Space-time exploration beyond our standard models

By your Next Speaker

Beyond our standard models

- Grand Unification Paradigm, we need experimental information:
  - Equivalence Principle violation and long range forces
  - Short range forces, compact dimensions and $1/r^2$ violations
  - Spin-mass and spin-spin interactions
  - Violation of basic symmetries, time dependence of fundamental constants
  - Dragging of frames, General Relativity testing and gravitational anomalies
  - The far end of the energy spectrum with cosmic rays
- Gravitational cosmology, μ-wave cosmology and the Grand Unification time
- Dark energy and matter

Quantum mechanics on (curved) space-time background

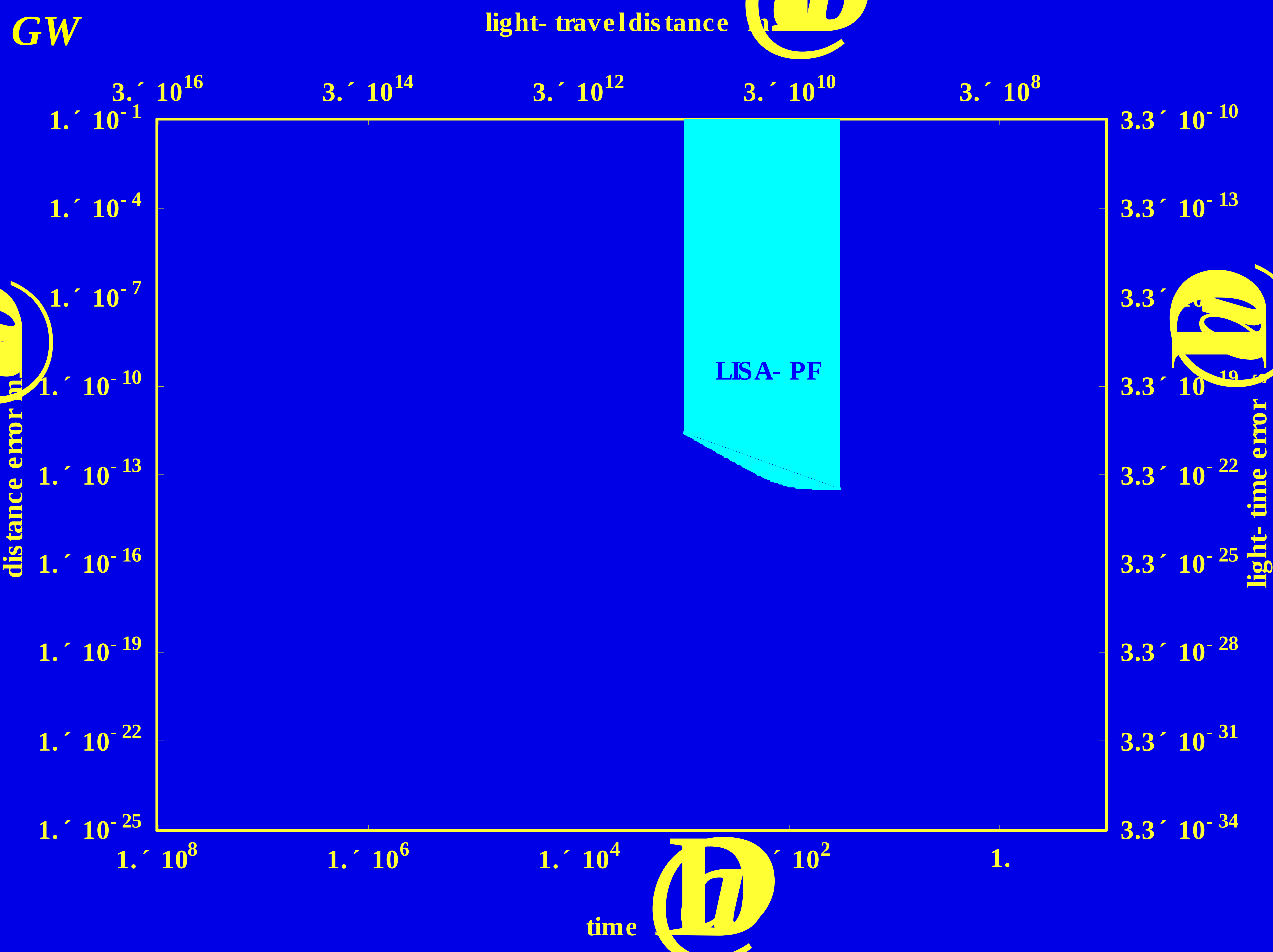
- What are the limits to quantum coherence?
- Is there any interaction between space-time geometry and quantum coherence
- What is the space-time behavior of the quantum measurement recipe?

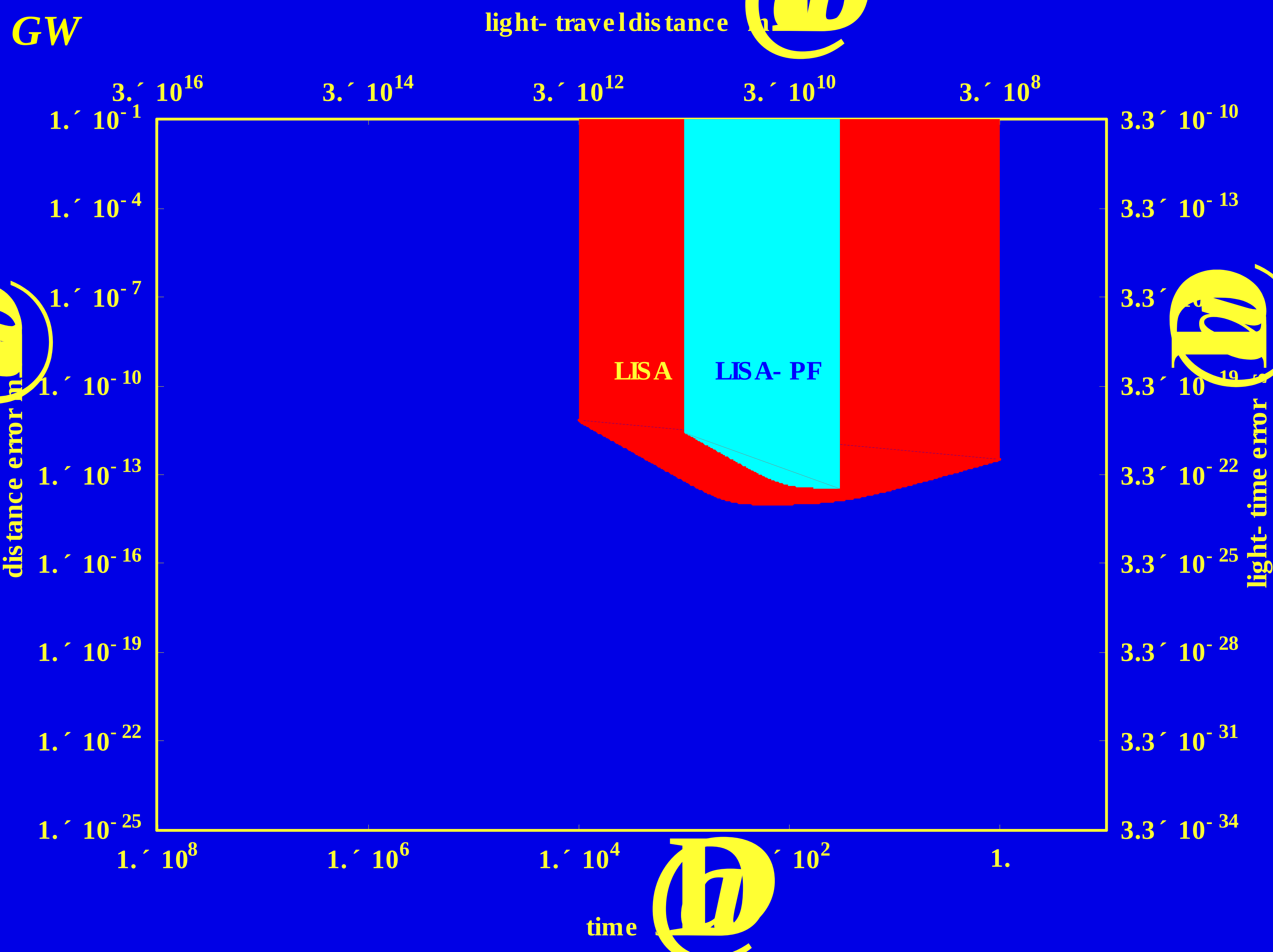
Gravitational wave research

- Strong gravitational field physics (cont'd from LISA)
  - Event horizon properties
  - Gravitational field in the GUT era
- The dark side of space-time
- Gravitational wave cosmology

A new frontier of space-time exploration

- Measuring geometry: the requested leaps
  - Distance (and time) resolution
  - Geodesic motion (free-fall) purity
  - Time and distance scales


GW
light- travel distance
3.´ 10^16
3.´ 10^14
3.´ 10^12
3.´ 10^10
3.´ 10^8
1.´ 10^-1
1.´ 10^-4
1.´ 10^-7
1.´ 10^-10
1.´ 10^-13
1.´ 10^-16
1.´ 10^-19
1.´ 10^-22
1.´ 10^-25
distance error
3.3´ 10^-10
3.3´ 10^-13
3.3´ 10^-22
3.3´ 10^-25
3.3´ 10^-28
3.3´ 10^-31
3.3´ 10^-34
light- time error
LISA- PF
1.´ 10^8
1.´ 10^6
1.´ 10^4
10^2
1.
time


