Gravitationswellen messen und in den Daten finden

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(Albert-Einstein-Institut Hannover)

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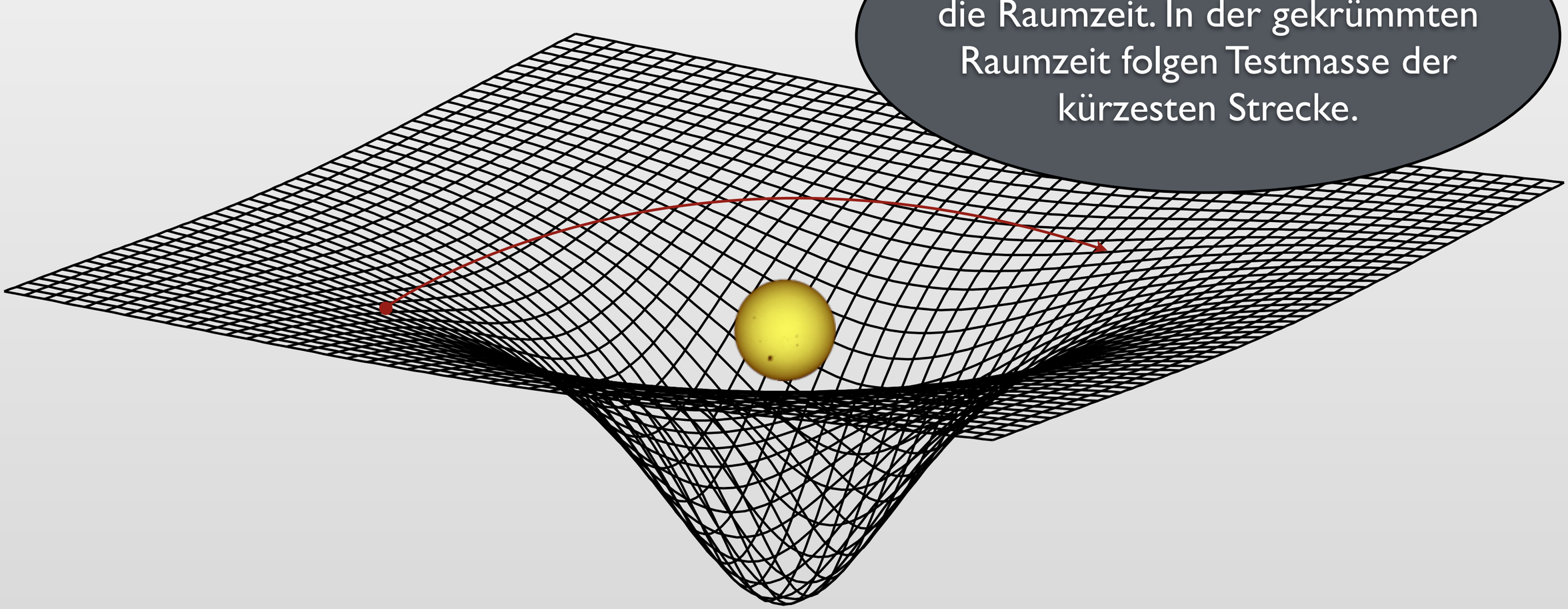
Gravitation

Albert-Einstein-Institut
Hannover

Die Sonne
hat Masse und erzeugt so
Gravitation. Die Gravitationskraft ist
auf das Zentrum der Sonne gerichtet.
So wird die Testmasse auf eine
Kurve gelenkt.

Die Masse der Sonne krümmt
die Raumzeit. In der gekrümmten
Raumzeit folgen Testmasse der
kürzesten Strecke.



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GW

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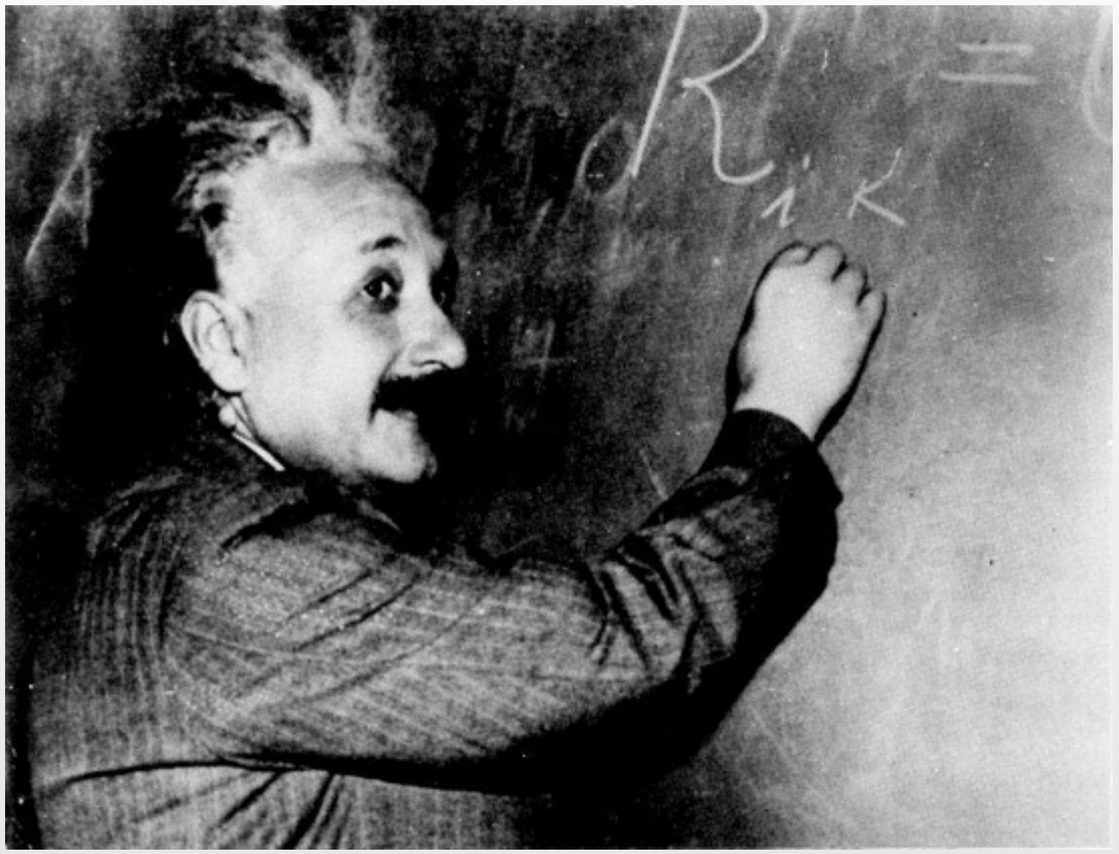
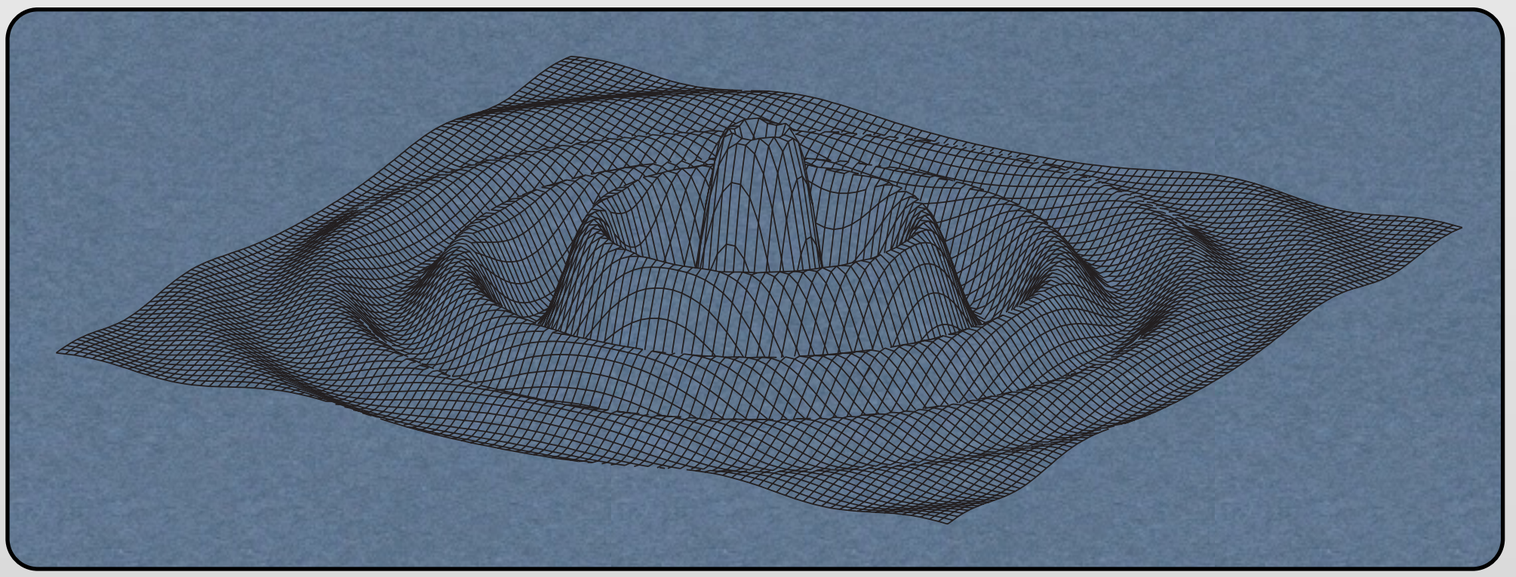
- Einstein (1916) berechnet wellenartige Lösungen seiner Gleichungen

- kleine Kräuselungen der Raumzeit, die sich mit Lichtgeschwindigkeit ausbreiten

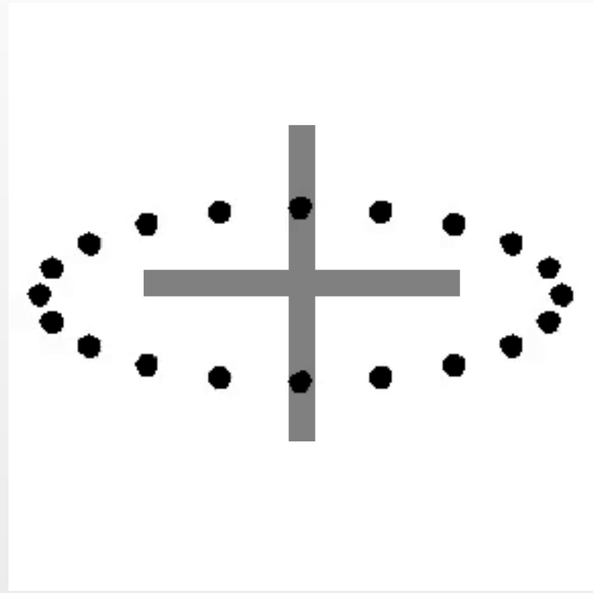


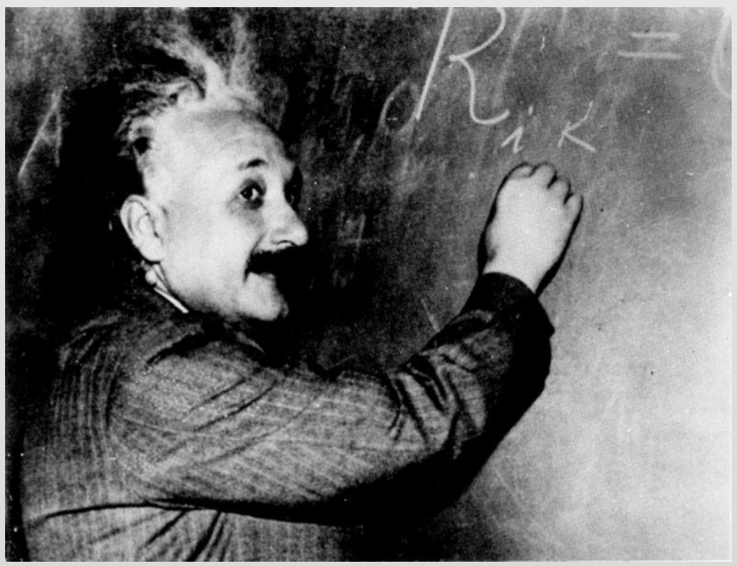
- **Wie lassen sich diese messen?**

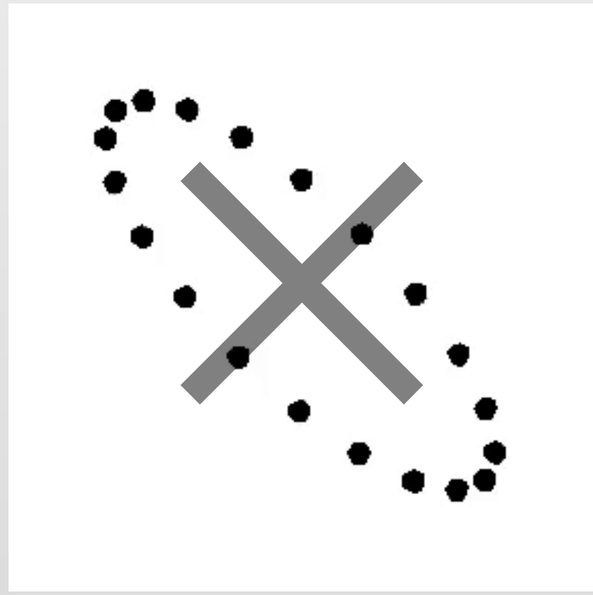


Messung?

- relative Längenänderung ~10^{-21}
- Erdbahn (10^{11} m) ändert sich um 10^{-10} m (1 Atom)
- 10^{11} m = 100000000000 m
- 10^{-10} m = 0.0000000001 m
- Geht das überhaupt?







Animationen: MOBIe/Wikipedia

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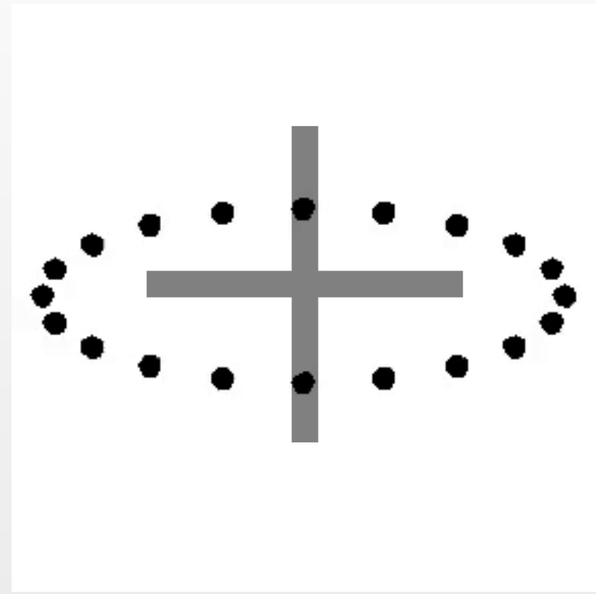
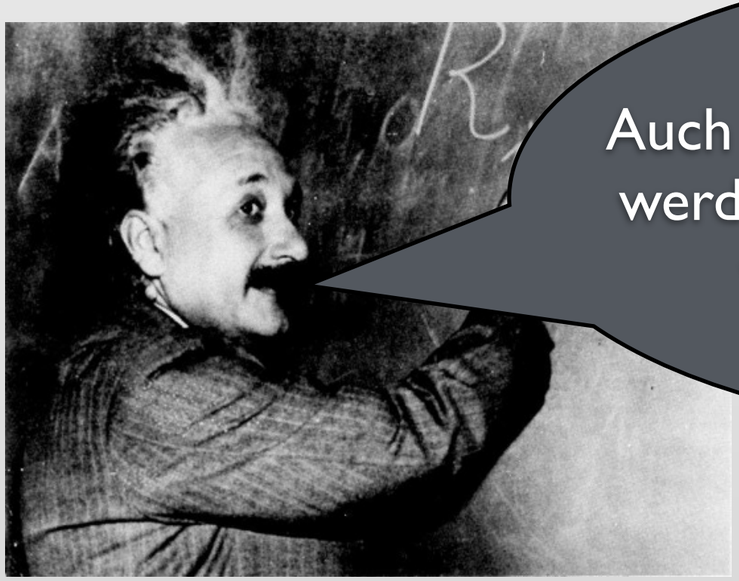
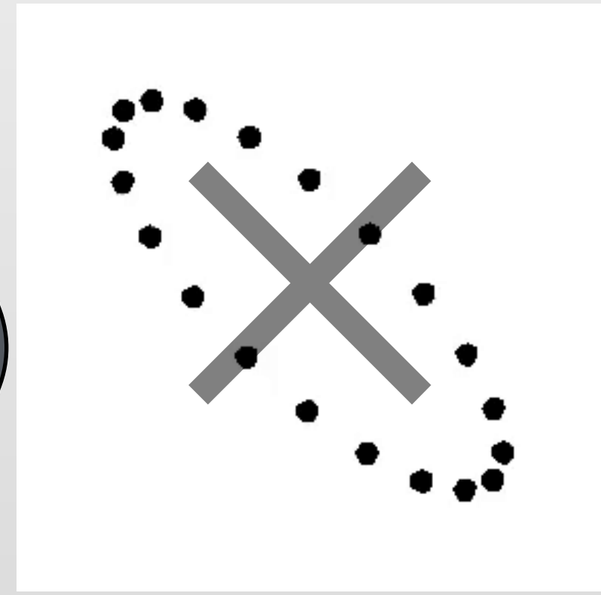




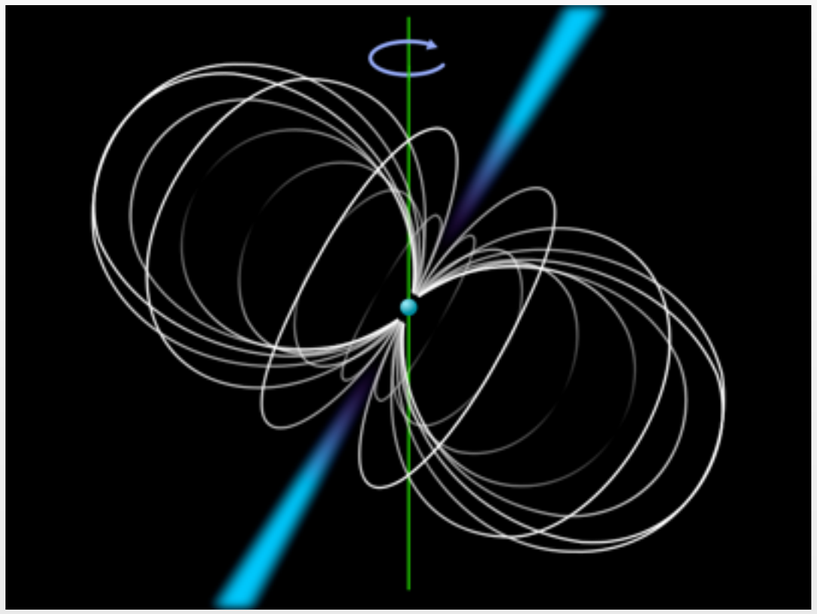
Auch wenn diese Wellen existieren, werden sie wohl kaum jemals eine wichtige Rolle spielen…

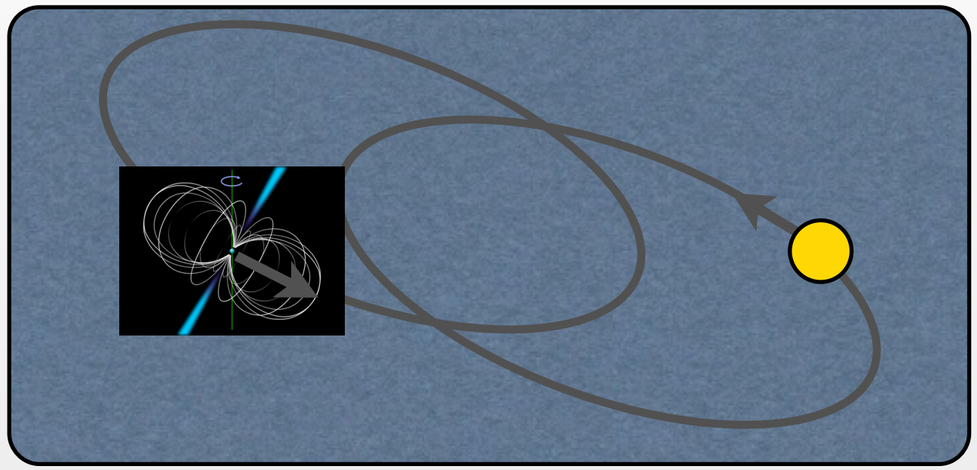


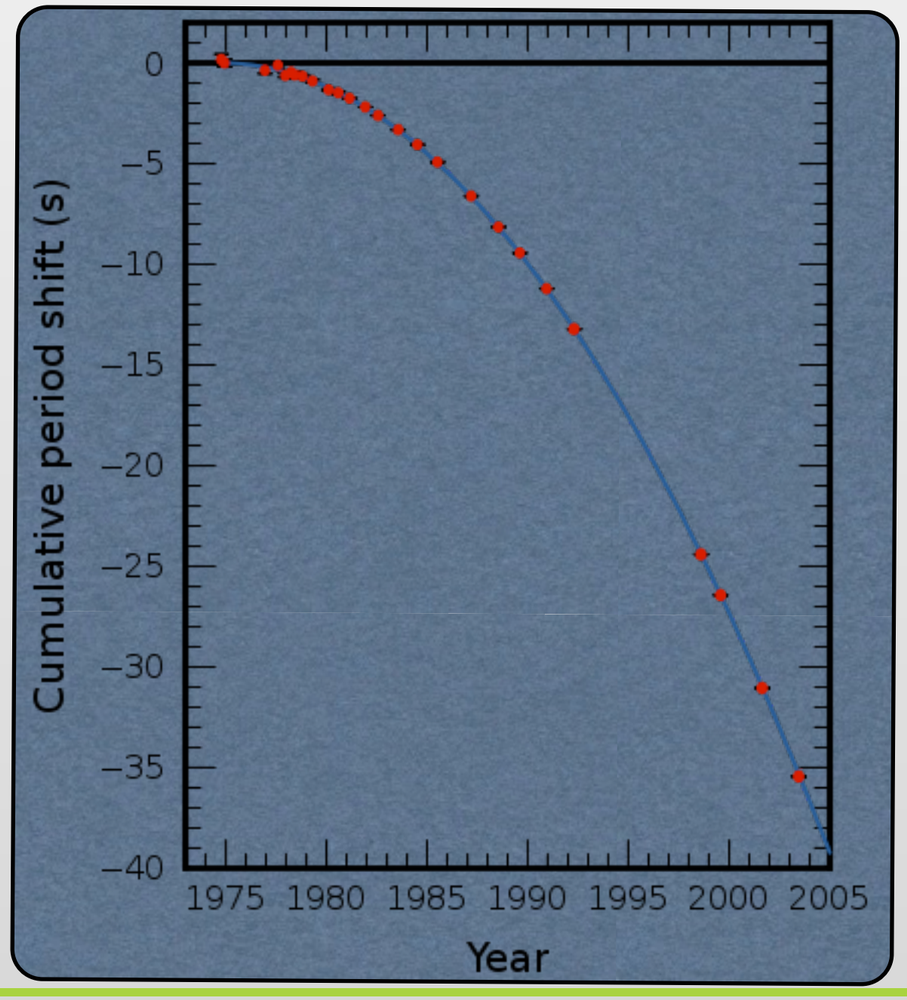
Animationen: MOBIe/Wikipedia

Indirekter Beweis!

- **Quellen:** ***massereiche, beschleunigte Objekte – Neutronensterne in Doppelsternen***







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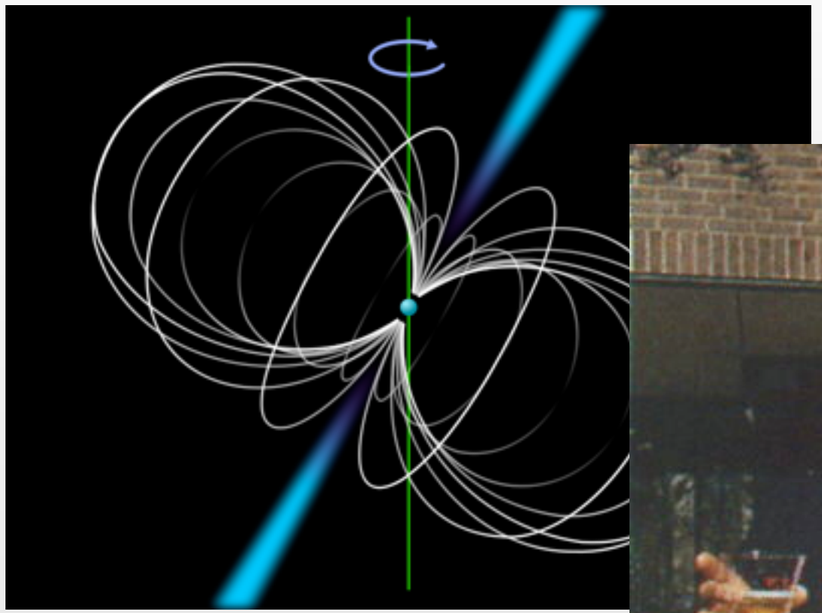
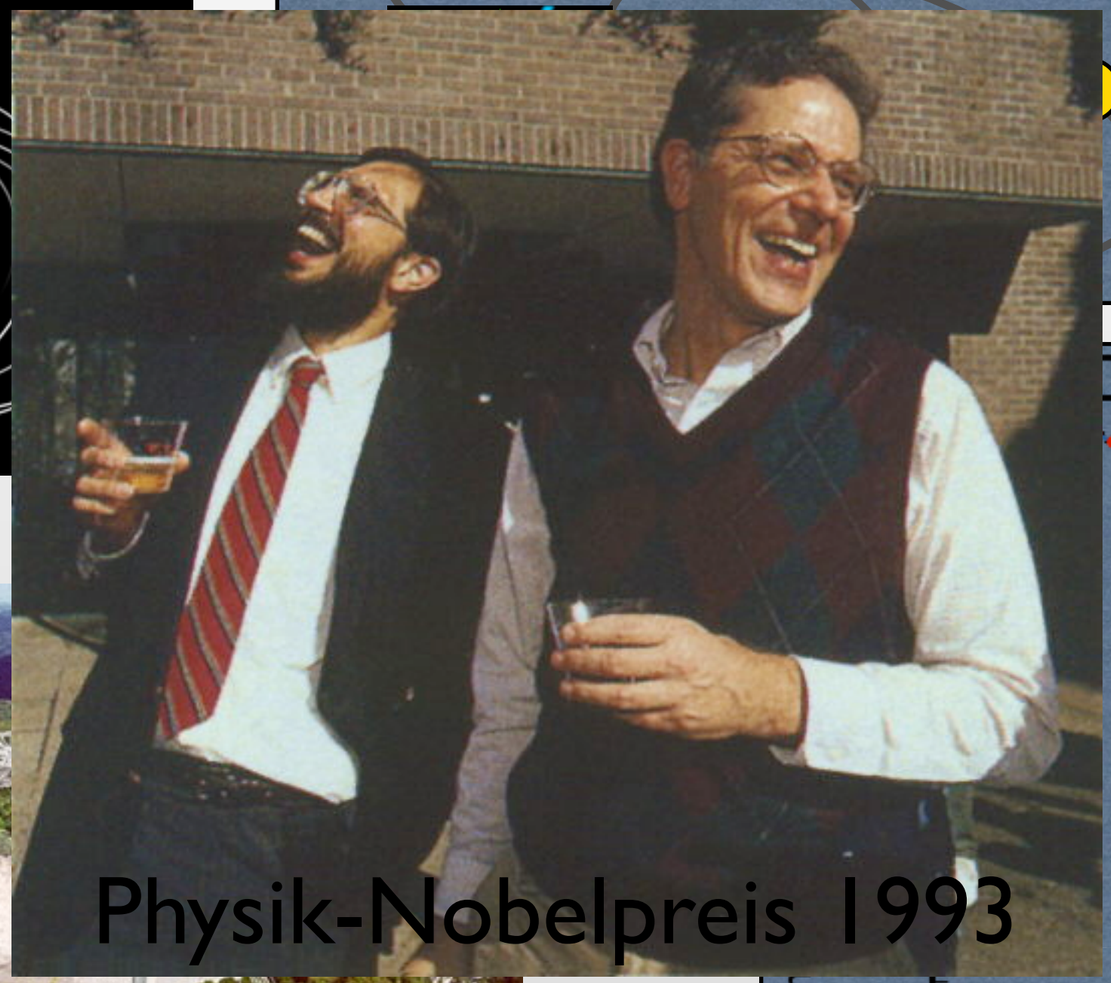
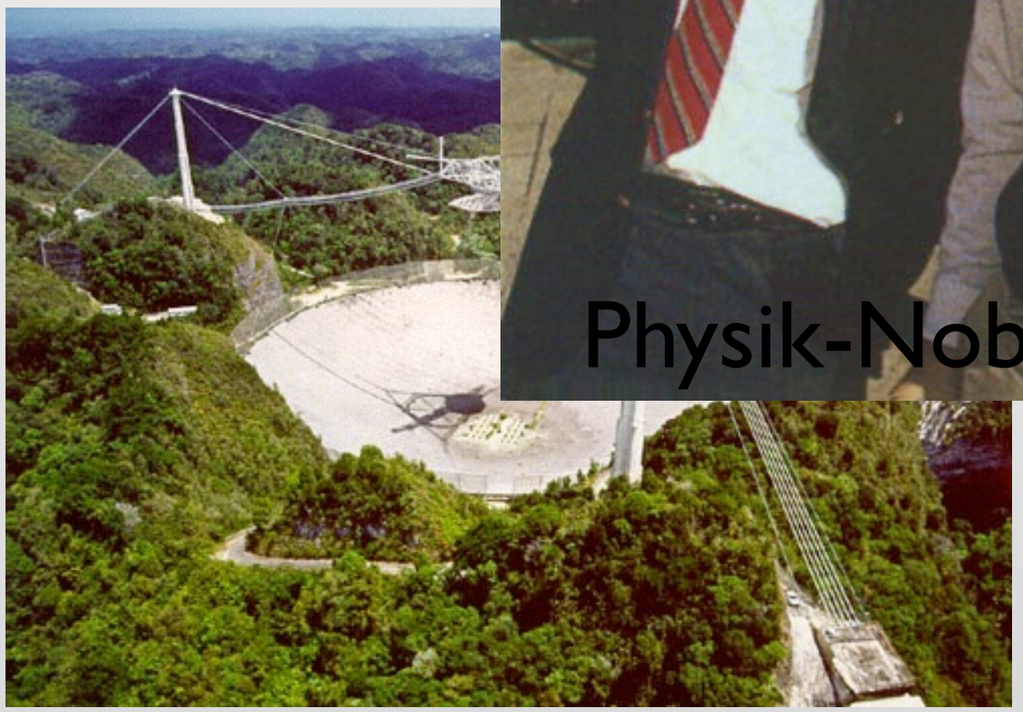
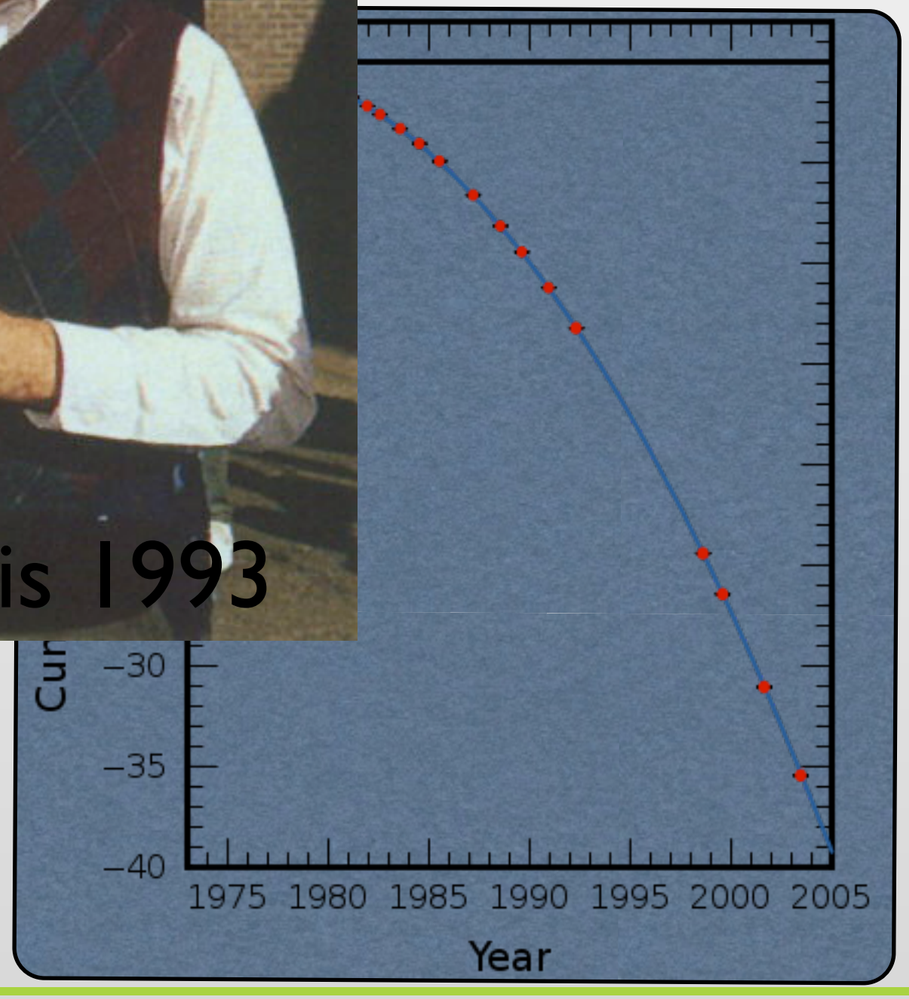




Physik-Nobelpreis 1993





Interferometer

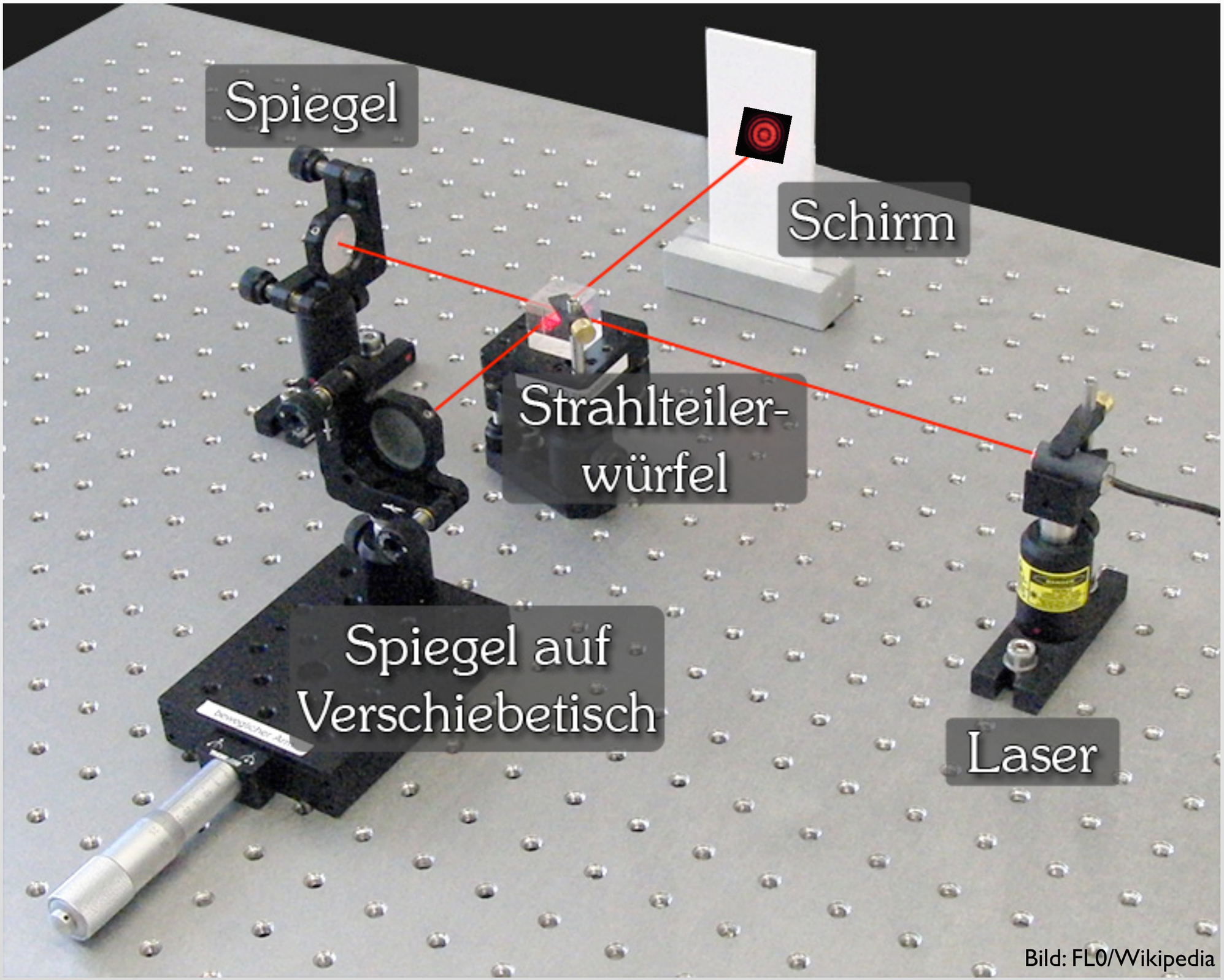
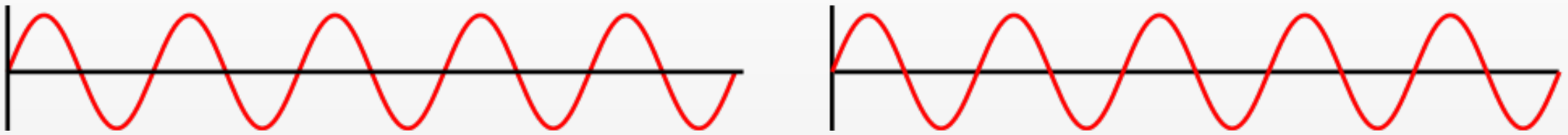


