# *Asteroseismology of PMS intermediate mass stars: the case of IP Per*

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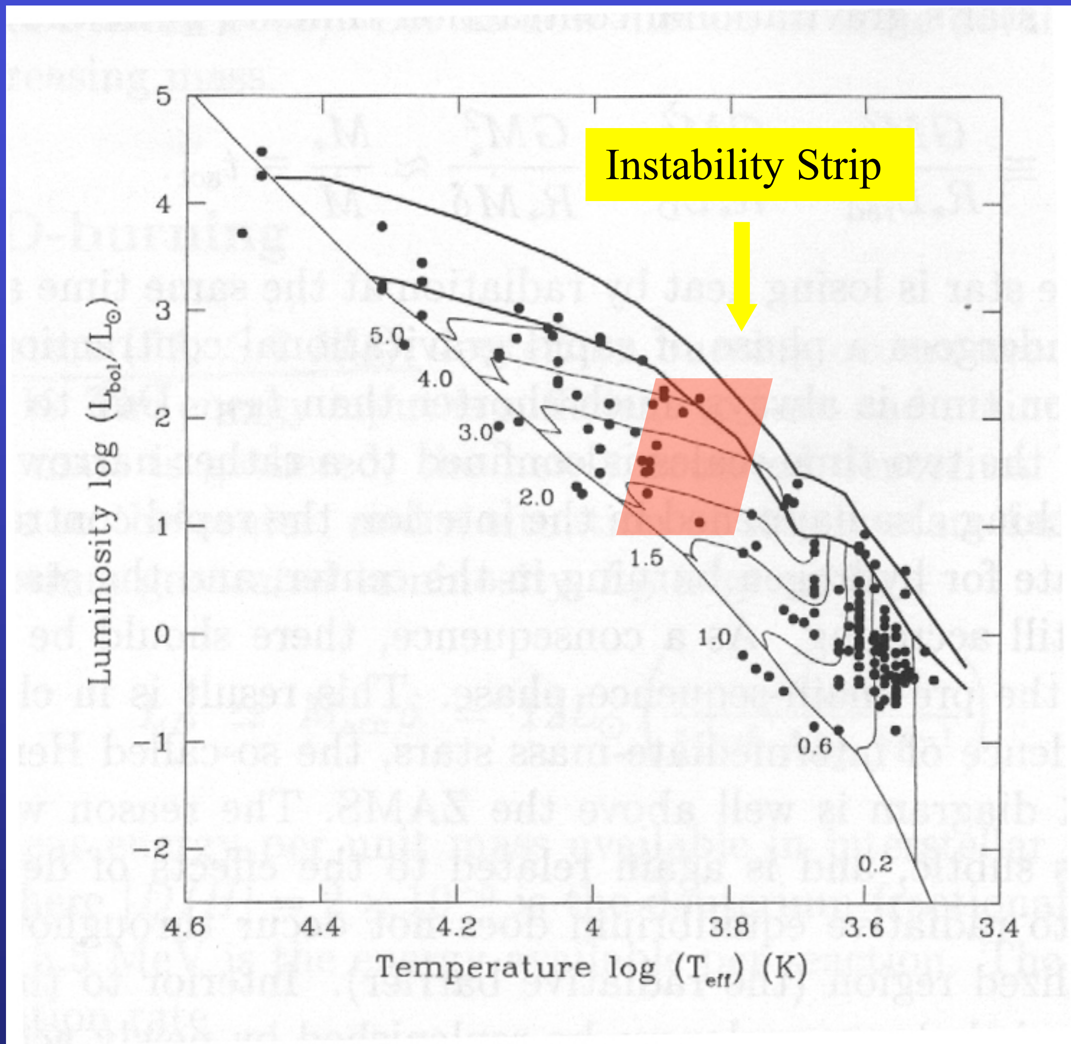
# PMS intermediate mass pulsating stars




Palla & Stahler (1993)

- Theory allows to calculate the so-called birth-line, i.e. the location of stars of different mass when they start their PMS phase.
- PMS stars contract from the birthline to their location on the Main-Sequence on the Kelvin-Helmoltz time scale: $t=3/7\cdot(GM^2)/RL$.
- During their evolution toward the MS a number of intermediate mass PMS stars are able to **cross the instability strip** of more evolved $\delta$ Scuti. Crossing times are of the order of $10^5 \div 10^6$ years

# Why to search for PMS δ Scuti stars ?

- **Determination of the intrinsic stellar parameters**

  $P\sqrt{\rho}$=cost. ⇒ P=P(M,R) but L=L(R,Te) ⇒ P=P(M,L,Te) ⇒ if L,Te are known indipendently, the comparison between a measured period and the theoretical value provides the stellar mass.

- **Determination of the inner structure**

  Pulsation (asteroseismology techniques) also allows us to probe the interior of Herbig Ae, whose structure is different from that of MS objects.

- **Stellar structure evolution**

  Frequency changes due to modifications of the interior:

  $(dP/dt)/P \approx 10^{-6}$ $yr^{-1}$ ⇒ 0.4 h in 10 years for the epoch of maxima

