12 years of *"CRÉME de la crème"* of eclipsing binaries

Krzysztof Hełminiak
NCAC Toruń
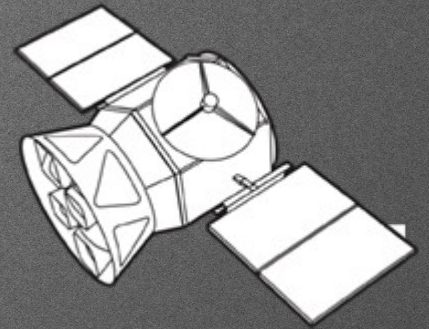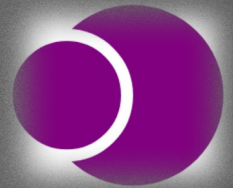
Outline

- Detached Eclipsing Binaries (DEBs)
- CRÉME – current status
- Satellite photometry – current status
- Highlights of recent (2022 - …) results
- Next steps and future plans

Detached Eclipsing Binaries (DEBs)

▪ DEBs that are also double-lined spectroscopic (SB2) allow to directly obtain absolute values of crucial stellar parameters.

▪ We get masses, radii, temperatures, distances, age, etc...

▪ DEBs are useful (for example) for:

   ▪ Testing stellar structure and evolution models
   ▪ Testing stellar formation scenarios
   ▪ Studying dynamical and tidal interactions
   ▪ Measuring precise and accurate distances
   ▪ Improving calibrations with new high-quality data
   ▪ Characterizing exoplanets
   ▪ **Finding and characterizing stars in rare stages of evolution**
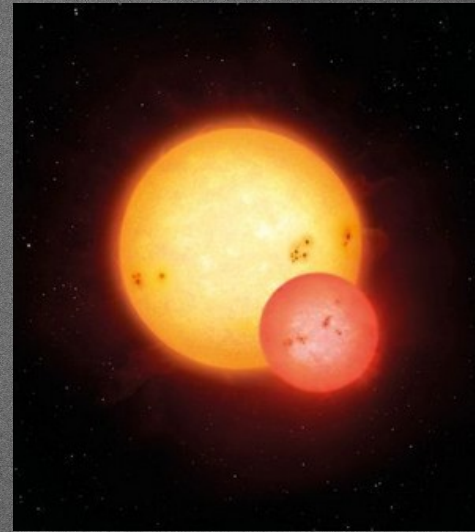
Detached Eclipsing Binaries (DEBs)

- 325 binaries with very precise (< 2%) parameters

- Large fraction of them has incomplete information

- Under-populated regions M/R and HR diagrams
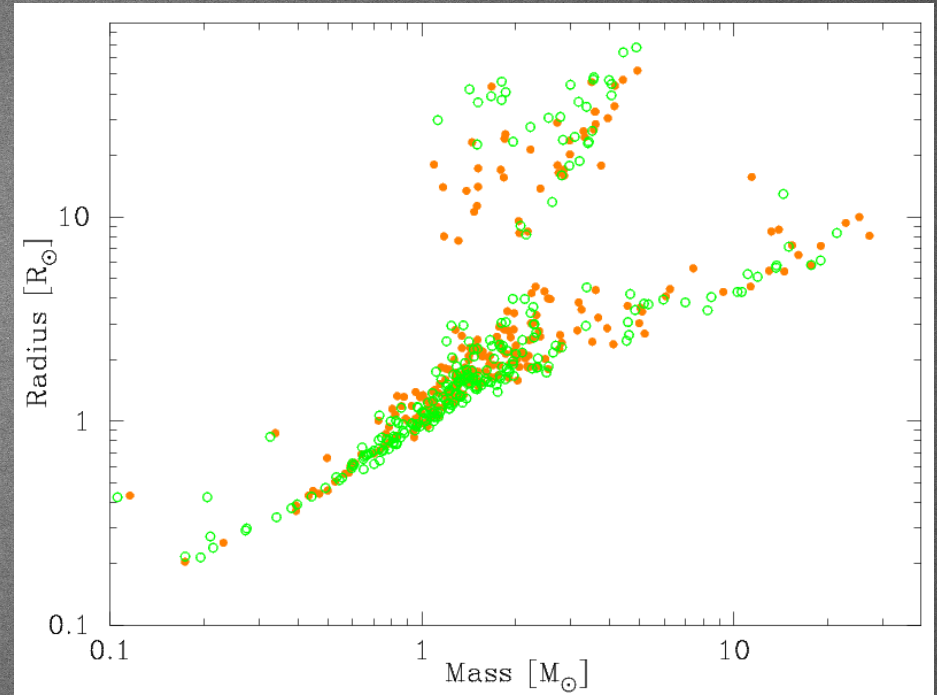
Southworth (2015)

The CRÉME project

- **C**omprehensive **R**esearch with **É**chelles on the **M**ost interesting **E**clipsing binaries

- Identification of new examples of rare, poorly studied or otherwise interesting DEBs

- Precise characterization of the studied systems, including: determination of masses, radii, temperatures, distances, metallicities, and ages of stars

