Deorbiting Mission of cm-Sized Space Debris by Laser Ablation

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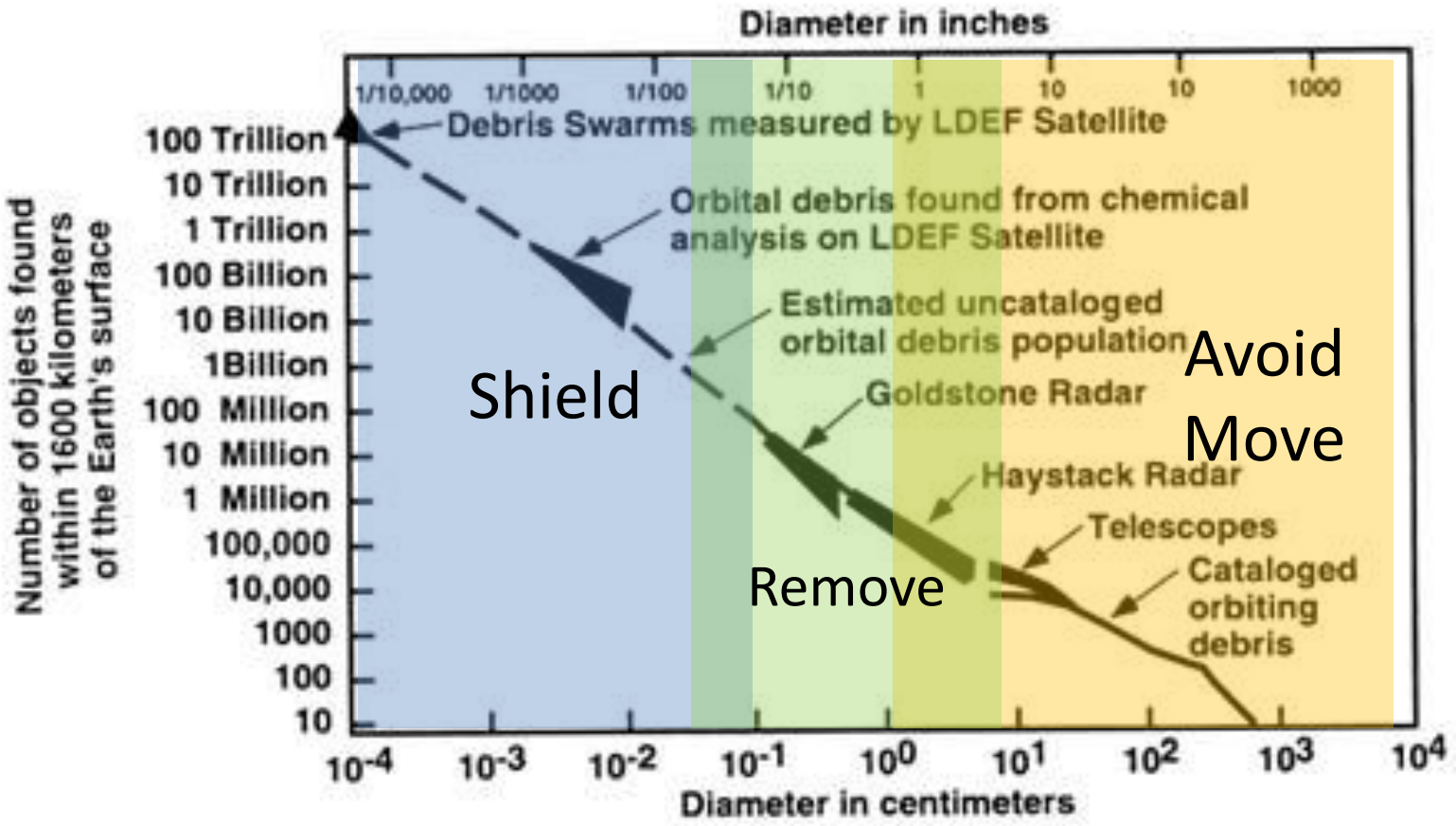
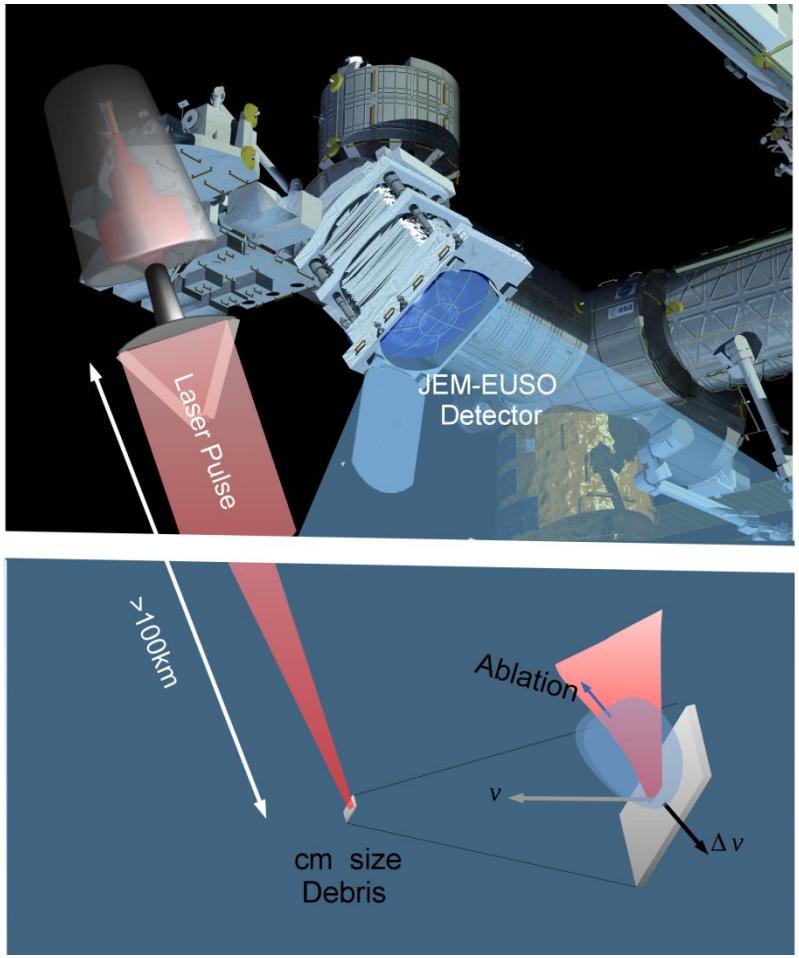
Debris population

