### Gaia Astrometric Alerts and Gaia-FUN-SSO follow-up :

### an opportunity for a Pro-Am collaboration

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### +DPAC colleagues (ESA, CNES)

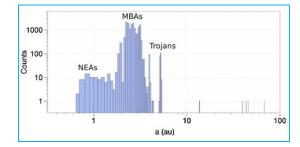




### Data access

through periodical data releases:

• DR1: 14 Sept. 2016 => no Solar System Objects

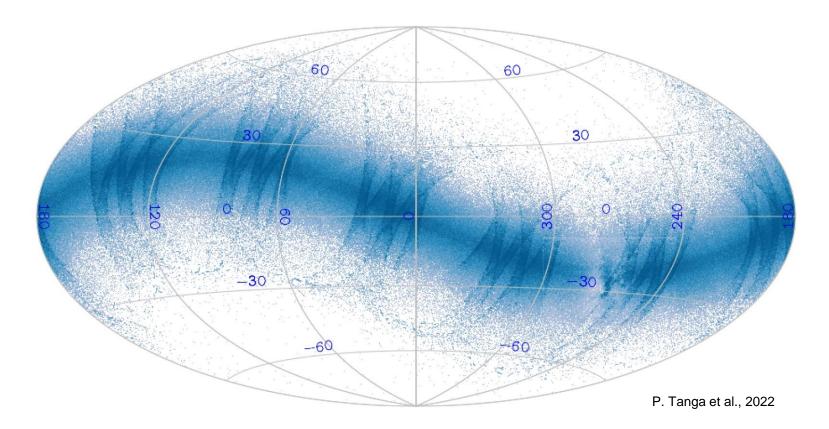


- DR2: 25 April 2018 => 14 099 asteroids (Spoto et al., 2018)
- early-DR3: 3 Dec. 2020
- DR3: 13 june 2022 (https://www.cosmos.esa.int/web/gaia/dr3)

158 152 SSO (including 31 natural satellites and 1320 unmatched)

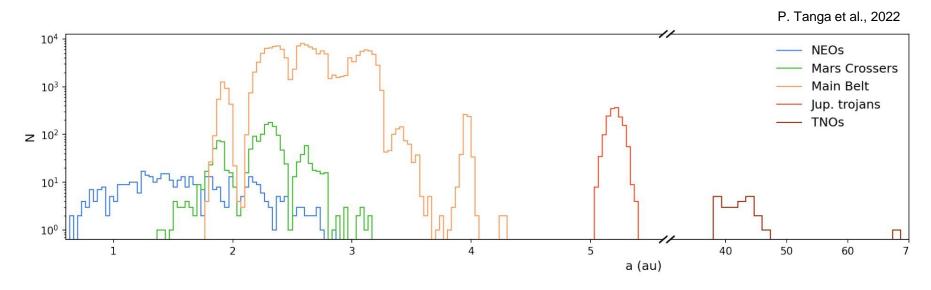
60 518 reflectance spectra

- + astrometry : 23 336 467 epoch astrometry
- + photometry : 60 518
- + osculating elements : 154 787



Distribution of the asteroids of the DR3 catalog (except Centaurs)





Distribution of the asteroids in semi major axis (AU) of the DR3 catalog (except Centaurs)

Details at Tanga et al. (2022): <u>https://arxiv.org/abs/2206.05561</u> and https://www.cosmos.esa.int/web/gaia/dr3

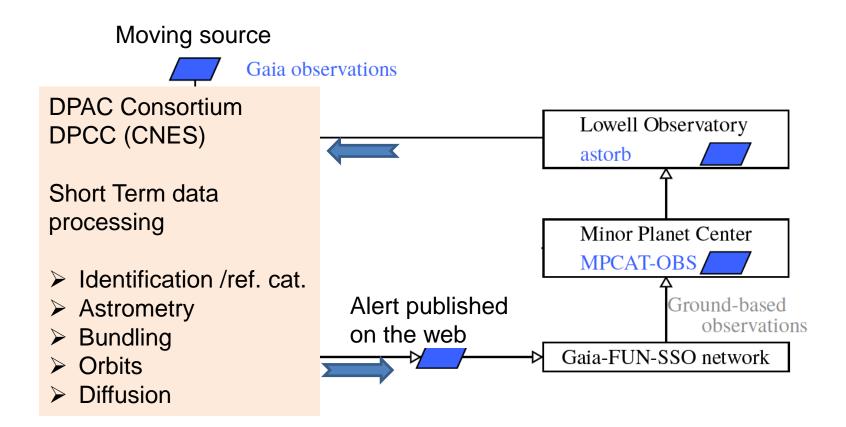


- Detection of all moving sources up to mag 20.7
- Gaia alerts triggered after detection of uncatalogued moving objects
- Gaia Scanning law => monitoring impossible
- Processed data publicly available through https://www.imcce.fr
- Need for recovery from the ground and follow-up
- A loop to feed back the Gaia SSO reference catalog



