Detection of Black Holes Using Eclipse Timing Variations of Triple Star Systems

Bryce Bolin

Ay 215 - 2021 March 10

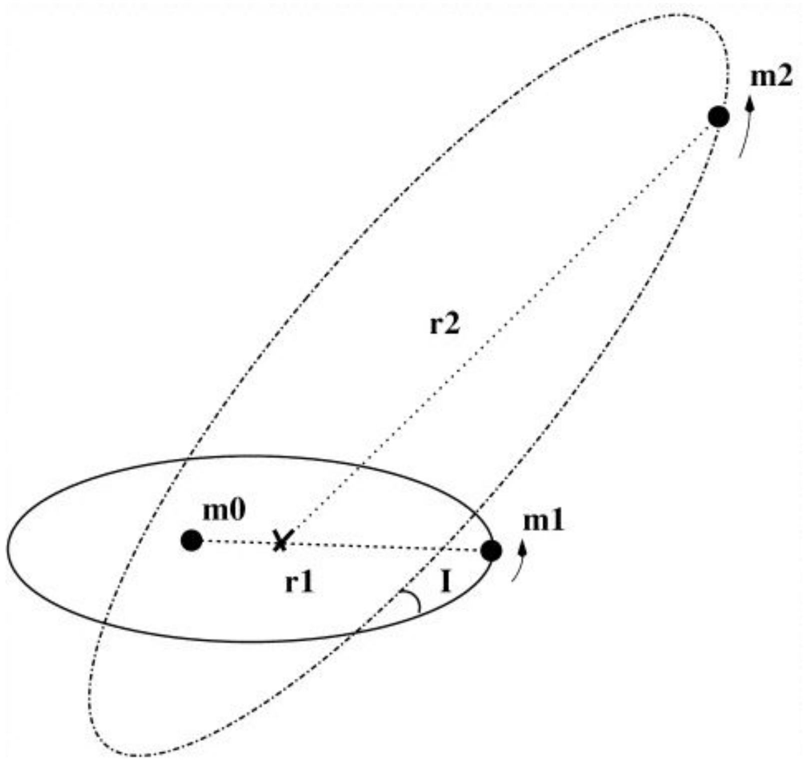
hierarchical triples

~25% of multiple systems consisting of solar-type stars

Minimum period ratio ~5

-Most longer period systems have a mass ratio q < 0.5

-Famous example includes Algol



hierarchical triples

~25% of multiple systems consisting of solar-type stars

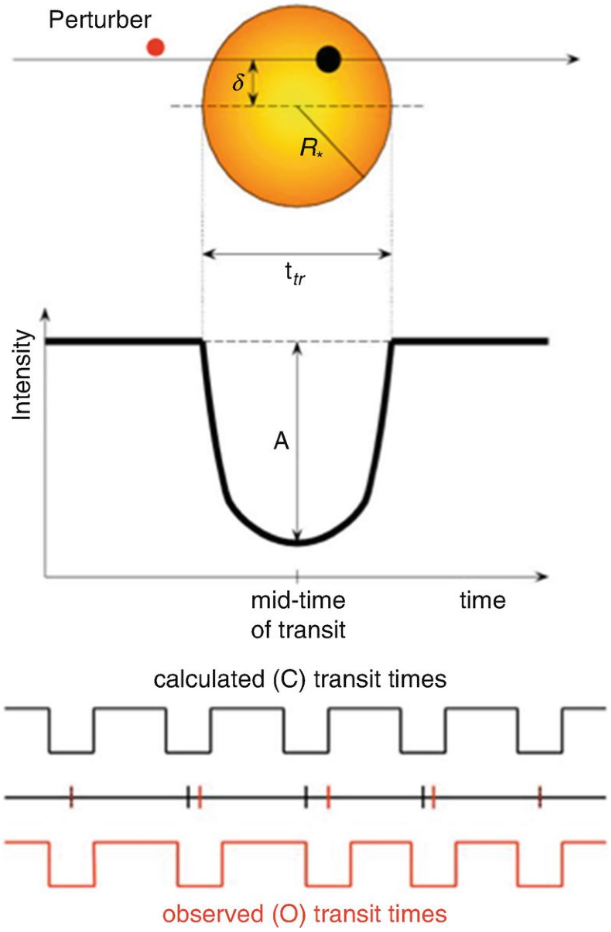
Minimum period ratio ~5

-Most longer period systems have a mass ratio q < 5

-Famous example includes Algol

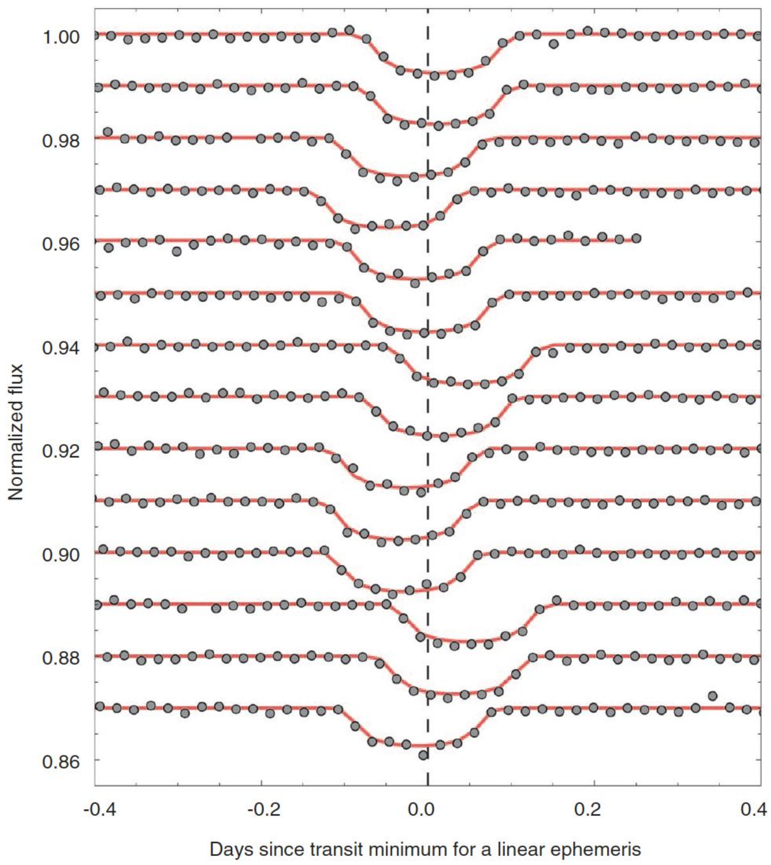
Eclipse timing variations

- Caused by a number of mechanisms including tidal interactions, light travel time variations, gravitational perturbations
- Can be a combination of effects
