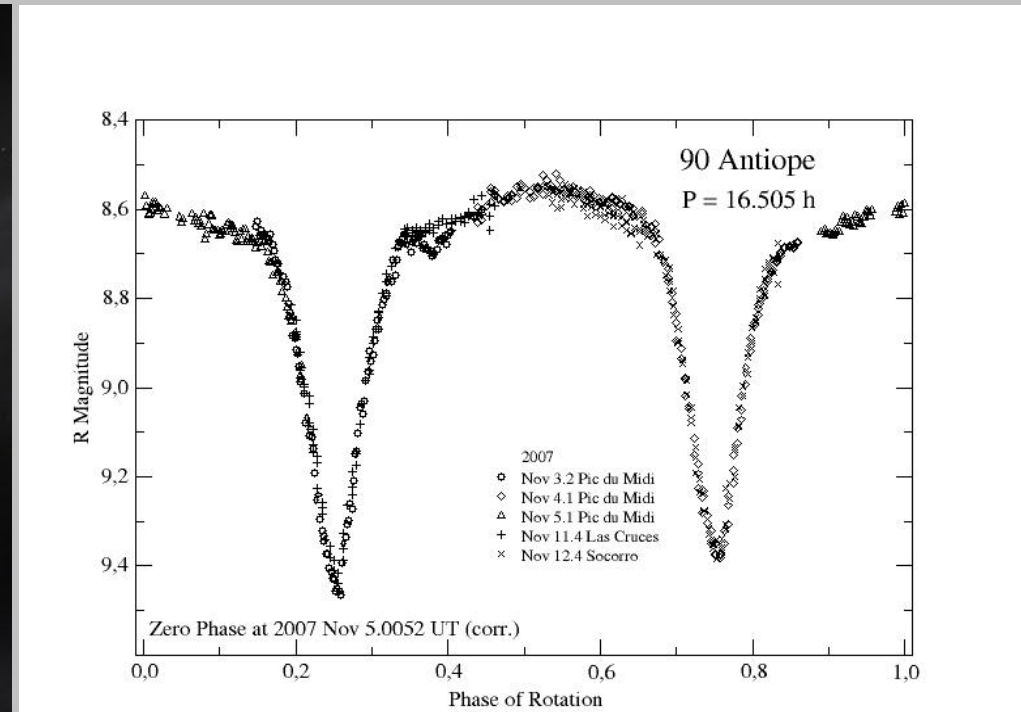


Asteroids masses from future ephemerides, densities from binaries

François COLAS
Petr KUCHYNKA

Institut de Mécanique Céleste – Observatoire de Paris
Jet Propulsion Laboratory



Pisa, Italy
May 4-6, 2011

Solar System science
before and after Gaia

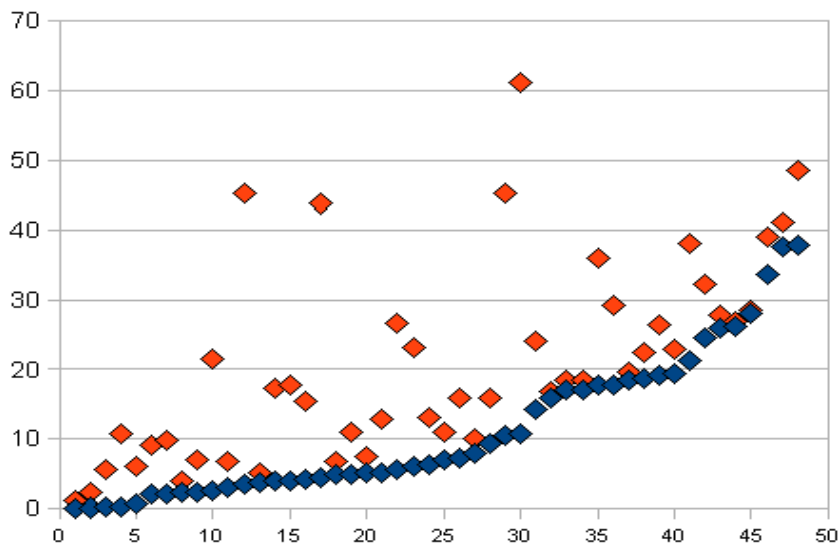
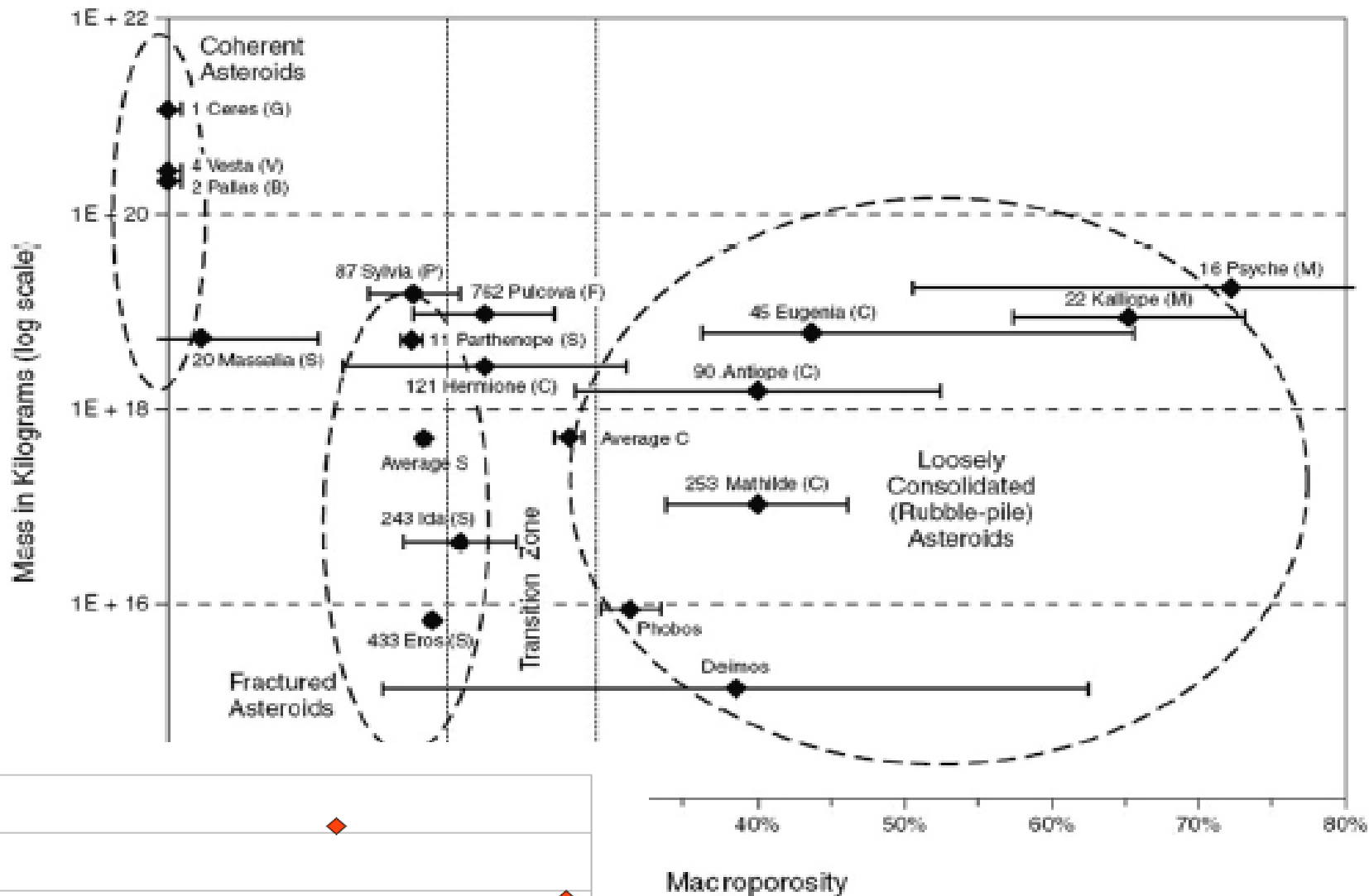
Densities measurements

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

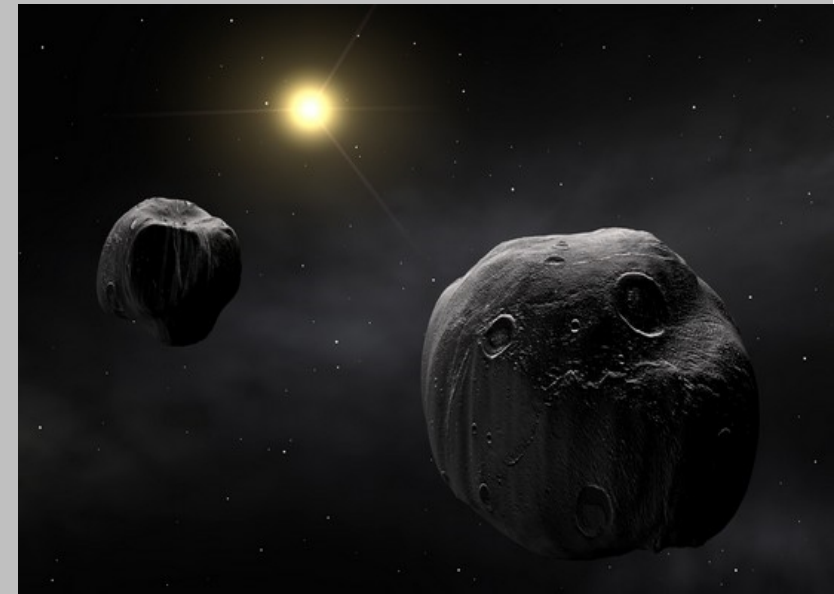


Accuracies of actual best masses (blue dots) and best densities (red dots)

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

**Mars orbit perturbations,
Mutual perturbations,
Flyby,
Binary asteroids**

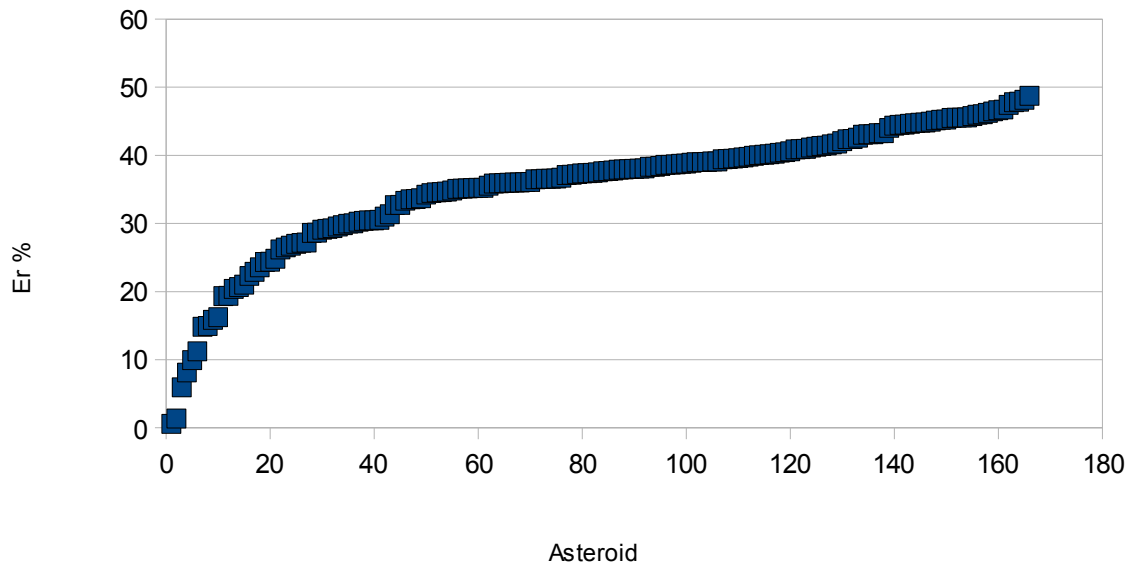
GAIA will permit to determine several masses



