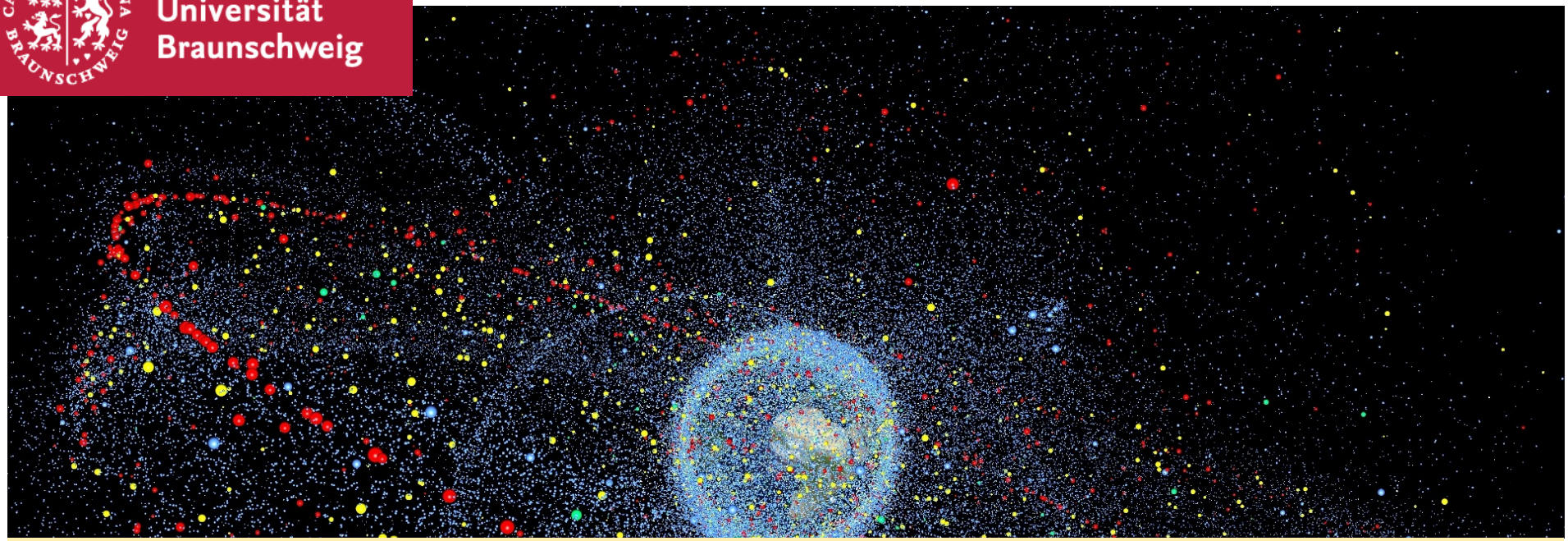


ISS SPHERES TETHER DYNAMICS EXPERIMENTS EVALUATION OF TETHERED ACTIVE DEBRIS REMOVAL ISSUES

H.-J. Zachrau[(1)], **M. Becker**[(2)], E. Stoll[(2)], I. Retat[(3)], D. Roascio[(4)], and D. Sternberg[(4)]

(1) Airbus Defense and Space Systems Inc., 555 Forge River Rd 115, Webster, TX 77598, USA
(2) Technische Universität Braunschweig, Institute of Space Systems, Hermann-Blenk-Str. 23, 38108 Braunschweig, Germany
(3) Airbus Defense and Space GmbH, Airbus-Allee 1, 28199 Bremen, Germany,
(4) MIT Department of Aeronautics and Astronautics, Massachusetts Avenue 33-207, Cambridge MA 02139 USA

