A new Australian conjunction assessment and threat warning service

James C. S. Bennett

Astrodynamics Group Leader, EOS Space Systems Pty Ltd

Space Asset Management Program Leader, Space Environment Research Centre

INTERNATIONAL WORKSHOP ON SPACE DEBRIS MANAGEMENT, 9th November 2018

Overview

- Brief introduction to SERC
  - RP3: Space Asset Management program
- Progress in operational conjunction and threat warning service.
- Timeline to initial operational capability and full operational capability.

SERC Founding Participants

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Australian National University

RMIT UNIVERSITY

Australian Government
Department of Industry, Innovation and Science

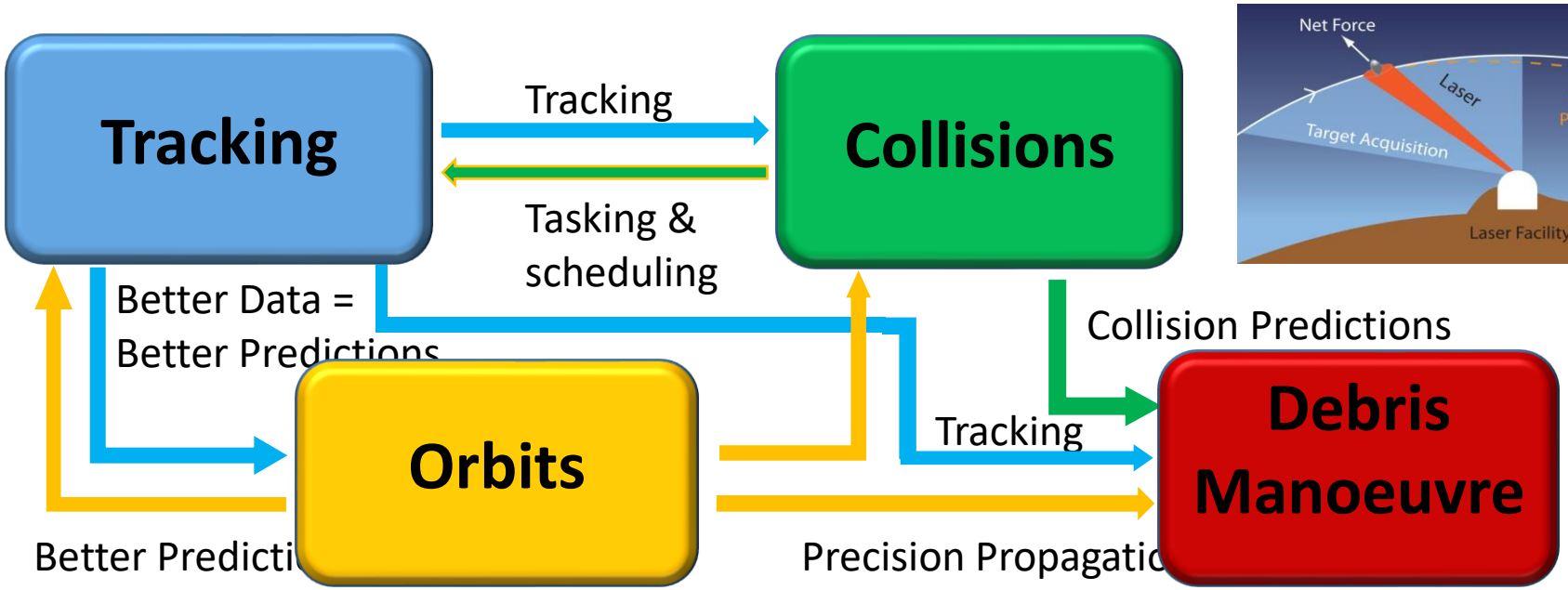
Business Cooperative Research Centres Programme

OPTUS yes

LOCKHEED MARTIN

NICT National Institute of Information and Communications Technology

SERC Research Programs



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The current team

Research staff:

- Dr James Bennett
- Dr Daniel Kucharski
- Dr Marek Möckel
- Dr Michael Lachut
- Dr Sven Flegel
- Mr Jeffrey Wardman
- Mr David Kooymans
- EOS Space Systems Team
- Industrial Sciences Group

PhD Candidates:

- Mr Joseph O'Leary
- Mr Richard Samuel
- Mr James Allworth
- Ms Hansani Kaushalya Perera THANIPPULI KANKANAMALAGE

Student Interns:

- Thomas La
- Nathaniel McGrath

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Other RP3 presentations

Tue 6th

11:45	12:00	Gravity field determination using post-Newtonian energy integral	Joseph O'Leary	University of South Australia / Space Environment Research Centre, Australia

Fri 9th

12:00	12:15	Orbit determination and prediction accuracy of TOPEX with a priori solar radiation force derived from photometrics and laser ranging data	Michael Lachut	EOS Space Systems, Queanbeyan / Space Environment Research Centre, Mt Stromlo, Australia
14:15	14:30	Assessing GEO close encounter warnings for spacecraft operations	Sven Flegel	Space Environment Research Centre, Canberra / Visiting Researcher to the Royal Melbourne Institute of Technology, Australia
16:15	16:30	High-definition Photometry - New tool for space debris characterization	Daniel Kucharski	Space Environment Research Centre, Canberra, Australia / The University of Texas, Austin, USA,

Fri 9th

SD11	Design of a high-performance conjunction assessment service	Marek Moeckel	Space Environment Research Centre, Mt Stromlo, Australia
SD12	Increasing the determinacy and uniqueness of solutions to the physical characteristics and non-natural behaviours of near-earth orbiting space objects	Richard Samuel	Space Environment Research Centre / Australian National University, Weston Creek, Australia
SD13	Design & development of an optimized sensor scheduling & tasking programme for tracking space objects	David Shteinman	Industrial Sciences Group, Sydney, Australia

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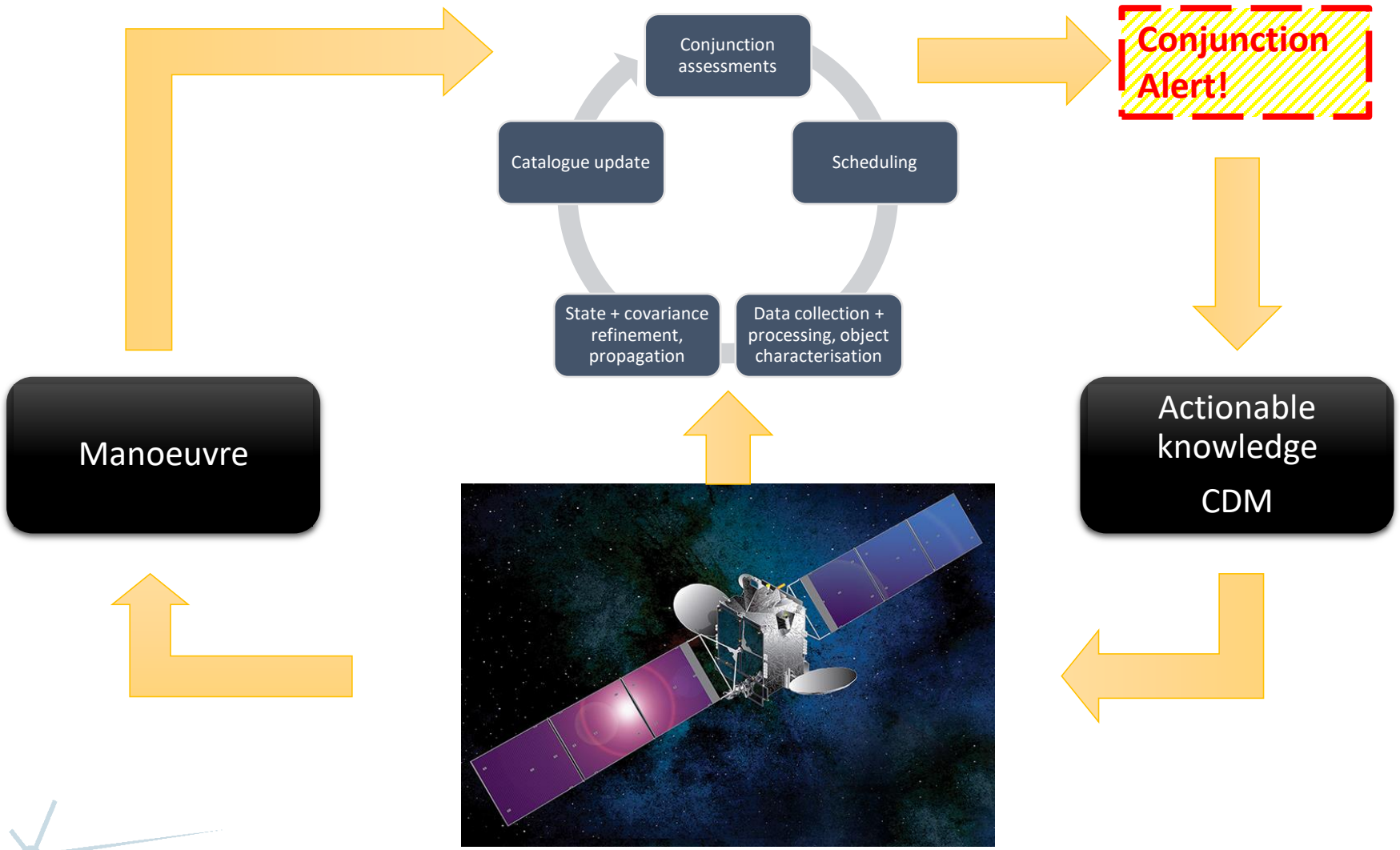
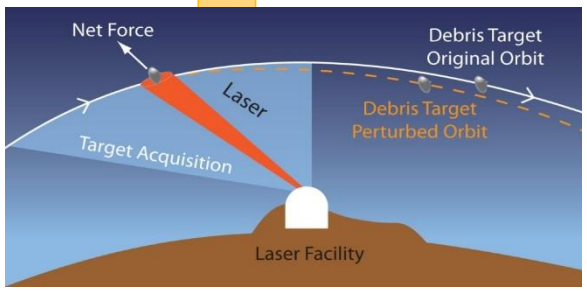
Research Program 3: Space Asset Management



Source: https://www.optus.com.au/about/network/satellite/fleet/optus-10



Manoeuvre

Conjunction assessments

Scheduling

Data collection + processing, object characterisation

State + covariance refinement, propagation

Catalogue update

Conjunction Alert!

