Analysis of light curves - extraction of the essentials

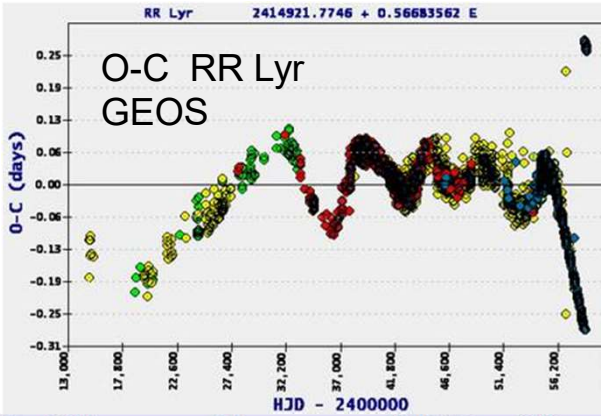
4th European Variable Star meeting

14-15 Sept, 2019

Lienhard Pagel

1. The aim of the observation of variable Stars

A. To get a **light curve** or a part of them (mostly)
B. Separation of **one** value – time of maximum or minimum (mostly)
C. Comparison with other values → O – C – Curve (mostly)



A light curve is more
then a minimum or a maximum.

Publications Max, Min e.g. BAVM GEOS

Table 1: cont.

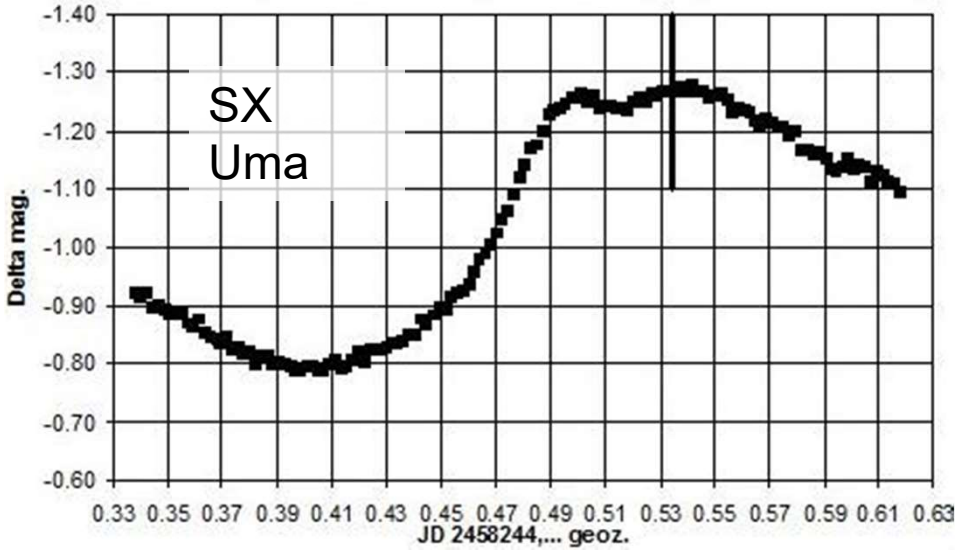
Variable	Ext	HJD 24.....	±	Obs	Type	Cam	Fil	n
QW And	min	58018.5128	0.0023	AG	EW	1603	-Ir	55
V0355 And	min	57992.5155	0.0015	AG	EA	1603	-Ir	44
V0382 And	min	57987.4031	0.0024	AG	EB	1603	-Ir	44
V0392 And	min	58023.3323	0.0015	AG	EA	1603	-Ir	58
V0404 And	min	58018.4451	0.0004	AG	EA/RS	1603	-Ir	57
V0441 And	min	57987.5137	0.0031	AG	EW	1603	-Ir	35
V0460 And	min	58079.3405	0.0010	ALH	DSCT	3200M	V	442
V0460 And	max	58079.3640	0.0004	ALH	DSCT	3200M	V	442
V0460 And	min	58079.4145	0.0010	ALH	DSCT	3200M	V	442
V0460 And	max	58079.4391	0.0005	ALH	DSCT	3200M	V	442
V0460 And	min	58079.4900	0.0010	ALH	DSCT	3200M	V	442
V0460 And	max	58079.5146	0.0005	ALH	DSCT	3200M	V	442
V0460 And	min	58079.5640	0.0015	ALH	DSCT	3200M	V	442
V0460 And	max	58079.5900	0.0008	ALH	DSCT	3200M	V	442
V0483 And	min	57973.5171	0.0022	AG	EW	1603	-Ir	36
V0488 And	min	57973.5426	0.0025	AG	EB	1603	-Ir	35
V0524 And	min	58040.3348	0.0011	ALH	SXPHE	3200M	V	506
V0524 And	max	58040.3703	0.0007	ALH	SXPHE	3200M	V	506
V0524 And	min	58040.4292	0.0011	ALH	SXPHE	3200M	V	506
V0524 And	max	58040.4647	0.0006	ALH	SXPHE	3200M	V	506
V0524 And	min	58040.5229	0.0012	ALH	SXPHE	3200M	V	506
V0524 And	max	58040.5592	0.0008	ALH	SXPHE	3200M	V	506
V0524 And	min	58040.6172	0.0019	ALH	SXPHE	3200M	V	506
V0525 And	min	58018.3246	0.0015	AG	EA/RS	1603	-Ir	56
V0527 And	min	58018.4364	0.0014	AG	EW	1603	-Ir	56
V0530 And	min	58023.5066	0.0014	AG	EB	1603	-Ir	57
V0531 And	min	58019.3390	0.0022	AG	EW	1603	-Ir	29
V0531 And	min	58023.4055	0.0025	AG	EW	1603	-Ir	57
V0538 And	min	58019.3729	0.0040	AG	EB	1603	-Ir	24
V0544 And	max	58019.3430	0.0010	AG	SXPHE	1603	-Ir	30

Star name	HJD	Unc. (day)	O-C (day)	E	period shift	Ref.	Observer	meth.	
RR Lyr	2414856.4083		-0.180	-115	0	Florya, 1936, Kukarkin, 1934a	B.V. Kukarkin	vis	nor
RR Lyr	2414856.4800		-0.109	-115	0	PZ 1,N.5	R.F. Sanford	vis	Ap.
RR Lyr	2414921.6750		-0.100	0	0	Wendell,1909, Wendell,1914	O.C. Wendell	vis	
RR Lyr	2414925.6350		-0.107	7	0	Wendell,1909, Wendell,1914	O.C. Wendell	vis	
RR Lyr	2414938.6410	:	-0.139	30	0	Wendell,1909, Wendell,1914	O.C. Wendell	vis	
RR Lyr	2414984.5600	:	-0.133	111	0	Wendell,1909, Wendell,1914	O.C. Wendell	vis	
RR Lyr	2415184.6460	:	-0.140	464	0	Wendell,1909, Wendell,1914	O.C. Wendell	vis	
RR Lyr	2418919.4580		-0.208	7053	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2418944.4270		-0.180	7097	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2419300.4200		-0.160	7725	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2419635.9700		-0.176	8317	0	Detre,1943	-	vis	
RR Lyr	2419659.7750		-0.179	8359	0	Detre,1943	-	vis	
RR Lyr	2419692.6560		-0.174	8417	0	Detre,1943	-	vis	
RR Lyr	2419697.7570		-0.175	8426	0	Detre,1943	-	vis	
RR Lyr	2419701.7160		-0.183	8433	0	Detre,1943	-	vis	
RR Lyr	2419957.8923		-0.217	8885	0	Florya, 1936, Kukarkin, 1934a	A. De Sitter	vis	nor
RR Lyr	2420008.3720		-0.185	8974	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2420012.3320		-0.193	8981	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2420021.4100		-0.185	8997	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2420038.4410		-0.159	9027	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2420042.4080		-0.160	9034	0	Hertzsprung,1922	E. Hertzsprung	pg	
RR Lyr	2420065.6200	:	-0.188	9075	0	Detre,1943	C.C. Kiess	vis	
RR Lyr	2420077.5520		-0.159	9096	0	Detre,1943	H. Shapley	vis	
RR Lyr	2420082.6470		-0.166	9105	0	Detre,1943	C.C. Kiess	vis	
RR Lyr	2420244.7550	:	-0.173	9391	0	Detre,1943	C.C. Kiess	pg	cf L
RR Lyr	2420269.6990		-0.170	9435	0	Detre,1943	C.C. Kiess	pg	cf L
RR Lyr	2420282.7390		-0.167	9458	0	Detre,1943	C.C. Kiess	pg	cf L

2. Some imperfections and problems

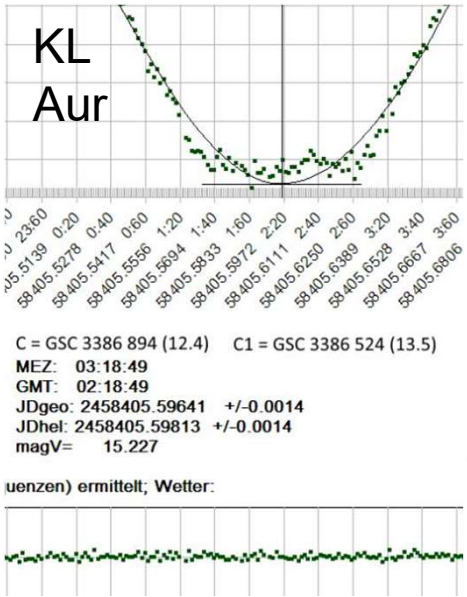
RRC stars – maximum:
SX Uma RRC

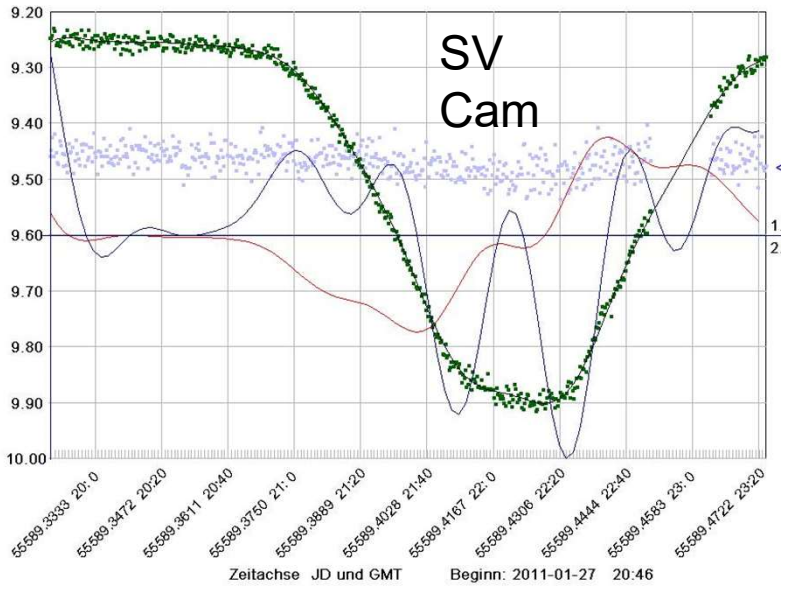
Where's maximum?



Eclipsing binaries – minimum:
SV Cam EA/DW/RS
KL Aur EA

Where's minimum?

