Updated Orbit of Apophis with recent observations

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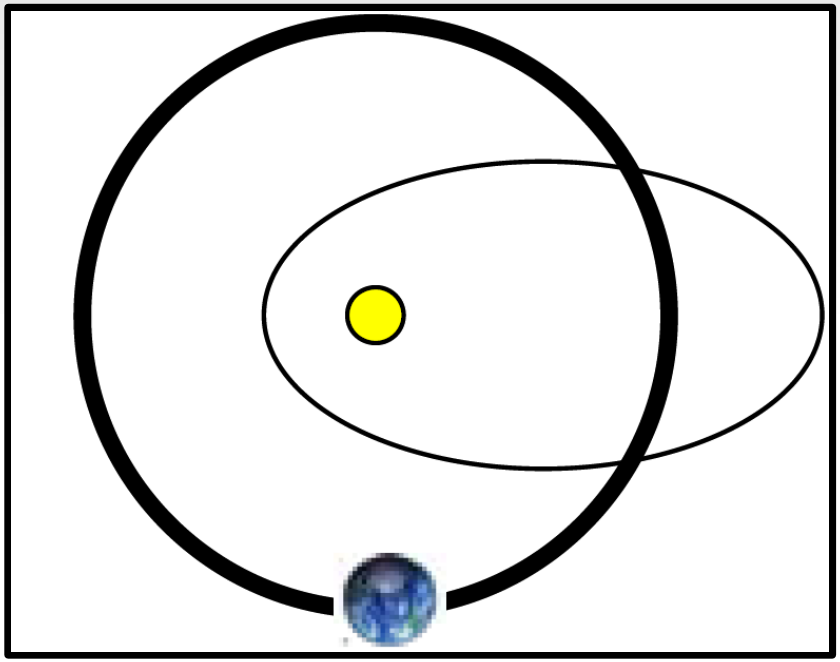
SF2A, Paris, June 22, 2011

Outline

- Past of Apophis
  - *Background*
  - *Dynamical study of the 2029-close encounter*
- Present of Apophis
  - *Observations of March 2011*
  - *Recent results*

Background

Who is Apophis ?



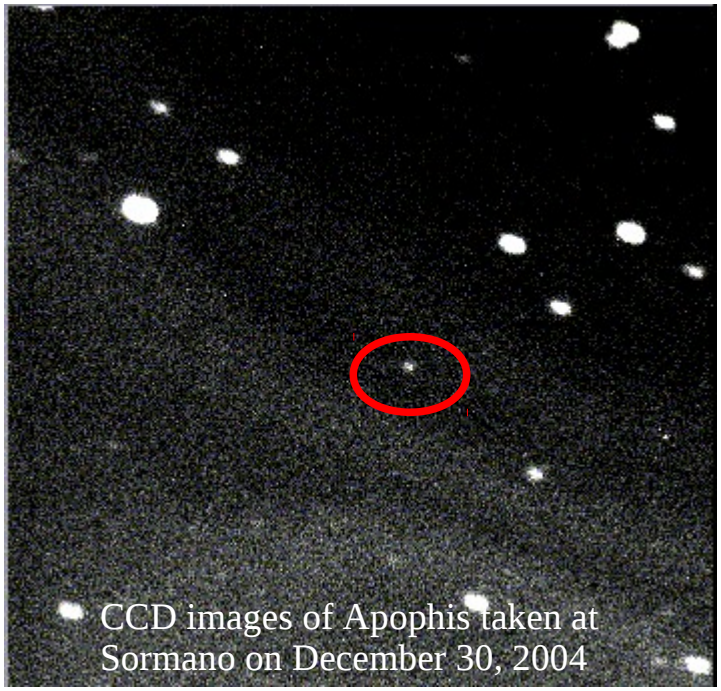
- Aten Family
- Discovered in June 2004 (Roy Tucker, David Thollen & Fabrizio Bernardi) at Kitt Peak Observatory (Arizona)
- Apophis = Apep: enemy of Râ / Stargate SG-1
- Physical parameters
  - ~ 270 m diameter, H ~ 19.7 (Delbo, Cellino, Tedesco 2007)
  - Sq family (Binzel et al.)

Background

2029 Threat

- Lost in June 2004 (6 obs.)

- December 2004



23/12/2004: 64 obs	1/62 (~ 1.6%)
25/12/2004: 101 obs	1/42(~ 2.4%)
26/12/2004: 169 obs	1/45 (~ 2.2%)
27/12/2004: 176 obs	1/37 (~ 2.7%) → ***Torino Scale 4***
27/12/2004: March 15 Precovery	~ 0.004% → ***Torino Scale 0***

Background

2036 Threat

- Radar obs. 2005 - 2006
  - 27-29/01/2005: 3 radar → 2029-close encounter ~ 5.6 $R_{\oplus}$
  - 07/08/2005: 1 radar → ***Torino Scale 1***
  - 06/05/2006: 1 radar → I.P./4 → ***Torino Scale 1***
- Optical 2006 & 2008
  - 06/08/2006: 996 obs → 1/45000
  - 07/10/2009: Precovery refinements & optical → 1/250000 → ***Torino Scale 0***

Background

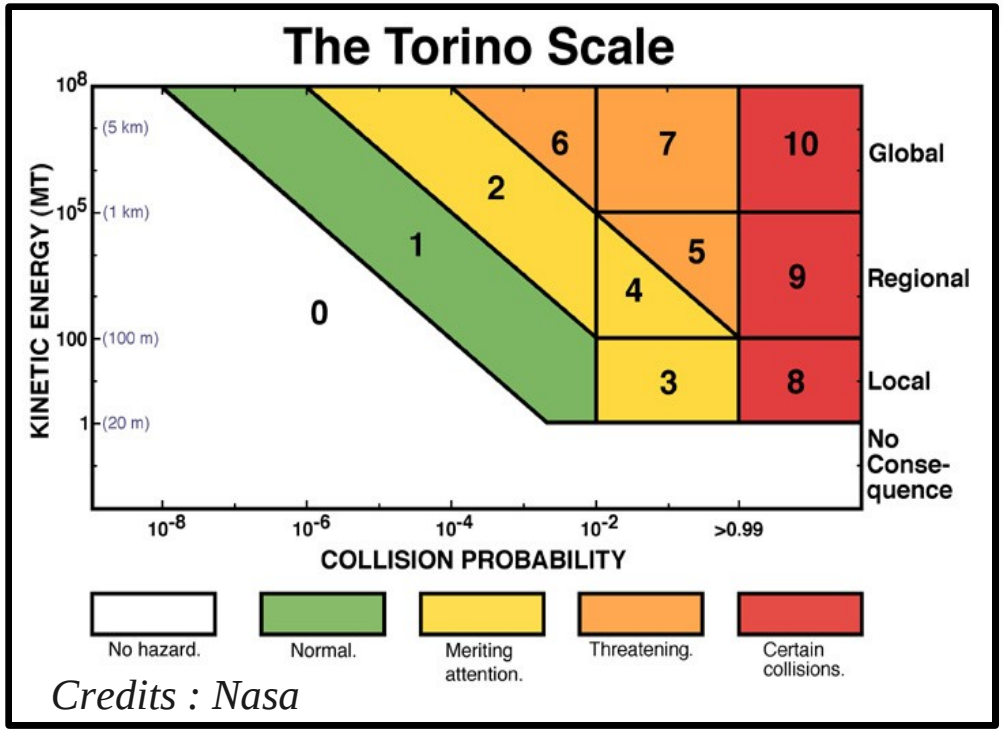
These results were computed on Oct 07, 2009

99942 Apophis (2004 MN4)

Earth Impact Table

Credits : Nasa

Date	Distance	Width	Sigma Impact	Sigma LOV	Stretch LOV	Impact Probability	Impact Energy	Palermo Scale	Torino Scale
YYYY-MM-DD.DD	(r_{Earth})	(r_{Earth})			(r_{Earth})		(MT)		
2036-04-13.37	0.53	< 1.e-04	0.000	-3.276	1.03e+03	4.3e-06	5.06e+02	-3.08	0
2056-04-13.37	0.66	< 1.e-04	0.000	0.304	5.53e+06	1.0e-07	5.06e+02	-4.97	0
2068-04-13.37	0.02	< 1.e-04	0.000	0.335	3.11e+05	2.5e-06	5.06e+02	-3.70	0
2068-04-13.37	0.00	< 1.e-04	0.000	1.039	4.09e+06	1.1e-07	5.06e+02	-5.04	0
2076-04-13.37	0.10	< 1.e-04	0.000	0.350	3.35e+06	2.2e-07	5.06e+02	-4.79	0
2103-04-13.37	0.61	< 1.e-04	0.000	0.334	4.25e+06	1.3e-07	5.06e+02	-5.17	0

