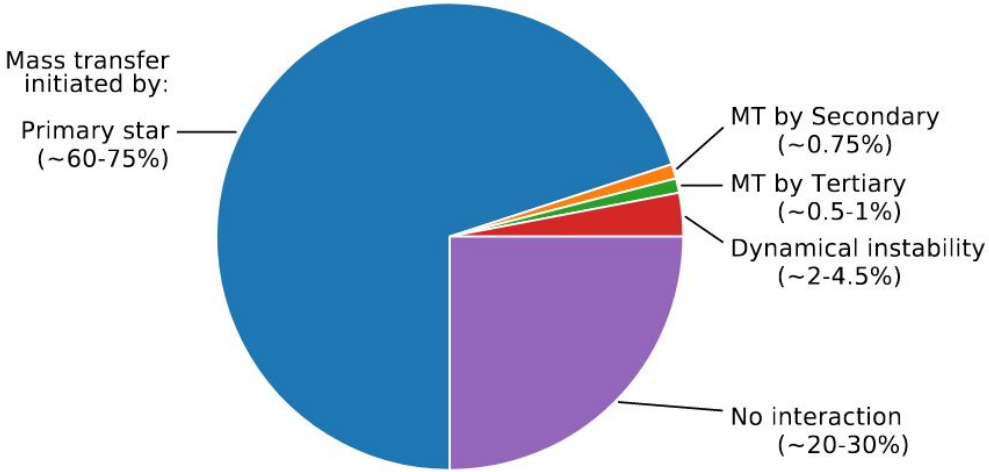
⊙ Alpha Cen System: Towards new worlds ⊙
Nice, 26-30 June, 2023

Evolution and dynamics of Compact Hierarchical Triples

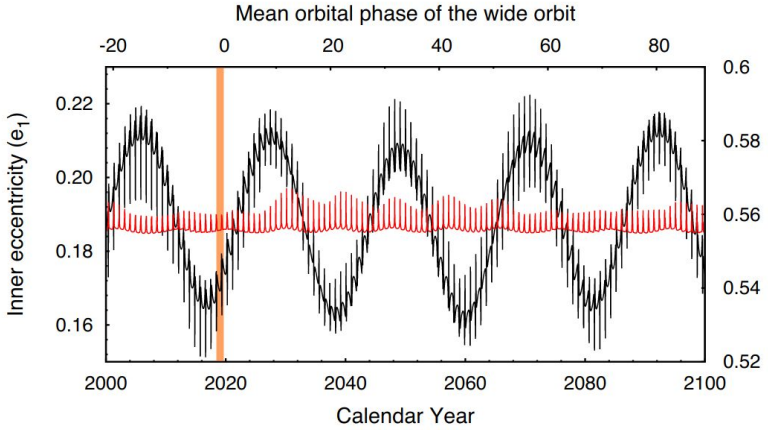
Ayush Moharana Nicolaus Copernicus Astronomical Center, Toruń

In collaboration with: Dr. hab. K.G. Hełminiak, Dr. F. Marcadon, Prof. M. Konacki, T. Pawar and G. Pawar
Funded by: NCN Preludium 2021/41/N/ST9/02746

Triples: Evolution and Dynamics



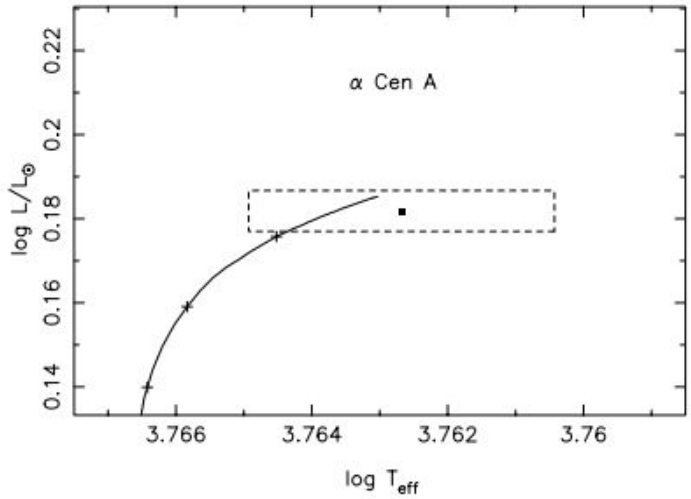
(Toonen+2020, A&A)

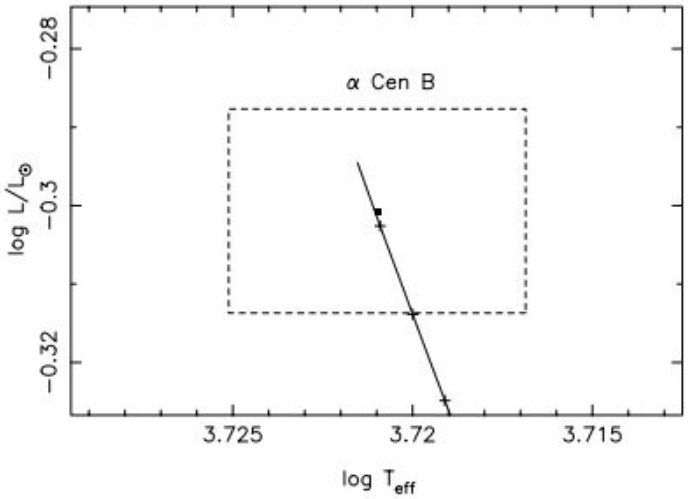


(Borkovits+2020, MNRAS)

Alpha Cen:
Towards precise parameters

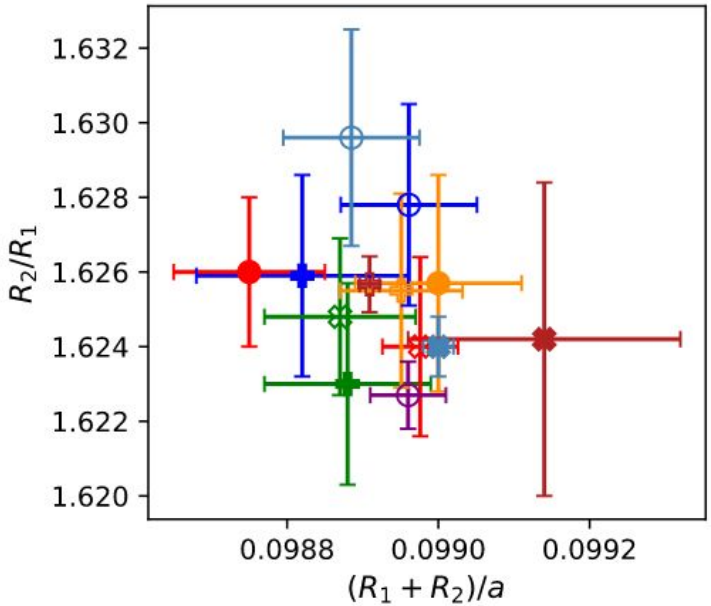
Thevenin+2002

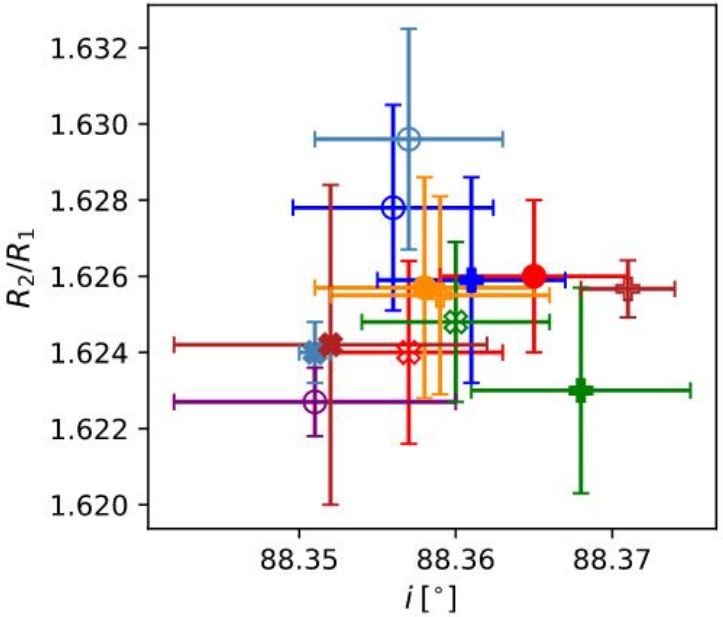




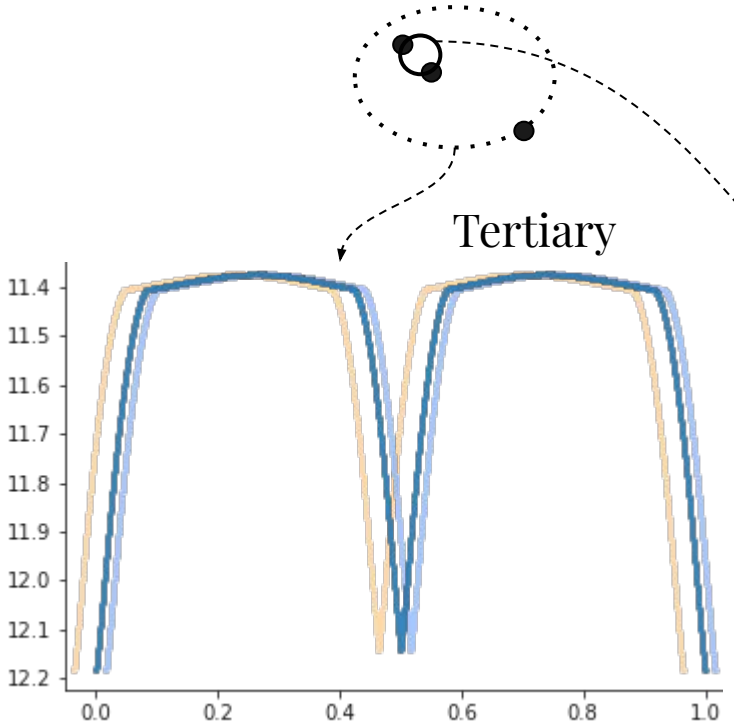
Detached Eclipsing Binaries

Source of precise params
(Maxted et. al, 2020, MNRAS)

