Motto

Hamlet Act. 1,
scene 5

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

GRAVI at DESY

A progress report

GRAVI

An experiment to test NEWTON

in the laboratory

at very small acceleration

with

W. Bartel, A. Glazov, B. Löhr,

C. Niebuhr, S. Schubert, E. Wünsch

DESY

E. Lohrmann, Univ. Hamburg

H. Meyer, Univ. Wuppertal

OUTLINE

- Motivation
- Big G at Wuppertal University
- Setup at DESY
- Data taking
- Preliminary results

Motivation in Wuppertal

In the early 1980 there was a discussion on

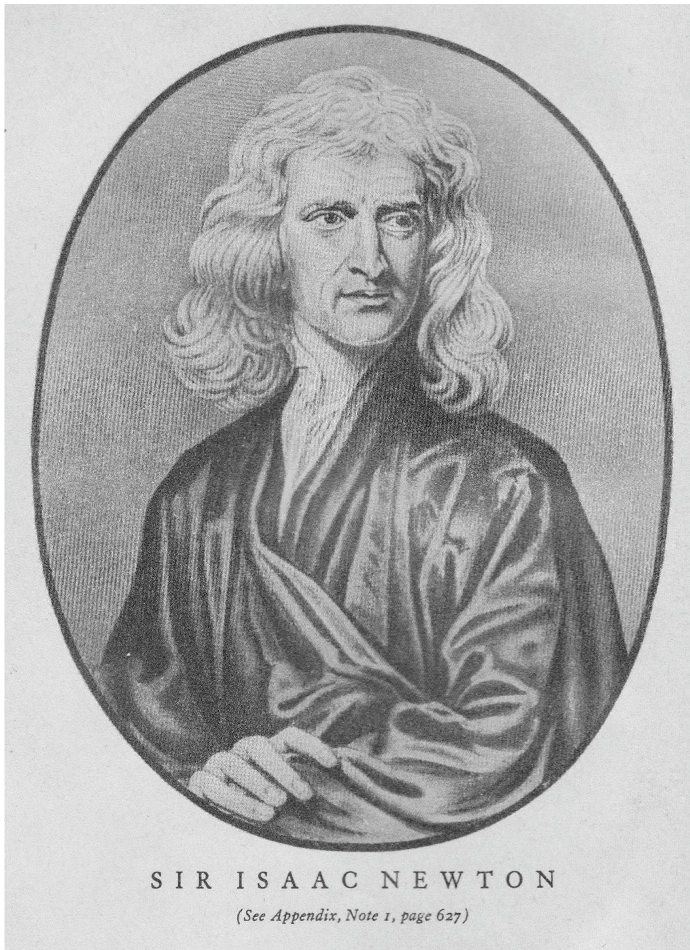
the possible existence of a 5th force, which

should be detectable by a deviation from the

$1/r^2$ law of NEWTON

But we decided to go for a precise determination of the gravitational constant G

Newton



$F = G\,M\,m\,/r^2$

Aim:

determine F by shifting m through the movement of M

Calibrate M, m, r very precisely

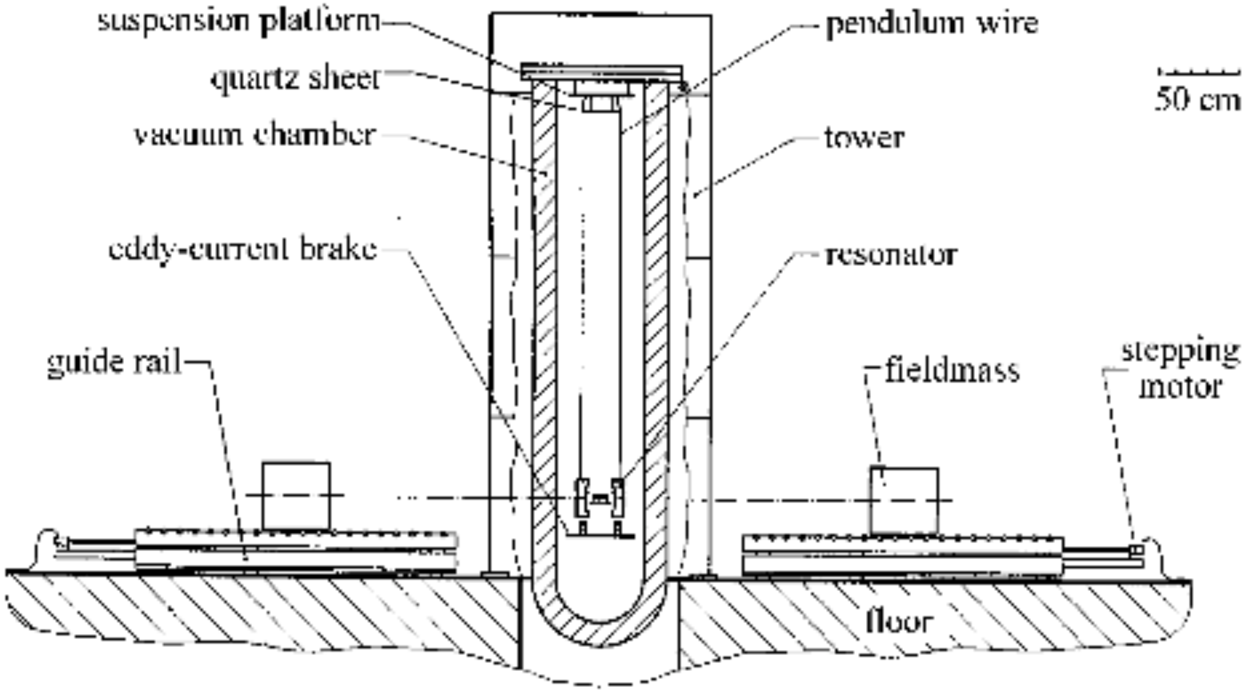
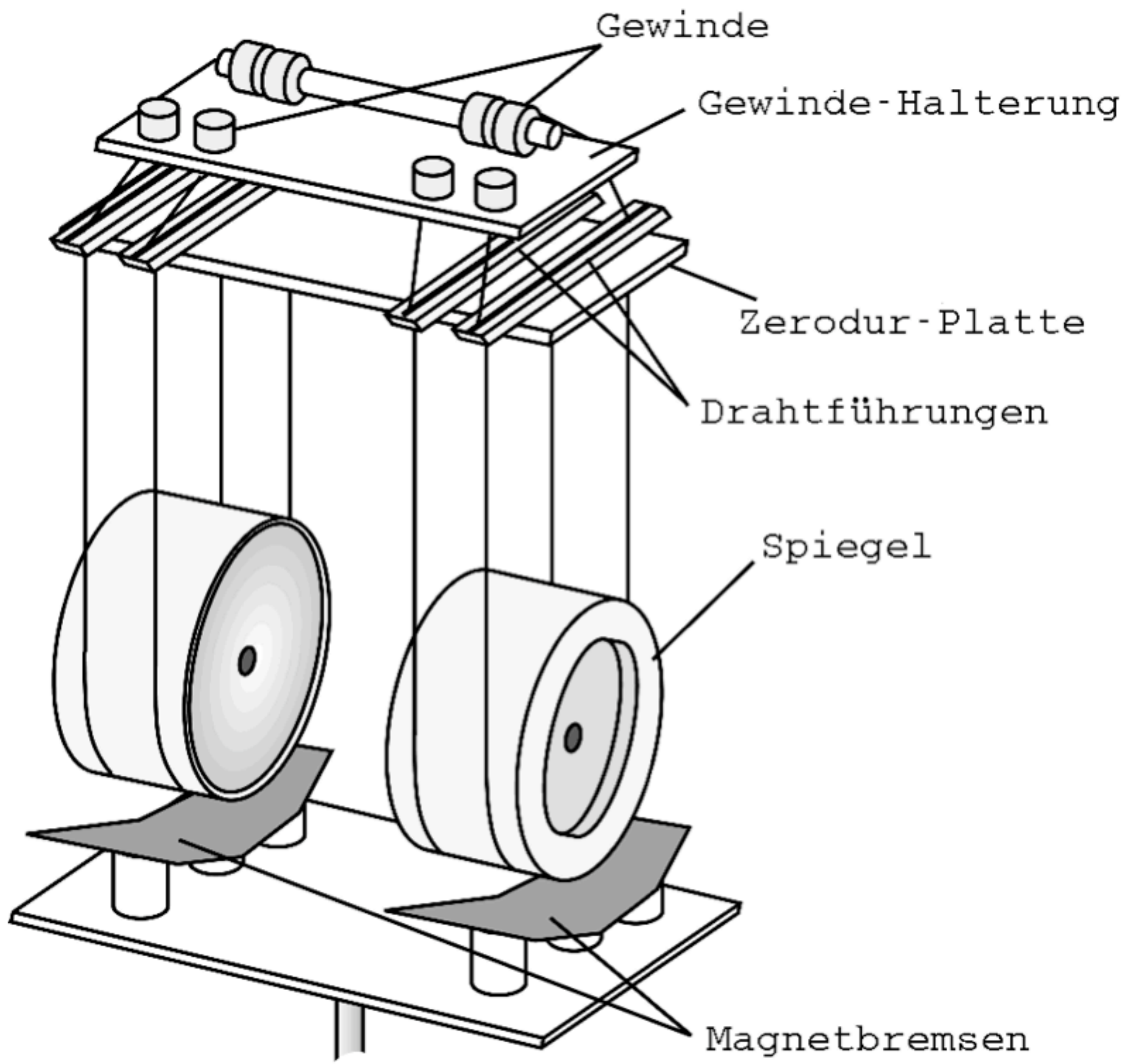


Figure 1. Schematic view of the experimental set-up with the Fabry–Pérot resonator and the two fieldmasses.

Fieldmass
M = 2 times
560 kg
small m
a "cavity"

thesis work by
J.Schurr, H.Walesch, A.Schumacher, U.Kleinevoss
1988 - 2002
with H. Piel
Univ. of Wuppertal


Gewinde
Gewinde-Halterung
Zerodur-Platte
Drahtführungen
Spiegel
Magnetbremsen

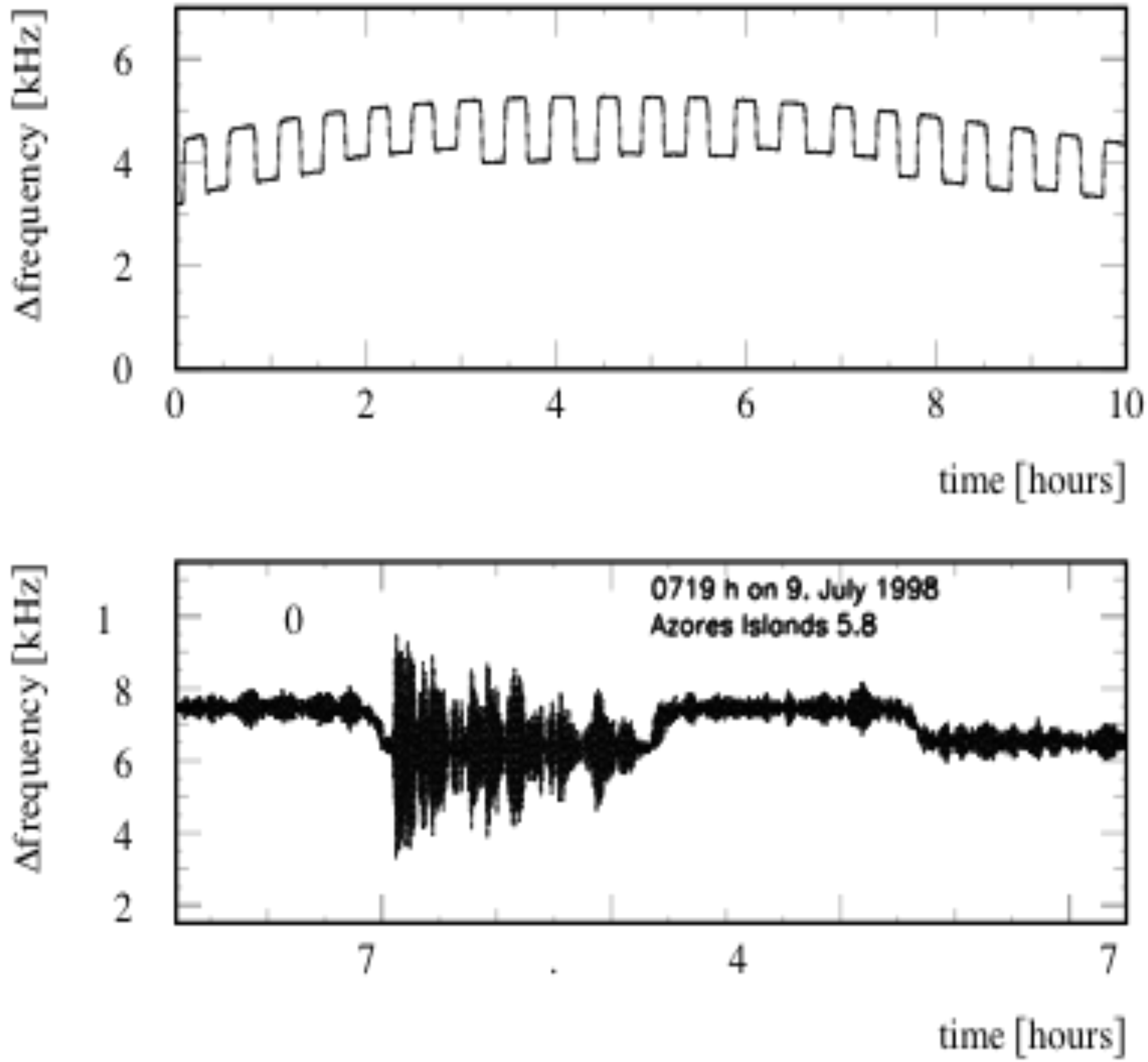


Figure 2. Measured resonance frequency change Δf plotted against time. The upper trace shows a 10 h portion of the measurements and lower trace shows a rather large earthquake.

