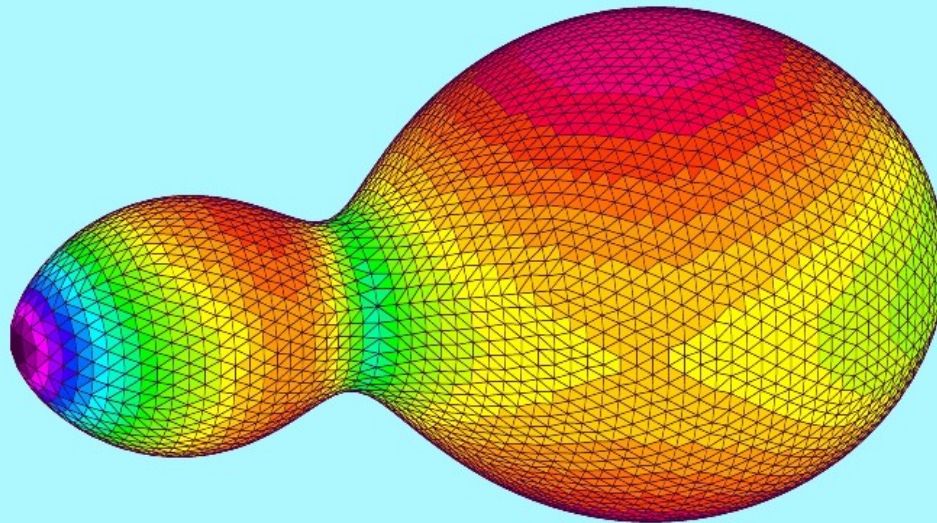


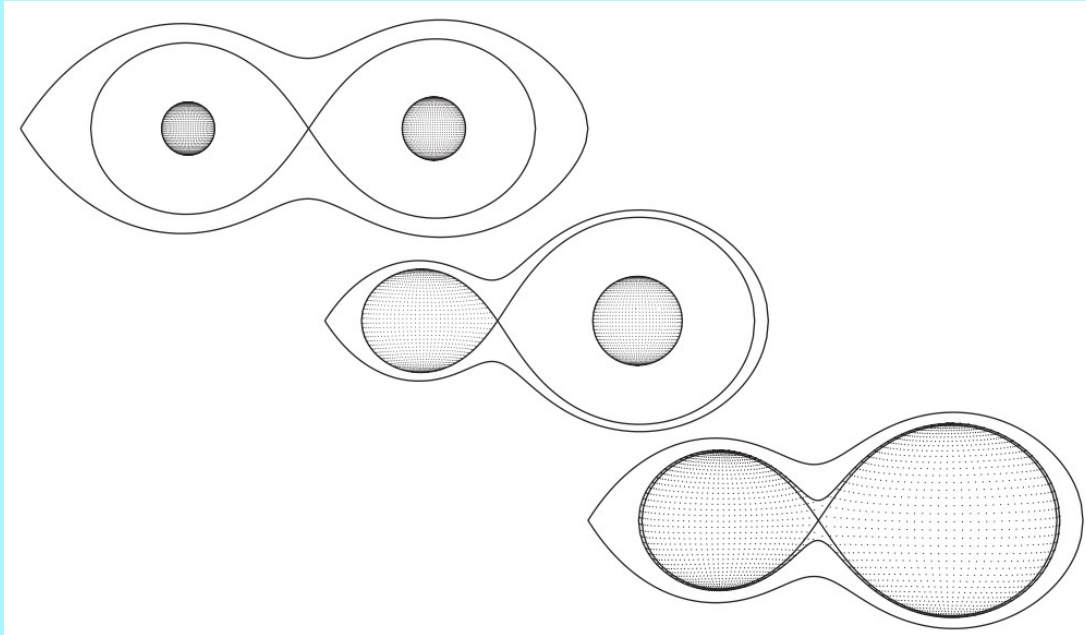
Minimum mass ratio of contact binaries

Theodor Pribulla



Institute seminar, AI SAS, March 12, 2026

Close binary stars



detached

semi-detached

contact

Contact binaries

- * Close binary stars where the components are embedded in a common (convective) envelope which redistributes energy and makes secondary over-luminous
- * The component's surface follows the Roche model, surface temperature - gravity darkening law
- * In principle: three photometric elements: mass ratio – q , inclination angle – i , fill-out factor – f
- * In reality: temperature ratio does not follow predictions: W and A sub-types, colder objects often spotted

$$\Omega = -\frac{\Psi a}{GM_1} - \frac{1}{2} \frac{q^2}{1+q} = \frac{1}{r_1} + \frac{q}{r_2} + \frac{1}{2}(1+q)[x^2 + y^2] - qx$$

$$f = \frac{\Omega_{\text{inn}} - \Omega}{\Omega_{\text{inn}} - \Omega_{\text{out}}}$$

Basic properties

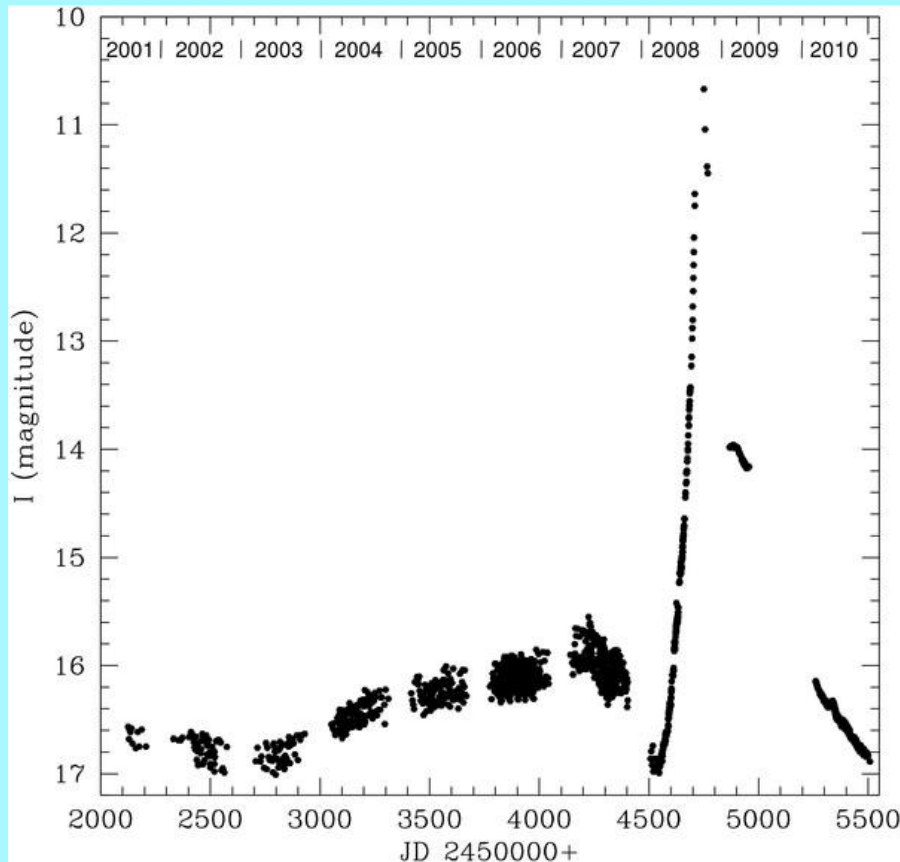
- * Orbital period 0.2 – 0.8 days, but never much shorter
- * Spectral types A to K, but never M or later
- * Main sequence primary: period-color-luminosity relation
- * Mass ratio 0.08 – 0.88, but seldom close to unity
- * Sinusoidal light-curve shape: not much information and parameter degeneracy unless total eclipses
- * Many objects in triple or multiple systems
- * Old objects: in old open clusters, globular clusters