Actionable knowledge

CDM

Manoeuvre simulations

Presentation Overview

- Sensors
- Scheduling
- Database/catalogue
- Object characterisation
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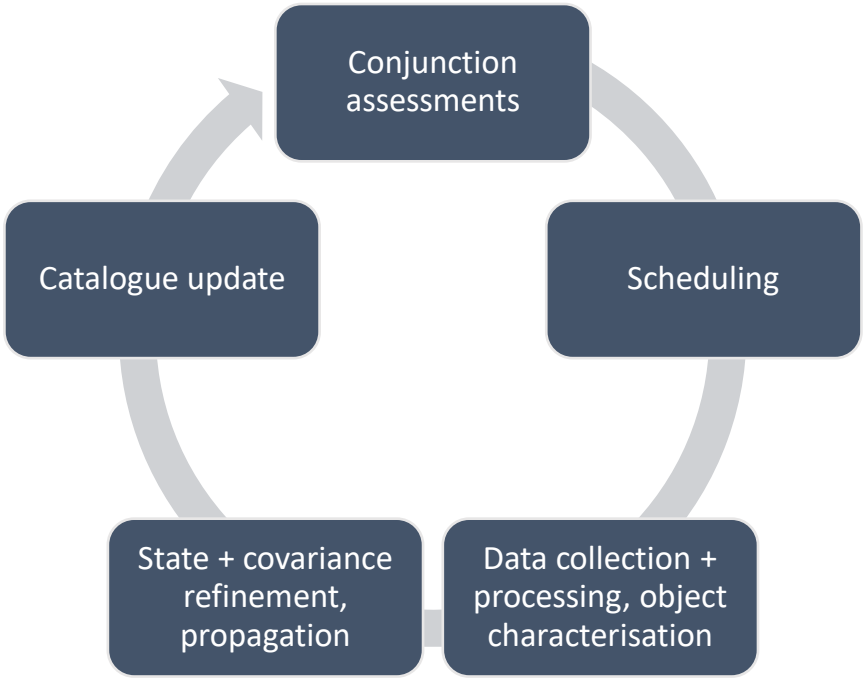
- Error propagation
- Conjunction assessments



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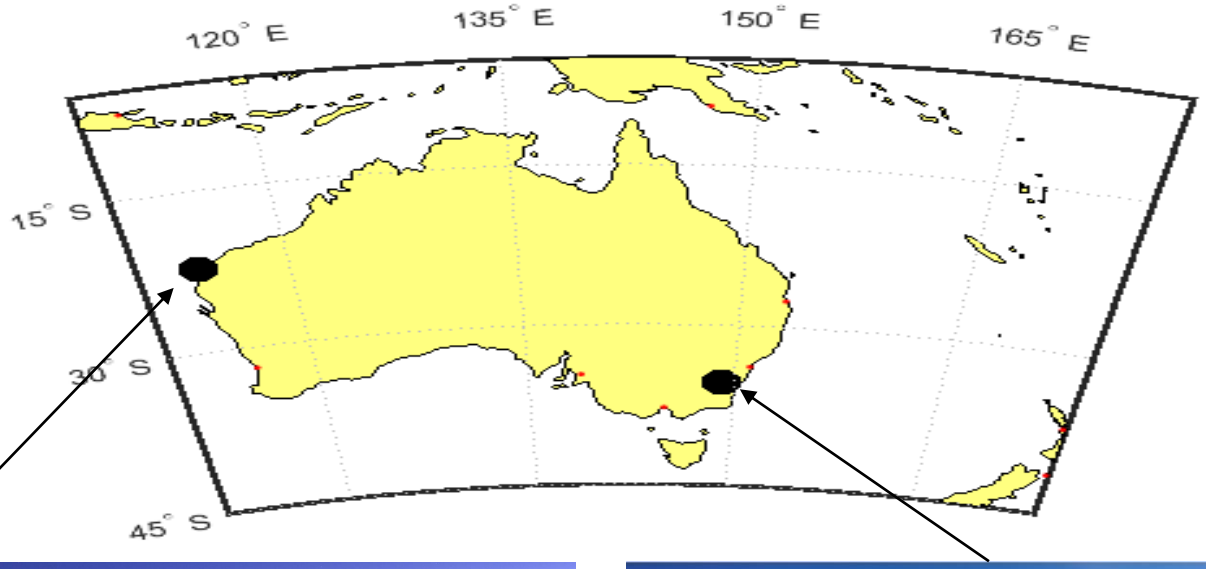
Sensor network

- EOS Space Systems' Space Debris Tracking Station at Mount Stromlo
- New operational site at Learmonth
  - Collaboration between EOS Space Systems & Lockheed Martin with support from AUS DoD



Learmonth, WA (22° S, 114° E)

Mt Stromlo, ACT (35° S, 149° E)

System ID	Site	Aperture	Configuration
A1	Mt Stromlo	1.8 m	Active + Passive
A2	Mt Stromlo	0.7 m	Passive
B1	Learmonth	1.0 m	Active + Passive
B2	Learmonth	1.0 m	Active + Passive
B3	Learmonth	0.7 m	Passive
B4	Learmonth	0.7 m	Passive

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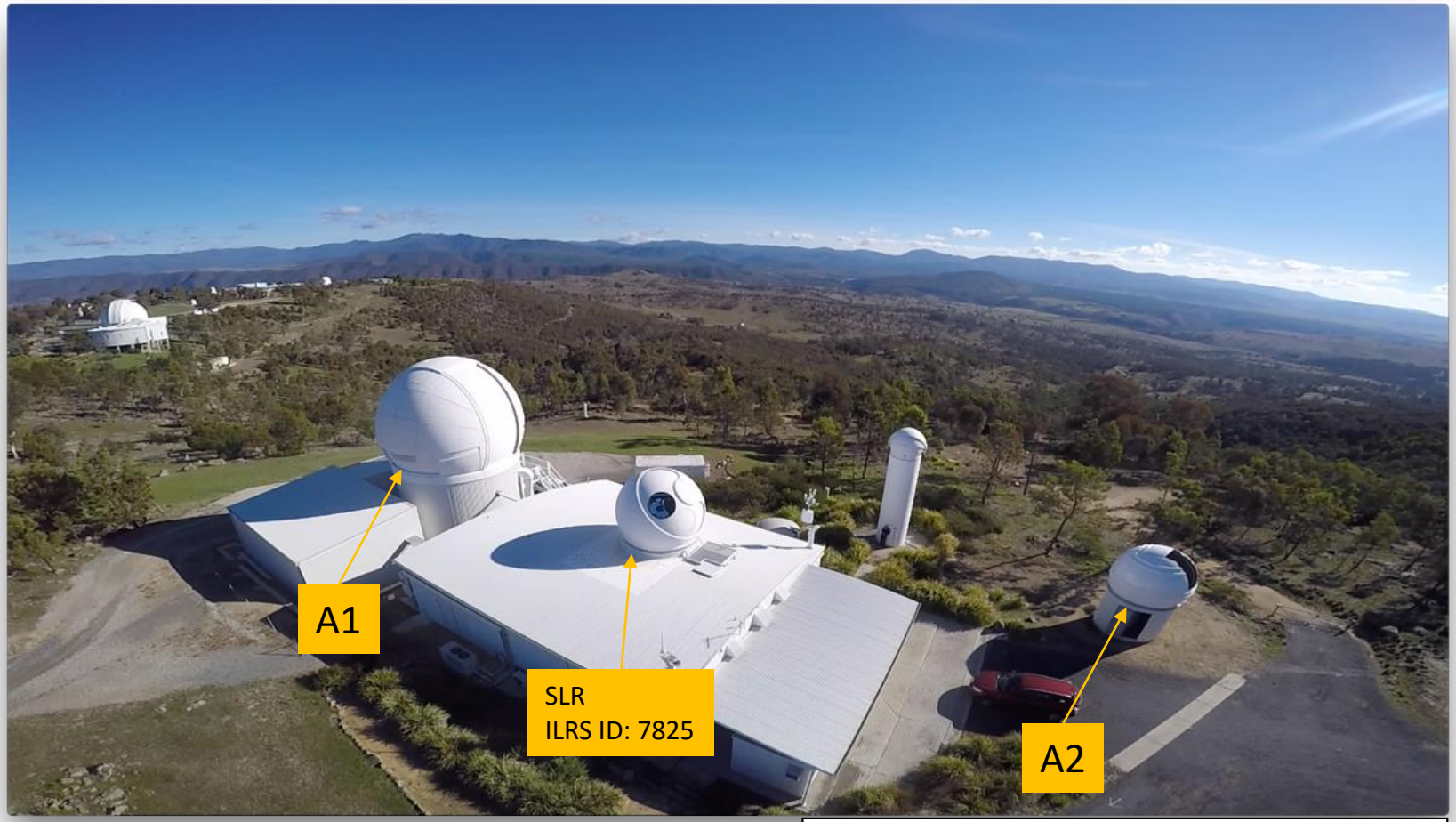
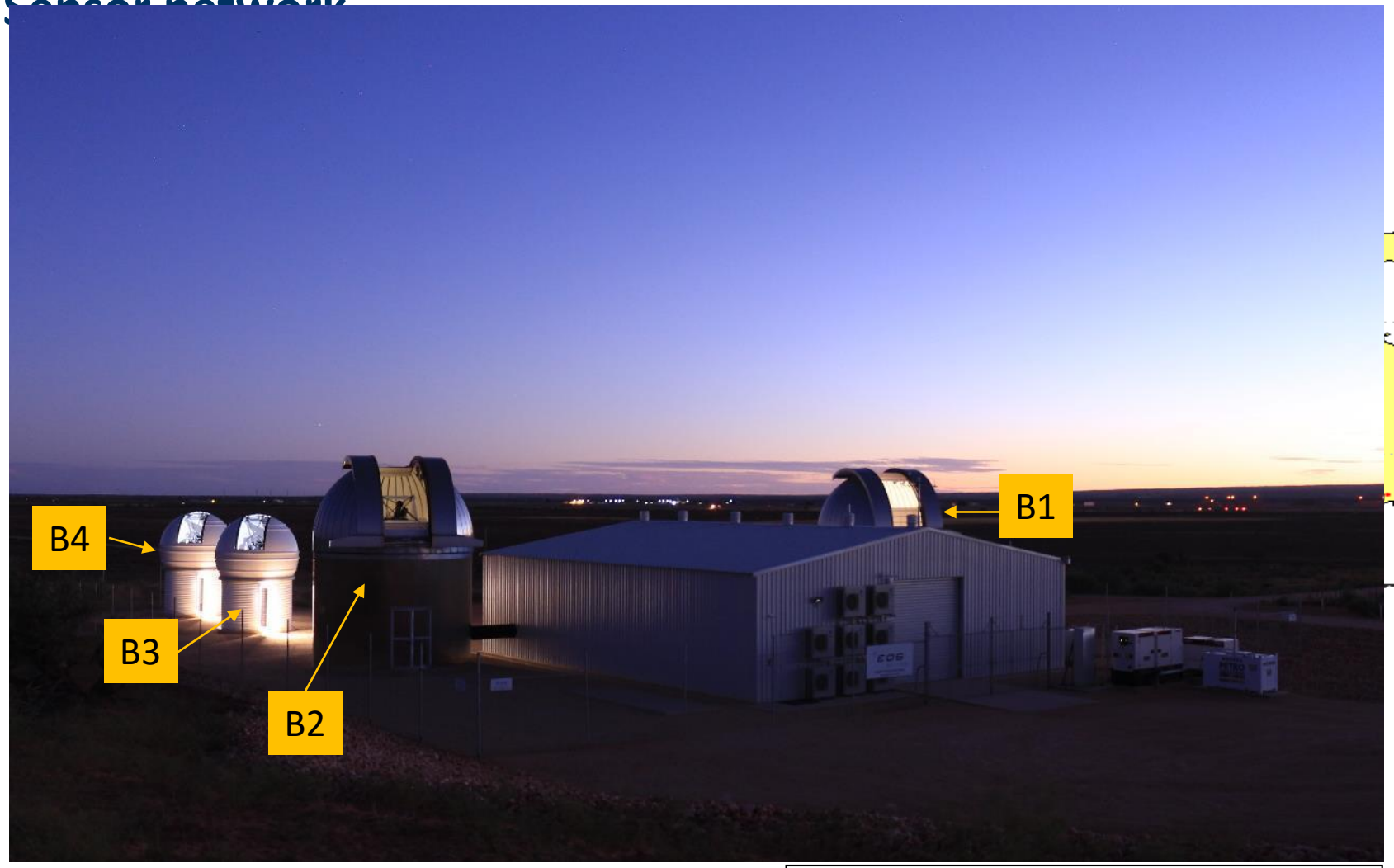
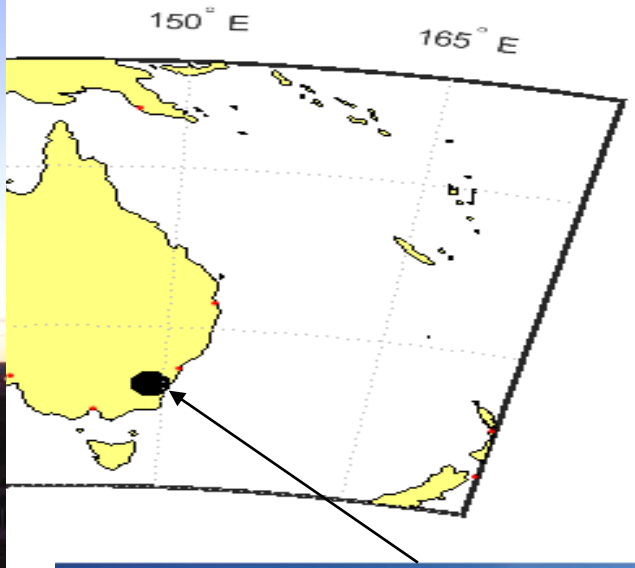
Sensor network – Mt Stromlo



