Radial Velocity /Time Series analysis of γ Equ

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Outline

- Introduction
- Method
- Analysis
- Results

Introduction

- γ-Equ belongs to a class of Rapidly Oscillating Ap stars (roAp)
- They show high abundance in metals especially in Praseodymium and Neodymium
- They rotate slower than normal *A* and *B* stars due to their strong magnetic fields
- They exhibit short-timescale (4-16 min) photometric variations of low amplitudes (15mmag)
- This leads to radial velocity variations of the spectral lines

γ-Equ

- γ-Equ is the second brightest roAp star out of 35 with rotation period of *77 years*.

* **gam Equ** -- Variable Star of alpha2 CVn type

Other object types:	* (*,AG,...), ** (**,ADS,...), IR (IRAS,2MASS), PM* (LSPM), a2* (Ref), V* (V*), UV (TD1)
ICRS coord. *(ep=J2000) :*	21 10 20.50005 +10 07 53.6763 (Optical) [5.79 4.58 90] A 2007A&A...474..653V
FK5 coord. *(ep=J2000 eq=2000) :*	21 10 20.500 +10 07 53.68 [5.79 4.58 90]
FK4 coord. *(ep=B1950 eq=1950) :*	21 07 54.57 +09 55 45.0 [33.32 26.64 0]
Gal coord. *(ep=J2000) :*	059.9329 -24.7630 [5.79 4.58 90]
Proper motions *mas/yr* :	48.74 -153.03 [0.66 0.52 0] A 2007A&A...474..653V
Radial velocity / Redshift / cz :	V(km/s) -16.50 [0.3] / z(~) -0.000055 [0.000001] / cz -16.50 [0.30] A 2006AstL...32..759G
Parallaxes *(mas)*:	27.55 [0.62] A 2007A&A...474..653V
Spectral type:	A9VpSrCrEu C 1985ApJS...59...95A
Fluxes (8) :	U 5.03 [~] C 2002yCat.2237....0D
	B 4.94 [~] C 2002yCat.2237....0D
	V 4.68 [~] C 2002yCat.2237....0D
	R 4.43 [~] C 2002yCat.2237....0D
	I 4.32 [~] C 2002yCat.2237....0D
	J 4.28 [~] C 2002yCat.2237....0D
	H 4.18 [~] C 2002yCat.2237....0D
	K 4.10 [~] C 2002yCat.2237....0D

Stellar Observations Network Group

- Launched in 2006 by astronomers at Aarhus University and the University of Copenhagen.

- SONG is a Danish-led project dedicated to the design and construction of a global network of small telescopes for the study of stars and planetary systems around stars.

- 1st telescope is 1 meter in diameter at Teide Observatory in Tenerife (Hertzsprung telescope)

Request	Object	Vmag	RA	DEC	RA PM	DEC PM
10622	GammaEqu	4.68	21:10:20.50	10:07:53.68	48.74	-153.03

Status	Updated at	Proposal PI	Project name	Project ID	Priority
done	2016-08-06T00:30:04	Vichi Antoci	P03-000	0	98

Mode	Slit	# ThAr	Exp. time	Exposures	Start window	Stop window
none-iodine	6	1	250	26 of 50	2016-08-05T21:50:00	2016-08-06T00:30:00

Please note that not all parameters for each OR are displayed!

Quick Look

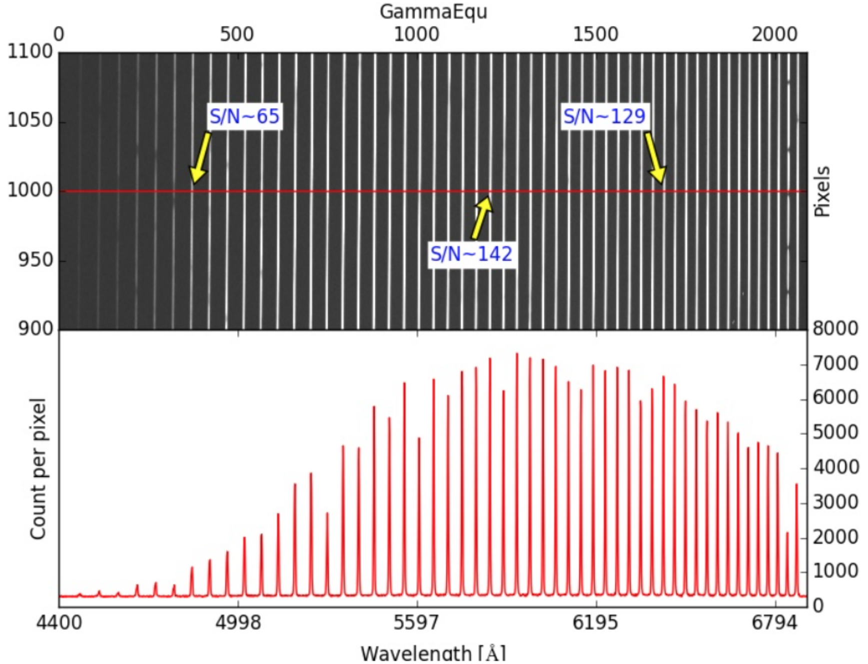
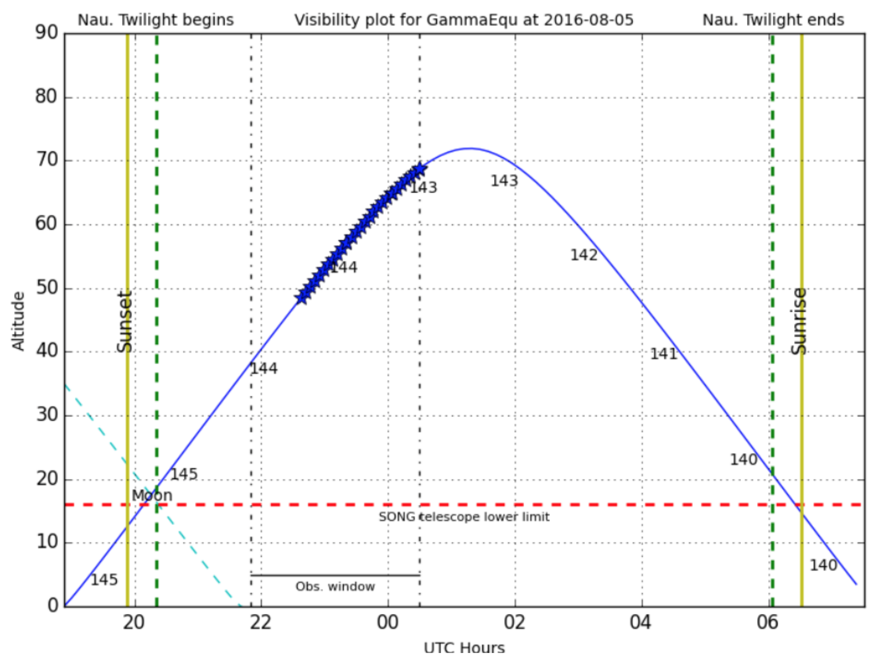


