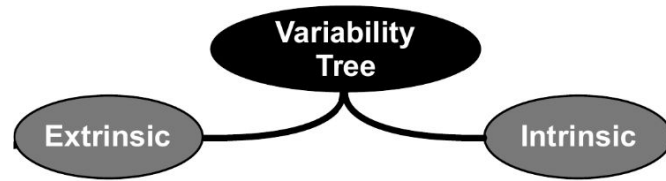


Mechanismy proměnnosti a klasifikace proměnných hvězd

Marek Skarka

Astronomical Institute of the CAS, Ondřejov
skarka@asu.cas.cz





$$L = 4\pi\sigma R_*^2 T_{\text{eff}}^4$$

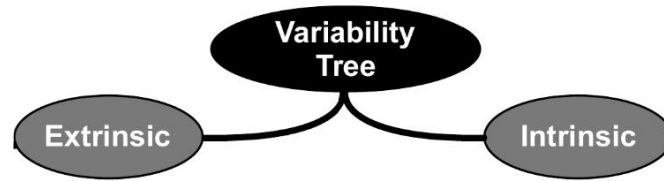
Změny díky geometrii pozorování a vlivů přímo nesouvisejících s hvězdou/systémem

Změny díky fyzikálním procesům uvnitř/na povrchu/v okolí hvězd

Nemění se zářivý výkon hvězd

Credit: Eyer et al. (2018)

Adapted from: Eyer & Mowlavi (2008)



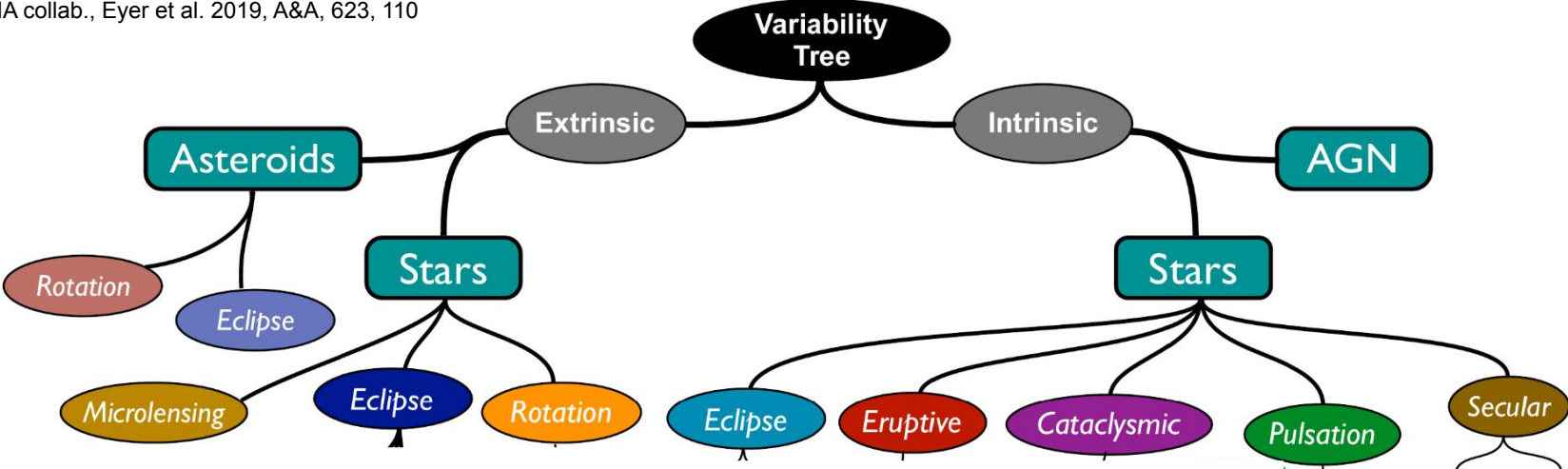
Změny díky geometrii pozorování
Nemění se zářivý výkon hvězd

Změny díky fyzikálním procesům
uvnitř/na povrchu/v okolí hvězd

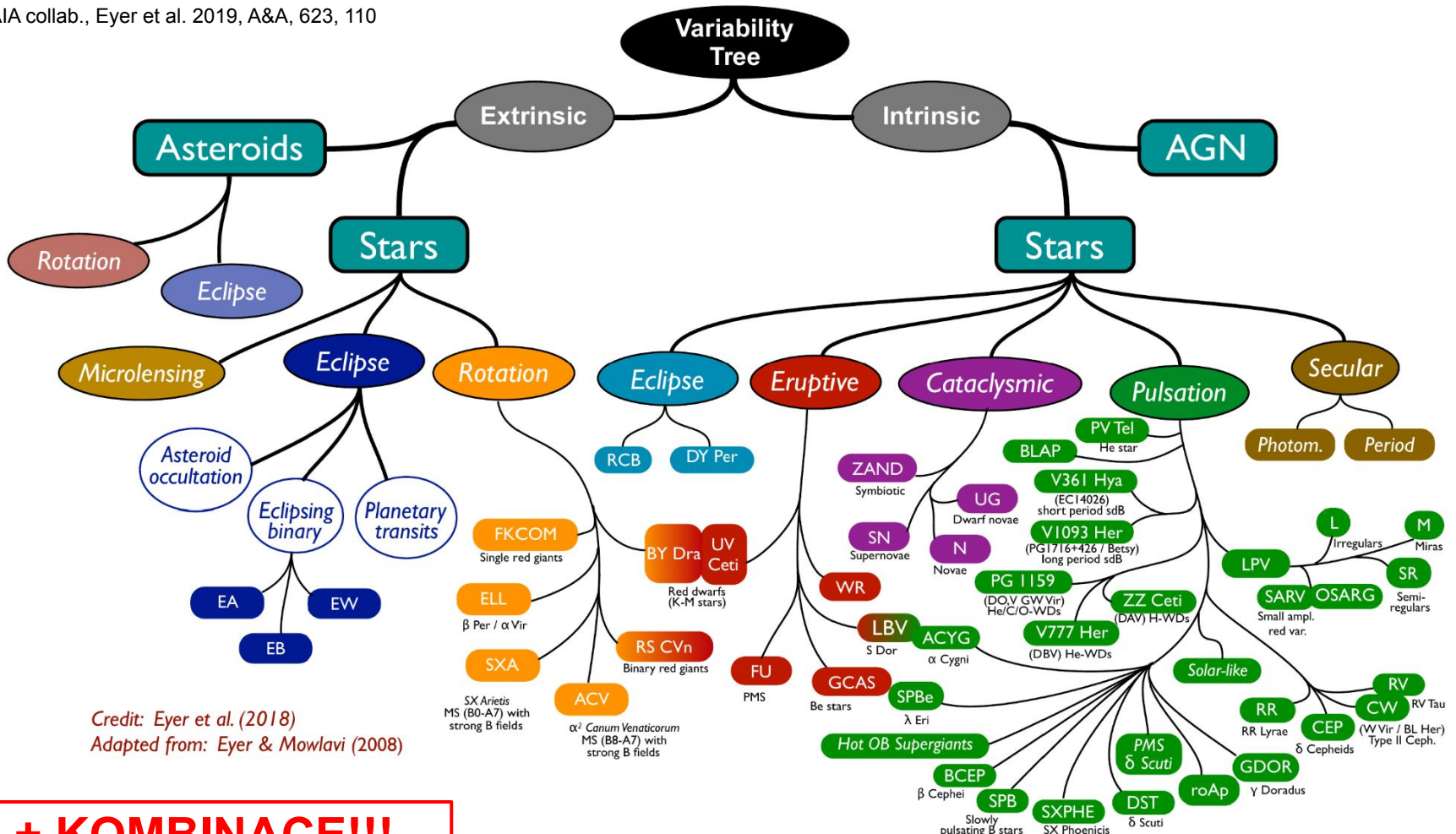
**Co tedy způsobuje hvězdnou
proměnnost?**

Credit: Eyer et al. (2018)

Adapted from: Eyer & Mowlavi (2008)



Credit: Eyer et al. (2018)
Adapted from: Eyer & Mowlavi (2008)



Credit: Eyer et al. (2018)
Adapted from: Eyer & Mowlavi (2008)

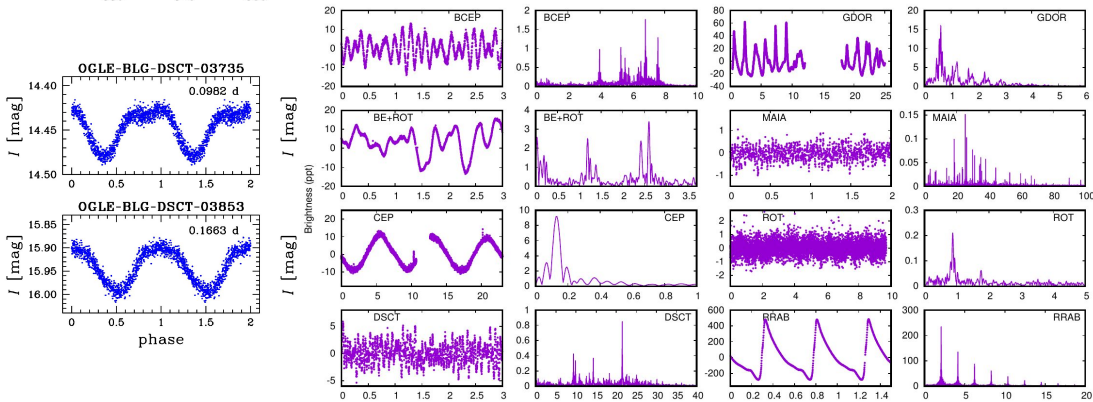
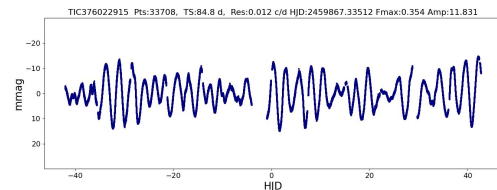
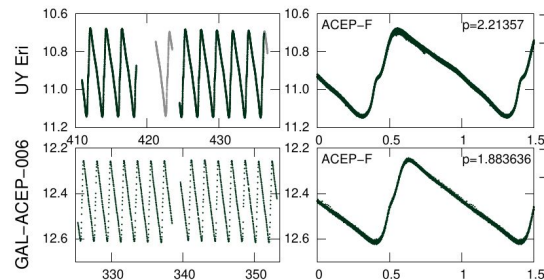
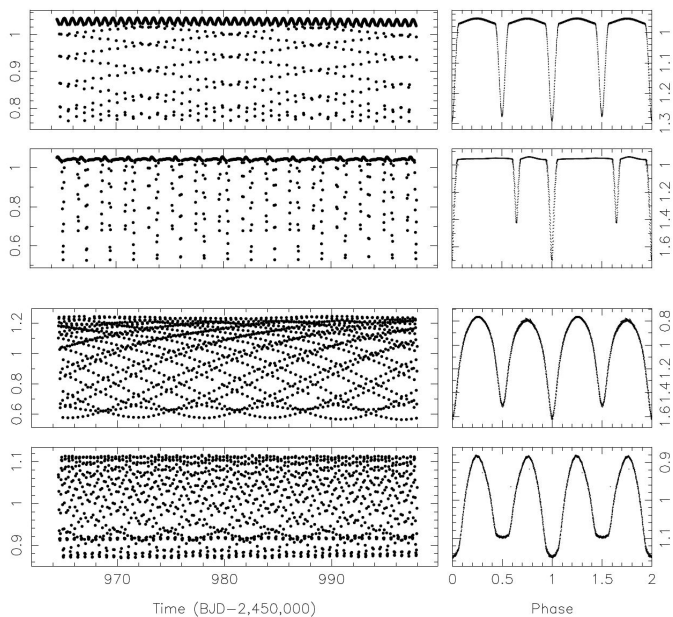
+ KOMBINACE!!!

Klasifikace proměnných hvězd

- Společné rysy (**světelná křivka, perioda, amplituda změn, teplota (barva), svítivost, poloha v galaxii, ...**)
- Různé typy proměnných hvězd sdílejí podobné charakteristiky
- -> **nutná víceparametrická klasifikace, použití více zdrojů dat, strojové učení**
- Nepřesná či nemožná definice limitů (fyzikální modely nepřesné -> klasifikace založena na pozorování)

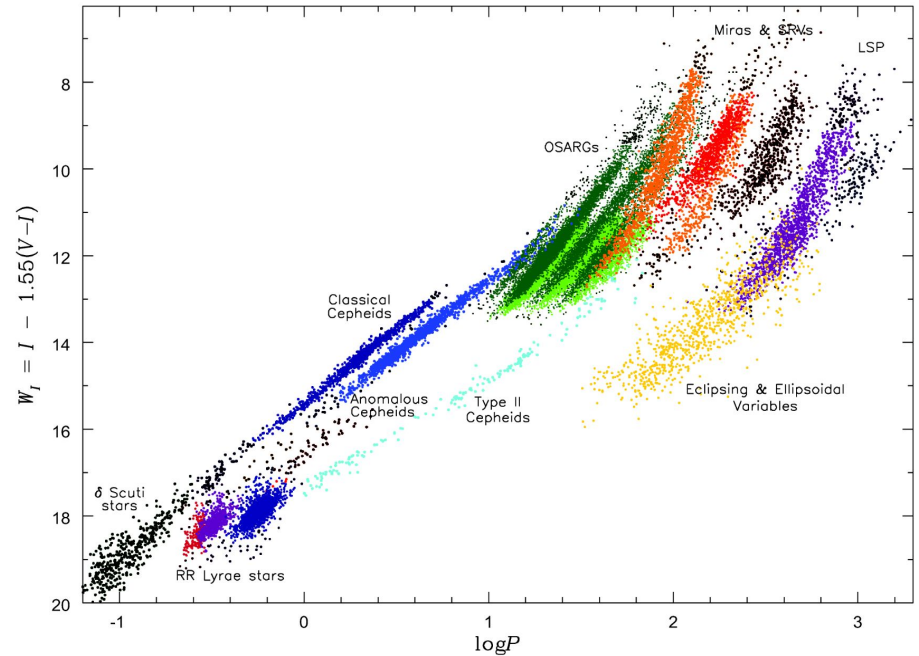
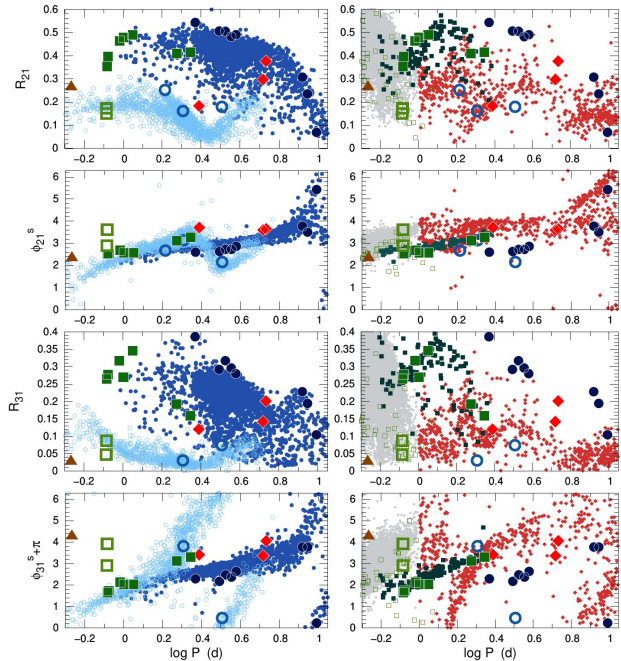
<https://www.aavso.org/vsx/index.php?view=about.vartypes>

