#### OKAPI ORBITS

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Making NewSpace Safer Space Traffic Management

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#### Agenda

- Summary of recent DRAMA activities
  - ARES updates
  - OSCAR updates
  - MIDAS updates
  - SARA updates
- DRAMA Architecture Summary
- Introduction of Coefficient Estimator
- Introduction of PROOF
- DRAMA Workflow Updates
- Further DRAMA-4.1 updates



# Summary of recent DRAMA activities Existing Tools

ARES:

- Support of attitude dependent cross-sectional areas i.e. no longer assuming spherical HBR.
- Electric Collision Avoidance Manoeuvre support for different transfer types. OSCAR:
- 6-DOF propagation support.
- Variable protected region intersection support.
- New disposal option types including resonance based, elliptical and circular de-orbiting. MIDAS:
- Surface definitions now support propagated attitude. SARA:
- New glass material.
- Added support for the simulation of spherical and cylindrical tanks.



With contributions by:



iTTi









# Summary of recent DRAMA activities New Tools

Coefficient Estimator:

- New software from the ground up.
- Generate mesh of 3D model and resulting databases.
- Databases required for 6DOF propagation in OSCAR.
- PROOF Program for Radar and Optical Observation Forecasting:
- Existing tool introduced in the year 2000.
- Extensively modified for new application of trackability analysis.
- Calculate the crossings of objects over sensors (in-orbit and on-ground).
- Simulate laser, optical and radar sensors detection probability.





With contributions by:









#### DRAMA 4 Architecture Summary

• Allows for user inputs.

Mission centric instead of tool centric.Sends request to backend server via REST API.

Electron based

Receives requests for analysis.Does the scheduling for all the workflows and tool processes.

r •Python

Where the run mode is executed.
Ensures all prerequisite tools and processes are executed e.g. determination of drag area.
Python

Tool specific python wrapper.Manages the inputs and outputs required by the tool.Executes process.

Python

Performs processing/analysis required.
For example, ARES, OSCAR, PROOF etc.

• Tool specific language e.g. Fortran, C++, Java, Python etc.



Screenshot of DRAMA 4.1 GUI

# Coefficient Estimator Meshing

- Pre-computes in the database:
  - Optical cross-section,
  - Illumination,
  - Radar,
  - Retroreflector visibility.
- Provides attitude detection properties for complex geometries.
- Surface visibility and reflection properties considered.
- Observed intensity is equal to the solar intensity time illumination coefficient, divided by the inverse square law.



Visualisation of Coefficient Estimator functionality

# Coefficient Estimator Detection Properties

- The radar equivalent area is stored in the database
- The diameter of this radar equivalent area is then used as input for the NASA SEM

- The optical cross-section database contains the projected area.
- Can replace CROC for cross-section calculation → no longer requiring OpenGL.
- The retroreflector database contains which reflectors are visible from each of the view angles.



Visualisation of Coefficient Estimator functionality

# PROOF Origins and Updates

- Legacy use case was to provide statistical pass characteristic of space debris populations → validate MASTER population.
- For the new functionality it was split into two new executables:
  - Crossing which from object state vectors can determine sensor passes.
  - Detection which uses sensor performance modelling to determine whether the object can be detected.



# PROOF Origins and Updates

- New functionality and changes also include:
  - Support for sensor networks instead of single sensors including both ground and space-based sensors
  - Laser ranging simulation.
  - Accept object state vectors instead of internal SGP4 propagation.
  - Automatic tracking instead of passive observations.
  - Light pollution simulation.
  - Extensive refactoring of certain packages.