- **High-quality spectroscopic and photometric data needed**
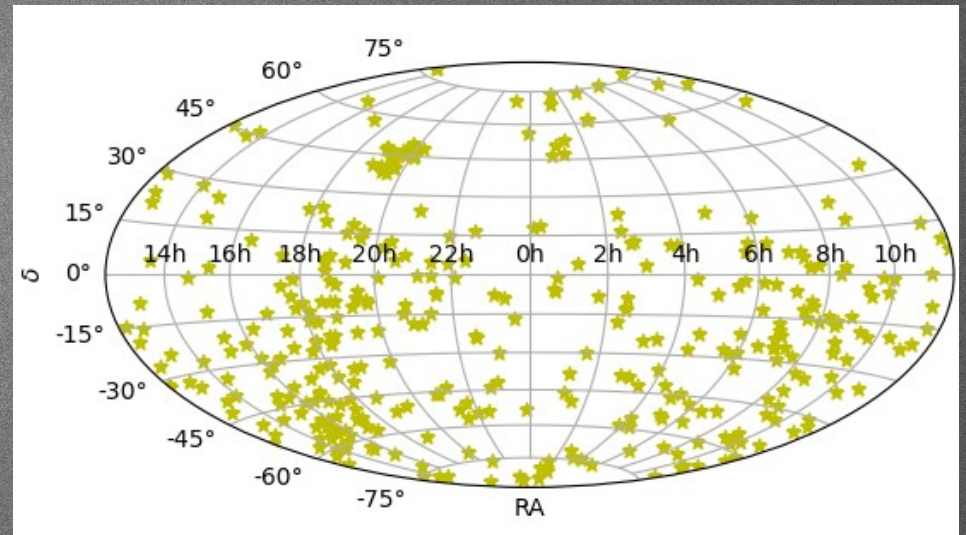
The CRÉME project statistics

- 383 targets observed (2011 - ...)
- 7000+ high-resolution spectra
- 19 spectrographs, 17 telescopes
- 300+ n of total telescope time

Tel./Spec.	Time	Tel./Spec.	Time	Tel./Spec.	Time
OAO 188cm/HIDES	87.5 n	TNG/HARPS-N	16 n	Magellan-Clay/PSF	4 n
CTIO 1.5m/CHIRON	753 h	SALT/HRS	101 h	NOT/FIES	4 n
Euler/CORALIE	40 n	ESO 3.6m/HARPS	4.5 n	OHP 1.9m/SOPHIE	3 n
MPG 2.2m/FEROS	30 n	Subaru/HDS+IRCS	4.5 n	VLT/UVES	3.5 h

Additionally: Radcliffe/GIRAFFE, AAT/UCLES, OUC-50cm/PUCHEROS, Keck I/HIRES, TNG/SARG, Hamilton/HamSpec

Archives: ESO, SOPHIE, ELODIE, KOA, APOGEE

TESS basic facts

- Launched 18.04.2018
  Observing since 24.07.2018

- Originally planed to cover 85% of the whole sky in 2 years. Towards 100% with the second extended mission.

