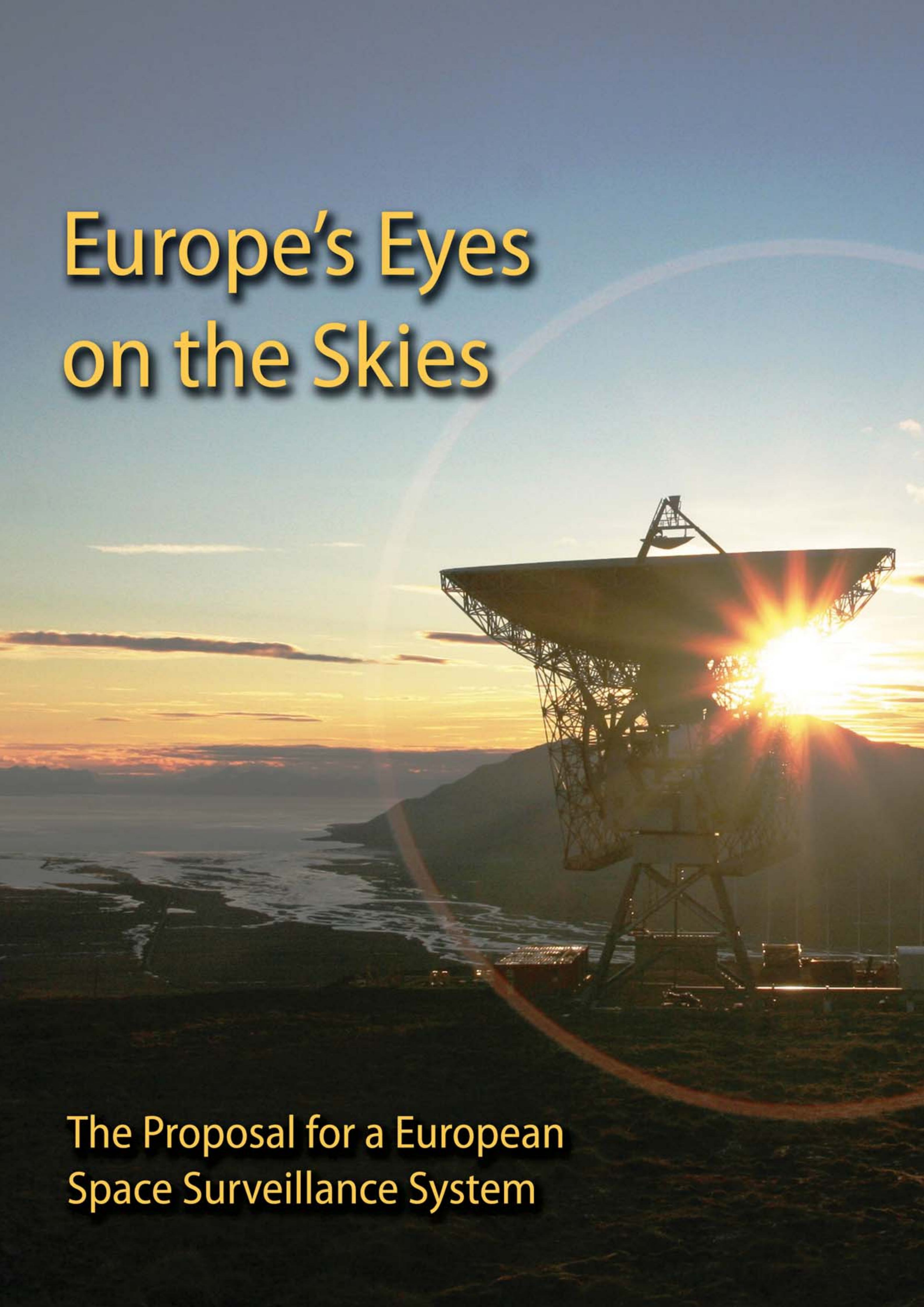

Europe's Eyes on the Skies

The Proposal for a European Space Surveillance System

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The EISCAT radar on Svalbard. This and similar radars could form the basis for a European space surveillance network (Y. Rinne)

Space surveillance is the detection, correlation, characterisation and orbit determination of objects in space. At present, only the USA and Russia have this operational capability with a routinely updated space object catalogue. Plans are now being discussed for a future European Space Surveillance System and, for eventually, a 'Space Situation Awareness System'.

