IADC-00-00
April 2015

Inter–Agency Space Debris Coordination Committee

33rd Inter-Agency Space Debris Co-ordination Committee Meeting, Houston, USA. WORKING GROUP 1 (Measurements) Minutes

Issued by IADC Working Group 1

IADC 33 Minutes

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Revision History

Issue	Revision	Date	Reason for Revision
1	0	2015-05-12	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
UK Space Agency	
Other	
A/m	Area-to-mass ratio
ADR	Active Debris Removal
AEDC	Arnold Engineering Development Complex
AI	Action Item
AIUB	Astronomical Institute of the University of Berne
ASAT	Anti-satellite
ASPOS OKP	Automated System for Prediction and Warning on dangerous situations in near-Earth space
CAESAR	Conjunction Analysis and Evaluation, Assessment and Recommendations
CCD	Charge-coupled Device
COSMOS	Centre Opérationnel de Surveillance Militaire des Objets Spatiaux
CTIO	Cerro Tololo Inter-American Observatory
DRAGONS	Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor
FoR	Field of Regard
FoV	Field of View
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
GRAVES	Grand Réseau Adapté à la Veille Spatiale
GTO	Geosynchronous Transfer Orbit
HAX	Haystack Auxiliary Radar
HEO	Highly Eccentric Orbit
HUSIR	Haystack Ultrawideband Satellite Imaging Radar
ISON	International Scientific Optical Network

KIAM	Keldysh Institute for Applied Mathematics
LEO	Low Earth Orbit
MASTER	Meteoroid and Space Debris Terrestrial Environment Reference
MCAT	Meter-Class Autonomous Telescope
MEM	Meteoroid Environment Model
MEO	Medium Earth Orbit
MLI	Multi-layer Insulation
MMT	Multichannel Monitoring Telescope
MODEST	Michigan Orbital DEbris Survey Telescope
NEO	Near Earth object
OGS	Optical Ground System
ORDEM	Orbital Debris Engineering Model
OSCEGEANE	Observation Spectrale et CaractErisation des satellites GEostAtioNnairEs
PROOF	Program for Radar and Optical Observation Forecasting
RCS	Radar cross-section
S/N	Signal-to-noise ratio
SATAM	Systéme d'Ácquisition et de Trajectographie des Avions et des Munitions
SDS	Space Debris Sensor
SG	Steering Group
SRMS	Solid Rocket Motor Slag
SSA	Space Situation Awareness
SSN	Space Surveillance Network
SST	Space Survey and Tracking
TAROT	Télescope à Action Rapide pour les Objets Transitoires
TIRA	Tracking and Imaging Radar
UCT	Un-correlated target
UKIRT	UK Infrared Telescope
USNO	US Naval Observatory
WG	Working Group
ZIMLAT	Zimmerwald Laser and Astrometric Telescope

1 Attendees

Delegation members attending the IADC 33 WG1 sessions:

ASI:	Tommaso Cardona
CNES:	Béatrice Hainaut
	Florent Muller
	Jocelyn Ramos
	Pascal Richard
CNSA:	Changyin Zhao
CSA:	Brad Wallace
DLR:	—
ESA:	Sven Flegel
	Thomas Schildknecht
ISRO:	—
JAXA:	Toshifumi Yanagisawa
NASA:	Brent Bukalew
	James Frith
	Joseph Hamilton
	Matt Horstman
	Sue Lederer
	Richard McSheeny
	Tim Payne
	Pat Seitzer
	Gene Stansbery
Roscosmos:	Nikolay Sakva
SSAU:	—
UK Space Agency:	Phil Herridge

1.1 Contact details

Contact details 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 — Monday 30th March 2015

3.1.1 14:00 – 15:30 Session 1.1 General

P. Herridge opened the meeting with a report on the elements of the SG meeting in October 2014 relevant to WG1. He noted that the report on AI 28.1 (2010 24-hr LEO Space Debris Measurement Campaign) had been accepted and the AI closed.

3.1.1.1 Agency status reports

Status reports were presented by seven agencies: ASI, CNES, CNSA, ESA, JAXA, NASA and UK Space Agency. Two agencies, CSA and Roscosmos would incorporate status reports into longer reports on agency activities later in the meeting. Four agencies were not represented at the meeting: DLR, ISRO, KARI and SSAU.

<u>ASI</u>:

ASI had been working on a laboratory satellite mock-up of URSA MAIOR, an Italian 3U cubesat, to simulate light curves. It was intended that the mock-up would be tested by NASA. ASI were building an equatorial observatory (EQUO) to be based at the Broglio Space Center in Malindi, Kenya consisting of two telescopes, one in the base camp and one on an off-shore platform.

<u>CNES</u>:

CNES had implemented a collision warning service called CAESAR including using the GRAVES radar to update the orbits of the target objects. CAESAR was being incorporated into the new French space surveillance operations centre, COSMOS. CNES was working on the automatic cueing of the TAROT optical telescopes in the CAESAR framework.

