# Mesosphere Magnetometry

Martin Losekamm, Peter Fierlinger, Stephan Paul

Florian Kuchler

Technische Universität München

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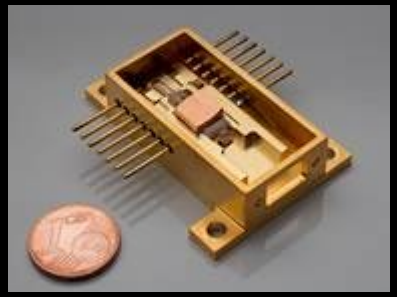
Kloster Irsee

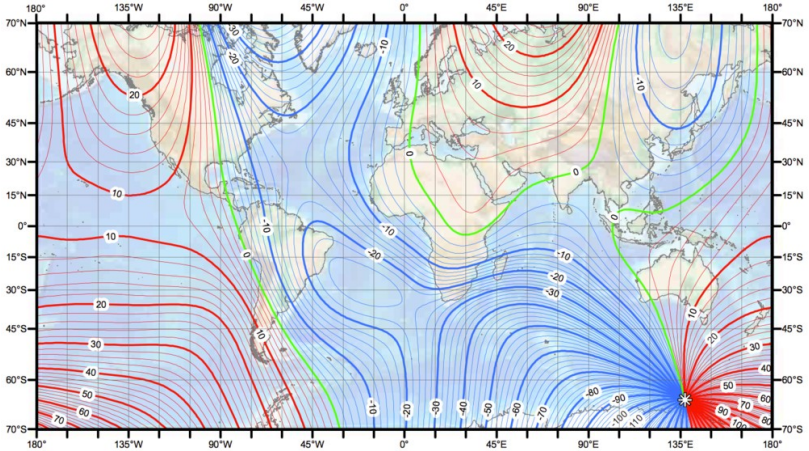


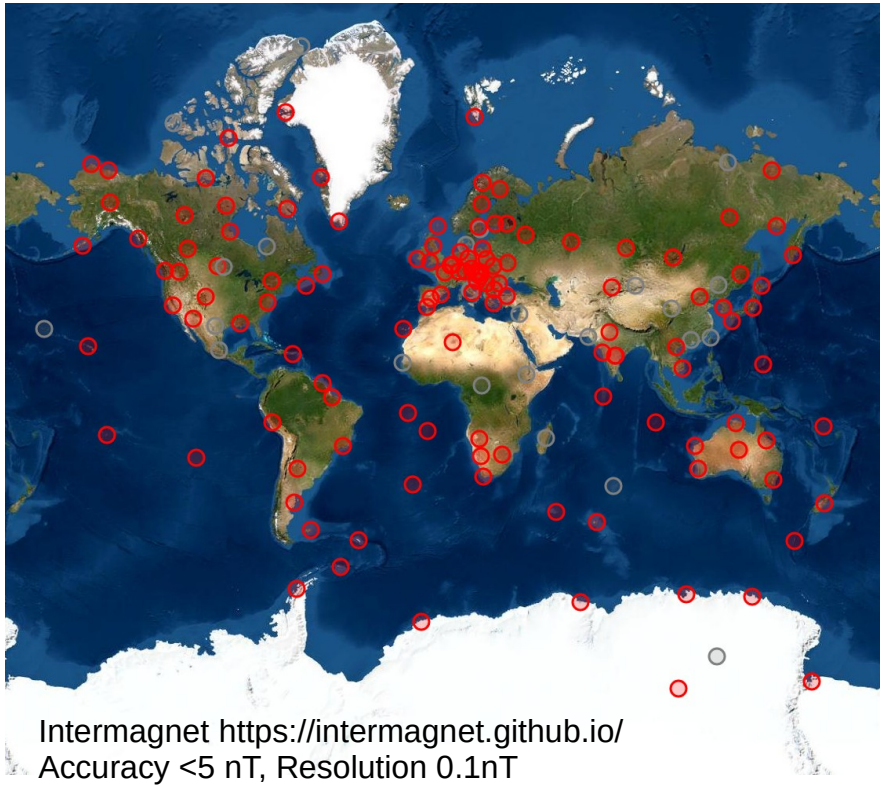
# Measurement of the Earth's magnetic field