# 34 known or suspected PMS δ Scuti stars

Pulsating PMS Stars — May 2005

| Name | RA (2000.0) | | | DEC (2000.0) | | | Spectral Type | V | Log Teff | Log L/Lsun | Type | number of puls. frequ. | freq. with highest amp. | amplitude for highest frequency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | hh | mm | ss | dd | mm | ss | | mag | | | | | [c/d] | [mmag] |
| V 589 Mon | 6 | 39 | 28.46 | 9 | 42 | 4.1 | F2 III | 10.32 | 3.85 | 1.51 | cluster member | 19 | 6.489 | 11.15 |
| V 588 Mon | 6 | 39 | 5.9 | 9 | 41 | 3.4 | A7 III/IV | 9.73 | 3.9 | 2.05 | cluster member | 12 | 5.138 | 6.8 |
| NGC 6823 HP57 | 19 | 43 | 6.78 | 23 | 16 | 37.8 | - | 14.6 | 3.86 | 1.25 | cluster member | 2 | 12.726 | 27.0 (Ic) |
| NGC 6823 BL50 | 19 | 43 | 9.07 | 23 | 17 | 49.6 | - | 14.5 | 3.86 | 1.6 | cluster member | 2 | 13.917 | 18.0 (Ic) |
| NGC 6383 198 | 17 | 34 | 48 | -32 | 37 | 24 | - | 12.83 | 3.87 | 1.3 | cluster member | 1 | 19.024 | 20.8 / 26.4 (V/B) |
| NGC 6383 170 | 17 | 34 | 37 | -32 | 36 | 17.9 | A5 IIIp | 12.6 | 3.91 | 1.7 | cluster member | 5 | 14.376 | 12.5 / 16.0 (V/B) |
| IC 4996 40 | 20 | 16 | 30 | 37 | 39 | 32.8 | A4 | 15.03 | 3.93 | 1.26 | cluster member | 1 | 33.569 | 7.6 / 8.5 (V/B) |
| IC 4996 37 | 20 | 16 | 22 | 37 | 39 | 31 | A5 | 15.21 | 3.91 | 1.26 | cluster member | 1 | 31.875 | 4.6 / 4.6 (V/B) |
| IC 348 H 254 ★ | 3 | 44 | 31.2 | 32 | 6 | 22.1 | F0 (A8 III-IV) | 10.6 | 3.85 | 1.62 | cluster member | 4 | 7.406 | 5.4 |
| NGC 6530 5 | 18 | 4 | 42.3 | -24 | 18 | 3.5 | - | 13.59 | 3.92 | 1.2 | cluster member | 2 | 46.596 | 1.4 / 1.8 (V/B) |
| NGC 6530 82 | 18 | 4 | 30.83 | -24 | 23 | 42.1 | - | 13.97 | 3.88 | 1.01 | cluster member | 3 | 38.531 | 2.4 / 2.8 (V/B) |
| NGC 6530 85 | 18 | 4 | 20.67 | -24 | 24 | 55.7 | A1 III | 13.07 | 3.86 | 1.37 | cluster member | 5 | 15.579 | 30.2 / 39.1 (V/B) |
| NGC 6530 263 | 18 | 4 | 21.78 | -24 | 15 | 46.9 | - | 13.67 | 3.87 | 1.13 | cluster member | 1 | 19.223 | 7.1 / 8.3 (V/B) |
| NGC 6530 278 | 18 | 4 | 13.95 | -24 | 13 | 28 | A0/A5 | 12.17 | 3.9 | 1.75 | cluster member | 9 | 7.199 | 6.6 / 9.4 (V/B) |
| NGC 6530 281 | 18 | 4 | 0.24 | -24 | 15 | 2.6 | - | 13.35 | 3.92 | 1.29 | cluster member | 7 | 43.418 | 4.2 / 4.7 (V/B) |
| V 351 Ori ★ | 5 | 44 | 18.79 | 0 | 8 | 40.4 | A7 IIIe | 8.9 | 3.87 | 1.15 | HAEBE | 5 | 15.687 | 22.9 |
| V 346 Ori ★ | 5 | 24 | 42.8 | 1 | 43 | 48.3 | A5 III | 10.1 | 3.89 | 0.98 | HAEBE | 4 | 35.200 | 3.9 / 3.6 / 2.9 (UBV) |
| UX Ori | 5 | 4 | 30 | -3 | 47 | 14.28 | A3e | 9.6 | 3.94 | 1.49 | HAEBE | suspected | suspected | suspected |
| IP Per ★ | 3 | 40 | 46.97 | 32 | 31 | 53.7 | A7 V | 10.4 | 3.89 | 0.97 | HAEBE | 9 | 22.890 | 6.0 |
| HR 5999 | 16 | 8 | 34.29 | -39 | 6 | 18.3 | A7 III/IVe | 6.98 | 3.85 | 2.12 | HAEBE | 1 | 4.812 | 7.5 / 5.7 / 5.6 (UBV) |
| HD 35929 ★ | 5 | 27 | 42.79 | -8 | 19 | 38.4 | F0 IIIe | 8.2 | 3.86 | 1.92 | PMS ? | 1 | 5.100 | 20.0 |
| HD 142666 | 15 | 56 | 40.2 | -22 | 1 | 40 | A8 Ve | 8.81 | 3.88 | 1.03 | HAEBE | 1 | 21.430 | 5.1 |
| HD 104237 | 12 | 0 | 5.08 | -78 | 11 | 34.6 | A4 V | 6.6 | 3.93 | 1.5 | HAEBE | 2 (3?) | 33.290 | 11.2 |
| CQ Tau ★ | 5 | 35 | 58 | 24 | 44 | 54 | F2 IVe | 10.7 | - | - | HAEBE | 1 | 14.000 | 40.0 |
| BF Ori ★ | 5 | 37 | 13.3 | -6 | 35 | 0.6 | A5II-IIIevar | 10.3 | 3.83 | 1.48 | HAEBE | 1 (?) | 5.700 | 60.0 |
| HD 34282 | 5 | 16 | 0.5 | -9 | 48 | 35.4 | A0e | 9.85 | 3.94 | 1.15 | HAEBE | 2 | 79.500 | 10.7 / 8.2 / 8.2 (uby) |
| V 1247Ori | 5 | 38 | 5.3 | -1 | 15 | 21.7 | A5III | 9.82 | 3.86 | 1.2 | PMS ? | 1 | 10.300 | 20.0 |
| beta Pic | 5 | 47 | 17.1 | -51 | 3 | 59.5 | A5 V | 3.86 | 3.91 | 1.05 | PMS ? | 2 (3?) | 47.436 | 1.52 (spectroscopic) |
| VV Ser ★ | 18 | 28 | 49 | 0 | 8 | 39 | A2e | 11.5 | 3.85 | 2.13 | HAEBE | 2 (3?) | 6.100 | 10.0 |
| V 375 Lac ★ | 22 | 34 | 40.9 | 40 | 40 | 5 | A7e | 12.94 | 3.86 | 2.08 | HAEBE | 2 | 5.100 | 36.0 |
| WW Vul ★ | 19 | 25 | 58.7 | 21 | 12 | 31 | A3e | 10.51 | - | - | HAEBE | 1 (?) | ~4 | 4.0 |
| PX Vul ★ | 19 | 26 | 40.3 | 23 | 53 | 49 | F0Ve | 11.67 | - | - | HAEBE | 1 (?) | ~5 | 40.0 |