db = df const

const = 10^{-8} m/kHz

thesis

H. Walesch

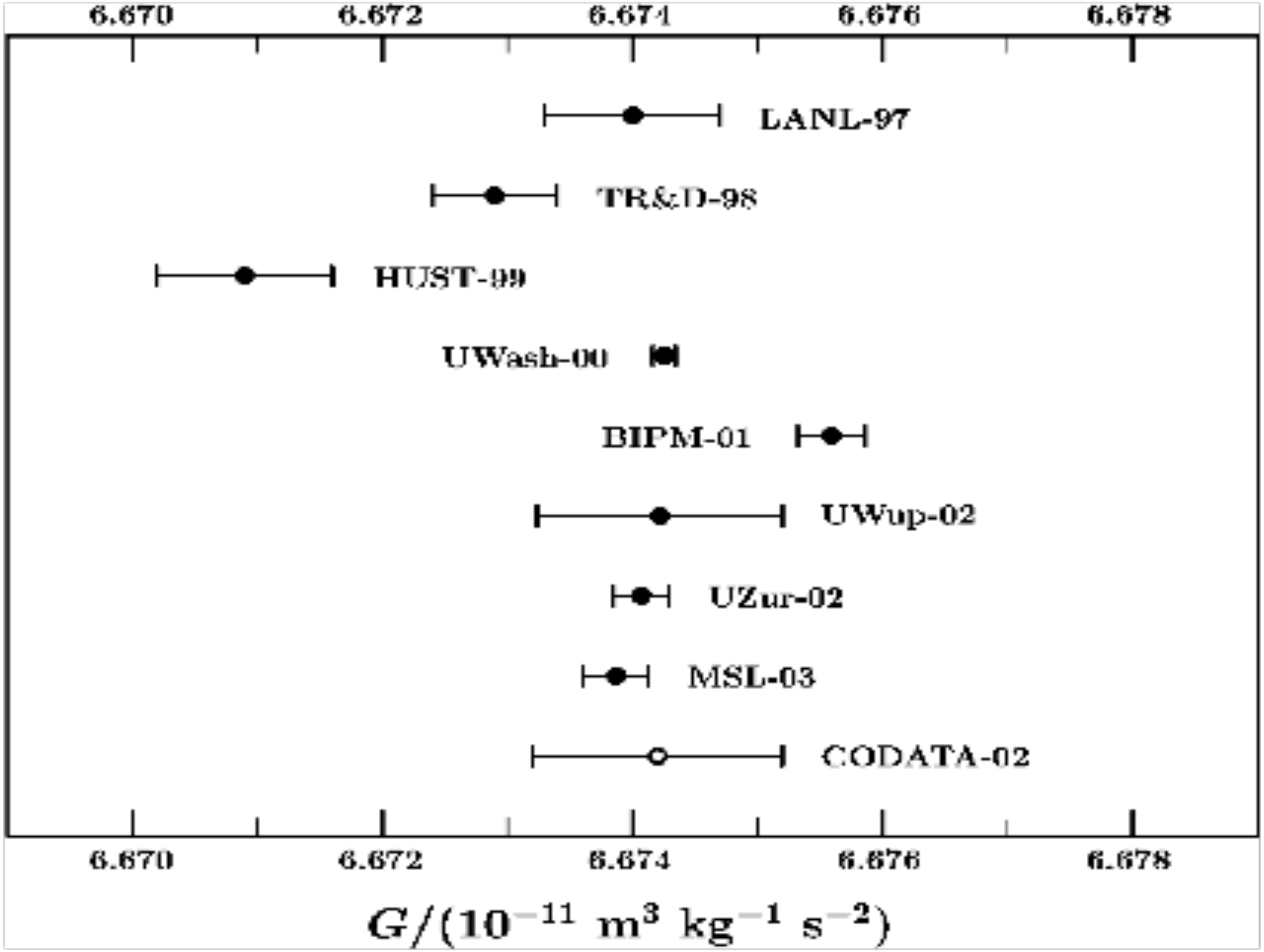


FIG. 1. Values of the Newtonian constant of gravitation G. See Glossary for the source abbreviation.

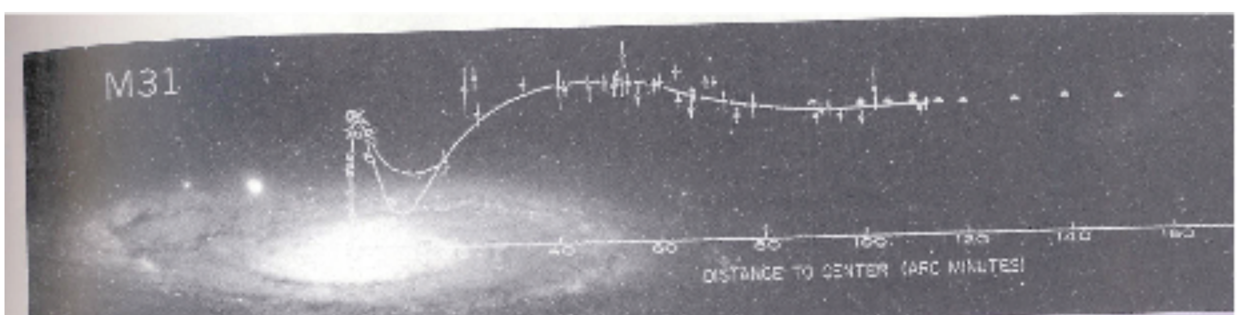
Goals with “GRAVI” at DESY

1: measurements in the MOND region at very small acceleration about 10^{-10} m/sec^2

2: accurate determination of big “G”

Vera Rubin 1970, with K. Ford

Rotation curves a general phenomenon



The M31 major axis mean optical radial velocities and the rotation curve,[4] $r < 120$ arcmin, superposed on the M31
from the Palomar Sky Survey. Velocities from radio observations[5] are indicated by triangles, $90 < r < 150$ arcmin. R
from the Palomar Sky Survey. Velocities from radio observations are indicated by triangles ... the M31 cumulative mass rises linearly with radius

Andromeda M31

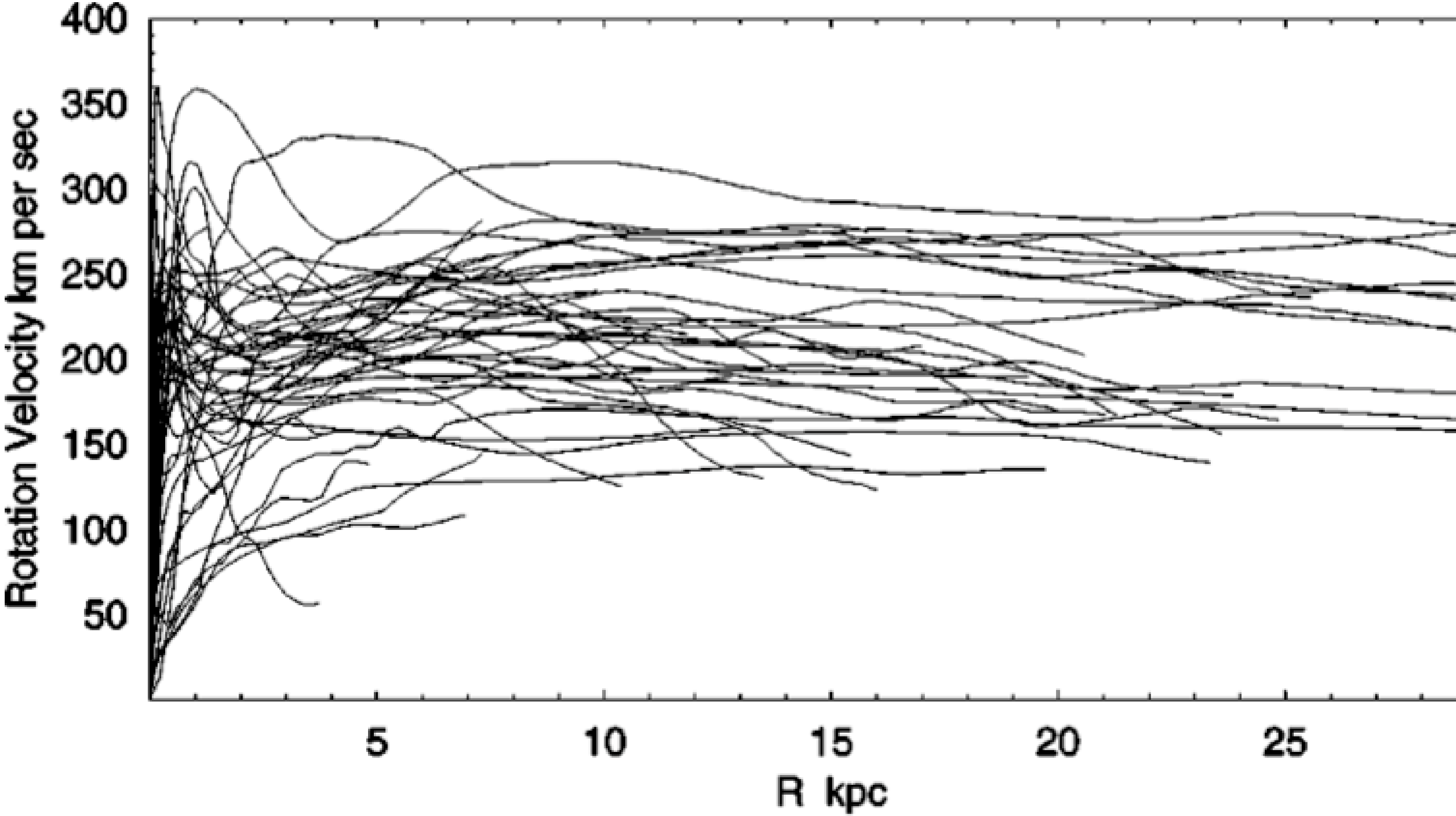
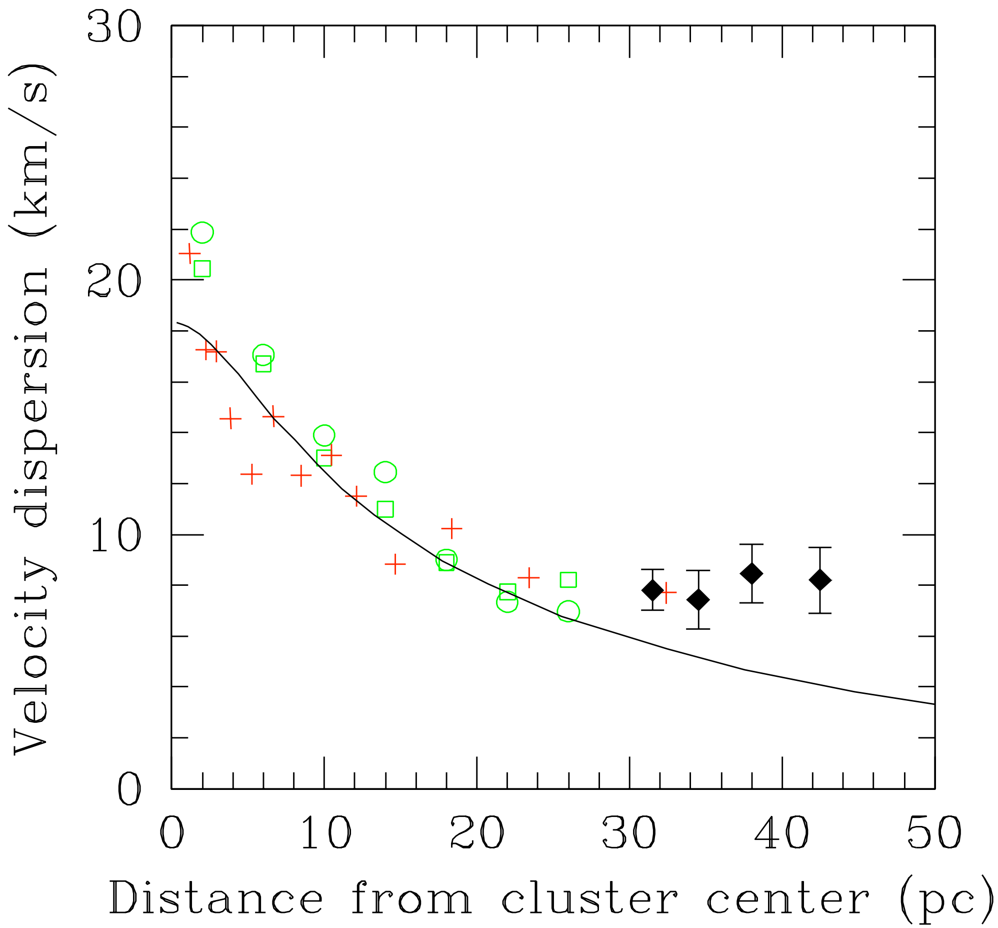


Figure 4 Rotation curves of spiral galaxies obtained by co
bining CO data for the central regions, optical for disks, and
for outer disk and halo (Sofue et al. 1999a)



Velocity dispersion profile of ω Cen. Proper motion data (**Circles** and **Squares**; van Leeuwen et al. 2000) and radial velocities (**Crosses**; Meylan et al. 1995 up to 20 pc, last two points from Meylan & Mayor 1986) agree well showing the cluster is isotropic. The solid line is the best fit model to the radial velocity data as in Meylan et al. (1995) (their fig 1). Our velocity dispersion dispersion data (**Diamonds**) show the dispersion starts to be constant for R>25 pc, where the acceleration falls below 10^{-7} cm s^{-2}.