ESA Clean Space Days 2017

Outline

1 ADR Net Capture System (NCS)

2 SPHERES Tether Demo Development and Mission Implementation

3 SPHERES Tether Demo on ISS

4 Experiment Evaluation and Results

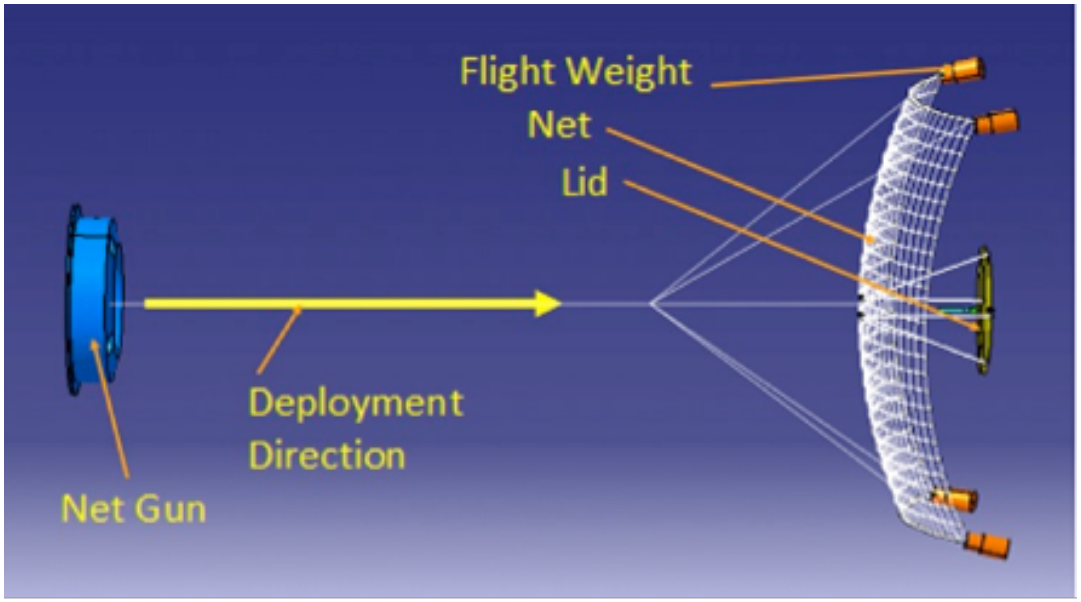
5 Summary & Outlook

ADR Net Capture System (NCS) Background

- Since the NCS concept was created back in 2003, Airbus Defence & Space has carried out a series of studies and tests on the NCS technology.

- The simplified figure shows the principal of the NCS, which consist of the deployment hardware, the tether, and the net.

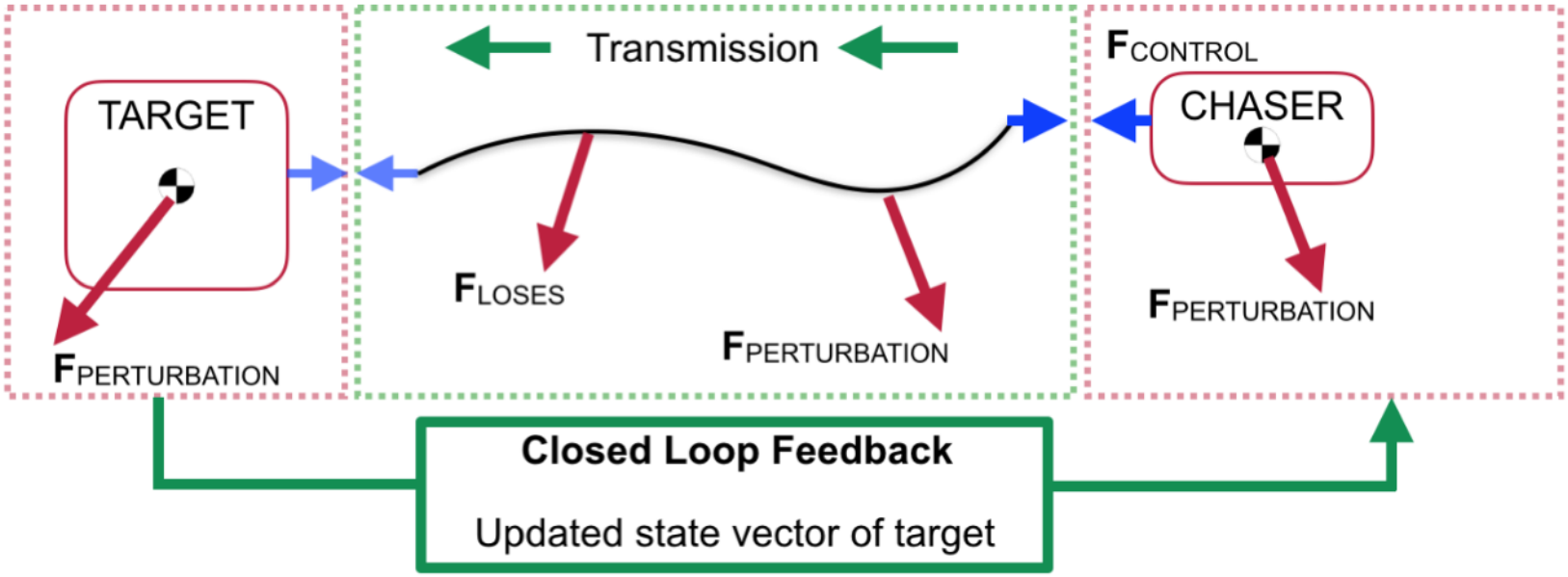
- The NCS was successively developed and tested in a drop tower, on a parabolic flight, and is planned to be deployed from the ISS next year as part of the "Remove Debris" project.



Simplified concept of the Net Capture System

SPHERES Tether Demo Development and Mission Implementation

- The SPHERES Tether Demo experiment fills one building block in the development chain, providing valuable test data on the dynamics between the chaser and target vehicle after the actual capture



Schematic structure TSS Guidance Navigation and Control (GNC) principle

SPHERES Tether Demo Development and Mission Implementation

- In ADR missions it will always be necessary to stabilise the captured target. Experimental runs on ISS provide the opportunity to repeat numerous variations of tests to obtain an extensive database in the field of space tether dynamics.

- As a result of inactivity, the target objects will build up a rotation or might tumble, which needs to be stabilised by the chaser to prepare a safe and controlled de-orbiting of the Tethered Space System (TSS).