<u>CNSA</u>:

CNSA had implemented a quad-channel optical telescope capable of tracking LEO debris and carrying out simultaneous multi-colour photometry. CNSA continued to track rocket bodies and satellites to perform assessment on Chinese mitigation procedures.

<u>ESA</u>:

ESA had continued to carry out observations using the I m telescope in Tenerife for maintenance of the high A/m ratio object catalogue. ESA had also completed a study on survey of MEO and Molniya objects. A study on streak detection and ESA's contribution to the LEO light curve AI 31.2 would also be reported.

ESA had authored the report for AI 28.1 and had reprocessed the data from 2013 radar beam park experiment for AI 31.1. The results of a theoretical study on radar beam park options would be presented.

ESA had a number of relevant on-going studies including laser tracking of debris, space based optical observations and stare and chase mode tracking.

ESA SSA initiative had now been limited to space weather, NEOs and SST preparatory activities; development had started on a 6.7° x 6.7° FoV NEO telescope.

<u>JAXA</u>:

JAXA had developed a new streak detection algorithm for detecting debris. Images were skewed and compressed to improve S/N. The new algorithm had been tested using data from the Australia Remote Observatory. Every skew angle and compress pattern had to be investigated so means to reduce analysis time were being investigated.

JAXA had been carrying out optical survey of LEO objects. JAXA was examining a proposal to use arrays consisting of large numbers of optical telescope for LEO monitoring.

JAXA had taken 127 LEO light curves for AI 31.2 less that 10% of which showed unambiguous periodic changes.
NASA:
Installation of the 1.3 m MCAT telescope on Ascension Island was underway and NASA hoped that first observations would be made during 2015. The telescope was expected to be able to observe debris as small as 10 cm in GEO as well as being capable of observing LEO objects.
NASA had developed an impact detector to be installed on ISS. The Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS) combined acoustic sensors, dual-layer films and resistive grids to enable a wide range of data on impactors to be collected in semi-real time.
NASA had carried out hyper-velocity impact tests on a model 60-cm/50-kg class satellite, designed to simulate a modern LEO payload, to study the break-up debris. A launch vehicle upper stage had also been simulated during the test shot.
NASA had a number of on-going measurement campaigns at a number of wavelengths and sizes including radar with HUSIR and HAX, IR using the UKIRT, and optical using the 0.6 m MODEST and 6.5 m Magellan telescopes.
UK Space Agency:
Radar/optical cueing and fusion studies sensors had been carried out using the Chilbolton radar in UK and optical telescopes in Australia and New Zealand and also using Starbrook optical sensors. A re-entry campaign was carried out on ATV-5 with radar and optical sensors in the UK, Australia and New Zealand.
Chilbolton Observatory and Space Insight continued to establish and extend links with UK universities.

3.1.2 16:00 – 17:00 Session 1.2 General (continued)

P.Herridge introduced the proposed IADC presentation and document templates. The templates had been placed in the WG1 section of the IADC website. Delegates were asked to provide comments on the documents. It was noted that it was unusual in scientific documents for references to be placed before the body of the text.

3.1.2.1 GSAT3 attitude motion (T. Cardona, ASI)

University of Rome Sapienza had developed a method for identification of the attitude motion of a satellite through analysis of the light curve. The method had been tested using a 3D model of GSAT3 an ISRO GEO satellite that had been inactive since 2010. The resulting simulated light curve had been compared to data collected by the University of Michigan 0.6 m aperture MODEST at Cerro Tololo Inter-American Observatory in Chile and the US Naval Observatory 1.3 m telescope at Flagstaff, Arizona, USA.

3.1.2.2 Preparation for WG1/WG2 joint session

A discussion was held whether the results from the ASI study should be included in the joint session between WG1 and WG2. It was agreed that there were aspects of the study that would be of interest to WG2 and which had resonance with AI 31.2, the preliminary results of which were also due to be presented.

3.1.2.3 Status of AI31.1 (International 24h LEO space debris measurement campaign 2013)

S. Flegel of ESA presented an update on the status of AI 31.1 on behalf of the report author K. Letsch of DLR who was unable to attend the meeting. The report had been completed in draft form and had been placed on the WG1 section of the IADC website prior to the meeting. It was agreed that delegates would study the report in detail and send comments to the author by the end of May 2015 and the report submitted to the SG Autumn meeting.

3.2 Second day — Tuesday 31st March 2015

3.2.1 08:30 – 11:00 Session 2.1 Presentations and discussion on AI31.2

3.2.1.1 Light curves for AI31.2 (T. Yanagisawa, JAXA)

Lead author on the AI, T. Yanagisawa, opened the session with a presentation on the observations and analysis carried out by JAXA. JAXA had obtained 127 light curves between May 2014 and February 2015. Analysis had shown a small number of objects that displayed clear periodic variation; a slightly larger group that displayed ambiguous variation; and the majority displayed only phase angle variation of brightness implying stable attitude motion.
T. Yanagisawa presented a number of light curves to demonstrate how JAXA had separated the light curves into the different categories.
T. Yanagisawa also noted that for some objects for which JAXA had more than one light curve the behaviour appeared to change between sets of observations.