- **Currently: sector 70 (Cycle 6)**
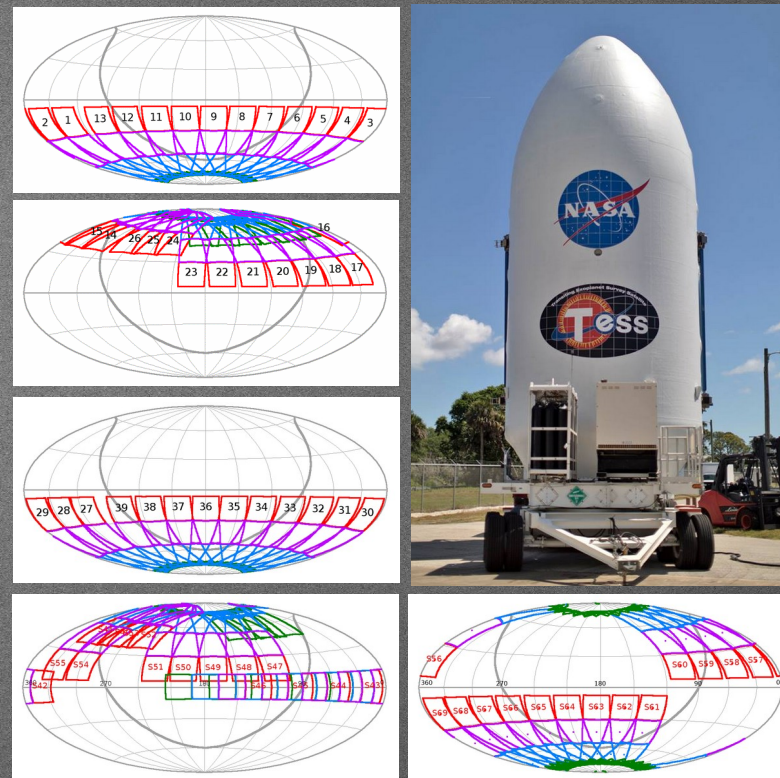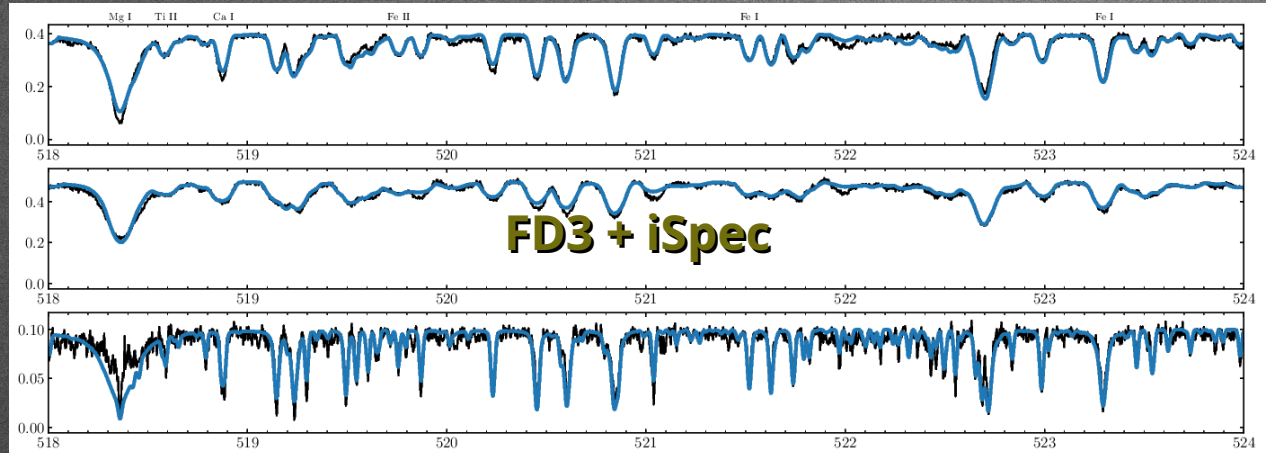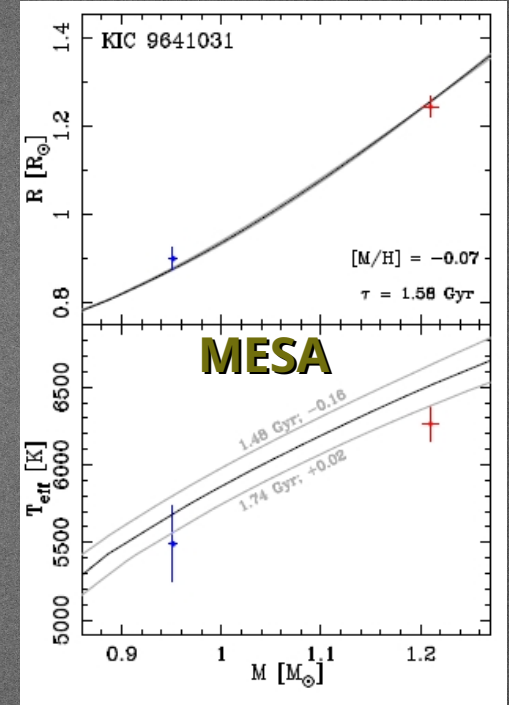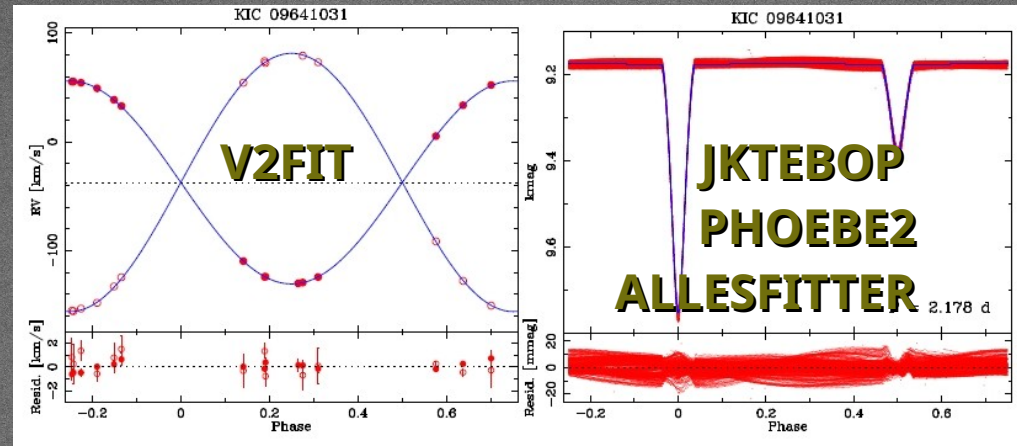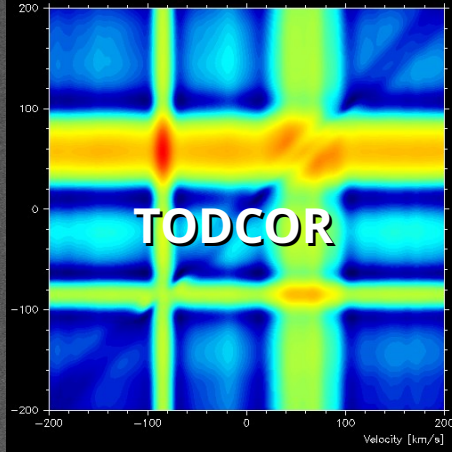
TESS GI programs of CRÉME targets