Image number: 1 of 26 Prev Next

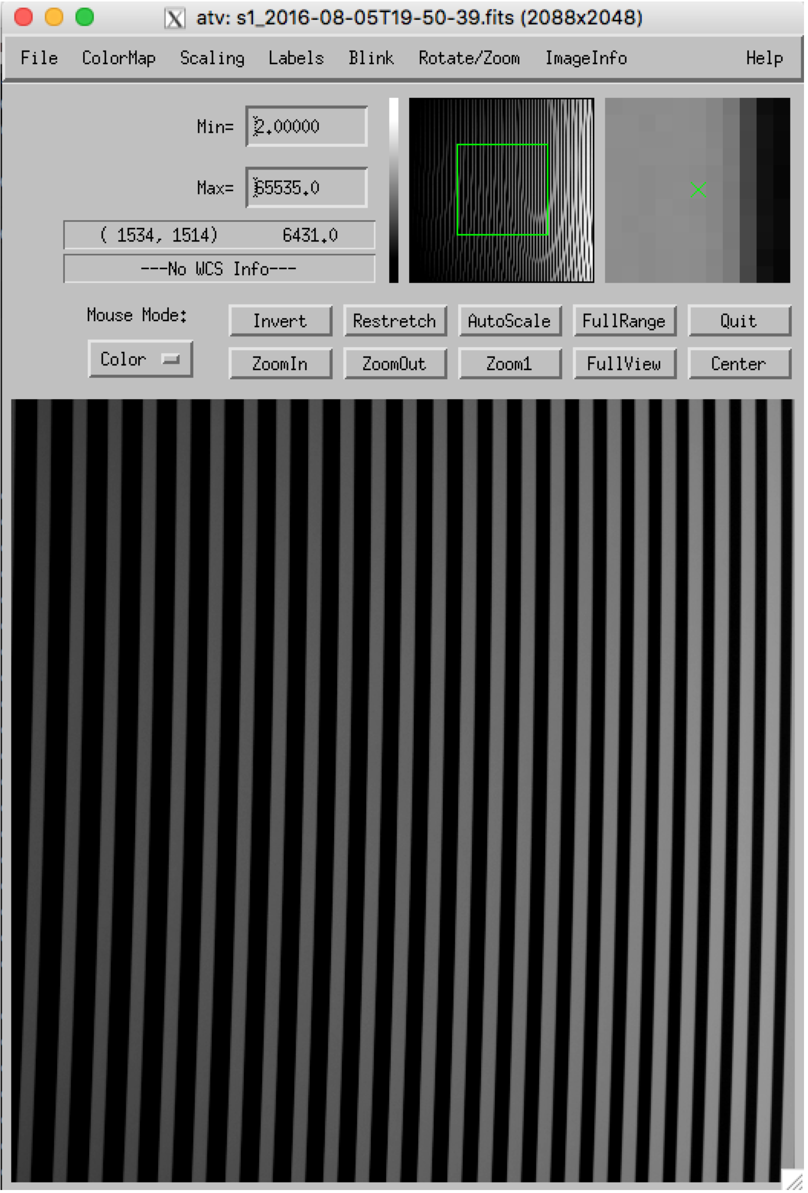


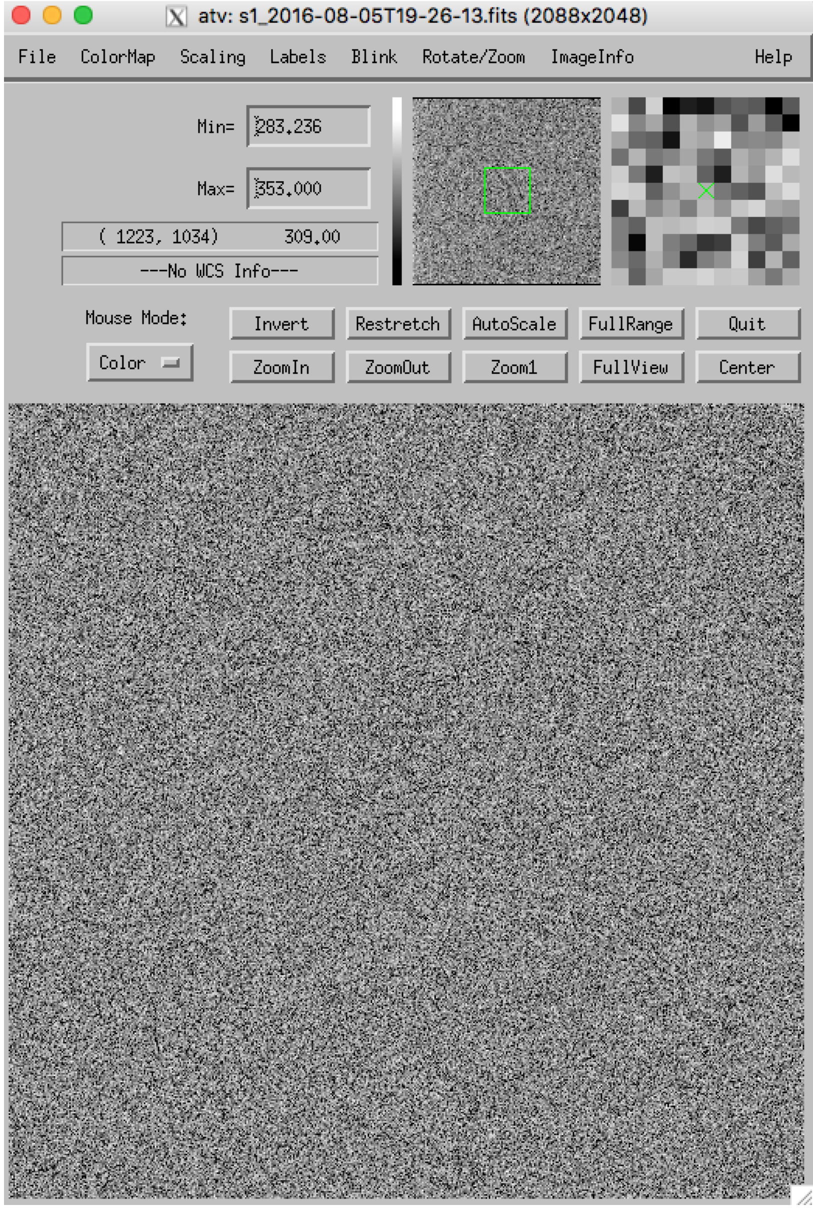
```
---TEL--= '-----TELESCOPE----' / -----------------------------------
TEL_RA  =           21.1723745 / Right Ascension of the telescope
TEL_DEC =           10.1307799 / Declination of the telescope
TEL_AZ  =          146.3059908 / Azimuth of the telescope
TEL_ALT =           68.8023324 / Altitude of the telescope
TEL_FOC =                2.987 / Focus of the telescope
TEL_TM  =                   12 / Third mirror position
TEMP_M1 =                17.56 / Temperature M1
TEMP_M2 =                19.93 / Temperature M2
TEMP_M3 =                20.19 / Temperature M3
TEMP_TT =                20.68 / Temperature Structure
```

```
---SP---= '---SPECTROGRAPH---' / ------------------------------------
SLIT    =                    6 / Slit position (1 to 9)
CAMFOCS =               187628 / The camera mirror focus
TEMP1   =                 29.0 / The temperature of camera flange inside
TEMP2   =                29.26 / The temperature of cross disperser
TEMP3   =                28.21 / The temperature of spectrograph table
TEMP4   =                19.18 / The temperature of container air
THAR    =                    0 / ThAr lamp (off=0, on=1)
HALOGEN =                    0 / Halogen lamp (off=0, on=1)
I2POS   =                    2 / Iodine pos (1=test-cell,2=free,3=iodine)
I2T_ACT =                 65.3 / The actual temp. of the iodine cell
I2T_SET =                 65.0 / The set temp. of the iodine cell
FILTWH  =                    4 / Filter wh. (1=n1.3,2=n2,3=n3,4=5=free,6=n0.7)
CALIB_M =                    1 / Calib. mirror: (1=out,2=in,3=ThAr,4=Aux)
MIRR_SL =                    3 / Beamsplit: (1=end,2=acqui,3=cube)
IODID   =                    1 / Cell-ID of the iodine cell in use.
```

```
---W----= '------WEATHER-----' / ------------------------------------
W_TIME  = 'Current Data'       / Reliability of weather data
OUTTEMP =                 18.8 / The temp (Celsius) outside the container
OUTHUMID=                 14.8 / The humidity (%) outside the container
OUTPRESS=                775.0 / The pressure (mb) outside the container.
WINDSPEE=                  9.6 / The windspeed (m/s) outside the container.
WIND-DIR=                318.0 / The wind direction outside the container
SEEING1 =                 1.89 / The current seeing value on slit guiders
SEEING2 =                 1.89 / The running mean seeing on slit guiders
PUPIL_FL=                22.95 / Left side pupil flux level
PUPIL_FR=                18.03 / Right side pupil flux level
```

