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Binary stars as a probe for massive star evolution: a case of δ Ori A

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Parameters of δ Ori A, O9.5II (V=2.23^m)

	Aa[1]	Aa[2]	Ab
Distance to Aa[1], $R_\odot$	-	33	25000
Spectral class	09.5II	B0.5III	B
Orbital period	-	5.7325d	200 Years
$R/R_\odot$	11	4	?
$M/M_\odot$	10.3	5.3	23
$\lg(L/L_\odot)$	5.26	4.08	?
T_{eff}, K	33000	27000	?
L/L_{total}	70%	7%	23%
Vsin i, km/s	157±6	138 ± 16	≈300
V_∞, km/s	2000	1500	-
dM/dt, $M_\odot$	1.1×10^{-6}	?	?

Sources of data:

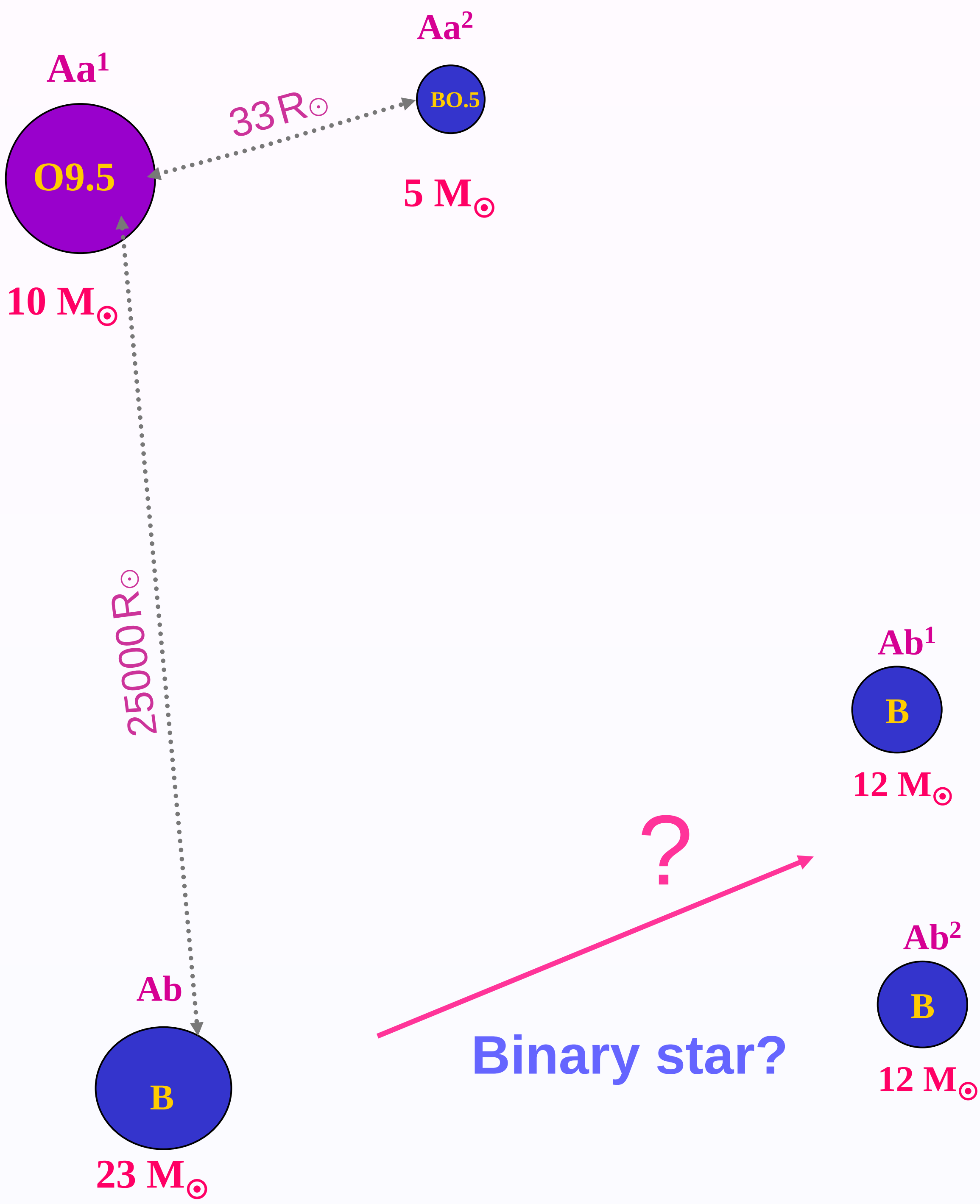
Miller et al., Ap.J., **499**, L195 (2002)

Harvin et al., Ap.J., **565,** 1216 (2002)

Lamers &Leitherer, Ap.J., **412**, 571 (1993)

