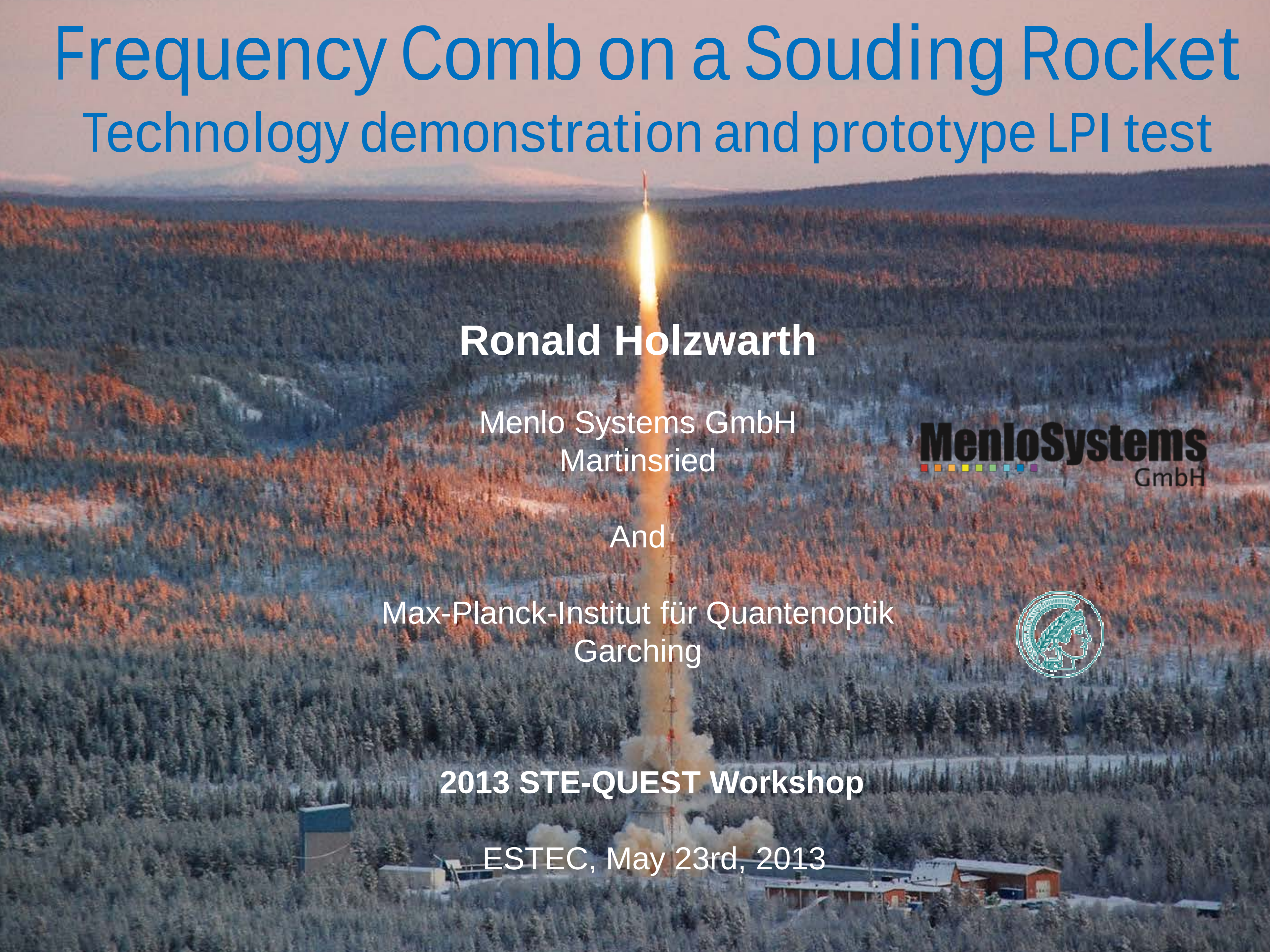
Frequency Comb on a Souding Rocket

Technology demonstration and prototype LPI test



Ronald Holzwarth

Menlo Systems GmbH
Martinsried

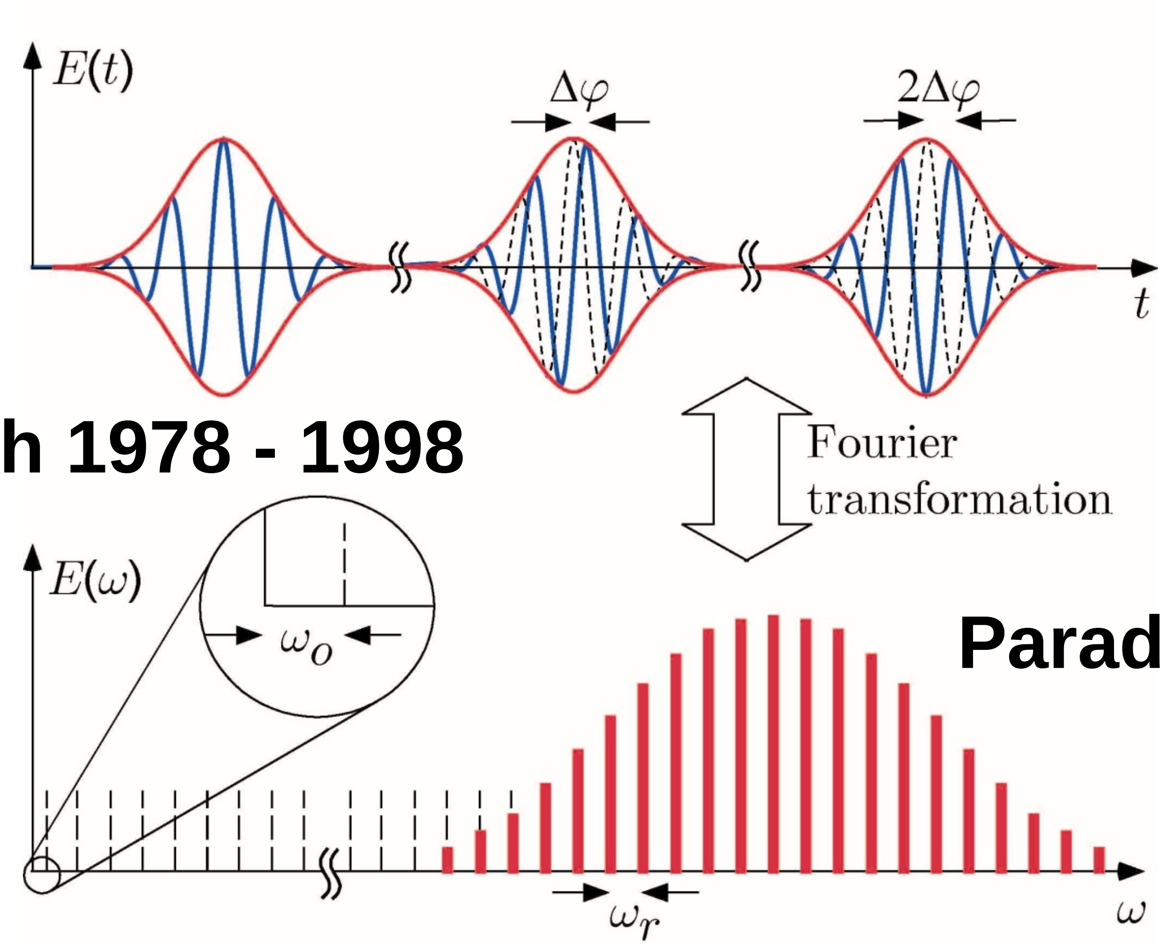
And

Max-Planck-Institut für Quantenoptik
Garching

2013 STE-QUEST Workshop

ESTEC, May 23rd, 2013

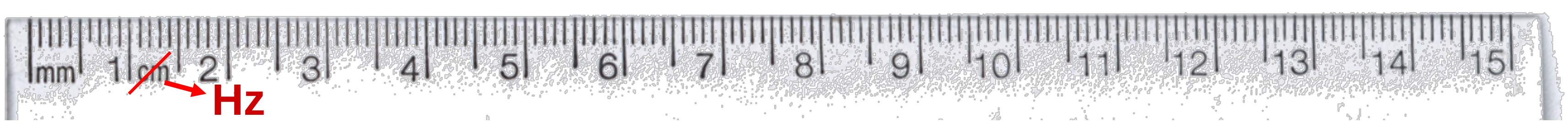
Frequency Combs



Ted Hänsch 1978 - 1998

Paradigm shift!

ω_{opt}=N ω_{rep} + ω_0



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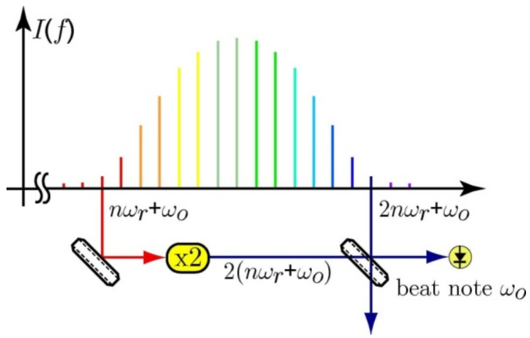
Nobel Prize (2005)



The Nobel Prize in Physics 2005

John L. Hall and **Theodor W. Hänsch**

„for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique“

Frequency Comb Technology gets scientific crown

Menlo Systems

- Spin-off from the Max-Planck-Institute for Quantum Optics (MPQ), founded 2001.
- No outside financing (some BMBF money and customer prepayment)
- Privately owned
- As of today: 70 employees (1/3 with PhD)
- >150 combs installed
- Located at a Innovation Centre (IZB) in the Munich area

➡ ***Bootstrapping***

What are Combs good for?

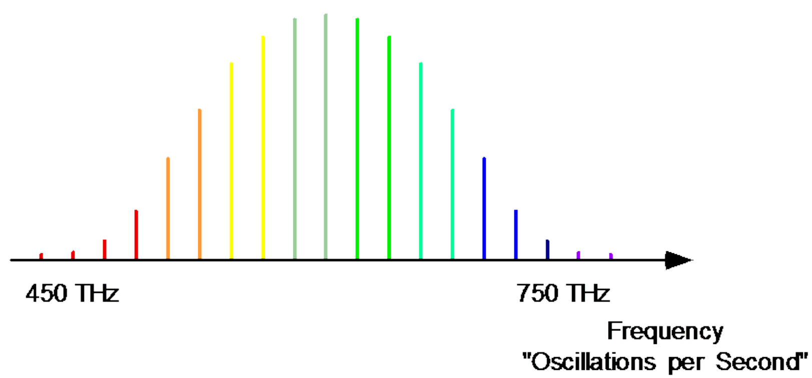
frequency combs

Time domain: Attosecond Physics

Stable microwaves

Direct comb Spectroscopy UV to THz

Distance measurement



Spectrograph calibration

