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

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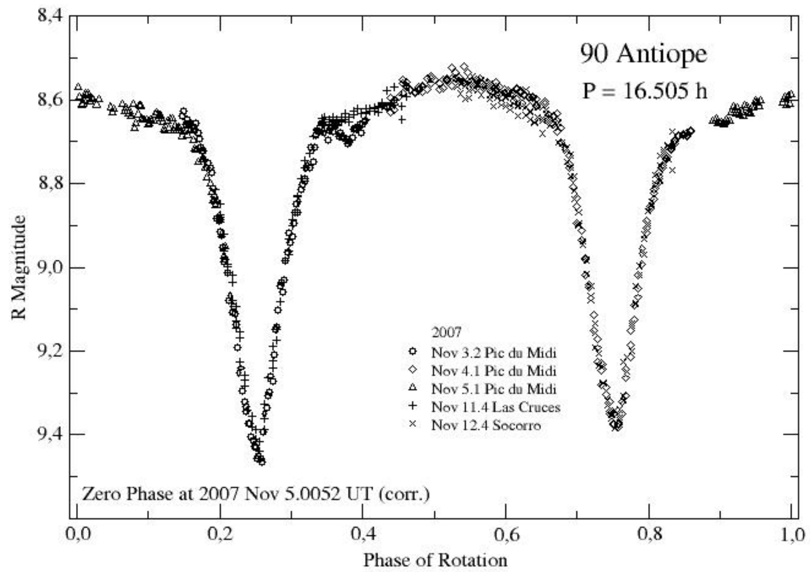
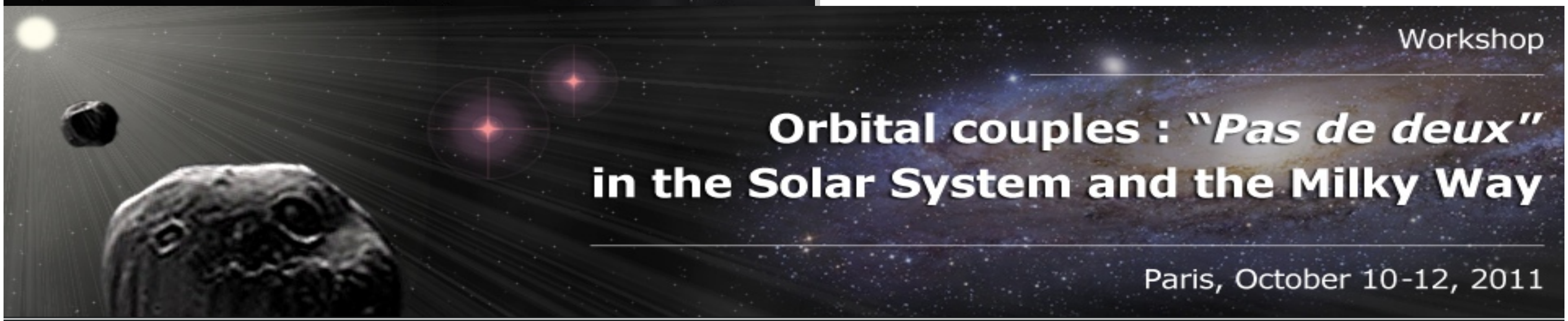
Petr ***KUCHYNKA*** *Jet Propulsion Laboratory*





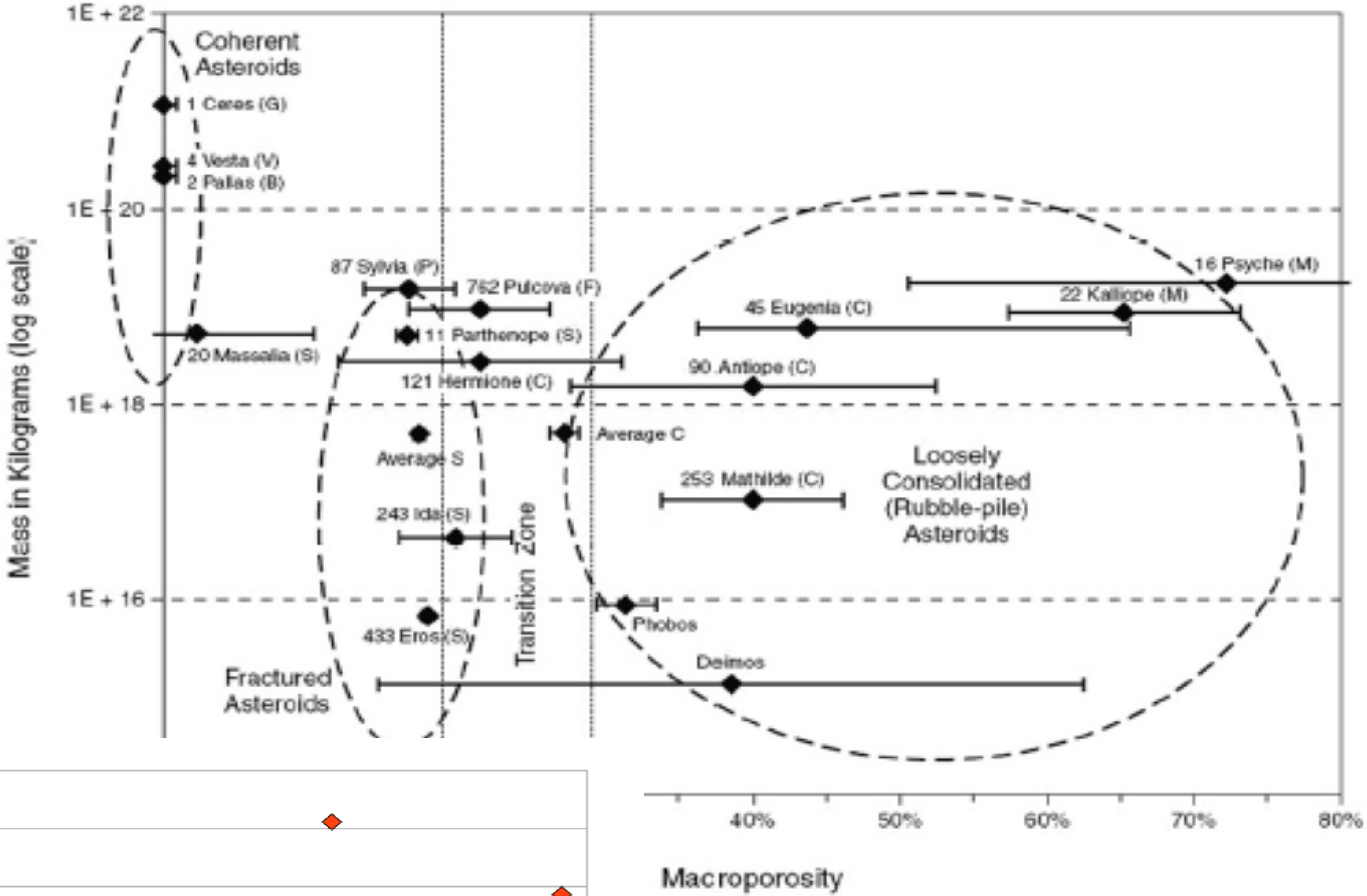
Densities measurements

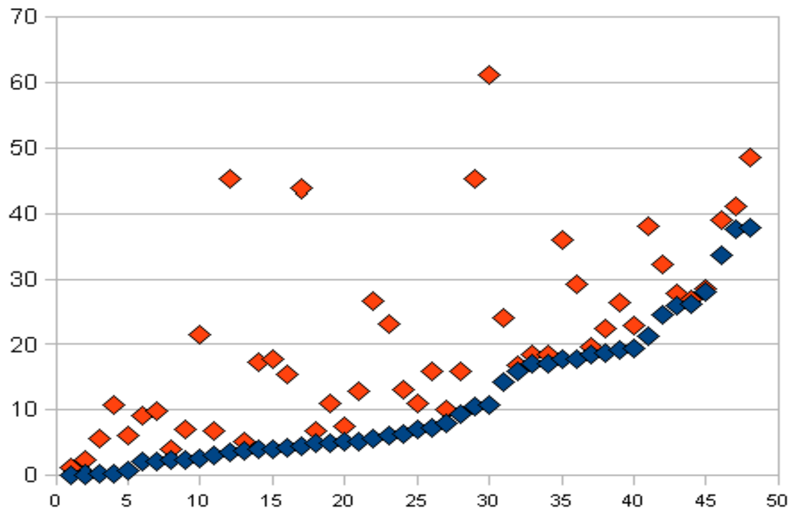
Most of the asteroids have not evolved since solar system formation

- 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
  - ...

spacecraft.

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,

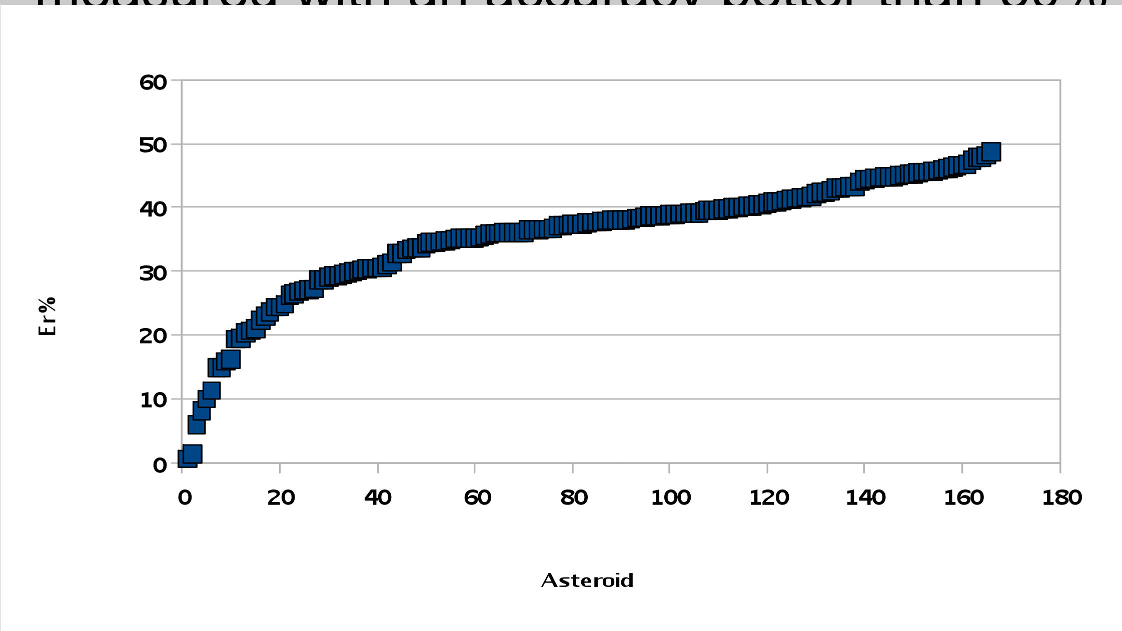
Binary asteroids

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)***

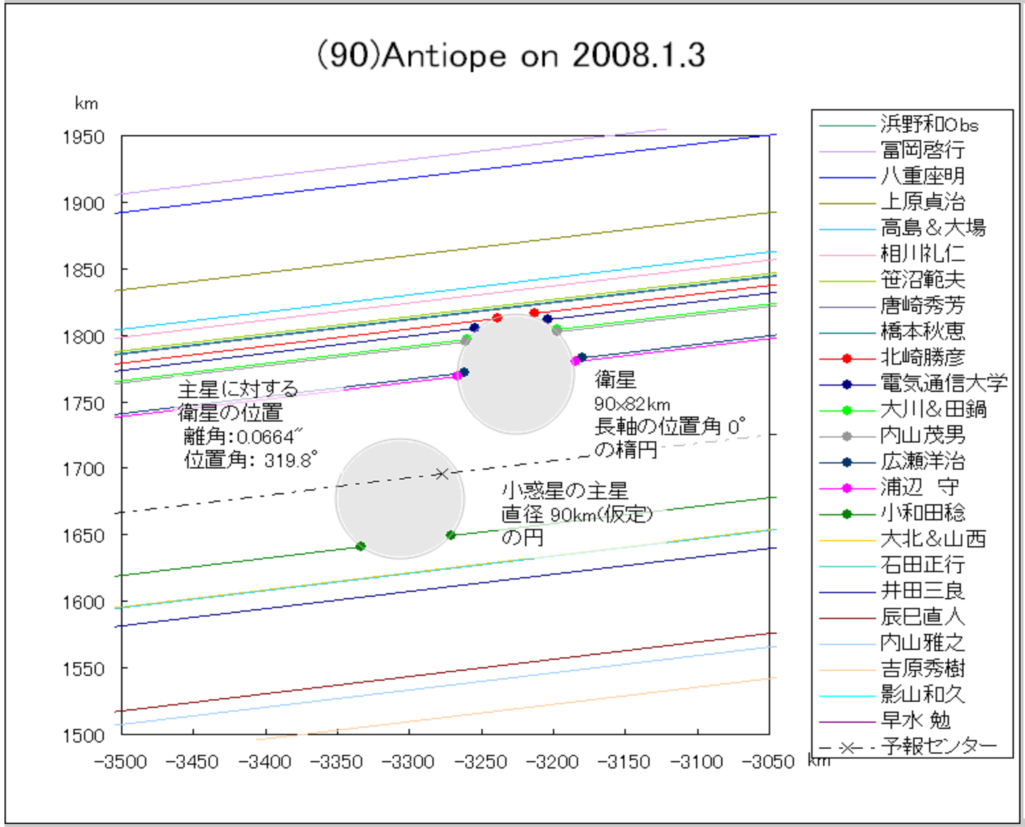
- we supposed that Mars orbit will be still known with an one meter accuracy until 2020, we found 167 objects with masses that can be measured with an accuracy better than 50%