Darwin (dynamical) instability

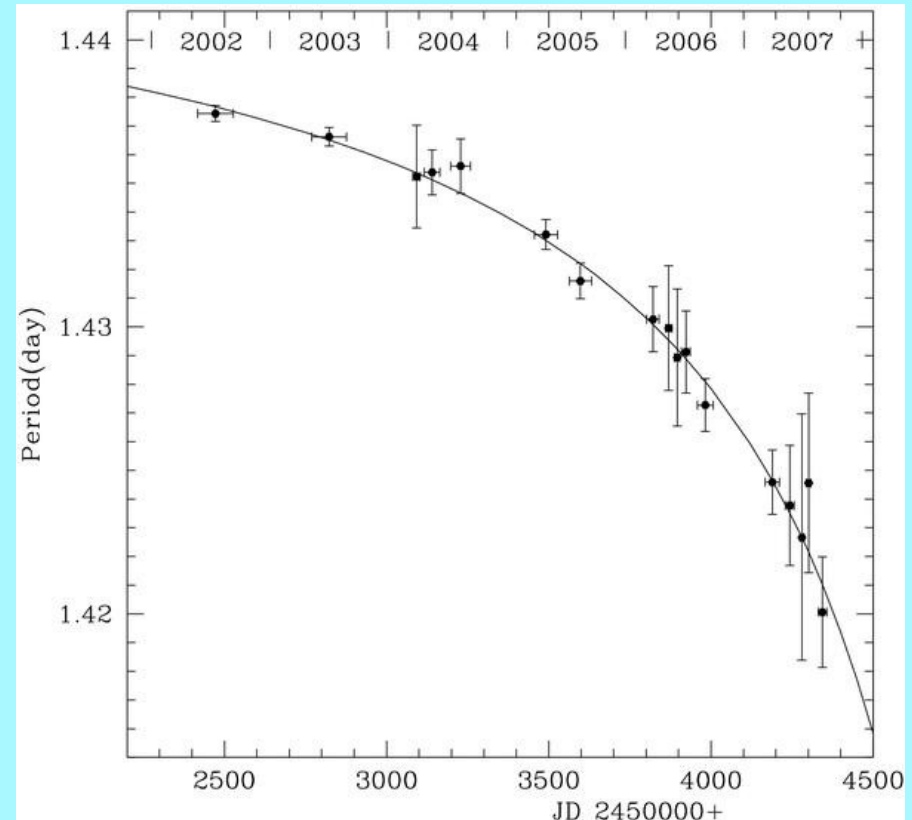
- * When spin angular momentum is more than 1/3 of the orbital angular momentum - merger
- * Rasio (1995) estimated $q_{\min} \sim 0.09$
- * Effects of metallicity and internal structure can possibly lead to $q_{\min} \sim 0.038 - 0.041$ (e.g., Wadhwa+, 2021, 2024)
- * pre-merger signature: exponential decay – failed prediction of KIC 9832227 (forecast to merge in 2022.2 ± 0.6)

$$\frac{J_{\text{spin}}}{J_{\text{orb}}} = \frac{1 + q}{q} \times [(k_1 r_1)^2 + q(k_2 r_2)^2].$$

Red nova V1309 Sco: unusual precursor

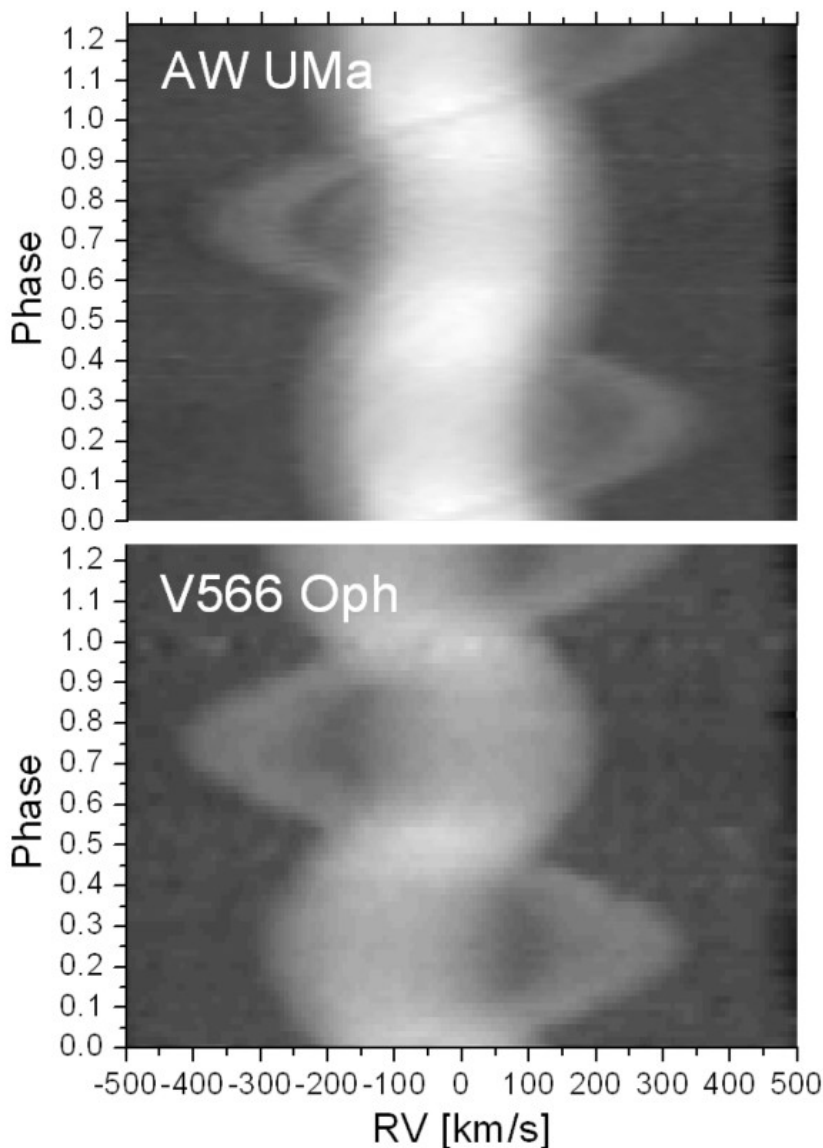


OGLE I-band light curve of V1309 Sco (Tylenda+, 2011)

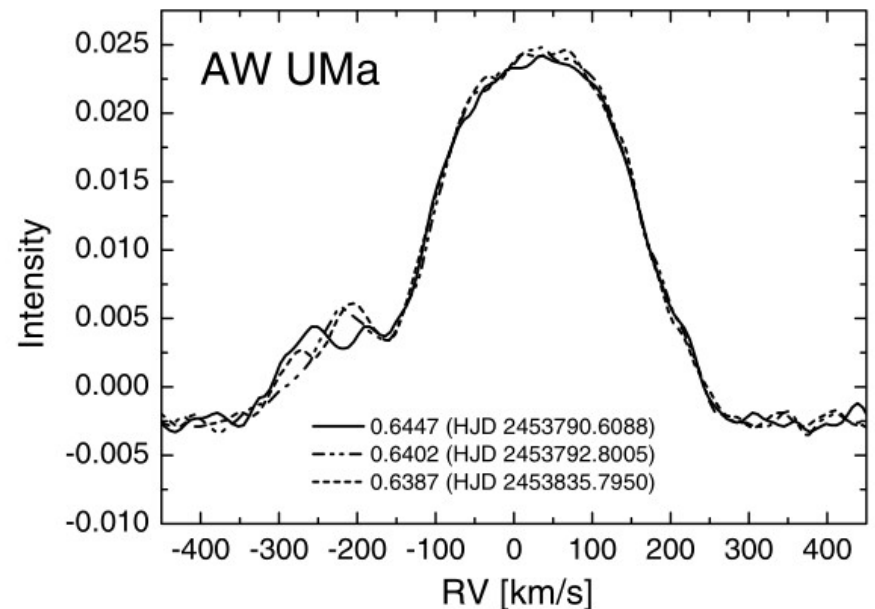


Pre-outburst period decay of V1309 Sco (Tylenda+, 2011)

AW UMa: peculiar case



The best studied prototype case: AW UMa, shows peculiar trailing spectra indicating that the secondary is detached and variable (Pribulla & Rucinski, 2008)

