

SkyVision: a whole sky monitoring software for SLR



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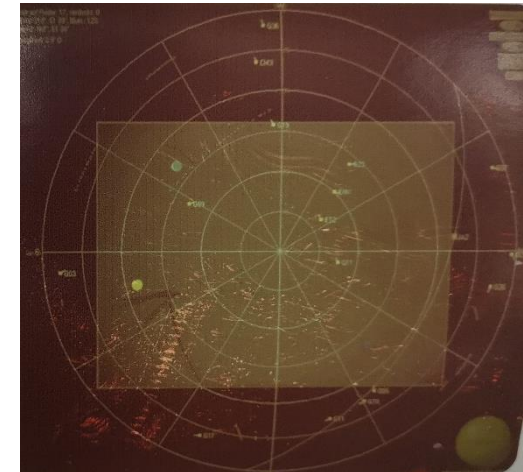
History and motivation

- Obsolete software and programming languages: Orbitron + Labview (sky picture).
- State-of-art cross-platform software: Qt for Window and Linux.
- Possibility and efficiency for upgrade and maintenance improvement.
- Way of heading to automated system.

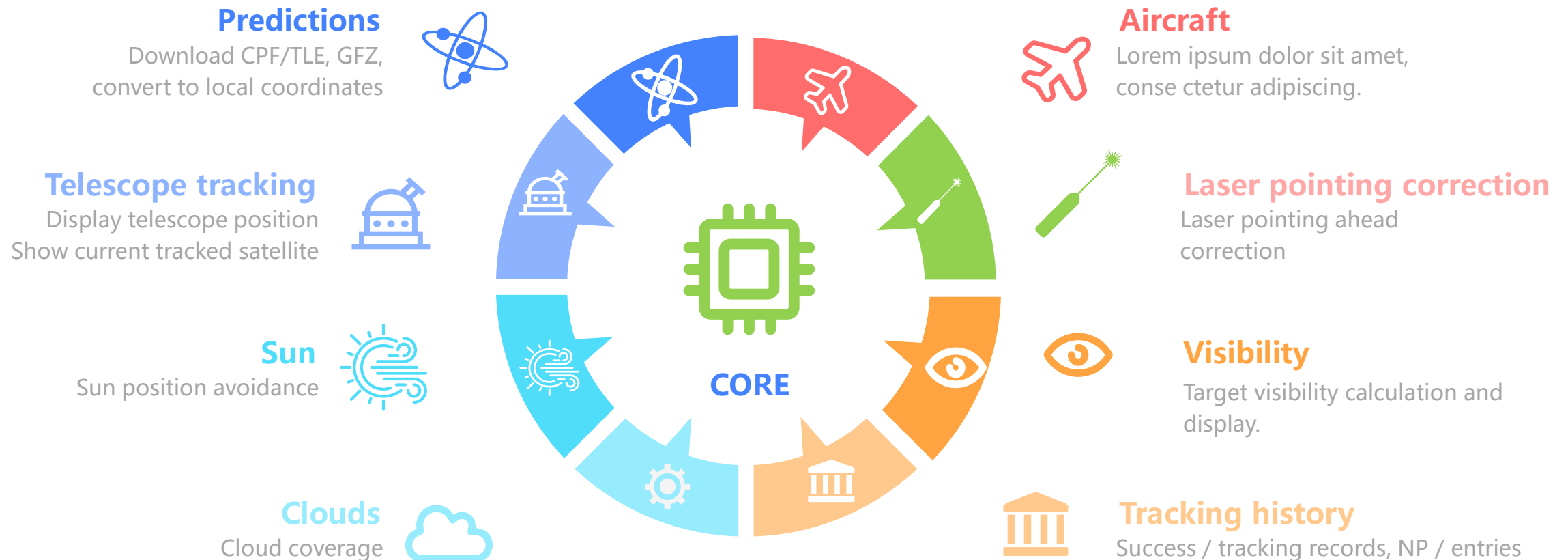


- Functionalities:

- | | |
|--|--|
| <ul style="list-style-type: none"> • Satellite schedule • Sun position and distance • Satellite visibility • Cloud coverage • Local hardware status | <ul style="list-style-type: none"> • Satellite characteristics • Laser point ahead • Tracking records • Tracking decision • Aircraft position & direction / laser shut down automatically |
|--|--|

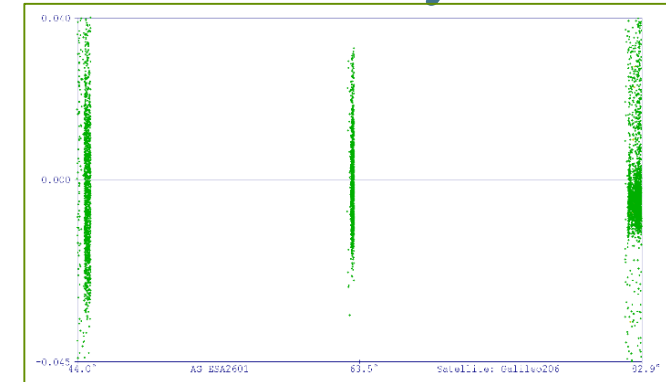


Pipeline of SkyVision



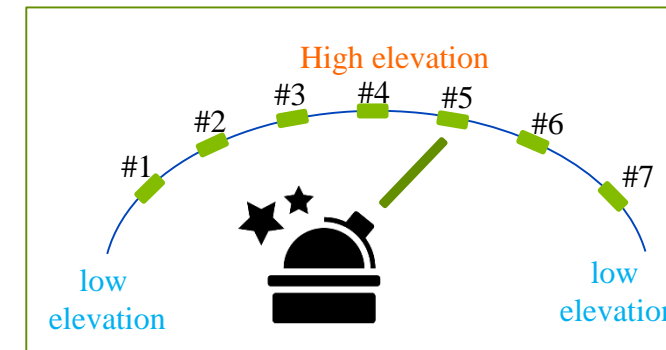
Scheduler on SkyVision

- Graz is tracking > 150 cooperative and > 300 uncooperative targets currently with SLR and LC.
- Tracking strategy: LEO, full pass; Lageos & HEO, entries / NP as many as possible.
- For HEO > 5 entries / distributed equally over the pass are suggested.
- Hide HEO which already has a successful NP in current entry time period.

