Optical surveillance of space

Philip Herridge

Space Insight Limited

What is surveillance of space?

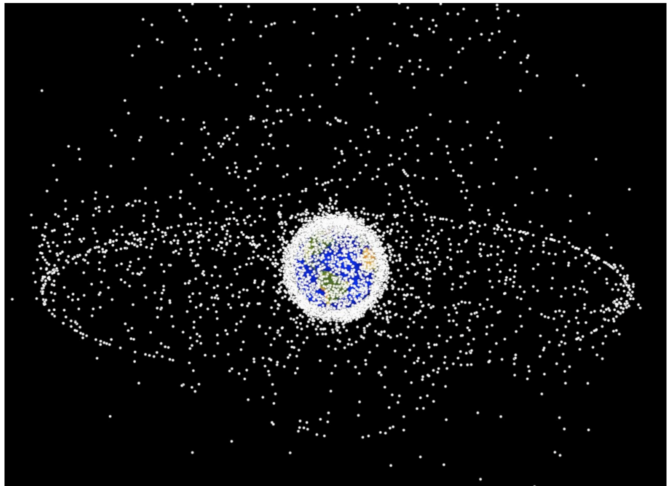
surveillance *of* space not surveillance *from* space

surveillance of space is the timely detection, identification, characterisation and orbit determination of *man-made* space objects

it is a primary element of SSA, Space Situational Awareness

surveillance of space seeks to answer:

- what is up there?
- what is it?
- where is it going?
- what is it doing?
- what could it do?



Graphic, NASA, Orbital Debris Program Office

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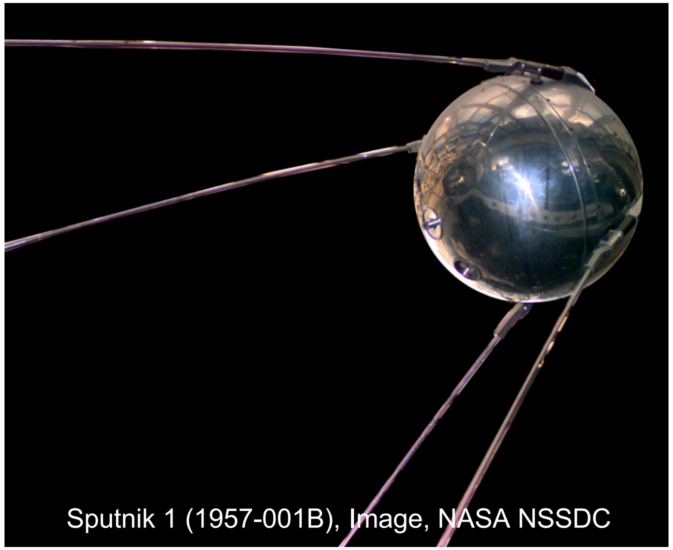
The Space Age

In October 1957, to great worldwide excitement, Russia launched Sputnik 1

It only remained in orbit for three months but it signalled the start of the Space Age


Sputnik 1 (1957-001B), Image, NASA NSSDC

Sputnik 1 also heralded the start of the observation of man-made space objects

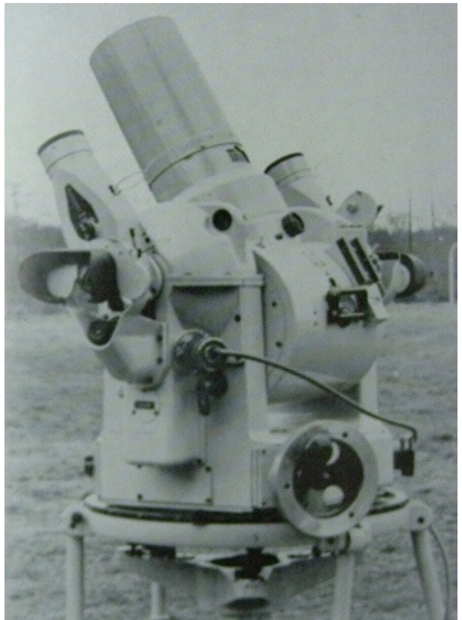
Early days of surveillance of space

numerous groups of professional and amateur observers, including:

- scientific organisations
  - e.g. Royal Aircraft Establishment, Royal Observatories
- and amateur groups, most notably
  - Kettering Grammar School

using a variety of instruments, such as:

- kinetheodolites
- wide-field of view survey telescopes
  - e.g. Hewitt-Schmidt, Baker-Nunn
- binoculars and stopwatches
- …


