Monitoring Space – Efforts Made by European Countries

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Abstract — The number of space objects monitored by USSPACECOM up to geostationary altitudes is on the order of 10,000. These objects need to be larger than 10 to 30 cm in order to be operationally trackable and identifiable. At present, the only nations with an operational space surveillance capability, and with a routinely updated space object catalog, are the USA and Russia. For several applications, ESA and the national space agencies in Europe so far largely depend on USSPACECOM data. In the past, only the German FGAN/TIRA radar, and the French ARMOR radar were able to provide additional, ad hoc orbit information on non-cooperative targets. For the acquisition of such objects, which contribute 94% of the catalog, these radars still require initial USSPACECOM data. This situation could improve with the French GRAVES system, which deploys an electronic fence into space. It detects and determines initial orbits of sub-meter objects passing through it. This information can be used for the tasking of additional sensors. Due to the range limitation of radars, telescopes are used to observe objects at larger distances, in particular at GEO altitudes. The ESA 1 meter telescope at Tenerife has demonstrated its capabilities for this orbit region. Several other instruments in the UK, France, and Switzerland are known to have comparable performances. In the small size region, below 10 cm diameters, experimental beam-park campaigns by the FGAN radar, in concert with the Effelsberg 100-meter radio telescope, and backscatter observations by the EISCAT system were able to detect objects down to 1 cm diameters. – The current status of capabilities of European radar and optical systems, and their possible contributions to a European space surveillance and monitoring system will be analyzed in this paper.

1 – Introduction

Most of the data on space debris is collected by the United States Space Command (USSPACECOM) using its Space Surveillance Network (SSN). This network of electro-optical and radar sensors detects, tracks, and identifies Earth orbiting objects, which are maintained in a space objects catalog, and published in different formats. Data histories of launch and release events, and on the status of space objects and their orbits are collected for instance in the NASA Satellite Situation Report, in the RAE Table of Earth Satellites (up to 1989), and in ESA's DISCOS database (Database and Information System Characterizing Objects in Space). USSPACECOM detects new objects, characterizes them, correlates them with a launch or release event, determines their orbits, and tasks the SSN sensors for subsequent follow-up observations. After a successful correlation of an object, its related data are entered into a catalog. The USSPACECOM catalog contains data of objects larger than about 10 cm to 30 cm in LEO, and larger than about 1 m in GEO. The detected objects comprise operational spacecraft (»6%), non-operation spacecraft (25.6%), rocket bodies (17.7%), mission related objects (10.8%), and large debris from fragmentations and release events (39.9%). By 31 Dec 2001, a total of 4,191 launches since Sputnik-1 had led to 27,050 trackable and identifiable objects. Of these, only 9,010 were still on orbit at this reference epoch. The remaining 18,040 objects had previously re-entered into the Earth atmosphere (the vast majority thereof due to natural decay). A small fraction of about 150 objects were injected into Earth escape orbits. Of the 9,010 operationally tracked, unclassified objects on orbit in Dec 2001, only about 550 can be assumed to be operational satellites (see also [2, 5]).

The combined tasks of the detection, characterization, correlation, and orbit determination of space objects describe the scope of "space surveillance". Apart from the US (supported by their SSN), only Russia has such an operational capability (supported by their Space Surveillance System, SSS). In the latter case, the corresponding catalog comprises orbit and characterization data of about 6,000 objects, due to the lack of SSS sensors at lower latitudes. Also France has an experimental surveillance system, the bi-static GRAVES installation (Grande R´eseau Adapt´e `a la Veille Spatial). The related catalog is limited to objects of typically 1 m size and larger, in low Earth orbits (LEO), with a total count of about 2,500 entries. Apart from sensors which are involved in routine space surveillance (SSN and SSS), there are also sensors which track known objects with higher accuracy (e.g. FGAN/TIRA and Monge/ARMOR [4, 1, 7]), and sensors which acquire more detailed statistical information on small-size objects (e.g. EISCAT [6, 8]). With a view from a European standpoint the current paper tries to give a survey of available European assets and processing capabilities for space surveillance (i.e. at sizes $d \gtrsim 10$ cm), and for a statistical monitoring of the terrestrial space object environment at hazardous, yet uncataloged size regimes (i.e. at diameters $d \gtrsim 1$ cm).

