Photometric Timing Analysis

of the

2009-2011 Eclipse of Epsilon Aurigae

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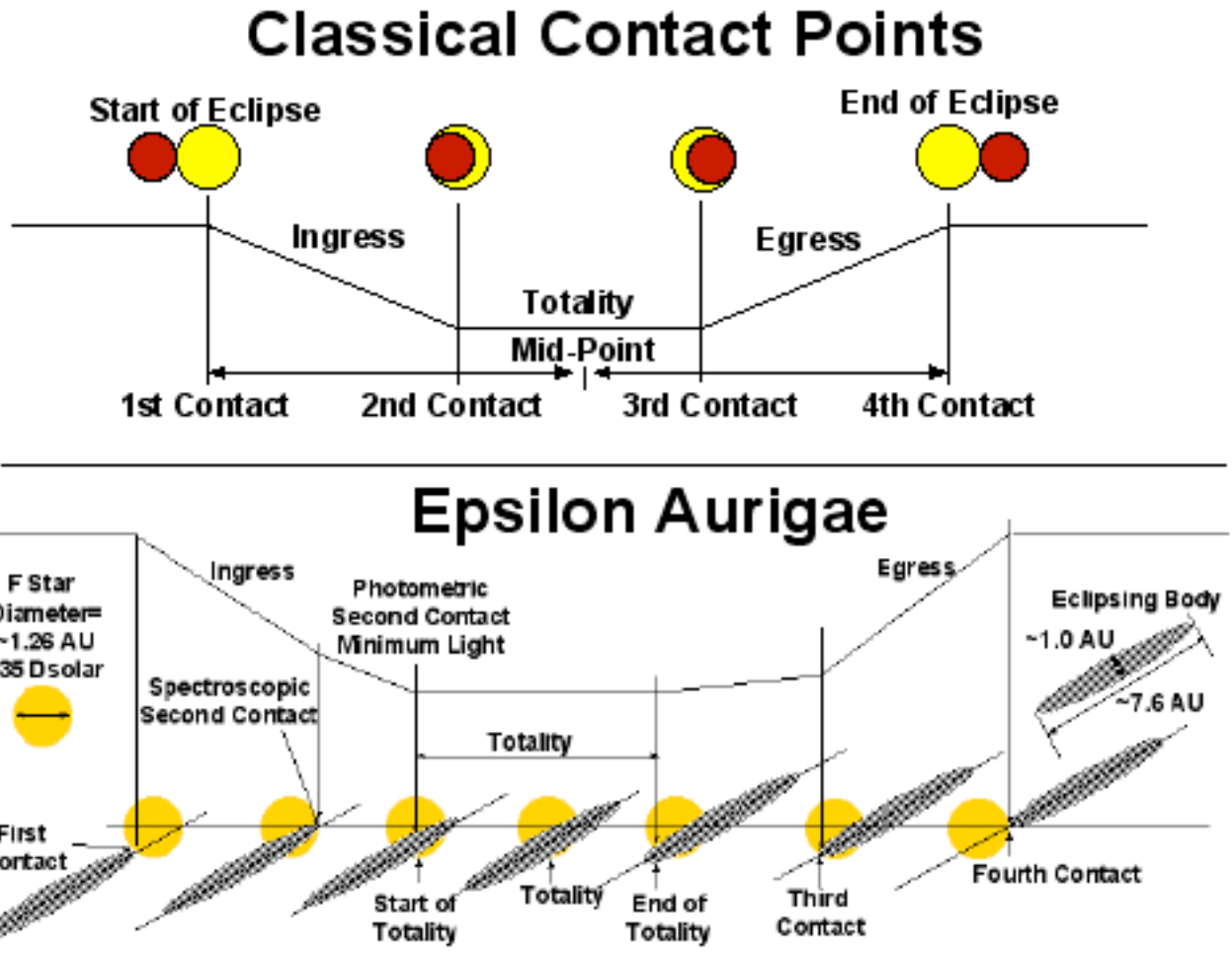
Introduction

Epsilon Aurigae is an eclipsing binary star system that eclipse every 27.1 years. The eclipse lasts nearly two years. Intense study of this system has revealed many interesting facts, but the exact nature is still elusive. During the recent eclipse, 2009 - 2011, the system was observed photometrically in the UBV bands, via spectroscopy, with polarimetry and with interferometry. There has been an International Campaign designed to coordinate observations. Data submitted for that Campaign are used for this paper. This paper will discuss analysis of the photometric data and determination of contact points and other timing.

Contact Points

With classical eclipsing binaries star systems where there are two approximately spherical shaped stars, the contact points are straight forward. The point where the leading edge of one star first touches the image of the star being eclipsed is the first contact point. This defines the start of the eclipse. The point where the trailing edge of the eclipsing star touches the trailing edge of the eclipsed star is the second point. This is the beginning of totality. As the leading edge of the eclipsing star touches the leading edge of the eclipsed star, 3rd contact arrives. When the trailing edge of the eclipsing star touches the leading edge of the eclipsed star, 4th contact arrives. This defines the point of the end of the eclipse. The mid-point of the eclipse is the point midway between the 1st and 4th contact. Since the system will probably have both a primary and secondary eclipse, that phase is also specified.



Methodology

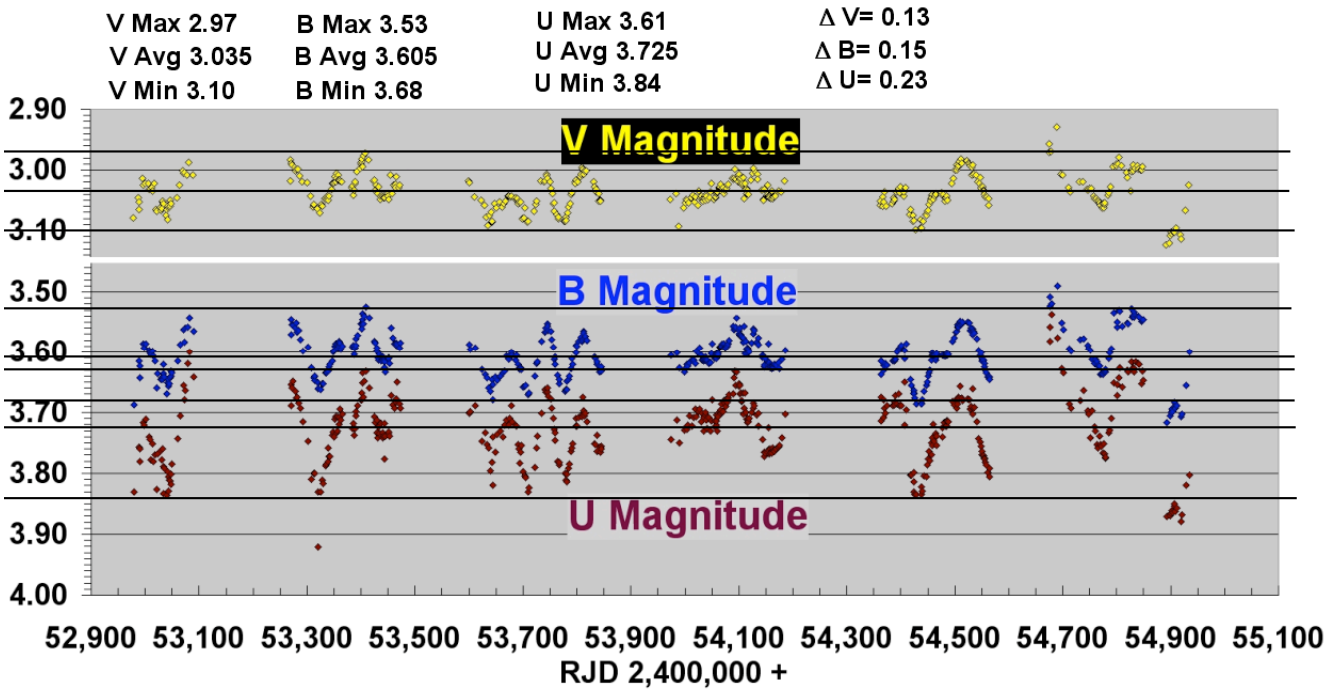
With epsilon Aurigae determination of contact points is anything but straight forward. There is a significant and random out-of-eclipse variation of changing amplitude and period that makes knowing what is the result of an eclipsing body and what is the results of the variation next to impossible to determine. There is a reported mid-eclipse brightening that adds to the problem. Perhaps the biggest problem is the fact that the eclipsing body is not a star and is not spherical, but elliptical. Indeed, it appears it may be even more complex that and the shape may be tear drop shaped with a long trailing tail.

What this means is the light curve will not be nicely defined at the contact points. To get around this and at least make some good approximations, the following methodology was used. First the maximum, minimum and average magnitudes in the UBV bands was determined. The maximum, minimum and average totality magnitudes determined. Finally the ingress and egress slopes determined.

UBV Bands

Out-of-Eclipse Variations

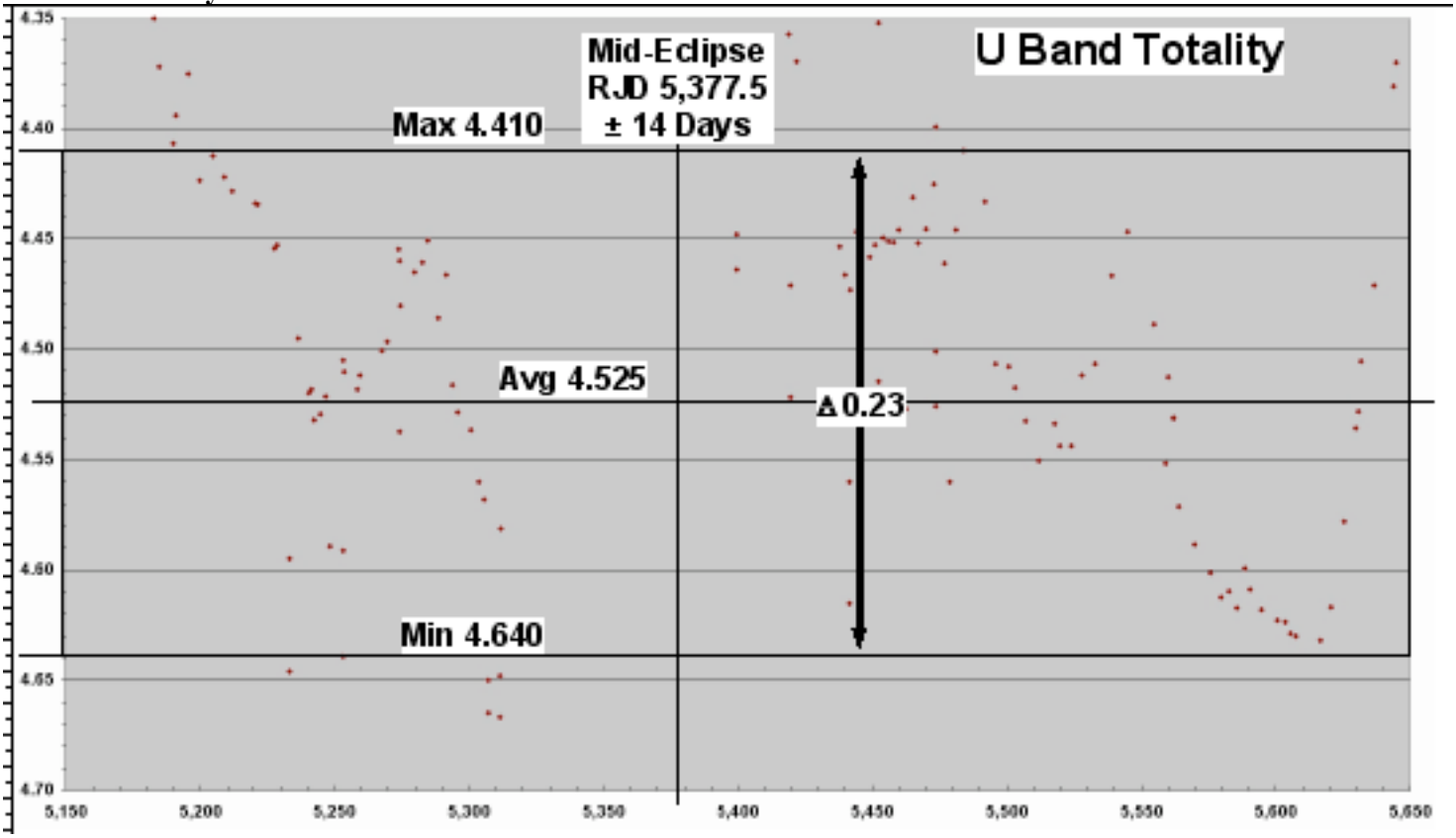
First, the out-of-eclipse variation maximum and minimum magnitudes were determined in each band. The average magnitude was then used as the out-of eclipse magnitude for that band. During totality this out-of-eclipse variation was fitted over the totality portion of the light curve, ignoring the mid-eclipse area. An average totality magnitude was then determined.



