FORTH—IESL

CRETANMATTERWAVES

OBST

Optical Beam
Steering Technology
For Complex Space Missions

Wolf von Klitzing

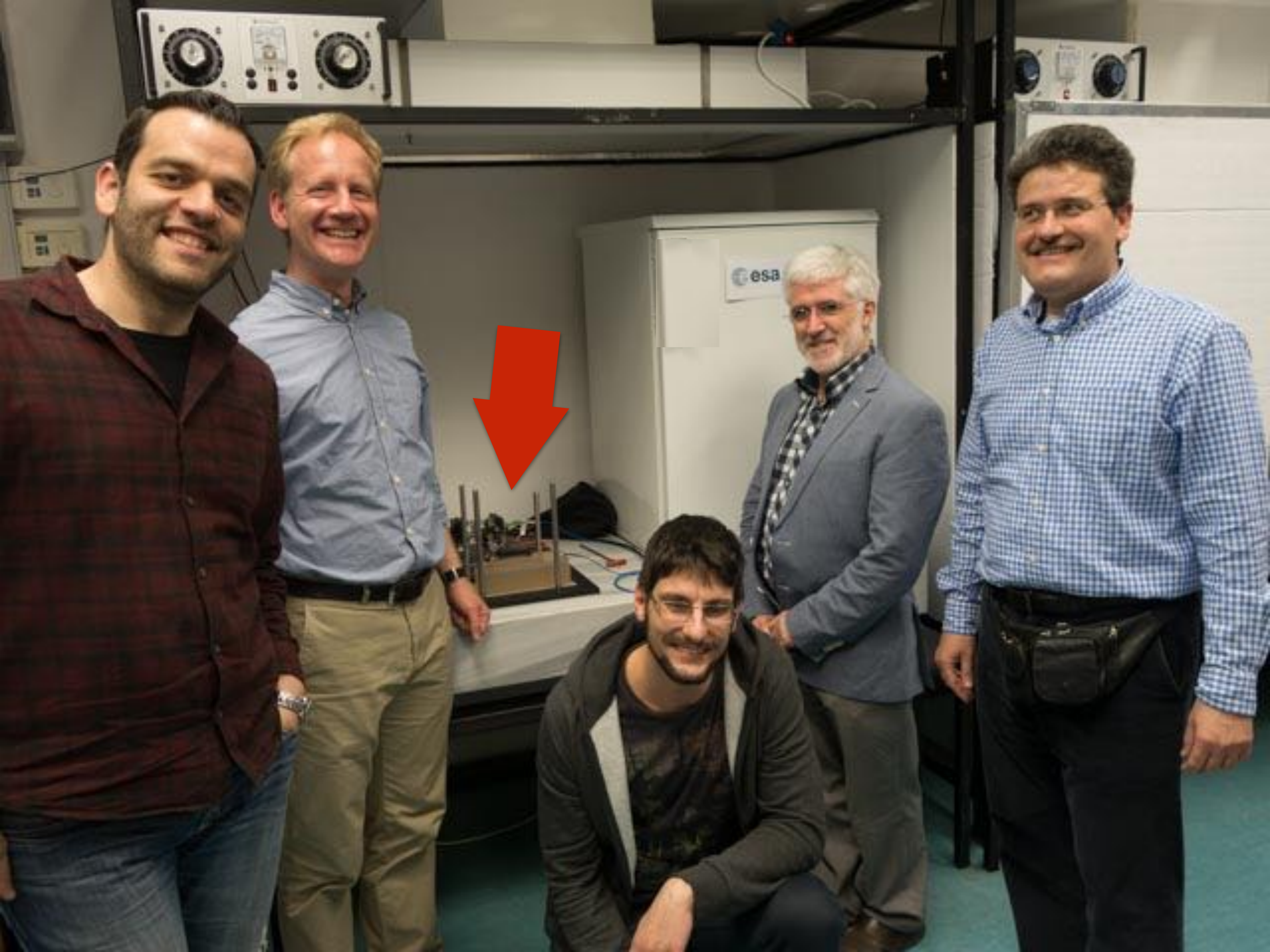
ESTEC
15/03/2018

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
AtomQT

FET
FUTURE & EMERGING TECHNOLOGIES scheme
MatterWave

esa
ESA-OBST

G. Vasilakis S. Pandey, G. Drougakis, K. Mavrakis, P. Christodoulou, K. Poulios, I. Alonso-Miguel
M. Mikis H. Mas, W. von Klitzing, V. Bolpasi

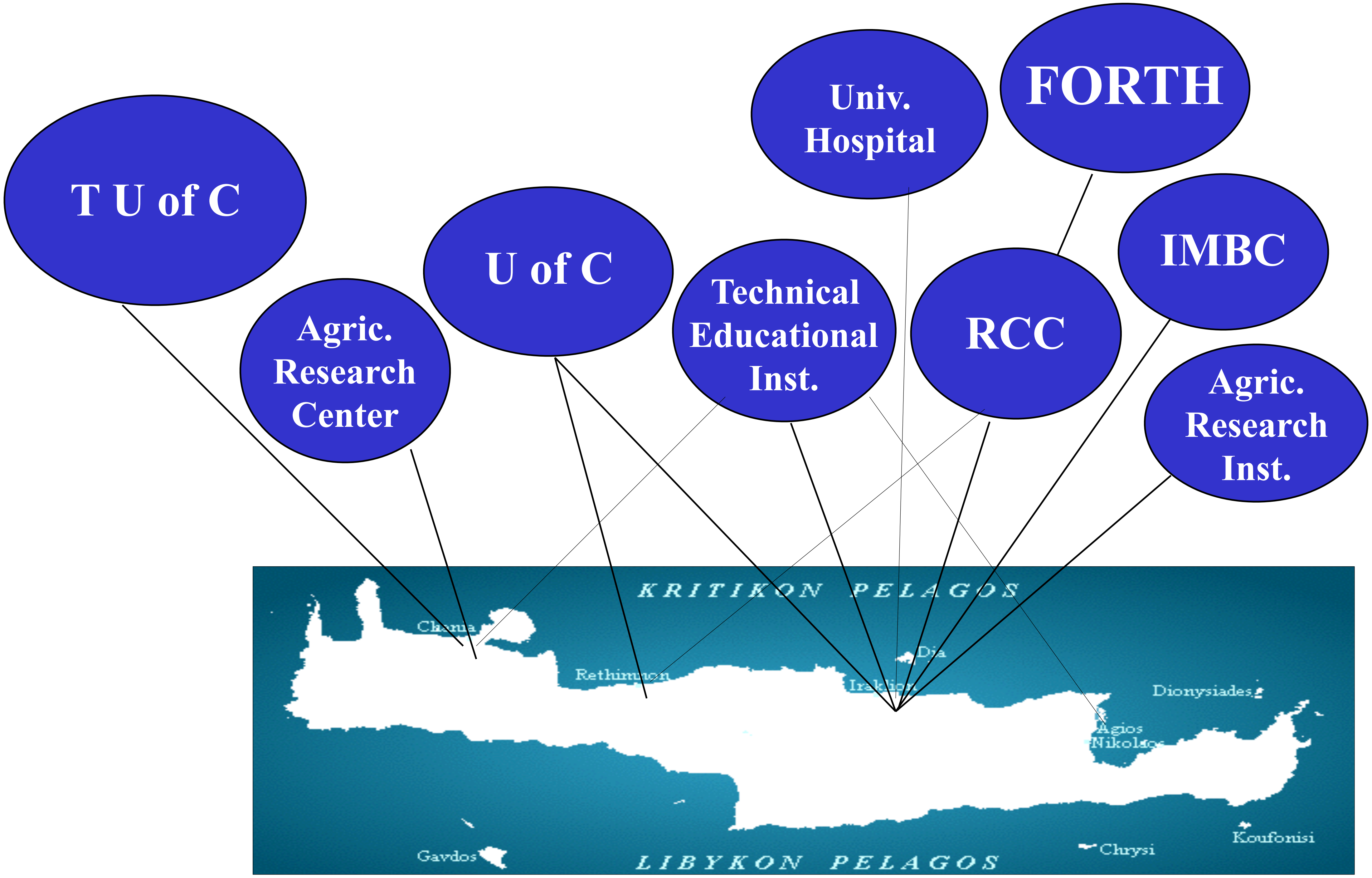

esa

FORTH

Foundation for Research and Technology - Hellas

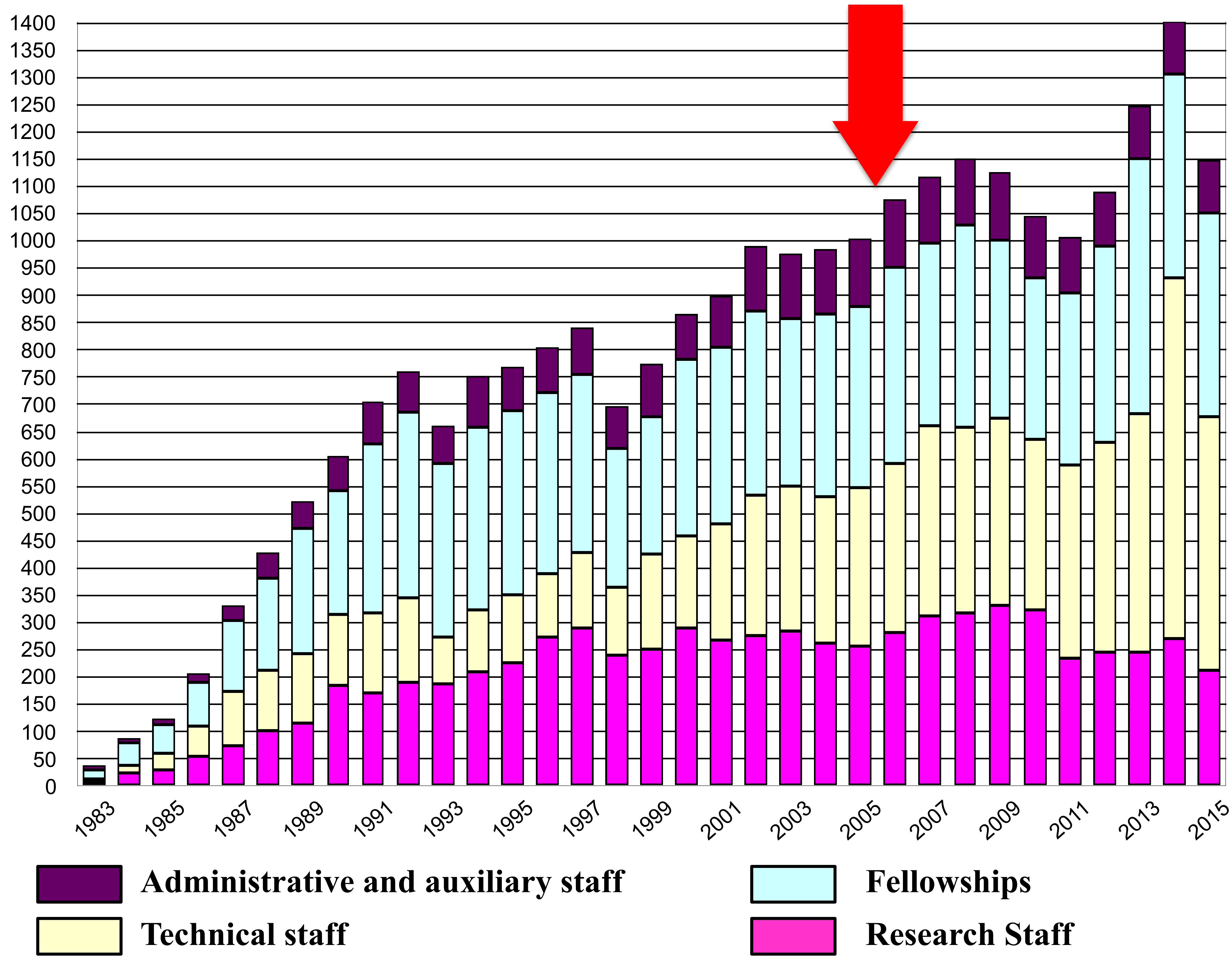
ISEL-FORTH

Research in Crete



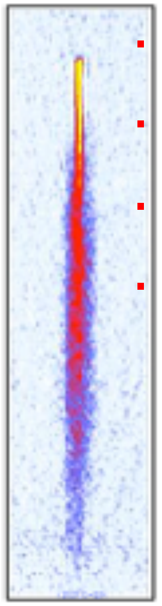
FORTH in Greece

People of FORTH

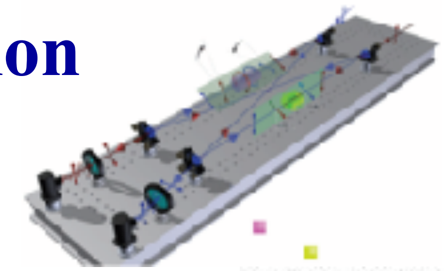


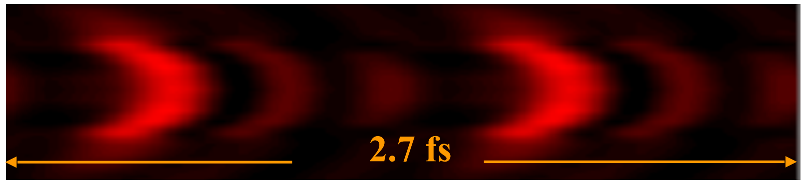
IESL-FORTH

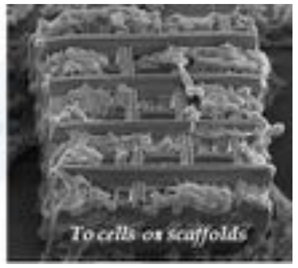
+ Laser Interactions and Photonics Division

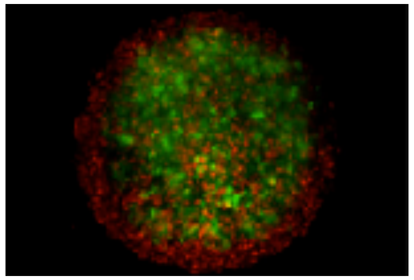


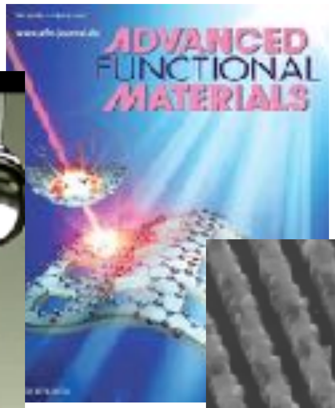
- Strong Field Physics
- Atoms, Molecules and Clusters
- Theoretical Atomic, Molecular & Optical Physics
- Photon Science Applications
  - Biophotonics
  - Laser Processing of Materials
  - Diagnostic Methods and Instrumentation
  - Lasers in Cultural Heritage

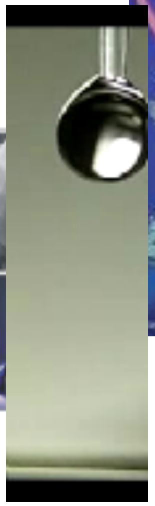






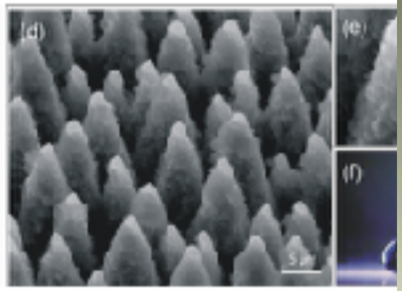


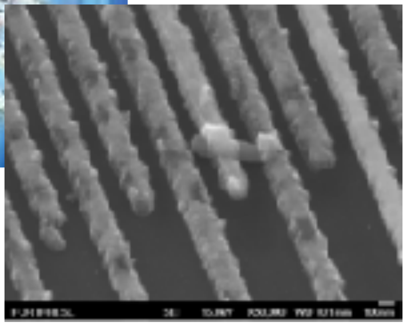


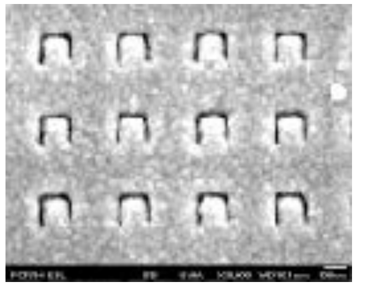


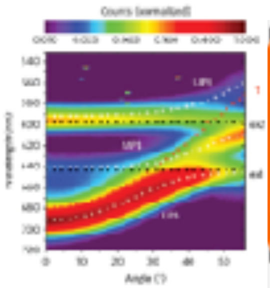
+ Materials and Devices Division

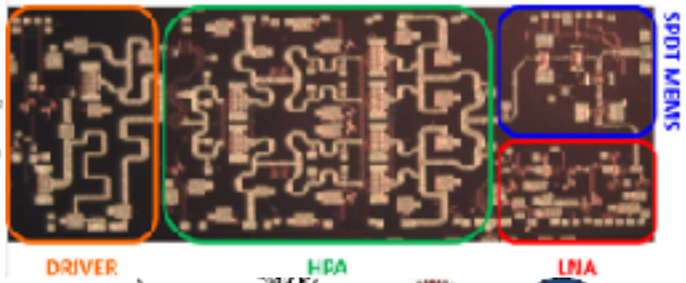
- Micro/Nano-electronics
- Soft Matter
  - Polymer & Colloid Science
  - Hybrid Nanostructures
- Transparent Conductive Materials
- Magnetic Materials
- Theoretical Condensed Matter Physics
- Photonic, Phononic and Metamaterials

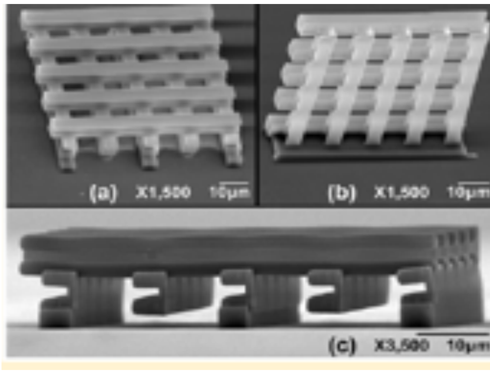












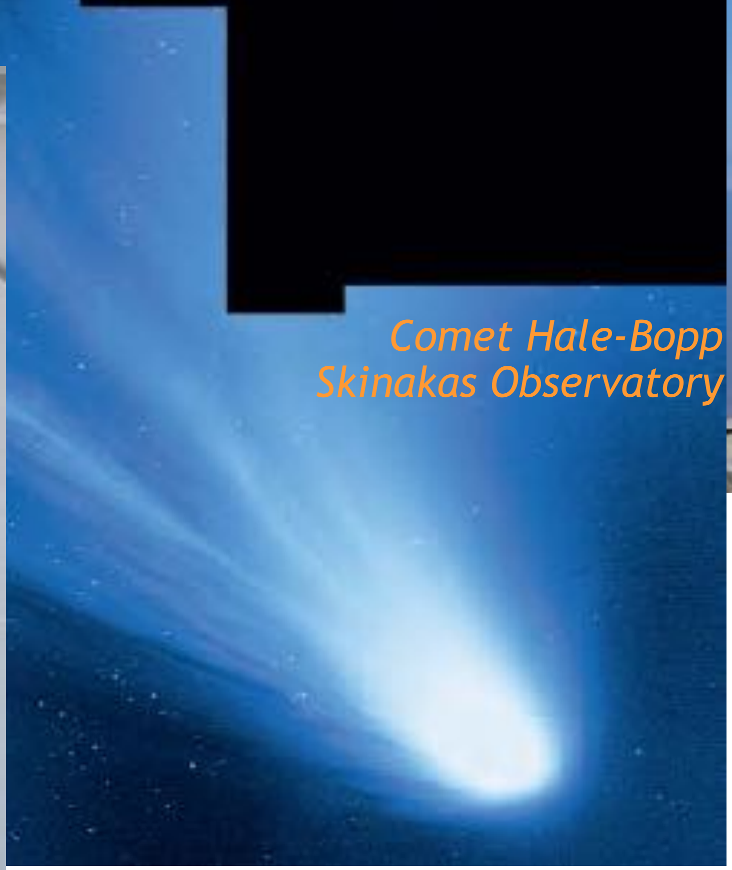
+ Astrophysics and Astronomy (Skinakas Observatory)

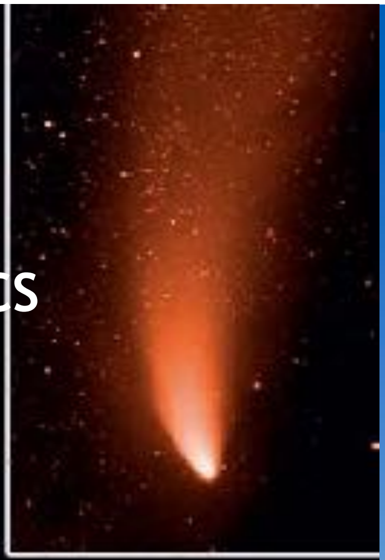
•FOUNDATION for RESEARCH & TECHNOLOGY - HELLAS

