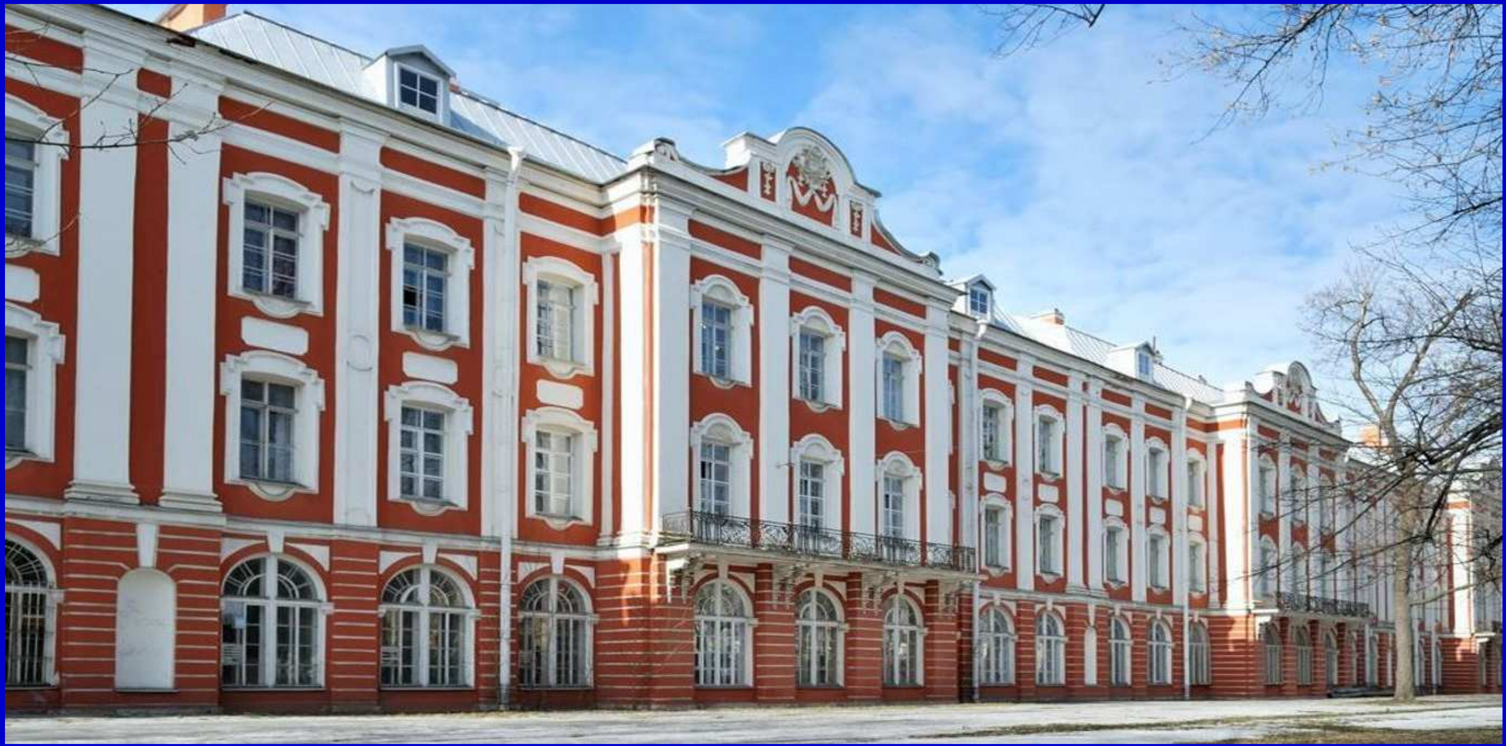
Superfast line profiles variability in spectra of OBA stars

A.F. Kholtygin[1], A.V. Moiseeva[2], A.F. Valeev[2,3], A.E. Kostenkov[1,2] , O.A. Tsiopa[4], I.A.Yakunin[2], S.N. Fabrika[2], M.A. Burlak[5], N.P. Ikonnikova[5], M.S. Kurdoyakova[1], E.B. Ryspaeva[3]

[1]Saint Petersburg State University, Russia
[2]Special Astrophysical Observatory of the Russian Academy of Sciences, Russia
[3]Crimean Astrophysical Observatory, Russia
[4]Main (Pulkovo) Observatory of the Russian Academy of Sciences, Russia
[5]Sternberg Astronomical Institute, Moscow State University, Russia



Why superfast spectral variability?

Perspective directions of spectral researches:
1) Increasing the spectral resolution (**R~200000**)
2) Larger S/N ratio (**~2000-3000**)
3) Longer time series of observations (**10-50 years**)
4) Detection of all Stokes parameters (**I,Q,U,V**)
5) Large surveys, …

Almost unprobed field of the researches:

Very fast line profile variations ($\Delta T \sim$ 1 s - 10-20 minutes), S/N >500

This research field of studies is close to fast photometry but allows to study the details of line profile variations associated with fluctuations of the velocity field in the photosphere and in the wind, chemical and temperature inhomogeneities (spots), and local magnetic fields.

What profile variations are expected?

Stochastic (irregular): **10 seconds - 5 minutes**
Regular (pulsations): 1 - 150 minutes

A: Irregular sfLPV

Stochastic LPV: typical time ~ plasma cooling time ~ recombination time => t_{sfLPV} = 5 - 300 s. Typical amplitude ~10^{-2} - 10^{-3} of the continuum flux → We need ΔT < 1 min (5 -60 s) and S/N ~ **2000**

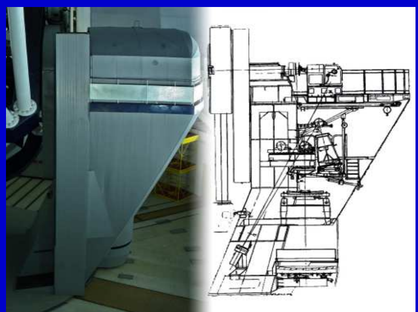
B) Regular and quasi-regular sfLPV:

Periods 1-150 minutes. Amplitudes ~1-3% of the neighboring continuum flux → ΔT < 10 min (10 -600 s) and S/N ≥**300**

We need 1-6 meter telescopes, Spectrograph and/or spectropolarimeters of low and medium resolved power R ~ 500-15000

Objects: bright OBA,… stars with V=1-10^m (may be 11-12m?)

