The Gaia-FUN-SSO observations campaign of Apophis: a preliminary test for the network

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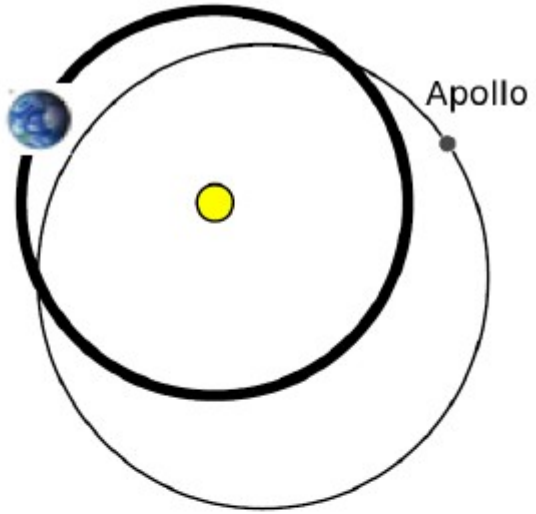
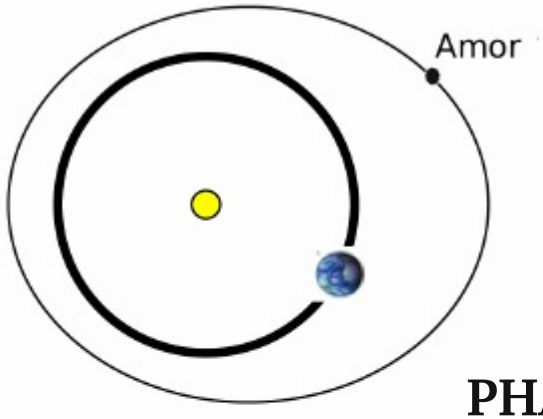
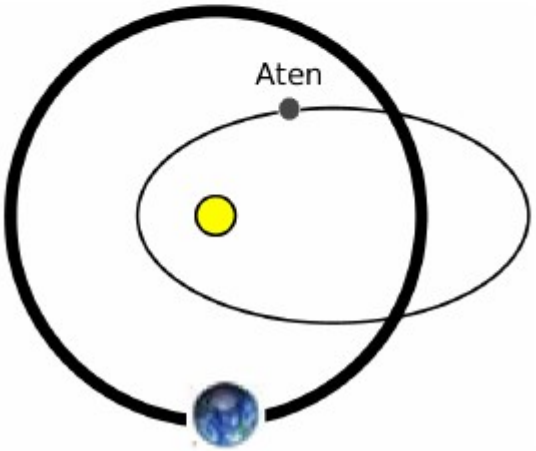
❶ Introduction
❷ Asteroid (99942) Apophis
❸ Observations
❹ Data analysis and results