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

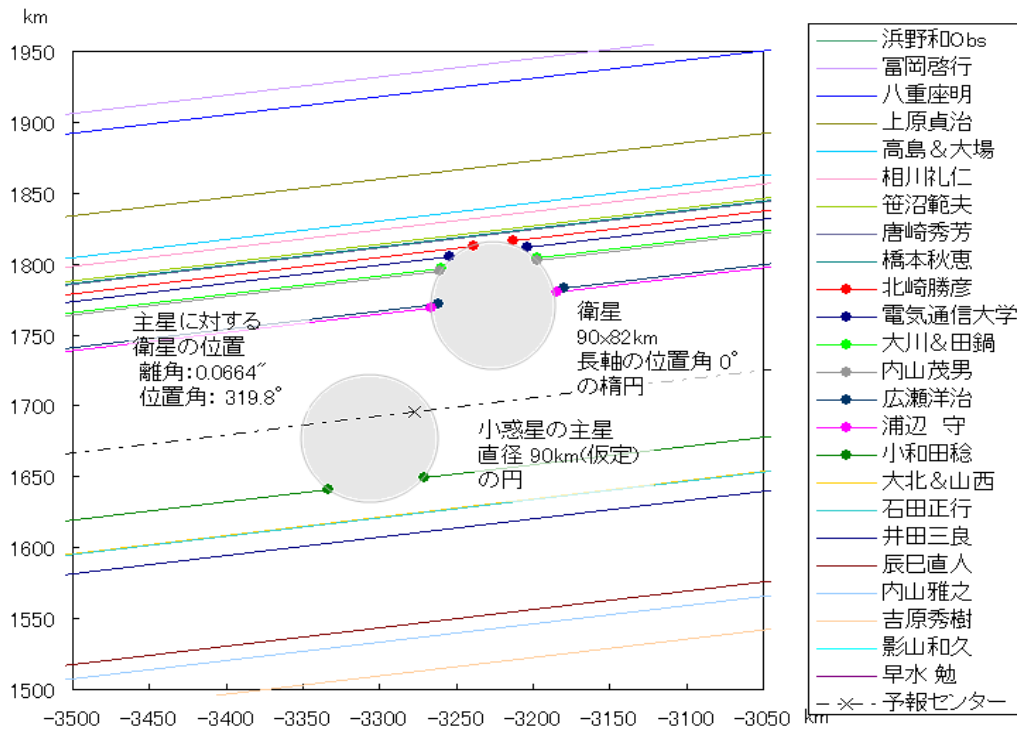
30% => 50

Mass determination

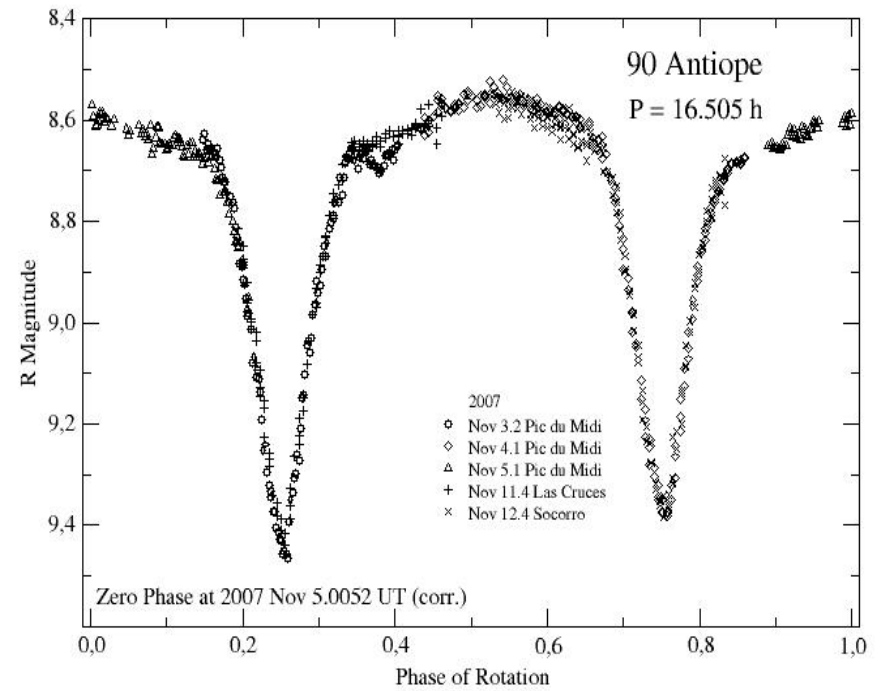


Binaries

(90)Antiope on 2008.1.3

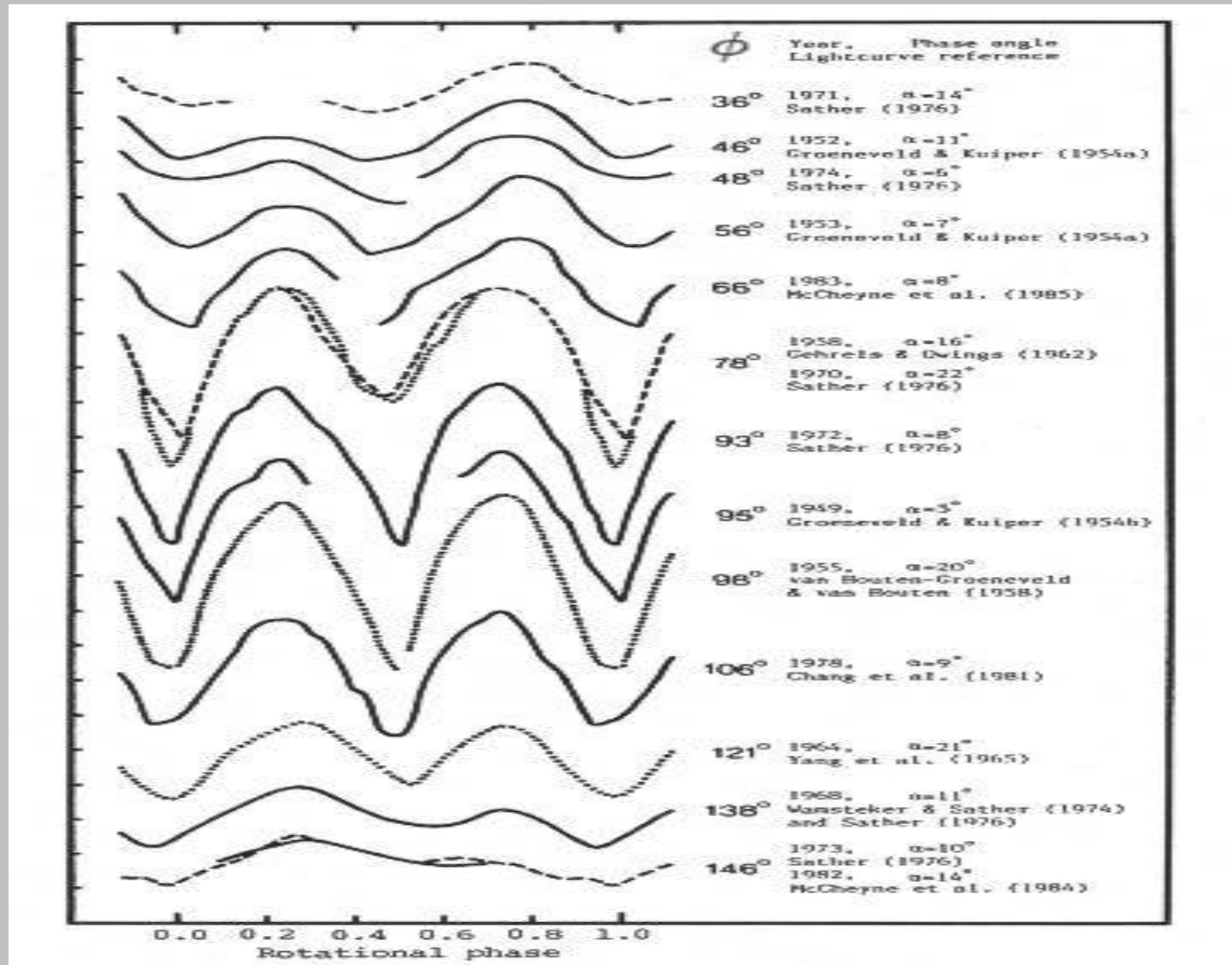


Occultations

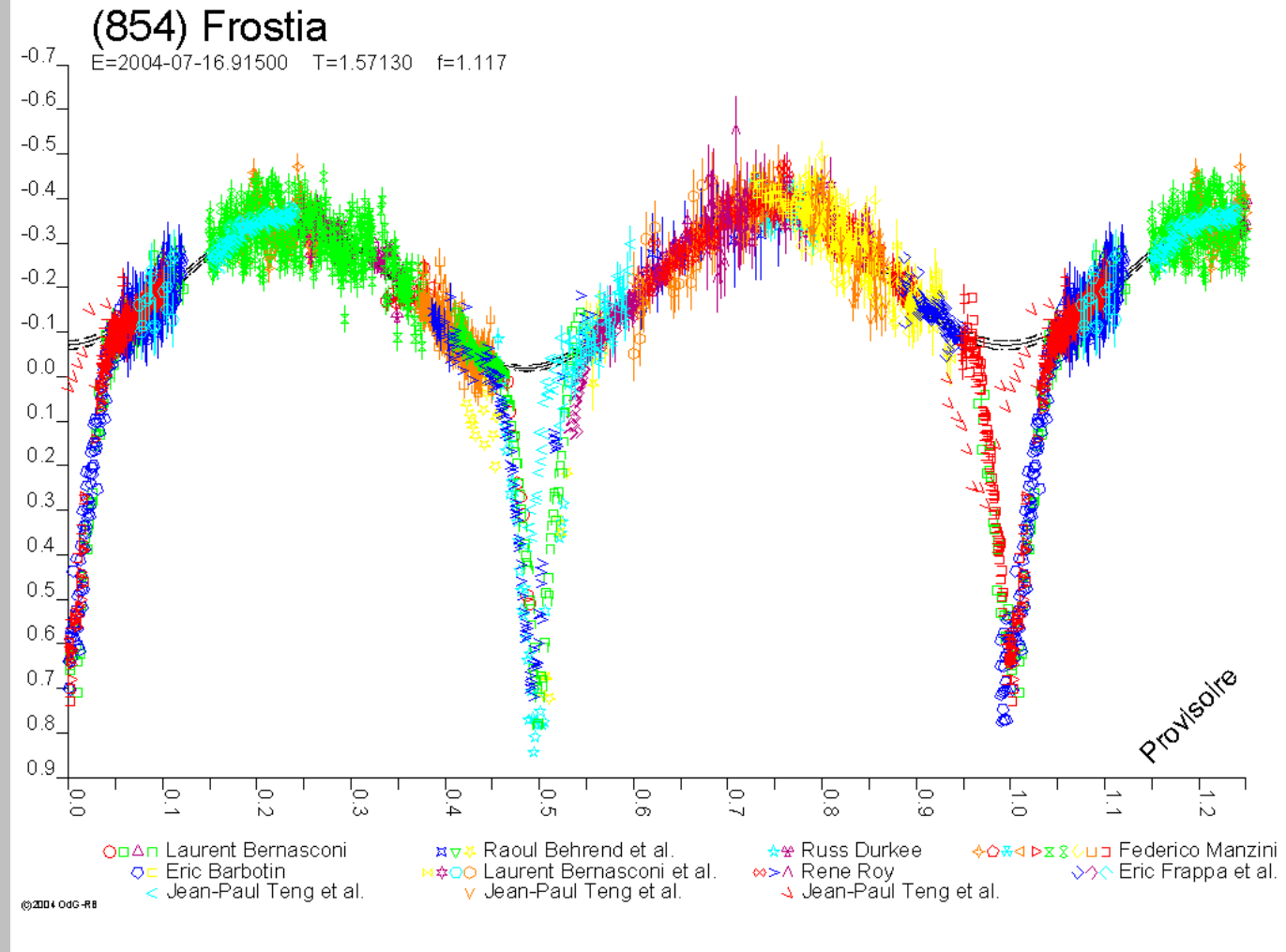
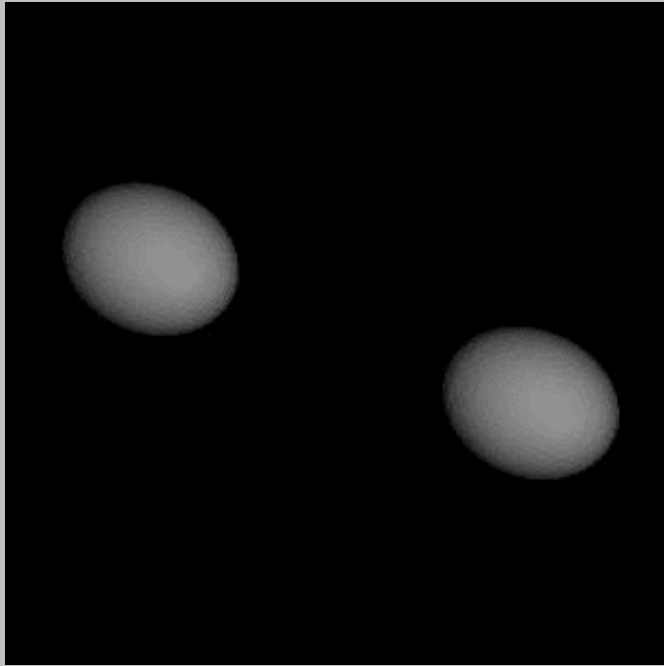


Light curves

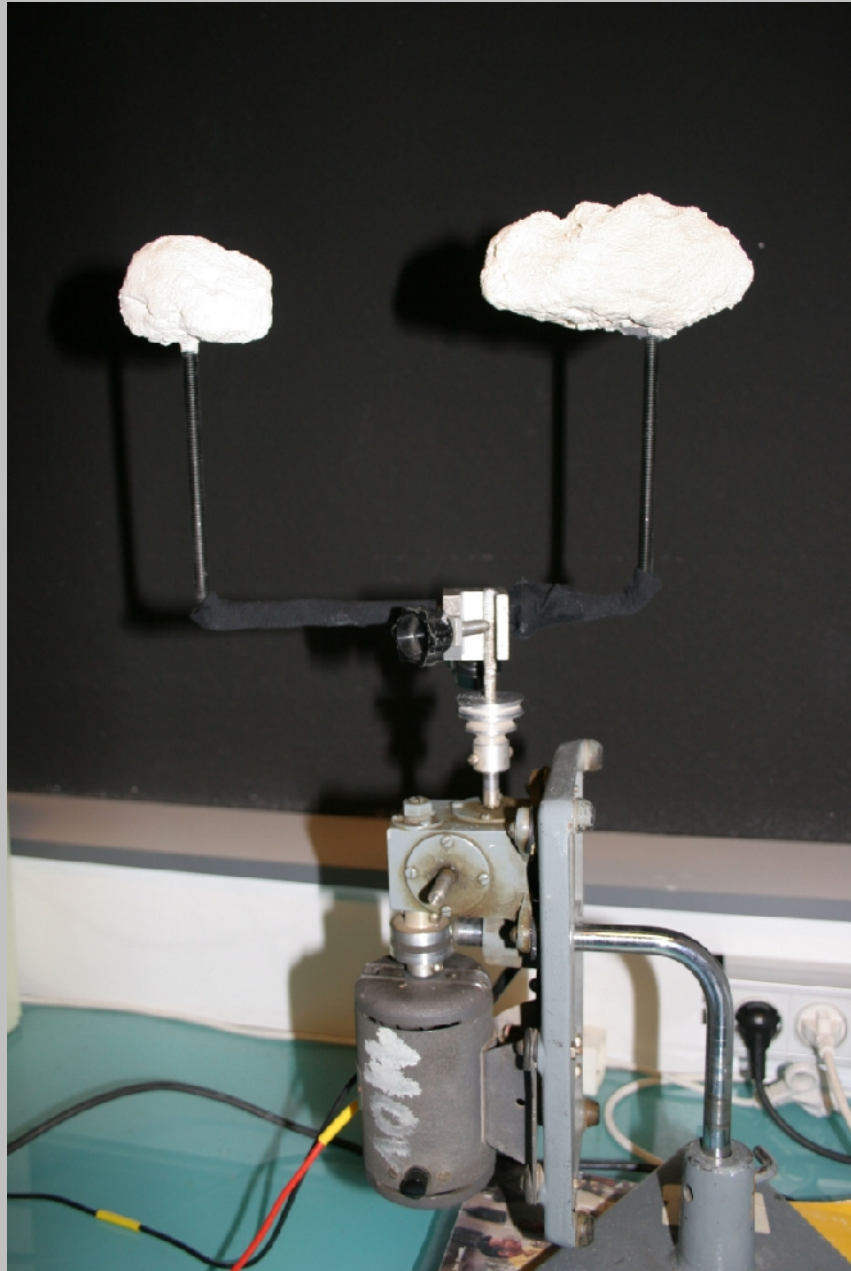
Single 39 Laetitia light curve



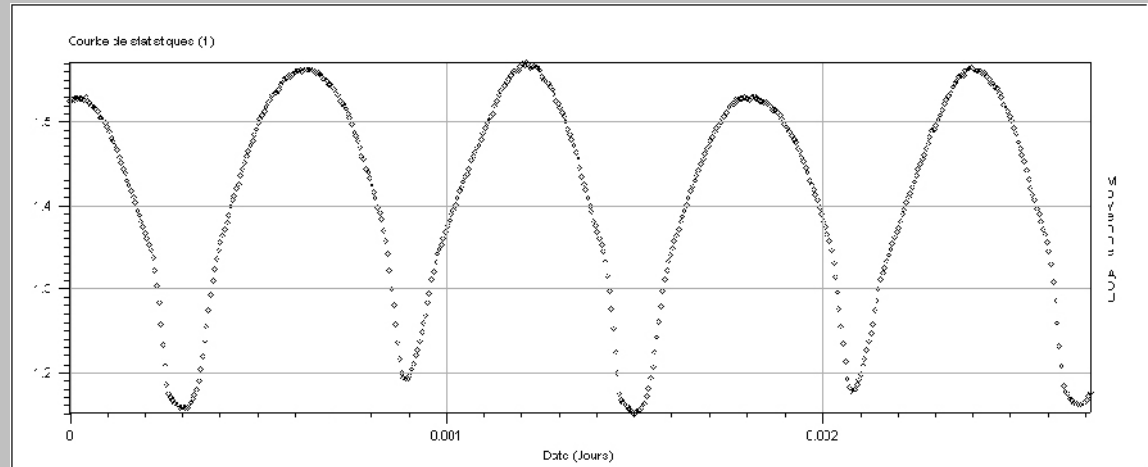
Binary asteroid light curves



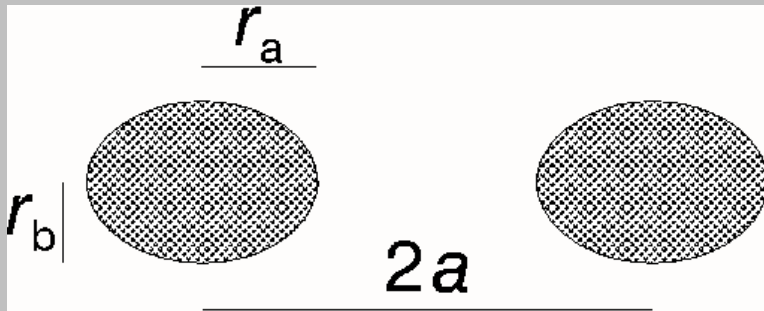
PHOTOMETRIE : Eléments physiques (λ_p, β_p) – travaux pratiques



