Variability of chemically peculiar HgMn stars

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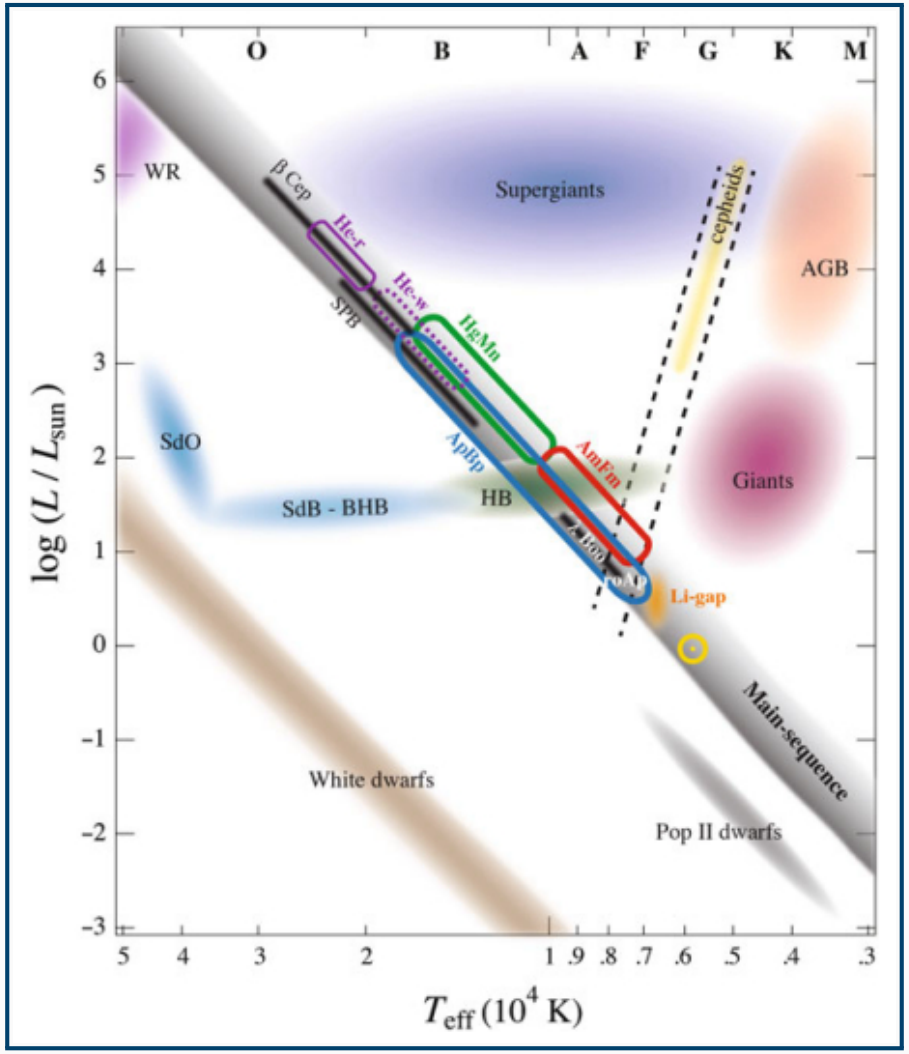
Chemically peculiar stars



Groups of stars showing abundance anomalies in the HR diagram (Michaud, Alecian, & Richer, "Atomic Diffusion in Stars", 2015).

Chemically peculiar stars

CP type	Classification criteria	Spectral type	Temperature range	Magnetic field
He-rich	He overabundant	B3 or earlier	20000–25000	Yes
He-weak	He deficient	B3 or later	14000–21000	Yes
HgMn	**strong lines of Mn and Hg deficient He enhanced metals**	**B6–B9**	**10000–16000**	**Yes**
ApBp	strong lines of Si II, Cr II, Sr II, Eu II enhanced metals	B6–F4	6500–16000	Yes
AmFm	weak Ca II and/or Sc II enhanced metals	A0–F4	7000–10000	Yes?
λ Boo	strong Mg II line deficient metals, except CNOS	B8–F4	7500–9000	No

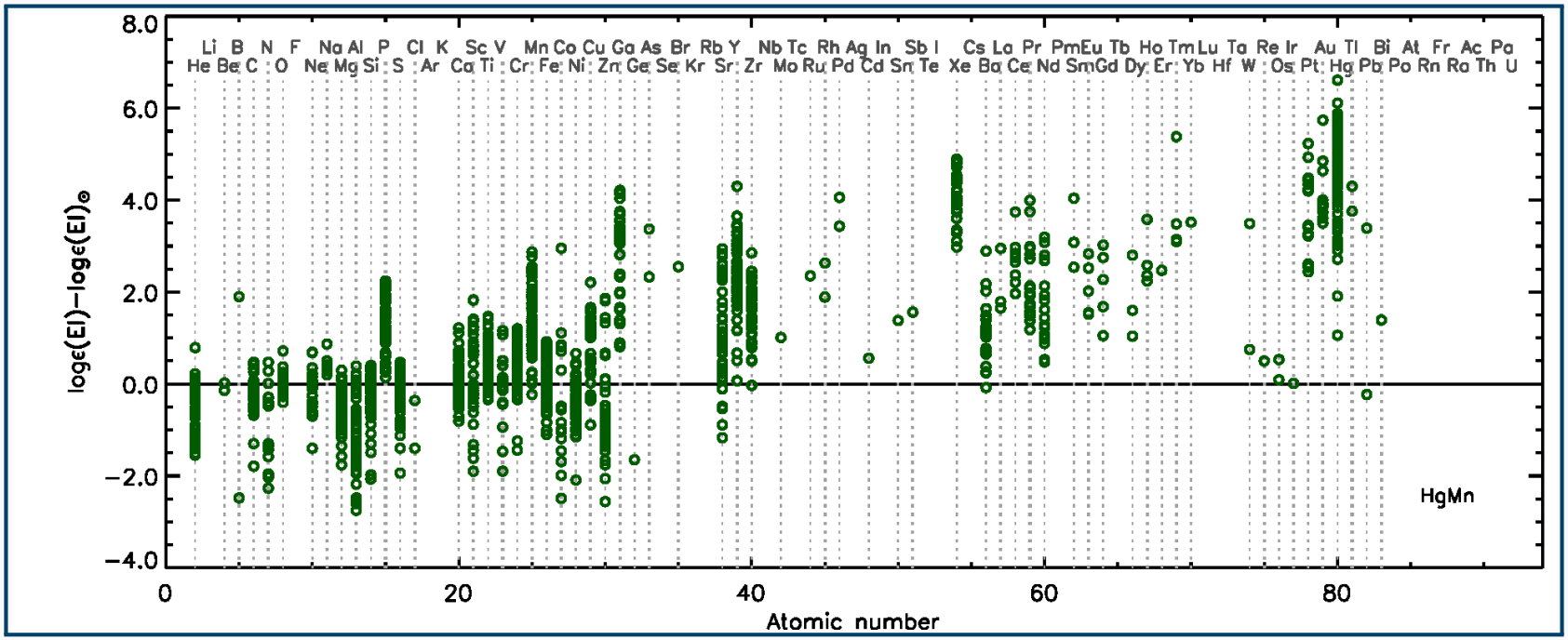
Table 1: Basic characteristics of main-sequence chemically peculiar stars ("Atomic Diffusion in stars", Michaud, Alecian, Richer 2015).