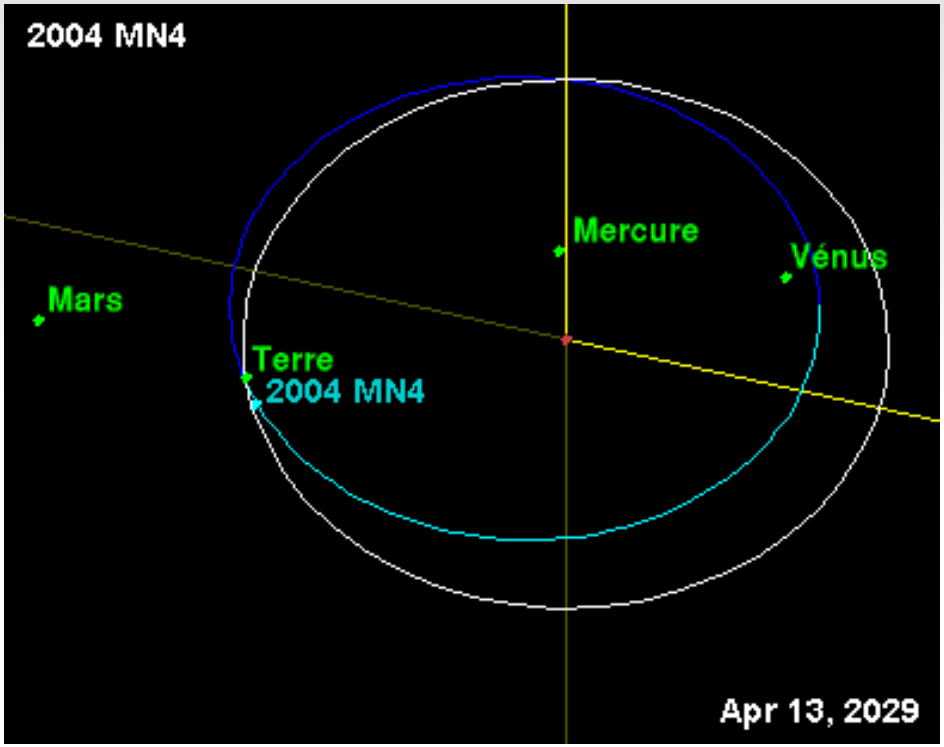


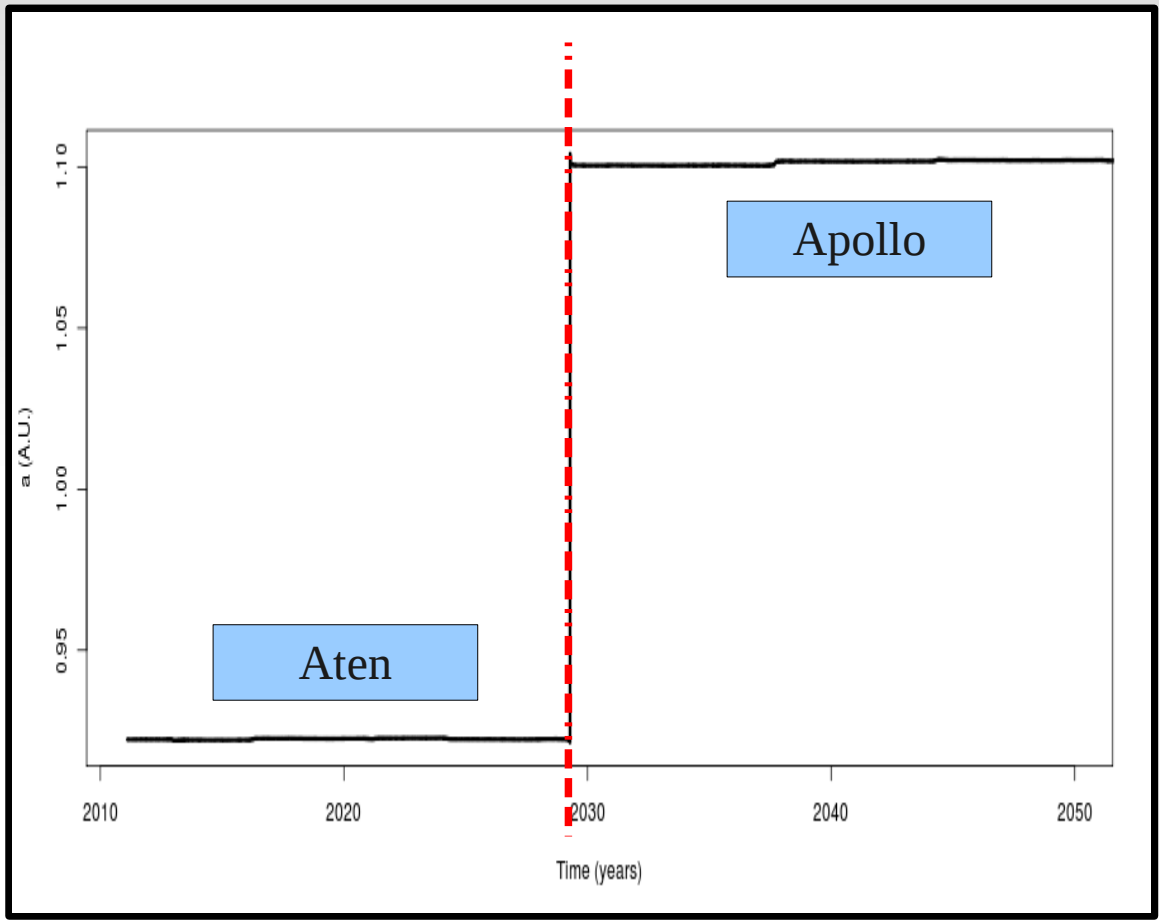
Credits : Nasa

Mass ~ 2.7e+10 kg
Vimpact ~ 12.59 km/s

~ 34000 x Hiroshima bomb

2029-close encounter study





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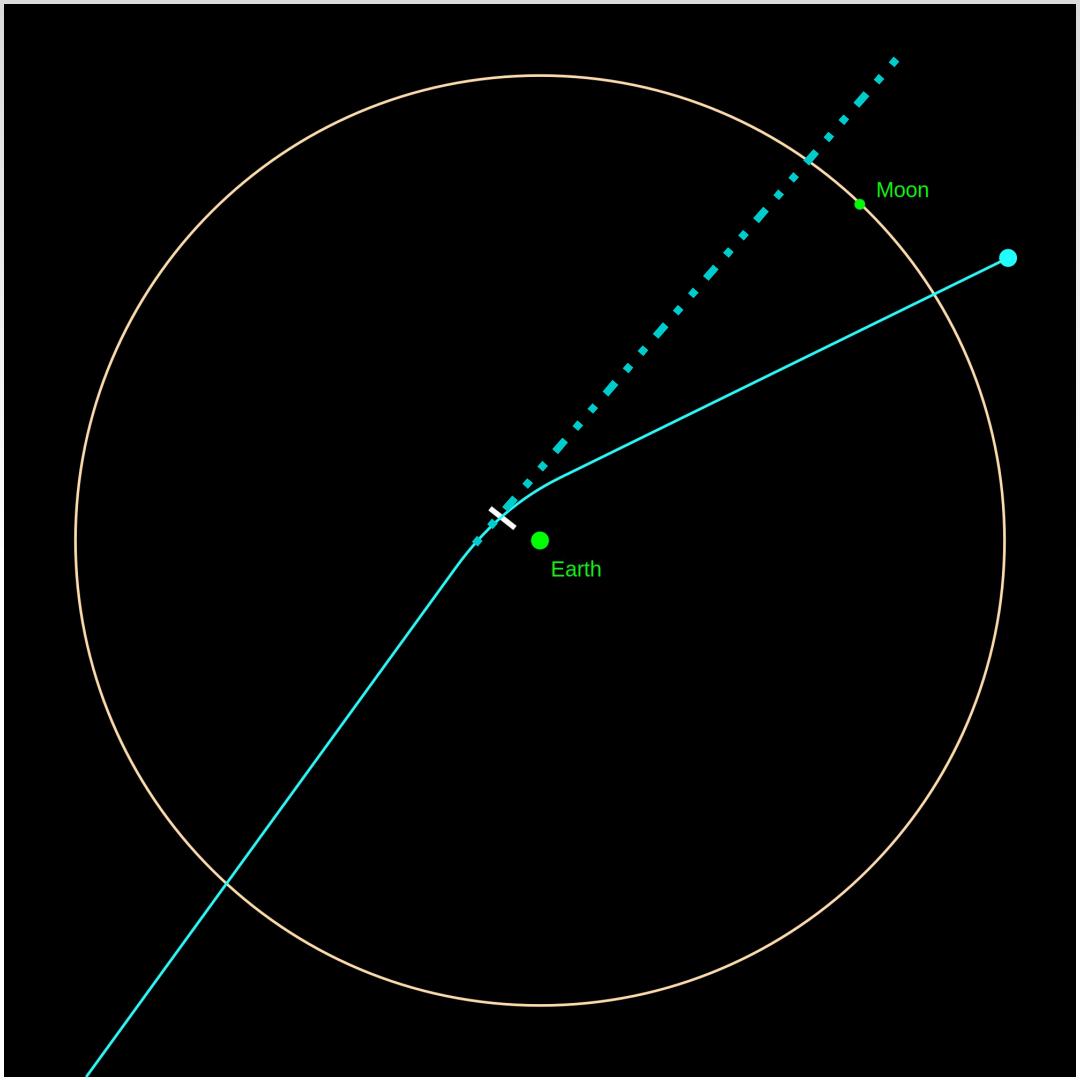

