G3

Remediation of cm-size space debris from the International Space Station

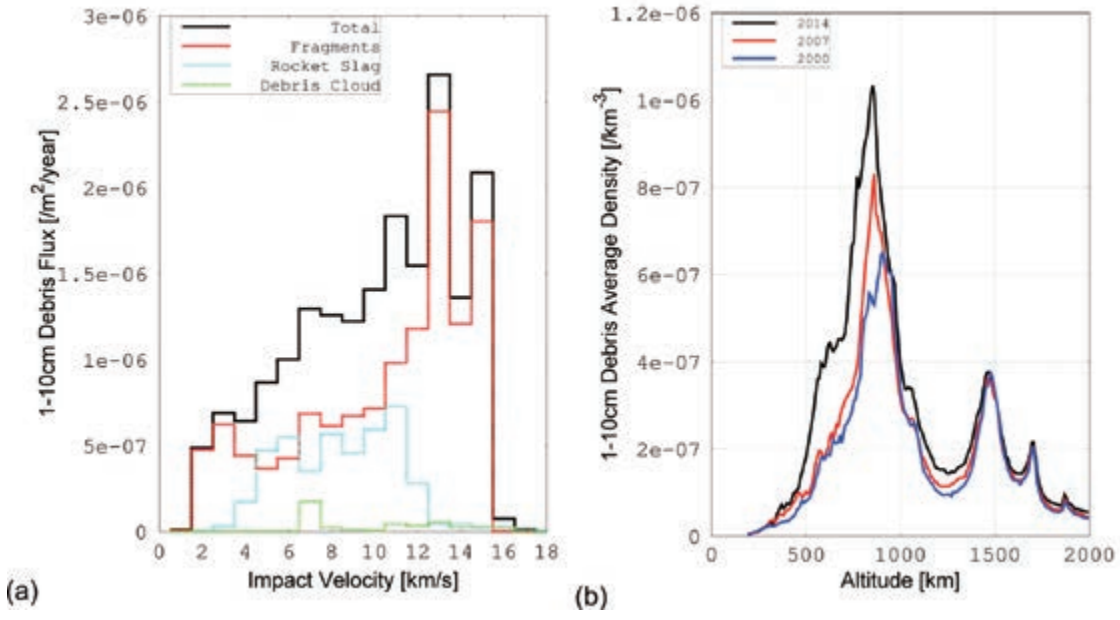
○Toshikazu Ebisuzaki^1, Mark N. Quinn^2, Satoshi Wada^1, Lech Wiktor Piotrowski^1, Yoshiyuki Takizawa^1, Marco Casolino^1,^3, and Mario Bertaina^4, Philippe Gorodetzky^5, Etienne Parizot^5, Toshiki Tajima^2,^6, Remi Soulard^2 and Gerard Mourou^2
1 RIKEN, 2-1, Hirosawa Wako, 351-0198, Japan
2 IZEST, EcolePolytechnique, 91128, Palaiseau, France
3 INFN
4 University of Torino
5 APC-CNRS/Paris7 University, 10 rue A. Domon et L. Duquet, 75013 Paris, France
6 Dept. of Physics and Astron. University of California at Irvine, Irvine, CA 92697

We present here a plan in 3 steps to design an orbiting debris remediation system comprised of a super-wide field-of-view telescope and a novel laser system operating from the International Space Station (ISS). The EUSO (Extreme Universe Space Observatory) telescope has been designed for operation onboard the ISS for the detection of ultra-high energy cosmic rays. Equipped with 2.5 m optics and a field of view of ±30 degrees, the EUSO module can also be utilized for the detection of high velocity fragmentation debris in orbit near the ISS. Once detected, the CAN laser system will deliver a sequence of pulses to the debris surface inducing ablation and hence momentum impulse to reduce its velocity. The range of the detection/removal operation can be as large as 100 km. We will use a step by step approach employing ISS : 1) Proof of principle demonstration of the detection (and, if possible, laser impulse technology) with ISS based small prototype 2) Technical demonstrator debris removal that consists of the EUSO telescope for the detection and a 1.5 m Cassegrain telescope with a space CAN laser for tracking and impulse delivery for debris re-entry, and 3) A free-flyer mission dedicated to debris remediation in a polar orbit with the alititude ~800 km.

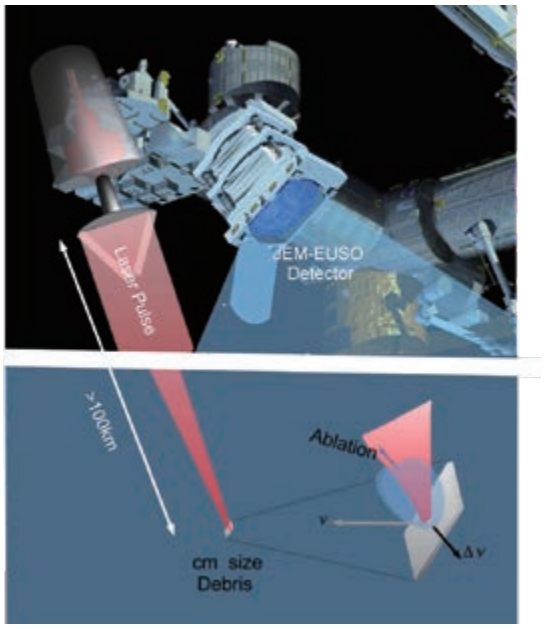
Remediation of cm-size space debris from the International Space Station

Toshikazu Ebisuzaki , S. Wada, L.W. Pitrowski, M. Casolino (RIKEN), R. Soulard, M. N. Quinn, G. Mourou (IZEST, Ecole Polytechnique, France)