- Cause a shift in the mid-time of the eclipse that is periodic in nature



Eclipse timing variations

- Caused by a number of mechanisms including tidal interactions, light travel time variations, gravitational perturbations
- Can be a combination of effects
- Cause a shift in the mid-time of the eclipse that is periodic in nature



Eclipsing timing variations, light travel time effect

Was first used to explain eclipse variations in observations of Algol in 1888

Can only place lower limits on mass assuming a total primary mass estimate

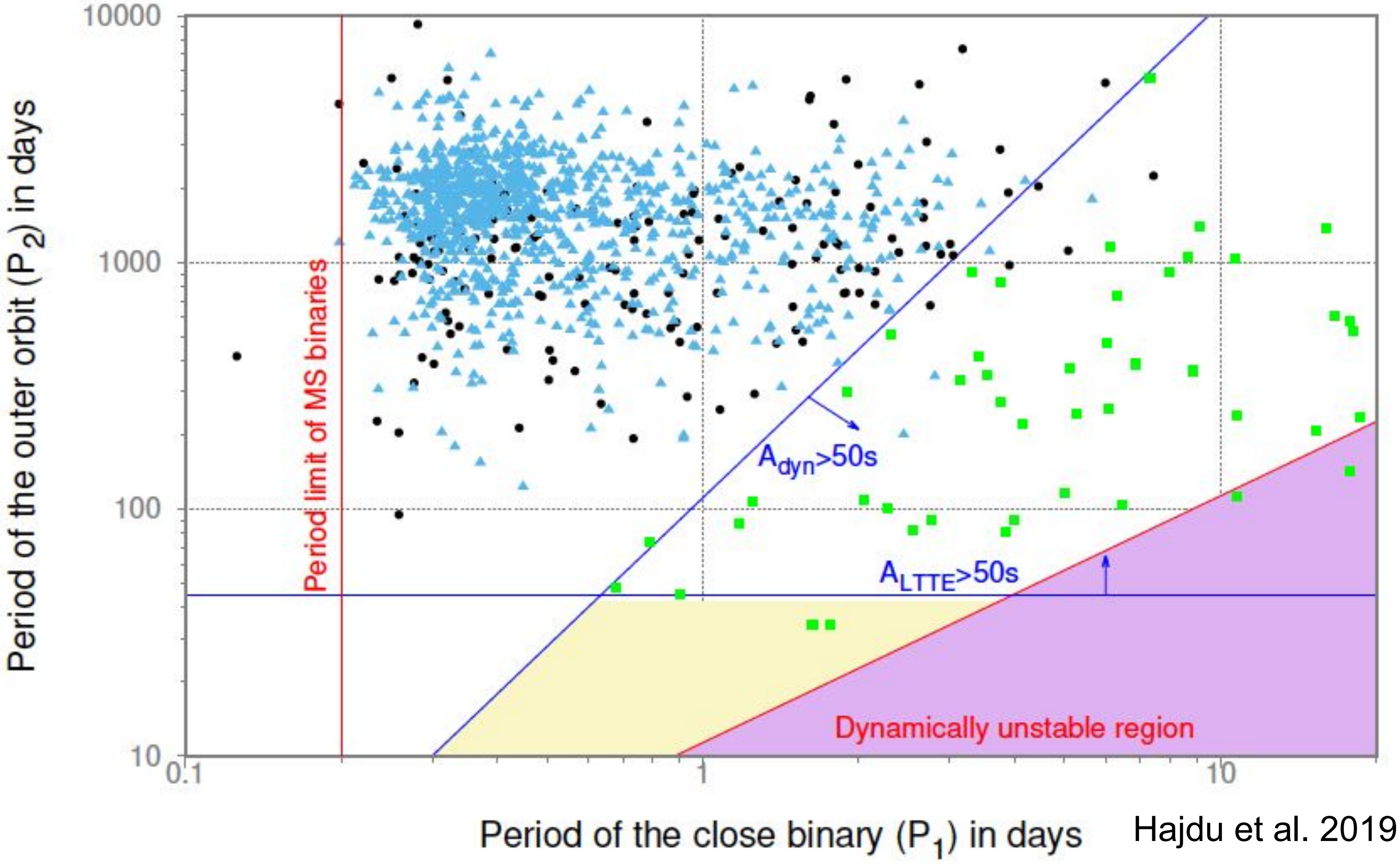
$$f(m_{\mathrm{C}}) = \frac{m_C^3 \sin^3 i_2}{m_{\mathrm{ABC}}^2} = \frac{4\pi^2 a_{\mathrm{AB}}^3 \sin^3 i_2}{G P_2^2}$$

$$\mathcal{A}_{\mathrm{LTTE}} \approx 1.1 \times 10^{-4} f(m_C)^{1/3} P_2^{2/3} \sqrt{1 - e_2^2 \cos^2 \omega_2}$$