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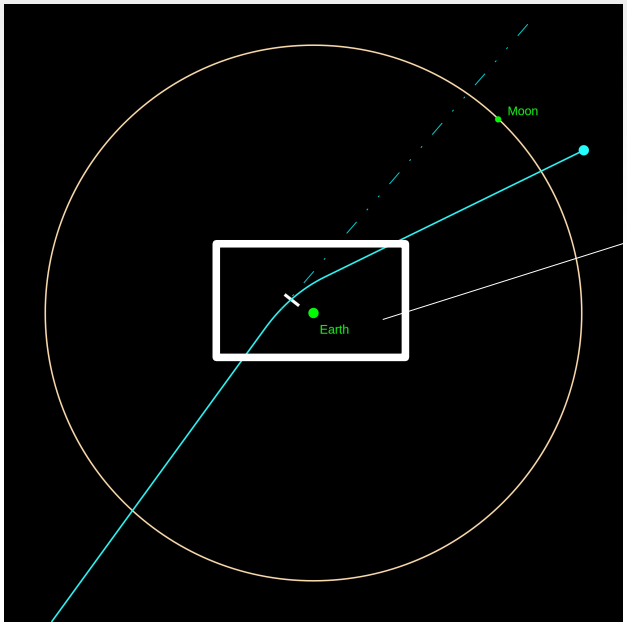
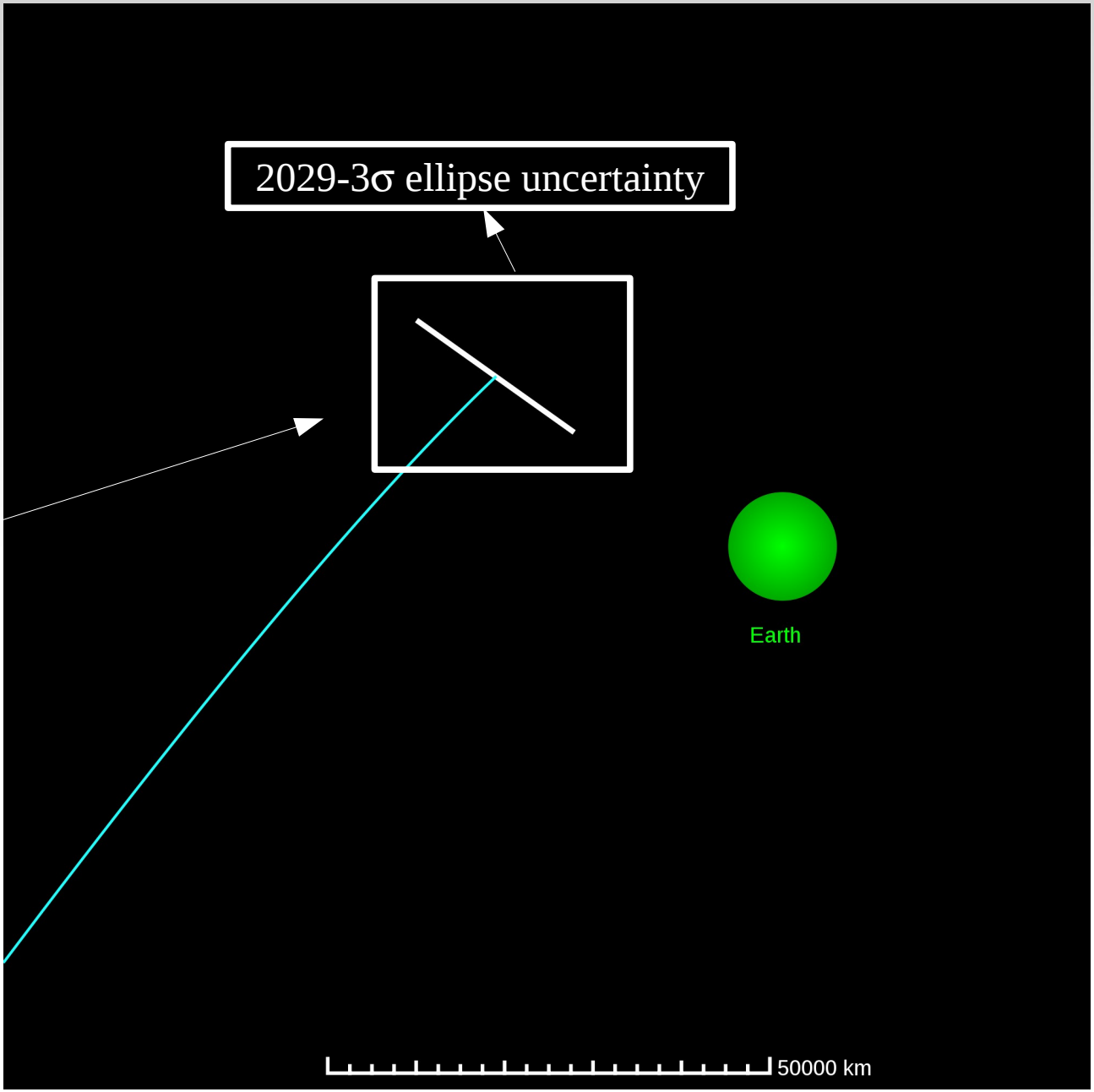
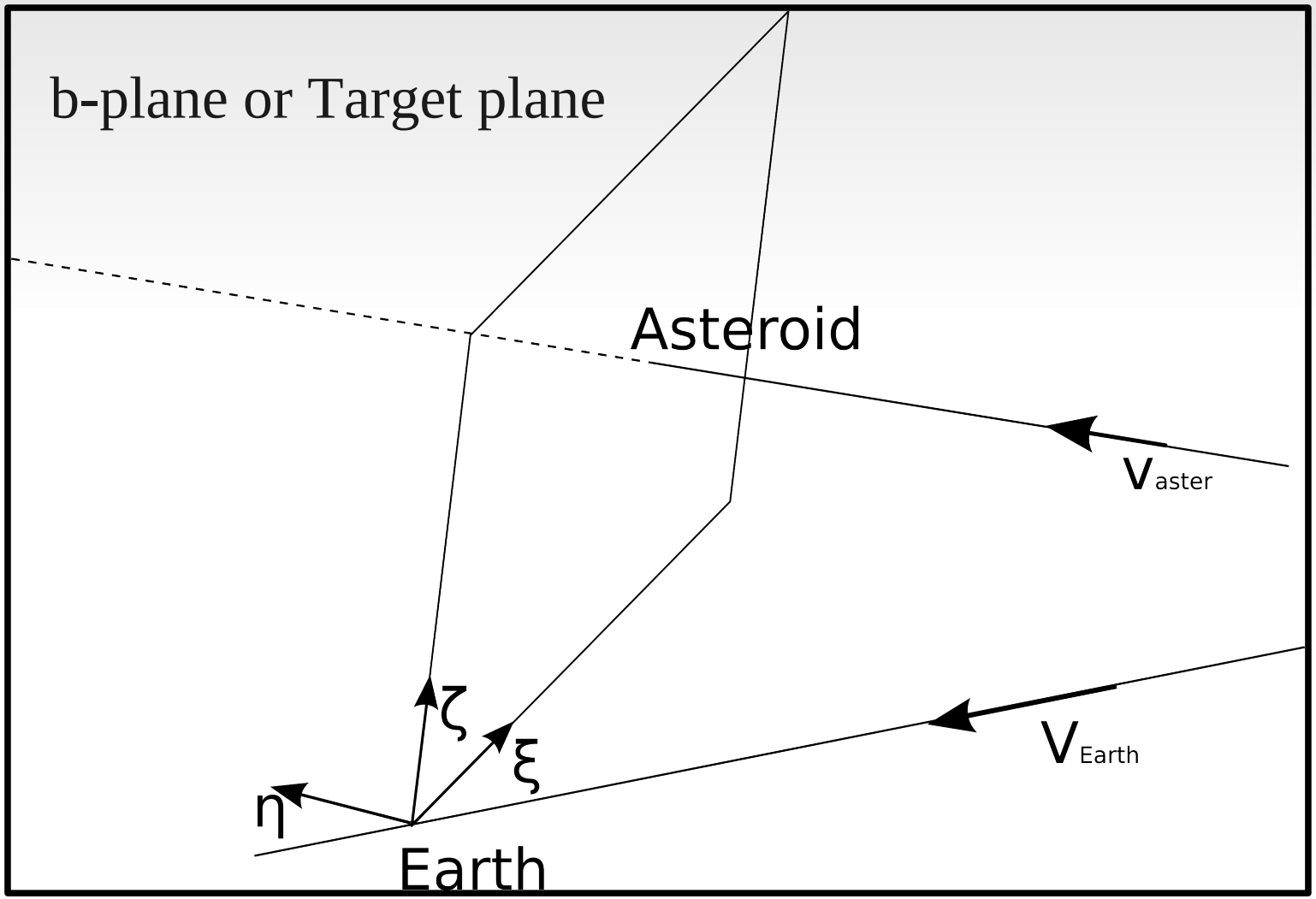




