A once in a lifetime experiment: SLR observations of the Apophis encounter Friday, April 13, 2029

J. del Pino, K. Salmins, J. Kauliņs

Institute of Astronomy, University of Latvia, Riga, Latvia

It is too early to start working on this, but

It is the proper moment to start talking about!

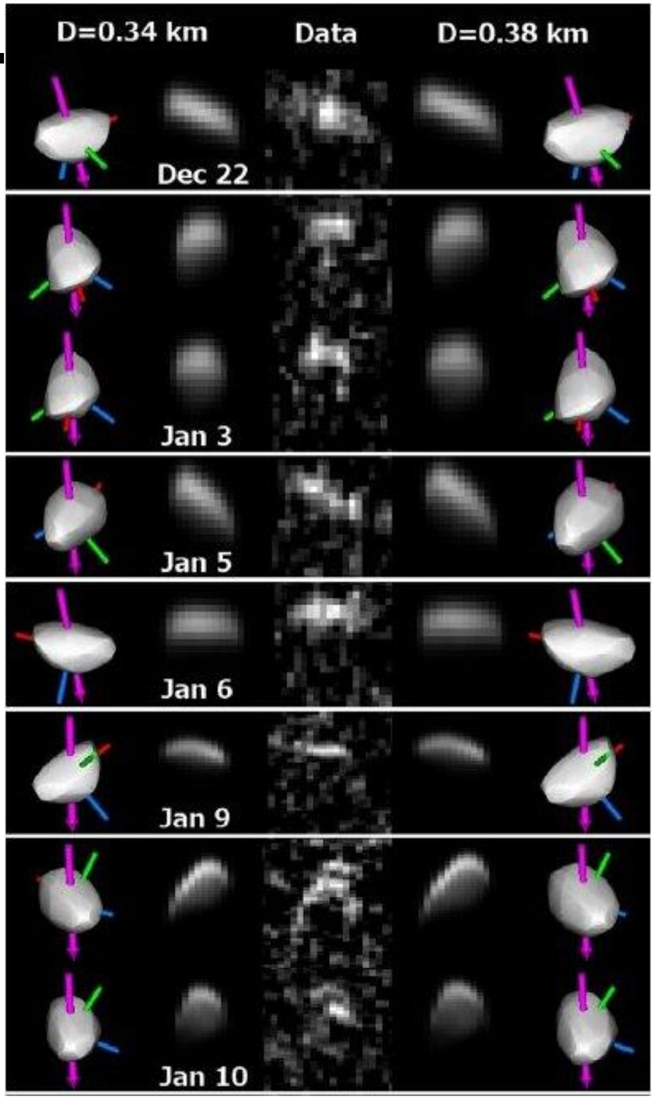
What we do know about 99942 Apophis

- Discovered on June 19, 2004.
- The preliminary orbit indicated a 2.7% impact probability on April 13th 2029 or later in 2036.
- Post & Prediscovery images + Radar observations, eliminated an impact for the next 100 years.
- Current orbit has an position error of ~2 km during the 2029 close encounter.

- The April 13 2029 encounter: Apophis will pass inside the geostationary belt.
- The Earth‘s close encounter will change Apophis orbit from 0.7461 x 1.0993 AU to 0.894 x 1.310 AU.
- Expected that tidal forces will resurface Apophis‘ regolith, changing the Albedo and Color index.

99942 Apophis important parameters

- Size: 450 x 170 m. (using radar), mean radius ~185 m.
- Albedo: 0.23 (from ESA Kepler observations)
- Rotation period: 30.56 h (photometric period)
- Tumbling on a short axis
- Precession 27.38 ± 0.07 h
- Rotation 263 ± 6 h



from Brozovics et. al. (2018)