Results of simulations for 1-10cm size debris, performed with the MASTER 2009

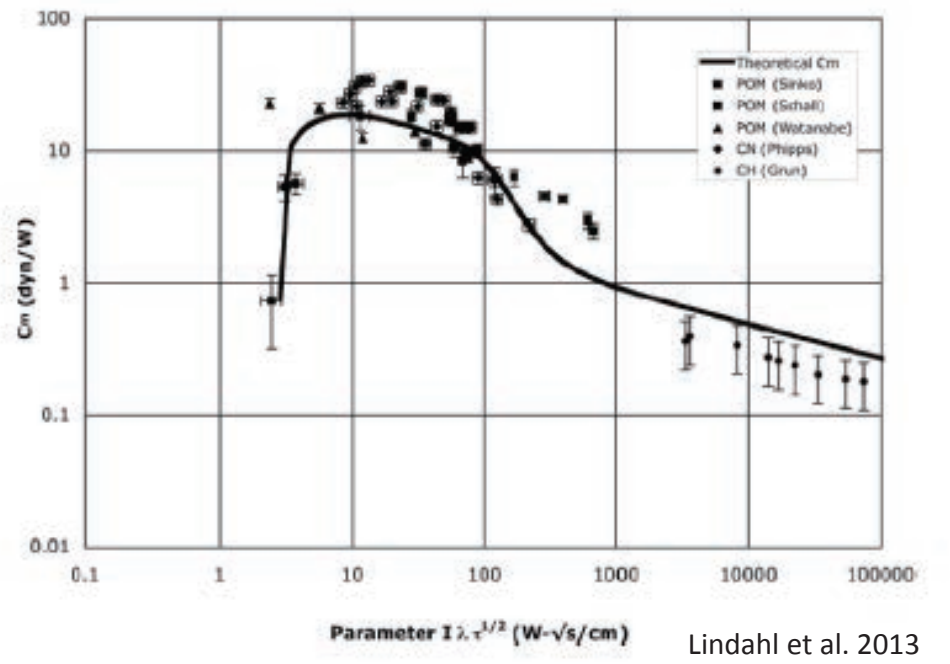


Concept of our technical demonstrator of the laser removal

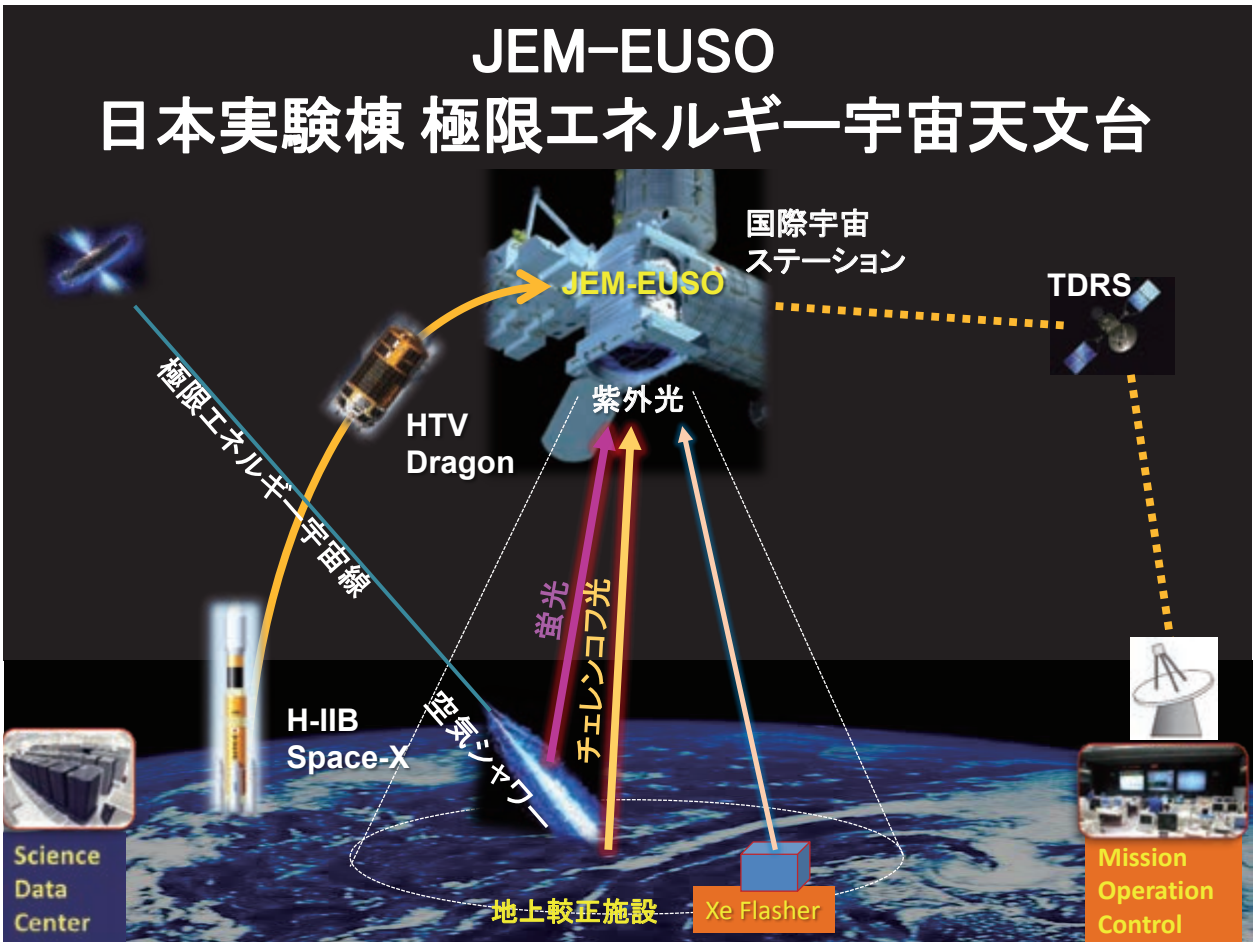


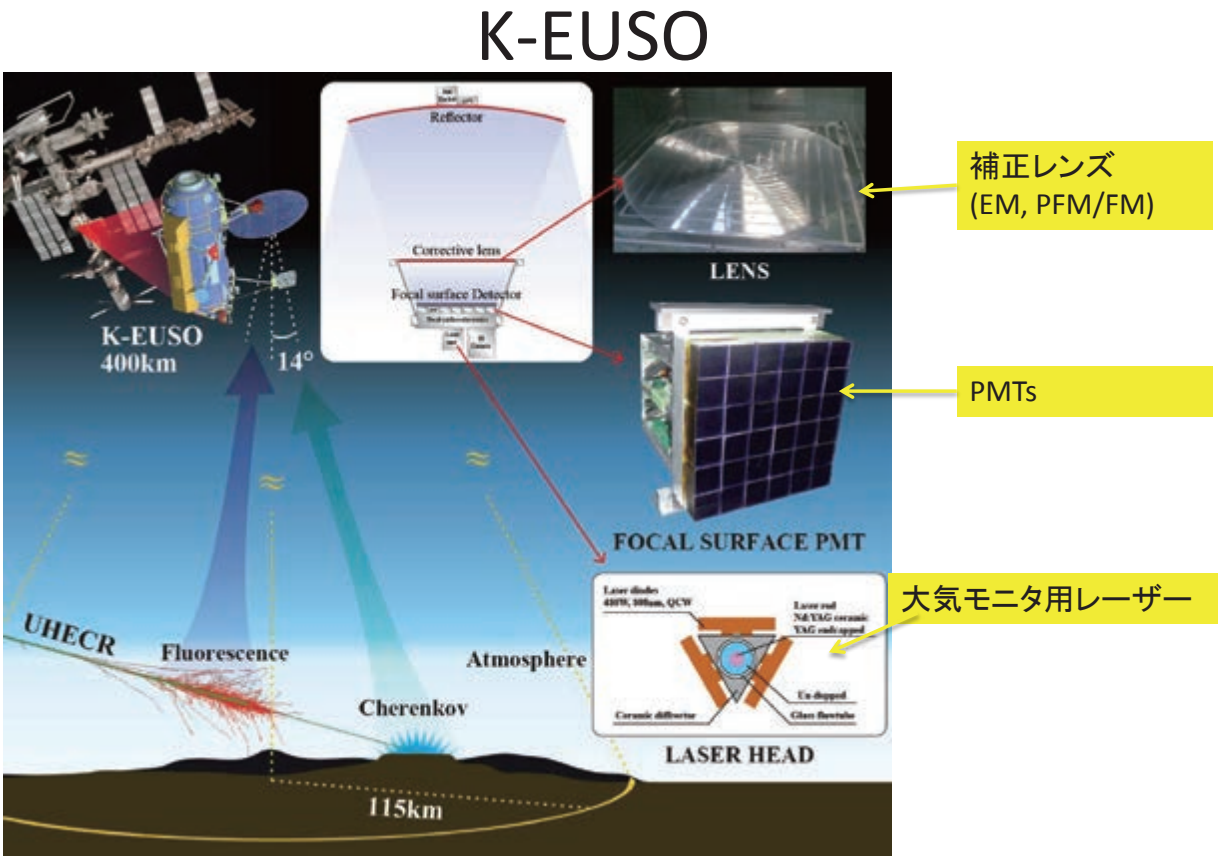
- EUSO
  - Detection
  - Position and velocity