2029-close encounter study

- 2029-close encounter geometry



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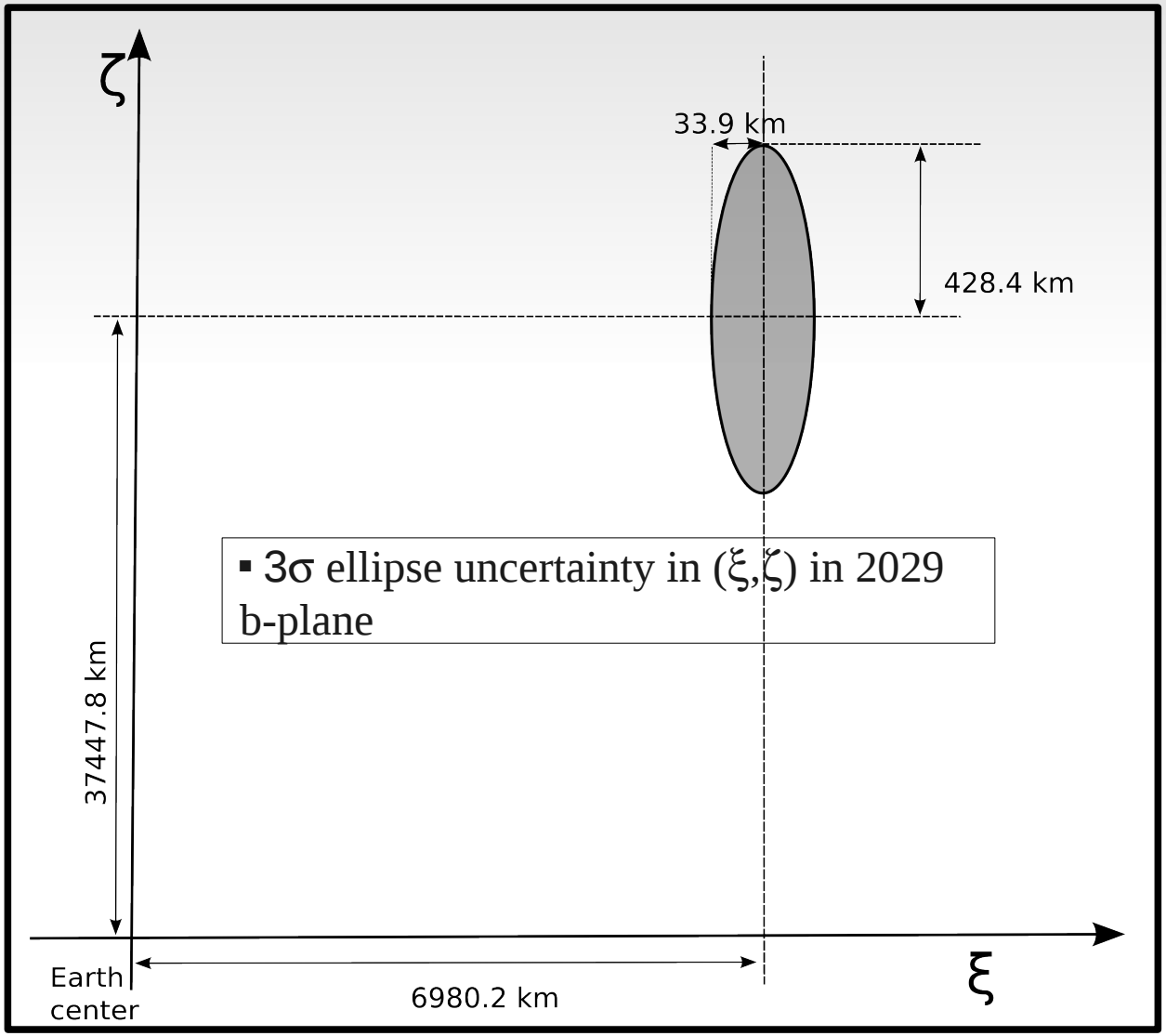

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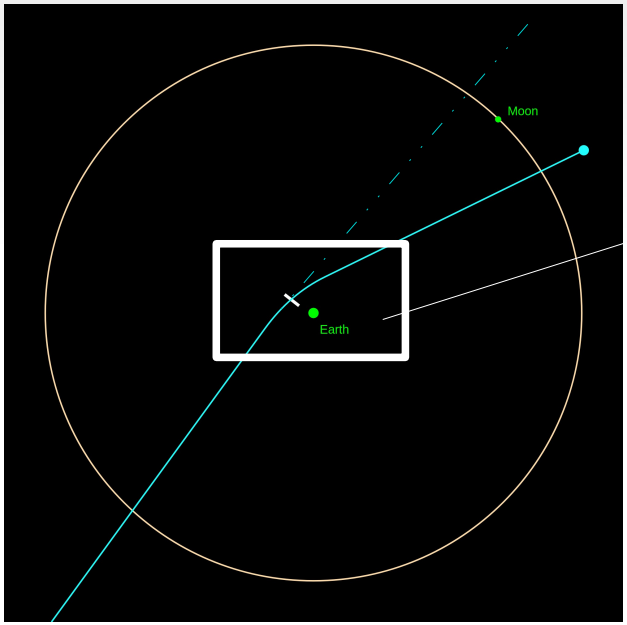
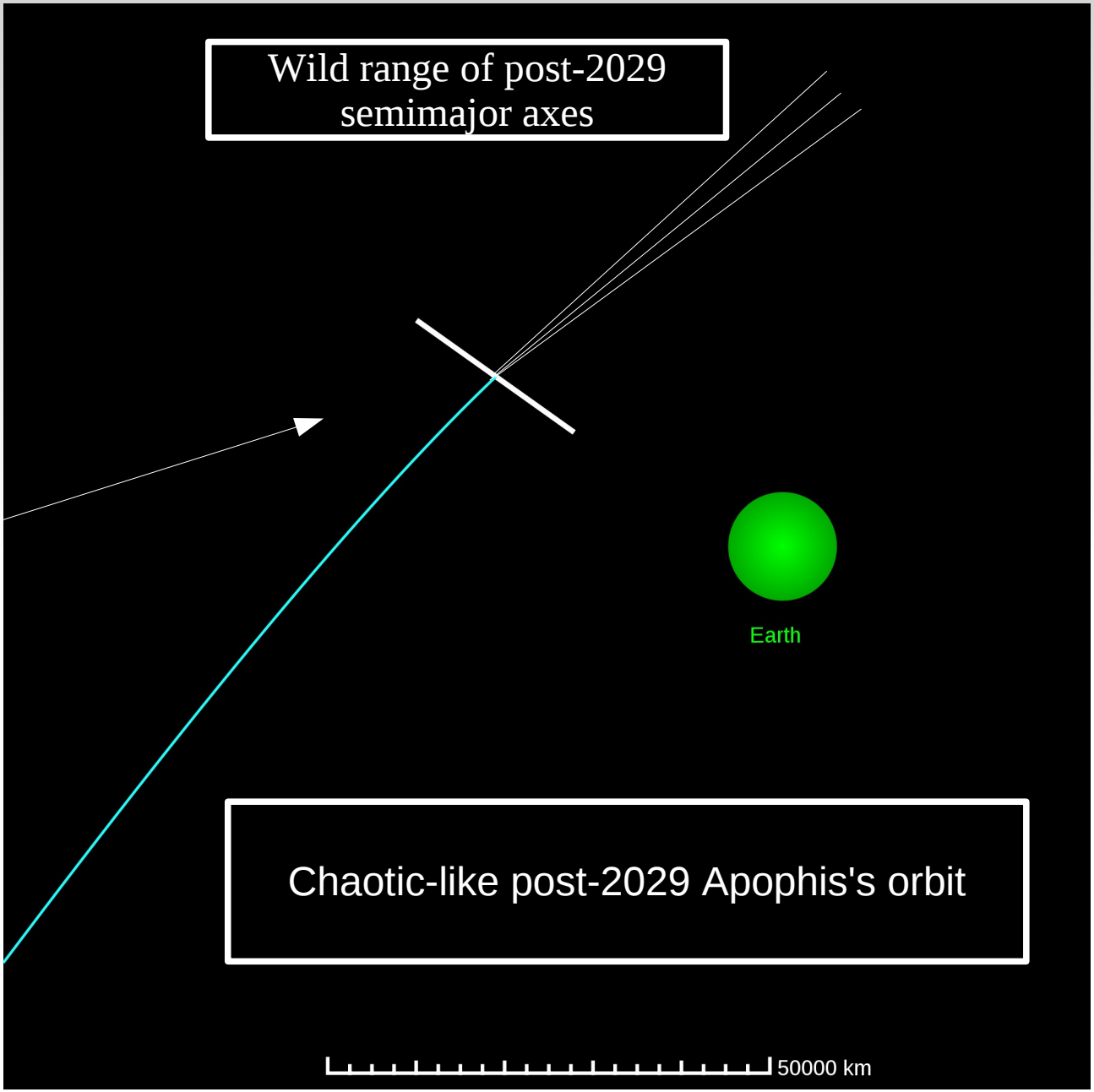




