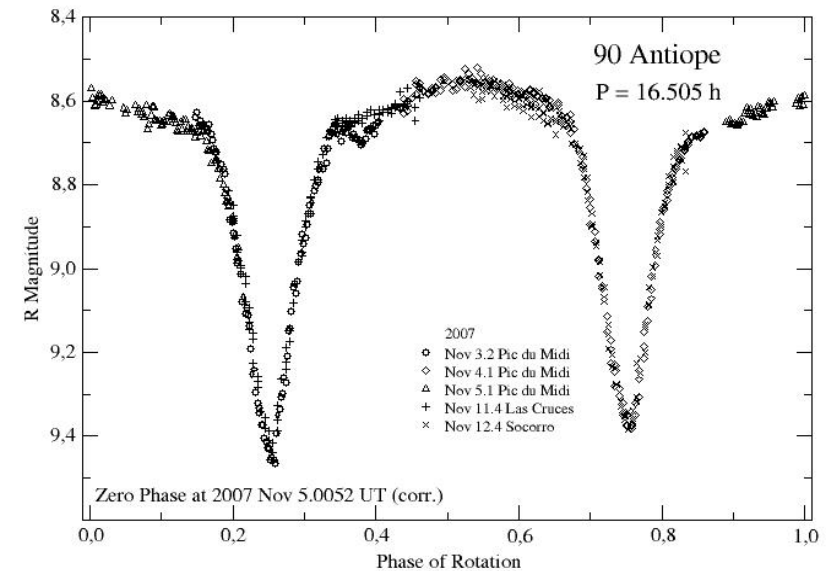
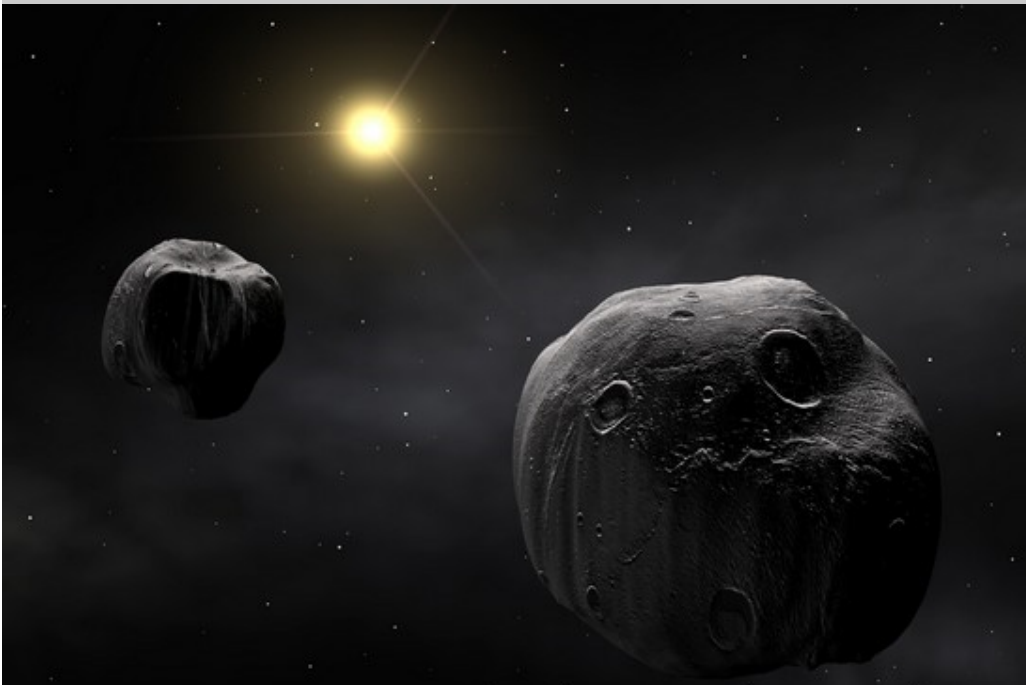


Binaries densities from light curves and occultations the case of (90) ANTIOPE

François **COLAS**, Jérôme **BERTHIER**, Frédéric **VACHIER**
Petr **KUCHYNKA**

IMCCE – Obs Paris
Jet Propulsion Laboratory



Workshop

**Orbital couples : "Pas de deux"
in the Solar System and the Milky Way**

Paris, October 10-12, 2011

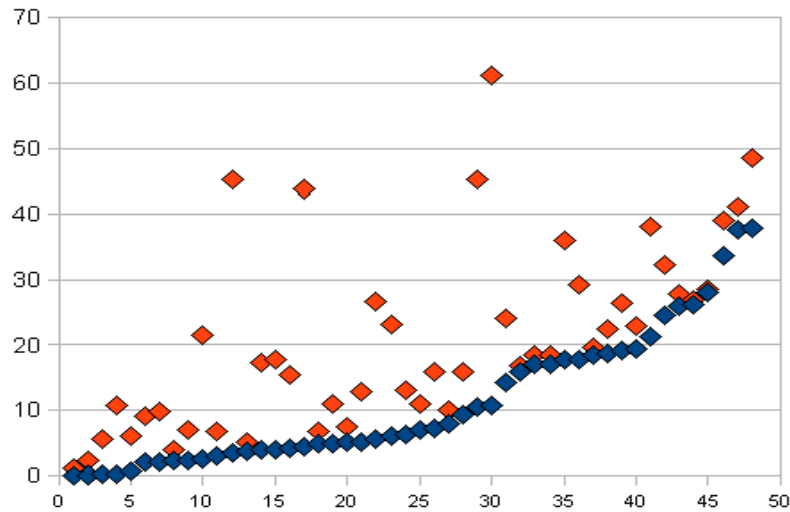
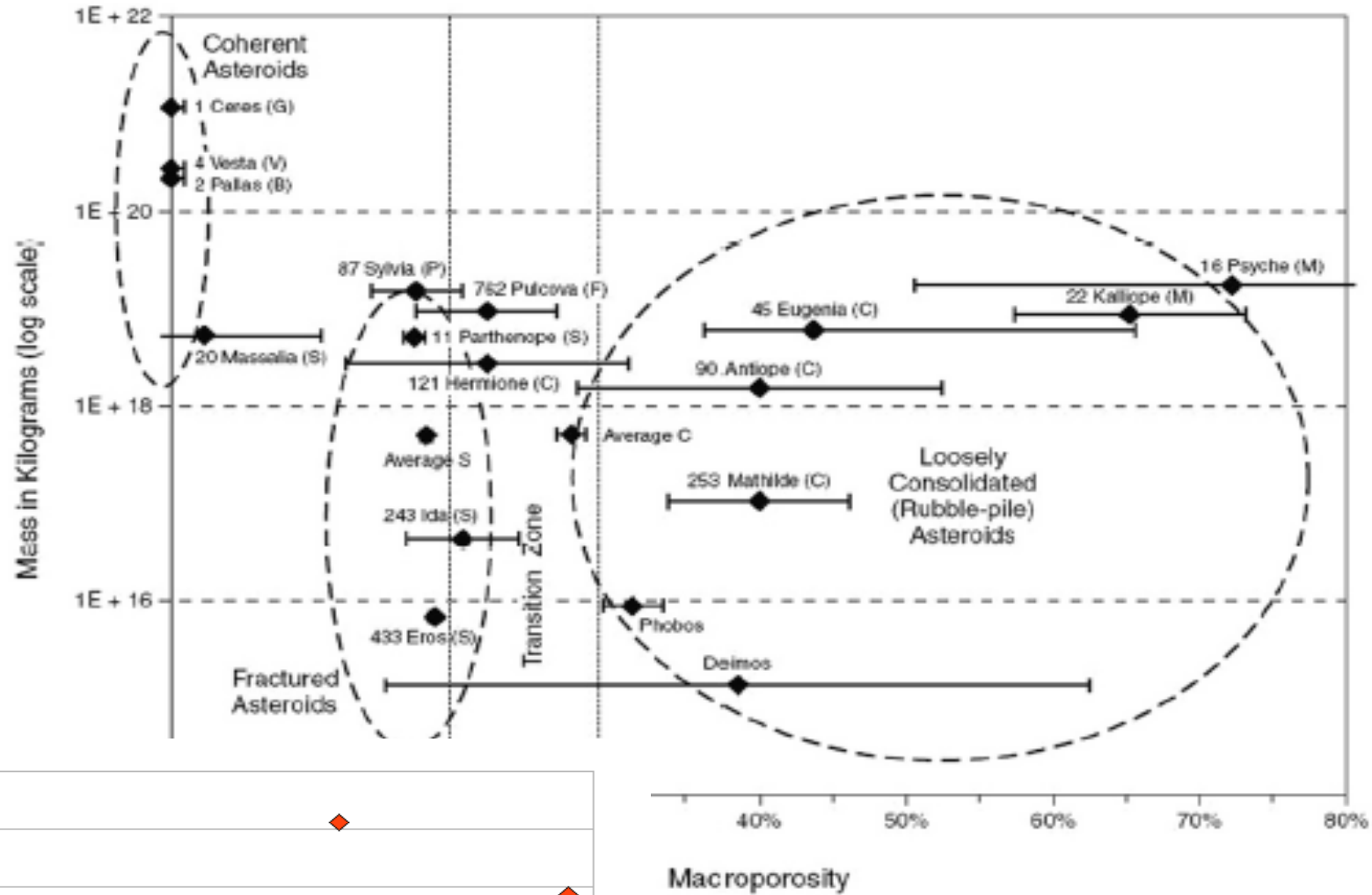
Densities measurements

Most of the asteroids have not evolved since solar system formation

- Asteroids densities are keys for :
 - Solar system formation
 - Evolution
 - Impacts and evolution of the solar system
- Densities + Spectroscopic observations => macro porosity
 - fracturation
 - rubble piles
 - collisional history
 - ...



Actual situation



Accuracies of actual best masses (blue dots) and best densities (red dots)

**About 200 asteroid masses will be known
in the next 10 years using different ways,**

Mars orbit perturbations,

Mutual perturbations (astrometry – GAIA)

Flyby,

Binary asteroids

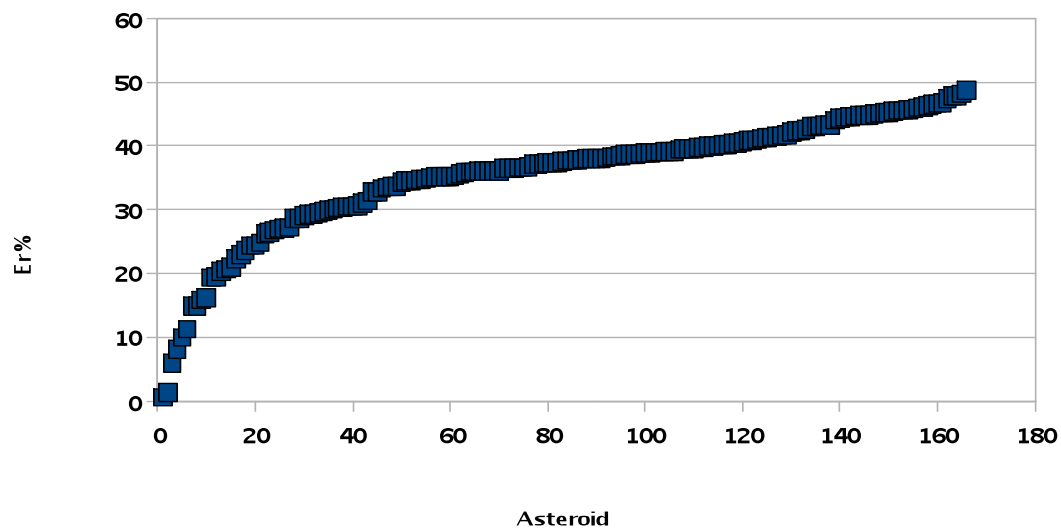


Mars perturbations

As we know Mars orbit with a meter accuracy and as asteroids can perturb Mars orbit of more than one kilometer, it is possible to measure some asteroids masses (INPOP-10a A.Fienga et al 2011)

- we supposed that Mars orbit will be still known with an one meter accuracy until 2020, we found 167 objects with masses that can be measured with an accuracy better than 50%

