

Identifying possible bias in astrometric observations of potentially hazardous asteroids and other high risk near-Earth objects

Anatoliy Ivantsov^{1,2,3}, Siegfried Eggel^{3,4,5,6}, Daniel Hestroffer³

¹Space Sciences & Technologies Department, Science Faculty, Akdeniz University, Antalya, Turkey

²Royal Observatory of Belgium, Ringlaan / av. Circulaire 3, Brussels, BE-1180, Belgium

³Paris Observatory – IMCCE, PSL University, Sorbonne Université, Lille University, CNRS, av. Denfert-Rochereau 77, Paris, F-75014, France

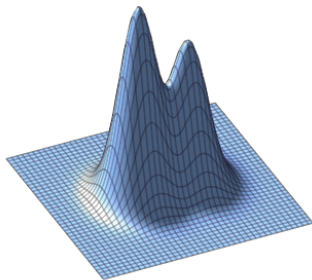
⁴Department of Astronomy, University of Washington, 3910 15th Ave NE, Seattle, WA 98195, USA

⁵Vera C. Rubin Observatory, Tucson, AZ 85719, USA

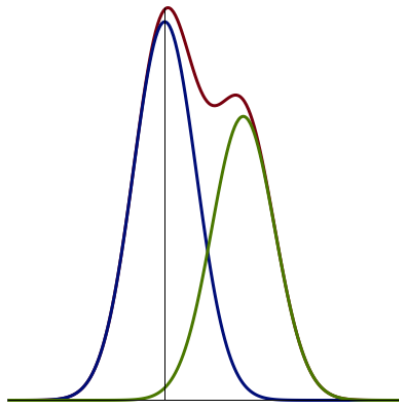
⁶Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, 306 Talbot Laboratory, 104 S. Wright St., Urbana, IL 61801, USA

an.ivantsov@gmail.com

A problem in measurement of image positions with overlapping profiles



(a) Two resolved sources with overlapping profiles



(b) Vertical section along maxima of Gaussian profiles

Impact risk objects taken from the JPL Sentry System

Impact probability $\geq 10^{-6}$, impact value ≥ -4 in the Palermo scale as of Jan. 18, 2021

No.	Asteroid designation	MOID, a.u.	RMS, ''	Total obs.	Data-arc span, day
1	(29075)	4.0×10^{-2}	0.48	732	25897
2	(99942) Apophis	9.1×10^{-5}	0.28	4716	6148
3	(101955) Bennu	3.2×10^{-3}	0.28	518	6821
4	1994 GK*	3.0×10^{-3}	1.04	11	3
5	2000 SB45*	1.3×10^{-3}	0.52	18	2
6	2000 SG344*	8.0×10^{-4}	0.51	31	507
7	2005 ED224*	1.4×10^{-3}	0.40	11	3
8	2005 QK76*	1.8×10^{-3}	0.82	14	1
9	2007 DX40*	6.8×10^{-4}	0.52	30	9
10	2007 FT3	1.5×10^{-2}	0.41	14	1
11	2008 EX5*	6.1×10^{-4}	0.57	61	33
12	2008 JL3*	1.1×10^{-3}	0.37	35	7
13	2008 UB7*	9.6×10^{-4}	0.40	69	5
14	2009 JF1*	1.0×10^{-4}	0.28	25	1
15	2010 RF12*	6.9×10^{-4}	0.28	323	5
16	2012 HG2*	5.6×10^{-5}	0.40	210	39
17	2012 QD8*	2.2×10^{-3}	0.33	41	20
18	2013 VW13*	2.0×10^{-3}	0.40	34	21
19	2017 WT28*	2.1×10^{-3}	0.44	28	19
20	2020 VV*	9.9×10^{-5}	0.50	79	61
21	2020 VW*	1.6×10^{-5}	0.36	20	15
22	2021 AL6**	9.1×10^{-3}	0.42	55	6

Cumulative number of possibly affected asteroid positions in the vicinity of the Gaia EDR3 stars