- The Institute of Space Systems of the Technische University at Braunschweig (IRAS) in cooperation with Airbus Defence & Space in Bremen, Germany, are developing a software tool (Tether Dynamics Toolbox - TDT), which provides the capability to analyse a tethered ADR mission starting from the initial capture until the deorbiting of the ADR system

SPHERES Tether Demo Development

- Airbus DS Houston acted as both the mission implementer responsible for the overall design, certification and verification, and as the Principle Investigator

- Partnered with MIT Space Systems Laboratory as the original developer of SPHERES, to develop dedicated ad-on hardware, developing the final test plans and providing continued support to all SPHERES related on-orbit activities

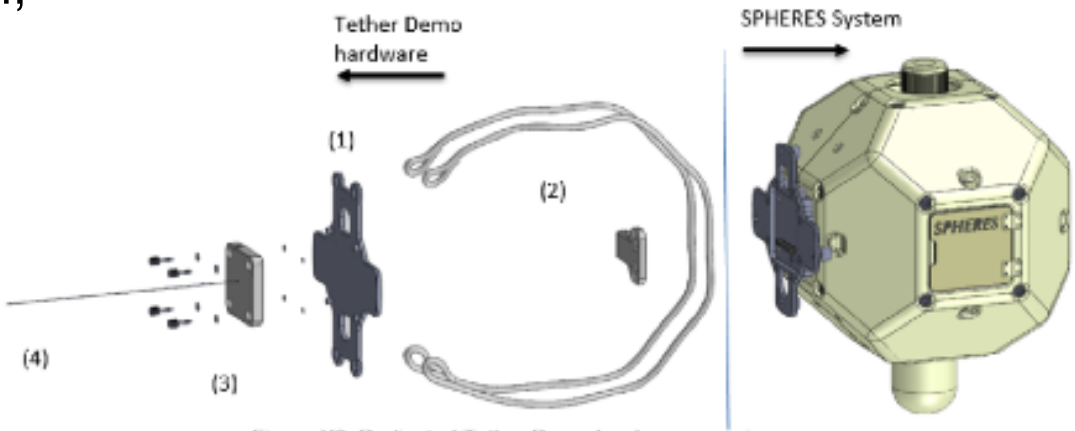


Figure X3: Dedicated Tether Demo hardware overview

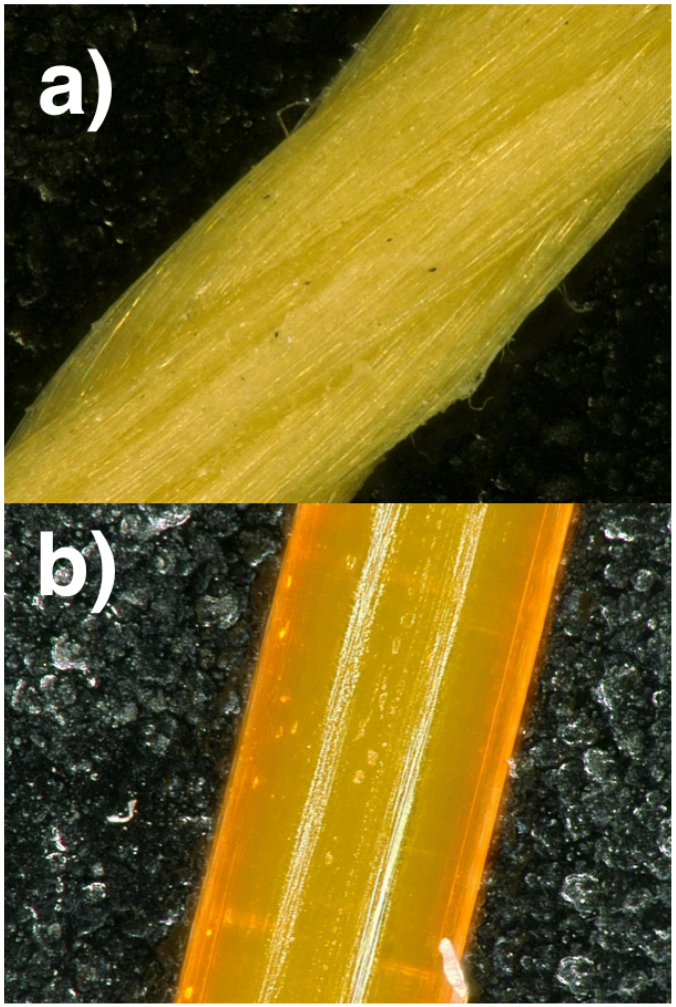
(1) Baseplate
(2) Strap assemblies
(3) Compressing panel
(4) Tether

Exploded view of the developed Tether Demo hardware

SPHERES Tether Demo Development

- Two sets of interfacing hardware have been produced, one with Kevlar (rigid) [a)] and one with Nylon monofilament (elastic) [b)] tether, enabling the crew to easily interchange tether materials between experiment runs.

