Morphological classification of eclipsing binary stars using computer vision methods

M. Gabdeev*, Š. Parimucha, Y. Markus , M. Vaňko , P. Gajdoš

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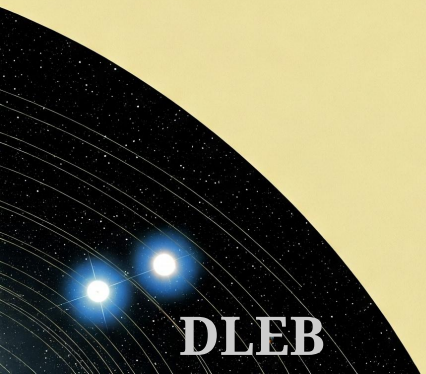

The task!

Why automation?

Survey	Number of Eclipsing Binary Candidates	Notes
Gaia	~2,184,47	Gaia Data Release 3 (GDR3)
OGLE	~525,000	OGLE-IV ~450,600 towards the Galactic Bulge; ~75,400 in the Magellanic Clouds
Zwicky Transient Facility	~350,000	ZTF Data Release 2 (DR2)
ASAS-SN	~136,600	Combination of known and new EA, EB, and EW types
TESS	~4,600 - ~6,700	TESS primary mission (Sectors 1-26) / Citizen Science

The Vera C. Rubin observatory with Legacy Survey of Space and Time (LSST) expects ~24 millions of new candidates (Prša, 2011)

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The task!

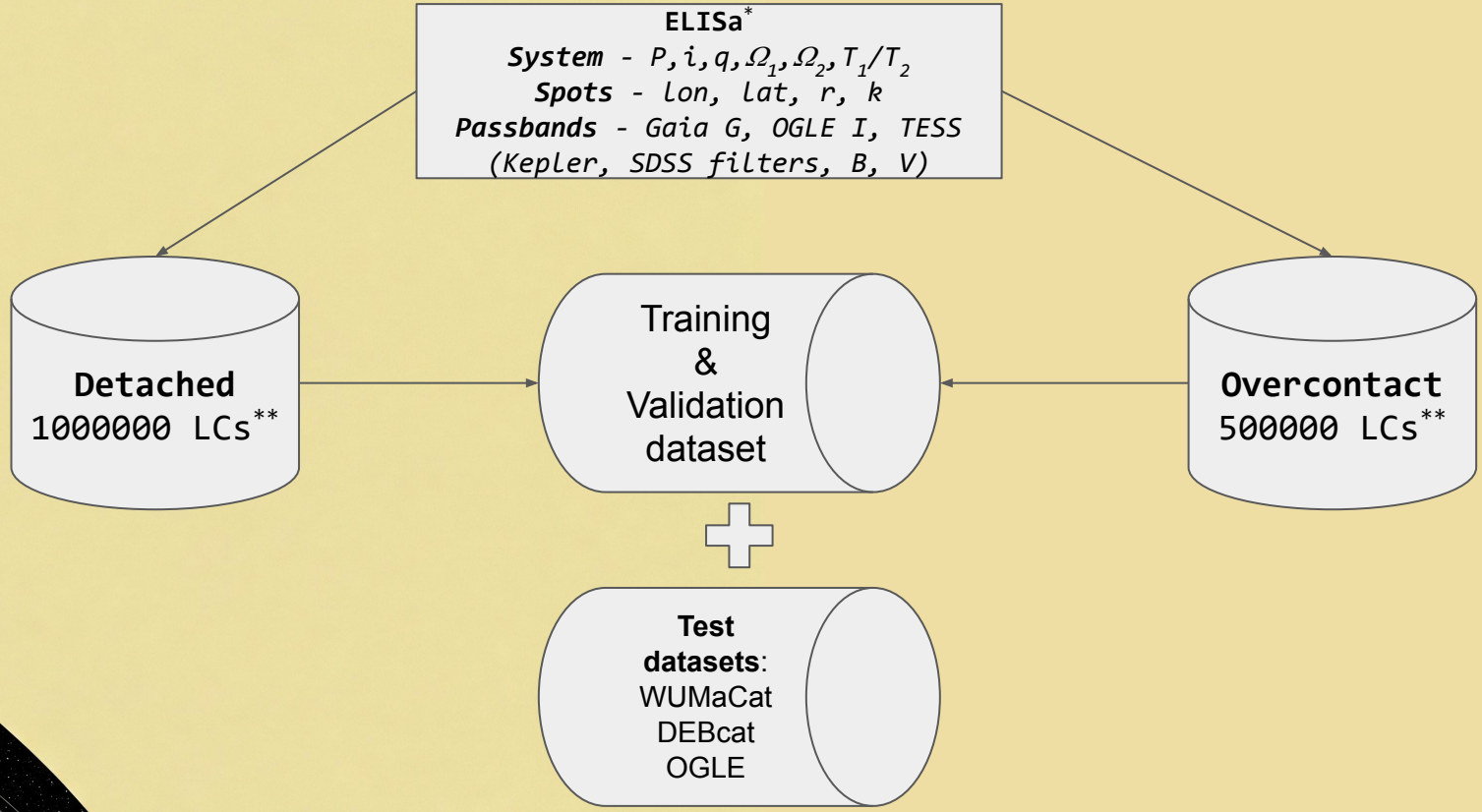
The perspective of systems' parameters determination