Réalisation du Lycée de l'Arc



Direct density estimation

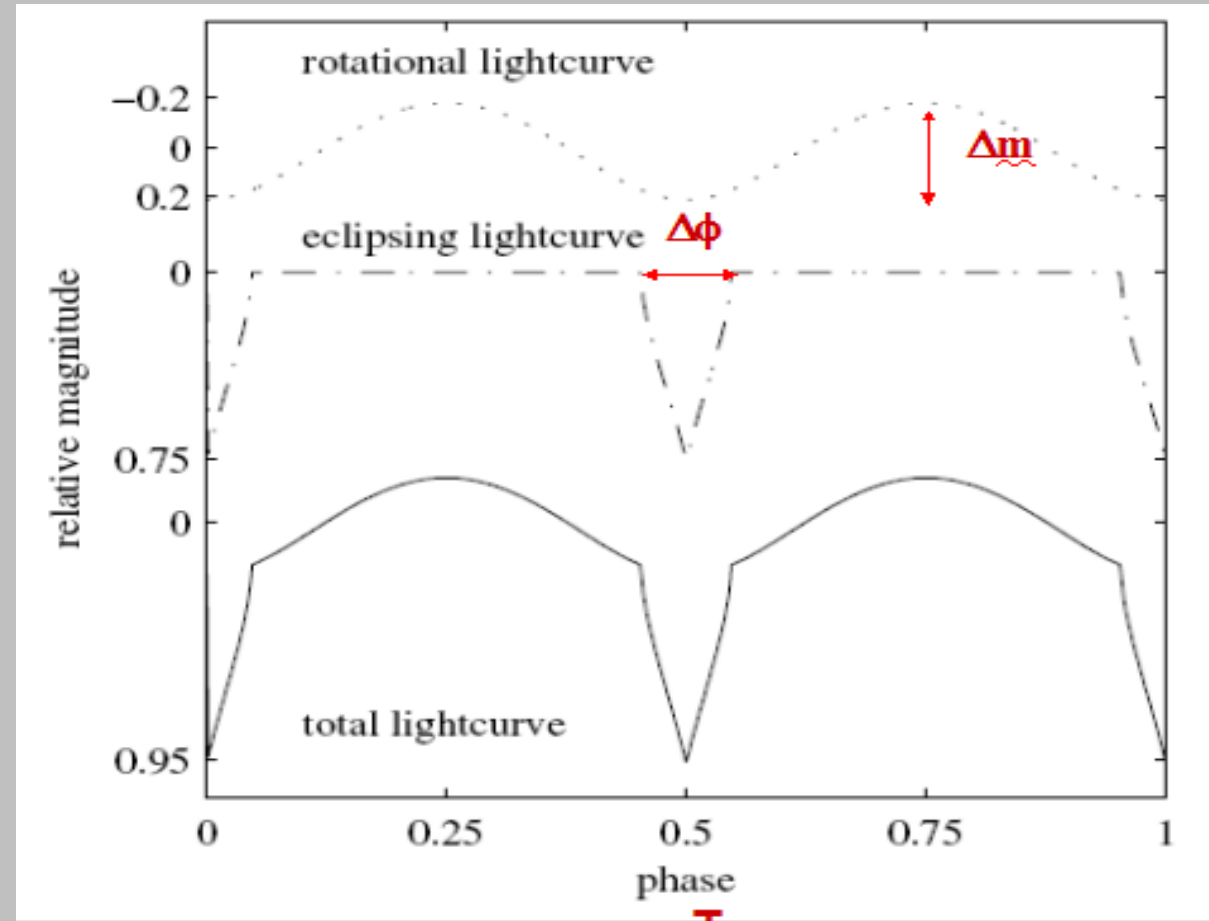


$$r_b/r_a = 10^{-0.4\Delta m}$$

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

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

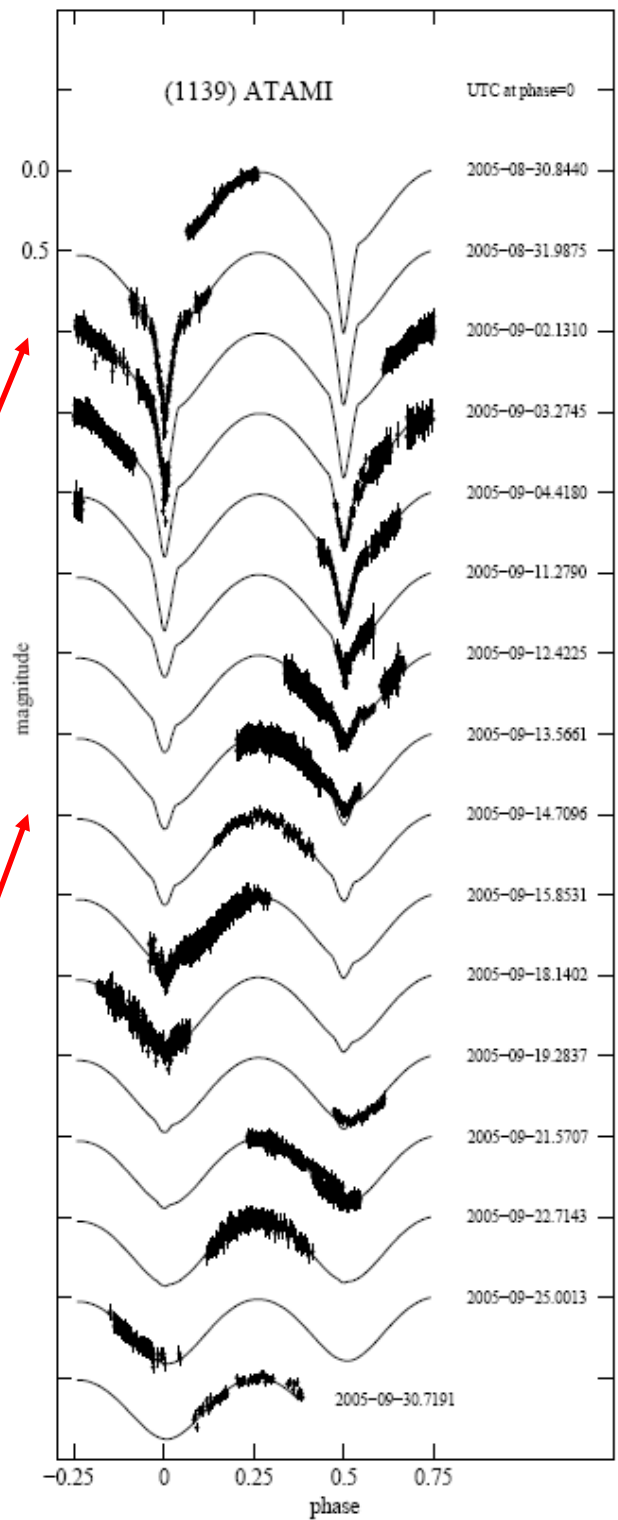
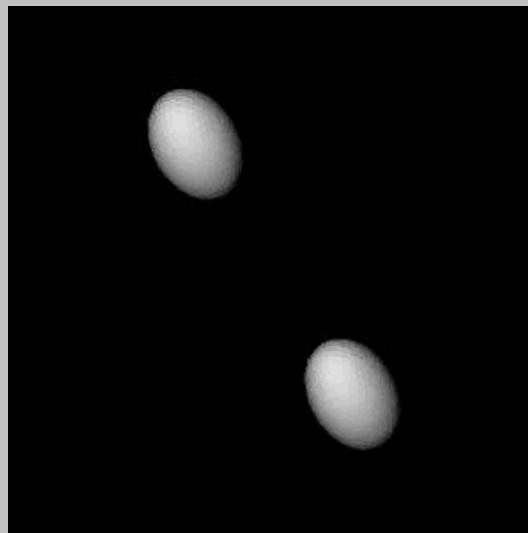
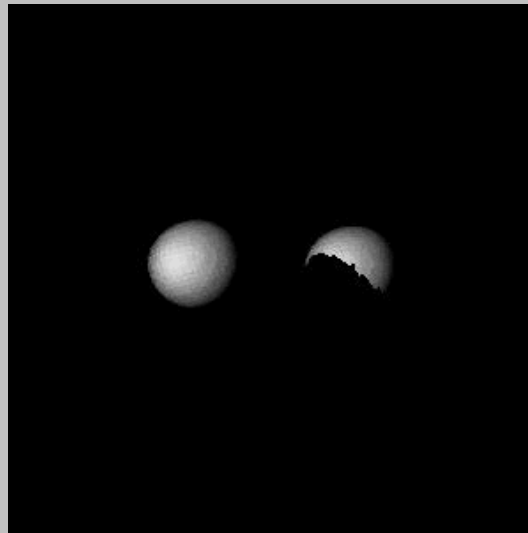
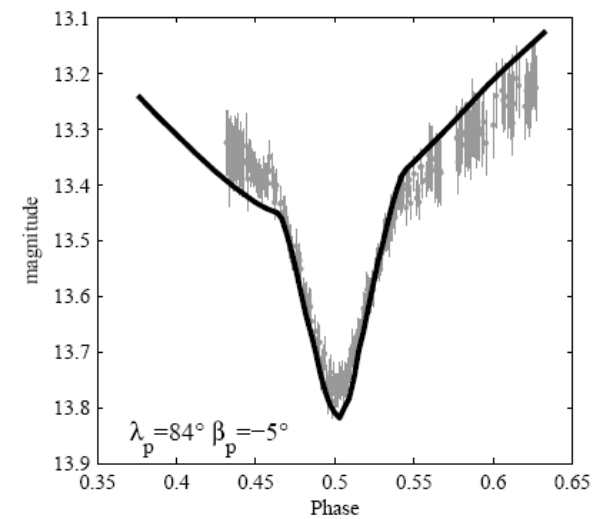
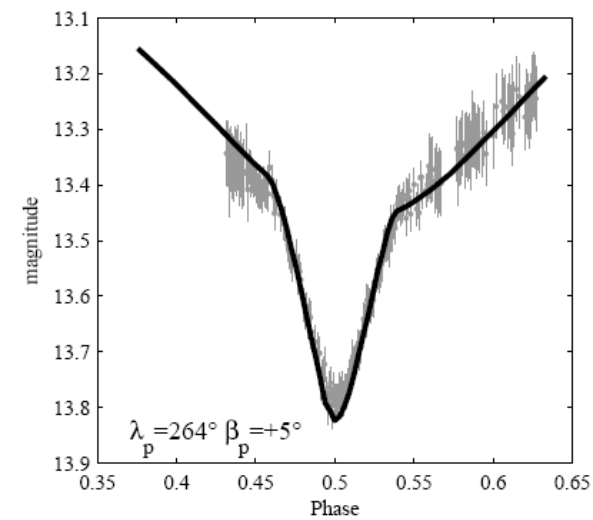
$$\rho = \frac{M}{\frac{4}{3}\pi r_a r_b^2}$$



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

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

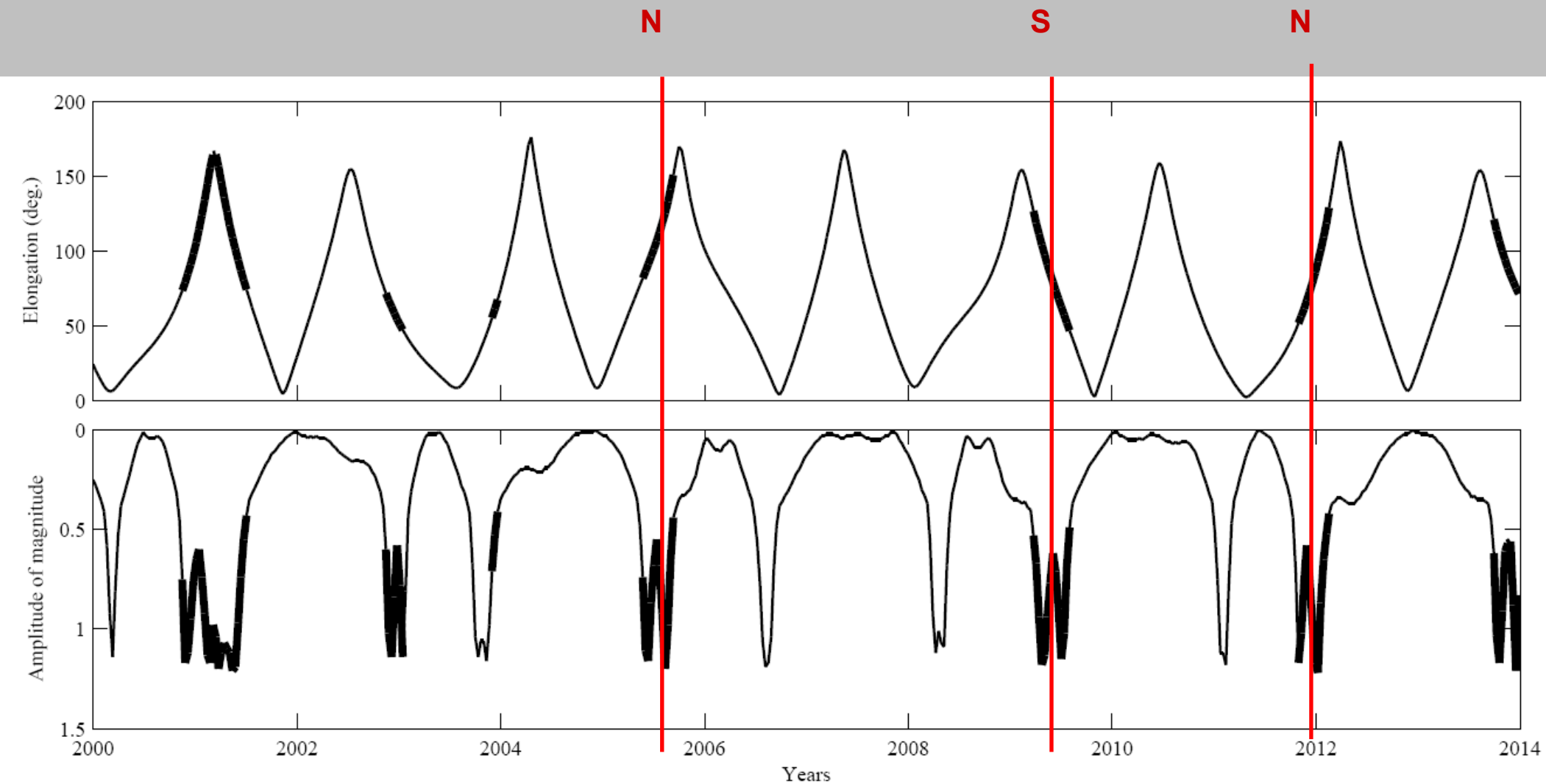
R. Behrend¹, F. Manzini², A. Klotz^{3,4}, F. Colas^{5,6}, Y. Damerdjji^{3,4}, S.J. Ostro⁷, P. Antonini^{8,6},
E. Barbotin⁶, L. Bernasconi^{9,6}, C. Cavadore¹⁰, S. Charbonnel^{11,6}, J. Coloma¹², R. Crippa¹³, F. Kugel¹⁴,
A. Leroy¹⁵, J.M Llapasset¹⁶, A. Oksanen¹⁷, P. Pääkkönen¹⁸, R. Poncy^{19,6}, R. Roy^{20,6},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



Prédications...