3.2.1.2 CNSA observations for AI31.2 (Changyin Zhao, CNSA)

C. Zhao presented the results of observations taken at the Purple Mountain Observatory by CNSA. Six night of observations had been obtained in March 2015 during which, from the full list of 137 rocket bodies schedules, 51 had been observed, 32 more than once. In all 132 passes had been observed. The data had been pre-processed to calibrate for extinction, range and phase angle.
17 objects had shown short-term variation in their light curves (~ 1/3 of the sample), most of the estimated variation periods were between 50 sec and 100 sec. A few targets had variations periods less than 30 sec. Variations in brightness were seen in both new launched and older targets, even in those which had been in orbit for decades. CNSA had also detected significant differences in light curves taken one year apart on the same object.

3.2.1.3 NASA observations for AI31.2 (S. Lederer, NASA)

S. Lederer presented a synopsis of observations taken by NASA for AI 31.2. NASA had observed 109 objects of which periods had been determined for 27 objects. Of these periodic objects 17 had periods that implied rotation rates greater than 1º/sec, too fast for ADR. According to NASA's categorization of their light curves ~25% were periodic; nearly 50% were probably periodic; 20% non-periodic with the remaining 7% undetermined.

3.2.1.4 ESA contribution to AI31.2 (T. Schildknecht, ESA)

T. Schildknecht reported that ESA had used the 1 m ZIMLAT telescope operated by AIUB at Zimmerwald, Switzerland. 98 objects had been observed at least once between December 2013 and March 2015.

A taxonomy had been adopted where light curves were designated flat with no special features; periodic with a repeated brightness pattern; structured which were not flat but contained no visible period; with a lower period limit approximation or unknown where current observations did not allow classification. Of the objects observed only two (~ 3%) had clear periods, a further 35 had lower limits estimated. 67% of those objects with good observations showed structure in their light curves.

3.2.1.5 RCS-Variations of 3 Rocket Bodies Obtained with TIRA before 2014 (S. Flegel, ESA)

S, Flegel outlined the contribution that TIRA had made to the WG1 light curve discussion. TIRA had been used to study the RCS variation (the radar equivalent of a light curve) of three rocket bodies and upper stages. The upper stages all showed large variation (a factor of 7 or 8) between largest and average RCS on periods of between 10 and 20 seconds.

3.2.1.6 Discussion

In the following discussion it was agreed that the overall picture that each group was seeing contained a degree of coherence although there were also significant differences. It was agreed that at least some of the differences between observing groups was due to choice of taxonomy rather than disparities in results and that efforts would need to be made to develop a common taxonomy before final results could be presented to WG2. It was clear however that variations in light curves were present in objects of all ages casting doubt on theories that suggested that tumbling should be damped out on timescales less than a year.

3.2.1.7 Status of final report for AI 23.2

T. Schildknecht reported the core report had been drafted and awaited agency specific input. It was agreed that a draft of the full report would be available for circulation to WG1 members by June so that a final report could be submitted to the SG for consideration at their Autumn meeting in Jerusalem.

3.2.1.8 NASA observations for IADC AI 23.2 (P. Seitzer, NASA)

P. Seitzer gave a presentation on observations that NASA had carried out in the frame of AI 23.2. NASA had obtained calibrated photometry on seven high A/m ratio objects using the 0.6 m MODEST telescope at CTIO, Chile, obtaining multiple observations on most objects. Observations were taken using B, V, broad R and I filters, each of which were reduced independently for zeropoint, extinction and colour term.
The telescope had taken groups of images using each filter in turn. Observations had shown little variation (< 0.5 mag) between observations with each filter but considerable variation (~ 2–4 mag) from filter to filter.

3.2.1.9 Orbital object detection algorithm using faint streaks (T. Yanagisawa, JAXA)

JAXA had developed a new algorithm for image processing to allow very faint objects, that were not visible by conventional means, to be detected. The new algorithm effectively improved the signal-to-background-noise ratio (S/N) of moving objects.
The image was morphed (skewed) and compressed (summing signals along the vertical axis). The streak position was then determined by taking a moving average and then correlation between streaks was carried out. The sequence was then carried out over all possible skewing angles to search for unknown streaks.

3.2.1.10 Streak detection and analysis pipeline for space debris optical images (T. Schildknecht, ESA)

T. Schildknecht presented a report on a study carried out by ESA to develop an automated processing pipeline for detection of streaks in single images. The algorithm was required to complete three tasks: robust extraction of interesting features; characterisation; and astrometry on resultant successful detections. The algorithm had been tested against a set of scenarios containing long, linear and uniform streaks, progressing to more complicated streaks, including curved and discontinuous samples.

