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W-UMa type binaries
The case of puzzling TZ Boo

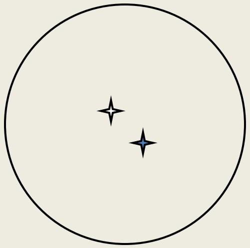
CCD photometric study of the puzzling W-UMa type binary TZ Boo

Christopoulou, P-E., Papageorgiou, A. and Chrysopoulos I. 2011, AJ, 142, 99

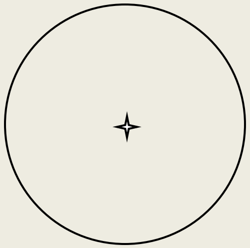
The 10th Hellenic Astronomical Conference, 5-8 September 2011, Ioannina

Binary Stars

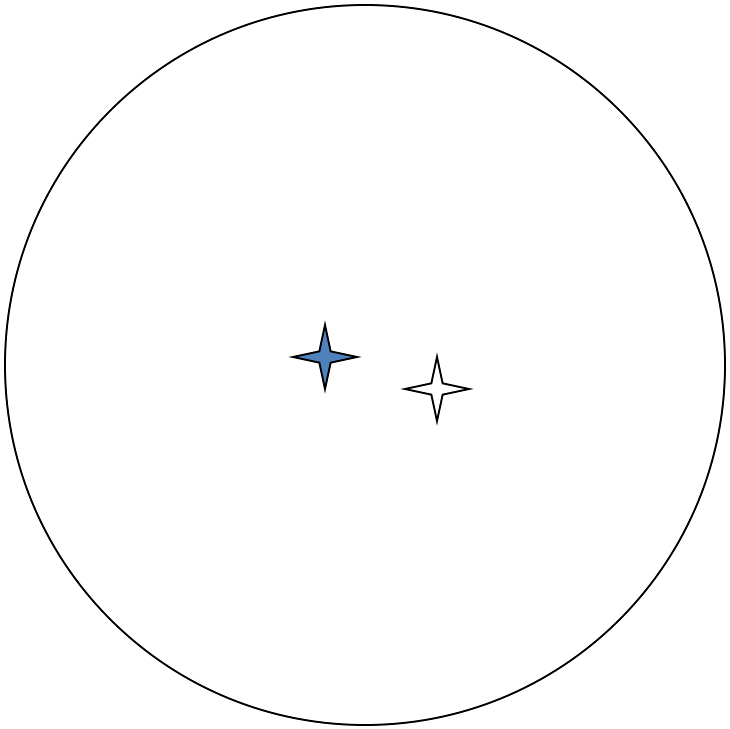
- Optical Doubles
- Visual Binaries



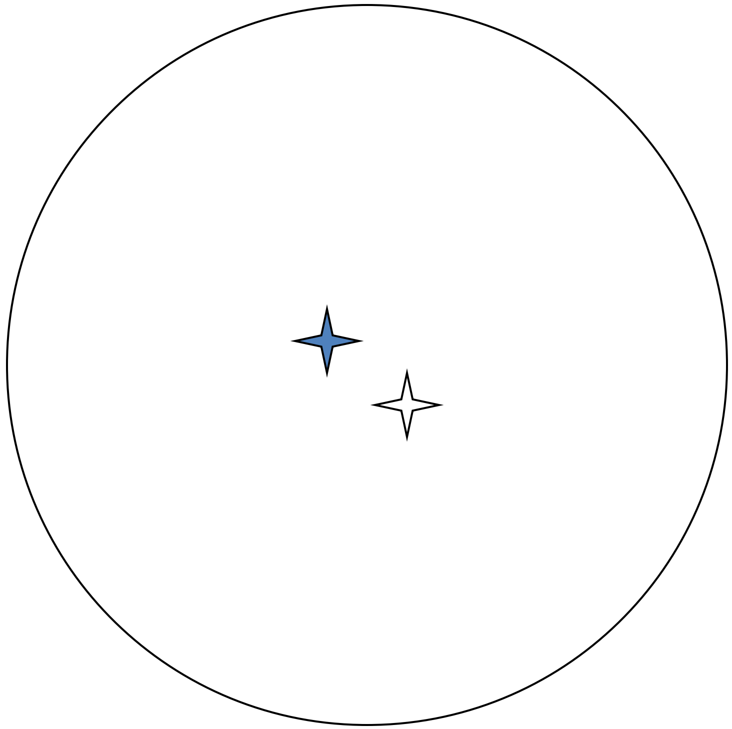
- Spectroscopic Binaries
- Eclipsing Binaries



What’s the difference?

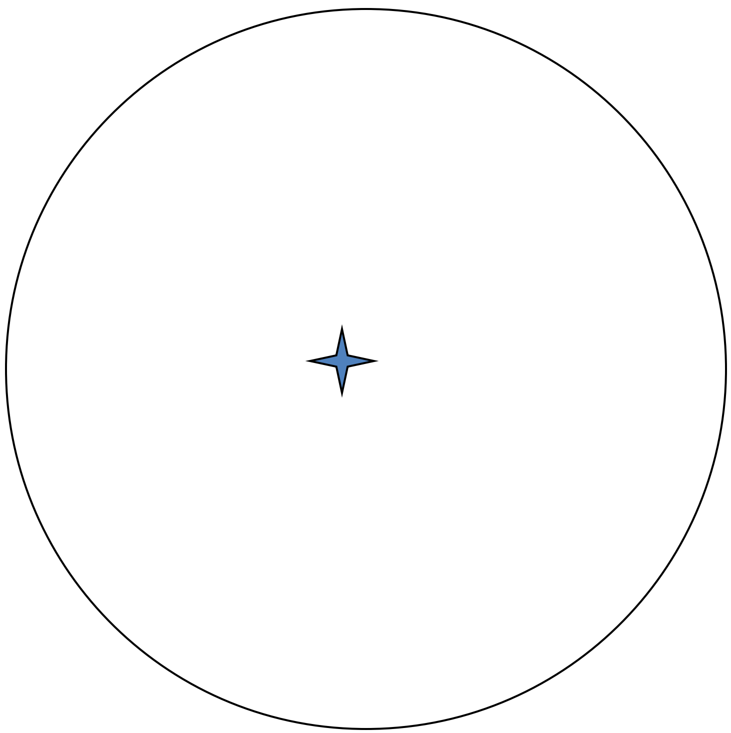


Optical Double

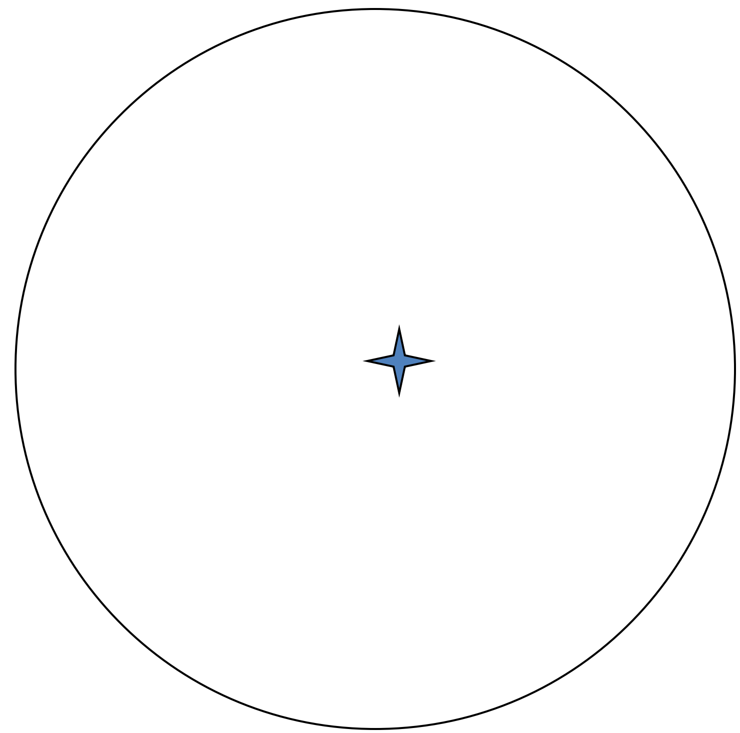


Visual Binary

What’s the difference?