We are looking from point of view of creating physical models using ELISa and here two potentials Ω_1 and Ω_2 play the main role in dividing to classes.

Detached = Semi-detached	Overcontact
$\Omega_1 \neq \Omega_2$	$\Omega_1 = \Omega_2 = \Omega$

Two classes!

The dataset!



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*https://github.com/mikecokina/elisa
**https://github.com/astroupjs/EBML

The transformation!

Inspired by Doppler tomography, we used transformation of LCs into polar coordinates plus hexbin representation. The final transformation formula looks like:

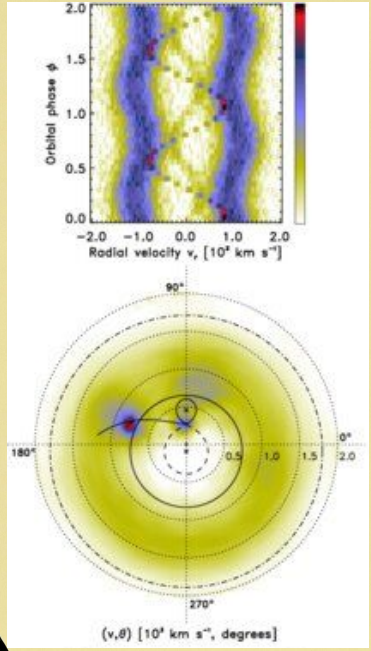
Equally distributed normalised fluxes
$[nf_1, nf_2, nf_3, \ldots nf_{100}]$

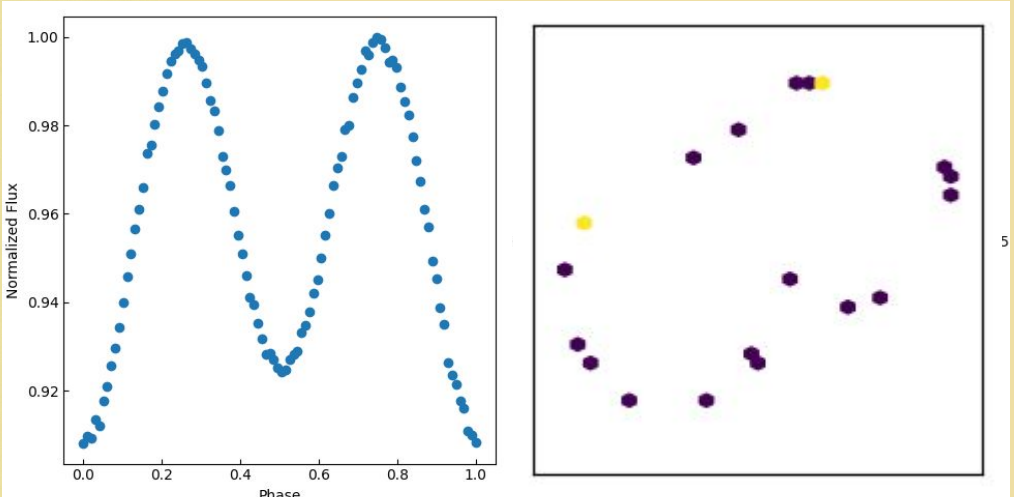
$$x = r \times \cos(\alpha)$$
$$y = r \times \sin(\alpha)$$