Known HgMn stars:

– 196 (visual, many publications)

– 260 (infrared APOGEE: Chojnowski et al. 2020)

HgMn stars

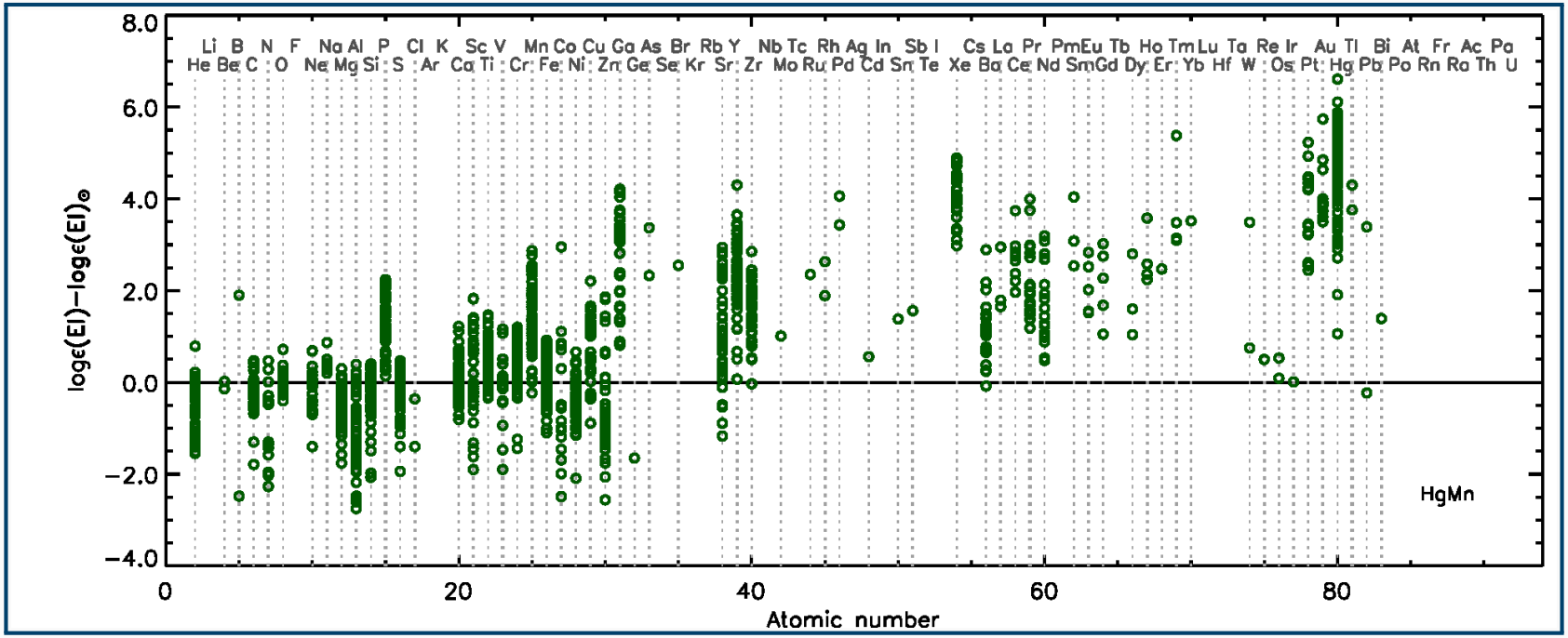


Overabundant elements: **Hg, Mn**, P, Ga, Y, Xe, Pt, Au
Underabundant elements: **He**, Mg, Al, Si, Zn
(Ghazaryan S. and Alecian G. 2016, MNRAS, 460, 1912)

$< v \sin i > \approx 30\,\mathrm{km\,s^{-1}}$

Binarity: 60% or more

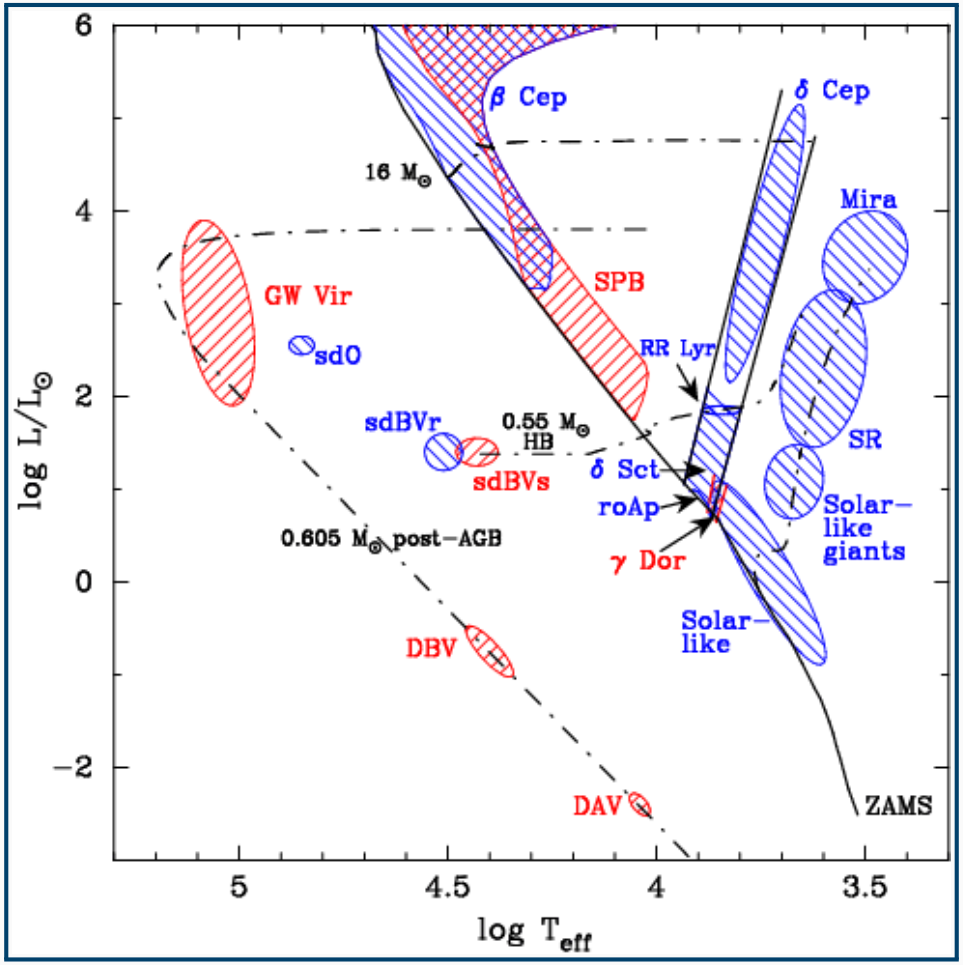
HgMn stars



Big questions concerning HgMn stars:

- the origin of peculiarity: diffusion, stratification of elements
- mass loss
- magnetic fields (is rotational variability a good proof?)
- binarity: are all HgMn stars in binary systems?
- pulsations?

