Modeling of re-entry events using data from global all-sky meteor cameras

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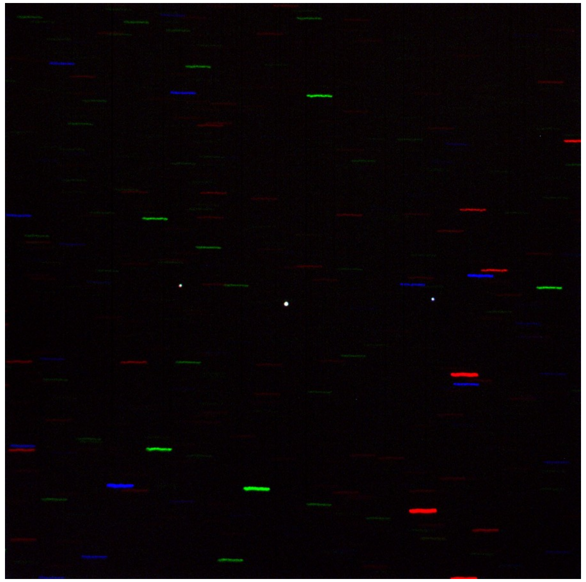
Space debris research at Comenius University

- Focus on space debris characterization and re-entry modeling using own instrumentation

Object outside the atmosphere

- Focus on object characterization
- Understanding of physical properties (surface material, albedo, size, shape)
- Understanding of dynamical properties (rotation and its evolution)
- 4xPhD + 1xMaster