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3.2.2 12:30 – 14:30 Session 2.2

3.2.2.1 Update on MCAT and UKIRT (S. Lederer, NASA)

S. Lederer presented an update on NASA's optical and infra-red assets, in particular the 1.3 m MCAT and 0.6 m MODEST optical telescopes and the 3.8 m UKIRT infra-red telescope. Installation was progressing on the MCAT telescope for which site preparation was underway on Ascension Island. First light was planned for June 2015 followed by an initial testing phase before full systems integration in the final quarter of 2015.
Lockheed Martin had a contract to operate UKIRT with University of Arizona providing day-to-day operations. NASA had 35% observing time for orbital debris studies. UKIRT would add spectral coverage that would provide insight into material type when combined with visual photometry.

3.2.2.2 Optical surveys for objects in highly-eccentric MEO - Final Results (T. Schildknecht, ESA)

ESA had been studying observation strategies for objects in MEO, particularly the Molniya orbits. The known Molniya population consists of 171 objects including 45 satellites, 73 rocket bodies and 53 other objects. The population split into two groups, those with $e < 0.65$ had $I > 65°$, those with $e > 0.65$ had I clustered around 63.4°.
ESA had observed with the OGS near the region of minimum angular velocity which occurred while the objects were close to apogee. Survey and follow-up observations were performed during 30 nights in 2013 and 2014. 30 uncorrelated targets (UCTs) were discovered during the 2013 surveys with follow-up observations on 25 objects and 17 UCTs in 2014 with follow-ups on 13. 7 objects were still in the catalogue.
Observation successfulness had been evaluated by using the ESA PROOF tool for comparison with the MASTER-2009 population. Correlated targets indicated a detection efficiency of 57.7 % implying a total Molniya UCT population brighter than 19 mag > 338 objects. This suggested a factor of 2 discrepancy between the observed UCTs and the MASTER-2009 population.

3.2.2.3 Canadian SSA Activities (B. Wallace, CSA)

B. Wallace reported on Canadian SSA activities since the previous meeting. The Sapphire space based optical sensor had been launched in February 2013, along with the experimental NEOSSat. Sapphire had been a contributing sensor to the US SSN since January 2014.

Problems had continued to be experienced with the experimental asteroid tracking and SSA satellite NEOSSat which remained in commissioning. B. Wallace had described a number of the problems experienced with the NEOSSat detector including a steadily increasing number of hot pixels, vertical stripping on the images and interference. Means to overcome these issues had been established and NEOSSat had started to obtain satellite images in August 2014 and of GPS orbit objects in November 2014.

3.2.2.4 Debris Observations Analysis with Automated System for Near-Earth Space Dangerous Events Warning (N. Sakva, Roscosmos)

N. Sakva presented an overview of Russian activities in the area of space debris monitoring. Roscosmos had developed an automated warning system (ASPOS OKP). Procedures had been developed to disseminate information on dangerous events to users and to obtain observations from various sites at a number of wavelengths. New dedicated observation facilities had started regular operations. At the end of 2014 there were 4 dedicated facilities with 11 telescopes of various sizes operating within the ASPOS OKP framework.
The sensors of ISON had obtained ~10.9 million observations of ~3500 GEO, HEO and MEO objects during 2014. 198 of the objects were not present in the US SSN catalogue. Additional telescopes had been used to collect photometric observations of very faint objects. Simulations from 3D models had been compared observed light curves to provide characterisation of detected objects. Roscosmos had continued to improve the orbit prediction accuracy for high area-to-mass ratio space debris.

3.2.3 15:00 – 15:30 Session 2.3

3.2.3.1 TAROT telescopes and operational collision avoidance (P. Richard, CNES)

P. Richard presented an update on the use of the TAROT telescopes for survey and tracking of GEO objects. A large amount of time was available outside TAROT's main mission searching for transient astronomical phenomena. A maximum of seven nights without debris observations had been experienced at either telescope. This maximum included outages for all reasons including transient alerts, maintenance, weather and equipment failure.
The TAROT sensors had been incorporated into the CNES CAESAR anti-collision service and support for the Air Force COSMOS Space Surveillance Center through the use of the OSMOSE planning and processing software. OSMOSE was used to create telescope requests, associate measurements and update the orbital elements in the French catalogue.

3.2.3.2 Ground based optical observation system for LEO objects (T. Yanagisawa, JAXA)

T. Yanagisawa presented a new proposal to JAXA for a ground-based optical observation system for detection of LEO objects. The proposal envisioned an array of 40 optical sensors located at a single site. The array would monitor two regions of sky to get a long arc of observations. In order to get two consecutive passes of the object two longitudinally separated sites were considered.
Simulations had been carried out to establish the effectiveness of the system and the quality of the orbits that would be obtained. Simulations using a pair of sites in Australia showed that ~ 60% of objects would be detected after 4 months.

3.2.3.3 Discussion and preparation for joint session (all)

The remainder of the session was taken up with discussion concerning the joint session planned for the following morning. It was agreed that T. Yanagisawa would present a summary of the work carried out for AI 31.2. WG1 would seek the views of WG2 on how a common taxonomy could be framed to maximise the usefulness of the data to WG2. It was further agreed that ASI's attitude determination study on GSAT3 provided a useful contribution to the discussion and could be readily adapted to the consideration of the suitability of objects for ADR. T. Cardona was asked to present an edited version of his material on the GSAT3 attitude study.