- Successful GI applications since Cycle 1
- Current status:
  - 1 sector: 80
  - 2 sectors: 109
  - 3 sectors: 42
  - 4 sectors: 24
  - 5–13 sectors: 30
  - 14-29 sectors: 13
- Additionally: *Kepler* (24) and *K2* (8) observations

TOTAL: **298** targets
(from 70 sectors)
+ FFI for ~10 targets
+12 more expected in C6

Methodology

TODCOR

V2FIT

JKTEBOP
PHOEBE2
ALLESFITTER

FD3 + iSpec
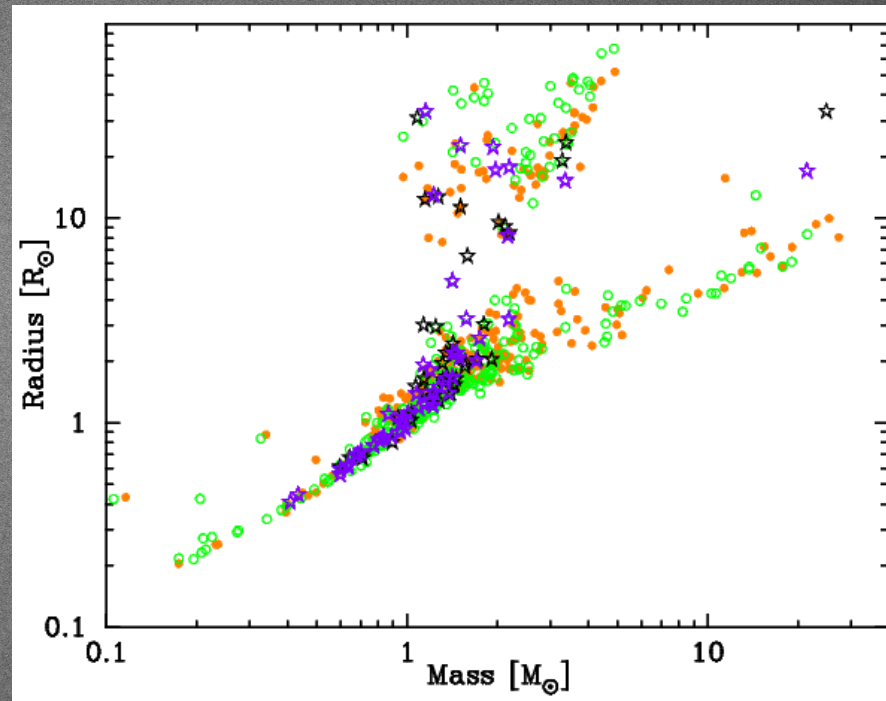
MESA
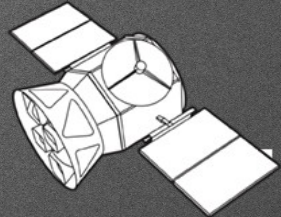
Hełminiak et al. 2021
Moharana et al. 2023

# Currently published results

- ~60 models of DEBs with CRÉME data

- 26 CRÉME targets in DEBCat

- Examples of results:
  - Low-mass stars
  - Late-type (sub-)giants
  - Pre-main sequence (PMS)
  - High-order (N>2) multiples
  - Pulsators
  - High-mass giants
  - Benchmark stars