Kinetheodolite, Image King-Hele

Jodrell Bank

Lovell telescope completed just in time for Sputnik 1 launch

only radar in the world capable of observing rocket body

undertook numerous satellite tracking activities during 1960s including independent verification of Russian Luna mission

Jodrell Bank was another early pioneer of satellite observing

Lovell Telescope, Image University of Manchester

MERLIN used in in collaboration with Russian Evpatoria radar

Royal Observatory Edinburgh

prominent amongst early UK pioneers of optical observing

satellite observations started from night of Sputnik 1 launch

initially from Blackford Hill

used kinetheodolite and 1m Hewitt Schmidt

satellite tracking continued at the Earlyburn outstation near Peebles until 1970s

Hewitt Scmidt camera at Earlyburn, Image Edinburgh University Press

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Astronomy → surveillance of space

surveillance of space uses well established astronomical methods

- astrographic optical systems
- astrometric position calculation/calibration
- photometry/colour photometry/spectroscopy
- orbit determination methods from asteroid/comet studies

available instruments adapted for satellite study

- binoculars/kinetheodolite
  - → tracking by eye
  - → positions from encoders
- wide FoV optics
  - → fly-through on photographic plate
  - → encoder position with astrometric calibration

satellite dynamics understanding

- Earth oblateness and gravitation studies
- upper atmosphere studies

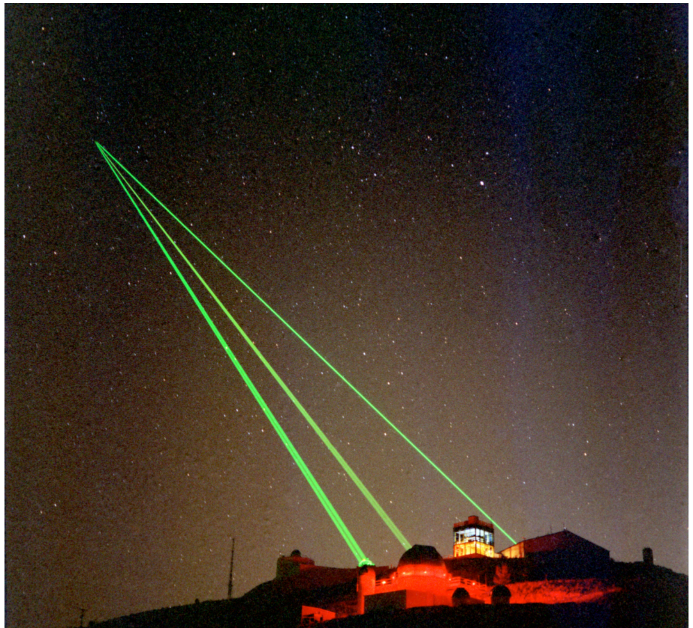
Surveillance of space → astronomy

(US) military adapted and developed astronomical ideas

- electronic sensors
  - large format CCDs, image intensifiers
- wide field of view optics
- adaptive optics
- artificial guide stars
- interferometry
- speckle techniques

telescope collaborations

- NEAT and LINEAR
- PanSTARRS



Starfire Optical Range, Image US Air Force (Wikimedia)

The rise of radar

optical surveillance of space suffers from two obstacles

- cloud
- targets must be sunlit against a dark sky

radar observations suffer no such restrictions

In the early 1960s the US radar BMEWS came into operation

US kept track of orbiting objects in order to prevent missile attack false alarms

Fylingdales radomes, image UK MoD

→ radar took over observing low Earth orbit objects

The need for optics

radars are active devices, i.e. transmit a beam and look for returns

power at target α square of range
$\rightarrow$ return signal α (transmitted power)$^{-4}$

very effective at short range but…
power requirements increase very rapidly with range

radar suited for LEO ranges up to few thousand km
struggle at MEO and GEO ranges of 10s thousand km

