

A Keck Target-of-Opportunity Program in Search of Free-floating Planets During K2C9

Calen B. Henderson
JPL/Caltech (NPP Fellow)



Microlensing 21
Friday, February 3, 2017

Program Description and Goals



Make first high-resolution flux measurement for short- t_E event



Minimize instrumental systematics for later baseline epoch



Improve precision-driven lens constraints



Generally gain experience with: Keck, high-res. data, AO, etc.



Help develop and refine lens flux characterization technique

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Help develop and refine lens flux characterization technique



Facilitate first secure free-floating planet (FFP) detection...!

On the shoulders of giants...

DISCUSSION

LENS-LIKE ACTION OF A STAR BY THE DEVIATION OF LIGHT IN THE GRAVITATIONAL FIELD

SOME time ago, R. W. Mandl paid me a visit and asked me to publish the results of a little calculation, which I had made at his request. This note complies with his wish.

The light coming from a star *A* traverses the gravitational field of another star *B*, whose radius is R_0 . Let there be an observer at a distance D from *B* and at a distance x , small compared with D , from the extended central line \overline{AB} . According to the general theory of relativity, let α_0 be the deviation of the light ray passing the star *B* at a distance R_0 from its center.

For the sake of simplicity, let us assume that \overline{AB} is large, compared with the distance D of the observer from the deviating star *B*. We also neglect the eclipse (geometrical obscuration) by the star *B*, which indeed is negligible in all practically important cases. To permit this, D has to be very large compared to the radius R_0 of the deviating star.

It follows from the law of deviation that an observer situated exactly on the extension of the central line \overline{AB} will perceive, instead of a point-like star *A*, a luminous circle of the angular radius β around the center of *B*, where

$$\beta = \sqrt{\alpha_0 \frac{R_0}{D}}$$

It should be noted that this angular diameter β does

not decrease like $1/D$, but like $1/\sqrt{D}$, as the distance

Of course, there is no hope of observing this phenomenon directly. First, we shall scarcely ever ap-

the angle β will defy the resolving power of our instruments. For, α_0 being of the order of magnitude of one second of arc, the angle R_0/D , under which the deviating star *B* is seen, is much smaller. Therefore, the light coming from the luminous circle can not be distinguished by an observer as geometrically different from that coming from the star *B*, but simply will manifest itself as increased apparent brightness of *B*.

The same will happen, if the observer is situated at a small distance x from the extended central line \overline{AB} . But then the observer will see *A* as two point-like light-sources, which are deviated from the true geometrical position of *A* by the angle β , approximately.

The apparent brightness of *A* will be increased by the lens-like action of the gravitational field of *B* in the ratio q . This q will be considerably larger than unity only if x is so small that the observed positions of *A* and *B* coincide, within the resolving power of our instruments. Simple geometric considerations lead to the expression

$$q = \frac{l}{x} \cdot \frac{1 + \frac{x^2}{2l^2}}{\sqrt{1 + \frac{x^2}{4l^2}}}$$

where

$$l = \sqrt{\alpha_0 D R_0}$$

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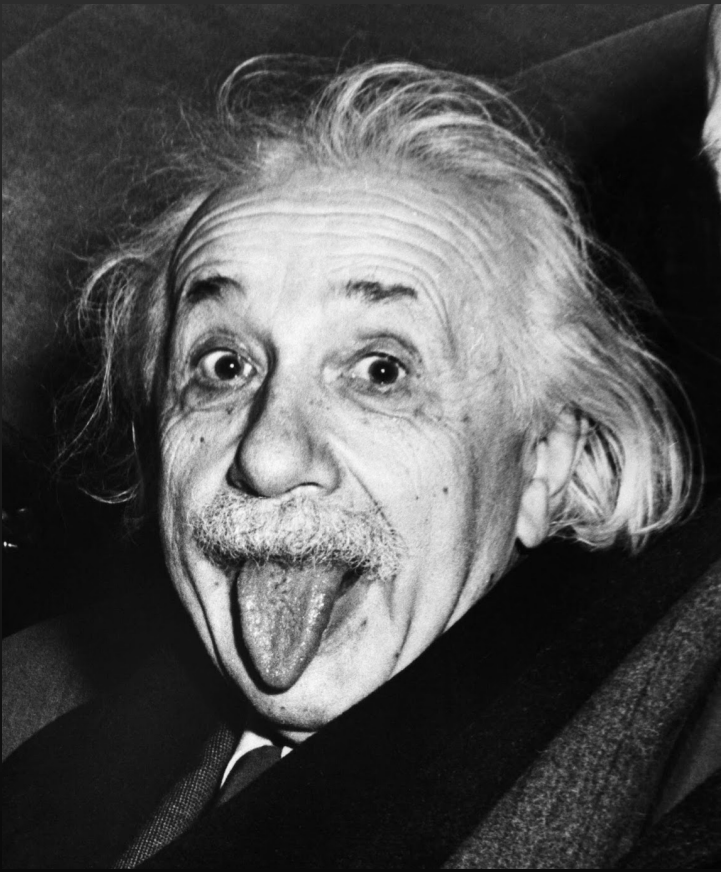
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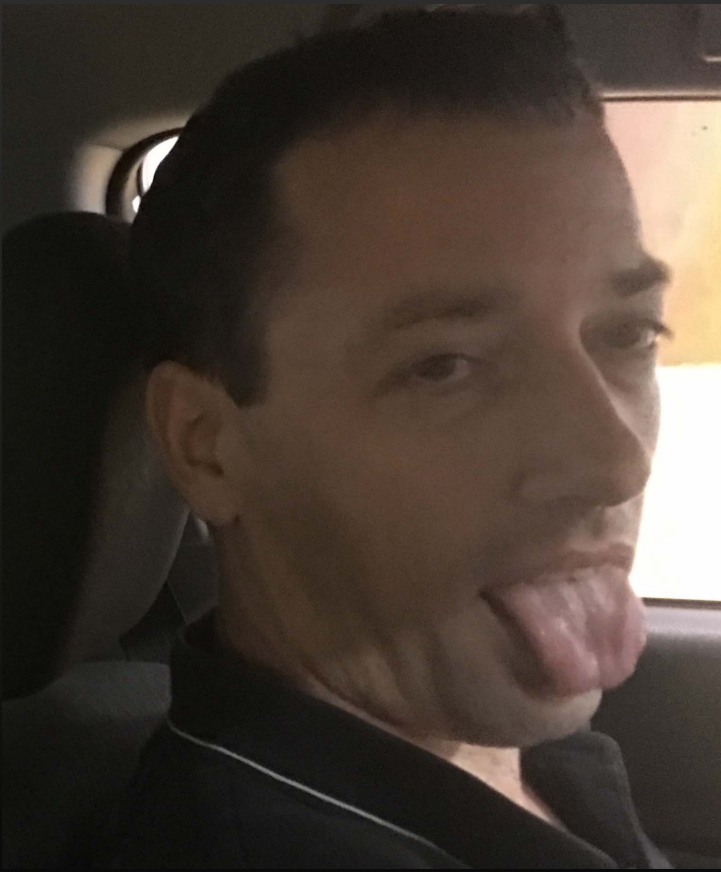
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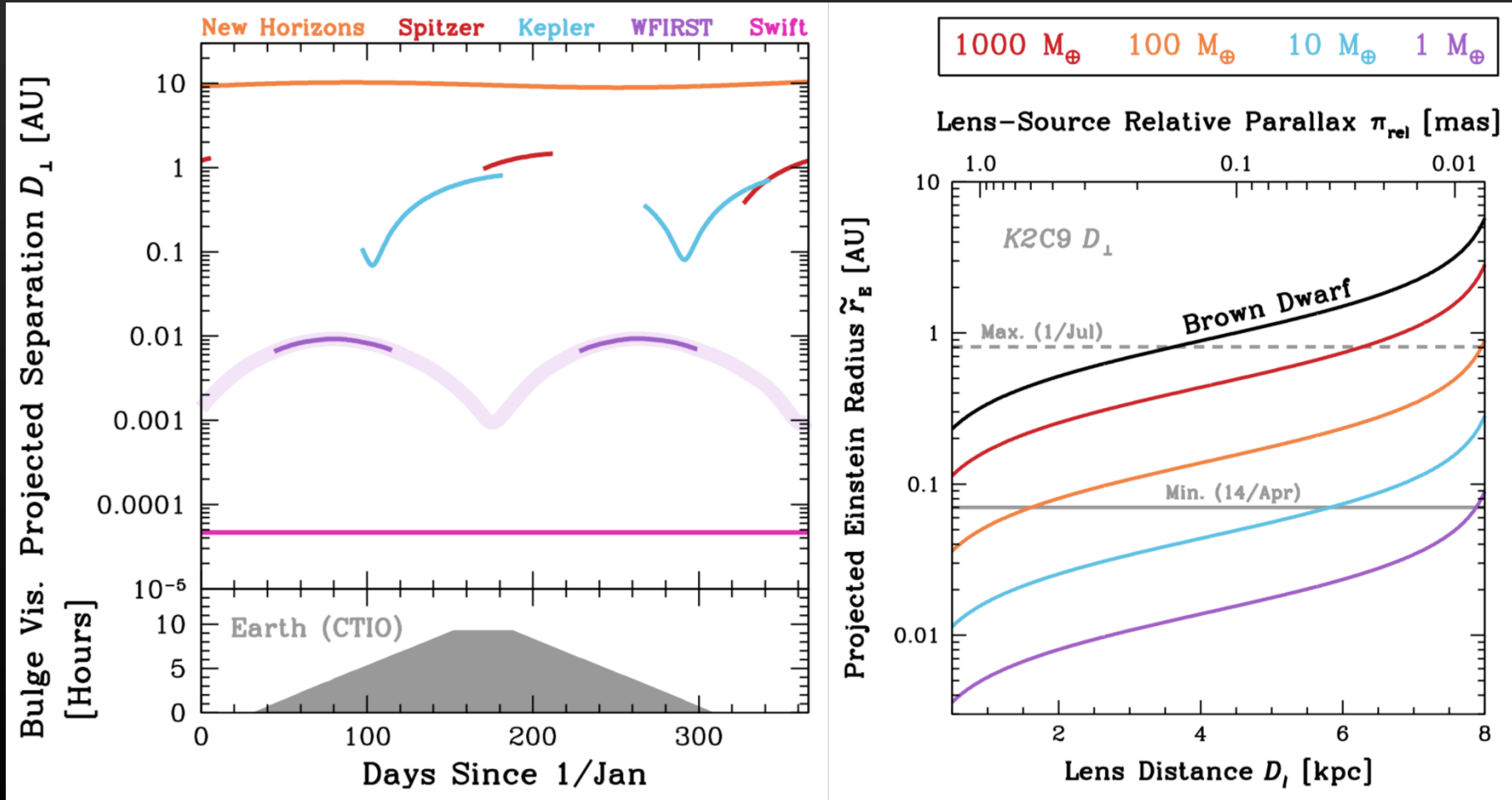
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The Era of Precision Microlensing

	short τ_E $\leq 2d$ OGLE	+ ulens	+ K2	$\leq 13 M_J$ → low-mass	Nature paper FFP
GB	3	1	\emptyset	\emptyset	\emptyset
CH	16	8	4	2	
YS	15	3	1	\emptyset	1
SCN	13	5	3	1	\emptyset
MP	>20				3