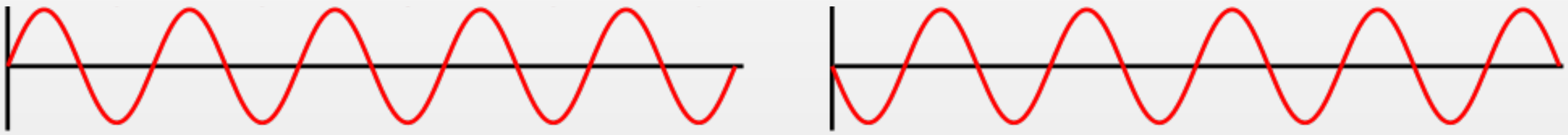
Bild: FL0/Wikipedia

Interferenz

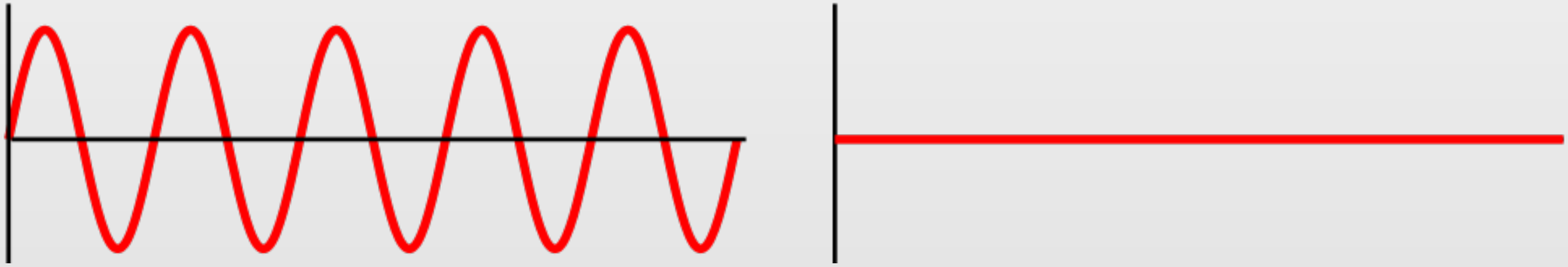
Laser aus Arm 1



Laser aus Arm 2



Überlagertes Licht



Konstruktive Interferenz

HELL auf dem Schirm

Destruktive Interferenz

DUNKEL auf dem Schirm

Stockholm
Estland
Ostsee
Saaremaa
Skagerrak
Rigaischer Meerbusen
Riga
Kattegat
Nordsee
Dänemark
Vesterhavet
Litauen
Kopenhagen
Oblast Kaliningrad
Sylt
Irish Sea
Großbritannien
Kanal
Niederlande
GEO 600
Berlin
Polen
Warschau
London
Belgien
Deutschland
Ärmelkanal
Prag
Slowakei
Paris
Wien
Budapest
Österreich
Ungarn
Frankreich
Bern
Slowenien
Laibach
Kroatien
Belgrad
Serbien
Biskaya
US Dept of State Geographer
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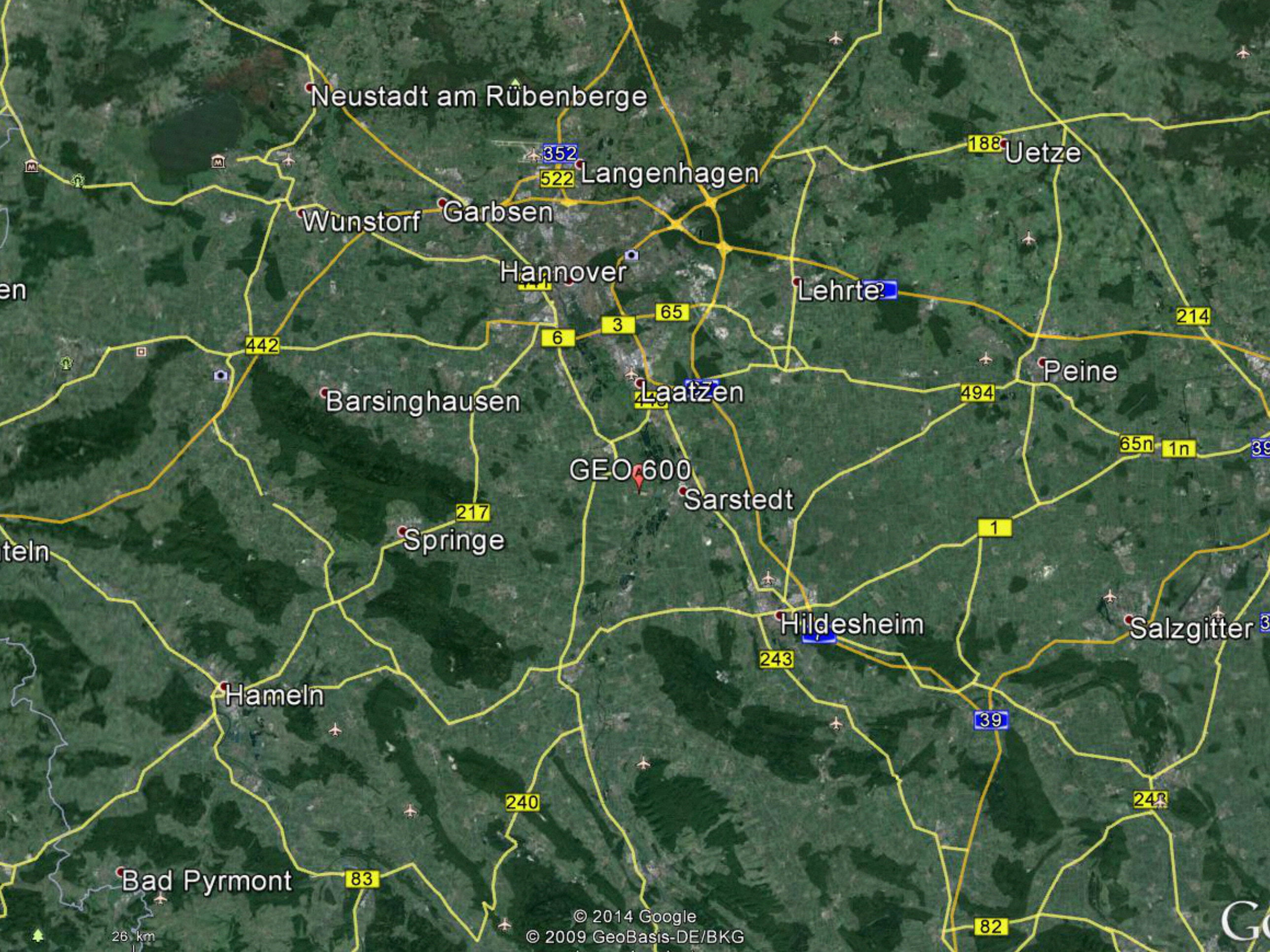

Neustadt am Rübenberge
352
522
Langenhagen
188
Uetze
Wunstorf
Garbsen
Hannover
Lehrte
65
3
6
214
442
Peine
Barsinghausen
Laatzen
494
65n
1n
GEO 600
Sarstedt
217
Springe
1
Hildesheim
Salzgitter
243
Hameln
39
240
Bad Pyrmont
83
82
26 km
© 2014 Google
© 2009 GeoBasis-DE/BKG

Ruther Weg

GEO 600

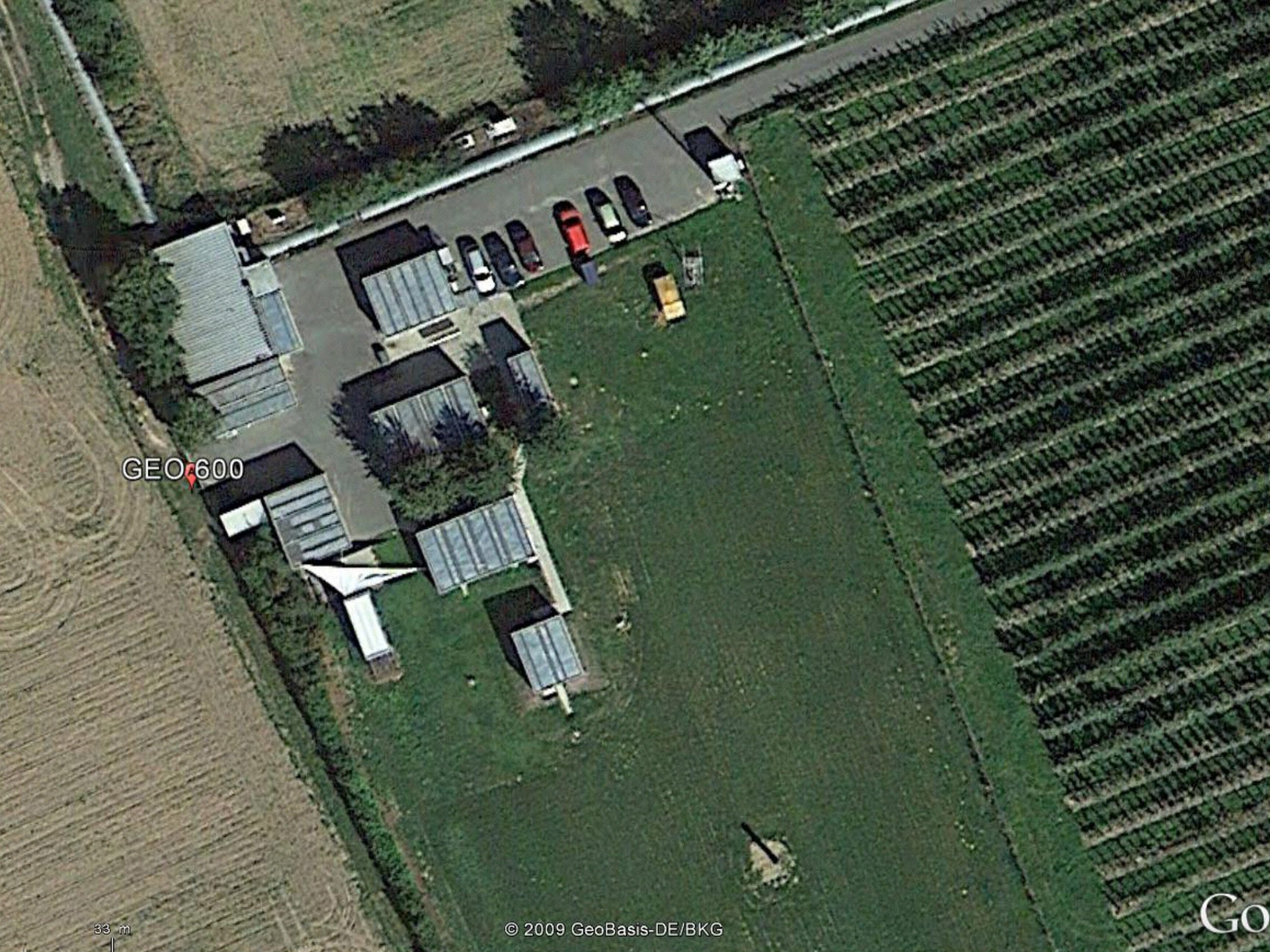
Schäferberg

Hopfenberg

Ruthe

632 m


GEO 600
218 m
© 2014 Google
© 2009 GeoBasis-DE/BKG


GEO 600
33 m
© 2009 GeoBasis-DE/BKG

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GEO600

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Hannover

Deutsch-britisches Projekt
18 km südlich von Hannover

Baubeginn 1994
Geschichte auf geo600.org

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Das Container-Dorf

Albert-Einstein-Institut
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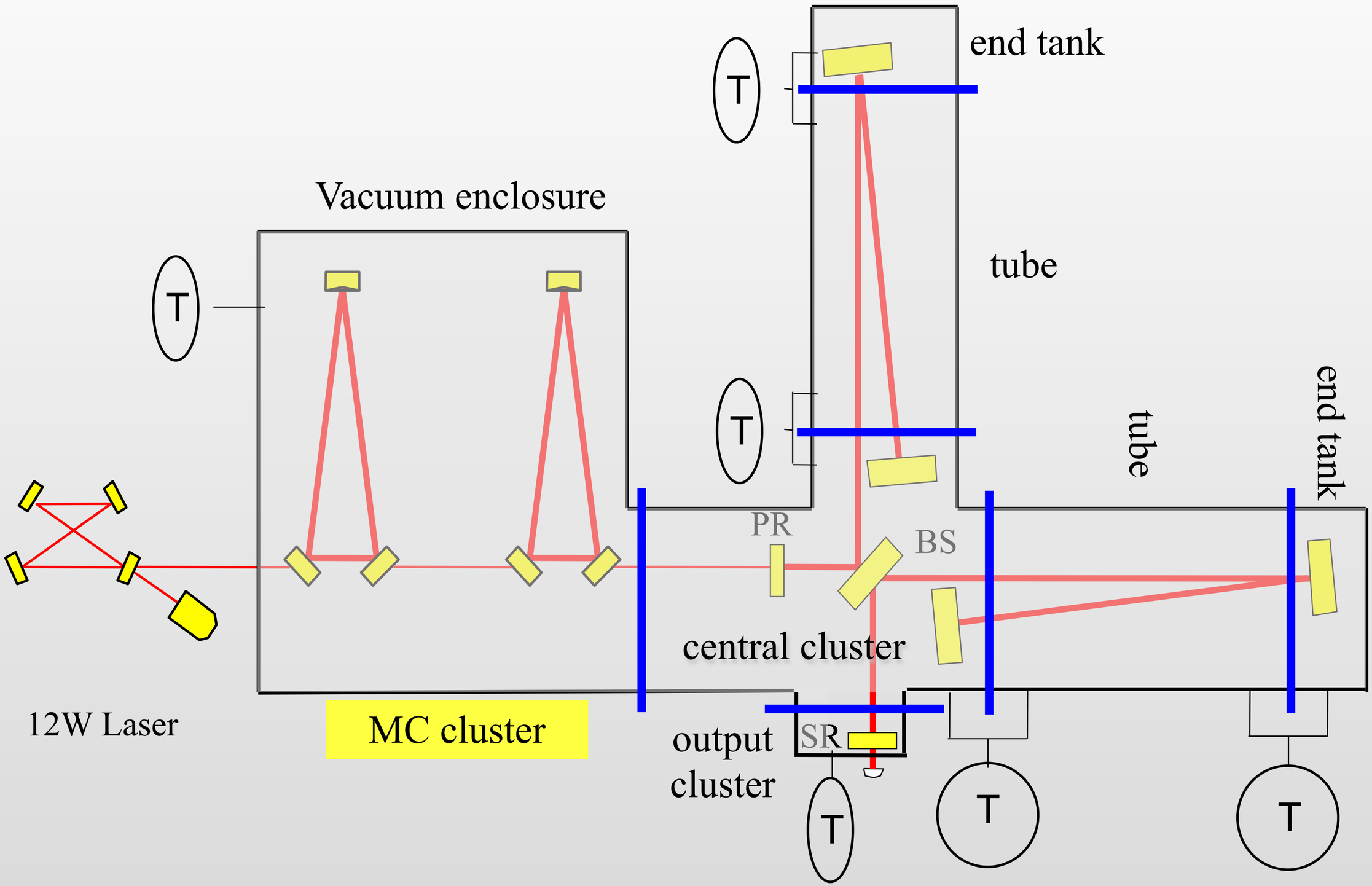
Blick vom Mast der Richtfunkantenne
Überträgt rund 150 GB Daten pro Tag

Vakuumsystem



Fast alles ist im Ultra-Hoch-Vakuum
Druck ca. 2×10^{-8} mbar

Vakuumsystem

Rohre und Vakuumtanks

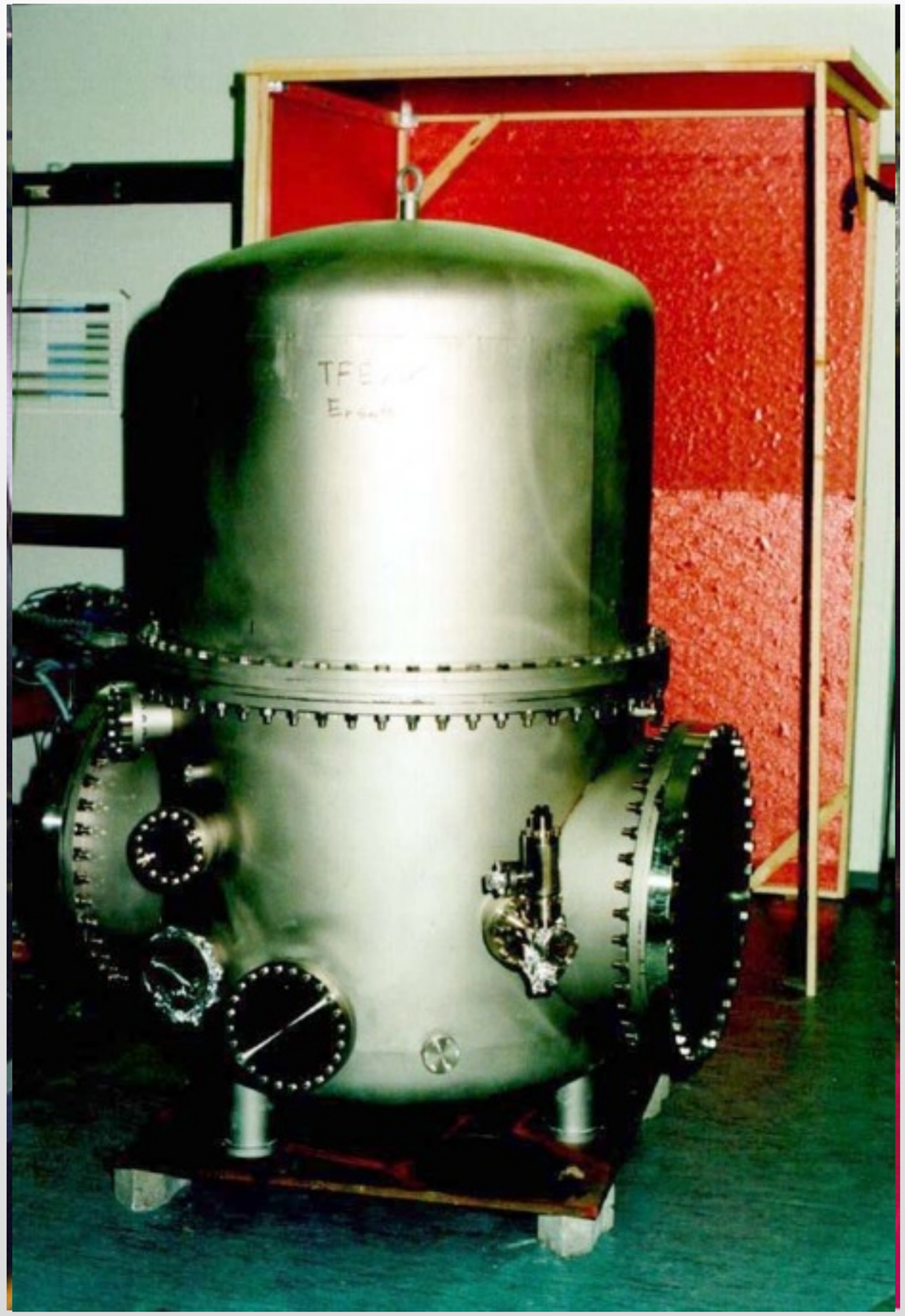
400 m^3 Volumen und 4000 m^2 Oberfläche

Pumpen

5 Scrollpumpen (25 m^3/h, 10^{-2} mbar)

4 Turbomolekular-Pumpen (10^{-8} bis 3×10^{-9} mbar)

Vakuumsystem



Rohre und Vakuumtanks

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Armrohre

2 Armrohre mit je

600 m Länge

60 cm Durchmesser

133 Einzelsegmente

0,9 mm Wandstärke (Edelstahl)

13 t Gewicht

Armrohre

Einmaliges „Ausbacken“ der Armrohre nach der Installation

Isolation mit 20 cm Steinwolle
Heizung mit Gleichstrom, 600 A bei 300 V

Passivierung in Luft: 2 Tage bei 200 °C
Ausheizen im Vakuum: 5 Tage bei 250 °C

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Neben dem Arm

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Im Tunnel

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Containerdorf

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Zentralgebäude

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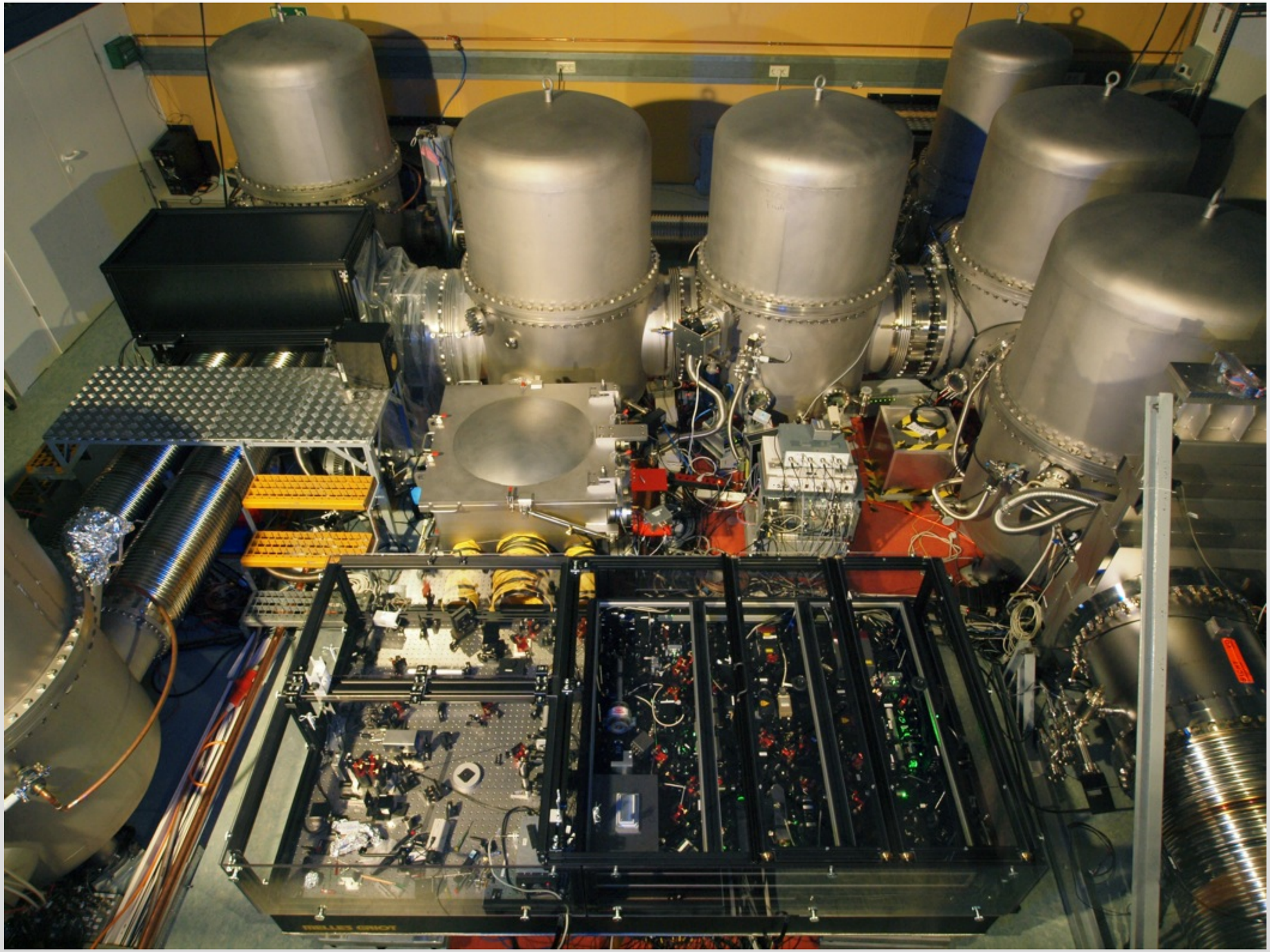
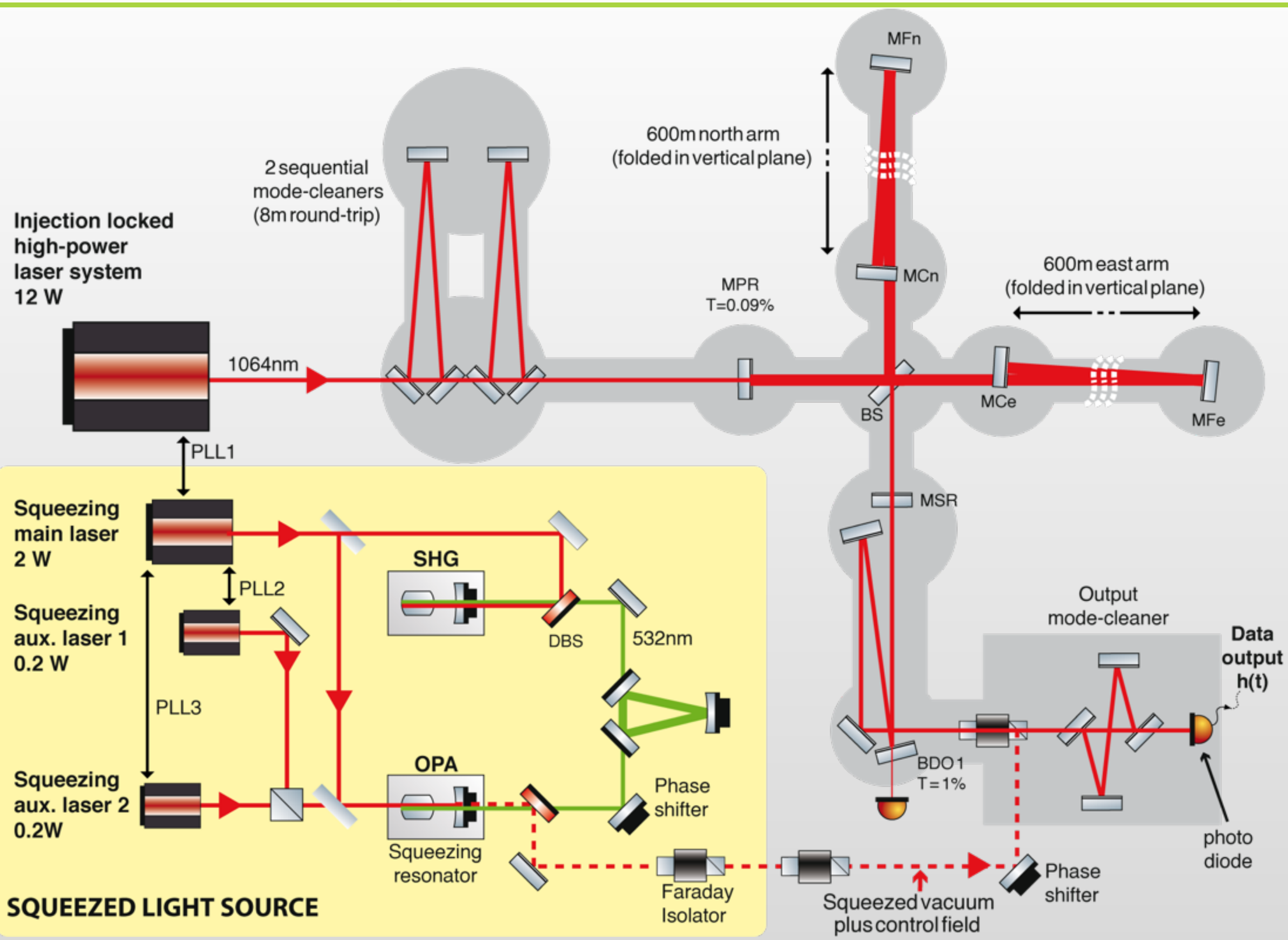
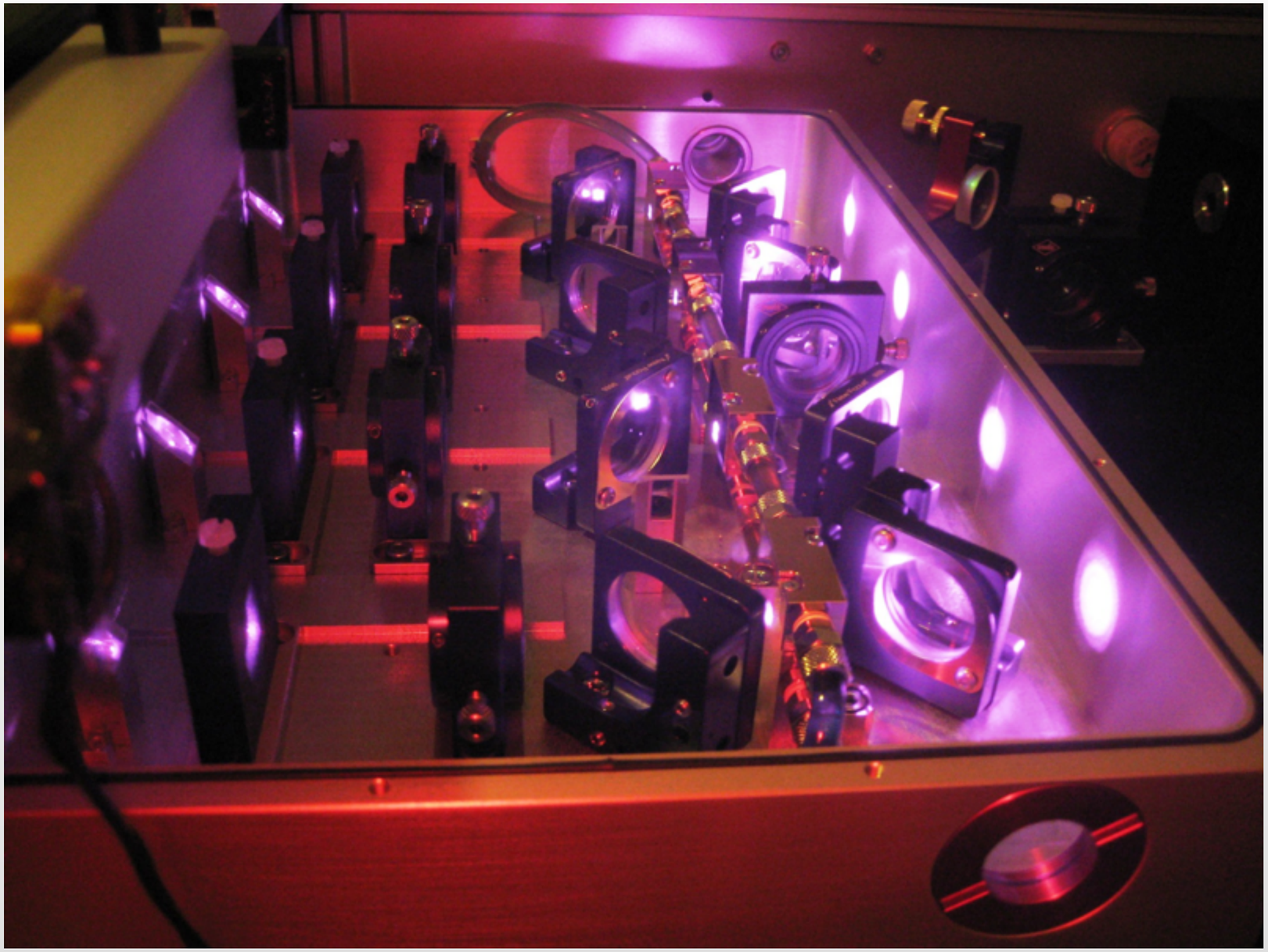


Optischer Aufbau



Der Laser



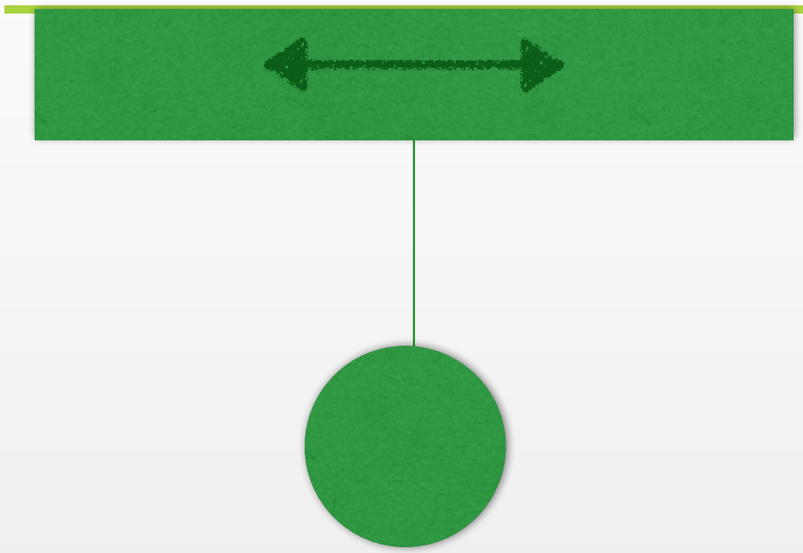
Lasersystem

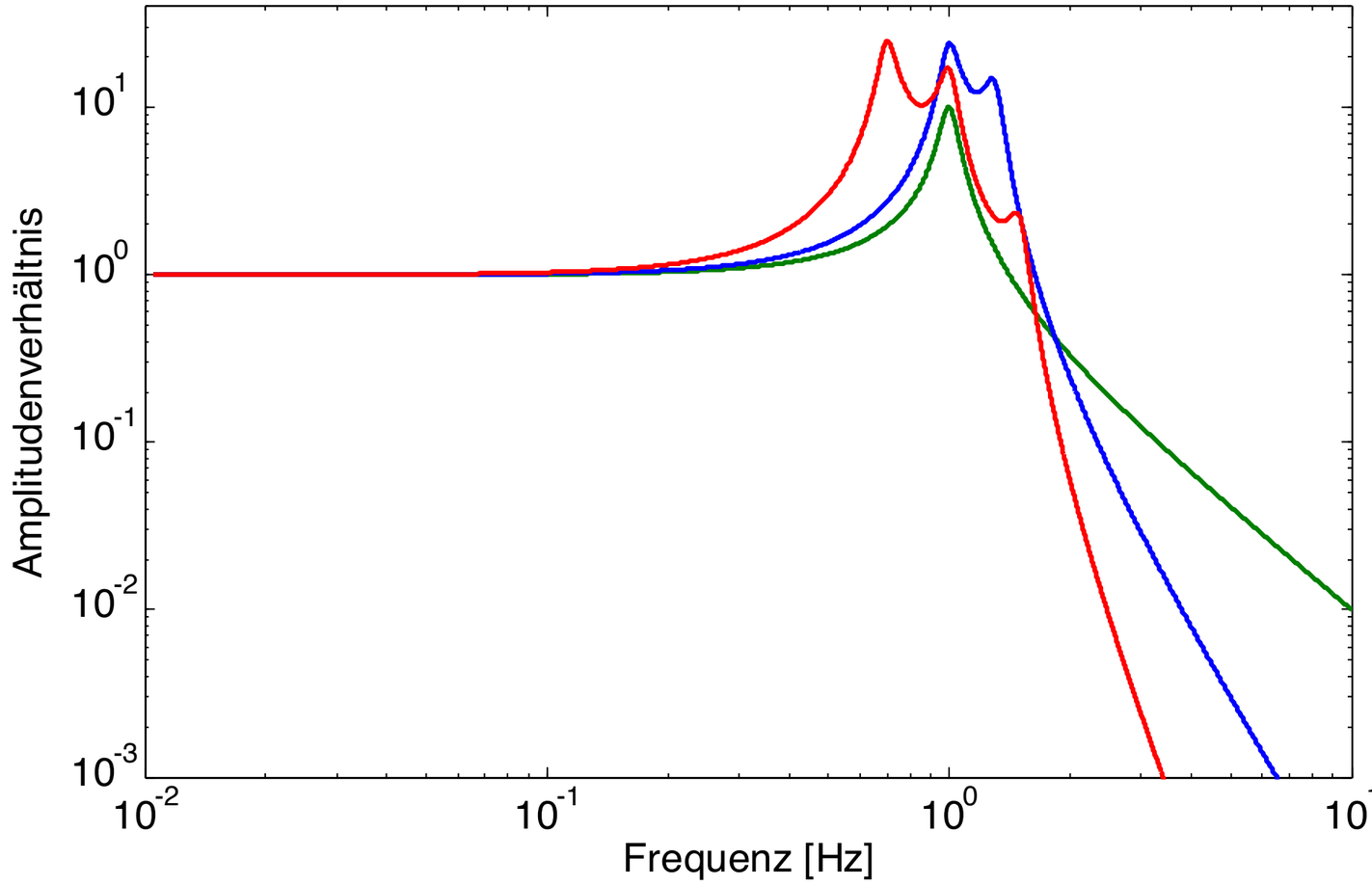
Nd:YVO_4-Laser
1064 nm Wellenlänge
(Nah-Infrarot)

gepumpt über Laserdioden
(808 nm)

Laserleistung max. 38 Watt

Seismische Isolierung





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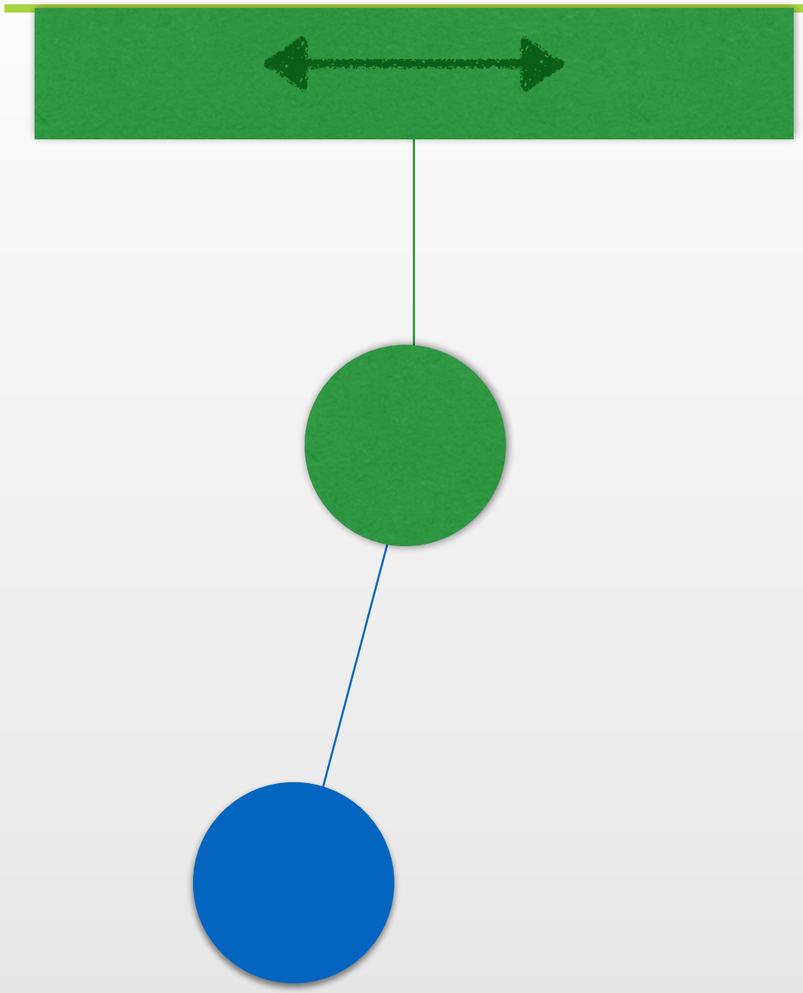