3.3 Third day — Wednesday 1st April 2015

3.3.1 08:30 – 09:00 Session 3.1 part 1

3.3.1.1 Preparation for joint sessions with WG2, WG2/WG3

WG1 held a short discussion regarding observations made for AI 31.2 prior to joining WG2 and WG3. The difference in the proportion of objects that were categorised as showing periodicity was considered. It was felt that without a common taxonomy frame the differences could not be regarded as significant. Means of reassigning the dataset were discussed.

3.3.2 09:00 – 10:00 Session 3.1 joint WG1/WG2/WG3

3.3.2.1 DebriSat in-situ measurements (H. Cowardin, NASA)

H. Cowardin gave a presentation on the project that NASA and collaborators were carrying out to conduct a hypervelocity impact test to characterise a realistic satellite break up. The data would represent the break up of a modern LEO satellite and would use the latest techniques to update the test last carried out in 1992. The DebriSat test target would be 63% more massive than the target used in 1992 and would be covered with MLI and equipped with solar panels neither of which had been included previously.

The test had been carried out at the Arnold Engineering Development Complex (AEDC) in April 2014, fragments were being extracted and would be measured in the upcoming months. The hypervelocity impact event was monitored by x-ray, high speed optical and infra-red cameras, piezoelectric sensors and lasers. The inside of the test chamber was lined with low-density foam panels to soft-catch resultant fragments. The dust from the chamber was sifted to extract as many small debris particles as possible.

A test of the procedure was carried out on simulation of a launch vehicle upper stage target pre-shot in order to maximize the usefulness of the test.

It had been estimated that ~85,000 fragments larger than 2mm were created by the DebriSat test, more than 40,000 of which had been collected so far. It was hoped to recover at least 90% of the target satellite mass. Radar and optical measurements would be made of a subset of fragments to better understand ground-based observations including deriving an optical cross section to compliment an improved radar cross section. The resultant data from the DebriSat test would be used to update the NASA Size Estimation Model.

3.3.2.2 ISS Space Debris Sensor (J. Hamilton, NASA)

J. Hamilton presented a new in-situ debris sensor that was planned to be fitted on ISS. The Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS) was expected to fly on the space station in ~October 2016 and be called the Space Debris Sensor (SDS). Data from the sensor would be used to improve the Orbital Debris Engineering Model (ORDEM). DRAGONS combined three particle impact detection methods to derive Impact time, impact location, impact direction, impact speed, size of impacting particle, and impact energy. SDS combined dual-layer thin films, an acoustic sensor system, a resistive grid sensor system, and sensored backstop. DRAGONS would measure the flux of particles in the range ~few hundredth to a few mm.

3.3.3 10:00 – 11:00 Session 3.1 joint WG1/WG2

3.3.3.1 ORDEM (M. Matney, NASA)

M. Matney gave an update on the latest upgrade to the NASA Orbital Debris Engineering Model (ORDEM). ORDEM 3.0 represented NASA's best estimate of the current debris environment. To improve on the previous models ORDEM 3.0 separately modelled environment dominating events, like the Chinese ASAT test and the Iridium/Cosmos collision. Impact features from returned spacecraft surfaces and ground impact tests were used to update the material distribution. In-situ data from Shuttle radiators and windows were combined with radar observations from the Goldstone, Haystack and HAX radar, fitting small and large particle populations separately.
ORDEM 3.0 covered a much wider range of altitude heights and orbit types than its predecessor ORDEM 2000, in particular it extended the population to highly elliptical orbits as well as circular. Unlike ORDEM 2000, the model was divided by material type and density and a separate meteoroid environment model (MEM) was available.

3.3.3.2 Feedback on WG1 light curve observations (T. Yanagisawa, JAXA)

T. Yanagisawa presented a collation of the data on ADR targets carried out by WG1 members. He noted that some of the collected light curves show clear periodical variation and the light curves of some rocket bodies appeared to change from day to day. The observations appeared to contradict model predictions that variation would be quickly damped away given at previous meetings.
WG1 requested direction from WG2 on how the study should be carried forward. WG1 and WG2 discussed of the implications of the observations and the merits of concentration on a smaller number of interesting cases rather than attempting to observe every possible target.

3.3.3.3 GEO attitude modeling (T. Cardona, ASI)

T. Cardona showed how ASI had modelled the light curve from a GEO satellite. Comparison between the observations and simulations based on a 3D model of the spacecraft showed good agreement. WG1 had proposed that this kind of comparison could be applied to the future collection of ADR related light curves.