Telescopes/spectrographs (6m + 1m telescopes)



BTA, MSS: V<=12m, Long slit ~500 A, R=12000

R=1000-2000,λλ4000-5700 Å

R=1000, λλ3600-8000 Å

Terskol Observatory, 2-m Telescope

Echelle spectrometer for Cassegrain focus R = 15000

Crimean SAI MSU station, 1.25-m telescope

A-low resolution spectrograph R~700 $\lambda\lambda$=4200-7200 Å

Spectral observations: telescopes and targets (~10000 spectra)

I. O-stars (10 objects, 818 spectra)

Star	Sp.Type	V	N_{sp}	Exp (s)	Telescope	Spectrograph	Dates	Total # of spectra
ξ Per	O7.5III	4.06	35	300	2-m Tseis	ESC	3-6/1/2020	35
15 Mon	O7V+B1.5/2V	4.64	3	210	2-m Tseis	ESC	04-05/03/2021	3
λ Ori A	O8IIIf	3.66	24	420	2-m Tseis	ESC	18-21/01/2019	24
α Cam	O9Ia	4.29	5	220	2-m Tseis	ESC	04-05/03/2021	5
19 Cep	O9Ib	5.11	22	420	2-m Tseis	ESC	2019-2020	22
ζ Ori A	O9.2I	1.88	76	90	6-m BTA	MSS	19.02.2019	76
δ Ori A	O9.5II+B1V+B0IV	2.41	49	120	2-m Tseis	ESC	18-24/01/2019	49
HD 93521	O9.5III	7.03	529	3	6-m BTA	Scorpio	19/20.01.2015	557
			28	900	6-m BTA	MSS	30.12.2021-2.2.2021	
HD 34078	O9.5V	5.96	27	300-420	6-m BTA	MSS	5-8.1.2020	27
HD 45314	O9:npe	6.64	20	600	6-m BTA	MSS	5-8.1.2020	20

Spectral observations: telescoppes and targets (~10000 spectra)

II. B-stars (8 **objects, 6851 spectra**)

Star	Sp.Type	V	N_{sp}	Exp (s)	Telescope	Spectrograph	Dates	Total # of spectra
β Cep	B0.5IIIs	3.21	74	60-180	6-m BTA	MSS	30.12.2021-2.2.2021	**74**
γ Cas	B0.5IVpe	2.39	1576	2	1.25-m	A-sp	13-14.9.2020	**1714**
			138	60	6-m BTA	MSS	1-2.2.2021	
ρ Leo	B1Iab	3.87	1271	1	6-m BTA	Scorpio	19-21.01.2015	**1614**
			80	90		MSS	19.02.2019	
			263	10	1.25-m	A-sp	26.10-2.11.2019	
ε Per	B1.5III	2.89	39	150	2-m Tseis	ESC	19-20.01.2019	**39**
δ Ori A	B0III+O9V	2.41	49	90-120	2-m Tseis	ESC	20-24.01.2019	**49**
γ Ori	B2V	1.64	42	50	2-m Tseis	ESC	18-21.01.2019	**42**
η UMa	B3V	1.86	10	50	2-m Tseis	ESC	18-21.01.2019	**10**
α And	B8IV-VHgMn	2.06	2600	2	1.25-m	A-sp	13-14.9.2020	**3309**
			709	10	1-m	UAGS	28-30.10.2020	

Spectral observations: telescopes and targets (~10000 spectra)

III. A-stars (4 **objects, 2157 spectra**)

Star	Sp.Type	V	N_{sp}	Exp (s)	Telescope	Spectrograph	Dates	Total # of spectra
α^2 CVn	A0spe	2.90	866	1	6-m BTA	Scorpio	21/22.01.2015	**937**
			71	90	6-m BTA	MSS	5.1.2020	
HD 21389	A0Ia	4.54	330	11	6-m BTA	Scorpio	25/26.09.2016	**330**
γ UMi	A2III	3.00	249	20	6-m BTA	Scorpio	25/26.09.2016	**249**
α Cep	A8Vn	2.46	641	10	1-m	UAGS	28-30.10.2020	**641**

Global results of observations

Number of spectra: **~10000**

Number of objects: **22**

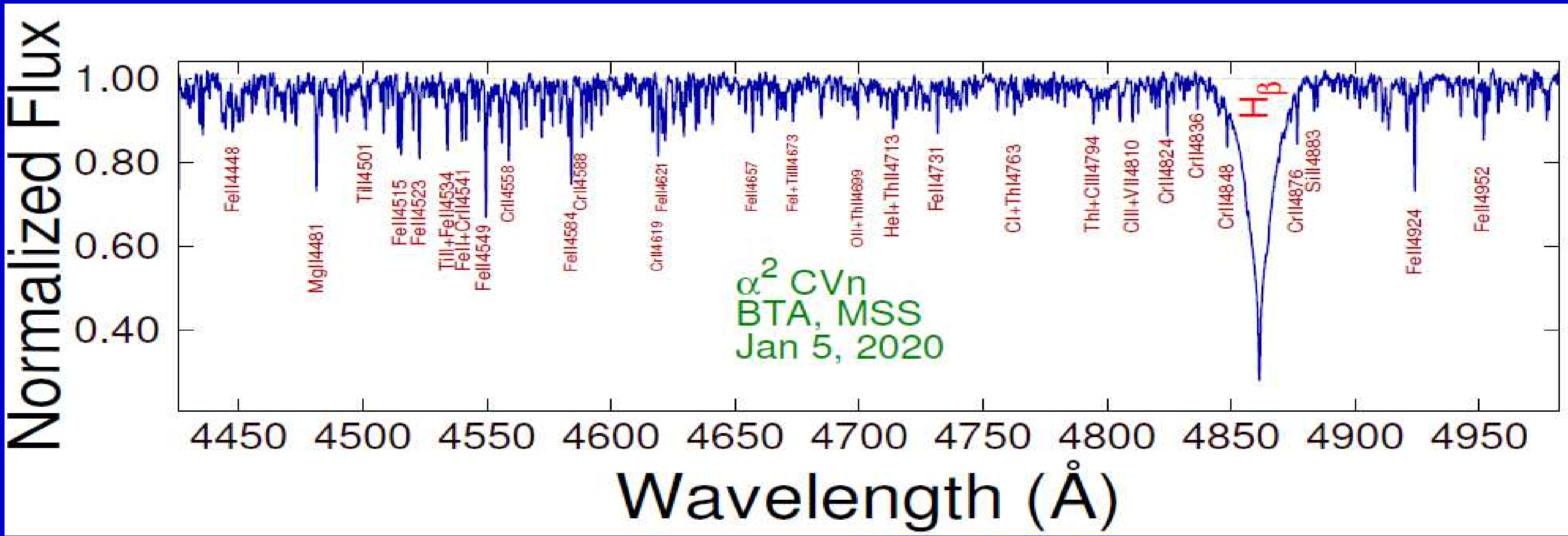
10 – O stars – 1146 spectra
8 – B stars – 680 spectra
4 – A stars – 2157 spectra

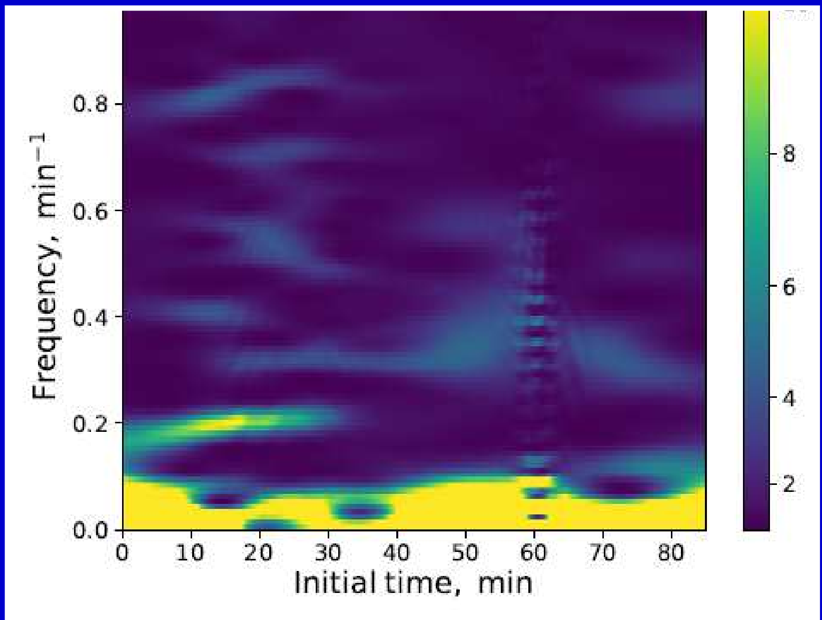
Exposures:

1 seconds – 15 minutes

$V=1^m.64 - 8^m.90$

α^2 CVn: MSS, 5.1.2020





Windowed Fourier spectrum of H_β

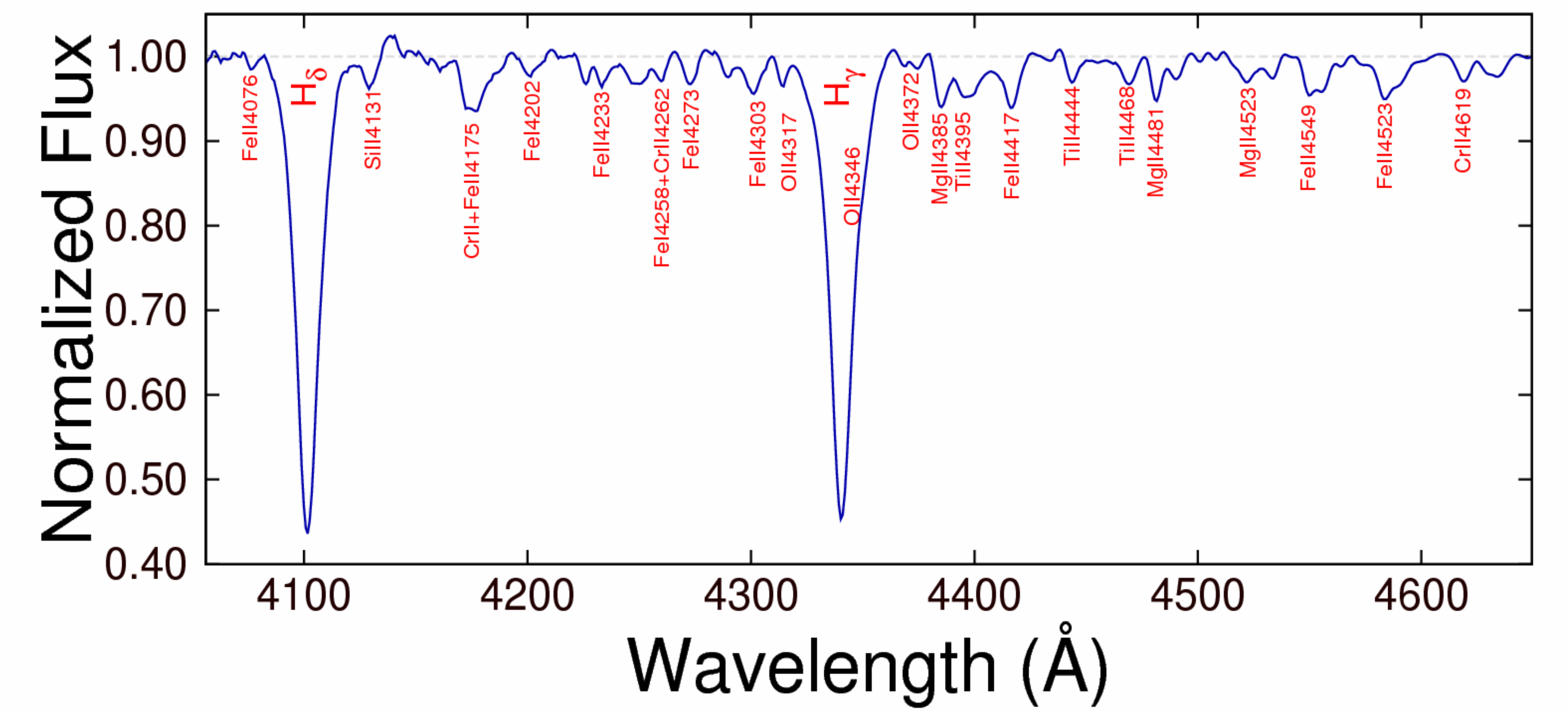
ν_1= 0.18 – 0.22 min^{-1}, P ≈ 5 min (t$_0$= 0 - 35 min)

ν_2 ≈ 0.32 min^{-1}, P ≈ 3.1±0.1 (t$_0$=15 - 45 min)

Transient quasi-regular components

Mean Spectrum: 25/26.09.2016 (Scorpio)