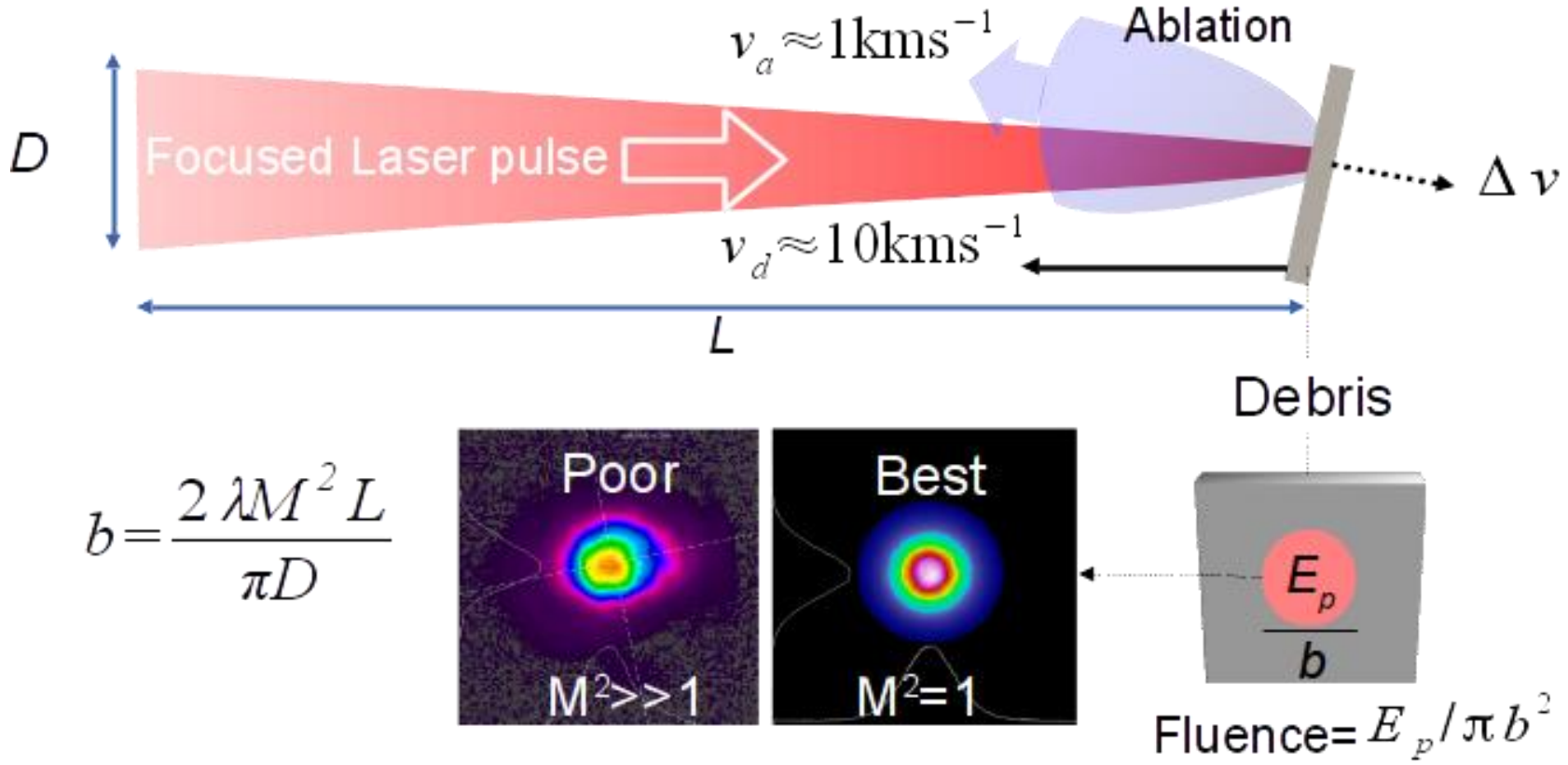


Concept of our the laser removal of 0.5-10 cm space debris

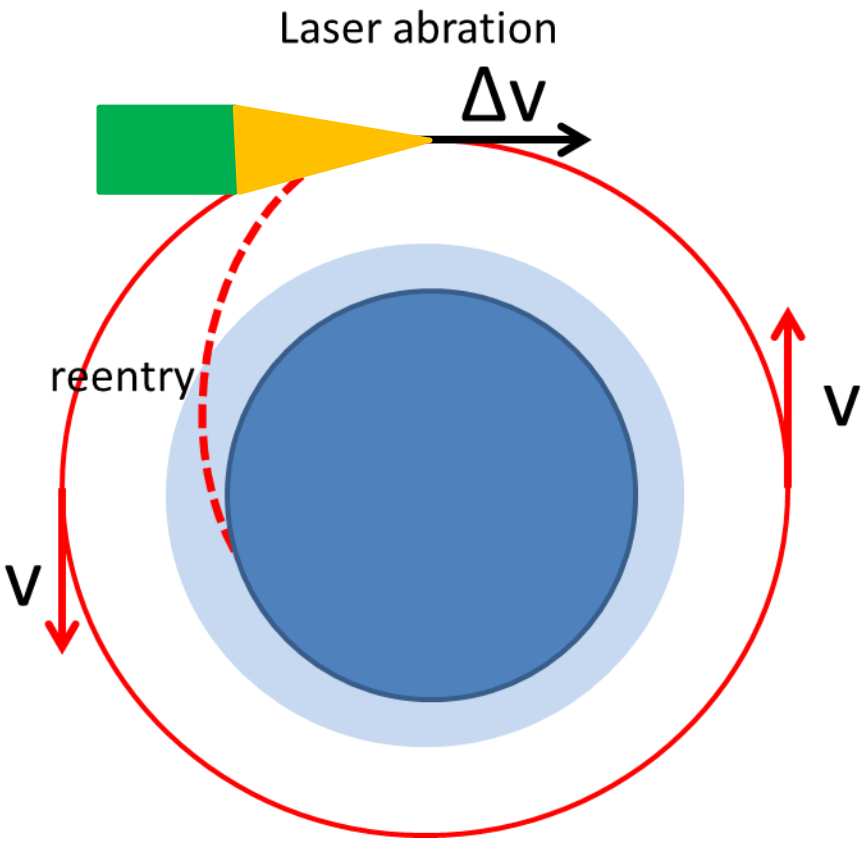


- EUSO
  - Detection
  - Position and velocity
    - Crude determination
- Space laser system
  - Search beam
  - Position and velocity
    - Fine determination
  - Shooting Operation

