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Inter–Agency Space Debris Coordination Committee

34th Inter-Agency Space Debris Co-ordination Committee Meeting, Harwell, UK. WORKING GROUP 1 (Measurements) Minutes

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IADC 34 Minutes

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Revision History

Issue	Revision	Date	Reason for Revision
1	0	2016-04-01	Initial Version

List of Abbreviations

Abbreviation	Description
Member Agencies	
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CSA	Canadian Space Agency
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ESA	European Space Agency
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
NASA	National Aeronautics and Space Administration
ROSCOSMOS	Russian Federal Space Agency
SSAU	State Space Agency of Ukraine
UKSA	United Kingdom Space Agency
Other	
ADR	Active Debris Removal
AFRL	(US) Air Force Research Laboratory
AI	Action Item
AIUB	Astronomical Institute of the University of Berne
ANU	Australian National University
BPE	Beam Park Experiment
CAESAR	Conjunction Analysis and Evaluation, Assessment and Recommendations
CCD	Charge-coupled Device
CMOS	Complementary metal-oxide semiconductor
COSMOS	Centre Opérationnel de Surveillance Militaire des Objets Spatiaux
DGA	La Direction Générale de l'Armement
EOL	End of Life
EQUO	EQuatorial Italian Observatory
FoV	Field of View
GEO	Geostationary Earth Orbit
GRAVES	Grand Réseau Adapté à la Veille Spatiale
GTO	Geostationary Transfer Orbit
HAMR	High Area-to-Mass ratio
HEO	Highly Eccentric Orbit
HUSIR	Haystack Ultrawideband Satellite Imaging Radar
IAC	International Astronautics Congress
iOTA	in-Orbit Tumbling Attitude model
ISON	International Scientific Optical Network

IT	Internal Task
JGT	James Gregory Telescope
JSpOC	(US) Joint Space Operations Center
KIAM	Keldysh Institute for Applied Mathematics
KSGC	Kamisaibara Space Guard Centre
LED	Light Emitting Diode
LEO	Low Earth Orbit
MASTER	Meteoroid and Space Debris Terrestrial Environment Reference
MCAT	Meter-Class Autonomous Telescope
MEO	Medium Earth Orbit
MITO	Mid latitude ITalian Observatory
MLI	Multi-Layer Insulation
NICO	Networked Instrument Coordinator
OGS	Optical Ground Station
ONERA	Office National d'Etudes et de Recherches Aérospatiales
POPACS	Polar Orbiting Passive Atmospheric Calibration Sphere
PROOF	Program for Radar and Optical Observation Forecasting
RAS	Russian Academy of Sciences
RCS	Radar cross-section
RMS	Root mean square
SATAM	Système d'Acquisition et de Trajectographie des Avions et des Munitions
SDS	Space Debris Sensor
SEMO	Southern (h)EMisphere Italian Observatory
SG	Steering Group
SLR	Satellite Laser Ranger
SOCIT	Satellite Orbital Debris Characterization Impact Test
SPADE	Italian SPAce DEbris observatory
SSA	Space Situational Analysis
SST	(EU) Space Survey and Tracking programme
TLE	Two-line Element
TIRA	Tracking and Imaging Radar
UIST	UKIRT Imaging SpecTrometer
UCT	Un-correlated target
UKIRT	UK Infrared Telescope
URSA MAIOR	University of Rome La SApienza– Microsatellite for Attitude In ORbit test
WFCam	Wide Field Camera
WG	Working Group

1 Attendees

Delegation members attending the IADC 34 WG1 sessions:

ASI:	Germano Bianchi
	Tommaso Cardona
	Fabrizio Piergentili
CNES:	Cedric Grondin
	Béatrice Hainaut
	Florent Muller
	Pascal Richard
CNSA:	Cai Lijian
	Zhang Xiaomin
	Changyin Zhao
CSA:	—
DLR:	—
ESA	Klemens Letsch
	Thomas Schildknecht
ISRO:	—
JAXA	Hideaki Hinagawa
	Ikumi Kurono
	Toshifumi Yanagisawa
KARI	—
NASA	Joseph Hamilton
	Sue Lederer
	Tim Payne
Roscosmos:	Igor Molotov
SSAU:	—
UK Space Agency	Phil Herridge
	Rosalind Redfern
	Aleks Scholz

1.1 Contact details

Contact details for WG1 delegates are listed in the Annex B.

1.2 Chairs

For this meeting WG1 Chair was Phil Herridge (UK Space Agency) and Deputy Chair was Toshifumi Yanagisawa (JAXA).

2 Agenda

The agenda of this meeting can be found in Annex A.

3 Minutes

3.1 First day — Tuesday 29th March 2016

3.1.1 14:00 – 15:30 Session 1.3 General

Delegates briefly introduced themselves.
P. Herridge, the WG Chair, gave a report regarding the Steering Group (SG) meeting on 14th October 2015, held alongside the IAC in Jerusalem, Israel. The report on action item AI 31.1 "International 24 hour LEO Space Debris Measurement Campaign 2013" [1] had been accepted and the AI officially closed. Concern had been expressed over the delay in the report of AI 23.2.
The agenda, circulated in advance of the meeting, was accepted without alteration although minor changes were made during the course of the meeting. The final version of the agenda is reproduced in Annex A, Section 4.

3.1.1.1 Agency status reports

Status reports were presented by seven agencies: ASI, CNES, CNSA, ESA, JAXA, NASA and UK Space Agency. Roscosmos did not present a status report; the usual lead delegate had left the agency at short notice and the delegate present had been given insufficient time to prepare a report. Five agencies were not represented at the meeting: CSA, DLR, ISRO, KARI and SSAU.
<u>ASI:</u>
ASI reported on observations from a number of sensors, including the 1.5 m telescope at Loiano and telescopes located at Malindi in Kenya. The SPADE observatory, now located in Matera, had been refurbished. A new telescope was being developed at the Observatory of the University of Rome.
ASI also reported on a cubesat, URSA MAIOR, being developed by the University of Rome, which would able to be used to test attitude observations.
<u>CNES:</u>
CNES provided an update on the French COSMOS space surveillance operations centre. The CAESAR anti-collision system was being used to monitor French satellites in LEO and GEO, resulting in 21 LEO collision manoeuvres. Radar support had been provided for 13 close approaches; no telescope support had been required. COSMOS had followed eight French re-entry events. CNES was participating in the proposed EU SST system.