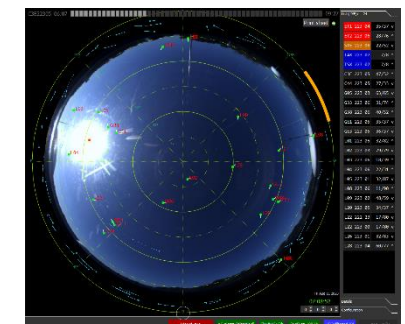


SLR residuals include attitude information of satellite (Steindorfer, 2019, doi.org/10.1007/s00190-019-01284-4)

pass	name	Pri.	NORAD	begin	dur./rem.	Predict.	TB e.	Az	El	Entrie	Campaign	vis.	ch
1	LS228906 Lares2	60.000	53105	06:19	39/ 13	SGF28901	-0.1 278.3	< 17.2/18.9	v	o o o o			
2	HYC28906 Hy2c	10.000	46469	06:38	13/ 5	SHA28901	71.4	< 40.7/51.9	v	o o o o			
3	PAZ28906 PAZ	10.000	43215	06:40	6/ 1	HDS28801	-31.3 257.0	< 8.3/14.7	v	o o o o			
4	JA328906 Jason3	10.000	41240	06:51 (5m)	18/----	CNE28801	-1.3 325.1	> 5.1/70.5	^				
5	L1228902 Galileo209		41174	02:47	312/ 74	ESA28801	-0.2 50.8	< 34.8/49.9	v	o o o o			
6	C3F28902 Beidou3m15		43648	03:03	280/ 57	SHA28601	0.8 184.0	< 54.7/78.6	v	o o o o			
7	G2728902 Glonass127		37869	03:04	232/ 11	COD28901	40.4	> 24.9/72.0	v	o o o o			
8	CM328903 CompassM3		38250	03:35	320/ 129	SHA28601	-0.0 228.9	< 71.3/73.5	v	o o o o			
9	C3328903 Beidou3m3		43208	03:39	284/ 97	SHA28601	1.8 55.8	< 64.1/81.5	v	o o o o			
10	L2328903 Galileo219		43566	03:47	244/ 66	ESA28801	124.1	> 33.3/76.9	v	o o o o			
11	GE228903 Glonass142		45358	03:56	264/ 95	COD28901	162.1	> 76.8/89.6	v	o o o o			
12	L1828903 Galileo214		41862	04:11	400/ 246	ESA28801	-0.6 136.8	< 68.0/72.3	^	o o o o			
13	G1628904 Glonass116		36111	04:28	272/ 135	COD28901	12.1	> 81.7/87.9	v	o o o o			
14	C4528904 Beidou3m21		44794	05:15	228/ 137	SHA28601	-0.8 286.3	< 56.5/59.8	^	o o			
15	L0628904 Galileo202		40129	05:15	200/ 110	ESA28801	0.3 275.8	< 40.1/40.8	^	o o o o			
16	L2528904 Galileo221		43564	05:15	384/ 294	ESA28801	-0.0 306.6	> 36.6/71.1	^	o o o o			
17	CA128905 Beidou3m20		41865	05:27	328/ 249	SHA28601	234.5	> 59.8/82.8	^	o o o o			



SLR Graz track more entries/NP for HEO



HEO hidden when the current entry acquired

Satellite schedule with high priority filter

Satellite/Debris	Aircraft	Star	Special Target	Configuration	Logs															
1	<input type="checkbox"/> LA229210	Lageos2	60.000	22195	10:38	66/ 9	SGF29201	63.1 >	27.2/86.8 v	o o o o o o o o										
2	<input type="checkbox"/> SEB29211	Sentinel3b	10.000	43437	11:48(13m)	4/----	ESA29101	337.6 <	5.2/ 8.0 ^											
3	<input type="checkbox"/> LAS29211	Lares	50.000	38077	11:50(15m)	15/----	SGF29201	286.5 >	5.3/19.7 ^											
4	<input type="checkbox"/> SWC29211	SwarmC	10.000	39453	11:54(19m)	8/----	ESA29101	1.7 >	5.6/66.4 ^											
5	<input type="checkbox"/> SWA29211	SwarmA	10.000	39452	11:55(20m)	8/----	ESA29101	3.7 >	5.4/56.0 ^											
6	<input type="checkbox"/> LAR29212	Larets	50.000	27944	12:13(39m)	4/----	SGF29201	58.6 >	5.0/ 7.3 ^											
7	<input type="checkbox"/> HYD29212	Hy2d	10.000	48621	12:17(42m)	13/----	SHA29201	206.7 <	5.5/76.6 ^											
8	<input type="checkbox"/> ENV29212	ENVISAT	75.000	27386	12:25(50m)	10/----	TLE7890	120.6 <	5.1/23.6 ^											
9	<input type="checkbox"/> LS229212	Lares2	60.000	53105	12:27(52m)	34/----	SGF29201	101.0 <	5.5/15.6 ^											
10	<input type="checkbox"/> IC229212	IceSat2	10.000	43613	12:53(1h)	2/----	GSF29101	311.5 <	5.0/ 6.0 ^											
11	<input type="checkbox"/> CRY29212	CryoSat2	10.000	36508	12:54(1h)	10/----	ESA29101	350.4 <	5.2/29.6 ^											
12	<input type="checkbox"/> HYC29213	Hy2c	10.000	46469	13:02(1h)	12/----	SHA29101	330.8 >	5.5/27.7 ^											
13	<input type="checkbox"/> TUB29213	Tubin	90.000	48900	13:11(1h)	8/----	TLE7890	33.8 >	5.2/20.8 ^											
14	<input type="checkbox"/> BEC29213	BeaconC	10.000	01328	13:15(1h)	12/----	SGF29201	186.8 <	5.0/17.3 ^											
15	<input type="checkbox"/> SWA29213	SwarmA	10.000	39452	13:30(1h)	5/----	ESA29101	321.7 <	5.3/10.8 ^											
16	<input type="checkbox"/> SWC29213	SwarmC	10.000	39453	13:30(1h)	4/----	ESA29101	318.7 <	5.0/ 9.3 ^											