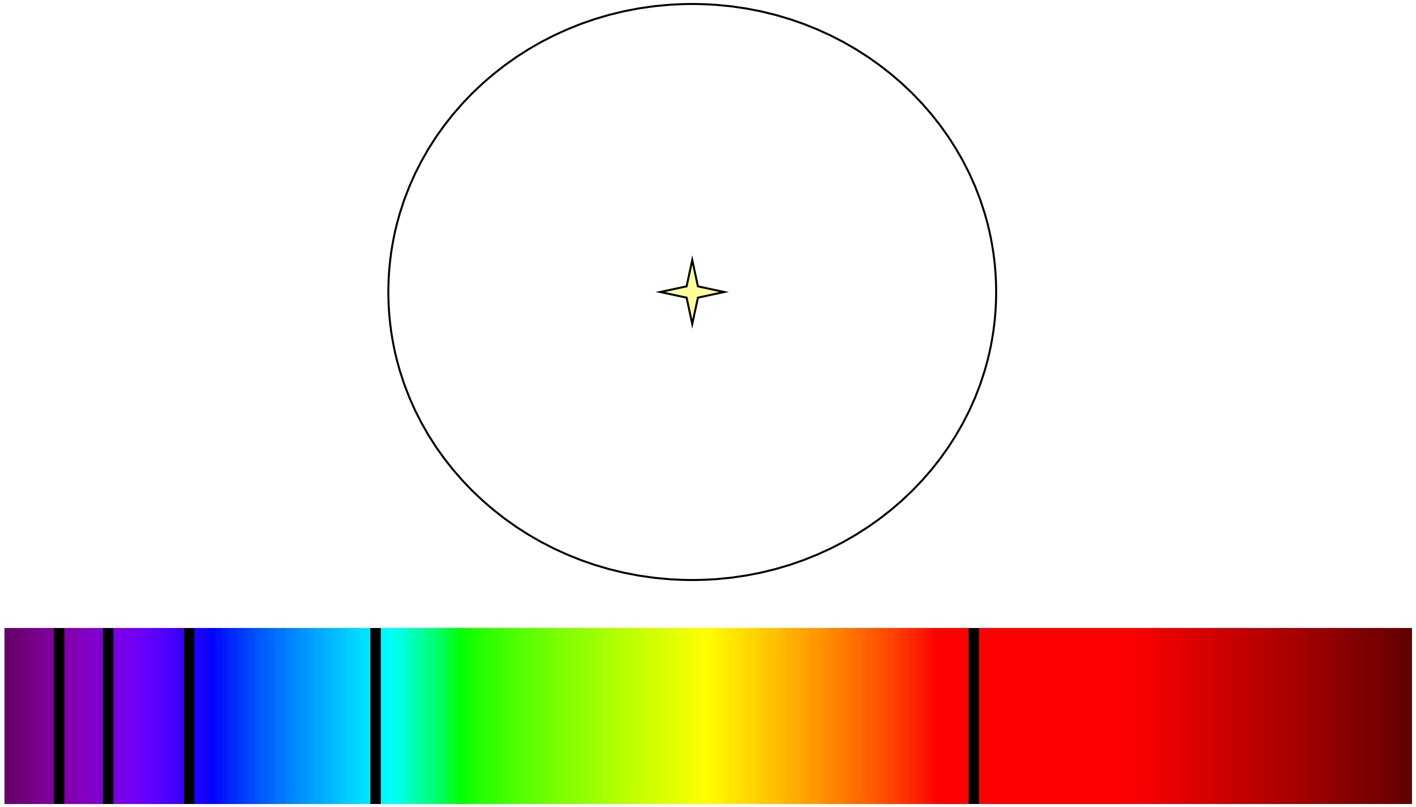


Spectroscopic Binary



Eclipsing Binary

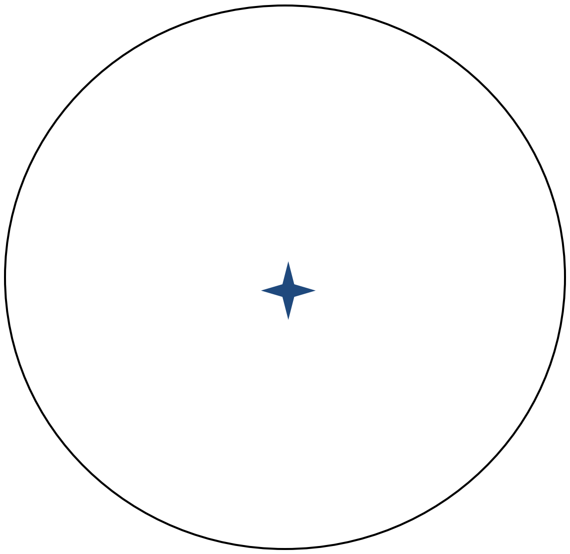
Spectroscopic Binary

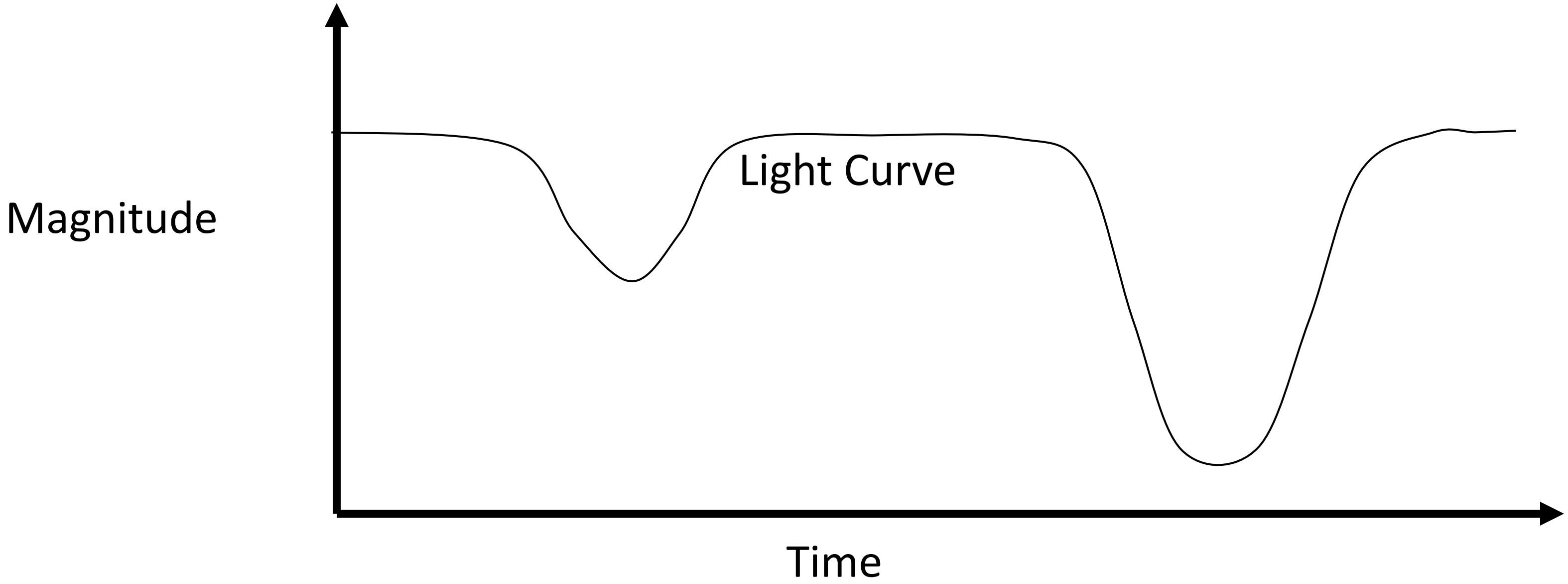


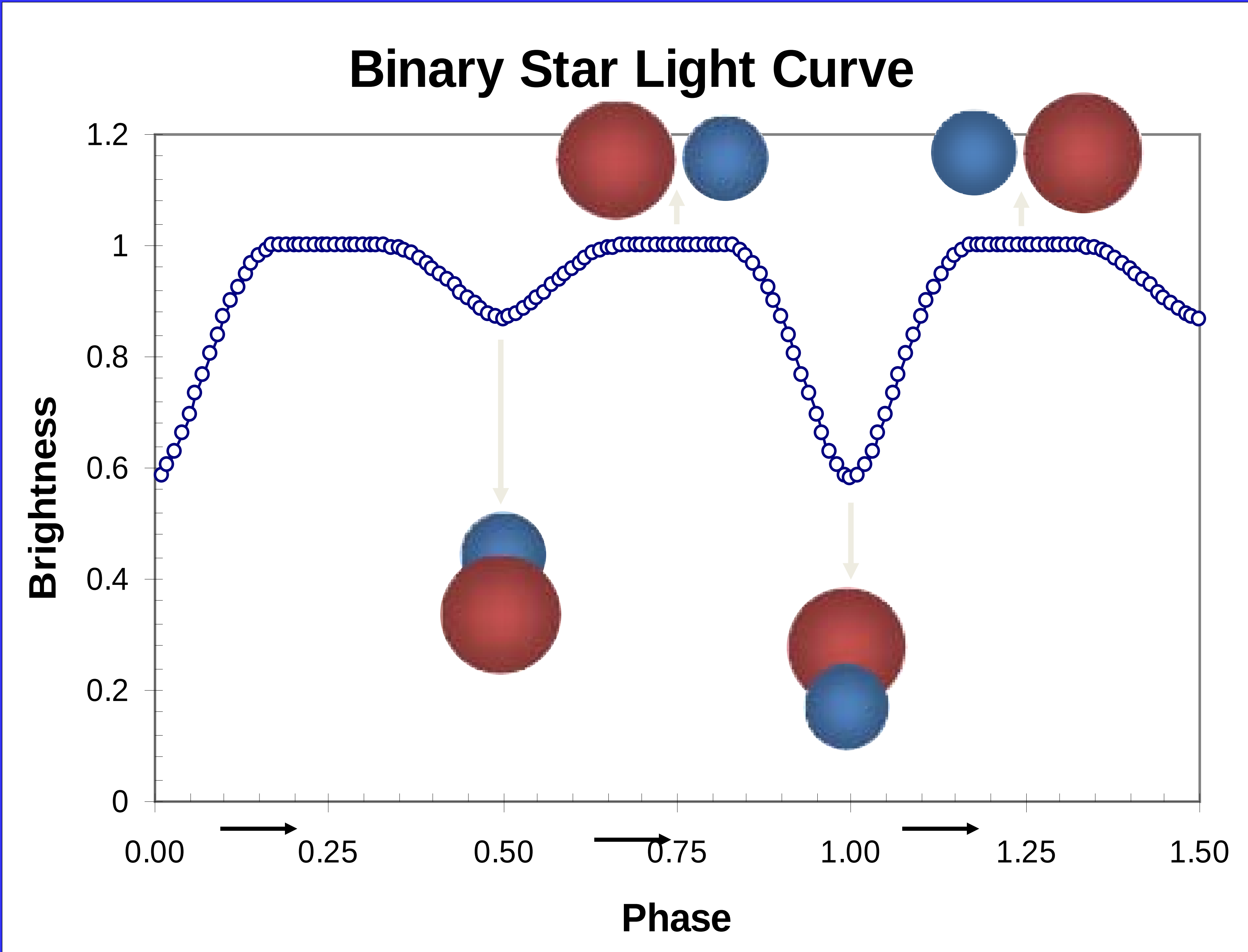
Radial Velocities

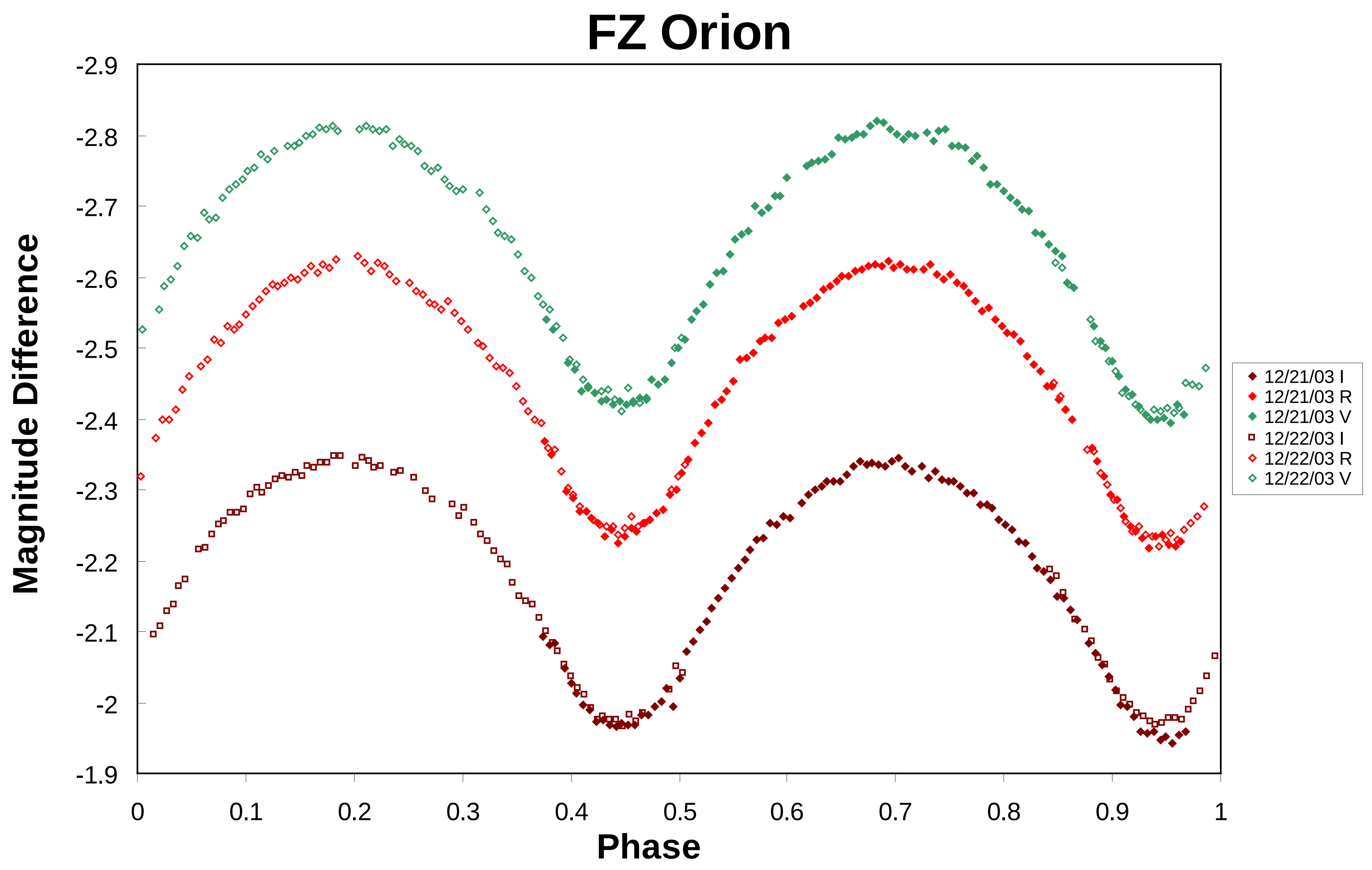
Stellar Masses

Eclipsing Binary Star






Binary Star Light Curve
1.2
1
0.8
0.6
0.4
0.2
0
Brightness
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Phase

