# Anniversary „Uraniae200 & AIUB100“

## Recent and current research at AIUB (Part I)

**Gerhard Beutler**

25th November 2022, Building of Exact Sciences (ExWi), Lecture Hall 099

UNIVERSITÄT BERN

# Preamble: Prof. Max Schürer's Legacy

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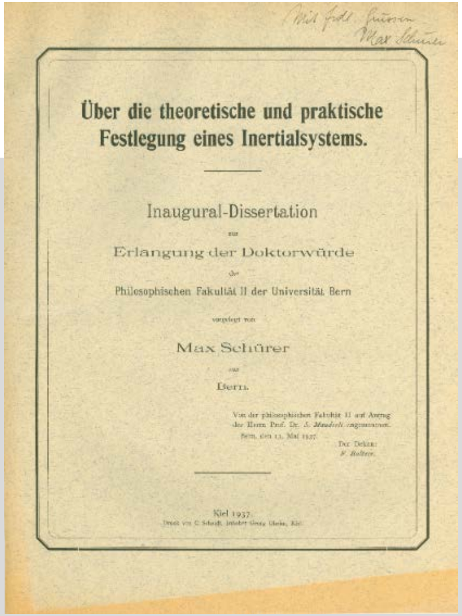


Über die theoretische und praktische Festlegung eines Inertialsystems.

Inaugural-Dissertation

zur

Erlangung der Doktorwürde

der

Philosophischen Fakultät II der Universität Bern

vorgelegt von

Max Schürer

aus

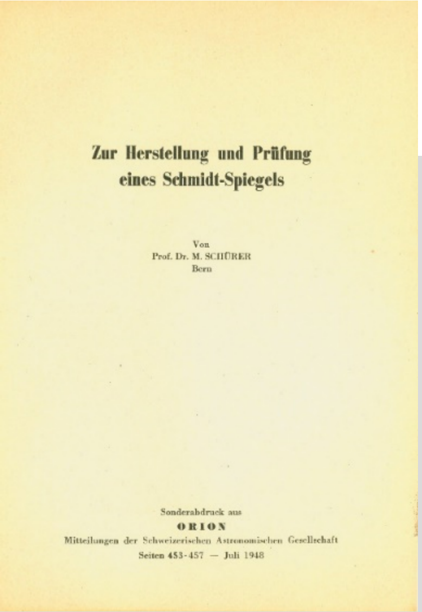
Bern.

Von der philosophischen Fakultät II auf Antrag des Herrn Prof. Dr. S. Mauderli angenommen.

Bern, den 13. Mai 1937

Der Dekan:
F. Baltzer.

Kiel 1937.



Zur Herstellung und Prüfung eines Schmidt-Spiegels

Von
Prof. Dr. M. SCHÜRER
Bern

Sonderabdruck aus
ORION
Mitteilungen der Schweizerischen Astronomischen Gesellschaft
Seiten 453-457 — Juli 1948

Prof. Max Schürer's Ph.D. thesis in 1937 (left) and his know-how in instrument manufacturing (1948) (center).

Max Schürer (second left), Robert Lehmann (left), Samuel Röthlisberger (right), from the AIUB mechanical workshop; Martin Frick, scientific co-worker (3rd left).

# The Zimmerwald observatory 1960

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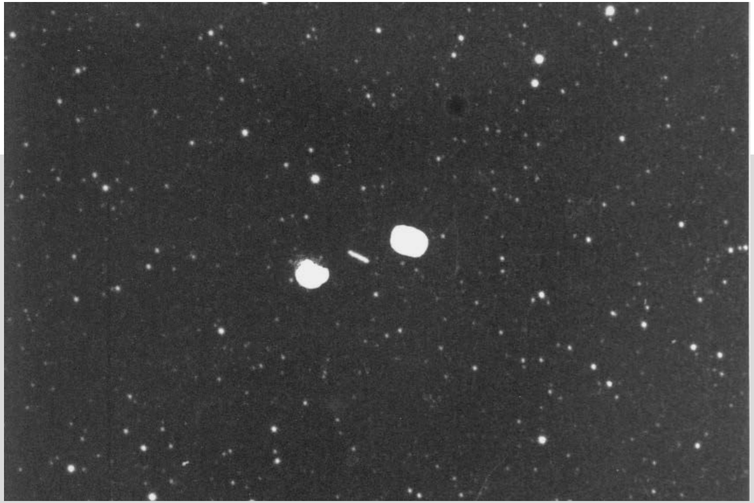


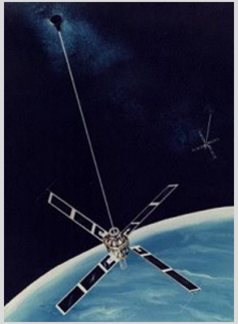
Zimmerwald observatory was built 1955/56 with a double instrument (Schmidt, Cassegrain) and the "Wohnhaus" (residence).

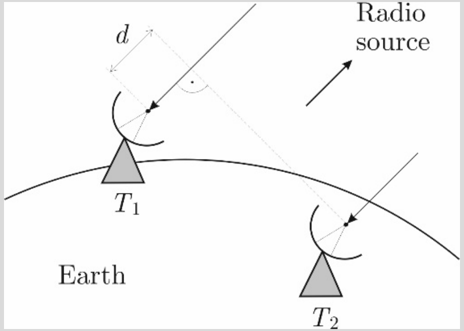
Schürer calculated the optics and the AIUB workshop manufactured the optical parts.

Paul Wild (center) used the Zimmerwald site to search for supernovae, but frequently found minor planets (above) and a few comets.

# New satellites, new observation techniques



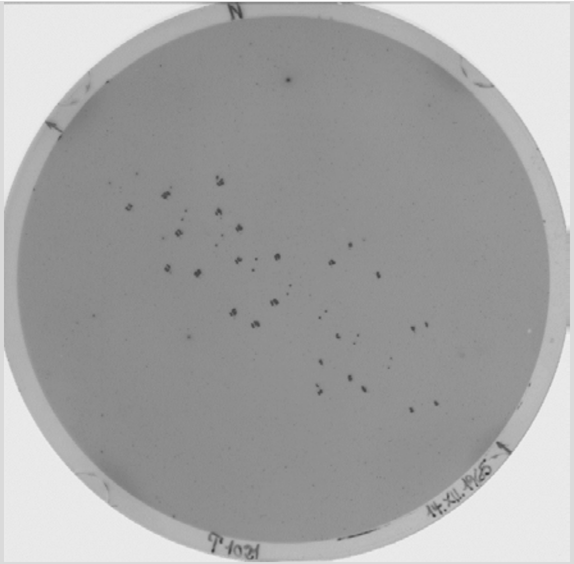


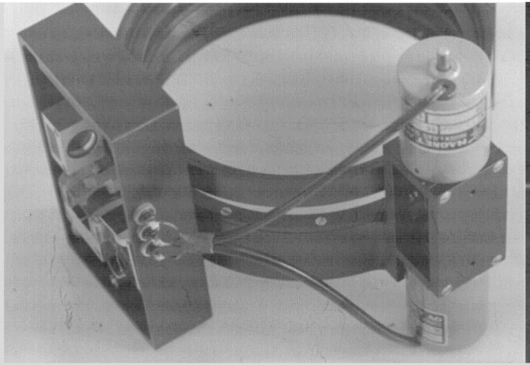


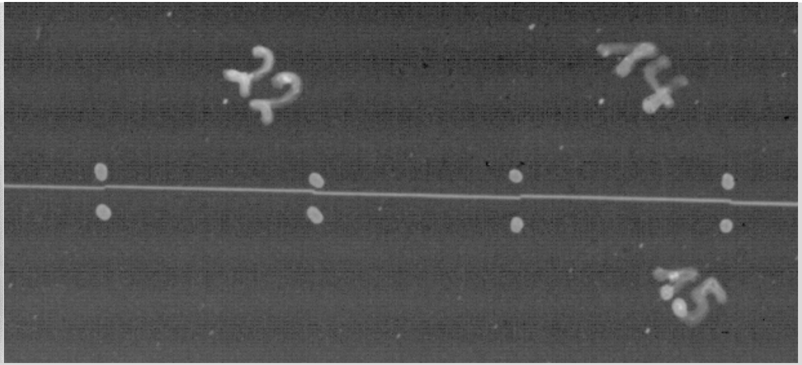

Earth orbiting satellites in space age: PAGEOS, 30m diameter (left), LAGEOS, 60cm diameter (center), Transit satellites (right).

Very Long Baseline Interferometry (VLBI), Wettzell telescope (left), simultaneous VLBI observations of QUASARS from different radio telescopes (right).

# Astrometry of artificial satellites in Zimmerwald





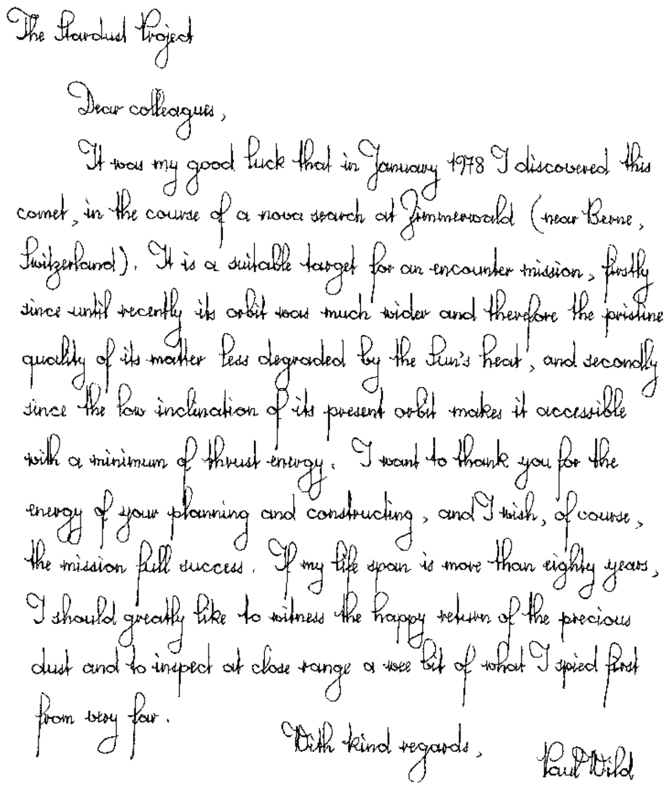

Schmidt plate with active satellite (left), "Kippkassette"="tilting cassette" (center) for timing (center), detail of passive satellite track with time marks (right).

Astrometry based on photography ended in Zimmerwald (and worldwide) around 1975.

# Paul Wild

Fig. 2


Quidquid nitet notandum
Alles was leuchtet ist zu be(ob)achten



The Stardust Project

Dear colleagues,

It was my good luck that in January 1978 I discovered this comet, in the course of a nova search at Zimmerwald (near Berne, Switzerland). It is a suitable target for an encounter mission, firstly since until recently its orbit was much wider and therefore the pristine quality of its matter less degraded by the Sun's heat, and secondly since the low inclination of its present orbit makes it accessible with a minimum of thrust energy. I want to thank you for the energy of your planning and constructing, and I wish, of course, the mission full success. If my life span is more than eighty years, I should greatly like to witness the happy return of the precious dust and to inspect at close range a wee bit of what I spied first from very far.

With kind regards,

Paul Wild

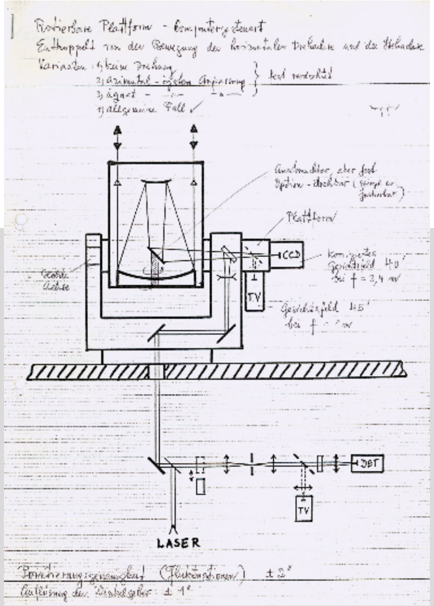
Left: Paul Wild and his life motto from the *Royal Astronomical Society*, used in his farewell lecture.

