Gerard Mourou, Toshi Ebisuzaki, Marco Casolino, Alexander Sergeev

Ecole polytechnique(Fr), RIKEN
Institut Applied Physics,

Space debris problem and possible methods for its solution

SPUTNIK: 60 YEARS ALONG THE PATH OF DISCOVERIES

Moscow, Oct.3-4 2017

ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

SPACE DEBRIS
A state of emergency!

Gerard Mourou, Moscow, 2017

ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

1957 Sputnik : The Dawn of the Space Era

Sputnik-1

Launch date : 4 October, 1957
Mass : 83 kg
Size : 58 cm
Power : 1 watt
Completed orbits : 1440
Distance travelled : 70 million km
Re-entry and burn up : 4 January, 1958

Sergey Korolev
''The Chief''

Gerard Mourou, Moscow, 2017

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

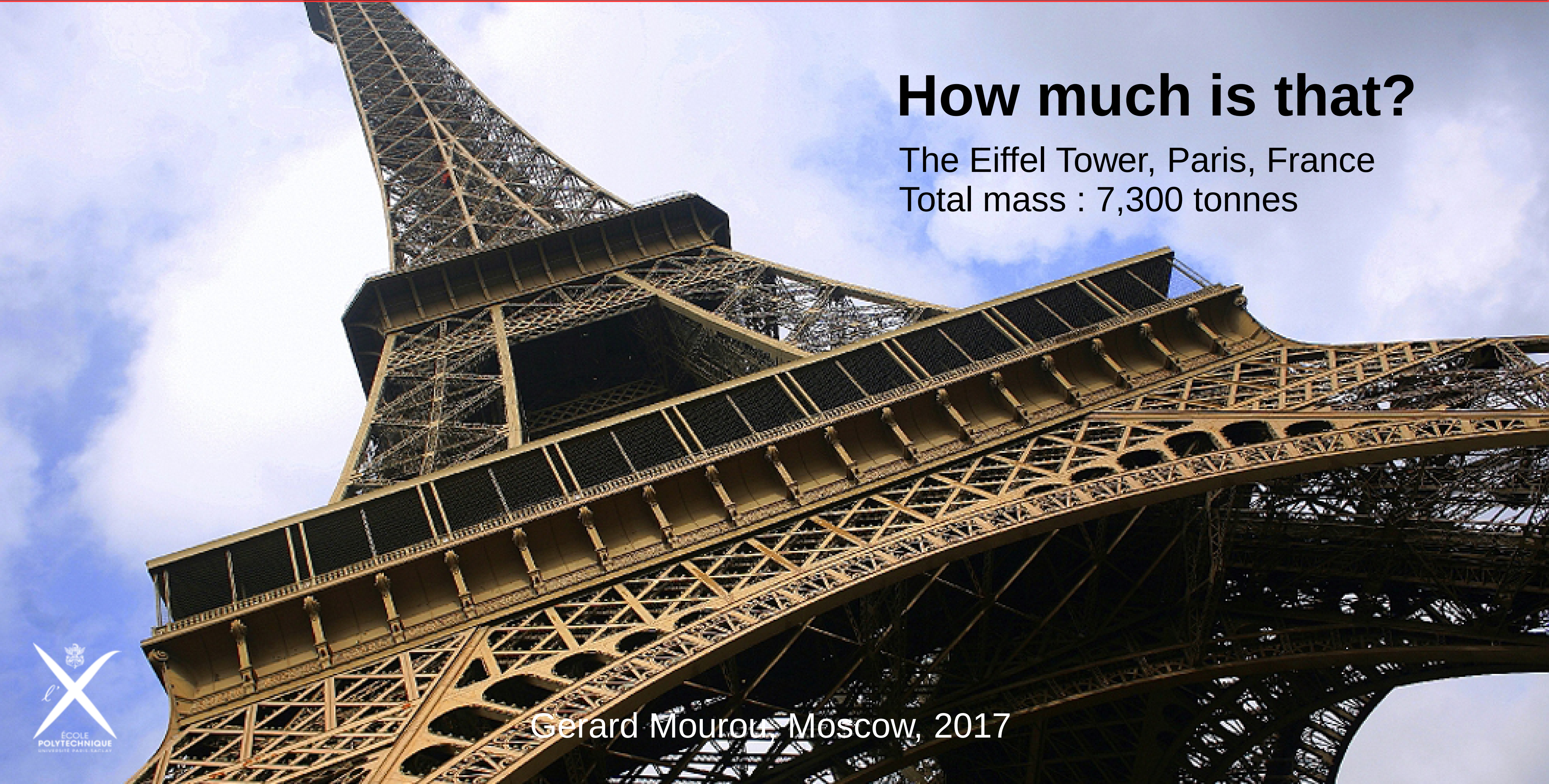
1957 - 2017

Spacecraft launched : ± 7000
Operational today : 1071

- Global positioning system (GPS)
- Remote sensing
- Environmental research
- Weather Forecasting
- Satellite television
- Space research

Gerard Mourou, Moscow, 2017

SPACE DEBRIS – **Negative legacy!**



How much is that?

The Eiffel Tower, Paris, France
Total mass : 7,300 tonnes

ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

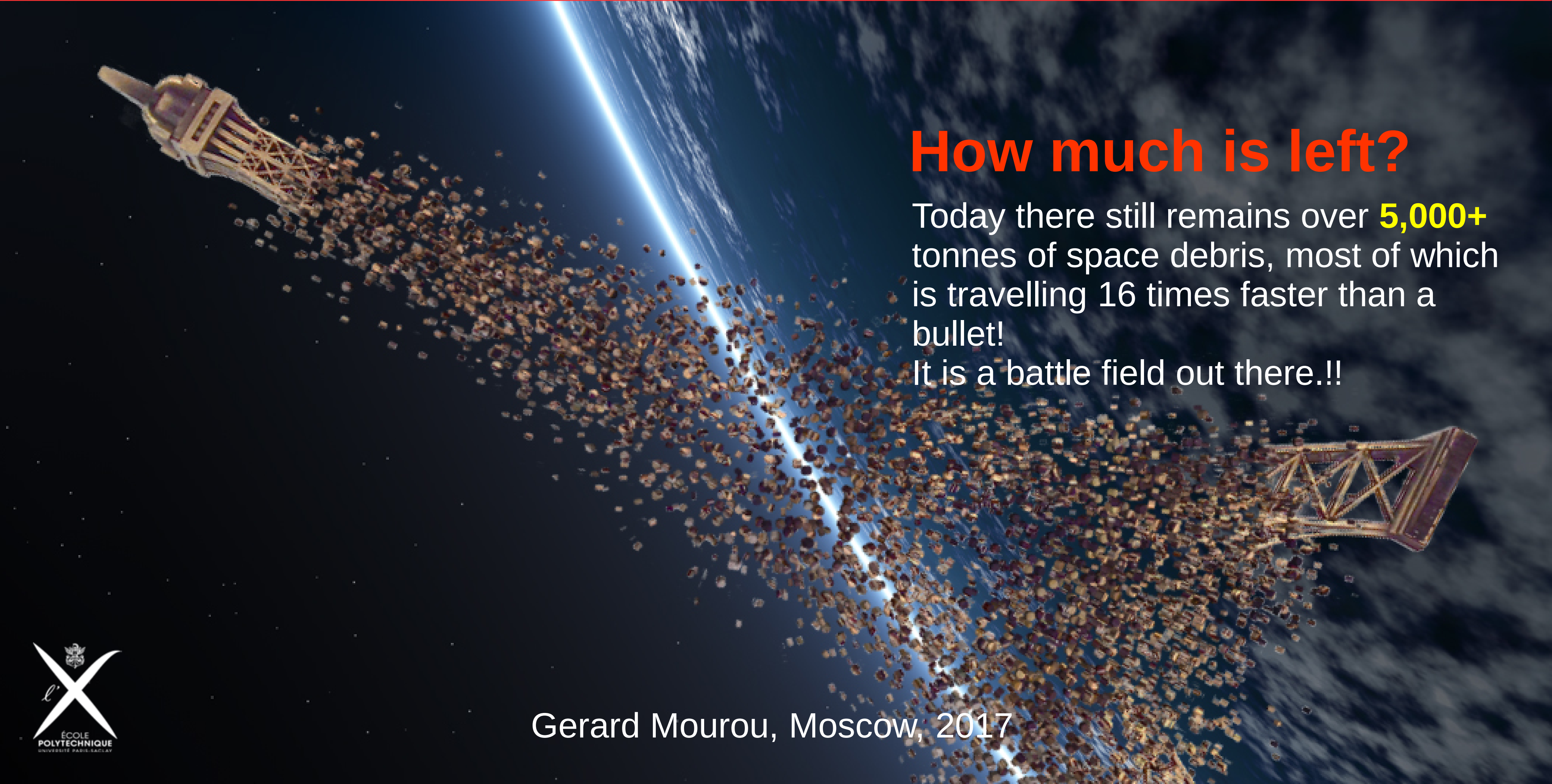
4x 7,000 tons = **28,000 tons!!!**

How much is that?

We have put the equivalent of over 4 Eiffel Towers into space!

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!



How much is left?

Today there still remains over **5,000+** tonnes of space debris, most of which is travelling 16 times faster than a bullet!
It is a battle field out there.!!

Gerard Mourou, Moscow, 2017

ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

SPACE DEBRIS - A state of emergency!