2 – Characterization of the Space Object Population

In Nov. 2002 the number of unclassified objects in the USSPACECOM catalog was» 9,400. These are typically larger than 10 cm in low-Earth orbit (LEO), and larger that 1 m in geostationary orbit (GEO), due to the decreasing sensor sensitivity, which is proportional to 1=ρ4 for radars, and 1=ρ2 for telescopes (where ρ is the slant range to the object). Hence, radars are primarily used for LEO, and optical systems are used for GEO surveillance and tracking. With 75.7% the vast majority of catalog objects resides in the LEO region, below 2,000 km altitude, with inclinations clustered around 65±, 74±, 82±, 90±, and 100± (FIG.1). Another 8.7% of the catalog orbits are in, or near the GEO ring at 35;786§2;000 km altitude, with inclinations below 15± (FIG.2). With 86.5%, near circular orbits of $e \cdot 0{:}1$ dominate in all orbit regimes. Another, though much smaller cluster, with 3.8% of the catalog, is at eccentricities around 0.7 due to geostationary transfer orbits (GTOs) and Molnija-type orbits. The remainder of the catalog belongs to the medium Earth orbit region, which also contains the semi-synchronous GPS and GLONASS constellation orbits near 20,000 km altitude.

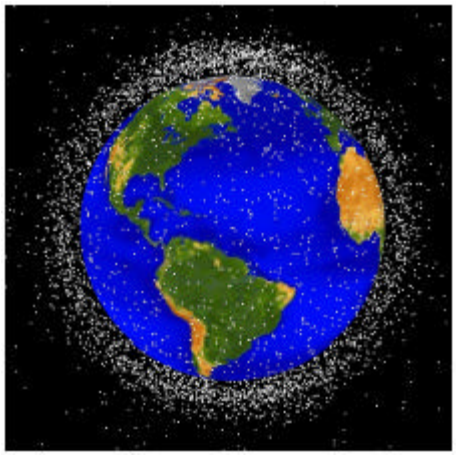

FIG 1: The 1997 USSPACECOM Catalog population in low Earth orbits (LEO).

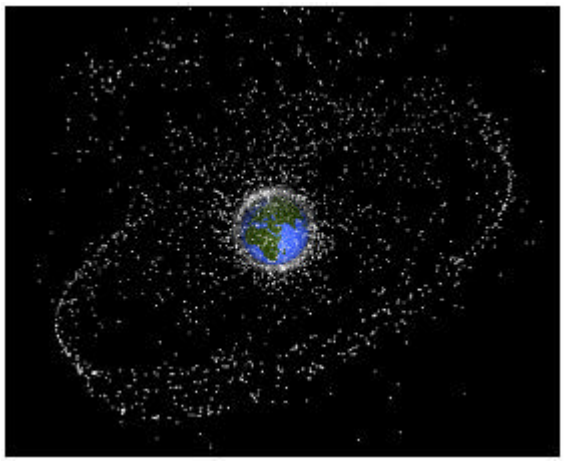

FIG 2: The 1997 USSPACECOM Catalog population up to geostationary altitudes (GEO).

Due to the given distribution of worldwide launch sites (with corresponding launch azimuth constraints), due to preferred injection orbits, and due to more that 170 on-orbit explosions of spacecraft and upper stages, the inclination and altitude distribution of catalog objects is inhomogeneous. Peaks in the spatial densities of LEO objects are noticeable at altitudes of 800 km to 1,000 km, and around 1,400 km. Peaks in the latitude distribution of objects are observed between 65± and 82±, were the dominant inclination bands have their highest resident probability. As a consequence, a zenith staring electronic fence deployed in Europe at 50±N will still be able to observe almost 80% of the entire catalog population. Due to the sparsely populated inclination bands at $i \cdot 50$±, the coverage would only improve by about +5% when moving ¡20± to the South. On the other

hand, it would deteriorate by ¡20% when moving +20± to the North. Hence, typical European latitudes are a good compromise between possible coverage of the orbit population, and frequent station passes (with pass frequency increasing with the station latitude ϕ according to $1=\cos\phi$ for an orbit of $i > \phi$). When pointing a radar located at $\phi = 50±$N in a southward direction, at an elevation of $h = 10±$, objects at the densely populated 900 km altitude band could still be observed on orbits of inclinations $i \cdot 30±$, at a range of » 2;500 km.