Flat and Bias frames



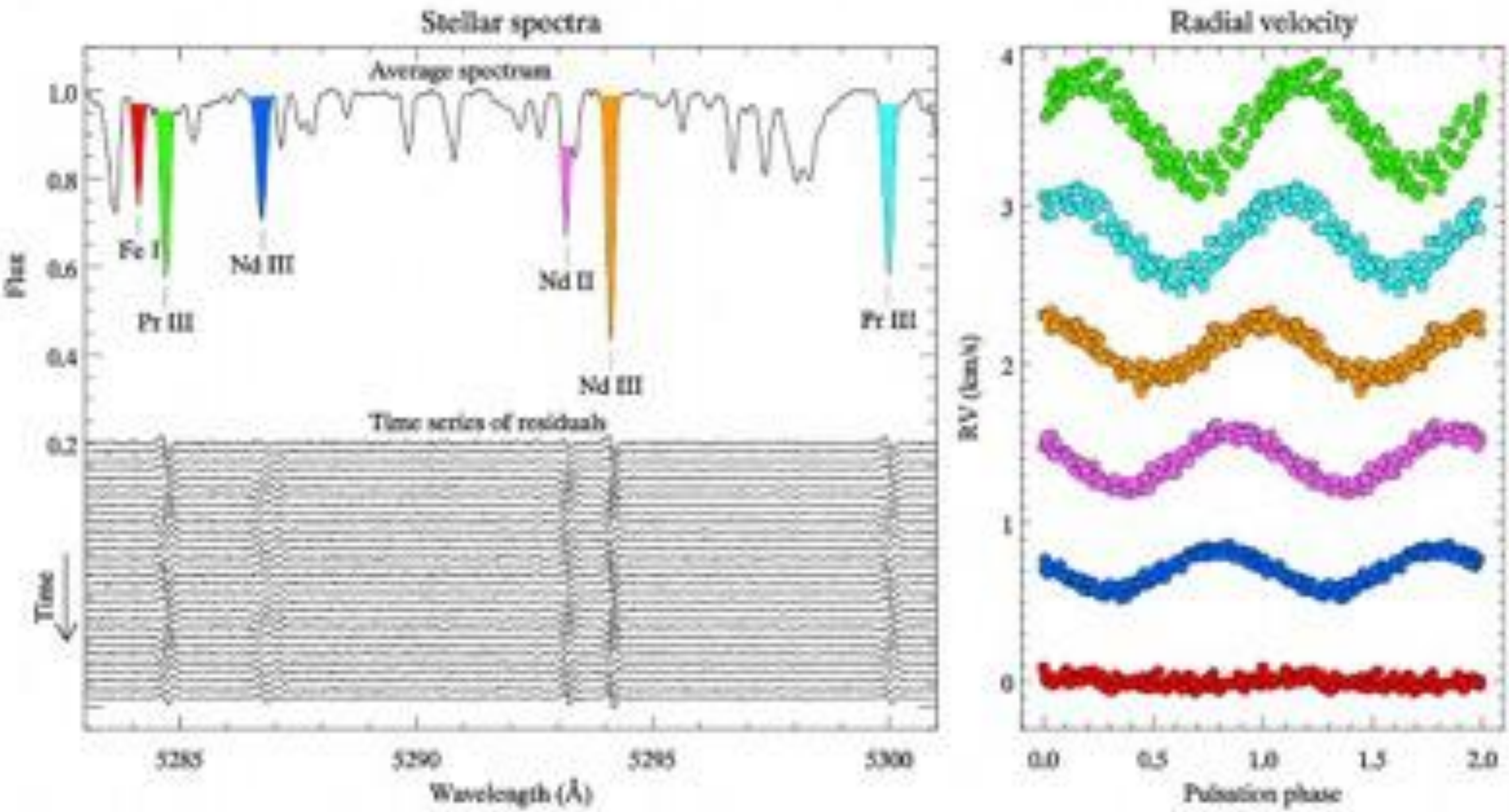


Objectives

- Calculate RV shift of prominent lines from SONG spectra.
- Obtain time-series of high-resolution high *S/N* spectra of γ -Equ to study in detail the line profile variations due to stellar pulsations.
- Obtain period of this pulsation.

Methods

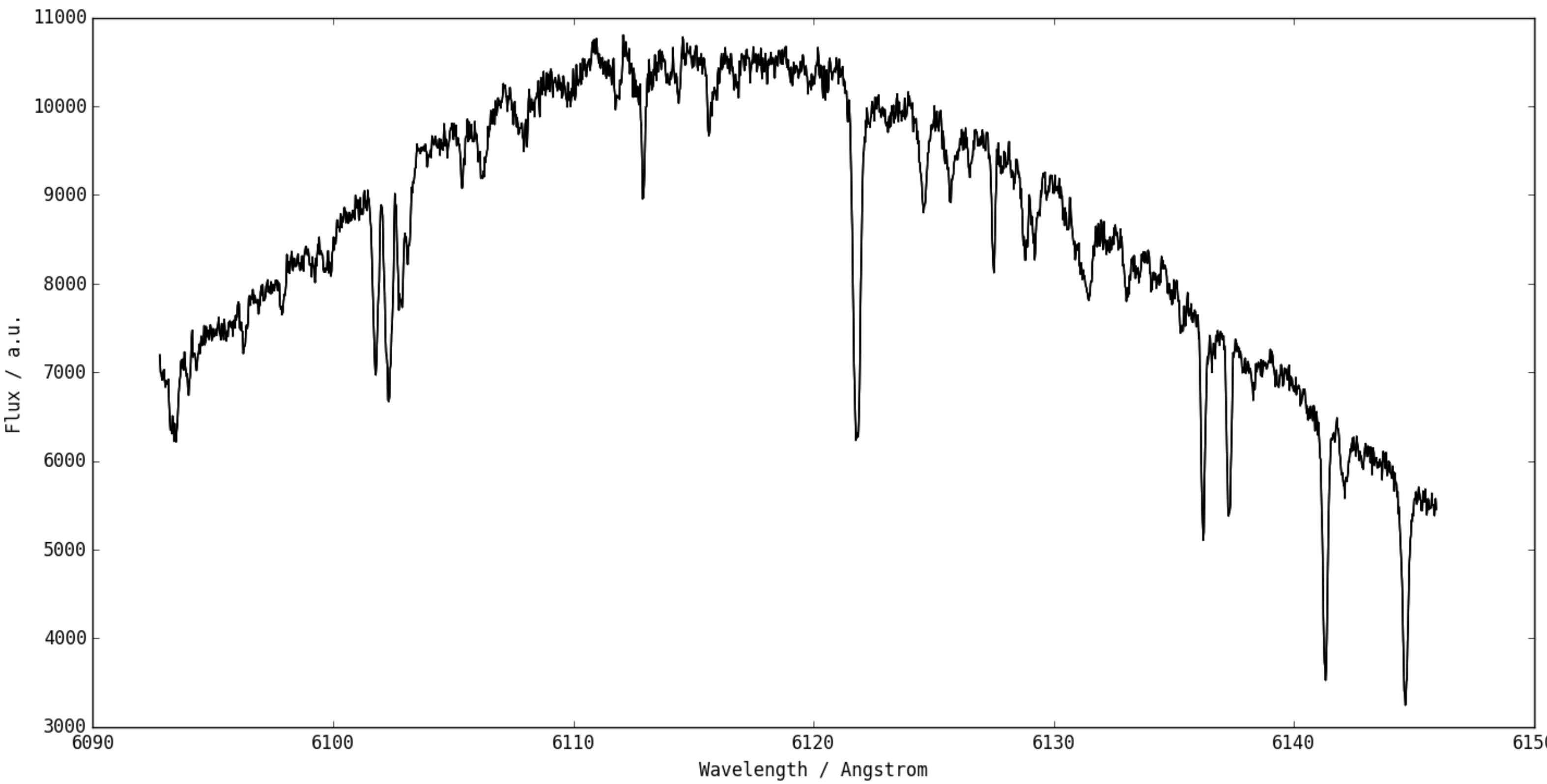
- Selection of spectral line with greatest RV shift and its order
- Spectrum Normalization
- RV calculation
- Times series plot
- Period determination


Stellar spectra
Average spectrum
Fe I
Pr III
Nd III
Nd II
Nd III
Pr III
Flux
1.0
0.8
0.6
0.4
0.2
Time series of residuals
Time
5285
5290
5295
5300
Wavelength (Å)
Radial velocity
RV (km/s)
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
Pulsation phase

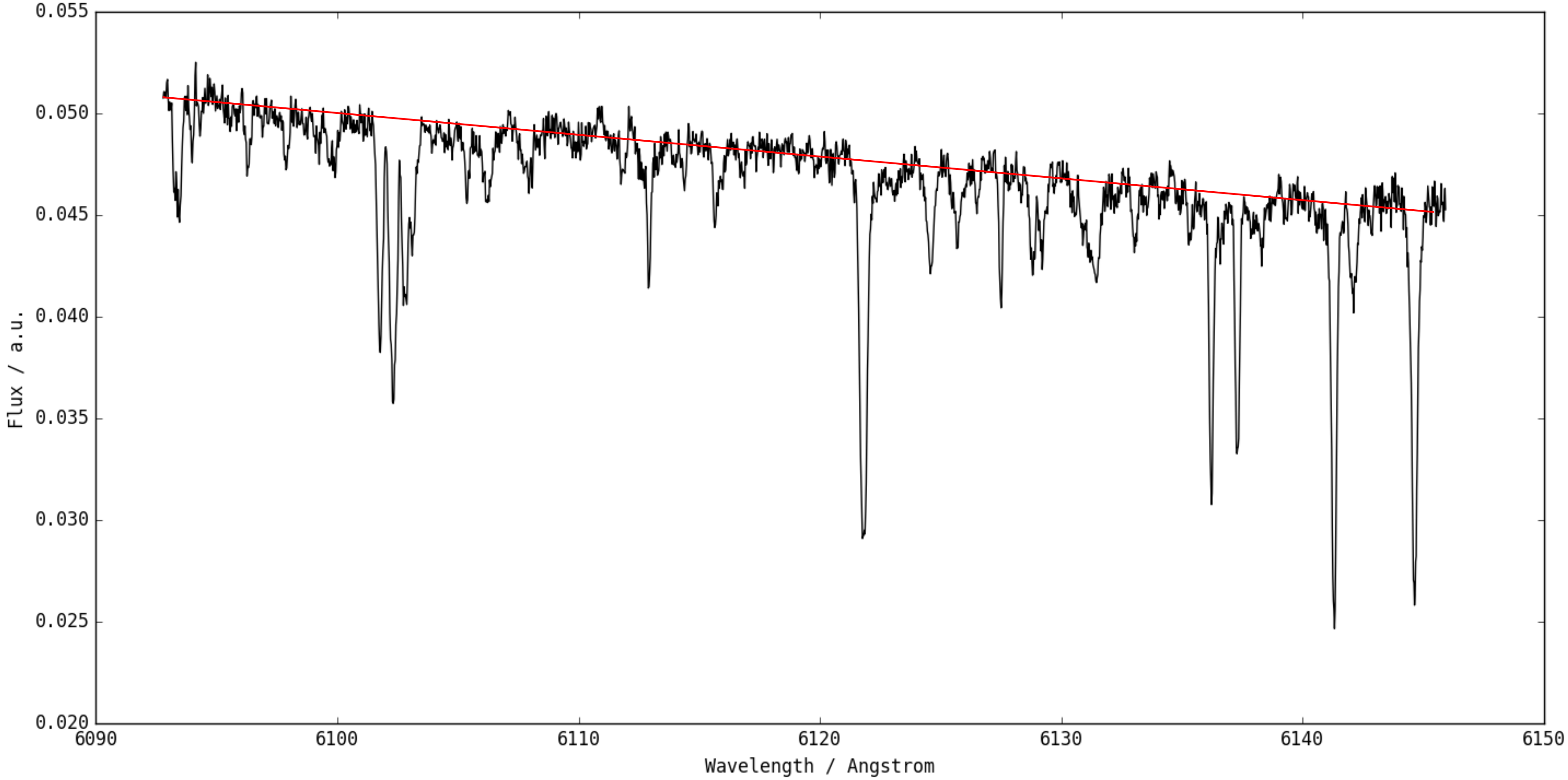
Ion	$\lambda_{\rm lab}$ Å	K $\rm m\,s^{-1}$	$\sigma_{\rm K}$ $\rm m\,s^{-1}$	φ	σ_φ	P
Fe II	6141.10	≤120				
Ba II	6141.71	93	16	0.899	0.031	2,3
Si I	6142.48	≤90				
Ce II	6143.38	296:	60	0.915:	0.034	2.1
Nd III	6145.07[1]	470	21	0.159	0.007	2,1
Si I	6145.02[1]					
La II	6146.52	216:	49	0.944:	0.039	2,3
Cr II	6147.14	≤60				
Fe II	6147.74	72:	16	0.674:	0.037	3,4
Pr II	6148.24	348	96	0.886	0.048	2
uncl.	6148.86	736	30	0.060	0.006	2
Fe II	6149.26	64:	14	0.667:	0.036	3,4
Fe II	6150.10	89:	35	0.473:	0.073	4,3
uncl.	6150.62	557	44	0.141	0.044	3,2
Fe I	6151.62	≤75				
Yb II	6152.57	377:	95	0.881:	0.045	4,3
Na I	6154.23	364	72	0.893	0.032	3,4
Si I	6155.13	≤70				
Sm II	6156.92	320	50	0.953	0.025	2,3
Fe I	6157.73[2]	209:	17	0.039:	0.013	2,3
Cr II	6158.11[3]	184	31	0.564	0.027	1,2
Cr II	6158.18[3]					
O I	6158.18[3]					
Ca II	6158.57[4]	137	47	0.056	0.052	1,2
Cr II	6158.62[4]					
Fe I	6159.38[5]	≤100				
Cr I	6159.48[5]					
Pr III	6160.24	788	37	0.169	0.007	1.2
Na I	6160.75	320	30	0.958	0.016	3,4
Pr II	6161.18[6]	339	33	0.151	0.016	1,2
Pr III	6161.22[6]					
Ca I	6161.30[6]					
Ca I	6162.17	≤30				
Ca I	6163.76	≤35				