3.3.4 12:30 – 14:30 Session 3.2

3.3.4.1 Theoretical Study of South-Staring BPE (S. Flegel, ESA)

Fraunhofer had carried out a study of beam park experiment parameters on behalf of ESA. S. Flegel reported that the study had considered the objects that would cross the TIRA beam if it were pointed south at an azimuth of 180º. The study had examined the known object populations with inclination, I < 51º. The US catalogue listed 313 objects, 130 payloads, 59 rocket bodies and 124 debris. Three break-up events were known to have occurred. PROOF simulations indicated that solid rocket motor slag (SRMS) could be expected to cross the beam, mostly from decaying 28º GTO trajectories.
The study had found that the best crossing and detection rates were at low elevation but that the best ratio of detected to crossing for small objects occurred at ~55º. The study showed that lost SRMS fell significantly below the detection threshold. The best chance to observe SRMS would be to filter range rates to exclude high inclination objects but decaying Molniya fragments would still be observed along with the SRMS.

3.3.4.2 ESA bistatic survey radar breadboard (F. Muller, CNES)

ONERA had developed a breadboard of a ground-based survey radar for ESA as a concept demonstrator as part of the SSA programme. The breadboard configuration had consisted of a transmitting site at Crucey, Normandy and a receiving site 80 km East at Palaiseau south of Paris. The performance requirement, to provide a 95% coverage of 100 cm objects with altitude up to 350 km, lead to a field of regard (FoR) of 30º azimuth and 20º elevation. The breadboard had adopted a Track While Scan tracking approach with autonomous detection. Track association and trajectory analysis had then been carried out separately through computation alone.

3.3.4.3 Discussion and proposal of new AI for 2015/6 24hr LEO campaign

It was agreed that a new 24 hour LEO radar beam park campaign should be carried out during 2015/2016. As for previous campaigns the timing would be arranged to accommodate the requirements at TIRA and Haystack. Any additional agencies wishing to take part should contact the campaign co-ordinators. It was agreed that a proposal for a new AI, based on previous proposals, would be prepared and presented to the SG. Joseph Hamilton (NASA) and Sven Flegel (ESA) had agreed to lead the AI.

3.3.4.4 Cosmos (B. Hainaut, CNES)

B. Hainaut gave a presentation on the development of a French Space Situational Awareness Operations Centre, designated COSMOS. COSMOS would be operated in partnership between the French Air Force and CNES to provide an autonomous space picture. The system would combine sensor data and applications to provide operational support for French satellites, including collision avoidance and manoeuvre planning. Sensors contributing to COSMOS include 3 SATAM radar at Sommepy, Captieux, and Solenzara, GRAVES at Dijon and Plateau d'Albion, the OSCEGEANE 41 cm optical sensor at Mont Agel.

3.3.4.5 *Bistatic observations of GEO objects (P. Seitzer, NASA)*

NASA had simultaneously observed the same region of GEO space with the 1.3 m USNO telescope at Flagstaff, Arizona and the 0.6 m MODEST telescope at Cerro Tololo, Chile. Objects would have the same incident sunlight angle but different reflection angles, the study aimed to investigate what can be learned about shape, material and change of attitude. Four hours of coordinated observations were obtained in February 2014 with a baseline of 7800 km and GEO parallax > 10º. One controlled and seven uncontrolled objects were observed with ~ 30 minutes R band photometry obtained on each. The light curves obtained were qualitatively similar but could have very different amplitudes and timing of features.

3.3.4.6 *Molniya HEO surveys 2014 (N. Sakva, Roscosmos)*

The Molniya orbit is defined to be at 63.4º inclination at which there is no precession of perigee. Orbital period is close to half a sidereal day (718 min) with eccentricity in the range 0.67 to 0.74. There had been18 known fragmentations in Molniya orbits leading to fragments with a more scattered distribution of parameters. N. Savka had reported a survey of these objects by Roscosmos using the ISON network, including a 18 cm aperture with a 7.1º x 7.1º FoV at Nauchnyi in Crimea. Over the last three years this telescope had observed on 458 nights obtaining observations of 281 objects. The ISON database contained 352 Molniya-type objects (as of March 2015), 78 of which were not included in the US SSN catalogue. 15 uncatalogued objects were discovered in 2014 with magnitudes in the range 10.3 to 17.4.

3.3.4.7 *Roscosmos observations 2014 (N. Sakva, Roscosmos)*

N. Sakva reported on two new observatories , built during 2014 with 3 sensors in each, comprising one 40 cm, one 25 cm and twin 19.2 cm telescopes. In addition three separate telescopes, of 65 cm, 50 cm and 25 cm aperture, had been installed. The observatories were located near Kislovodsk, North Caucasus and near Byurakan, Armenia. An additional observatory with 65 cm, 40 cm and quad 19.2 cm sensors was being put into operation near Kislovodsk in 2015. The 19.2 cm aperture sensors were conducting GEO surveys with the 25 cm sensors providing follow up observations. The 40 cm and 65 cm sensors performed GEO surveys and follow ups for faint objects. All observations were scheduled and catalogued by KIAM. More than 2 million observations had been obtained by these new sensors during 2014.