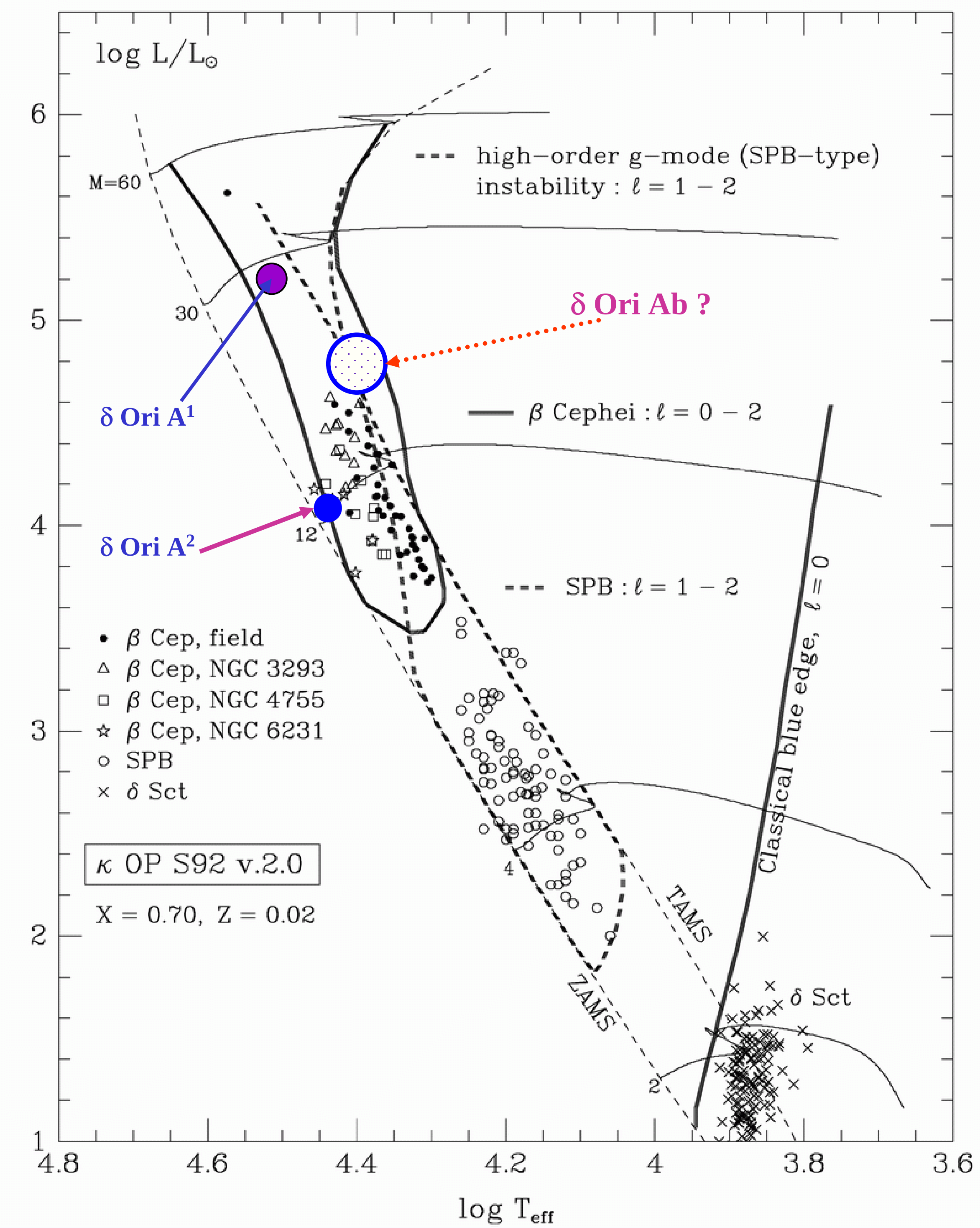
Voels et al, Ap.J., **340**, 1073 (1989)

δ Ori A, O9.5II



Aa1
O9.5
10 M☉
33R☉
Aa2
BO.5
5 M☉
25000R☉
Ab
B
23 M☉
?
Binary star?
Ab1
B
12 M☉
Ab2
B
12 M☉

Stars of δ Ori A system on HR diagram



Pamyatnykh, ActaAstr, 49, 119 (1999)

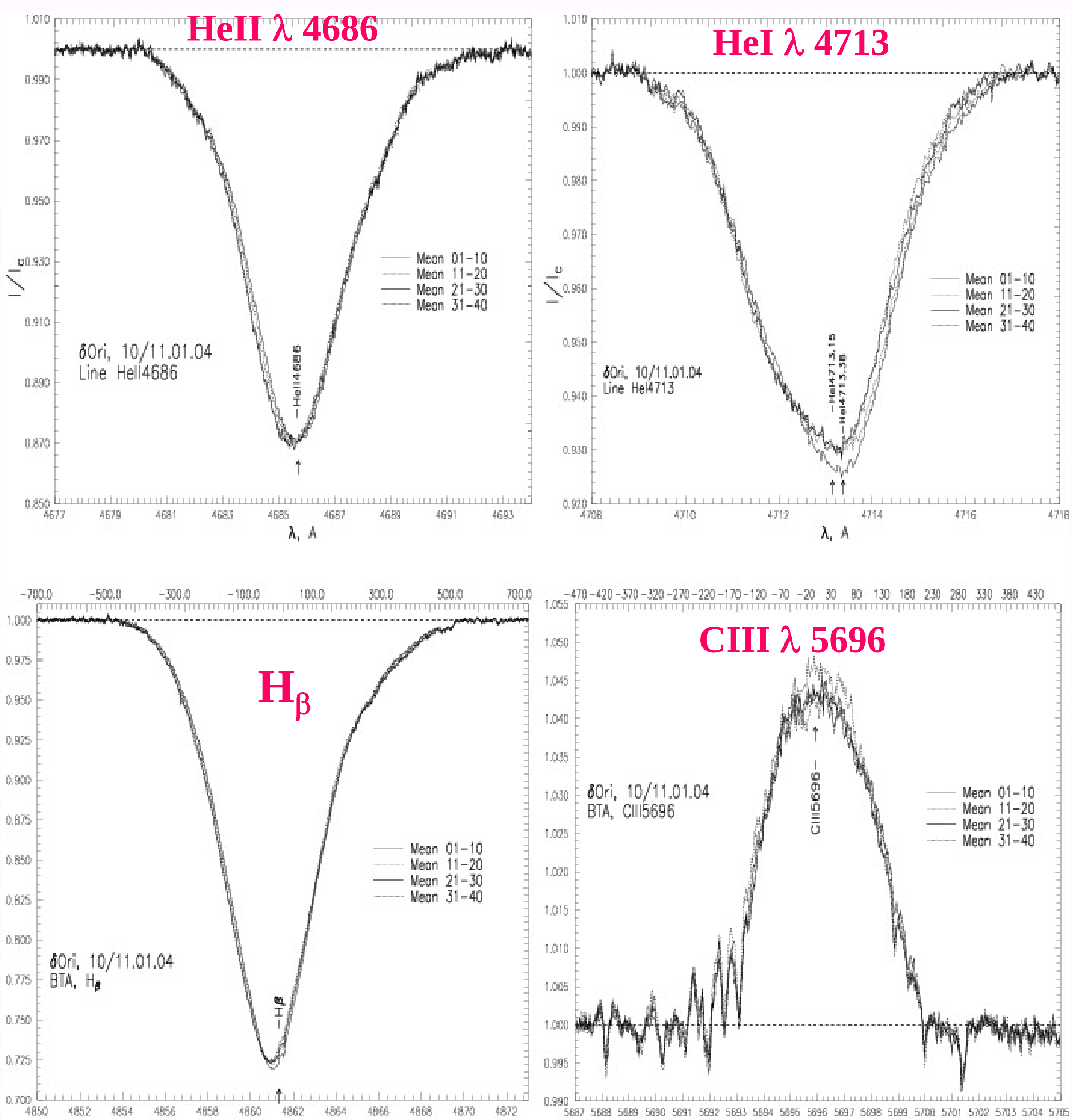
Observations:

SAO, 6m telescope, Jan 10/11 2004

NES, R=60000   λλ 4521 –6003 Å

CCD 2K*2K, 40 spectra, T=2^h50^m

S/N=500-800



Smooth Time variation spectra

$$\sigma^2(\lambda, S) = TVS(\lambda, S) =$$

$$\frac{1}{N-1}\left(\sum_{1}^{N}\left[g_i \Delta F(\lambda_j, t_i, S) - \overline{g_i \Delta F(\lambda_j, t_{i,} S)}\right]^2\right)$$