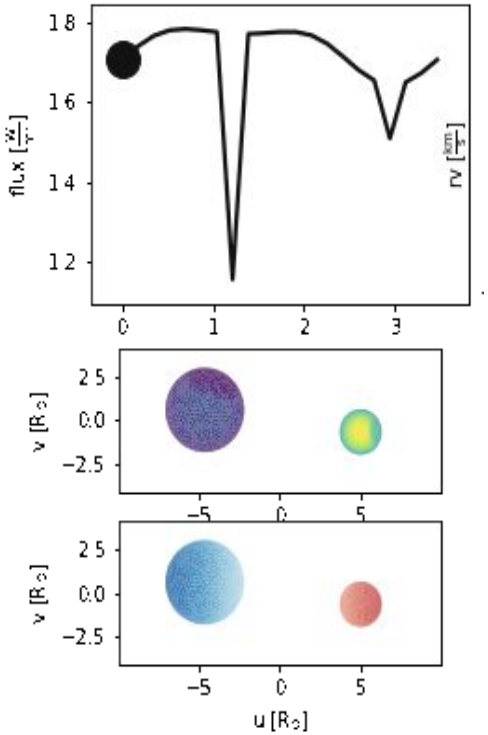




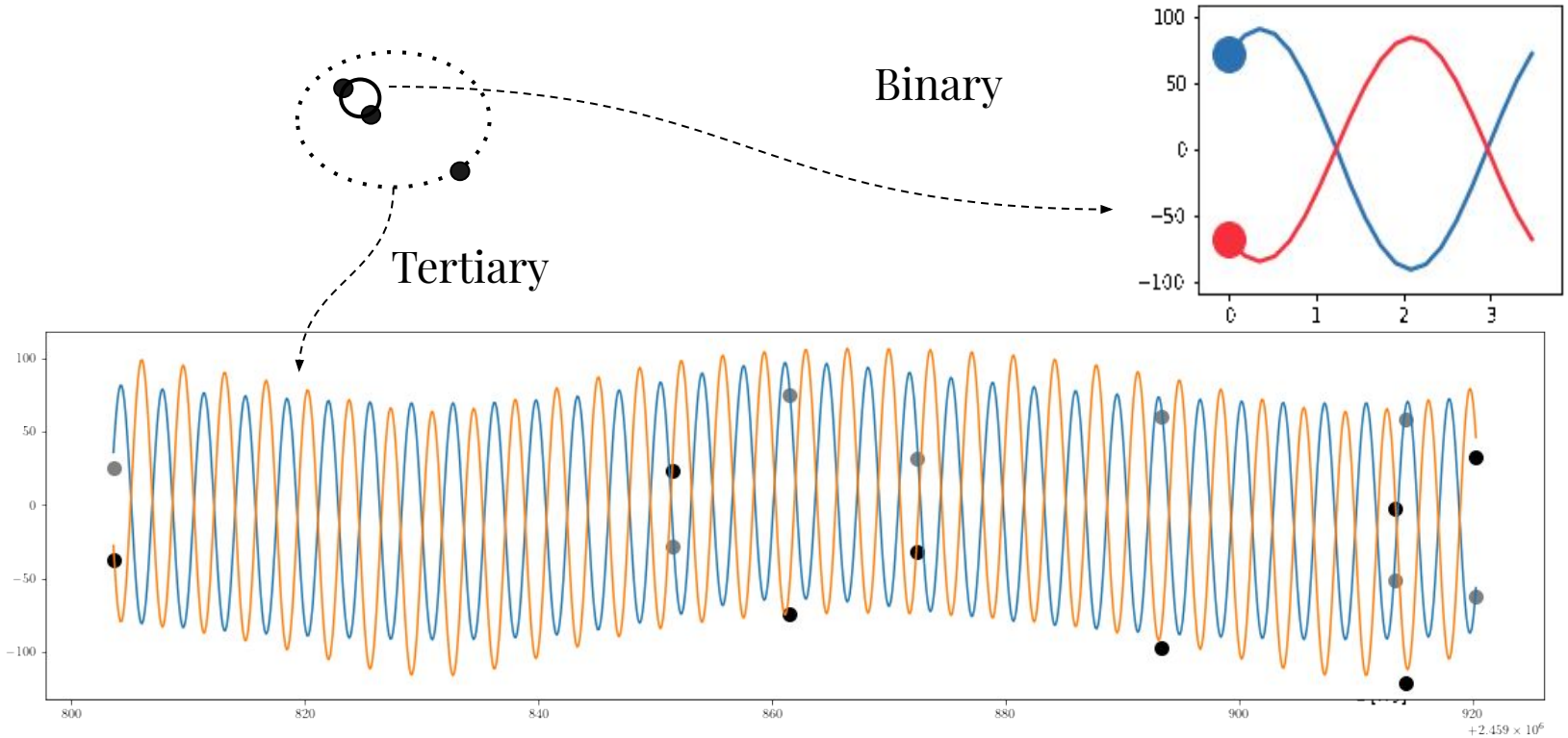
Eclipse Timing Variations



Binary

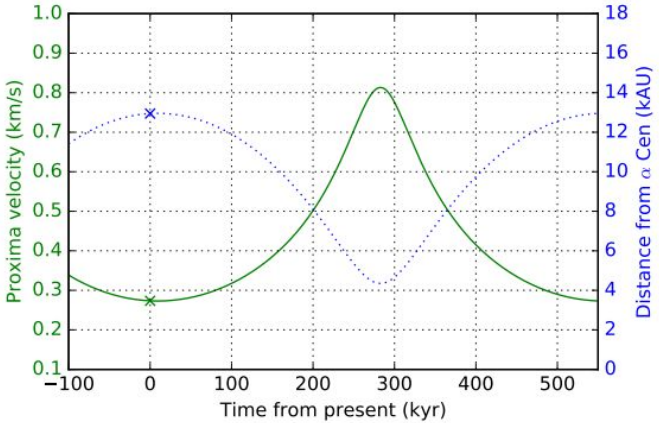


Radial Velocities

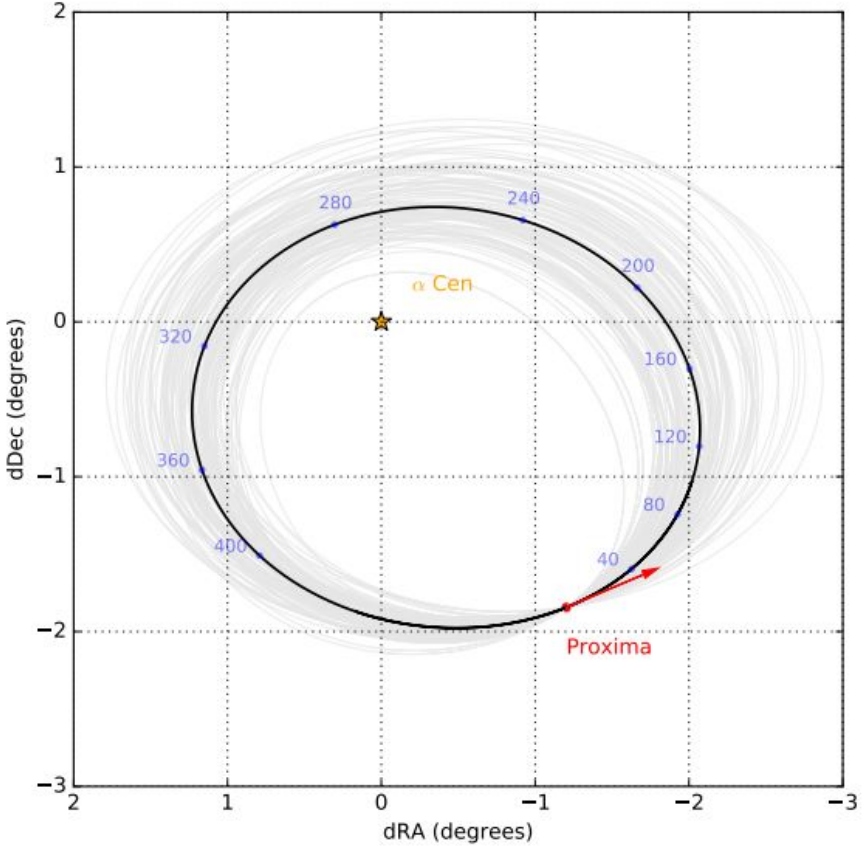


Alpha Cen:

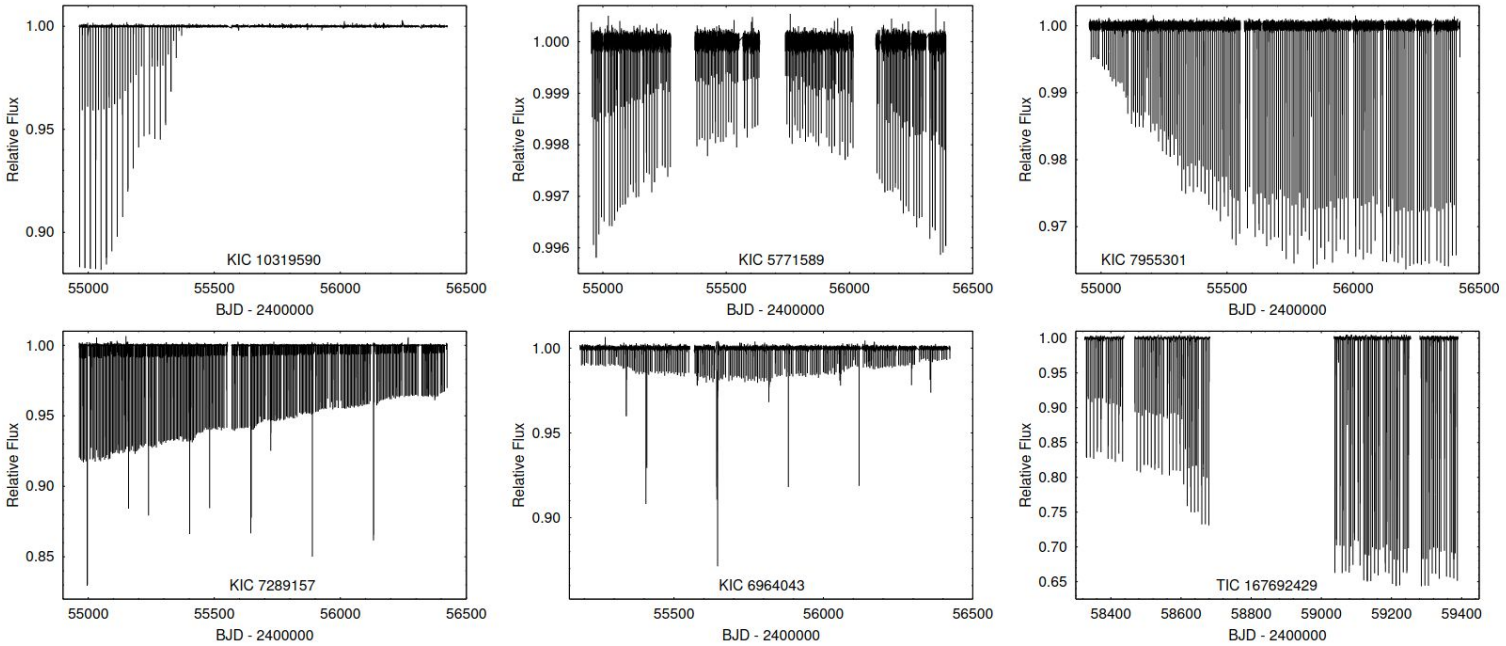
Towards new worlds



Kervella+2017



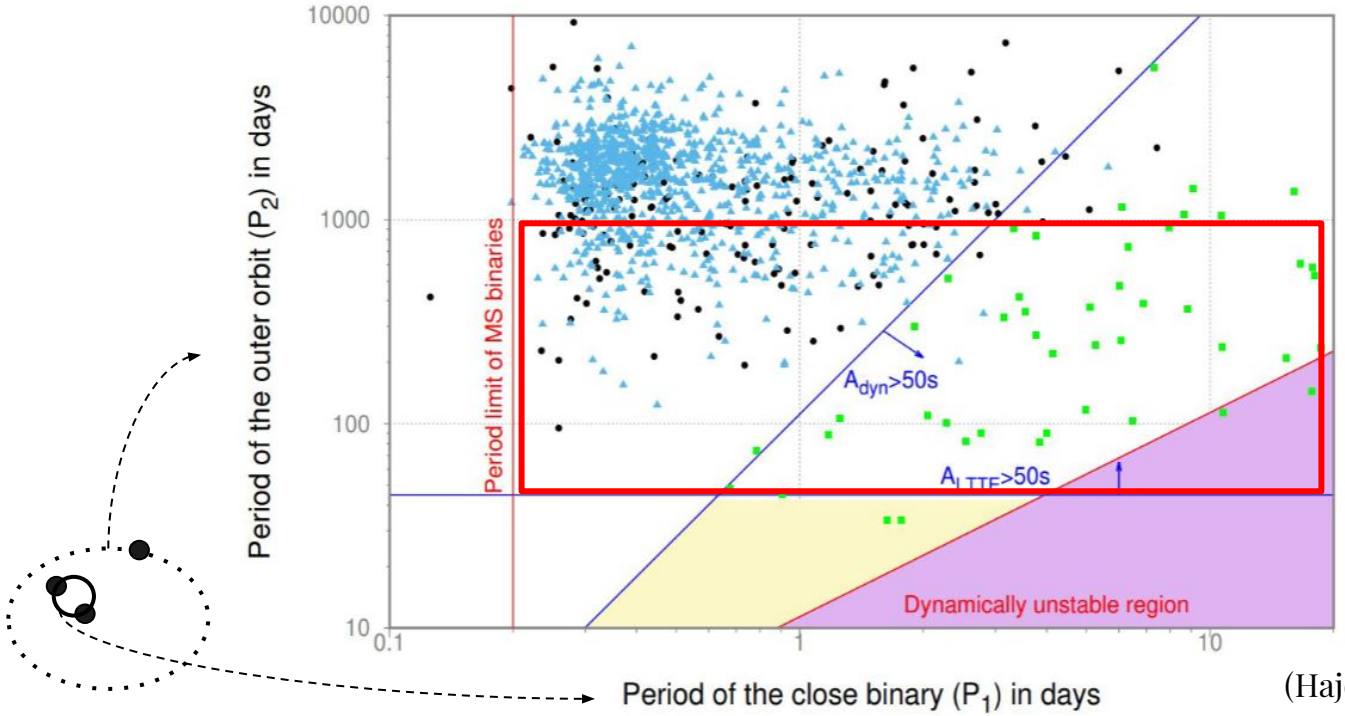
Compact Hierarchical Triples



(Borkovits, 2022, Galaxies)

Observable Dynamical Changes

Compact Hierarchical Triples



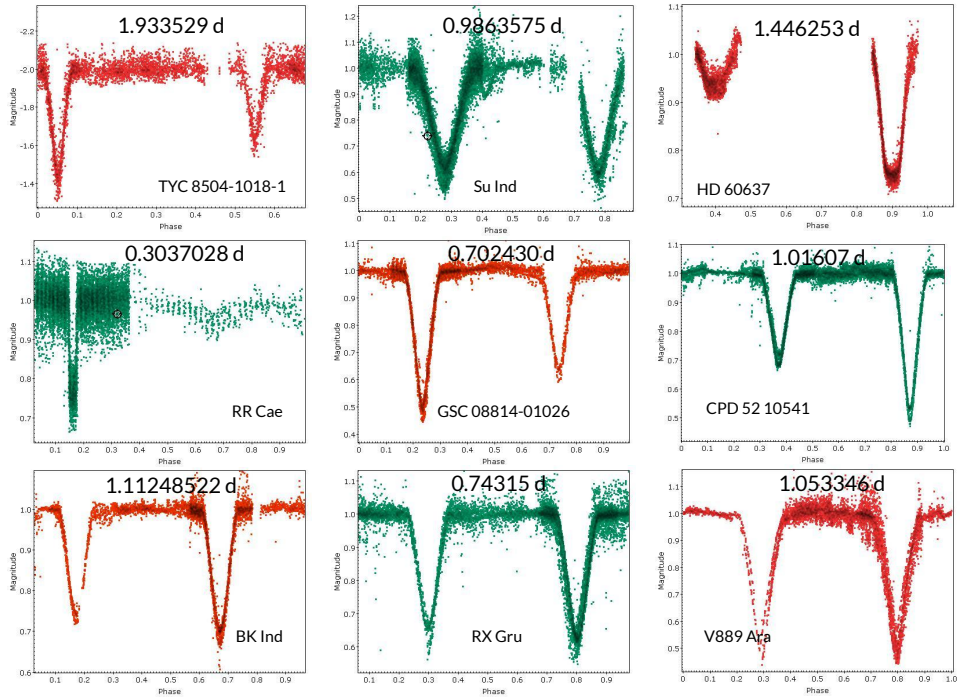
Were thought to be rare, increased detection since last decade

(Hajdu+2019, MNRAS)

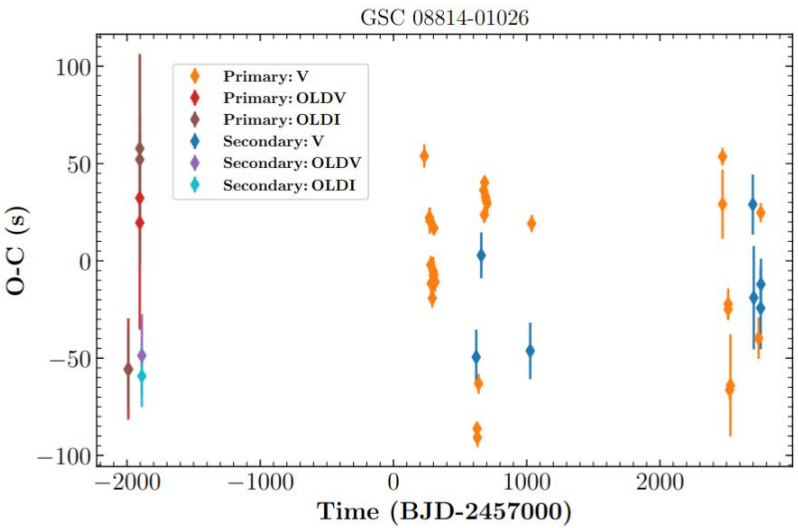
Observing more CHTs.

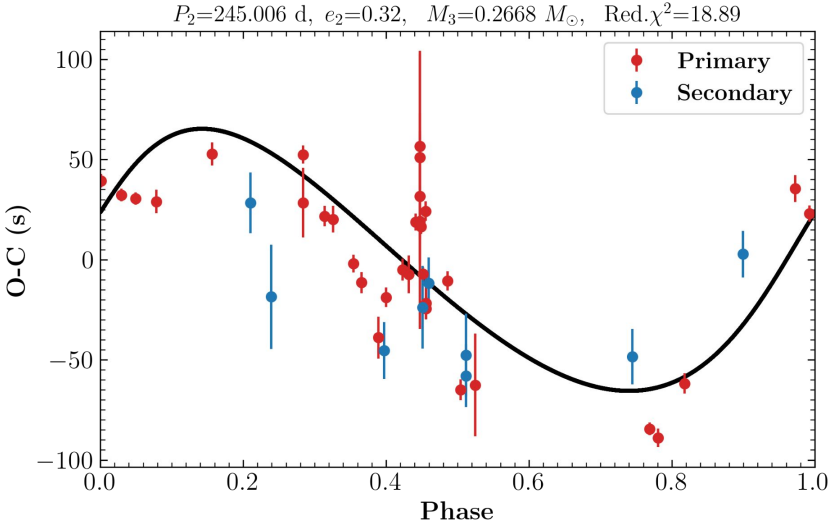
Eclipse Timing Variations: SOLARIS

PI: M. Konacki



Eclipse Timing Variations: SOLARIS

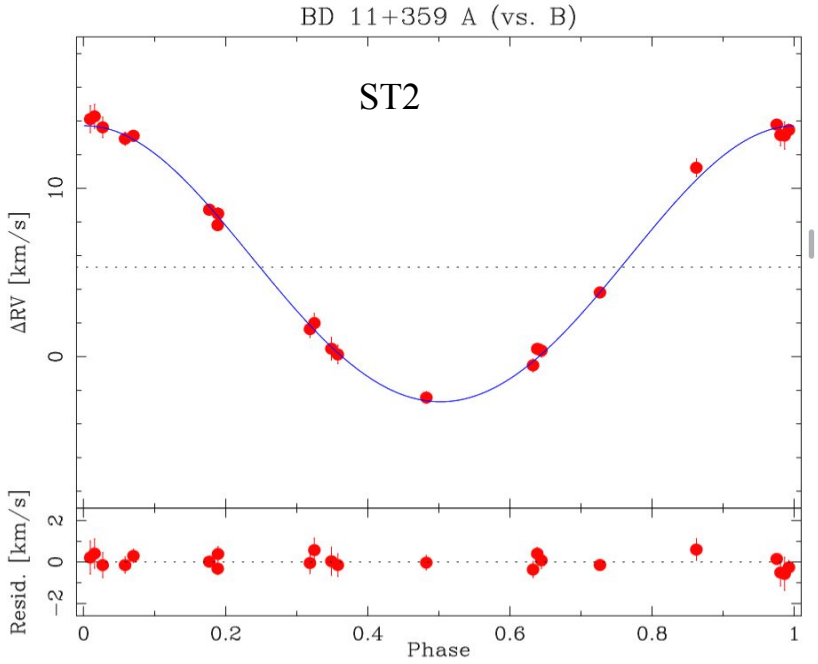


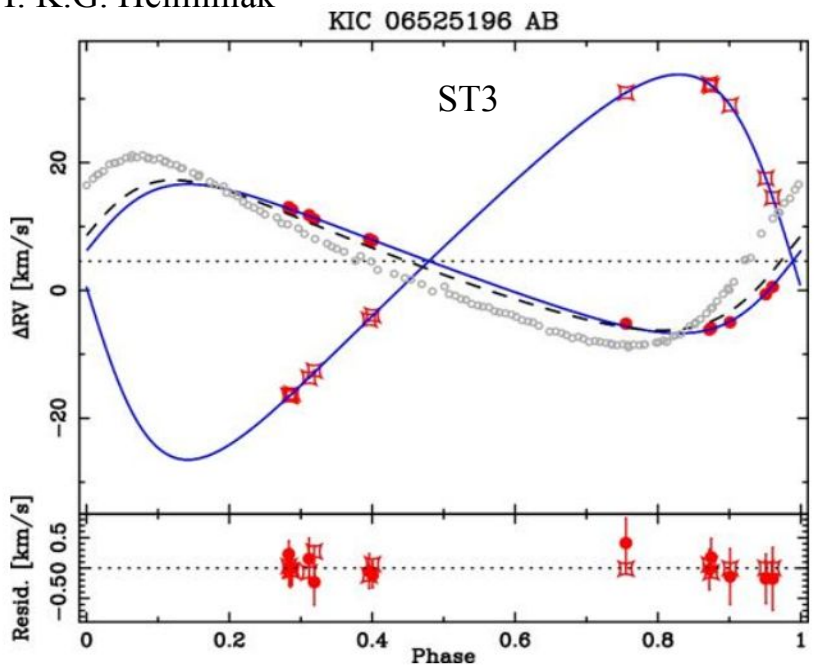


(Moharana et al, submitted to MNRAS)