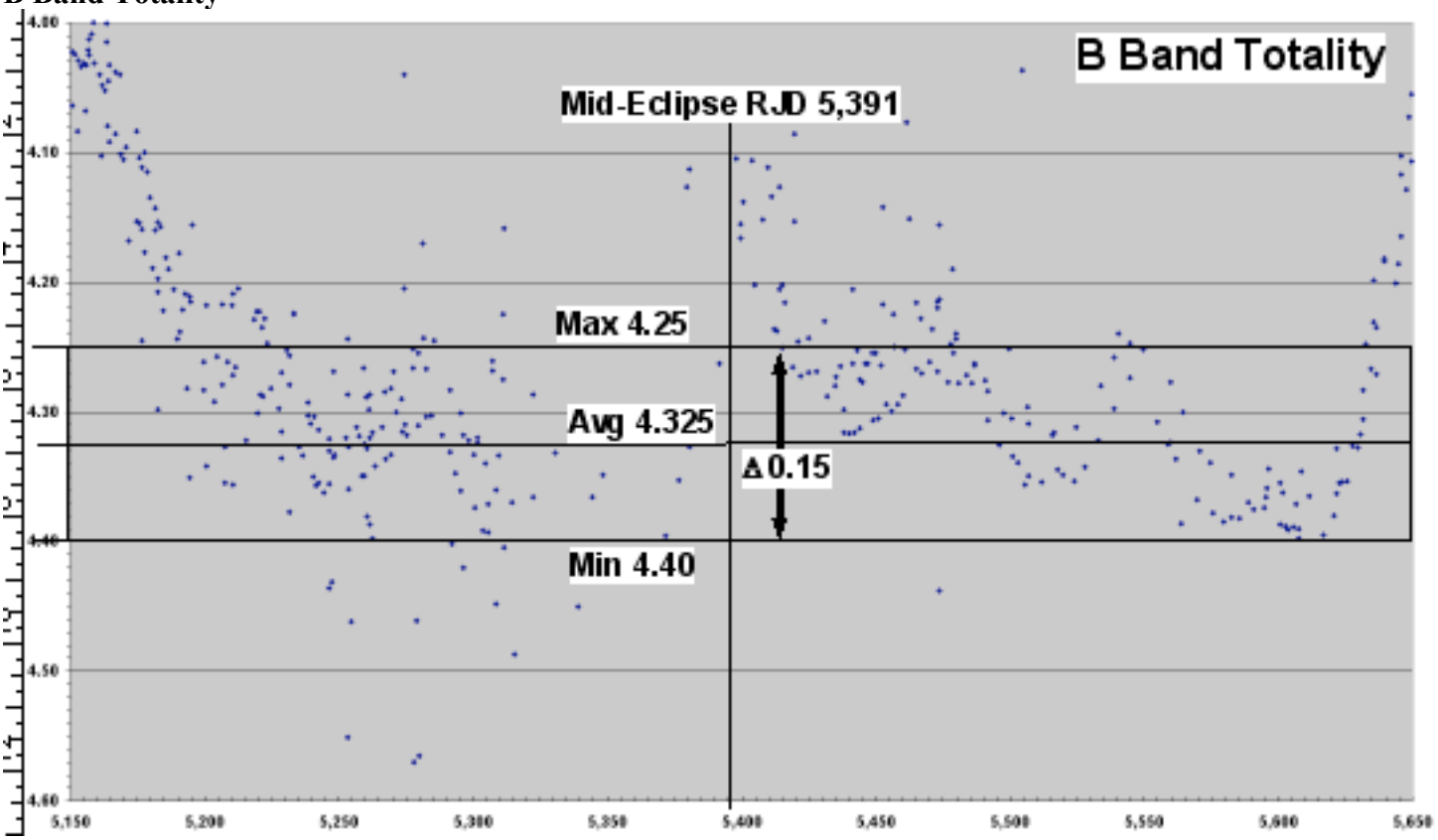
Totality

The differential out-of-eclipse magnitude for each band was vertically centered over that band's totality light curve to determine the maximum, average and minimum totality magnitudes. The exact placement of the lines was subjective out of necessity.

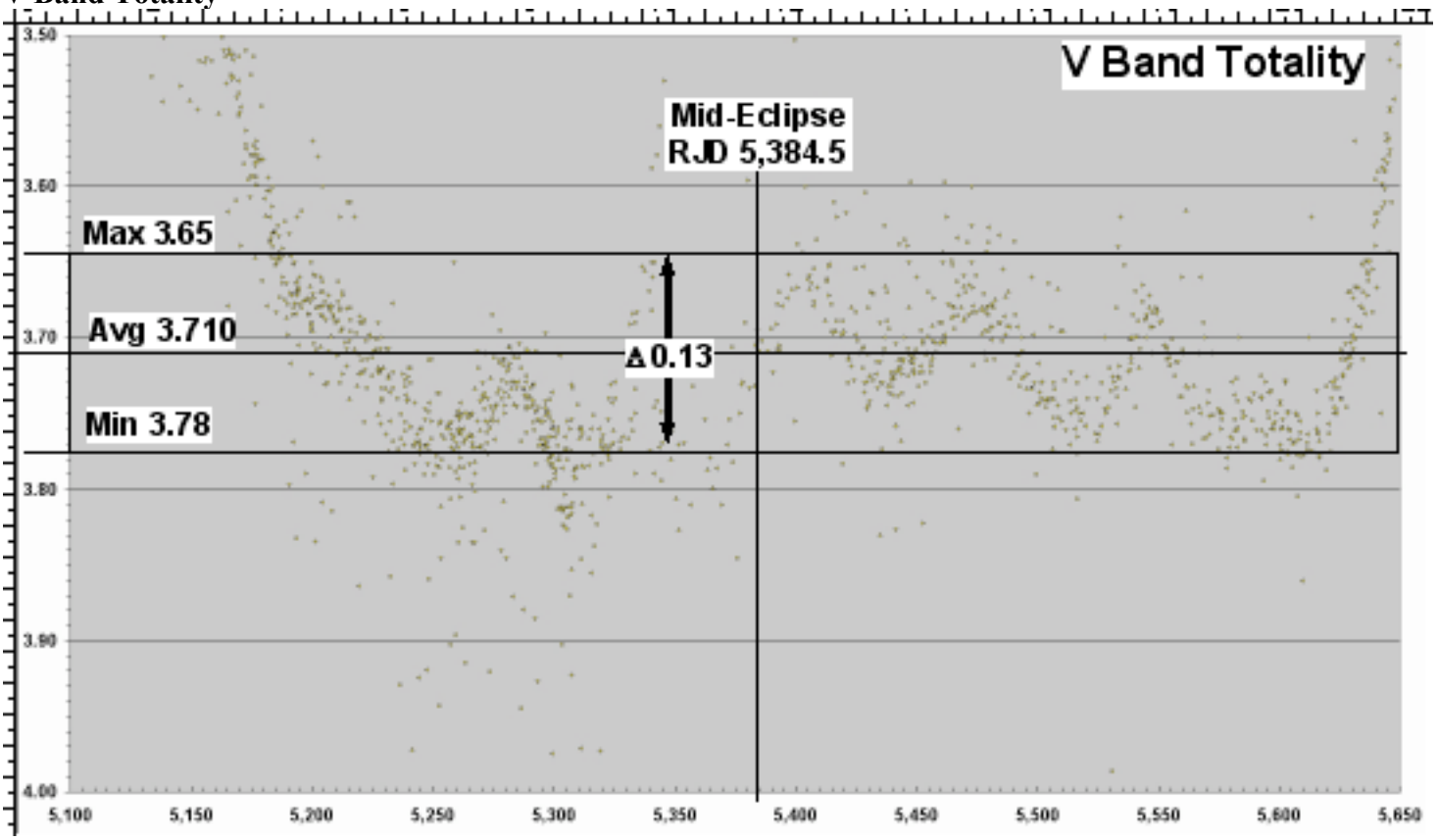
U Band Totality



B Band Totality



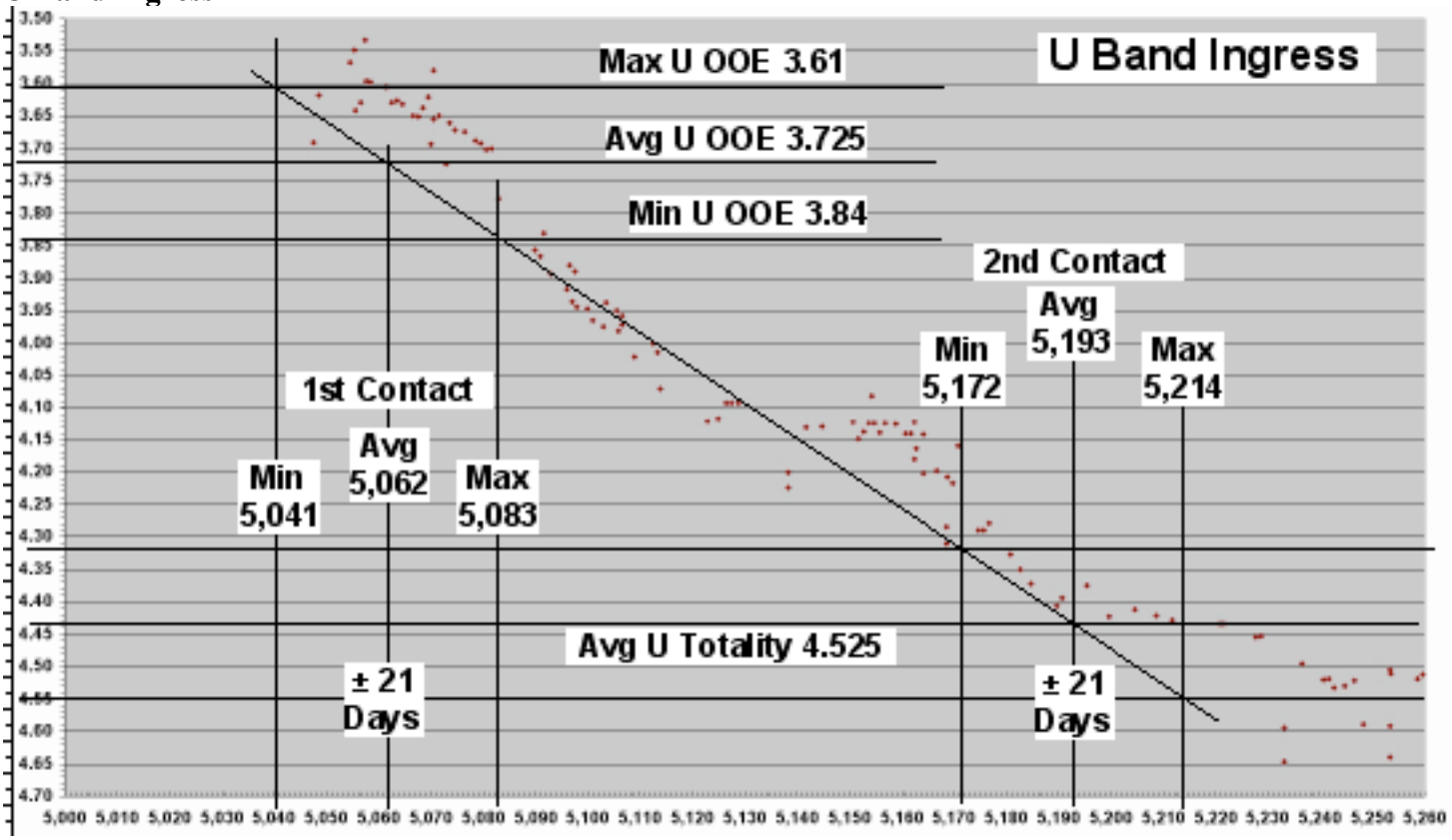
V Band Totality



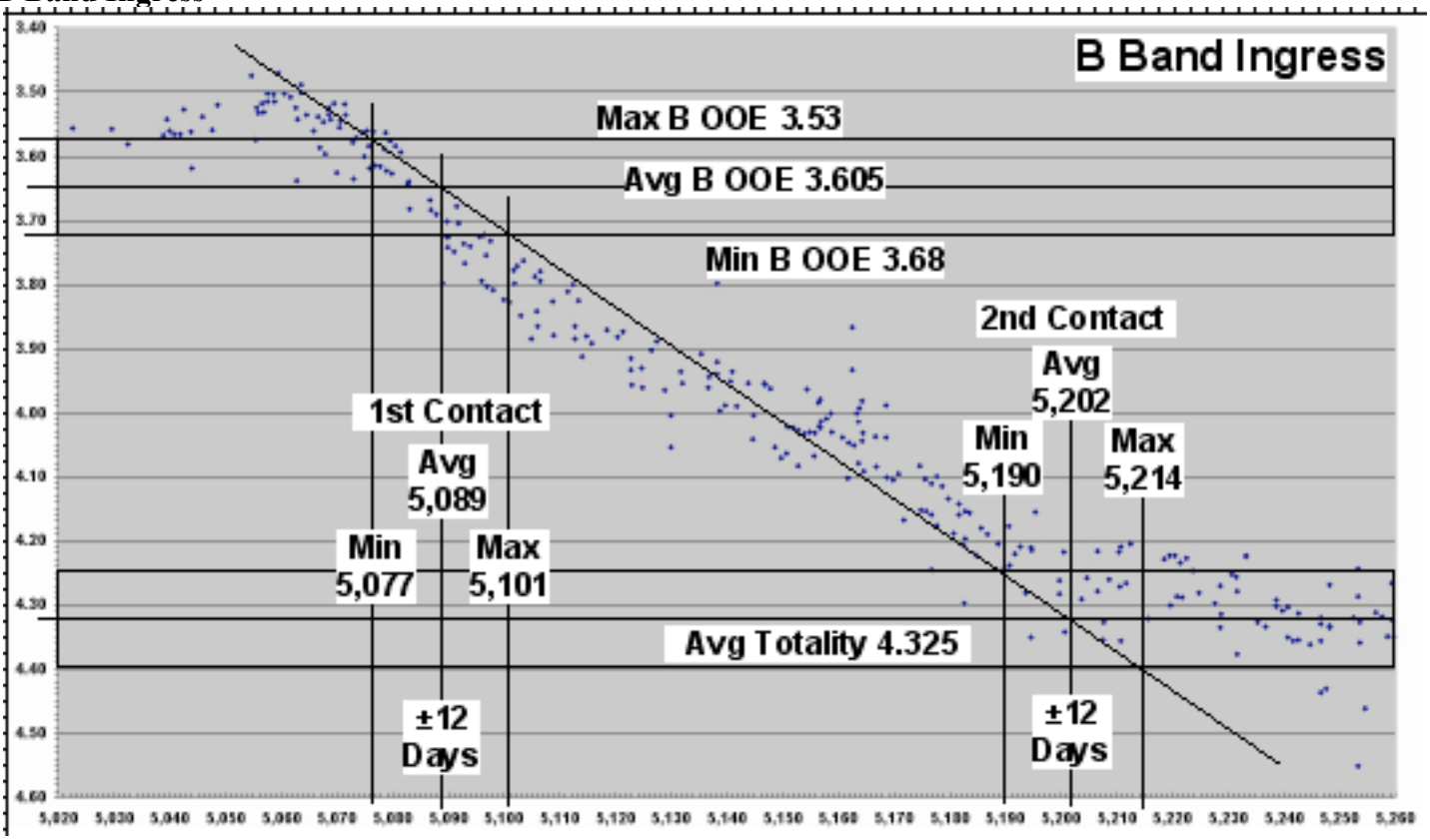
Ingress

Ingress was determined by finding approximate lines for minimum and maximum times for the ingress slope and then determining a median line for the average ingress. Minimum, average and maximum contact points were then determined for first and second contact. Again, exact placement of the lines was subjective.