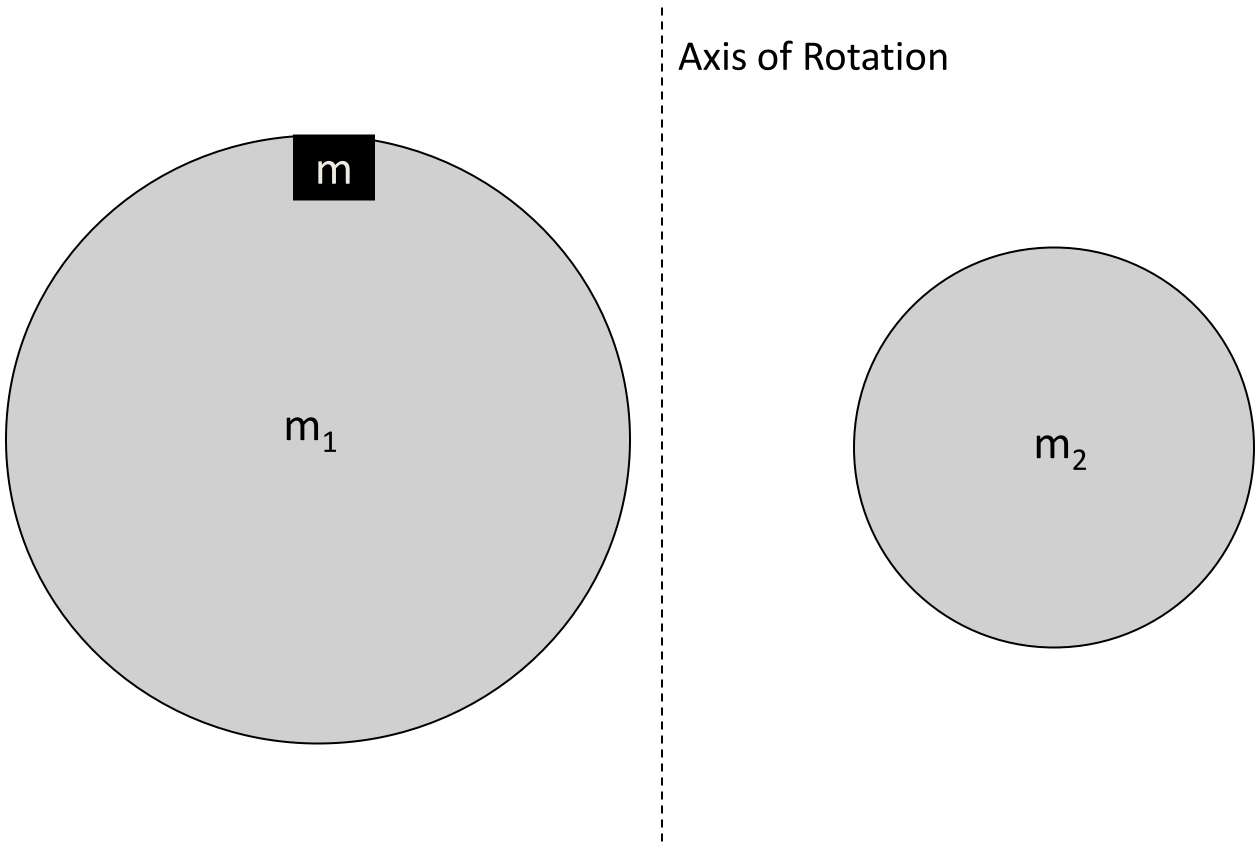

FZ Orion
Magnitude Difference
-2.9
-2.8
-2.7
-2.6
-2.5
-2.4
-2.3
-2.2
-2.1
-2
-1.9
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Phase
12/21/03 I
12/21/03 R
12/21/03 V
12/22/03 I
12/22/03 R
12/22/03 V

Question

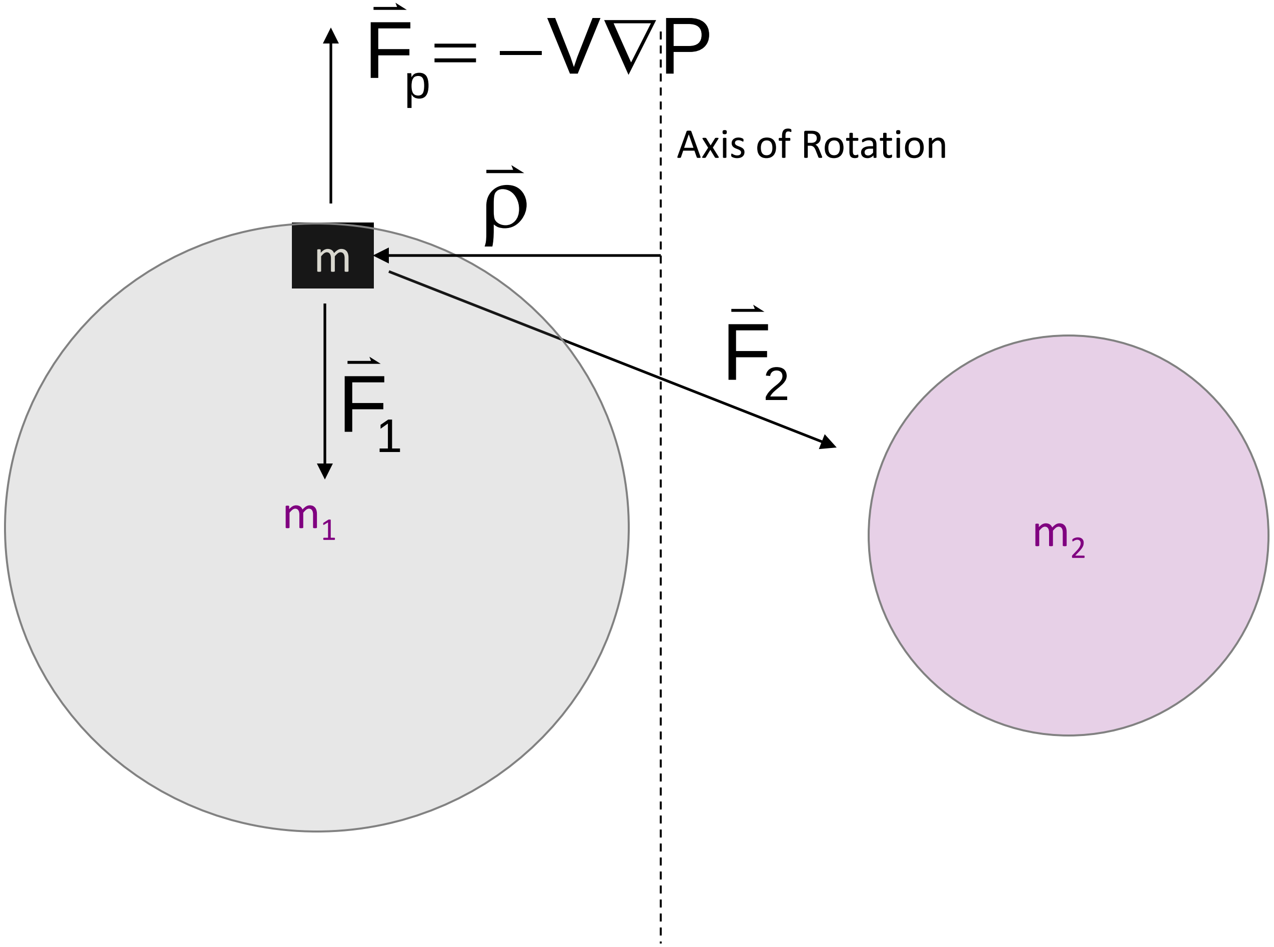
Why are the light curves not flat when stars are not eclipsing?

Answer: The stars are not spherical.

To determine the true shape of close binary stars we have to find a solution to the three body problem.

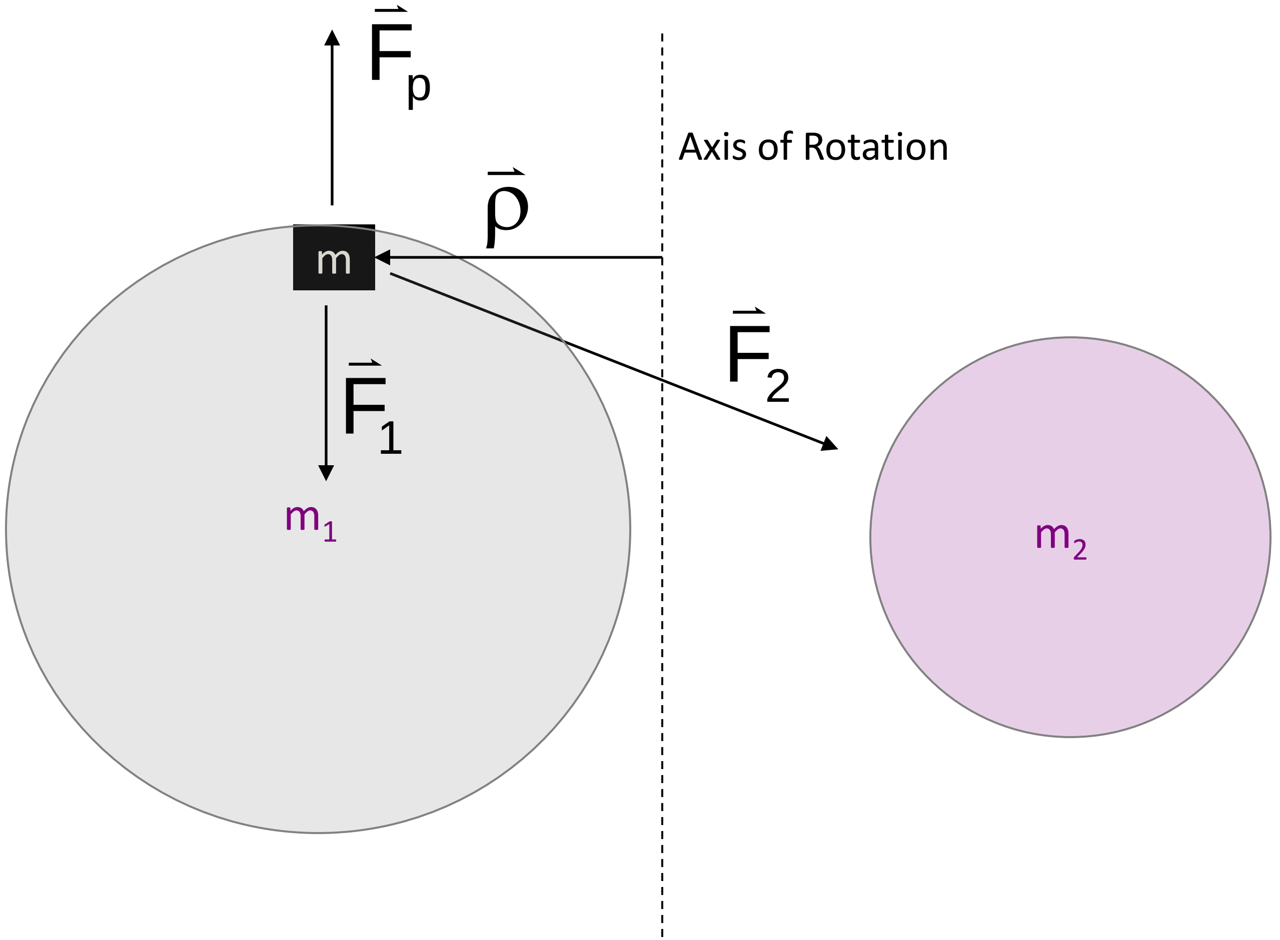


Hydrostatic Equilibrium



$$\sum \vec{F} = m\vec{a}$$

$$\vec{F}_p + \vec{F}_1 + \vec{F}_2 = -m\omega^2\vec{\rho}$$



$$\sum \vec{F} = m\vec{a}$$

$$\vec{F}_p + \vec{F}_1 + \vec{F}_2 = -m\omega^2\vec{\rho}$$

$$-\frac{Gm_1 m}{r_1^2}\hat{r}_1 - \frac{Gm_2 m}{r_2^2}\hat{r}_2 + m\omega^2\vec{\rho}' = -m\nabla\Psi$$