K2C9 Sensitivity to Free-floating Planet π_E Measurements



Henderson (fine, & Shvartzvald) (2016), AJ, 152, 96

Target of Opportunity (ToO) Calendar

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
April 2016					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
Notes:						

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
May 2016						
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	Notes:			

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
June 2016						
			1	2	3	4
5	6	7	8	9	10	11
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31	Notes:					

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Dates of space-based campaign

Target of Opportunity (ToO) Calendar

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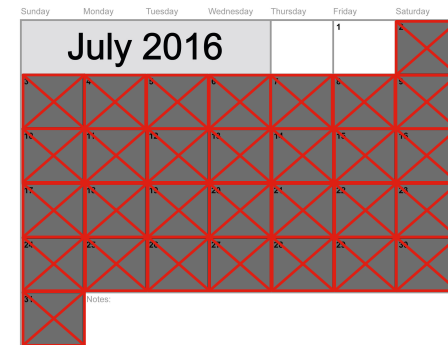
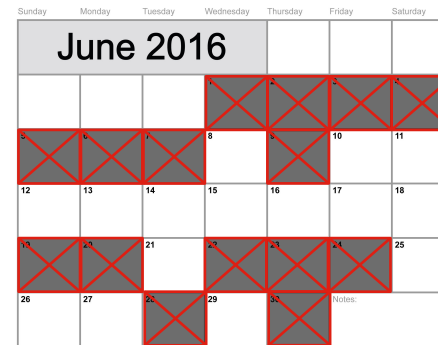
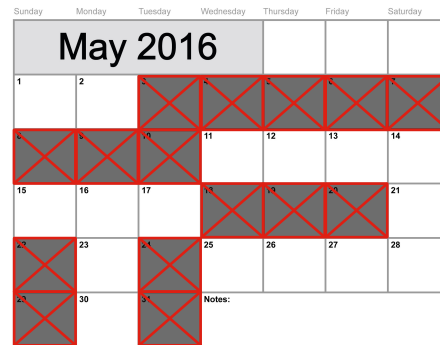
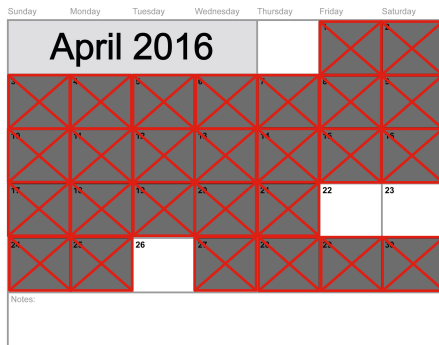


Dates of space-based campaign



Dates of *actual* space-based campaign...

Target of Opportunity (ToO) Calendar



Dates of space-based campaign

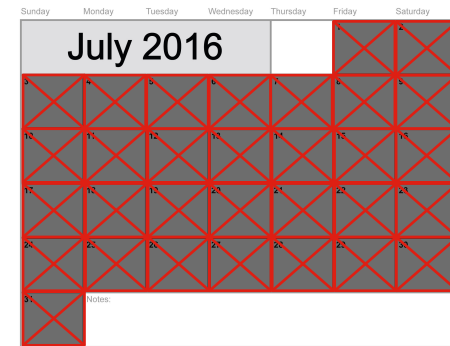
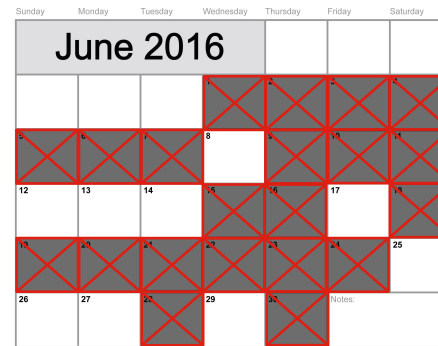
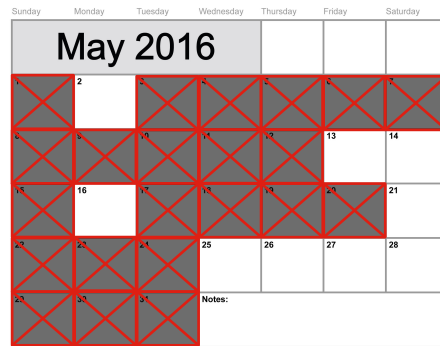
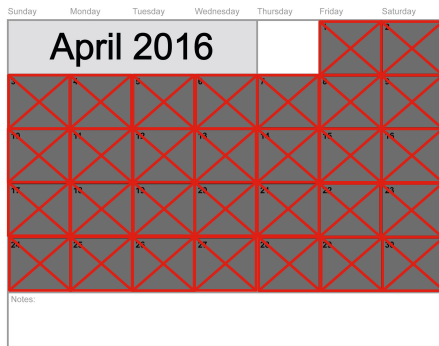


Dates of *actual* space-based campaign...



Dates for which NIRC2 is on-sky

Target of Opportunity (ToO) Calendar



Dates of space-based campaign



Dates of *actual* space-based campaign...

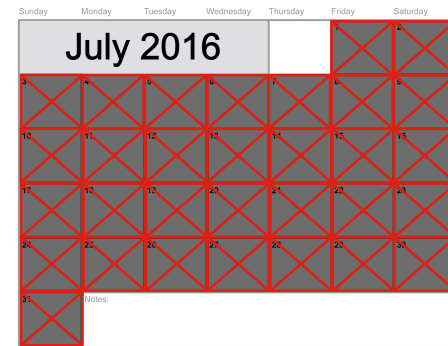
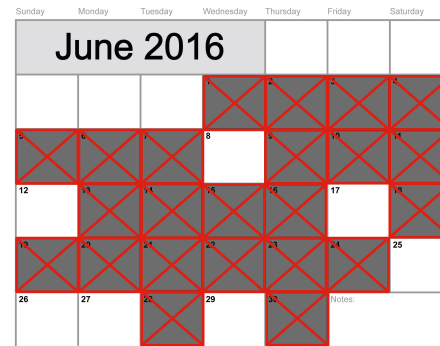
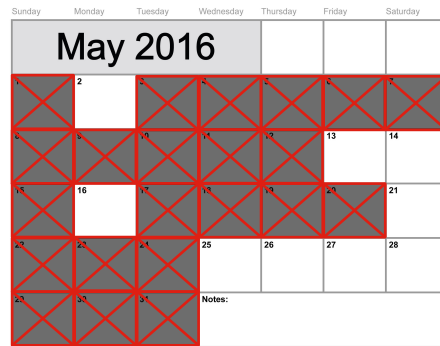
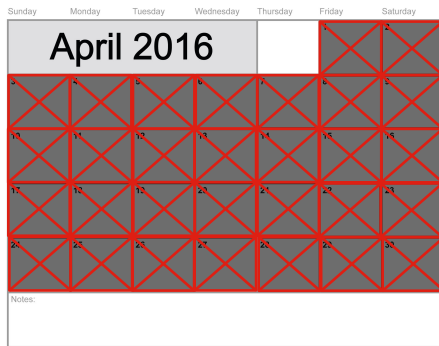


Dates for which NIRC2 is on-sky



...and being used by UoC or CIT PI

Target of Opportunity (ToO) Calendar



Dates of space-based campaign



Dates of *actual* space-based campaign...



Dates for which NIRC2 is on-sky

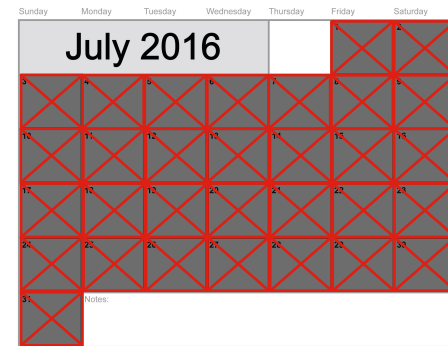
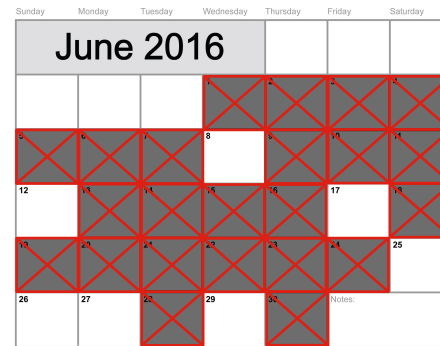
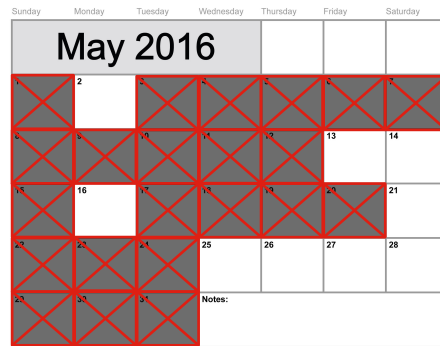
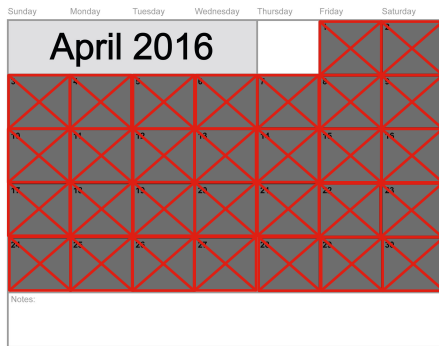


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Oh! And no snow on Mauna Kea...

Target of Opportunity (ToO) Calendar



Dates of space-based campaign



Dates of *actual* space-based campaign...



Dates for which NIRC2 is on-sky



16 nights!