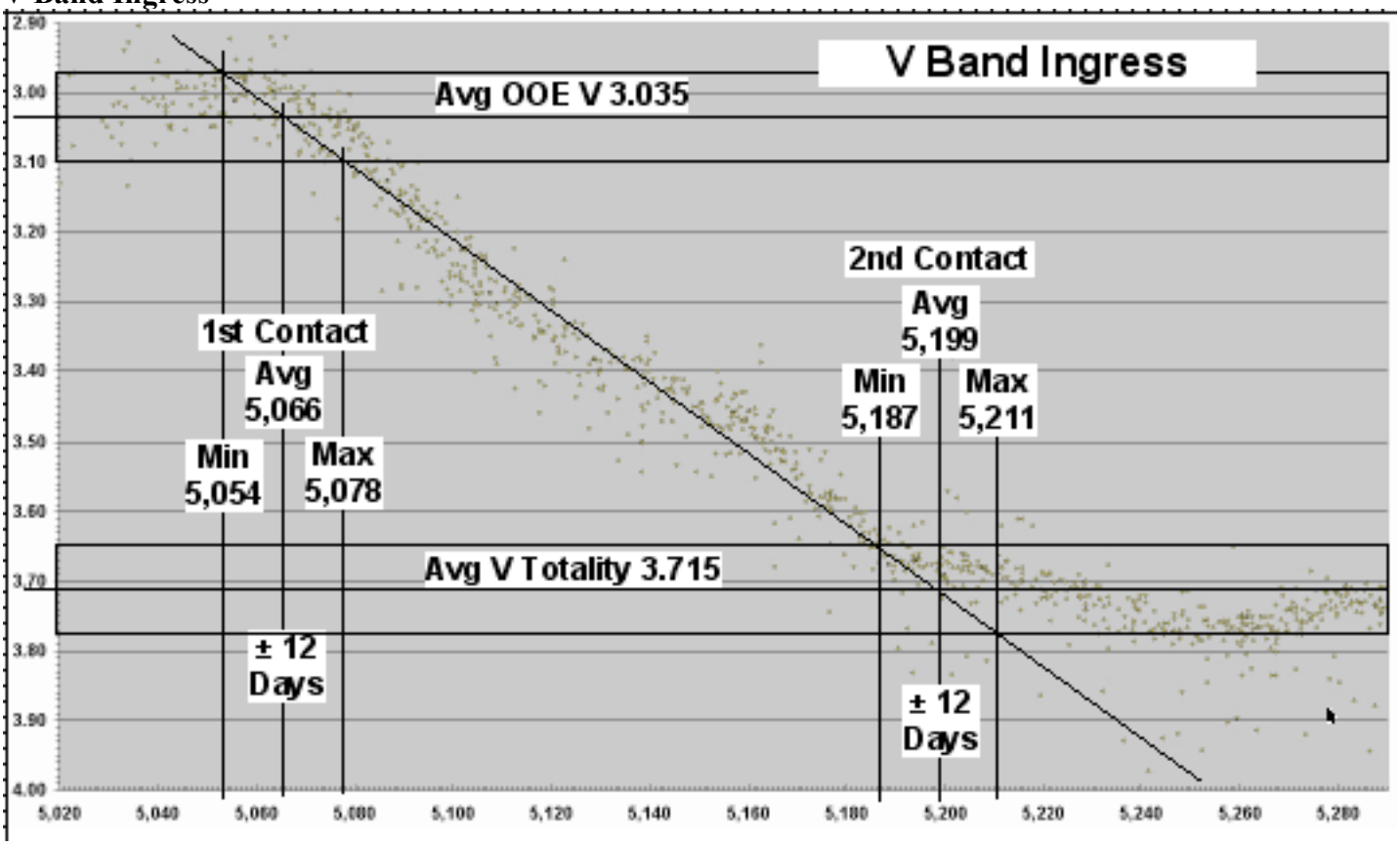
U Band Ingress



B Band Ingress



V Band Ingress



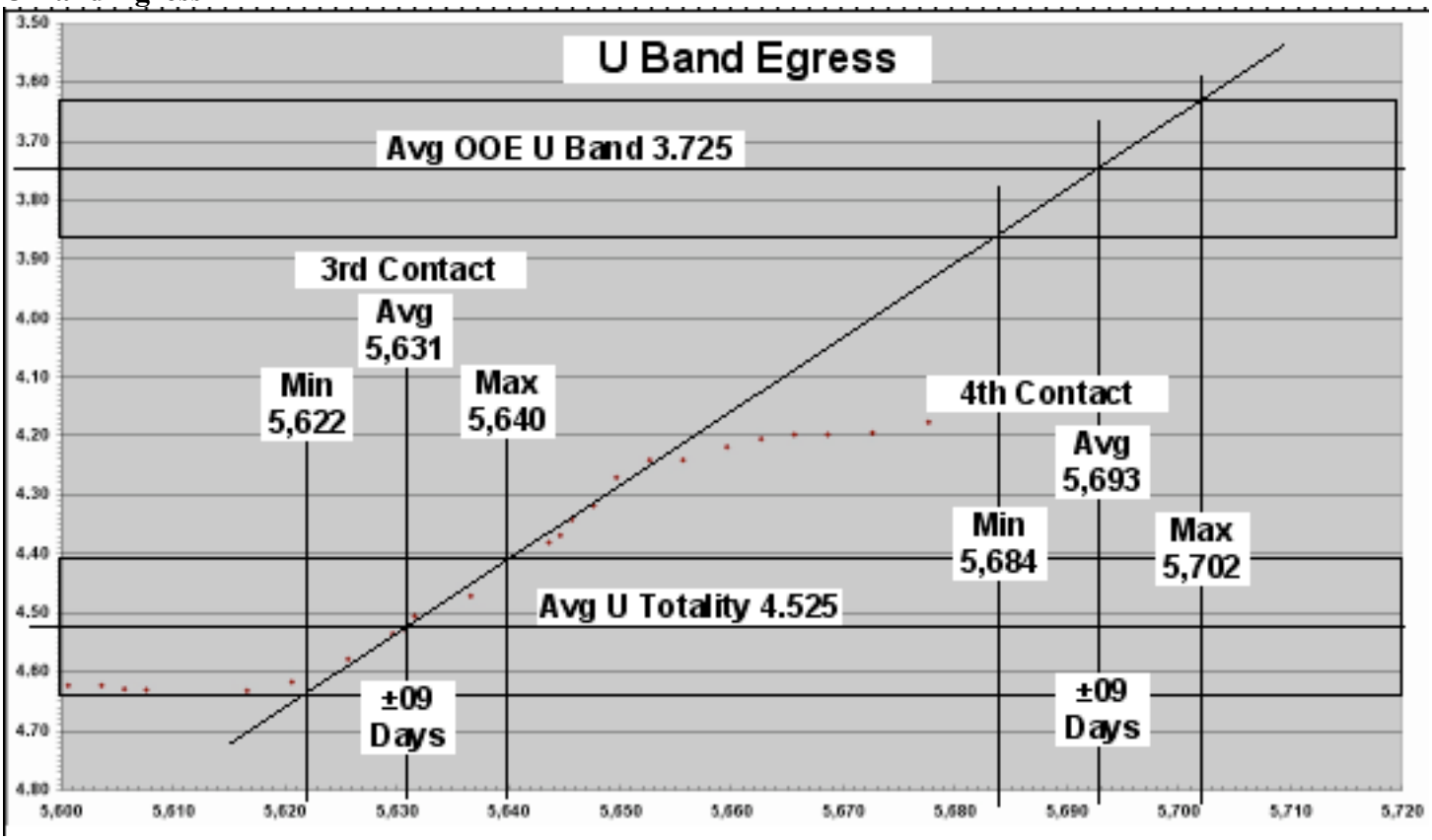
Ingress was fairly smooth, but there was a knee about mid-way, most likely due to the out-of-eclipse variations. What was needed was the slope of the ingress. From that the out-of-eclipse magnitude and totality magnitude

intercepts could be determined. Since the data was slightly noisy (except for some obvious flyer data) bracketing slopes were estimated and an average slope used.

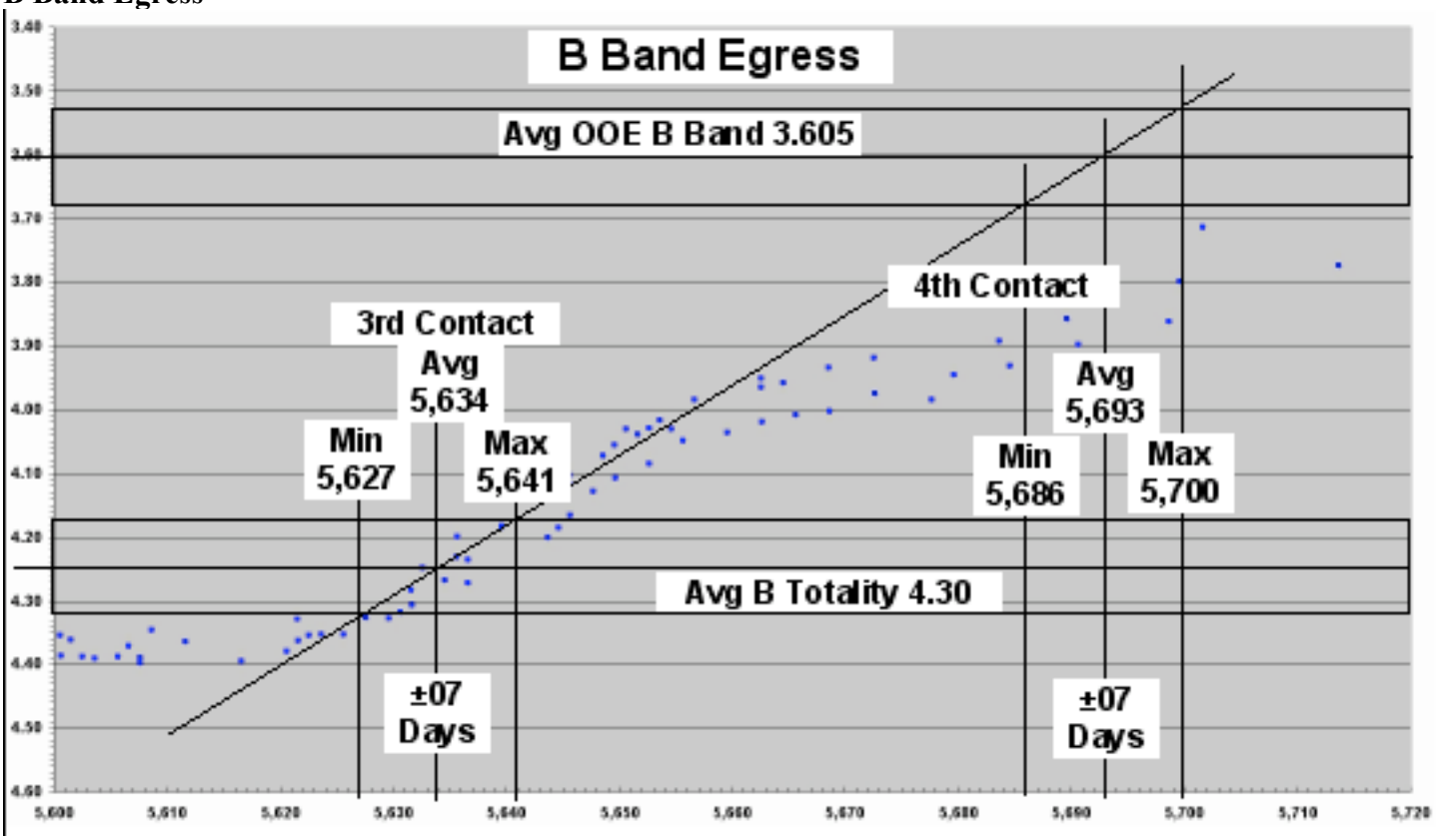
Egress

Egress was determined by finding approximate lines for minimum and maximum times for the egress slope and then determining a median line for the average egress. Minimum, average and maximum contact points were then determined for third and fourth contact. Again, exact placement of the lines was subjective.