γ UMi
HD 137422 Pherkad

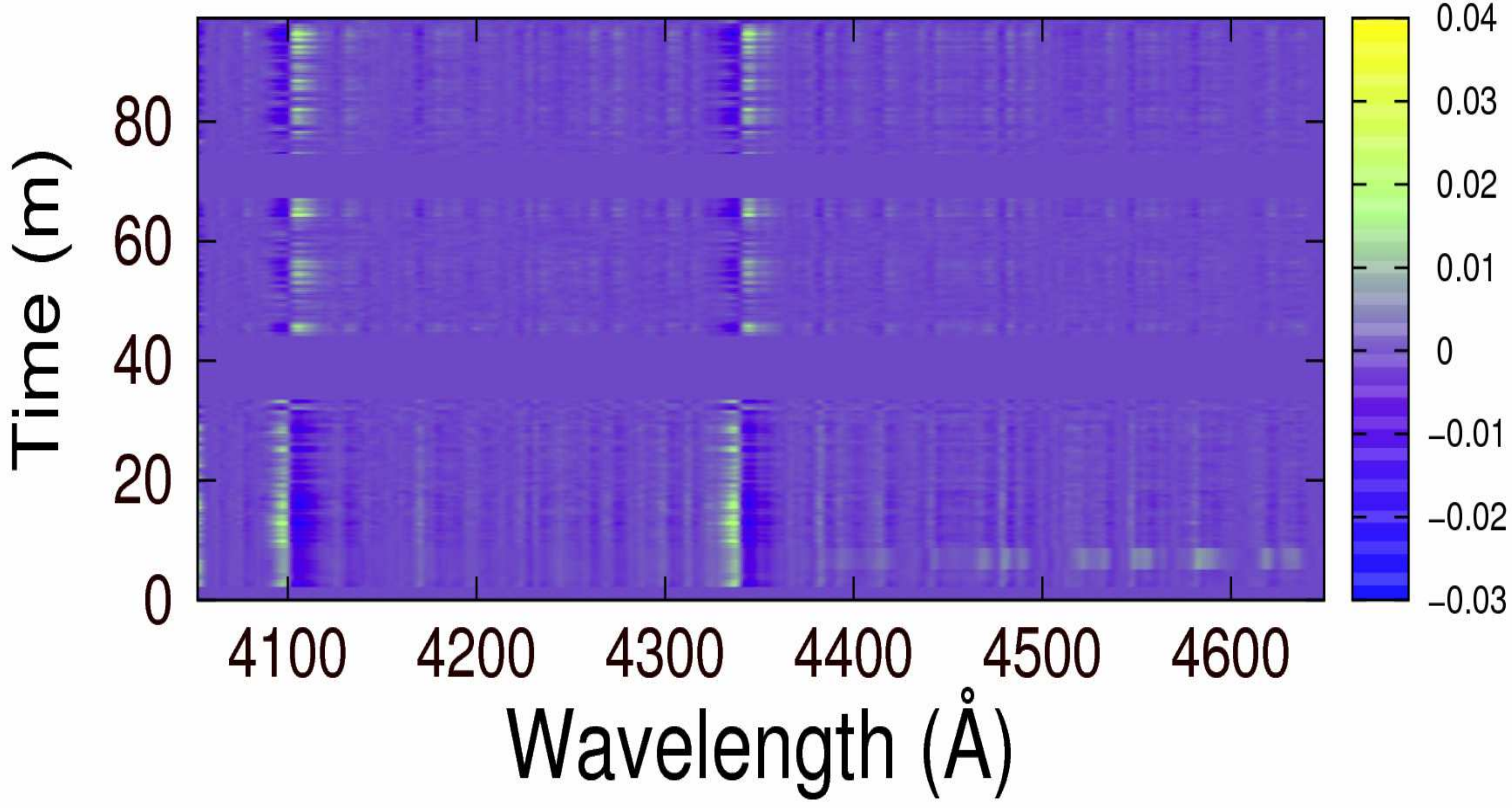


Non variable star, Percy & Wilson, 2000, Hypparcos Data

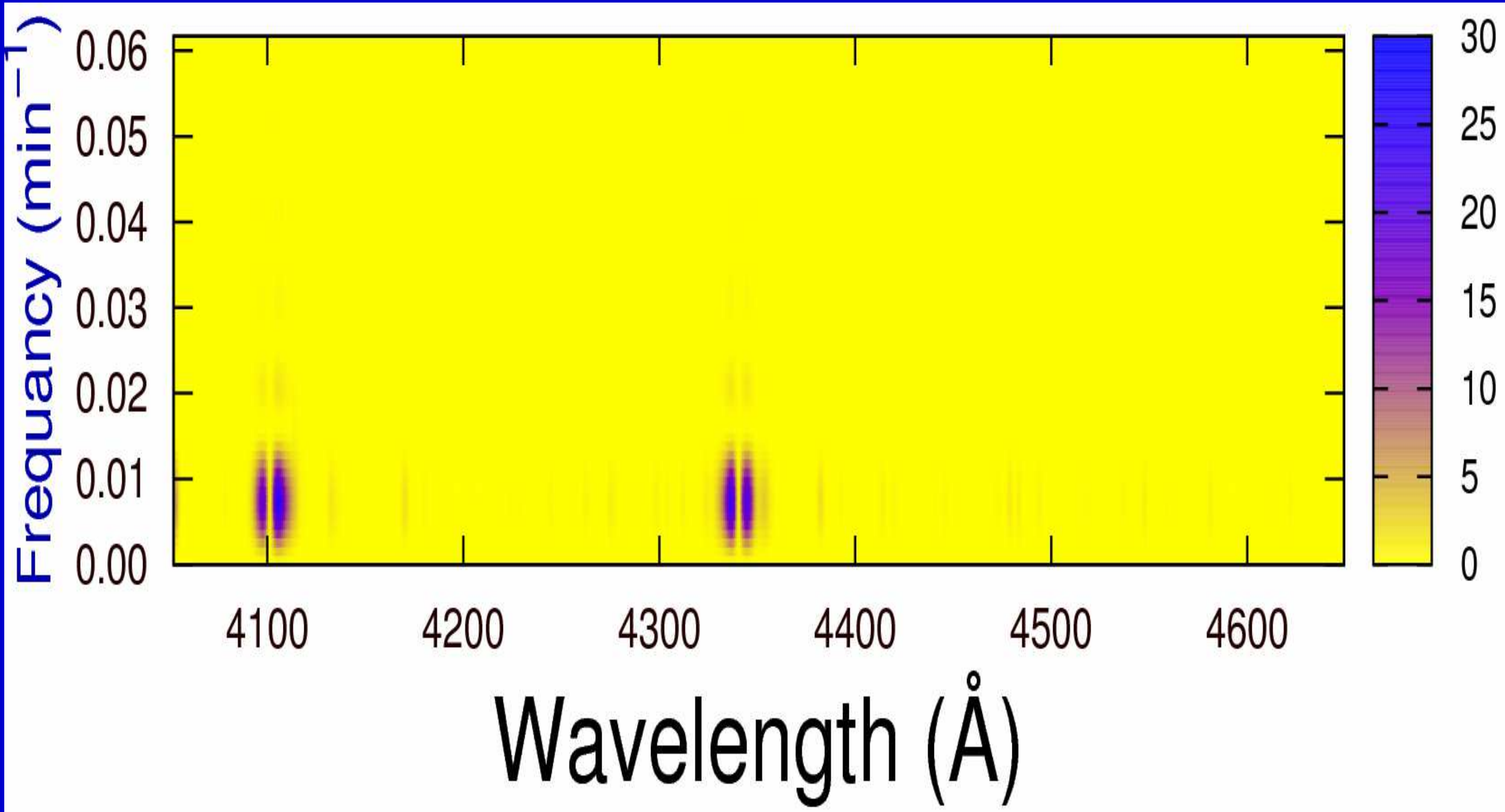
Sp. Type A2III, Variable Star of δ Sct type