3.3.4.8 *EQUO Equatorial Observatory for Space Debris (T. Cardona, ASI)*

T. Cardona provided detail on the equatorial observatory in Kenya reported during the agency status reports. The site location lay along the same Earth shadow terminator as Italy at summertime sunrise and winter sunset allowing both sites to track the same high inclination LEO objects. A test campaign had been carried out in 2010 using the ALMASCOPE 25 cm telescope which had been installed on an ocean platform. Over 9% of the objects detected during the test were MEO and LEO. A new 23.2 cm telescope equipped with an 8k x 6k CCD detector had been acquired to replace ALMASCOPE.

3.3.4.9 *Discussion and proposal for co-ordinated higher Earth orbit (MEO) campaign (all)*

A co-ordinated campaign at MEO was discussed. It was agreed that an AI should be prepared for presentation to the SG.

3.4 Fourth day — Thursday 2nd April 2015

3.4.1 08:30 – 10:30 Session 4.1 Future plans for WG1

3.4.1.1 Discussion of co-ordination at higher Earth orbit (all)

T. Schildknecht outlined a proposal for a co-ordinated MEO campaign concentrating on the Molniya orbit regime. Studies of Molniya orbits had detected previously uncatalogued objects. Characterization would require determination and maintenance of orbits, which would require co-operative observations and data sharing. The presence of bright objects, both catalogued and uncatalogued, meant that only moderate size telescopes would be necessary allowing a wide participation by delegations. Observation of the Molniya apogee region was proposed as this would be the most easily accessible region for co-ordinated observations. A survey region with inclination 60º - 67º, argument of perigee 240º - 300º, period 600 min - 800 min and eccentricity 0.67 – 0.75 was suggested. Observations could be astrometrically and photometrically calibrated through the observation of reference objects.
T. Schildknecht had suggested that data on objects fainter than 13 mag should be shared to allow orbits to be collaboratively maintained. He had suggested that observations could be collected starting in Autumn 2015.
It had been agreed that a proposed AI should be prepared for submission to the SG at their meeting in October 2015.

3.4.1.2 Discussion of LEO light curve taxonomy (all)

The different taxonomies applied by each delegation to the light curves that they had collected was discussed. Mechanisms to re-evaluate the existing light curves into a new common taxonomy were discussed. It was agreed that, if possible, a method whereby some of each delegations light curves would be re-assessed by a different agency would lead to a more consistent categorisation. It was agreed that T. Yanagisawa would propose a common taxonomy through discussion with the other delegations.

3.4.1.3 Discussion of follow-on LEO light curve observation campaign (all)

Options for future LEO light curve observations were discussed. It was noted that the usefulness of any observation had to be judged against whether it helped define suitable targets for ADR. It was agreed that a better understanding of a small number of interesting case examples would be more useful at this stage than collecting observations of every object.

3.4.1.4 MMT Observation Database for Light Curve Analysis (V. Agapov, Roscosmos)

P. Seitzer (NASA) presented a report on behalf of V. Agapov on serendipitous acquisition of light curves by a multi telescope sensor designed for observing astronomical optical transients. The Multichannel Monitoring Telescope (MMT) had ten 7.1 cm f/1.2 lenses which together produced a 900 square degree FoV operating at up to 10 frames/sec. The sensor did no dedicated space debris observations but orbiting objects were detected as optical transients a few hundred of which crossed the sensor FoV per night. The astrometric accuracy of the sensor was low but the sensor also collected photometric light curves. Data was accessible via the website http://astroguard.ru/satellites. Data for 1800 satellite, observed between June 2014 and March 2015 were available via the website. A number of sample light curves were presented.

3.4.1.5 Discussion of population sampling at higher Earth orbit (all)

The problems of sampling higher Earth orbit populations were discussed. Survey population measures were contaminated by erroneous attribution of objects due to incorrect orbit parameter assumptions, but observational demands of full orbit determination made it problematic as a method of reconciliation. P. Herridge questioned whether comparison with population models which simulated observations, including contamination, could provide an upper limit on the accuracy of the model.

3.4.1.6 Preparation for Closing plenary

Since there was no further business the meeting was declared closed at 10:15.

4 Annex A — Agenda

4.1 IADC 33 Houston – WG1 Agenda

4.1.1 Day 1: Monday 30th March 2015

08:00 – 09:00 Registration (Norris Convention Center)

09:00 – 12:30 Opening Plenary of 33rd IADC Meeting
Location: Norris Convention Center, Magnolia Room

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 – 15:30 Session 1.1 General – Room B

1. Meeting overview and objectives, status of AIs, summary of October 2014 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 2013/2014 (ASI, CNES, CNSA, CSA, DLR, ESA, ISRO, KARI, JAXA, NASA, ROSCOSMOS, UKSpace, 5 min per WG1 member Agency)

15:30 – 16:00 Coffee/tea break

16:00 – 17:00 Session 1.2 General (continued) – Room B

1. IADC presentation and document templates (P. Herridge, UKSA, 5 mins)
2. GSAT3 attitude motion (T. Cardona, ASI, 20 mins)
3. Preparation for WG1/WG2 joint session (all, 10 mins)
4. Status of AI31.1 (International 24h LEO space debris measurement campaign 2013) (S. Flegel, ESA,10min)
5. Discussion of AI31.1 (All)

