Yale

Seismic Constraints on Helium Abundances from the TESS Southern CVZ

J. M. Joel Ong[1] Mikkel N. Lund[2] Sarbani Basu[1] Keivan G. Stassun[3] Jamie Tayar[4] Mutlu Yıldız[5]
Zeynep Çelik Orhan[5] Sibel Örtel[5] H. M. Antia[6] Thierry Appourchaux[7] Enrico Corsaro[8] Guy R. Davies[9]
Nathalie Themeßl[10] Lucas S. Viani[1] Daniel Huber[4]

[1]Yale; [2]SAC, Aarhus; [3]Vanderbilt; [4]Hawai'i; [5]İzmir; [6]TIFR; [7]Institut d'Astrophysique Spatiale; [8]INAF; [9]Birmingham [10]MPS

Mixed-Mode Asteroseismology from the TESS Southern CVZ (and other sources) yields initial helium abundances that are **inconsistent** with a single linear helium-enrichment law.

Motivation

Helium is an underconstrained input into stellar modelling; a linear helium-enrichment law (i.e. $Y_i = Y_p + (\mathrm{d}Y/\mathrm{d}Z)Z_i$) is typically assumed (with Y_p supplied from BBN).

- **Is this a generally valid assumption?**
- **Can** $\mathrm{d}Y/\mathrm{d}Z$ **be constrained?**

Seismic Constraints on Helium Abundances

- Helium abundances are **difficult to constrain** with spectroscopy in cool stars
- **Solar-like oscillations** constrain surface helium abundances from p-mode frequencies (fig. 1).

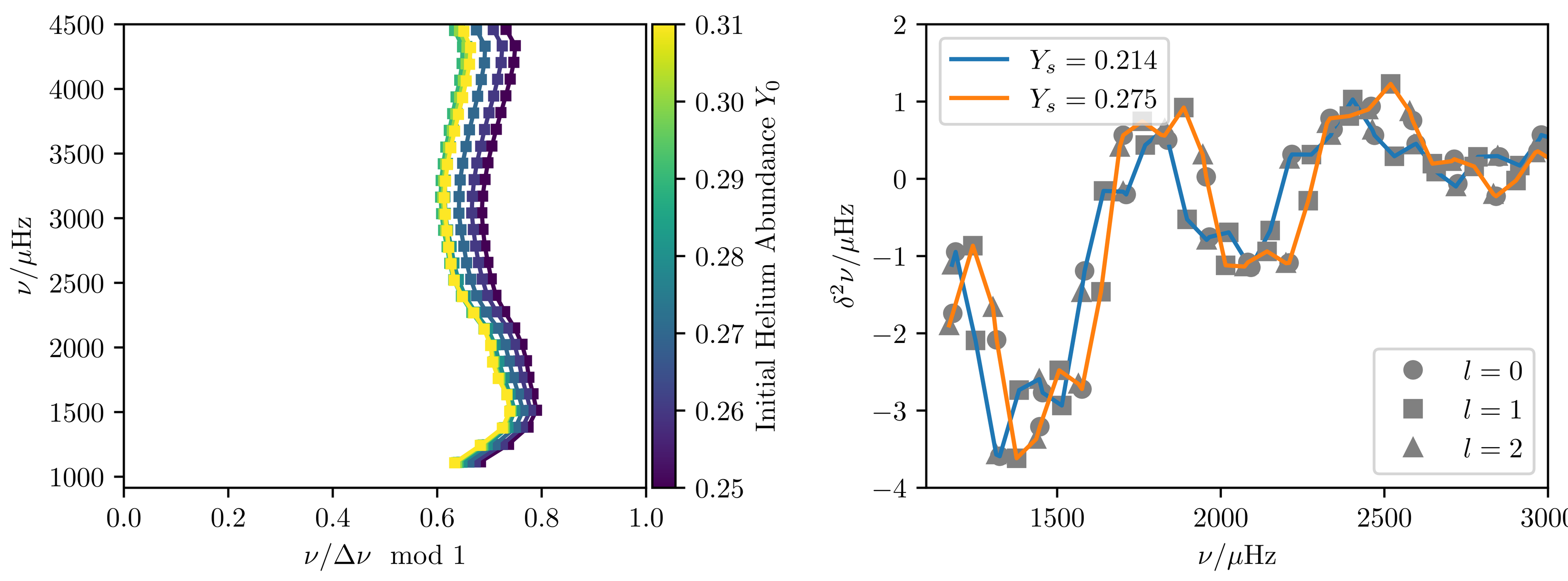

Figure 1: Variations in the p-mode frequencies resulting from different helium abundances (left panel) yield an oscillatory "glitch signature" (right panel) which can be used to constrain surface abundances (and initial helium abundances through stellar modelling).