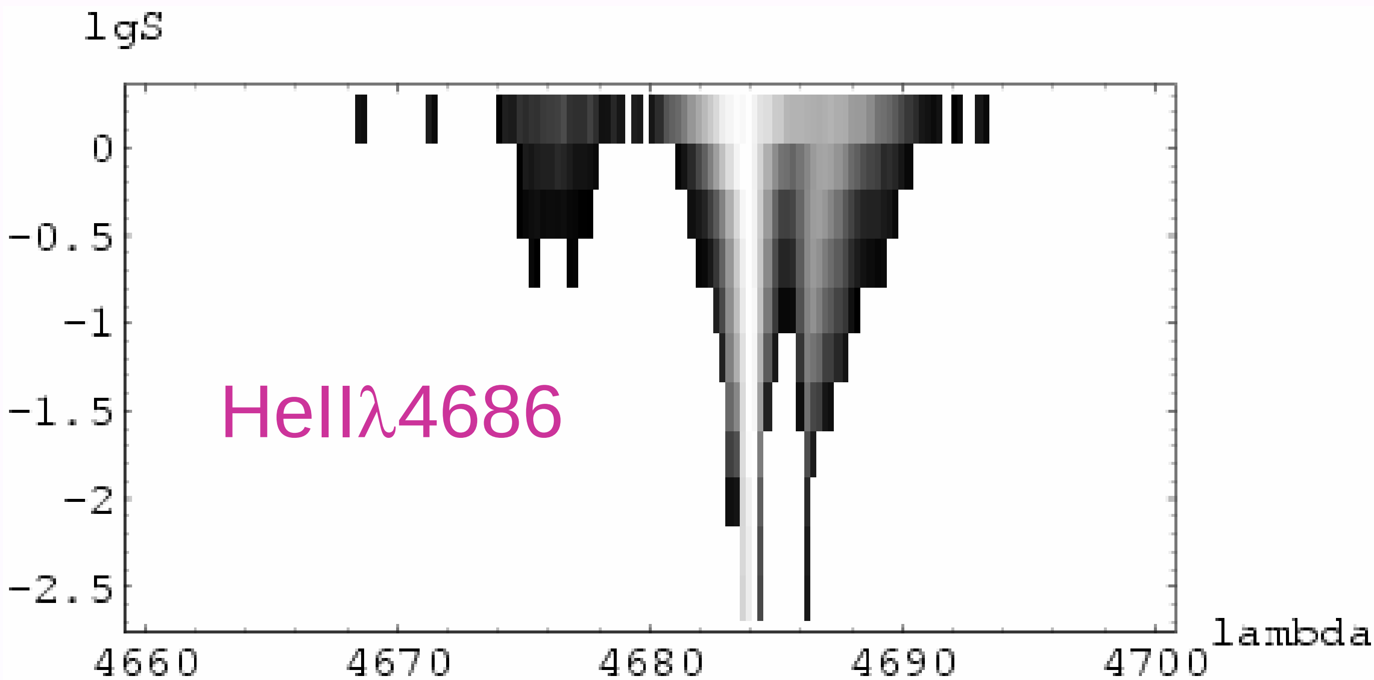
$\Delta F(\lambda,t,S)=F(\lambda,t,S)-F_{mean}(\lambda,t,S)$

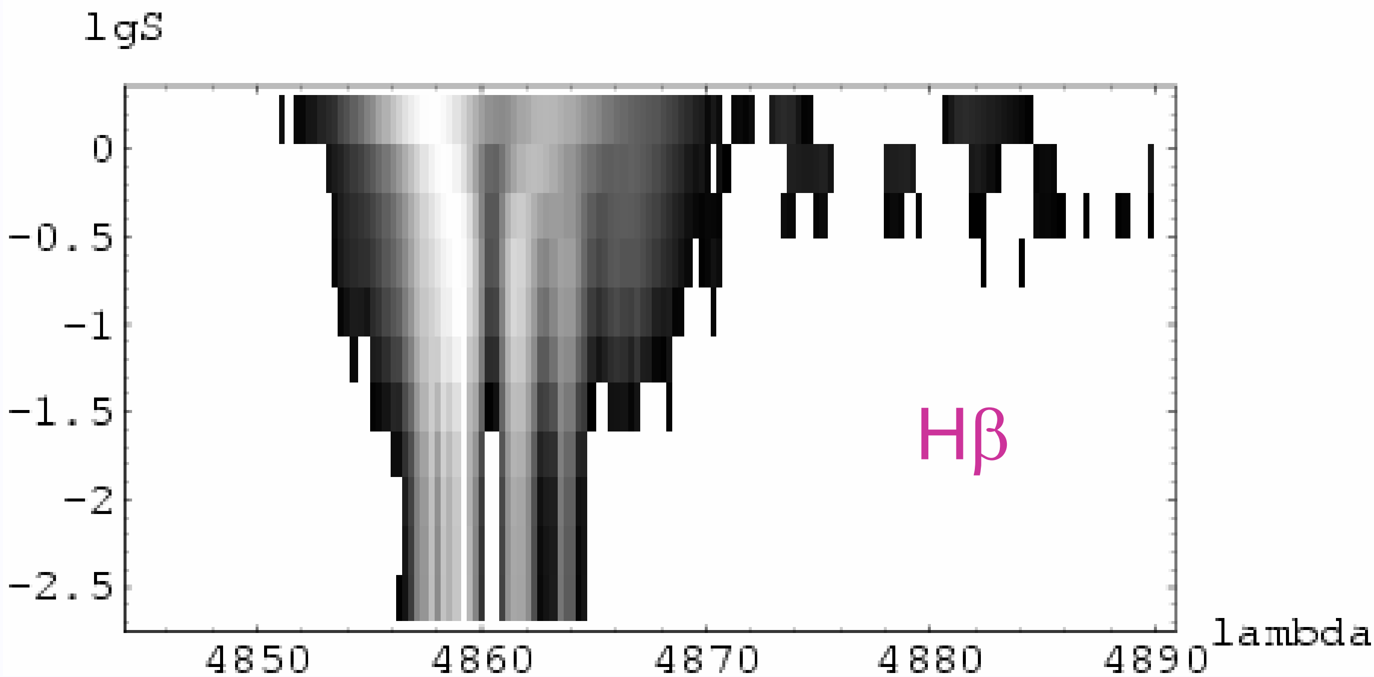
$\Delta F(\lambda,t,S)=<\Delta F(\lambda,t)>_S$ -
smoothed with Gauss filter flux in the [λ, λ+d λ] interval at the time t.
S is the filter width.