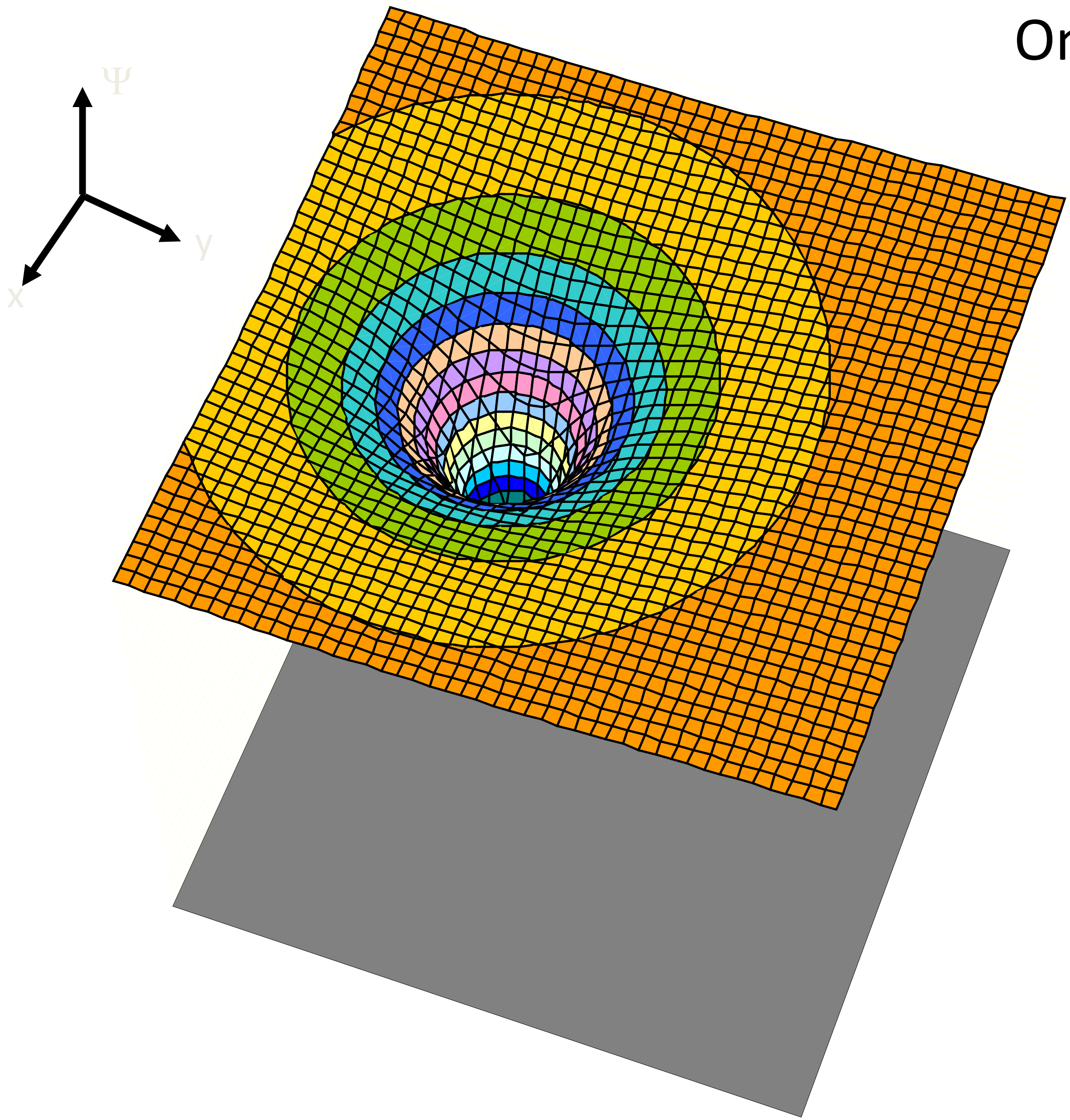
It can be shown that the surfaces of constant density, pressure and potential coincide.

$$\Psi = -\frac{Gm_1}{r_1} - \frac{Gm_2}{r_2} - \tfrac{1}{2}\omega^2\rho'^2$$

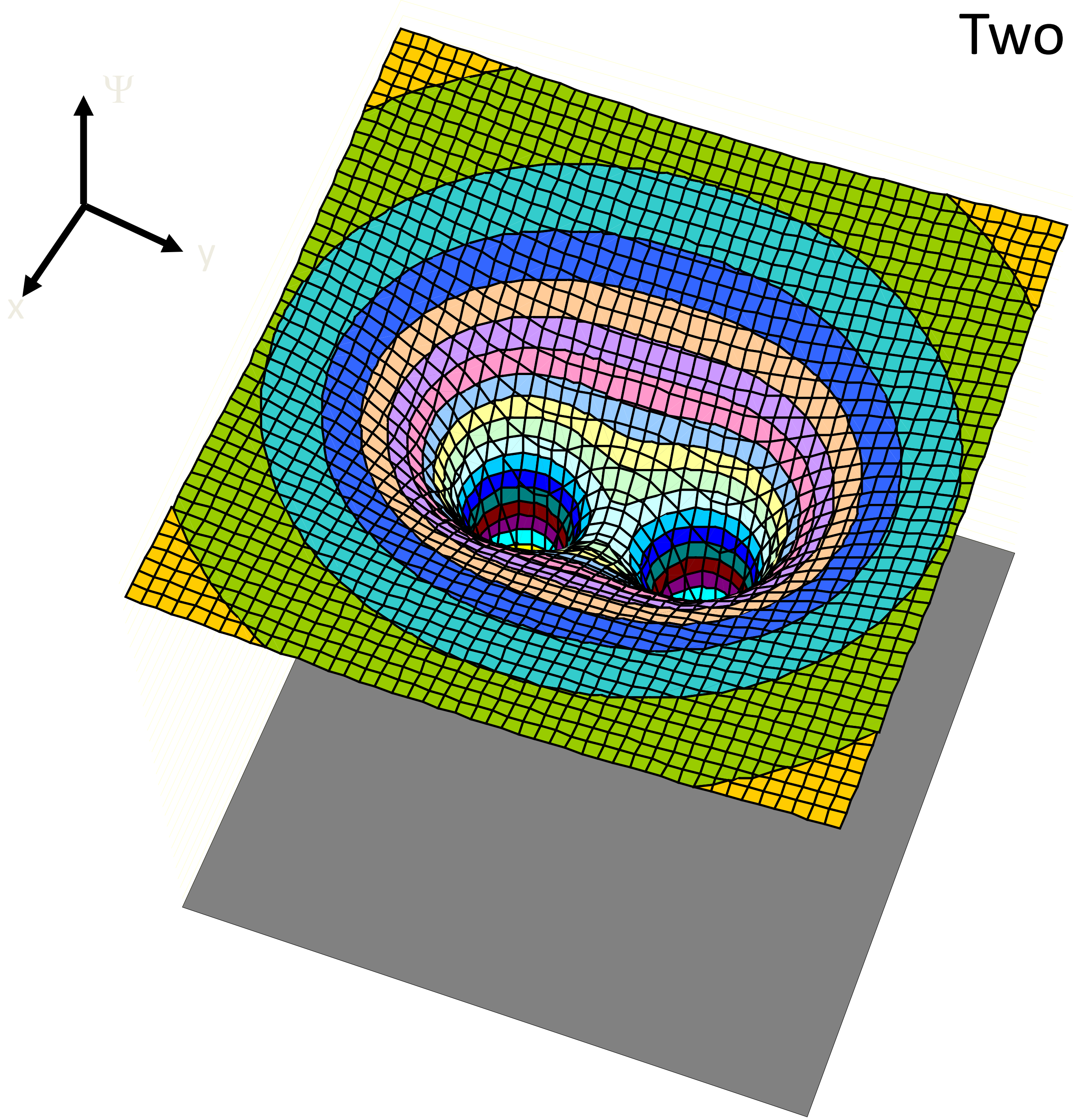
What does this potential function look like?