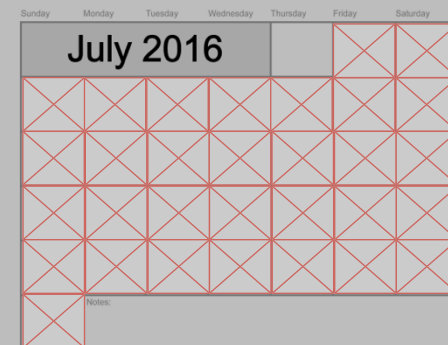
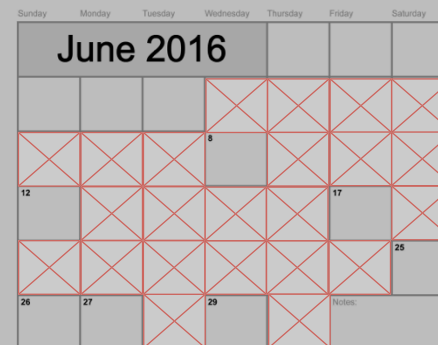
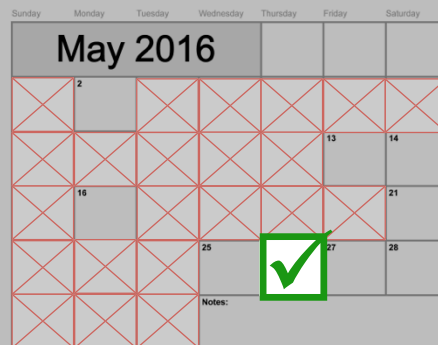
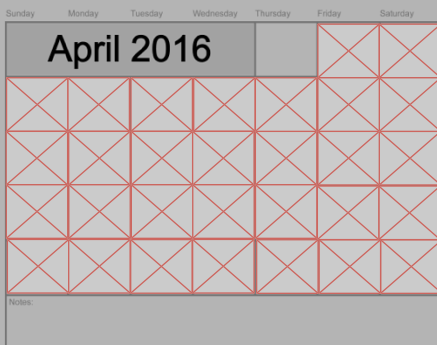
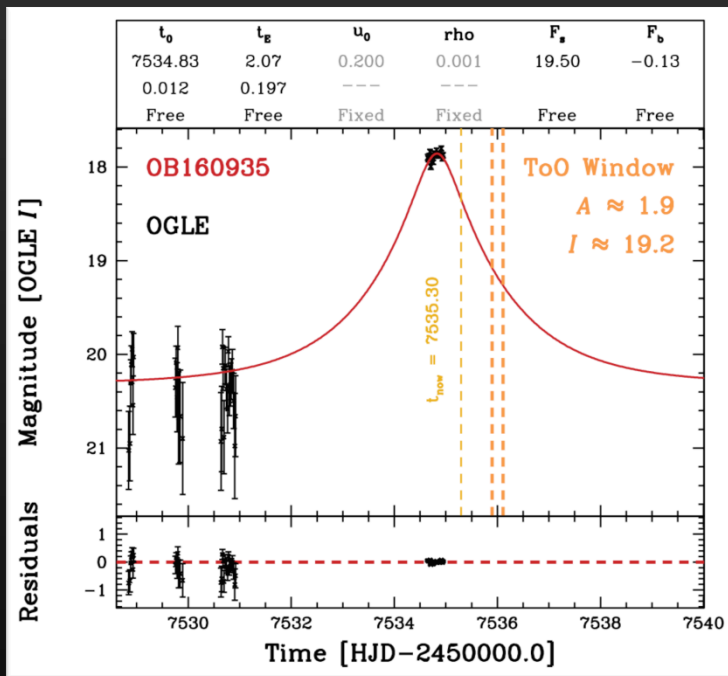
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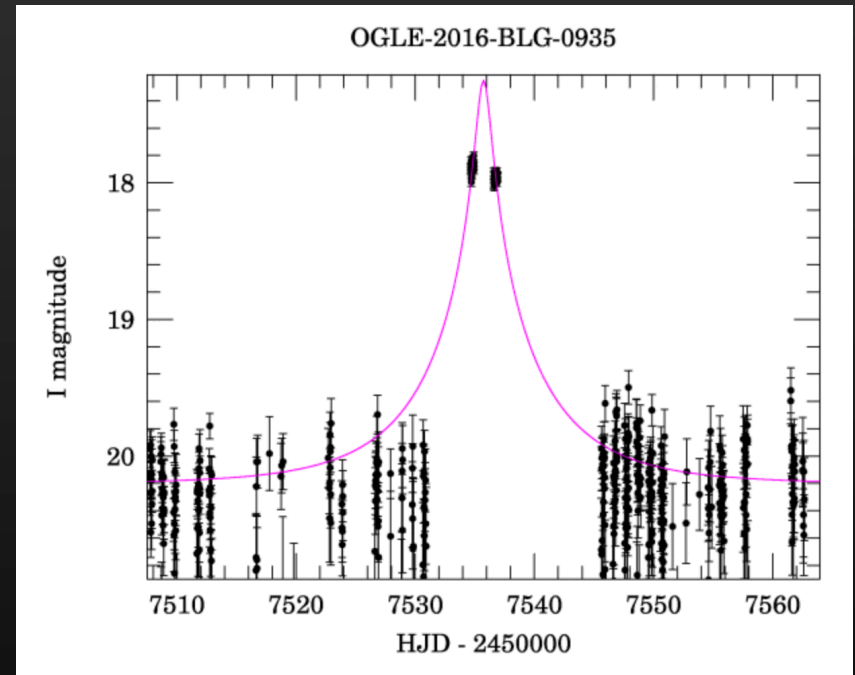
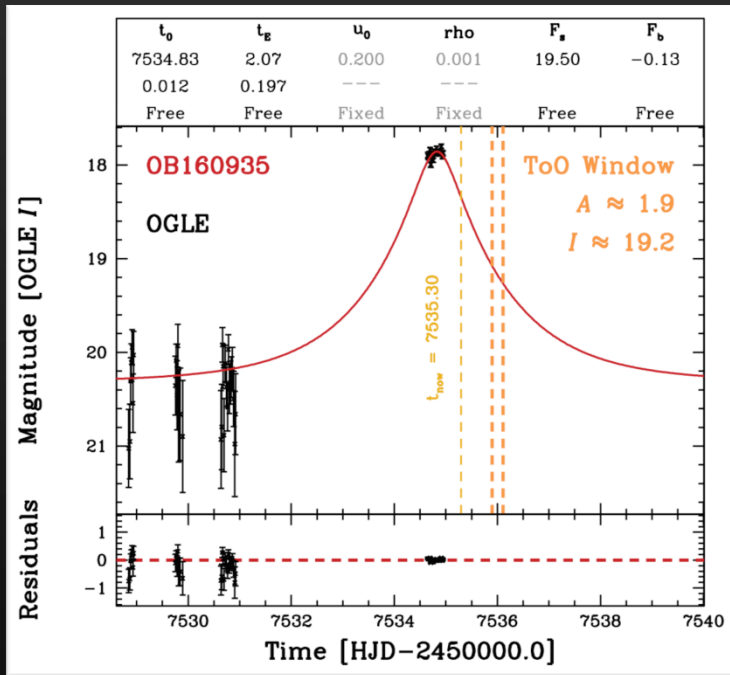
26/May: OB160935...?!

[0.54 AU]

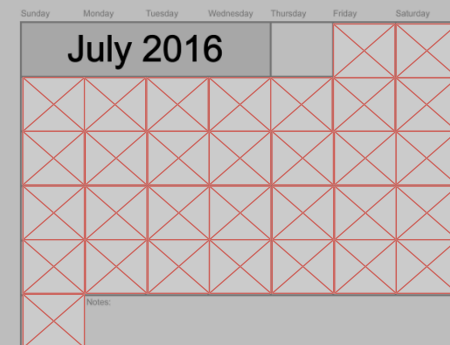
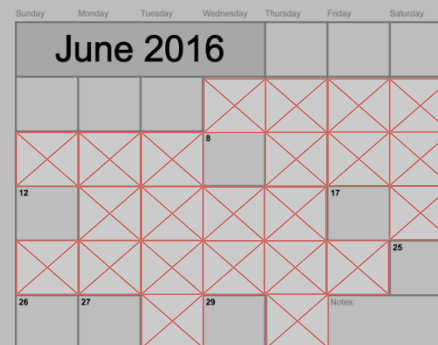
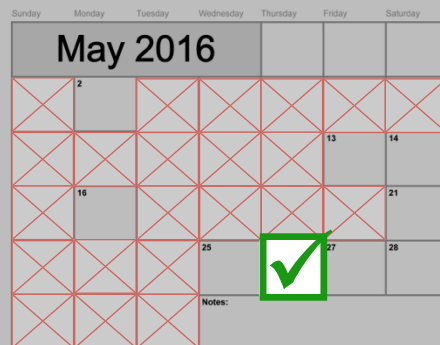
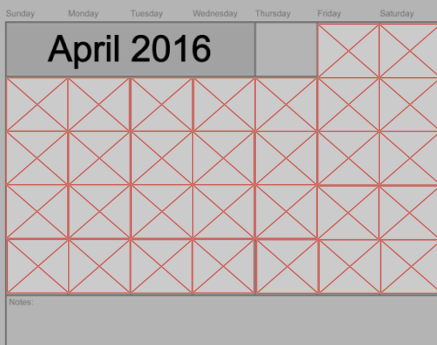


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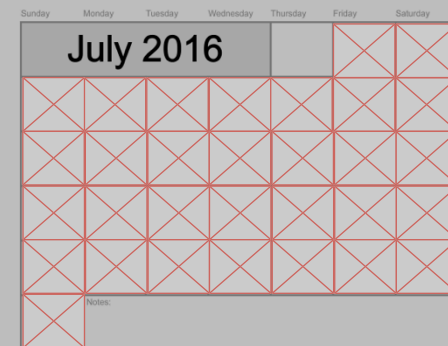
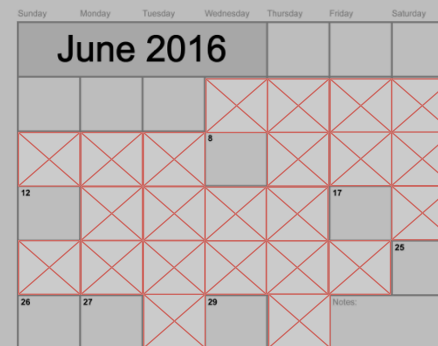
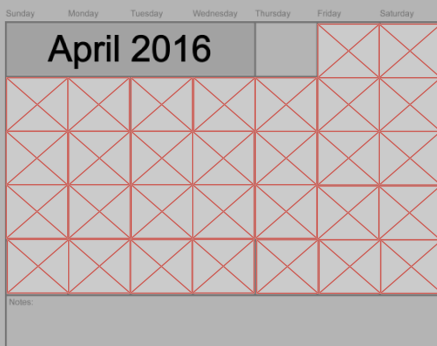
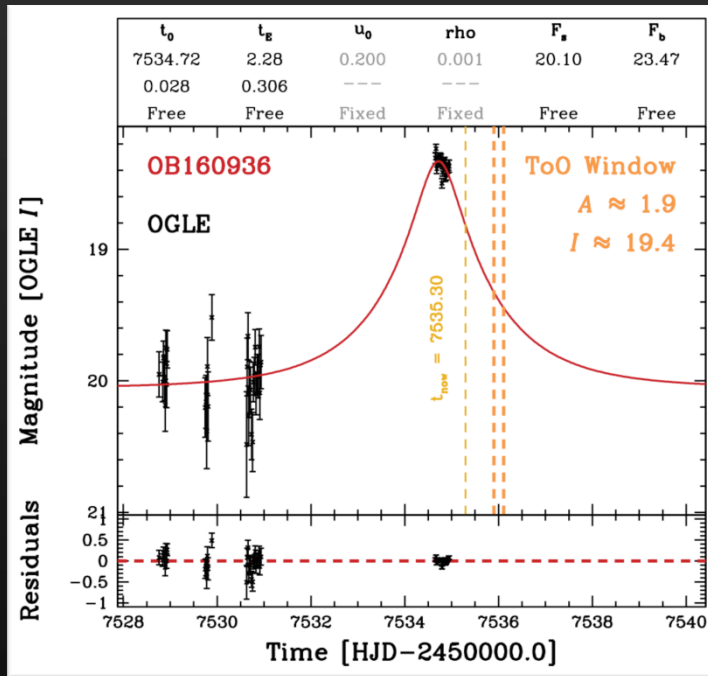