Mt Stromlo, ACT (35° S, 149° E)

Sensor network





Learmonth, WA (22° S, 114° E)

Mt Stromlo, ACT (35° S, 149° E)

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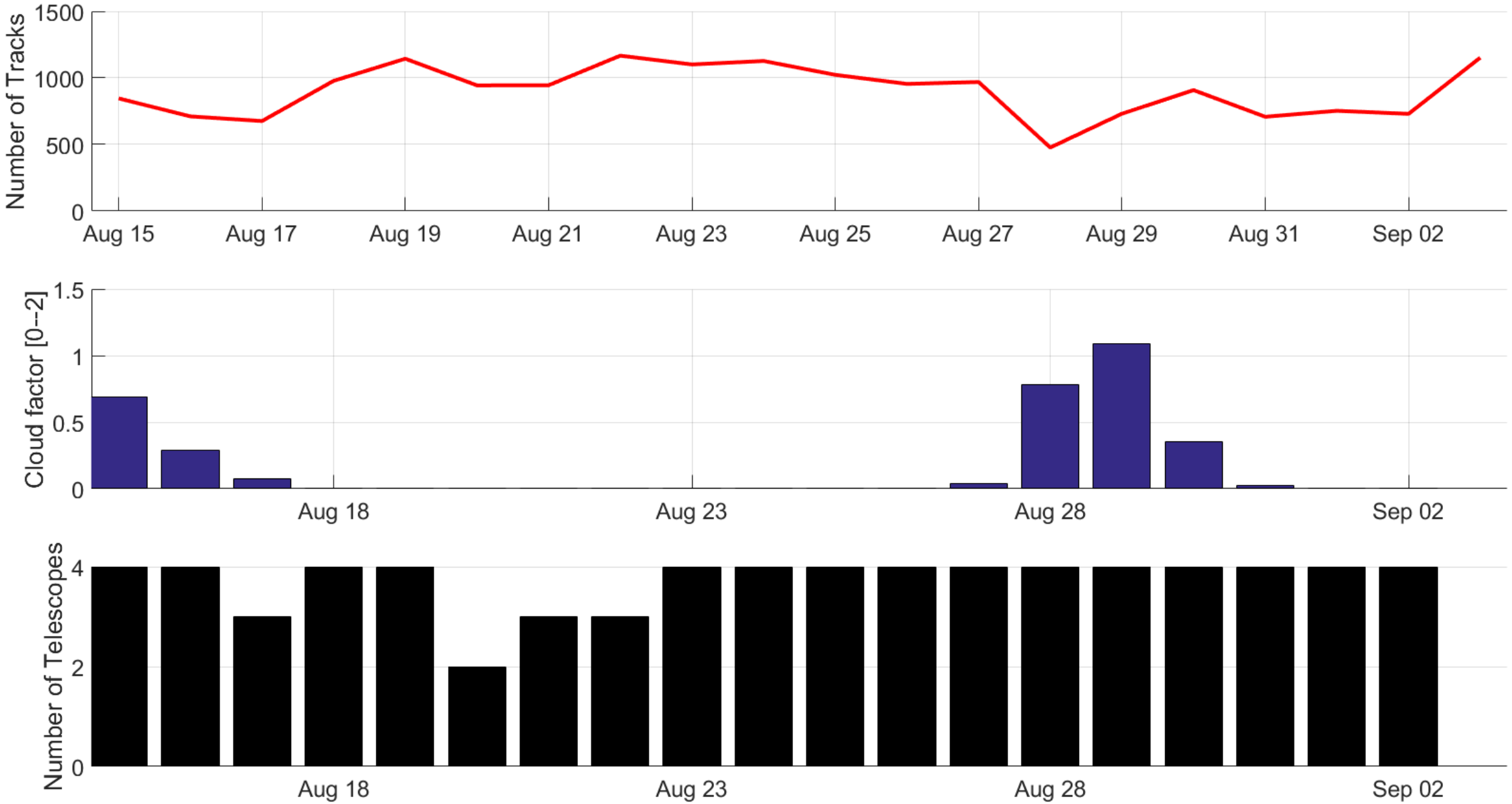
Recent tracking – Learmonth only



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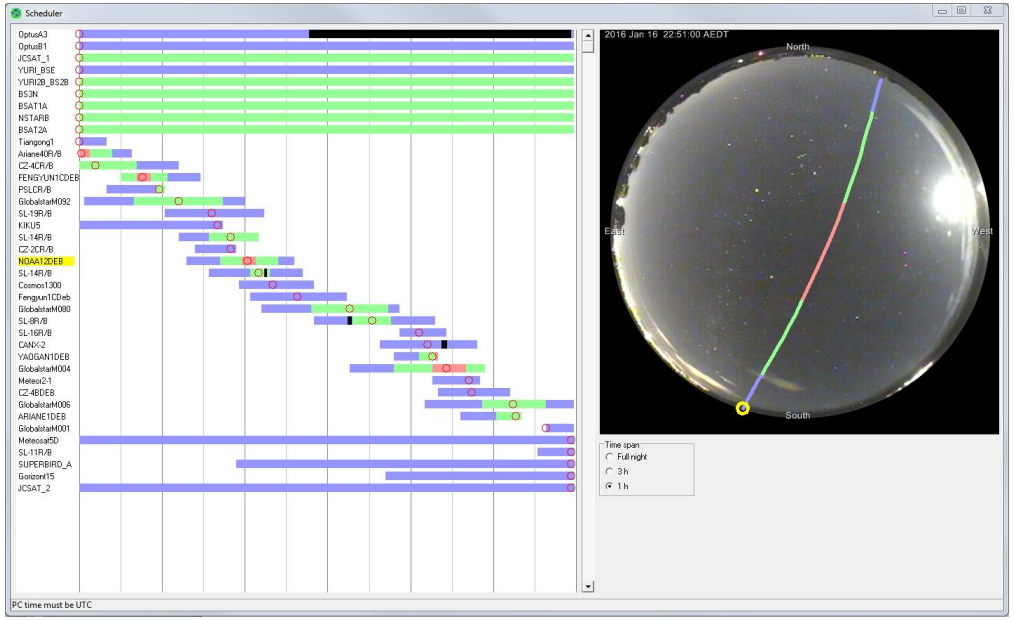
Network scheduling

- EOS have several methods of tasking the network
- SERC have developed an information gain based scheduler that
  - Started by Dr. Steve Gehly*
    - Recoded for use in operations (James Allworth)
  - Interface with EOS sensor network completed and single-sensor testing has been achieved.
  - Contracted to The Industrial Sciences Group: http://www.industrialsciences.com.au/
    - Phase 1 completed, multi-sensor functionality across 6 active and passive sensor network, under testing.
    - Phase 2 started
- Phase 2 of the scheduler will see it optimised in C++ to handle a larger network of sensors and a catalogue of 100,000+ objects (late 2018)



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* Gehly, S. and J. Bennett, *Incorporating Target Priorities in the Sensor Tasking Reward Function*, in *Advanced Maui Optical and Space Surveillance Technologies Conference*. 2015: Maui, Hawaii.
Gehly, S. and J. Bennett, *Distributed Fusion Sensor Networks for Space Situational Awareness*, in *68th International Astronautical Congress*. 2017: Adelaide, Australia.