Introduction

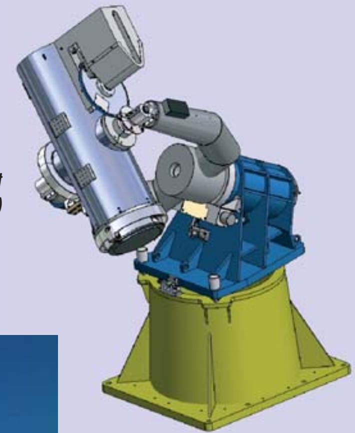
While some European radar and optical facilities exist for tracking and imaging space objects, Europe has no systematic, operational capability for space surveillance, and is therefore strongly dependent on external information, mainly from the USA.

Following an ESA Council Resolution (ESA/C(89)24) calling for a risk assessment of spaceflight, two tasks were identified : the acquisition of space object data and the analysis of the feasibility European space surveillance capability.

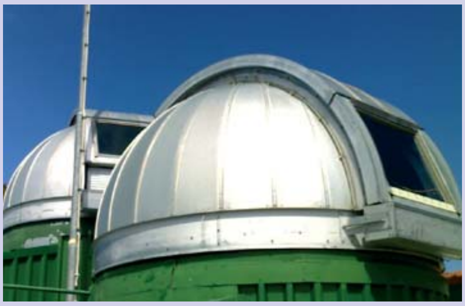
The latter task became the responsibility of the European Coordination Group on Space Debris. Its members (BNSC, CNES, DLR and ESA) were asked to do a feasibility study for a

Existing Optical Sensors

The ESA Space Debris Telescope at Tenerife, Spain (ESA)



The TAROT telescope of CNRS at Calern/France and in Chile (CNRS)



The Starbrook telescope of BNSC at Cyprus (SpaceInsight)

The ZIMLAT telescope at Zimmerwald, Switzerland (AIUB)

The ZimSMART telescope at Zimmerwald, Switzerland (AIUB)

Tenerife

ESA operates a space debris telescope on Tenerife that covers a sector of 120° of the GEO ring. From single observations, initial orbits can be derived which are generally adequate for re-acquisition of the object within the same night, and which can then be successively improved.
Technical specs: Telescope of 1 m aperture and 0.7° field of view, located on Tenerife. It uses a 2x2 mosaic of CCDs of 2048 by 2048 pixels each, with a detection threshold of +19 to +21 visual magnitude (corresponding to 15 cm objects at GEO altitudes).

TAROT

CNES uses observation time of the TAROT telescope (Télescope à Action Rapide pour les Objets Transitoires) to survey the GEO ring. TAROT's primary mission is to detect the optical afterglow of gamma-ray bursts. A companion telescope, TAROT-S has been deployed in Chile.
Technical specs: Telescope of 25 cm aperture, and field of view of 2° x 2°. It is equipped with a CCD of 2048 by 2048 pixels for detections and follow-up measurements of objects up to visual magnitude +17 in and near the GEO ring.

Starbrook

The British National Space Centre (BNSC) has sponsored the Starbrook wide-field telescope as an experimental survey sensor since 2006. The telescope is located at Troodos/Cyprus, It can detect GEO objects down to 1.5 m sizes (visual magnitude of +14).
Technical specs: The telescope has an aperture of 10 cm, a field of view of 10° x 6°, and a CCD of 4008 by 2672 pixels.

ZIMLAT/ZimSMART

The Astronomical Institute of the University of Bern (AIUB) operates a ZIMLAT telescope. From its location in Zimmerwald, the telescope covers a sector of 100° of the GEO ring. The primary applications of ZIMLAT are astrometry and laser ranging. However, up to 40% of its night-time observations are used for follow-ups of GEO objects discovered by the ESA telescope. ZIMLAT was complemented in 2006 by the 20 cm ZimSMART telescope (Zimmerwald Small Aperture Robotic Telescope).
Technical specs: ZIMLAT telescope with aperture of 1 m and a field of view of 0.5°. A CCD of 2048 by 2048 pixels allows the detection of objects up to visual magnitude +19. The ZimSMART is dedicated to GEO survey, using a CCD of 3056 by 3056 pixels with a field of view of 4.2°.

European space surveillance capability. A Space Surveillance Task Force was formed and its 2006 report, 'Space Surveillance for Europe – a Technical Assessment', defined the main criteria for a future European Space Surveillance System (ESSS).