CNSA:
CNSA continued to undertake simultaneous multi-channel photometry using the quad-channel telescope. Amongst other targets the sensor had been used to obtain observations of Globalstar satellites and GSat-3.
CNSA had been carrying out orbit updates on Chinese rocket bodies in LEO and higher orbits. During 2015 nearly 25,000 tracklets of 91 different objects had been obtained.
ESA:
ESA continued to use the OGS telescope for GEO and GTO surveys, with specific observations to maintain the catalogue of HAMR objects. The OGS had carried out a survey of fragments from the recent Briz-M break up. The OGS had made observations of mission-related debris from the MSG4 class of satellites. The OGS had also been used to provide input for updating the MASTER catalogue.
ESA had participated in AI 33.3, the South-staring radar beam park campaign.
ESA had been studying laser tracking of non-cooperative targets to provide operational support and attitude determination.
On spacecraft construction, ESA was pursuing the cross-program CleanSpace initiative. In particular, the initiative was investigating the options for producing demisable fuel tanks.
JAXA:
JAXA had collaborated with the Japanese company for use of a remote observatory at Oakey, Queensland and with ANU for remote observations from Siding Springs.
Observations had been made of faint debris using a 0.35 m telescope at the Mt Nyukasa Observatory. A dedicated processing board had been developed to facilitate detection of faint debris.
JAXA had plans for a possible LEO optical fence, based in two locations in Japan, capable of tracking objects down to ~ 13th magnitude. Trials, including observing the Popacs satellites in LEO, had been carried out.
JAXA was planning a new 0.6 m telescope for higher orbit observations. First light was planned for winter 2016.
NASA:
NASA had used the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) as well as the Goldstone dish radar and the Cobra Dane antenna array for IADC 33.3 and other LEO debris observations.
MCAT on Ascension Island had its first remote data collection in January 2016. A small 0.4 m companion telescope had been installed alongside the 1.3 m MCAT sensor. MCAT would be used for low inclination LEO surveys as well as GEO surveys.
The 6.5 m Magellan telescope had been used in a rate-track survey to look specifically for Titan 3C transtage debris. The survey data would be compared to simulations from NASA's models. UKIRT had been used for a number of campaigns using both its wide-field camera and spectrographs.
The in situ Space Debris Sensor (SDS) was expected to be launched to the ISS in October 2017. Analysis of the results of the DebriSat test destruction of a realistic mock-up of a modern satellite was on-going.
UK Space Agency:
The Starbrook optical sensors had been used to provide checks on UK-registered objects.
The University of St Andrews had been using its James Gregory 1 m telescope for observing Molniya and MEO debris.
The Chilbolton radar had taken observations during the ATV-5 re-entry campaign. It had been involved in a number of radar-optical fusion trials.

The UK was participating in the EU SST programme. The Chilbolton radar was being upgraded to meet EU tracking requirements.

3.1.2 15:45 – 16:00 Session 1.4

It was noted that there were no obvious candidates for the next deputy chair. Three agencies were current, or immediately past, post holders; JAXA was the present deputy chair, UKSA the outgoing chair, ASI the previous chair. One ESA delegate was the chair in 2012 and the other did not expect to remain a delegate. NASA and CNES delegates had been instructed that their agencies wished to take the deputy chairs of other WGs. Changyin Zhao of CNSA said that he would prefer not to be put forward as Zizheng Gong of CNSA was the present deputy chair of WG3.
P. Herridge agreed to query with the SG how hard and fast the “preferences” were for sharing chair and deputy chair posts amongst the agencies and whether there were restrictions on the frequency by which an agency held the post of chair.

3.2 Day 2: Wednesday 30th March 2016

3.2.1 09:00 – 10:30 Session 2.1

3.2.1.1 Light curves for AI 31.2 (T. Yanagisawa, JAXA)

Lead author on AI 31.2, T. Yanagisawa had collected together the light curves obtained by the four participating agencies: CNSA, ESA, JAXA and NASA. He had applied the same criteria to each light curve. During the three year observing period from 12th January 2012 to 28th December 2015 a total of 1087 light curves had been obtained of 121 objects from the original target list prepared by Gene Stansbery of NASA of 137 large intact LEO rocket bodies that might be potential targets of active debris removal (ADR).
Only a small proportion of the objects (~ 6 %) showed clear, unambiguous periodic behaviour. A further ~ 9% had more ambiguous light curves which had clearly evident features but it was not possible to conclude from the existing observations whether the behaviour was periodic.
However the simple interpretation masked significantly more complicated behaviour that required further study. A large number of objects showed apparent changes in behaviour between smooth light curves with little in the way of features and apparently periodic behaviour. In many cases the change from smooth to periodic took place over very small timescales, in some cases a single or a few days.
He showed a number of examples that exhibited this clear change of behaviour between smooth and periodic light curves. Similarly, he showed a number of examples where the light curve changed from smooth behaviour to exhibiting clear features but which did not display any unambiguously definable repetition period. Other objects had light curves that contained some form of feature, for example, bumps or spikes, but these features were too ill-defined to be classified as having any kind of repetition. These were classed as containing non-periodic features.
Few of the objects that showed variations in their light curves, beyond those resulting from simple geometric considerations of range and phase angle, did so in every light curve obtained. In general, for a given object, the proportion of variable to smooth light curves was low. The frequency of periodic features compared to smooth light curves had a median event ratio of around 9.0, and an average of ~ 15.3. If these event ratios were repeated across the

population it would be expected that more than half of objects would sometimes show periodic behaviour that was being lost in the sparseness of the data.