Spectra showing order 40

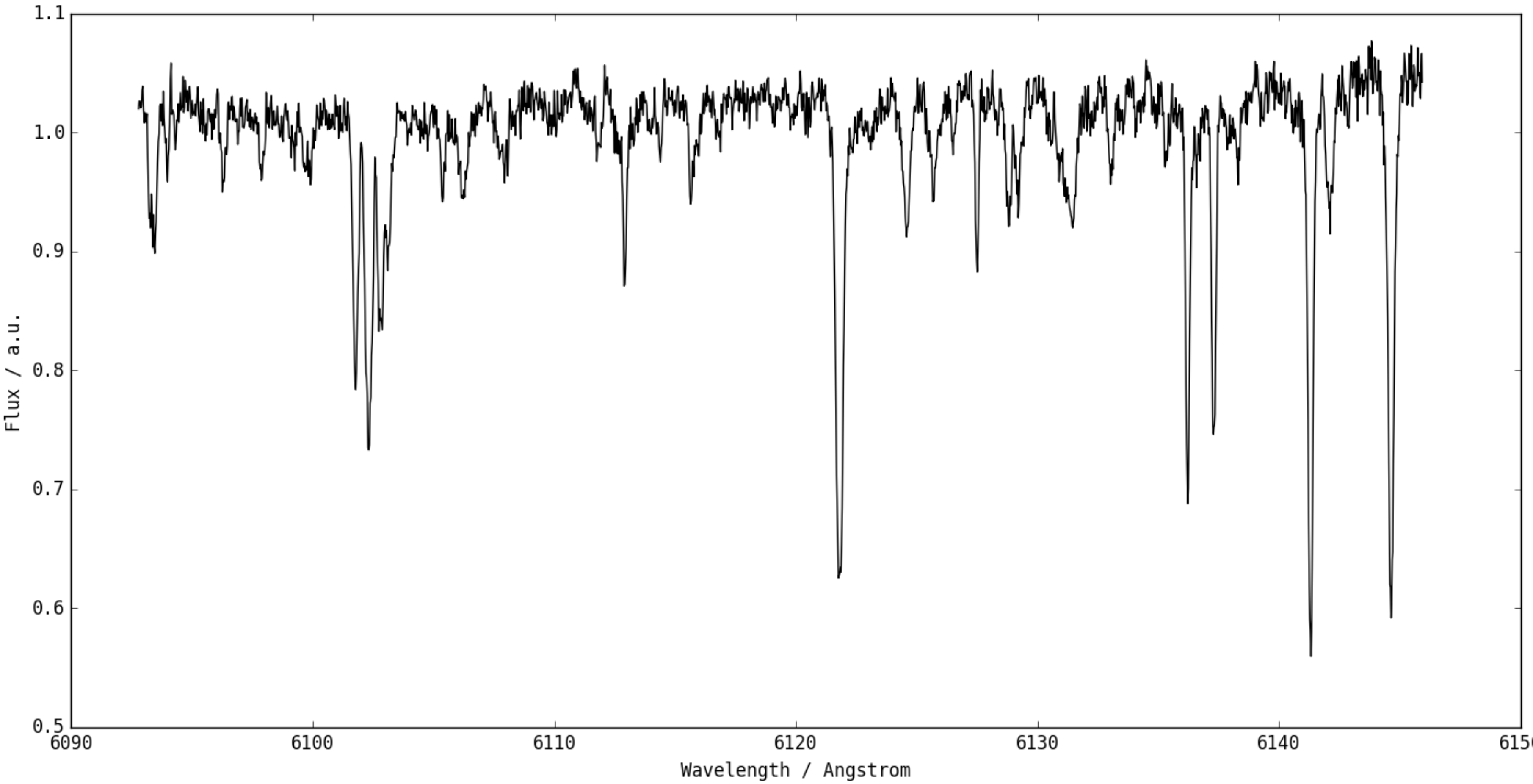
- Line selected is that of Nd III at 6145.07 Å