Radial Velocities: CRÉME

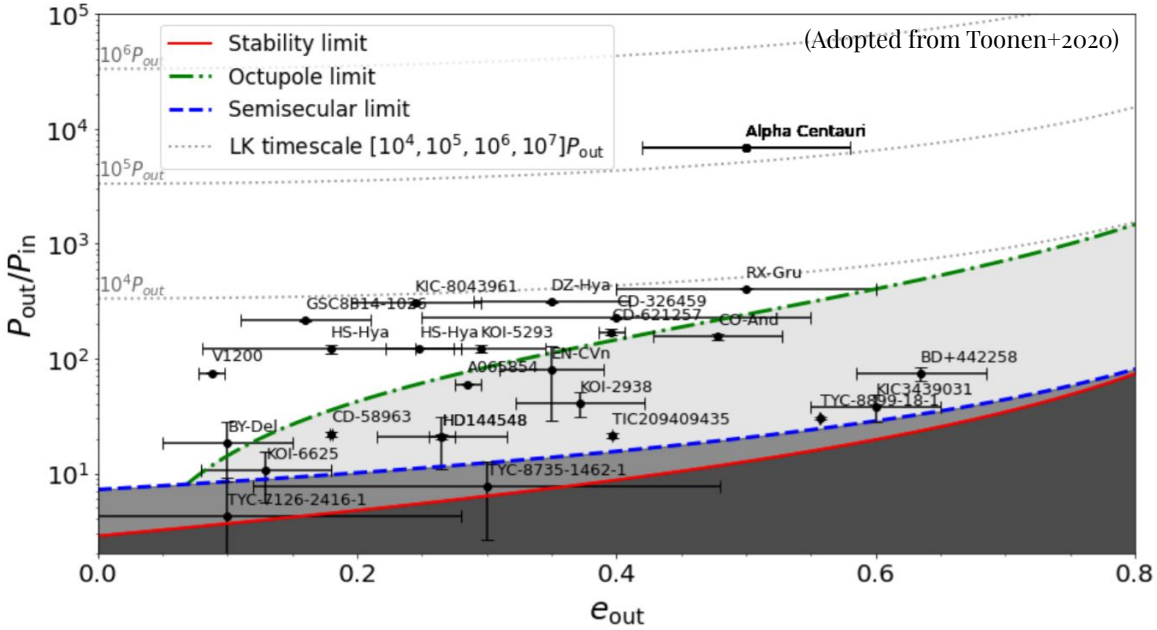
PI: K.G. Hełminiak





(Hełminiak et al., 2017, MNRAS)

Sample: CRÉME



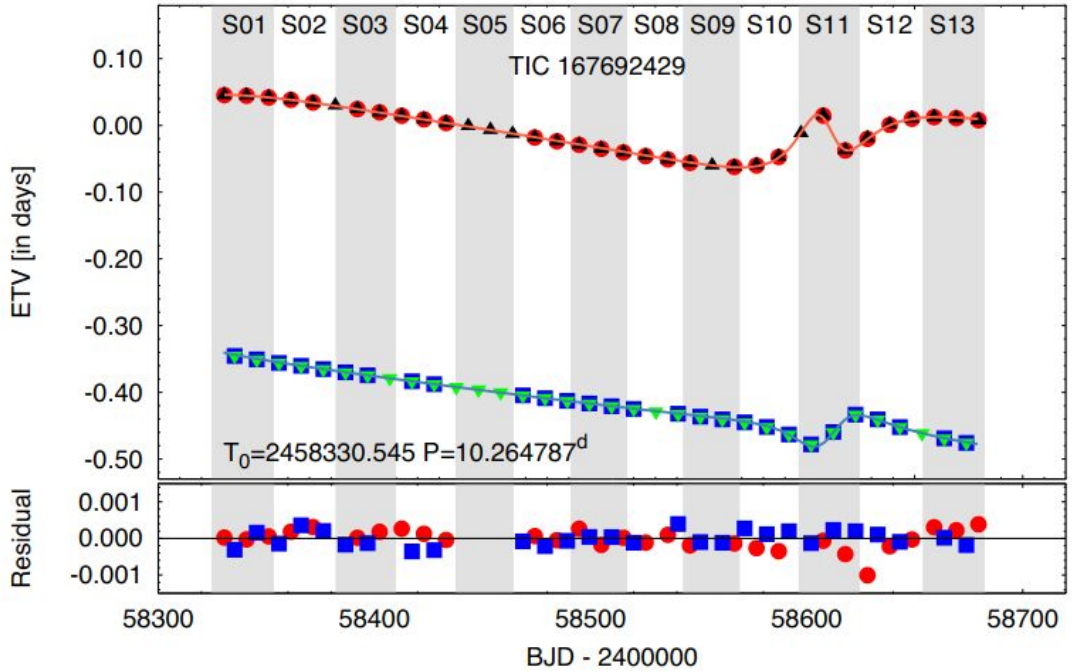
(Adopted from Toonen+2020)

(Moharana et al., 2022, PPASM)

Detailed look into evolution and dynamics.

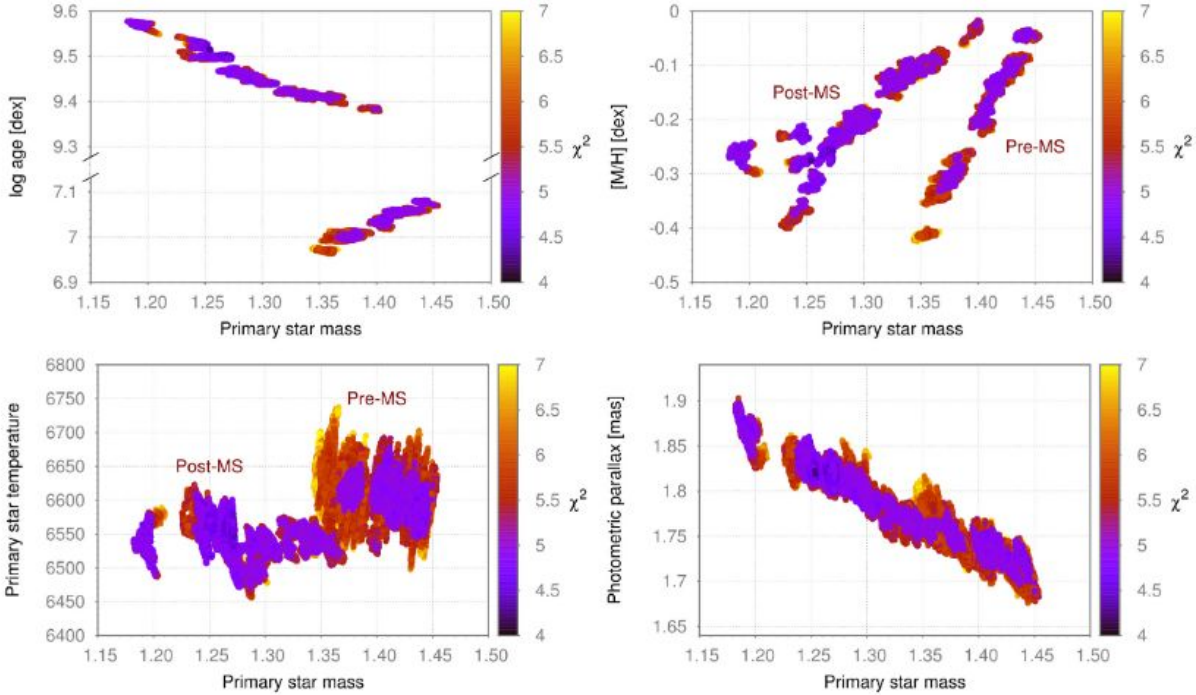
Constraining Evolution

TIC 167692429 (TIC167) (Borkovits+20)

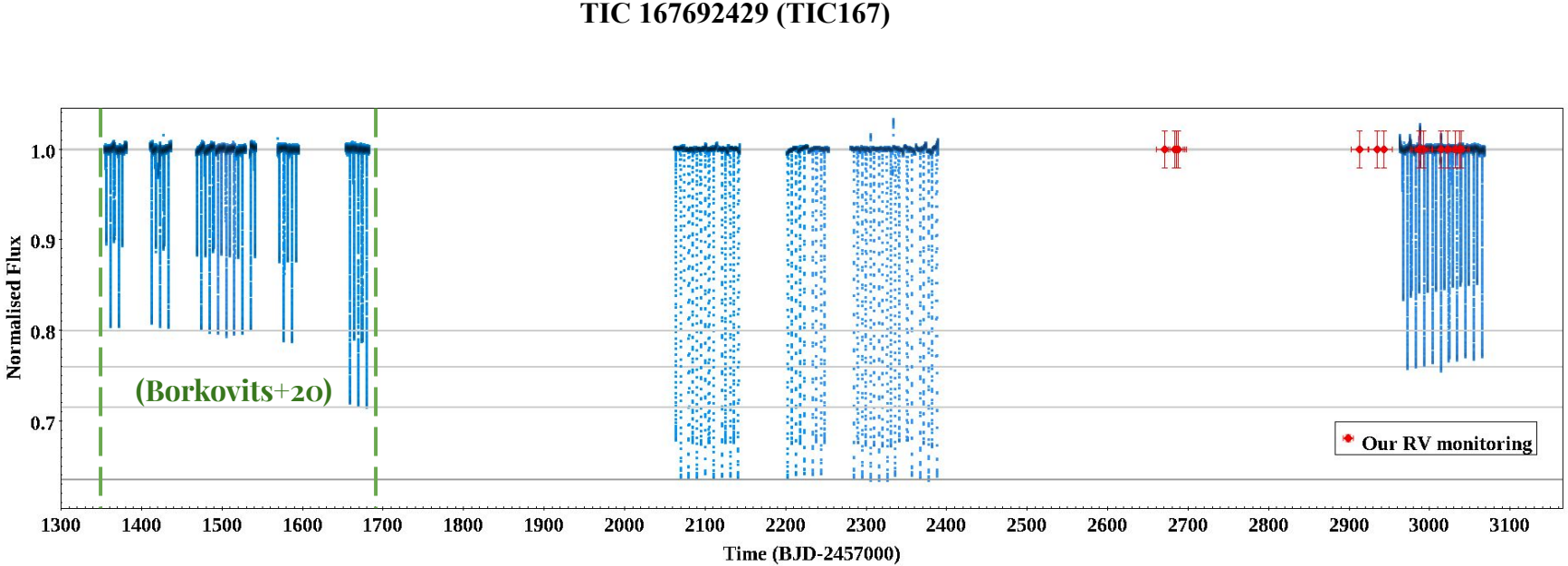


Constraining Evolution

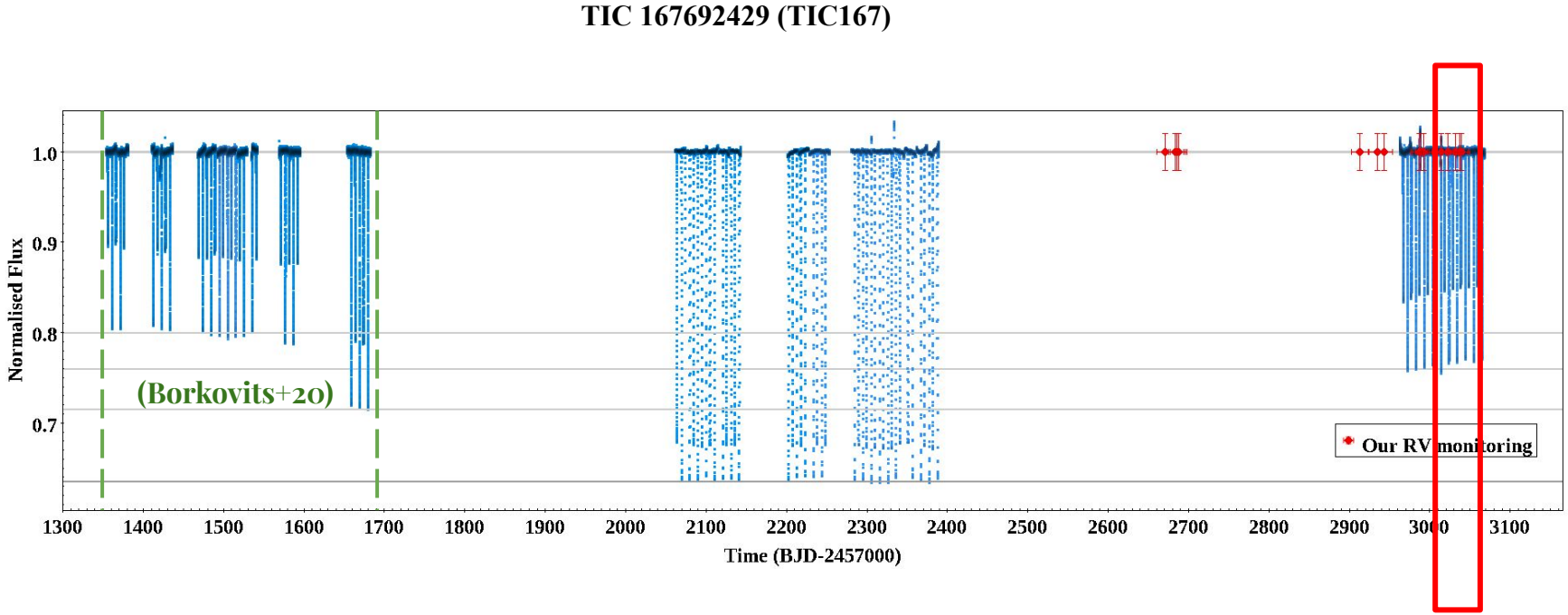
TIC 167692429 (TIC167) (Borkovits+20)



