# LAD-C: A large area debris collector on the ISS

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**Abstract**

The Large Area Debris Collector (LAD-C) is a 10 m$^2$ aerogel and acoustic sensor system under development by the U.S. Naval Research Laboratory (NRL) with main collaboration from the NASA Orbital Debris Program Office at Johnson Space Center, JAXA Institute of Space and Astronautical Science (ISAS), Chiba University (Japan), ESA Space Debris Office, University of California at Berkeley, and University of Kent at Canterbury (UK). The U.S. Department of Defense (DoD) Space Test Program (STP) has assumed the responsibility for having the system manifested and deployed on the International Space Station (ISS), and then having it retrieved and returned to Earth after one to two years.

LAD-C will attempt to utilize the ISS as a scientific platform to characterize the near-Earth meteoroid and orbital debris environment in the size regime where little data exist. In addition to meteoroid and orbital debris sample return, the acoustic sensors will record impact time, location, signal strength, and acoustic waveform data of the largest collected samples. A good time-dependent meteoroid and orbital debris flux estimate can be derived. Analysis of the data will also enable potential source identification of some of the collected samples. This dynamical link can be combined with laboratory composition analysis of impact residuals extracted from aerogel to further our understanding of orbital debris population, and the sources of meteoroids – asteroids and comets.

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## 1. Introduction

Meteoroids and man-made orbital debris exist in the near Earth environment. While the former is a natural component of the Solar System, the latter is a byproduct of half a century of human space activities. Meteoroids originated primarily from collisions among asteroids or disintegration of comets near the Sun. Orbital debris includes satellite breakup fragments, mission-related debris (rings, bolts, *etc.*), spent upper stages, and retired spacecraft. The existence of these two populations in the near Earth space presents both challenges and opportunities for space scientists and engineers. Since the beginning of space age, it has been recognized that impacts by meteoroids pose a threat to satellite operations in the near Earth environment and in interplanetary space (*e.g.*, Anon 1969). With the increased space activities around the globe, man-made orbital debris has become a new and additional threat to near-Earth satellite operations (*e.g.*, Anon 1999), and the trend is expected to become worse in the future (*e.g.*, Krisko *et al.* 2001; Liou and Johnson 2006).

To protect critical space assets (including satellites, ISS, Space Shuttle, and future exploration vehicles), a reliable meteoroid and orbital debris environment definition (for particles about 0.1 mm and larger) is needed. A better understanding of the environment is also key to cost-effective shielding designs to mitigate the risks. Ground-based optical telescopes and radars

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are limited to objects several millimeters and larger. A large detection area *in situ* sensor, with long mission duration, is the only means to characterize the small particle populations. The ISS is an ideal platform for such a sensor. Since the orbital debris population is highly dynamic, a regular monitoring of the population is also required. Unfortunately, there has been a lack of large area *in situ* sensors in the last decade. Dedicated sensors, such as the DEBris In orbit Evaluator (DEBIE, *e.g.*, Schwanethal *et al.* 2005) and the Micro-PArticle Captured (MPAC, *e.g.*, Neish *et al.* 2005), are limited to particles about 20 μm and smaller due to their small sensing area. Such particles are not a safety concern due to their small sizes. Although large surfaces returned from space, such as Shuttle window panels and radiators (*e.g.*, Hyde and Bernhard 2006) and Hubble Space Telescope Solar Arrays (*e.g.*, Moussi *et al.* 2005), have been used to deduce the larger meteoroid and orbital debris populations, the results are not as useful as those from surfaces designed to be used as impact sensors. Additional factors, such as the lack of impact timing information, also add deficiency to the results. From the safety and satellite operations' perspective, there is a need for a dedicated, large detection area, meteoroid and orbital debris sensor to monitor and update the populations on a regular basis.

*In situ* measurements and sample return of orbital debris and meteoroids from the ISS provide not only a means to characterize the small particle environment, but also an opportunity to analyze compositions of the collected samples. It is a cost-effective way to capture and collect small meteoroids as samples from asteroids and comets. The information extracted, including mineralogical and isotopic compositions, can be used to improve the knowledge of the environment at the time when the Solar System was formed, and the physical processes through which their parent objects went (*e.g.*, Brownlee 1985; Bradley *et al.* 1988; Zolensky *et al.* 2000). Although small meteoroids (also called micrometeoroids or interplanetary dust particles) have been collected by high altitude aircraft and by other *in situ* experiments, the collections have always been passive. There is a lack of impact timings and orbit estimates of the collected samples. Such data, if included as part of the sample return, would provide valuable dynamical signatures of the collected samples. A link to infer the source of each collected sample may be established.

