“Testing Gravity”

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and
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DESY, 20.06.2008

Outline:

1.) Astronomy and Astrophysics
2.) Experiments in the laboratory

Hamlet Act1,
scene5

The are more things in heaven and earth,
Horatio,
Than are dreamt of in your philosophy

anno 1632

Galilei, Galileo:

Dialogo sopra I due massimi sistemi del mondo

Dialog about the two main world systems

Dialog über die beiden hauptsächlichsten Weltsysteme

Диалог о двух важнейших мировых системах

Q: how much matter there is in the Universe???

Halo missing baryons

Table 1. Ω_b by method*.

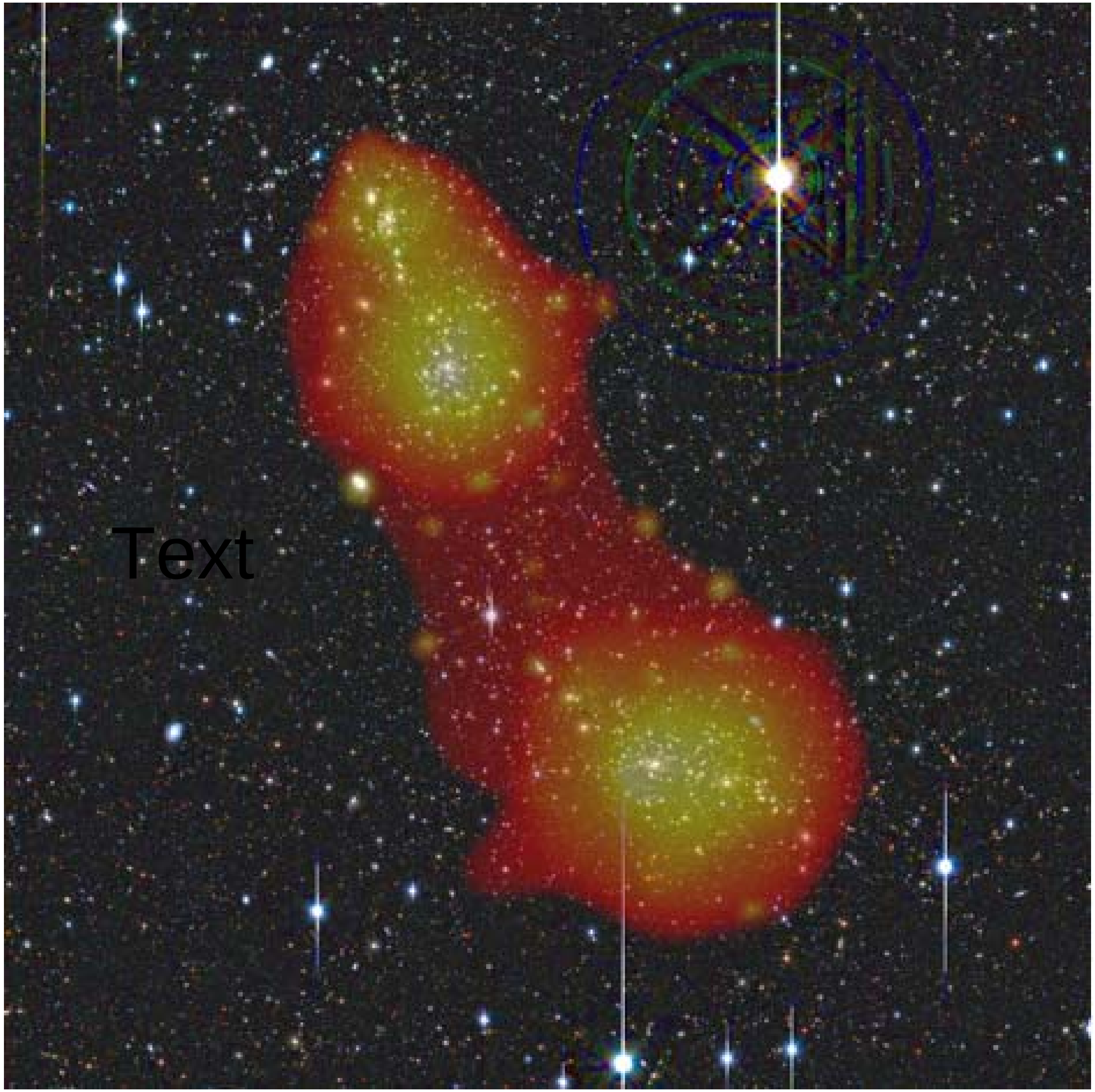
	W91[†]	^{2}H	^{4}He	^{7}Li	CMB	W3[‡]	M01[*]
Ω_b	0.021	0.038	0.021	0.028	0.046	0.0430	0.033
σ	0.005	0.005	0.008	0.005	0.007	0.0014	0.006

*Assumes $H_0 = 72$ km s^{-1} Mpc^{-1}.
†Compilation of Walker *et al.* (1991).
‡WMAP-only ΛCDM fit from Λ website
*CMB without CDM — see McGaugh (2004).

BBN successfully describing light element abundances in the universe (BUT!!!!!)
all but H
missing baryon problem
Fukugita, Peebles 1988

XMM Newton
ESA X-RAY
Satellite

observing
missing
baryon fraction
solved??



also spectral lines from intergalactic clouds

virial law

E(kin)=-1/2E(pot)

Fritz Zwicky, geboren 1898 in Warna und als Schweizerbürger im Kanton Glarus aufgewachsen, studierte an der Eidgenössischen Technischen Hochschule in Zürich und wurde dort 1922 zum Dr. sc. nat. promoviert. Seit 1925 lebt er in den USA; er ist heute Professor für Astrophysik am California Institute of Technology in Pasadena und Astronom der Mount-Wilson- und der Mount-Palomar-Sternwarte. Auch auf humanitärem Gebiet ist Professor Zwicky sehr aktiv. Besonders wichtig aber sind seine Bemühungen als Morphologe, wie er sie in diesem Buch darstellt: Es geht ihm darum, als «Spezialist des Unmöglichen» mit einem Minimum an Arbeit und Zeit zu einem Optimum von Lösungen gegebener Probleme zu gelangen und dabei zugleich neue Probleme zu entdecken.

Helvetica Physica Acta

1933

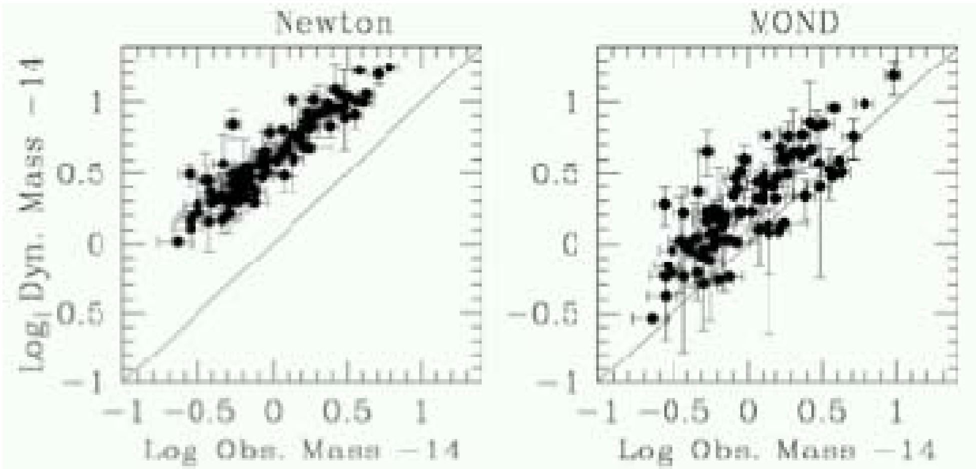


FIGURE 8. (Left) The Newtonian dynamical mass for galaxy clusters plotted against the total observable mass (gas+stars). The solid line represents the locus of no mass discrepancy. **(Right)** The factor ten discrepancy is reduced by MOND down to a factor two. Reproduced from [19].