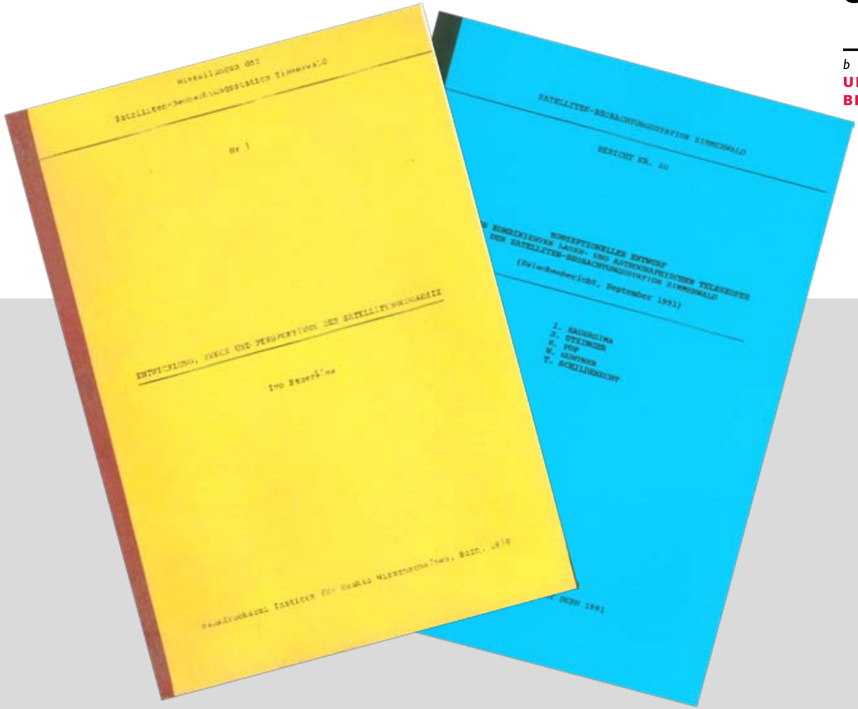
Paul Wild detected ~50 supernovae, ~100 minor planets, and a handful of comets.

Center: Letter, sent to the scientists of the NASA *Stardust mission,* was traveling with the spacecraft to comet *Wild-2*.

Apart from his *role as a/the observer* in Zimmerwald (during the night) Paul Wild played the *role of AIUB Director* (during the day) from 1980 to 1991.

# Ivo Bauersima

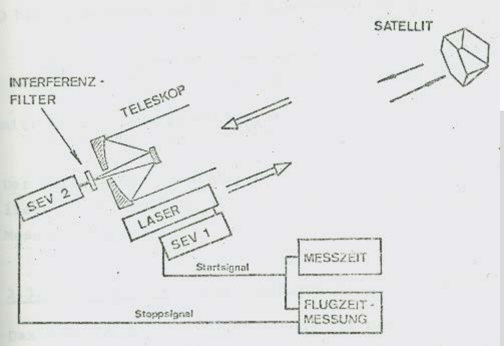


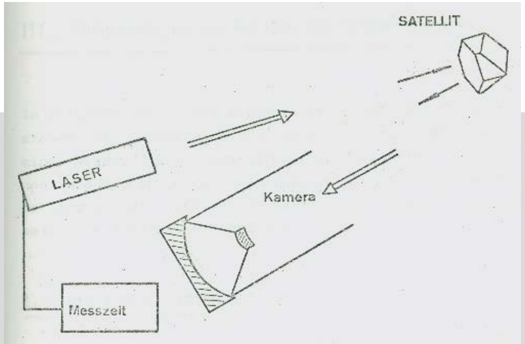



Ivo Bauersima joined the AIUB in 1968. He was the *spiritus rector* for the development of  the Zimmerwald observatory towards a fundmental station. His trademark was hand-written manuscripts (2nd left).

He (co-)authored many volumes of the "Mitteilungen/Berichte der Satellitenbeobachtungsstation Zimmerwald", e.g., in 1980 "Entwicklung, Zweck und Perspektiven der Satellitengeodäsie" (yellow). With colleagues he documented the first design for the ZIMLAT in 1990 (blue).

# SLR in Zimmerwald




A laser from University of Bern's Institute of Applied Physics (IAP) mounted on the Zimmerwald telescope (left) was marginally successful in 1968-72: only one shot was possible per satellite pass!

The new set-up in the dedicated laser dome is described in Willy Lüthy's Ph.D. thesis. The concept included

(a) laser for range measurements (third from left) tracking the satellites, similar to previous laser.

(b) dye-laser (fourth from left) to illuminate satellites. The plan was to photograph the illuminated satellites using the Schmidt telescope in the "classical" dome.

Both lasers were tested in the 1970s, due to the "phasing out" of internationally coordinated astrometry campaigns of artificial satellites. The illumination laser was never used operationally.

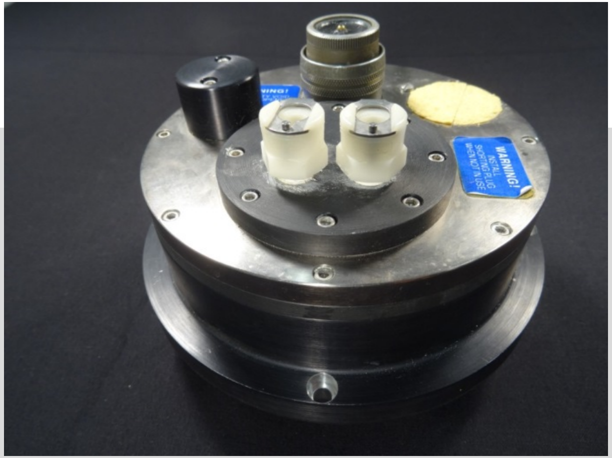
# SLR in Zimmerwald

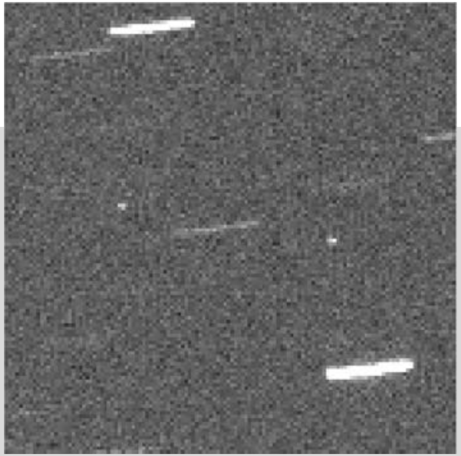
First laser telescope in Zimmerwald laser dome (left) with emission (black, small tube) and signal detection telescopes (green tube) – essentially Willy Lüthy's design.

In 1983 Werner Gurtner (right) became the manager of the Zimmerwald SLR Observatory. Routine operations were established. Based on the experiences in the 1980s, the ZIMLAT (**ZIM**merwald **L**aser and **A**strometry **T**elescope*)* was planned in the early 1990s and became operational in 1997 (right).

With ZIMLAT our observatory became one of the most productive SLR sites worldwide in the newly created ILRS (*International Laser Ranging Service*) and a *pioneer for astrometry* of rapidly moving objects.

# CCD Astrometry in Zimmerwald





Around 1985 Thomas Schildknecht started to use the "new" CCD-camera (left) to observe objects in the near-Earth space with the telescope of the SLR dome in Zimmerwald. The figure (right) shows two space debris objects with a size of about 10cm in the geostationary belt as dots, observed against the moving background stars (trails).

Volume 49 of the "Geodätisch-geophysikalische Arbeiten in der Schweiz" contains Thomas Schildknecht's  Ph.D. thesis, reviewed by Ivo Bauersima, Richard Langley, and Gerhard Beutler.

# The Bernese GNSS Software


Astronomisch-geodätische Arbeiten in der Schweiz

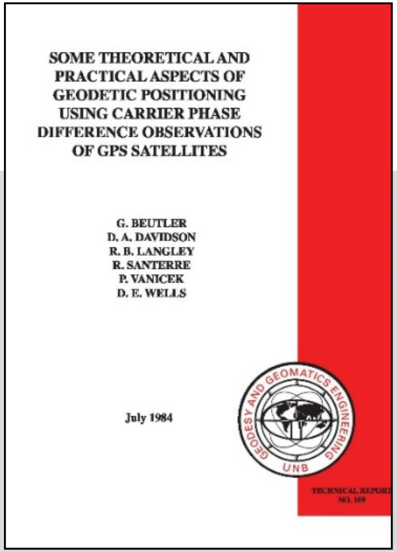
herausgegeben von der
Schweizerischen Geodätischen Kommission
(Organ der Schweizerischen Naturforschenden Gesellschaft)

Dreiunddreißigster Band

Integrale Auswertung von Satellitenbeobachtungen

G. Beutler

1977

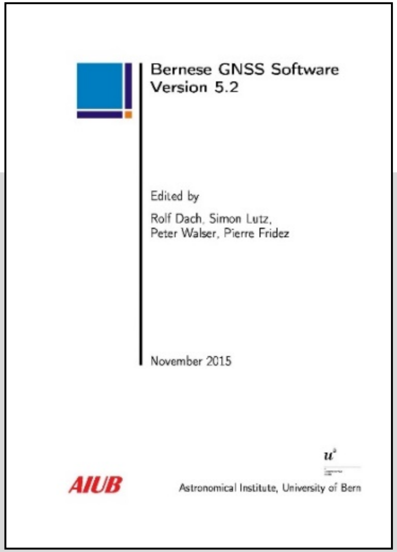

SOME THEORETICAL AND PRACTICAL ASPECTS OF GEODETIC POSITIONING USING CARRIER PHASE DIFFERENCE OBSERVATIONS OF GPS SATELLITES

G. BEUTLER
D. A. DAVIDSON
R. B. LANGLEY
R. SANTERRE
P. VANICEK
D. E. WELLS

July 1984

GEODESY AND GEOMATICS ENGINEERING
UNB

TECHNICAL REPORT NO. 109


Bernese GNSS Software
Version 5.2

Edited by
Rolf Dach, Simon Lutz,
Peter Walser, Pierre Fridez

November 2015

AIUB
Astronomical Institute, University of Bern

My Ph.D. thesis in 1976 (left) was designed to analyze all observation types in satellite geodesy. The method was applied to PAGEOS observations made in Europe.

The tool developed in the thesis was modified and used in 1983-84, on the occasion of a research stay at University of New Brunswick, to analyze the GPS observations made near Ottawa, Canada, in 1983. The *Bernese GNSS Software* was born (right).

# The Bernese GNSS Software

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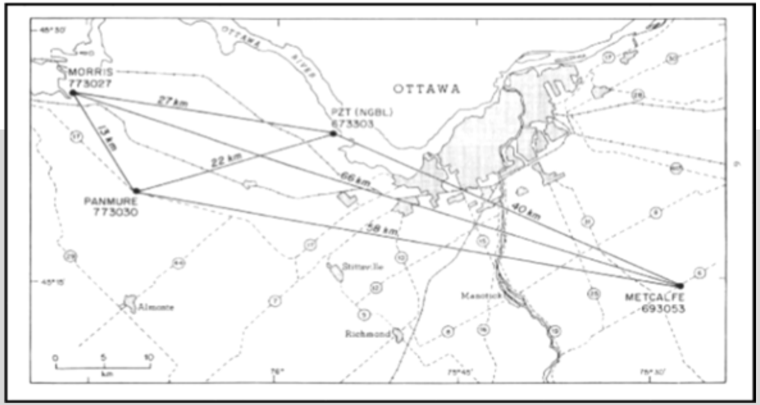
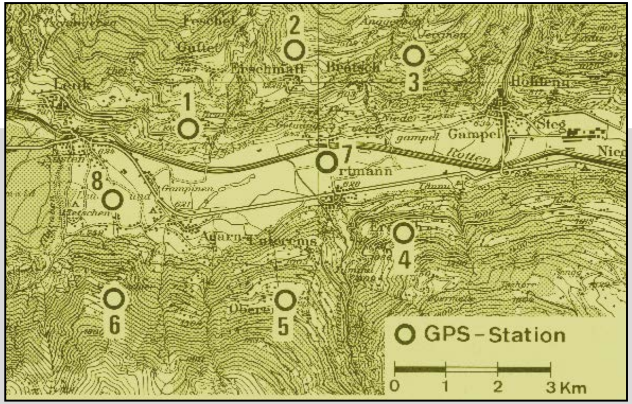
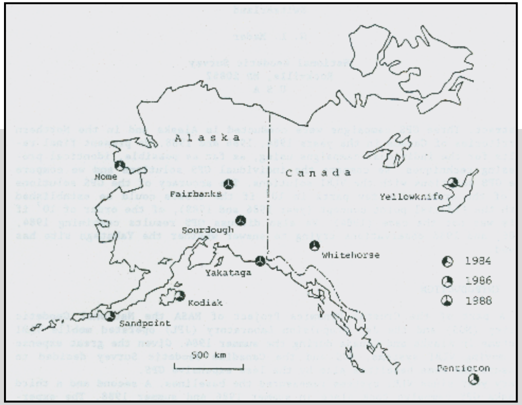


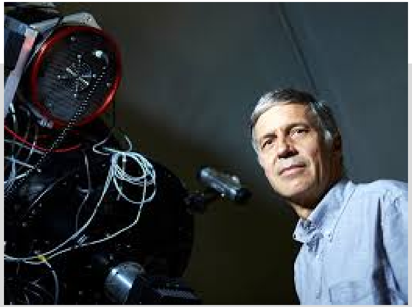

Left: The first GPS campaign processed by the (precursor of the) Bernese GNSS software in 1983-84 at UNB.

