary

- Mode identification is now tractable for young, intermediate-mass stars.
- Asteroseismic ages for young stars can (re-)calibrate stellar ages
  - Cluster ages are often determined relative to each other
  - Improve your benchmarks, and you improve the whole system.
- HD139614 is young, planet-forming disk. Still on the pre-MS.
  - Asteroseismic age 10.7 Myr, 7% uncertainty.
- The Pleiades are an exciting “new” target.
- Rotation is very important and troublesome.

Details in:

- Bedding et al. (2020) Nature 581, 147
- Murphy et al. (2021) MNRAS 502, 1633
- Murphy et al. (2022) MNRAS 511, 5718

Look out for:

- Age dispersion measurements of Cepheus Far North (Kerr et al. 2022, in rev.)
- TESS observations of dSct stars in the Pleiades (Bedding et al., in prep.)