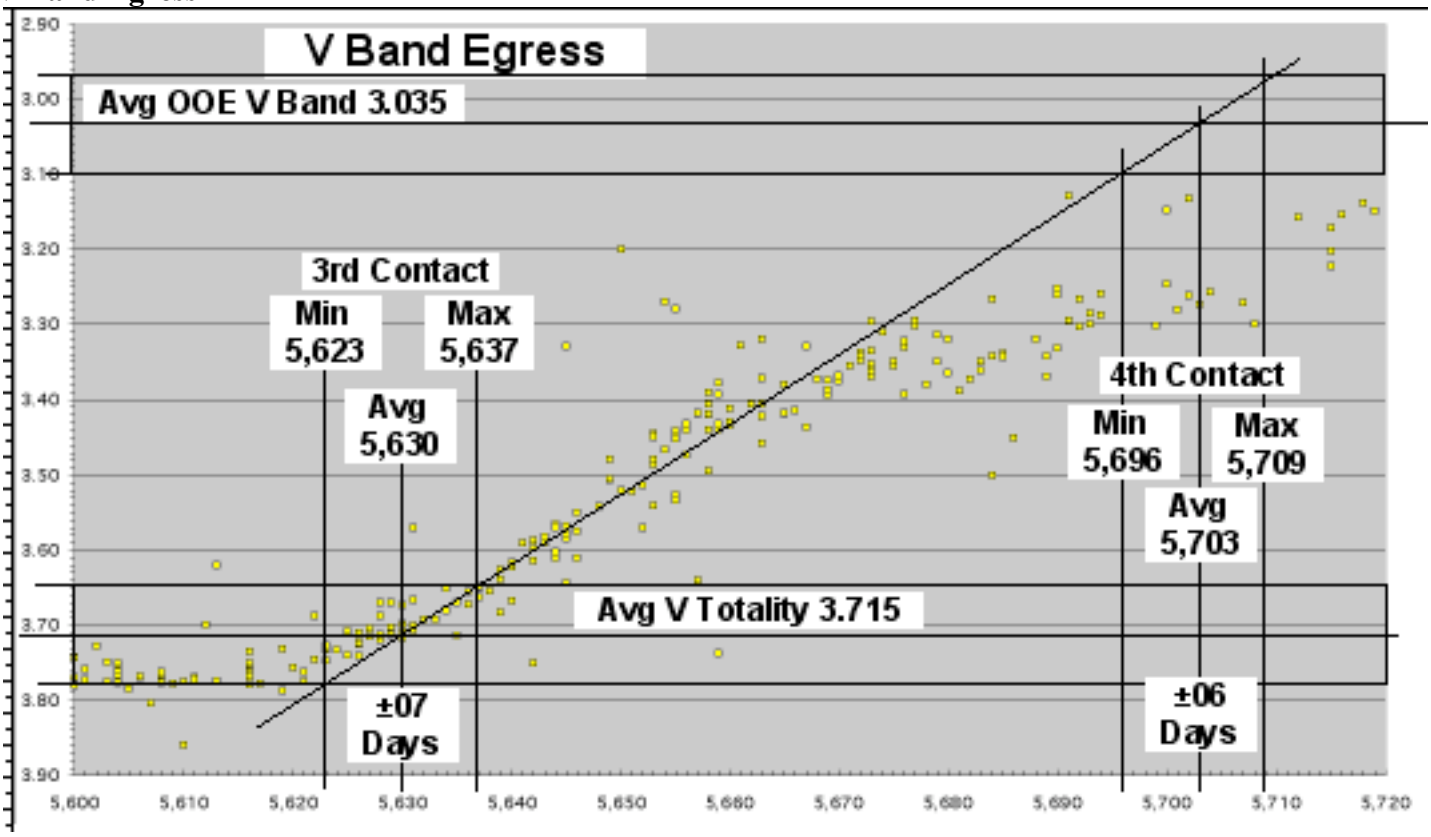
U Band Egress



B Band Egress

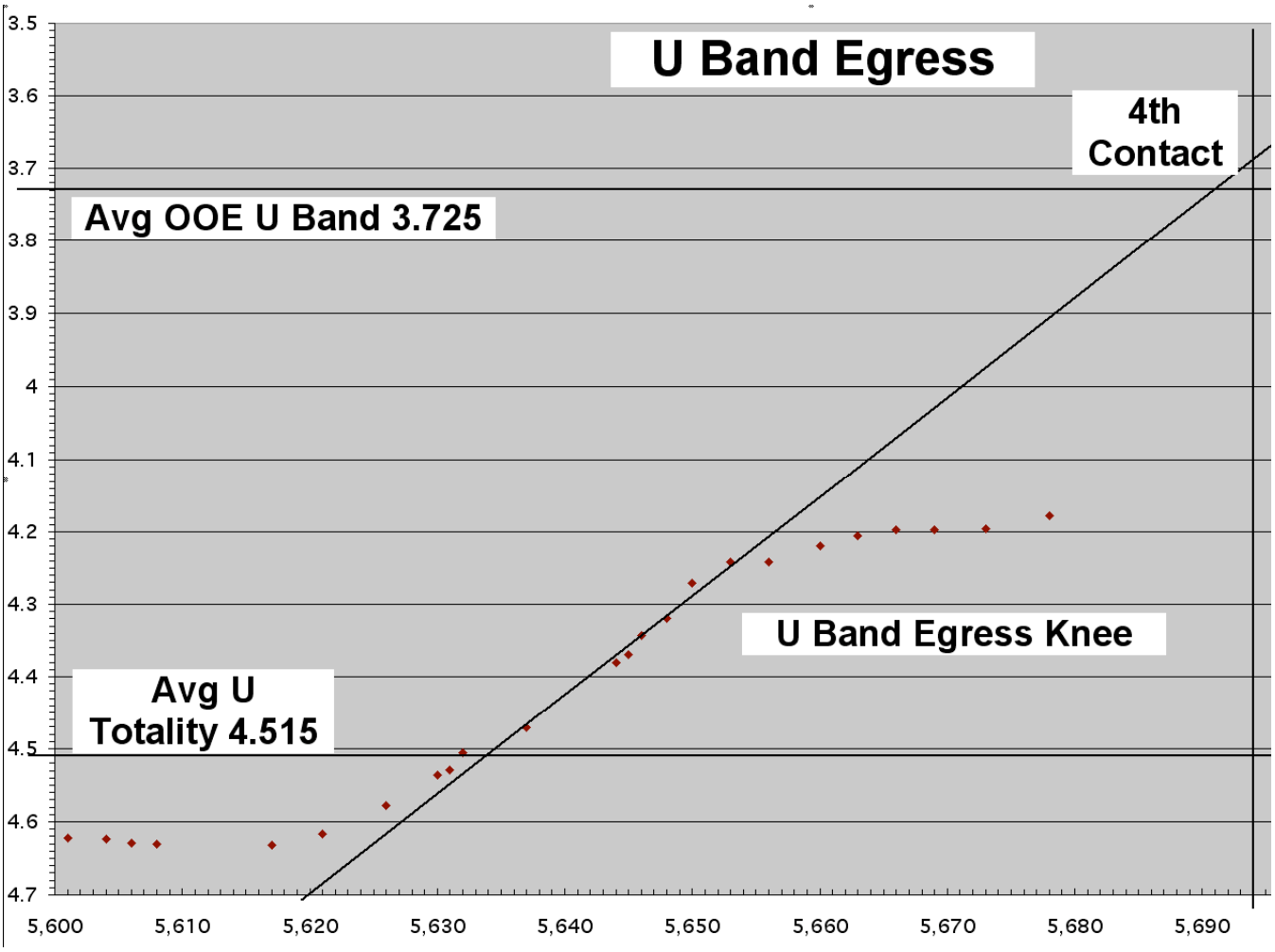


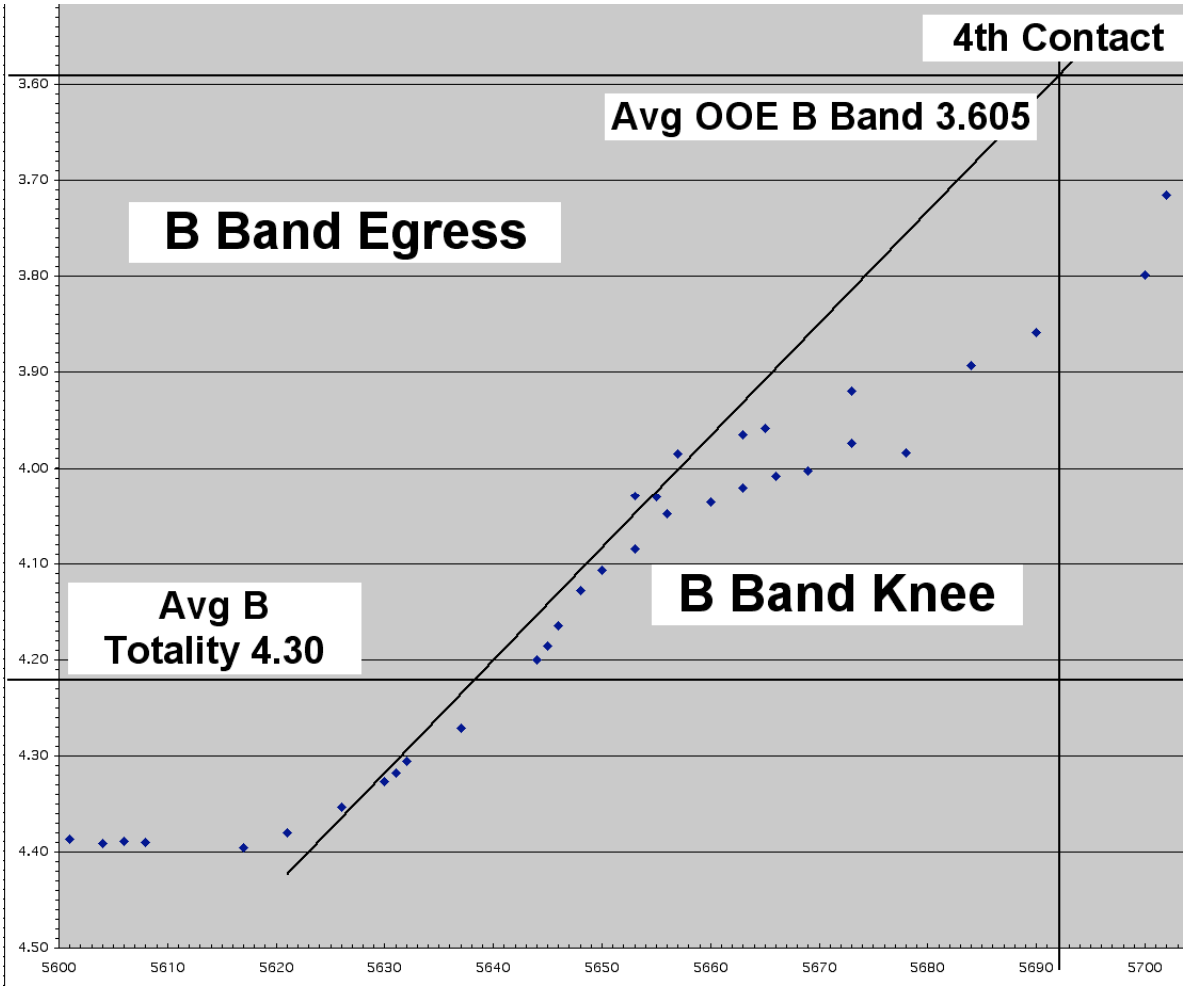
V Band Egress



Egress Knee

Egress was fairly smooth up until about midway. The magnitudes seemed to level off and stay leveled off far longer than one would suspect due to the out-of-eclipse variations. The knee is most pronounced in the U band and to a lessor degree in the B band.




4th Contact
Avg OOE B Band 3.605
B Band Egress
B Band Knee
Avg B
Totality 4.30
3.60
3.70
3.80
3.90
4.00
4.10
4.20
4.30
4.40
4.50
5600
5610
5620
5630
5640
5650
5660
5670
5680
5690
5700

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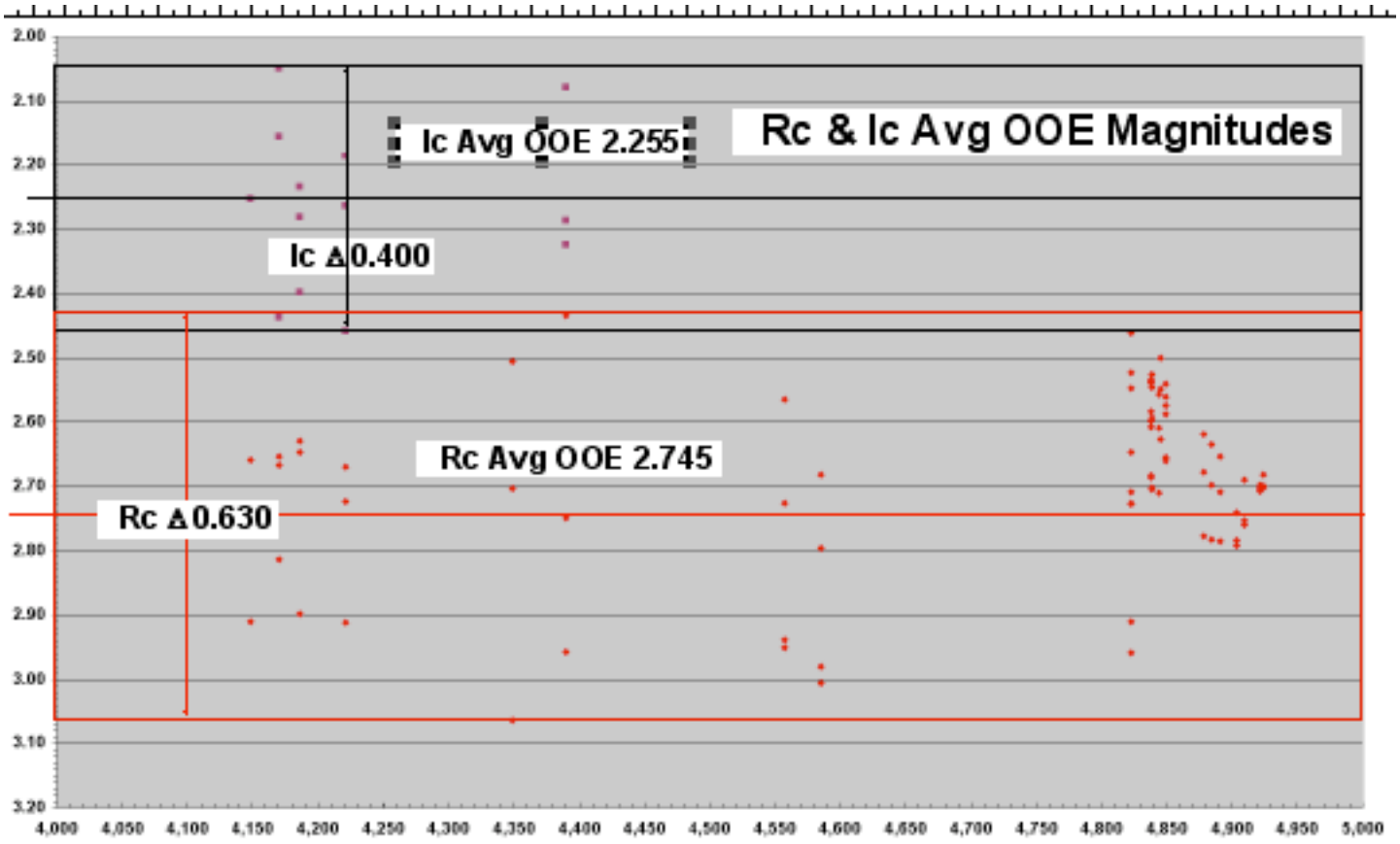
RcIc Bands