    - Crude determination
- CAN laser system
  - Search beam
  - Position and velocity
    - Fine determination
  - Shooting Operation

アブレーションによる反力



Lindahl et al. 2013

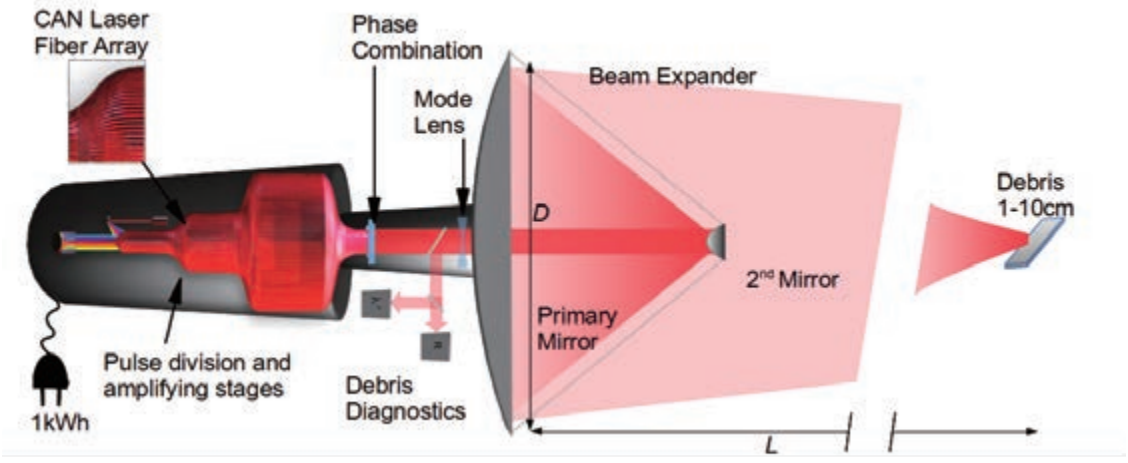




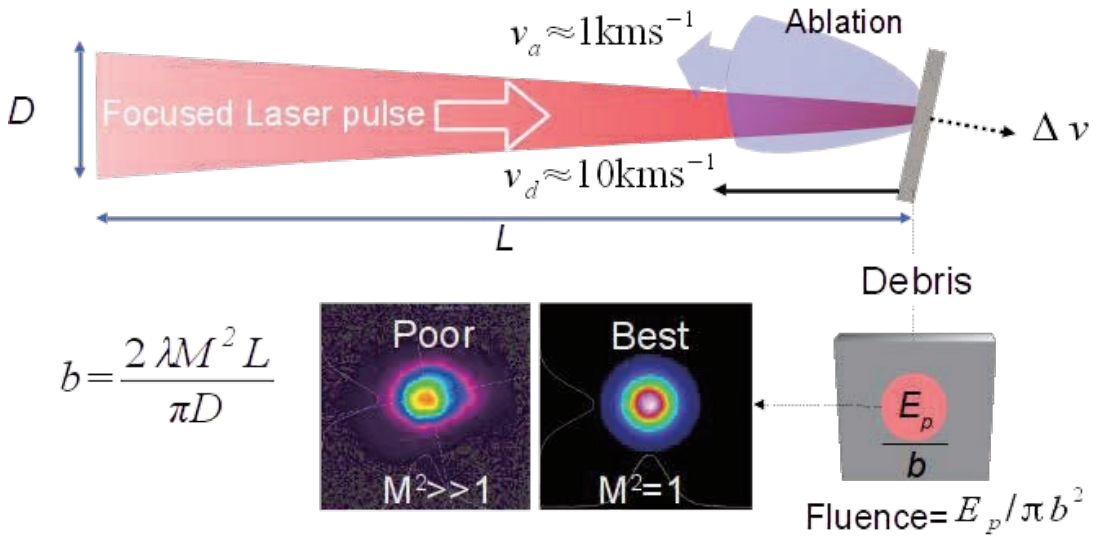
CAN (Coherent Amplification Network) Laser System