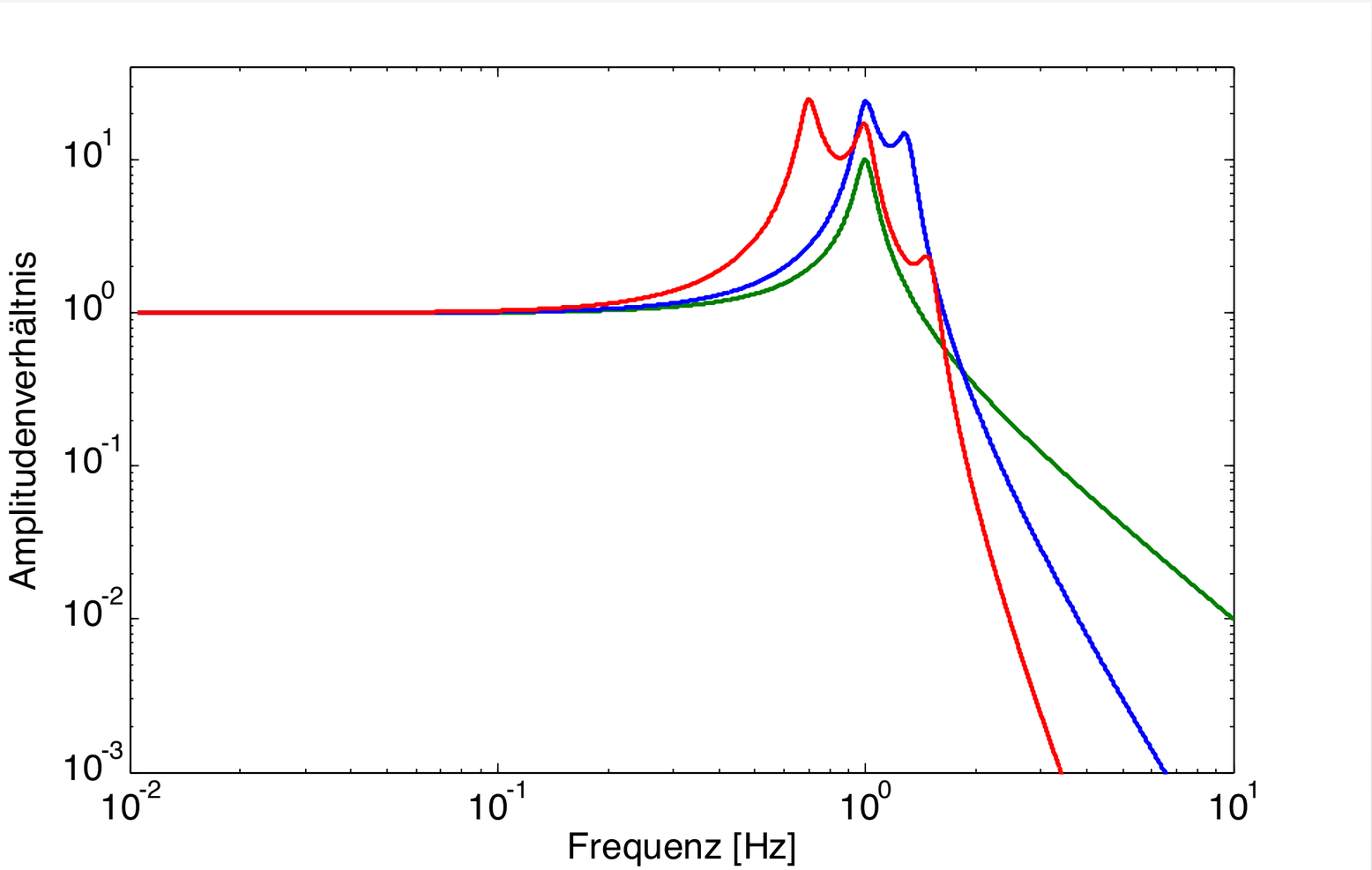

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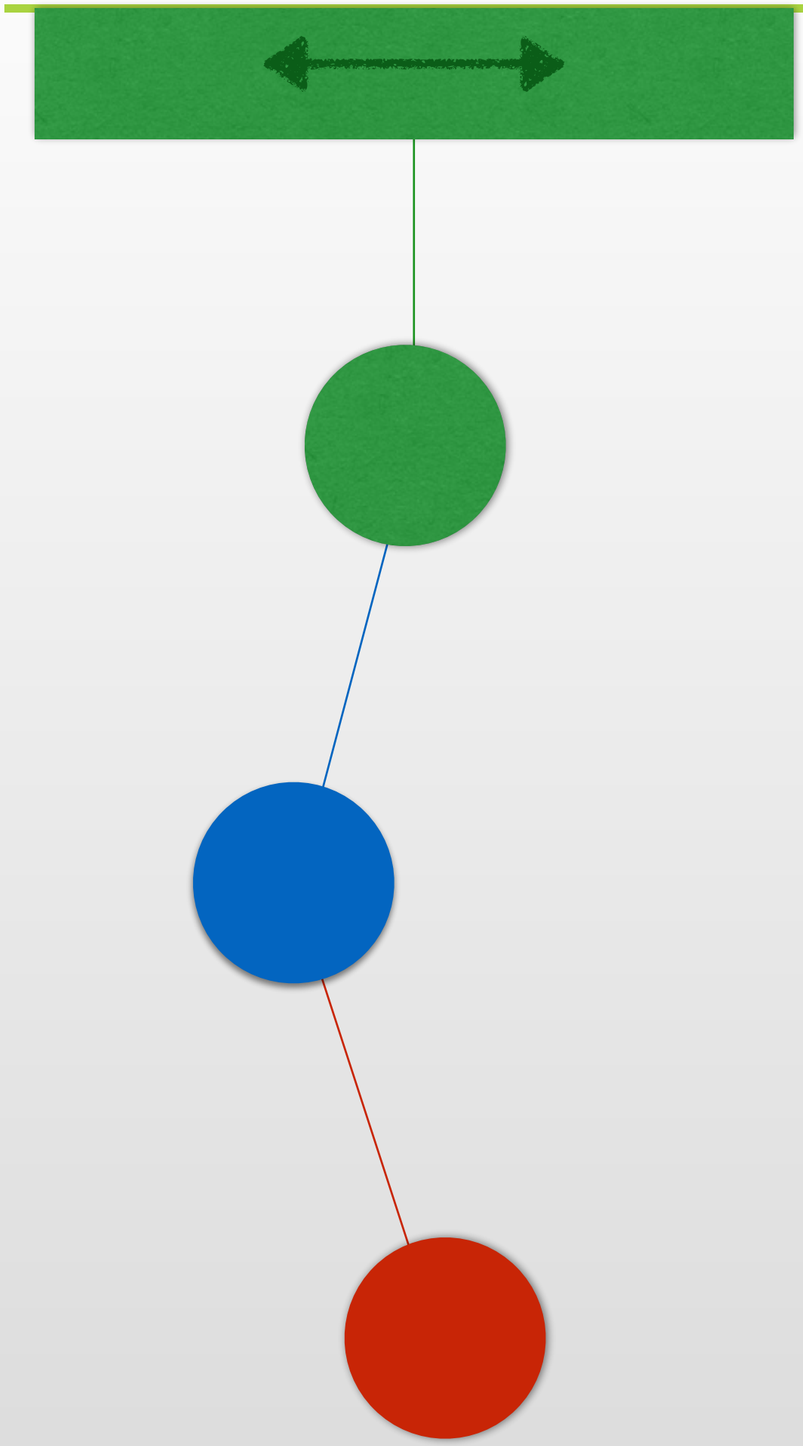

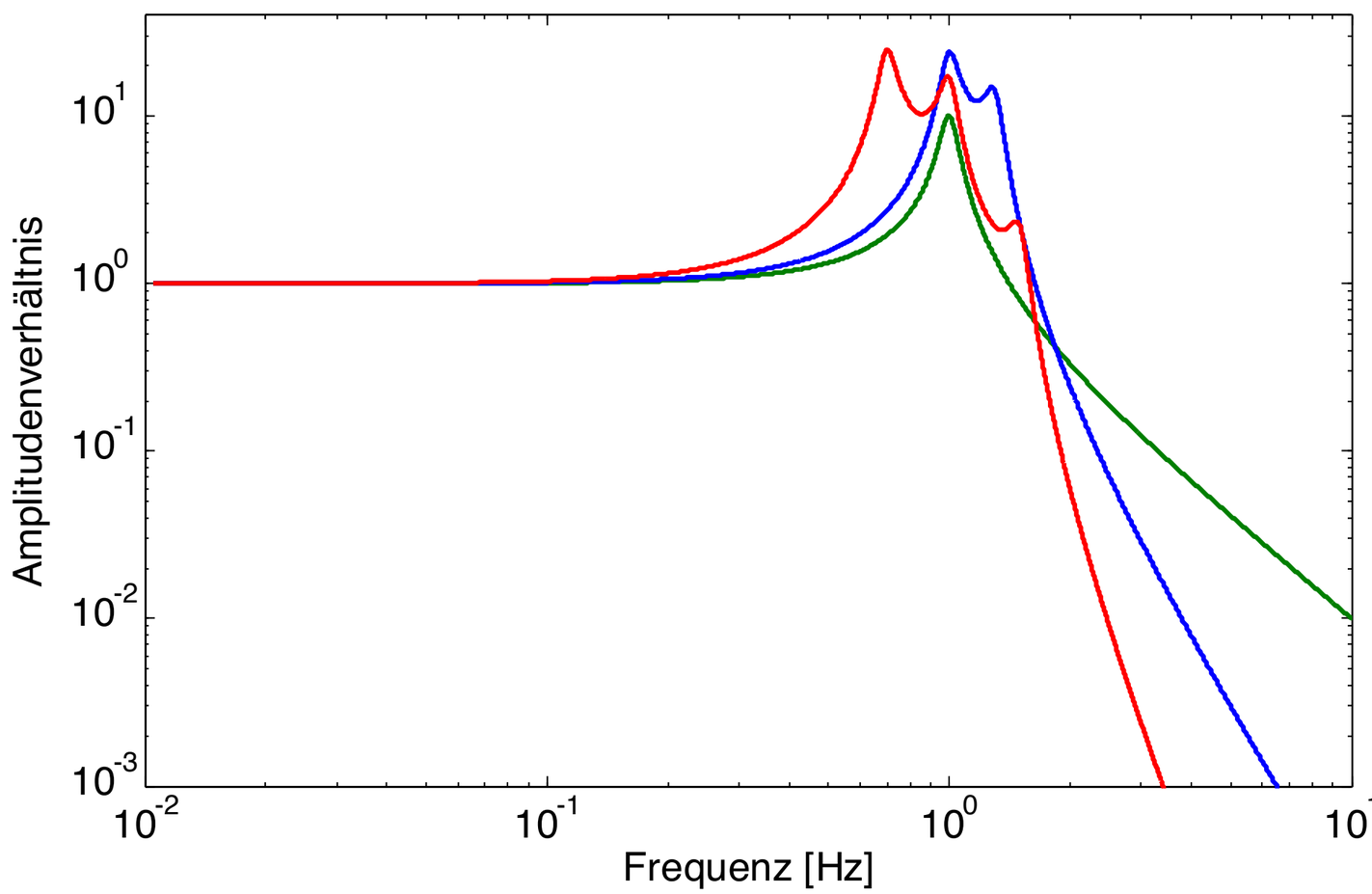

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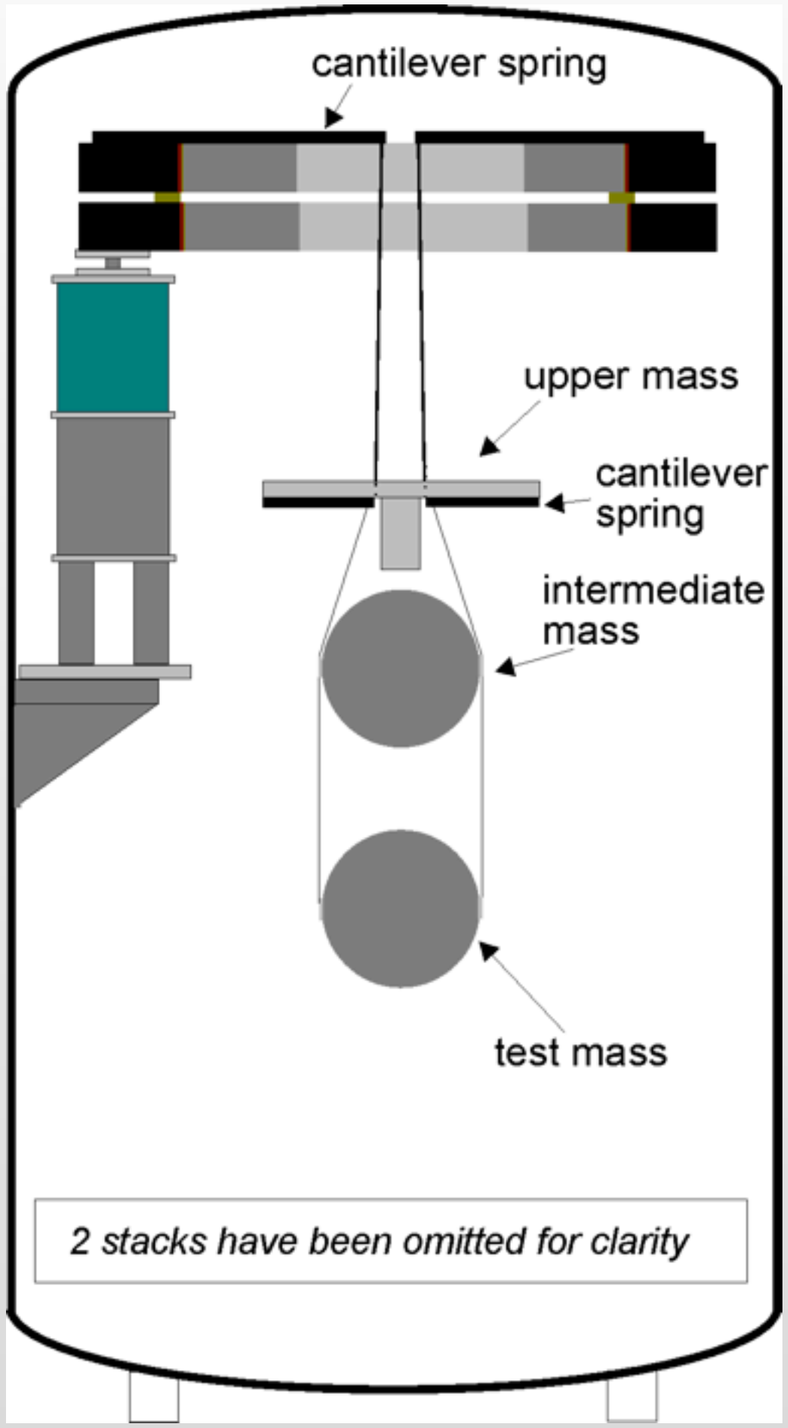
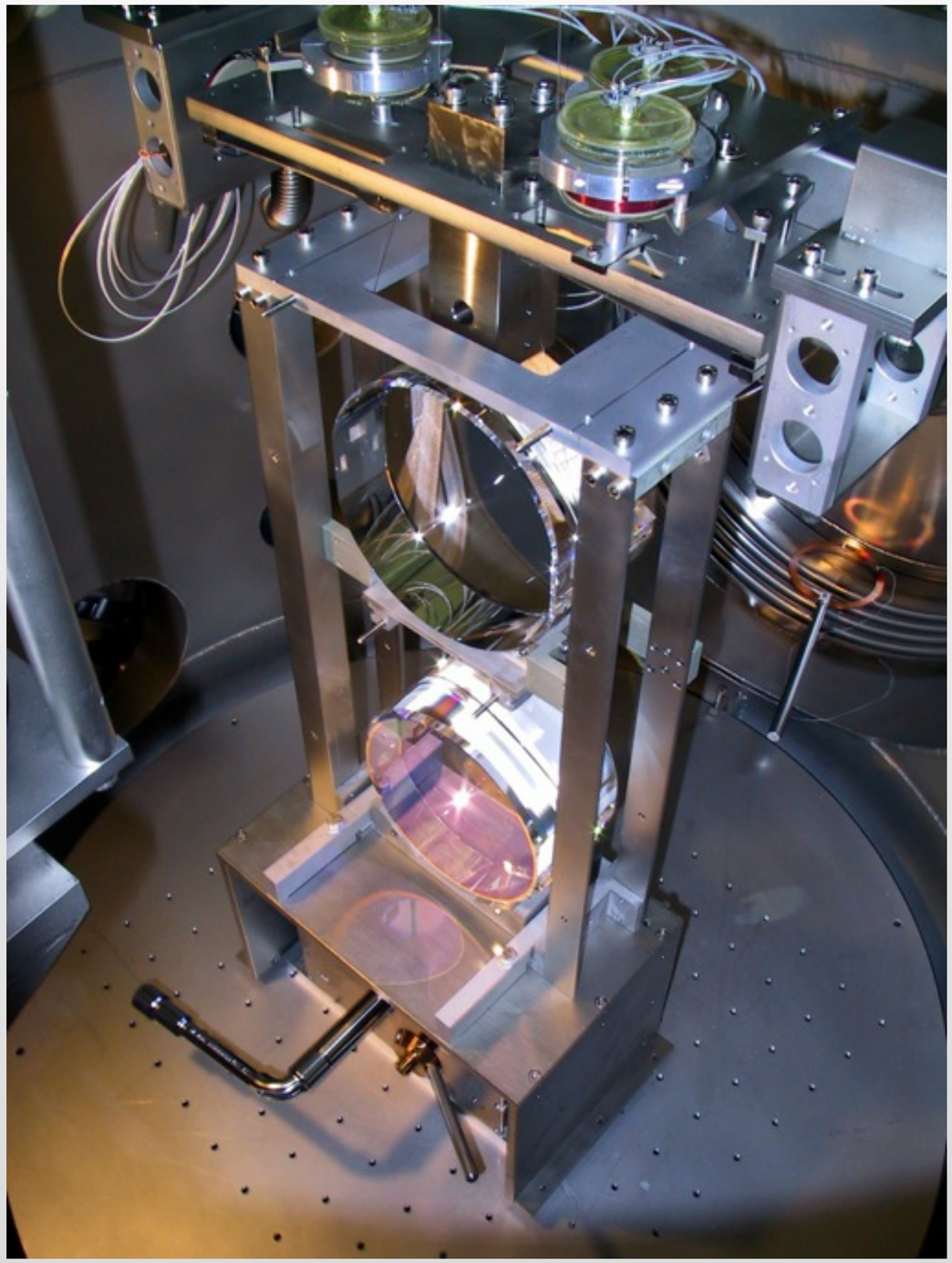
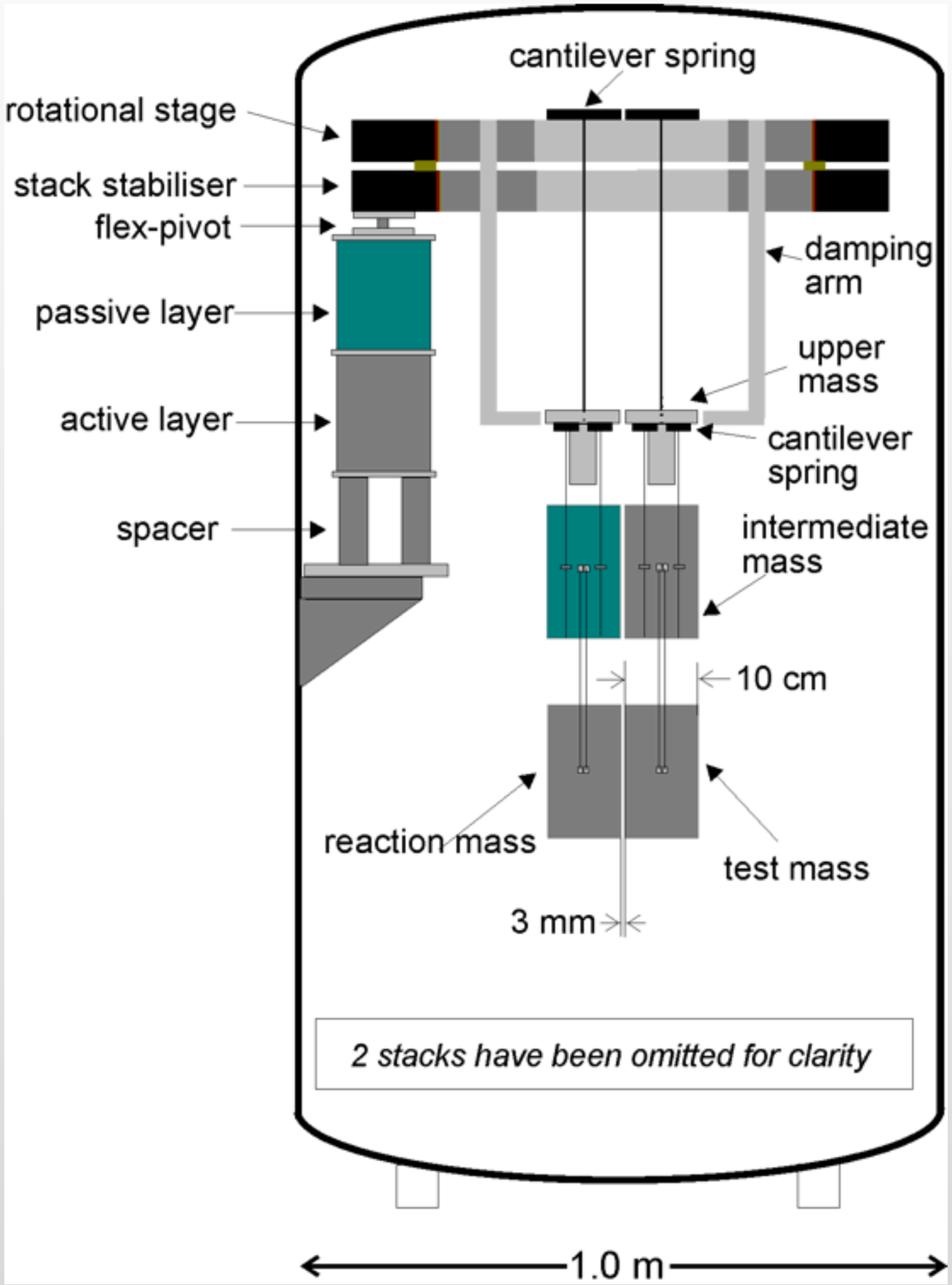
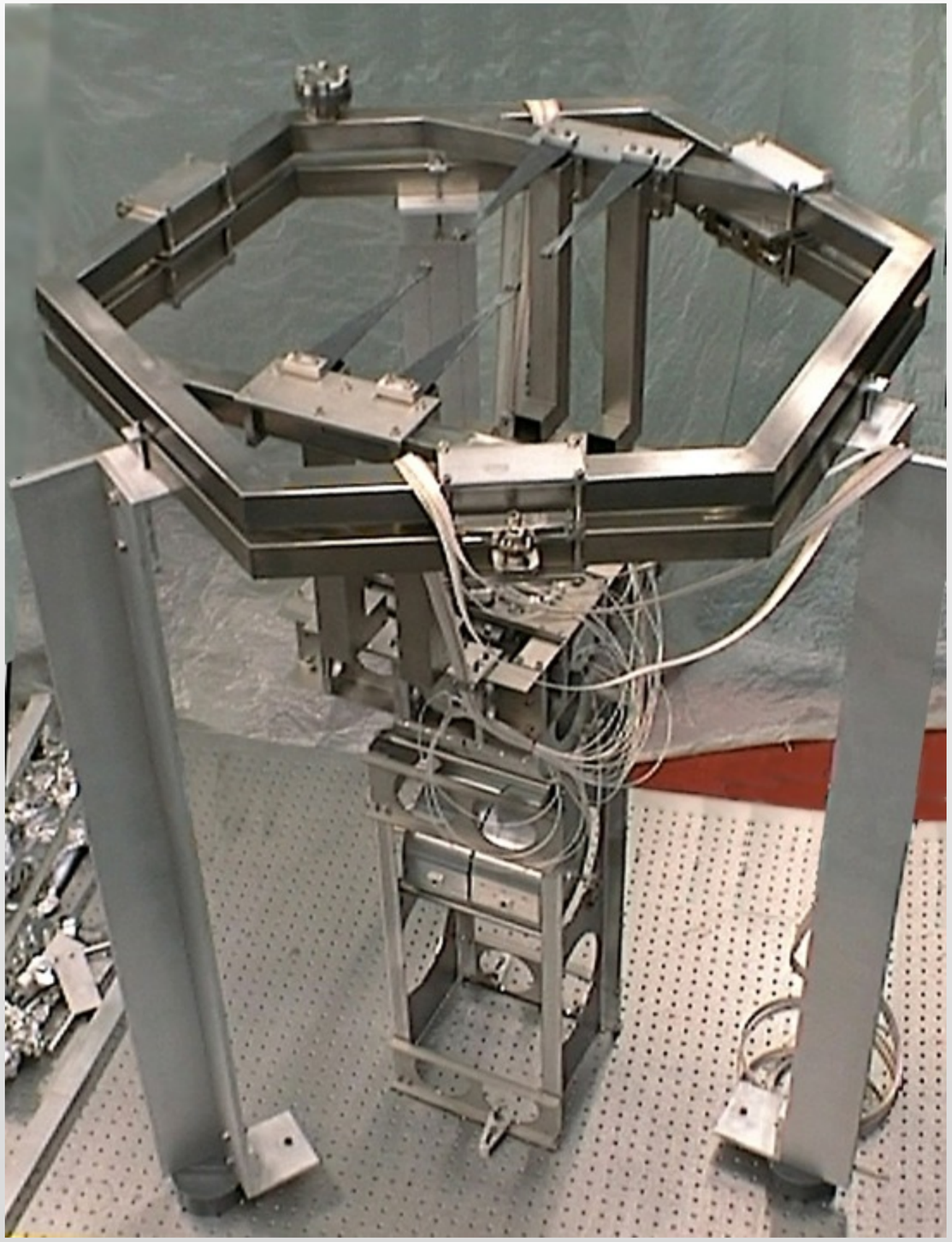


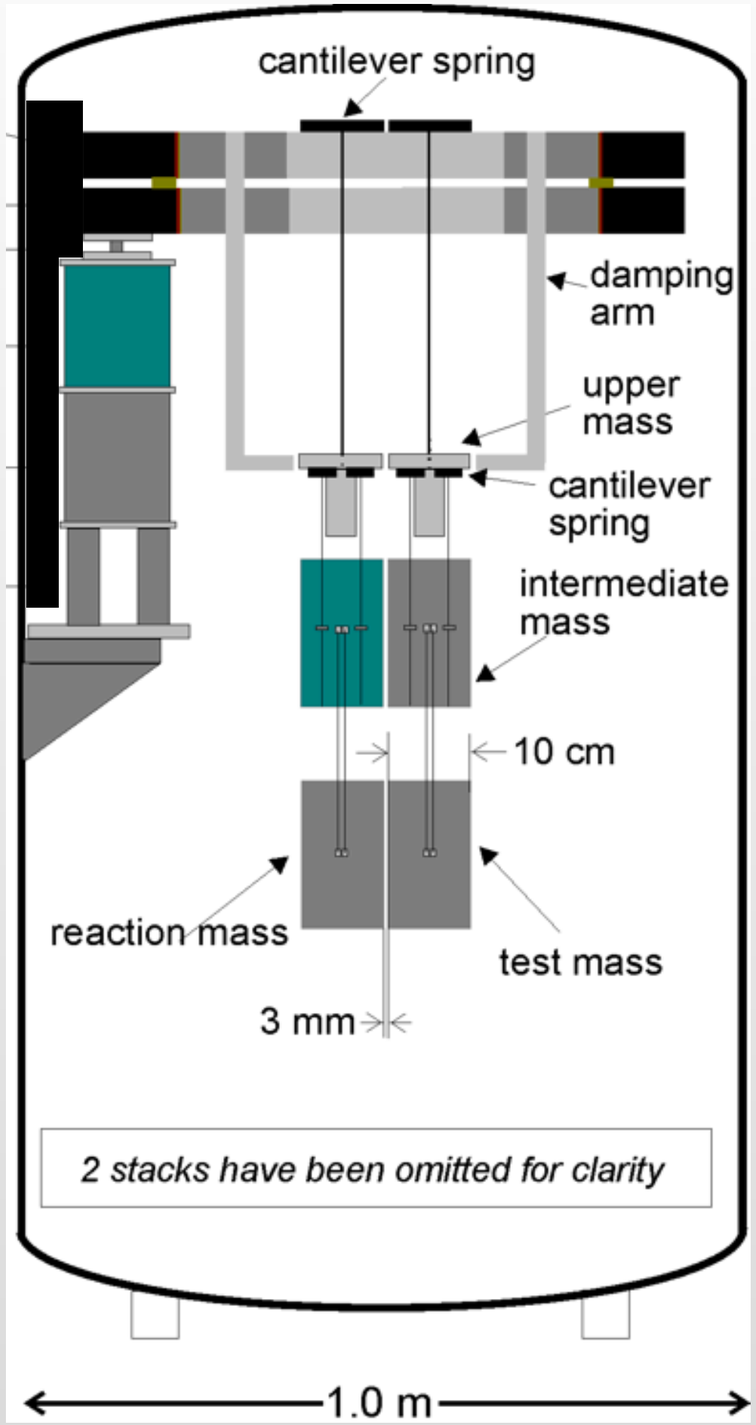


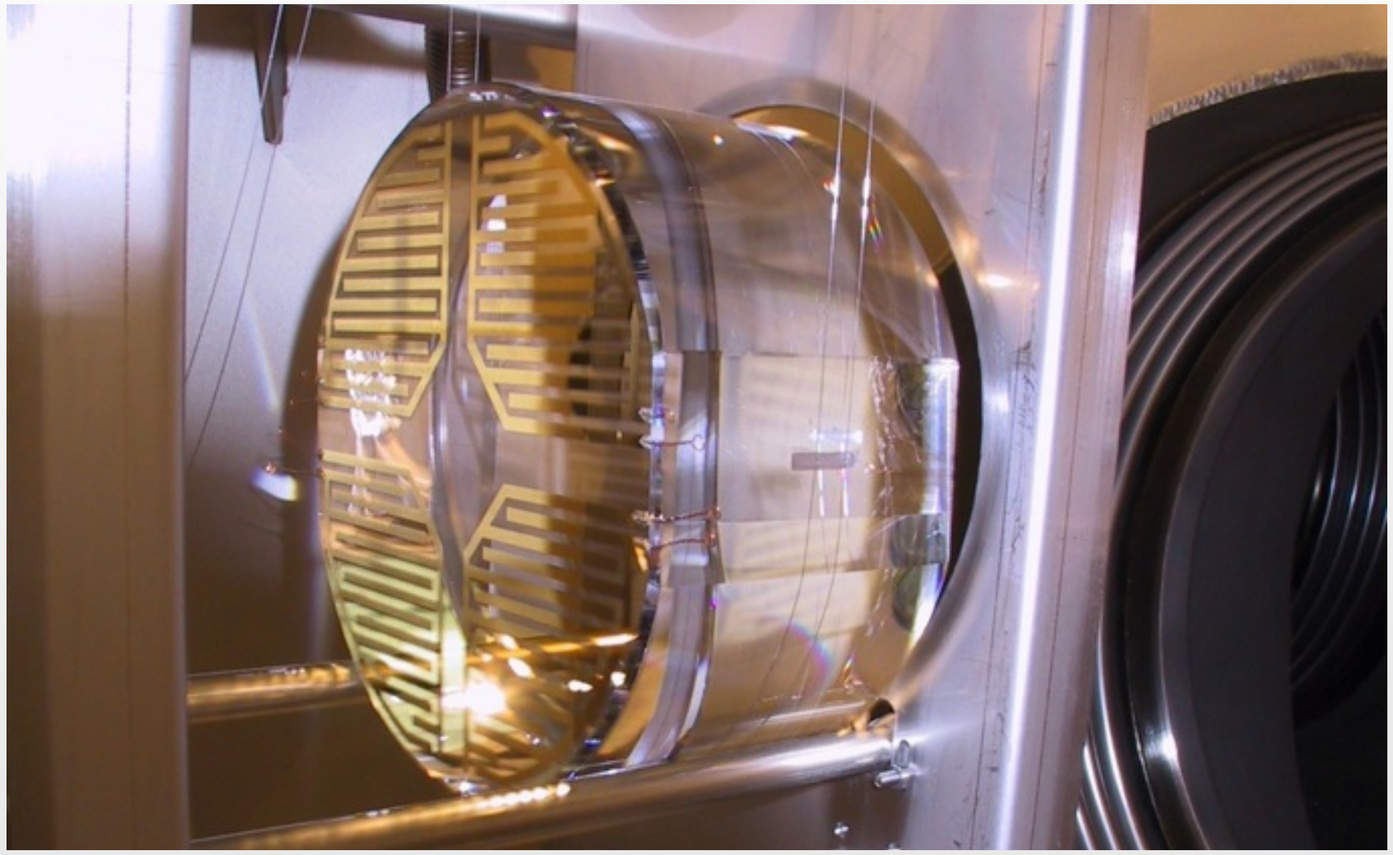
Referenzpendel





Aktuatoren

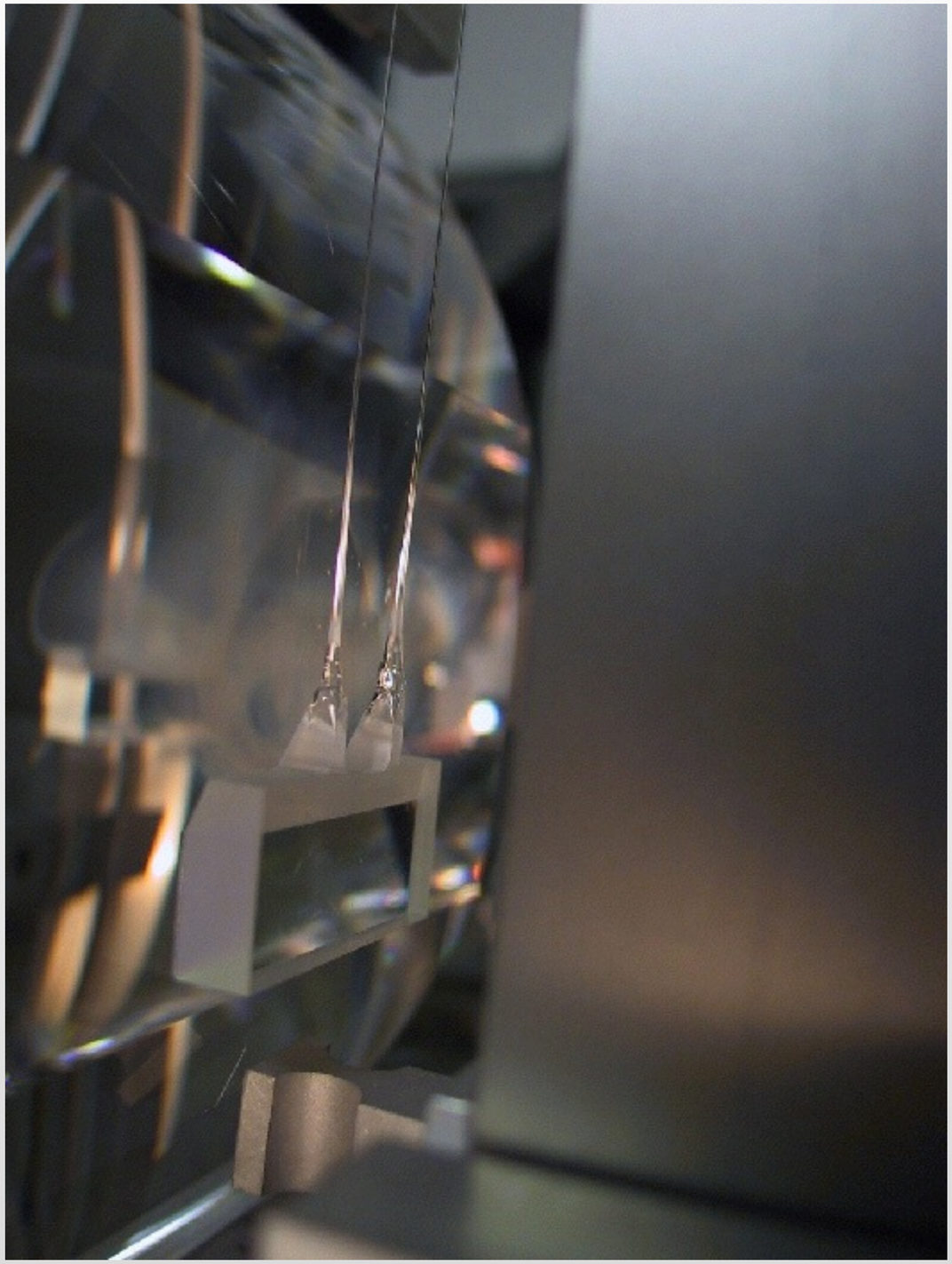




Magnetische Aktuatoren an der Zwischenmasse

Elektrostatische Aktuatoren („Kämme“) am Spiegel

Monolithische Aufhängung



Quarzglasfasern als tragende Elemente

„Bonding“-Technik verbindet auf molekularer Ebene mit Testmasse

Besonders „reine“ Schwingungen mit hoher Güte

Konzentriert thermisches Rauschen auf sehr schmales Frequenzband

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Im Tank

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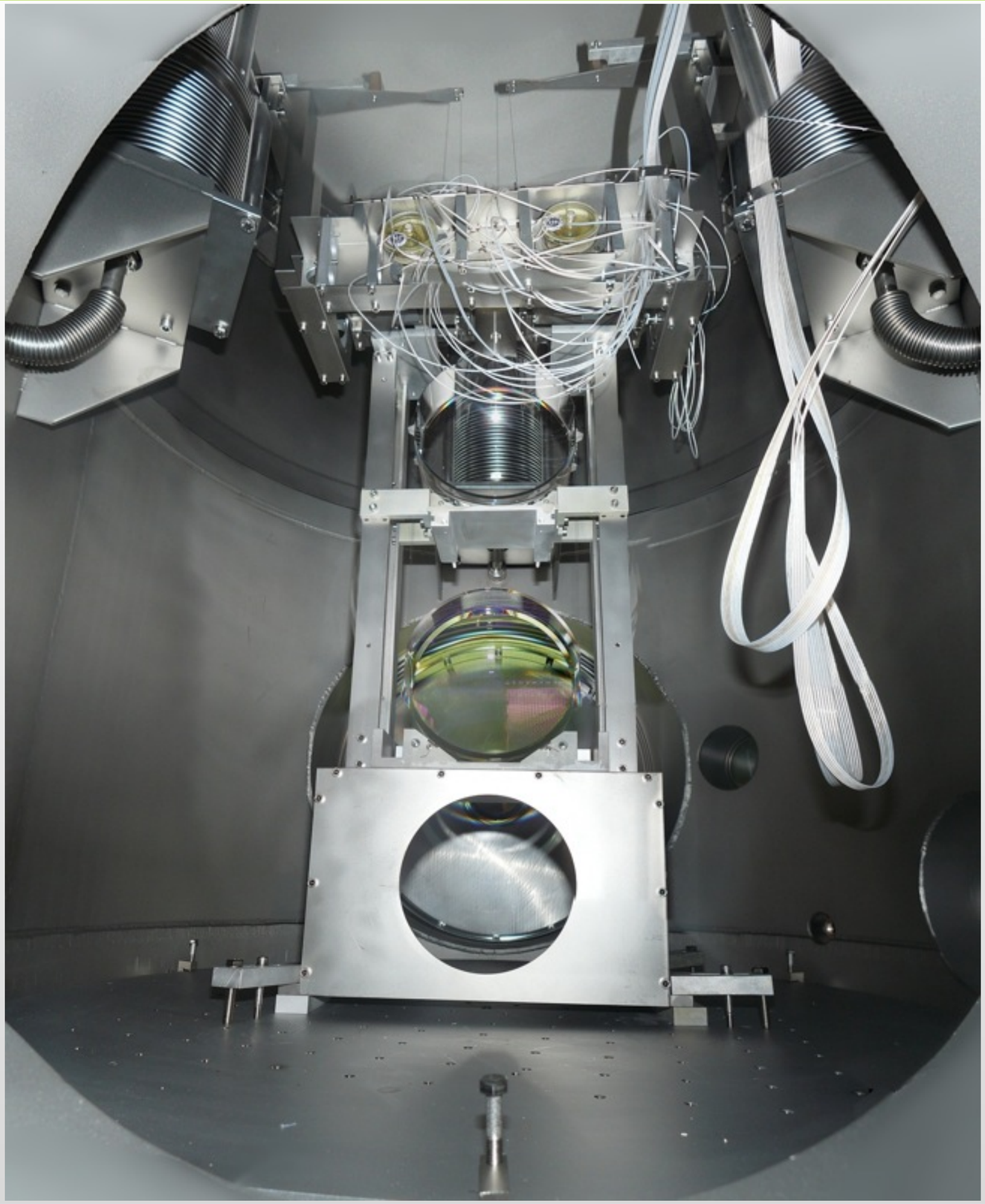