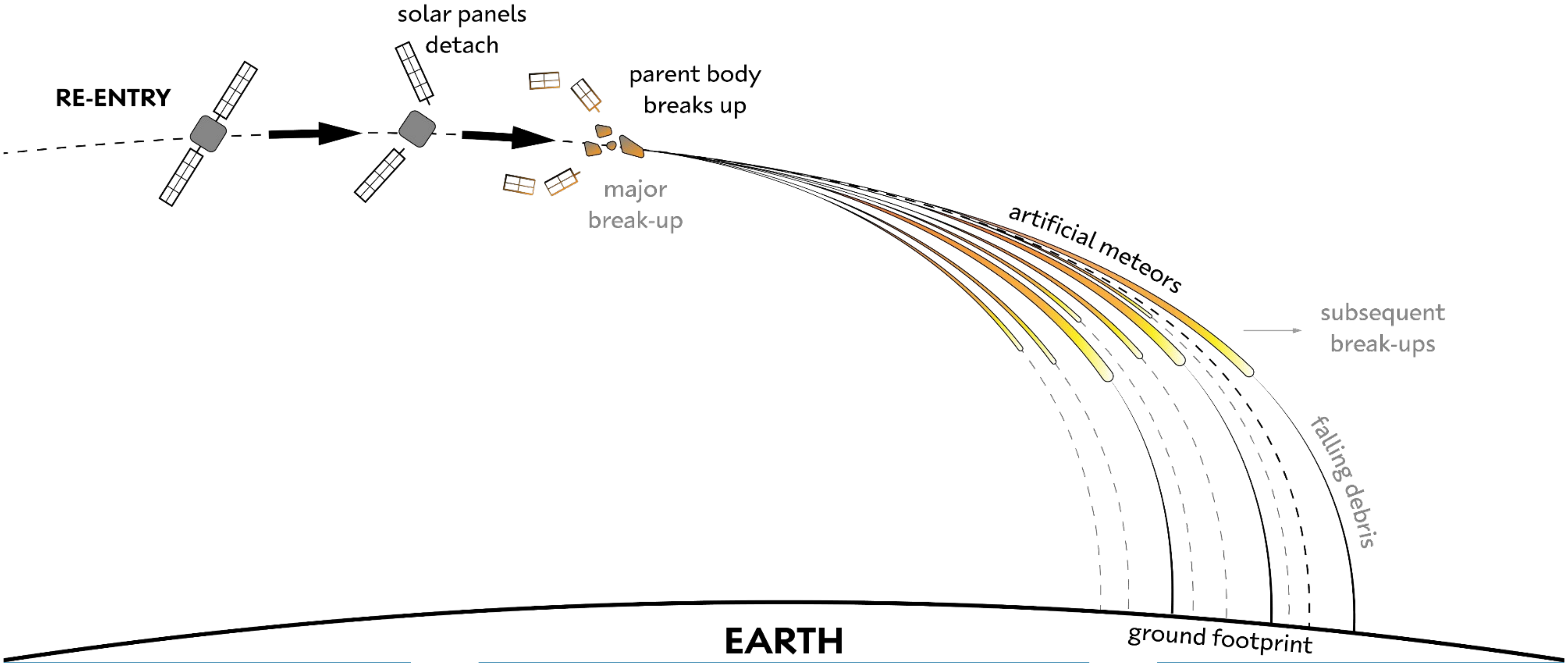


Object inside the atmosphere

- Focus on event reconstruction and modelling
- Object fragmentation modelling
- Fragments dynamical properties (position, velocity, deceleration)
- Modelling of survivability and impact area
- Damage estimation
- Modelling of production of aluminum oxide*
- 2xPhD + 1xMaster

Re-entry event

- Re-entry event occurs when satellite, rocket upper stage or space debris enter denser layers of the atmosphere, where they usually ablate and burn up. During this process, a fragmentation can occur and created fragments can survive and impact the ground/ocean.
- The goal of our research is to better understand the complex physics of atmospheric entry which supports the assessment of re-entry events on the ground population and environment.



Meteor research and AMOS system

- Meteors are phenomena which accompany meteoroids colliding with the Earth’s atmosphere with very high velocities (11-72 km/s), causing the meteoroid to ablate and radiate heat and light, which is detected from ground or space.
- One of the techniques to observe meteors and calculate the incoming meteoroid stream flux and chemical composition are optical cameras, very often all-sky cameras are exploited.