# The SSO-ST daily processing

SSO-ST « Unknown » SSOs => Short Term Processing => alerts

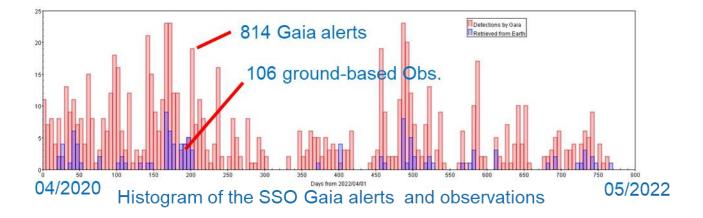




- ✓ Validation of the Gaia discoveries of new moving objects (~ 48h)
- ✓ Avoid possible false Gaia detections (artifacts, star spikes,...)
- Recovery + complementary astrometry measurement
- Prepare the next identifications by feeding the reference catalog
- ✓ Contribution to NEO survey, for example => 2021 PO41

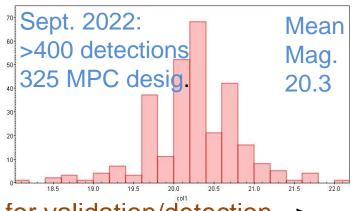


- ✓ Observability conditions: 50% North 50% South hemisphere
- ✓ Need of various locations (geographical coverage)
- ✓ Irregular flux of alerts





- Before 2016...follow-up observations by pro and amateurs expected
- Workshops 2010 + 2012 + 2014
- Starting in 2016...Most of the alerts in the 20-21 magnitude range



- Observations for validation/detection =>
  - 0.8m 1m diameter well adapted / smaller diameters possible
  - Iow S/N & low precision astrometry acceptable
  - 5 exposures are enough (blink + astrometry in MPC format)
  - UTC timing

### Alerts publicly release through the web site: https://gaiafunsso.fr

Goal												
The Gala Follow-Up Network for Solar System Objects (Gala-FUN-	650) has bee	n set up in the f	amework of a ta	sk (DU459) of	the Coordinat	tion Unit 4 (D	bject processing	) of the				
als Data Processing and Analysis Consortium (geag). Its goal is x the confirmation of newly detected moving objects or for the in uch ground-based observations are required to avoid the loss of r	mprovement of	orbits of some	critical targets. (	Bala will scan	the sky follow	uing a pre-de	fined scenning l					
hese pages provide an access to the alerts, including the ephen presists in about 80 observers in 27 observing sites, spread all or	neris to help fin	ding the targets						umentily				
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- List of alerts daily updated
- Low precision ephemerides
- Sky maps
- Notification on the detection already done
- Button to report positive observation



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#### Potential discoveries of Solar System Objects by Gaia

This page lists all the calls, dubbed alerts for follow-up observations on Solar System Objects recently discovered by the ESA Gaia mission, currently visible for the criteria you specified for your instrument (W85). You can obtain detailed information on each alert in the Details pages and report the results (positive, missed) of your observations in the Report pages (see links in the table).

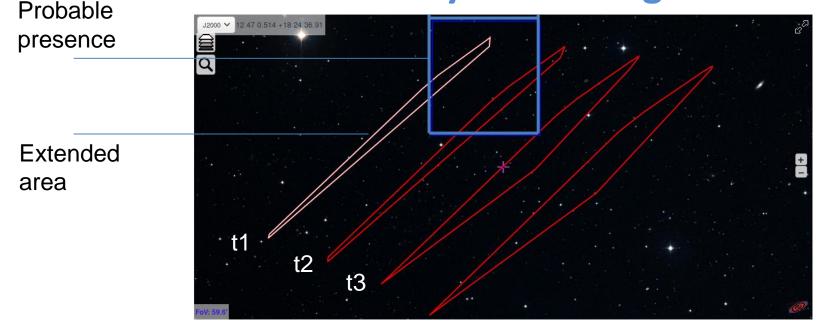
If you observed an alert which is no longer listed below, use this link to report observations.