Pass SE329210 Satellite Sentinel3a Prediction# ESA29101 Az 357.7 EL 5.3 Distance 2788.4 TB na

944.90 [mBar]; 16.2 [°C]; 75.6 [%]

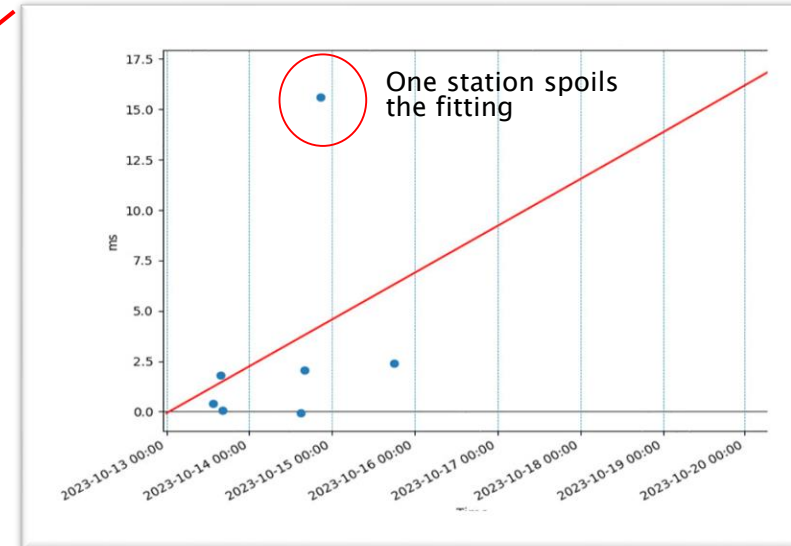
Satellite LIVE (20): 0 0 1 0 0 19 Aircraft: 146 23 10

TB from GFZ / DiGOS

- ◆ TB from JSON public server (e.g. <http://slr.gfz-potsdam.de:5000/tb/v1/cpf/CompassI5/SHA28601>)
- ◆ Color coded TB values ($> +10$ ms Red; < -10 ms blue;)

pass	name	Pri.	NORAD	begin	dur./rem.	Predct.	TB e.	Az	El	Entrie s	Campaign	vis.	ch 9-----10---
7	C3D29304 Beidou3m13		43622	04:23	312/ 27	SHA28601	-1.0	77.5	> 35.8/88.1	v	o o o o o o o o		
8	L1229304 Galileo209		41174	04:55	440/ 188	ESA29201		54.9	> 66.7/84.7	v	o o o o o		
9	G3329305 Glonass133		40001	05:40	228/ 21	COD29301		204.0	< 33.1/71.5	v	o o o o o o o o		
10	C3929306 Beidou3m9		43245	06:23	184/ 19	SHA28601	-2.2	239.1	< 34.3/47.5	v	o o o o o o o o		
11	C3229306 Beidou3m2		43002	06:35	336/ 183	SHA28601	3.1	328.9	> 77.2/78.6	^	o o o o o		
12	L1829306 Galileo214		41862	06:59	480/ 352	ESA29201	0.5	243.4	> 54.7/80.6	^	o o		
13	L2729306 Galileo223		49809	06:59	300/ 172	ESA29201	-0.1	291.7	< 54.6/57.4	^	o o o		
14	L0529306 Galileo201		40128	07:03	136/ 12	ESA29201		249.0	< 14.1/23.3	v	o o o o o o o o		
15	GE429307 Glonass144		52984	07:17	200/ 89	NER29201		273.0	< 54.5/54.9	v	o o o o		
16	G2929307 Glonass129		37868	07:40	312/ 225	COD29301		287.1	> 50.9/66.6	^	o o		
17	G3929307 Glonass139		43687	07:56	96/ 25	COD29301		36.6	< 21.3/22.8	v	o o o o o o o o		
18	C3529308 Beidou3m5		43581	08:27	64/ 23	SHA28601	0.5	61.3	< 25.1/25.2	v	o o o o o		
19	GE629308 Glonass146		54377	08:37	156/ 125	NER29201		94.3	< 28.0/37.2	^	o o		
20	C3129308 Beidou3m1		43001	08:51	168/ 151	SHA28601	-2.1	274.6	> 31.1/86.4	^	o		
21	C4029308 Beidou3m16		43647	08:55	80/ 67	SHA28601	0.4	306.3	< 25.4/27.1	^	o		
22	L1329308 Galileo210		41550	08:59	76/ 68	ESA29201	-12.1	48.0	< 8.3/ 9.8	^	o		
23	C4229308 Beidou3m18		43707	09:03	172/ 167	SHA28601	17.1	129.4	> 28.0/43.7	^	o		