•UNIVERSITY OF CRETE

•MAX PLANCK INSTITUTE for EXTRATERRESTRIAL PHYSICS

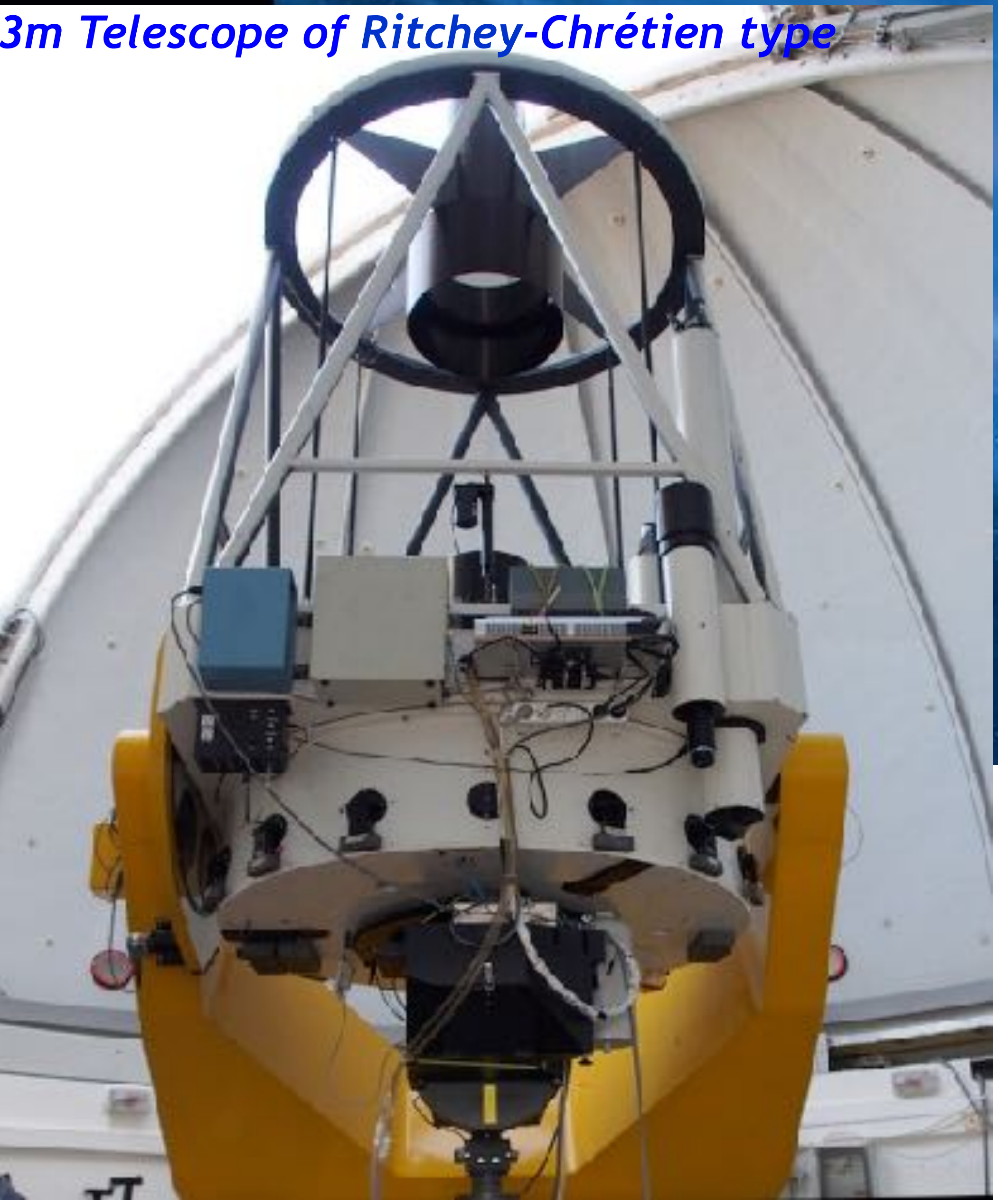
SKINAKAS OBSERVATORY





Comet Hale-Bopp
Skinakas Observatory

3m Telescope of Ritchey-Chrétien type



At an altitude of 1750 m on Psiloritis mountain at an excellent observing site Skinakas Observatory operates 3 telescopes equipped with a large suite of modern astronomical instruments

Near Infrared Camera

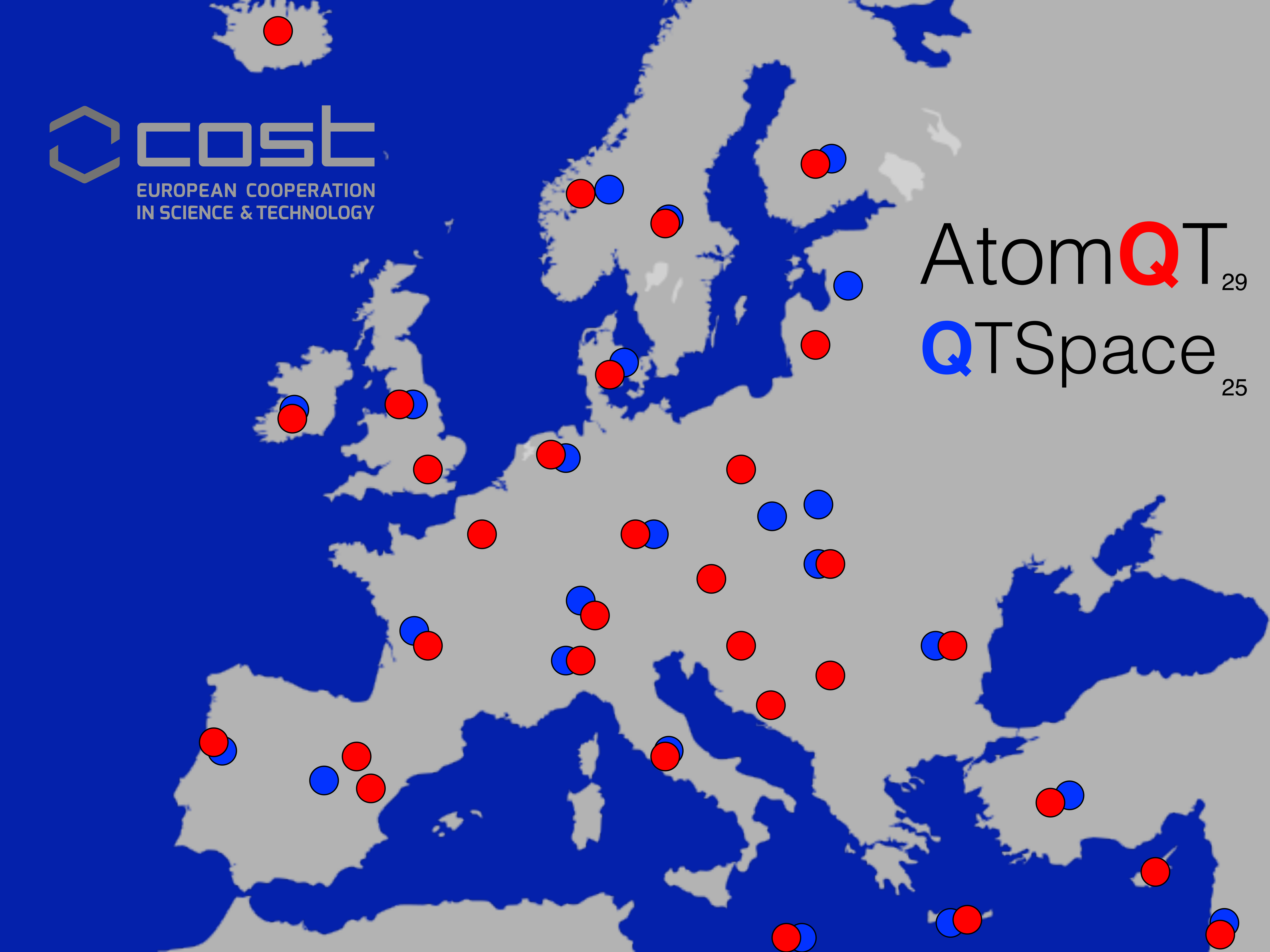
Echelle Spectrograph

Polarimeter

RoboPol

Laserlab Europe

+ A network of big European national laboratories
+ Transnational Access (4000 days of access)


cost
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY
AtomQT 29
QTSpace 25

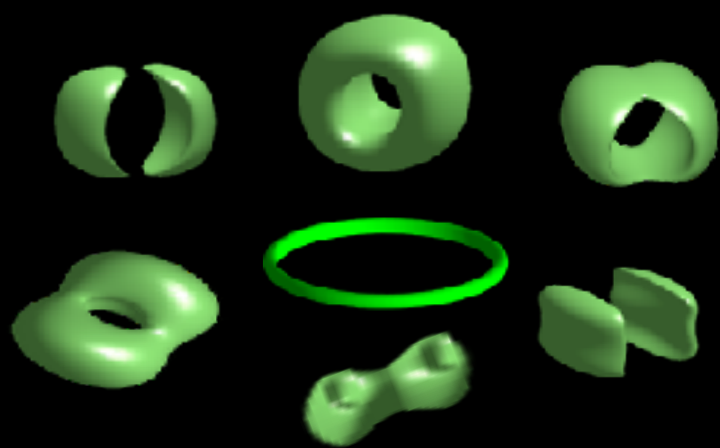
BEC and MatterWaves at IESL-FORTH

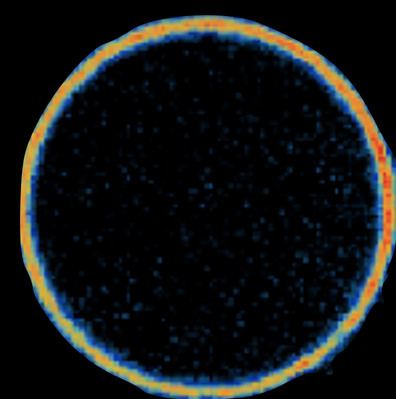
CRETAN MATTERWAVES

FORTH INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

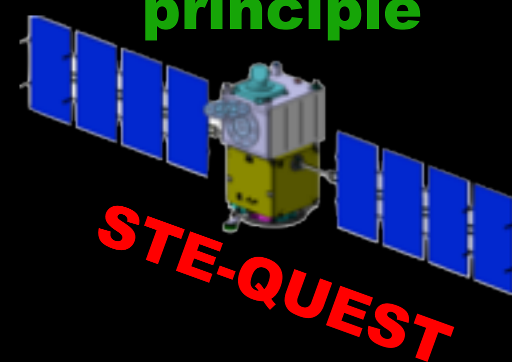
Matter-Wave Interferometry

Guided for Matter-Wave Interferometry for inertial navigation

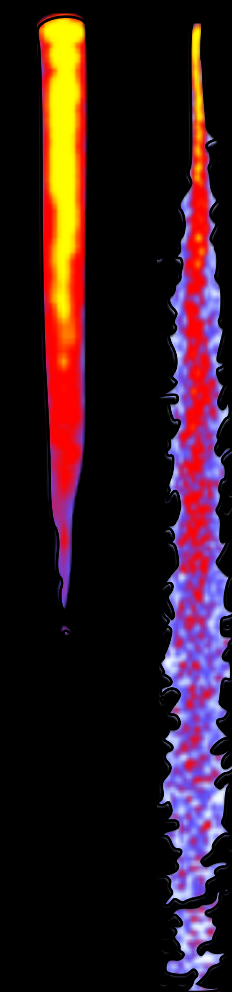




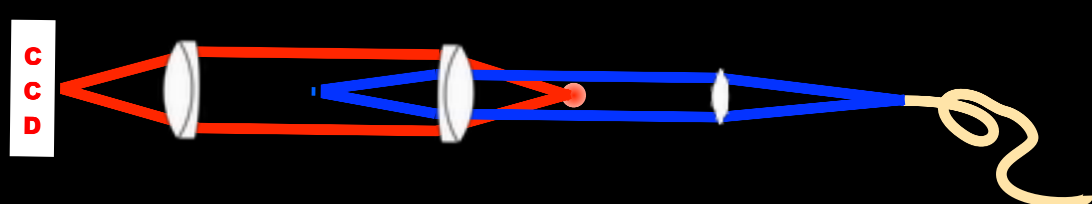
BEC in Space: Testing Einstein's Weak equivalence principle

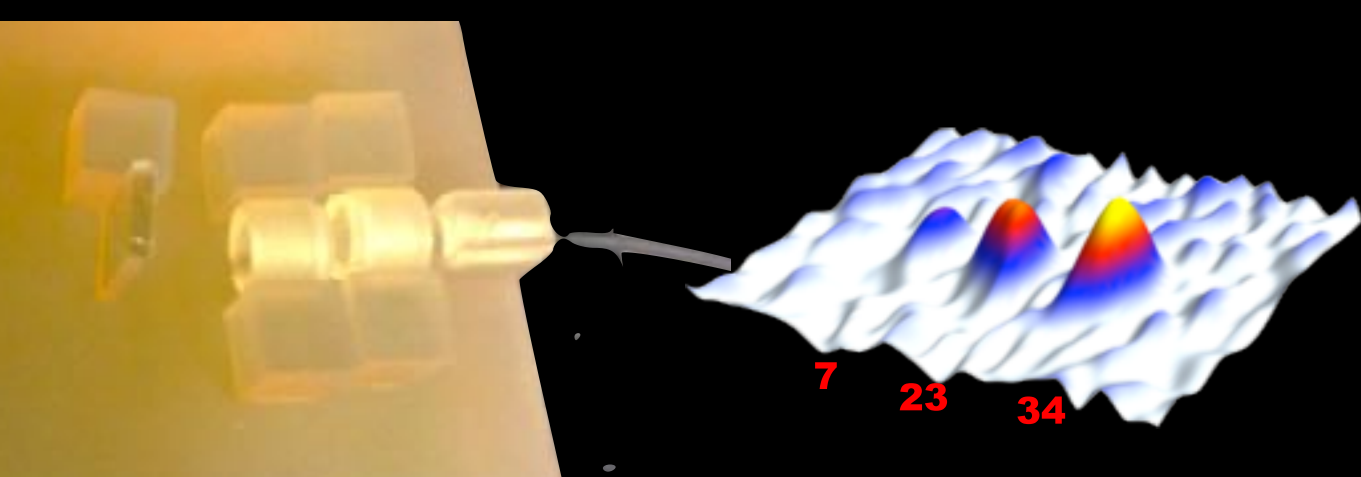


Ultra-Bright Atom Lasers

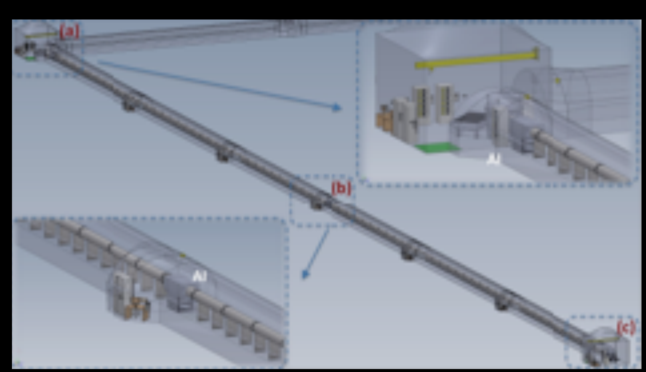


Matter-Wave&Quantum Tools





Very long Baseline Matterwave interferometry

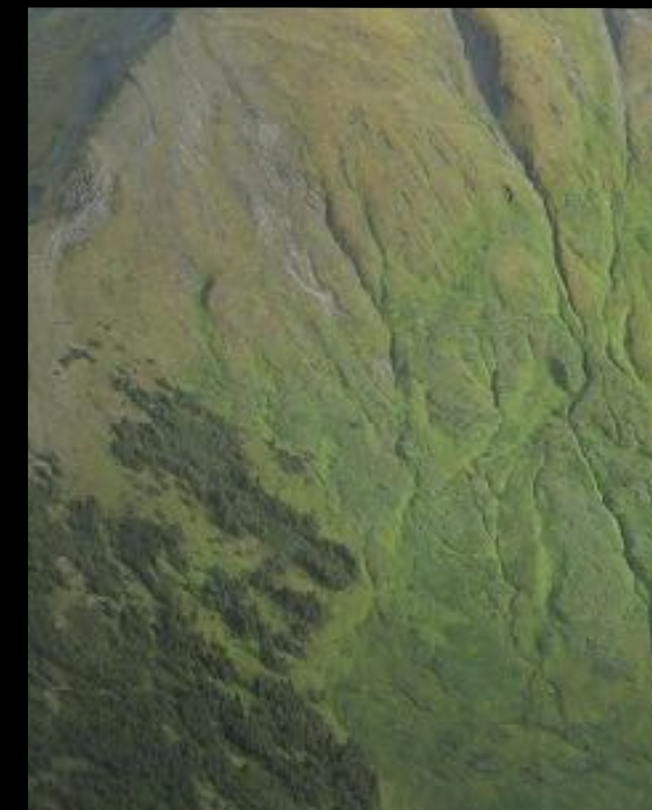


ELGAR

SAGE

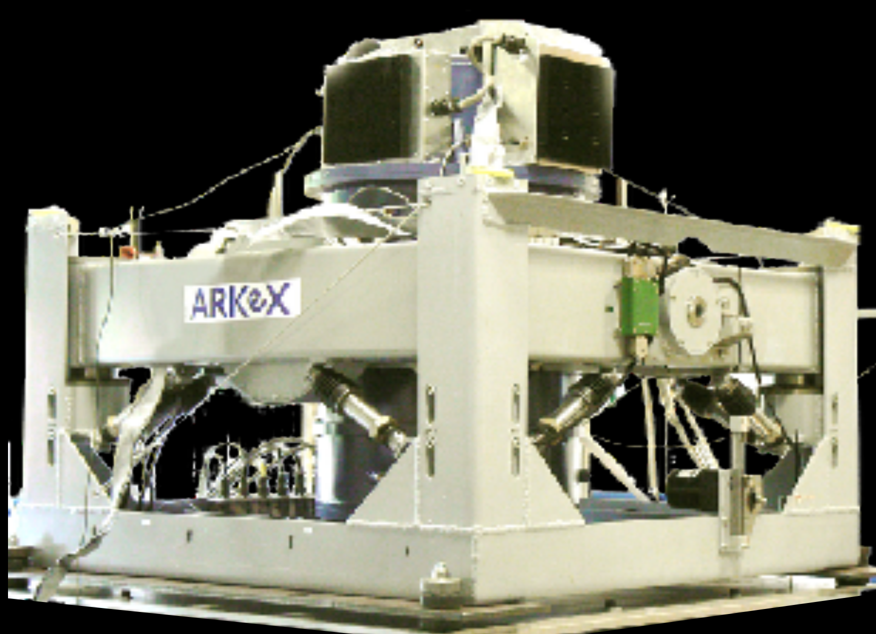
Why Precision Gravity ?