(most) optics are passive devices, use Sun as transmitter

struggle at LEO (Earth shadow)
much more effective than radar at large range

The role of optical surveillance

optical surveillance is used for higher orbits

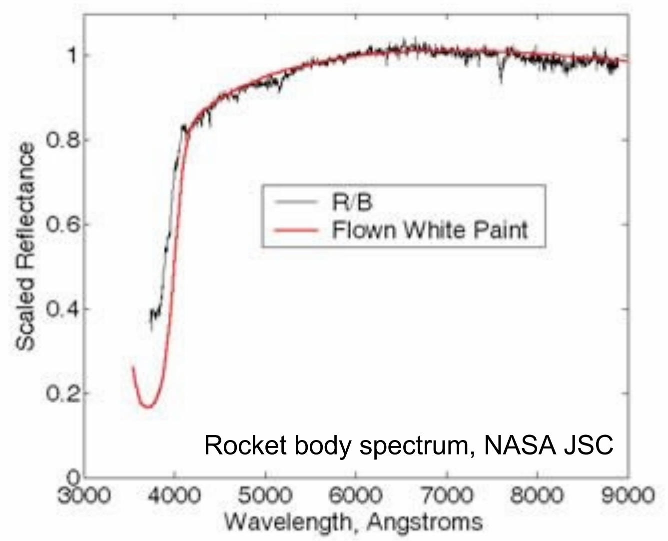
but also for specialist tasks

active illumination

high precision (co-operative) orbit determination
lidar
interferometric imaging

characterisation studies

photometry
colour photometry
spectroscopy



Rocket body spectrum, NASA JSC

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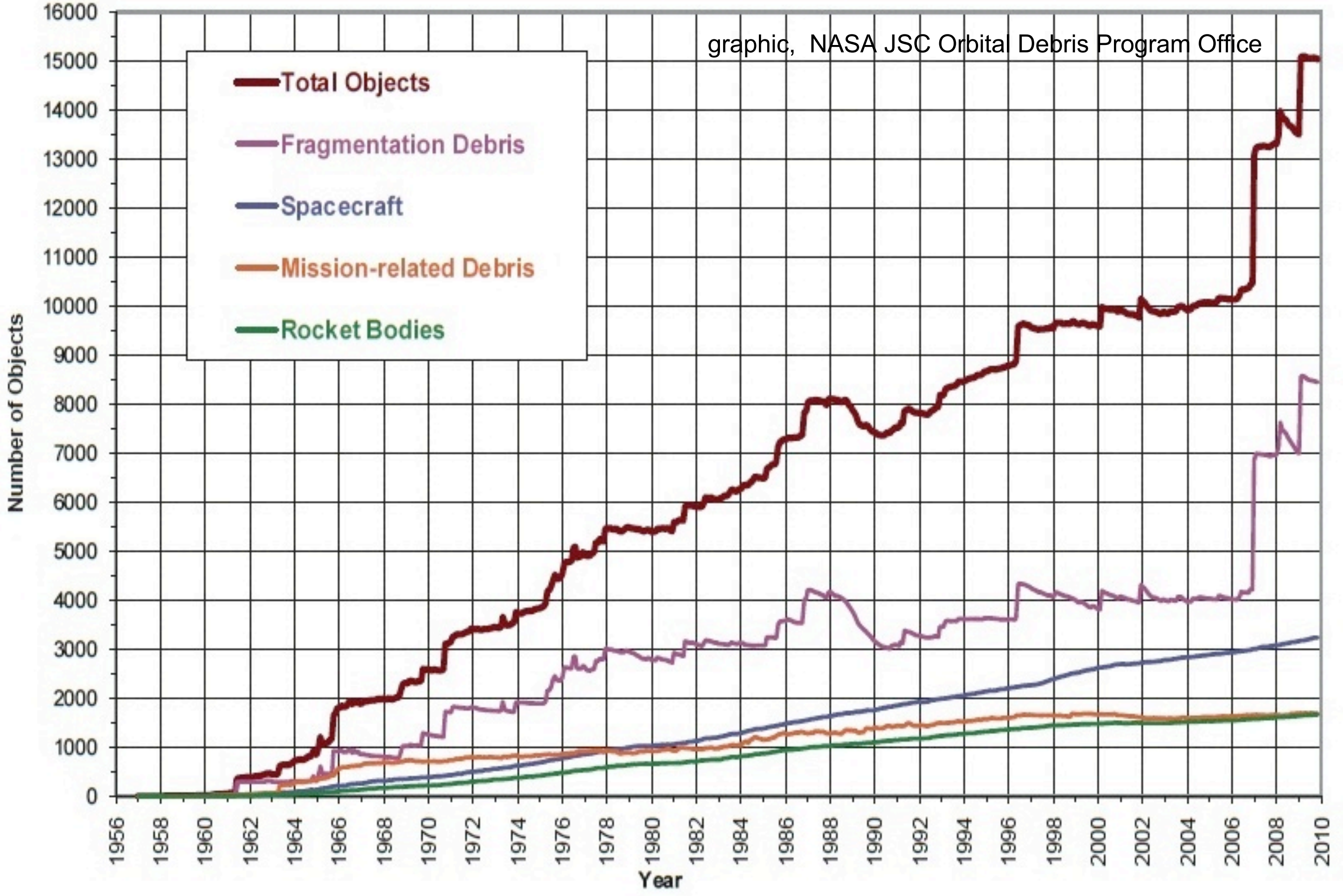
Population growth



