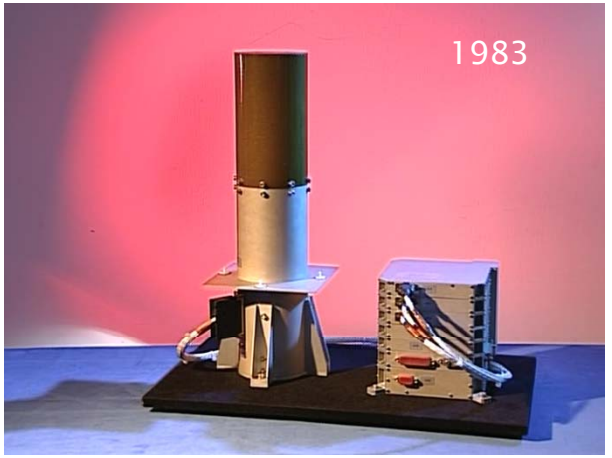
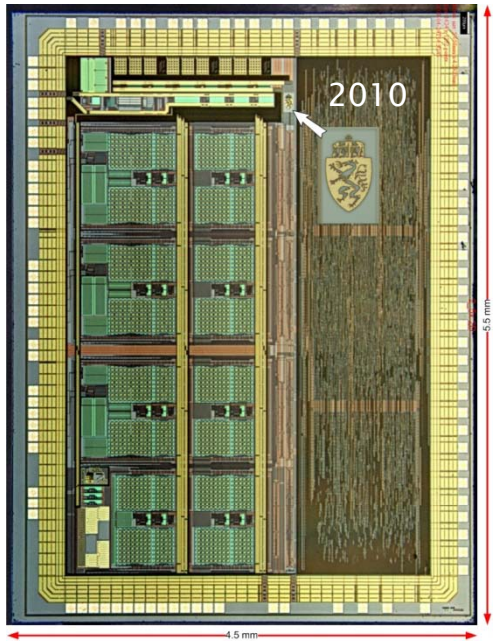
Development of Space Magnetometers at IWF Graz



Graz in Space 2010
September 10, 2010

Dr. Werner Magnes
Space Research Institute (IWF)
Austrian Academy of Sciences



Outline

- Magnetic Field – Magnetometer
- Fluxgate Magnetometer
- IWF – Eighties and Nineties
  - Russian Missions, Spacelab …
- IWF – New Millennium
  - Cluster, Rosetta, Themis, VENUS EXPRESS …
- Future Directions
  - Laser/Atomic Magnetometer
- Calibration and Test
- Magnes and Magnetic Field