HR diagram and pulsating stars

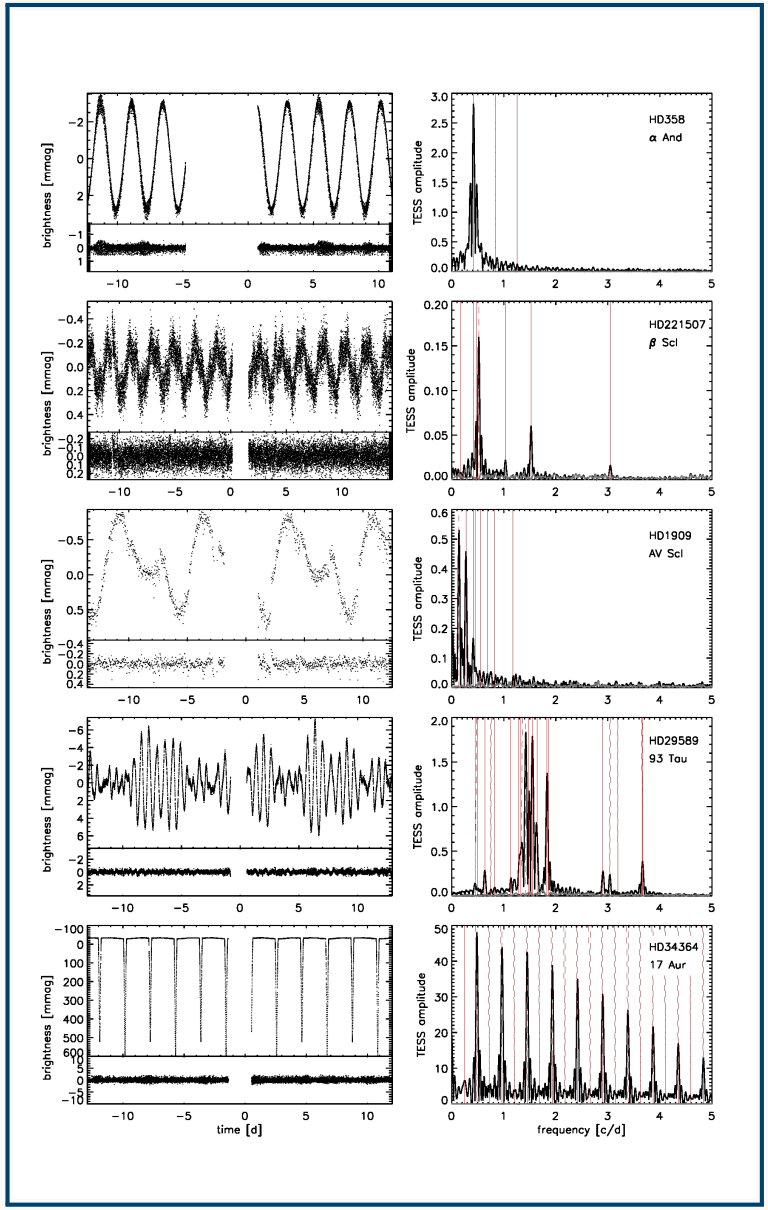


– SPB (B3-B8): variability is caused by gravity modes;
– κ-mechanism operating in a layer where the main source of opacity is bound–bound transitions of Fe-group elements;
– diffusion – the increase in opacity – variability!

HgMn stars – TESS photometry

TESS data:

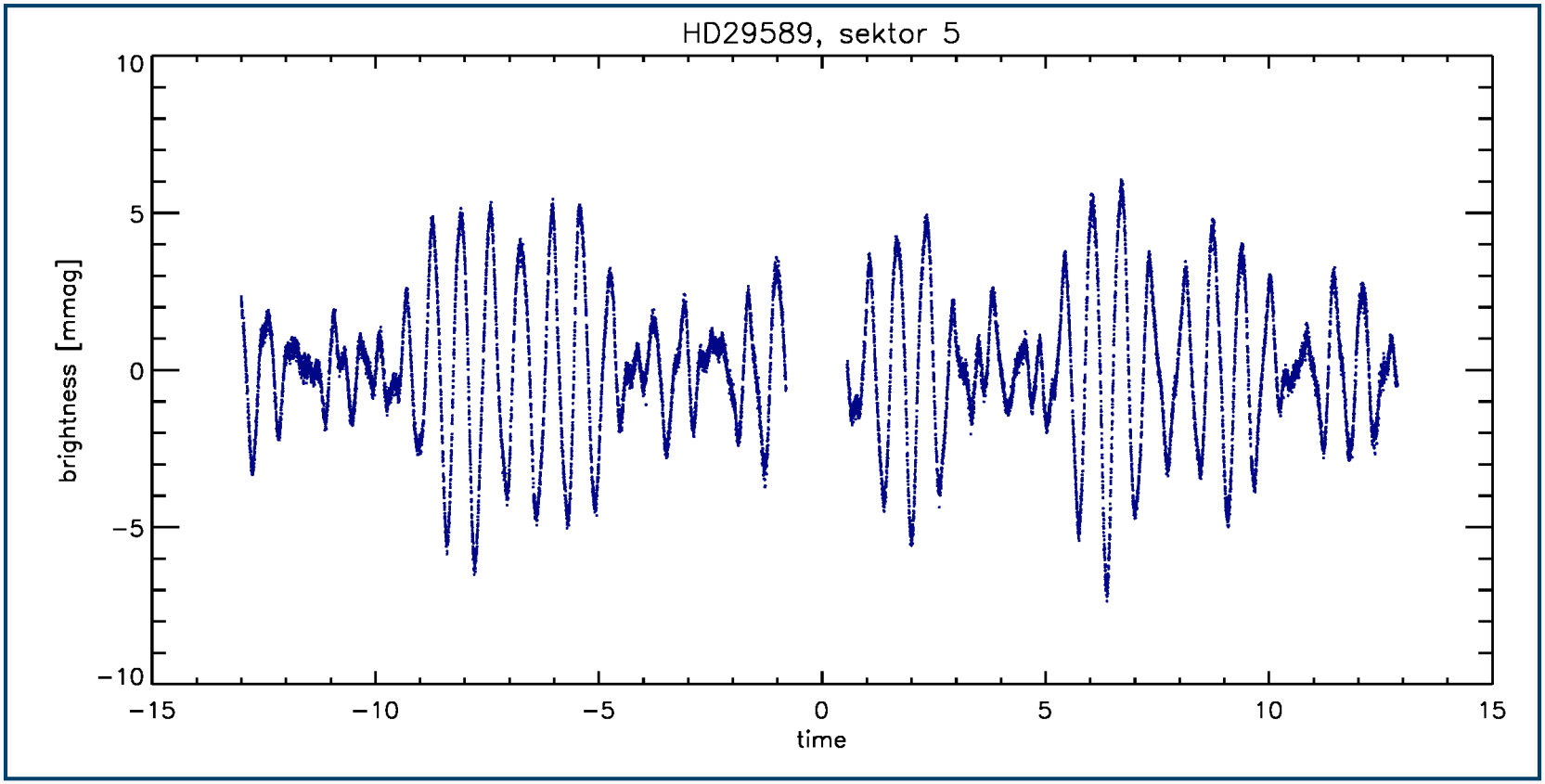
- $\approx$ 300 HgMn stars observed;
- 70: 2-min (MAST); FFI (TESScut);
- >200 stars: good quality data;
- binarity/rotational variability;
- constant stars;
- pulsations!



HD 29589

HD 29589: chemically peculiar HgMn & SPB pulsator?

TESS, 2-min, sectors: 5, 32, 43, 44



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HD 29589

HD 29589 (93 Tau, HR 1484, B8 IV); CP star (He): Frost et al. (1926), Mn star: Wolff & Wolff (1974); HgMn star: Wolff & Preston (1978).

No magnetic field? (Makaganiuk et al.2011).

Binarity:
– X-ray emission (Rosat) $\rightarrow$ binary system, PMS star (Hubrig et al. 1998, 2001);
– IR, ESO Adonis@3.6 m $\rightarrow$ secondary: K=17.3 mag, distance 10" (field star?; Hubrig et al. 2001);
– Gaia DR2 astrometry $\rightarrow$ secondary: 0.12 $M_\odot$ (Kervella et al. 2019).

Interferometry: PIONIER@VLTI (2017), H-band, secondary: separation $73 - 75$ mas, position angle: $\approx 119^\circ$, linear distance $9.1 - 9.3$ au ($\pi = 8.02 \pm 0.16$ mas, Gaia DR2); $\Delta H = 2.40 \pm 0.07$ mag.