GW
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LISA- PF
distance error
light- time error
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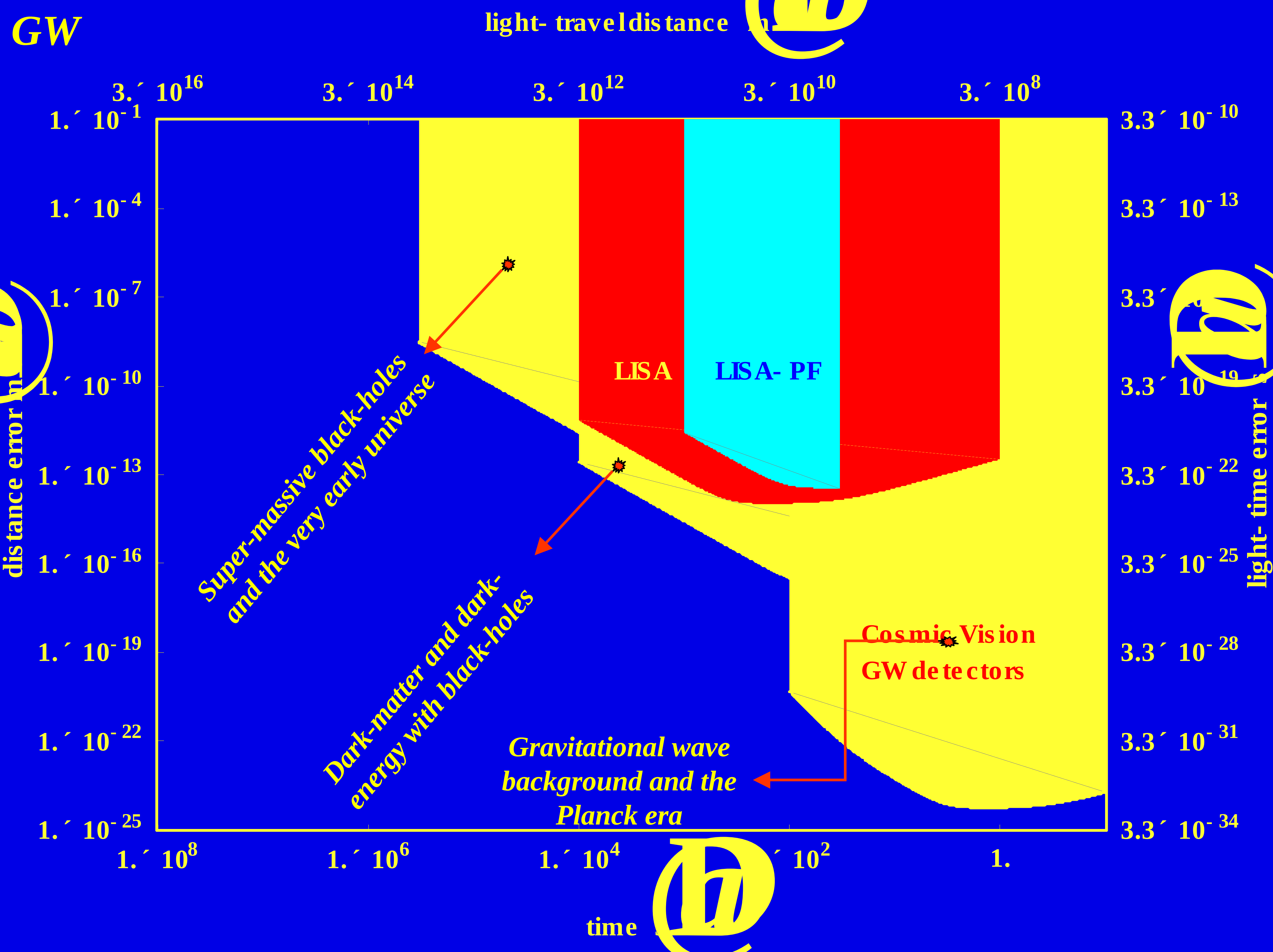
GW
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3.3´ 10^-13
3.3´ 10^-19
3.3´ 10^-22
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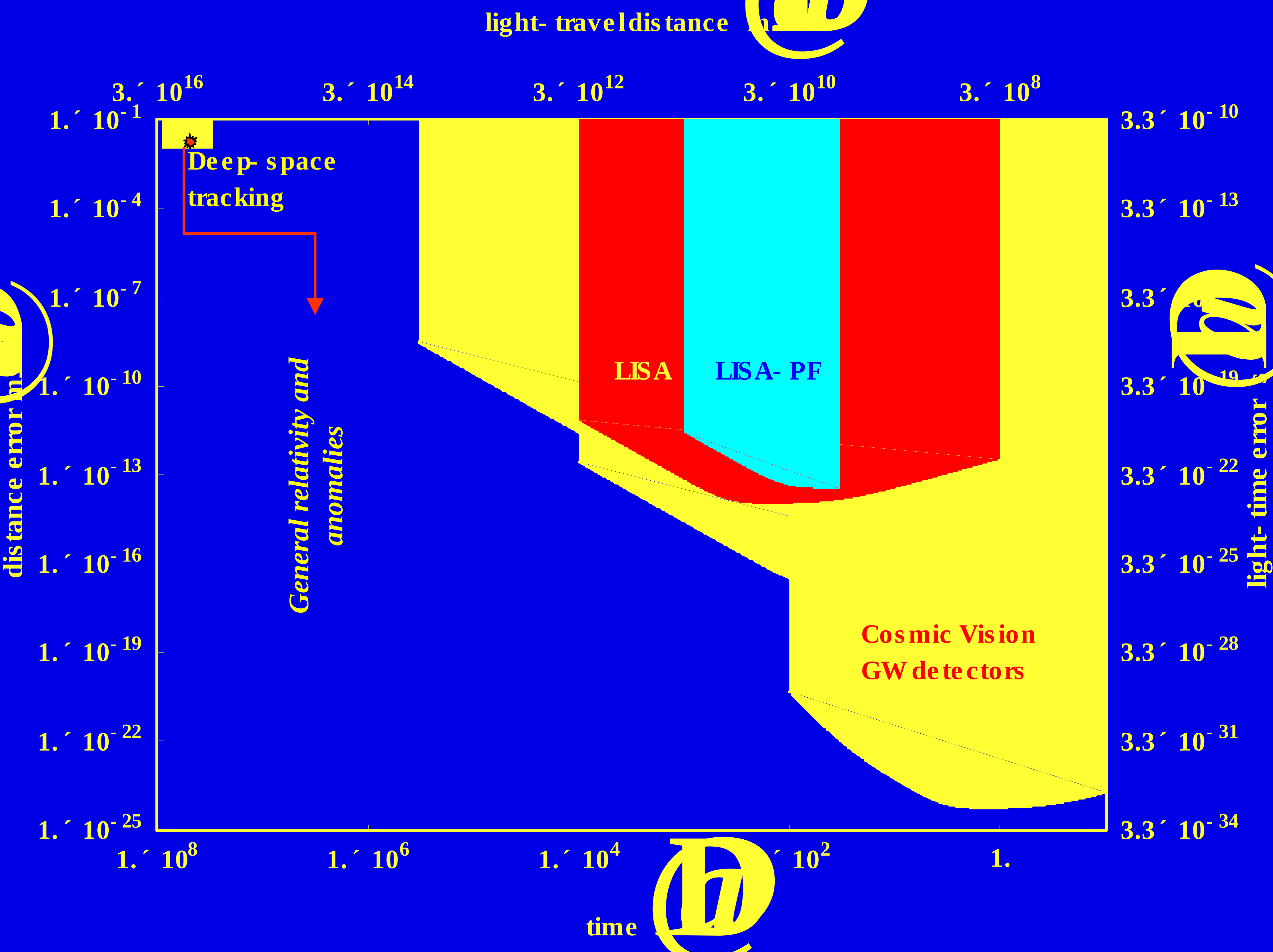
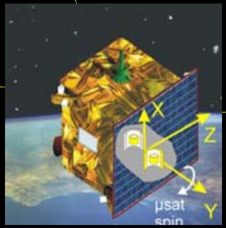
3.3´ 10^-28
3.3´ 10^-31
3.3´ 10^-34
distance error
light- time error
LISA
LISA- PF
Super-massive black-holes
and the very early universe
Dark-matter and dark-
energy with black-holes
Cosmic Vision
GW detectors
Gravitational wave
background and the
Planck era
1.´ 10^8
1.´ 10^6
1.´ 10^4
´ 10^2
1.
time



light- travel distance
3.´ 10^16
3.´ 10^14
3.´ 10^12
3.´ 10^10
3.´ 10^8
1.´ 10- 1
1.´ 10- 4
1.´ 10- 7
1.´ 10- 10
1.´ 10- 13
1.´ 10- 16
1.´ 10- 19
1.´ 10- 22
1.´ 10- 25
3.3´ 10- 10
3.3´ 10- 13
3.3´ 10- 22
3.3´ 10- 25
3.3´ 10- 28
3.3´ 10- 31
3.3´ 10- 34
distance error
light- time error
Deep- space tracking
General relativity and anomalies
LISA
LISA- PF
Cosmic Vision GW detectors
1.´ 10^8
1.´ 10^6
1.´ 10^4
1.
time

Beyond the SM

Microscope



Acceleration [m s^{-2}]