$$\alpha = \varphi \times 360 - 90$$

$$r = r_{max} - (r_{max} - r_{min}) * (F_{max} - F) / (F_{max} - F_{min})$$

$$r_{max} = 1,\ r_{min} = 0.2$$





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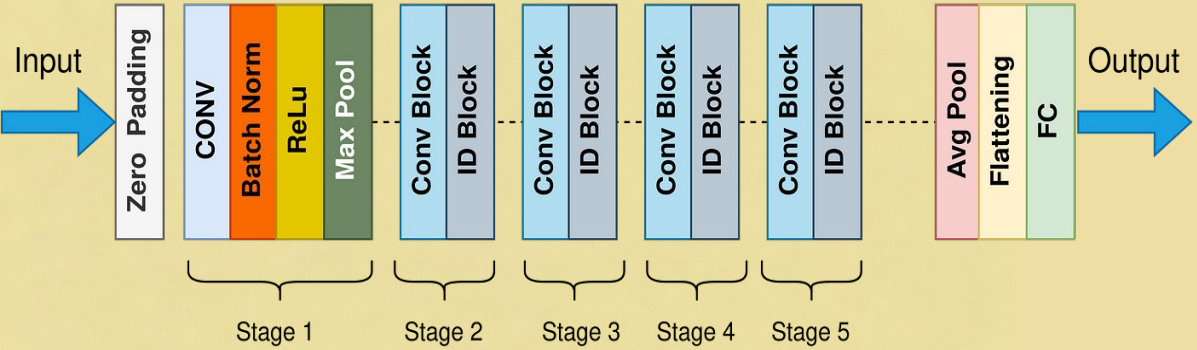
The method!