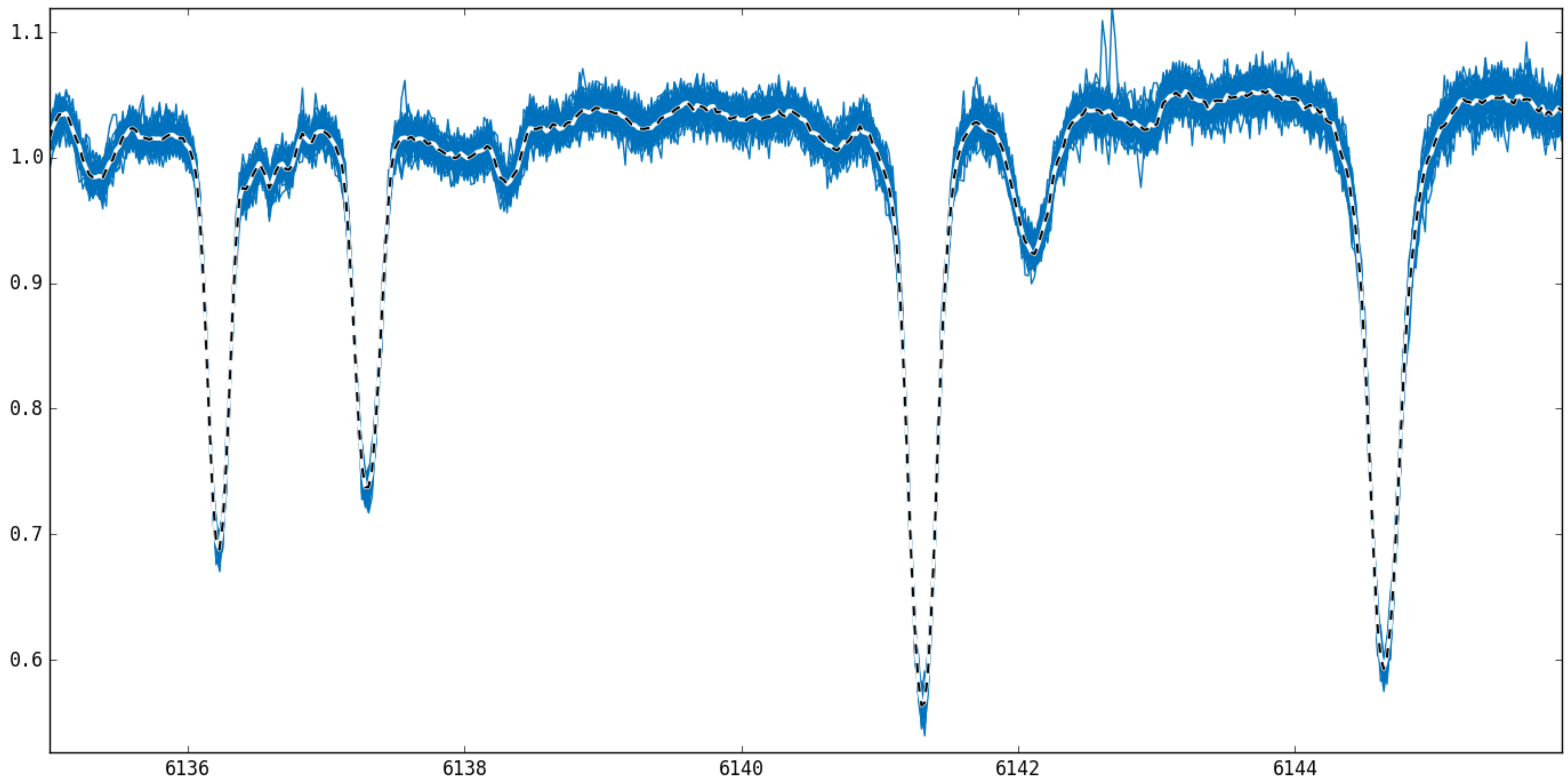
Blaze function correction



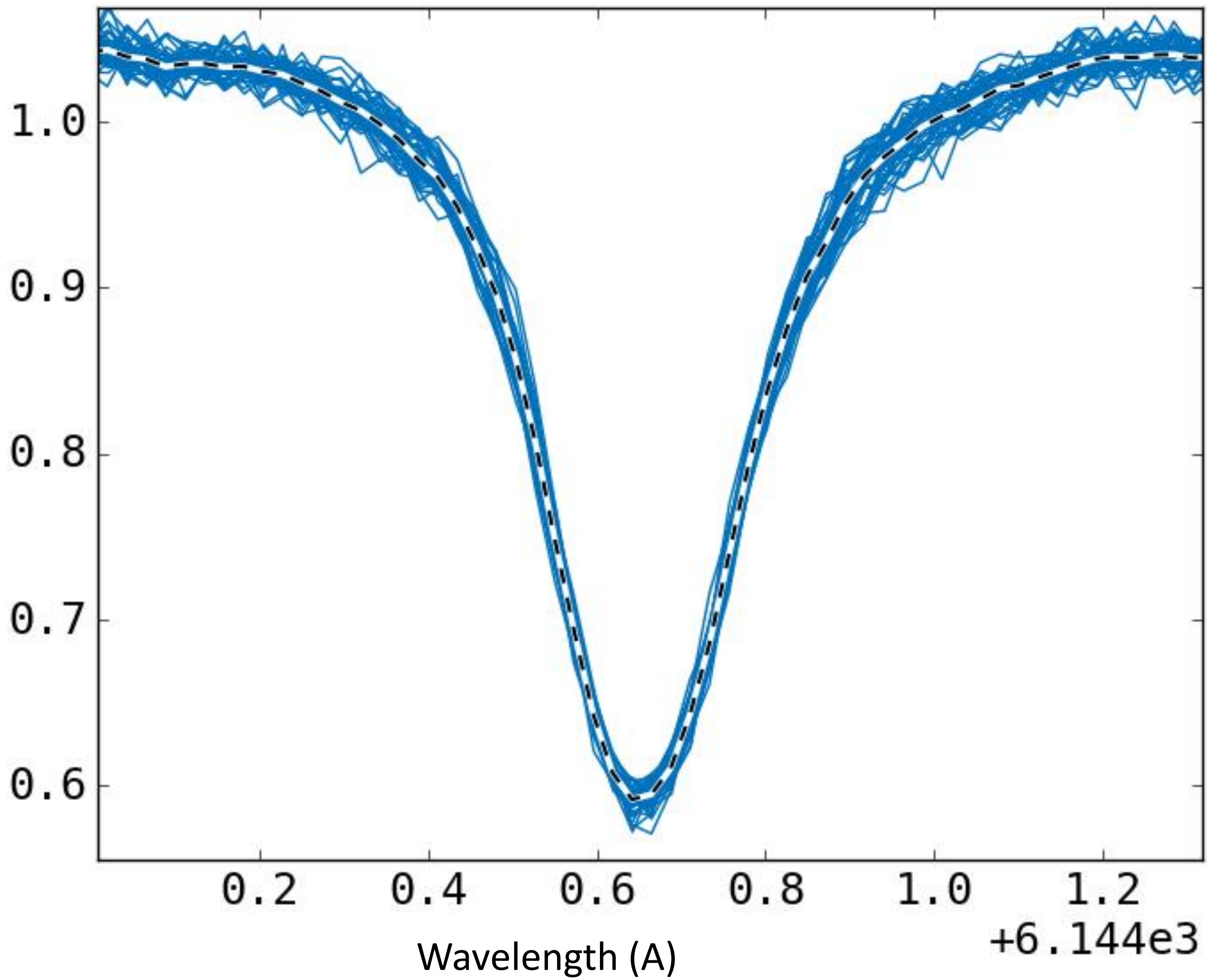
Normalization



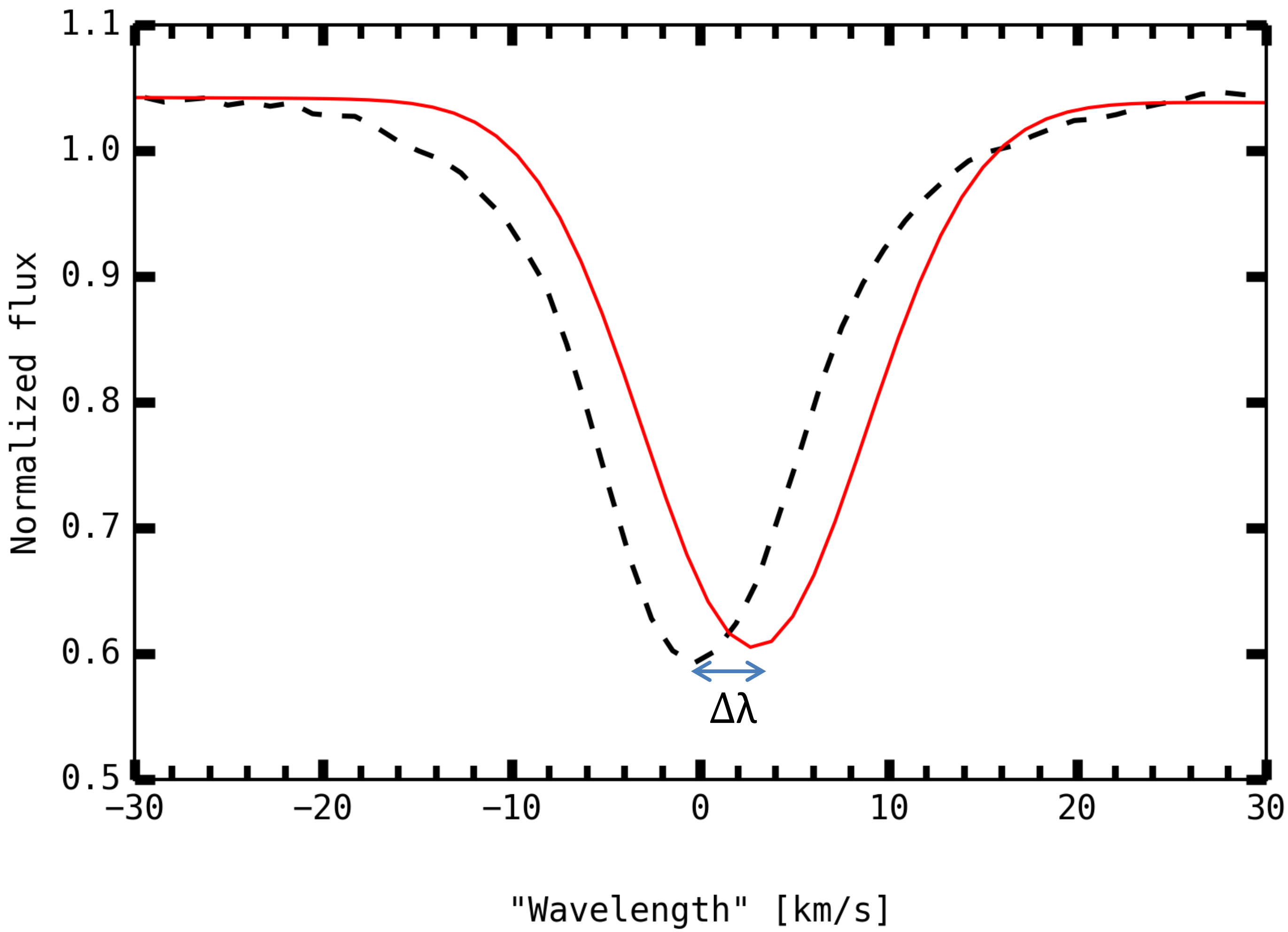
Plot of all spectra for one night and the mean