40% => 115
30% => 50

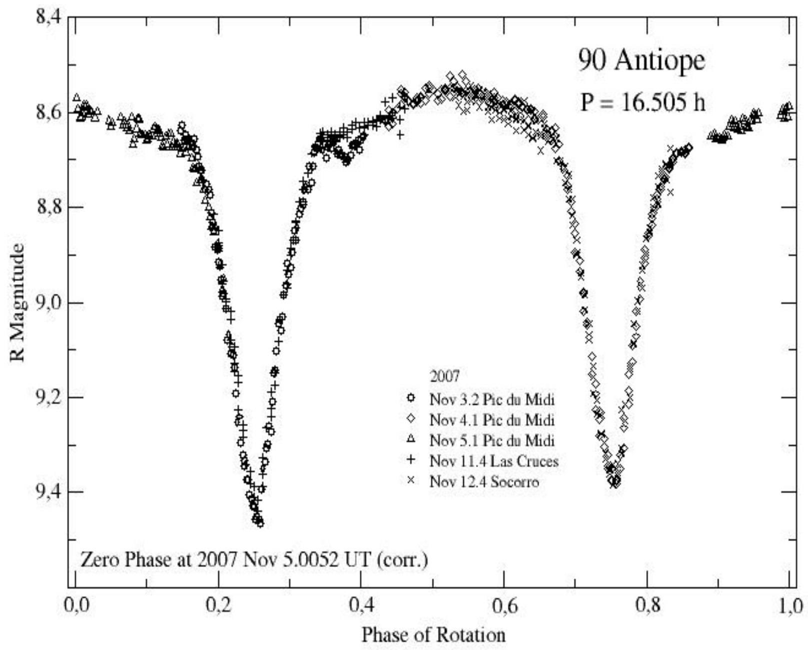


Mass determination

(90) Antiope – mutual phenomena and occultation

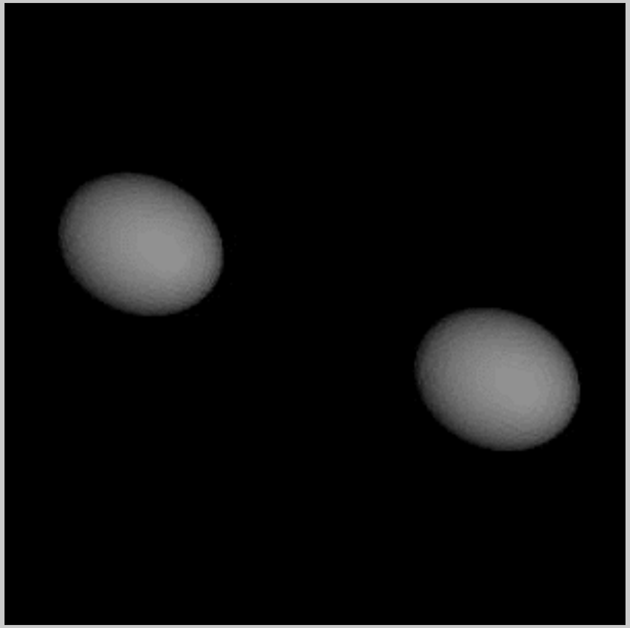


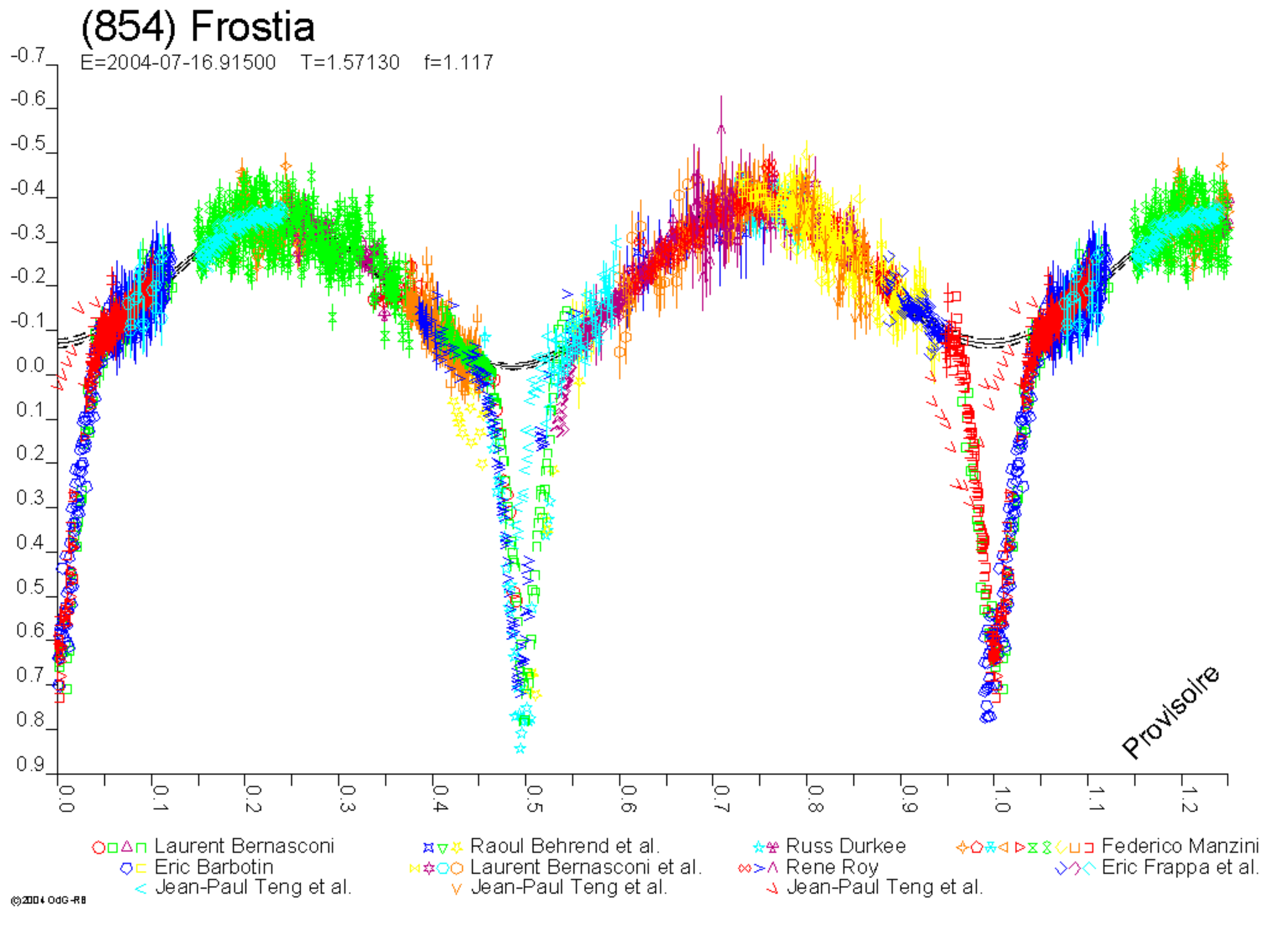
Occultations



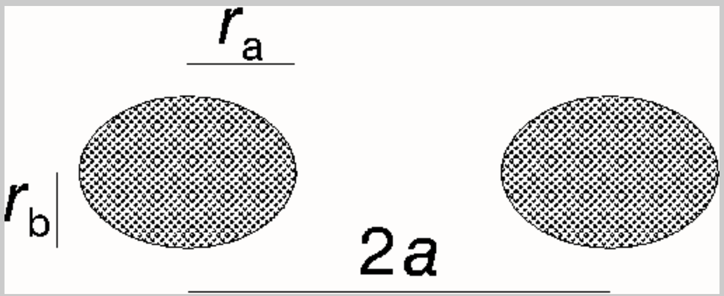
Light curves

Binary asteroid light curves





Direct density estimation

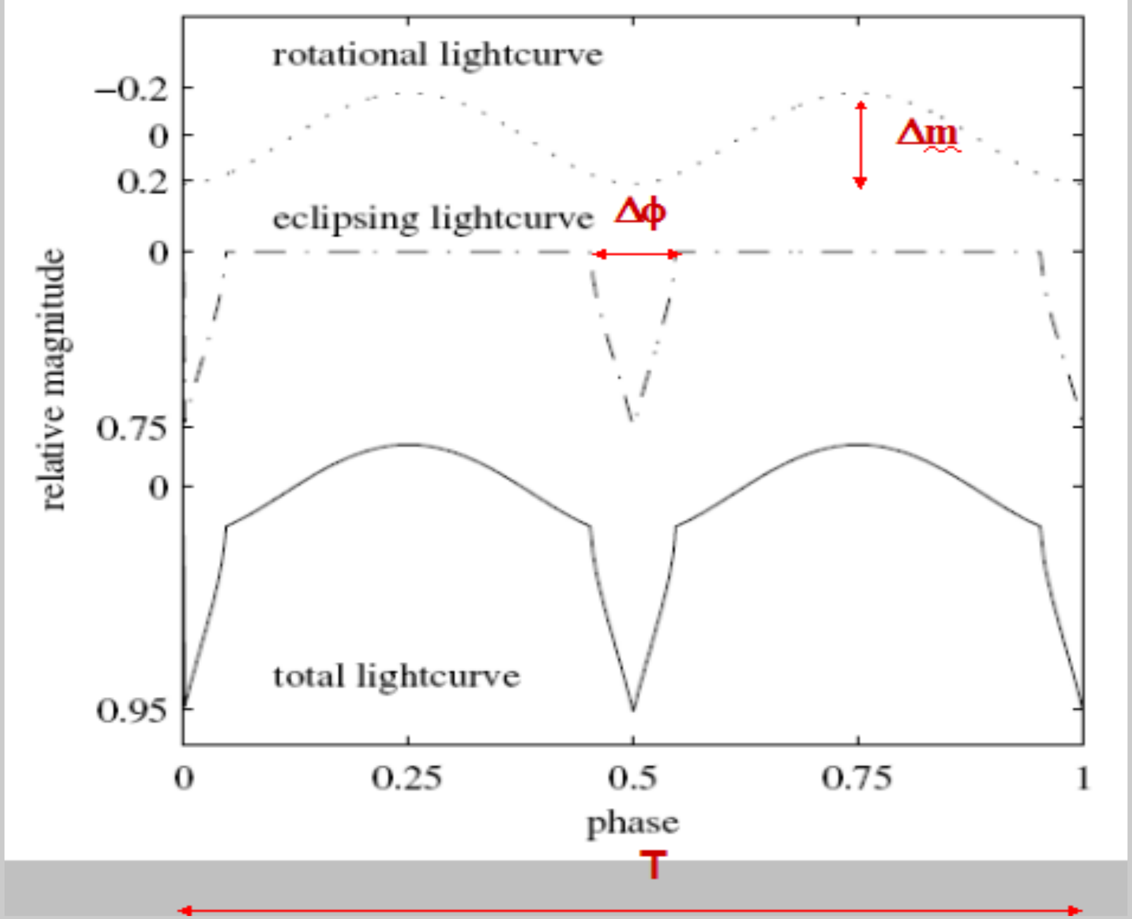


$$r_b/r_a = 10^{-0.4\,\Delta m}$$

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

$$M = \frac{16\,\pi^2\,a^3}{G\,T^2}$$

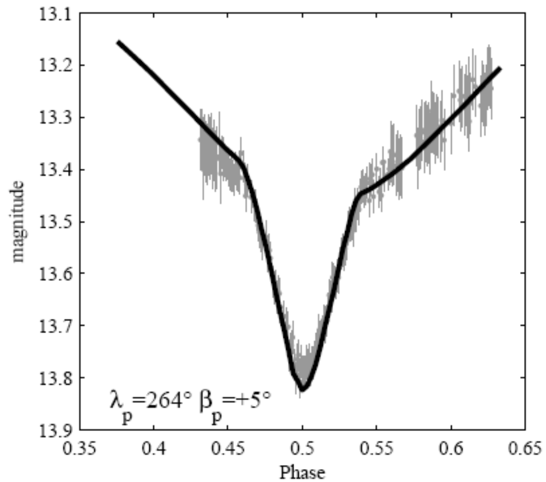
$$\rho = \frac{M}{\frac{4}{3}\,\pi\,r_a\,r_b{}^2}.$$

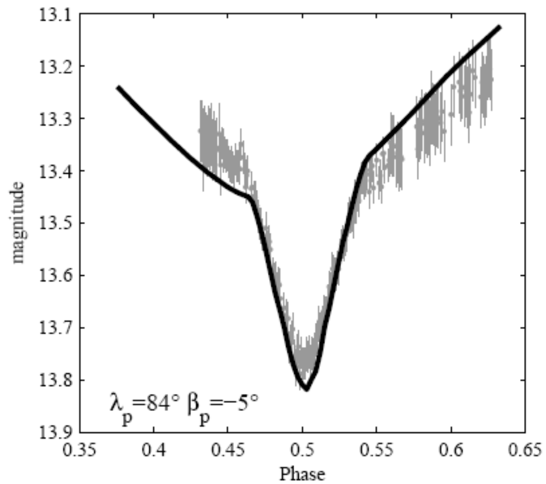


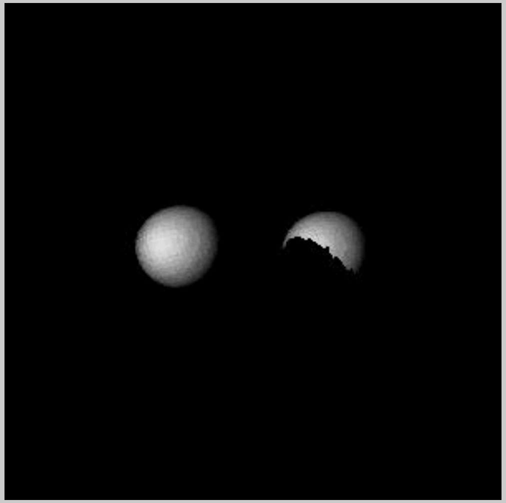
$$\rho = \frac{12\,\pi}{G}\,\frac{1}{T^2}\,\frac{10^{-0.4\,\Delta m}}{\sin^3(\Delta\phi/2)}.$$

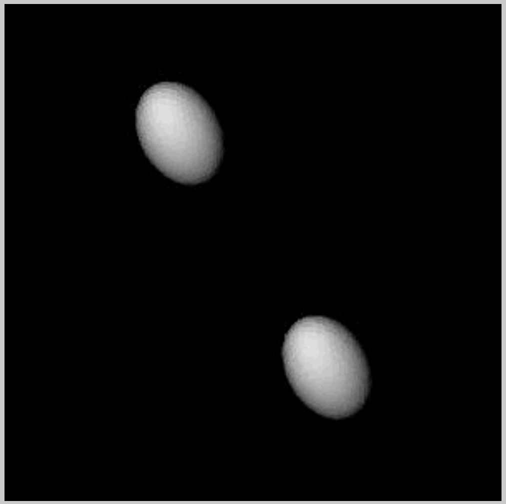
Discovery of the binary nature of the Mars–crosser (1139) Atami ⋆

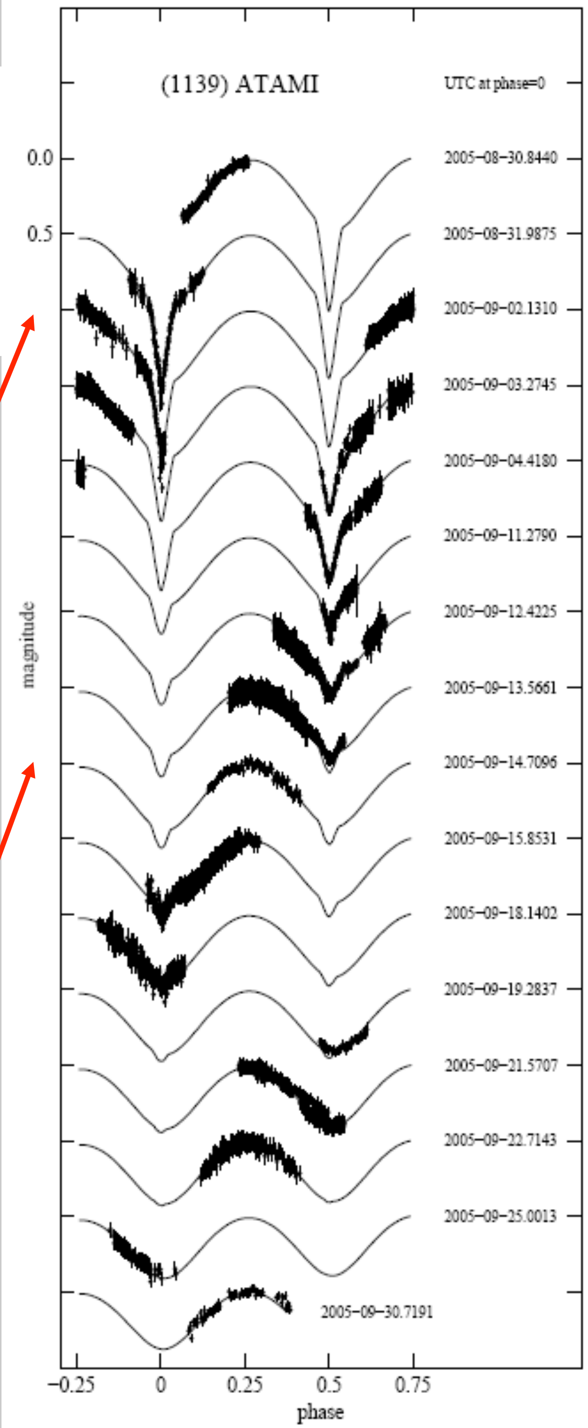
R. Behrend[1], F. Manzini[2], A. Klotz[3,4], F. Colas[5,6], Y. Damerdji[3,4], S.J. Ostro[7], P. Antonini[8,6], E. Barbotin[6], L. Bernasconi[9,6], C. Cavadore[10], S. Charbonnel[11,6], J. Coloma[12], R. Cripa[13], F. Kugel[14], A. Leroy[15], J.M Llapasset[16], A. Oksanen[17], P. Pääkkönen[18], R. Poncy[19,6], R. Roy[20,6], and D. Starkey[21]











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-ϵ	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 ⋆

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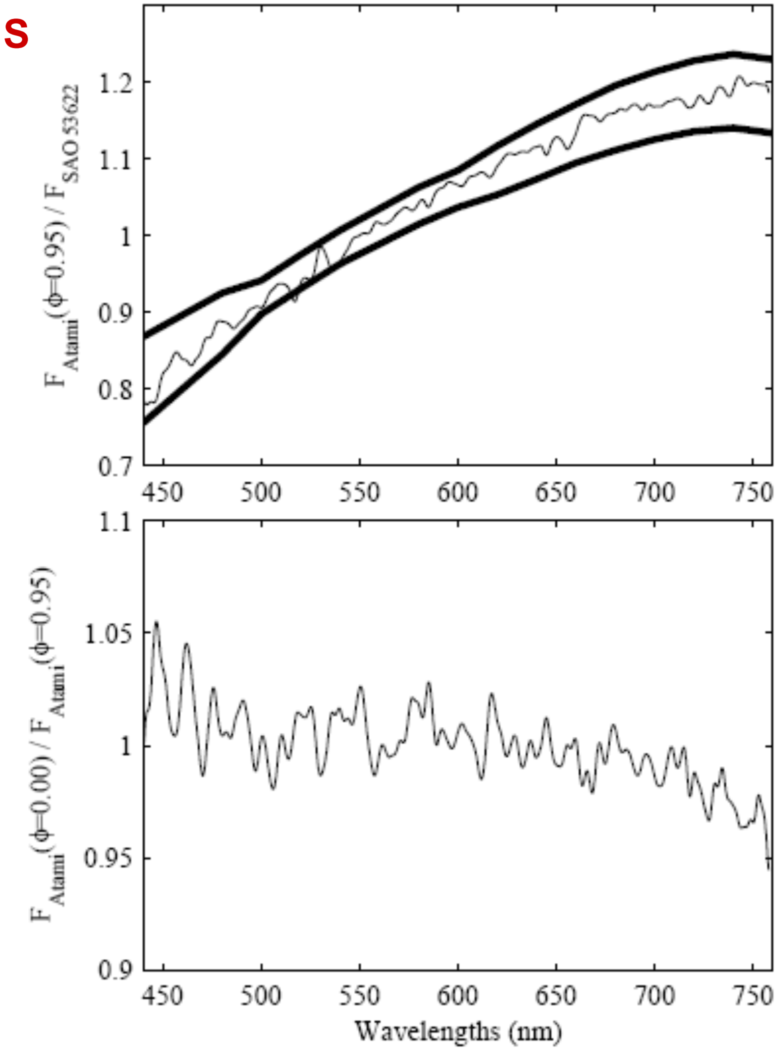
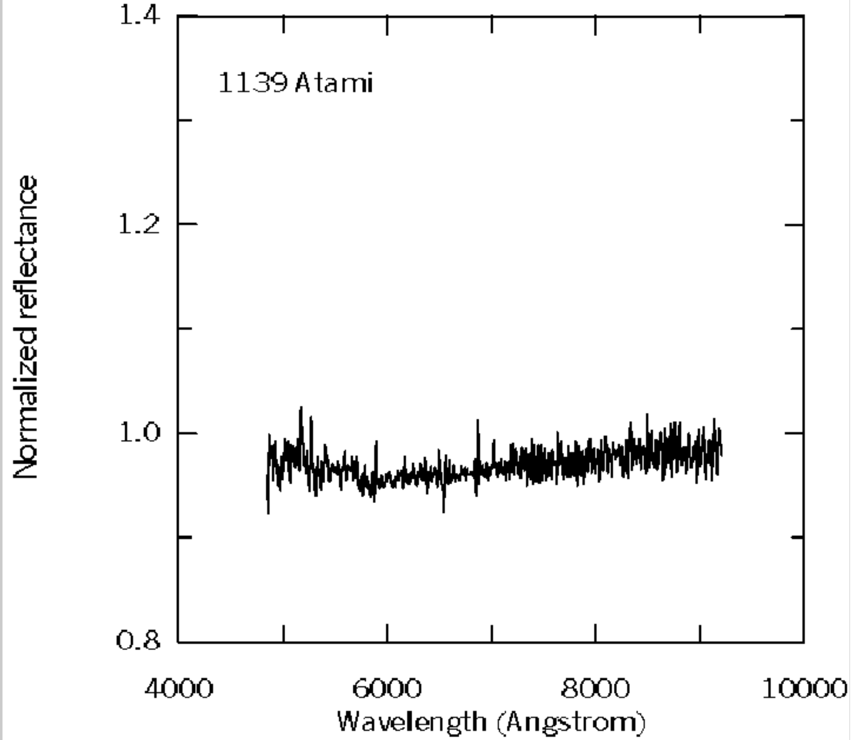
Infrared photometry from ground based observations
=>
Thermal inertia (eclipse observations)

