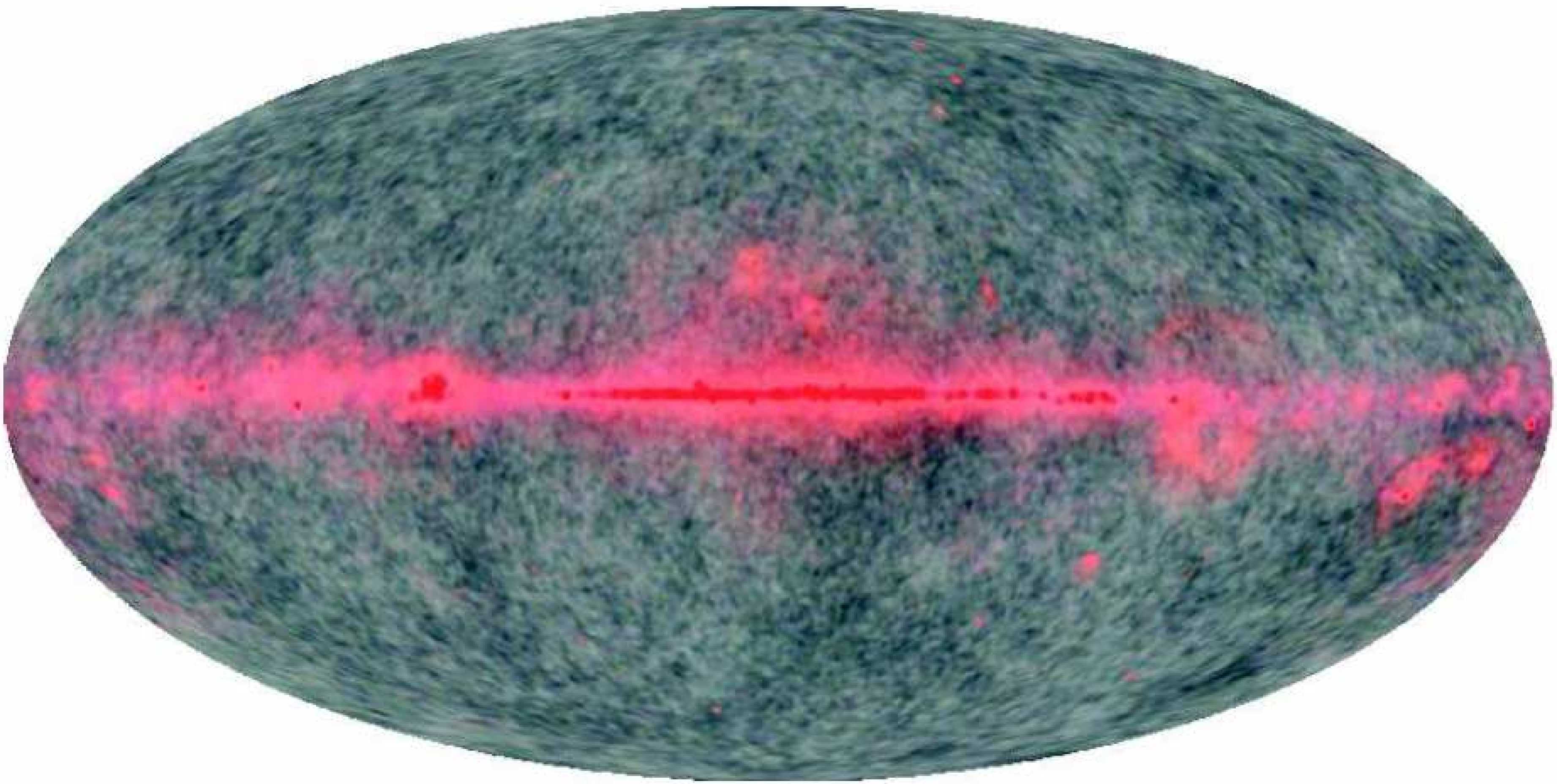
Laboratory Tests of Gravity Workshop
Eöt-Wash Laboratory
Jan 5. 2007

Schedule:

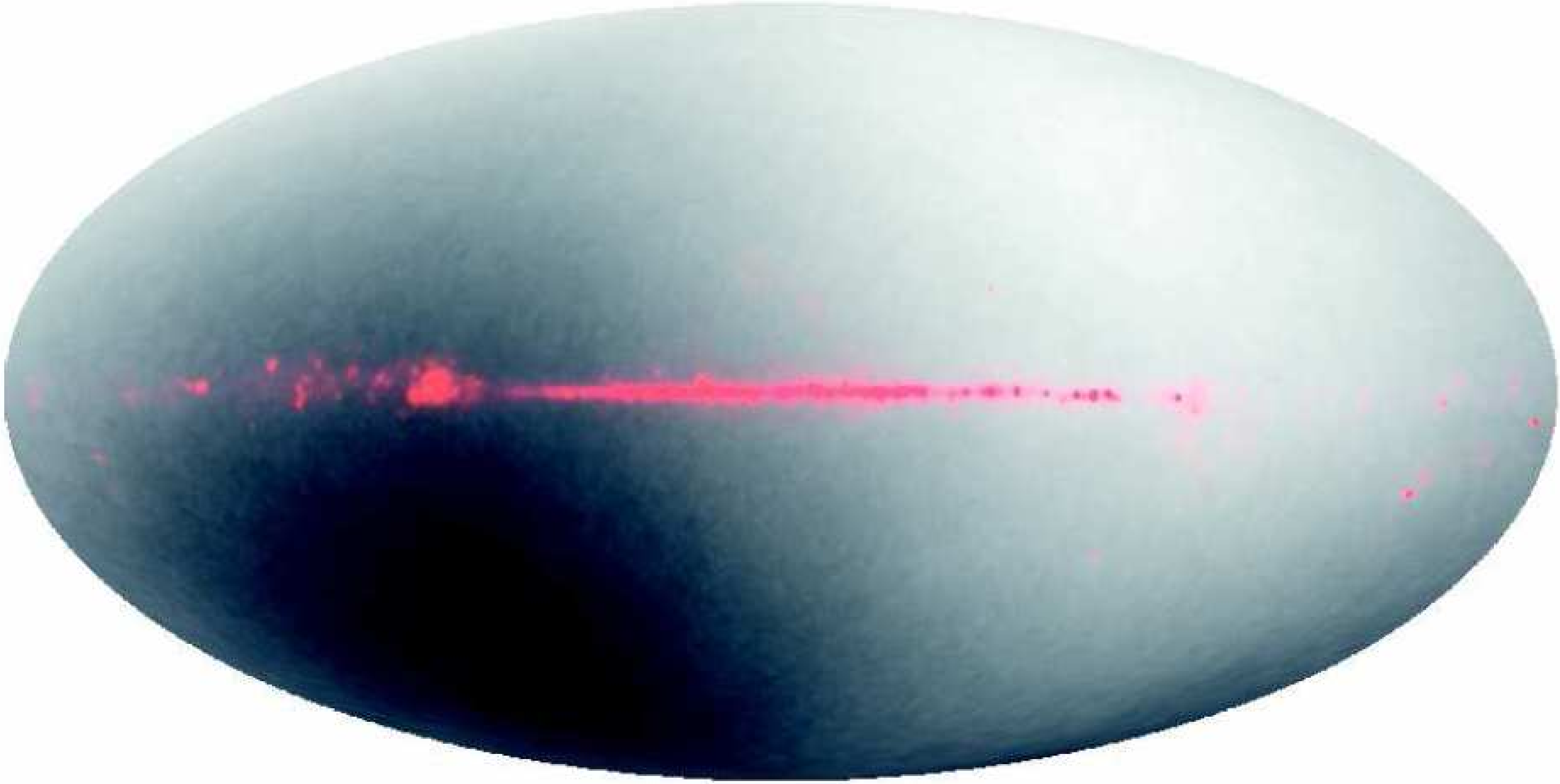
1:00 Welcome and introductions
1:10 Overview of lab tests of gravity (Eric Adelberger)
1:25 Tests of the gravitational inverse-square law (Eric Adelberger)
1:45 Tests of Einstein's Equivalence Principle (Stephan Schlamminger)
2:05 Measurements of Newton's constant G (Jens Gundlach)
2:25 First laboratory tour
2:55 Coffee, cookies and discussion
3:20 Lunar Laser Ranging (James Battat)
3:40 LISA gravitational wave detector (Scott Pollack)
4:00 Preferred frame (Lorentz invariance) tests (Claire Cramer)
4:20 Second lab tour
5:00 Bus arrives to pick up participants

- Problems in unifying gravity with the other forces in physics have convinced many of us that we must be missing something BIG.
- Important to test cherished concepts for possible clues about what that could be
- $1/r^2$ law
- Equivalence Principle
- Preferred frames?

WMAP view of the Anisotropy of the Cosmic Microwave Background



WMAP anisotropy before removing the effects of our velocity through the CMB



There really is a preferred frame set by the universe as a whole!

The Eöt-Wash® group in experimental gravitation

Faculty
- EGA
- Jens Gundlach
- Blayne Heckel

Staff
- Erik Swanson

Postdocs
- Seth Hoedl
- CD Hoyle
- Stephan Schlamminger

Current Grad students
- Claire Cramer
- Ted Cook
- Charlie Hagedorn
- William Terrano
- Todd Wagner

ISL
EP
spin

Primary support from NSF Grant PHY0355012 with supplements from the DOE Office of Science and to a lesser extent NASA

3 FAMOUS PROBLEMS WITH GRAVITY

- WHY IS GRAVITY SO WEAK?

  comparison of electrical & gravitational attractions of e and p at a given separation r.

  $$F_e = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} \qquad F_g = G\frac{m_1 m_2}{r^2}$$

  $$\frac{F_e}{F_g} = 2\times10^{39}$$

- WHY IS THE COSMOLOGICAL CONSTANT SO SMALL?
  - Einstein's biggest blunder?
  - discovery of cosmic acceleration (Type 1A supernovae)
  - particle-physics predictions for Λ (vacuum energy)

  $\sim 10^{120}$ larger than observed value!