Kessler syndrome

Debris objects collide with each other
The destruction creates a cascade
The volume of debris increases faster

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

Gerard Mourou, Moscow, 2017

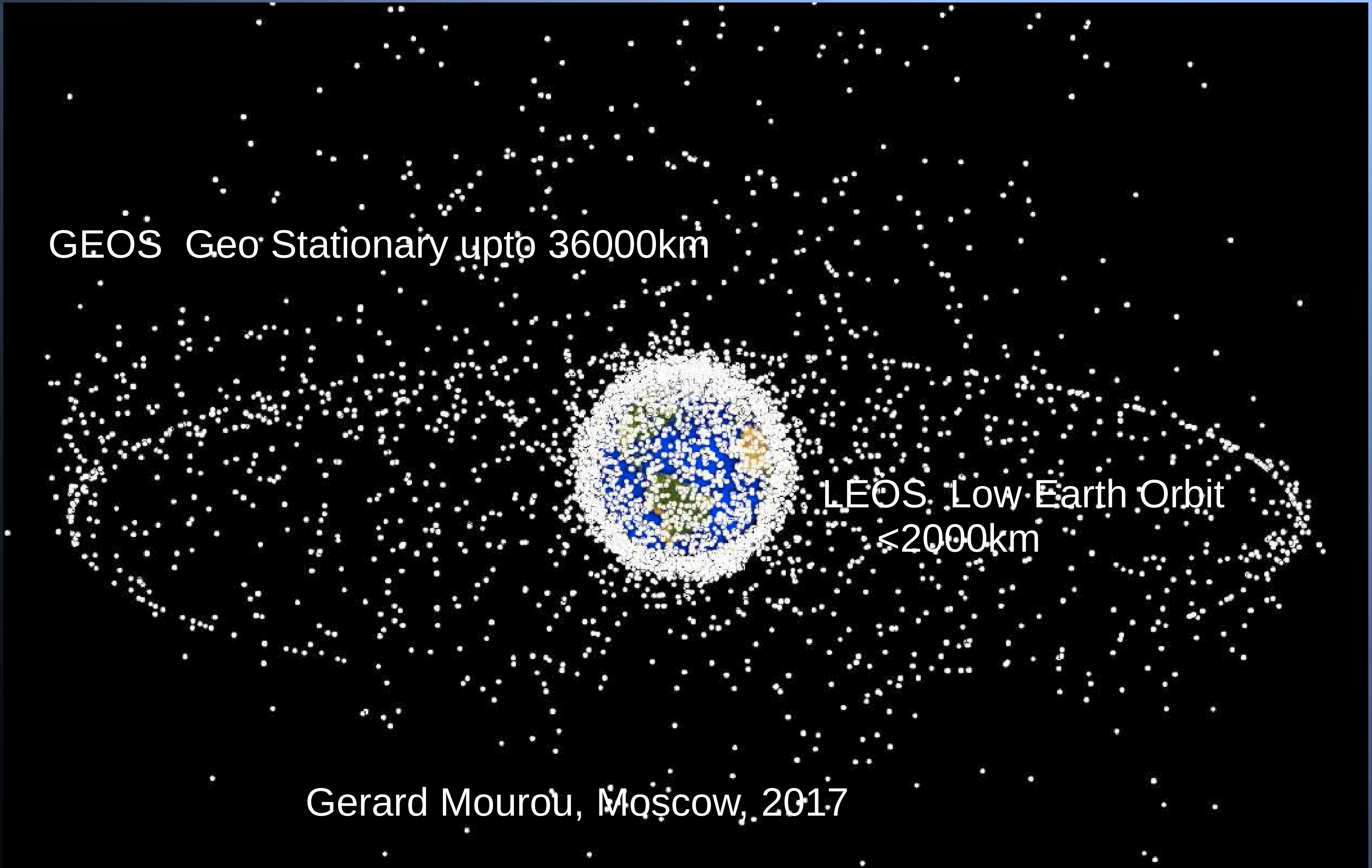
SPACE DEBRIS - A state of emergency!

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

Gerard Mourou, Moscow, 2017

SPACE DEBRIS DISTRIBUTION



DEBRIS detection From the ground

RADAR, COBRA DANE
Resolution >5cm

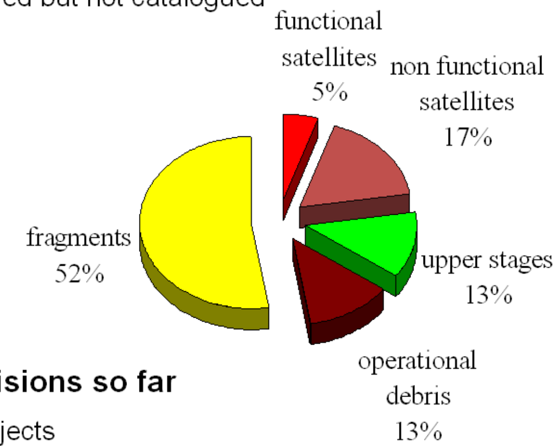
Telescope ARES
Resolution >5cm

SPACE DEBRIS DISTRIBUTION

NUMBER OF OBJECTS IN ORBIT

Roughly 23,000 large objects in space:

- **17,200 catalogued objects (> 10 cm)**
  - roughly 6,000 additional objects, identified but not catalogued
- **720,000 debris larger than 1 cm**
- **135 million debris larger than 1 mm**



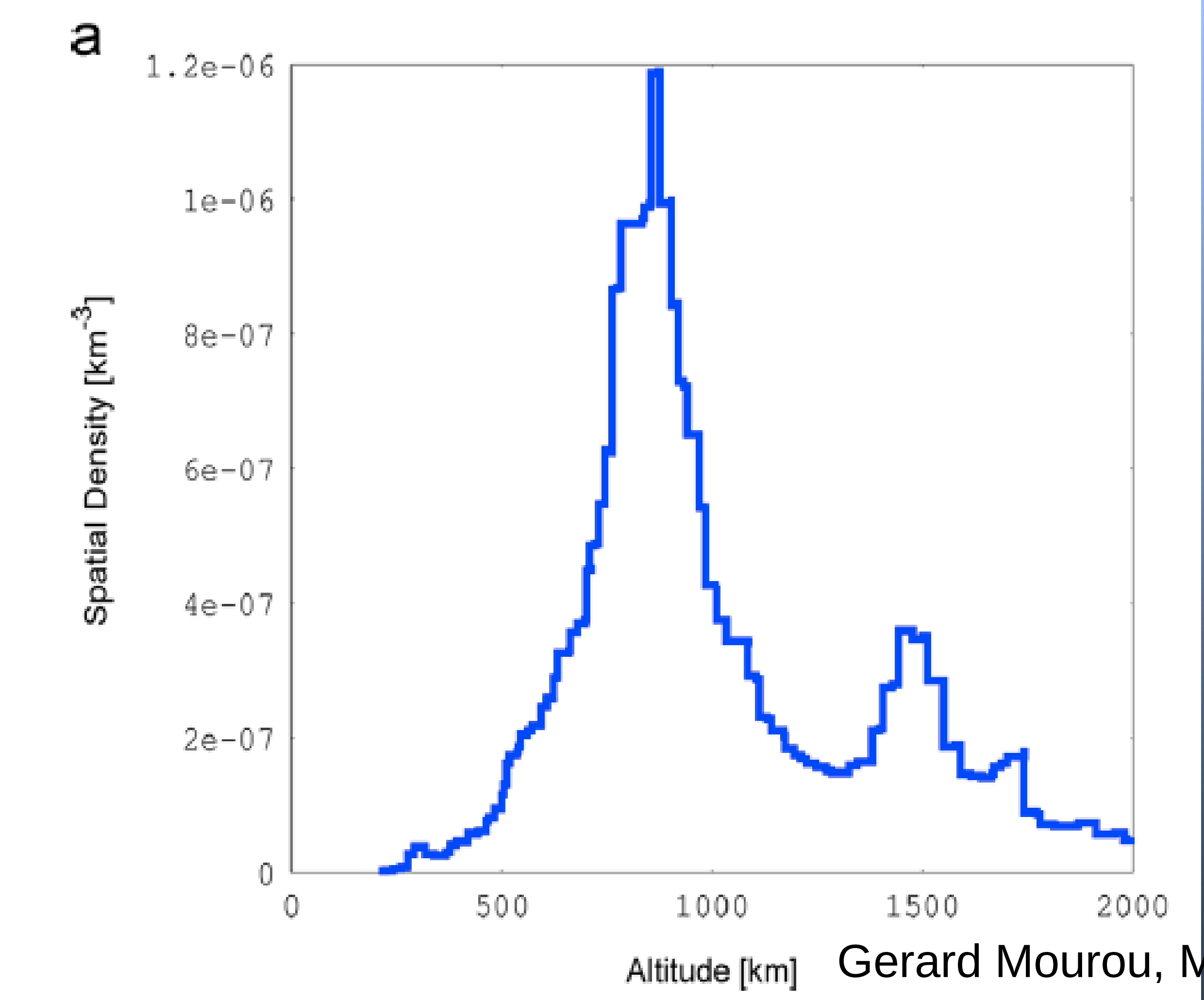
But orbital debris density is very low:

- **Very limited number of registered collisions so far**
  - 5 official collisions between catalogued objects
  - 64 suspected with smaller debris