<http://www.sai.msu.su/gcvs/gcvs/>



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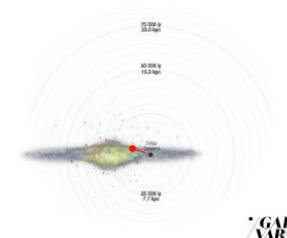
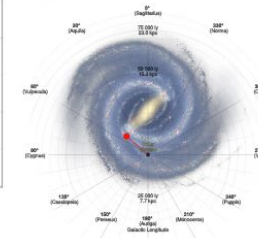
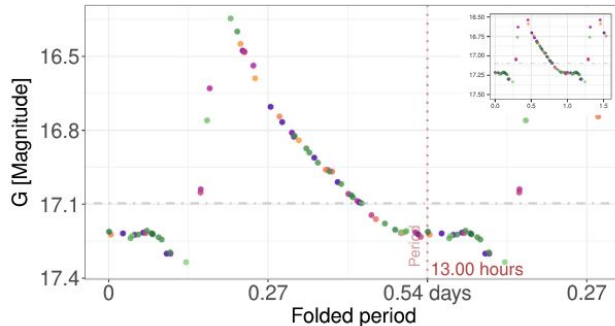
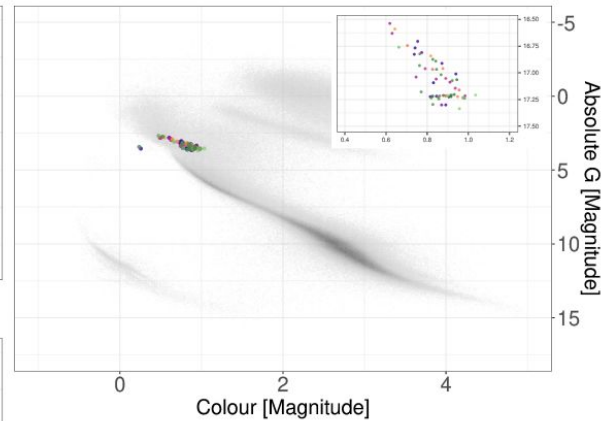
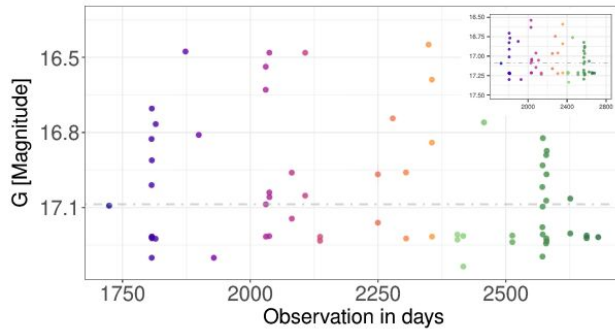
Klasifikace proměnných hvězd

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<https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari>

HR diagram

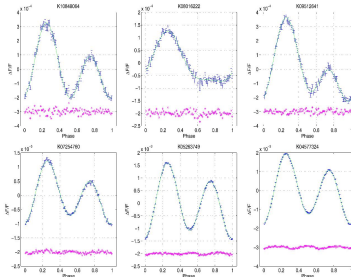
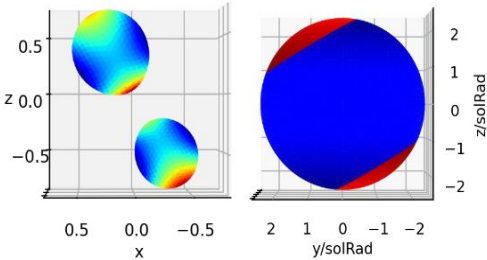
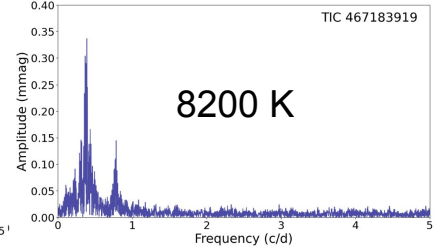
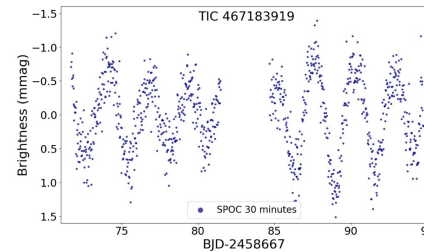
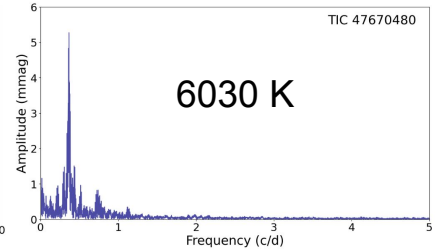
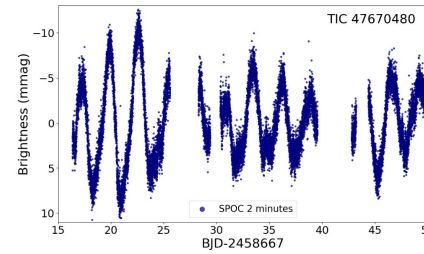
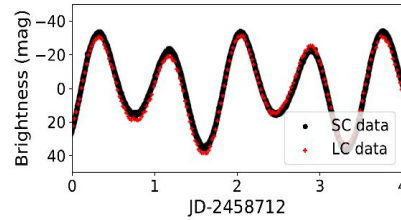
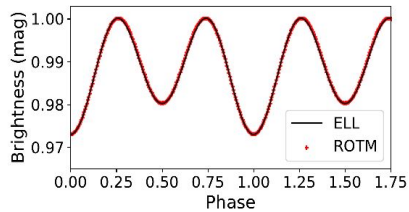
gaia esa



GAMA

Klasifikace proměnných hvězd

- Společné rysy (**světelná křivka**, **perioda**, **amplituda změn**, teplota (barva), svítivost, poloha v galaxii, ...)
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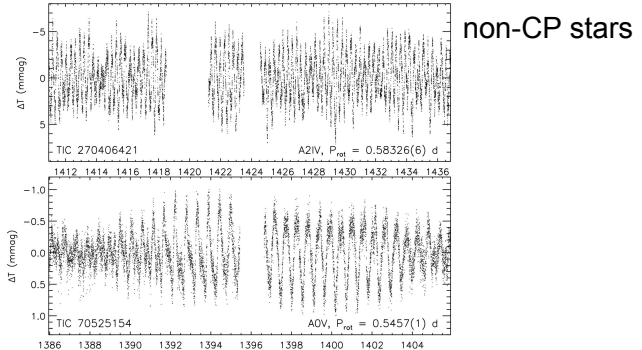
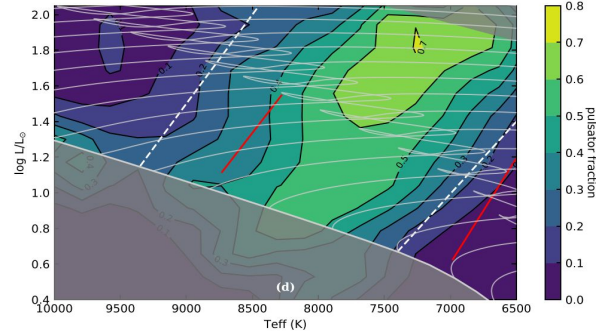
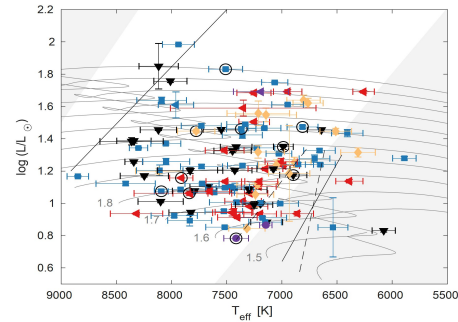
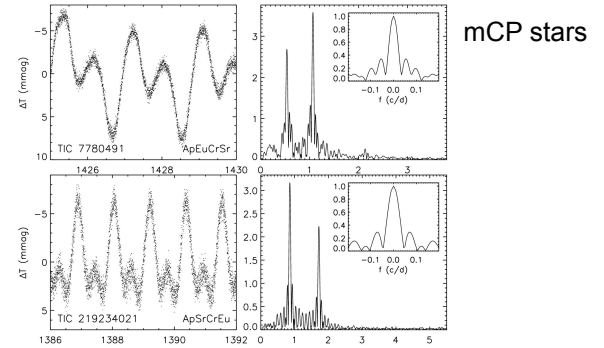
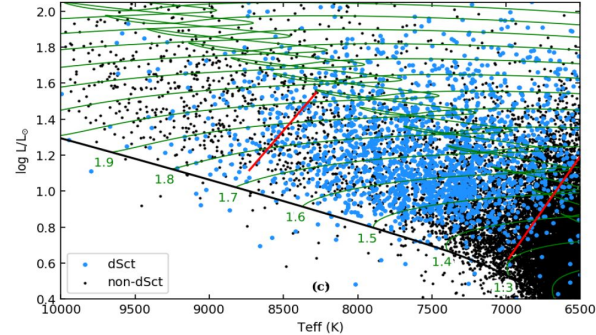
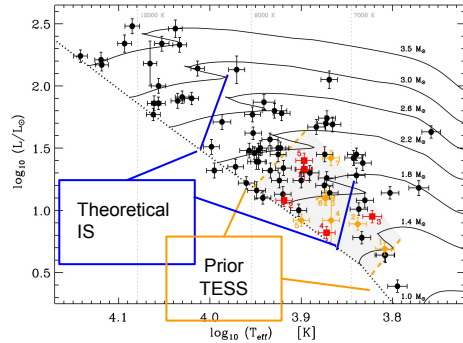
Faigler et al. 2012, ApJ,
746, 185 - ELL hvězdy

Barevná měření + spektra - odlišení binarity od skvrn

Klasifikace proměnných hvězd

- Společné rysy (**světelná křivka, perioda, amplituda změn, teplota (barva), svítivost, poloha v galaxii, ...**)
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Cunha et al. 2019, MNRAS, 487, 3523 - roAp z TESS



dSct+gDor stars z TESS

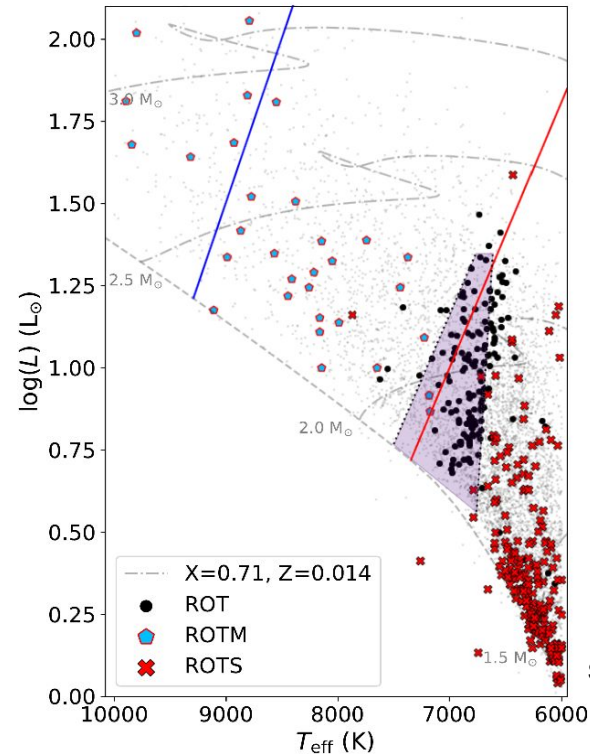
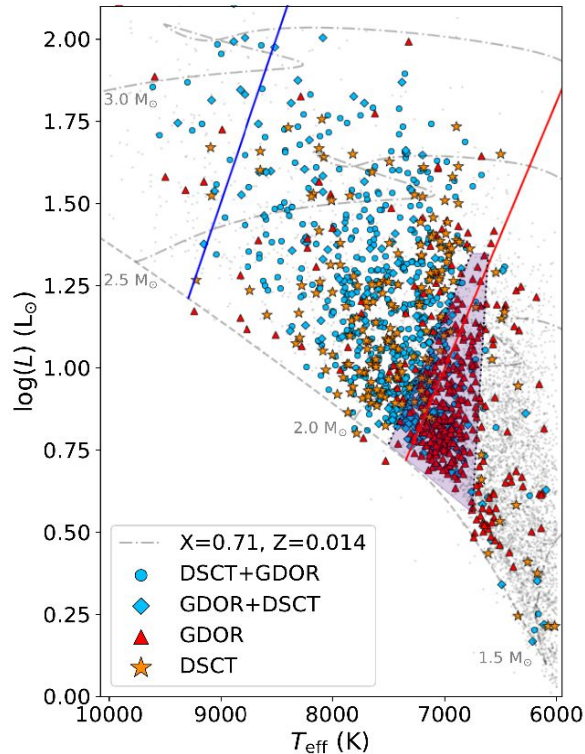
Antoci et al. (2019), MNRAS, 490, 4040

Murphy et al. (2019), MNRAS, 485, 2380

Sikora et al. 2019, MNRAS, 487, 4695

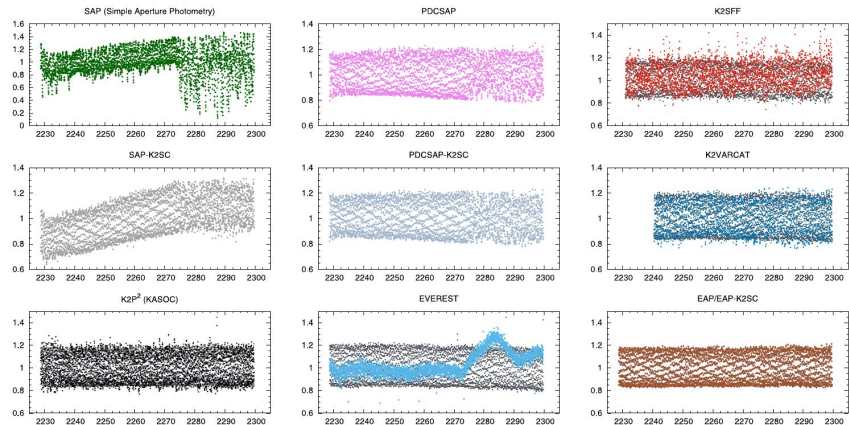
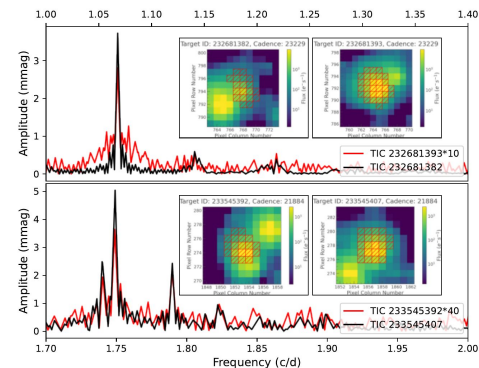
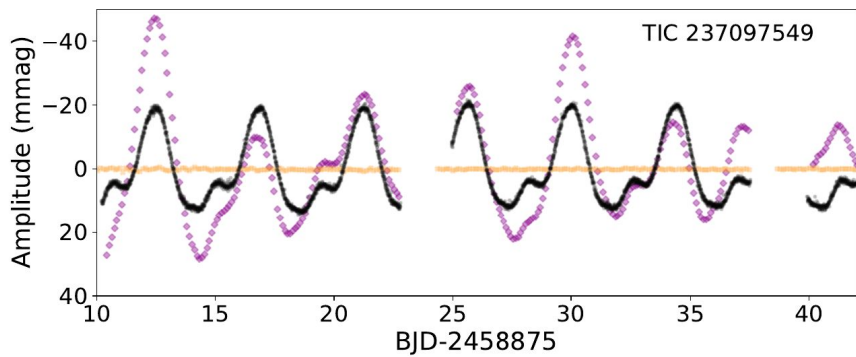
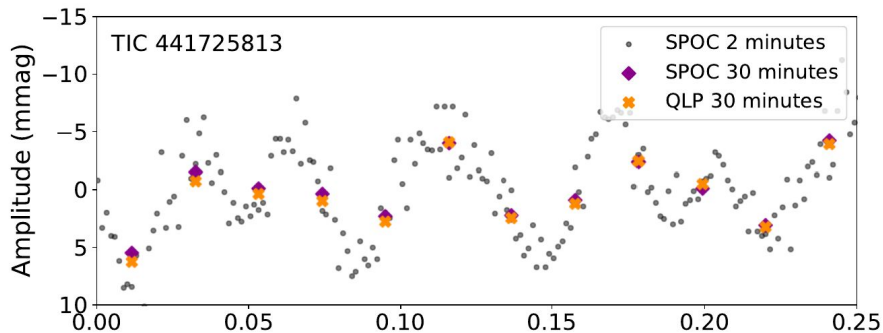
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- Nepřesná či nemožná definice limitů (fyzikální modely nepřesné -> klasifikace založena na pozorování)