3 – A Survey of European Radar Sensors

Within Europe the initial development and deployment of tracking and surveillance sensors for space objects was mainly driven by national security requirements, with funding by the relevant ministries of defense. In some instances, sensors were also deployed under special agreements with USSPACECOM. Basic characteristics and (if available) performance figures of the most powerful European radar and optical installations will be provided in the following.

FIG 3: The GRAVES receiver at Apt, France (GRAVES = Grande R´eseau Adapt´e `a la Veille Spatial).

FIG 4: The GRAVES VHF transmitter station at Dijon, France.

FIG 5: Phased-array surveillance radar and tracking radars at Fylingdales, UK.

3.1 The Collateral Sensors Fylingdales and Globus II

The most powerful space surveillance sensor in Europe is located at Fylingdales (UK), and is operated by the British military. Most of the activities are geared to the US Space Surveillance Network (SSN) early warning and space surveillance missions. The Fylingdales complex (FIG.5) consists of 3 traditional tracking radars with 25 m antennas, housed in radomes, and a high performance 3-face, phased-array radar. Though details on its performance are not available, they can be expected to be similar to the American PAWS installations (Phased-Array Warning System), which operate in the UHF band, have active aperture diameters of 22 m, face tilts of 20± with elevation coverages of $3± \cdot h \cdot 85±$, and azimuth coverages of 120± for each face. For the

3 faces of the Fylindales phased array installation, this leads to near-hemispheric coverage (only excluding a small elevation horizon mask, and a gap of §5± around the zenith).
A second facility which is associated with the US SSN is the Norwegian Globus II radar. It is located at Vardø, at the northernmost tip of Norway, at $\phi = 70.35^{\pm}$N, and it is operated by the Norwegian Intelligence Service, under agreements with USSPACECOM. Globus II is an X band mono-pulse radar, with a 27 m parabolic dish antenna of 0.08± 3 dB beamwidth, housed in a radome of 35 m diameter. The radar can be operated in search or track mode, using different bandwidths, with corresponding range resolutions down to sub-meter levels. Globus II is currently entering its routine operations phase.
Due to the special bi-lateral agreements between the Fylingdales operators and USSPACECOM, and between Globus II operators and USSPACECOM, data from either site have so far not been available for unclassified use at space agency level within Europe.

3.2 The GRAVES Experimental Space Surveillance System
The French GRAVES system (Grande R´eseau Adapt´e `a la Veille Spatial) is presently the only European installation
outside the US SSN which can perform space surveillance in its classical sense. GRAVES is owned by the French Department of Defense (DoD), and is operated by ONERA. The concept of GRAVES is based on VHF transmitters with planar phased-array antennas of 15 m £ 6 m each, which are located near Dijon (FIG.4). Several of these tilted antennas can ultimately be arranged around a circle to deploy a conical detection fan up to altitudes of 1,000 km (at present there is one South-West facing and one South-East facing transmitter). Objects which pass through the detection volume (composed of individual detection fans) reflect the transmitted power, which is then received by a planar phased array of Yagi antennas located at Apt (FIG.3), 380 km South of the transmitter. The array of receiver antennas is arranged in a circular area of 60 m diameter.
The idea of the GRAVES continuous wave (CW) bi-static radar has its roots in the 1930-ies, when such systems were used as electronic fences for aircraft detection. The GRAVES system was developed during the 1990-ies, and started operational tests in 2001. It determines direction angles (azimuth and elevation), Doppler, and Doppler rates for a large number of simultaneous targets. From these data the processing software determines orbital element sets, of which initial estimates are sufficiently accurate to task other sensors, and to correlate subsequent detections of the same objects. As such, GRAVES produces a ”self-starting catalog” which can be autonomously built up and maintained. The detection size threshold up to 1,000 km altitude is on the order of 1 m, and the orbit coverage reaches down to inclinations of » 28±. A 1-month experimental catalog build-up in 2001 produced more than 2,200 entries.


FIG 6: The French tracking ship ”Monge”, with its ARMOR tracking radars.