40% => 115
30% => 50

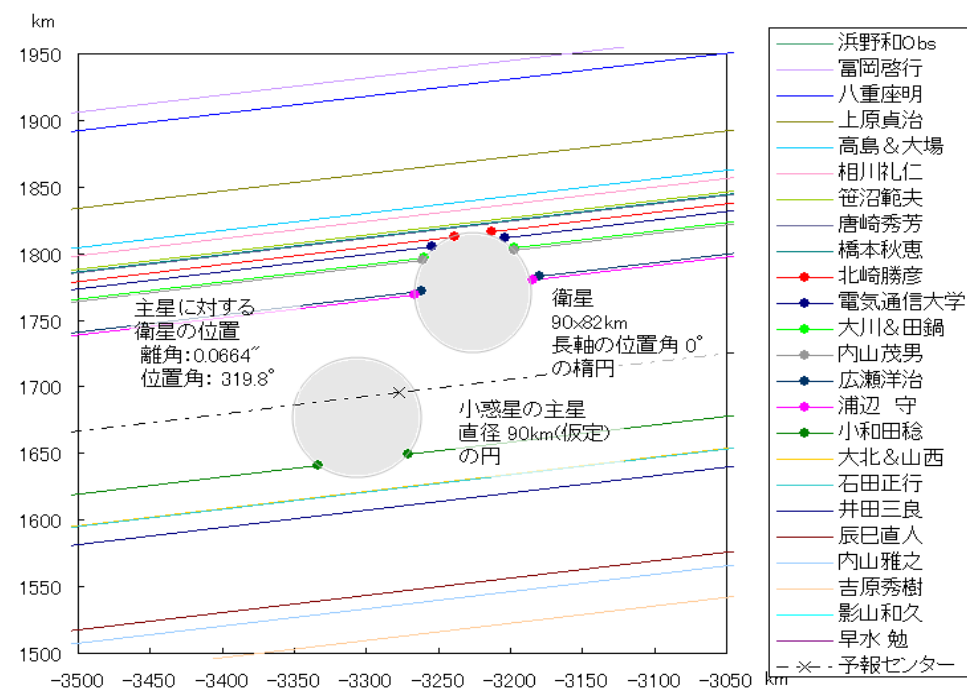


Mass determination

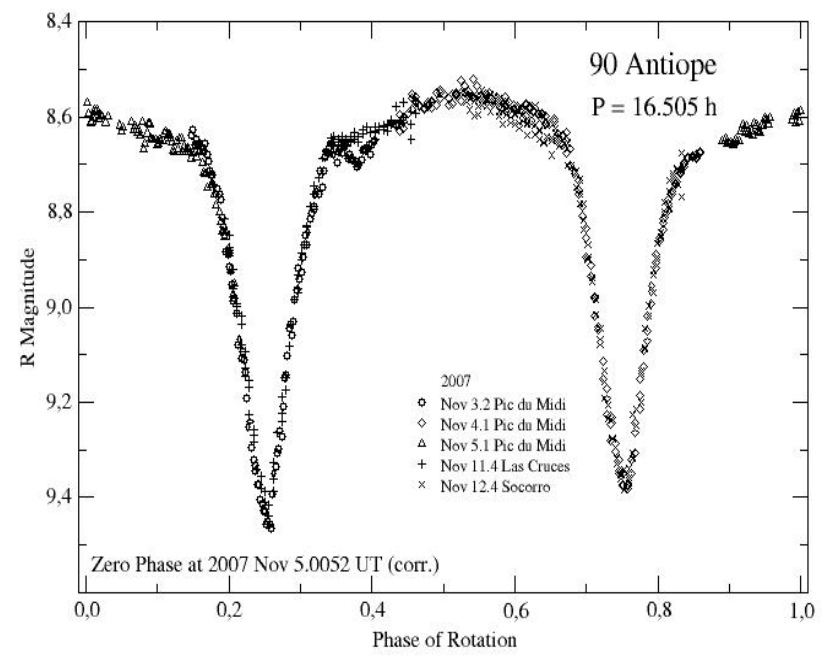


(90) Antiope – mutual phenomena and occultation

(90)Antiope on 2008.1.3

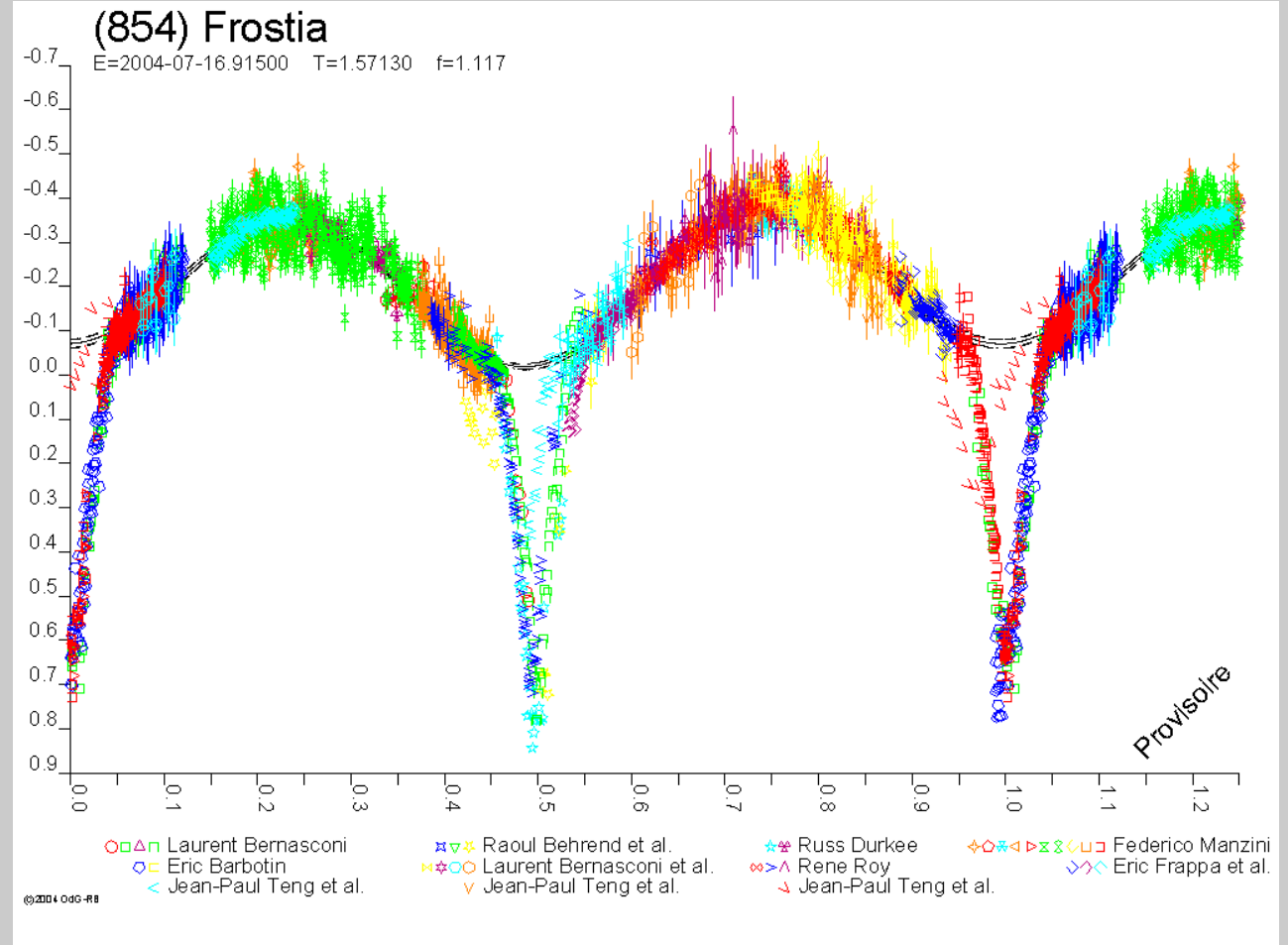
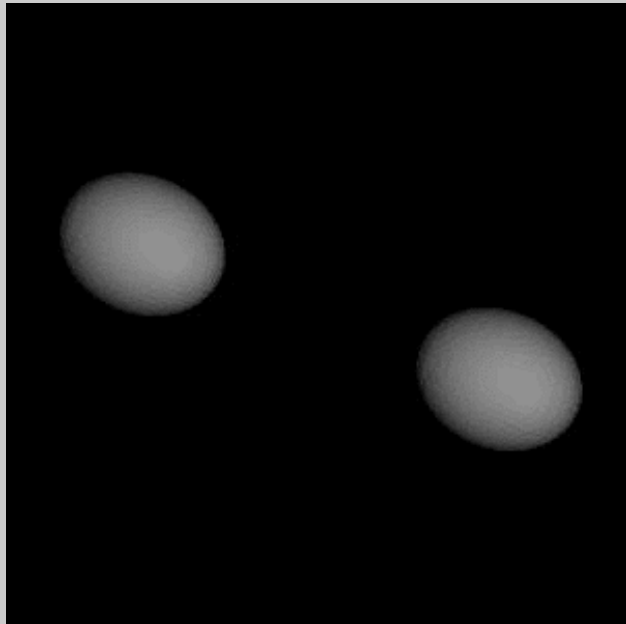


Occultations

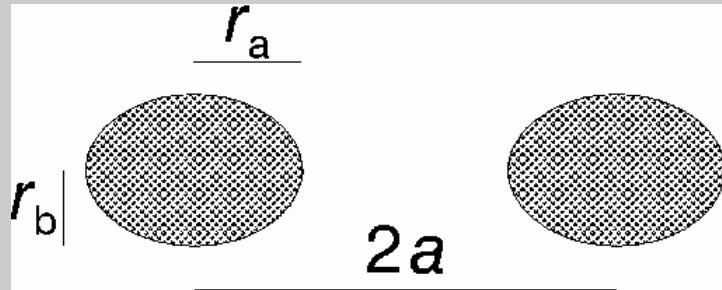


Light curves

Binary asteroid light curves



Direct density estimation

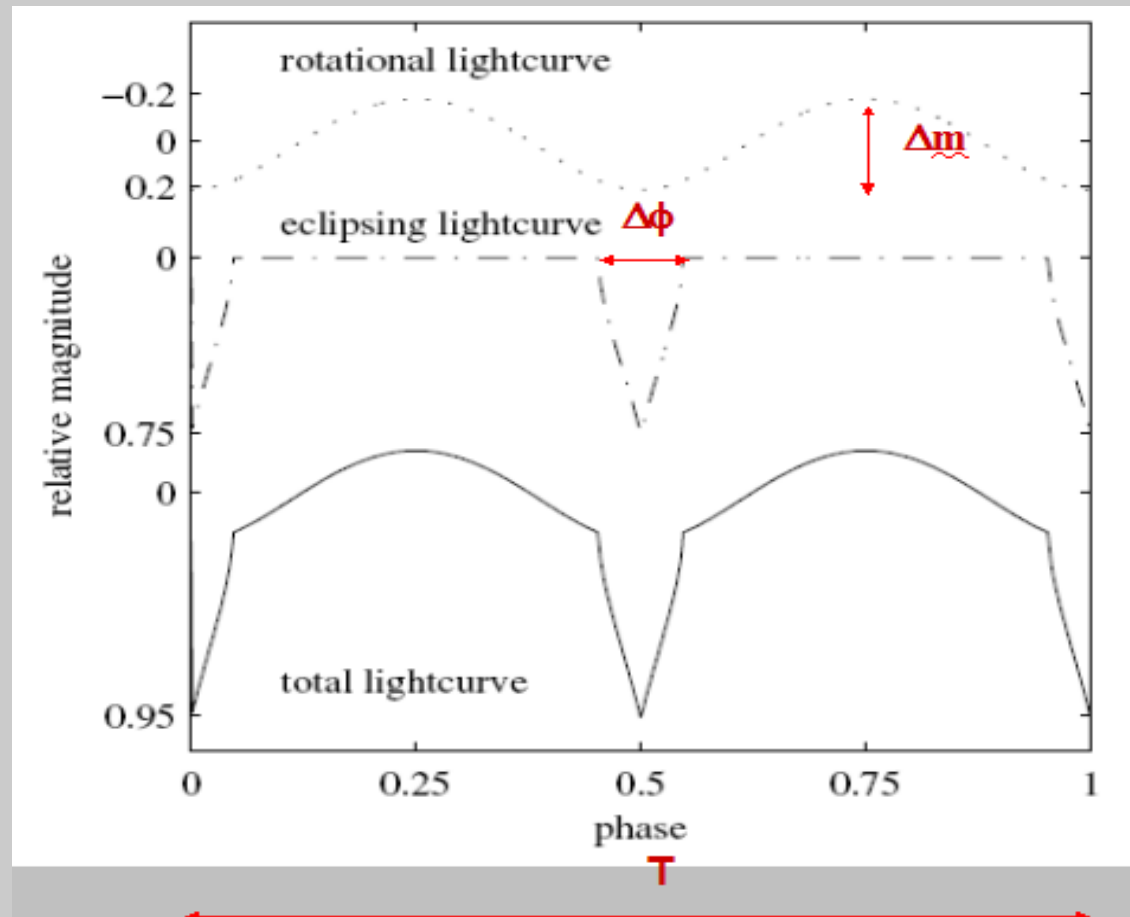


$$r_b/r_a = 10^{-0.4\Delta m}$$

$$a = \frac{r_b}{\sin(\Delta\phi/2)}$$

$$M = \frac{16\pi^2 a^3}{GT^2}$$

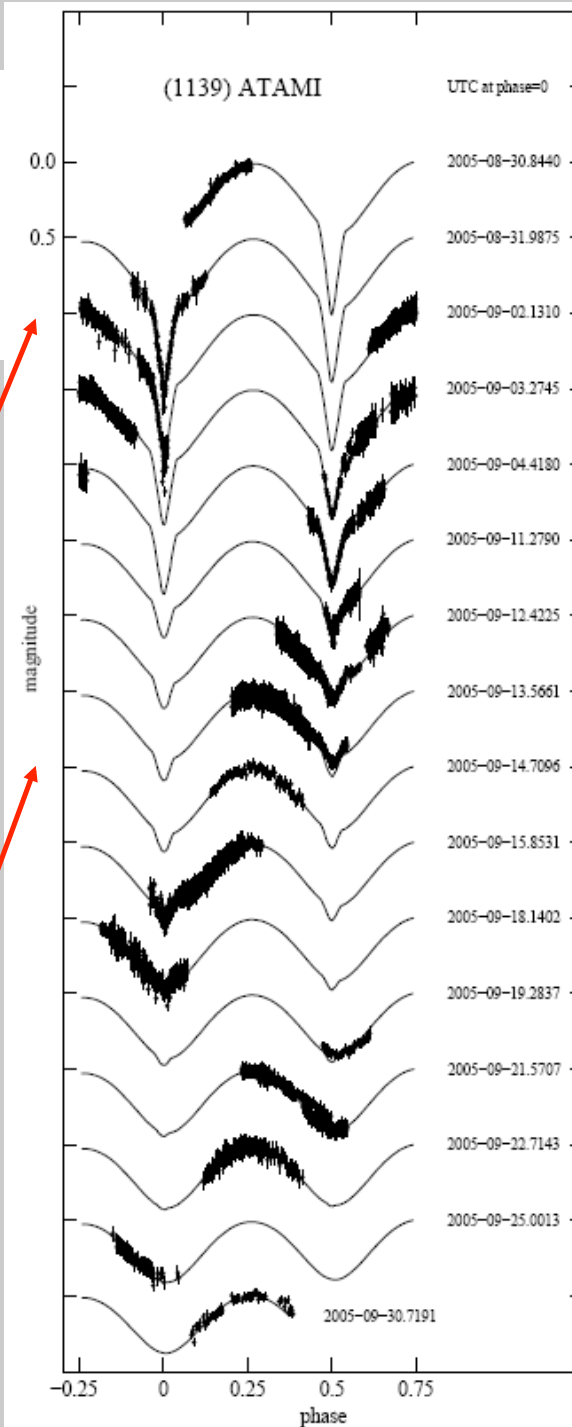
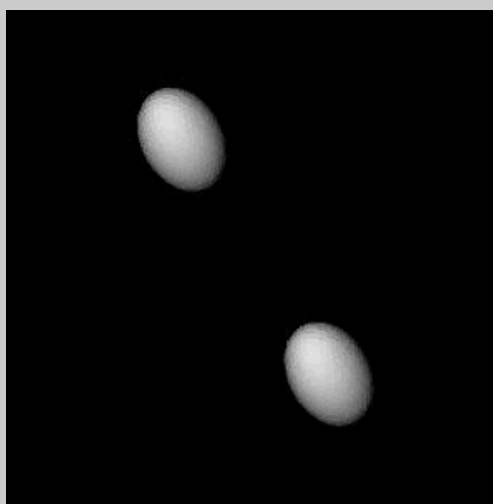
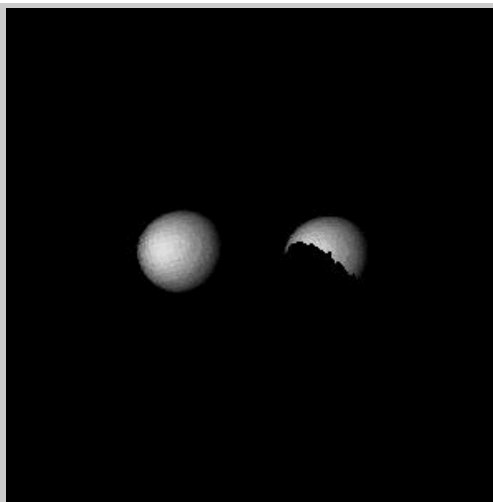
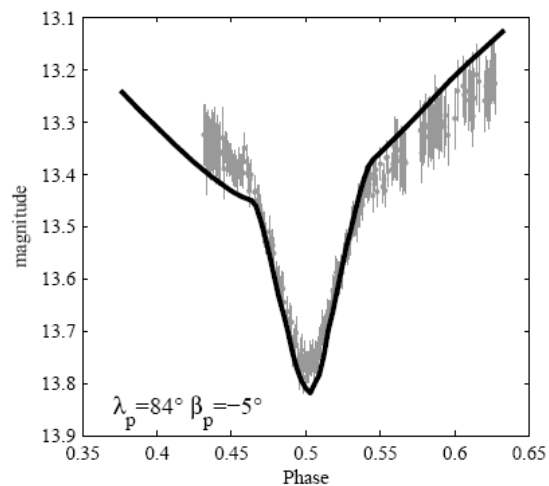
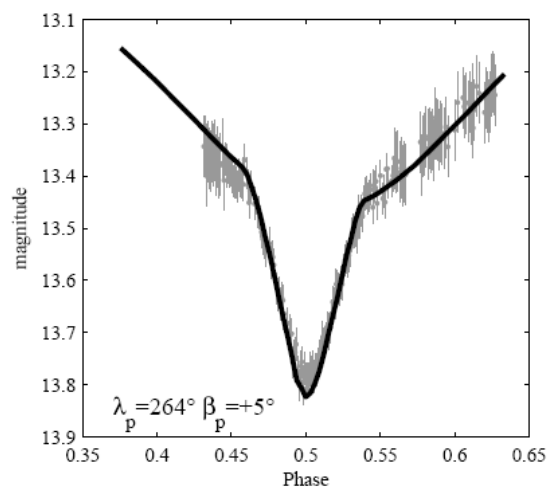
$$\rho = \frac{M}{\frac{4}{3}\pi r_a r_b^2}$$



$$\rho = \frac{12\pi}{G} \frac{1}{T^2} \frac{10^{-0.4\Delta m}}{\sin^3(\Delta\phi/2)}$$

Discovery of the binary nature of the Mars-crosser (1139) Atami [★]

R. Behrend¹, F. Manzini², A. Klotz^{3,4}, F. Colas^{5,6}, Y. Damerджи^{3,4}, S.J. Ostro⁷, P. Antonini^{8,6},
E. Barbotin⁶, L. Bernasconi^{9,6}, C. Cavadore¹⁰, S. Charbonnel^{11,6}, J. Coloma¹², R. Crippa¹³, F. Kugel¹⁴,
A. Leroy¹⁵, J.M Llapasset¹⁶, A. Oksanen¹⁷, P. Pääkkönen¹⁸, R. Poncy^{19,6}, R. Roy^{20,6}, and D. Starkey²¹



Four binaries founded on 400 light curves

	(854) Frostia	(1089) Tama	(1313) Berna	(4492) Debussy
r_a (km)	4.08–9.65	5.08–5.99	4.48–10.7	2.99–7.09
r_b (km)	2.95–6.99	3.48–4.11	3.54–8.39	1.92–4.56
a (km)	9.57–25.0	9.47–12.2	9.63–24.8	5.23–13.5
M (10^{13} kg)	11–201	57–121	25–426	3.7–63
ρ (g cm^{-3})	0.75–1.02	2.23–2.82	1.07–1.36	0.80–1.01
r_b/r_a	0.724	0.685	0.790	0.643
a/r_a	2.34–2.59	1.86–2.03	2.14–2.33	1.74–1.90
a/r_b	3.23–3.59	2.71–2.95	2.71–2.96	2.71–2.96
$1-\epsilon$	0.84–0.89	0.72–0.79	0.76–0.82	0.71–0.77

**No bias on
statistic
We can do the same
with Gaia by searching
light curves
with anomamies**

If we admit the validity of the detection criteria given above, and a mean value $\frac{r_b}{2a} \sim \frac{1}{6}$, we can compute

$$p\left(\zeta = \frac{1}{6}\right) \sim 0.17.$$

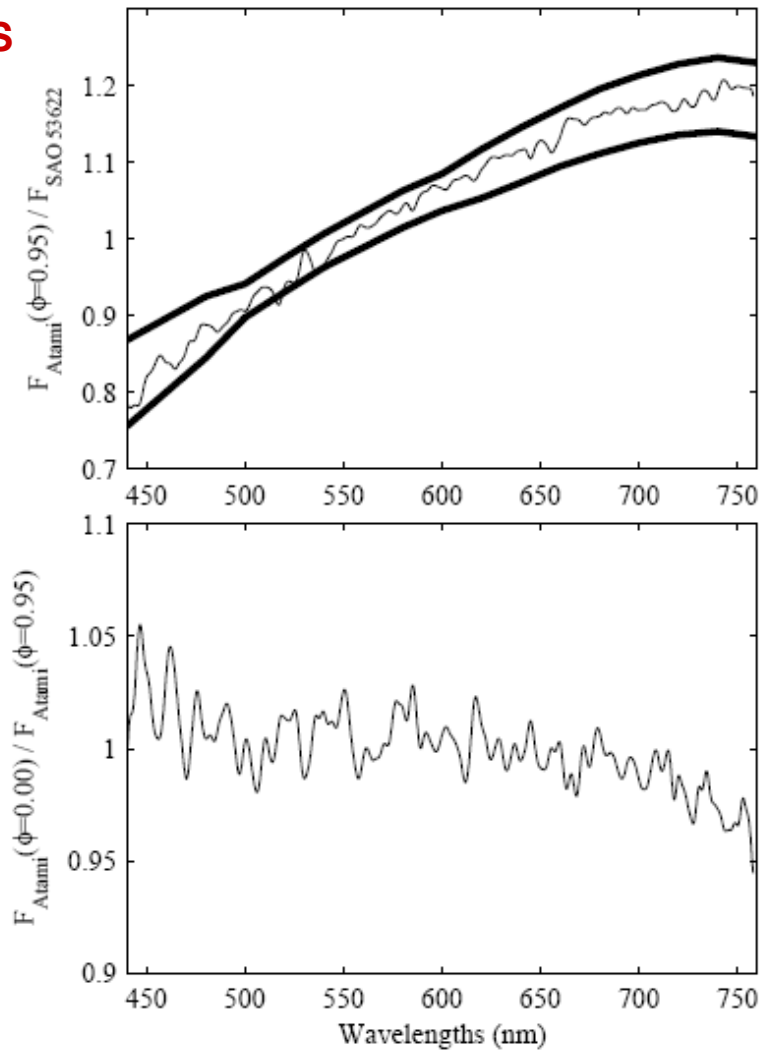
This means that only 17% of the binary asteroids that have a ratio $r_b/(2a) \sim 1/6$ can be detected at a given opposition. As four asteroids were recognized as binary, about $4/0.17 \simeq 24$ of the total (4.0×10^2) should be of the same type. Taking account of the uncertainties, the proportion of binary systems in the main belt is thus probably around 6 ± 3 percents.