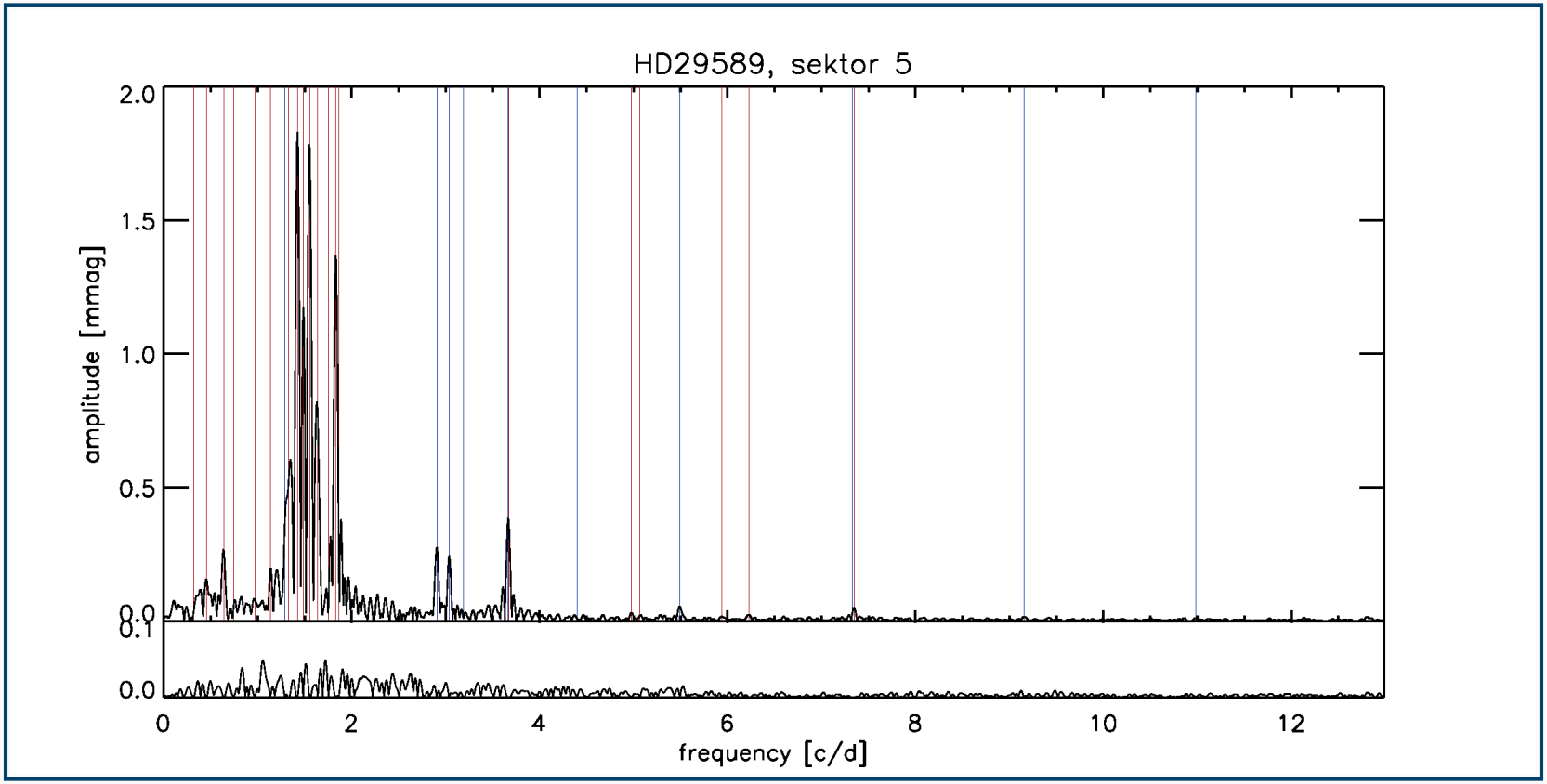
No sign of secondary in spectroscopic data.

HD 29589: TESS photometry

HD 29589: chemically peculiar HgMn & SPB pulsator

TESS, 2-min, sectors: 5, 32, 43, 44

15 independent frequencies + combinations and harmonics



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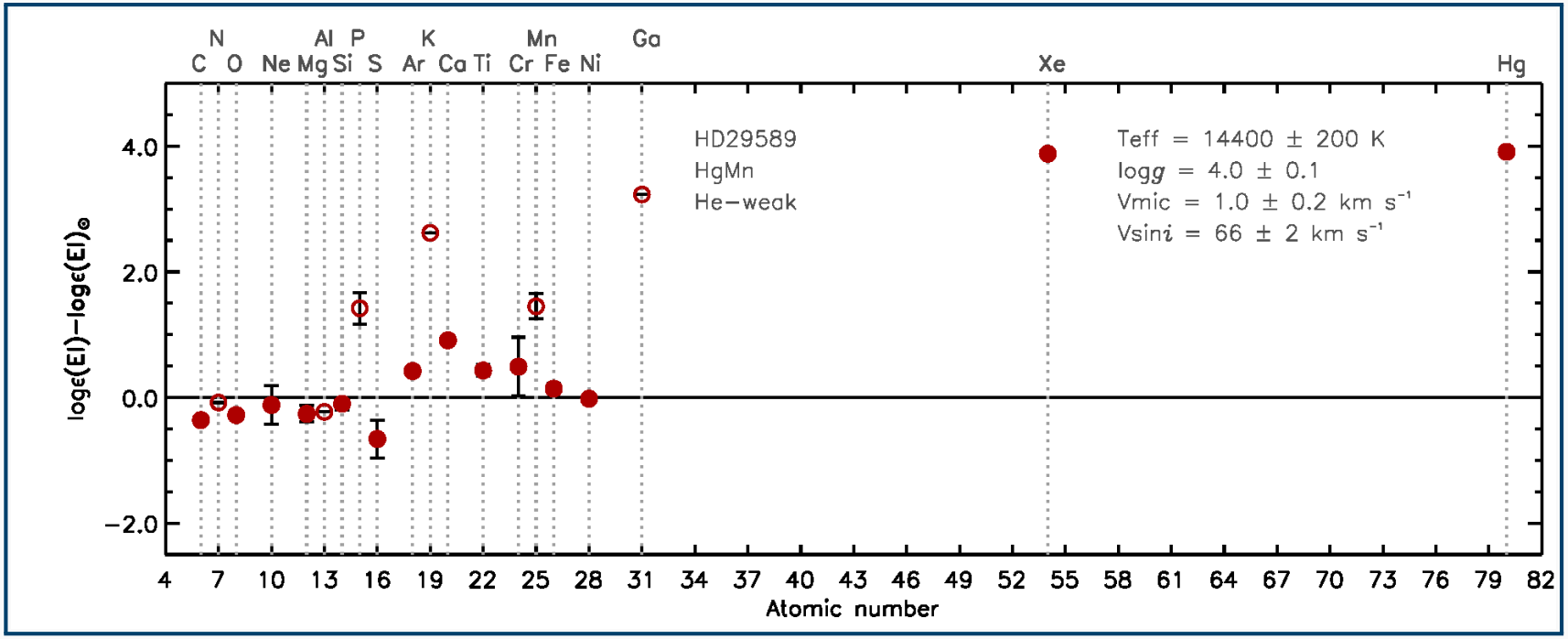
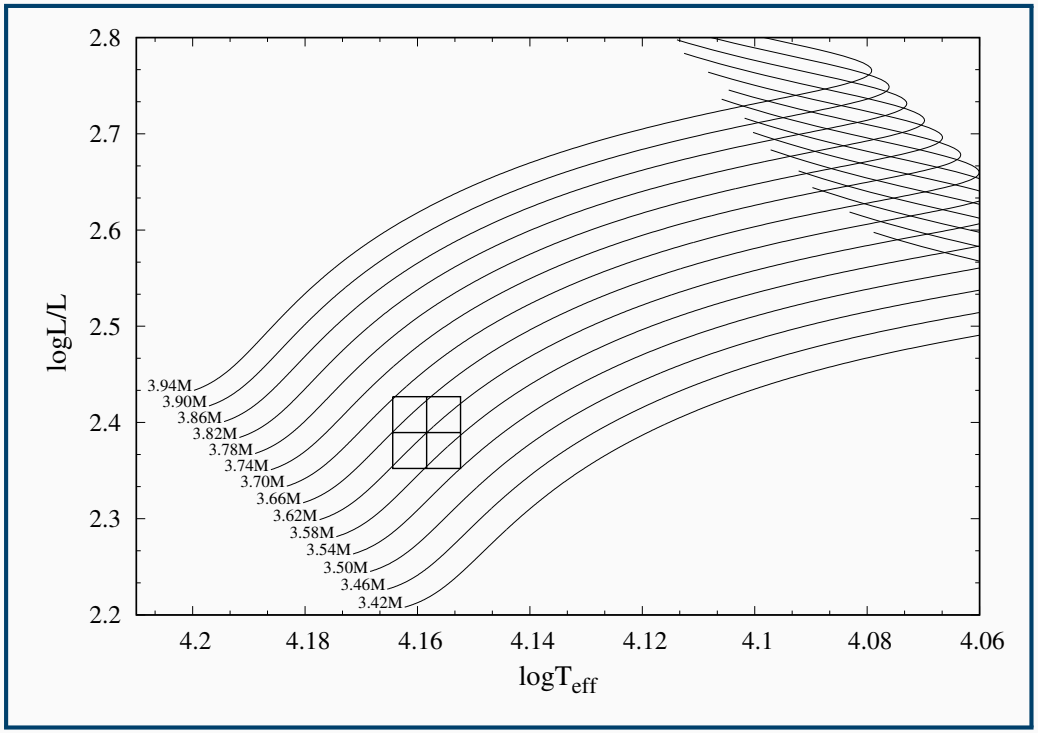
HD 29589: spectroscopy