$$\Psi$$

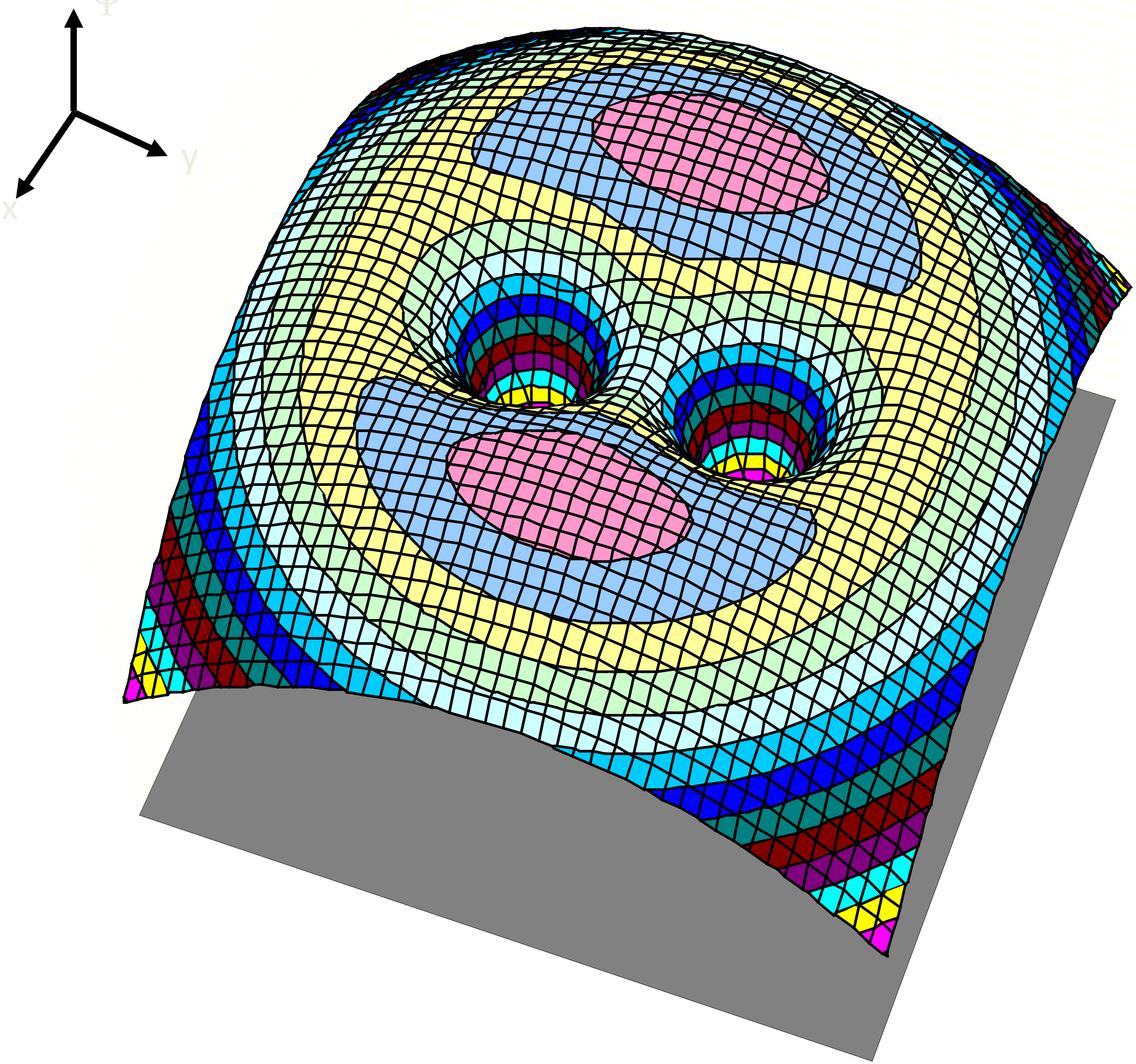
One Star



Two Stars

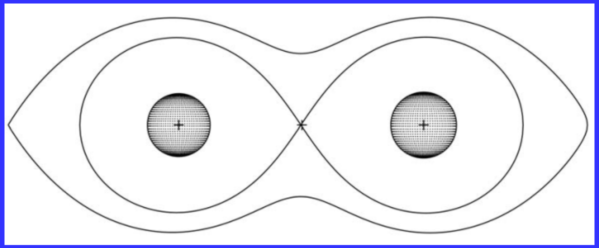


Two Stars with Rotation



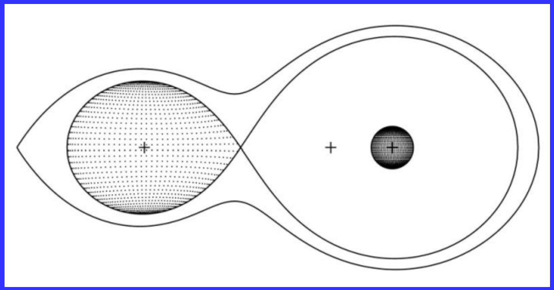
The overall classification of eclipsing binary systems is founded upon Roche equipotentials

1. detached

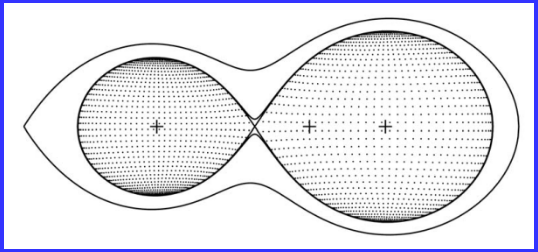


Their evolution is more-or-less independent from one another, as ideal physical laboratories

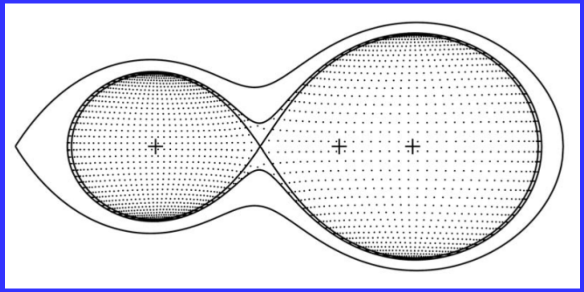
2. semi-detached



3. contact



4. overcontact



W Uma overcontact binaries

- 0.2<P<0.8 days (CC Comae 0.22 d and ASAS star)
- MS components A-K , fill Roche lobes, share a common convective envelope $T_1 \sim T_2$
- Maxima of LC rounded, shape tidally distorted , proximity
- A –types and W-types, larger the hotter?
- W-type q>0.3, G-K, P<0.3 days, LC asymmetries time variable, magnetically active (starspots, matter streams…)
- B-type –"poor thermal contact" ΔT~1000K (Czizmadia & Klagyvic 2004)
- O-type -"early type" contact, V382 Cyg, TU Mus, P<2d (Qian et al. 2007)
- Not very common 1/500 late type dwarfs (~1 x 10^{-5} pc^{-3}) but easy to discover

What can cause changes in P?

- Intrinsic

1. Angular momentum loss (gravitational radiation, mass loss, magnetic breaking)
2. Mass transfer through between the stars…
3. Applegate effect (Applegate 1992, Lanza et al. 1998). P modulations can be explained as the gravitational coupling of the orbit to variations of the shape of a magnetically active star in the system

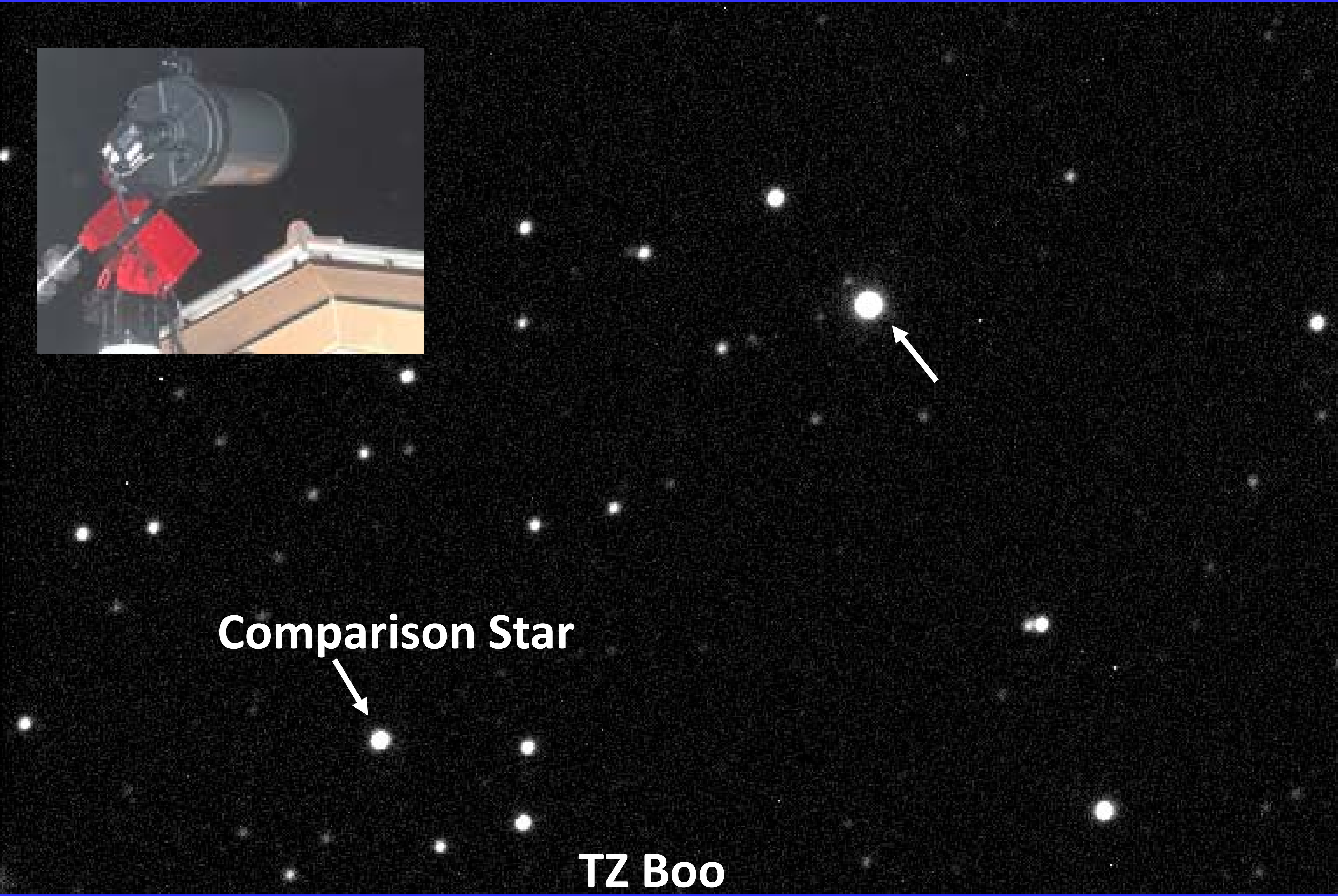
Real period changes and apparent period changes (starspots)

- Third body induced changes (independent of other period changes)

  Periodic variation in the eclipse minima, movement of the binary system about the third/binary barycenter and the light travel time difference (LITE)