Low resolution spectrography : minéralogy

Discovery of the binary nature of the Mars-crosser (1139) Atami *

R. Behrend¹, F. Manzini², A. Klotz^{3,4}, F. Colas^{5,6}, Y. Damerdjji^{3,4}, S.J. Ostro⁷, P. Antonini^{8,6},
E. Barbotin⁶, L. Bernasconi^{9,6}, C. Cavadore¹⁰, S. Charbonnel^{11,6}, J. Coloma¹², R. Crippa¹³, F. Kugel¹⁴,
A. Leroy¹⁵, J.M Llapasset¹⁶, A. Oksanen¹⁷, P. Pääkkönen¹⁸, R. Poncy^{19,6}, R. Roy^{20,6}, and D. Starkey²¹

2005 type S
(pôle N)

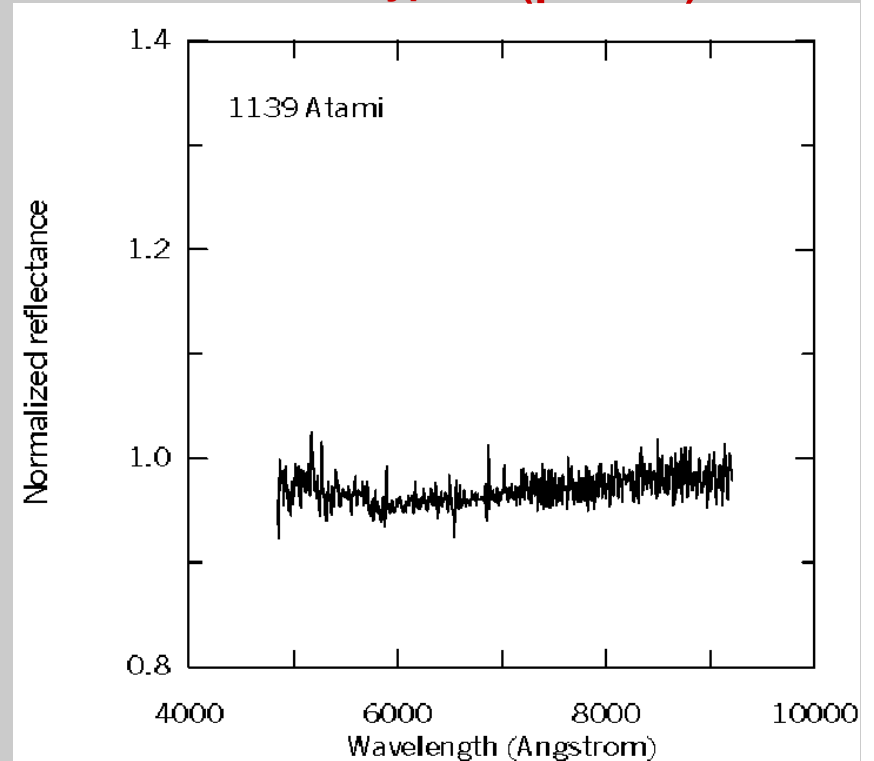


Infrared photometry
from ground based
observations

=>

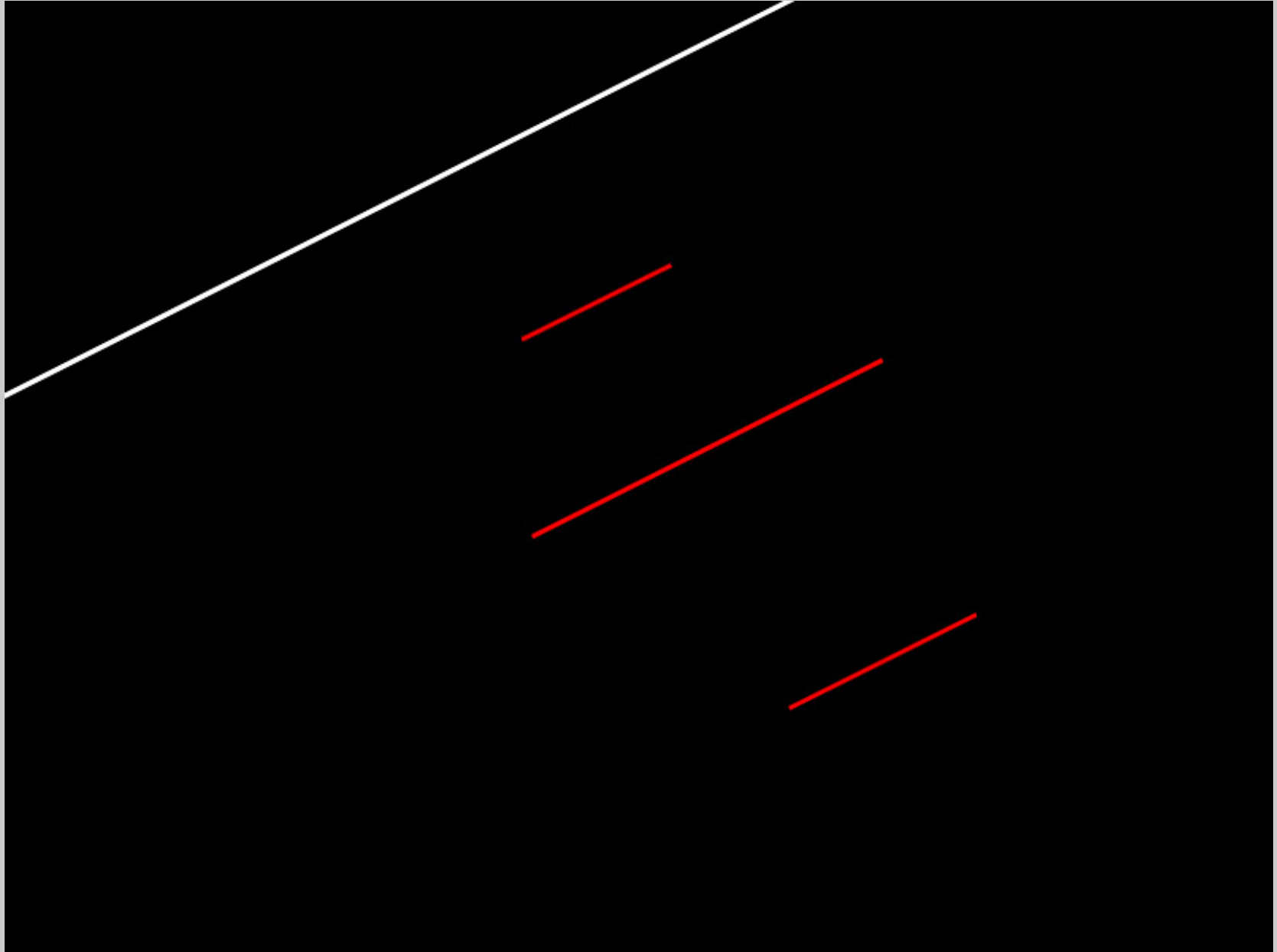
Thermal inertia
(eclipse observations)

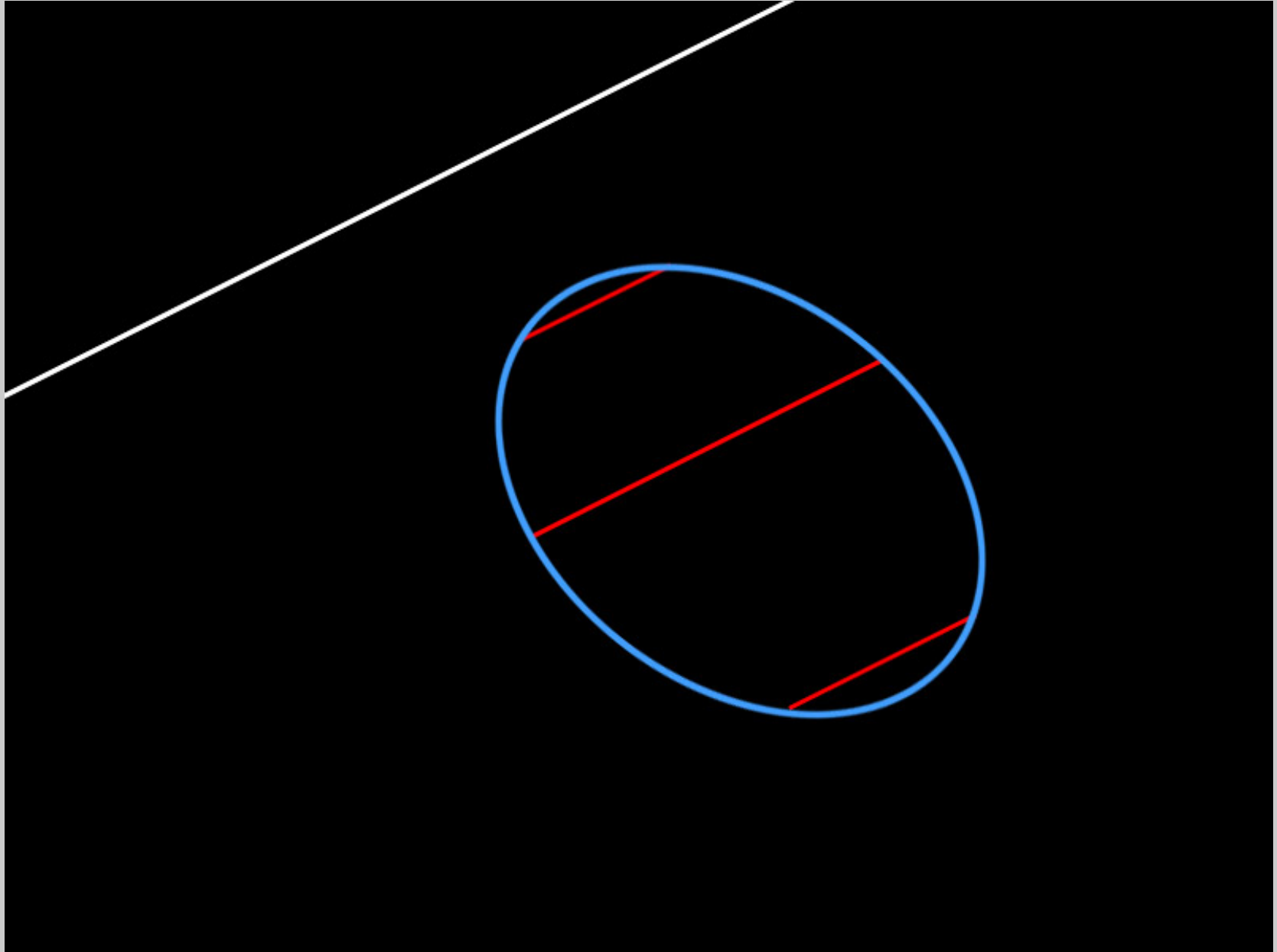
1996 type S (pôle N)
1997 type C (pôle S)