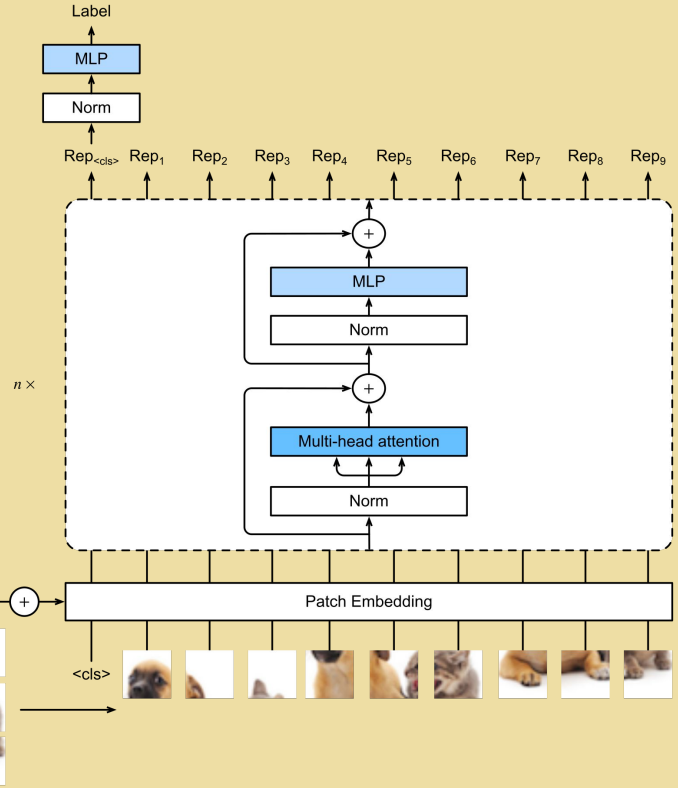
ResNet50 Model Architecture



Vanishing gradients
Skip connections

Global attention algorithm

ViT Model Architecture



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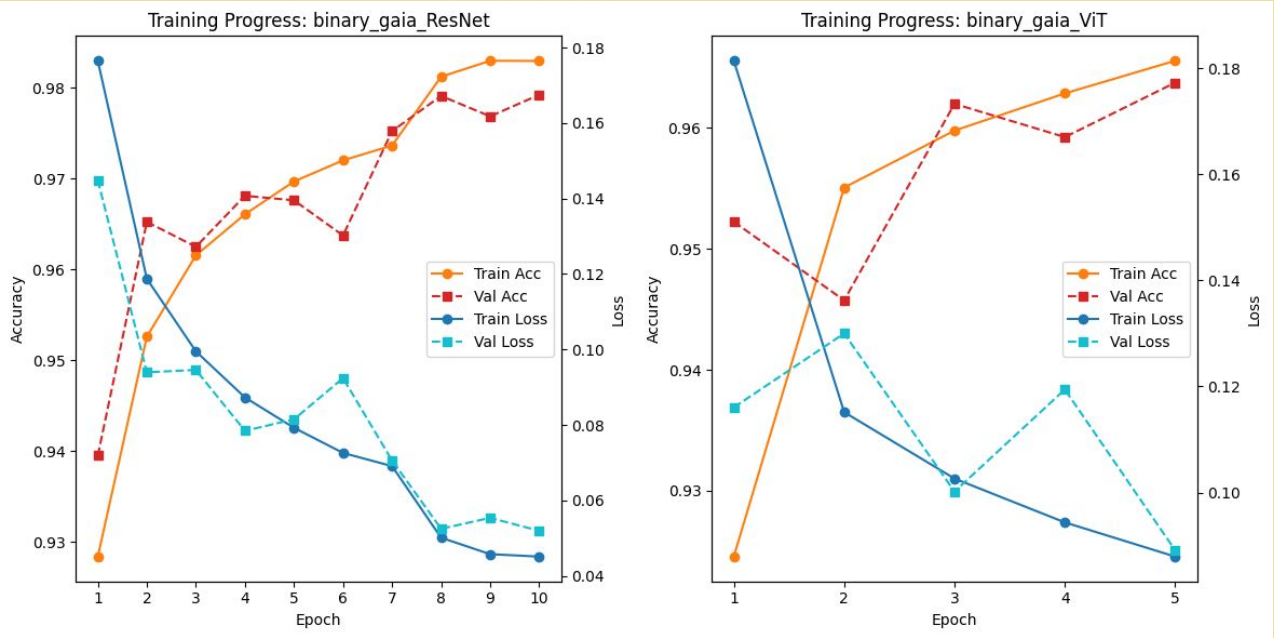
The training!

- In total we trained **18** models*
- GPU - RTX 4070 **12GB**, RAM - **64GB**, CPU - AMD Ryzen 9



*https://github.com/astroupjs/EBML

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The results!

Predicted accuracy of models for different passbands tested on the validation datasets.