Sanders, 1996

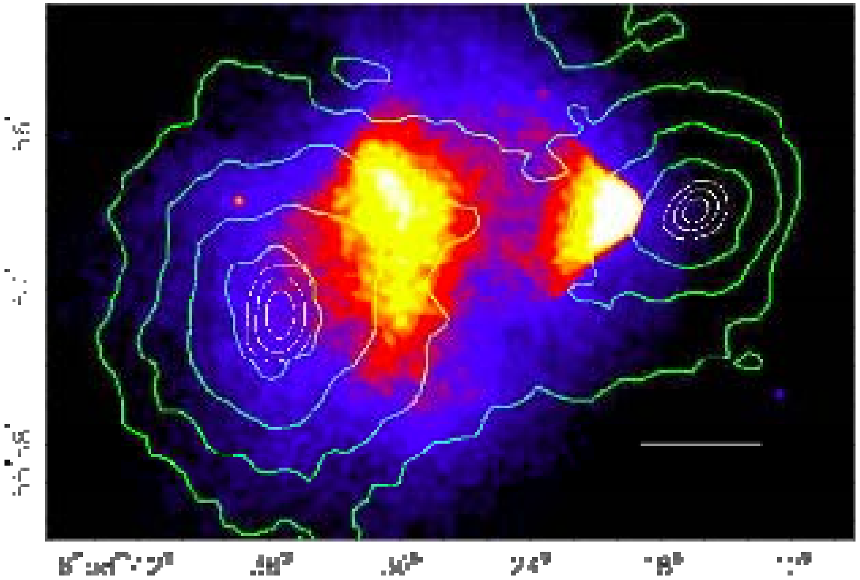
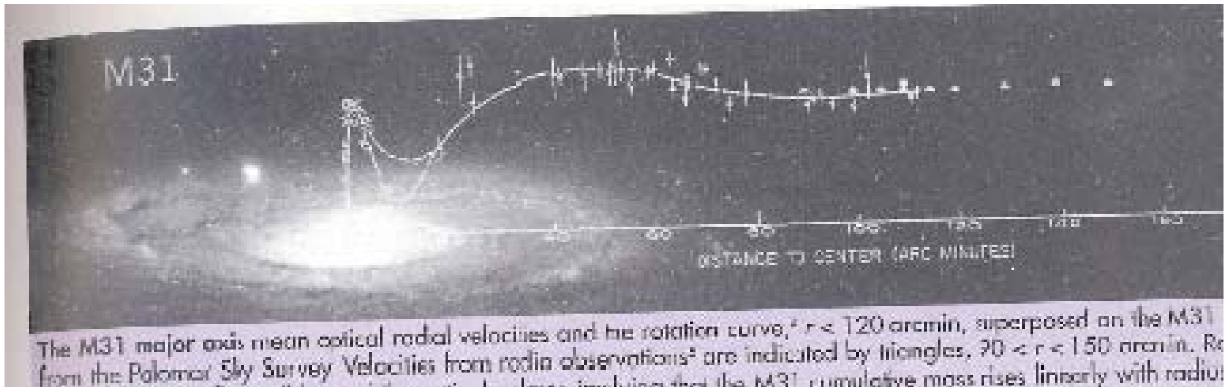


FIG. 6. The colliding clusters 1E0657-56. The bullet cluster (right) rammed through the cluster on the left. Hot gas stripped off both clusters is colored red-yellow. Green and white curves are level surfaces of gravitational lensing convergence; the two peaks of this do not coincide with those of the gas which makes up most of the visible mass, but are skewed in the direction of the galaxy concentrations. The white bar corresponds to 200 kpc. Figure reproduced from Ref. 85 by permission of the American Astronomical Society.

MOND works:
however
needs
Neutrinos with mass
see
Zhao 2007

Vera Rubin 1970, with K. Ford

Rotation curves a general phenomenon



Andromeda M31

Spiral Galaxies

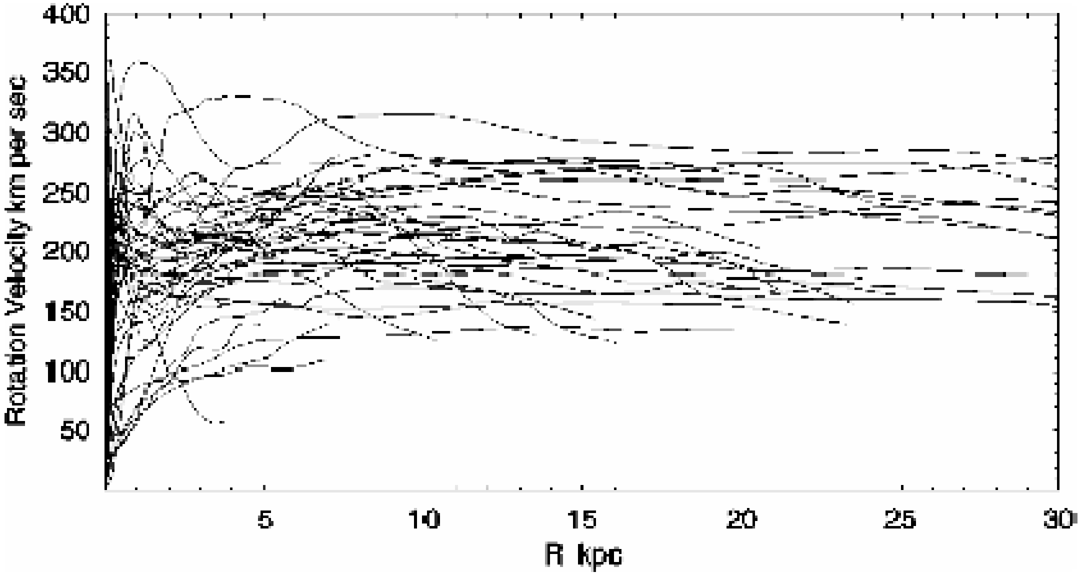


Figure 4 Rotation curves of spiral galaxies obtained by combining CO data for the central regions, optical for disks, and HI for outer disk and halo (Sofue et al. 1999a).

dwarf spheroidals

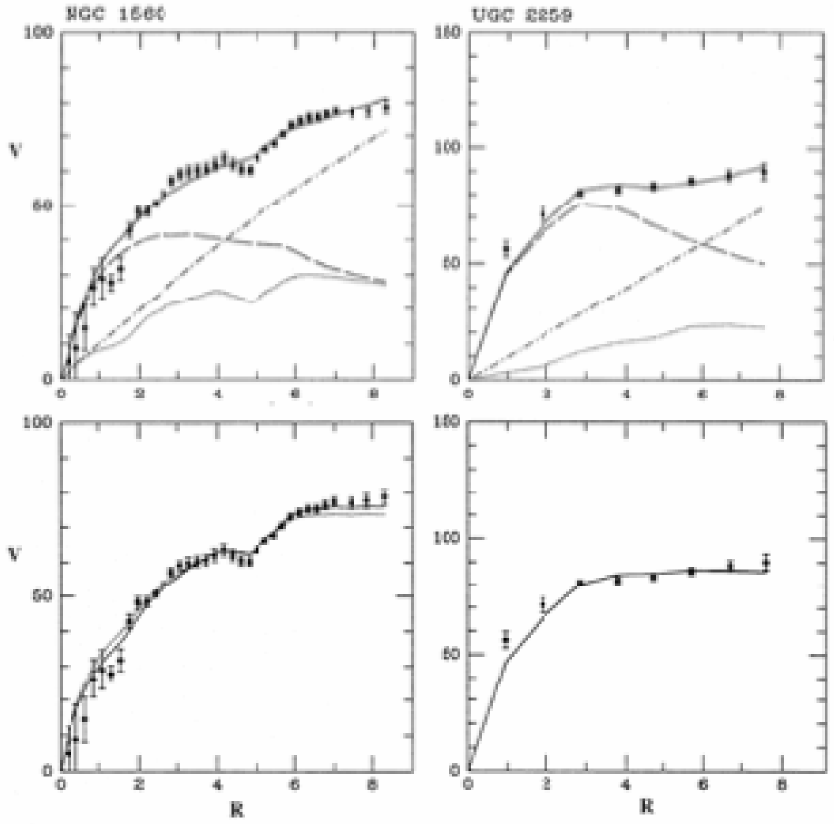
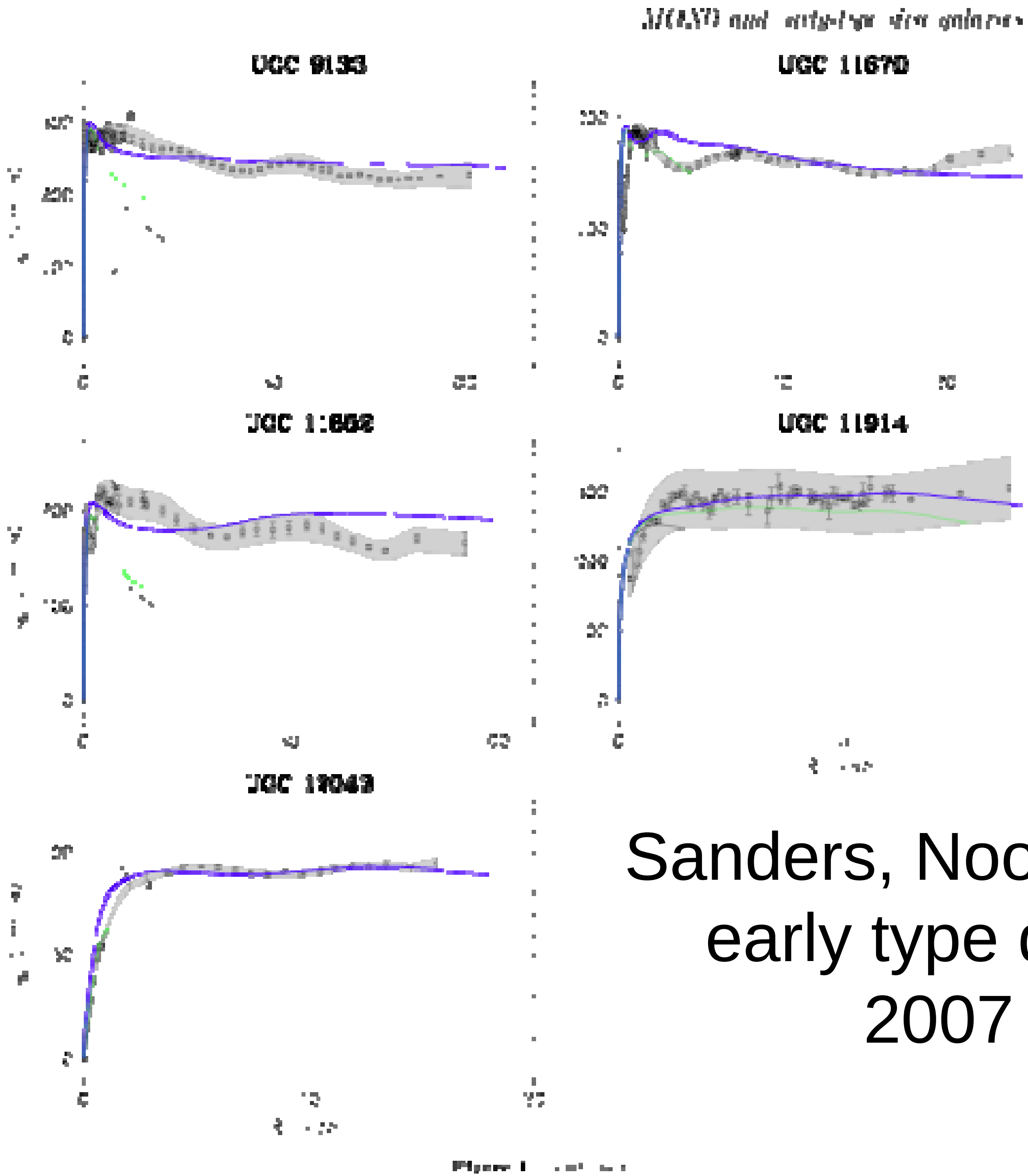