# DRAMA Workflow Update New Run Modes

- Objective was to support mission designers in detectability and trackability guidelines verification.
- 4 new run modes:
  - Object trackability
  - Light pollution analysis
  - Population trackability analysis
  - Generate ARES uncertainty tables
- All run modes use the new extendedProofWorkflow, starting with the following.
- Start of the workflow:



workshop_demo     INPUT OUTPUT   Control inputs   Compliance verification   Oscar only   Ares only   Ares only   Midas only   Croc only   Sara only   Master only   CState only   Object trackability analysis   Population trackability analysis   Generate ares catalogue uncertainty table   Light pollution analysis   Coefficient Estimator only	+ NEV	(† 1 OPEN	R SAVE	R SAVE AS Y	PDF PDF	IM	Ð Port
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Coefficient Estimator only	L	ght pollutio	n analysis	5			
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#### Screenshot of DRAMA 4.1 Run Mode selection

# DRAMA Workflow Update Propagation

- NEPTUNE NPI Ephemeris Propagation Tool with Uncertainty Extrapolation, was also integrated into the DRAMA framework.
- Same integration as with all other DRAMA tools: executable  $\rightarrow$  python wrapper  $\rightarrow$  workflow.
- Object is propagated for a user-defined duration equivalent to the orbit determination fit span.



# DRAMA Workflow Update PROOF Crossing

- PROOF crossing used to determine sensor network crossings.
- Crossings are interpolated to generate 24time steps.
- Important vectors are provided for later processing:
  - Object state vector
  - Object→sensor vector
  - Object→transmitter vector (bi-static sensors)
  - Object  $\rightarrow$  sun vector (telescopes)



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07) Epochs									
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09) X			[km]						
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18) X-component	z-component								
19) X component									
20) 7-component									
Object-Transmitter	(hi_static)		[km]						
Object-Sun	(telescope)		[40]						
not used	(mono-static)		[-]						
EPOCH		OBJECT STATE						ADDITIONAL VECT	101
07)	08)	09)	10)	11)	12)	13)	14)	15)	1
2018-05-01 12:17:48.462	58239.512366458	-2078.179367	802.093809	6212.018390	7.353237	0.859854	2.350148	1268.523130	
2018-05-01 12:18:02.765	58239.512531999	-1972.719617	814.278318	6244.751174	7.393204	0.843906	2.226871	1161.988164	
2018-05-01 12:18:17.067	58239.512697540	-1866.703137	826.233007	6275.716141	7.431080	0.827721	2.102974	1054.897350	
2018-05-01 12:18:31.370	58239.512863081	-1760.159918	837.954543	6304.904816	7.466858	0.811303	1.978490	947.280681	
2018-05-01 12:18:45.673	58239.513028623	-1653.120065	849.439635	6332.309077	7.500526	0.794658	1.853456	839.168261	
2018-05-01 12:18:59.976	58239.513194164	-1545.613813	860.685063	6357.921303	7.532075	0.777790	1.727906	730.590328	
2018-05-01 12:19:14.278	58239.513359705	-1437.671526	871.687671	6381.734372	7.561497	0.760704	1.601875	621.577246	
2018-05-01 12:19:28.581	58239.513525246	-1329.323682	882.444370	6403.741665	7.588784	0.743405	1.475400	512.159495	
2018-05-01 12:19:42.884	58239.513690787	-1220.600872	892.952144	6423.937068	7.613929	0.725896	1.348515	402.367667	
2018-05-01 12:19:57.187	58239.513856328	-1111.533783	903.208041	6442.314974	7.636925	0.708185	1.221257	292.232451	
2018-05-01 12:20:11.489	58239.514021869	-1002.153183	913.209164	6458.870138	7.657766	0.690274	1.093660	181.784614	
2018-05-01 12:20:25.792	58239.514187410	-892.489950	922.952723	6473.598094	7.676446	0.672170	0.965761	71.055037	
2018-05-01 12:20:40.095	58239.514352951	-782.575030	932.435990	6486.494816	7.692959	0.653877	0.837596	-39.925334	
2018-05-01 12:20:54.398	58239.514518492	-672.439432	941.656305	6497.556754	7.707303	0.635401	0.709200	-151.125488	
2018-05-01 12:21:08.700	58239.514684033	-562.114225	950.611080	6506.780870	7.719473	0.616746	0.580609	-262.514355	
2018-05-01 12:21:23.003	58239.514849574	-451.630526	959.297805	6514.164637	7.729465	0.597918	0.451860	-374.060818	
2018-05-01 12:21:37.306	58239.515015115	-341.019494	967.714039	6519,706041	7.737278	0.578923	0.322988	-485,733715	

Screenshot of Proof Crossing output

# DRAMA Workflow Update Coefficient Estimator

- If a population is being analysed, the coefficient estimator will not be called and predefined detection properties will be used.
- Coefficient Estimator will:
  - Generate databases, if they haven't been already.
  - Determine retroreflector visibility (Boolean).
  - Determine illumination coefficient.
  - Determine radar and optical cross-section .
- All these values are tabulated and not assumed constant.