Gravity Gradiometry
Using the Meissner Effect and a Squids



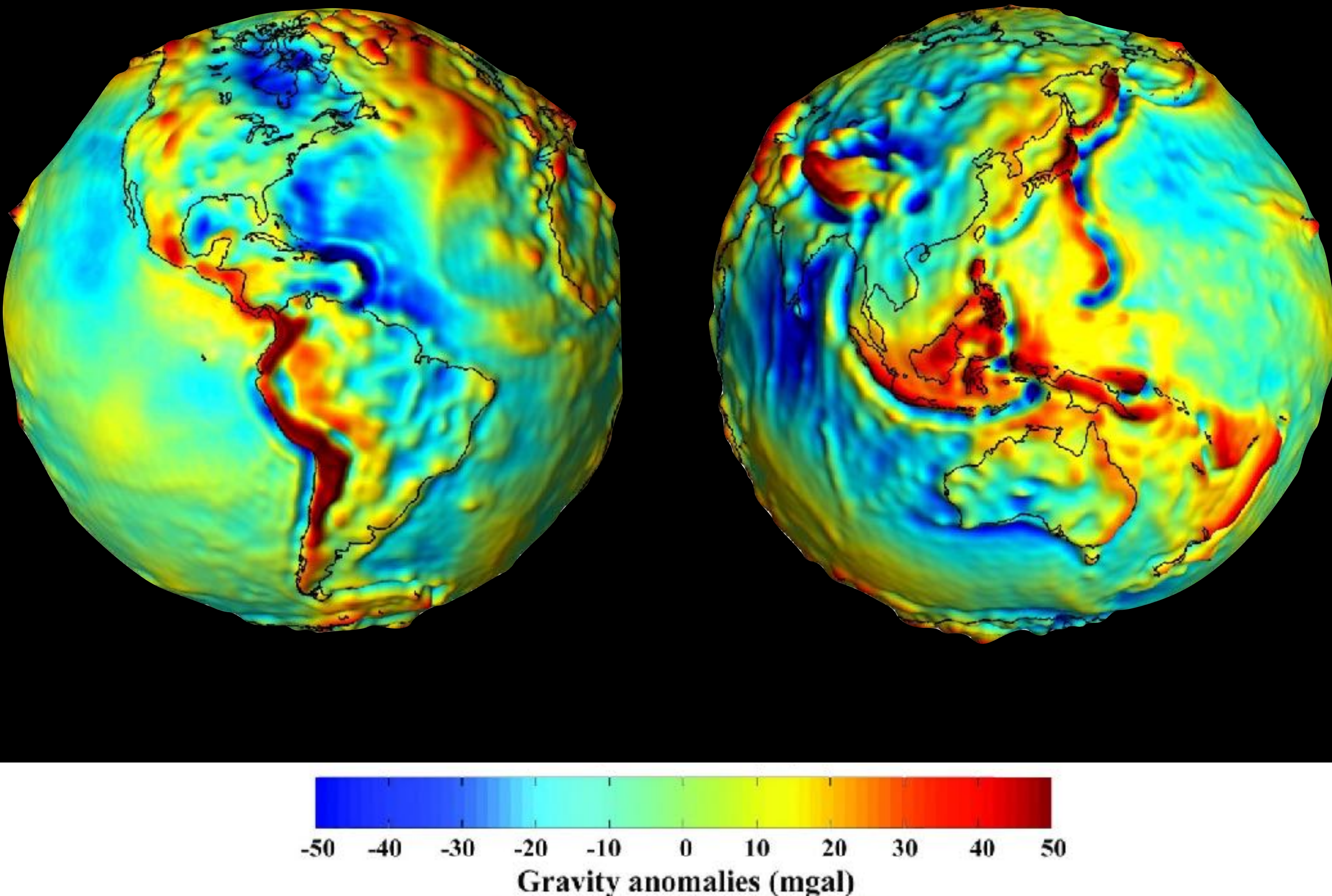
ARKeX
A member of
Tea

Gabon, 2009



Images used with the kind permission of ARKeX

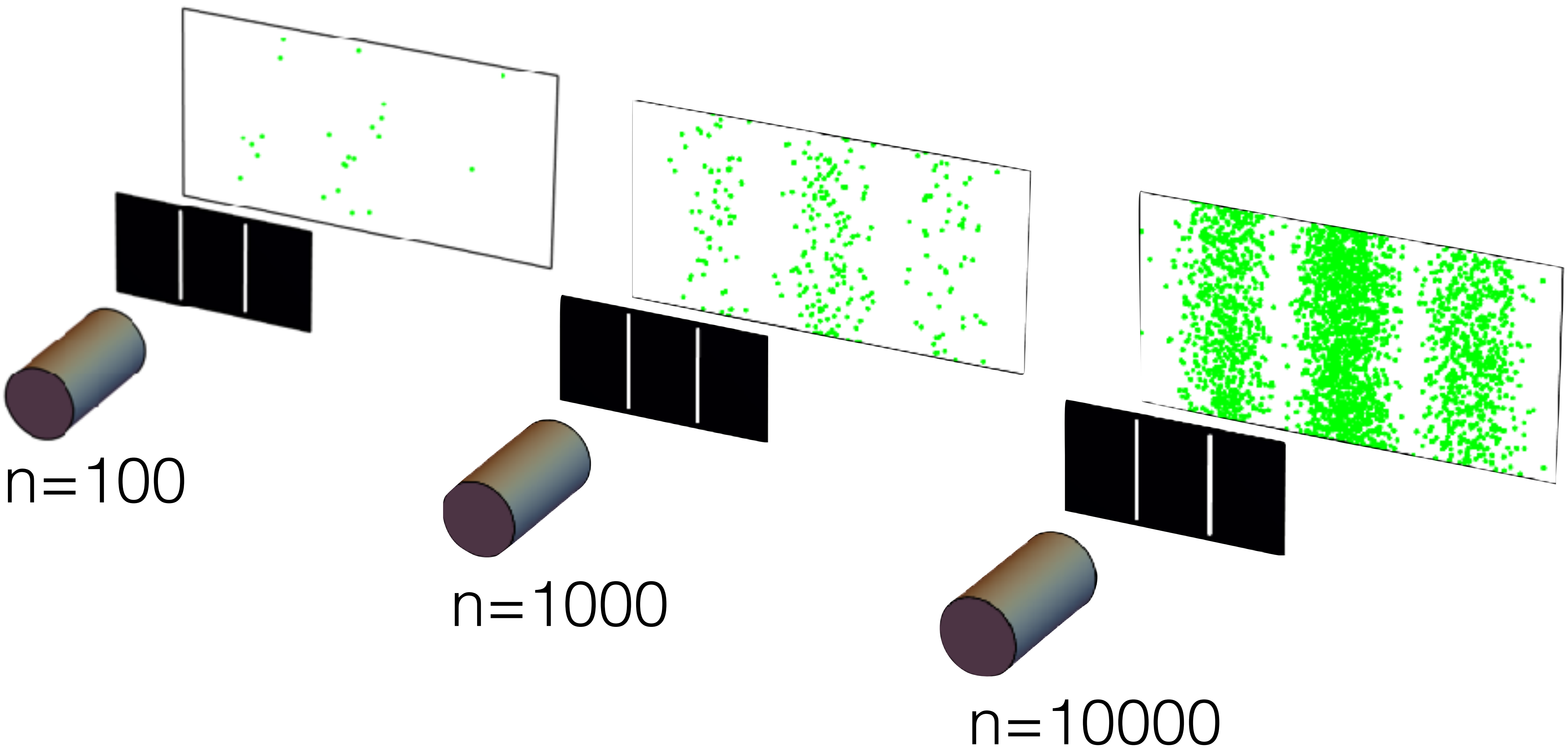
Grace Monthly Mass Grid



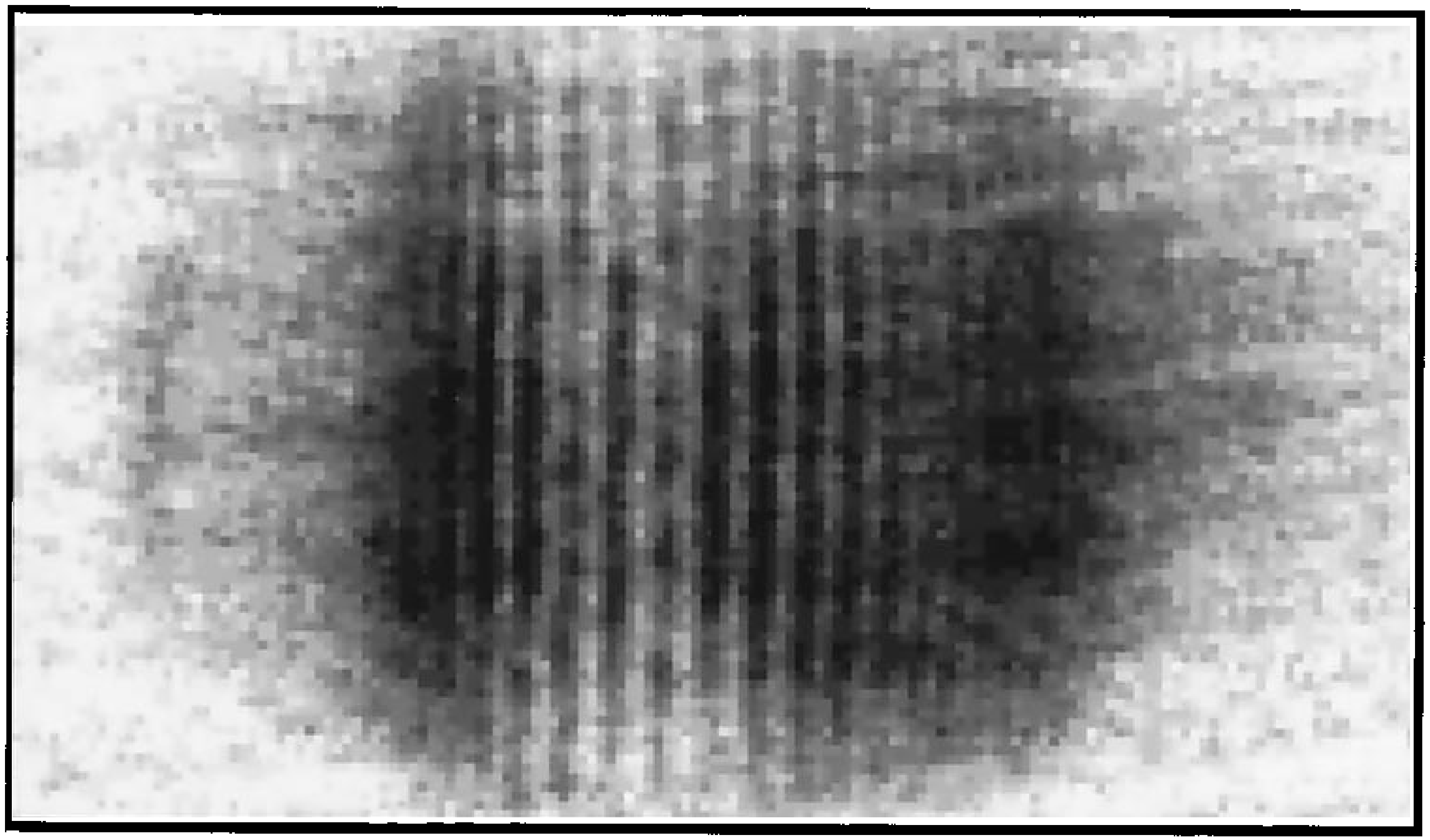
Matterwave Interferometry & Clocks

Cretan Matter-Waves Group

The Double Slit



BEC Ketterle Interference



R. Andrews et al. *Observation of Interference Between Two Bose Condensates Science* ***275:5300*** *637-641 (1997)*

Why Matterwaves?

Matter-Wave Interferometry
Why???

A Sagnac Gyroscope:

$$\Delta\phi = \frac{4\pi}{\lambda v}\Omega A$$

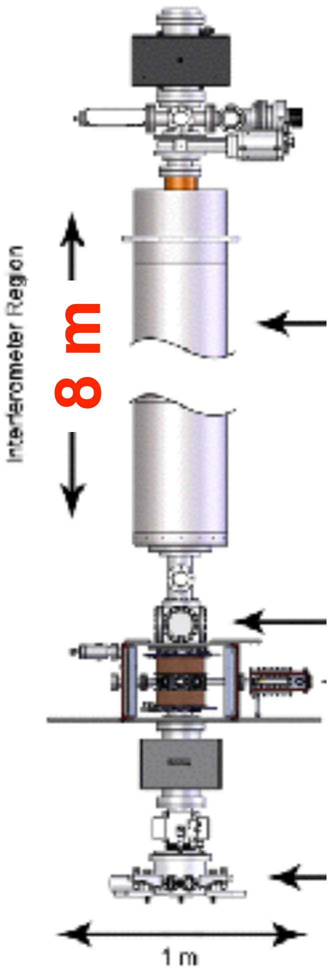
$$\frac{\Delta\phi_{\mathrm{atom}}}{\Delta\phi_{\mathrm{light}}} = \frac{\lambda_{\mathrm{light}}\, c_0}{h/m} = 5\mathrm{x}10^{10}$$

Plus

+ Internal States
+ Gravitation
+ Atom-Atom Interaction
  +Heisenberg Limited Detection