Klasifikace proměnných hvězd

- Pozor na data! Různé rutiny pro redukci dat produkují různá data
- Pozor na kontaminaci blízkými objekty - problém u přehlídek a vesmírných misí



Klasifikace proměnných hvězd

Feature	Description	Importance (per cent)	Reference
LS_Per	Best Lomb–Scargle period	1	–
LS_Pow	Power corresponding to the best Lomb–Scargle period	24	–
log(LS_FAP)	Base 10 logarithm of the FAP corresponding to the best Lomb–Scargle period	11	–
T(t)	Lafler–Kinman string length statistic of the light curve sorted by time	4	Jayasinghe et al. (2019a)
T(ϕ P)	Lafler–Kinman string length statistic of the light curve sorted by phase	18	Jayasinghe et al. (2019a)
δ	Normalized difference between T(t) and T(ϕ P)	5	Jayasinghe et al. (2019b)
Skew	Skewness of the magnitude distribution	2	–
Kurt	Kurtosis of the magnitude distribution	2	–
Median	Median of the magnitude distribution	1	–
σ	Standard deviation of the light curve	2	–
IQR	Difference between the 75th and 25th percentiles in magnitude	2	–
A_{HL}	Ratio of magnitudes brighter or fainter than the average	2	Kim & Bailer-Jones (2016)
MAD	Median absolute deviation of the light curve	2	–
$1/\eta$	Inverse of the η (Von Neumann index) value for the light curve	3	Von Neumann et al. (1941)
$J - K_s$	2MASS $J - K_s$ colour		
$H - K_s$	2MASS $H - K_s$ colour		

Metody strojového učení a neuronových sítí

Nutnost dobrých trénovacích vzorků

Jayasinghe 2020, MNRAS, 491, 13
Klasifikace proměnných hvězd z ASAS-SN

Využití informací z periodogramu, statistických ukazatelů dat a barvy hvězd

Class	Summarized refinement criteria
δ Scuti (HADS, DSCT)	Skew < 0.15, LS.Pow>0.25, log(LS.FAP)<-7, $A < 0.5$ mag, T(ϕ P) < 0.5, $-1 < W_{JK} < 3$ mag
RR Lyrae (RRAB, RRC, RRD)	RRAB and log(LS.FAP)<-10, LS.Pow>0.2, $A > 0.08$ mag, T(ϕ P) < 0.6, Skew < 0.15, $\delta < -0.25$ RRC/RRD and log(LS.FAP)<-10, LS.Pow>0.2, $A > 0.08$ mag, T(ϕ P) < 0.6, Skew < 0, $\delta < -0.25$
Cepheids (DCEP, DCEPS, CWA, CWB, RVA)	Skew < 1, log(LS.FAP)<-10, LS.Pow>0.3, $A < 2$ mag, T(ϕ P) < 0.6, $\delta < -0.25$
Rotational variables (ROT)	Period>0.6 d and log(LS.FAP)<-5, LS.Pow>0.2, $A > 0.08$ mag, T(ϕ P) < 0.6, $\delta < 0$ Period \leq 0.6 d and $W_{JK} > 2.5$ mag, Prob > 0.9
Eclipsing binaries (EA, EB, EW)	EA (GLS) and $\alpha < 100$, T(ϕ P) < 0.6, $A > 0.08$ mag EB (GLS) and log(LS.FAP)<-7, LS.Pow>0.2, $A > 0.08$ mag, T(ϕ P) < 0.6 EW (GLS) and log(LS.FAP)<-7, LS.Pow>0.2, $A > 0.08$ mag, T(ϕ P) < 0.6, Skew > 0 EA (BLS) and $\alpha < 100$, T(ϕ P) < 0.45, Prob > 0.8
Semiregular and irregular variables (SR, L)	$\alpha < 5$, $V_{mean} > 11$ mag, $A > 0.08$ mag Period>100 d and log(LS.FAP)<-3, $J - K_s > 1.1$, $A > 0.1$ mag, T(t) < 0.7 10 \leq Period \leq 100 d and log(LS.FAP)<-8, $A > 0.08$ mag
Mira variables (M, M:)	log(LS.FAP)<-3, LS.Pow>0.5, T(ϕ P) < 0.5
YSO	Period<100 d and $\alpha < 5$, log(LS.FAP)<-10, LS.Pow>0.25, T(ϕ P) < 0.6
Outbursting Be stars (GCAS, GCAS:)	$\alpha < 5$, $V_{mean} > 11$ mag, $J - K_s < 1.1$, $0.25 < A < 1$ mag, T(t) < 0.5
Generic variables (VAR)	$\alpha < 5$, $0.1 < A < 2$ mag, $W_{JK} > -4$ mag, $V_{mean} > 11$ mag, T(ϕ P) < 0.5 OR T(t) < 0.5

Klasifikace proměnných hvězd

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THE ASTRONOMICAL JOURNAL, 162:209 (25pp), 2021 November

Audenaert et al.

THE ASTRONOMICAL JOURNAL, 162:209 (25pp), 2021 November

Audenaert et al.

Stellar Variability Classification

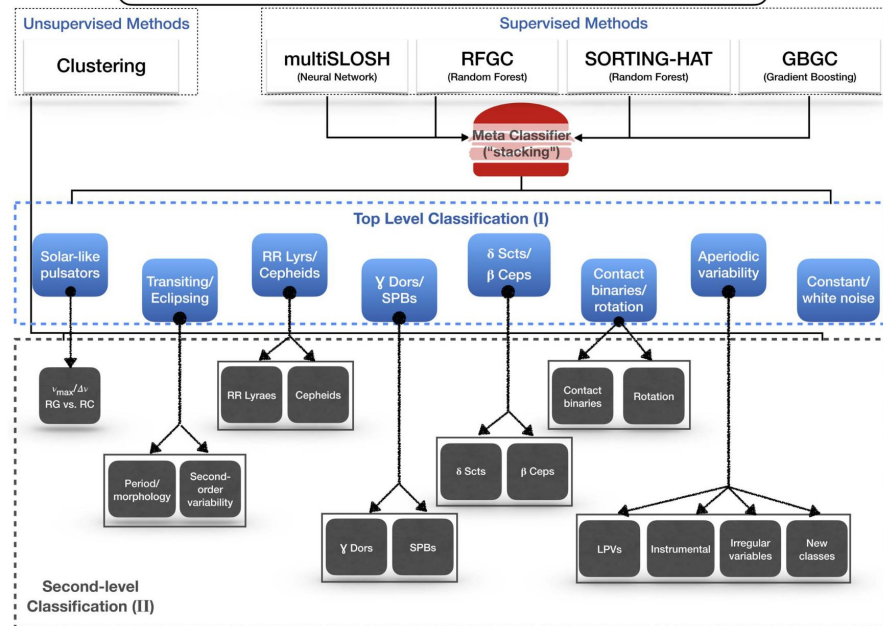


Table 1

Overview of Classification Features Employed by the Individual Algorithms

Algorithm/Feature	SLOSH	RFGC	SORTING-HAT	GBGC	Notes
PDS	x				Power density spectrum
f_i, \tilde{f}_i^a			x	x	Frequencies and their harmonics
A_{ij}				x	Amplitudes
$\frac{A_{21}}{A_{11}}, \frac{A_{31}}{A_{11}}$		x			Amplitude ratios
ϕ_{ij}				x	Phases
$\phi_{ij} = \phi_{i1} - \phi_{j1}, i = 2,3$		x			Phase differences
FltPer (F_p) ^b					Mean power in a given frequency range
$F_p \{0.7, 7, 20, 50\}$		x			0.7, 7, 20, 50 μ Hz onwards
SOM_loc			x		Location on the trained self-organizing maps
ϕ_{p2p_98}			x		Point-to-point difference, 98th percentile
$p2p_98$			x		ϕ refers to the phase-folded light curve
ϕ_{p2p_mean}			x		Mean of the point-to-point difference
$p2p_mean$			x		ϕ refers to the phase-folded light curve
ϕ_range			x		Range of phase-folded light curve
D_k			x		Number of zero crossings in a light curve
ψ^2			x		Coherency parameter
η_e^c				x	Variability index
skewness ^d			x		Light-curve skewness
MAD ^e		x			Median absolute deviation
Rcs ^f				x	Range of the cumulative sum of the fluxes
σ^2				x	Variance
SW ^g				x	Shapiro-Wilk test for normality
kurt ^h				x	Kurtosis
varrat ⁱ			x		Variance ratio
SH			x		Number of significant harmonics of f_1
FR			x		Flux ratio
$h(x)$			x		Differential entropy
MSE				x	Multiscale entropy
MSE avg,std,max,pow			x		Mean, standard deviation, max, and power

Klasifikace proměnných hvězd

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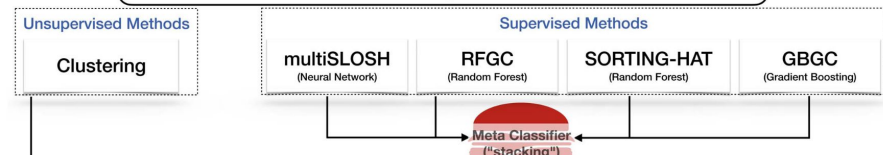


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PDS	x				Power density spectrum
f_{ν}, \tilde{f}_T^a		x	x	x	Frequencies and their harmonics
A_{ij}				x	Amplitudes
$\frac{A_{21}}{A_{11}}, \frac{A_{31}}{A_{11}}$		x			Amplitude ratios
ϕ_{ij}				x	Phases
$\phi_{ij} - \phi_{ij-2}$		x			Phase differences
FR			x		Flux ratio
$h(x)$			x		Differential entropy
MSE				x	Multiscale entropy
MSE avg,std,max,pow			x		Mean, standard deviation, max, and power

Funguje spolehlivě pouze pro proměnnky s velkou amplitudou a pouze pokud jsou dobré trénovací vzorky

Neřeší problém pulzace vs rotac ani ELL vs ROTM



Second-level Classification (II)

Klasifikace proměnných hvězd

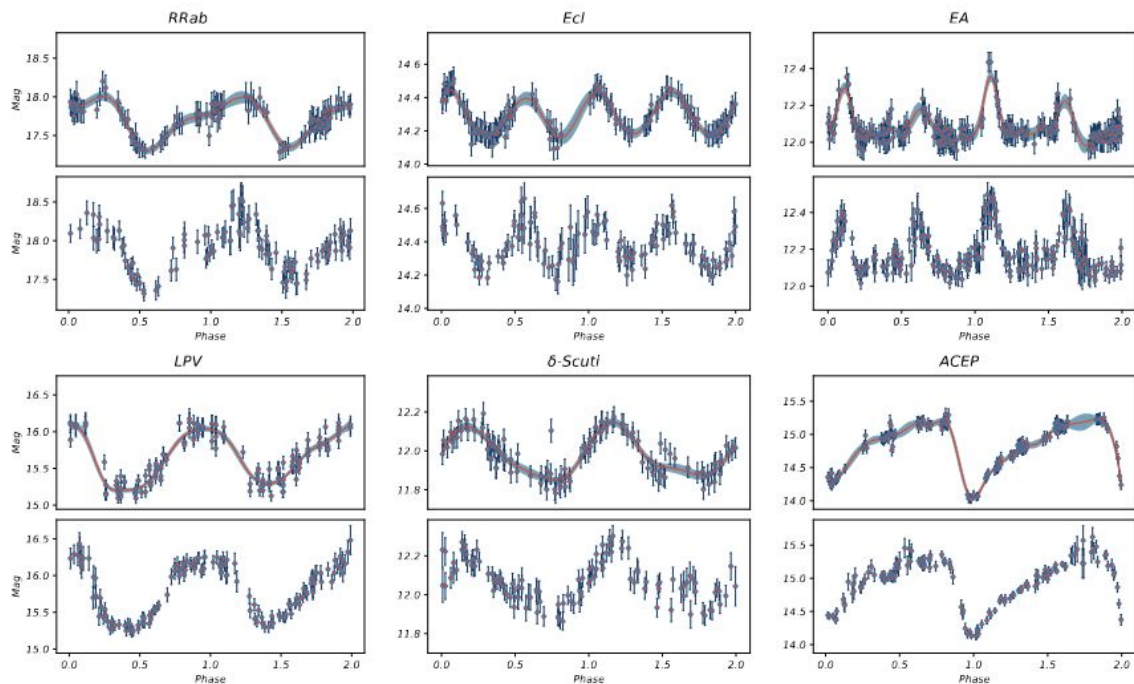


Table 1. The number of different classes of CRTS variable stars.