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Users of space

US public domain SSN catalogue:

- 37166 objects "launched"
- 21108 decayed
- 628 US objects with no orbital elements
- 18 non-US objects with no orbital elements

biggest space users

	Payloads	R/B	Debris	Total
CIS	1449	968	3635	6052
US	1140	642	3081	4863
PRC	98	51	3343	3492
FR	49	123	306	478
Others*	794	93	282	1169

* Others includes 60 nations and organisations

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Space object populations

Can split the population into groups

Low Earth orbit (LEO) (~ 75%)
– circular, apogee < 2000km (~ 90 minute)
– Earth observation, ISS, etc.

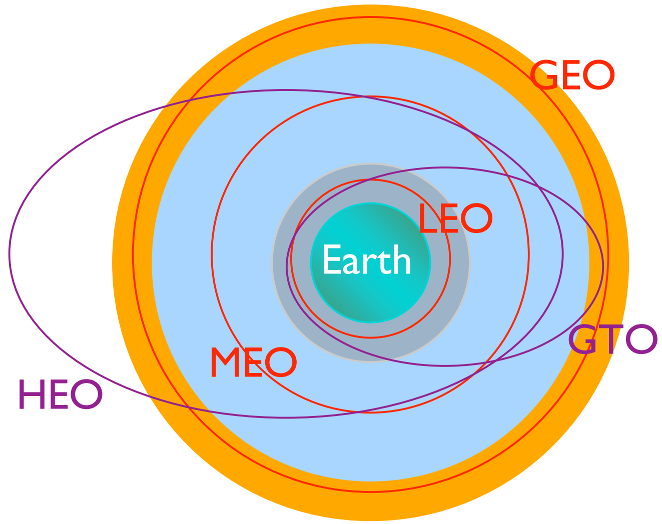
Medium Earth orbit (MEO) (~ 1%)
– circular, ~ 12 hour orbit (~ 25000 km)
– GPS, navigation

Geosynchronous orbit (GEO) (~ 10%)
– circular, 24 hour orbit (42164 km)
– broadcasting, communications, etc.

Transfer orbits (GTO,MTO)(~ 2%)
– elliptical (e ~ 0.7), LEO to GEO, LEO to MEO

Highly elliptical orbits (HEO) (~10%)
– elliptical (e ~ 0.7), ~ 12 hour orbit, inclination 63.4°

Everything else (~2%)



Graphic: Space Insight, based on ESA original idea

1980s and 90s - increasing population

primarily military, civil side disinterested - big “ocean”

US GEODSS system

3 main sites in New Mexico, Maui and Diego Garcia, each with three 1m, 2° FoV telescopes
+ 1 auxiliary site in Spain

small field of view sensors

increasing demand for real-time data
→ move away from photography
→ move to electronic sensors

image intensifiers + TV
human operator
target-on-crosswires
positions from encoder readings


GEODSS telescope, Image US Air Force

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Modern surveillance of space

- large population of objects, useful orbits crowded
- civil as well as military needs
- survey instead of tracking individual targets
- computers handle image analysis automatically
- positions of targets often calculated from star background
- new generation of large FoV surveying sensors

  e.g. US AMOS Phoenix
  Space Insight Starbrook sensors
  proposed ESA SSA sensors
- minimal operator intervention

UK optical surveillance - Starbrook sensors

since 2006 Space Insight has used Starbrook sensors to:

provide data to UK Space Agency on UK registered objects

advise UK MoD on space picture methods

contribute to international information exchanges

input to European SSA initiatives

Starbrook is believed to be the only dedicated European sensor for surveillance of space

Starbrook's core workload

Space object registration monitoring

UN Outer Space Treaty obligations:

- to register objects launched into space
- to avoid placing other space users at risk
- to mitigate against debris
- responsibility is indefinite (includes re-entry and graveyard)

Increasingly these treaty obligations are enshrined in national law (e.g. UK Outer Space Act, 1986)

Government needs ability to police legislation

until April 2010 in UK this responsibility lay with BNSC
now being transferred to new UK Space Agency