Out-of-Eclipse Variations

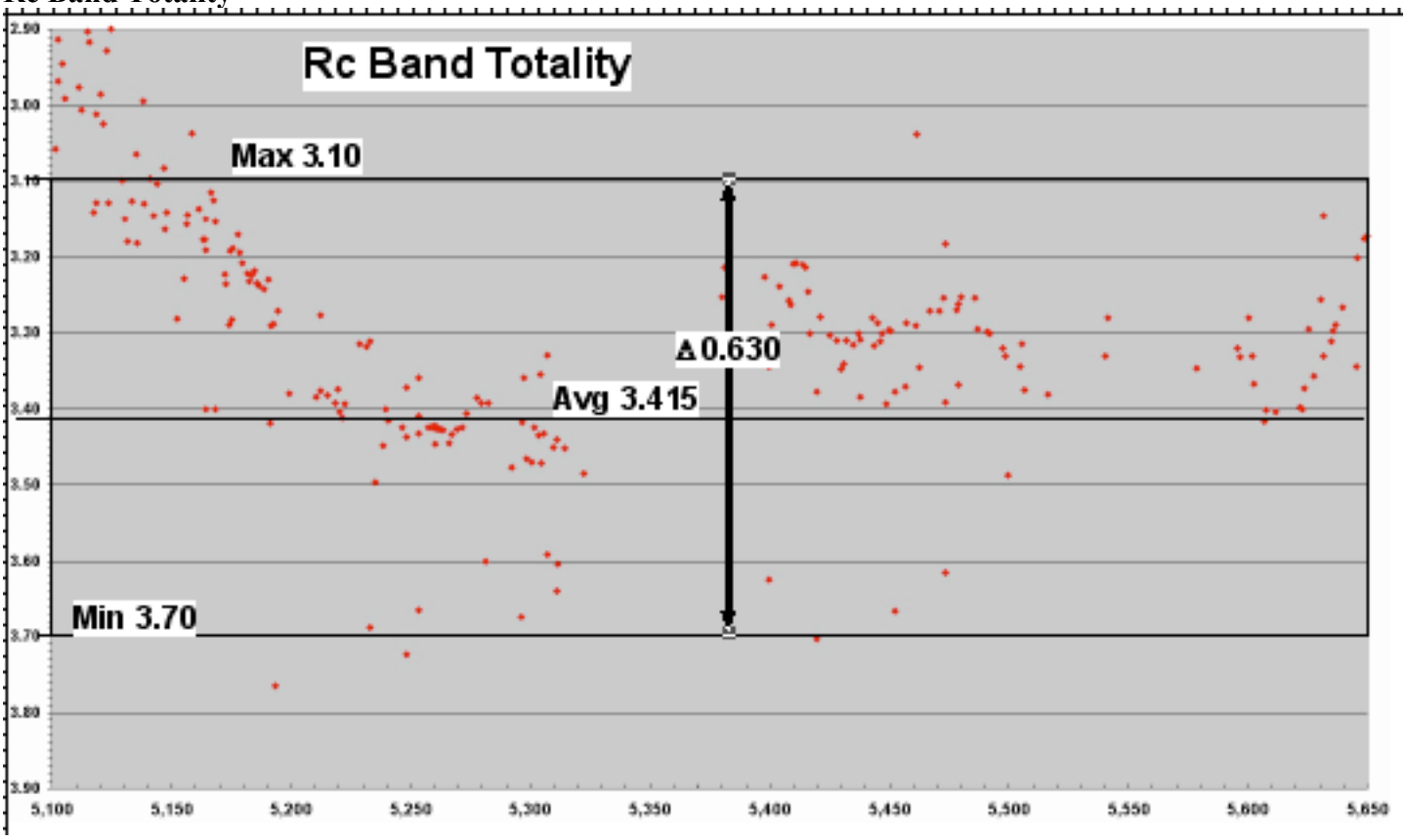
First, the out-of-eclipse variation maximum and minimum magnitudes were determined in each band. The average magnitude was then used as the out-of eclipse magnitude for that band. During totality this out-of-eclipse variation was fitted over the totality portion of the light curve, ignoring the mid-eclipse area. An average totality magnitude was then determined.



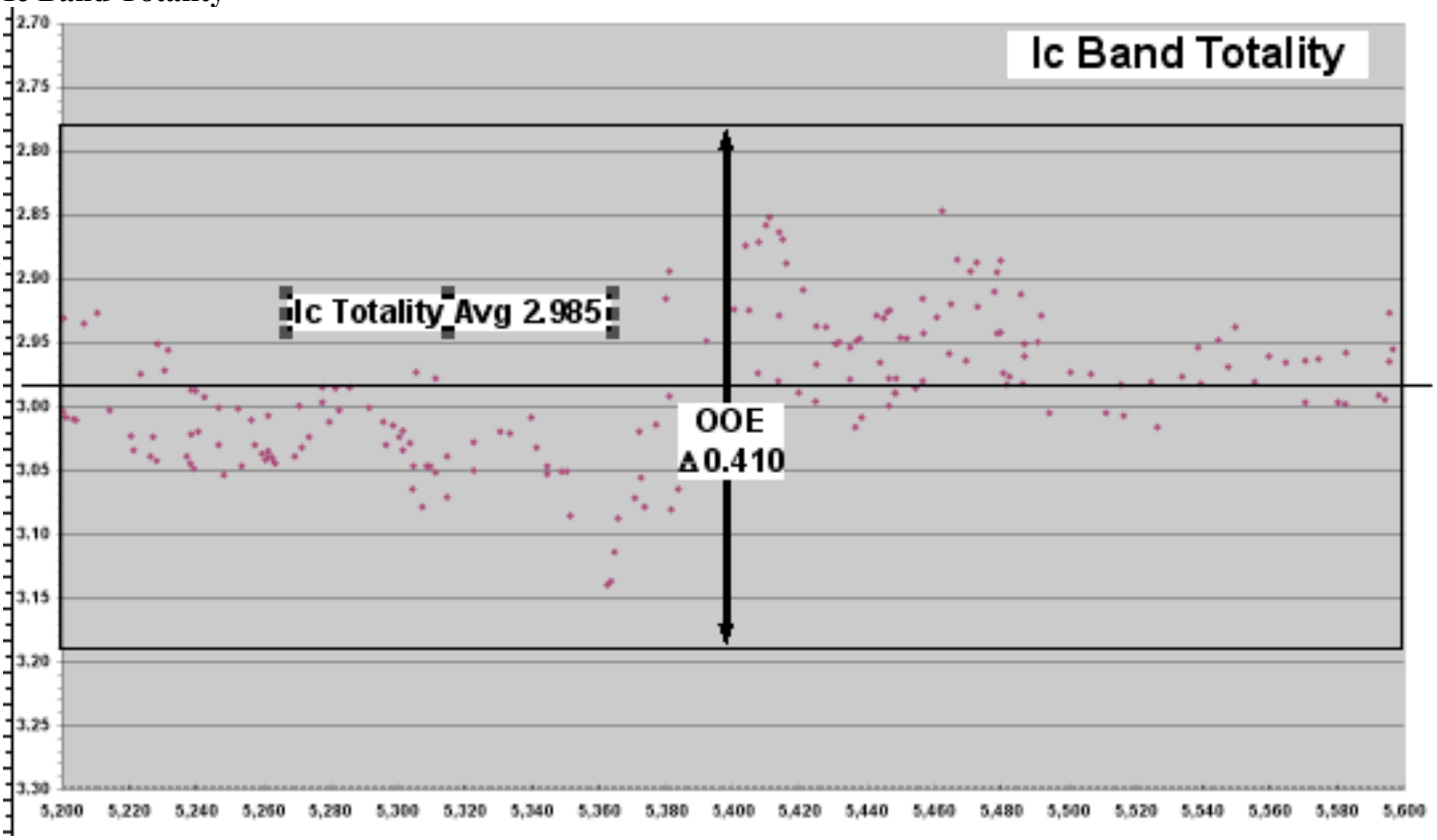
Totality

The differential out-of-eclipse magnitude for each band was vertically centered over that band's totality light curve to determine the maximum, average and minimum totality magnitudes. The exact placement of the lines was subjective out of necessity.

Rc Band Totality



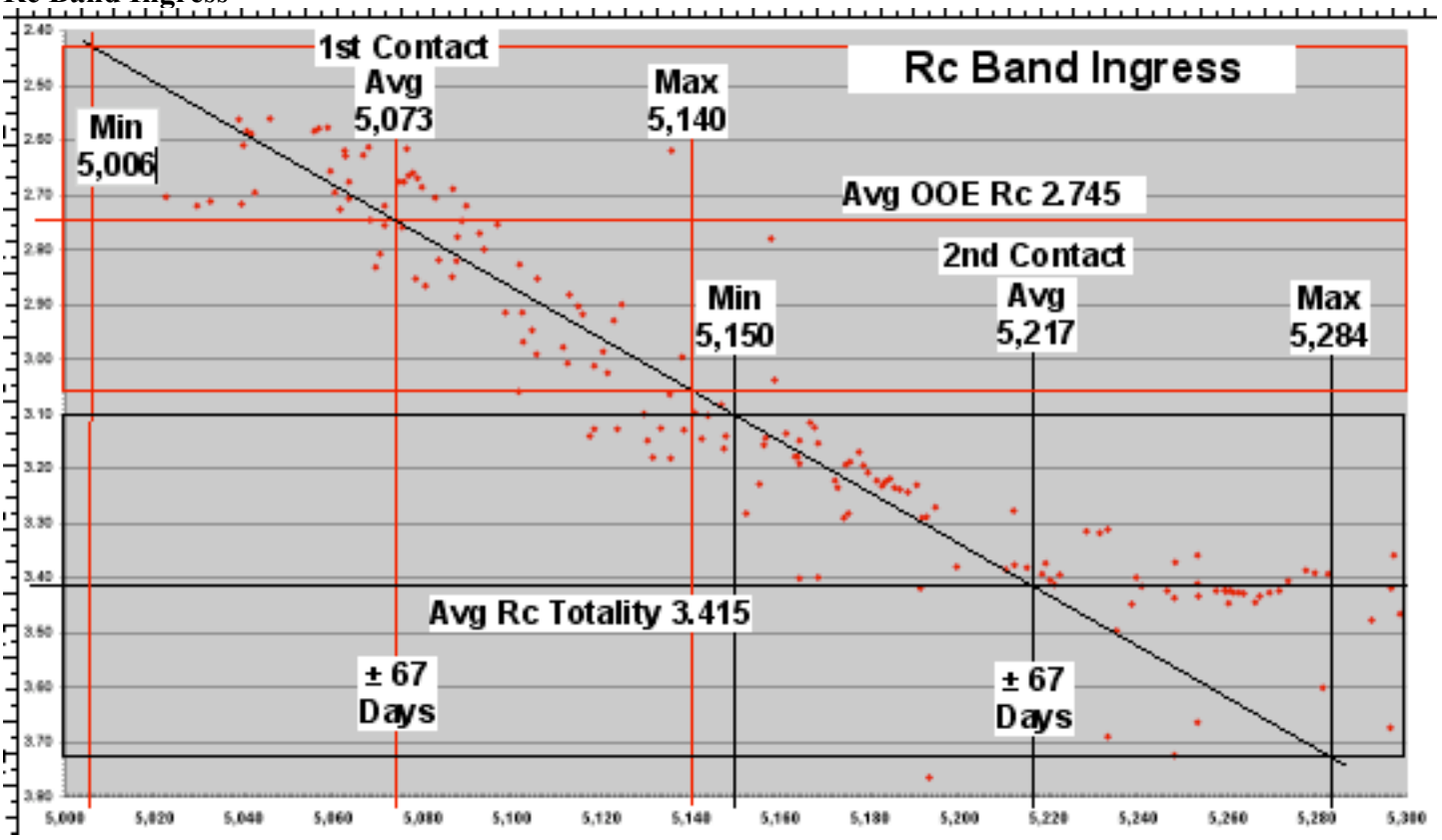
Ic Band Totality



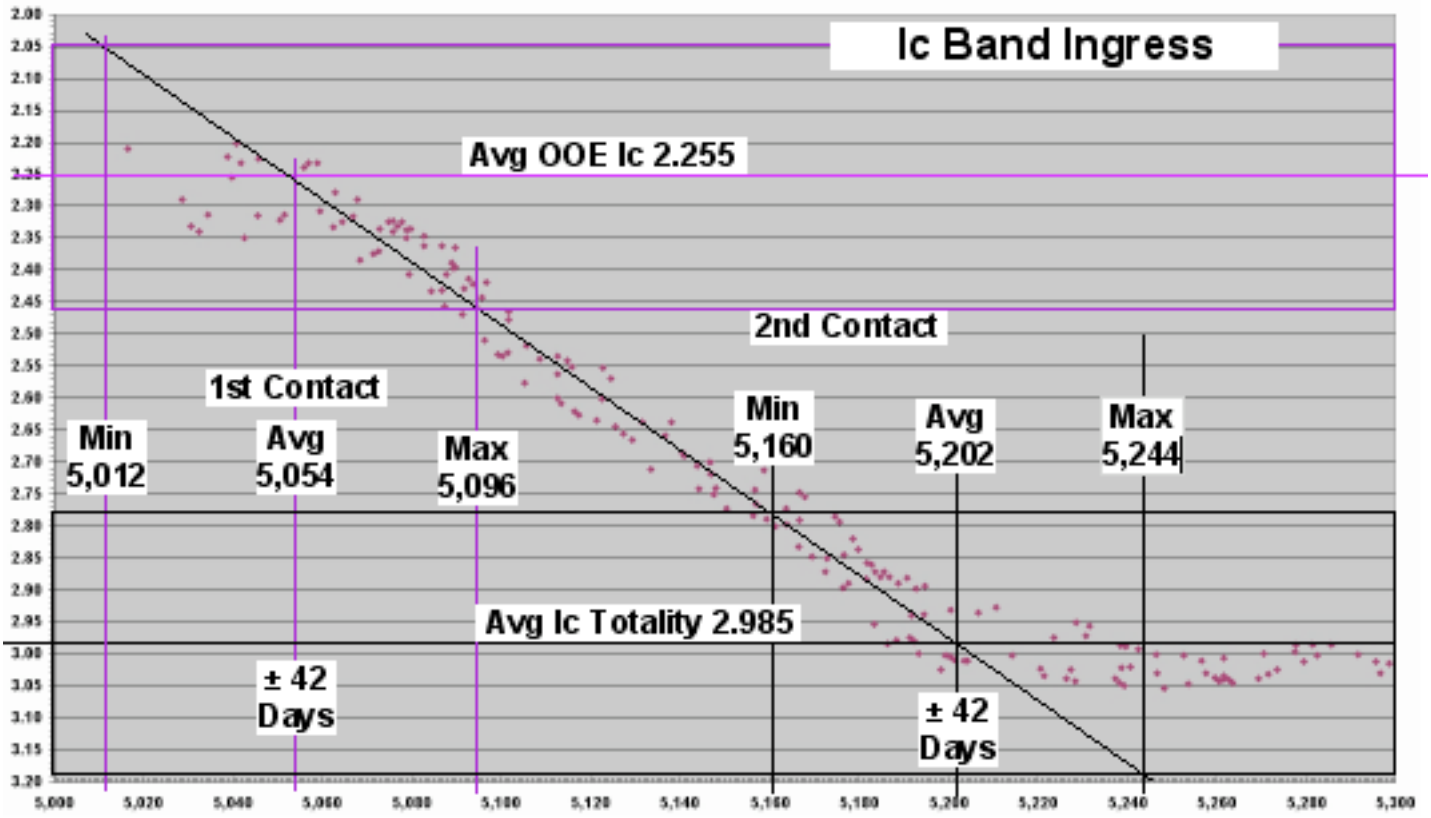
Ingress

Ingress was determined by finding approximate lines for minimum and maximum times for the ingress slope and then determining a median line for the average ingress. Minimum, average and maximum contact points were then determined for first and second contact. Again, exact placement of the lines was subjective.