Contributions to Earth's magnetic field:
- currents in Earth's core and mantle
- ionospheric
- tropospheric
- oceanic currents
- magnetization in Earth's crust

→ several percent

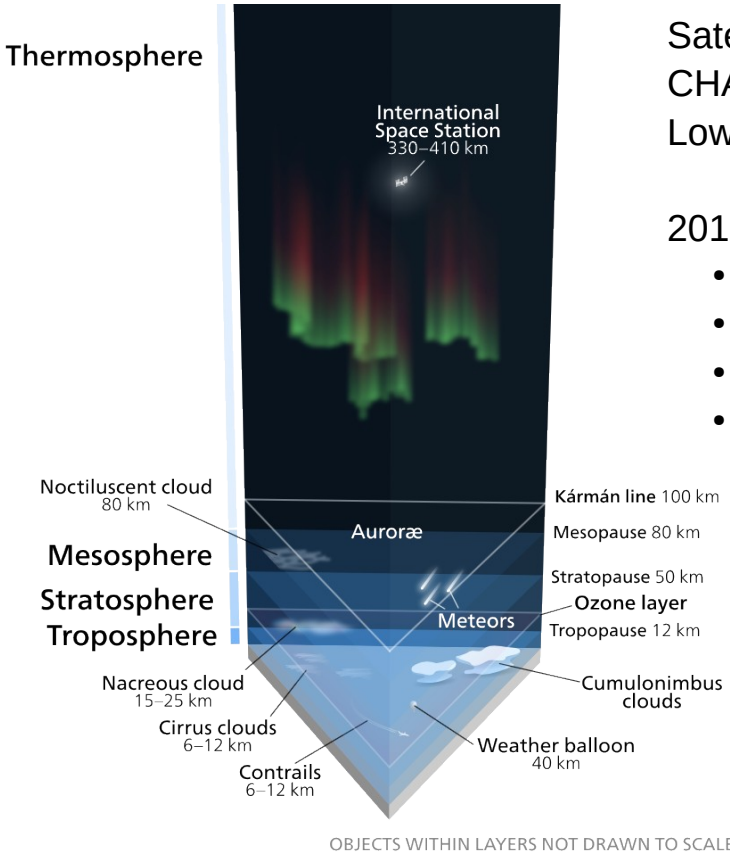
Important e.g. for navigation: GPS coordinate + direction → declination maps





Intermagnet https://intermagnet.github.io/
Accuracy <5 nT, Resolution 0.1nT

# Status of earth field magnetometry in space




Satellite based data:
CHAMP 2000-20210: mapped Earth's magnetic field (and gravity field)
Low Earth Orbit (450km), 0.5 nT resolution on 100-200km scales

2019 MagQuest competition (2.1 M$):

- 400-800km orbit
- accuracy/noise <5 nT (vector and scalar magnetometer)
- five winners (Oct 2020) CubeSat based and land/sea floor
- target operation 2027

→ No measurement yet in the mesosphere
(altitude 50-100km, Earth's magnetic field ~40 uT)

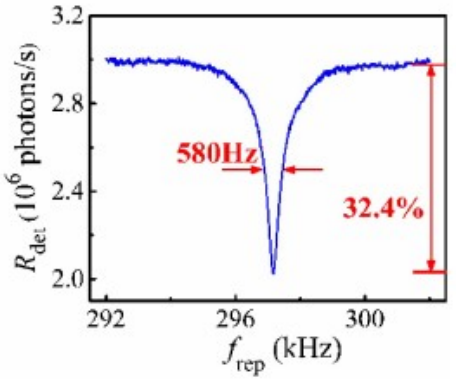
~5-10 km thick Layer of Na vapor in 85-100 km altitude