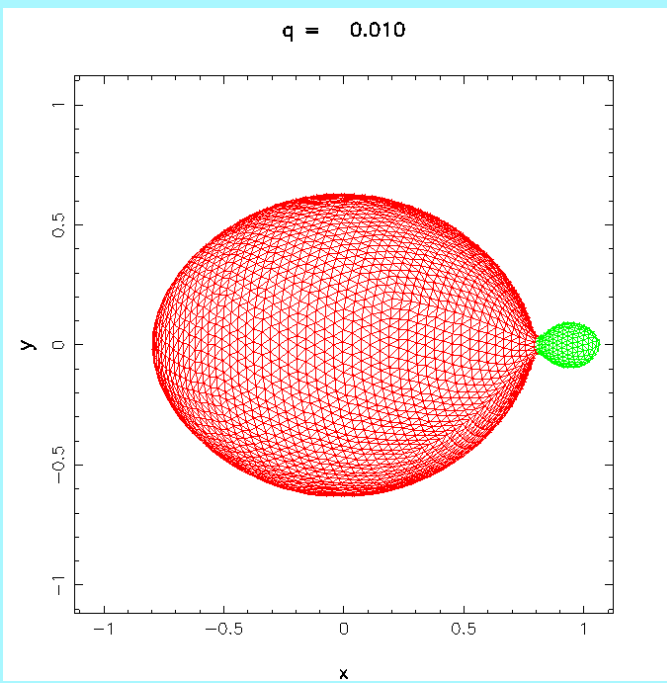


Extreme mass-ratio candidates

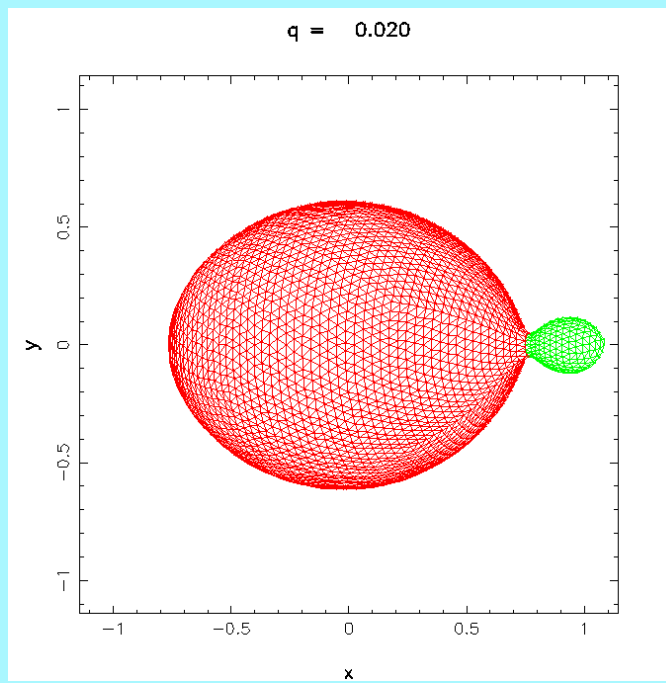
- * Caveat: mass ratio is strongly correlated with the inclination angle and third light ==> photometric results are inconclusive
- * Candidates except AW UMa and SX Crv do not have RVs
- * Surface flows: BFs do not fully reflect geometry

Object	V/G	RA2000	DEC2000	q	Author(s)	Reference
TYC 3801-1529-1	12.25	08 41 18.8	+56 50 41	0.024	Poro+(2026)	ApJ 998, 108
UCAC4 632-056541	12.99	17 52 00.3	+36 18 05	0.027	Guo+ (2025)	AJ 170, 101
V1187 Her	11.51	16 29 19.9	+35 40 03	0.044	Caton+(2019)	PASP 131, 999
TYC 4002-2628-1	11.48	23 09 27.9	+54 51 23	0.0482	Guo+(2022)	MNRAS 517, 1928
UCAC4 757-051371	13.33	18 55 03.6	+61 18 04	0.0514	Guo+ (2023)	MNRAS 521, 51
GSC 03415-02229	13.49	08 27 00.8	+46 28 50	0.055	Li+ (2021)	ApJ 922,122
V857 Her	10.87	16 46 53.6	+38 38 28	0.065	Qian+ (2015)	AJ 130, 1206
SX Crv	09.11	12 40 15.0	-18 48 01	0.066	Rucinski (2001)	AJ 122, 1007
CRTS J075442.6+555622	14.12	07 54 42.5	+55 56 23	0.083	Liu+ (2025)	MNRAS 540, 1290
NW Aps	09.15	14 55 38.5	-79 48 21	0.086	Zhou (2025)	MNRAS 541, 3401
UCAC4 730-051446	12.95	13 28 29.1	+55 52 45	0.089	Li+ (2021)	ApJ 922,122
AW UMa	06.84	11 30 04.3	+29 57 53	0.10	Pribulla+ (2008)	MNRAS 386, 377