This estimate was based on the assumption that the attitude motion did not change over time and that the occurrence of variability in light curves was a result of viewing angle changes only, not the spinning up and down of the target object. Although at this stage this assumption seemed the most likely, the result remained highly uncertain.

T. Yanagisawa's presentation generated considerable discussion as to the likely explanation of the results. The WG agreed that the set of 1000+ light curves represented an invaluable resource in trying to understand the behaviour of this class of object. However the meaning remained highly uncertain. It was agreed that it would be useful to investigate the post-mission disposal of the rocket bodies to discover whether their fuel had been vented at the end of mission. Since the changes in behaviour occurred in objects from both historic and relatively recent launches, dynamic behaviour changes could not be ruled out at this stage, and it was agreed that this was likely to have significant importance for ADR planning.

S. Lederer noted that she had seen the results of a study on targets that show spin-up and spin-down behaviour on quite a short timescale. She was uncertain regarding the precise details of the targets examined in the study but noted that this also meant that the possibility of changes in attitude motion on very short timescales could not be ruled out without further study.

It was agreed that a second LEO light curve AI would be needed in order to help to clarify the nature of the results. It seemed clear that a similar study trying to observe every possible rocket body was unlikely to rule in or out any modes of behaviour. It was agreed that it would be better to select a small number of interesting targets and attempt to study these in greater depth using a higher frequency of observations and, if possible, contemporaneous multi-frequency observations.

However care would need to be taken in the choice of "interesting" targets. It was not entirely clear what would constitute "interesting" targets. Did it make more sense, from the perspective of the original aim of the exercise, to intensively study objects that had exclusively smooth light curves to see if variability could be ruled out in some cases? It was agreed that this question should be put to WG2 at the joint session for its guidance on the choice of targets for a future AI. It was also agreed that delegations would look again at the possibility of taking observations at different frequencies.

3.2.1.2 Status of report on AI 31.2 - LEO light curves (T. Yanagisawa, JAXA)

T. Yanagisawa stated that most of the re-analysis of the data had been completed. He thought that it would be possible to complete the report in time for presentation to the SG during the Autumn 2016 meeting.

3.2.1.3 Status of report on AI 23.2 - HAMR (T. Schildknecht, ESA)

The SG had raised the question of the report for AI 23.2 during the WG report on the previous evening. The present lead author for this AI was no longer a member of the Roscosmos delegation or a member of WG1. The SG had proposed that the co-author, T. Schildknecht of ESA, should be promoted to lead author and that I. Molotov of Roscosmos would provide support, in particular on the Roscosmos contribution to the AI. This approach was agreed by the WG. T. Schildknecht had produced the core of a report that had been sent to the ex-lead author.

T. Schildknecht would revise the existing version of the report and, with the contribution from I. Molotov, would produce a report that would allow the AI to be closed. It was noted that many of the results of the study of the HAMR objects had been presented at various meetings so it would only be necessary to produce a summary of results. T. Schildknecht agreed to try to get the report ready in time for the SG meeting in the Autumn but thought that the hiatus of the transfer of responsibility might result in the report being delayed until IADC 35 in Spring 2017.

3.2.2 11:00 – 13:00 Session 2.2

3.2.2.1 MCAT and UKIRT (S. Lederer, NASA)

S. Lederer presented an update on the report that she had given at the previous meeting on the MCAT telescope and the UKIRT.
MCAT was a long-running NASA and US AFRL joint project to place a telescope on a low latitude site. The observatory had been built on Ascension Island in the mid Atlantic Ocean at 7° 58' South, 14° 24' West, ~ 350 m elevation.
The goal of the MCAT project was to provide survey and characterisation of the GEO and near-GEO region as well as to study the under-sampled population of low inclination LEO objects. It was expected that objects ~ 20 - 30 cm should be detectable at GEO. The special horseshoe mount was designed to be agile enough to track LEO objects.
A second 0.4 m telescope, named Mini-CAT, had been installed alongside MCAT to allow co-ordinated follow-on observing. Each sensor had a full set of broadband filters available allowing observation into the near-IR.
Since the last IADC the MCAT dome and telescope had been installed on site with engineering first light on 2nd June 2015. Remote data collection had commenced in January 2016. Mini-CAT had been installed during April/May 2015.
Amongst its early successes MCAT had been used to observe debris from the historic first LEO break up of the Transit 4A rocket body in 1961. It had also been used to search for objects from the break up of the Briz-M 2015-075B which was detected on 20th January 2016. Surveys for debris from this event had also been carried out using UKIRT.
NASA had been allocated approximately one third of the available telescope time for debris studies. The Wide Field Camera (WFCam) provided a spectral coverage between 0.8 and 2.4 μm. UKIRT also had two spectrographs, UIST (1 - 5 μm) and Michelle (8 - 25 μm).
The combined use of IR and visible data along with an estimate of the object's albedo provided insight into the size, mass and material type of the target object. IR spectra allowed the surface material to be characterised as well as allowing the thermal characteristics to be studied.

3.2.2.2 Observations with JGT at St Andrews (A. Scholz, UKSA)

A. Scholz presented an account of the debris observations being carried out at the University of St Andrews using the James Gregory Telescope (JGT), which is the largest operational optical telescope in the UK. The JGT is a 0.94 m diameter, f/3 Schmidt Cassegrain with a 1K x 1K CCD detector at a relayed prime focus. The relayed prime focus restricts the field of view to a usable 0.25° x 0.25°. The telescope is operated for between 50 and 80 nights per year, limited by weather and available observers.
Initial trials on GEO objects were carried out during 2012. In 2014/5 the telescope had been used to search for Molniya objects with the telescope pointed at ~ 60° - 63° declination close to the anti-solar point. Detection rates are similar to (or a little better than) detection rates given for AIUB and ISON surveys.