  $\sim 10^{60}$ if supersymmetry is just around the corner

- WHAT IS THE DARK MATTER?

  we know that most of the "gravitational" effects in the universe are not produced by normal matter

Parameterising breakdowns of $1/r^2$ law

- Old-fashioned way

$$F(r) = G\frac{m_1 m_2}{r^{2+\epsilon}}$$

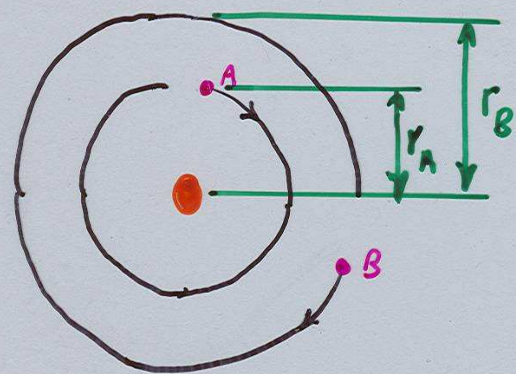
no theoretical basis

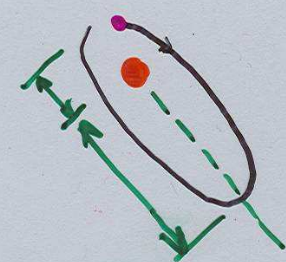
- modern way

$$F(r) = G\frac{m_1 m_2}{r^2}\left[1 + \alpha\left(1 + \frac{r}{\lambda}\right)e^{-r/\lambda}\right]$$

- exchange of boson with $m > 0$
- extra dimensions scenario when $r \sim R^*$

Any given test of the $1/r^2$ law is sensitive to a restricted range of length scales



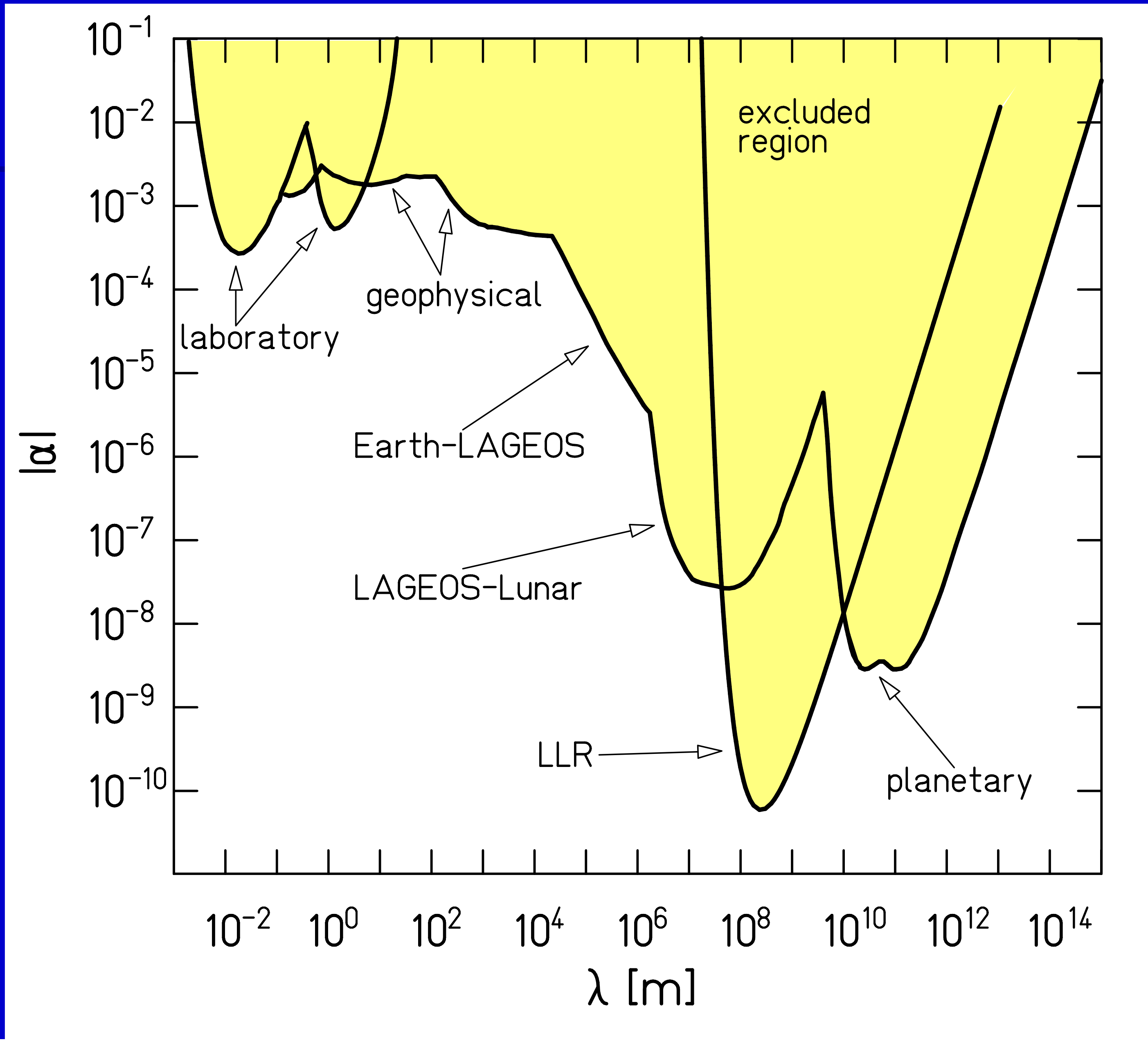


$$\frac{T_A^2}{r_A^3} = \frac{T_B^2}{r_B^3} \ ?$$

precession of perigee ?

∴ need many different approaches to cover a wide range of length scales

95% confidence limits as of 2000



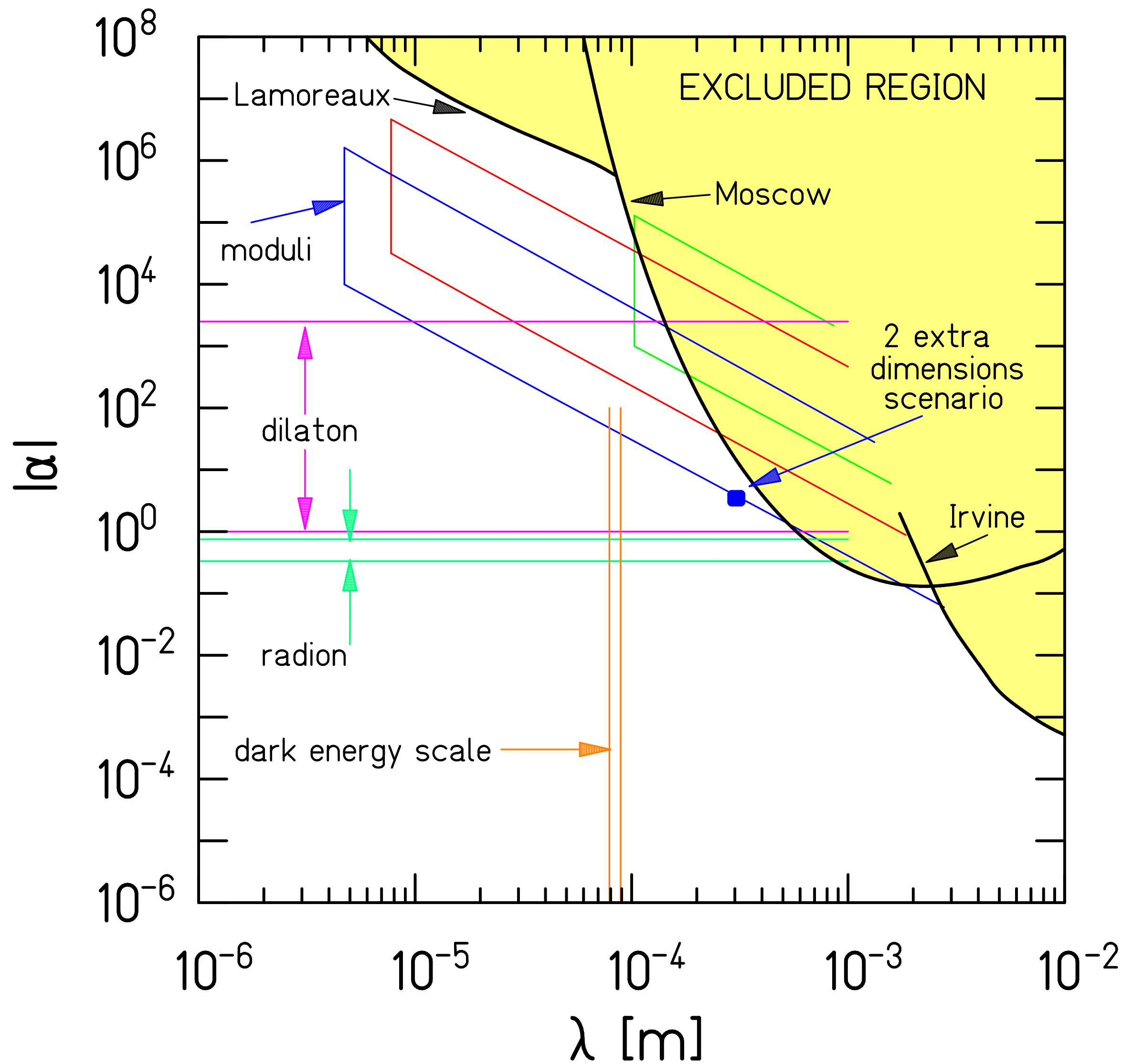
Does dark energy define a new fundamental length scale in physics?