FIG 7: The FGAN Tracking & Imaging Radar (TIRA) at Wachtberg, Germany.

3.3 The FGAN Tracking and Imaging Radar (TIRA)

The German FGAN Radar belongs to the Research Establishment for Applied Science at Wachtberg. It is a mono-pulse tracking and imaging radar (TIRA), located at 50:6±N, with a parabolic dish antenna of 34 m diameter, housed in a 49 m diameter radome (FIG.7). The radar uses L-band for tracking (1.333 GHz, 1 MW peak power, 0:45± 3 dB beamwidth), and Ku-band for SAR imaging (1.67 GHz, 13 kW peak power, 0:031± 3 dB beamwidth). In its tracking mode, the TIRA system determines azimuth and elevation angles, range, and Doppler for a single target. A near real-time processing software can determine orbits, which are compatible with the US SSN's Two-Line Element catalog format, from single station passes. The accuracy is generally sufficient to re-acquire the object a few days later. The detection threshold for TIRA is » 2 cm at 1,000 km range. This sensitivity can be enhanced when operating TIRA and the nearby (21 km away) Effelsberg 100 m radio telescope (FIG.8) in a bi-static beam-park mode. This was done during 4 campaigns in 1997, 1999, 2001, and 2002, leading to detection statistics for objects as small as 0.9 mm, with orbit information limited to altitude and Doppler inclination. In the future, an upgrade of the Effelsberg receiver system would allow full orbit determinations of such objects.

The TIRA L-band system has in the past provided time critical information on orbits of re-entry risk objects (e.g. Skylab, Cosmos-1402, Salyut-7), and of potential collision partners of ESA satellites (e.g. ERS-1). This information was used to improve the assessment of risk levels, and to issue alerts with a reduced false alarm probability. The imaging capabilities of TIRA's Ku-band radar were also called upon at several occasions of spacecraft emergencies, or for the post-launch verification of the deployment of spacecraft appendices. TIRA's range-Doppler SAR imaging technique exploits the changing aspect angles due to the orbital motion and due to the spacecraft attitude motion to produce images with range resolutions of » 18 cm.

3.4 Monge/ARMOR and the DGA Radars

DGA/DCE, the Systems Evaluation and Test Directorate of the French Ministry of Defense, is operating several radar and optical sensors throughout France. Their radar sensors are of 4 different types:

- ARMOR: C-band (» 5:5 GHz), monopulse system, with 1 MW peak power; 10 m dish antenna, with 0:4± 3 dB beamwidth; 2 units located on the Monge
- B´earn: C-band, scanning system, with 1MWpeak power; 4 m dish antenna, with 0:96± 3 dB beamwidth; 3 units located at Toulon, 2 at Quimper, and 4 at Cazaux
- Provence: C-band, monopulse system, with 1 MW peak power; 4 m dish antenna, with 0:96± 3 dB beamwidth; 1 unit located at Toulon
- Gascogne: C-band, monopulse system, with 0.5 MW peak power; 4 m dish antenna, with 0:9± 3 dB beamwidth; 1 unit located on the Monge

The most powerful of these systems, ARMOR, is located on the tracking ship Monge (FIG.6), which displaces 21,040 tonnes, has dimensions of 230 m £ 25 m, and mainly supports French ballistic missile tests. Outside test and support campaigns the Monge is stationed at Brest. The two ARMOR radars on the Monge are dedicated to tracking tasks. Within their main beam they can observe up to 3 objects simultaneously at up to 4,000 km range. The ARMOR tracking radar generates high resolution angular data (azimuth and elevation), and range data. The quality of ARMOR and TIRA data has been verified against high-precision ephemerides of SPOT-4

[1]. In an on-line mode the Monge data can be processed to generate TLE data sets. More precise osculating element sets require off-line processing. ARMOR tracking data and orbit determinations have in the past been called upon for similar applications as TIRA data (i.e. support for risk object re-entry and conjunction event predictions). As for TIRA, also ARMOR data can be processed to generate SAR images of spacecraft.