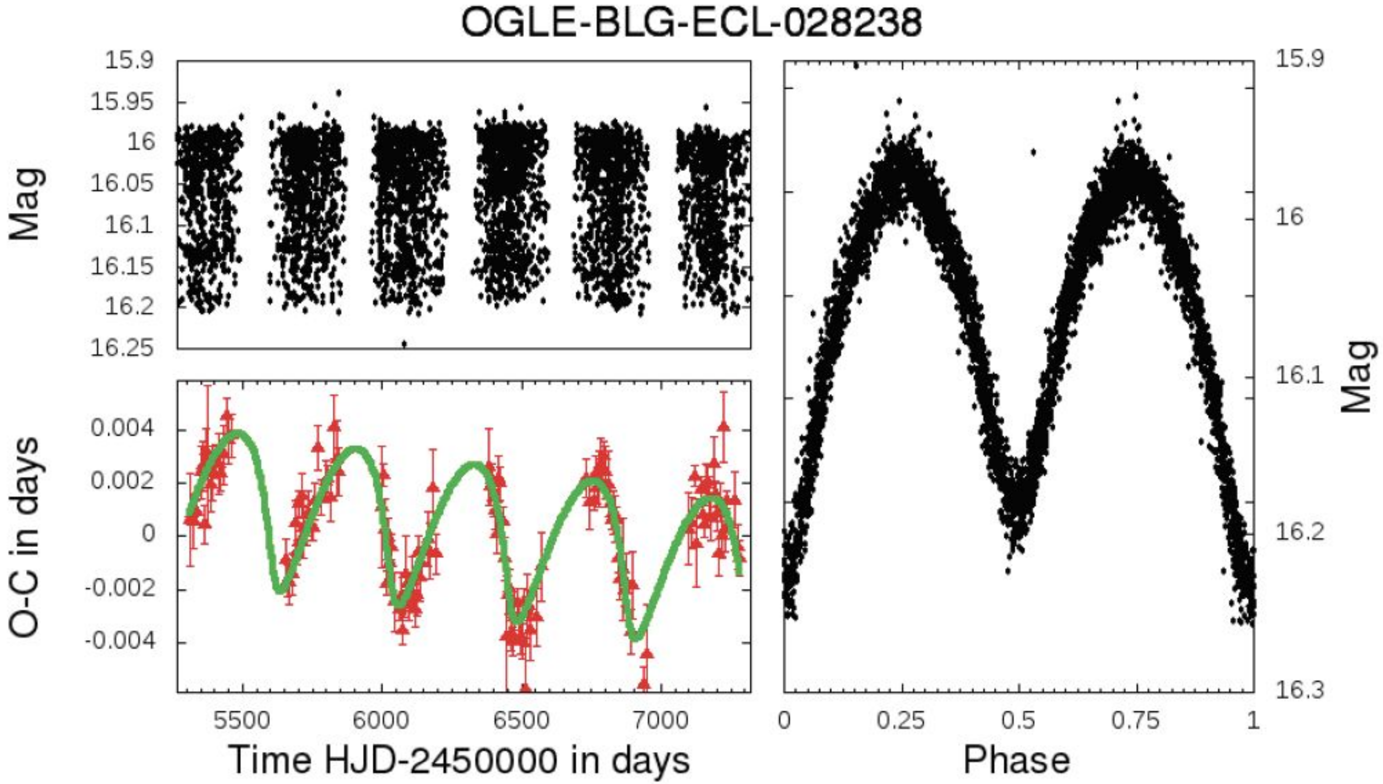
Eclipsing timing variations, dynamics

$$\mathcal{A}_{\rm dyn} = \frac{1}{2\pi} \frac{m_{\rm C}}{m_{\rm ABC}} \frac{P_1^2}{P_2} \left(1 - e_2^2\right)^{-3/2}$$