	Gaia G	I	$TESS$
ResNet50			
binary	0.98	0.98	0.98
detached_spot	0.94	0.92	0.93
overcontact_spot	0.88	0.77	0.87
vit_base_patch16_224			
binary	0.96	0.98	0.98
detached_spot	0.92	0.89	0.91
overcontact_spot	0.83	0.75	0.84

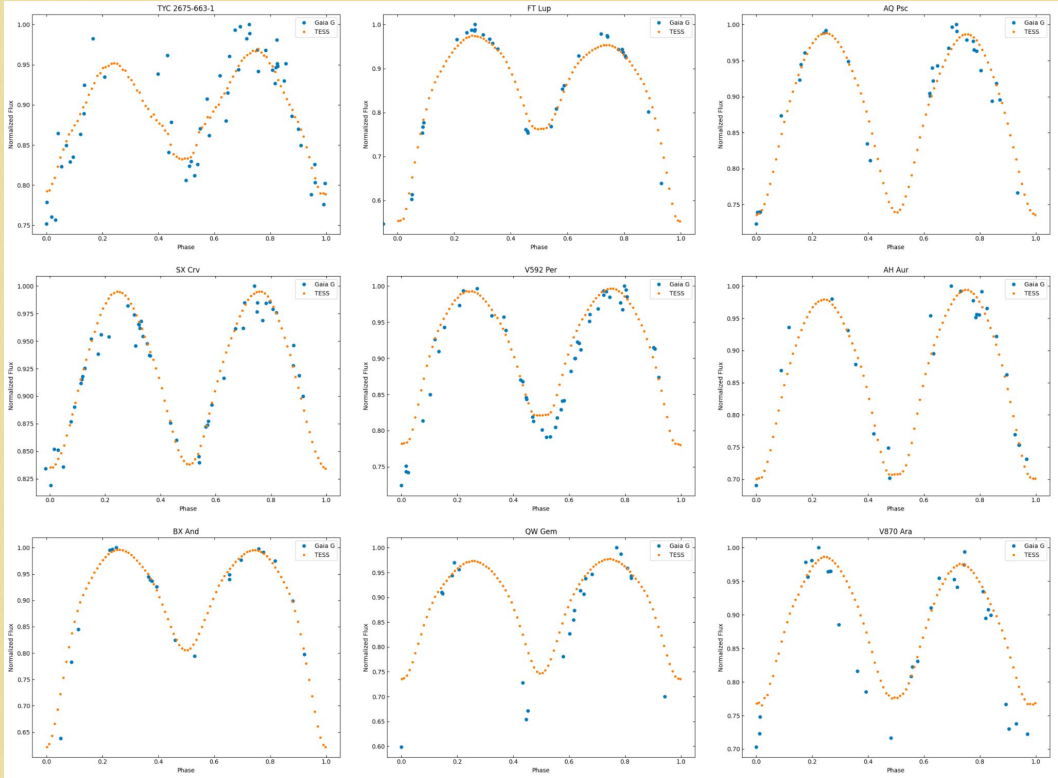
The results!

Optimistic

WUMaCat(90) & DEBcat(52) for *TESS* passband - 100% accuracy for both ResNET50 and ViT
for *Gaia* passband - 100% for detached, 3 and 8 errors for overcontact systems

Table 3
Binary classification metrics for the test datasets. Upper section — the results for DEBCat detached objects as Negatives, WUMaCat overcontact objects as Positives. Lower section — 200 random OGLE-IV objects with the same encoding.

Model	Accuracy	Precision	Recall	F1	TN	FP	FN	TP
DEBcat and WUMaCat								
tess_res	1.00	1.0	1.00	1.00	52	0	0	90
tess_vit	1.00	1.0	1.00	1.00	52	0	0	90
gaia_res	0.98	1.0	0.97	0.98	52	0	3	87
gaia_vit	0.94	1.0	0.91	0.95	52	0	8	82
OGLE-IV								
i_res	0.90	0.81	0.96	0.88	107	17	3	73
i_vit	0.87	0.77	0.95	0.85	102	22	4	72
gaia_res	0.97	0.95	0.97	0.96	120	4	2	74
gaia_vit	0.94	0.90	0.96	0.93	116	8	3	73



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The results!

Semi-optimistic

200 random OGLE objects, 124 detached and 76 overcontact systems, LCs in I and Gaia G passbands, OGLE classification as a ground truth.