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



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**

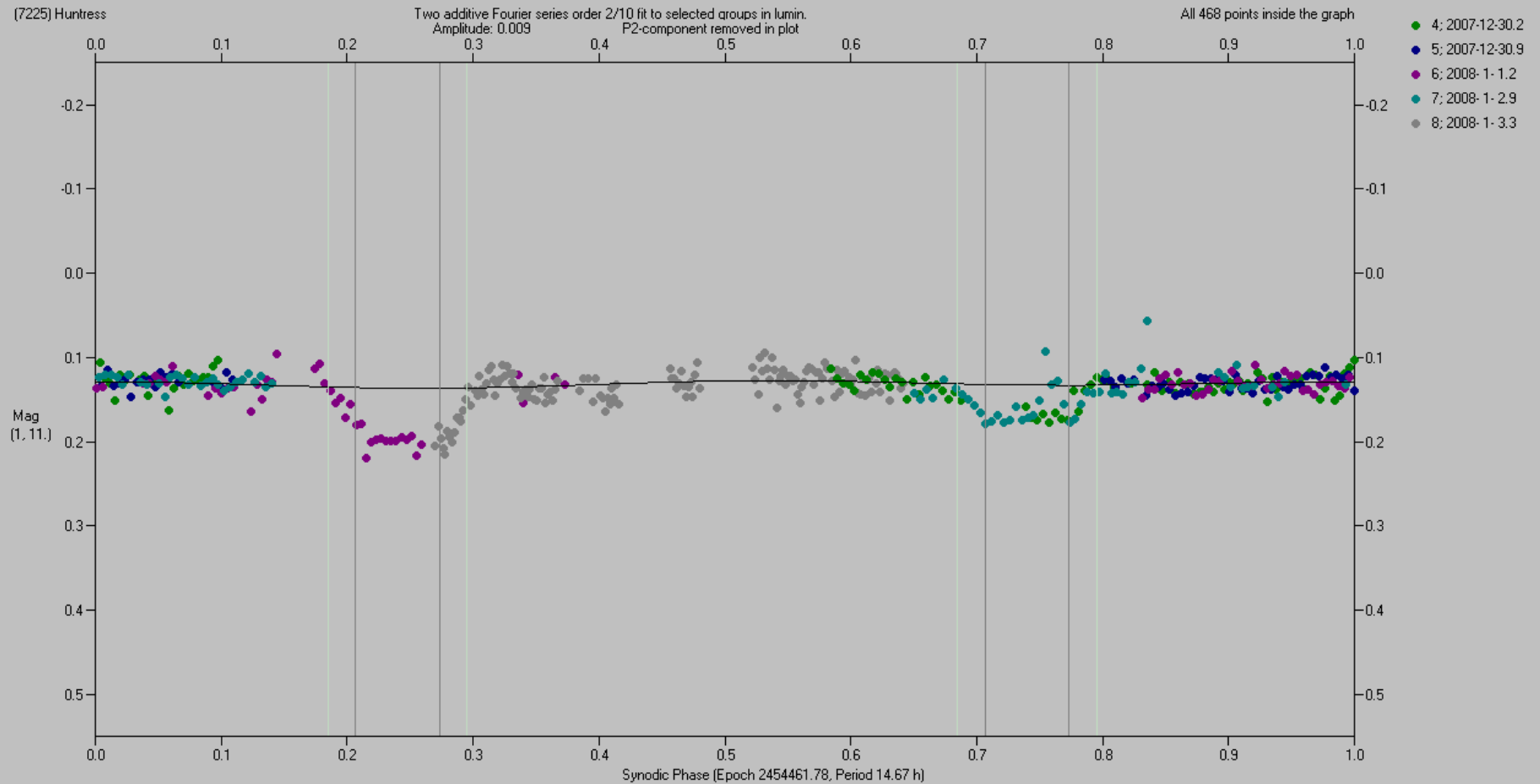
If we admit the validity of the detection criteria given above, and a mean value $\frac{r_b}{2a} \sim \frac{1}{6}$, we can compute

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

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.

(7225) Huntress

An exemple of low amplitude transit / occultation



$$P_{orb} = 14.67 \pm 0.01 \text{ h}$$
$$D_2/D_1 = 0.21 \pm 0.02$$
$$P_1 = 2.4400 \pm 0.0001 \text{ h}$$
$$A_1 = 0.11 \text{ mag}$$

P.Pravec

We know 162 multiple astéroïds (5 triples, 1 quadruple) (*may 2010*)

**35 NEOs, 7 Mars-Crossers,
62 MBO, 2 Trojans, 56 TNOs**

- ***Discoveries,***

- **HST (47) --**
- **Ground based (29) – 8 m class telescopes (8-10m) with AO**
- **Ground based, light curves (62) – Small telescopes (1m-30cm),**
- **Radar (21) – Mainly Arecibo - NEO**
- **Space missions (1)**

Low resolution spectrography : minéralogy

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

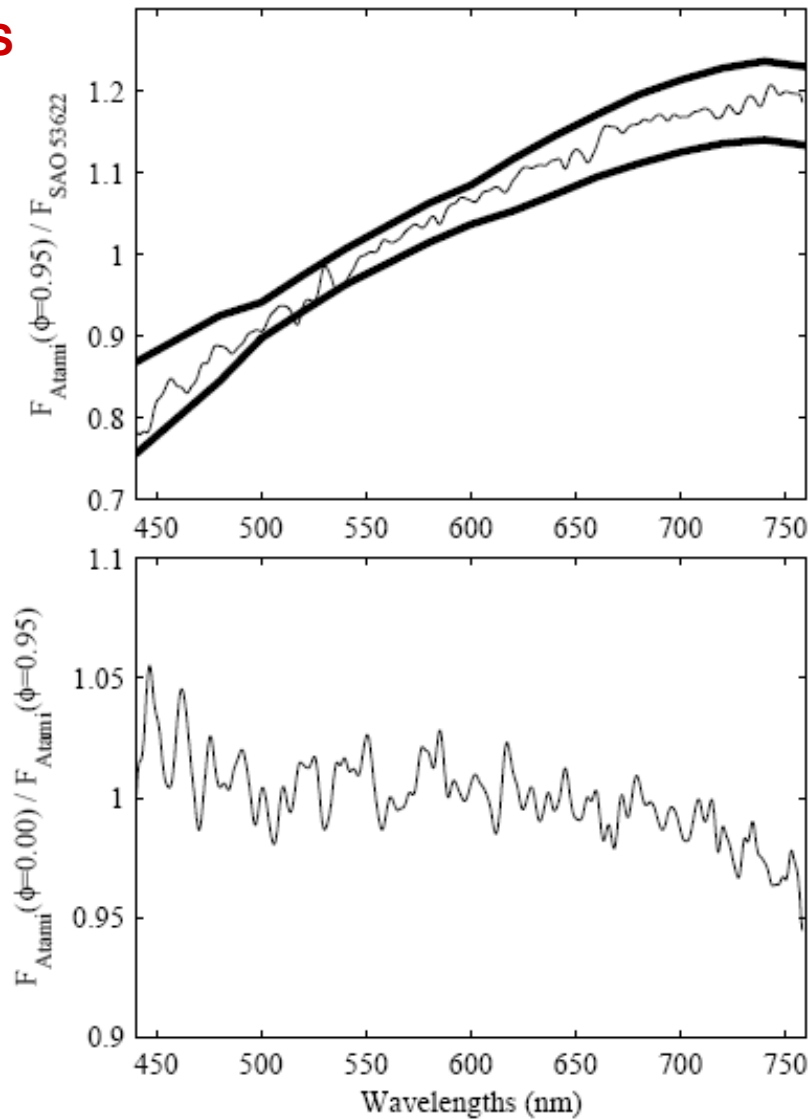
R. Behrend¹, F. Manzini², A. Klotz^{3,4}, F. Colas^{5,6}, Y. Damerdjji^{3,4}, S.J. Ostro⁷, P. Antonini^{8,6},
E. Barbotin⁶, L. Bernasconi^{9,6}, C. Cavadore¹⁰, S. Charbonnel^{11,6}, J. Coloma¹², R. Cripa¹³, F. Kugel¹⁴,
A. Leroy¹⁵, J.M Llapasset¹⁶, A. Oksanen¹⁷, P. Pääkkönen¹⁸, R. Poncy^{19,6}, R. Roy^{20,6}, and D. Starkey²¹

Infrared photometry
from ground based
observations

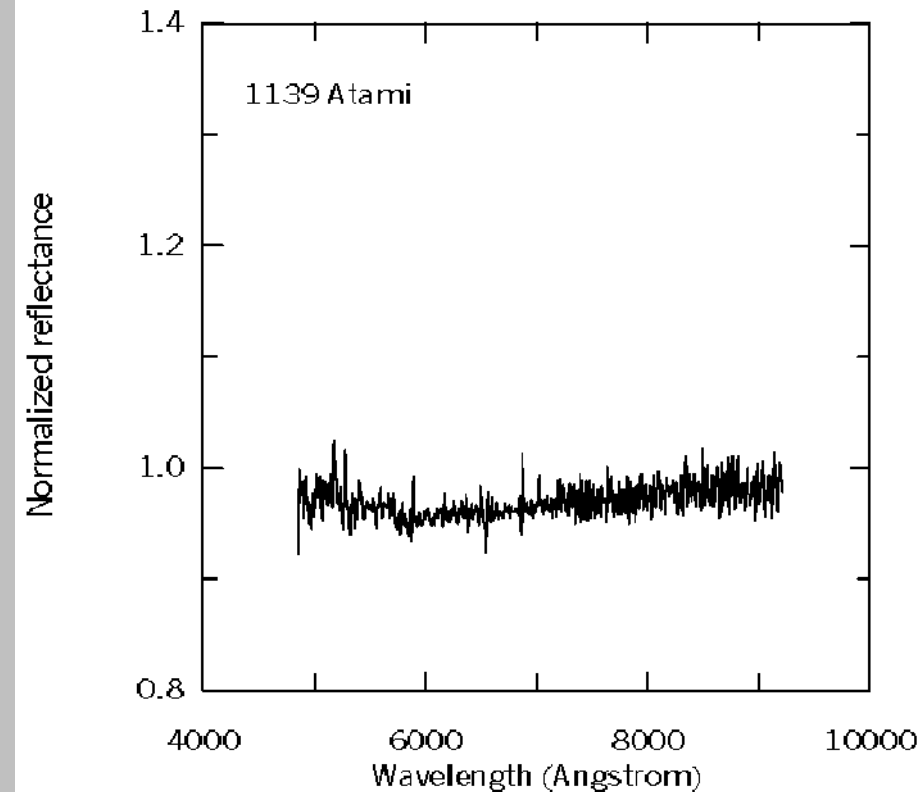
=>

Thermal inertia
(eclipse observations)

2005 type S
(pôle N)