Optical Reference

Precision spectroscopy

Optical Frequency Synthesizer

Clockwork for optical clocks

Dissemination of time and frequency

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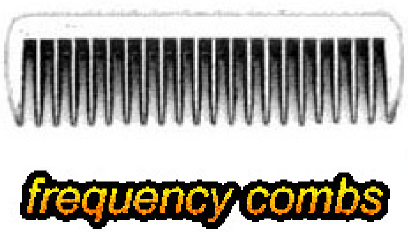
Combs in Space: Areas of Interest

Earth Observation:
LIDAR, Gravimetry

Navigation
clocks, time and frequency dissemination

Science Missions
Tests of Relativity, Fundamental Constants, Astronomy



The Rocky Road from Lab to Space

For
- space optical clocks
- distance measurements
- etc.

Drop tower Bremen
(2011)

Sounding rocket
(2013)

Satellite
(20XX)

Zero g for 5 sec | 5 min | years

Funded by and in cooperation with DLR

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FOKUS Project

„Faseroptischer Kamm unter Schwerelosigkeit“

Goal: Development of a frequency comb for the use in microgravity (µ-g) on a sounding rocket.

Work packages:

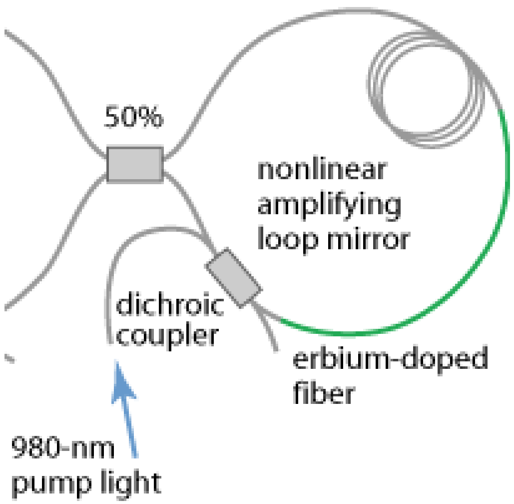
- Specially designed
  - mechanics
  - optics
  - electronics
  - software
  - interface

Partners:

MPQ, Menlo Sytems, DLR RY

Funded by

FOKUS Laser



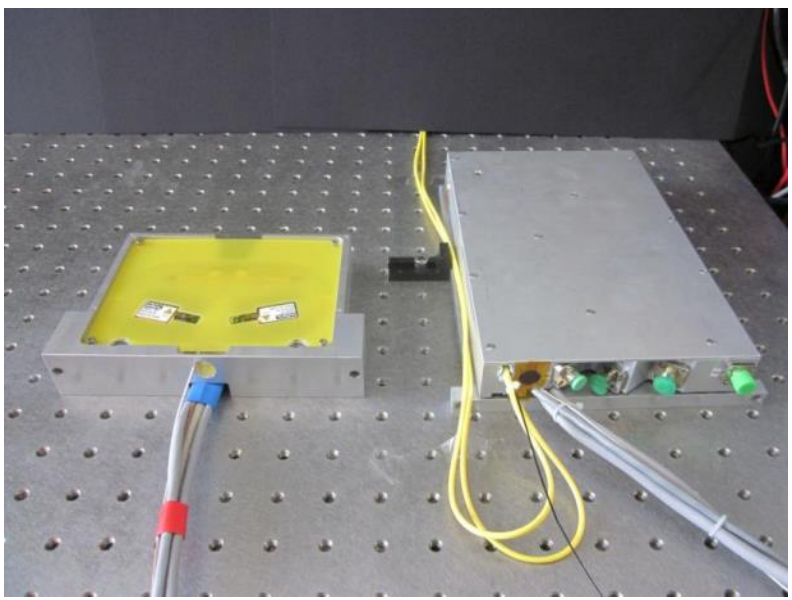
- NOLM (nonlinear optical loop mirror) mode locking
- All PM fiber
- Only standard telecom components
- Extremely robust and easy to handle
- Design choice: 100 MHz repetition rate