Rc Band Ingress



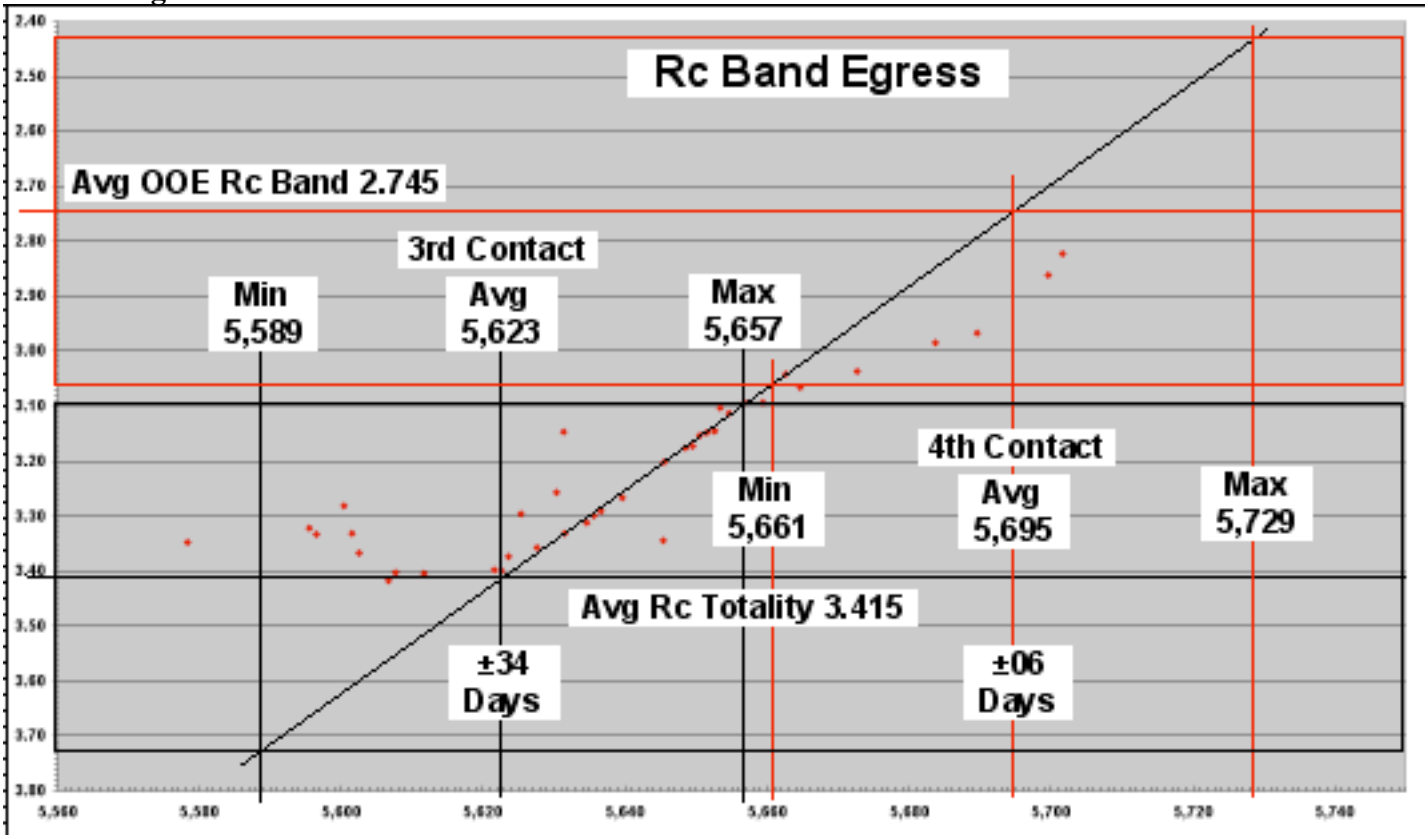
Ic Band Ingress



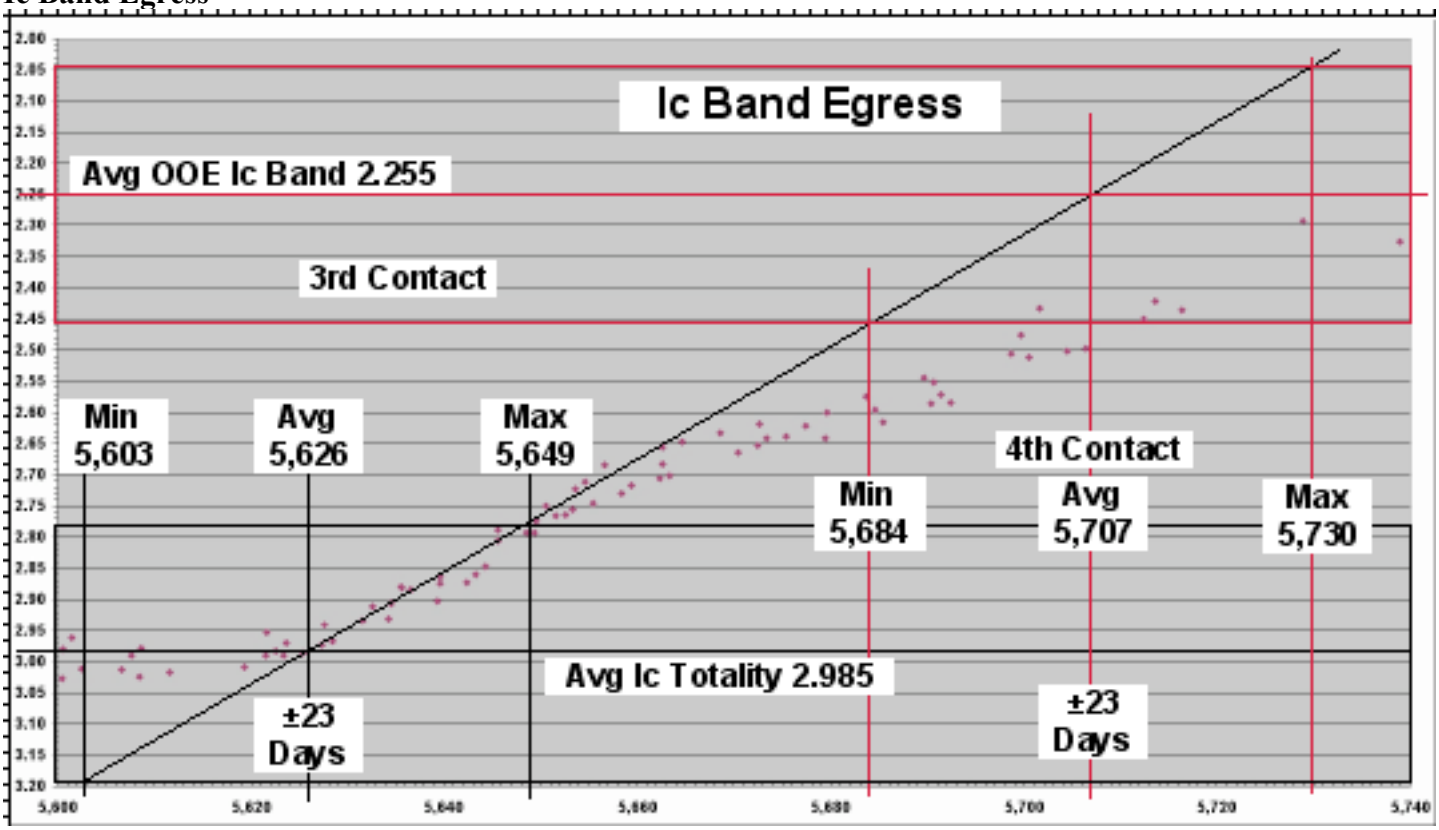
Egress

Egress was determined by finding approximate lines for minimum and maximum times for the egress slope and then determining a median line for the average egress. Minimum, average and maximum contact points were then determined for third and fourth contact. Again, exact placement of the lines was subjective.

Rc Band Egress



Ic Band Egress



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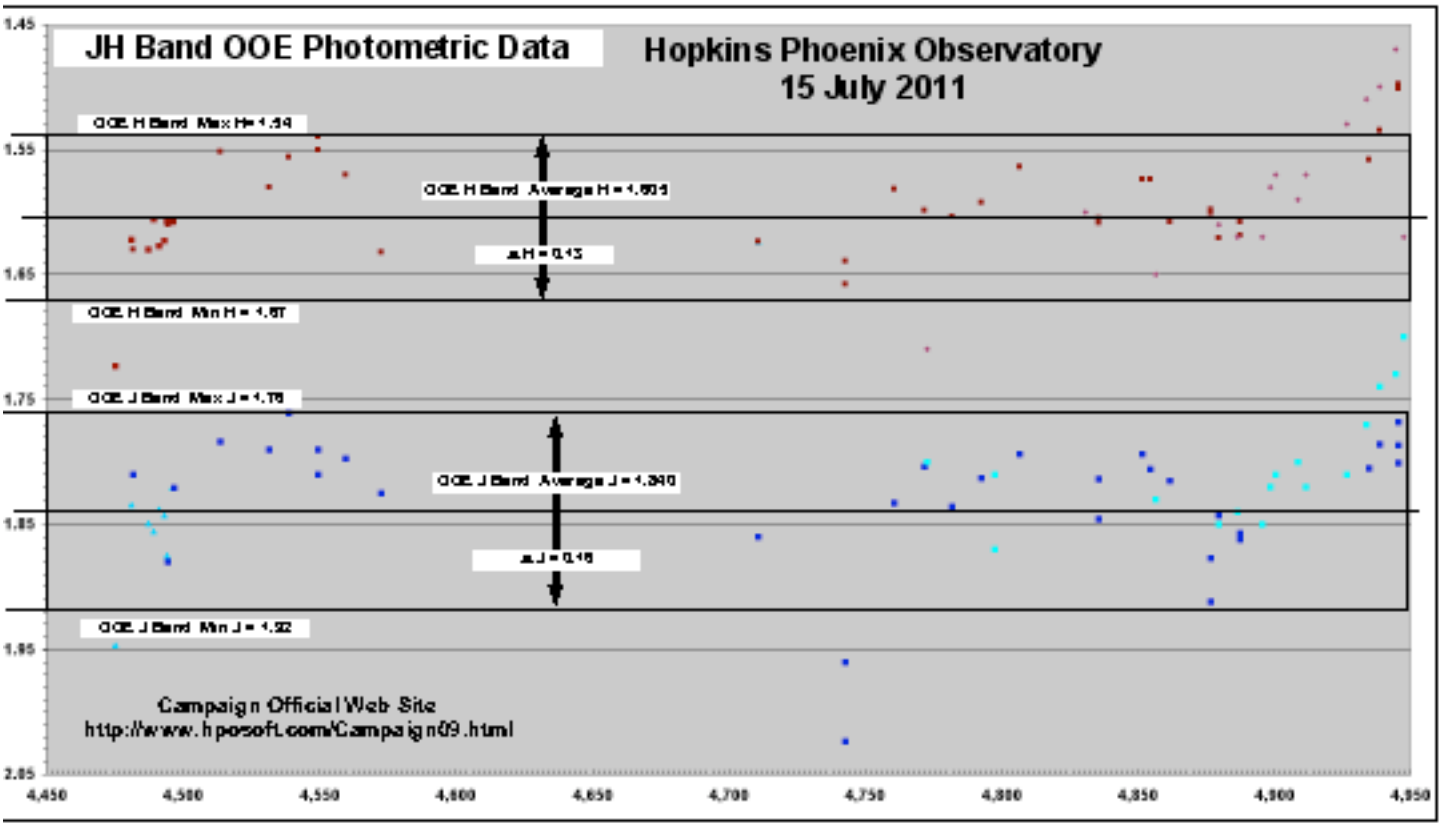
JH Bands

Out-of-Eclipse Variations

First, the out-of-eclipse variation maximum and minimum magnitudes were determined in each band. The average magnitude was then used as the out-of eclipse magnitude for that band. During totality this out-of-eclipse variation was fitted over the totality portion of the light curve, ignoring the mid-eclipse area. An average totality magnitude was then determined.