Pass C4229308 SatelliteBeidou3m18 Predictione SHA28601 Az 121.0 El 27.5 Distance24364.0 TB 17.0



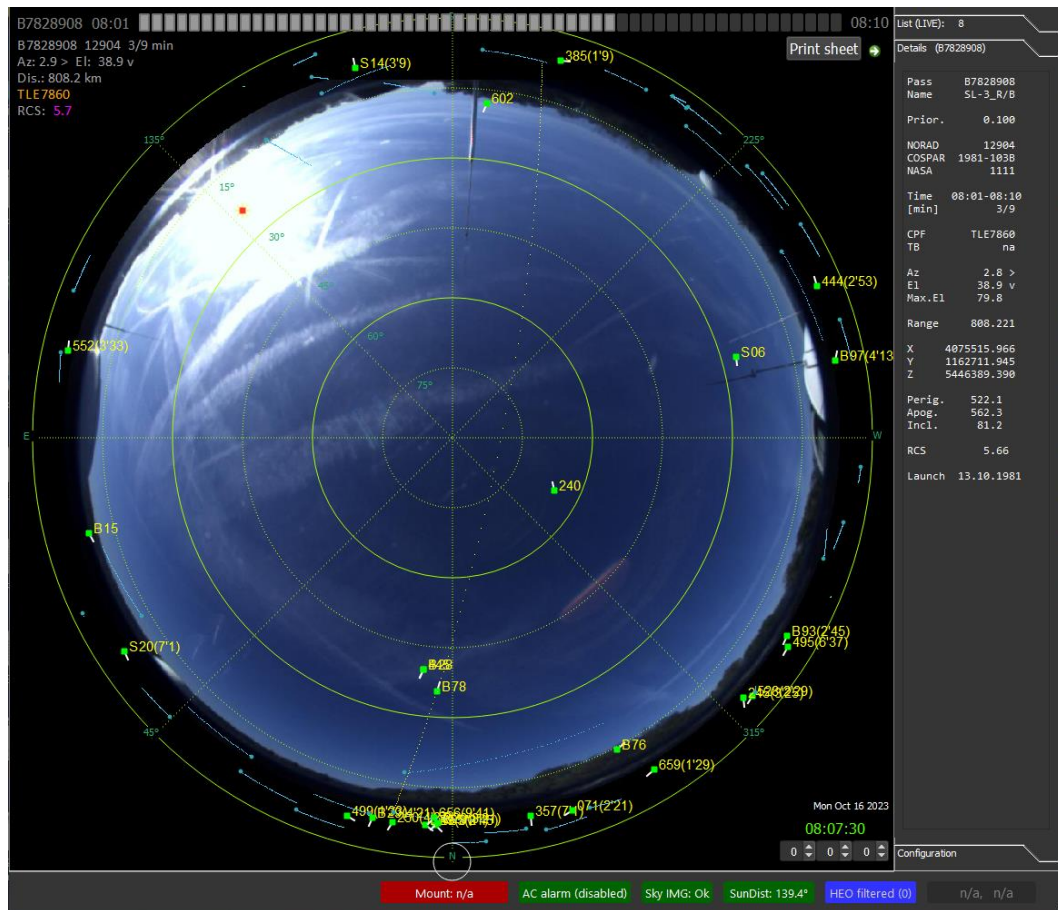
NP vs. TB from different stations

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  }
}

```

- ◆ RCS, orbits parameters are crucial for SDLR.
- ◆ Historical records help observer selecting targets – more than one target at the same time.



Satellite/Debris	Aircraft	Star	Special Target	Configuration	Logs
1	<input type="checkbox"/>	24028907	SL-19_R/B	36589 07:58	15/ 1 338.7 > 12.2/71.6 v 2798.3 874.0 1208.8 6.32 02.06.2010
2	<input type="checkbox"/>	44528908	CZ-4B_DEB	25733 08:03	12/ 3 202.6 > 22.2/79.9 v 1723.0 825.1 846.6 8.10 10.05.1999
3	<input type="checkbox"/>	B2828908	THOR_AGENA_D_R/B	00733 08:03	12/ 3 202.6 > 22.2/79.9 v 1723.0 759.2 806.2 4.71 19.01.1964
4	<input type="checkbox"/>	38528908	OA0_2	03597 08:08	8/ 3 148.5 > 12.3/12.7 v 2068.6 734.3 742.5 2.41 07.12.1968
5	<input type="checkbox"/>	49928908	SL-8_R/B	11327 08:09	10/ 6 51.0 > 15.2/15.6 ^ 2347.6 953.3 995.8 6.29 11.04.1979
6	<input type="checkbox"/>	07128908	NIGERIASAT_X	37790 08:09	7/ 4 304.8 > 13.5/13.5 ^ 1914.7 687.6 705.8 0.21 17.08.2011
7	<input type="checkbox"/>	52828908	SL-14_R/B	16409 08:10	6/ 3 284.3 > 8.5/ 8.6 v 2801.1 936.8 956.7 4.79 26.12.1985
8	<input type="checkbox"/>	B9328908	SL-8_R/B	05730 08:10	5/ 2 246.3 > 12.7/13.4 v 1248.0 378.7 1326.2 5.69 27.12.1971
9	<input type="checkbox"/>	44428908	NIMBUS_7	11080 08:10	7/ 4 270.9 > 9.4/ 9.6 ^ 2712.0 942.2 954.7 3.34 24.10.1978
10	<input type="checkbox"/>	S1428908	CZ-4C_R/B	32290 08:10	6/ 3 160.3 > 66.8/87.2 ^ 334.9 376.1 429.1 8.85 11.11.2007