Reaction Force by Laser Abration



Reentry by reaction force of laser ablation



Three steps of debris removal

Target Debris

a=0.5-10 cm, d～50 km, v_{rel}～1-15 km

1. **Detection** （～0.1 seconds）
   - EUSO telescope ±30°
   - position（$\Delta\theta < 0.07°$） and velocity (1%)
2. **Tracking** （～1 seconds）
   - Cassegrain telescope（1.5m） （～1 s）
   - Pencil beam illumination（$\Delta\varphi \sim 0.07° \Delta\tau \sim 1\mathrm{ns}$）
   - position（$\Delta\theta < 10^{-6}\mathrm{rad}, \Delta R \sim 1\ \mathrm{km}$）
3. **Laser Shooting** （～10 seconds）
   - $E_p \sim 10\ \mathrm{J}$、$R_p \sim 10^4\ \mathrm{Hz}$

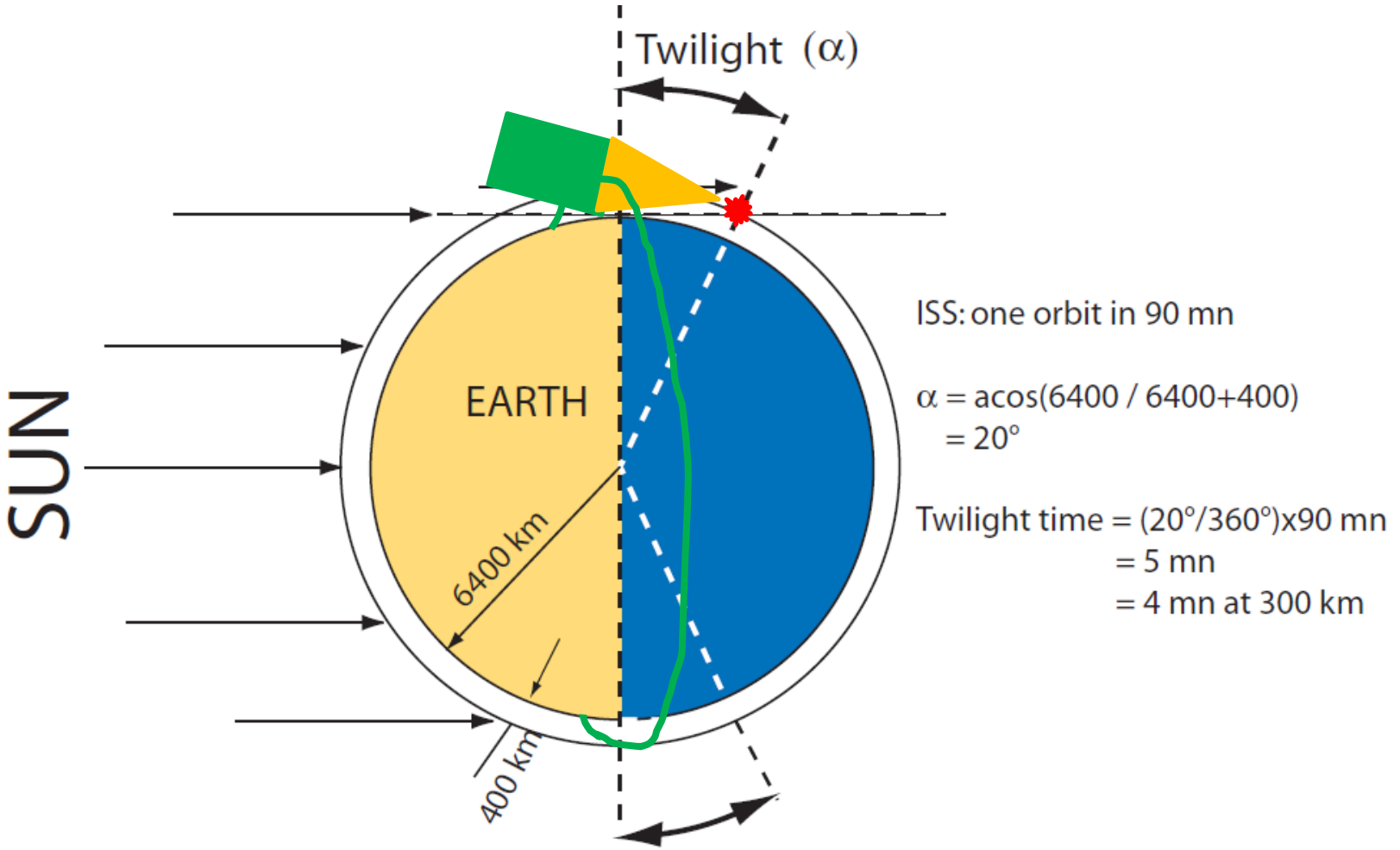
Dedicated Free Flyer mission

- Eccentric orbit with **altitude 900-600** km
- **Sun-synchronous**: inclination=98.3 degree
- **Always in twilight zone**

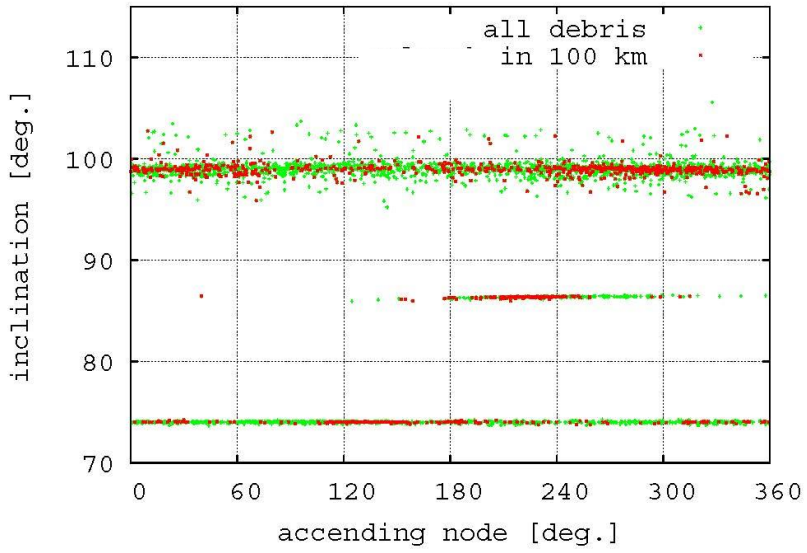
  Observe anti-sun direction
- 2.5 m **EUSO** + **Space laser** (100 kW)
- Range: <50km
- 10^5 operation per year
- Significant fraction of