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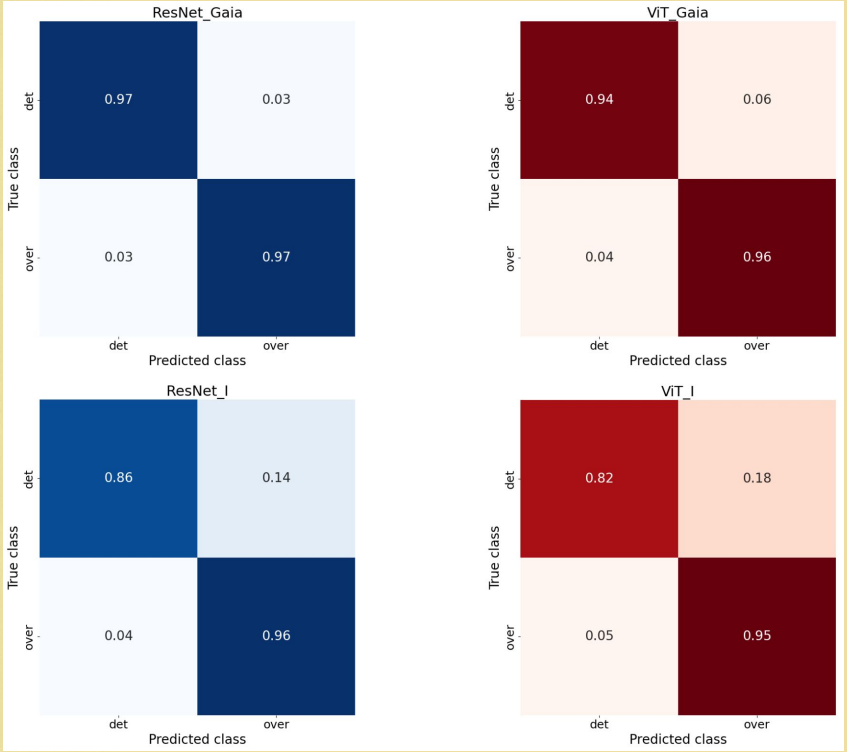

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The results!

Negative

WUMaCat has information about spots, DEBcat has not.
We used two approaches: visual examination of TESS LCs and literature search (only 19 objects)

Table 4

Spot detection classification metrics for objects from DEBcat and WUMaCat. Upper section — the results for overcontact objects with no spots as Negatives, with spots as Positives. Lower section — for detached objects with the same encoding.

Model	Acc	Prec	Recall	F1	TN	FP	FN	TP	AUC
Overcontact									
gaia_resnet	0.60	0.63	0.52	0.57	30	14	22	24	0.64
tess_resnet	0.50	0.51	0.83	0.63	7	37	8	38	0.59
gaia_vit	0.53	0.52	1.00	0.69	2	42	0	46	0.60
tess_vit	0.49	0.50	0.76	0.60	9	35	11	35	0.6
Detached									
gaia_resnet	0.63	0.42	0.29	0.34	28	7	12	5	0.53
tess_resnet	0.62	0.43	0.59	0.50	22	13	7	10	0.54
gaia_vit	0.67	0.00	0.00	0.00	35	0	17	0	0.51
tess_vit	0.63	0.00	0.00	0.00	33	2	17	0	0.36

Positive - with spots, Negative - without spots

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Conclusions and future plans

1. We created a dataset to use in future works which is publicly available
2. We developed the transformation that showed excellent results in *TESS* and *Gaia G* passbands, and appropriate results in OGLE *I* for morphological classification
3. ResNet50 is faster and more precise than ViT for this task
4. OGLE inner classification is robust and show no discrepancy with results of our classification
5. OGLE *I* classification and spots detecting should be improved
6. The results of the work are published in Astronomy and Computing, Volume 53, id.100998