DEBCat vs. CRÉME published

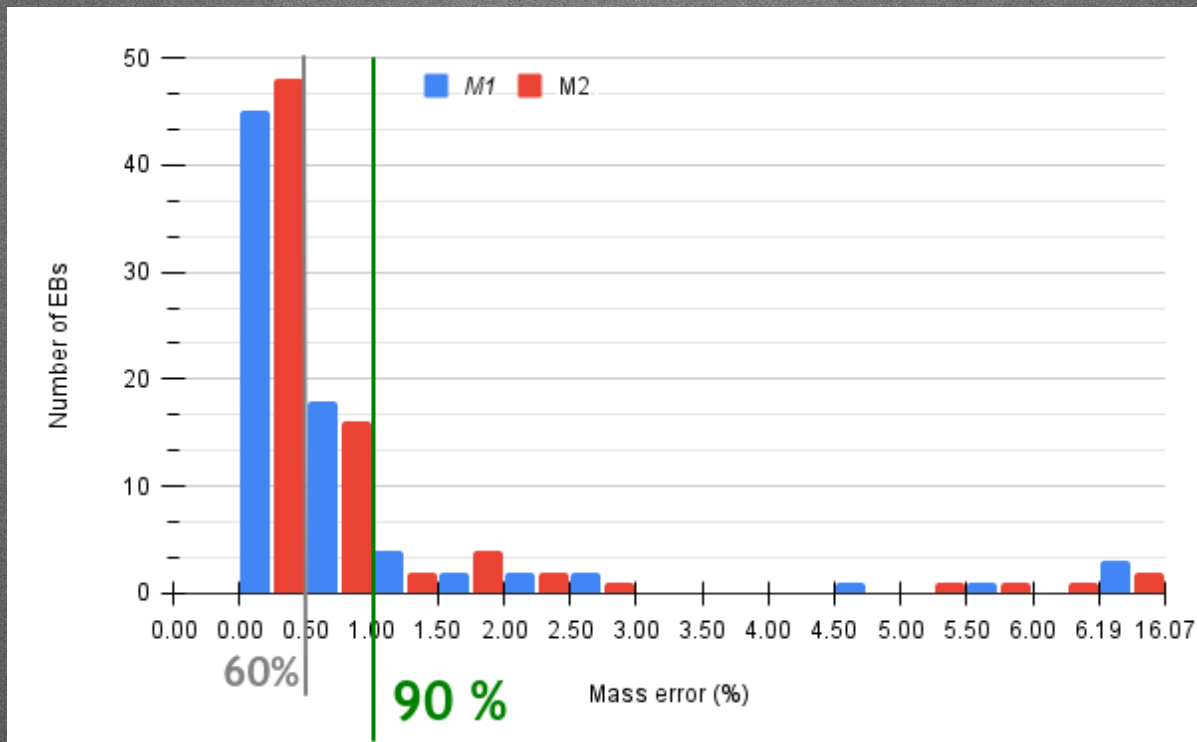# Results: The *321*

- Mass $M\sin^3(i)$ estimates (not final!) for 642 stars in **321** double-lined CRÉME eclipsing binaries

- **~300** of them with TESS or *Kepler/K2* photometry

- **Masses are enough to identify a lot of interesting cases**
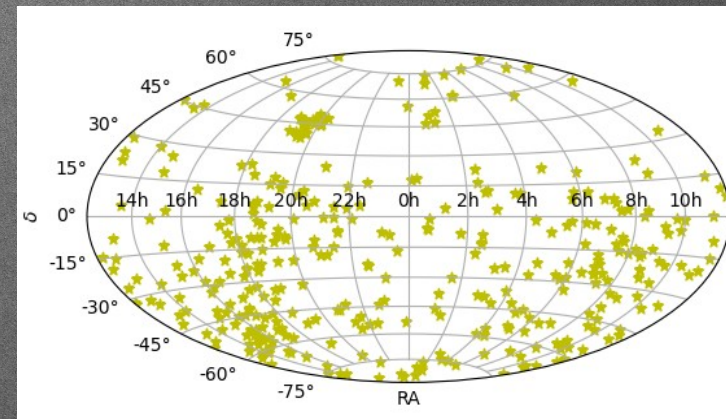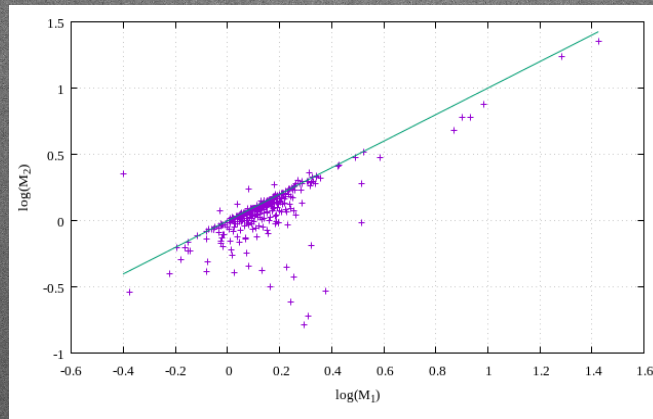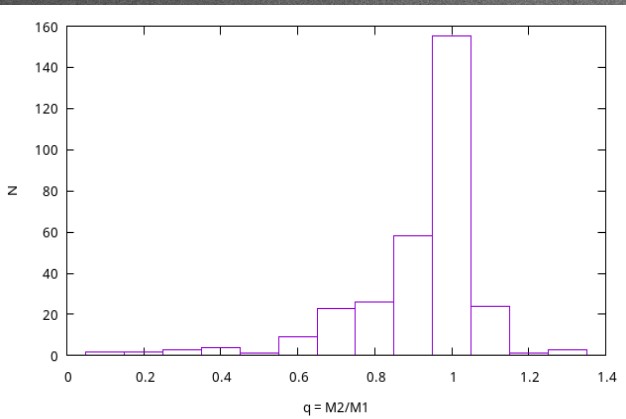
Results: Mass precision