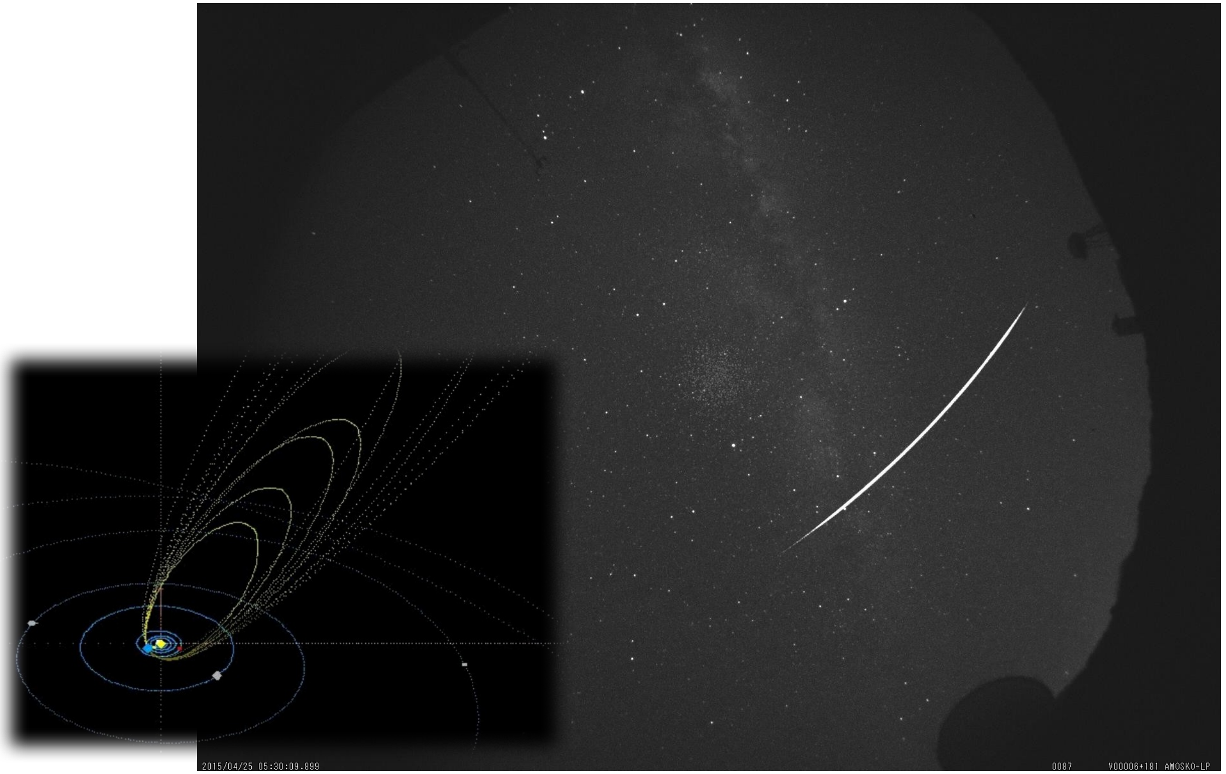


Fig. Heliocentric orbits of Lyrids (2009) calculated from AMOS observations (Tóth et al., 2011).