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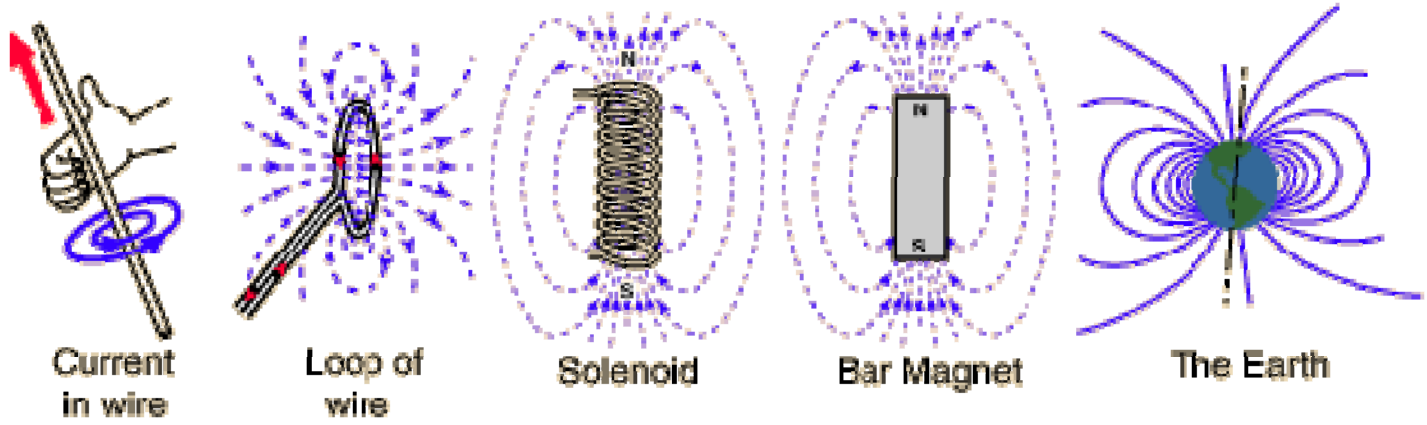
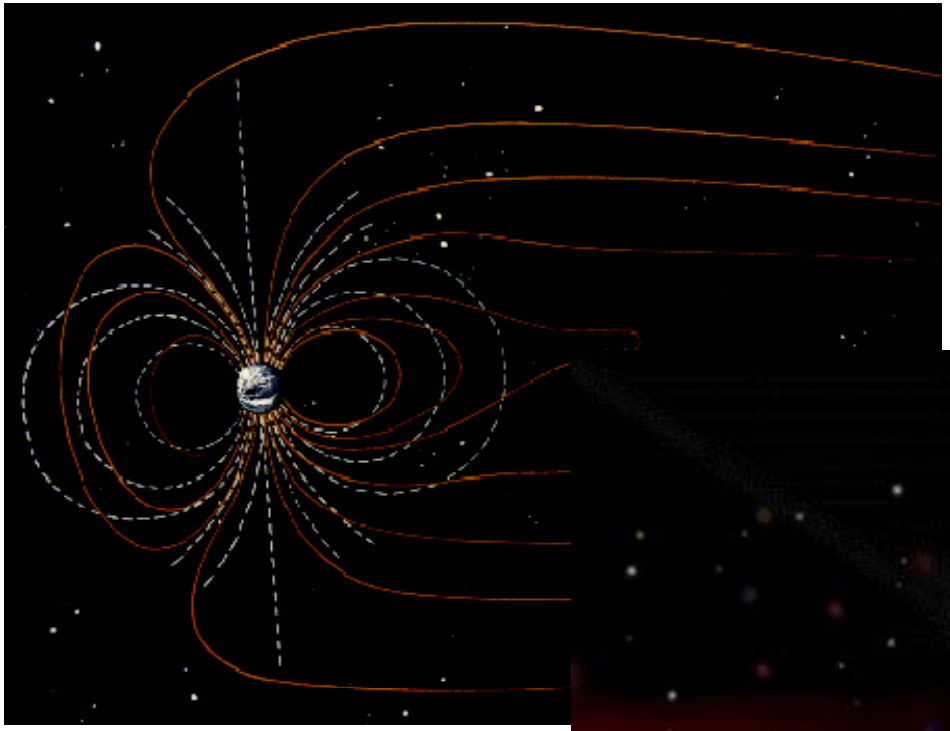
Magnetic Fields