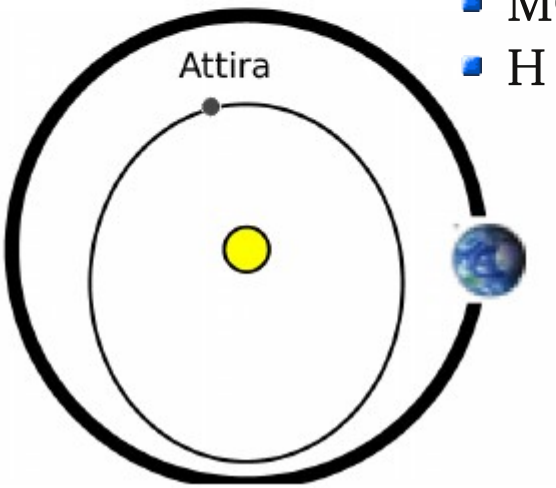
❶ Introduction

NEA population





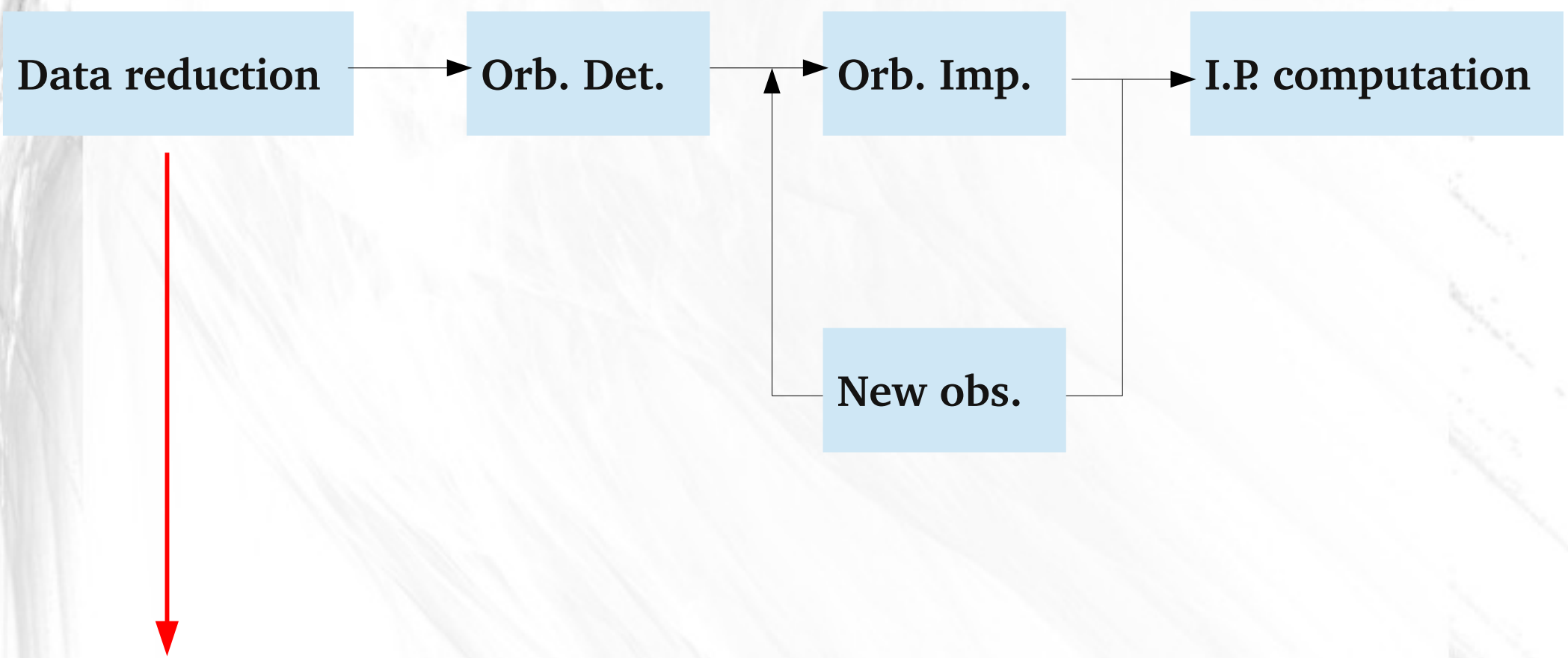




PHA ≡ NEA with :

- MOID ≤ 0.05 au (warning indicator)
- H ≤ 22.0

❶ Introduction



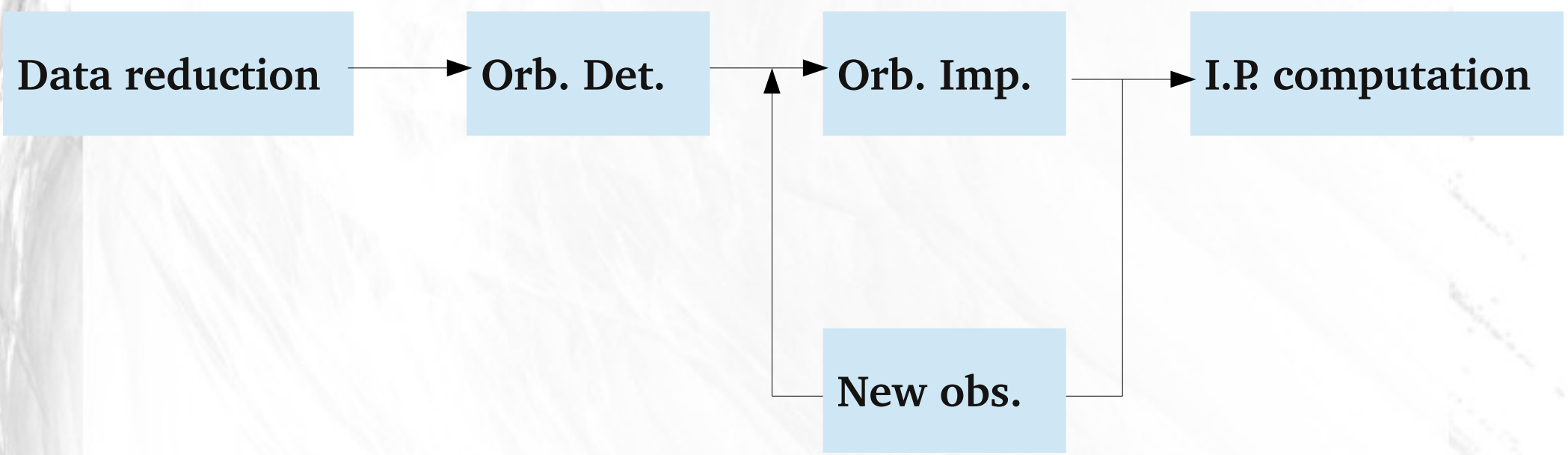
<u>1st biais in IP computation</u> :

- inhomogenous data in MPC database
- X images sent by Y observers
- X images reduced by Y catalogues

<u>Aim of this campaign</u> :

- homogenous data
- X images sent by Y observers
- X images reduced by 1 catalogue (UCAC4)

❶ Introduction



<u>Aim of this campaign</u> :

- homogenous data
- X images sent by Y observers
- X images reduced by 1 catalogue (UCAC4)

- Recovery and follow-up
- Test orbital improvement of PHA

❷ (99942) Apophis : historical background

- **Aten asteroid discovered in June 2004 (~320m)**
- **Brief 2029-impact threat (TS=4)**
- **2029-close encounter ~ 38000 km**
- **2036-threat → TS=0 and discarded in 2013**

- **Chesley 06 + Giorgini et al. 08 :** past and future radar obs.
- **Chesley et al. 10 :** debiais treatment on stellar catalog
- **Bancelin et al. 12 + Farnocchia et al. 13 :** impact of astrometric measurement

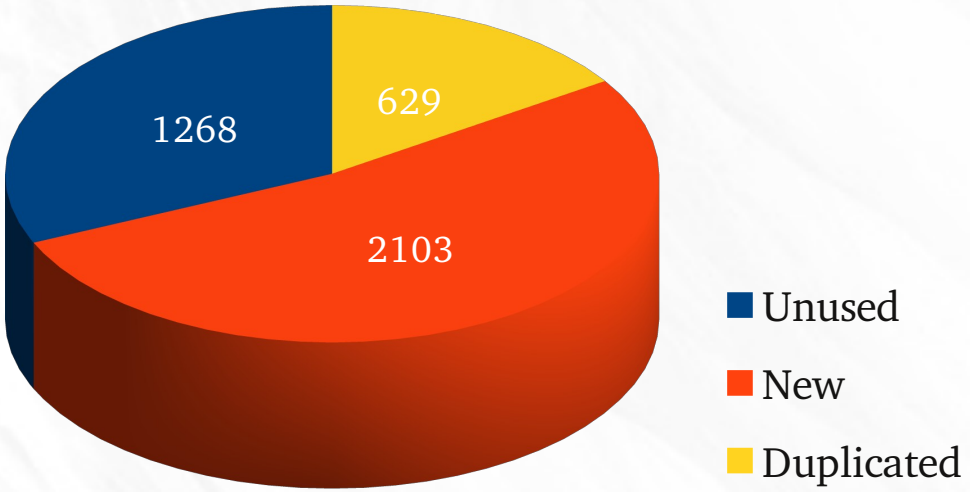
- **=> reducing uncertainties on Apophis'orbit and drift parameters**