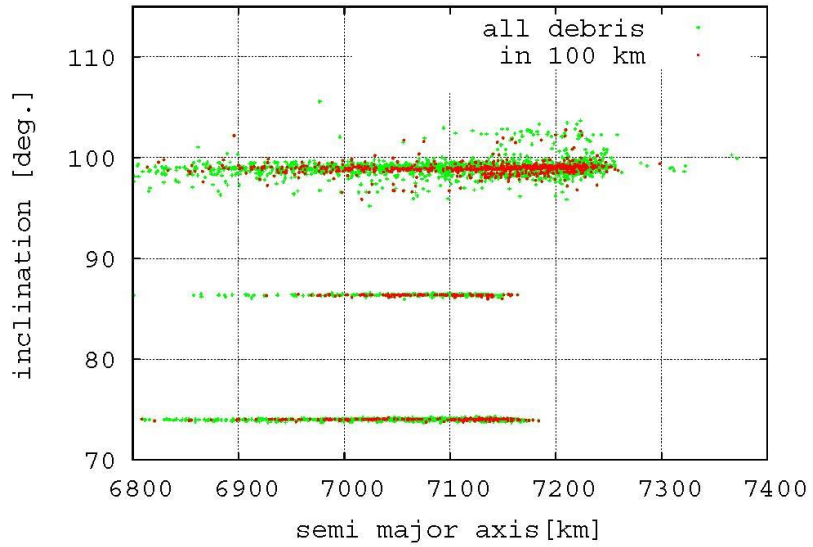
  the orbital debris (0.5m-10 cm) ～five years

Dedicated Mission in the Sun-synchronous orbit



Removal simulation of three major debris clouds: Fungun 1C, Iridium 33, COSMOS 2251





1993 approaches (<100 km) in one week
→100,000 operations per year

Many Challenges

- Build **High Power Space Laser**
  - High Energy Pulse:~10 J
  - High power efficiency:~30%
  - High repetition Rate:~10,000 Hz
  - High Average Power:
    ~100 kW (10sec)
- **Tracking Optics**
  - Diffraction Limited Optics (λ ~1 μ m)
  - Rapid Movement (10degree/s)
  - Power Tolerance
- **Software** (semi/full automatic)
  - Detection to Shooting
  - Characterization

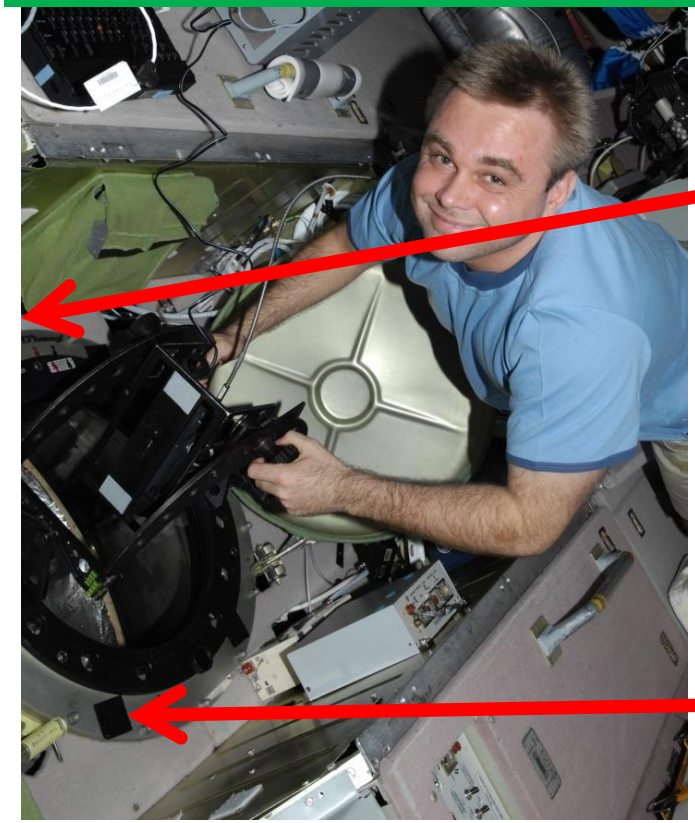
- Safety
- Legal Issues
- Open access and International Society

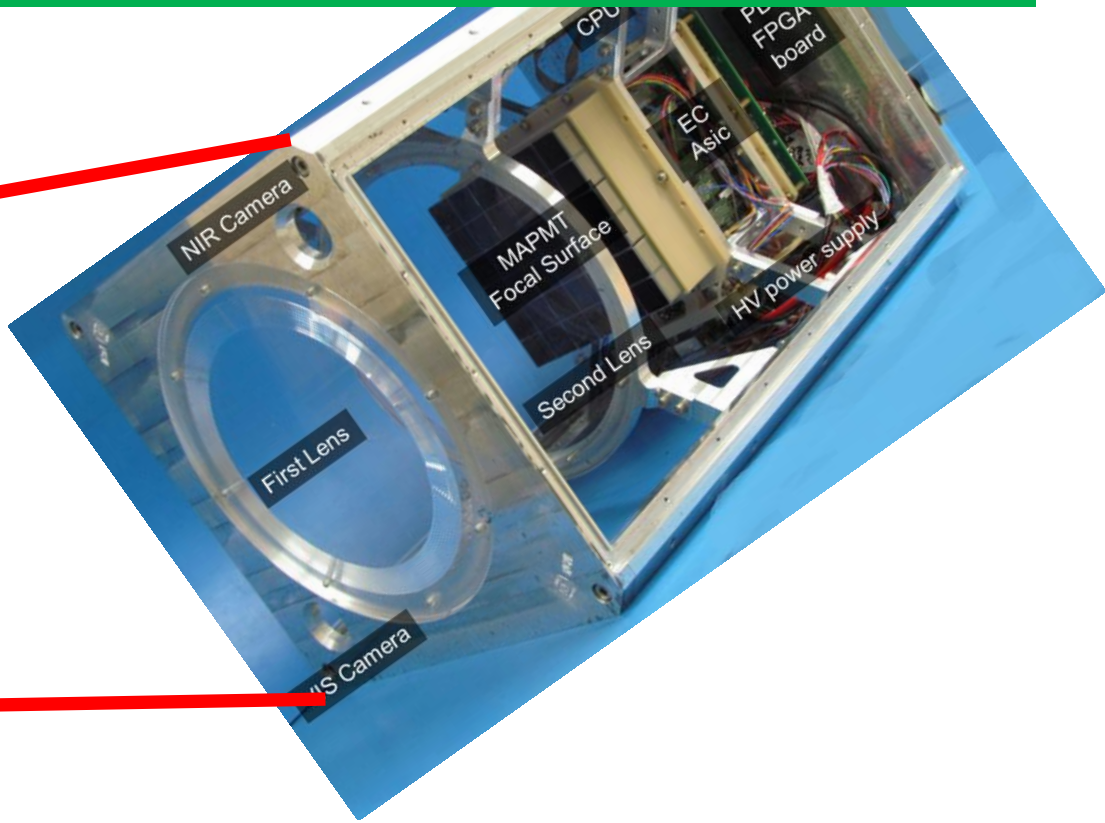
Three Step Approach with ISS cosmic-ray missions