FIGURE 2. Rotation curves for two low surface brightness, gas-dominated galaxies (data from [5]). **Top**: Three-parameter dark-matter halo fits (solid curve). The rotation curve of the stellar (dashed line), gas (dotted line), and dark-halo (dash-dotted line) components are also shown. The fitting parameters are the M/L ratio of the disk, the halo core radius, and the halo asymptotic velocity. **Bottom**: the same rotaion curves as before, fitted with the MOND prescription. The dotted line shows the one-parameter (M/L) fit, while the solid line show the two-parameter (M/L and distance) fit. For UGC2259 the two lines coincide. The important thing here is that these galaxies are gas dominated so that M/L becomes irrelevant and the fit has no free parameters at all. Velocities in km/s and distances in kpc.



Sanders, Noordmeer
early type disks
2007

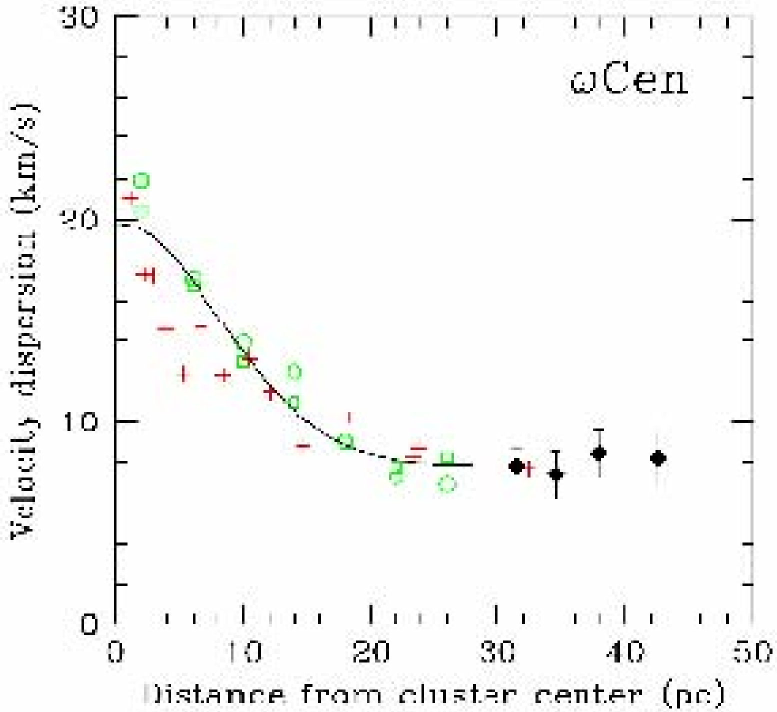


Fig. 1. The velocity dispersion profile of ω Centauri. Circles and squares represent the dispersion as derived from proper motion data. Crosses are radial velocity dispersions from the literature, to which we added data for 75 stars (the four last points with error bar). The solid line is not a fit to the data. It is a Gaussian plus a constant drawn to emphasize the flattening of the dispersion at large radii.

Scarpa, Gilmozzi, et al. 2006, globular clusters

In the solar system??

at least two dramatic effects

a: “Pioneer” anamoly

b: “fly by” effect

again seem to be ruled by
a(0) about cH!!

Newtons law

$F(grav)=GmM/r2$

rules all bound systems in the universe

a: change M , by introducing CDM

b: change accel. by introducing a(0) at very small accel. a MOND

actually, a(0) is about cH

c: adding an Yukawa like term at very small distance

d: consider G to be time dependent

“MOND”
Milgrom 1983
nonrelativistic

“TeVeS”
Bekenstein 2004
relativistic extension

Proposals, to change
Newtons Law

Thus, it is my personal opinion – and I am the only one responsible for it if proved wrong-- that if Newtonian dynamics fails below a0, this should be true irrespectively of the total field and one should be able to observe MOND effect also here on earth. For instance, I think a refined version of the Cavendish experiment studying gravitational forces in the horizontal plane should detect MOND effects.