❸ Observations of Apophis : The observers

MPC code	Observatory	long. deg.	lat. deg.	Country	Tel. diam. m.	FOV arcmin	pixel arcsec.
010	C2PU Cote-d'Azur obs.	6.92097	43.75100	France	1.00	40x40	0.17
071	NAO Rozhen instit. of astron.	24.73877	41.69725	Bulgaria	0.50	73.7x73.7	1.08 and 2.16
089	Nikolaev astronomical obs.	31.97358	46.97114	Ukraine	0.50	43x21	0.84
119	Abastunami obs.	42.81941	41.75403	Georgia	0.70	44x30	0.87
188	Maidanak obs.	66.89555	38.67337	Uzbekistan	1.50	11x11	0.21
300	Bisei Spaceguard center	133.54527	34.67192	Japan	1.00	73x36	2.11
511	Haute-Provence obs.	5.71516	43.93174	France	1.20	12x12	0.68
585	Astron. obs. of Kyiv univ.	30.52424	50.29761	Ukraine	0.70	16x17	0.95
586	Pic-du-Midi observatory	0.14268	42.93631	France	1.05	8x8	0.44
950	William Herschel telescope	-17.87759	28.76212	Canaries Isl., Spain	2.54	9x10	0.25
A84	TUBITAK obs.	30.33648	36.82342	Turkey	1.00	21x21	0.31
		30.33561	36.82576	Turkey	1.50	8x8	0.24
B04	OAVdA	7.47852	45.78975	Italy	0.81	16x16	0.96
B17	Evpatoria obs.	33.16286	45.21949	Ukraine	0.70	45x45	1.76
B18	Terskol obs.	42.50004	43.27475	Russia	0.60	11x11	1.24
C01	Lohrmann obs.	13.92293	51.02727	Germany	0.60	51x51	0.75
C20	Kislodov st. of Pulkovo obs.	42.66297	43.74155	Russia	0.50	20x20	1.19
D20	Zadko obs.	115.71317	-31.35594	Australia	1.00	24x24	1.38
O44	Lijiang station Yunnan obs.	100.02985	26.69503	China	2.40	10x10	0.28
Z20	Mercator telescope	-17.87848	28.76237	Canaries Isl., Spain	1.20	10x14	0.55

❸ Observations of Apophis : The observations

4000 observations from images but ….



2732 valuable astrometric measurments

❸ Observations of Apophis : Data reduction

PRAIA software (*Assafin et al 2011*)

- UCAC4 catalog to identify reference stars
- 3rd degree polynomial for (x,y) positions

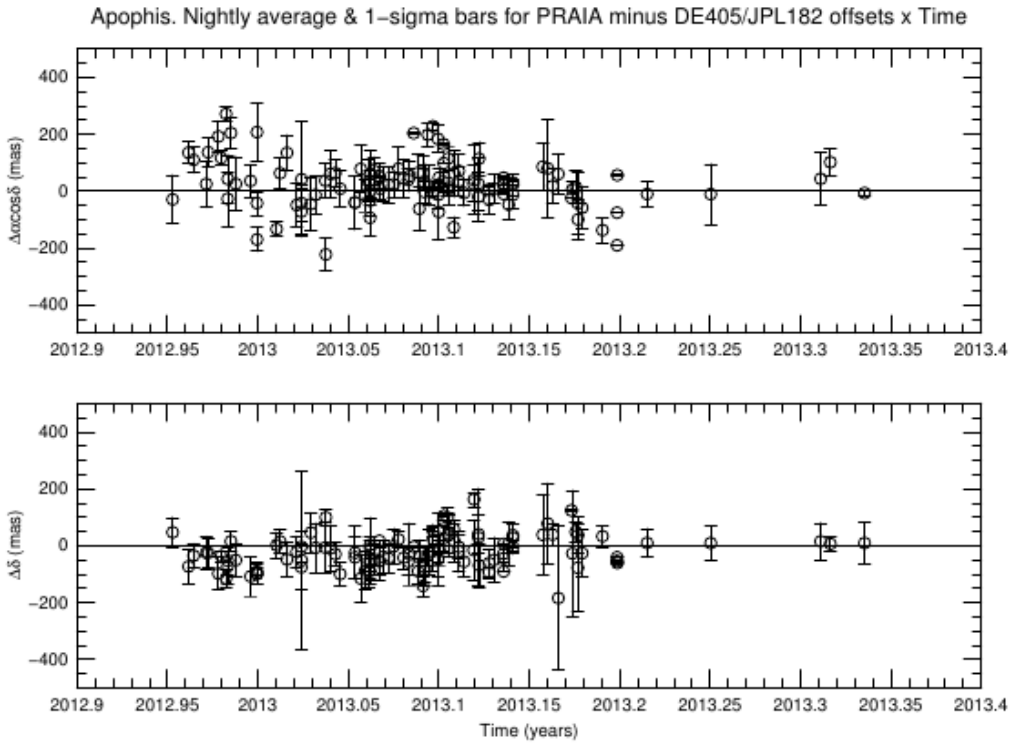
- **Identification of stars :**
  - (O-C)<120 mas (2.5 times UCAC4 error)