Scarpa, Gilmozzi, et al. 2006,
globular clusters

Newtons law

$$F(grav)=GMm/r^2$$

rules all (bound) systems in the universe

1: change M, by introducing CDM

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

3: adding an Yukawa like term at very small distance

4: consider G to be time dependent

MOND

- MOdified Newtonian Dynamics 1983 M. Milgrom
- Change Newtons Law at accelerations below about 10^{-10} m/sec^2
- Provides an excellent description of the non-Newtonian behavior with just one additional universal parameter a(0)

“MOND”
Milgrom 1983
is non-relativistic
but

“TeVeS”
Bekenstein 2004
is one
relativistic extension

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

Fritz Zwicky

Entdecken Erfinden Forschen

Droemer Knaur

Fritz [illegible]cky

Entdecken, Erfinden, Forsche

im morphologischen Weltbild

Droemer Knaur

Fritz Zwicky

1933 and 1937 he proposed

- SN explosions to produce N-Stars
- Introduced the term Dark Matter
- observed Newton to fail for the Coma-CL
- Gravitational lensing of distant galaxies by foreground galaxies

Clover Leaf

And in the solar system??

at least two dramatic effects

1: "Pioneer" anomaly

2: "fly by" effect

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

Sanders and McGaugh

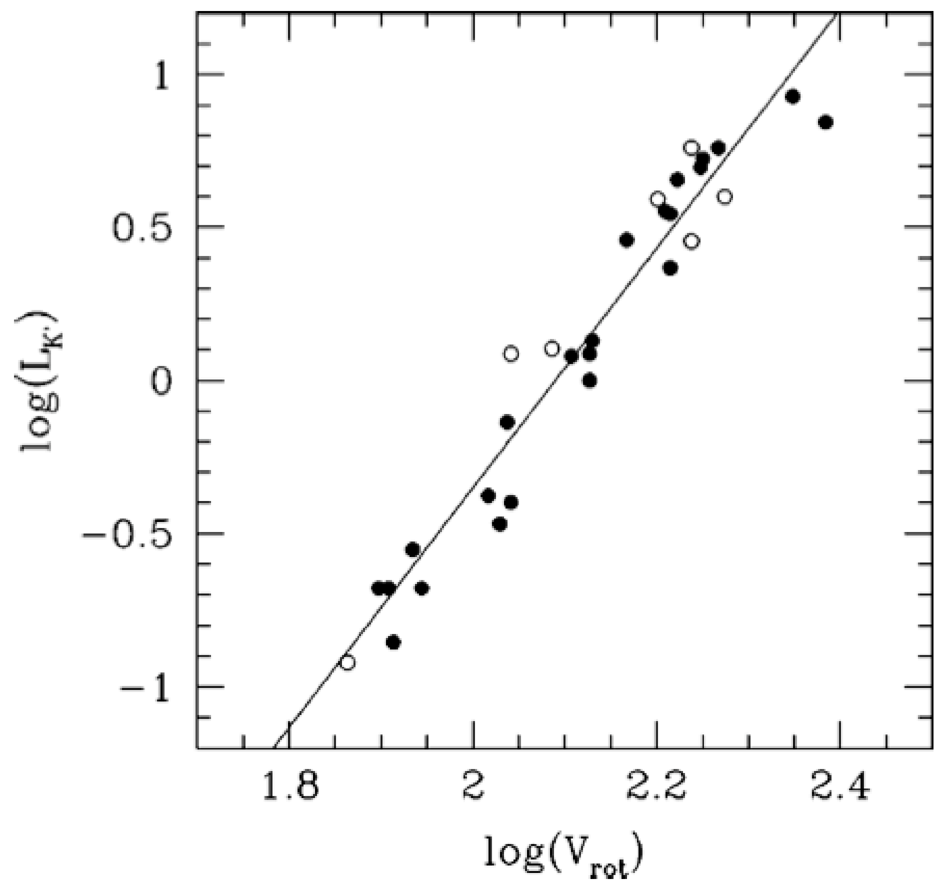
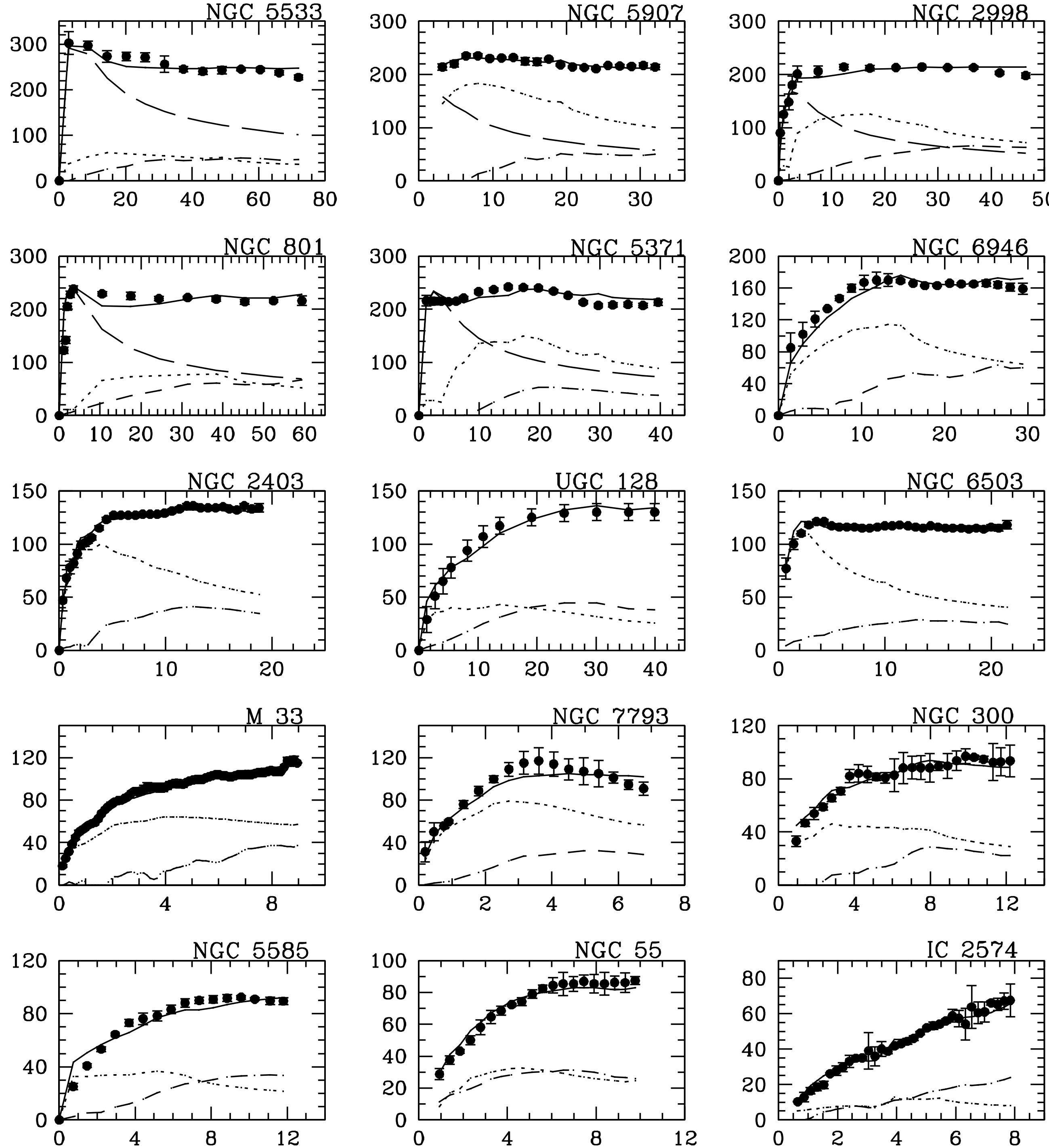
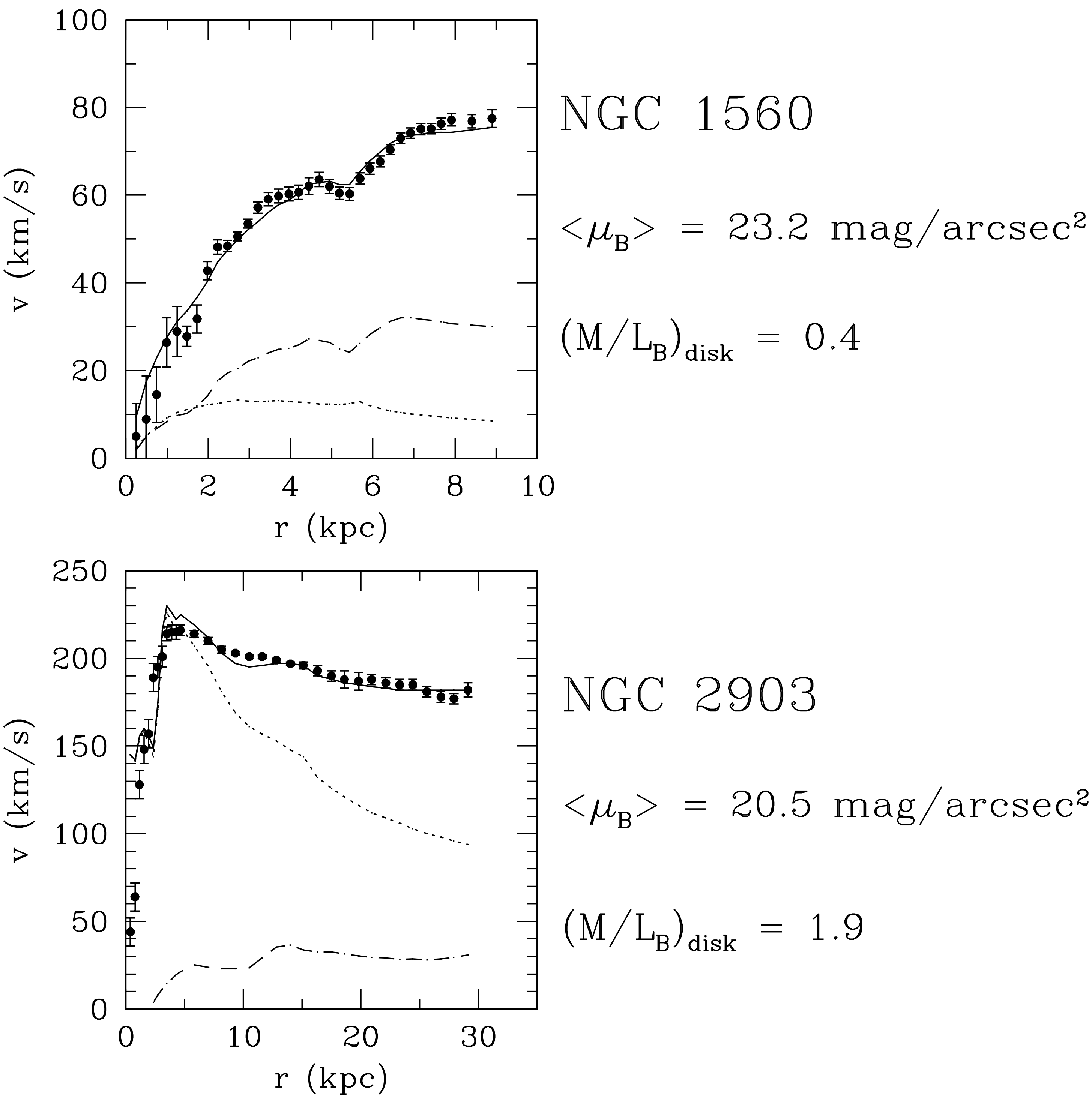


Figure 2 The near-infrared Tully-Fisher relation of Ursa Major spirals (Sanders & Verheijen 1998). The rotation velocity is the asymptotically constant value. The velocity is in units of kilometer/second and luminosity in 10^{10} $L_\odot$. The unshaded points are galaxies with disturbed kinematics. The line is a least-square fit to the data and has a slope of 3.9 ± 0.2.

Rotation in MOND




NGC 1560
$\langle \mu_B \rangle$ = 23.2 mag/arcsec^2
$(M/L_B)_{disk}$ = 0.4
v (km/s)
r (kpc)
0
20
40
60
80
100
0
2
4
6
8
10
NGC 2903
$\langle \mu_B \rangle$ = 20.5 mag/arcsec^2
$(M/L_B)_{disk}$ = 1.9
v (km/s)
r (kpc)
0
50
100
150
200
250
0
10
20
30

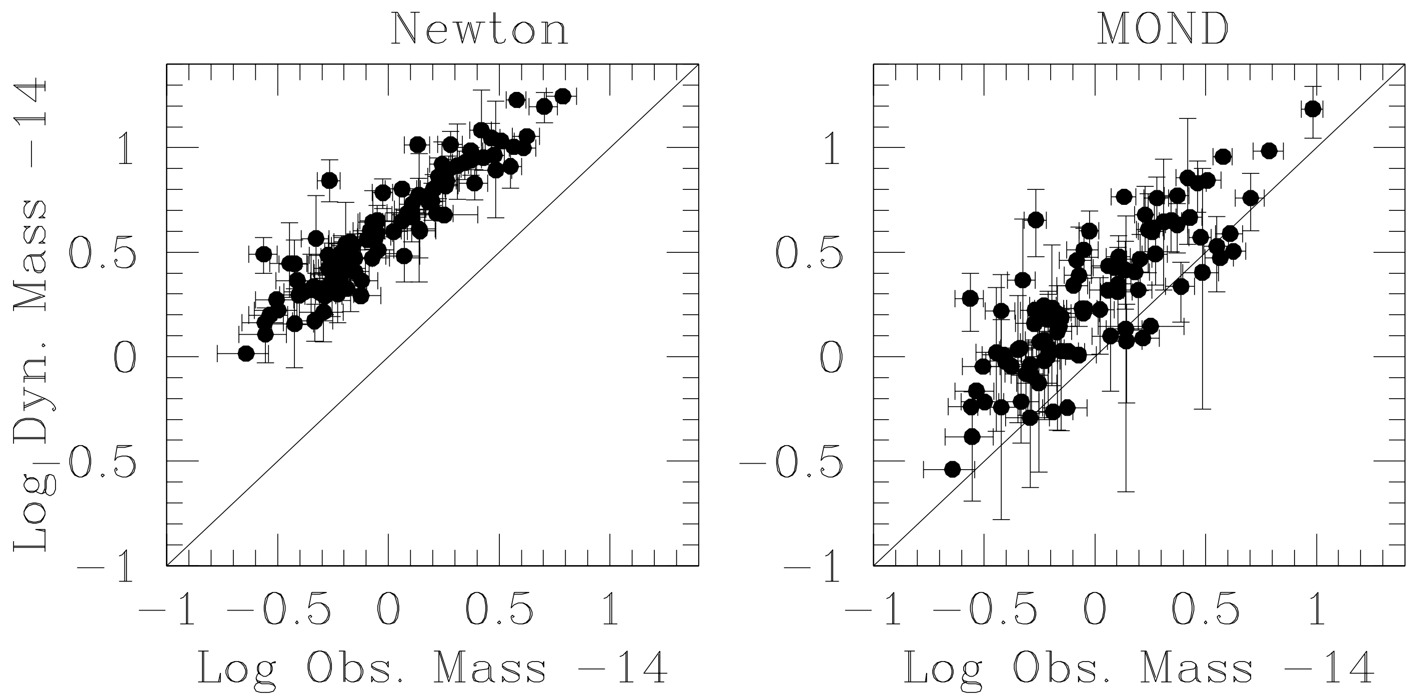


Figure 10: (*Left*) the Newtonian dynamical mass of clusters of galaxies within an observed cutoff radius (r_{out}) vs. the total observable mass in 93 X-ray emitting clusters of galaxies (White et al. 1997). The solid line corresponds to $M_{dyn} = M_{obs}$ (no discrepancy). (*Right*) the MOND dynamical mass within r_{out} vs. the total observable mass for the same X-ray emitting clusters. From Sanders (1999).