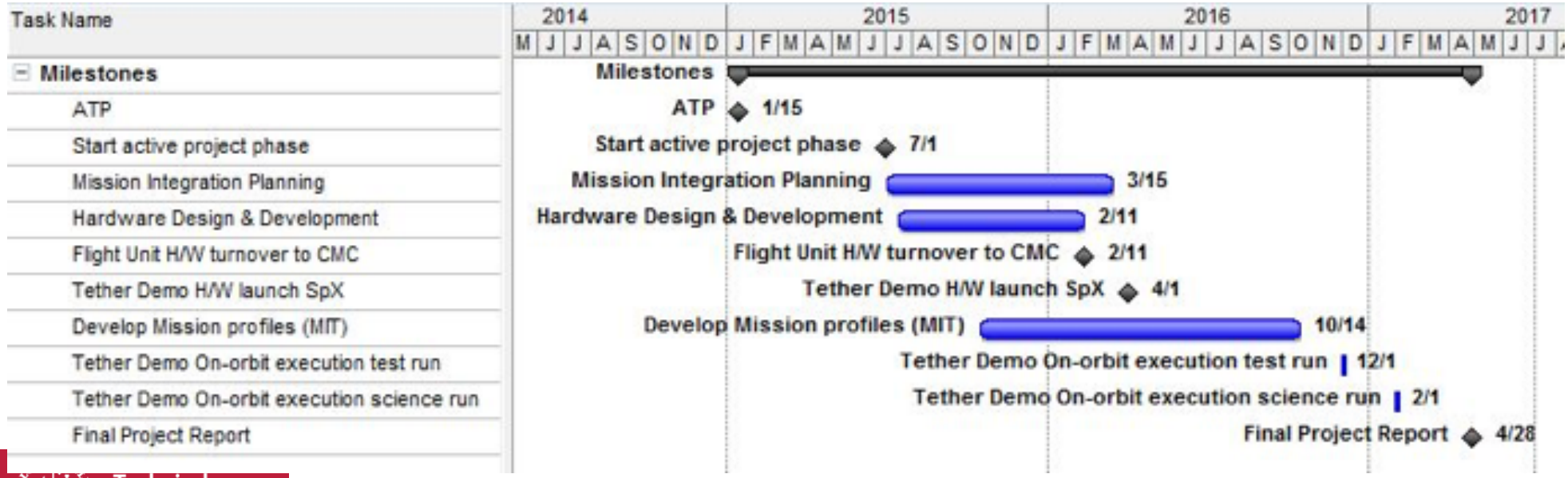
- The tether length was set to 40 cm (18”) to allow meaningful experiment runs within the roughly 2 x 2 x 2 m^3 operational envelope of the SPHERES, dictated by the ISS module



SPHERES Tether Demo Mission Implementation

- Through our user agreement with the Center for the Advancement of Science in Space (CASIS) we gained all the access and resources required to efficiently develop all ISS mission integration products and certification milestones.

- Close cooperation with the SPHERES Payload Integration Manager enabled valuable support from all ISS program disciplines as needed, leading to a comparably rapid completion of all the major milestones. **Hardware readiness and certification could be achieved within about 8 months.**



Experiment Profile Development and Execution on ISS

- Independent of the ISS mission implementation activities we utilized the SPHERES ground testing capabilities at MIT to develop and refine on-orbit experimental runs. With a second set of identical hardware on ground we were in the comfortable position to have several months available to define and test our experiments prior to the on-board execution on ISS.

- A main advantage of the SPHERES operational concept is that the experiment profiles are internal to the SPHERES project and don't require external approval. Therefore the final version needs to be available only within 2 weeks of the actual execution, providing a great range of flexibility.