- 78 "long-period" ($P > 4d$) systems with mass error determination

Best case:
0.051+0.058%

Results: Low-mass stars

- 19 DEBs with two $M < 0.9$ M_{sun} components

ASAS ID	TIC	RA (°)	DEC (°)	TESS Sectors	V (mag)	G (mag)	T (mag)	d_{GEDR3} (pc)
011328−3821.1	183596242	18.3679518	−38.3510354	2,3,29,30	11.72	11.442	9.785	50.13(10)
012726−4928.4	158582802	21.8579947	−49.4735722	2	11.45	10.663	10.101	141.3(7)
022311+1630.6	408627978	35.7963686	+16.5099728	42,43	12.09	11.377	10.689	128.9(5)
024013+6144.0	50191648	40.0544455	61.7330474	18,59	10.42	10.233	9.731	119.0(2)
024946−3825.6	215258019	42.4419509	−38.4273681	3,4	11.71	11.191	10.341	59.58(9)
030807−2445.6	88479623	47.0291965	−24.7591243	4,31	10.19	9.587	8.736	32.23(3)
032923−2406.1	144539611	52.3463638	−24.1004384	4	9.36	8.802	8.093	31.14(3)
045304−0700.4	9380768	73.2685086	−7.0066604	5	11.13	11.133	10.507	133.6(6)
050816−4449.1	200363294	77.0643897	−44.8193630	4,6,31,32[a]	10.15	9.687	9.231	63.09(4)
082552−1622.8	409797166	126.4641538	−16.3797396	34	10.29	9.754	8.941	37.8(8)
093814−0104.4	14307980	144.5561535	−1.0745686	8,35,62	12.31	11.862	11.210	159.5(1.1)
095039−0530.7	78151317	147.6638052	−5.5120566	8	10.07	9.810	9.370	152.4(1.1)
112122−4736.1	162585265	170.3406886	−47.6009034	10,63,64	10.39	9.980	9.305	70.72(16)
115632+0717.8	380642488	179.1342228	+7.2974779	46,49	9.53	9.237	8.667	71.13(12)
122408−1914.0	423591132	186.0343834	−19.2325385	37	11.41	11.075	10.381	82.62(17)
125516−3156.7	103683084	193.8187276	−31.9462195	10,64	11.51	10.698	9.943	62.7(3)
174044−0746.2	295936907	265.1824243	−7.7702703	—	10.30	9.958	9.235	43.91(4)
204117−1445.4	327589375	310.3211516	−14.7574544	—	10.65	10.243	9.558	60.32(7)
212954−5620.1	381857817	322.4749409	−56.3348664	1	11.93	11.418	10.717	120.5(4)

[a] Only in sectors 31 and 32 the target was requested with the correct TIC number ...294. However, data for all four sectors exist for the (formally incorrect) number ...295.
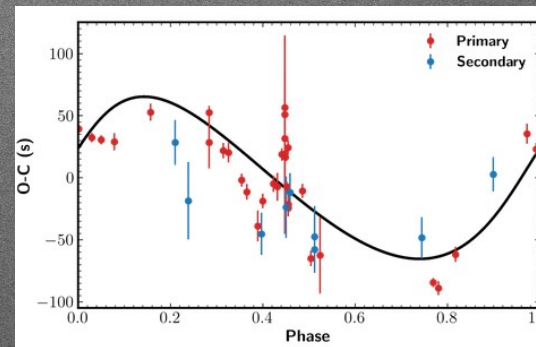
Results: Compact Hierarchical Triples (CHT)