$$\rho_{\rm d} \approx 3.8 \ \mathrm{keV/cm^3}$$

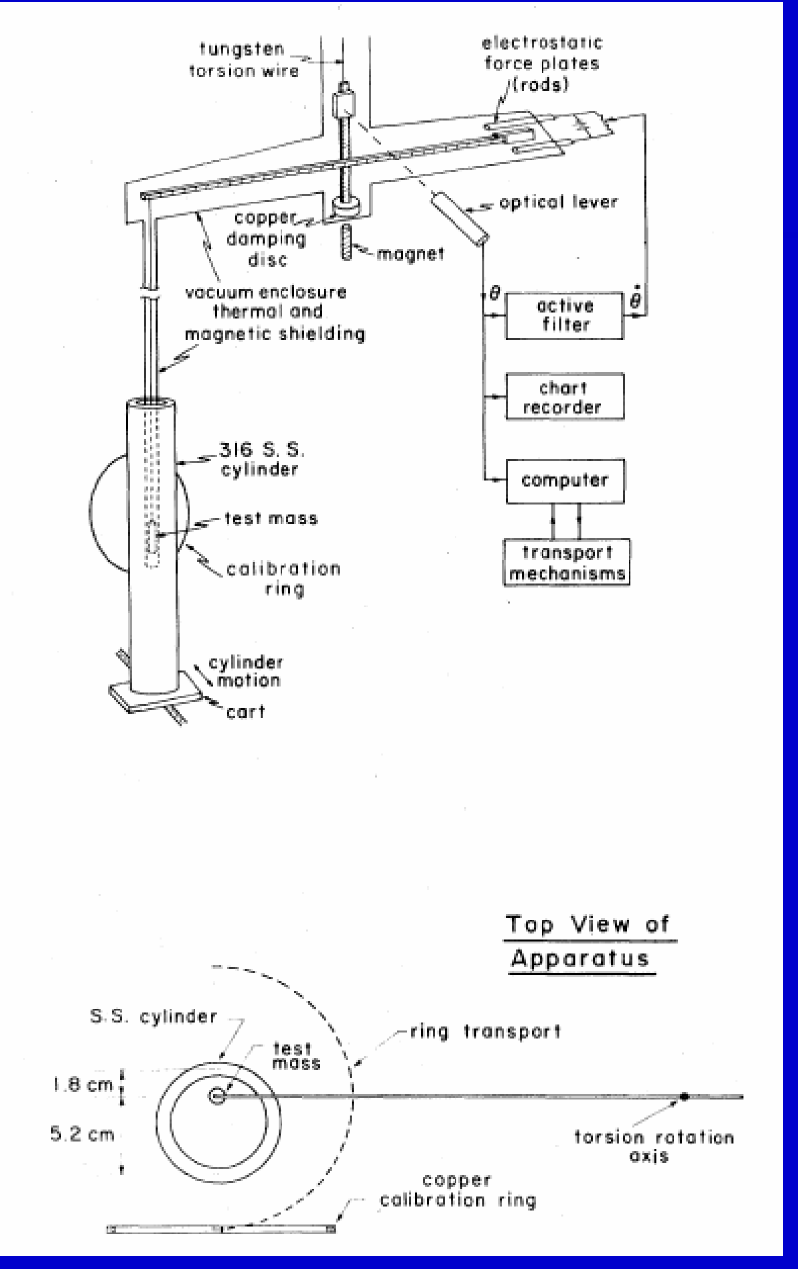
$$\lambda_{\rm d} = \sqrt[4]{\hbar c/\rho_{\rm d}} \approx 85 \ \mu\mathrm{m}$$

a second "Planck length"?

95% confidence limits as of 2000



the Irvine experiment



Hoskins et al. PRD 32, 3084 (1985)

The hierarchy problem

- mass scale of gravity

$$V_N(r) = G\frac{mm}{r} = \frac{\hbar c}{M_p^2}\frac{mm}{r}$$

$$\longrightarrow M_p = \sqrt{\hbar c/G} \sim 10^{16}\ \text{TeV}$$

- mass scale of particle physics

$$\longrightarrow M_{SM} \sim 1\ \text{TeV}$$

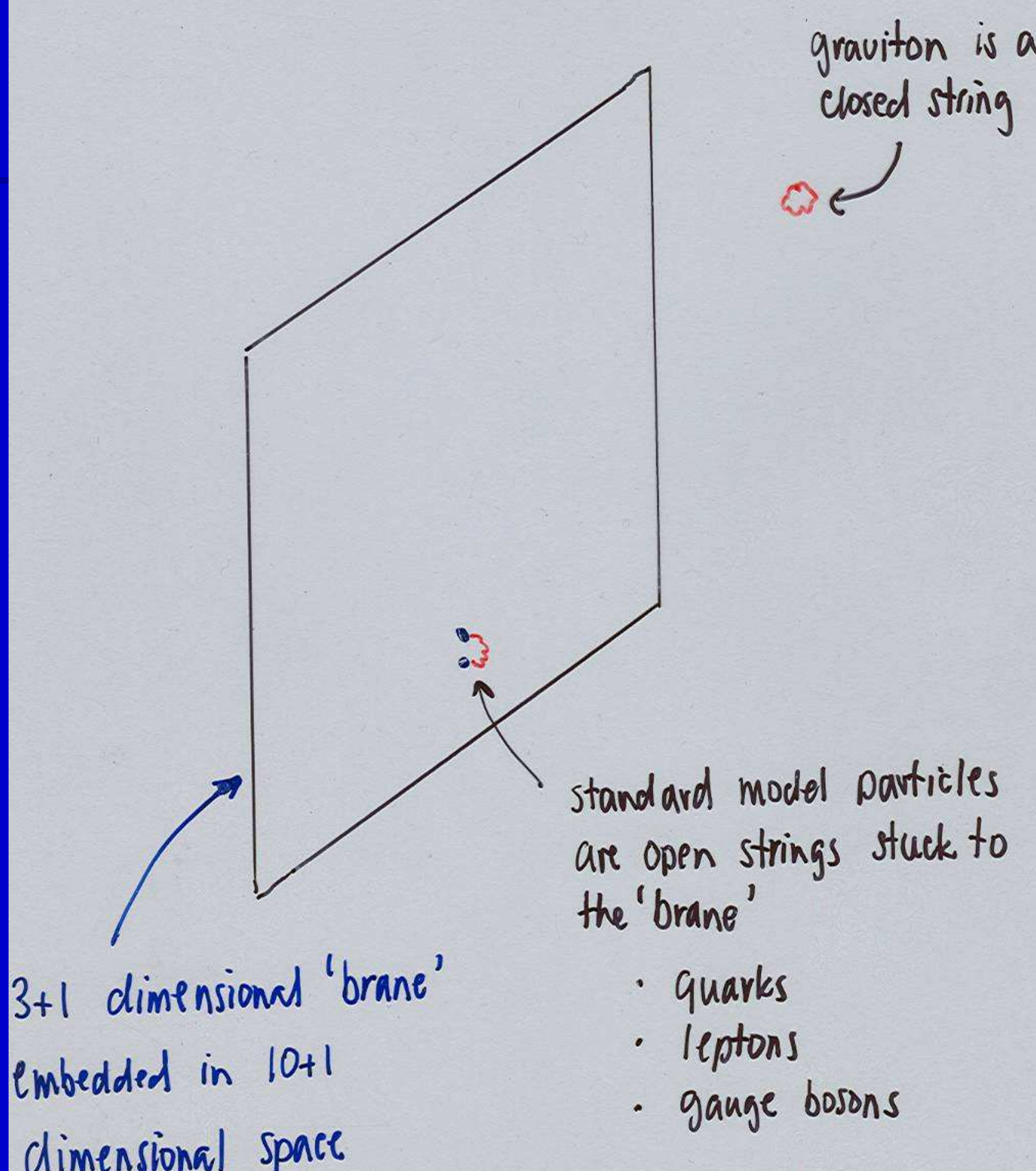
- Arkani-Hamed et al. solution to the problem

  Phys. Lett. B 429 (1998) 263

  assume that:

  - gravity propagates in all of the 7 extra dimensions of string theory
  - SM particles are confined to a 4-dim "brane"
  - some of the 7 extra dimensions are "large" while the remainder are "curled up" at the Planck scale $R_p = \sqrt{G\hbar/c^3} = 1.6\times10^{-33}$ cm