V=3.002, G=2.876 π=6.70 mas, d=149 pc

Dynamical spectrum γ Umi



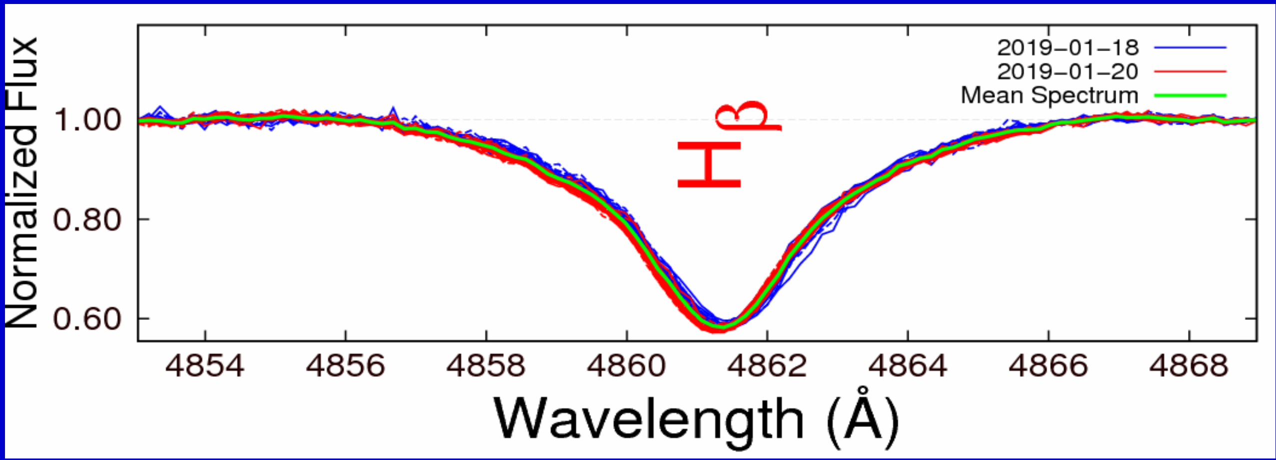
Fourier spectrum, 4040-4600 Å γ Umi

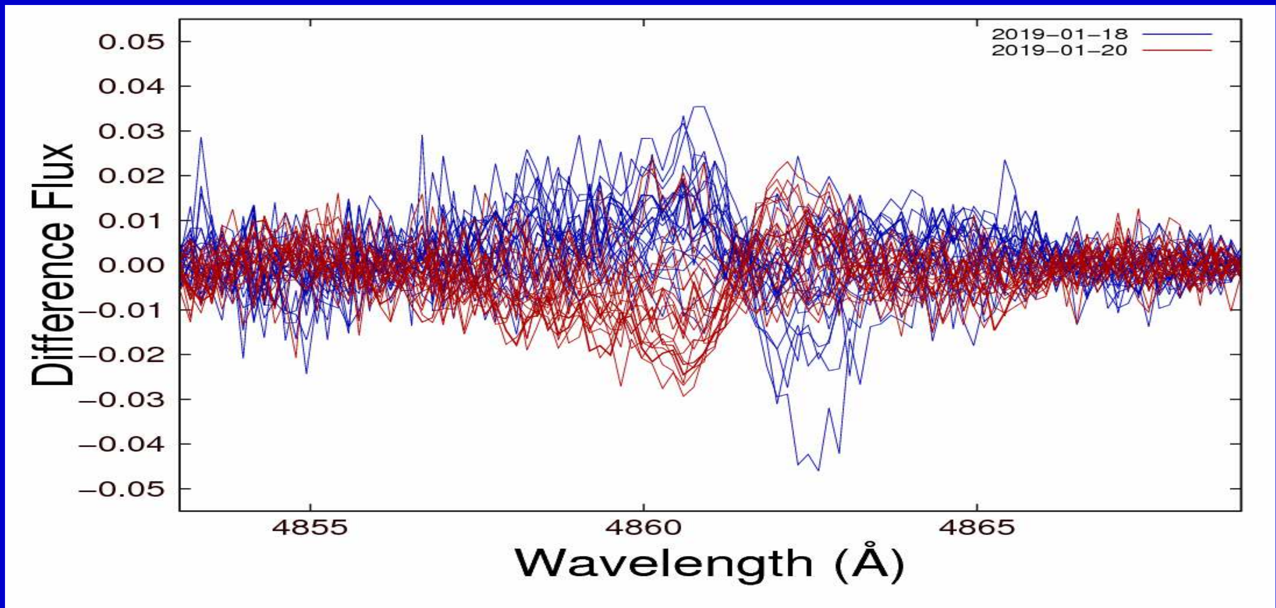


Period of pulsations, min: 9.9, 12.0, 64.9

LPVs H_β line

γ Ori





B2III
V=1.635±0.010

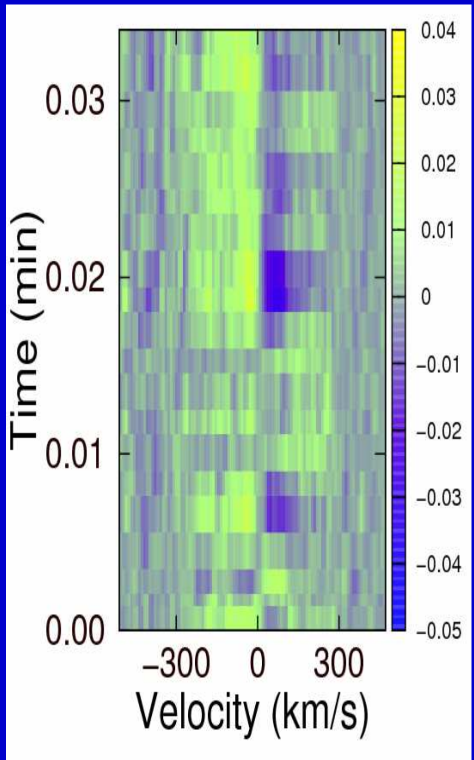
The amplitude of the profile variations is 1-3% in units of the adjacent continuum.

Terskol < 2-м telescope, 18-21.01.2019

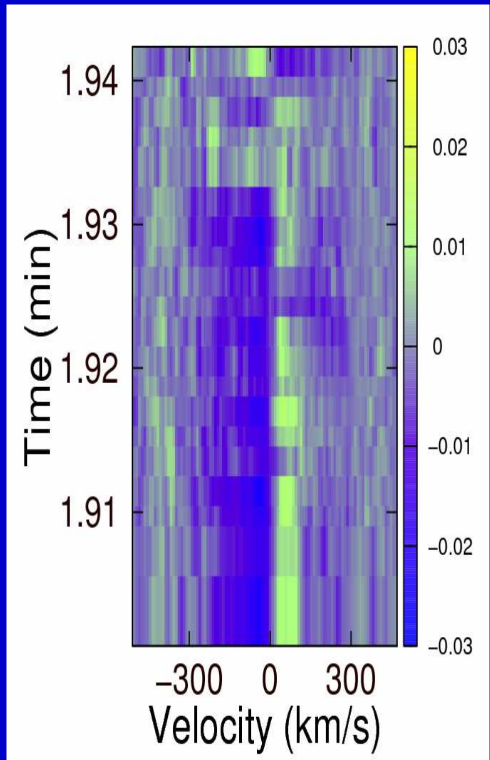
Observations: January 18-21, 2019, 2-m telescope, Terskol Observatory, 42 spectra : λλ 4000 -7500 Å