(used to create light sources for adaptive optics
→ Laser Guide Stars)

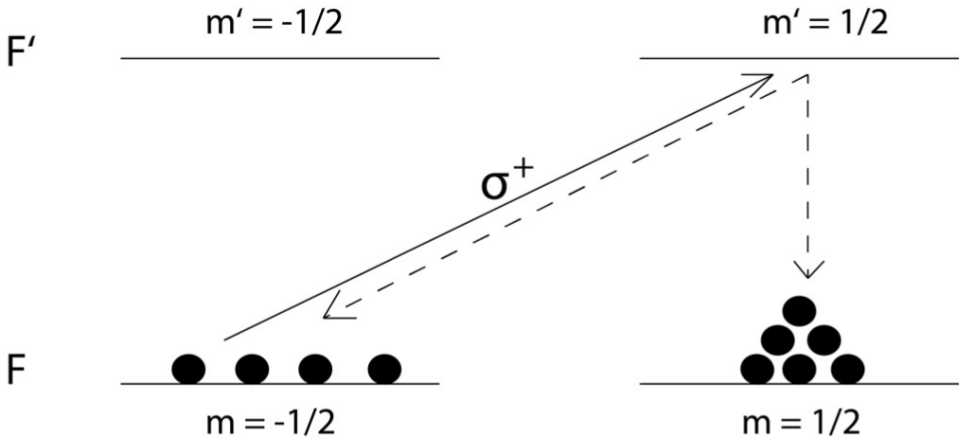
# Na magnetometry

<u>Na properties</u>
Gyromagnetic ratio: 6.99812 Hz/nT ($\rightarrow \omega_L$ = 260 kHz @ 37μT)

D1 line (**589**.7558 nm, $3^2S_{1/2} \rightarrow 3^2P_{1/2}$, nat. linewidth 61.35 MHz)
D2 line (**589**.1583 nm, $3^2S_{1/2} \rightarrow 3^2P_{3/2}$, nat. linewidth 61.54 MHz)




Example from:
Fan et al, Opt. Lett. 43, 1-4 (2018)




Optical pumping of Na vapor by intensity modulation: $\omega_L - \Delta\omega < \omega_{AOM} < \omega_L + \Delta\omega$

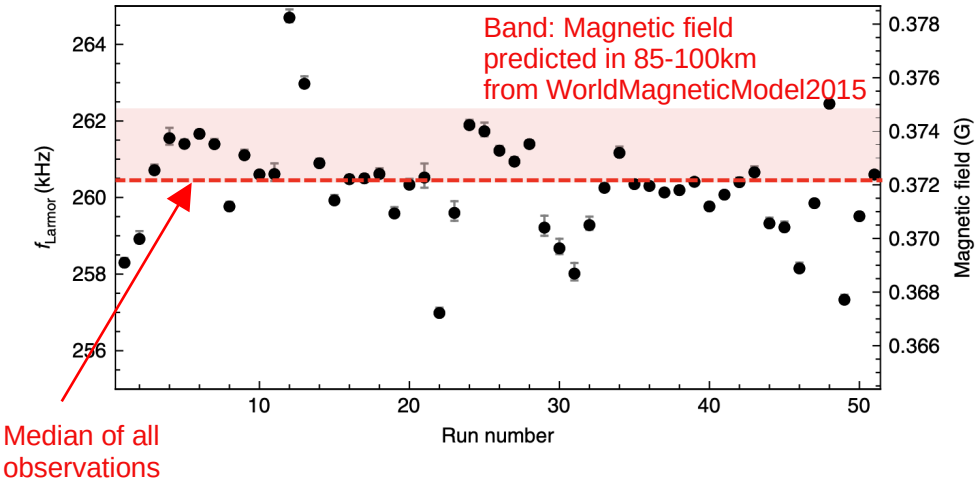
→ modulation using acousto-optical modulator (AOM)