- 7 new short-period DEBs with a third star on a P < 1000 d orbit

- Fundamental parameters of up to 3 components

**See presentation by
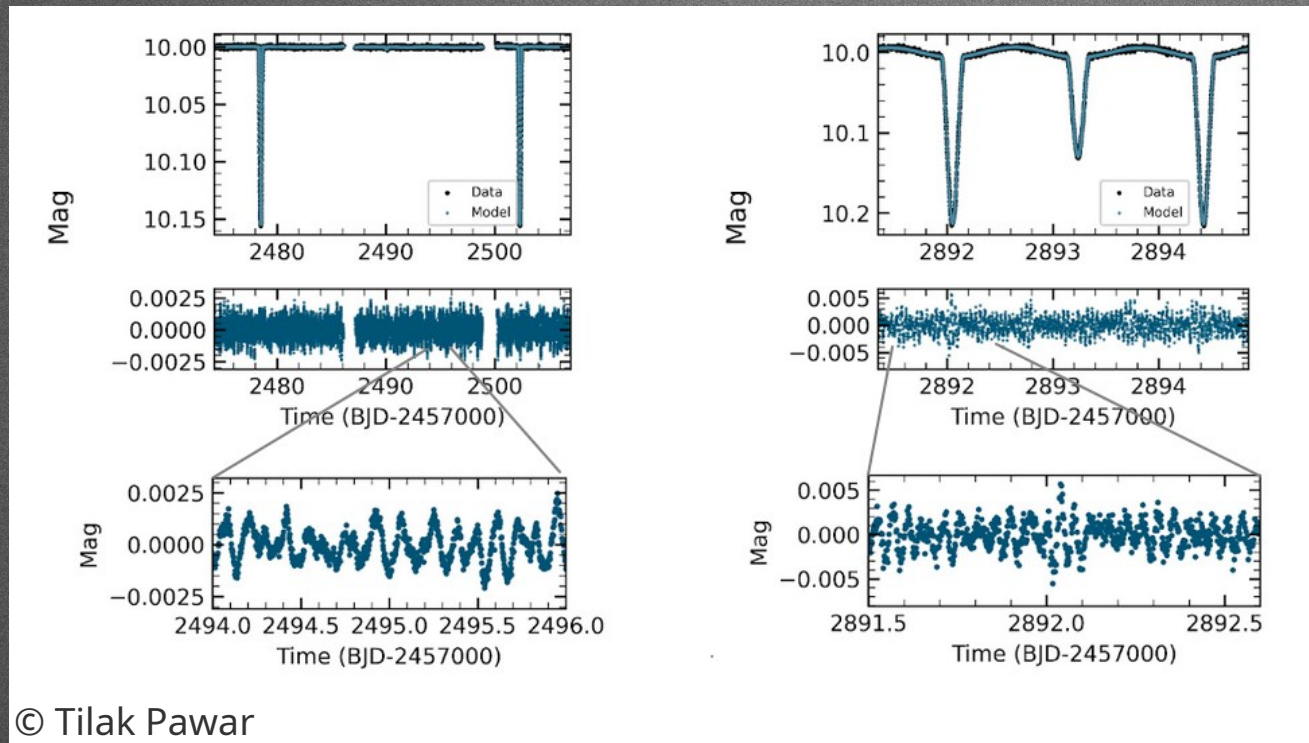Ayush Moharana
(Thursday, 10:11)
and his poster**
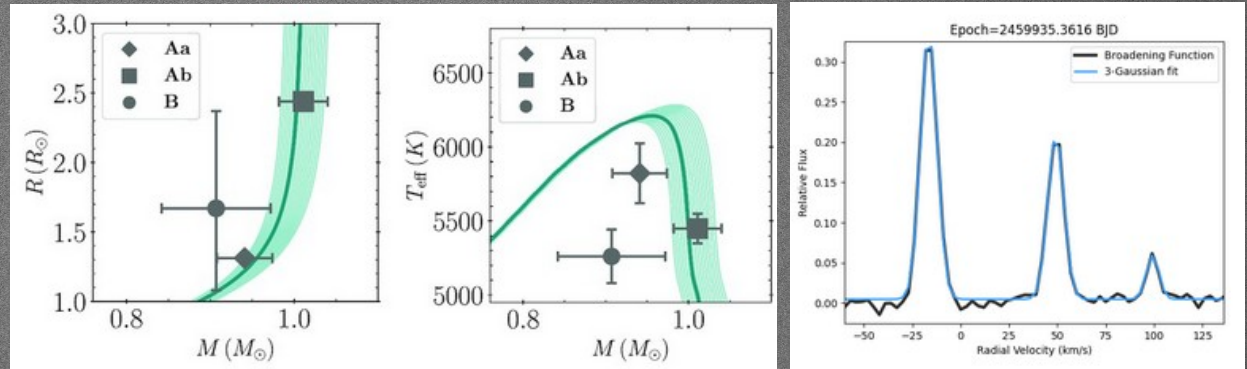
Also:
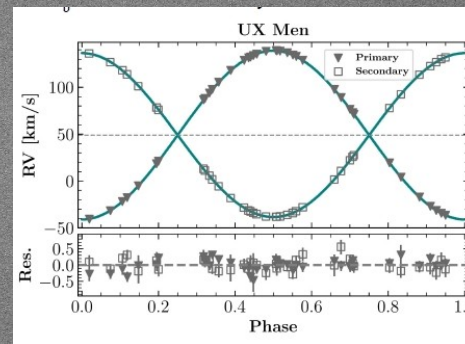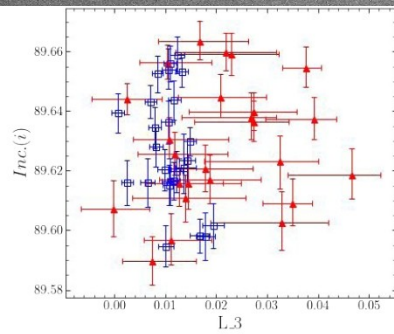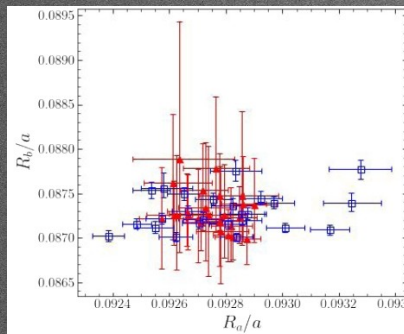Moharana et al. 2023

Results: Pulsating stars in DEBs
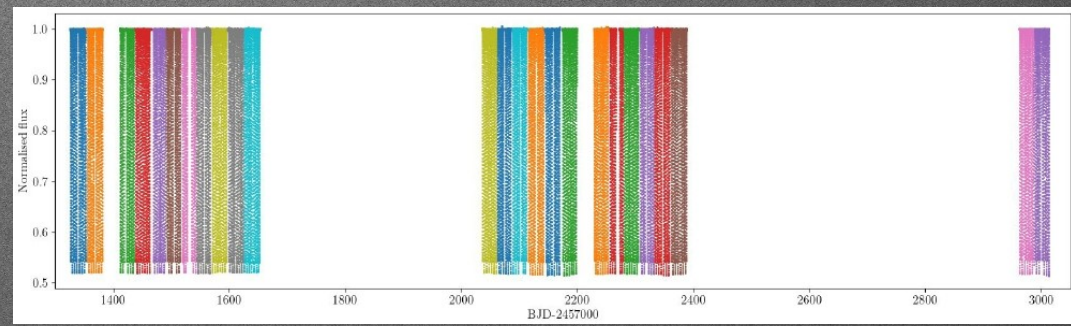
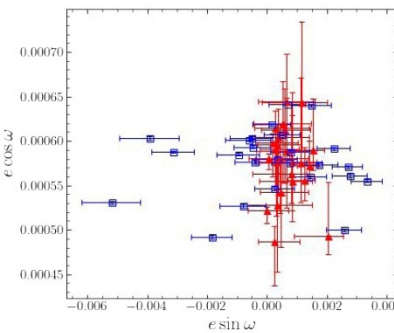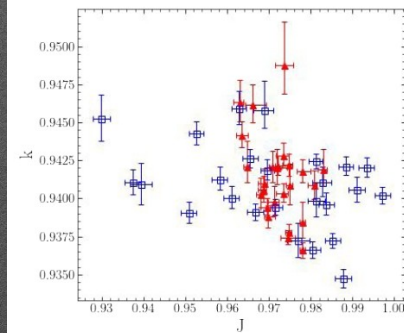- Stellar parameters of 10 new DEBs with δ-Sct pulsators