Aktive Stabilisierung

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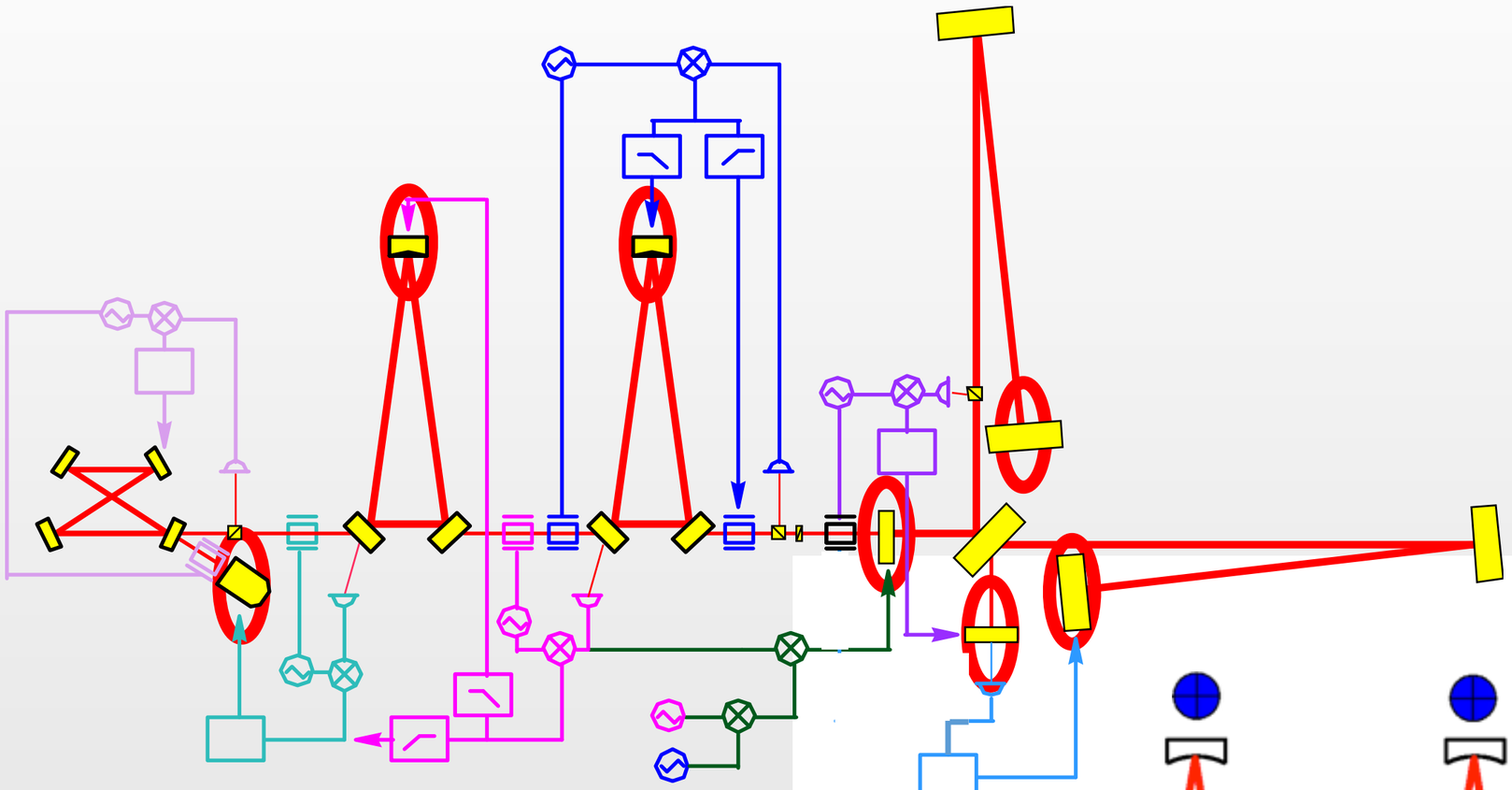
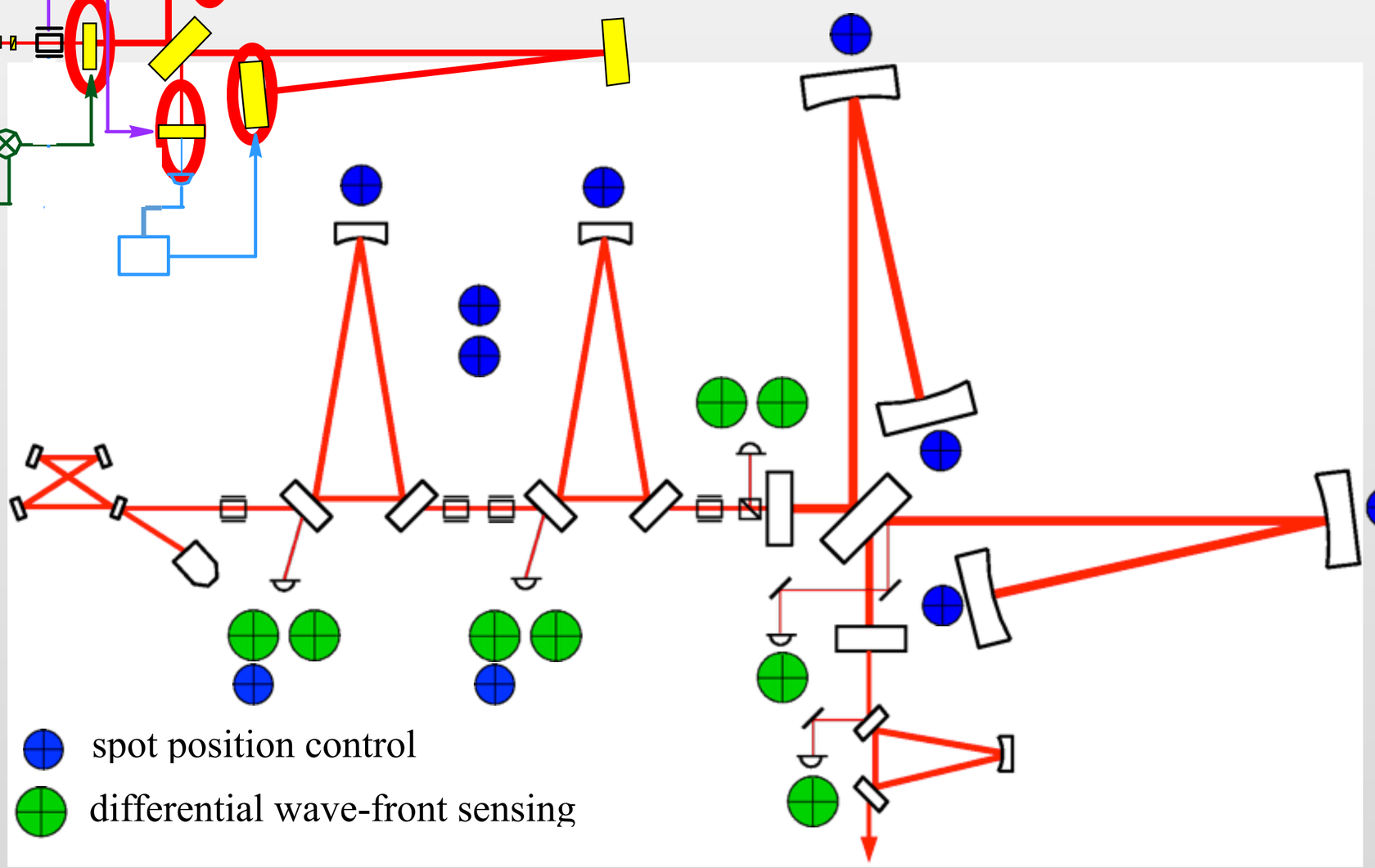


Längen-/Frequenzstabilisierung

Ausrichtungsstabilisierung



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Kontrollraum

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Kontrollraum

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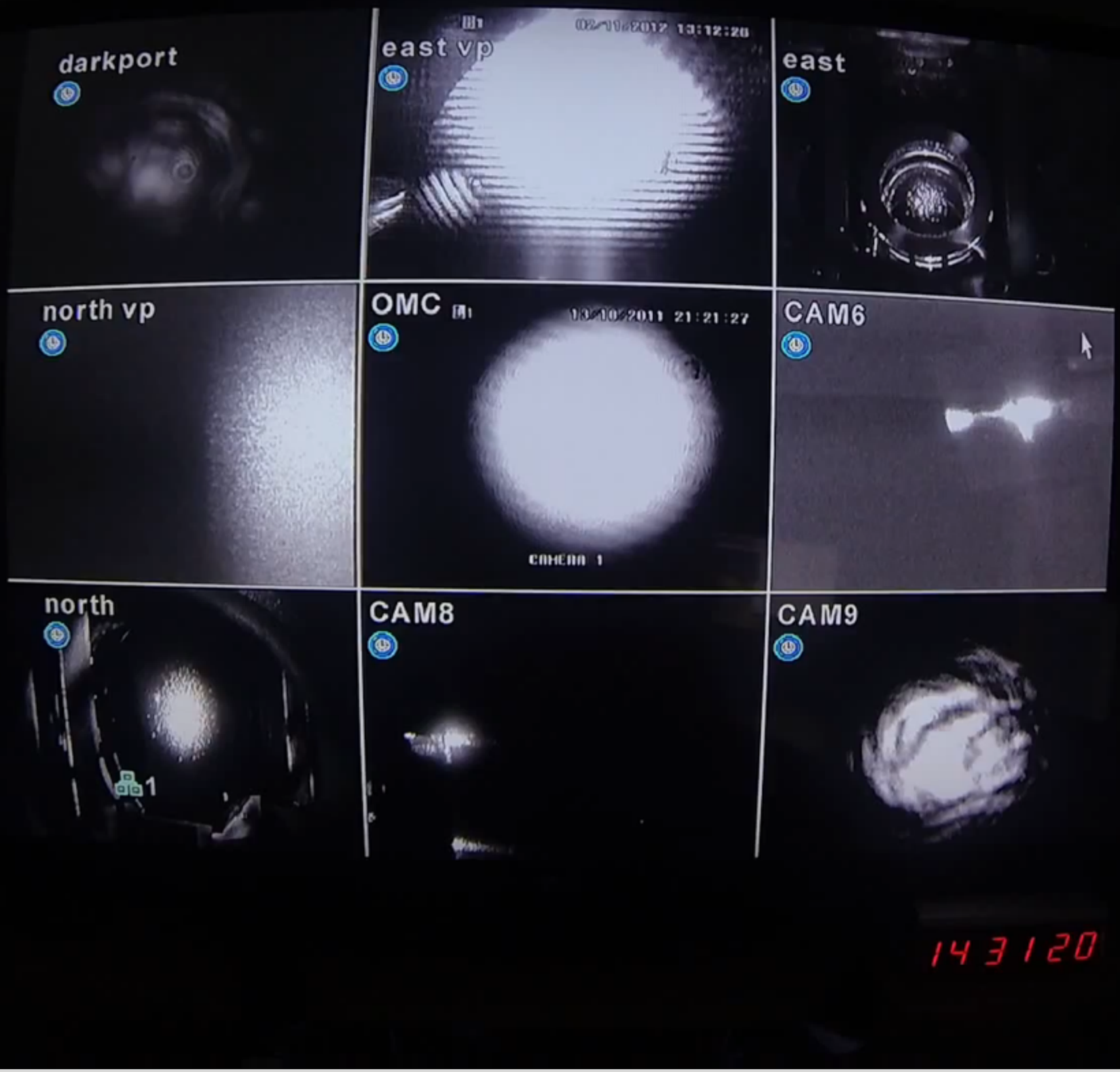
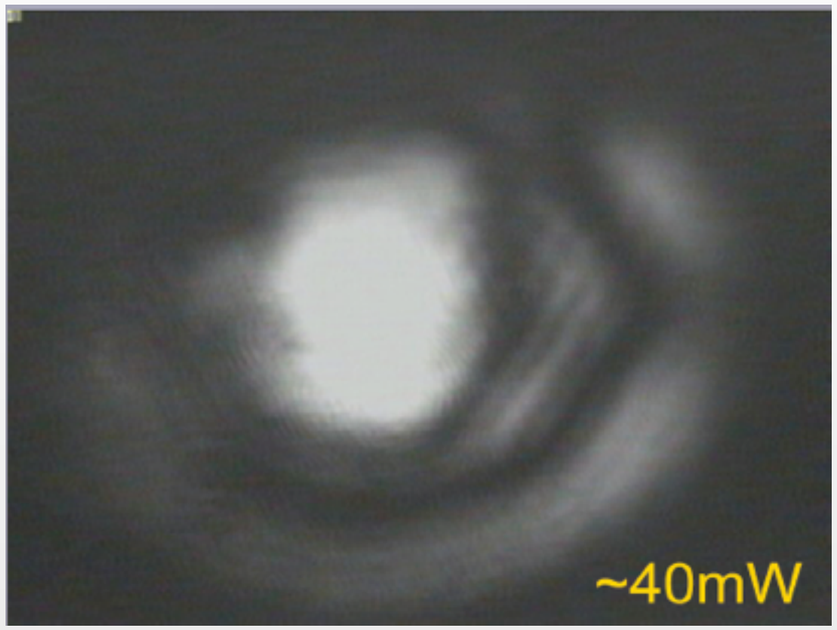
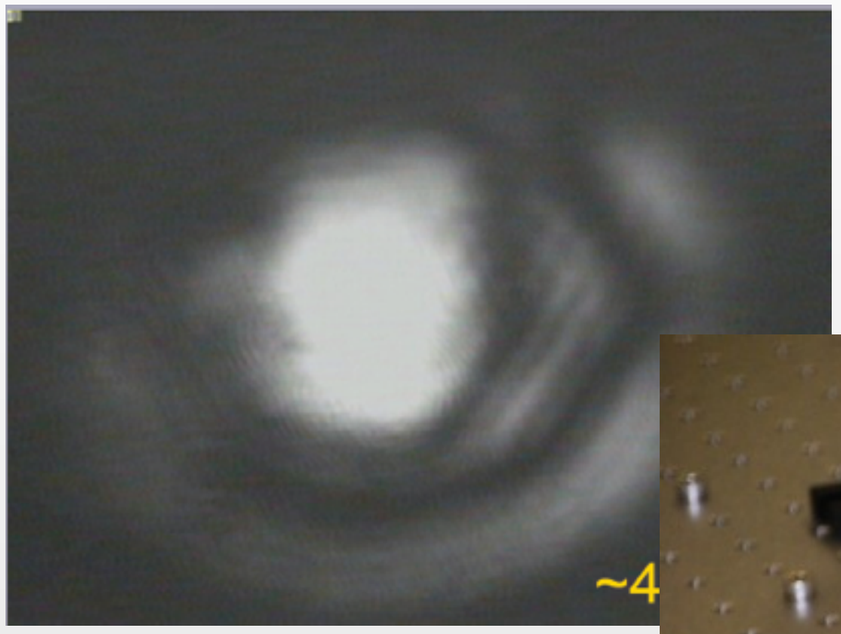


Ausgangsmodenfilter



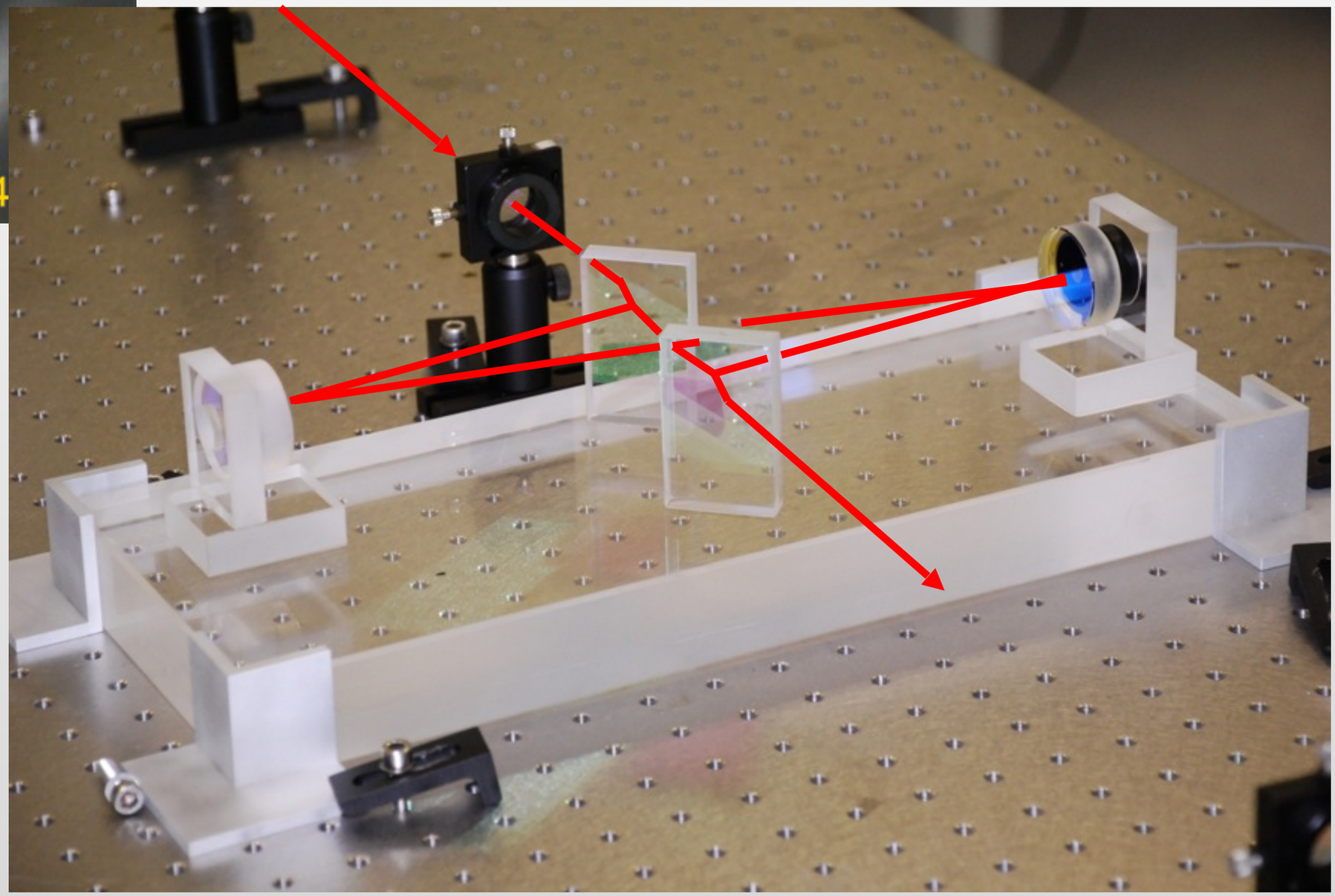
Ausgangsmodenfilter



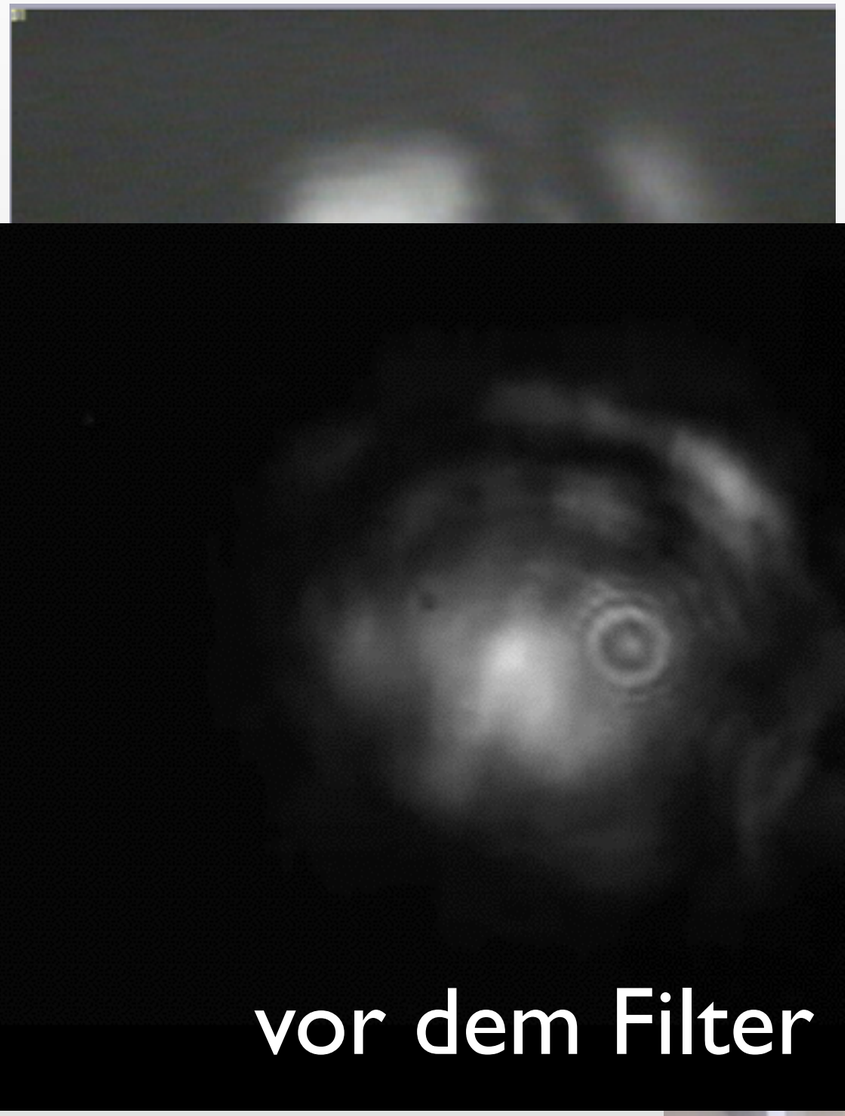
Filter-Resonator

– unterdrückt Lasermoden höherer Ordnung

– filtert Strahlprofil-Unebenheiten (von optischen Oberflächenfehlern)