3.2.2.3 ASI SPAce DEbris Observatory (O. Lanciano, ASI)

O. Lanciano reported on the development of ASI's SPADE observatory located at the Space Geodesy Centre at Matera. SPADE was developed by the University of Rome before being transferred to ASI in 2012.
SPADE's main sensor is a 0.3 m f/2.8 Baker-Schmidt telescope equipped with a 4K x 4K pixel detector giving a 2.26° x 2.26° field of view. The mount allows the sensor to track at all rates from LEO to GEO.
SPADE will support Italian national activities including space surveillance for the Italian MoD and monitoring of EOL operations of Italian satellites.

3.2.2.4 Results from ESA's Attitude Determination Study (T. Schildknecht, ESA)

T. Schildknecht summarised a study to determine the attitude of objects. The study had two main aims: to determine the attitude of intact objects that might be chosen as targets for ADR and to develop mechanisms to investigate anomalies resulting in spacecraft contingencies. The study involved fusion of data from synthetic aperture radar, optical observations and laser ranging and the development of a 3D simulator.
The study classified objects into three classes: stable, slow tumblers and fast tumblers. As anticipated the stable objects show no variation in their light curves except for phase and aspect angle changes.
Slow tumblers show time signals in their signature but any period is too long to be determined during passes of the object which are typically ~ 500 - 1200 seconds.
The trial examined the quality of modelling according to the availability of the various sources of data. Some objects, for example, Envisat, which had been intensively studied at the time of its failure in April 2012, had extensive archives of available data from multiple sources. The data showed that since its failure Envisat's rotation had been gradually increasing over time but with bursts of apparently more rapid spinning up.
The study showed that the availability of SLR data as part of the data set was crucial in determining whether a good attitude model could be developed from the observational data. A tumbling model, designated iOTA (in-orbit tumbling model), had been developed which used physical models of the target object along with environmental models and simulated behavioural models to simulate light curves and RCS signatures for comparison with observational data.

3.2.2.5 University of Rome "La Sapienza" 2015/2016 optical observation campaigns overview (T. Cardona, ASI)

T. Cardona presented a summary of observations taken using the Loiano observatory and SPADE observatory in Italy and the EQUO equatorial observatory in Kenya.
Loiano observatory 1.5 m telescope had started taking observations for ASI in pilot campaigns in 2011. Loiano had been used to carry out multi-colour photometry of rocket bodies, showing them to have a red colour excess of R and I over B and V when using Johnson broadband filters.
Tests had been undertaken using the SPADE observatory to see if its large FoV would allow tracking of LEO objects. Observations to test orbit improvement and LEO characterisation were carried out on a small number of targets and are still being analysed.
EQUO was being located at the Broglio Space Centre in Malindi, Kenya. The sensor was tested at two sites, one inside the space centre base camp and a second on the offshore San Marco platform.

A study is being carried out to assess methods to automatically discriminate cluster members in GEO surveys to avoid contaminating data through cross-tagging. Trial observations indicated that data over a minimum of nearly six hours is necessary in order to maintain recognition capability on the second and subsequent nights.

3.2.3 14:00 – 15:15 Session 2.3

3.2.3.1 South-Staring BPE – First TIRA Results (K. Letsch, ESA)

K. Letsch presented a report on the ESA data taken by TIRA under the auspices of AI 33.3. Simulations, reported at IADC 33, had suggested that there were possible interesting debris sources that should be sampled in a South-staring beam park campaign without sacrificing the populations sampled by the traditional East-staring campaign. Thus it was agreed to attempt a South-staring campaign for the 2015 campaign to test these simulations.
TIRA had observed for ~ 23 hours during the 2015 campaign at azimuth 165°, elevation 10° with a sampled range of between 1500 and 3000 km equivalent to 423 - 1275 km altitude. When the beam points South there is ambiguity in the Doppler inclination derived for detected objects. In East-staring beam park campaigns the possible Doppler inclinations are sufficiently close to each other that it is reasonable to use the mean of the two derived values. However in the South-staring case there are two widely different possible range rates. PROOF simulations show that most objects have smaller range rates and inclinations < 90°. It is reasonable to assume that true inclination is the minimum of the two possible Doppler-derived inclinations.
270 objects were detected during the December 2015 campaign compared to 320 anticipated using a PROOF 2009 simulation. Of the detected objects 24 could be correlated with the catalogue. Three large (> 1 m) uncorrelated targets were detected during the campaign. Detection rates in inclination ranges between 30° and 40° and between 44° and 48° were significantly higher than expected from PROOF simulations, suggesting a larger population at low inclination than anticipated. This excess could be the result of hitherto unknown fragmentation events. Comparison of data with that obtained by NASA will help to validate this result.

3.2.3.2 Status of report on AI 33.3

K. Letsch noted that, whilst further analysis of the data from TIRA would be required, ESA was on schedule and did not anticipate any delay in the AI. Although the NASA data was not ready for this meeting J. Hamilton confirmed that NASA had started the analysis of data from Haystack taken during the campaign and would soon start on that from Cobra Dane and Goldstone. Neither participant foresaw any likely delay in producing the report on schedule for the SG meeting in Autumn 2017.

3.2.3.3 Azimuthal Rotating Antenna for Space Debris Detection (K. Letsch, ESA)

K. Letsch presented the results of a study using the TIRA radar that aimed to address some of the issues raised by the South-staring beam park experiment. Assumptions need to be made to calculate orbits for the objects detected during beam park experiments. For real objects the assumptions do not hold in the South-staring case, in particular, the ambiguity between the range rate and inclination had to be resolved.
The study investigated whether the outcome of the beam park experiment could be improved by rotating the antenna during the observations. By this innovation the time between

observations could be extended allowing a better approximation to the target's orbit. For TIRA, the rotation rate of the antenna was limited mechanically to 24°/s.
In ~ 20% of cases double detections were made of the target object allowing a more accurate and more realistic orbit to be calculated.