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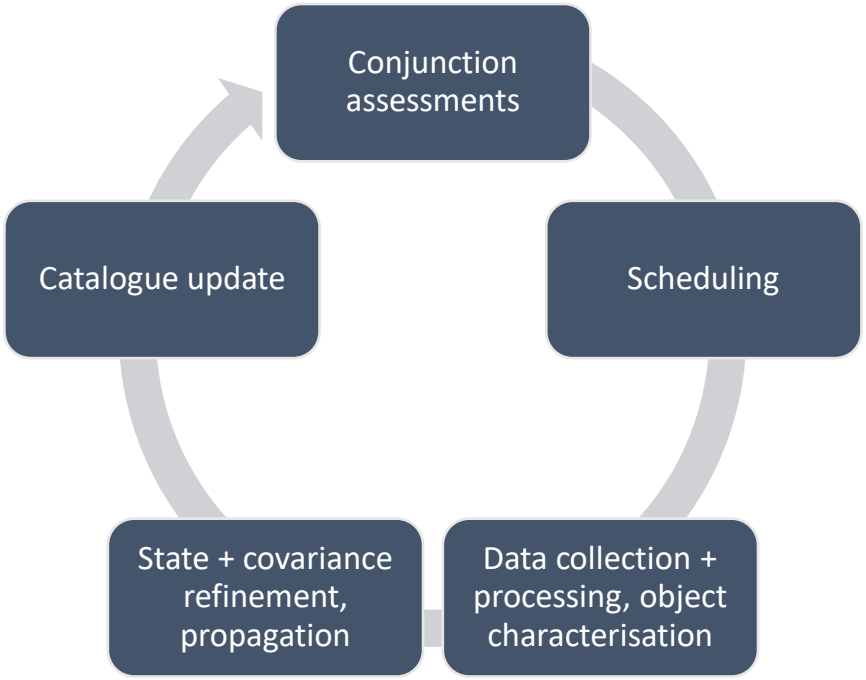
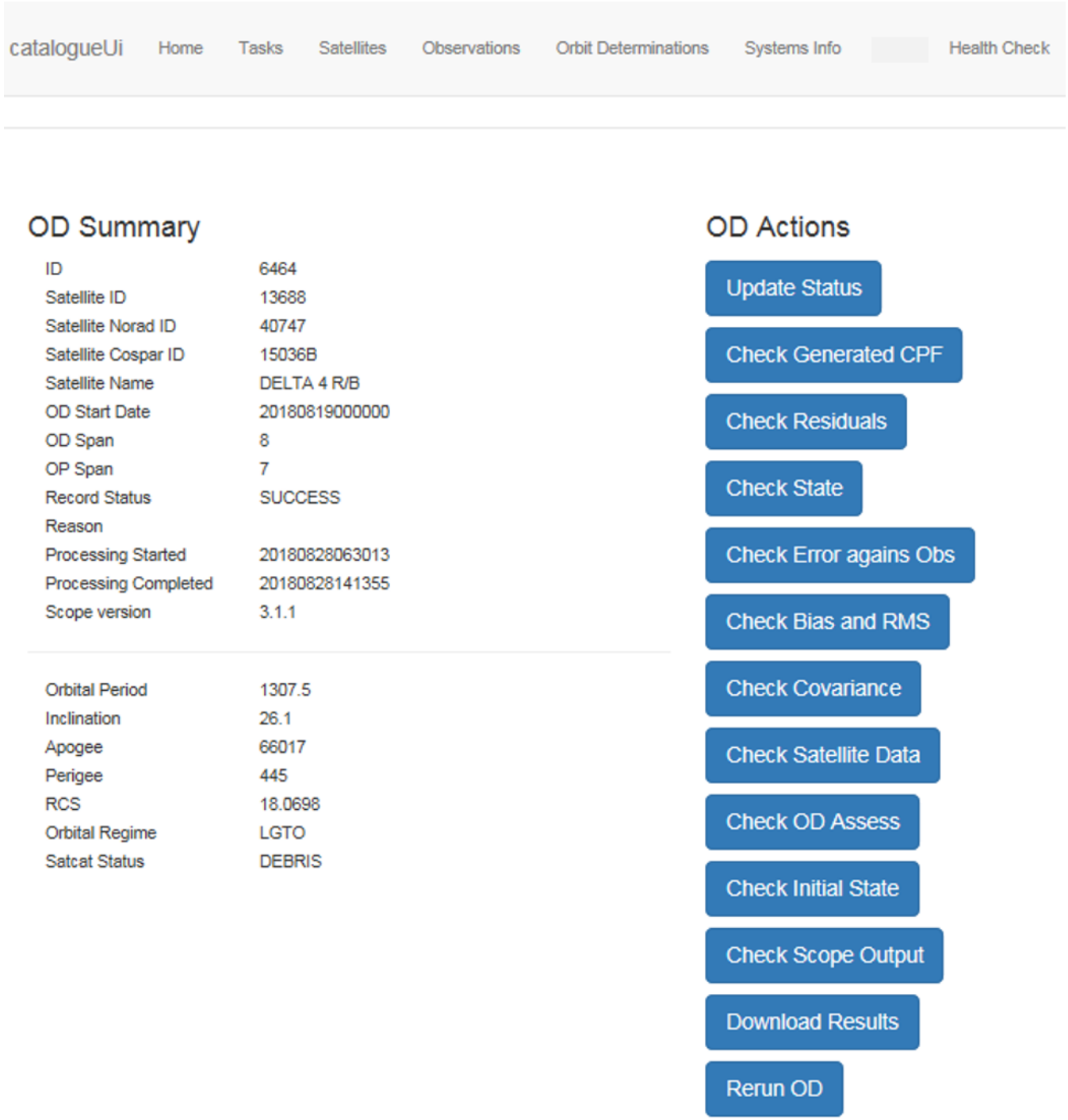


Database/Catalogue

- Central database-backed application
  - Storage, association, processing tracking data, light curves, object characteristics, calibrations
  - HTTP interface with small html frontend
- Relational database
  - Traceability – e.g. Orbit determination: what tracks, what sensors, what force models, EOP, solar flux, observation weighting etc.
- Automation of track correlations & orbit determinations
- System monitoring



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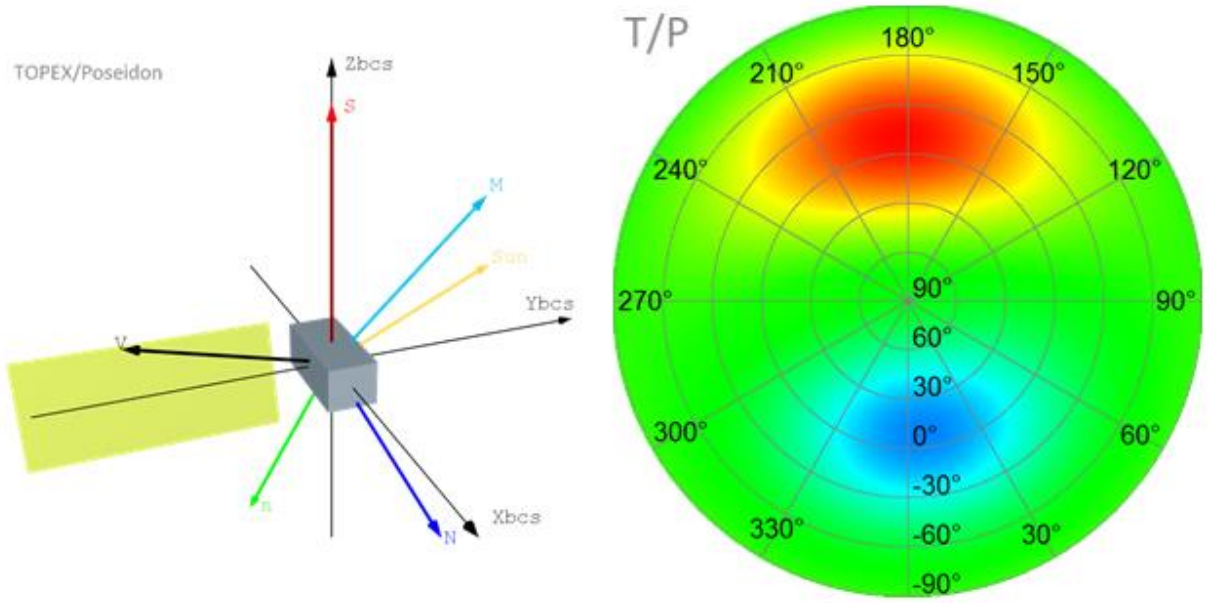
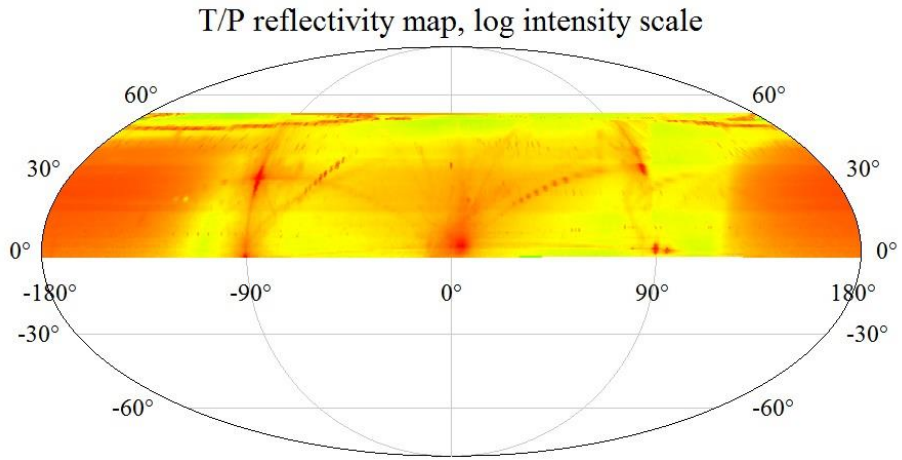
Object Characterisations

- Characterisation for the laser manoeuvre experiment, spin analyses
- High rate detector capable of 100 kHz sampling of photons
  - Mounted on the A2 telescope at Mt Stromlo
- Collaboration between SERC, EOS, Graz, NICT, Borowiec, University of Texas at Austin
- Andor Zyla 5.5 Front Illuminated sCMOS camera has been mounted to A2.



Left: TOPEX/Poseidon: satellite body and force vectors. Right: body surface response to the incoming photon flux indicates a larger area where the positive torque can be generated: red) spin-up, blue) de-spin.