★ =Variables studied by our group

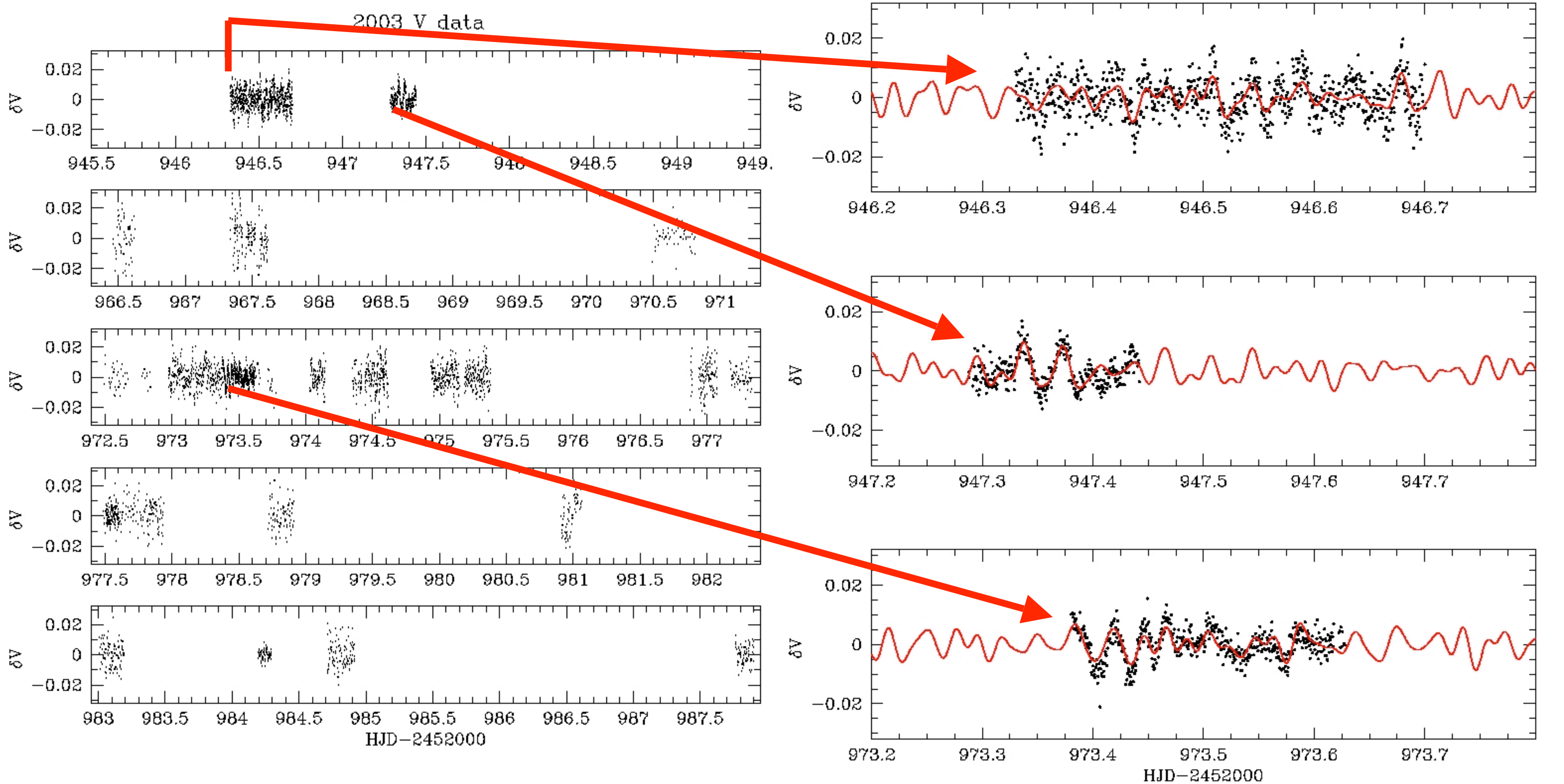
From http://ams.astro.univie.ac.at/pms.php

# Pulsation in IP Per: results from a multisite campaign

•IP Per is a Herbig Ae star with: V=10.34, sp. type A7V, logL/L~1.0±0.05, Teff ~8000±200 K (Miroshinichenko et al. 2001).

•We carried out a multisite campaign in BV involving 9 telescopes for a total of ~170h of observations (Ripepi et al. 2005 A&A submitted).