Gerard Mourou, Moscow, 2017

cnes

SPACE DEBRIS DISTRIBUTION

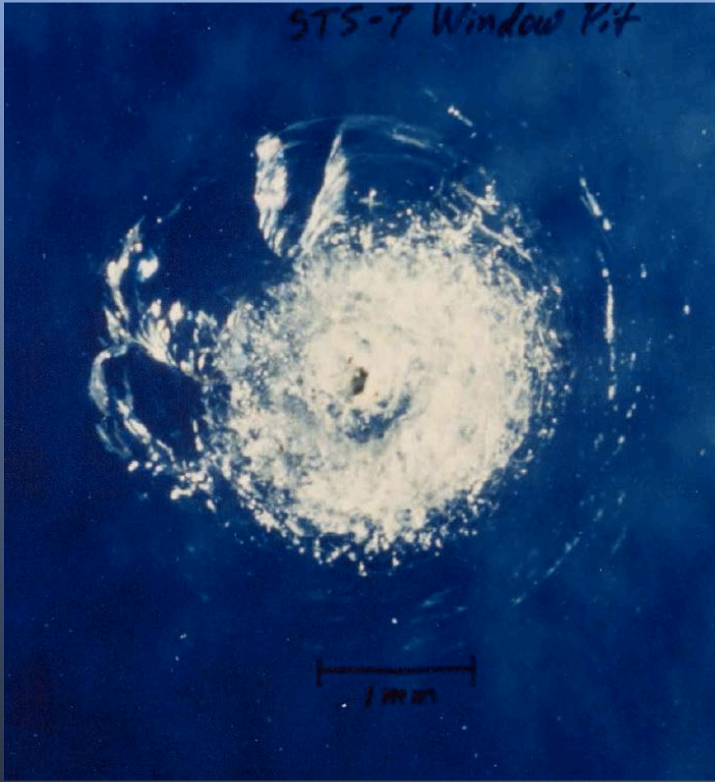


Feng-yung

-Cosmos-Iridiu

Gerard Mourou, Moscow, 2017

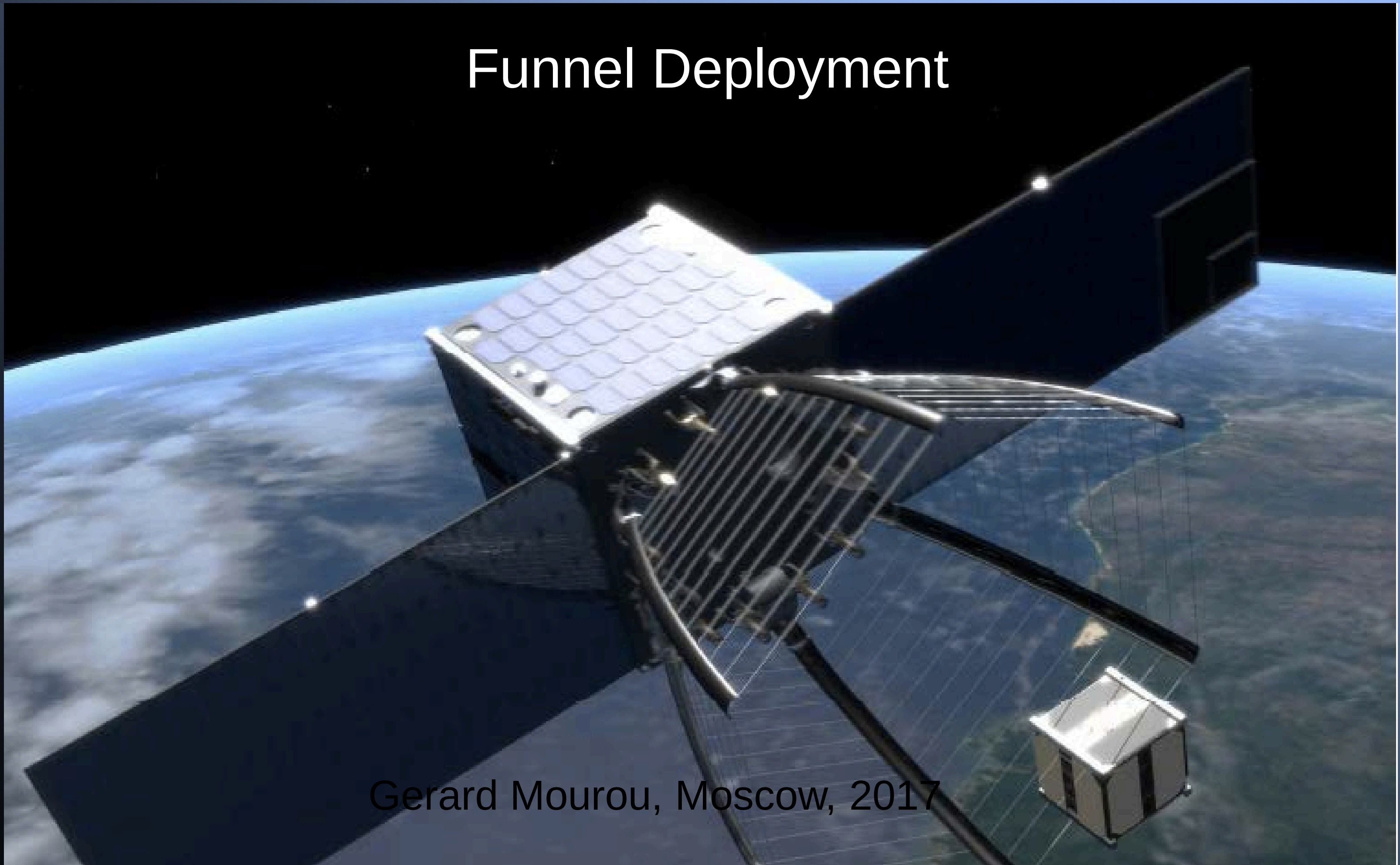
SPACE DEBRIS: Range from Meter to submm -



Strategy for Space Cleaning Challenge: Gros Debris

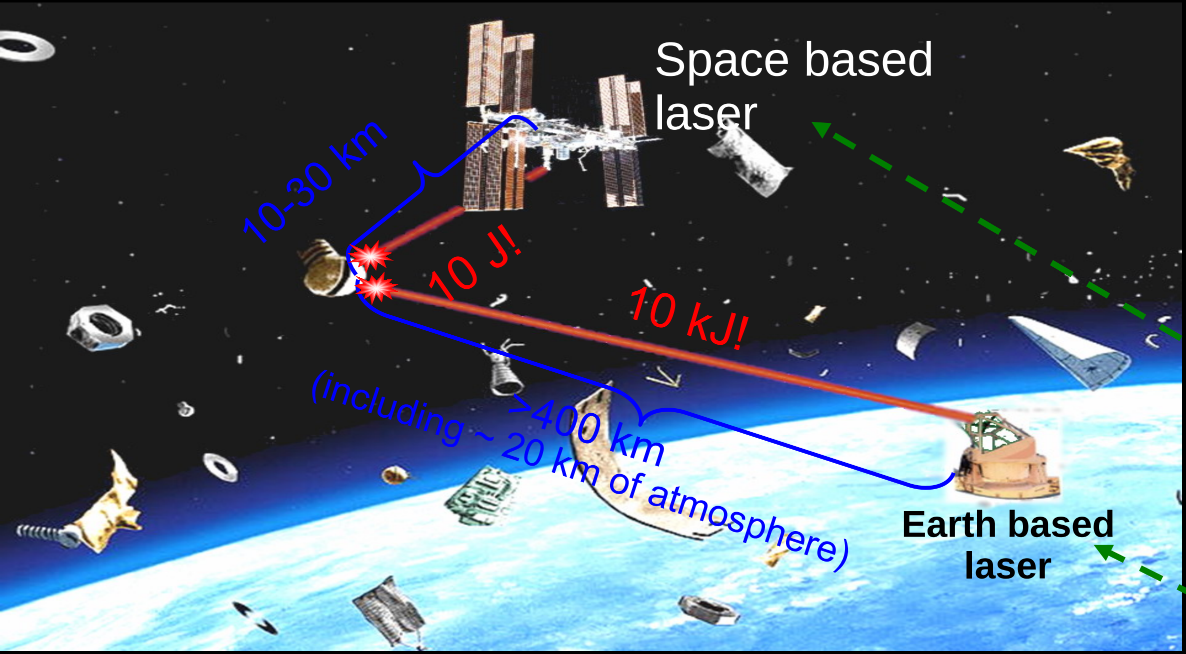
Gerard Mourou, Moscow, 2017

Strategy for Space Cleaning Challenge: Gros Debris



Gerard Mourou, Moscow, 2017

De-orbiting by space based laser



Low distance

Absence of atmospheric distortions

Ps pulse duration for ablation

[*Ebisuzaki, T., et al., Demonstration designs for the remediation of space debris from the International Space Station. Acta Astronautica, 2015. 112: p. 102–113*]

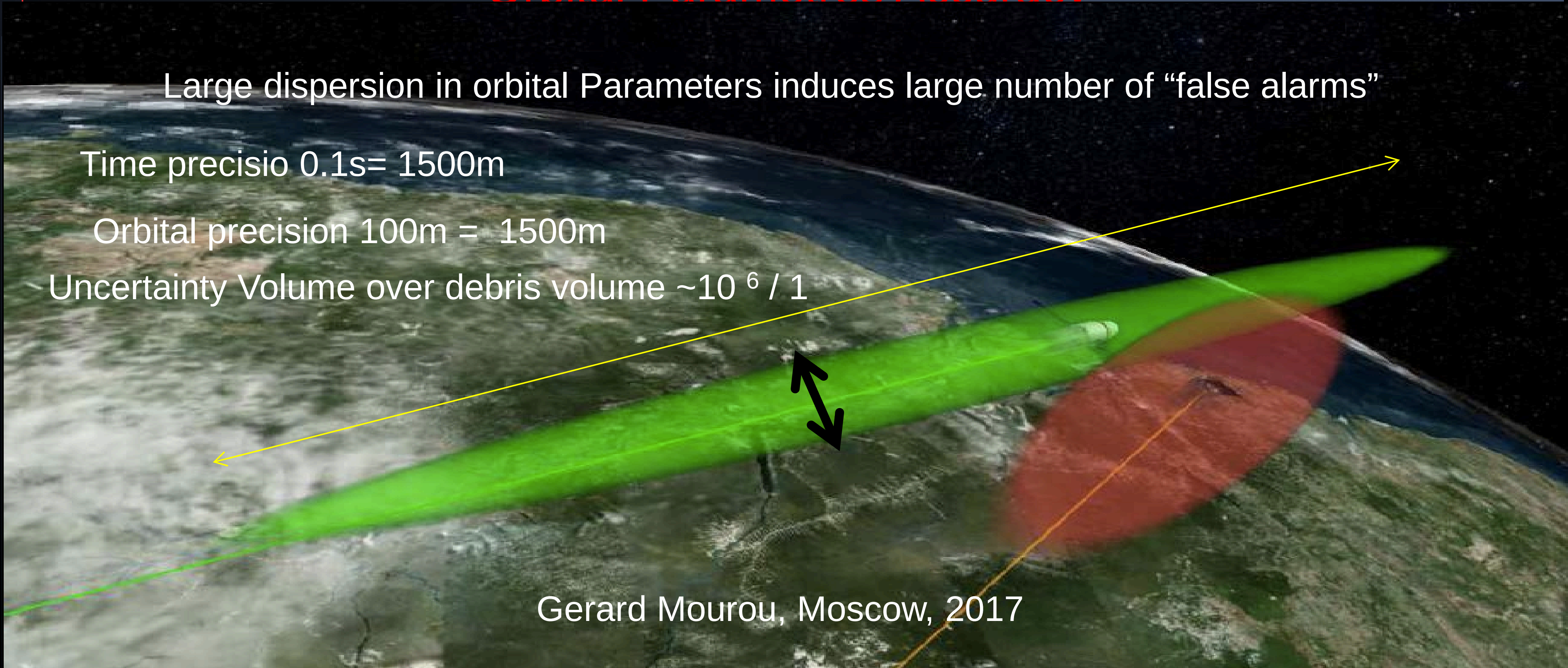
[Phipps, C. and H. Friedman, *ORION: clearing near-Earth space debris using a 20-kW, 530-nm Earth-based, repetitively pulsed laser.* Laser]

Only few Joules at ~ kHz rep rate is enough for the de-orbiting of small scale (up to 10 cm in size) space debris