$$TVS(\lambda, S) \xrightarrow[S \to 0]{} TVS(\lambda)$$

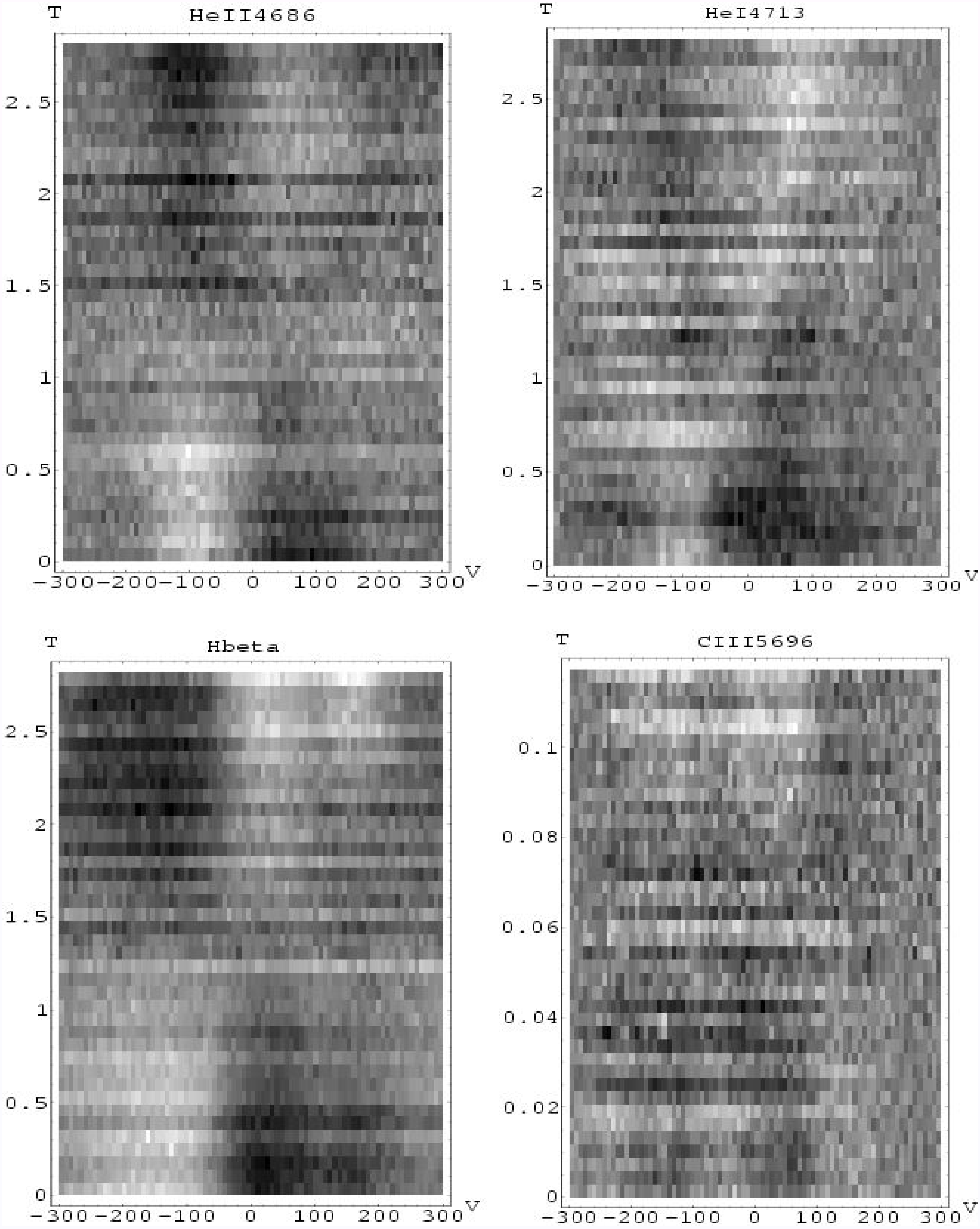
where $TVS(\lambda)$ is determined by Fullerton et al., Ap.J. Suppl. Ser.,103. P. 475 (1996)