# Pulsation in IP Per: results from a multisite campaign




All campaign data

Loiano data

# Frequency analysis results

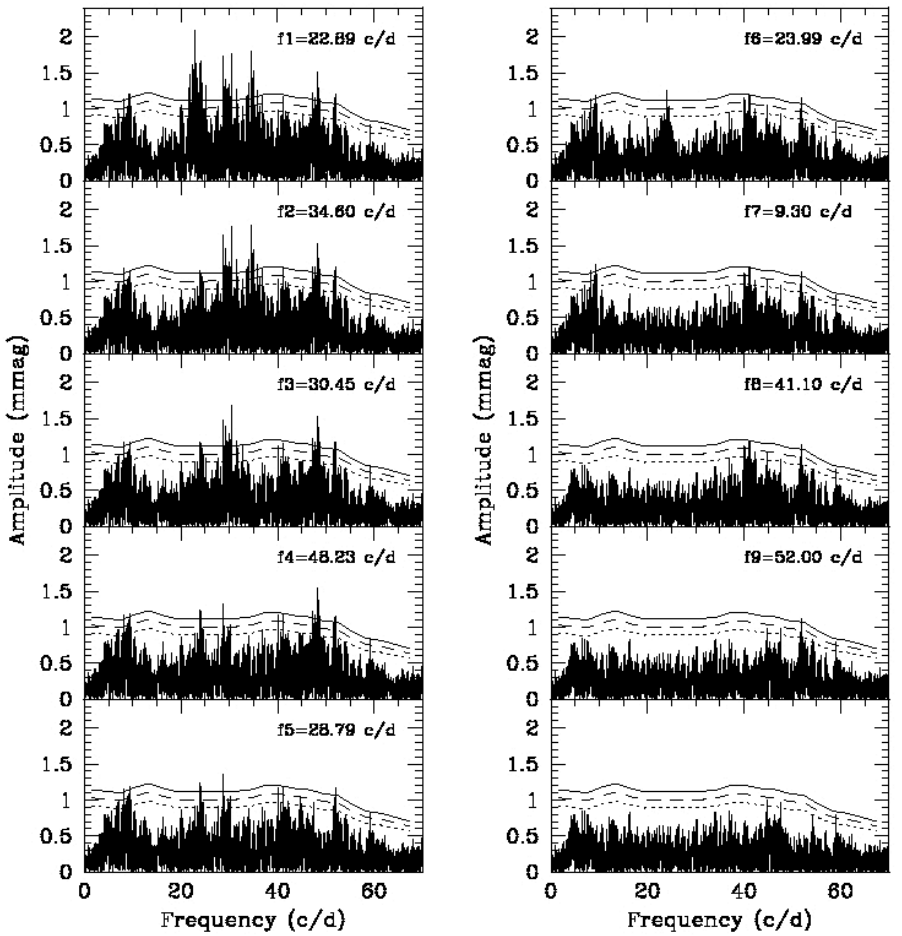
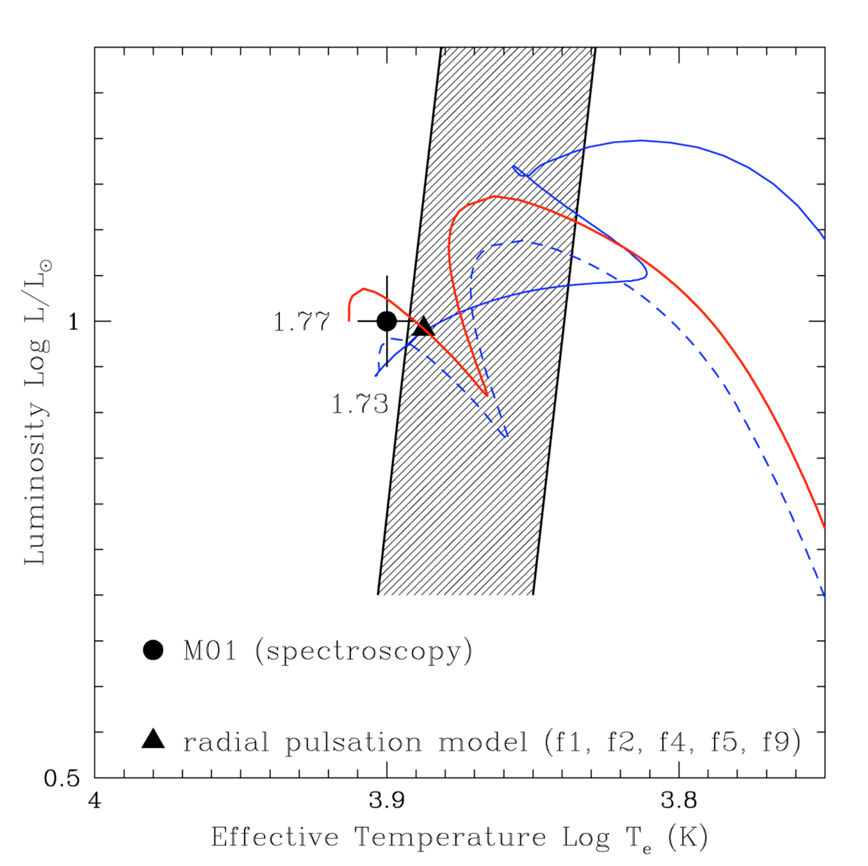



**Table 3.** Frequencies, amplitudes and confidence levels for the three dataset analysed in this paper. The errors on the frequencies are 0.25 c/d, 0.15 c/d and 0.11 c/d for the datasets 2002 B, 2003 B and 2003 V respectively.

| | 2002 B dataset | | | | 2003 B datset | | | | 2003 V dataset | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frequency (c/d) | Amplitude (mmag) | confidence (%) | | Frequency (c/d) | Amplitude (mmag) | confidence (%) | | Frequency (c/d) | Amplitude (mmag) | confidence (%) |
| $f_1$ | 30.48 | 3.2 | 99.9 | $f_1$ | 22.89 | 3.1 | 99.9 | $f_1$ | 22.89 | 1.9 | 99.9 |
| $f_2$ | 22.88 | 3.3 | 99.9 | $f_2$ | 34.82 | 2.4 | 99.9 | $f_2$ | 34.60 | 1.5 | 99.9 |
| $f_3$ | 34.64 | 3.3 | 99.9 | $f_3$ | 48.45 | 2.3 | 99.9 | $f_3$ | 30.45 | 1.8 | 99.9 |
| $f_4$ | 42.27 | 2.3 | 99.9 | $f_4$ | 42.37 | 1.9 | 99.9 | $f_4$ | 48.23 | 1.6 | 99.9 |
| $f_5$ | 48.31 | 1.9 | 99.9 | $f_5$ | 30.32 | 1.7 | 90.0 | $f_5$ | 28.79 | 1.5 | 99.9 |
| $f_6$ | 27.73 | 1.9 | 99.9 | $f_6$ | 51.45 | 1.3 | 90.0 | $f_6$ | 23.99 | 1.3 | 99.9 |
| | | | | | | | | $f_7$ | 9.30 | 1.3 | 99.9 |
| | | | | | | | | $f_8$ | 41.11 | 1.2 | 99.9 |
| | | | | | | | | $f_9$ | 52.00 | 1.1 | 99.9 |