Center: Many GPS campaigns were analyzed by the AIUB in the 1980-90s, e.g., the Turtmann campaigns, in collaboration with *swisstopo* and *Swiss Geodetic Commission*. → GNSS for new 1st order surveys! → presentation by Elmar Brockmann.

Right: Our analysis of the 1984 Alaska GPS campaign, organized by the US National Geodetic Survey (NGS) using dual-band GPS receivers, included orbit determination and revealed the potential of the Bernese Software for regional and global analyses (results published in 1987).

# New AIUB structure in 1991





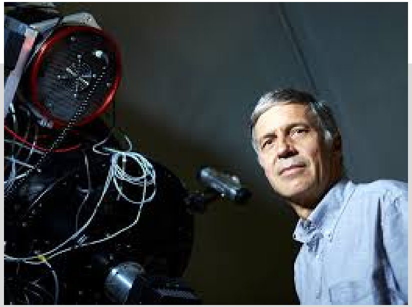

In 1991 I (left) was appointed as professor of astronomy and director of the AIUB. The work was organized in three research groups: *GNSS* with Markus Rothacher (second from left), *CCD-Astrometry* with Thomas Schildknecht (third from left), *Observatory Zimmerwald* with Werner Gurtner (fourth from left).

Early highlights include: Markus Rothacher showing that GPS (today GNSS) is able to contribute to nutation and high-frequency Earth rotation, Thomas Schildknecht developing in Zimmerwald CCD astrometry of fast moving objects, Werner Gurtner "inventing" the RINEX-format for GNSS data exchange.

# Change in 1997





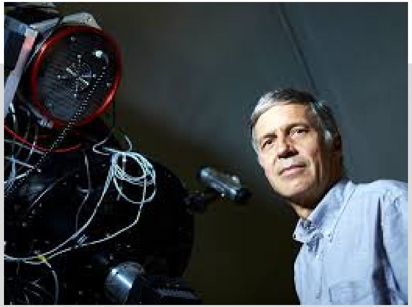


In 1997 a group on the *history of 18th century science* was created with Andreas Verdun (fifth from left).

Prior to 1997 Andreas Verdun was a member of the astrometry group, where he also wrote his Ph.D. thesis.

# Change in 1999



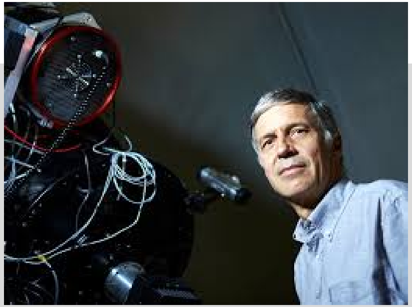


In 1999 Urs Hugentobler (second from left) succeeded Markus as head of the GPS group.

Prior to 1999 Urs Hugentobler was member of the astrometry group. In his Ph.D. thesis in 1997 he provided strong arguments for the continued use of astrometric observations based on CCD.

# Change in 2006



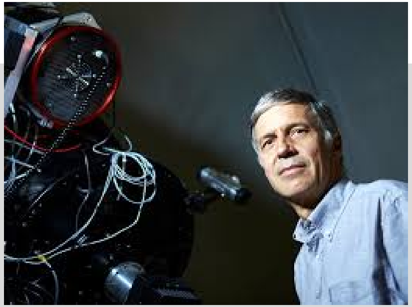


In 2006 Rolf Dach (second from left) became the successor of Urs Hugentobler as head of the GNSS group.

Rolf Dach came from TU Dresden in 1999 to join our GNSS group. He put the emphasis on multi-GNSS.

# Change in 2009



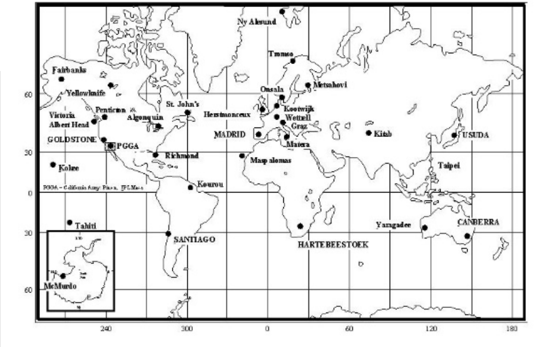


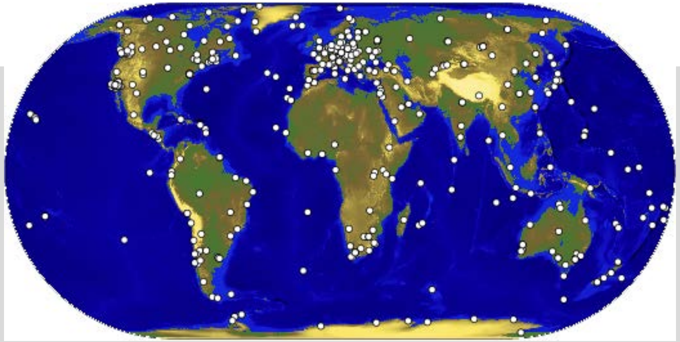

Sadly, Werner Gurtner passed away in 2009, at the age of 61 years.

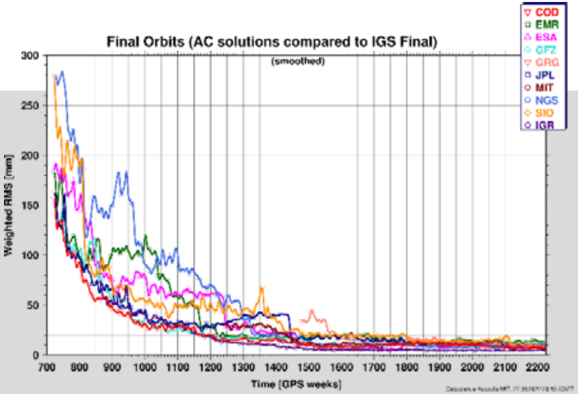
Werner's responsibilities in Zimmerwald were shared between Thomas Schildknecht (third from left), in particular AIUB deputy director 2009-2011, director ad interim 2011 and Martin Ploner (fourth from left), responsible for technical developments in Zimmerwald.

A new group was created with the focus on orbit determination for LEOs and gravity field determination, led by Adrian Jäggi (fifth from left).

# The International GNSS Service (IGS)







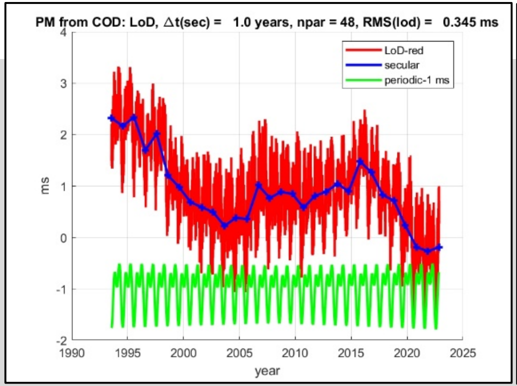

The IGS is based on an initiative by Prof. Ivan Mueller of Ohio State University around 1989. I succeded him in 1991 as Chair of the IGS Campaign Oversight Committee and became the founding Chair of the IGS Governing Board in 1994.

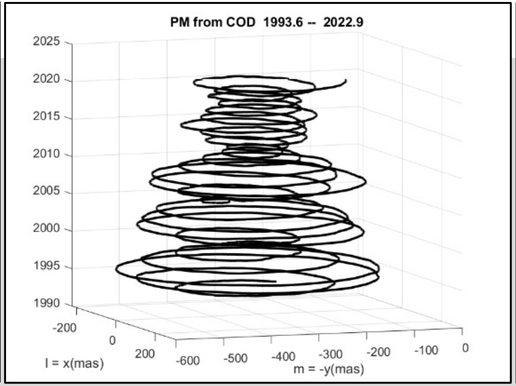
Ruth Neilan from JPL was the Director of the IGS Central Bureau from 1992 to 2017, succeeded by Allison Craddock.

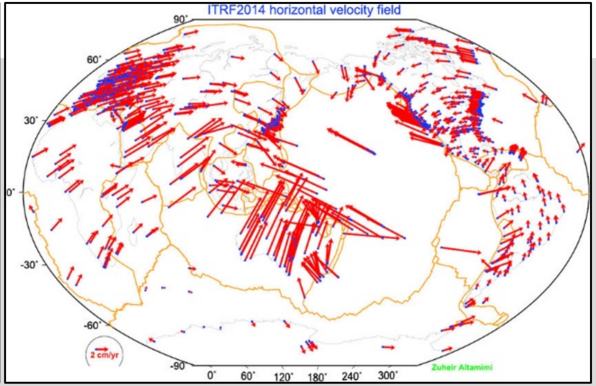
The IGS was based on 20+ tracking sites in 1992 (left) and 500+ sites today (center); the observations are collected by data centers, the products generated by the Analysis Centers (ACs). The AC products are validated and combined regularly into official IGS products by the IGS Coordinator.

The orbit consistency (right), regularly established and issued by the IGS coordinator, documents the «*IGS learning curve*», from about 25cm in 1994 to 1-3 cm today.

# CODE: Center for Orbit Determination in Europe



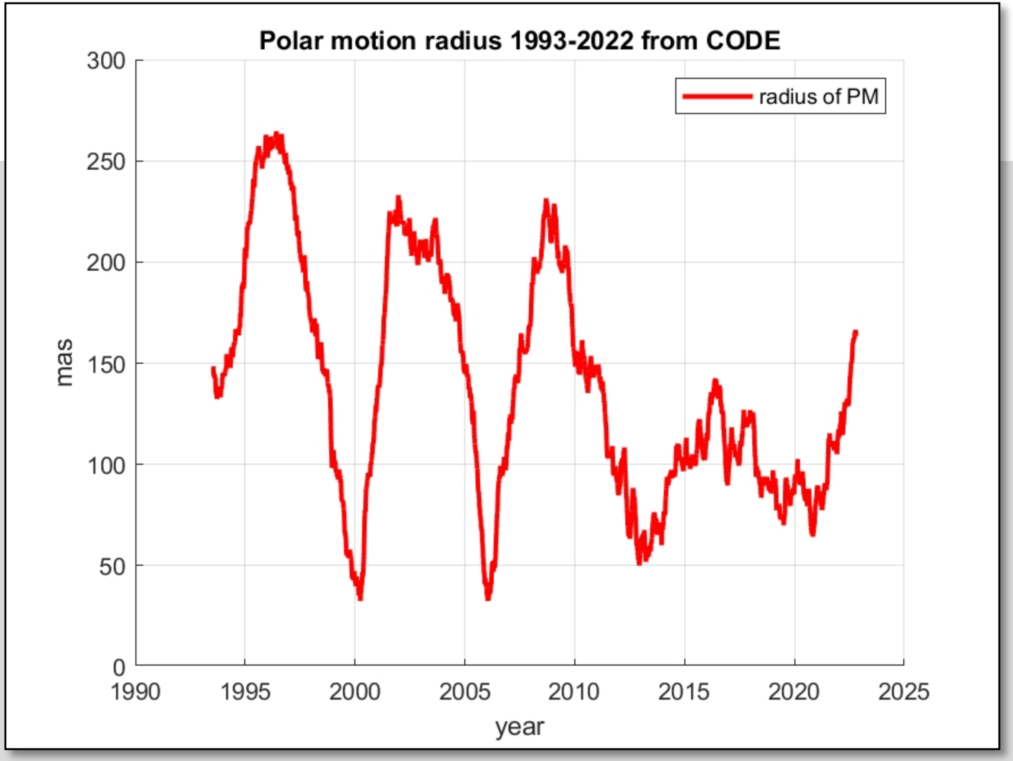




Today, CODE is a joint venture of *AIUB*, *swisstopo* in Wabern, the *Bundesamt für Geodäsie und Kartographie* (*BKG*) in Frankfurt, and the *Institute for Astronomical and Physical Geodesy* (IAPG) of the Technical University of Munich, Germany.