These can be summarised as follows:

- full coverage of LEO (Low-Earth orbit (below 2000 km altitude)), GEO (Geostationary Earth orbit (35 786 ± 2000 km altitude)) and 12-hour, near-circular MEO (Medium Earth orbit) orbits; limited coverage of orbits outside these regions;
- autonomous build-up and maintenance of a catalogue of all observable space objects;
- detection, tracking, orbit determination, target correlation, and physical characterisation for objects in LEO, MEO and GEO with a reliability and sensitivity matching the one of the US Space Surveillance Network (SSN);
- estimation of orbit manoeuvres;
- detection of on-orbit break-up events and correlation with the source object(s).

Later, aspects of space situational awareness were studied:

- extended object characterisation attributes, including mission objectives and capabilities;
- well-defined accuracy and timeliness of data products, dissemination and sharing;
- data security, confidentiality, integrity and high availability;
- incorporation of available national sensors.

Space Object Observation

In early 2006 (all population data in this article shall refer to Jan. 2006), the number of un-classified objects in the US Space Surveillance Network (SSN) catalogue was in the order of 10 000. These catalogue objects are typically larger than 10 cm in LEO and larger that 1 m in GEO. Due to sensitivity ranges, radars are primarily used for surveillance and tracking in LEO and optical systems for GEO. With 75.7%, the vast majority of catalogue objects reside in the LEO region. Another 8.7% of the catalogue objects are in or near the GEO ring. The remainder of the catalogue mainly belongs to the MEO region, which also contains the near-circular, semi-synchronous GPS and GLONASS constellation orbits near 20 000 km altitude.

Peak concentrations of catalogue objects exist at altitudes of 800 km to 1000 km and again around 1400 km. Peaks in the latitude distribution are located between 65° and 82°. As a consequence, a zenith-facing 'electronic fence' deployed in Europe at 50°N is able to observe almost 80% of the entire US SSN catalogued objects. Hence, European latitudes are a good compromise between coverage of the orbit population and frequent station passes.

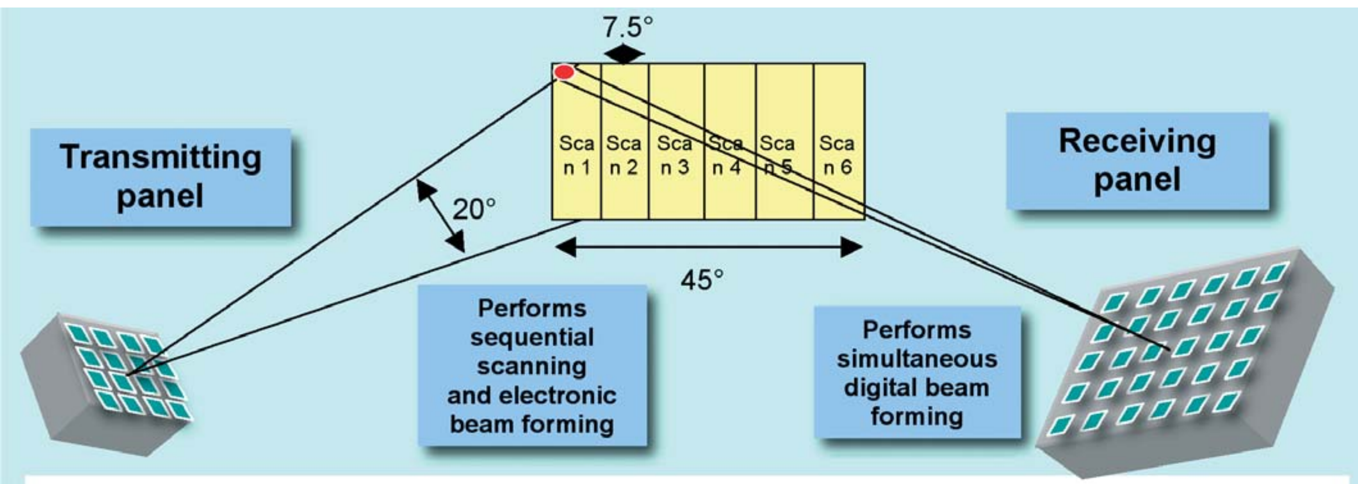
Assessment of a Proposed European Surveillance System

Ground-Based LEO Surveillance Concept

A survey of existing sensors (see pages 44 and 47), in combination with findings from several ESA studies, has led to the following core recommendations for a European Space Surveillance System (ESSS) radar design to cover the LEO region:

- radar design: bistatic continuous-wave radar operating at 435 MHz (with increased transmitter power, the cataloguing performance remains close to the technically optimal 600 MHz frequency);
- transmitter: four phased arrays (26 elements each with 16 kW transmitted power);
- receiver: four phased array receivers (1500 elements each).