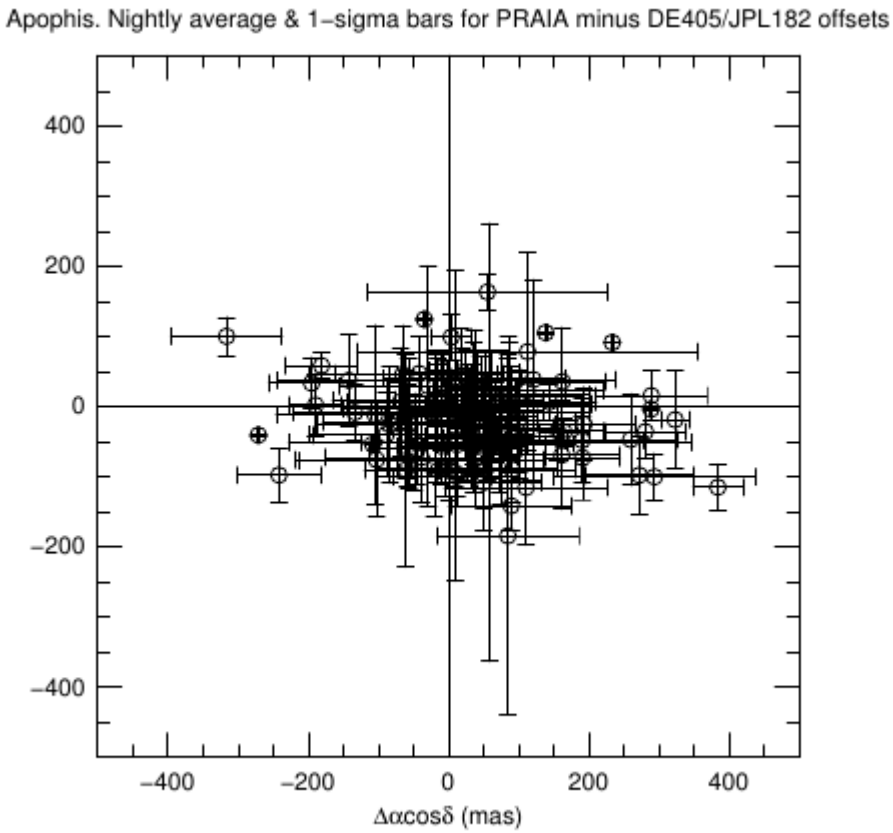
- **Identification of Apophis :**
  - Ephemeris from SPICE/JPL
  - (O-C)<3σ (JPL ephemeris as reference)

IAU code	S. D. to JPL σ_α mas	σ_δ mas	No. nights	No. pos.	UCAC4 stars	Mean errors σ_α mas	σ_δ mas
010	48	49	1	137	94	61	63
071	69	53	11	114	1336	57	56
089	101	137	5	80	540	56	62
119	99	64	2	7	621	59	58
188	85	52	1	22	20	52	52
300	48	34	4	13	528	60	60
511	43	50	1	7	83	56	53
585	69	63	3	15	180	57	56
586	58	59	6	960	36	63	66
950	47	25	1	5	24	72	50
A84	23	29	15	154	155	57	55
B04	227	210	4	22	110	60	62
B17	39	34	6	22	738	63	64
B18	67	71	4	126	71	60	58
C01	68	186	2	7	1822	58	62
C20	60	62	18	664	210	61	62
D20	48	46	22	147	247	62	56
O44	27	38	5	70	102	58	60
Z20	48	53	4	160	16	62	62

Mean errors are the r.m.s. in the (O−C) residuals from the (α, δ) reductions with the UCAC4 catalogue. S. D. regards to the (α, δ) standard deviations about the nightly average offsets with respect to the JPL reference ephemeris, after the elimination of discrepant positions (see text). Detailed telescope data for each observatory is given in Sect. 2 (Observations).