Reflectivity map of TOPEX/Poseidon measured by Graz photon counting system on July 10, 2015

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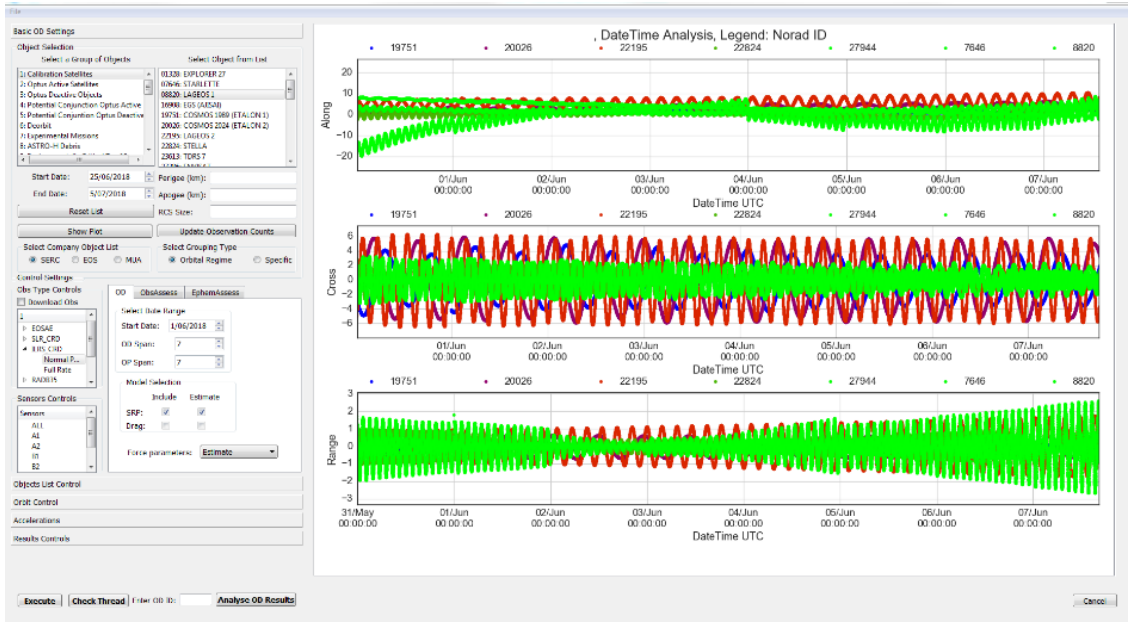
Orbit determinations

- In-house orbit determination software in C++;
- Automated ephemeris generation and sensor cueing
- Batch process, will also include filters and run side-by-side comparisons
- Störmer-Cowell predictor-corrector numerical integrator
- New observation sources can be integrated quickly
- Spherical/aspherical satellite geometry



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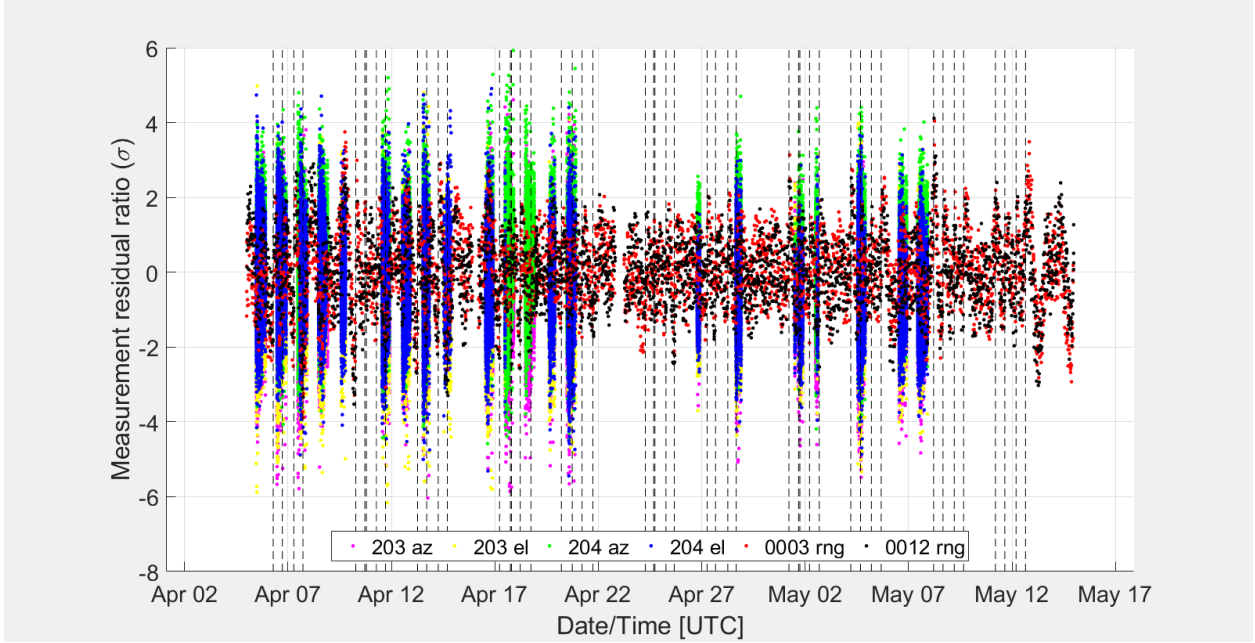
Manoeuvre fitting

- Can successfully fit multiple manoeuvre types
- Example:
  - GEO object: Optus 10
  - 40 day OD, 49 SPT (N-S), 5 bi-prop (E-W)
  - Two station RF range, optical from B3 & B4.
- Needs to be automated
  - Automate delivery of manoeuvre plans
  - Automate manoeuvre detection algorithms
    - Collaboration with UT Austin & UNSW



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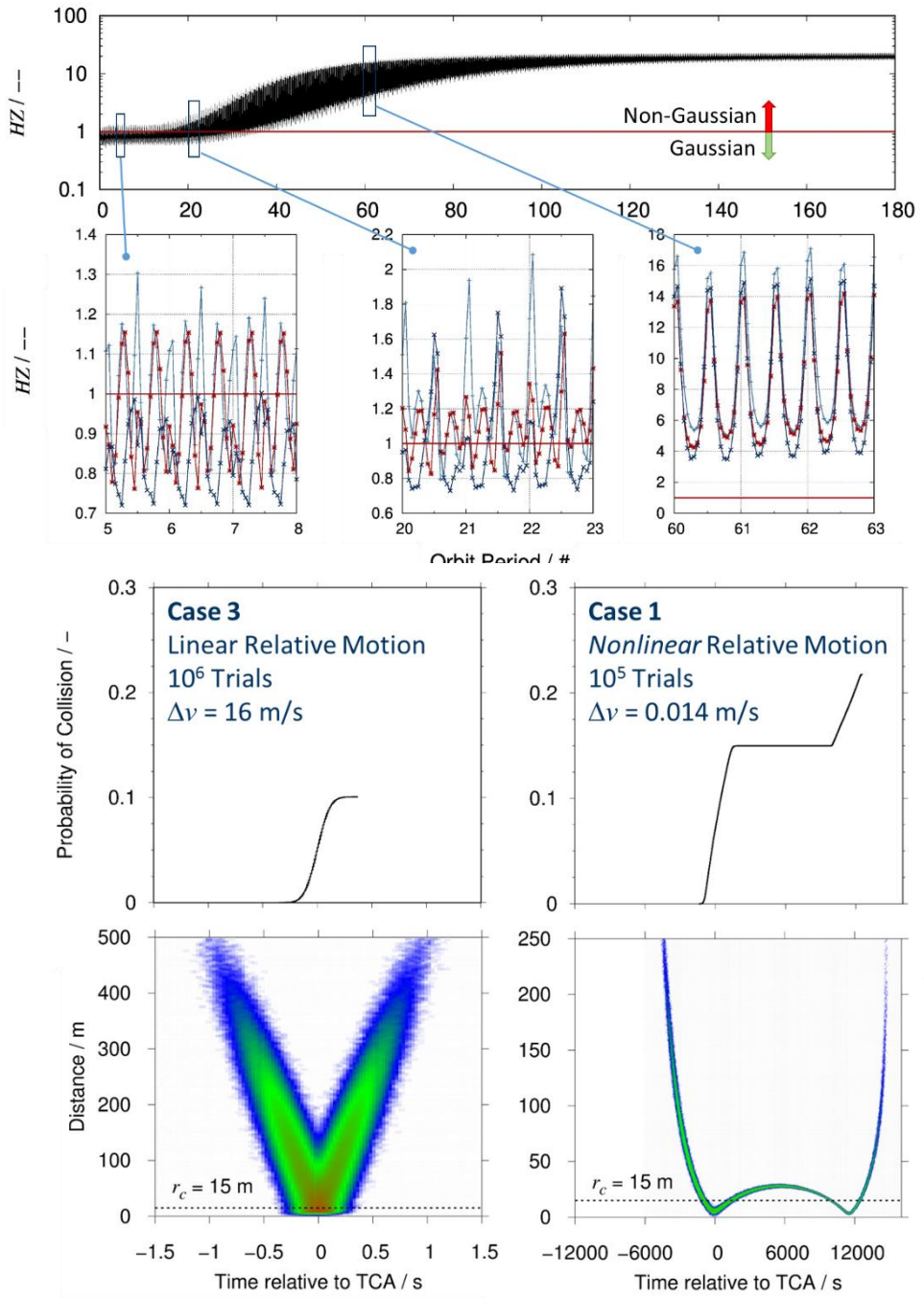
State uncertainty prediction

- Rigorous assessment of the breakdown in Gaussianity of the state uncertainty
  - Henze-Zirkler test for multivariate normality
  - Store in object catalogue, use for scheduling, conjunction assessments, track associations, OD assessments
- Probability of collision in conjunction assessments
- Actionable conjunction assessments