		lerts: 20/21	Selected a									ctive alerts	List of a
		Details	Report	Name • •	Area 🔺 🕇	Dyn. 🔺 🔻	N <sub>Transit</sub> • •	Dec • •	RA • •	V <sub>mag</sub> • •	End • •	Begin 🔺 🕇	
		0	C	g6n002	0.04446	MainBelt	4	44.1087	344.7717	19.88	2022-10-21	2022-10-03	7159 <mark>1</mark>
		0	C	g6n001	0.18674	MainBelt	4	28.6324	327.8644	20.48	2022-10-21	2022-10-03	71589
		0	C	g6m00A	0.0834	MainBelt	5	28.6793	327.9415	20.17	2022-10-20	2022-10-02	71585
_	a d6n002	ed information o	Detaile	g6m009	0.11923	MainBelt	3	5.0286	316.5126	20.42	2022-10-19	2022-10-01	71581
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	Carbons a		Aspert etc	g6n000	1.07226	NEO	3	44.4361	344.8472	20.34	2022-10-14	2022-10-03	71596
				g6m007	1.34377	NEO	3	19.2355	321.0527	20.39	2022-10-14	2022-09-30	71571
	11/17		Y.	g6m000	0.06935	MainBelt	5	5.6403	315.0266	20.05	2022-10-14	2022-09-26	70838
Sky Ma	8			g6l02C	2.43283	NEO	3	-7.8361	314.6893	20.53	2022-10-11	2022-09-25	70830
SKY WA				g6l020	0.47572	MainBelt	5	-32.7748	319.9562	20.11	2022-10-11	2022-09-23	70810
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		20ch 194 222-10-09 14 32,38 23,09	<b>B</b> 23	g6l01E	0.15152	MainBelt	3	-25.8587	319.5254	20.67	2022-10-10	2022-09-22	70799
	8.822 441842340 119 <sup>24</sup> ct 355 248.6 34.0971 6 8.176 441523440 110 <sup>24</sup> ct 356 248.1 356228 € 5.086 44154345 148 <sup>24</sup> ct 356 247.5 317.5 312555 €	122-10-05 20 52:30         20:30           122-10-06 02 52:30         25:30           123-10-06 02 52:30         25:30           123-10-06 02 52:30         25:40           123-10-06 14:52:30         25:50	5 21 5 21 5 21	g6m005	3.05055	MainBelt	3	5.5202	315.1733	20.25	2022-10-09	2022-09-28	71535
	2728 441115868 189 <sup>4</sup> 12 254 2445 82025 € 1517 44003580 189 <sup>4</sup> 15, 827 2418 87068 € 1521 44064422 112 <sup>4</sup> 12 829 2483 82080 €	123-10-06 20 32-38 22-58 123-10-07 22-39 22-58 123-10-07 22-39 22-59 123-10-07 14 32-39 22-59	5 21 5 71 0 22	g6l015	1.97375	NEO	3	-13.2837	315.0612	19.66	2022-10-09	2022-09-21	70784
Ephem	x112 440455169 1199 <sup>03</sup> 13 553 242 316914 <b>8</b> 2234 44035220 110 <sup>44</sup> 13 554 24 <sup>2</sup> 310936 <b>0</b> 6158 410138449 1199 <sup>13</sup> 21 3154 2129 310567 <b>8</b>	22-19-67 20 52:38 22:58 226-19-68 02 52:38 22:58 227-19-68 02 52:38 22:59	D 20 D 20 D 20	g6l012	2.46321	NEO	4	-6.8273	314.4211	19.8	2022-10-09	2022-09-21	70790
· ·	8246 010733.003 1849 <sup>0</sup> c, 0.07 238.0 0.07910 0 7888 0100051.250 1849 <sup>70</sup> c, 0.07 238.4 0.07700 0 8688 4155.28.233 110 <sup>64</sup> 13 155 235.4 0.05465 0	122-16-00         14-32-30         22-58           177-16-00         16-32-33         22-58           177-16-00         06-32-33         22-57           122-16-00         06-32-38         22-57	D 71 D 71 D 21	g6l011	1.22914	MainBelt	3	-33.8315	320.735	20.45	2022-10-09	2022-09-21	70783
	8.84 4151.48.60 1197 <sup>44</sup> 16 8.81 2.871 3.1072 <b>8</b> 16.42 41.46.25.02 1197 <sup>4</sup> 16 3.00 20 3.1097 <b>0</b> 4.644 41.47.31.720 119 <sup>42</sup> 17 3.51 232.8 3.1782 <b>6</b>	123-10-00 14:32:33         22:57           122-10-00 20:32:36         12:57           122-10-10 32:32:30         12:57           122-10-10 40:32:38         12:57           122-10-10 40:32:38         12:57	0 21 0 22 0 20	g6m008	4.15757	MainBelt	3	5.6195	315.1455	20.23	2022-10-07	2022-09-30	71572
	2.566 (1-46-17.003) 18.6 <sup>10</sup> /c, 55 7.545 3.15756 (8) 6488 (12-6635.243) 18.9 <sup>10</sup> /c) 5.56 231.5 3.14663 (8)	122-10-10         14.32:31         12.38           127         0         0.70:70         22.52           122         14.10:10:20         22.59         22.59           122-10-10         10.22:35         22.59         22.59	D 70	g6l001	4.79857	NEO	3	-27.955	316.5608	20.45	2022-10-07	2022-09-19	70771