11	<input type="checkbox"/>	24528908	CZ-4C_DEB	36417 08:10	16/ 14 304.3 > 17.0/43.8 ^ 2527.5 766.5 1412.3 8.93 05.03.2010
12	<input type="checkbox"/>	55228908	SL-14_R/B	15495 08:11	4/ 2 79.6 > 8.3/ 8.4 ^ 2126.1 603.0 628.8 3.34 24.01.1985
13	<input type="checkbox"/>	B9728908	SL-16_R/B	19120 08:11	11/ 10 267.3 > 12.0/22.9 ^ 2320.3 810.6 844.9 10.50 15.05.1988
14	<input type="checkbox"/>	B2928908	CZ-4B_R/B	25732 08:11	12/ 11 11.0 > 13.9/76.0 ^ 2217.0 806.7 859.0 6.72 10.05.1999
15	<input type="checkbox"/>	25028908	ARIANE_1_DEB	17129 08:12	12/ 11 7.4 > 12.2/63.2 ^ 2215.3 783.5 832.5 5.52 22.02.1986
16	<input type="checkbox"/>	49528908	SL-14_R/B	19275 08:14 (1m)	4/---- 307.4 < 5.0/ 7.7 ^ 2356.3 605.4 633.3 4.68 05.07.1988
17	<input type="checkbox"/>	35728908	COSMOS_2228	22286 08:14 (1m)	10/---- 348.5 < 5.4/76.9 ^ 2317.6 584.5 614.2 4.99 25.12.1992
18	<input type="checkbox"/>	S2028908	GAOFEN_11	43585 08:14 (1m)	5/---- 50.9 > 5.3/10.1 ^ 2055.7 488.4 501.1 1.11 31.07.2018
19	<input type="checkbox"/>	B4928908	SL-14_R/B	20262 08:15 (2m)	20/---- 1.8 > 5.4/36.5 ^ 3507.6 497.8 2437.6 4.93 28.09.1989
20	<input type="checkbox"/>	B2028908	SL-16_R/B	25861 08:15 (2m)	9/---- 4.0 < 5.5/42.0 ^ 2377.4 621.8 642.4 13.30 17.07.1999

Pass B7828908 Satellite SL-3_R/B Prediction# TLE7860 Az 2.3 EL 40.8 Distance 781.7 Perigee 522.1 Apogee 562.3 RCS 5.66

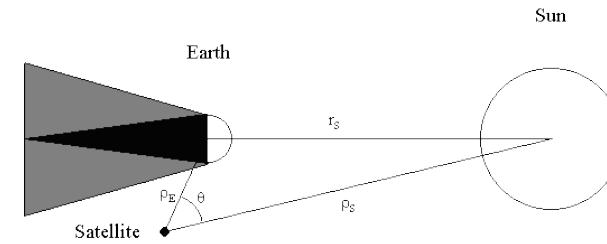
08:01 08:10

965.47 [mBar]; 5.2 [C]; 89.1 [%]

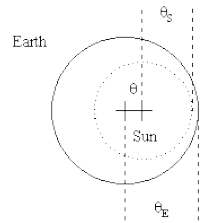
Debris LIVE (15): 1 8 5 1 0 Aircraft: 132 17 2

Visibility information

- Visualizing satellite helps for TB correction and tracking correction.