G.Mourou et al (2013 ?): ICAN laser for space debris removal

Gerard Mourou, Moscow, 2017

Collision Prediction Requires Extreme Orbital Paramètres Accuracy



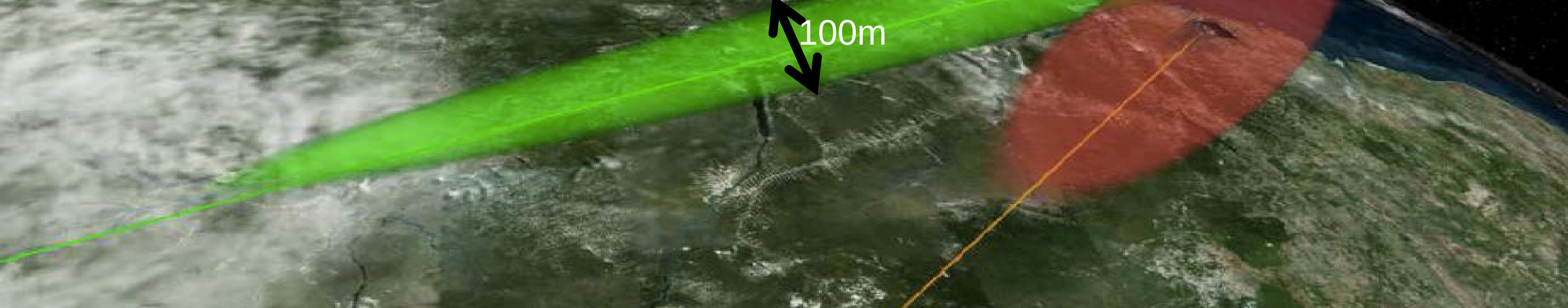
Debris Strategy : Minimize false alarms

Large dispersion in orbital position induces a large number of “false alarms”

CNES, the French Space Agency, dealt with more than 1 million collision notifications in 2016 to protect 16 satellites in Low Earth Orbit.

Because of the lack of precision 100000 notifications/1 for a serious one (10^{-4}).
Improving ephemerid accuracy to 1m would eliminate to 0 the number of false alarm.

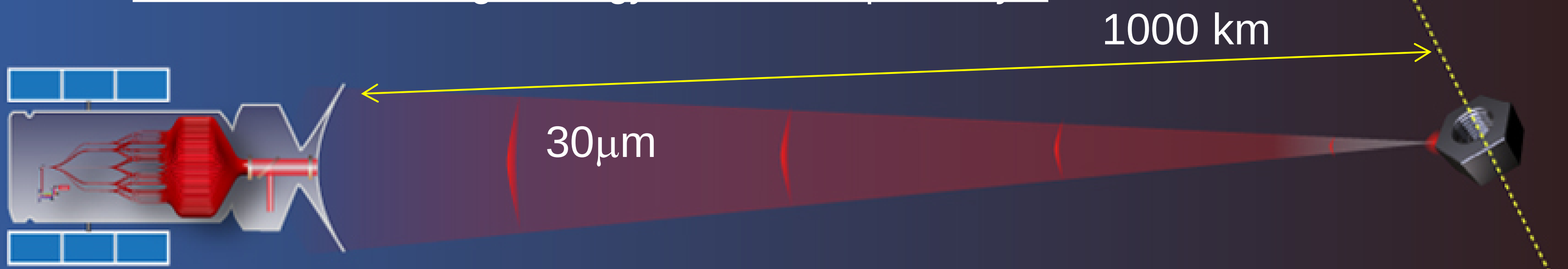
Plus smaller change in velocity vector. Saving fuel!



Precise Orbital Debris Parameters: High Energy-Ultra short Pulses

Why High Energy and Short Pulse ?

How to solve the High Energy Short Puls quandary ?



1 High energy and short pulse for precision ranging <<1mm
over long distance (1000km) 10^9/ 1

2. Precision measuring Shape with Sub mm precision

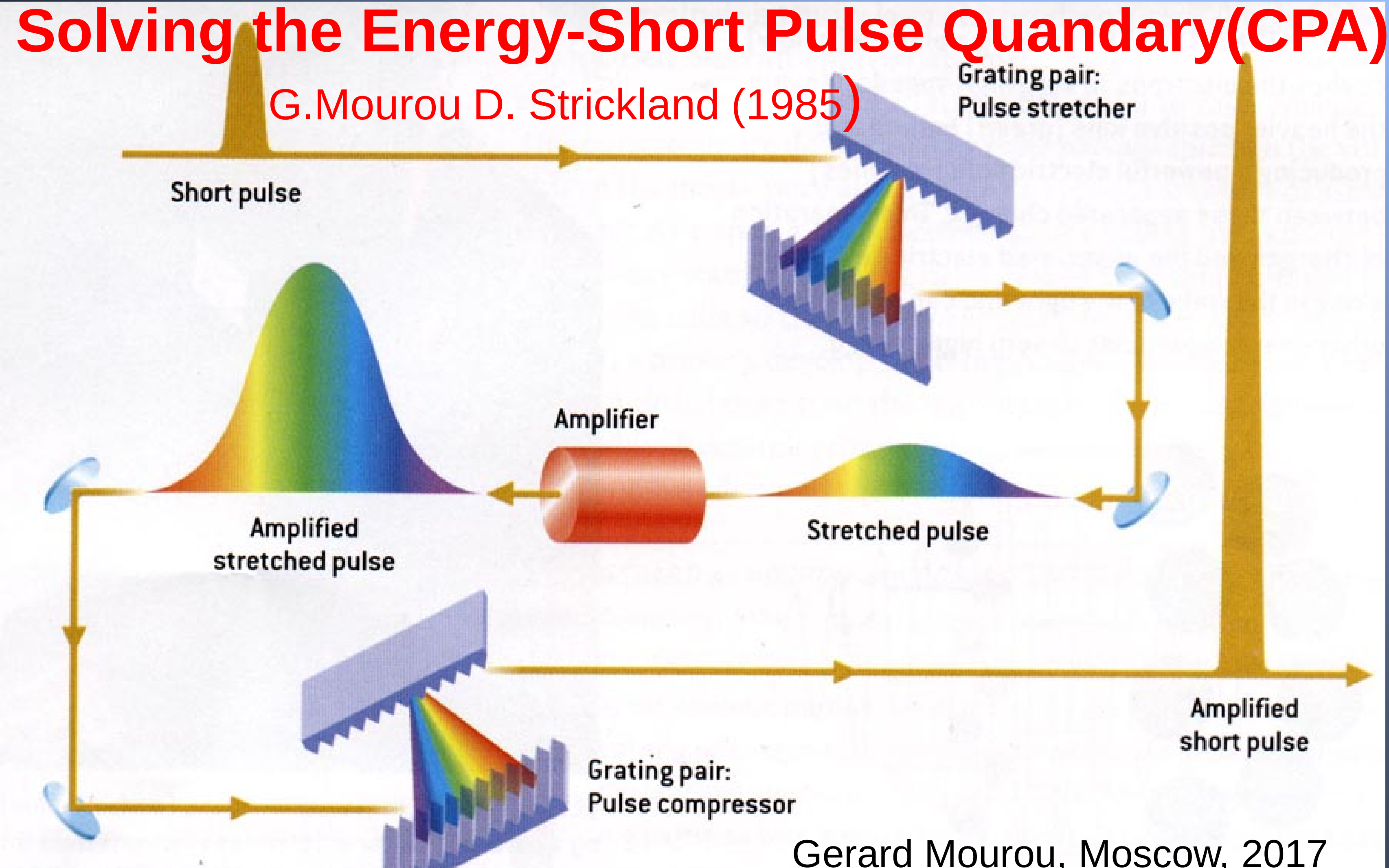
3. Very high peak power for laser-induced breakdown and plasma ejection.
   a. deorbiting by rocket effect
   b. elemental analysis for material identification

Gerard Mourou, Moscow, 2017

ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

Solving the Energy-Short Pulse Quandary(CPA)

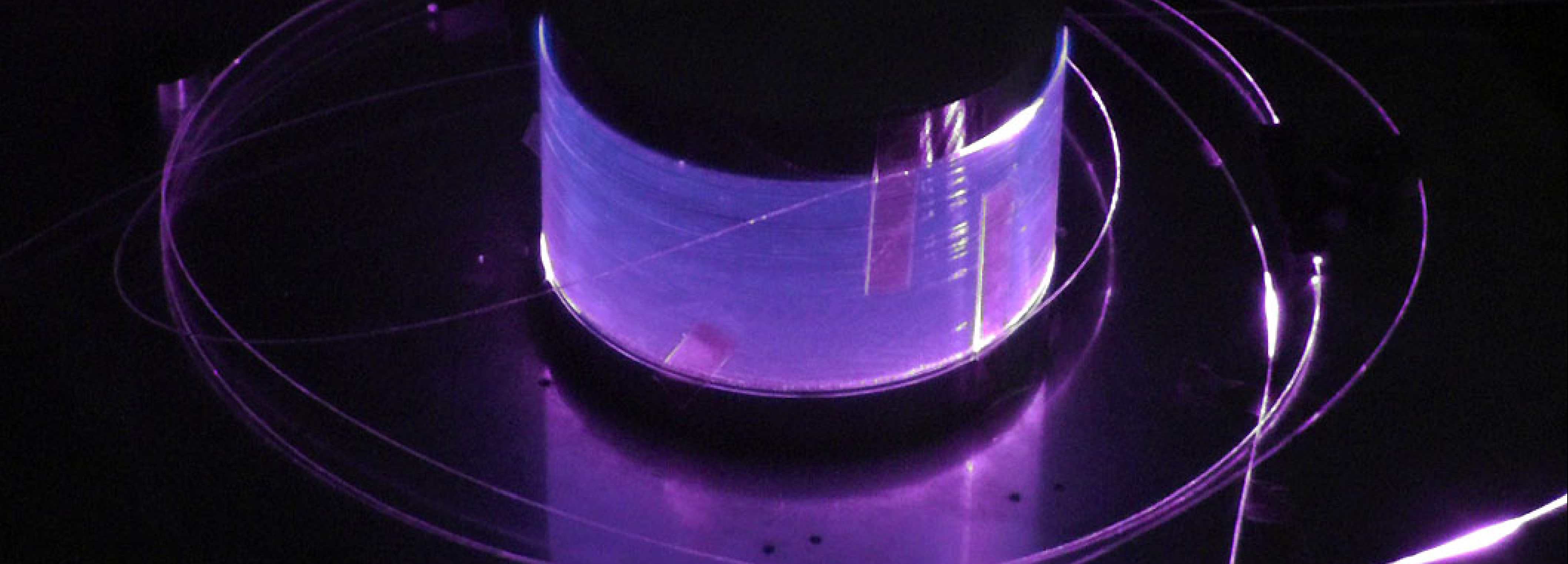
G.Mourou D. Strickland (1985)



Gerard Mourou, Moscow, 2017

Laser for Debris Mitigation

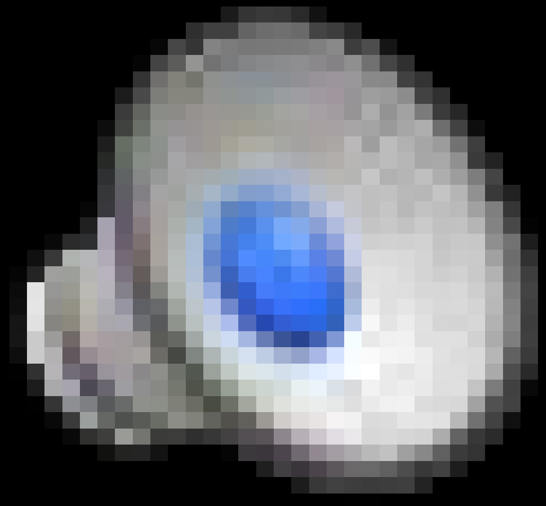
High energy, Short Pulse, High Rep. rate, Efficiency



Optical fibres can also be use as lasers!