Constraining Evolution



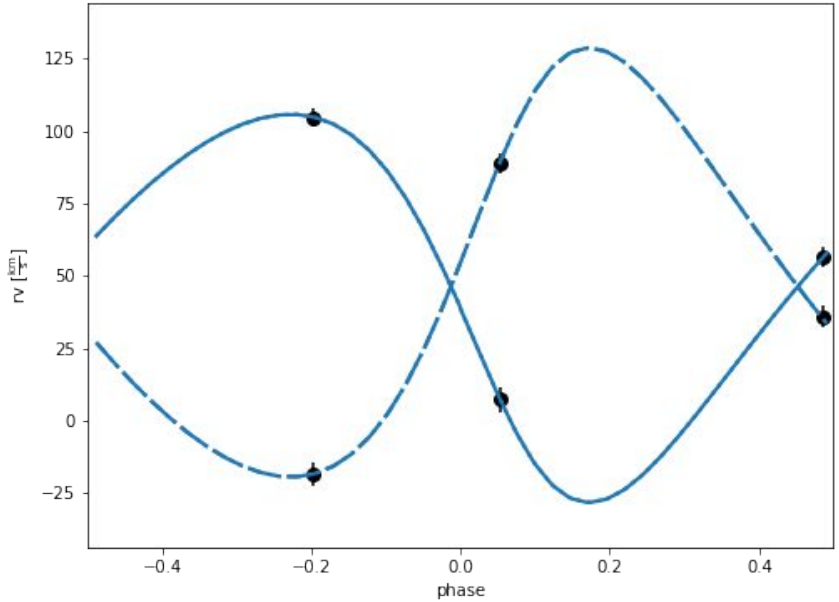
Constraining Evolution



Constraining Evolution

TIC 167692429 (TIC167)

Parameters	Post-MS	Pre-MS	SALT HRS (Select)
Binary Mass Ratio	1.008	**0.993**	**0.910**
Primary Mass	1.284	**1.402**	**1.482**

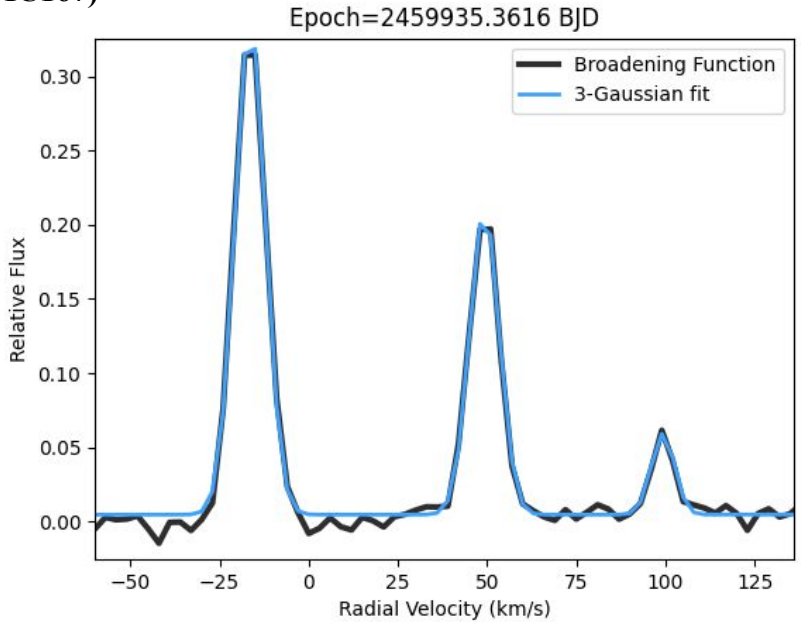


(Moharana + (c), in prep.)

Constraining Evolution

TIC 167692429 (TIC167)

Parameters	Post-MS	Pre-MS	SALT HRS (ALL)
Binary Mass Ratio	1.008	**0.993**	**0.910**
Primary Mass	1.284	**1.402**	**1.482**
Fractional Flux Primary	**0.5370**	0.4873	**0.5782**

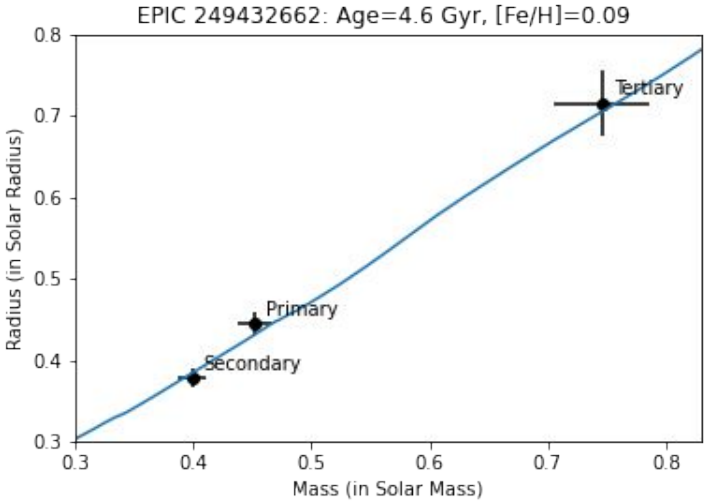


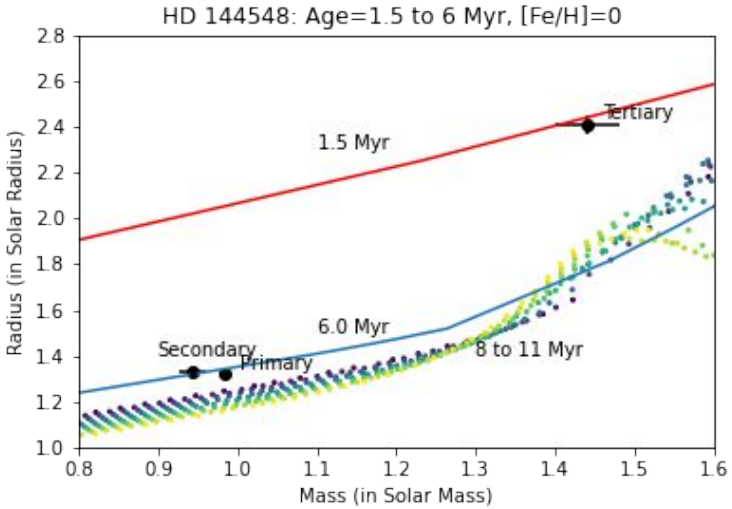
(Moharana + (c), in prep.)

Assumption of co-evolving CHT wrong?

Constraining Evolution

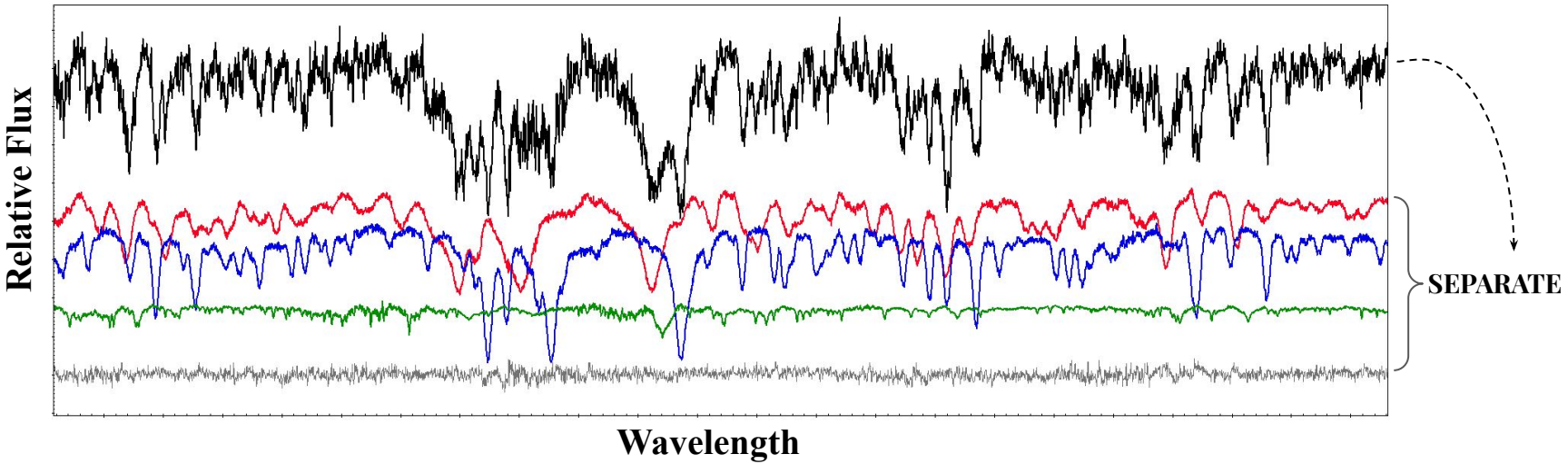
- **Are such compact triples co-evolving?**
- **Is the triple captured or formed late?**
- **Different tertiary metallicity ?**





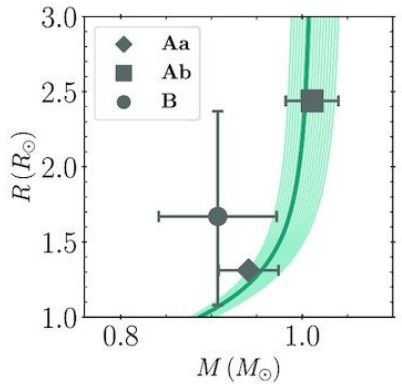
Spectral Disentangling

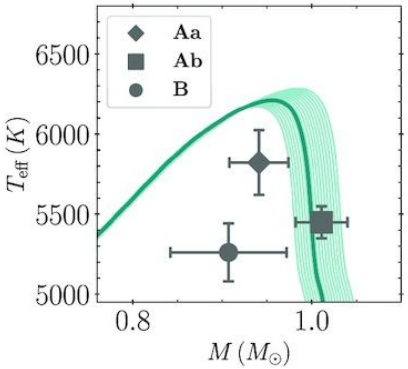
- **Separate out the component spectra from time-series composite using Fourier decomposition in fd3 (Ilijic+2004).**
  Python wrapper: github.com/ayushmoharana/fd3_initiator