Mourou et al. 2013, nature Photonics, 7, 258-261

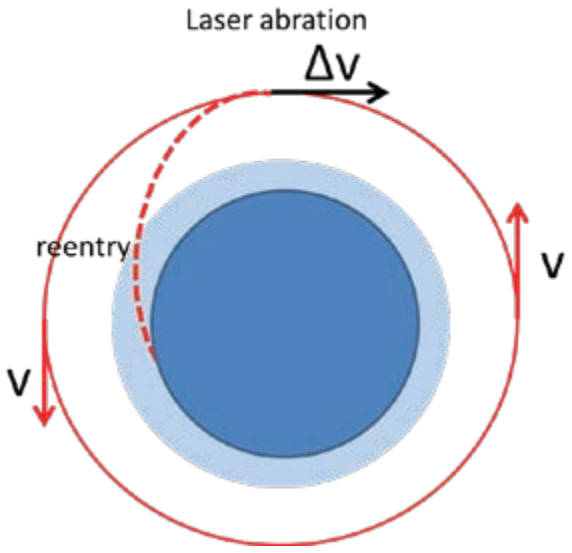
Space CAN laser system
CAN=Coherent Amplify Network



Reaction Force by Laser Abration



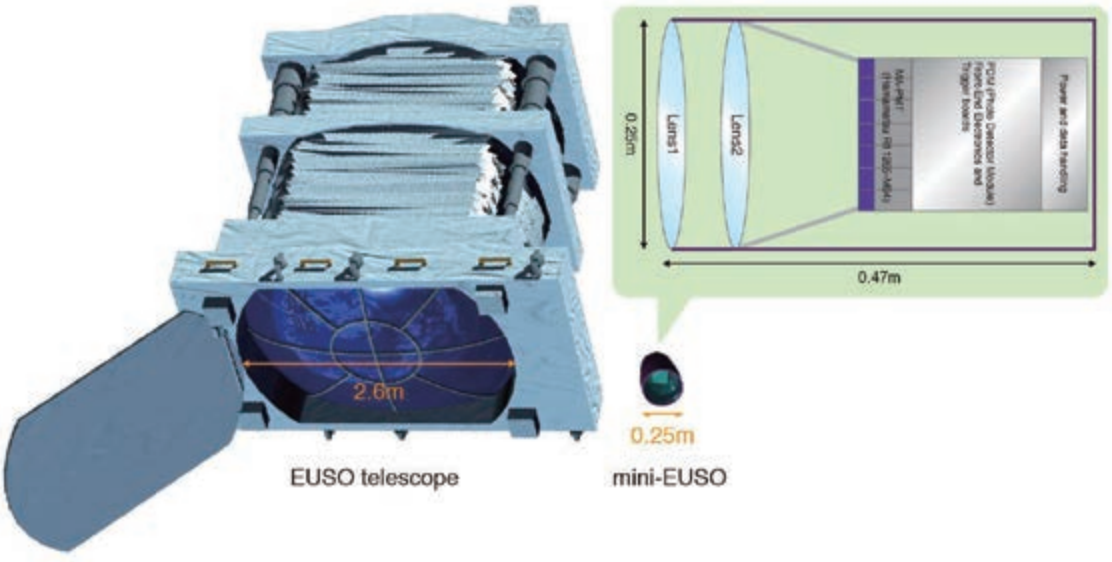
Reentry by reaction force of laser ablation



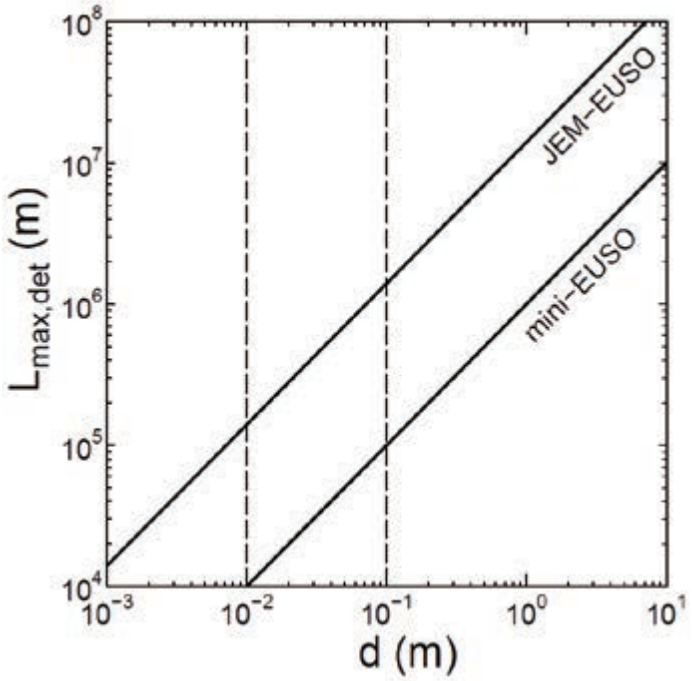
Three steps of debris removal

- Target Debris
  - a=1-10 cm、d～100 km、v_{rel}～1-10 km
- Detection（～0.1 seconds）
  - EUSO telescope ±30°
  - position（Δθ<0.07° ）and velocity (1%)
- Tracking（～1 seconds）
  - Cssegrain telescope（1.5m）（～1 seconds）
  - Pencil beam illumination（Δϕ～0.07° Δτ～1ns）
  - position（Δθ<10^{-6} rad, ΔR～1 km）
- Laser Shooting（～10 seconds）
  - E_p～10 J、R_p～10^4 Hz