LPVs-1

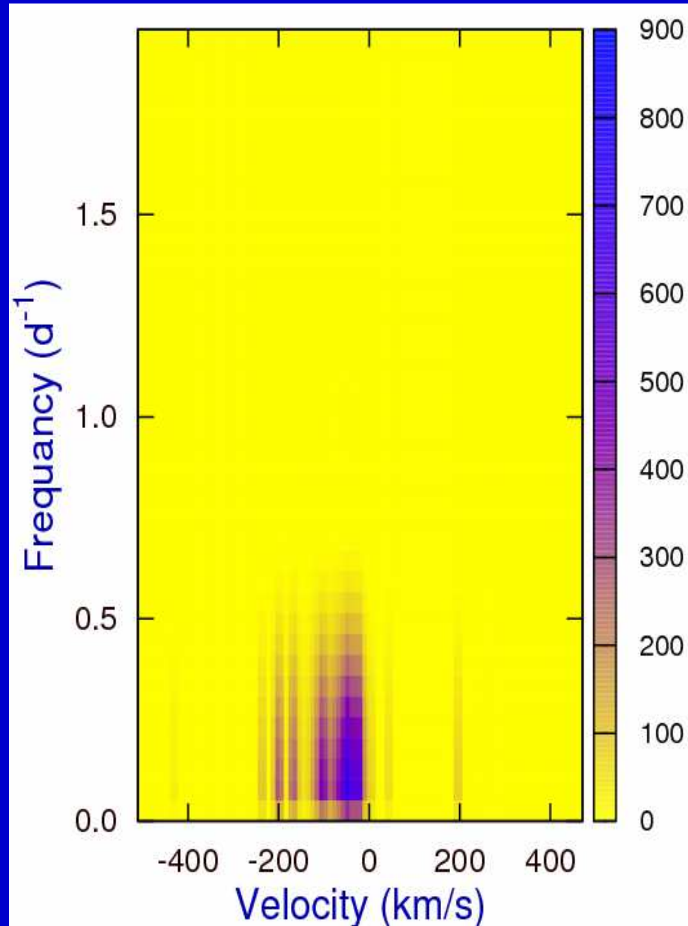
γ Ori



18.01.2019



20.01.2019



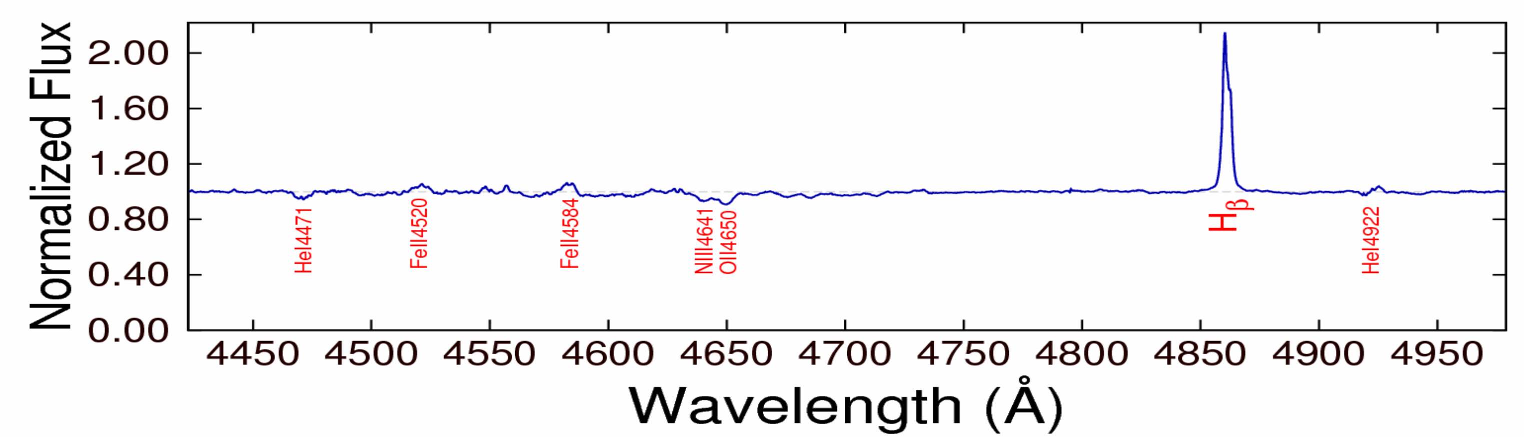
Dynamical spectra of LPVs for H_β

#	$\nu(d^{-1})$	P
1	0.257	3.88^d
2	25.38	$54\text{-}57^{min}$
3	440.65	$3.1\text{-}3.3^{min}$

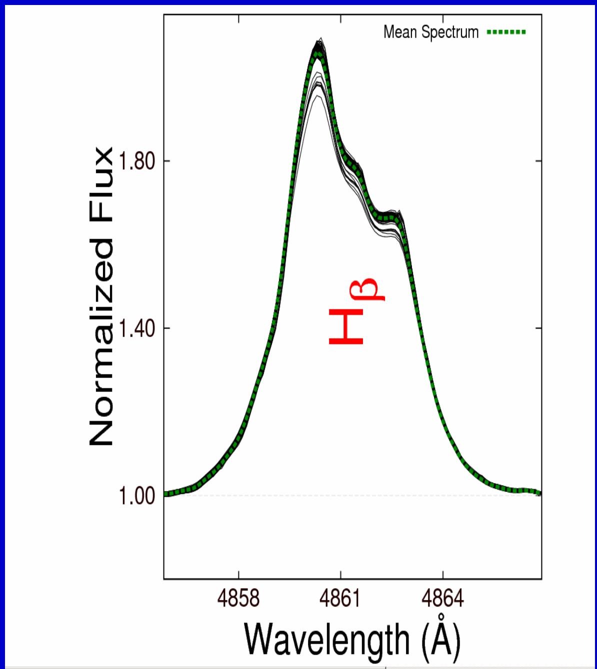
BTA, MSS, 04.11.2020

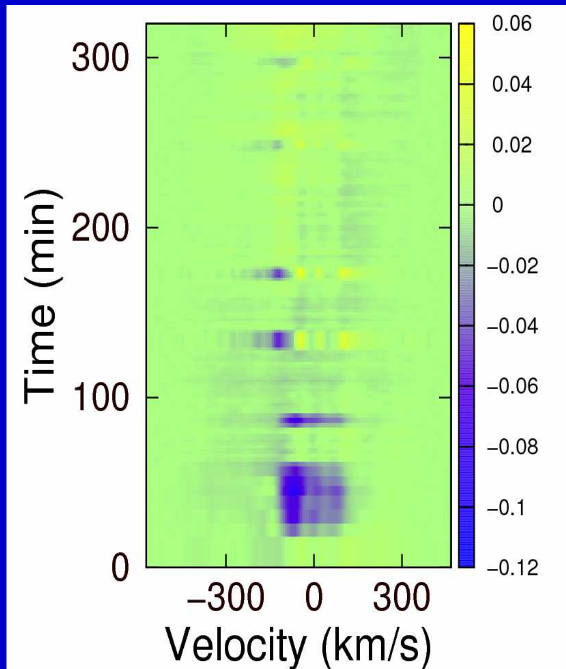
γ Cas

B0.5IVpe
V=2.39



P_{rot}=1.215811± 0.000030 days





Clean Spectrum (H_β):

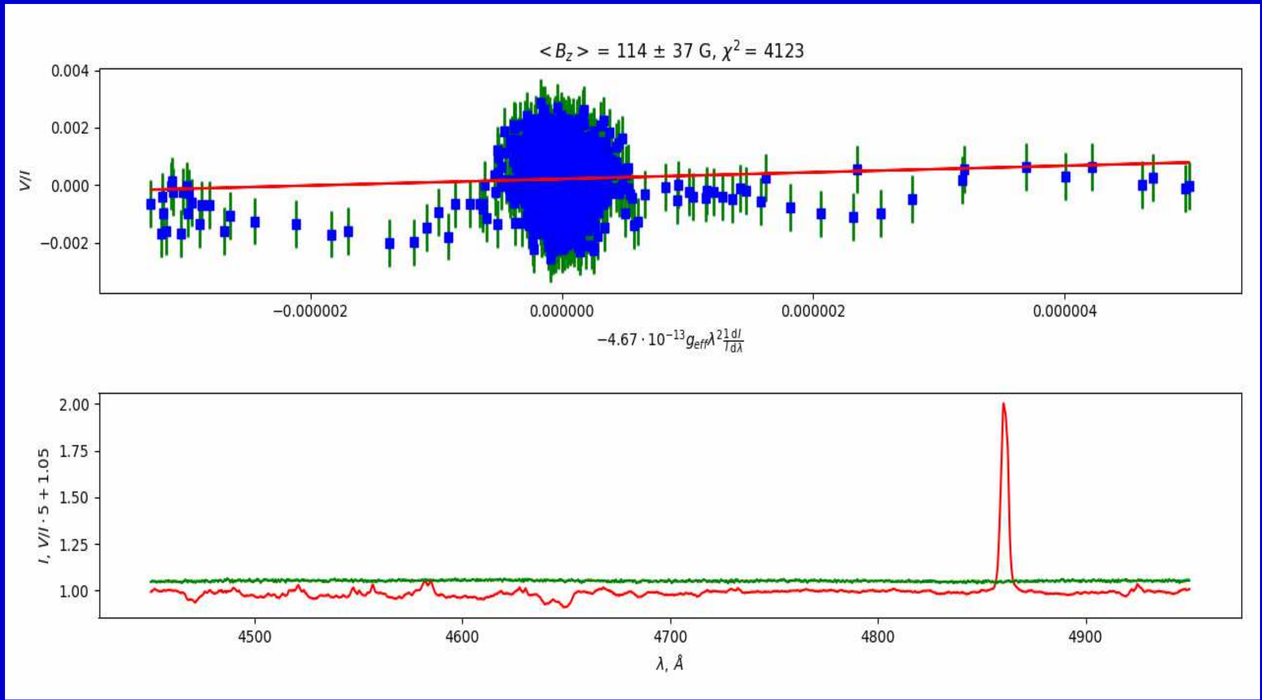
P= 45.1 min
P= 59.3 min
P=145.5 min
P=188.3 min
P=266.8 min
P=291.1 min