…from the observational site

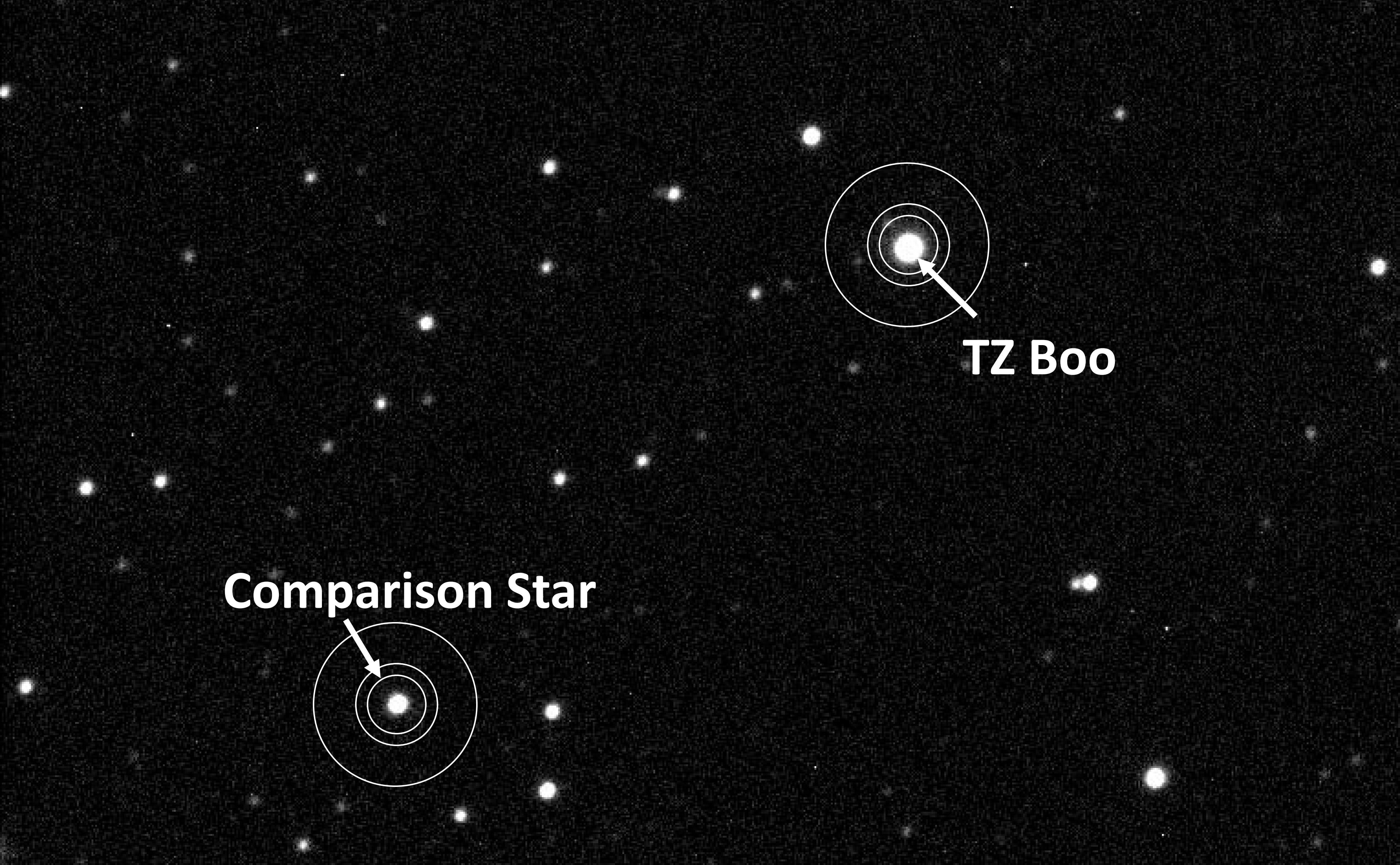
- high resolution spectroscopy versus high-quality photometry
- What are the timescales for changes in the asymmetries of W-Uma light curves?
- Aim of our program: Intensive photometry: not disjointed snapshots but movies daily-monthly-yearly

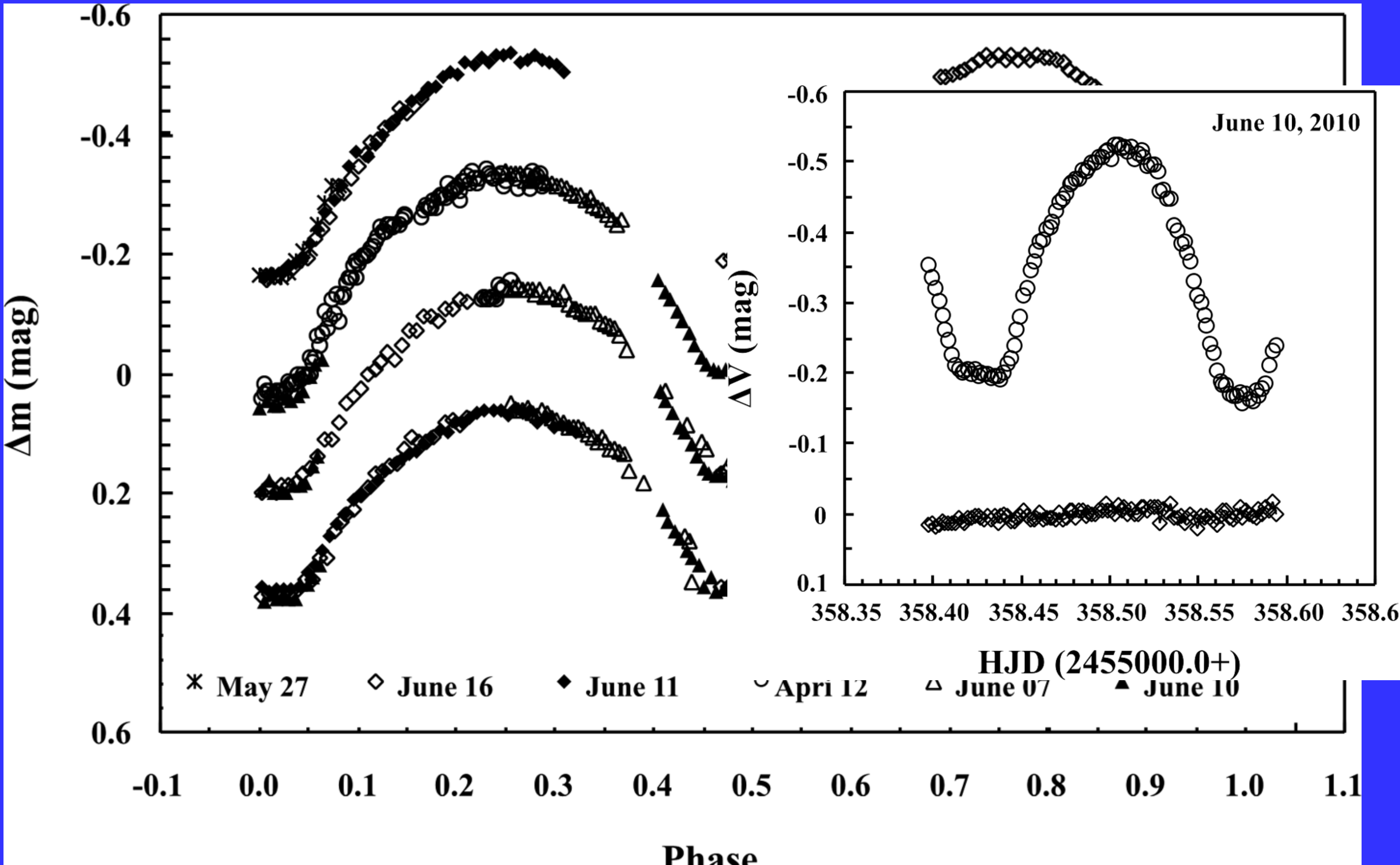


An Eclipsing Binary Star

CCD Photometry

Software: AIPWIn, IRAF

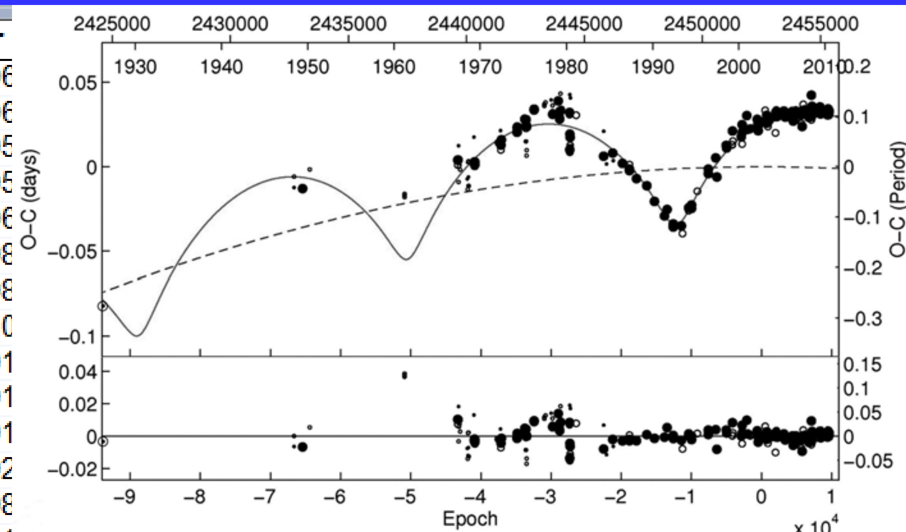




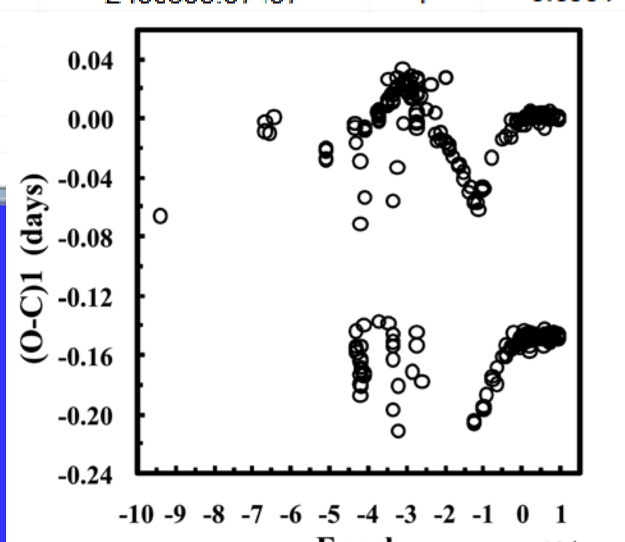
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Δm (mag)
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Phase
May 27
June 16
June 11
June 07
June 10
June 10, 2010
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
ΔV (mag)
358.35
358.40
358.45
358.50
358.55
358.60
358.65
HJD (2455000.0+)

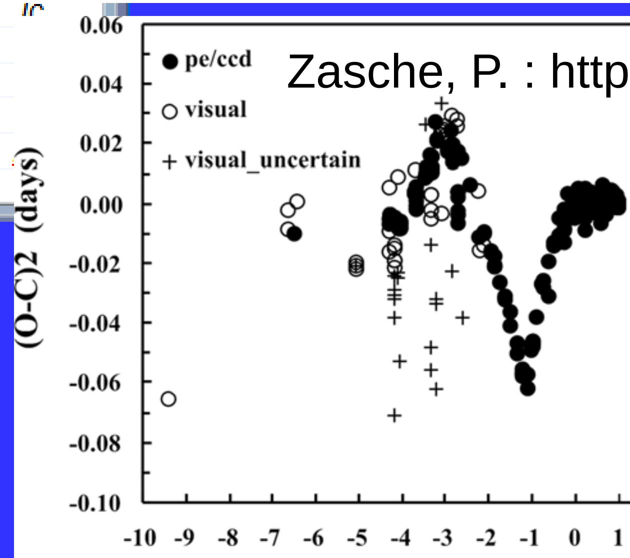
New Times of Light Minimum for TZ Boo derived from our observations

No	JD (Hel)	Min	Error
1	2455299.43755	I	±0.0006
	2455299.43796	I	±0.0006
2	2455343.41756	I	±0.0005
	2455343.41776	I	±0.0005
	2455343.41726	I	±0.0006
3	2455355.45272	II	±0.0008
	2455355.45315	II	±0.0008
	2455355.45388	II	±0.0010
4	2455358.42656	II	±0.0001
	2455358.42607	II	±0.0001
	2455358.42609	II	±0.0001
5	2455358.57411	I	±0.0002
	2455358.57425	I	±0.0008
	2455358.57457	I	±0.0001
6			
7			