p-modes are **not directly accessible** in post-main-sequence solar-like oscillators. Even if they were, comparable methods would become **less sensitive** over the course of stellar evolution (fig. 2).

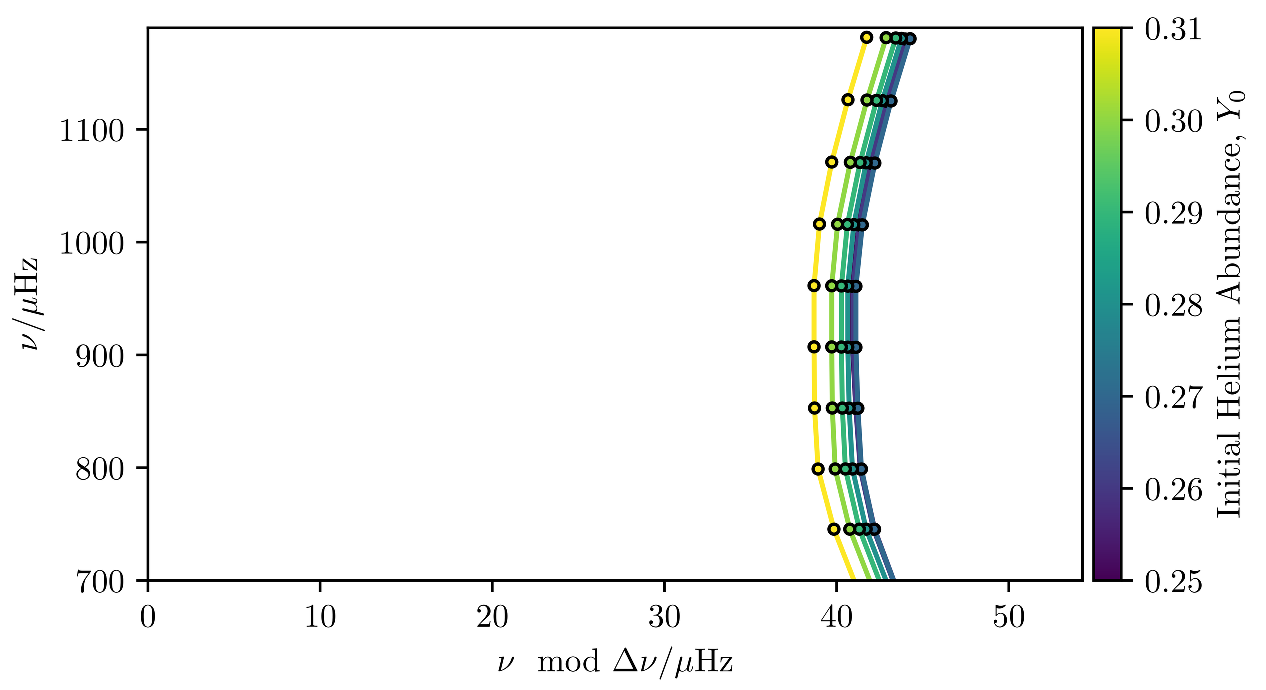

Figure 2: Echelle diagrams of notional pure p-modes for subgiant stellar models

Instead, these evolved stars exhibit **mixed dipole modes**, whose p-modes undergo avoided crossings with underlying g-modes. These are **highly sensitive** to the initial helium abundances of the star (fig. 3).