Time resolution
ΔT=2-3 min

P=188.3±118 min P(TESS)=190 min
P=291.1±282 min P(TESS)=285 min

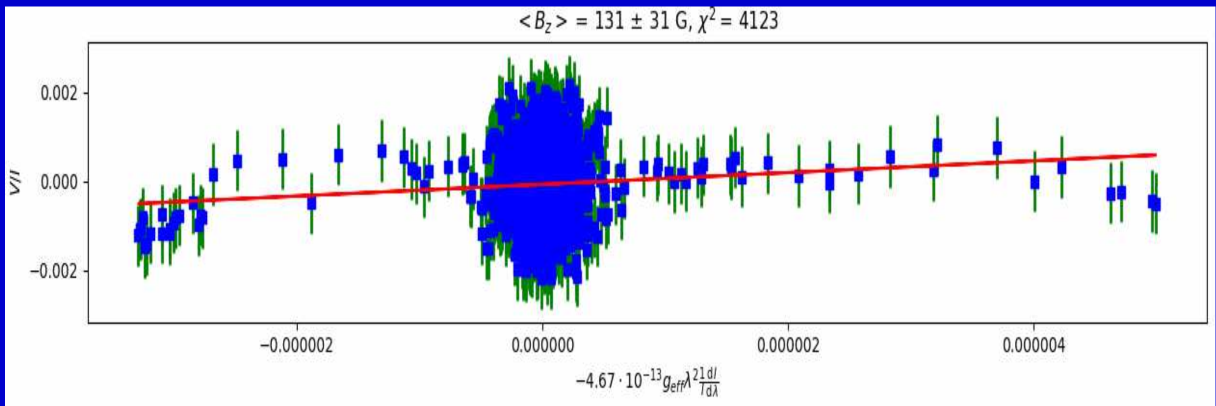
BTA, MSS, 1-2.2.2021. Magnetic field

γ Cas



$$\frac{V}{I} = -4.67 \cdot 10^{-13} (\lambda)^2 \; g_{\text{eff}} \cdot B_l \frac{dI}{I d\lambda}$$

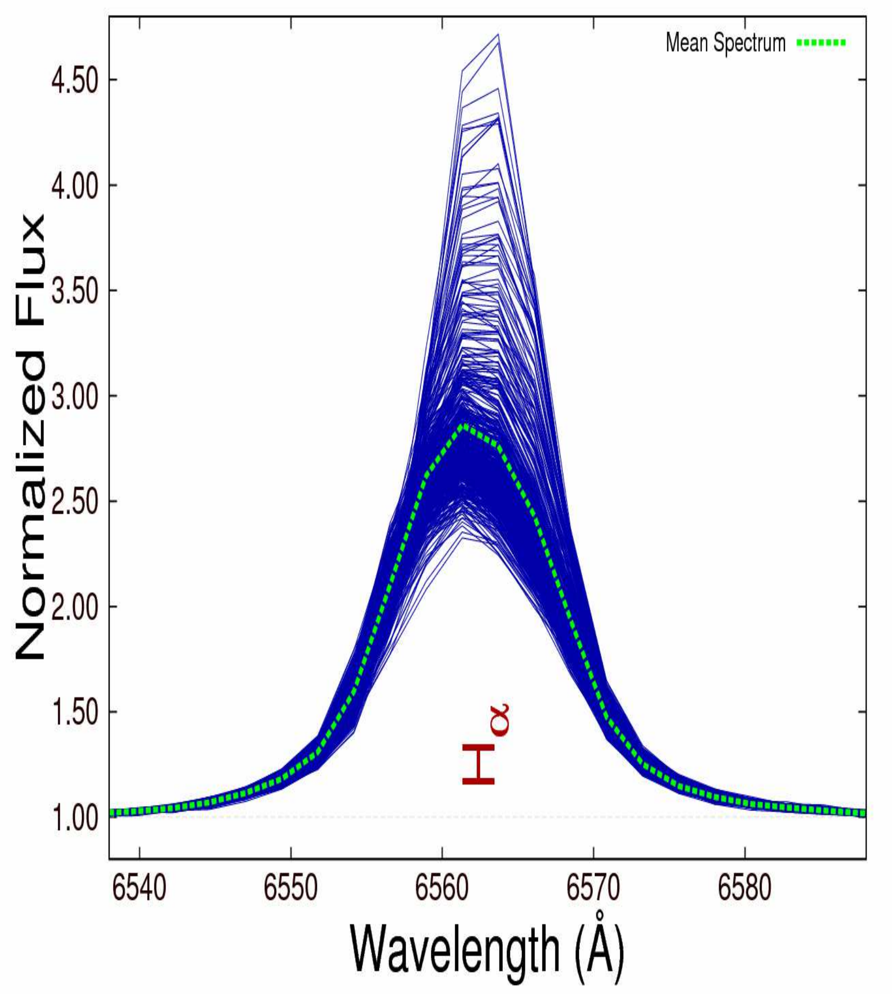
$$\langle B_{\text{rms}} \rangle = 74G \Rightarrow B_p \approx 370G$$