The concept of a joint meteoroid and orbital debris *in situ* experiment was developed by several team members in 2002. NRL subsequently took the lead to materialize the LAD-C concept (with F. Giovane as PI), and to sponsor the flight of the system as a DoD STP payload. The major contributing organizational members of LAD-C and their responsibilities are: NRL (lead, management, acoustics, engineering), NASA Orbital Debris Program Office (science planning and operations), JAXA/ISAS and Chiba University (aerogel, calibration), ESA Space Debris Office (system software, calibration), UC Berkeley (calibration), University of Kent at Canterbury (calibration). The STP is in charge of the manifestation of the flight, including system integration and safety. The responsibility of post-flight analysis and modeling will be shared by all team members. The current schedule for LAD-C is Preliminary Design Review (PDR) and Critical Design Review (CDR) in 2006, system delivery in 2007, deployment in early 2008, and retrieval in 2009.

## 2. LAD-C components

LAD-C consists of two major components: aerogel tiles and acoustic sensors. The former are used for intact capture of hypervelocity impact particles while the latter are designed to record impact characteristics of the collected samples. The basic structure of LAD-C is made of panels arranged as an upside down T-shaped system. The three arms are connected to a base hub mounted on the starboard truss, S3, on ISS. An illustration of the LAD-C mounting configuration is shown in Fig. 1. Each one of the three arms consists of four 1 m × 1 m × 2 cm trays. Each tray is further divided into two half-panels. Each aluminum (6061-T6) panel contains many small aerogel tiles and twelve acoustic sensors attached to the aluminum frame. The total aerogel collection area is about 10 $m^2$.

The LAD-C acoustic sensor system is called Particle Impact Noise Detection and Ranging On autonomous Platform (PINDROP, Corsaro *et al.* 2004, 2006). The development of the system was supported by the NASA Planetary Instrument Definition and Development (PIDD) Program between 2004 and 2006. The sensor design was optimized by fabricating and testing sensors of various configurations and materials. The final sensor material selected for LAD-C is poly-vinylidene fluoride (PVDF) copolymer, which has high acoustic sensitivity, low mass, and good transient response. Preliminary acoustic propagation was examined in an airgun facility using PVDF sensors attached to an aerogel-populated aluminum tray. It was not an acoustically simple mechanical structure, involving at least four wave types each with distinct characteristics (*i.e.*, speed, damping). Mode conversion between these wave types was prevalent during signal propagation, complicating the algorithm needed to estimate the impact location from the acoustic time records. This issue was partly resolved by matching the sensor amplifier to reduce undesired wave components.
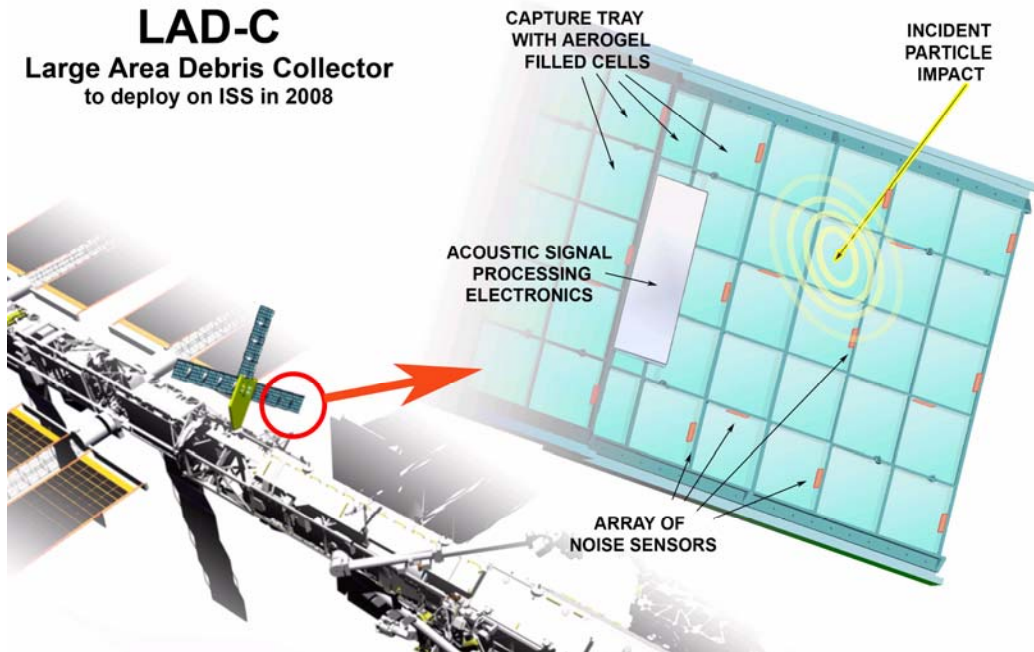
Fig. 1. Illustration of LAD-C aerogel collector and its integrated PINDROP acoustic impact detector subsystem (and configuration to be deployed on the ISS). The starboard direction is, along the truss, toward the left. Only the back panels of the trays are visible. Aerogel tiles are mounted on the other side of the trays, facing the starboard direction.