- Visibility calculation algorithm: “Visually Observing Earth Satellites”, Dr. T.S. Kelso, <https://celestrak.org/columns/v03n01/>, only umbral eclipse used.
- SkyVision displays the visibility distribution through the pass and the change time.

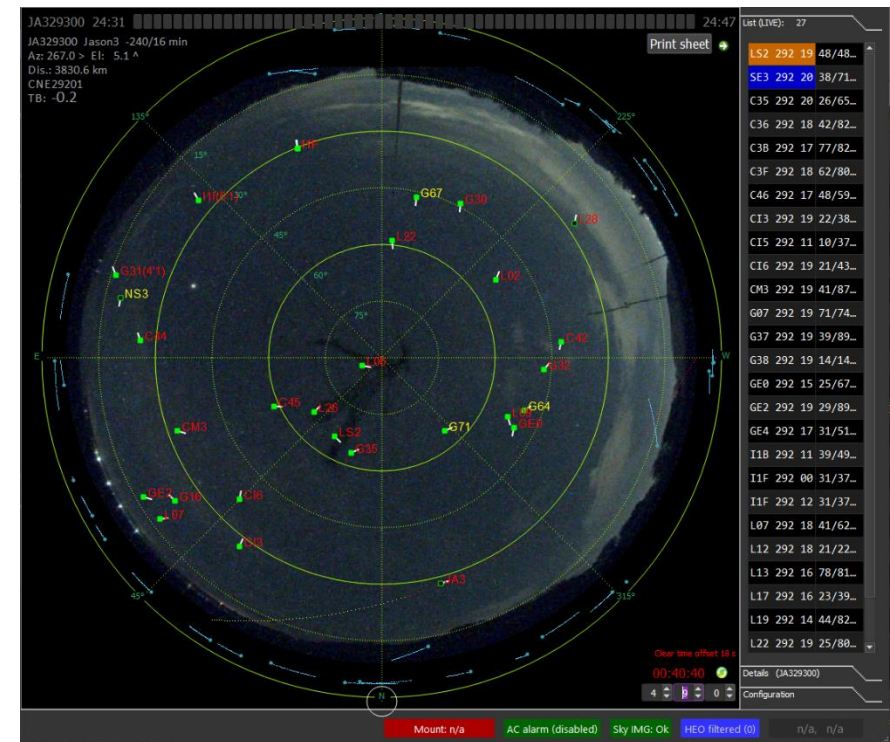


Satellite-Earth-Sun Geometry



Umbral Eclipse

Satellite/Debris	Aircraft	Star	Special Target	Configuration	Logs
94	C4429300	Beidou3m20			
95	JA329300	Jason3			
96	NS329300	NETSAT-3			
97	G3129300	Glonass131			
98	I1129300	IRNSS1I			
99	NS129300	NETSAT-1			
100	LAR29300	Larets			
101	L2029300	Gallileo216			
102	ALO29300	ALOS			
103	JA229300	Jason2			
104	NS429300	NETSAT-4			
105	L1529300	Gallileo207			
106	JA129301	Jason1			
107	NS229301	NETSAT-2			
108	G0629300	Glonass106			
109	G3429300	Glonass134			
110	L0129300	Gallileo101			
111	C4829301	Beidou3m24			
112	C3E29301	Beidou3m14			
113	TUB29301	Tubin			
114	AD229301	Adeos2			
115	STA29301	Starlette			



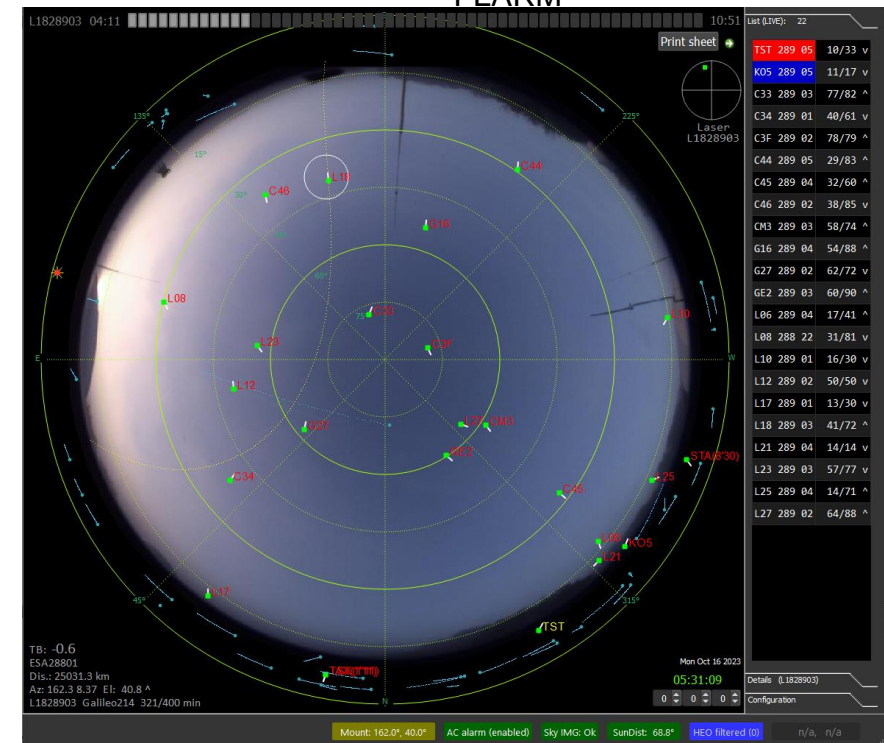
ADS-B and Aircraft avoidance

- AirSquitter equipped with ADS-B, MLAT, FLARM, GPS.
- Laser switched off automatically when any Aircraft appears in protect zone.
- Protect zone: 5° at low elevation; 10° at high elevation.



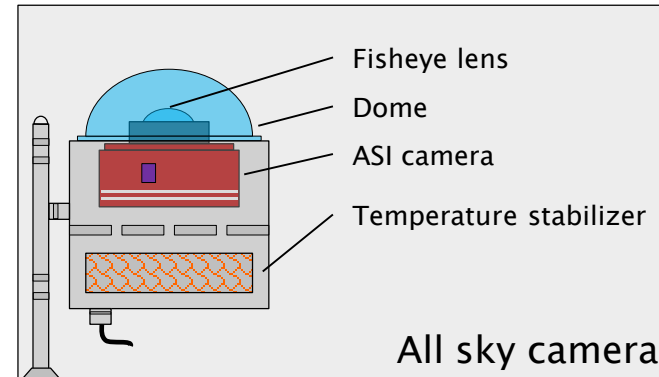
ADS-B Receiver with MLAT
FLARM

Satellite/Debris	Aircraft	Star	Special Target	Configuration	Logs	Last msg	Last valid	ICAO	Callsign	Azi	Elv	Dis. [km]	Track	GNSS alt [m]	Bar alt [m]	Ground spd. [m/s]	Vertical spd. [m/s]	Lat	Lon	Squawk	Type	Departure	Arrival	
1	21:29:49		447AC2	FFNSKL	0.000	0.000	0.000	0	0	1402	0.000	0.0	0.0	7777	N/A									