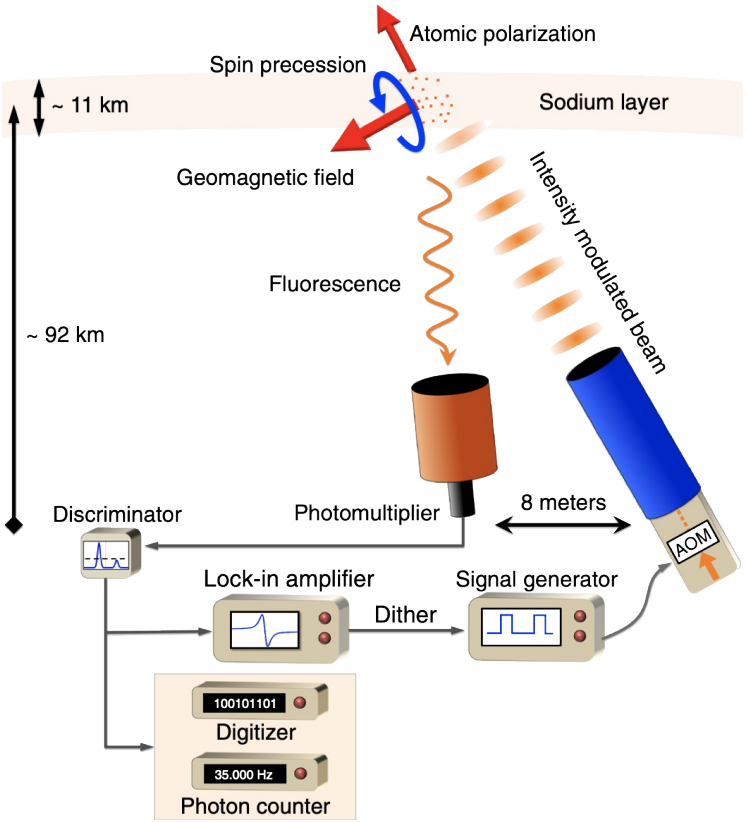
→ resonance signal, fit yields magnetic field

# Status of mesosphere magnetometry

Ground based

- Na layer excitation by high power guidestar laser
- Fluorescence detection by large telescope
- Sensitivity: 28 nT/sqrt(Hz)
- Demonstrated for one point
- Limited view per station




F. Bustos et al., Nature Comm. 9 3981 (2018)

# Idea: Satellite based mesosphere magnetometry

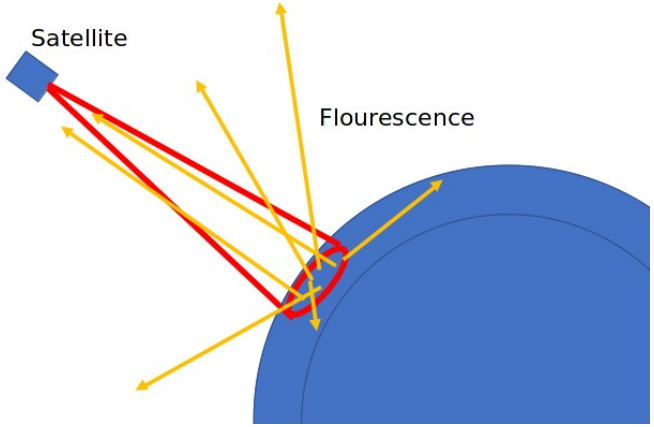
CubeSat platform, up to 3U (10cm x 10cm x 30cm)
Orbit in 450 km height

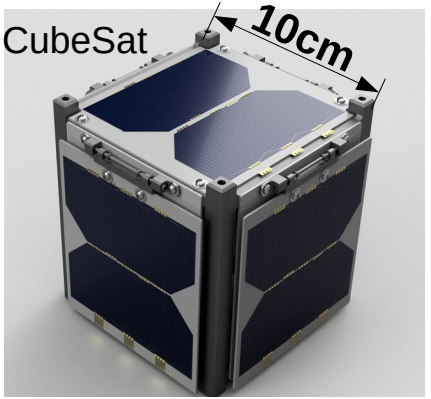
- Optical pumping of Na atoms at 589nm (D1 or D2 line)