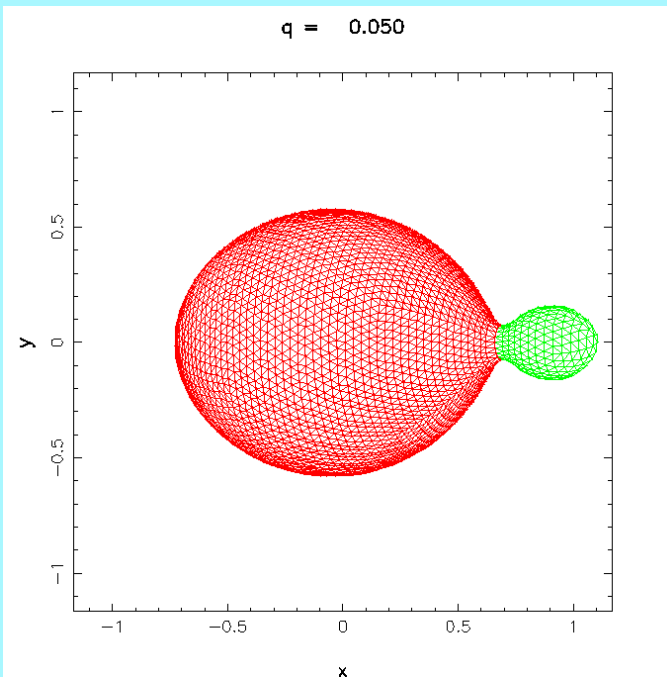
$q = 0.01$



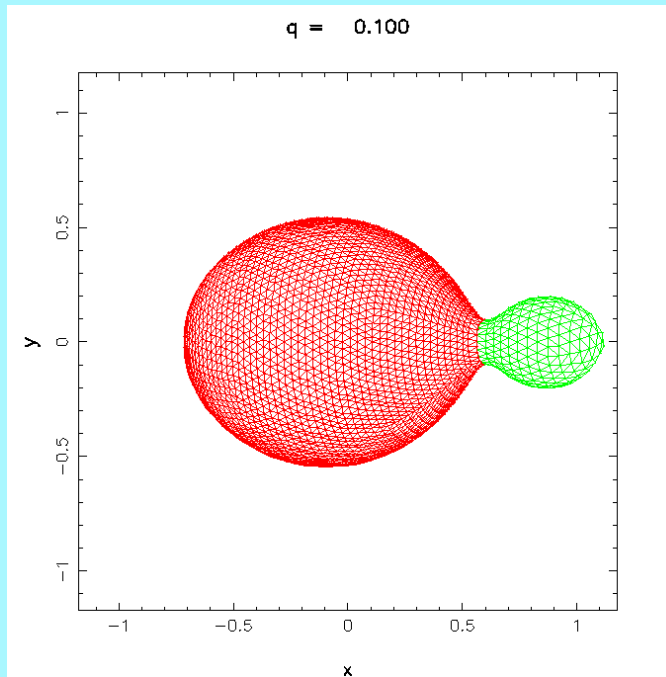
$q = 0.02$



$q = 0.050$



$q = 0.100$

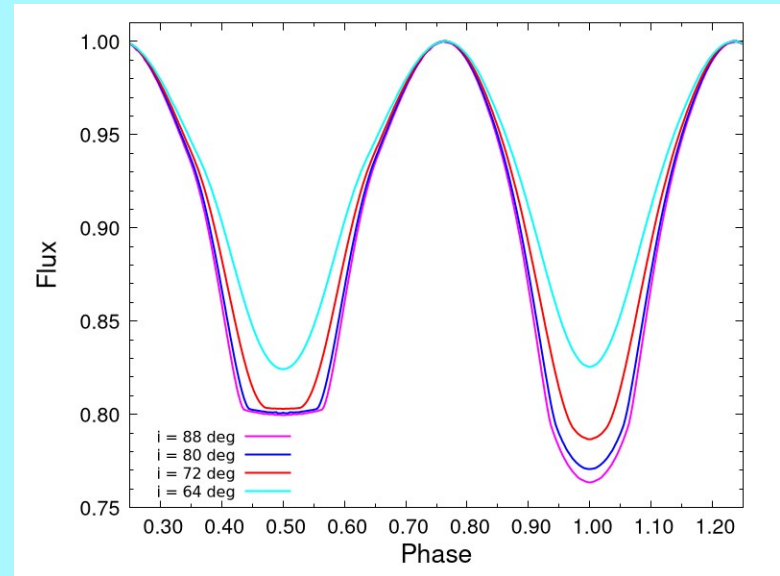
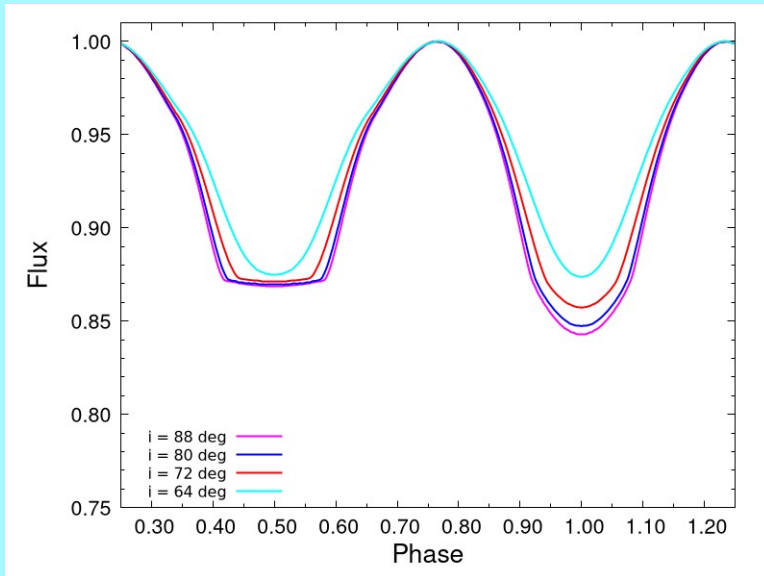
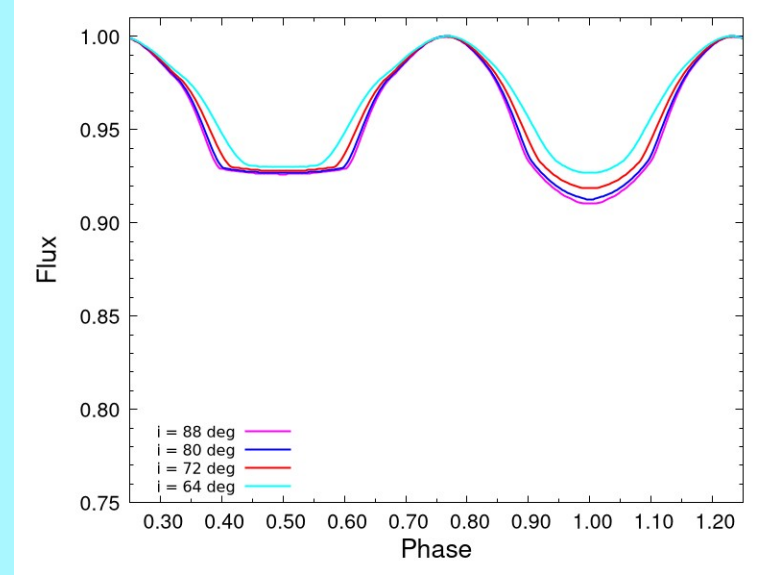
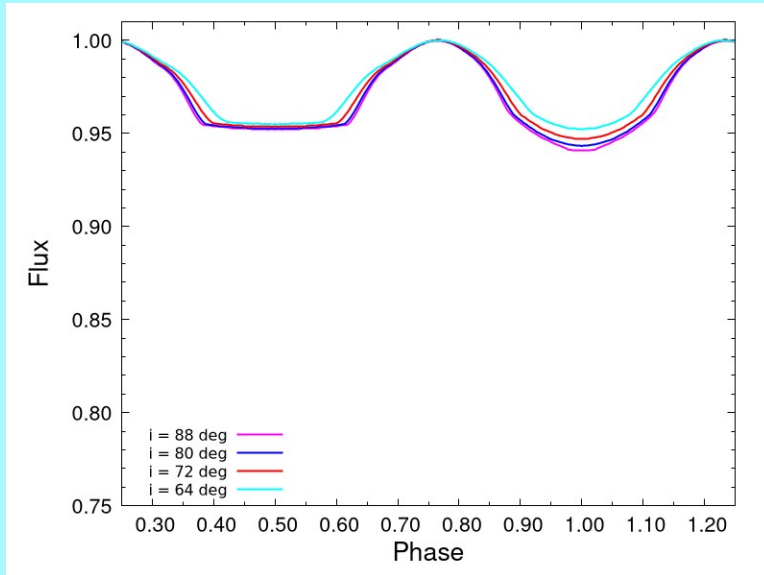