At the conclusion of the PIDD-supported project, the PINDROP system capability was evaluated in a series of successful hypervelocity impact tests on similar aerogel trays. These tests were conducted at University of Kent at Canterbury using particles of various sizes, and speeds of 2 to 5 km/sec. The tests confirmed the ability of the system to detect and locate impacts from particles at least as small as 30 μm, and illustrated the relationship between signal amplitude and impacting particle size and speed.

Aerogel has been used to capture orbital debris and micrometeoroids in the near-Earth environment. For example, the Orbital Debris Collector (ODC) was deployed on the *Mir* Station between 1996 and 1997 (Hörz *et al.* 2000) and MPAC was placed on ISS between 2001 and 2005 (Kitazawa *et al.* 2004). Two key features make LAD-C stand out from previous experiments. First, the collection area of LAD-C aerogel is 10 m$^2$. It is more than one order of magnitude larger than all previous aerogel experiments combined. With a long mission duration (at least 12 months), the LAD-C aerogel collector will be able to capture a significant number of large particles - 0.1 mm and larger, for laboratory analysis. Second, the acoustic sensors attached to the aluminum frame will record impact time and location (from signal triangulation), signal strength, and acoustic waveform of those particles. After the aerogel collector is returned from the ISS, the acoustic signals will be analyzed and correlated with samples embedded in the aerogel. The impact timing data and aerogel impact features will be combined to estimate the time-dependent meteoroid and orbital debris flux. The dynamical signatures of some of the collected sample, based on additional analysis on acoustic signals and aerogel features, will be used for possible source identification.