2	21:29:23	21:29:24	4D2347	RYRBSVH	79.895	0.453	208.761	79	5599	5470	202.691	-7.407	47.4	18.2	0406	B38M	Bergamo(LIME)	Budapest(LH)						
3	21:29:52	21:28:59	040172	ETH07	165.541	-0.070	382.794	141	11565	11261	273.170	-0.325	43.7	16.7	2570	A359	Frankfurt(EDDF)	AddisAbaba(HA)						
4	21:29:39	21:29:39	D008F1		39.127	-1.816	400.024	270	408	408	0.000	0.102	49.8	19.0	Unknown		N/A							
5	21:29:36	21:29:37	D02326		307.613	-1.336	300.833	180	614	614	0.000	-0.295	48.7	12.3			N/A							
6	21:29:19	21:29:19	48C133	RYR40G	39.228	0.793	292.561	358	11290	11290	226.355	0.366	49.1	18.0	6567	B738	Malta(LMML)	Poznan(EPI)						
7	21:29:18	21:29:18	4B1903	SMR138	276.266	1.756	192.081	100	9307	9117	281.915	-3.277	47.2	13.0	3012	A343	Zur-ich(LSZH)	Hongkong(VH)						
8	21:29:07	21:29:08	ACA56E	RYRBLV	314.947	1.329	261.512	302	11955	11788	182.113	4.658	48.7	13.0	1000	B738	Sofia(LBSF)	Charleroi(EB)						
9	21:29:36	21:29:37	48C126	RYRBYW	71.961	0.172	224.558	303	5157	5157	128.611	-9.271	47.7	18.3	1000	B738	Bourgas(LBG6)	Bratislava(LZ)						
10	21:29:48	21:29:46	4BCD06		114.657	0.553	308.767	0	10973	10973	0.000	0.000	45.9	19.1	3232	B738	N/A	N/A						
11	21:29:52	21:29:52	4D248F		53.542	0.495	312.181	123	10859	10668	251.049	-0.325	48.7	18.9	0516		N/A							
12	21:29:52	21:29:52	89645A	UAE4	321.455	1.234	259.879	111	11423	11278	301.464	0.000	48.9	13.3	4624	A388	London(EGLL)	Dubai(OM)						
13	21:29:52	21:29:51	89644B	UAE13U	13.212	1.338	232.772	122	10219	10059	271.626	0.000	49.1	16.2	7646	B77W	Frankfurt(EDDF)	Dubai(OM)						
14	21:29:46	21:29:46	3949F9	AFR116	291.511	1.564	217.044	101	10143	9944	288.603	-19.015	47.8	12.8	4501	B772	Paris(LFPF)	Shanghai(ZSP)						