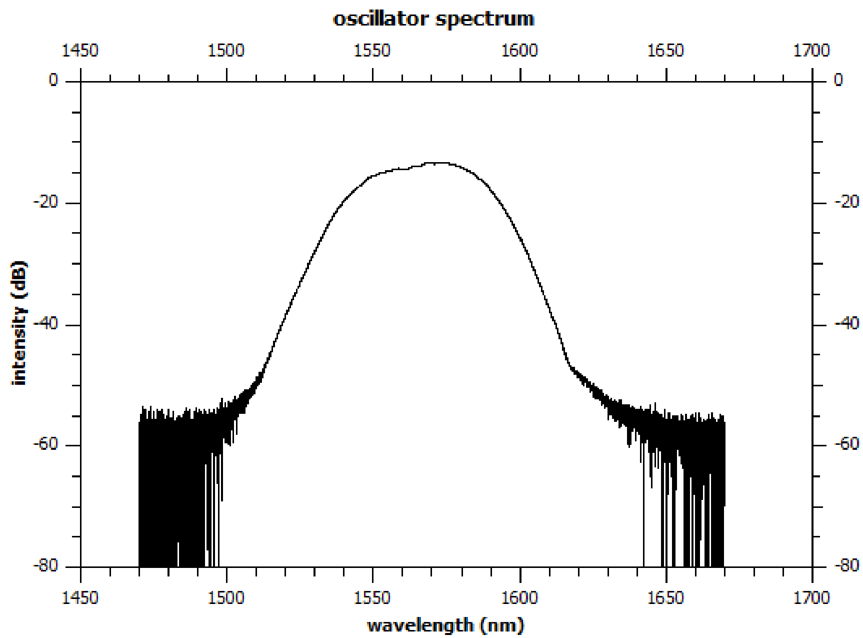
NOLM:
Phase shift depended on optical power

FOKUS Comb

Key data:

- Repetition rate: 100MHz
- Output power: 3mW
- Spectral bandwidth: 39nm
- Startup time: <10s





Radiation Sensitivity

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 59, NO. 2, APRIL 2012 425

Radiation Induced Absorption in Rare Earth Doped Optical Fibers

M. Lezius, K. Predehl, W. Stöwer, A. Türler, M. Greiter, Ch. Hoeschen, P. Thirolf, W. Assmann, D. Habs, A. Prokofiev, C. Ekström, T. W. Hänsch, and R. Holzwarth

***Abstract*—We have investigated the radiation induced absorption (RIA) of optical fibers with high active ion concentration. Comparing our results to the literature leads us to the conclusion that RIA appears to be only weakly dependent on the rare earth dopant concentration. Instead, co-dopants like Al, Ge, or P and manufacturing processes seem to play the major role for the radiation sensitivity. It is also observed that different types of irradiation cause very similar RIA at the same dose applied, with the exception at very high dose rates. It has been studied how RIA can be efficiently reduced via moderate heating. Recovery of up to 70% of the original transmission has been reached after annealing at 450 K. We conclude that radiation induced color centers have weak binding energies between 20 and 40 meV. This suggests that annealing could become a key strategy for an improved survival of rare earth doped fibers in radiative environments, opening up new possibilities for long-term missions in space.**

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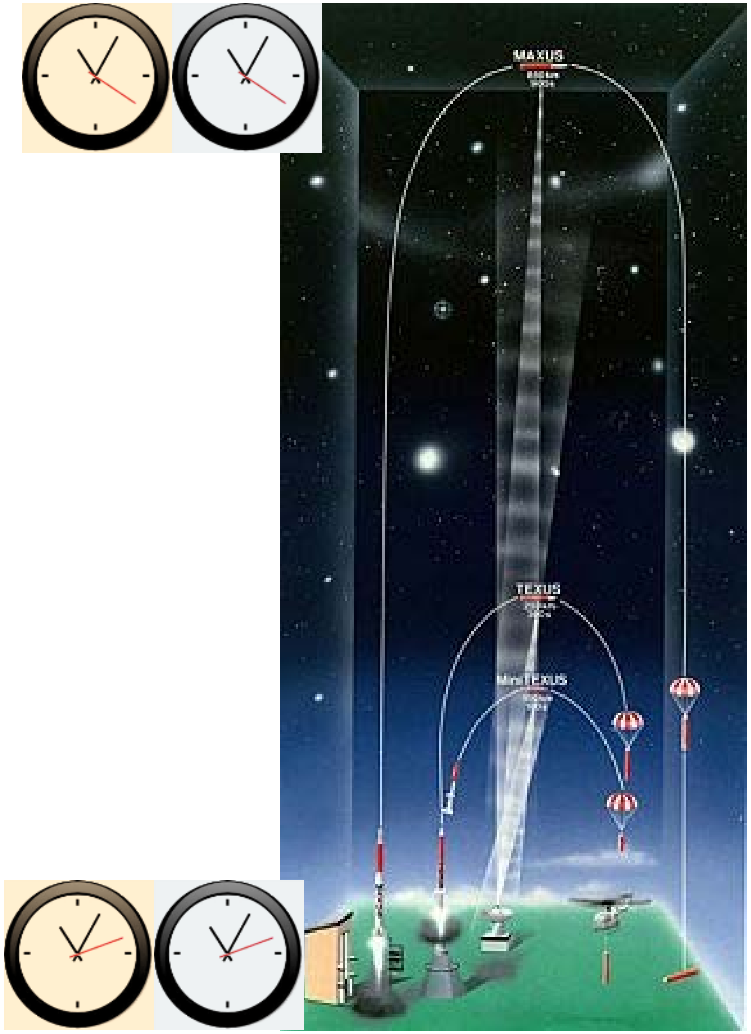
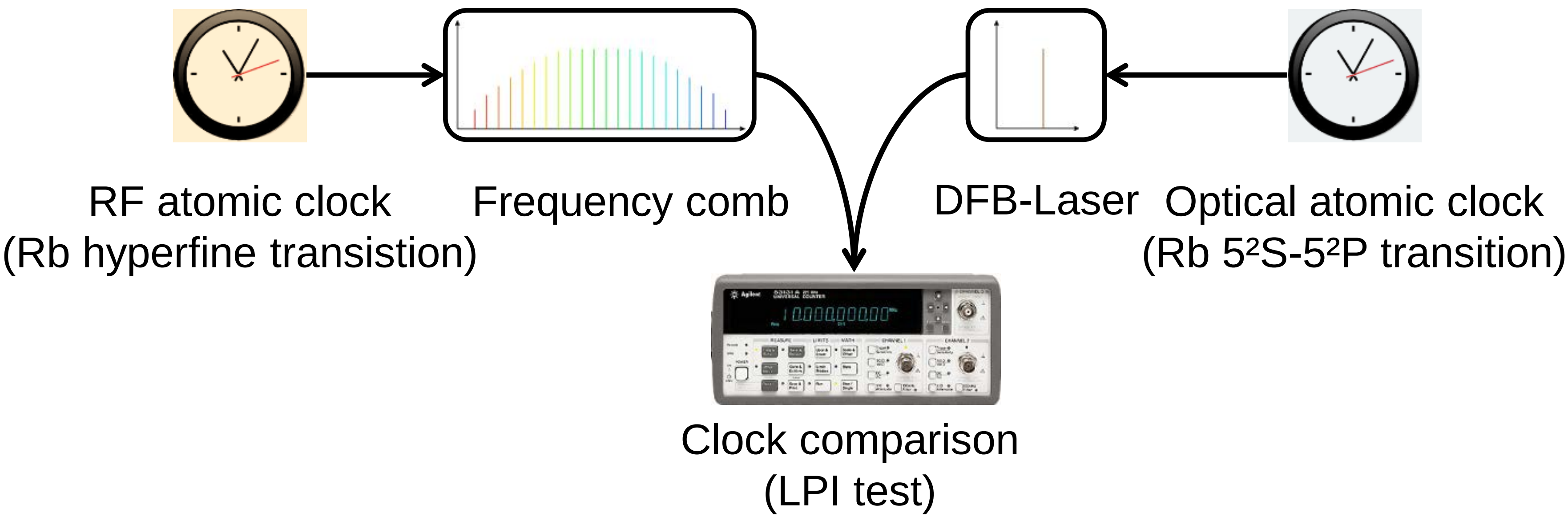
Local Position Invariance