Classes of variable stars	No.
RRab	4325
Blazhko	171
RRc	3752
RRd	502
Rot (Rotational)	3636
Ecl (Contact and Semi-Detached Binary)	18803
EA (Detached Binary)	4509
LPV (Long Period Variable)	1286
δ -Scuti	147
ACEP (Anomalous Cepheids)	153
Cep-II (Type-II Cepheids)	153

Nevhodný trénovací vzorek

Špatná data

Nevhodná metoda fitování

=> **zavádějící výsledky**

DRAFT VERSION SEPTEMBER 26, 2023
Typeset using L^AT_EX twocolumn style in AASTeX631

Pozor na analýzy s použitím moderních metod strojového učení

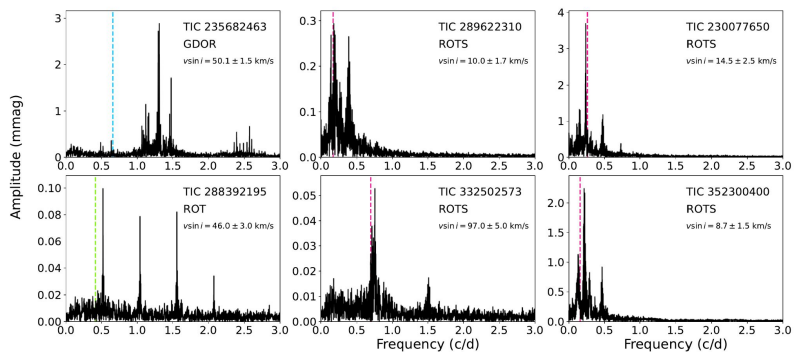
Periodic variable star classification with deep learning:
handling data imbalance in an ensemble augmentation way

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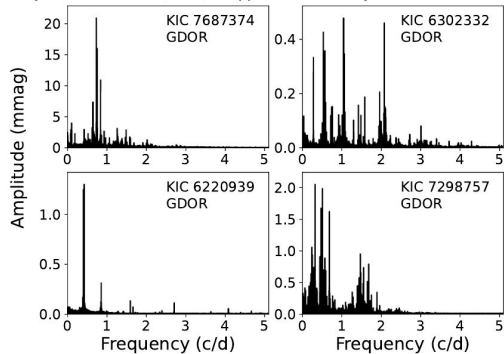
Klasifikace proměnných hvězd

Skarka et al. 2022, A&A, 666, 142

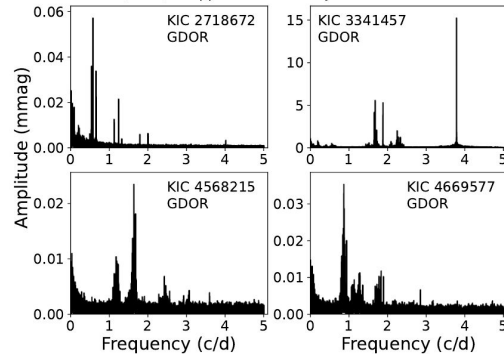
M. Skarka et al.: Periodic variable A-F spectral type stars in the northern TESS continuous viewing zone



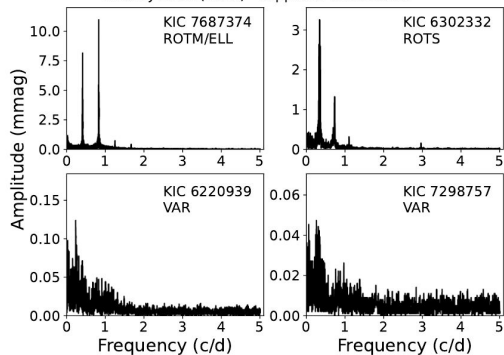
Uytterhoeven et al. (2011) - supposed rotationally modulated stars



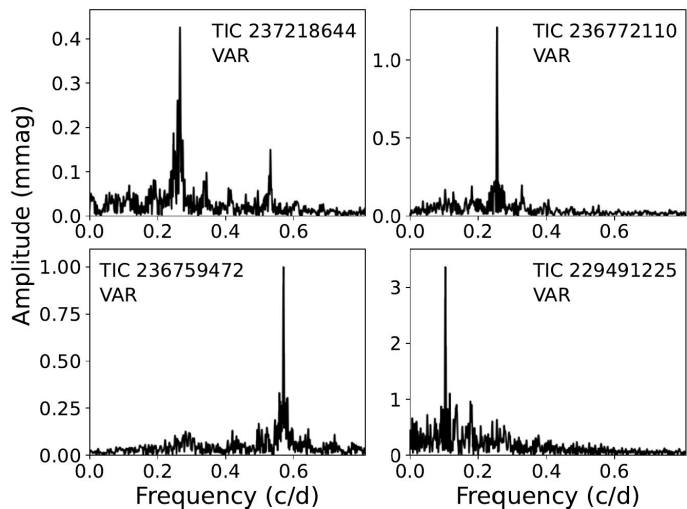
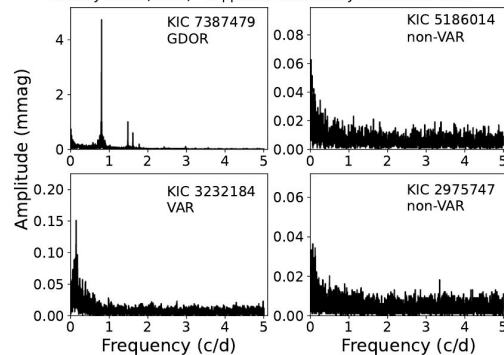
Balona (2013) - supposed rotationally modulated stars



Bradley et al. (2015) - supposed GDOR stars

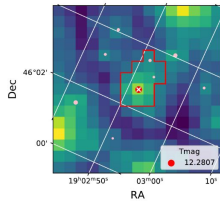
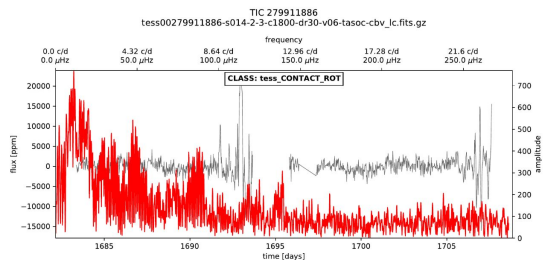


Bradley et al. (2015) - supposed rotationally modulated stars



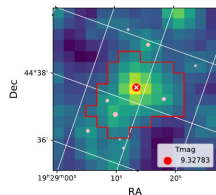
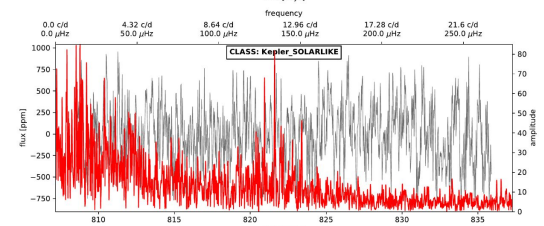
Manuální klasifikace silně subjektivní

Automatická vs manuální klasifikace



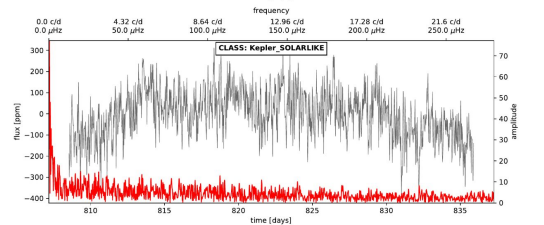
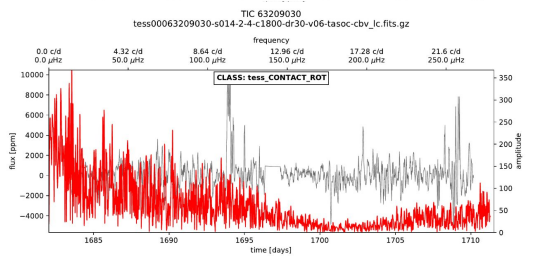
TESS Probability (TOP)	
APERIODIC	0.038
CONSTANT	0.002
CONTACT_ROT	0.154
DSCT_BCEP	0.199
ECLIPSE	0.075
GDOR_SPB	0.116
RRLYR_CEPHEID	0.058
SOLARLIKE	0.158

KEPLER Probability (BOTTOM)	
APERIODIC	0.001
CONSTANT	0.000
CONTACT_ROT	0.002
DSCT_BCEP	0.001
ECLIPSE	0.001
GDOR_SPB	0.004
RRLYR_CEPHEID	0.002
SOLARLIKE	0.990

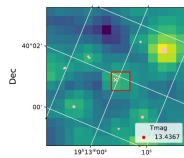
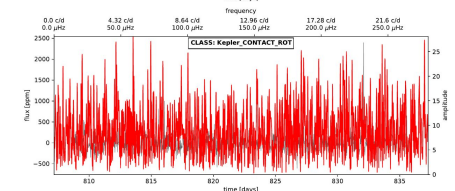
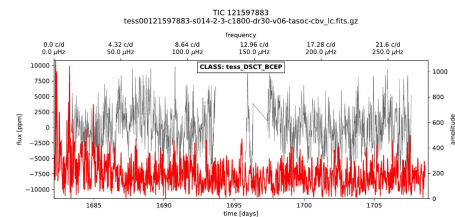


TESS Probability (TOP)	
APERIODIC	0.034
CONSTANT	0.002
CONTACT_ROT	0.361
DSCT_BCEP	0.121
ECLIPSE	0.134
GDOR_SPB	0.171
RRLYR_CEPHEID	0.092
SOLARLIKE	0.073

KEPLER Probability (BOTTOM)	
APERIODIC	0.025
CONSTANT	0.002
CONTACT_ROT	0.178
DSCT_BCEP	0.029
ECLIPSE	0.012
GDOR_SPB	0.103
RRLYR_CEPHEID	0.058
SOLARLIKE	0.603



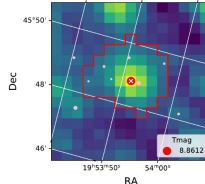
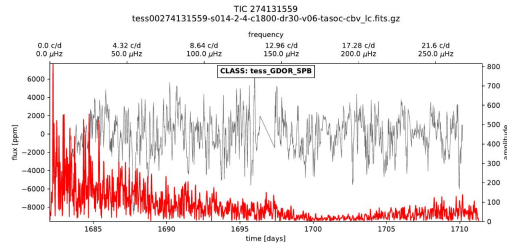
	A	B	C	D	E	F
1	TIC	ML class	Human class	Comment		
2	279911886	CONTACT_ROT	DSCT_BCEP	Based on Kepler; TESS Unclear/Unclear		
3	63209030	CONTACT_ROT	?	Unclear		
4	121597883	DSCT_BCEP	?	Unclear		
5	137151703	ECLIPSE	?	Unclear		
6	137890129	RRLYR_CEPHEID	?	Unclear		
7	377913325	CONTACT_ROT	?	Kepler aperiodic/rot; TESS Unclear/Unclear		
8	169558022	CONTACT_ROT	CONTACT_ROT	Based on Kepler; TESS Unclear/Unclear		
9	299154262	GDOR_SPB	CONTACT_ROT	Based on Kepler; TESS Unclear/Unclear		
10	271884852	GDOR_SPB	?	Kepler aperiodic/rot; TESS Unclear/Unclear		
11	184244074	ECLIPSE	DSCT_BCEP	Unclear		
12	273130555	CONTACT_ROT	?	Unclear		
13	26656764	CONTACT_ROT	CONTACT_ROT	Apparent in both Kepler and TESS		
14	121867412	CONTACT_ROT	CONTACT_ROT	Based on Kepler; TESS Unclear/Unclear		
15	27642606	SOLARLIKE	?	Kepler aperiodic/rot; TESS Unclear/Unclear		
16	184418463	ECLIPSE	?	Unclear		
17	274199051	GDOR_SPB	?	Unclear		
18	123409362	CONSTANT	?	Unclear		
19	169464625	ECLIPSE	?	Unclear		
20	377916358	CONTACT_ROT	?	Unclear		
21	240178698	DSCT_BCEP	?	Unclear		
22	164525536	GDOR_SPB	?	Unclear		
23	164892194	DSCT_BCEP	ECLIPSE	Based on Kepler; TESS Unclear/Unclear		



TESS Probability (TOP)	
APERIODIC	0.022
CONSTANT	0.000
CONTACT_ROT	0.341
DSCT_BCEP	0.241
ECLIPSE	0.060
GDOR_SPB	0.291
RRLYR_CEPHEID	0.057
SOLARLIKE	0.026

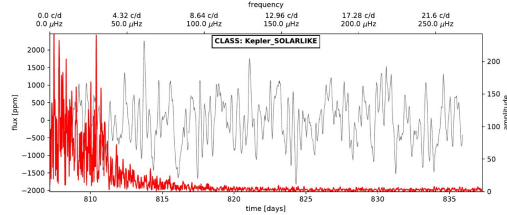
KEPLER Probability (BOTTOM)	
APERIODIC	0.033
CONSTANT	0.000
CONTACT_ROT	0.193
DSCT_BCEP	0.284
ECLIPSE	0.068
GDOR_SPB	0.121
RRLYR_CEPHEID	0.011
SOLARLIKE	0.029

Automatická vs manuální klasifikace

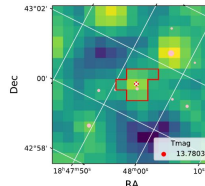
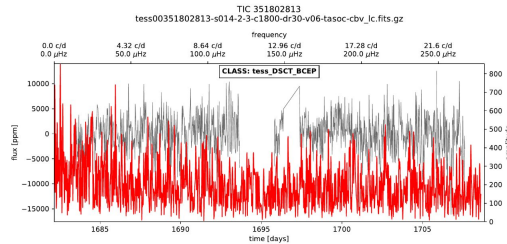


TESS Probability (TOP)	
APERIODIC	0.036
CONSTANT	0.002
CONTACT_ROT	0.231
DSCT_BCEP	0.004
ECLIPSE	0.175
GDOR_SPB	0.413
RRLYR_CEPHEID	0.004
SOLARLIKE	0.024

KEPLER Probability (BOTTOM)	
APERIODIC	0.001
CONSTANT	0.000
CONTACT_ROT	0.002
DSCT_BCEP	0.001
ECLIPSE	0.012
GDOR_SPB	0.003
RRLYR_CEPHEID	0.002
SOLARLIKE	0.985

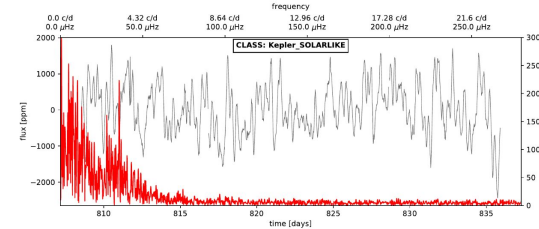
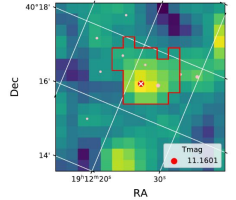
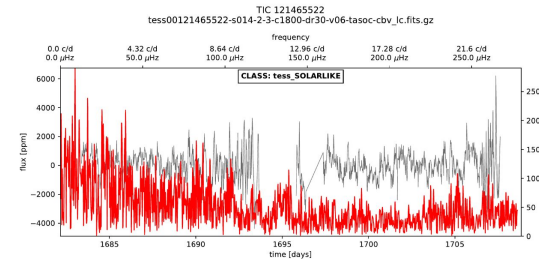
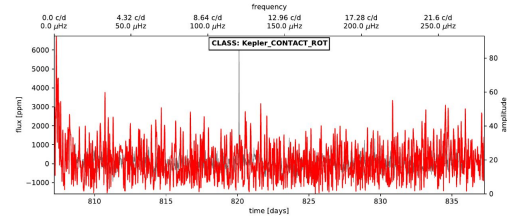


TIC	ML class	Human class	My class
274131559	<u>GDOR_SPB</u>	<u>solarlike</u>	<u>GDOR_SPB</u>
159171113	CONTACT_ROT	<u>solarlike</u>	?
137095610	CONTACT_ROT	contact_rot	<u>CONTACT_ROT+DSCT</u>
351802813	<u>DSCT_BCEP</u>	contact_rot	?
394175802	<u>DSCT_BCEP</u>	<u>solarlike</u>	?
184014866	ECLIPSE	?	?
272605606	CONTACT_ROT	<u>gdor_spb</u>	?
271430666	<u>DSCT_BCEP</u>	<u>solarlike</u>	?
121465522	<u>SOLARLIKE</u>	<u>solarlike</u>	<u>GDOR_SPB</u>



TESS Probability (TOP)	
APERIODIC	0.035
CONSTANT	0.002
CONTACT_ROT	0.183
DSCT_BCEP	0.312
ECLIPSE	0.087
GDOR_SPB	0.255
RRLYR_CEPHEID	0.000
SOLARLIKE	0.046

