A Metastable Positronium Inertial Sensor

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Gravity and Standard Model – the state of the art

Galileo's Pisa leaning tower thought experiment

parmi che ben potremo con molto probabil coniettura credere che nel vacuo sarebbero le velocità loro del tutto eguali

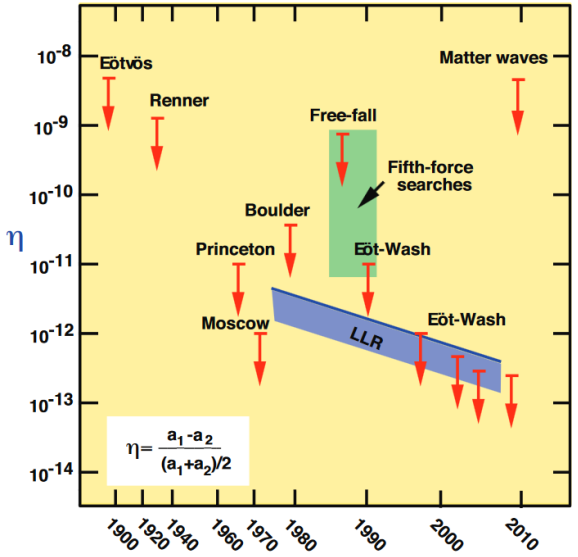
$$\begin{cases} \mathbf{F} = m_i \mathbf{a} \\ \mathbf{F_g} = m_g \mathbf{g} \end{cases} \xrightarrow{UFF} m_i = m_g$$

... also known as the Universality of the Free-Fall (UFF), a cornerstone beyond Einstein's Equivalence Principle and General Relativity.

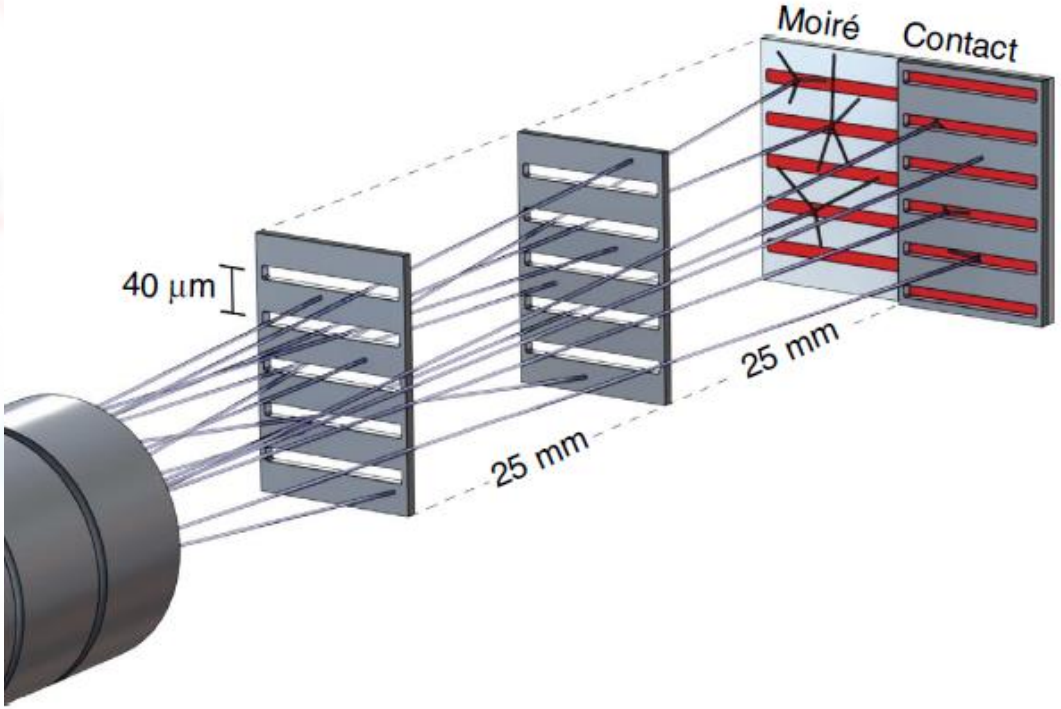
Searches for violations of the Universality of the Free-Fall

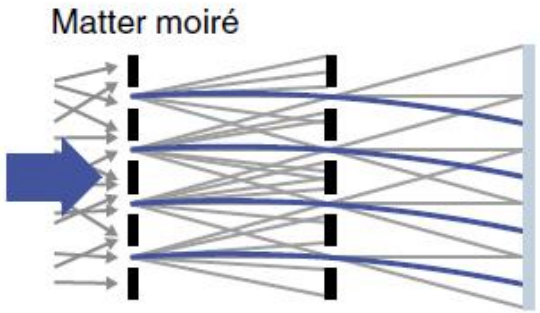
- Very accurate tests were done with matter
- Attempts with charged positrons ~ 1967, failed
- Attempts with charged antiprotons ~ 1985, failed
- Some indirect limits ~ 1987-2000, unconclusive
- Only one limited attempt with antihydrogen by ALPHA (2014)