Compass needle in Earth‘s field

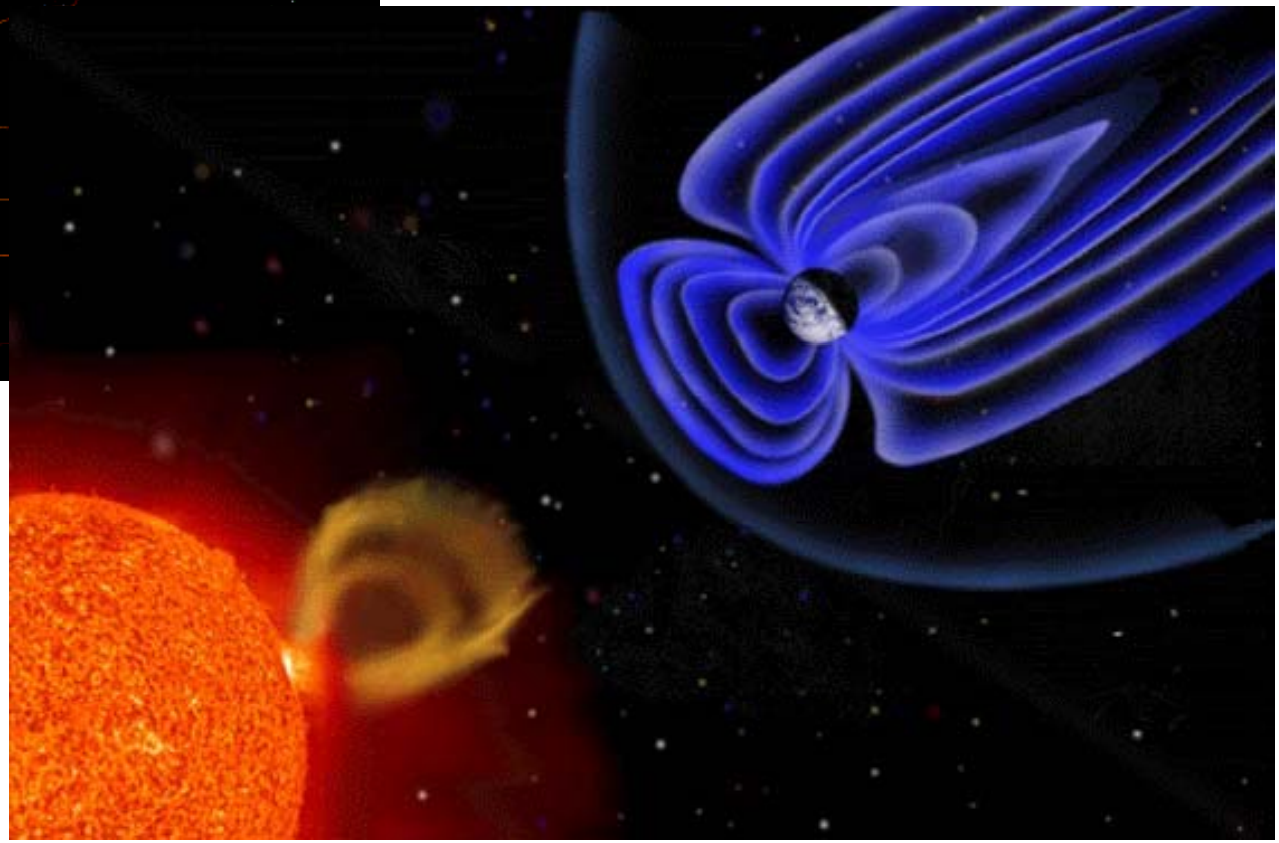
Sources of magnetic fields



Earth's Magnetic Field

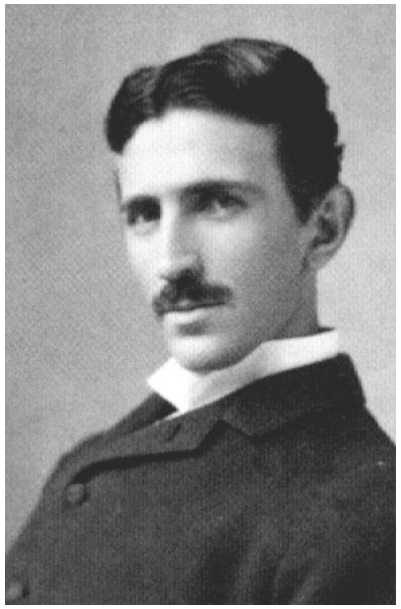


… driven by the Sun and the Interior!



Nano – Tesla (nT)

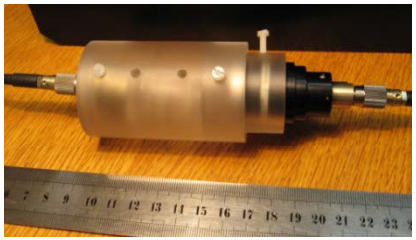
- Magnetic field – Value and Direction
- Tesla is the unit for the magnetic flux density
- We measure nano-Tesla (nT) or *'Dwarf-Tesla'*
- *Nano … 10^{-9}*



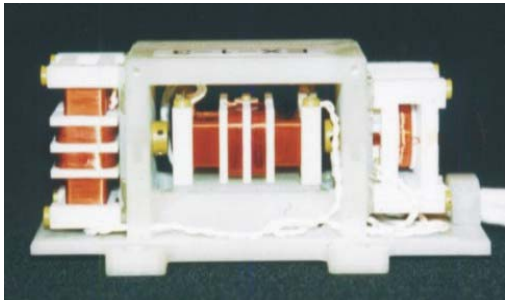
- Nikola Tesla: * 10th July 1856 in Smiljan
- Studied in Graz 1875/76
- Brilliant Inventor