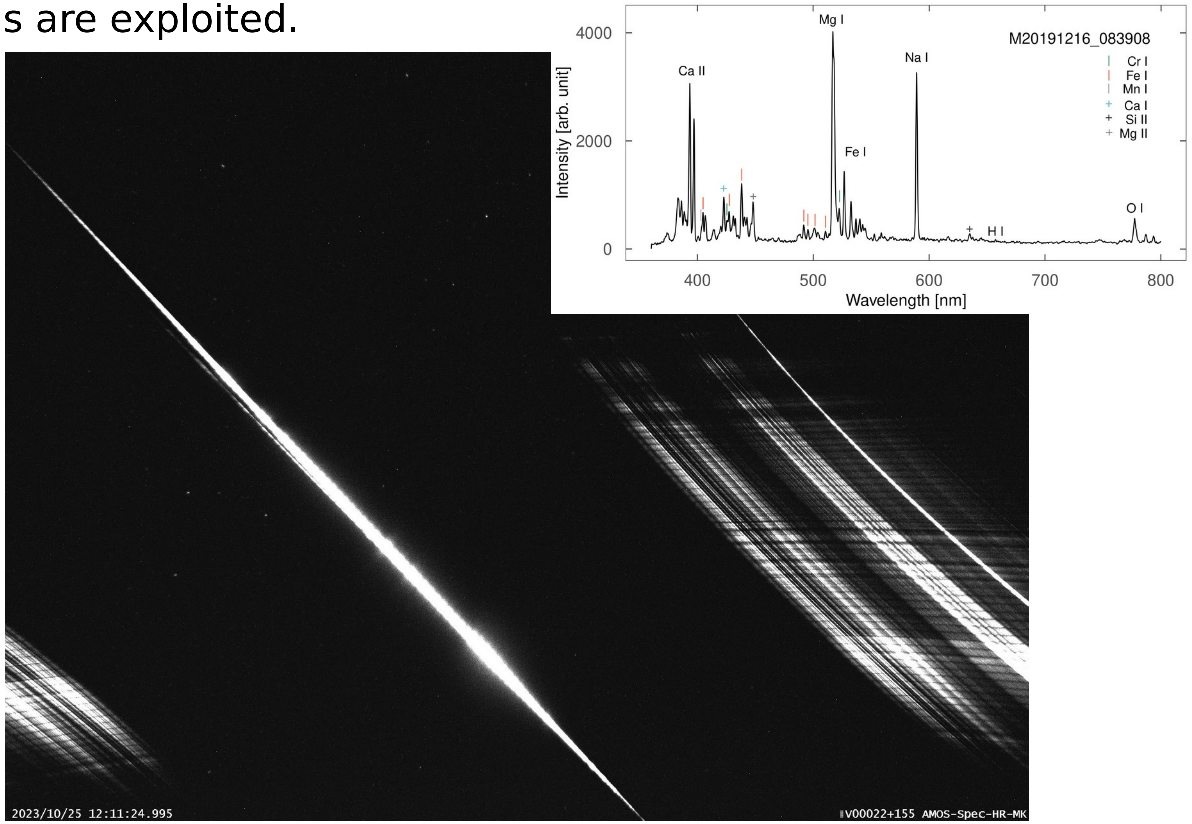
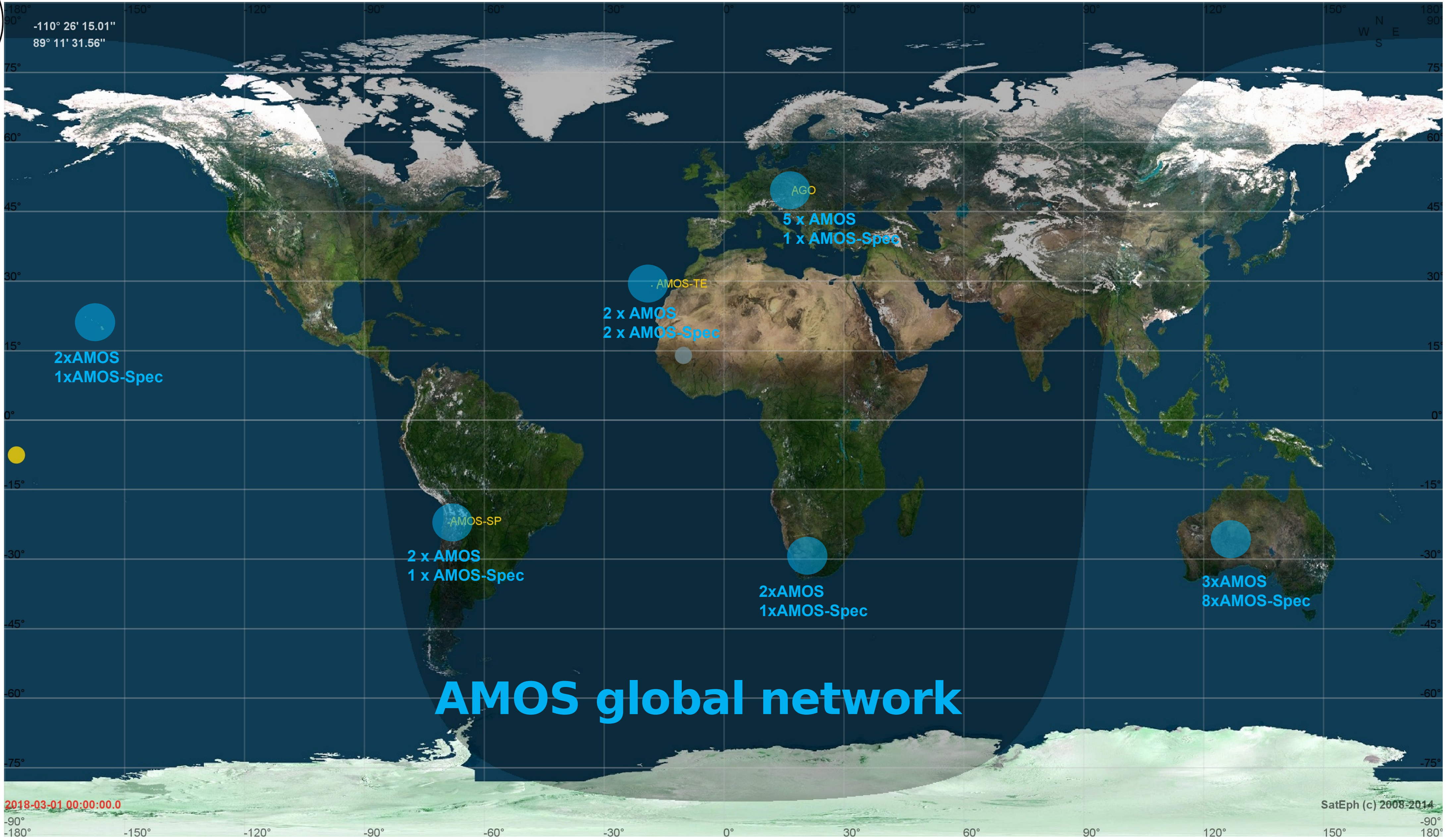


Fig. Example of meteor spectrum of σ Hydrids. Taken from Matlovič et al. (2019).