- Classify all EB candidates from Gaia DR3 using our ResNET50 models (done)
- Work on outlier removal to improve OGLE *I* smoothing (done)
- Start creating models to predict physical parameters from a light curve using deep learning methods. (done)

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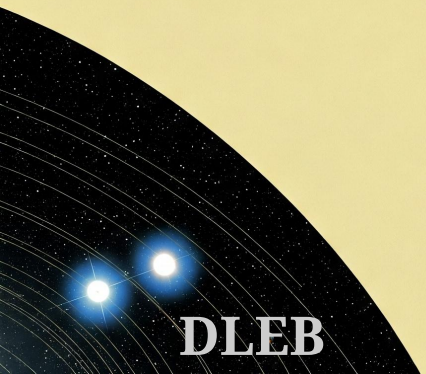
Thank you for attention!

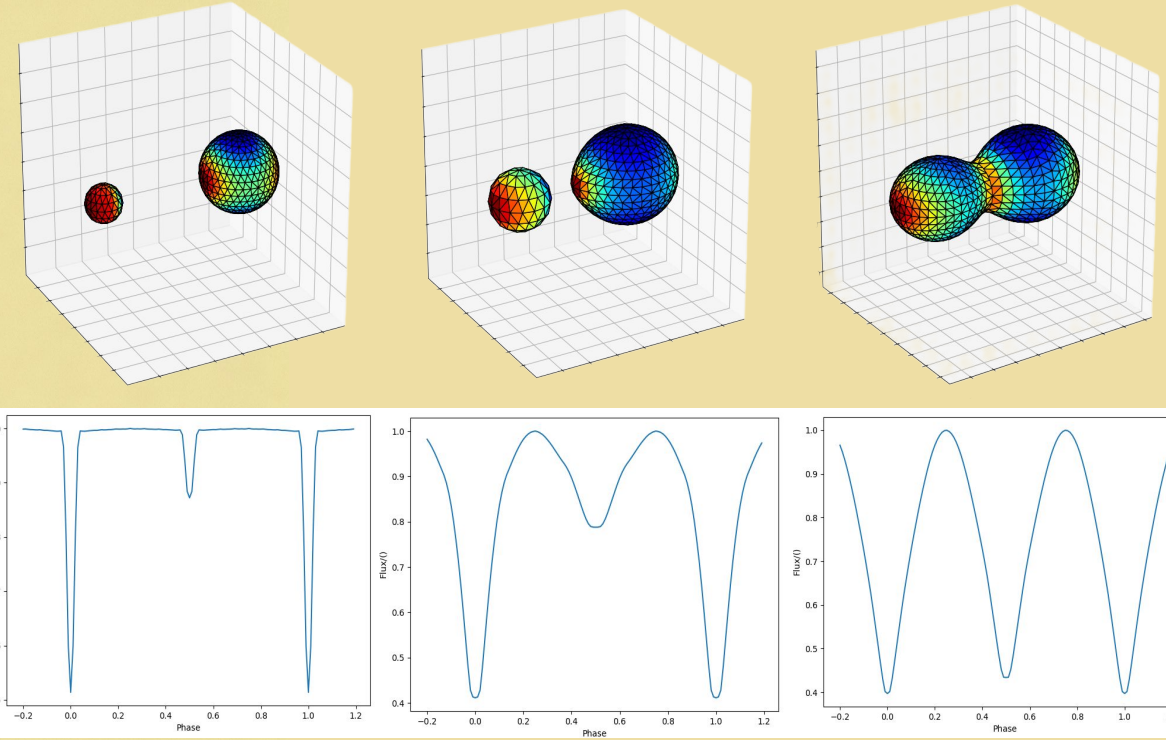


Eclipsing binaries

Classification of EB

♦ Based on LCs shape
Algol, β Lyr, W UMa

♦ By Kopal, 1959 based on Roche lobe:
Detached, semi-detached, contact or overcontact



Examples of detached, semi-detached and overcontact EBs models (top, row from left) and corresponding LCs (bottom, row from left).

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