❸ Observations of Apophis : Data reduction

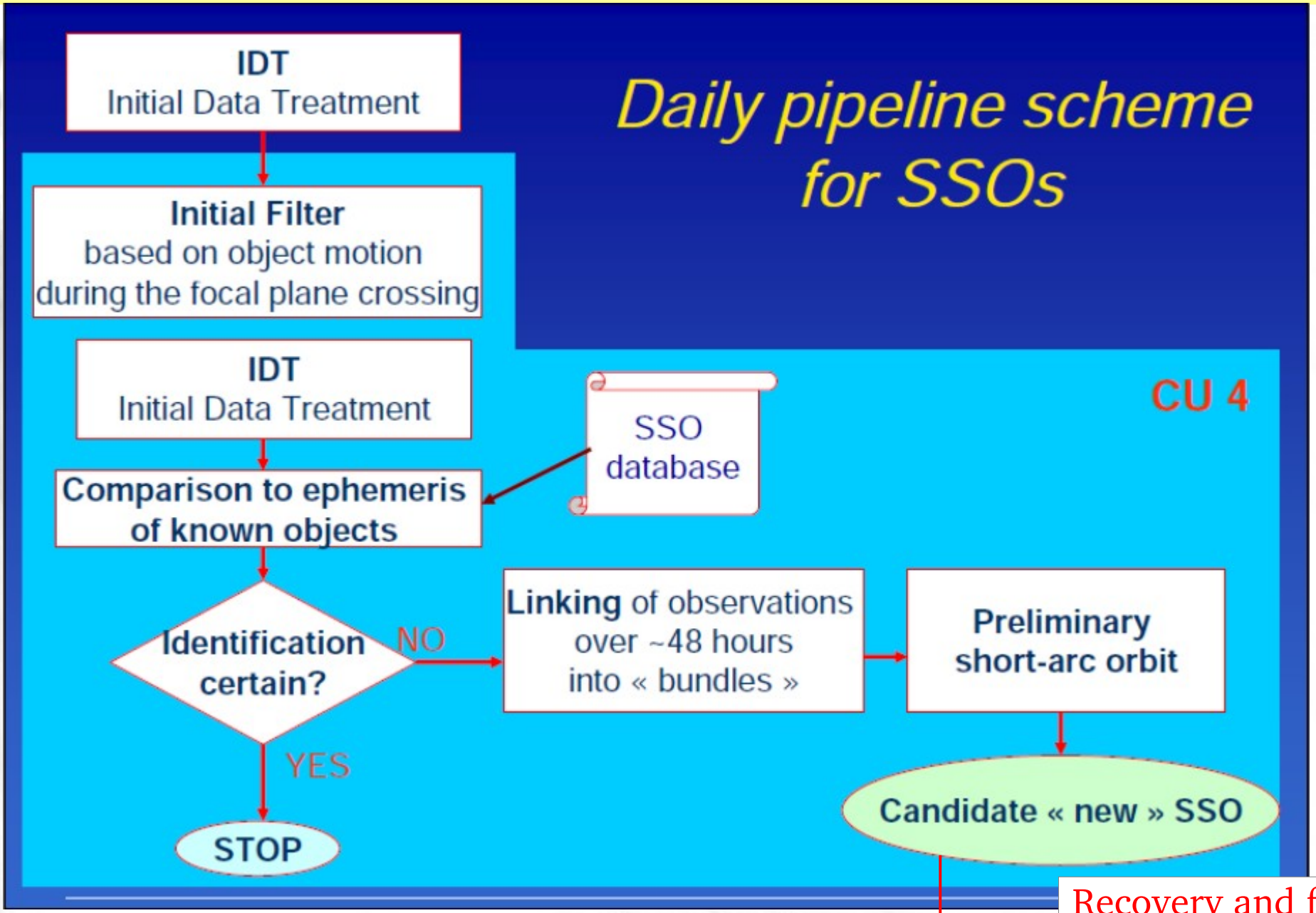




❹ Data analysis

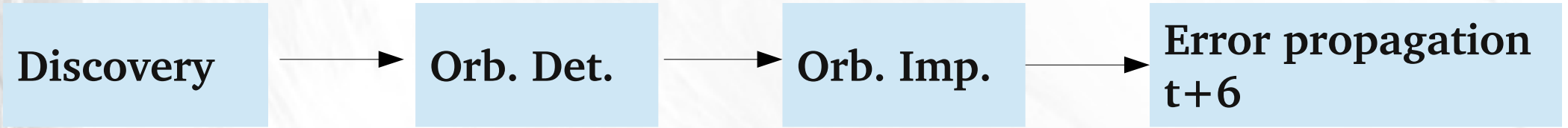
- S_{NEW} = 2103 unsent Gaia-FUN-SSO obs. and reduced by PRAIA
- D_{MPC} = 629 duplicated Gaia-FUN-SSO obs. non-uniformly reduced and already sent to MPC
- D_{PRAIA} = 629 duplicated Gaia-FUN-SSO obs. already sent to MPC but re-reduced by PRAIA