Only gravity propagates in all the space dimensions



Gauss's Law and extra dimensions

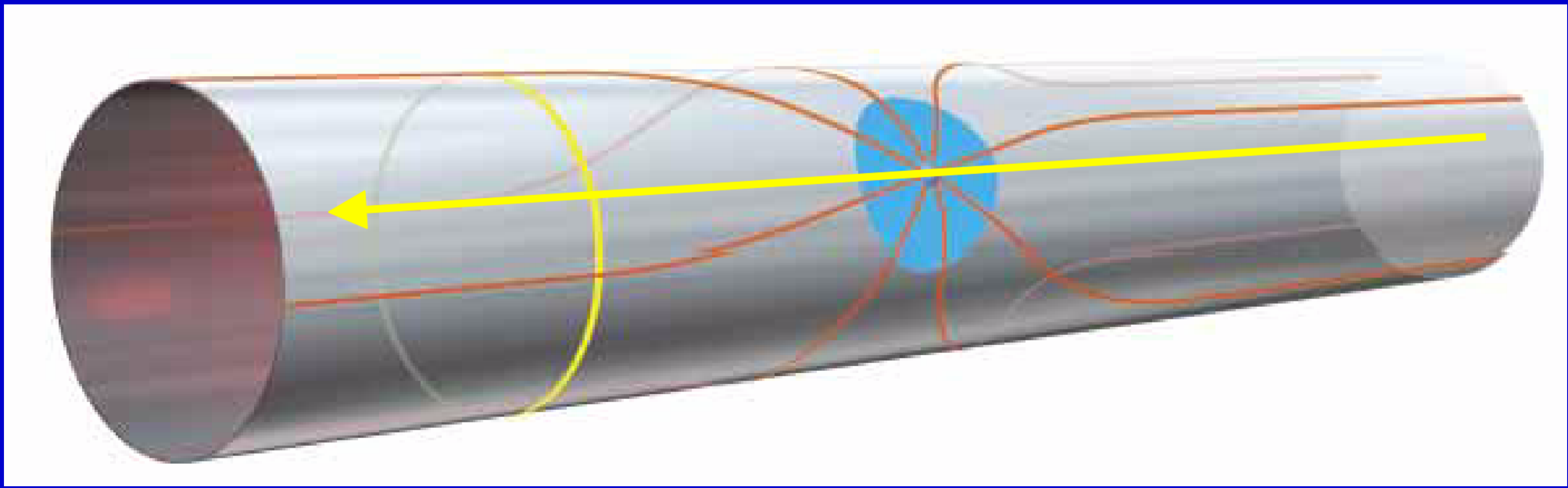
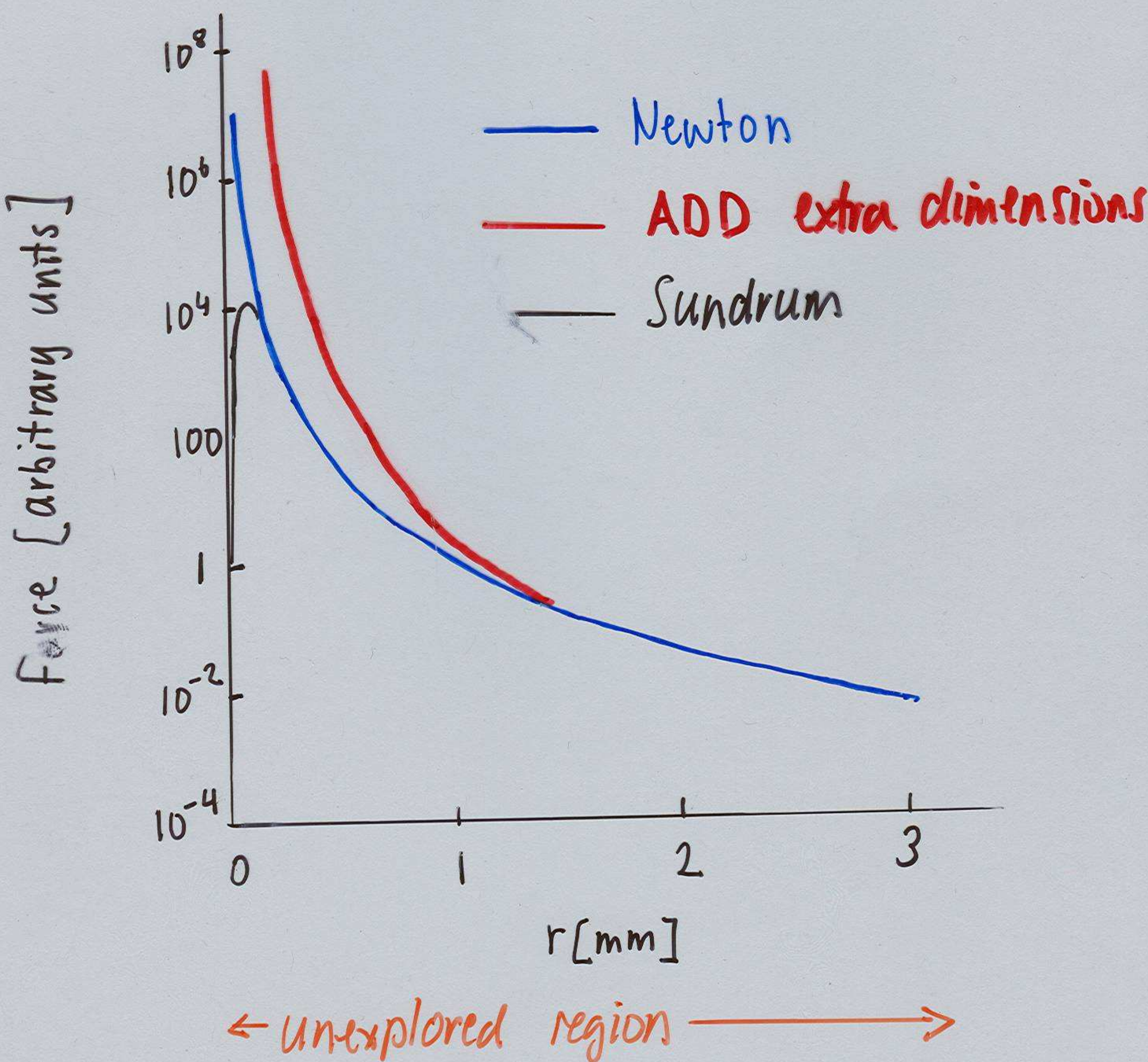


illustration from Savas Dimopoulis

Why might gravity get weak at separations less than 0.1 mm?

- the repulsive "gravity" deduced from cosmological data indicates that empty space has an energy of $\rho = 4\,\text{keV}/\text{cm}^3$.
- this corresponds to a length scale
  $d = \sqrt[4]{\hbar c/\rho} \sim 0.1\,\text{mm}$
- Sundrum's suggestion: the graviton string has a size of 0.1 mm. this prevents it from "seeing" the short-distance physics that produces most of the predicted vacuum energy
- prediction: gravity gets very weak at separations less than 0.1 mm

PREDICTIONS FOR 1/r² LAW BREAKDOWNS



The original Eöt-Wash instrument for testing the ISL at short length scales

Advantages:

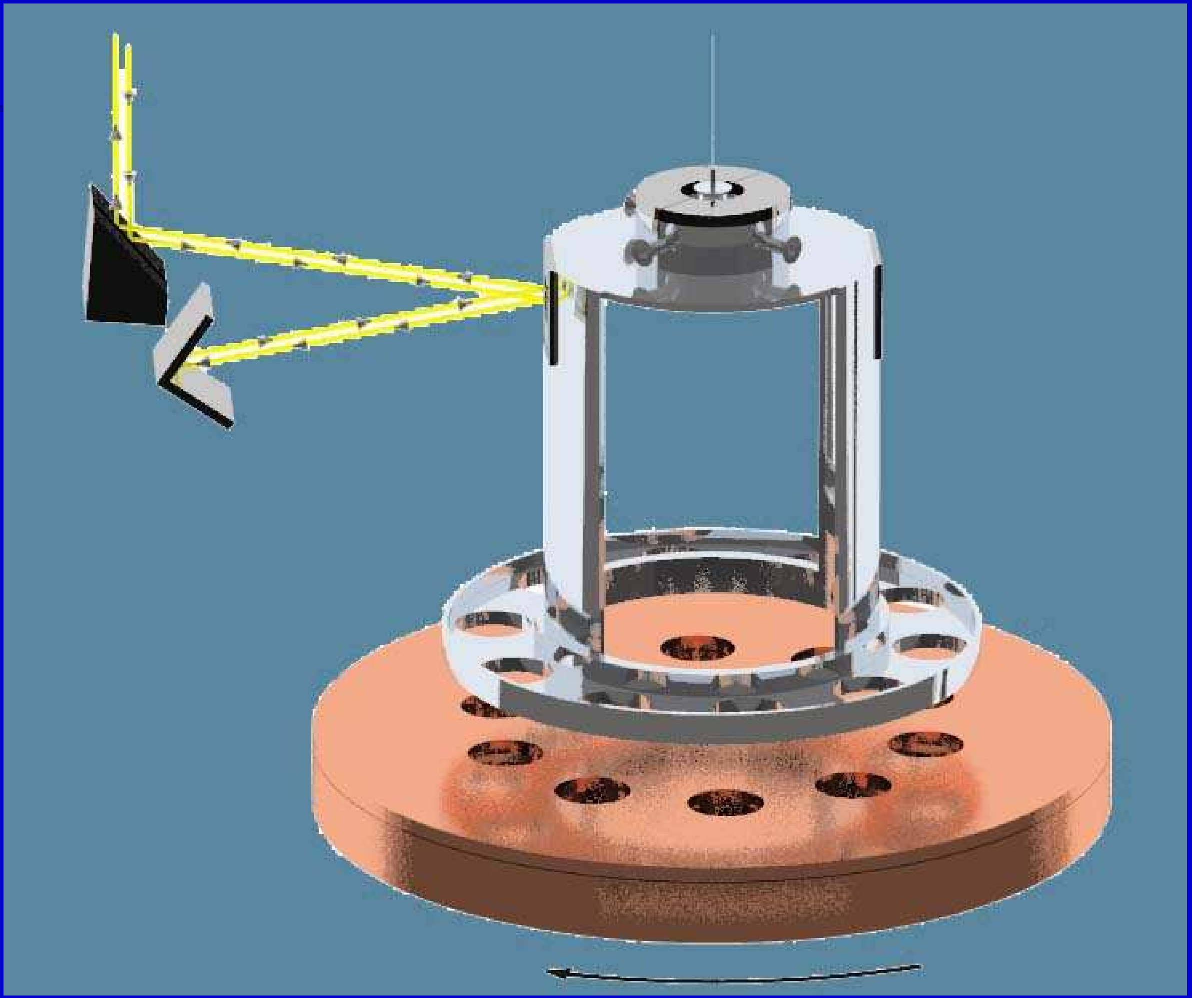
planar geometry

can place rigid conductor between detector & attractor

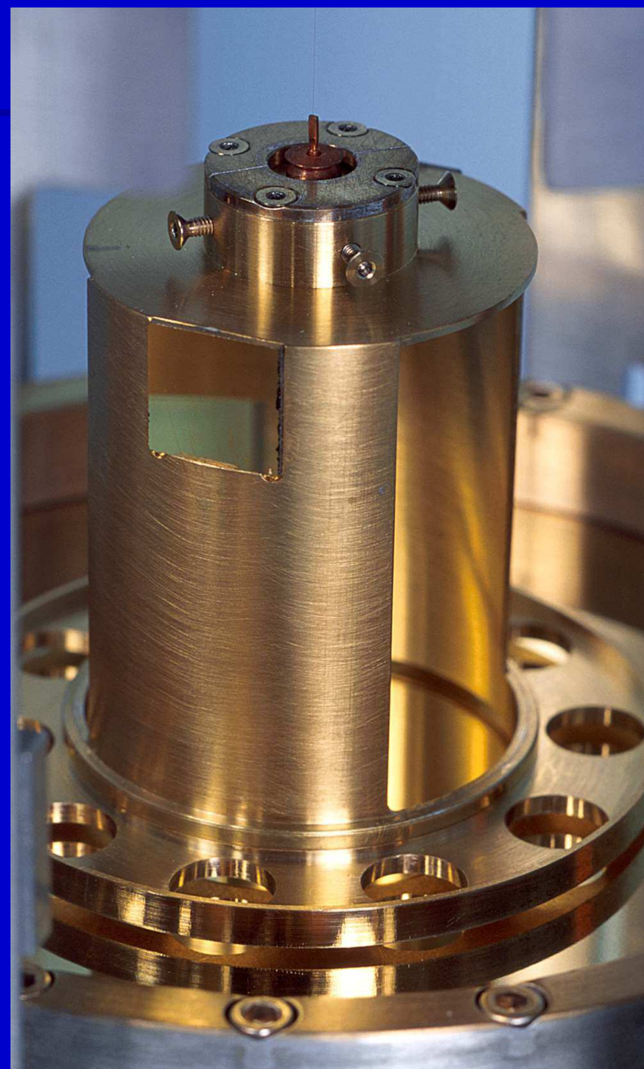
signal ω ≠ disturbance ω

approximate null for Newtonian gravity with no cancellation of new short-range physics

