Collision Avoidance and Space Debris Mitigation: An Approach

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The Situation

Public Available Catalogue
Space Debris Generation

- Unused Satellites
- Explosions (Tank, ca. 5 Tanks per year)
- Upper rocket bodies
- Collisions
- West Ford Dipole
- Fragmentation
- ...

→ Consequences:
- Tracking prerequisite
- Collision avoidance necessary
- Shorter Mission time
- Loss of mission objectives

New Objects: 2006 – 2014

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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<td>10</td>
<td>9</td>
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<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>7</td>
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</tbody>
</table>

![Graph showing new objects from 2006 to 2014 with a peak in 2011 and 2012. A note on Cosmos 2421 is highlighted.](image-url)
Collision between Iridium 33 and Cosmos 2251

Satellites:
- Cosmos: 950 kg
- Iridium: 560 kg

Velocity: 11.7 km/s

Debris:
- Cosmos: 1301
- Iridium: 469

Orbit: 789 km above Taymyr, Siberia

Prediction: 584 m distance

Maneuver: none
Short-Term Development of Debris Clouds

1 Month

1 Year

3 Years

Homogeneous distribution after short time

Assumed Collisions:

NCO: Non-catalogued object
Evolution of Population (Publicly Available Data)
A Possible Future

Non-Mitigation Projection (averages and 1-σ from 100 MC runs)

- LEO (200-2000 km alt)
- MEO (2000-35,586 km alt)
- GEO (35,586-35,986 km alt)

Effective Number of Objects (>10 cm) vs. Year
New Players: The Mega-Constellations

12,000 new satellites
Spatial Density

Critical Orbits:
- Sun-synchronous (Earth observation)
- 1400km (low perturbances)
- Geostationary Orbits

→ Protection of favourable orbits strongly necessary!
Why Do We Care

- **S/C Owners/Operators**
  - Safety of flight
  - Prevent collisions (traffic management, collision avoidance maneuvers)
  - Contingency: cause?

- **S/C designers**
  - Risk analysis
  - Shielding (shields, passive shielding)
  - \( \rightarrow \) spacecraft reliability

- **Mission analysts, launch campaigns**
  - Risk analysis, trajectory optimization, orbit selection
  - Launch conjunction analysis

- **Governments, Space Agencies, Scientists**
  - Protecting vital space services
  - Long term sustainable use of space
  - Evolution
Space Surveillance And Tracking

First Steps:
- Detection, tracking and cataloguing
- International exchange of (raw) data
- Provision of free catalogues with all objects to spacecraft operators

Next Steps:
- Holistic SSA Approach
- Prevent proliferation of space debris (e.g. 25-year guideline)
- Perform collision avoidance (e.g. laser nudging)
- Support active debris removal
- International binding agreements
First Step: Cataloguing

Requirements:
- Extension to smaller sizes (ideally below lethal threshold, i. e. 1-2cm)
- Completeness
- Extremely high accuracy need for “just in time collision avoidance”

Challenges:
- New Space Fence: 200,000-300,000 new objects expected
- Improved algorithms and tracking techniques
- Object identification, object correlation, …
- Better physics models
- Better characteristics of objects for e. g. orbit propagation
- …
SMARTnet™
Small Robotic Telescope Network
Optical Network for Monitoring
Geostationary Orbits
SMARTnet™ Sensor Network

- (almost) autonomous operations
- redundancy concept: 2 of 3 are alive (two computer, one internet connection)
- pre-processing (30GB → 1MB)
- UPS, Webcam, weather monitoring

MAC: Monitoring and Control System
BACARDI: Backbone Catalogue of Relational Debris Information
SMARTnet™ Conditions and Terms (Excerpt)

Partners bring to SMARTnet™

- Sensor, e.g. telescope with minimum aperture size of 20cm
- Year-round operational system
- Tracklets (e.g. pairs of RA/DEC of objects; ITAR free: NO object identification)

Partners get from SMARTnet™

- All tracklets for free produced within SMARTnet™ of all contributing sensors
- Free exchange platform
- Support if desired

Do with data

- Develop products (e.g. sell them)
- Research
- Operate satellites safely (in GEO)

RA - DEC: Right Ascension – Declination
Tracklet: Time sequence of measured object positions belonging to the same object
SMARTnet™ Overview

Partners (April 2018)
- 1 established partner (US, several sensors)
- negotiation with several potential partners

Zimmerwald: Operational
Australia: 2018
South America: Survey 2018
Sutherland: Operational
SMARTnet™ Station: Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald

80–cm ZimMET Switzerland

40–cm ZimTFT Switzerland

1–m ZIMLAT Switzerland
SMARTnet™ Station: SMART-01-SUTH

Mount with 2 telescopes
Aperture 50cm, 0.7° FOV, 0.6“/Pixel
Aperture 20cm, 3.4° FOV, 3.1“/Pixel

South African Astronomical Observatory, South Africa

Telerobotic operations at GSOC/AIUB
First light: 04.04.2017
SMARTnet™: Monthly Bulletin Example – Tracklets I
SMARTnet™: Monthly Bulletin Example – Tracklets II

20 cm SMART-01 at Sutherland

Magnitude distribution, 2017-08, SMART-01-B-SUTH

20 cm SMART-01 at Zimmerwald

Magnitude distribution, 2017-08, ZimSMART
SMARTnet™: Monthly Bulletin Example – Calibration

Time Calibration

20 cm SMART-01 at Zimmerwald

20 cm SMART-01 at Sutherland
SMARTnet™: Monthly Bulletin Example – Weather Information

Rain

Rain sensor readings, 2017-08, SMART-01-SUTH

Temperature

Station Shut Down

Cloud Height

Cloud level (m)

Wind

Wind speed and direction, 2017-08, SMART-01-SUTH
Space Debris Research

Population
• How many?
• Size distribution?
• Orbit regions?
• Nature of objects?
• Sources, sinks?

Physics / Mechanisms
• Creation of new debris
• Evolution of orbits
• Long-term evolution
• ...
Challenges

Correlation
- Tracklet-tracklet association
- Tracklet-orbit association

Orbit
- Initial orbit determination
- Orbit Propagation
- Uncertainty propagation
- Maneuver estimation

Data Fusion
- Radar, Optical, Laser

Observation
- Optimized observation strategy
- Survey / follow-up
- Multiple station concept

Physical Characterization
- Size, shape, area-to-mass-ratio, material

BACARDI:
Backbone Catalogue of Relational Debris Information
Space Debris Viewer

- SWISSCUBE (09051B)
- UME 1 (ISS 1) (76019A)
- UME 2 (ISS-B) (78018A)
- ISS (ZARYA) (98067A)
- SWISSCUBE (09051B)
- AISSAT 1 (10035C)
- AISSAT 2 (14037G)

# visible objects: 16363
Conclusion

- **Near-Earth space becomes more and more congested**
- **Hollistic approach is required**
  - Need to include data from trusted sources: government, commercial, academia, ...
  - Exchange of sensor raw data, observations: verification, traceability, transparency
  - Data sharing standards / mechanisms required
  - Development of algorithms to cope with massive data volumes (multi-sensor, data fusion, …)
- **Change of paradigms needed**
  - Hiding in space is not anymore an option (during peace times)
  - Abandon classification
- **“Open source SSA“:**
  - SMARTnet™ as example of a civil, non-commercial sensor network
Thank you for your attention

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