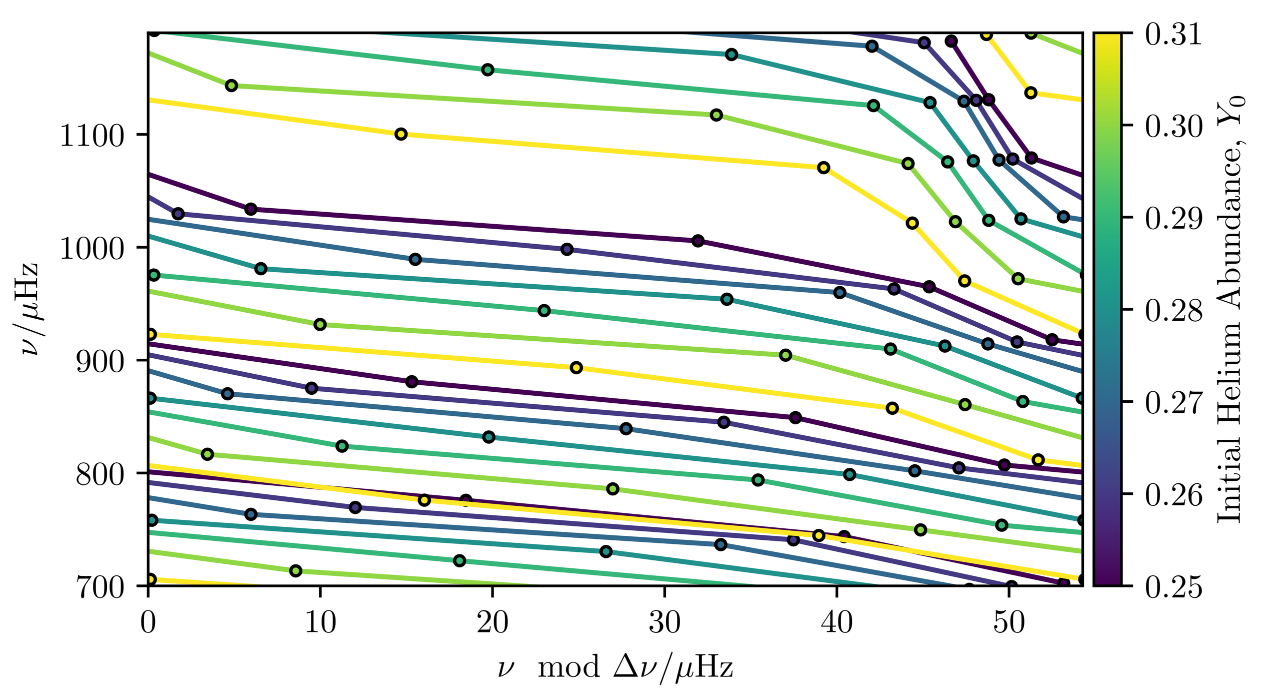

Figure 3: Echelle diagrams of dipole mixed modes for the same stellar models

Stellar modelling using both spectroscopy and asteroseismology of these evolved oscillators thus yields estimates of **both** initial helium abundances **and** initial metal fractions; **ensemble asteroseismology** in turn permits constraints on the helium enrichment over the observed stellar population.

Observational Sample

- Of the subset of the ATL lying in the Southern CVZ, we found a very large fraction of our sample to exhibit no significant seismic power excesses in their spectra, with a pronounced **detection bias towards more evolved stars** (fig. 4)