❸ Data analysis (1) : Alert and recovery process



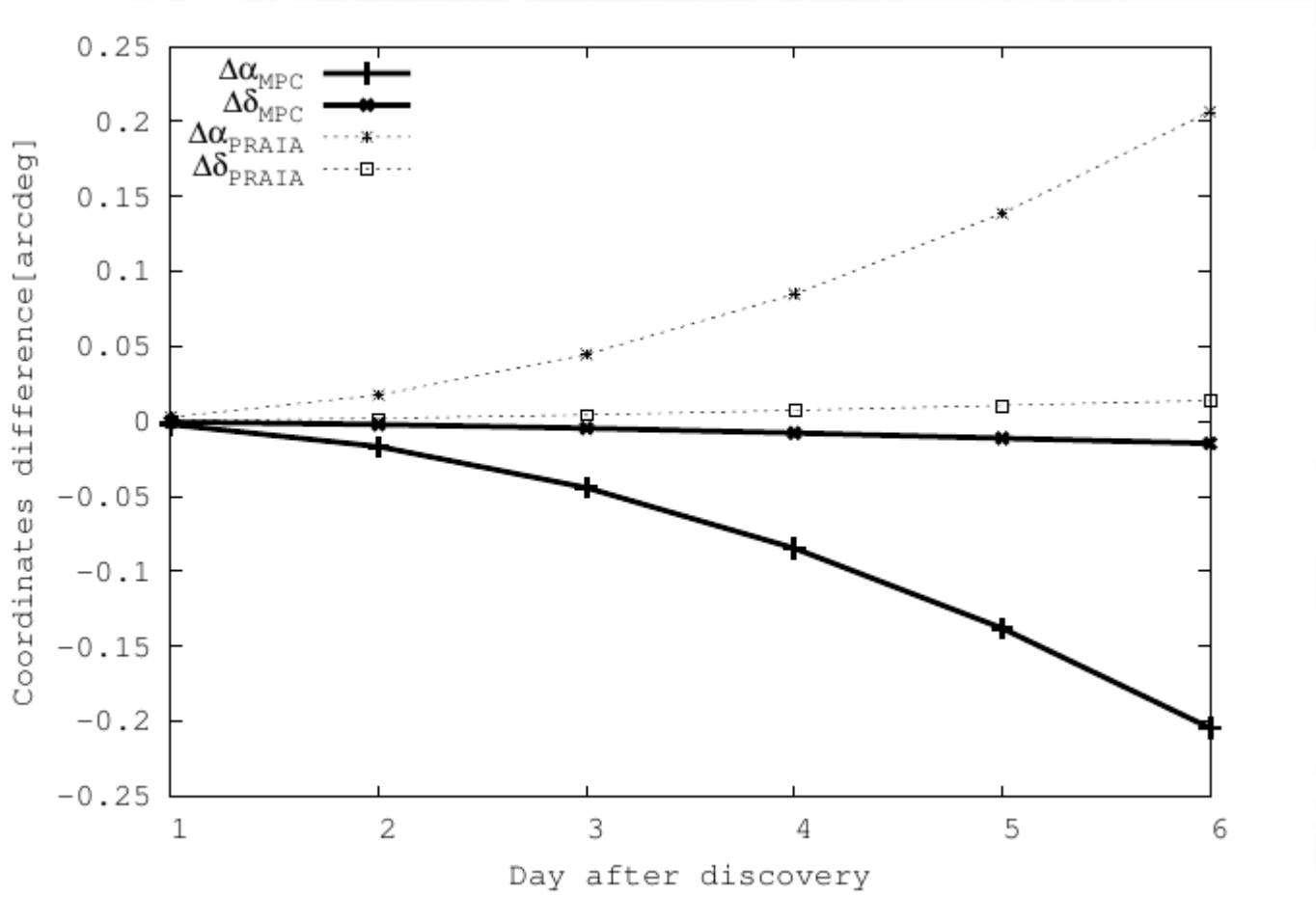
❹ Data analysis (1): Alert mode

1st night

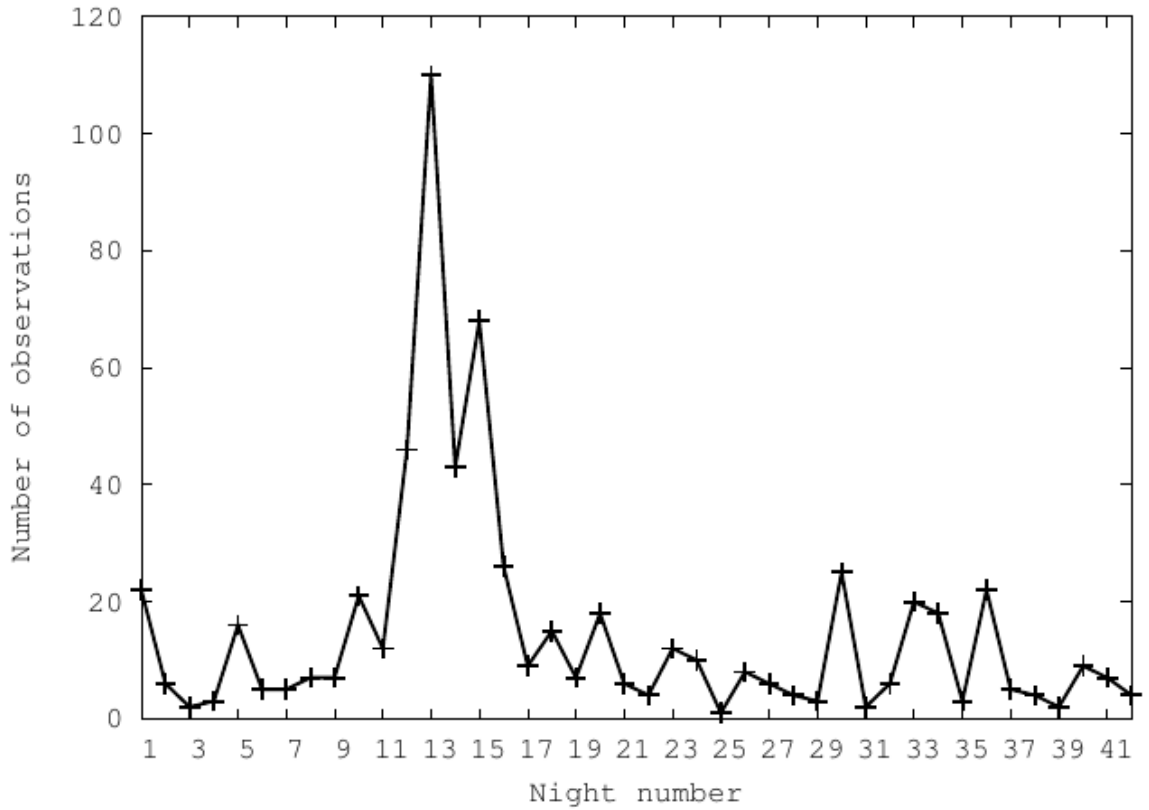


Compare $(\alpha,\delta)_{MPC}$ and $(\alpha,\delta)_{PRAIA}$ with NEODyS solution (using all available observations)