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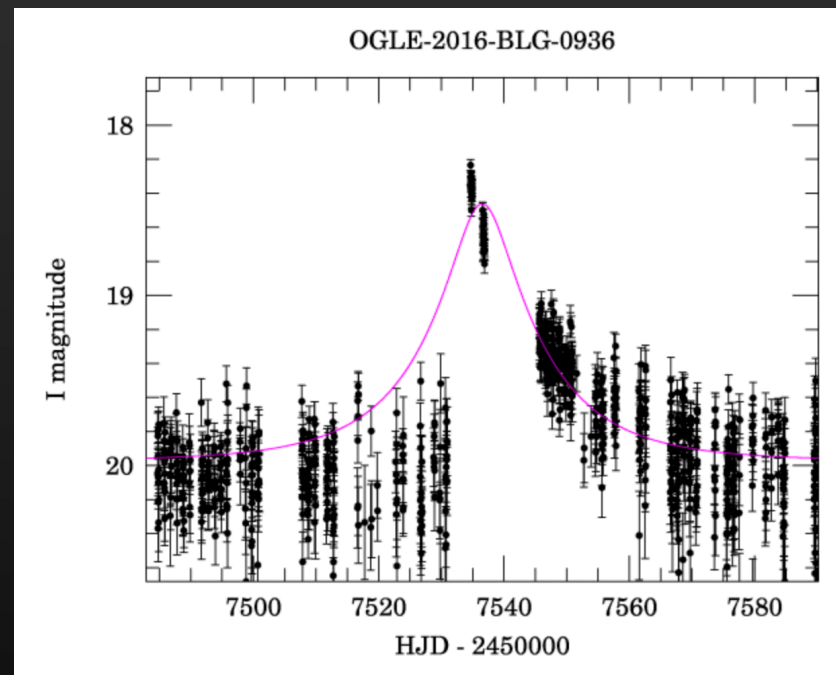
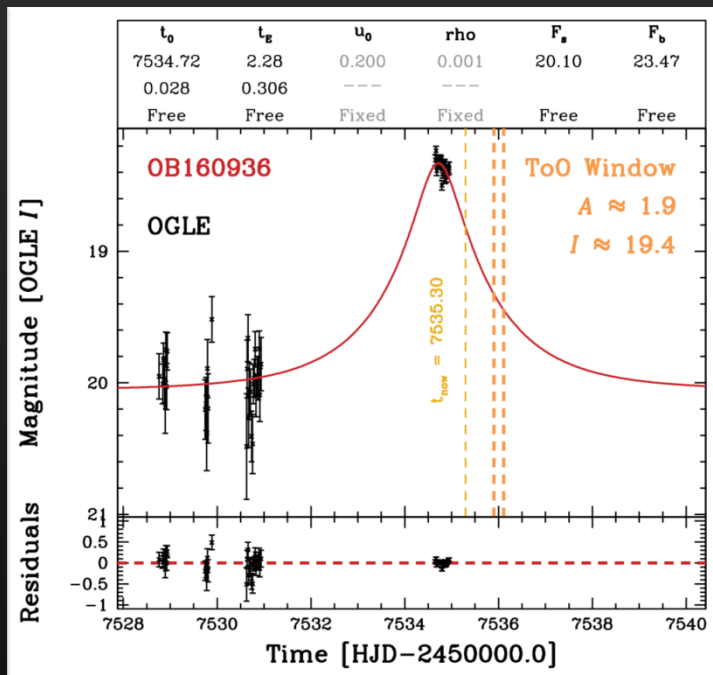
26/May: OB160936...?!

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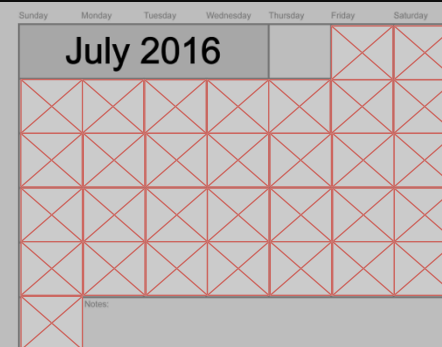
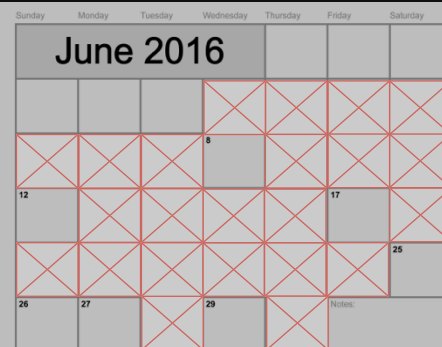
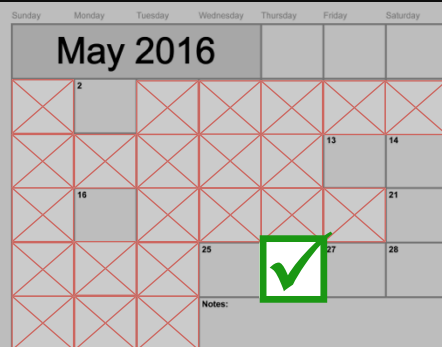
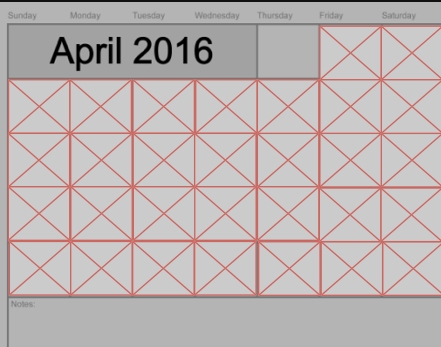


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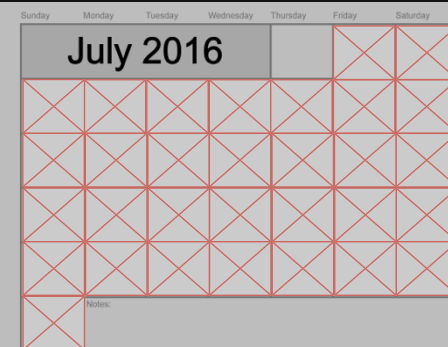
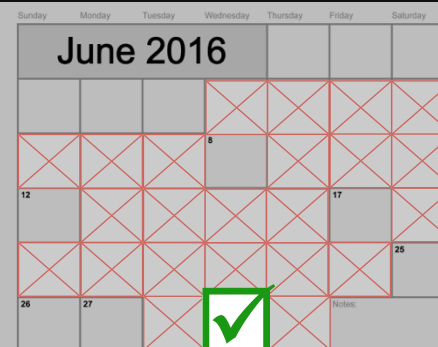
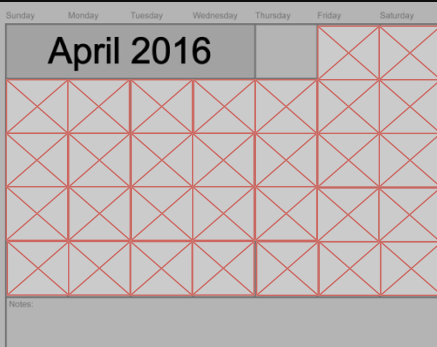
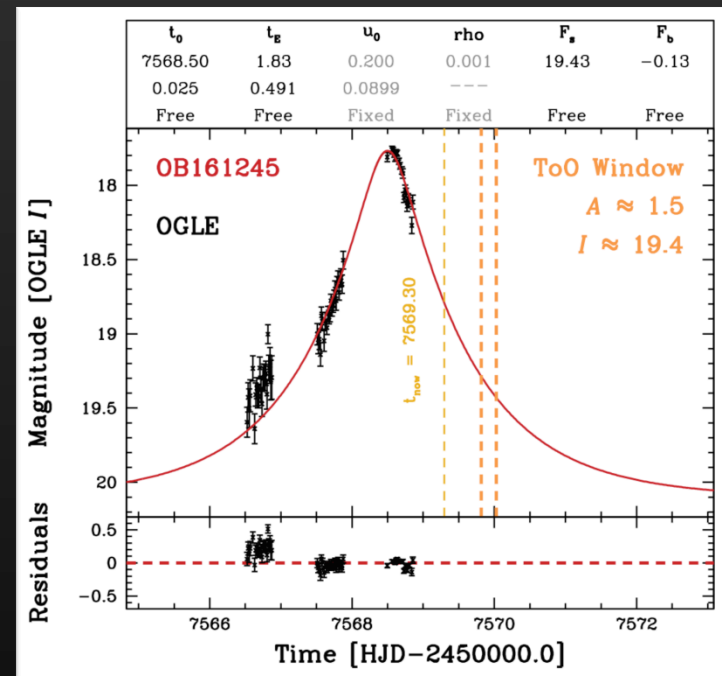
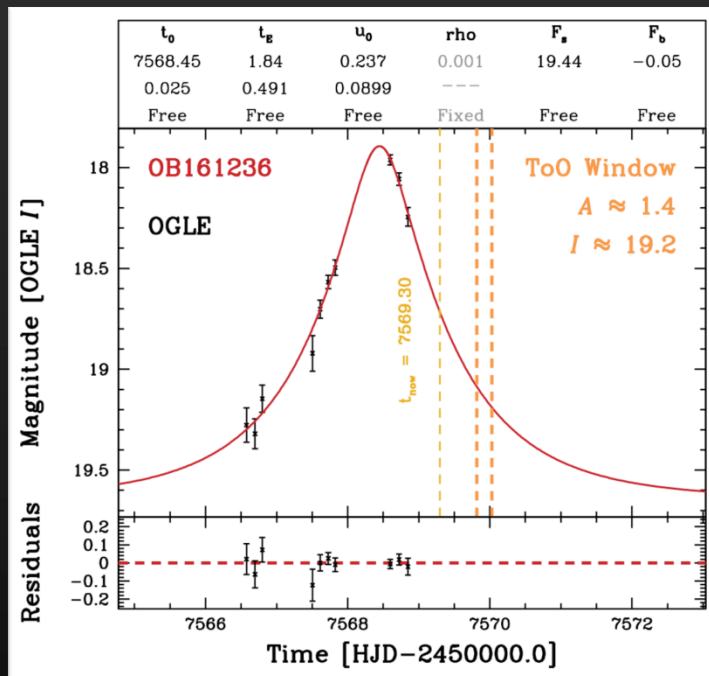


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29/June: OB161236, OB161245...?!