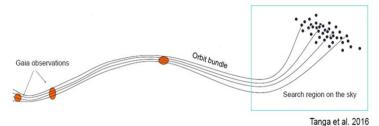
O Finance report maps have to propert "data fritti SUC", or context as al pairs for



# **Asteroid recovery: a challenge**



- On the basis of short arcs of orbit
- MCMC method (Oszkiewiczs 2009, Muinonen 2015) => bundle of orbits
- Projected on the sky => areas for recovering
- « Ephemerides » and sky maps on the web





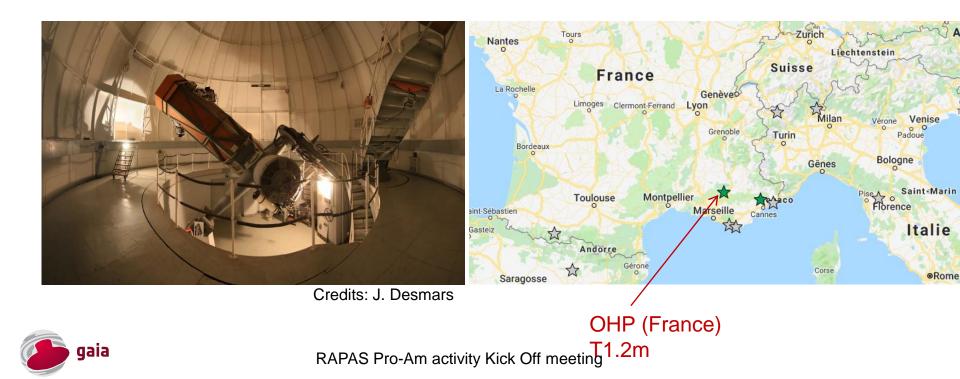
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Deta	iled informati	on on ale	rt						https://	gaiafunsso.imcce.fi
You will find	d below detailed information on the	target and its probable po	sition on the plane of the	sky.						
Object Infor	mation			Instrument and F	ield of View					
• Datat • Name • Magr • Date	ID: -4194967176 base ID: 10148 e: GAIA120 nitude (V): 19.6 <sup>+06</sup> <sub>-03</sub> of observation: 11/13/2016 observation C Back to Gaia a	ilerts I		Field of V		RA 03:55:02.6		ec 13:05:05.640		Information — on the alert <b>+nb of transits</b>
2000 × 12.47	7 0.514 + 18 24 36.91						1	22		Sky map Field of View Here 12'x12' Most probable zone (blue)
59.6'	. /					•		Ø		Zone to explore if not in the FoV (red) on date 1
Available	e epochs							•		and on date 2,
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Show?	Epoch	RA	Dec	V <sub>mag</sub>	Rate	Orientation	Area	Polygon		4
<b>V</b>	2019-02-10 15:21:02	10:52:54.816	-22:07:43.320	20.4 <sup>0.3</sup> 0.2	0.36	-51.1	0.04945	۲		
	2019-02-11 03:21:02	10:52:40.416	-22:04:13.800	20.4 <sup>0.3</sup> 0.2	0.39	-52.6	0.05296	•		England and shares
	2019-02-11 15:21:02	10:52:26.352	-22:01:58.440	20.4 <sup>0.3</sup> 0.2	0.37	-50.3	0.05711	•		
<b>V</b>	2010 00 10 00 01 00	40.50 11 500	04.50.10.000	00.003			0.00107			Ephemerides
	2019-02-12 03:21:02	10:52:11.568	-21:58:48.000	20.40.3	0.41	-51.7	0.06137	•		+ Velocity
	2019-02-12 03:21:02 2019-02-12 15:21:02 2019-02-13 03:21:02	10:52:11.568 10:51:57.048 10:51:41.856	-21:58:48.000 -21:56:58.920 -21:53:38.400	20.4 <sup>0.3</sup> 0.2 20.4 <sup>0.3</sup> 0.2 20.4 <sup>0.3</sup> 0.2	0.41	-51.7 -49.5 -50.8	0.06137	<ul> <li></li></ul>		+ Velocity