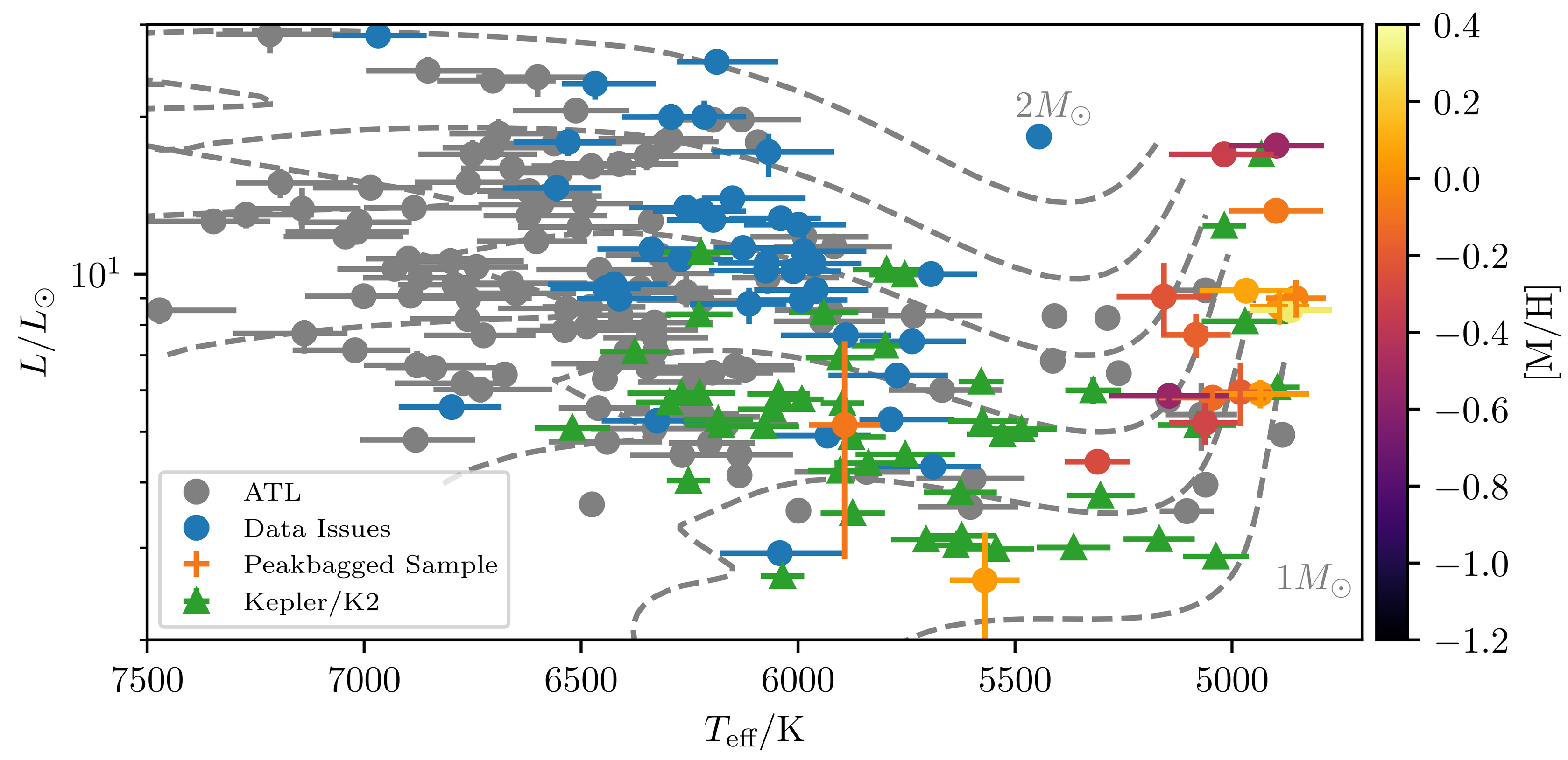

Figure 4: HR diagram showing the seismic target list grouped by data quality

- Mode frequencies were fitted against the power spectra with **7 different peakbagging pipelines**, with each set of results treated as independent measurements.
- Luminosities were found with SED measurements in conjunction with Gaia parallaxes
- Other spectroscopic properties (metallicities and effective temperatures) were assembled from the literature

To overcome the sampling biases induced by this low seismic yield, we supplement this sample with **known subgiant oscillators** observed by Kepler and K2.

Results from Stellar Modelling

We constrain the initial metal and helium mass fractions by stellar modelling, using three different model grids.