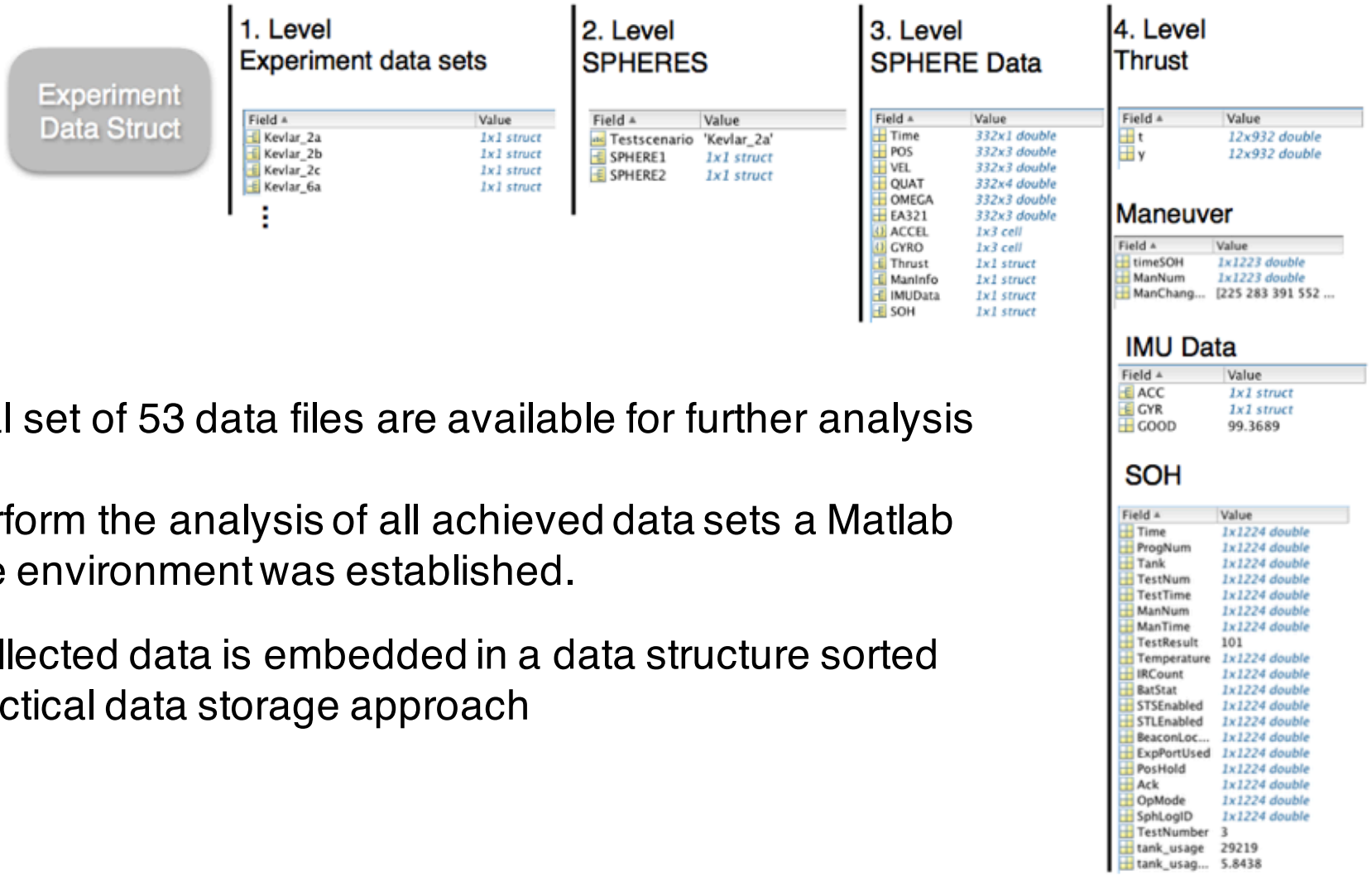
- Due to this flexibility we were able to react on short notice when crew time became available for both of our test runs, on 12-01-2016 and 2-1-2017.

SPHERES Tether Demo on ISS

- The SPHERES Tether Demo test marked the 85th and 88th SPHERES ISS test sessions
- The second test sessions also made it possible to redefine and adapt some predefined experiments.
  - Adaption of thrust profiles
- A total set of 53 successful experiment data sets have been collected s