R. Scarpa 2006

Laboratory experiments

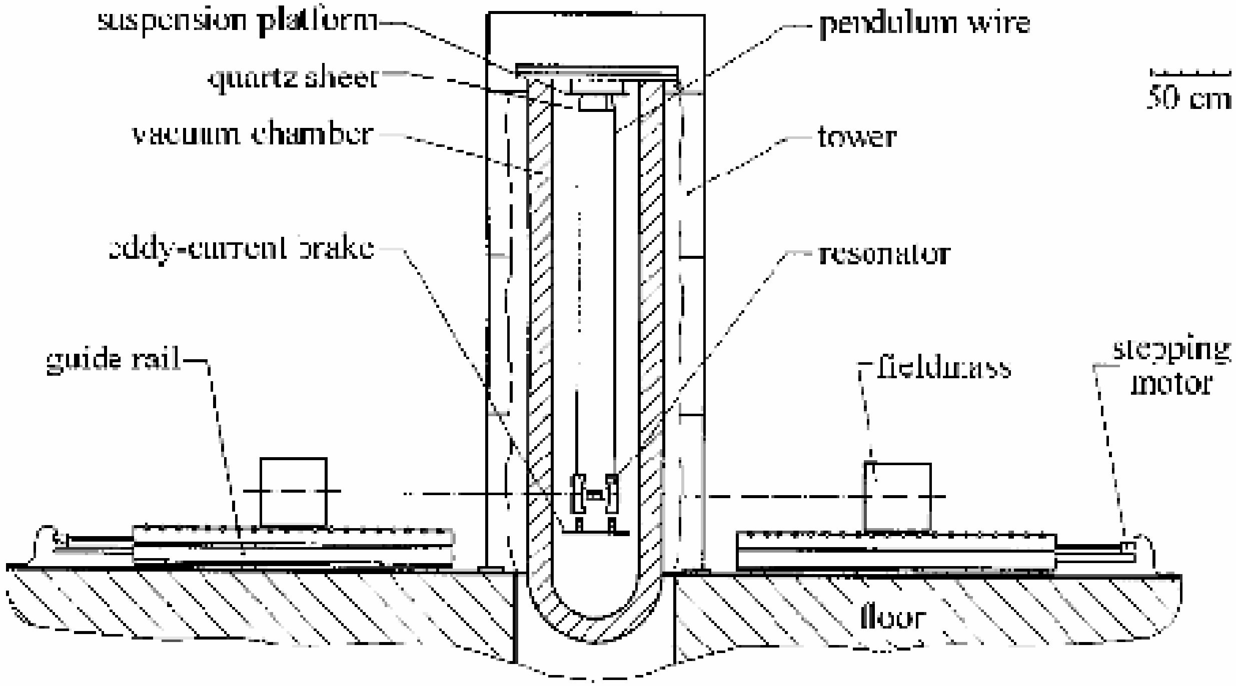
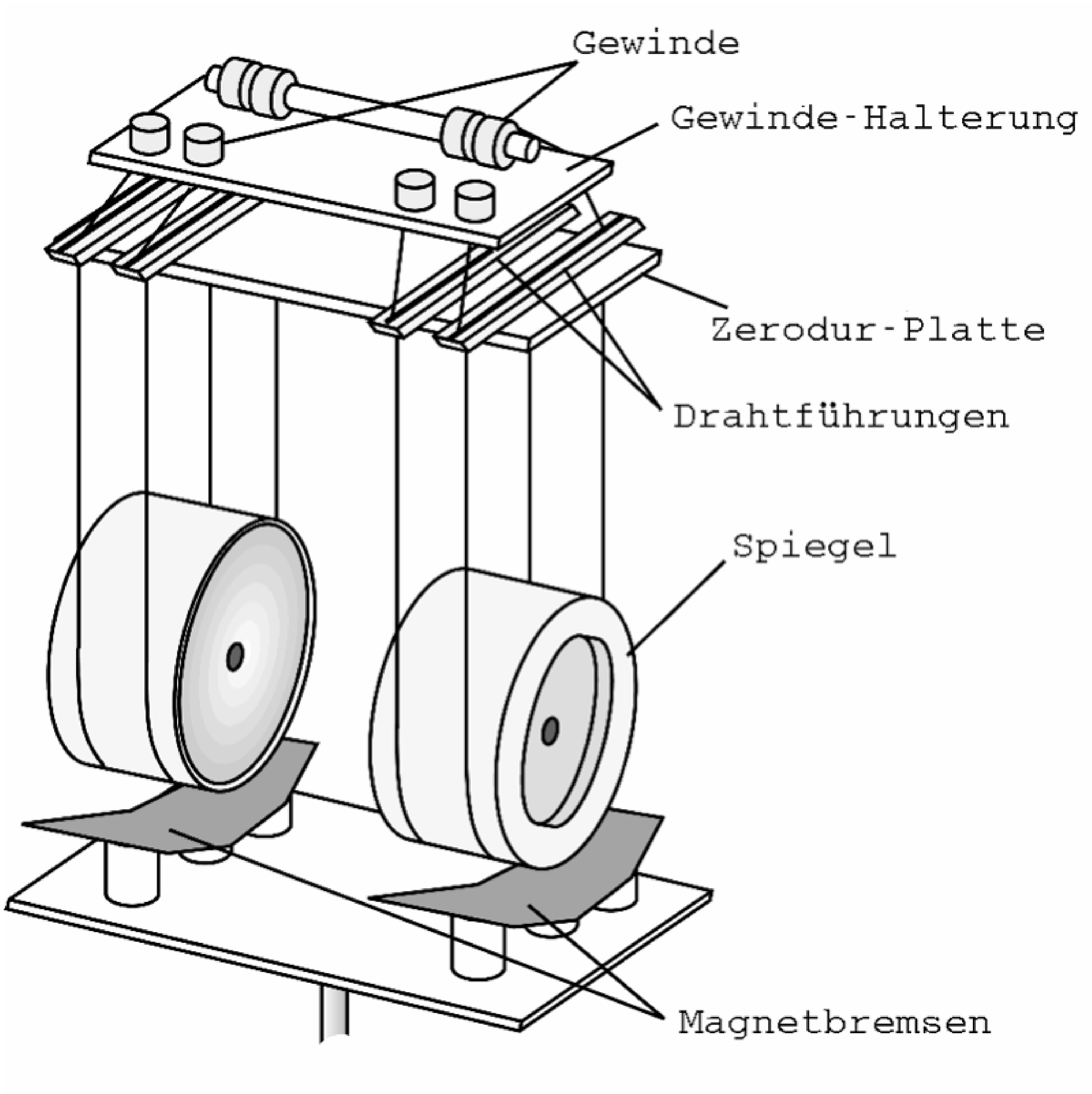


Figure 1. Schematic view of the experimental set-up with the Fabry–Pérot resonator and the two fieldmasses.

fieldmass
560kg

now only
5-40kg

thesis work by
Schurr, Walesh, Schumacher,
Kleinevoss
1992 - 2002
with H. Piel
Univ. of Wuppertal


Gewinde
Gewinde-Halterung
Zerodur-Platte
Drahtführungen
Spiegel
Magnetbremsen

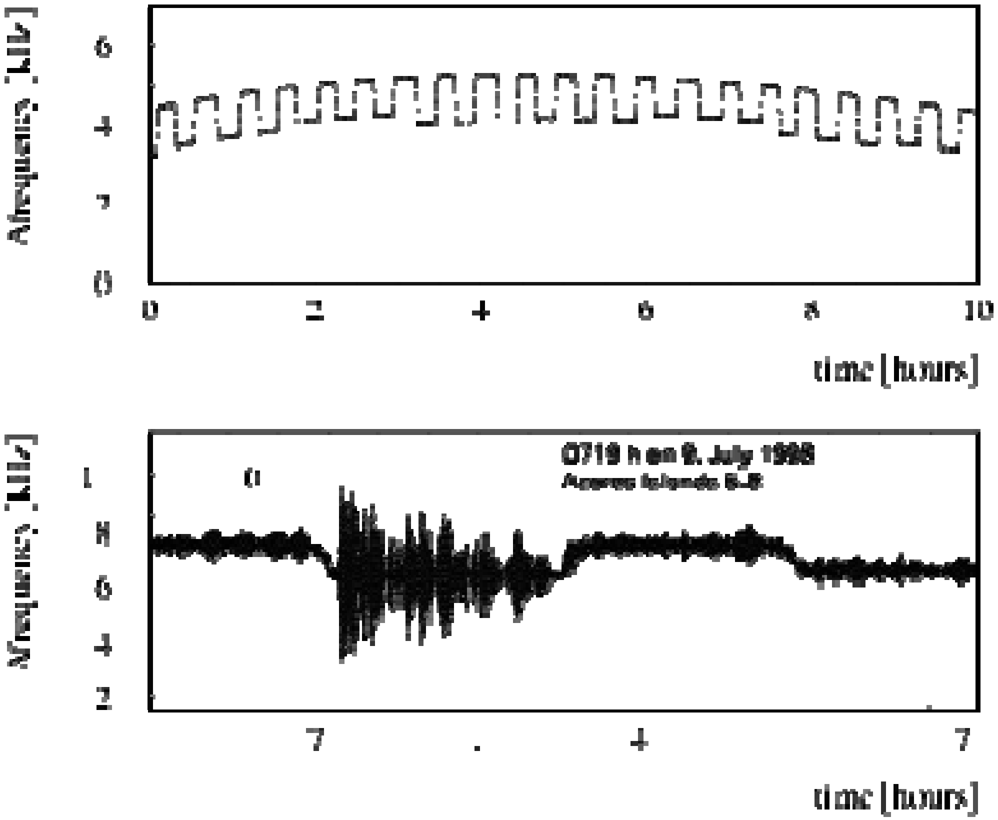


Figure 2. Measured resonance frequency change Δf plotted against time. The upper trace shows a 10 h portion of the measurements and lower trace shows a rather large earthquake.

db =df const
const=10-9
(m/kHz)

thesis
H. Walesch

recent "G" results 2006

TABLE X. Summary of the results of measurements of the Newtonian constant of gravitation relevant to the 2002 adjustment together with the 1986, 1998, and 2002 CODATA recommended values. See the text for brief discussions of the experiments.

Item	Source	Identification	Method	$10^{11}\,G$ $\mathrm{m^3\,kg^{-1}\,s^{-2}}$	Rel. stand. uncert. u_r
	1986 CODATA Adjustment	CODATA-86		6.672 59(85)	1.3×10^{-4}
	1998 CODATA Adjustment	CODATA-98		6.673(10)	1.5×10^{-3}
a	Bagley and Luther (1997)	LANL-97	fiber torsion balance, dynamic mode	6.674 0(7)	1.0×10^{-4}
b	Karagioz *et al.* (1998)	TR&D-98	fiber torsion balance, dynamic mode	6.672 9(5)	7.5×10^{-5}
c	Luo (2003); Luo *et al.* (1999)	HUST-99	fiber torsion balance, dynamic mode	6.669 9(7)	1.0×10^{-4}
d	Gundlach and Merkowitz (2000, 2002)	UWash-00	fiber torsion balance, dynamic compensation	6.674 255(92)	1.4×10^{-5}
e	Quinn *et al.* (2001)	BIPM-01	strip torsion balance, compensation mode, static deflection	6.675 59(27)	4.0×10^{-5}
f	Kleinevoß (2002); Kleinvoß *et al.* (2002)	UWup-02	suspended body, displacement	6.674 22(98)	1.5×10^{-4}
g	Schlamminger *et al.* (2002)	UZur-02	stationary body, weight change	6.674 07(22)	3.3×10^{-5}
h	Armstrong and Fitzgerald (2003)	MSL-03	strip torsion balance, compensation mode	6.673 87(27)	4.0×10^{-5}
	2002 CODATA Adjustment	CODATA-02		6.674 2(10)	1.5×10^{-4}