15	21:29:52	21:29:52	4D22AD	RYR5X	190.775	2.074	196.210	16	10653	10363	218.124	0.000	45.3	15.0	1000	A320	Rome(LIRF)	Vienna(LO)						
16	21:29:52	21:29:52	471F65	HMT91	217.084	1.404	240.603	88	10965	10683	263.910	0.000	45.3	13.6	0413	A321	N/A	N/A						
17	21:29:52	21:29:51	4070E8	EXS82T	217.454	1.024	282.985	309	11864	11583	189.830	0.000	45.0	13.3	3732	B738	KerkyracorFu(LGKR)	Birmingham(EG)						
18	21:29:51	21:29:52	4BCCAE	SXS8XH	71.896	0.800	300.184	303	11773	11583	206.806	-0.325	47.8	19.3	2642	B738	Antalya(LTAI)	Cologne(ED)						
19	21:29:52	21:29:52	8964FE	ETD69K	319.053	3.217	159.420	112	11468	11285	297.349	-0.650	48.1	14.1	7315	B78X	London(EGLL)	Abu Dhabi(OM)						
20	21:29:52	21:29:51	3C482B	DLH778	325.110	3.542	126.958	109	9639	9449	273.684	0.000	48.0	14.5	7654	B748	Frankfurt(EDDF)	Singapore(WS)						
21	21:29:51	21:29:52	4CA56F	RYR66PG	6.755	1.767	182.549	307	8778	8778	228.928	6.680	47.7	15.8	4413	B738	Bratislava(LZIB)	Dublin(EG)						
22	21:29:52	21:29:52	407795	EZY54GK	157.843	1.567	234.935	309	11285	10988	200.633	0.000	45.1	16.6	2276	A20N	Paphos(LCPH)	Manchester(EG)						
23	21:29:52	21:29:52	4BC847	PGT74PF	63.649	1.073	257.913	303	10569	10363	204.234	0.000	48.1	18.6	3265	A21N	Istanbul(LTFJ)	Cologne(ED)						

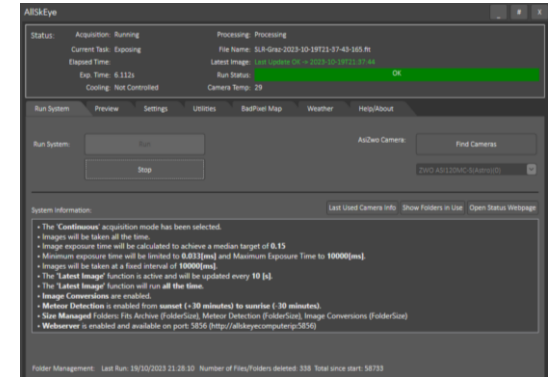


All sky camera & Keogram image

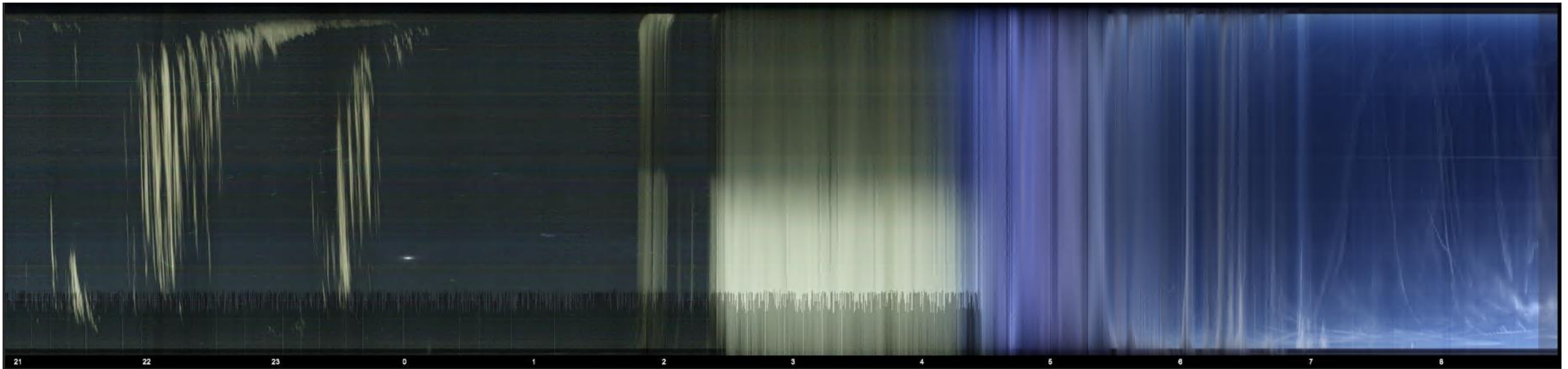
- ◆ Home made all sky camera.
- ◆ AllSkeye software for image organization.
- ◆ 24H Keogram image for checking back.



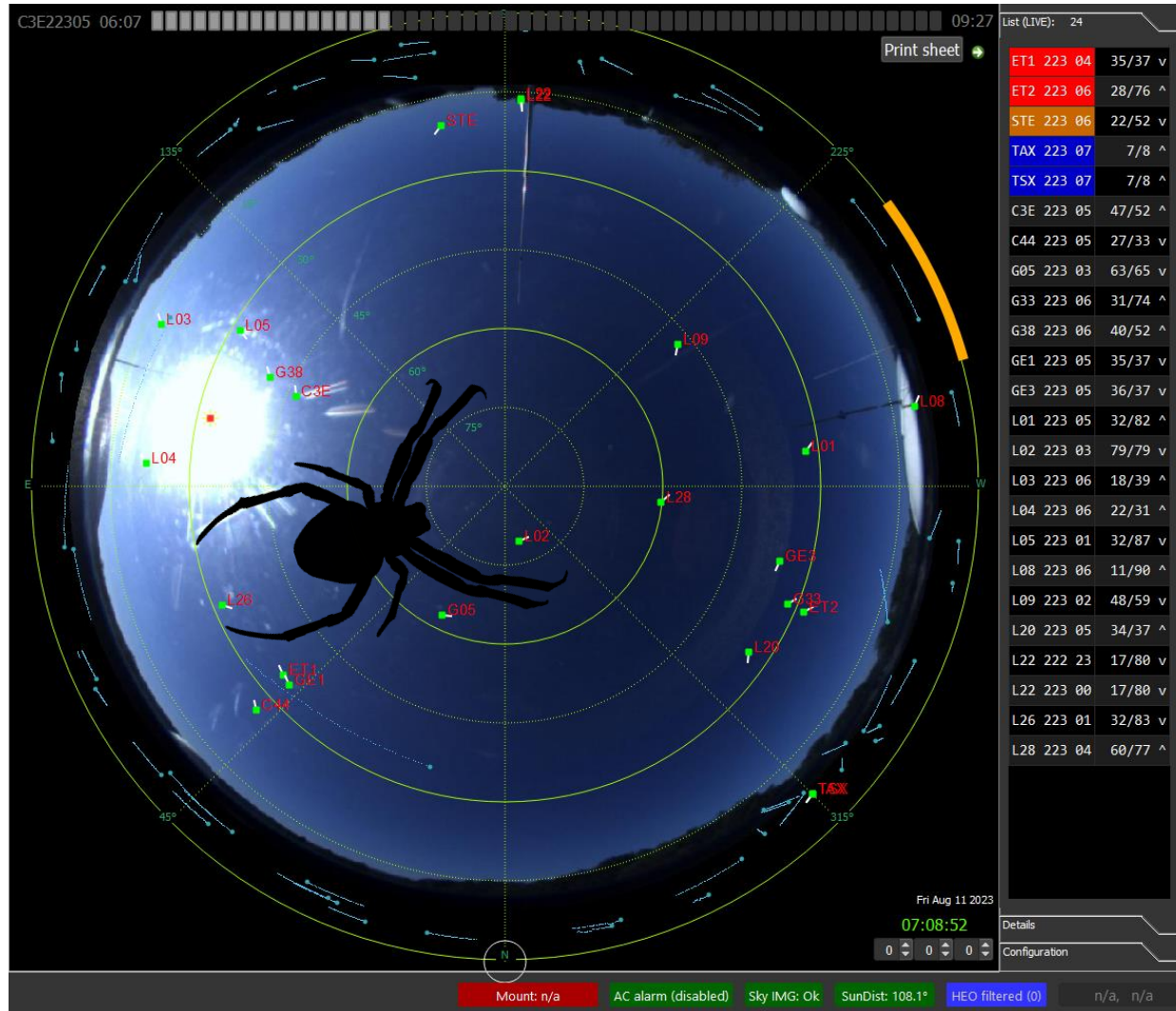
Structure of all sky camera



Allskeye interface



Keogram image stores sky condition in last 24 H



****We are not alone****

Thanks for you kind attention