Jet Propulsion Laboratory
California Institute of Technology

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Horizons System

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Horizons Web Application

Save/Load Settings... | Set Defaults

1 Ephemeris Type: Observer Table

2 Edit Target Body: **99942 Apophis (2004 MN4)**

3 Edit Observer Location: **0**°E, **0**°N, **0** km

4 Edit Time Specification: Start=**2022-10-04** UT , Stop=**2022-11-03**, Step=**1** (days)

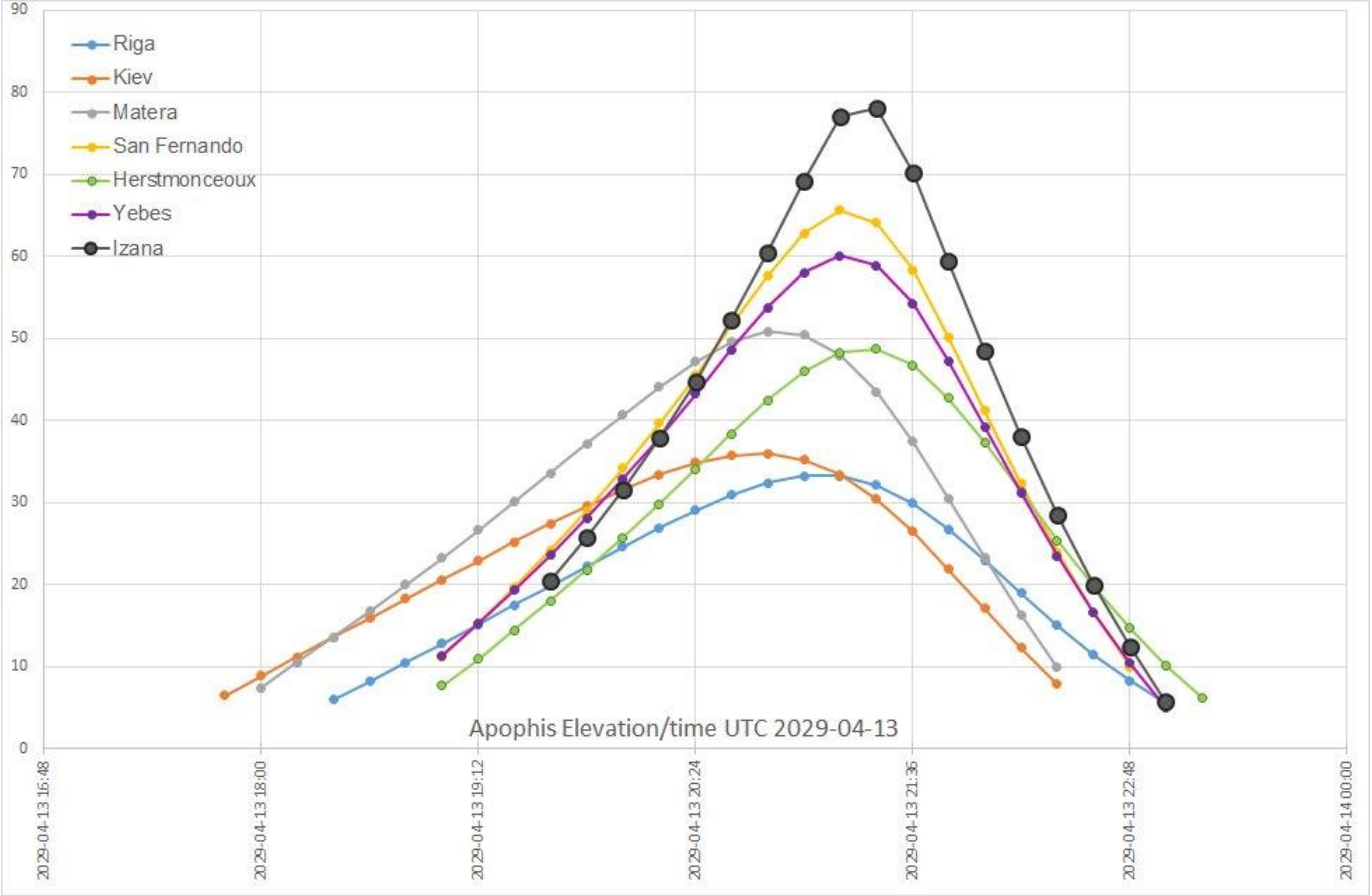
5 Edit Table Settings: *defaults*

After specifying settings above (items 1 to 5), generate an ephemeris by pressing the "Generate Ephemeris" button below. If you plan to use one of the "batch" modes to access Horizons, the batch-file corresponding to the settings above can be viewed by using this link.