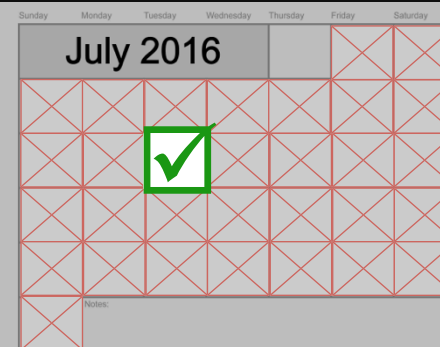
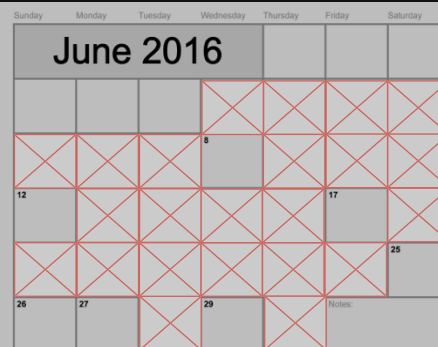
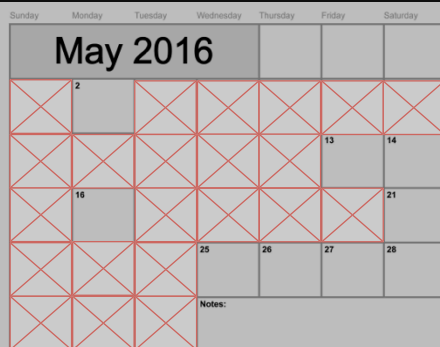
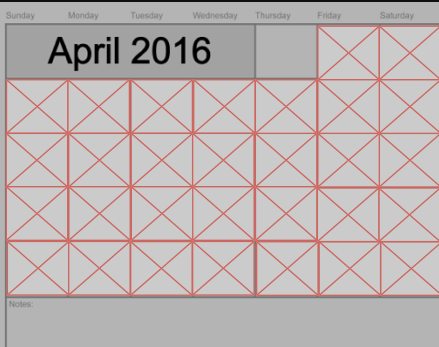
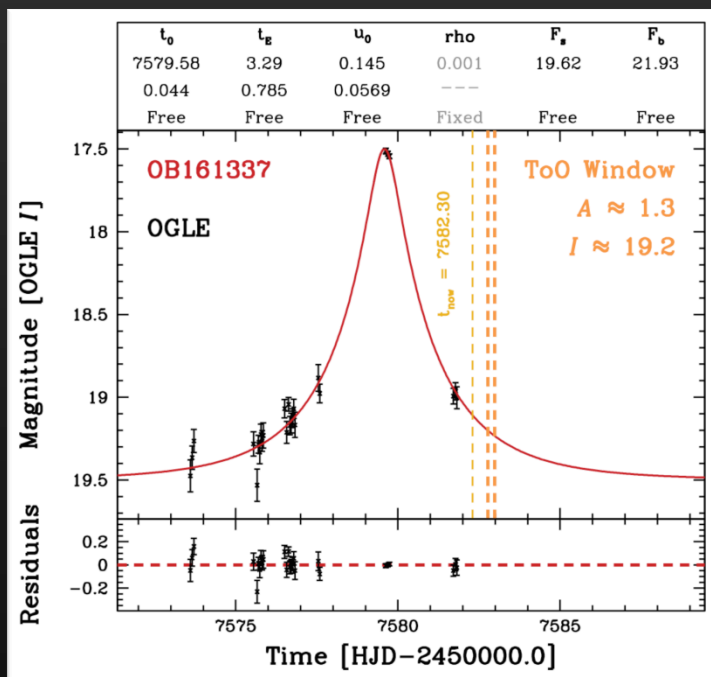
[0.80 AU]



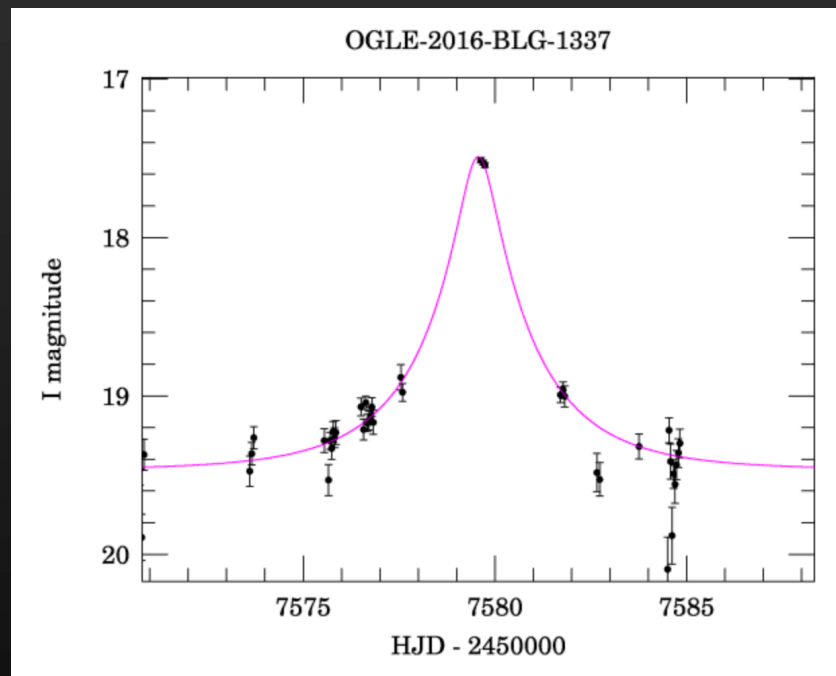
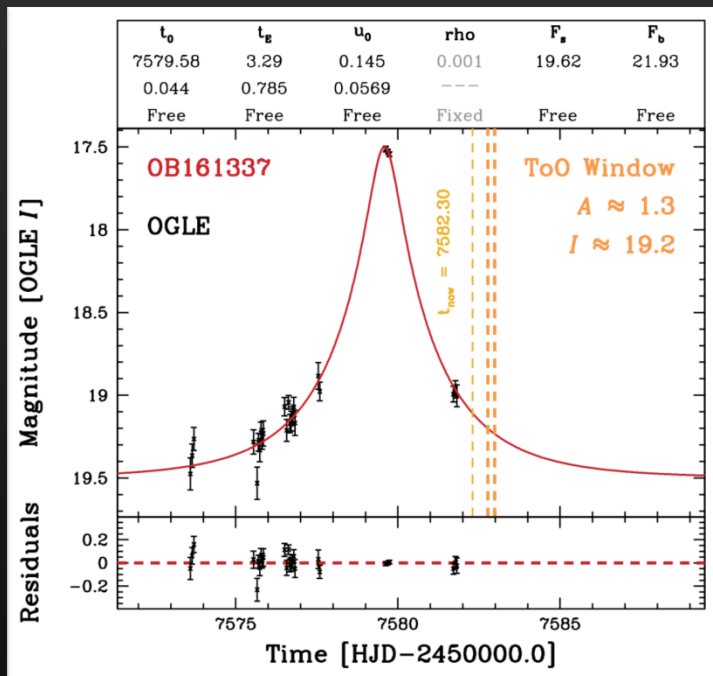
Rogue ~~One~~?! Zero...



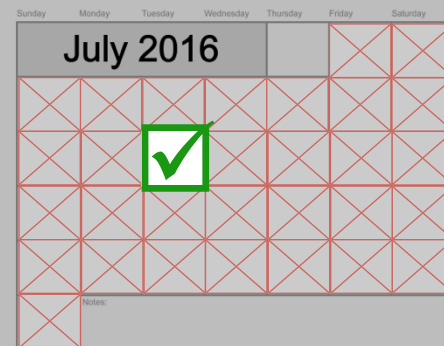
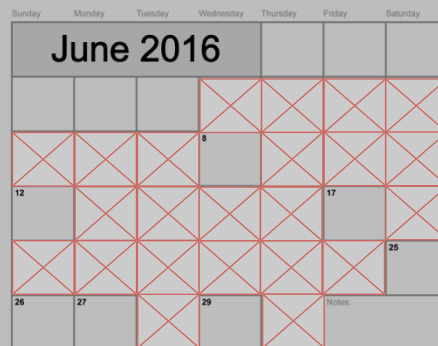
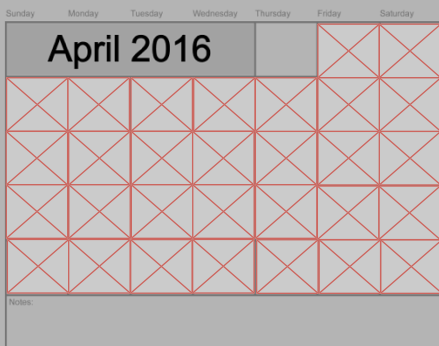
But wait, one more! 12/July: OB161337...?