It is expected that 98.6% of the US SSN catalogue and 96.1% of the more complete MASTER-2001 (Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) model (ESA)) debris environment population larger than 10 cm can be detected and catalogued for a radar range of



Concept of the proposed bistatic LEO surveillance radar (ONERA)

1500 km. The simulations done for the performance evaluation are based on ONERA's Surveillance System Simulation (S3) software, run over a simulation timespan of one month.

For the location of the bistatic LEO radar, two sites in Spain are considered: Pico Villuercas in Extremadura for the transmission and the Arenosillo military base in Andalucia for the reception. Spain constitutes a near-optimal deployment location due to sufficiently frequent sensor passes with acceptable observation gap times. A three-phase ESSS radar development is foreseen to extend over a period of five years. Its estimated costs at completion are €114.3 million. First operational test campaigns could begin three years after the start of the ESSS development.

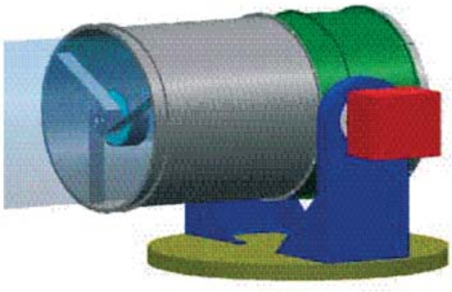
Ground-Based GEO Surveillance Concept

Due to large distances to the targets, the survey of this family of orbits is normally done with optical instruments. In an assessment study two different types of sensors were identified to be necessary:

– detection and tasking: 0.5 m telescopes with a wide field of view of 3° x 3°;
– survey: 1.0 m telescopes of a field of view of 1.2° x 1.2° (alternative: 0.5 m telescopes).

The proposed GEO survey strategy implies a continuous coverage of a strip of ±17° in latitude, centred on the equator. Each GEO object crosses this strip once within 24 hours. Since a single sensor cannot cover this strip continuously (due to visibility constraints and nighttime limitations), a network of low-latitude optical sensors equally distributed in longitude is required. The observation strategy uses a combination of survey observations (searching for new objects) and tasking observations (for initial orbit determination and orbit improvement).

The GEO sensors (telescopes) should be uniformly distributed in longitude, at sites of low latitude, with acceptable meteorological and visibility conditions.



Concept of the proposed GEO observation telescope (AIUB)

A first network of sensors could consist of three sites for instance: Tenerife (E), Perth (AUS) and the Marquesas Islands (F). Each site would be equipped with a detection and tasking telescope, and with a survey telescope. The coverage of the GEO ring from these sites is about 85%. It can be extended to 95% by adding a fourth site at Cyprus. Each of these telescopes should be collocated with a telescope for tasked observations. The total cost of the GEO surveillance system is expected to be €16.2 million, distributed over five years.

Ground-Based MEO Surveillance Concept

About 2% of the US SSN catalogue population is related to MEO objects in the vicinity of the 12-hour, near-circular orbits of navigation satellite constellations. This small, yet important population of space objects can be monitored down to size thresholds of 0.3 m to 1.0 m by means of two dedicated survey telescopes of aperture 0.8 m, with a field of view of 4.7°, for instance located on Tenerife and the Marquesas Islands. The proposed 0.5 m GEO tasking telescopes could also provide the needed MEO tasking capability.

The development and deployment cost of this MEO system will be approximately €8.0 million over a three-year period. Its cataloguing performance is expected to reach up to 95% of the US SSN MEO catalogue population.

Surveillance of Orbits outside LEO, MEO and GEO

The share of objects in the US SSN catalogue, which do not belong to the LEO, GEO, or near-circular MEO class, is approximately 20%. In an operational space surveillance system, the survey of this class objects would have lower priority in view of the limited return for effort spent.