CODE contributes to all IGS product series since 1993, e.g, to length of day (left), to polar motion (center), and to horizontal station motion (right), from ITRF14 analysis by Zuheir Altamimi.

Tim Springer and Robert Weber were *IGS Coordinators* 1999-2002 as members of CODE.

# CODE: Center for Orbit Determination in Europe



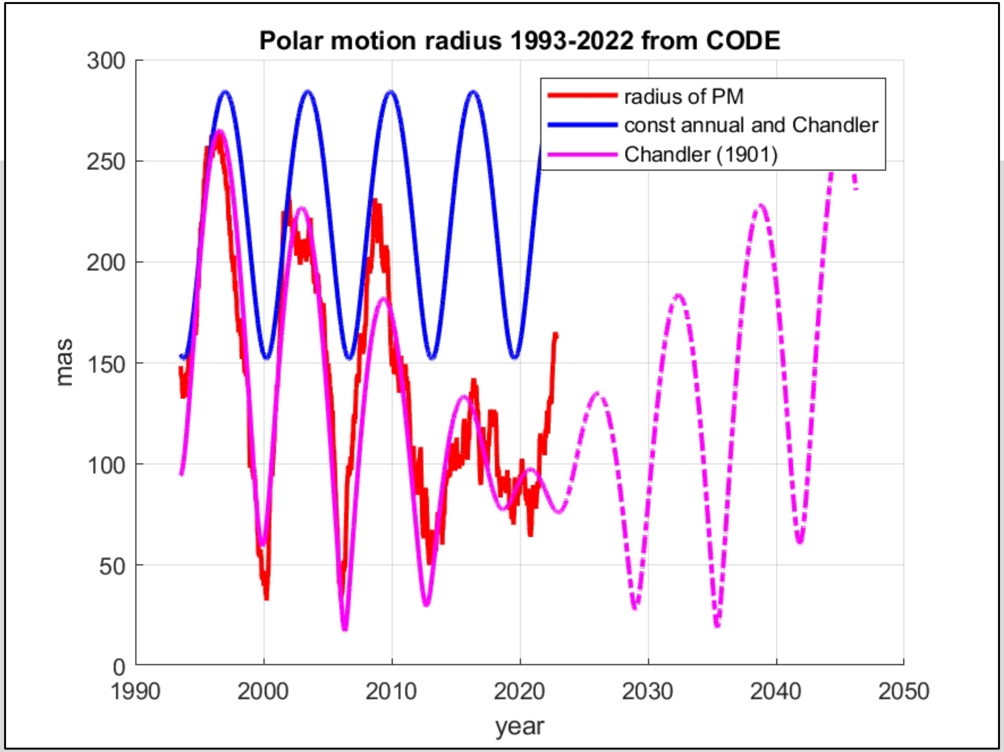

The PM radius shows the expected ~6.45y variation, the beat period of the annual and the Chandler motion using nominal values for the annual and Chandler periods, till 2014.

From ~2015 to ~2020 the variation virtually disappears to show up again in 2022.

The last such event was recorded roughly 90 years ago, around 1930.

Seth Carlo Chandler predicted events of this kind in 1901 in an article published in the *Astronomical Journal*!

# CODE: Center for Orbit Determination in Europe




The blue curve represents the PM radius series with constant amplitudes for the annual and Chandler constituents, using the PM info from 1993 and the original Chandler theory (1891, 1892).

The magenta curve shows the PM curve based on the Chandler theory (1901), representing the Chandler constituent by two parts differing in period by 5.7 days, corresponding to a beat period of about 90 years.

Only six parameters were estimated using daily PM positions on more than 10000 days of data. Dash-dot line is prediction (!)

More information in Beutler et al. (2020, ASR).

# handshake

My presentation is coming to a "grinding halt". I leave the floor to Adrian Jäggi for his report about current AIUB research activities.

His presentation starts around the year 2000, when he was still a student, and when orbit and gravity field determination, based on GNSS receivers on Low Earth Orbiters (LEOs), became important – also at AIUB.

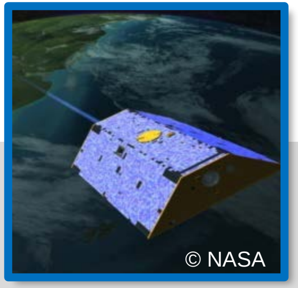
# Anniversary „Uraniae200 & AIUB100“

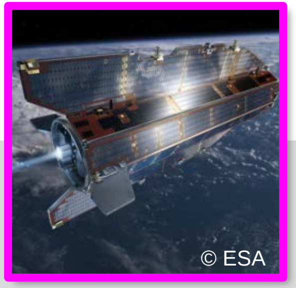
## Recent and current research at AIUB (Part II)

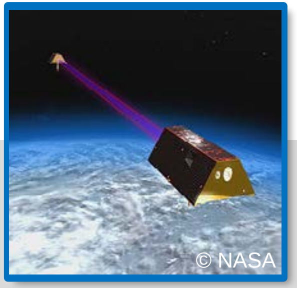
**Adrian Jäggi**

25th November 2022, Building of Exact Sciences (ExWi), Lecture Hall 099

# Dedicated Gravity Missions








CHAMP (GFZ, 2000-2010)

GRACE (NASA/DLR, 2002-2017)

GRACE-FO (NASA/GFZ, 2018-…)

GOCE (ESA, 2009-2013)

- High-low satellite-to-satellite tracking (hl-SST)
- Low-low satellite-to-satellite tracking (ll-SST)
- Satellite gravity gradiometry (SGG)

# Measuring Satellite Motion

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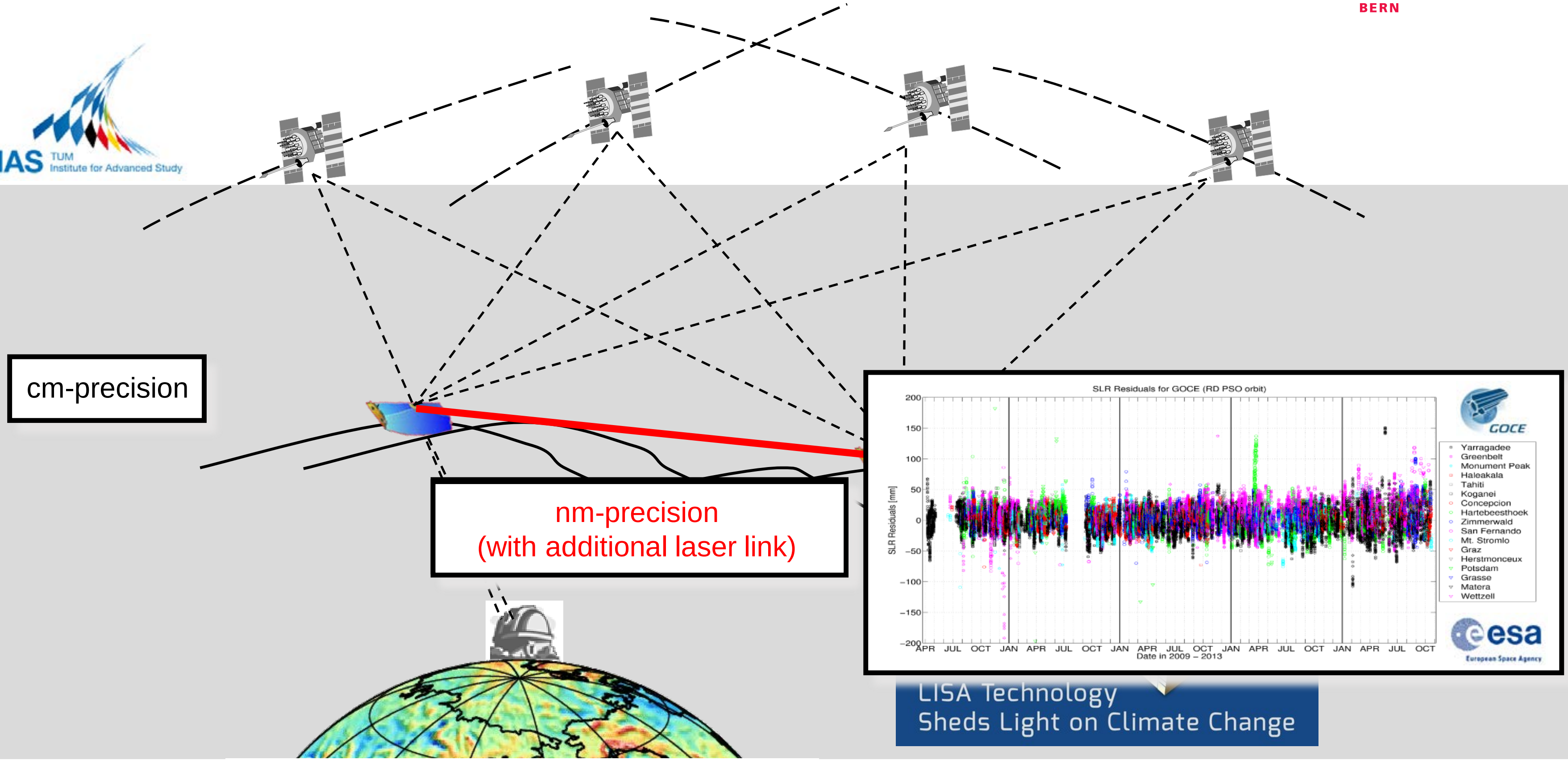
IAS TUM Institute for Advanced Study



# Swiss Optical Ground Station and Geodynamics Observatory in Zimmerwald (AIUB's SwissOGS)

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Landestopografie swisstopo
Office fédéral de topographie swisstopo
Ufficio federale di topografia swisstopo
Uffizi federal da topografia swisstopo

SGC
Swiss Geodetic Commission
sc | nat
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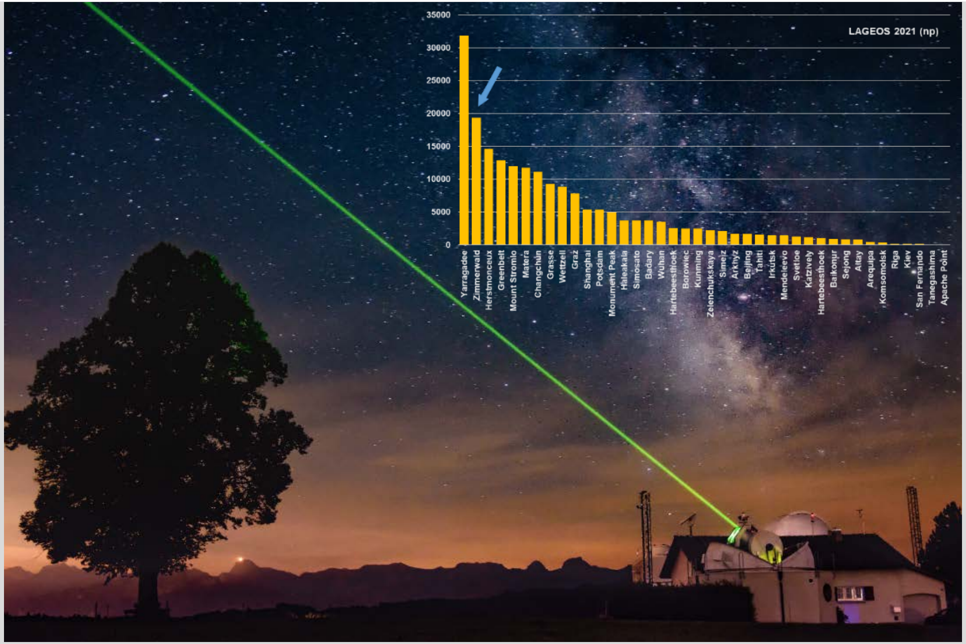
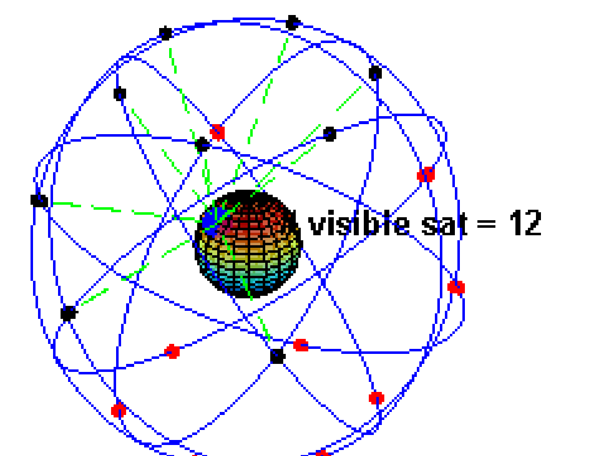
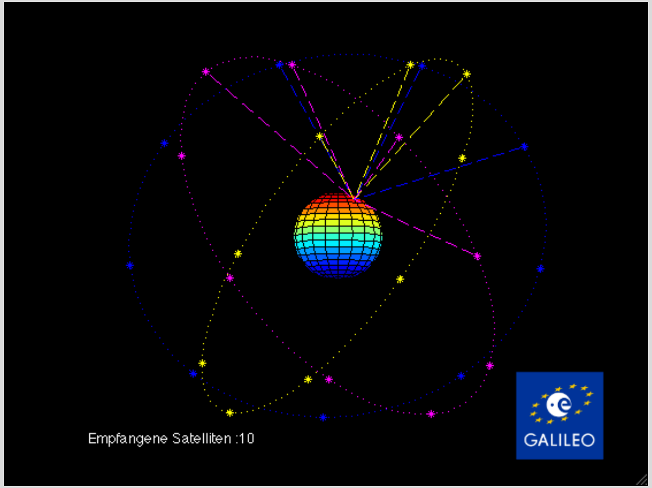