User Generate Object loop Propagate Crossing Population OCoefficient Estimator

# DRAMA Workflow Update PROOF Detection

- Use of the PROOF detection software to determine whether crossing would result in a detection.
- Ability for the user to select their own network of sensors.
- Possibility to select preconfigured networks such as US-SSN.
- Detection process then returns tracklets that were detected.



#### Screenshot of DRAMA 4.1 User defined network settings



### DRAMA Workflow Update Covariance Determination

- Differential correction method based on linear least squared is used to determine the resulting "initial OD" covariance.
- Bias and noise of the observing sensors is used.
- Resulting covariance is propagated to user-specified duration.

INPUT OUTPUT	DEFAULT	
SATELLITES	at     Satellite:     3U_Cubesat       Satellite:     3U_Cubesat       Mission Phase:     Operational       Epoch:     2016-11-01T12:00.00Z       Analysis Mode:     assessment_workflow       Run Mode:     Object trackability analysis       Number of detections: 5     Statellite:	Object trackability analysis
EPOCHS 2016-11-01 12:00:00 Analysis modules	Show crossing results Detection results: Show detection results	
assessment_workflow	Show trackability results	
Compliance Report No results	Trackability results           trackability covariance matrix in RTN: [7.790600029435412e-05, 4.9163475453381306e-05, -9.439123119621298e-05]           trackability covariance matrix in RTN: [7.790600029435412e-05, 4.9163475453381306e-05, -0.00013308899819062904]           [4.916347545337163e-05, -0.00013308899819062373, 0.0002974373206605715]           radial standard deviation:         26.618776949115244 m           tangential standard deviation:         1698.8454002299433 m           normal standard deviation:         8.450829000246115 m	

Screenshot of DRAMA 4.1 results of object trackability run mode



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### Further DRAMA 4.1 updates OSCAR

- New functionality was integrated into the GUI:
  - Protected regions are synced with ESA server.
  - New disposal opens.
  - Renaming of drag tether.
- 6DOF propagation was integrated into MIDAS and ARES workflows.
- Coefficient estimator integration for drag area calculation and 6DOF integration.

Edit Mission Phas	e						
BASIC SETTINGS	ORBIT DEFINITION	SPACECRAFT ATTITUDE	SPACECRAFT SETTINGS	SSA NETWORK			
7				•			
8				1			
9							
10							
Prediction to event time*	:	1	$\diamond$				
Disposal optior	าร		dram				
Disposal option*:		Direct D	)e-Orbit				
Direct de orbit perigee alt	itude*:	Circular	Circular Delayed De-Orbit				
		Elliptic	Elliptic Delayed De-Orbit				
ragments attitude after	breakup:	Re-Orbi	Re-Orbit				
On around risk options		Resona	Resonance based analysis				
		None					
Re-entry type*:		Uncontro	olled	Ŧ			
clination angle*:							
Uncontrolled method*:			Circular -				

Screenshot of DRAMA 4.1 showing new disposal options

### Further DRAMA 4.1 updates ARES

- ARES can now account for different crosssections from different impact directions for different time-steps.
- The ARES specific workflow has been updated.
- Initialise 6DOF attitude propagation from OSCAR and the Coefficient Estimator to generate the ares.css file.

# ===== <esa drama="">== # # _/_/_/_/ _ # / / / / /</esa>	 גר, גר.	 געיר עניר	 , لے لے لے لے لے ا
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# # #	ESA Debris Risk As Assessmen	sessment and Mitigation t of Risk Events Statis	Analysis Tool tics
" # #		DRAMA - ARES	
#	ARES cros	s-section ephemerides f	ile
<pre># # ares.css specifies # different impact d #</pre>	s the cross-section ex directions for differe	posed by the target spa nt time steps.	cecraft towards the
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Screenshot of new ARES cross-section ephemerides (ares.css) file

# Further DRAMA 4.1 updates MIDAS

- Wrapper now calculates failure (penetration) probability of each/all surfaces.
- MIDAS supports epoch specific surface attitude information.
- MIDAS workflow initialises 6DOF attitude propagation and calculates the surface file(s).