Zoom in on the line(Nd III)

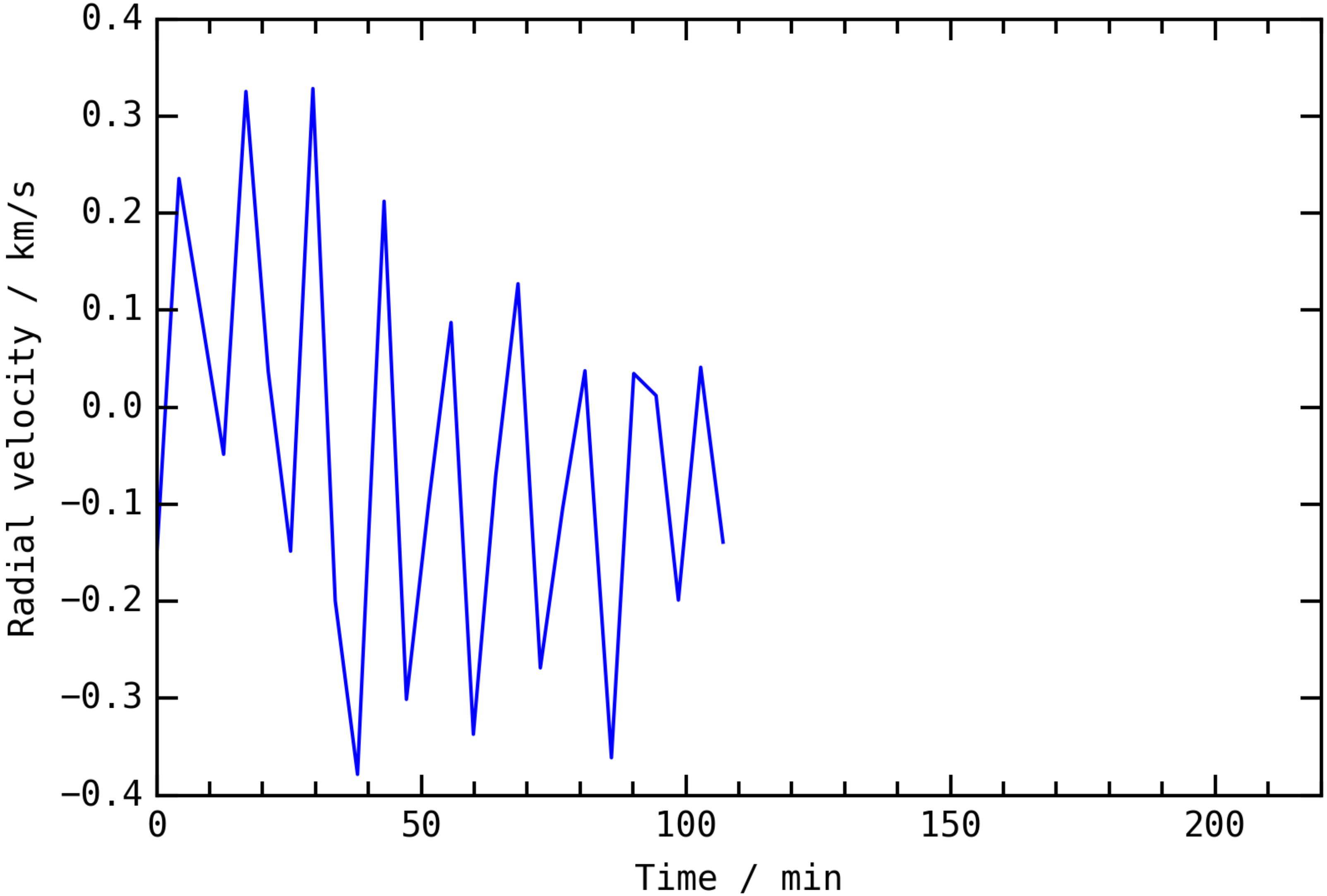


Fitting Gaussian to a spectral line

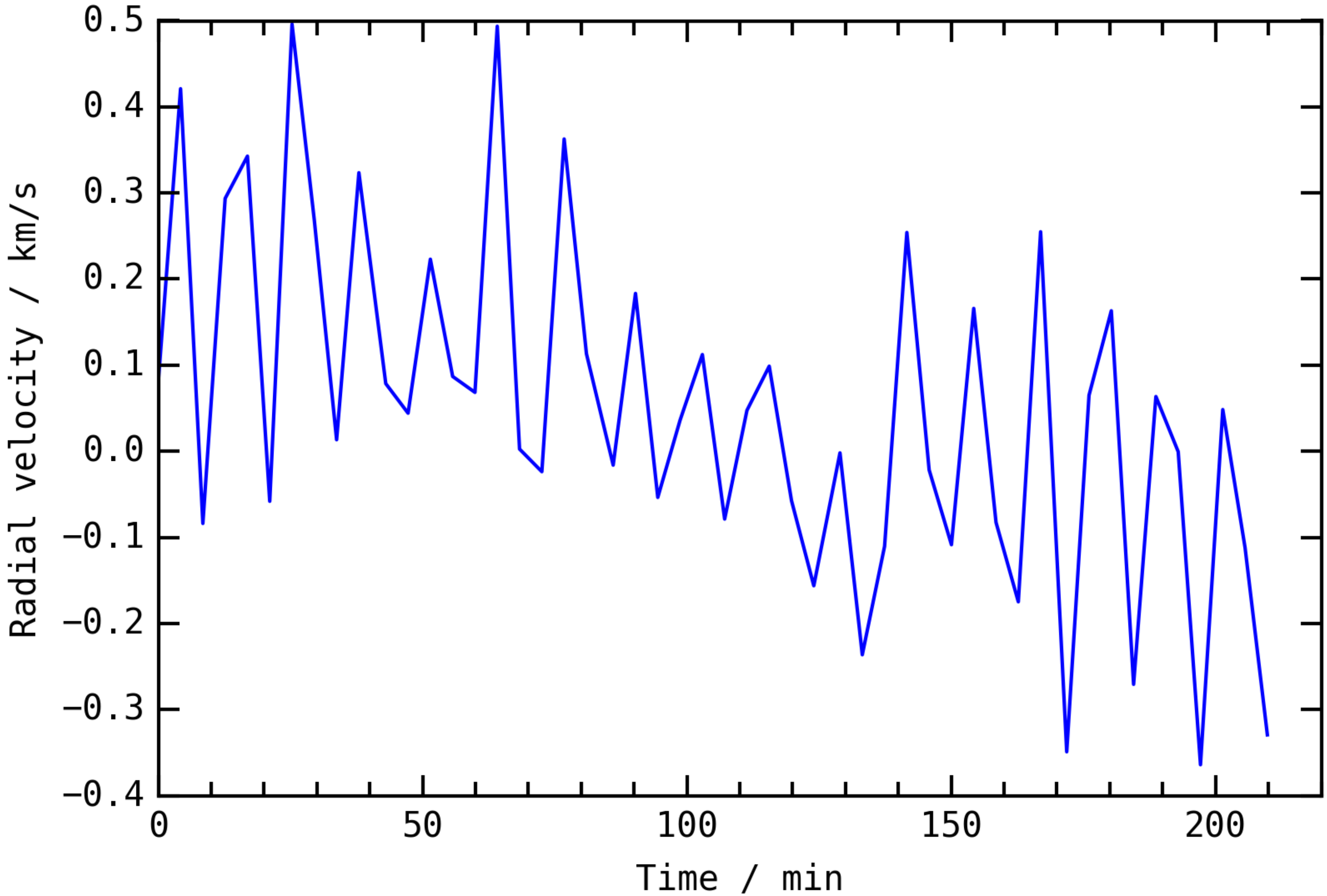


$$v = \frac{\Delta\lambda}{\lambda} c$$