2029-close encounter study

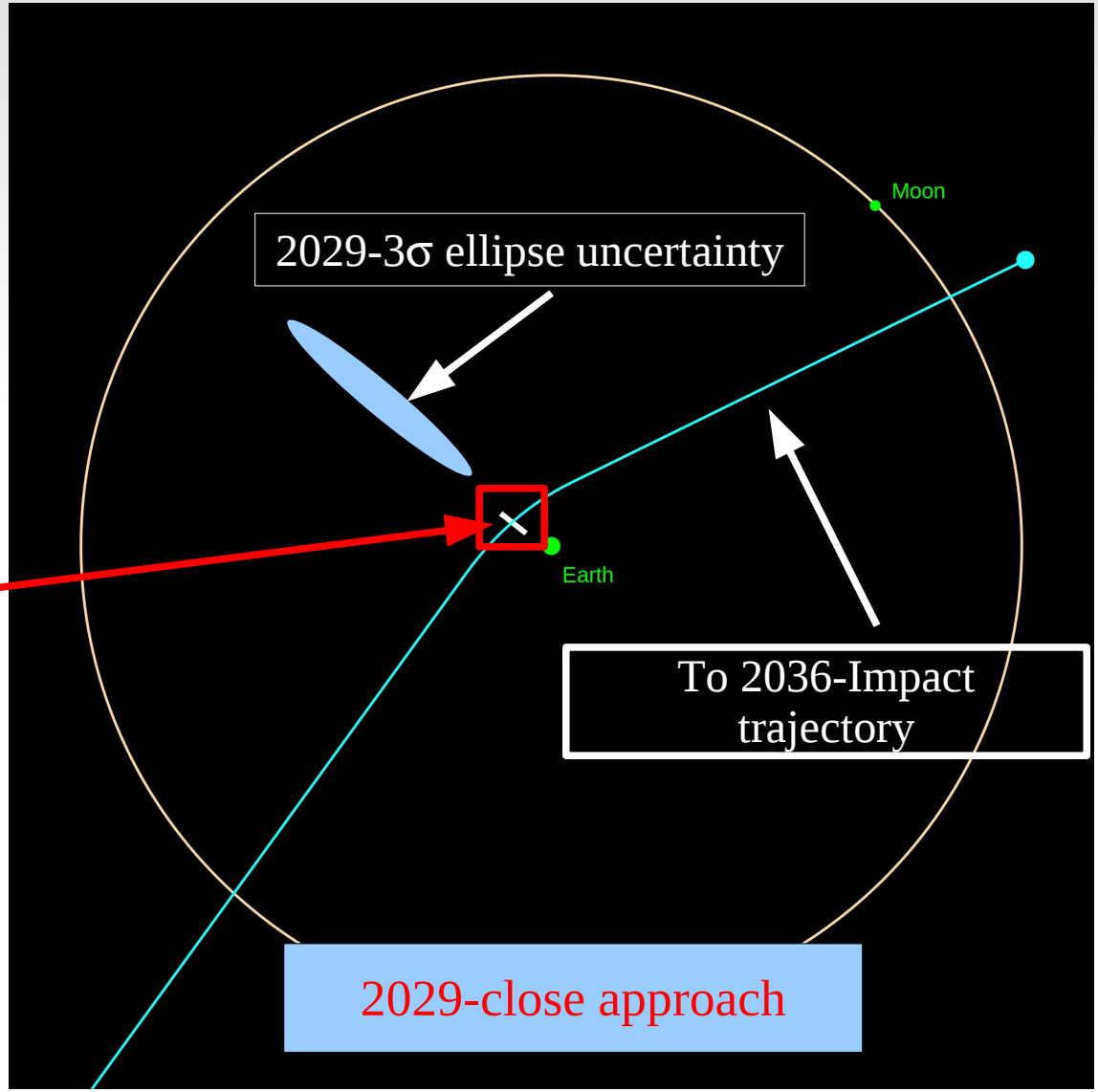
- 2029-post orbit → Resonant Return encounters

$$k*T_{ap} = h*T_{\oplus} \quad h, k \in \mathbb{N}^*$$

Year	Resonance	2029-post period range (days)
2034	5:4	[456.2:456.9]
2035	6:5	[437.9:438.6]
2036	7:6	[425.7:426.5]
2037	8:7	[417.1:417.8]
2038	9:8	[410.5:411.3]
2046	17:15	[413.6:414.3]
2048	19:17	[407.9:408.6]
2051	22:19	[422.5:423.3]

2029-close encounter study

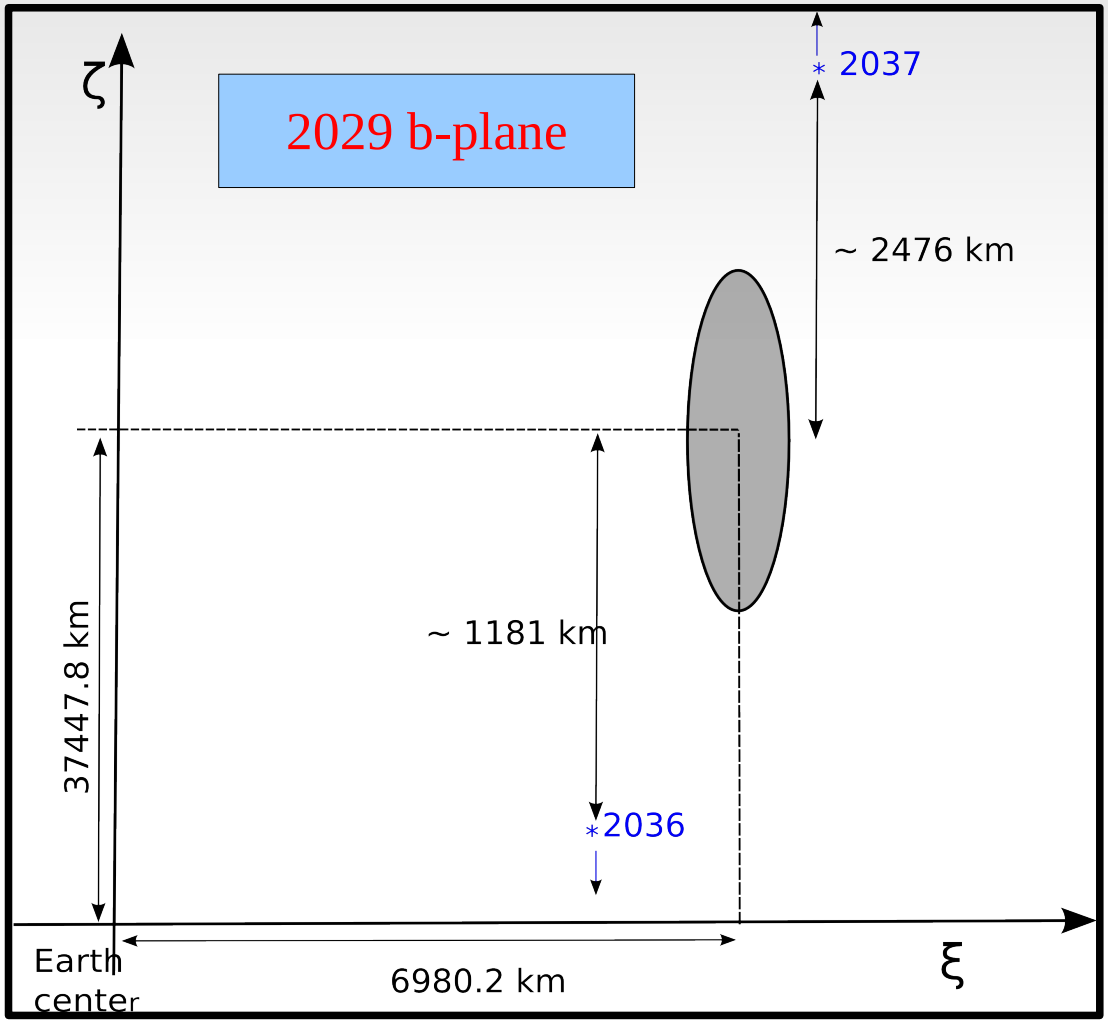
- 2029-post orbit → Resonant Return encounters → keyholes



2029-close encounter study

- 2029-post orbit → Resonant Return encounters → primary keyholes

Year	Resonance	keyhole size (m)
2034	5:4	560
2035	6:5	560
2036	7:6	610
2037	8:7	570
2038	9:8	
2046	17:15	660
2048	19:17	410
2051	22:19	



2029-close encounter study

- 2029-post orbit → Resonant Return encounters → secondary keyholes

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2068-04-13.37	0.02	< 1.e-04	0.000	0.335	3.11e+05	2.5			
2068-04-13.37	0.00	< 1.e-04	0.000	1.039	4.09e+06	1.1			
2076-04-13.37	0.10	< 1.e-04	0.000	0.350	3.35e+06	2.2			
2103-04-13.37	0.61	< 1.e-04	0.000	0.334	4.25e+06	1.3			