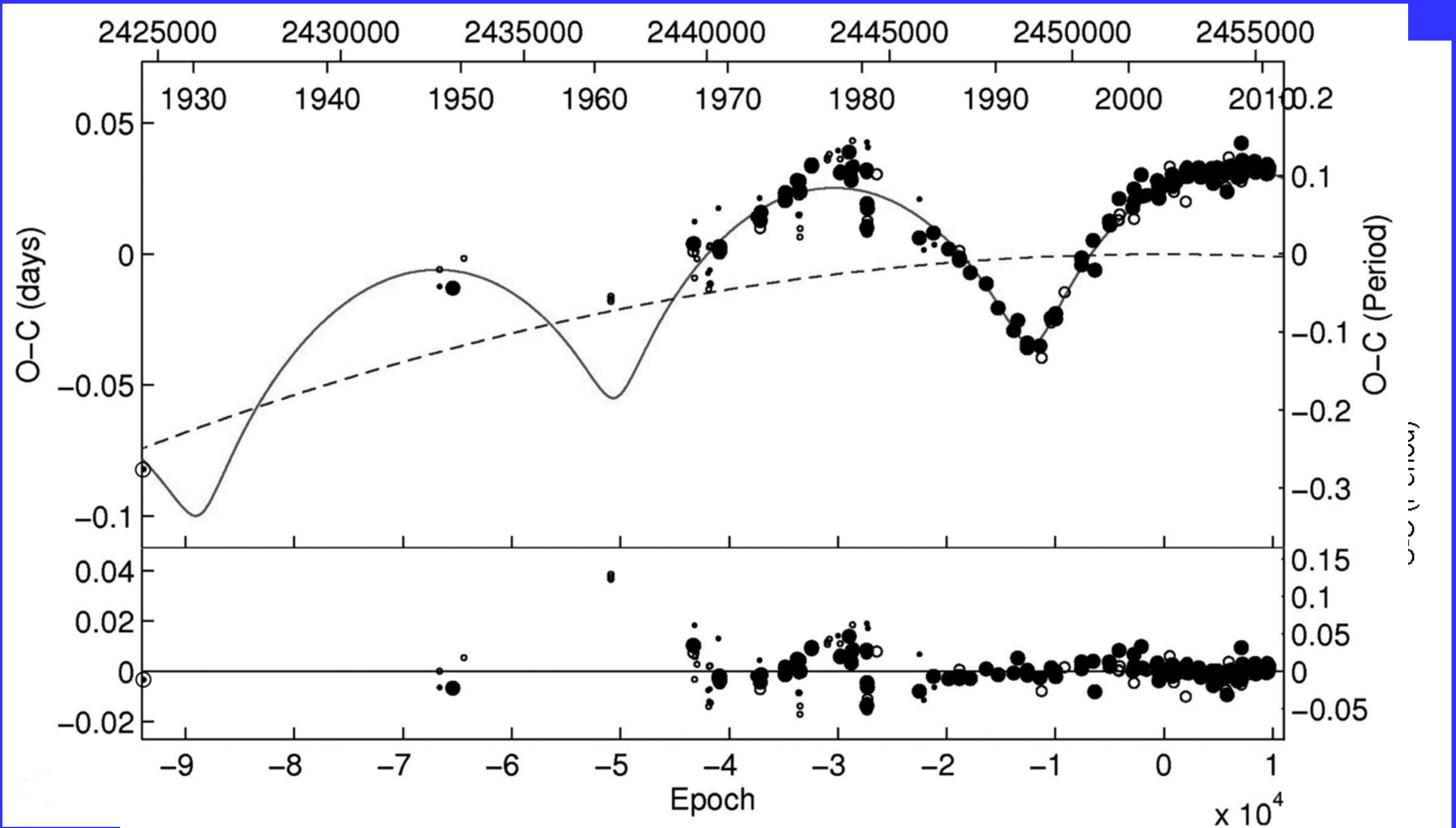


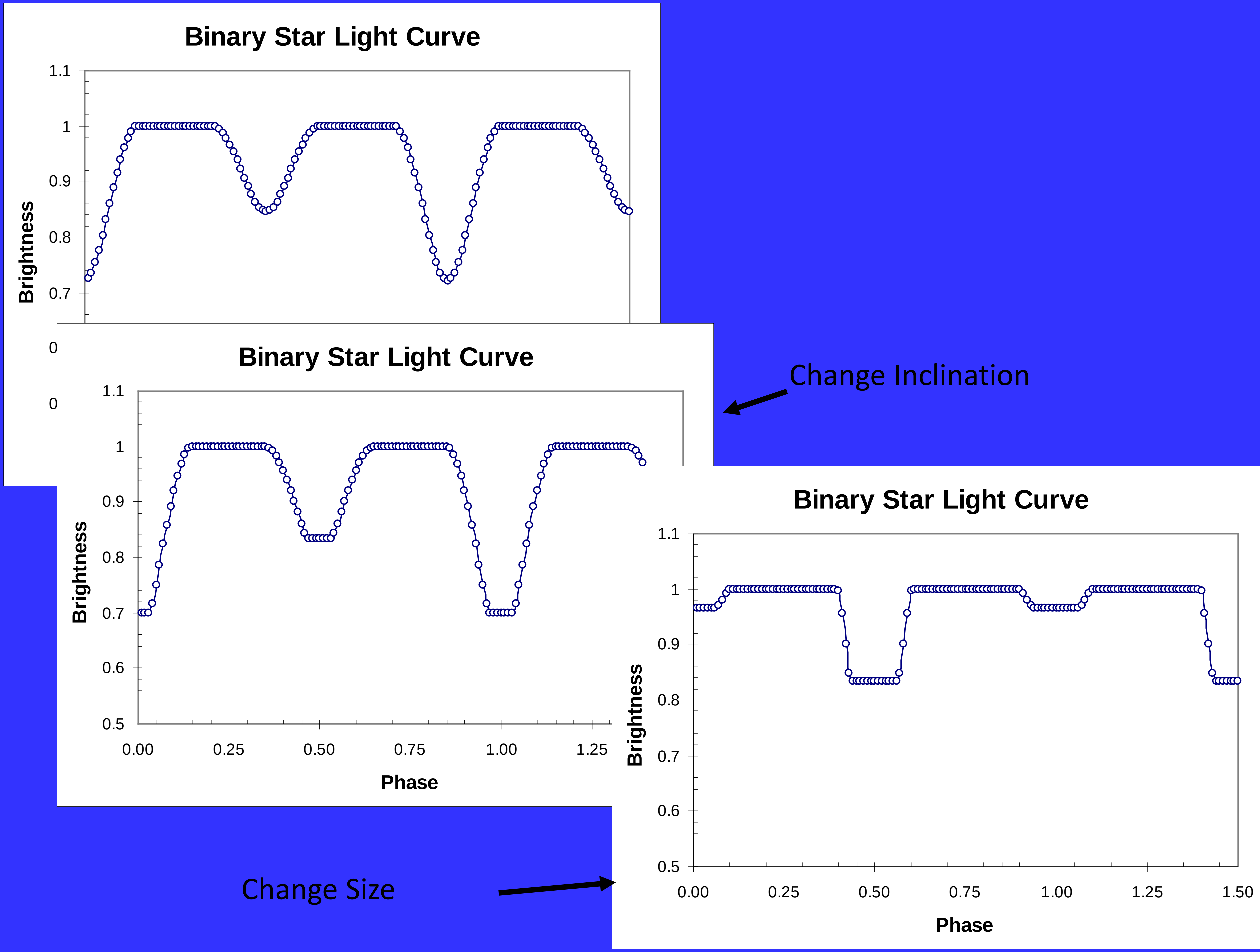
Zasche, P. : http://sirrah.troja.mff





Kang, Y. W., Oh, K.-D., Kim, C.-H., et al. 2002, MNRAS, 331, 707 (TY UMa), V802 Aql, FG Hya, CU Tau, EM Psc


2425000
2430000
2435000
2440000
2445000
2450000
2455000
1930
1940
1950
1960
1970
1980
1990
2000
2010
0.05
0
−0.05
−0.1
O−C (days)
0.2
0.1
0
−0.1
−0.2
−0.3
O−C (Period)
0.04
0.02
0
−0.02
0.15
0.1
0.05
0
−0.05
−9
−8
−7
−6
−5
−4
−3
−2
−1
0
1
Epoch
x 10^4


Binary Star Light Curve
Brightness
1.1
1
0.9
0.8
0.7
Binary Star Light Curve
Brightness
1.1
1
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
Phase
Change Inclination
Binary Star Light Curve
Brightness
1.1
1
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Phase
Change Size

A Real Model

Assumptions

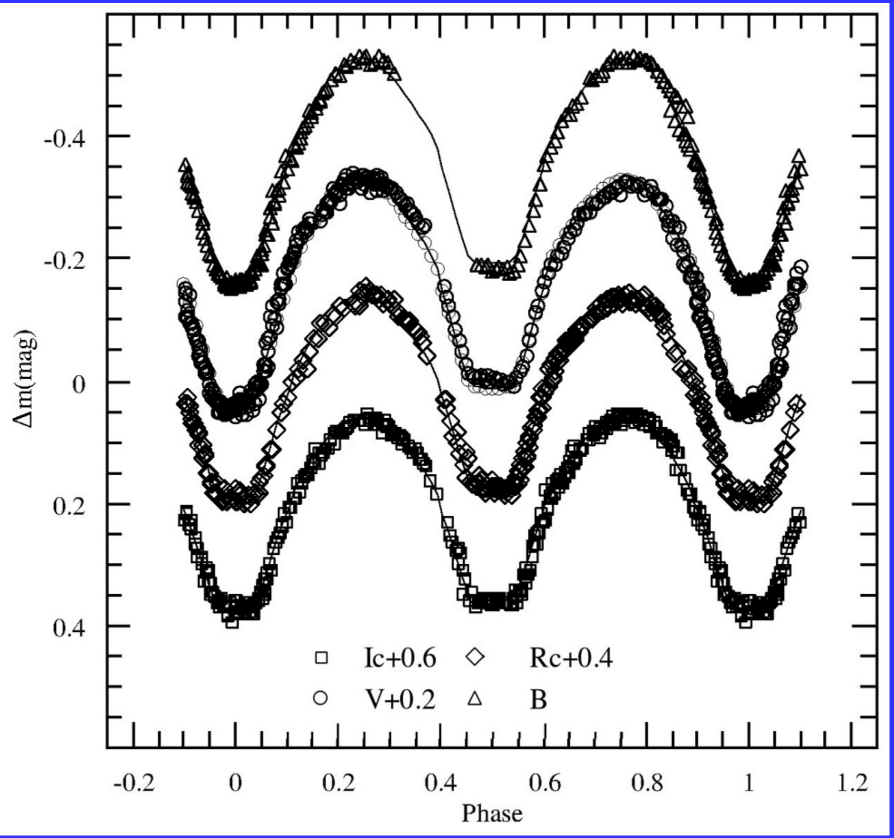
- Limb Darkening
- Non-spherical stars
- Color Filters