Many hypervelocity impact tests on aerogel have been performed to correlate impact features embedded in aerogel with impact speed, impact angle, projectile properties, and aerogel density (*e.g.*, Hörz *et al.* 1998; Kitazawa *et al.* 1999; Burchell *et al.* 1999; Burchell *et al.* 2001, 2006). Below 7 km/s impact speed, clear tracks in aerogel are present in most cases. The impact direction can be reconstructed to within 2° of accuracy. Track length, track volume, entry hole diameter, and other features can be used to estimate impact speed and the size of the impactor. For impacts above 7 km/s, the correlation is less certain due to a lack of laboratory data. However, aerogel collection on *Mir* and the subsequent analysis show a clear transition in impact feature morphology that are most likely a result of impacts from different velocity regimes (Hörz *et al.* 1999). Many calibrations up to 7 km/s will be carried out for LAD-C aerogel to aid the post-flight analysis and data interpretation.
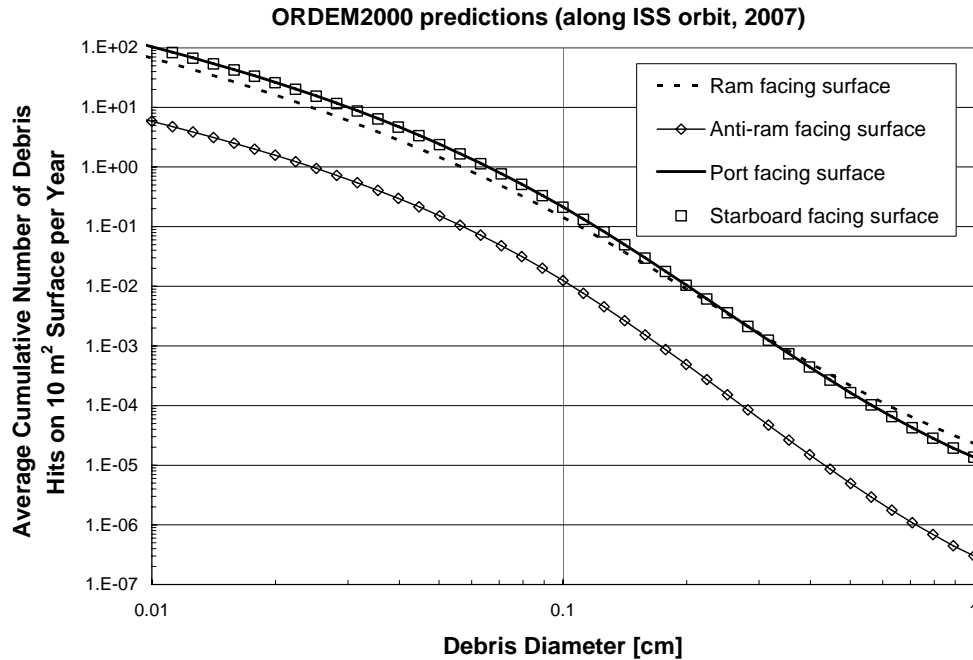
Fig. 2. Estimated orbital debris impact rates on sensors with four different orientations mounted on ISS in 2007. For an Earth-orbiting sensor, the starboard and port side debris fluxes are expected to be identical.

The LAD-C aerogel is a special water-resistant silica aerogel originally developed for Cherenkov counters at Japan's national KEK high energy lab (Adachi *et al.* 1995; Tabata *et al.* 2005). Similar KEK-produced aerogel was flown on the ISS as part of the MPAC package (Kitazawa *et al.* 2004). The aerogel density considered for LAD-C is between 0.04 and 0.06 g/cm3. The final density selection will be determined before the CDR in 2006, after additional hypervelocity impact tests in the summer. A balance between two competing factors, strong acoustic signals (higher density) and longer aerogel tracks (lower density) must be reached.

In addition to PINDROP and aerogel, several small area instruments, proposed by ESA, JAXA/ISAS, and UC Berkeley, may be integrated into one of the panels. Their different sensing capabilities can also serve to cross-calibrate the acoustic and aerogel data.

### 3. Deployment configuration

LAD-C deployment consideration is driven by the objectives to maximize the science return and to minimize contamination. Meteoroid and orbital debris impact rates and impact speeds are very sensitive to the orientation of the collection surface. Unfortunately the two populations do not have the same dependence on orientation. A compromise is needed to maximize the sample collection for both of them. A simple orbital debris flux estimate, based on the NASA Orbital

Debris Engineering Model ORDEM2000 (Liou *et al.* 2002), is shown in Fig. 2. It is clear that port and starboard facing orientations lead to the highest orbital debris impact rate between debris 0.1 and 1 mm in size while the forward (ram) facing orientation has a slightly lower rate. The reason ram facing direction does not yield the maximum flux is due to the fact that the orbital debris population does not have a uniform inclination distribution in the environment. In other words, the orientation dependence is a function of the ISS orbit inclination (51.6°) and the inclination distribution of the orbital debris population. A similar calculation can be made to estimate the impact speed distributions on the same four orientations. As shown in Fig. 3, a significant portion of impacts on the port and starboard surfaces is less than 7 km/s, where the impact characteristics are better understood and the tracks embedded in aerogel are better preserved for impact speed estimation. Therefore, the best orientations for orbital debris are in the port or starboard directions, followed by orientations toward the ram direction. Out of the local horizontal plane orientations, such as zenith or nadir facing directions, should be avoided since very few orbital debris impacts are expected.