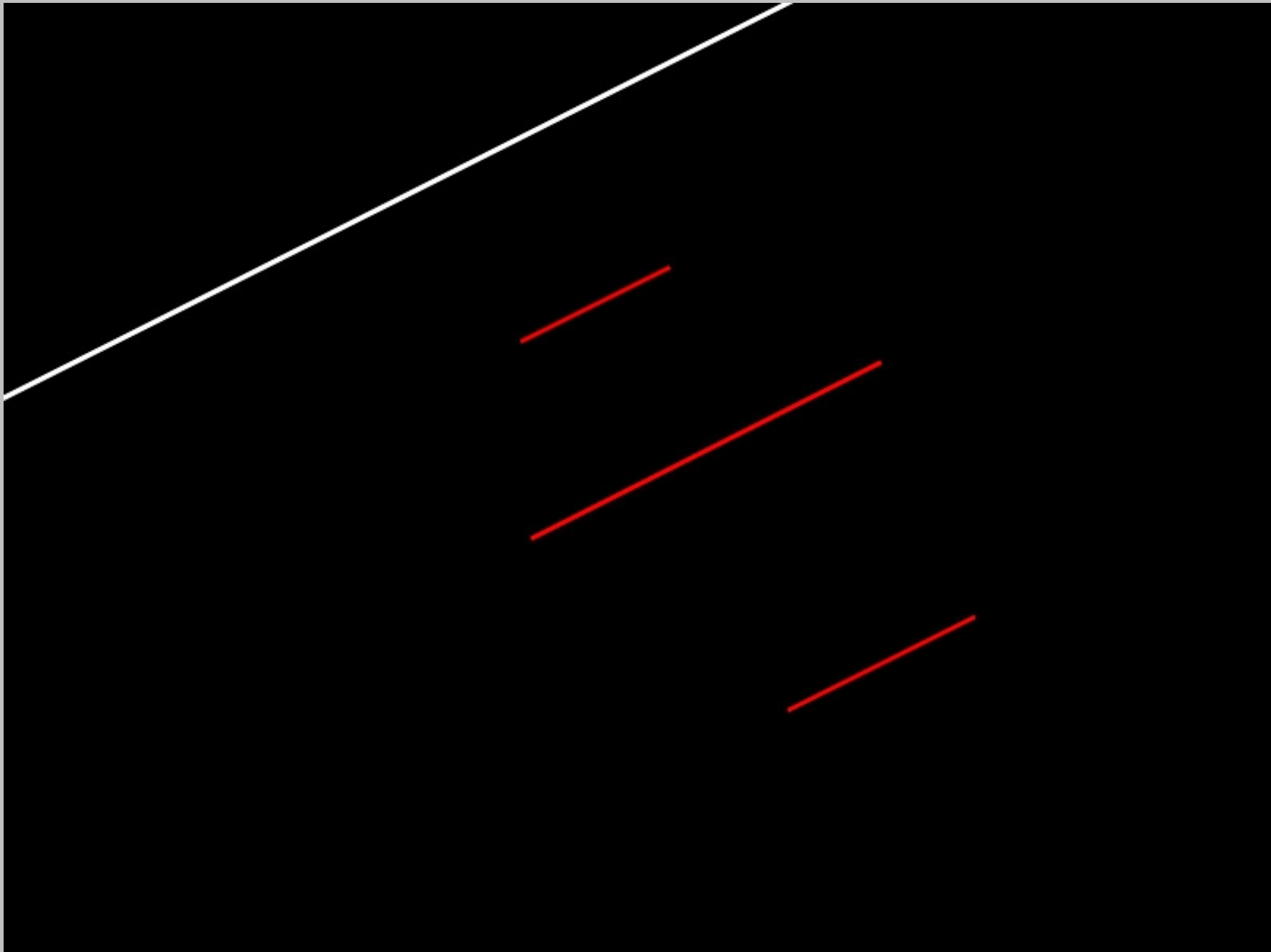


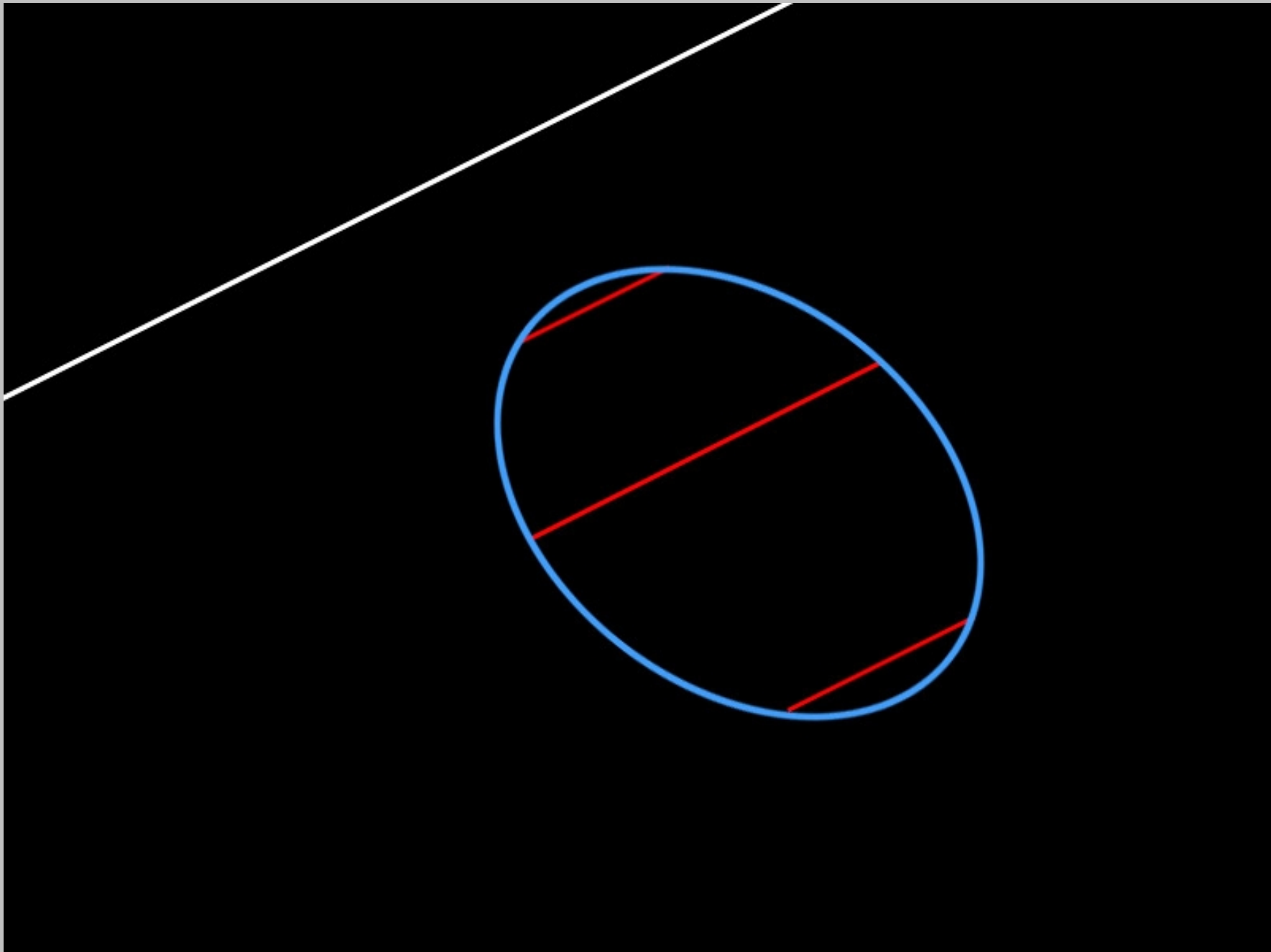
1996 type S (pôle N)
1997 type C (pôle S)

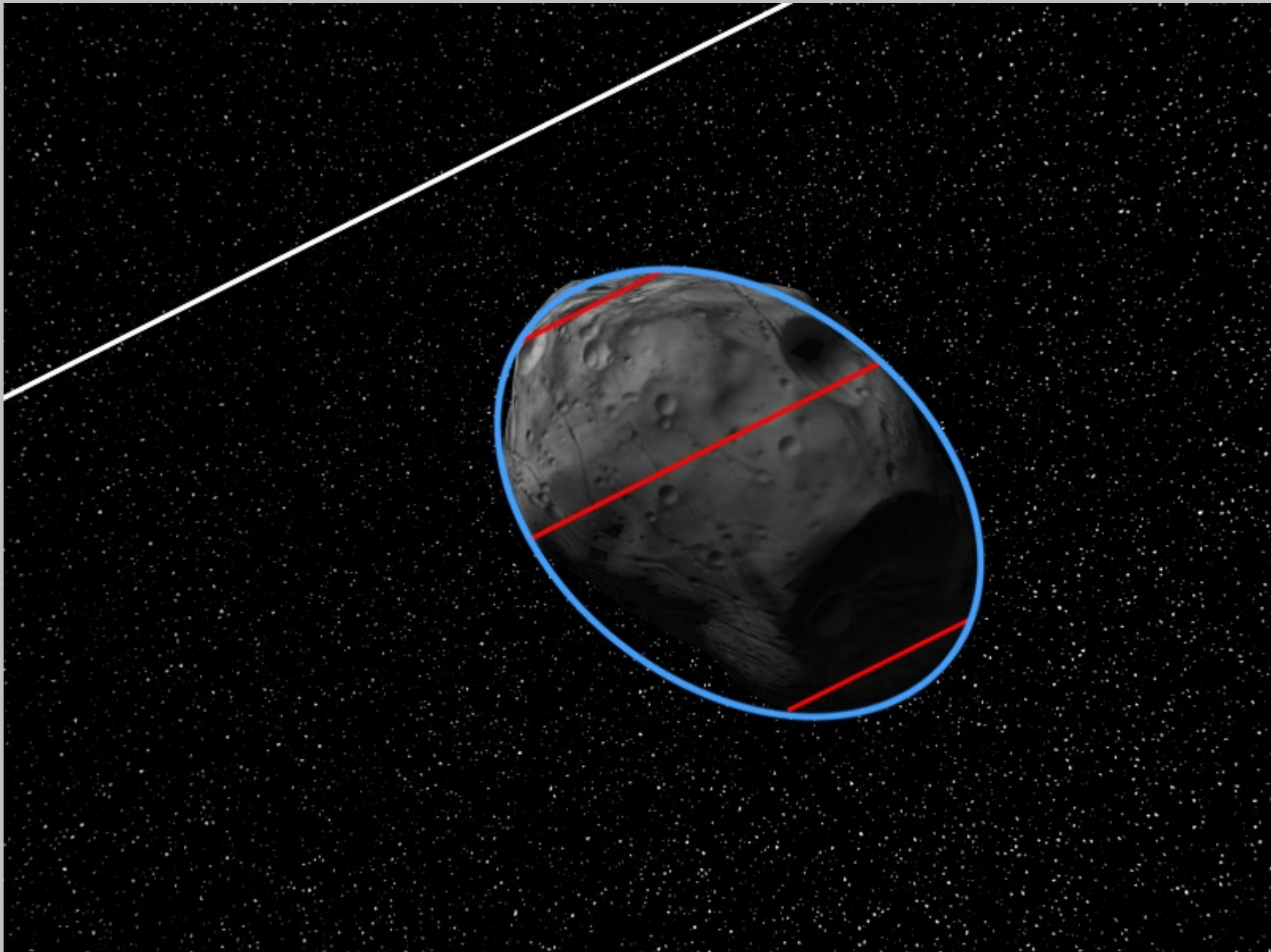


Occultations

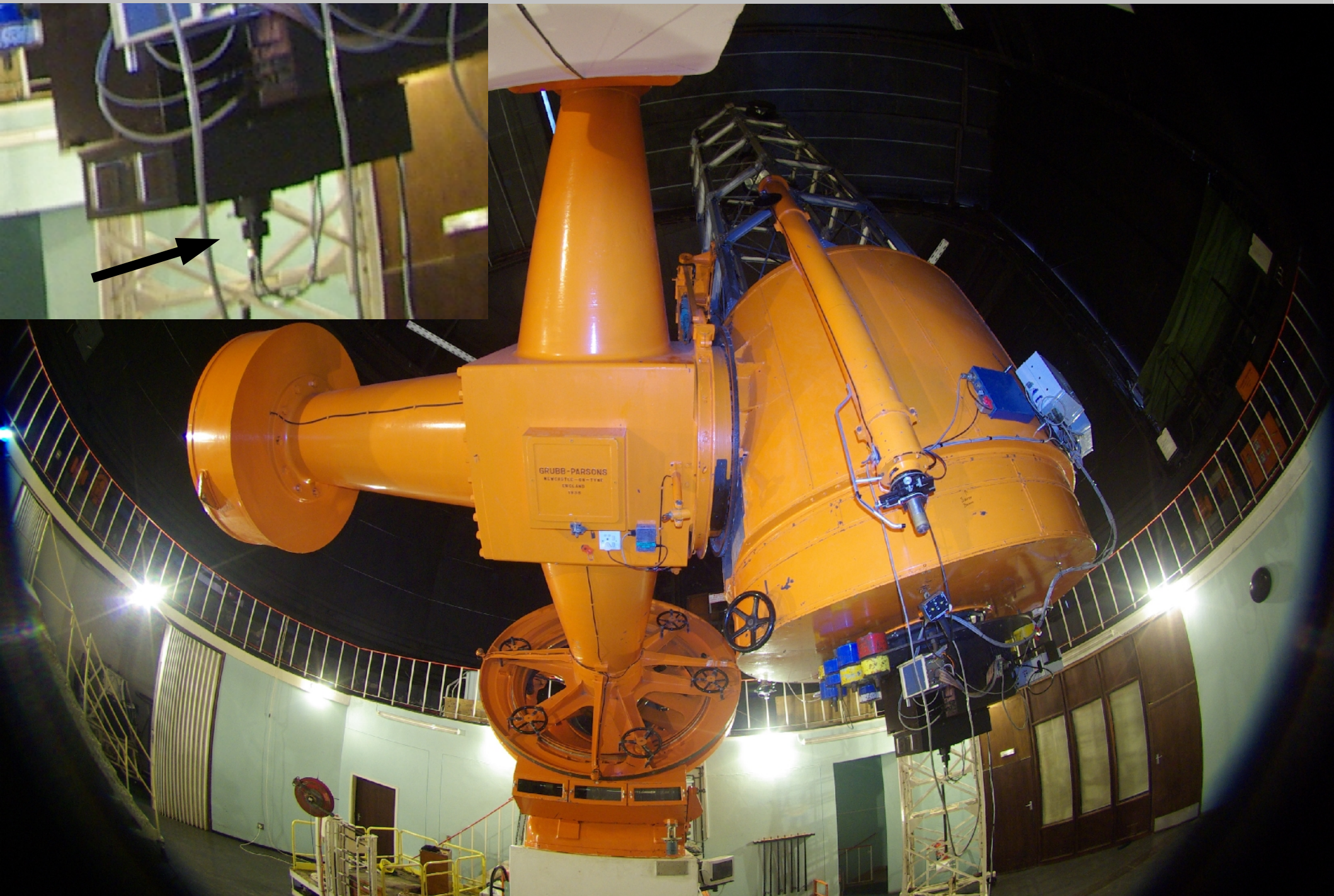








T 193 – Sutherland RSA – Pluto Occultation – june 2008



Small size
observatory !



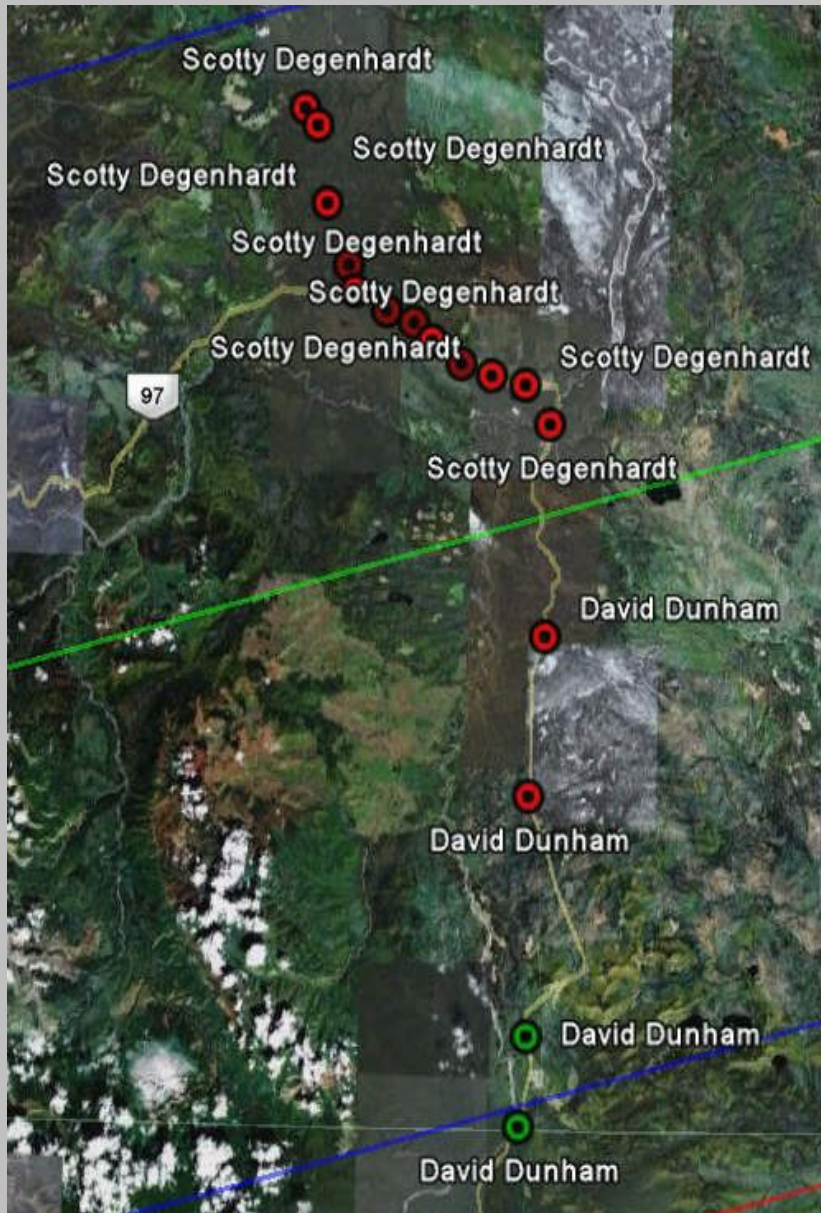
Video Observatory

Caméra basse lumière
(2046XAI pour le test)