$q = 0.05$

$q = 0.1$

$q = 0.01$

$q = 0.02$

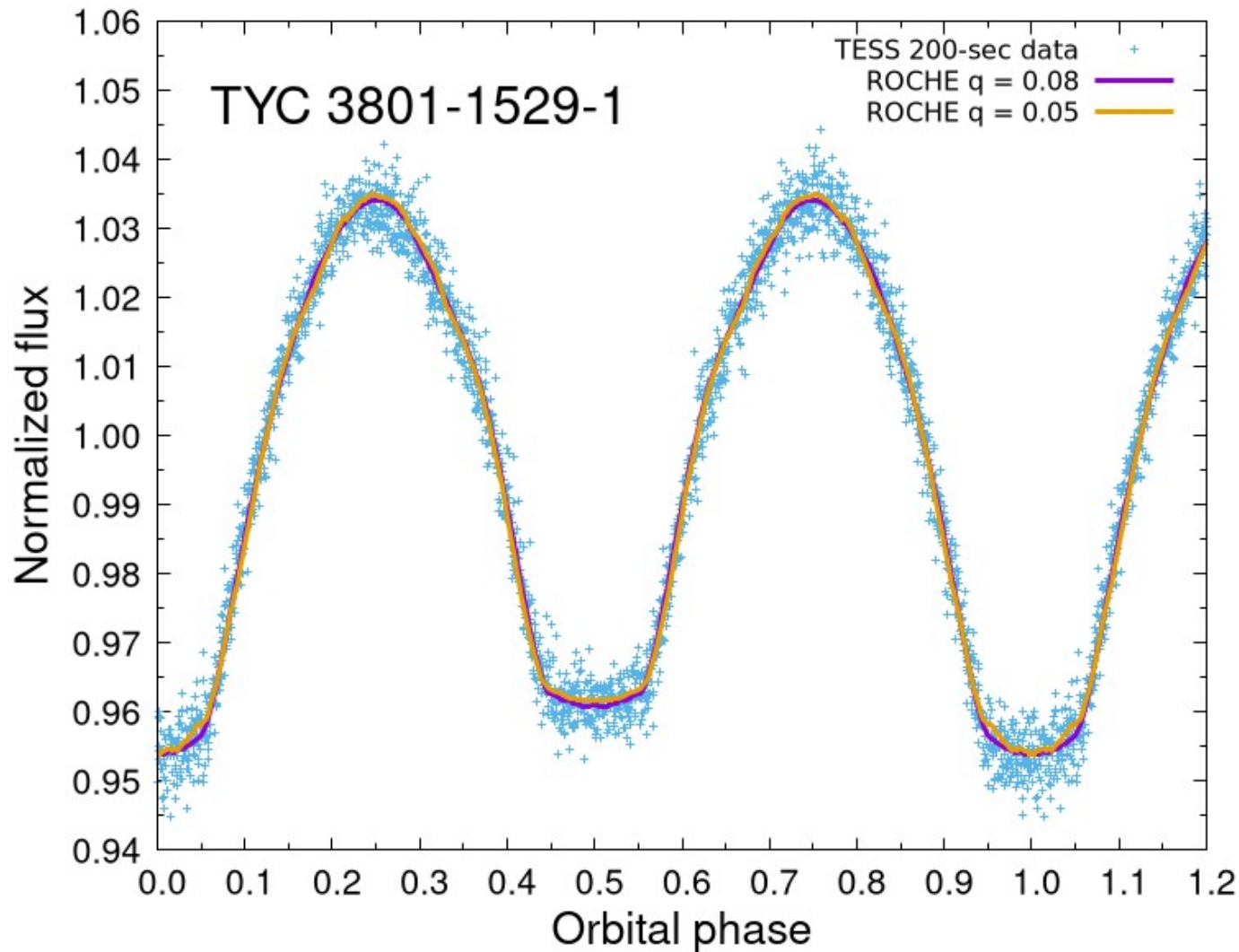


$q = 0.05$

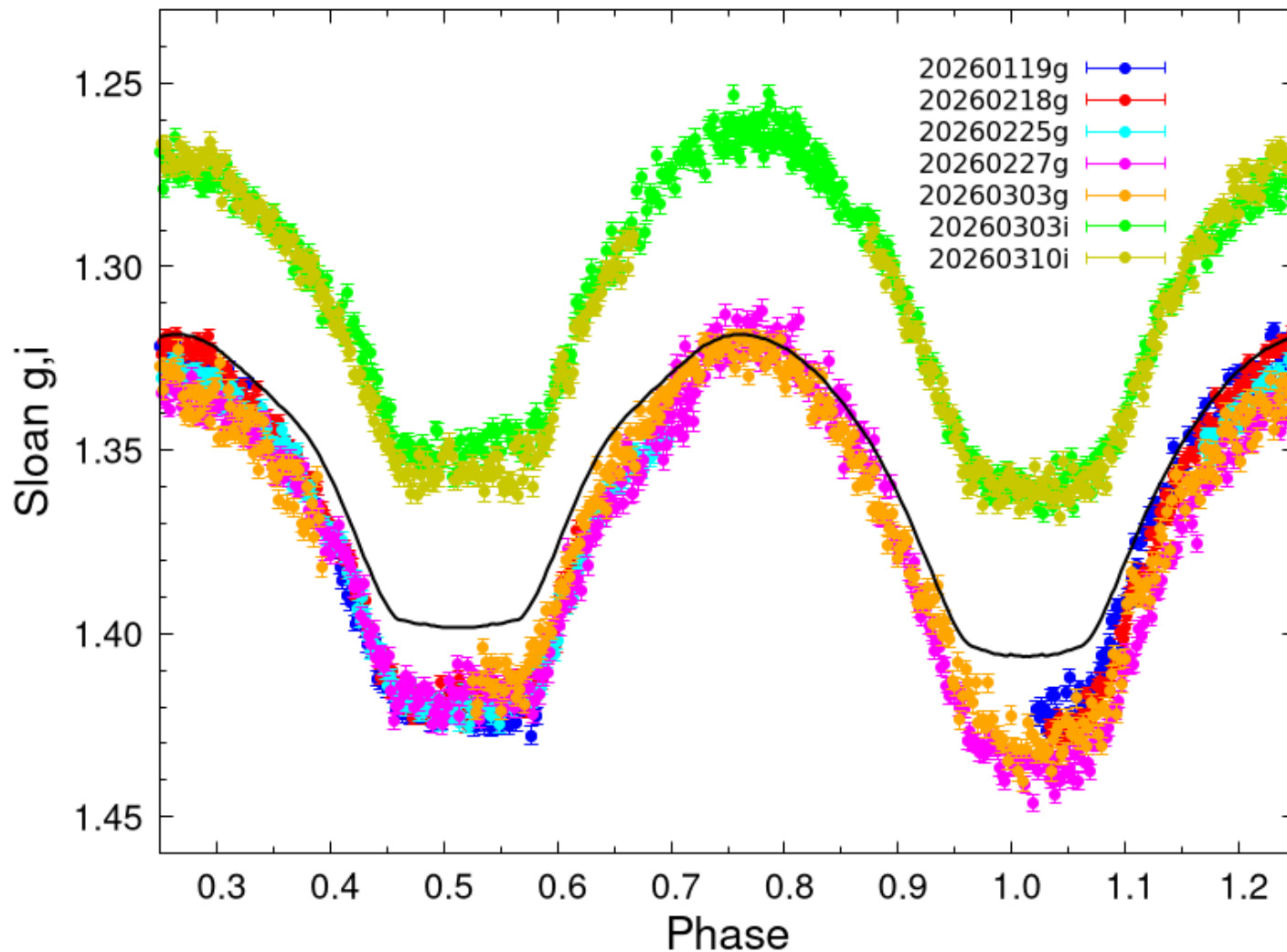
$q = 0.1$

Hypothesis and how to test it

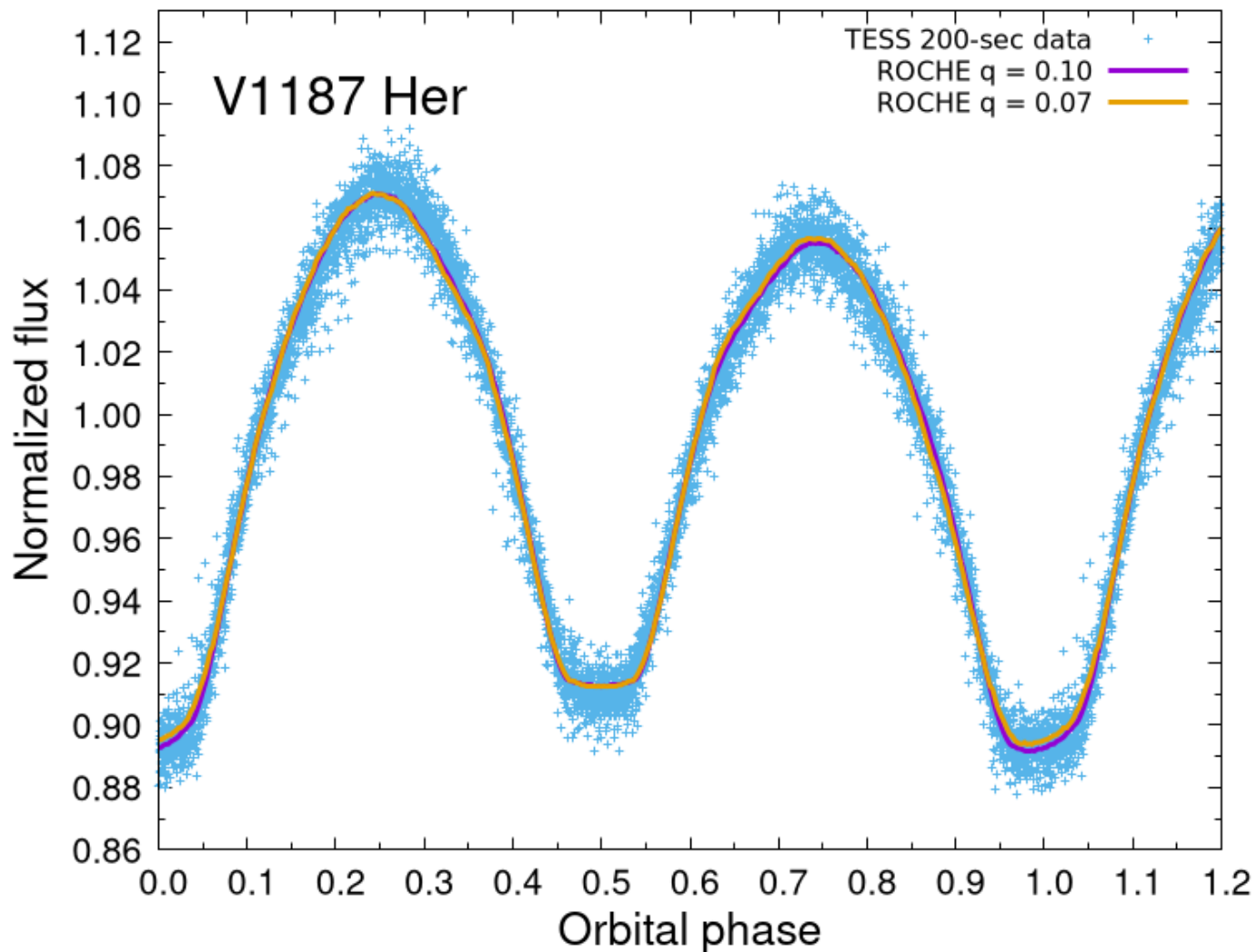
- * Hypothesis: all systems claimed to have $q < 0.05$ - false detections!
- * TESS LCs available for 5 out of 6 objects with $q_{\text{phot}} < 0.06$, only QLP (Quick Look Pipeline) for 200 sec exposures
- * TESS: excellent accuracy and good stability
- * Problem: single-band data
- * Multi-band data: photometric indication of l_3 if spectral type of the contact pair and third (multiple) components differs
- * Problem: low mass ratio systems have low photometric amplitudes and low relative precision...