JEM-EUSO and Mini-EUSO



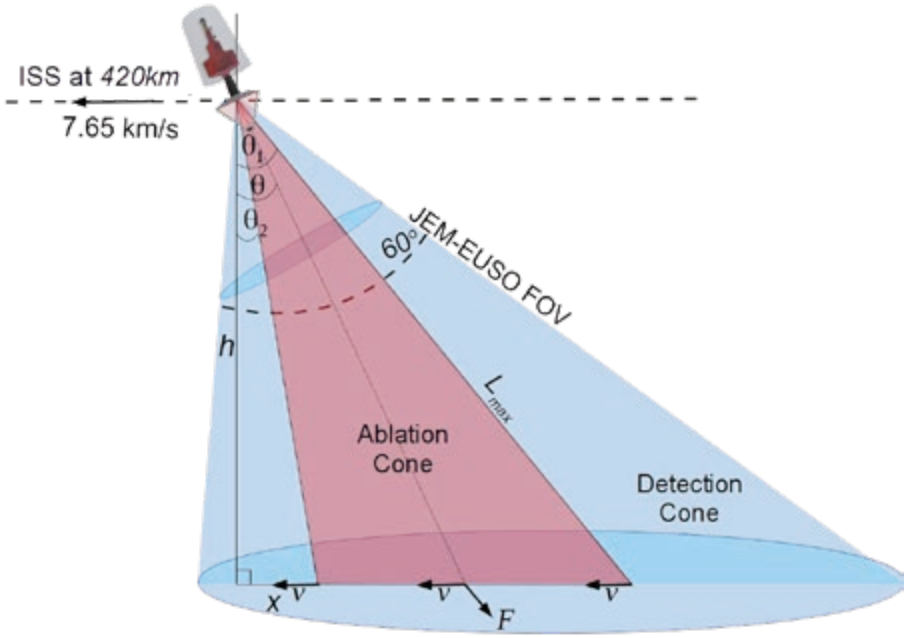
Detection Limit



Three steps of demonstration

1. Mini-EUSO on ISS
   - Proof of Principle Mission
   - 25 cm UV telescope
2. EUSO class telescope (K-EUSO) on ISS
   - Technical Demonstrator for Laser Removal
   - 2.5 m UV telescope CAN Laser System
3. Dedicated Removal Mission
   - Dedicated system of Laser removal

Laser Shooting Operation



1. Mini-EUSO

- Proof of principle system
- Selected by ASI asVUS-2 (Human Space Flight 2)
- Russian International Collaboration mission
  - long-term program of space experiments on the ISS
- Detection
- Tracking
  - and Irradiation by Lidar (if possible)

Mini-EUSO mechanics

- Experiment "Relaxation" on the

Mechanical interface with UV window could be similar.

Decision

- From the May, 26 the experiment is included in the long-term program of space experiments on the ISS

Координационный научно-технический совет
Федерального космического агентства
по программам научных и прикладных исследований и экспериментов
на пилотируемых космических комплексах
ул. Пионерская, 4, г. Королёв, Московская обл., 141070

УТВЕРЖДАЮ
Председатель КНТС Роскосмоса
В.А. Соловьев
«26» мая 2014 г.

РЕШЕНИЕ № 5

О введении космического эксперимента «УФ атмосфера» в «Долгосрочную программу научно-прикладных исследований и экспериментов, планируемых на Российском сегменте МКС»

В соответствии с п.3 Приложения 2 к «Долгосрочной программе научно-прикладных исследований и экспериментов, планируемых на Российском сегменте МКС» (версия 2012 года) о порядке изменения Долгосрочной программы и учитывая, что для космического эксперимента «УФ атмосфера» полностью выполнены требования, установленные процедурой введения новых космических экспериментов в «Долгосрочную программу научно-прикладных исследований и экспериментов, планируемых на РС МКС», принимается

РЕШЕНИЕ:

Ввести космический эксперимент «УФ атмосфера» в «Долгосрочную программу научно-прикладных исследований и экспериментов, планируемых на Российском сегменте МКС».

И.о. учёного секретаря
КНТС Роскосмоса Б.В. Загреев

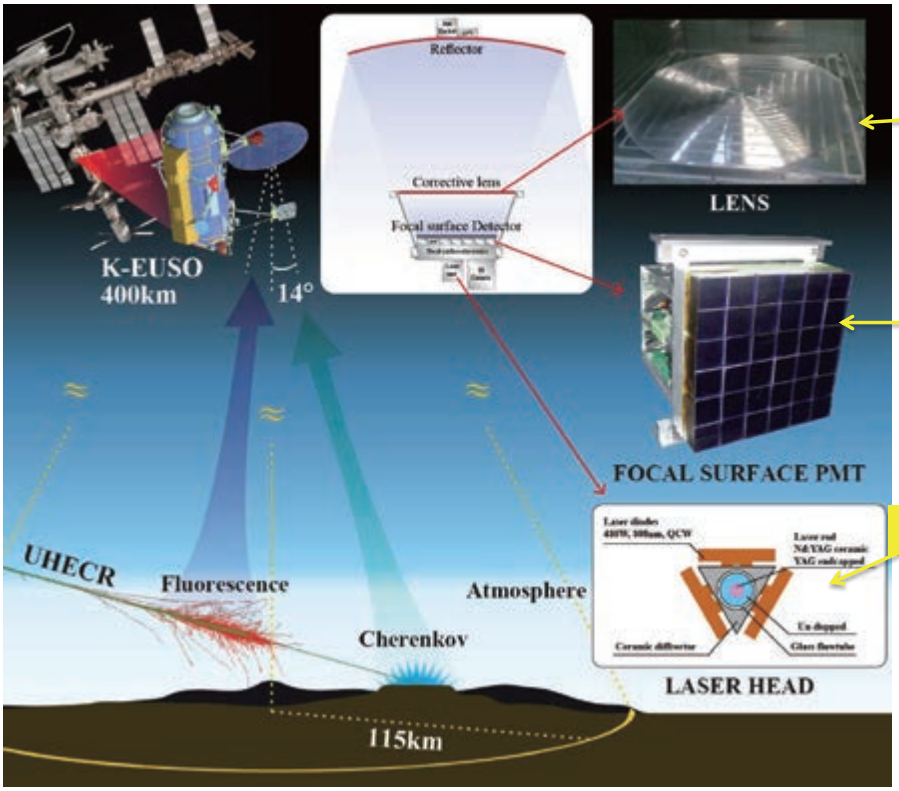
Three steps of demonstration

1. Mini-EUSO on ISS
   - Proof of Principle Mission
   - 25 cm UV telescope
2. EUSO class telescope (K-EUSO) on ISS
   - Technical Demonstrator for laser Removal
   - 2.5 m UV Telescope CAN Laser System
3. Dedicated Removal Mission
   - Dedicated system of Laser removal