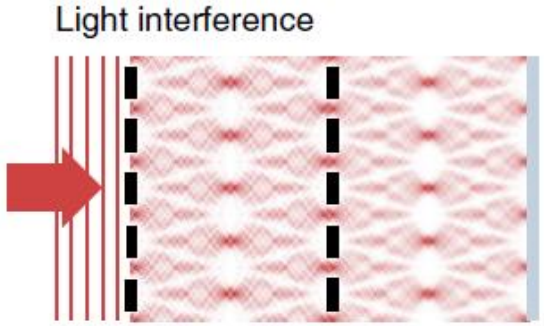
any deviation from *g* would be an indication of new physics!



Universality of the Free-Fall with antimatter atoms







The experiment goal and concept

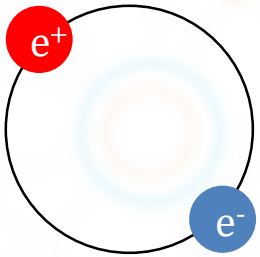
- Detect the vertical displacement of a free-falling beam of antiatoms
- ... either with antihydrogen or positronium atoms ...
- ... by comparing their annihilation positions to a light reference

Universality of the Free-Fall with antimatter atoms

One needs

- a suitable source of cold antiatoms ⟵ **the real bottleneck**
- a very high-resolution imaging detector for antiparticles
- a classical deflectometer/light interferometer
- patience (i.e. beam time ☺)

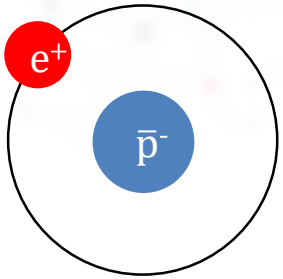
AMPIS



Positronium (Ps)

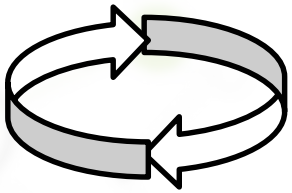
- electron + positron
- short-lived (only 142 ns!)
- table-top experiments

AEgIS



Antihydrogen ($\bar{H}$)

- antiproton + positron
- only «stable» atom
- small amounts only @ CERN



Two joint ventures with one single goal – developing the first source of cold antiatoms for a test of the Universality of the Free-Fall

Published results so far with FELLINI acknowledgment

- Antonello M. et al. (The AEgIS collaboration), Phys. Rev. A 100 (2019) 063414
- Mariazzi S., Caravita R. et al., Eur. Phys. Jour. D 74 (2020) 78
- Amsler M. et al. (The AEgIS collaboration), Nat. Comm. Phys. (2020), accepted

Research skills and techniques

Research skills and techniques acquired or planned to be improved

- Experimental skills in gamma-ray spectroscopy with state-of-the-art fast scintillation calorimeters ($PbWO_4$, $LaBr_3$) – **achieved**
- Experimental skills with low-energy positron beams and cold positronium production techniques – **achieved**
- Experience with ultra-high-resolution position-sensitive and imaging detectors for low-energy charged particles (MCP with phosphor/pixel readout) – **in progress**
- Experience with ultra-high-resolution laser spectrum diagnostics in the vacuum ultraviolet domain – **in progress**
- Theoretical insights of the impact of positronium gravitational measurements to general physics – **planned**
- Atom interferometry with cold atoms – **planned**

Management of research funds

Funds availability and management

- FELLINI (for AMPIS) – 18 k€/year available to each Fellow for new develoments
- ATTRACT – 100 k€ for the laser cooling laser development
- INFN-CSN3 (for AEgIS) – support for mantainance of existing infrastructure

FELLINI funds allocation	Year 1	Year 2	Year 3
Funds income	+18 k€	+18 k€	+18 k€
Missions budget	5 k€	5 k€	5 k€
Total funds available	13 k€	26 k€	39 k€

Expenditure plan	Year 1	Year 2	Year 3
Missions	4 k€	6 k€ (est)	5 k€ (est)
Laser and optics	1.4 k€	15 k€ (est)	3 k€ (est)
Interferometer			10 k€ (est)
Vacuum technology		5 k€ (est)	
Detectors		6 k€ (est)	