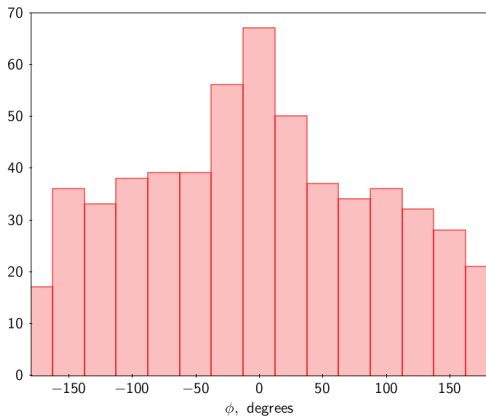
No.	Asteroid designation	Vicinity radii, ''				
		1	3	5	7	9
1	(29075)	3	15	27	50	83
2	(99942) Apophis	39	283	693	1211	1735
3	(101955) Bennu	2	10	29	53	95
4	1994 GK*	0	0	0	0	0
5	2000 SB45*	0	0	0	1	2
6	2000 SG344*	0	1	1	3	5
7	2005 ED224*	0	0	1	1	1
8	2005 QK76*	0	0	0	0	1
9	2007 DX40*	0	0	0	0	1
10	2007 FT3	0	1	3	6	11
11	2008 EX5*	0	0	0	1	5
12	2008 JL3*	0	4	6	10	16
13	2008 UB7*	0	2	2	2	2
14	2009 JF1*	0	1	1	2	4
15	2010 RF12*	0	4	9	15	30
16	2012 HG2*	1	5	10	21	40
17	2012 QD8*	0	1	2	2	5
18	2013 VW13*	0	0	0	0	0
19	2017 WT28*	0	0	0	1	1
20	2020 VV*	0	1	2	2	6
21	2020 VW*	0	0	0	0	1
22	2021 AL6**	0	0	1	3	3

Direction to the nearby star (S) within $5''$ and

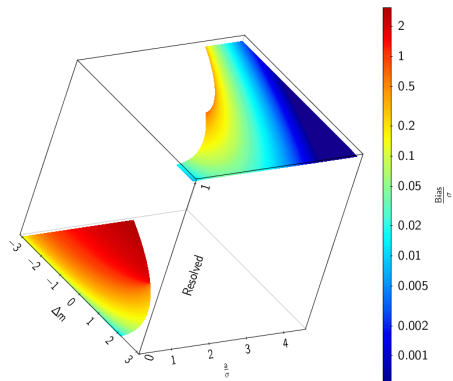
$$\overrightarrow{CO} = \vec{i}(O - C)_\alpha \cos \delta + \vec{j}(O - C)_\delta$$

$$\sin \phi = \frac{|\overrightarrow{OS} \wedge \overrightarrow{CO}|}{|\overrightarrow{OS}| |\overrightarrow{CO}|}$$

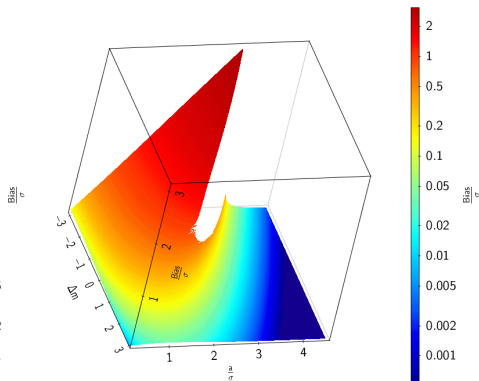
$$\cos \phi = \frac{|\overrightarrow{OS} \cdot \overrightarrow{CO}|}{|\overrightarrow{OS}| |\overrightarrow{CO}|}$$



Astrometric bias is found as $\sigma W_r \left(\frac{a}{\sigma}, \Delta m \right)$



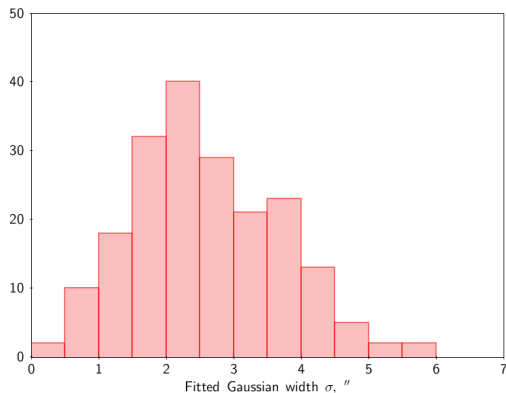
(a) Resolved and unresolved cases, $\sigma = 2''$



(b) Photocenter bias of the target, $\sigma = 2''$

Fitting the astrometric bias to $\overrightarrow{CO}$

- We considered only those measurements that have $|\phi_i| \leq 90^\circ$ (2047 positions).
- We fitted Gaussian widths for 197 individual groups of observations.
- Visual magnitudes of asteroids were used instead of the actual, if the latter were not reported.



Conclusions

- Accurate astrometry of asteroids and other small Solar System bodies can be corrected for astrometric bias originated due to image blending. The **proximity of an asteroid to a nearby star in the focal plane can be characterized by $\frac{a}{\sigma}$** where a is the distance and σ is the width of the PSF. The difference in brightness to nearby stars (Δm) is color-dependent. Correcting the bias described requires observations to be done in **standard photometric bands**.
- Since the **PSF width σ** can depend on many factors, we recommend it **be measured and reported by the observers** while submitting the measurements to the IAU Minor Planet Center.
- **Past astrometric observations** of asteroids measured close to the stars **are likely biased**. We recommend these measurements be down-weighted or eliminated from the orbit fitting process.