OOE H Band Max H = 1.54
OOE H Band Average H = 1.605 ΔH = 0.13
OOE H Band Min H = 1.67

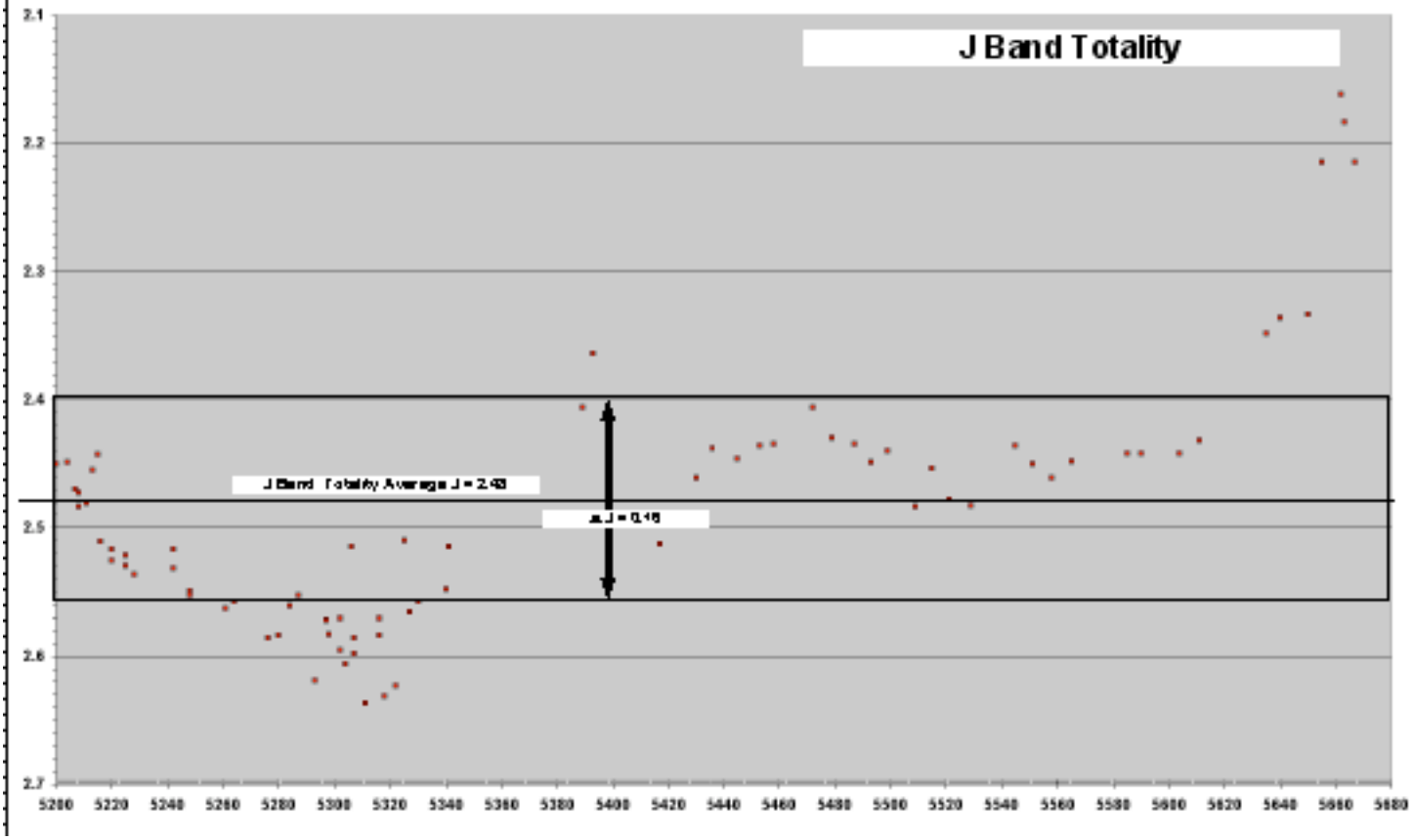
OOE J Band Max J = 1.76
OOE J Band Average J = 1.840 ΔJ = 0.16
OOE J Band Min J = 1.92



Totality

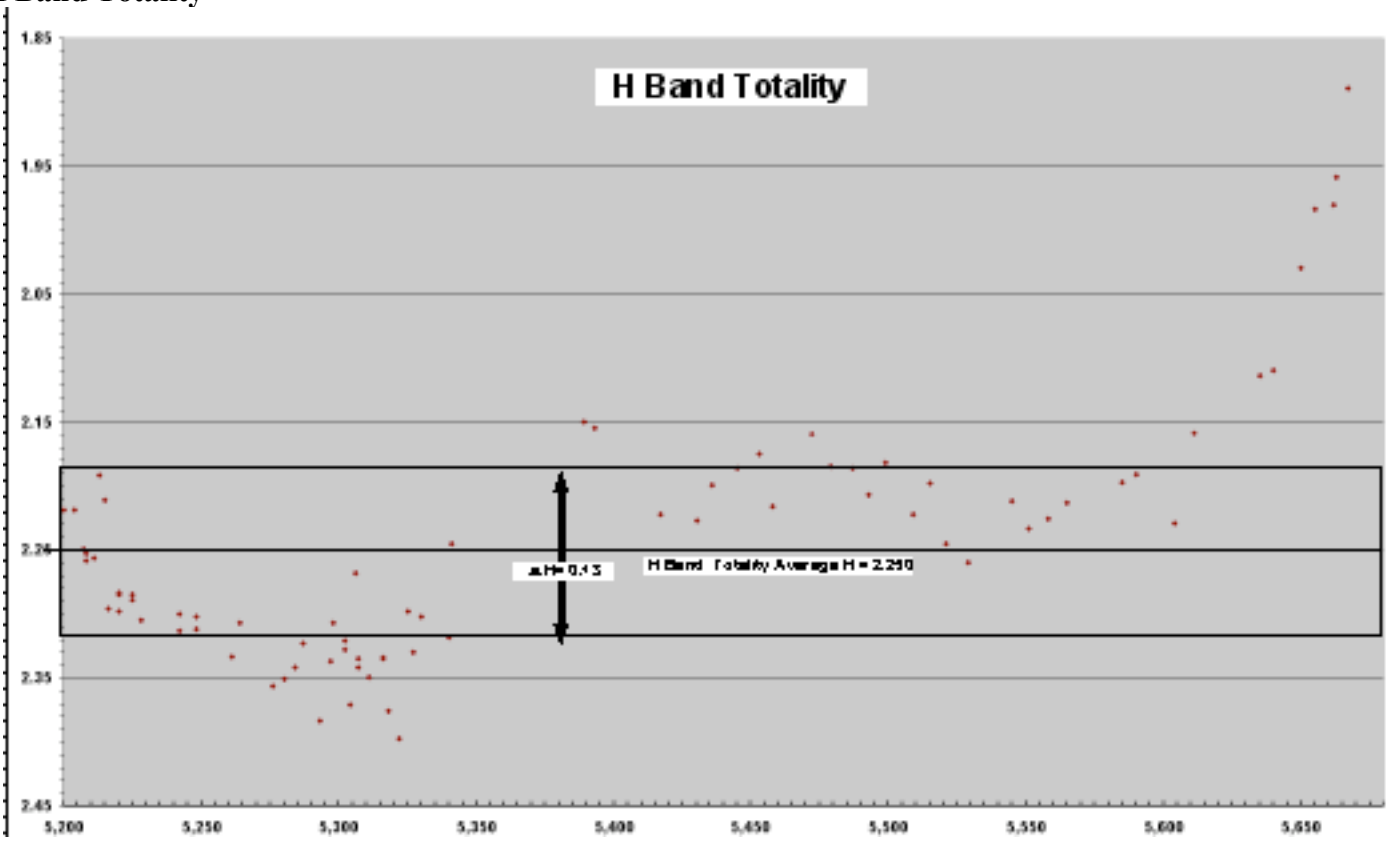
The differential out-of-eclipse magnitude for each band was vertically centered over that band's totality light curve to determine the maximum, average and minimum totality magnitudes. The exact placement of the lines was subjective out of necessity.

J Band Totality



Average J Band Totality = 2.480 ±0.080

H Band Totality

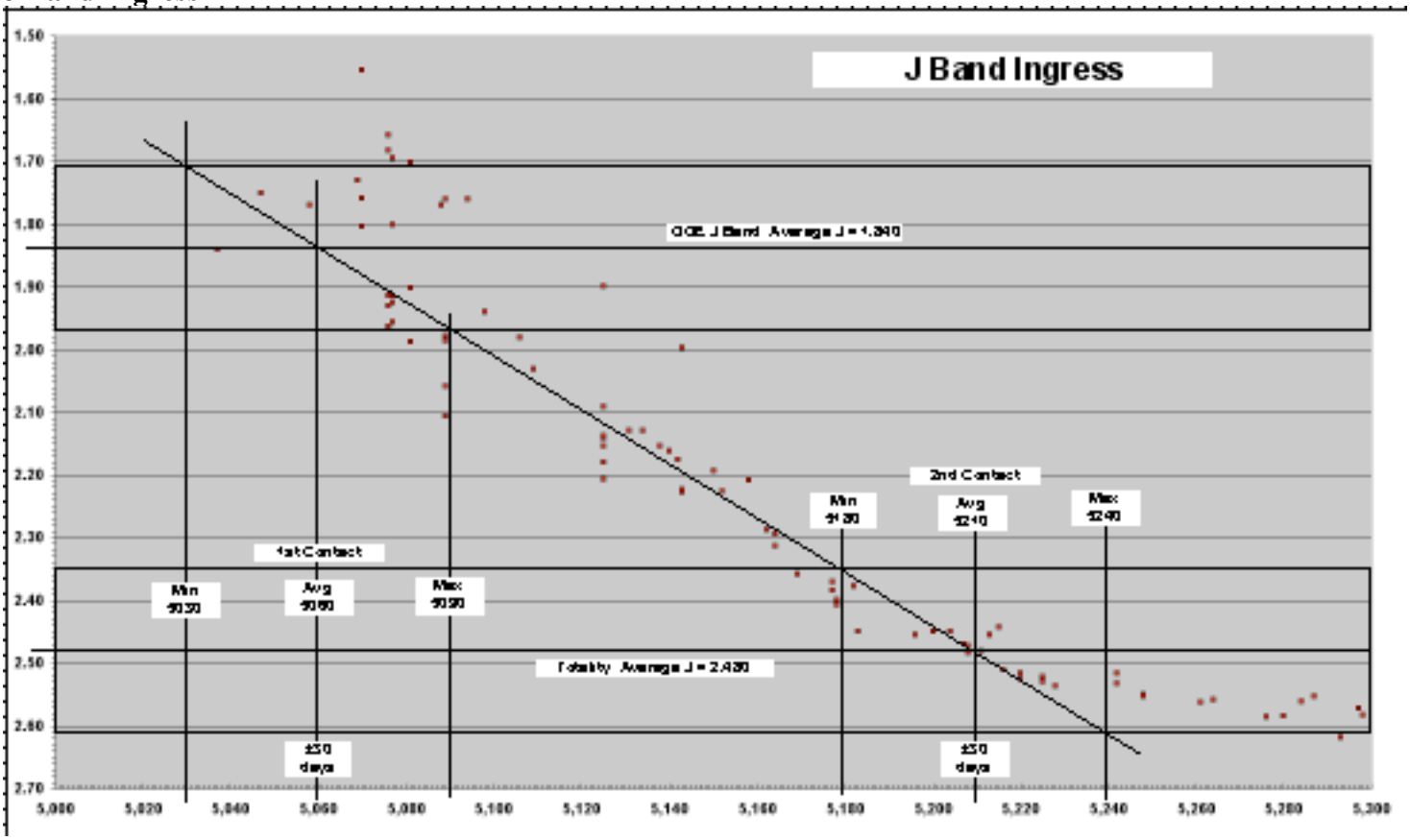


Average H Band Totality = 2.250 ±0.065

Ingress

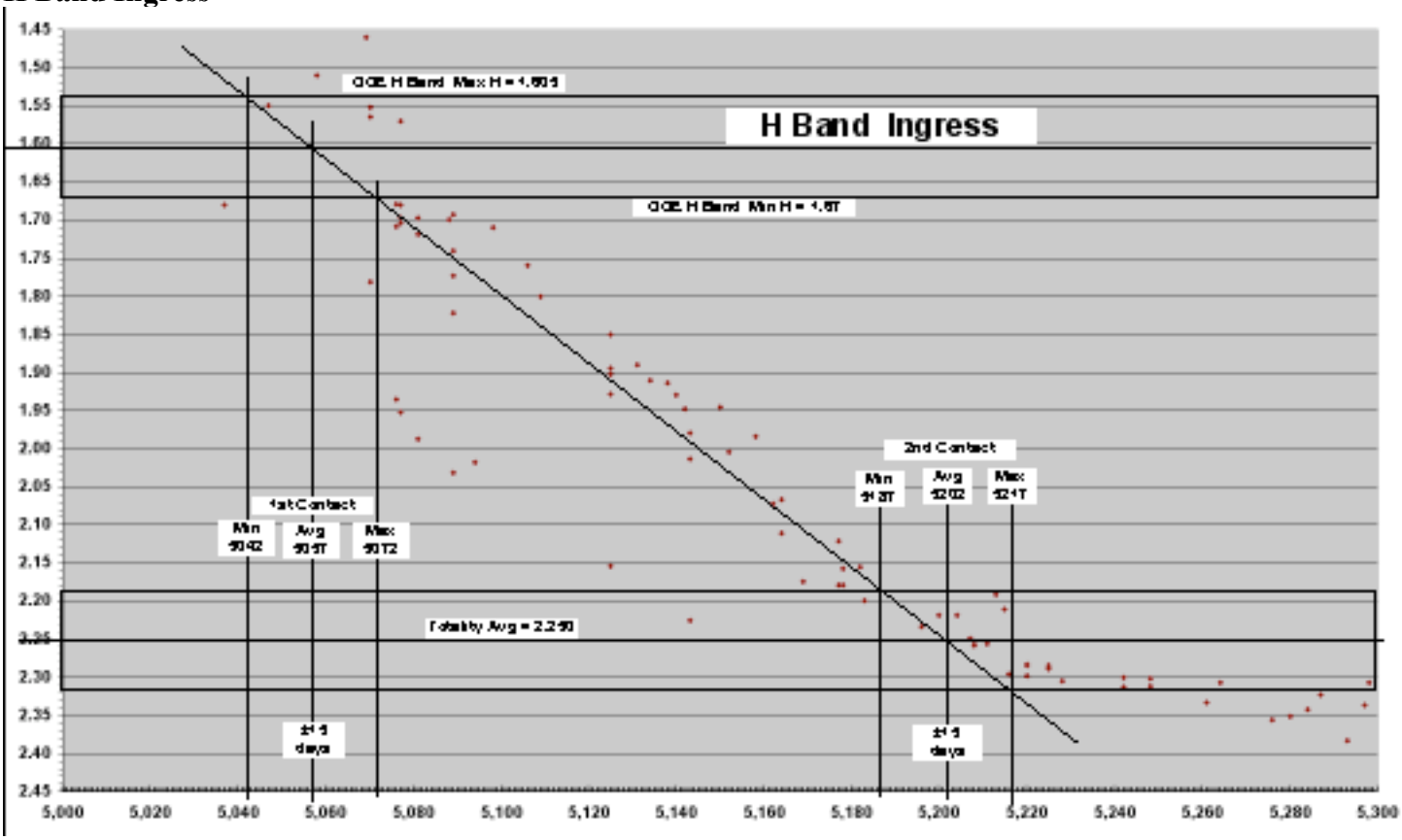
Ingress was determined by finding approximate lines for minimum and maximum times for the ingress slope and then determining a median line for the average ingress. Minimum, average and maximum contact points were then determined for first and second contact. Again, exact placement of the lines was subjective.