Sanders, 1999

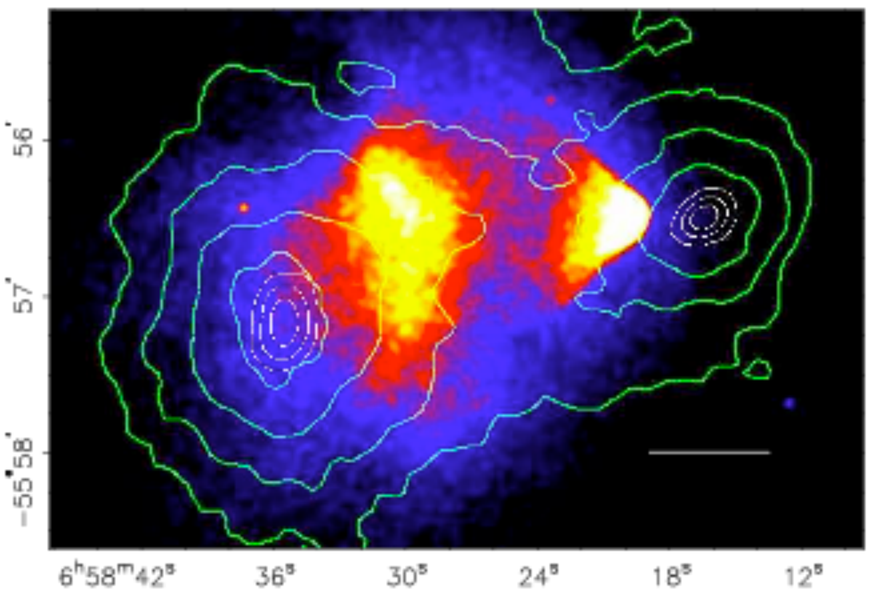


FIG. 6: The colliding clusters 1E0657-56. The bullet cluster (right) rammed through the cluster on the left. Hot gas stripped off both clusters is colored red-yellow. Green and white curves are level surfaces of gravitational lensing convergence; the two peaks of this do not coincide with those of the 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

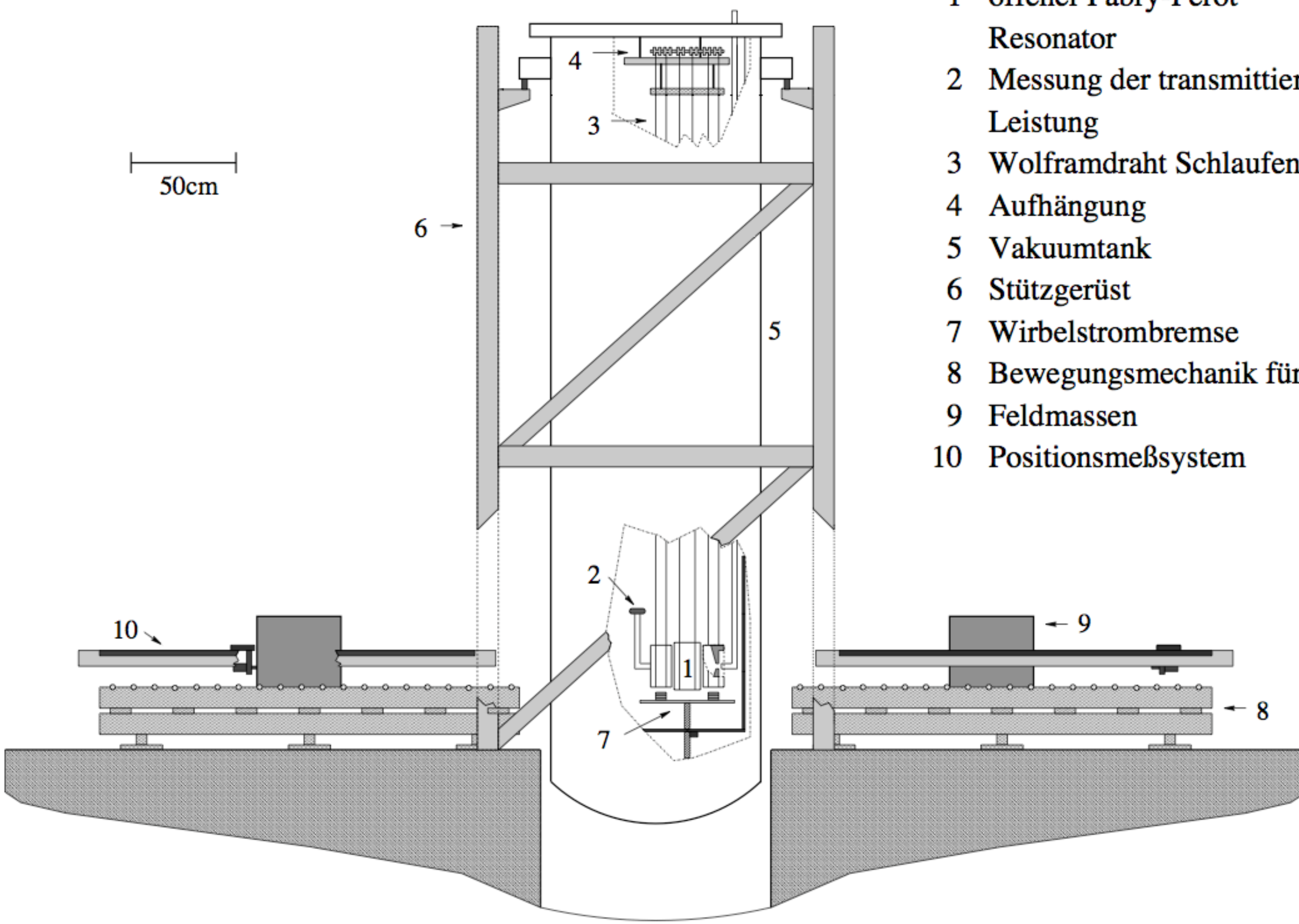
Vera Rubin (final remarks)

10. Dark halos may finally be understood. We will know their extent and their relation to the intracluster dark mass. We may even know the rotation velocity of the halo. Will the concept of a "rotation curve" apply at such large distances from the disk? Will we learn if our halo brushes the halo of M31?
11. We will ultimately know what is the dark matter—the major mass constituent of the Universe. Elementary particle physics will teach us its origin and physical properties.
12. Perhaps we will be able to put to rest the last doubt about the applicability of Newtonian gravitational theory on a cosmic scale, or enthusiastically embrace its successor.

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

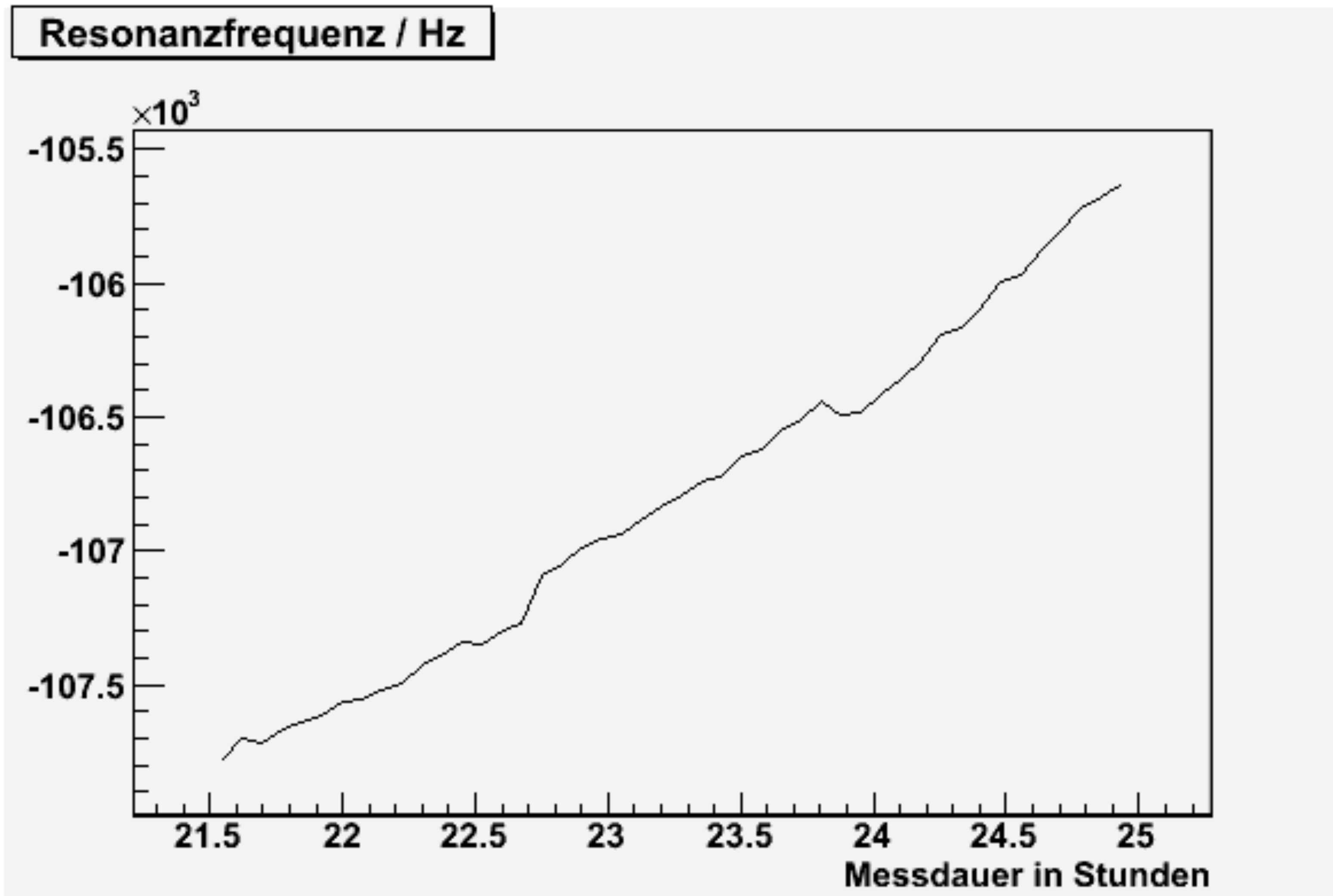
Setup in Wuppertal



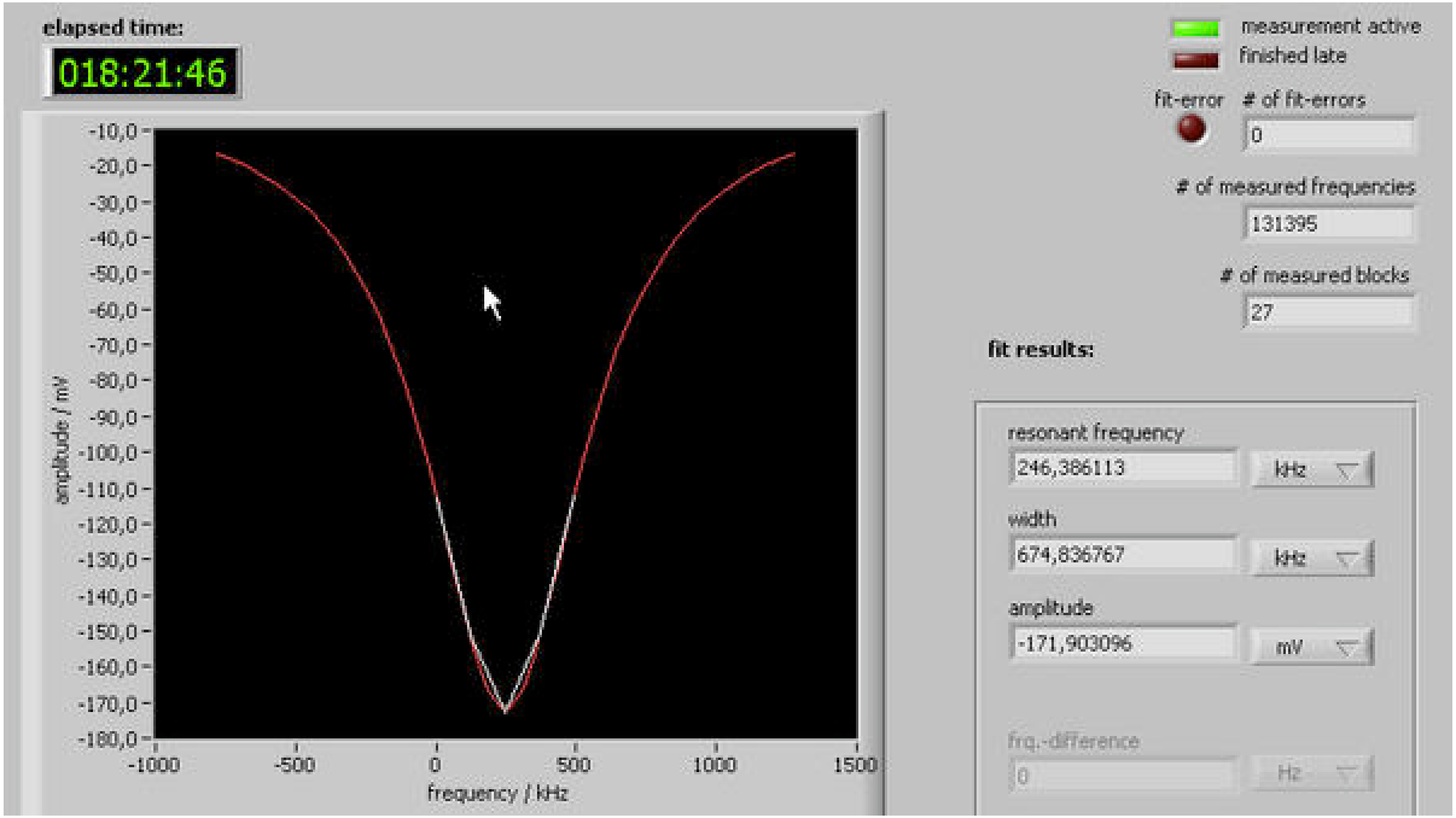
1 offener Fabry-Pérot Resonator
2 Messung der transmittierten Leistung
3 Wolframdraht Schlaufen
4 Aufhängung
5 Vakuumtank
6 Stützgerüst
7 Wirbelstrombremse
8 Bewegungsmechanik für 9
9 Feldmassen
10 Positionsmeßsystem