10^{-14}

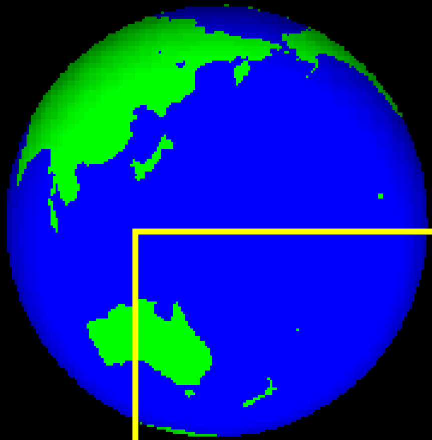
10^{-15}

10^{-16}

10^{-17}

10^{-18}

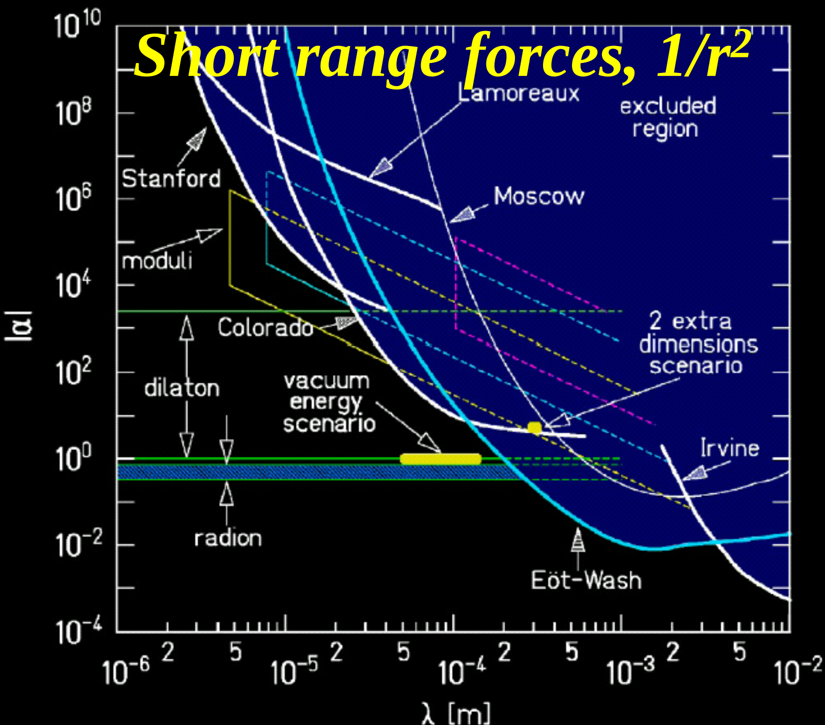
10^{-19}

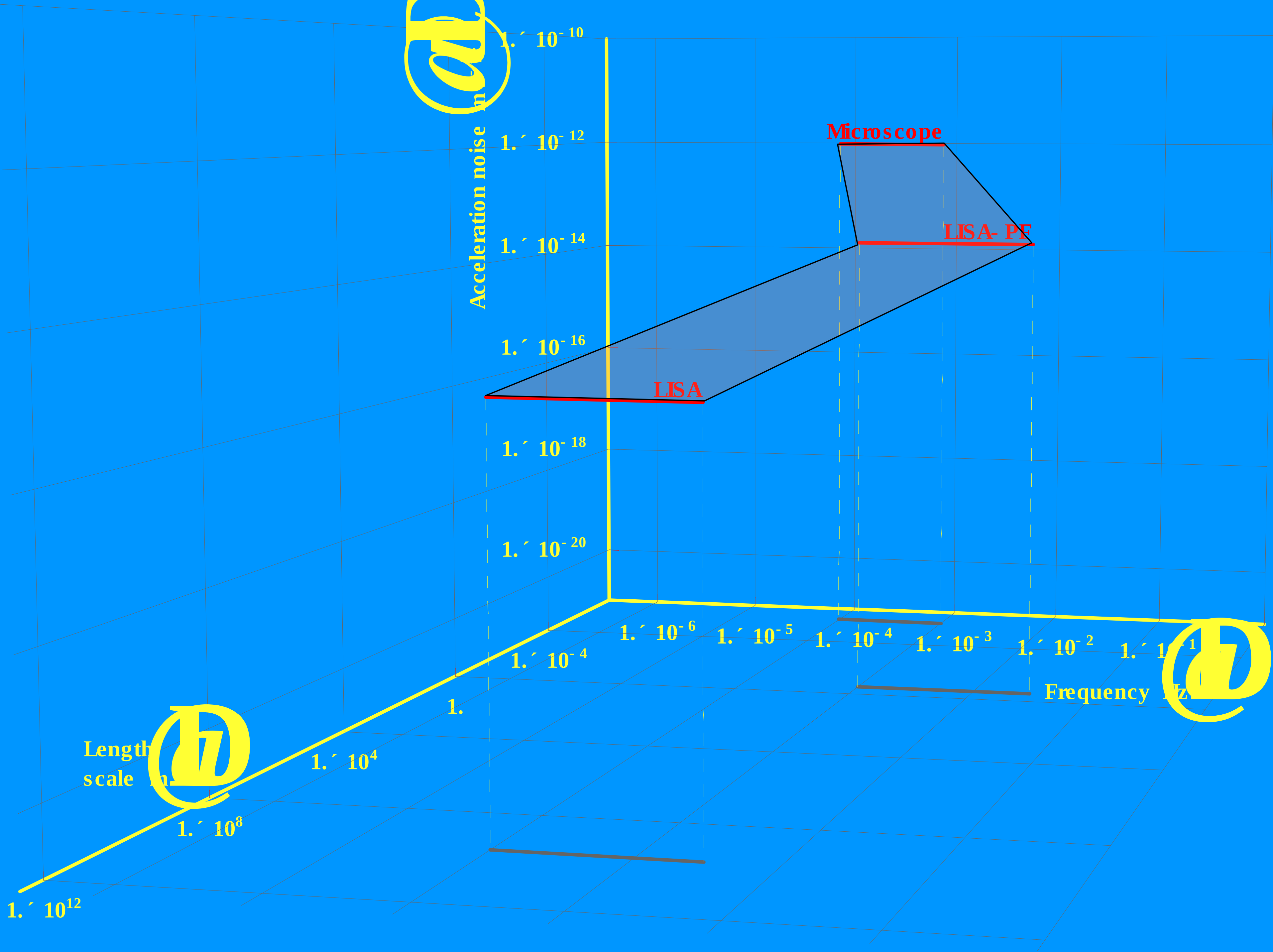


Long range EP

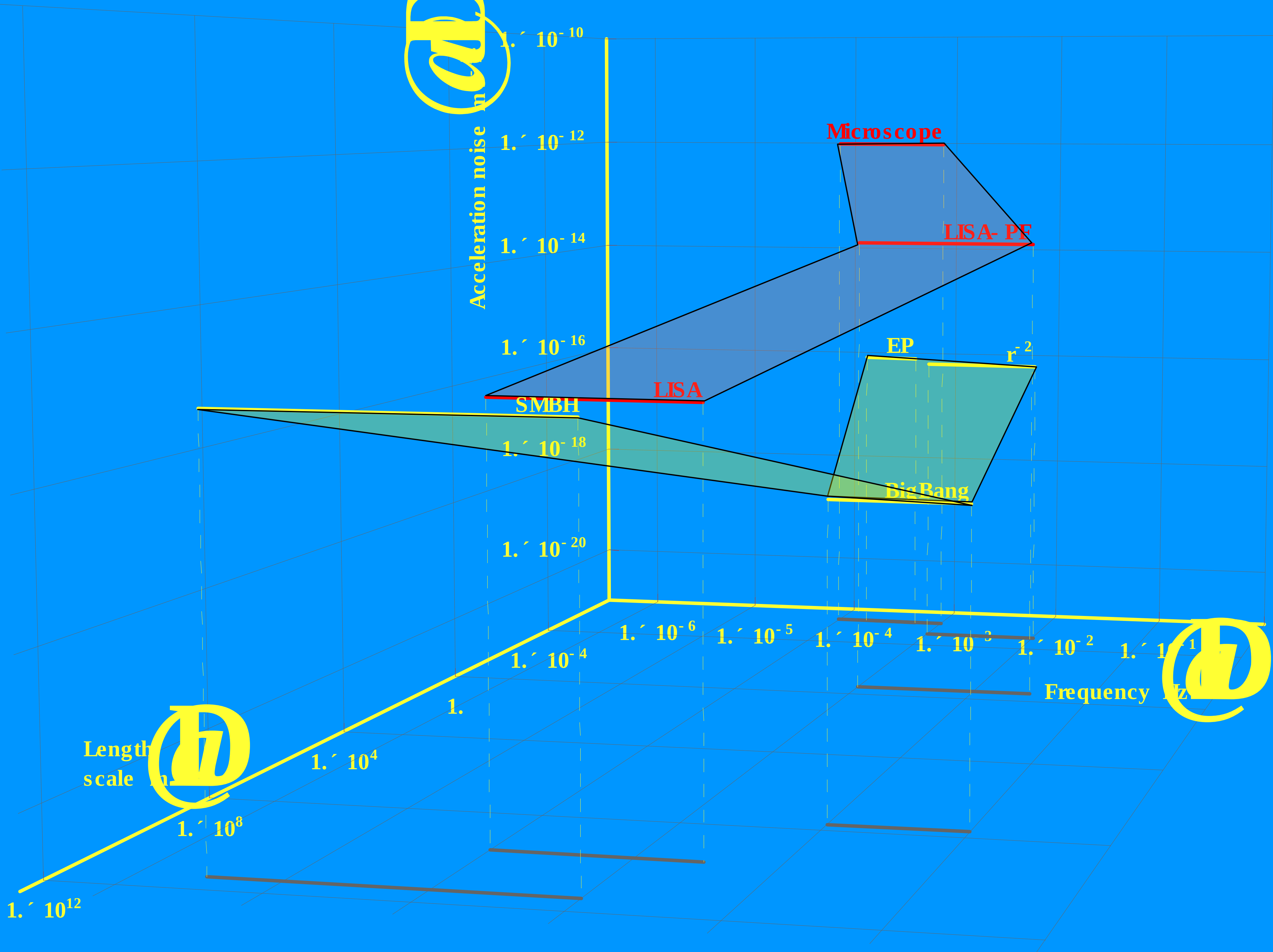
Very long range EP

Short range forces, 1/r^2





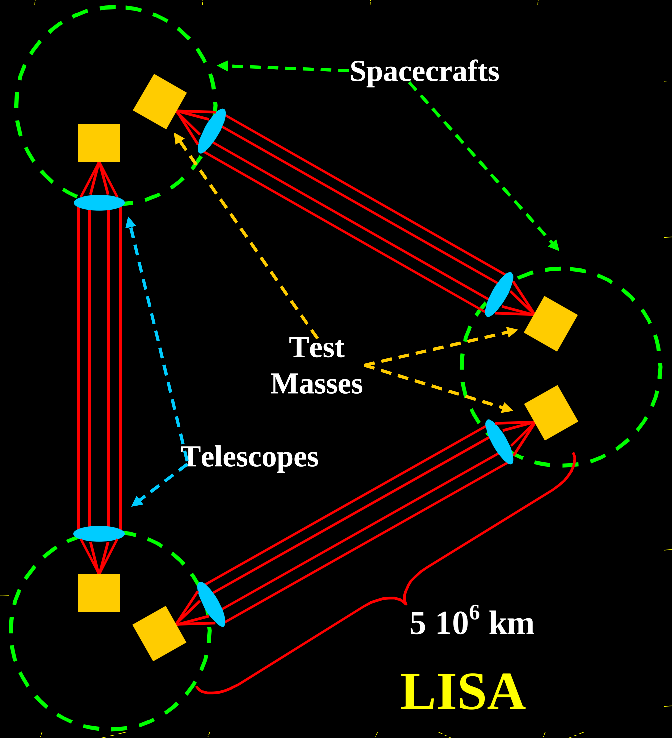
Acceleration noise
1. ´ 10- 10
1. ´ 10- 12
1. ´ 10- 14
1. ´ 10- 16
1. ´ 10- 18
1. ´ 10- 20
Microscope
LISA- PF
LISA
1. ´ 10- 6
1. ´ 10- 5
1. ´ 10- 4
1. ´ 10- 3
1. ´ 10- 2
Frequency
1. ´ 10- 4
1.
Length scale
1. ´ 10^4
1. ´ 10^8
1. ´ 10^12



Acceleration noise
1.´ 10- 10
1.´ 10- 12
1.´ 10- 14
1.´ 10- 16
1.´ 10- 18
1.´ 10- 20
Microscope
LISA- PF
EP
r- 2
LISA
SMBH
BigBang
1.´ 10- 6
1.´ 10- 5
1.´ 10- 4
1.´ 10- 3
1.´ 10- 2
Frequency
1.´ 10- 4
1.
1.´ 104
1.´ 108
1.´ 1012
Length
scale

Technology toward the Atto-(10^{-18}) era

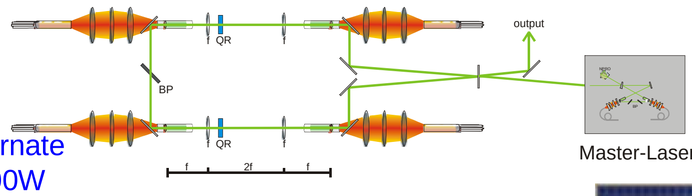
- New distance meters
- New coordinate markers (test-bodies)

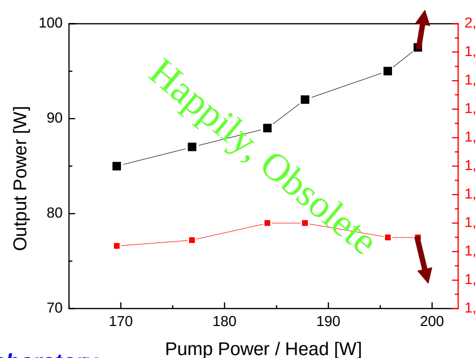


LIGO

Pre-stabilized Laser

- Challenge is in the high-power 'head'
  - » Coordinated by Univ. of Hannover/LZH
  - » Three groups pursuing alternate design approaches to a 100W demonstration
    - – Master Oscillator Power Amplifier (MOPA) [Stanford]
    - – Stable-unstable slab oscillator [Adelaide]
    - – Rod systems [Hannover]
  - » LZH approach chosen as baseline March 2003
  - » With ½ of power head, P: 110 W, M^2x,y: 1.05





LIGO Laboratory

G030399-00-D

The distance meter

High Power Lasers

PHOTONICS SPECTRA

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Photonics TechnologyWorld
July 2004 Edition

Send News to photonics@laurin.com or submit online here

Frequency-Doubled Nd:YAG Generates 200 W

A high-power green Nd:YAG laser has been developed at Mitsubishi Electric Corp.'s Advanced Technology R&D Center in Amagasaki, Japan, and is being studied for the crystallization of amorphous silicon films into polycrystalline silicon films during the fabrication of thin-film transistor display screens. The laser's 200-W second-harmonic average output power apparently sets a world record and is at least a factor of two greater than any commercial competitor.

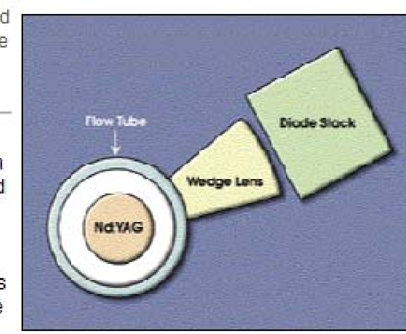
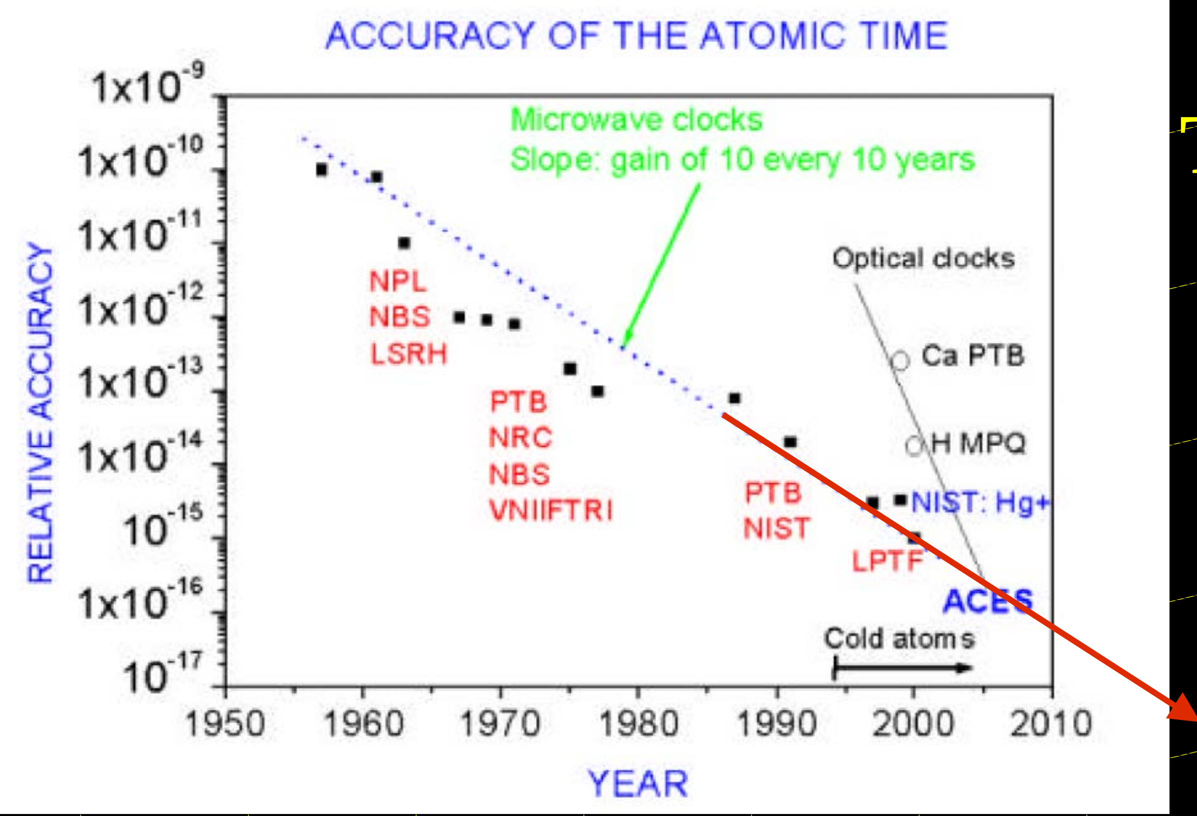


Figure 1. A wedge lens coupled the pump power from the diode stacks into the Nd:YAG laser rods.