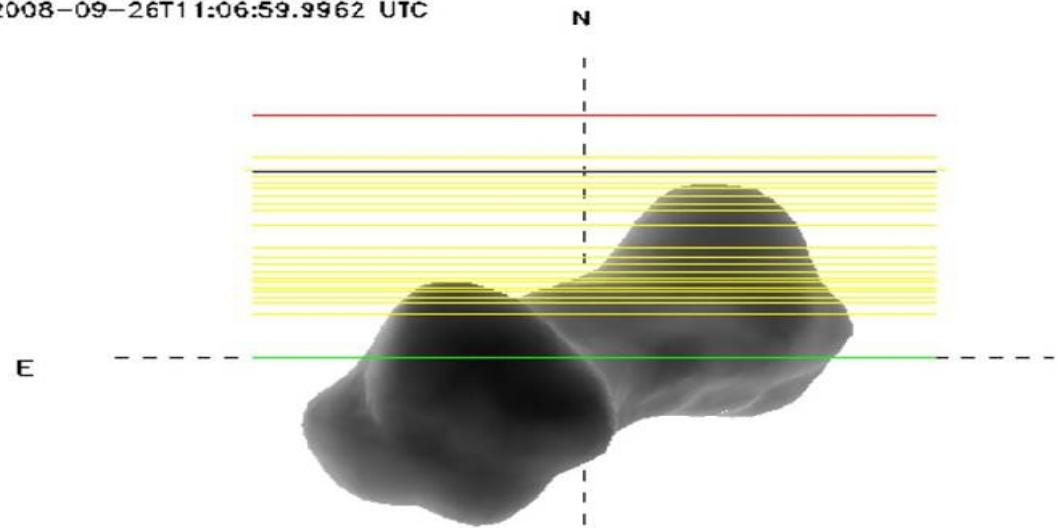
Garmin GPS16 HVS (1PPS)

Incrustateur vidéo
(blackboxcamera)

Enregistreur numérique miniDV
(camescopie Canon MV600I)



2008-09-26T11:06:59.9962 UTC



KLEOPATRA

λ SEP= 30.8° β SEP=-12.2°

λ SSP= 39.5° β SSP=-15.5°

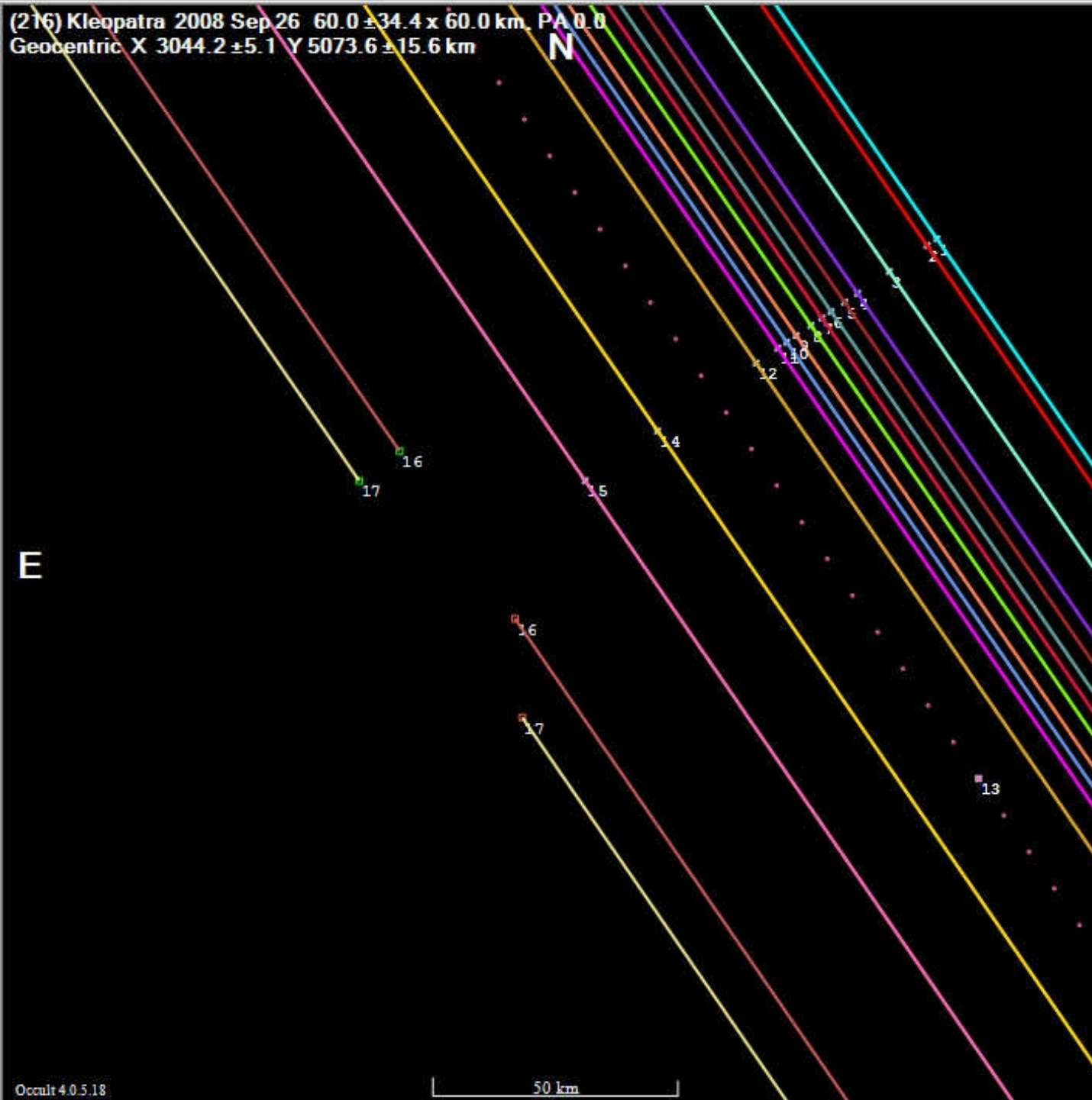
NP= 45.7°

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 -19.6 -6.2
 Center Y -5.0 -3.4

Major axis (km) 60.0 0.4 a/b=1.00
 Minor axis (km) 60.0 0.0 dM=0.00
 Orientation 0.0 0.0

Double star
 Seprn (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 5.4 ± 7.3 km

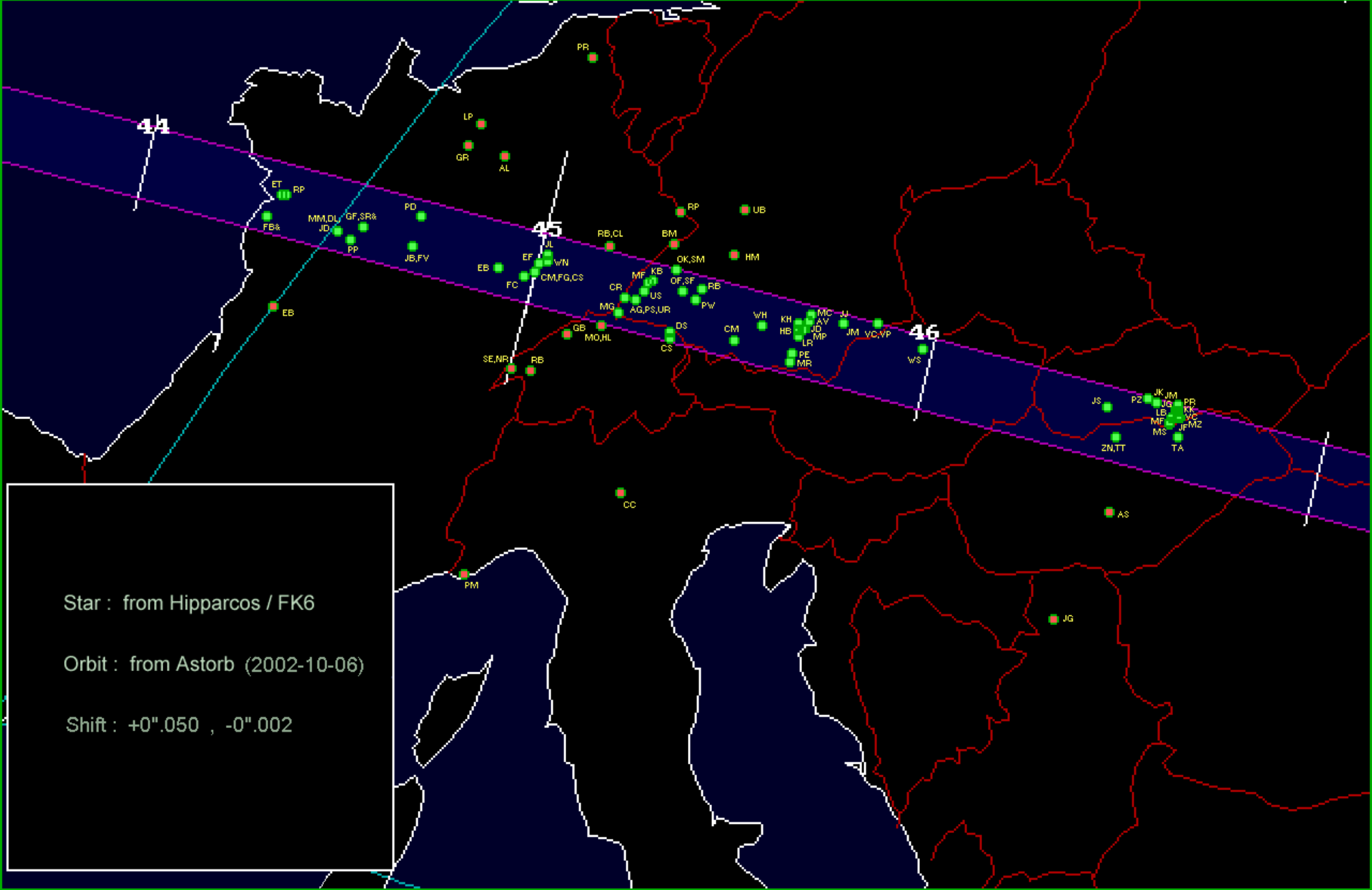
—	1 (M)	S Degenhardt, Fort Ne
—	2 (M)	S Degenhardt, Fort Ne
—	3 (M)	S Degenhardt, Fort Ne
—	4 (M)	S Degenhardt, Fort Ne
—	5 (M)	S Degenhardt, Fort Ne
—	6 (M)	S Degenhardt, Fort Ne
—	7 (M)	S Degenhardt, Fort Ne
—	8 (M)	S Degenhardt, Fort Ne
—	9 (M)	S Degenhardt, Fort Ne
—	10 (M)	S Degenhardt, Fort Ne
—	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

Star (2000):
Mag = 5.5
RA = 4 09 09.988
Dec = +19 36 33.10

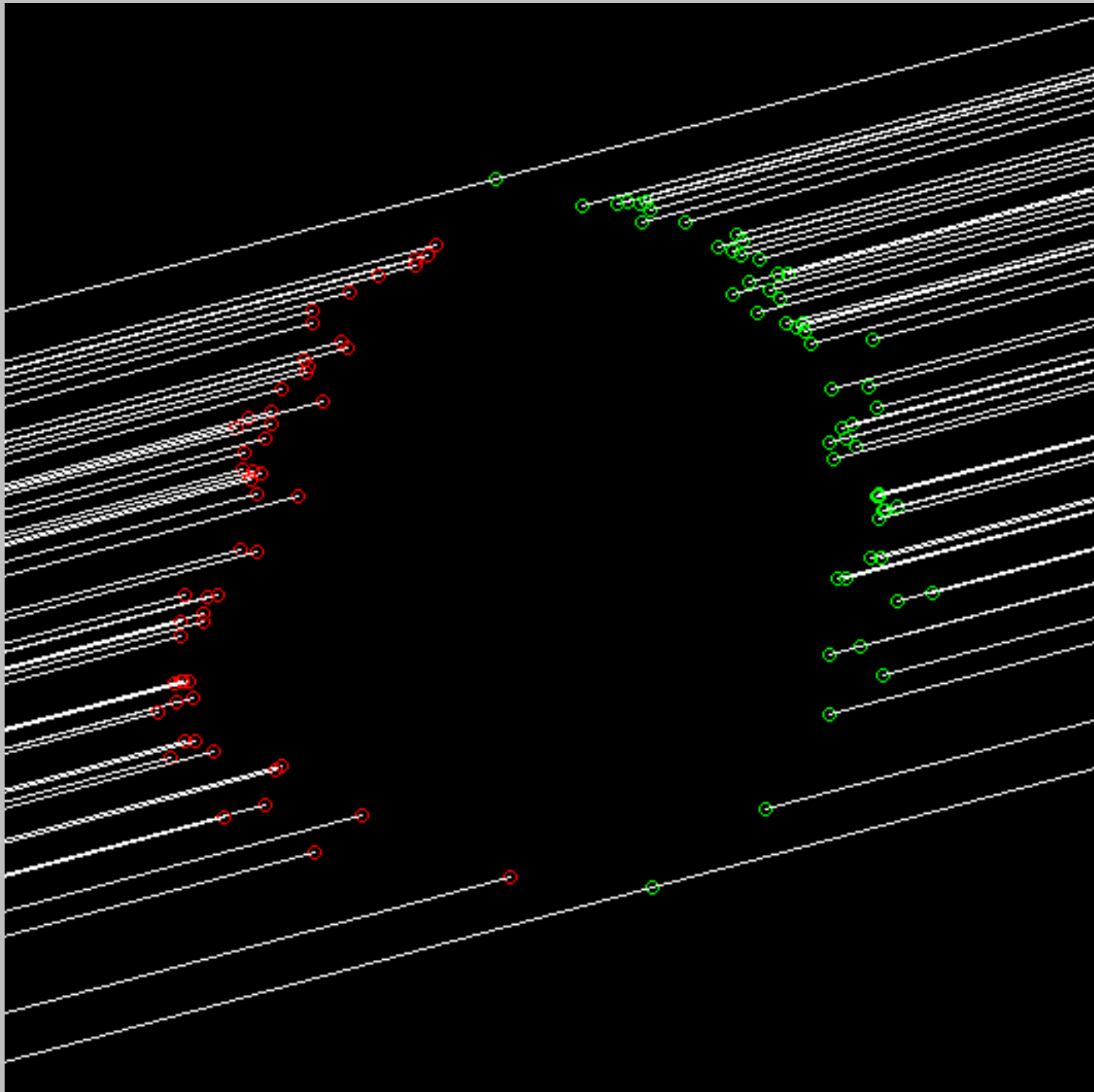
Max Duration = 10.5 secs
Mag Drop = 7.3
Sun : Dist = 110°
Moon: Dist = 122°
illum = 81%

Asteroid:
Mag = 12.8
Dia = 94km, 0.078"
Parallax = 5.279
Hourly dRA = 1.821s
dDec = -6.97"