Gerard Mourou, Moscow, 2017

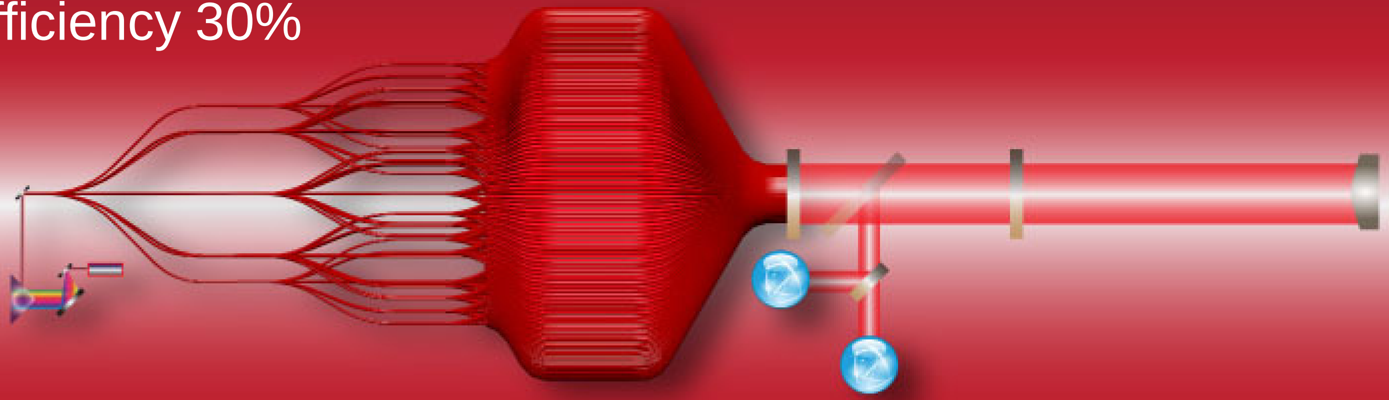
l'X ÉCOLE POLYTECHNIQUE UNIVERSITÉ PARIS-SACLAY



Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

Seeking a laser with:
Short Pulse 100fs
High energy Joules
High Repetition (high rep.rate) :kHz
High efficiency 30%



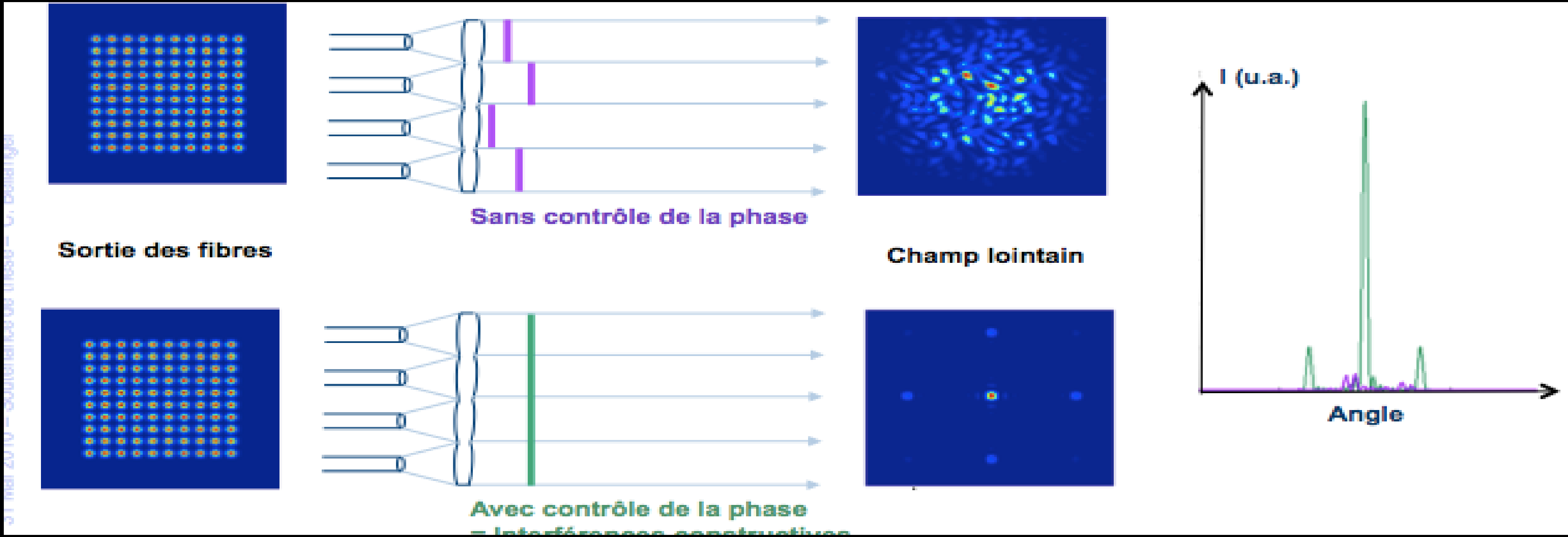
Starts with a single fibre laser
Fibre is spliced into 10,000 fibres
Power output becomes enormous!

XCAN *– X Coherent Amplification Network*

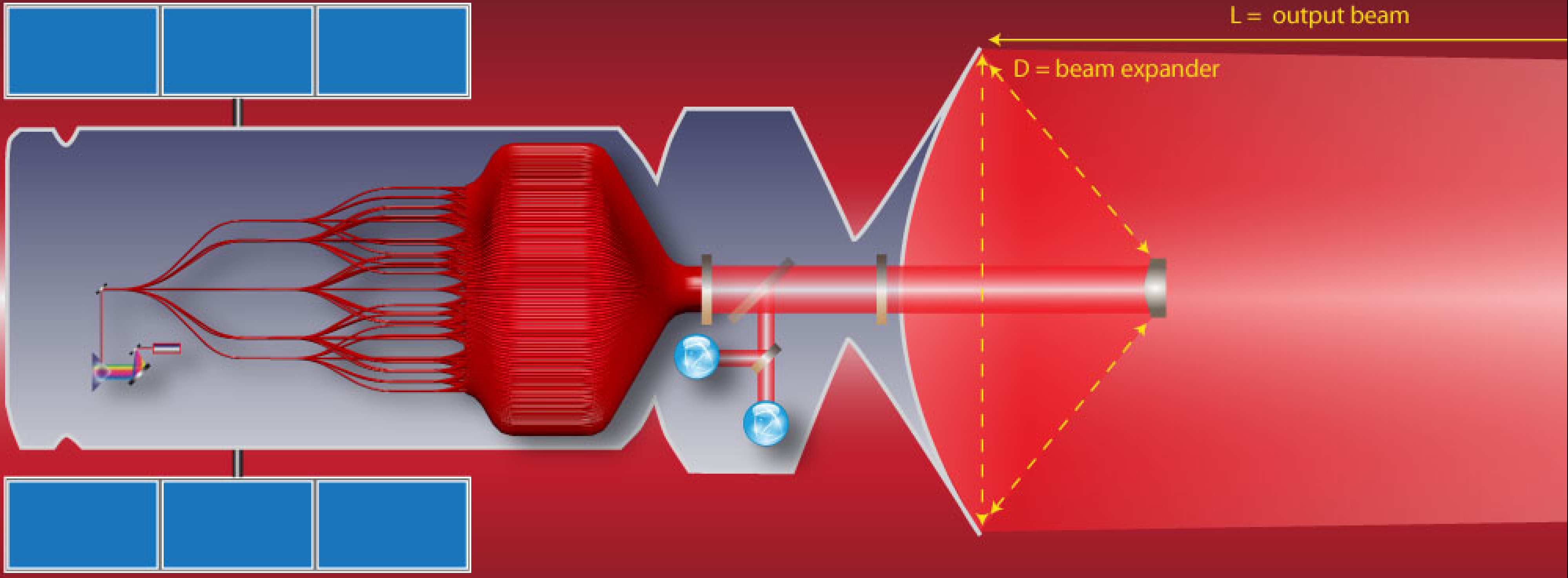
Gerard Mourou, Moscow, 2017

64 CW fibers have been phased

(This experiment in fact validates an extension possible to >10^4 phased fibers at 1kHz)



SPACE DEBRIS - A state of emergency!