Tetsuo Kojima, who described the laser at CLEO in San Francisco in May, provided additional details in a discussion after the conference. He explained that each Nd:YAG rod in the laser is pumped by six individual diode stacks and that the diodes' output is coupled into the rods with a wedge lens (Figure 1). The laser comprises four rods, with a 90° polarization rotator between each pair of rods to alleviate thermal birefringence (Figure 2).

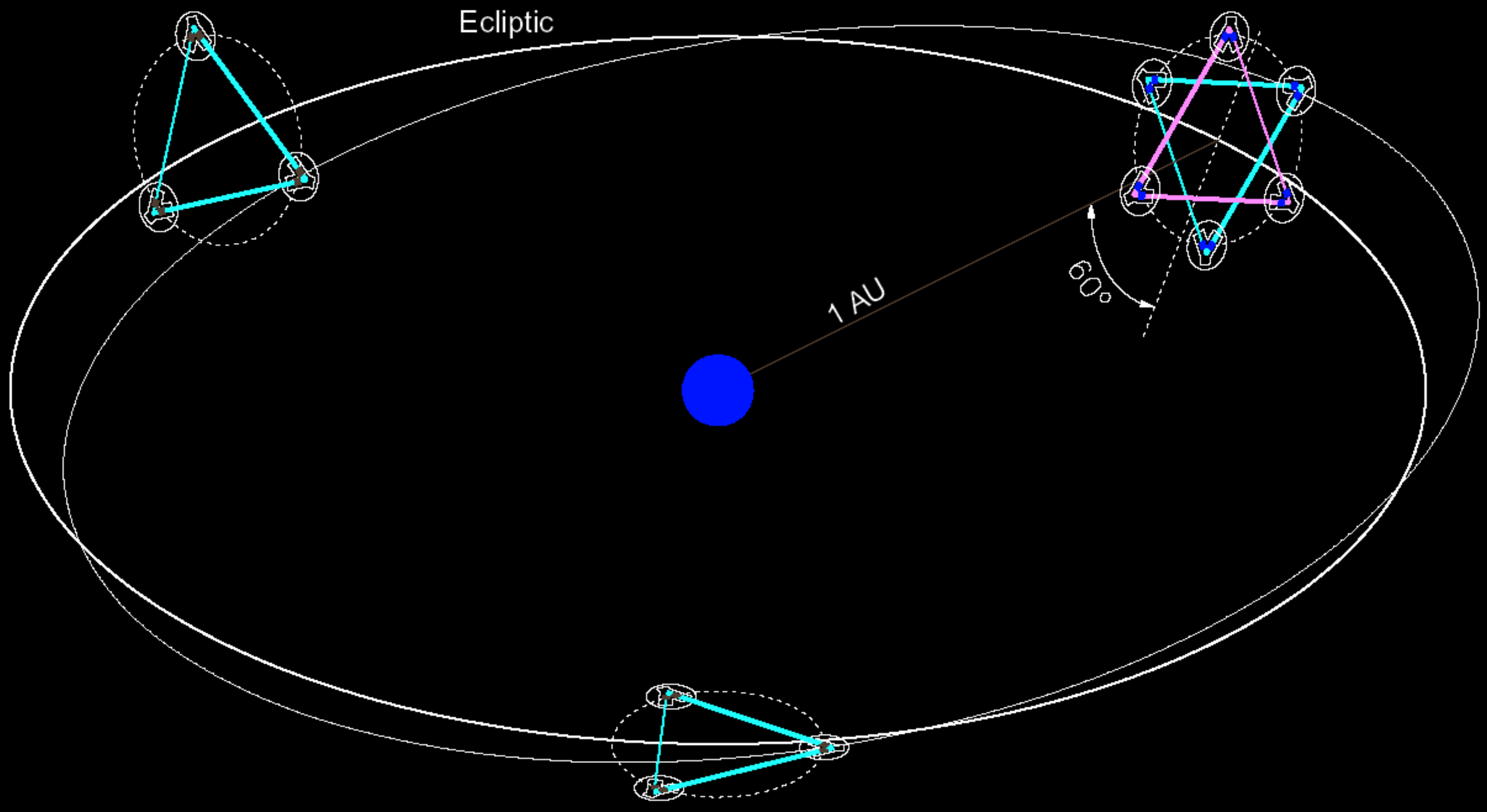
The distance meter



10^{-18} !

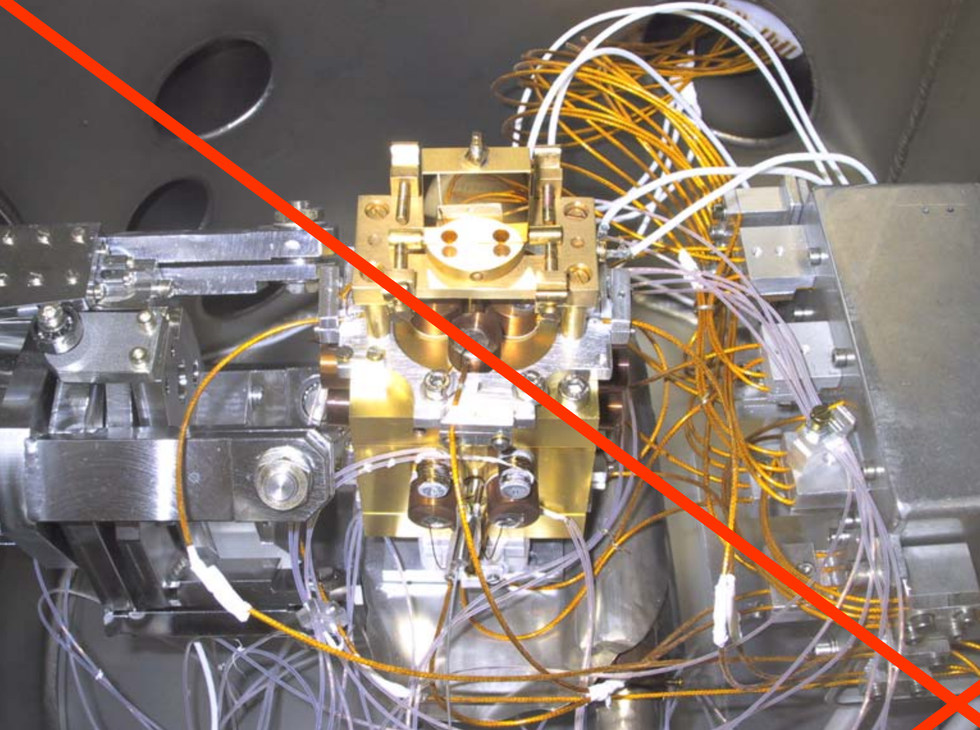
Accurate clocks and ultimate frequency stabilization

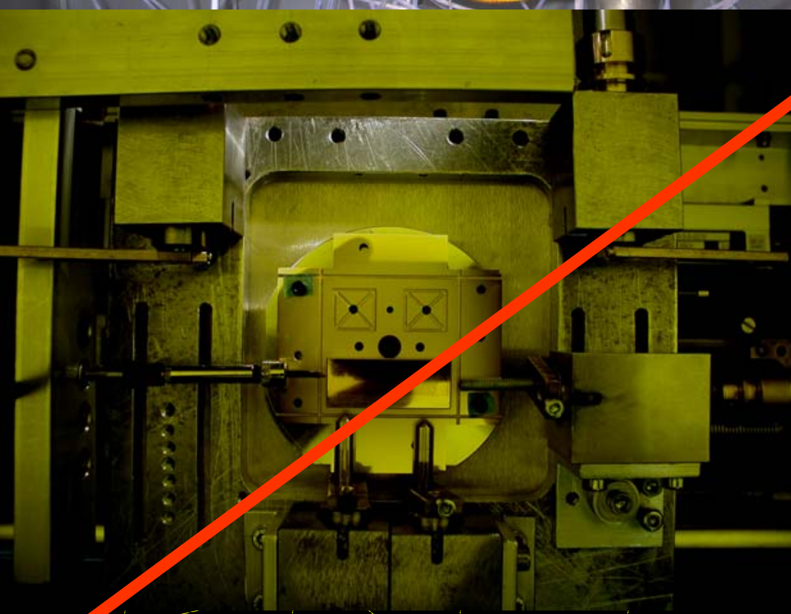
The distance meter

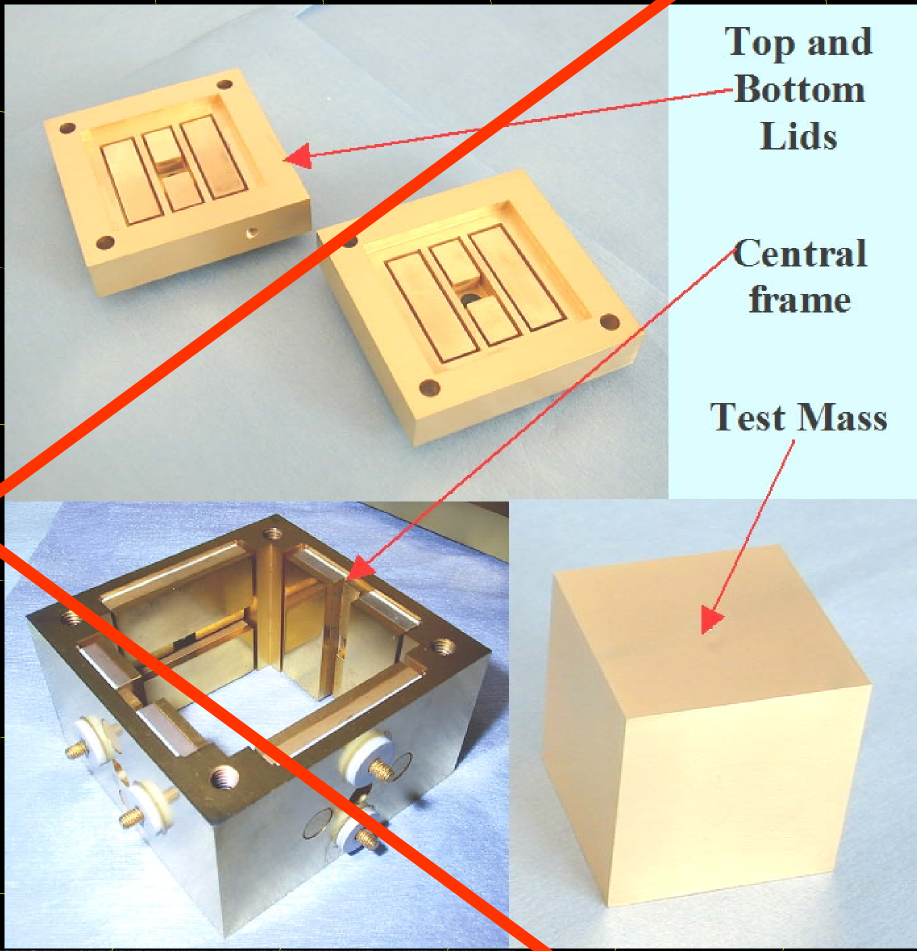


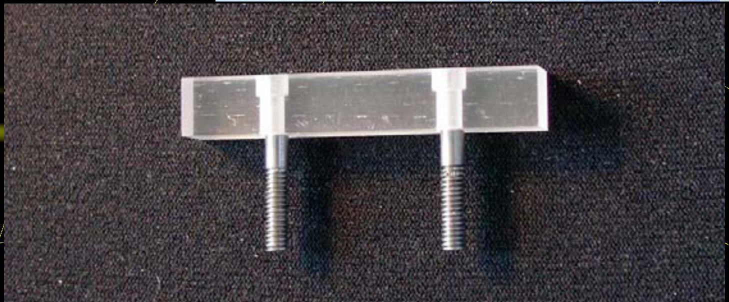
Very Long Baseline (2 AU) Gravitational Interferometry