1. 25cm class Telescope: **mini-EUSO** at International Space Station
   - Technical demonstration of debris detection
   - Launch Scheduled in the **first quarter of 2019**
   - 25 cm UV telescope
   - Collaboration of ASI and ROSCOSMOS with JEM-EUSO collaboration (Italy, Russia, France, Japan: 16 countries)
2. 2.5m Class telescope (**KLYPVE/K-EUSO**)
   - Planning in collaboration with Russia, Italy, France and Japan
   - +High intensity laser? Demonstration of Tracking
3. Dedicated Free-Flyer
   - EUSO＋Space laser
   - Altitude 600-900km
   - Sun-synchronous orbit

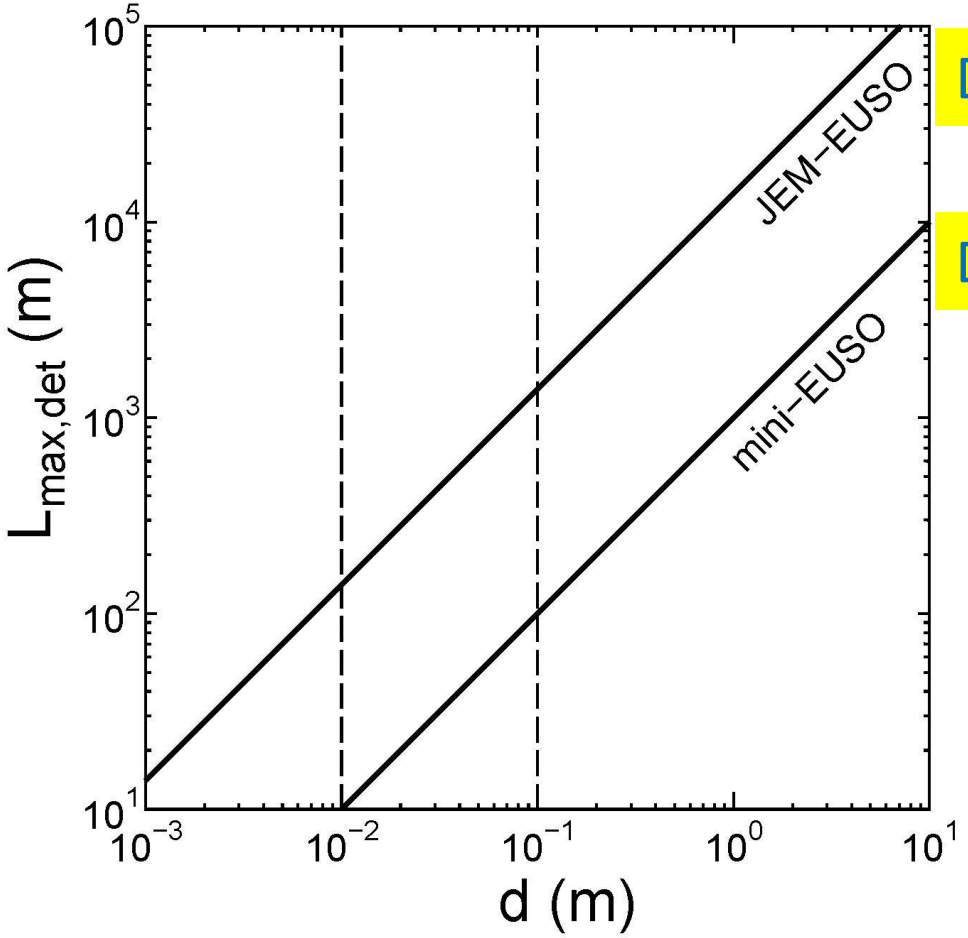
Step 1: Demonstration of Detection Mini-EUSO