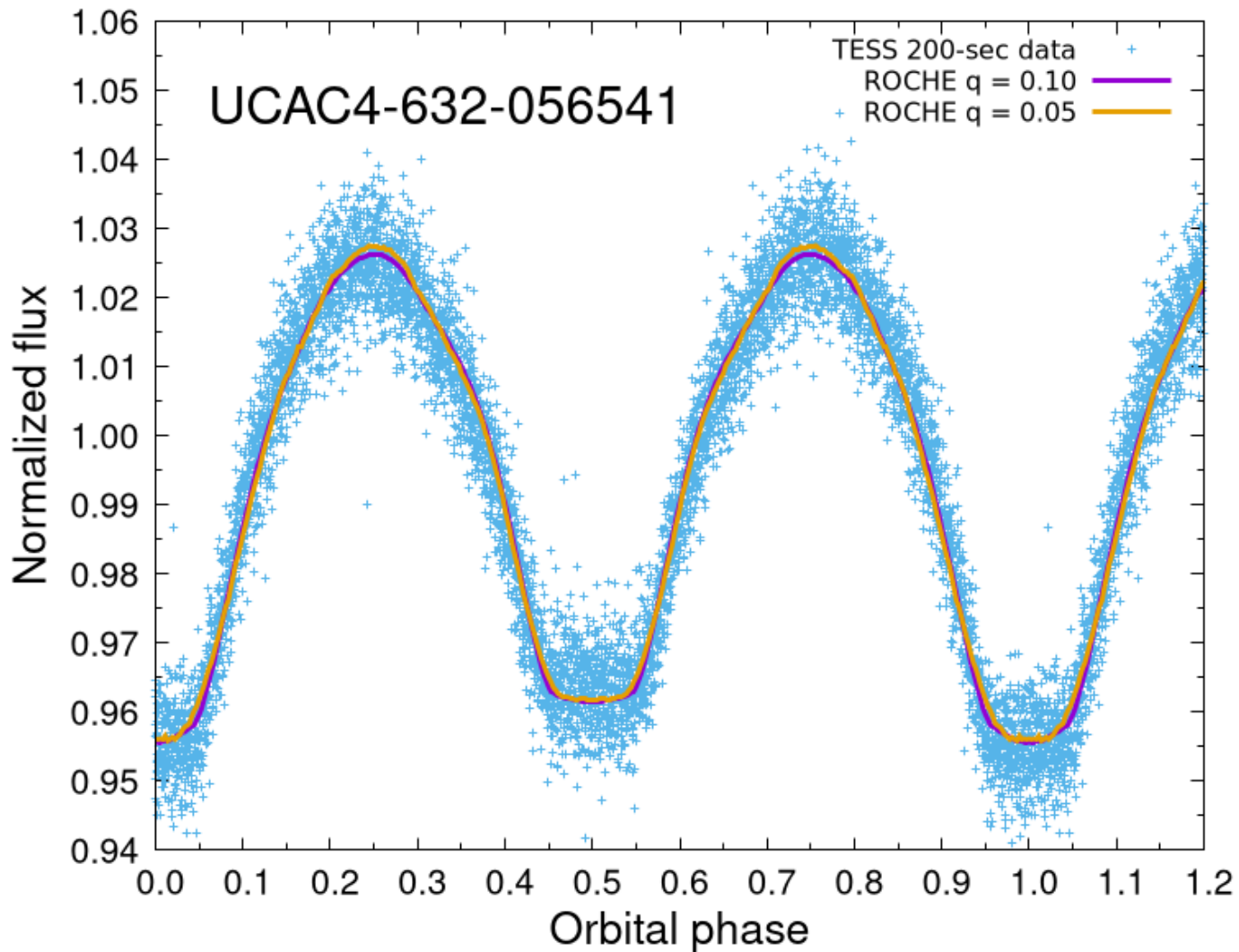
TYC 3801-1529-1, solutions require strong l_3 , best $q \sim 0.08$, Poro+ (2026), $q = 0.024$!



Comparison of Sloan g , i LCs (ASA800 Szombathely) and fit to the TESS LCs: 3rd component is much colder than the contact binary



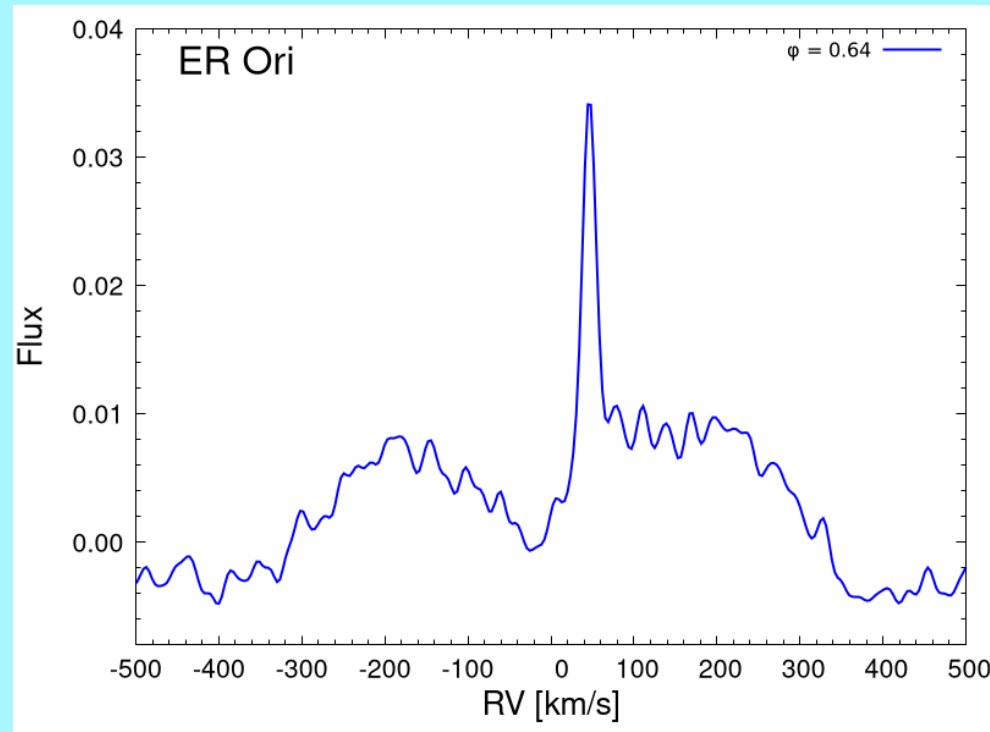
V1187 Her, solutions require strong l_3 , a spotted system, best $q \sim 0.08$, Caton+ (2019), $q = 0.044$