Meteoroid impact rate and impact speed distributions are different from those of orbital debris. Since meteoroids appear to enter Earth's atmosphere with an isotropic distribution, the highest flux is expected on a ram facing surface. The distribution on surfaces with different orientations depends on the
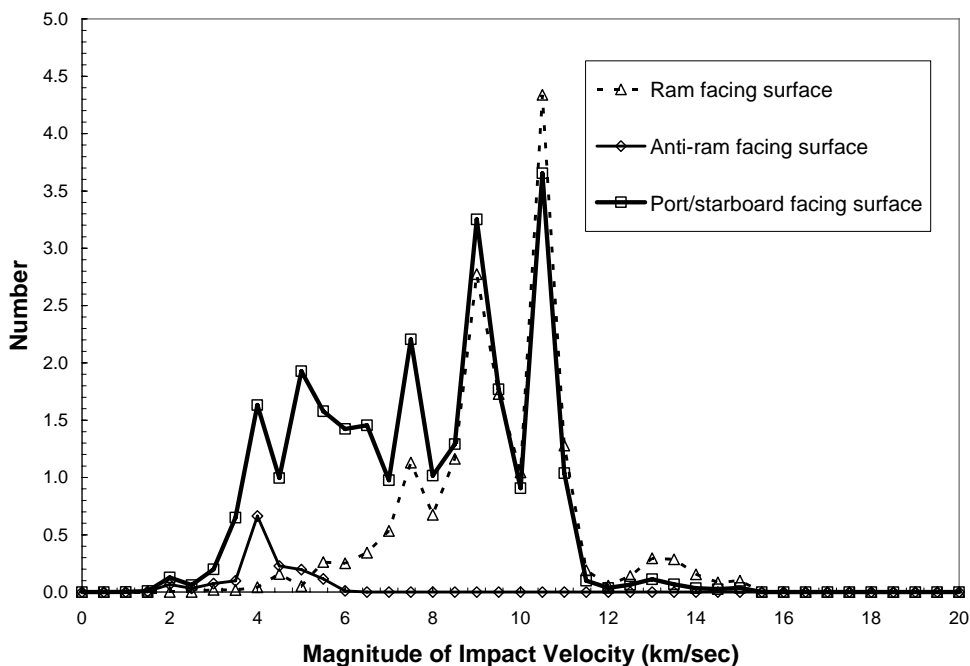
Fig. 3. Estimated orbital debris impact speed distributions on sensors with four different orientations mounted on ISS. The curves are normalized to the impact rates as shown in Fig. 2.

velocity distribution of meteoroids in interplanetary space (*e.g.*, Zook 1991), which in turn, depends on the orbits of their parents (asteroids or comets) and their relative contributions. Asteroidal meteoroids typically have a lower velocity distribution than cometary particles although some overlap may exist between the two (Jackson and Zook 1992; Liou and Zook 1996). Infrared observations and analysis on atmospheric entry heating of meteoroids in the 5 to 25 μm regime provide clues to their relative contributions at 1 AU (Brownlee *et al.* 1993; Liou *et al.* 1995). But the relative asteroidal versus cometary proportions in the 0.1 mm and larger size regime is uncertain. Additional factors such as Earth's gravitational focusing and shielding effects also make the calculation more difficult. The best estimate appears to suggest the port/starboard side fluxes are about a factor of 2 lower than the ram side flux (Zook 2001). The best orientation for meteoroids is in the ram direction, followed by orientations toward the port or starboard directions. Therefore, a good balance between meteoroid and orbital debris collections can be reached anywhere between port/starboard and ram directions, in the local horizontal plane.

Any *in situ* sample capture experiments on ISS must evaluate the contamination issue carefully. Possible sources of contamination include thruster plume (from Space Shuttle, Progress, Soyuz, Automated Transfer Vehicle, *etc.*), water and waste dumps from ISS, and outgassing from other ISS components. For example, the Shuttle Reaction Control System (RCS) thrusters can release gas, solid, and liquid droplets with speeds up to about 2 km/s (Soares *et al.* 2003). Some of the particles may be as big as 10 μm in size. Recent analysis on MPAC, mounted near the Russian module with ram and anti-ram facing aerogel surfaces, indicates that the aerogel was heavily contaminated, possibly by plume particles (Kitazawa *et al.* 2004; Neish *et al.* 2005).