**IP Per is a multiperiodic pulsator probably showing a mixture of radial and nonradial modes!**

# Radial pulsation analysis: evaluation of the mass and the position in the HR diagram



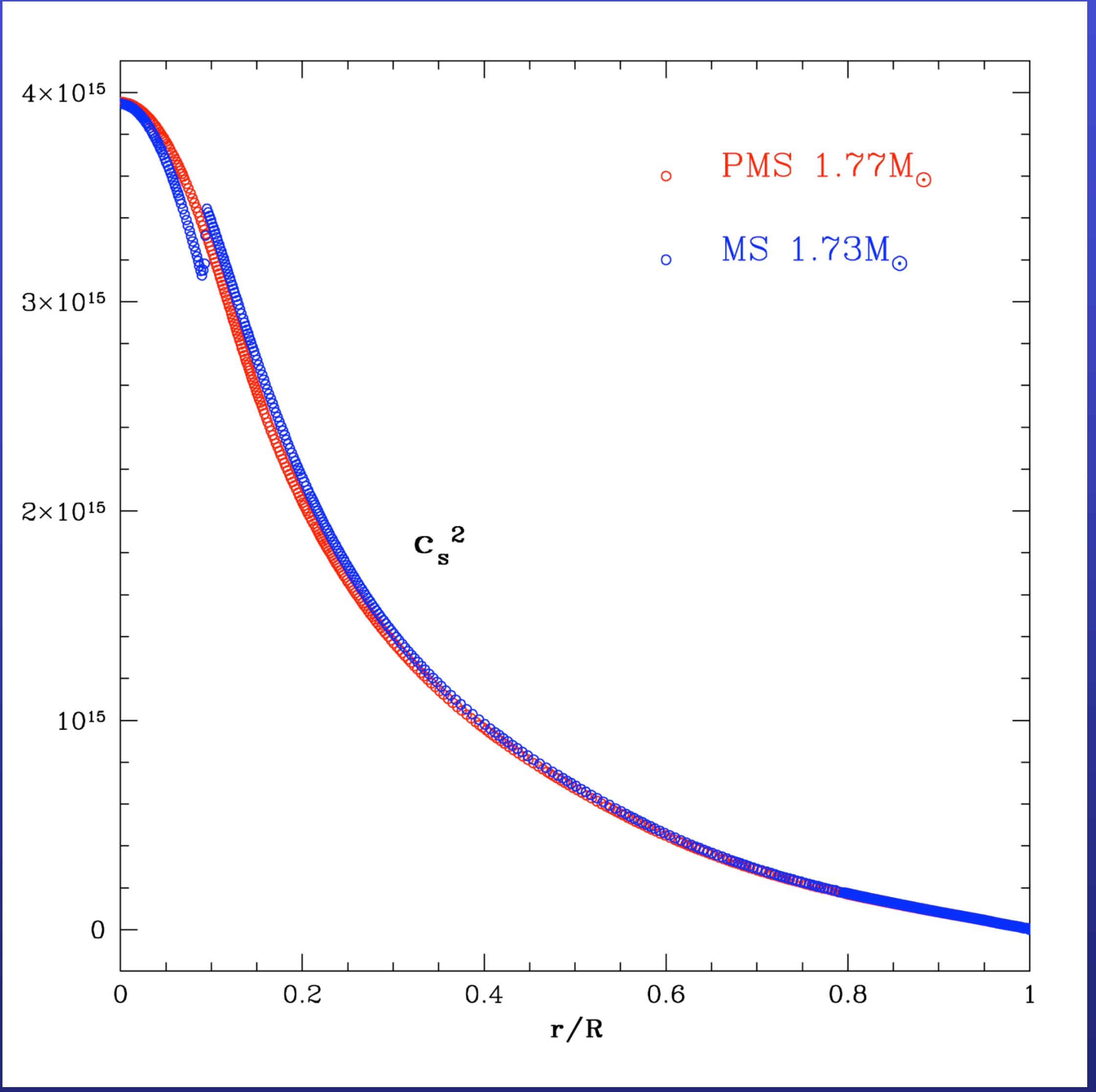

**From the computation of linear nonadiabatic pulsation models and the comparison between predicted and observed frequencies we find a best fit PMS model with 1.77Mo, logL=0.99, logTe=3.887, consistent with the empirical spettroscopic determination and reproducing five of the seven frequencies with radial modes.**

**Evolutionary tracks are computed with the FRANEC code with the physical and numerical assumptions of the ESTA/COROT Task 1**