Meteor research and AMOS system

- All-Sky Meteor Orbit System – AMOS – developed and operated by Comenius University
- Program active since 2007
- Two parallel programs, AMOS Cam and AMOS-Spec
- **AMOS-Cam**, main purpose:
  - orbit determination
  - brightness extraction
  - association with meteor streams
  - identification of new streams, parent bodies
  - meteorite recovery
- **AMOS-Spec**, main purpose:
  - spectra observation and analysis

Fig. All-sky AMOS-Cam (left) and AMOS-Spec (right).


-110° 26' 15.01''
89° 11' 31.56''
AGO
5 x AMOS
1 x AMOS-Spec
AMOS-TE
2 x AMOS
2 x AMOS-Spec
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1xAMOS-Spec
AMOS-SP
2 x AMOS
1 x AMOS-Spec
2xAMOS
1xAMOS-Spec
3xAMOS
8xAMOS-Spec
AMOS global network
2018-03-01 00:00:00.0
SatEph (c) 2008-2014

Case of CZ-3B upper stage - observations

Fig. CZ-3B R/B under Preparation, Photo credit: en.sasac.gov.cn

- On 25th of October 2020 AMOS cameras in Hawaiian Islands (USA) detected re-entry of CZ-3B R/B (2008-055B).
- Two video sequences available from two different locations, 2xAMOS-Cam and 1xAMOS-Spec.
- Data reduction and cloud reconstruction funded by **ESA activity**, coordinated by Slovak private sector.

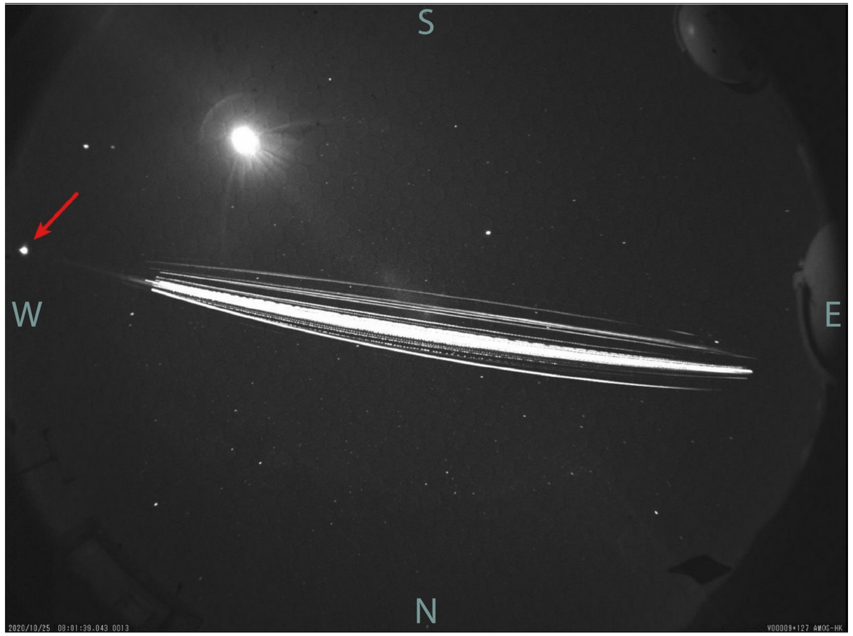

Fig. Composition frame from video sequence of re-entry object captured by AMOS-HK camera.

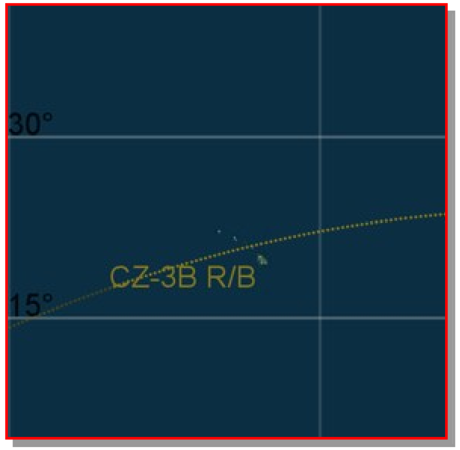

Fig. Re-event of CZ-3B R/B (2008-055B, 33415) predicted by Space-Track.org service.