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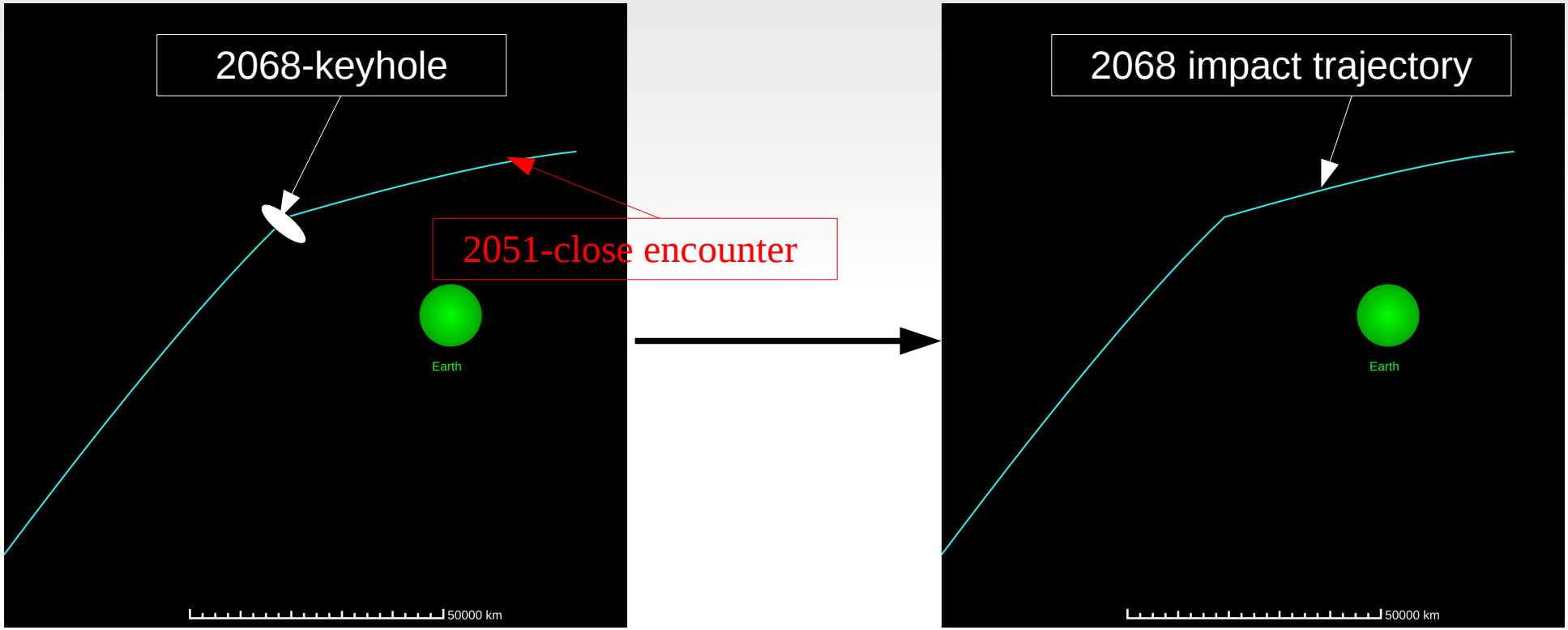
2029-close encounter study

- 2029-post orbit → Resonant Return encounters → secondary keyholes



2029-close encounter ~ 38000 km

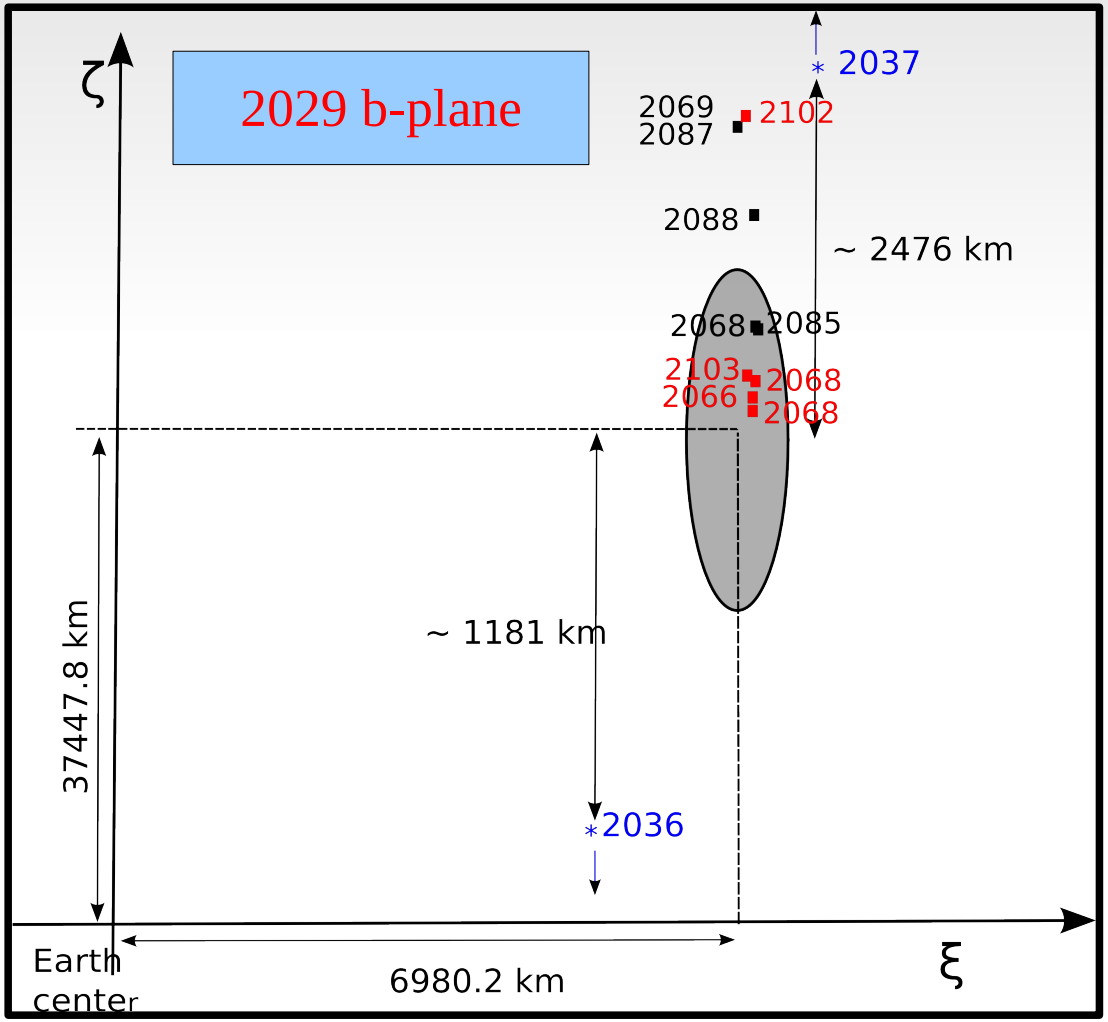
2051-close encounter ~20000 km

2029-close encounter study

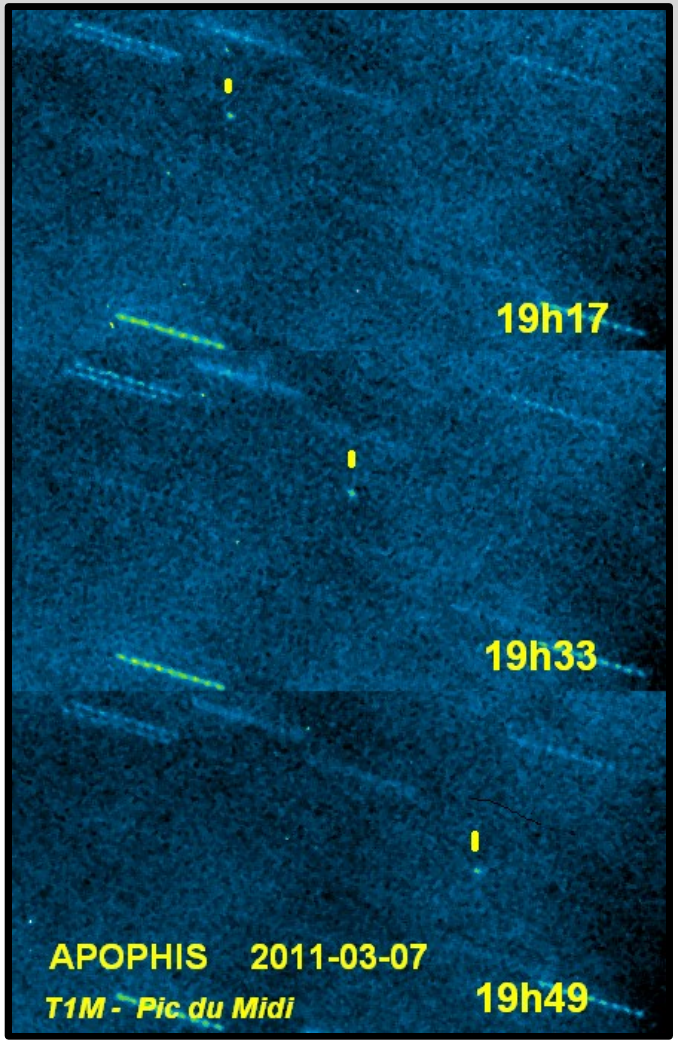
- 2029-post orbit → Resonant Return encounters → secondary keyholes

▪ 3σ ellipse uncertainty in (ξ, ζ) in 2029 b-plane

▪ Primary (✳) and Secondary keyholes at ascending (■) and descending (■) node.