### **GFSSO** stations

### • Haute-Provence Observatory (OHP code 511)

Joint programme GFSS0 + Sc. Alerts (photometry SN, gravi. Lens,...) 4 nights every 2 months T 1.2m

« classical observations »



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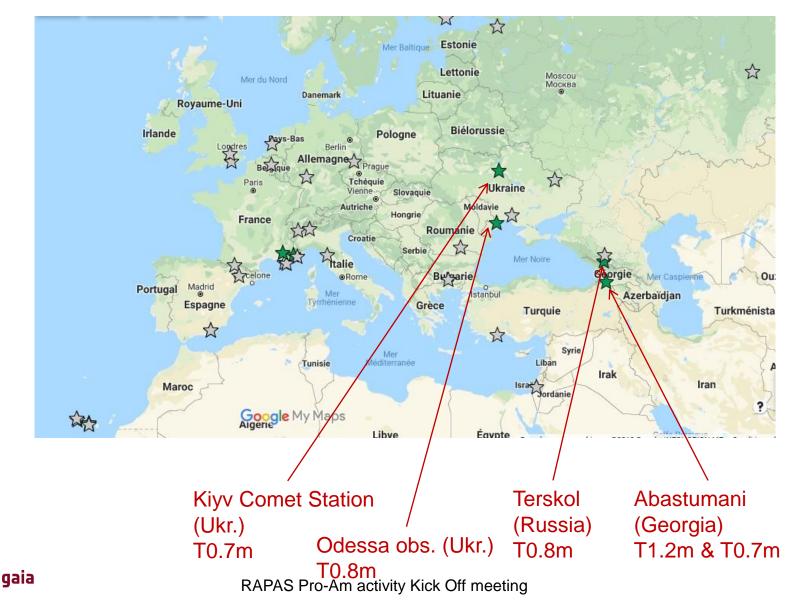
### • C2PU remote telescope (OCA Calern Code 010