ROSCOSMOS-ASI mission
Will be launched in 2019





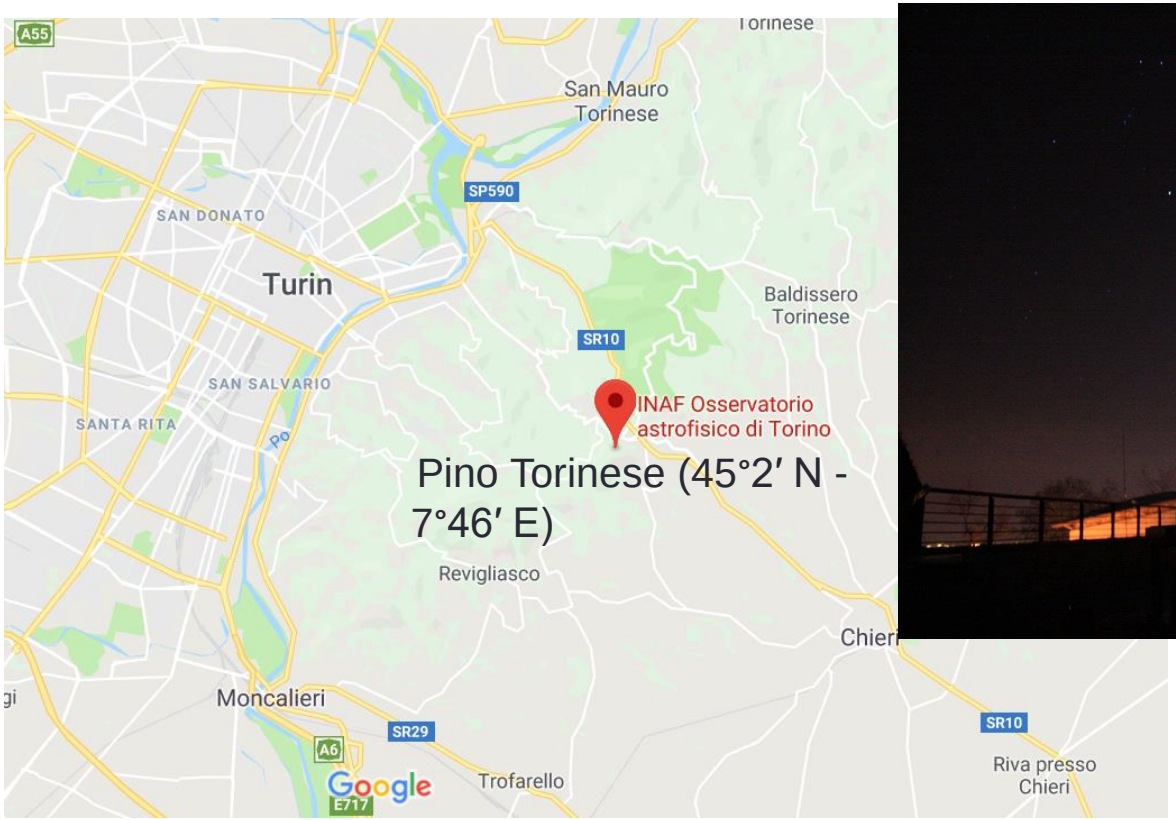
Detection Limit: Reflection of sunlight



D=2.5 m

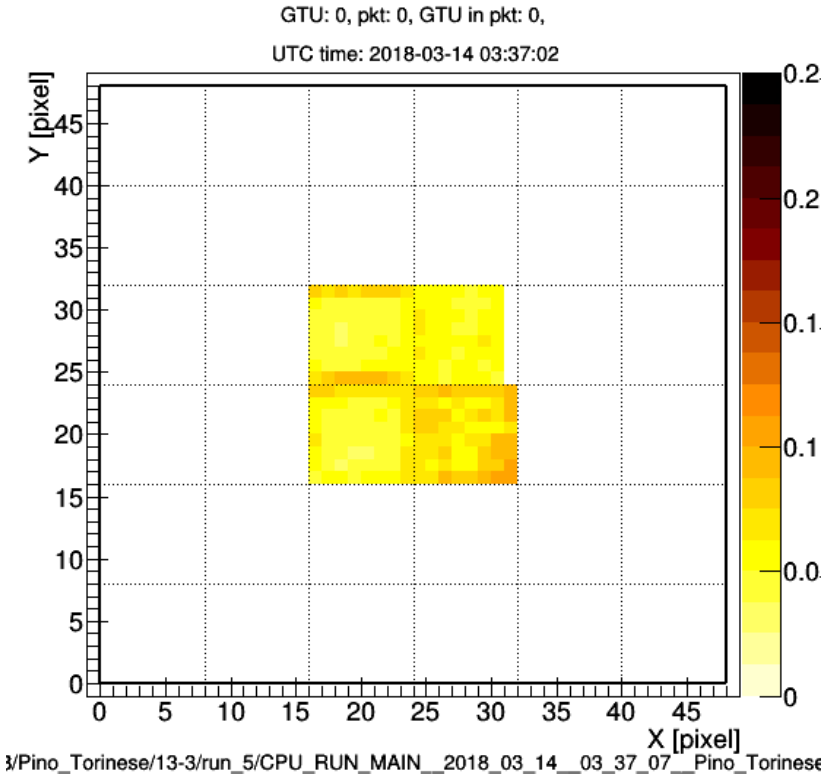
D=0.25m

Tests at Pino Torinese Observatory



- Chieri and Moncalieri city lights
- Stars, Jupiter
- Planes

Tested using Pino Torinese observatory data

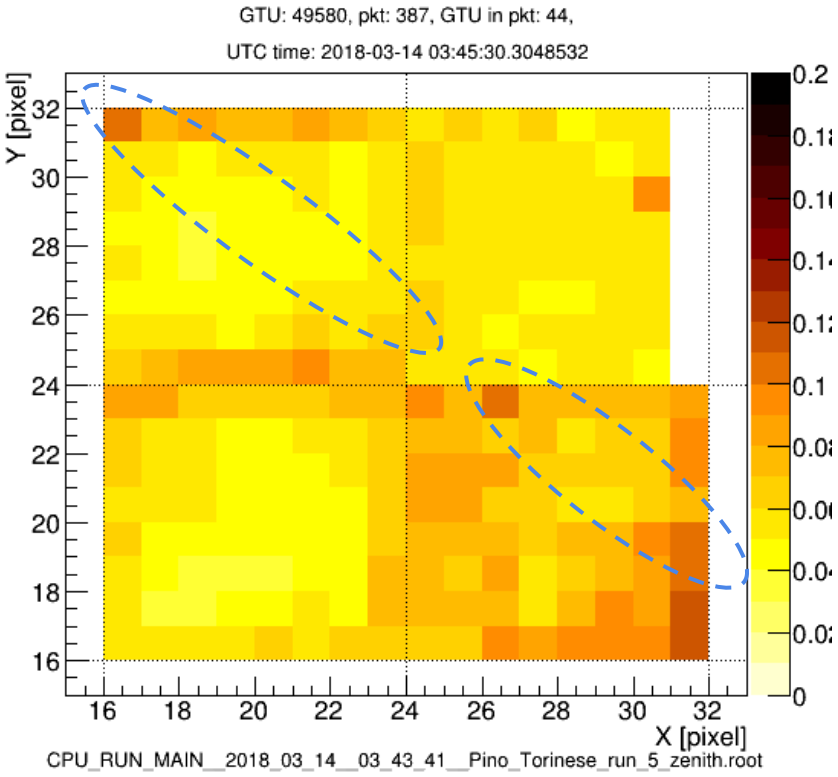


- Dim stars mimicking space debris.
- Considered only 1 GTU every 5*128GTUs or every 10*128 GTUs (different velocity) + initial 640 GTUs for background estimation
- Analysed offline via a C++ code
- Able to trigger on moving stars
- Ultraviolet magnitude up to m_U~4

"New techniques for the detection of space debris"; Id Project: CSTO164394

Possible satellite transit at zenith

2018/03/14 at 04:10:52 UTC from Pino Torinese Observatory



In the animation: 1 frame every 10 GTUs

In the FOV for 400 GTUs (182 GTUs in the first PMT, 173 GTUs in the second PMT, 45 GTUs not visible), for a total of 16.4s.