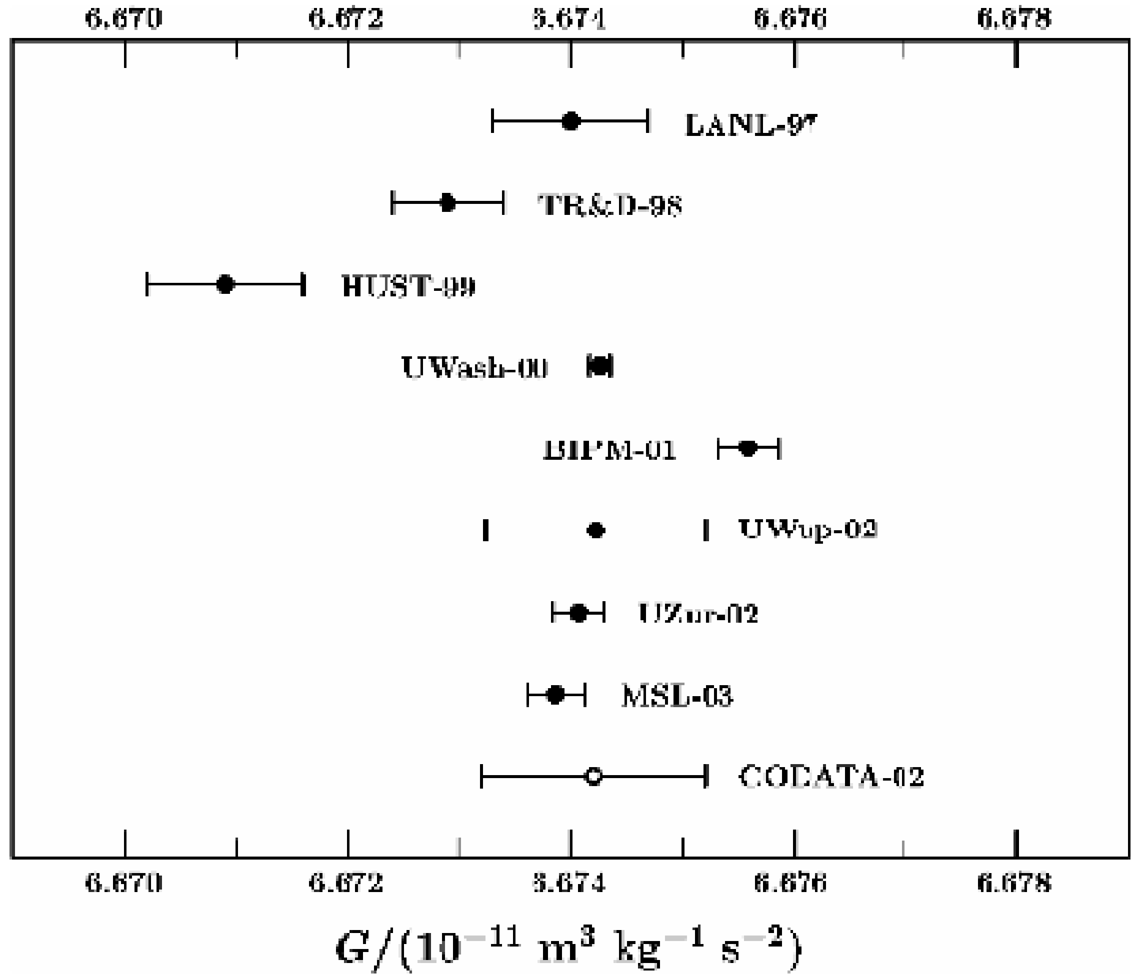
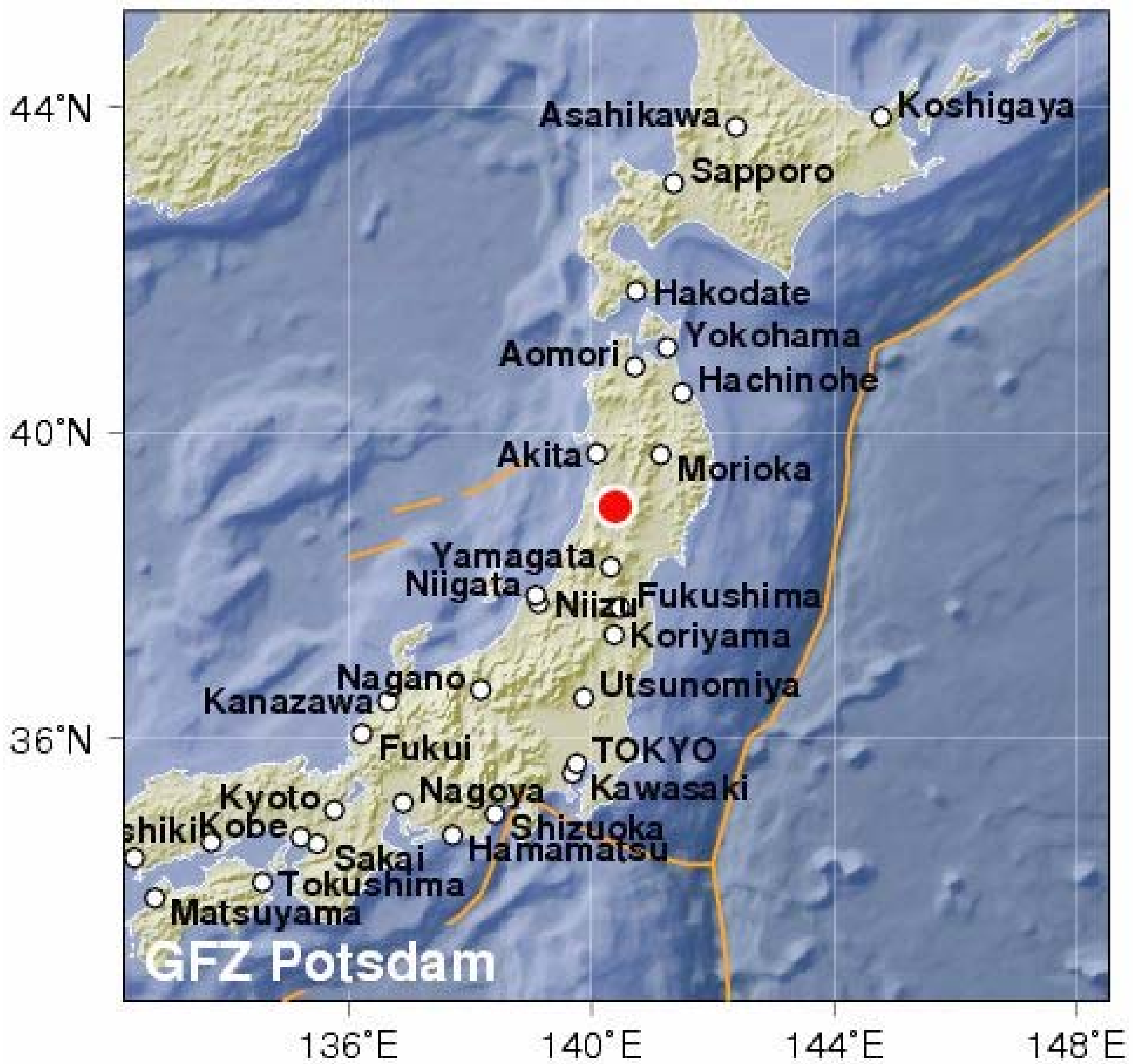
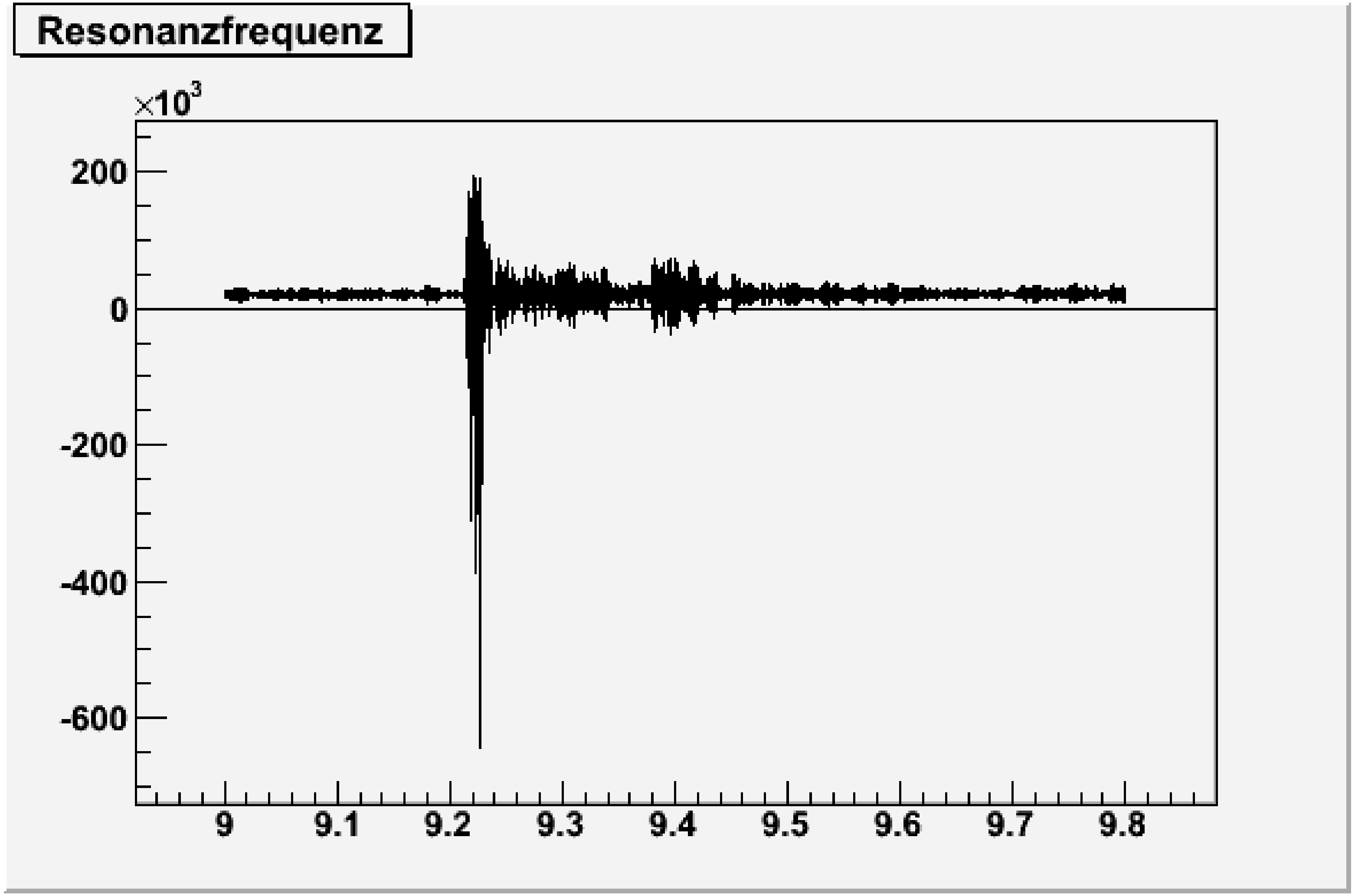