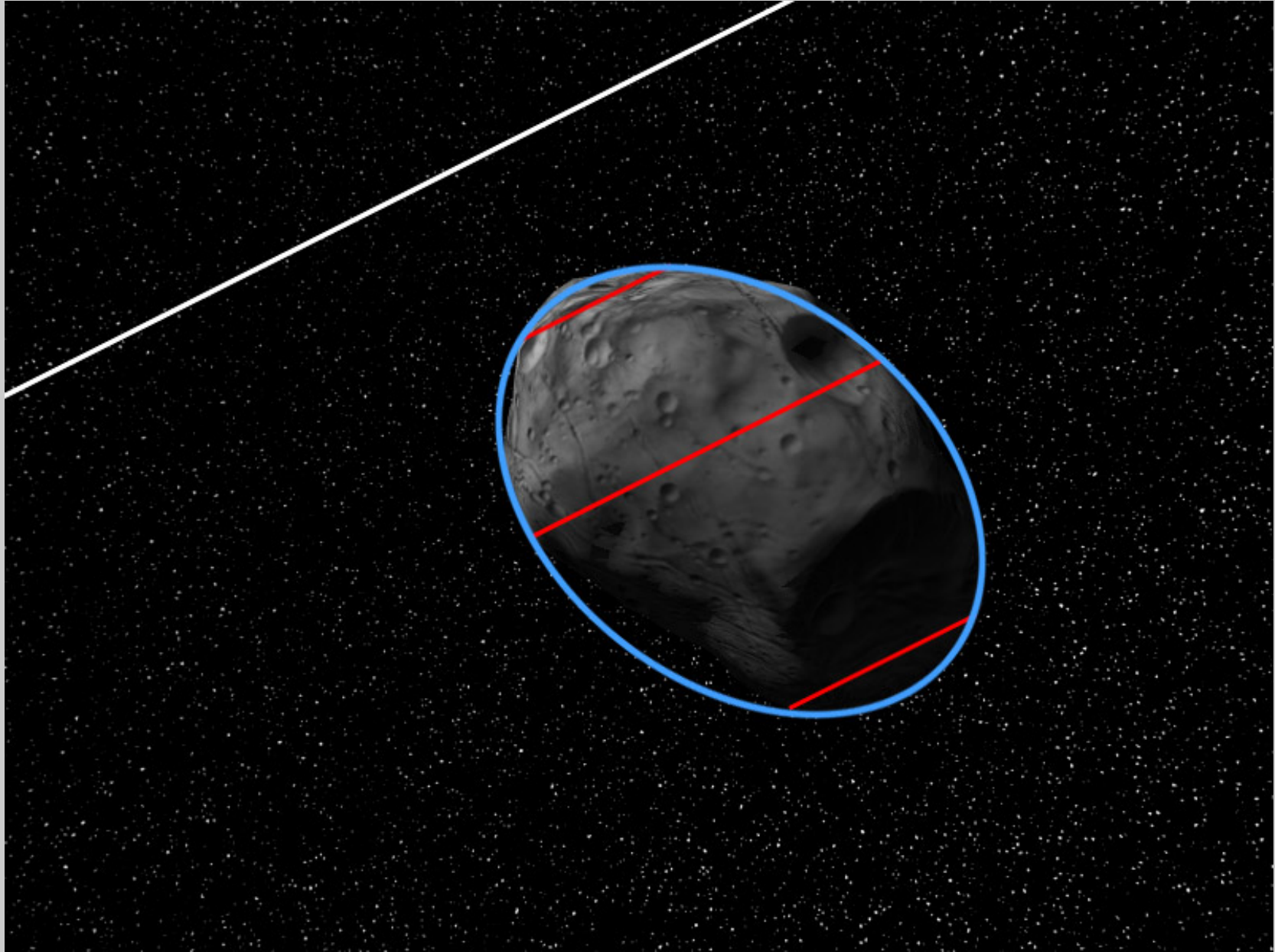


Stellar Occultations





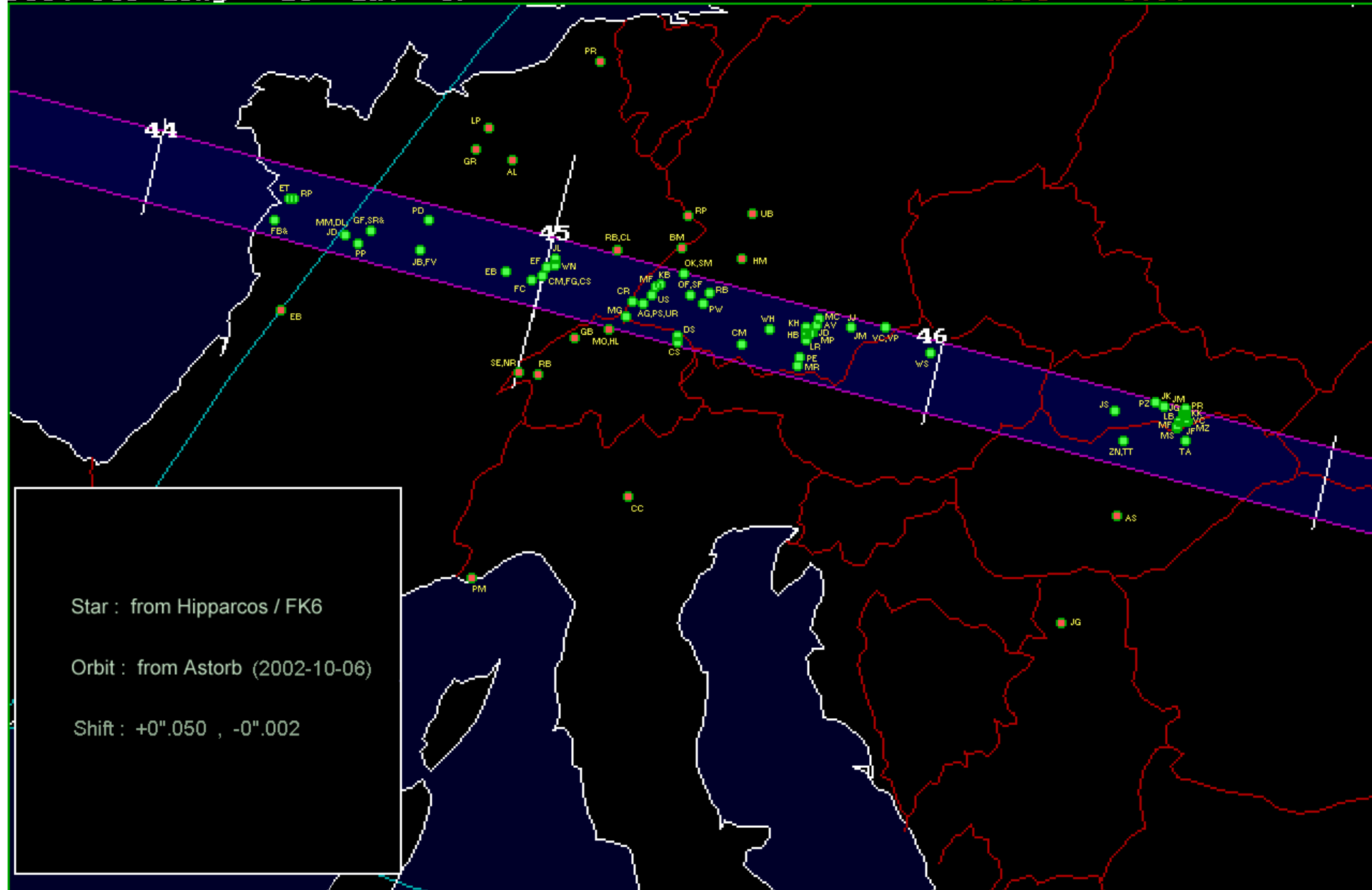


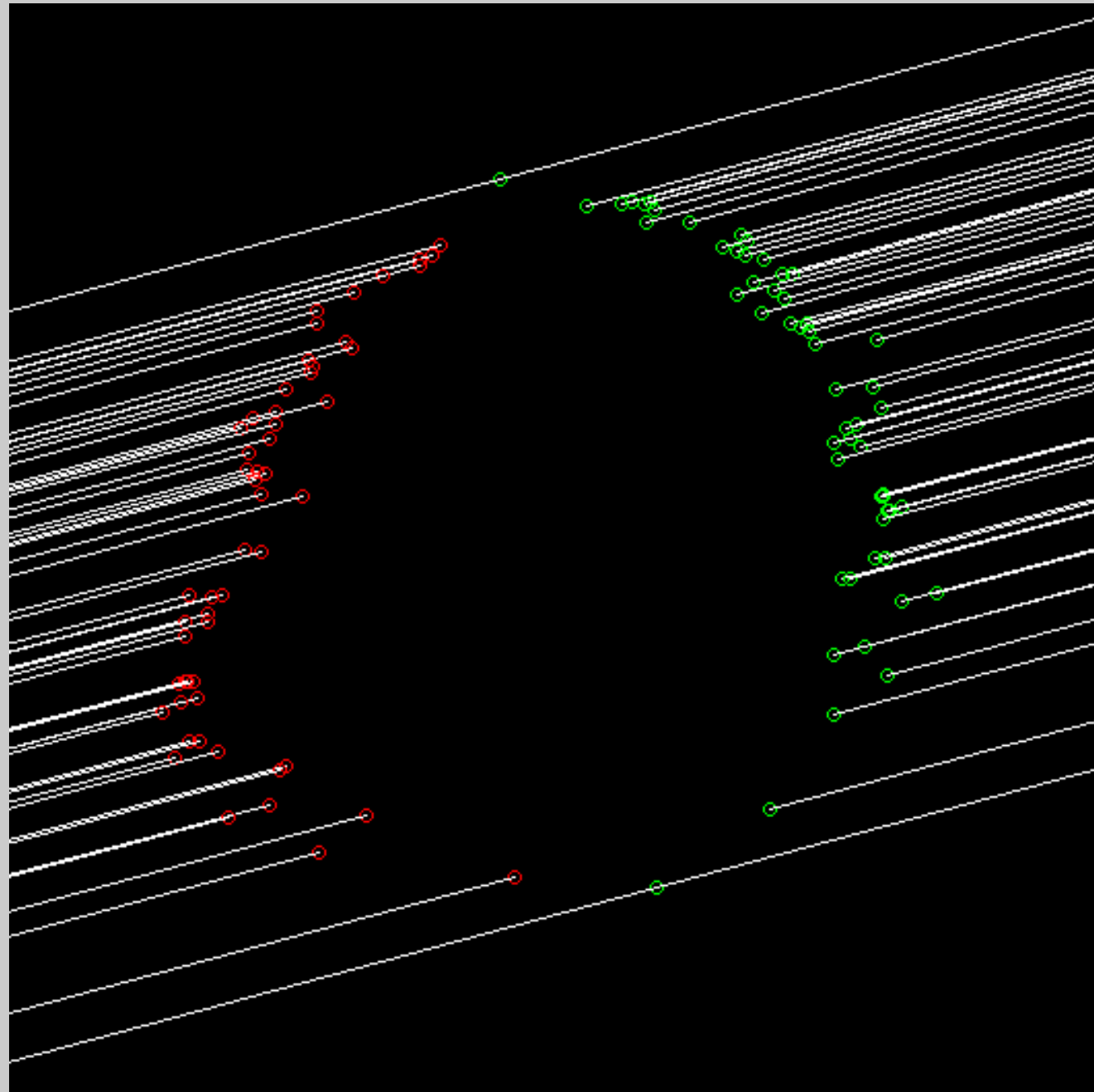


Occultation of HIP19388 by 345 Tercidina on 2002 Sep 17 at 0h 53.115m UT

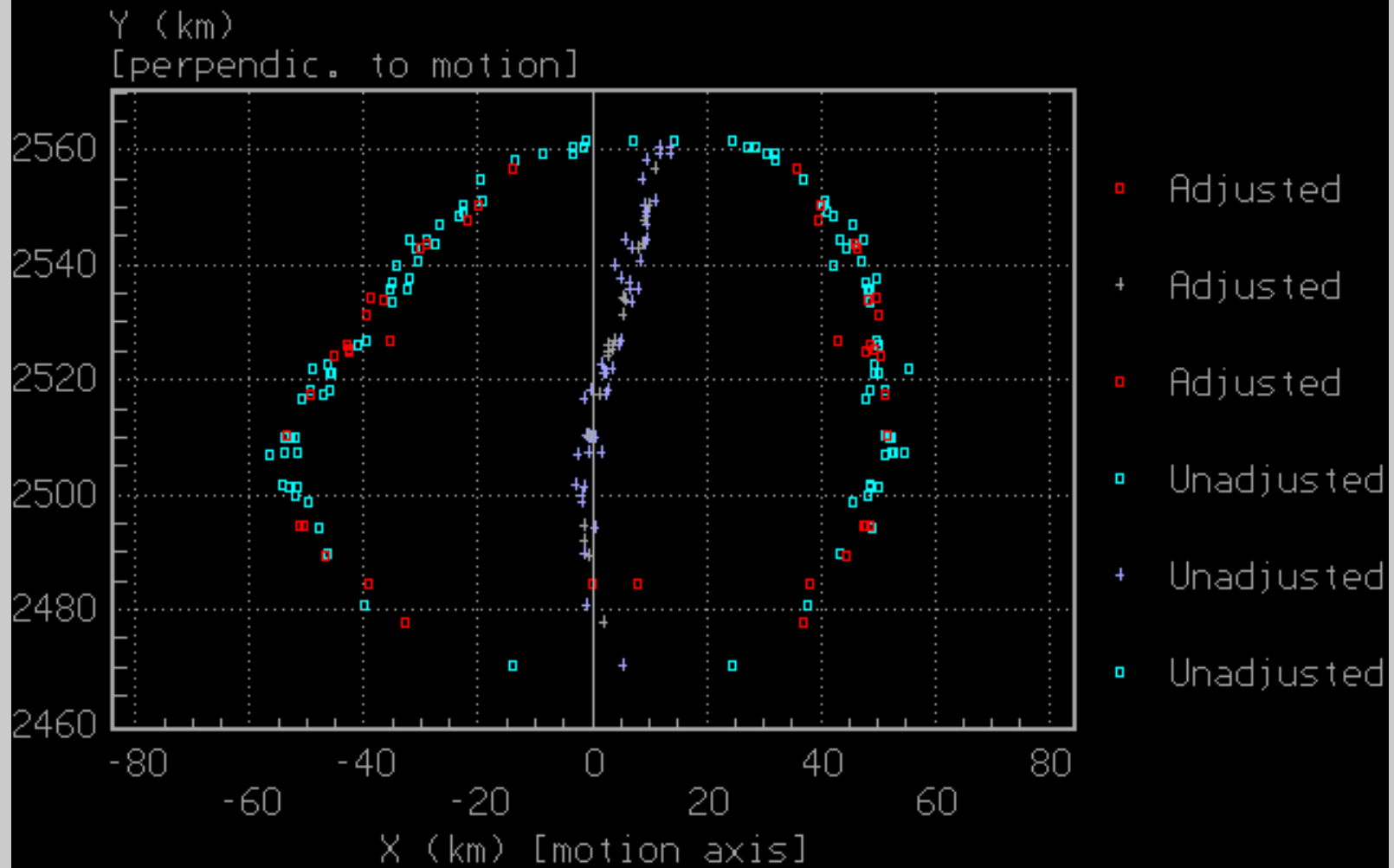
Star (2000):	Max Duration = 10.5 secs	Asteroid:
Mag = 5.5	Mag Drop = 7.3	Mag = 12.8
RA = 4 09 09.988	Sun : Dist = 110°	Dia = 94km, 0.078"
Dec = +19 36 33.10	Moon: Dist = 122°	Parallax = 5.279
	illum = 81%	Hourly dRA = 1.021s
		dDec = -6.97"

Plot for Long +16 Lat +47





Occultation by TERCIDINA (2002-09-17)



Accuracy ?

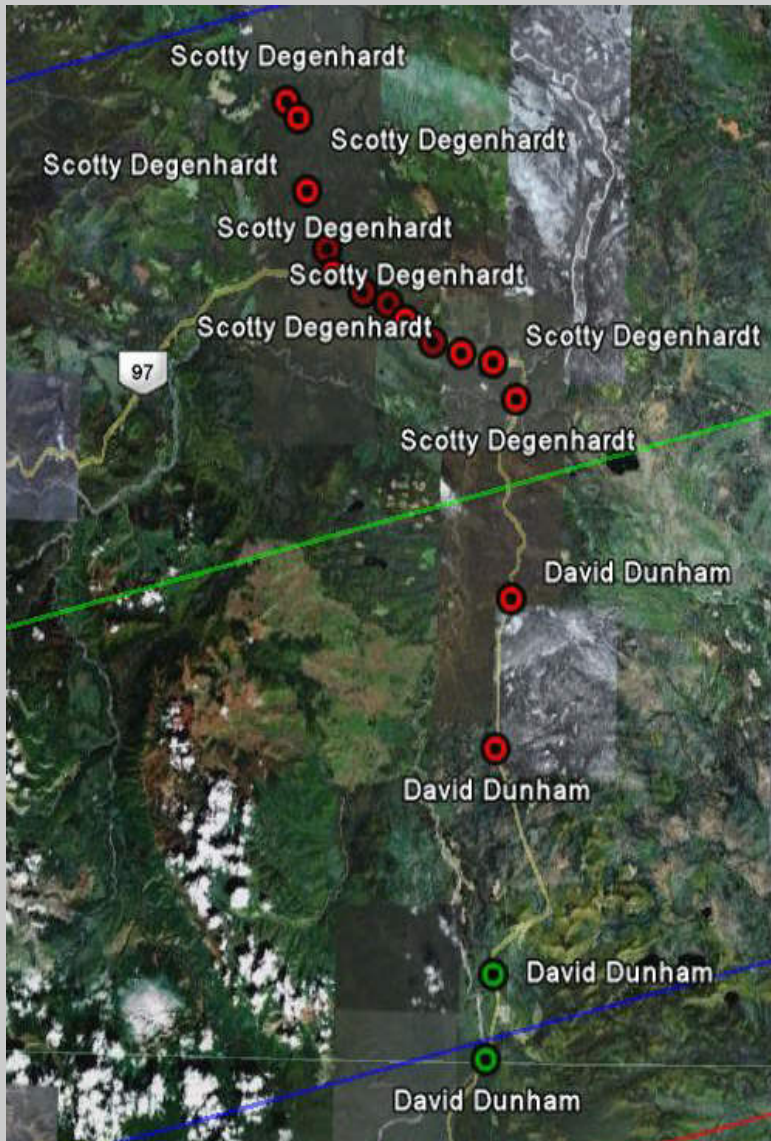
Occultation of HIP 19388
by (345) Tercidina
17 september 2002



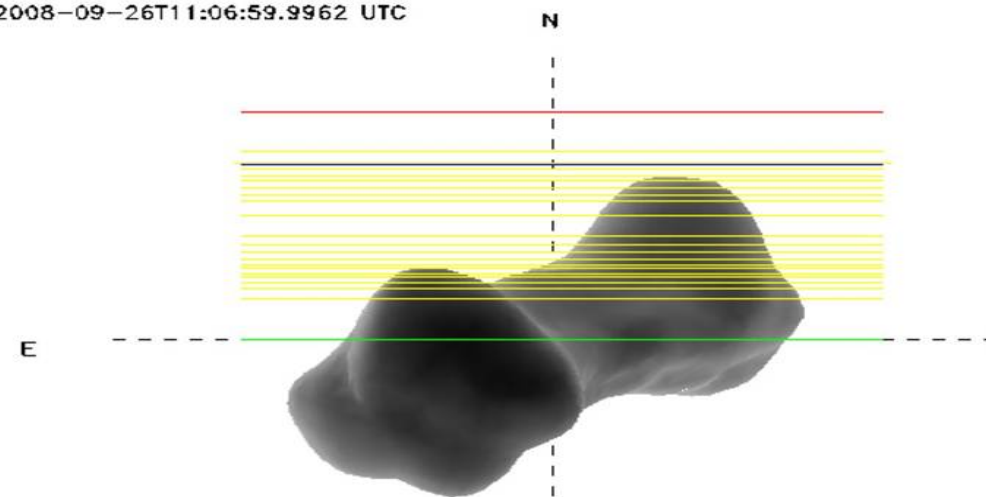
Apparent motion on the sky :
 $25.92''/h \Rightarrow 7.2 \text{ mas/s}$

Timing accuracy: $0.04s$

For tercidina $0.29 \text{ mas} \Rightarrow 350m$



2008-09-26T11:06:59.9962 UTC



KLEOPATRA

λ SEP= 30.8° β SEP= -12.2°

λ SSP= 39.5° β SSP= -15.5°

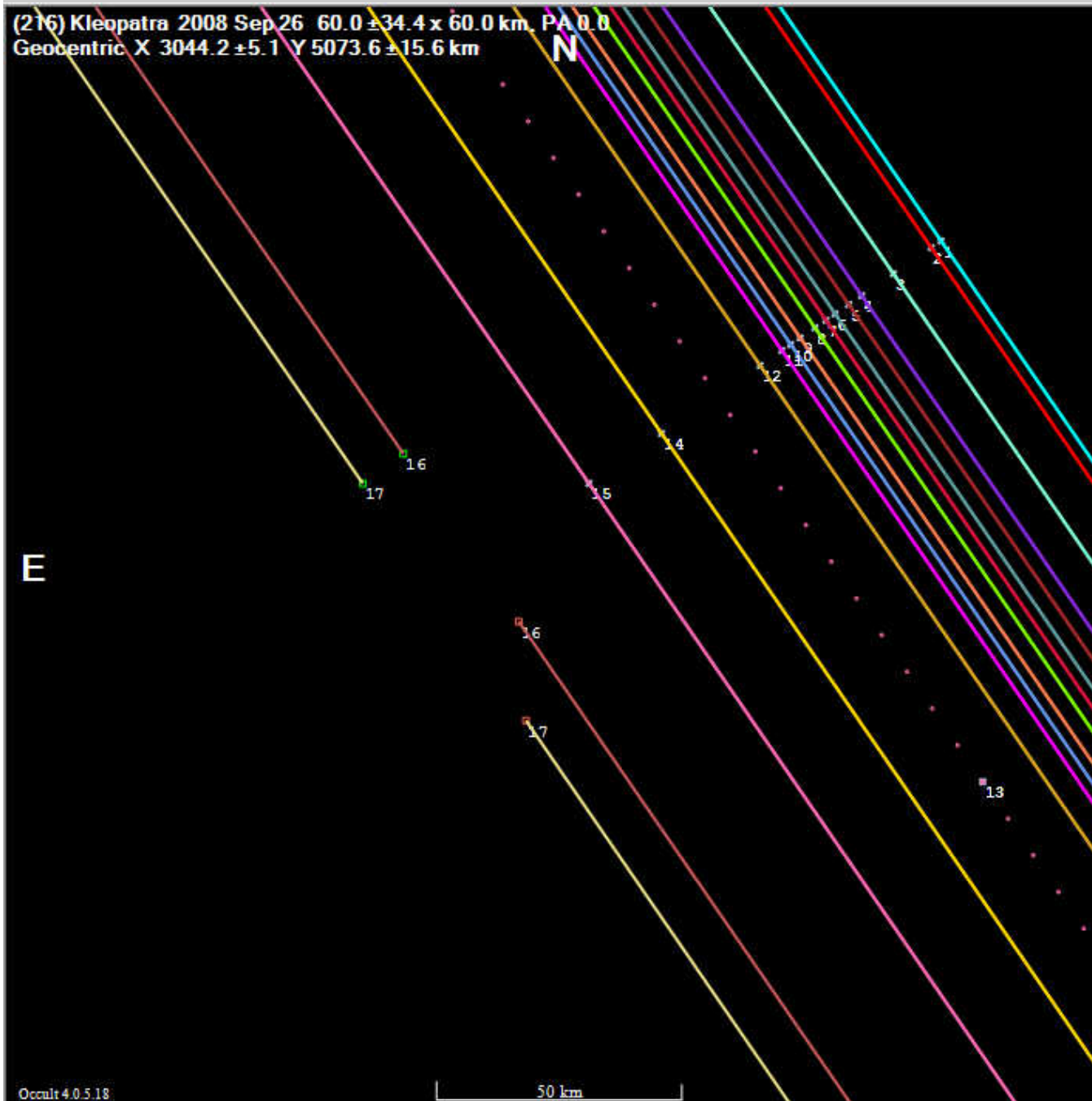
NP= 45.7°

56.98 km -63.48 mas

New observational strategy :

- good spatial resolution
- many small observatories
- bright occulted star
- go anywhere on Earth...