Equivalent distance travelled in the first PMT (~9.2 pxl) in 7.45s (182 GTU x 41ms/GTU)
(1 pixel FOV ~ 0.55°)

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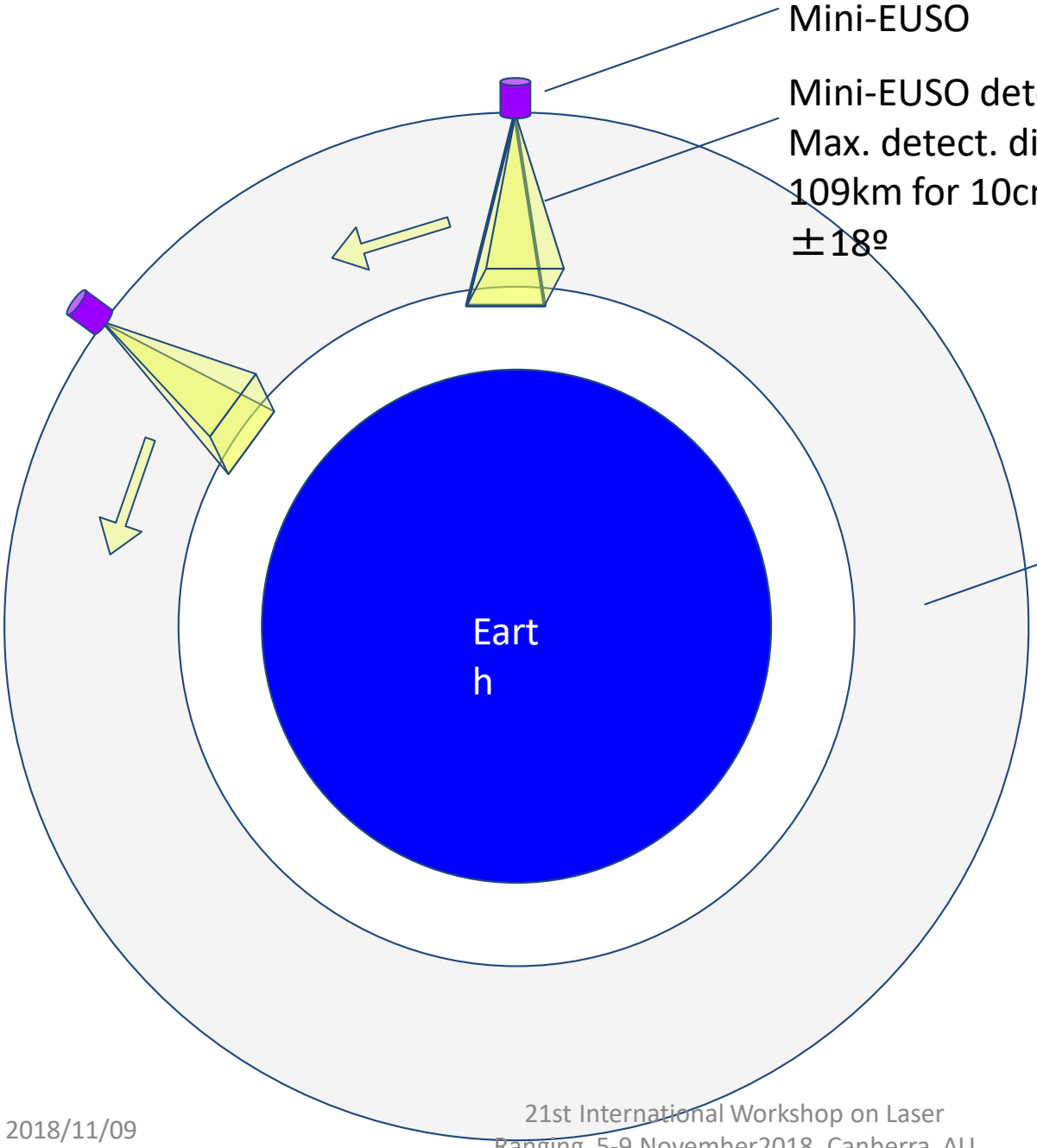
Mini-EUSO lens and Italian Astronaut Paolo Nespoli


Mini-EUSO
Mini-EUSO detection volume:
Max. detect. distance (e.g.,
109km for 10cm debris), FoV
±18º
Space debris
(e.g., 1.84e-09[/km^3]
for 10 cm diameter
debris, right scention
±51.64º)
Eart
h

Obtained values from MASTER for the parameters obtained by ESAF simulation(1): reflectance 0.5

debris diameter[m]	altitude[km]	distance from Mini-EUSO[km]	average_nSD_root[¥km^3] for dec ±51.64[deg, refl 0.5]	nDetection_per_day
0,095-0,105	291	109	1,84E-09	1,79E-01
0.085-0.095	301	99	5,19E-13	4,17E-05
0.075-0.085	308	92	5,49E-13	3,81E-05
0.065-0.075	319	81	6,07E-13	3,27E-05
0.055-0.065	339	61	3,23E-11	9,84E-04
0.045-0.055	347	53	5,03E-10	1,16E-02
0.035-0.045	353	47	8,79E-10	1,59E-02
0.025-0.035	365	35	1,35E-08	1,36E-01
0.015-0.025	381	19	1,52E-08	4,51E-02
			TOTAL(nDetection/day)	**3.88E-01**