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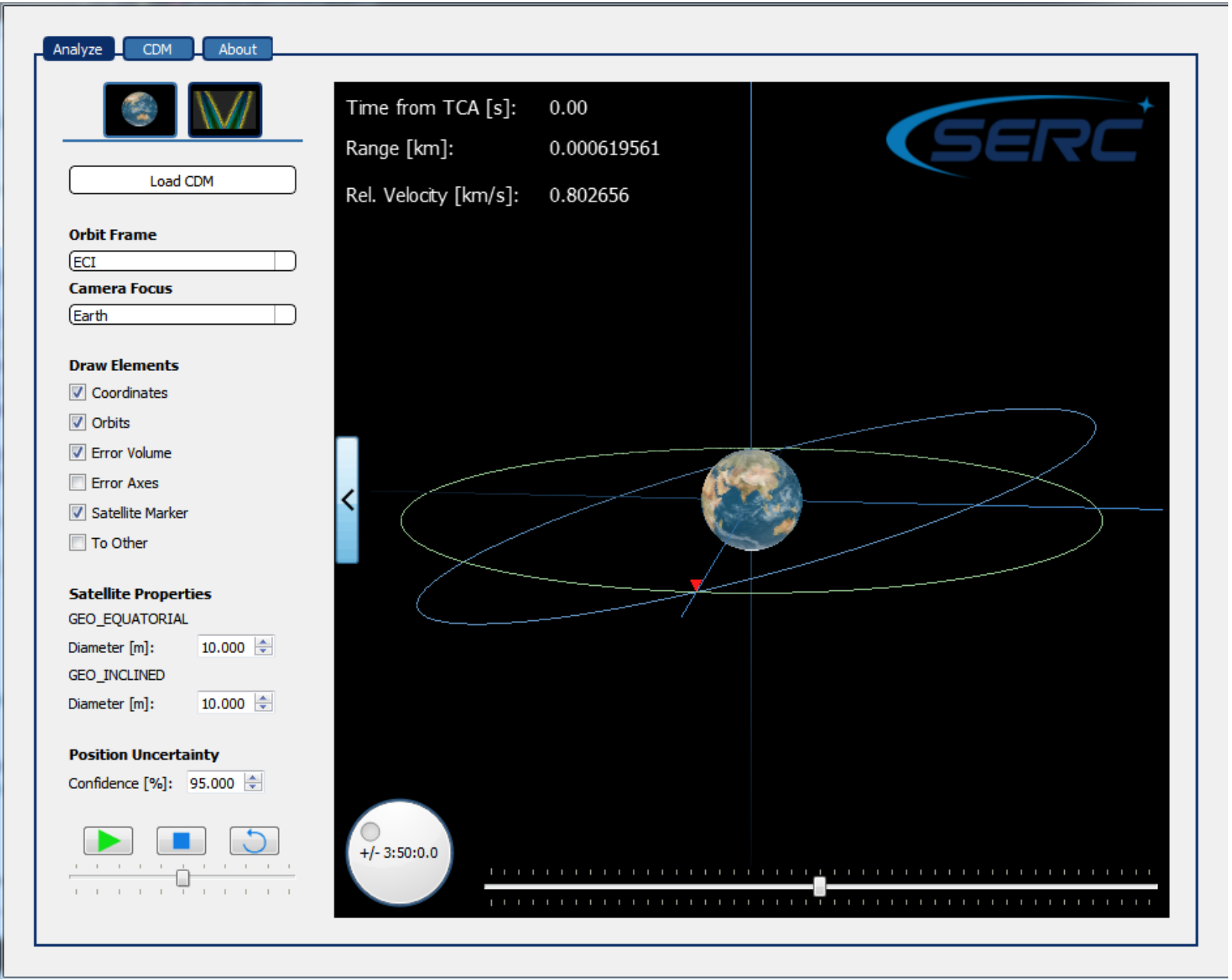
CDM visualisation



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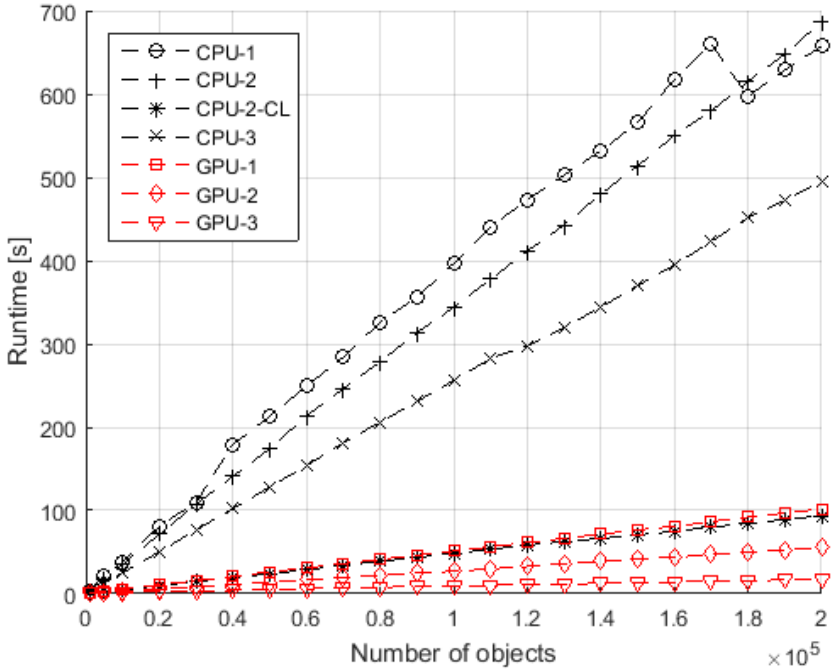
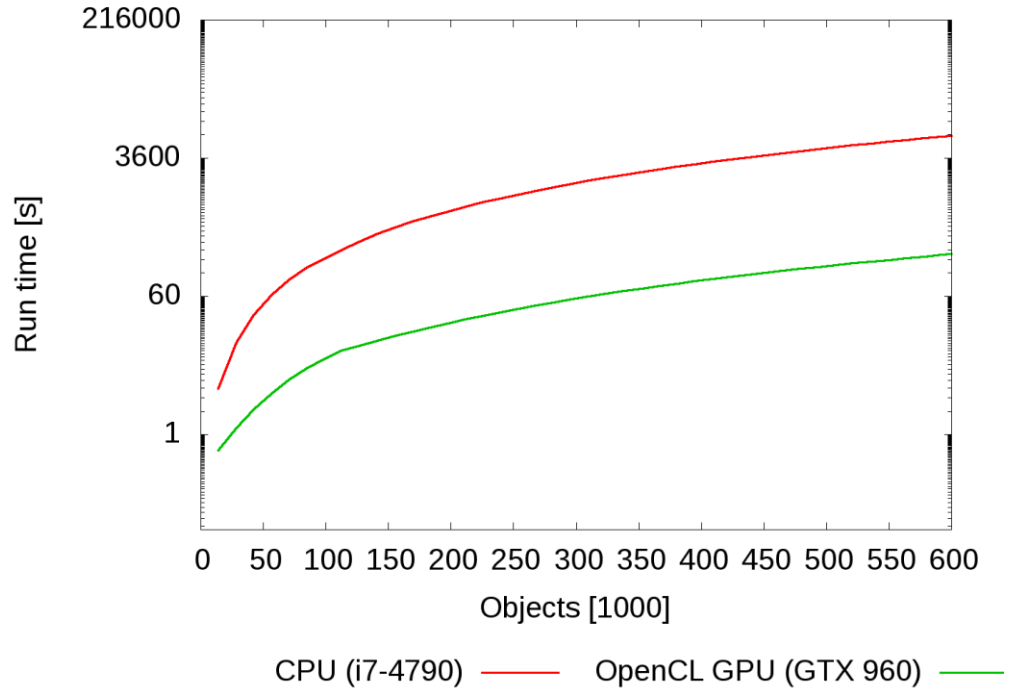
Conjunction assessments

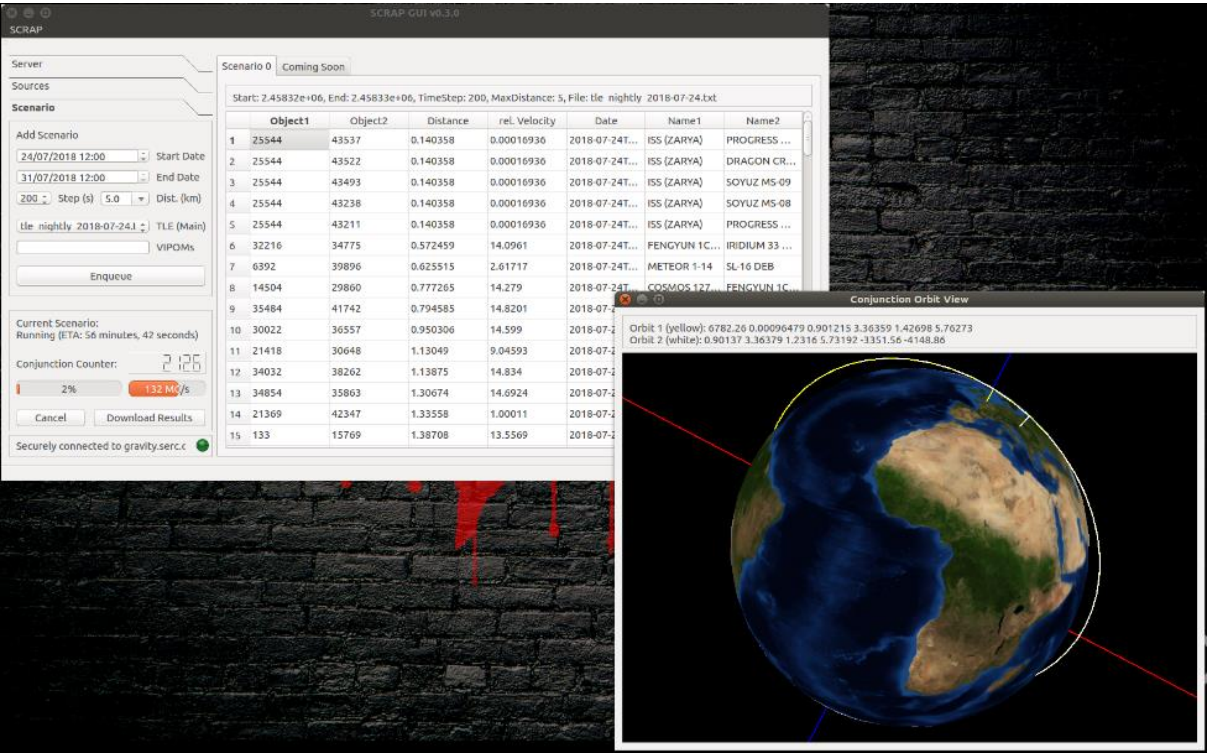
- Parallelised conjunction assessments can run on multi-core CPU and GPU
  - Large speed-ups achieved with SGP4;
  - All-on-all 7-day conjunction assessment in 48 minutes, down from 8 hours
  - Generic propagator interface
- Implemented full force model numerical integration
  - Currently being parallelised
  - Early indication is scales linearly with number of objects
- Ability to integrate other ephemeris information such as operator ephemerides (e.g. Optus)



CPU-1	Intel i7-4710HQ 3.5GHz (1 core)
CPU-2	Intel Xeon E5-1620 3.6GHz (1 core)
CPU-2-CL	Intel Xeon E5-1620 3.6GHz (OpenCL, 8 cores)
CPU-3	Intel i7-7700 3.6GHz (1 core)
GPU-1	Nvidia GeForce 860m (OpenCL)
GPU-2	Nvidia GeForce GTX960 (OpenCL)
GPU-3	Nvidia GeForce GTX1070 (OpenCL)



Simple interface



Conjunctions: 87451, Start Date: 2018-09-04T12:00:00, End Date: 2018-09-11T12:00:00 Compare