ESA astronaut Thomas Pesquet performing the Tether Demo science runs

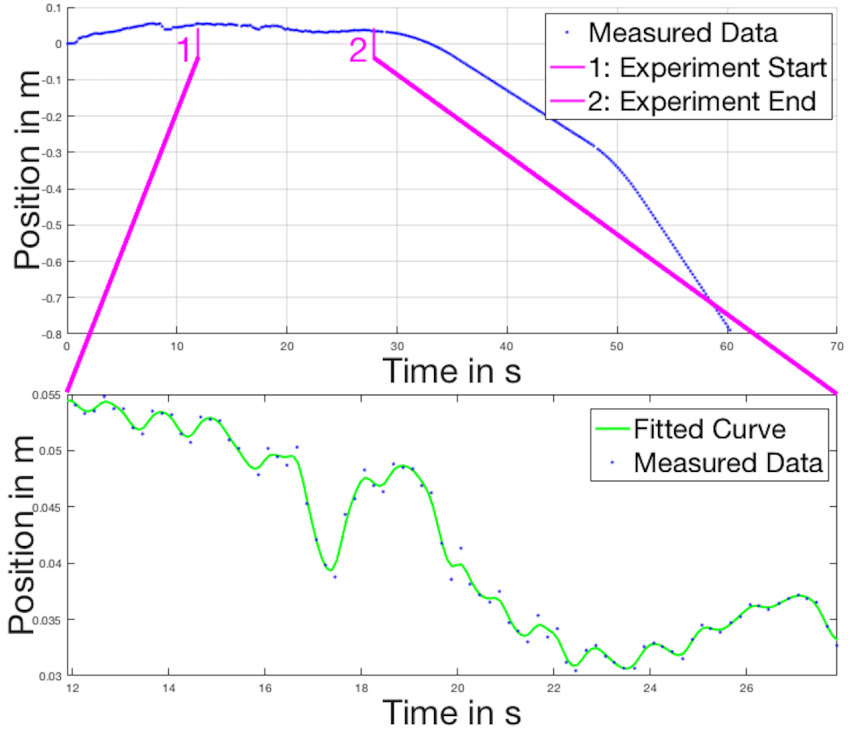
Experiment Evaluation and Results

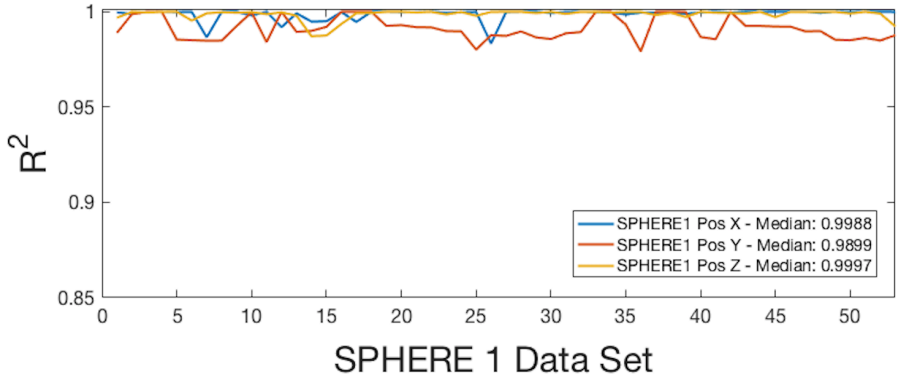


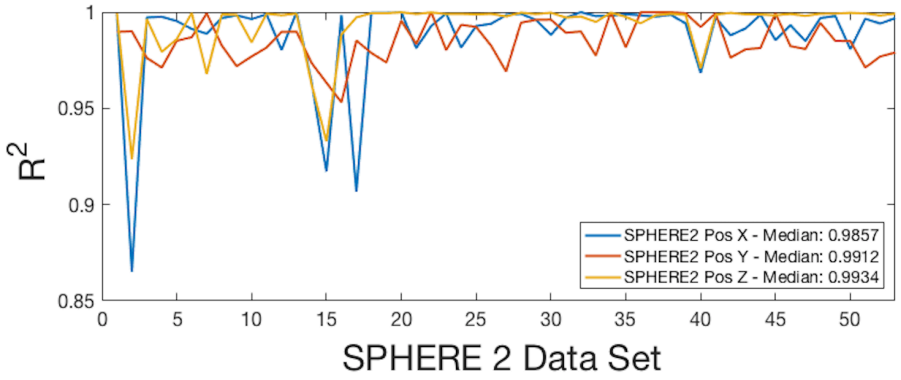
- A total set of 53 data files are available for further analysis
- To perform the analysis of all achieved data sets a Matlab software environment was established.
- All collected data is embedded in a data structure sorted by a practical data storage approach

Experiment Data Processing

Determine Experiment Period → Data Extraction → Data Synchronisation → Data Fitting **$R^2 > 0.996$**







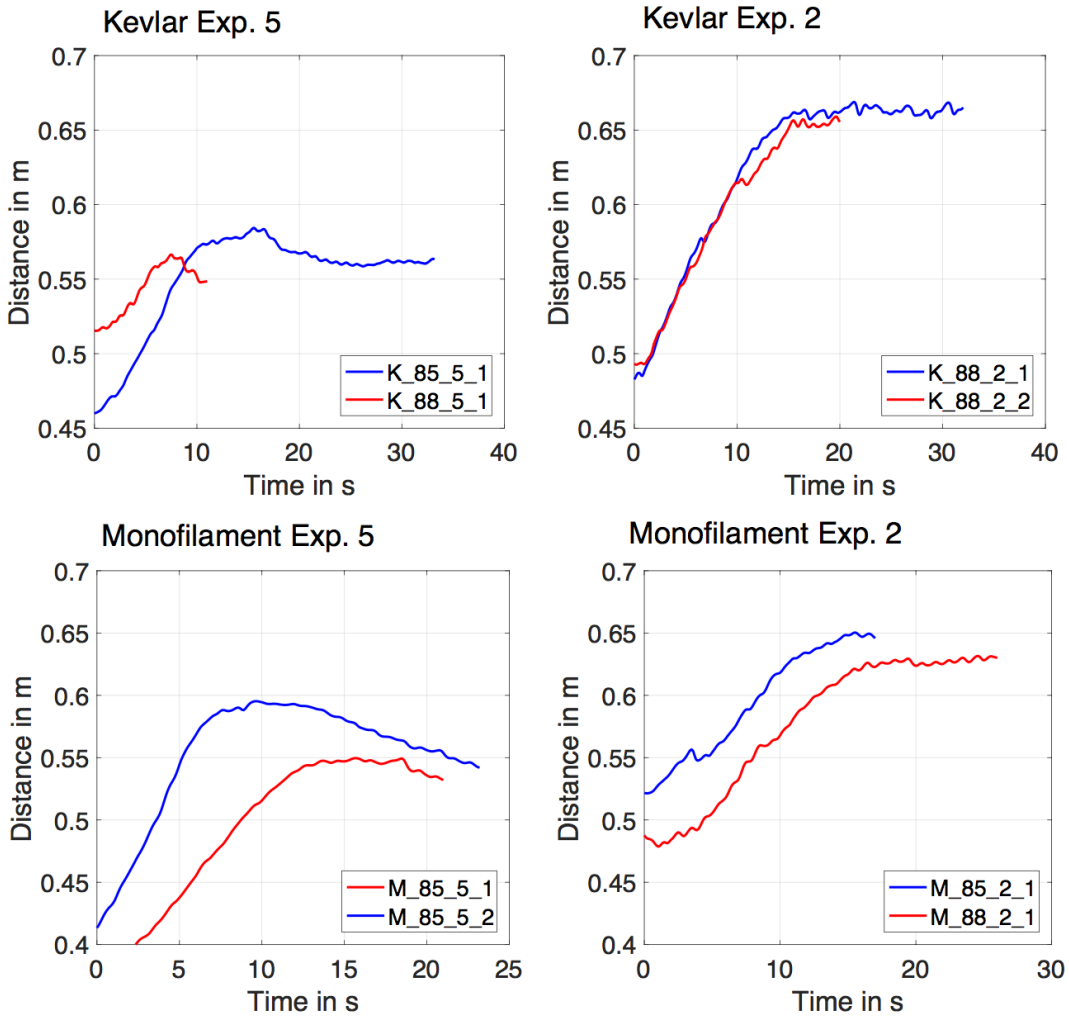
Tether Material Influence on TSS Stability