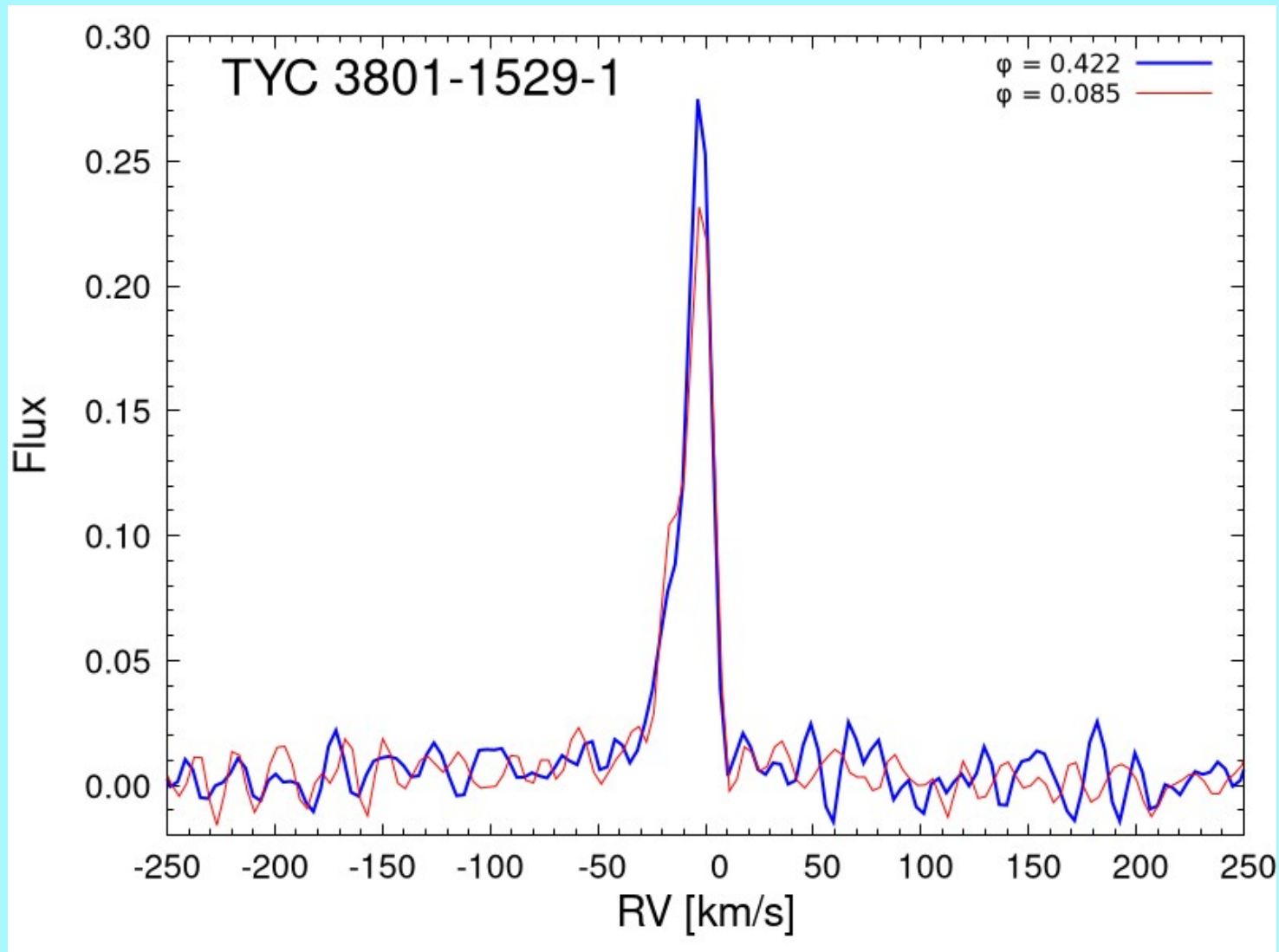
UCAC4-632-056541, solutions require strong l_3 , best $q \sim 0.10$, Guo+ (2026), $q = 0.027$

Skalnaté Pleso spectroscopy

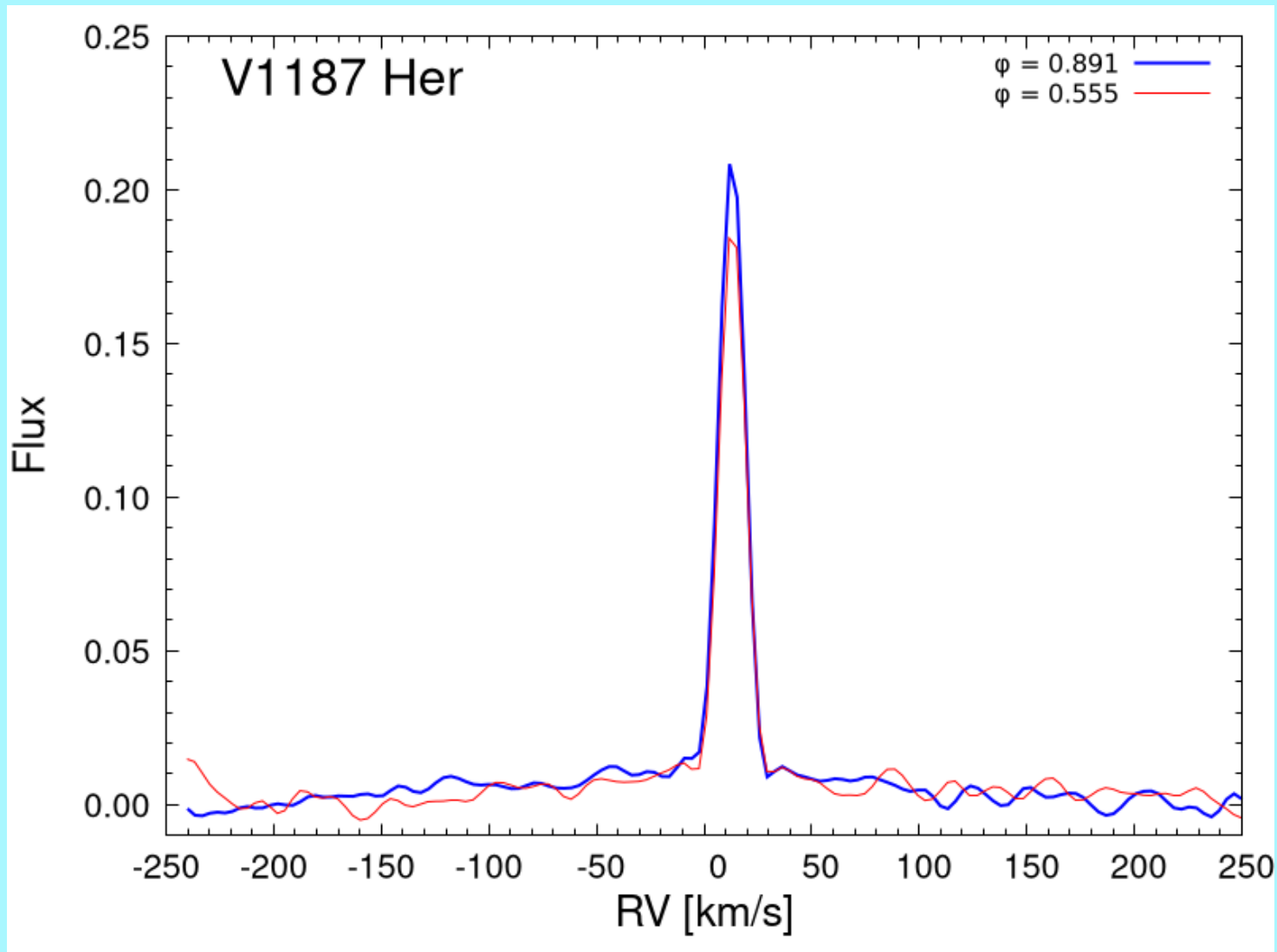
- * Three most extreme cases observed: TYC3801-1529-1 ($V=12.25$), V1187 Her ($V=11.51$) and V857 Her ($V = 10.87$)
- * BF technique used to analyze the data (Rucinski, 1992)
- * 3 exposures of 900 seconds to boost SNR: phase smearing...