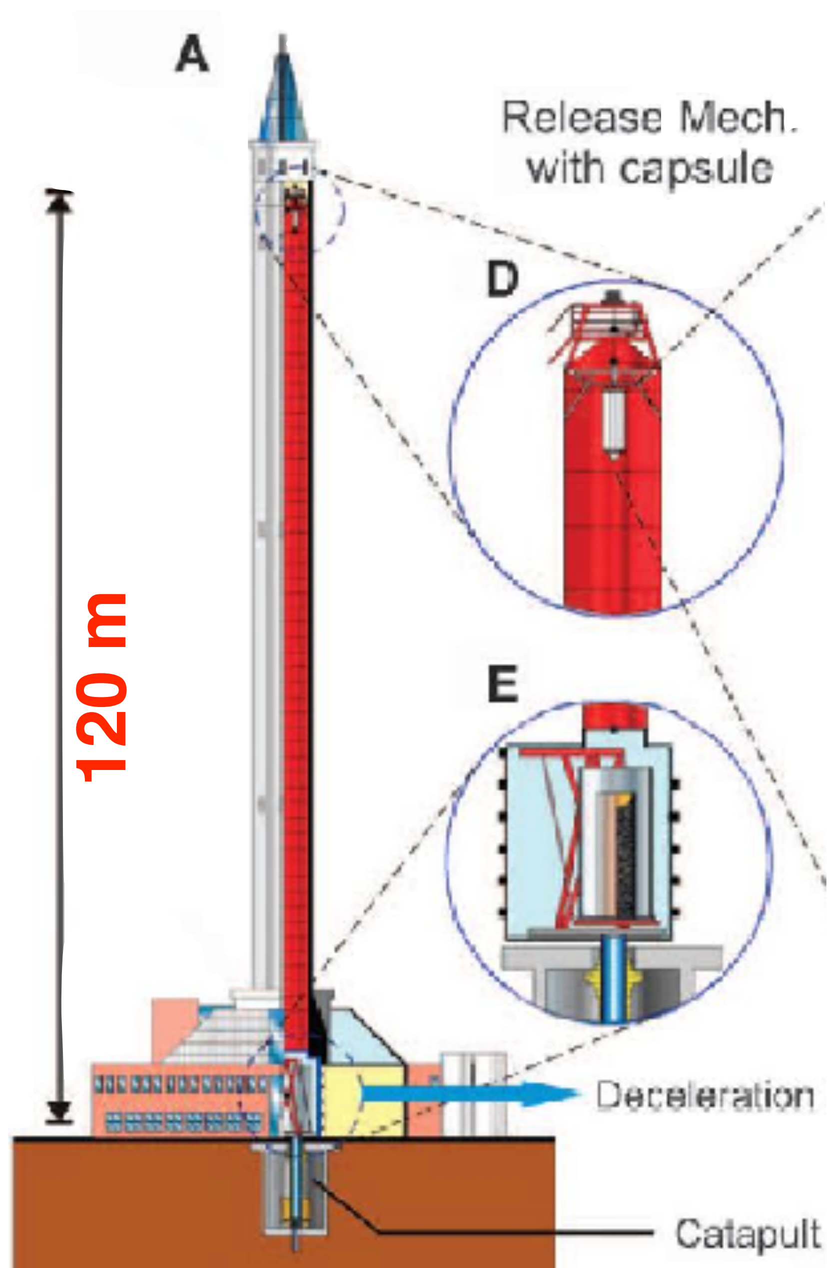
Matter-Wave Interferometers

Free Space

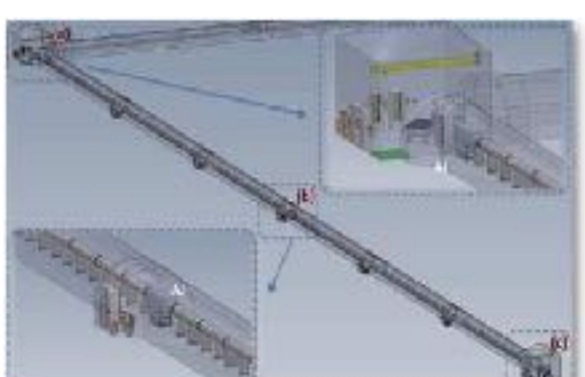


Stanford

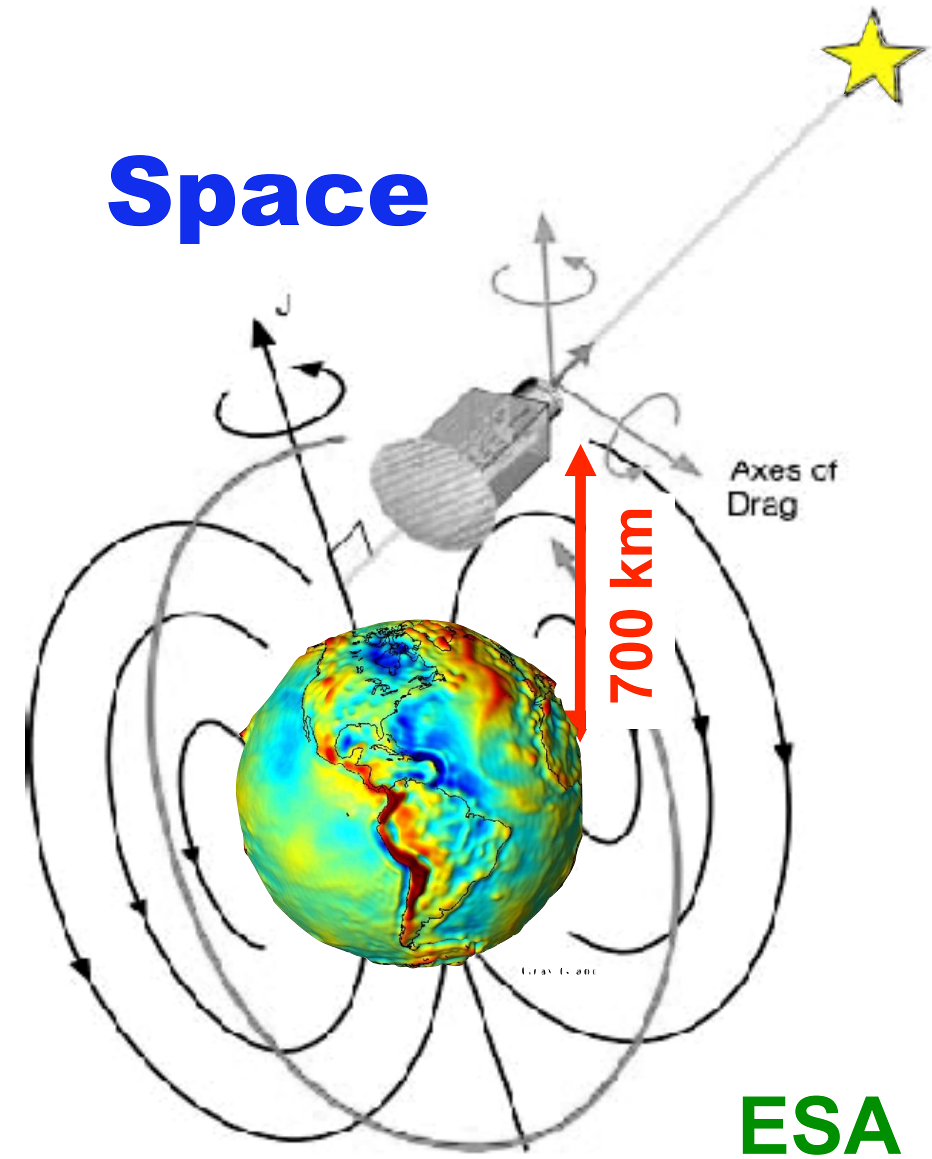
ZARM drop Tower



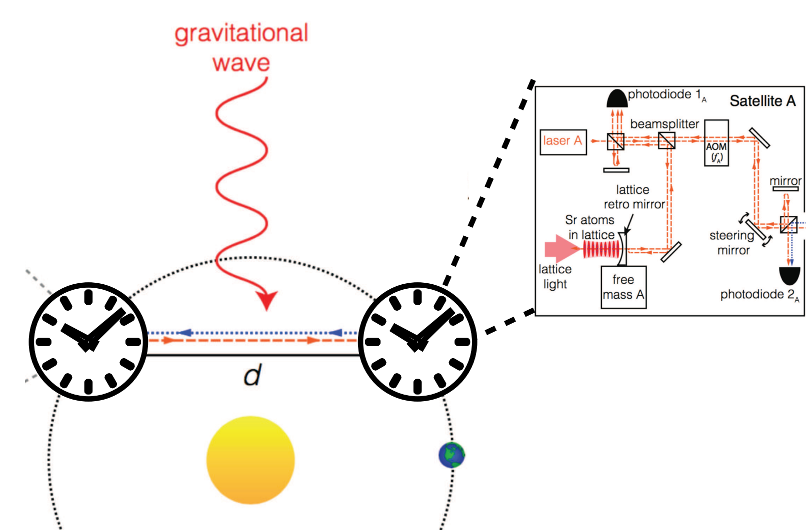
ELGAR



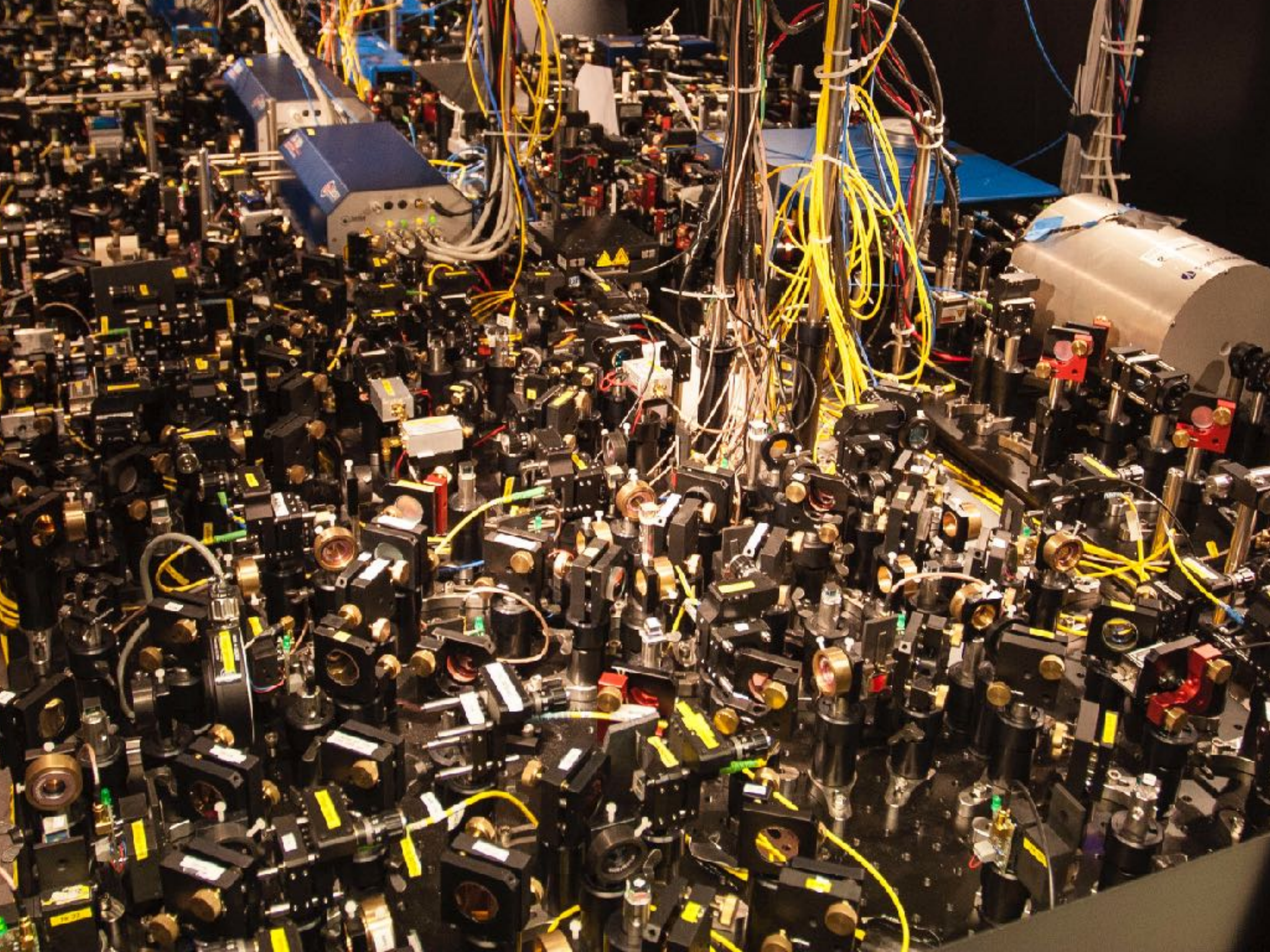
Space



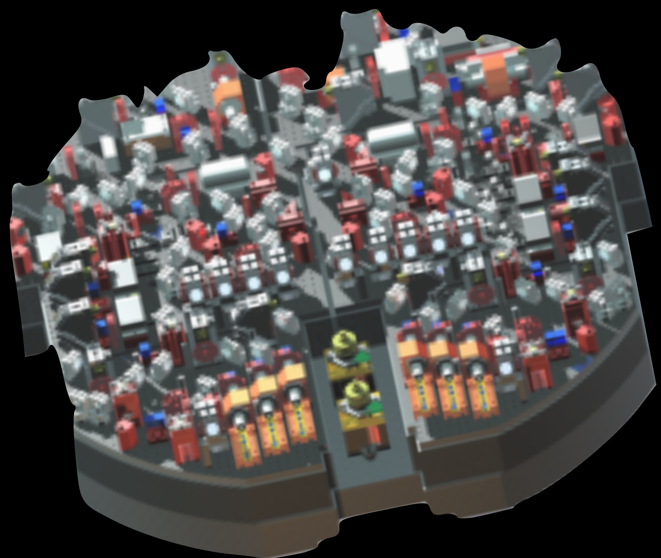
ESA STE-QUEST

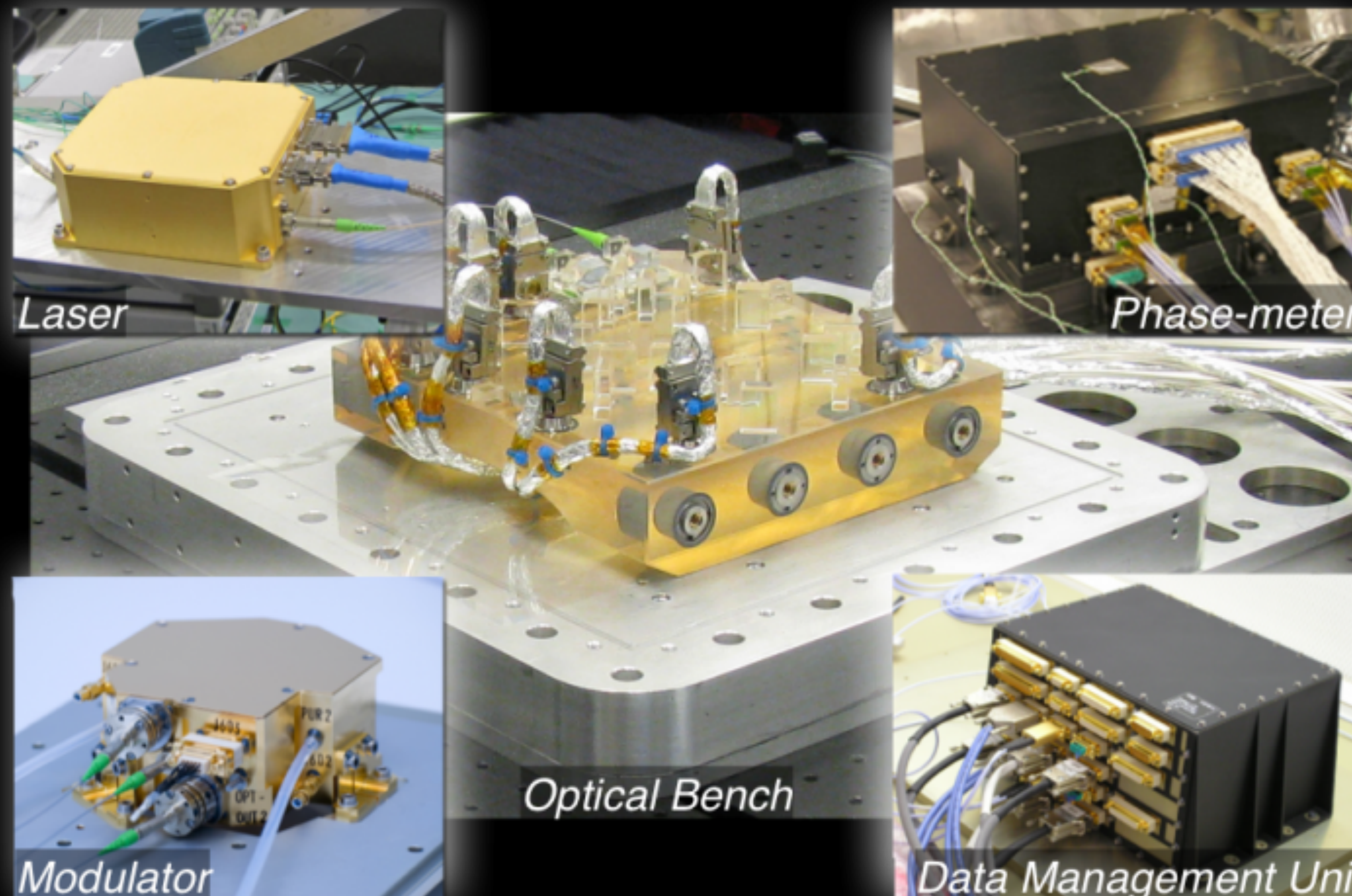


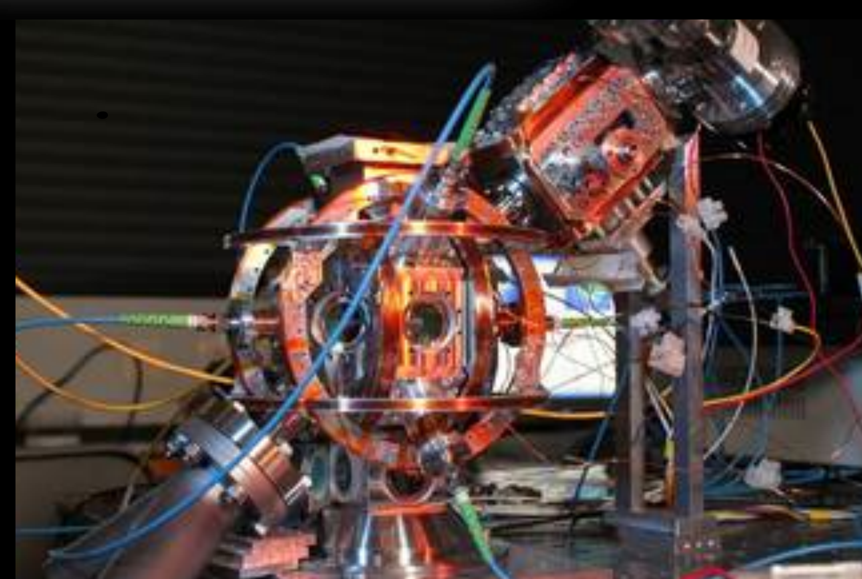
Why not?

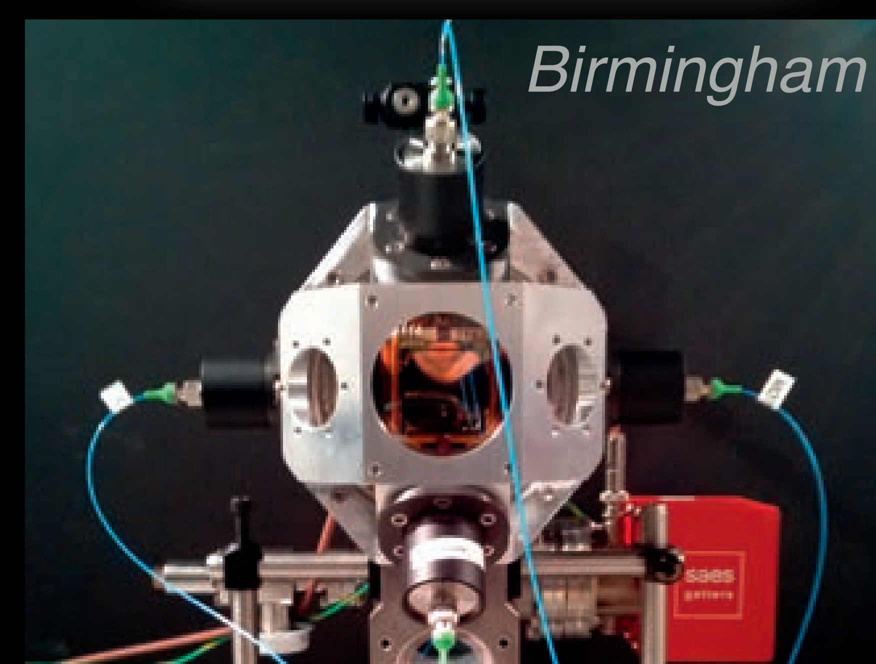


Advances in Space-Compatible Atom Physics









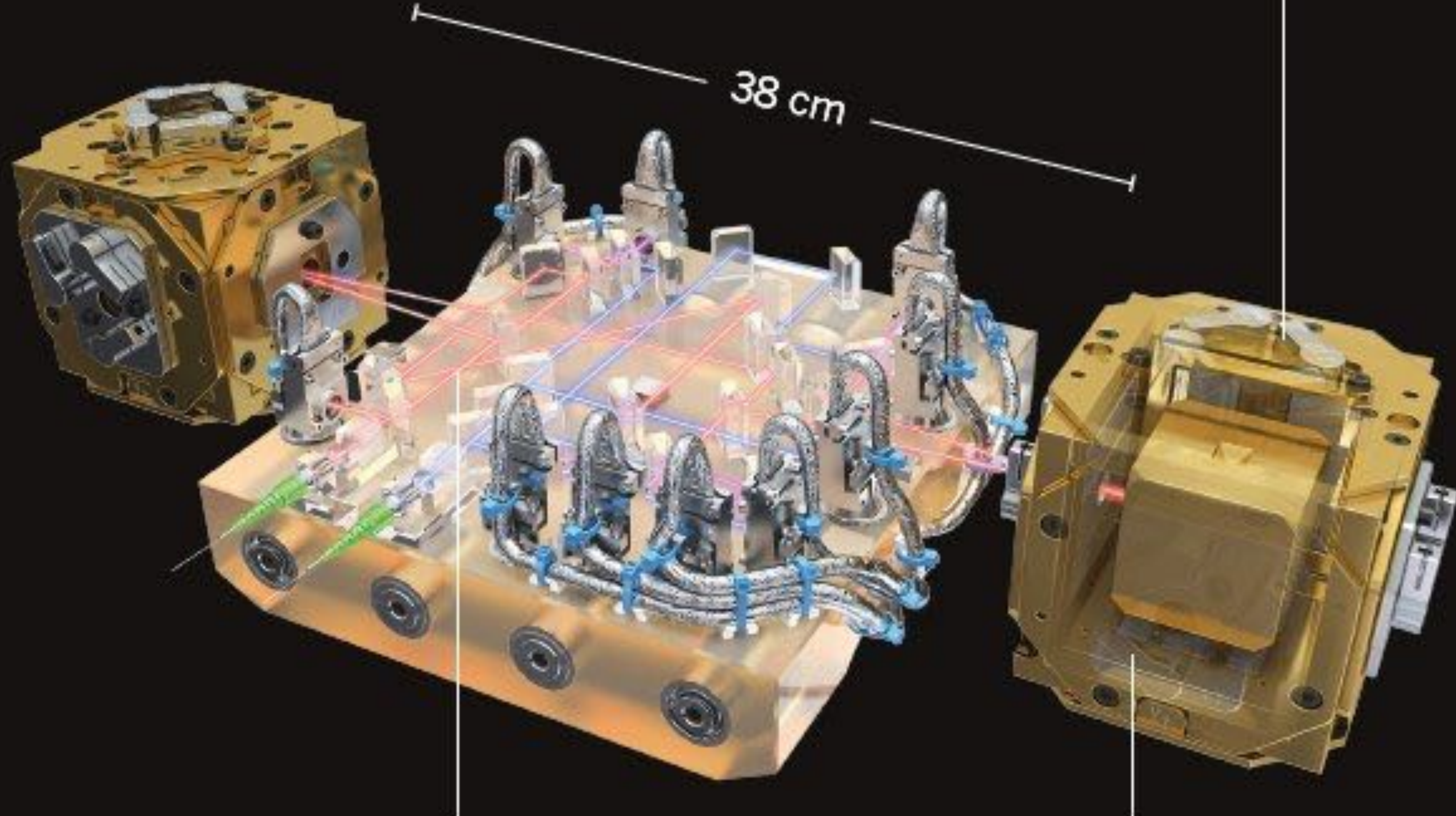
Optical Breadboards & OBST

GRAVITY LABORATORY

LISA Pathfinder showed that it could measure tiny variations in the distance between two free-falling cubes, paving the way for a full-scale experiment in which the falling masses will reside on different satellites, millions of kilometres apart.

At the heart of Pathfinder are two free-falling metal cubes, shielded from all forces except gravity by their housing.

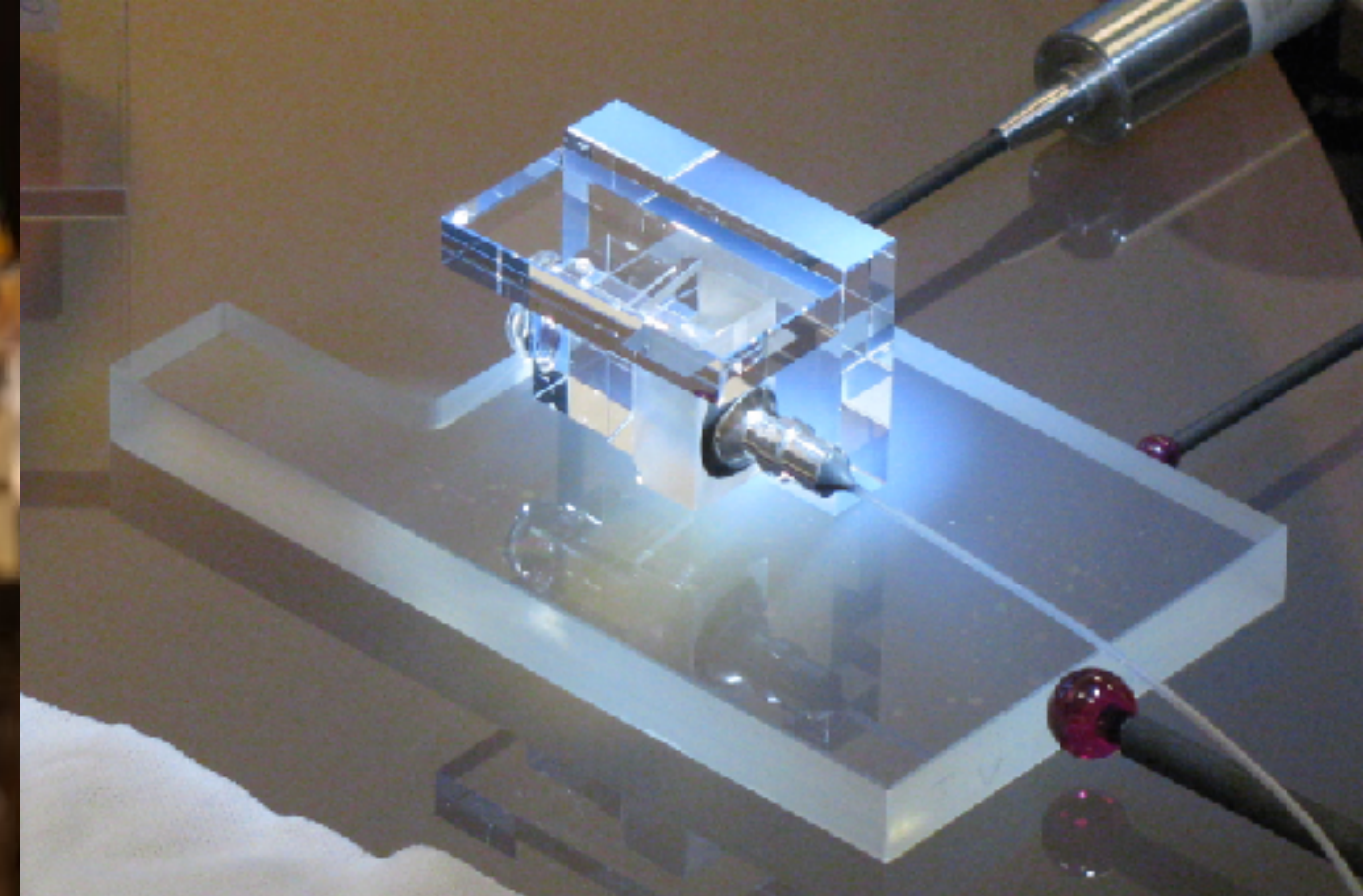
The housing monitors each cube's position and commands the craft to move so that the cube is always at its centre.

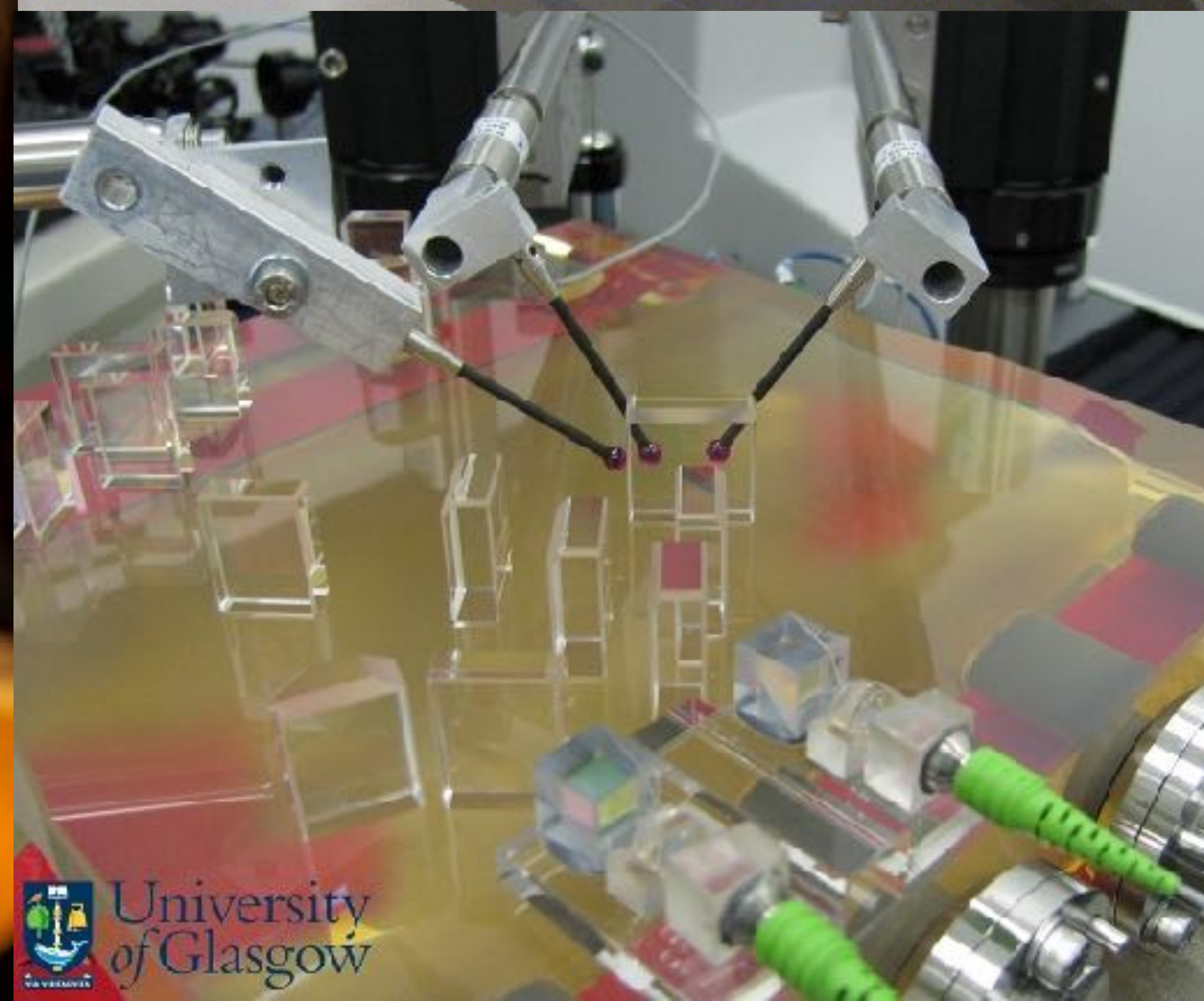


Any disturbance to the relative motion of the cubes affects the frequency of the laser bouncing between them.

The cubes float in a vacuum, surrounded by instruments that mitigate stray forces.