FEROS: 5 spectra.
Atmospheric parameters and chemical composition of HD 29589.

HD 29589: HR diagram

- $V = 5.445(9)$ mag
  $G = 5.399$ mag (Gaia)
- $d = 123.826^{+3.1}_{-2.6}$ pc (Starhorse Catalogue, Gaia)
- $E(B-V) = 0.0205$ mag (Green et al. 2018)
- Bolometric corrections: Pedersen et al. (2020)
  $BC_{\mathrm{V}} = -1.139(35)$
  $BC_{\mathrm{G}} = -1.112(35)$
- Final value:
  $\log L/L_{\odot} = 2.390 \pm 0.037$



HR diagram and the position of HD 29589.

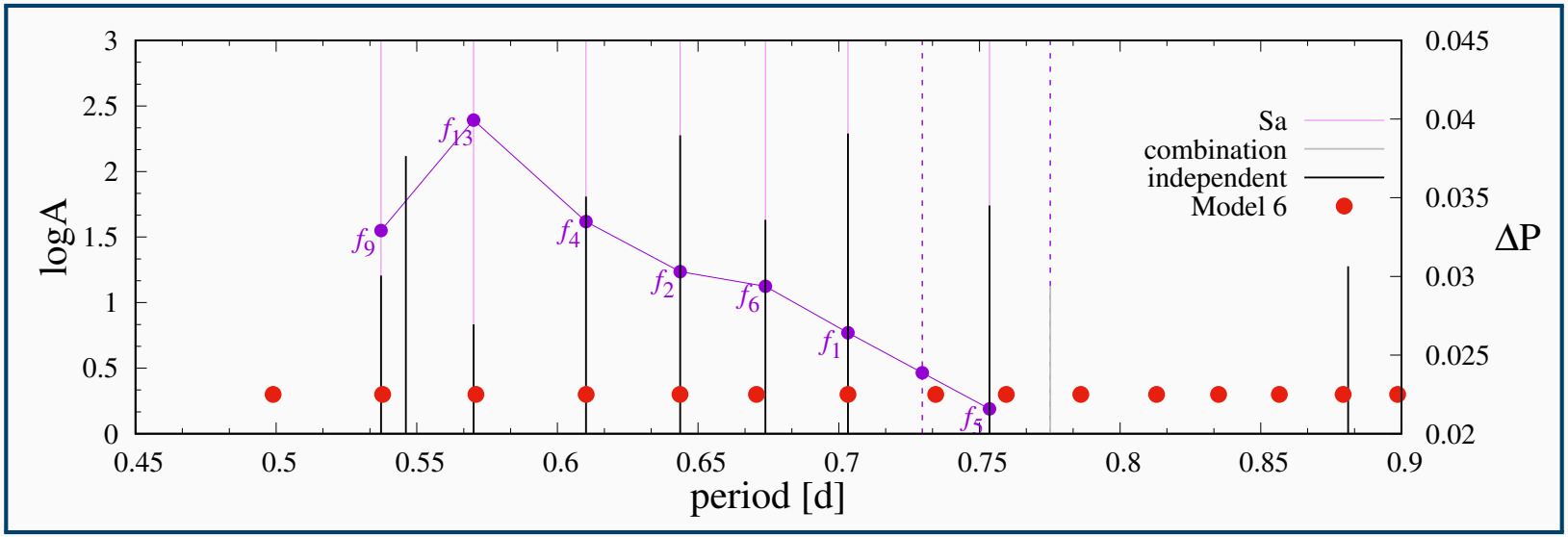
HgMn stars – seismic modelling

HD 29589: chemically peculiar HgMn & SPB pulsator

15 independent frequencies + combinations and harmonics

Frequencies: g-modes – SPB

Regular period spacing



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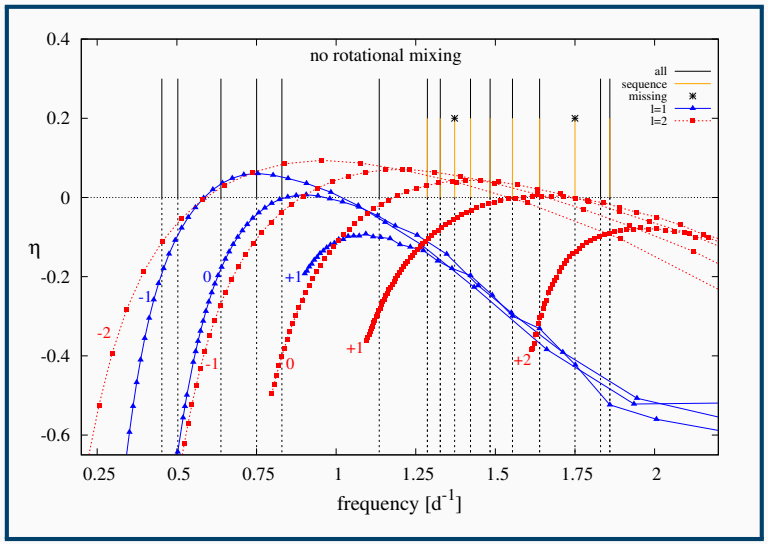
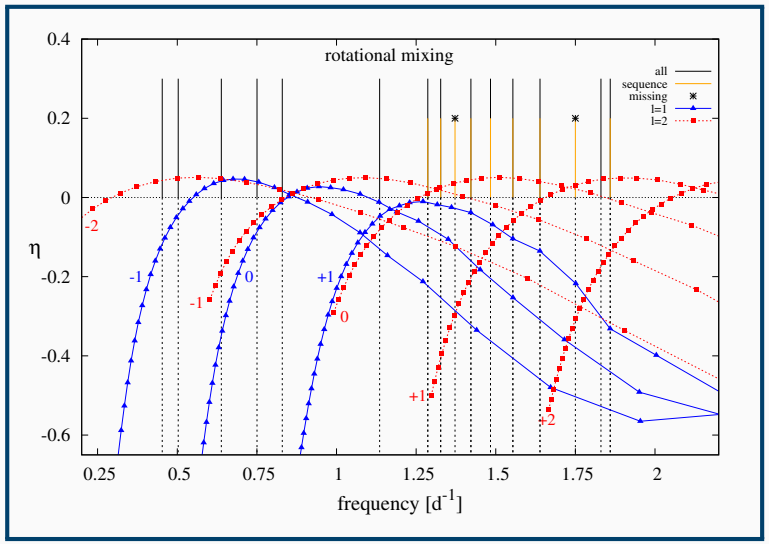
Asteroseismology