Abbildung 4.1: *Schematische Darstellung des Wuppertaler Gravitations-Experimentes.*

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

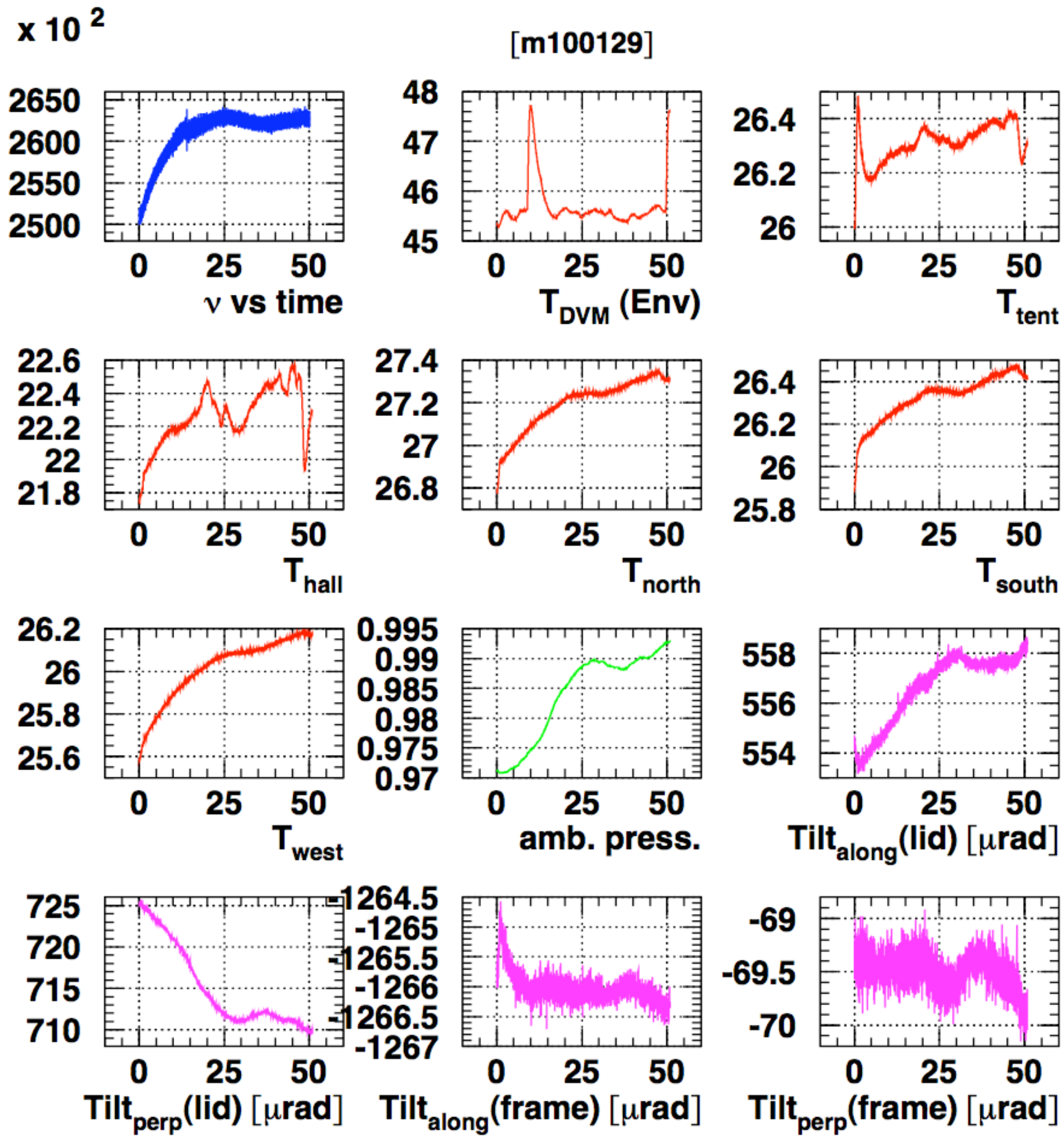


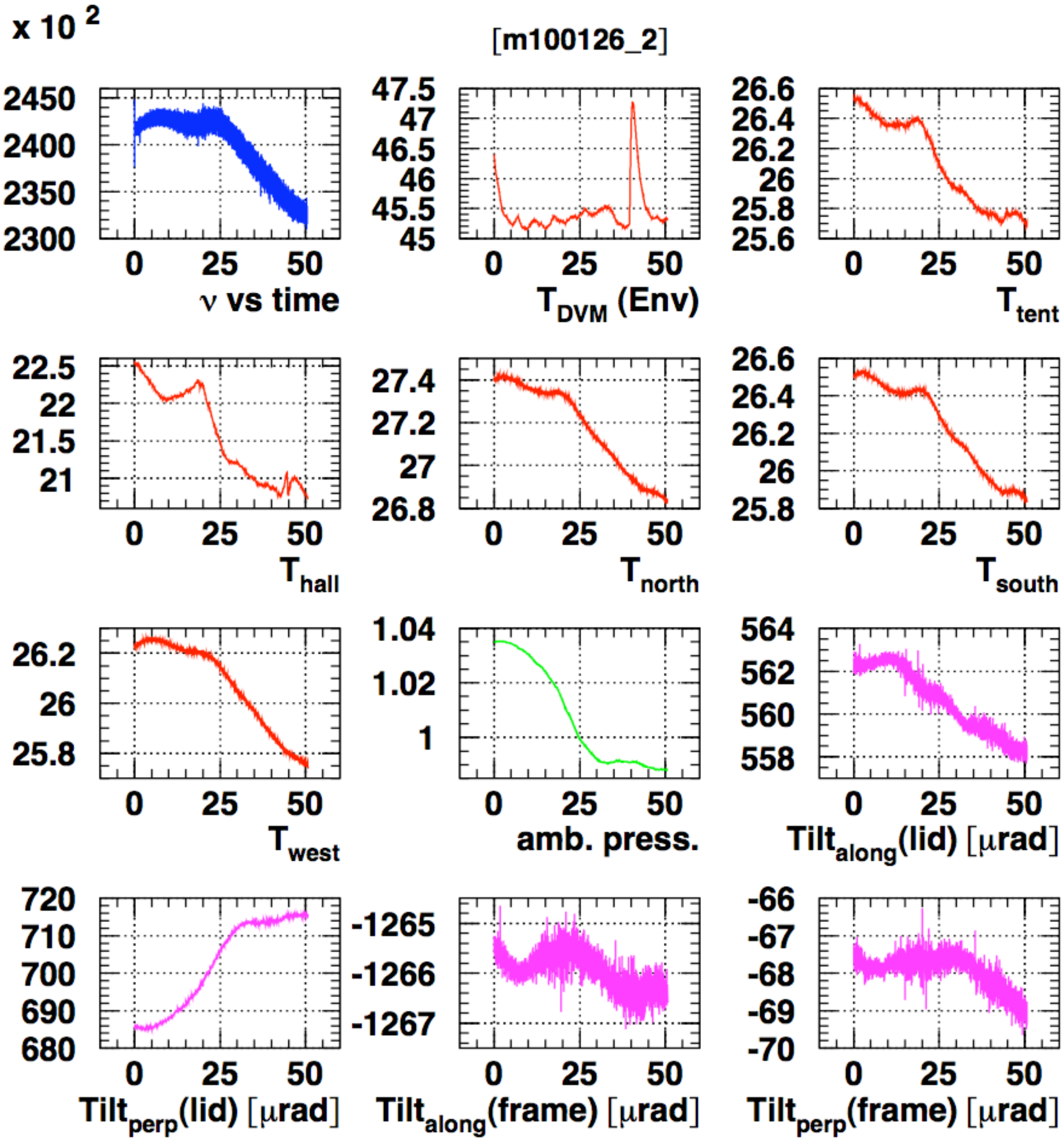
21 GHz resonance in our cavity



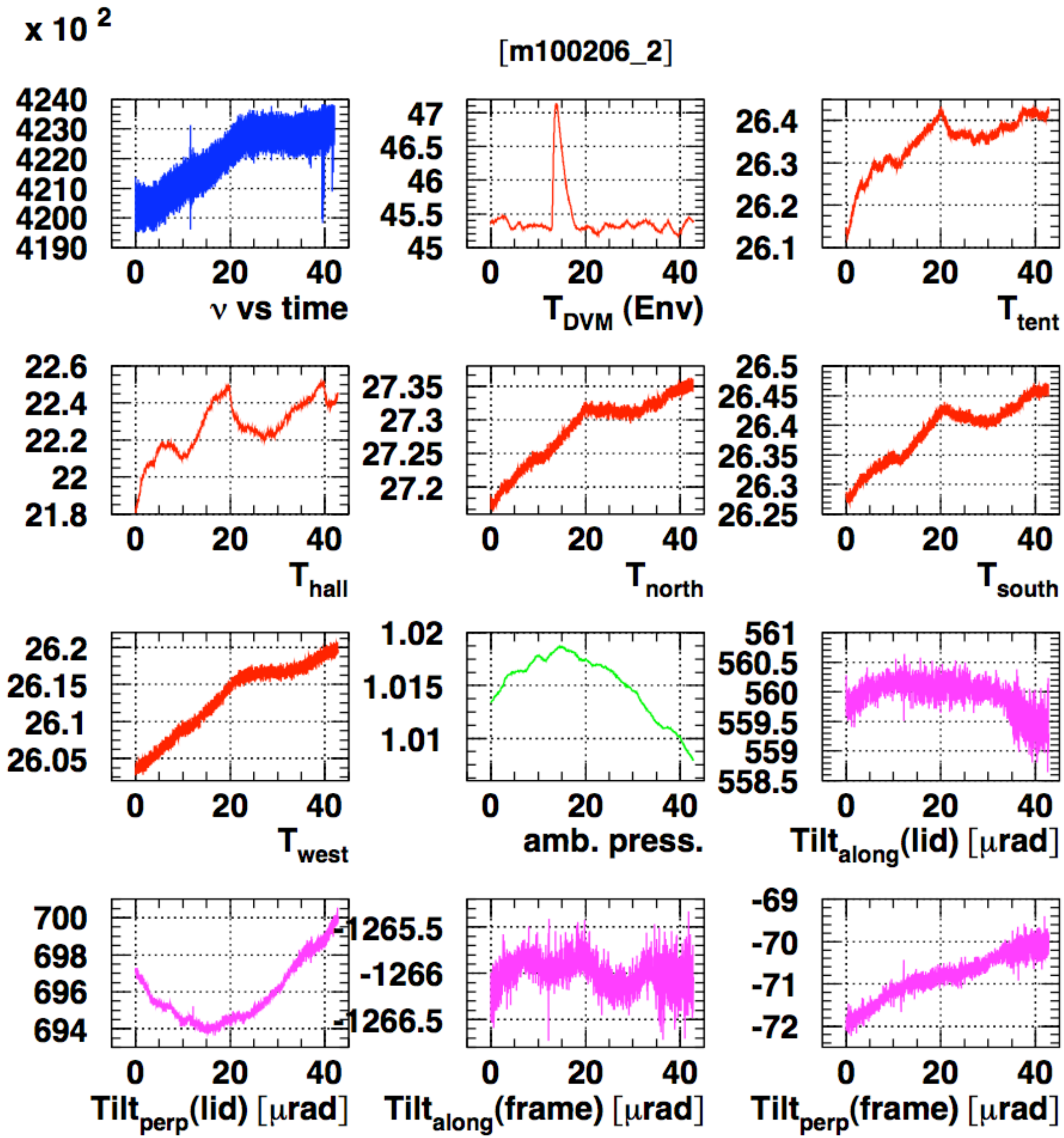
About 1/sec, 5 point fit, our basic signal