3 Types of Magnetometers

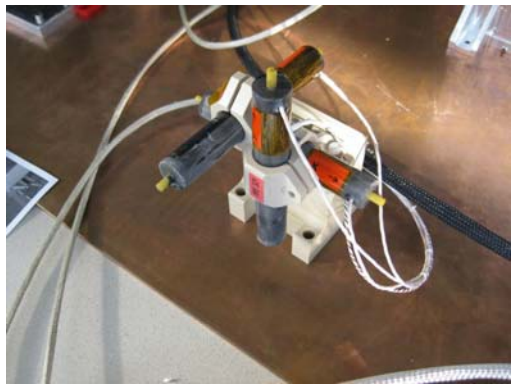
- Scalar Magnetometers
  - measure just the scalar value but with very high accuracy
- Fluxgate Magnetometers
  - measure value and direction of the DC and low frequency magnetic field up to a few hundred Hz
- Search Coil Magnetometers
  - measure value and direction of the high frequency magnetic field (from a few Hz up to several kHz)



Austrian Scalar Sensor (TUG)



German Equator-S Sensor (TU-BS)



French MMS Sensor (LPP)

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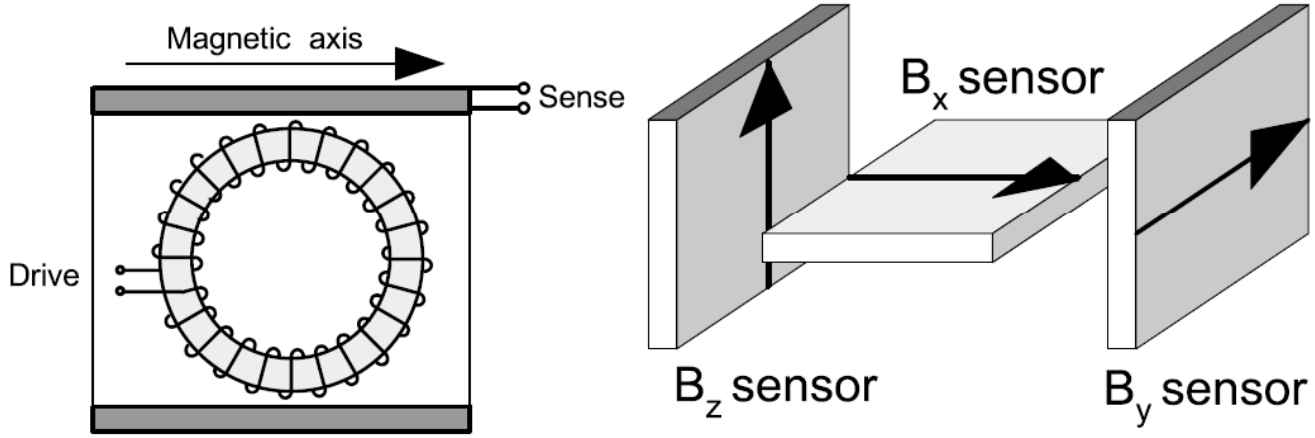
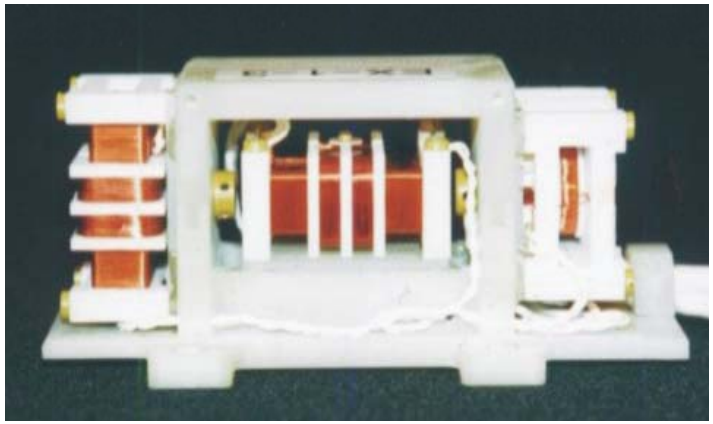
Traditional Fluxgate Sensors