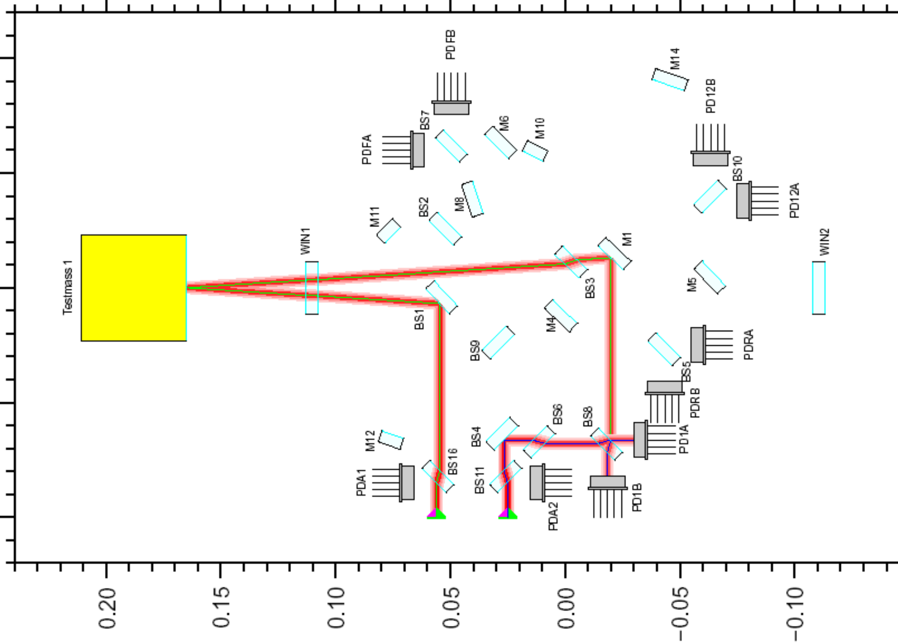
The reference bodies



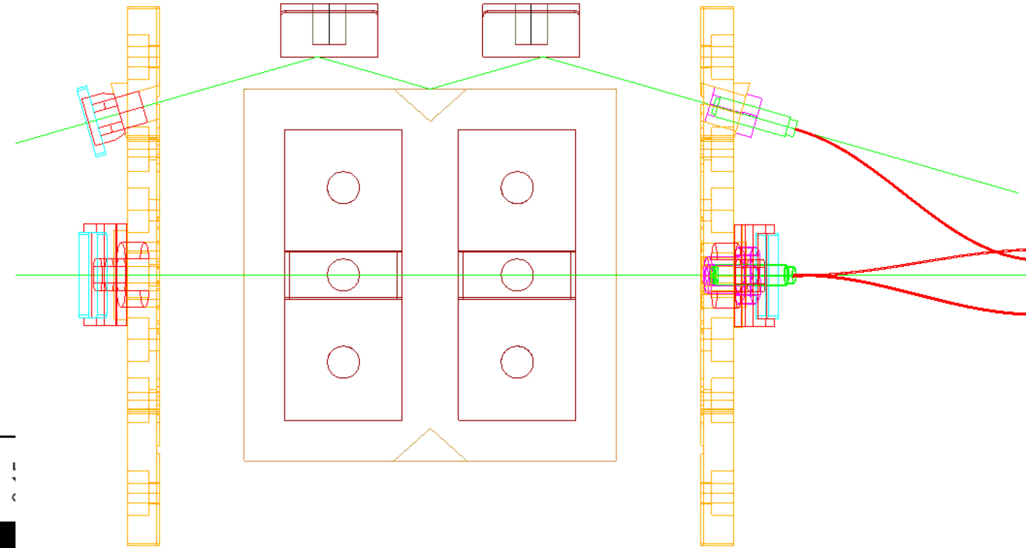




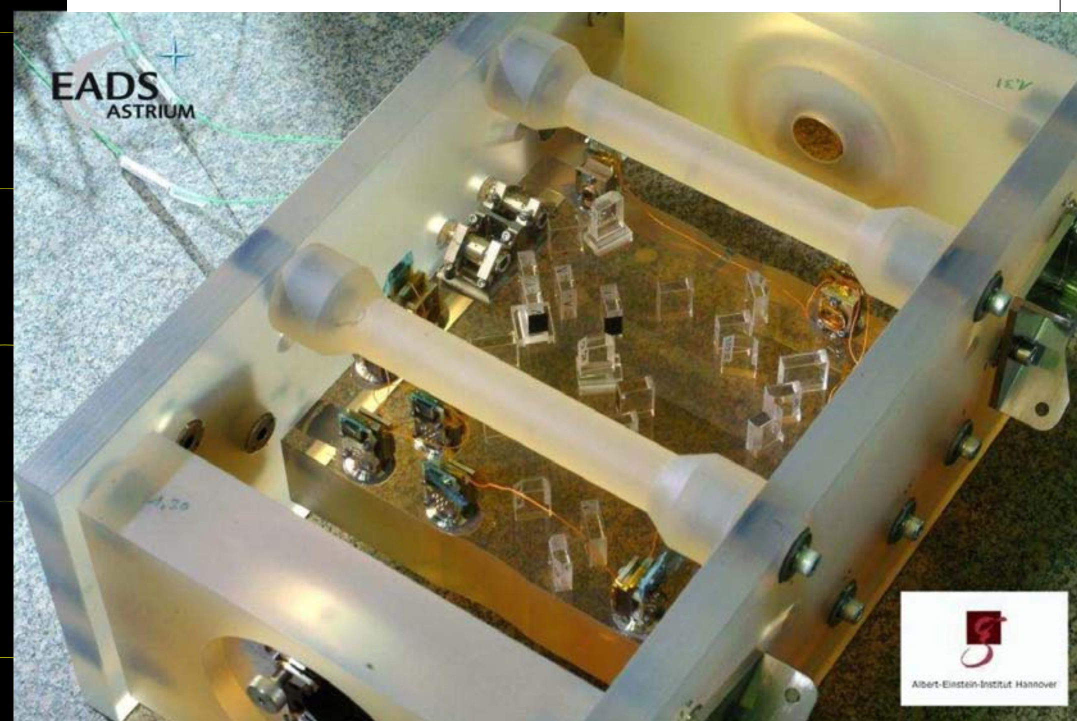




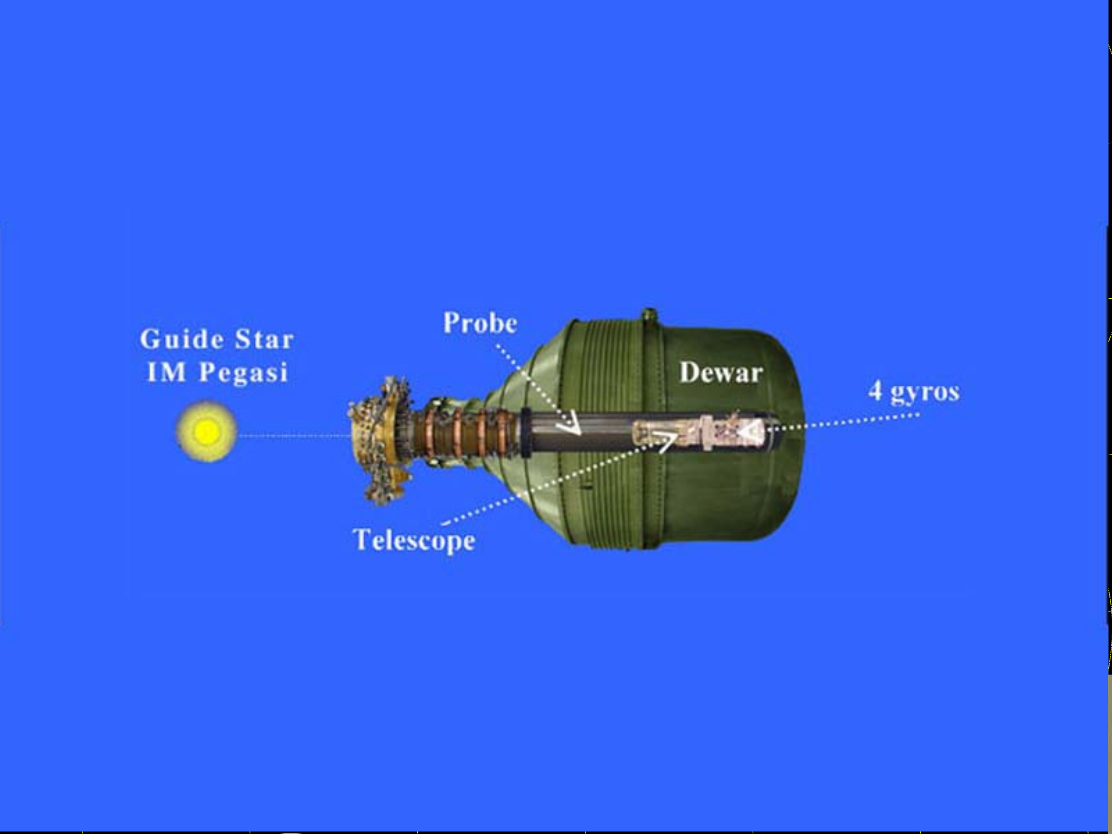
The reference bodies



Optical readout and very large gaps (beat electromagnetic field)