Data vs run time

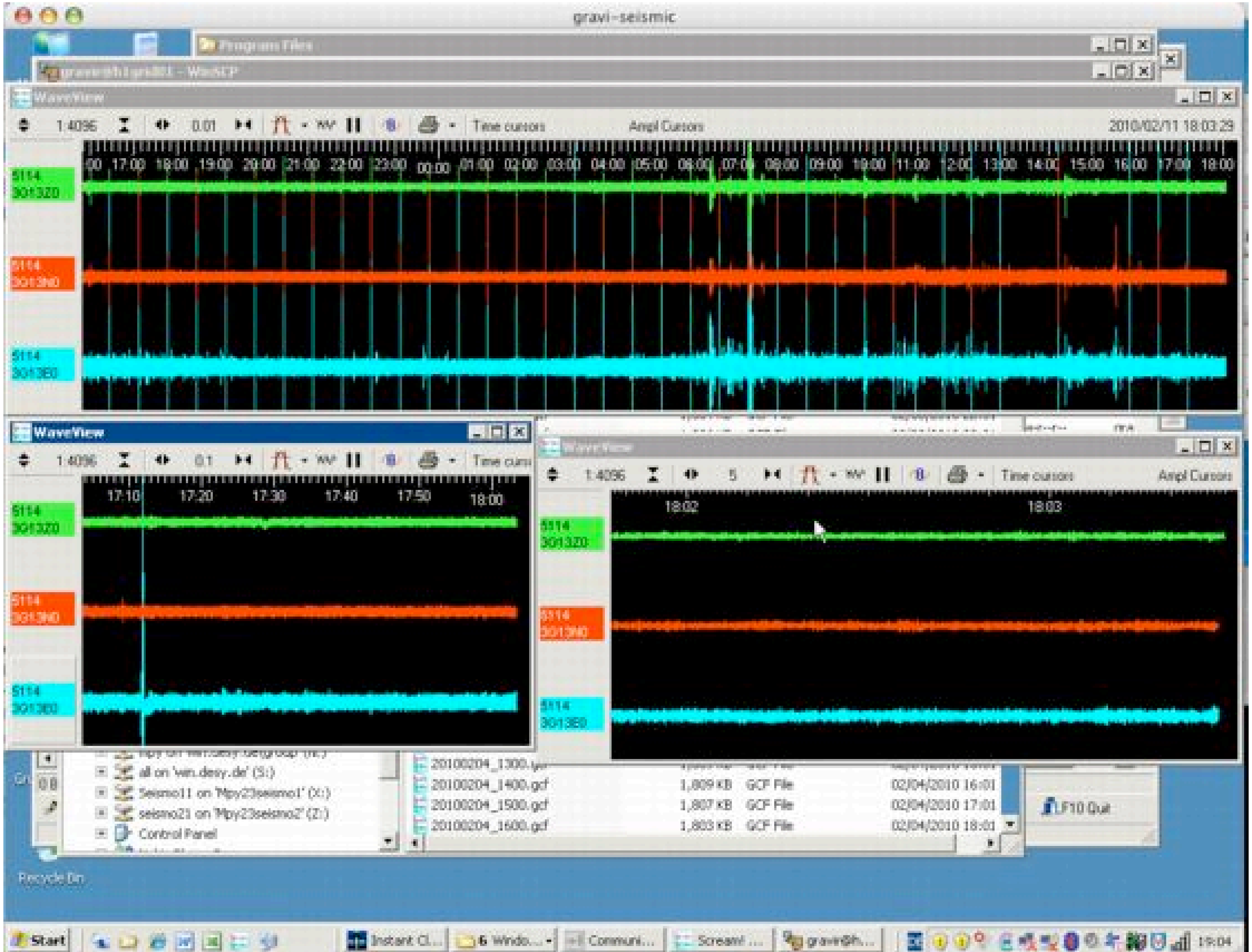




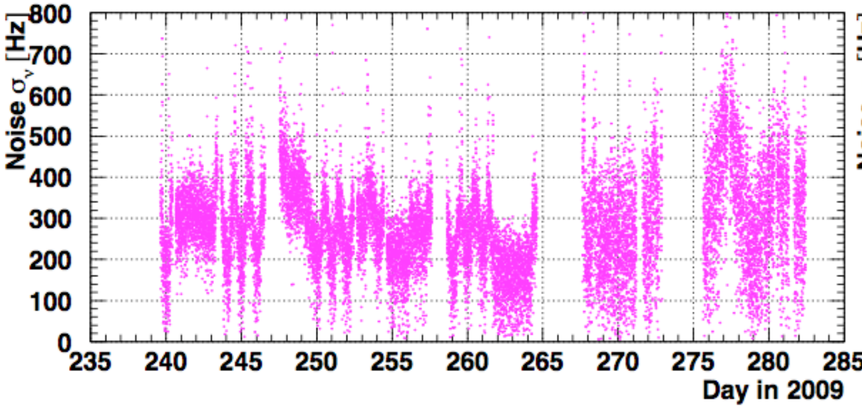
[m100126_2]
x 10 2
2450
2400
2350
2300
0 25 50
ν vs time
47.5
47
46.5
46
45.5
45
0 25 50
T DVM (Env)
26.6
26.4
26.2
26
25.8
25.6
0 25 50
T tent
22.5
22
21.5
21
0 25 50
T hall
27.4
27.2
27
26.8
0 25 50
T north
26.6
26.4
26.2
26
25.8
0 25 50
T south
26.2
26
25.8
0 25 50
T west
1.04
1.02
1
0 25 50
amb. press.
564
562
560
558
0 25 50
Tilt along (lid) [μrad]
720
710
700
690
680
0 25 50
Tilt perp (lid) [μrad]
-1265
-1266
-1267
0 25 50
Tilt along (frame) [μrad]
-66
-67
-68
-69
-70
0 25 50
Tilt perp (frame) [μrad]

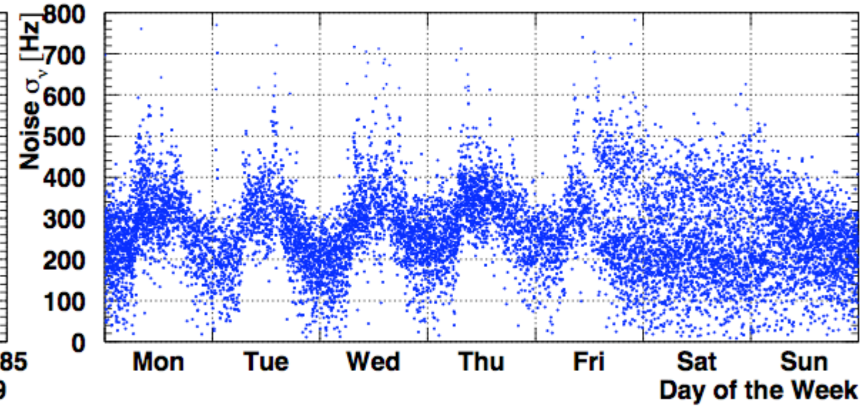

x 10 2
[m100206_2]
4240
4230
4220
4210
4200
4190
0
20
40
ν vs time
47
46.5
46
45.5
45
0
20
40
T DVM (Env)
26.4
26.3
26.2
26.1
0
20
40
T tent
22.6
22.4
22.2
22
21.8
0
20
40
T hall
27.35
27.3
27.25
27.2
0
20
40
T north
26.5
26.45
26.4
26.35
26.3
26.25
0
20
40
T south
26.2
26.15
26.1
26.05
0
20
40
T west
1.02
1.015
1.01
0
20
40
amb. press.
561
560.5
560
559.5
559
558.5
0
20
40
Tilt along (lid) [μrad]
700
698
696
694
0
20
40
Tilt perp (lid) [μrad]
-1265.5
-1266
-1266.5
0
20
40
Tilt along (frame) [μrad]
-69
-70
-71
-72
0
20
40
Tilt perp (frame) [μrad]

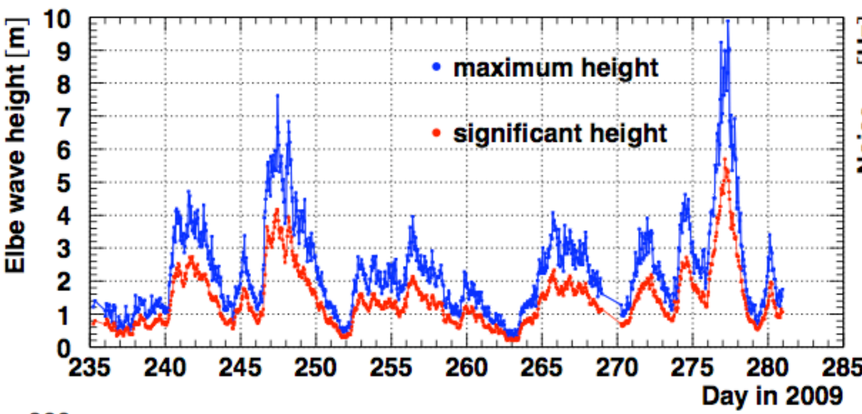
Seismic signal

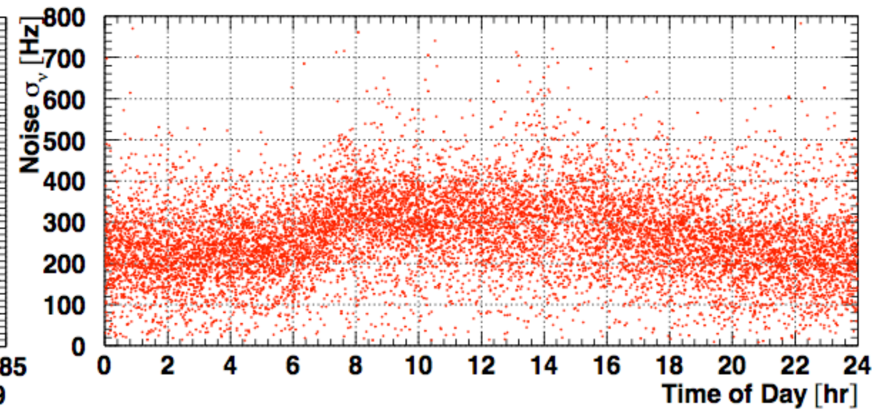


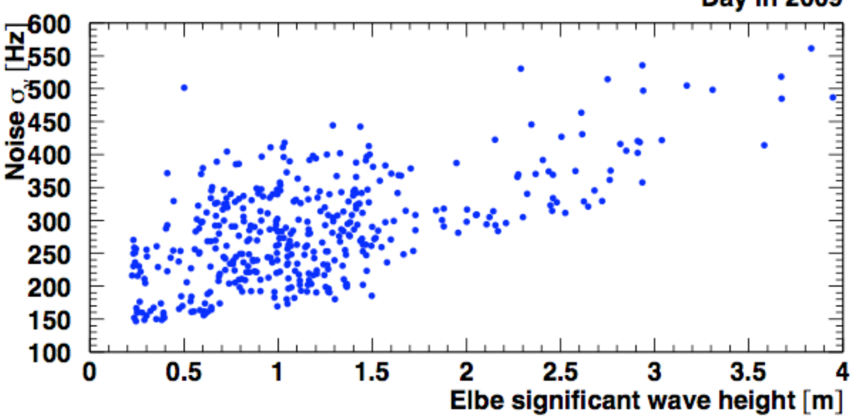
NOISE


Noise σν [Hz]
0
100
200
300
400
500
600
700
800
235
240
245
250
255
260
265
270
275
280
285
Day in 2009

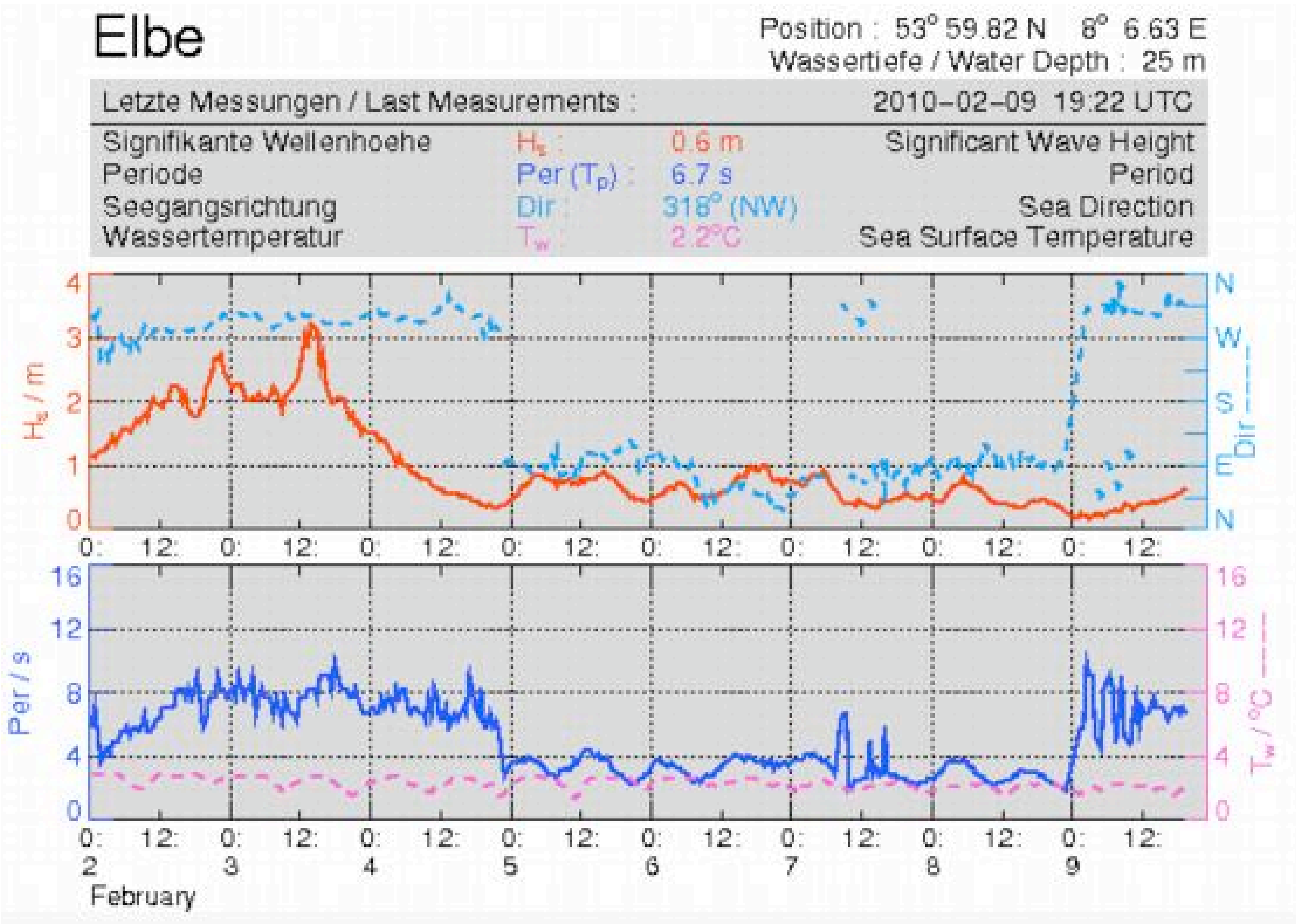

Noise σν [Hz]
0
100
200
300
400
500
600
700
800
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Day of the Week


Elbe wave height [m]
0
1
2
3
4
5
6
7
8
9
10
maximum height
significant height
235
240
245
250
255
260
265
270
275
280
285
Day in 2009