3.2.3.4 ESA survey radar breadboard (F. Muller, CNES)

F. Muller presented an update on progress of ESA's radar breadboard, which was being carried out by ONERA as part of the ESA SSA preparatory programme. The breadboard radar consisted of ~ 1/100th of the full system. The breadboard system had been designed to detect a 1 m object at 350 km. The system had a revisit rate of 10 s over the whole field of regard.
Trial campaigns amounting to six weeks of observations had taken place between March 2015 and February 2016 during which 302 tracks had been gathered on 234 different objects. Analysis of the data indicated an RMS angular accuracy of ~ 0.2° and Doppler rate ~ 0.5 m/s. Correlation of objects against the TLE catalogue had been successfully demonstrated.

3.2.4 15:45 – 16:00 Session 2.4

3.2.4.1 Nomination for deputy chair

P. Herridge reported back to the WG that the SG had stated that distributing the WG chairs and deputy chairs amongst the agencies was only a preference and would not limit their choice. They would select the best person for the role regardless of any other considerations. Any balancing amongst agencies was purely a nice-to-have option.
Changyin Zhao of CNSA, Tim Payne of NASA and Pascal Richard of CNES accepted nomination to the SG for the post of WG1 deputy chair.

3.2.4.2 Preparation for a new AI on optical observations of Molniya orbits

Whilst the chair and deputy chair gave their report to the SG the remaining members of WG1 discussed plans for higher Earth orbit optical campaign. The WG1 decided that it was premature to propose an AI at IADC 34 but that a new IT would be adopted to draw up plans for an observing campaign to take place in 2017/8.

3.3 Day 3: Thursday 31st March 2016

3.3.1 09:00 – 10:30 Session 3.1 joint WG1/WG2

The SG was present during the joint session between WG1 and WG2.

3.3.1.1 Light curves for AI 31.2 (T. Yanagisawa, JAXA)

T. Yanagisawa presented to WG2 the results from AI 31.2 that he had given during the WG1 session the previous morning. A flavour of the discussion that had taken place in WG1 was also conveyed to WG2. WG2 queried what corrections had been applied to the light curve data, in particular whether it had been corrected for range or for solar phase angle. WG1 reported that the data as presented had not been corrected as it was felt that it was more effective for the modeller to carry out any correction to avoid potential confusion. WG1 requested that WG2 carry out modelling of light curves to see how it would be possible to differentiate spin up of the target from viewing angle effects. WG2 queried whether it would be possible to observe calibration objects.

3.3.1.2 DebriSat hypervelocity impact simulation (P. Krisko, NASA)

P. Krisko presented an update on DebriSat, the ground-based hypervelocity impact simulation. DebriSat was an update on the previous hypervelocity trial (SOCIT) that had been carried out in 1992 and formed much of the basis for NASA's break up model. The aim was to update the previous work to ensure that it continued to represent modern satellite design. The target satellite used for DebriSat consisted of all of the seven major satellite subsystems. To reduce cost the components were represented by emulations based on the same design and using the same materials.

The target was larger and more realistic than that used for the SOCIT impact in 1992. Importantly, the DebriSat simulation included MLI sheets and a solar panel array, although the hollow aluminium sphere impactor did not directly hit the array.

A pre-test shot was carried out using a mock-up of a launch vehicle upper stage, DebriSatLV. The DebriSat impact had been carried out on 15th April 2014 using a 570 g projectile fired at 6.8 km/s.

It was anticipated that more than 90% of the mass of DebriSat will be recovered following the test. The pieces of the foam panels surrounding the target were being X-rayed and any pieces > 2 mm collected. It was expected that the total number of fragments larger than 2 mm will exceed 200,000. For each object a record was made of its characteristics.

Optical and radar measurements will be performed on a subset of the objects recovered to update radar cross sections and derive optical cross sections.

3.3.1.3 Optical Observations of Briz-M Fragments in GEO (T. Schildknecht, ESA)

T. Schildknecht presented the results of an early optical observation campaign on the Briz-M upper stage (id 2015-075B), which had fragmented on 16th January 2016, about a month after inserting a Russian military payload into geostationary orbit. US JSpOC had detected the break up on 20th January 2016 and ESA had been approached to obtain observations the following day.

The ESA OGS and the Zimmerwald telescopes had been tasked with an initial three-day survey. Two fragments were discovered (with > 2 tracklets) in addition to the nominal rocket body on the first night and a further six fragments detected on the second night. Three of those fragments seen on the second night had significantly elliptical orbits whilst the rest were in near circular, near-GEO orbits.

ESA had calculated a time of closest approach of the discovered objects which indicated a break up at 06:42 UTC on 15th January 2016, around 24 hours earlier than the JSpOC estimate and published estimate by the US Air Force.

Photometric observations of the parent body indicated that the upper stage had an apparent spin period of ~ 0.9 s. In comparison, a similar Briz-M rocket body launched in August 2015 was observed to have an apparent spin period ~ 6.4 s.

3.3.1.4 Re-entry Analysis Using Radar Measurements (H. Hinagawa, JAXA)

H. Hinagawa completed the session with a report on the combination of radar data from multiple sites to provide improved re-entry estimates. JAXA uses radar data from the Kamisaibara Space Guard Centre (KSGC) for re-entry predictions. For two re-entries JAXA combined data from the KSGC with radar data from CNES/French MoD and the US JSpOC. For the re-entries of Progress M27-M and the Long March upper stage used as the IADC 2015 test object, JAXA combined its own data with that from the French and the US radar. The orbits were then propagated to provide predictions of the re-entry epochs for the test targets. In both cases the effects of the solar radiation conditions were also considered.

The study compared the predictions based on data from individual sites and combined data. The orbit determination from individual site data was only successful when a full range of data parameters was available (range, azimuth and elevation). With only slant range data available the orbit determination became unreliable unless the data collection interval was below 1 s, which was only the case for the French radar. Orbit determination was always successful when data from multiple sites could be combined, although only limited improvement in predictions was obtained.
The study also showed that the re-entry epoch got earlier as the solar flux increased. However only the results of the solar flux on the Progress M27-M re-entry were presented. The study found that where the orbit determination could be based on an orbit arc greater than 24 hours the error in the prediction was less than 20%.