Starbrook provides independent source of verification

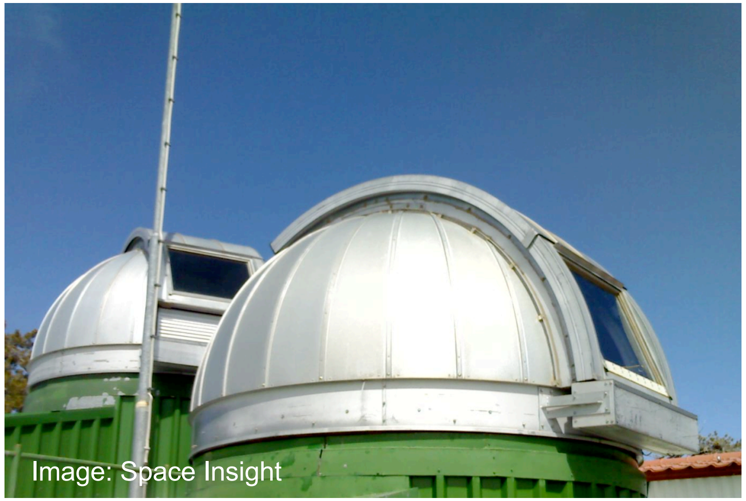
Starbrook sensors

suite of surveillance of space sensors

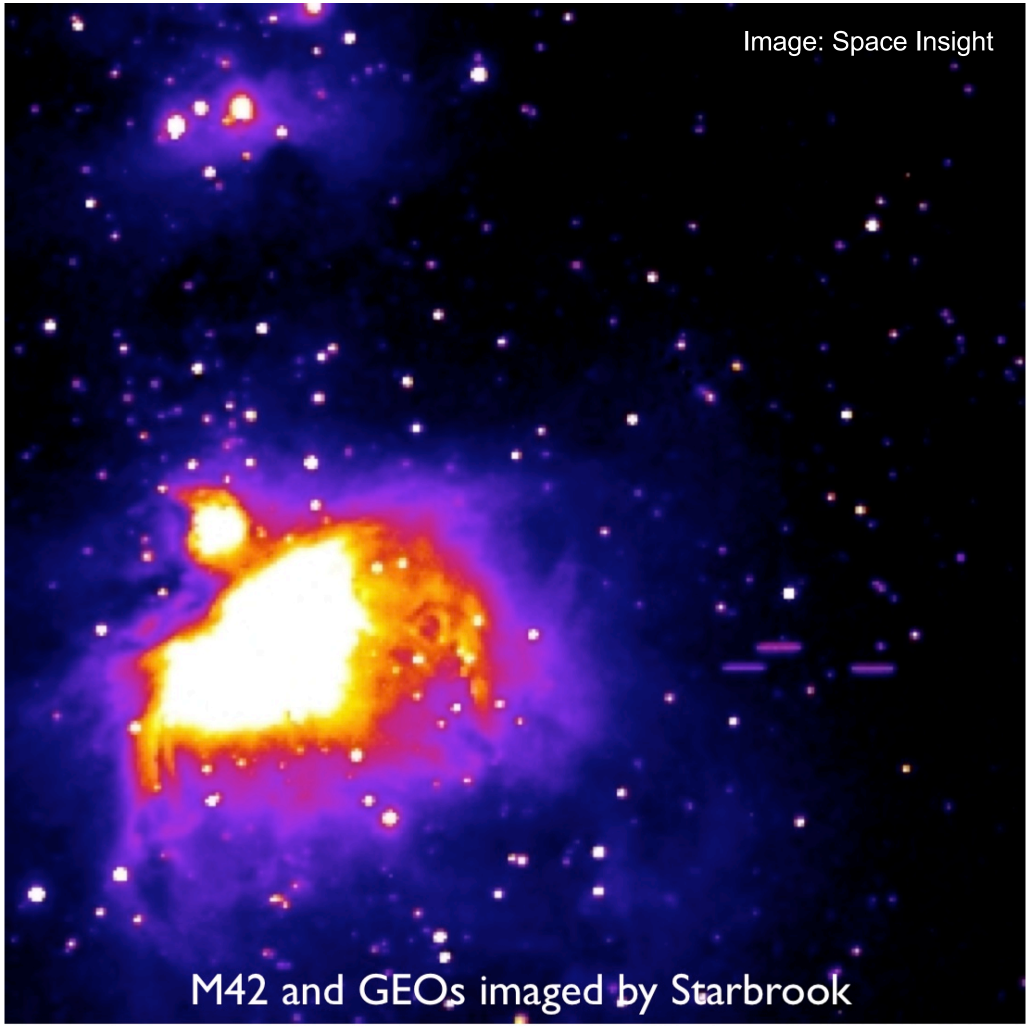
- astrographic camera
- surveying method
- large field of view
- fully automatic and robotic