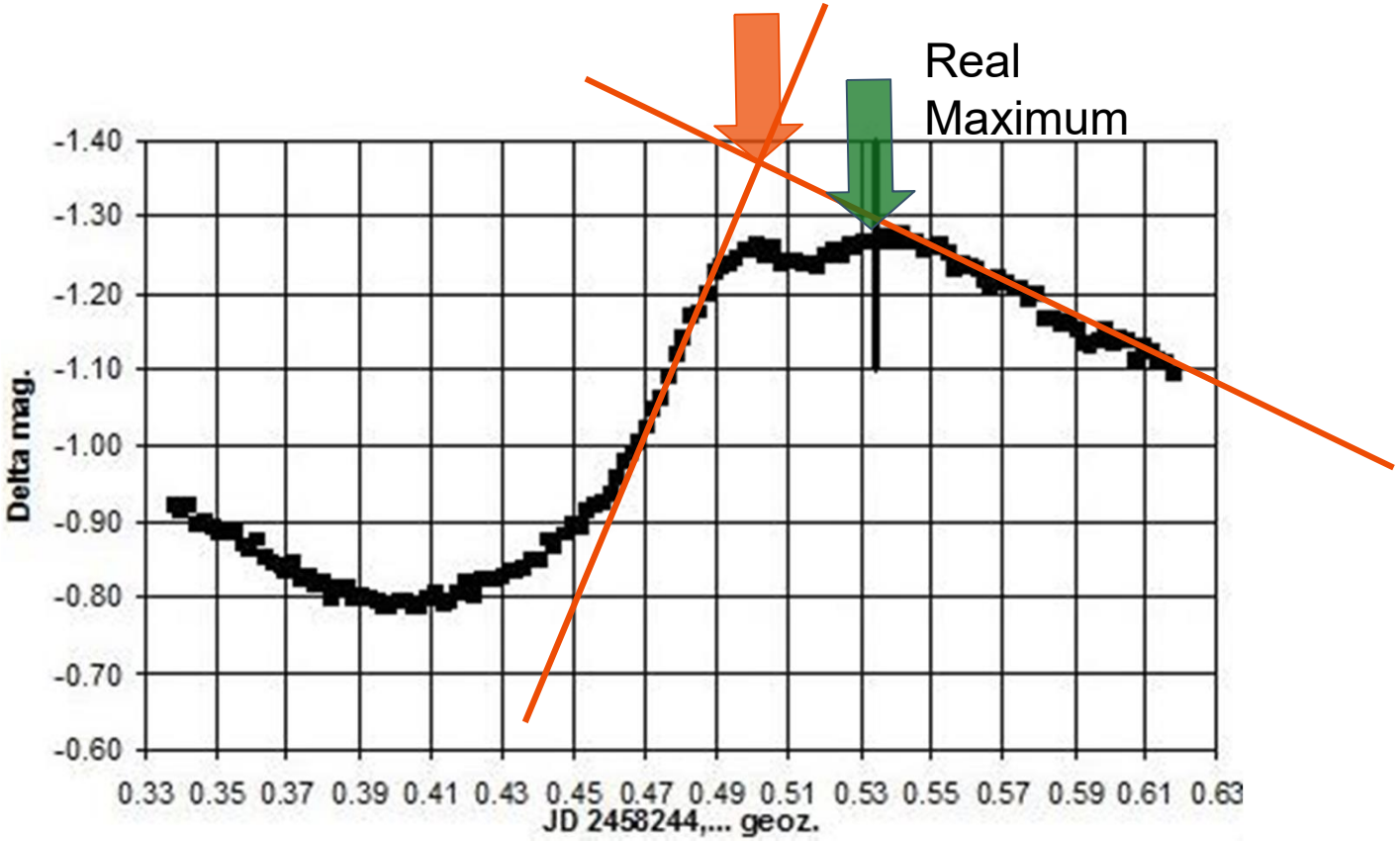




An often used procedure:

Loss of information.

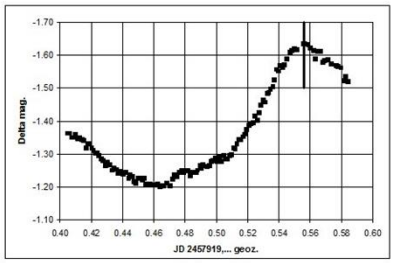
„Global maximum“
Is that a maximum?



A point of interest – moving humps

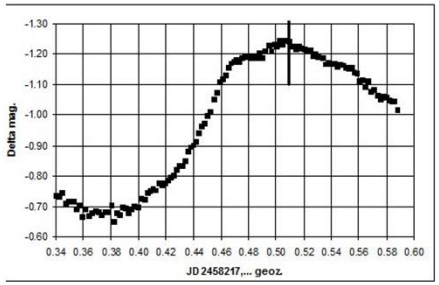
An example: moving humps

SX Uma **18. Juni 2017**



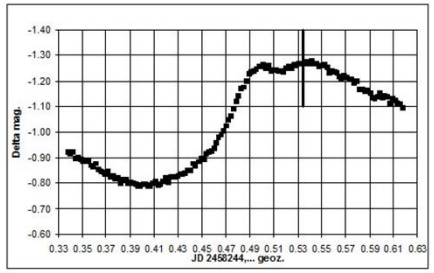
Max : 01:20:38 UT JD geoz.: 2457923,5560
JD hel.: 2457923,5553 +- 0,00012
Beobachter : U. Schmidt (SCI)
Vergl.-Sterne : GSC 3853 216, GSC 3853 636
Anzahl Punkte: 128
Instrument : ST 7 ungefiltert, 20 cm Schmidt-Cassegrain, f/3,5
Belichtung 30 sec.
Auswertung : Polynom durch Maximumwerte
Standardabweichung der Vergl.-Sterndifferenzen : ~ + - 0,048 mag.
Aufgetragen ist die Differenz des Veränderlichen gegen
(GSC 3853 216 + GSC 3853 636) / 2

SX Uma **08. April 2018**



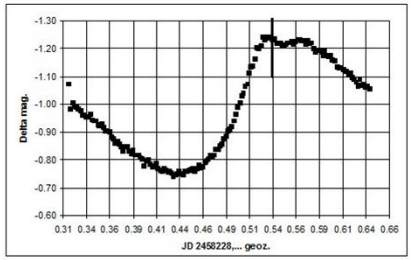
Max : 00:13:32 UT JD geoz.: 2458217,5094
JD hel.: 2458217,5119 +- 0,00011
Beobachter : U. Schmidt (SCI)
Vergl.-Sterne : GSC 3853 571, GSC 3853 636
Anzahl Punkte: 124
Instrument : ST 7 ungefiltert, 20 cm Schmidt-Cassegrain, f/3,5
Belichtung 30 sec.
Auswertung : Polynom durch Maximumwerte
Standardabweichung der Vergl.-Sterndifferenzen : ~ + - 0,045 mag.
Aufgetragen ist die Differenz des Veränderlichen gegen
(GSC 3853 571 + GSC 3853 636) / 2

SX Uma **05. Mai 2018**



Max : 00:49:49 UT JD geoz.: 2458244,5346
JD hel.: 2458228,5361 +- 0,00021
Beobachter : U. Schmidt (SCI)
Vergl.-Sterne : GSC 3853 571, GSC 3853 636
Anzahl Punkte: 134
Instrument : ST 7 ungefiltert, 20 cm Schmidt-Cassegrain, f/3,5
Belichtung 30 sec.
Auswertung : Polynom durch Maximumwerte
Standardabweichung der Vergl.-Sterndifferenzen : ~ + - 0,020 mag.
Aufgetragen ist die Differenz des Veränderlichen gegen
(GSC 3853 571 + GSC 3853 636) / 2

SX Uma **19. April 2018**

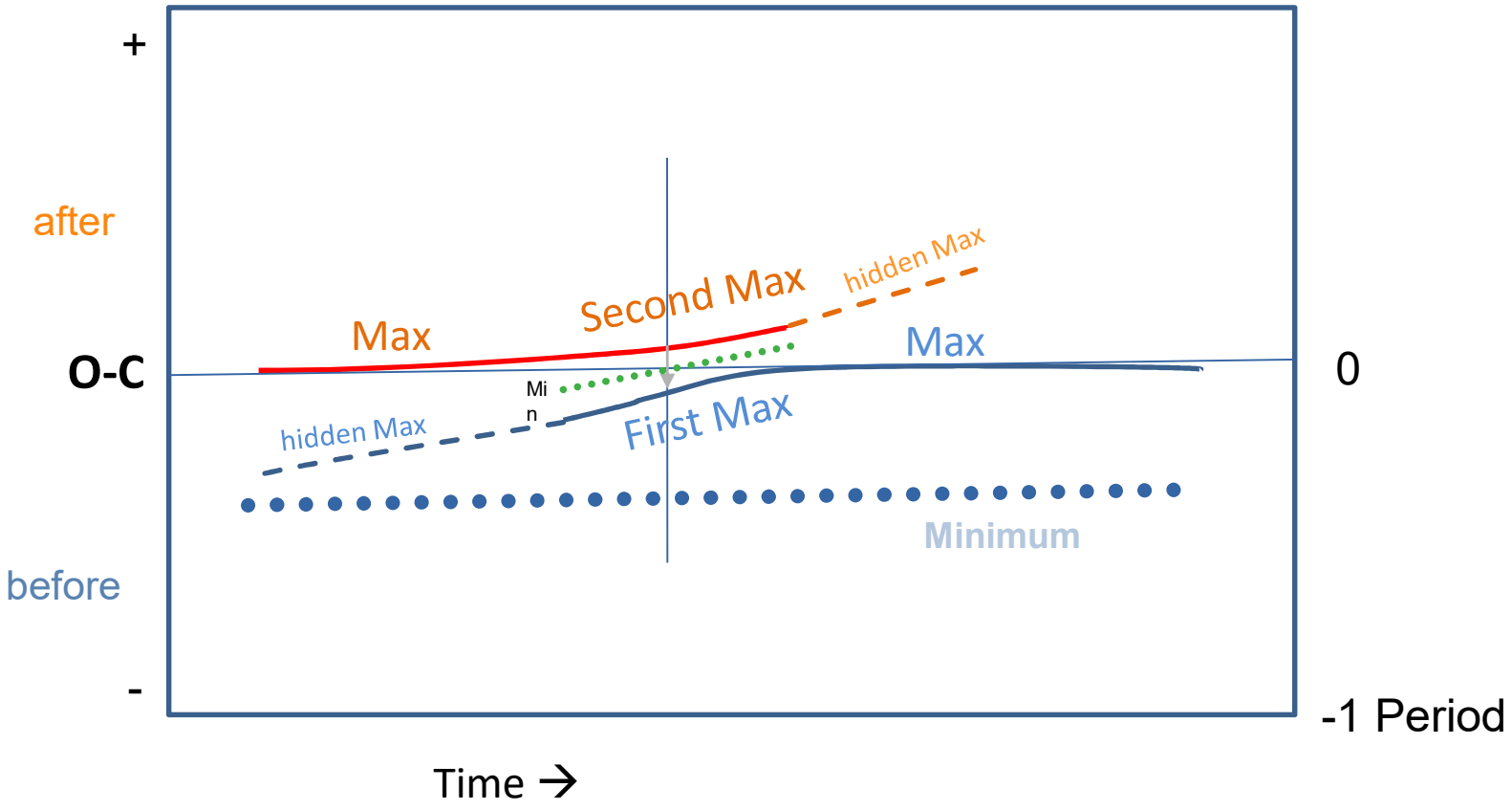


Max : 00:48:58 UT JD geoz.: 2458228,5340
JD hel.: 2458228,5362 +- 0,00026
Beobachter : U. Schmidt (SCI)
Vergl.-Sterne : GSC 3853 571, GSC 3853 636
Anzahl Punkte: 155
Instrument : ST 7 ungefiltert, 20 cm Schmidt-Cassegrain, f/3,5
Belichtung 30 sec.
Auswertung : Polynom durch Maximumwerte
Standardabweichung der Vergl.-Sterndifferenzen : ~ + - 0,032 mag.
Aufgetragen ist die Differenz des Veränderlichen gegen
(GSC 3853 571 + GSC 3853 636) / 2

We see more detail when we measure local maxima.