Smooth TVS spectra





Dynamical spectra

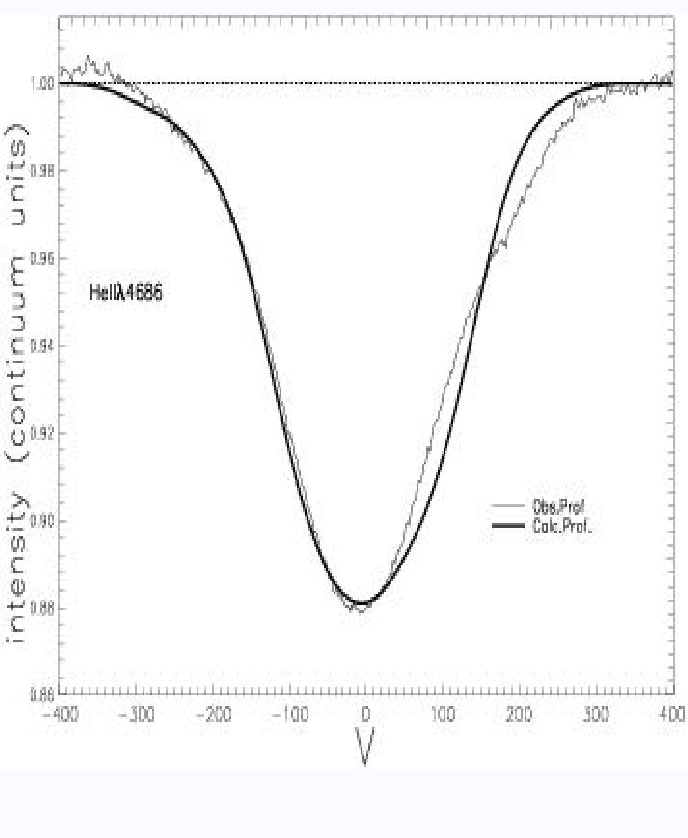


Modeling line profiles

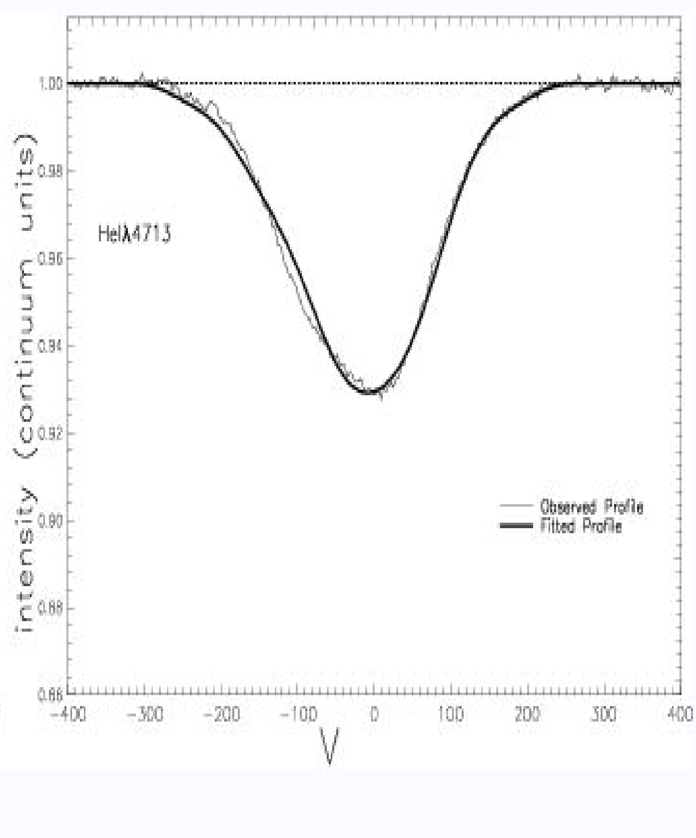
$I(\delta\,Ori\,A) = r_1 \times I(\lambda, Aa^1) + r_2 \times I(\lambda, Aa^2) + r_3 \times I(\lambda, Ab)$