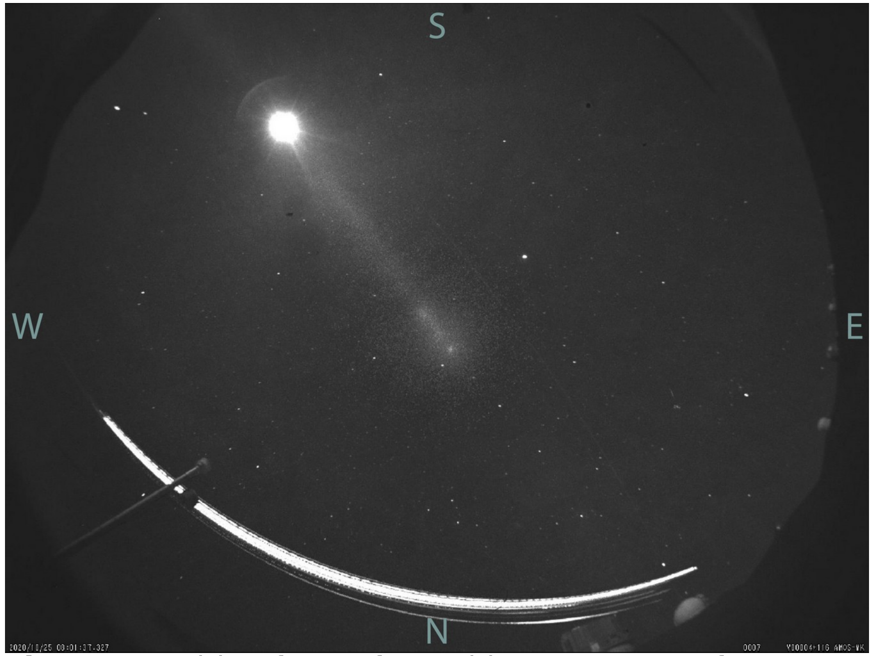

Fig. Composition frame from video sequence of re-entry object captured by AMOS-MK camera.

Case of CZ-3B upper stage – data reduction

- Data reduction challenging with meteor tools, necessary to link meteors between recordings.
- More than 50 fragments visually distinguishable on the recording but coupled 17 fragments in total.
- Triangulation used for atmospheric trajectory reconstruction for each fragment to get the dynamical motion.