Sketch of a signel axis based fluxgate sensor



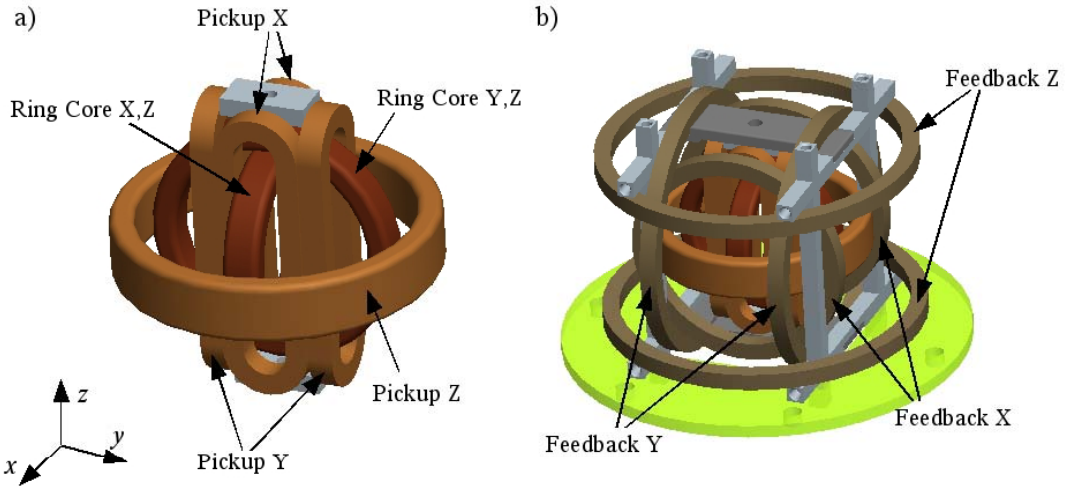


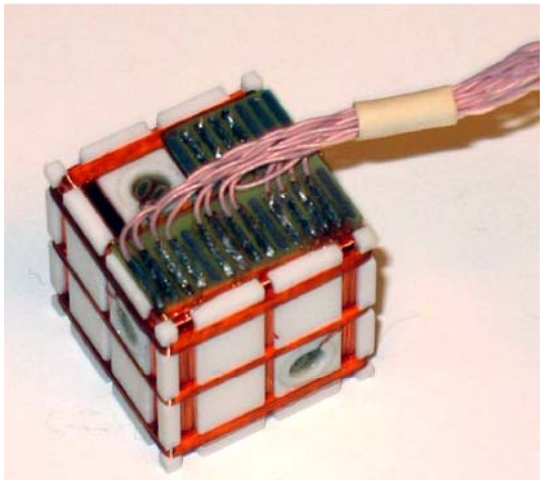
German Equator-S Sensor (TU-BS)
240 g

US MARS-96 Sensor (UCLA)
350 g

Miniaturized Fluxgate Sensors

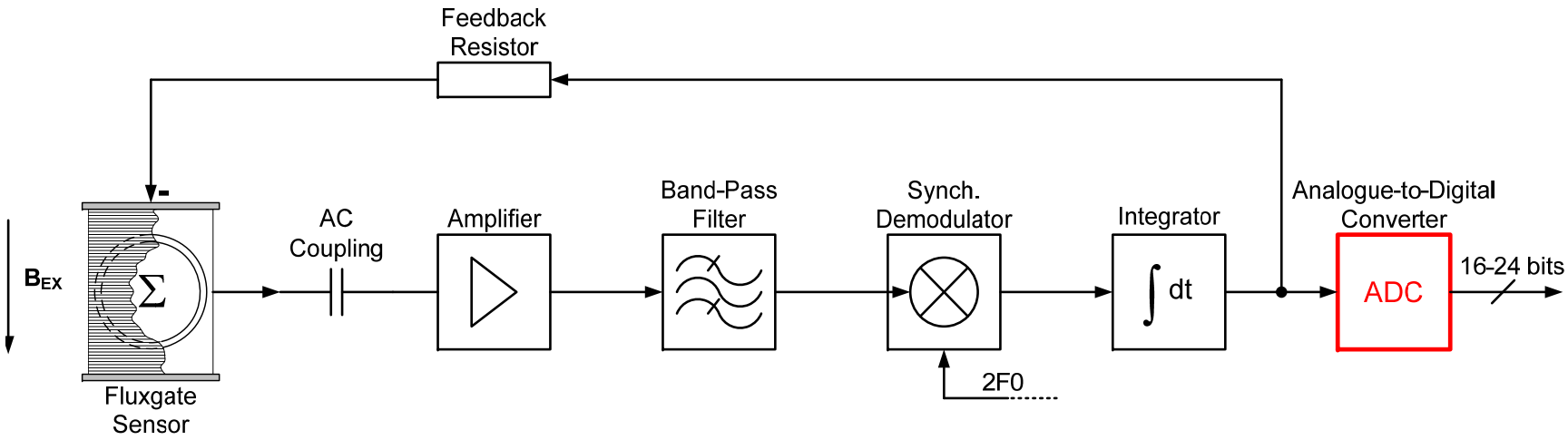
Present and future German design (TU Braunschweig): Rosetta, Venus Express, Themis; 40g, < 10pT/√Hz, 35mm Ø