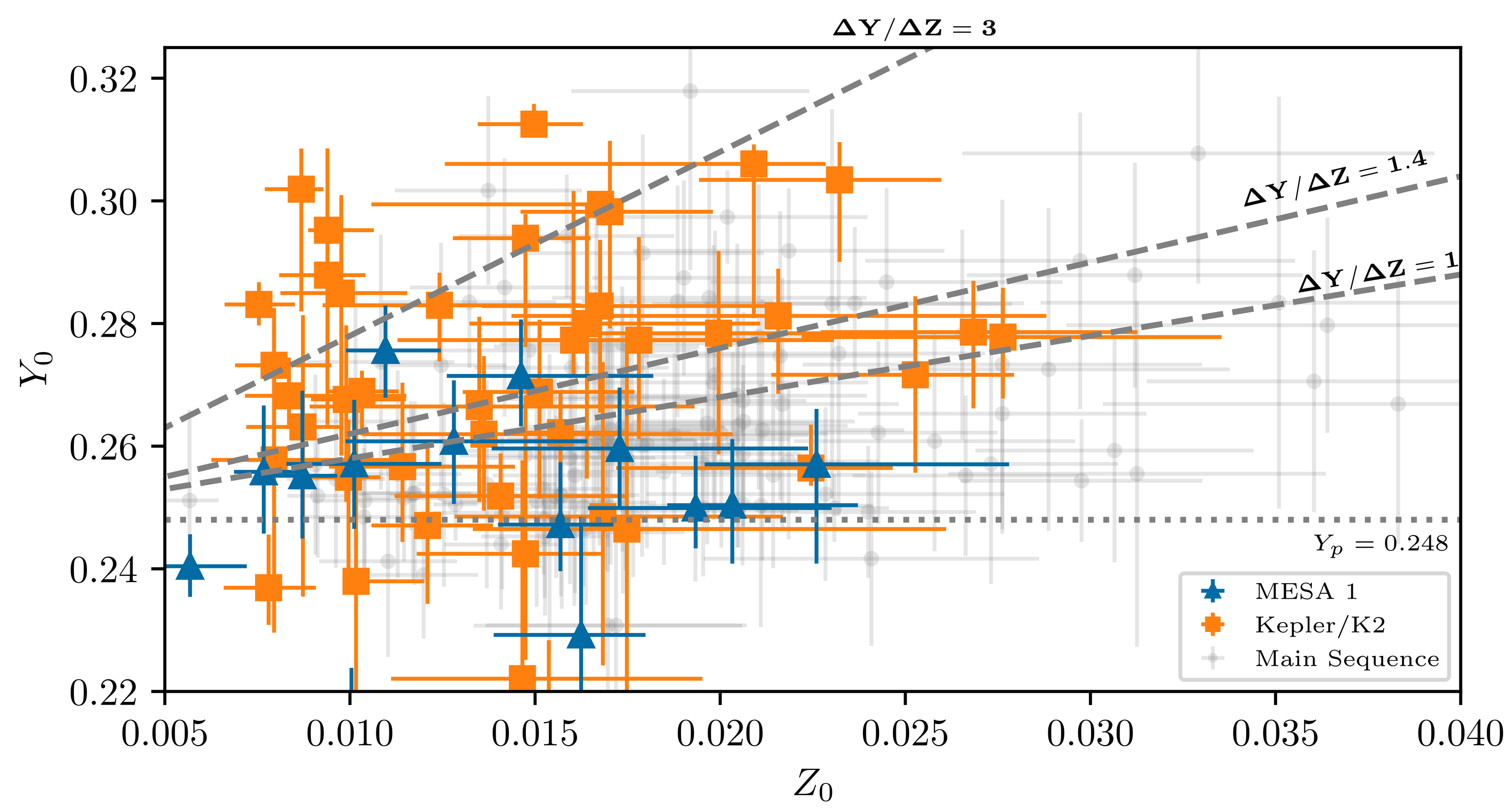

Figure 5: Inferred quantities from stellar modelling; literature values from main-sequence Kepler solar-like oscillators are also included in this figure

- Direct inspection of the Y_0-Z_0 plane does not reveal any preferred helium-enrichment relation.
- This is **consistent with earlier attempts** to constrain helium enrichment from main-sequence solar-like oscillations!
- Many sub-primordial Y values; likely a result of incompleteness of physics used in stellar modelling
- Substantial systematic error (much larger than statistical) resulting from uncertainties in **other stellar modelling inputs** (e.g. overshoot, EOS, surface term correction)

Potential improvements from **Gaia DR3**?