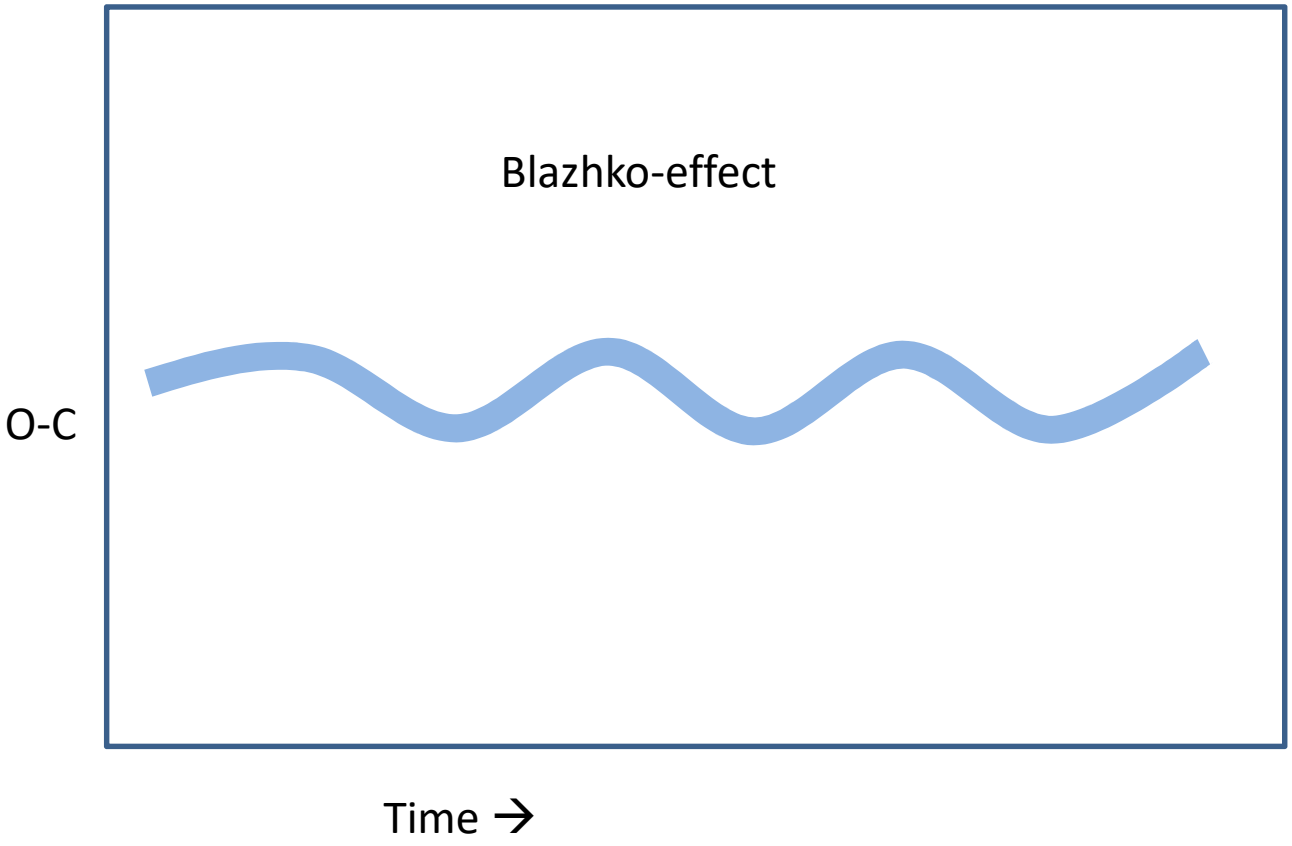
3. Effect of O-C-Diagram in case of Blazhko-effct

Short timescale



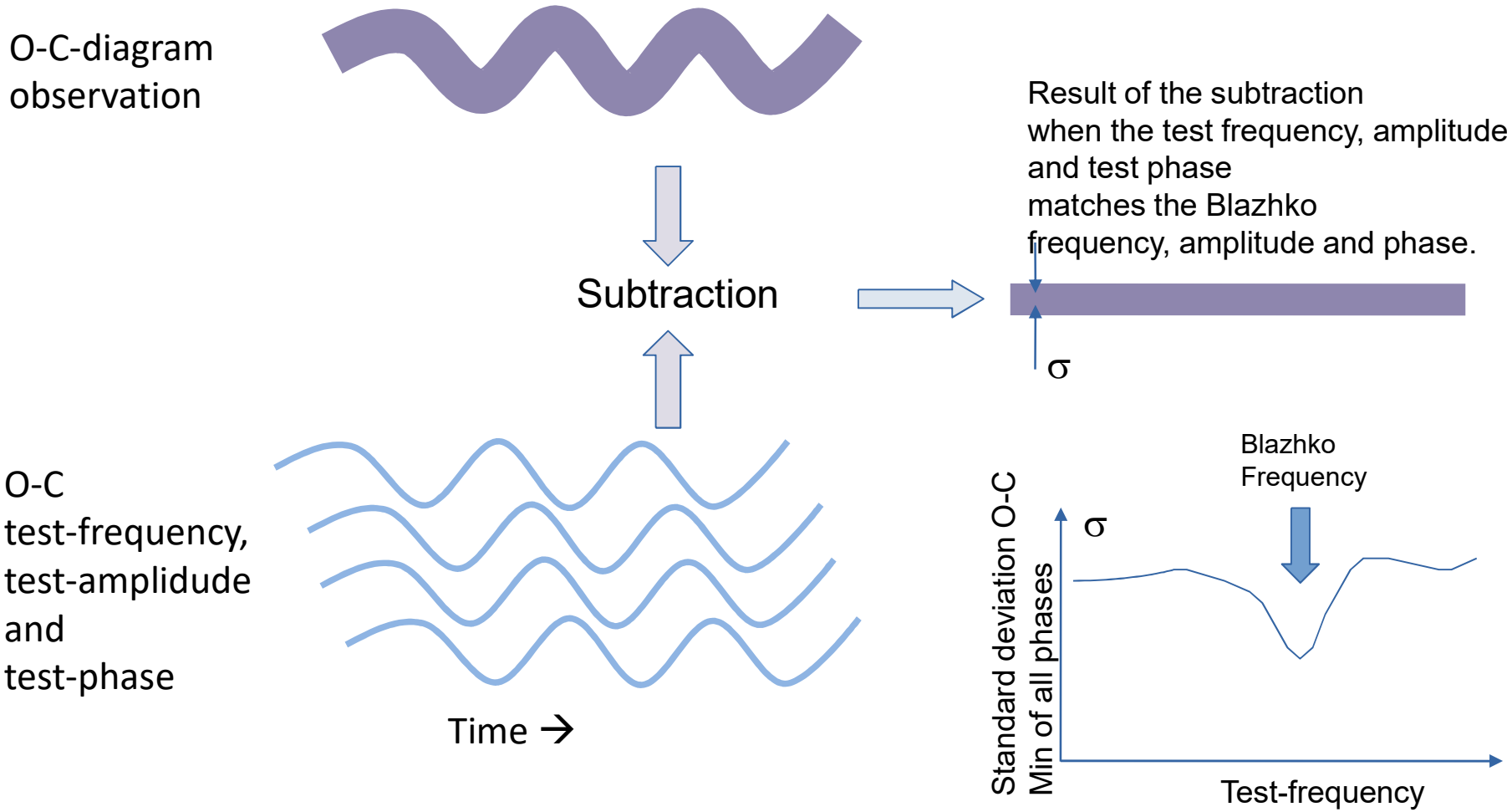
Effect of O-C-Diagram in case of Blazhko-effect

Long timescale

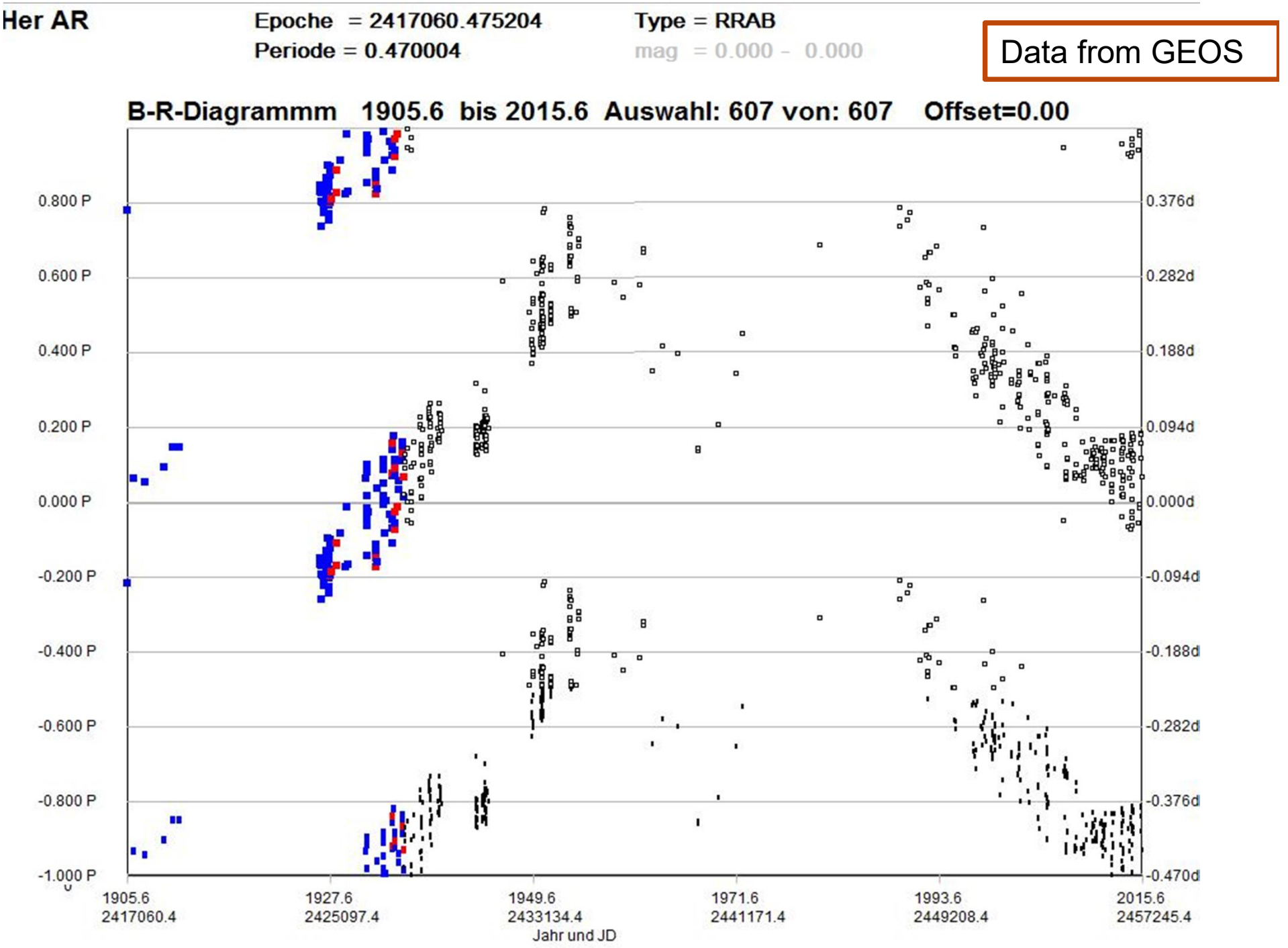


In high frequency technology
we would speak of a
phase modulation or frequency-Modulation.

Example for using local maxima: Searching Blazhko-Period

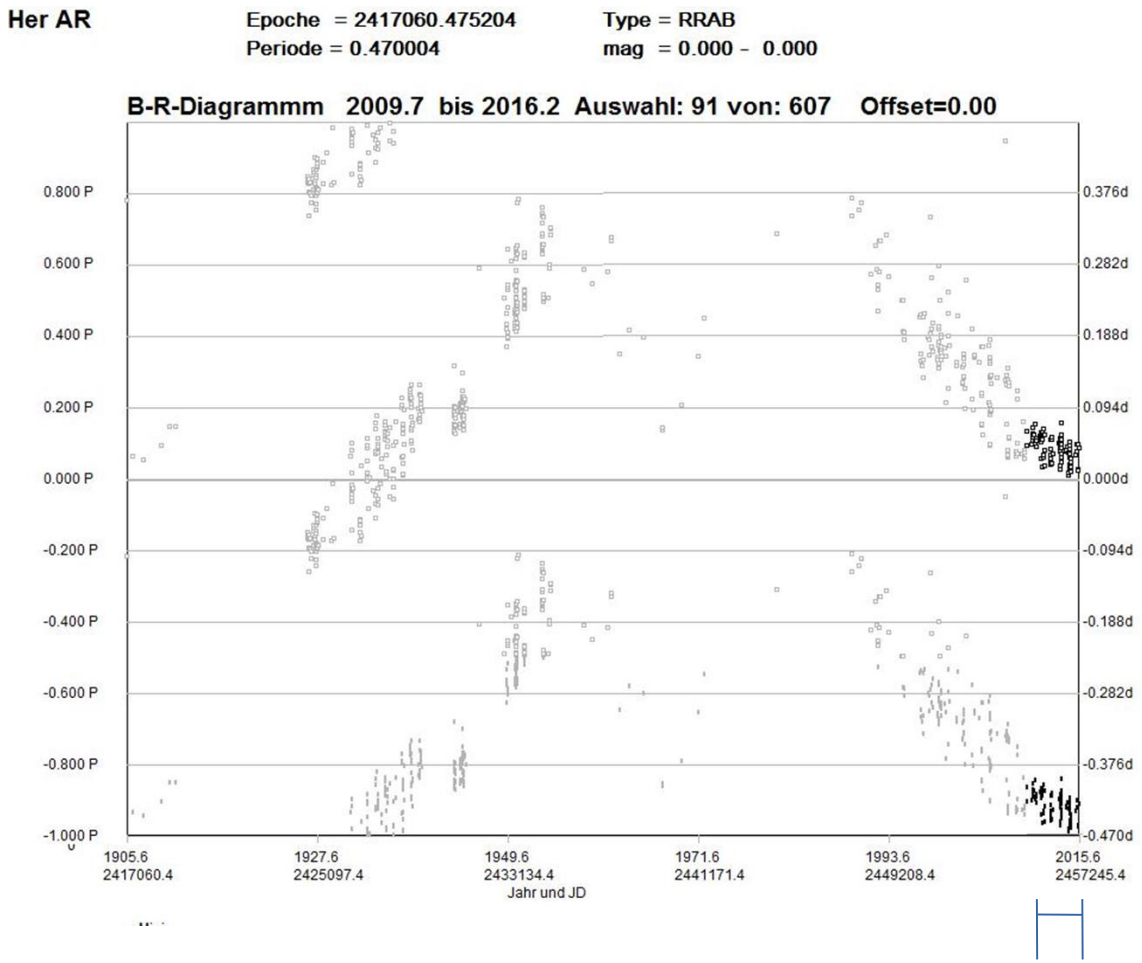


Result: Blazhko-Period/Frequency, Amplitude(max. phase-shift, Phase(Epoch)