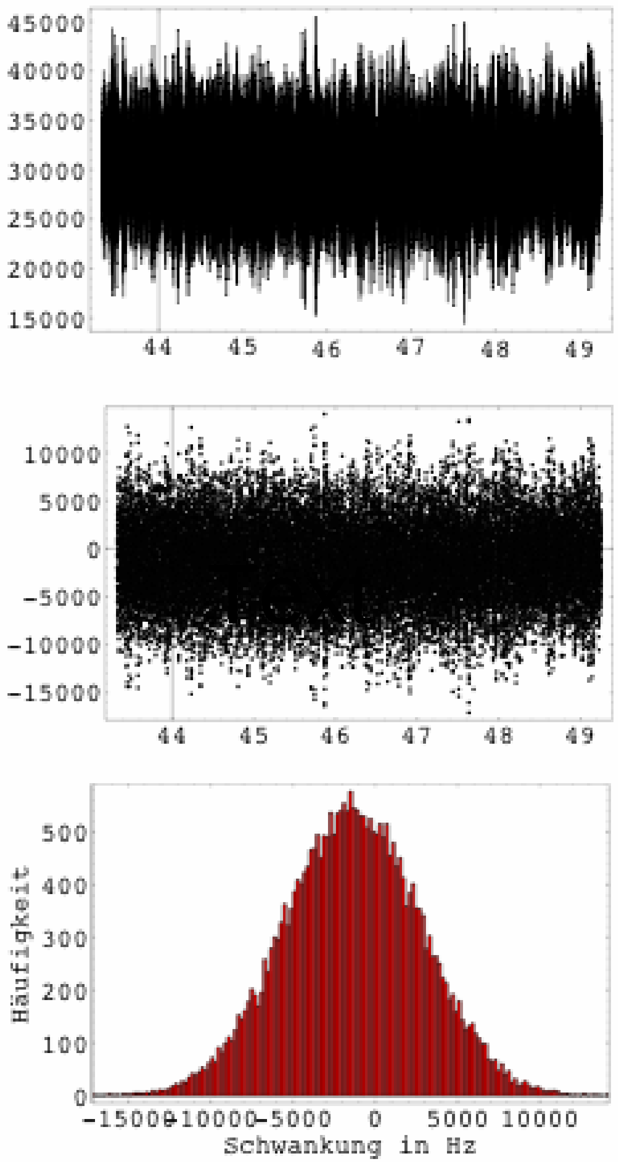
FIG. 1. Values of the Newtonian constant of gravitation G. See Glossary for the source abbreviation.


44°N
40°N
36°N
136°E
140°E
144°E
148°E
Asahikawa
Koshigaya
Sapporo
Hakodate
Yokohama
Aomori
Hachinohe
Akita
Morioka
Yamagata
Niigata
Niizu
Fukushima
Koriyama
Nagano
Kanazawa
Utsunomiya
Fukui
TOKYO
Kawasaki
Kyoto
Nagoya
Kobe
Shizuoka
Sakai
Hamamatsu
Tokushima
Matsuyama
GFZ Potsdam