Experiment 2:

SPHERES are aligned axially, Primary fires thrusters to pull away from Secondary. The tether is initially taut. The open loop thrust is 6s for the tug.

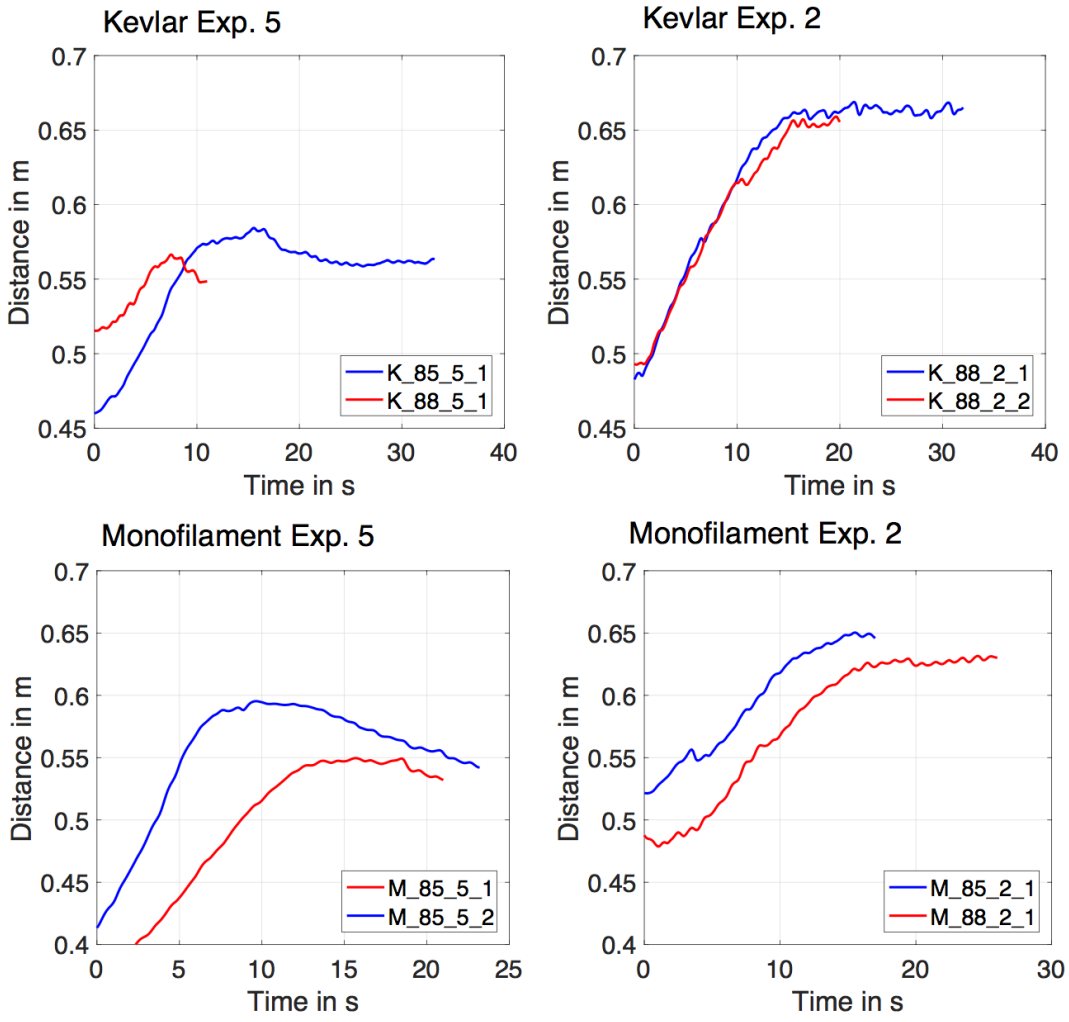
Experiment 5:

SPHERES are rotated 90deg relative to the target and tether axis, tether is taut them. The tug pulls



Tether Material Influence on TSS Stability

- Position data follow same trend curve in defined experiments
- Reproducibility of the experiment data is given.
- Slight differences occur from minor changes of SPHERES rotation rated