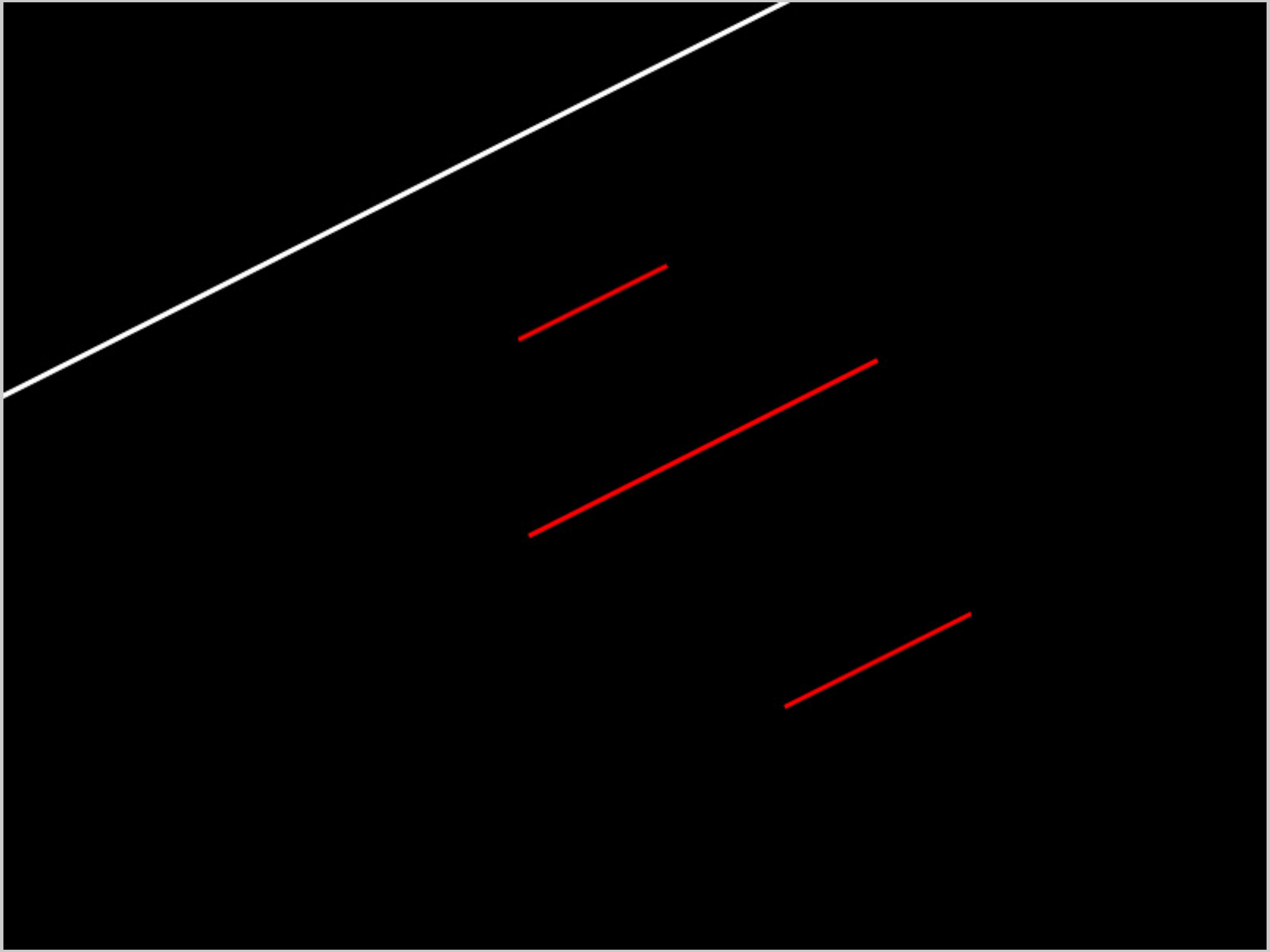
2005 type S
(pôle N)

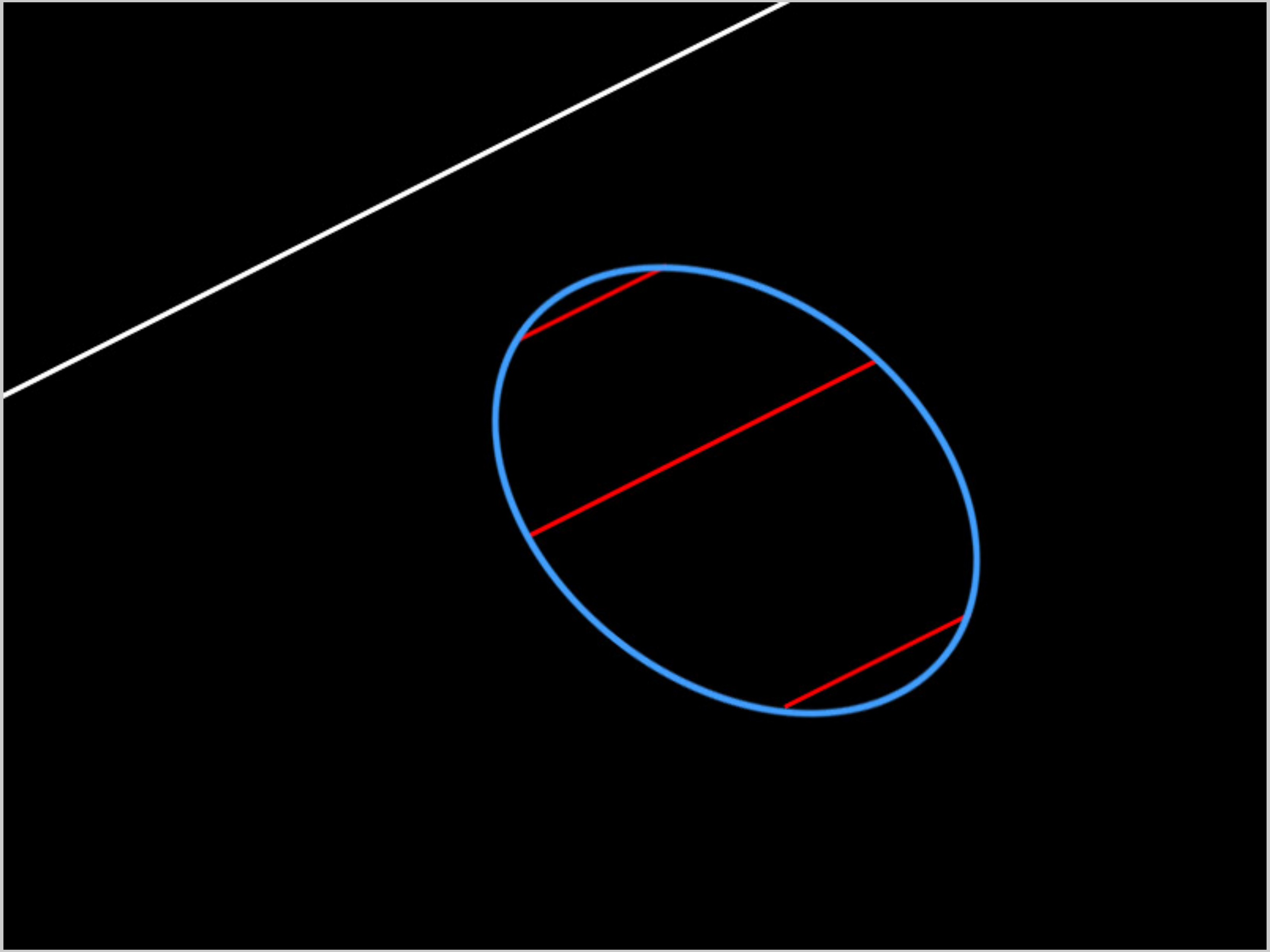


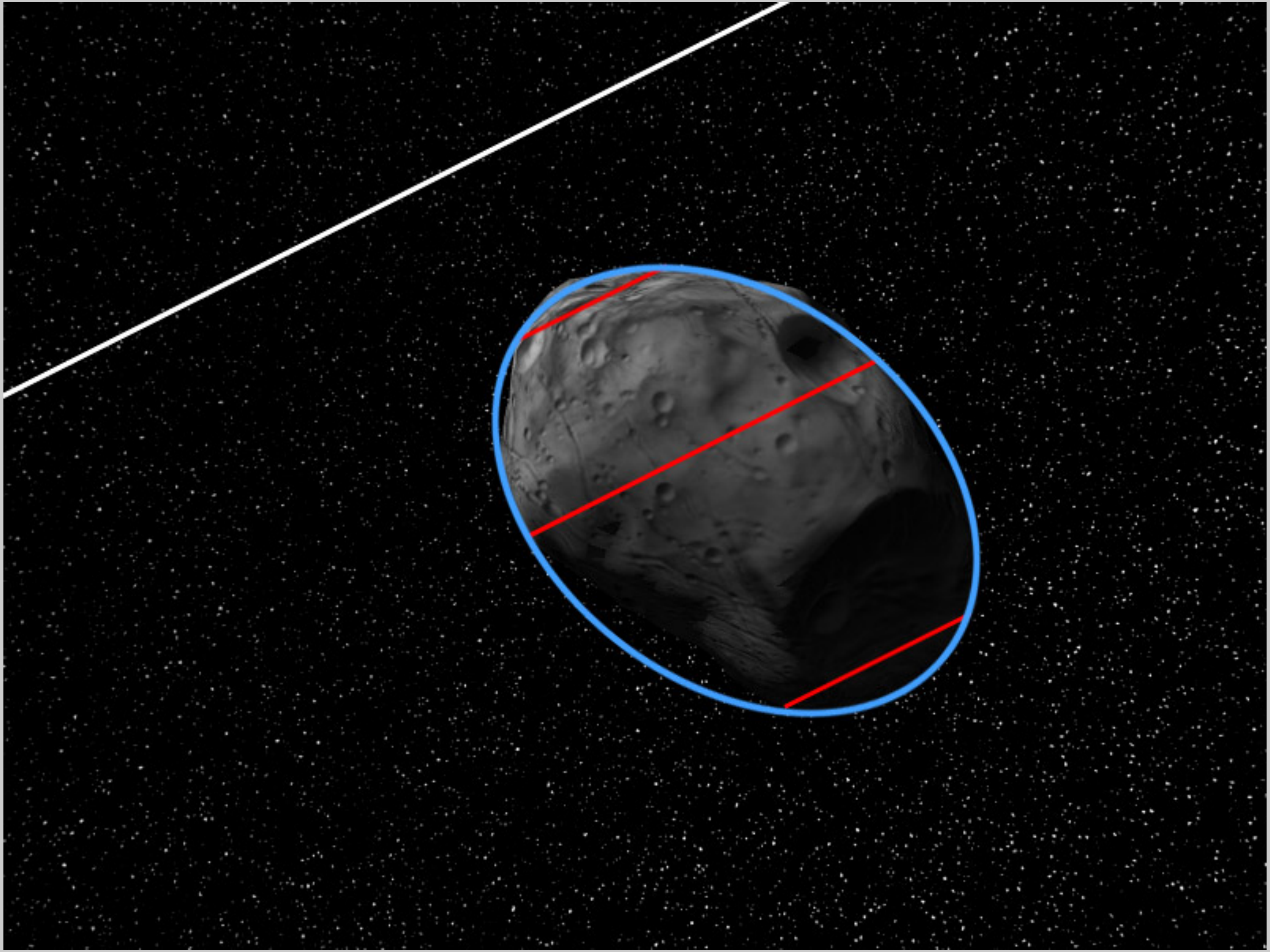
1996 type S (pôle N)
1997 type C (pôle S)