University
of Glasgow




University
of Glasgow

Requirements
LISA vs Atoms

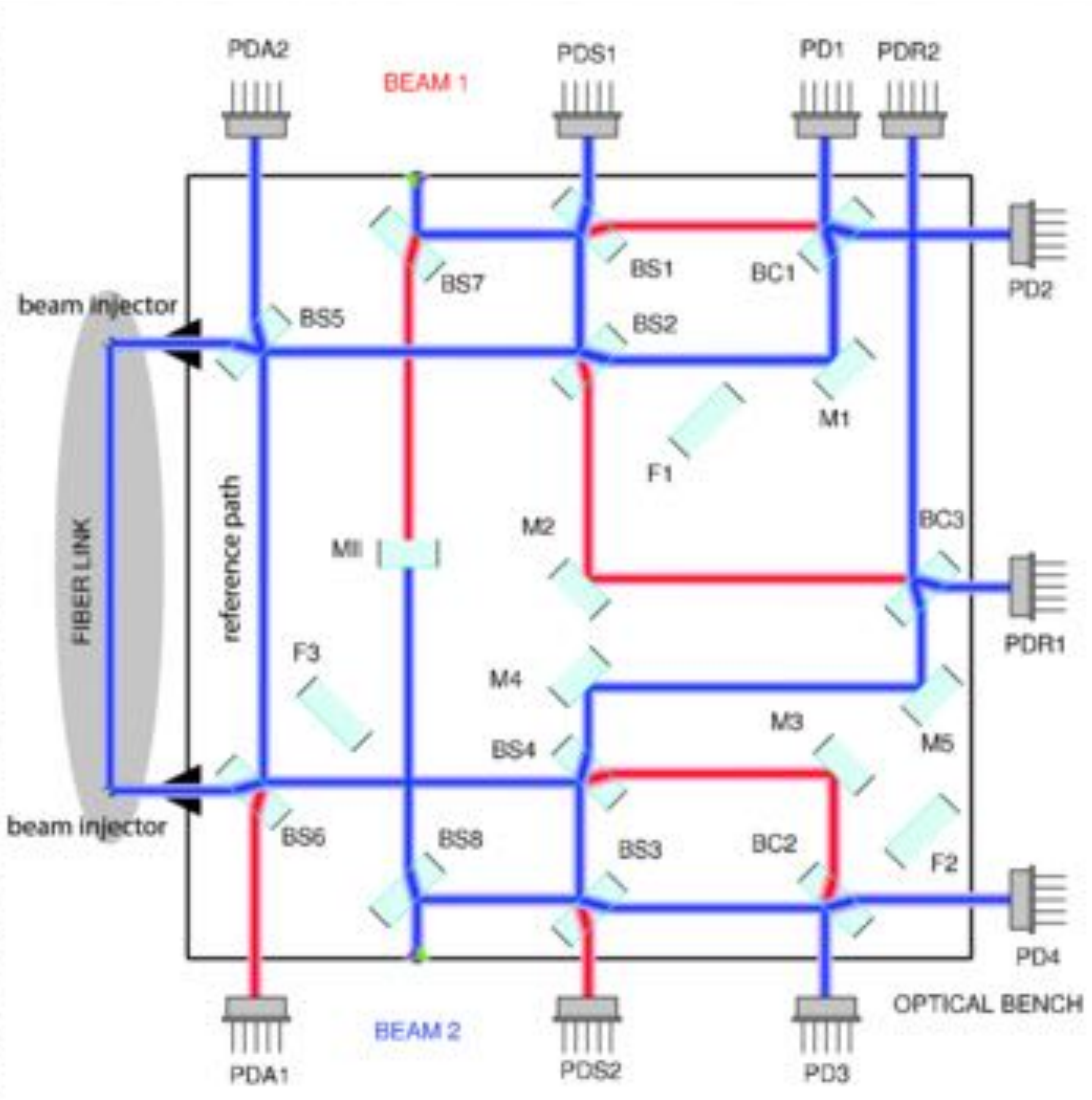
LISA

1. Fiber to Free-Space
2. Priority: Pointing Stability
3. Angular Stability
4. Distance Stability
5. Low Complexity

ATOMS

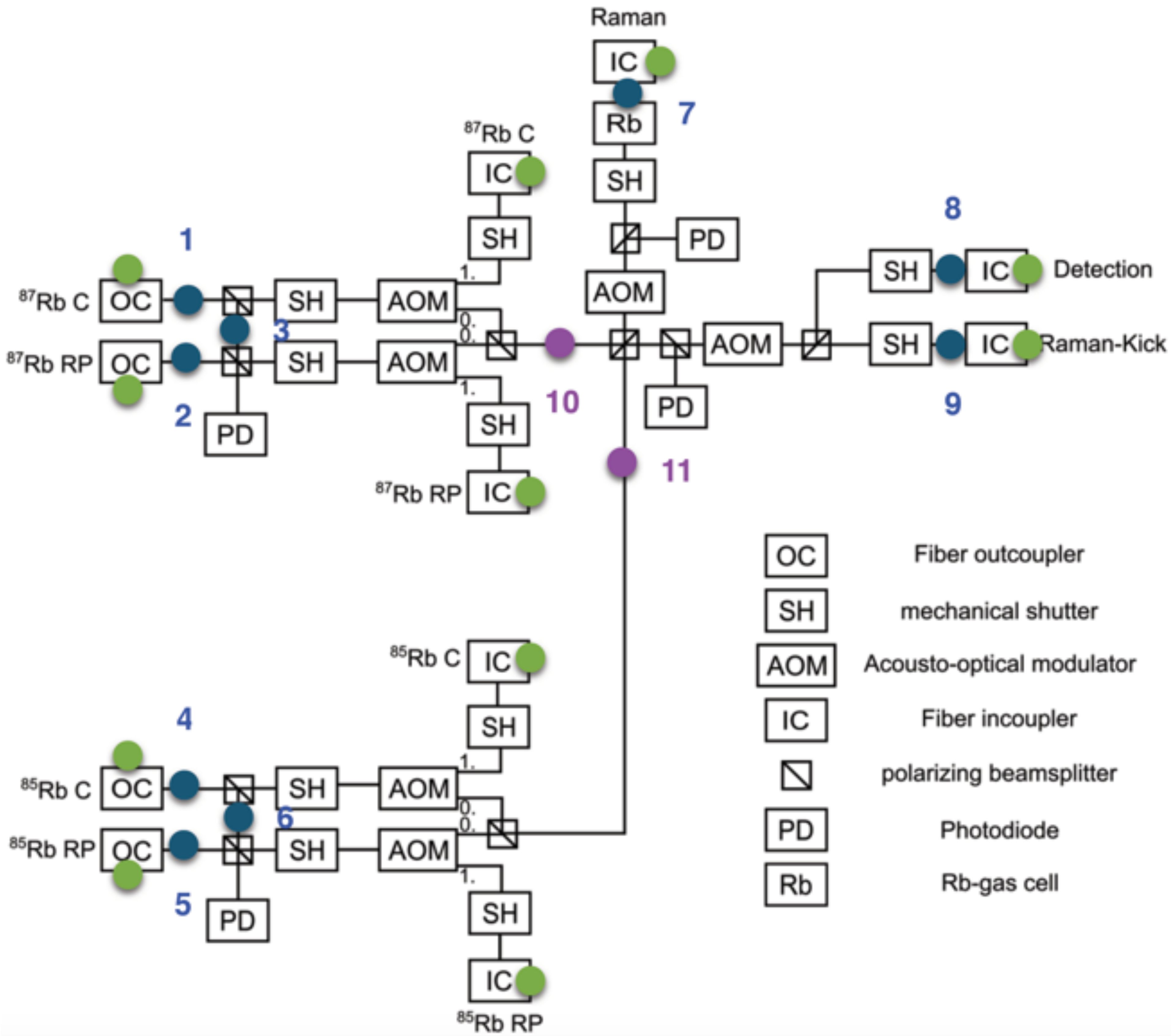
1. Fiber to Free-Space to Fiber
2. Priority: Coupling efficiency
3. Active Elements
4. High Complexity

LISA



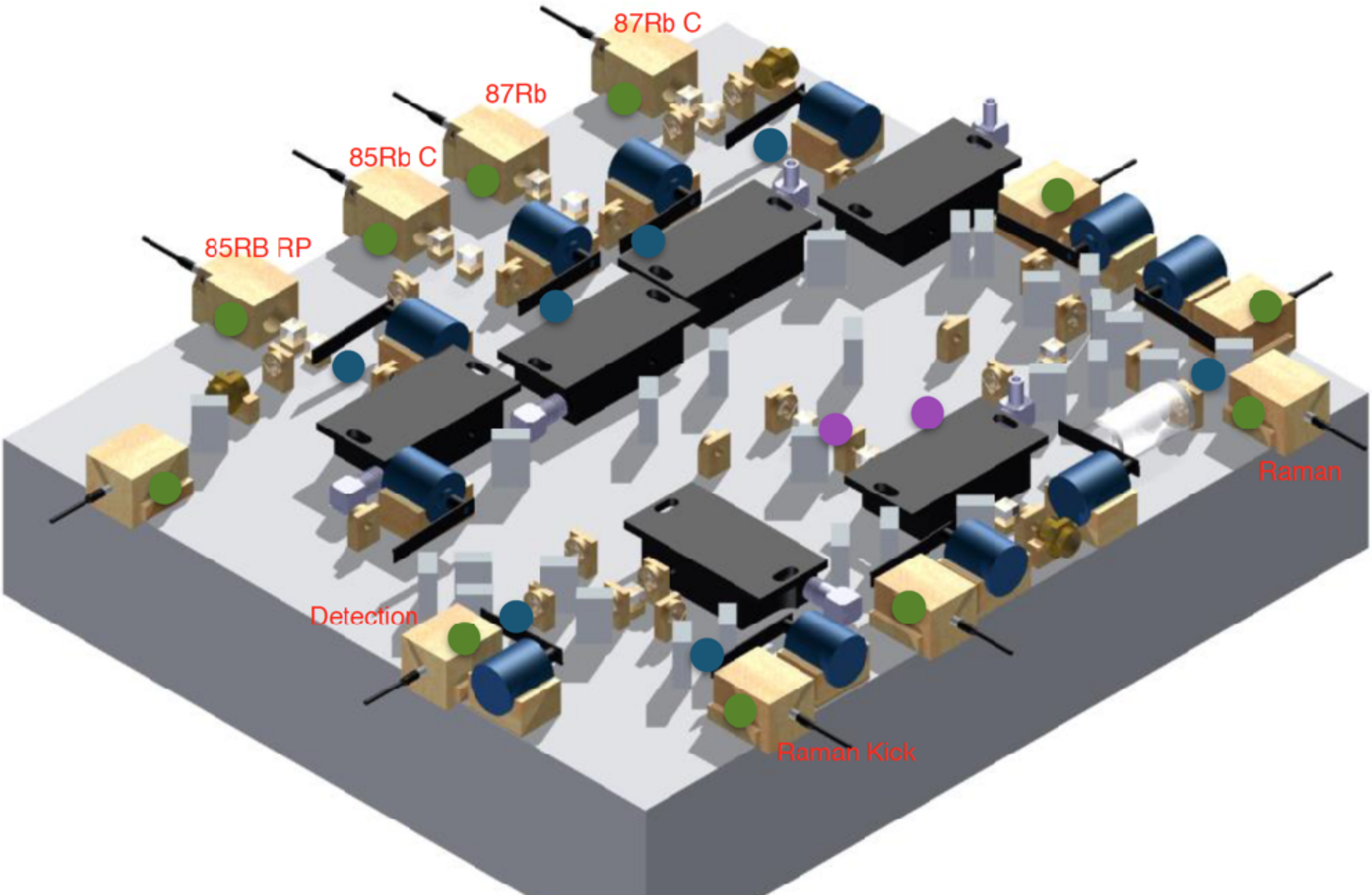
PDA2
BEAM 1
PDS1
PD1
PDR2
BS7
BS1
BC1
PD2
beam injector
BS5
BS2
M1
F1
FIBER LINK
reference path
MII
M2
BC3
PDR1
F3
M4
M3
M5
BS4
beam injector
BS6
BS8
BS3
BC2
F2
PD4
PDA1
BEAM 2
PDS2
PD3
OPTICAL BENCH

STE-QUEST

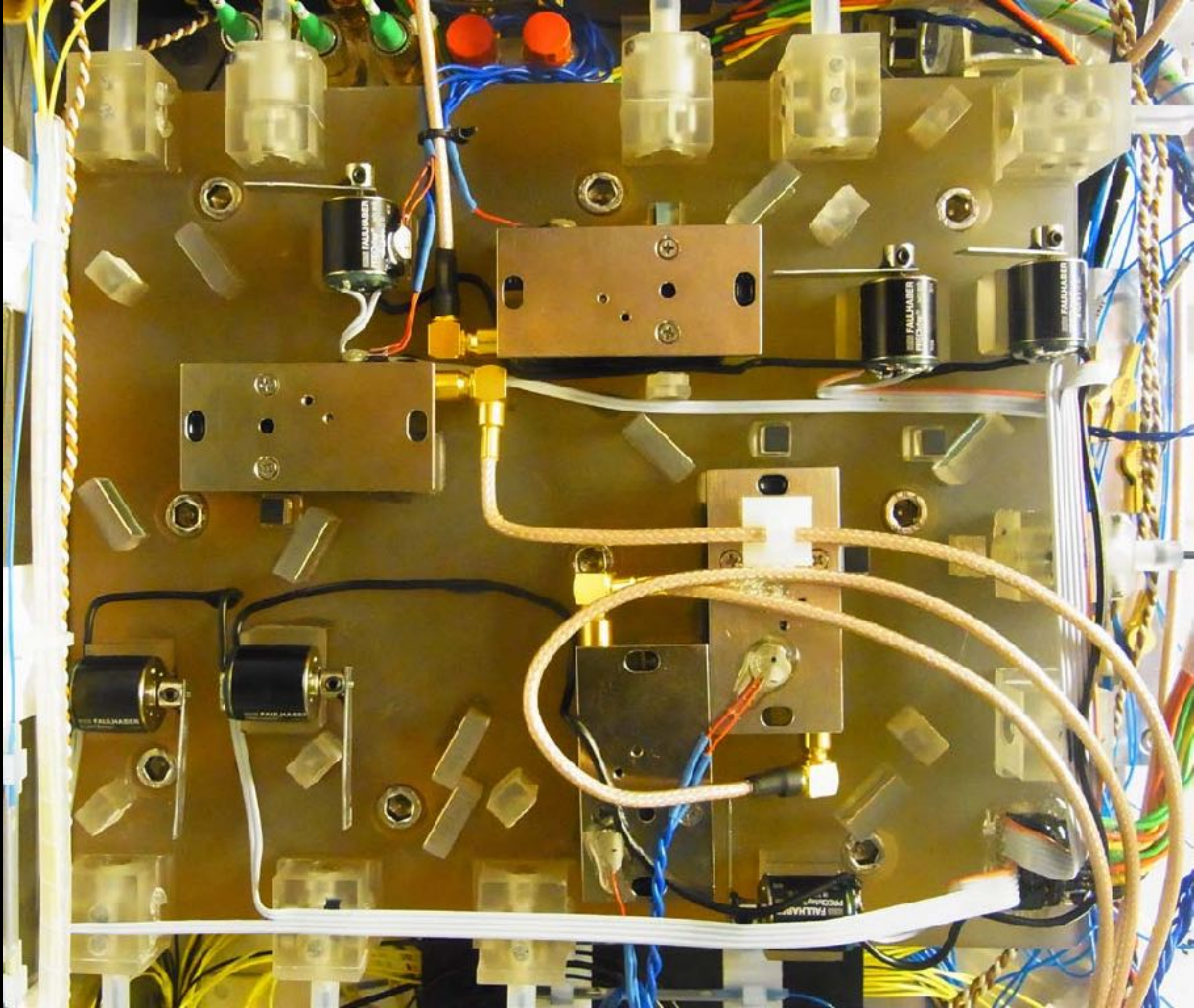


Raman
IC
Rb
SH
PD
AOM
7
87Rb C
IC
SH
1.
0.
0.
1.
SH
87Rb RP
IC
8
SH
IC
Detection
SH
IC
Raman-Kick
9
AOM
PD
10
11
1
87Rb C
OC
SH
AOM
3
87Rb RP
OC
SH
AOM
2
PD
85Rb C
IC
SH
4
85Rb C
OC
SH
AOM
6
85Rb RP
OC
SH
AOM
5
PD
SH
IC
85Rb RP
OC
Fiber outcoupler
SH
mechanical shutter
AOM
Acousto-optical modulator
IC
Fiber incoupler
polarizing beamsplitter
PD
Photodiode
Rb
Rb-gas cell

STE-QUEST



MAIUS



Solutions
Atoms & LISA

LISA

1. Hydroxyl Bonding
2. All alignment done by machining and polishing
3. Only custom components

MAIUS

1. Epoxy/UV Bonding
2. Complex Mounts

OBST

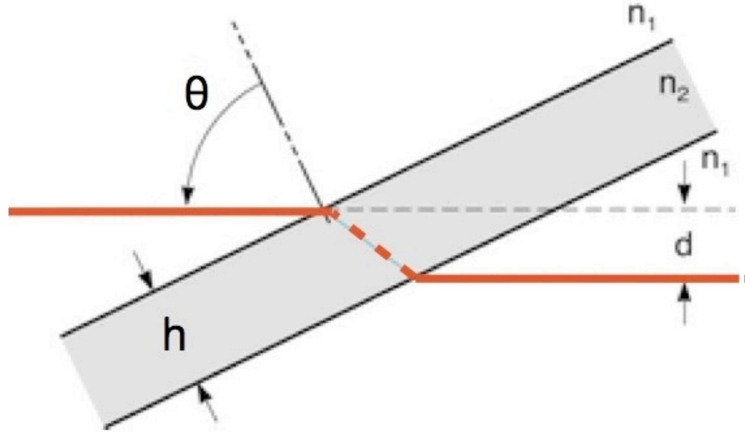
1. Independent of Bonding technology
2. Simple Mounts
3. Separate Fine Alignment

Aim of the OBST project

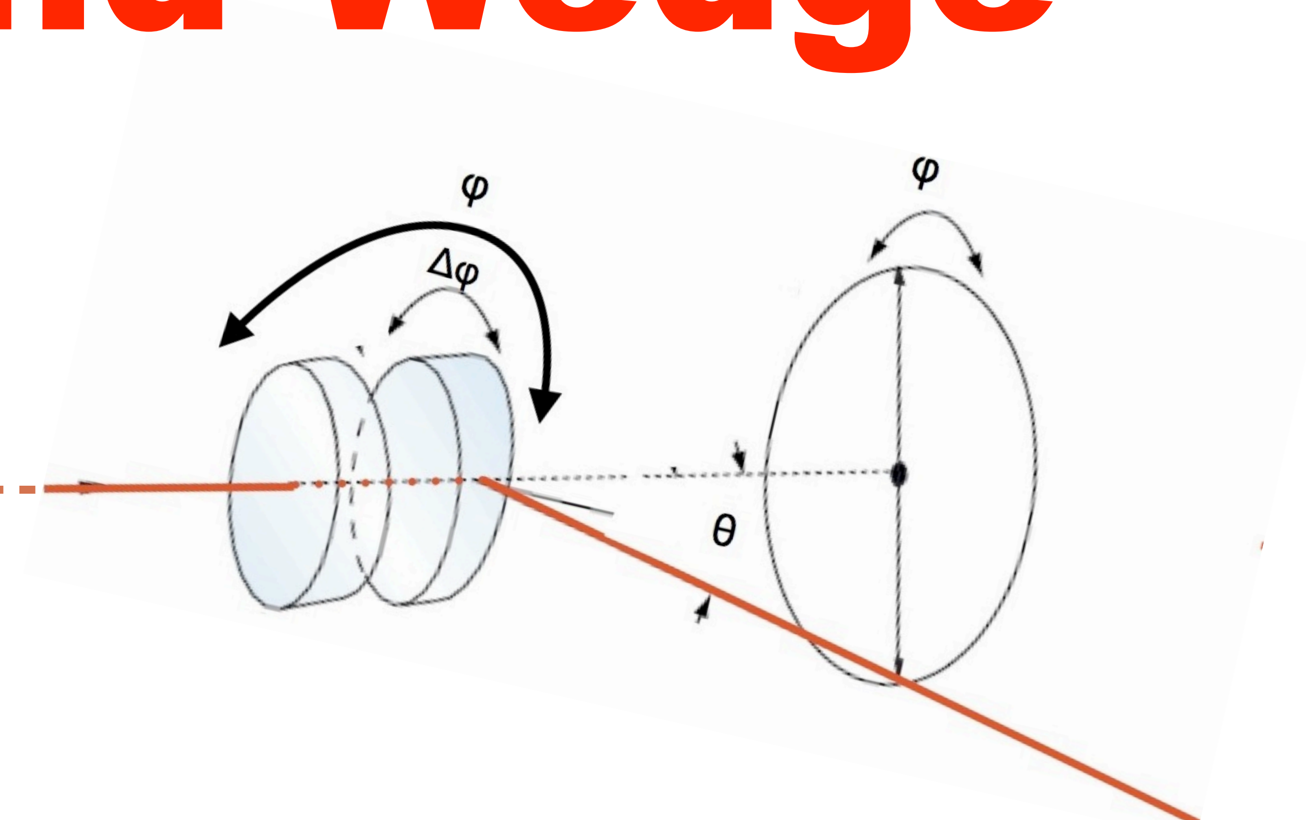
To demonstrate

1. Novel Beam Steering for Bread boards
2. Very High stability (coupling efficiency)
3. Reduction in production difficulties/costs
4. Simplification of assembly procedures
5. Learn how to deal with ESA