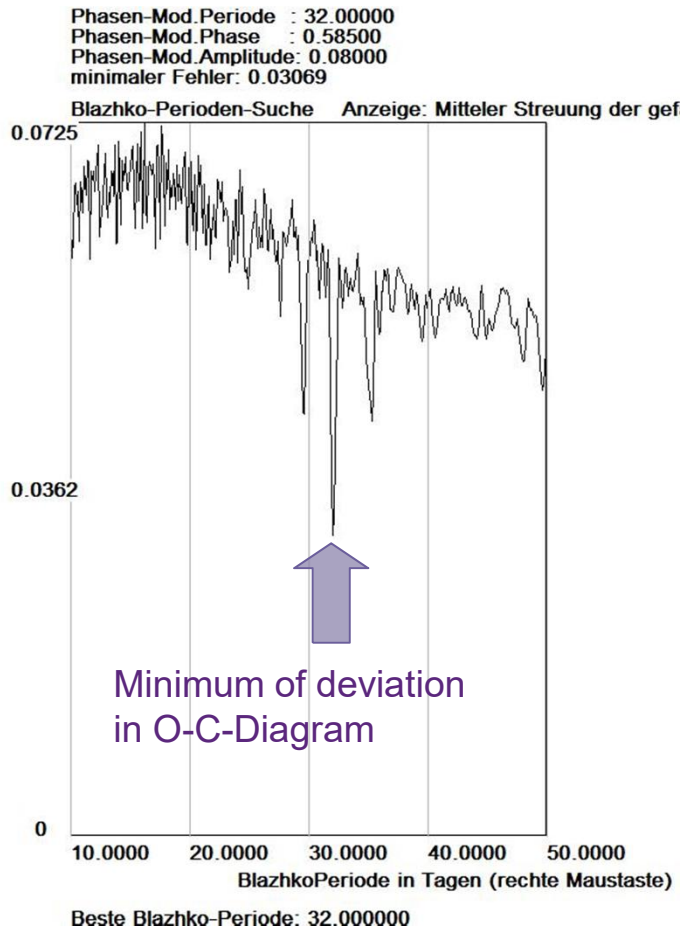

Her AR
Epoche = 2417060.475204
Periode = 0.470004
Type = RRAB
mag = 0.000 - 0.000
Data from GEOS
B-R-Diagrammm 1905.6 bis 2015.6 Auswahl: 607 von: 607 Offset=0.00
0.800 P
0.600 P
0.400 P
0.200 P
0.000 P
-0.200 P
-0.400 P
-0.600 P
-0.800 P
-1.000 P
0.376d
0.282d
0.188d
0.094d
0.000d
-0.094d
-0.188d
-0.282d
-0.376d
-0.470d
1905.6
2417060.4
1927.6
2425097.4
1949.6
2433134.4
1971.6
2441171.4
1993.6
2449208.4
2015.6
2457245.4
Jahr und JD

First Example: Search of Blazhko-Period 2009 – 2016

AR Her RRAB/BL

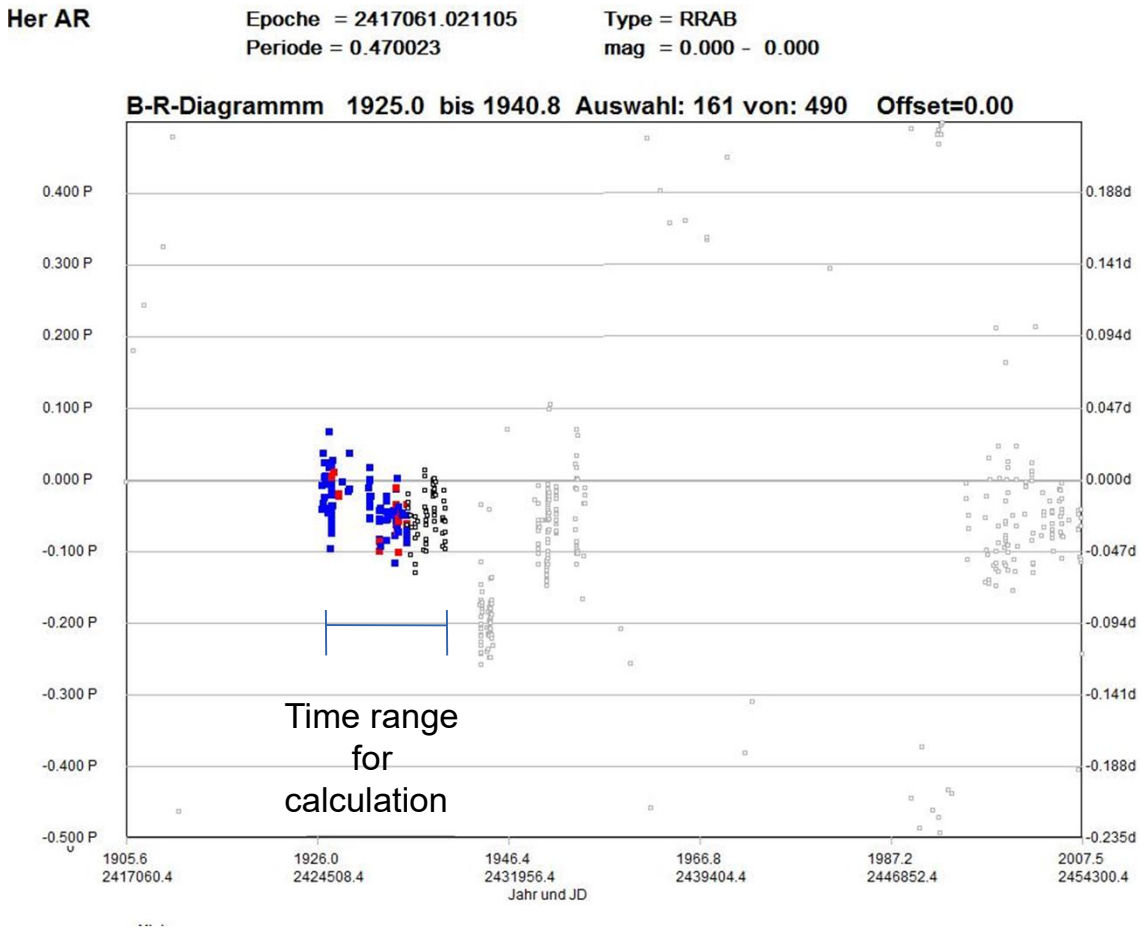


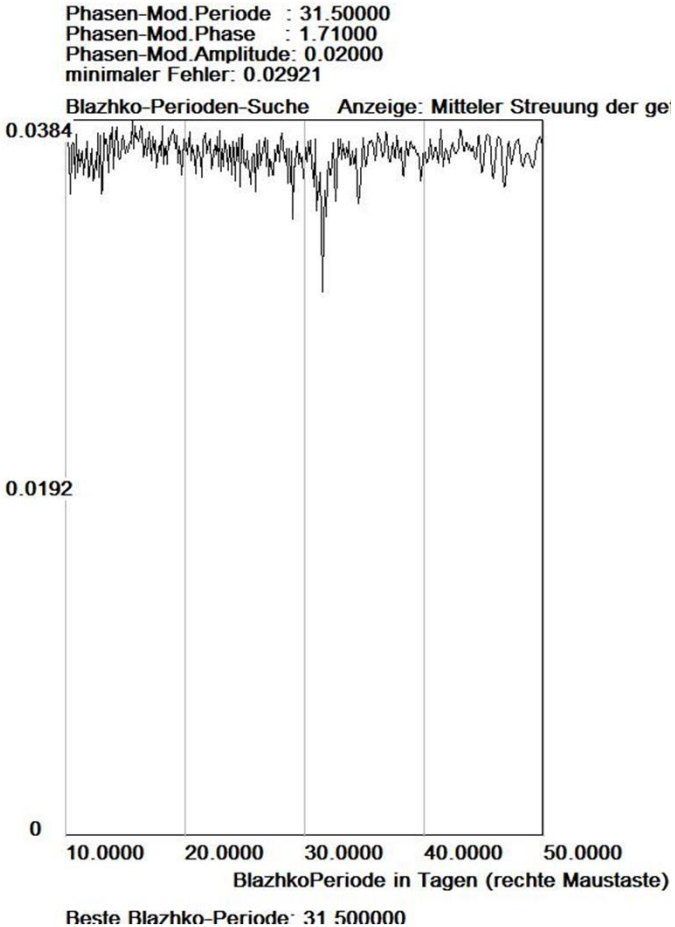
Time range for calculation



Mostly photometric maxima

Search of Blazhko-Period 1925 - 1940





Visual maxima

4. How can we determine outstanding points?

Detection of maxima, minima, humps and hidden humps

Four Steps:

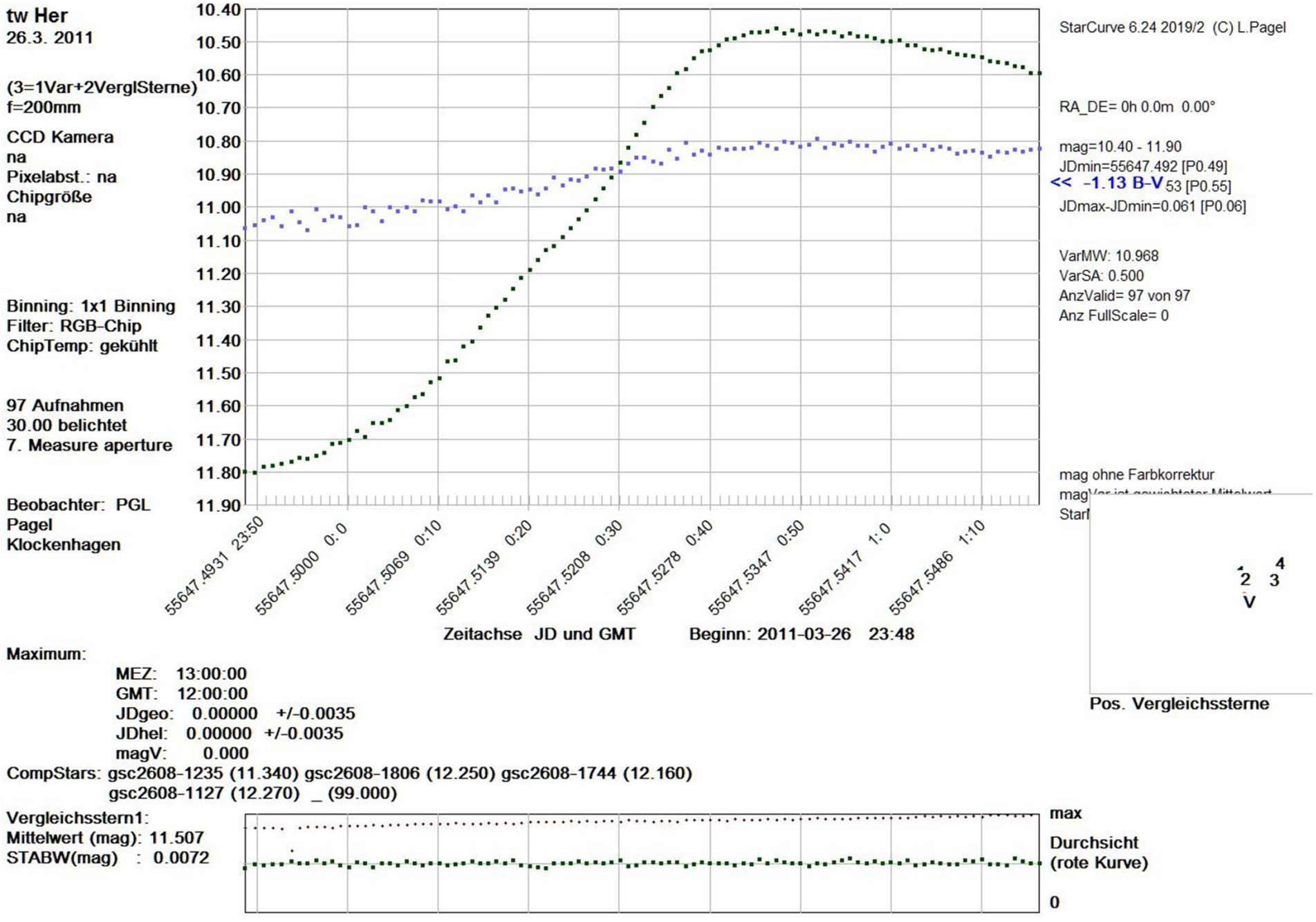
1. Fourier-Approximation of light curve
   Finding a curve with minimum square error