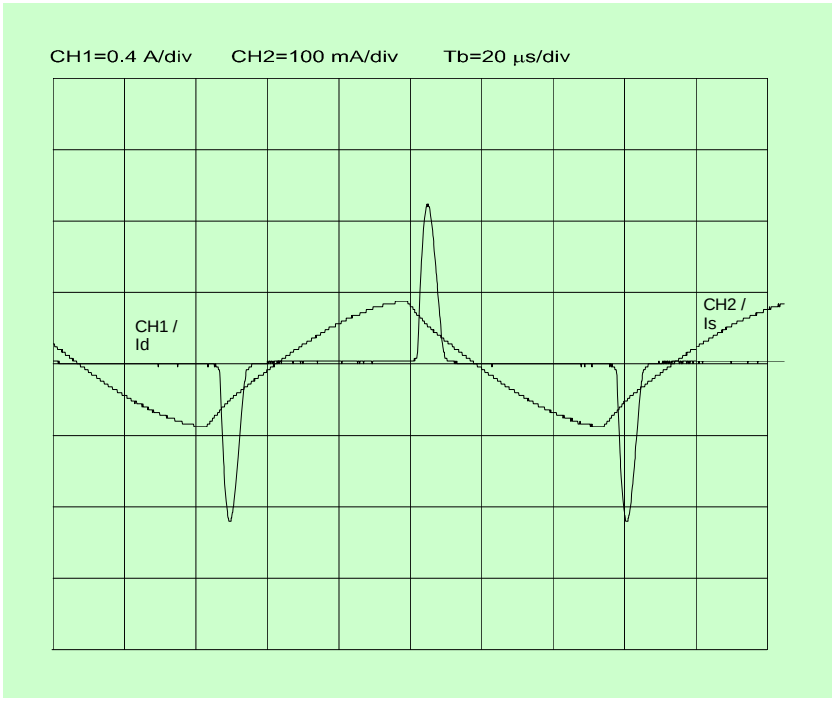


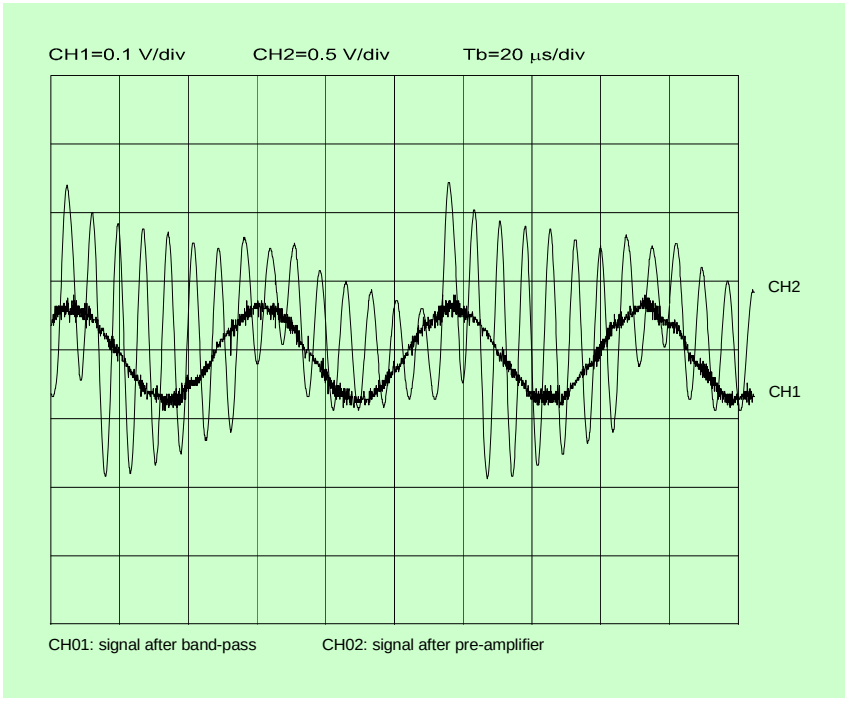


Ukrainian design (Lviv, Space Research Institute): dual rod cores in a Macor cube; 25g, < 30pT/√Hz, 20mm side length