Plate and Wedge



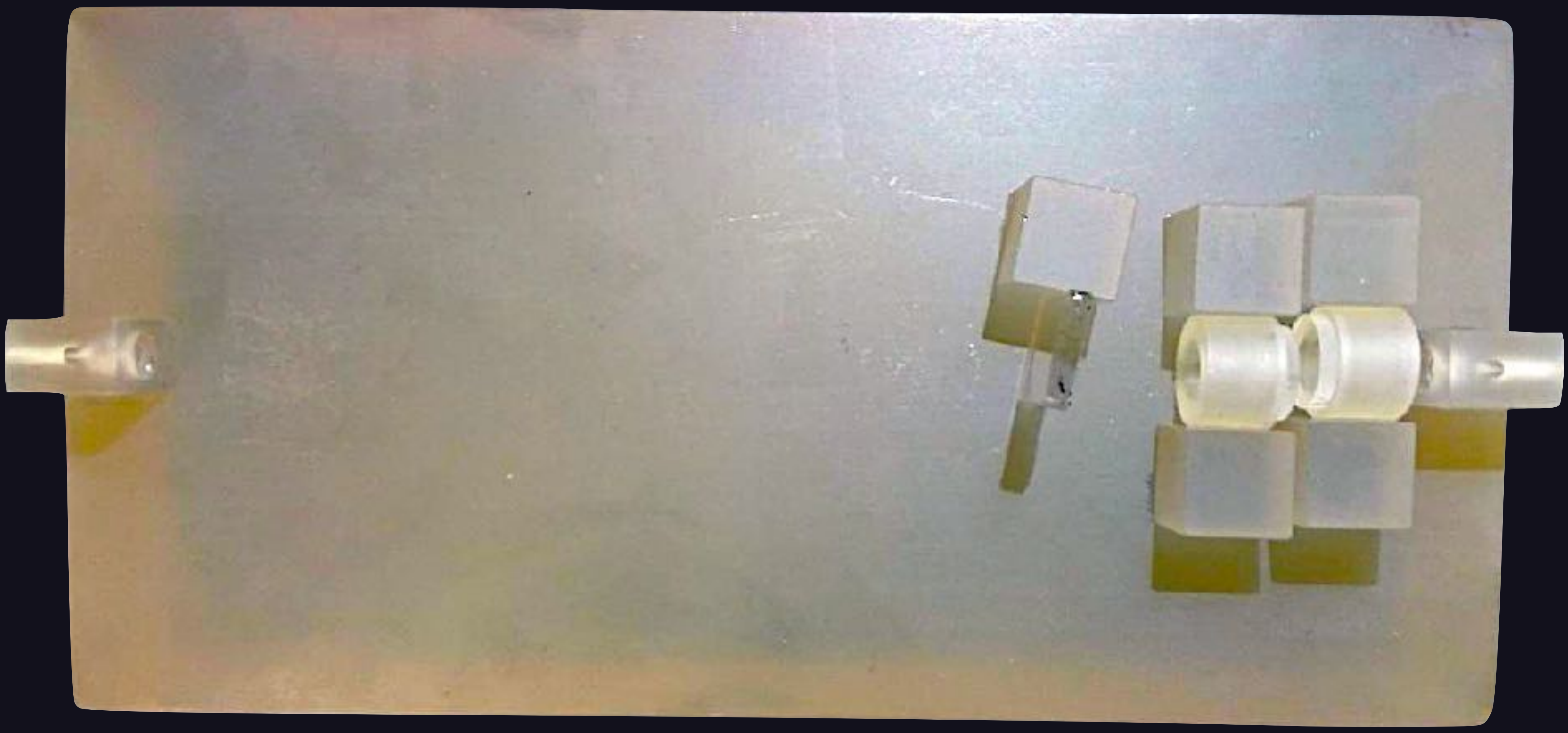
Optical Plate



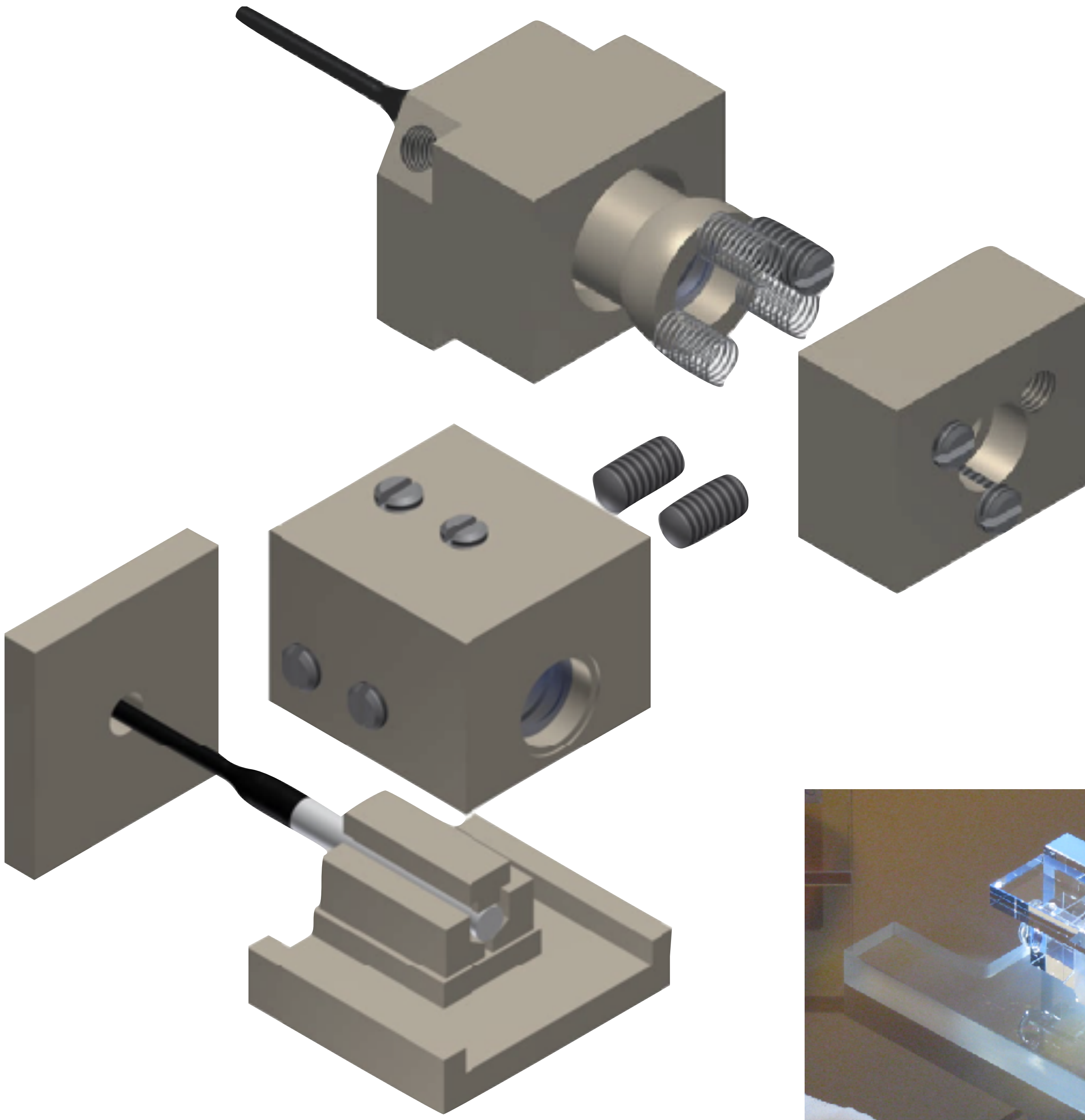
Pair of Wedges

Alignment methods		Prediction*	Typical Sensitivity	Assumptions*
Beam positioning	beam plate rotation	$\Delta h \approx \theta\, d\, \frac{n-1}{n}$	19 µm/mrad	d=1 mm n=1.5
Beam pointing (pitch/yaw)	wedge rotation	$\Delta\varphi \approx \frac{4}{\pi}(n-1)\, a\, \theta$	45 µrad/mrad	α=4 deg n=1.5