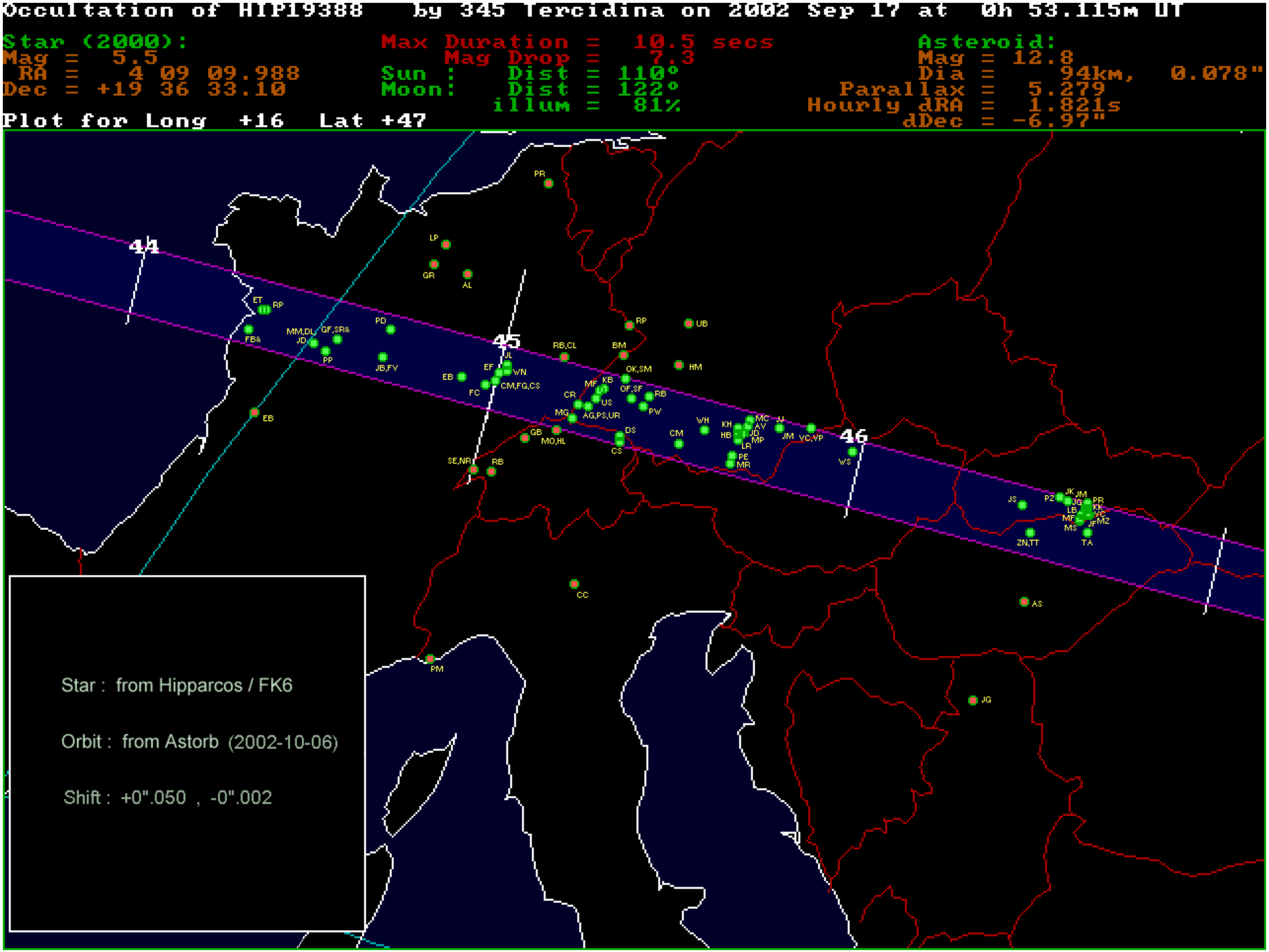


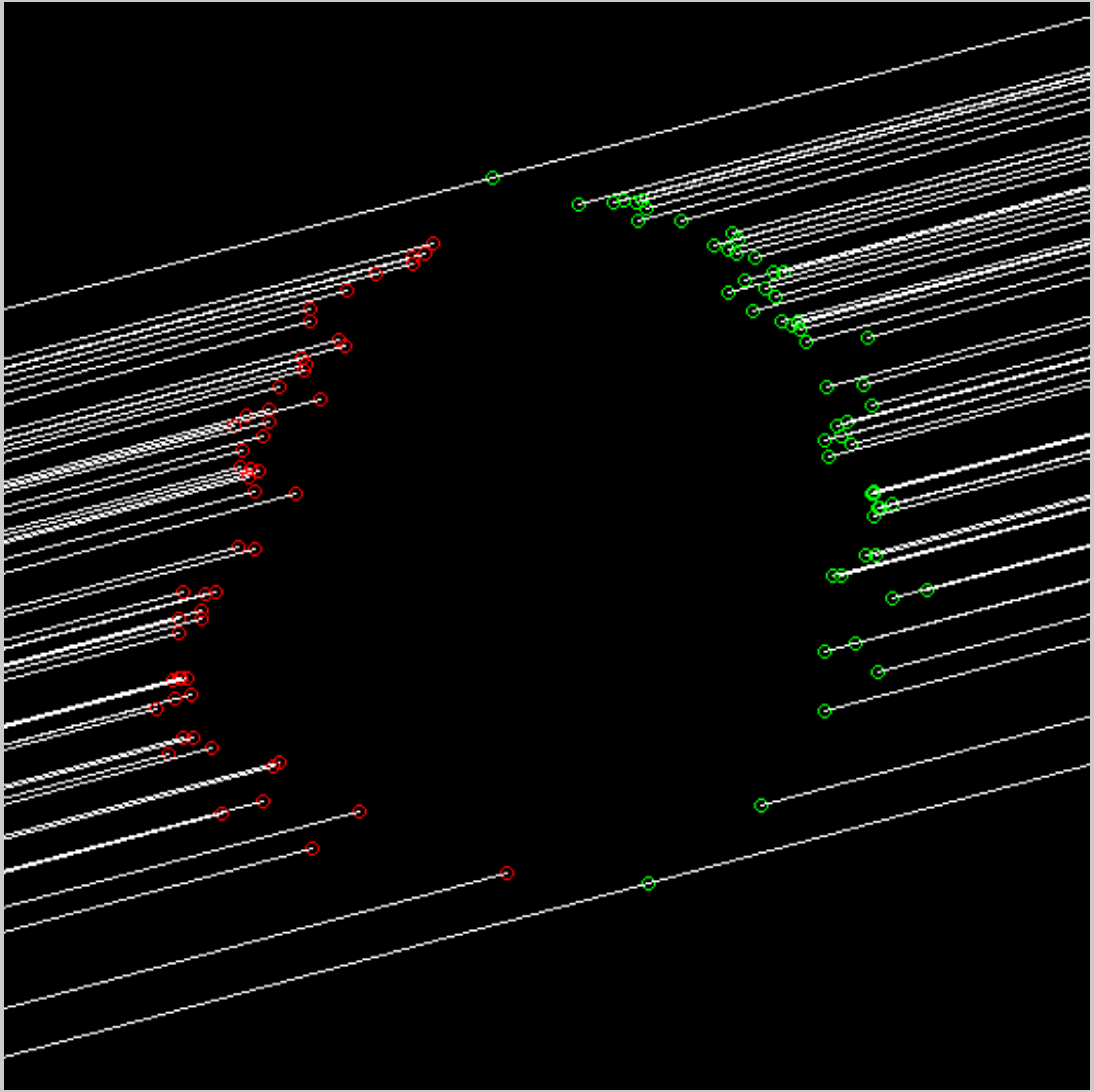
Stellar Occultations

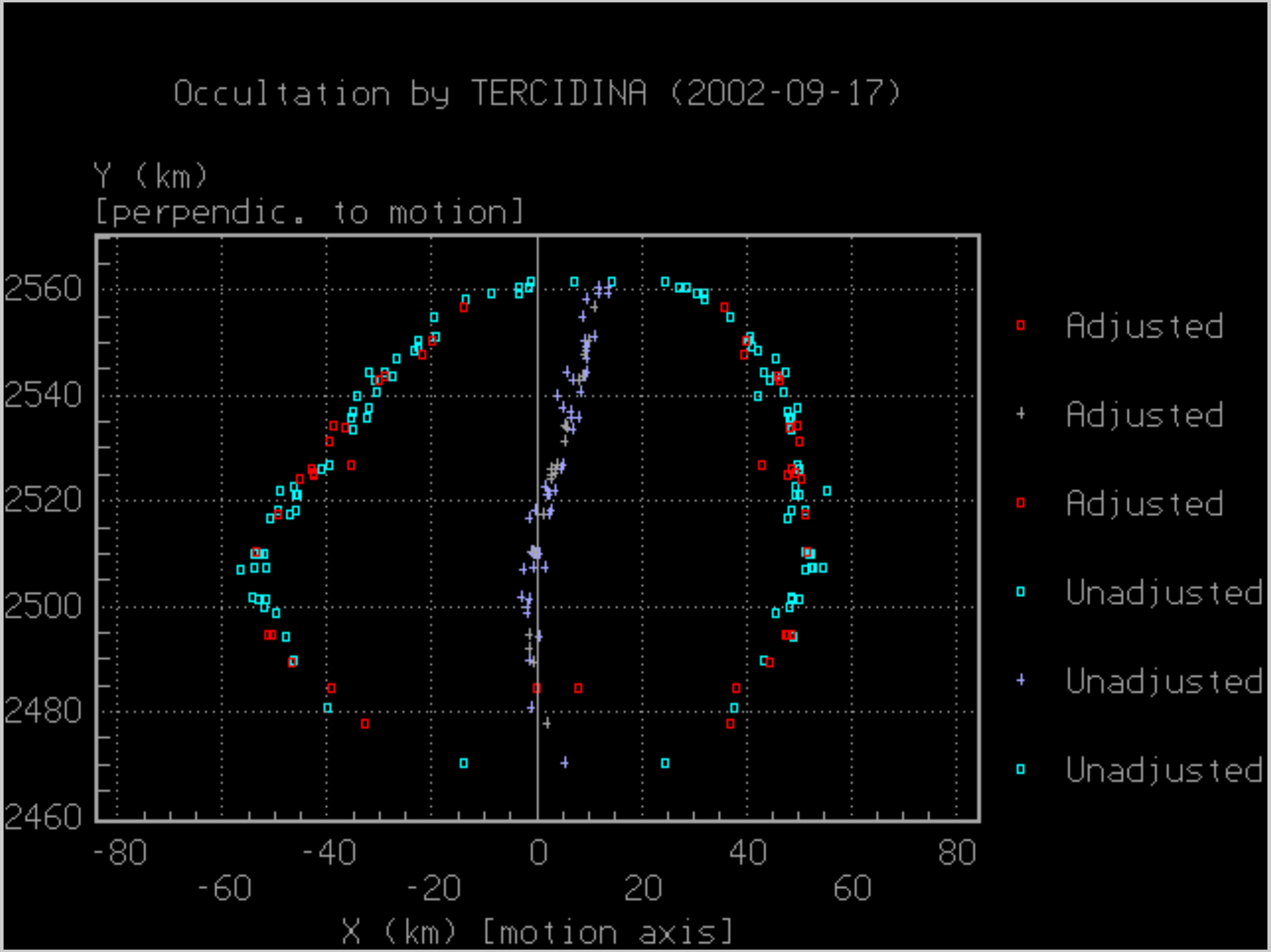







Occultation of HIP19388 by 345 Tercidina on 2002 Sep 17 at 0h 53.115m UT
Star (2000):
Mag = 5.5
RA = 4 09 09.988
Dec = +19 36 33.10
Max Duration = 10.5 secs
Mag Drop = 7.3
Sun : Dist = 110°
Moon: Dist = 122°
illum = 81%
Asteroid:
Mag = 12.8
Dia = 94km, 0.078"
Parallax = 5.279
Hourly dRA = 1.821s
dDec = -6.97"
Plot for Long +16 Lat +47
44
45
46
Star : from Hipparcos / FK6
Orbit : from Astorb (2002-10-06)
Shift : +0".050 , -0".002





Occultation by TERCIDINA (2002-09-17)
Y (km)
[perpendic. to motion]
2560
2540
2520
2500
2480
2460
-80
-60
-40
-20
0
20
40
60
80
X (km) [motion axis]
Adjusted
Adjusted
Adjusted
Unadjusted
Unadjusted
Unadjusted

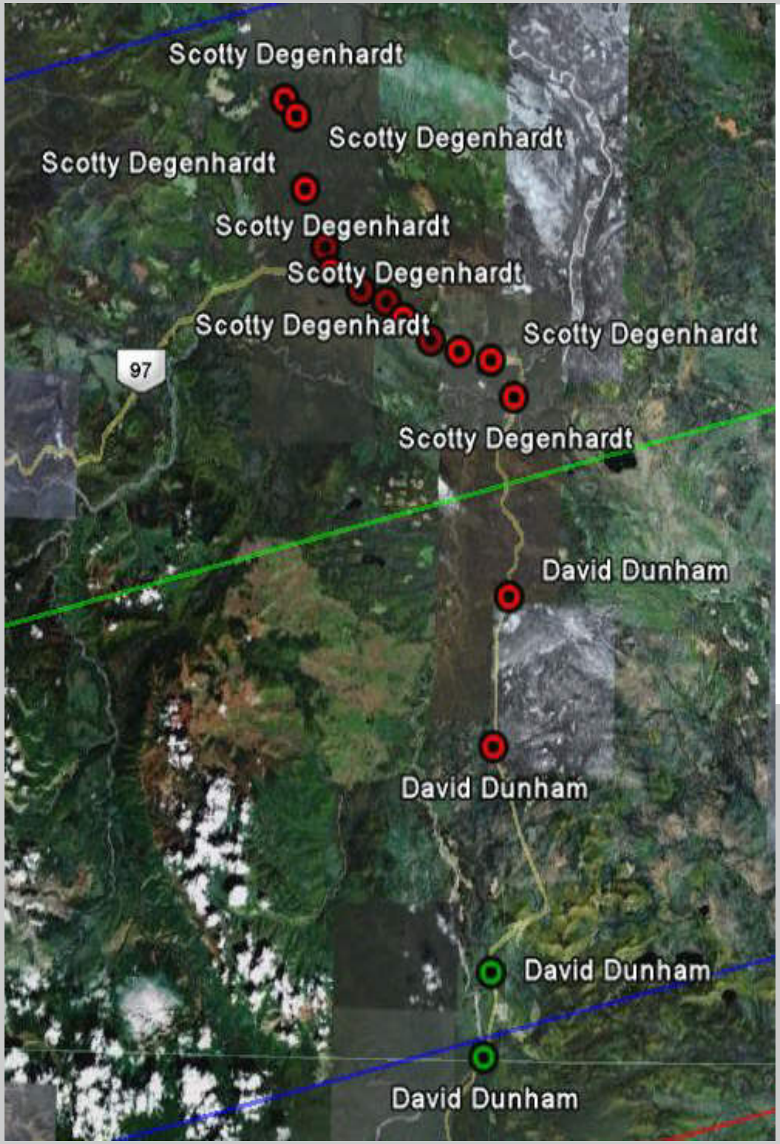
Accuracy ?

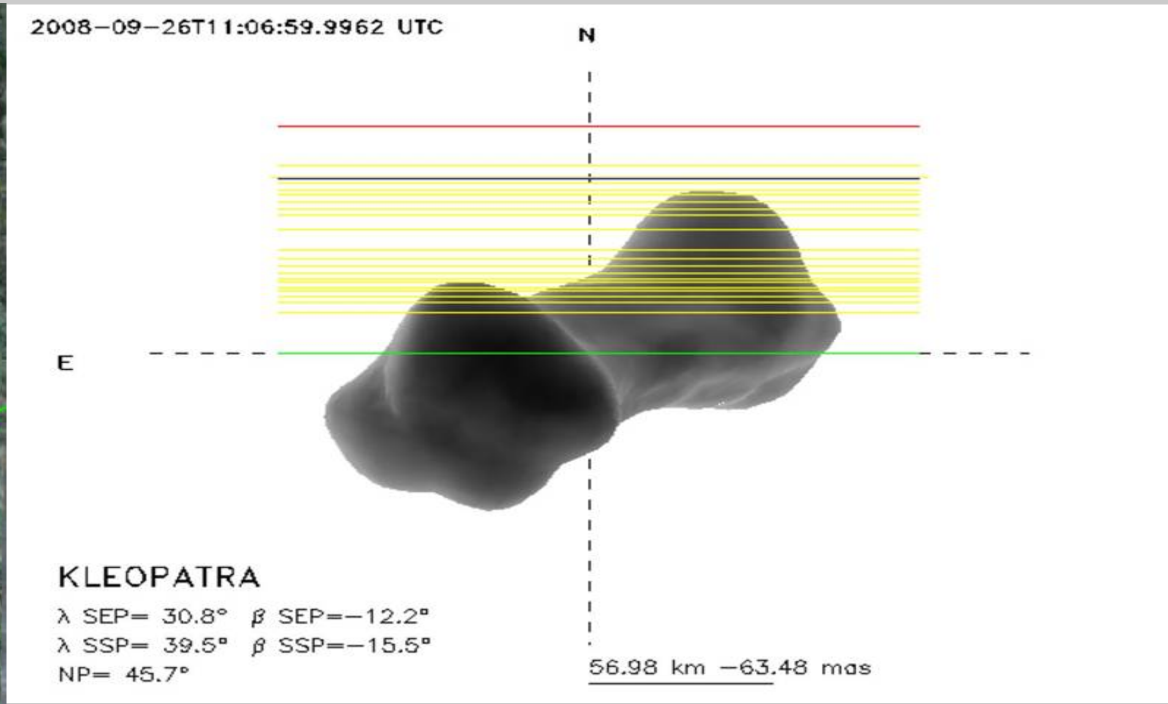
Occultation of HIP 19388
by (345) Tercidina
17 september 2002

Apparent motion on the sky :
25.92"/h => 7.2 mas/s

Timing accuracy: 0.04s

For tercidina 0.29 mas => 350m

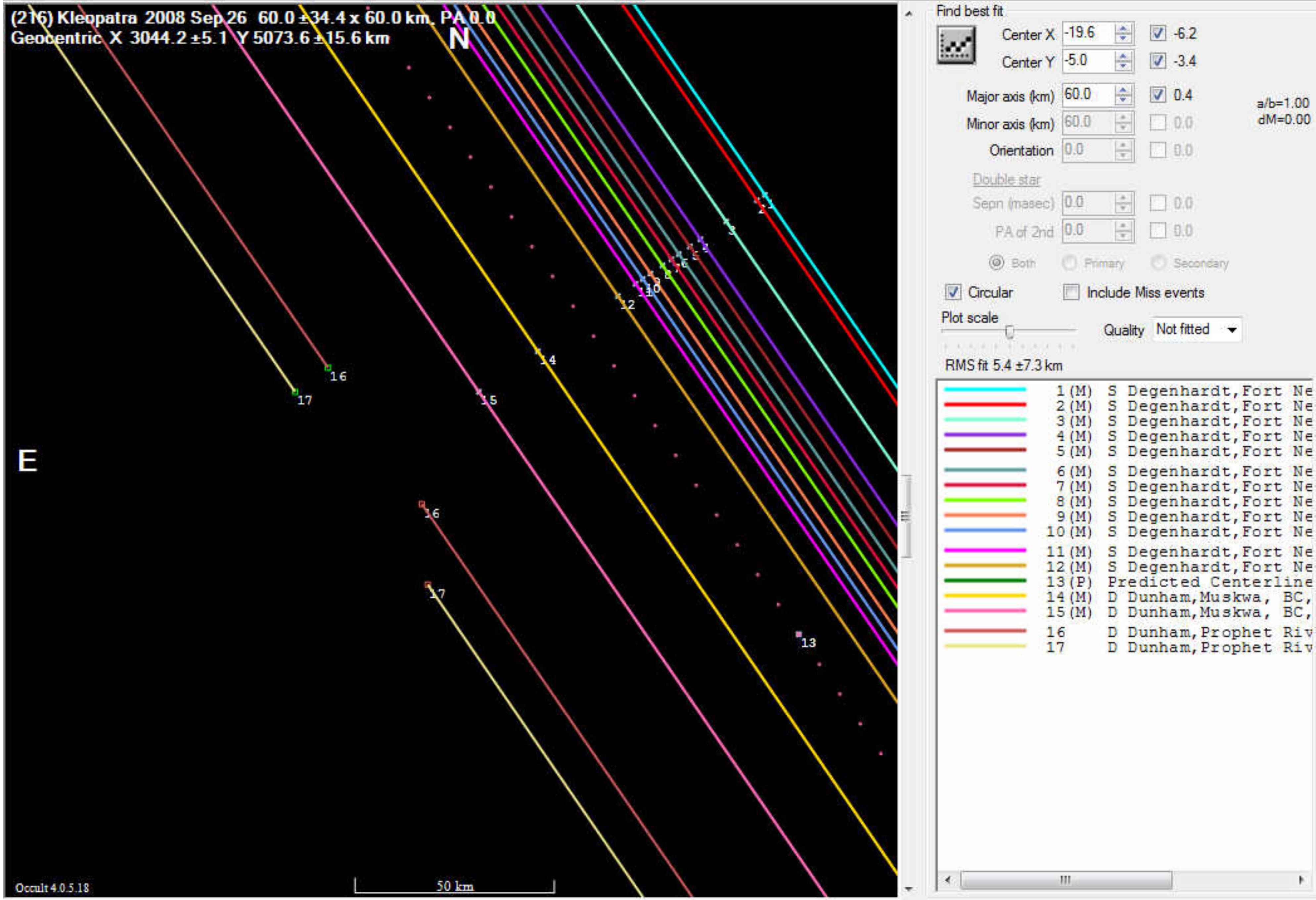




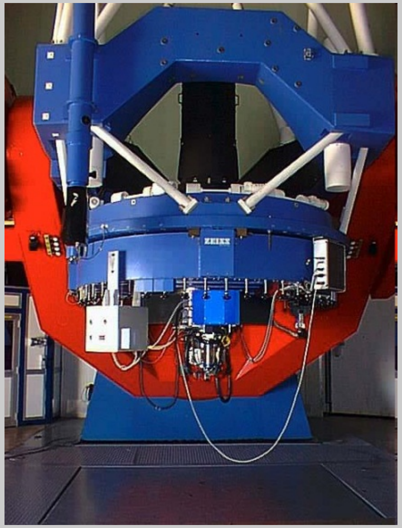
New observational strategy :

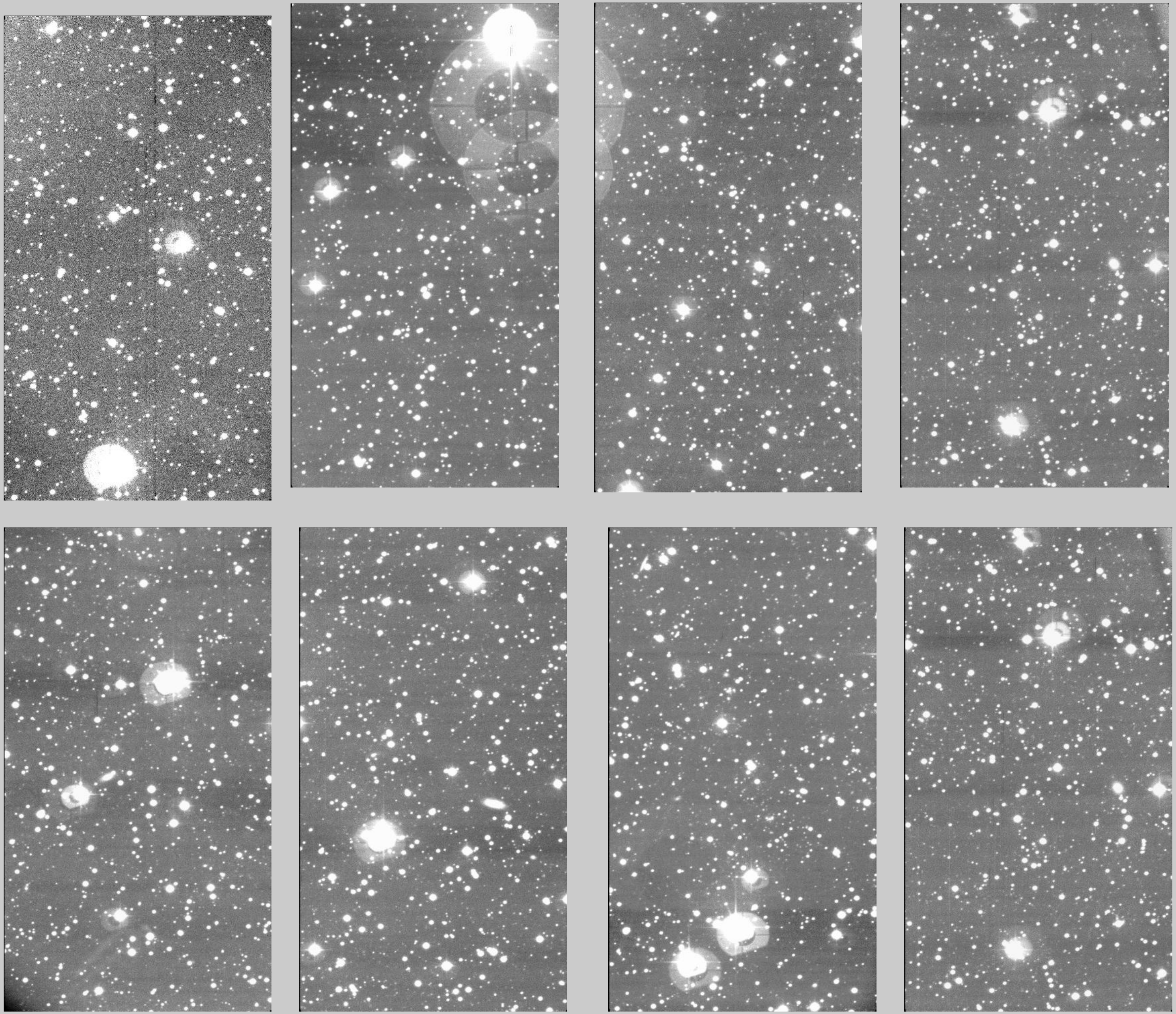
- good spatial resolution
- many small observatories
- bright occulted star
- go anywhere on Earth...