Observations in remote programme GFSS0 T 1.0m

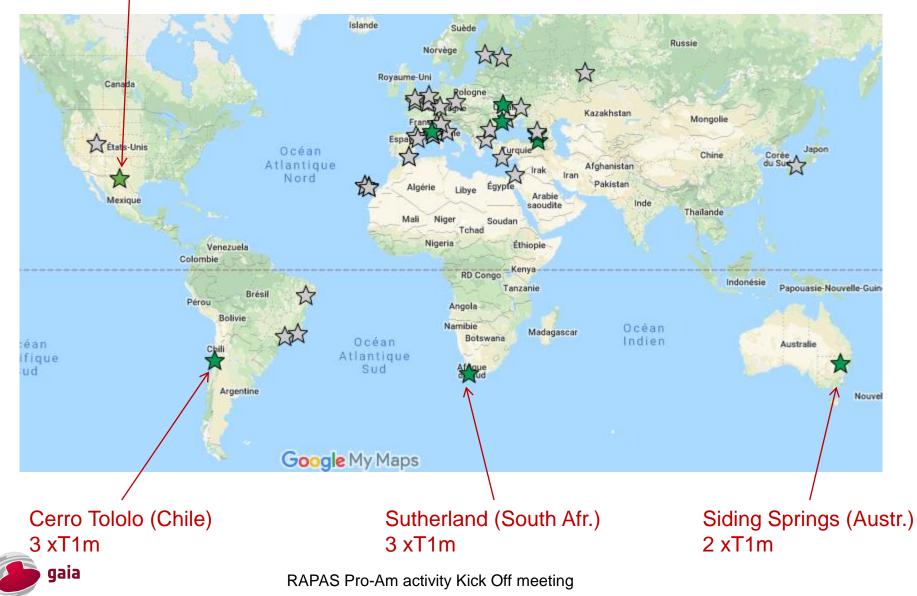




## **GFSSO collaborations**



### McDonald (USA, TX) 2 xT1m LCOGT 1m robotic telescopes

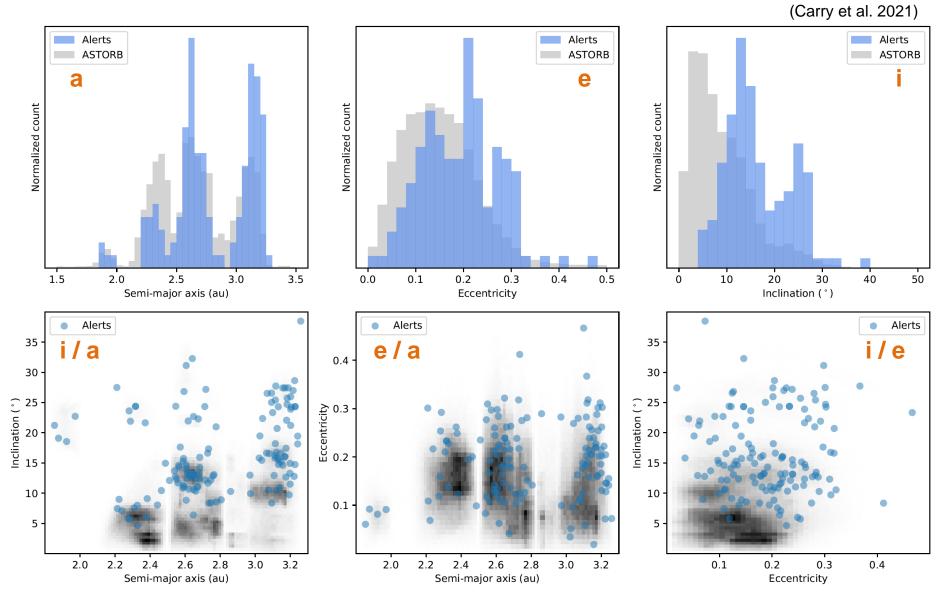


# The results (sept. 2022)

- More than 400 objects detected on alert
- 75% performed at Las Cumbres (LCOGT)
- Almost 325 designations assigned by MPC
- 10% objects were « new » (days, weeks)
- A few will be assigned to Gaia
- Many objects are not new but very badly known (uncatalogued) or even lost



## Gaia detections (blue) vs. ASTORB (grey)





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### Potential asteroid discoveries by the ESA Gaia mission

#### **Results from follow-up observations**

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R. A. Mendez<sup>5</sup>, J.-P. Rivet<sup>2</sup>, A. Le Van Suu<sup>6</sup>, A. Dell'Oro<sup>7</sup>, G. Fedorets<sup>8,9</sup>, B. Frezouls<sup>10</sup>, M. Granvik<sup>8,11</sup>, J. Guiraud<sup>10</sup>, K. Muinonen<sup>8,12</sup>, C. Panem<sup>10</sup>, T. Pauwels<sup>13</sup>, W. Roux<sup>10</sup>, G. Walmsley<sup>10</sup>, J.-M. Petit<sup>14</sup>, L. Abe<sup>2</sup>, V. Ayvazian<sup>15,16</sup>,
K. Baillié<sup>1</sup>, A. Baransky<sup>17</sup>, P. Bendjoya<sup>2</sup>, M. Dennefeld<sup>18</sup>, J. Desmars<sup>1,19</sup>, S. Eggl<sup>1,20</sup>, V. Godunova<sup>21</sup>, D. Hestroffer<sup>1</sup>, R. Inasaridze<sup>15,16</sup>, V. Kashuba<sup>22</sup>, Y. N. Krugly<sup>23</sup>, I. E. Molotov<sup>24</sup>, V. Robert<sup>1,19</sup>, A. Simon<sup>25,26</sup>, I. Sokolov<sup>27</sup>, D. Souami<sup>28,29</sup>, V. Tarady<sup>21</sup>, F. Taris<sup>4</sup>, V. Troianskyi<sup>22,30</sup>, V. Vasylenko<sup>25,26</sup>, and D. Vernet<sup>2</sup>

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## **Summary**

- SST works well up to 10 to 15 days after Gaia detection
- More than 400 detections of « new » asteroids (oct. 2022)
- Few Gaia discoveries + many re-discoveries
- Bias to high inclinations + outer main belt : poorly known population of asteroids + observational bias
- Amateurs can make a valuable contribution

Carry et al. : article to be published in A&A accessible at <u>https://arxiv.org/abs/2010.02553</u>