twist readout insensitive to pendulum & wobble modes

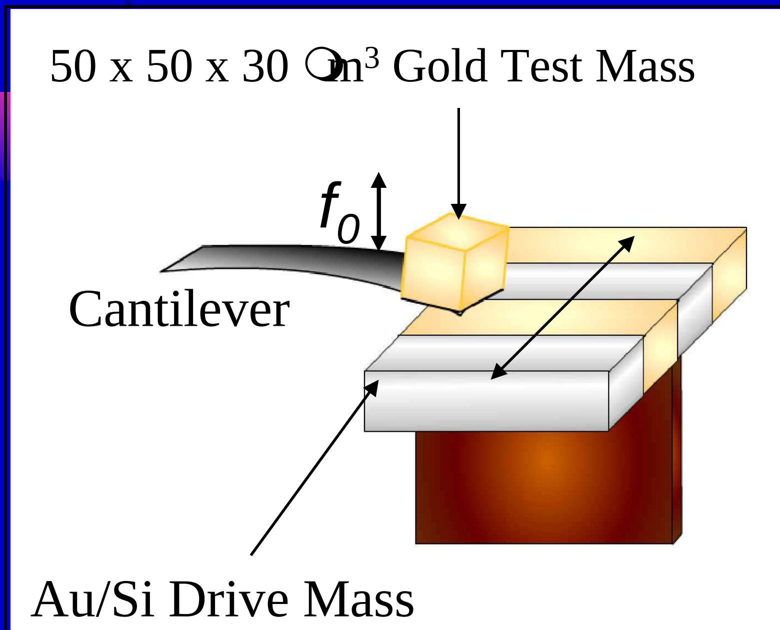


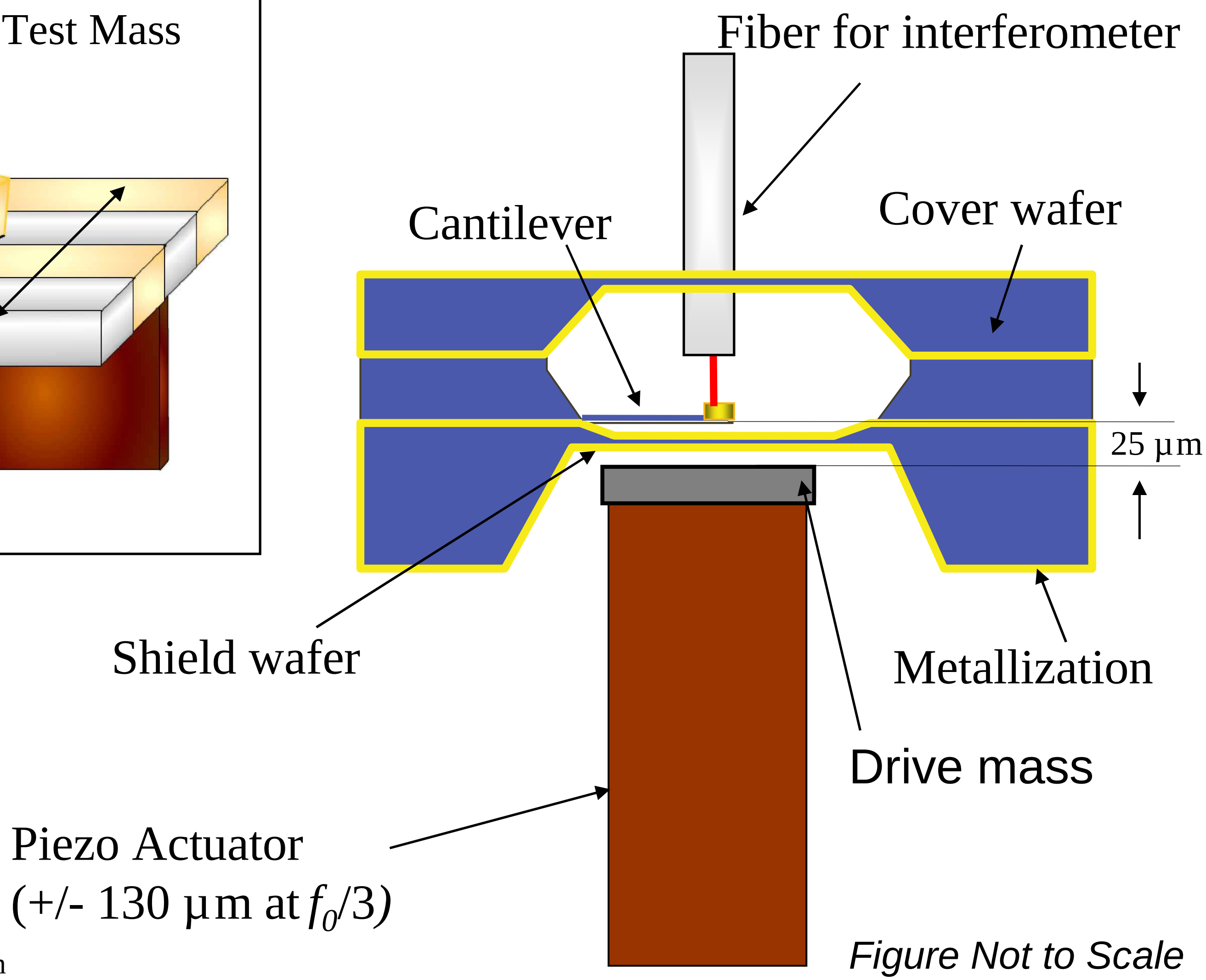
the 10-hole pendulum



PhD project of CD Hoyle

the Stanford ISL Experiment
using low-temperature micro-cantilevers

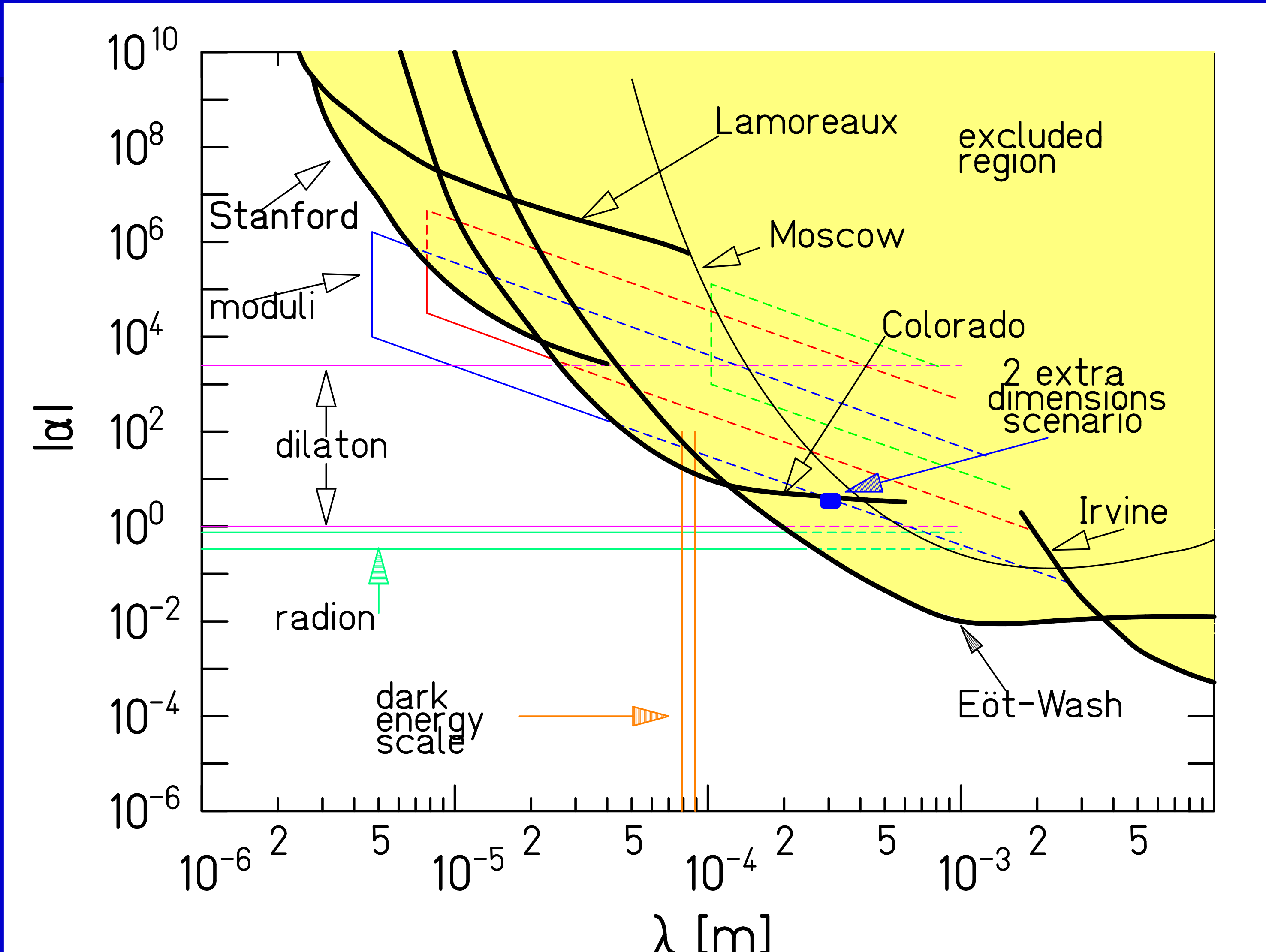




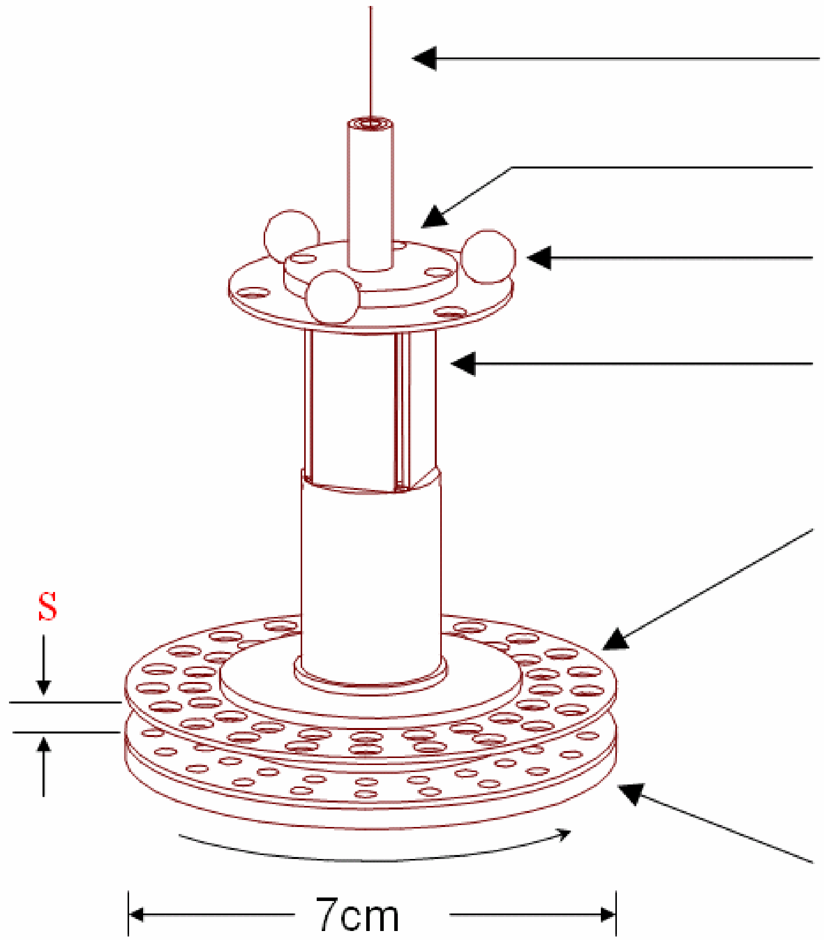
All Figures courtesy of S.J. Smullin

J. Chiaverini et al, PRL 90, 15101 (2003); S.J. Smullin et al., PRD 72, 122001 (2005)

95% confidence-level constraints as of 2004



the 42-hole pendulum



tungsten fiber, 20μm diameter, 80cm length

leveling mechanism

3 aluminum calibration spheres

4 mirrors for tracking angle of deflection

detector: 1mm thick molybdenum ring with 42 holes arranged in 21-fold rotational symmetry

not pictured, 10μm thick Au-coated BeCu membrane, electrostatic shield

attractor : **rotating pair** of discs with 21-fold rotational symmetry, holes in lower attractor out of phase with holes in upper attractor to **cancel Newtonian gravity**