© Tilak Pawar

See also poster by Tilak Pawar

Results: Benchmarks & long-term stability

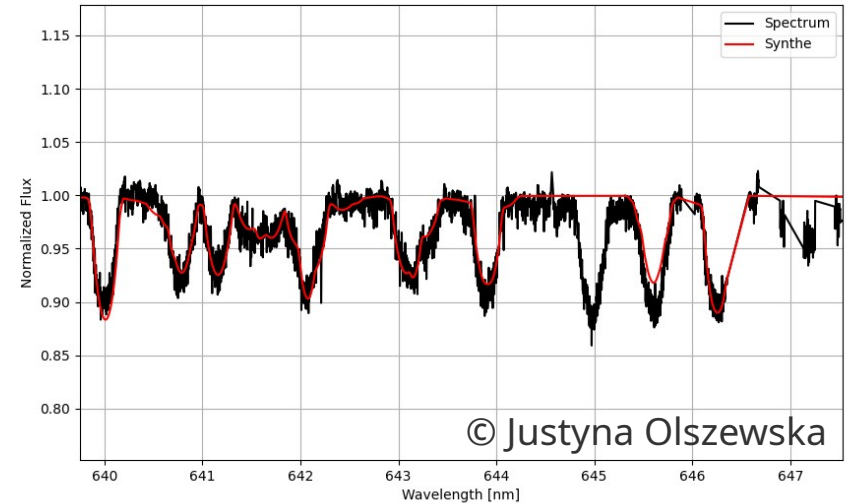- 22 TESS sectors of data, two different codes
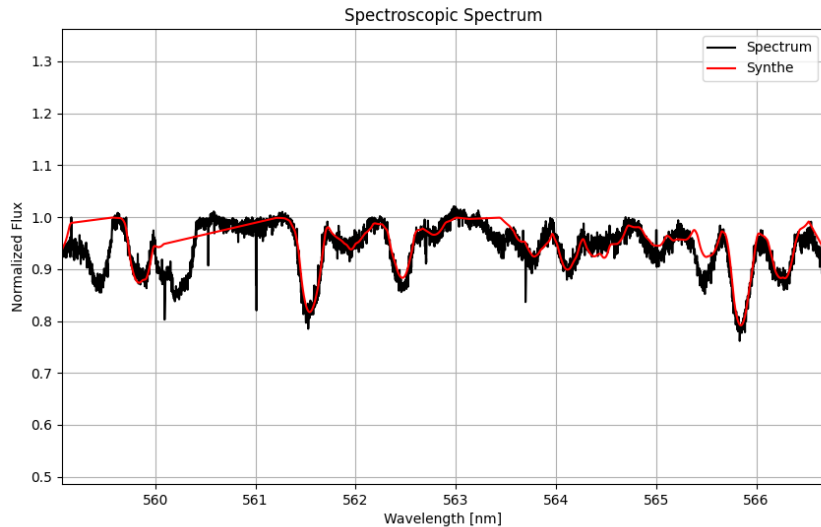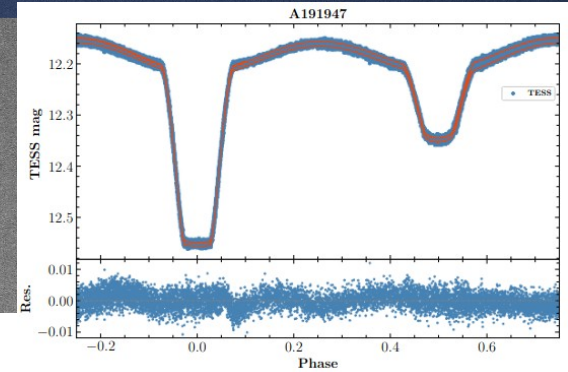- Variations of results from sector to sector

See poster by Ganesh Pawar

# Results: Total eclipses

- Spectra taken in total eclipses

- Independent estimate of T_{eff} and [Fe/H] for better age estimate

© Justyna Olszewska

Future plans and prospects

- Finalize the work on low-mass stars, CHTs & pulsators

- PLATO benchmarks (data sets and targets)

- "Filling gaps" in TESS coverage in Cycle 6 and 7

- Other interesting scientific topics:

    - SB+SB quadruples and doubly-eclipsing systems (started)
    - High-mass stars (started)
    - Pre-Main Sequence
    - Calibration of the M-f_{ov} relation
    - Testing "abundance clocks"
    - …
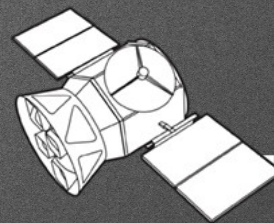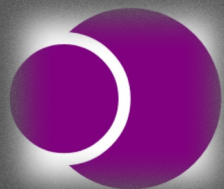
THANK YOU

FOSSILS IN THE FACULTY OF ECONOMIC SCIENCES AND MANAGEMENT (i.e. our corridor)