Orbit of Apophis from recent observations (2011 March)



Observers: F. Colas, F. Vachier and M. Birlan (IMCCE)

Pic du Midi Observatory:

- French Pyrenean mount. (2877 m)
- 4.8 to 7.8 March 2011
- 69 observations
- 1 m telescope

Apophis observations:

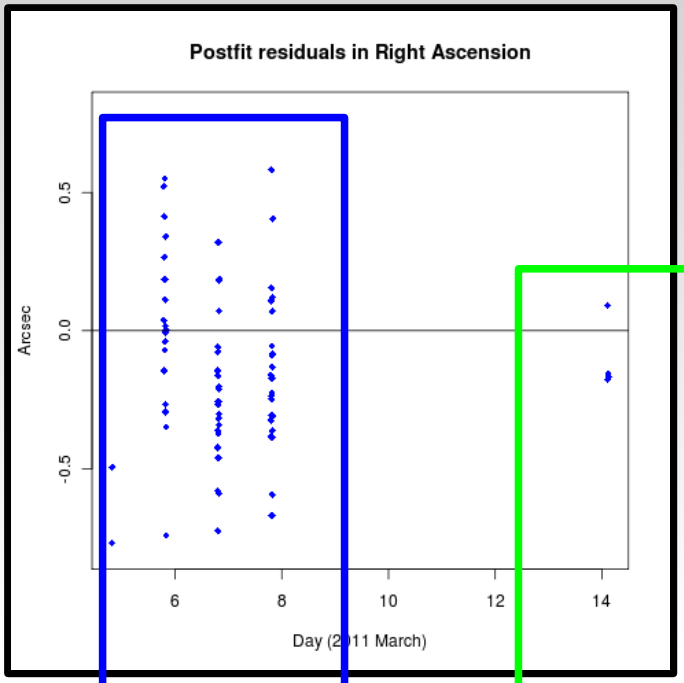
- Solar Elong: 49 °
- V ~ 21
- Velocity ~ 2.7 "/min

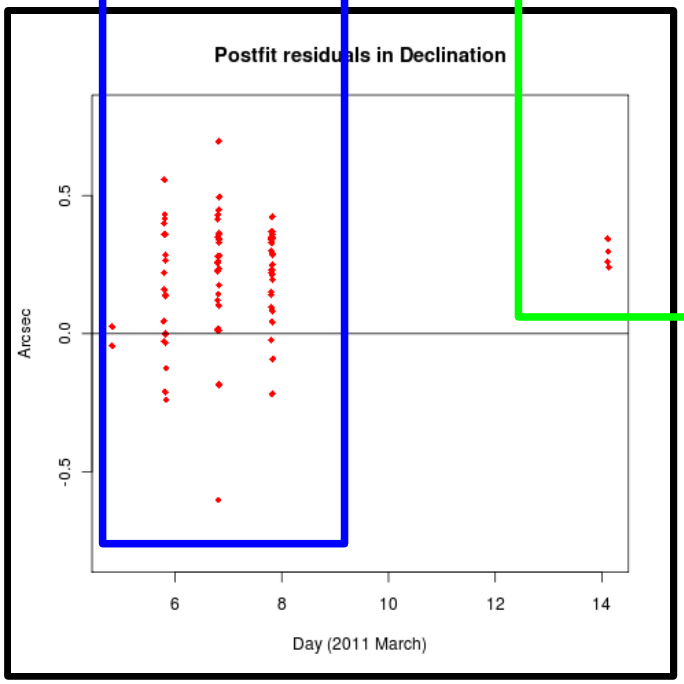
Magdalena Ridge Observatory (New Mexico):

- Magdala mount (3230 m)
- ~ 30 min 14 March 2011
- 4 observations
- 2.4 m telescope

Apophis observations:

- V ~ 21





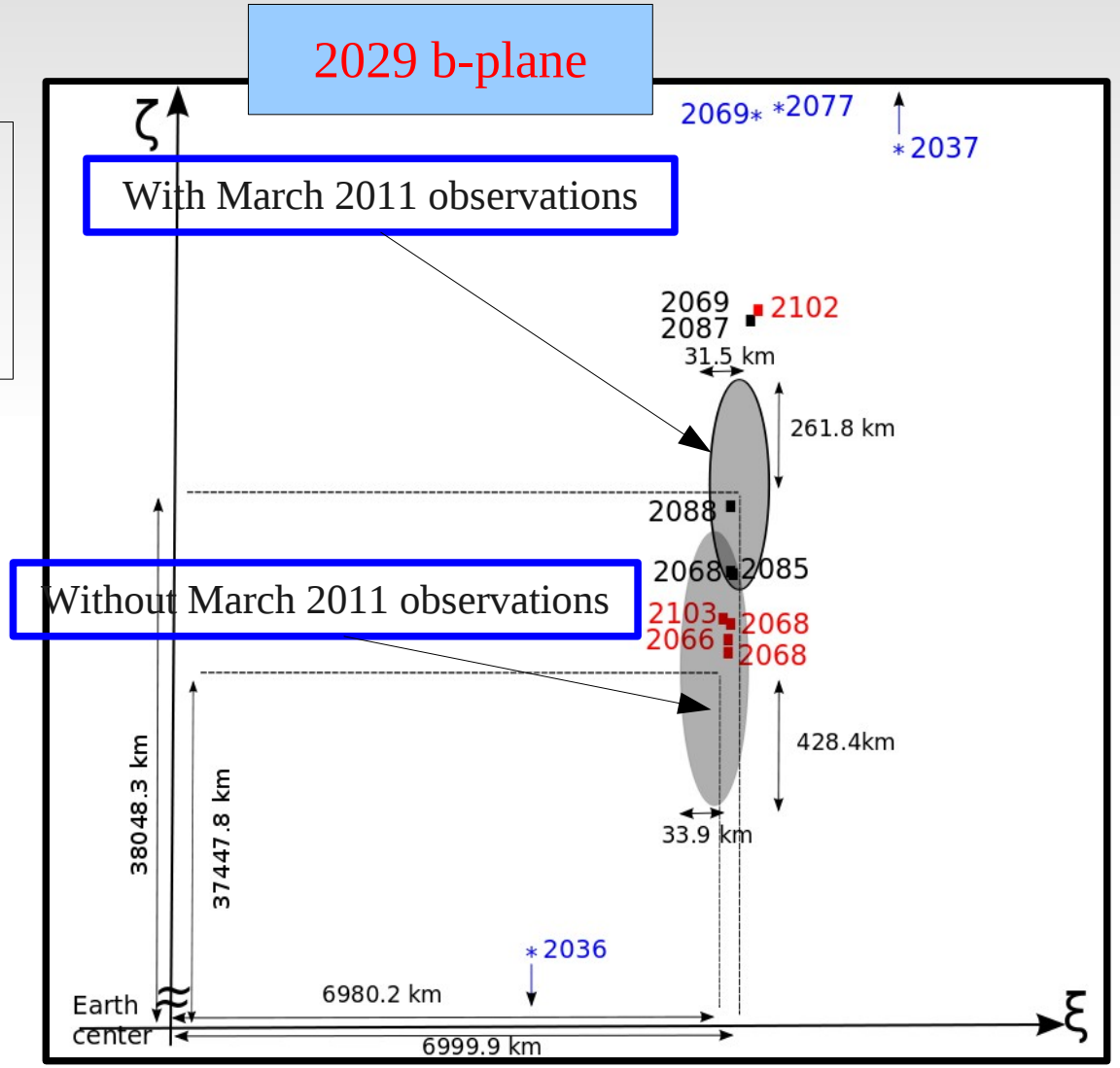
Recent Results

- 2029-close approach geometry

▪ 3σ ellipse uncertainty in (ξ,ζ) in 2029 b-plane

▪ Primary (✳) and Secondary keyholes at ascending (■) and descending (■) node.