3.3.2 11:00 – 13:00 Session 3.2

3.3.2.1 Cosmos (B. Hainaut, CNES)

B. Hainaut gave a presentation on the development of the French Space Situational Awareness Operations Centre, COSMOS. The French Air Force and CNES operated COSMOS to provide operational support for French satellites and to maintain a French autonomous space picture. COSMOS had the responsibility to provide support for launches, manoeuvres, station keeping, and de-orbit and re-entry. To do this it maintained and evaluated orbits to be able to warn of possible approaches and respond to anomalies. COSMOS also monitored space weather.
Sensors contributing to COSMOS included three SATAM radar and the GRAVES radar. The GRAVES radar was an uncued sensor, dedicated to space surveillance, that can detect ~ 1 m^2 objects at 1000 km. The three SATAM radar, which detect complementary sized objects, were cued as required for collision risk assessment and other tasks. The French procurement agency, DGA, also operated a number of radar, including those on board Monge, which can provide data on request if needed.
COSMOS supported space operations by providing a collision risk and a re-entry monitoring service. For the collision risk the centre shared data with CNES; it can task directly up to 13 radar when alerted. COSMOS forecasted and tracked three potentially hazardous re-entry events during 2015.
At this time COSMOS did not have any dedicated optical sensors for GEO monitoring. New telescopes were being built under the banner GEOPOLARSAT. These telescopes were planned to be able to provide photometry, spectroscopy and polarimetry for characterisation of objects at GEO. The two cued telescopes will be dedicated to their SSA mission.

3.3.2.2 Development of University of Rome “La Sapienza” International network of observatories for space surveillance (F. Piergentili, ASI)

F. Piergentili provided a summary of Italian efforts to develop a network of observatories dedicated to space surveillance. In addition to a telescope based in Italy, referred to as the Mid latitude ITalian Observatory (MITO), a trial of a telescope, called the EQUatorial Italian Observatory (EQUO), at the Broglio Centre in Malindi, Kenya was under way. A site for a third observatory, to be called the Southern (h)EMisphere Italian Observatory (SEMO), was being sought in either Australia or Chile.
The Italian and Kenyan sites lie along the same day-night terminator; for sun-synchronous LEO objects the same pass could be seen over both sites. Orbit determination error

calculations had shown that accuracy was significantly improved when tracks could be obtained from passes over two sites.
MITO consisted of a 0.25 m f/3 Cassegrain telescope located north of Rome. The automatic and remote-controlled telescope was equipped with a 2184 x 1510 detector resulting in a 1.4° x 1° field of view. It was planned to upgrade the detector which would increase the field of view to ~ 2.5° x 2°.
A 0.2 m f/4 telescope with a 3k x 3k CCD, giving a 2.5° x 2.5° FoV, had been used for trial observations at the EQUO sites in Malindi, Kenya. Observations had been made on-shore at the project control centre and off-shore on the San Marco launch platform. It was intended that the new telescope would be fully operational on the off-shore platform during 2017.
Trials for the southern hemisphere observatory had taken place in 2016 at the Observatorio de la Sagra in Spain. Two possible sites were under consideration, one in southern Australia, the other at San Pedro de Atacama, Chile.
F. Piergentili outlined work with a number of partners to the ASI debris research effort at the University of Rome, including SPADE and the Loiano observatory. Discussions had been carried out with a view to the future use of an INAF 0.6 m telescope at Teramo observatory. The University of Rome had been working on a suite of software for standardisation of telescope control. Called NICO (Networked Instrument Coordinator for space debris Observations), the software would provide common observation planning.

3.3.2.3 Increasing of GEO/HEO space debris discovery rate due to annual development of the ISON network (I. Molotov, Roscosmos)

I. Molotov outlined the developments that had taken place in the ISON optical telescope network during the preceding year. The network co-operated with 37 facilities around the world giving access to 79 telescopes in 15 countries. Ten telescopes had been added to the network during 2014, with a further eleven in 2015. The Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences (RAS) provided co-ordination for the network. KIAM maintained a database of objects from which it provided conjunction analysis for Roscosmos.
From its inception in 2004 until the end of 2015 the ISON network had collected in excess of 15 million observations, and now obtained ~ 5 million observations per year. These observations were now approximately evenly divided between GEO, HEO and LEO. The ISON network had discovered 339 new objects during 2015.

3.3.2.4 Detection of LEO Objects Using CMOS Sensor (T. Yanagisawa, JAXA)

JAXA had developed an optical LEO observations system, based around a CMOS detector, which was capable of observing 10 cm objects at 1000 km altitude. A full scale 40-sensor array of optical telescopes based at a single site had been proposed, but to obtain sufficient orbit determination accuracy two such sites would be required.
Trial observations had been carried out using an 0.18 m optical telescope equipped with a CCD detector which gave a field of view of 3.5° x 3.5°. Target objects were identified by applying a linear motion detection algorithm to a stack of 50 ms exposure frames. In this configuration 30 cm LEO objects could be detected with a limiting magnitude ~ 11. 15% of the objects detected could not be correlated to any in the existing public catalogue.
In an attempt to improve on the detection capability of the CCD detector a CMOS detector was tested using the same optical telescope assembly. The processing time to detect faint objects moving in arbitrary directions was found to be very long so a dedicated processor board had been built to reduce the analysis time.

During four nights of two hours observing each night 22 objects were detected eight of which were uncatalogued. The trial showed that the CMOS configuration was able to detect objects at least one magnitude fainter than the CCD configuration. To investigate the usefulness of the configuration observations were made of the POPACS test objects. The POPACS mission consisted of three 10 cm aluminium spheres coated in flat white paint. POPACS was detected on two passes with magnitudes 12.1 and 12.8.
The trials using CMOS detectors proved that the configuration offered an effective addition to existing radar observations of LEO objects. JAXA was developing a large CMOS detector in collaboration with Canon. The large detector would provide a 4.70° × 2.61° FoV when fitted to the 0.18 m telescope.