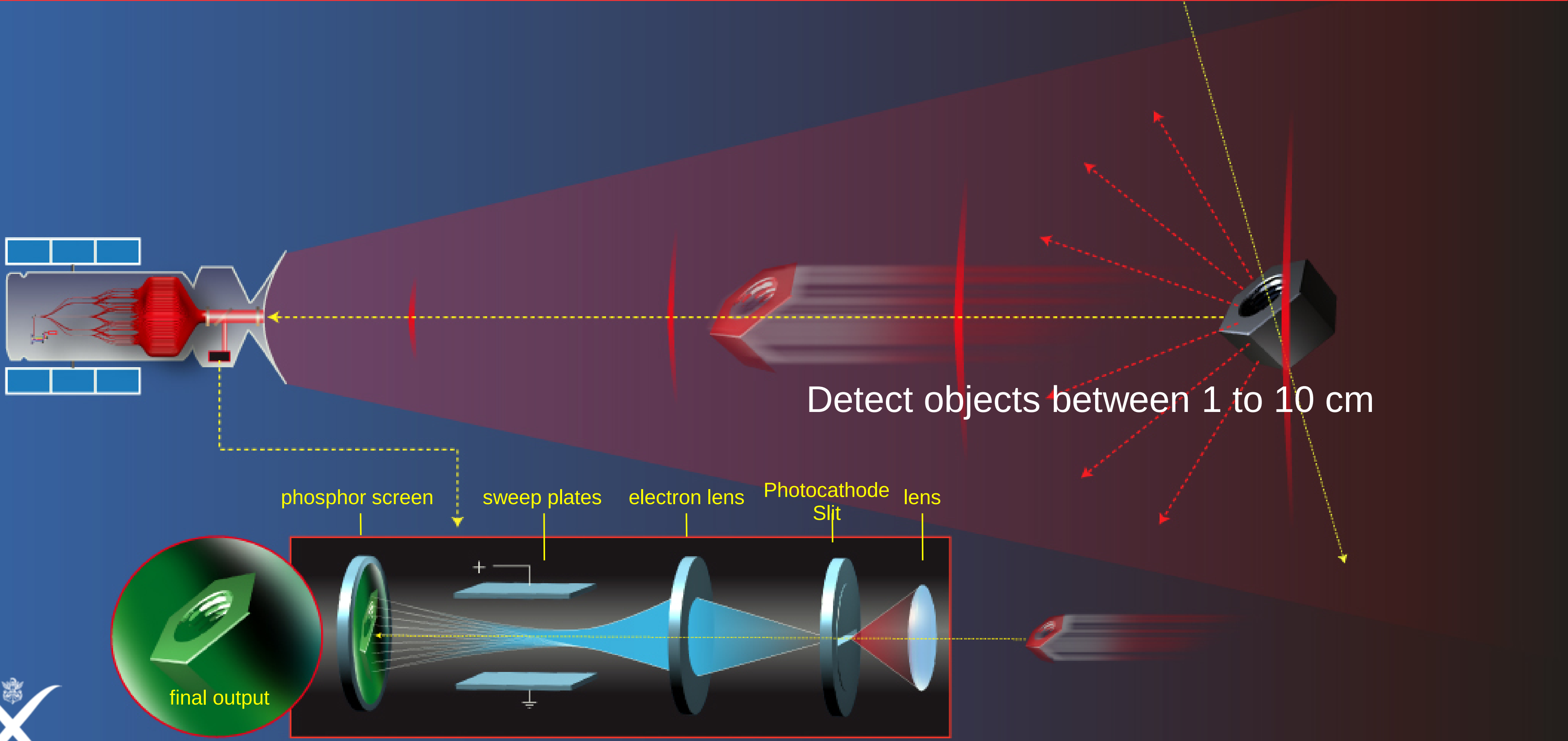
XCAN *– X Coherent Amplification Network*

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

Gerard Mourou, Moscow, 2017

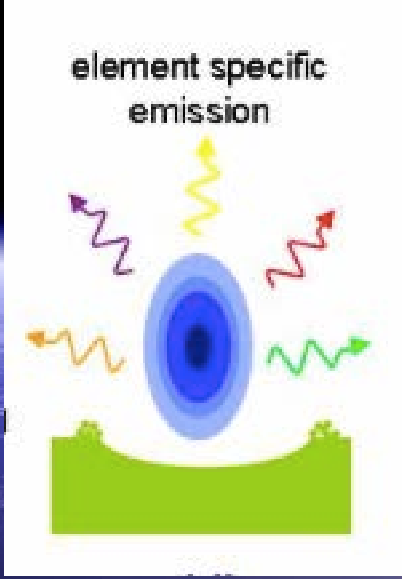
Measuring Ephemerids with very high precision ($10^9/1$)

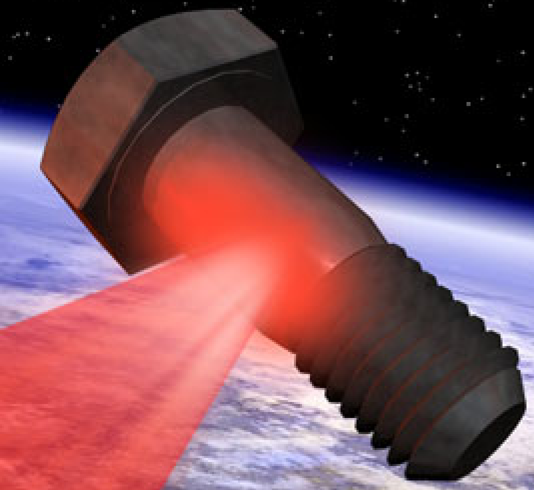


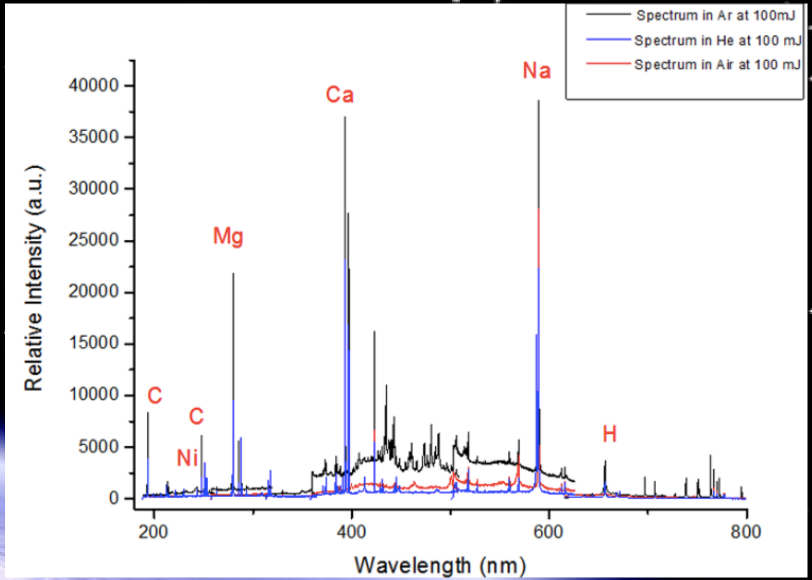
Streak camera Ultrafast Detector

Gerard Mourou, Moscow, 2017

Debris identification: Laser Induced Breakdown Spectroscopy







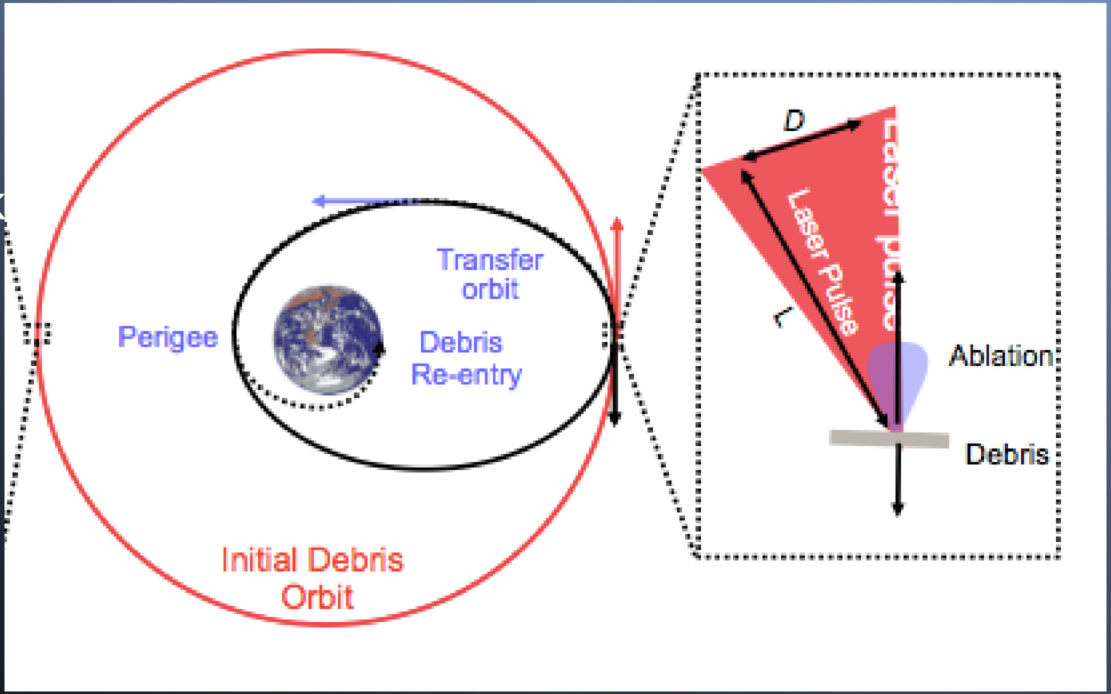
Gerard Mourou, Moscow, 2017

Ultrashort Laser-Deorbiting Concept

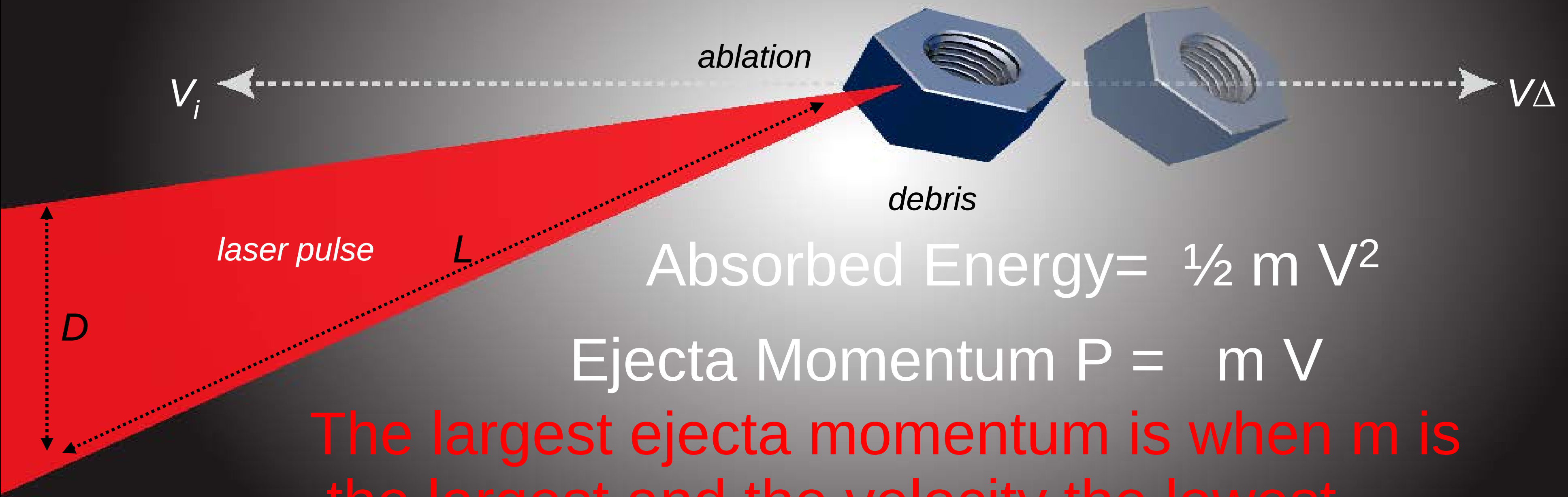
C.Phipps, C. Bonnal Acta Astronautica118, P224(2016)
T. Ebisuzaki et al. Acta astronautica .112, 102 (2015)