- Measuring distances to satellites equipped with retro-reflectors with Satellite Laser Ranging (SLR)
- Fully automated 24/7 operations
- Telescope used for both, SLR and astrometry
- One of the most productive SLR stations worldwide, usually the most productive one on the Northern hemisphere.

# Center for Orbit Determination in Europe (CODE)



© El pak, Wikipedia




Precise orbits for GPS, Galileo and other Global Navigation Satellite Systems (GNSS) are operationally computed at CODE, which is hosted at the AIUB.

# Center for Orbit Determination in Europe (CODE)

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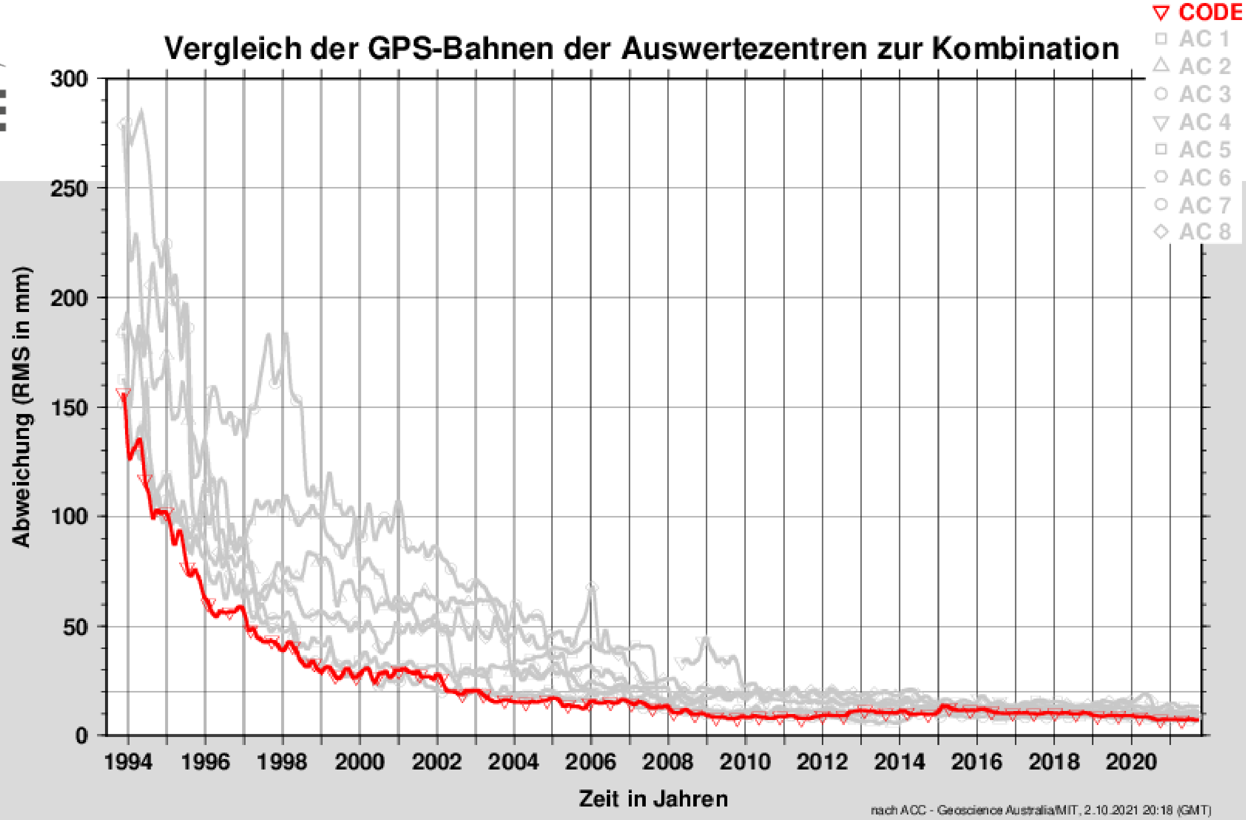
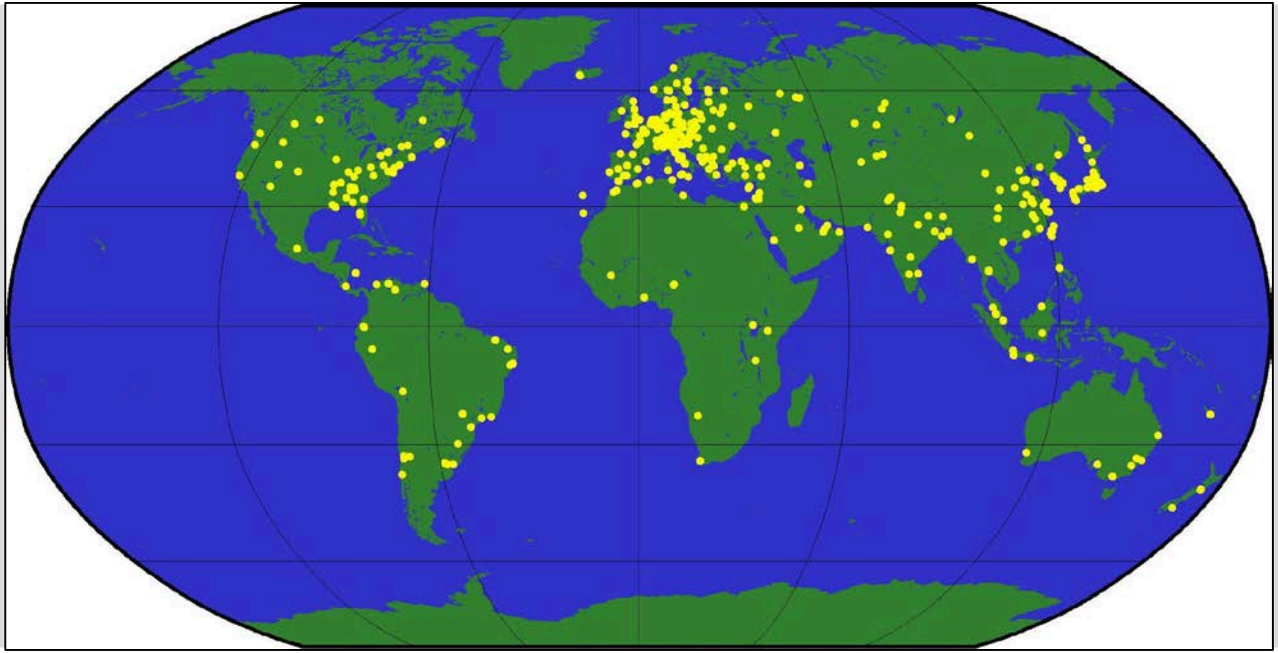



See presentation by O. Montenbruck

See presentation by E. Brockmann

# Bernese GNSS Software

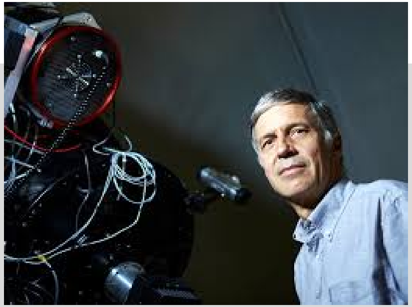


The Bernese GNSS Software is a scientific software package for high precision analysis of various space geodetic data. It is developed since many years at the Astronomical Institute of the University of Bern and it is meanwhile used by almost 800 institutions worldwide.

**Version 5.4 was released on 28 Sep 2022**

# Change in 2012





In 2012 I (left) was appointed as professor and director of the AIUB. The work was organized in three research groups:

*Satellite Geodesy* with Rolf Dach (2nd left)

*Optical Astronomy* and *Zimmerwald Observatory* with Thomas Schildknecht (3rd left) and Martin Ploner (4th left)

*History of Astronomy* with Andreas Verdun (5th left)