Ausgangsmodenfilter



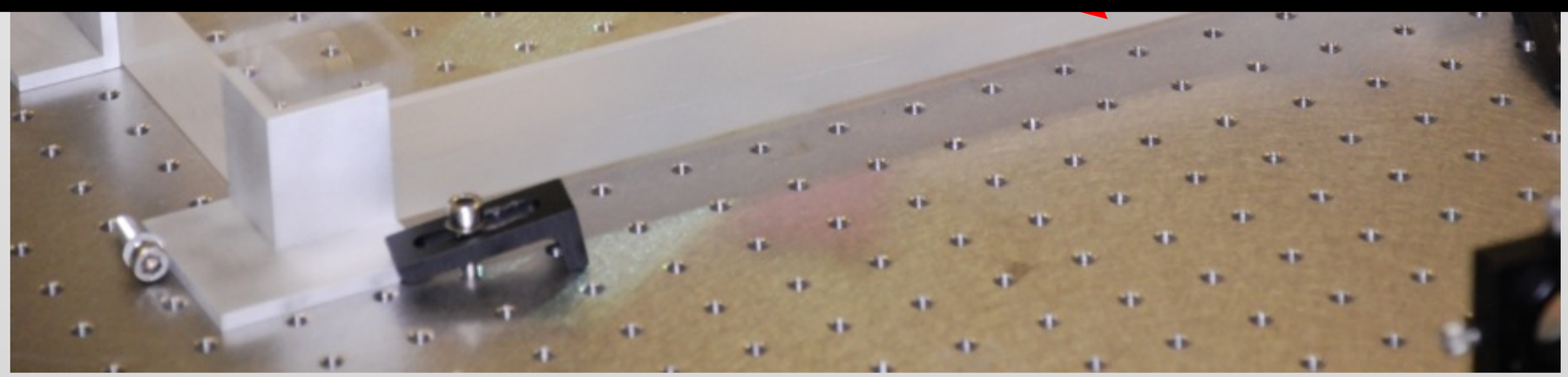
Filter-Resonator

– unterdrückt Lasermoden höherer Ordnung

– filtert Strahlprofil-Unebenheiten (von optischen

vor dem Filter

hinter dem Filter



Strahl im GEO600-Strahlteiler

– Absorption von 0.5 ppm/cm

– 5 kW zirkulierende Laserleistung

– thermische Linse mit 10 km Brennweite

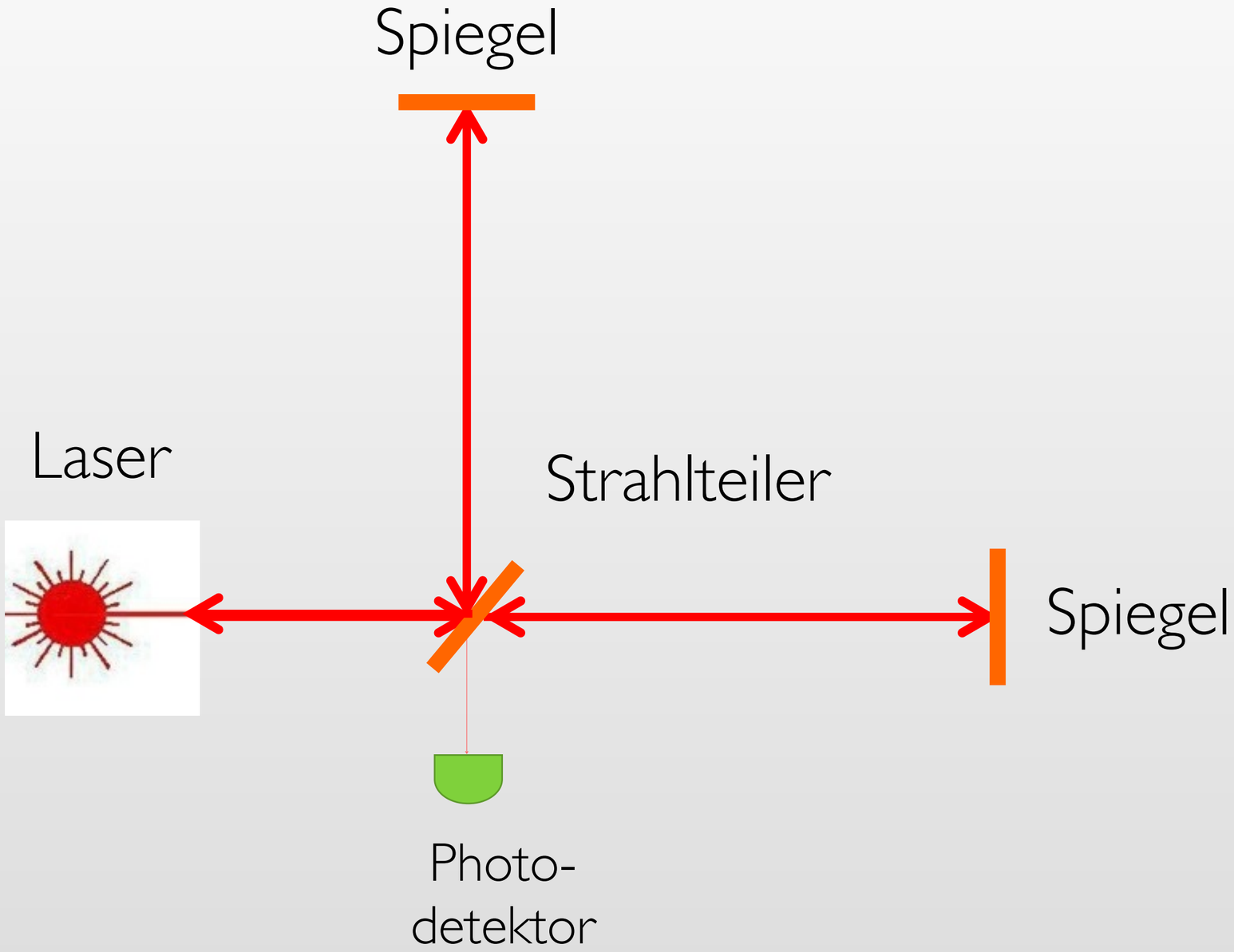
– *muss korrigiert werden!*

– GEO600 setzt gezielte Erwärmung ein

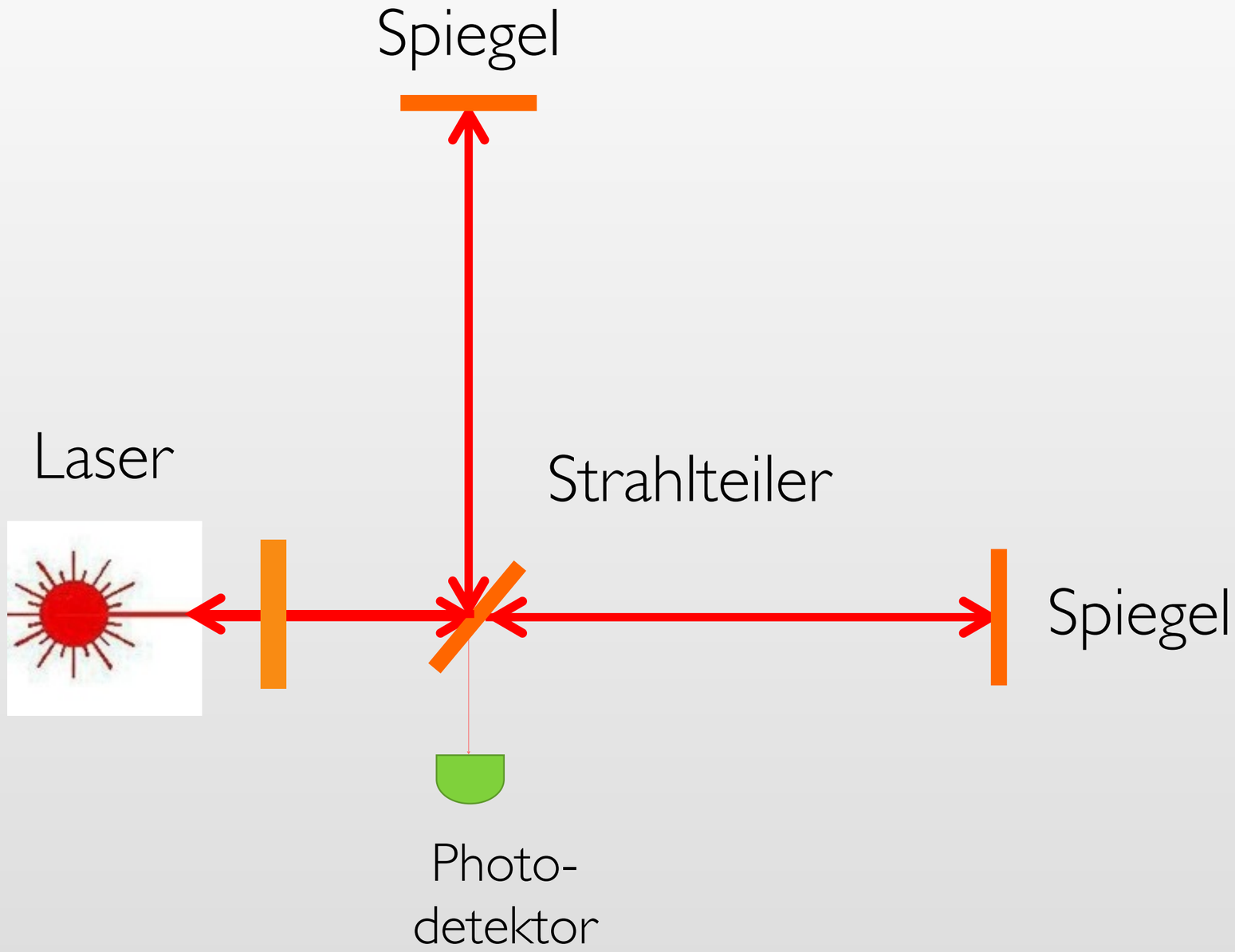
– Heizelemente und -ringe

– neueste Entwicklung: „Heizmatrix“

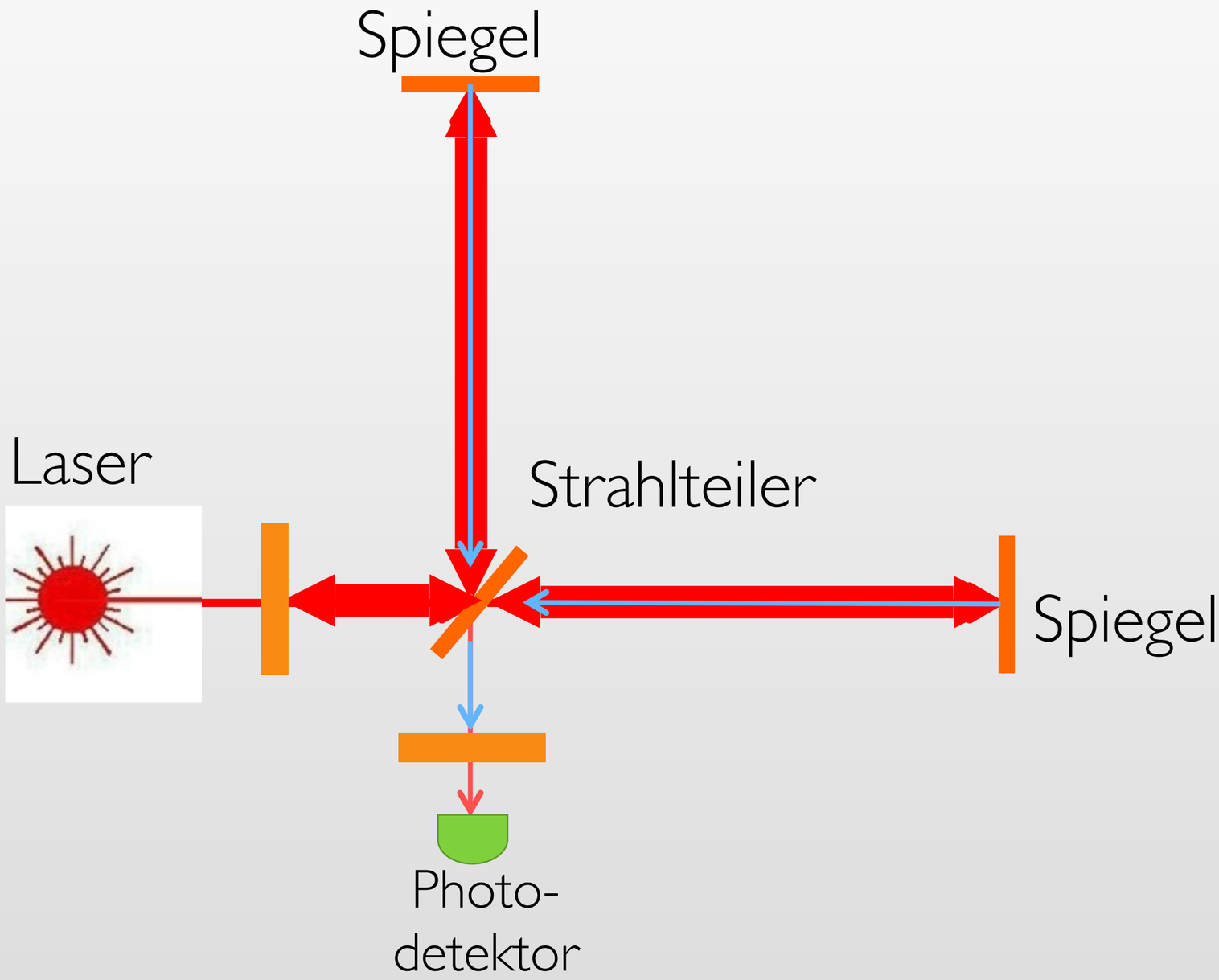
„Power Recycling“



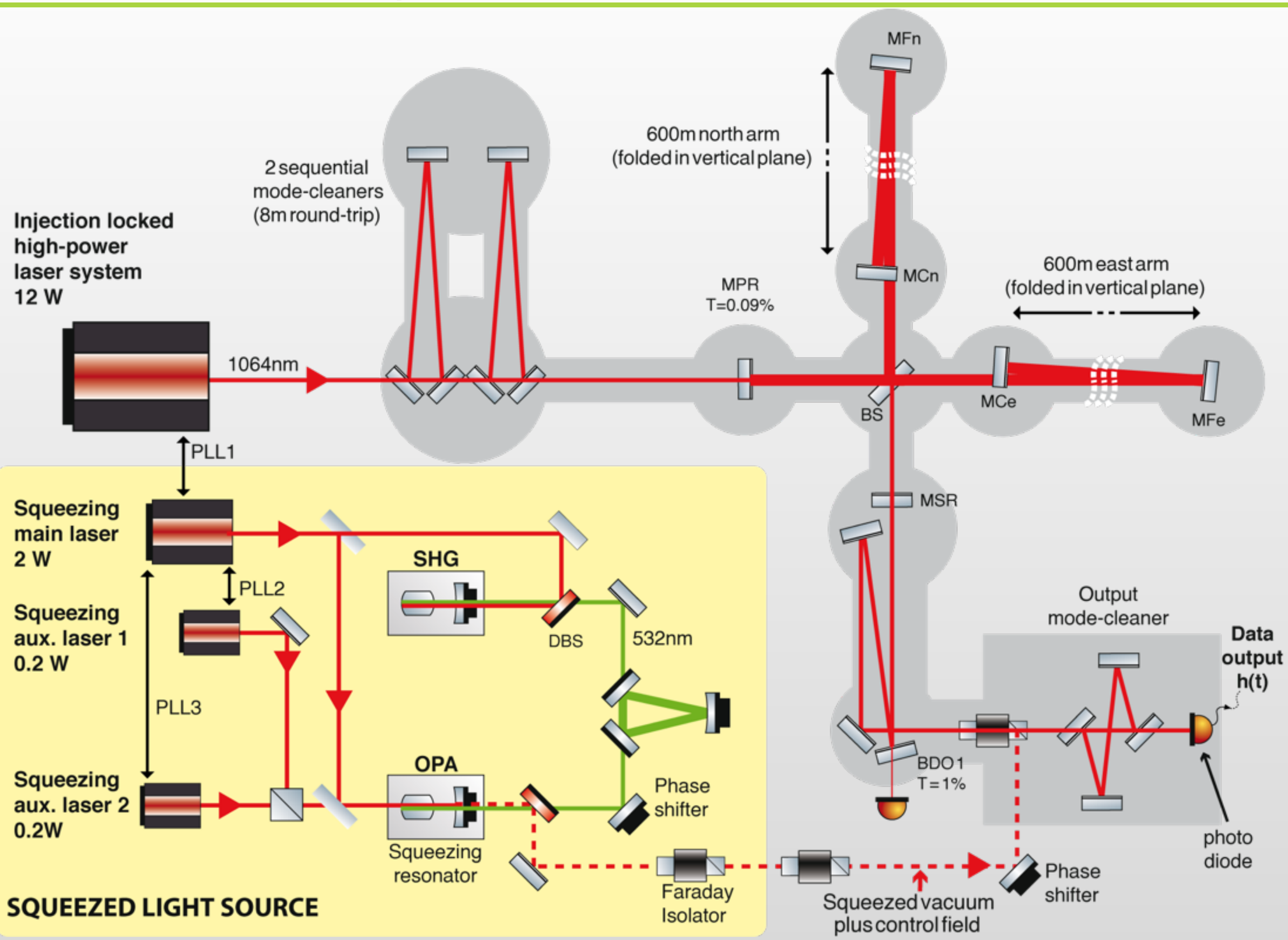
„Power Recycling“



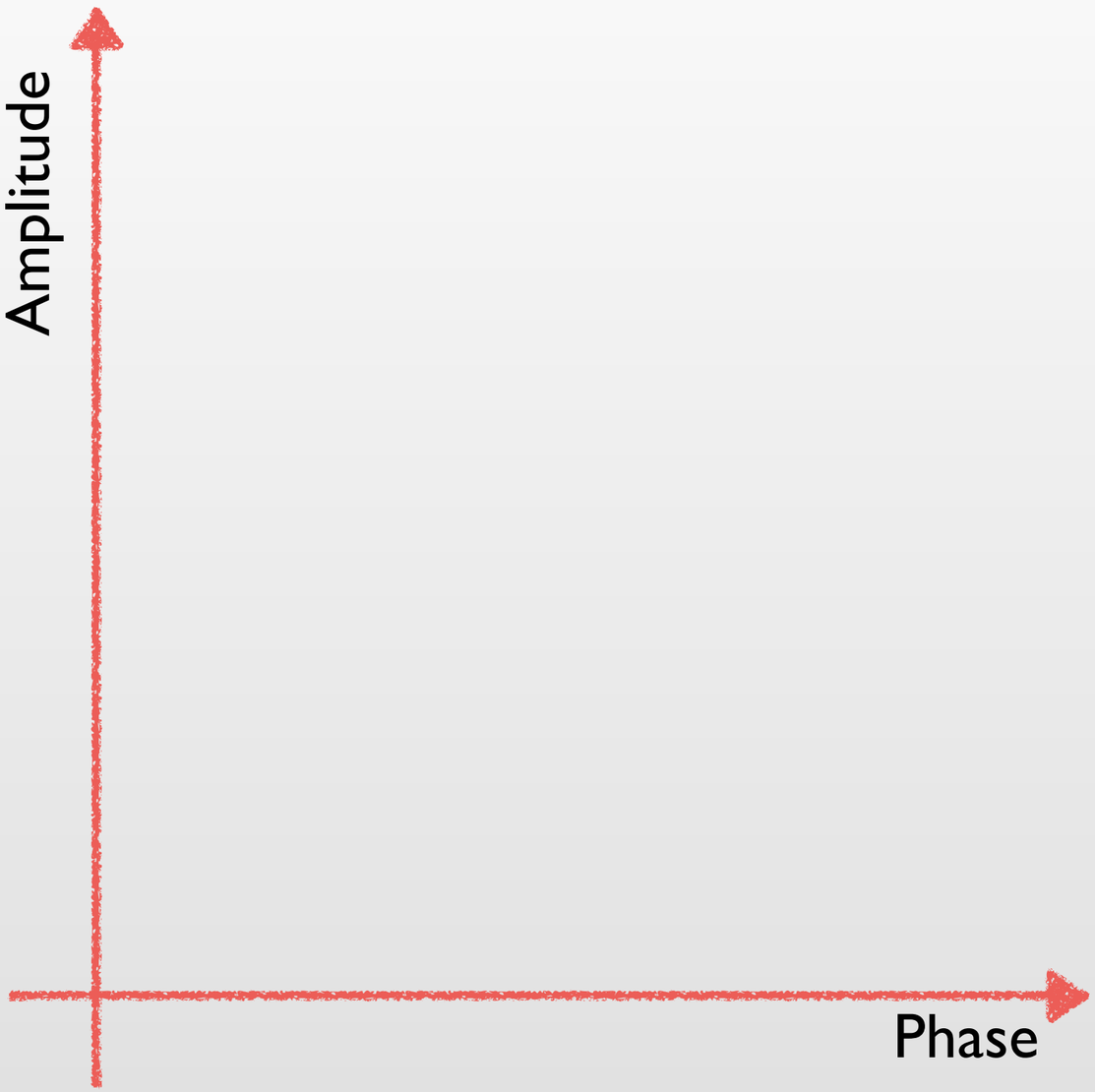
„Signal Recycling“



Optischer Aufbau

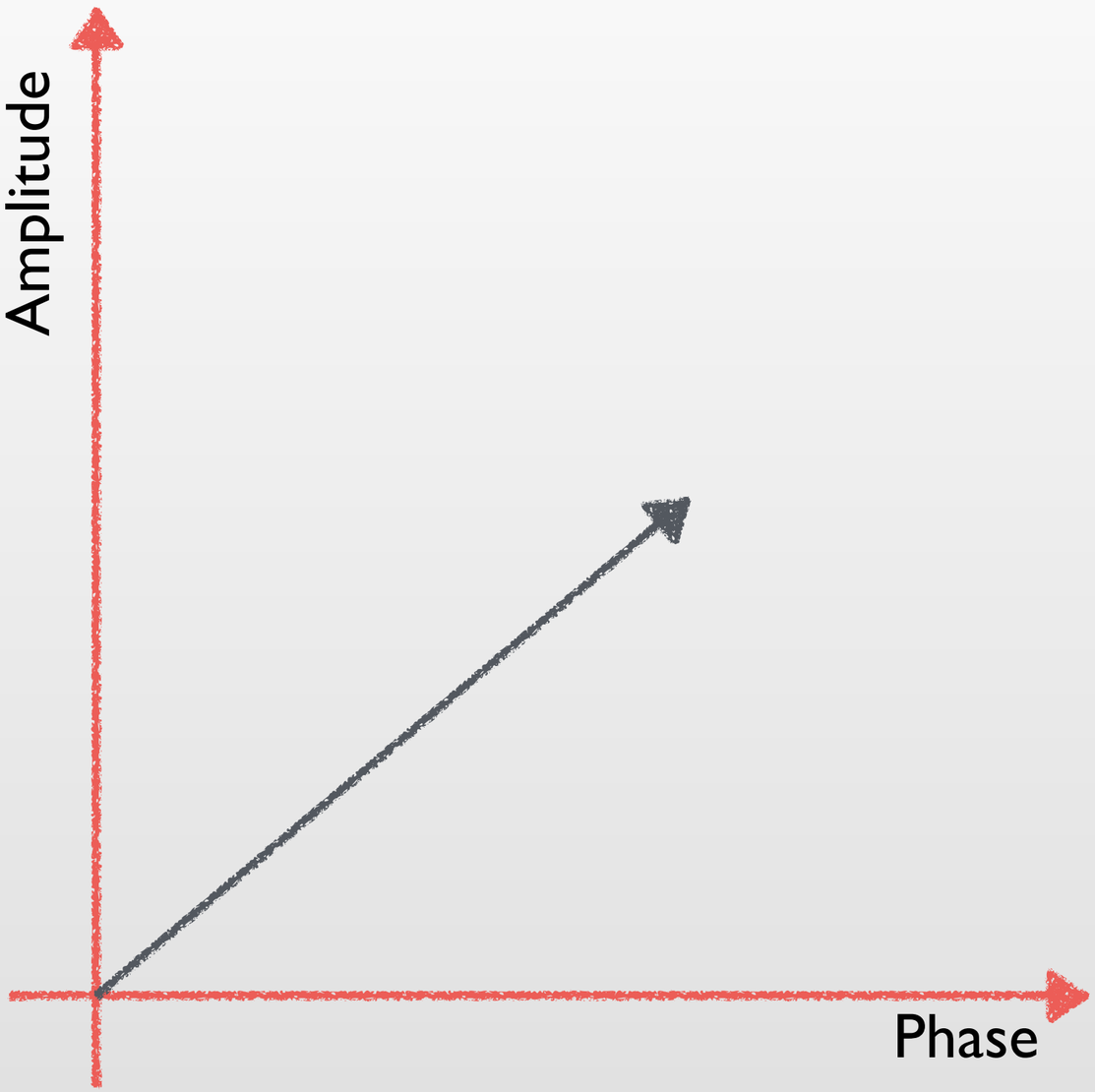


Licht quetschen



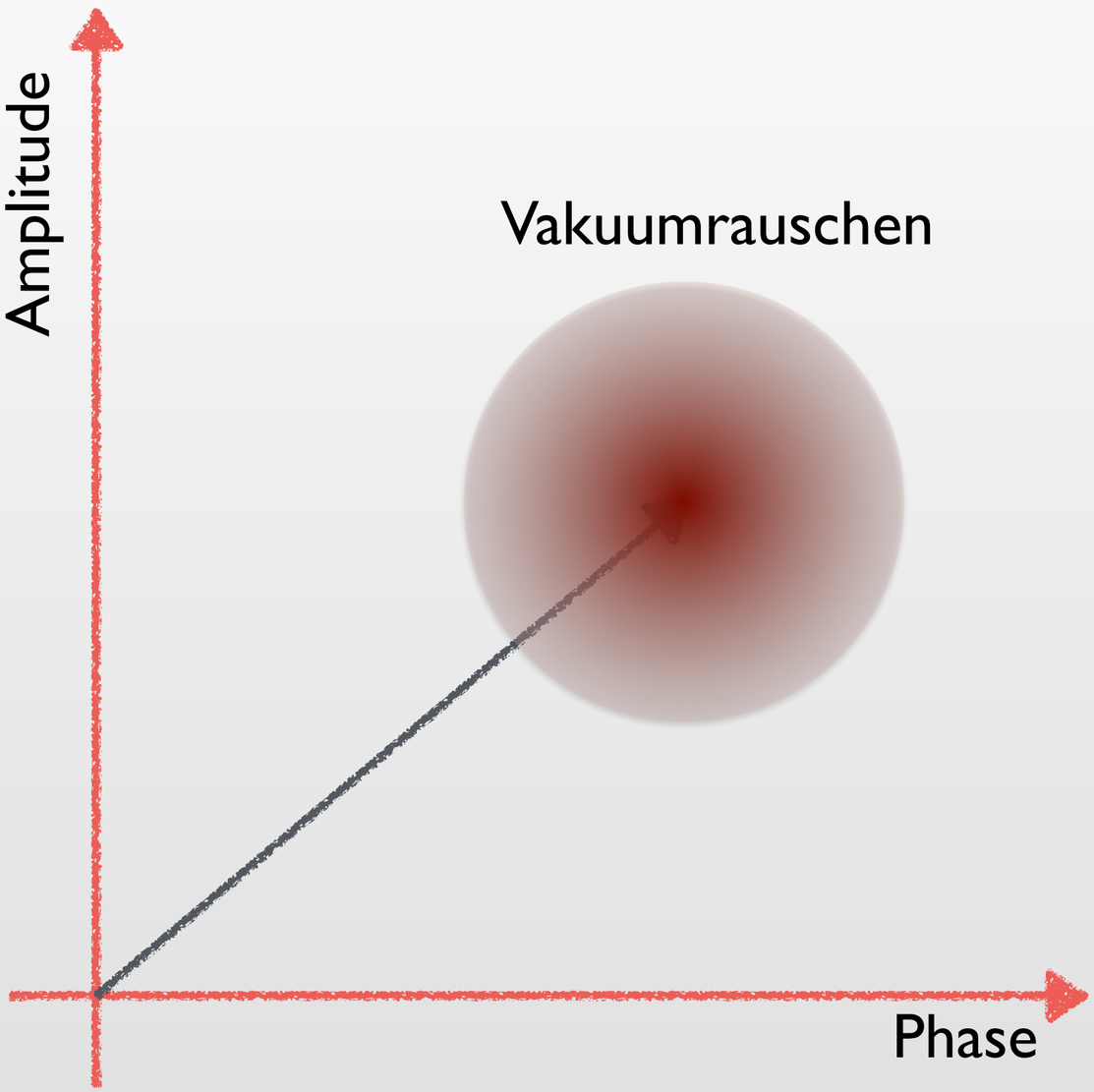
Lichtfeld

Licht quetschen



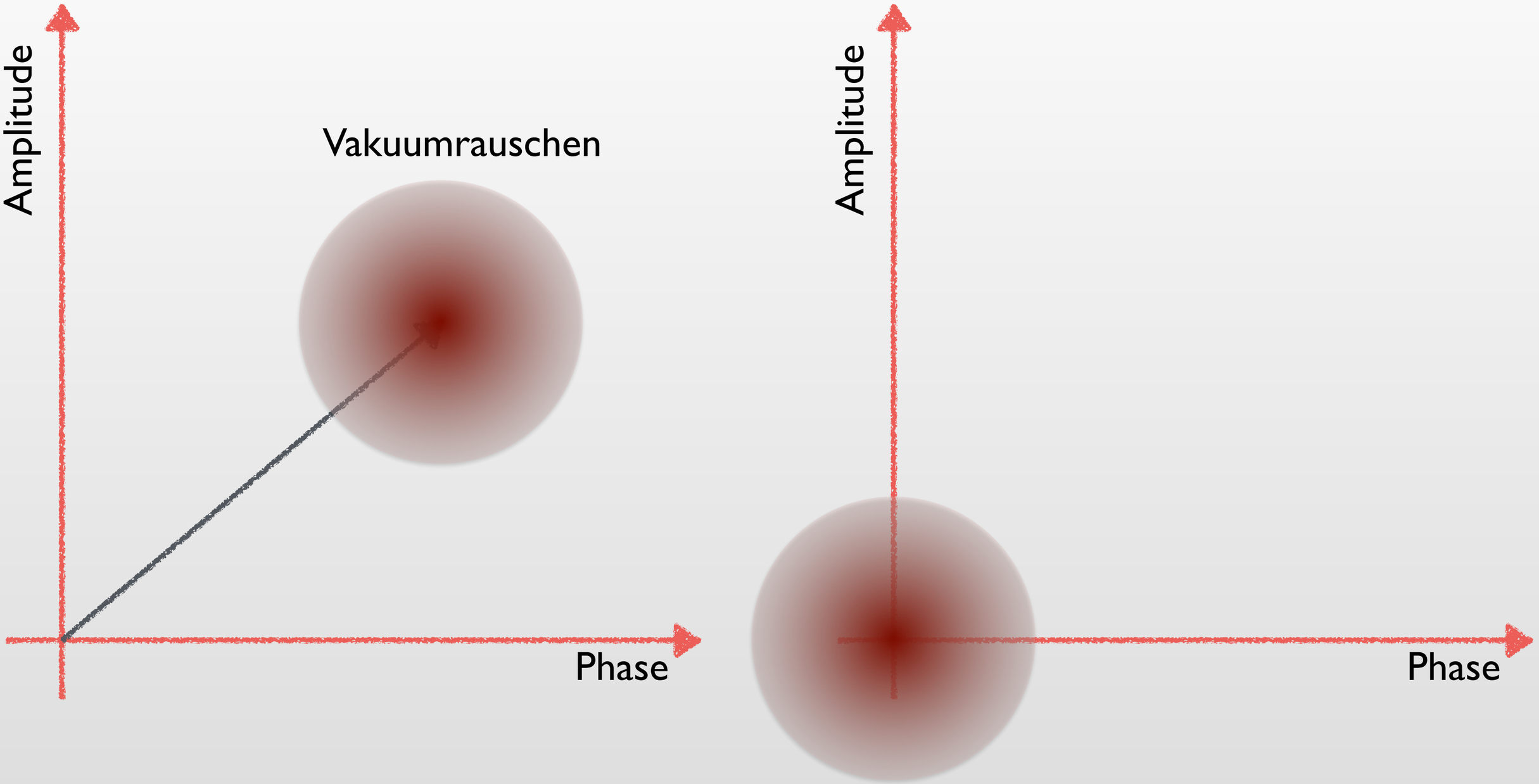
Lichtfeld

Licht quetschen



Lichtfeld

Licht quetschen



Lichtfeld

Vakuumzustand

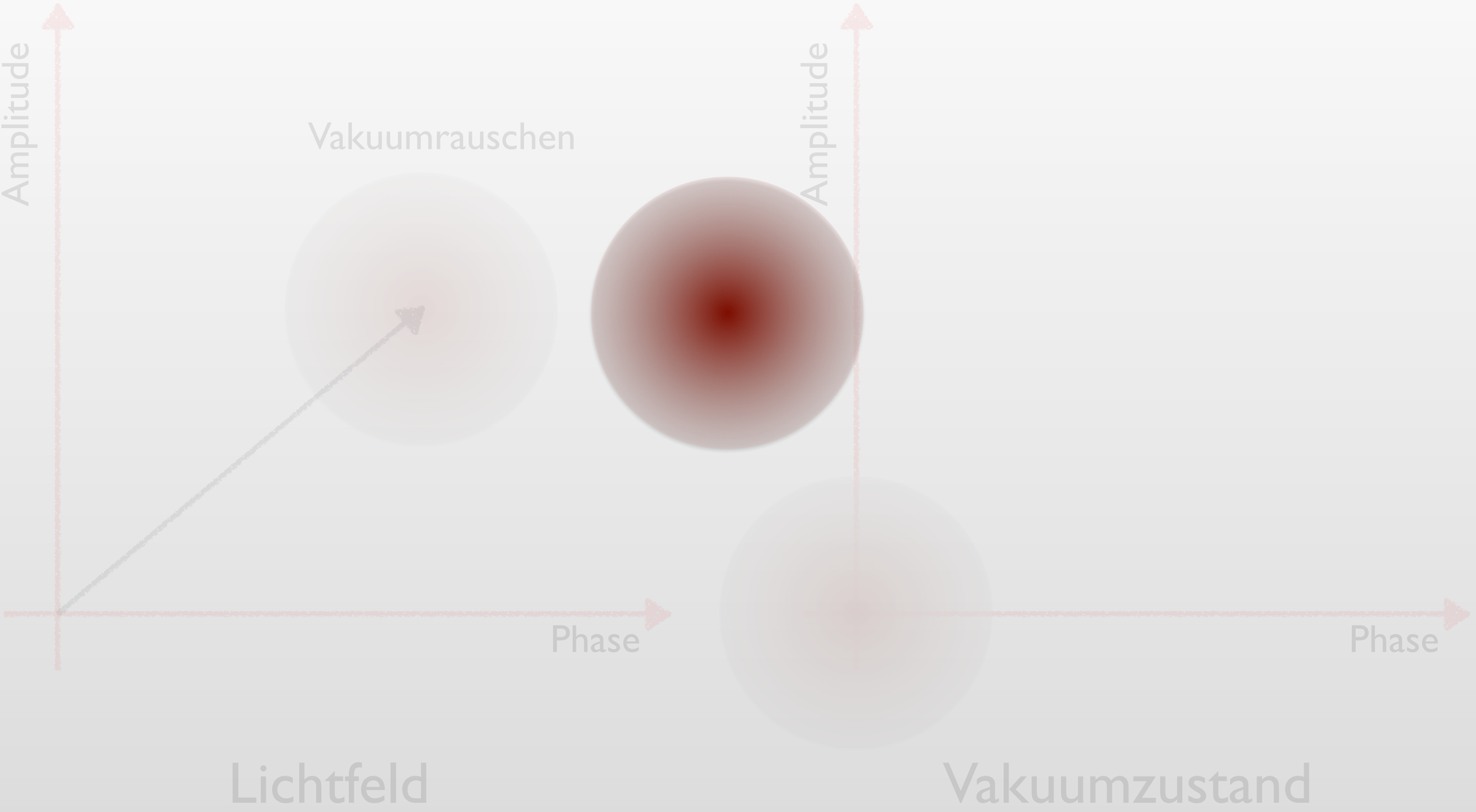
Licht quetschen

Lichtfeld

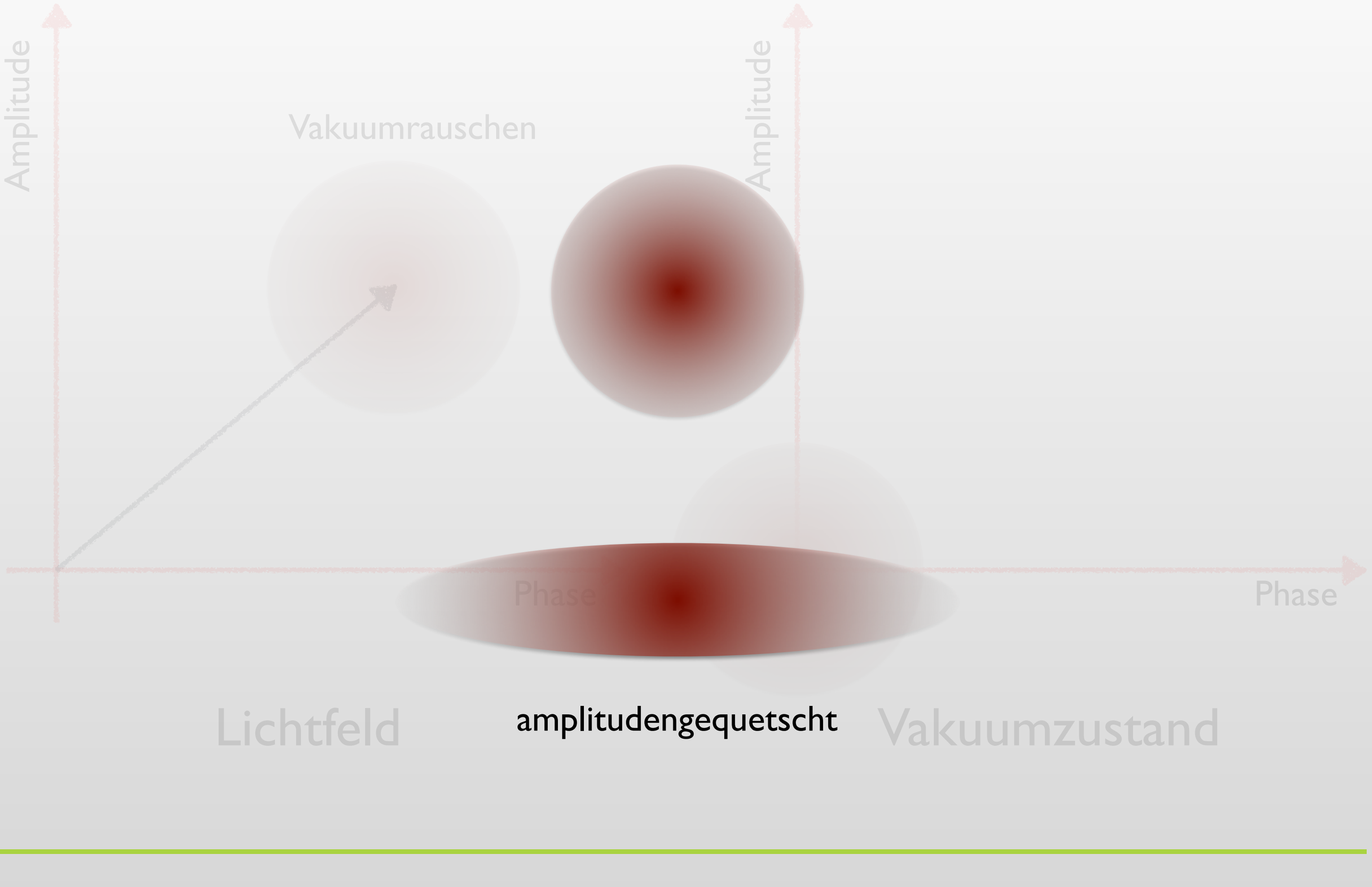
Vakuumrauschen

Vakuumzustand

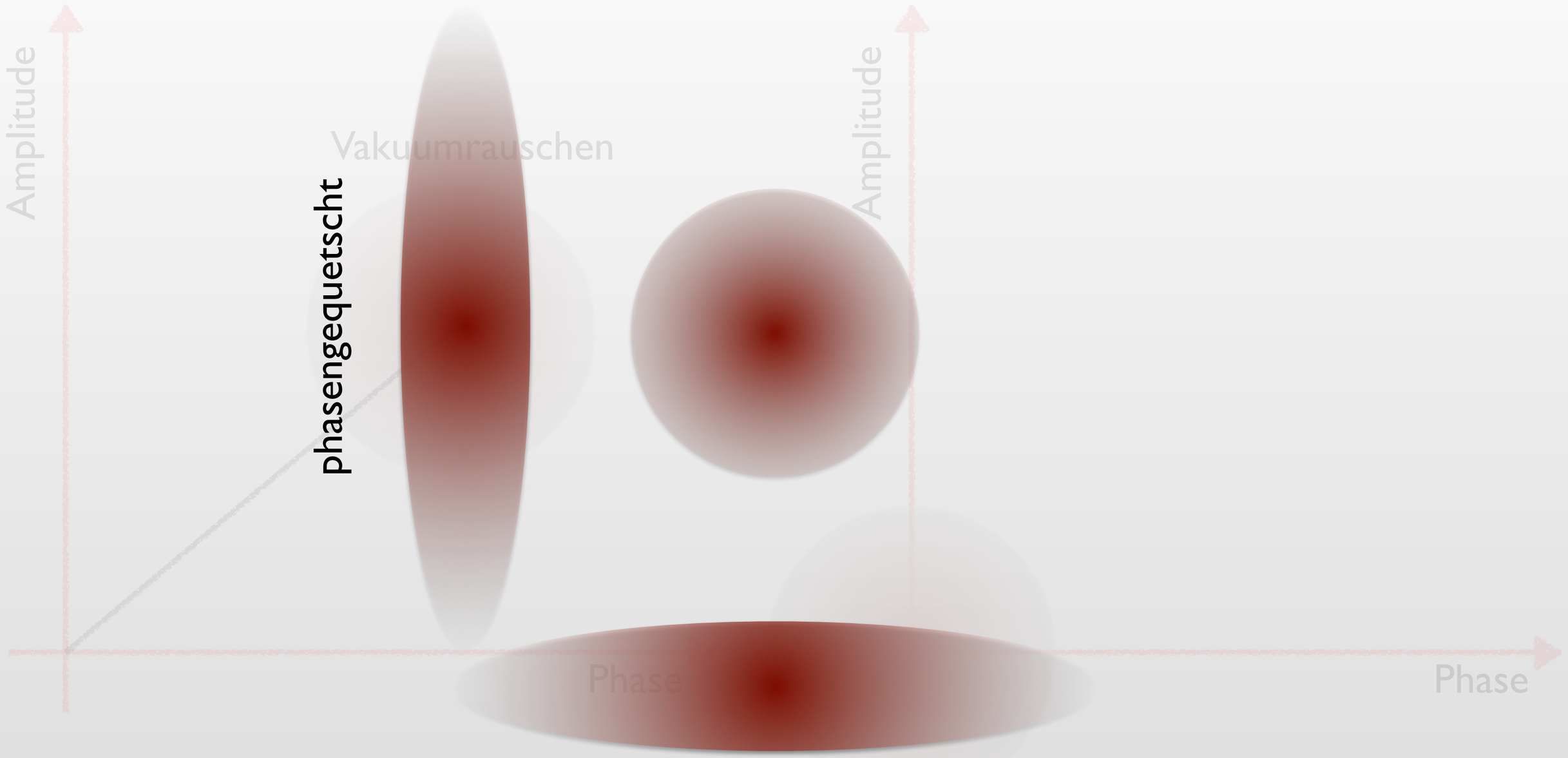
Licht quetschen



Licht quetschen



Licht quetschen



MAX-PLANCK-GESELLSCHAFT

Quetsch-Vakuum

Albert-Einstein-Institut
Hannover

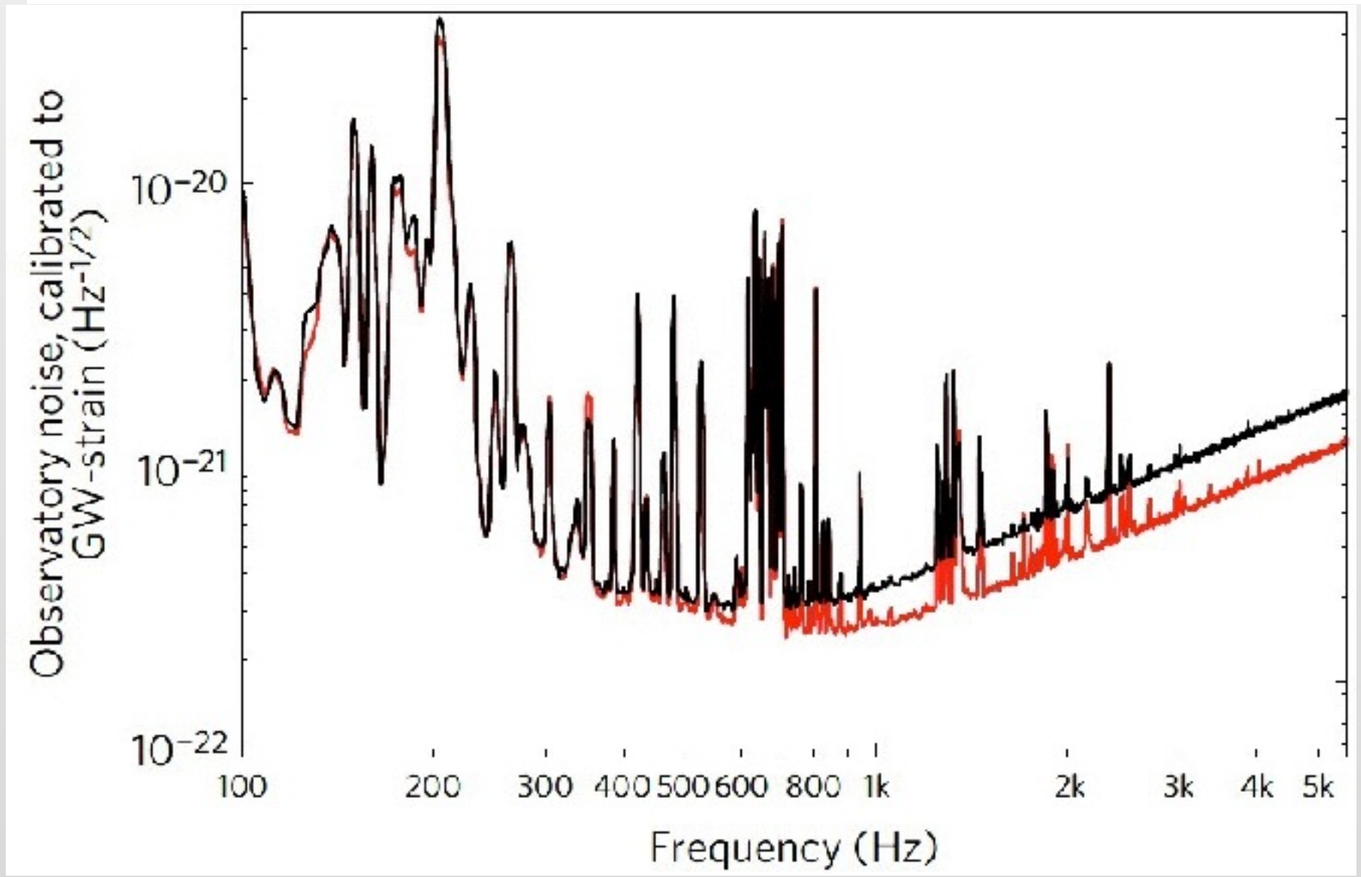
nature physics

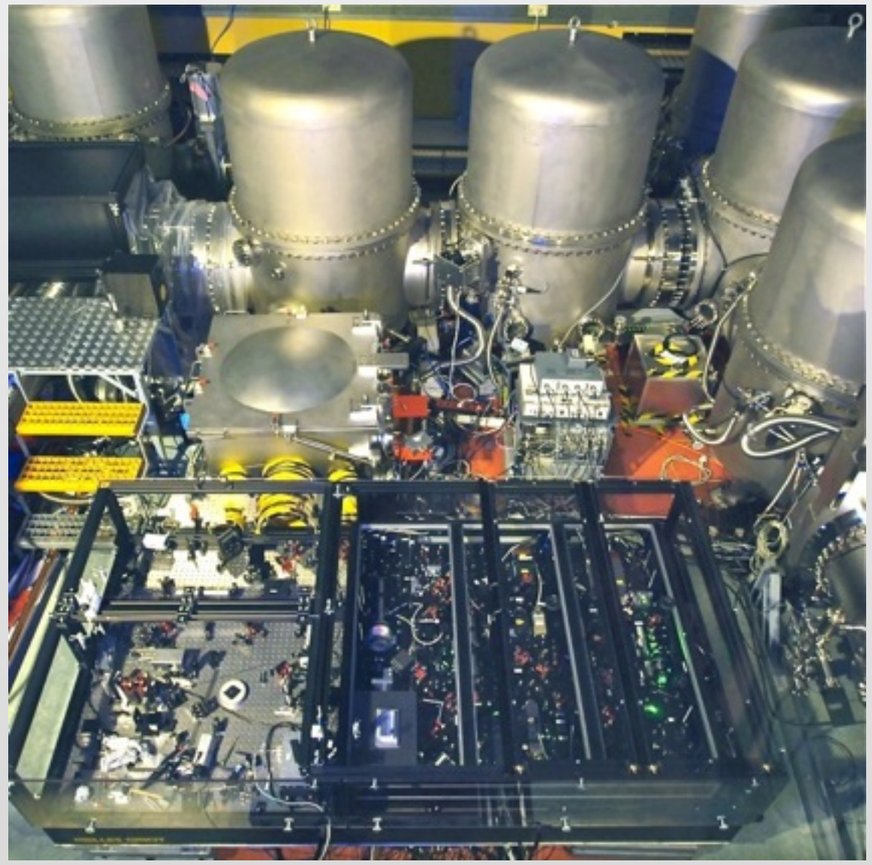
LETTERS

PUBLISHED ONLINE: 11 SEPTEMBER 2011 | DOI: 10.1038/NPHYS2083

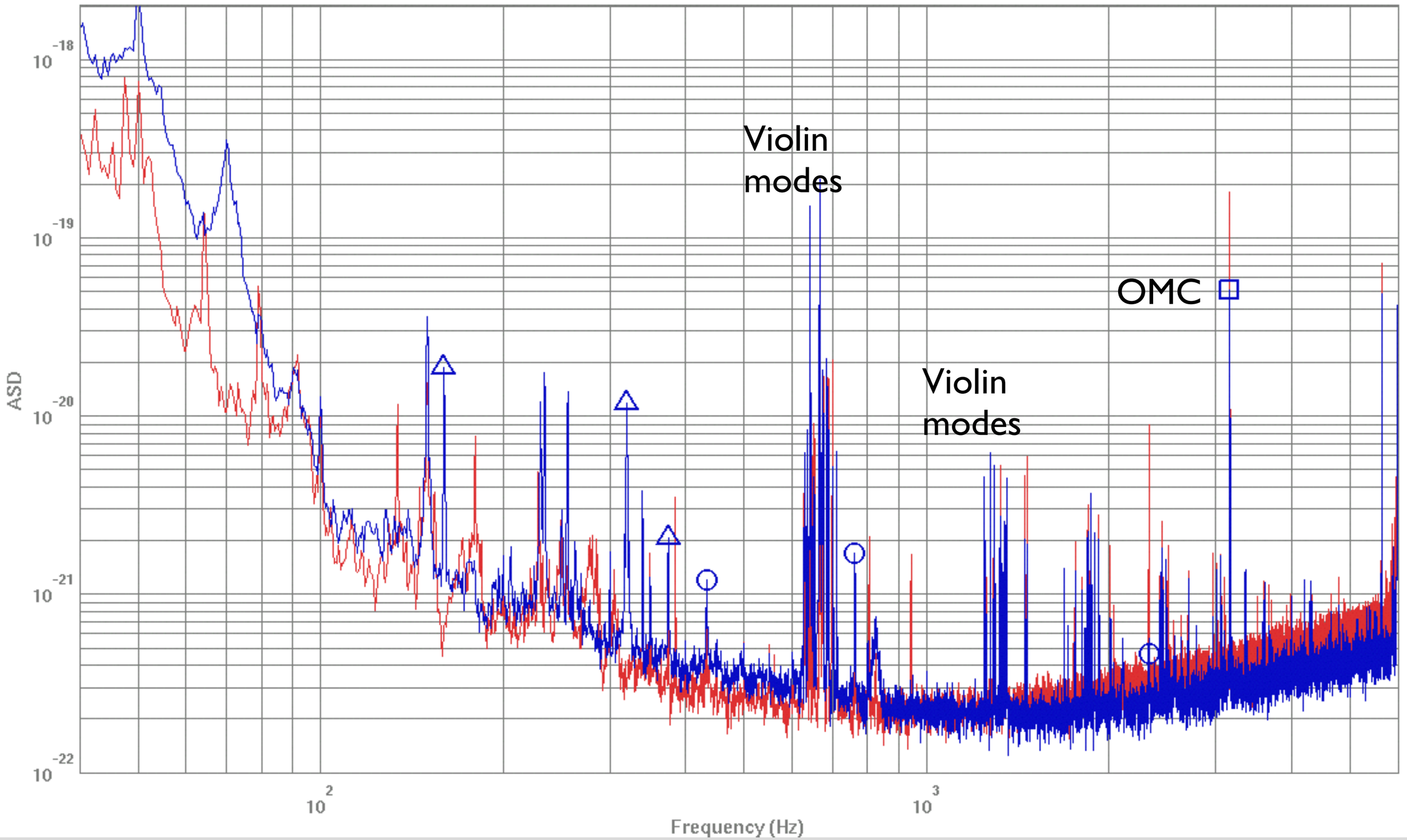
A gravitational wave observatory operating beyond the quantum shot-noise limit

The LIGO Scientific Collaboration †*





Ins All lauschen



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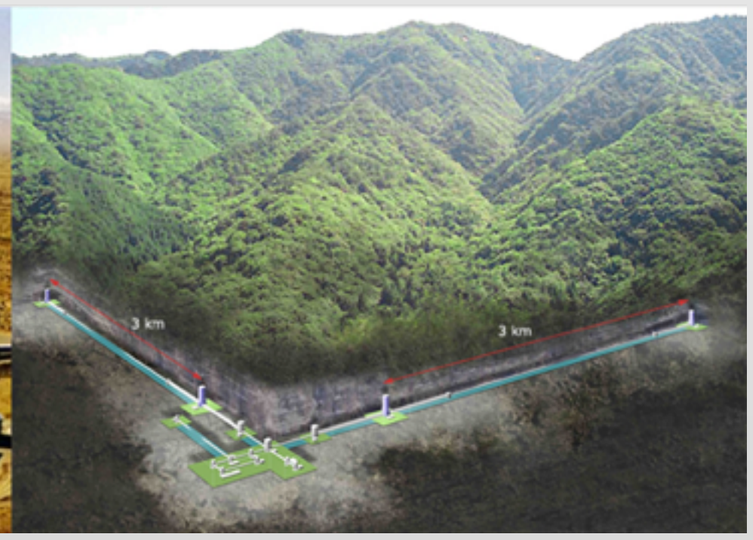
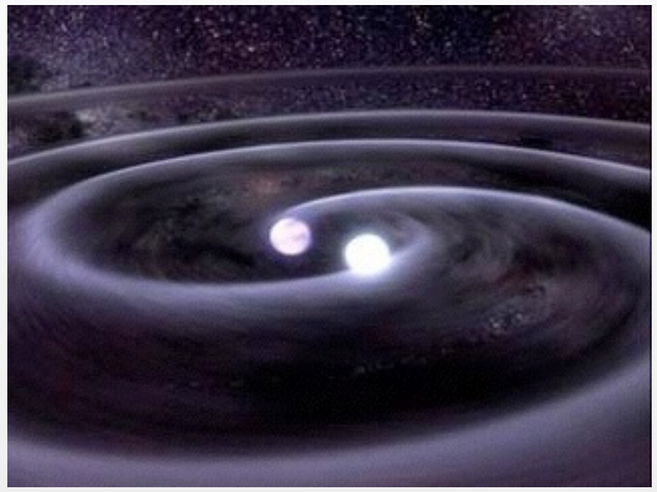
In der ganzen Welt

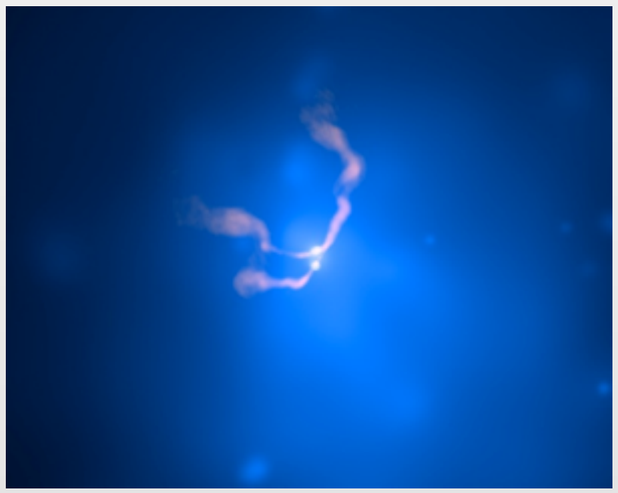
Albert-Einstein-Institut
Hannover

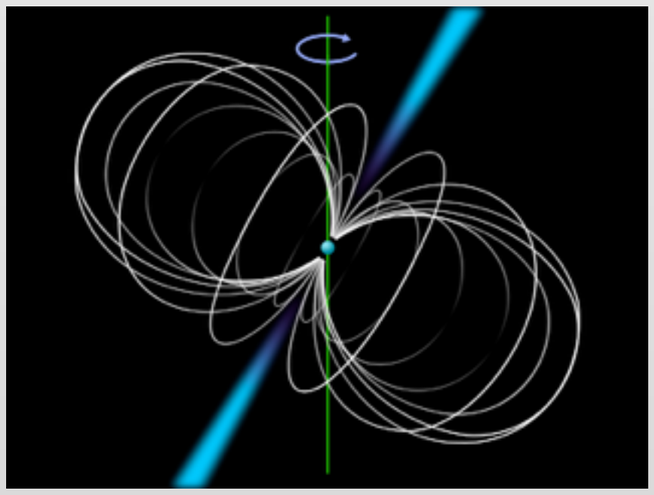


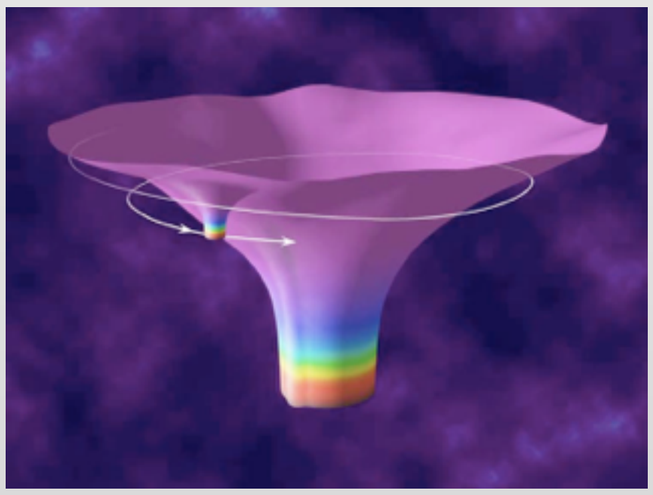
Was gibt's zu hören?