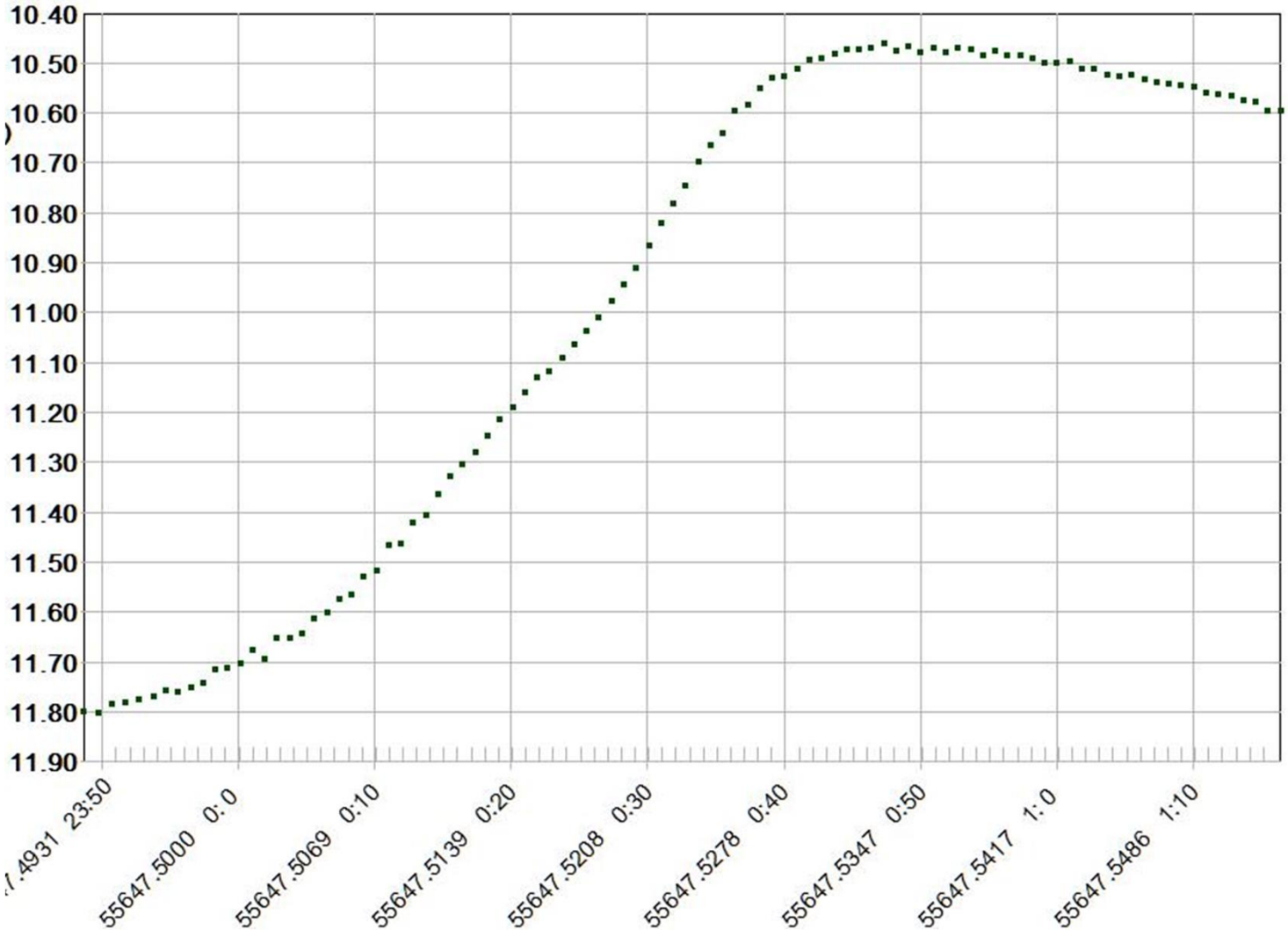
2. Differentiation of the light curve: 1. derivatives, increase rate

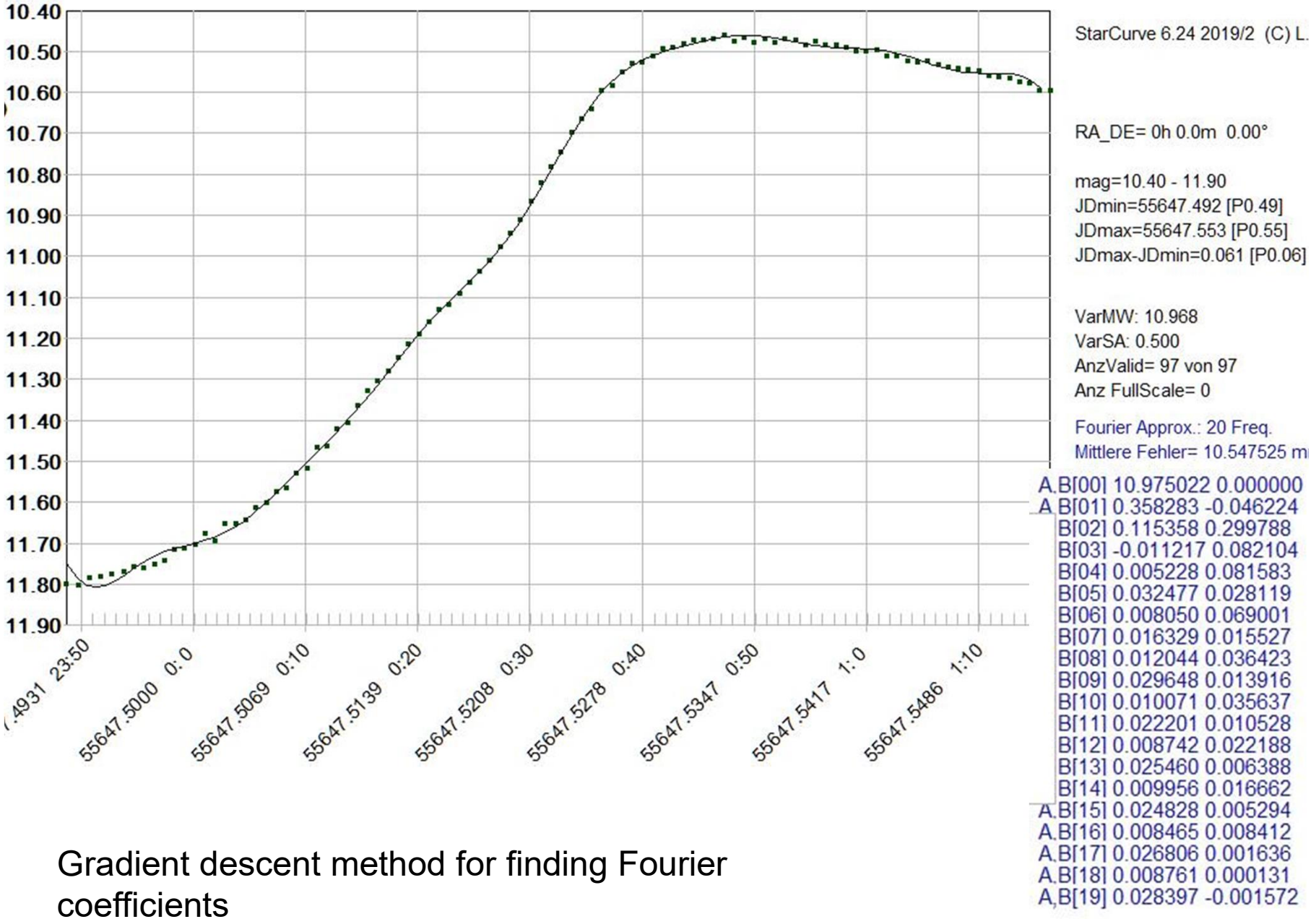
3. One more time: 2. derivatives, curvature

4. Determination of zeroes

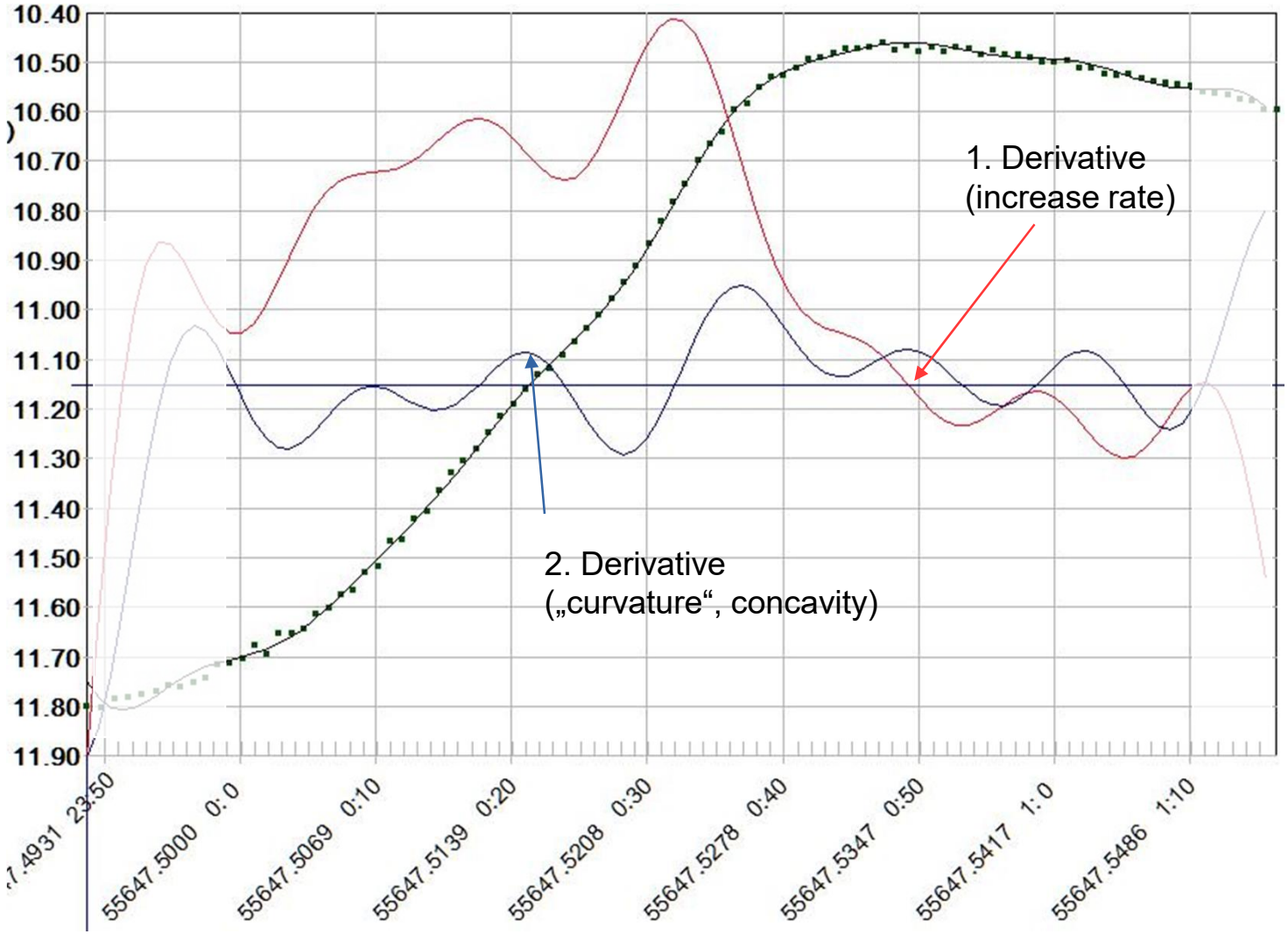
Software: StarCurve


tw Her
26.3. 2011
(3=1Var+2VerglSterne)
f=200mm
CCD Kamera
na
Pixelabst.: na
Chipgröße
na
Binning: 1x1 Binning
Filter: RGB-Chip
ChipTemp: gekühlt
97 Aufnahmen
30.00 belichtet
7. Measure aperture
Beobachter: PGL
Pagel
Klockenhagen
10.40
10.50
10.60
10.70
10.80
10.90
11.00
11.10
11.20
11.30
11.40
11.50
11.60
11.70
11.80
11.90
55647.4931 23:50
55647.5000 0:0
55647.5069 0:10
55647.5139 0:20
55647.5208 0:30
55647.5278 0:40
55647.5347 0:50
55647.5417 1:0
55647.5486 1:10
Zeitachse JD und GMT
Beginn: 2011-03-26 23:48
StarCurve 6.24 2019/2 (C) L.Pagel
RA_DE= 0h 0.0m 0.00°
mag=10.40 - 11.90
JDmin=55647.492 [P0.49]
<< -1.13 B-V 53 [P0.55]
JDmax-JDmin=0.061 [P0.06]
VarMW: 10.968
VarSA: 0.500
AnzValid= 97 von 97
Anz FullScale= 0
mag ohne Farbkorrektur
1
2
3
4
V
Pos. Vergleichssterne
Maximum:
MEZ: 13:00:00
GMT: 12:00:00
JDgeo: 0.00000 +/-0.0035
JDhel: 0.00000 +/-0.0035
magV: 0.000
CompStars: gsc2608-1235 (11.340) gsc2608-1806 (12.250) gsc2608-1744 (12.160)
gsc2608-1127 (12.270) _ (99.000)
Vergleichsstern1:
Mittelwert (mag): 11.507
STABW(mag) : 0.0072
max
Durchsicht
(rote Kurve)
0