Surveillance Capabilities of On-Orbit Sensors

Preliminary assessments suggest that the most promising space-based telescope scenario* would be a survey of the GEO region from a Sun-synchronous low-Earth orbit. The proposed telescope could have an aperture of 20 cm and a conical field of view of 6°. The detection threshold would be at visual magnitudes of +15.8 in GEO. The unit price of this payload sub-system, including the in-orbit and ground-support hardware and software, is estimated to be €6.8 million.

Assessment of Cataloguing and Data-processing Performances

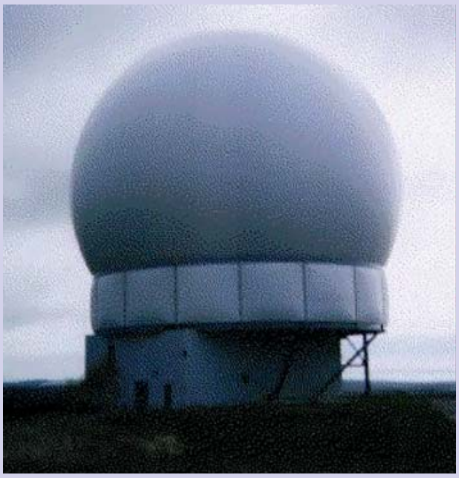
To assess the performance of a generic space surveillance system, an Advanced Space Surveillance System Simulator (AS4) was developed. It uses radar and telescope system models to translate sensor-specific field-of-view crossings of orbital objects into estimated instrument detection rates for a space object population according to ESA's MASTER-2001 space debris environment model. This MASTER-2001 population consists of 17 800 'real' objects larger than 10 cm (as opposed to about 10 000 US SSN catalogue objects of the same size), of which approximately 55% are in the LEO regime.

The AS4-simulated catalogue build-up process is self-starting, with no initial information required. In a test, the simulator was applied to 20 000 tracks, with 4 500 000 measurements, covering 93% of the entire observable population larger than 10 cm. After one day of simulated radar operations more than 90% of the LEO population was

* *This observation concept was successfully demonstrated by the SBV (Space-Based Visual) sensor of 15 cm aperture on the American MSX satellite. For a limited time, it contributed about 20% of the SSN GEO catalogue.*

Existing Radar Sensors in Europe

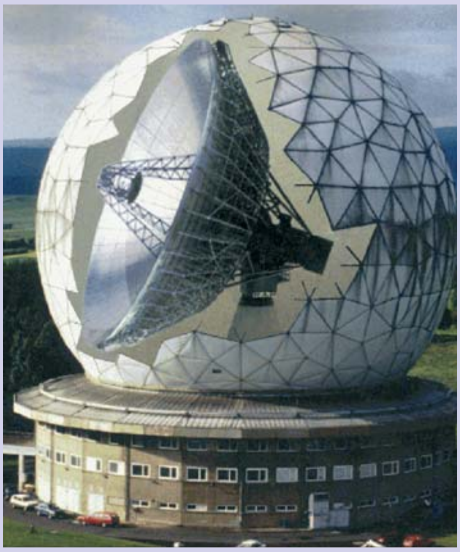
Fylingdales
The most powerful space surveillance sensor in Europe is located in Fylingdales (UK) and is operated by the British armed forces. Most of the activities are geared to the US Space Surveillance Network (SSN) early warning and space surveillance mission.
Technical specs: The Fylingdales complex consists of a high-performance 3-face, phased-array radar operating in the UHF-band. Technical details not openly available.



The Globus II X-band radar of the NIS at Vardø, Norway (NIS)

Globus II
A second facility associated with the US SSN is the Norwegian Globus II radar. It is located in Vardø, at the northernmost tip of Norway. Due to special bilateral agreements between the US SSN and the operators of Fylingdales and Globus II, data from these sites have so far not been available for unclassified use within Europe.
Technical specs: Globus II is an X-band mono-pulse radar, with a 27 m parabolic dish antenna, housed in a 35 m radome.