Square pependence on P_1 makes measurement in P_1<~ 1 days difficult

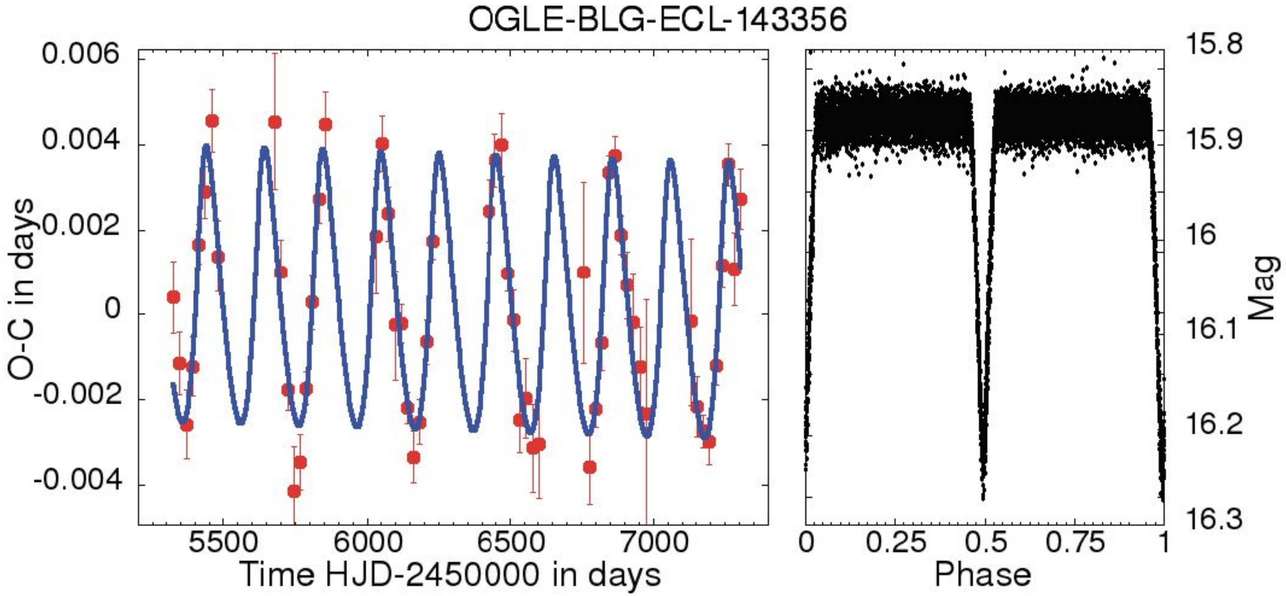


Hajdu et al. 2019



Hajdu et al. 2019

Dynamical + LTTE fits



Hajdu et al. 2019

Dynamical + LTTE fits

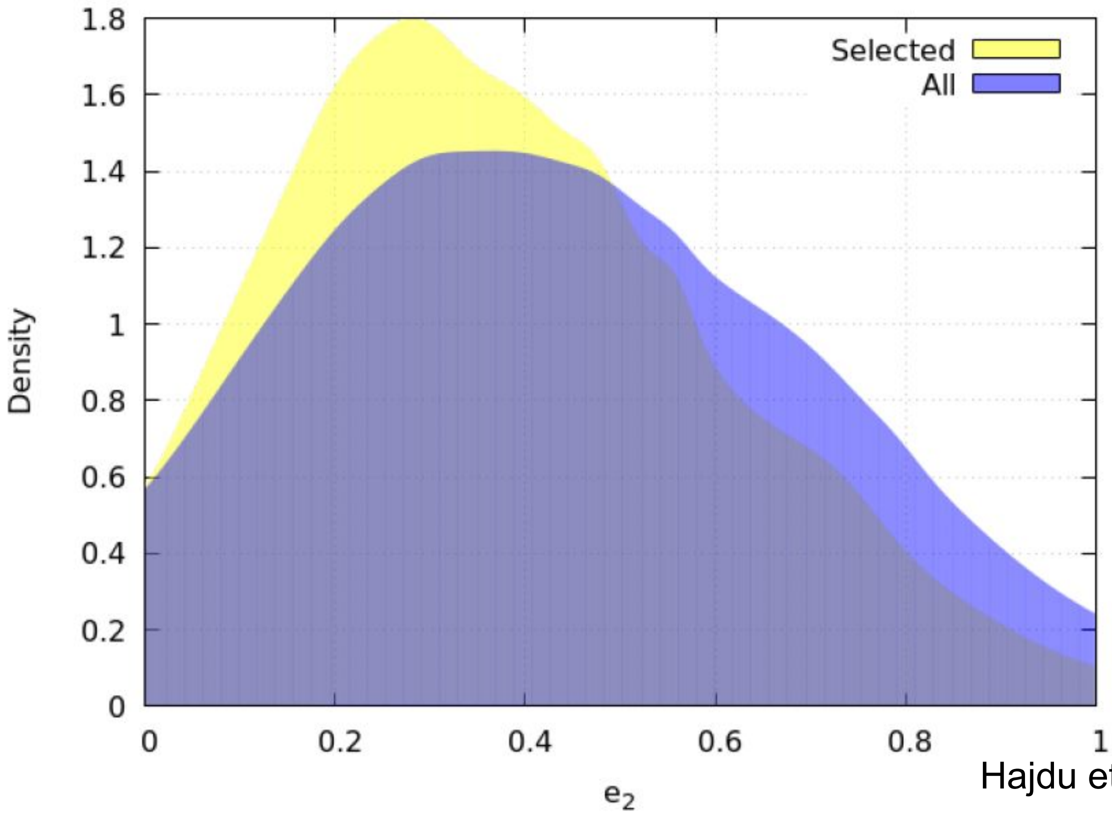
Can be used to constrain mass of

Tertiary directly

ID		143356	169255
T_0	[days	5258.631022	5258.554303
P_1	[days]	2.442595	2.804854
P_2	[days]	202.43 ± 0.20	339.28 ± 1.03
a_2	[$R_\odot$]	254.9 ± 15.32	330.19 ± 27.49
e_2		0.32 ± 0.02	0.3 ± 0.04
ω_2	[°]	239.19 ± 8.12	288.05 ± 11.31
τ_2	[days	5218.02 ± 5.5	5245.44 ± 13.21
$\mathcal{A}_{\mathrm{LTTE}}$	[days]	0.0021 ± 0.0002	0.0031 ± 0.0005
$\mathcal{A}_{\mathrm{dyn}}$	[days]	0.0016	0.0013
$\frac{\mathcal{A}_{\mathrm{dyn}}}{\mathcal{A}_{\mathrm{LTTE}}}$		0.78	0.44
$f(m_C)$		0.16 ± 0.05	0.18 ± 0.09
$\frac{m_C}{m_{ABC}}$		0.31 ± 0.03	0.35 ± 0.05
m_{AB}	[$M_\odot$]	3.74 ± 0.86	2.74 ± 0.87
m_C	[$M_\odot$]	1.69 ± 0.45	1.46 ± 0.58