LPI implies that the frequencies of two atomic clocks of different internal structure should suffer identical redshifts as they move together through a changing gravitational potential.

LPI Test Experiment



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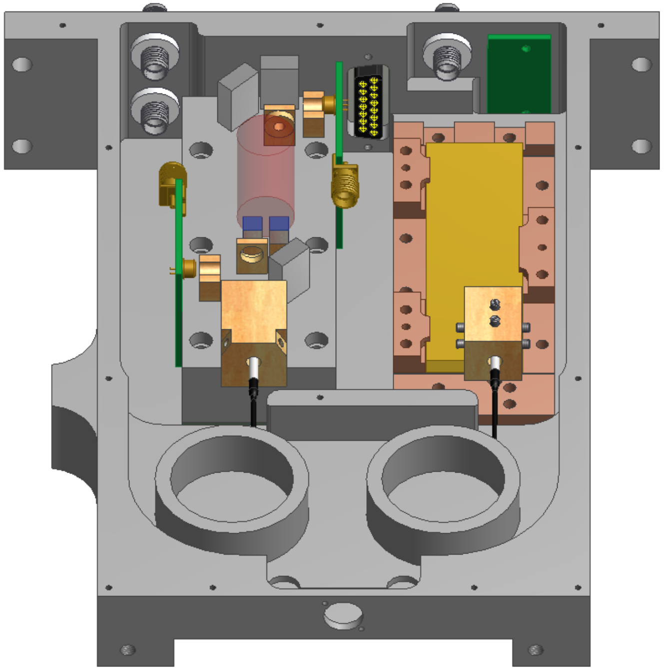
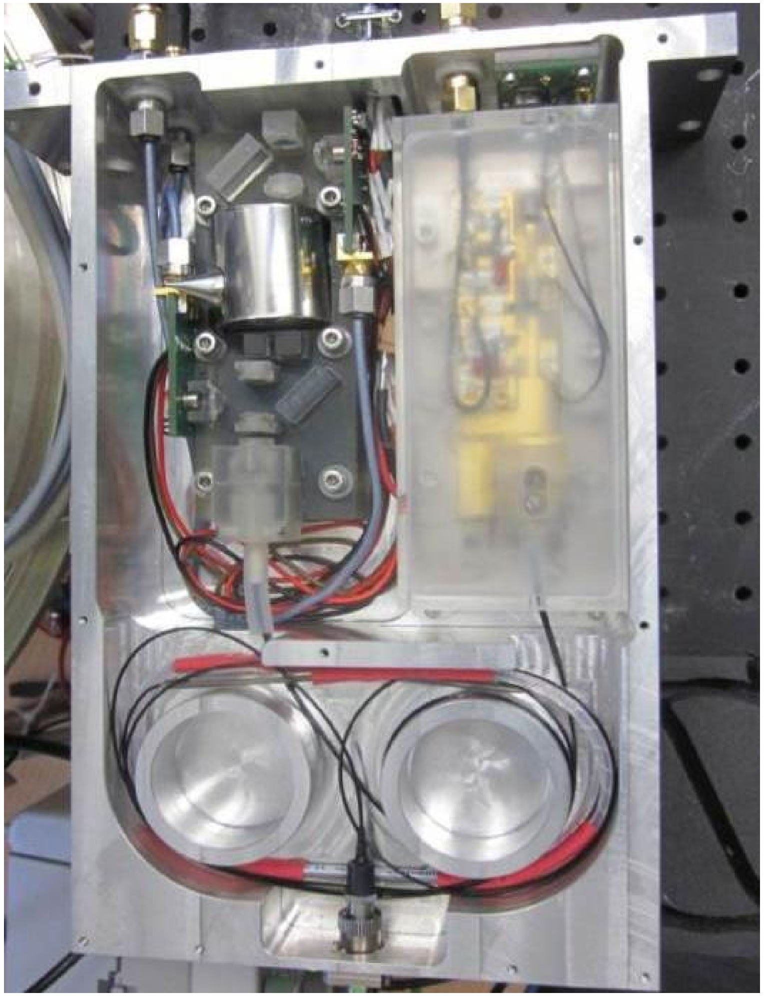
LASUS Project

- At FBH/HUB/UHH a DFB laser + rubidium spectroscopy cell has been developed.
  - Robust mechanical design based on ceramics (DFB) / zerodur (Rb)
  - Integrated photodiodes for Doppler-free and Doppler-broadened signal.
  - Fibercoupled output
  - power: ~7mW, linewidth: ~1MHz