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



ESO 2.2m/WFI CCD mosaic de 30’x30’





1 CCD: 7.5’x15’
(2048x4096px)

1 pixel: 238mas

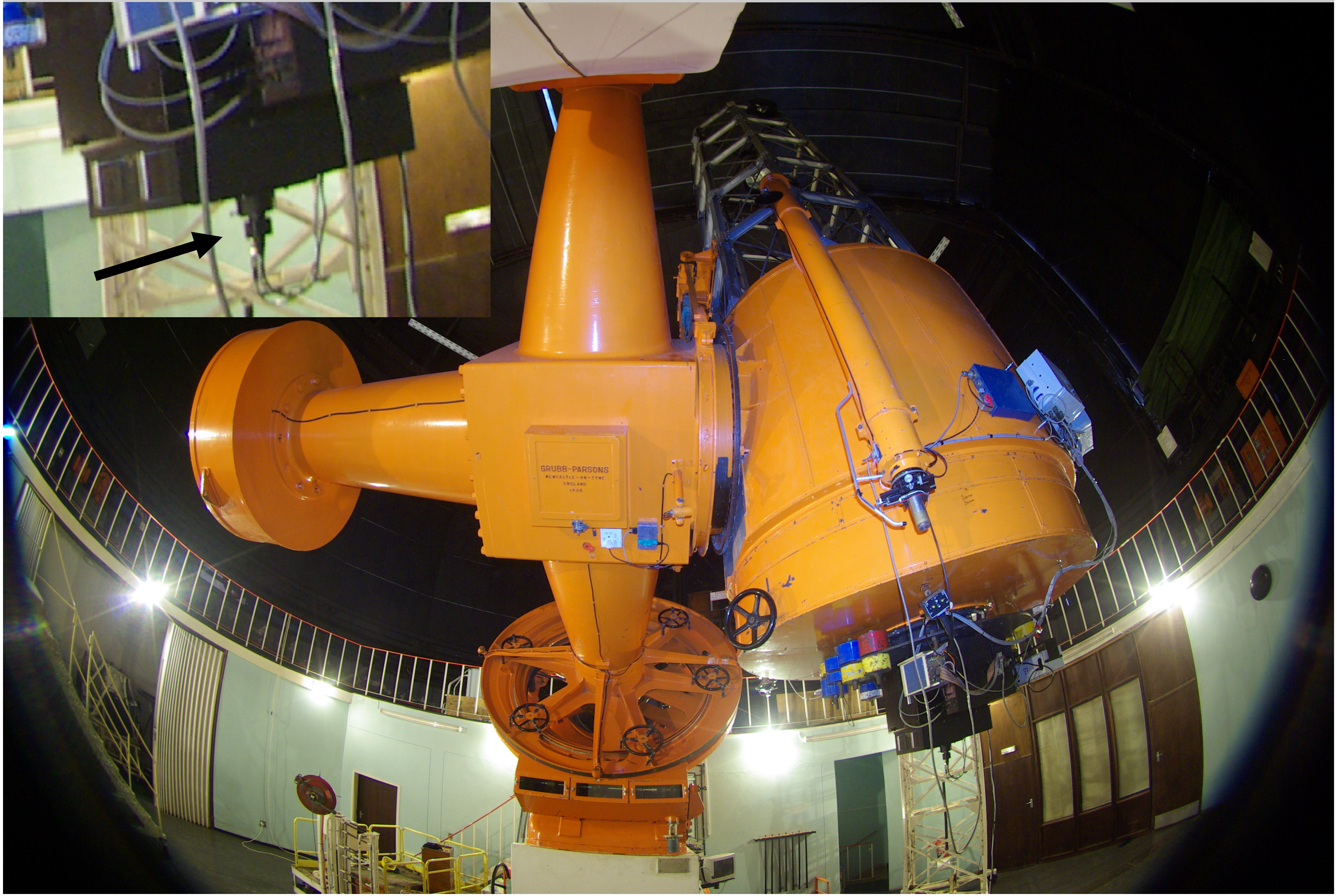
800 WFI mosaics

6000 CCD frames

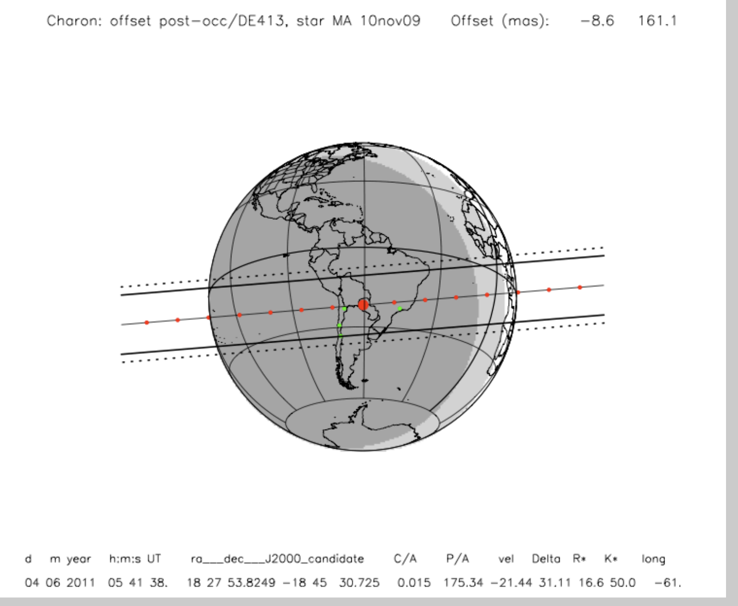
216 GB FITS

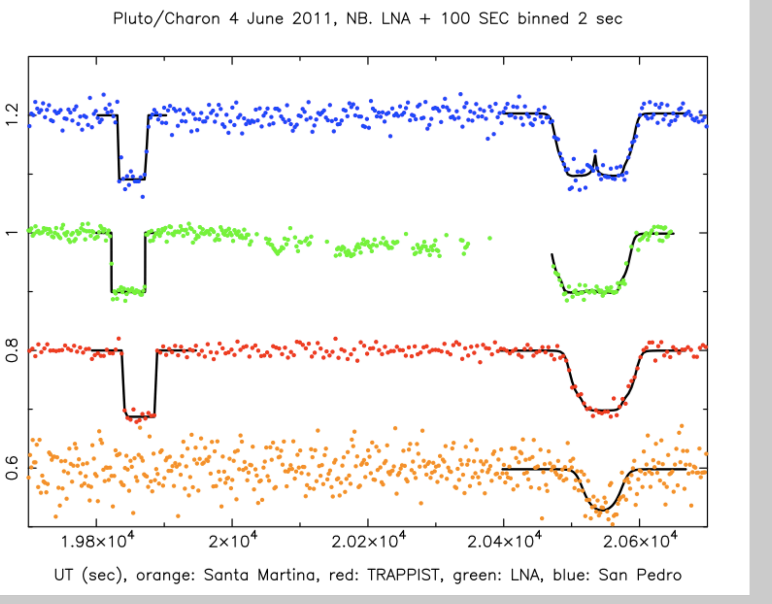
→ PRAIA

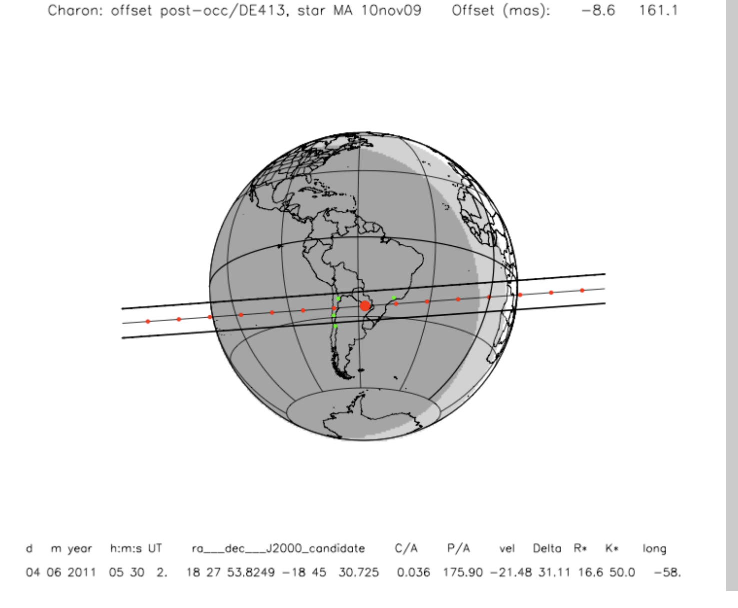
T 193 – Sutherland RSA – Pluto Occultation – june 2008

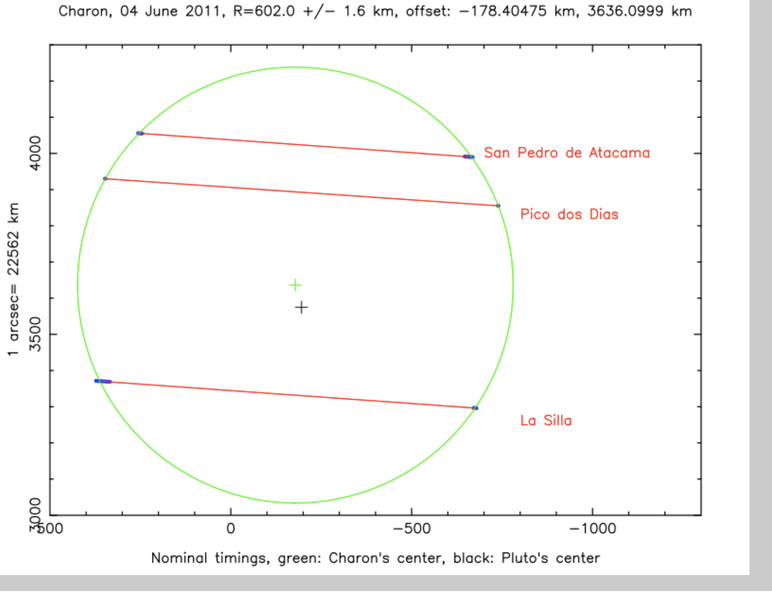


Pluto Charon

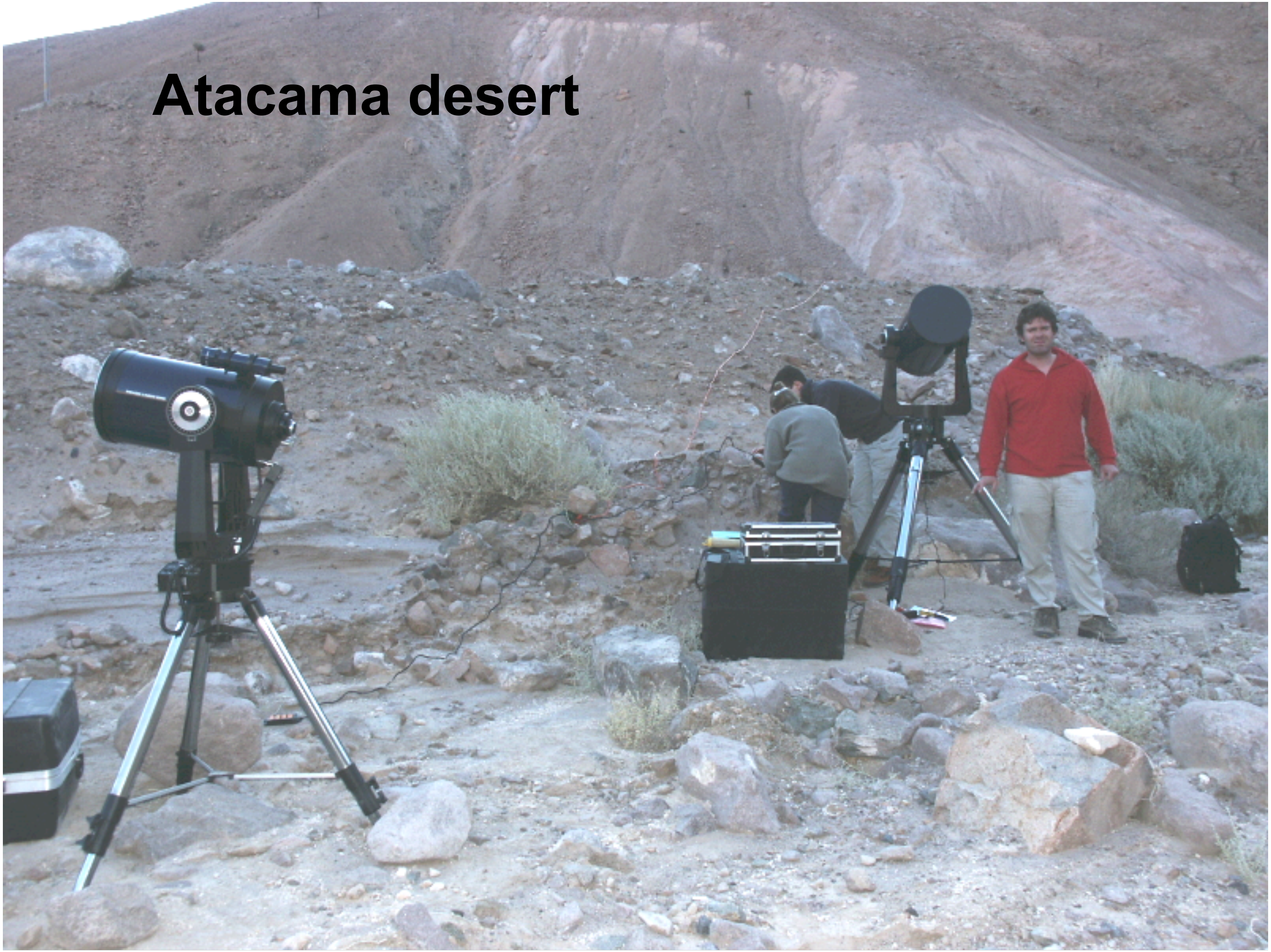






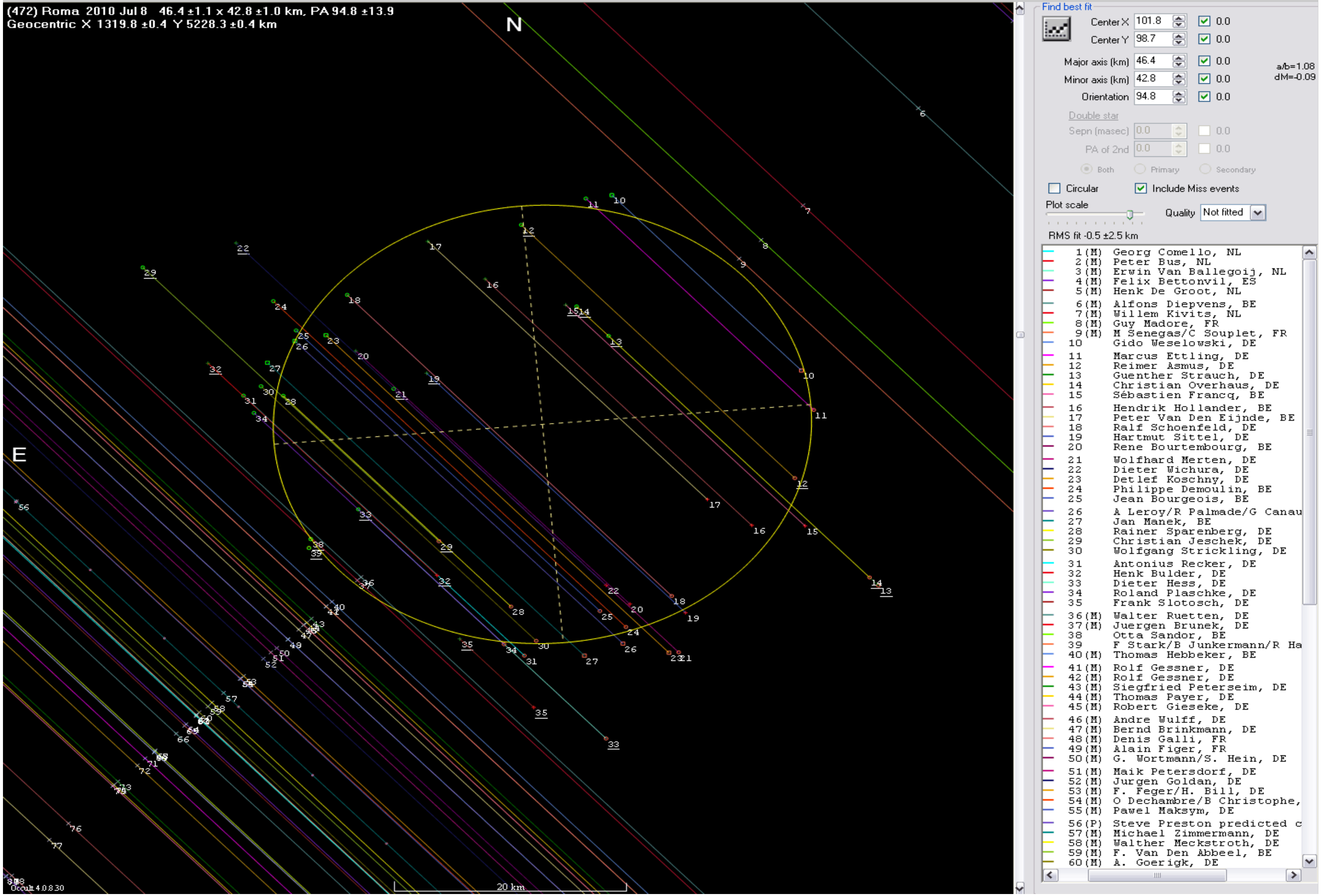


Setting up a mighty mini at my station #5 in Newman, Calif.


Atacama desert

Small size observatory !