Asteroseismology – the study of the internal structure of stars through the interpretation of their frequency spectra.

Different oscillation modes penetrate to different depths inside the star – stellar interiors can be probed from oscillations.

Asteroseismology – the only available method to derive the internal structure of the stars with high precision.





The instability parameter η for the model without and with rotational mixing.

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Asteroseismology of HD 29589

Analysis of HD 29589:

- first HgMn star & SPB pulsator;
- regular period spacing;
- results of seismic analysis:
  overshooting parameter: $f_{\rm ov} = 0.028 - 0.03$;
  mass: $M \sim 3.4 M_{\odot}$;
  $X \sim 0.7$, $Y = 0.292$, $Z = 0.008$;
- rotational mixing in the star;

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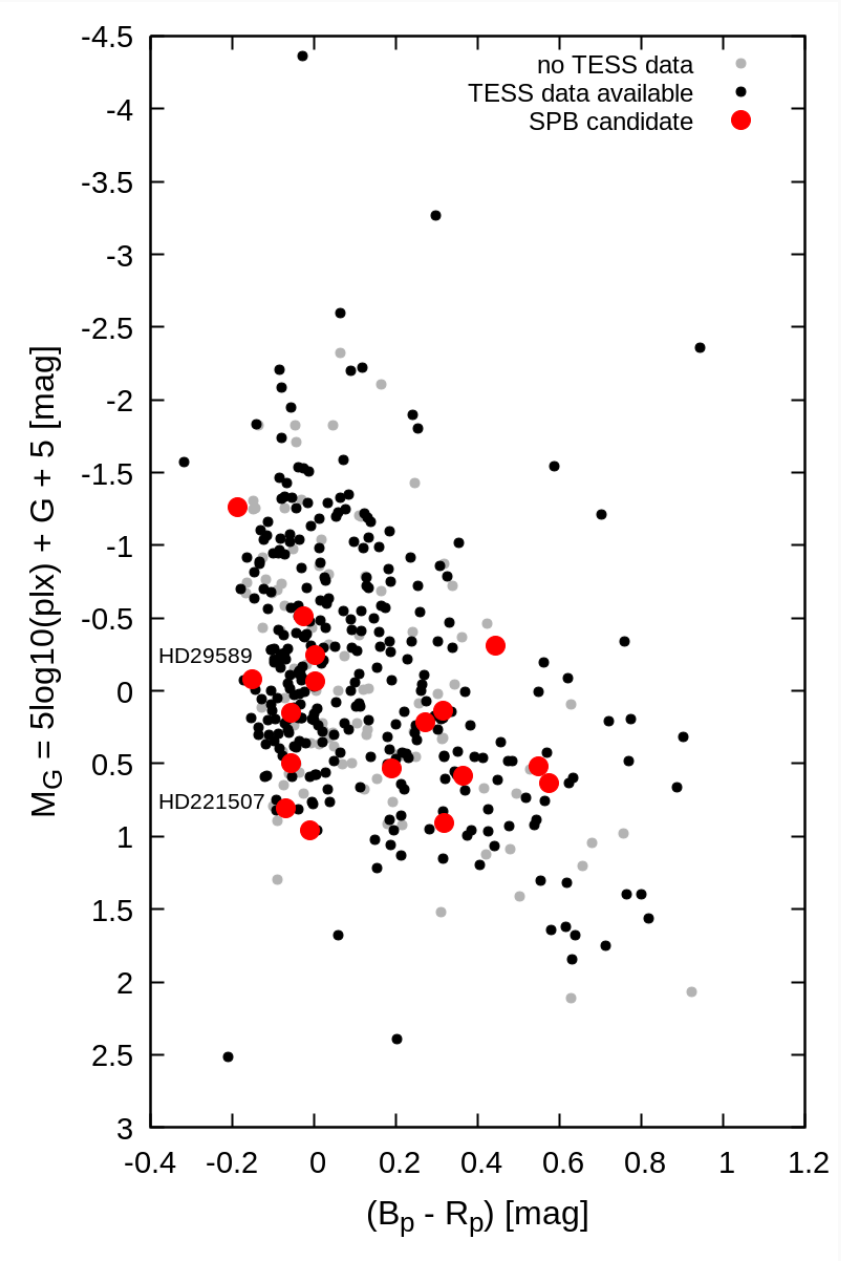
HgMn stars – photometry

TESS data:

- $\approx$ 300 HgMn stars observed;
- 70: 2-min (MAST); FFI (TESScut);
- $>$200 stars: good quality data;
- binarity/rotational variability;
- constant stars;
- pulsations: 18 stars