2.EUSO class telescope (K-EUSO) on ISS

- Technical demonstrator of Laser Removal
- 2.5m UV telescope FoV=±30°
- 1.5 m Cassegrain for tracking
- CAN laser system 100 kW and 10^4Hz
- Operation Range: 100 km
- 10 (Backward)-300 (forward) debris

K-EUSO

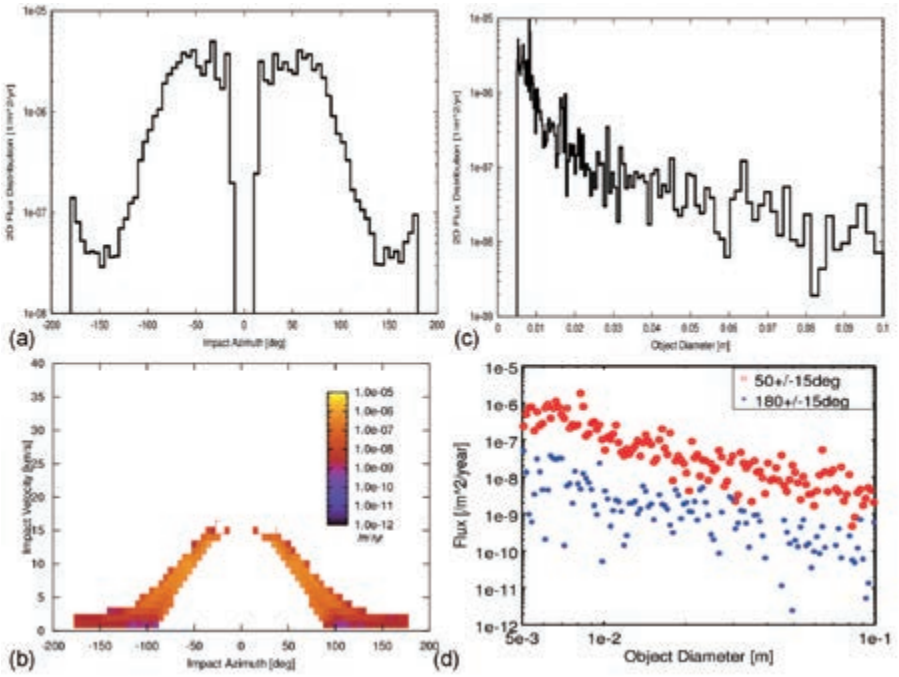


補正レンズ
(EM, PFM/FM)

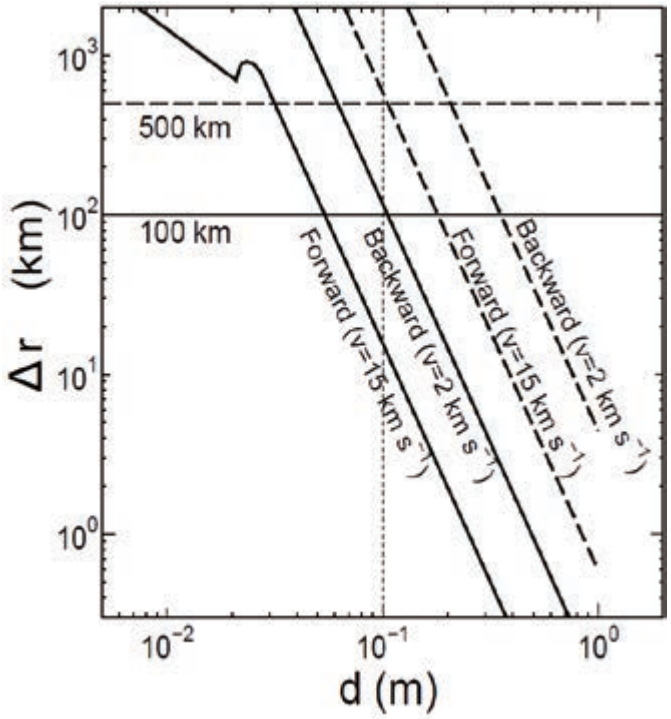
PMTs

大気モニタ用レーザー

Debris Flux at ISS orbit (~400 km)