Funded by

LASUS

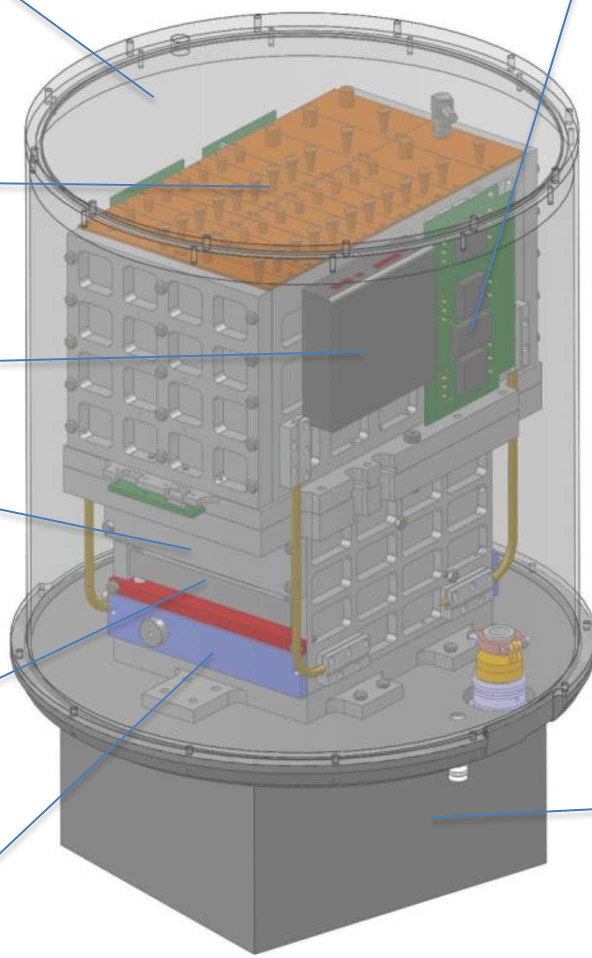


A. Kohfeldt, A. Wicht, A. Peters — FBH

V. Schkolnik, M. Krutzik — HU

H. Duncker, O. Hellmig,
P. Windpassinger, K. Sengstock — UHH

The FOKUS System



Weight: 23kg

Size: 30 cm (height) x
30 cm (diameter)

Volume: 28 l

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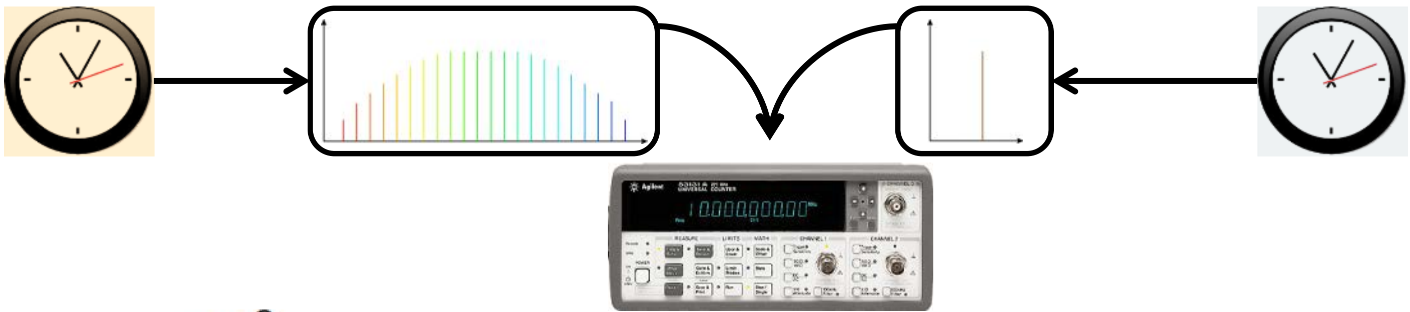
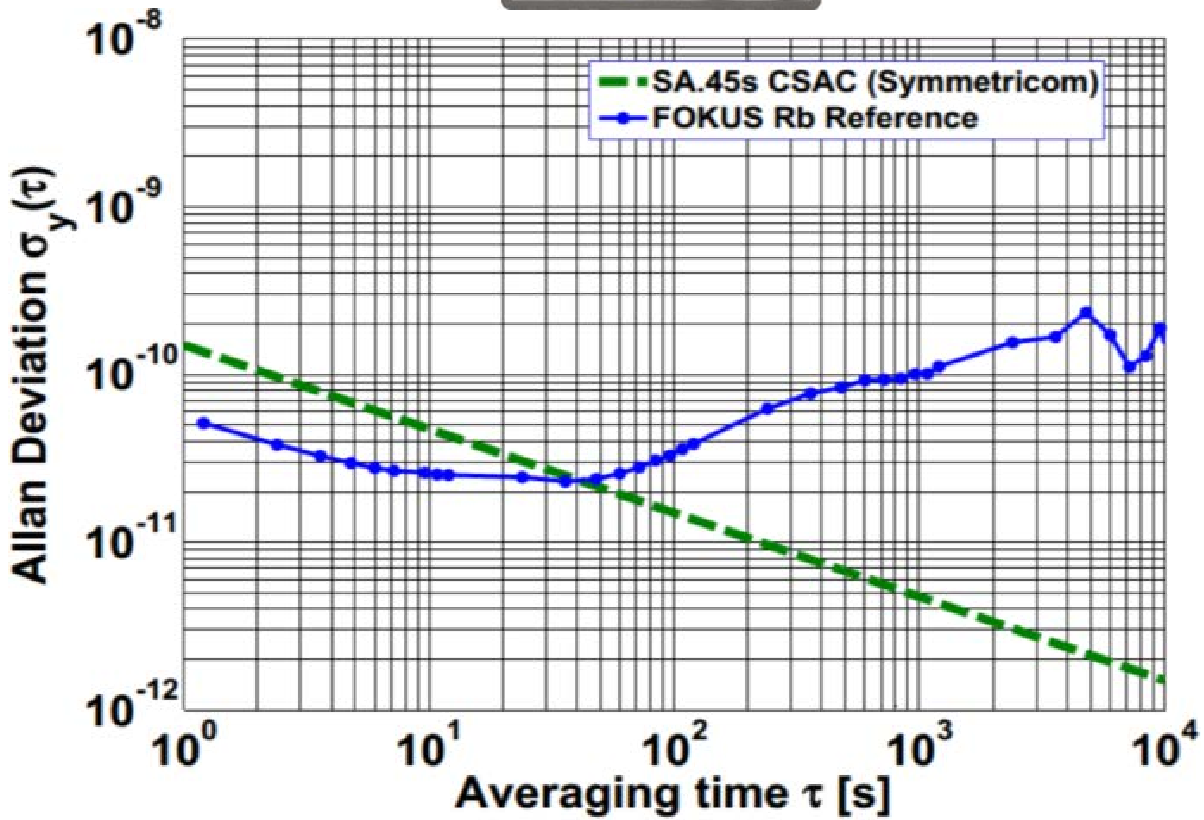
Measurement limit