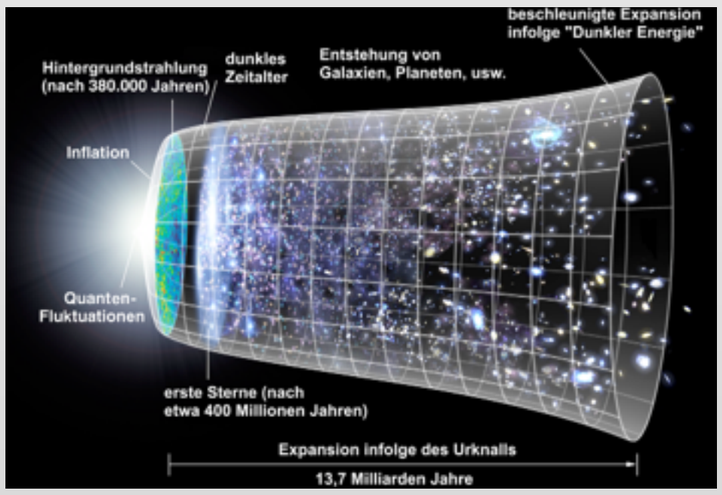
- Supernovae
- Schwarze Löcher
- Echo des Urknalls?
- Neutronensterne











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Neutronenstern

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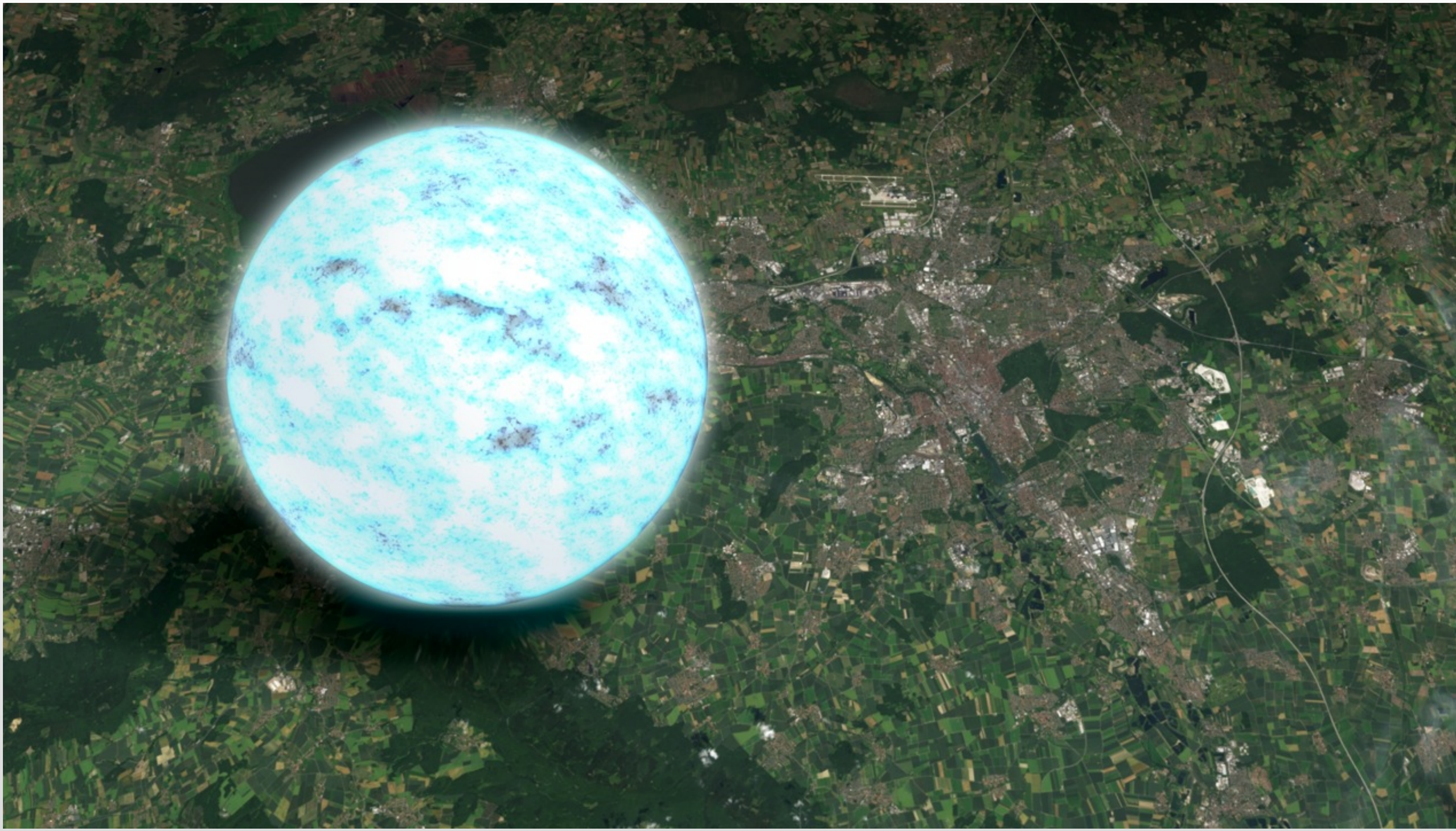
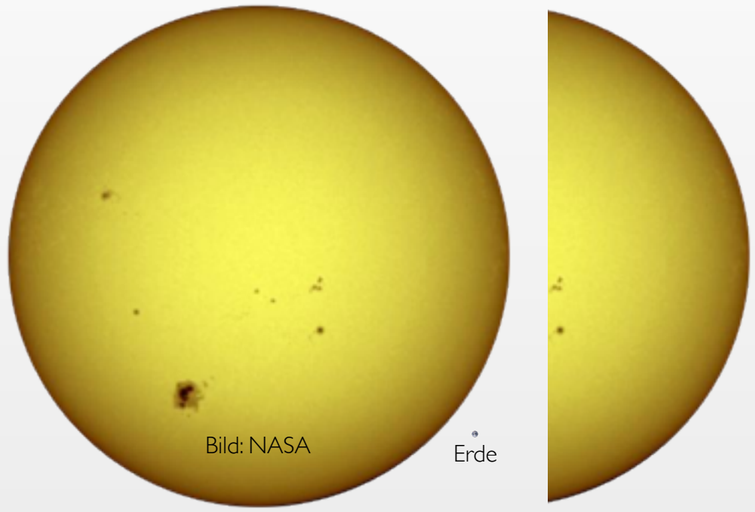
Hannover

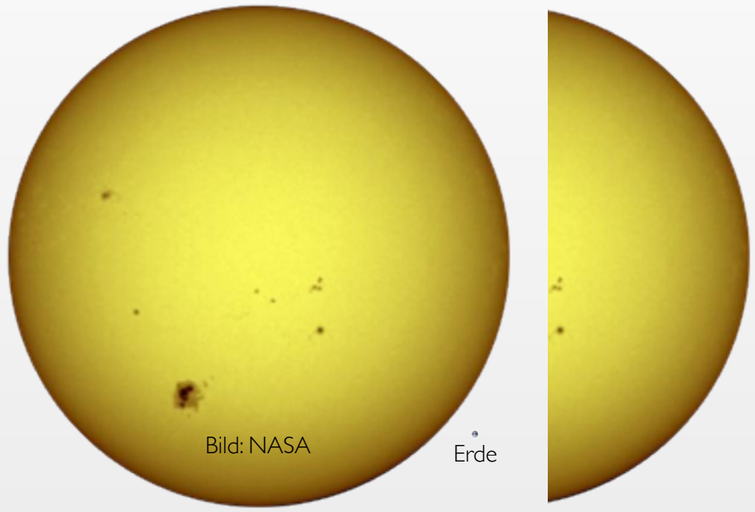


Masse und Dichte



rund 1,5-mal so schwer wie unsere Sonne

Masse und Dichte



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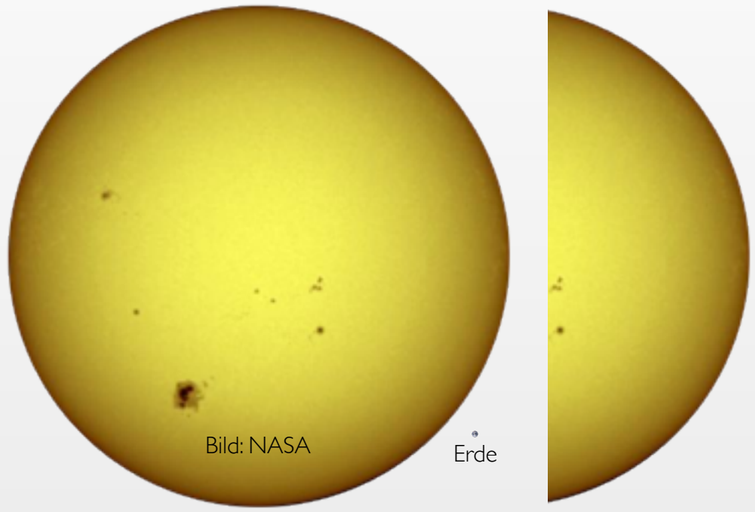
~500000-mal so schwer wie die Erde

Masse und Dichte



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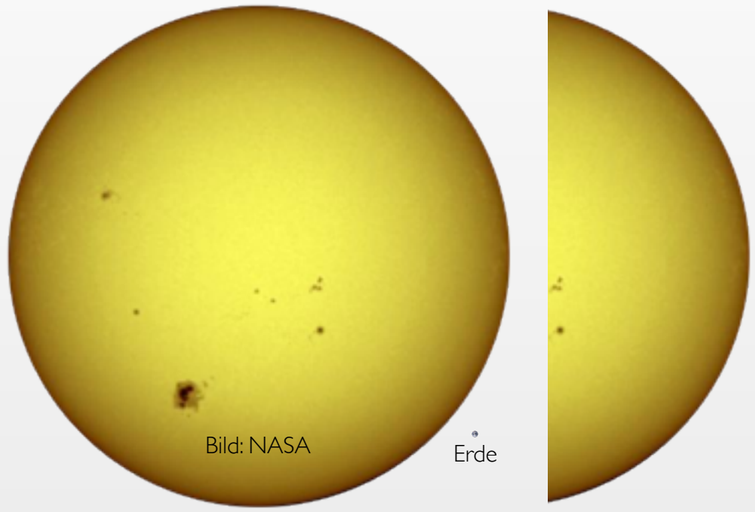

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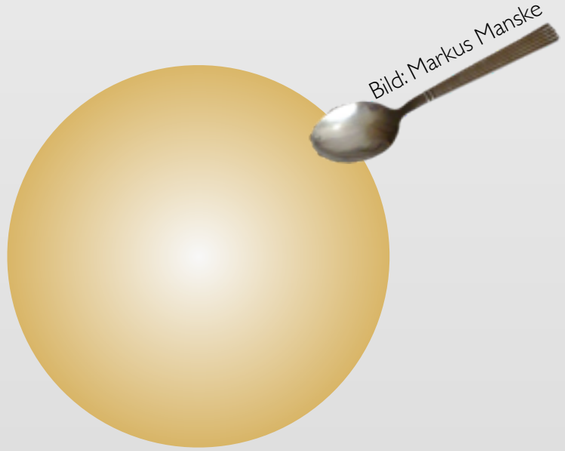
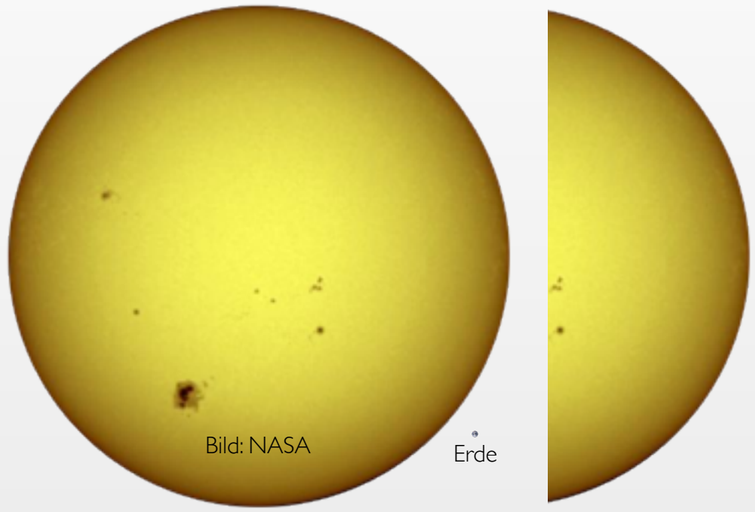


Masse und Dichte



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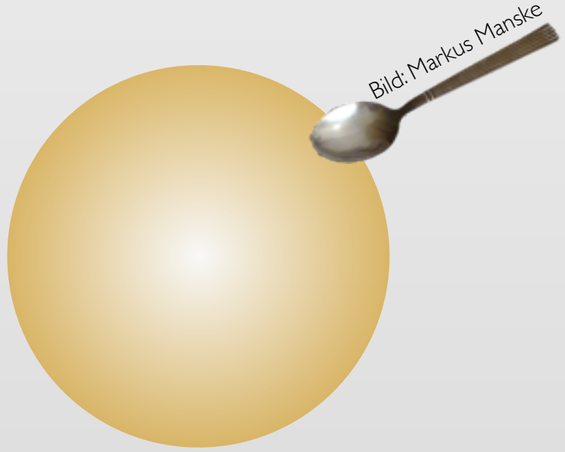
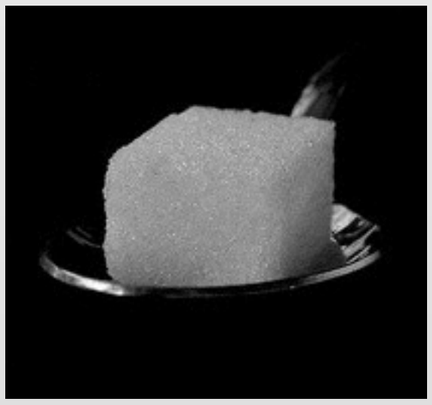
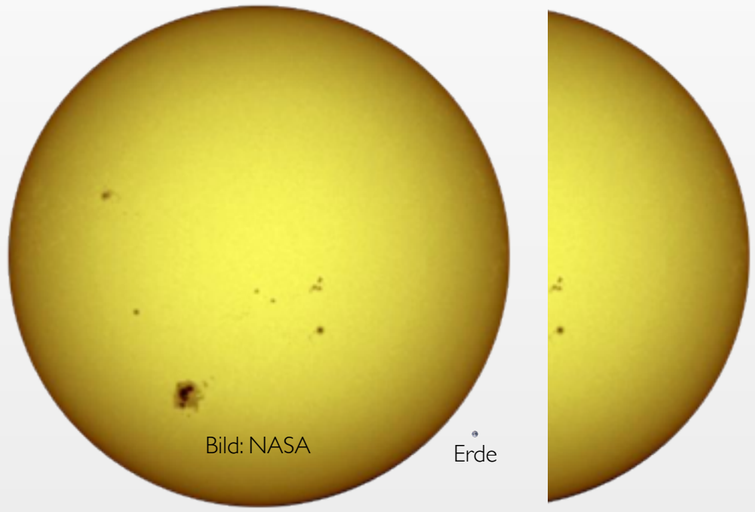




Masse und Dichte



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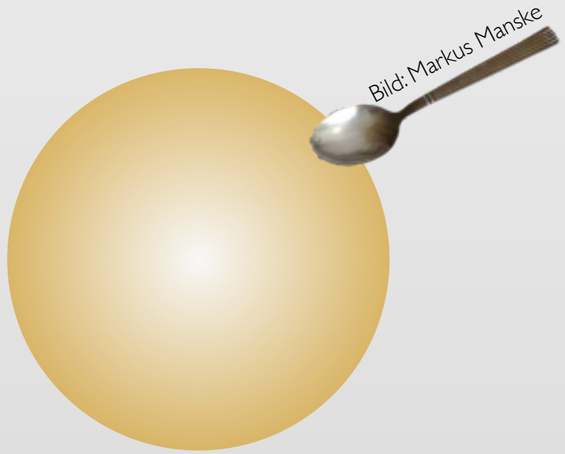
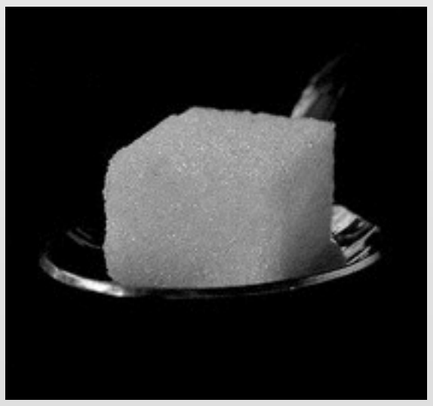




Rotation / Magnetfeld

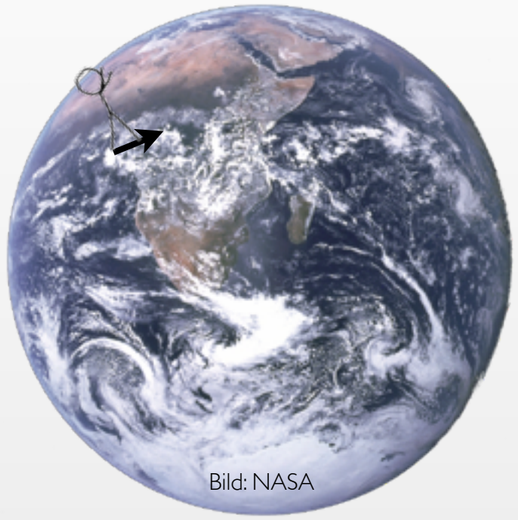
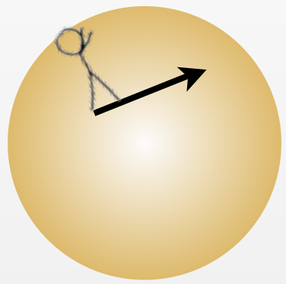


Bild: NASA



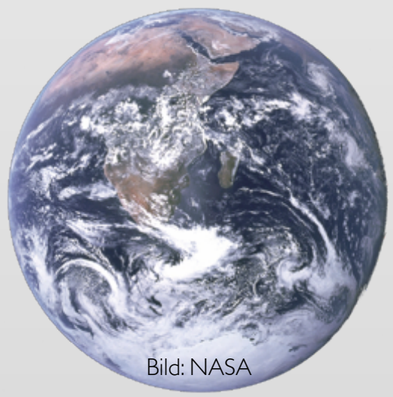
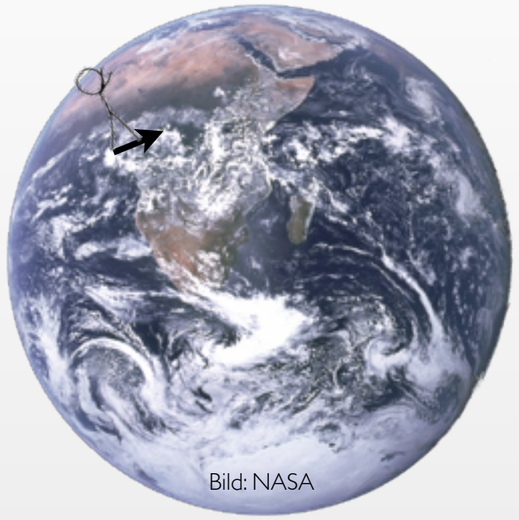


Bild: NASA

Rotation / Magnetfeld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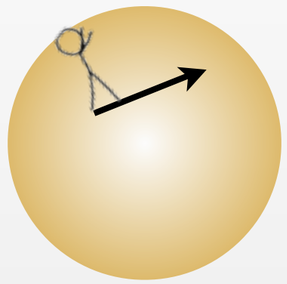


- langsame Rotation: 1x in 24 h = 11.6×10^{-6} Hz

  » 1700 km/h = 0,46 km/s am Äquator

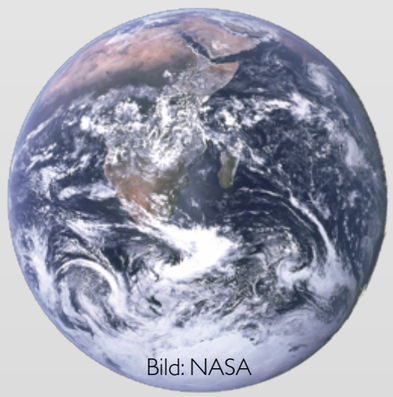
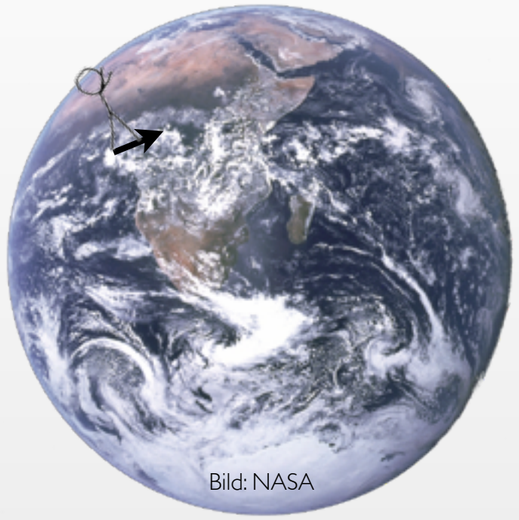


Bild: NASA

Rotation / Magnetfeld



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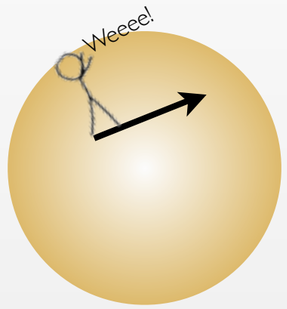
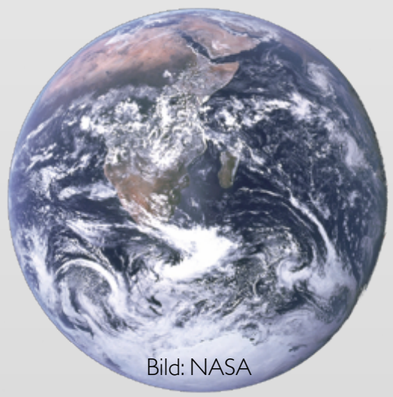
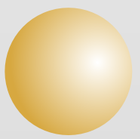


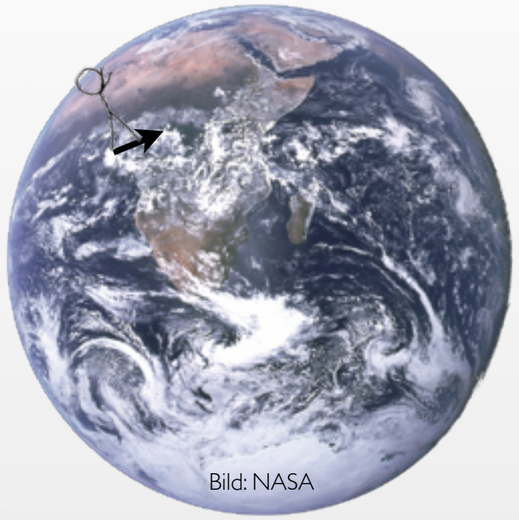
- **schnelle Rotation:** bis zu 716 Hz

  » 45,000 km/s am Äquator





Rotation / Magnetfeld



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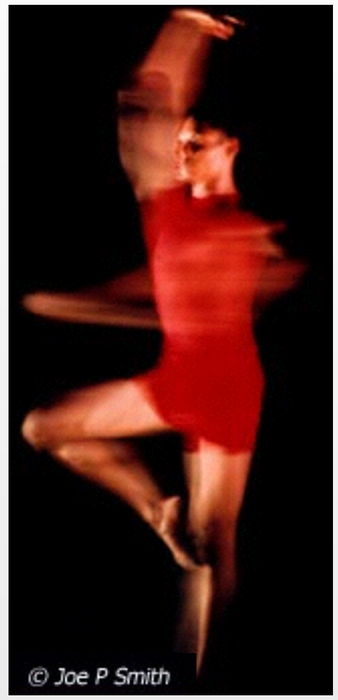

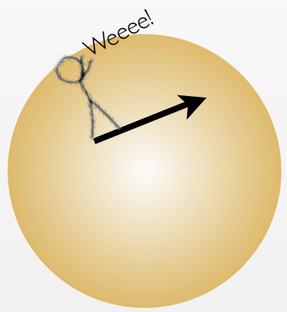

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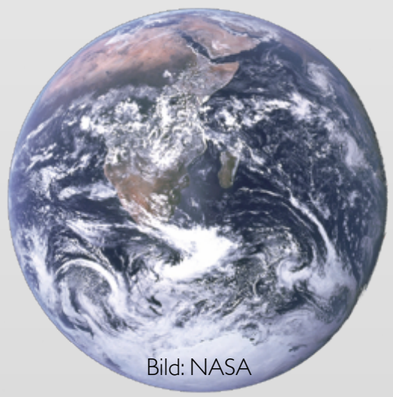

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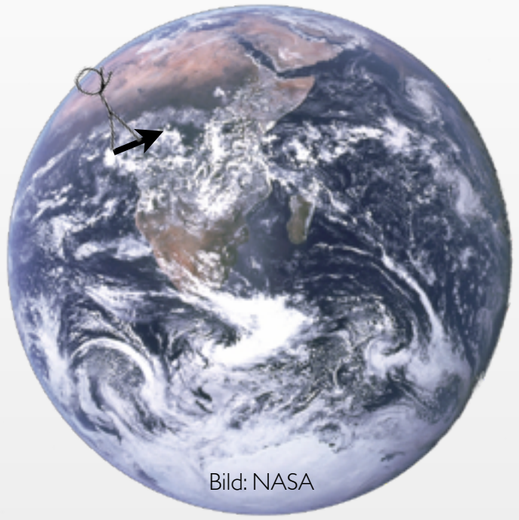
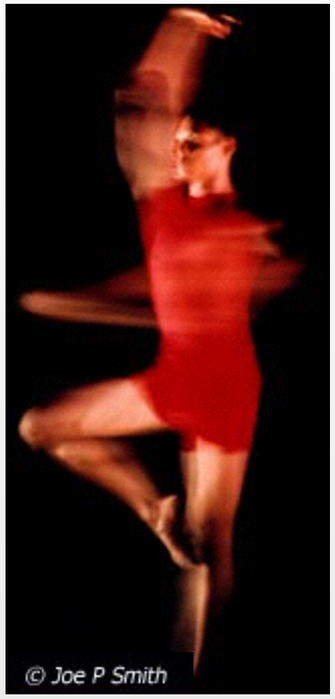
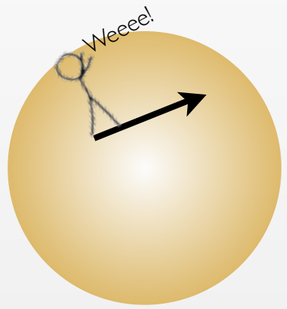


- **langsame Rotation:** 1x in 24 h = 11.6×10^{-6} Hz

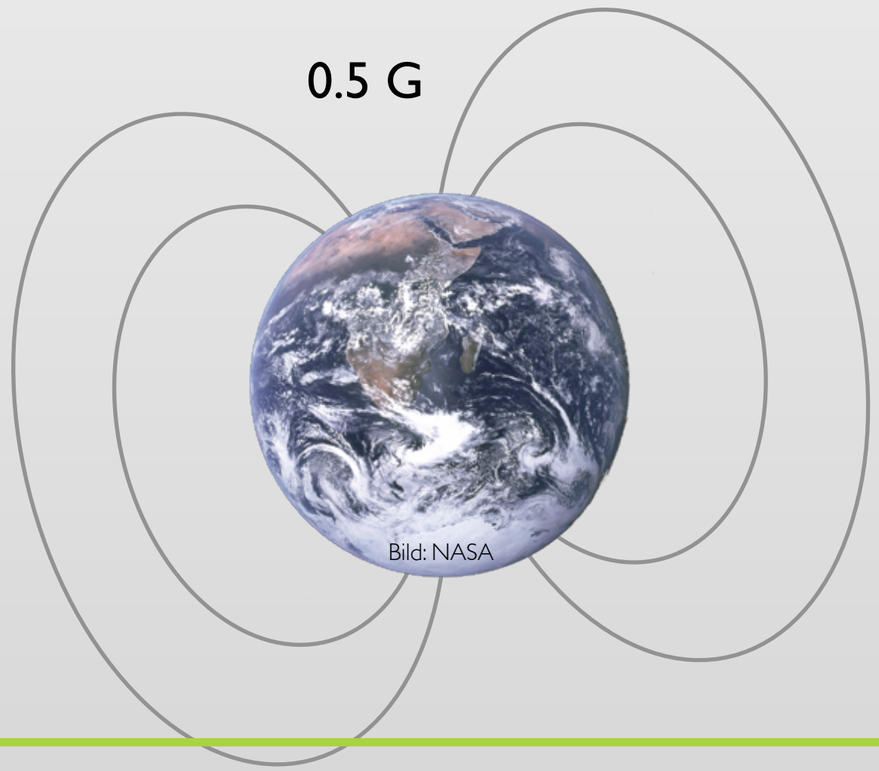
» 1700 km/h = 0,46 km/s am Äquator



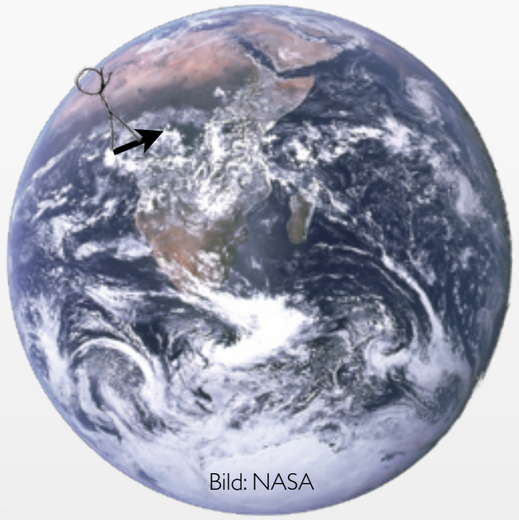


- **schnelle Rotation:** bis zu 716 Hz

» 45,000 km/s am Äquator

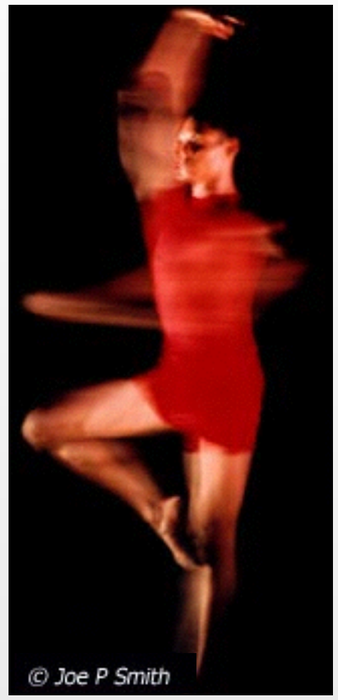


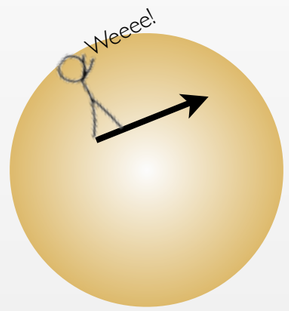
Rotation / Magnetfeld



- **langsame Rotation:** 1x in 24 h = 11.6×10^{-6} Hz

» 1700 km/h = 0,46 km/s am Äquator

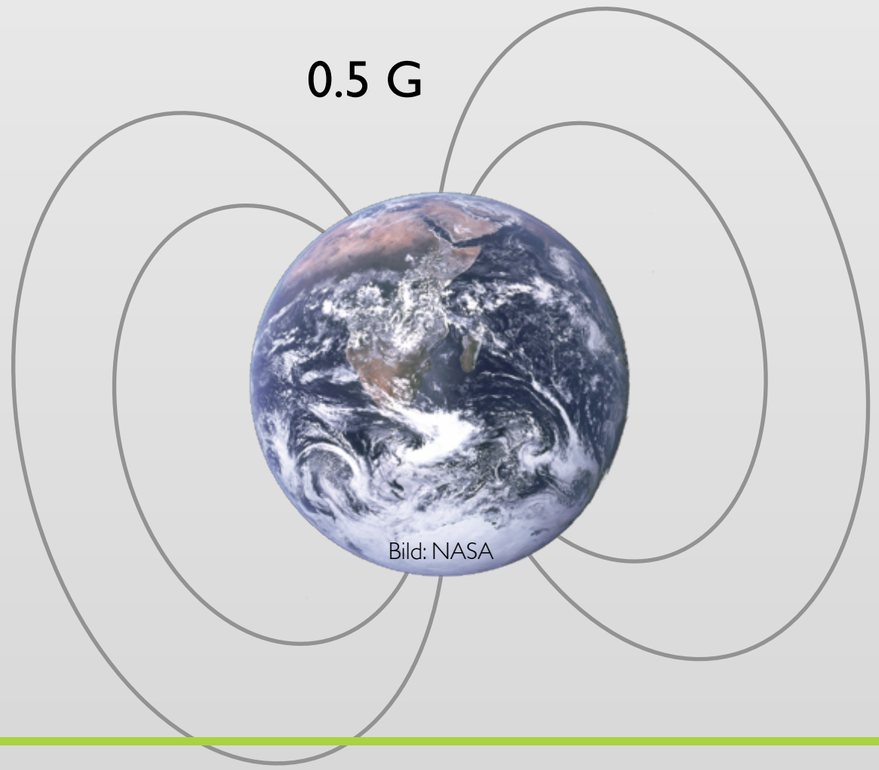




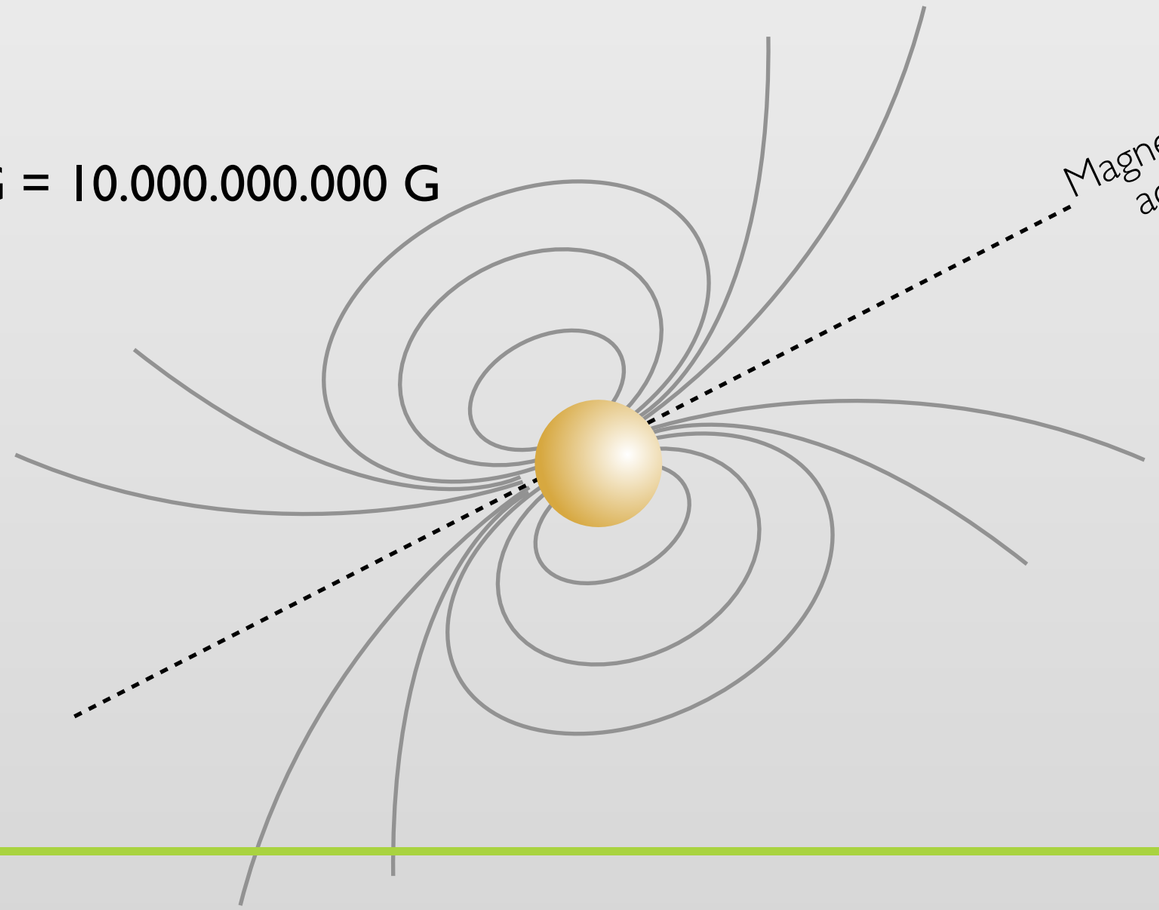
- **schnelle Rotation:** bis zu 716 Hz

» 45,000 km/s am Äquator

0.5 G



10^{10} G = 10.000.000.000 G



MAX-PLANCK-GESELLSCHAFT

Pulsare

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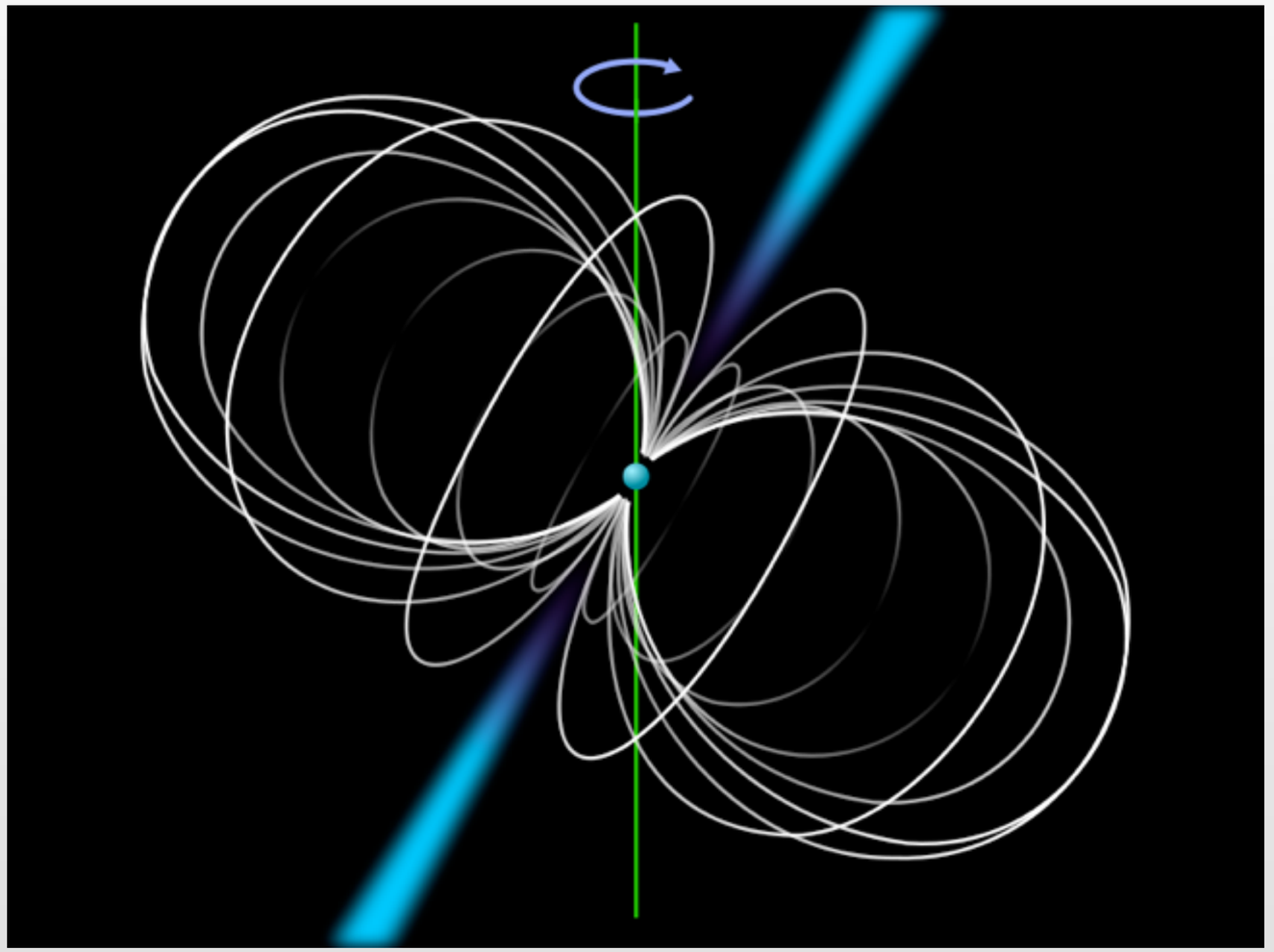
Hannover

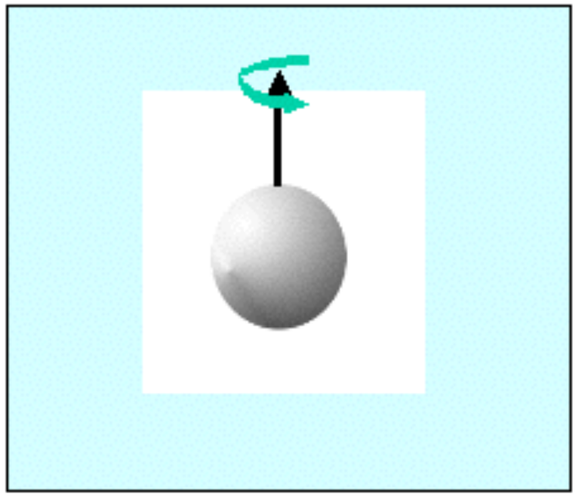


Pulsare

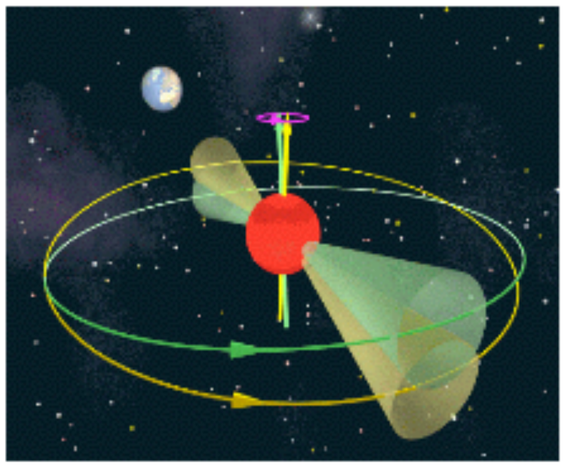
Von den rund 200 Millionen erwarteten Neutronensternen in unserer Galaxie kennen wir nur rund 2300.