Reduction in orbit radius by an operation



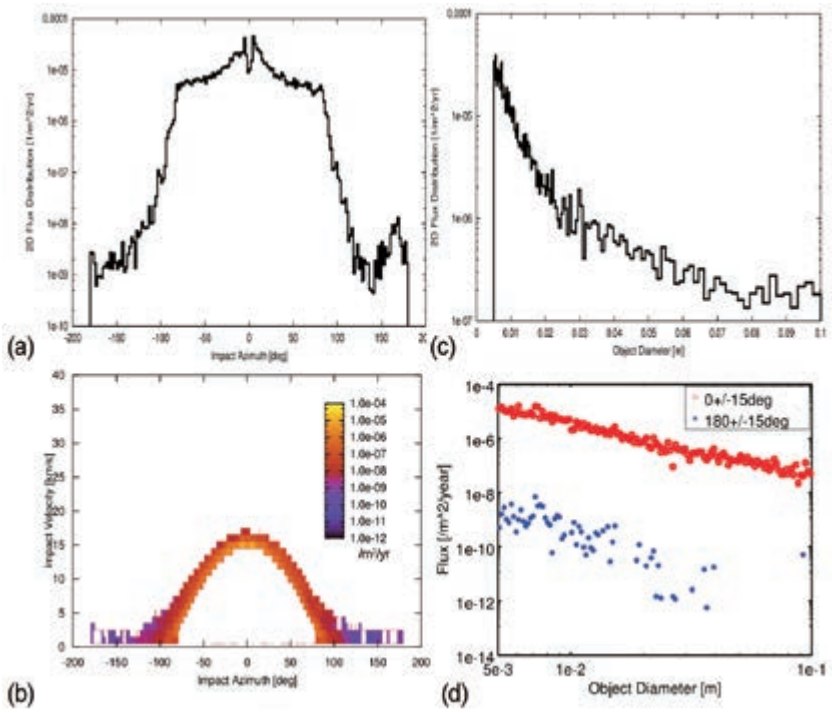
Three steps of demonstration

1. Mini-EUSO on ISS
   - Proof of Principle Mission
   - 25 cm UV Telescope
2. EUSO class telescope (K-EUSO) on ISS
   - Technical Demonstrator for laser Removal
   - 2.5 m UV Telescope CAN Laser System
3. Dedicated Removal Mission
   - Dedicated System of Laser Removal

3. Dedicated Debris Removal System

- Polar orbit from 1000 km→600 km
- 2.5 m EUSO + Space CAN laser (500 kW)
- Operation Range: 100km
- 10^3(backward)-10^5 (forward) operation
- Most of debris (1-10 cm can be remove)

Polar orbit (~800 km)



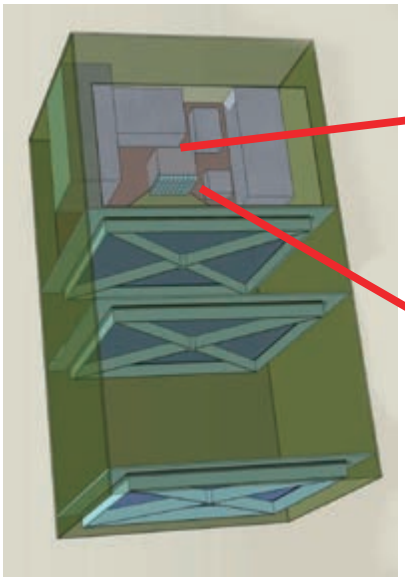
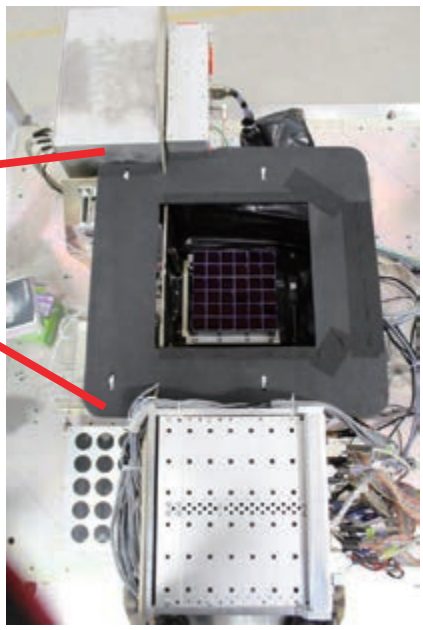
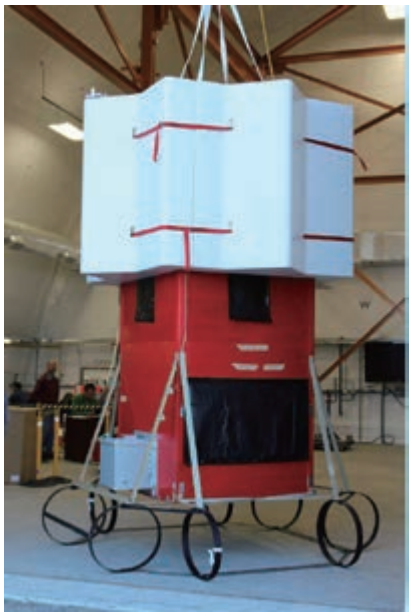
Parameters of Systems

	Prototype on ISS	Technical Demonstrator on ISS	Dedicated system
Target Debris Size (cm)	>1	10>a>0.5	10>a>0.5
Target Debris Distance (km)	10-100	100	100
EUSO Aperture (m)	0.25	2.5	2.5
EUSO FoV	±14°	±30°	±30°
Tracking Optics (m)	0.1	1.5	1.5
Laser system	Solid state	10^4 fibre	10^4 fibre
Pulse Energy (J)	0.1	10	10
Pulse Duration (ns)	1	0.1	0.1
Repetition rate (kHz)	0.1	10000	50000
Average power (kW)	0.001	100	500
Event per year	20-30 (detection) 2-3 irradiation)	10 (backward) 300 (forward)	10^5(forward) 10^3(backward)

Summary

- Reentry by Laser Ablation: 1-10 cm
- Laser ejection from Space craft
  - Detection EUSO telescope
    - Super wide field（～60° ）, super high speed （~microseconds）
  - Tracking system of 1.5 m and CAN laser (100-500 W)
- Three steps
  - Mini-EUSO: IUV window on ISS
  - EUSO+ CAN laser on ISS
  - Dedicated free flyer polar orbit 1000 km→500 m
- Rotation suppression: ~1W