- Detect fluorescence with encoded magnetometer signal
  → losses ~$1/r^2$
  → large area collection mirror (>$1m^2$)
  → background light (natural, Na lamps,...)
- Use laser pulse sequences for timing and background suppression

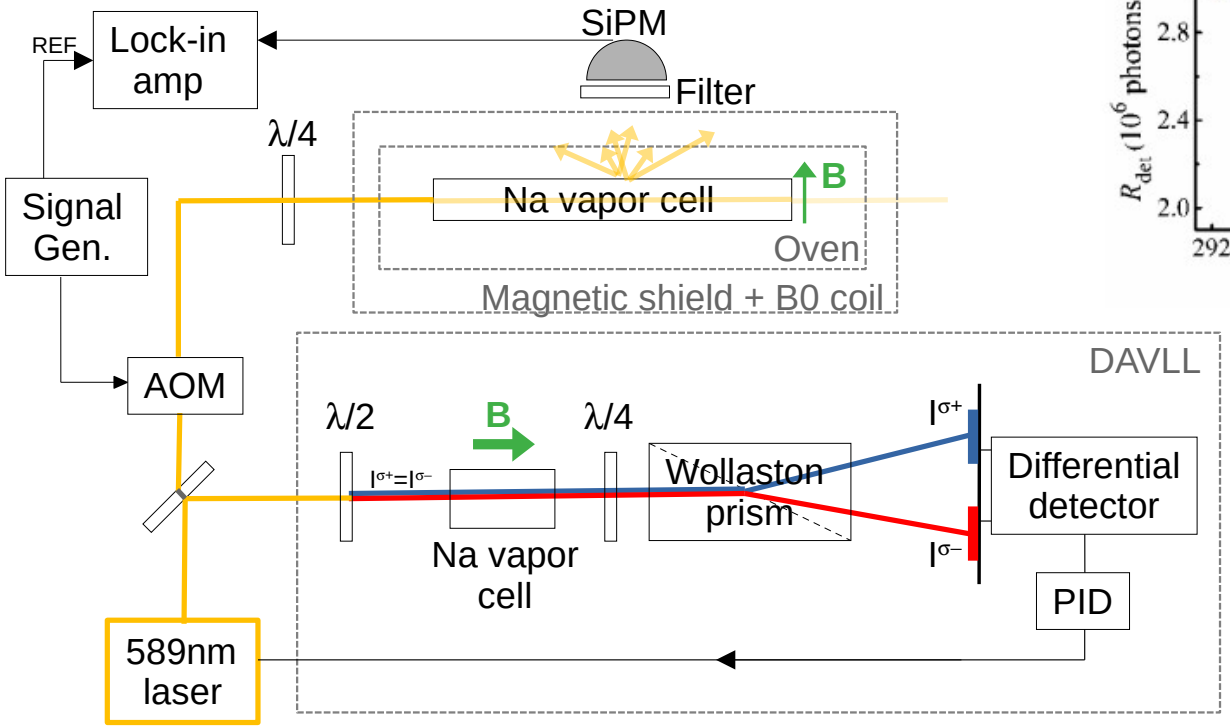
- Expected signal:
  200 mW laser → 0.37 photons/pulse/$m^2$

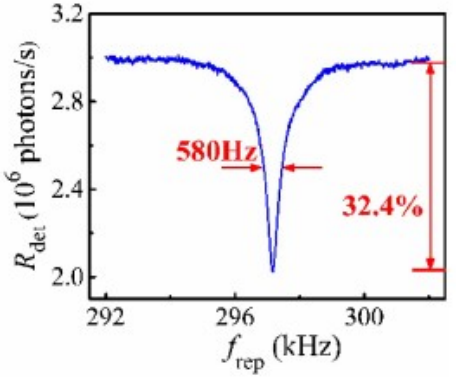
→ Magnetometry from EDM experiments applied to LRSM