17:00 – 17:15 Preparation of WG1 report to SG

17:15 – 18:00 WG reports to SG

4.1.2 Day 2: Tuesday 31st March 2015

08:30 – 11:00 Session 2.1 Presentations and discussion on AI31.2 – Room E

1. Light curves for AI31.2 (T. Yanagisawa, JAXA, 15 mins)
2. CNSA observations for AI31.2 (Changyin Zhao, CNSA, 10 mins)
3. NASA observations for AI31.2 (S. Lederer, NASA, 5 mins)
4. ESA contribution to AI31.2 (T. Schildknecht, ESA, 20 mins)
5. RCS-Variations of 3 Rocket Bodies Obtained with TIRA before 2014 (S. Flegel, ESA, 10 mins)
6. Discussion (all, 10 mins)
7. Status of final report for AI 23.2 (investigation of high A/m ratio debris in higher Earth orbits) (T.Schildknecht, ESA, 10min)
8. NASA observations for IADC AI 23.2 (P. Seitzer, NASA, 20 mins)
9. Orbital object detection algorithm using faint streaks (T. Yanagisawa, JAXA, 10 mins)
10. Streak detection and analysis pipeline for space debris optical images (T. Schildknecht, ESA, 20 mins)

11:00 – 12:30 Lunch break – Stan Love, luncheon, Studio Movie Grill

12:30 – 14:30 Session 2.2 – Room E

1. Update on MCAT and UKIRT (S. Lederer, NASA, 20 mins)
2. Optical surveys for objects in highly-eccentric MEO - Final Results (T. Schildknecht, ESA, 20 mins)
3. Canadian SSA Activities (B. Wallace, CSA, 15 mins)
4. Debris Observations Analysis with Automated System for Near-Earth Space Dangerous Events Warning (N. Sakva, Roscosmos, 15 mins)

14:30 – 15:00 Coffee/tea break

15:00 – 15:30 Session 2.3 – Room E

1. TAROT telescopes and operational collision avoidance (P. Richard, CNES, 15 mins)
2. Ground based optical observation system for LEO objects (T. Yanagisawa, JAXA, 20 mins)
3. Discussion and preparation for joint session (all, 10 mins)

15:30 – 15:45 Preparation of WG report to SG

15:45 – 16:30 WG reports to SG

4.1.3 Day 3: Wednesday 1st April 2015

08:30 – 09:00 Session 3.1 part 1 – Room B

1. Preparation for joint sessions with WG2, WG2/WG3

09:00 – 10:00 Session 3.1 joint WG1/WG2/WG3 – Room D

2. Presentation DebriSat in-situ measurements (H. Cowardin, NASA 30min)
3. Presentation ISS Space Debris Sensor (J. Hamilton, NASA, 15min)

10:00 – 11:00 Session 3.1 joint WG1/WG2 – Room D

4. Presentation ORDEM (M. Matney, NASA)
5. Feedback on WG1 light curve observations presentation and discussion (T. Yanagisawa, JAXA)
6. Discussion on light curve (all)
7. GEO attitude modeling (T. Cardona, ASI)

11:00 – 12:30 Lunch break

12:30 – 14:30 Session 3.2 – Room B

1. Theoretical Study of South-Staring BPE (S. Flegel, ESA, 20 mins)
2. ESA bistatic survey radar breadboard (F. Muller, CNES, 20 mins)
3. Discussion and proposal of new AI for 2015/6 24hr LEO campaign (all)
4. Cosmos (B. Hainaut, CNES, 15 mins)
5. Bistatic observations of GEO objects (P. Seitzer, NASA, 20 mins)
6. Molniya HEO surveys 2014 (N. Sakva, Roscosmos, 15 mins)
7. Roscosmos observations 2014 (N. Sakva, Roscosmos, 10 mins)
8. EQUO Equatorial Observatory for Space Debris (T. Cardona, ASI, 15 mins)
9. Discussion and proposal for co-ordinated higher Earth orbit (MEO) campaign (all)

14:30 – 15:00 Coffee/tea break

15:00 – 15:15 Preparation of WG report to SG

15:15 – 16:00 WG reports to SG

18:00 – 20:00 Aerospace Banquet – Norris Convention Center, Magnolia Room

4.1.4 Day 4: Thursday 2nd April 2015

08:30 – 10:30 Session 4.1 Future plans for WG1 – Room B

1. Discussion of co-ordination at higher Earth orbit (all)
2. Discussion of LEO light curve taxonomy (all)
3. Discussion of follow-on LEO light curve observation campaign (all)
4. MMT Observation Database for Light Curve Analysis (V. Agapov, Roscosmos, presented by P. Seitzer)
5. Discussion of population sampling at higher Earth orbit (all)
6. Preparation for Closing plenary

10:30 – 12:30 Closing plenary – Norris Convention Center, Magnolia Room

5 Annex B — WG1 Delegate contact information

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