Mit Gravitationswellen können wir vielleicht weitere aufspüren.

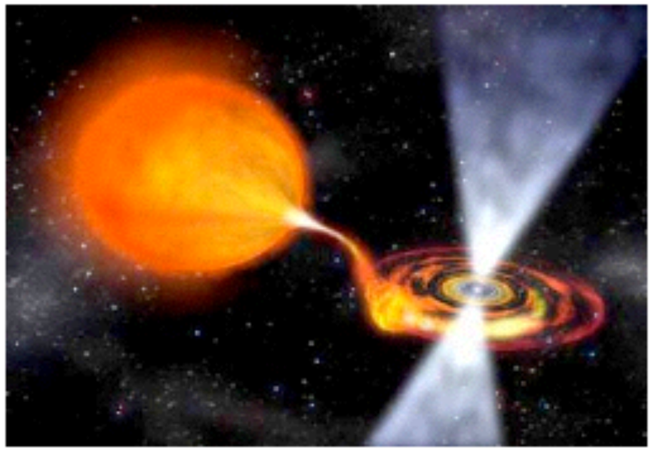
Gravitationswellen



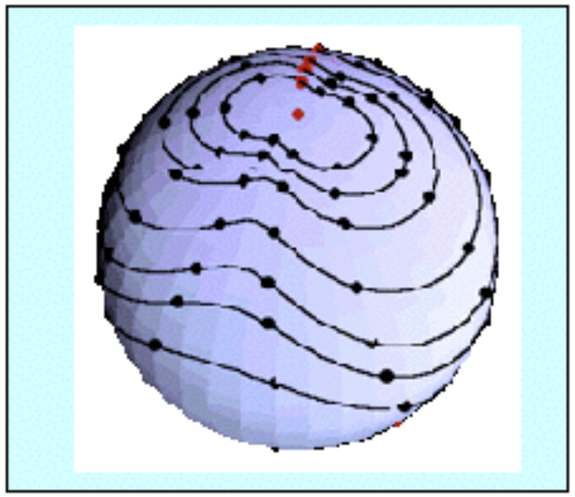
Mountain on a star



Wobbling star

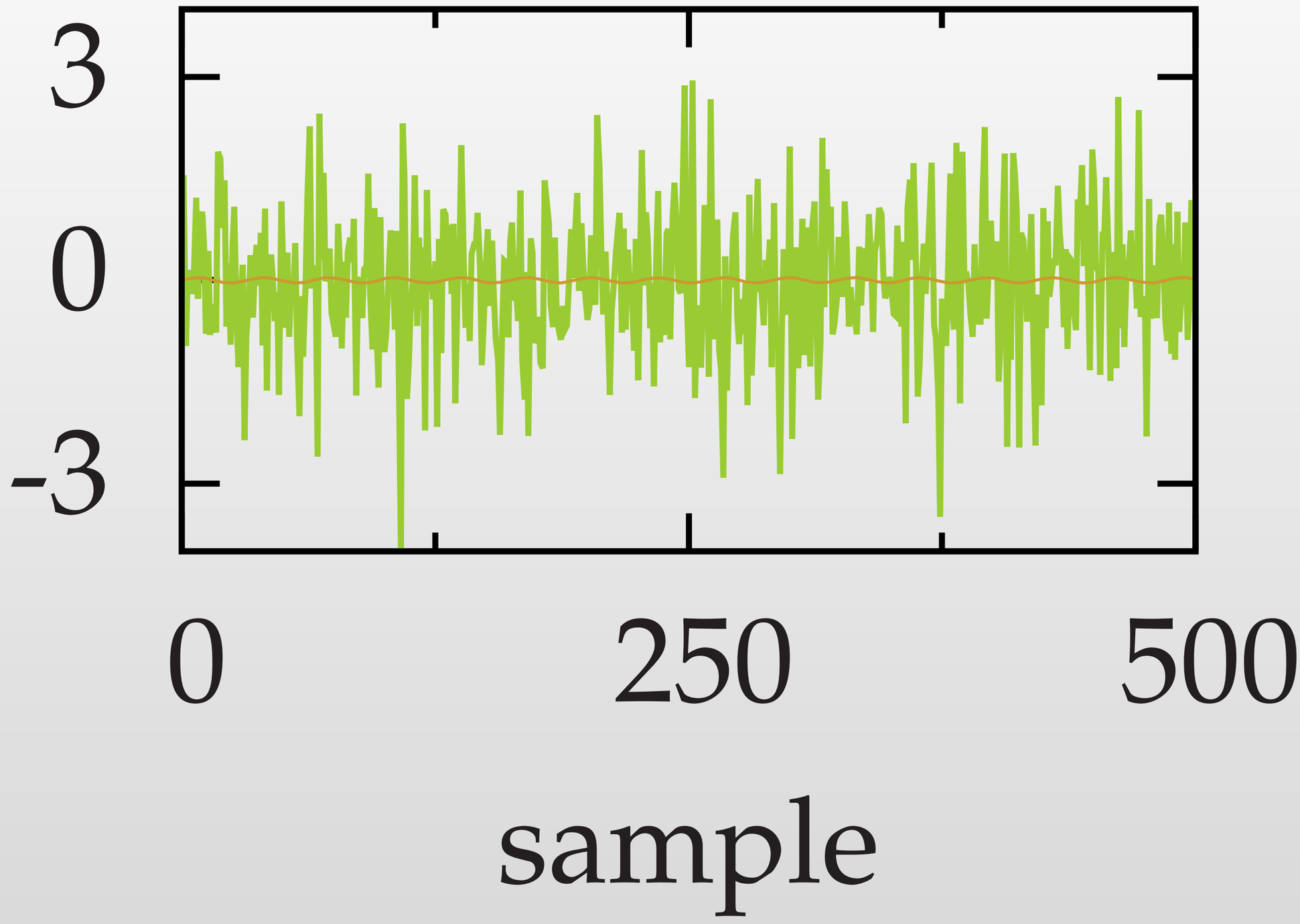


Accreting star

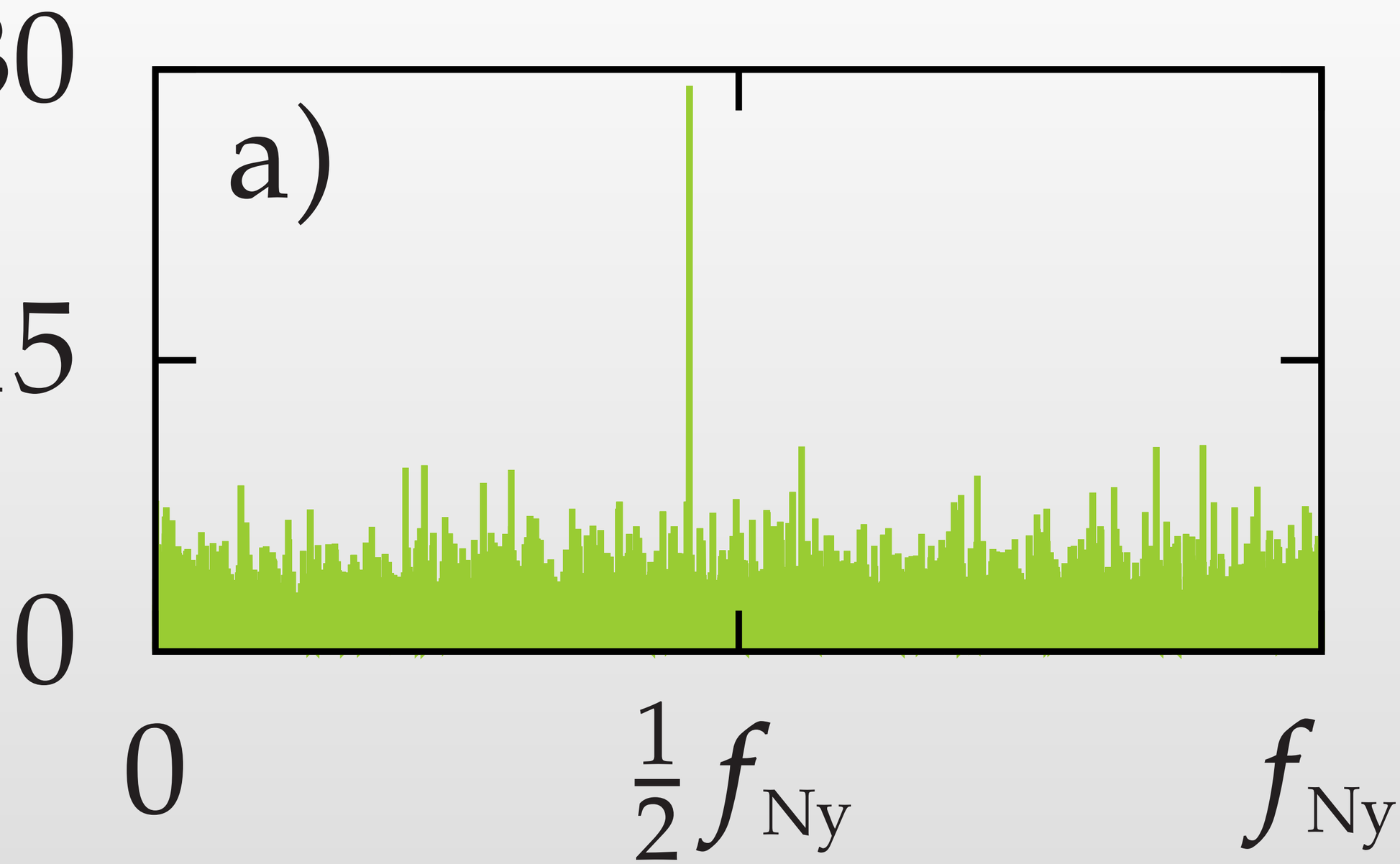


Oscillating star

Fourier-Methoden



Fourier-Methoden



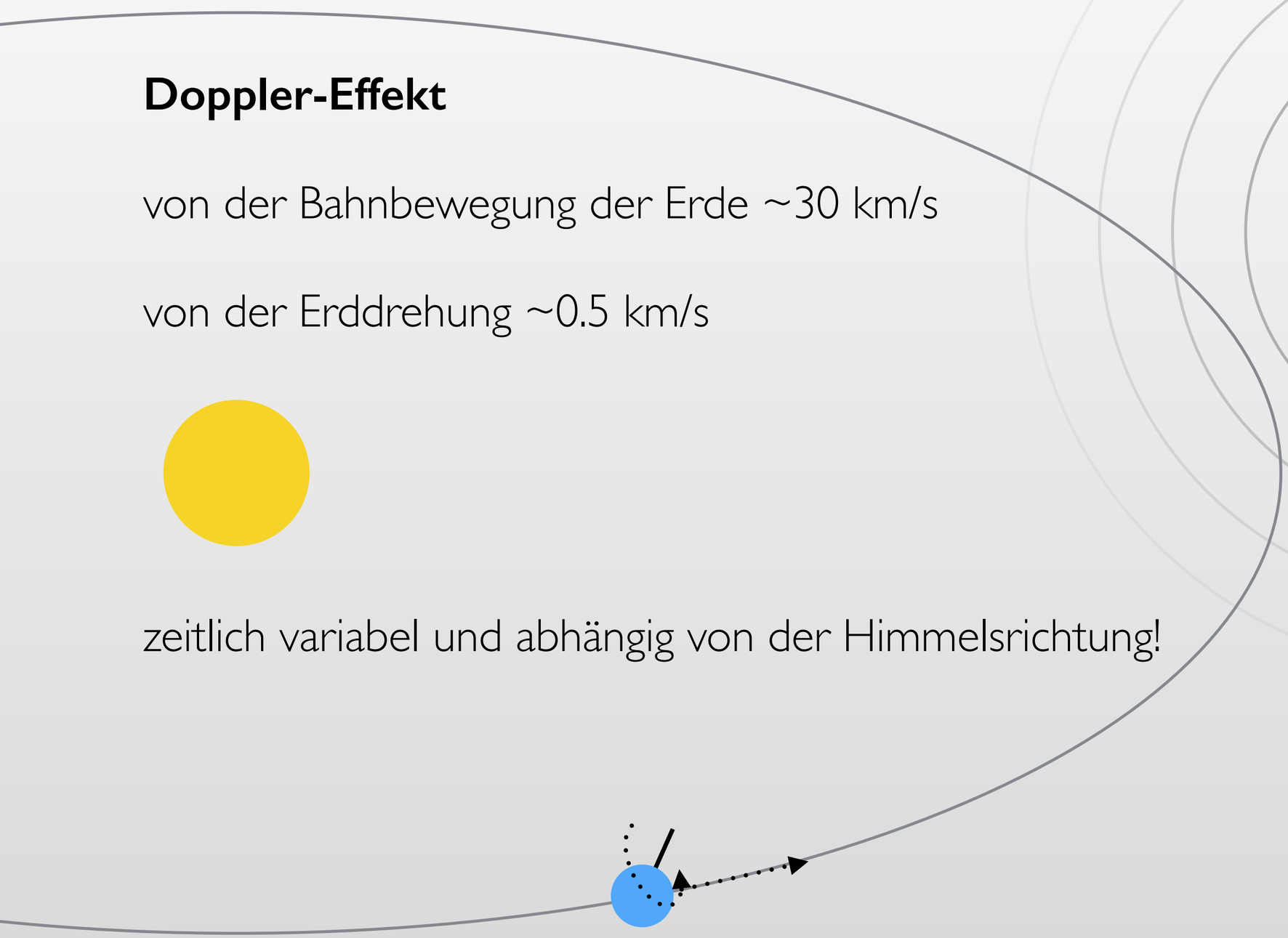
Doppelt schwierig

Doppler-Effekt

von der Bahnbewegung der Erde ~30 km/s

von der Erddrehung ~0.5 km/s

zeitlich variabel und abhängig von der Himmelsrichtung!



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Atlas am AEI Hannover

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Rechenkraft

Albert-Einstein-Institut
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Einstein@Home

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BOINC Server

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Daten

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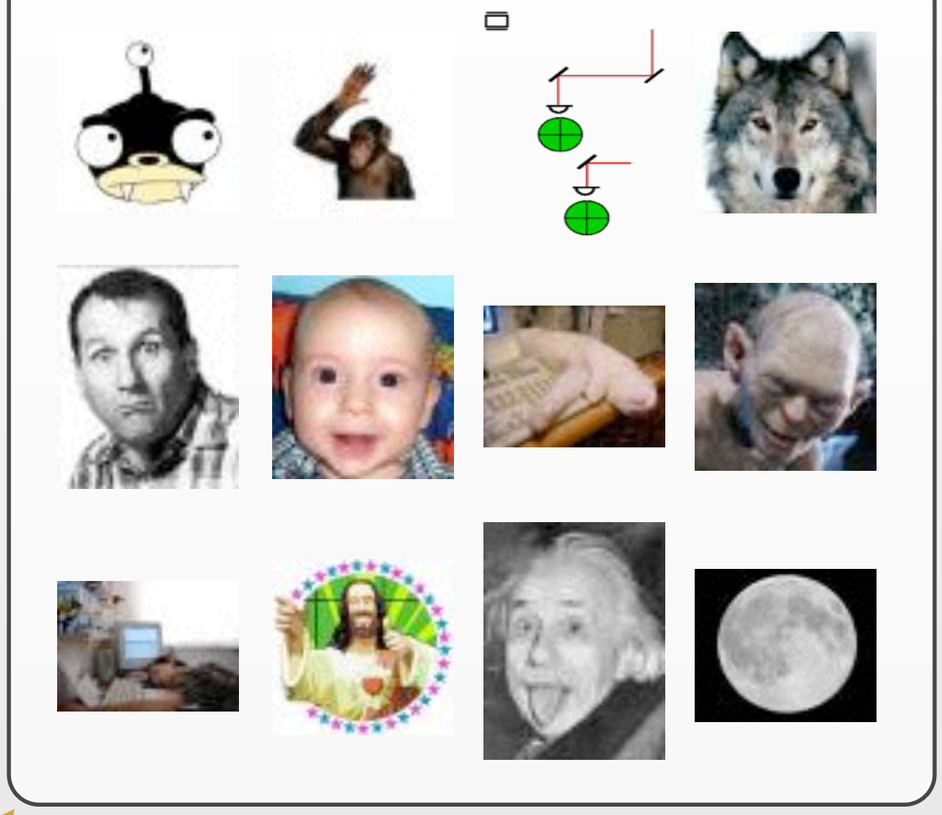

Daten

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Aufgaben

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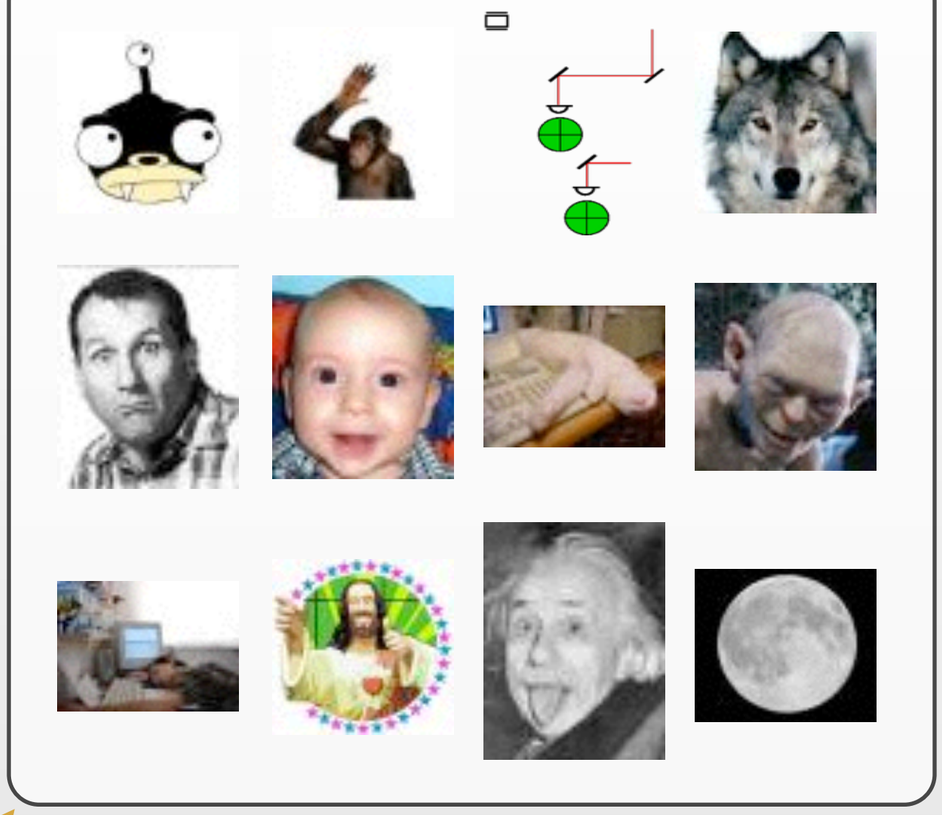
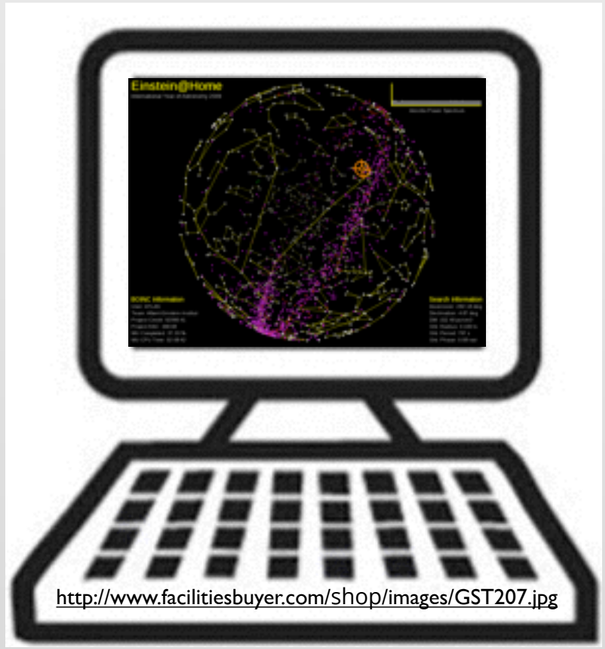


Daten

BOINC Server

Aufgaben



http://www.facilitiesbuyer.com/shop/images/GST207.jpg

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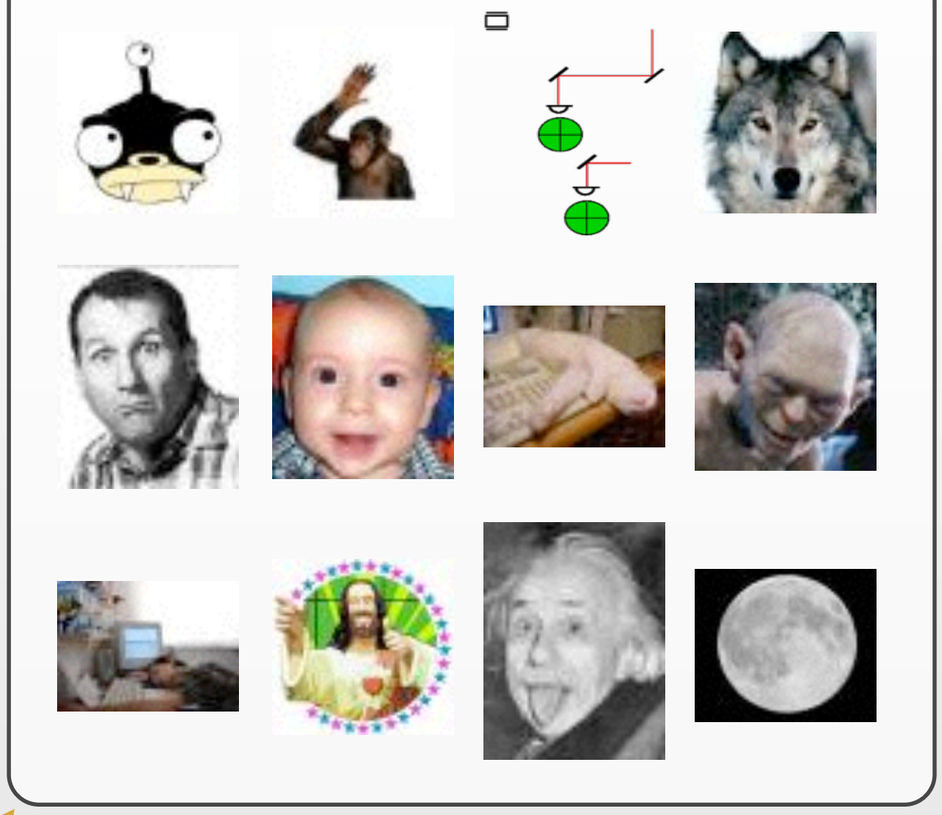
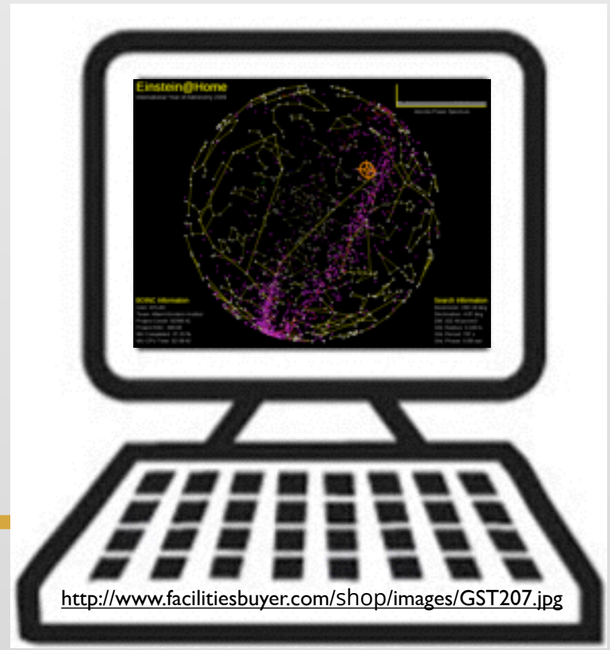


Daten

BOINC Server

Aufgaben

Ergebnisse



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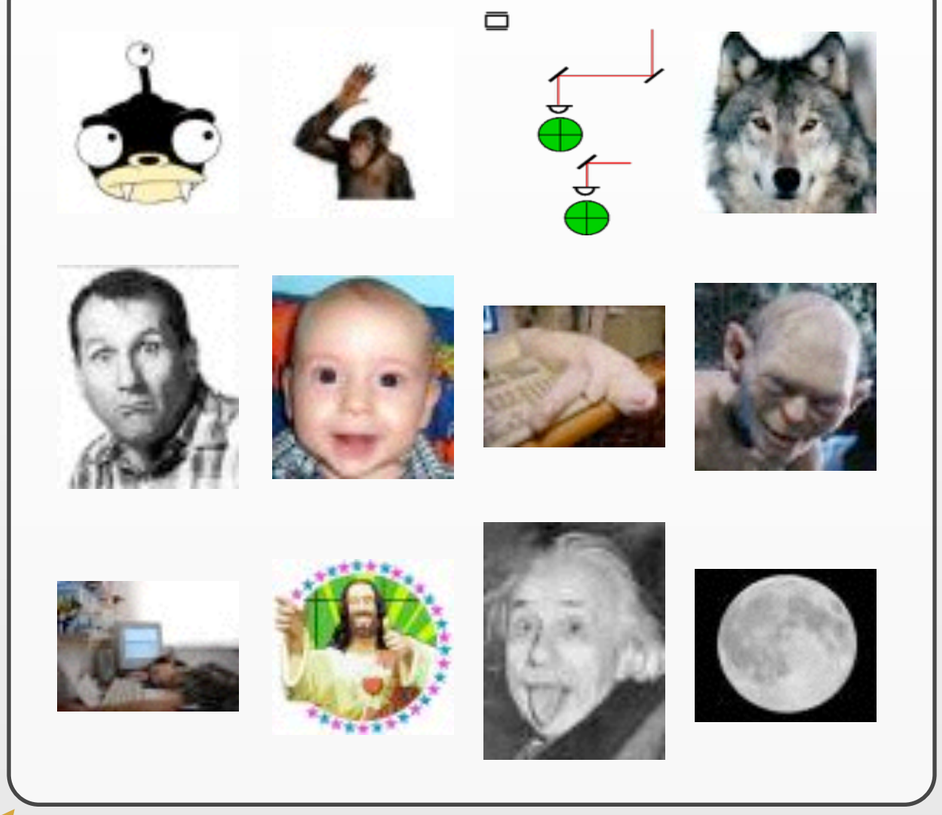
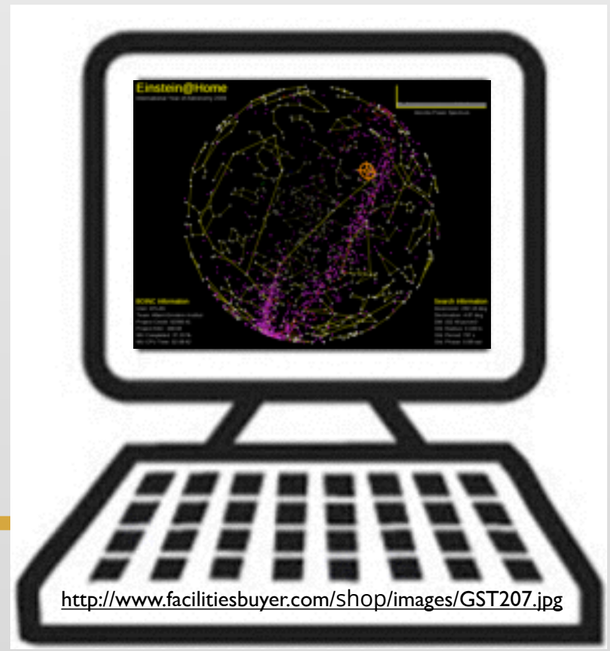


Daten

BOINC Server

Aufgaben

Ergebnisse



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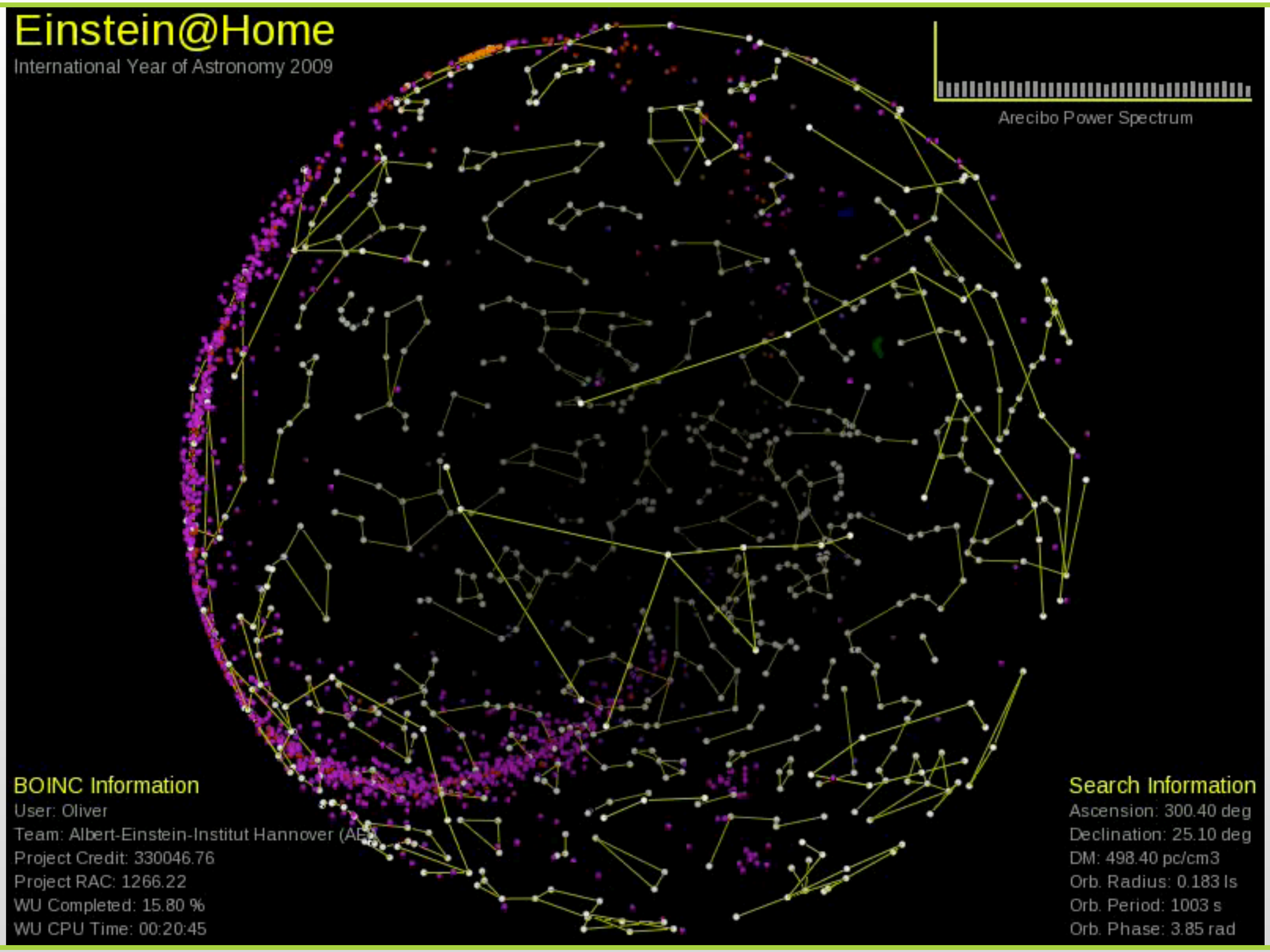

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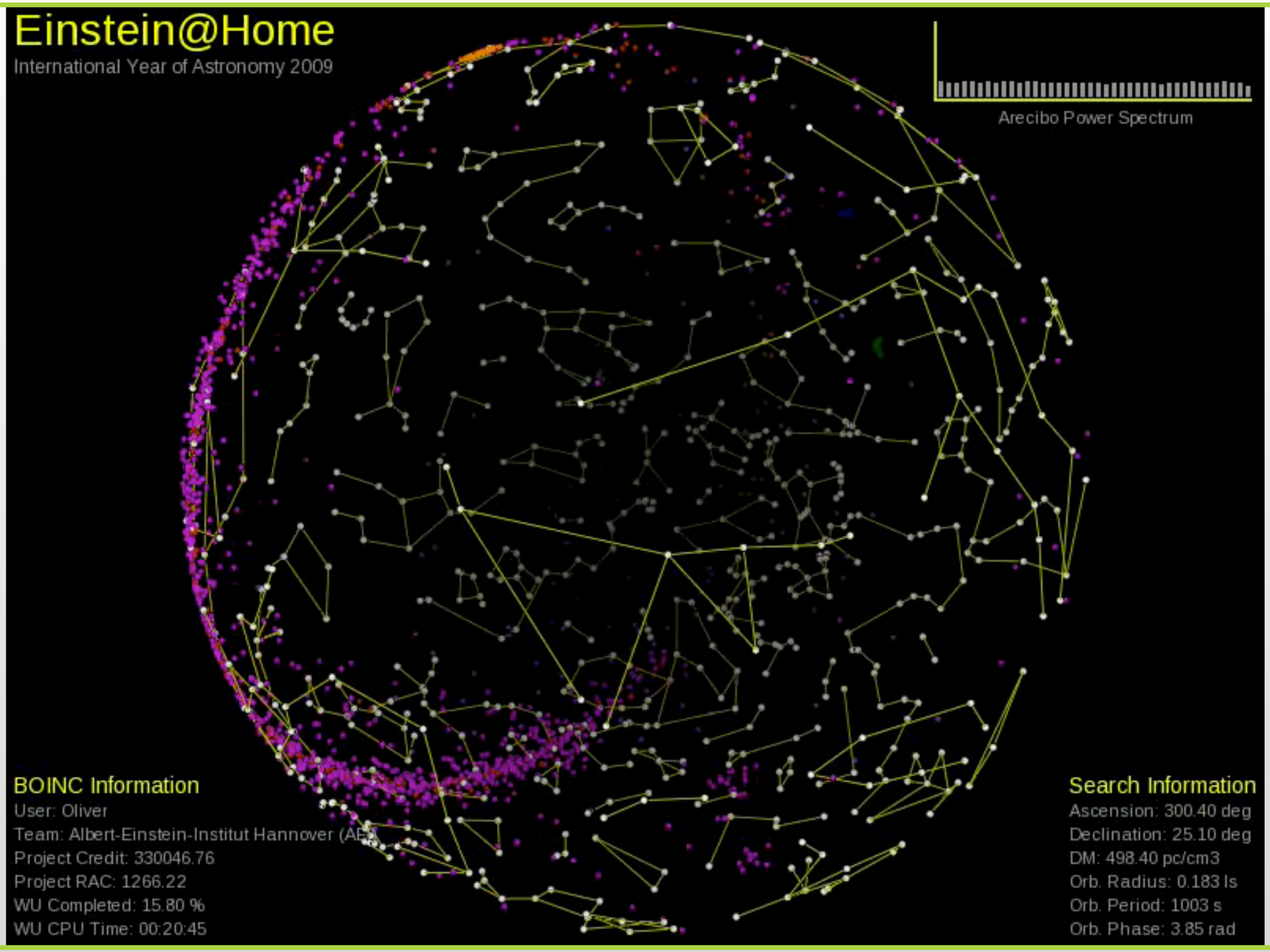
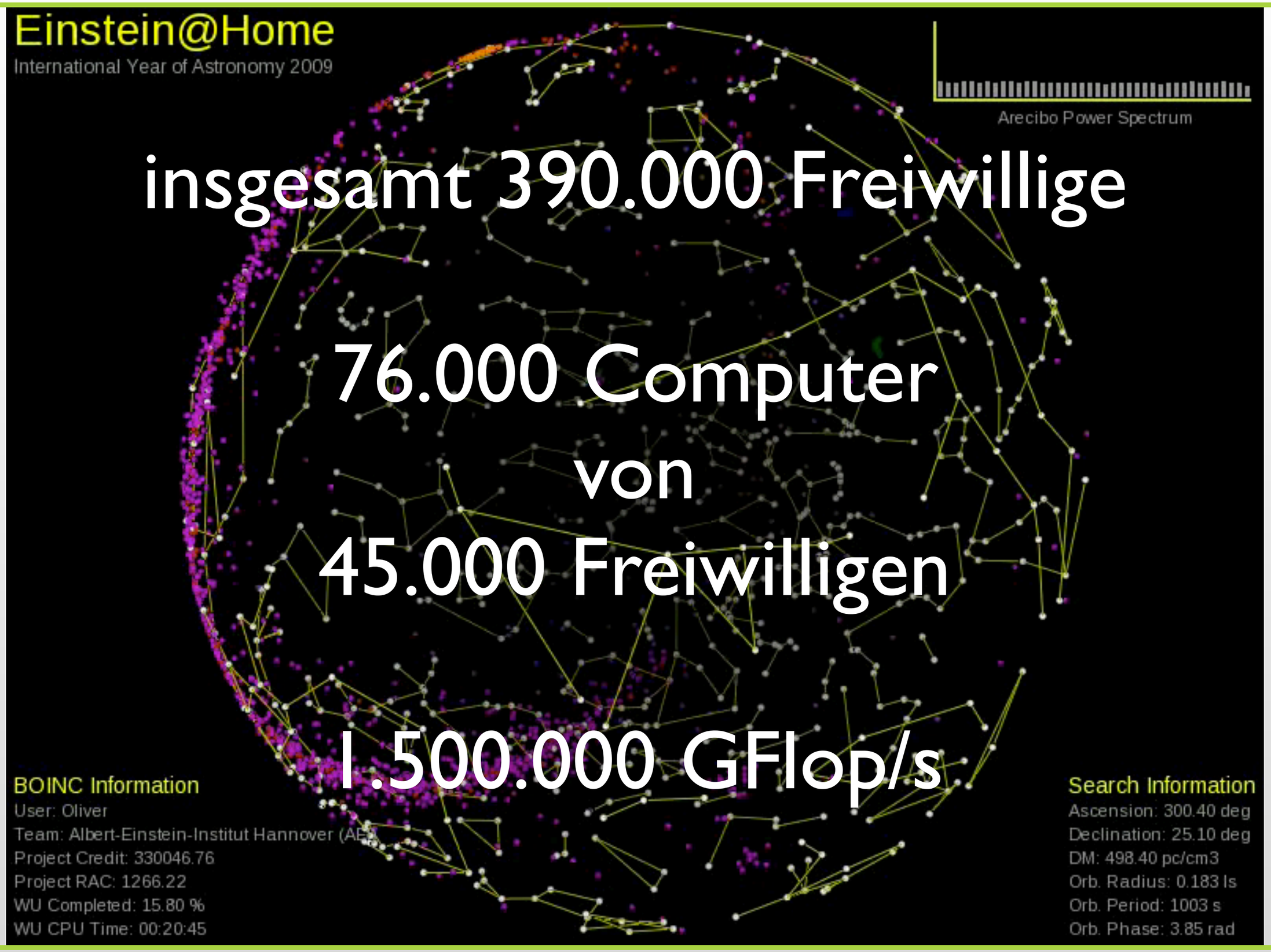