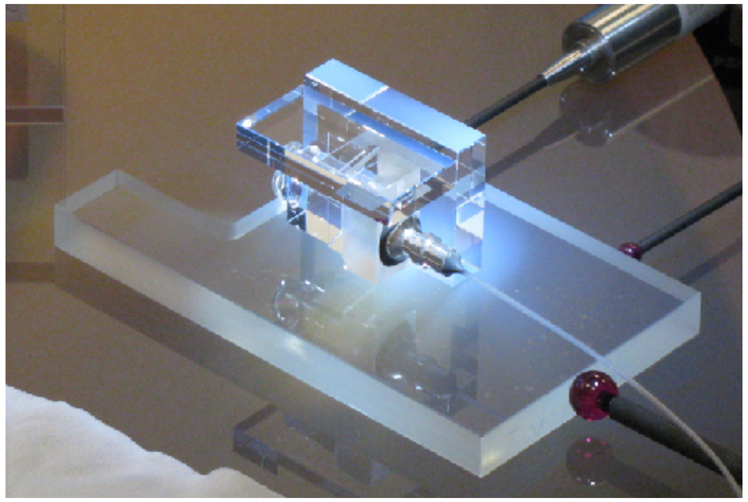
The Fully Integrated OBST



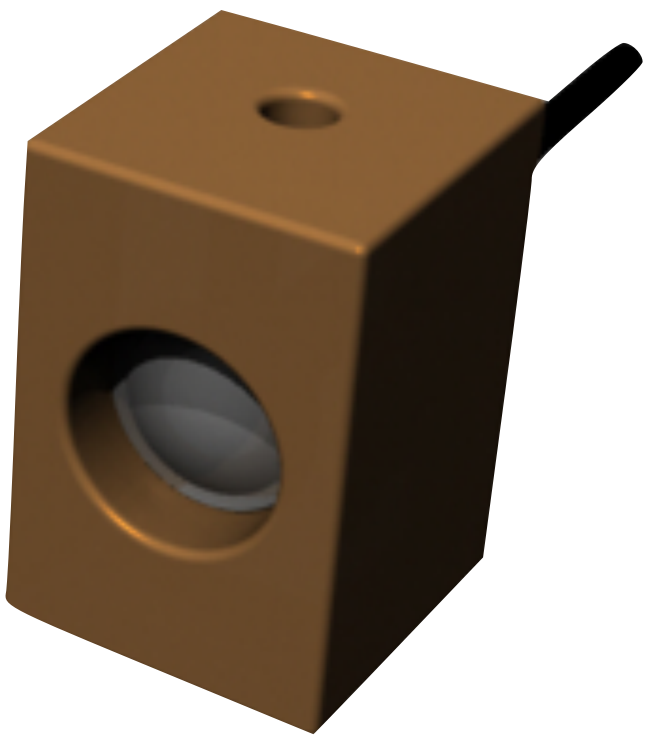
Comparison of Couplers



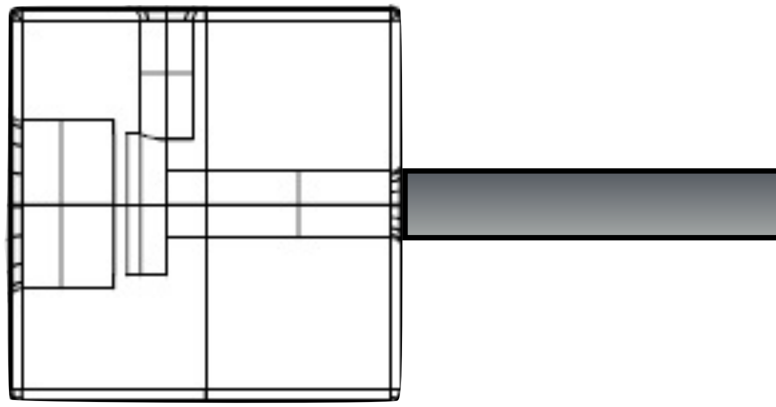
MAIUS Couplers



LISA Coupler

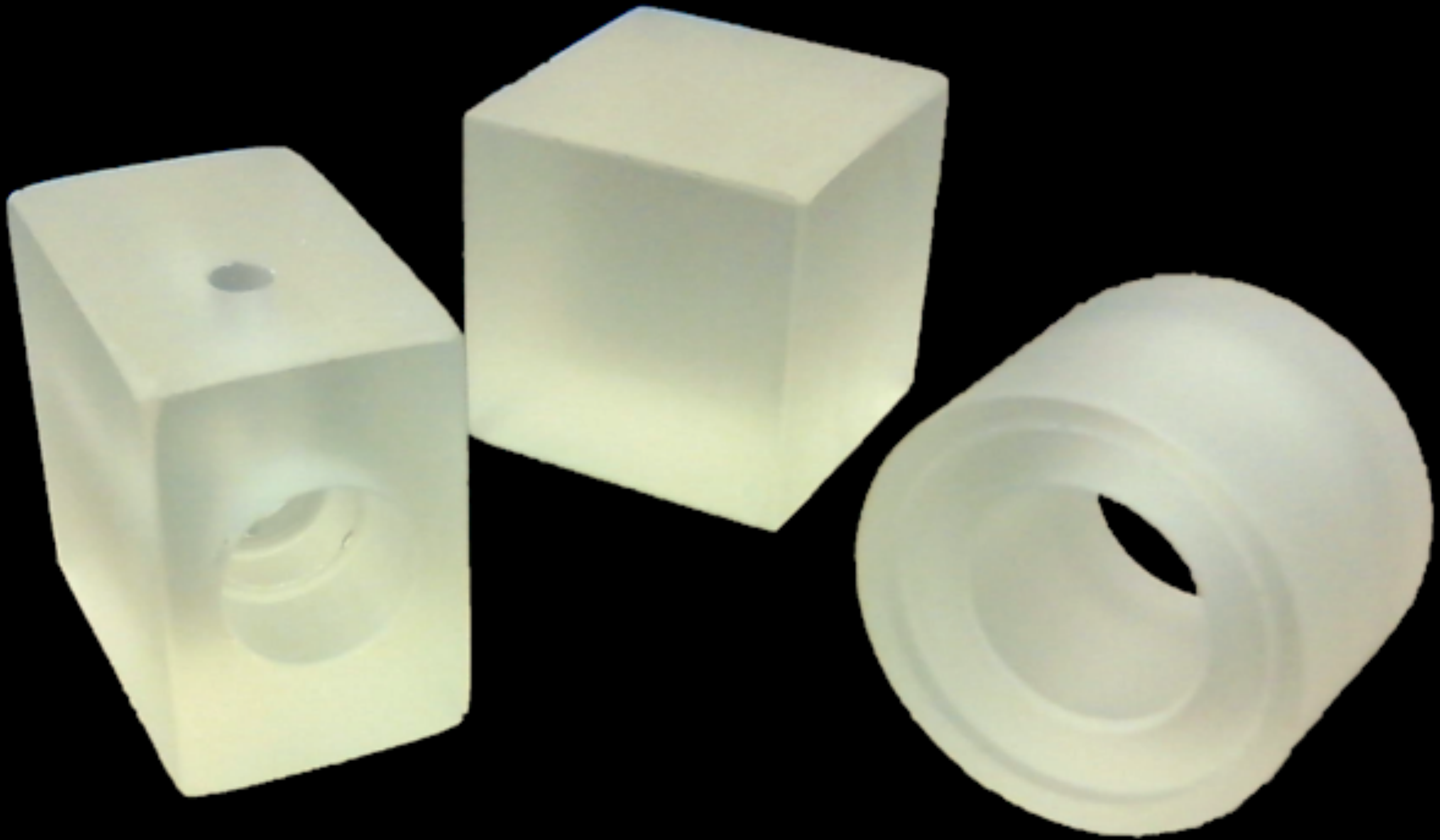


OBST Coupler

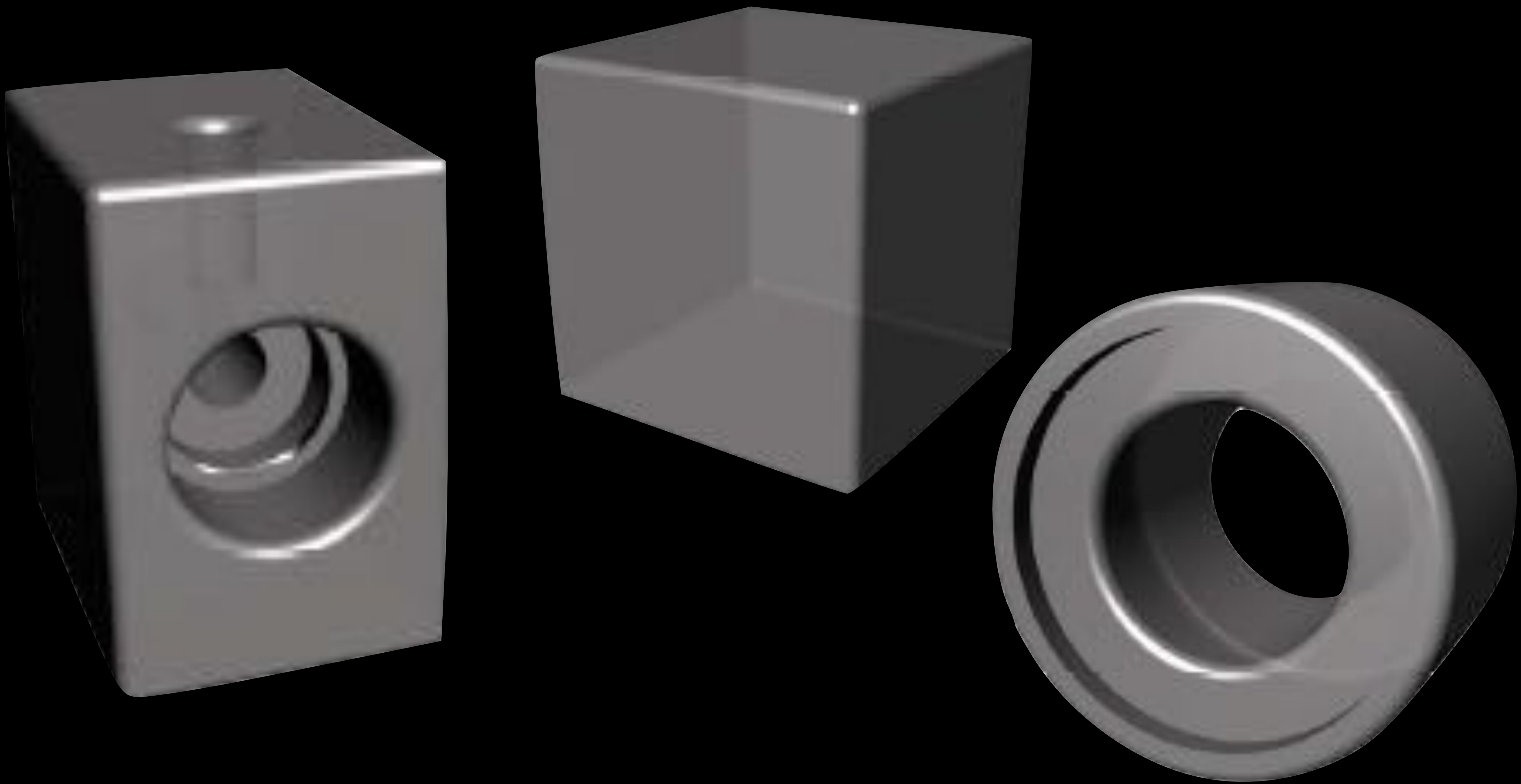


Side View

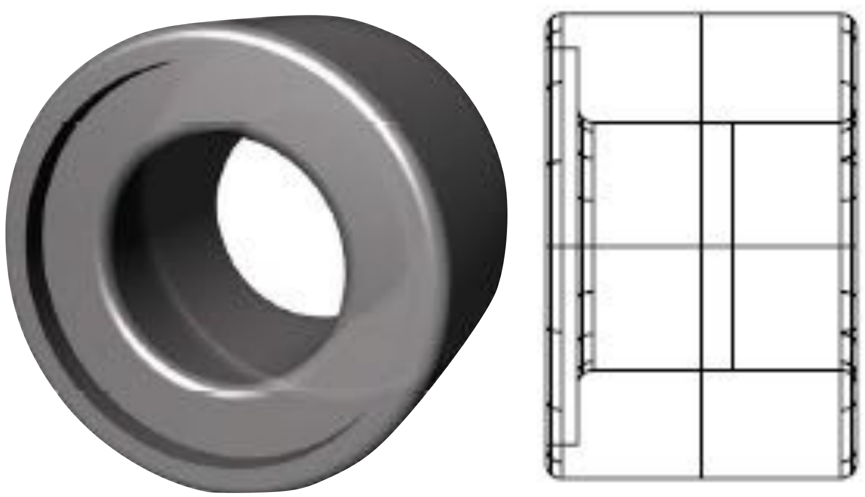
ALL Mechanical Elements of OBST



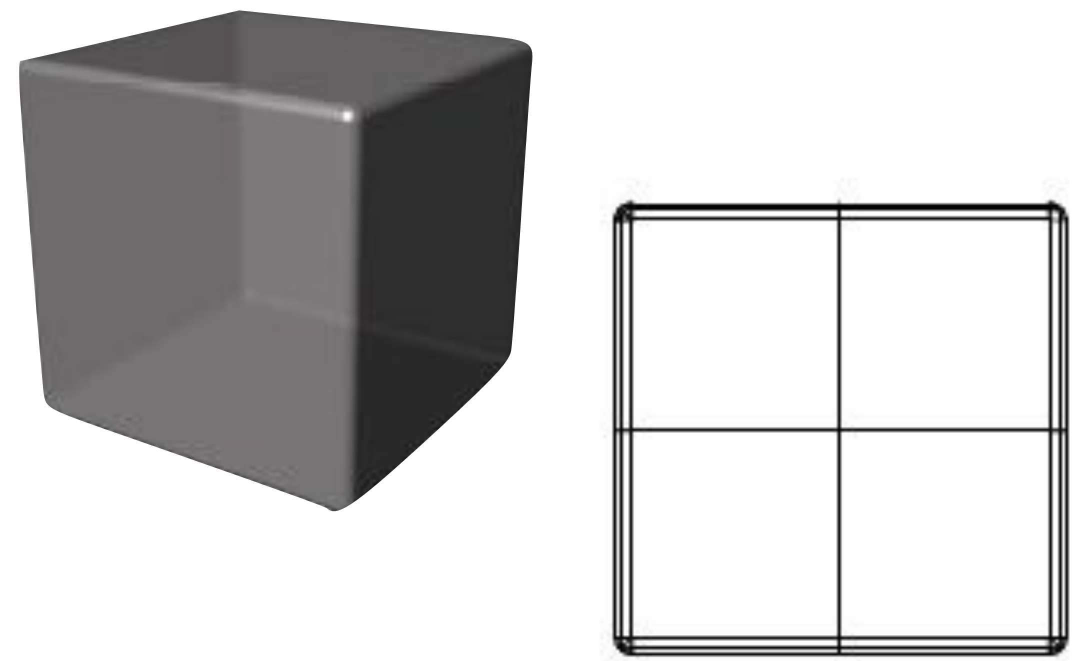
ALL Mechanical Elements of OBST



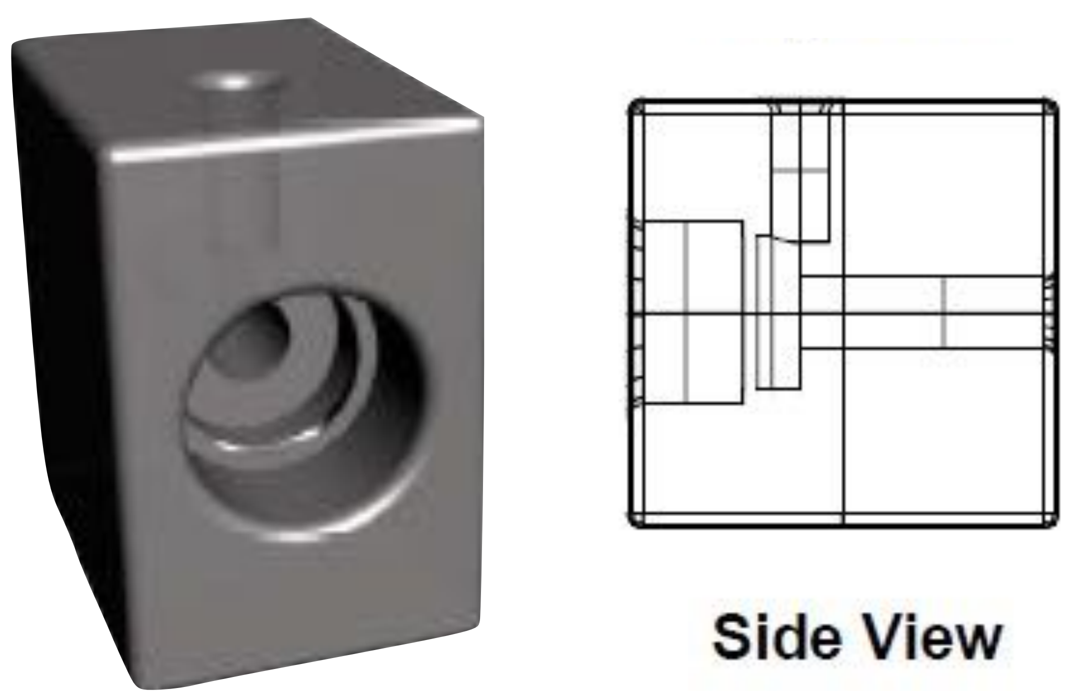
ALL Mechanical Elements of OBST



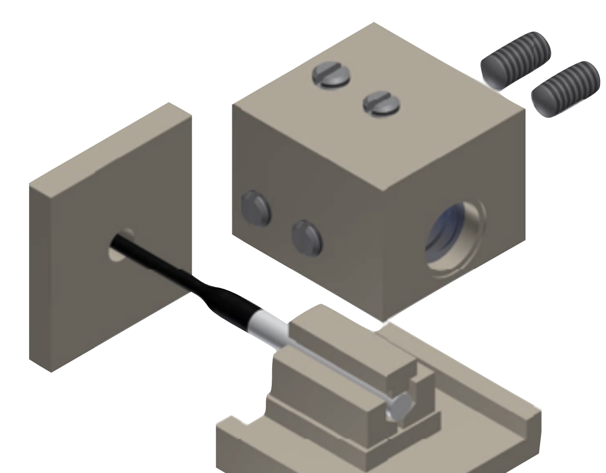
Side View



Side View



Side View

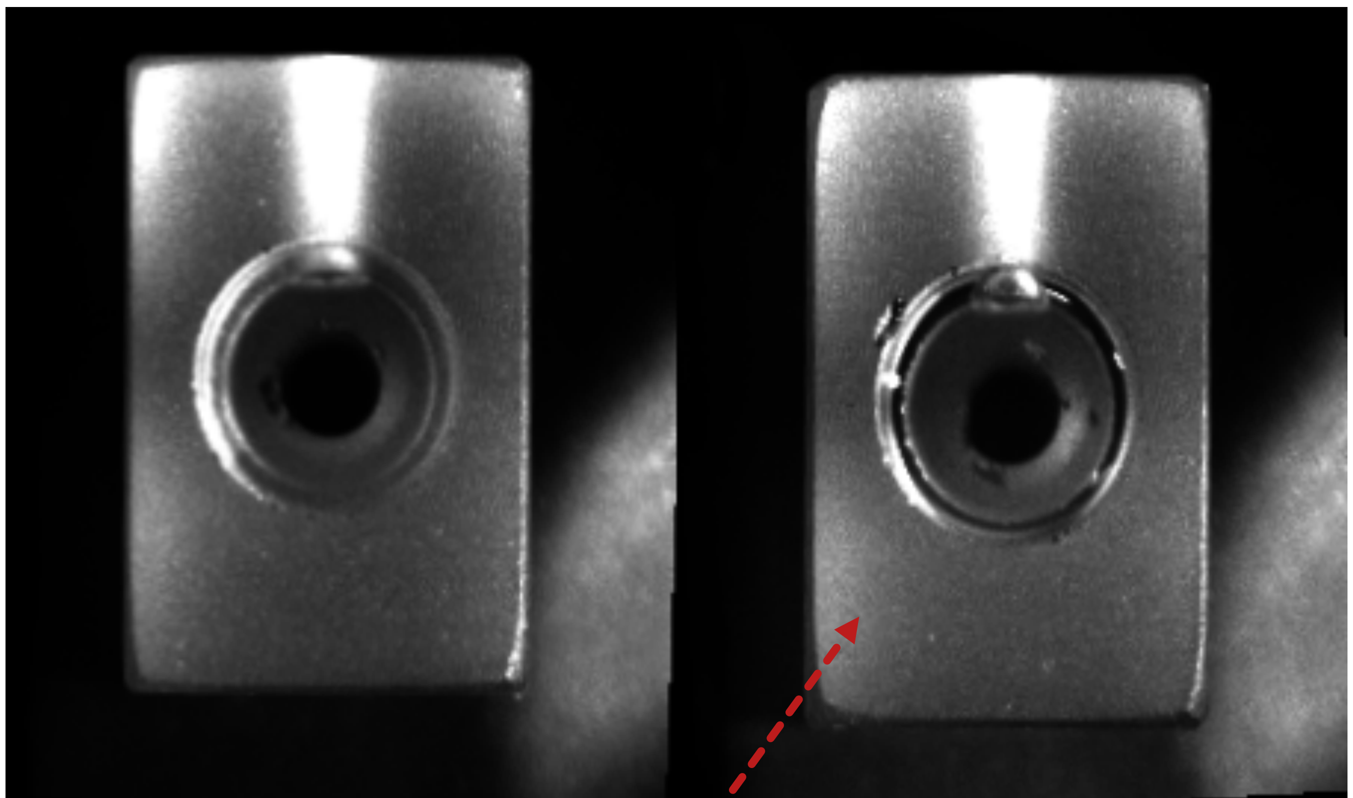


Aim of the OBST project

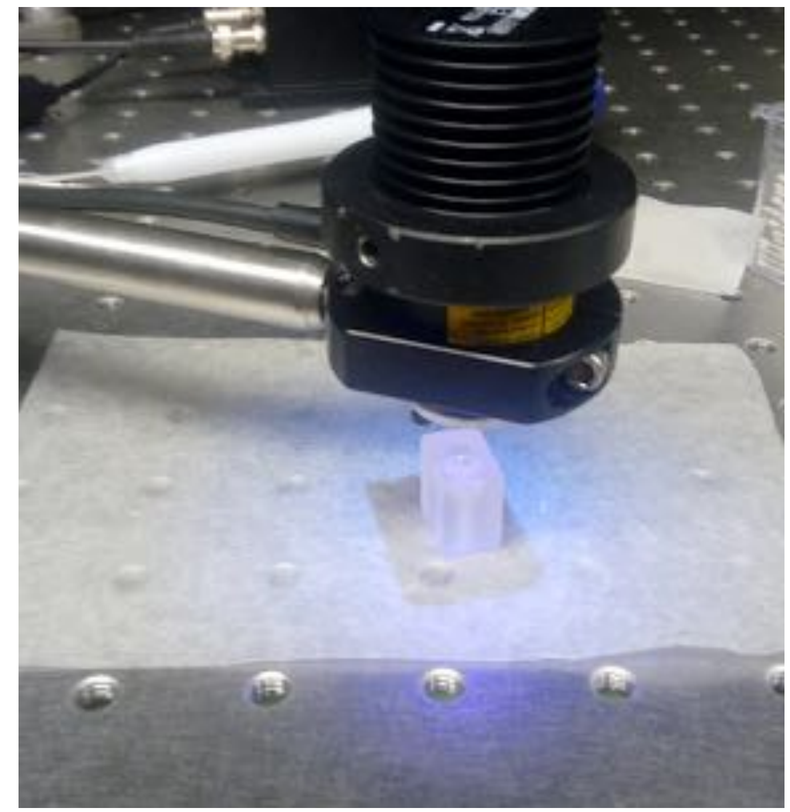
ID	Requirement description	Unit	Required Value	Theory Value	Achieved Values	Better than required by
OBST-010	Reduction in complexity	n/a	n/a	Consider-able	Consider-able	equaled
OBST-041	Coupling Efficiency	%	> 85	≥95%	≥89%	**35% lower**
OBST-051	Long & Short Term Fluctuations	% RMS	< 5 %	< 5 %	<2 %	**150%**
OBST-062	Beam alignment	μrad μm	< 100 < 100	5 5	< 5 < 5	**1900%**
OBST-061	Positional alignment	μm	< ±100	______	< 100 μm.	equaled
OBST-052	Operating Temperature Range	°C	10-40	______	10-40	______
OBST-021	Surface polish accuracies	nm	<158	______	< 63	150%
OBST-053	Temperature stability (Testing environment)	$K/Hz^{½}$	~ $1x10^{-2}$	______	< $6x10^{-4}$	1500%
OBST-022	Angular tolerances of components	arcmin	5	______	5	______

Assembly: Lens

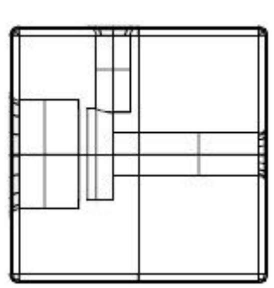
Zerodur coupler before (left) and after (right) applying the UV adhesive