Résultat :-((((We need a good astrometry !! (1 mas at 2UA = 1.5km)



Find best fit

Center X -6.2
 Center Y -3.4

Major axis (km) 0.4 a/b=1.00
 Minor axis (km) 0.0 dM=0.00
 Orientation 0.0

Double star
 Sepn (masec) 0.0
 PA of 2nd 0.0

Both Primary Secondary

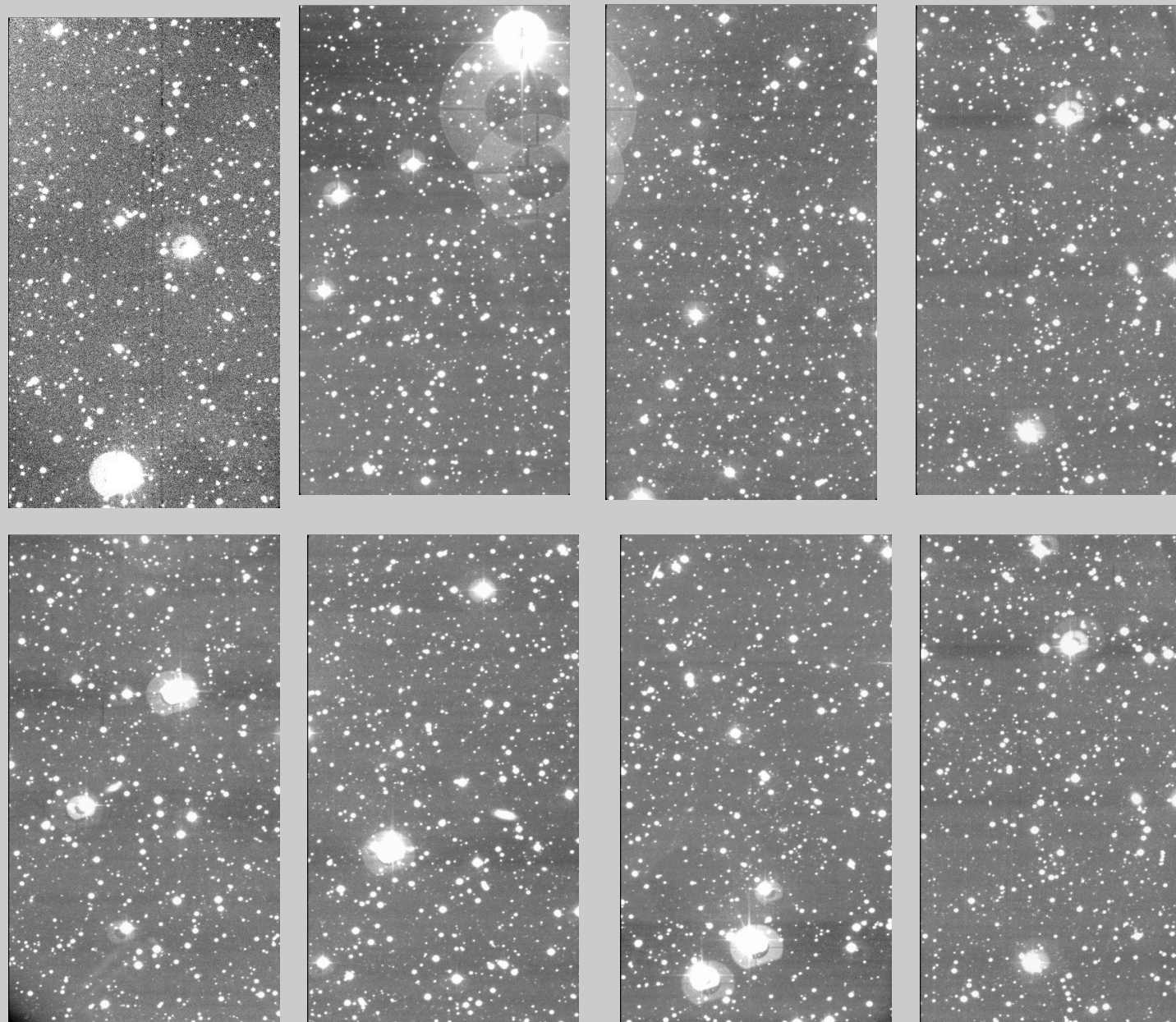
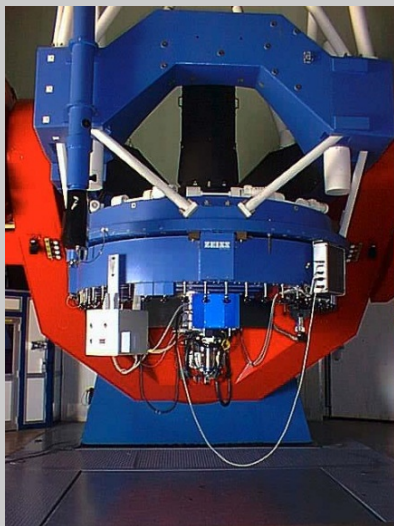
Circular Include Miss events

Plot scale Quality

RMS fit 5.4 ± 7.3 km

—	1 (M)	S Degenhardt, Fort Ne
—	2 (M)	S Degenhardt, Fort Ne
—	3 (M)	S Degenhardt, Fort Ne
—	4 (M)	S Degenhardt, Fort Ne
—	5 (M)	S Degenhardt, Fort Ne
—	6 (M)	S Degenhardt, Fort Ne
—	7 (M)	S Degenhardt, Fort Ne
—	8 (M)	S Degenhardt, Fort Ne
—	9 (M)	S Degenhardt, Fort Ne
—	10 (M)	S Degenhardt, Fort Ne
—	11 (M)	S Degenhardt, Fort Ne
—	12 (M)	S Degenhardt, Fort Ne
—	13 (P)	Predicted Centerline
—	14 (M)	D Dunham, Muskwa, BC,
—	15 (M)	D Dunham, Muskwa, BC,
—	16	D Dunham, Prophet Riv
—	17	D Dunham, Prophet Riv

ESO 2.2m/WFI CCD mosaic de 30'x30'



1 CCD: 7.5'x15'
(2048x4096px)

1 pixel: 238mas

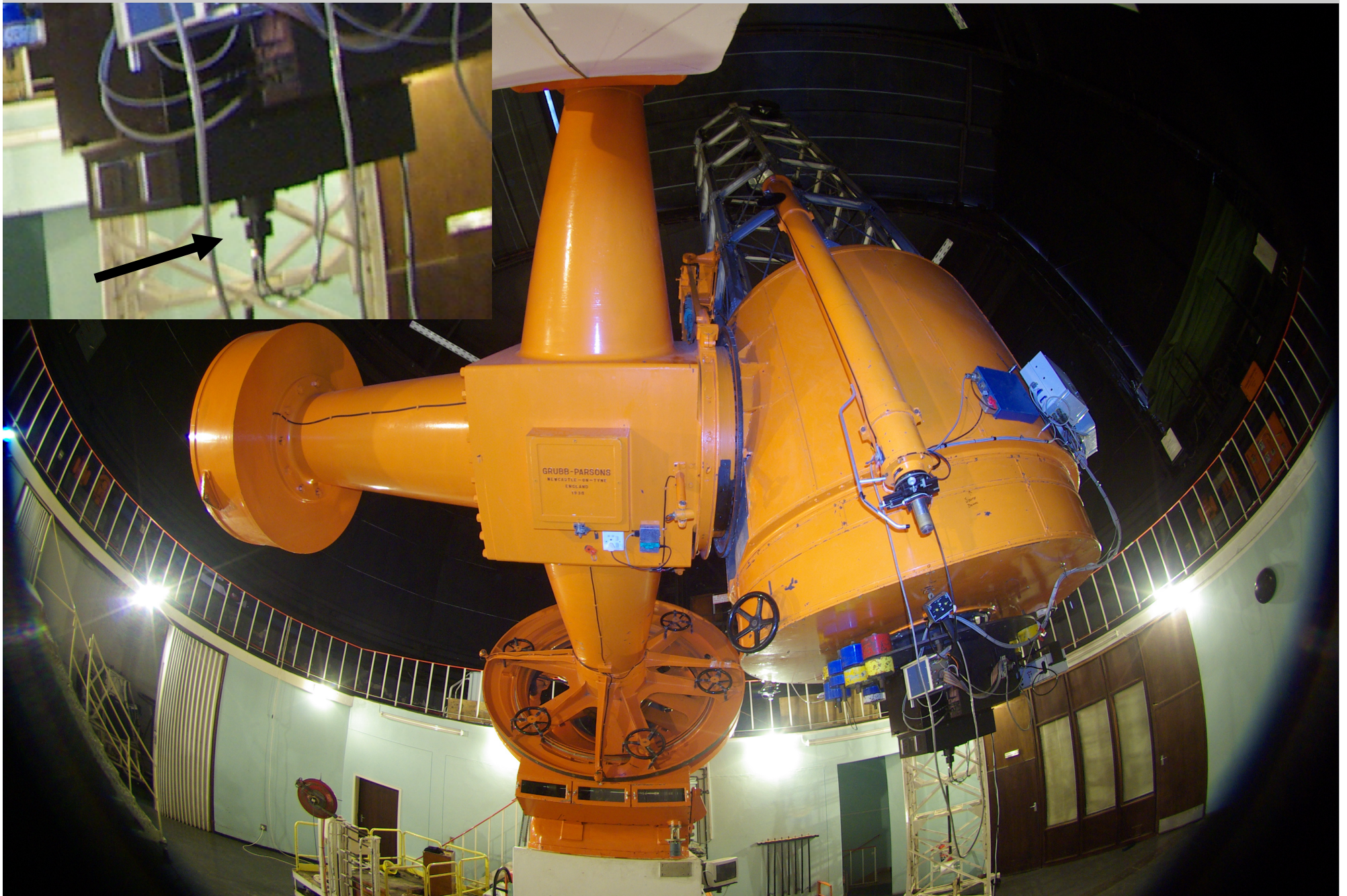
800 WFI mosaics

6000 CCD frames

216 GB FITS

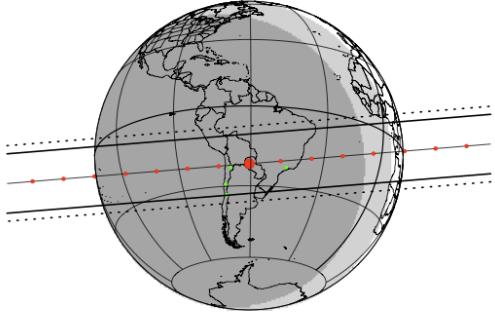
→ PRAIA

T 193 – Sutherland RSA – Pluto Occultation – june 2008



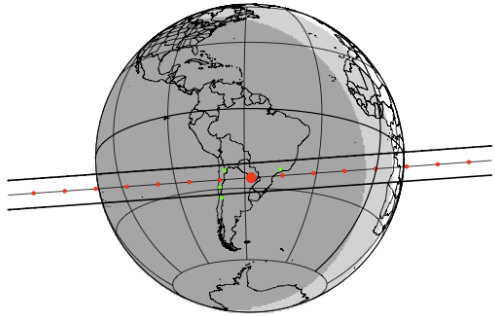
Pluto Charon

Charon: offset post-occ/DE413, star MA 10nov09 Offset (mas): -8.6 161.1



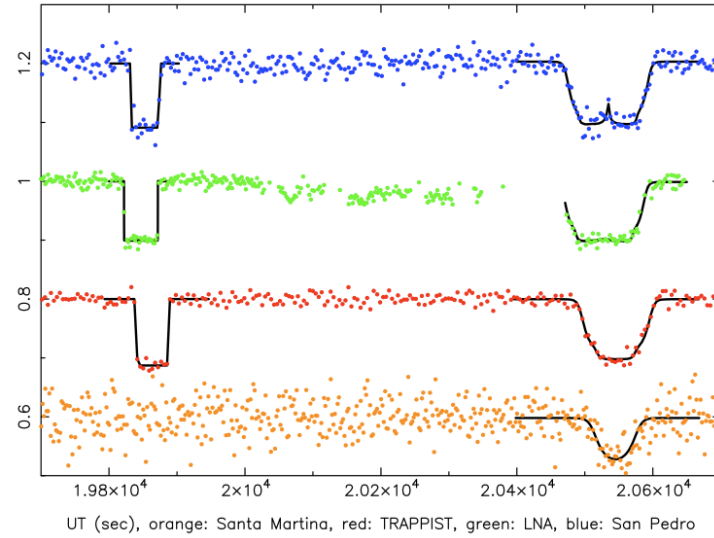
d	m	year	h:m:s UT	ra__dec__J2000_candidate	C/A	P/A	vel	Delta R*	K*	long
04	06	2011	05 41 38.	18 27 53.8249 -18 45 30.725	0.015	175.34	-21.44	31.11	16.6	50.0 -61.

Charon: offset post-occ/DE413, star MA 10nov09 Offset (mas): -8.6 161.1

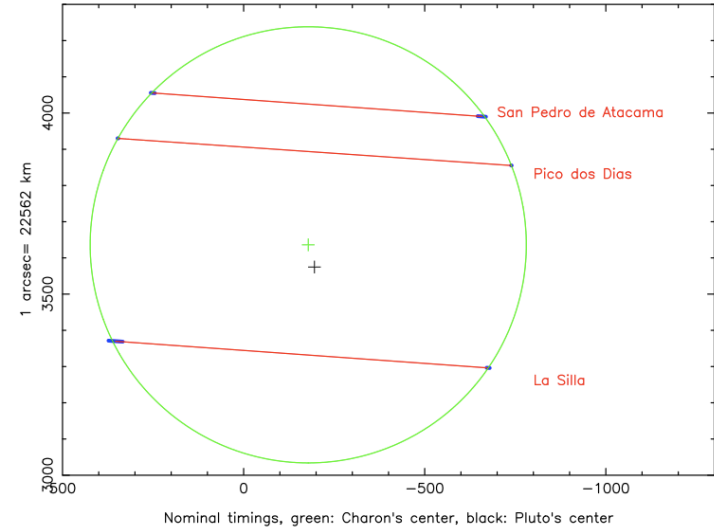


d	m	year	h:m:s UT	ra__dec__J2000_candidate	C/A	P/A	vel	Delta R*	K*	long
04	06	2011	05 30 2.	18 27 53.8249 -18 45 30.725	0.036	175.90	-21.48	31.11	16.6	50.0 -58.

Pluto/Charon 4 June 2011, NB. LNA + 100 SEC binned 2 sec



Charon, 04 June 2011, R=602.0 +/- 1.6 km, offset: -178.40475 km, 3636.0999 km



Setting up a mighty mini at my station #5 in Newman, Calif.



Atacama desert



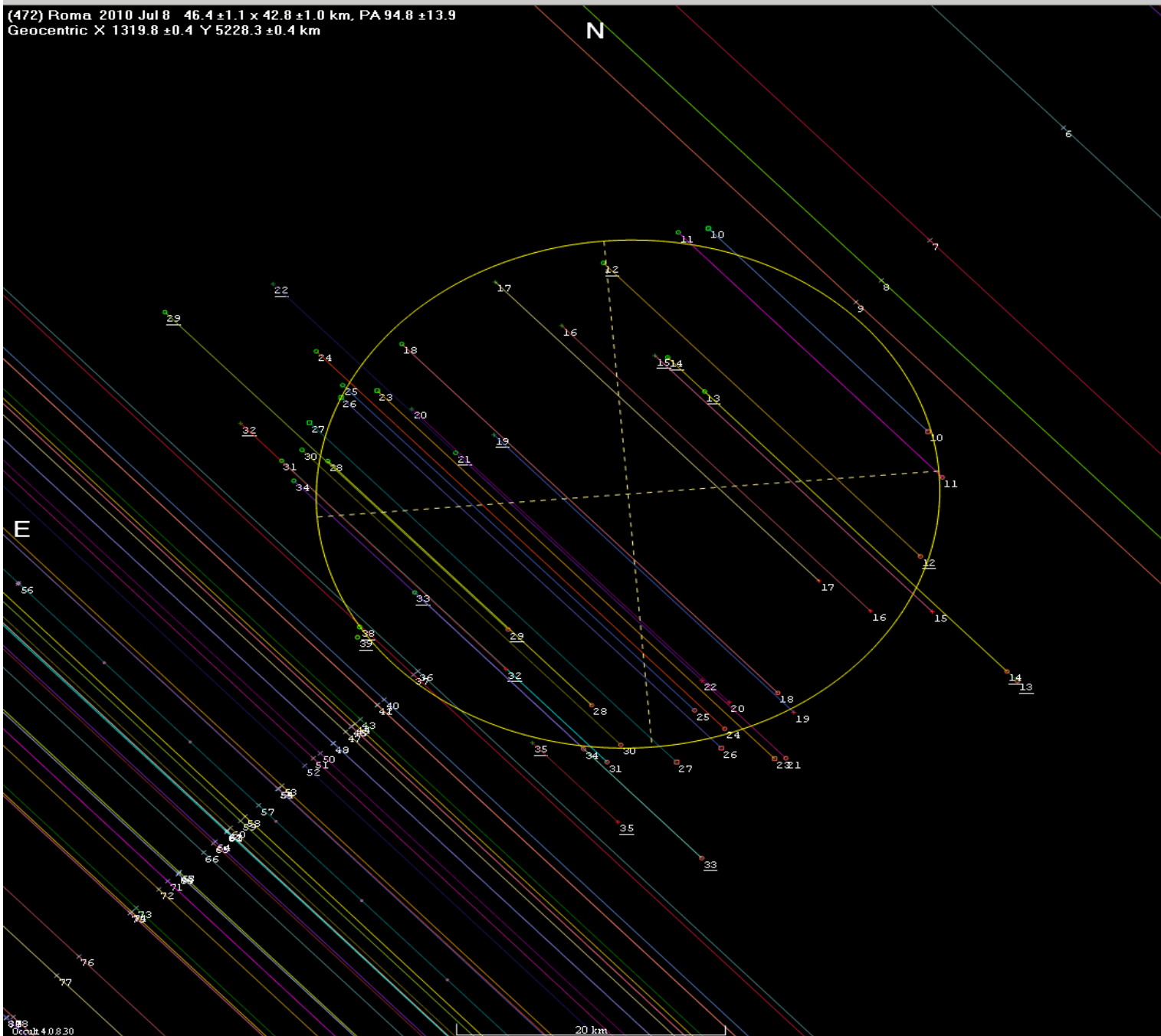
Small size
observatory !