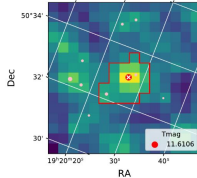
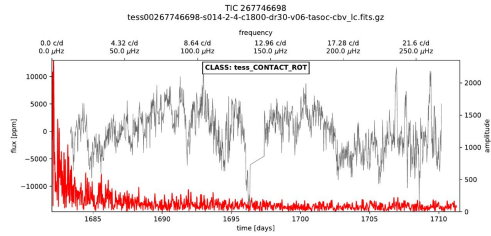
KEPLER Probability (BOTTOM)	
APERIODIC	0.001
CONSTANT	0.013
CONTACT_ROT	0.611
DSCT_BCEP	0.051
ECLIPSE	0.084
GDOR_SPB	0.088
RRLYR_CEPHEID	0.107
SOLARLIKE	0.022



TESS Probability (TOP)	
APERIODIC	0.040
CONSTANT	0.002
CONTACT_ROT	0.203
DSCT_BCEP	0.114
GDOR_SPB	0.216
RRLYR_CEPHEID	0.037
SOLARLIKE	0.231

KEPLER Probability (BOTTOM)	
APERIODIC	0.001
CONSTANT	0.000
CONTACT_ROT	0.003
DSCT_BCEP	0.012
ECLIPSE	0.012
GDOR_SPB	0.010
RRLYR_CEPHEID	0.002
SOLARLIKE	0.971

Automatická vs manuální klasifikace

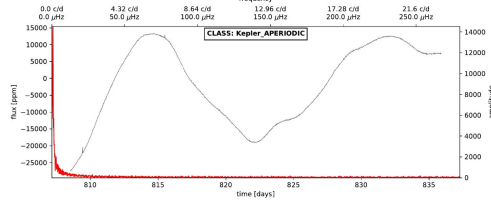


TESS Probability (TOP)

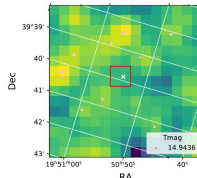
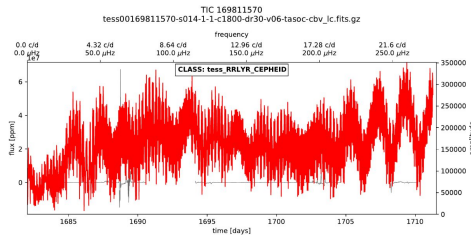
APERIODIC	0.053
CONTACT_ROT	0.903
CONSTANT	0.012
DISCT_BCEP	0.055
ECLIPSE	0.142
GDOR_SPB	0.150
RRLYR_CEPHEID	0.090
SOLARLIKE	0.195

KEPLER Probability (BOTTOM)

APERIODIC	0.971
CONTACT_ROT	0.005
CONSTANT	0.009
DISCT_BCEP	0.001
ECLIPSE	0.001
GDOR_SPB	0.001
RRLYR_CEPHEID	0.003
SOLARLIKE	0.015



TIC	ML class	Human class	My class
267746698	CONTACT_ROT	<u>APERIODIC</u>	?
169811570	RRLYR_CEPHEID	CONSTANT	?
268166607	CONTACT_ROT	<u>GDOR_SPB</u>	CONTACT_ROT
138641345	ECLIPSE	<u>GDOR_SPB</u>	<u>GDOR_SPB</u>
48029739	CONTACT_ROT	CONSTANT	?
159305945	ECLIPSE	<u>GDOR_SPB</u>	CONTACT_ROT
171972060	CONTACT_ROT	<u>APERIODIC</u>	?
272178884	<u>SOLARLIKE</u>	<u>SOLARLIKE</u>	<u>GDOR_SPB</u>

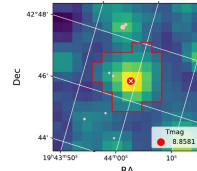
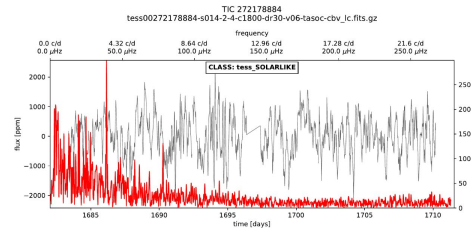
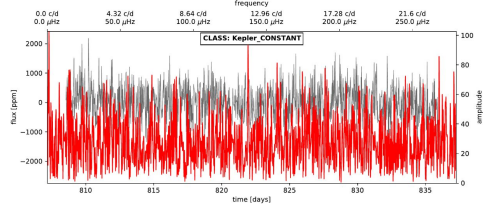


TESS Probability (TOP)

APERIODIC	0.065
CONTACT_ROT	0.001
CONSTANT	0.383
DISCT_BCEP	0.200
ECLIPSE	0.042
GDOR_SPB	0.044
RRLYR_CEPHEID	0.463
SOLARLIKE	0.064

KEPLER Probability (BOTTOM)

APERIODIC	0.942
CONTACT_ROT	0.248
CONSTANT	0.102
DISCT_BCEP	0.025
ECLIPSE	0.025
GDOR_SPB	0.153
RRLYR_CEPHEID	0.085
SOLARLIKE	0.034

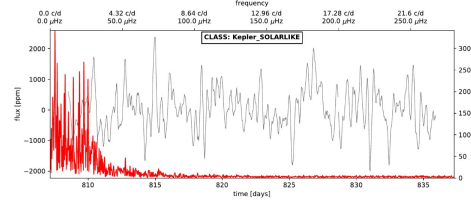


TESS Probability (TOP)

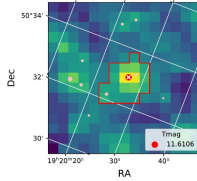
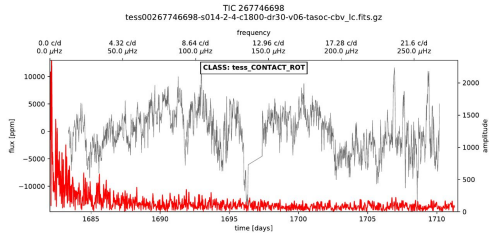
APERIODIC	0.008
CONTACT_ROT	0.079
CONSTANT	0.037
DISCT_BCEP	0.001
ECLIPSE	0.008
GDOR_SPB	0.294
RRLYR_CEPHEID	0.033
SOLARLIKE	0.626

KEPLER Probability (BOTTOM)

APERIODIC	0.001
CONTACT_ROT	0.007
CONSTANT	0.004
DISCT_BCEP	0.002
ECLIPSE	0.002
GDOR_SPB	0.031
RRLYR_CEPHEID	0.004
SOLARLIKE	0.974

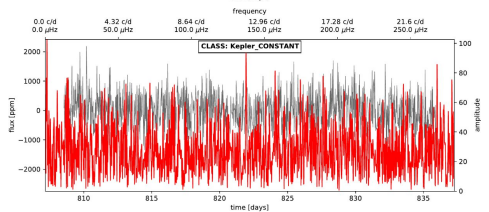
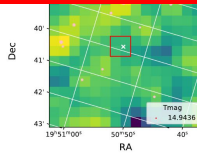
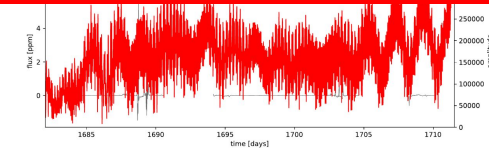


Automatická vs manuální klasifikace



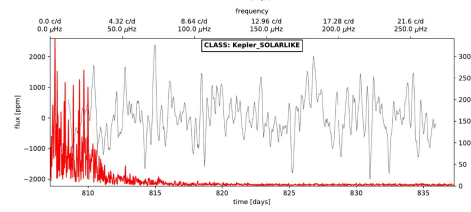
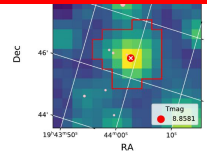
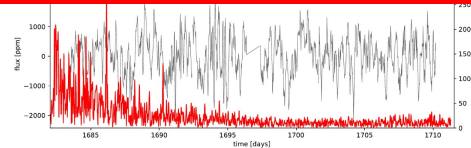
TIC	ML class	Human class	My class
267746698	CONTACT_ROT	<u>APERIODIC</u>	?
169811570	<u>RRLYR_CEPHEID</u>	CONSTANT	?
268166607	CONTACT_ROT	<u>GDOR_SPB</u>	CONTACT_ROT
138641345	ECLIPSE	GDOR_SPB	GDOR_SPB

Klasifikace v literatuře a katalozích nemusí být jednoznačná ani správná



TESS Probability (TOP)	
APERIODIC	0.163
CONSTANT	0.001
CONTACT_ROT	0.383
DISC_BEP	0.200
ECLIPSE	0.042
GDOR_SPB	0.044
RRLYR_CEPHEID	0.463
SOLARLIKE	0.064

KEPLER Probability (BOTTOM)	
APERIODIC	0.142
CONSTANT	0.334
CONTACT_ROT	0.248
DISC_BEP	0.108
ECLIPSE	0.025
GDOR_SPB	0.113
RRLYR_CEPHEID	0.085
SOLARLIKE	0.034

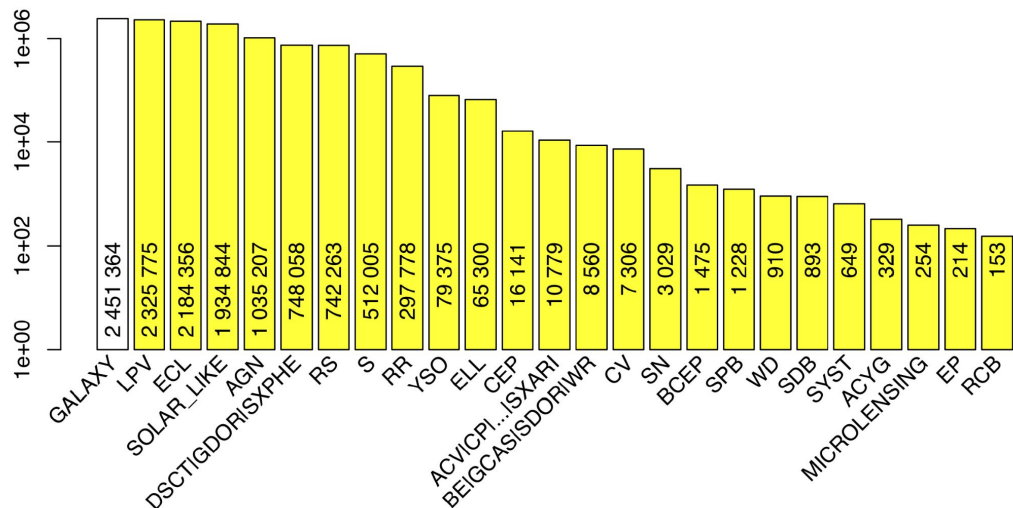


TESS Probability (TOP)	
APERIODIC	0.098
CONSTANT	0.088
CONTACT_ROT	0.079
DISC_BEP	0.037
ECLIPSE	0.008
GDOR_SPB	0.299
RRLYR_CEPHEID	0.033
SOLARLIKE	0.026

KEPLER Probability (BOTTOM)	
APERIODIC	0.001
CONSTANT	0.080
CONTACT_ROT	0.007
DISC_BEP	0.000
ECLIPSE	0.002
GDOR_SPB	0.031
RRLYR_CEPHEID	0.004
SOLARLIKE	0.074

Zastoupení proměnnostních typů

	VSX		ASAS-SN	
TOTAL	2277868		666502	
EW	409449	18	76378	11.5
EA	106996	4.7	48409	7.3
EB	33661	1.5	24994	3.8
ELL	26484	1.2	70	0
RRAB	101130	4.4	32727	4.9
RRC	40658	1.8	11015	1.7
DCEP	5497	0.2	2183	0.3
DSCT	17717	0.8	4690	0.7
GDOR	1445	0.1		0
ROT	101532	4.5	90712	13.6
SR	458483	20.1	194830	29.2
VAR	147932	6.5	62557	9.4
ACV	2027	0.1		0
LPV	3543	0.2		0