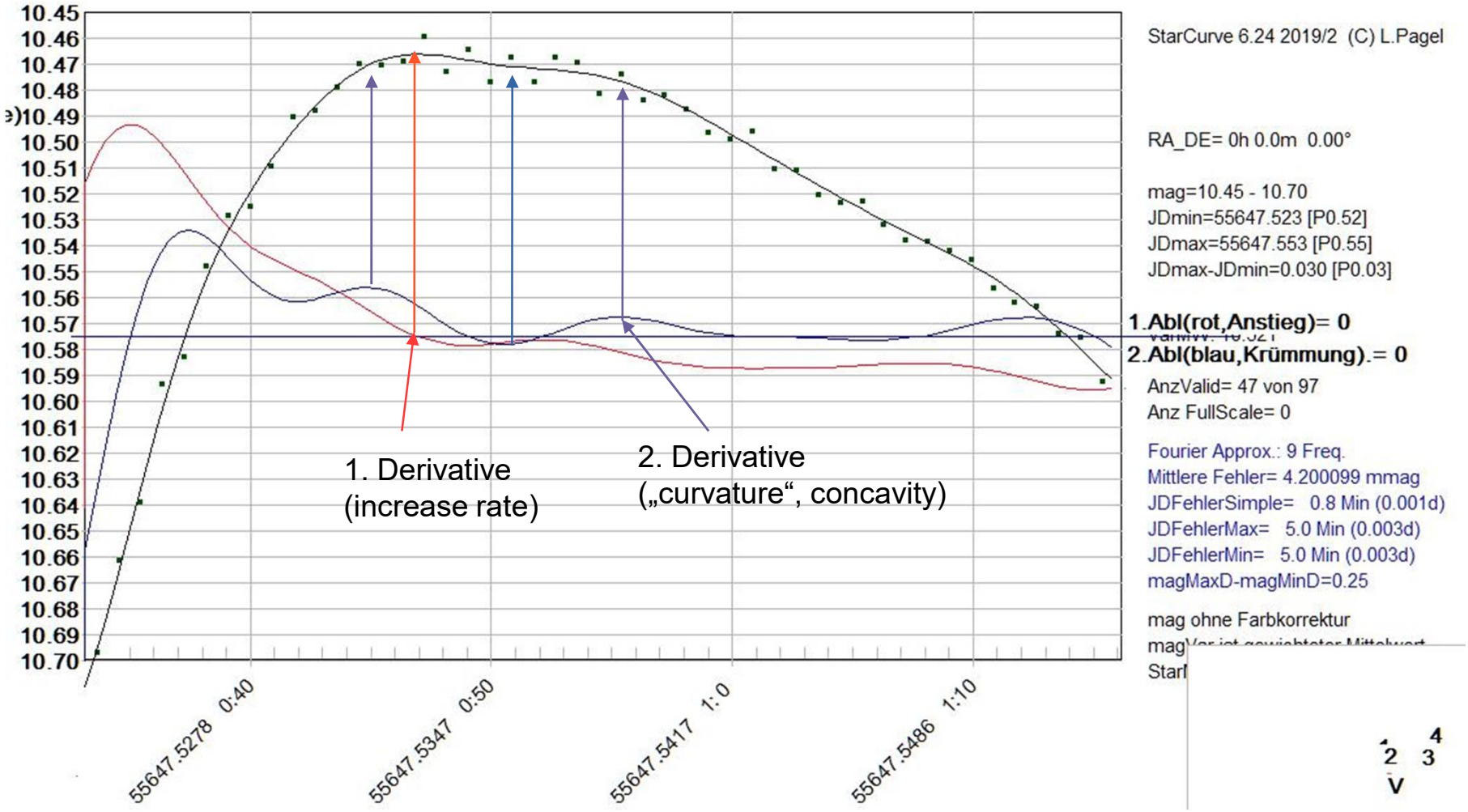

10.40
10.50
10.60
10.70
10.80
10.90
11.00
11.10
11.20
11.30
11.40
11.50
11.60
11.70
11.80
11.90
.4931 23:50
55647.5000 0: 0
55647.5069 0:10
55647.5139 0:20
55647.5208 0:30
55647.5278 0:40
55647.5347 0:50
55647.5417 1: 0
55647.5486 1:10



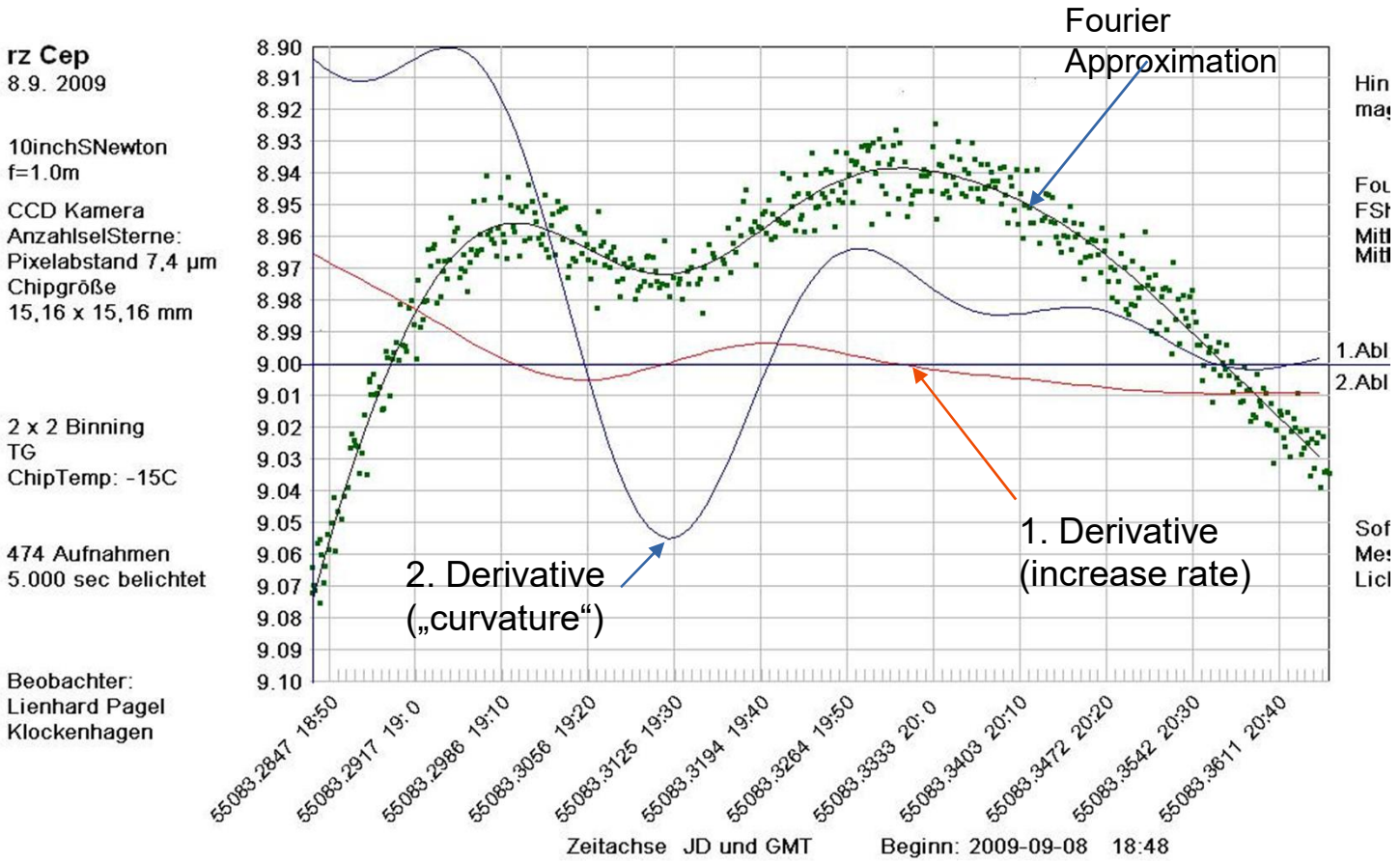
Gradient descent method for finding Fourier coefficients


10.40
10.50
10.60
10.70
10.80
10.90
11.00
11.10
11.20
11.30
11.40
11.50
11.60
11.70
11.80
11.90
1. Derivative
(increase rate)
2. Derivative
(„curvature“, concavity)
55647.5000 0:0
55647.5069 0:10
55647.5139 0:20
55647.5208 0:30
55647.5278 0:40
55647.5347 0:50
55647.5417 1:0
55647.5486 1:10