r_1 = 70 %
r_2 = 7%
r_3 = 23 %

HeIIλ4686

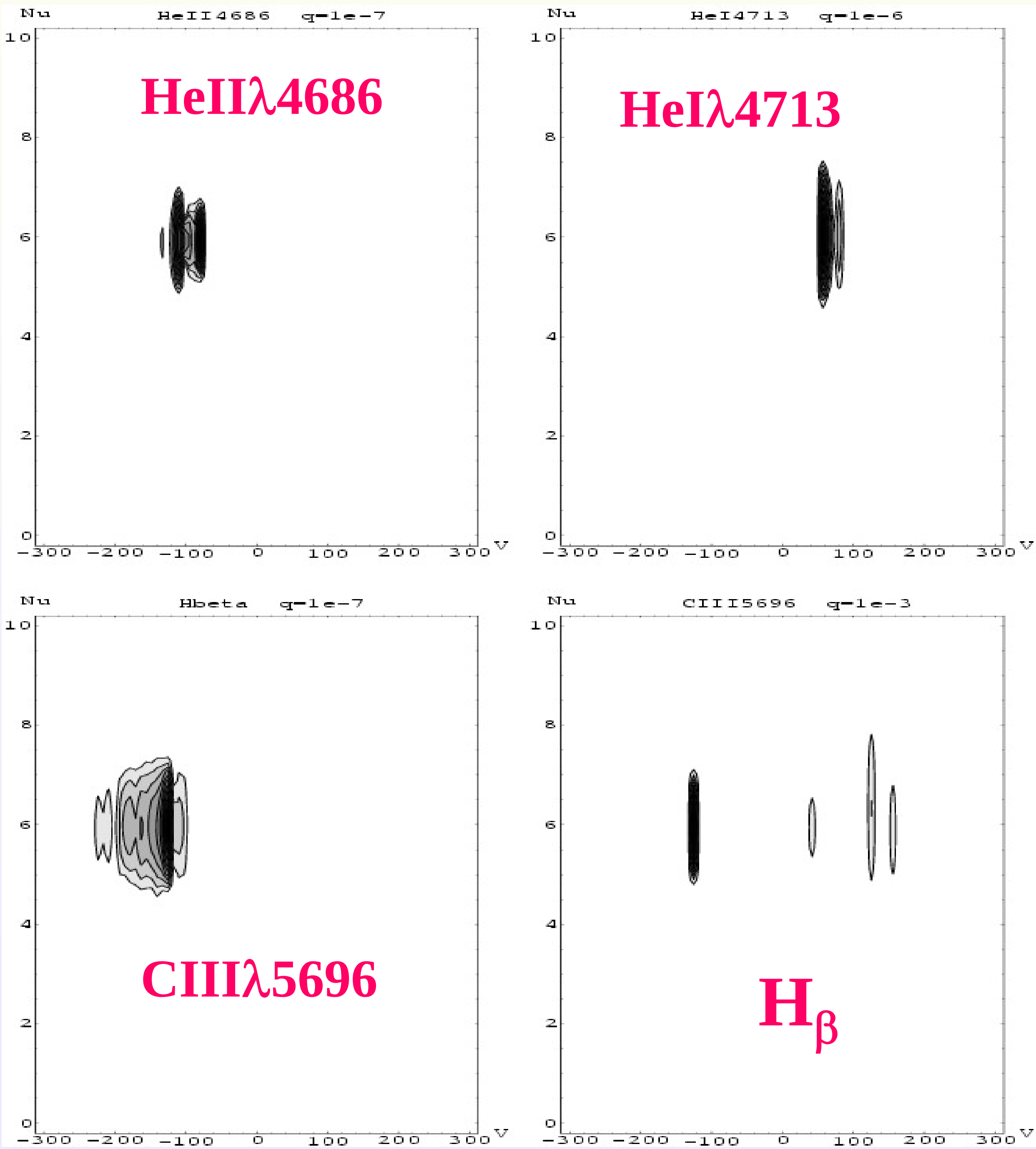


HeIλ4713

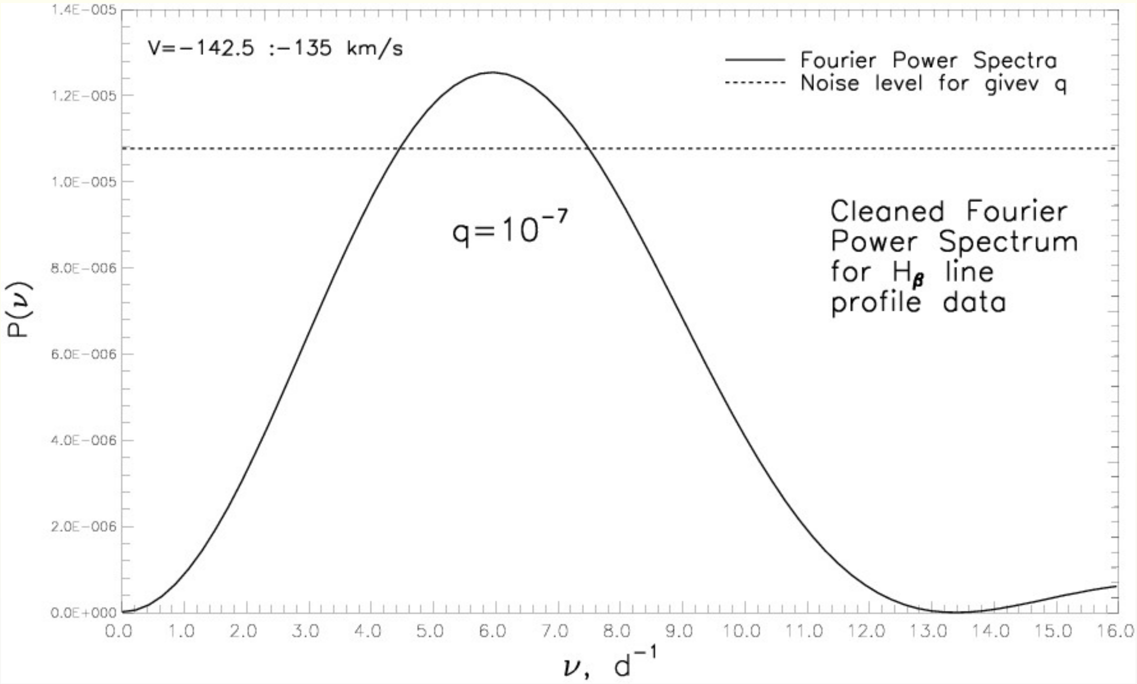


Fourier spectra of LPV

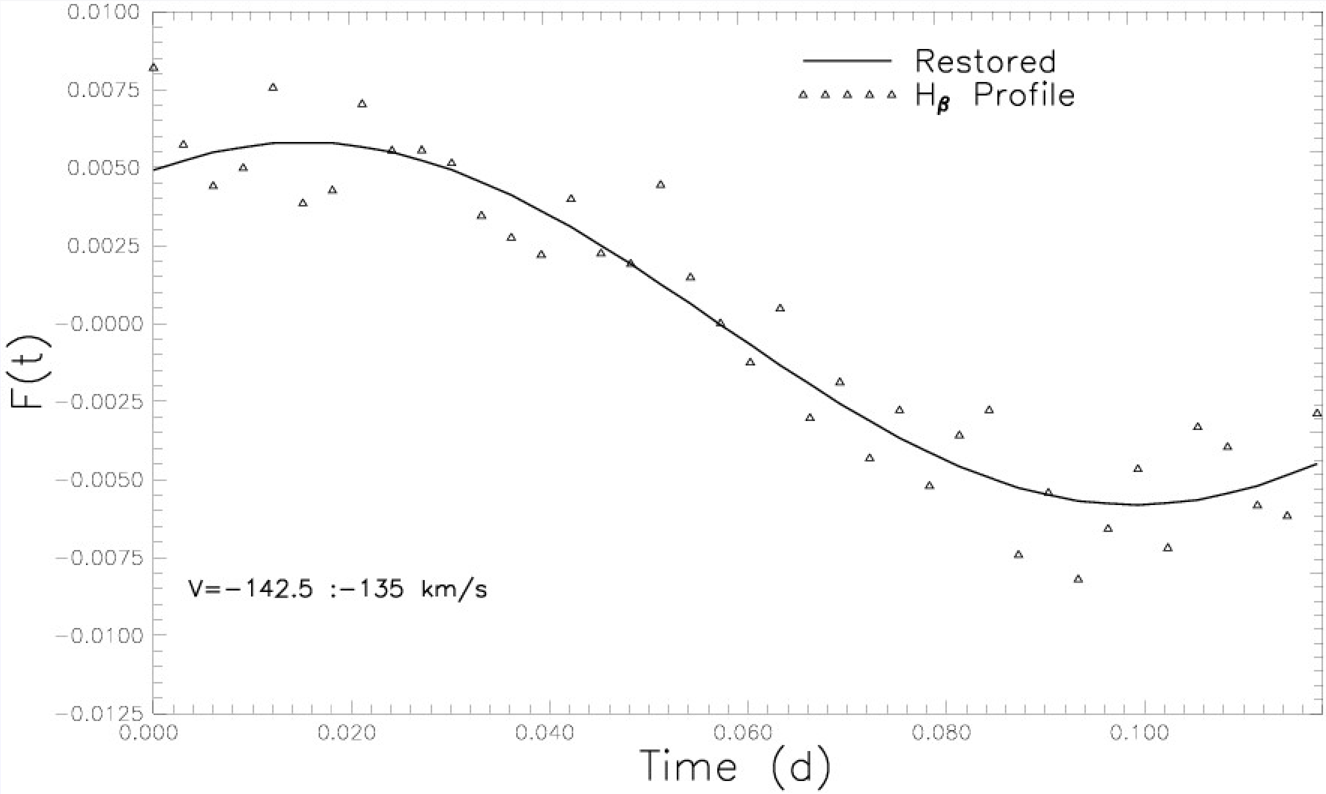
$\nu = \approx 5.9 \pm$ d^{-1} P= $3.5^h - 4.9^h$



Hβ: Restored LPV (-142.5 :-135 km/s)



Fourier power spectrum



Restored vs. real LPV

Wavelet analysis of LPV in spectra of δ Ori A

$$W(s,u) = \frac{1}{s} \int_{-\infty}^{\infty} f(x)\psi\left(\frac{x-u}{s}\right) dx$$