Earthquake signal in GRAVI

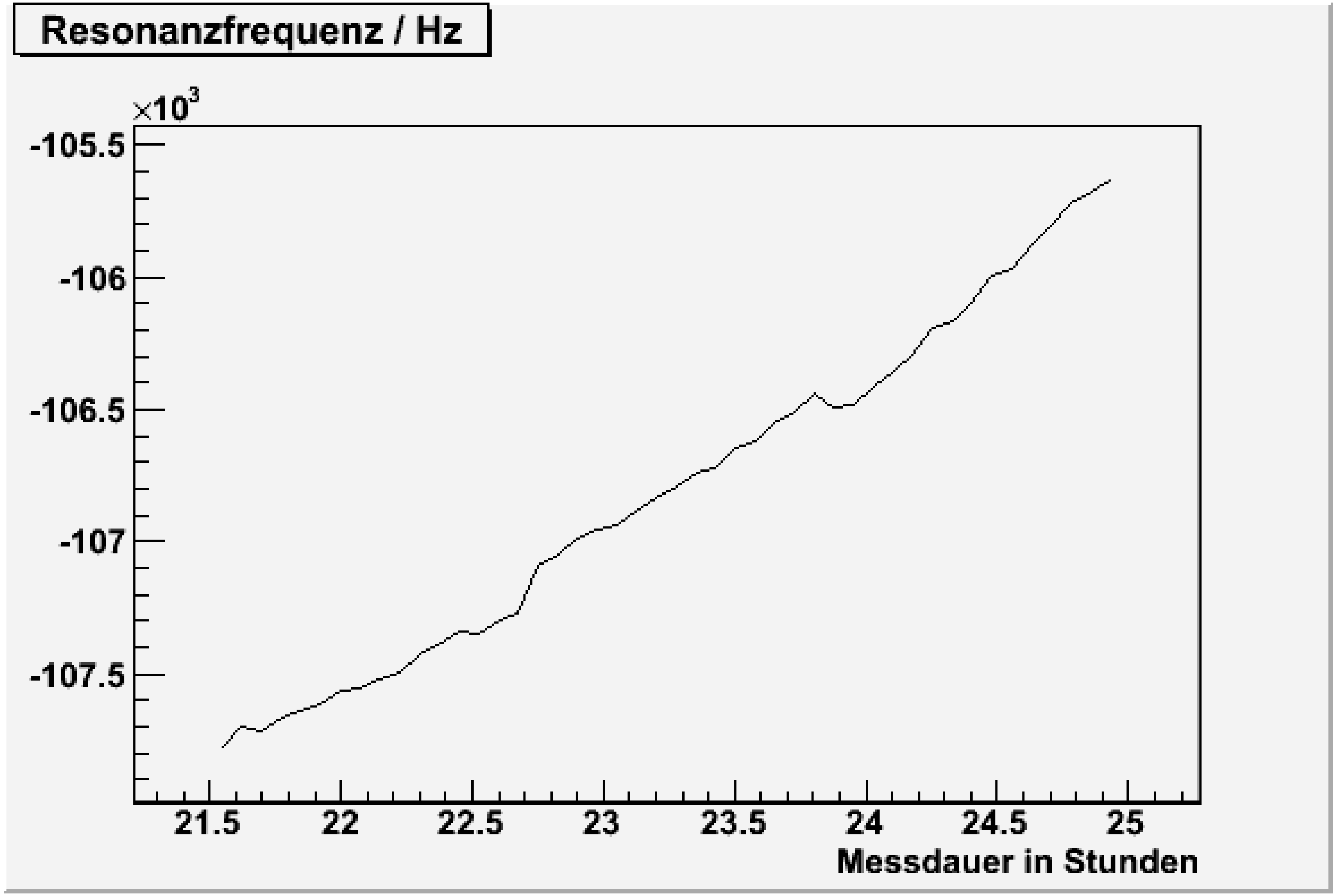


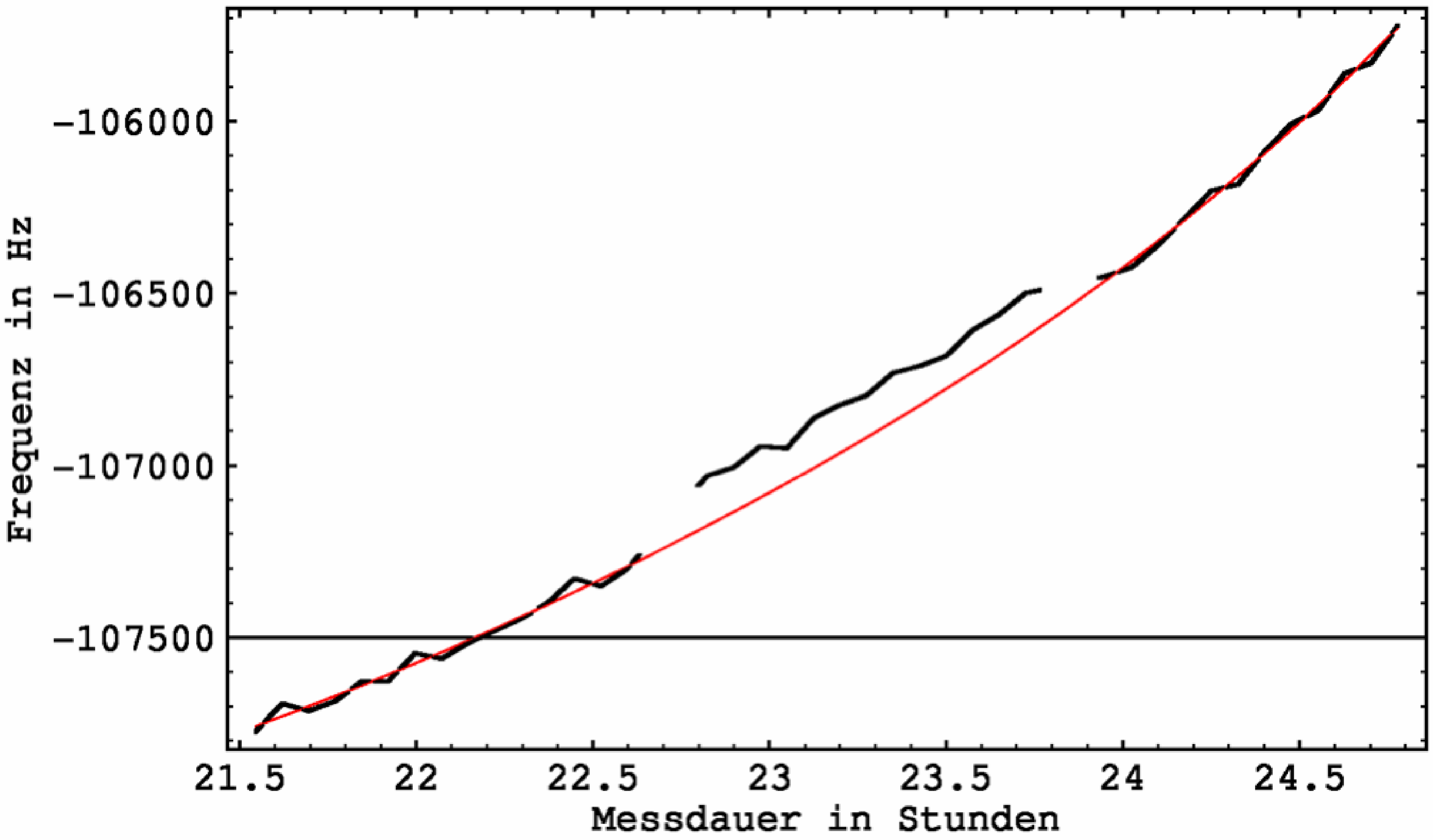
Noise nicely Gaussian, very crucial



frequency vs. time

“Gravi” at DESY works!!! (18.6.2008)
127Hz in 22GHz (1/10 nm)





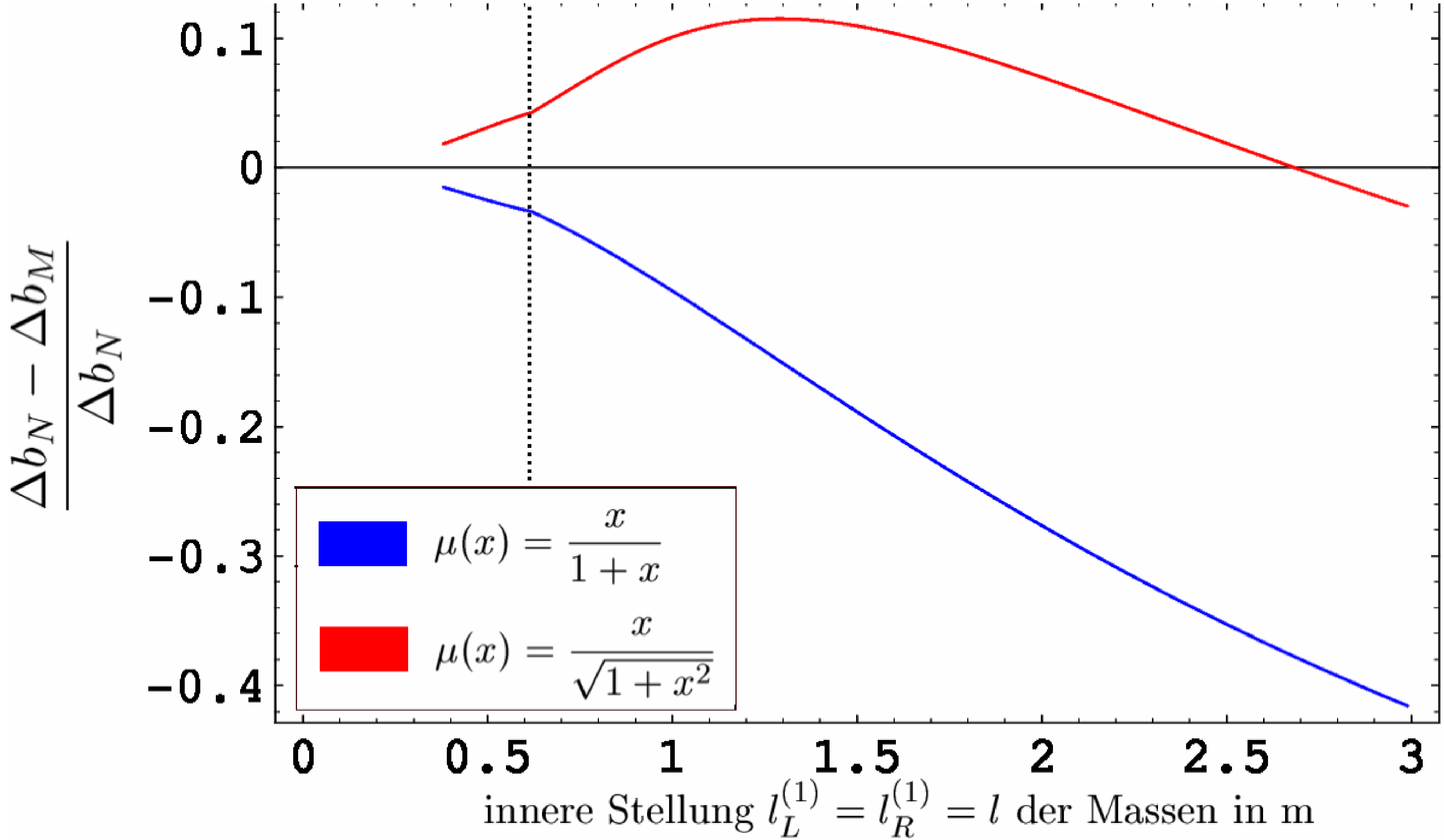
−106000
−106500
−107000
−107500
Frequenz in Hz
21.5
22
22.5
23
23.5
24
24.5
Messdauer in Stunden