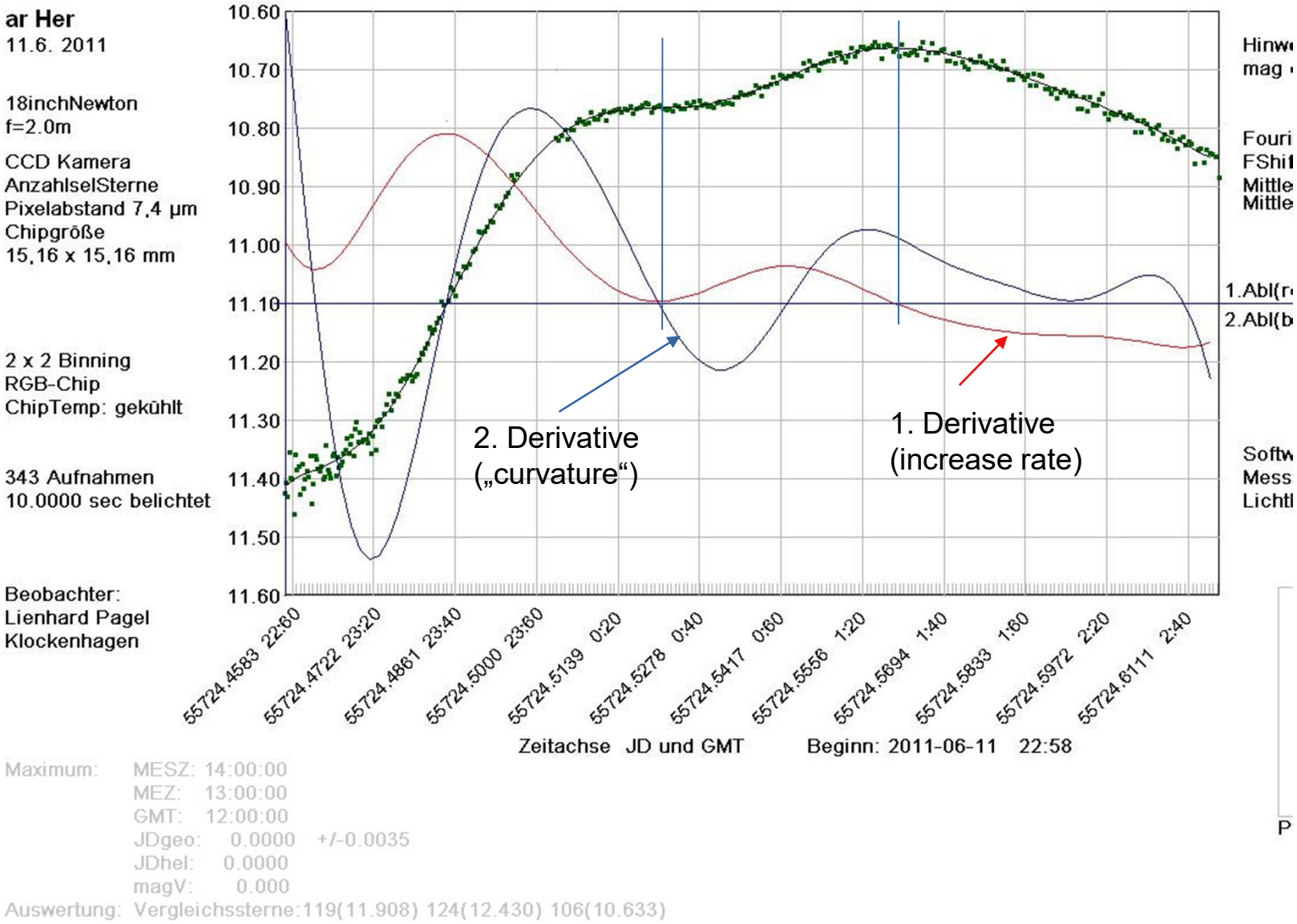
More details in the maximum range



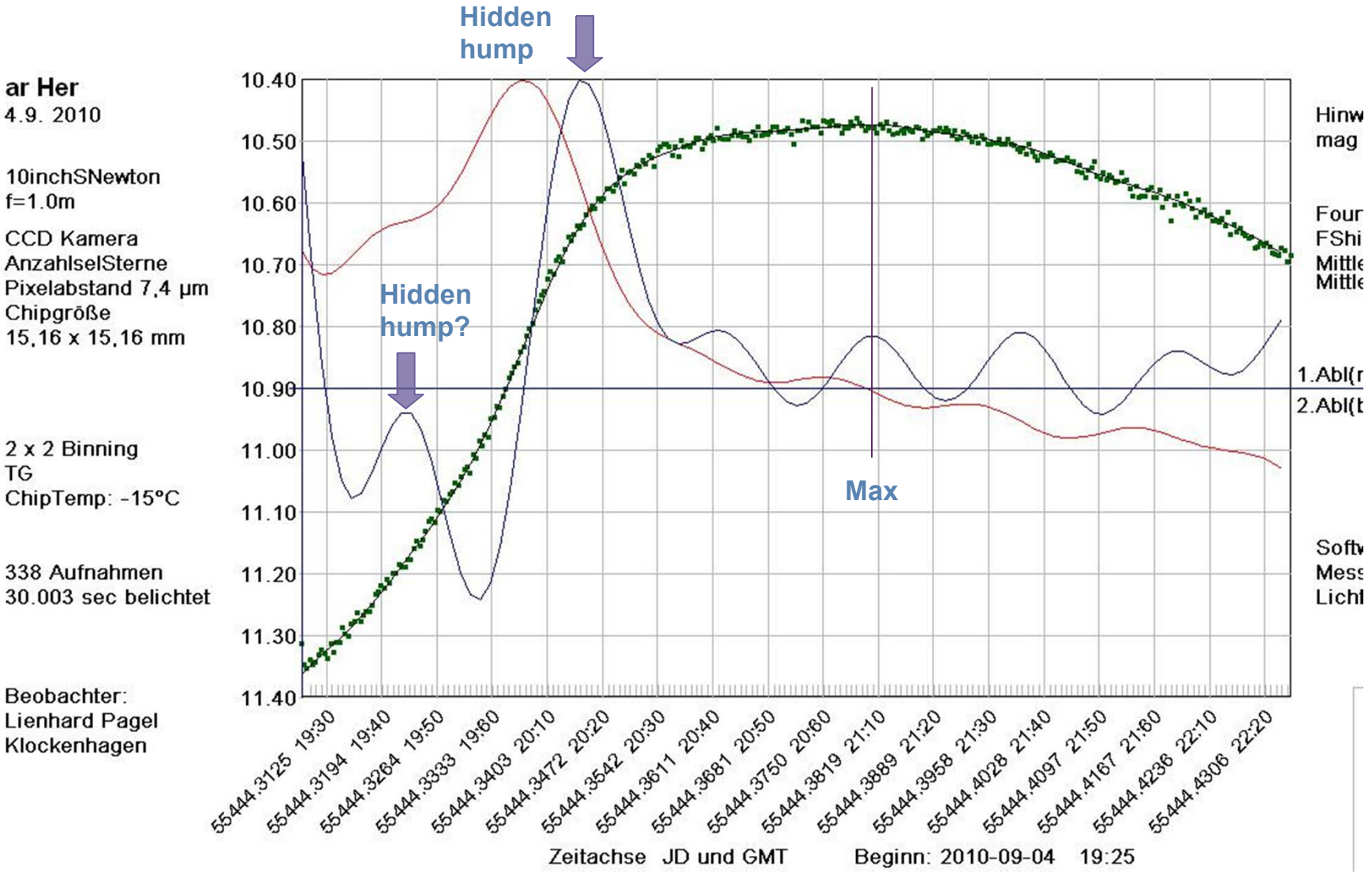
RZ Cep two maxima in detail



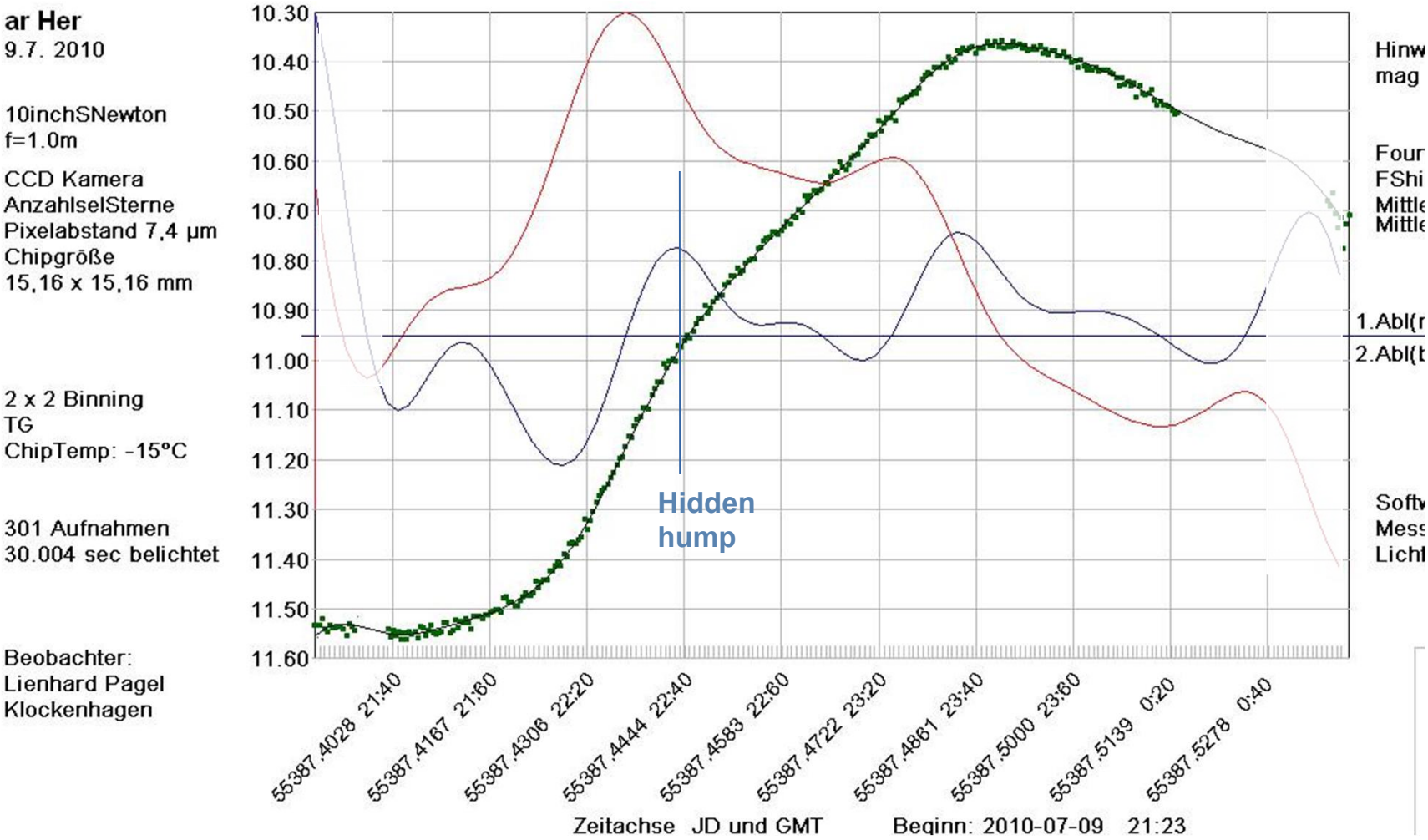
Detection of a hump



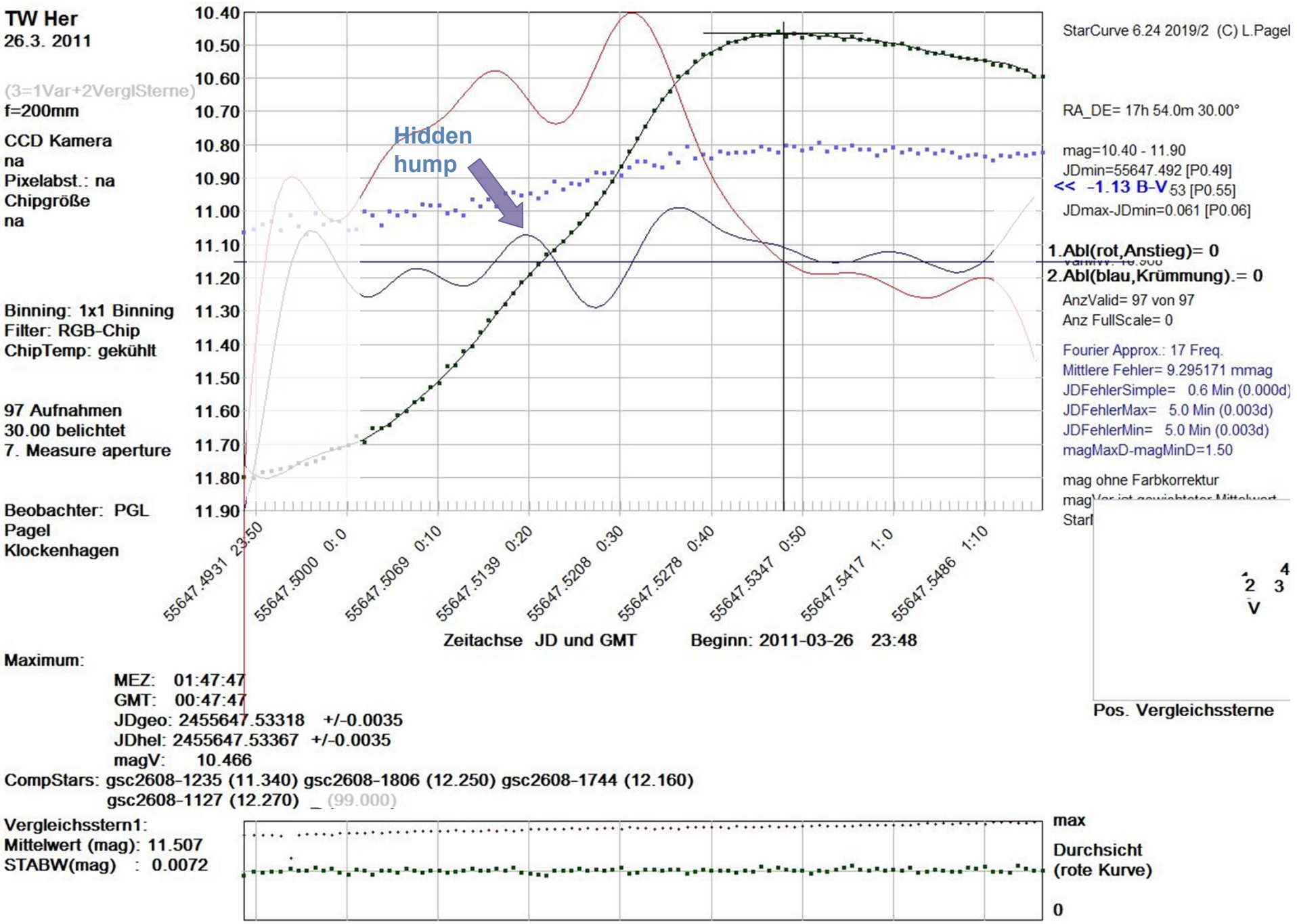
Detection of a hump



Detection of a hump



Detection of a hump



5. Suggestion

More effects become visible if we extract more significant data from a light curve.