# GRACE Measurement Principle

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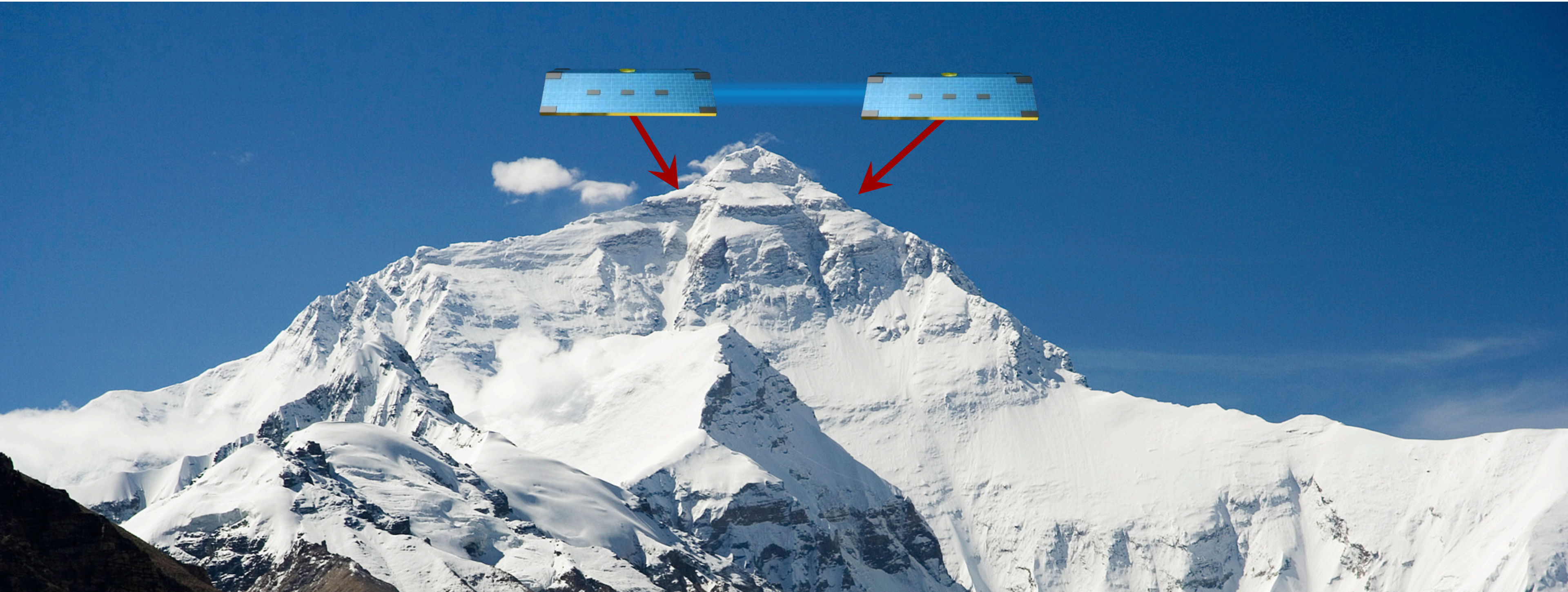
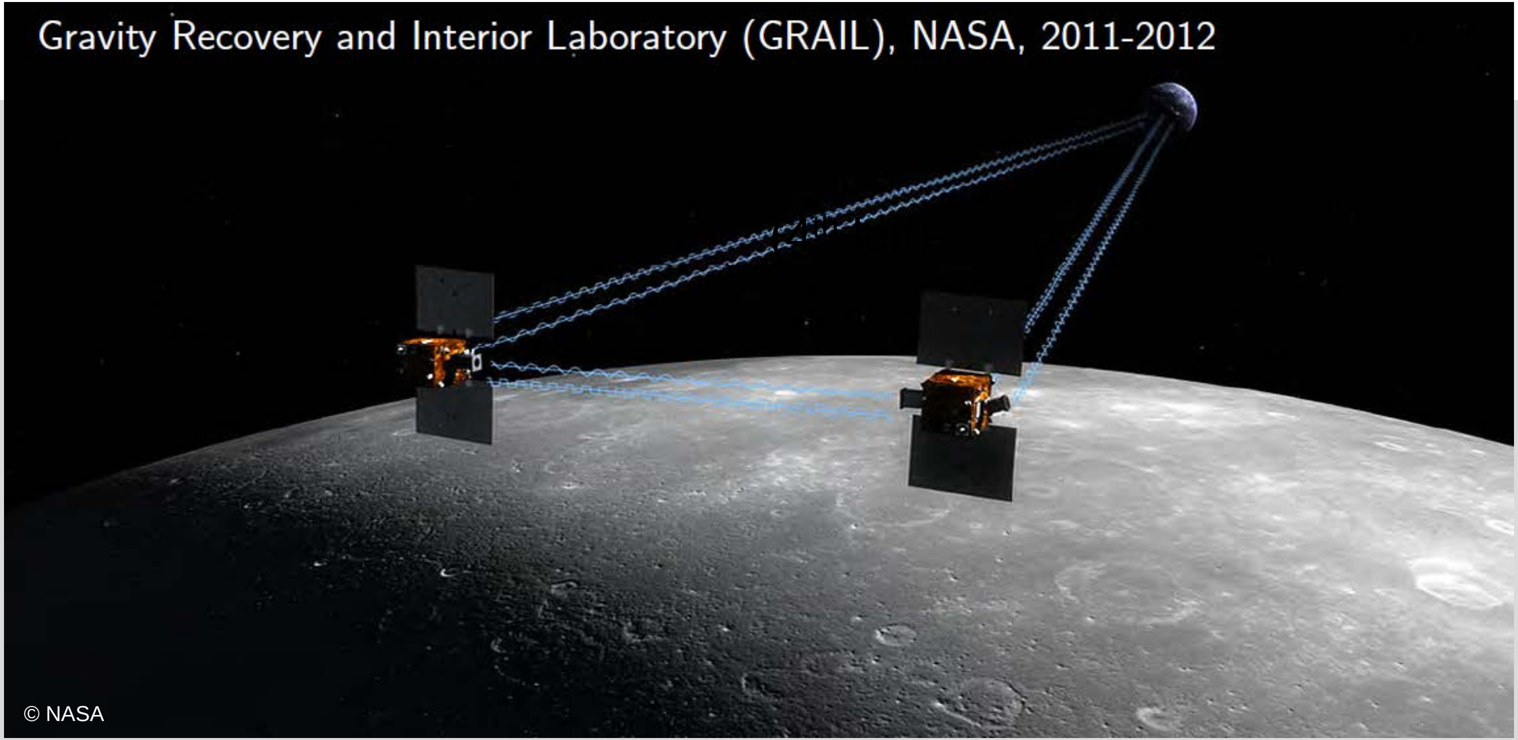
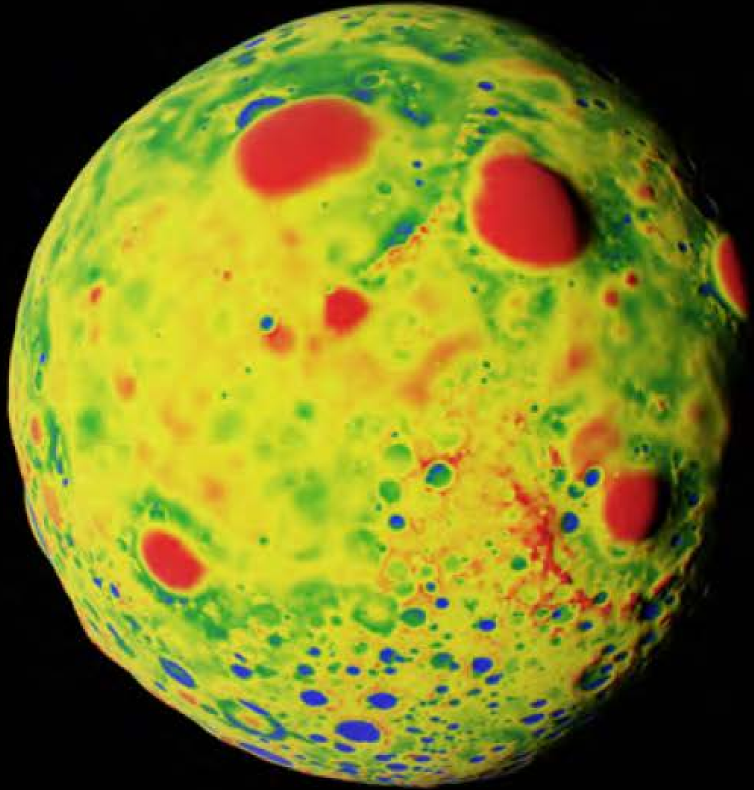


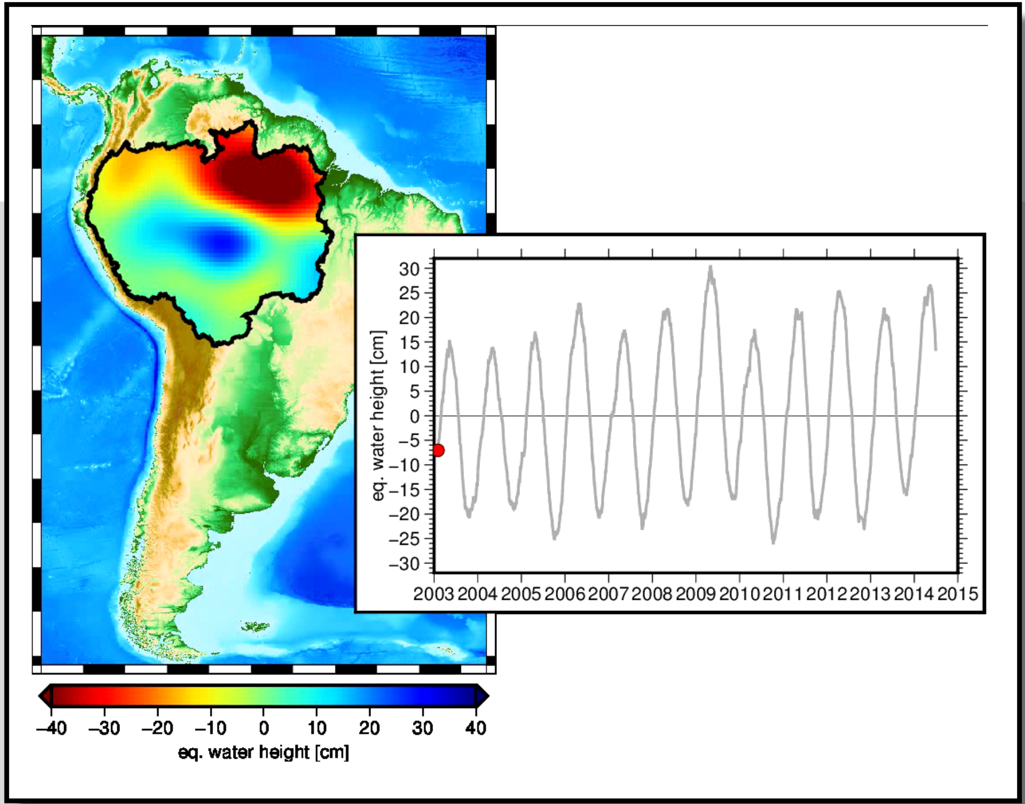
# Planetary Geodesy






# Amazon Basin

EGSIEM
European Gravity Service for Improved Emergency Management



# Melting Ice in Greenland

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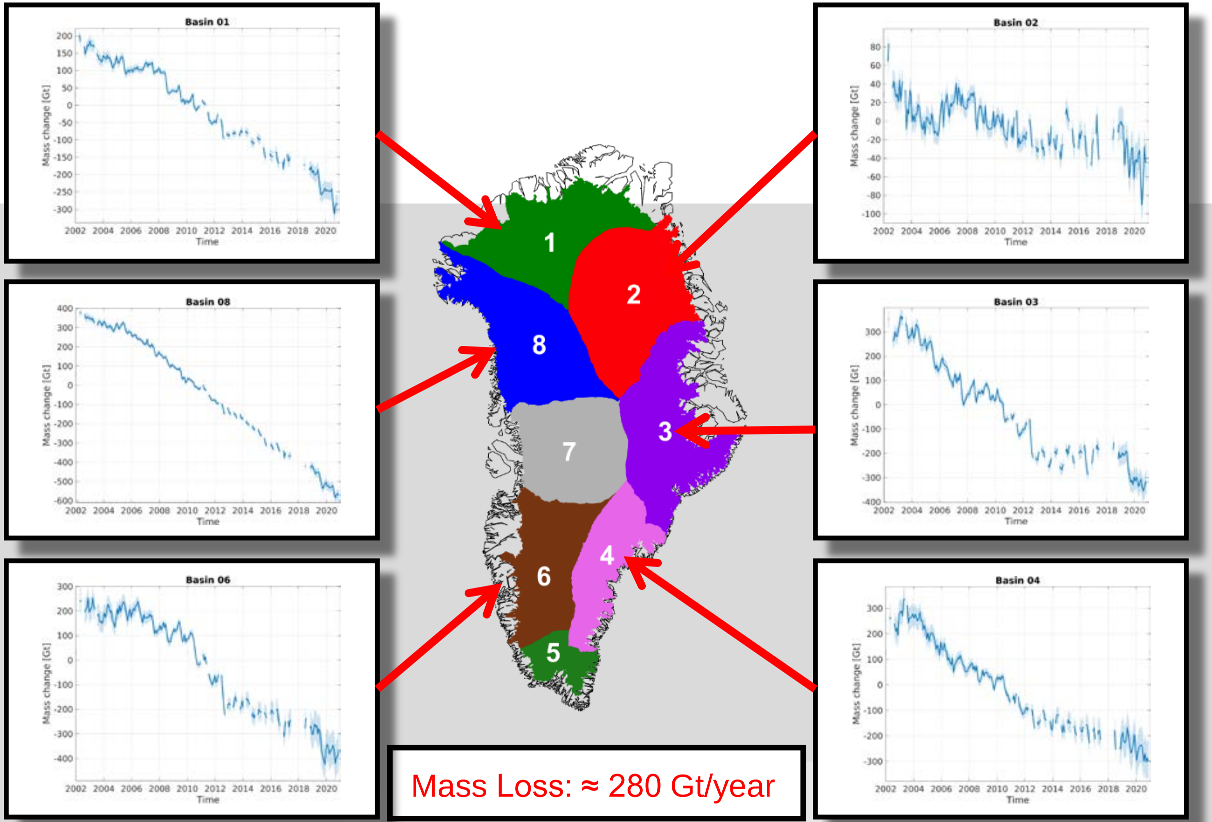
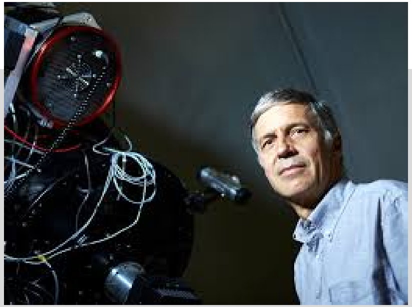
COST-G
Combination Service for Time-variable Gravity Fields




Mass Loss: ≈ 280 Gt/year

# Change in 2016

The work was still organized in three research groups with one split in two sub-groups:

*Satellite Geodesy* with

Rolf Dach (2nd left) focusing on CODE and Bernese

Daniel Arnold (3rd left) focusing on LEO orbit and gravity field determination

# European Gravity Initiatives



European Gravity Service for Improved Emergency Management

The University of Bern coordinated the H2020 project EGSIEM (2015-2017). It was explicitly mentioned in NASA's Decadal Survey and paved the way for current activities.