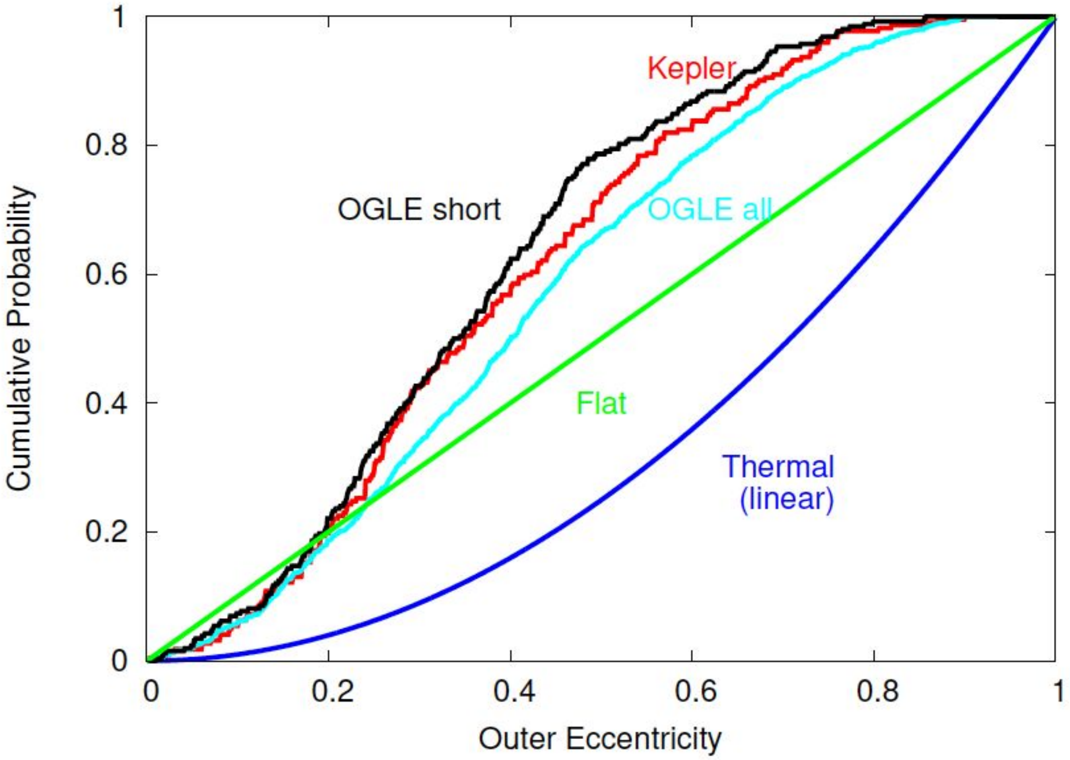
Hajdu et al. 2019

Eccentricity properties



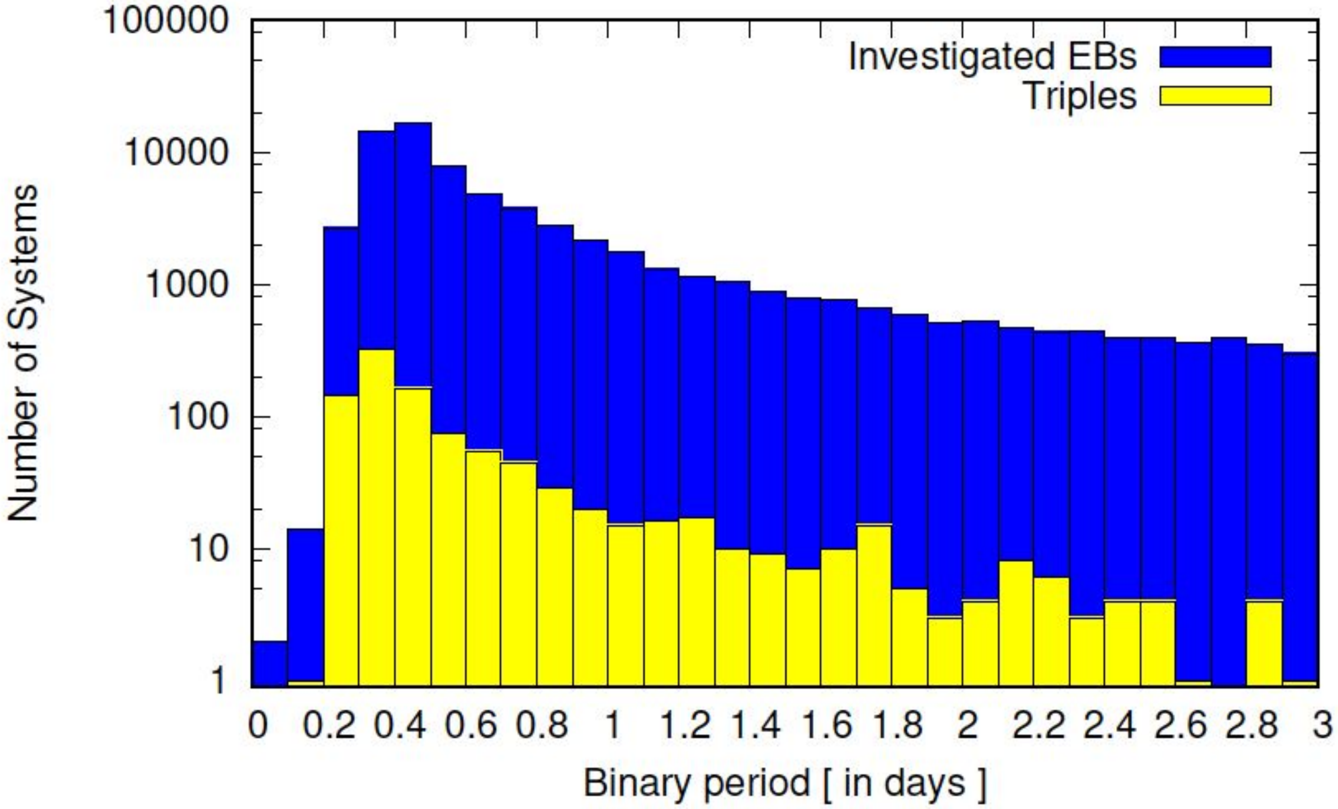
Hajdu et al. 2019

Eccentricity properties



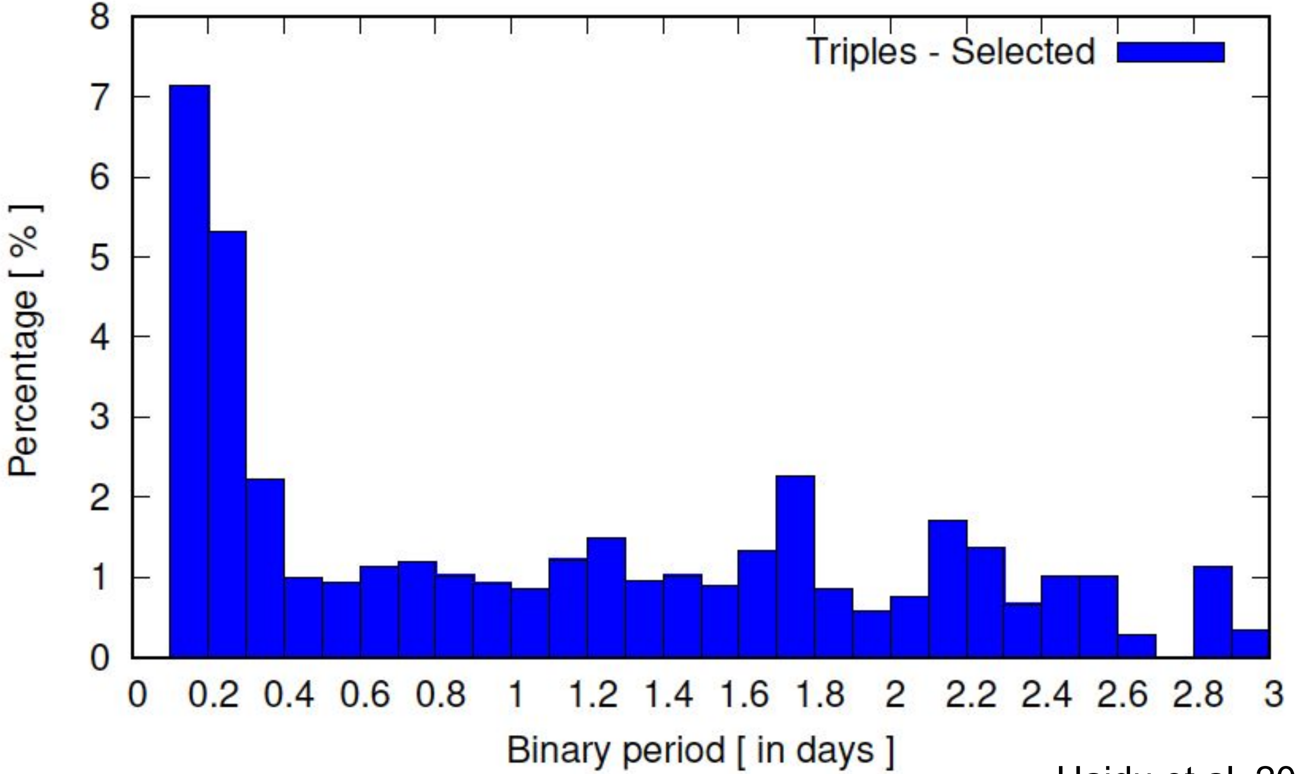
Hajdu et al. 2019

Primary period properties