3.3.3 14:00 – 15:15 Session 3.3

3.3.3.1 URSA MAIOR: a cubesat to be used as calibration target (F. Piergentili, ASI)

The University of Rome had been developing a cubesat microsatellite that could be used as an attitude motion test target.
The microsatellite, URSA MAIOR, would be deployed into a 480 km, 98° inclination LEO orbit. It carried LEDs for trajectory and attitude analysis and a de-orbit drag sail to be deployed at the end of its operating life. The addition of a passive corner reflector for possible laser ranging was being considered.
Two pairs of high power LEDs had been installed on URSA MAIOR, green on one side, red on the other. The LEDs would make it possible to observe the microsatellite even when it was in Earth shadow, not illuminated by the Sun. The red LEDs would be ~ 12.7 magnitude at 700 km range, ~13.5 mag at 1000 km; the green LEDs would be ~13.5 mag and 14.3 mag at 700 km and 1000 km respectively.
The de-orbit sail would be set to automatically deploy one year after the start of the mission and would effectively end the mission. The sail for the URSA MAIOR mission would have an area of 2.1 m^2. The sail's deployment would be set in advance of URSA MAIOR's launch and would be independent of any of the satellite's other components.

3.3.4 15:45 – 16:00 Session 3.4

3.3.4.1 Definition of an Internal Task to prepare for future AI to survey for Molniya orbit debris

During the final session of day 2 the WG had agreed that the planning process for a higher Earth orbit optical survey was not sufficiently mature to allow an AI to be proposed at this meeting. It was agreed that the Molniya orbit space remained the most suitable regime at which to target a survey. The orbit regime remained poorly studied; in particular it had never been systematically studied to determine the disposition of debris. Preliminary studies by UKSA, ESA and others, reported in past meetings, suggested that a population of unrecorded debris did exist in the Molniya orbits, possibly including some large fragments. The regime was more challenging than previous targets for IADC co-ordinated campaigns because of the motion of the target population, but remained within the capabilities of all agencies.
There were difficulties in how to define a co-ordinated campaign. There were no simple-to-follow definitions that would allow all agencies to sample the same populations. It was unclear how a co-ordinated campaign could be defined such that results from participating agencies could be combined into a coherent picture of the orbit debris population.

It was agreed that, as a first order plan, the campaign should be targeted at the apogee culmination ring. All of the agencies represented in the meeting expressed an intention, in principle, in participating.
It was proposed and decided that an internal task should be adopted to investigate options to co-ordinate observing amongst geographically spread participating teams. The text of such an IT was proposed and agreed. The WG decided that T. Cardona of ASI would lead the IT with P. Herridge of UKSA acting as co-lead. The text of the IT is reproduced in Appendix 3. The timetable for the IT was agreed such that the results of the IT would be presented to the WG sufficiently in advance of IADC 35 that delegations could study it before a concluding discussion at the next meeting. The IT authors would, therefore, report the finding of the IT in January 2017.

3.3.4.2 Report to SG

The SG announced that Changyin Zhao, of CNSA, had been selected to be the new WG1 deputy chair.

3.4 Day 4: Friday 1st April 2016

3.4.1 09:00 – 10:30 Session 4.1

3.4.1.1 Closing discussions

A discussion on the future plans for WG1 was held on the final morning. The WG had significant areas of future work; an IT had been agreed to define a co-ordinated higher Earth orbit optical campaign, a second low Earth orbit large debris study had been proposed, the next 24-hour radar beam park campaign was anticipated. These plans would keep radar and optical observers busy for the immediate future.
It was noted, however, that the radar observations had become restricted to just two agencies that had large radar suitable for the beam park campaigns. A discussion took place as to what other radar were available that could potentially be involved if appropriate campaigns could be defined.
Most agencies had radar facilities that could be utilised for suitable IADC related activities ASI had a radio telescope in Sardinia, albeit it had no active radar, and although the military had transmitters at ~ 400 MHz these were unlikely to be easily available for IADC use. ASI had previously done sensitivity tests with the Evpatoria radar in Crimea. CNES did not think that any access to GRAVES would be possible but low priority use of the SATAM radar might be possible. The ESA breadboard radar used a low frequency at present but its availability could be discussed with ESA. CNSA said that most Chinese radar were military so access was unlikely. They had a few meteorological radar whose availability was unknown. The KSGC radar was not operated by JAXA but might be open to an appropriate programme. The UK Chilbolton radar might also be interested in participation in an appropriate study.
The most immediately obvious possibility was to see if some of these radar could be used during a possible follow on to AI 31.2. The original wording of the AI had allowed for the possibility of obtaining radar signatures as well as optical light curves for large intact LEO rocket bodies. The AI had deliberately been written to refer to gathering signatures rather than light curves. The inclusion of radar signatures could help to explain the changes in signature characterisation seen in the optical light curves collected in AI 31.2 and might help to clarify the behaviour of the target objects. In particular, it would be useful if simultaneous observations, or observations taken during the same orbit pass, could be collected to allow

comparison of optical and radar signatures. All agencies agreed to look into opportunities for radar participation in the second phase of the study of low Earth orbit signatures.
It was also queried whether the experience described by ESA during session 2.2 could be applied to a follow on study of low Earth orbit signatures. Laser ranging had proved particularly useful for attitude determination in the ESA study; however it was noted that most of the objects investigated during ESA’s study were cooperative, in that they had retro-reflectors. Laser ranging to non-cooperative targets was much more difficult to achieve and the results much more difficult to interpret. However some laser ranging sensors carried out photon counting at the same time as laser ranging and this might prove useful.
There was no further formal business so discussions returned to consideration of the results of the AI 31.2. The meeting was declared closed at 11:30 so that the delegates had time to return for the closing plenary and the Chair and co-Chair could prepare the closing report.