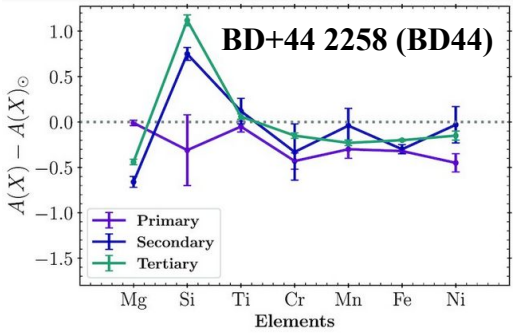


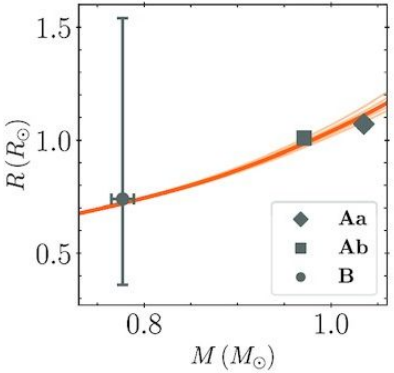
Constraining Evolution

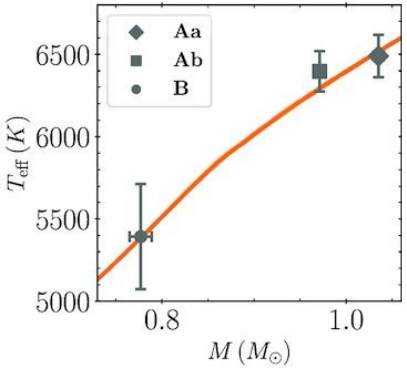
(Moharana+2023, MNRAS)

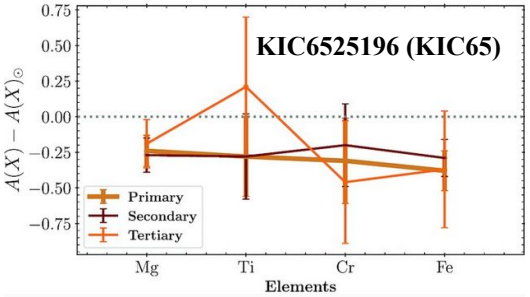












Predicting Dynamics

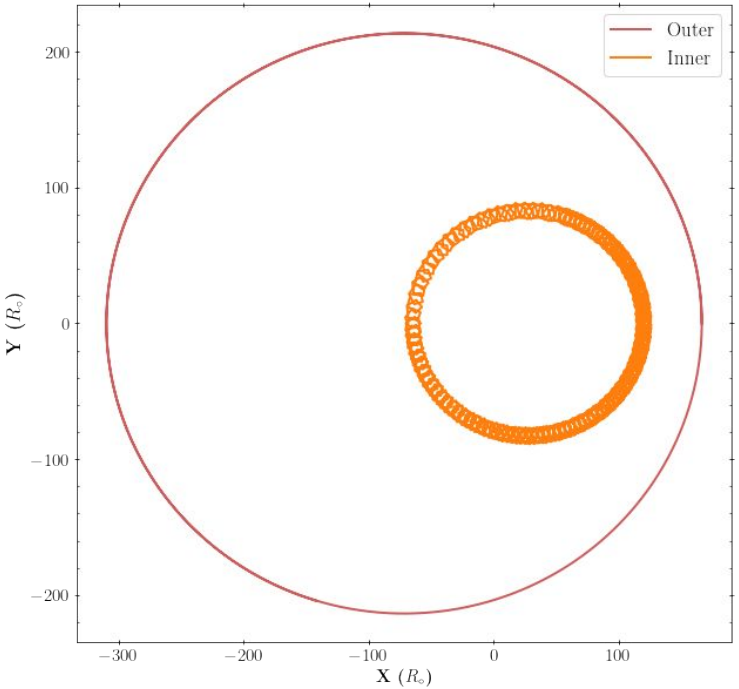
3-body numerical orbital simulations:

- **REBOUND (Rein & Liu 2012)**
- **WHFAST (Rein & Tamayo 2015)**

Additional dissipative tidal forces:

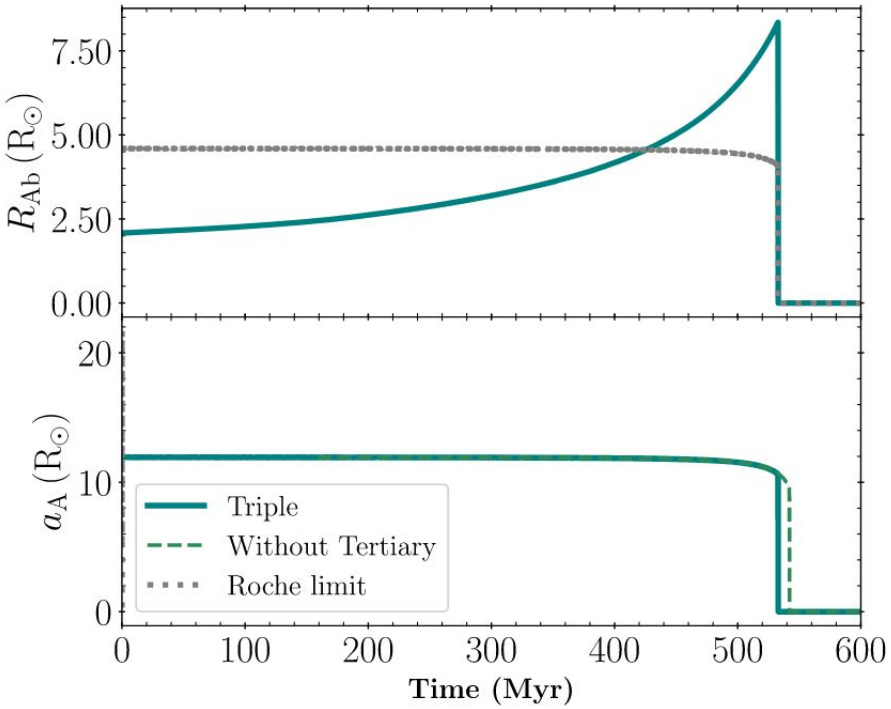
- **REBOUNDx (Tamayo+2019)**
- **Interpolated Mass and Radius from MESA tracks**
- **Constant time lag parameter introduces dissipation (Baronett+2022) :**

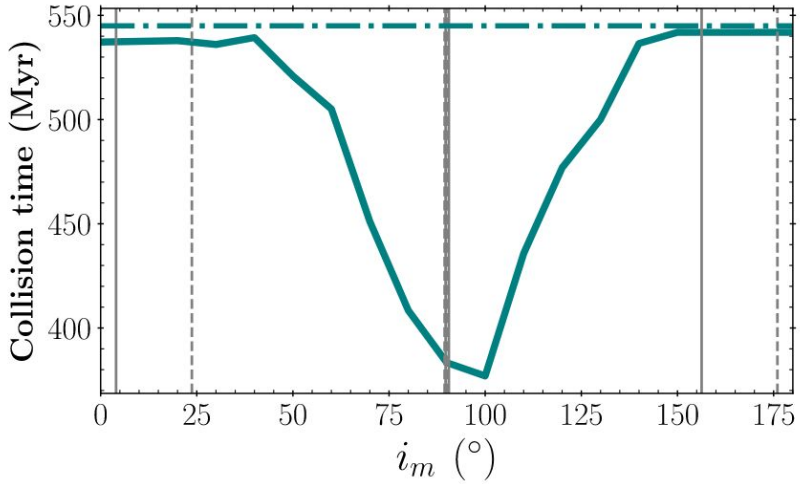
$$\tau = \frac{2R^3}{GMt_f}$$



Mergers and Collisions

BD+44 2258 (BD44)





(Moharana+2023, MNRAS)

Future work: Looking back

(Tokovinin , 2022, Universe)

Scenario	Predictions
Sequential disk instability (DI+DI)	Aligned orbits with moderate eccentricity, $q_{in} \geq q_{out}$, moderate period ratios, no 2+2 quadruples.
Sequential core fragmentation (CF+CF, DI+CF)	Non-coplanar, eccentric orbits. Wide range of mass ratios.
Late disk instability (CF+DI2)	Small q_{in}, misaligned inner subsystems.
Cloud collisions	Wide 2+2 quadruples, comparable masses
Dynamical interactions	Eccentric and misaligned orbits, small period ratio

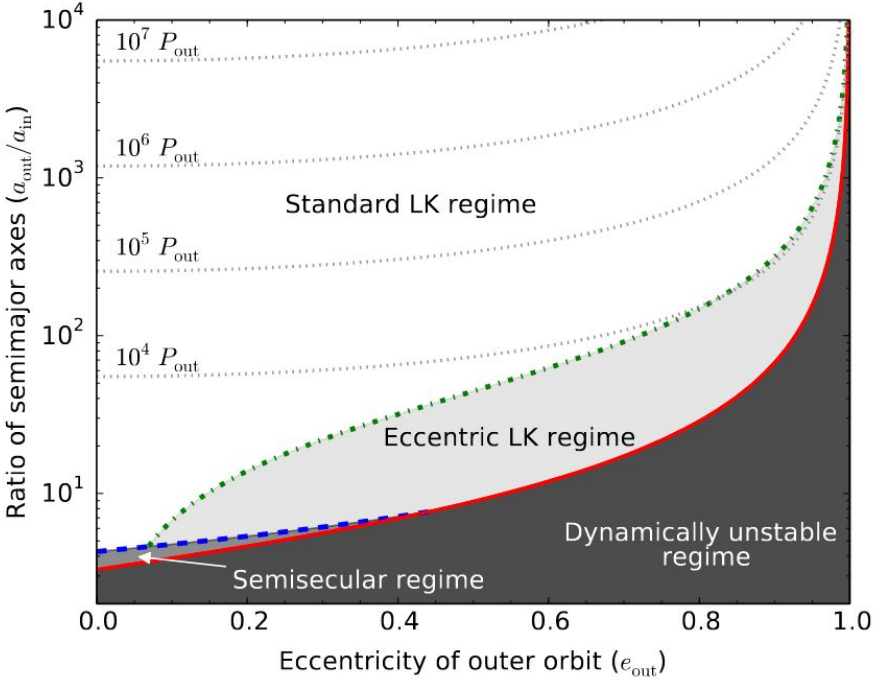
Summary

- **Need for accurate and independent measurement of parameters:**
  - Measurement of parameters for CHT not trivial but possible.
  - A database to facilitate modelling and testing.
  - More observations of eclipsing binaries=> CHT
- **The dynamical effect from tertiary can affect the evolution of the inner binary:**
  - Tertiary can affect the timescale of contact/common-envelope phases and mergers. Complete set of observed parameters => Realistic simulations.
- **Future Work:**
  - Distribution of inclinations, abundance of tertiary and rotation speeds => Formation scenarios

Thank You.