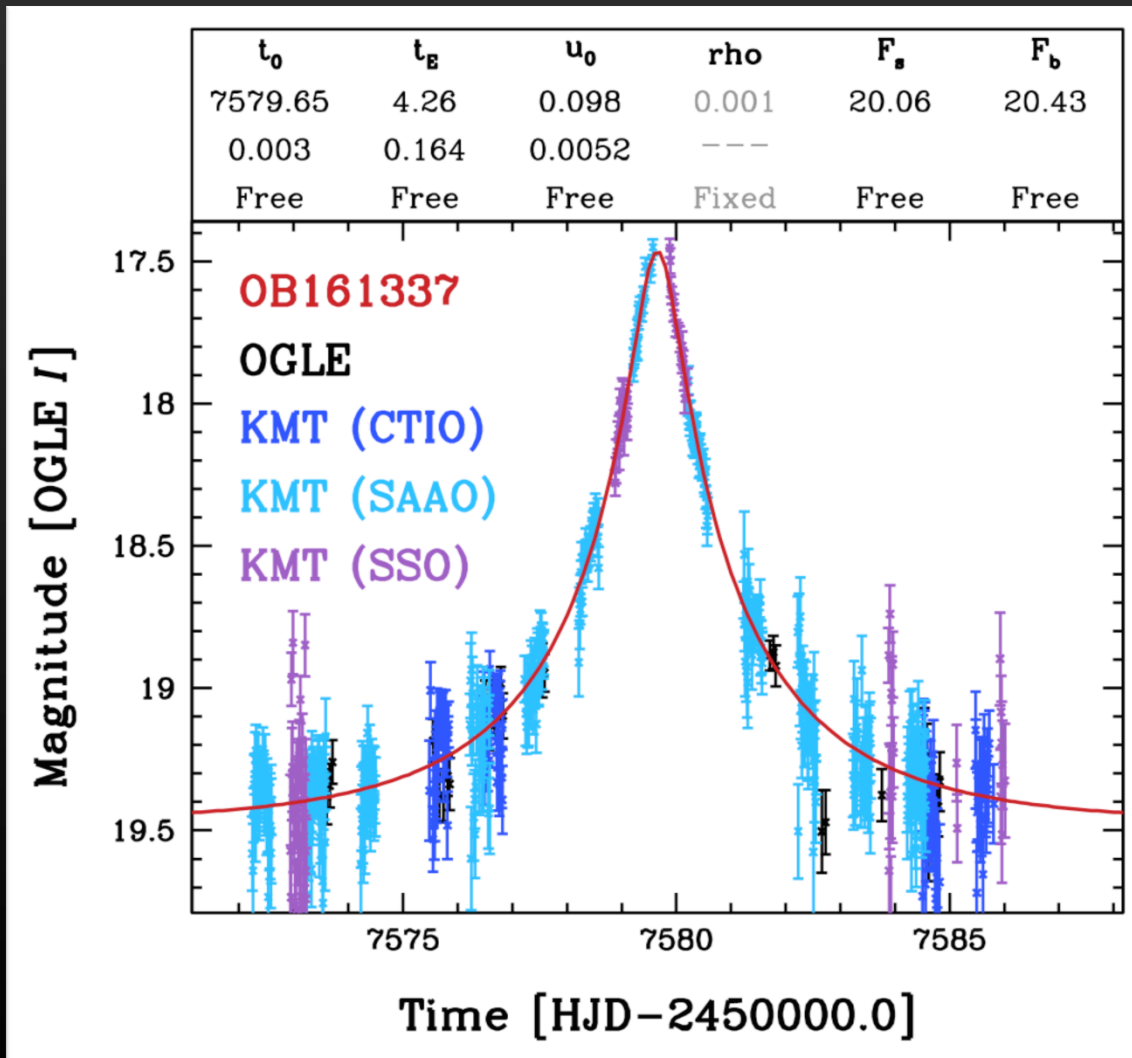
But wait, one more! 12/July: OB161337...?



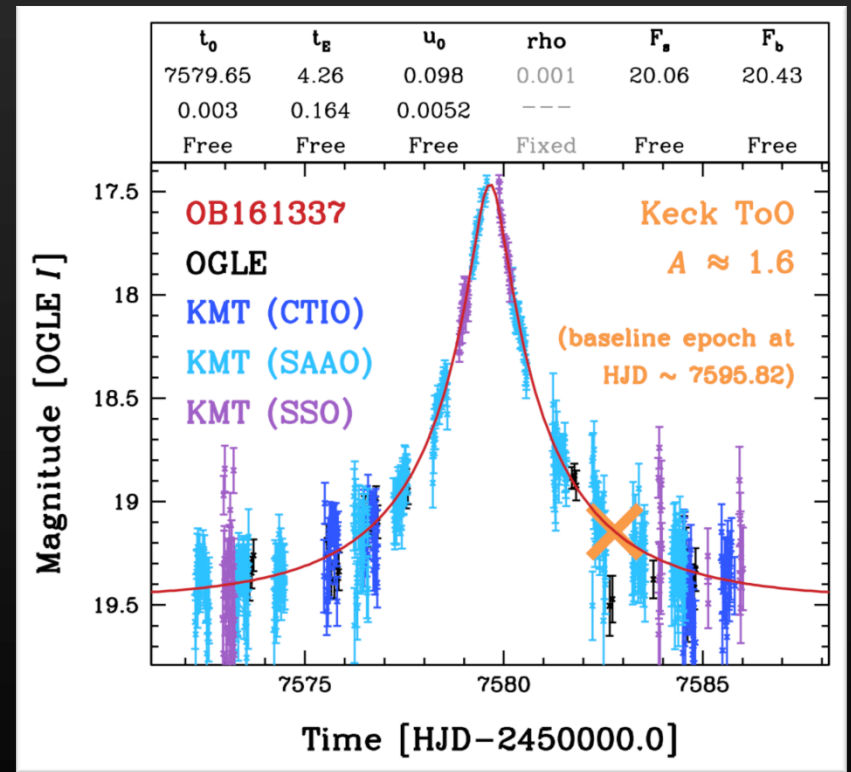
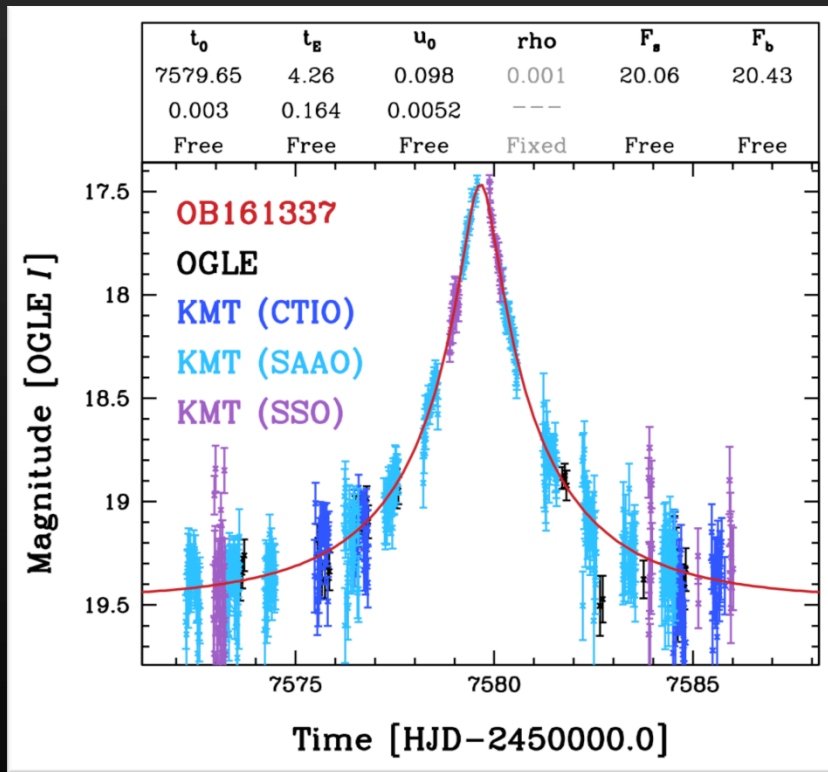
<http://ogle.astrouw.edu.pl/ogle4/ews/ews.html>



OB161337: OGLE+KMTNet

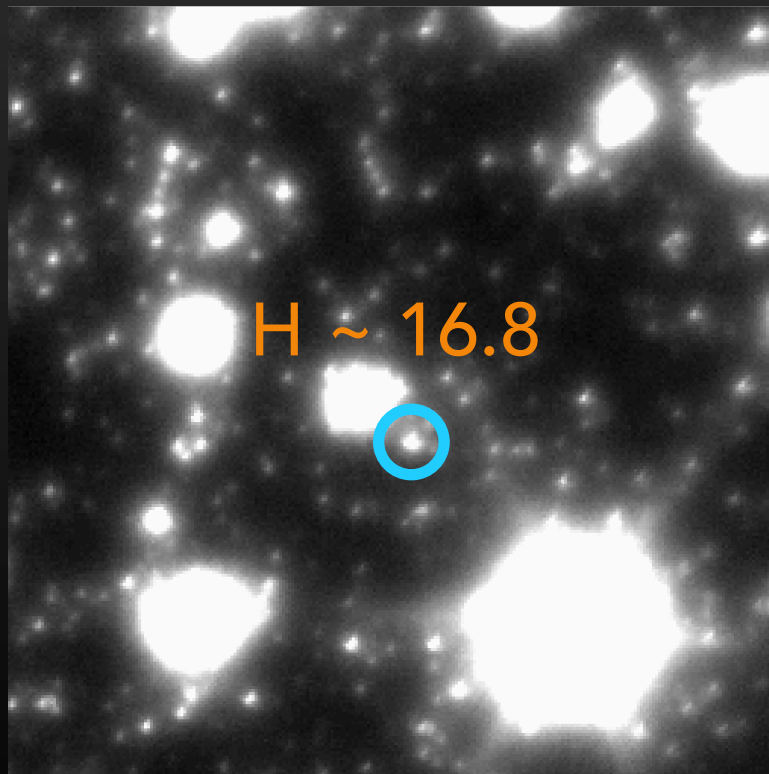


OB161337: OGLE+KMTNet+Keck!

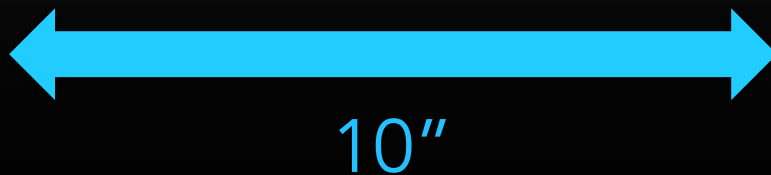
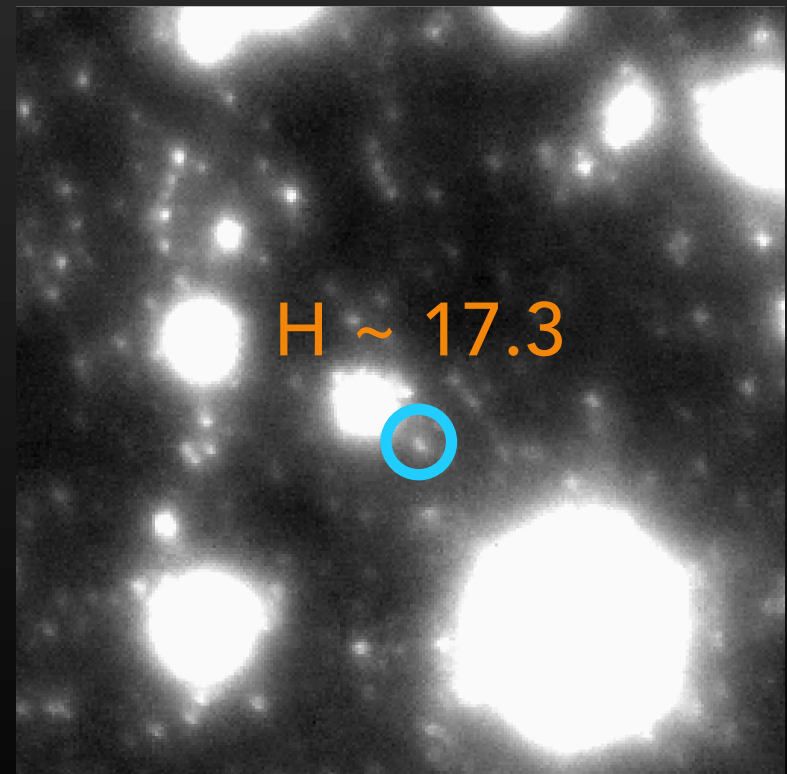