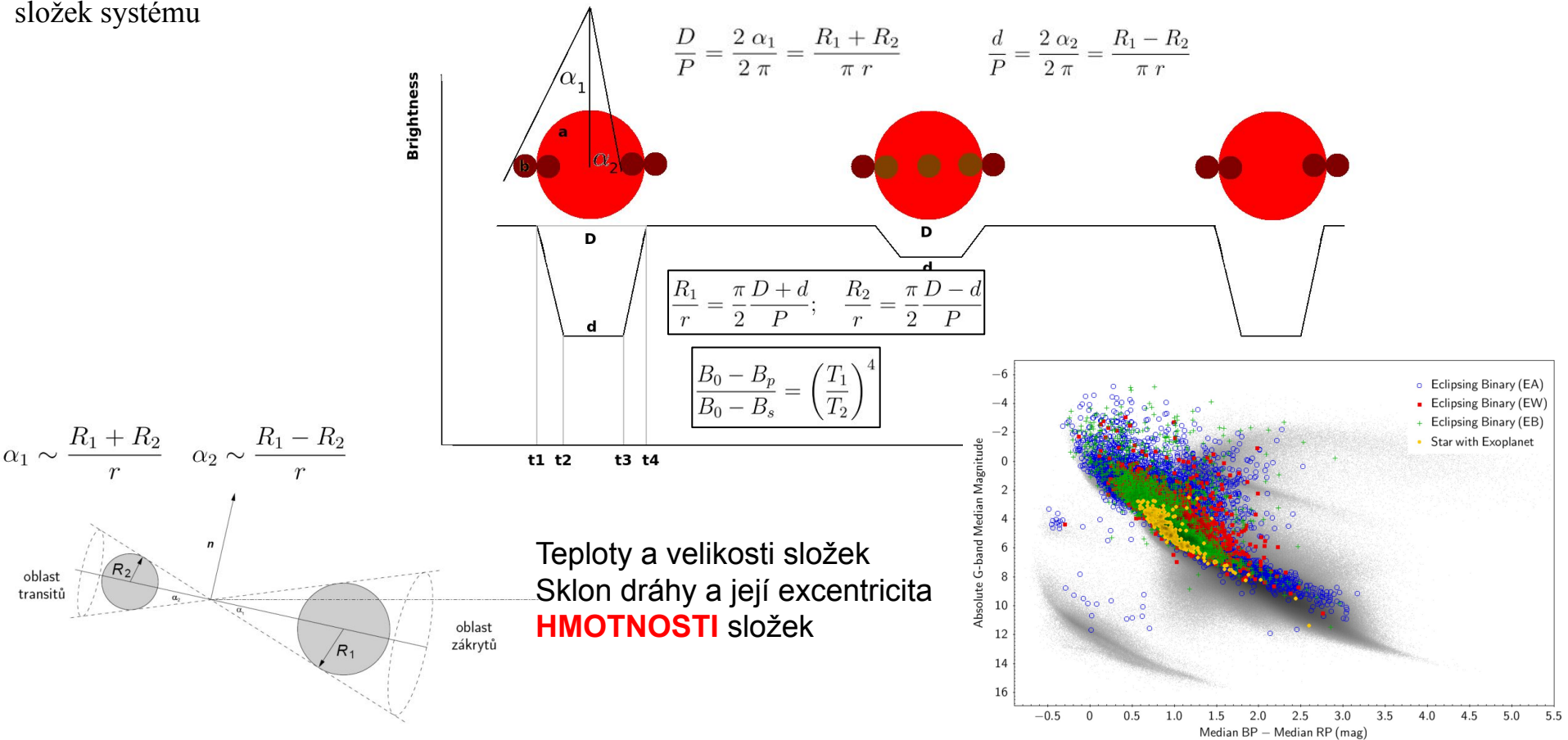


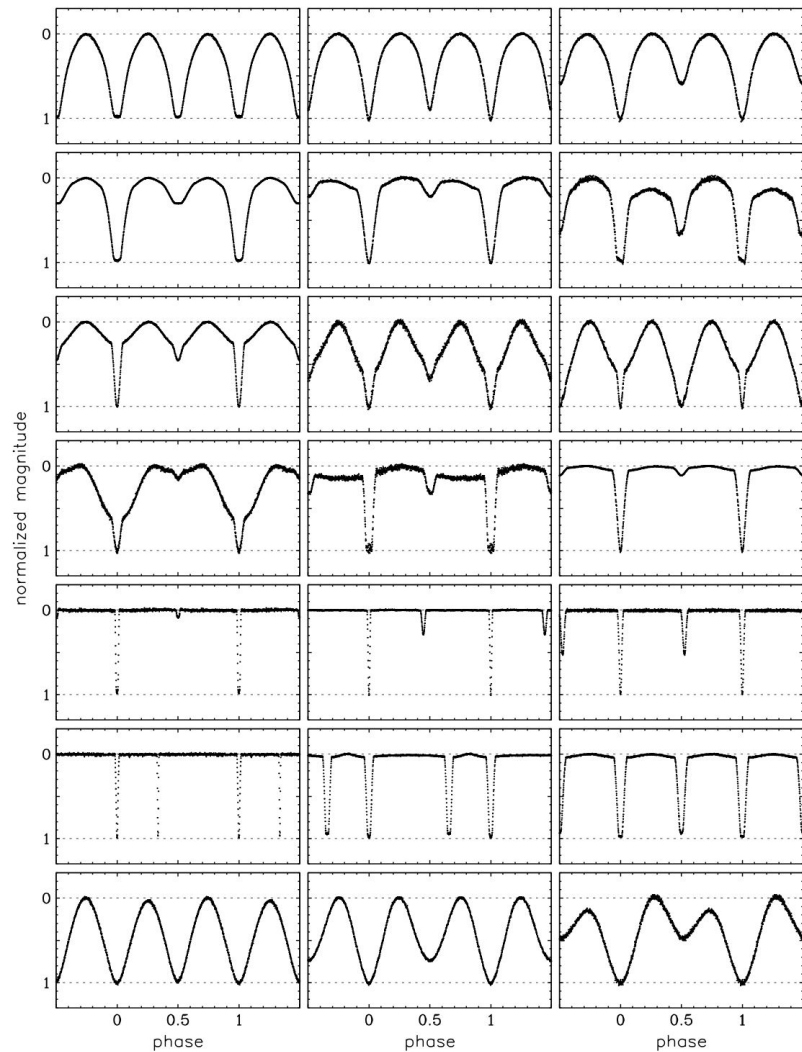
Rimoldini et al. 2023, A&A, 674, 14, 12.4 milionu proměnných objektů

Pozor na zdroje statistik

Zákrytové dvojhvězdy

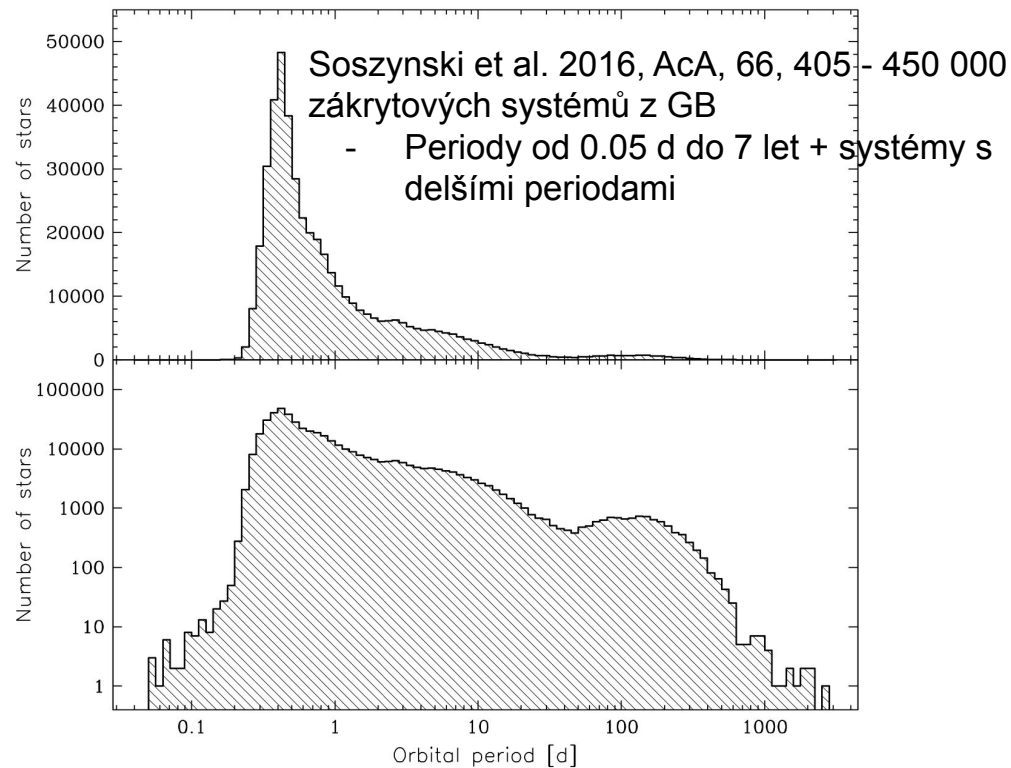
Systém dvou hvězd jejichž dráha je vhodně orientována tak, že z pohledu pozorovatele dochází k zákrytům jednotlivých složek systému





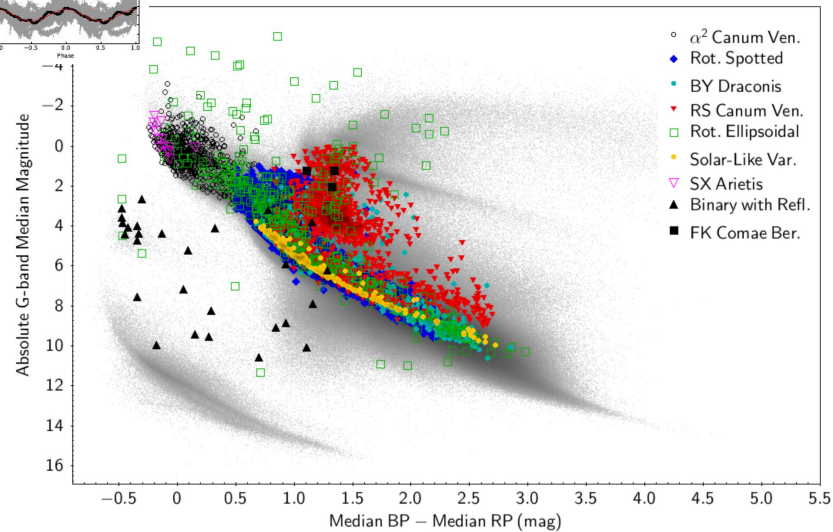
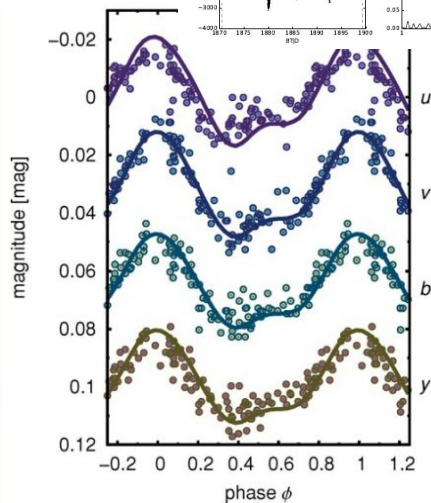
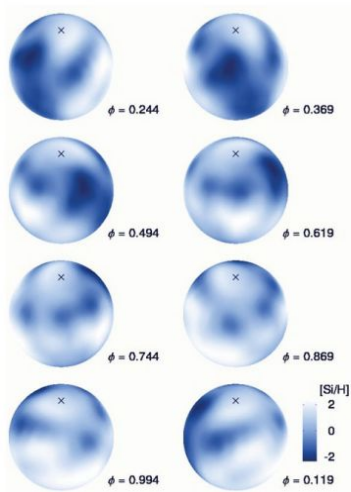
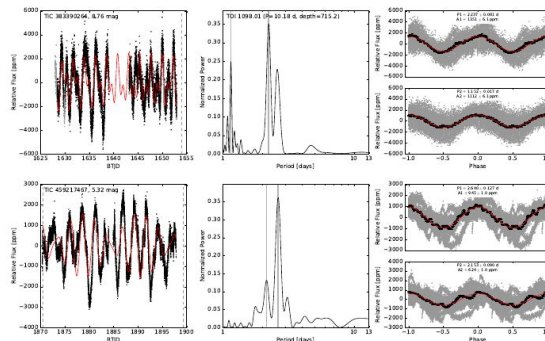
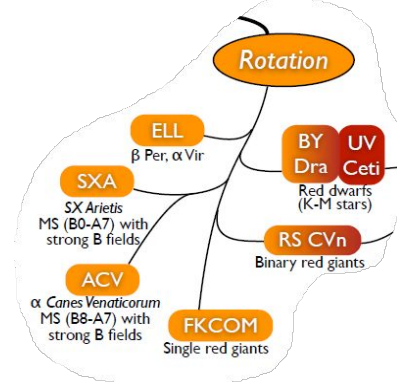
	Kepler	ASAS	OGLE
EA	52	25	68
EB	7	26	26
EW	25	49	6

Statistiky silně závisí na kvalitě dat a jejich časové základně

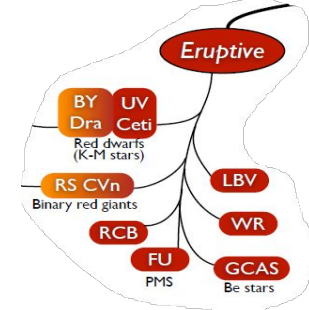


Rotační proměnné

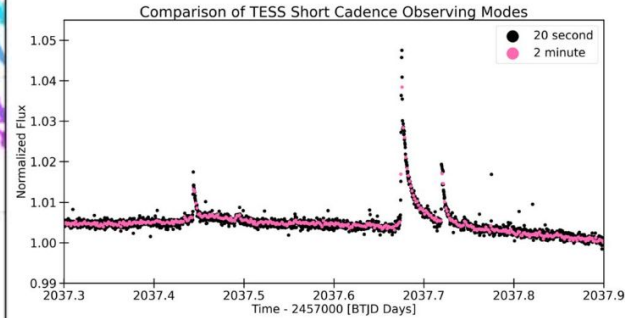
Změny dány rotací hvězdy v kombinaci s povrchovými anomáliemi (skvrny různé teploty a/nebo chemického složení), asférickým tvarem hvězdy (rychle rotující hvězdy)



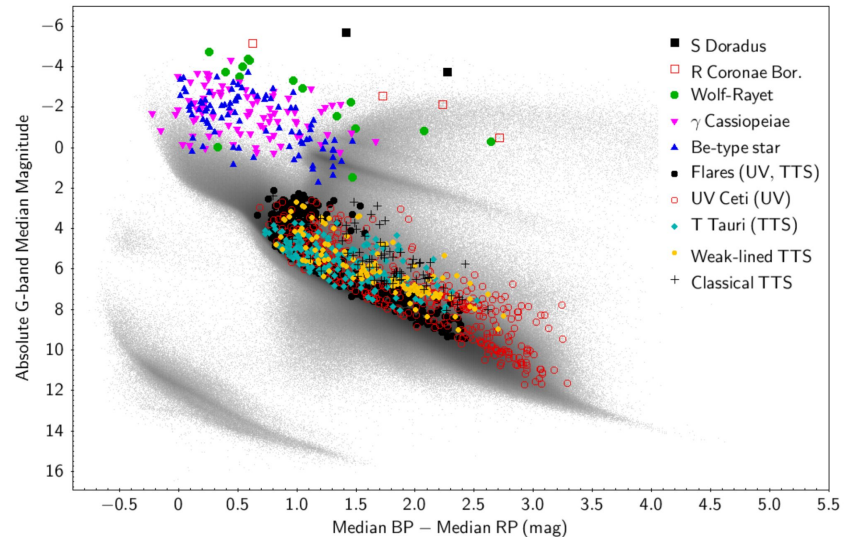
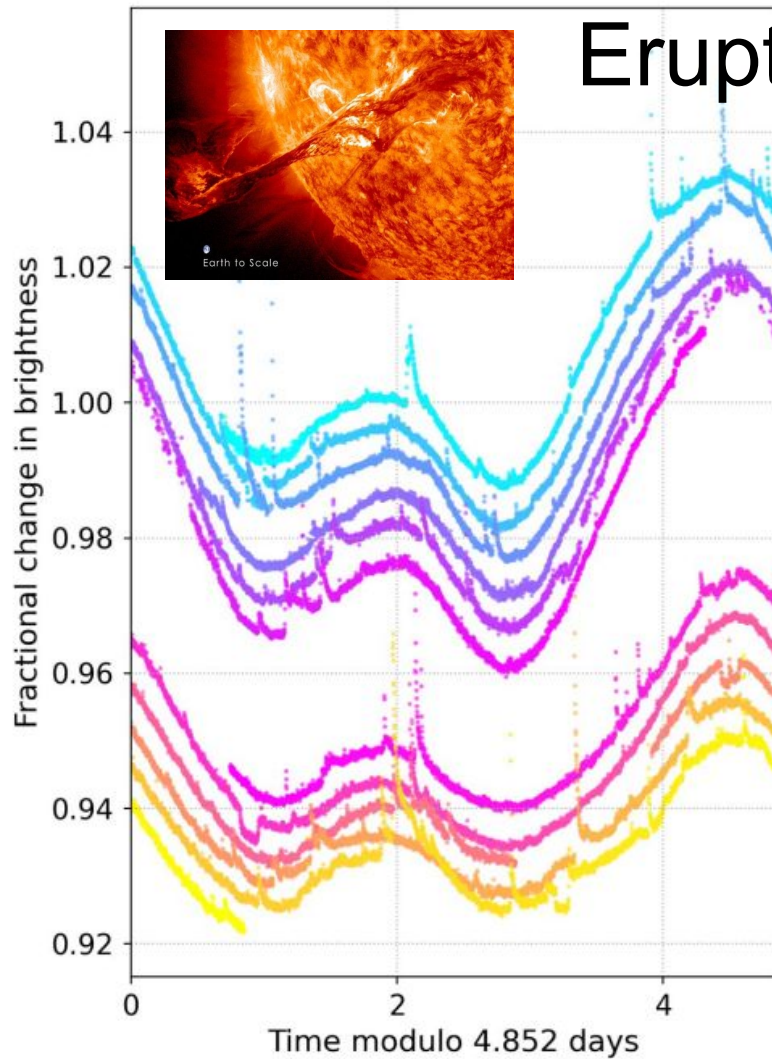
Eruptivní proměnné