Plot for Long +16 Lat +47

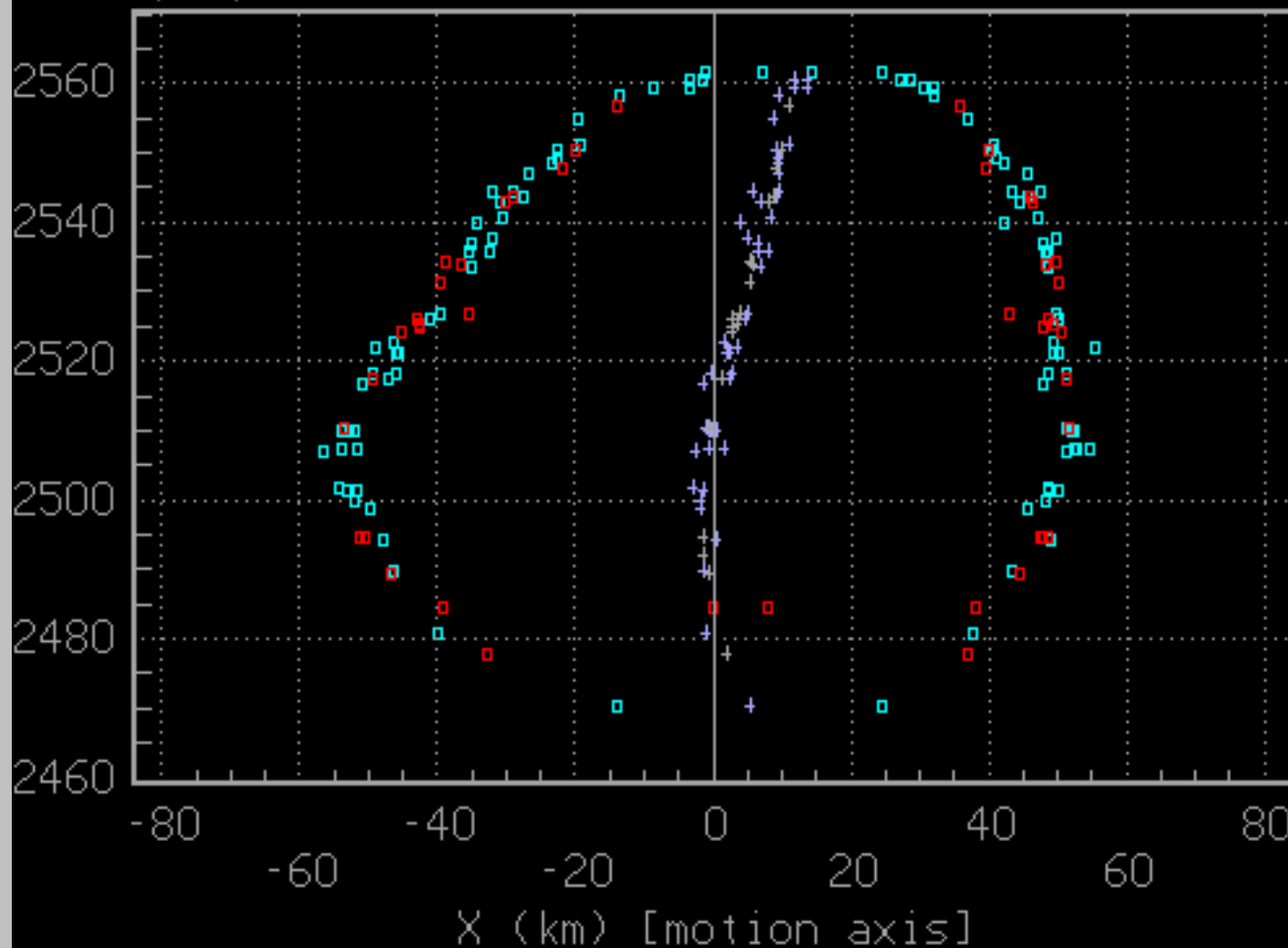


Star : from Hipparcos / FK6
Orbit : from Astorb (2002-10-06)
Shift : +0".050 , -0".002



Occultation by TERCIDINA (2002-09-17)

Y (km)
[perpendic. to motion]

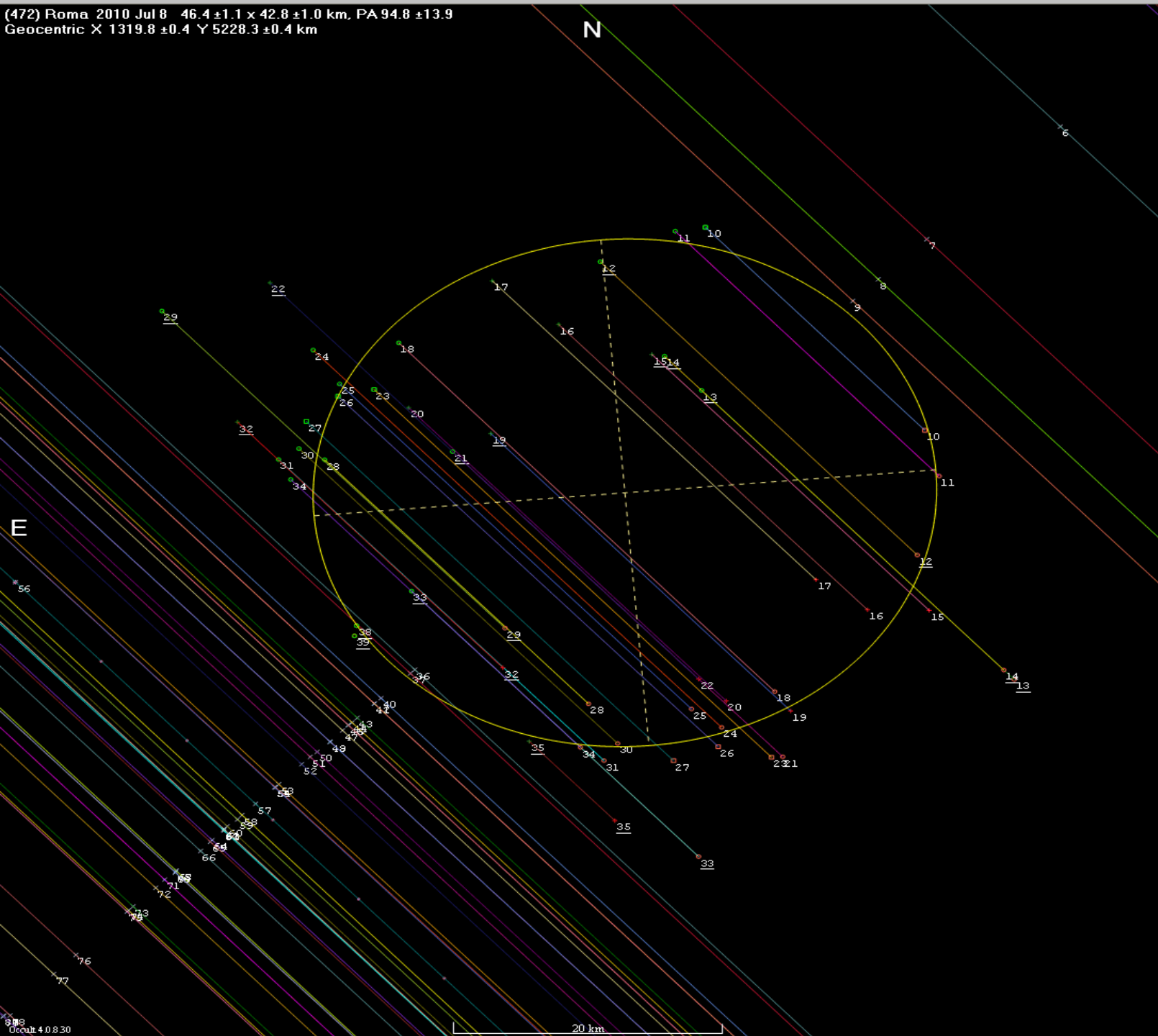


- ◻ Adjusted
- + Adjusted
- ◻ Adjusted
- ◻ Unadjusted
- + Unadjusted
- ◻ Unadjusted

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
a/b=1.08
dM=-0.09

Double star
Seprn (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 Ettlting, 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 Bourtembourg, BE
21	Wolfhard Merten, DE
22	Dieter Wachura, 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

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

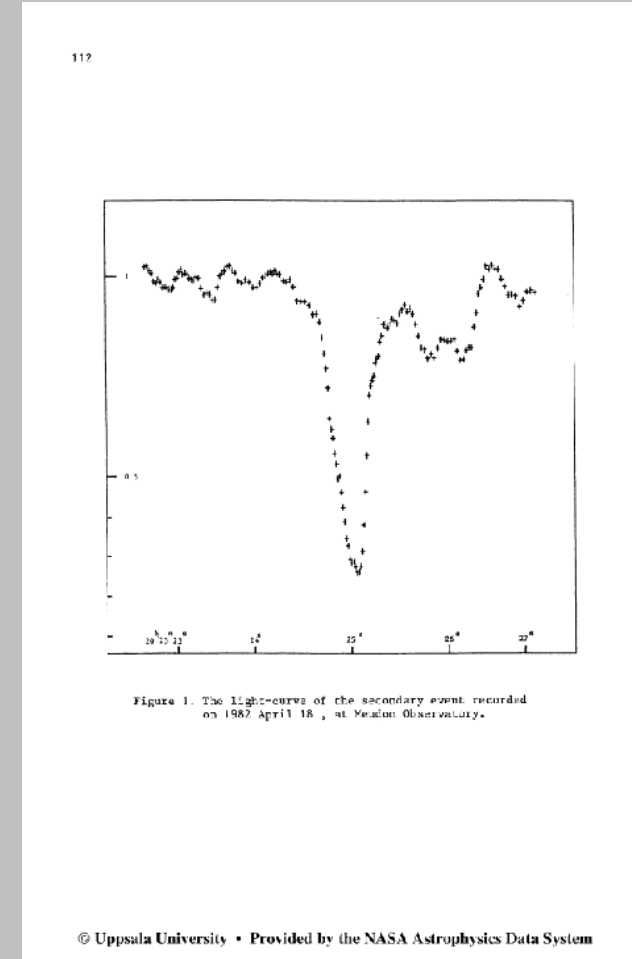
Occultations of binary Asteroids



(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 :