OB161337: NIRC2 AO Photometry

Epoch 1 (A ~ 1.6)



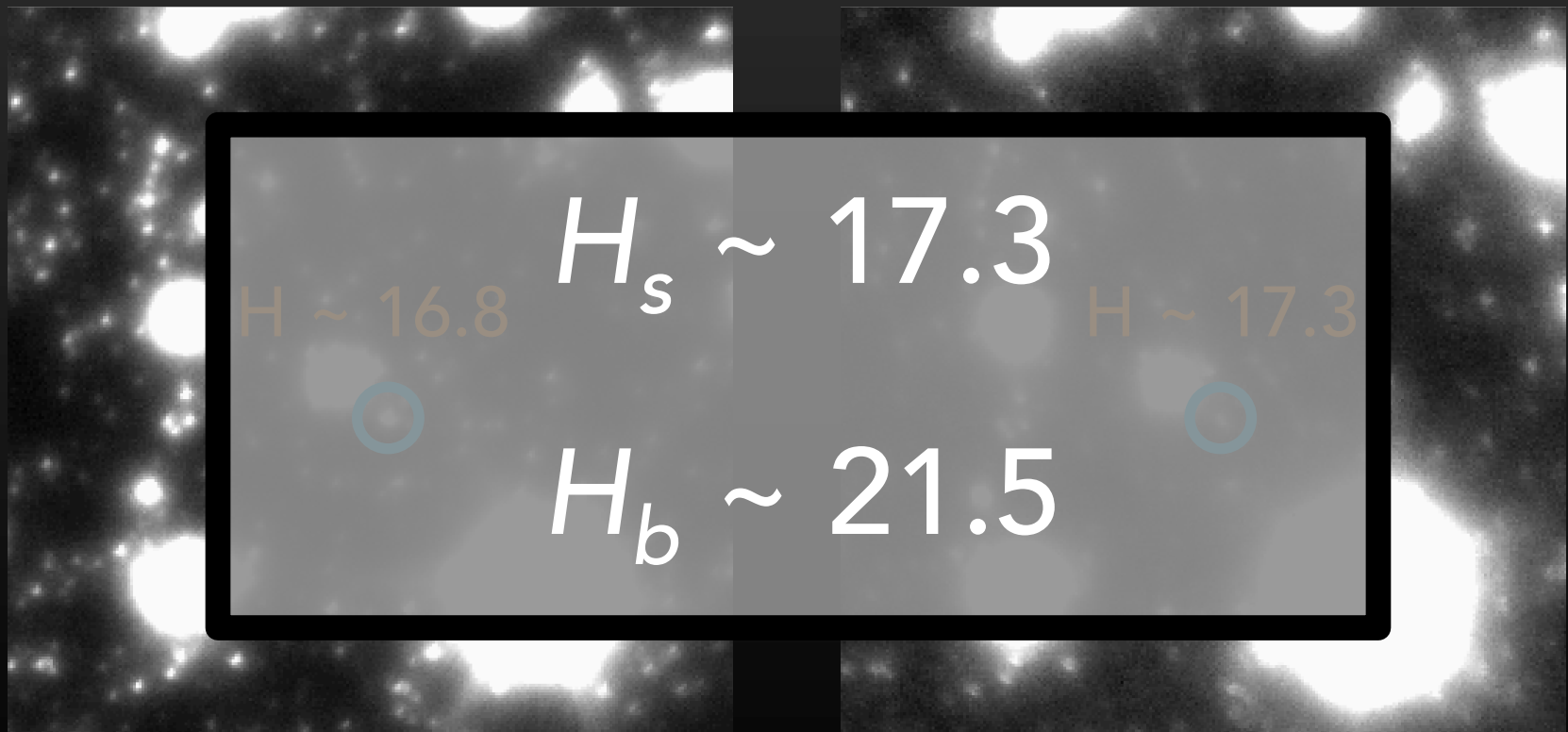
Epoch 2



OB161337: NIRC2 AO Photometry

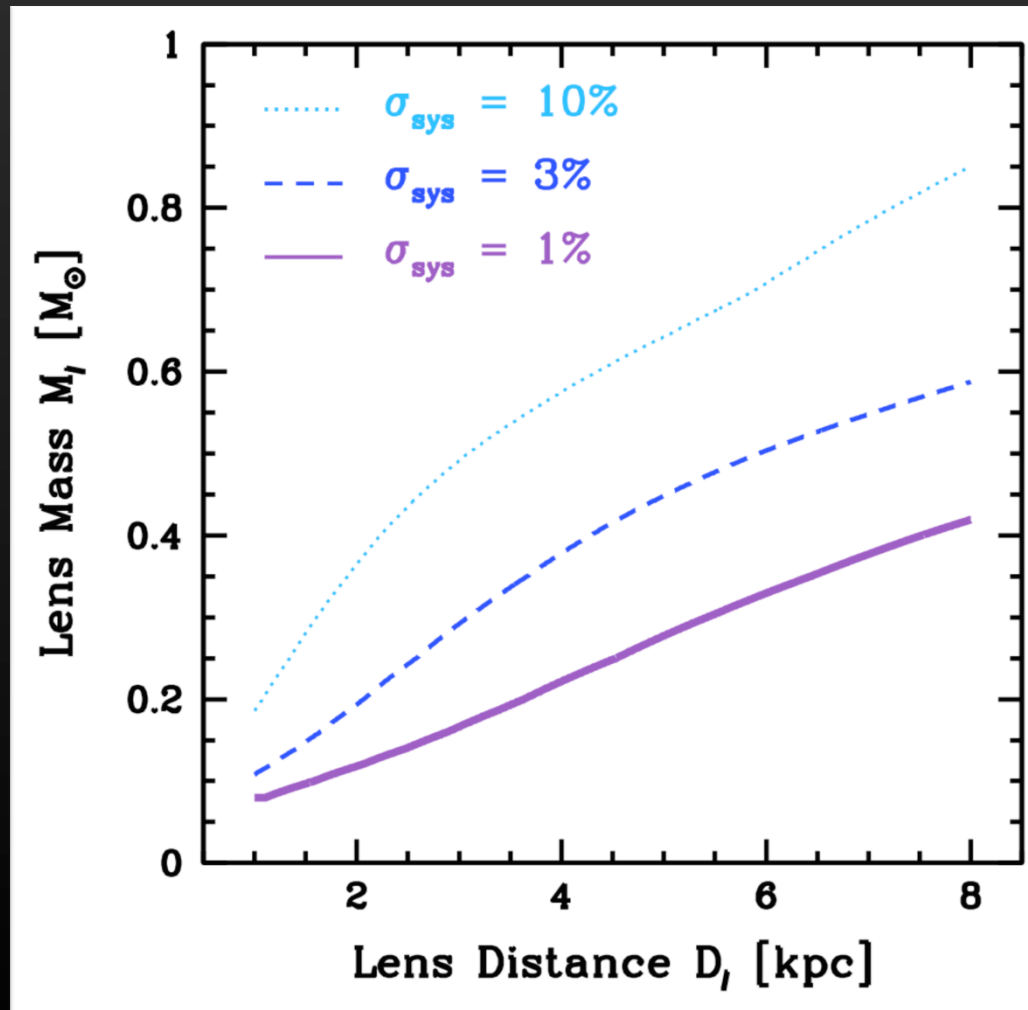
Epoch 1 (A ~ 1.6)

Epoch 2



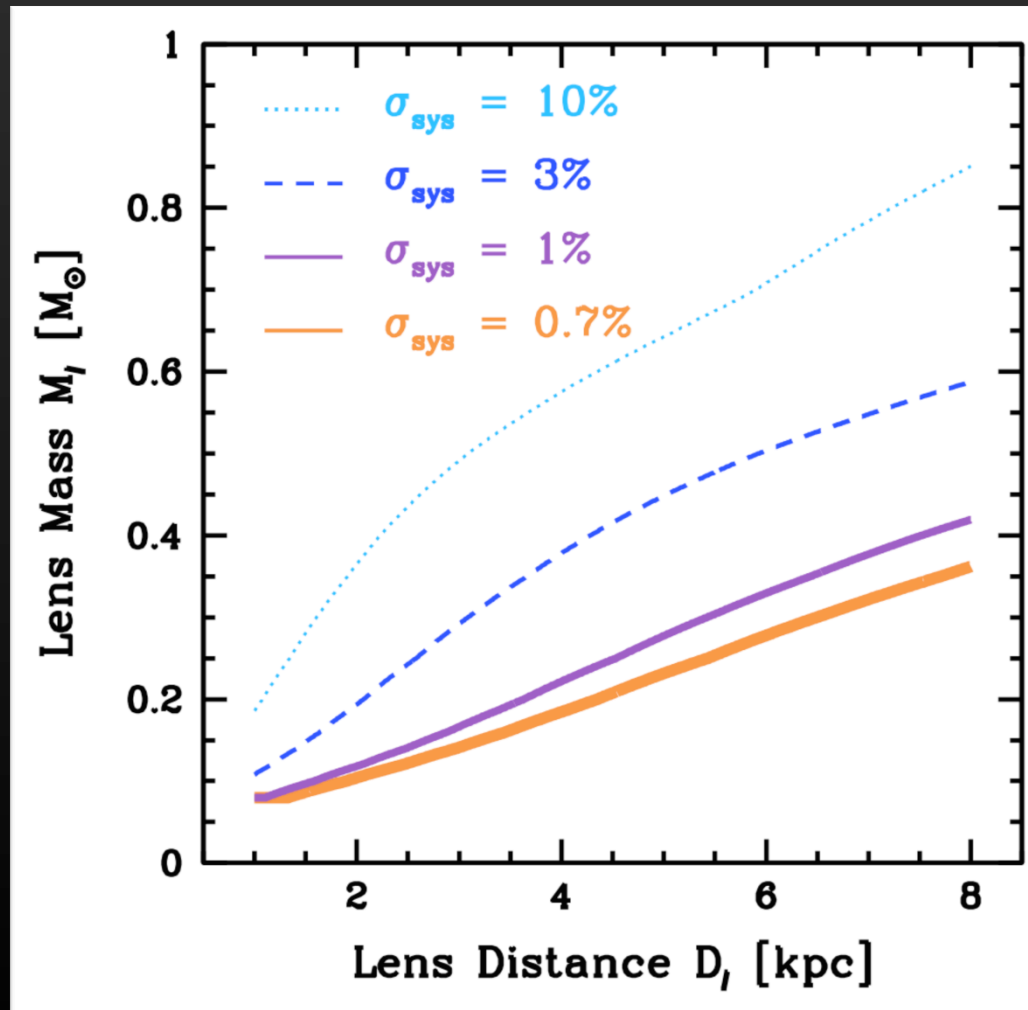
10''

OB161337: Lens Constraints



Bressan+ (2012), MNRAS, 427, 127

OB161337: Lens Constraints, <or> Understand Your Systematics!!!