3.5 The Chilbolton Radar

The Chilbolton radar is located in Winchester/UK, and it is operated by the Radio Communications Research Unit (RCRU) of the Rutherford Appleton Laboratory (RAL). This monopulse S-band (3 GHz) radar is presently used mainly for atmospheric/ionospheric research, and for radio communications research. It has a 25 m parabolic dish antenna with a 3 dB beamwidth of 0:28±. The current magnetron transmitter of peak/mean power level 600 kW/0.187 kW is currently being replaced by a traveling wave tube with 120 kW/2.7 kW, to make the radar more suitable for the tracking of LEO objects, with a expected detection threshold diameter of » 10 cm at 600 km altitude. In this upgraded constellation the Chilbolton radar could contribute as a tracking sensor to a European surveillance system.

3.6 The European Incoherent Scatter Radar (EISCAT)

EISCAT is a network of European Incoherent Scatter Radars, with sites at Tromsø/Norway (UHF transmitter & receiver at 69:58±N, FIG.9), Kiruna/Sweden (UHF receiver at 67:87±N), Sodankyl¨a/Finland (UHF receiver at 67:37±N), and Longyearbyen/Svalbard (UHF transmitter & receiver at 78:15±N). The EISCAT system is mainly used for high latitude atmospheric and ionospheric research. Its data, however, also contain information on LEO objects. After an upgrade of their system, the Tromsø transmitter with its 32 m antenna, and the colocated receiver performed a proof-of-concept campaign in Feb. 2002 [8]. Within 4.5 hours, 56 objects of sizes from 0.5 m down to 1.9 cm diameter could be detected at altitudes of 490km · H · 1;480km. These EISCAT debris measurements generate range and Doppler data only, and they are not sufficient to deduce complete orbits. However, they can be generated as low-cost, piggy-back products during routine atmospheric research, and they provide a valuable means of validation for catalogs and debris models.

FIG 8: The 100-meter radio-telescope at Effelsberg, Germany.


FIG 9: Parabolic EISCAT receiver antenna at Tromsø, Norway.

4 – A Survey of European Optical Sensors

Optical sensors are mostly used to observe objects beyond LEO altitudes, particularly near the important GEO ring. This is due to the higher sensitivity of telescopes ($\propto 1/\rho^2$), as opposed to radars ($\propto 1/\rho^4$, where ρ is the range to the target). The reason is a 1-way power dilution (target ! telescope) for optical systems, due to the illumination by the Sun, as opposed to a 2-way power dilution (radar!target!radar) for actively illuminated targets in case of radars. As a disadvantage versus radars, optical observations are constrained in their useful observation times: (1) the target must be illuminated by the Sun, and the observer must be in the Earth shadow, more than 18± away from the Sun terminator, (2) nights around full Moon must be avoided, and (3) meteorological conditions must be acceptable. High performance telescopes have CCD detectors (charge-coupled devices), which are often cooled to reduced thermal noise, and which often have (GPS-)time-synchronised read-out electronics. Europe has several optical systems which could form part of a surveillance and tracking network, and which shall now be reviewed.

4.1 The ESA Space Debris Telescope

ESA operates a Zeiss telescope of 1 m aperture and 0:7± field of view (FoV), which is located on Tenerife at 28:17±N (FIG.10). The telescope is of the Cassegrain type, with an English mount, and with a Coud´e focus for optical communication applications (e.g. with Artemis), and a Ritchey-Chr´etien focus for space debris observations. The Ritchey-Chrétien system of $f = 4{:}47$ focal length leads the light through a hole in the primary mirror to a 4£4 array of CCD chips of 2048£2048 pixels each. The liquid nitrogen cooled CCD array cumulates the received energy of the photons during integration times of typically 2 sec, before reading it out within » 19 sec. Up to 3 read-outs (images) per minutes can be produced, with a detection threshold of +19 to +21 mag for a signal-to-noise of S/N ¸ 5. This allows to detect and follow objects of d ¸ 15 cm at GEO altitudes (assuming an object albedo of 0.1).

The ESA Space Debris Telescope (ESA SDT) covers a sector of »120± of the GEO ring. During a campaign in 1999, with 49 hours of observations in total, 206 unique objects could be identified, of which only 27% could be correlated with the USSPACECOM catalog. From single observations, initial orbits can be derived which are generally adequate for re-acquisition of the object, and which can be successively improved.