Summary & Outlook

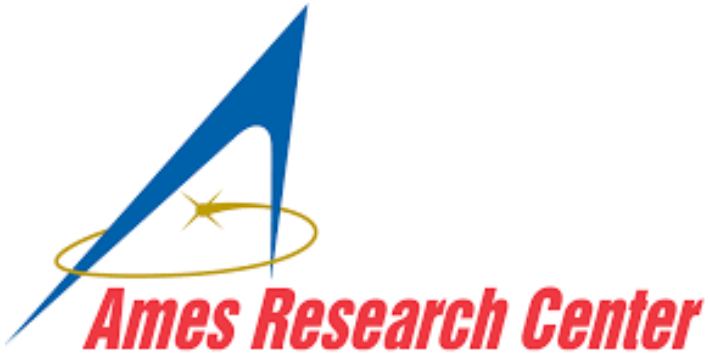
- Successful experimental study. Especially in the field of TTS dynamics and interactions of the connected end-bodies with the flexible connecting tether.

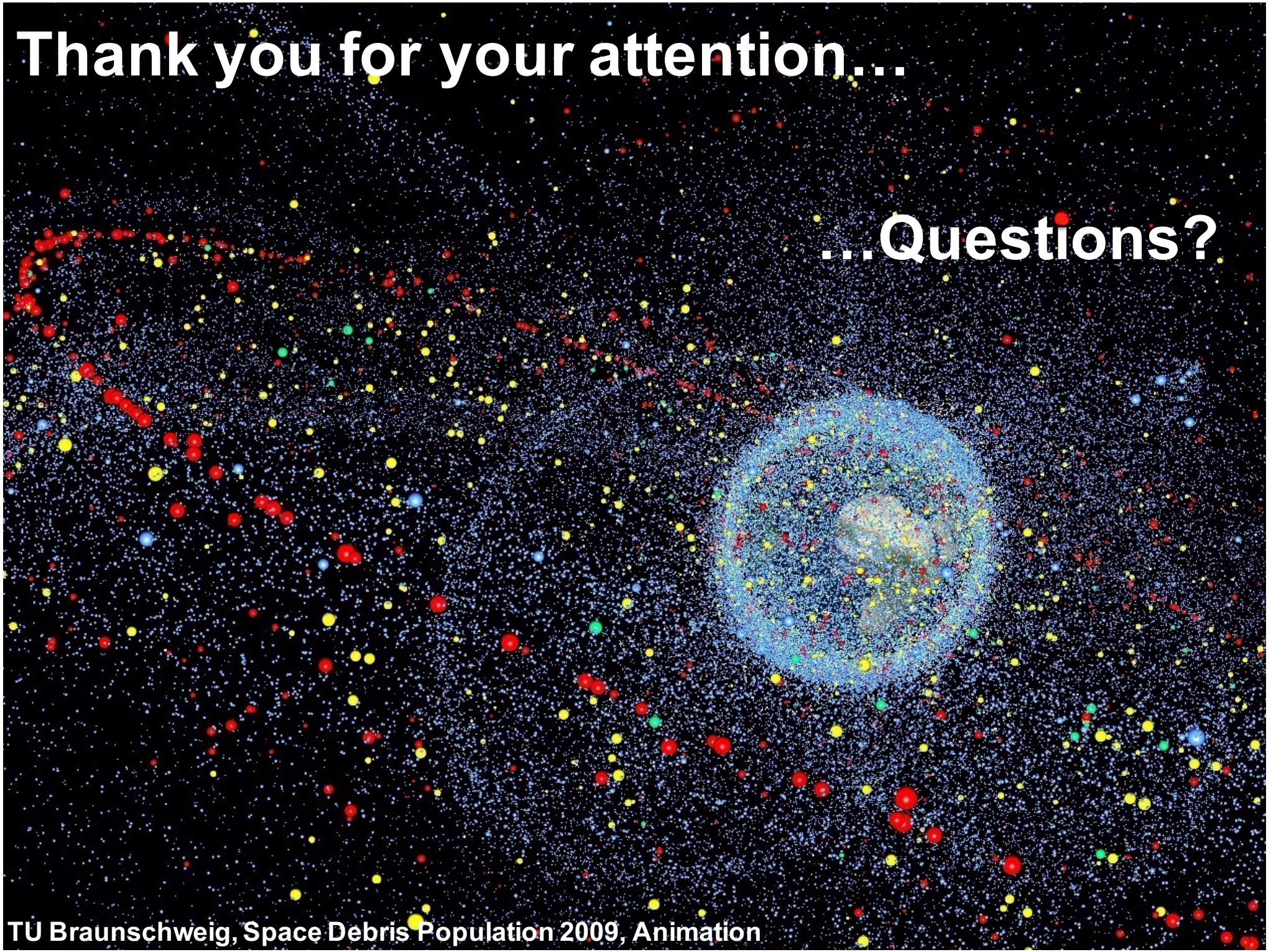
- Detailed studies on tether dynamics are on-going

- Further it is planned to build on the achievements to define the next step, gradually completing the building blocks involved in a successful capture and relocation of an on-orbit object.
    - Therefore a full 6doF analysis plug-in is currently under development.

- Experimental data will be used for TSS dynamics dynamics validation

Credits




Thank you for your attention…
…Questions?
TU Braunschweig, Space Debris Population 2009, Animation