The laser provides the means to deliver a brief recoil impulse by ablating a thin surface layer on the debris. As shown in Figure.
The ablated material forms a jet normal to the surface which induces a recoil in the opposite direction slowing the debris by v.

Click



Strategy
Space Debris Laser Ablation with the Highest Momentum Transfer
(C. Phipps 1988)



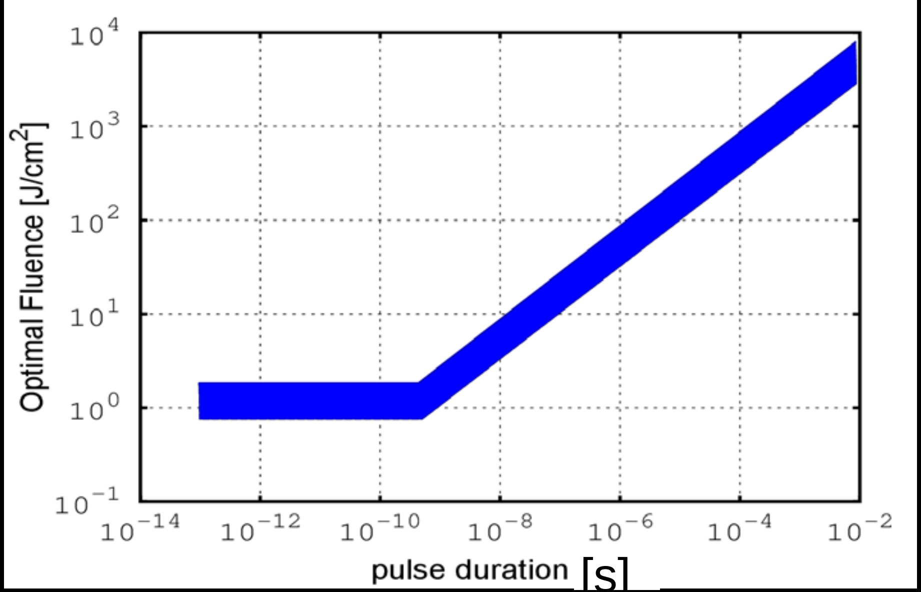
Absorbed Energy= $\frac{1}{2}$ m V^2

Ejecta Momentum P = m V

The largest ejecta momentum is when m is the largest and the velocity the lowest

Gerard Mourou, Moscow, 2017

Laser Pulse Energy



Optimal fluence for momentum coupling[6]

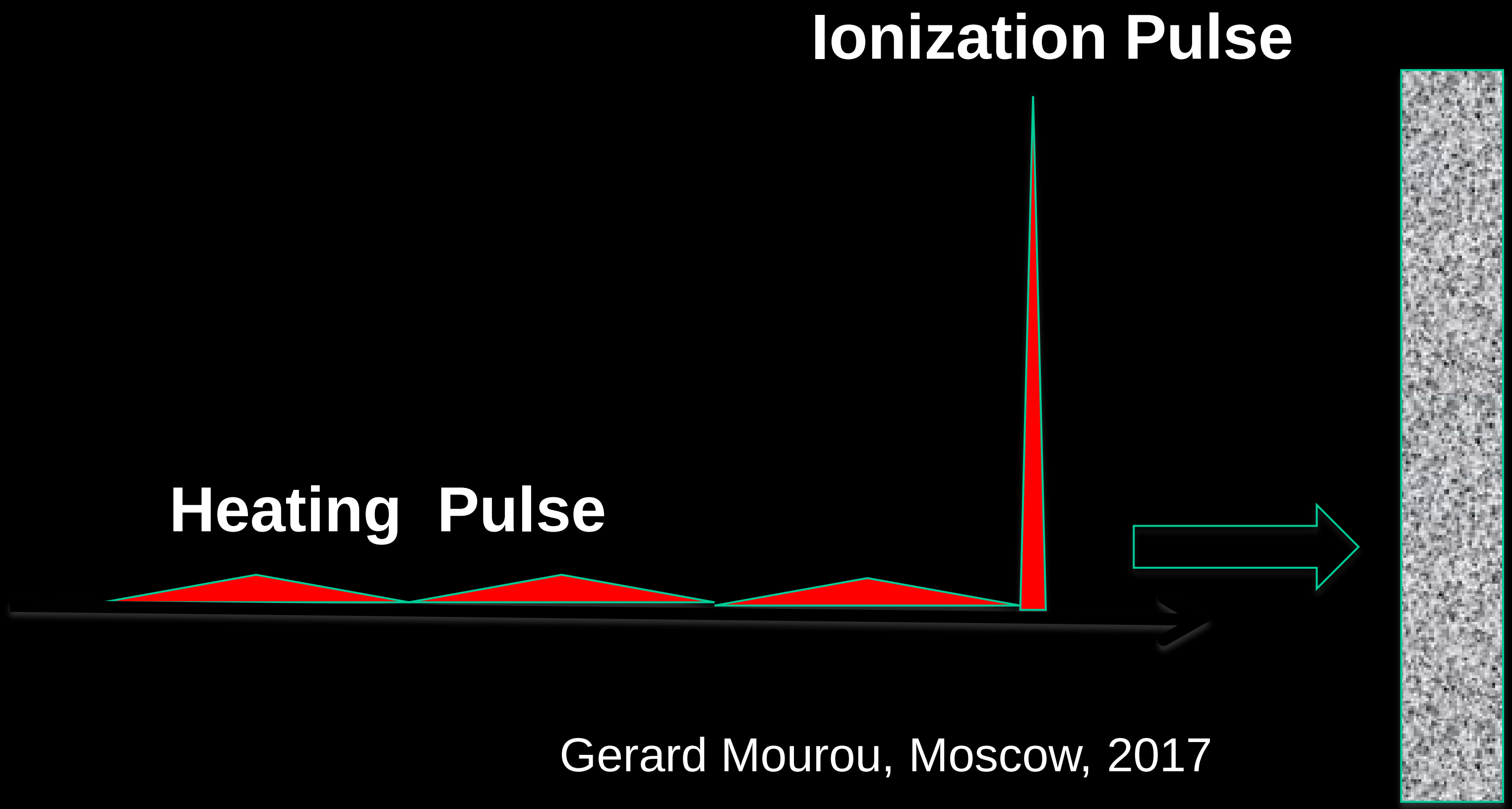
$F_{opt} \leftrightarrow$ Pulse duration

Spot size to within 10cm

At 800 km orbit

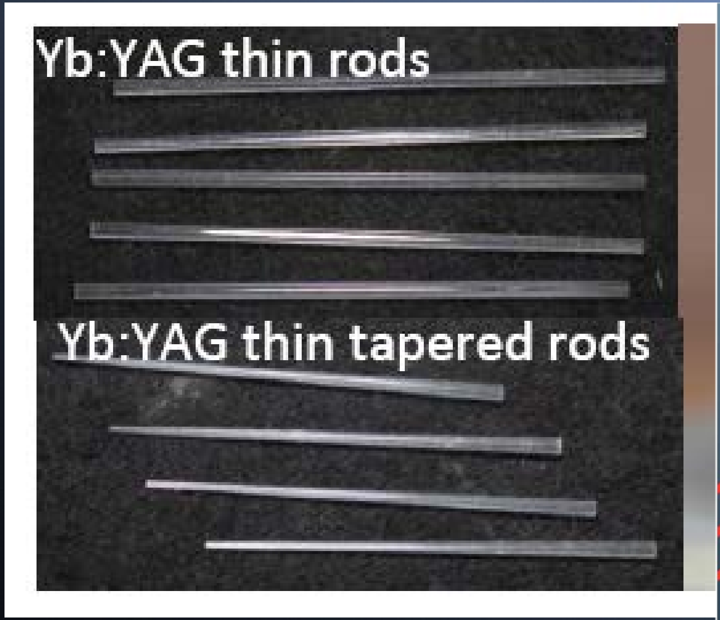
Optimal pulse energy:

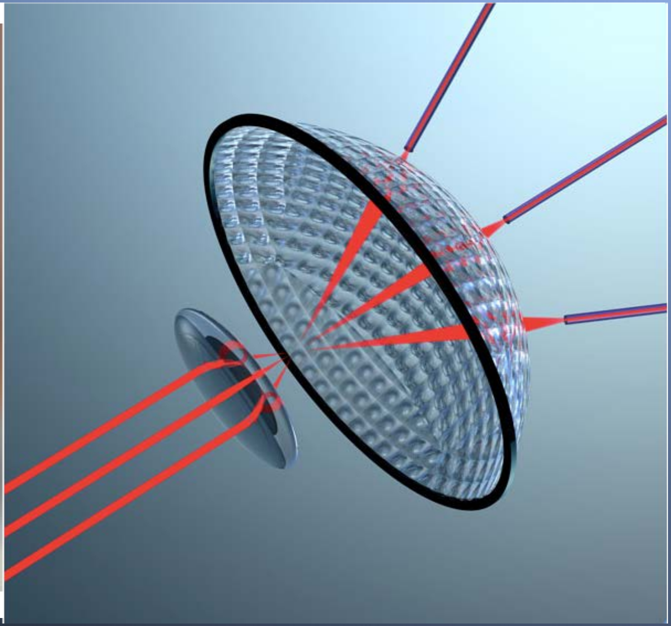
Pulse Composite(short et Long) Scenario for the Largest Momentum Change