UV adhesive formed a black ring

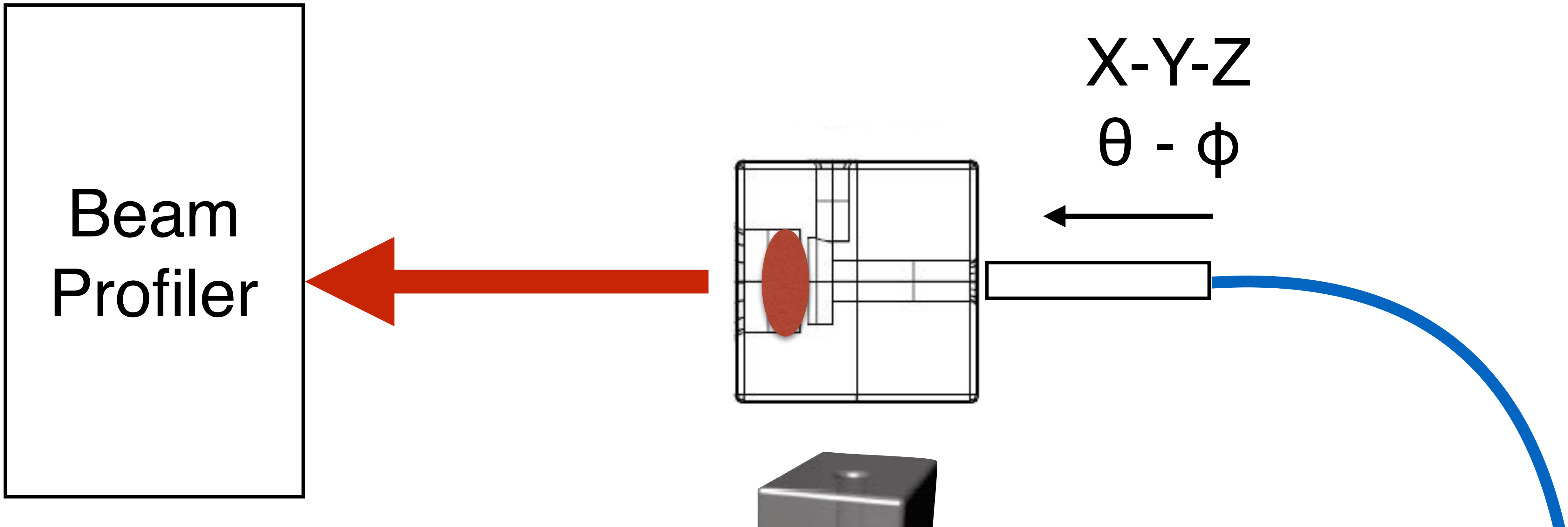


Curing with UV light

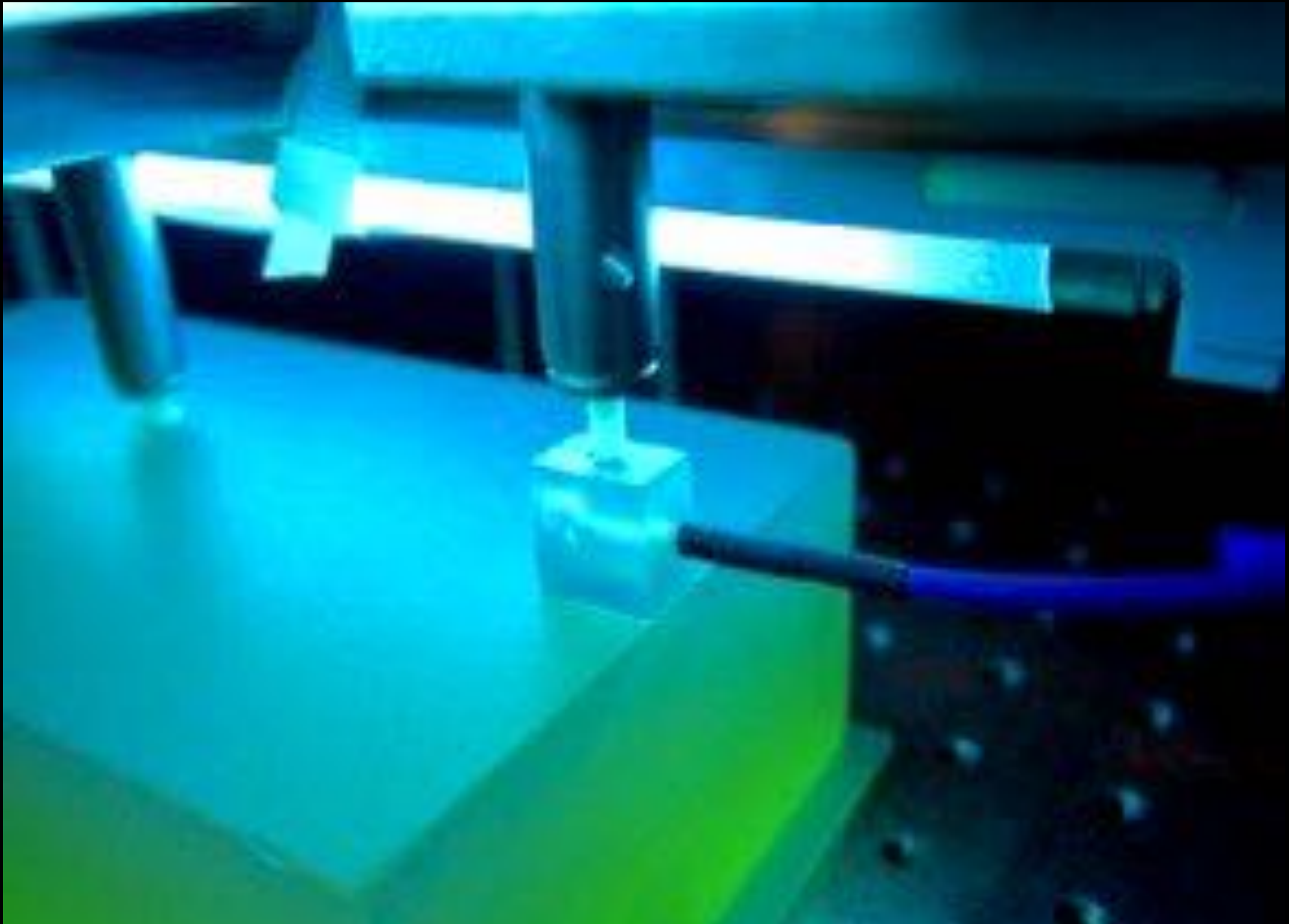


Side View

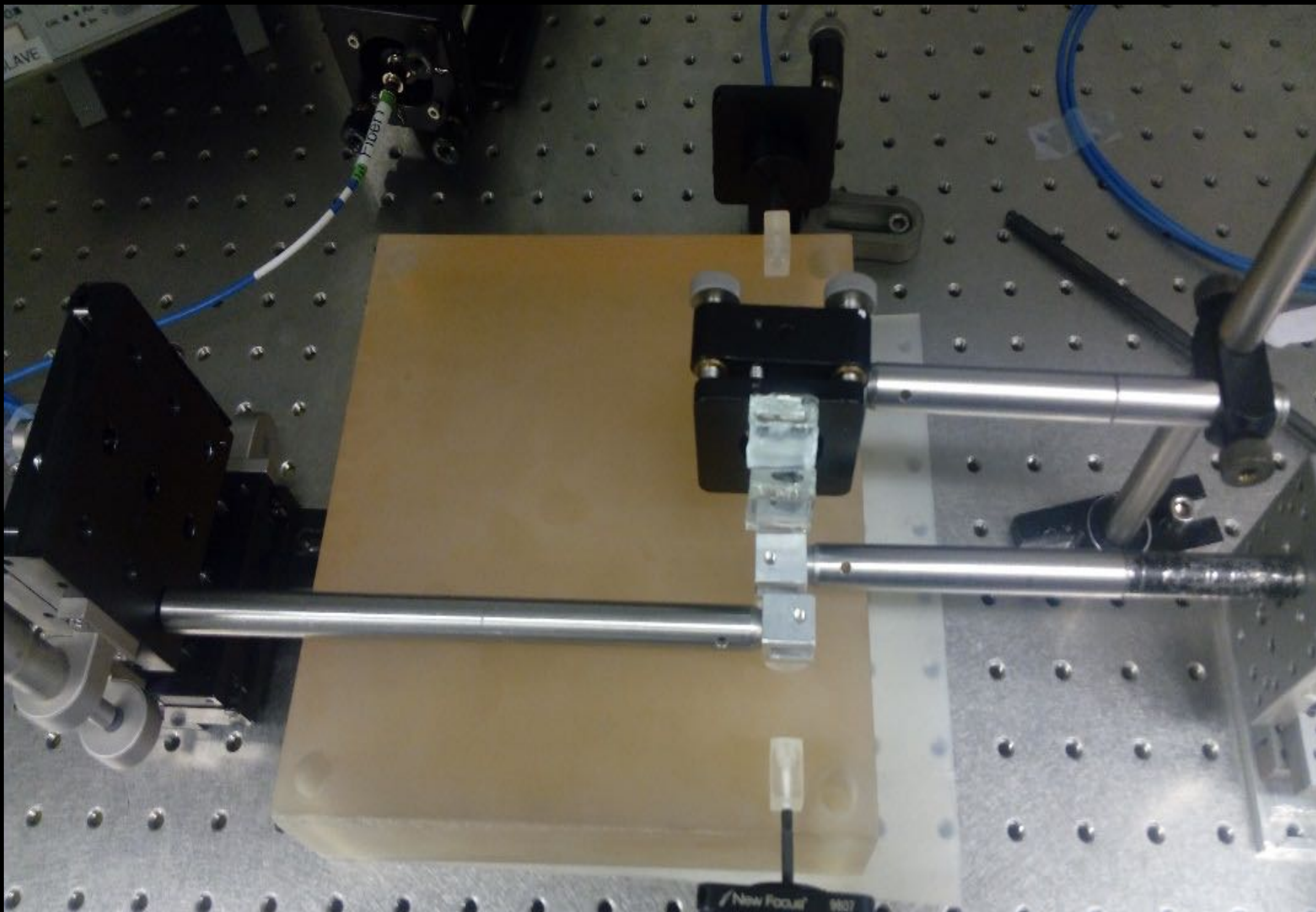
Assembly: Fibre



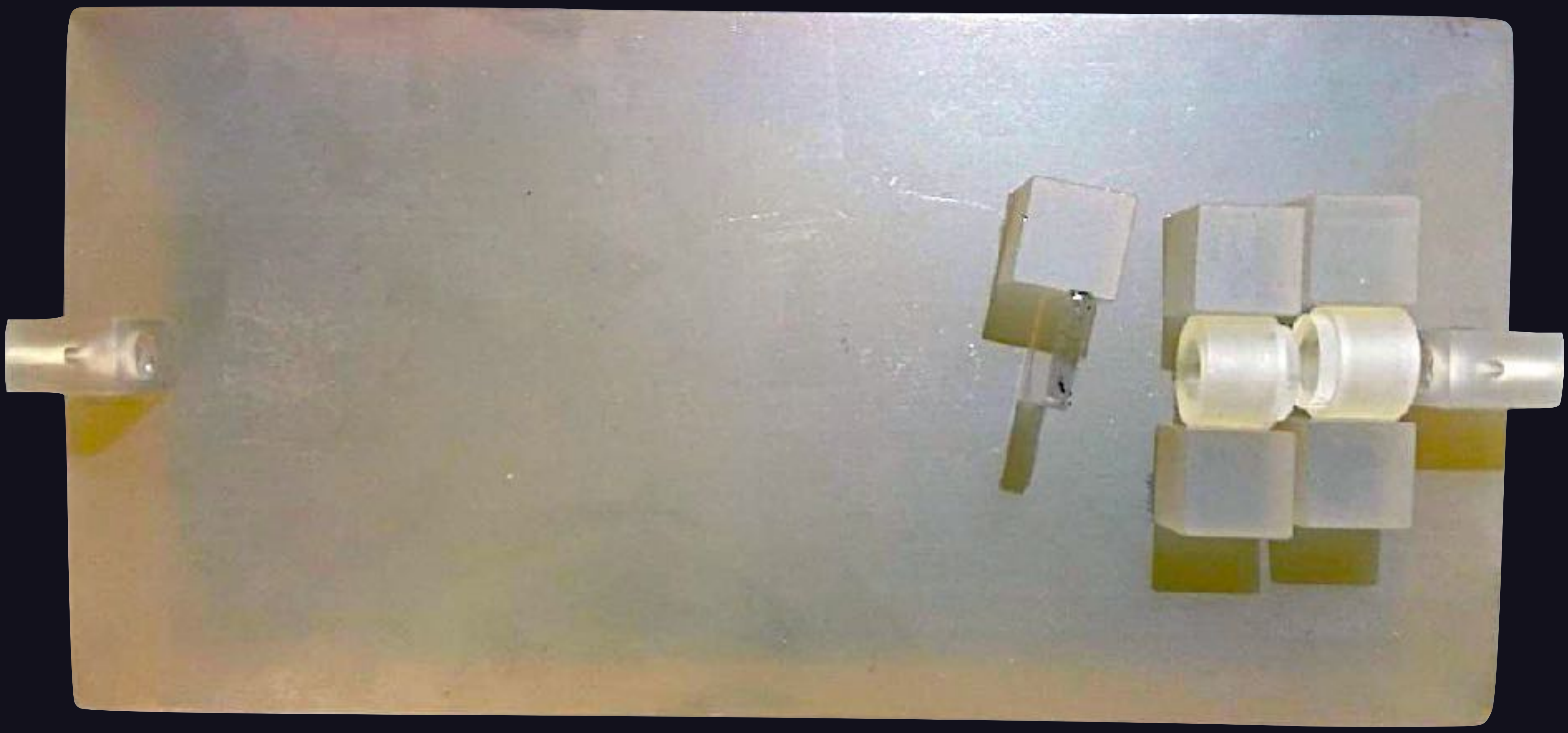
Coarse-align and bond in place



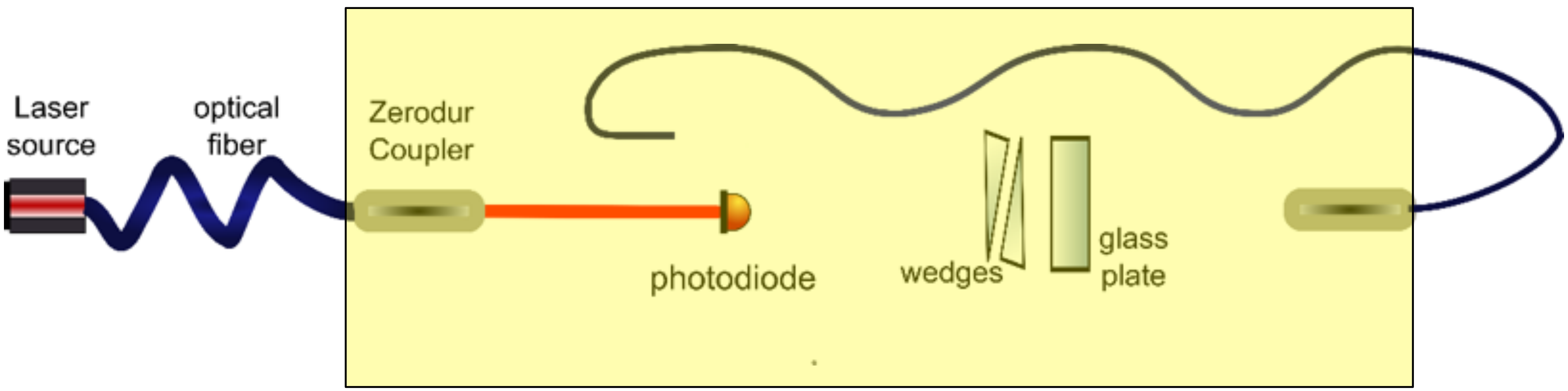
Fiber to fiber alignment

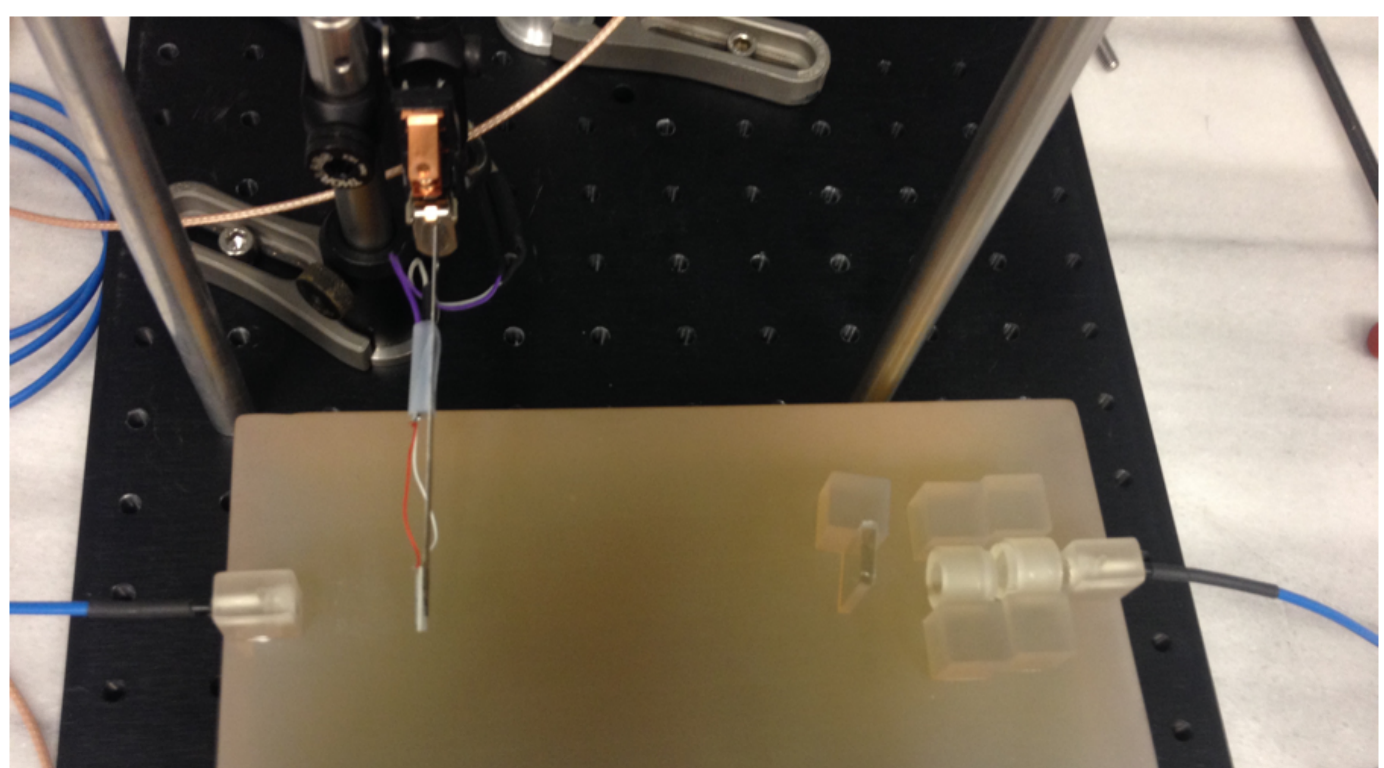


The Fully Integrated OBST



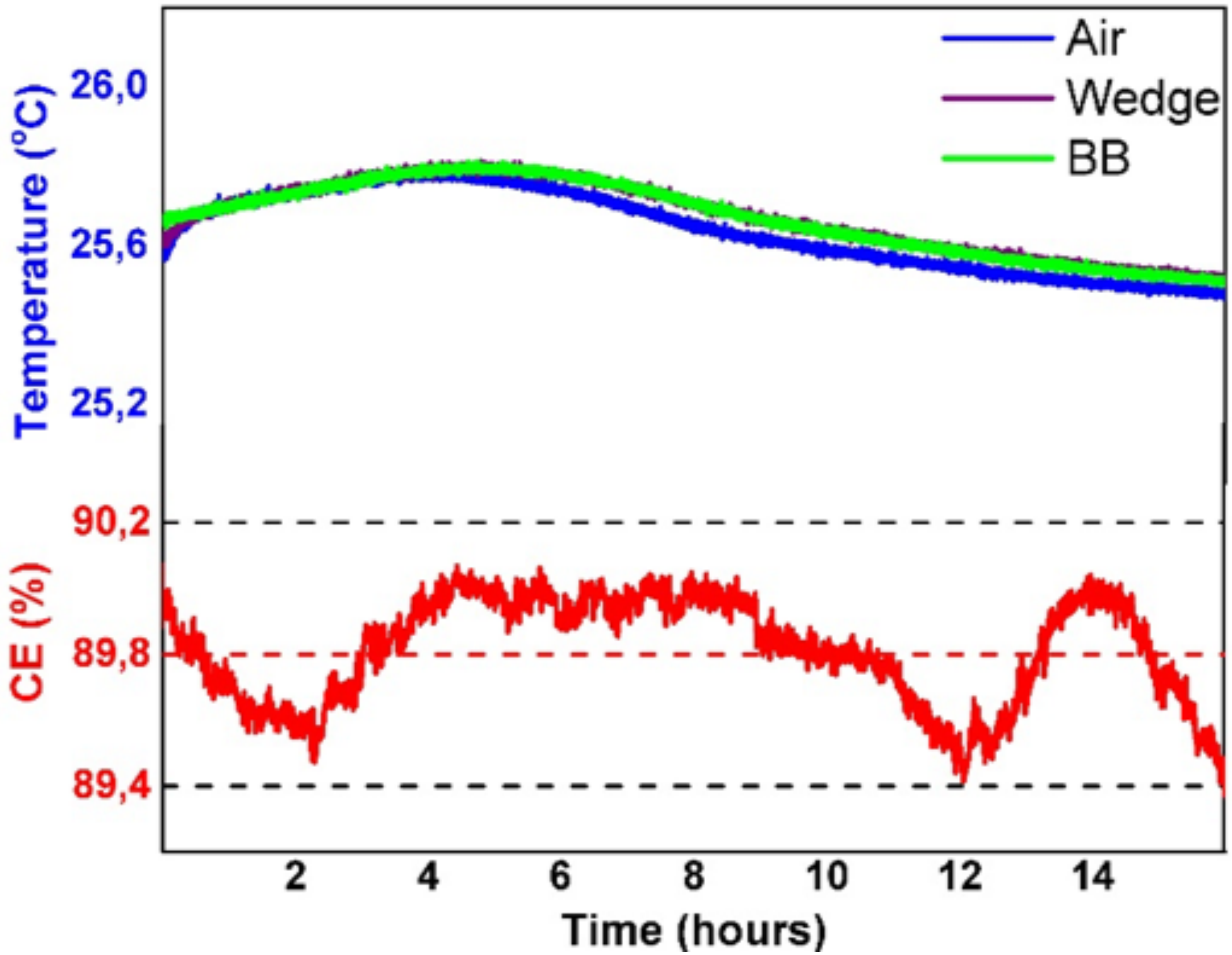
Measuring the Coupling Efficiency





Thermal Stability

Stable Temperature



0.3K

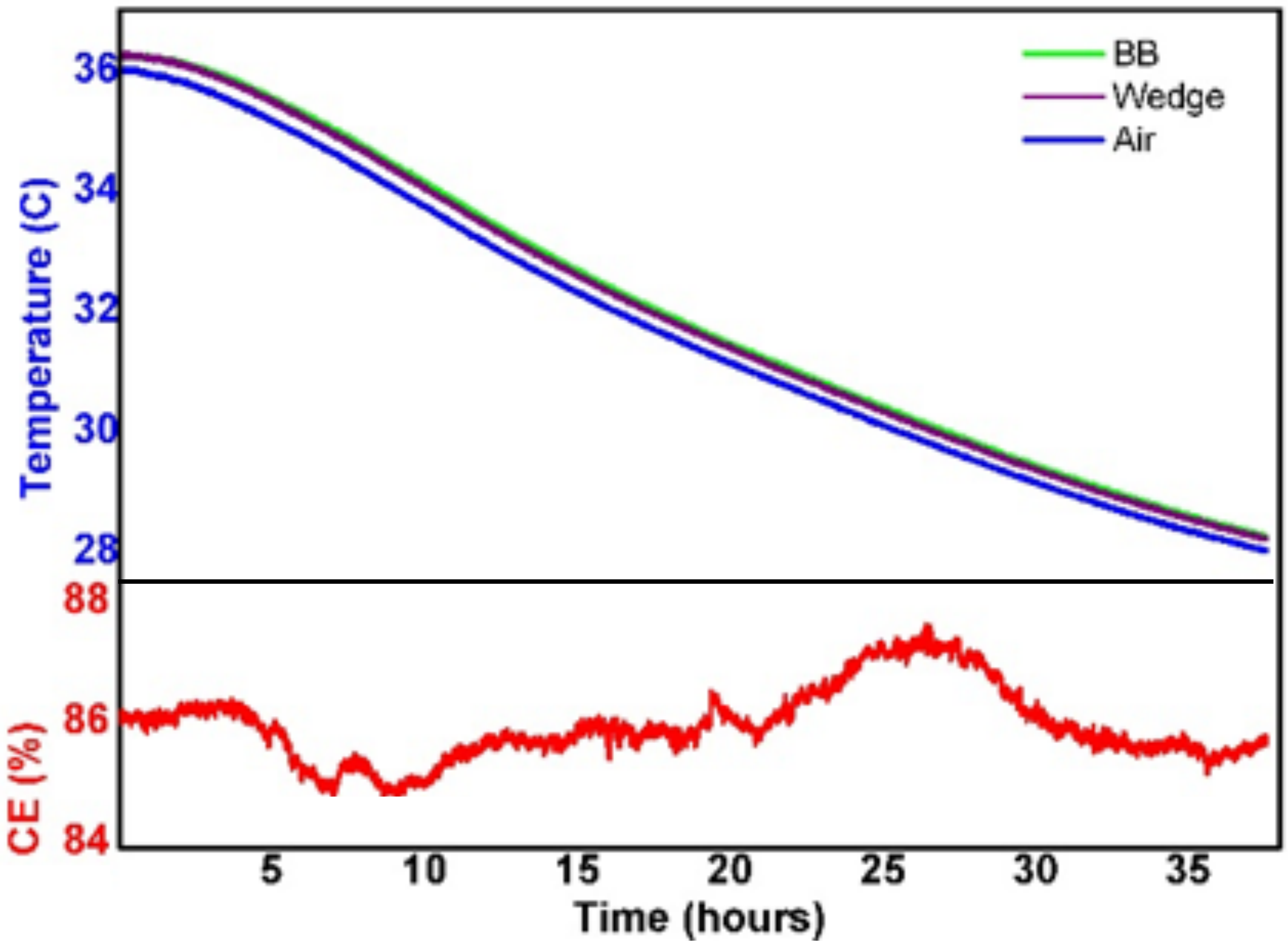
0.6%

RMS=0.2%

for 15 hours.

Thermal Stability

Large temperature *drift*



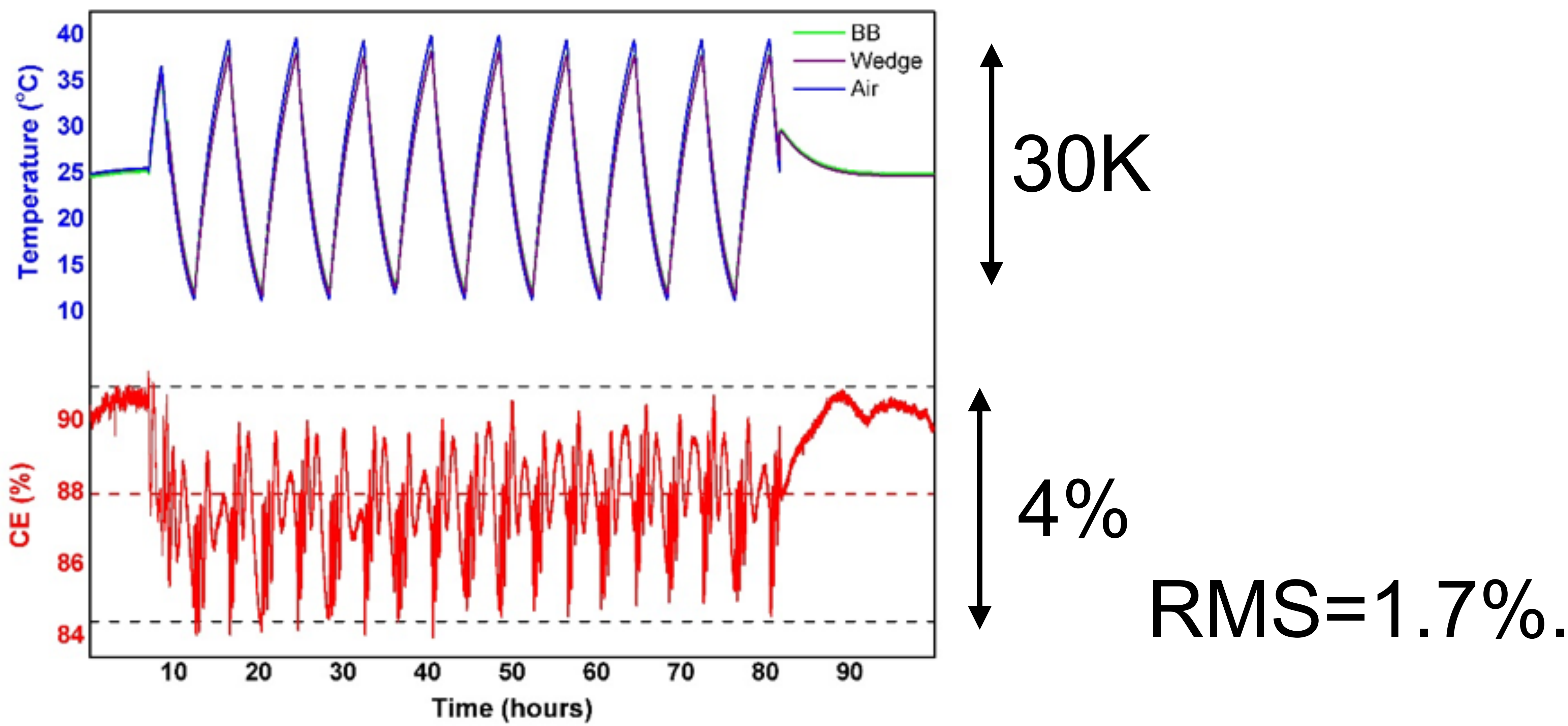
8K

2%

RMS of 0.4%

over 36h

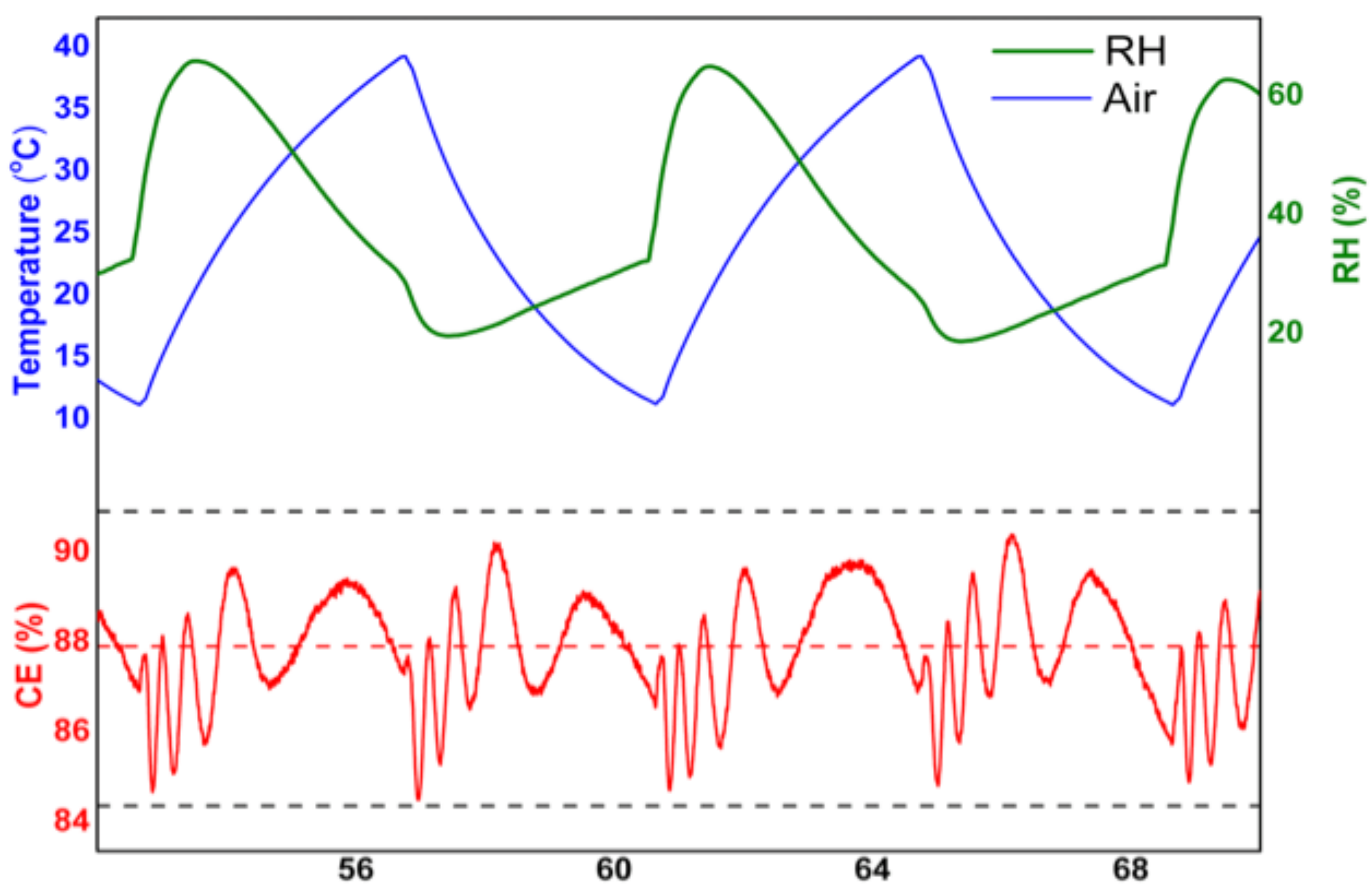
Thermal Cycling



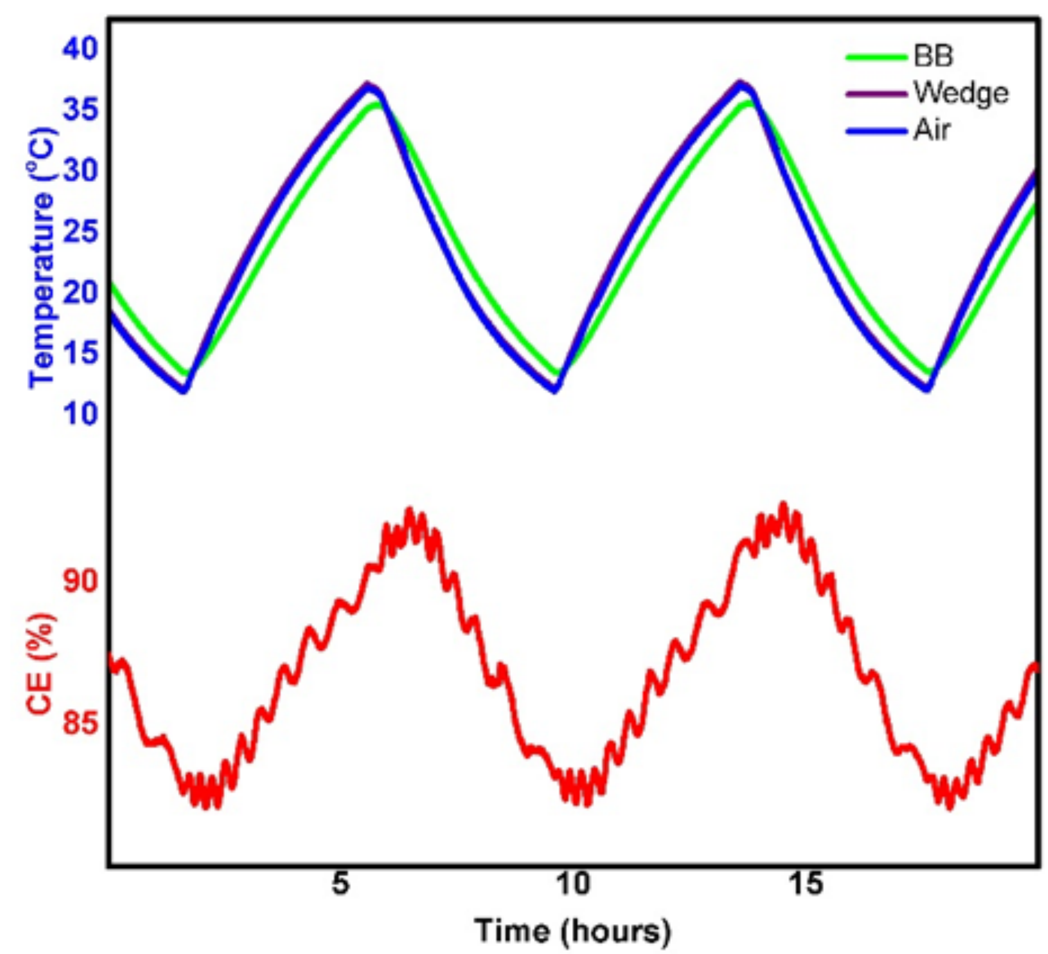
CE over multiple cycles between 10° and 40°C. Temperature was monitored in air (blue), wedge surface (purple) and breadboard surface (green). Mean value of CE is 88% and is represented by the dashed red line while the black dashed lines correspond to the peak values.

Thermal Stability
Origin of the fast fluctuations

AR coated to non-coated fiber



AR to AR coated fiber



Conclusions

OBST works:

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Lessons

- Good to work with ESA !
- How to document
- Deliver on time (workflow)
- We can do it !

Outlook

- Take OBST to the next level
  - Complex setups
  - Vibration testing
  - Integration of active components
  - …
- C-COOL
- Develop a laboratory version (Spinoff?)
- STE-QUEST // Earth observation


BEC-Lab this way
www.bec.gr


COST - Network on **Atom Quantum Technologies**
16-18 April, CRETE
AtomQT
2018
www.bec.gr
(ESA) Advanced
School on Optics
12-17 May 2019
FOMO
2018