FOKUS in real life

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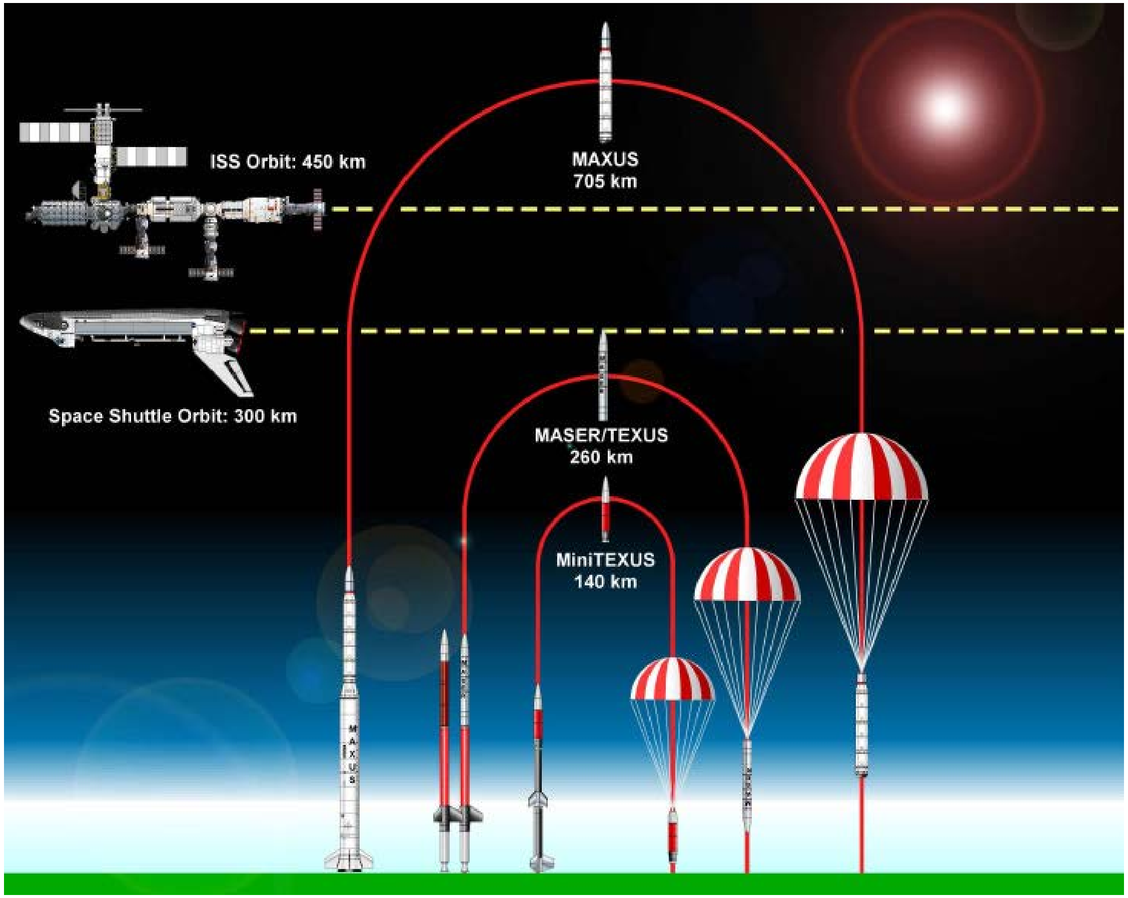
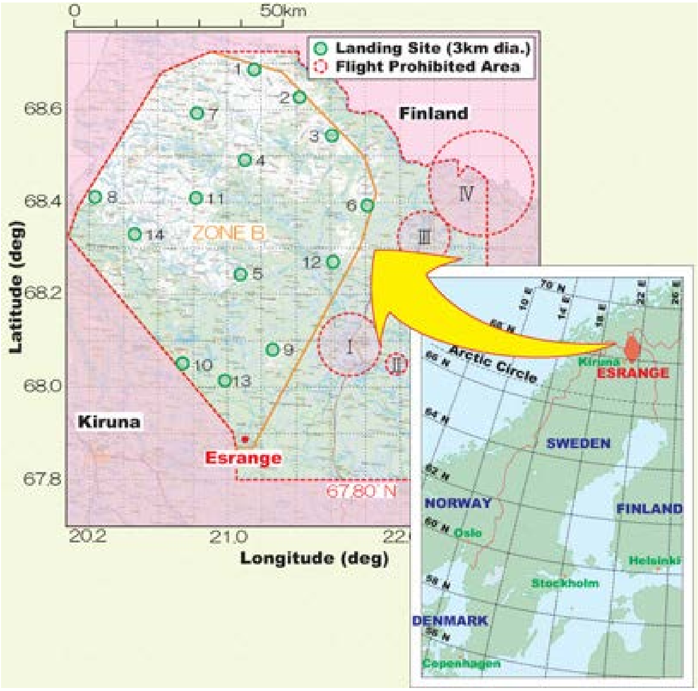
Flight Opportunity: TEXUS

TEXUS: DLR program since 1970's, 50 successful flights
400kg payload, zero g for 6 min.
TEXUS 50 was launched on April 12, 2013,



Scheduled on TEXUS 51

- TEXUS 51 launch in April 2013 was cancelled the day before launch (April 19th, 2013).
- Miss aligned guiding rails
- Relaunch scheduled for November 2013



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The extended FOKUS team

T. Wilken, T.W. Hänsch	MPQ
M. Lezius, R. Holzwarth	Menlo Systems

A. Kohfeldt, A. Wicht, A. Peters	FBH
V. Schkolnik, M. Krutzik	HU
H. Duncker, O. Hellmig, P. Windpassinger, K. Sengstock	UHH

Thanks to:

The workshops at the Institutes

The Menlo Systems team

DLR for funding

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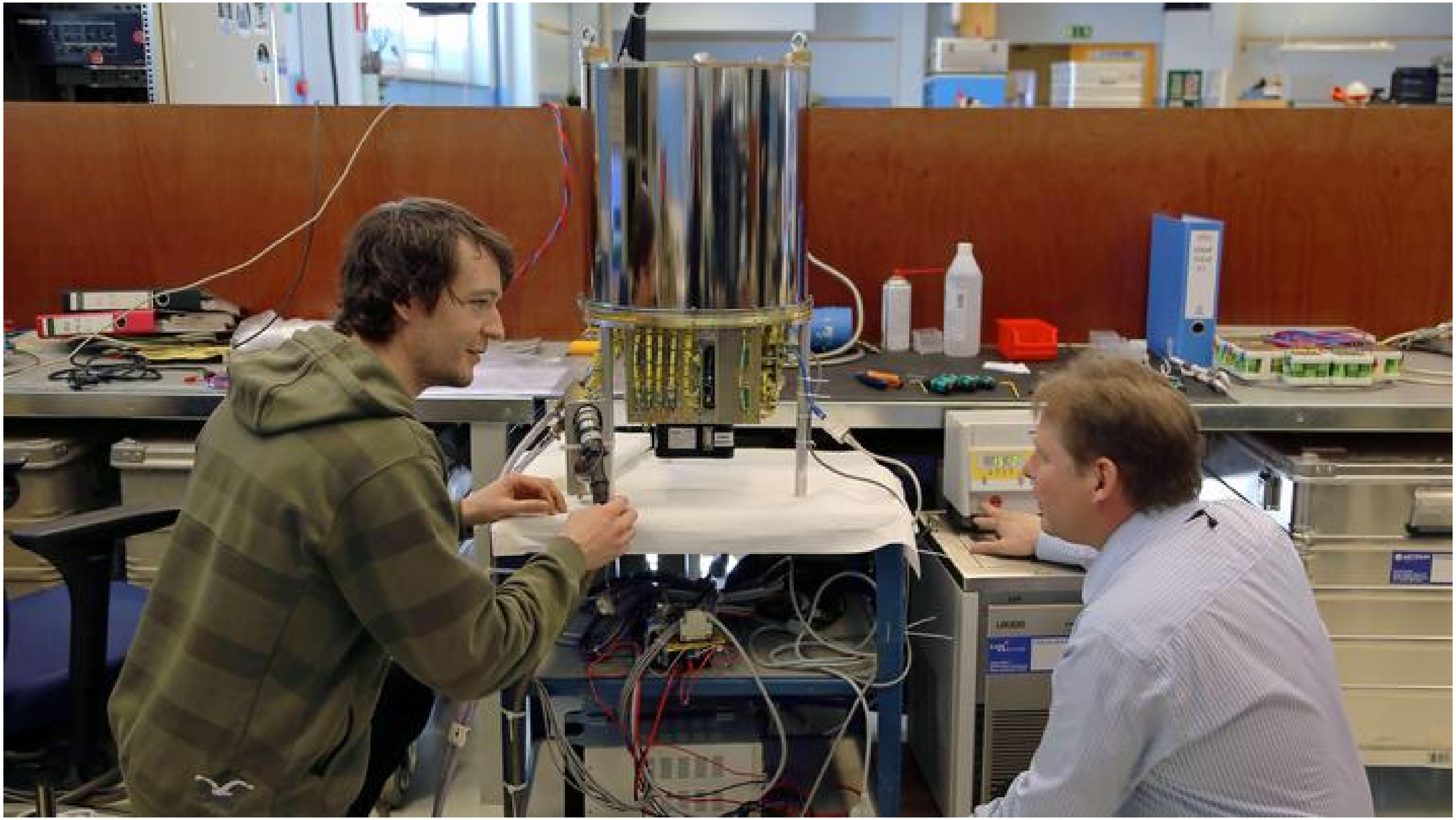
FOKUS before Integration into TEXUS 51