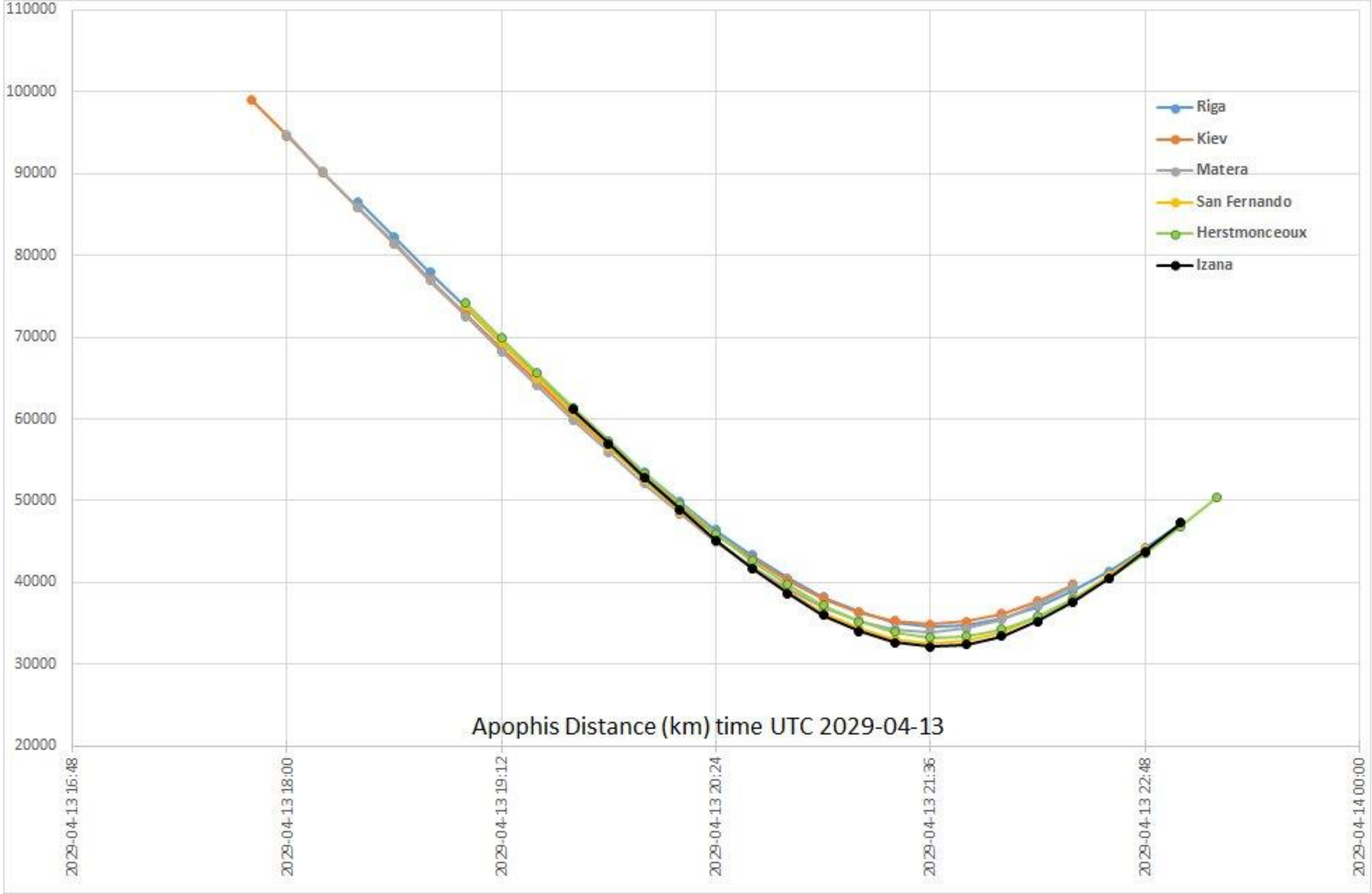
Generate Ephemeris

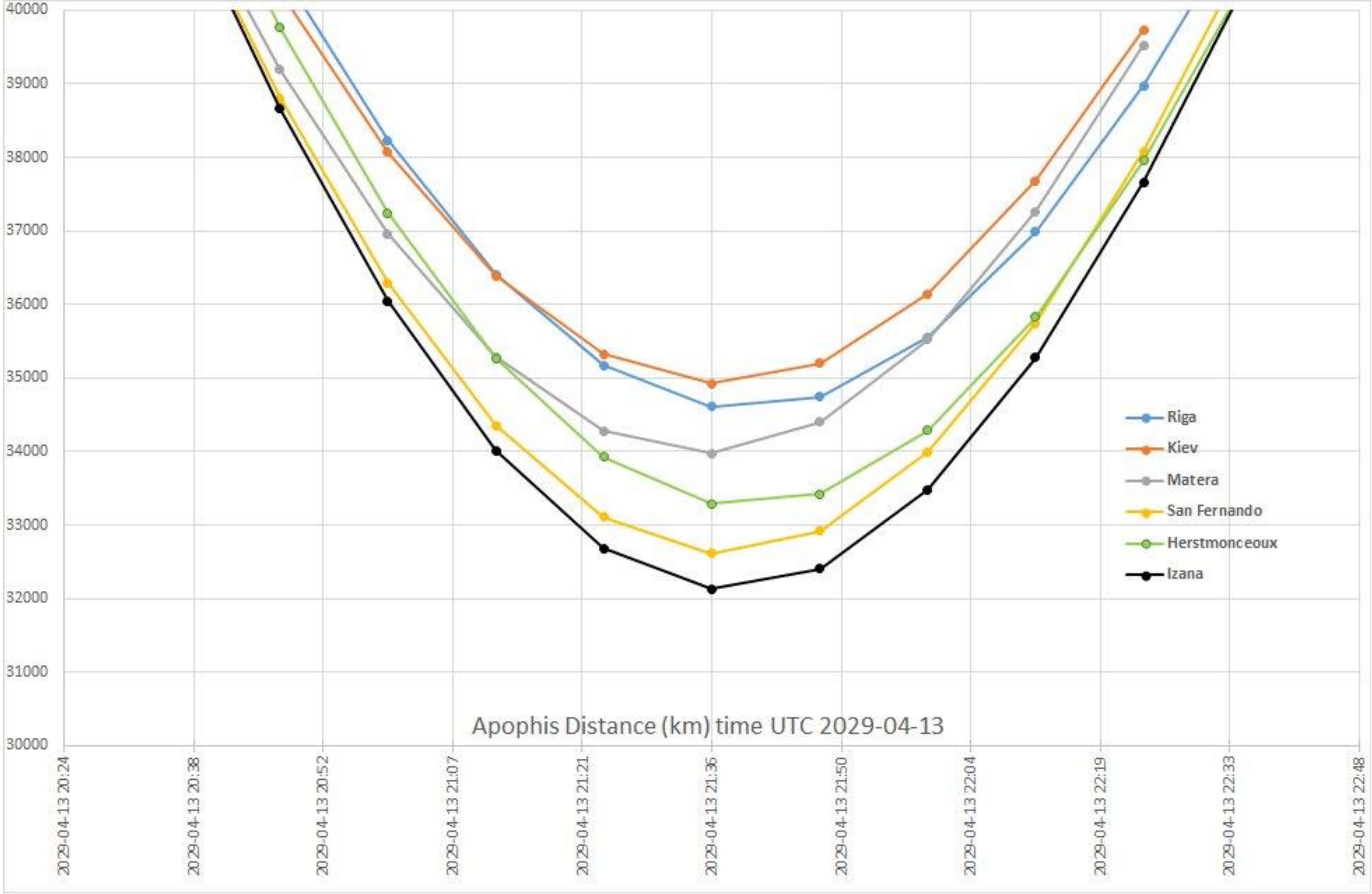
https://ssd.jpl.nasa.gov/horizons/app.html#/

Metsahovi
Riga
Borowiec
Potsdam
Herstmonceux
Wettzell
Golosiiv
Graz
Zimmerwald
Grasse
Yebes
Matera
San Fernando
Izana

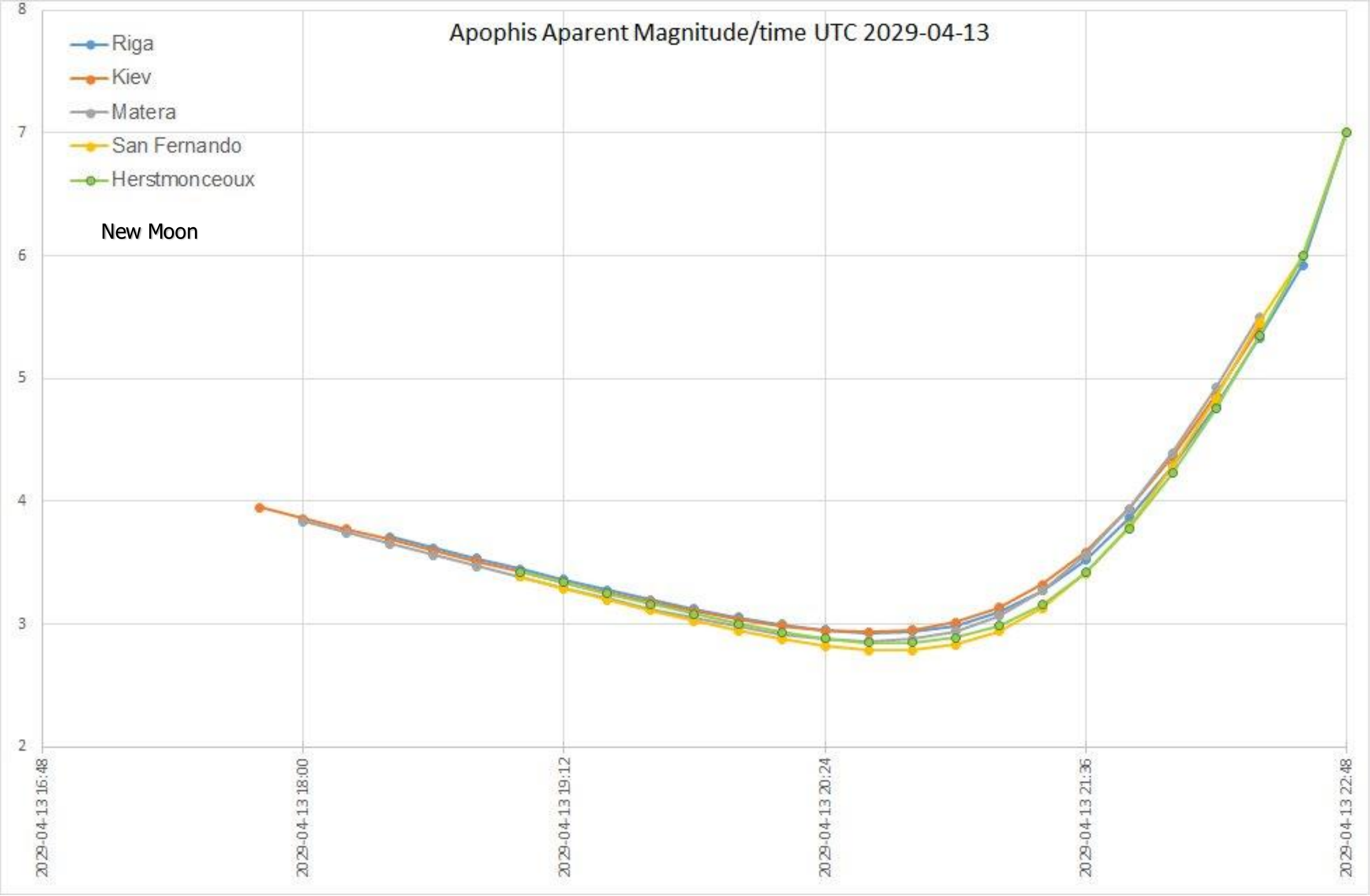


Riga
Kiev
Matera
San Fernando
Herstmonceoux
Yebes
Izana
90
80
70
60
50
40
30
20
10
0
2029-04-13 16:48
2029-04-13 18:00
2029-04-13 19:12
2029-04-13 20:24
2029-04-13 21:36
2029-04-13 22:48
2029-04-14 00:00
Apophis Elevation/time UTC 2029-04-13