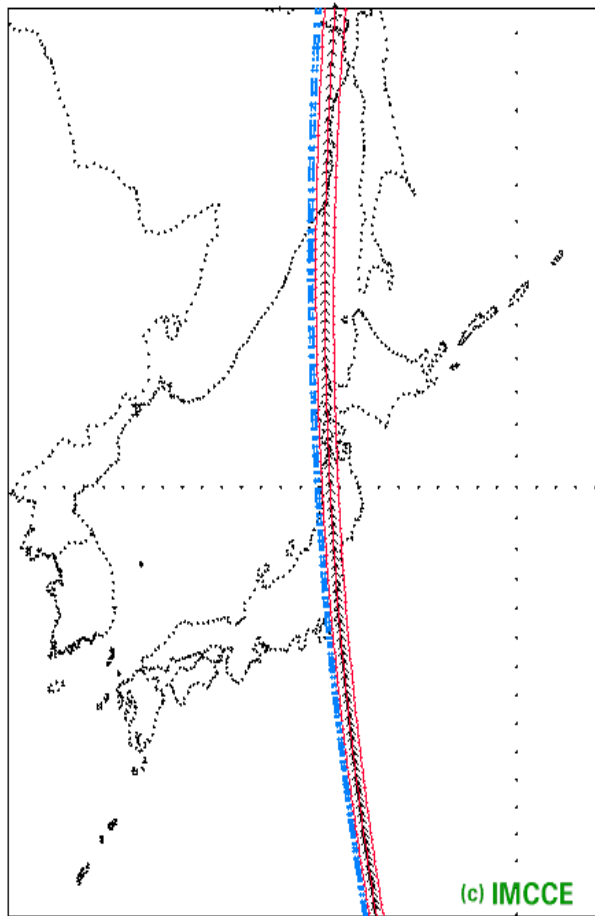
(134340) Pluto - Charon



Kalioppe

Occ. TY2 188601206 / 22 Kalioppe

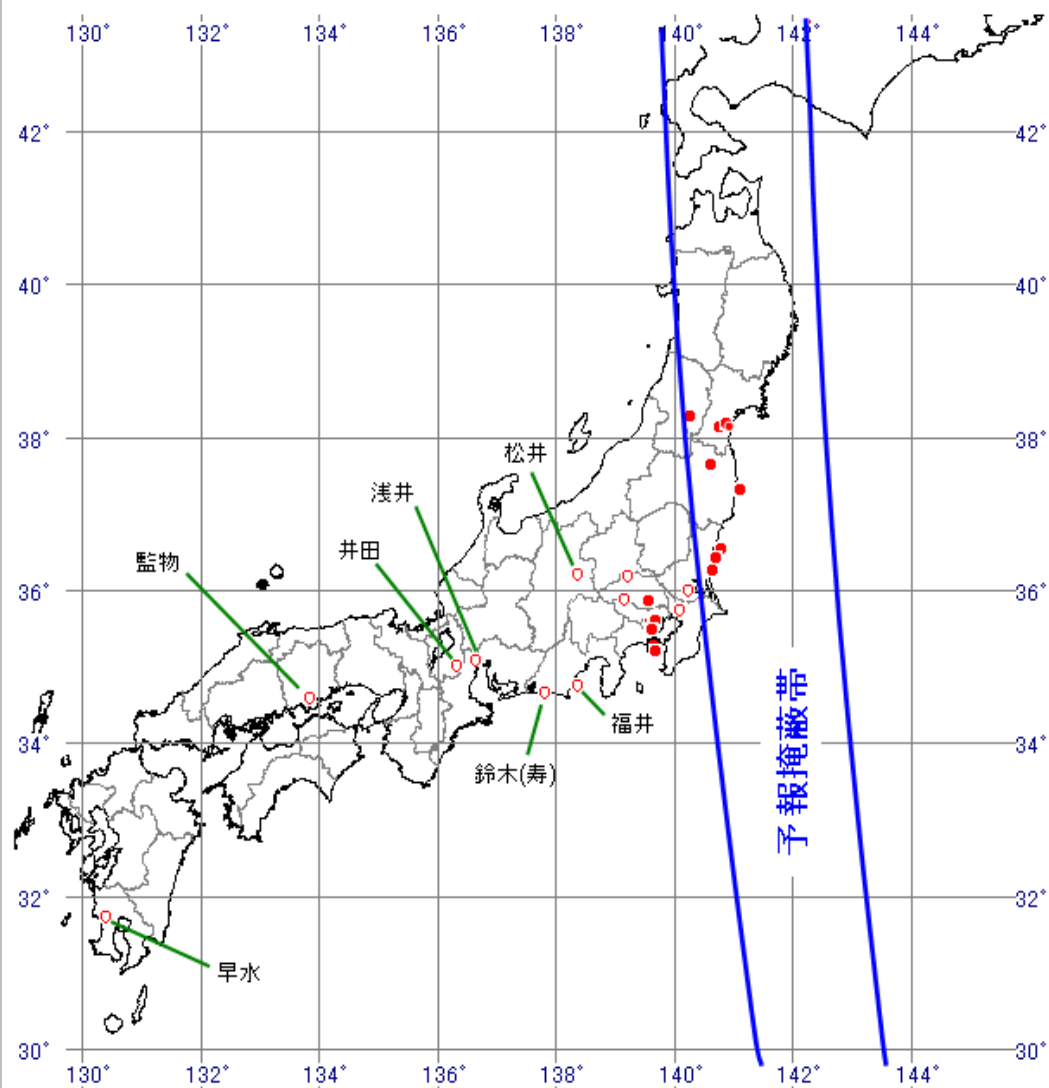
KALLIOPE
LINUS



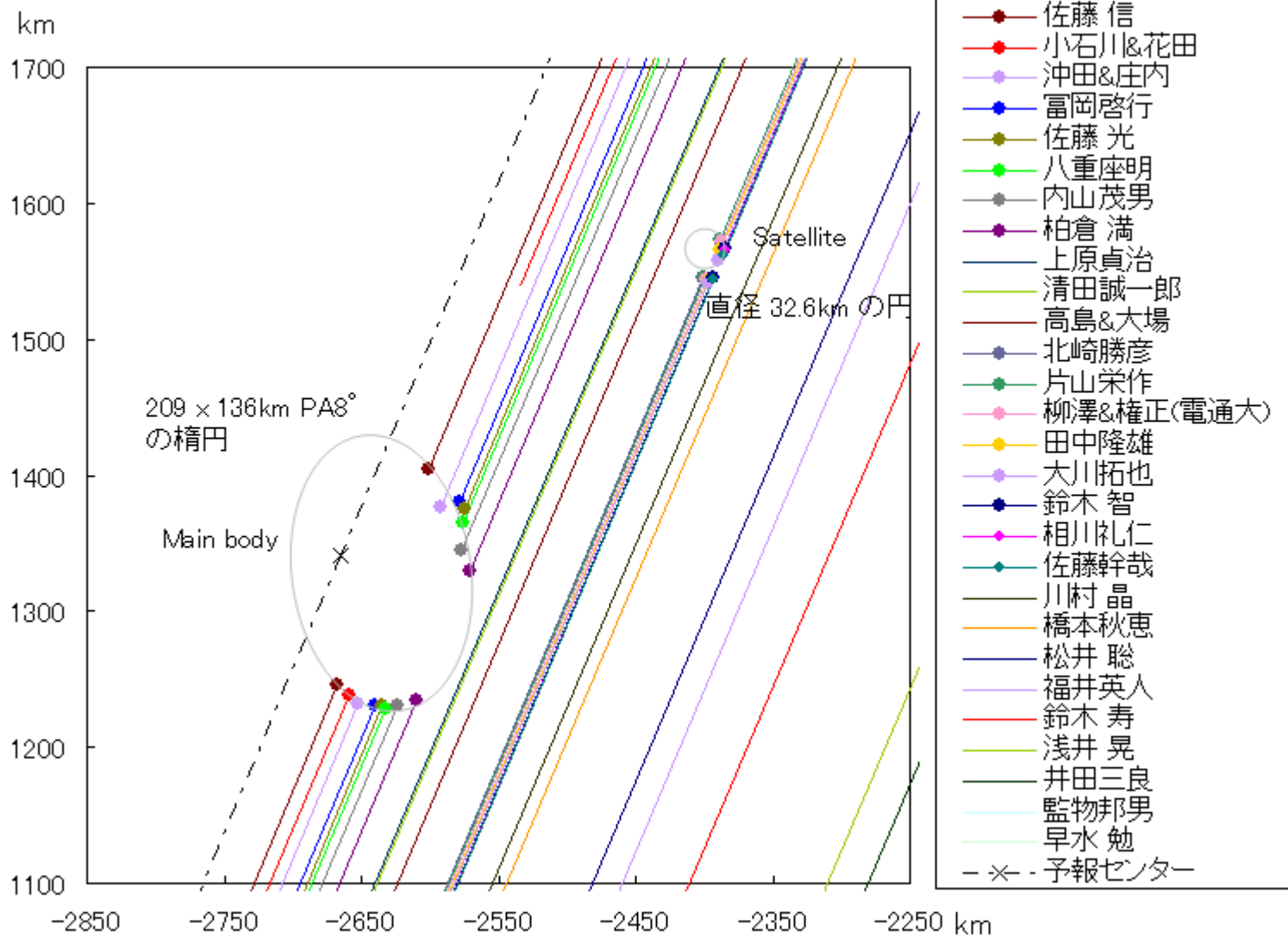
(c) IMCCE

7-11-2006

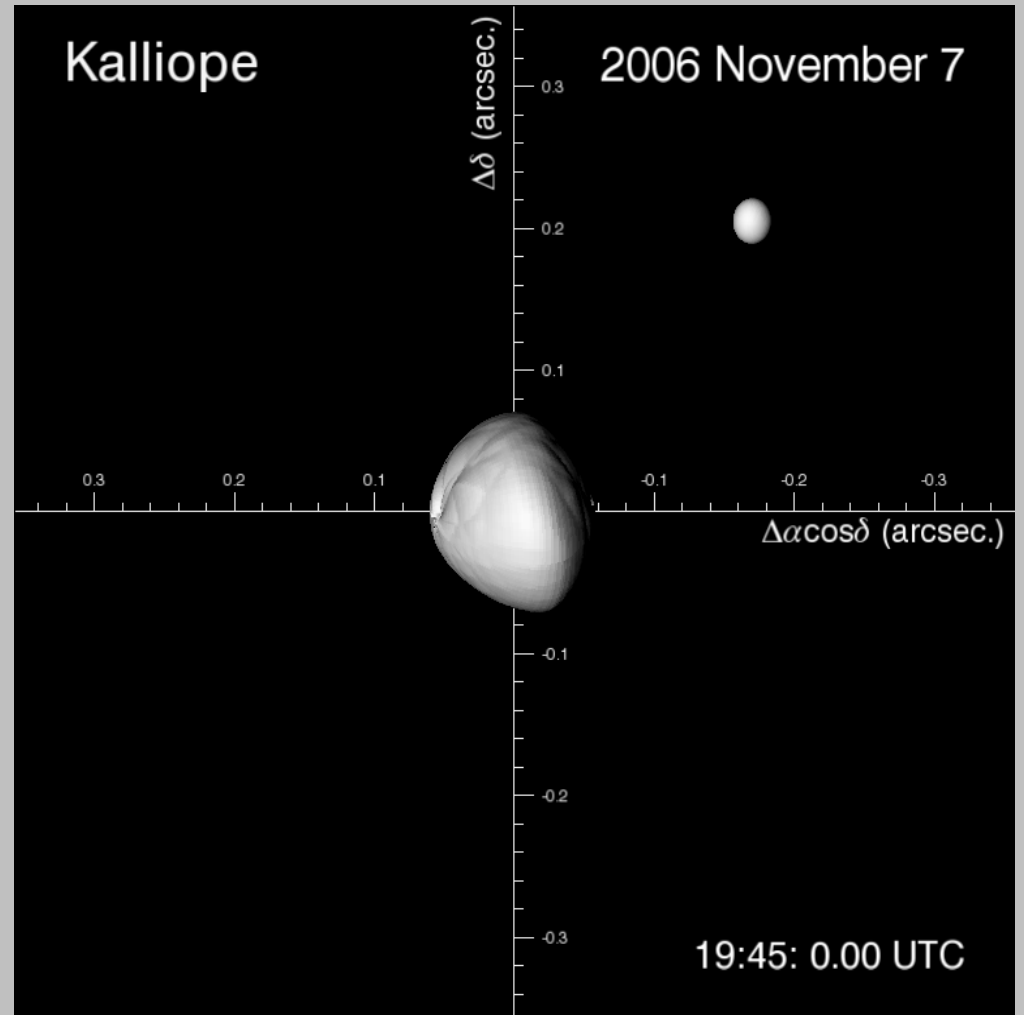
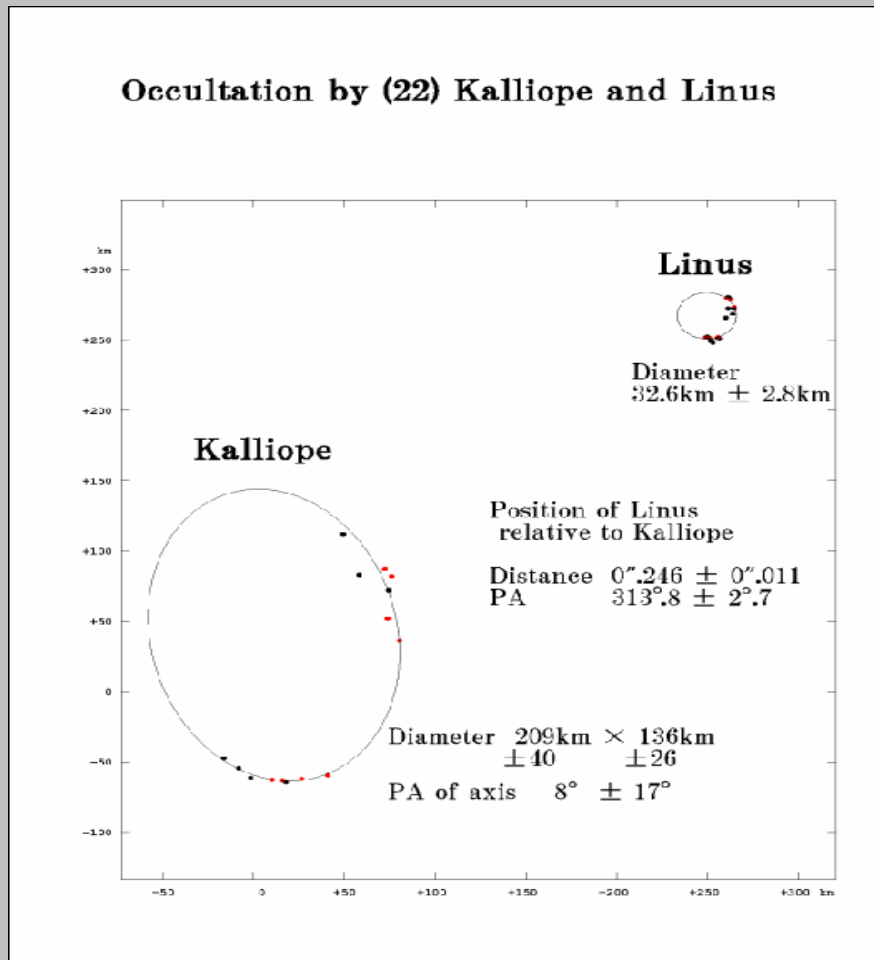
19^h 33^m 30^s - 20^h 4^m 50^s ; inter. = 5.00 sec.



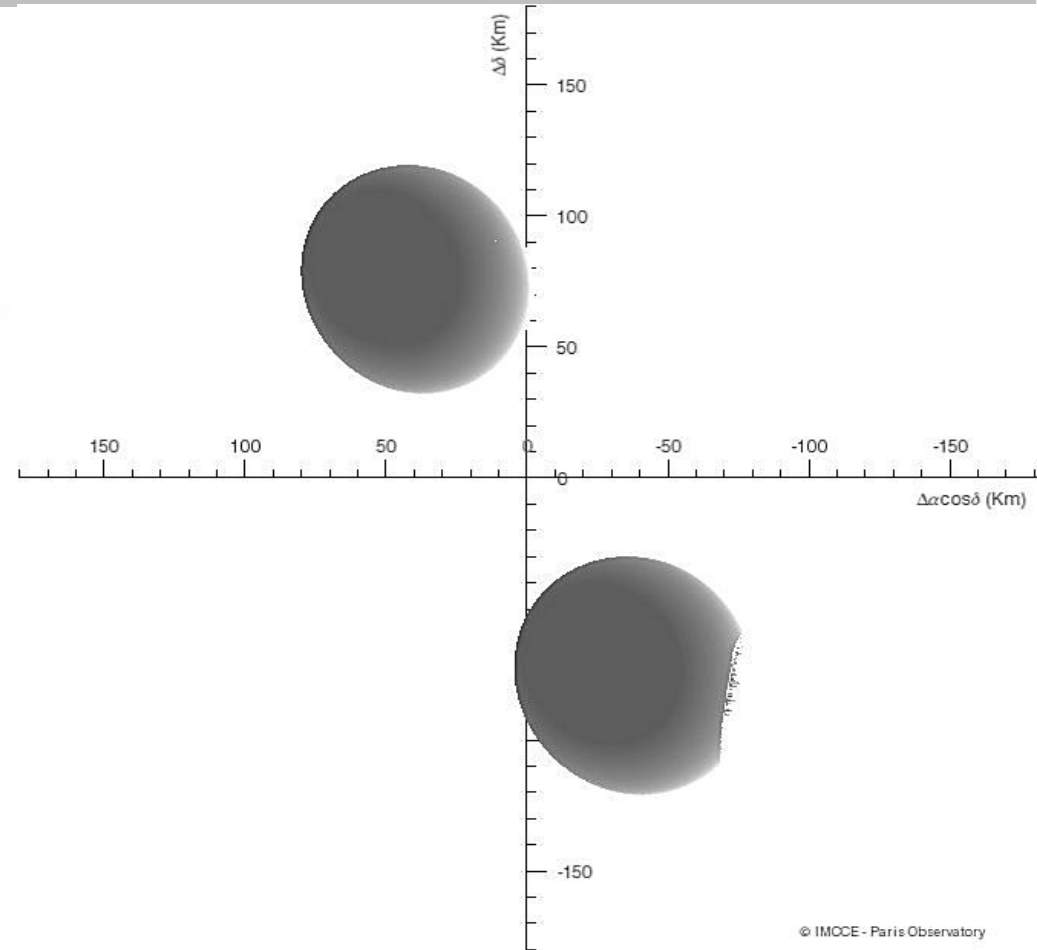
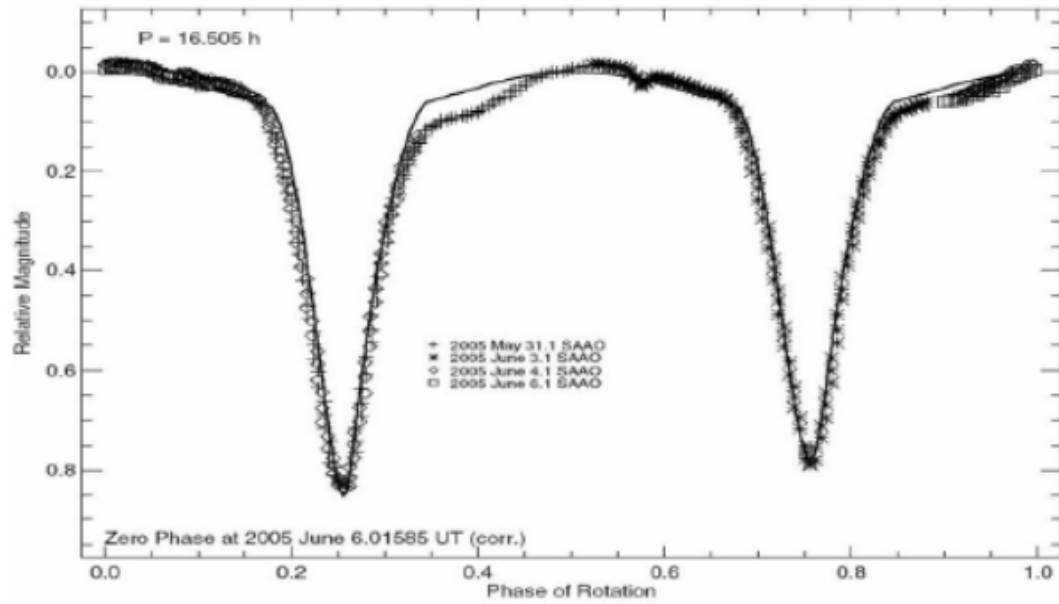
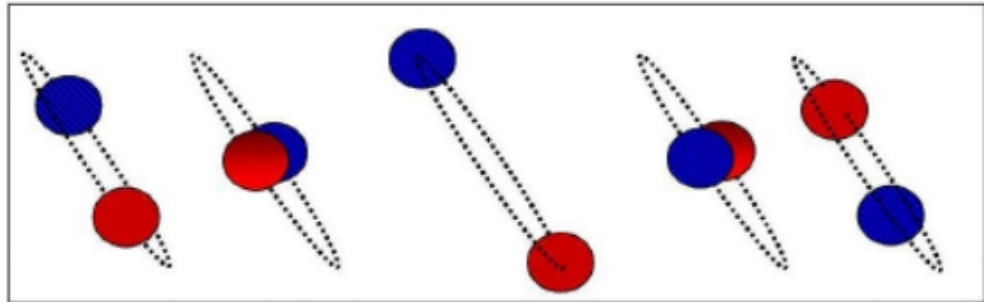
(22)Kalliope & Linus on 2006.11.08



Observations



Antiope occultation – 2011 July 19th



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"

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