Timing problems

(472) Roma – 2011 July 8th

(472) Roma 2010 Jul 8 46.4 ± 1.1 × 42.8 ± 1.0 km, PA 94.8 ± 13.9
Geocentric X 1319.8 ± 0.4 Y 5228.3 ± 0.4 km



Find best fit

Center X: 101.8 0.0
Center Y: 98.7 0.0

Major axis (km): 46.4 0.0
Minor axis (km): 42.8 0.0
Orientation: 94.8 0.0

Double star
Sepn (masec): 0.0 0.0
PA of 2nd: 0.0 0.0

Both Primary Secondary

Circular Include Miss events

Plot scale: Quality: Not fitted

RMS fit -0.5 ± 2.5 km

1 (M)	Georg Comello, NL
2 (M)	Peter Bus, NL
3 (M)	Erwin Van Ballegoij, NL
4 (M)	Felix Bettonvil, ES
5 (M)	Henk De Groot, NL
6 (M)	Alfons Diepvens, BE
7 (M)	Willem Kivits, NL
8 (M)	Guy Madore, FR
9 (M)	M Senegas/C Souplet, FR
10	Gido Weselowski, DE
11	Marcus Ettling, DE
12	Reimer Asmus, DE
13	Guenther Strauch, DE
14	Christian Overhaus, DE
15	Sébastien Francq, BE
16	Hendrik Hollander, BE
17	Peter Van Den Eijnde, BE
18	Ralf Schoenfeld, DE
19	Hartmut Sittel, DE
20	Rene Bourtenbourg, BE
21	Wolfhard Merten, DE
22	Dieter Wichura, DE
23	Detlef Koschny, DE
24	Philippe Demoulin, BE
25	Jean Bourgeois, BE
26	A Leroy/R Palmade/G Canau
27	Jan Manek, BE
28	Rainer Sparenberg, DE
29	Christian Jeschek, DE
30	Wolfgang Strickling, DE
31	Antonius Recker, DE
32	Henk Bulder, DE
33	Dieter Hess, DE
34	Roland Plaschke, DE
35	Frank Slotosch, DE
36 (M)	Walter Ruetten, DE
37 (M)	Juergen Brunek, DE
38	Otta Sandor, BE
39	F Stark/B Junkermann/R Ha
40 (M)	Thomas Hebbeker, BE
41 (M)	Rolf Gessner, DE
42 (M)	Rolf Gessner, DE
43 (M)	Siegfried Peterseim, DE
44 (M)	Thomas Payer, DE
45 (M)	Robert Gieseke, DE
46 (M)	Andre Wulff, DE
47 (M)	Bernd Brinkmann, DE
48 (M)	Denis Galli, FR
49 (M)	Alain Figer, FR
50 (M)	G. Wortmann/S. Hein, DE
51 (M)	Maik Petersdorf, DE
52 (M)	Jurgen Goldan, DE
53 (M)	F. Feger/H. Bill, DE
54 (M)	O Dechambre/B Christophe,
55 (M)	Pawel Maksym, DE
56 (P)	Steve Preston predicted c
57 (M)	Michael Zimmermann, DE
58 (M)	Walther Meckstroth, DE
59 (M)	F. Van Den Abbeel, BE
60 (M)	A. Goerigk, DE

Video Observatory

Caméra basse lumière
(2046XAI pour le test)

Garmin GPS16 HVS (1PPS)

Incrustateur vidéo
(blackboxcamera)

Enregistreur numérique miniDV
(camescope Canon MV600i)

TEST INCRUSTATION VIDEO HEURE GPS 1PPS POUR MANIP OCCULTATION TITAN (LA REUNION - NOVEMBRE 2003)

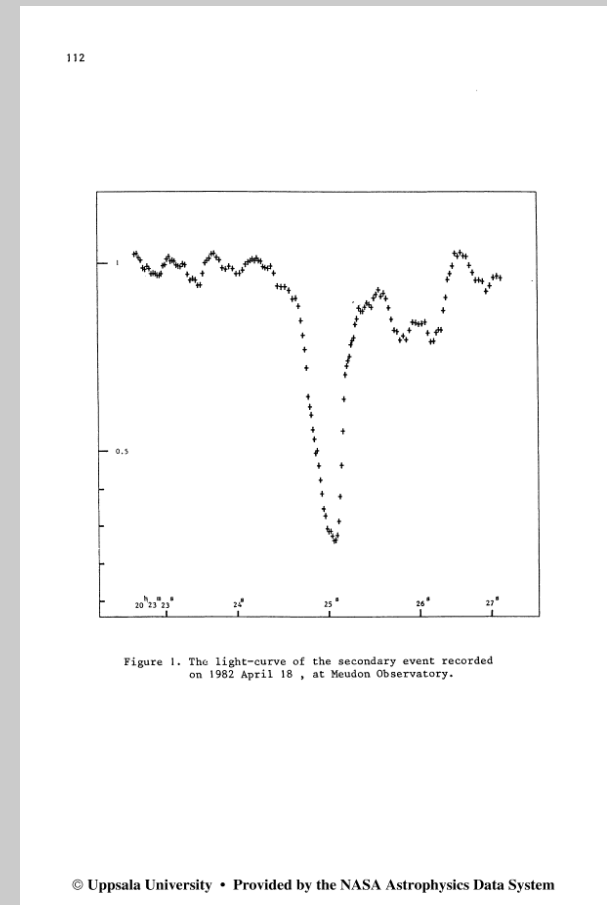
Occultations of binary Asteroids



(532) Herculina	1978
(216) Kleopatra	1980
(146) Lucina	1982
(71) Niobe	2005
(22) Kalliope	2006
(90) Antiope	2008
(216) Kleopatra	2009
(234) Barbara	2010

Et bien sur :

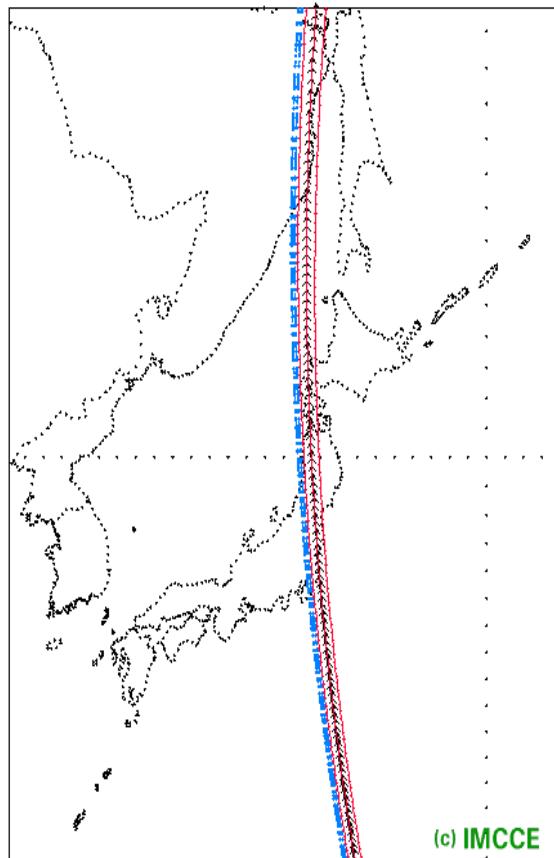
(134340) Pluto - Charon



Kalioppe

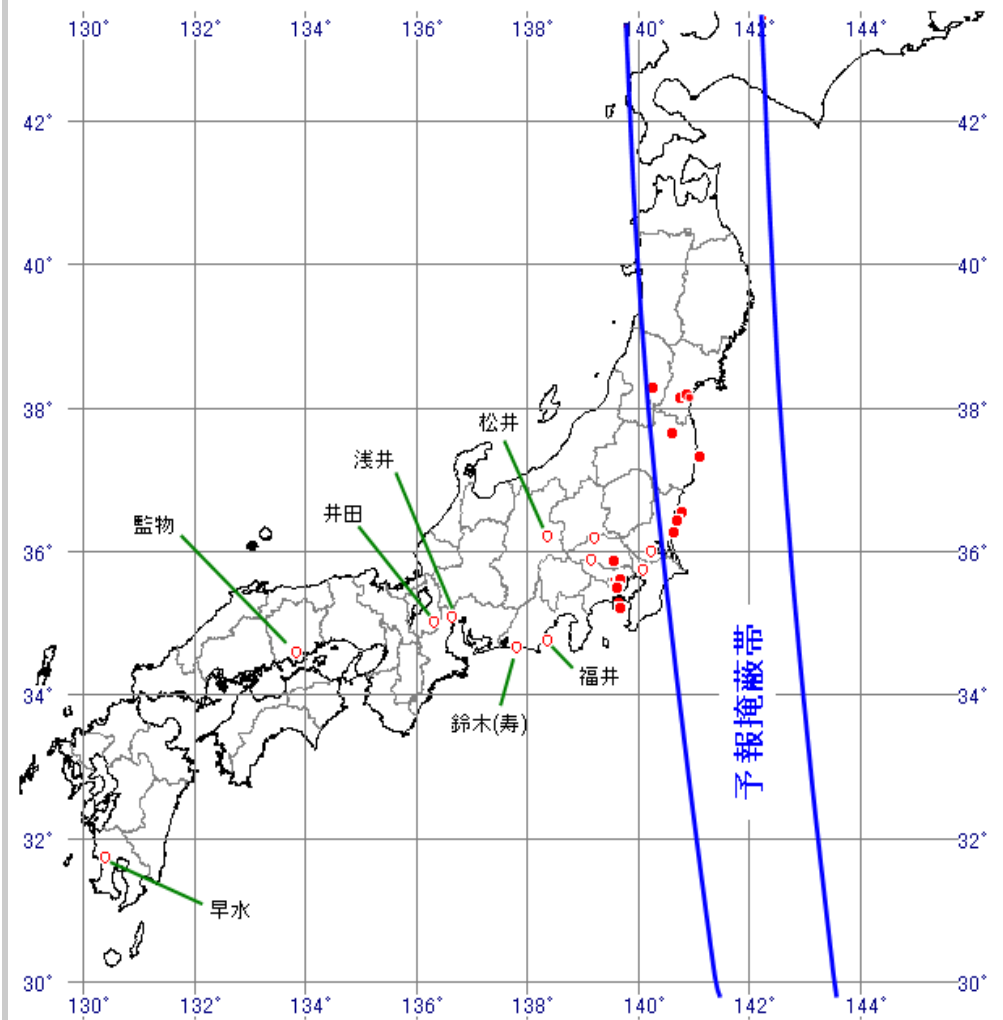
Occ. TY2 188601206 / 22 Kalioppe

KALLIOPE
LINUS

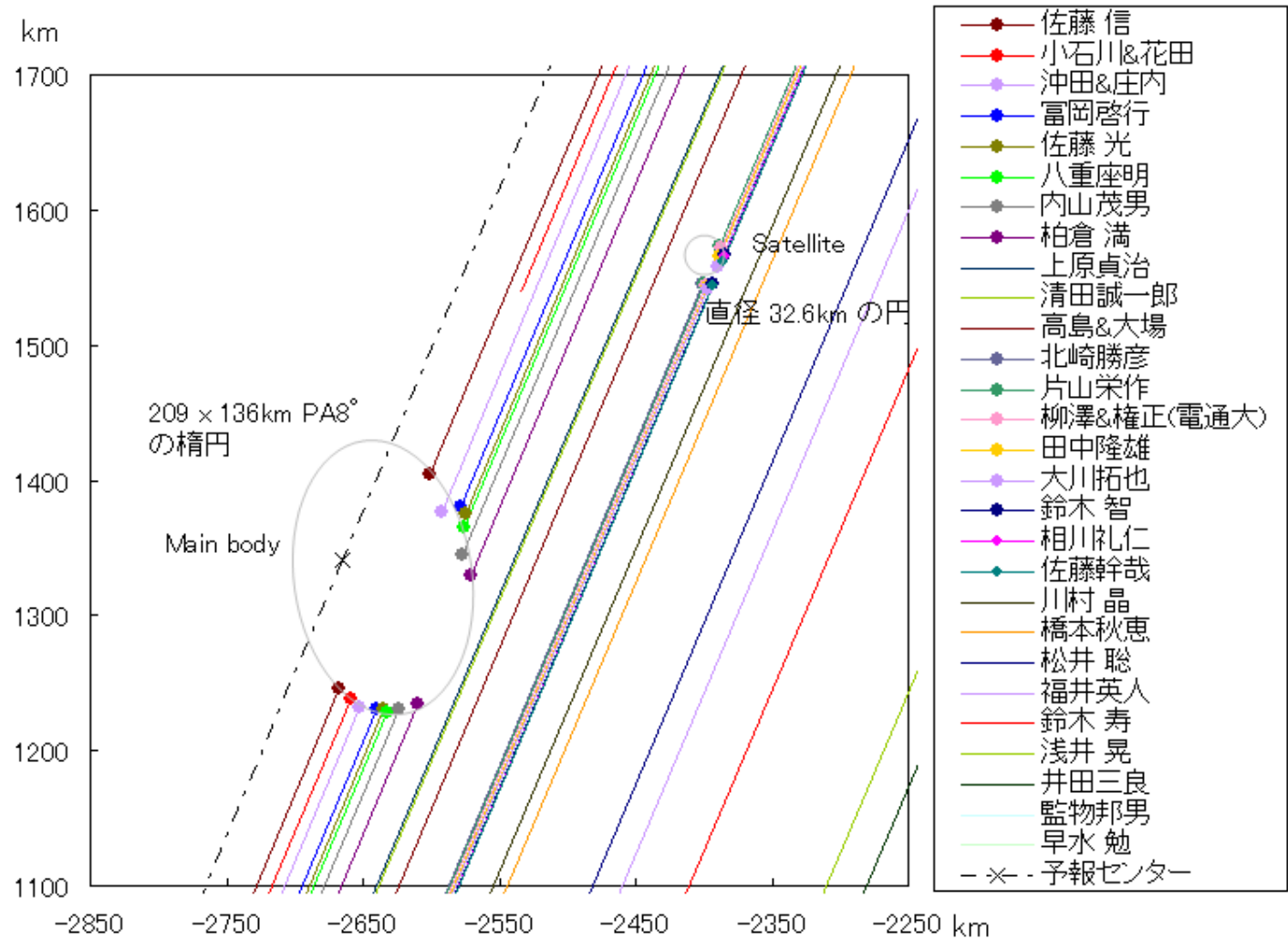


7-11-2006

19^h 33^m 30^s - 20^h 4^m 50^s ; inter. = 5.00 sec.