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Rocket Engine VSB 30

TEXUS 50 inside the launcher

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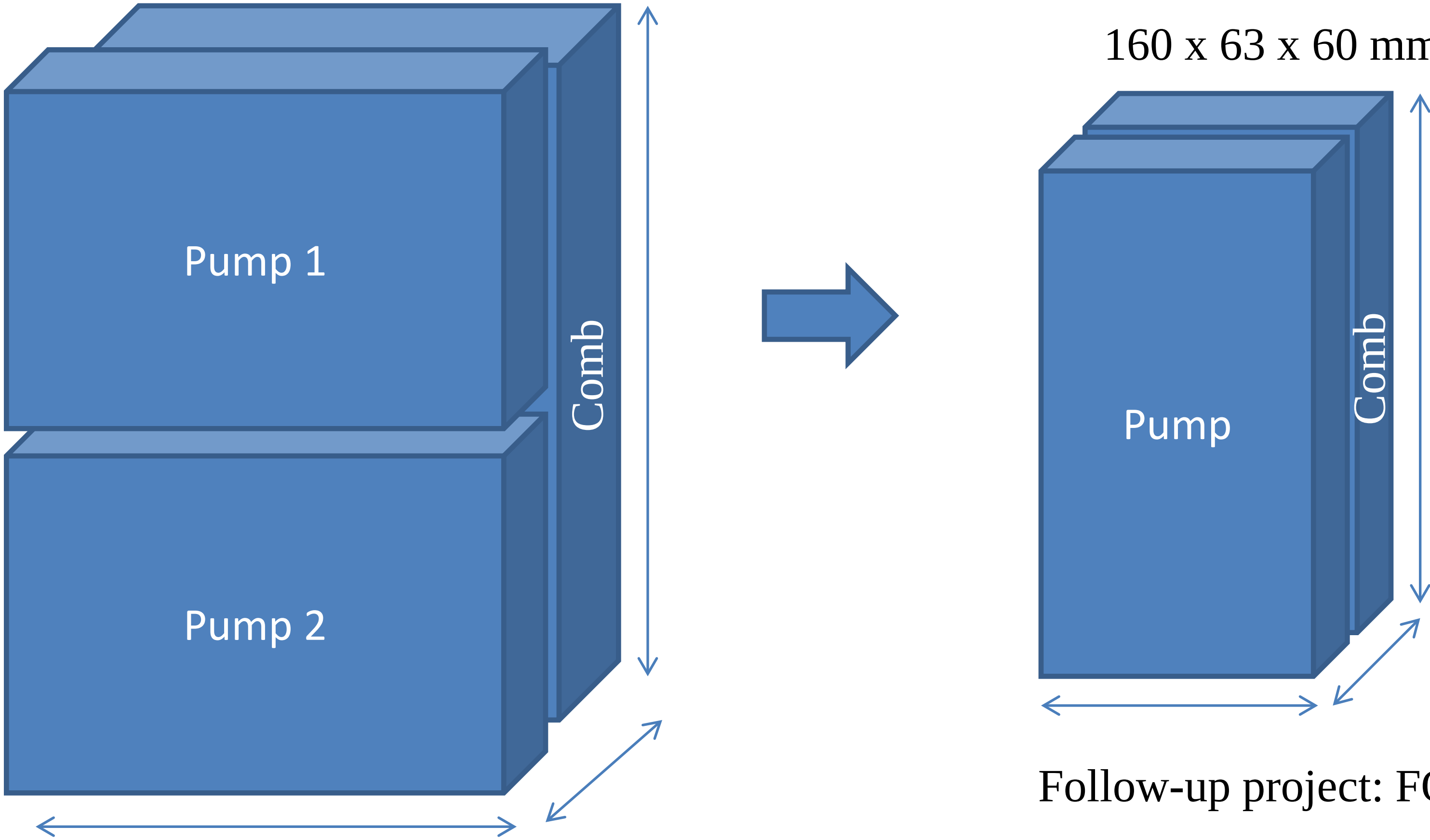
Launch of TEXUS 50

Future Space Combs

ca. 190 x 140 x 75 mm



160 x 63 x 60 mm

Follow-up project: FOKAL

Fiber Link Munich - Braunschweig

- 2 *dark* fibers (ITU-T G.652)
  - n ~ 1.4681 at 1550 nm
  - A~ 0.23 dB/km
  - CD~18 ps/(nm·km)
  - 920 km total length