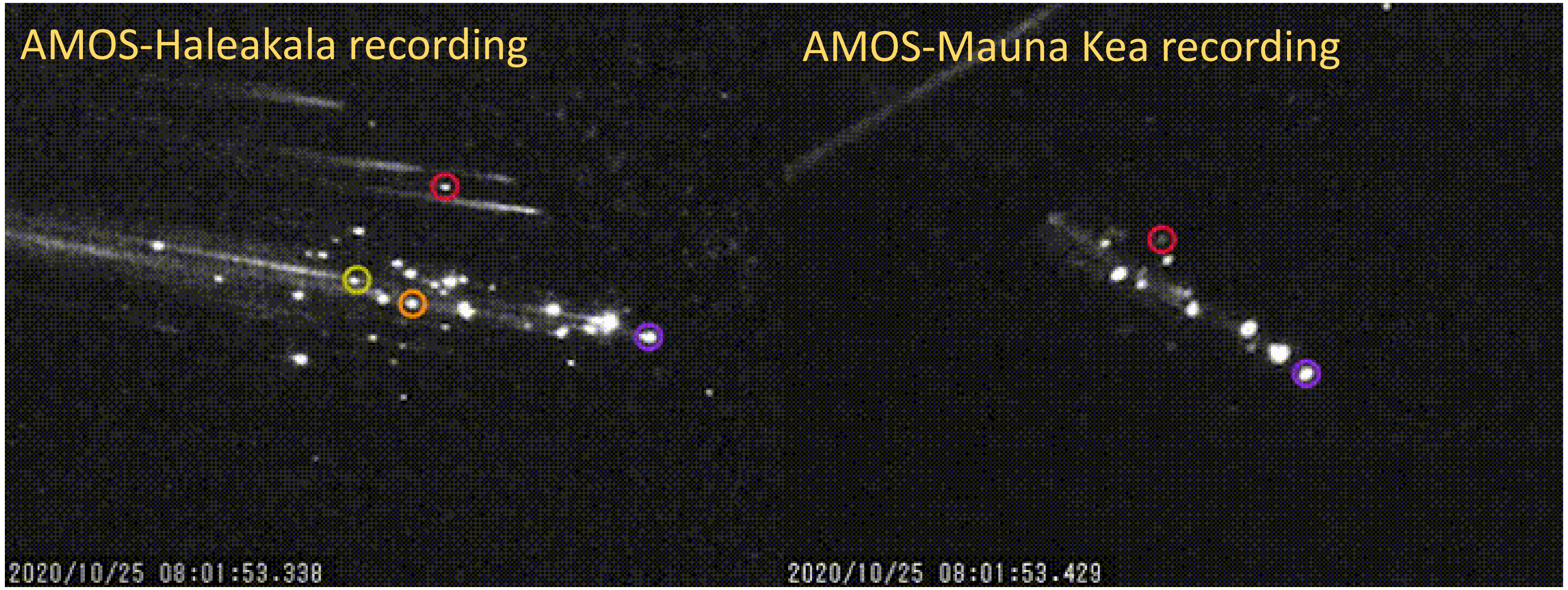

Fig. Object association between recordings using human eye.

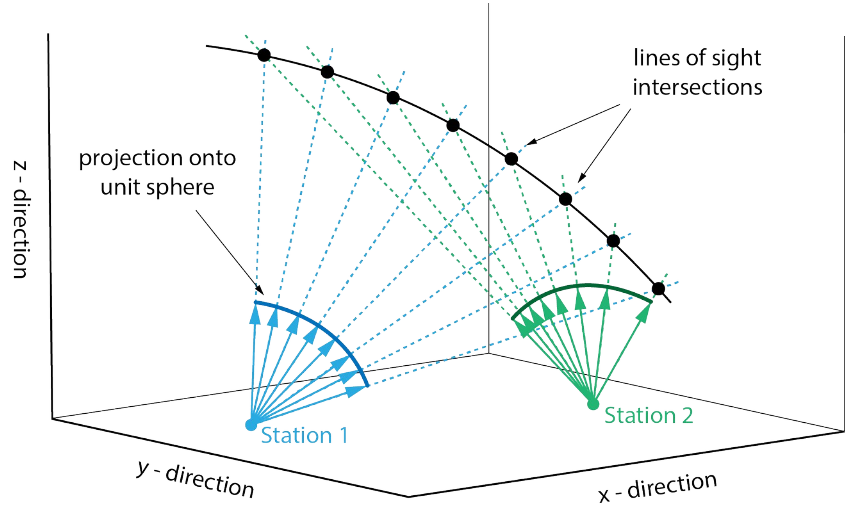

Fig. Illustration of intersecting lines of sight. In an ideal case with highly-precise time-synchronized observations of a meteor/re-entry fragment fall, the lines of sight emanating from each station would intersect in a single point in 3D space, lying on the real trajectory of the object. In reality, the intersection does not exist.

Case of CZ-3B upper stage – cloud reconstruction

- Primary objective to reconstruct the 3D shape of the fragments cloud using available data.
- Once cloud available, possible to move forward with modelling of dynamics, physics/ablation/loss of mass, fragments survivability estimation, rocket break-up event modelling – research continuing.