110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
Riga
Kiev
Matera
San Fernando
Herstmonceoux
Izana
Apophis Distance (km) time UTC 2029-04-13
2029-04-13 16:48
2029-04-13 18:00
2029-04-13 19:12
2029-04-13 20:24
2029-04-13 21:36
2029-04-13 22:48
2029-04-14 00:00

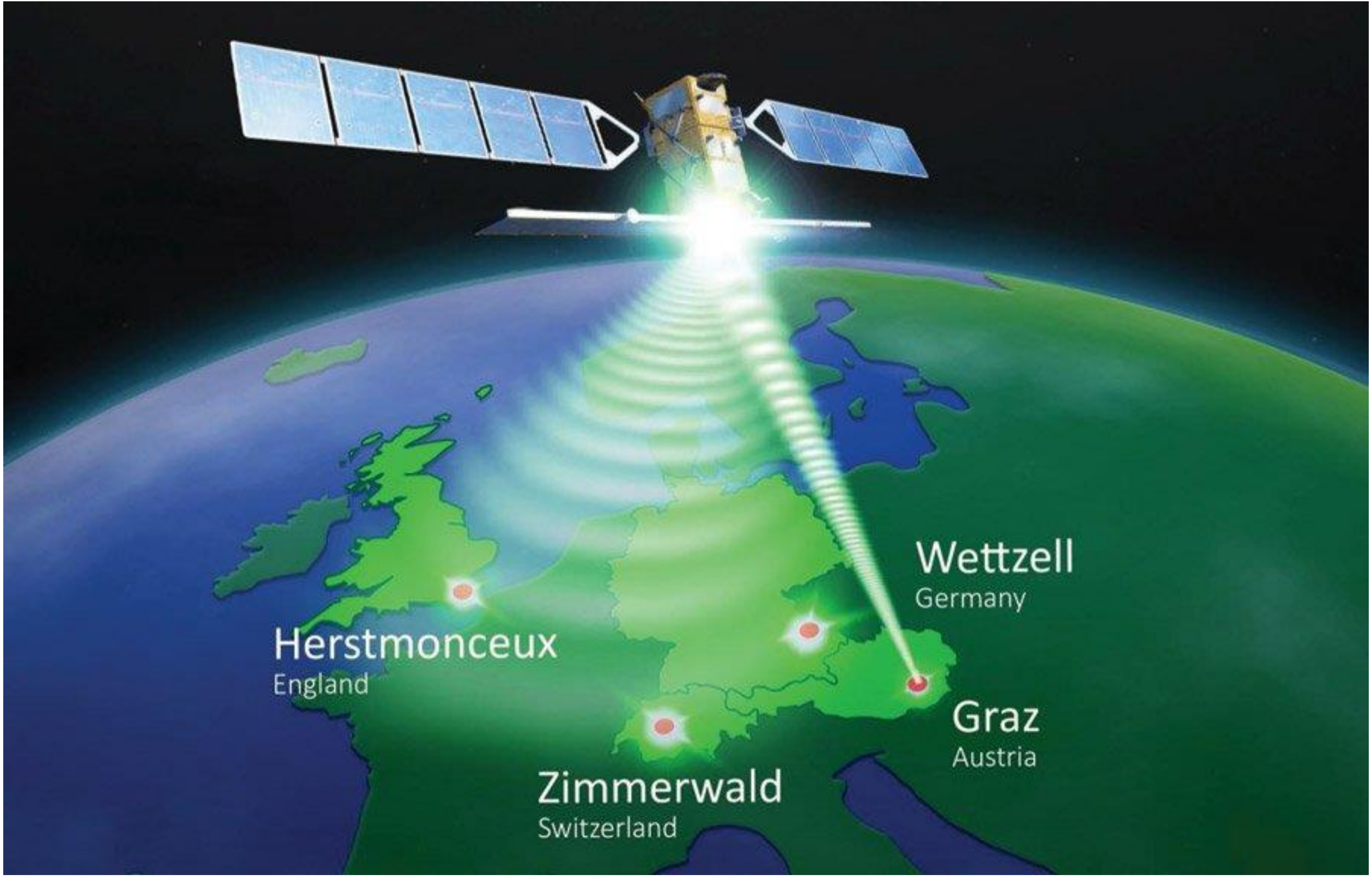


40000
39000
38000
37000
36000
35000
34000
33000
32000
31000
30000
Riga
Kiev
Matera
San Fernando
Herstmonceoux
Izana
Apophis Distance (km) time UTC 2029-04-13
2029-04-13 20:24
2029-04-13 20:38
2029-04-13 20:52
2029-04-13 21:07
2029-04-13 21:21
2029-04-13 21:36
2029-04-13 21:50
2029-04-13 22:04
2029-04-13 22:19
2029-04-13 22:33
2029-04-13 22:48


Apophis Aparent Magnitude/time UTC 2029-04-13
Riga
Kiev
Matera
San Fernando
Herstmonceoux
New Moon
8
7
6
5
4
3
2
2029-04-13 16:48
2029-04-13 18:00
2029-04-13 19:12
2029-04-13 20:24
2029-04-13 21:36
2029-04-13 22:48

So, everybody can track Apophis, but

what about Ranging *to* Apophis?



from Kirchner et. al. (2014)

SLR Link Equation

$$n_s = \frac{E_t}{h\nu}\eta_t \frac{2}{\pi(\theta_d R)^2} \exp\left[-2\left(\frac{\Delta\theta_p}{\theta_d}\right)^2\right]\left[\frac{1}{1+\left(\frac{\Delta\theta_j}{\theta_d}\right)^2}\right]\left(\frac{\sigma A_r}{4\pi R^2}\right)\eta_r\eta_c T_a^2 T_c^2$$

n_s = detected satellite photoelectrons per pulse
E_t = laser pulse energy
$h\nu$ = laser photon energy = 3.73×10^{-19}J @ 532 nm (Doubled Nd:YAG)
η_t = transmitter optical throughput efficiency
θ_d = Gaussian beam divergence half angle
R = slant range between station and satellite (signal decreases as $1/R^4$)
$\Delta\theta_p$ = laser beam pointing error
$\Delta\theta_j$ = RMS tracking mount jitter
σ= satellite optical cross-section = sole link contribution of space segment
A_r = Telescope Receive Area.
η_r= receiver optical throughput efficiency
η_c = detector counting efficiency
T_a = one way atmospheric transmission
T_c = one way cirrus cloud transmission