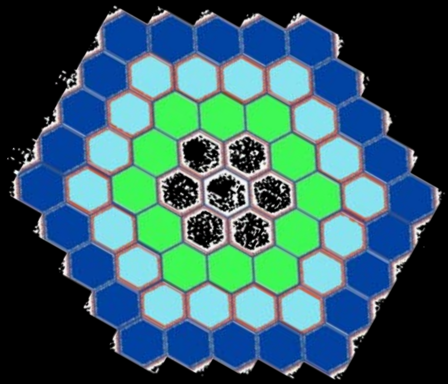
Gerard Mourou, Moscow, 2017

Laser Architectures

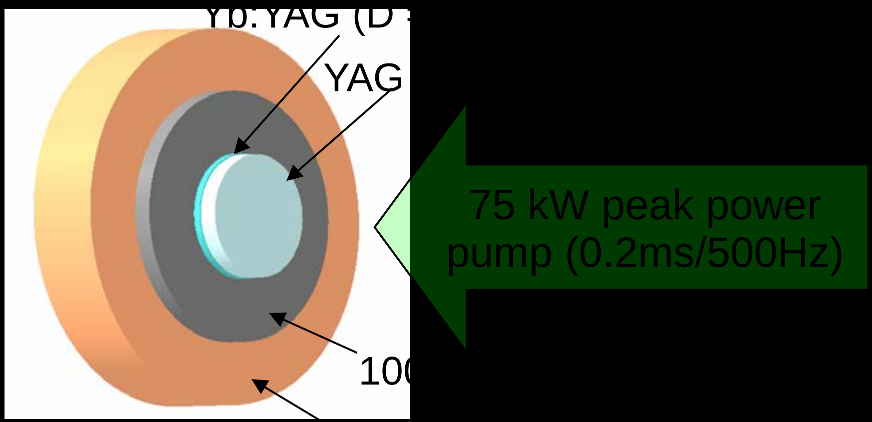


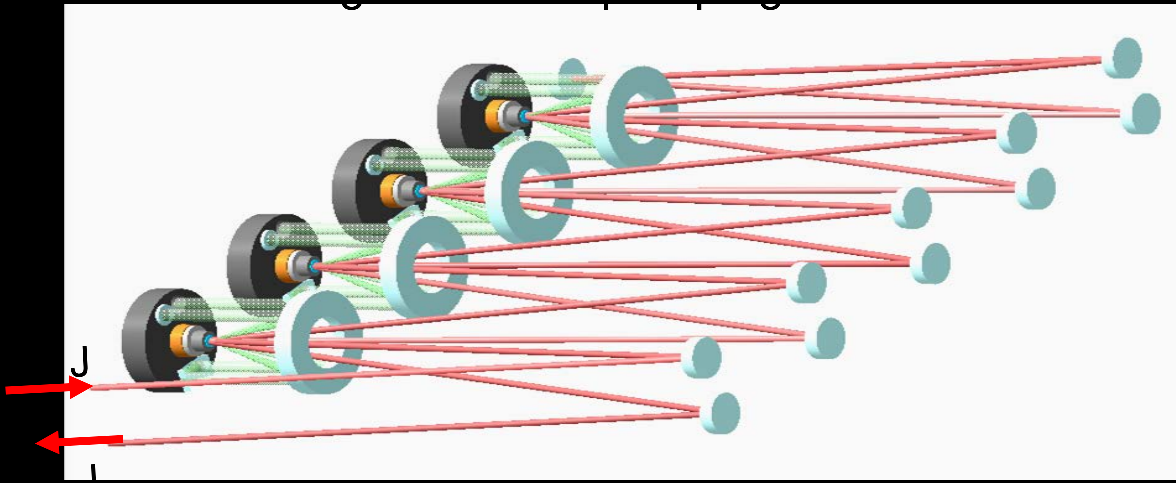


61 channels
350 fs
>10 mJ
50 kHz



Alternative approach based on a disk laser





Gerard Mourou, Moscow, 2017

Prototype Experiment on EUSO-ISS

Cosmic ray detection

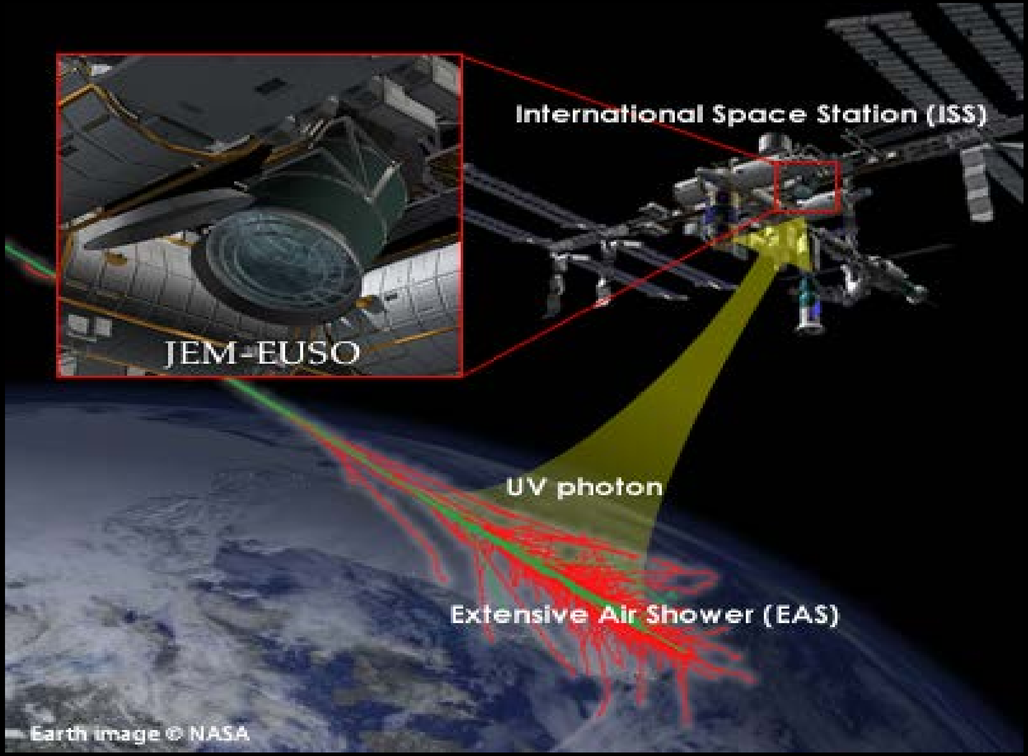
Module on ISS

Telescope with 60 deg FOV

Other function?

Debris tracking?

Use in tandem with XCAN?



EUSO + XCAN = Debris sweeper?

Additional Module on ISS for XCAN

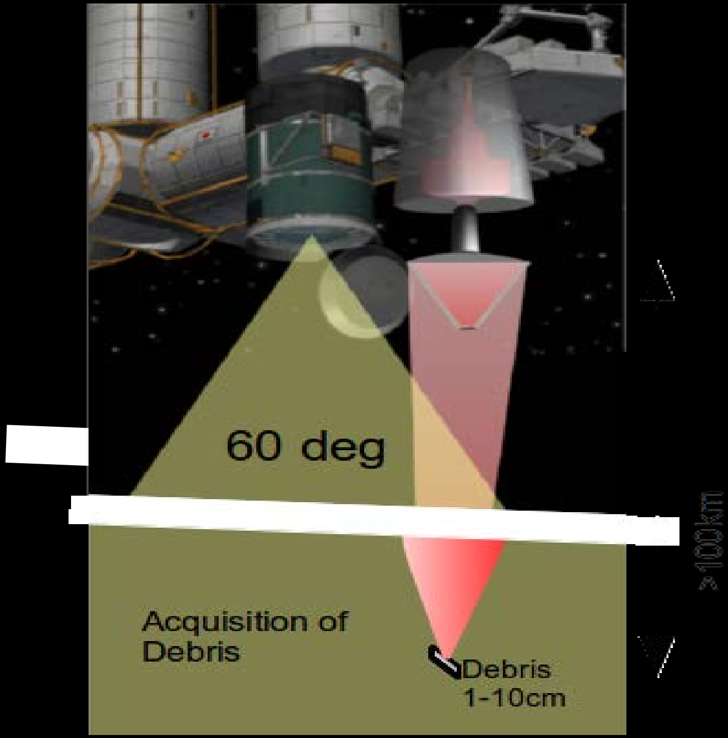
EUSO gives 60 deg FOV

- Acquisition of debris at L>100km
- Catalogue debris over orbital cycle

Provide time to point XCAN system

Burst mode of laser

Pointing along orbit?



Gerard Mourou, Moscow, 2017

Conclusion

Small Debris Mitigation Strategy

Small debris can not be detected from the earth.

1. Their velocity and large number make them dangerous.
2. ephemerid precision (10^{-8}) is needed to evaluate collision probabity to less than 10^8 /1.
3. This precision could be reached with stabiized Mode-locked laser (100fs)coupled with a streak camera in the ps regime

Conclusion
Small Debris Mitigation Strategy (Continued)

4. Precision also makes collision avoidance less fuel demanding.

5. Femtosecond pulses make possible:
   a. Measure the shape of the debris
   b. Elemental analysis of the debris for debris identification

École Polytechnique Université Paris-Saclay

Space Pollution at a state of urgency

Considering the mounting activities that
Space experience, in all walks of life,
it is paramount that a serious effort be made
to develop strategies, policies, technologies to
to keep our Space Clean.

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - A state of emergency!

Gerard Mourou, Moscow, 2017

SPACE DEBRIS - *A state of emergency!*

SPACE DEBRIS
Toshikazu Ebisuzaki
MarkN.Quinn b,
SatoshiWada a,
Lech Wiktor Piotrowski a,
YoshiyukiTakizawa a,
MarcoCasolino a,c,
Mario E.Bertaina c,d,
PhilippeGorodetzky e, EtienneParizot e,
ToshikiTajima b,f,
RémiSoulard,

XCAN
J.C. Chanteloup
L. Daniault
A. Brignon
M. Antier,
J. Bourderionnet

Gerard Mourou, Moscow, 2017