Appendix

Dynamic regimes



Spots from ETV

(Tran et. al, 2013, ApJ)

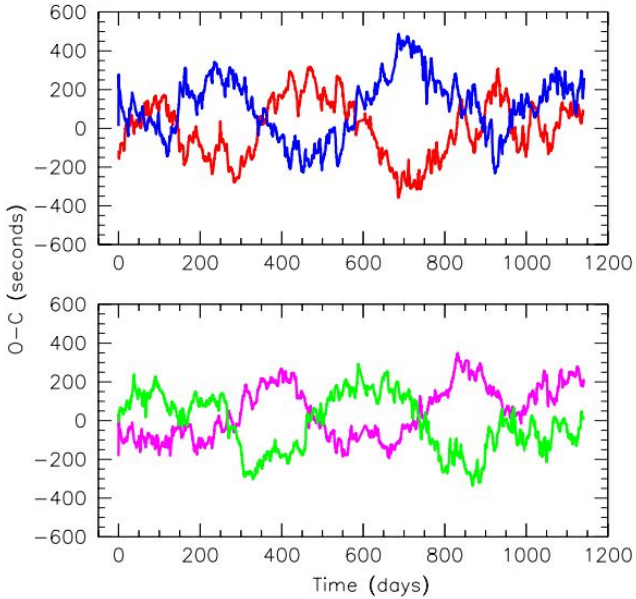
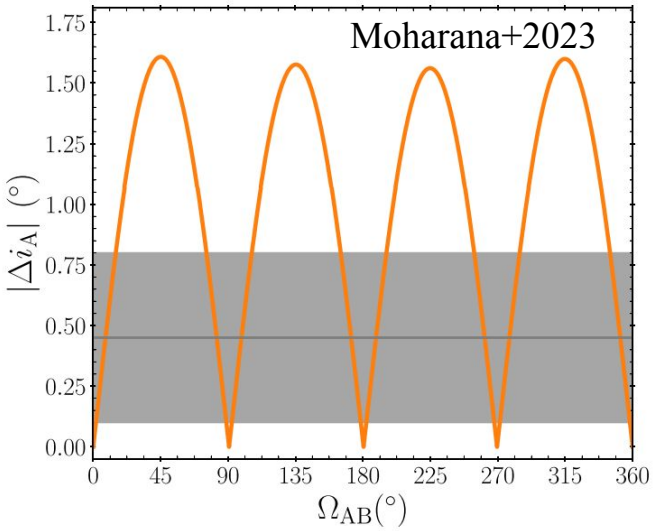


Figure 6. $O-C$ curves for KIC 9451598 showing anticorrelated behavior between the minima (top panel) as well as the maxima (bottom panel). Note that the curves in the bottom panel are ∼90° out of phase with respect to those in the top panel.

Mutual Inclination

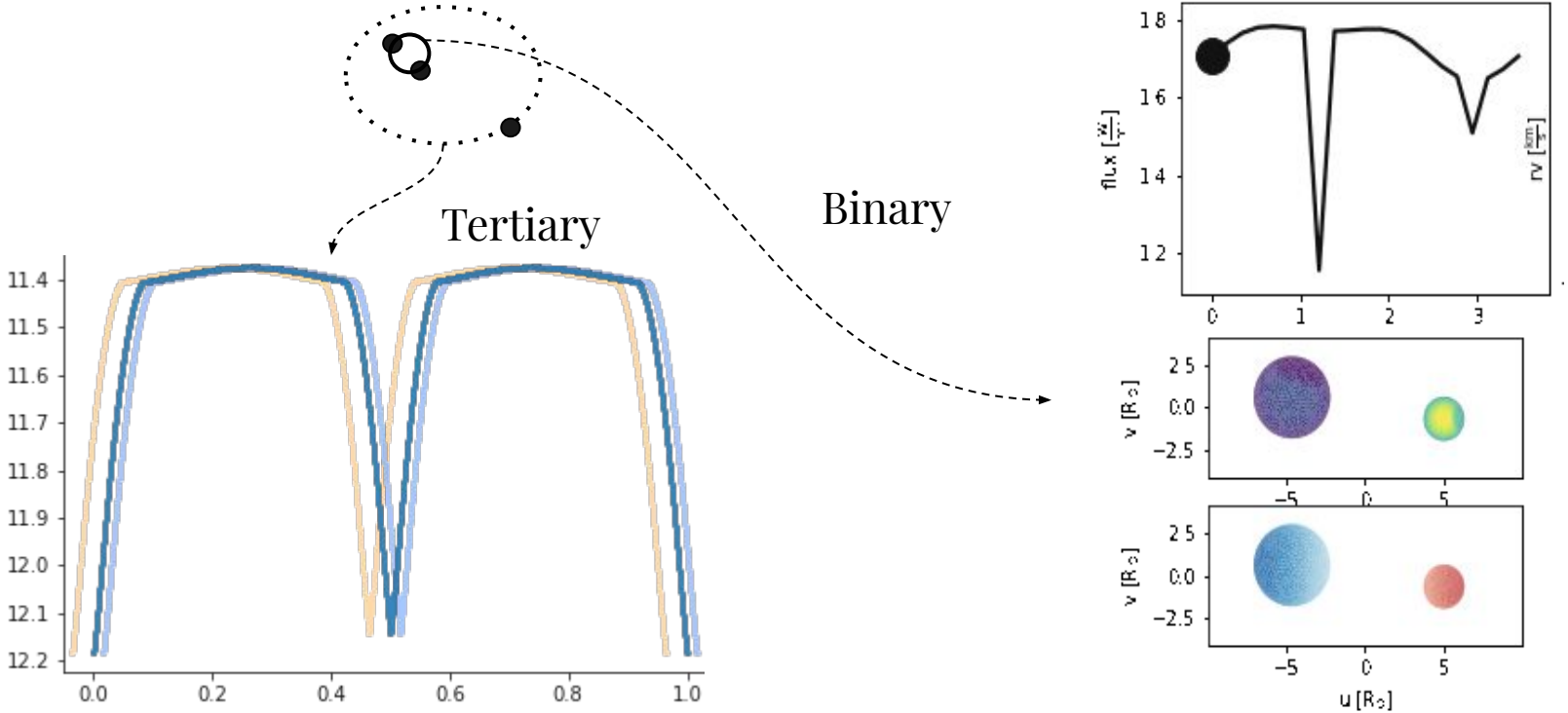


System	Ω_{AB}	i_m	
		Config.A	Config.B
BD44	359.46 ± 0.76	4.03 ± 0.10	175.97 ± 0.01
	266.97 ± 0.79	90.56 ± 0.76	89.45 ± 0.76
	180.23 ± 0.83	156.27 ± 0.01	23.73 ± 0.01
	92.16 ± 0.80	89.71 ± 0.77	90.29 ± 0.77
KIC65	353.80 ± 4.85	6.18 ± 4.83	173.82 ± 4.83
	269.41 ± 11.12	90.09 ± 11.02	89.91 ± 11.02
	180.42 ± 11.18	164.60 ± 0.30	15.40 ± 0.30
	90.67 ± 11.10	90.16 ± 11.00	89.83 ± 11.00
	6.19 ± 4.85	6.17 ± 4.83	173.83 ± 4.83

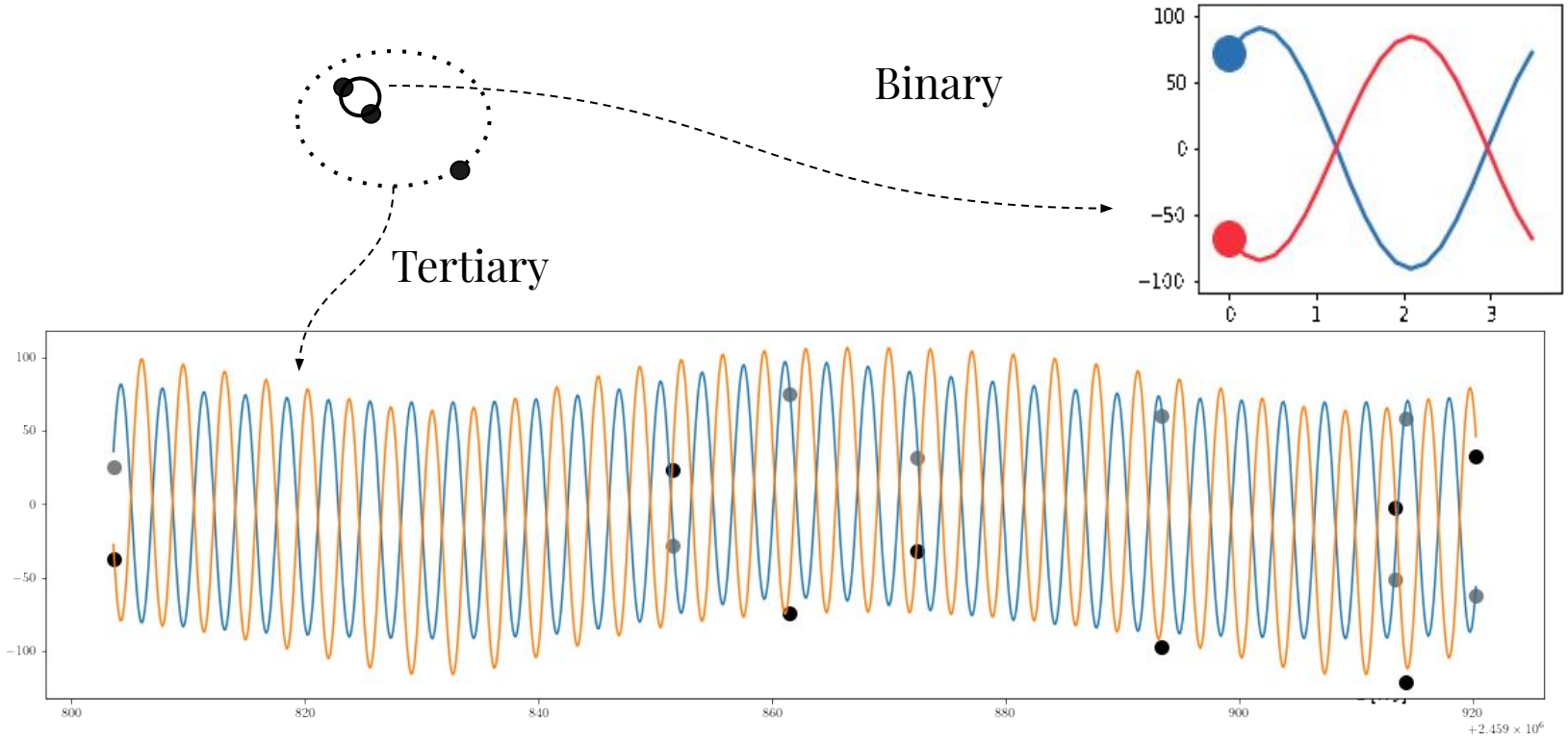
$$\cos i_m = \cos(\Omega_A - \Omega_{AB}) \times \sin i_A \sin i_{AB} + \cos i_A \cos i_{AB}.$$

Gronchi & Tommei (2007)