# ==== <esa drama="">====</esa>	
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#//	
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# =====================================	
#	
<pre># MIDAS (MASTER-based</pre>	Impact Flux and Damage Assessment Software) Attitude Ephemeris File
# [v3.2.0, 03/2022]	
#	
#	
#	
# Attitude Ephemeris	
#	
" #	
#	
# # Encel of TSO2601 of	
# Epoch as 1506601 SC	ring (Chak~20)
#	
# A - Azimuth / Right	ascension
#	-180 deg < A < 180 deg : azimuth of surface normal for Earth-oriented
#	-180 deg < A < 180 deg : right asc. deviation from sun LOS for Sun-oriented
#	-180 deg < A < 180 deg : right asc. of surface normal for inertially fixed
<pre># h - Elevation / dec</pre>	lination
#	-90 deg < h < 90 deg : elevation of surface normal for Earth-oriented
#	-90 deg < h < 90 deg : declination deviation from sun LOS for Sun-oriented
#	-90 deg < h < 90 deg : declination of surface normal for inertially fixed
#	
#	
# Epoch / UTC	A/deg h/deg
#	
2016-11-01700.00.00	0000 0 0012 0 0116
2010-11-01100.00.00.00	
#	
#	eot

Screenshot of new ARES cross-section ephemerides (surface.att) file

# Further DRAMA 4.1 updates Compliance Updates

- Since DRAMA 4.0 development ESSB space debris mitigation standards have been updated.
- New compliance in accordance with ESSB-ST-U-007:
  - Re-entry compliance: which now accounts for the stricter fatality risks for constellations of >100 satellites.
  - Collision avoidance assess uses ARES to approximate a recommended ACPL that reduces collision risk by 90%.
  - Collision risk compliance: used to calculate collision risk with objects of different ranges (and in future, with manned spacecraft).
  - Orbit interference compliance: uses a 100-year OSCAR propagation and collision risk to assess LEO and GEO violations.

Standards definition ESSB-ST-U-007 Compliance Re-entry Compliance 5.5 Collision Avoidance Compliance  $\checkmark$ 5.3.3.3 Collision Risk Compliance Orbit Interference Compliance 5.4.2.3 a.b.c & 5.4.2.2.a Mission Related Object Compliance 5.2.1.a Maneuver Requirement Compliance 5.3.3.2 Trackability Compliance 5.3.3.5 Dark and Quiet Skies Compliance П 5.6 Avoiding break-ups in Earth orbit 6.2 Disposal to minimize interference with the GEO/LEO protected region 6328633

DRAMA 4.1 ESSB compliance selection

# Further DRAMA 4.1 updates Compliance Updates

- Orbit interference compliance: uses a 100-year OSCAR propagation and collision risk to assess LEO and GEO violations.
- Maneuver requirement compliance: determines whether a spacecraft mission requires maneuver capabilities.
- Trackability compliance: determines trackability of a mission in LEO and GEO and whether thresholds are met (100m and 1000m respectively).
- Dark and quiet skies compliance: performs a light pollution analysis and compares the results with IAU guidelines (brightness of magnitude 7.

Standards definition
ESSB-ST-U-007 Compliance
Re-entry Compliance
5.5
5.3.3.3
Collision Risk Compliance
Orbit Interference Compliance
Mission Related Object Compliance
Maneuver Requirement Compliance
Trackability Compliance
Dark and Quiet Skies Compliance
Avoiding break-ups in Earth orbit
Disposal to minimize interference with the GEO/LEO protected region 6.3.2 & 6.3.3

DRAMA 4.1 ESSB compliance selection



#### Commercial Mission Analysis Tool ESA - Market Study

- OKAPI: Orbits and ESA are conducting a market study for viability analysis of a commercial mission analysis tool.
- The <u>survey</u> is anonymous and takes about 5 minutes to complete.
- The goal is to understand the importance of sustainable mission design and the important key factors for the industry and academia.