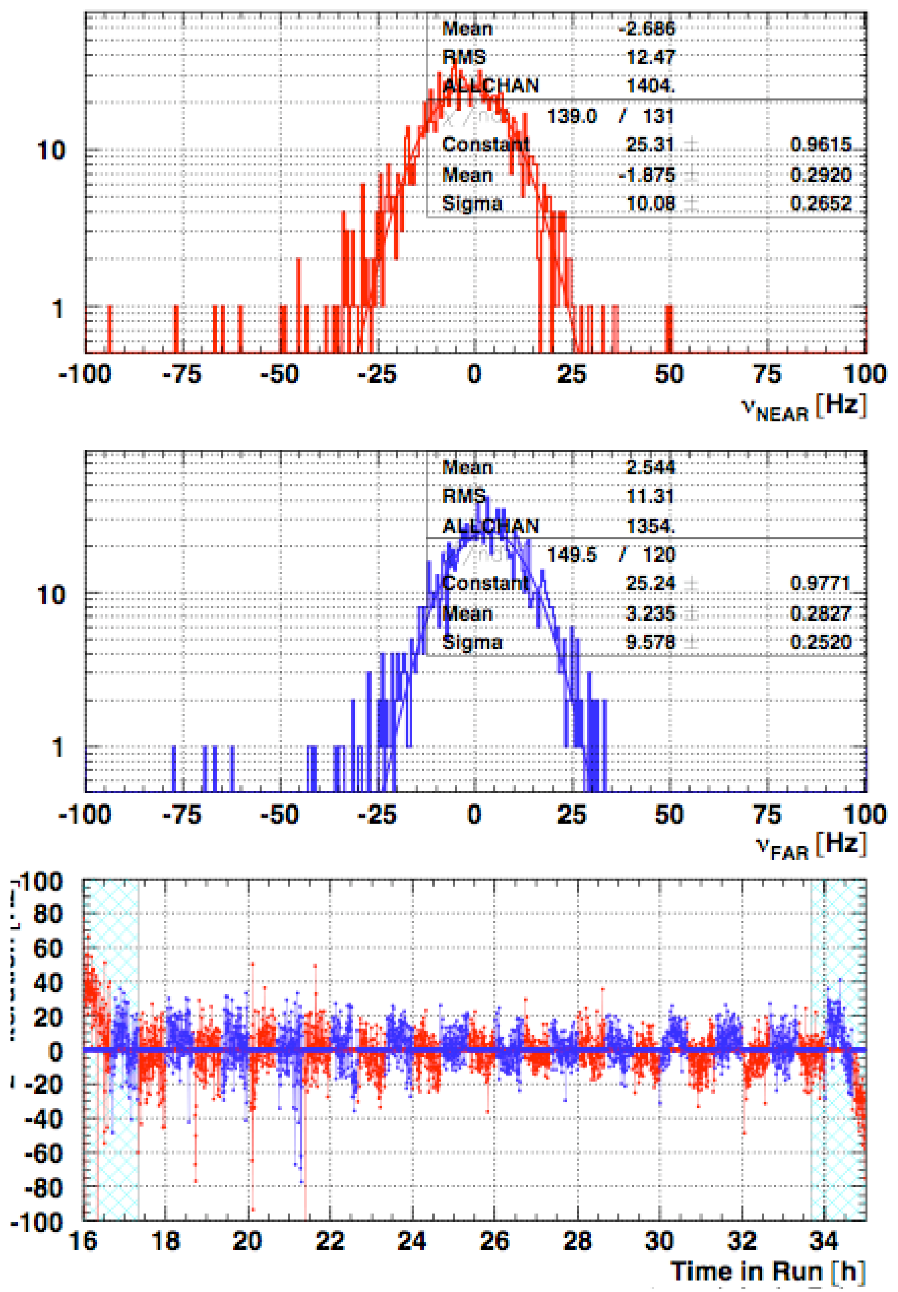

Noise σν [Hz]
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Day [hr]


Noise σν [Hz]
100
150
200
250
300
350
400
450
500
550
600
0
0.5
1
1.5
2
2.5
3
3.5
4
Elbe significant wave height [m]

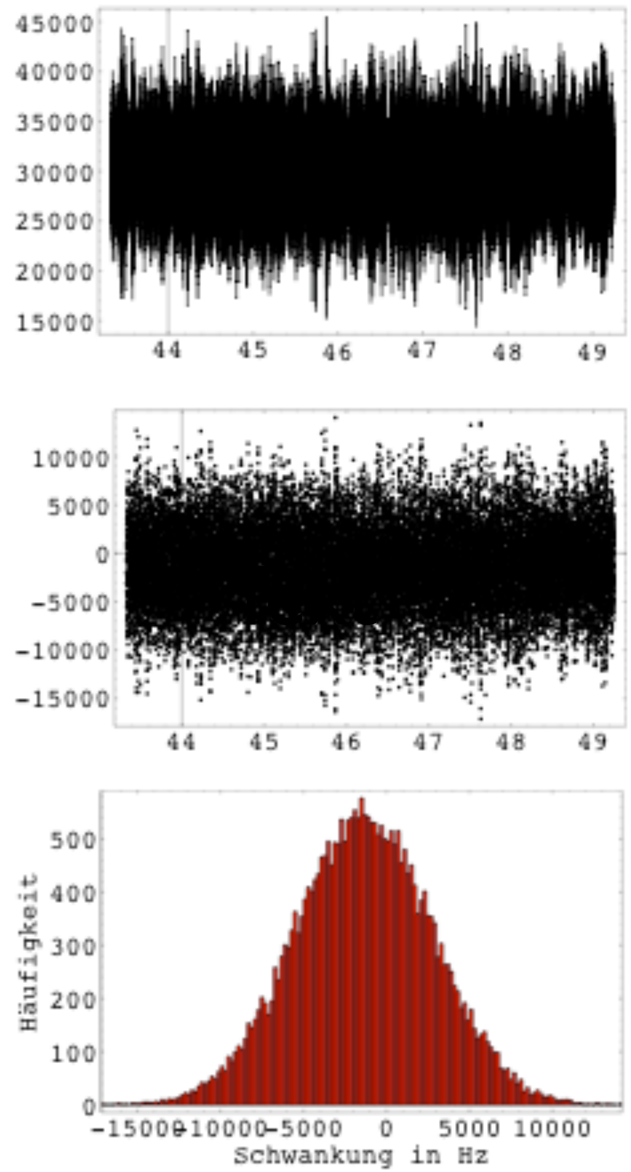
Wave height


Elbe
Position : 53° 59.82 N 8° 6.63 E
Wassertiefe / Water Depth : 25 m
Letzte Messungen / Last Measurements : 2010–02–09 19:22 UTC
Signifikante Wellenhoehe Hs : 0.6 m Significant Wave Height
Periode Per (Tp) : 6.7 s Period
Seegangsrichtung Dir : 318° (NW) Sea Direction
Wassertemperatur Tw : 2.2°C Sea Surface Temperature
Hs / m
Dir
N W S E N
Per / s
Tw / °C
0: 12: 0: 12: 0: 12: 0: 12: 0: 12: 0: 12: 0: 12: 0: 12:
2 3 4 5 6 7 8 9
February

Gaussian distribution ??

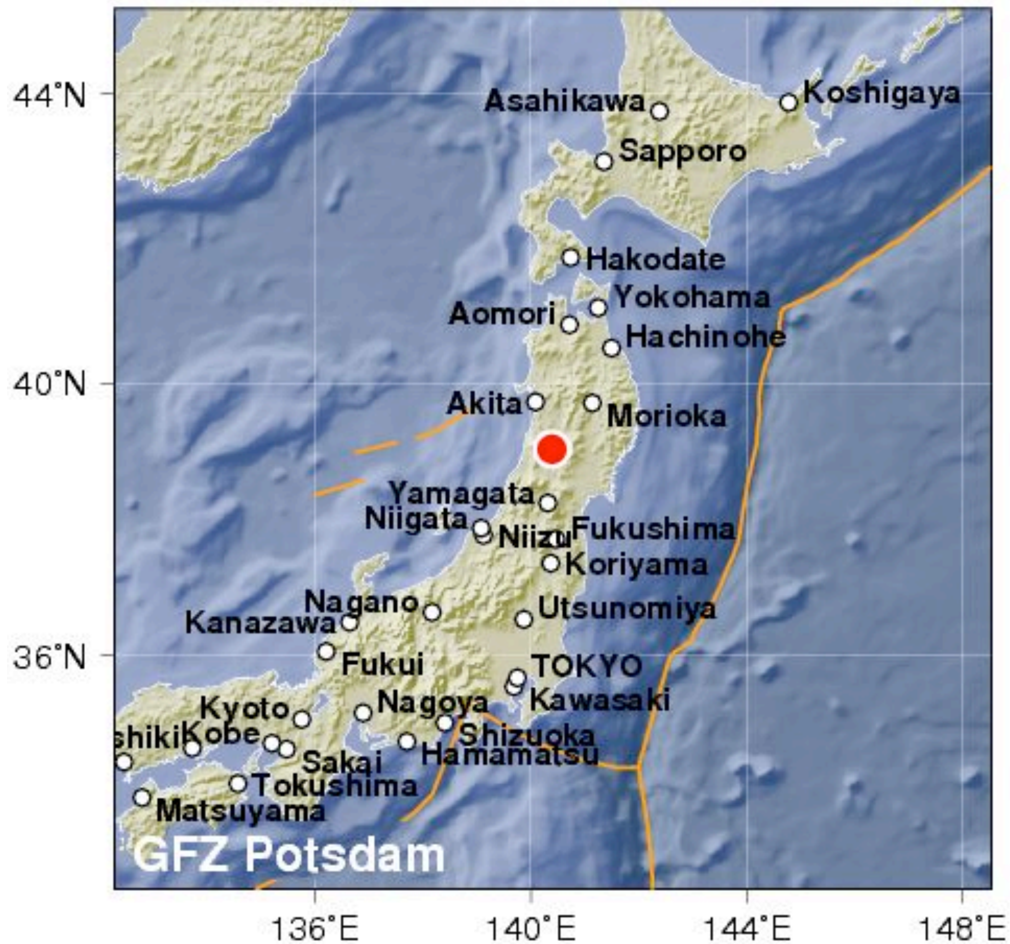


Noise nicely Gaussian, very crucial

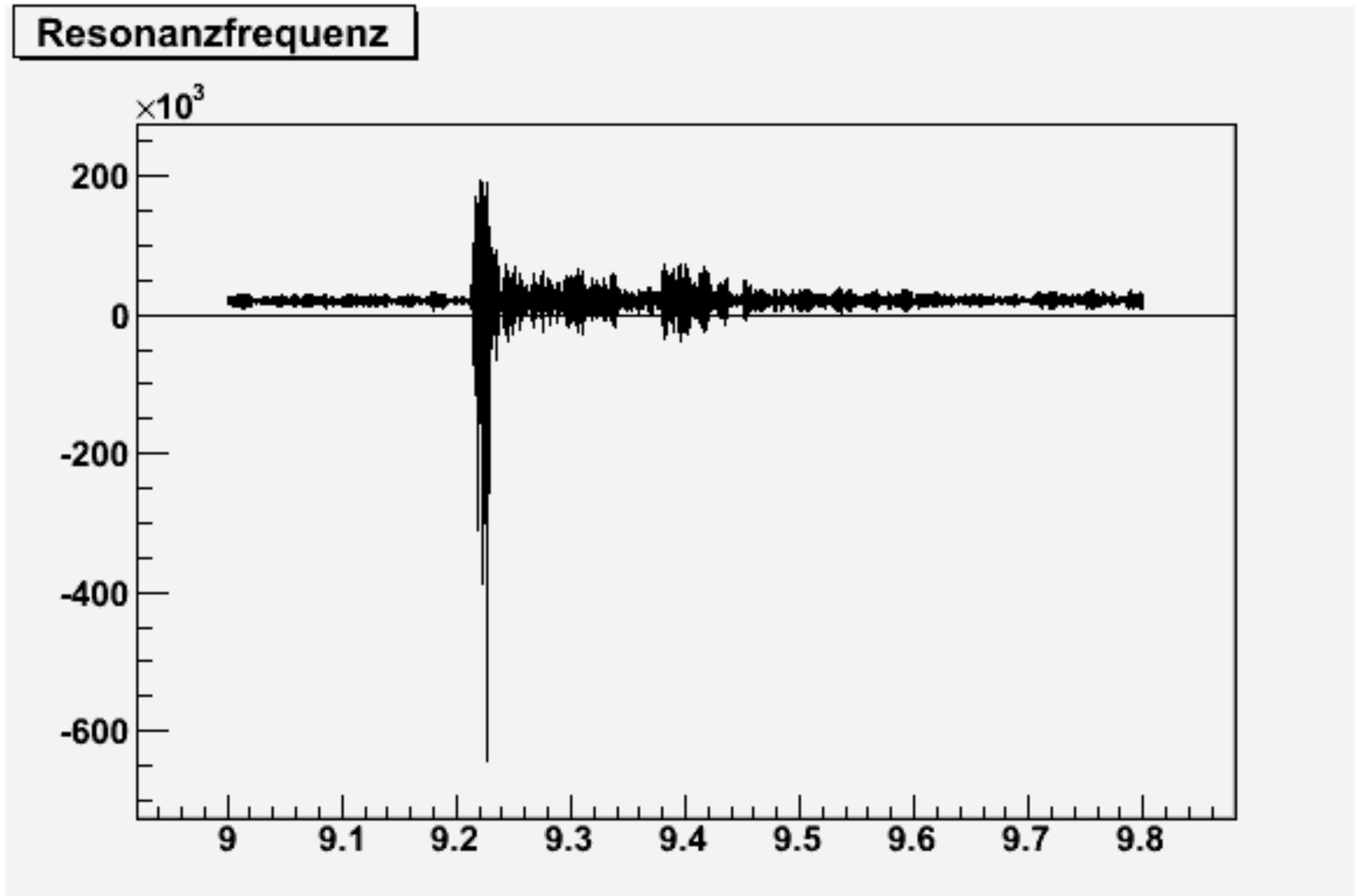


frequency vs. time

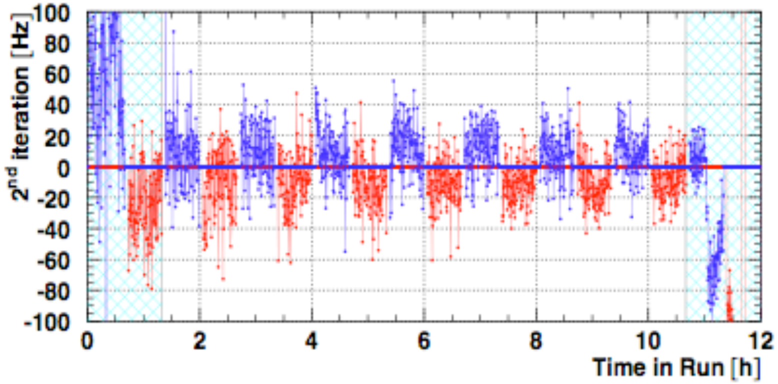
Earthquake in Japan



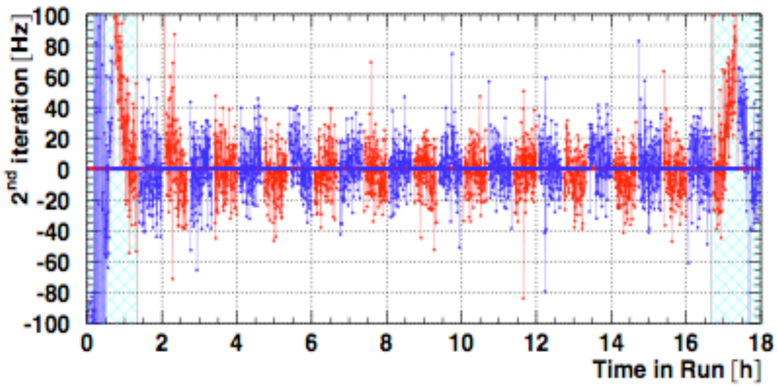
Earthquake signal in GRAVI



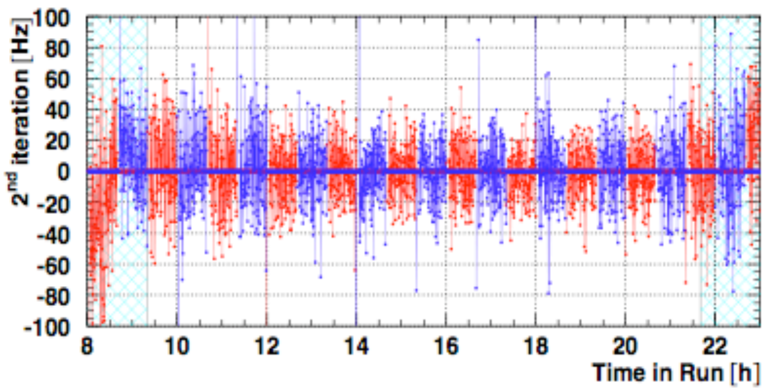
F-Signal (in/out)