FIG 10: The ESA 1-meter telescope at Tenerife, Spain.


FIG 11: The French SPOC optical sensor.

4.2 The SPOC and ROSACE Telescopes

SPOC (Syst`eme Probatoire d'Observation du Ciel, FIG.11), a wide field-of-view (50± £50±) optical space observation system, is part of the network of tracking facilities of the French DGA (D´el´egation G´en´erale pour l'Armement), with observation sites at Toulon and Odeillo. Each of the presently 2 stations has 4 cameras, facingWest, North, East (at elevations > 20±), and vertical. The cameras are equipped with CCDs of 576£384 pixels, with threshold sensitivities of » 6 mag to 7 mag. In clear nights, this allows the detection of 100 to 400 objects, of which typically 80% to 90% can be correlated with the catalog. The azimuth and elevation measurement data can be processed to generate initial orbits (assuming eccentricity *e* ¼ 0). The SPOC system has also been used to deduce the intrinsic attitude motion of spacecraft (as for SPOT-3) from an analysis of photometric data (light curve histories).

CNES, the French Space Agency, is using the ROSACE Newton-type telescope for the observation of slowly moving, near-GEO objects down to limiting magnitudes of 19 mag. ROSACE has an aperture of 50 cm, and a CCD camera with an array of 1024£1556 pixels, corresponding to a field of view of 0:3± £0:4±. Orbit determinations are performed on the basis of precise azimuth and elevation direction angles, with point errors · 1 arcsec (3 σ). In 2001, 53 test campaigns were performed to validate the determination of GEO orbits against benchmark results of the French T2A & T2D satellites. CNES is planning to combine the ROSACE performance with the flexibility of the TAROT telescope, which is located on the Calern Plateau, and which has been used by CNRS mainly to detect γ-ray bursts. TAROT has a 25 cm aperture, and a FoV of 2±£2±. It is equipped with a CCD chip of 2048£2048 pixels, with a fast read-out time of 2 sec. CNES intends to use TAROT as a detection instrument, which forwards pointing information to the ROSACE telescope for followup measurements and subsequent off-line orbit determinations of objects in and near the GEO ring. Tests of the combined ROSACE/TAROT system are ongoing.

4.3 The PIMS Telescopes

PIMS (Passive Imaging Metric Sensor) is an optical system for the surveillance of the GEO and deep space region, operated by the United Kingdom Ministry of Defense. PIMS telescopes are located at Herstmonceux (UK), Gibraltar, and Cyprus. The three sensors cover 165± of the GEO ring (65±W to 100±E). The azimuthelevation mounted Cassegrain-type telescopes have an aperture of 40 cm, and a FoV of 40 arcmin £ 40 arcmin.

The images are captured on a CCD chip of 1024£1024 pixels, which can be read out within less than 5 sec. The PIMS system can detect GEO objects down to 1 m diameter, with a position accuracy better than 10μrad.

4.4 The Zimmerwald Telescope

The Astronomical Institute of the University of Berne (AIUB) is operating a Cassegrain telescope, with Ritchey-

Chr´etien optics, an aperture of 1 m, and a field of view of 0:5±. The telescope has an azimuth-elevation mount, and is housed in a hemispheric, foldable dome. From its location at 46:8±N the sensor can cover a sector of » 100± of the GEO ring. Images are taken with a CCD chip of 2048£2048 pixels, with a sensitivity down to 20 mag. The Zimmerwald telescope was used as a test site for validating procedures and processing algorithms of the ESA telescope. During two short observation campaigns in 2000, the instrument detected 75 uncorrelated objects in GEO. The primary objectives of the site are, however, astrometry (also for GEO and GTO objects), and Laser ranging (for satellite geodesy applications).

FIG 12: The 1 m telescope of the University of Berne (AIUB) at Zimmerwald, Switzerland.

FIG 13: The atmosphere & communication research radar of RAL at Chilbolton, UK.

5 – Outlook to a European Space Surveillance System

From the preceeding survey of European space surveillance assets it becomes evident, that during the past decade European research and development related to space surveillance has made significant progress. The existing experimental and operational radar and optical sensors, in conjunction with corresponding hard- and software for measurement data processing, have demonstrated their suitability as corner stones, or at least as stepping stones for future developments of a coordinated European space surveillance program.