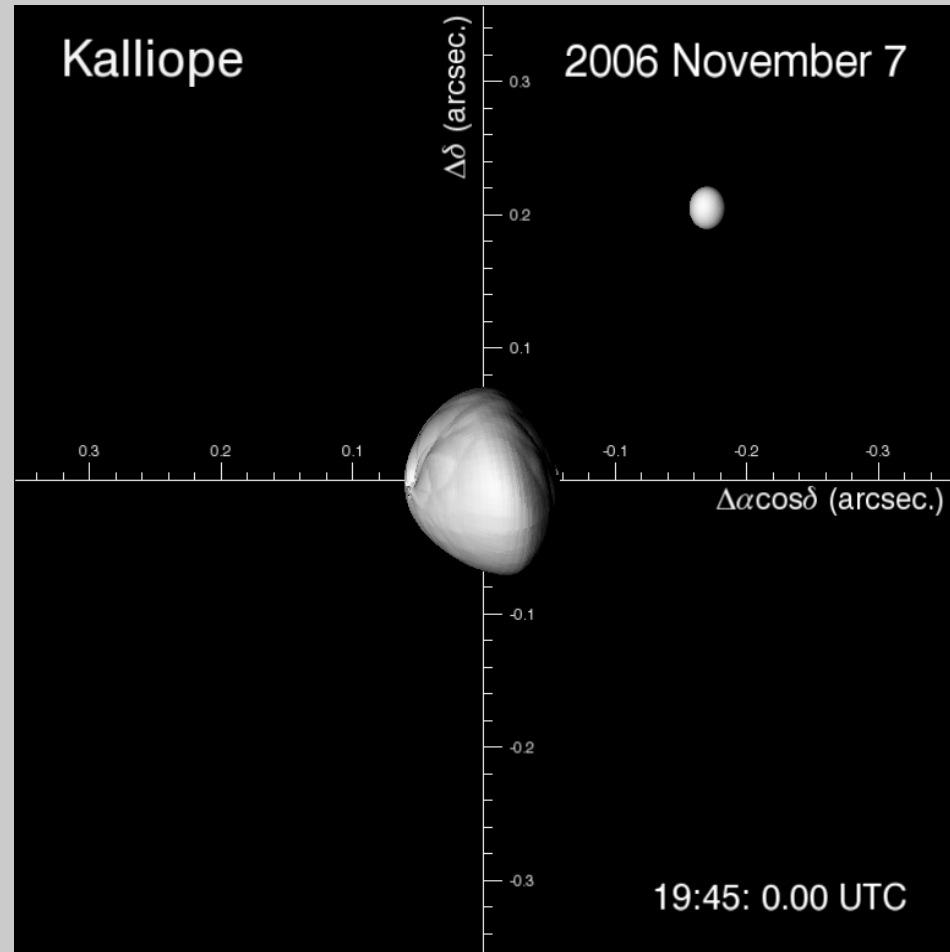
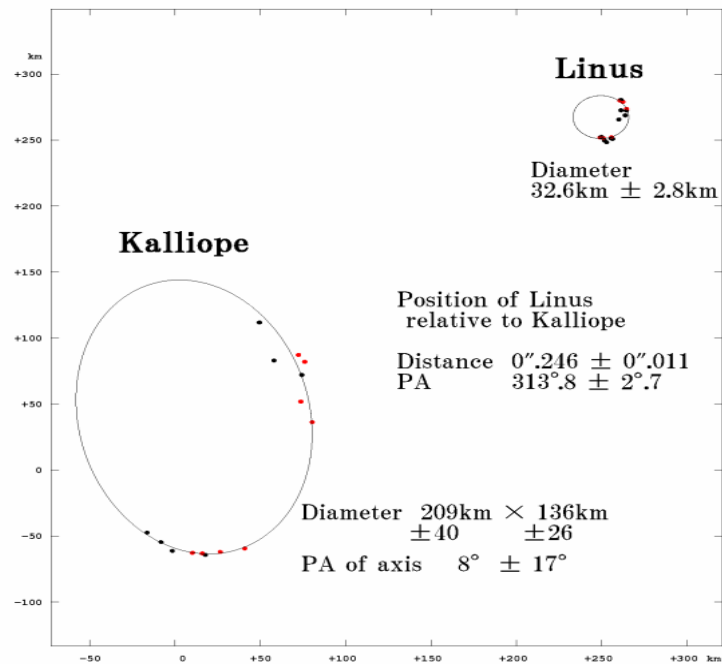


(22)Kalliope & Linus on 2006.11.08



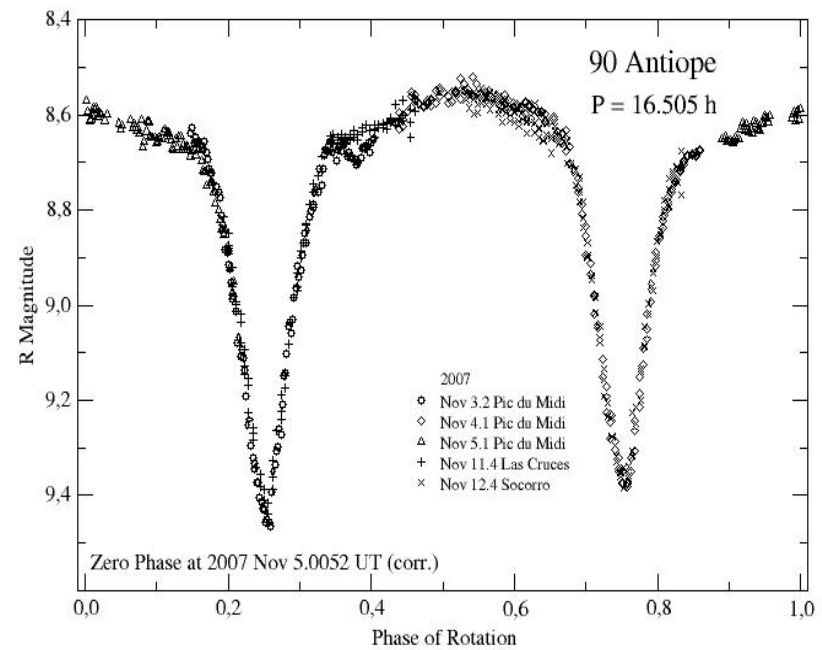
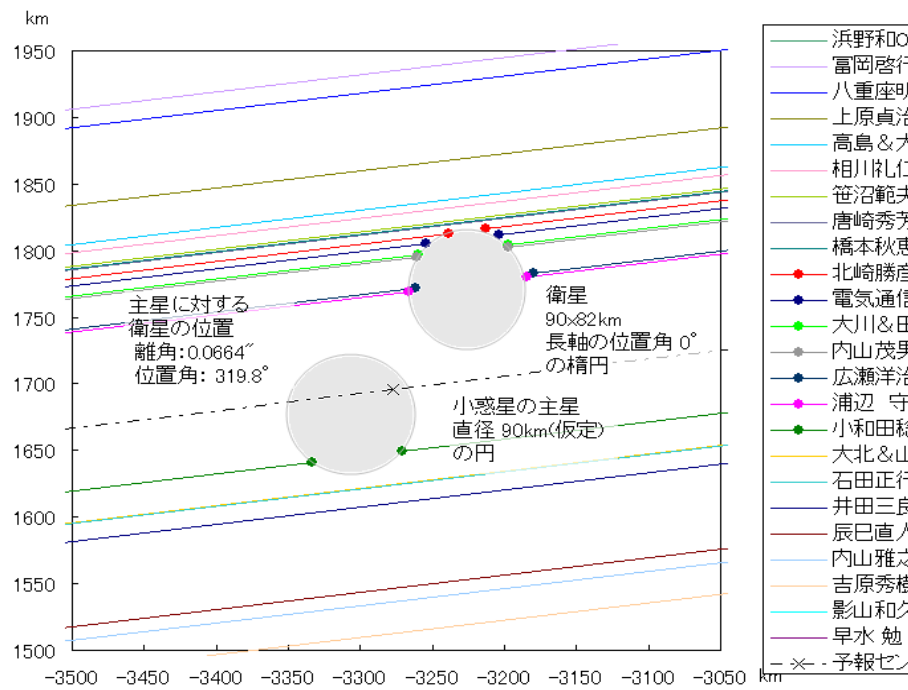
Observations

Occultation by (22) Kalliope and Linus



Antiope occultation

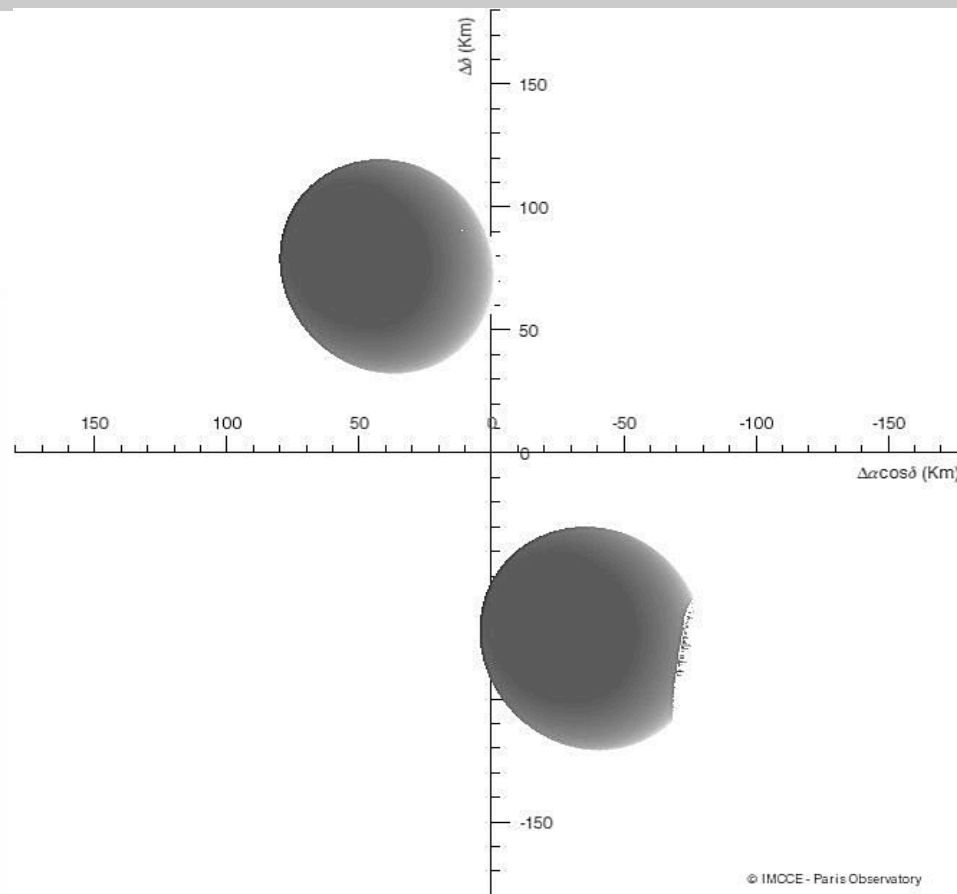
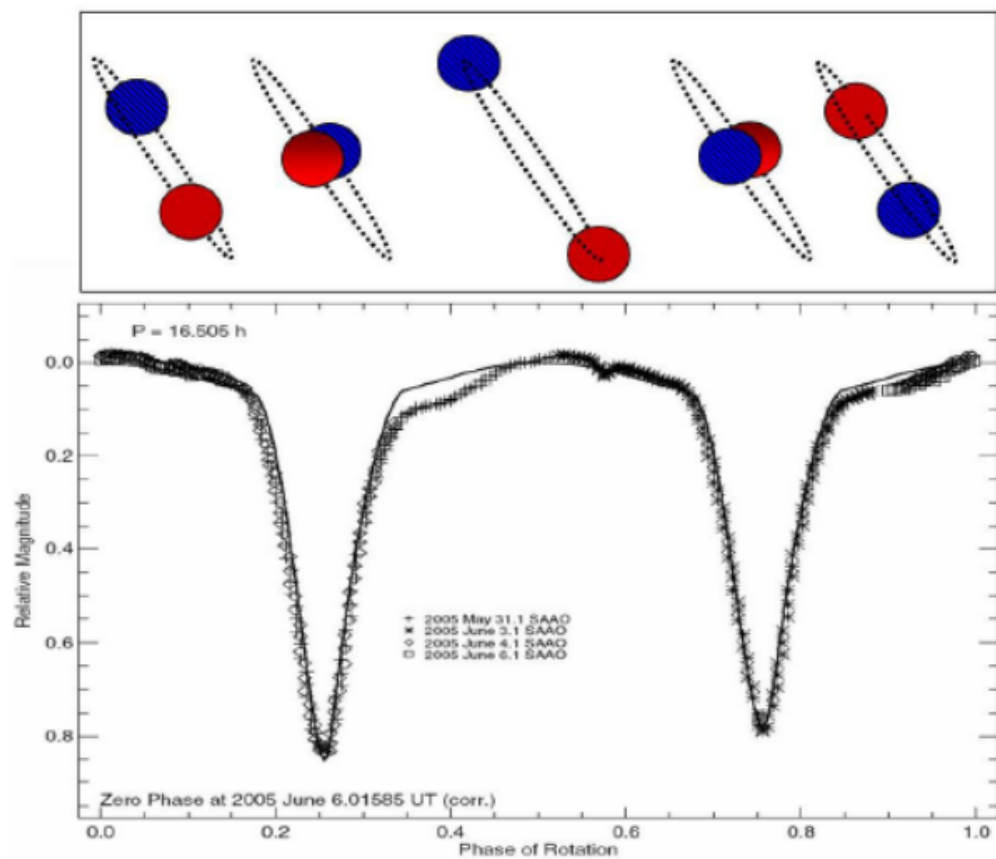
(90)Antiope on 2008.1.3



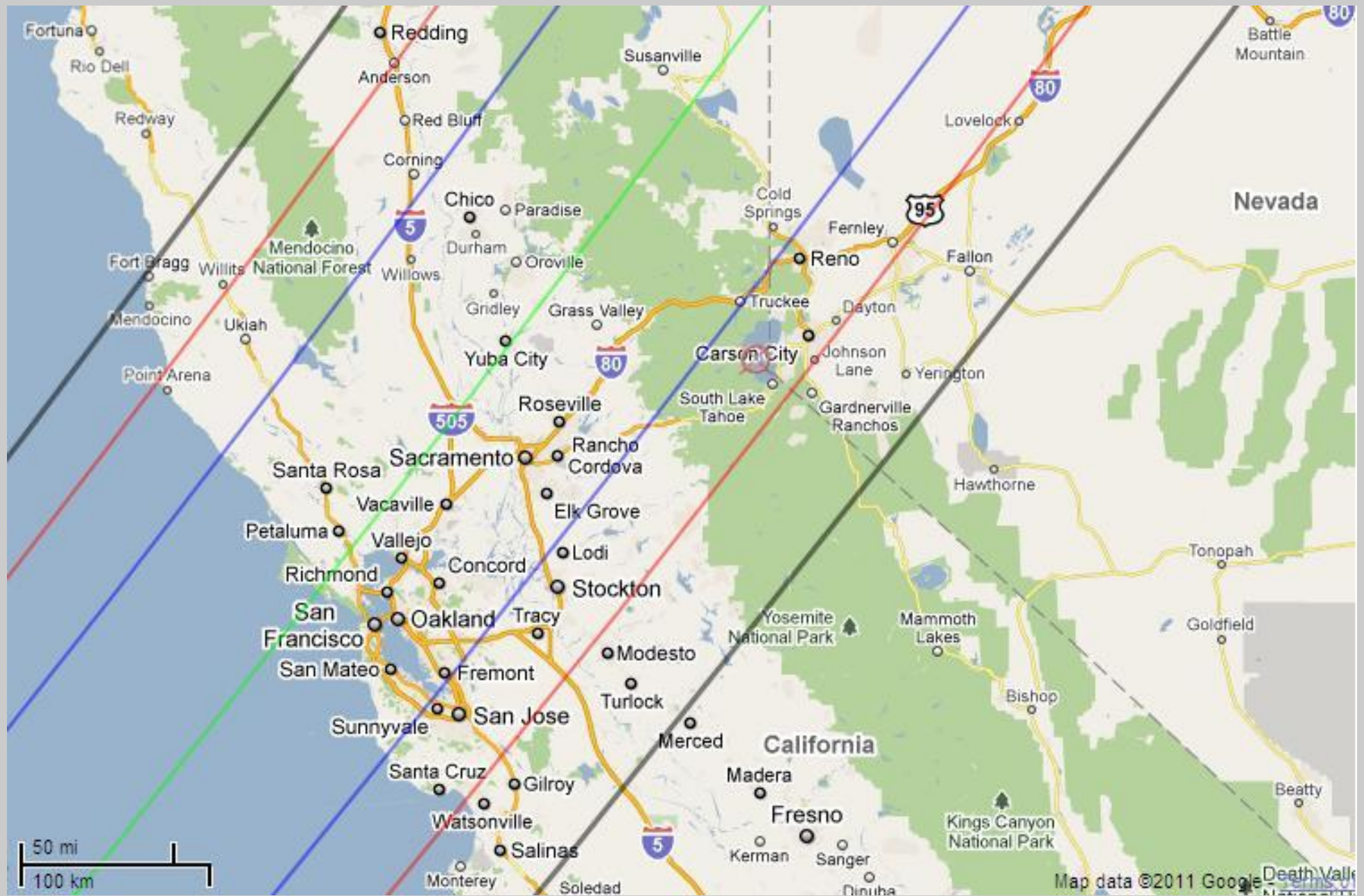
Occultations

Light curves

Antiope occultation – 2011 July 19th



The path over northern Calif. & Nevada



90 Antiope occults HIP 112420 on 2011 Jul 19 from 10h 10m to 11h 5m UT

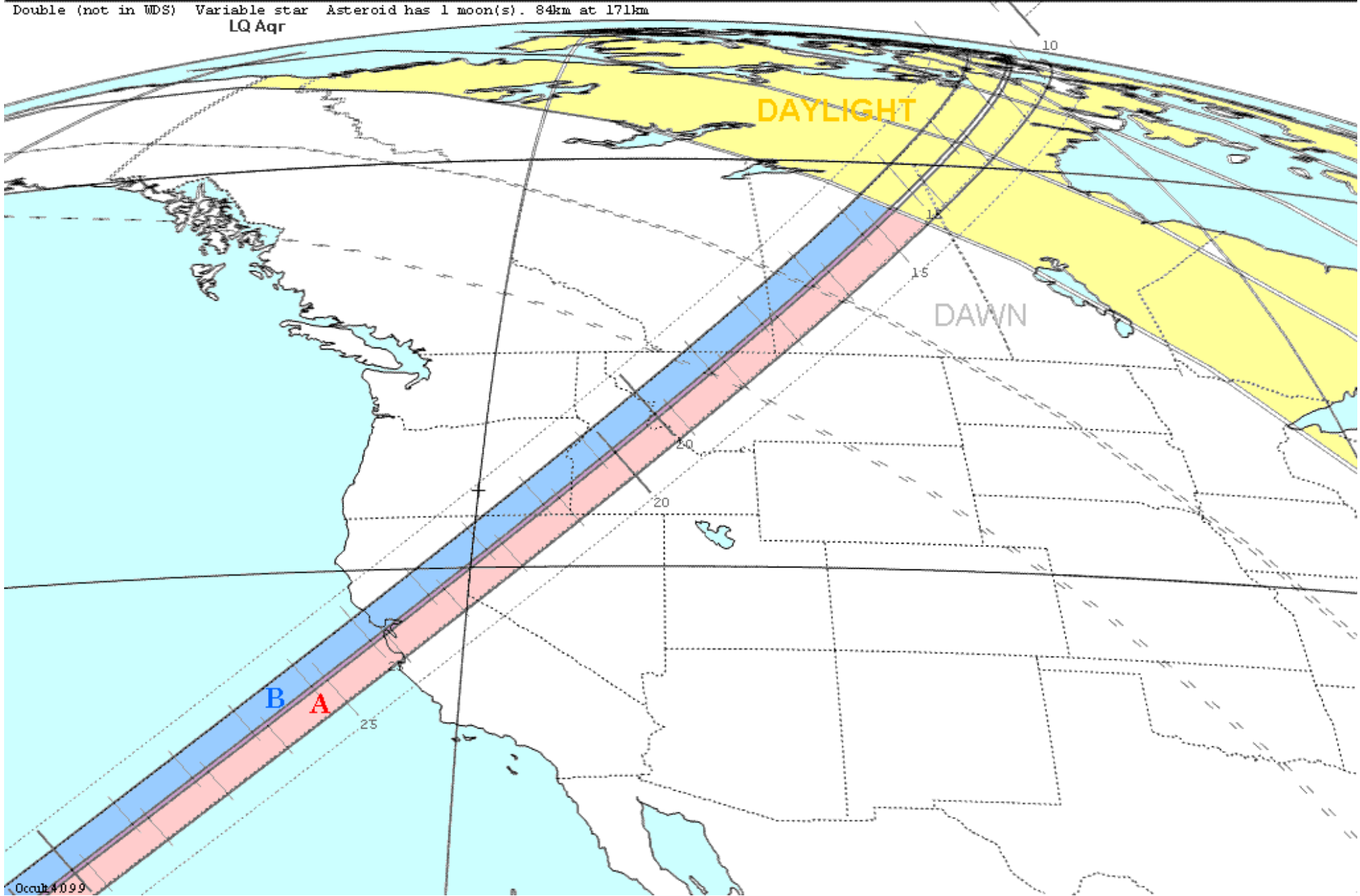
Star:
Mv = 6.7 Mp = 8.3 Mr = 5.8
RA = 22 46 14.213 (J2000)
Dec = -11 9 59.06
[of Date: 22 46 53, -11 6 6]
Prediction of 2010 Sep 30.0