MHAT wavelet

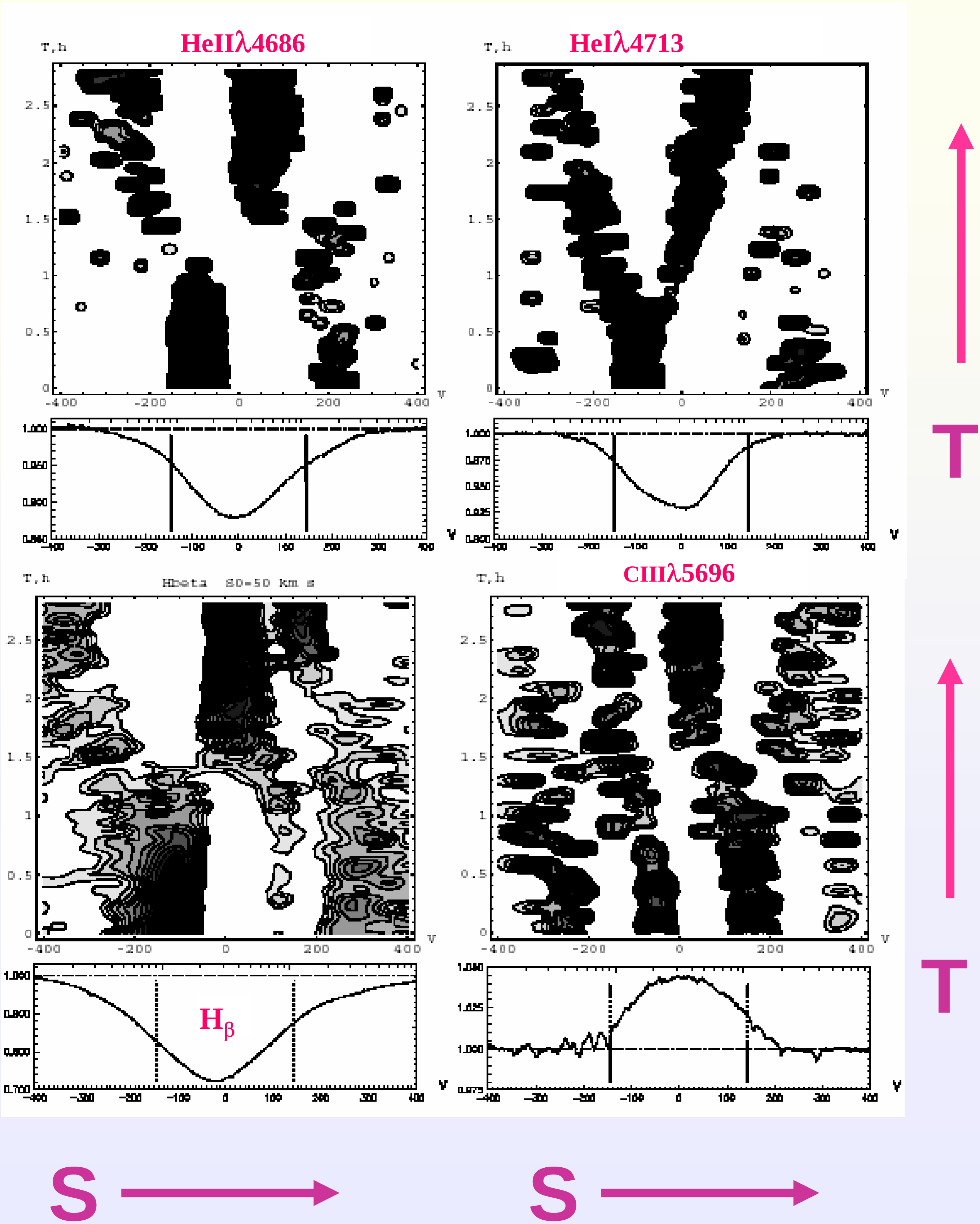
$$\psi(x) = (1 - x^2)\exp(-x^2/2)$$

Dynamical wavelet spectra:

W(s,u) ⟶ W(s,u,T)

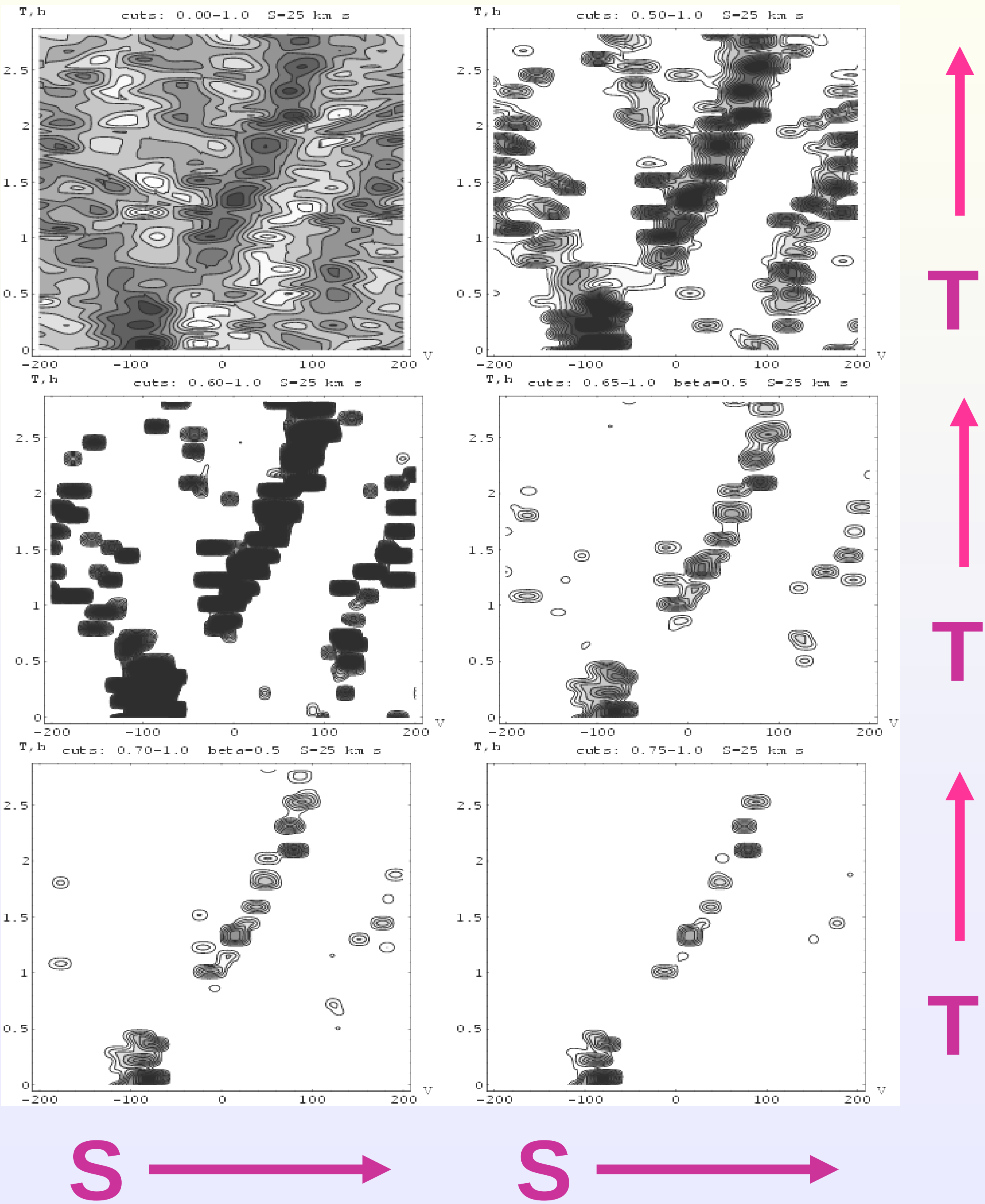
T – time of observations

Dynamical wavelet spectra



HeI λ 4713: dynamical wavelet spectra for S=25 km/s for different cuts levels

from 0.0 to 0.75



NRP Pulsation mode (l,m)

$$\ell \approx 0.10 + 1.09|\Delta\Psi_0|/\pi$$
$$|m| \approx -1.33 + 0.54|\Delta\Psi_1|/\pi$$

→ (l,m)= (2,-2)

Telting & Schrijvers, A&A Suppl. Ser., **317**, 723 (1997)

$V(\theta,\varphi) \propto e^{im\varphi + \sigma t}$

$\nu_{LPV} \approx 5.9\ d^{-1}$ $P_{LPV} =\ d = 4.1^h$

if pulsation mode (l,m)=(2,-2).