Bressan+ (2012), MNRAS, 427, 127

Challenges for Anticipating *WFIRST*



PSF distortion across image



Construction of robust background sky map



Systematics in absolute calibration



ToOs for events with minimal baseline are difficult



ToOs prior to t_0 are riskier

Challenges for Anticipating *WFIRST*



PSF distortion across image



Construction of robust background sky map



Systematics in absolute calibration



ToOs for events with minimal baseline are difficult

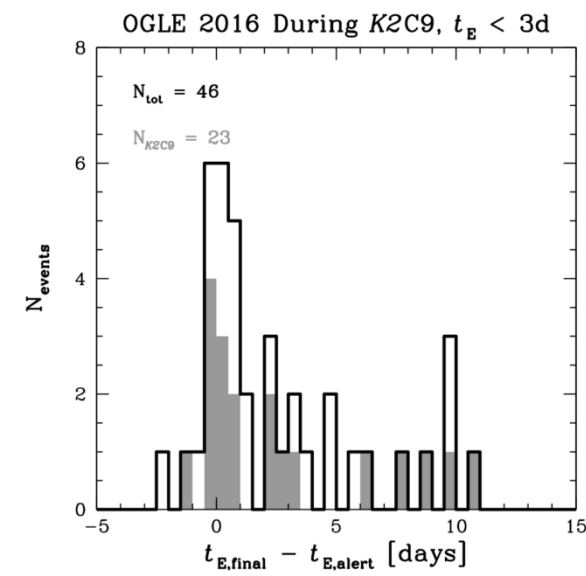
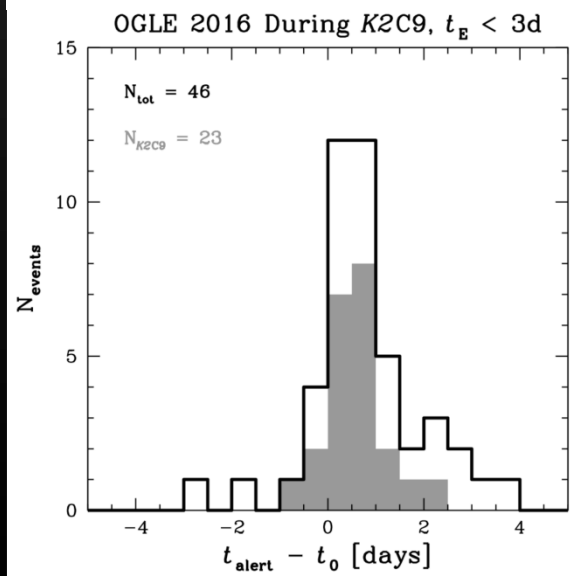
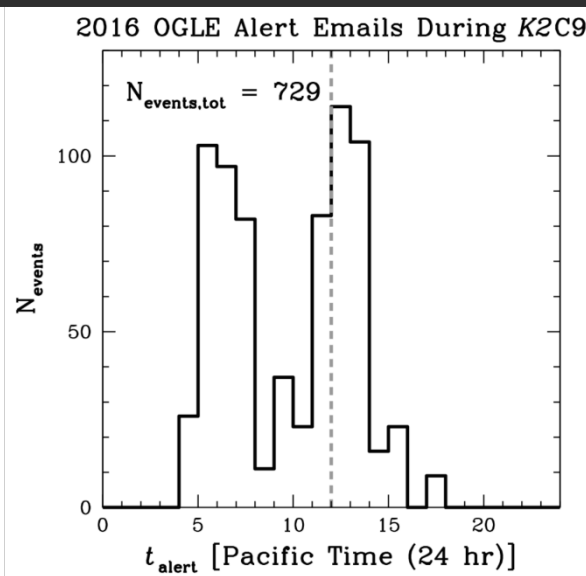
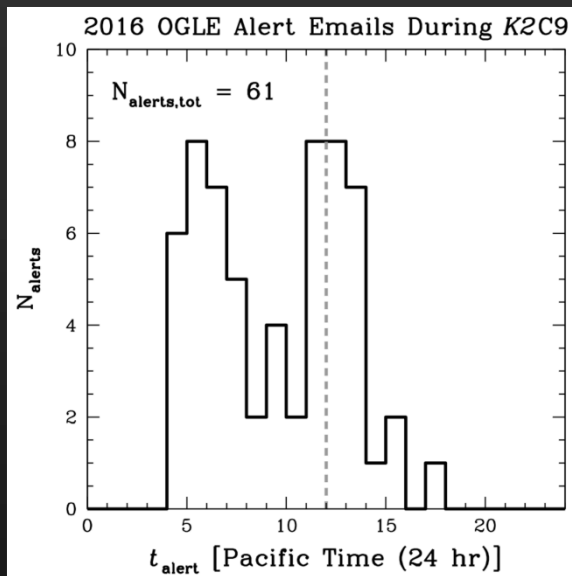


ToOs prior to t_0 are riskier

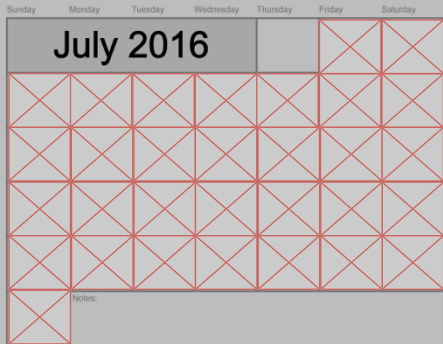
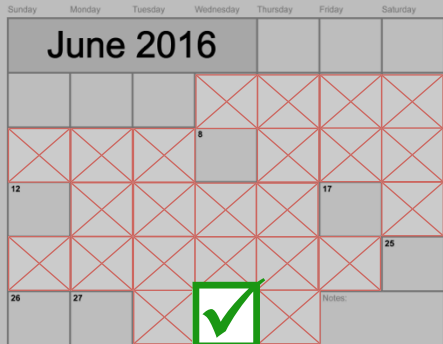
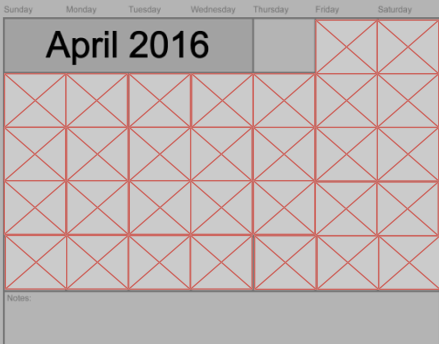
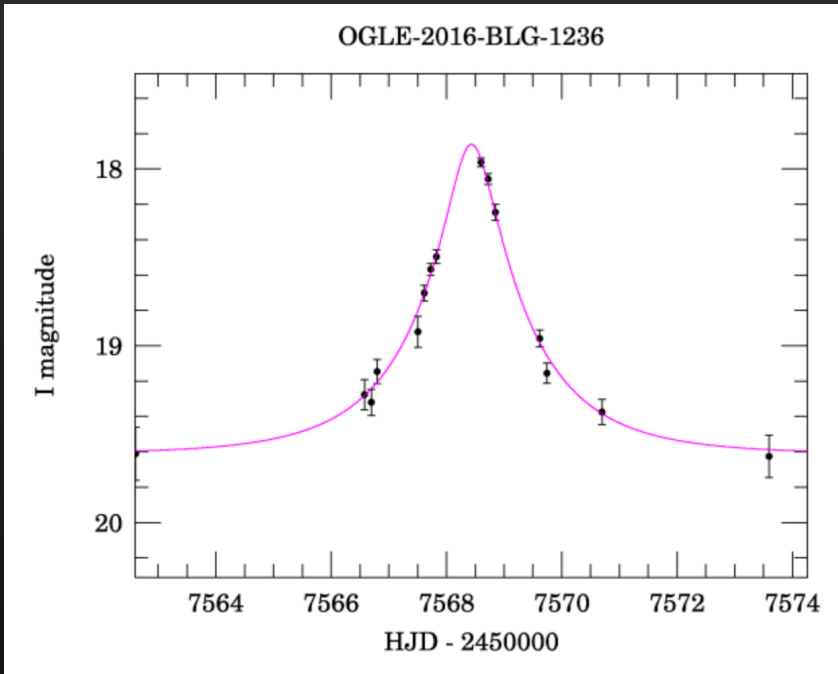
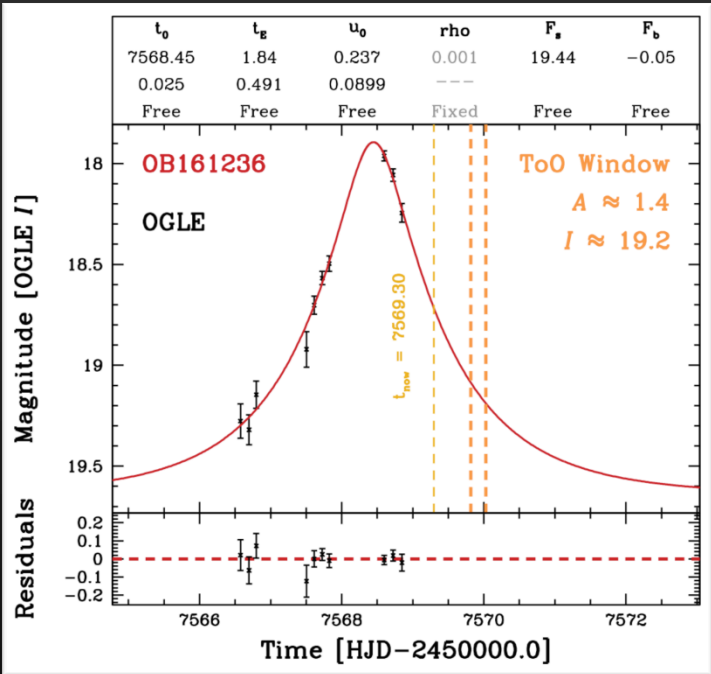


Alerts from *WFIRST*?!

Quick 2016 K2C9 OGLE Alert Statistics



May 26, 2016: OB161236...?!



May 26, 2016: OB161245...?!