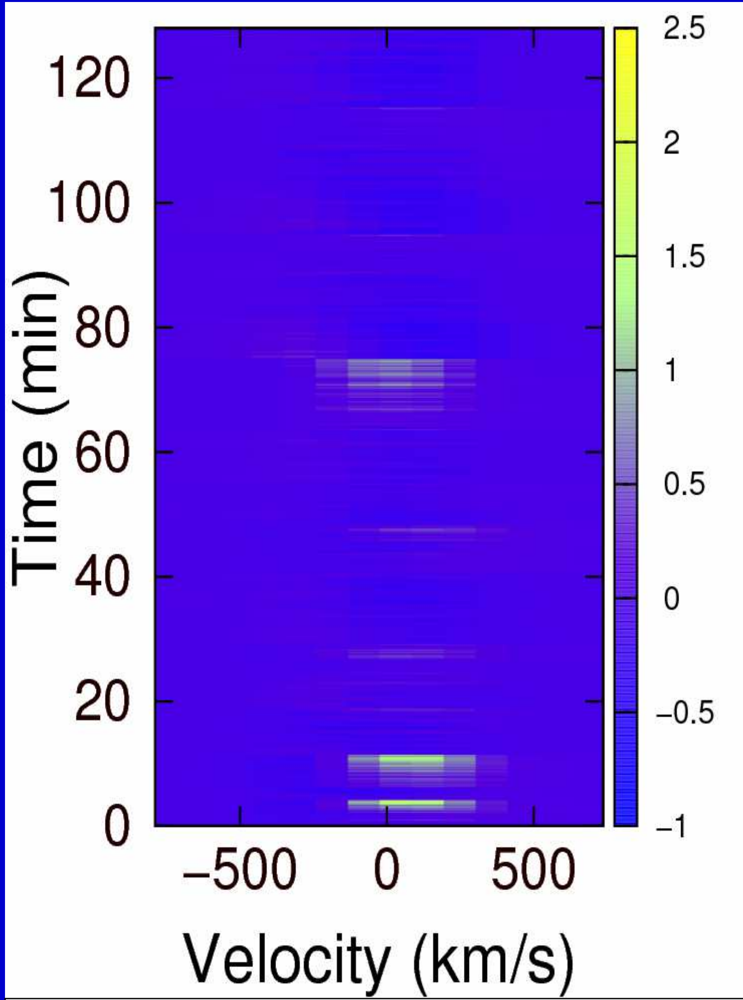
sp	Bl	sigma	Bl/sigma
1	-154	37	4.16
2	-6	34	0.18
3	78	38	2.05
4	20	42	0.48
5	80	41	1.95
6	-167	96	1.74
7	12	39	0.31
8	-99	36	2.75
9	-63	46	1.37
10	-6	34	0.18
11	-125	37	3.38
12	-77	39	1.97
13	69	46	1.50
15	28	43	0.65
16	-15	34	0.44
17	-12	39	0.31
18	-164	35	4.69
19	66	33	2.00
20	54	32	1.69
21	7	45	0.16
22	36	30	1.20
23	29	34	0.85
24	-14	44	0.32
25	67	41	1.63
27	73	49	1.49
28	-94	40	2.35
29	79	37	2.14
30	-46	48	0.96
31	6	35	0.17
32	-18	35	0.51
33	-37	37	1.00
34	-62	32	1.94

1.25-m - 13-14.9.2020 - Halpha

γ Cas



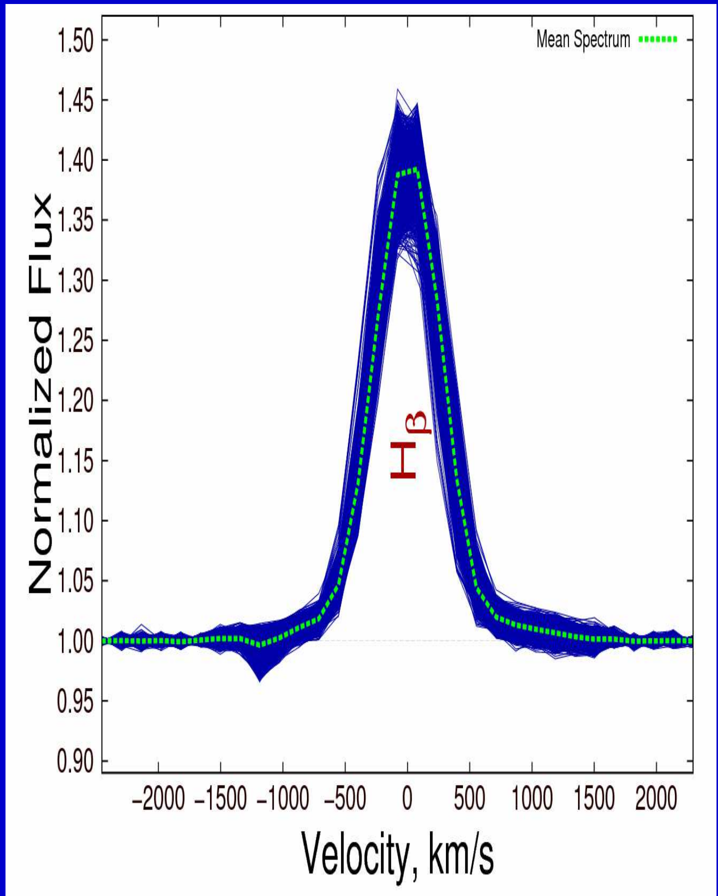
Hα LPVs

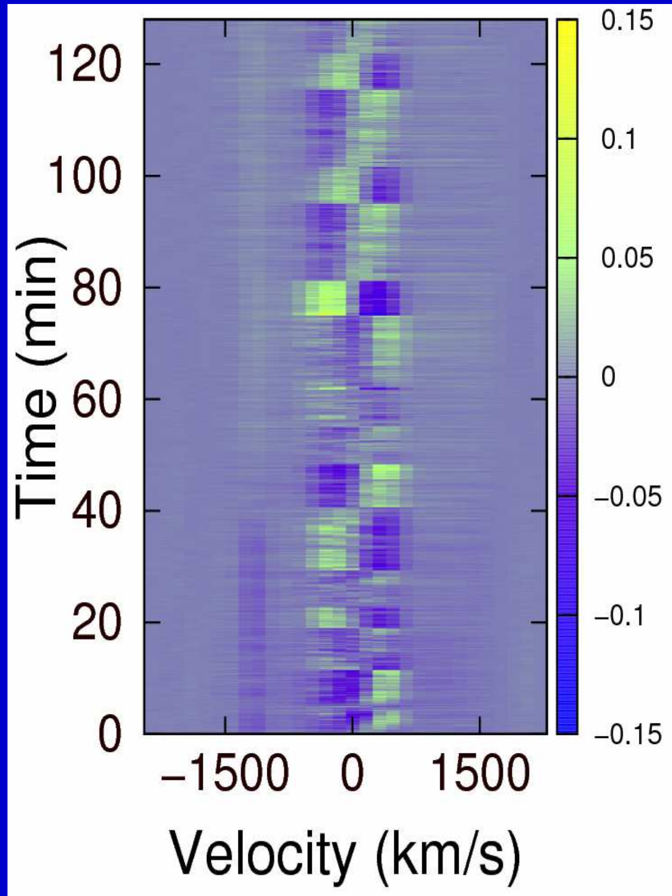


Dynamical spectrum of Hα

1.25-м - 13-14.9.2020 - Hβ

γ Cas





ΔT=8 seconds

CLEAN spectrum: H_α,H_β and HeI5678

No. comp.	1	2	3	4	5	6
Period (min)	3.68±0.16	4.22±0.15	6.38±0.53	8.23±0.24	10.72±1.065	19.50±0.95

Conclusions

1. 22 OBA stars were observed in order to find the sfLPVs;
2. ***Fast line profiles variations in spectra of all the studied stars with periods from 1 to ~ 150 minutes were detected. These variations are "highly likely" related to high NRP modes;***
3. ***LPVs in spectra ρ Leo and α^2 CVn with $\nu > 0.1$ min^{-1} are transient with slightly variable periods could be explained by fast generation and quenching the NRP modes $l >> 1$;***
4. ***Most of the program stars with detected LPVs are magnetic;***
5. ***Superfast LPVs can be detected in spectra of bright OBA stars using the moderate diameter telescopes and low-resolution (R=500-2000) spectrographs;***
6. At the same time, the measurement of their magnetic fields is possible only with large telescopes.

Questions?