Then at m=2 $\omega_{NRP} = 2\pi \bullet \sigma/2$

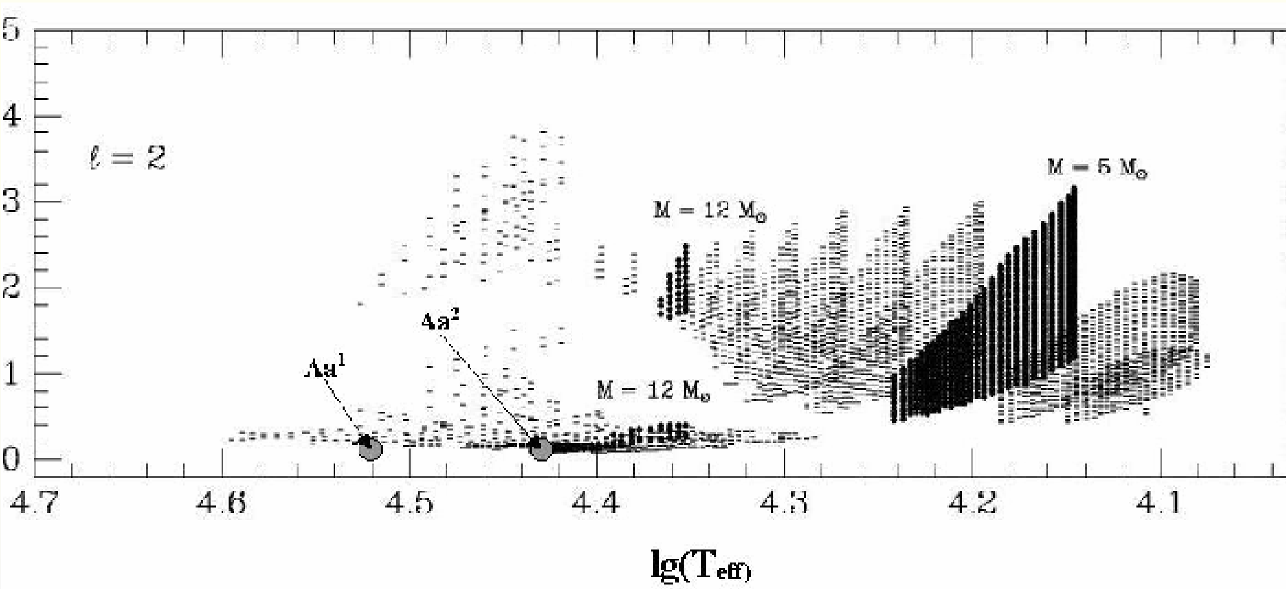
$T_{rec} = 2 * P_{LPV} = 0.32\ d = 7.4^h$

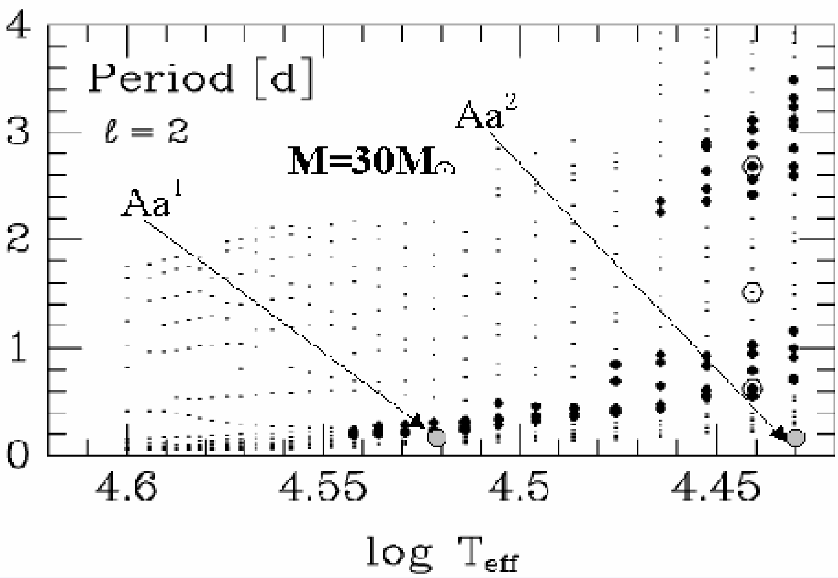
Phase velocity: $\omega_{NRP} = 2\pi \times \sigma / m = 40.3$ rad/d

$T_{cross} = 3.5^h$ – crossing time for main details of wavelet spectra

$T_{cross} \approx P_{LPV} \approx 4.1^h$ ⟶ the wavelet analysis support the hypothesis about the NRP nature the **LPV in spectra of δ Ori A**

Pulsation frequencies on the Period – T_{eff} diagram





from Pamyatnykh A.A., Acta Astron., 49, 119-148 (1999)
Points : NRP pulsation modes
Filled circles: β Cep stars

Large circles are positions of Aa^1 and Aa^2 stars on the diagram

What stars pulsate?

The main component Aa[1] is out of the pulsation domain for 12 M⊙ star, but is exactly in the pulsation domain for 30 M⊙ star.

This means:

a) The set of pulsation frequencies of the star with strong wind and mass M are not in agreement with pulsation modes of the main sequence star with the same mass, but without mass loss;

b) Only second (Aa[2]) and third (Ab) components of δ Ori A triple system are pulsating stars.

Conclusions

1. All investigated lines are variable wit amplitude 0.5-1\%;
2. In dynamical wavelet spectra of lines HeIλ4686, HeIλ4713, Hβ and CIIIλ5696 the large scale components were detected in the zone [-Vsin i - Vsin i] for the main star Aa^1 with crossing time $4\text{-}5^h$. The regular components out of this zone were detected ;
3. The regular LPV variations with the recurrence time $P \approx 4^h$ are detected. The evidences, that the variations are connected with non-radial pulsations in the quadrupole mode $(l,m)=(2,-2)$ are found;
4. The nature of the pulsation of the stars in δ Ori A system are unknown.