ID 1	ID 2	Distance	Relative Velocity	Time	Name 1	Name 2
31547	36658	0.0210061	10.5082	2018-09-09T06:02:38	FENGYUN 1C DEB	FENGYUN 1C DEB
25490	38329	0.0287375	15.0094	2018-09-07T08:29:43	TAURUS R/B	DMSP 5D-2 F11 DEB
31901	40500	0.0332068	11.3349	2018-09-10T18:02:05	FENGYUN 1C DEB	DMSP 5D-2 F13 DEB
27126	37307	0.0424915	7.92719	2018-09-10T23:42:08	PSLV DEB	COSMOS 2251 DEB
19922	29965	0.0454632	14.711	2018-09-06T01:29:52	SL-8 R/B	FENGYUN 1C DEB
26930	33901	0.0476115	12.2392	2018-09-05T10:55:51	PICOSAT 9	COSMOS 2251 DEB
134	31012	0.0480762	14.6184	2018-09-06T03:13:43	THOR ABLESTAR DEB	FENGYUN 1C DEB
733	38510	0.0498728	14.4551	2018-09-11T01:03:51	THOR AGENA D R/B	FENGYUN 1C DEB
31336	34570	0.05016	13.7216	2018-09-05T13:08:54	FENGYUN 1C DEB	COSMOS 2251 DEB
31167	34270	0.0512025	14.7952	2018-09-05T01:13:41	FENGYUN 1C DEB	COSMOS 2251 DEB
18681	38840	0.056241	13.7476	2018-09-08T07:18:06	SL-8 DEB	NOAA 8 DEB
12373	42550	0.0579649	14.1192	2018-09-09T02:40:46	DELTA 1 DEB	THORAD AGENA D DEB
420	34011	0.0595775	4.76017	2018-09-08T06:57:05	THOR ABLESTAR DEB	COSMOS 2251 DEB
42247	42425	0.0604704	13.8144	2018-09-11T07:59:41	SL-16 DEB	NOAA 16 DEB
14223	31068	0.062459	14.9889	2018-09-09T00:59:07	SCOUT G-1 DEB	FENGYUN 1C DEB
43547	43549	0.0629221	0.000460819	2018-09-09T01:05:09	TEMPEST-D	HALOSAT
31491	37686	0.0653341	14.0745	2018-09-06T14:24:39	FENGYUN 1C DEB	FENGYUN 1C DEB
32200	34192	0.0679	12.638	2018-09-05T23:53:11	FENGYUN 1C DEB	ARIANE 42P+ DEB
35225	36309	0.071062	14.7817	2018-09-07T02:25:46	FENGYUN 1C DEB	METEOR 2-6 DEB
31119	37988	0.0711577	14.1161	2018-09-10T15:40:36	SAUDICOMSAT 7	COSMOS 2251 DEB
30053	35129	0.0753762	0.721383	2018-09-10T08:09:40	FENGYUN 1C DEB	FENGYUN 1C DEB
41771	42051	0.0757076	0.648598	2018-09-10T03:00:17	SKYSAT C4	FLOCK 3P 72
21797	37637	0.0758537	14.7205	2018-09-04T12:49:49	SL-8 R/B	DELTA 1 DEB
6080	20891	0.0783068	14.4483	2018-09-10T01:14:52	SL-3 R/B	CZ-4 DEB
31404	38310	0.0831987	2.70006	2018-09-09T01:42:24	METEOR 2-5 DEB	CZ-4B DEB
36305	41858	0.0833316	14.969	2018-09-05T11:44:05	METEOR 1-11 DEB	CZ-2D R/B
32101	36100	0.0840153	13.5813	2018-09-09T06:09:35	FENGYUN 1C DEB	DMSP 5D-3 F18 DEB
41399	42245	0.0853848	14.689	2018-09-07T22:44:56	NOAA 16 DEB	SL-16 DEB
33826	42416	0.0854106	11.7038	2018-09-05T21:47:37	COSMOS 2251 DEB	NOAA 16 DEB
21796	30564	0.0865438	14.6248	2018-09-10T00:20:11	COSMOS 2173	FENGYUN 1C DEB
10658	11134	0.0883476	14.2104	2018-09-07T20:53:03	DELTA 1 DEB	COSMOS 1057
30660	40995	0.0885832	14.969	2018-09-06T15:03:25	FENGYUN 1C DEB	IRIDIUM 33 DEB
29911	34472	0.0894965	14.8852	2018-09-10T03:29:41	FENGYUN 1C DEB	COSMOS 2251 DEB
29899	30856	0.0904635	14.4428	2018-09-07T22:13:31	FENGYUN 1C DEB	FENGYUN 1C DEB
17716	25114	0.0915027	13.5355	2018-09-11T08:14:36	THORAD AGENA D DEB	ORBCOMM FM 11
26069	41353	0.092915	14.7861	2018-09-06T00:35:40	COSMOS 2369	NOAA 16 DEB
12343	30684	0.0943078	13.867	2018-09-11T05:16:12	COSMOS 1174 DEB	FENGYUN 1C DEB
13468	18161	0.0964023	12.1694	2018-09-07T03:10:33	COSMOS 1275 DEB	SL-8 R/B

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Index of /archive/

Duplicate entries excluded	1.3%
Low velocity entries excluded	1.4%
Of the remaining entries:	
Good matches	99.38%
Deviating in minimum range	0.41%
Deviating in relative velocity	0.0%
SCRAP misses	0.21%

Automated comparisons with:

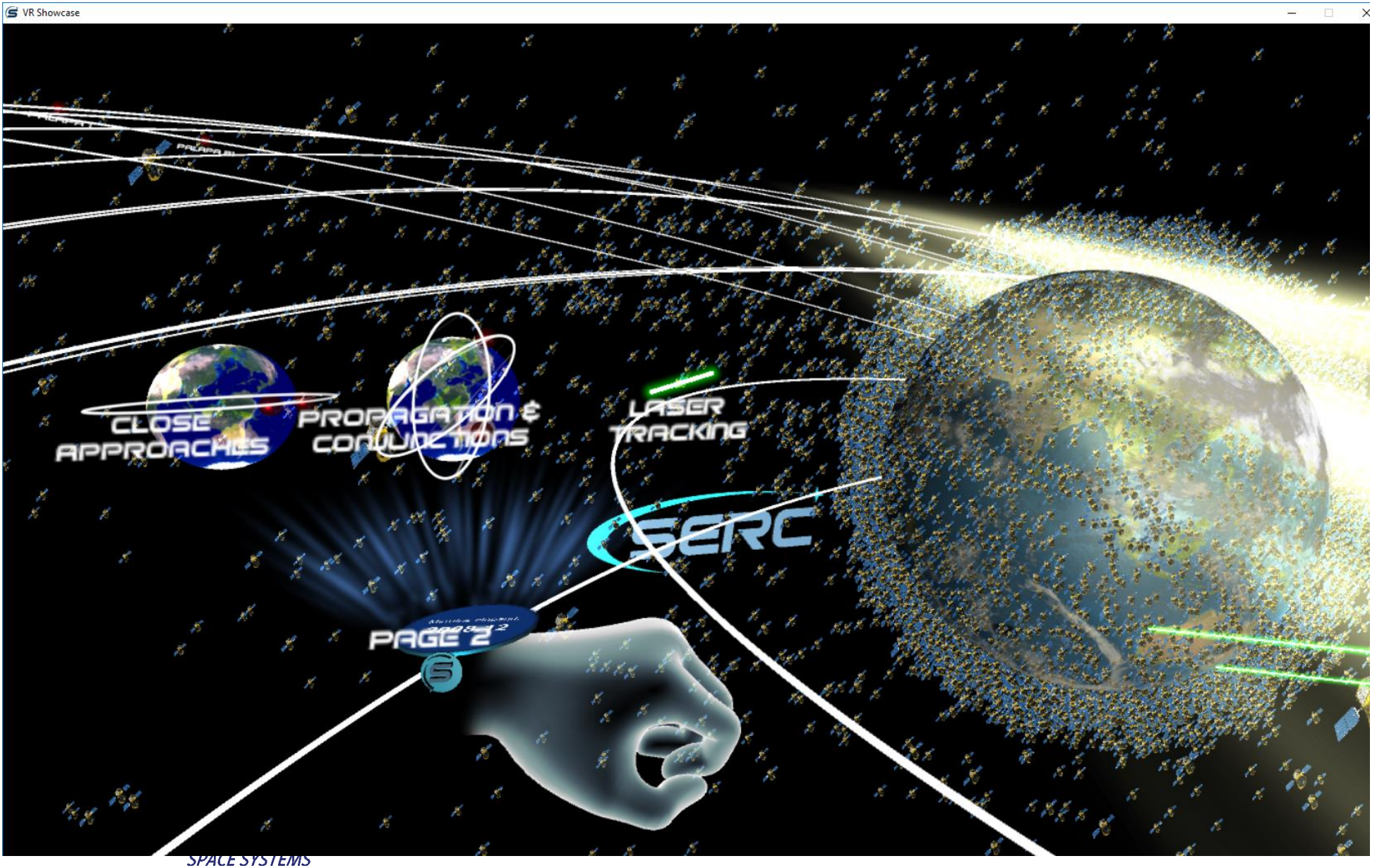
SOCRATES

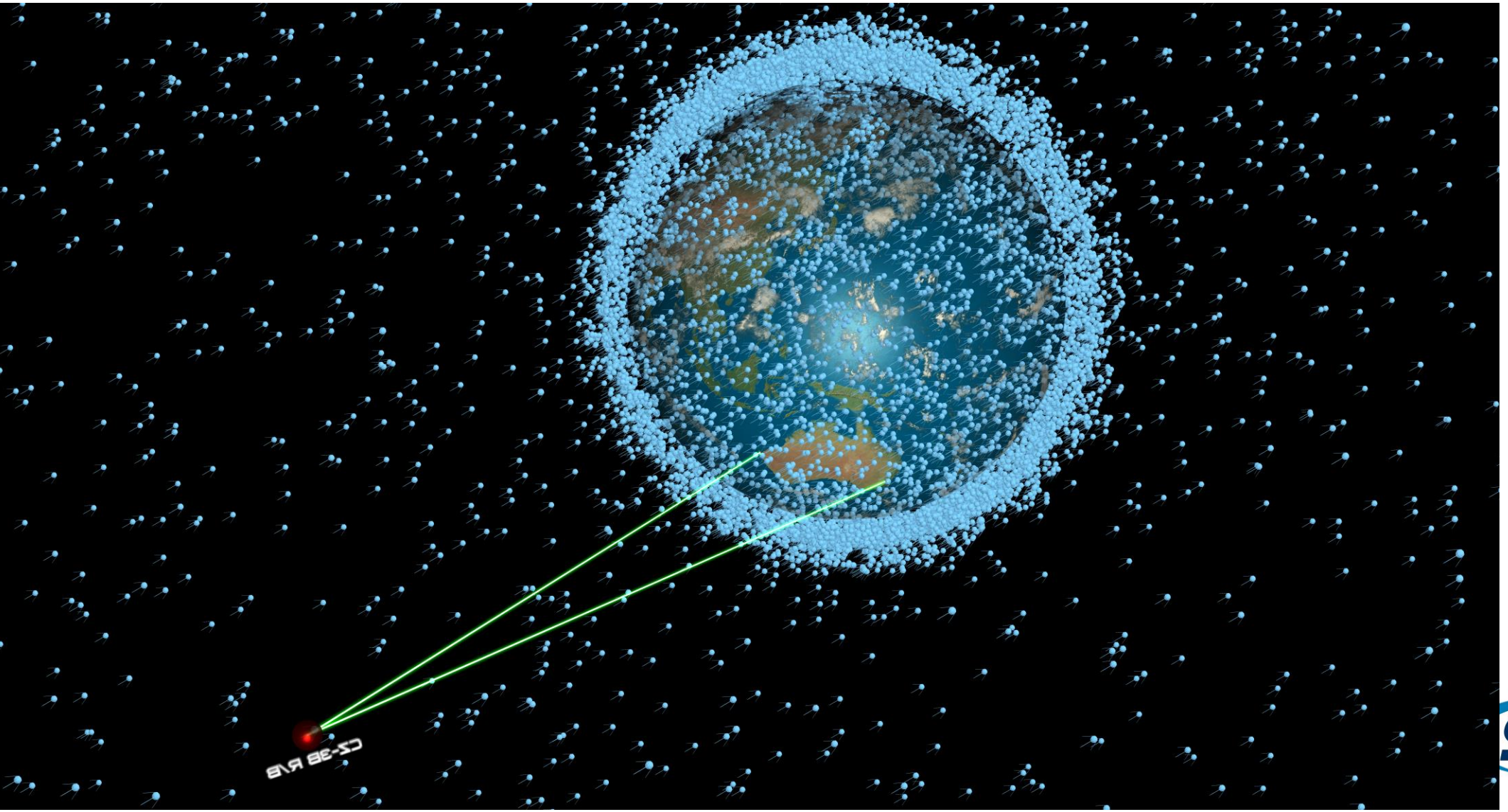
Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space