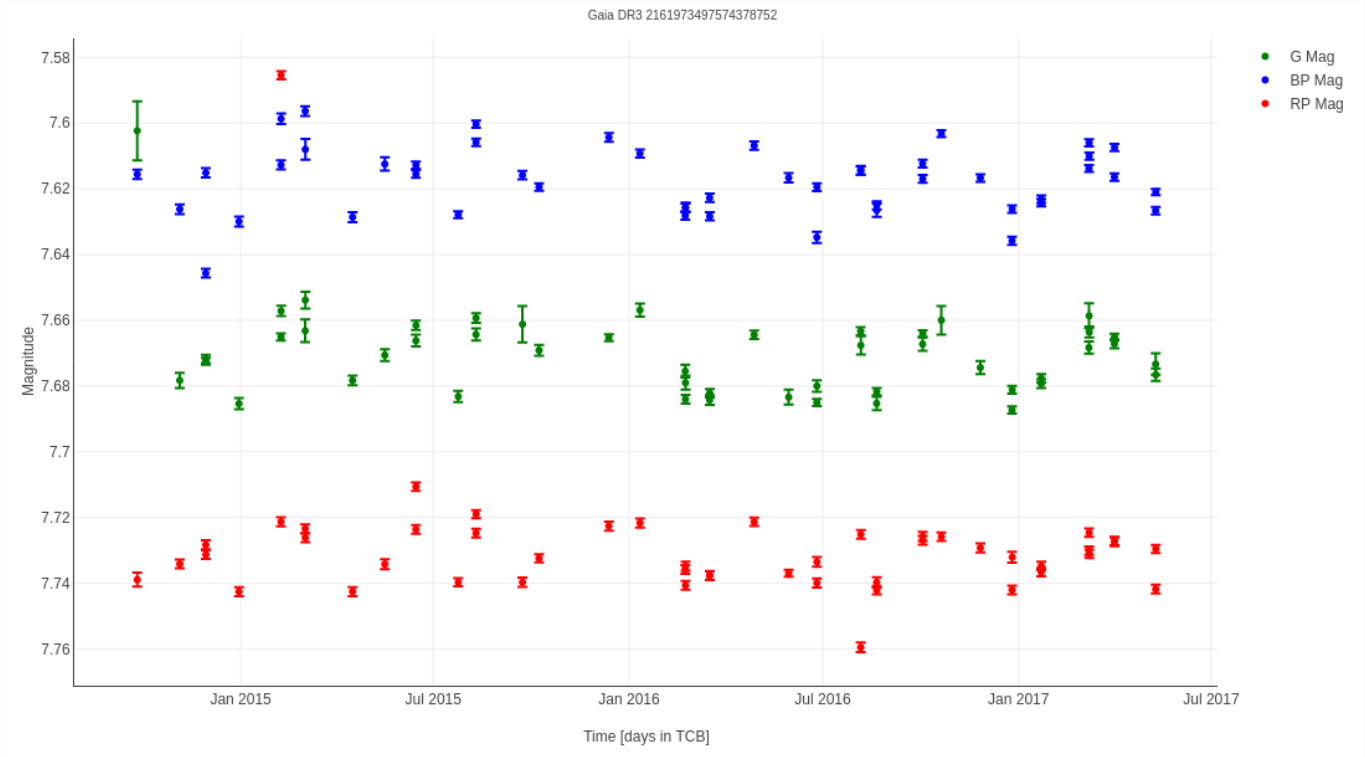
HgMn stars

Best set of data:

Photometric data (like TESS): the type of variability.

Spectroscopy: high-resolution data: atmospheric parameters, chemical abundances, rotational velocity.

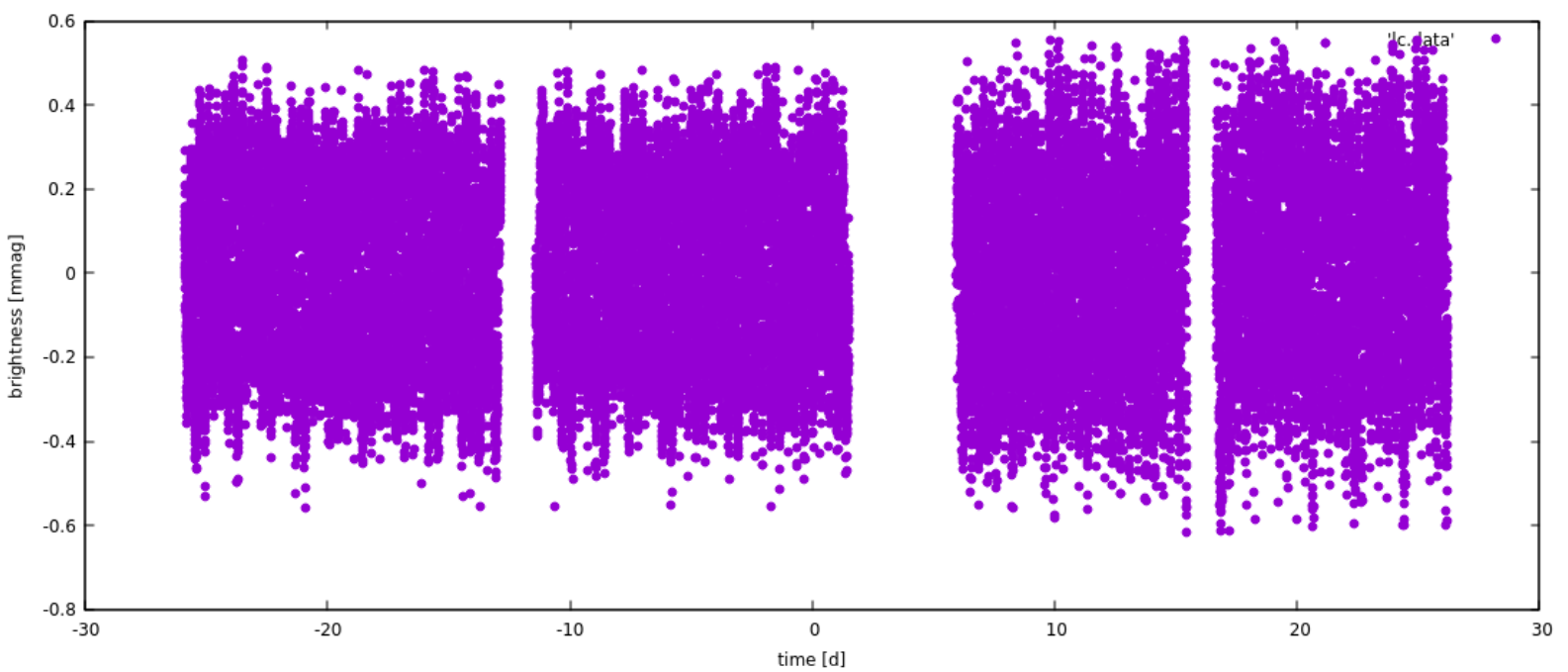
Gaia: binarity indication, parallaxes, variability?, atmospheric parameters?