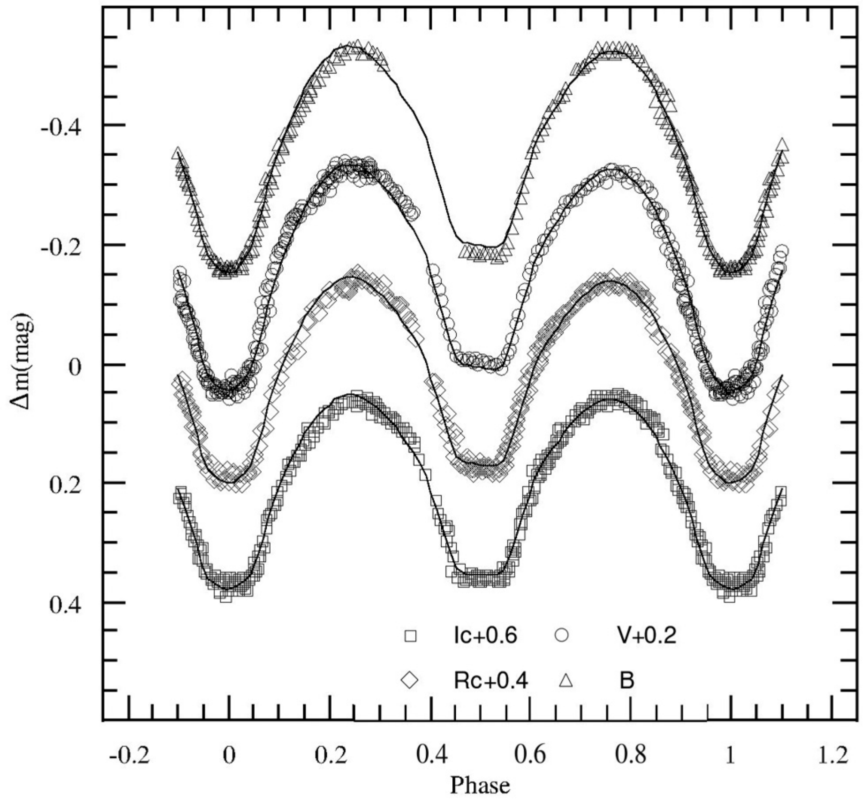
PHOEBE Prsa & Zwitter 2005

Outcomes

- Stellar Morphologies
- Orbital inclination, eccentricity, and period
- Relative sizes, masses, and brightness
- Temperatures, star spot activity, and more

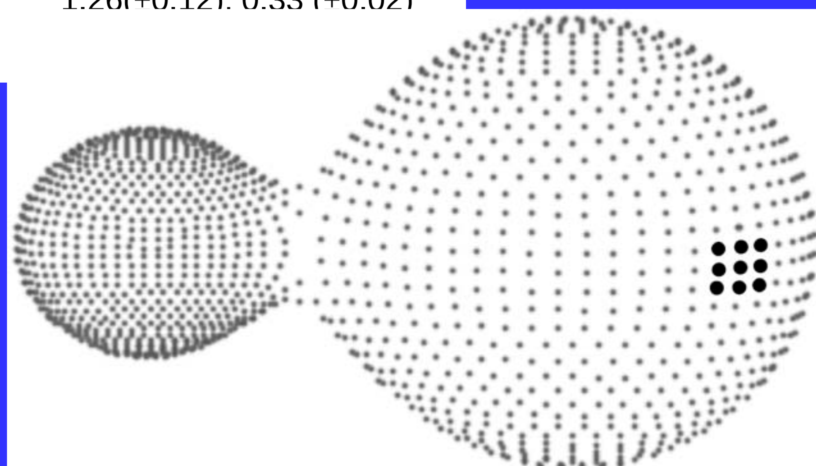
PHOEBE Prsa & Zwitter 2005





Parameters	Value
T_o (HJD)	2452500.1608 (±0.0017)
P (days)	0.29715993 (±1.6 x 10^{-7})
dP/dE (days/cycle)	-0.17 x 10^{-10}(±0.08 x 10^{-10})
$a_{12}sini_3$ (AU)	5.7985 (± 0.19043)
e_3	0.6344(±0.0593)
ω_3(deg)	274.8(±5.2)
P_3 (yr)	31.18(±0.31)
T_p (HJD)	2448919.276(±138.533)
A (days)	0.033(±0.001)
$f(m_3)$ ($M_{\odot}$)	0.200(±0.001)

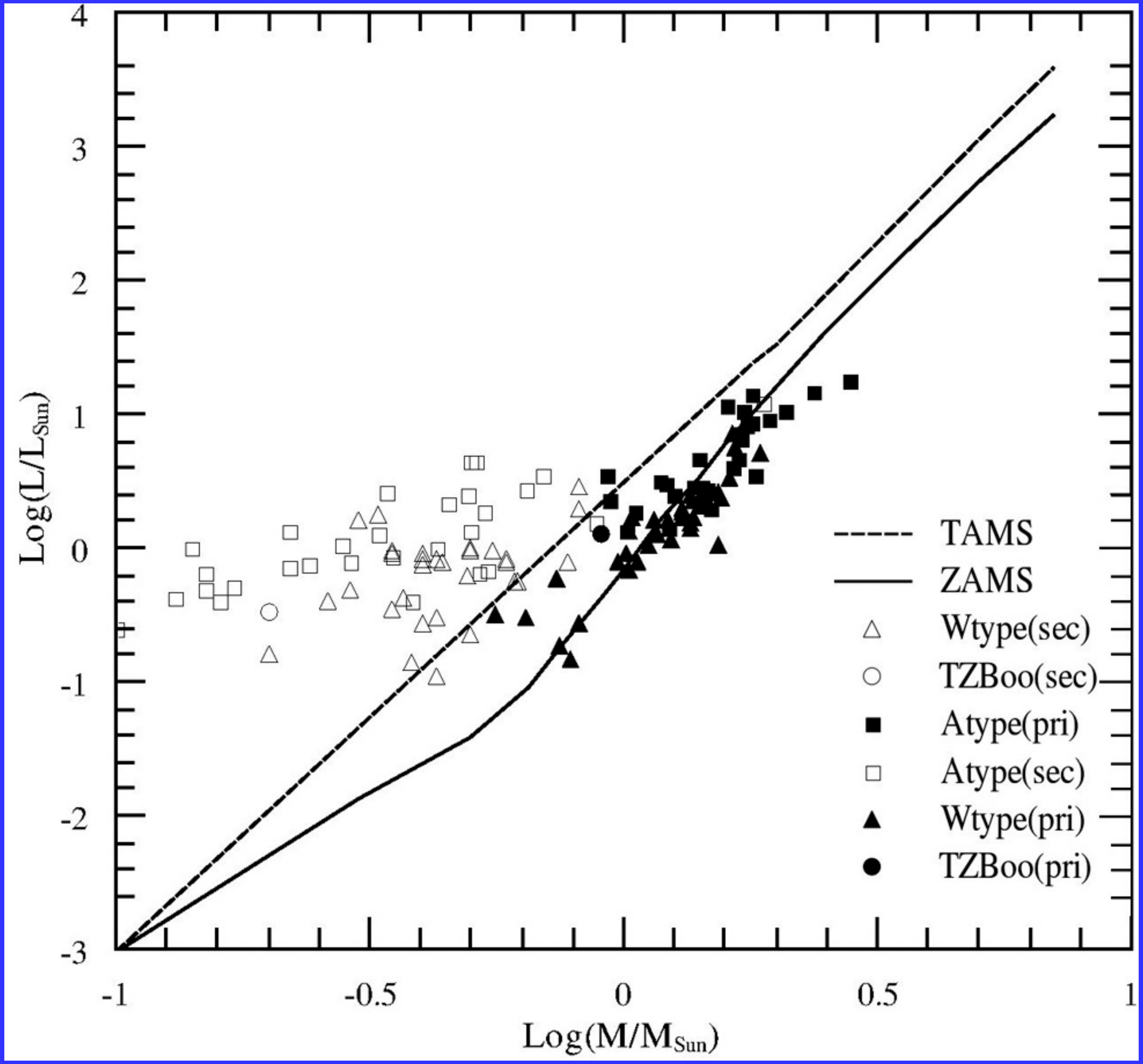
M_1+M_2 ($M_{\odot}$)	1.20 (± 0.03)
M_{3min} ($M_{\odot}$)	0.98 ((±0.0005)
M_1 ($M_{\odot}$), M_2 ($M_{\odot}$)	0.99(±0.03), 0.21 (±0.01)
R_1 ($R_{\odot}$), R_2 ($R_{\odot}$)	1.08 (±0.05), 0.56 (±0.02)
L_1 ($L_{\odot}$), L_2 ($L_{\odot}$)	1.26(±0.12), 0.33 (±0.02)



Parameters	Unspotted solution	Spotted solution
$i(^o)$	84.21 (±0.36)	85.45(±0.54)
$q=M_2/M_1$	0.207 (±0.005)	Pribulla et al. 2009
$g_1=g_2$	0.32	
$A_1=A_2$	0.5	
$T_1(K)$	5890	
$T_2(K)$	5926 (±10)	5873(±10)
$\Omega_1=\Omega_2$	2.19609(±0.0020)	2.18084(±0.0018)
$f(\%)$	40.9(±1.5)	52.5(±1.4)
$L_{1B}(\%)$	63.20 (±7.22)	61.79 (±7.32)
$L_{1V}(\%)$	67.54 (±5.90)	65.58 (±6.03)
$L_{1R}(\%)$	64.00 (±6.02)	62.40 (±6.07)
$L_{1I}(\%)$	63.30(±5.60)	61.69(±5.66)
L_{3B} (%)	20.64(± 0.61)	22.45 (± 0.74)
$L_{3V}(\%)$	15.10(± 0.51)	17.65 (± 0.64)
$L_{3R}(\%)$	19.59(± 0.51)	21.64 (± 0.67)
$L_{3I}(\%)$	20.27(±0.48)	22.60 (± 0.63)
r_1(pole)	0.497	0.501
r_1(side)	0.545	0.550
r_1(back)	0.572	0.579
r_2(pole)	0.250	0.254
r_2(side)	0.262	0.267
r_2(back)	0.310	0.322
σ_B (mag)	0.011	0.012
σ_V (mag)	0.016	0.015
σ_R (mag)	0.010	0.010
σ_I (mag)	0.010	0.010
Colatitude(deg)	-	90.5
Longitude (deg)	-	134.6
Radius (deg)	-	9.2
T_{spot}/T_{local}	-	0.85

Lian & Qian 2010 64% of EW type binaries show cyclical variations -----LITE

Evolutionary stage?



Eclipsing binaries, why they are important?

- Study star formation and stellar structure
- Test the theories of stellar evolution
- Determine the physical parameters of stars from the geometry and their orbits
- Standard candles to determine the size and structure of the Galaxy (Paczynski 1997)
- Constrain the cosmological distance ladder (Bonanos et al. 2006)

Explosion of photometric time series data

- Mid 1990s search gravitational microlensing effects (**OGLE**: Udalski et al. 1994; **EROS**: Beaulieu et al. 1995; **DUO**: Alard & Guibert 1997; MACHO: Alcock et al. 1998
- Search gamma ray bursts (ROTSE: Akerlof et al. 2000) and general photometric variabilities (e.g., ASAS: Pojmanski 1997)
- 2nd wave : After the first transiting extrasolar planet (Charbonneau et al. 2000; Henry et al. 2000;Mazeh et al. 2000) OGLE-III: Udalski 2003; TrES: Alonso et al. 2004;HAT: Bakos et al. 2004; SuperWASP: Christian et al. 2006;XO: McCullough et al. 2006;
- 3d wave: Exoplanets Pan-STARRS: Kaiser et al. 2002;LSST: Tyson 2002), ultra-sensitive space-based surveys(e.g., KEPLER: Borucki et al. 1997; COROT: Baglin & The COROT Team 1998; GAIA: Gilmore et al. 1998)

- Needles in a haystack and then the haystack was abandoned
- GAIA 2013 June (millions EB), LSST 2018 (tens of millions EB)
- !

CCD photometric study of the puzzling W-UMa type binary TZ Boo

Christopoulou, P-E., Papageorgiou, A. and Chrysopoulos I. 2011, AJ, 142, 99