Combination Service for Time-variable Gravity Fields

Parts of EGSIEM are continued as a new IAG activity called COST-G, coordinated by the University of Bern.

The University of Bern triggered to strive for a H2020 follow-up of EGSIEM with the same gravity core-group as in EGSIEM: Global Gravity-based Groundwater Product (G3P), a H2020 project coordinated by GFZ (2020-2022).


EGSIEM
Hydrological Extreme Events
as Seen by GRACE
November 01, 2005
−25 −15 −5 5 15 25
Total Water Storage Anomaly [cm]
(seasonal and secular variations removed)

# Groundwater and the Earth's Gravity Field

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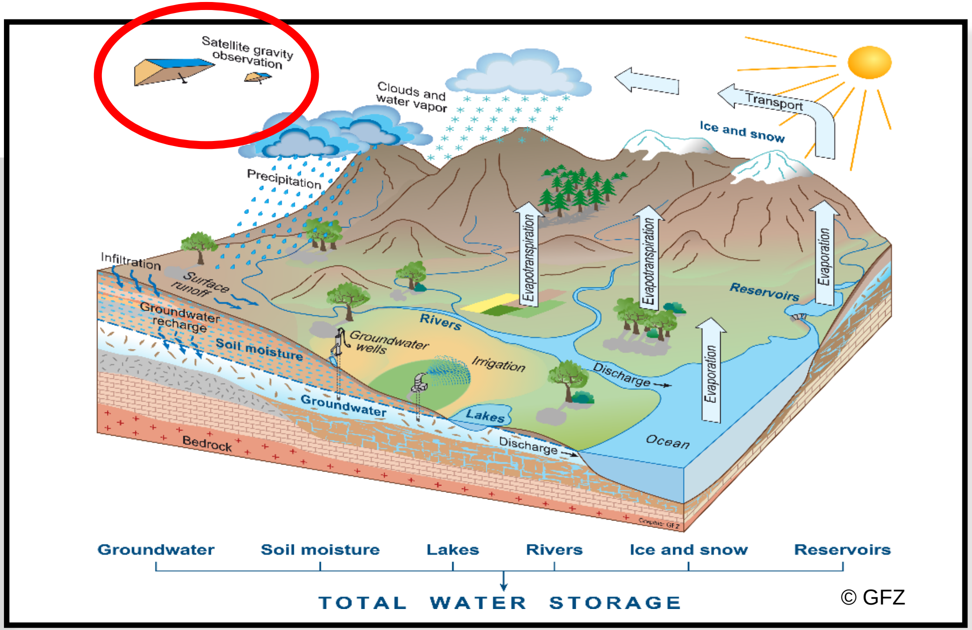
Combination Service for Time-variable Gravity Fields

G3P

- Satellite gravimetry with GRACE (2002 - 2017) and GRACE-FO (2018 - …) is the only technique available to observe **Terrestrial Water Storage** (TWS) variations

- A prototype for a global groundwater product is currently being established for later implementation in the Copernicus Climate Change Service.




Groundwater = TWS - glaciers - snow - soil moisture - storage in surface water bodies

G3P =  -  -  -  - 

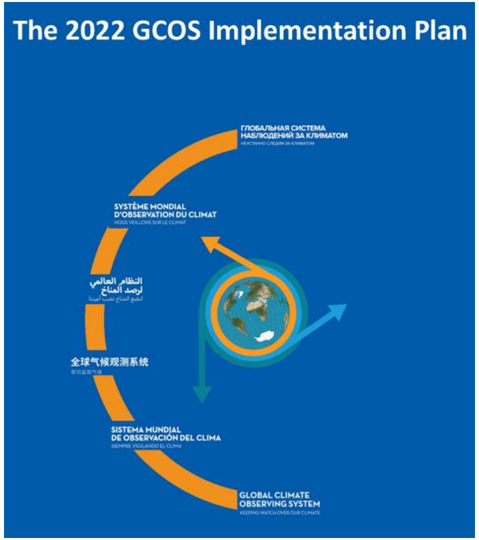
# Groundwater and the Earth’s Gravity Field



The **Global Climate Observing System** (GCOS) defines several so-called **Essential Climate Variables** (ECVs):

- a variable which is critical for characterizing the climate system and its changes

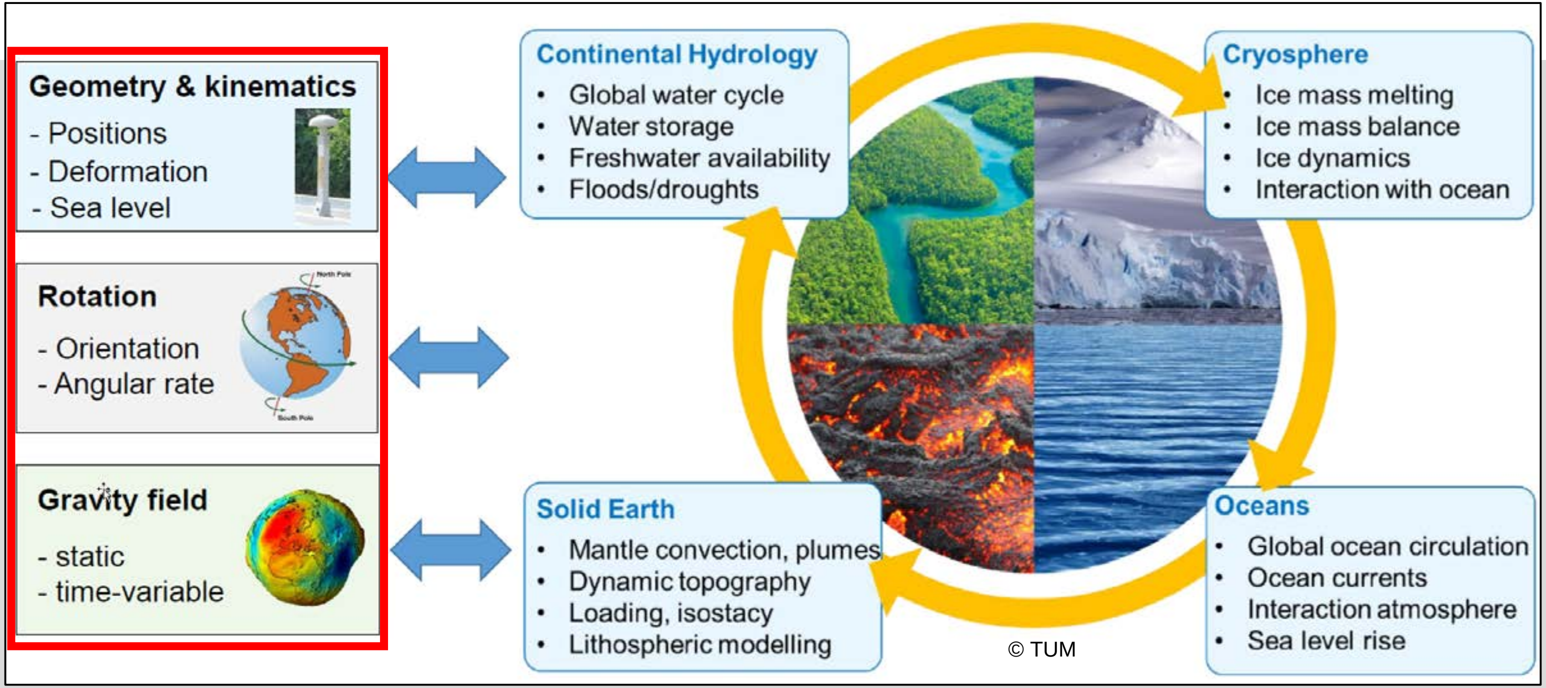
- ECV datasets provide the empirical basis to understand and predict the evolution of climate, to assess risks, to guide adaptation measures, to underpin climate services, …




Recent News: New ECV Terrestrial Water Storage now approved by GCOS


ECV Groundwater

# Earth System Processes and Geodetic Products




See presentation by M. Rothacher

# ERC Project SPACE TIE

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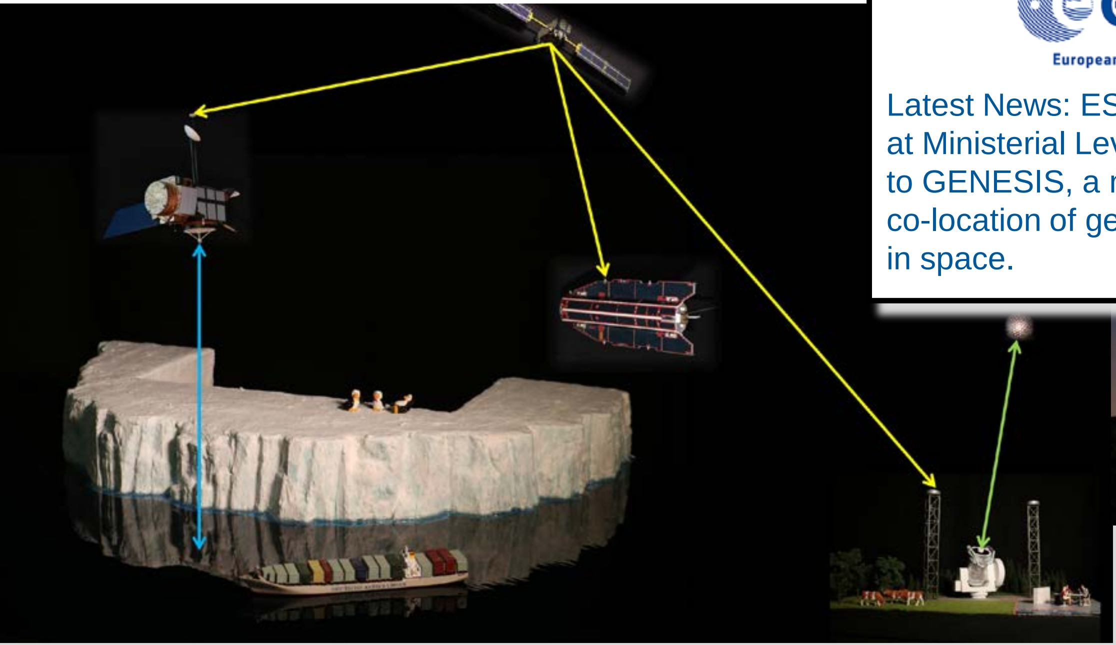
European Research Council
Established by the European Commission



European Space Agency

Latest News: ESA Council Meeting at Ministerial Level gave green light to GENESIS, a mission aiming at co-location of geodetic techniques in space.