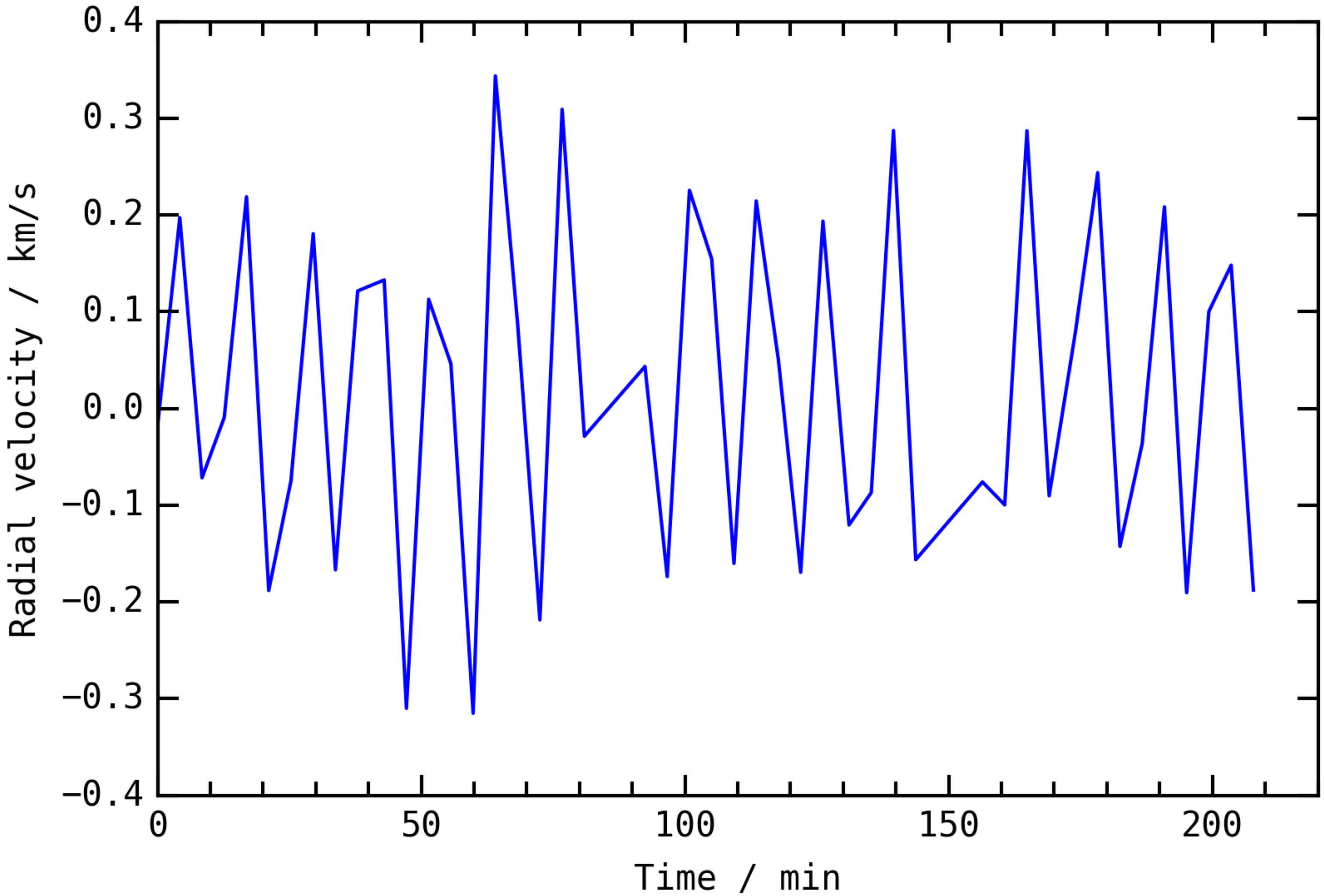
Time series (night 1)



Time series(night 2)

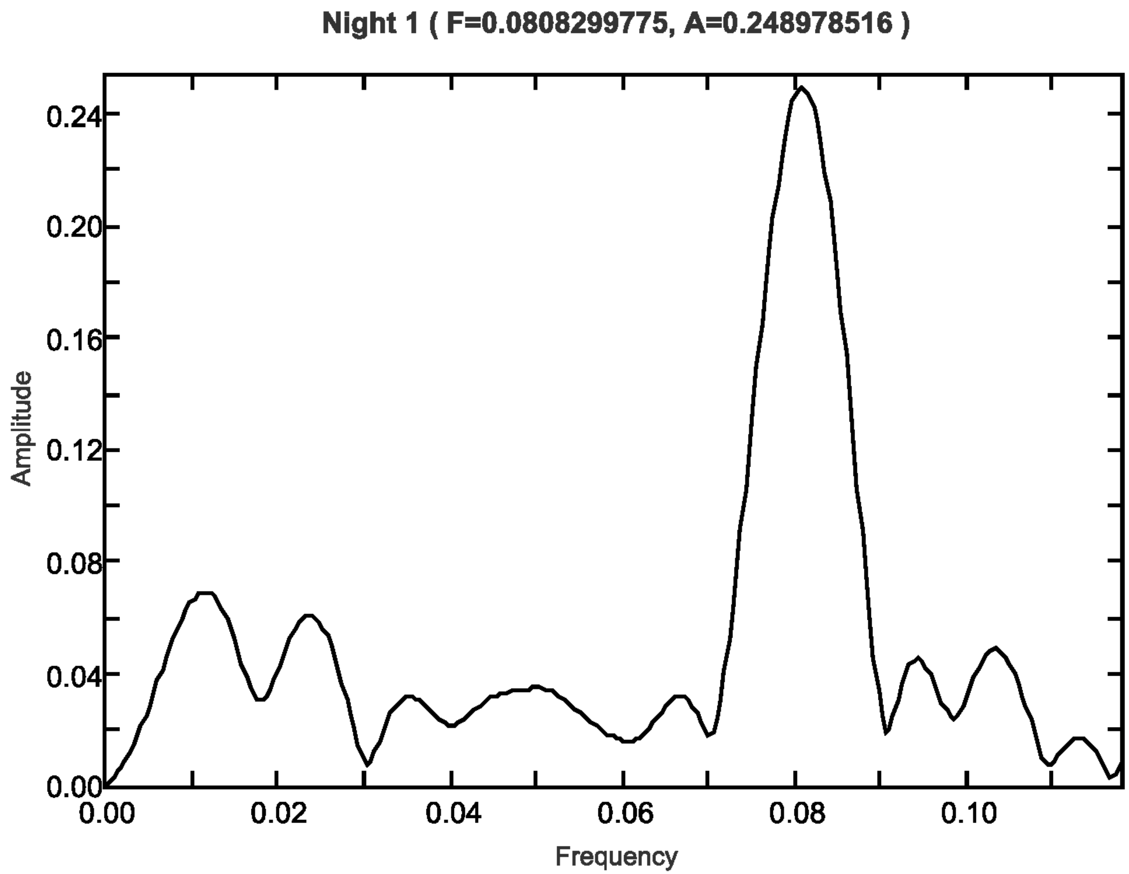


Time series(night 3)