HgMn stars: TESS photometry

HD 14228

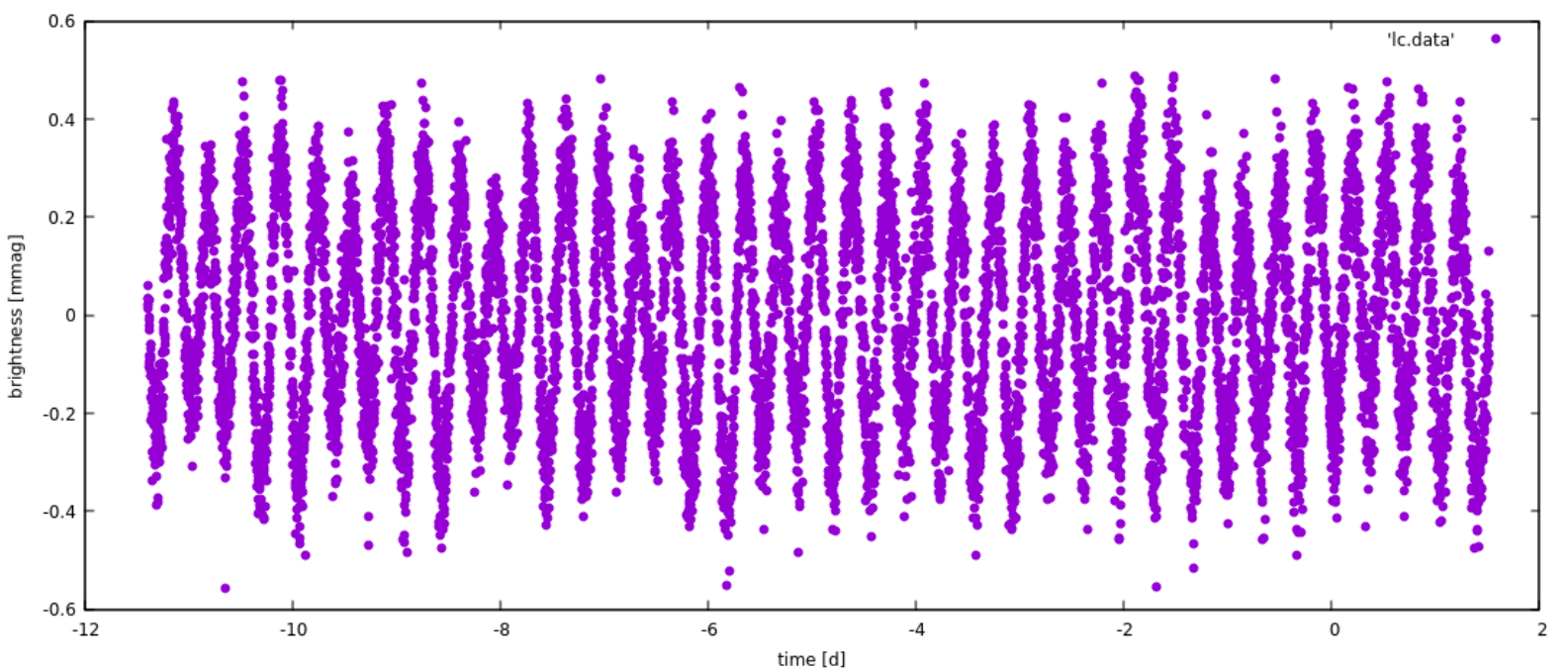
2-min i FFI; sectors: 2, 3, 29, 30



HgMn stars: TESS photometry

HD 14228

2-min i FFI; sectors: 2, 3, 29, 30



HgMn stars: TESS photometry

HD 14228, ϕ Eri, $V = 3.57$, B8 IV Mn Hg, $T_{\rm eff} = 12400 - 14100$ K

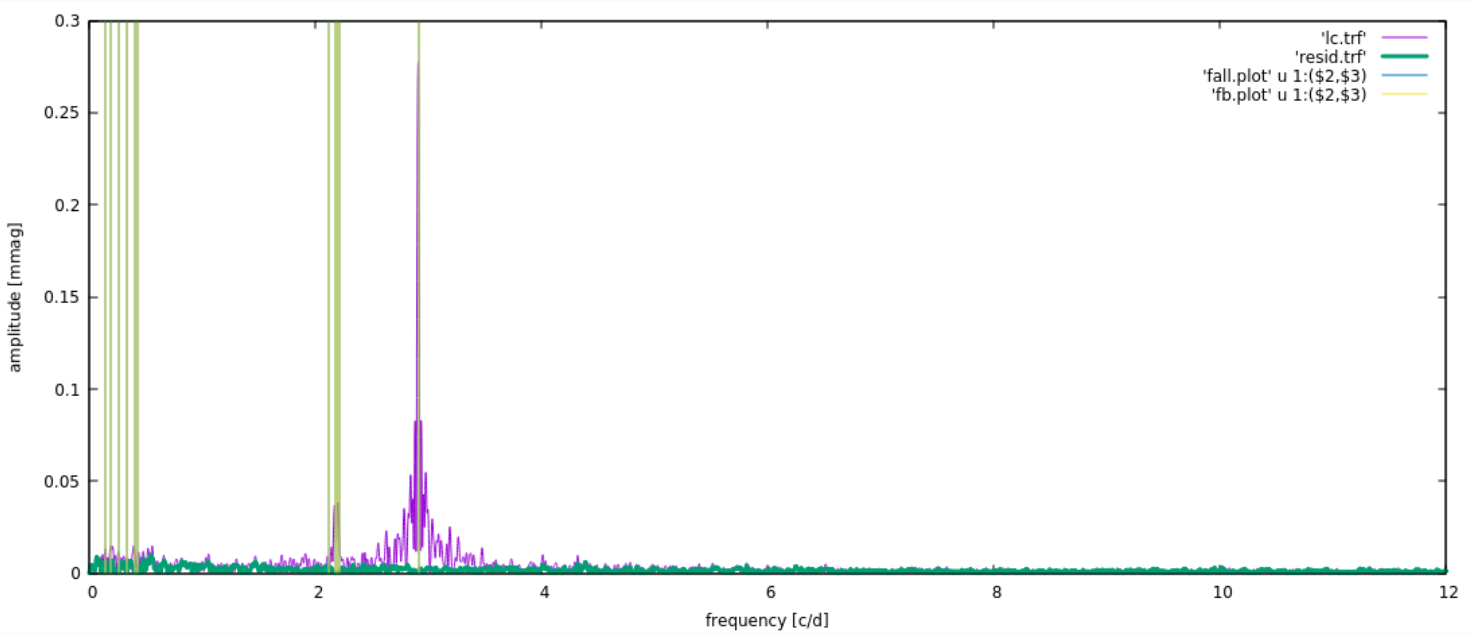
– 11 independent frequencies (0.2 - 3 d^{-1})

– amplitudes: 0.276 - 0.012 mmag

– rot?: Balona et al. (2019); SPB?/rot: Pedersen et al. (2019), SPB/rot: Kochukhov et al. (2021)

– HgMn (Schneider 1981, Renson & Manfroid 2009)

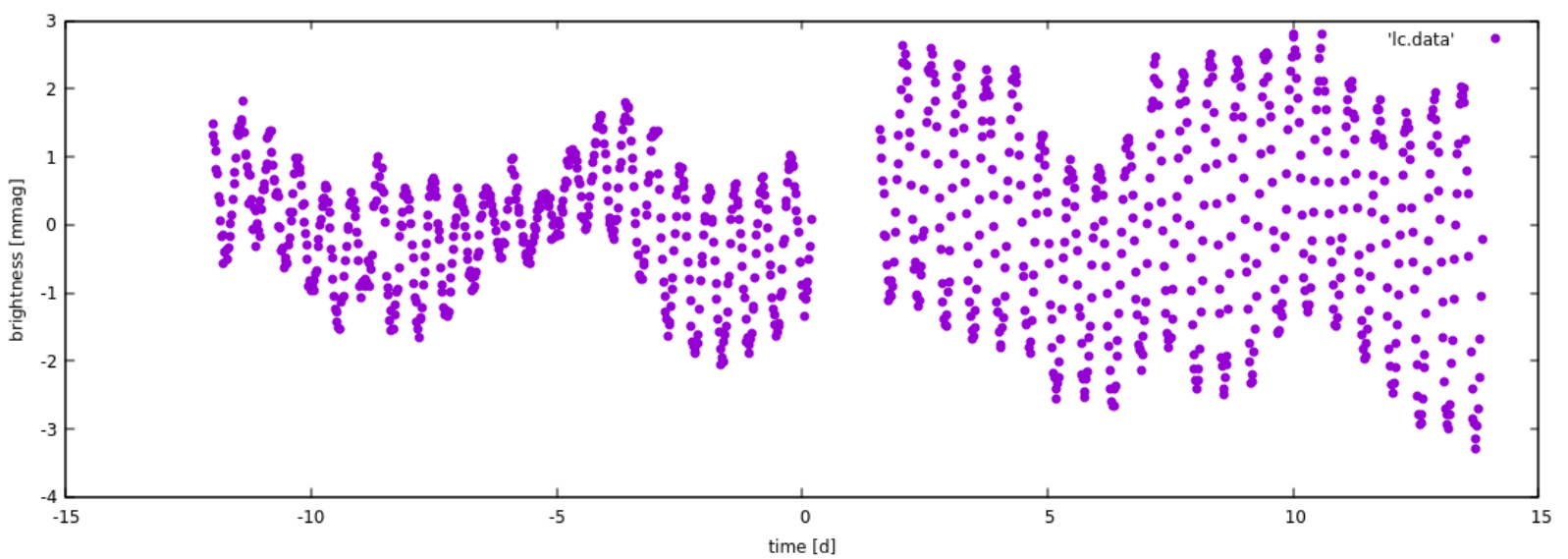
– binary system: separation 90" (Washington Double Star Catalogue)



HgMn stars: TESS photometry

HD 33647

FFI; sectors 5, 32



HgMn stars: TESS photometry

HD 33647, $V = 6.667$, B8 II/III, B9 Mn Hg, $T_{\rm eff} = 11780$ K

– independent frequencies (10) plus combinations and harmonics

– amplitudes: 1.450 - 0.040 mmag

– triple system: SB2 ($P = 25.365$ d) + 0.109" ($P \sim 120$ yr)