located on dark, mountain site

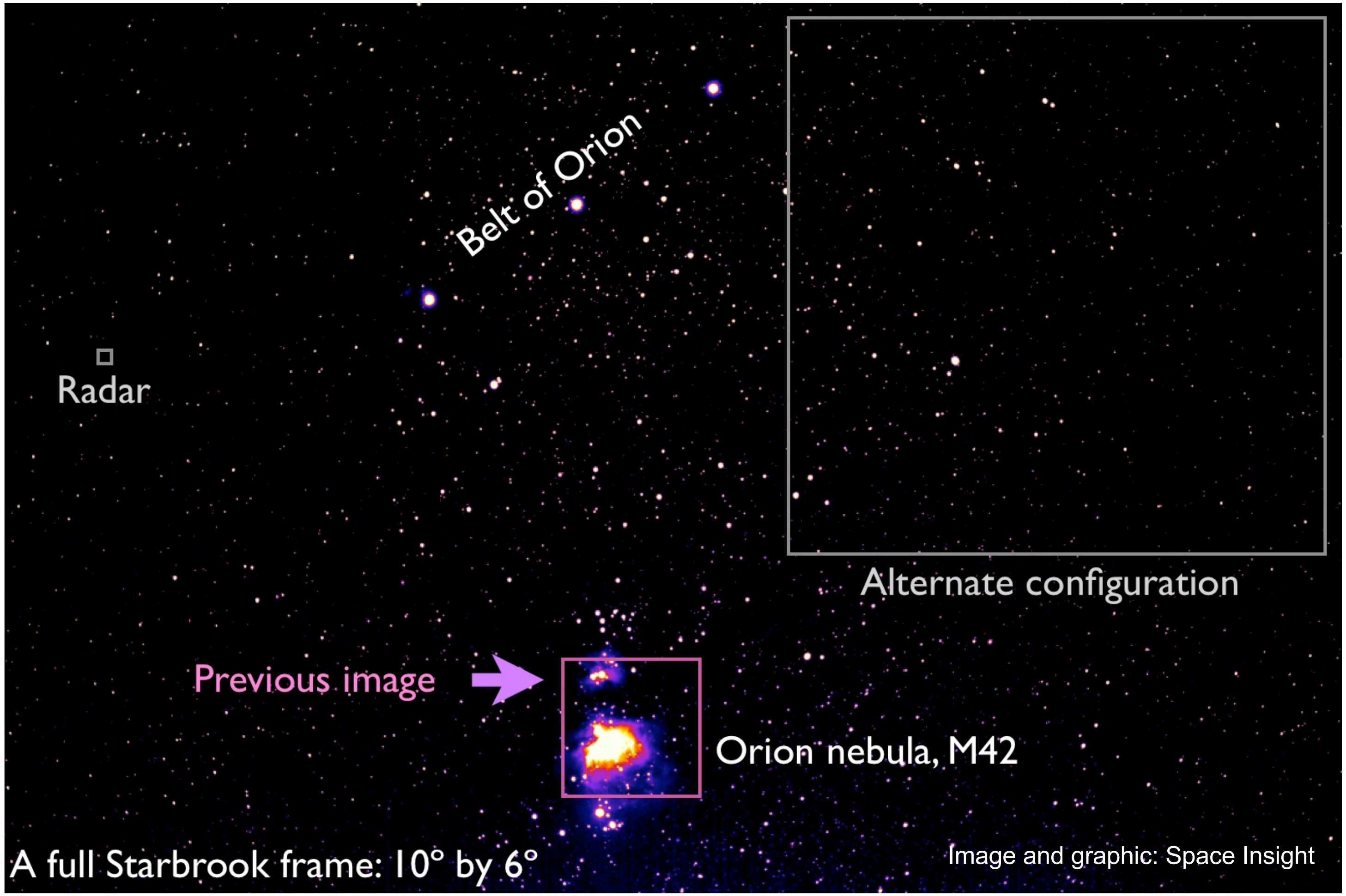
sees objects of ~ $1m^2$ at GEO



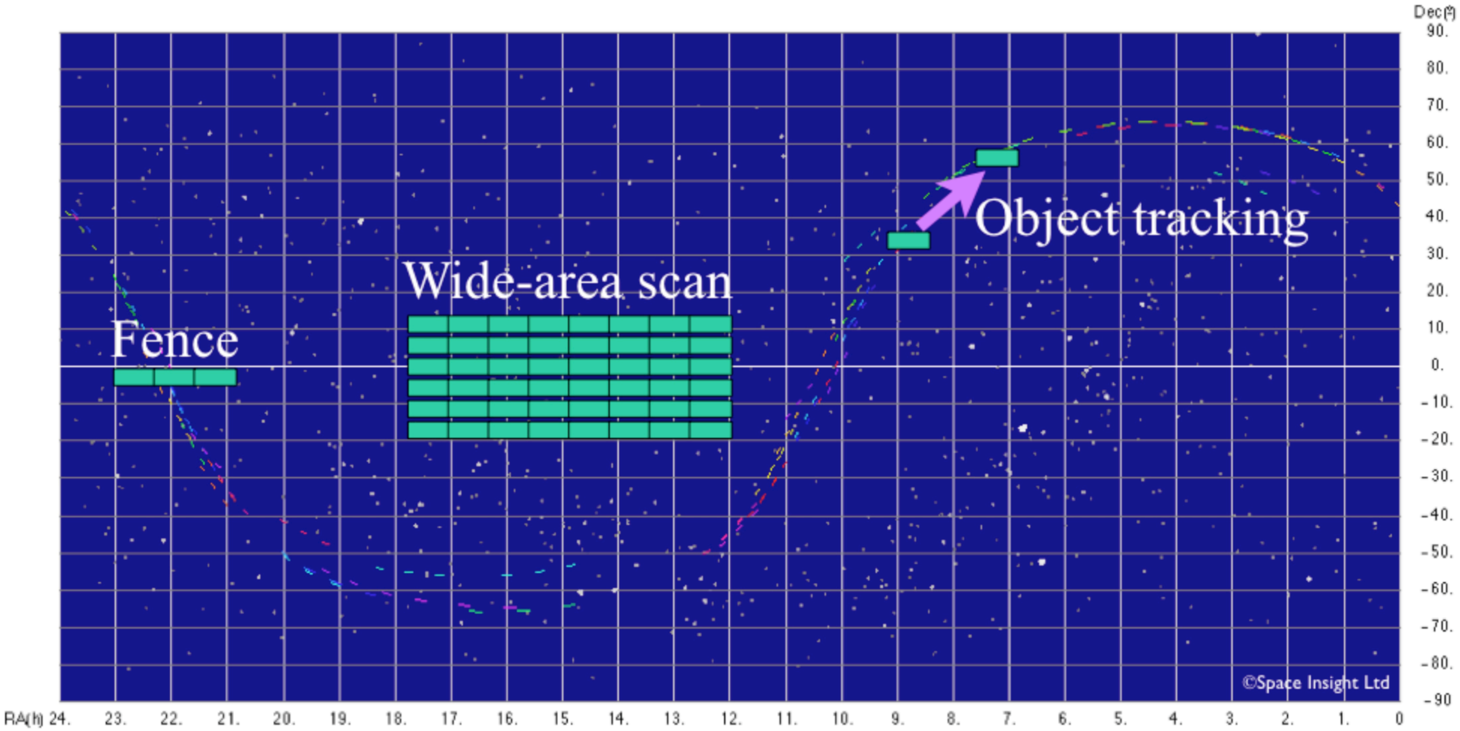
A Starbrook image



A *full* Starbrook image



Starbrook observing modes



rapid wide-area scan (GEO scan in ~ 3 hours)
leak-proof fence for MEOs (~ 10° wide)
tracking (hand-in for follow-on orbit update, etc.)

The need for surveillance of space

Users and requirements are evolving

- once seen as almost exclusively military
- recently - civil interests demanding capabilities

Users of surveillance products and their needs

Users		Needs
operators civil authorities insurance industry international bodies mission planners military …	→	collision avoidance registration regulation liability risk traffic management space picture intelligence …