Total number of space debris detection if the reflectance is 0.5: 142 debris/yr

"New techniques for the detection of space debris"; Id Project: CSTO164394

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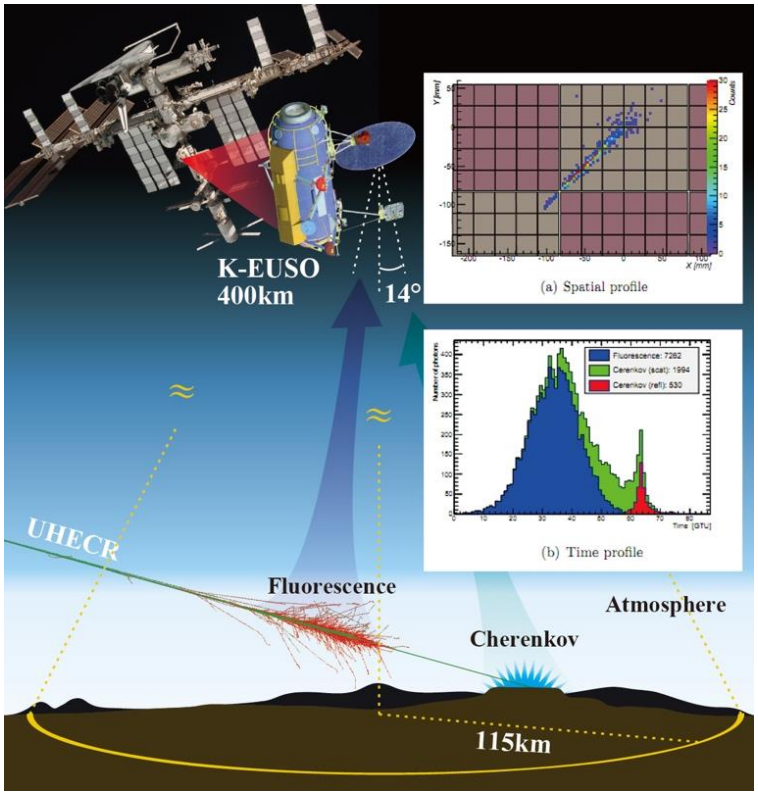
Technical demonstrator of Debris Detection EUSO class telescope →KLYPVE/K-EUSO

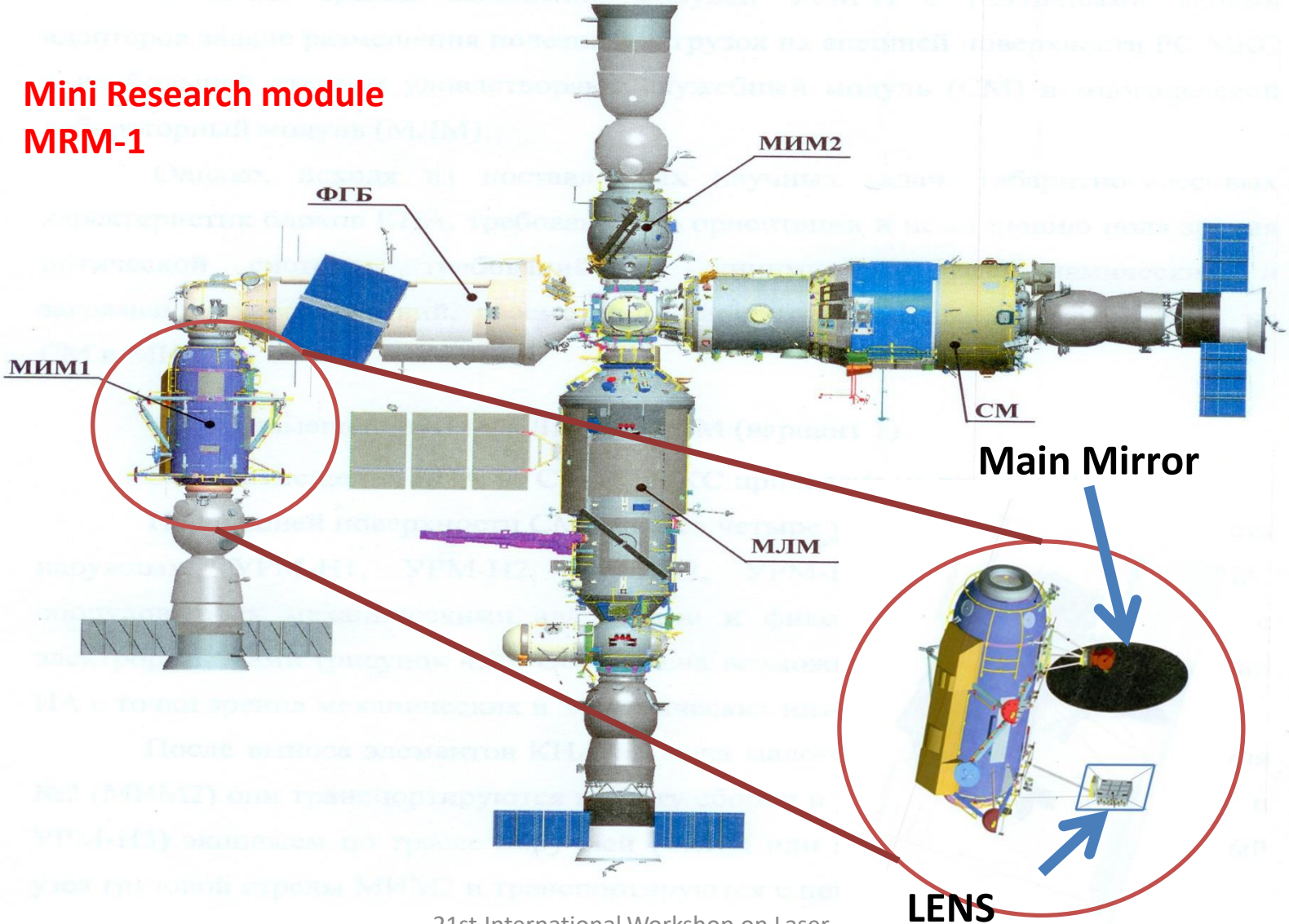
step 2

Demonstration of the debris detection & de-orbiting using EUSO class telescope

K-EUSO



Location on ISS



Summary

- Reentry by Laser Ablation:　1-10 cm
- Laser ejection from Spacecraft
  - Detection **EUSO telescope**
    - Super wide field（～60°）, super high speed (~microseconds)
  - Tracking system of 1.5 m and CAN laser (100 kW)
  - **Space (CAN) laser:** Multi-Step approach
  - **Mini-EUSO**: UV transparent window on ISS
  - **K-EUSO**+ laser on ISS
  - **Dedicated free flyer**　polar orbit 1000⇔500 km