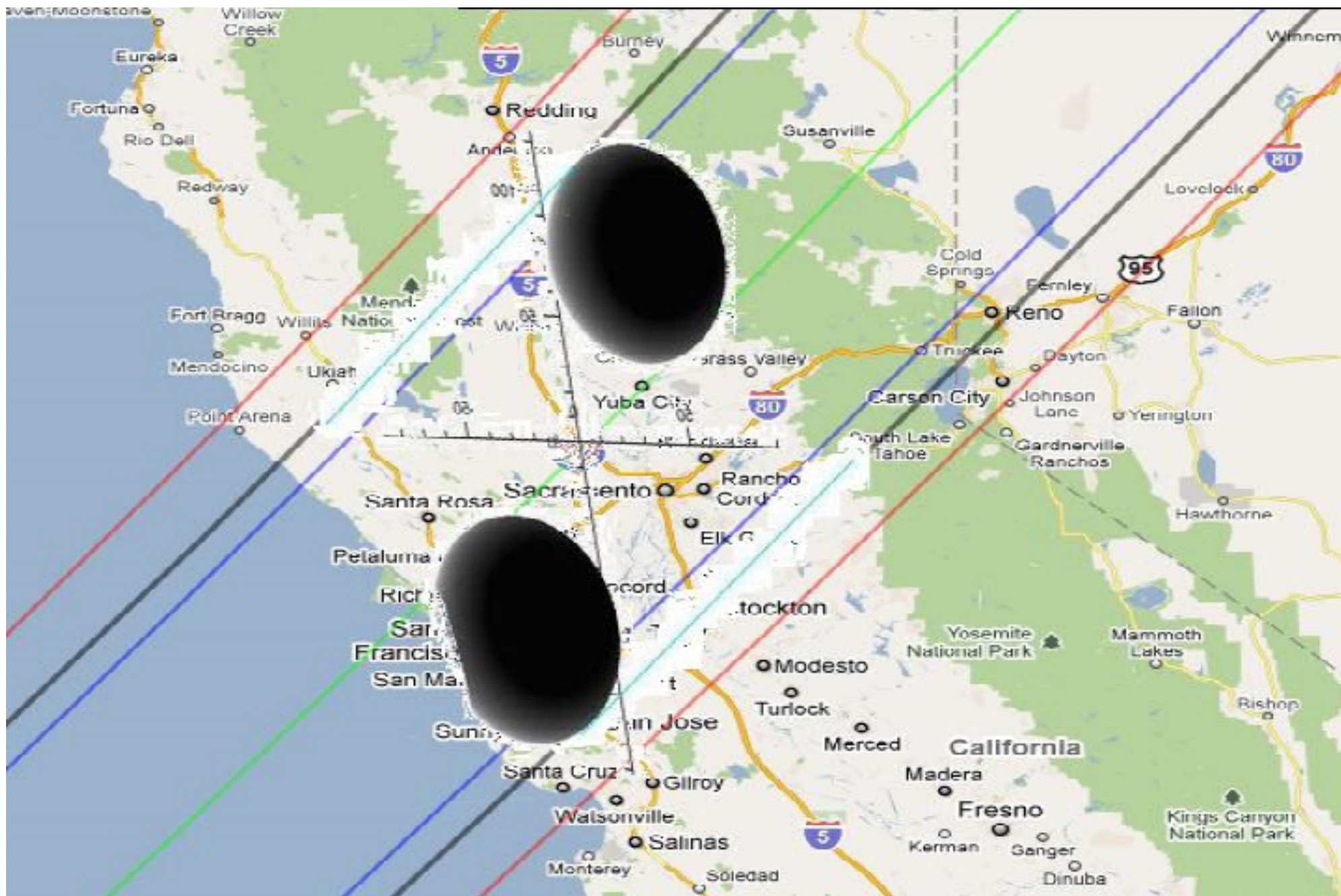
M1 III star

Max Duration = 26.7 & 25.4 secs
Mag Drop = 5.8 (6.2r)
Sun : Dist = 138 deg
Moon: Dist = 10 deg secs
: illum = 83 %
E 0.050"x 0.050" in PA 90

Asteroid:
Mag = 12.5
Dia = 88 & 84 km, 66 & 63 mas
Parallax = 4.811"
Hourly dRA = -0.421s
dDec = -5.47"

Double (not in WDS) Variable star Asteroid has 1 moon(s). 84km at 171km
LQ Aqr





(90) Antiope occultation, July 20

IOTA meeting at Sierra College, Rocklin, CA





(90) Antiope 2011 Jul 15 15:08:13 UT

Keck AO Kp-band, exp 3 sec

rotation sense is CCW

31 min plus 5.5 cycles prior to occultation

Merline, Neyman, Tamblyn, et al.

PA 189 deg, projected separation 146 km

0 2000 4000 6000 8000 10000 12000 14000 16000

(90) Antiope occultation, july 20

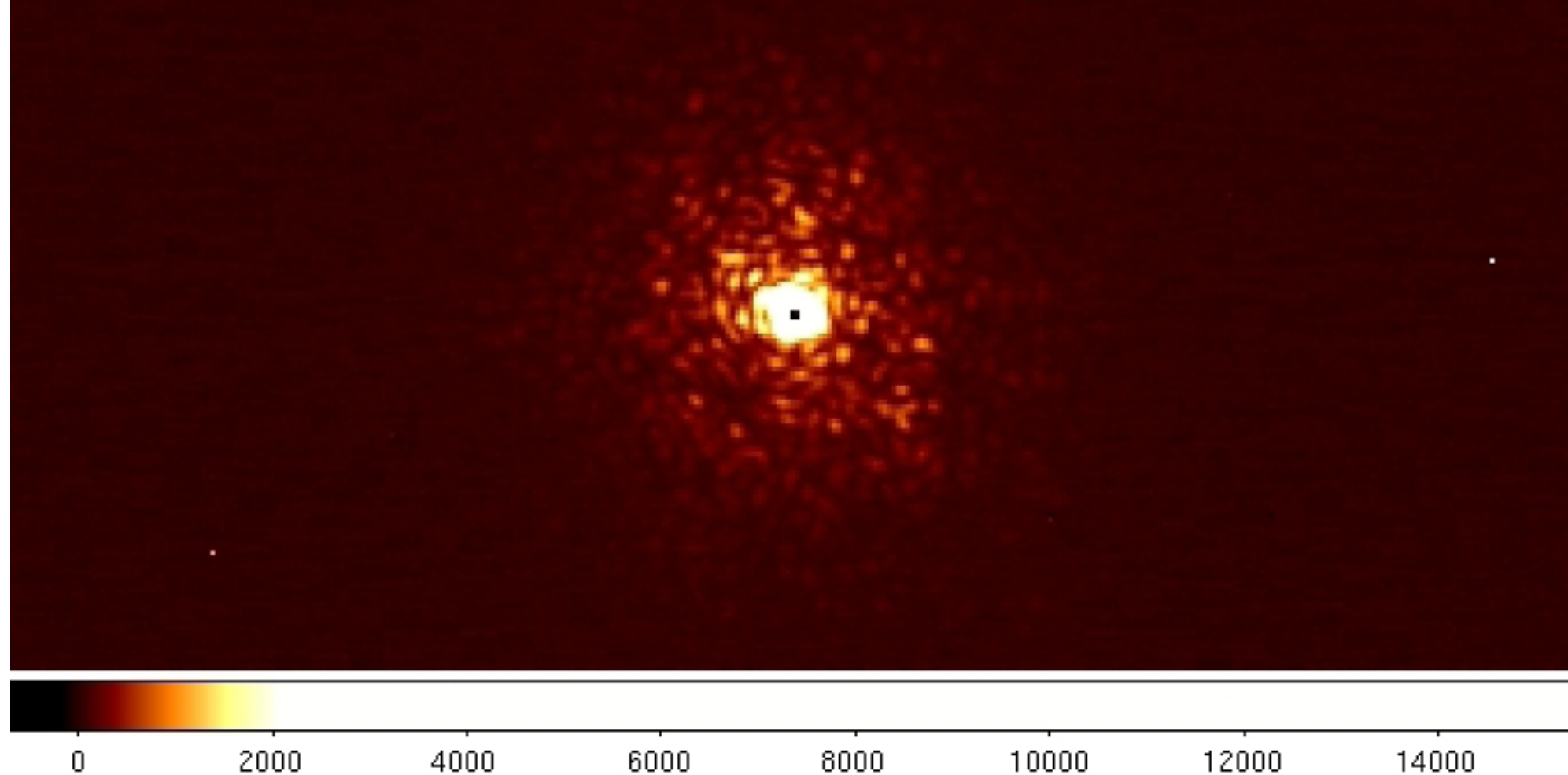
SAO165285, Antiope Occultation Star for 7/19/2011

Keck AO 2011 Jul 15 UT J-cont band, exp 50ms

Field Width as shown = 2.5 arcsec

Merline, Neyman, Tamblyn, et al.

No evidence of duplicity at level 0.1 arcsec, < 3mag



Setting up a mighty mini at my station #5 in Newman, Calif.



(90) Antiope 2011 Jul 19 92.7 ± 243.5 × 79.0 ± 400.3 km, PA 6.3 ± 1511.1
Geocentric X -140.2 ± 190.0 Y 5435.1 ± 128.1 km

N

E

OSCAR 4.1.9.30

50 km

Find best fit

Center X 48.1 487.4
 Center Y 57.4 148.4

Major axis (km) 92.7 100 alt 1.7 / eM=0.17
Minor axis (km) 79.0 00
Orientation -6.3 -0

Double star
Sept. (massec) 0.0 0.0
FA of 2nd 0.0 0.0

Equi Elliptic Secondary

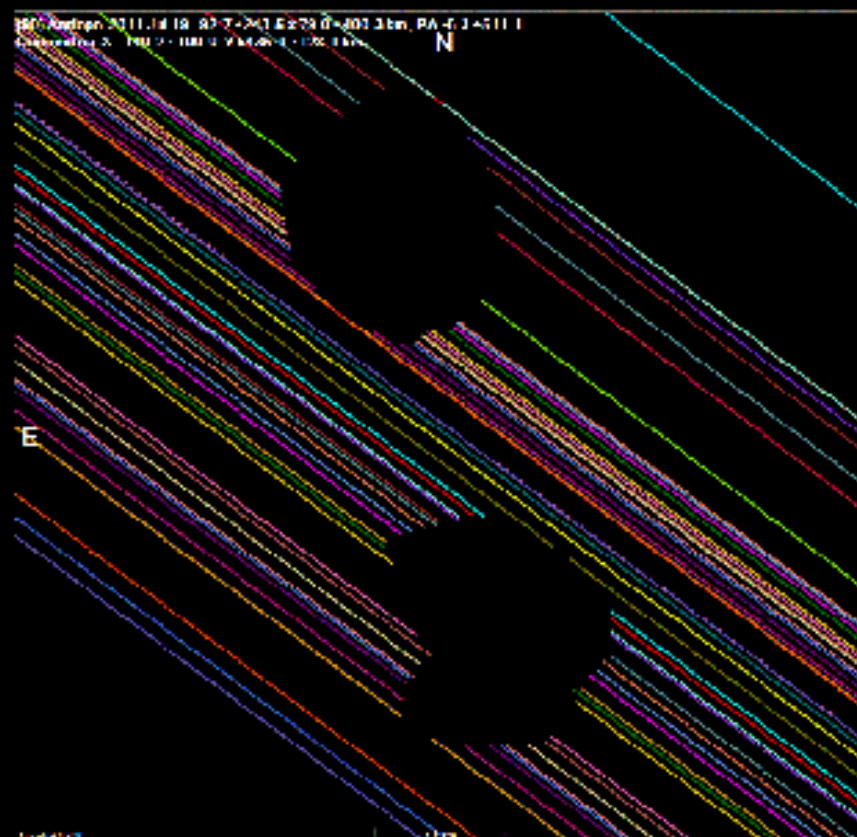
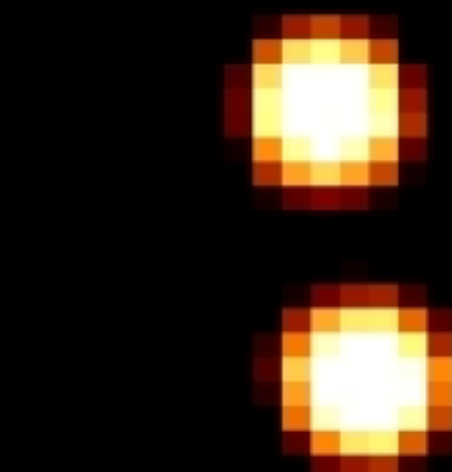
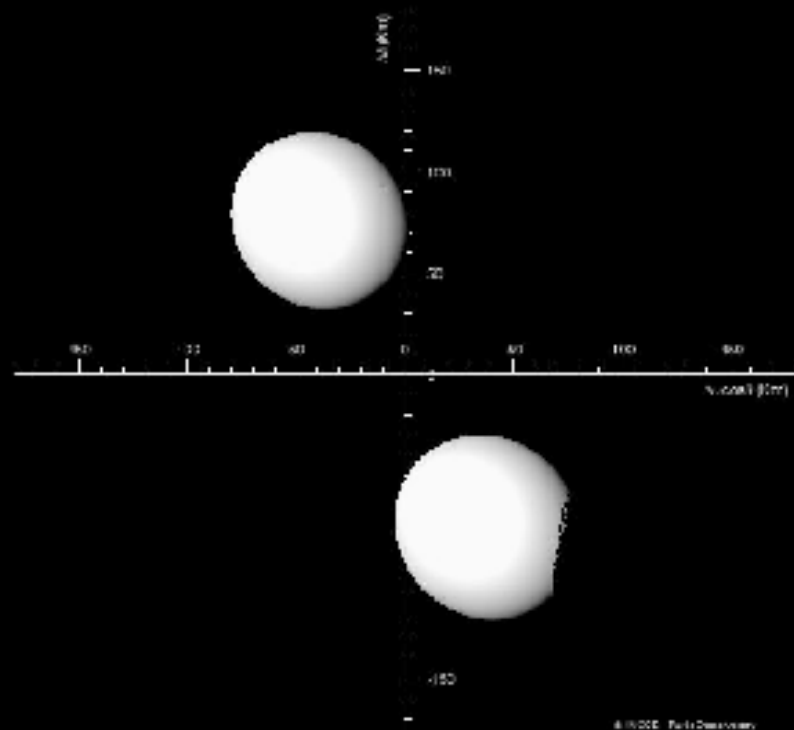
Circular Include Miss events

Plot scale Quality Not fitted

HMS II 23.7 ± 21.8 km

22	Wahly/R. Mertens
23	S. Dedenhardt, Hohen
24 (M)	J. Berghner/H. Alia
25 (P)	Predicted Center 1
26 (M)	E. Biedner, Woodlan
27 (M)	T. Wahly/M. Hopkins
28 (M)	R. Venable, Standish
29 (M)	S. Maximoff, Vaccav
30	M. Wineman, Woodlan
31	T. Swill, Davis, CA
32	R. Sumner/R. Borden
33	P. Dunkel, Grass Va
34	R. Venable, Doyle, C
35	R. Venable, Doyle, C
36	D. Kenyon, Rocklin,
37	D. Machholz, Colfax,
38	T. Case, Walnut Cree
39	D. Becker, Boise, ID
40	R. Venable, Chiloon
41	R. Venable, Chiloon
42	T. Vachier/F. Enrig
43	T. Vachier/J. Fixel
44	Vachier/Cooper/Mel
45	D/J. Dunham, Mountai
46	T. Beard, Reno, NV
47	D/J. Dunham, Tracy, C
48	J. Albers, San Jose,
49	D/J. Dunham, San Jos
50	T. Colan, IMCCF - T
51	T. Colan, IMCCF - T
52	T. Colan, IMCCF - T
53	D/J. Dunham, Westley
54 (M)	D/J. Dunham, Newnan,
55 (M)	D/J. Dunham, Ingham
56 (M)	D/J. Dunham, Santa X

(90) Antiope occultation, July 20



Keck Telescope vs 20 mm lens ;-)

(90) Antiope occultation, July 20