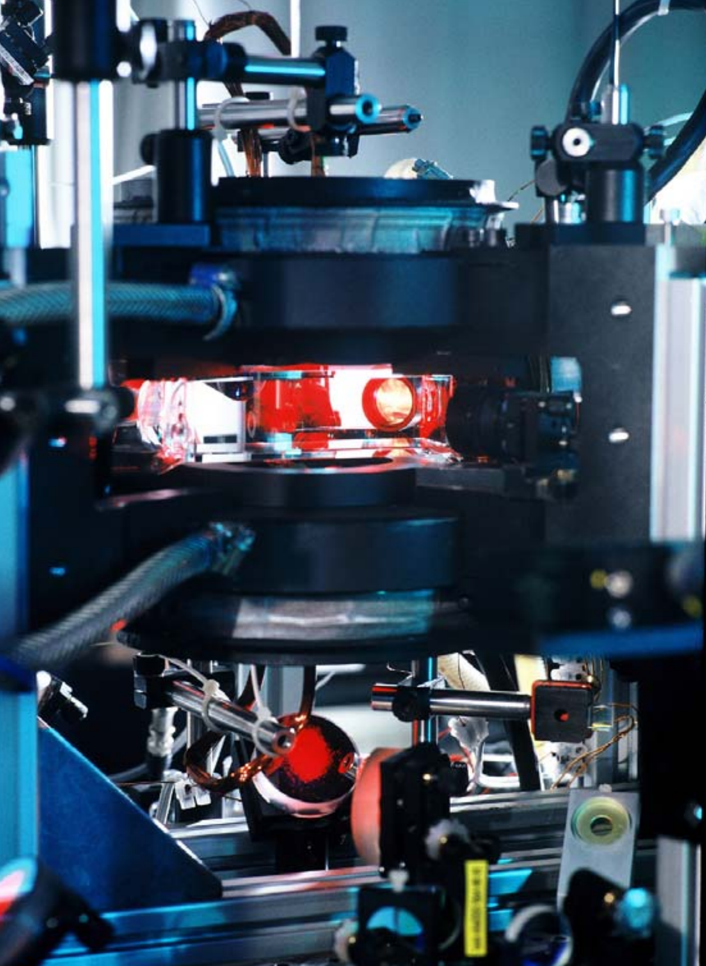
The reference bodies

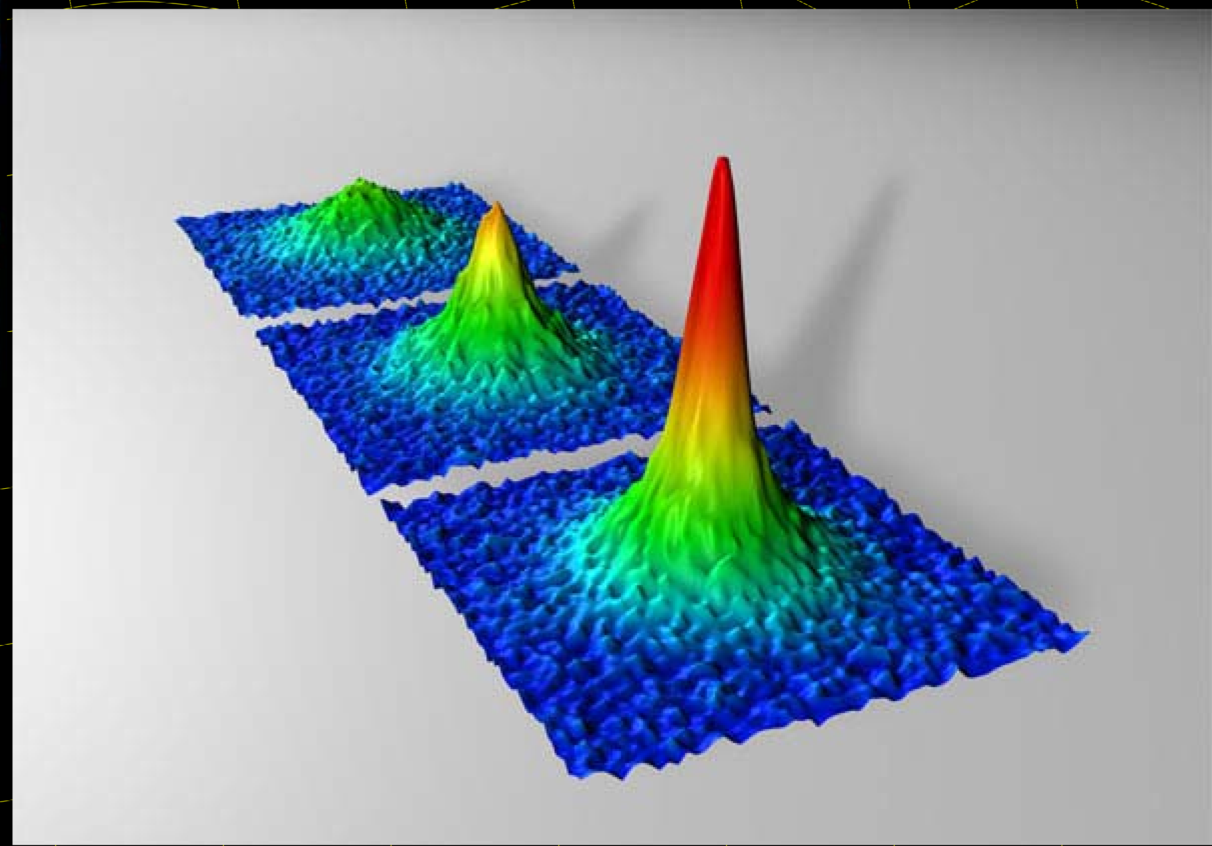


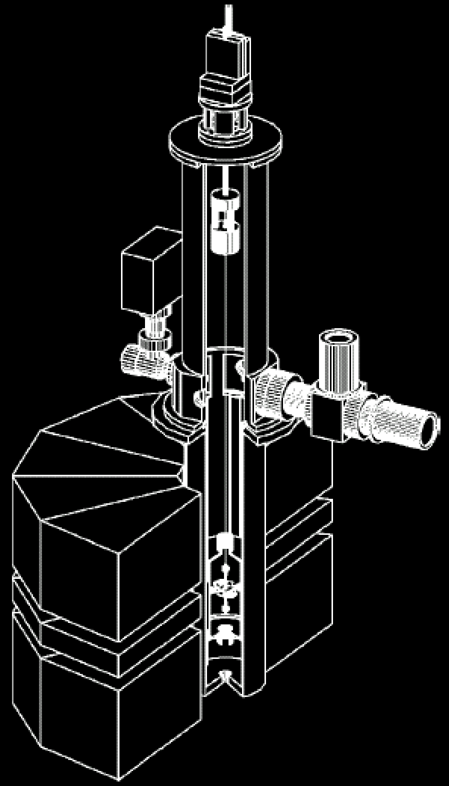
Cryogenics

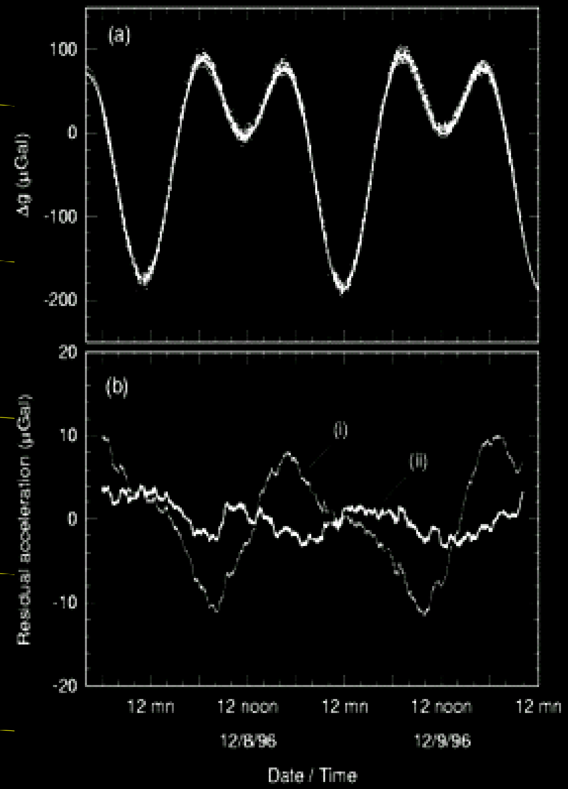
The reference bodies

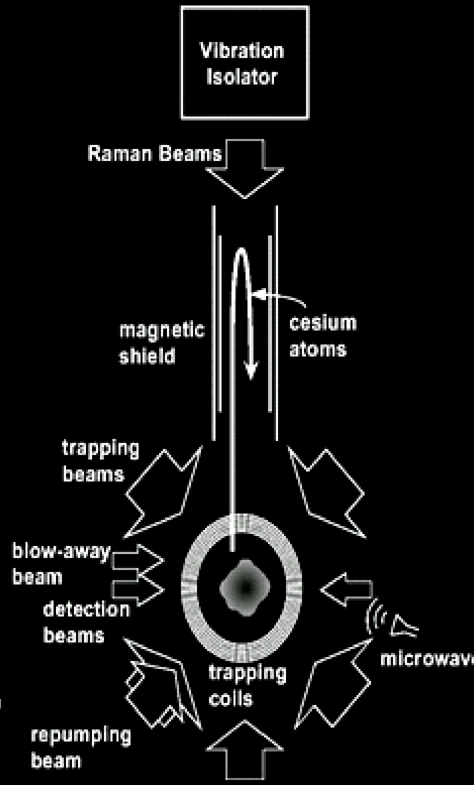
Or ultra-cold neutral atoms (and molecules) as a reference











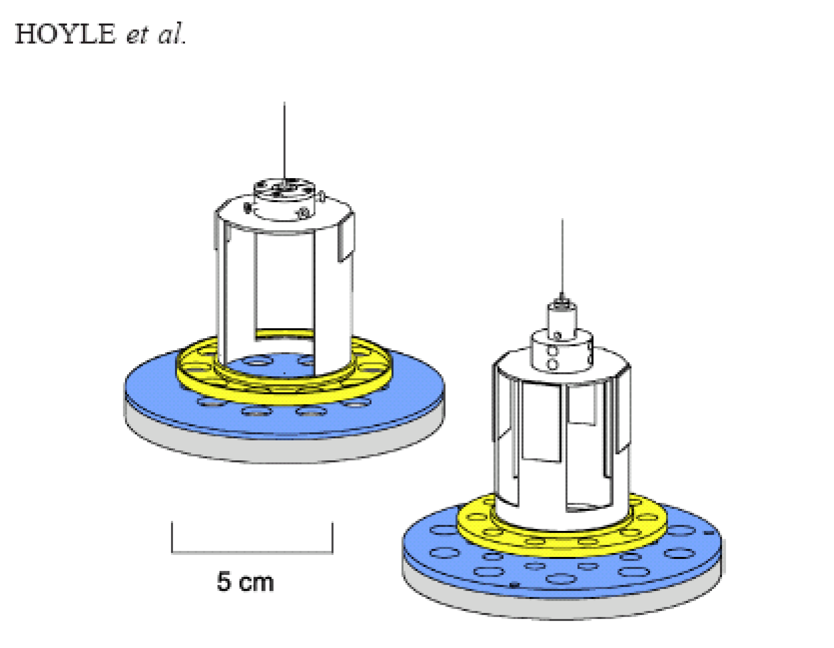
E. Adelberger's group

S. Chu (Stanford), A. Peters (Konstanz) and other groups

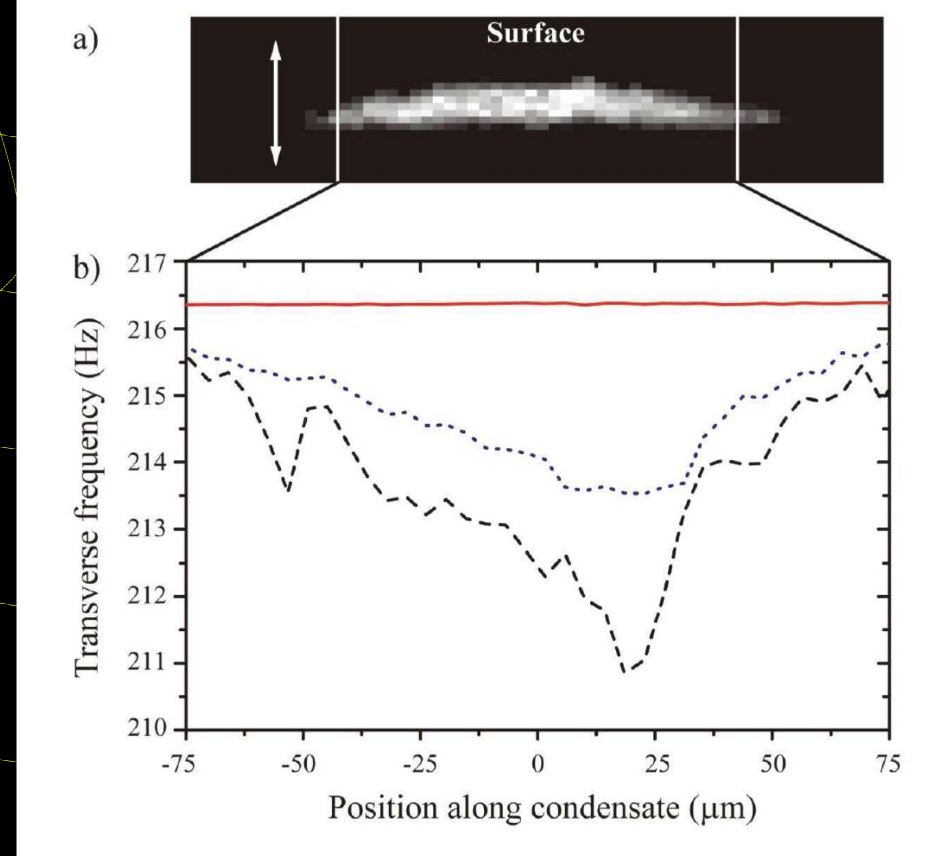
Equivalence Principle

Test-mass (torsion balance)