# Lab setup for feasibility studies




Fan et al, Opt. Lett. 43, 1-4 (2018)

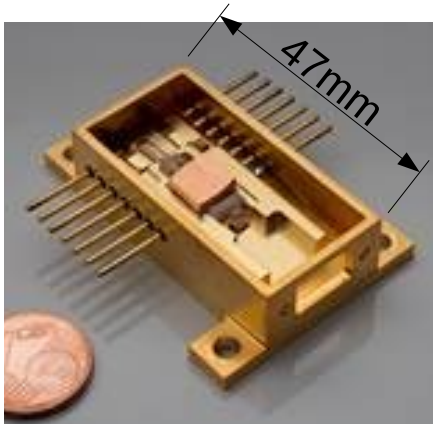
**D**ichroic **A**tomic **V**apor **L**aser **L**ock
Corwin, Appl. Opt. 37, 809 (1998)
Lee, Rev. Sci. Instr. 82, 043107 (2011)

(used in Cs magnetometers for neutron EDM)

# Critical paths identified

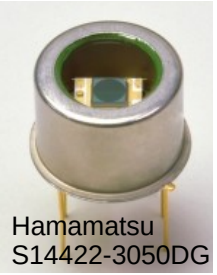
Light source:

- High power light source development in new collaboration with FBH Berlin
  - Maximize output power min 1-1.5W,
  - Starting with demonstrator module (50mW, linewidth <10pm)
- Modulation (~260 kHz) using AOM
- Stabilization <MHz using DAVLL




Light detection:

- Silicon Photo Multiplier (SiPM)
- Narrow optical filters
- Detector and optical filter test on ISS in 2022 (>1/2 yr timescale)
- Background?


Hamamatsu
S14422-3050DG

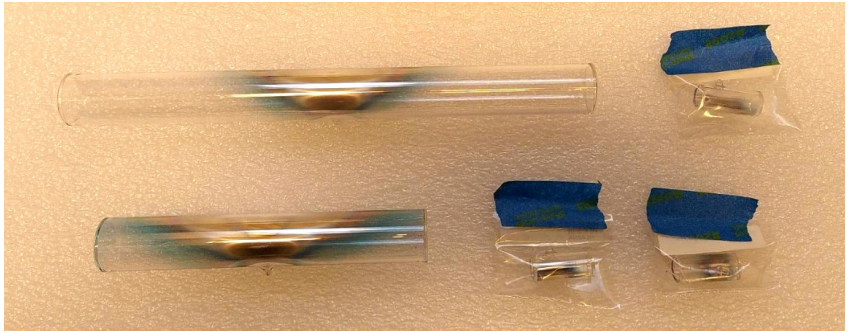
# Spectroscopy cells for feasibility studies

„Standard“ sodium magnetometry and spectroscopy
(→ laser lock, DAVLL)

Designed to imitate conditions in the lab

- sealed, prefilled with Na: 150 & 250mm length
- valved: 300mm length
- valved, prefilled with Na: 200mm

Idea is to vary Na density, pressure, gas composition



Na layer properties:

$\rho = 3 \times 10^3\ cm^{-3}$

$\tau = 250\ \mu s$ ($Na\text{-}O_2$ collisions, $\sigma_{NaO}$ not yet measured)

$T = 180\ K$

Magnetometer sensitivity ~ (Na density * spin coherence time * photons detected)$^{-1}$

# Status and outlook

- Our approach has never been done before
  → identified challenging items and found promising solutions → funding proposals