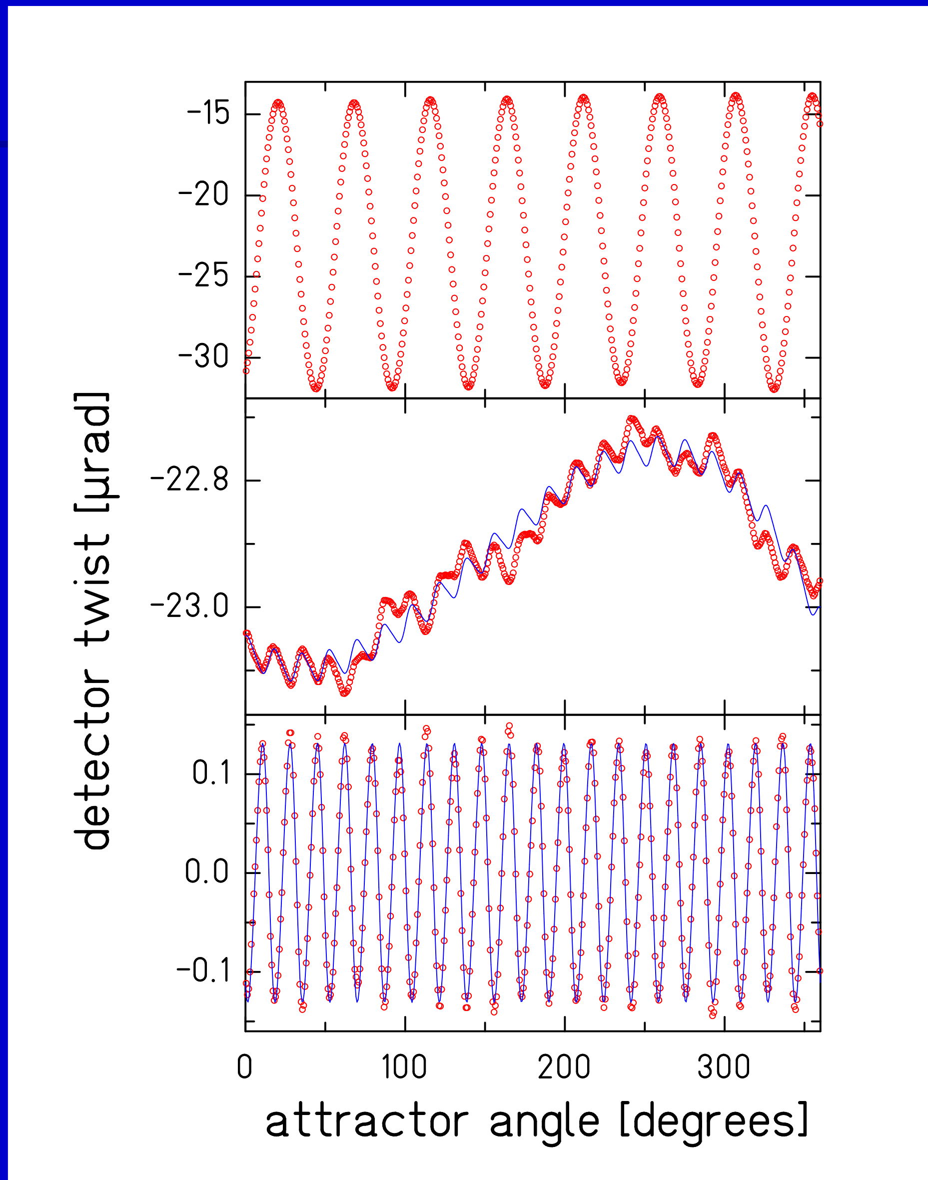
PhD project of Dan Kapner

Dan Kapner assembling the 42-hole instrument

It doesn't show, but he had a beard also

signal processing

these data
Were taken
with
calibration
turn-table
stationary

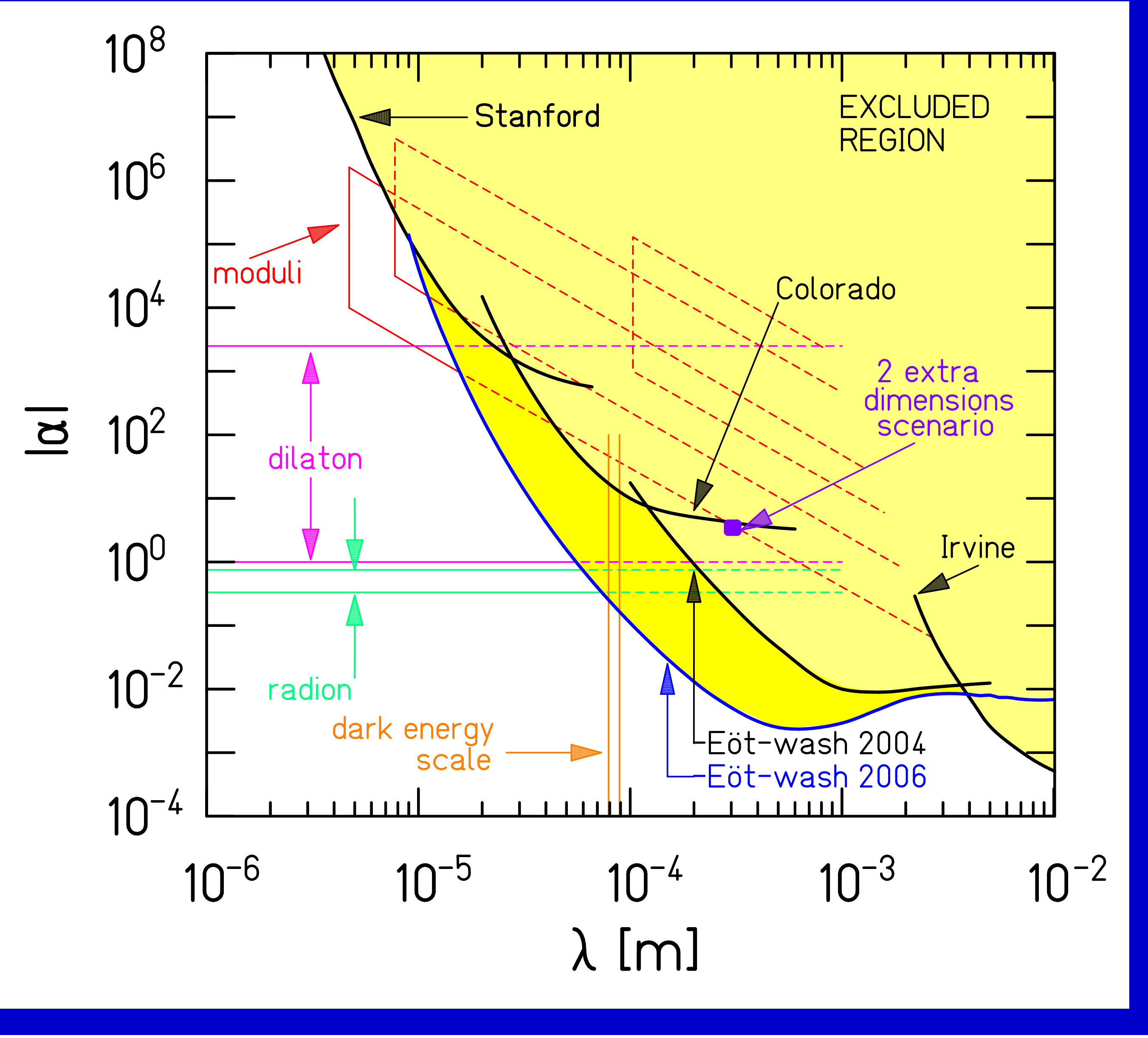


raw signal

2-pt digital filter
used in our
10-hole work

5-pt digital filer

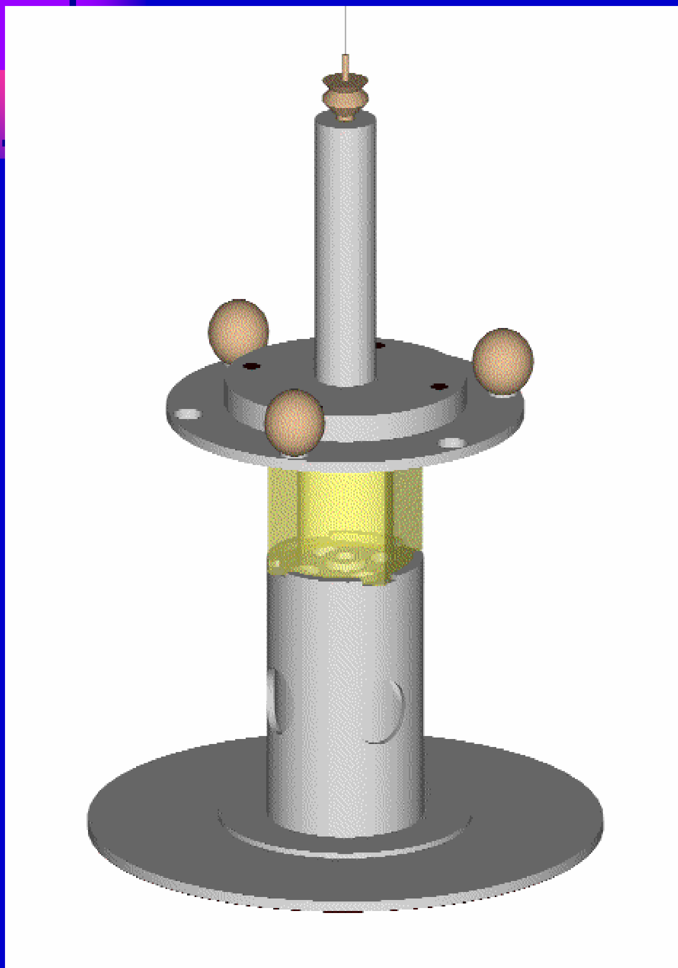
combined analysis of all 3 experiments

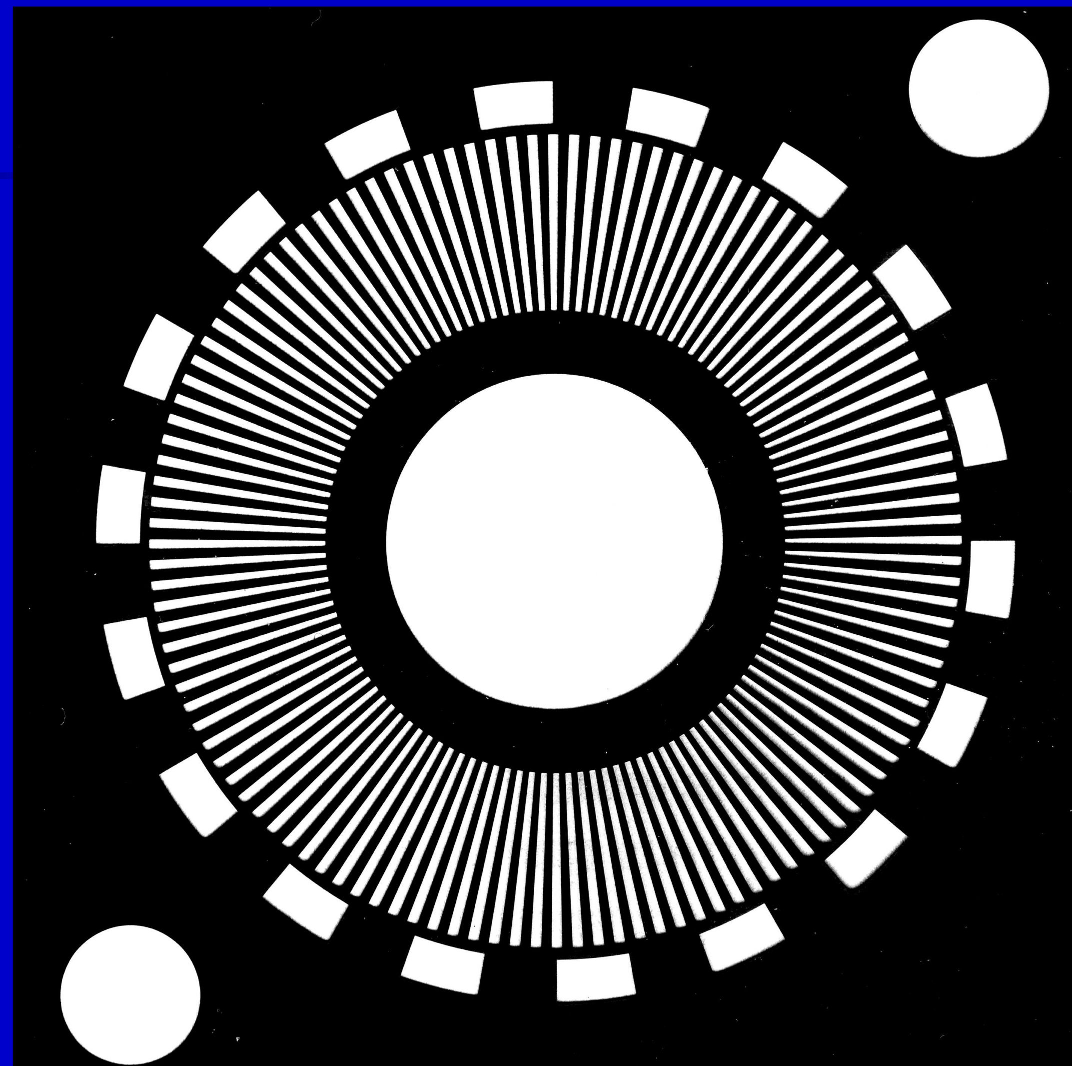


some “gee-whiz” numbers

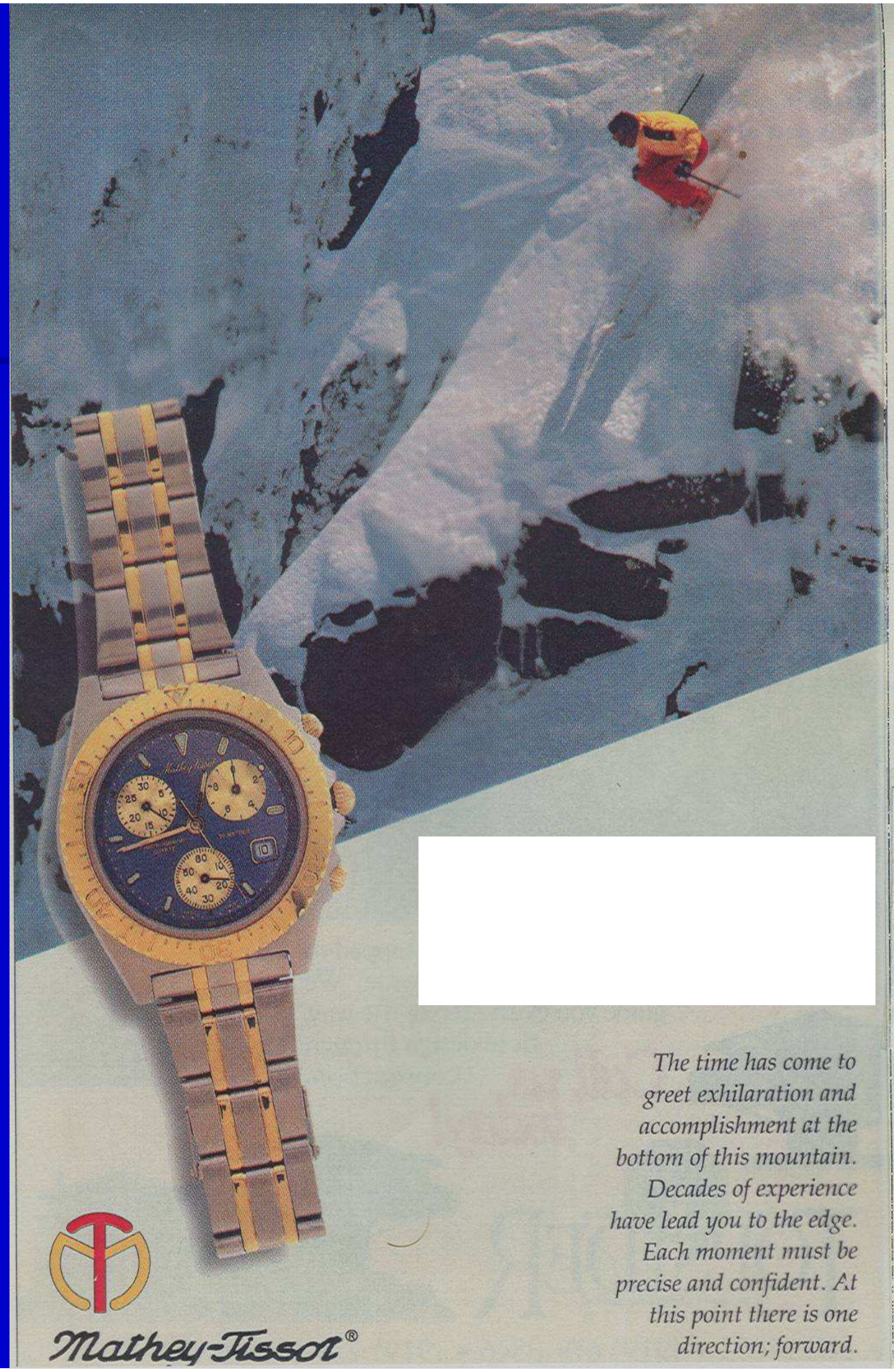
- typical error corresponds to light spot on detector moving by 0.6 nm
- typical torque in our 42-hole experiments is ~ 1fN-m with statistical uncertainty of ~0.006 fN-m