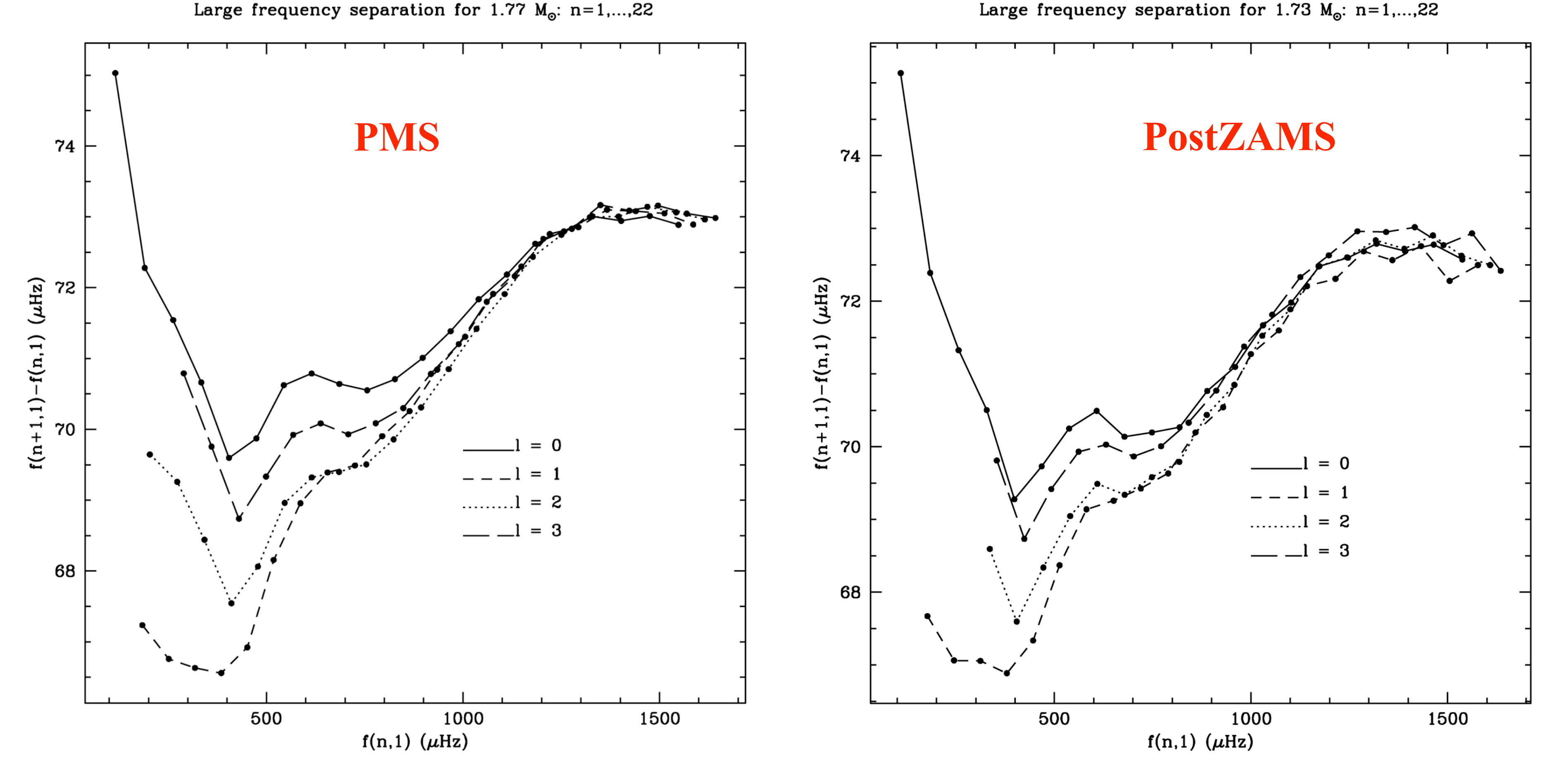
**The 1.77 Mo PMS and the 1.73 Mo postZAMS tracks intersect each other in the best-fit model position. Radial mode periodicities are quite similar for these two models ! But in both cases not all the frequencies are reproduced**

# Nonradial pulsation analysis: PMS versus post-MS models

**We applied to the evolutionary structure of the 1.77Mo PMS models and of the 1.73 MS model the Aarhus adiabatic pulsation code and computed the theoretical frequencies for l=0,1,2,3**