To maintain the same signal strength, the satellite cross-section must increase as R^4

*Reference: J. Degnan, "Millimeter Accuracy Satellite Laser Ranging: A Review", in Contributions of Space Geodesy to Geodynamics: Technology Geodynamics, 25, pp. 133-162, 1993.

we can rewrite the equation as:

sufficient photoelectrons! = [parameters]*(σ/R^4)

Case Envisat

$\sigma_{envisat}$ =19.49 m^2

R ≈ 1000 km = 10^6 m

(σ/R^4) ≈ 1.9 10^{-23} 1/m^2

for SL-16 R/B, σ=11.2 m^2

(σ/R^4) ≈ 1.1 10^{-23} 1/m^2

for 39104, σ=7.7 m^2

(σ/R^4) ≈ 0.8 10^{-23} 1/m^2

Case Apophis

$\sigma_{Apophis}$ ≈ 2.5 10^4 (π*mean radius²*albedo)

R ≈ 32000 km = 3.2 10^7 m

(σ/R^4) = 1.7 10^{-26} 1/m^2

Range: 0.5-1.3 10^{-26} 1/m^2

3 orders of magnitude less!

Unique research and development facility for the detection of space debris

The telescope at the Johannes Kepler Observatory is the largest of its kind in Europe for observing objects in orbit. The telescope, with a primary mirror measuring 1.75 metres in diameter, is housed in an almost 15-metre-high round tower with a rotating dome. The focus of the research and development work will be on high-precision orbit measurement using special lasers. The DLR researchers are looking to detect and locate objects down to 10 centimetres across and determine their trajectory as precisely as possible. The project is concentrating primarily on objects in Low Earth Orbit (LEO) located at a height of between 400 and 2000 kilometres above Earth. More and more satellites are orbiting our planet in LEO. That is why space debris at these altitudes poses a particular danger – for both uncrewed and crewed spaceflight, including the International Space Station (ISS).

Izaña-1 at a glance

- Izaña-1 was installed in mid-2021 at the Teide Observatory in Tenerife. ESA's European Space Operations Centre (ESOC) began operating the station in February 2022.
- The station uses short laser pulses to determine the distance, velocity and orbit of space objects with millimetre precision, using the time the pulses take to return to the station.
- The laser currently operates at 150 mW, enough to track satellites fitted with retroreflectors. It will soon be upgraded to 50 W to allow it to track small space debris objects, even those lurking above blue daytime skies.
- Izaña-1 provides support for vital collision avoidance and is a testbed for new technologies such as optical communication and space traffic control.

sufficient photoelectrons! = [parameters]*(σ/R^4)

Case SLR Johannes Kepler

$\sigma_{minlimitdebris}$ =0.01 m^2

R ≈ 1000 km = 10^6 m

(σ/R^4) ≈ 1 10^{-26} 1/m^2

Case Apophis

$\sigma_{Apophis}$ ≈ 2.5 10^4 (π*mean radius²*albedo)

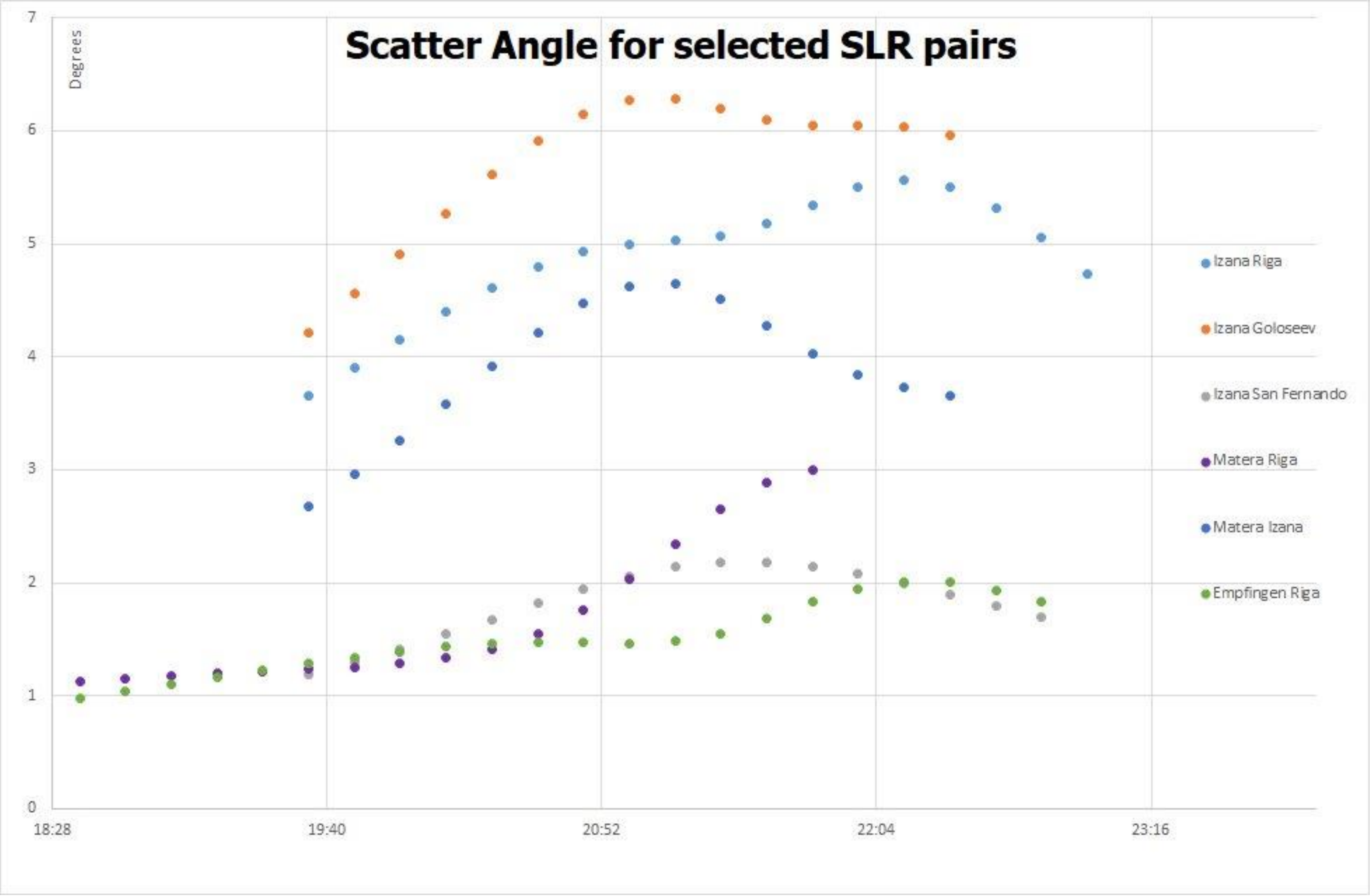
R ≈ 32000 km = 3.2 10^7 m

(σ/R^4) = 1.7 10^{-26} 1/m^2

Range: 0.5-1.3 10^{-26} 1/m^2

Station	m.
Grasse (MeO)	1.54
Matera	1.50
Riga	1.00
Zimmerwald	1.00
Izana	0.80
Wettzell-8834	0.75
Borowiec	0.65
San Fernando	0.60
Wettzell-7827	0.50
Graz	0.50
Herstmonceux	0.50
Potsdam	0.44
Kiev	0.40

Modify the SLR link equation for bistatic ranging!