Einstein@Home



insgesamt 390.000 Freiwillige

76.000 Computer

von

45.000 Freiwilligen

1.500.000 GFlop/s

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Gravitationswellen

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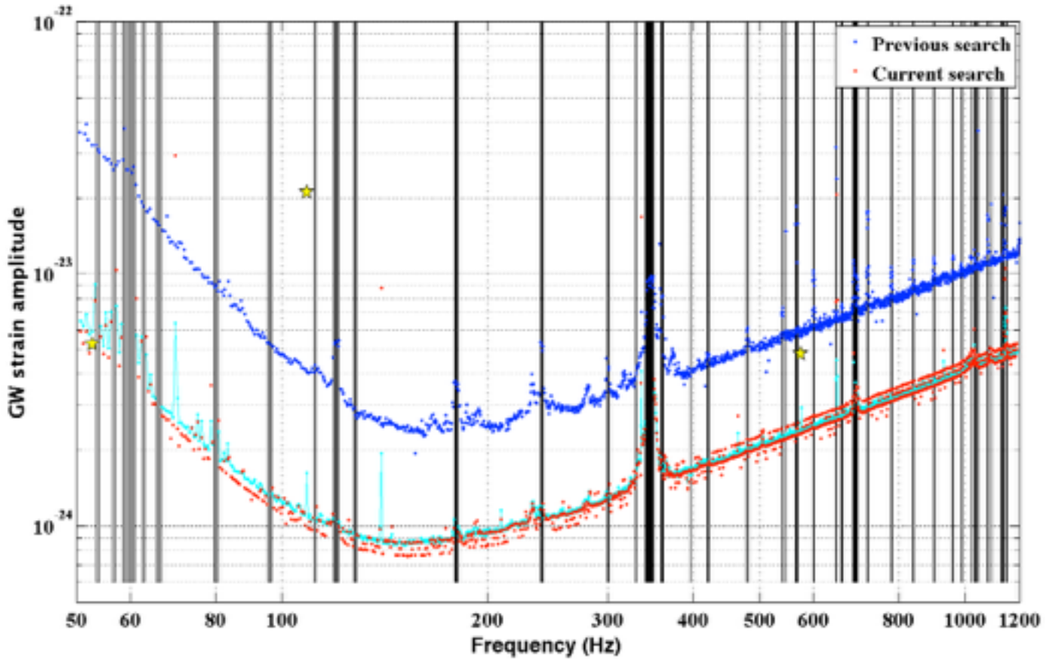

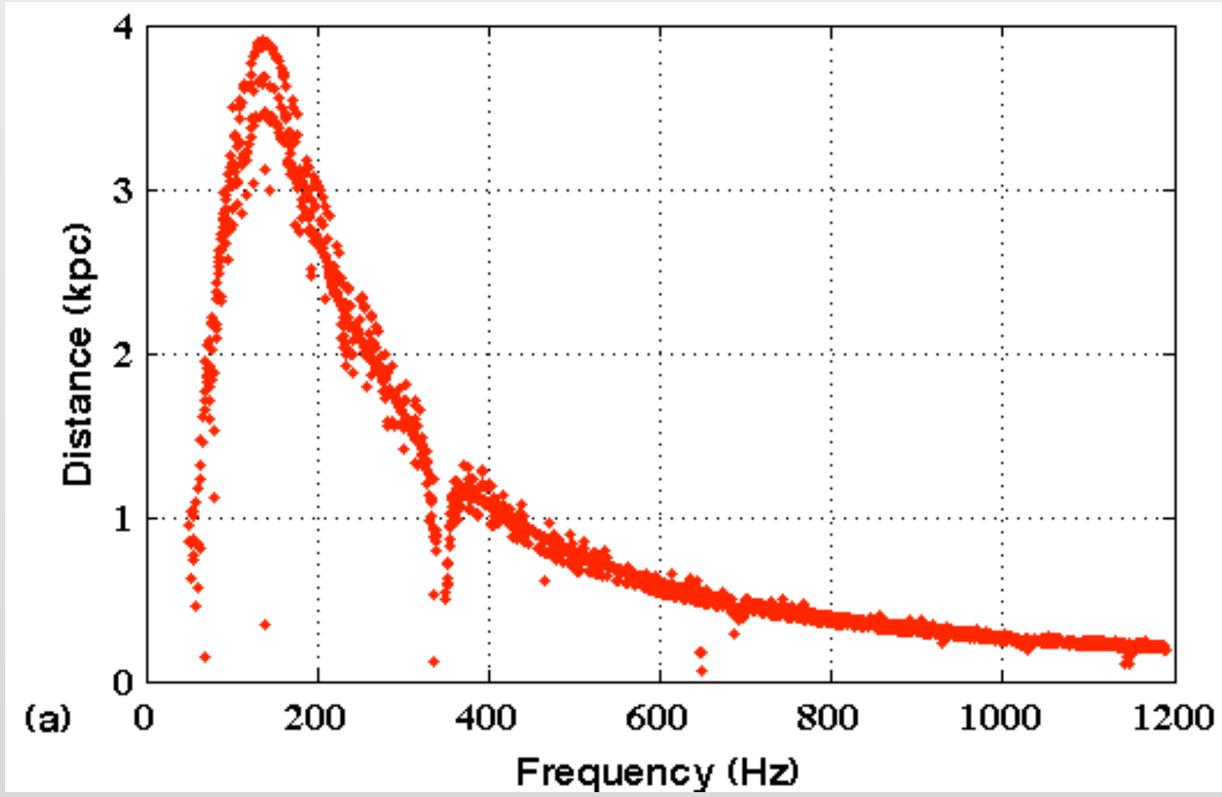

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Radiopulsare

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Radiopulsare

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Bild: Stephen West

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Bild: Stephen West

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Radiopulsare

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Bild: Stephen West

Radiopulsare

27 neue Pulsare entdeckt

Bild: Stephen West

24 neue Pulsare entdeckt

Radiopulsare

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ACKNOWLEDGEMENTS

We thank all *Einstein@Home* volunteers, especially those whose computers found the pulsars with the highest statistical significance[22]. PSR J0811−38: the Atlas computer cluster at the Albert Einstein Institute, Hannover, Germany and the Nemo computer cluster at the Department of Physics, University of Wisconsin–Milwaukee, Milwaukee, USA. PSR J1227−6208: Rolf Schuster, Neu-Isenburg, Germany and Darren Chase, Adelaide, Australia. PSR J1305−66: Dušan Pirc, Domžale, Slovenia and 'Victor1st'. PSR J1322−62: Vadim Gusev, Petrozavodsk, Russia and David Mason, Leawood, USA. PSR J1455−59: David Peters, Kiel, Germany and James Drews (UW-Madison), Madison, USA. PSR J1601−50: Sirko Rosenberg, Bautzen, Germany and Ton van Born, Nieuw-Vennep, Netherlands. PSR J1619−42: 'Metod, S56RKO' and Peter Grosserhode, Las Vegas, USA. PSR J1626−44: Aku Leijala, Veikkola, Finland, and 'Og'. PSR J1637−46: Riaan Strydom, South Africa and 'Edelgas'. PSR J1644−44: Jesse Charles Wagner II [USA] and 'Ras'. PSR J1644−46: Augusto Cortemiglia, Tortona, Italy, and 'Axiel'. PSR J1652−48: Brian Adrian, Dade City, USA and 'Craig G'. PSR J1726−31: Bogusław Sobczak, Krakow, Poland and Steve Mellor, Perth, Australia. PSR J1748−3009: Jürgen Sauermann, Berlin, Germany and 'Stan Galka'. PSR J1750−2536: Frederick J. Pfitzer, Phoenix, USA, and Benjamin Rosenthal Library, Queens College, CUNY, Flushing, USA. Independent detection of PSR J1750−2536 in a second PMPS beam: 'Masor_DC' and Gordon E. Hartmann, Dover, USA. PSR J1755−33: 'Omega Sector - Game Systems' and Dwaine Maggart, Van Nuys, USA. Independent detection of PSR J1755−33 in a second PMPS beam: 'revoluzzer' and 'Jacek Richter'. PSR J1804−28: Drew Davis, Urbandale, Iowa, and John-Luke Peck, TerraPower & Intellectual Ventures, Seattle, USA. PSR J1811−1049: Ingo Eberhardt, Gross-Zimmern, Germany and 'Paul Serban'. PSR J1817−1938: 'Jaska' and Keith Sloan, Nr Winchester, UK. Independent detection of PSR J1817−1938 in a second PMPS beam: Chris Sturgess, New Canaan, USA and 'Companion_Cube'. PSR J1821−0331: 'Robert Hoyt' and Kevin Battaile, Bolingbrook, USA. PSR J1838−01: Eric Nietering, Dearborn, USA and 'Tim Taylor'. PSR J1838−1849: 'gwyll' and 'IG_the_cheetah'. PSR J1840−0643: Terry Dudley, San Francisco, USA and Nemo (see above). Independent detection of PSR J1840−0643 in a second PMPS beam: Trey Todnem, Tucson, USA and Nemo (see above). PSR J1858−0736: Christoph Donat, Ingolstadt, Germany and 'gone'.

[22] Where the real name is unknown or must remain confidential we give the *Einstein@Home* user name and display it in single quotes.

Radiopulsare

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SPIEGEL ONLINE FOTOSTRECKE

Home > Fotostrecken > Astronomische Entdeckung: Ein Pulsar in der Datenflut

Astronomische Entdeckung: Ein Pulsar in der Datenflut

Zum Artikel 4 von 4 Alle Fotost

Daniel Gebhardt

Entdecker Daniel Gebhardt: Die Datenflut wird, zerlegt in kleine Pakete, an All-Enthusiasten rund um den Globus verschickt - unter an auch an die Universität Mainz.

Zum Artikel 4 von 4 Alle Fotost

Hooray for citizen scientists! The Einstein@Home project has discovered a unusual pulsar approximately 17,000 light-years away in the constellation Vulpecula. The project works by people "donating" idle time on their home computers. This is the first deep-space discovery by Einstein@Home, and the finding is credited to Chris and Helen Colvin, from Ames, Iowa in the US, and Daniel Gebhardt of Universitat Mainz, Musikinformatik,Germany.

The newly discovered pulsar, PSR J2007+2722, is an isolated neutron star that rotates 41 times per second and has an unusually low magnetic field.

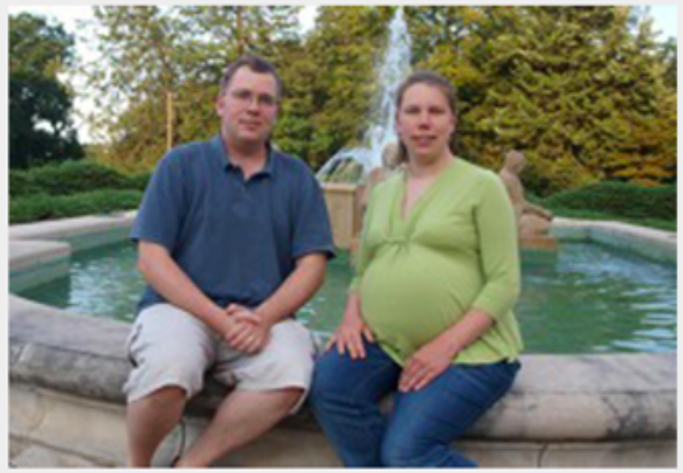
Jim Cordes, Cornell professor of astronomy, said the object is particularly interesting because it is likely a recycled pulsar: a neutron star that once had a companion star from which it acquired mass; but whose companion exploded, kicking it free.

Unlike most pulsars that spin as quickly and steadily, PSR J2007+2722 sits alone in space, and has no orbiting companion star. However, the scientists say they can not rule out that it may be a young pulsar born with an lower-than-usual magnetic field.

"We think there should be more of these disrupted binary pulsars, but there haven't been that many found," said Cordes. "No matter what else we find out about it, this pulsar is bound to be extremely interesting for understanding the basic physics of neutron stars and how they form."

The discovery demonstrates the power of the network used to collect and sort through vast amounts of data, Cordes said.

Einstein@Home was originally organized to find gravitational waves — ripples in space-time — using the Laser Interferometer Gravitational Wave Observatory (LIGO). In 2009, data from the Arecibo Observatory were included in the processing.



Chris and Helen Colvin who were credited with discovering a new pulsar. Image courtesy Chris Colvin.

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Gammapulsare

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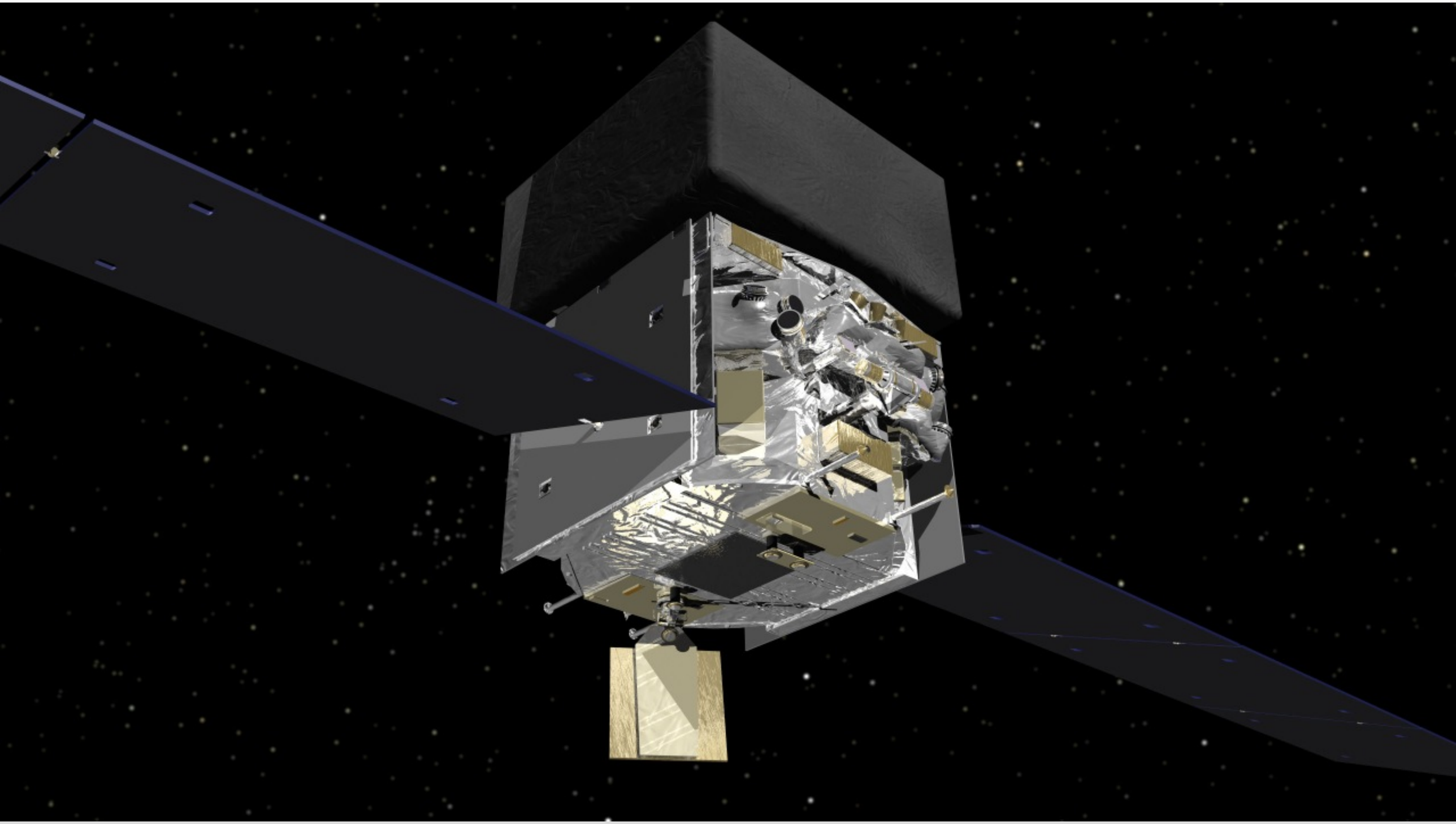

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Gammapulsare

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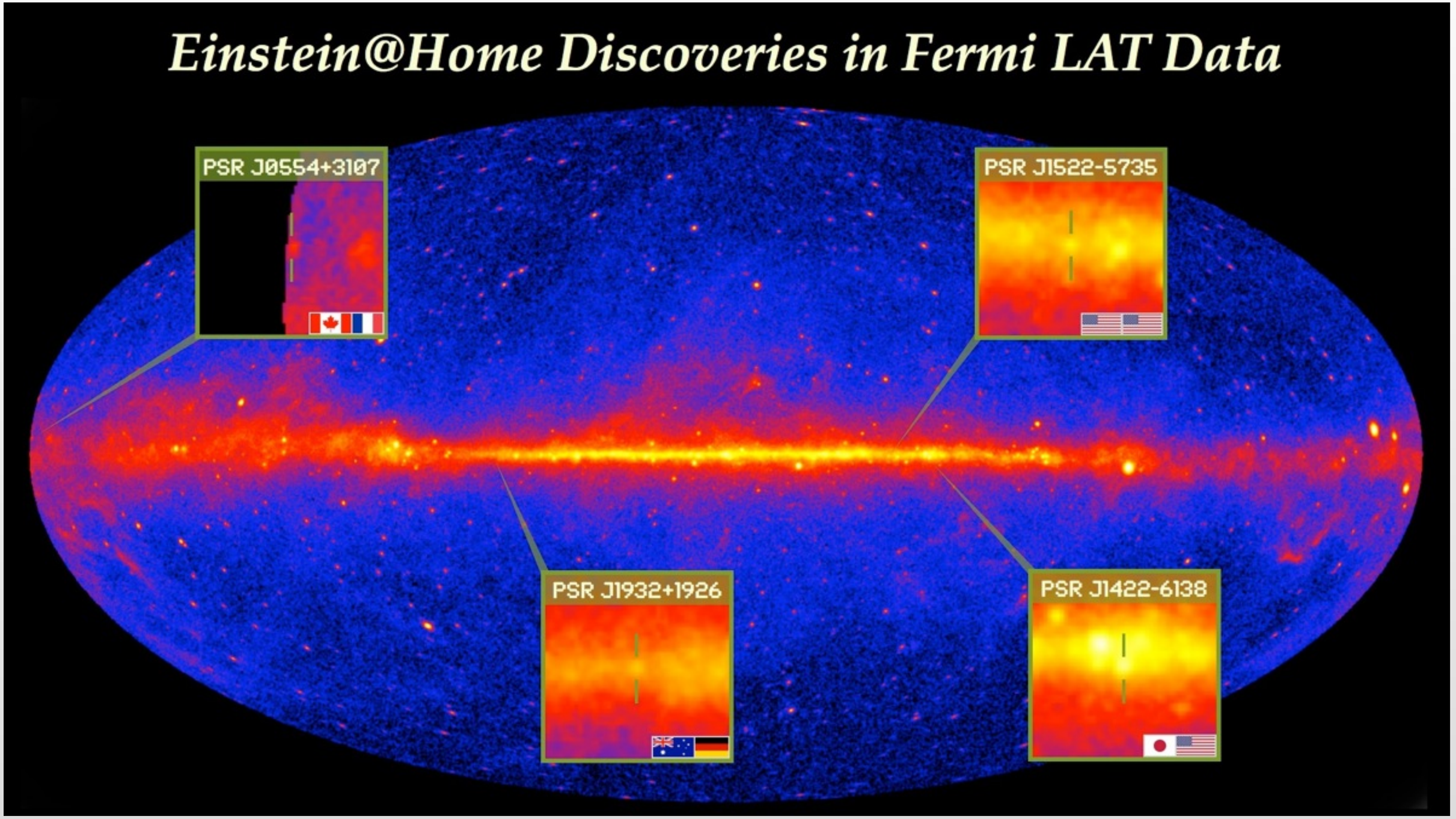
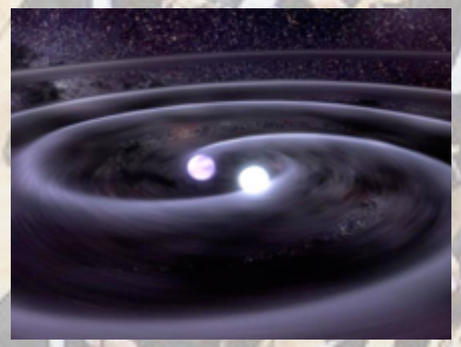
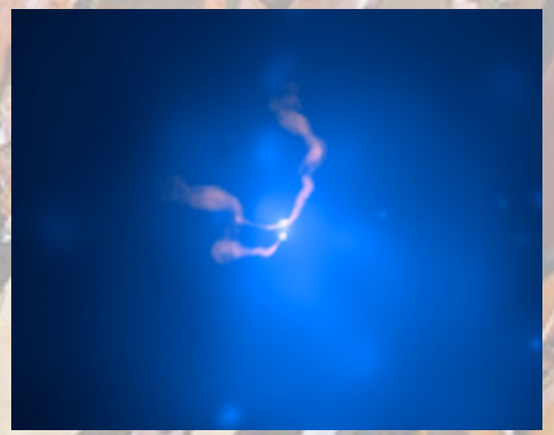


GW-Orchester

???

???





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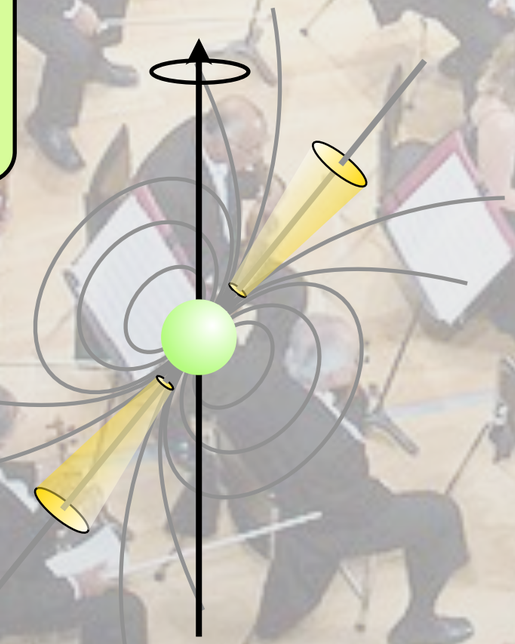

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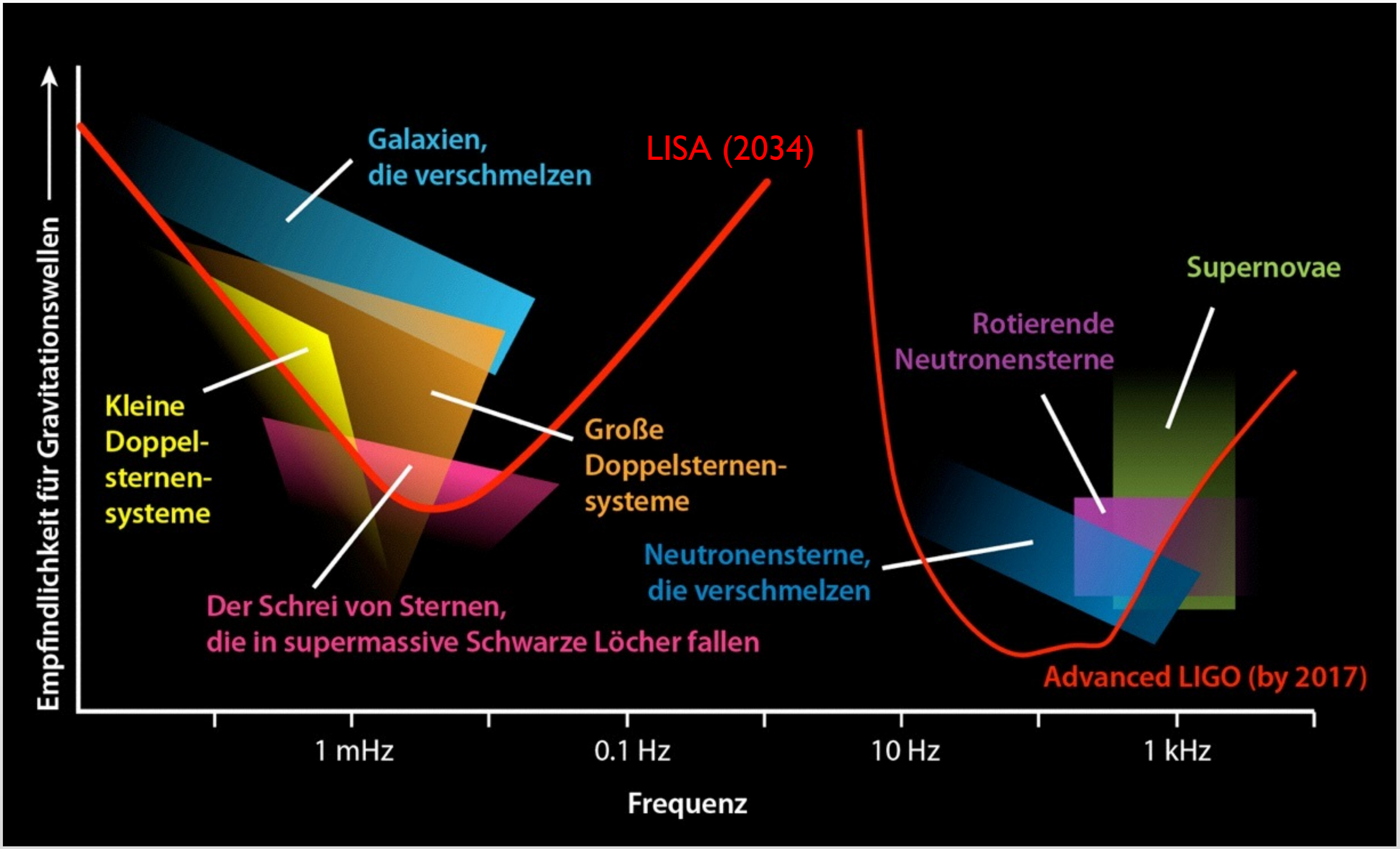
Quellen


Empfindlichkeit für Gravitationswellen
Galaxien,
die verschmelzen
LISA (2034)
Supernovae
Rotierende
Neutronensterne
Kleine
Doppel-
sternen-
systeme
Große
Doppelsternen-
systeme
Neutronensterne,
die verschmelzen
Der Schrei von Sternen,
die in supermassive Schwarze Löcher fallen
Advanced LIGO (by 2017)
1 mHz
0.1 Hz
10 Hz
1 kHz
Frequenz

MAX-PLANCK-GESELLSCHAFT

LISA

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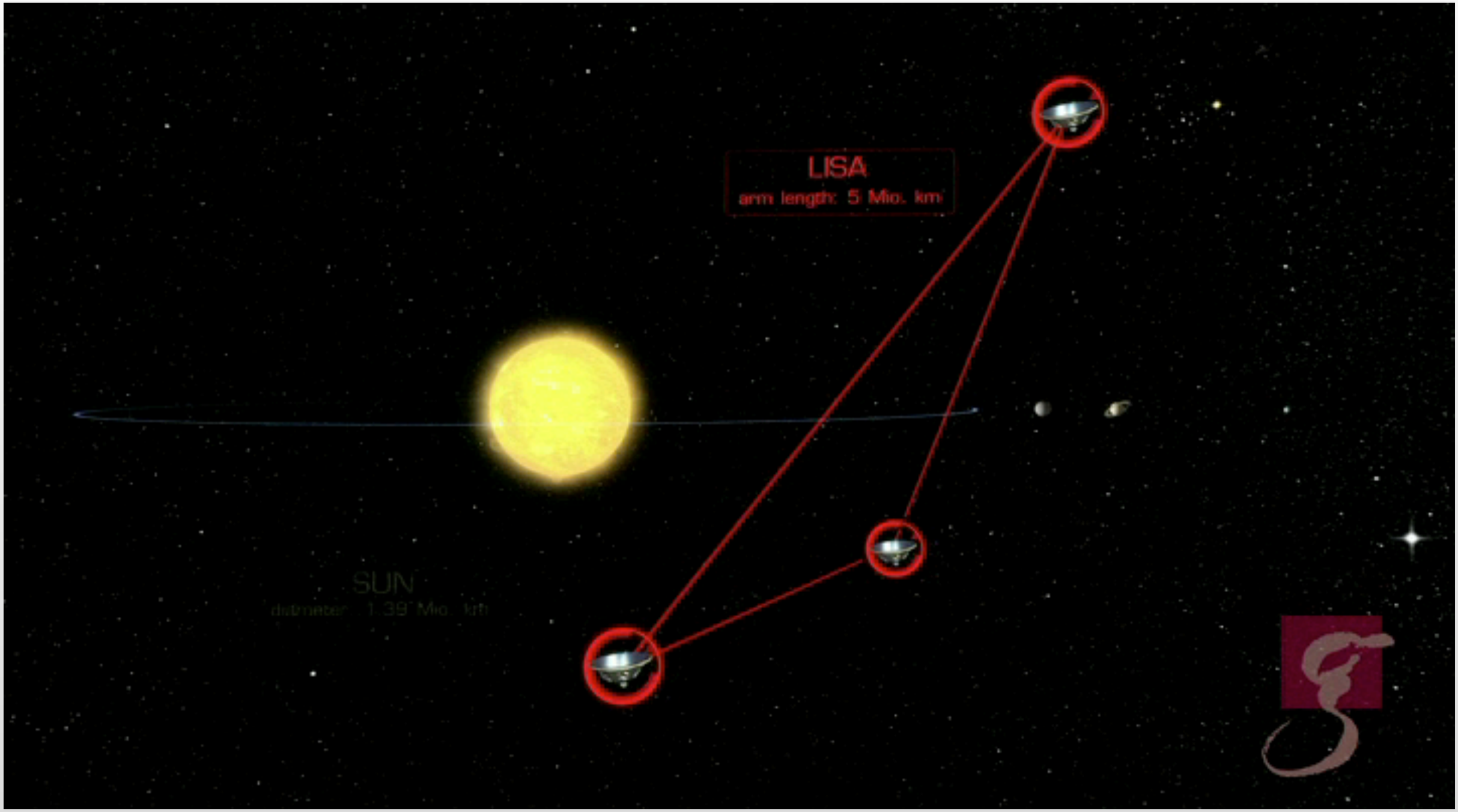
Hannover



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Laser im All!

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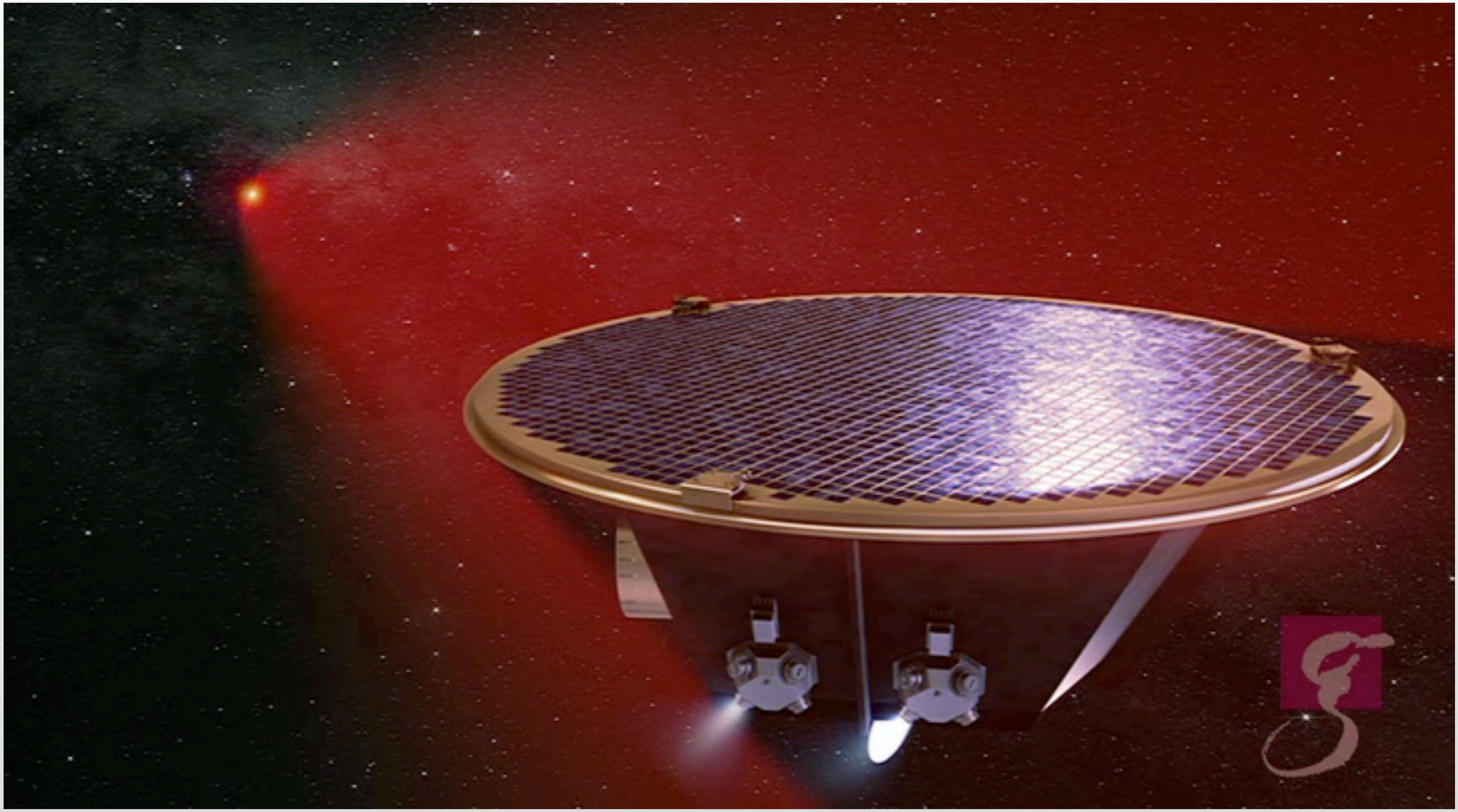

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LISA Pathfinder

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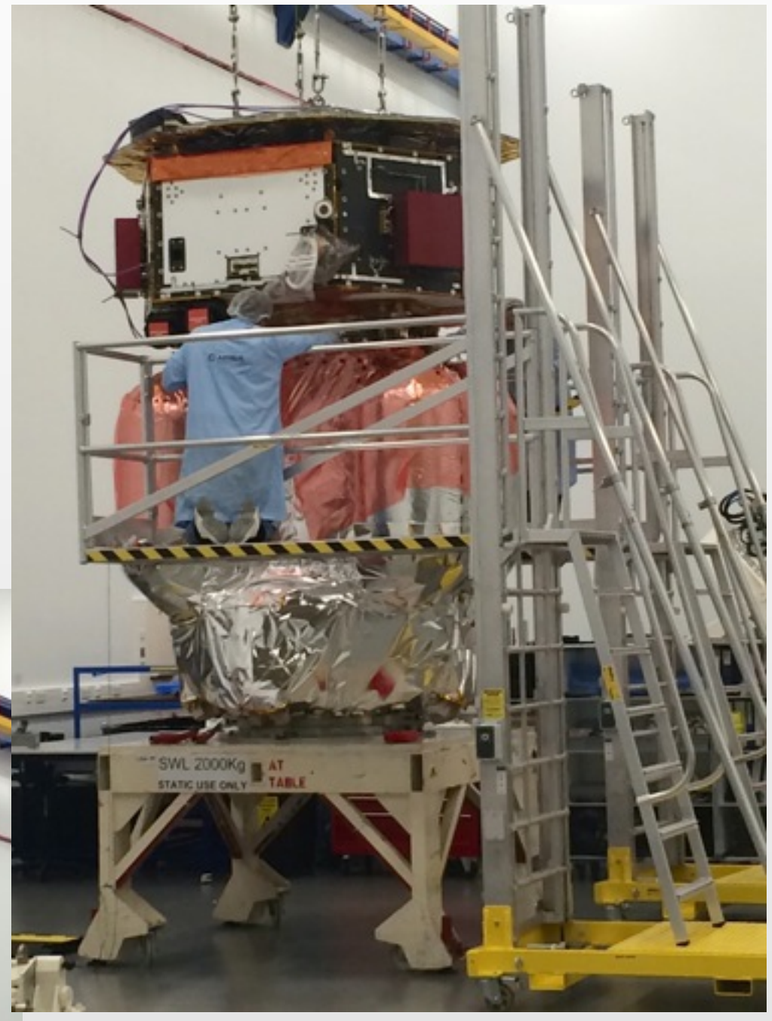

Bilder: Dr. Stuart Clark

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LISA Technology Package

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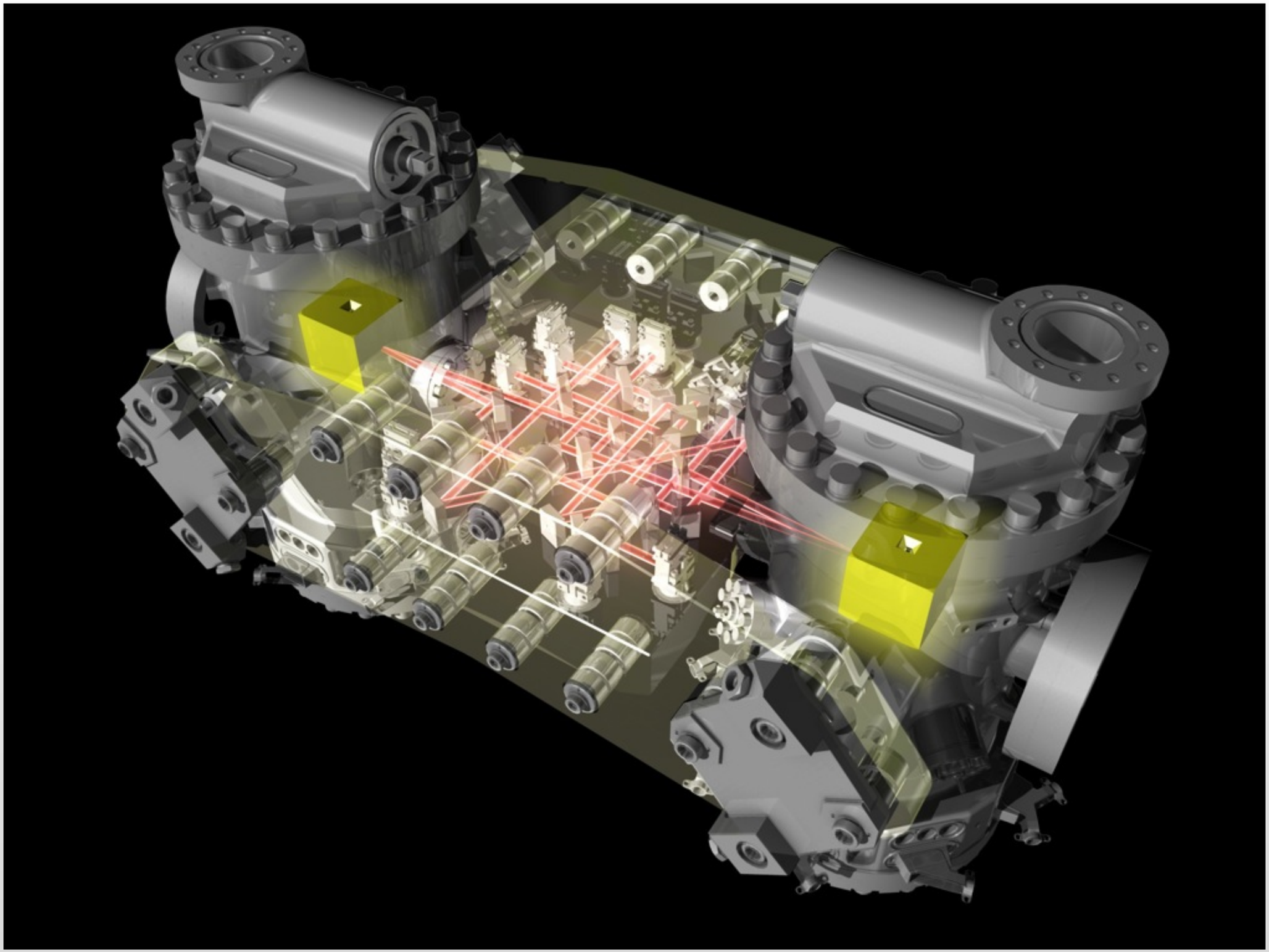
Hannover



Neues Fenster

Zusammenarbeit mit EM/Teilchen-Astronomie

Die unsichtbare „Dunkle Seite“ des Universums hören.

Neutronensterne

Das Echo des Urknalls

Schwarze Löcher

Sternenbeben

Binärsysteme

Entdeckung unbekannter und unerwarteter Objekte

MAX-PLANCK-GESELLSCHAFT

Albert-Einstein-Institut
Hannover

Vielen Dank für die Aufmerksamkeit! Fragen?

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