Atomic fountains



E. Adelberger's group

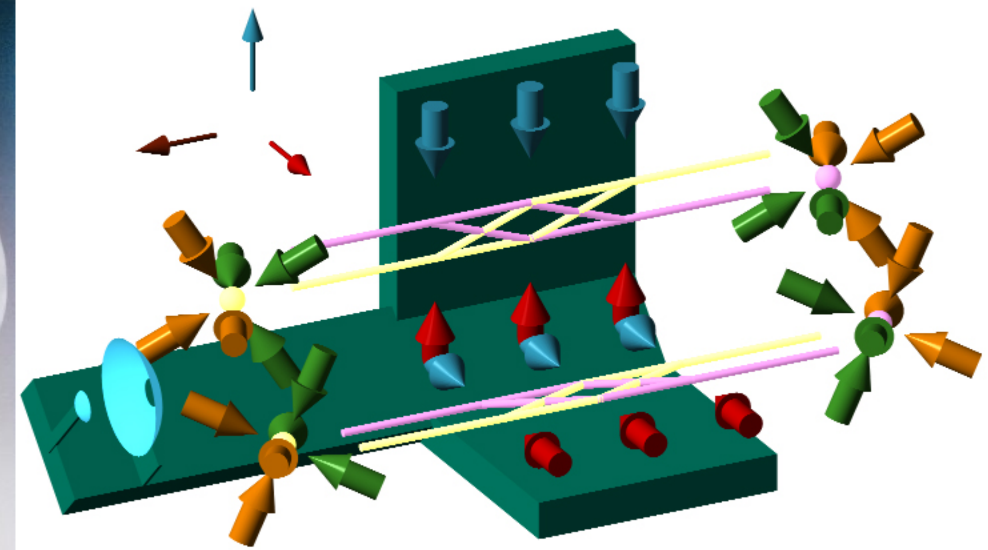


E. A. Cornell's group

Short range forces

Test-mass (torsion balance)

Cold-atoms (BEC near surfaces)



Dragging of frames

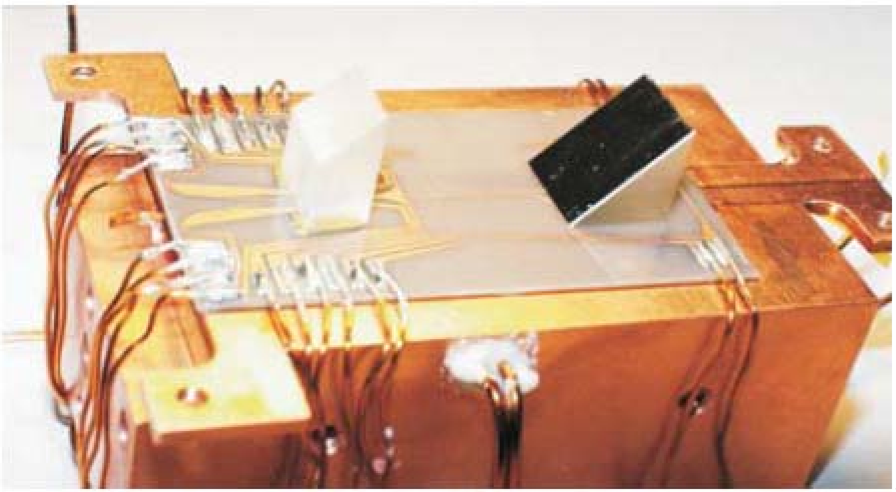
Test-mass (GP-B)

Cold-atom interferometer (Hyper)

An Atom Michelson Interferometer on a Chip Using a Bose-Einstein Condensate

Ying-Ju Wang,[1] Dana Z. Anderson,[1] Victor M. Bright,[2] Eric A. Cornell,[1] Quentin Diot,[1] Tetsuo Kishimoto,[1*]
Mara Prentiss,[3] R. A. Saravanan,[2] Stephen R. Segal,[1] and Saijun Wu[3]
[1] *Department of Physics, University of Colorado, and JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309-0440, USA*
[2]*Department of Mechanical Engineering, University of Colorado, Bould*
[3]*Department of Physics, Harvard University, Cambridge, Mas*

(b)



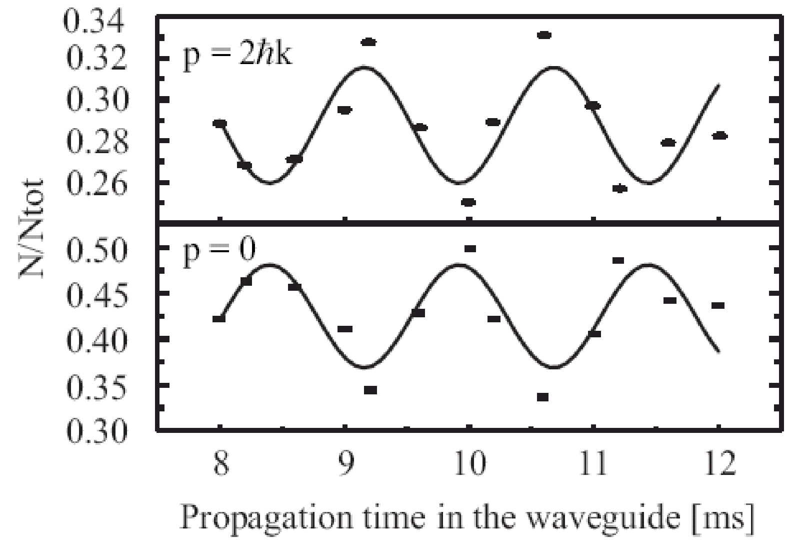
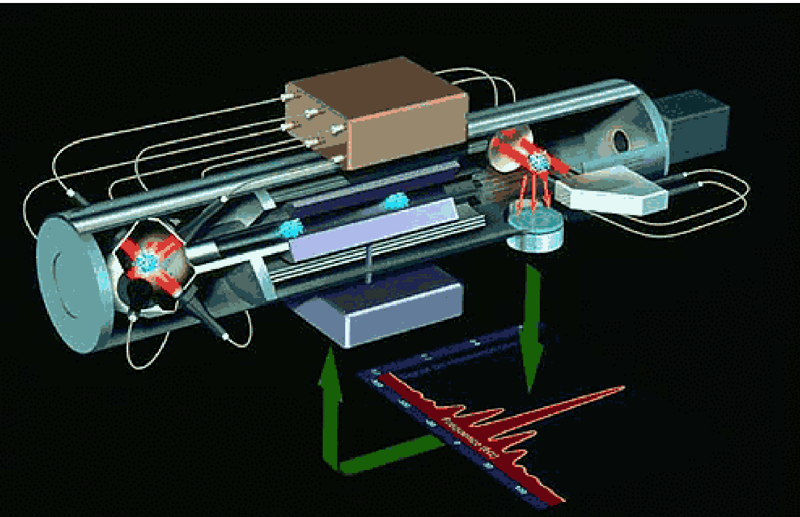
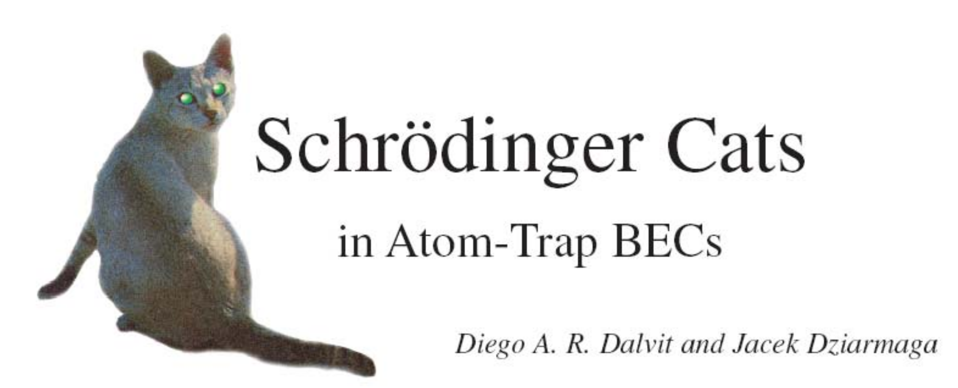


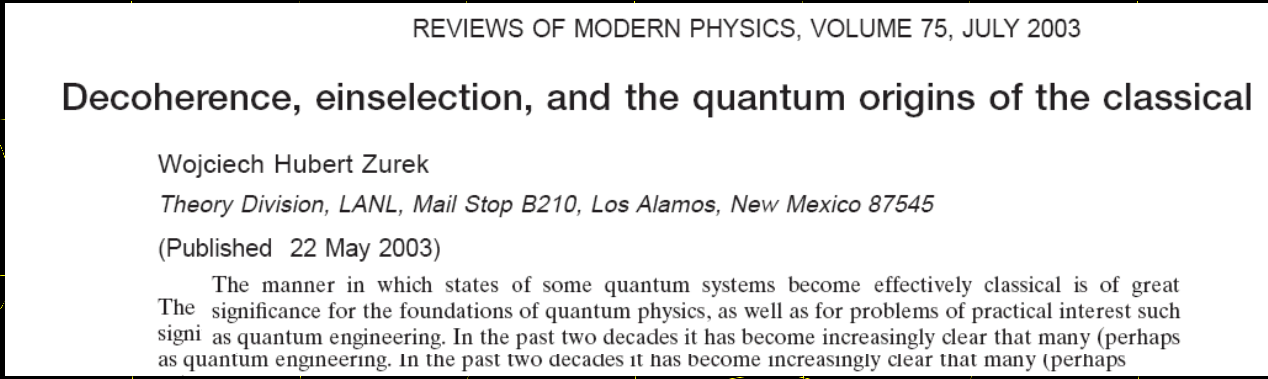
FIG. 5. Interference fringes after about 10 ms propagation in the waveguide.