Scatter Angle for selected SLR pairs
Degrees
7
6
5
4
3
2
1
0
18:28
19:40
20:52
22:04
23:16
Izana Riga
Izana Goloseev
Izana San Fernando
Matera Riga
Matera Izana
Empfingen Riga

Questions:

- Can we really get returns from Apophis in 2029?
- What accuracy and precision can provide the SLR measurements?
- Can we do a positive impact for the Apophis orbit improvement?
- A multistatic debris observation test at the GEO graveyard?
- Can we support non SLR observations instead?
- How to organize the PR activities?

A possible timetable:

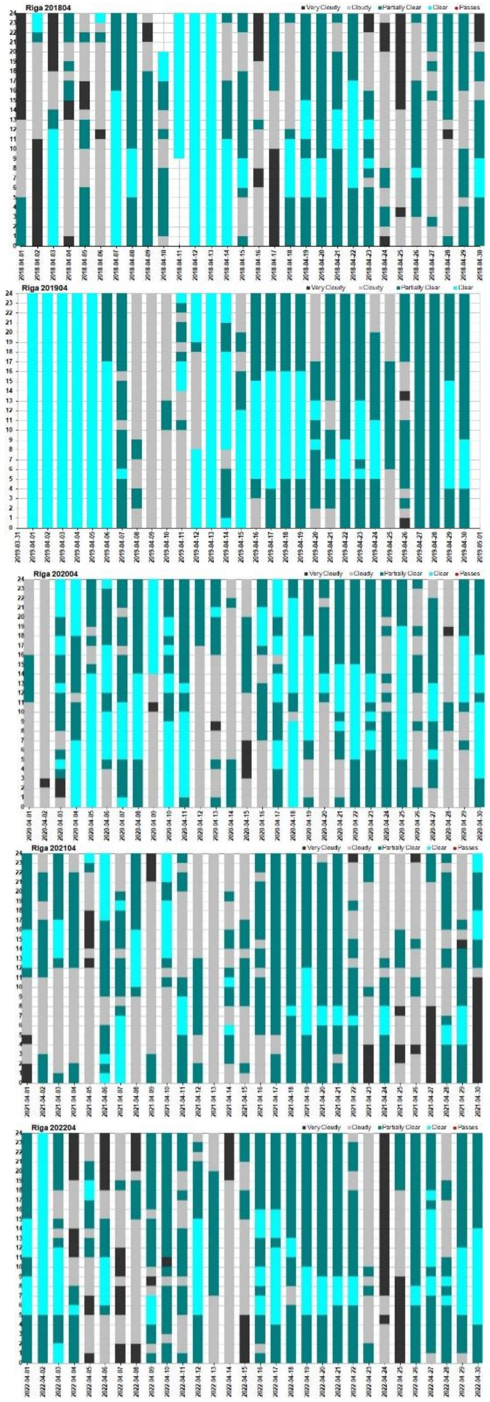
- 2022-2027: Regular Contacts between the interested groups.
- Steering group?
- Improved parameters.
- 2026-2027: Go-NoGo.
- Apply for funding (if Go and needed).
- April or September 2028, a test at the Geostationary Graveyard?
- April 13, 2029: **The big Friday**.
- After April 13, 2029: Publications & Meetings.