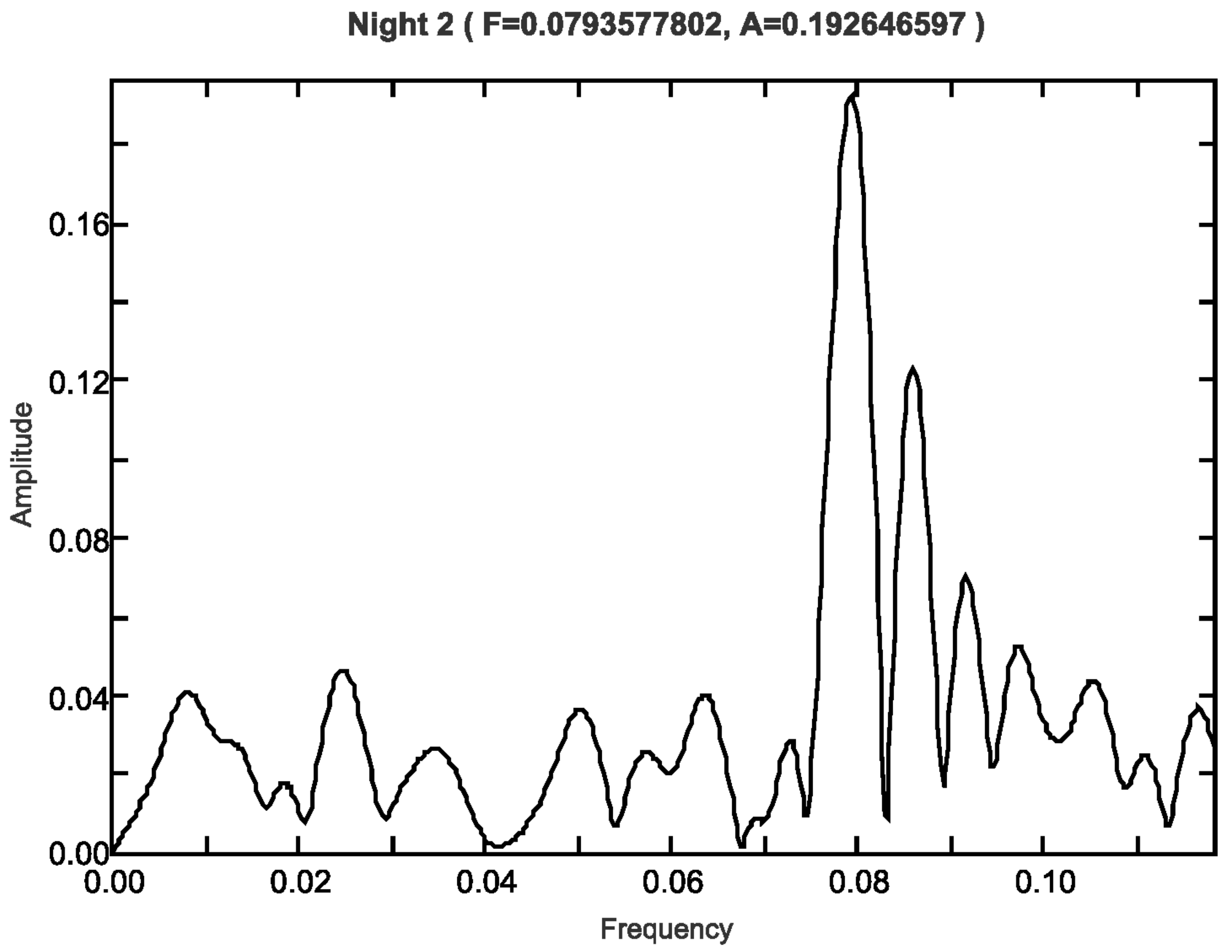


Period determination

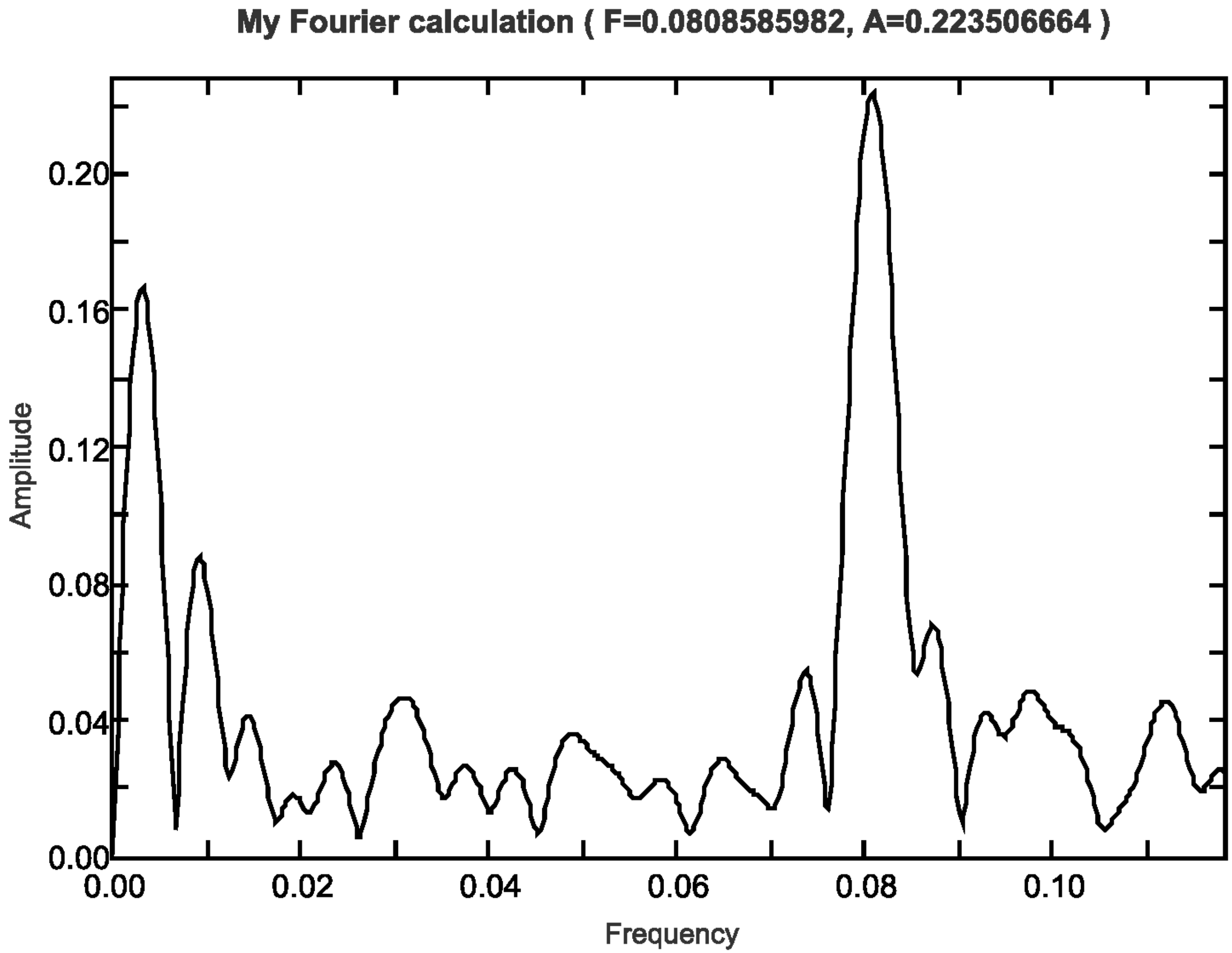
- Make a Fourier transform of the time series



Night 1


Night 2 (F=0.0793577802, A=0.192646597)
Amplitude
0.16
0.12
0.08
0.04
0.00
0.00
0.02
0.04
0.06
0.08
0.10
Frequency

Night 2


My Fourier calculation (F=0.0808585982, A=0.223506664)
Amplitude
0.00
0.04
0.08
0.12
0.16
0.20
0.00
0.02
0.04
0.06
0.08
0.10
Frequency

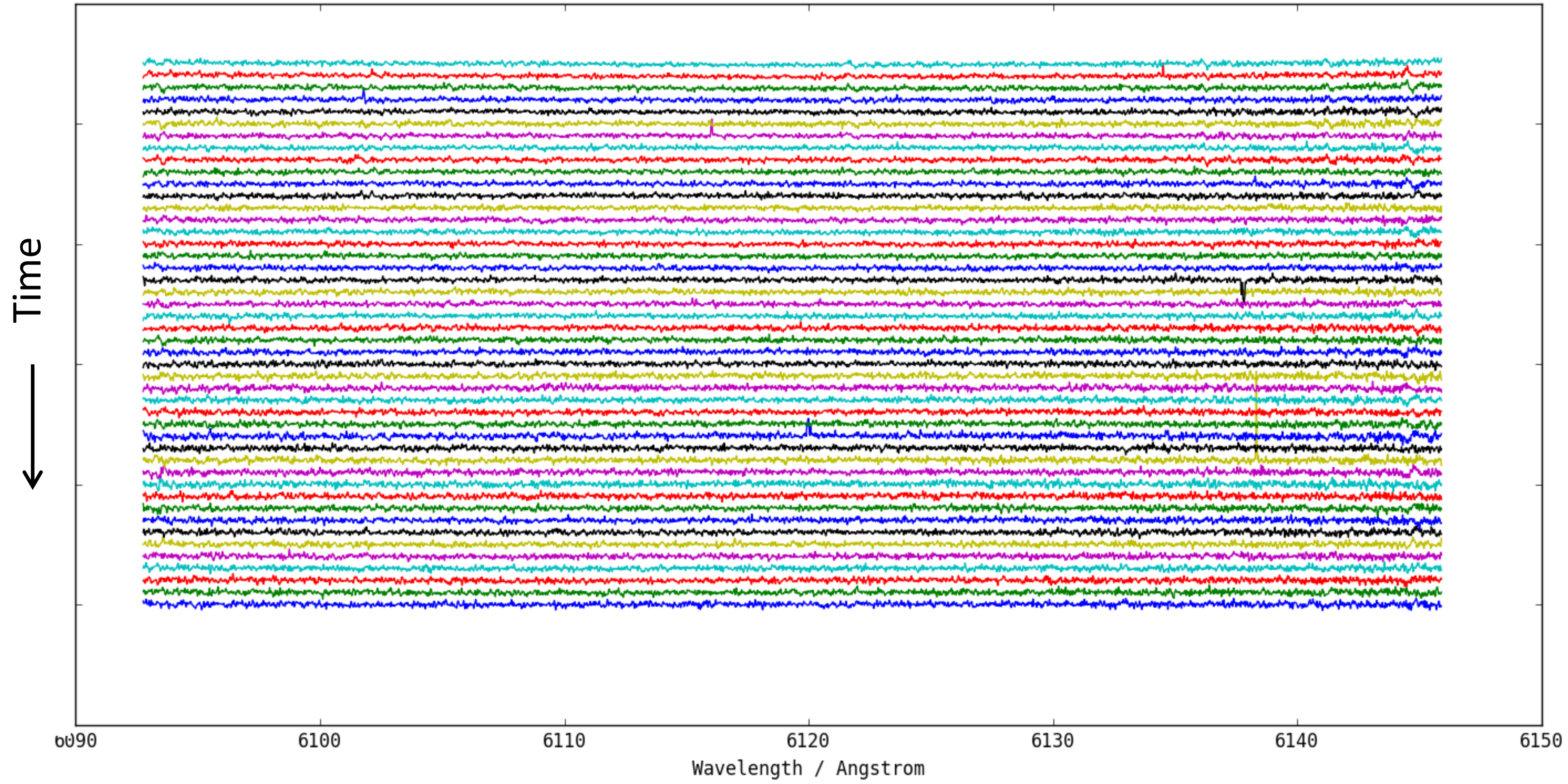
Night 3

Results

Night	Frequency (min^{-1})	Period (min)
1	0.0808	12.37
2	0.0793	12.61
3	0.0809	12.37

Mean period=12.45 minutes; which is in close agreement with Period of 12 minutes gotten from the literature. *Kochukhov et al 2001*

Time series Residuals



Final Remarks

- This shows detection of metal line profile variability due to the rapid oscillation in a roAp star
- The result is consistent with that obtained by the paper by *Kochukhov et al 2001*