J Band Ingress



Average J Band 1st Contact JD 5,060 ± 30 days
Average J Band 2nd Contact JD 5,210± 30 days

H Band Ingress

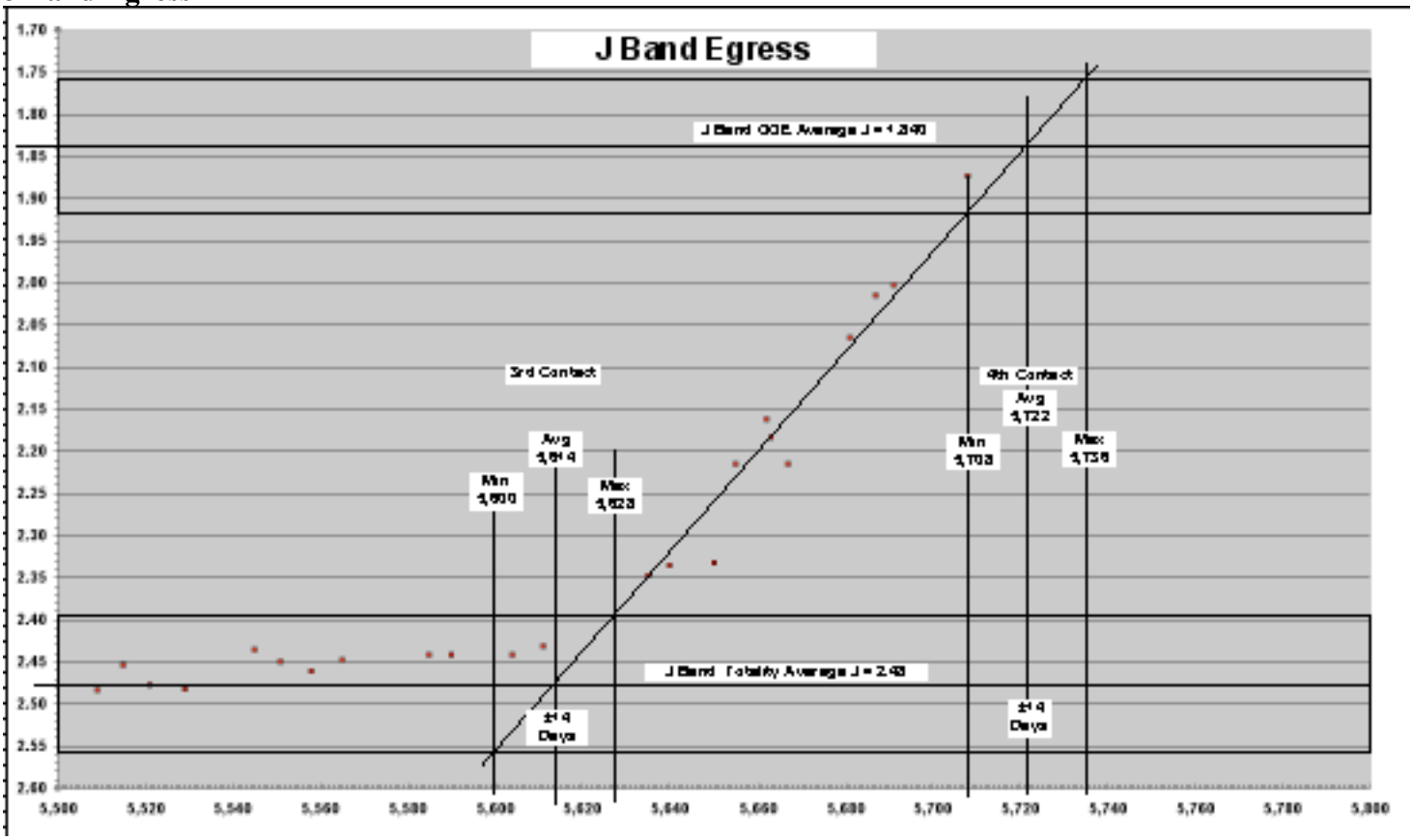


Average H Band 1st Contact JD 5,057 ± 15 days
Average H Band 2nd Contact JD 5,202± 15 days

Egress

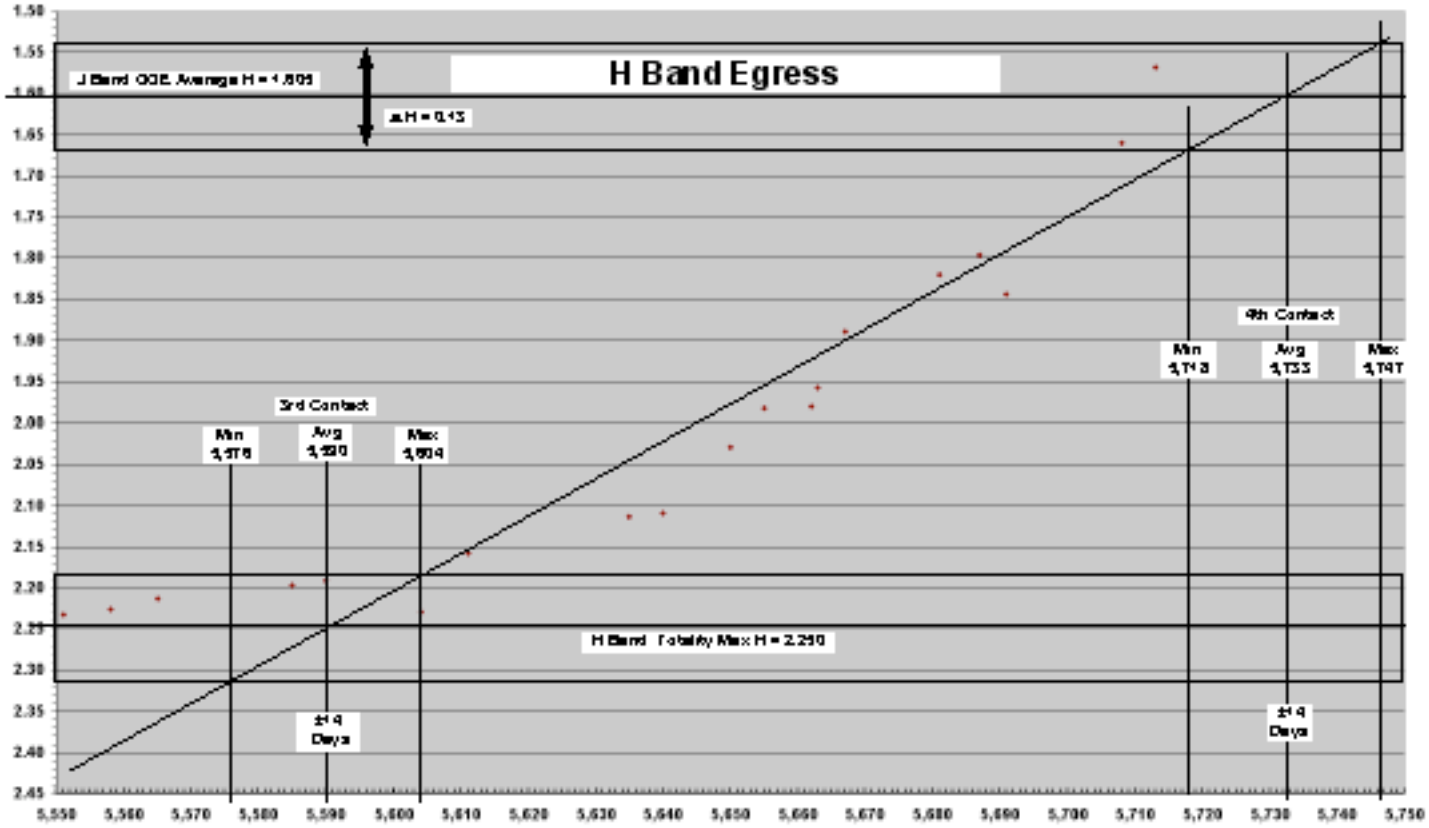
Egress was determined by finding approximate lines for minimum and maximum times for the egress slope and then determining a median line for the average egress. Minimum, average and maximum contact points were then determined for third and fourth contact. Again, exact placement of the lines was subjective.

J Band Egress



Average J Band 3rd Contact JD 5,614 ± 14 days
Average J Band 4th Contact JD 5,722 ± 14 days

H Band Egress



Average H Band 3rd Contact JD 5,590 ± 14 days
Average H Band 4th Contact JD 5,733 ± 14 days

Eclipse Summary

U Band

	RJD= JD-2,400,000 Observed		RJD= JD-2,400,000 Predicted
OOE Magntiude	3.725 Mag Δ 0.230 Mag		3.73 Mag (1982/84)
1st Contact	RJD= 55,062	± 21 days	RJD= 55,065
2nd Contact	RJD= 55,193	± 21 days	RJD= 55,237
Ingress	131 days	± 26.5 days	120 days (1982/84)
Mid-Eclipse	RJD= 55,377	±14 days	
Totality			
Average Magnitude	4.525 Mag		4.57 Mag (1982/84)
Average Depth	0.800 Mag		
Duration	438 days	±10 days	455 days (1982/84)
3rd Contact	RJD= 55,631	±09 days	
4th Contact	RJD= 55,693	±09 days	
Egress	62 days	±37.5 days	55 days (1982/84)
Eclipse			
Duration	631 days	±14 days	630 days (1982/84)
Average Depth	0.800 Mag		0.84 Mag
Period	9,882 days	± 21 days	9,885 days

B Band

OOE Magntiude	3.605 Mag Δ 0.150 Mag		3.61 Mag (1982/84)
1st Contact	RJD= 55,089	± 12 days	RJD= 55,054
2nd Contact	RJD= 55,202	± 12 days	RJD= 55,214
Ingress	113 days	± 12 days	135 days (1982/84)
Mid-Eclipse	RJD= 55,391	±19.5 days	
Totality			
Average Mag	4.325		4.32 Mag (1982/84)
Average Depth	0.720 Mag		
Duration	432 days	±09.5 days	437 days (1982/84)
3rd Contact	RJD= 55,634	±07 days	
4th Contact	RJD= 55,693	±07 days	
Egress	59 days	±07 days	71 days (1982/84)
Eclipse			
Duration	604 days	±19.5 days	643 days (1982/84)
Average Depth	0.720 Mag		0.71 Mag
Period	9,919 days	± 12 days	9,884 days

V Band

OOE Magntiude	3.035 Mag		3.03 Mag (1982/84)
	Δ 0.130 Mag		
1st Contact	RJD= 55,066	± 12 days	RJD= 55,056
2nd Contact	RJD= 55,199	± 12 days	RJD= 55,213
Ingress	133 days	± 12 days	142 days (1982/84)
Mid-Eclipse	RJD= 55,384.5	±09.5 days	
Totality			
Average Mag	3.710 Mag		3.73 Mag (1982/84)
Average Depth	0.675 Mag		0.70 Mag (1982/84)
Duration	430 days	±09.5 days	447 days (1982/84)
3rd Contact	RJD= 55,629	±07 days	
4th Contact	RJD= 55,703	±07 days	
Egress	74 days	±07 days	65 days (1982/84)
Eclipse			
Duration	637 days	±09.5 days	654 days (1982/84)
Average Depth	0.675 Mag		0.70 Mag
Period	9,898 days	± 12 days	9,908 days

Rc Band

OOE Magntiude	2.745 Mag	
	Δ 0.630 Mag	
1st Contact	RJD= 55,073	± 67 days
2nd Contact	RJD= 55,217	± 67days
Ingress	144 days	± 67days
Mid-Eclipse	RJD= 55,333	± 45.5 days
Totality		
Average Mag	3.415 Mag	
Average Depth	0.670 Mag	
Duration	406 days	±17.5 days
3rd Contact	RJD= 55,623	± 34 days
4th Contact	RJD= 55,695	± 34 days
Egress	72 days	±34 days
Eclipse		
Duration	622 days	±45.5 days
Average Depth	0.670 Mag	
Period ?		

Ic Band

OOE Magntiude	2.255Mag	
	Δ 0.410 Mag	
1st Contact	RJD= 55,054	± 42 days
2nd Contact	RJD= 55,202	± 42days
Ingress	148days	± 42 days
Mid-Eclipse	RJD= 55,414	± 32.5 days
Totality		
Average Mag	2.985 Mag	
Average Depth	0.720 Mag	
Duration	424 days	±32.5 days
3rd Contact	RJD= 55,626	± 23 days
4th Contact	RJD= 55,707	± 23 days
Egress	81 days	±23 days
Eclipse		

Duration	625.3 days	±37.5 days
Average Depth	0.730 Mag	
Period ?		

J Band

OOE Magntiude	1.840 Mag	
	Δ 0.160 Mag	
1st Contact	RJD= 55,060	± 30 days
2nd Contact	RJD= 55,210	± 30days
Ingress	150 days	± 30 days
Mid-Eclipse	RJD= 55,391	± 18 days
Totality		
Average Mag	2.480 Mag	
Average Depth	0.640 Mag	
Duration	404 days	±18 days
3rd Contact	RJD= 55,614	± 14 days
4th Contact	RJD= 55,722	± 14 days
Egress	108 days	±14 daya
Eclipse		
Duration	662 days	±18 days
Average Depth	0.640 Mag	
Period ?		

H Band

OOE Magntiude	1.605Mag	
	Δ 0.645 Mag	
1st Contact	RJD= 55,057	± 15 days
2nd Contact	RJD= 55,202	± 15days
Ingress	145 days	± 15 days
Mid-Eclipse	RJD= 55,395	± 15.5 days
Totality		
Average Mag	2.050 Mag	
Average Depth	0.645 Mag	
Duration	388 days	±15.5 days
3rd Contact	RJD= 55,590	± 14 days
4th Contact	RJD= 55,733	± 14 days
Egress	143 days	±14 days
Eclipse		
Duration	676 days	±09.5 days
Average Depth	0.645 Mag	
Period ?		

Conclusion

The estimated contact times have a large variation. These variations are mainly due to the out-of-eclipse variations and the shape of the eclipsing body. Previous eclipse timings did not take these factors into consideration and thus the times reported for those eclipses could be significantly off.