=> **A more rigorous joint adjustment is envisaged**

# Sustainable Satellites are serving Society

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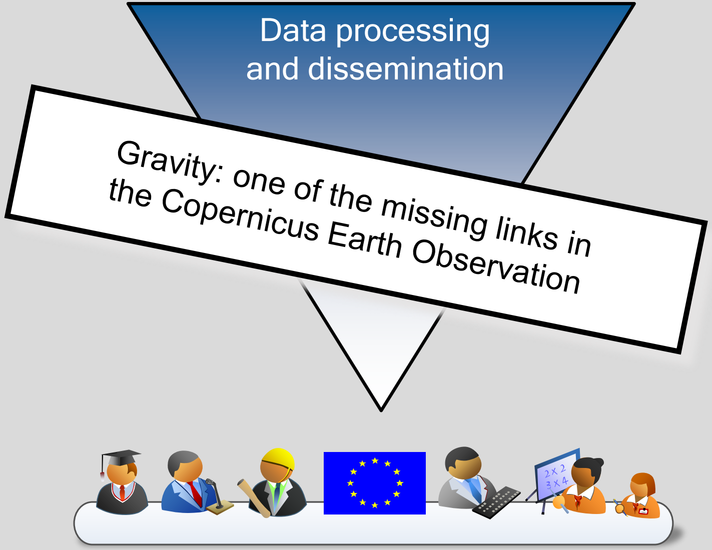
BERN




**Service evolution:**

- Atmosphere monitoring
- Marine environment monitoring
- Emergency management
- Land monitoring
- Climate change

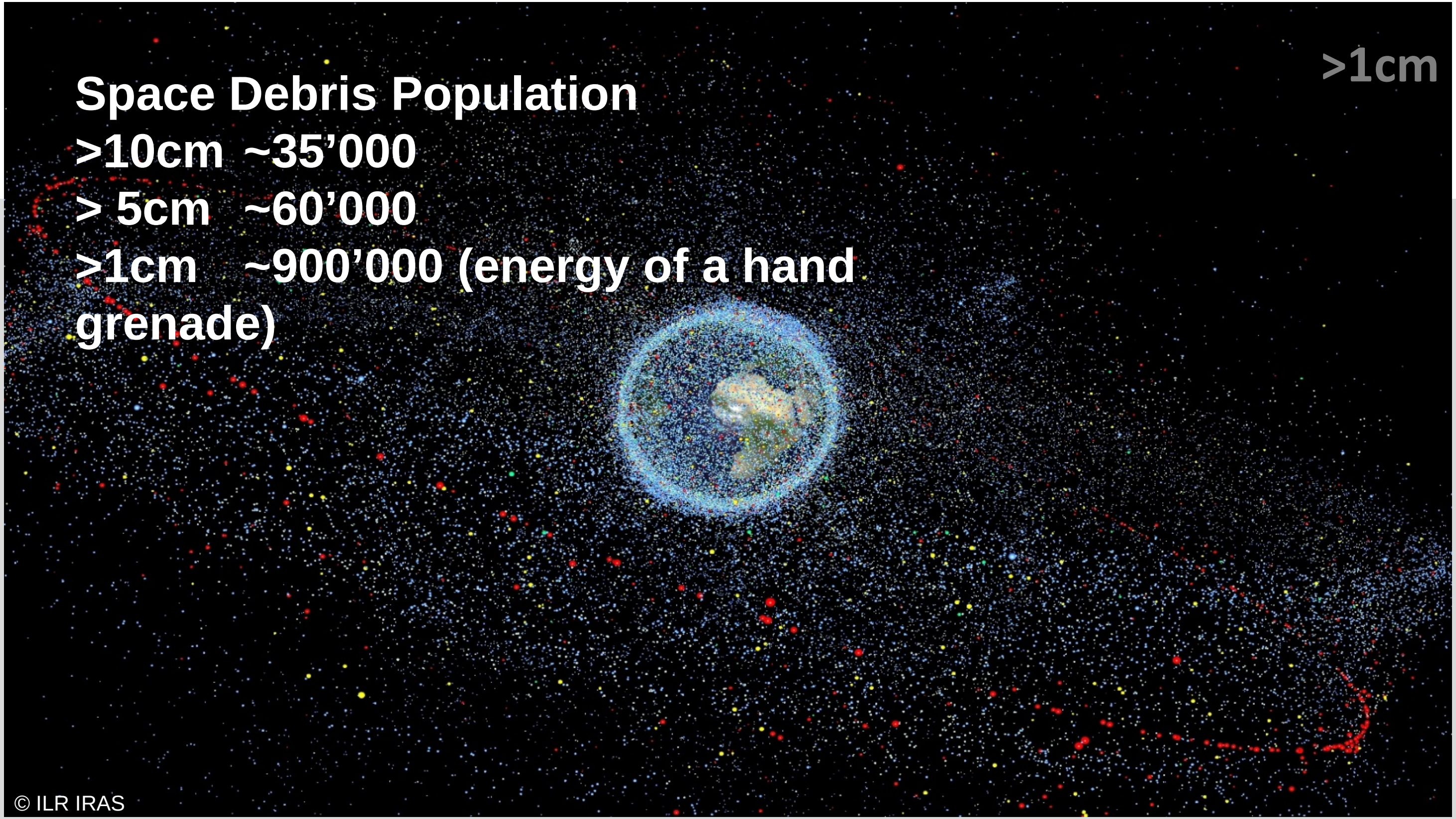
Copernicus
Europe's eyes on Earth



esa
European Space Agency

Latest News: ESA Council Meeting at Ministerial Level gave green light to Mass change And Geosciences International Constellation (MAGIC)

# Long-Term Sustainability of Outer Space Activities




See presentations by T. Flohrer and C. Nicollier

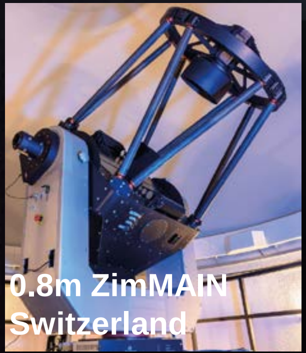
# Observing and Cataloguing Space Debris

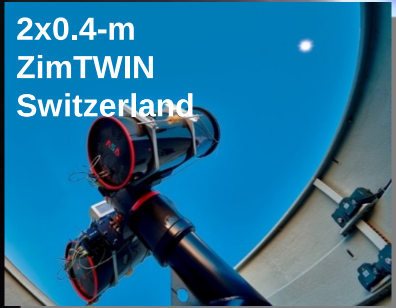
**Observation data to be processed per night**

- **from up to 6 telescopes**
- **> 10’000 images**
- **up to 400GB**

**Orbits of 1000+ objects computed and propagated daily**





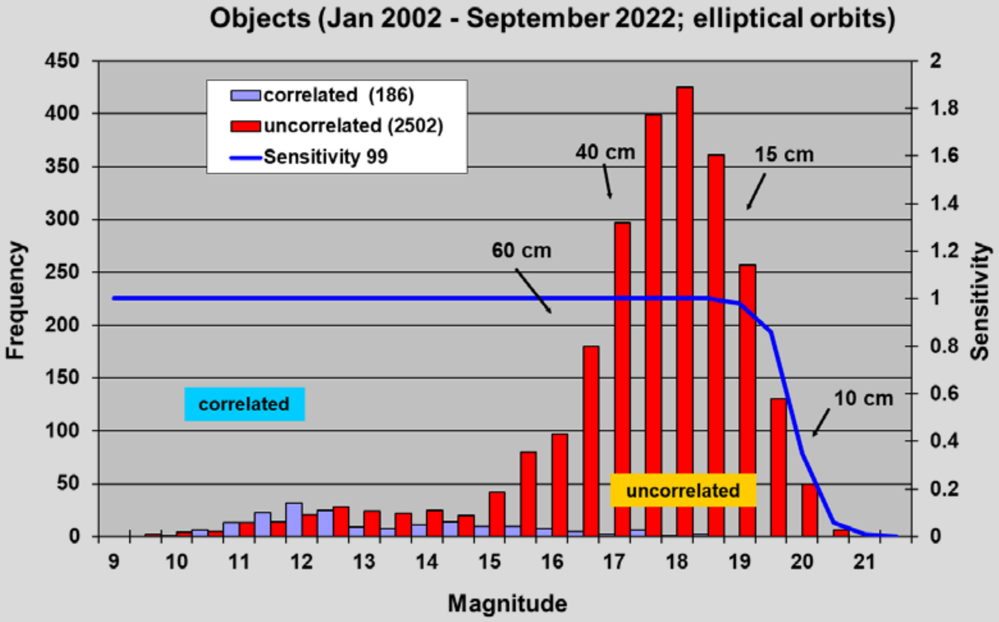





See presentation by T. Flohrer

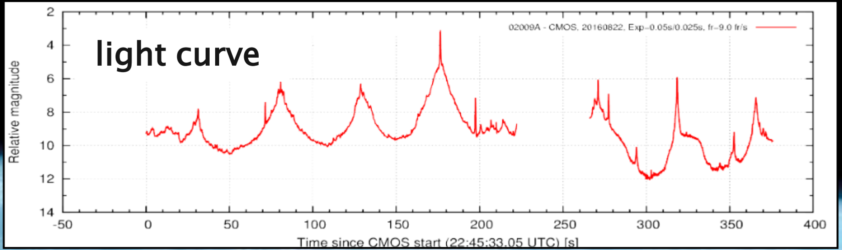
# Observing and Cataloguing Space Debris





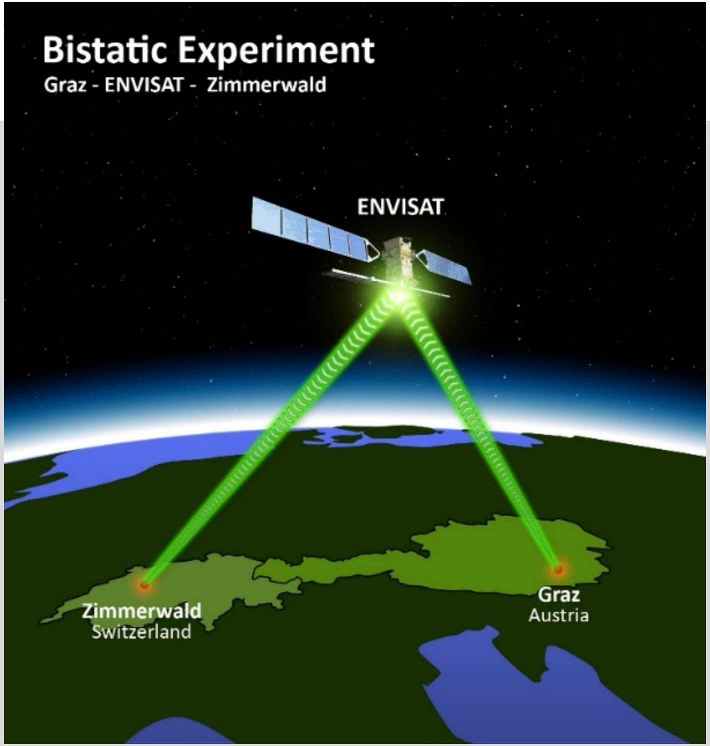

- Discovery of a new, unexpected population of small objects in GEO/GTO orbits.
- red bars: discovered by AIUB/ESA surveys
- blue bars: “known” objects
- discovery of high A/m objects
- blue line: sensitivity limit of sensors

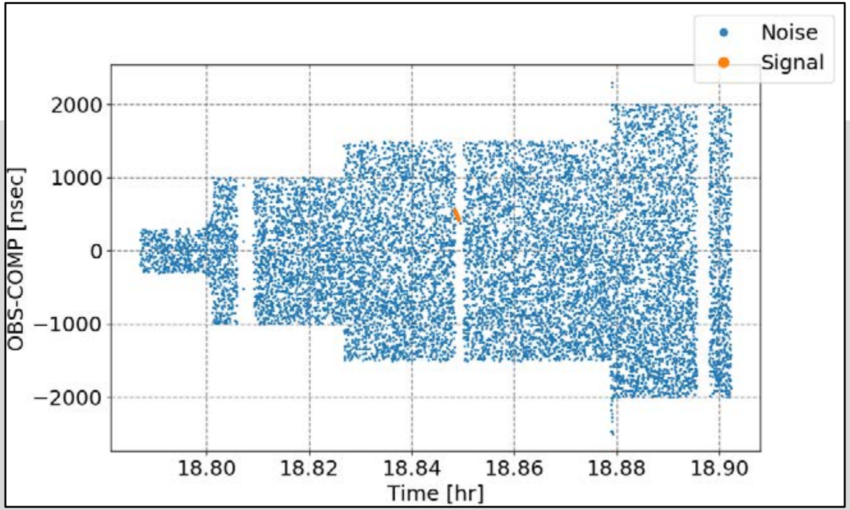
# Determination of Attitude Motion for Debris Removal





# High-Accuracy Orbits of Space Debris



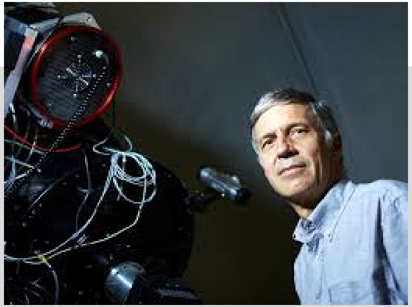




Space Debris Laser Ranging

- determination of high-accuracy orbits
- allows for efficient collision avoidance maneuvers
- night & daytime

# Change in 2022



The work is currently organized in four research groups. The new research group is addressing:

*Space Weather* with

Lucia Kleint (5th left) focusing on machine learning to understand solar eruptions

Lucia Kleint (5th left) also acting as Vice-Director of the Zimmerwald Observatory

Many thanks to the AIUB team,

both former and current members,

for all the contributions over so many years!

Thank you very much for your attention!