Harald Schnatz
Gesine Grosche
Osama Terra
Fritz Riehle

Katharina Predehl
Stefan Droste
Thomas Udem
Theodor Hänsch
Ronald Holzwarth

Science, Vol. 336, p. 441, 27 APRIL 2012

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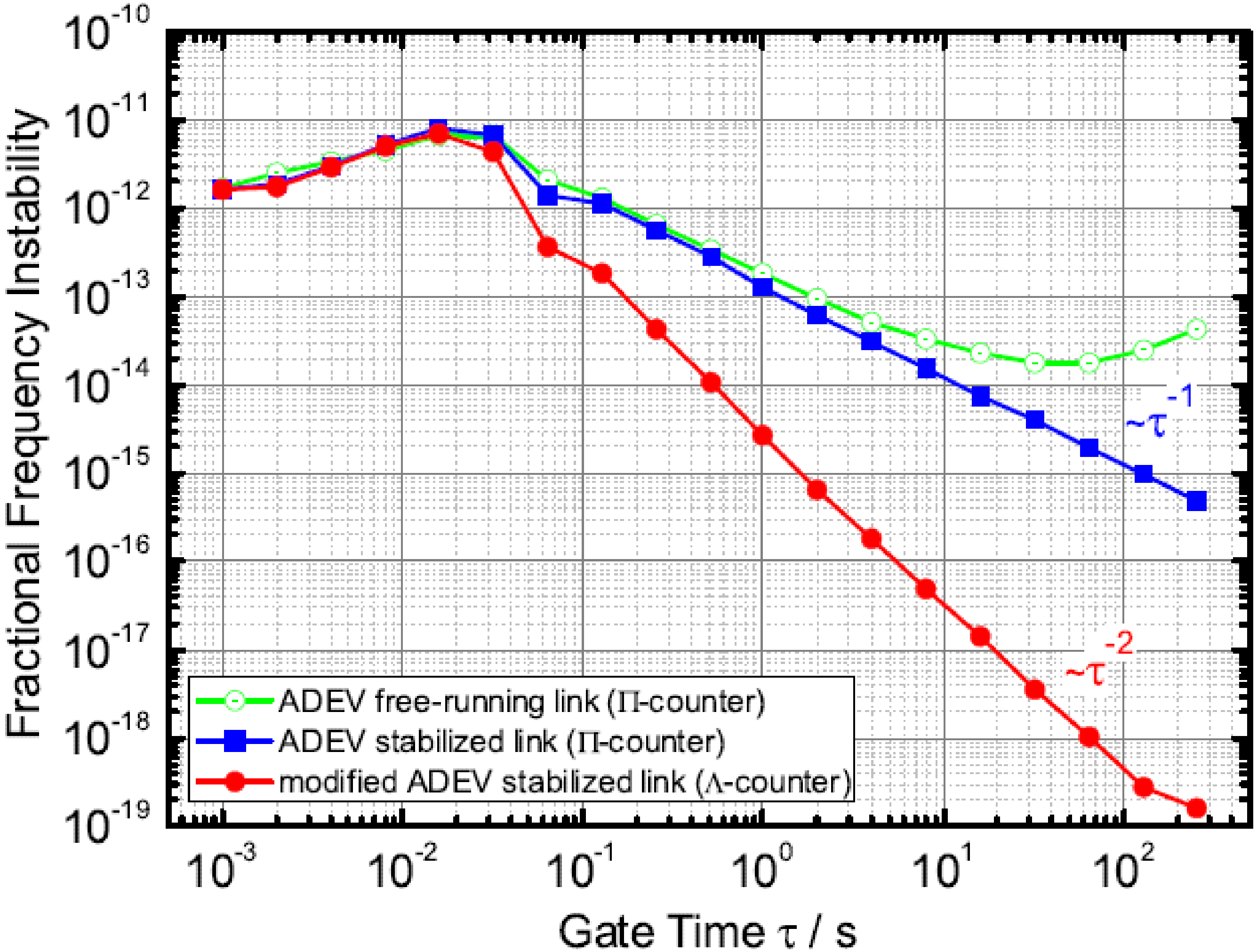
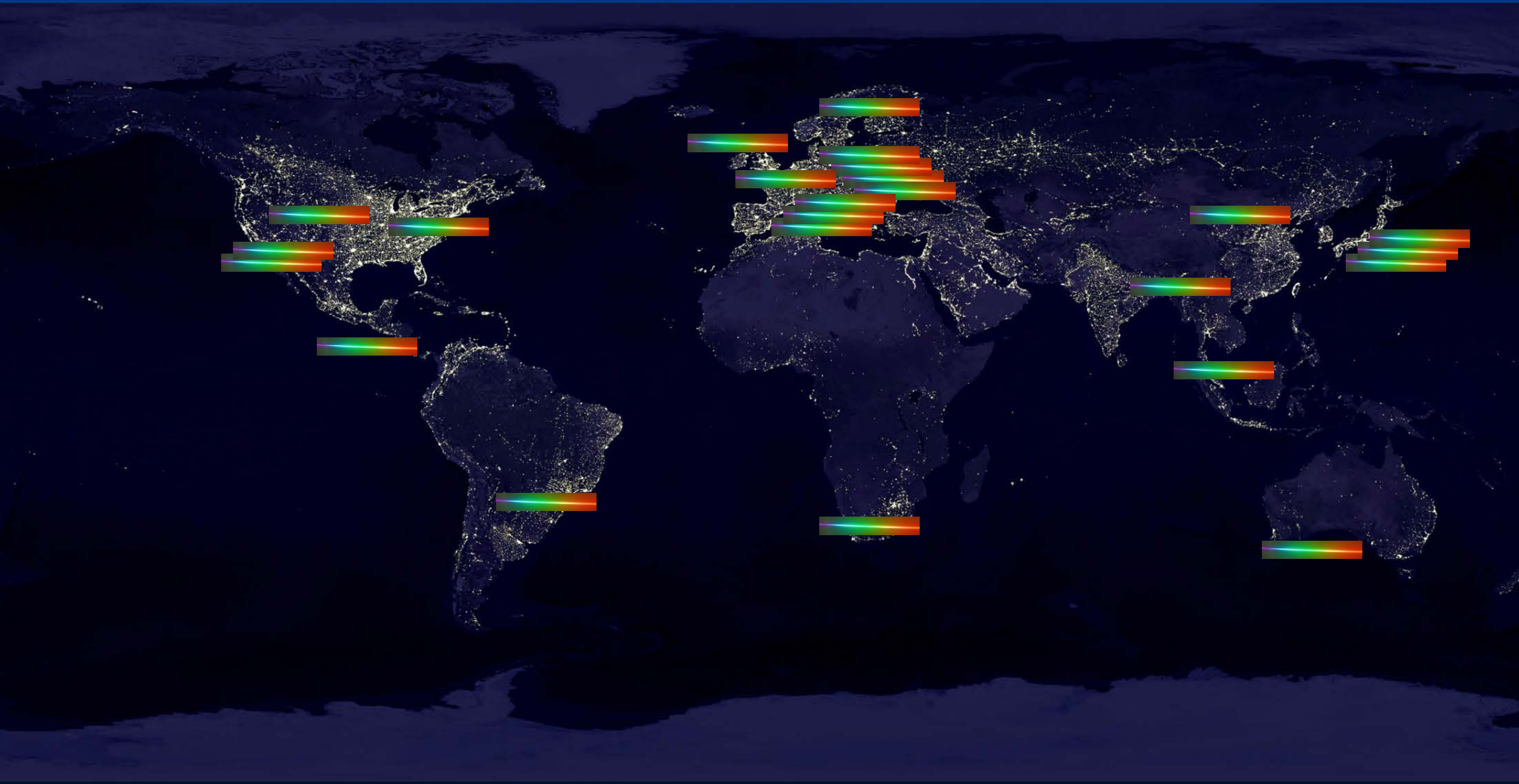
Now : 1840km



10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
Fractional Frequency Instability
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Gate Time τ / s
$\sim\tau^{-1}$
$\sim\tau^{-2}$
ADEV free-running link (Π-counter)
ADEV stabilized link (Π-counter)
modified ADEV stabilized link (Λ-counter)



Menlo Systems WE TURN THE LIGHTS ON