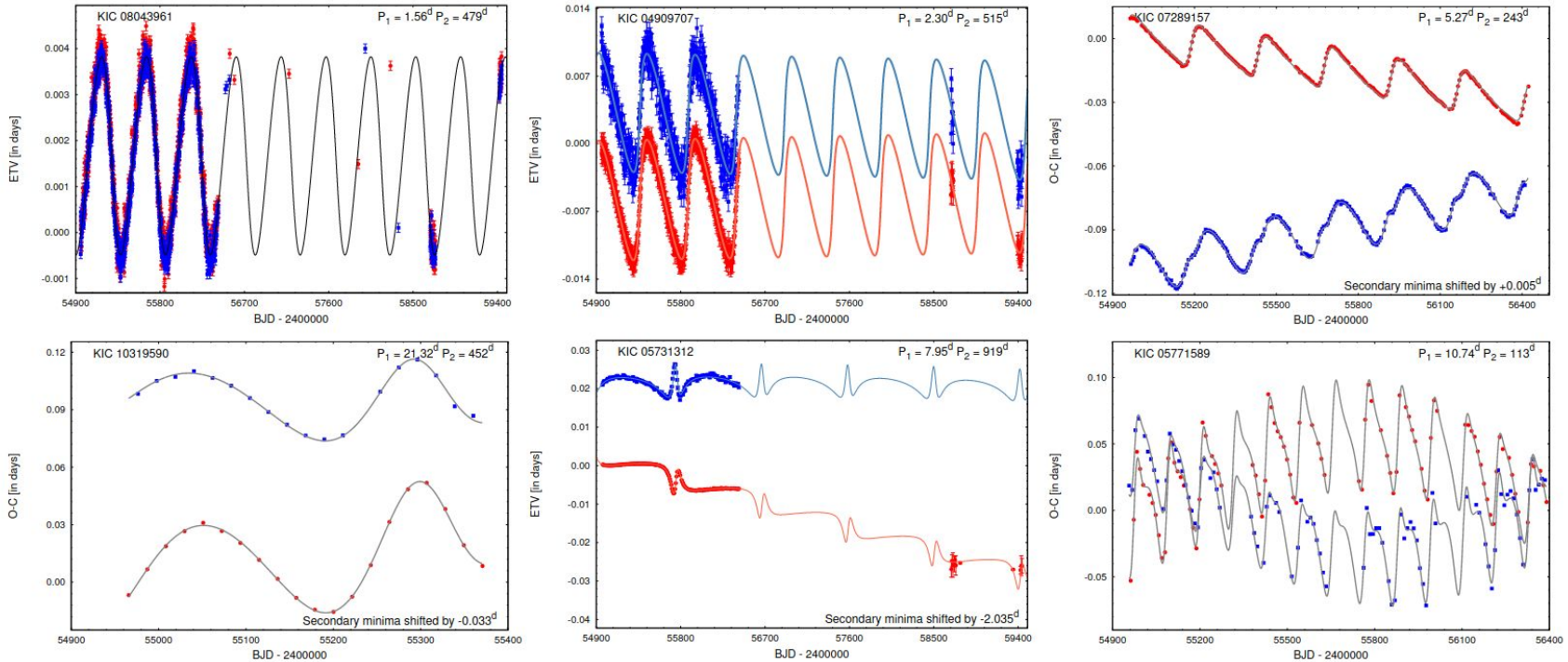
Eclipse Timing Variations



Radial Velocities

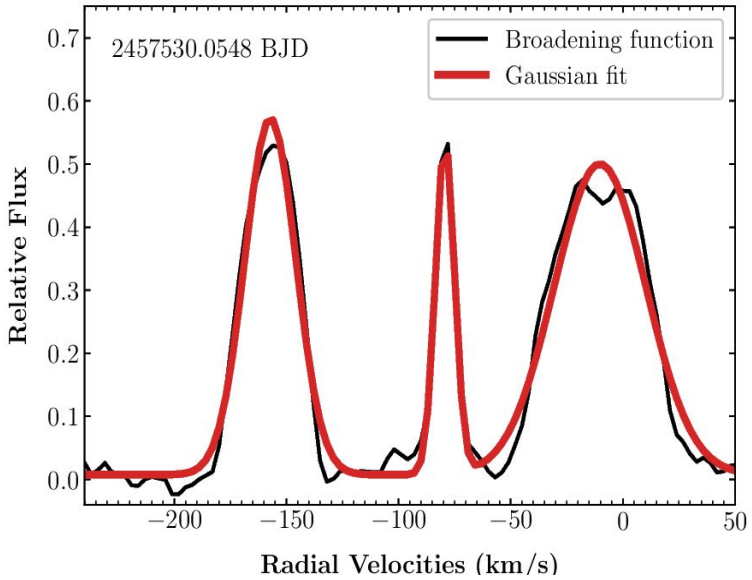


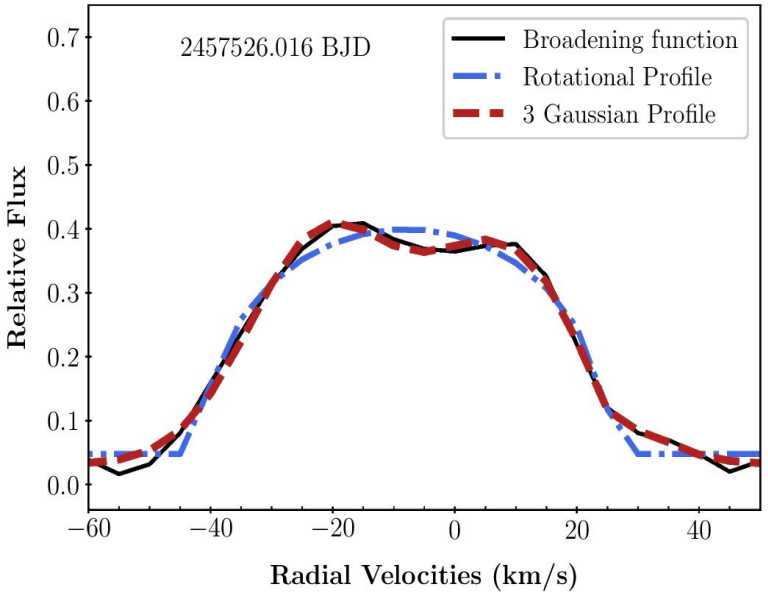
Detections: ETVs



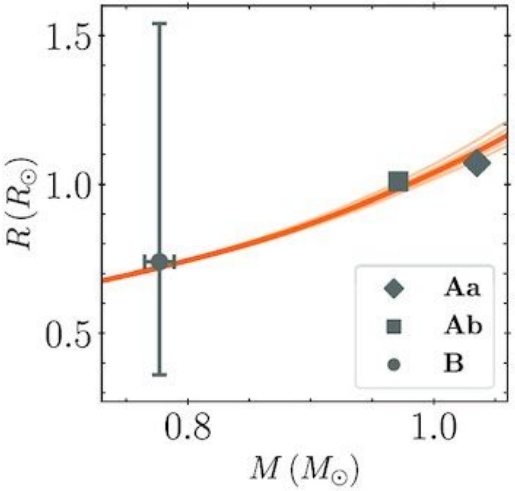
(Borkovits, 2022, Galaxies)

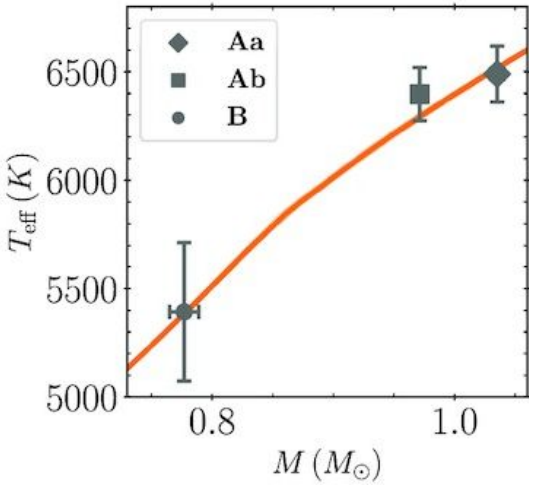
Broadening Functions

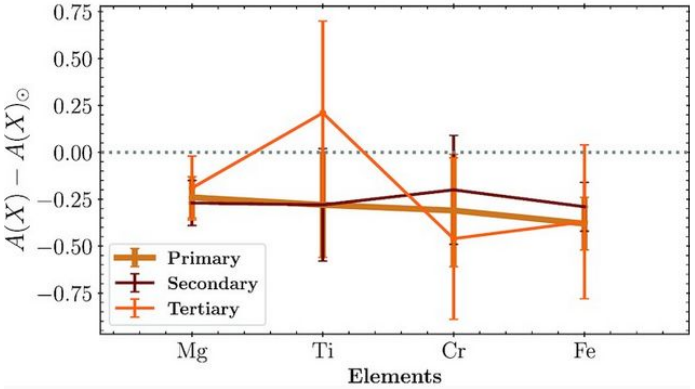




Testing Evolution



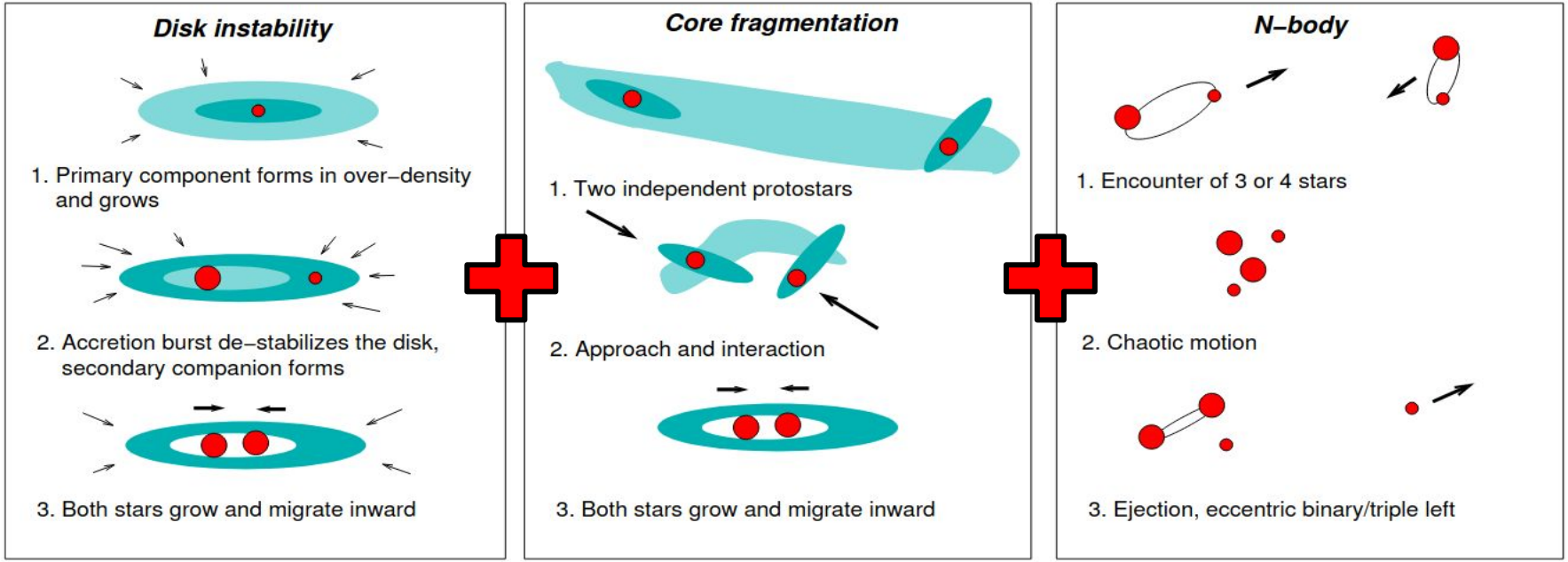




(Moharana et. al, 2023, MNRAS)

Triples: Formation

(Tokovinin , 2022, Universe)



Multiples: Formation

(Tokovinin , 2022, Universe)

Scenario	Predictions
Sequential disk instability (DI+DI)	Aligned orbits with moderate eccentricity, $q_{in} \geq q_{out}$, moderate period ratios, no 2+2 quadruples.
Sequential core fragmentation (CF+CF, DI+CF)	Non-coplanar, eccentric orbits. Wide range of mass ratios.
Late disk instability (CF+DI2)	Small q_{in}, misaligned inner subsystems.
Cloud collisions	Wide 2+2 quadruples, comparable masses
Dynamical interactions	Eccentric and misaligned orbits, small period ratio

Mergers and Collisions