9 kg
m090930



2.9 kg
m090918



1.0 kg
m091216

Newtons Law

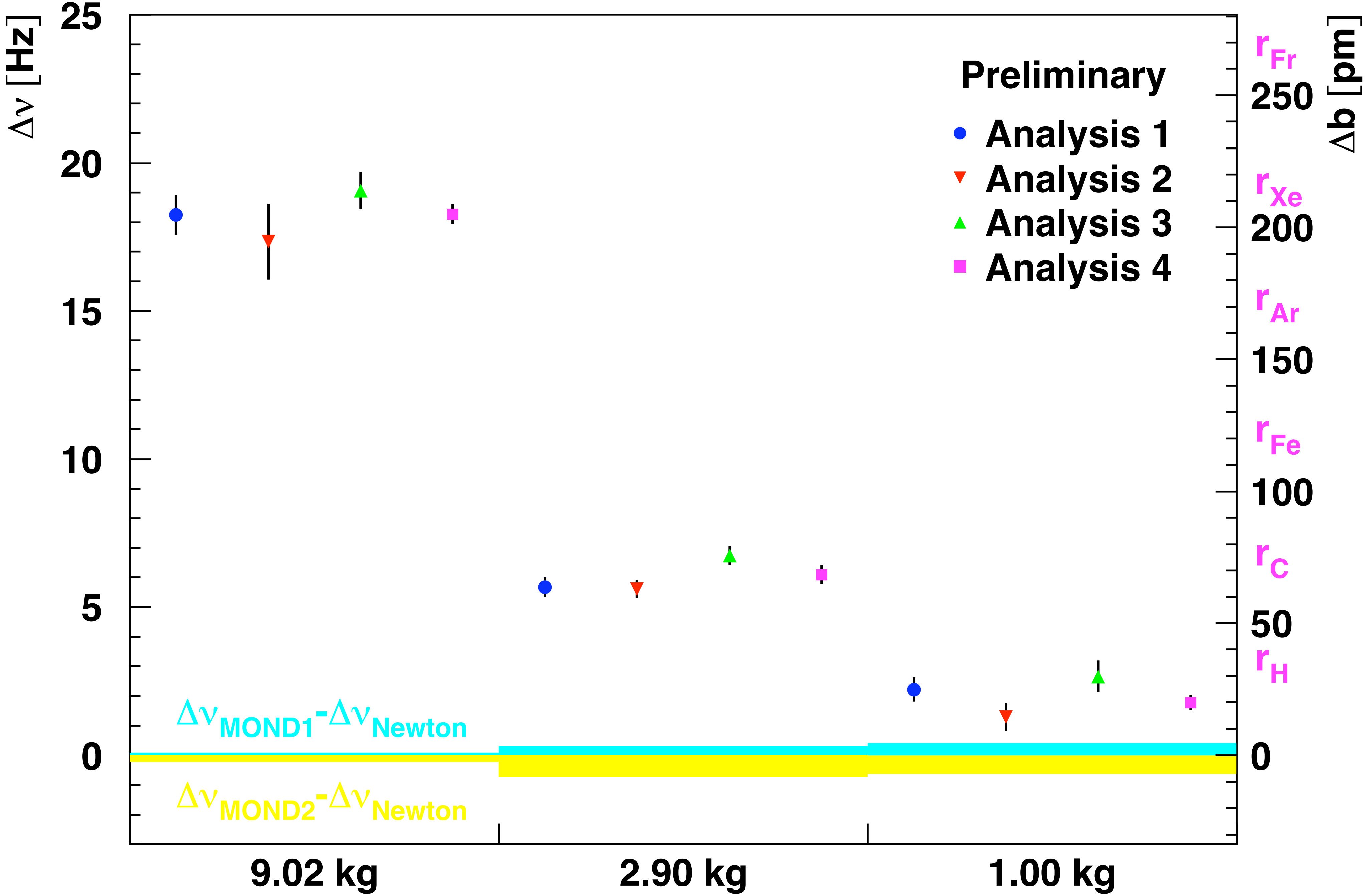
strictly proportional

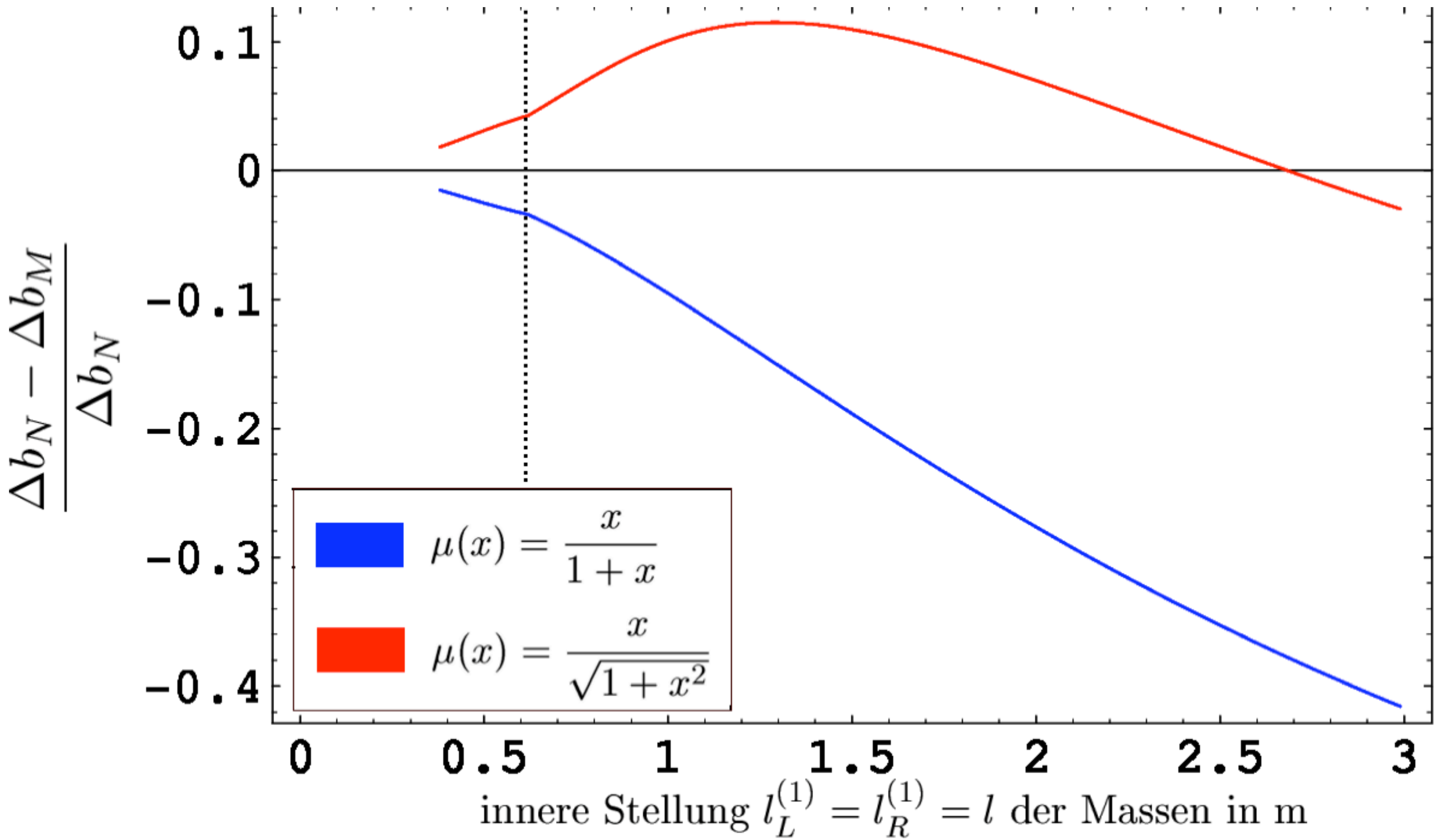
to the fieldmass

Analysis

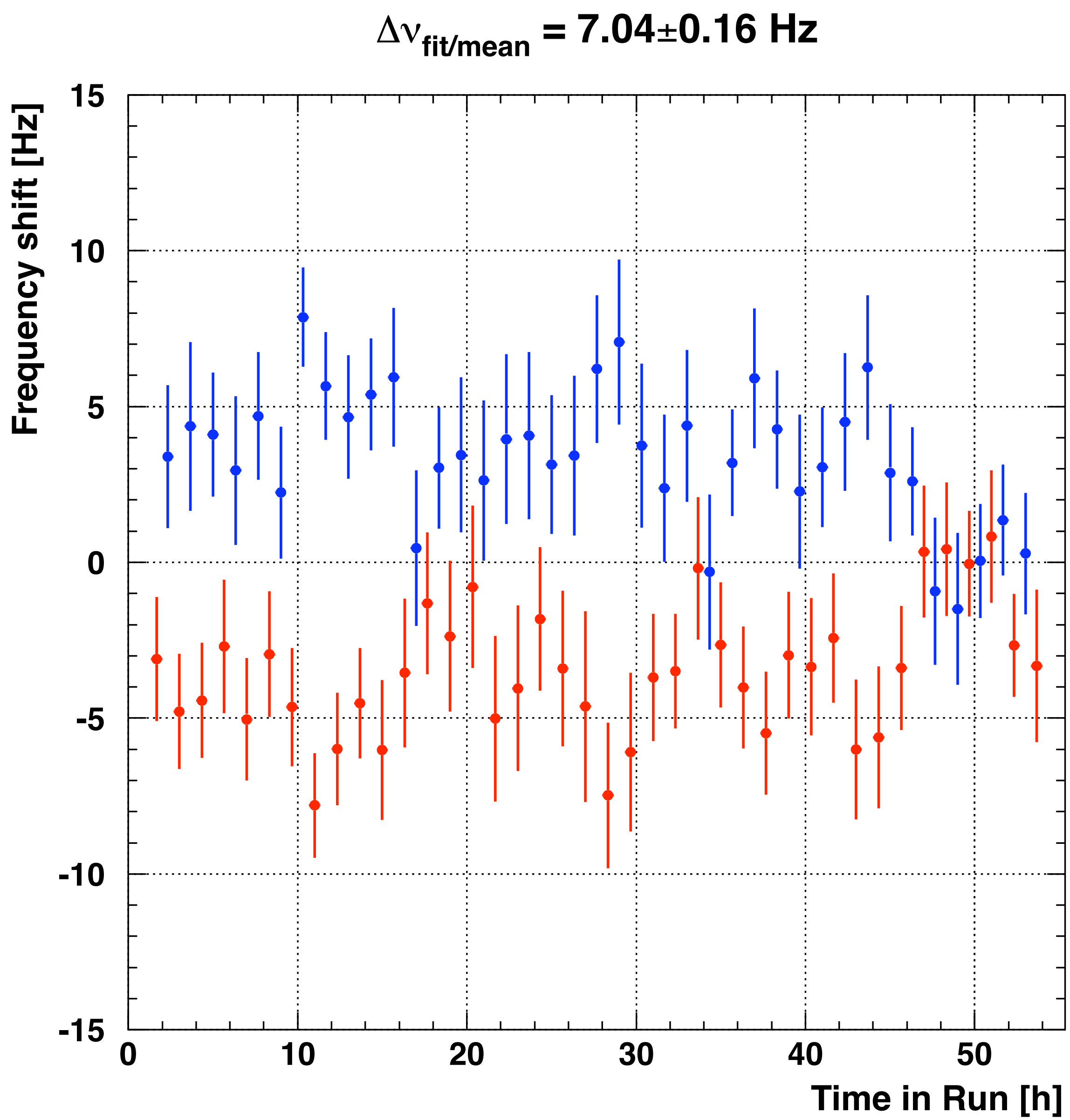
Have 4 independent lines of analysis
Consider this to be absolutely crucial
for such a fundamental experiment

“Preliminary”




0.1
0
-0.1
-0.2
-0.3
-0.4
$\frac{\Delta b_N - \Delta b_M}{\Delta b_N}$
$\mu(x) = \frac{x}{1+x}$
$\mu(x) = \frac{x}{\sqrt{1+x^2}}$
0
0.5
1
1.5
2
2.5
3
innere Stellung $l_L^{(1)} = l_R^{(1)} = l$ der Massen in m

Problem?


$\Delta\nu_{fit/mean}$ = 7.04±0.16 Hz
Frequency shift [Hz]
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
Time in Run [h]

Summary

- Take data since about 9/2009
- Use 3 Masses (9, 2.9 and 1kg) at 77cm
- Get results roughly in agreement with Newton
- Have still some unexplained systematic problems
- Have to do some further adjustments to the setup, but we are optimistic to come out soon with a word on Newton vs. MOND

fascinating times
testing
GRAVITY
in the lab

I like to thank DESY
for unbureaucratic
support

Not to forget!!!
H.J. Seidel
U. Cornett, T. Külper
C. Muhl, D. Habercorn
J. Schaffran