Timing problems (472) Roma – 2011 July 8th



Video Observatory

Occultations of binary Asteroids

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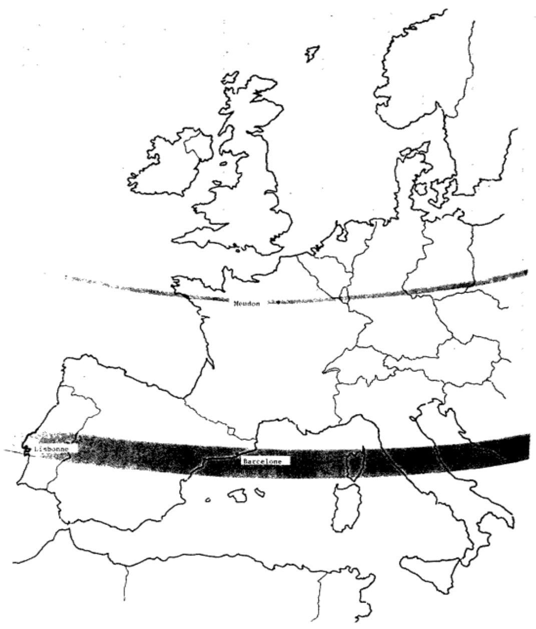

Figure 2. Occultation track of 146 Lucina and its probable satellite on 1982 April 18.

(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

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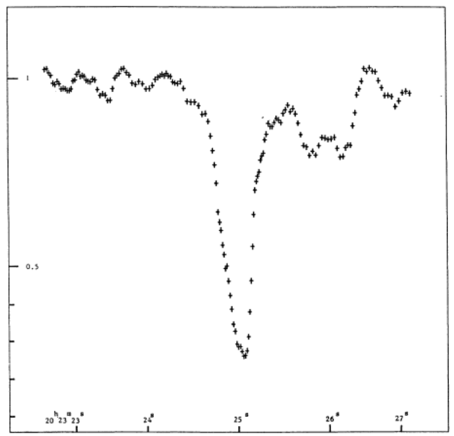
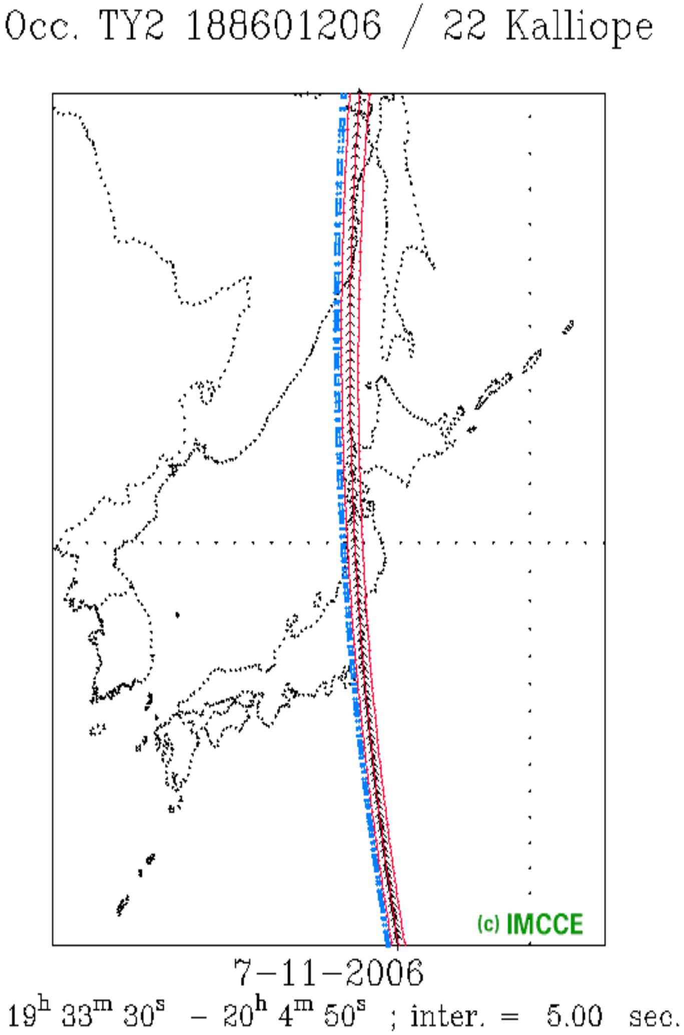
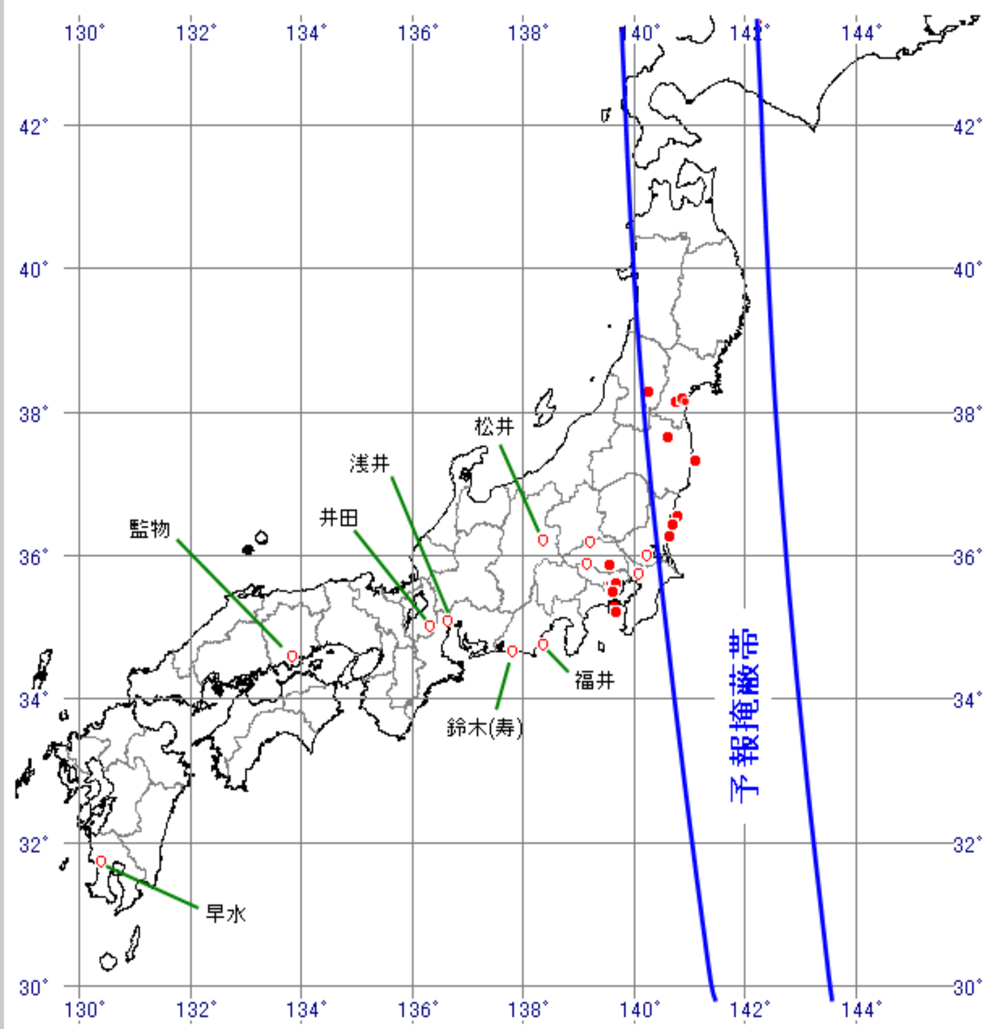


Figure 1. The light-curve of the secondary event recorded on 1982 April 18 , at Meudon Observatory.