Distance of keyhole from center of ellipse		
	Without March obs.	With March obs
2036	1181 km	1781 km
2037	2476 km	1875 km



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▪ 3σ ellipse uncertainty in (ξ, ζ) in 2029 b-plane

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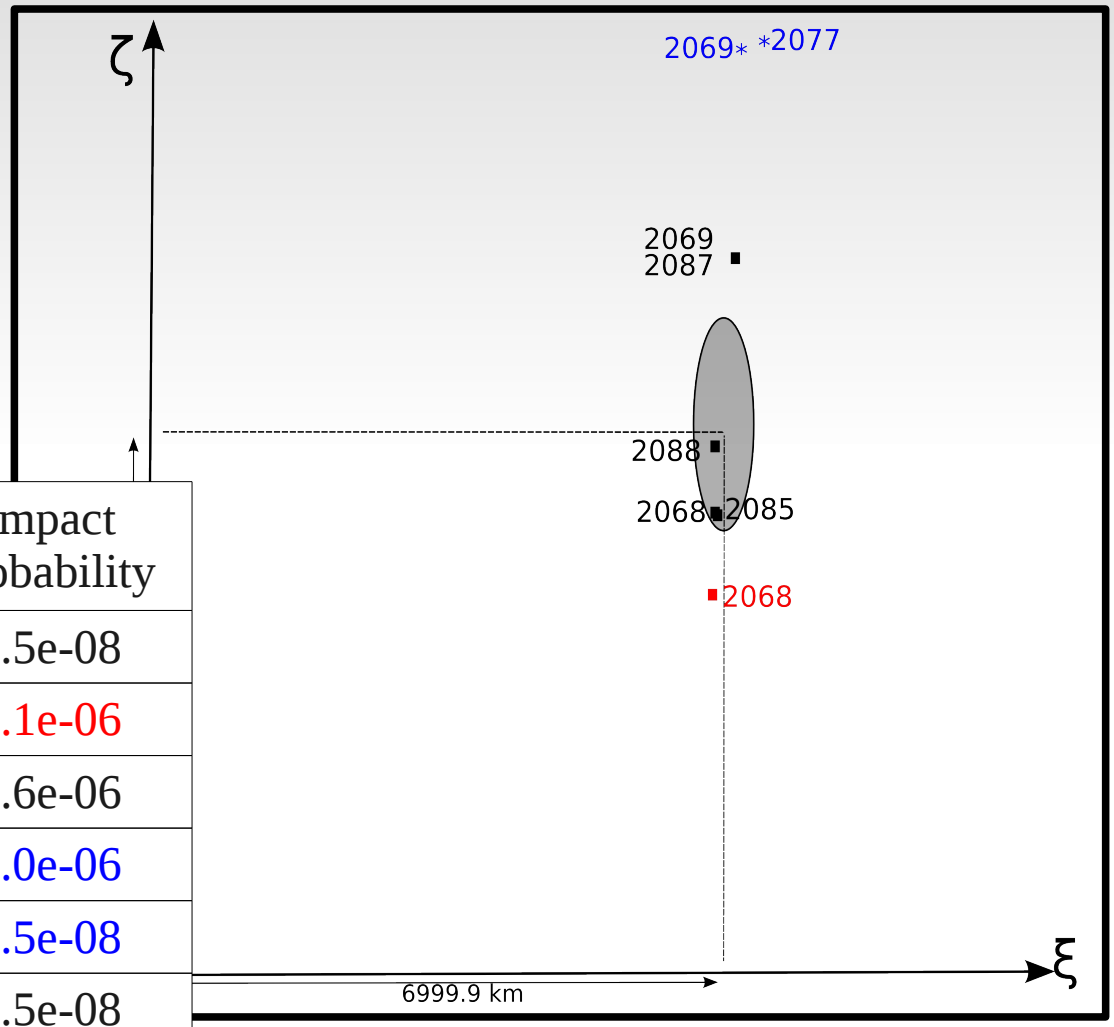
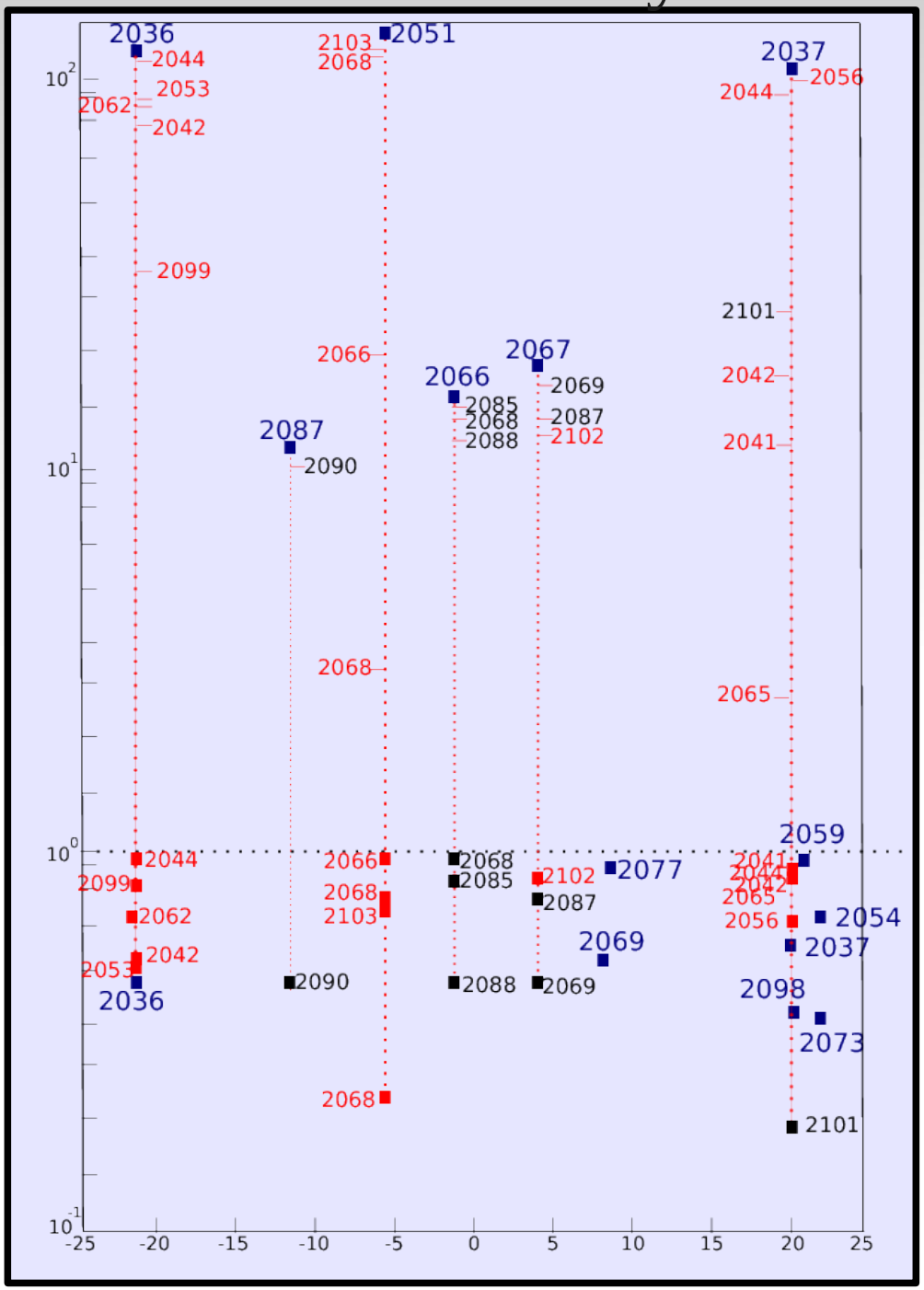
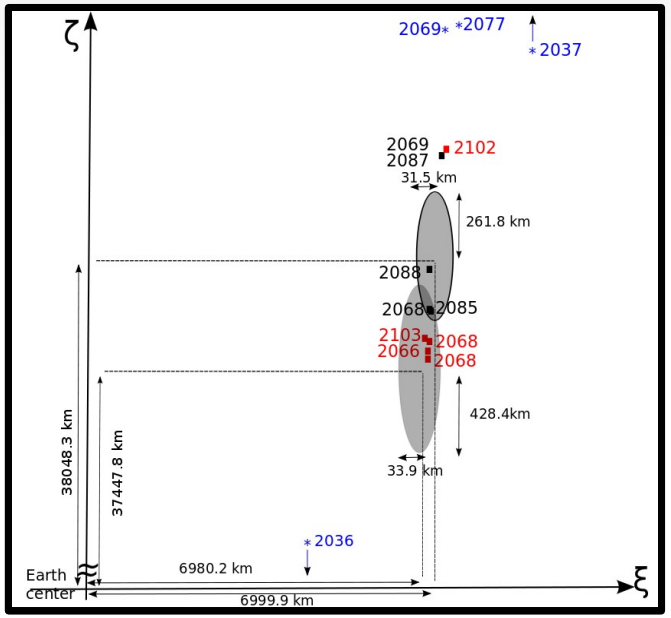


	Distance from center (km)	Keyhole size (m)	Impact Probability
2068	250	< 1	9.5e-08
2068	500	~ 40	1.1e-06
2069	355	~ 90	1.6e-06
2069	700	~ 110	1.0e-06
2077	730	~ 65	9.5e-08
2085	250	< 1	9.5e-08
2087	355	< 1	9.5e-08
2088	42	< 1	9.5e-08

Keyhole Map

Primary (✳) and Secondary keyholes at ascending (■) and descending (■) node.





Conclusion

- Apophis:
  - no danger ? OK but still a good study case
  - Need good accuracy for Deflection/rdv missions
- Uncertainties
  - Yarkovsky effect
  - Biases in astrometric catalogue
  - Non-linear effect