❹ Data analysis (1): Alert mode



❹ Data analysis (2): Recovery process



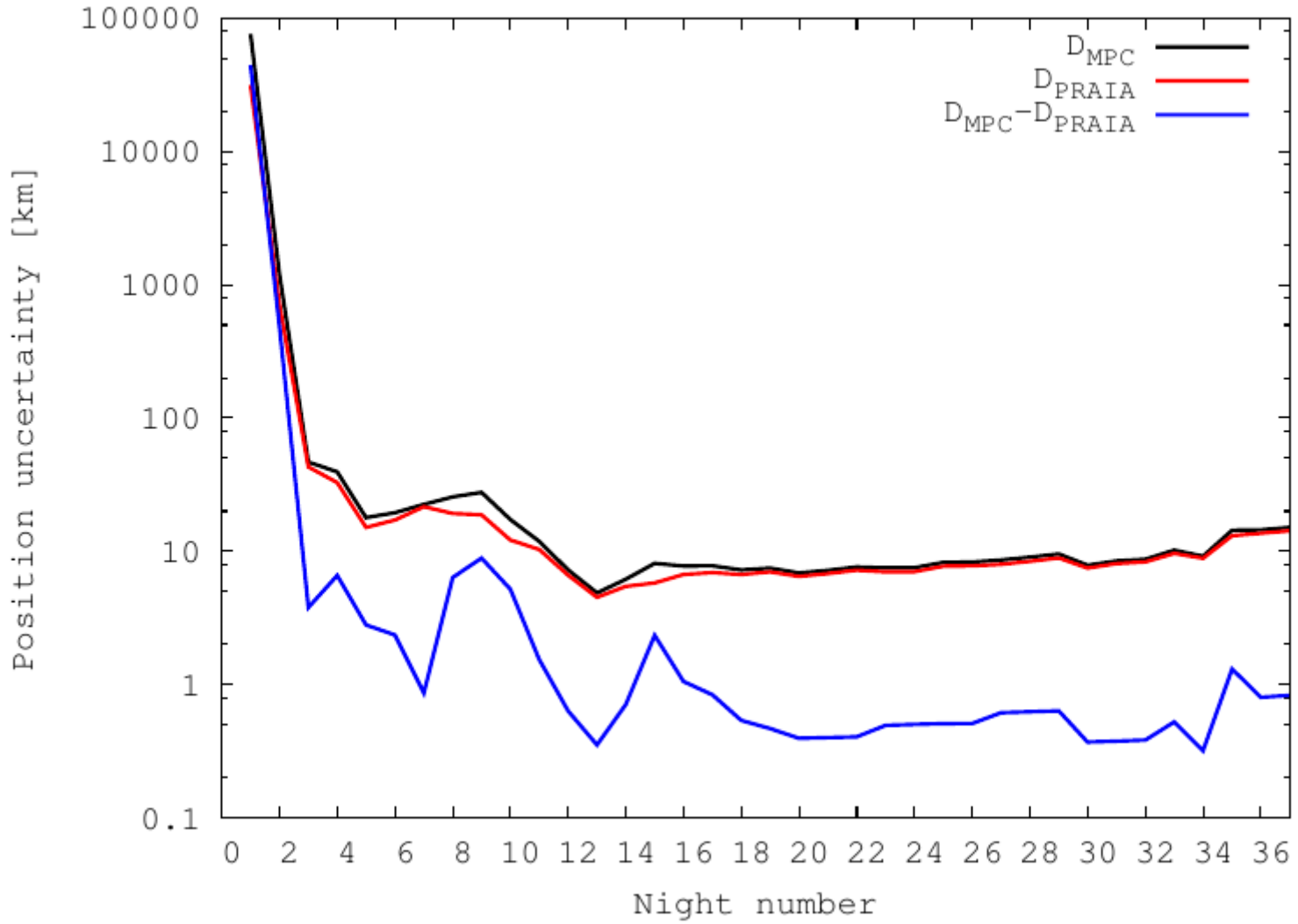
1st night

Discovery → Orb. Det. → Orb. Imp. → Error propagation t+1

Night : 2 – 41

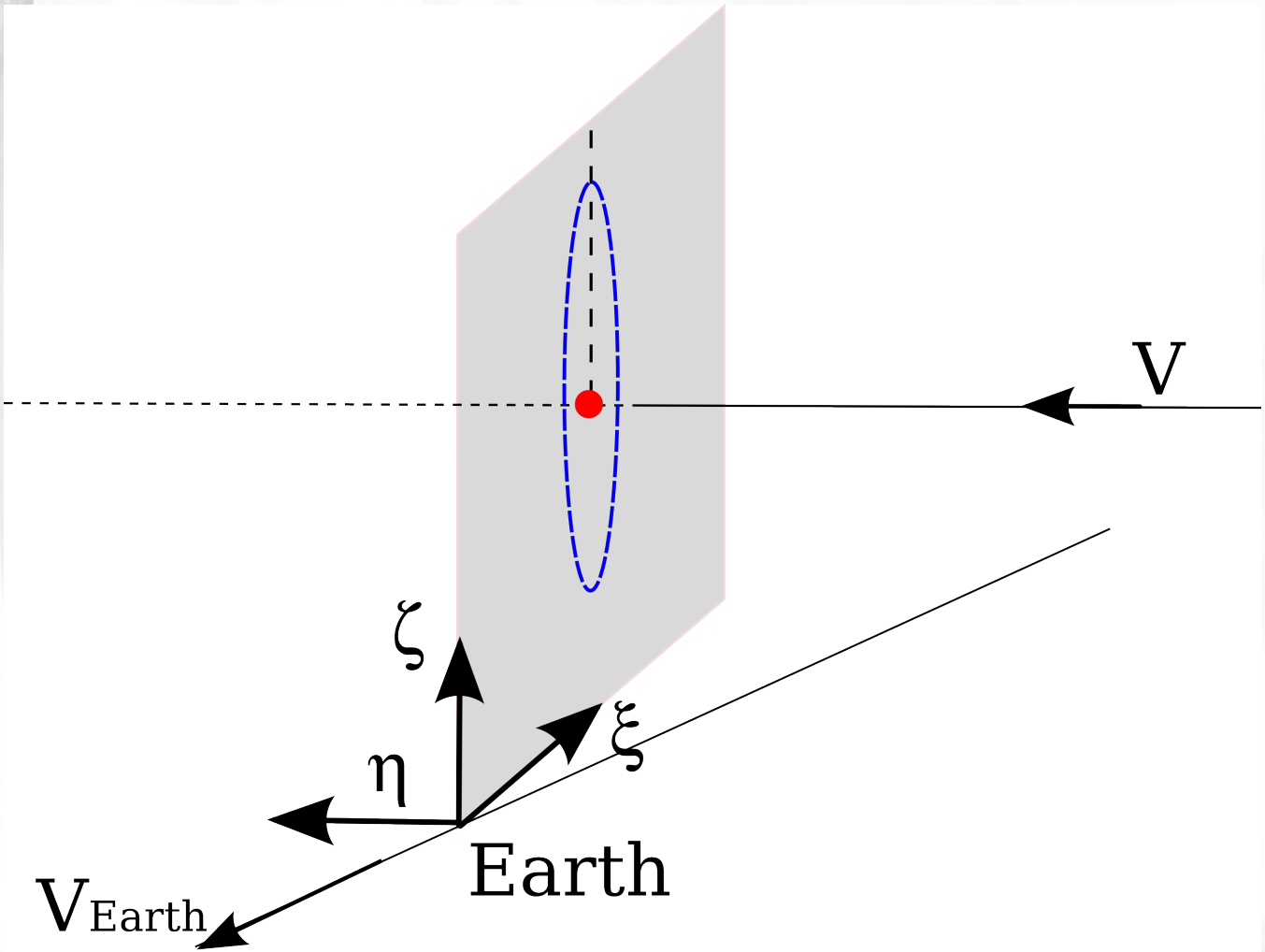
New obs.