Suggestion:
1. determination and storage of all maxima and minima
2. determination and storage of all hidden humps
3. determination and storage of all outstanding/critical points in the light curve,
also inflection points (no curvature),
points of maximum curvature.
4. determination of Blazhko period, amplitude and phase(epoch)

Outstanding/critical points represent the curve.
This is an illustrative type of data compression.

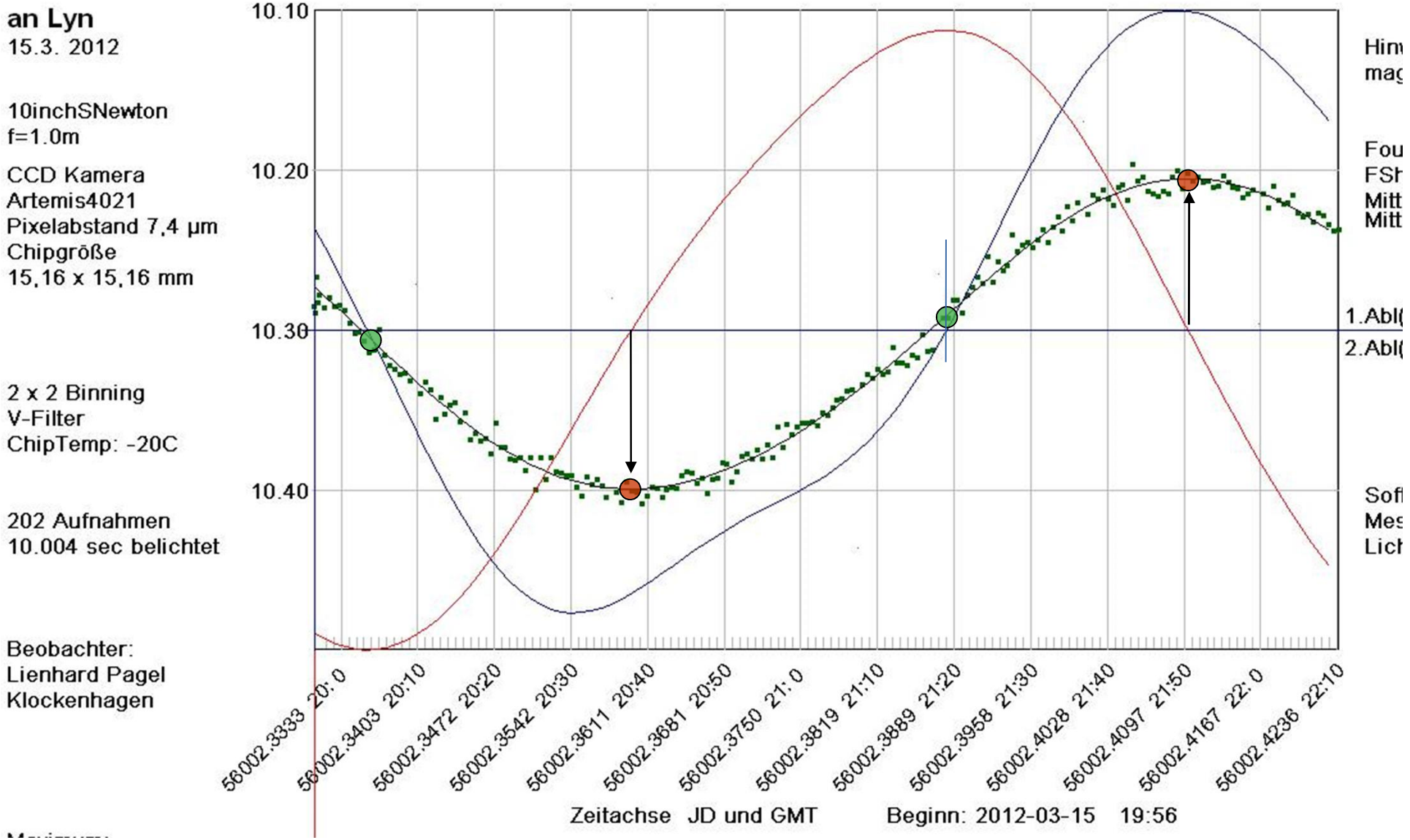
Alternative: Fourier spectrum (like in Kepler data analysis)

The BAV has decided
to determine and store all maxima/minima
for pulsating stars.

highest maximum	= max
another maximum	= max2
minimum	= min

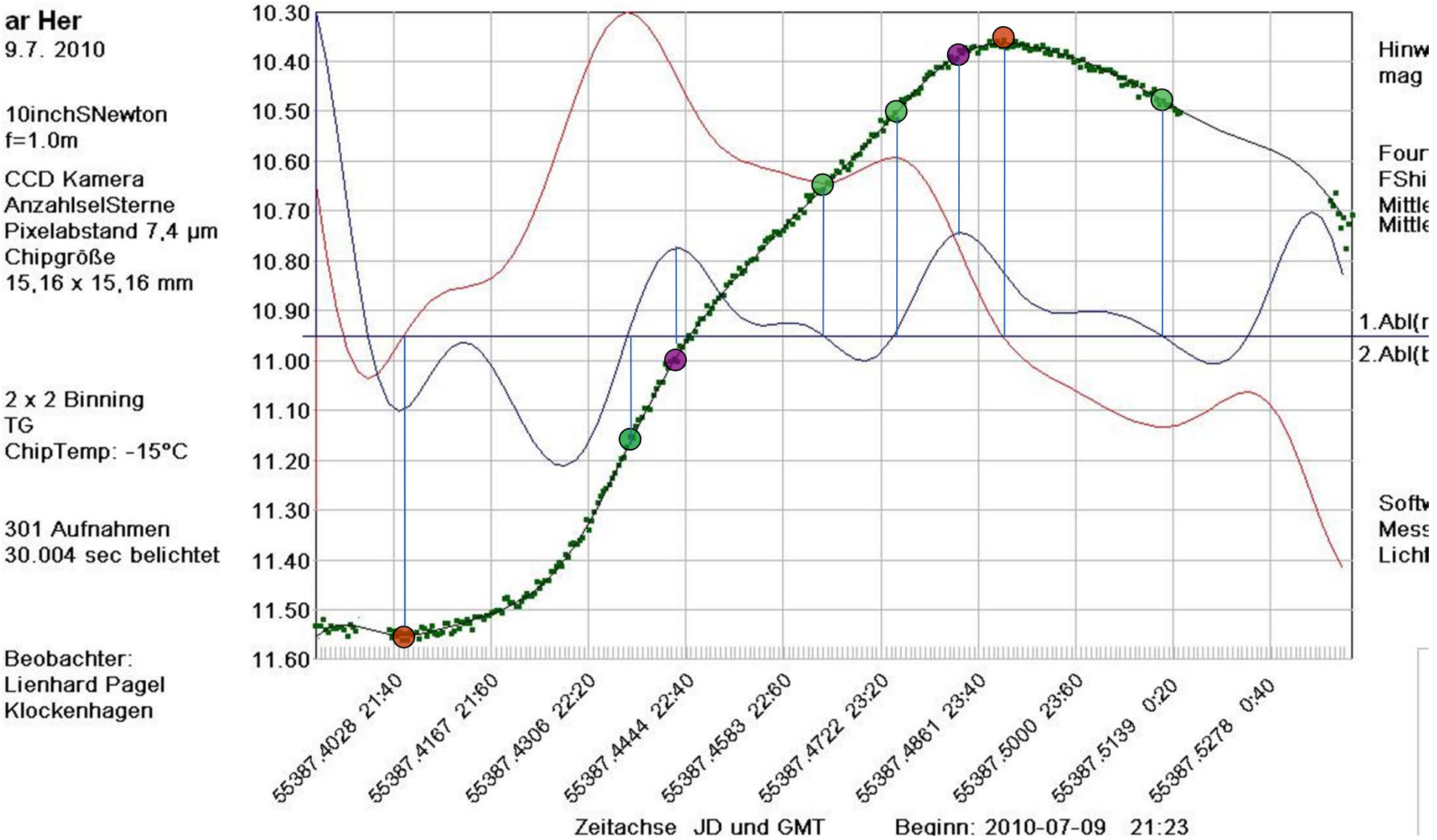
- Extremum (max/min)
- Max curvature
- (hump)
  Inflection points

Outstanding/critical Points represent the curve

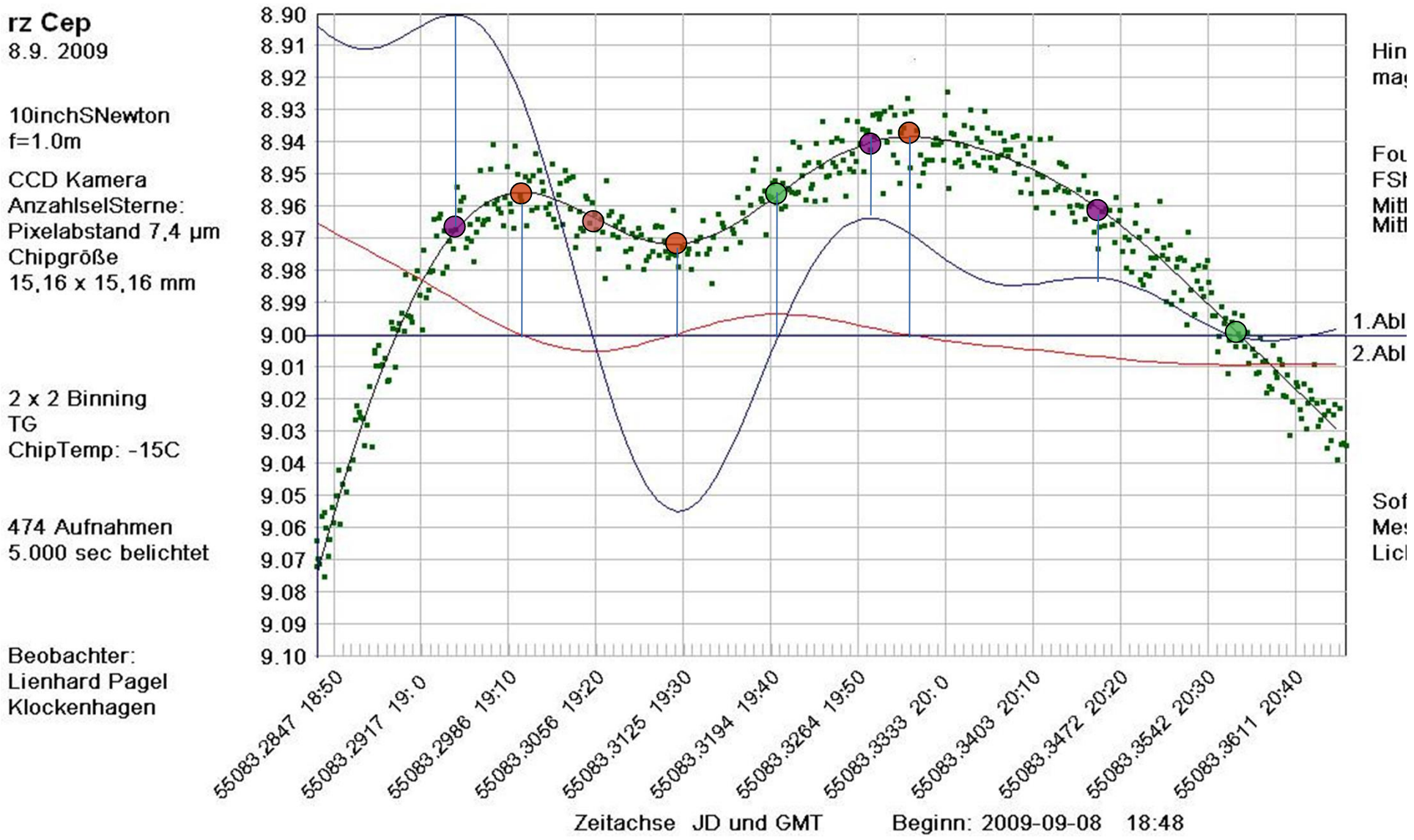


Outstanding/critical Points

- Extremum (max/min)
- Max curvature
- (hump)
  Inflection points



Outstanding/critical Points



Many thanks for your attention.