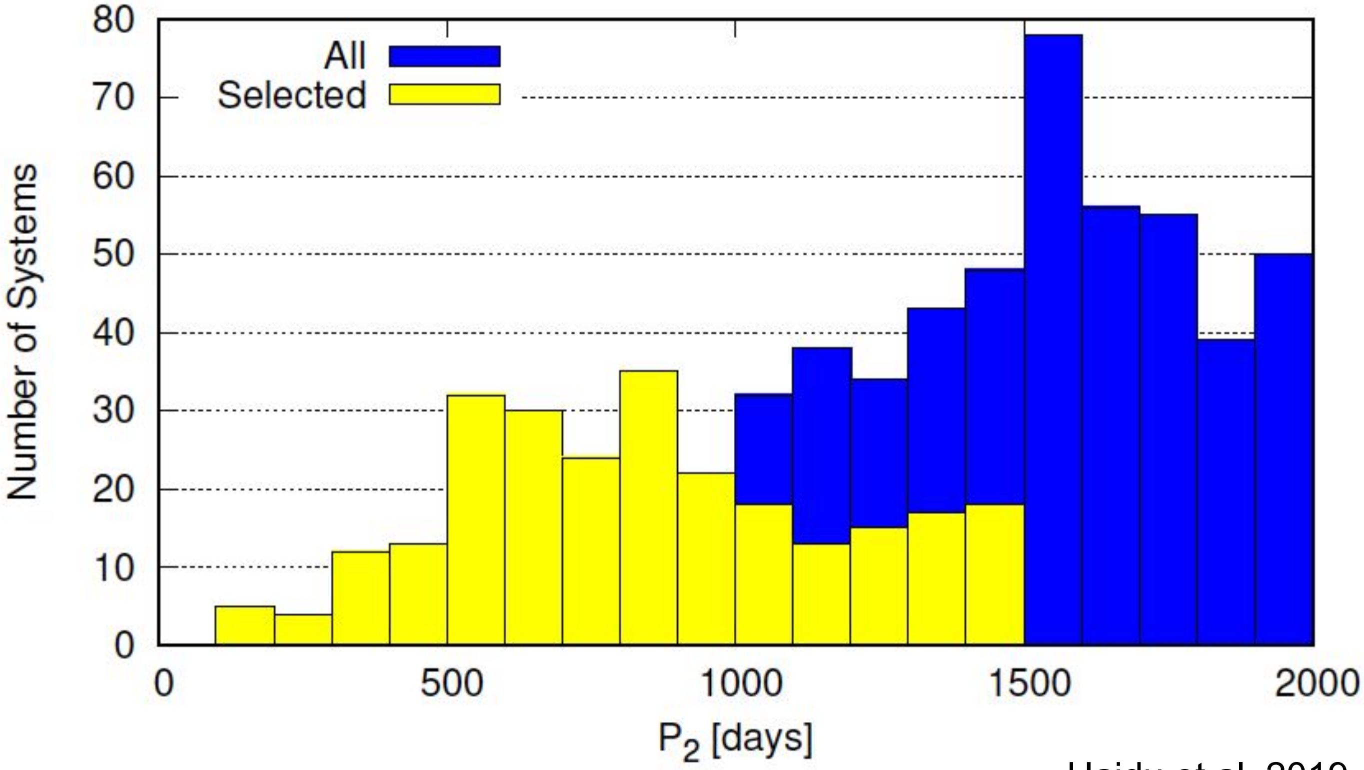
Hajdu et al. 2019

Triple system frequency

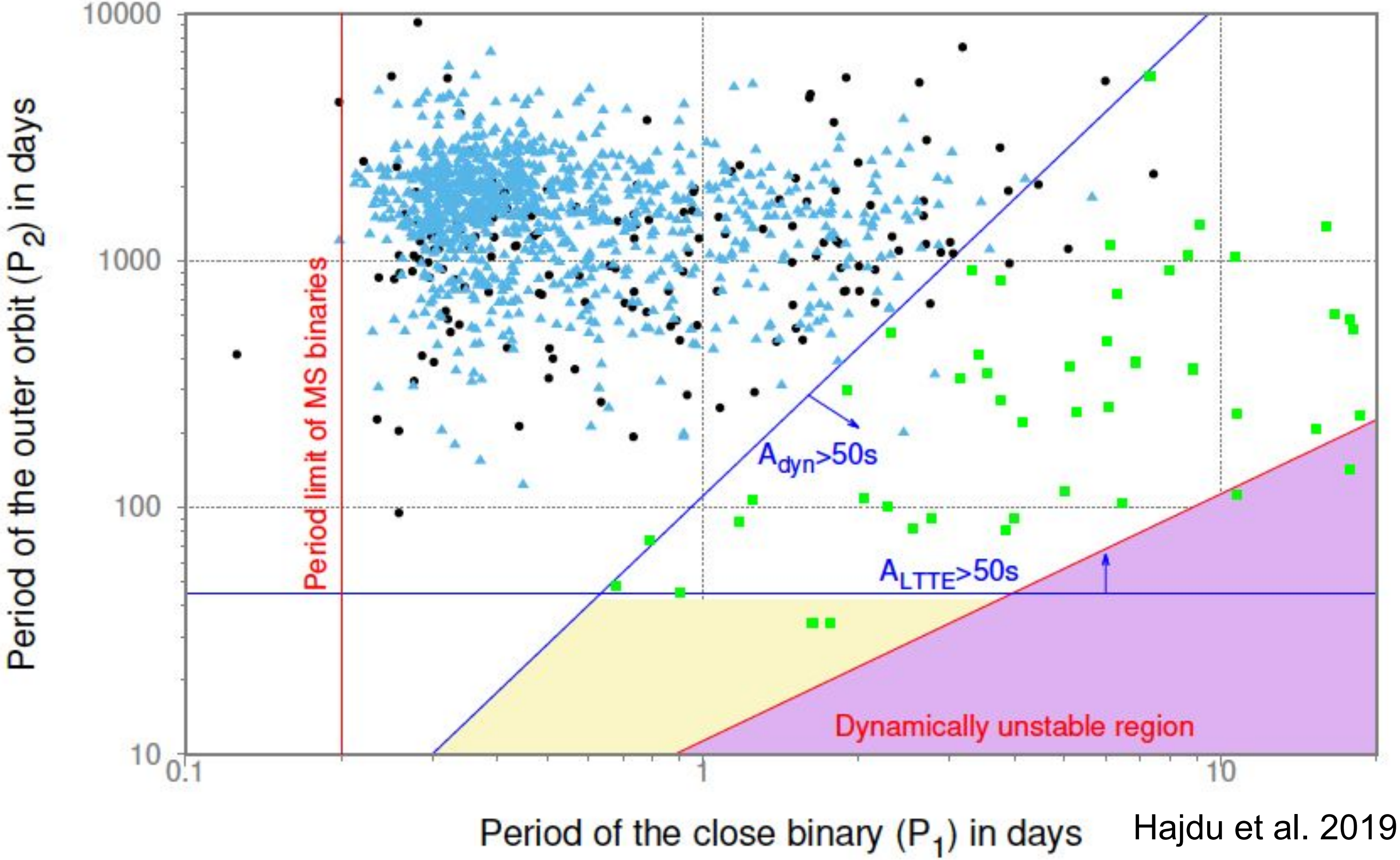


Hajdu et al. 2019

Tertiary period properties

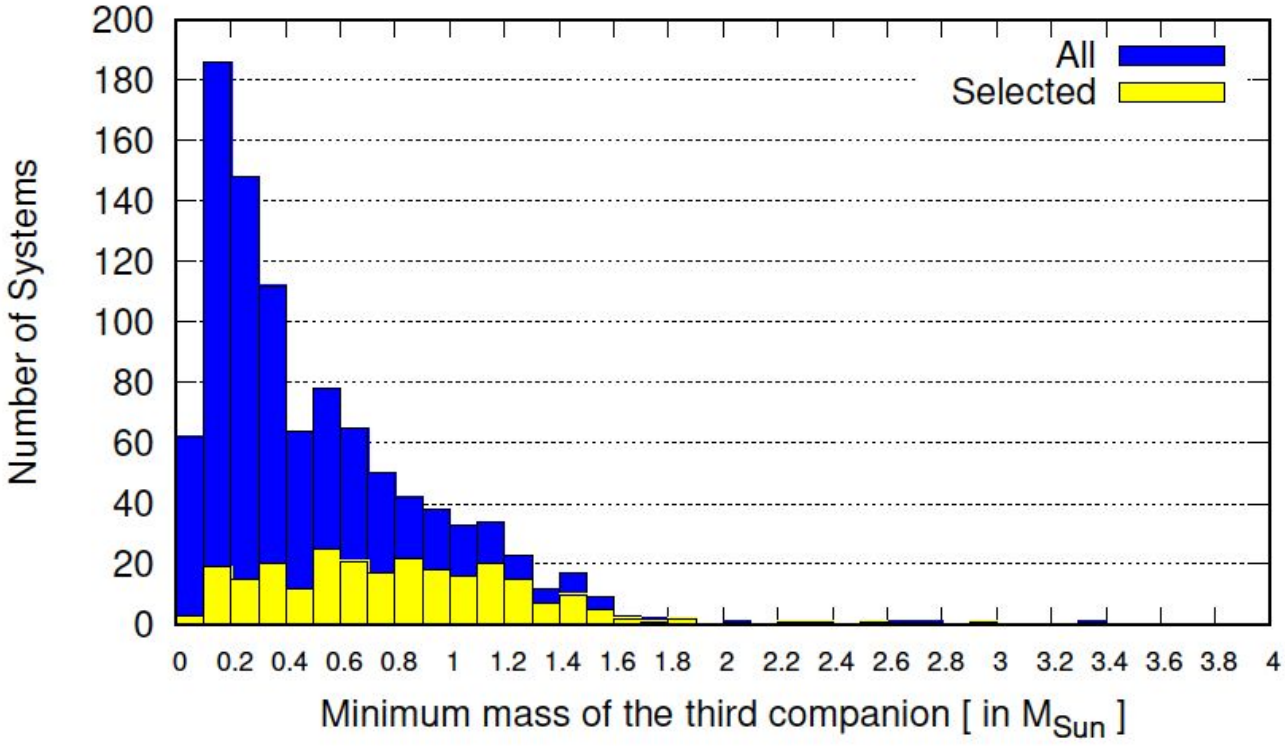


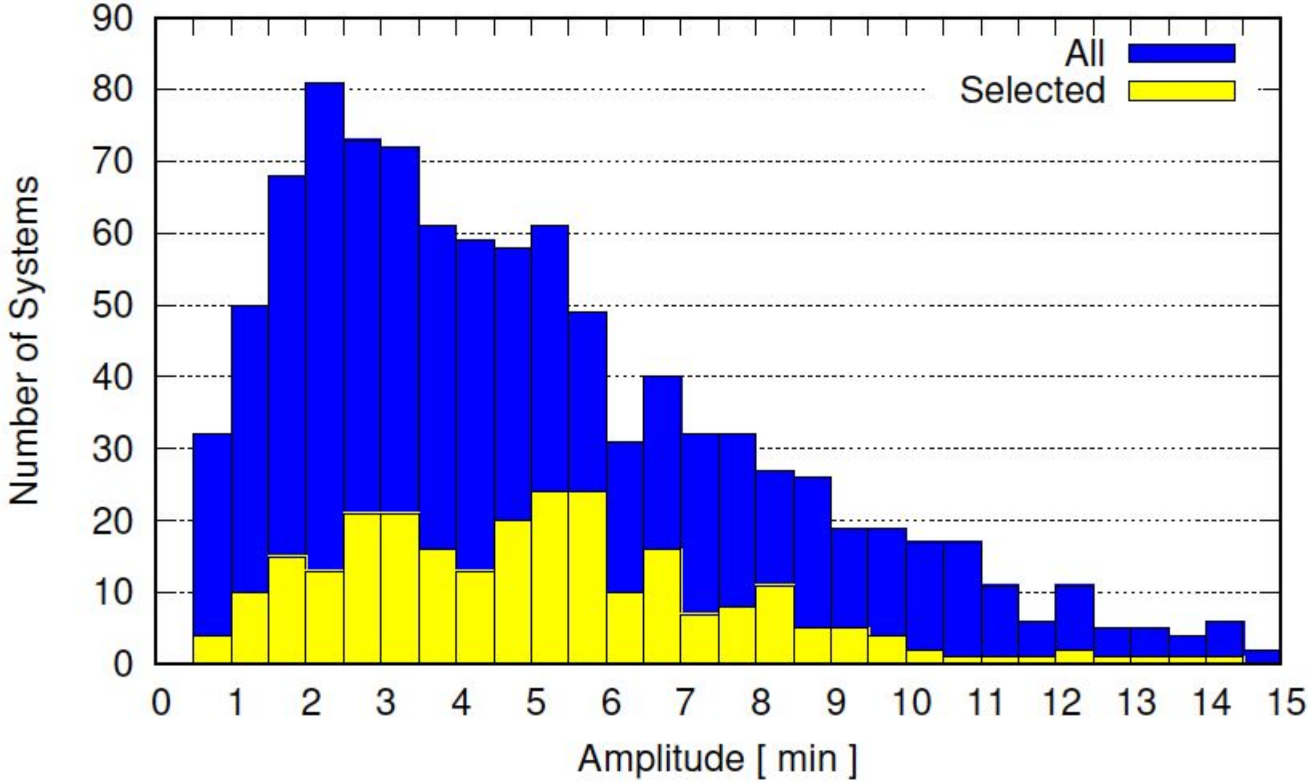
Hajdu et al. 2019



Hajdu et al. 2019

Lower mass limit distirbution





Amplitude < 1 minute compatible with tertiary period <1000 days, shorter than baseline of most observations

By the numbers

From Hajdu et al. 2019

- Analyzed ~400,000 eclipsing binaries
- 1/5th had enough data to be suitable for eclipse time variation fits
- Only ~1,000 were able to identify a tertiary via eclipse time variations
- 2 had light travel time + dynamical fits for mass determination
- 6 had a tertiary mass larger than the primary, ~2.5 $M_{\odot}$