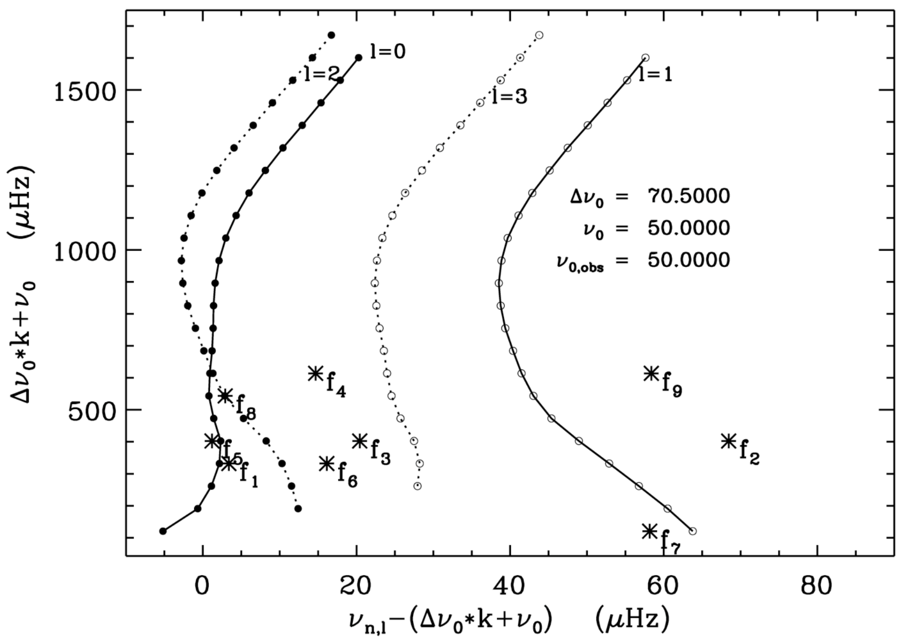


# Nonradial pulsation analysis: PMS versus post-MS models

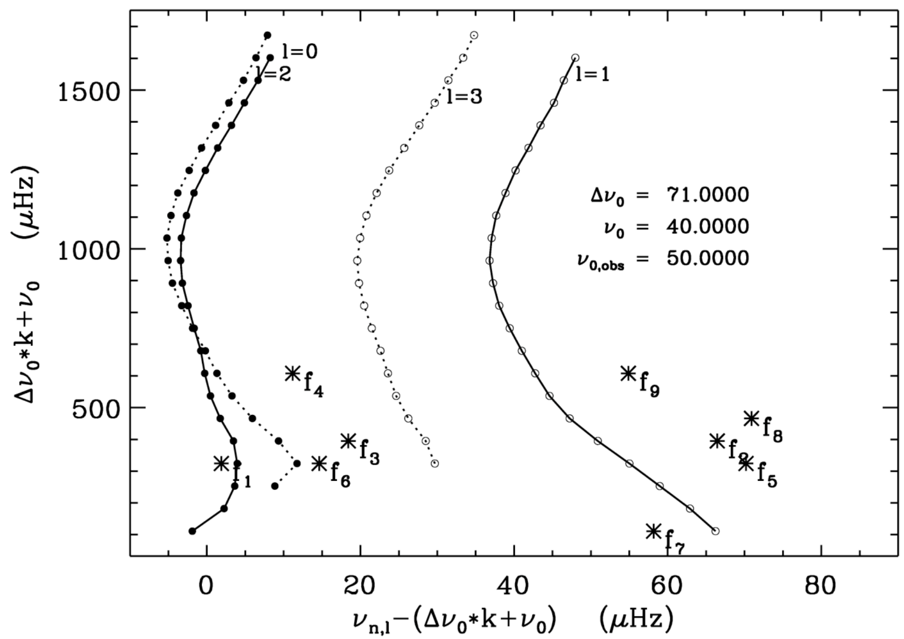


# Echelle diagram

PMS

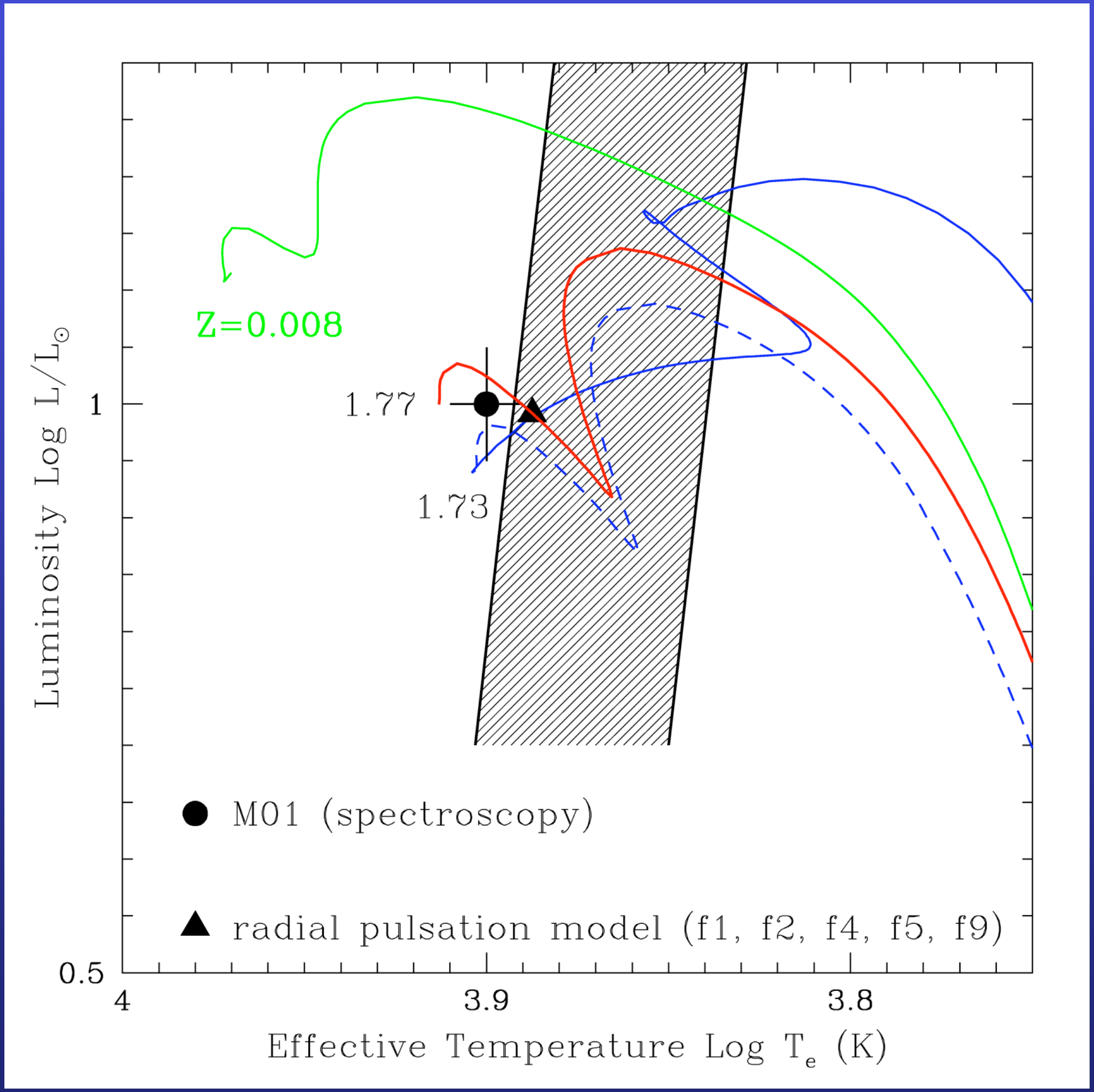



PostZAMS



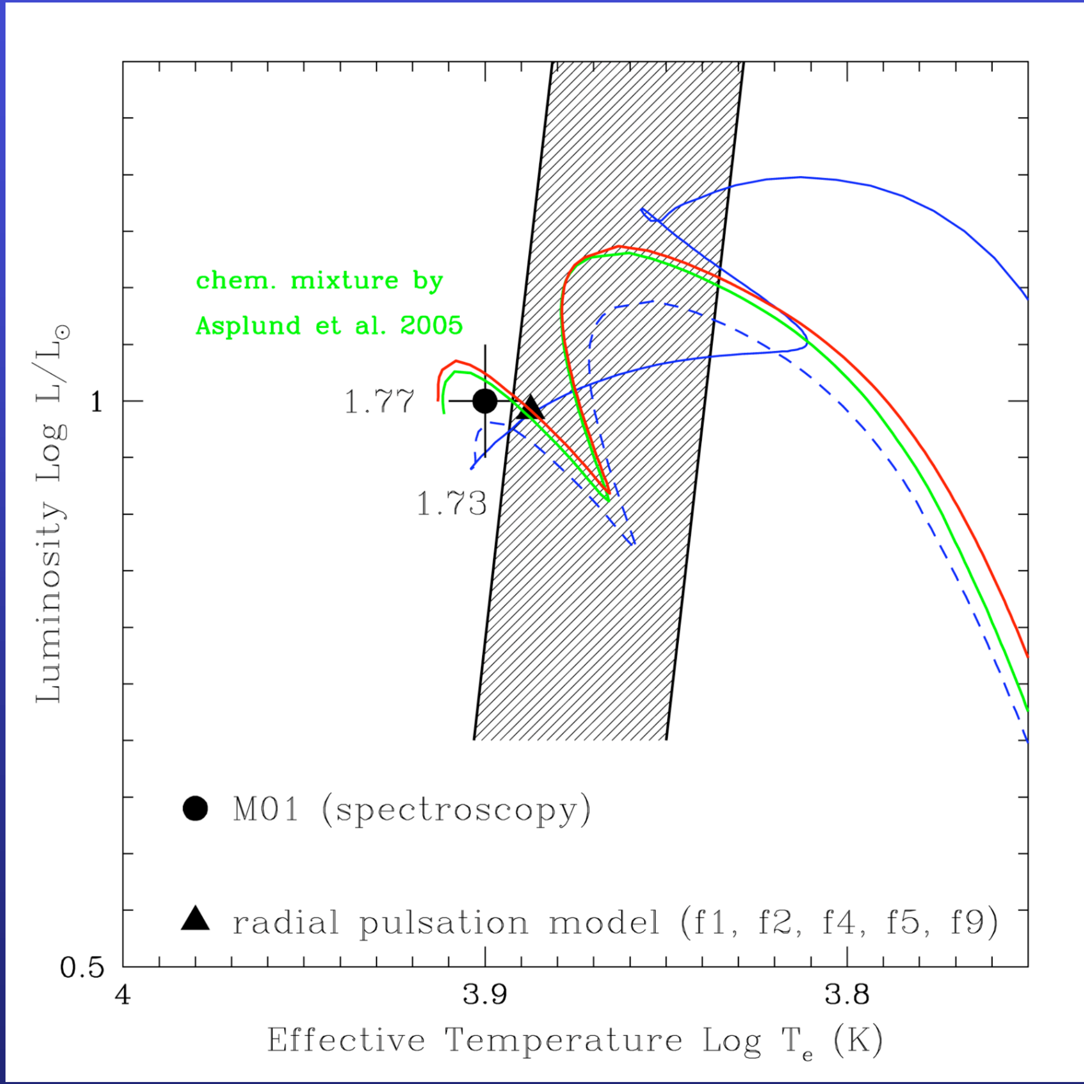
# Evolutionary models depend on many ingredients!