Management of research teams

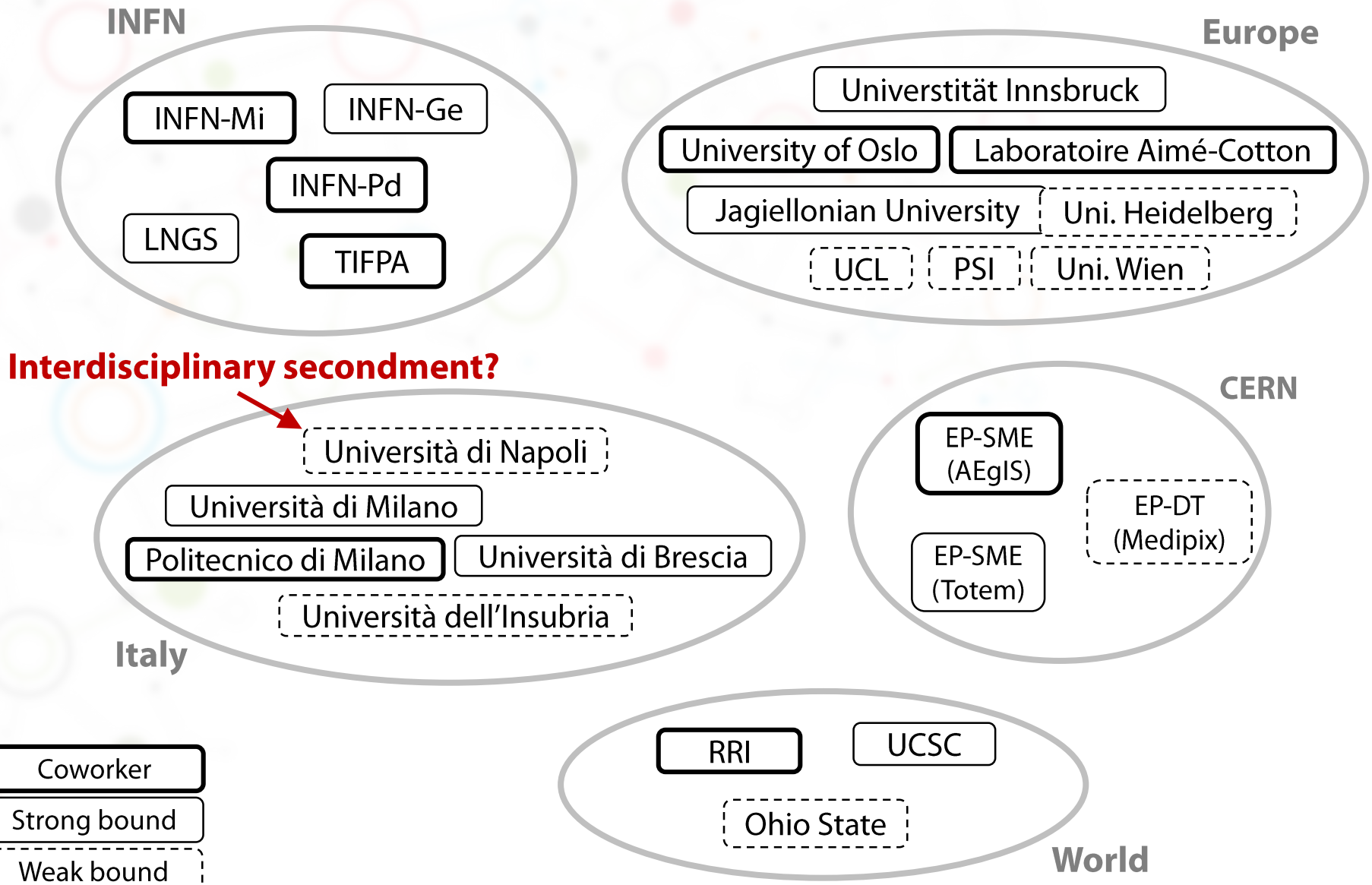
Coordination of the AEgIS experiment scientific activity

- Acting AEgIS physics coordinator since October 15, 2019
- Drafting and planning of AEgIS phase2 scientific activities
- Planning and execution of FELLINI Ps physics experiments

Experimental fieldworks coordination

- On-site coordination of AEgIS Ps physics working group for experimental activities (3 post.doc, 2 Ph.D.)
- Remote coordination of AEgIS non-neutral plasma working group (1 post.doc, 2 Ph.D.)
- Collaborating with TIFPA/CERN polarized Ps working group (2 post.doc, 1 Ph.D.)
- Collaboration with INFN-GE LAr calorimetry group (4 post.doc)

Research network and connections



Professional training and communication skills

Professional Training

- Lecturing at a Ph.D. advanced course
- Ph.D. theses being followed/mentored
  - *«high resolution position-sensitive detector for slow positronium» (L.G.)*
  - *«first inertial measurements with neutral antimatter systems» (M.V.)*
  - *«ballistic production of a beam of antihydrogen» (S.H.)*

Communication skills and outreach

- Wish-to participate to the Festival of Science in Genova, 2021, with a guided experiment
- Wish-to participate to Pint of Science events after the COVID-19 crisis is over