European countries, via their national Space Agencies and/or Ministries of Defense, and the European Space Agency have procured several new developments, or have used (in many cases upgraded) existing facilities to monitor the Earth orbital environment up to and beyond GEO altitudes. Several optical systems for surveys of the important GEO region and its neighborhood have reached, or are close to reaching an operational status.

The ESA Space Debris Telescope, the French ROSACE/TAROT system, and the UK PIMS sensors, in combination with related processing hard- and software, have demonstrated that they can detect GEO objects well below the stated USSPACECOM size threshold of 1 m diameters. All of these systems can also correlate observations with known objects, and identify new ones, with good orbit determination accuracies, and photometric fingerprints of the detected objects. For altitude regions between LEO and GEO, the existing optical observation techniques may have to be adjusted to accept larger mean motions of the space objects to be observed. The

tracking and imaging of (known) LEO objects by the German FGAN/TIRA radar, and by the French ARMOR radars is meeting highest international standards with respect to sensitivity and accuracy. Further radar sensors of the French DGA, and the upgraded UK Chilbolton radar would be able to cover additional tracking tasks, with lower requirements on sensitivity. All of these radar sensors could be tasked with inputs from an upgraded GRAVES system (or of a new, dedicated system with improved capabilities), thus avoiding the current dependence on USSPACECOM TLE orbit data for the station pass prediction. The GRAVES system is presently the only LEO sensor which performs true space surveillance, with a self-starting catalog build-up, an initial orbit determination process, and a correlation of detections with known objects. From its location near 45±N GRAVES could observe up to 85% of the current USSPACECOM catalog, if its sensitivity would be improved, and if its range would be extended beyond LEO. The deployment of more transmitters (currently 2) and more receivers (currently 1) would also extend the system capabilities. Beam park experiments, combining an efficient transmitter (e.g. FGAN) with a large receiver antenna (e.g. Effelsberg), and piggy-back measurements in context with atmospheric research radars (e.g. EISCAT) would add to the statistical knowledge on cm-size objects in LEO. Information on sub-mm objects can be deduced from returned space hardware, while data on μm-size objects can be collected by in-situ detectors. The ESA MASTER model (Meteoroid & Space Debris Terrestrial Environment Reference), and its associated observation planning tool PROOF (Program for Radar & Optical Observation Forecasting) can be used to predict statistical detection rates for a given instrument, or to predict radar or telescope pass characteristics in case of known objects [3].
At present a consortium of some of the most experienced developers in Europe is studying which steps need to be taken to arrive at a European Space Surveillance System. Alternative system proposals with different levels of cost, complexity, and capabilities will be elaborated. The definition phase of this ESA study took benefit from a recently installed Space Debris Network of Centers, where all major Space Agencies of Europe are represented (i.e. ESA, ASI, BNSC, CNES, and DLR).

6 – Summary and Conclusions

ESA and European countries with space monitoring capabilities are strongly dependent on initial object and orbit information provided by USSPACECOM. This dependence may be reduced, and ultimately resolved with the installation of an operational European Space Surveillance Network. With currently existing observation and data processing capabilities, both in the radar and optical domains, researchers and developers in Europe have demonstrated that all major tasks associated with space surveillance can be covered today, though in some areas not yet to an adequate level of completeness and accuracy. An industrial study, sponsored by ESA, is presently analyzing how the existing assets can be most efficiently used, and which new developments would have to be performed, in order to attain an autonomous European surveillance capability.
Several obstacles will have to be overcome on the way to a European Space Surveillance Network. The currently operated sensors are often tailored to a partial surveillance or tracking autonomy by individual states, or by ESA. Hence parallel developments often resulted in different systems of comparable performance. Moreover, also within the different countries, systems are sometimes operated by national space agencies, and/or by national ministries of defense. These divided responsibilities often touch on national security aspects, which may pose a problem to open information exchange within a given nation, and particularly across national boundariest. It is not clear yet, if and how existing national assets may contribute to a European system, or to what extent new developments under joint European responsibility must be procured instead. Another issue to be resolved is the cost of deploying and operating a European Space Surveillance Network. Both the technical, administrative, and financial aspects will need high-level programmatic decisions at a European level.

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