- Metallicity is important: according to some authors the metal abundance of IP Per could be as low as Z=0.008



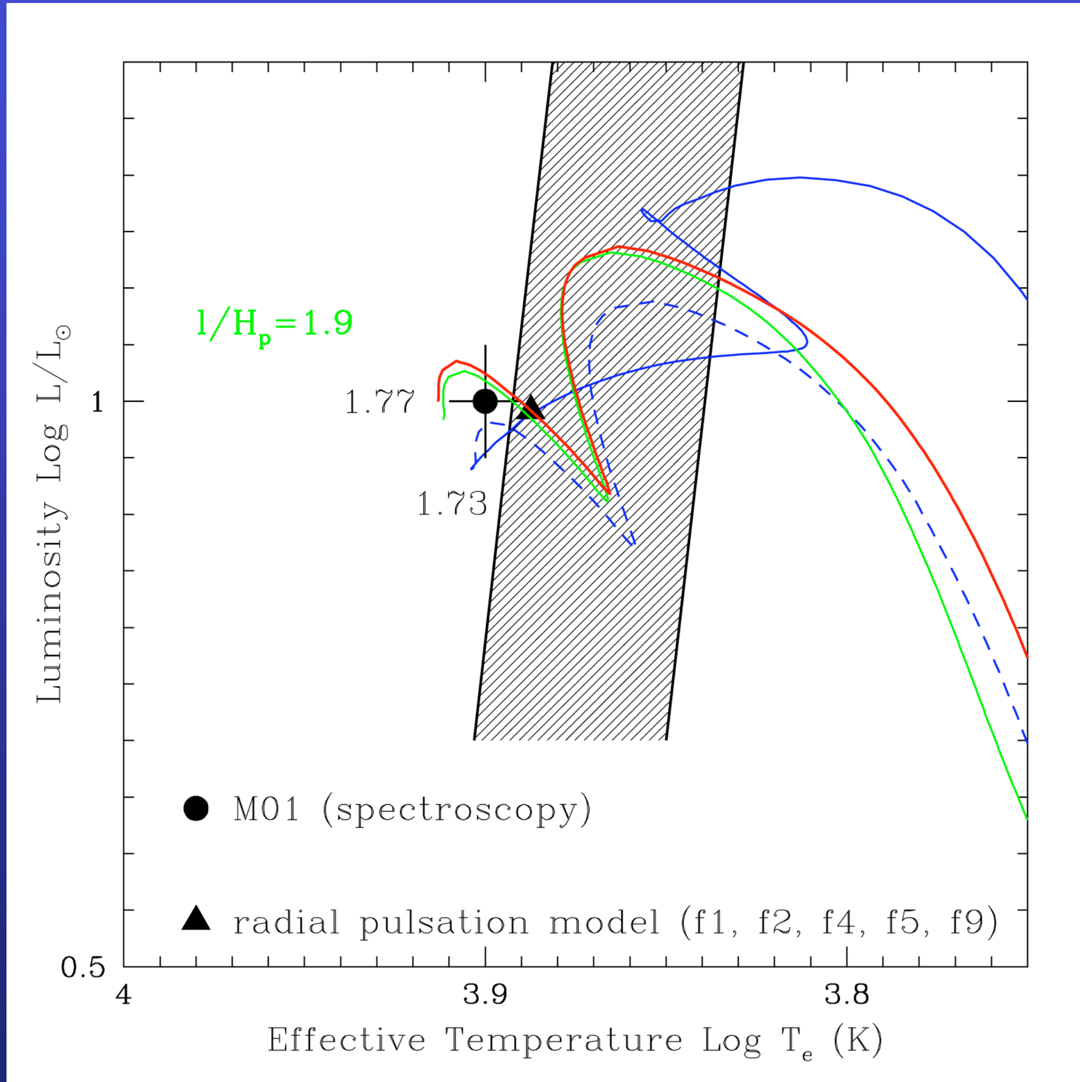
# Evolutionary models depend on many ingredients!

- The adopted opacity, equation of state, chemical mixture can also affect the models.



# Evolutionary models depend on many ingredients!

- **The mixing lnght α=l/Hp parameter is also crucial.**



# *Next steps*

- To compare the results with the ones obained from other evolutionary and pulsation codes

- To explore in detail the dependence on the various physical inputs

- To extend the analysis to other pulsators