Pharao



High resolution quantum coherence on space-time background


REVIEWS OF MODERN PHYSICS, VOLUME 75, JULY 2003

Decoherence, einselection, and the quantum origins of the classical

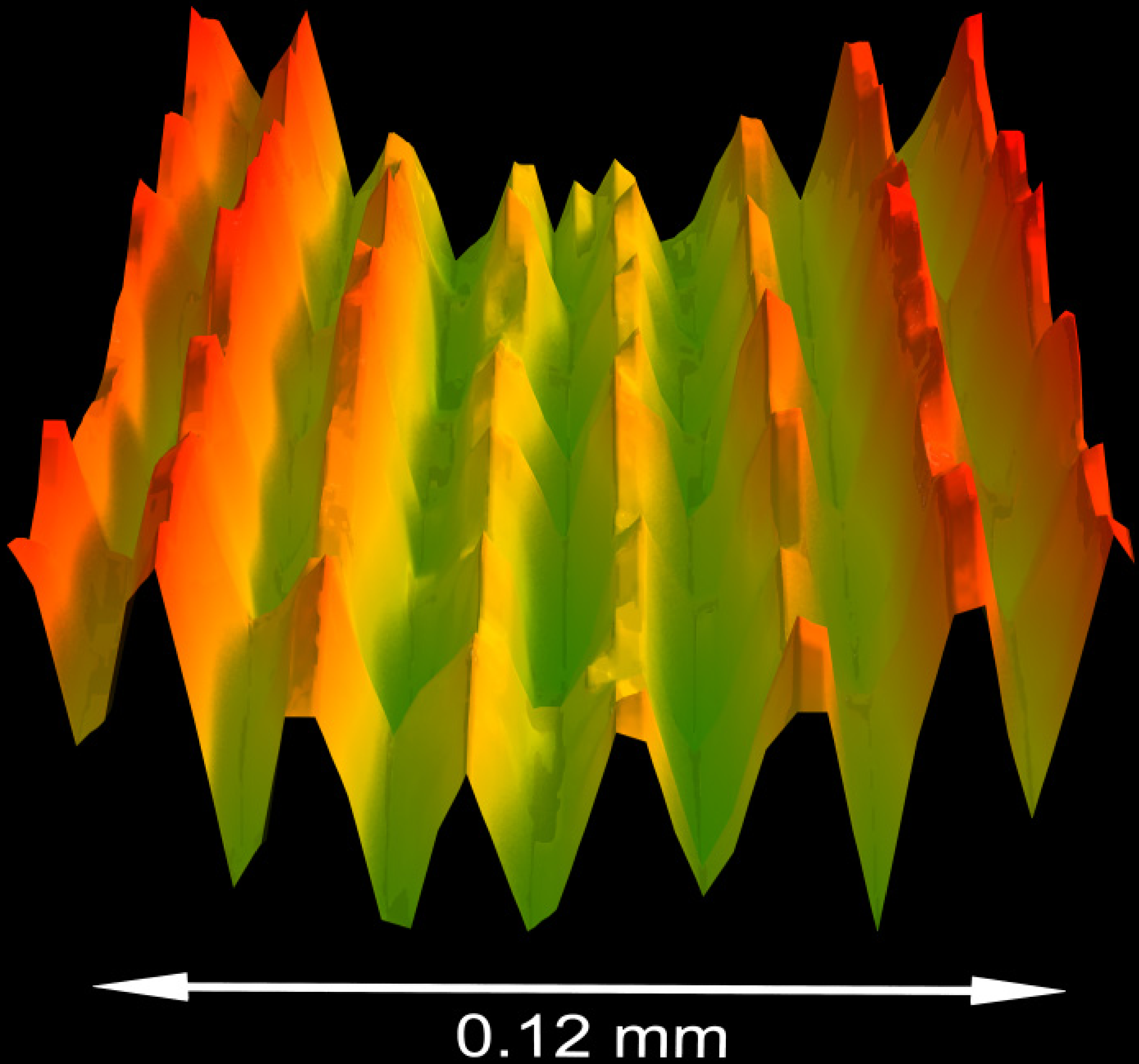
Wojciech Hubert Zurek

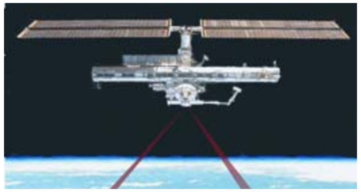
Theory Division, LANL, Mail Stop B210, Los Alamos, New Mexico 87545

(Published 22 May 2003)

The manner in which states of some quantum systems become effectively classical is of great significance for the foundations of quantum physics, as well as for problems of practical interest such as quantum engineering. In the past two decades it has become increasingly clear that many (perhaps

The
signi
as quantum engineering. In the past two decades it has become increasingly clear that many (perhaps


0.12 mm



Quantum Entanglement in Space Experiments

T. Jennewein, [1]
M. Aspelmeyer, R. Kaltenbaek, C. Brukner, A. Zeilinger [1,2]
M. Pfennigbauer, W. R. Leeb [3]

[1] Insitut für Quantenoptik und Quanteninformation, Austrian Academy of Sciences
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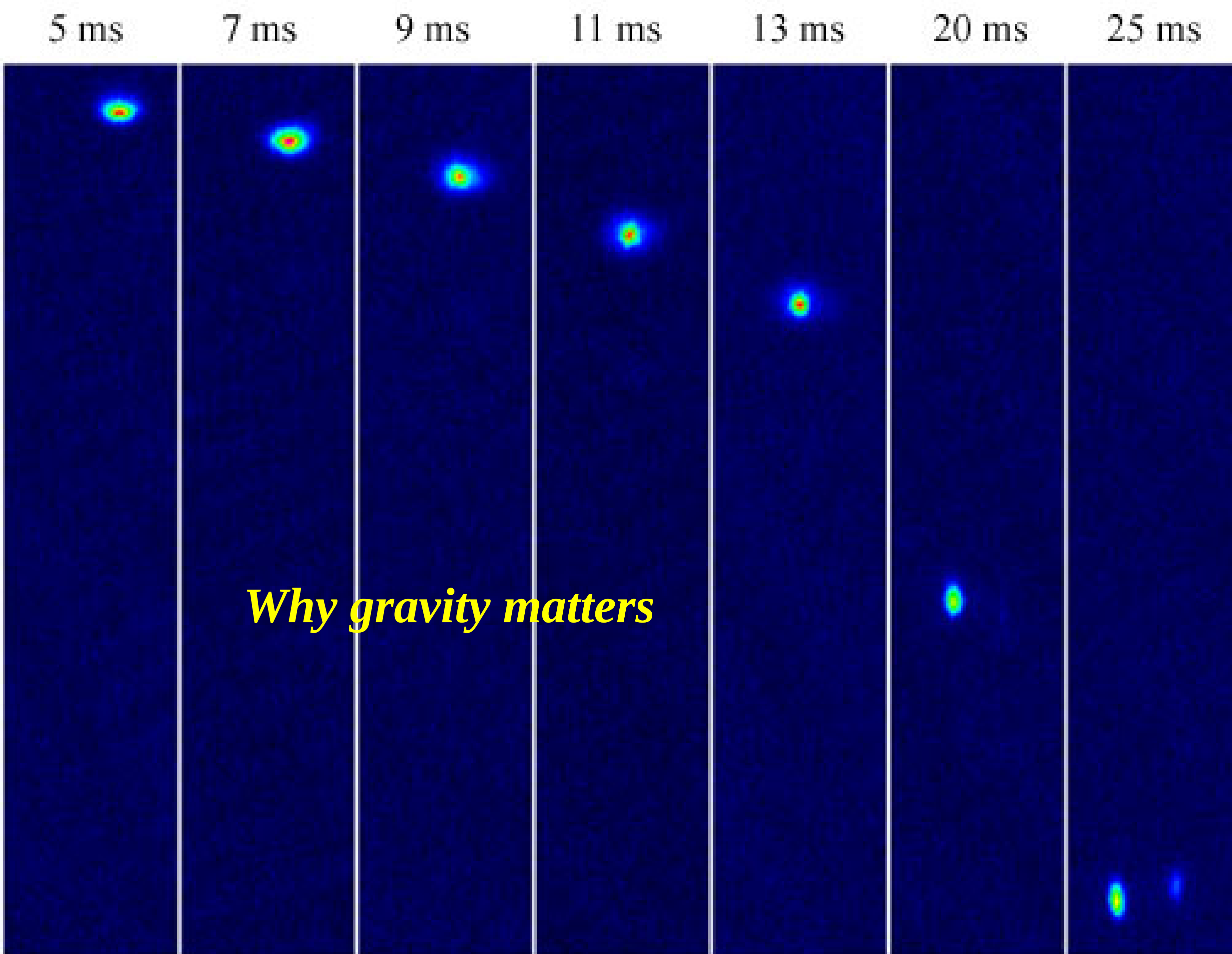
[3] Institut für Nachrichtentechnik und Hochfrequenztechnik, Technische Universität Wien, Vienna, Austria

Long-distance distribution of quantum entanglement II

Why gravity matters



Parameter	Present experiments on ground	In μ-gravity environment
Free evolution	Time: 10 ms < t < 80 ms free fall	5s < t < 100 s
Measurement time	Time: 10 ms < t < 100 ms	Up to 100 s
Temperature	typically: 1 nK, record: 500 pK	PK to fK
Dynamics	Trap frequencies: f > 1Hz	0.01 Hz (orbital platform) < f < 1 Hz
Size of trapped condensate	L: up to several 100 μm	100μm < L < 10 mm
Matter-wave dimensions	Diameter: d < 1 mm	Diameter: 1mm < d < 100 mm
Healing length	L: < 1 μm	1μm < L < 100 μm

Coupling wave functions $\psi = \psi_o e^{i\phi(\vec{r},t)} = \psi_o e^{i\frac{\vec{p}\cdot\vec{r} - E\cdot t}{\hbar}}$

and their phase shifts: $\Delta\phi = \frac{1}{\hbar}\int \vec{p}\cdot d\vec{r} - \frac{1}{\hbar}\int E dt$

to gravitational fields $\vec{p} \rightarrow \vec{p} + mc\vec{h}_o$ $E \rightarrow E + mc^2 h_{oo}$

$$ds = g_{ij}dx^i dx^j = \left(\eta_{ij} + h_{ij}\right)dx^i dx^j$$

$$\vec{h}_o \equiv \left\{h_{01}, h_{02}, h_{03}\right\}$$

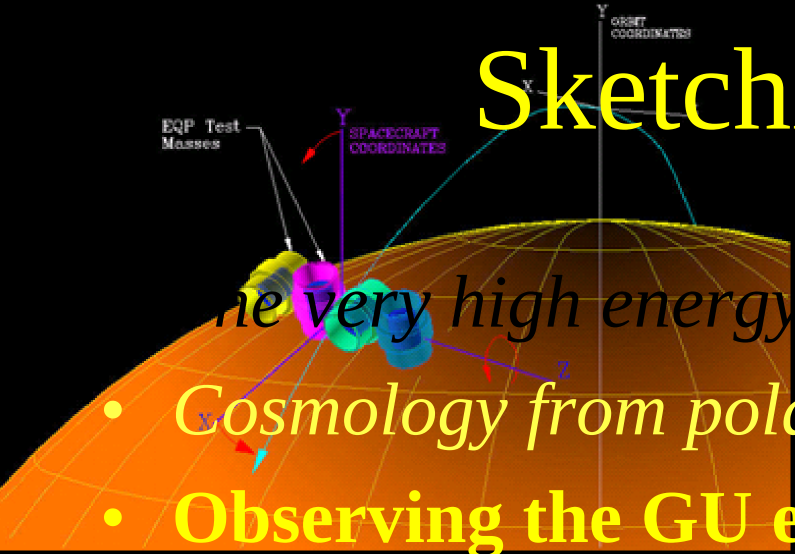
$$c^2\vec{\nabla}h_{oo} \approx \vec{g} \qquad \frac{1}{2}c\nabla \times \vec{h}_o \approx \vec{\Omega}$$

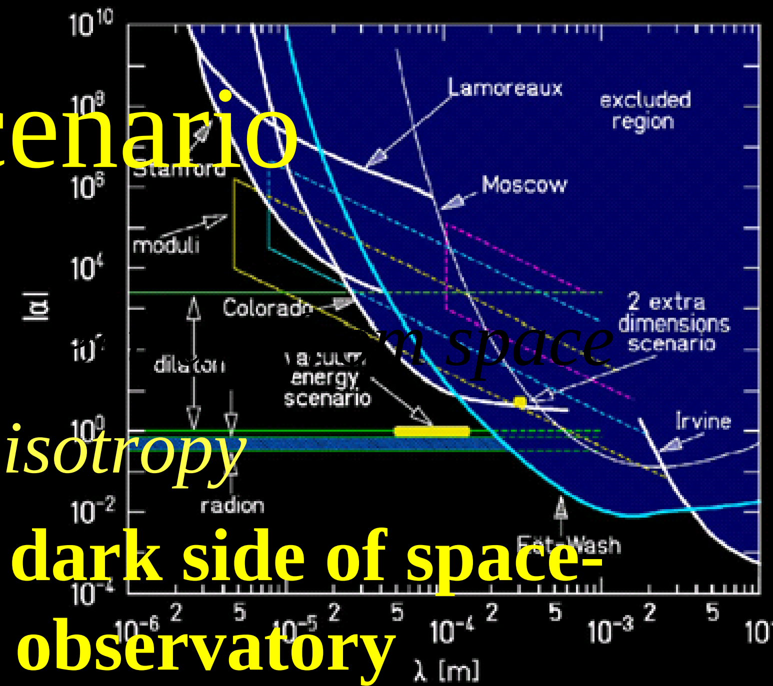
$$\psi_o e^{i\frac{\vec{p}\cdot\vec{r}-E\cdot t}{\hbar}} \qquad E \to E + mc^2 h_{oo}$$

$$\frac{\partial \Delta\phi}{\partial t} \approx \frac{mc^2}{\hbar}\Delta h_{oo} \approx 10^{24}\frac{rad}{s}\Delta h_{oo}$$

Gravity is the ultimate disturbance on quantum phase

Sketching a scenario





- *…he very high energy … m space*
- *Cosmology from polarization anisotropy*
- **Observing the GU era and the dark side of space-time with a gravitational wave observatory**
- **A laboratory in free-fall to explore beyond the current paradigm of fundamental physics**