- corresponds to a force ~(40±0.24) fN
- suppose you could cut a postage stamp into 10^{12} equal pieces
- typical force is 60 times the weight of 1 of those pieces
- typical statistical error is ~1/3 the weight of 1 piece

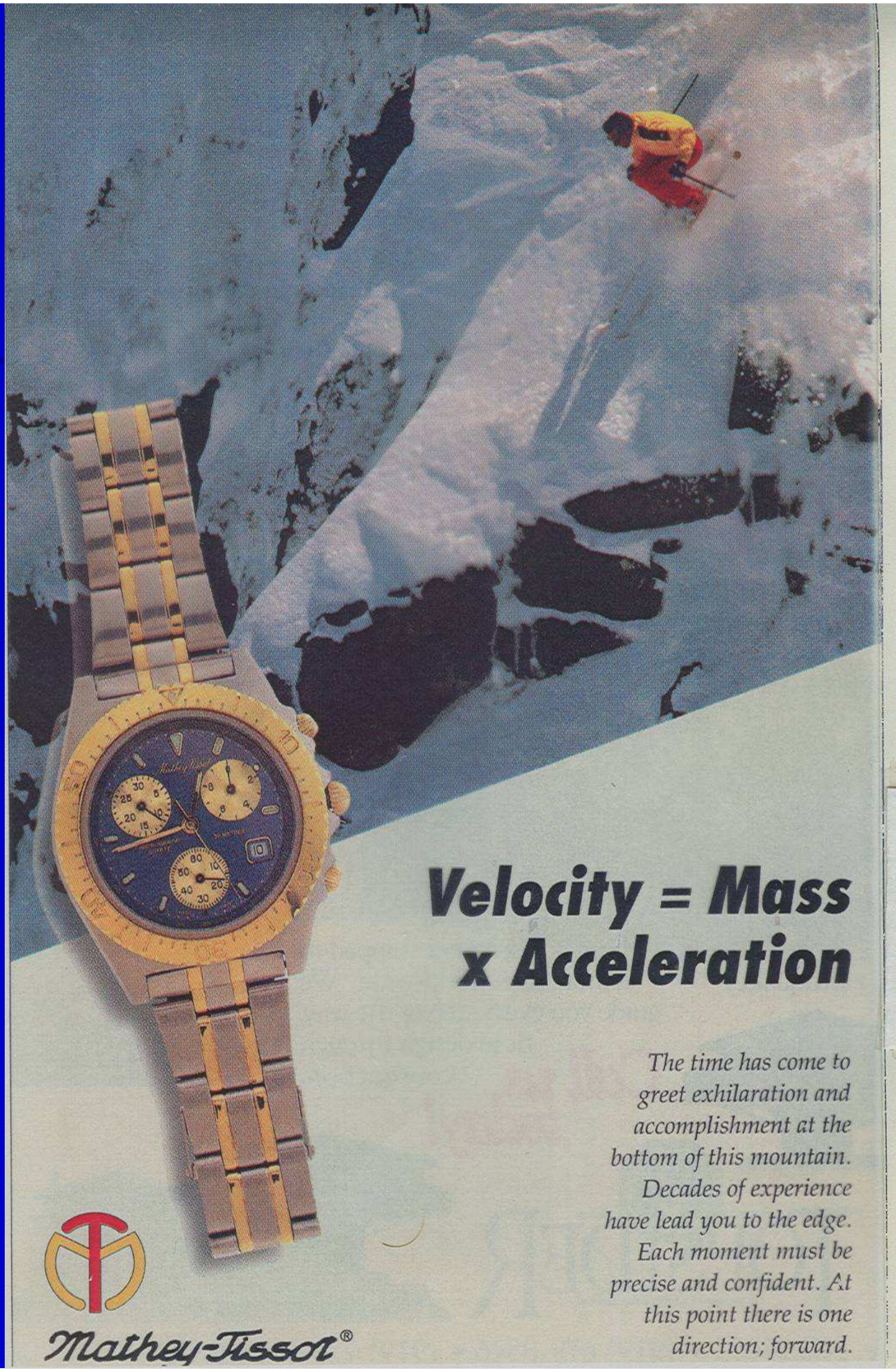
the Fourier-Bessel pendulum





will be the PhD project of Ted Cook


The time has come to
greet exhilaration and
accomplishment at the
bottom of this mountain.
Decades of experience
have lead you to the edge.
Each moment must be
precise and confident. At
this point there is one
direction; forward.
Mathey-Tissot®



Velocity = Mass
x Acceleration
The time has come to
greet exhilaration and
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