❹ Data analysis (2): Recovery process



❹ Data analysis (3): b-plane uncertainty

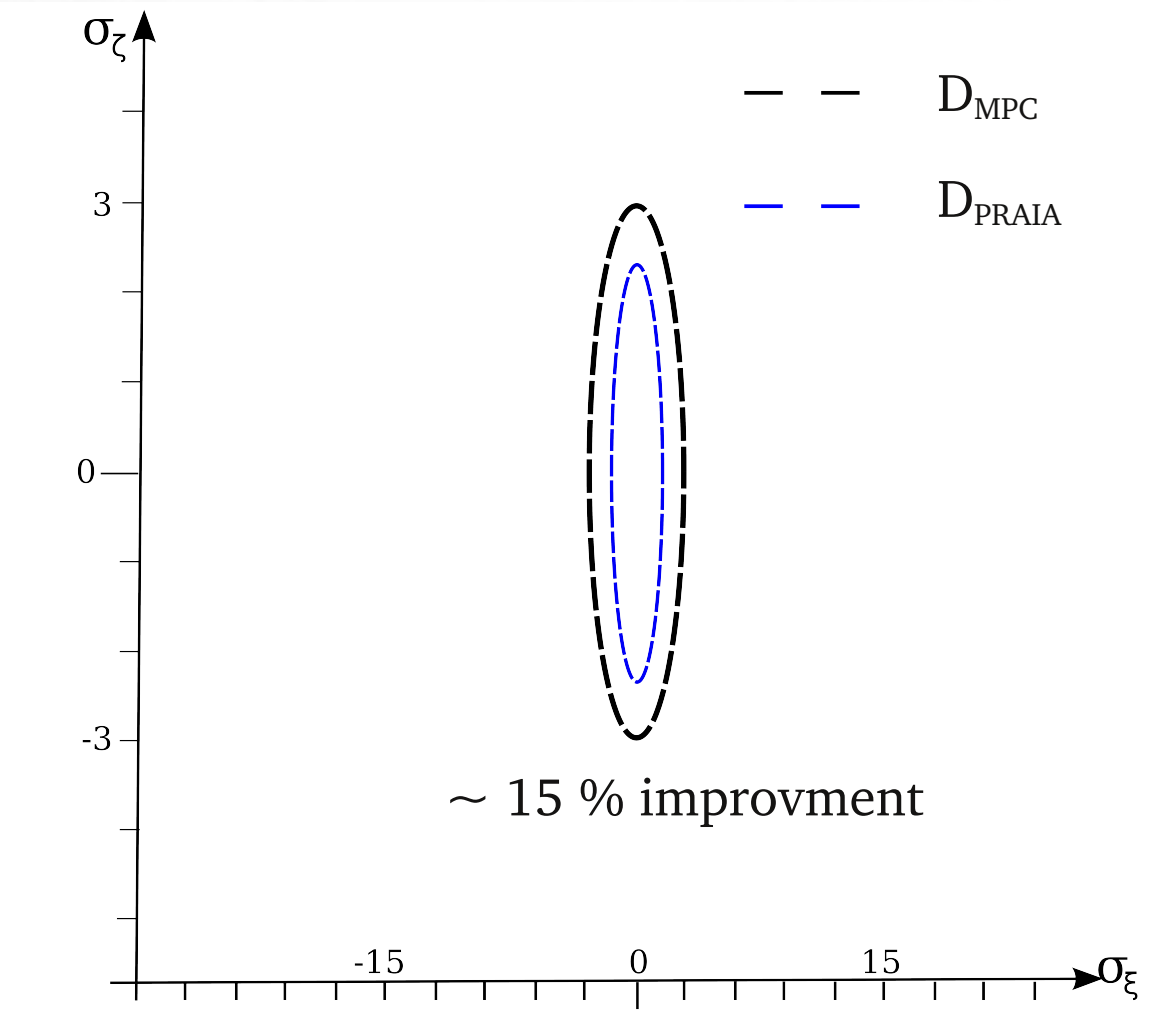
Orbit propagation for risk assessment : the b-plane



- b-plane at the date of closest approach
- (ξ,ζ) = geocentric coordinates
- 3sigma ellipse uncertainty $(\sigma_\xi,\sigma_\zeta)$ centered on nominal position of the asteroid
- $\sigma_\zeta \equiv$ distance uncertainty
- → important for keyholes and IP

❹ Data analysis (3): b-plane uncertainty

- Comparison of D_{MPC} and D_{PRAIA}
- « short » arc (41 nights)
- Propagation of nominal solution → 2029-b-plane
- → σ_ζ ~15 % better wih D_{PRAIA}
- Important for IP risk assessment



❹ Data analysis (4): Current orbit of Apophis

- $S_1 = [2004\text{-}2014]_{MPC}$ + radar
- $S_2 = [2004\text{-}2014]_{MPC} - D_{MPC} + D_{PRAIA}$ + radar
- $S_3 = S_2 + S_{NEW}$
- $S_4 = S_1 + S_{NEW}$
- $S_5 = S_{NEW} + D_{PRAIA}$ + radar

	χ^2_{opt}	χ^2_{rad}	σ_ζ (km)	$\Delta_i - \Delta_1$ (km)
S_1	0.454	0.282	2.99	0
S_2	0.448	0.277	2.94	0
S_3	0.310	0.113	2.43	1.5
S_4	0.314	0.114	2.45	1.5
S_5	0.042	0.062	3.24	3

Conclusion

- Homogenous data give better orbital informations

- For PHA : debiased impact probabilities
- For Yarkosky candidate : better drift estimation