GRAVES
The French GRAVES system (Grand Réseau Adapté à la Veille Spatiale) is presently the only European installation outside the US SSN that can perform space surveillance in the classical sense. GRAVES is owned by the French Ministry of Defence and operated by the French air force. The system produces a 'self-starting' catalogue which can be autonomously built up and maintained. It is limited to objects of typically 1 m size and larger in low Earth orbits (LEO), with a total count of about 2200. Routine operations started in 2005.
Technical specs: GRAVES is based on VHF transmitters with four planar phased-array antennas of 15 m by 6 m each, which are located near Dijon. These tilted antennas are arranged in a south-facing semi-circle to deploy a conical detection fan up to altitudes of about 1000 km. Objects which pass through the detection volume reflect a fraction of the transmitted power, which is then received by a planar phased array of dipole antennas, arranged in a circular area of 60 m diameter, located at Apt, 380 km south of the transmitter. The GRAVES system determines orbital element sets from measurements of direction angles, Doppler, and Doppler rates for a large number of simultaneous targets.



The TIRA L and Ku-band radar of FGAN at Wachtberg, Germany (FGAN)

TIRA
The German FGAN Radar belongs to the Research Establishment for Applied Science at Wachtberg. In its tracking mode, the TIRA system determines orbits from direction angles, range, and Doppler for single targets. The detection size threshold is about 2 cm at 1000 km range. For statistical observations this sensitivity can be enhanced to about 1 cm, when operating TIRA and the nearby Effelsberg 100 m radio telescope in a bistatic beam-park mode with TIRA as transmitter and Effelsberg as receiver.
Technical specs: This is a mono-pulse tracking and imaging radar (TIRA) with a parabolic dish antenna of 34 m diameter, housed in a 49 m diameter radome. The radar uses L-band for tracking at 1.333 GHz, with 1 MW peak power, and Ku-band for Inverted Synthetic Aperture Radar (ISAR) imaging at 16.7 GHz, with 13 kW peak power. TIRA's range-Doppler ISAR imaging in Ku-band produce images with range resolutions better than 7 cm.

The Armor C-band radars on the French naval vessel Monge *(DGA)*

The Chilbolton S-band radar of RAL at Chilbolton, UK (RAL)

FS Monge

DGA/DCE, the Systems Evaluation and Test Directorate of the French Ministry of Defence, is operating several radar and optical sensors throughout France. The most powerful of these systems, Armor, is located on the tracking ship Monge. The two radars are dedicated to tracking tasks, based on high resolution angular and range data.
Technical specs: Armor C-band radars 5.5 GHz, 1 MW peak power

Chilbolton

The Chilbolton radar is located in Winchester, UK, operated by the Rutherford Appleton Laboratory (RAL). It is mainly used for atmospheric and ionospheric research. With a planned upgrade the radar will be able to track LEO objects down to 10 cm sizes at 600 km altitude.
Technical specs: Monopulse S-band (3 GHz) radar with a 25 m parabolic dish antenna

EISCAT

EISCAT is a network of European Incoherent Scatter Radars, with sites in Tromsø/Norway, Kiruna/Sweden, Sodankylä/Finland and Longyearbyen/Svalbard. The EISCAT system is mainly used for high-latitude ionospheric research. Its radar echoes, however, also contain information on LEO space objects. The Tromsø transmitter/receiver site is able to detect objects down to 2 cm sizes at altitudes of 500 to 1500 km. Since these measurements are insufficient to determine complete orbits, EISCAT is only of limited value for space surveillance.
Technical specs: 32 m antenna

catalogued. The final product is a database with identification and characterisation data for each unique object, estimated orbital parameters, and information on the orbit determination uncertainty. The achievable orbit determination position accuracy is on the order of 1–10 m in LEO, and 10–1000 m in GEO and MEO regions.

Dual-use Requirements on Space Surveillance Data

The term 'dual use' in the context of space surveillance data refers to civilian users, and military or state authorities. The information required by these communities can differ.

Next steps

These ESSS feasibility studies on the system design and operational concepts were performed with the intention to define a modular space surveillance system, which can be composed of subsystem building blocks with proven, low-risk technologies, and which can be used as a starting point for a more comprehensive 'space situation awareness system'.

Existing European and ESA assets could be used to test and validate critical technologies and data processing concepts during the development and deployment of the proposed European Space Surveillance System. They could subsequently be employed for dedicated surveillance tasks, for space situation awareness applications, and for dedicated national investigations and database maintenance, either stand-alone or in cooperation.

The preliminary technical, programmatic and cost information provided here is intended as an aid for interagency and intergovernmental discussions for a future European Space Surveillance System and, eventually, for a Space Situation Awareness System. This topic is intended to be discussed at the next ESA Council Meeting at Ministerial Level in 2008.