CSSI Center For Space Standards & Innovation

R_Soc	ID1	ID2	Name1	Name2	Rv_Soc	Rv_Scr	D_Soc	D_Scr	TCA_Soc	TCA_Scr	R_Scr
1	39678	13499	SL-8 DEB *	EGYPTSAT 2	12.910	12.91	0.028	0.028	2018 Aug 30 21:43:52.841	2018-08-30 21:43:52	2
2	43556	43557	AEROCUBE 12A	AEROCUBE 12B	0.000	0.0	0.029	0.032	2018 Aug 31 03:33:30.673	2018-08-31 03:35:20	3
3	08799	30065	METEOR 1-24	FENGYUN 1C DEB	13.101	13.101	0.042	0.042	2018 Aug 31 19:38:58.646	2018-08-31 19:38:58	7
4	41183	36680	FENGYUN 1C DEB	ORBCOMM FM 118	14.352	14.352	0.044	0.044	2018 Aug 26 19:38:56.580	2018-08-26 19:38:56	8
5	27842	32129	DTUSAT	FENGYUN 1C DEB	5.263	5.263	0.050	0.05	2018 Aug 30 16:09:35.406	2018-08-30 16:09:35	9
6	40020	31455	FENGYUN 1C DEB	BRITE TORONTO	14.580	14.58	0.066	0.066	2018 Aug 31 21:51:23.936	2018-08-31 21:51:23	15
7	07734	40443	GEOS 3	DMSP 5D-2 F13 DEB	12.897	12.897	0.067	0.067	2018 Aug 27 16:30:54.852	2018-08-27 16:30:54	16
8	39026	42767	KMS 3-2	CARTOSAT 2E	6.274	6.274	0.081	0.081	2018 Aug 30 01:32:09.644	2018-08-30 01:32:09	18
9	04419	31368	METEOR 1-5	FENGYUN 1C DEB	14.797	14.797	0.082	0.082	2018 Sep 01 02:18:30.611	2018-09-01 02:18:30	21
10	39186	31280	FENGYUN 1C DEB	RESURS P1	14.982	14.982	0.082	0.082	2018 Sep 01 11:39:16.052	2018-09-01 11:39:16	20
11	22565	41212	COSMOS 2237	NOAA 16 DEB	13.109	13.109	0.095	0.095	2018 Aug 30 15:12:30.313	2018-08-30 15:12:30	31
12	42002	42024	FLOCK 3P 67	FLOCK 3P 71	0.003	0.003	0.098	0.117	2018 Sep 01 03:46:17.920	2018-09-01 03:45:52	48
13	43192	36461	COSMOS 2251 DEB	FENGMANIU-1	15.002	15.002	0.099	0.099	2018 Sep 02 06:02:22.150	2018-09-02 06:02:22	34
14	21976	08139	THORAD DELTA 1 DEB	COSMOS 2187	12.204	12.204	0.113	0.114	2018 Aug 27 05:21:47.648	2018-08-27 05:21:47	46
15	01814	34422	FR 1	COSMOS 2251 DEB	11.089	11.089	0.138	0.138	2018 Aug 29 10:08:26.548	2018-08-29 10:08:26	58
16	25777	36557	IRIDIUM 14	COSMOS 2251 DEB	6.445	6.445	0.144	0.144	2018 Aug 31 07:20:14.734	2018-08-31 07:20:14	67
17	36798	35383	CZ-4 DEB	ALSAT 2A	14.621	14.621	0.144	0.144	2018 Sep 01 07:00:30.231	2018-09-01 07:00:30	66
18	03229	27255	COSMOS 220	PSLV DEB	14.858	14.858	0.145	0.145	2018 Aug 27 09:58:10.574	2018-08-27 09:58:10	69
19	25338	37932	NOAA 15	CZ-2D R/B	9.036	9.036	0.147	0.147	2018 Sep 01 12:32:52.558	2018-09-01 12:32:52	73
20	38038	30553	FENGYUN 1C DEB	ZY 1	14.747	14.747	0.150	0.15	2018 Sep 02 00:38:36.097	2018-09-02 00:38:36	76
21	42047	36159	FENGYUN 1C DEB	FLOCK 3P 78	15.112	15.112	0.155	0.155	2018 Sep 01 23:10:37.532	2018-09-01 23:10:37	82
22	39087	31385	FENGYUN 1C DEB	AAUSAT3	7.551	7.551	0.158	0.158	2018 Aug 27 15:53:11.958	2018-08-27 15:53:11	86
23	29479	37568	HINODE (SOLAR B)	CZ-4C DEB	14.794	14.794	0.160	0.16	2018 Sep 01 00:13:09.573	2018-09-01 00:13:09	90
24	00729	22574	SECOR 1B	SL-16 DEB	7.402	7.402	0.161	0.161	2018 Aug 26 14:32:48.970	2018-08-26 14:32:48	91
25	30774	27741	SL-3 DEB	OE (NEXTSAT)	14.080	14.08	0.165	0.165	2018 Aug 27 07:38:27.752	2018-08-27 07:38:27	93
26	43119	43122	FLOCK 3PP 3	FLOCK 3PP 4	0.001	0.0	0.166	0.553	2018 Aug 28 22:56:55.310	2018-08-28 23:58:01	1141
27	09509	19136	COSMOS 864	SL-14 DEB	13.028	13.028	0.168	0.168	2018 Aug 27 15:40:57.729	2018-08-27 15:40:57	95
28	37790	34725	COSMOS 2251 DEB	NIGERIASAT X	14.907	14.907	0.170	0.17	2018 Aug 30 11:37:50.849	2018-08-30 11:37:50	99
29	35635	04651	THORAD AGENA D DEB	COSMOS 2454	14.668	14.668	0.177	0.177	2018 Aug 29 05:43:59.898	2018-08-29 05:43:59	112
30	23087	38129	COSMOS 2278	FENGYUN 1C DEB	14.471	14.471	0.181	0.181	2018 Aug 27 15:59:38.779	2018-08-27 15:59:38	116
31	40019	29539	CZ-4B DEB	APRIZESAT 10	10.812	10.812	0.182	0.182	2018 Sep 01 08:17:34.286	2018-09-01 08:17:34	117
32	12456	30771	METEOR 2-7	FENGYUN 1C DEB	14.855	14.855	0.184	0.184	2018 Aug 30 03:03:24.016	2018-08-30 03:03:24	120

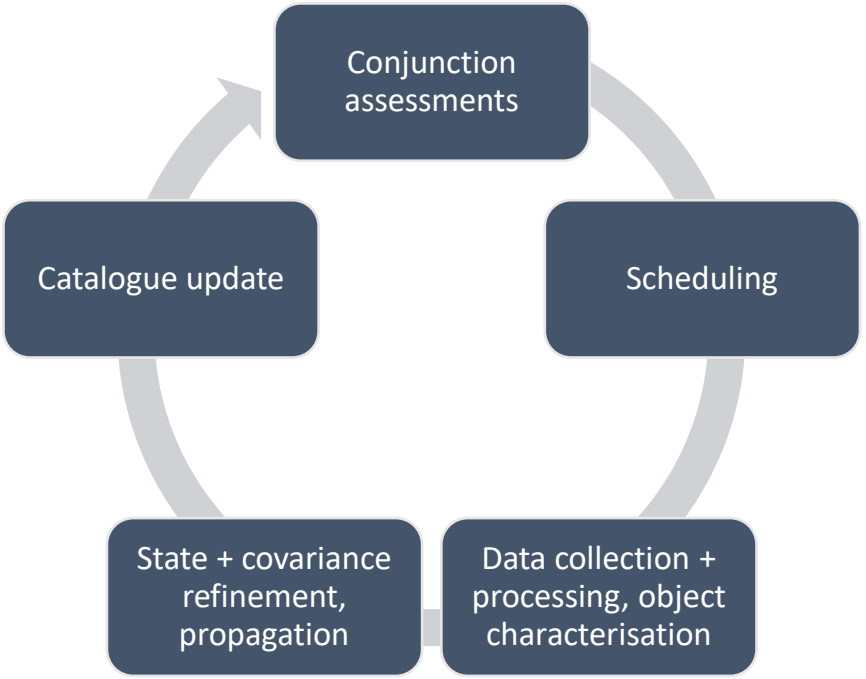
VR visualisation





Status

- Initial operational capability – December 2018
  - Test runs with Optus
  - Conjunction data messages produced, assessed
- Full operational capability – Feb-Apr 2019



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Questions?

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Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Program

Other RP3 research – PhD candidates

- Conservation of First Post-Newtonian Energy Integral (University of South Australia)

- Collision probability estimation for short encounter times using a three dimensional Generalized Gaussian Distribution (University of South Australia) - Hansani Thanippuli Kankanamalage

- Multivariate optimisation assessment strategies and their application to conjunction assessments (Australian National University) – Richard Samuel

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