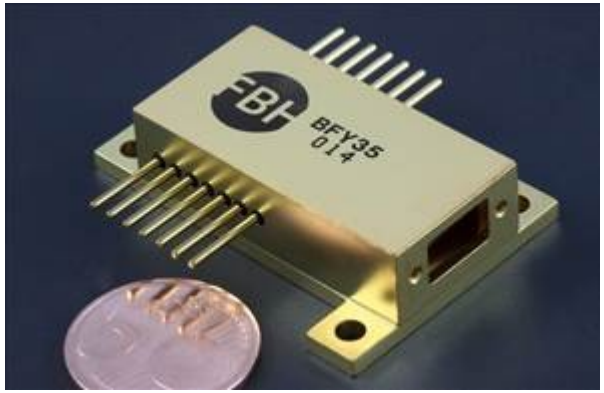
- Initiating collaboration with K. Paschke at FBH Berlin (and space mission experts)
  → Delivery of 50 mW (linewidth <10pm) demonstrator module (now)
  → Development of high power laser module (up to 1.5 W already possible)

- Planning detector test in space to determine background
  (2-3 SiPM detectors incl optical filters on ISS in 2022:
  IOV-1 experiment → see M. Losekamm's talk)

- Spectroscopy cells designed and (almost all) delivered

- Dedicated lab in the Physics Department at TUM being setup now

- Integration and implementation of equipment on (3U) CubeSat

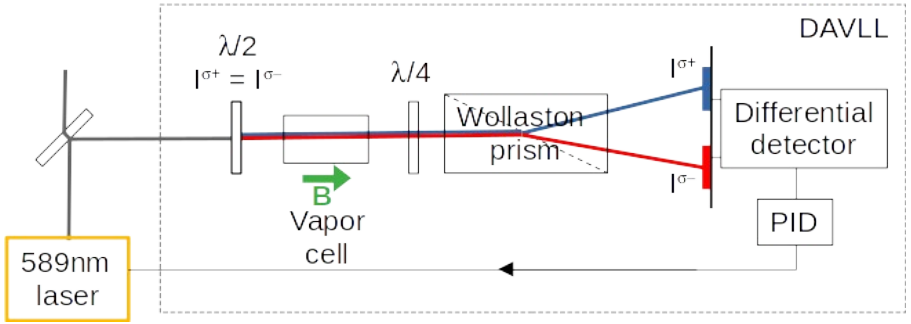


# Conclusion

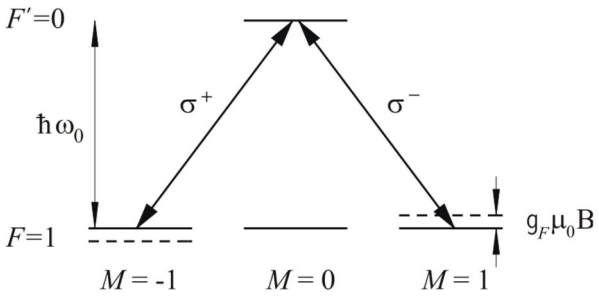
- New approach to map Earth's magnetic field from space → highly valuable data
- Applying atomic magnetometry techniques from fundametal physics
- Broad project scope:
  - Application of fundamental physics techniques (E18 S. Paul, E66 P. Fierlinger)
  - Satellites and space missions (LRSM, Chair of Astronautics U. Walter)
  - Geodesy, Geophysics,…