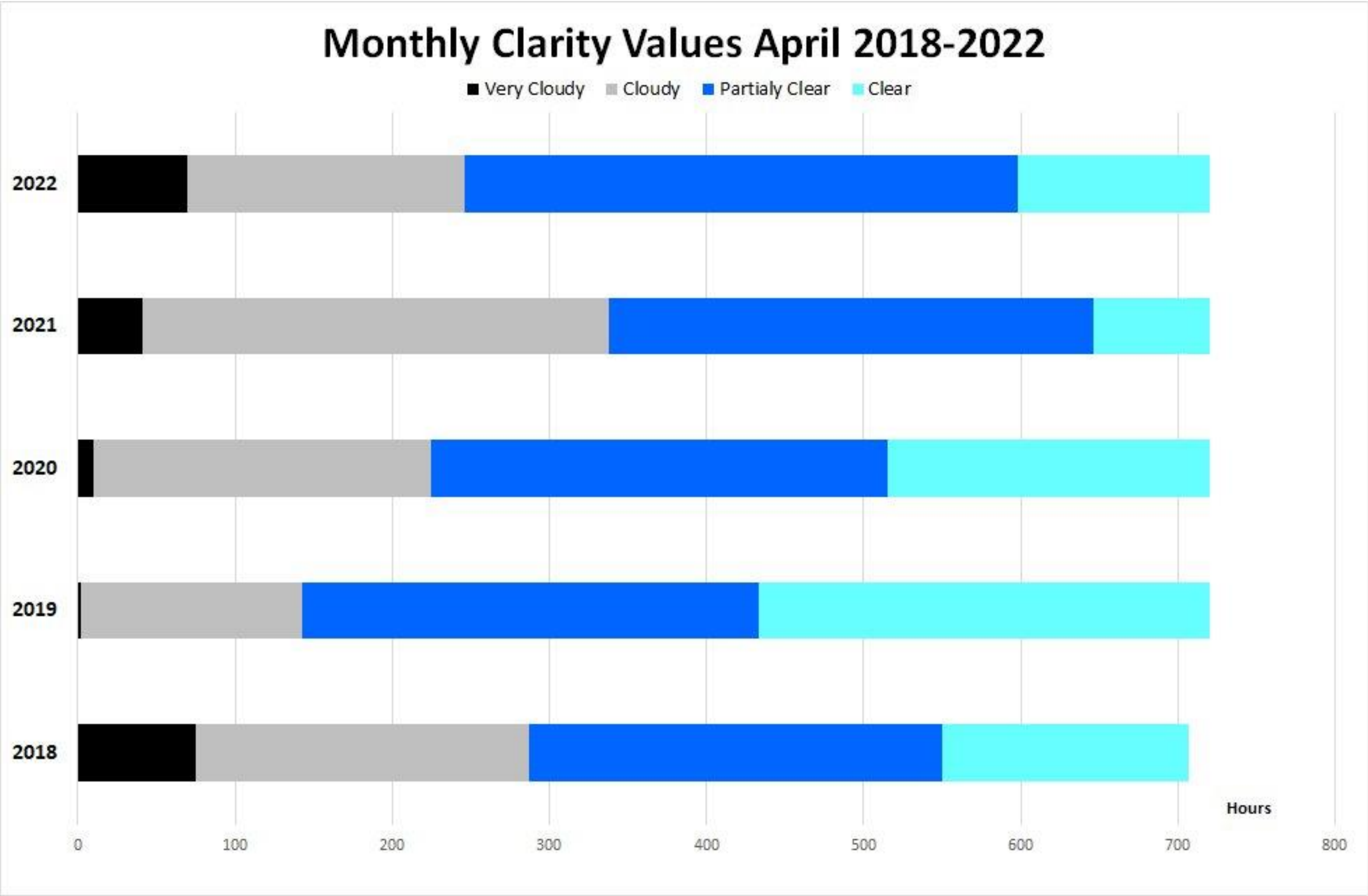
In any case, during 2022 - 2027

- Develop a reliable Apophis cross section model based on it‘s shape and orientation during the encounter. [1]
- For all stations: Better statistics for the April mean cloud cover values. Helps to distribute the roles.
- We need to include analysis group(s) into the discussion not only for providing the CPF‘s but to try to improve the CPF‘s on real time, by using fixed time observing sessions.

- The wavelenght problem: In this moment 8834 & 7827 Wettzell and 7701, Izaña are the only Eurolas SLRs ***not*** working at 532 nm

[1] see: https://cddis.nasa.gov/lw15/docs/papers/Possibility of the Near Earth Objects Distance Measurement with Laser Ranging Device.pdf


Riga 201804
Riga 201904
Riga 202004
Riga 202104
Riga 202204

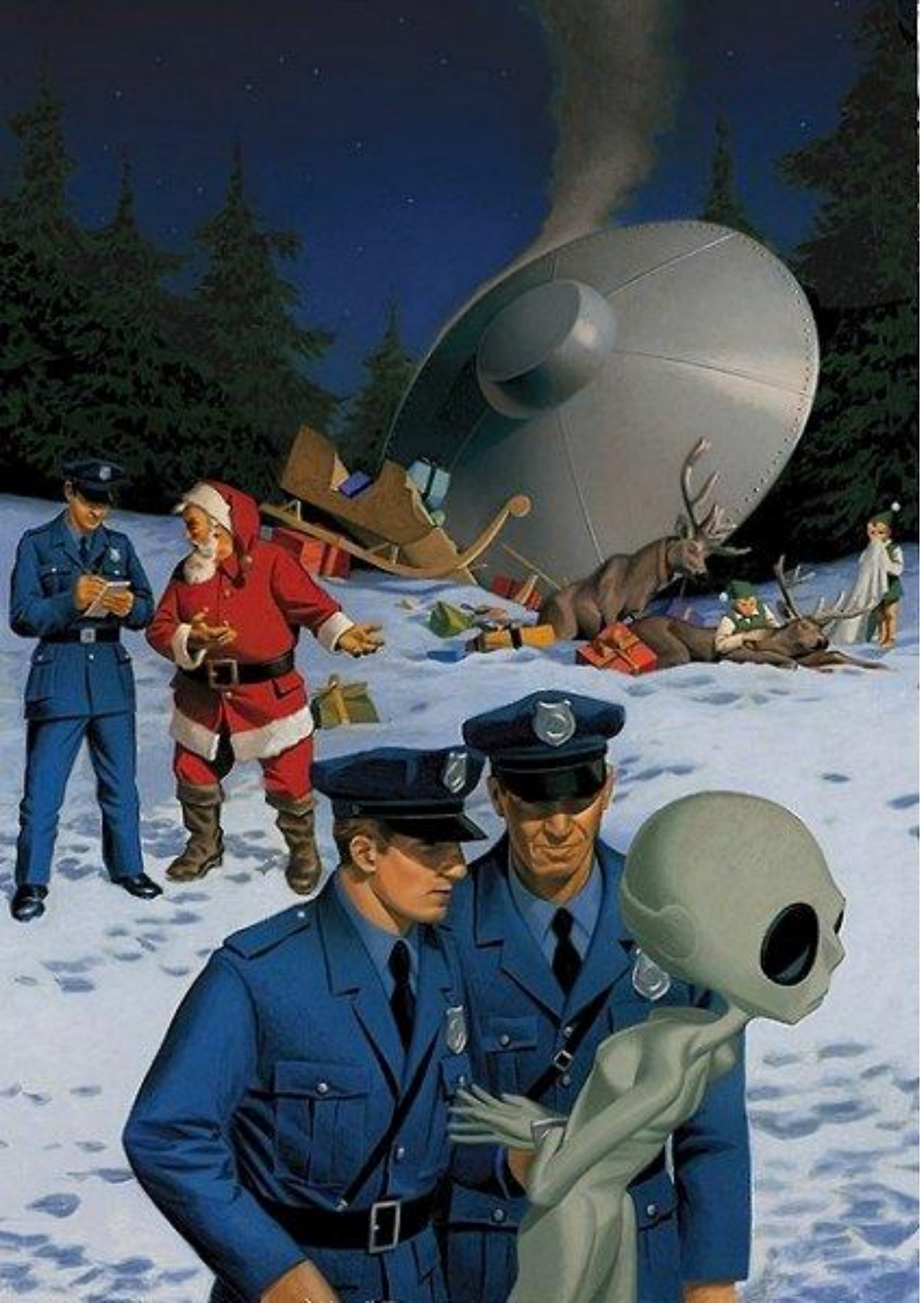

Monthly Clarity Values April 2018-2022
Very Cloudy
Cloudy
Partialy Clear
Clear
2022
2021
2020
2019
2018
Hours
0
100
200
300
400
500
600
700
800

Conclusion: It is **not** physically impossible to laser range to Apophis.

In case someone will try to land a probe in Apophis, we should ask to include one or two cheap LRR‘s or hemispherical Mylar reflectors!

(Does anyone has Elon Musk private email?)