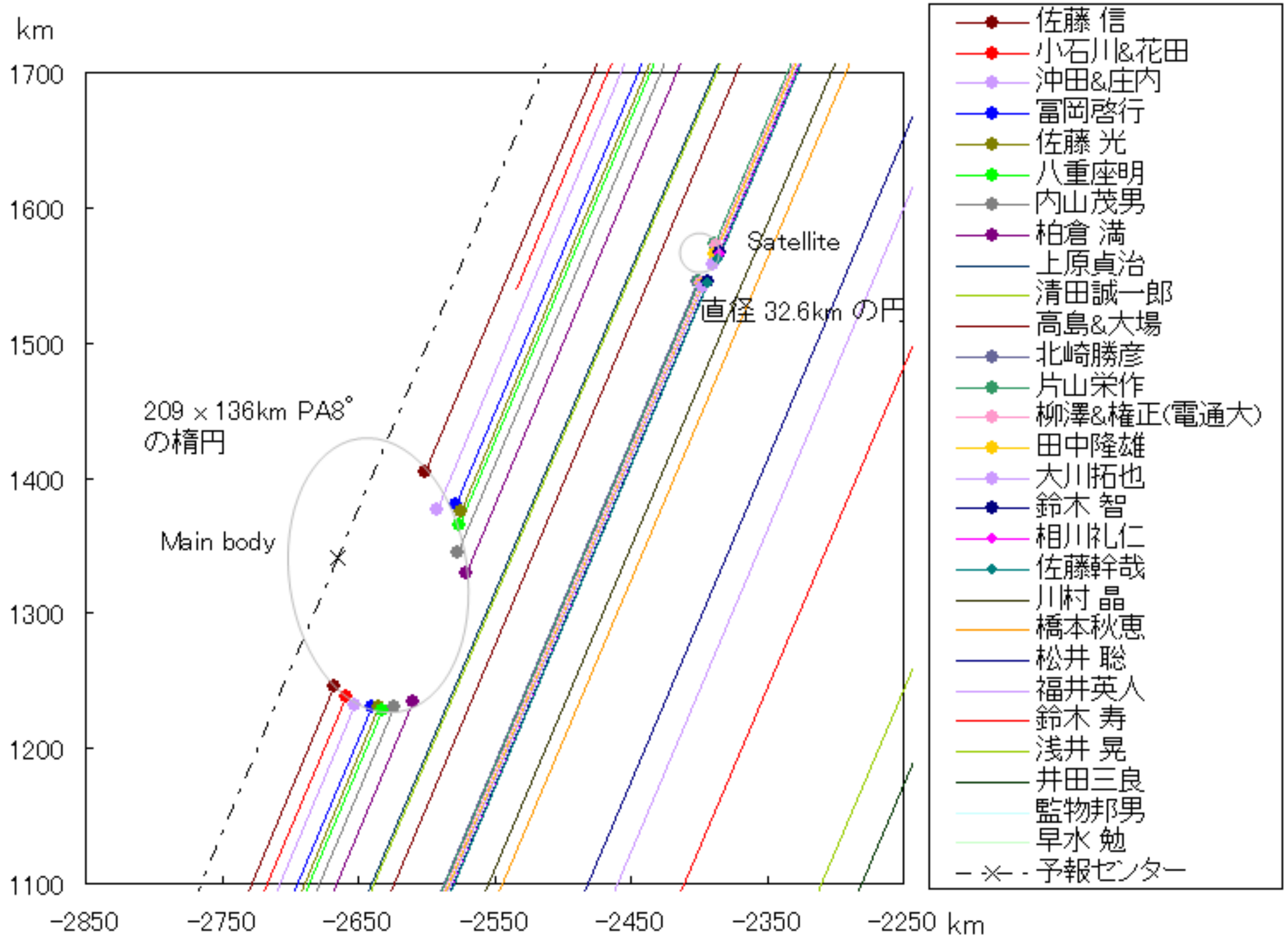
Kalioppe

KALLIOPE
LINUS

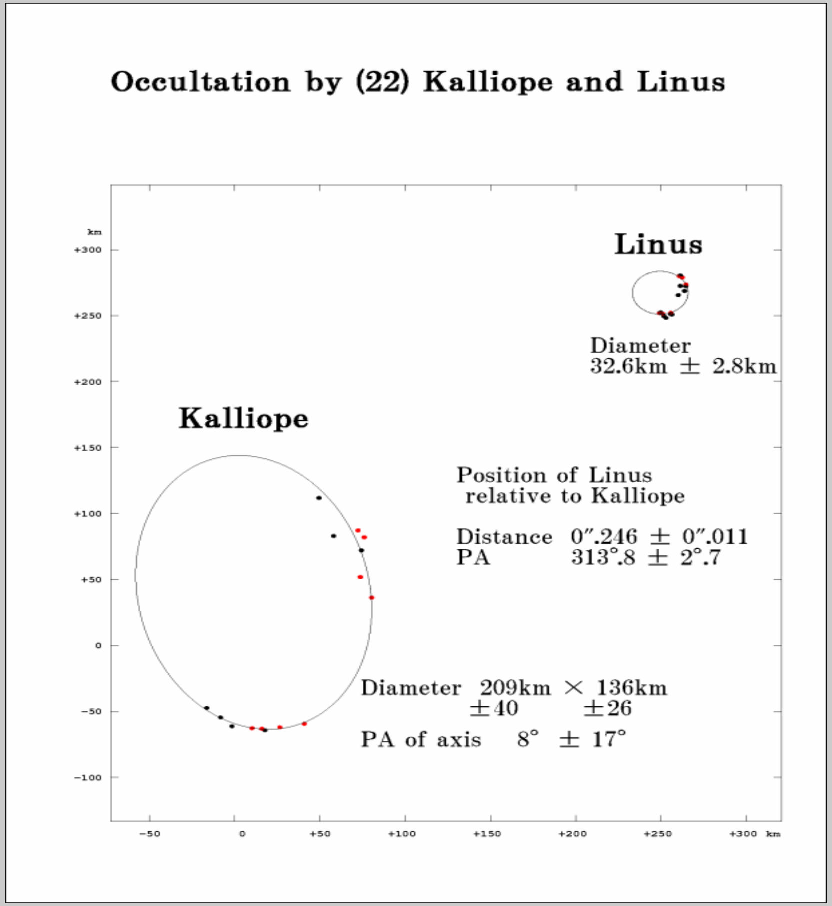


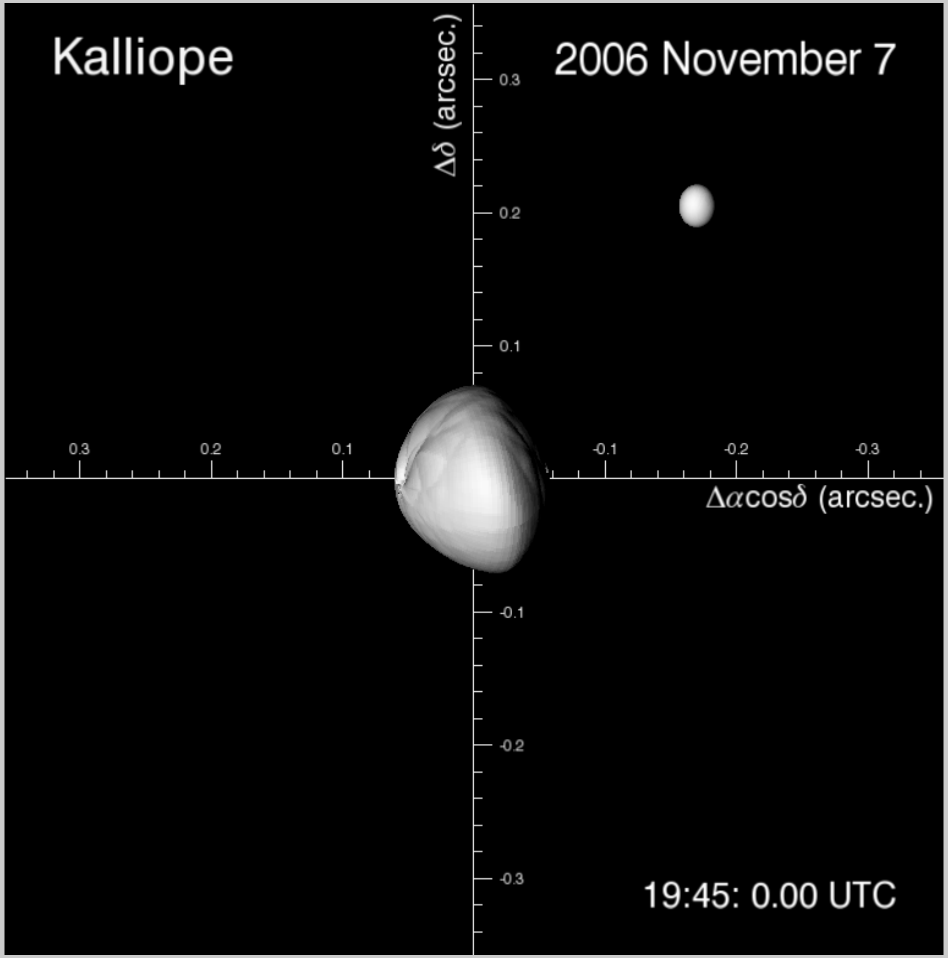


(22)Kalliope & Linus on 2006.11.08

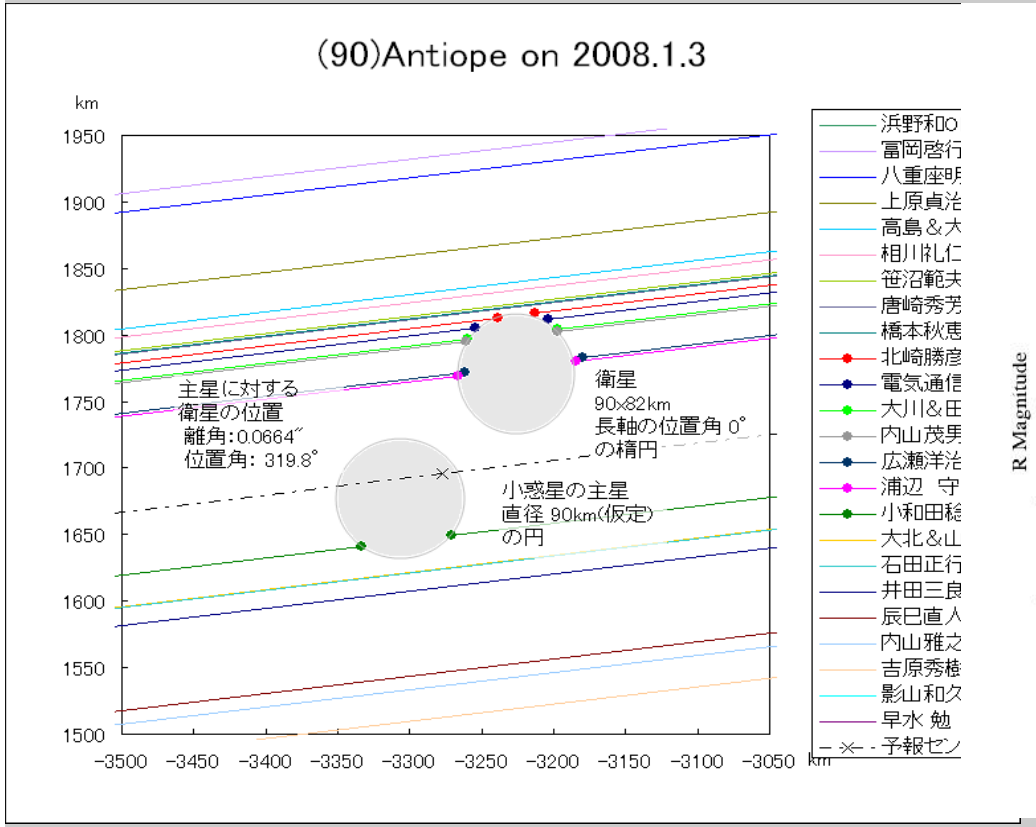


Observations

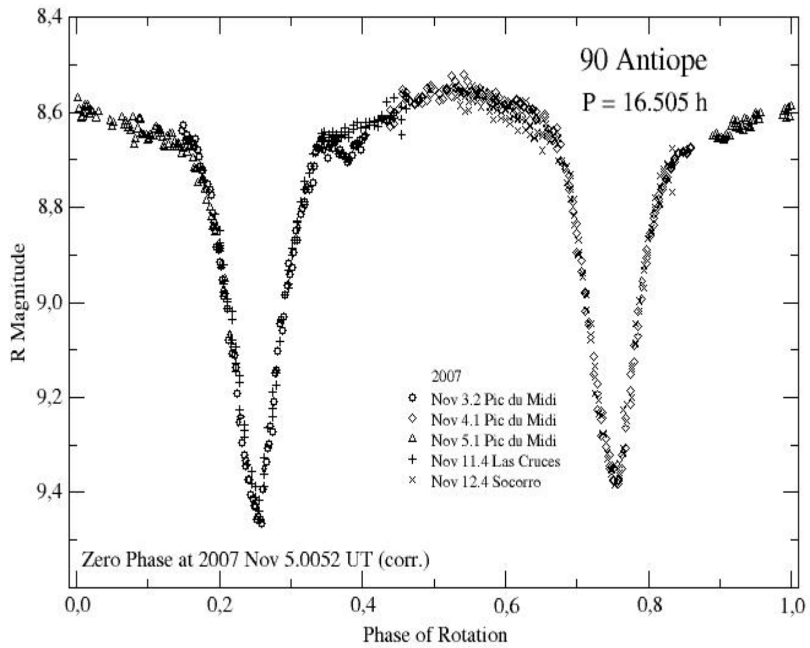




Antiope occultation

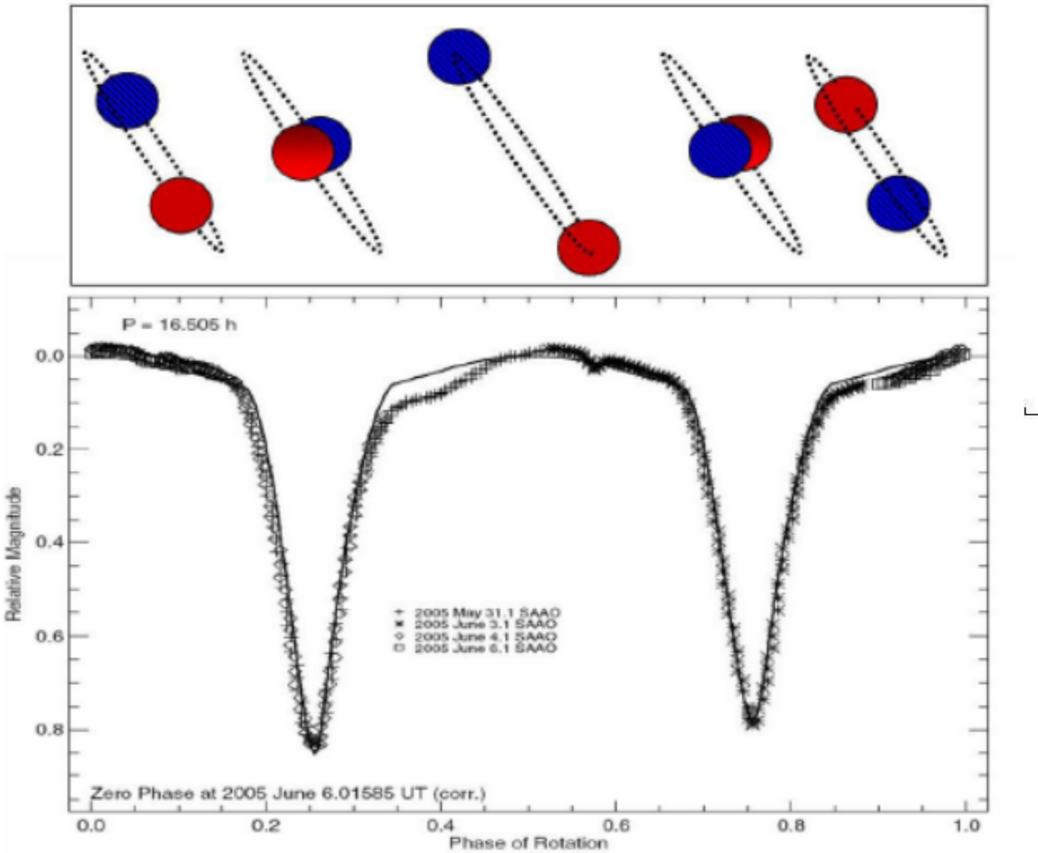


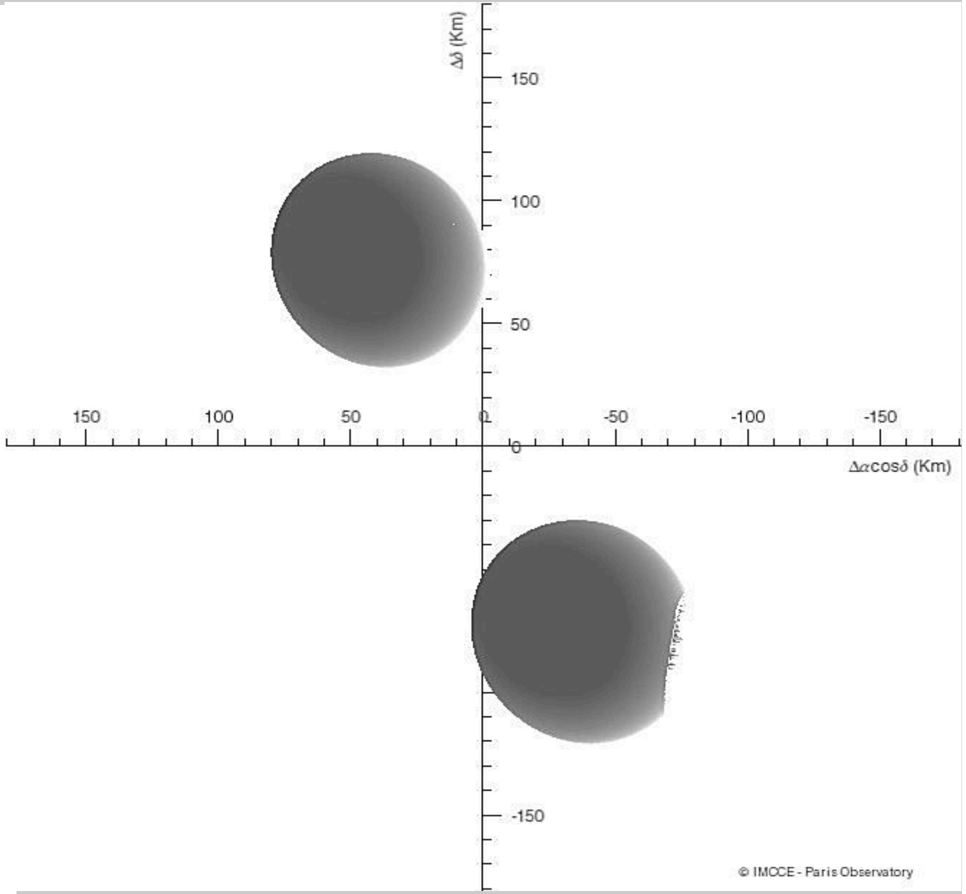
Occultations



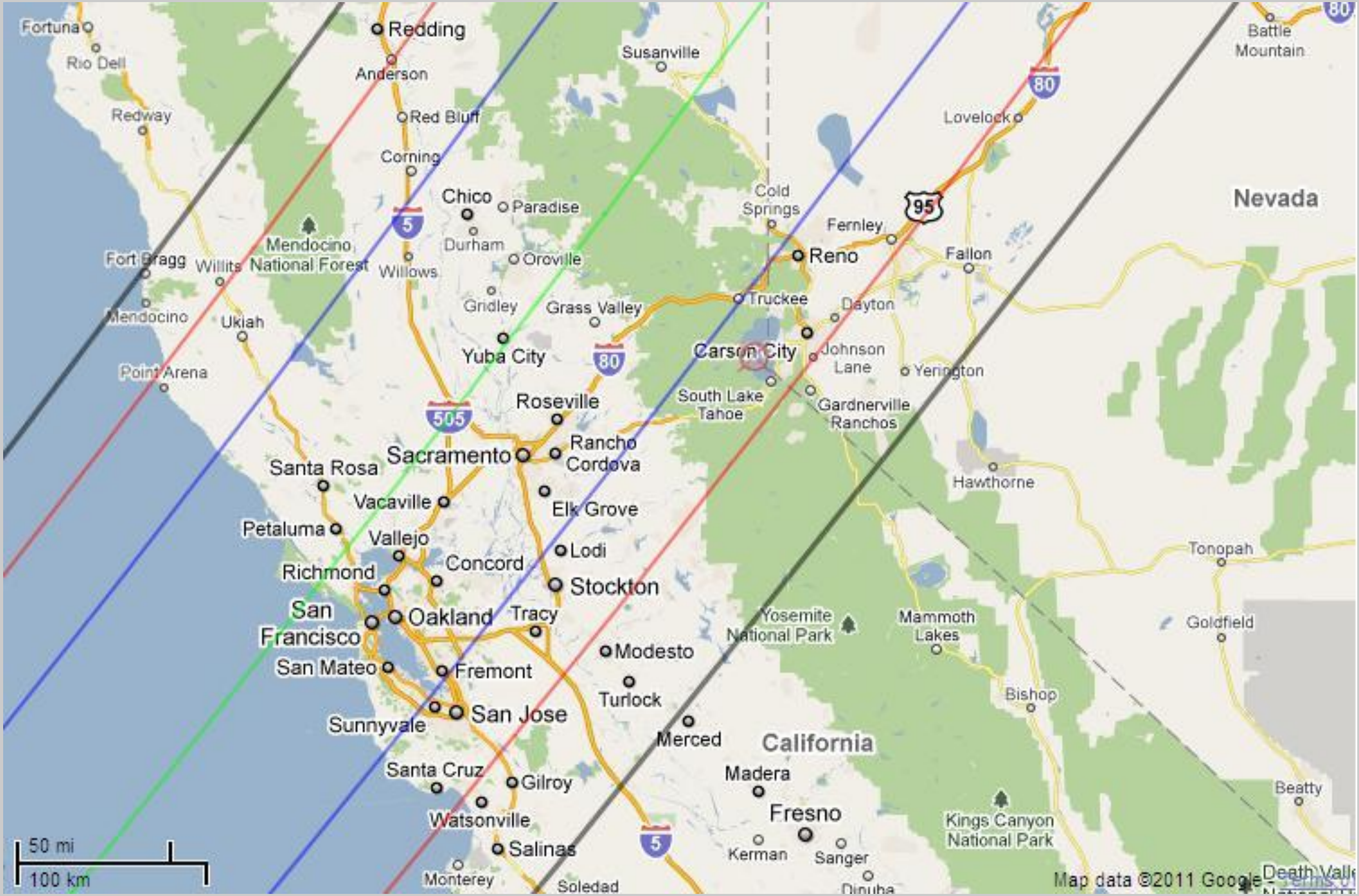
Light curves

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

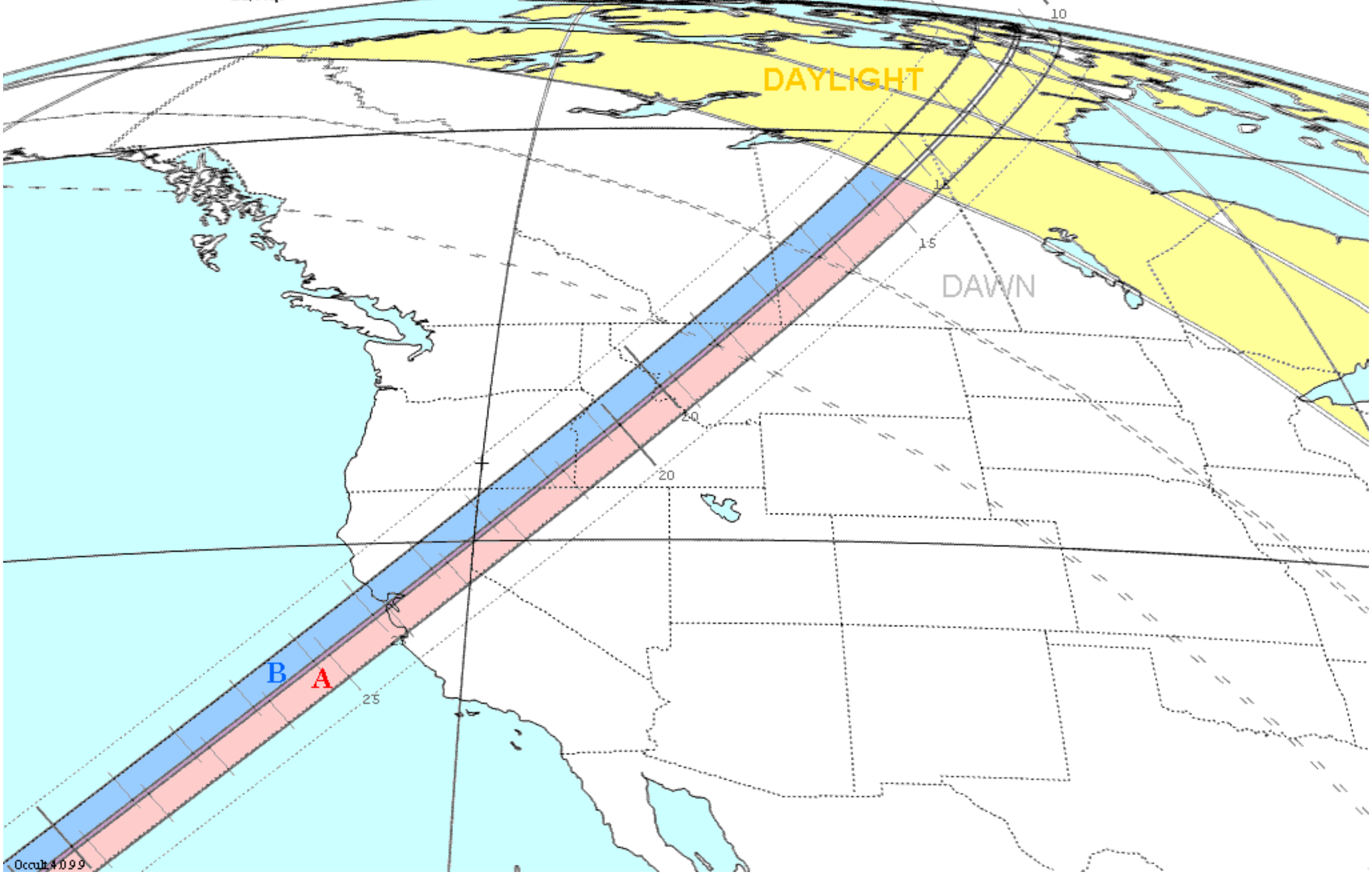
Star:
Mv = 6.7 Mp = 8.3 Mr = 5.8
RA = 22 46 14.213 (J2000)
Dec = -11 9 59.06 ...
[of Date: 22 46 53, -11 6 6]
Prediction of 2010 Sep 30.0

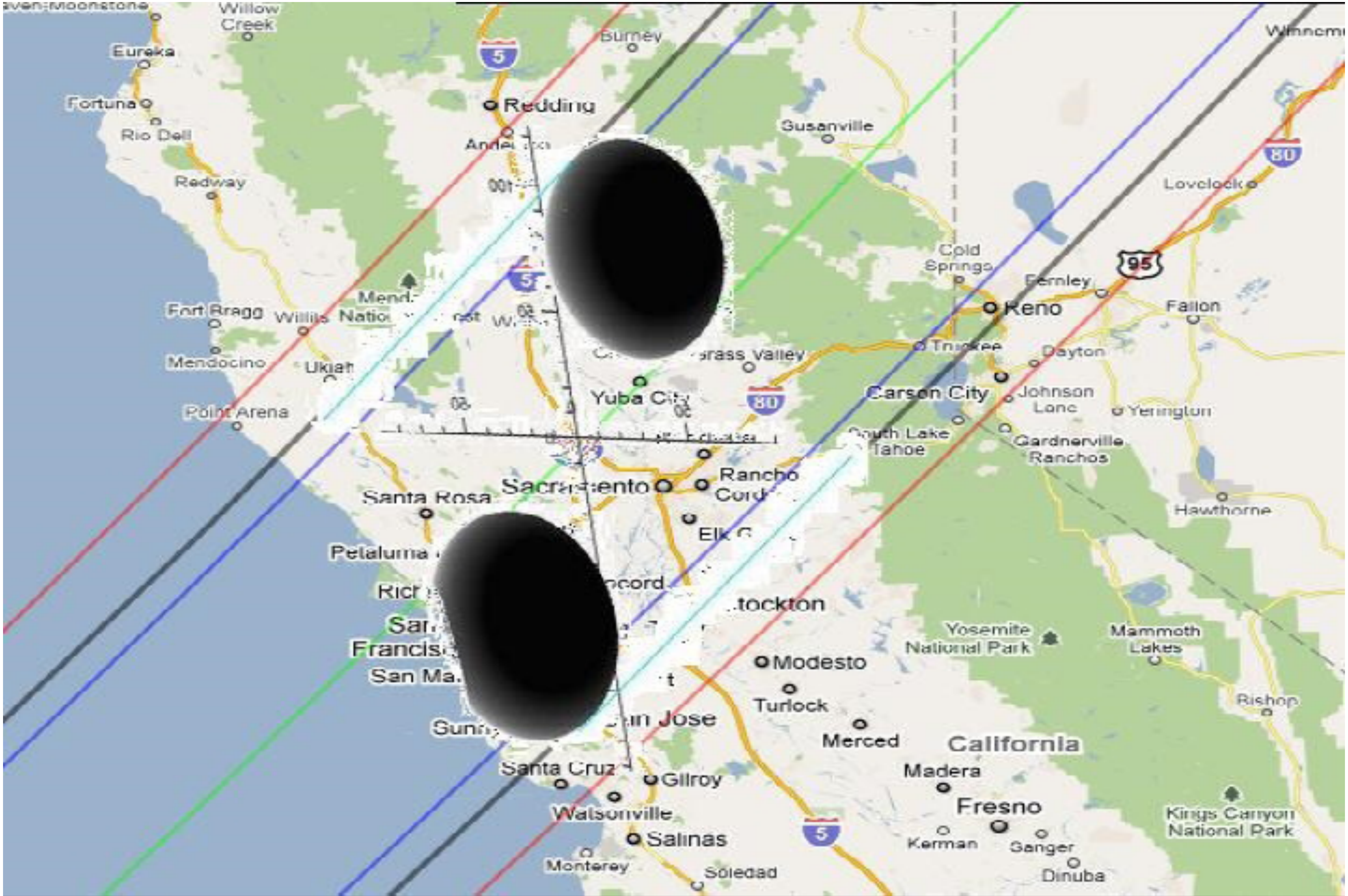
M1 III star

Max Duration = 26.7 & 25.4 secs
Mag Drop = 5.8 (6.2r)
Sun : Dist = 138 deg
Moon: Dist = 10 deg
: 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"
secs