According to the ISS contamination analysis, the port side environment is heavily contaminated. A strong and firm structure is also needed to mount LAD-C. Therefore, the location on the starboard side truss S3, indicated by the white cross in Fig. 4, appears to be a good option for the system. However, this location is sensitive to plume contamination. When Shuttle is approaching, docked to, and departing from ISS, the RCS thrusters on the nose of the Shuttle release significant amount of plume particles in the vicinity of the truss. A ram-facing aerogel orientation will put the collection surface in the direction of the plume particles. As a result, the aerogel surface has been selected to be in the starboard direction (90° away from ran direction, in the local horizontal plane). The RCS plume particles will only hit the back side of LAD-C and will have minimum effect on the aerogel. The starboard side facing orientation also reduces the chances of the aerogel surface being hit by other contaminants released from ISS.
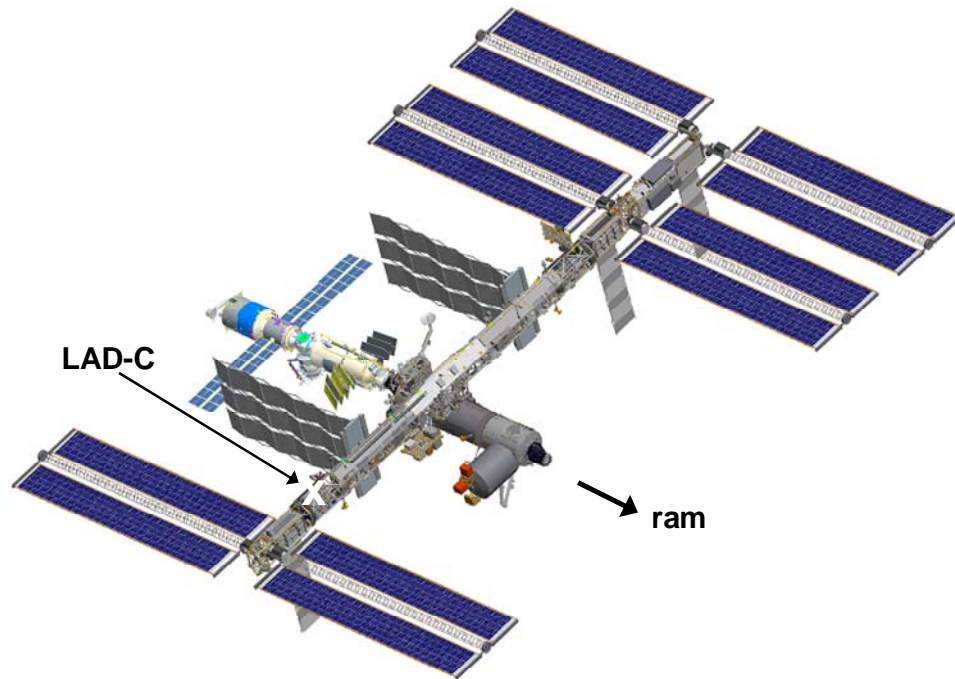
Fig. 4. The planned configuration of ISS just before the deployment of LAD-C. The forward (ram) direction of ISS is indicated by the black arrow. The starboard side is less contaminated than the port side where water/waste dumps occur. LAD-C will be mounted on the starboard truss indicated by the white cross. Aerogel tiles will face the starboard direction.

As the International Partners moves forward to complete the construction of ISS, additional modules and components will be brought up and assembled. It is highly likely that before the deployment of LAD-C, the truss will be extended, and at least one set of rotating solar panels will be added to the right of the LAD-C location. An analysis is underway currently to evaluate potential shadowing effects. It may become necessary to rotate the aerogel surface by some small angle toward the ram direction to reduce the blockage effects, but not to the point where RCS plume can contaminate aerogel.

## 4. Concluding remarks

LAD-C will attempt to utilize ISS as a scientific platform to characterize the near-Earth meteoroid and orbital debris environment in the size regime where little data exist. With the addition of acoustic sensors, impact characteristics of the aerogel-collected samples will be recorded. This will provide good flux data for particles larger than 0.1 mm, and enable potential source identification of some of the collected samples. This dynamical link can be combined with laboratory analysis of the residuals extracted from aerogel to further our understanding of orbital debris and the sources of meteoroids − asteroids and comets.

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