4 Annex A — Agenda

4.1 IADC 34 Harwell – WG1 Agenda

4.1.1 Day 1: Tuesday 29th March 2016

08:00 – 09:00 Registration (Rutherford Appleton Lab)

09:00 – 12:30 Opening Plenary of 34th IADC Meeting

Location: Pickavance Lecture Theatre

1. Welcome addresses
2. Address by the previous IADC Chair
3. Statements by IADC Heads of Delegation
4. Working Group reports
5. Group photo

12:30 – 14:00 Lunch break

14:00 – 15:15 Session 1.3 General

Conference Room, ECSAT (European Centre for Space Applications and Telecommunications)

1. Meeting overview and objectives, status of AIs, summary of October 2015 SG meeting (P. Herridge, T. Yanagisawa, 15 min)
2. Update and approval of agenda (P. Herridge, T. Yanagisawa, 5 min)
3. Agency status reports space debris related activities in 2015/2016 (ASI, CNES, CNSA, CSA, DLR, ESA, ISRO, KARI, JAXA, NASA, ROSCOSMOS, SSAU, UKSA, 5 min per WG1 member Agency)

15:15 – 15:45 Coffee/tea break

15:45 – 16:00 Session 1.4 General (continued)

Conference Room, ECSAT

1. Nominations for new Deputy Chair

16:00 – 16:15 Preparation of WG1 report to SG

16:15 – 17:15 WG reports to SG

17:30 – 19:00 Welcome drinks/Tour of Satellite Application Catapult

19:30 Bus to Oxford leaves from Satellite Applications Catapult

4.1.2 Day 2: Wednesday 30th March 2016

09:00 – 10:30 Session 2.1

Conference Room, ECSAT

1. Large LEO object light curves - results of reanalysis (T. Yanagisawa, JAXA, 20 mins)
2. Status of report on AI 31.2 - LEO lightcurves
3. Status of report on AI 23.2 - HAMR (T. Schildknecht, ESA, 10 mins)

10:30 – 11:00 Coffee Break

11:00 – 13:00 Session 2.2

Conference Room, ECSAT

1. MCAT and UKIRT (S. Lederer, NASA, 25 mins)
2. Observations with JGT at St Andrews (A. Scholz, UKSA, 15 mins)
3. IADC campaign trial observations using SPADE (O. Lanciano, ASI, 15 mins)
4. Results from attitude determination study (T. Schildknecht, ESA, 20 mins)
5. Results from 2015/2016 observation campaigns (T. Cardona, ASI, 20 mins)

12:30 – 14:00 Lunch break

14:00 – 15:15 Session 2.3

Conference Room, ECSAT

1. South-Staring BPE - First TIRA Results (K. Letsch, ESA, 20 mins)
2. Status of report on AI 33.3
3. Azimuthal Rotating Antenna for Space Debris Detection (K. Letsch, ESA, 15 mins)
4. Update on ESA bistatic breadboard (F. Muller, CNES, 20 mins)

15:15 – 15:45 Coffee/tea break

15:45 – 16:00 Session 2.4

Conference Room, ECSAT

1. Nominations for new Deputy Chair
2. New AI on optical observations of Molniya orbits

16:00 – 16:15 Preparation of WG1 report to SG

16:15 – 17:15 WG reports to SG

17:30 Bus to Oxford leaves from Satellite Applications Catapult

4.1.3 Day 3: Thursday 31st March 2016

09:00 – 10:30 Session 3.1 *Joint session with WG2*

Conference Room 12/13, Building R68

1. Large LEO object light curves - results of reanalysis (T. Yanagisawa, JAXA, 20 mins)
2. Characterisation of orbital debris via hyper-velocity ground-based tests (H. Cowardin, NASA, 20 mins)
3. Optical observations of Briz-M fragments in GEO (T. Schildknecht, ESA, 20 mins)
4. Re-entry Analysis Using Radar Measurements (H. Hinagawa, JAXA 20 mins)

10:30 – 11:00 Coffee Break

11:00 – 13:00 Session 3.2

Conference Room, ECSAT

1. Use of COSMOS for debris tracking (B. Hainaut, 20 mins)
2. Development of la Sapienza international network of observatories for space surveillance (F. Piergentili, ASI, 20 mins)
3. Increasing of GEO/HEO space debris discovery rate due to annual development of the ISON network (I. Molotov, Roscosmos, 20 mins)
4. Detection of LEO objects using CMOS sensor (T. Yanagisawa, JAXA 20 mins)

12:30 – 14:00 Lunch break

14:00 – 15:15 Session 3.3

Conference Room, ECSAT

1. Ursa Maior: a cubesat to be used as calibration target (F. Santoni, ASI, 20 mins)

15:15 – 15:45 Coffee/tea break

15:45 – 16:00 Session 3.4

Conference Room, ECSAT

16:00 – 16:15 Preparation of WG1 report to SG

16:15 – 17:15 WG reports to SG

17:30 Bus to Oxford leaves from Satellite Applications Catapult

19:00 – 22:30 Conference Dinner

Randolph Hotel, Beaumont Street, Oxford

4.1.4 Day 4: Friday 1st April 2016

09:00 – 10:30 Session 4.1

Conference Room, ECSAT

1. Future directions for WG1

10:30 – 11:00 Coffee Break

11:00 – 12:00 Session 4.2

Conference Room, ECSAT

1. A.O.B.
2. Preparation of final presentation to plenary meeting

12:00 – 13:00 Closing Plenary of 34th IADC Meeting

Pickavance Lecture Theatre

12:30 – 14:00 Lunch break

14:00 Bus to Oxford, Departure

5 Annex B — WG1 Delegate contact information

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References

[1] IADC-13-09 WG1 AI 31.1 “International 24 hour LEO Space Debris Measurement Campaign 2013”, 2015