# Backup slides

# DAVLL laser lock




Dichroic Atomic Vapor Laser Lock

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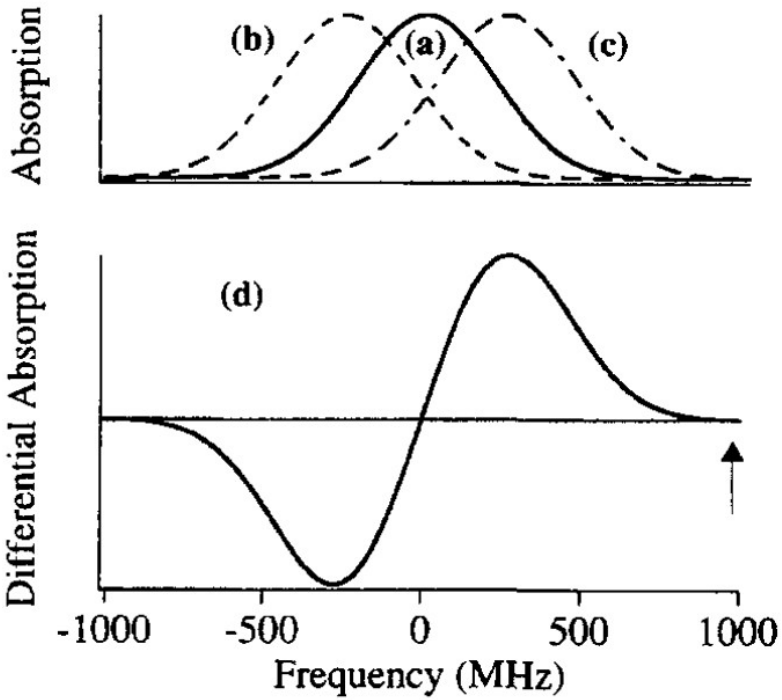
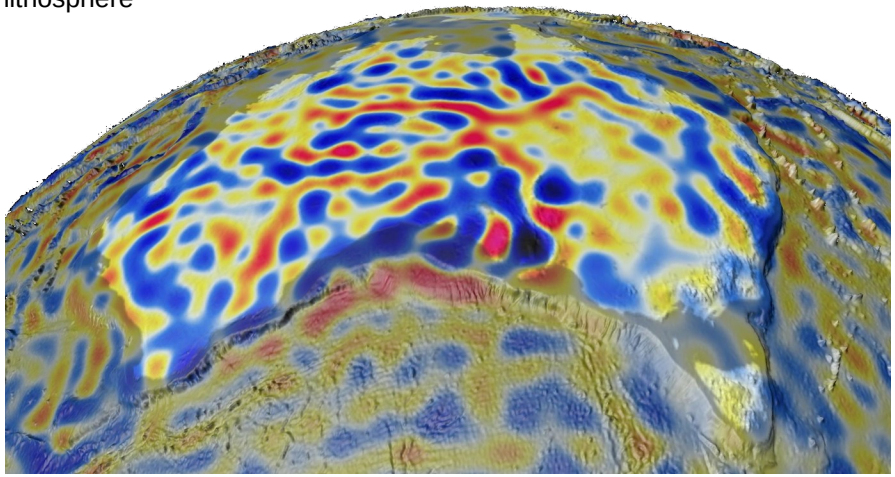


# CHAMP mission

**CHA**llenging **M**inisatellite **P**ayload
522kg, 8.33m length, designed for 5 years

Overhauser and Fluxgate Magnetometers

The most detailed map ever of the tiny magnetic signals generated by Earth's lithosphere



https://www.esa.int/ESA_Multimedia/Images/2018/04/Magnetic_lithosphere_detailed

## CHAMP Satellite Subsystem Parameters

### Attitude & Orbit Control System (AOCS)

- Three -axis attitude stabilised
- Earth-pointing
- Pointing accuracy < 5°
- Stability: 0,1°/s

### Electrical Power

- Power consumption: 150W
- Payload: 50W
- Generation (solar array) 6,9m$^2$
- Storage capacity (NiH2-Battery): 16Ah

### Thermal Control

- Average temperature (Equipment platform): +20°C
- Radiator: e = 0,5
- 18 layer flat foil heaters, each 7W
- 60 Sensors Pt 1000
- Power Sensitivity: 3,1°C/10W

### Data Handling

- Central Processor Type: P3/1750
- Operating frequency: 12 MHz
- Data Storage:
  - RAM/ROM: 1024/256 kByte
  - Mass Memory Capacity: 1Gbit

### RF Communication

- Uplink (S-Band) Carrier Frequency: 2093,5MHz Data Rate: 4kbit/s
- Downlink (S-Band) Carrier Frequency: 2280 MHz
- Data Rate: 32kbit/s or 1Mbit/s
- RF Output Power: 0,5 or 1,0 W