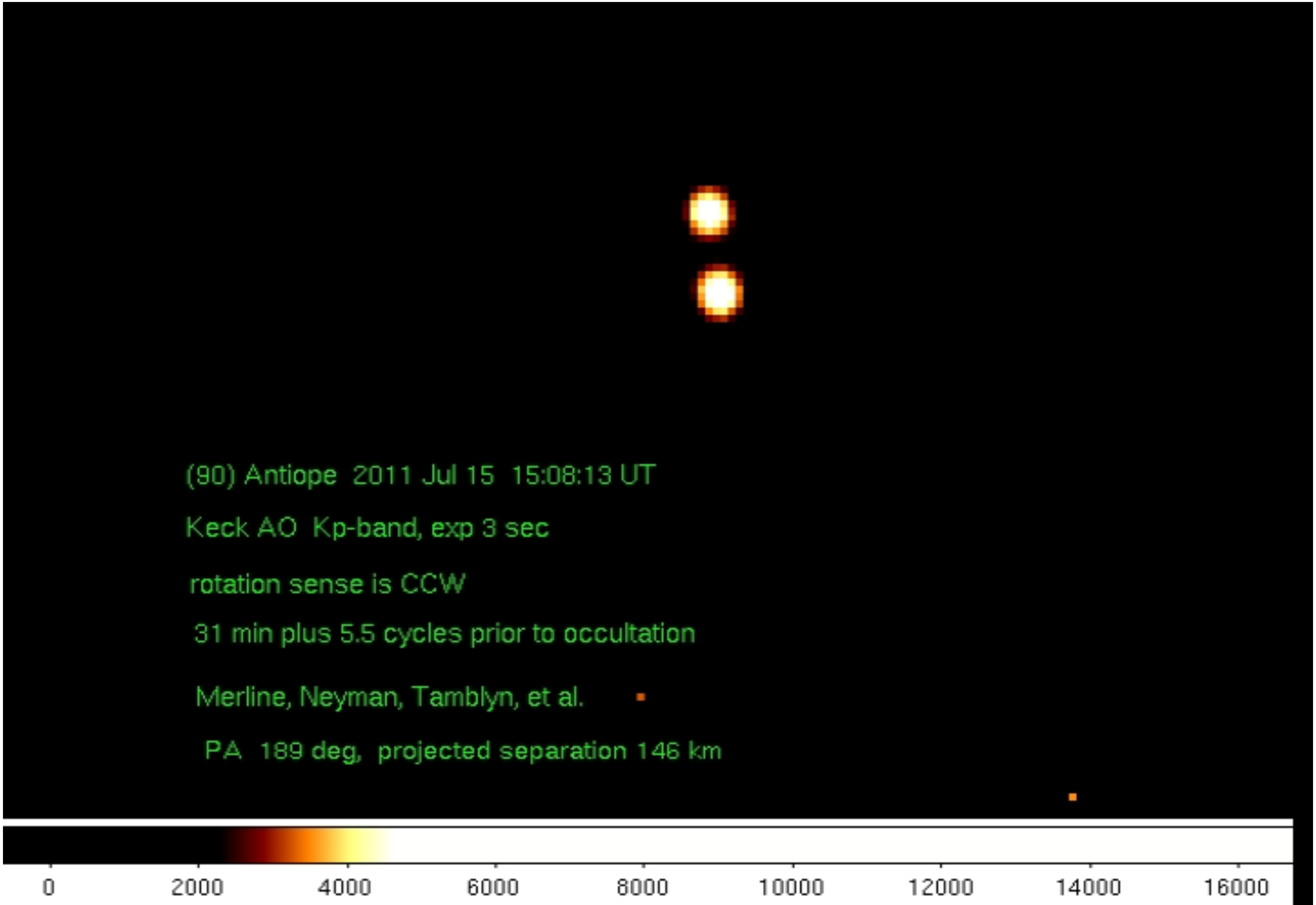
Double (not in WDS) Variable star Asteroid has 1 moon(s). 84km at 171km
LQ Aqr



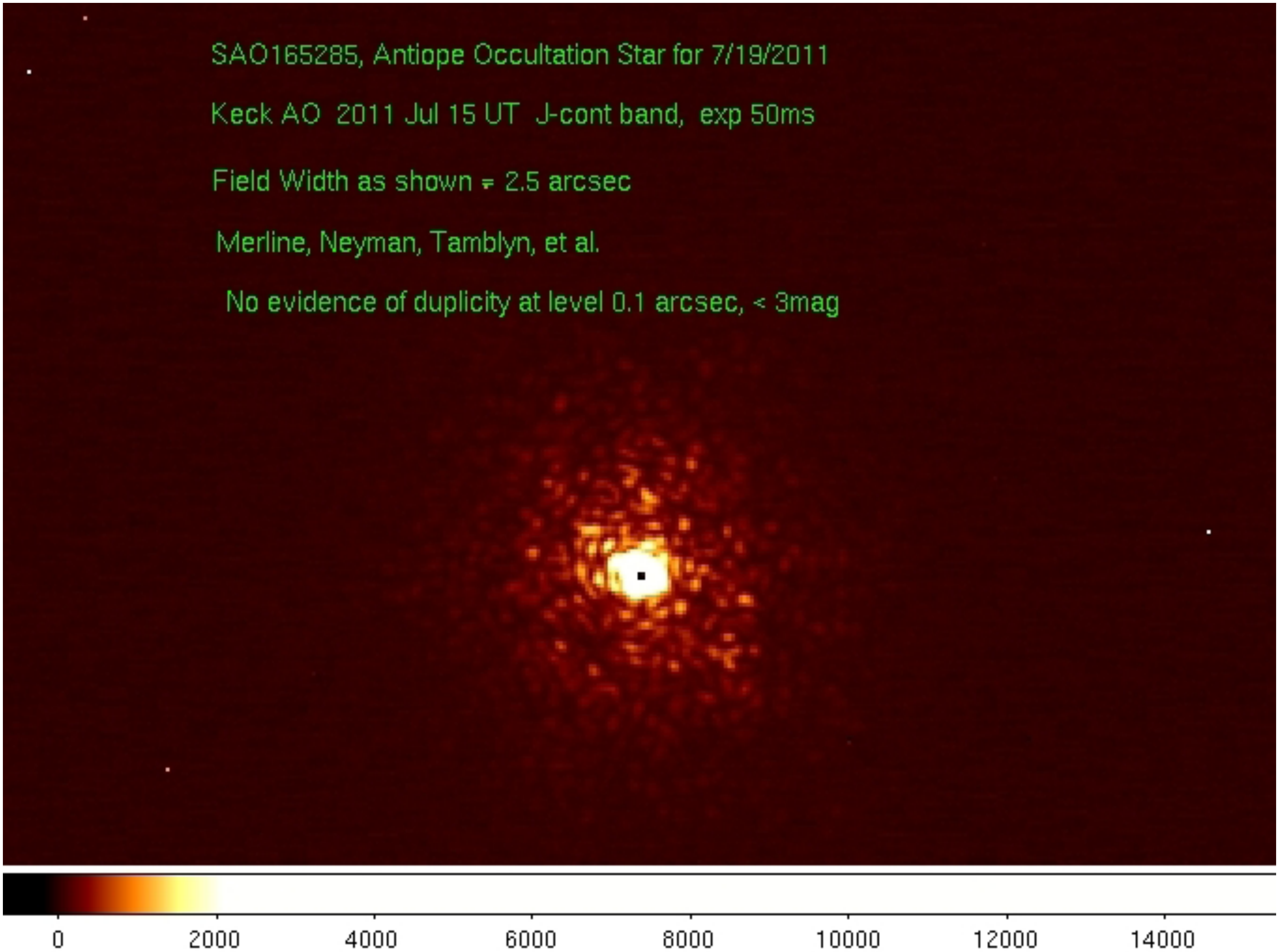


(90) Antiope occultation, july 20

IOTA meeting at Sierra College, Rocklin, CA

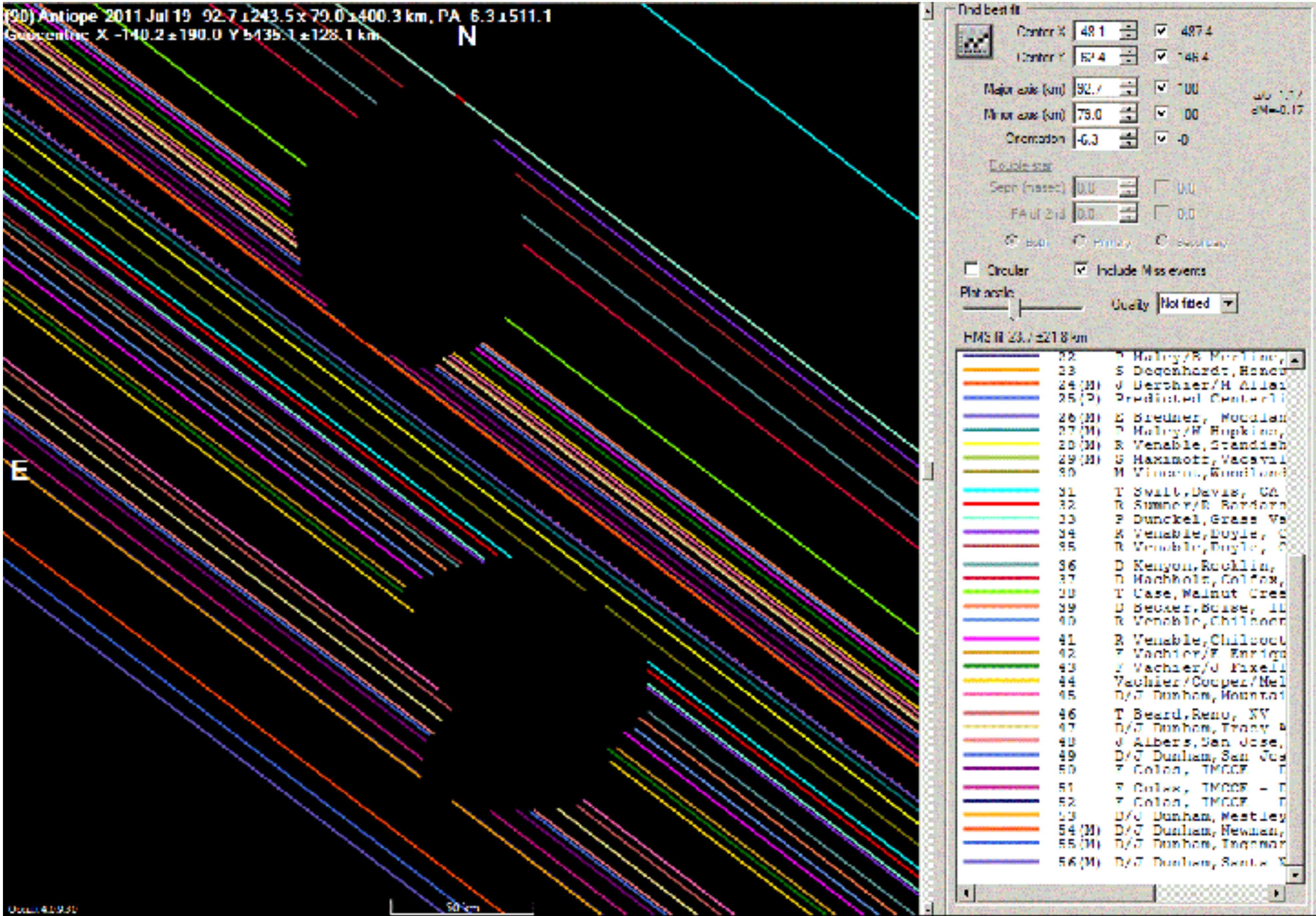


(90) Antiope occultation, july 20

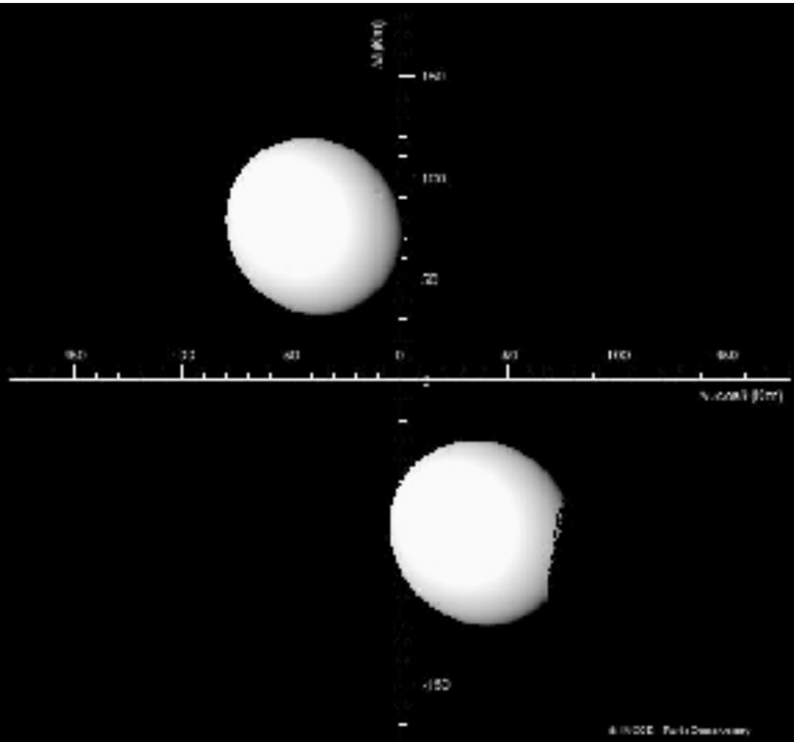


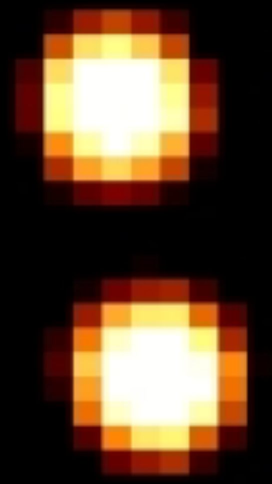
SAO165285, Antiope Occultation Star for 7/19/2011
Keck AO 2011 Jul 15 UT J-cont band, exp 50ms
Field Width as shown = 2.5 arcsec
Merline, Neyman, Tamblyn, et al.
No evidence of duplicity at level 0.1 arcsec, < 3mag
0
2000
4000
6000
8000
10000
12000
14000

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

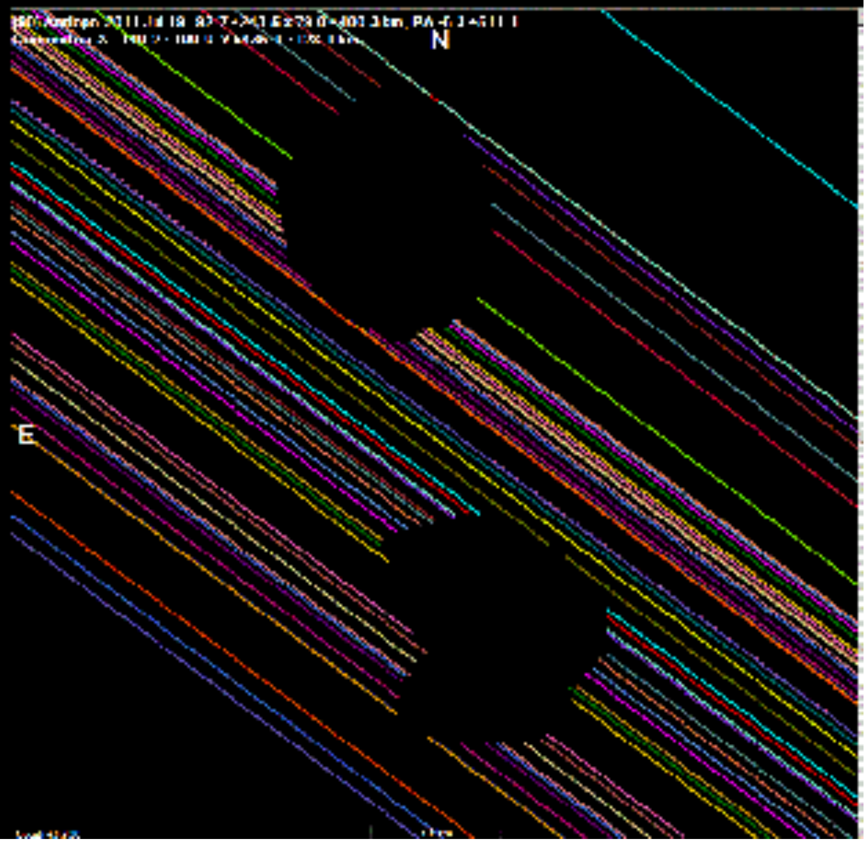


(90) Antiope occultation, july 20





Keck Télescope vs 20 mm lens ;-)



(90) Antiope occultation, july 20