Goals with “GRAVI” at DESY

a: measurements in the MOND region

b: accurate determination of big “G”

blue line prefered by astrophysical considerations



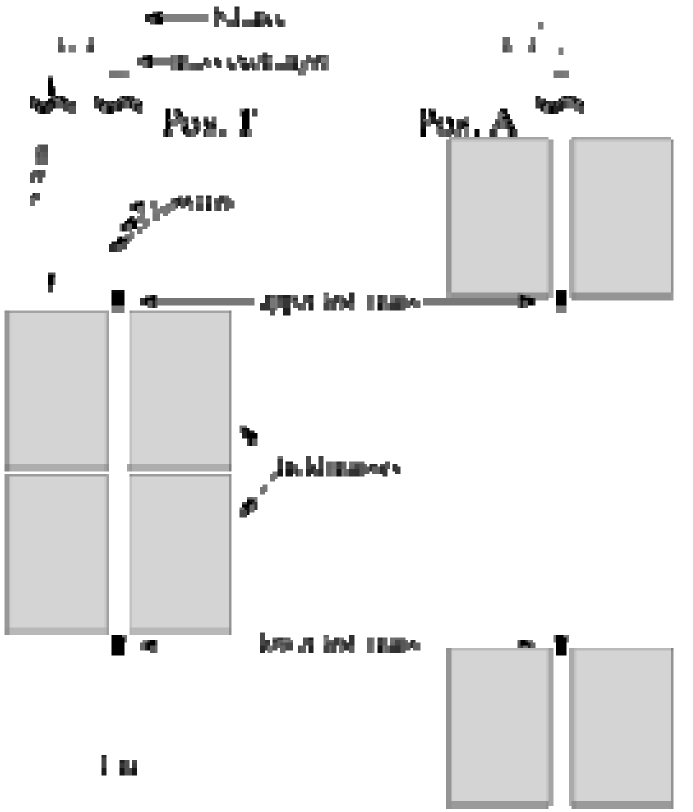
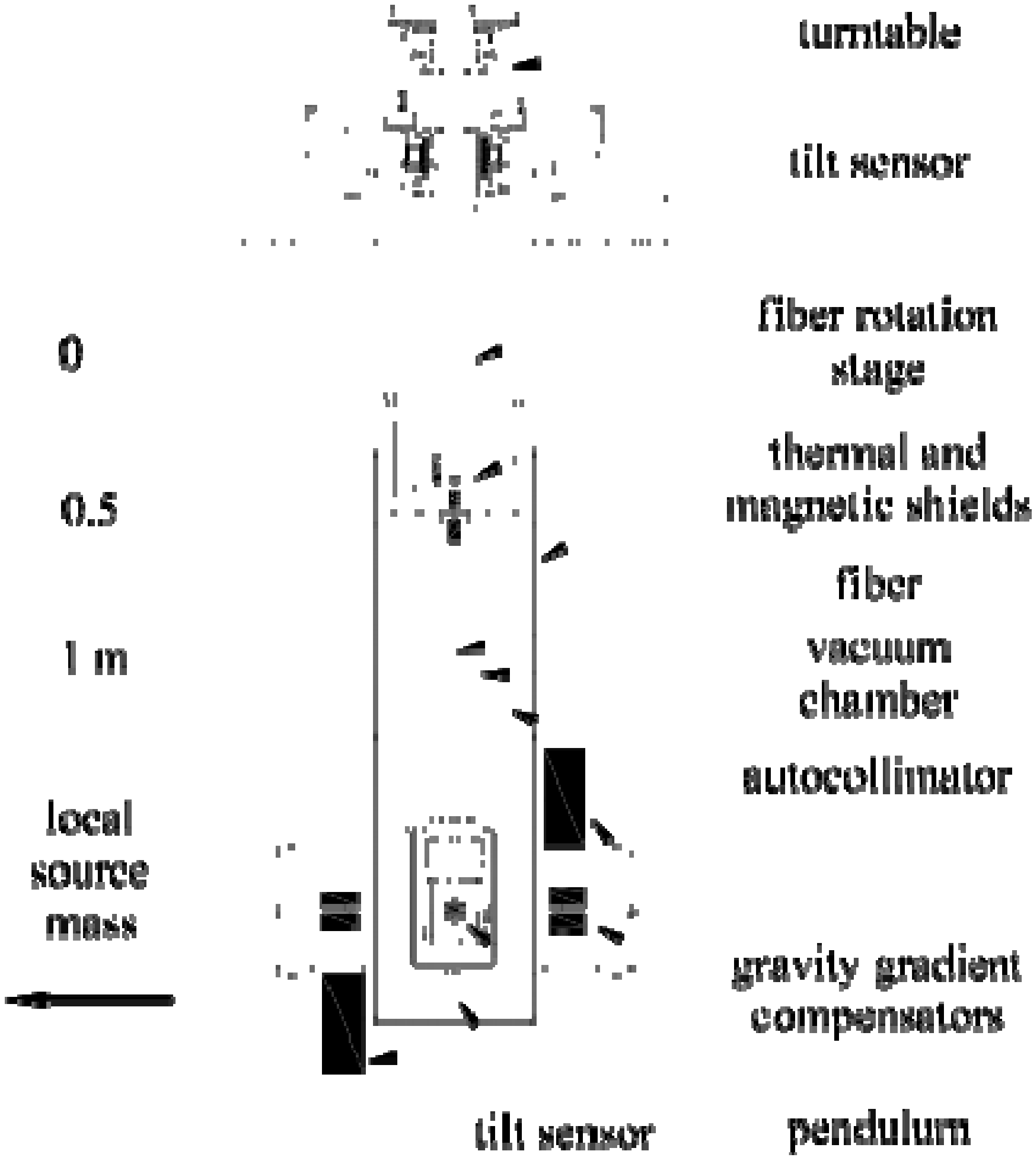


FIG. 1. Principle of the measurement. The TMs are shown in the position together (Pos. T) and the position apart (Pos. A).

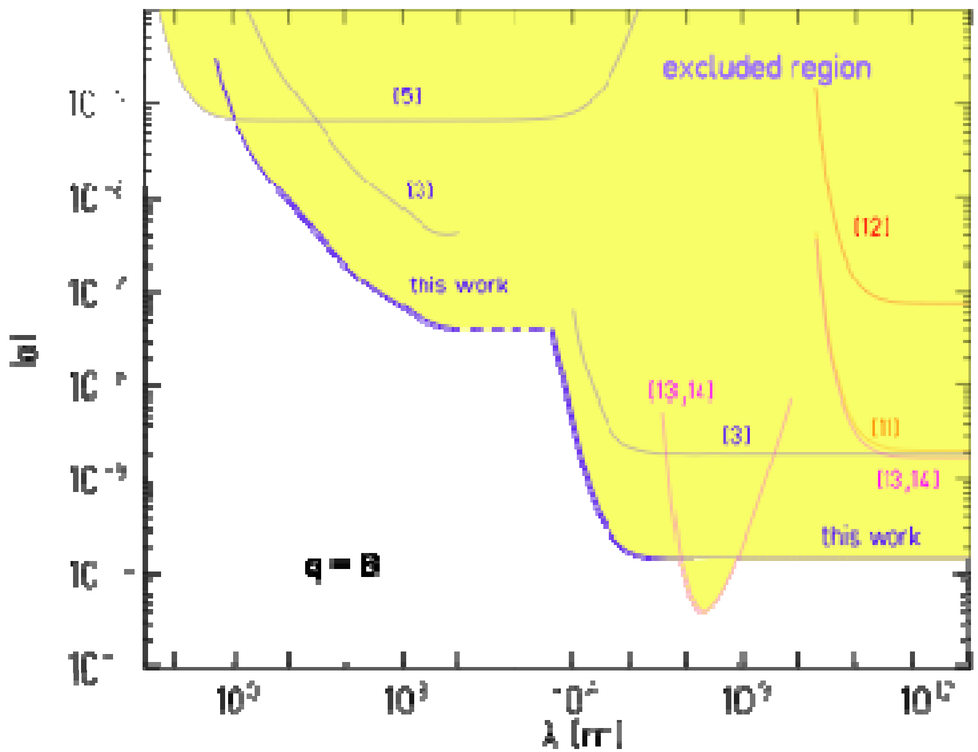
Schlamminger et al. Zürich

G measurment



Eötwash

Adelbergers group Seattle



IG. 3: New upper limits on Yukawa interactions coupled to aryon number with 95% confidence. The uncertainties in he source integration is not included in this plot. The num ers indicate references. The shaded region is experimentally xcluded. Preliminary models for 10 km $< \lambda <$ 1000 km

terial violate the equivalence principle. We parameterize such equivalence-principle violating interactions by a Yukawa potential, which for two point objects is

$$V(r) = \alpha G \left(\frac{q}{\mu}\right)_1 \left(\frac{q}{\mu}\right)_2 \frac{m_1 m_2}{r_{12}} e^{-r_{12}/\lambda}. \qquad (1)$$

where the interaction range $\lambda = \hbar/(m_b c)$ is given by the Compton wavelength of the presumed exchange boson of mass m_b, and which couples to the "new charge" q. The coupling strength α is measured in units of the Newtonian gravitational constant G, and μ represents the mass in atomic mass units. The instrument consists of a

equivalence
principle
test
Schlamminger et al.
2008

fascinating times
testing
GRAVITY
in the lab

I like to thank DESY
for unbureaucratic
support