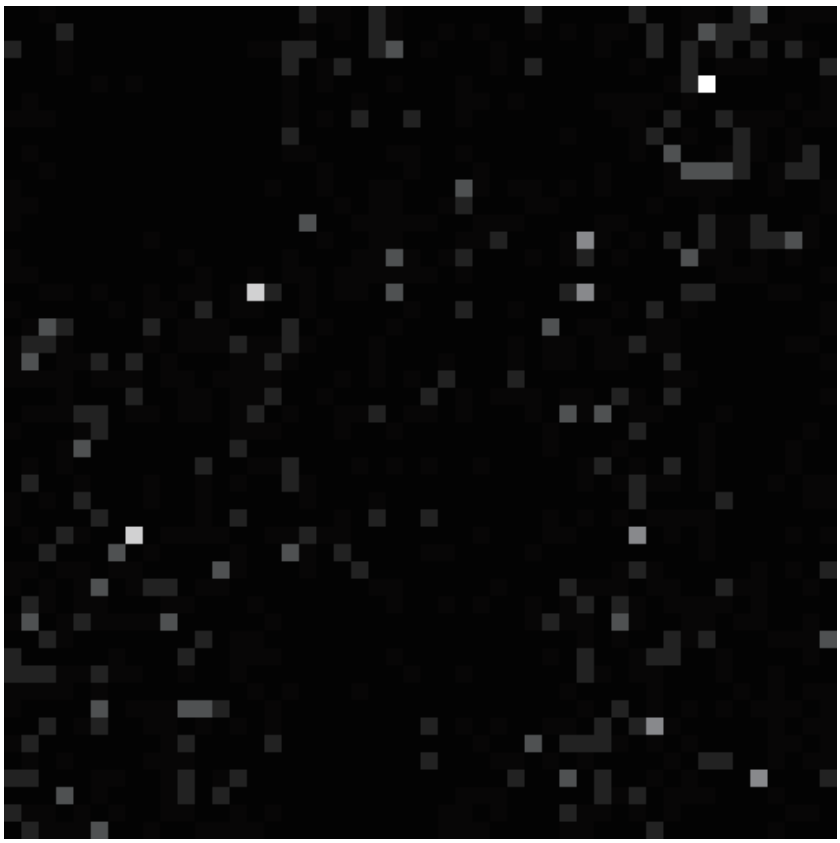
気球実験
CNES+JEM-EUSO Collaboration

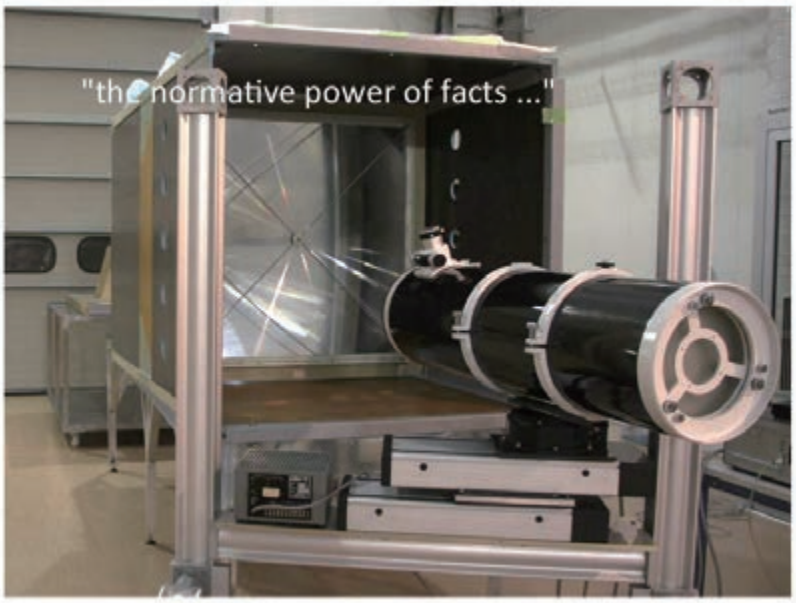
気球飛行 2014 August 23



Laser flasher event

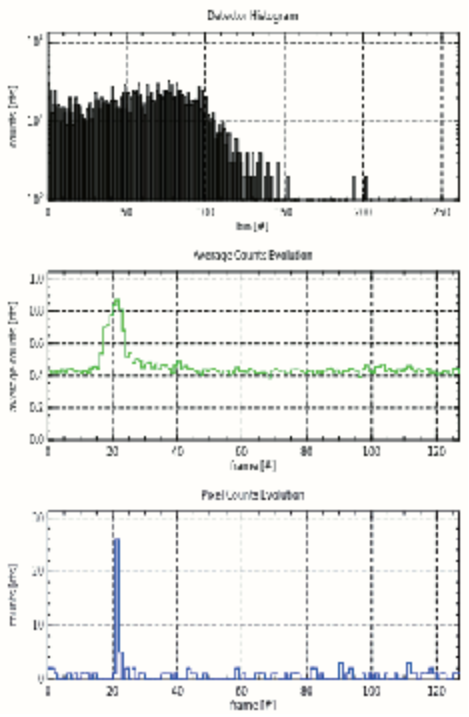


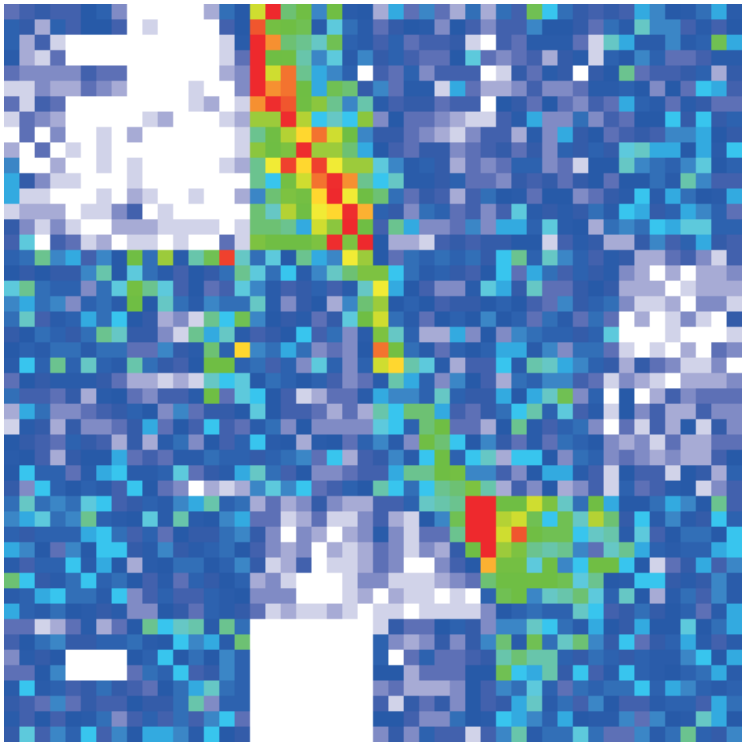
光学試験



Laser track

Event profile





Helicopter equipped with laser and xenon flasher (NASA funding)

無事着水