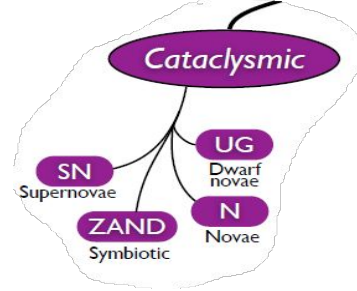
Vida et al. 2017, ApJ, 841, 124



Náhlé uvolnění energie
díky interakcím v
magnetických polích

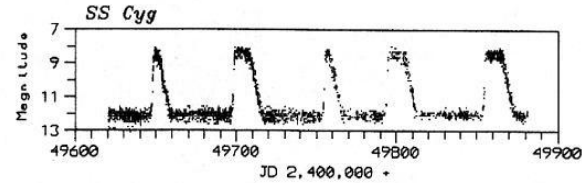


Kataklyzmické proměnné

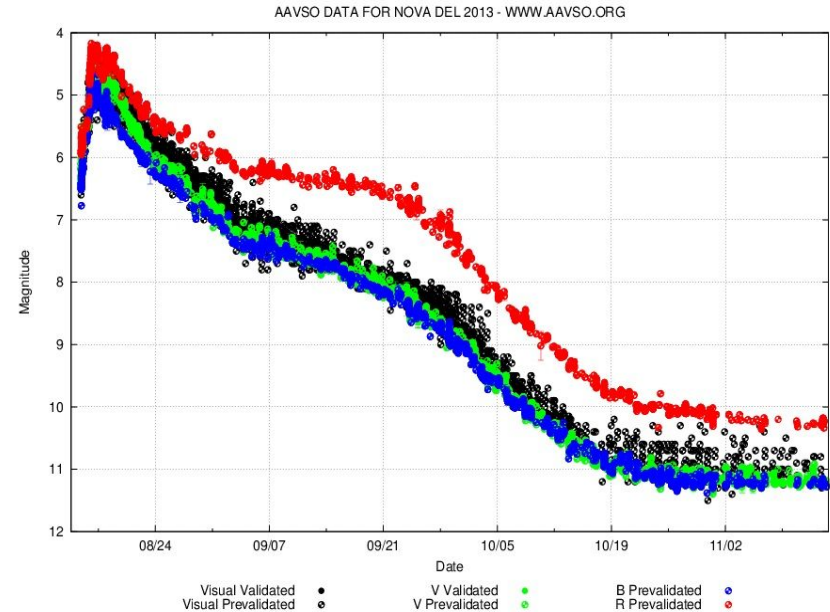
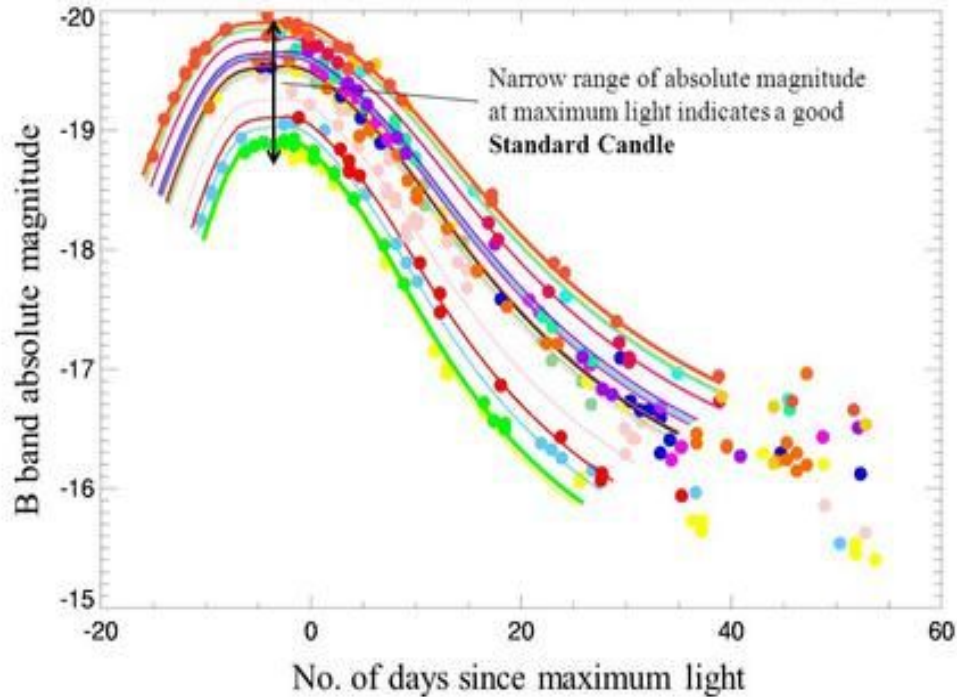


Zjasnění při výbuchu nov/supernov

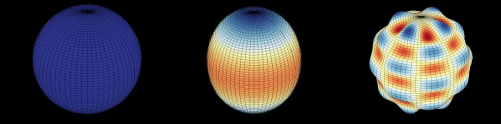
- Původ v akreci materiálu nebo splnutí hvězd



Some examples of Type I supernova light curves

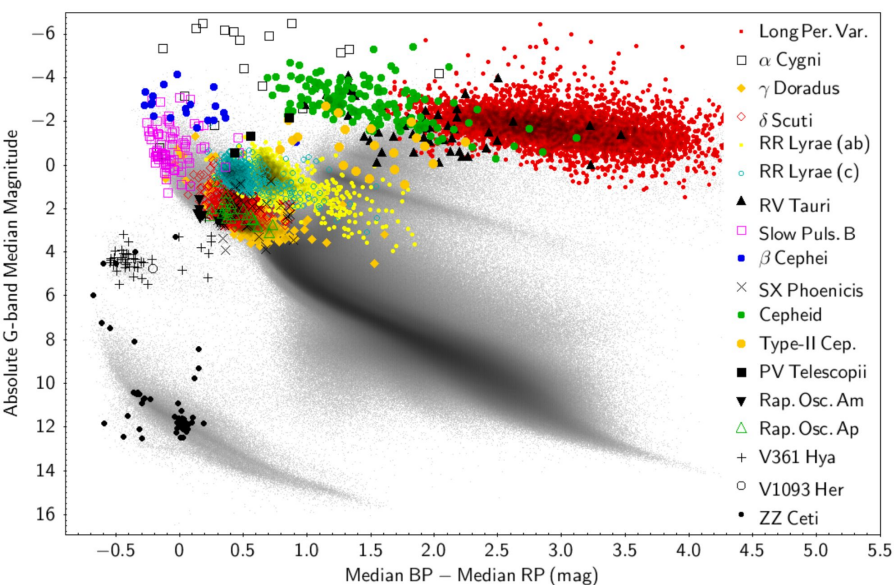
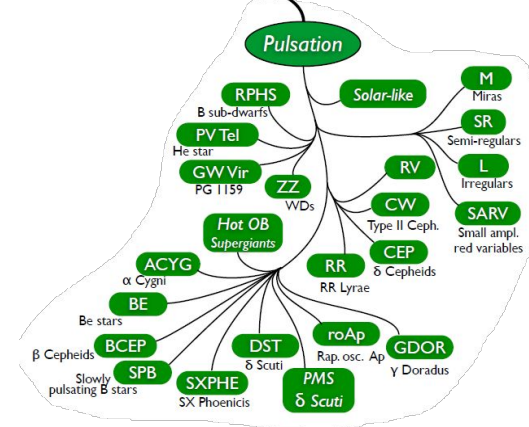
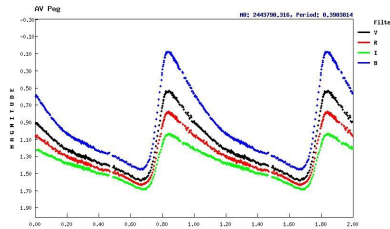
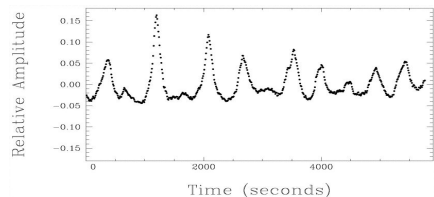


“Standardní” svíčky



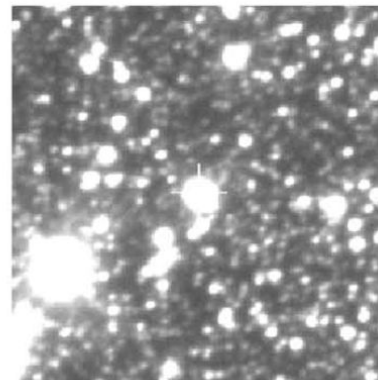
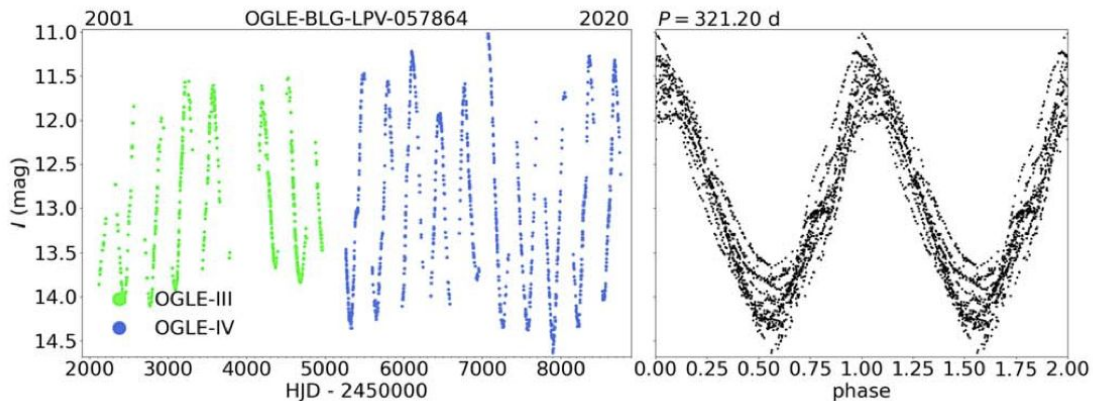
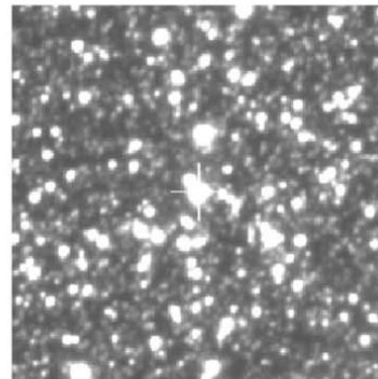
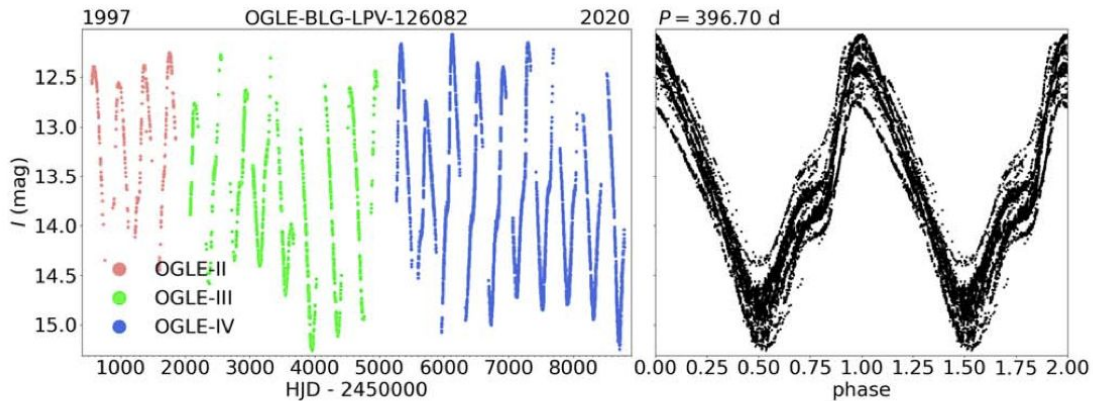
Pulzující proměnné

Změny jasnosti díky změně rozměrů (změna poloměru a teploty) a tvaru hvězd (neradiální pulzace)



Name	Approx. Periods	Discovery/Definition
Mira variables	100 - 1000 d	Fabricius (1596)
Semiregular (SR) variables	20 - 2000 d	Herschel (1782)
δ Cephei stars	1 - 100 d	1784, Pigott, Goodricke (1786)
RR Lyrae stars	0.3 - 3 d	Fleming (1899)
δ Scuti stars	0.3 - 6 h	Campbell & Wright (1900)
β Cephei stars	2 - 7 h	Frost (1902)
ZZ Ceti stars (DAV)	2 - 20 min	1964, Landolt (1968)
GW Virginis stars (DOV)	5 - 25 min	McGraw et al. (1979)
Rapidly oscillating Ap (roAp) stars	5 - 25 min	1978, Kurtz (1982)
V777 Herculis stars (DBV)	5 - 20 min	Winget et al. (1982)
Slowly Pulsating B (SPB) stars	0.5 - 3 d	Waelkens & Rufener (1985)
Solar-like oscillators	3 - 15 min	Kjeldsen et al. (1995)
V361 Hydrae stars (sdBVr)	2 - 10 min	1994, Kilkeny et al. (1997)
γ Doradus stars	0.3 - 1.5 d	1995, Kaye et al. (1999)
Solar-like giant oscillators	1 - 18 hr	Frandsen et al. (2002)
V1093 Herculis stars (sdBVs)	1 - 2 hr	Green et al. (2003)
Pulsating subdwarf O star (sdOV)	1 - 2 min	Woudt et al. (2006)

Pulzující proměnné



Miridy z OGLE připomínající rotační proměnnost

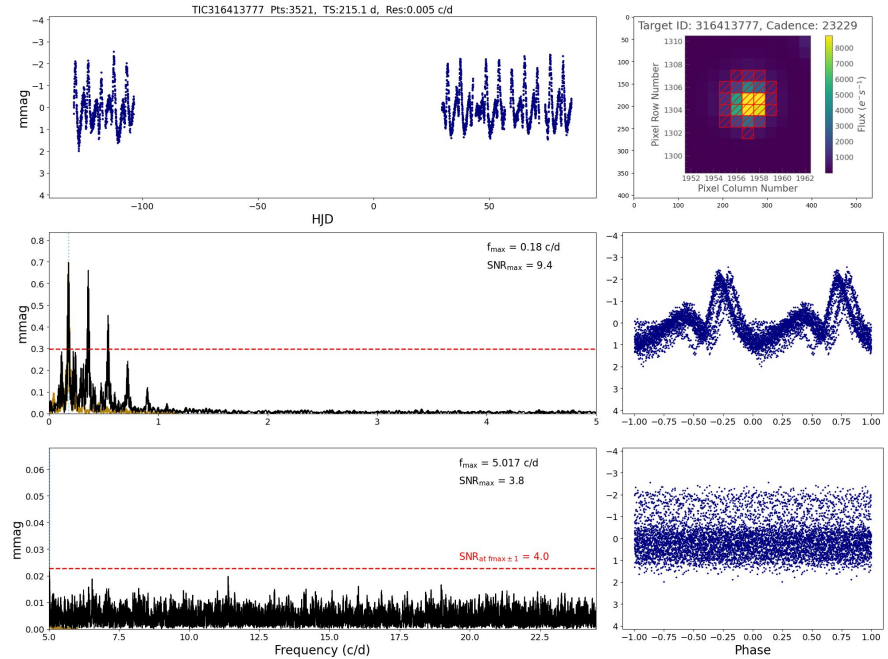
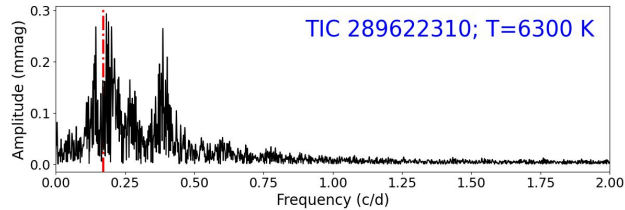
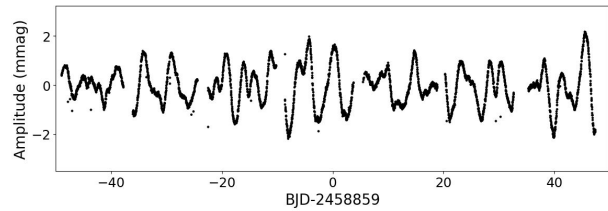
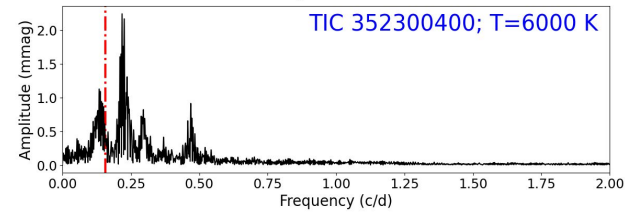
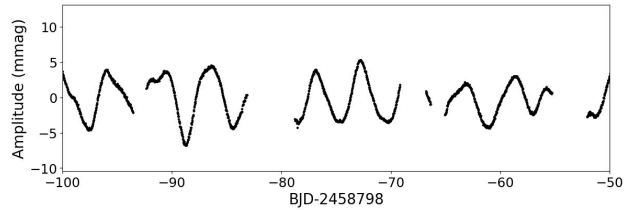
Zajímavé články:

<https://ui.adsabs.harvard.edu/abs/2023A%26A...674A..14R/abstract> (GAIA variables)

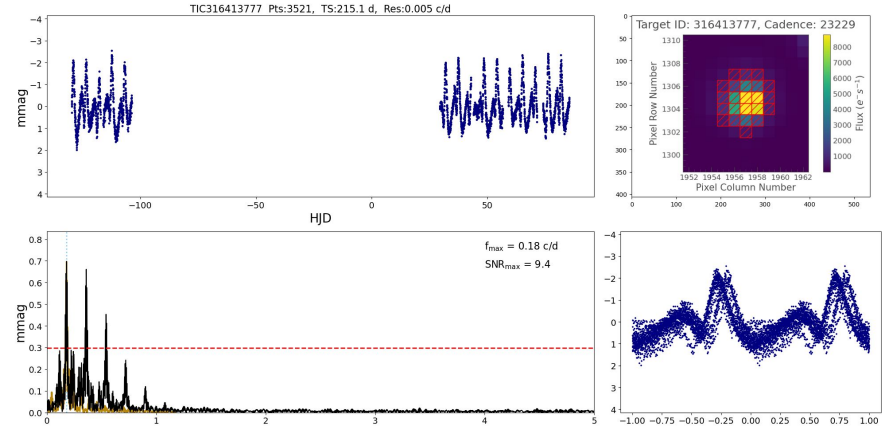
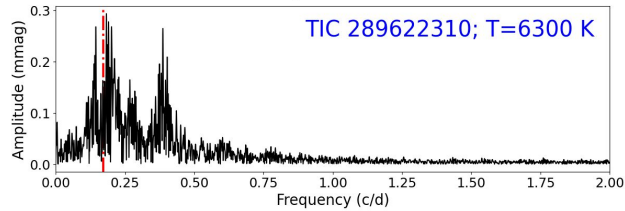
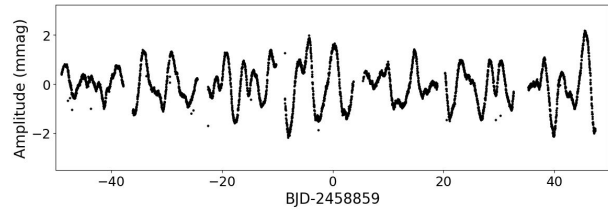
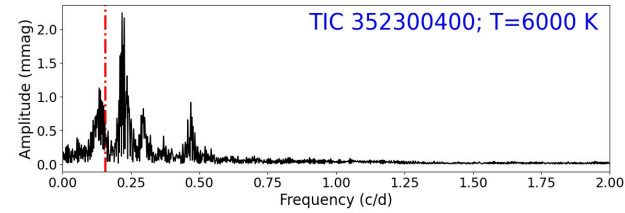
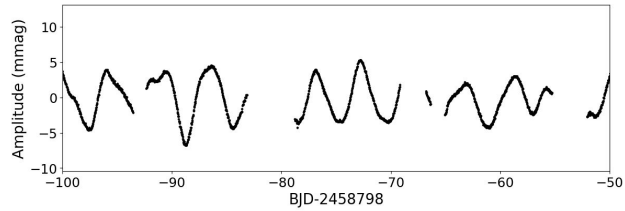
<https://ui.adsabs.harvard.edu/abs/2016AcA....66..405S/abstract> (OGLE binaries)

<https://ui.adsabs.harvard.edu/abs/2018MNRAS.477.3145J/abstract> (ASAS-SN)

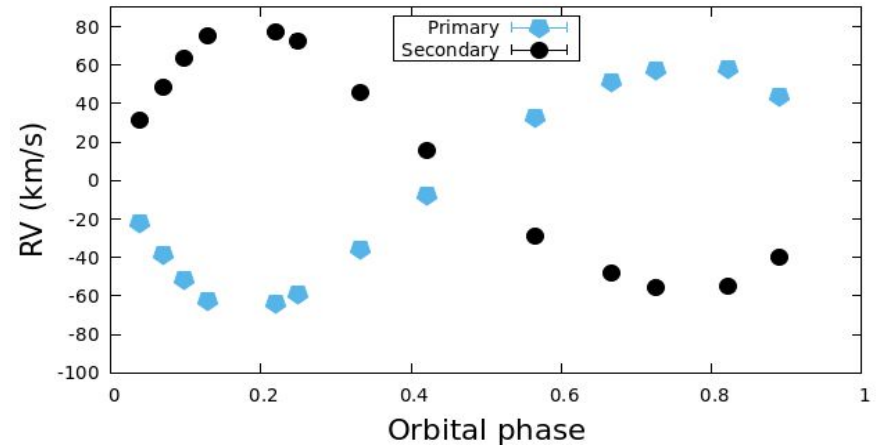
Klasifikace?



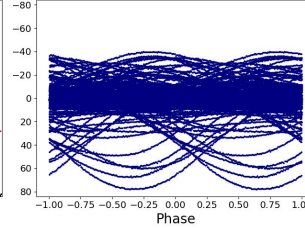
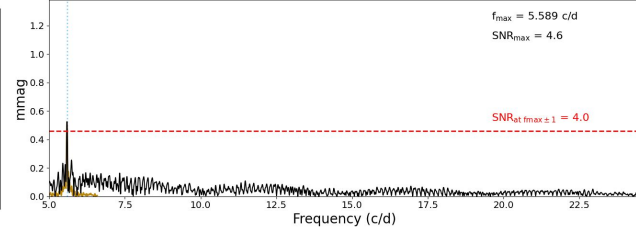
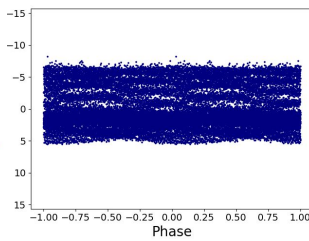
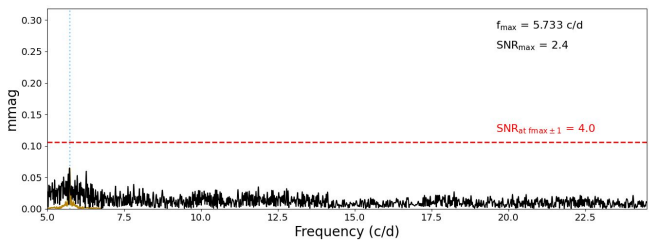
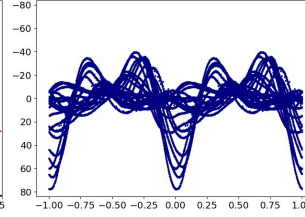
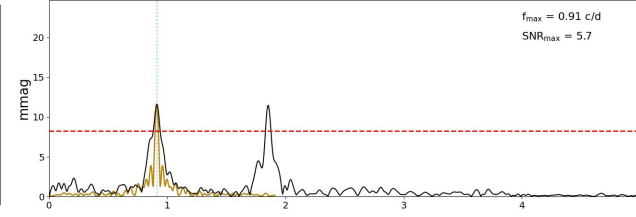
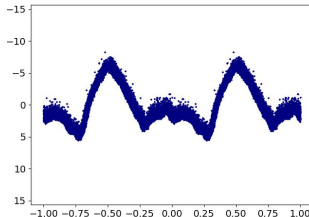
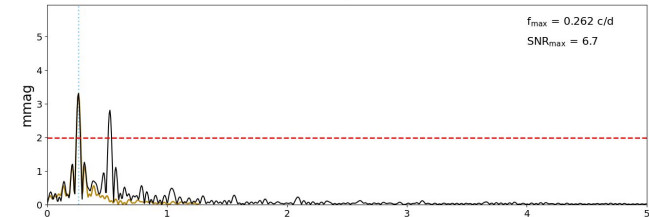
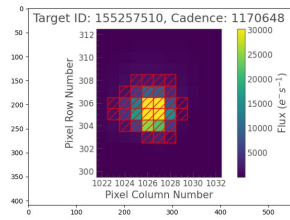
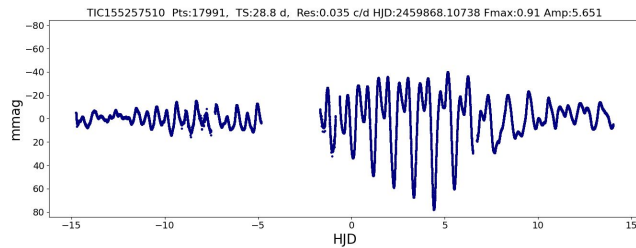
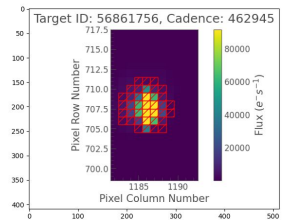
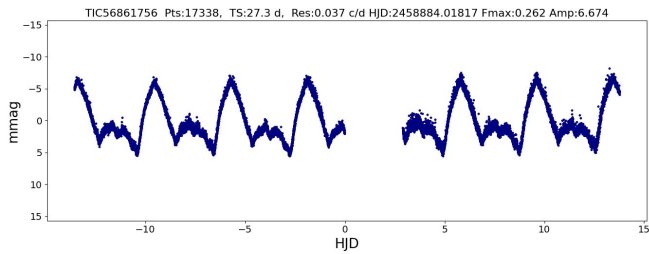
Klasifikace?



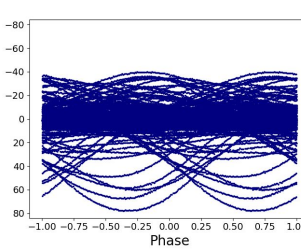
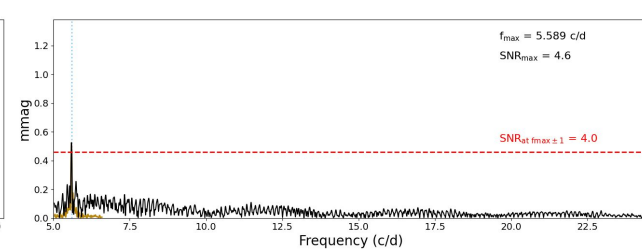
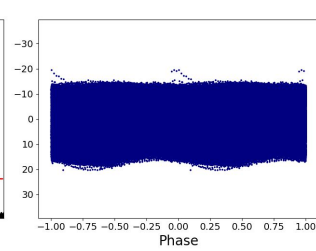
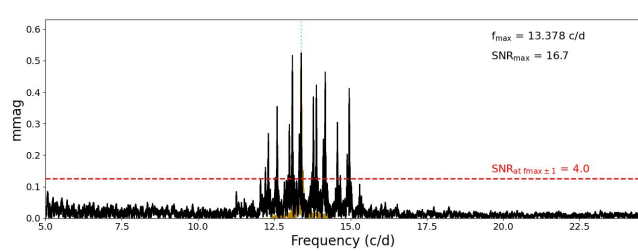
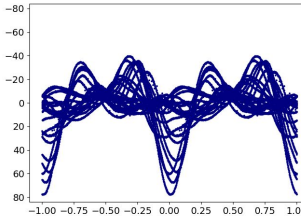
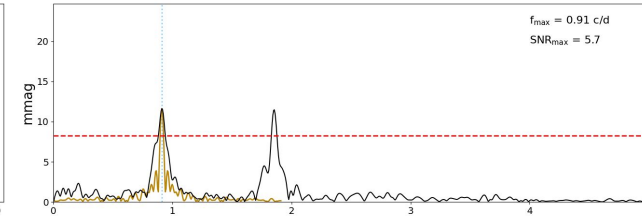
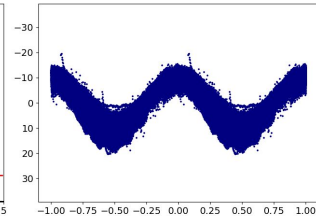
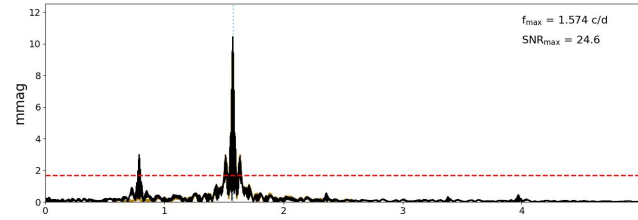
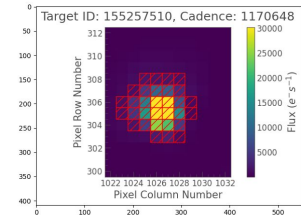
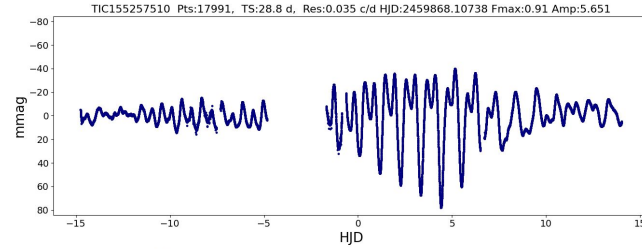
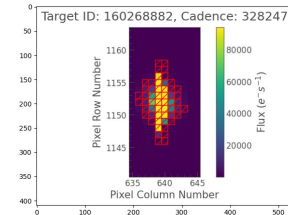
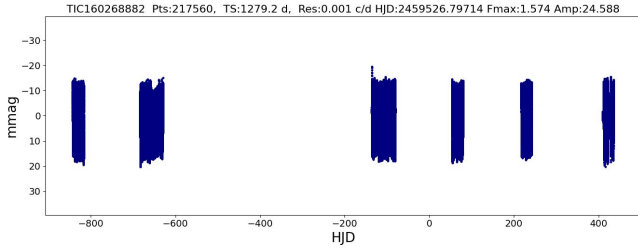
TIC 316413777 (HD 109495)



Klasifikace?



Klasifikace?



Klasifikace?