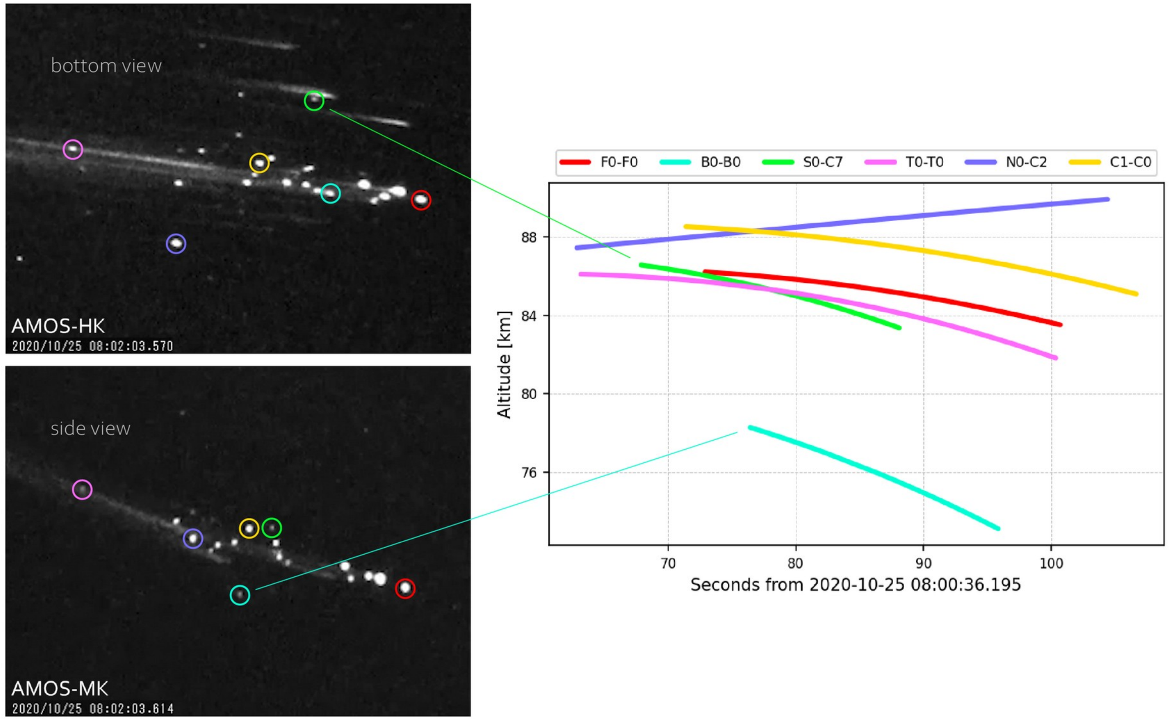

Fig. – Time vs heigh for four selected fragments for which the trajectories were estimated using new proposed method of LOS intersections.

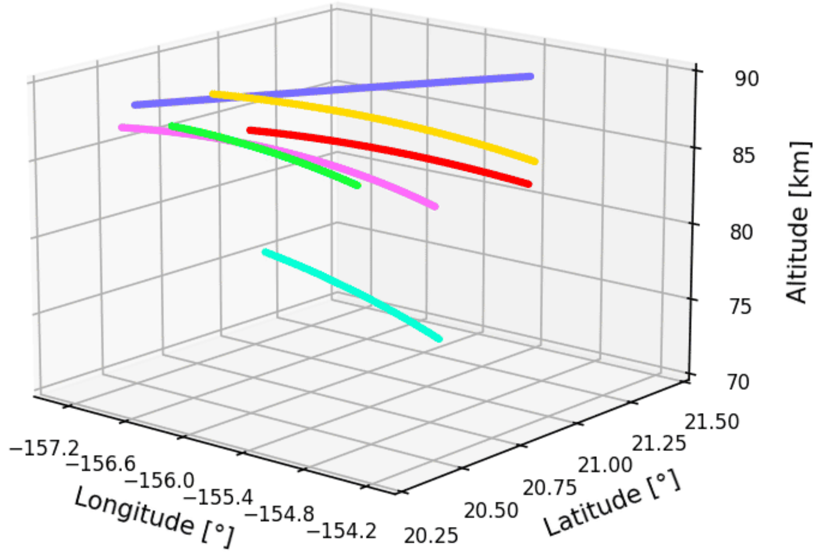

Fig. – Time vs heigh for 6 of 17 processed fragments for which the trajectories were estimated using new proposed method of LOS intersections. Pure geometry is considered at this stage.

Summary

- Space debris objects population constantly increasing → increased number of re-entry events.
- From AMOS recordings reconstructed 3D cloud of re-entry event CZ-3B R/B detected in 2020 over Hawaiian islands → extracted positions, velocities and decelerations for 17 individual fragments.
- Data to be used to further model dynamics of fragments forward (deceleration, ablation/mass loss, survivability and impact area estimation) and backwards (fragmentation point identification, fragmentation event modeling).
- Conduct new science – analysis of other re-entry events detected by AMOS, modelling of alumina production.

Thank you for your attention!

Questions?

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