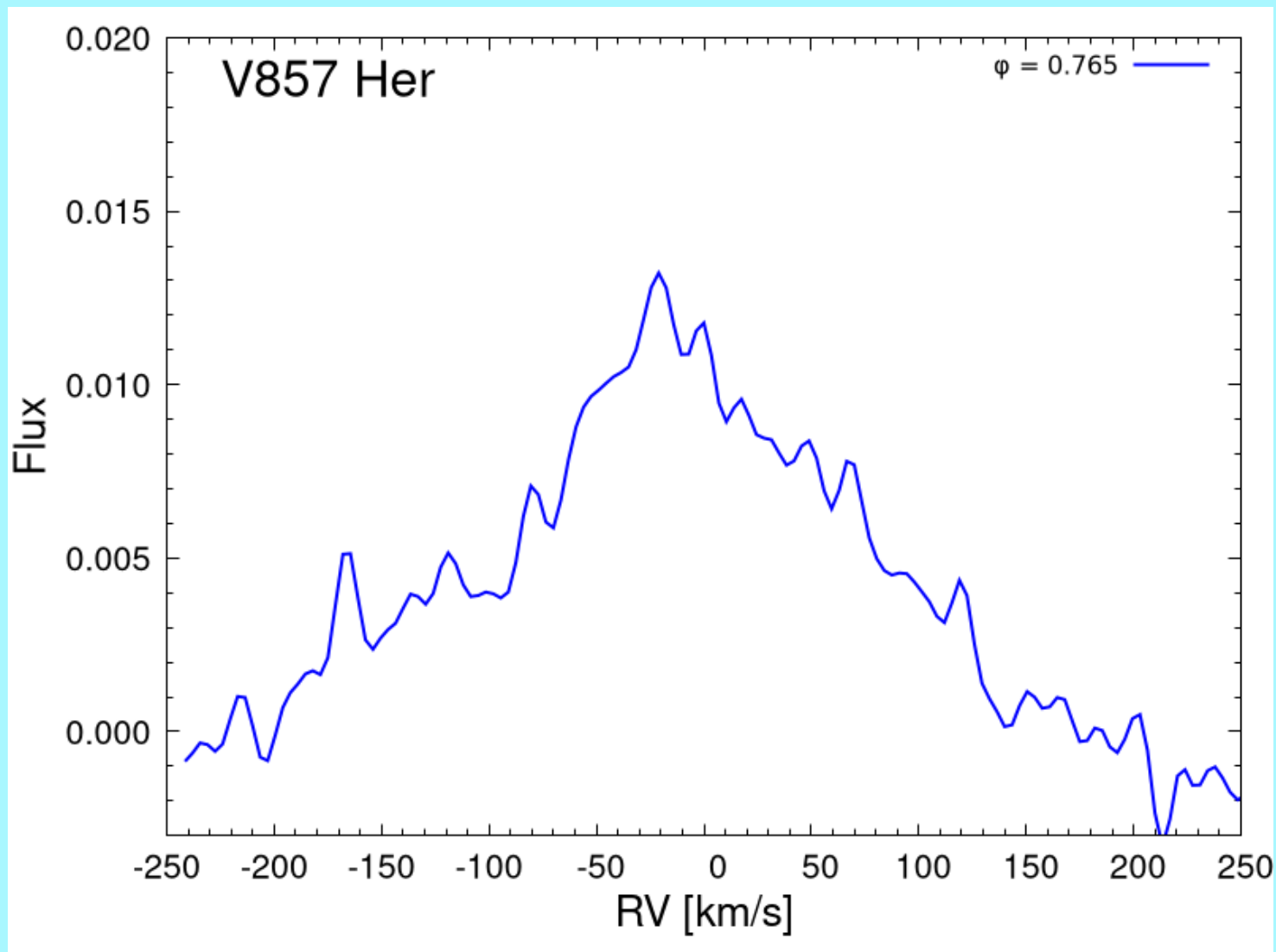
ER Ori: an easy case
two rapid rotators +
slowly rotating third
component



BFs of TYC 3801-1529-1, HD128167 used as a template, SNR at 5500Å 15 and 19, contact binary not visible -> dominant third component



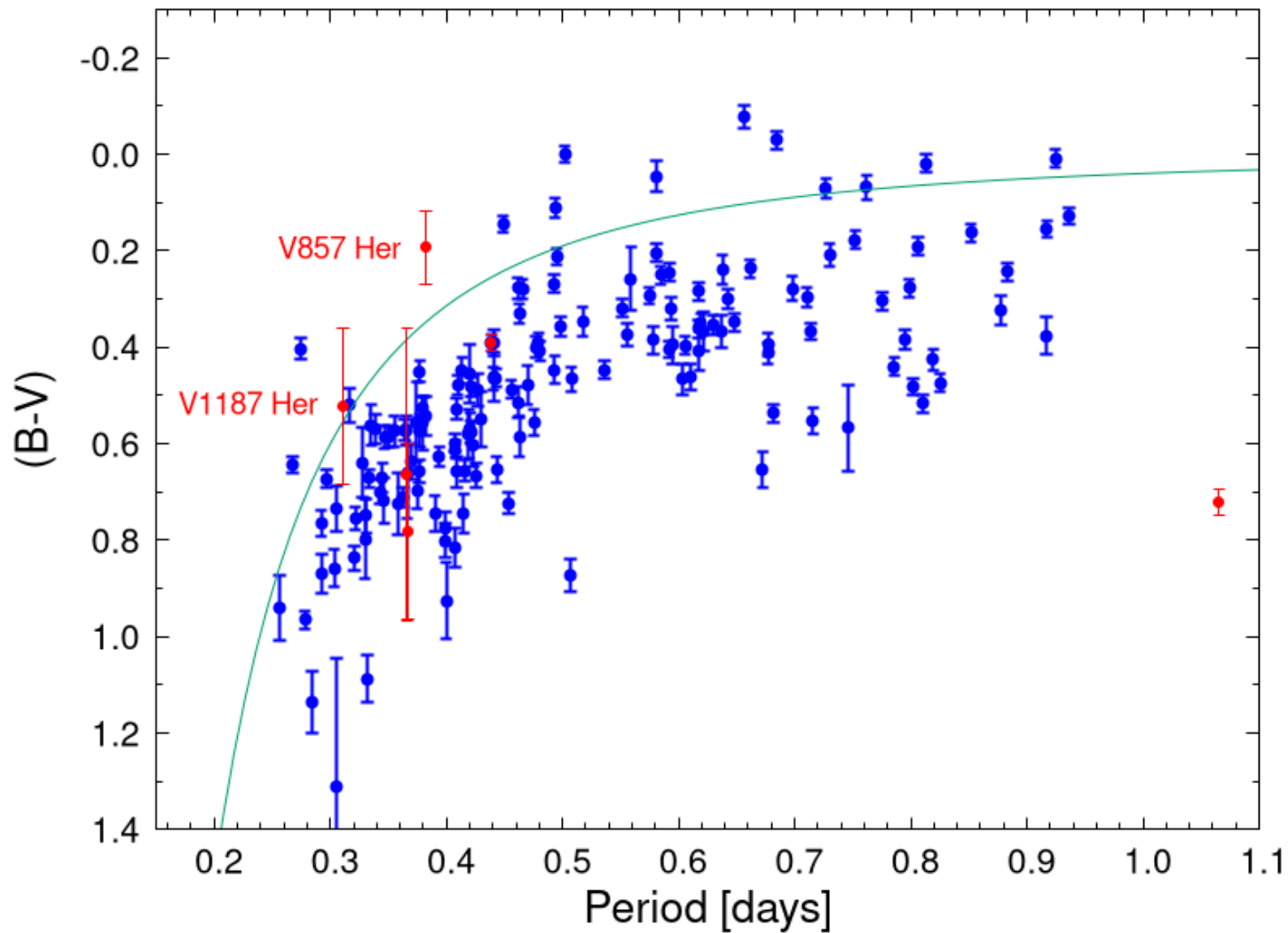
BFs of V1187 Her, HD128167 used as a template, SNR at 5500Å 26, contact binary not visible -> dominant third component



BFs of V857 Her, HD128167 used as a template, dominated by early-type (A5 ?) third star: contact binary not visible or three rapid rotators

Short-period blue envelope

- * Contact binaries: primary is a MS star: for a given orbital period one can predict the bluest possible color index
- * MS evolution and extinction work opposite: we cannot expect bluer contact binaries
- * SPBE: multiplicity indicator: dominant third component makes the object bluer, pulsating object with a sine LC, metallicity effects
- * SPBE $(B-V) = 0.04 P^{-2.25}$ (Rucinski, 1998, Pribulla & Rucinski, 2006)



SPBE for 151 contact binaries, and five extreme mass ratio candidates with available $B-V$ colors (TYCHO 2 catalog)

Conclusions

- * Dynamical stability: $q > 0.05$
- * Current evolutionary models cannot produce secondaries with $M_2 < 0.165 M_\odot$ for and F-type contact binary
- * Still several objects with $q < 0.05$ announced
- * Preliminary spectroscopy of TYC3801-1529-1, V1187 Her and V857 Her with MUSICOS@1.3m telescope do not confirm extreme mass ratios and the third component is the culprit
- * Multi-color photometry needed: temperatures of the contact binary and the third component often differ
- * High-resolution spectroscopy needed: conclusive results
- * Genuine cases: objects with the totality lasting $\Delta\phi > 0.18$: phenomenological modeling or machine learning

Thank you !