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Collision warning

one of main drivers for surveillance of space

becoming more important as useful orbits get more crowded

collisions expected to become more frequent

well known that publicly available orbits are not good enough

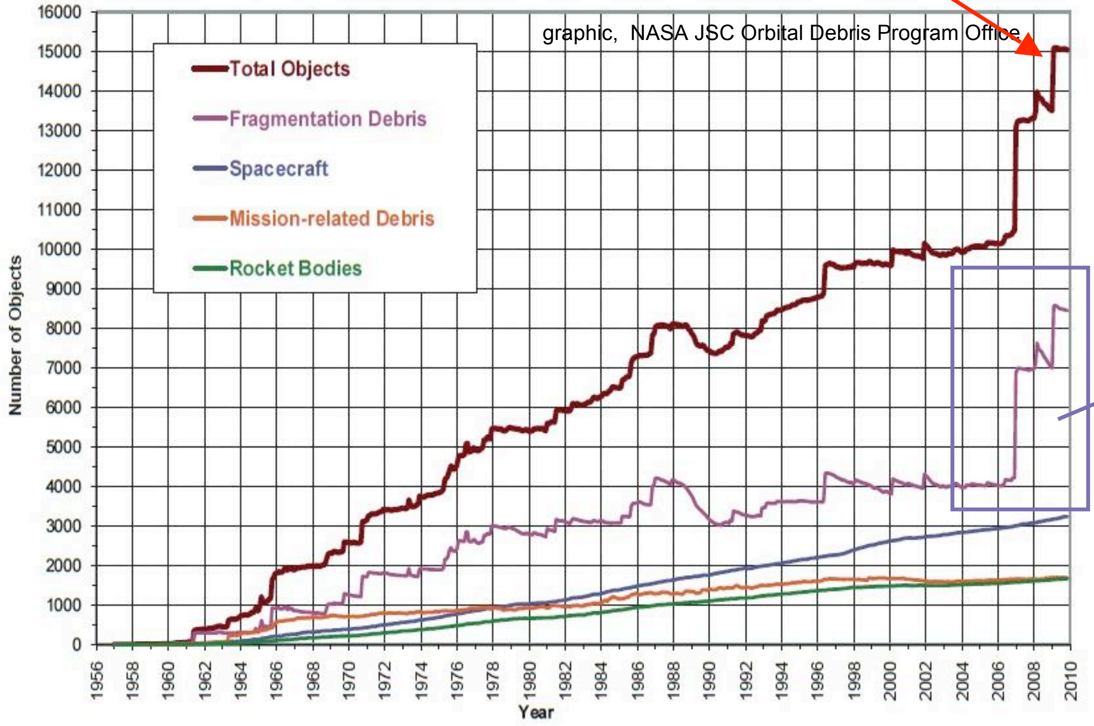
presently when there is a predicted close approach ESA enhances public domain orbits with specific orbit improvement observations

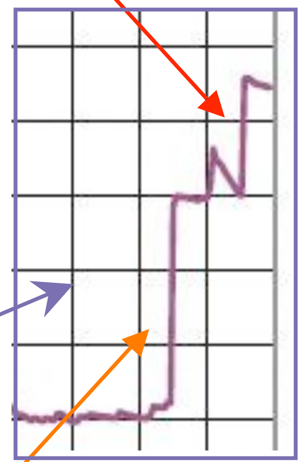
not an option for most other organisations

definition of user requirement for orbit accuracy in planned ESA SSA system is based on collision avoidance

10th February 2009 16:56 GMT

Iridium 33 – Cosmos 2251 collision





Chinese Fengyun 1C ASAT test

Modified graphic, Space Insight

Iridium 33 – Cosmos 2251 collision created over 1200 pieces of trackable (larger than 10cm) debris

Commercial demand

added new demand for surveillance of space services

collision warning service called SOCRATES

Iridium 33 – Cosmos 2251 approach rated 25th most dangerous

CelesTrak Powered by: CSSI Center for Space Standards & Innovation 25 YEARS 1985 - 2010

three major operators formed Satellite Data Association to coordinate timely provision of accurate collision warning data for commercial satellite operators

SES

inmarsat

INTELSAT Closer, by far

new demand will bring new opportunities

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Opportunities for the future

historically very few opportunities outside military

now other parties beginning to take serious interest

- ESA SSA programme (approved at Ministerial Council in 2008)
  - suite of new sensors by ~2020
  - initial commitment €50million
  - includes space weather and NEOs
- UN Debris Mitigation and Space Traffic Management
- Commercial operators, e.g. SDA

Summary

optical surveillance of space mainly higher Earth orbits

adapted and developed astronomy techniques

diverse populations of objects

dual military/civil interest

wider customer base demanding capabilities

European SSA programme agreed

Some companies involved with ESA SSA programme

Space Insight
UKATC
RAL
Qinetiq
E2V
EADS-Astrium
GMV
ONERA
Indra
Deimos
AMOS
Alenia
Thales
etamax
Cobham