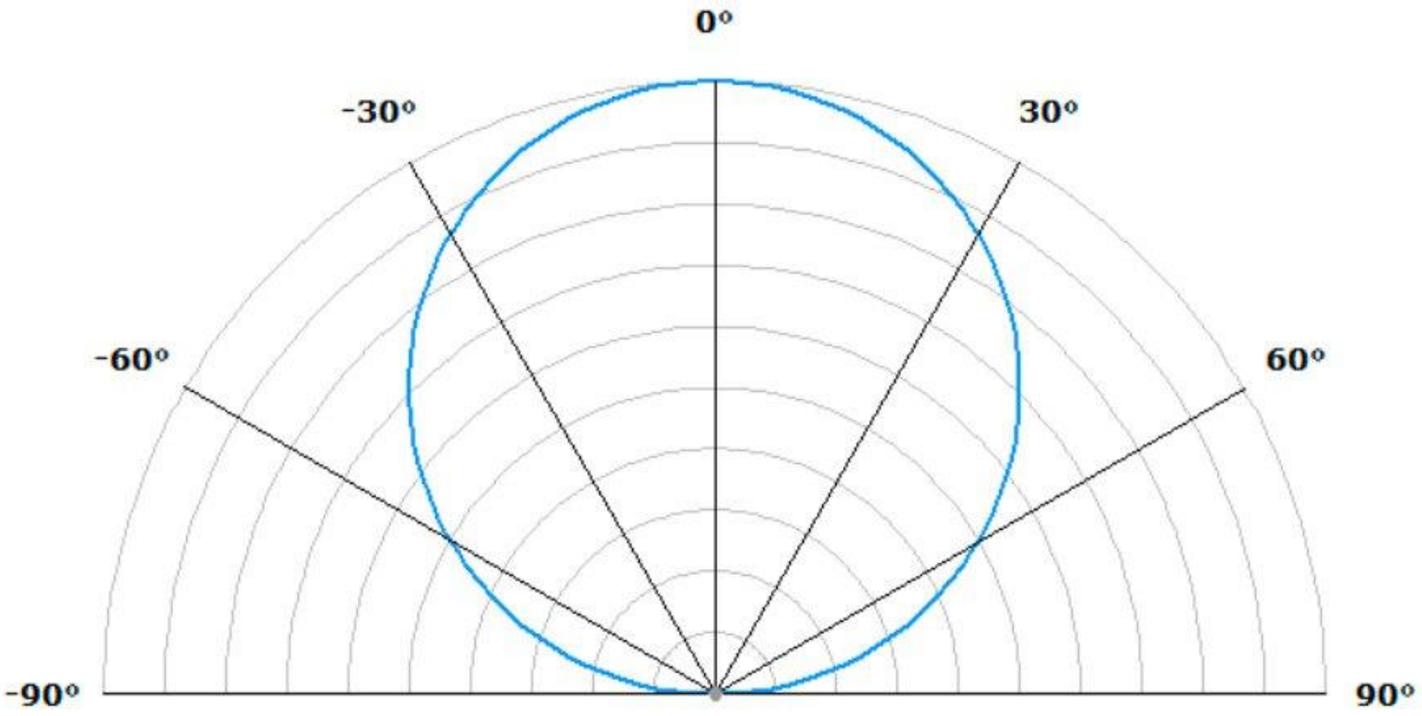
SSA



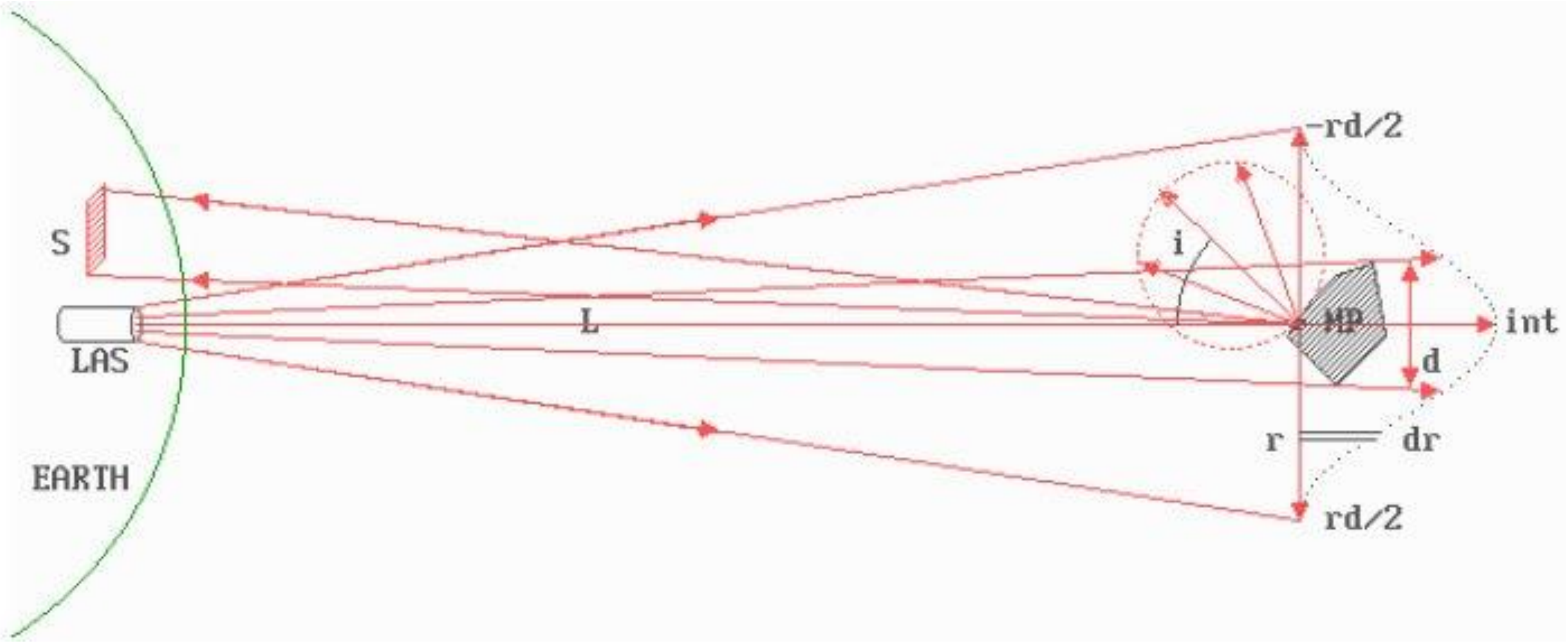
Thanks!

¡Gracias!

Reduction Factor	
Empfingen	100.0%
Grasse (MeO)	77.4%
Matera	73.5%
Riga	32.7%
Zimmerwald	32.7%
Izana	20.9%
Wettzell-8834	18.4%
Borowiec	13.8%
San Fernando	11.8%
Wettzell-7827	8.2%
Graz	8.2%
Herstmonceux	8.2%
Potsdam	6.3%
Kiev	5.2%



Polar plot of a perfect Lambertian Reflector



Modeling the signal response (Abele et. al. Camberra 2006)

Carl Zeiss Jena Baldone 1.2m. Schmidt
the 12th biggest Schmidt Telescope in use