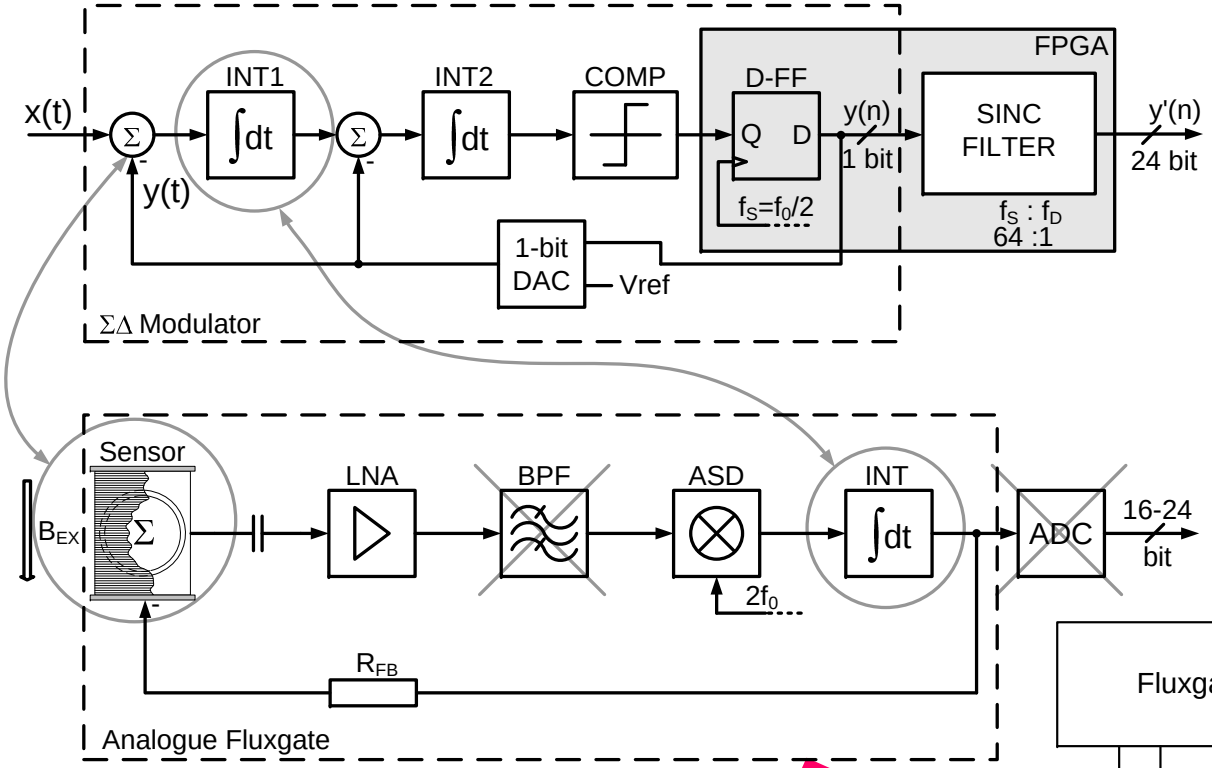
Fluxgate Electronics

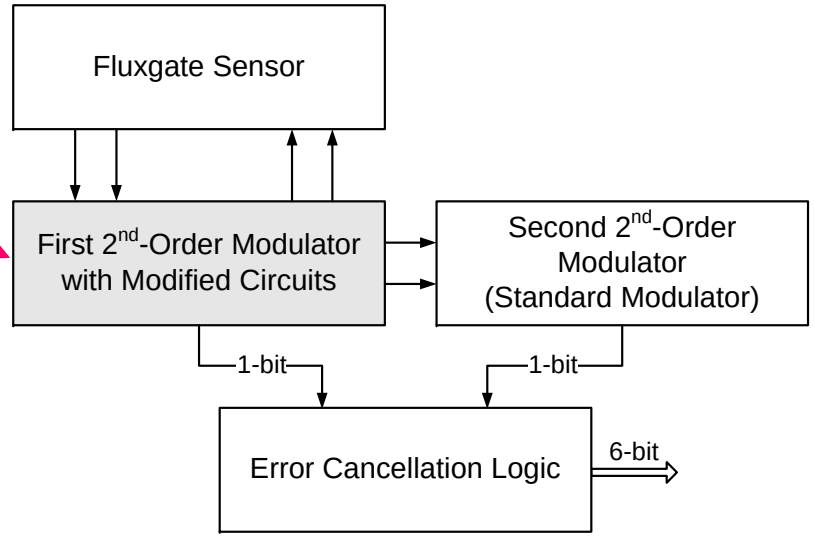






Way of Miniaturization





Magnes et al. 2003 A sigma–delta fluxgate magnetometer for space applications, Meas. Sci. Technol. 14 1003–1012

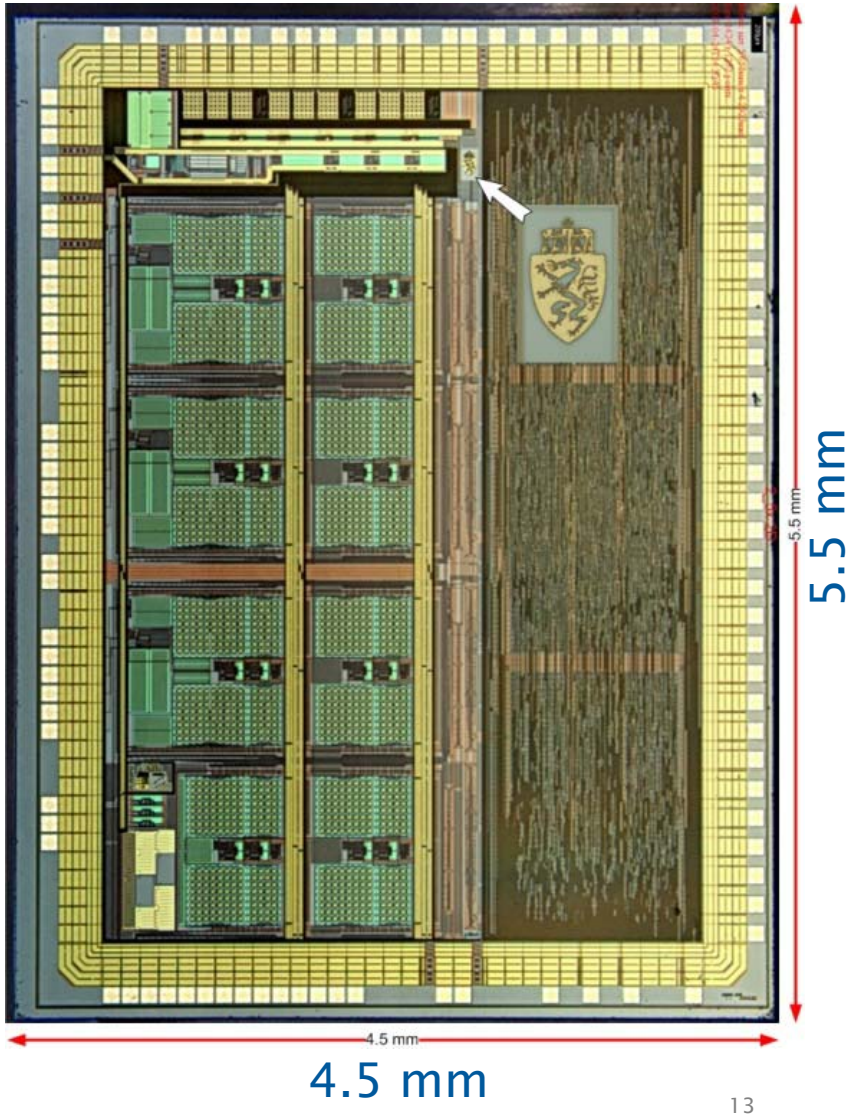
Magnes et al. 2008 Highly integrated front-end electronics for spaceborne fluxgate sensors, Meas. Sci. Technol. 19 doi:10. 1088 /0957– 233/19/11/115801

Magnetometer Front-end ASIC

Complete active readout electronics for a fluxgate sensor on 20 mm² of silicon with 350nm structures (manufactured in Unterpremstätten by AMS) – 15,000 transistors; 25,000 logic gates;

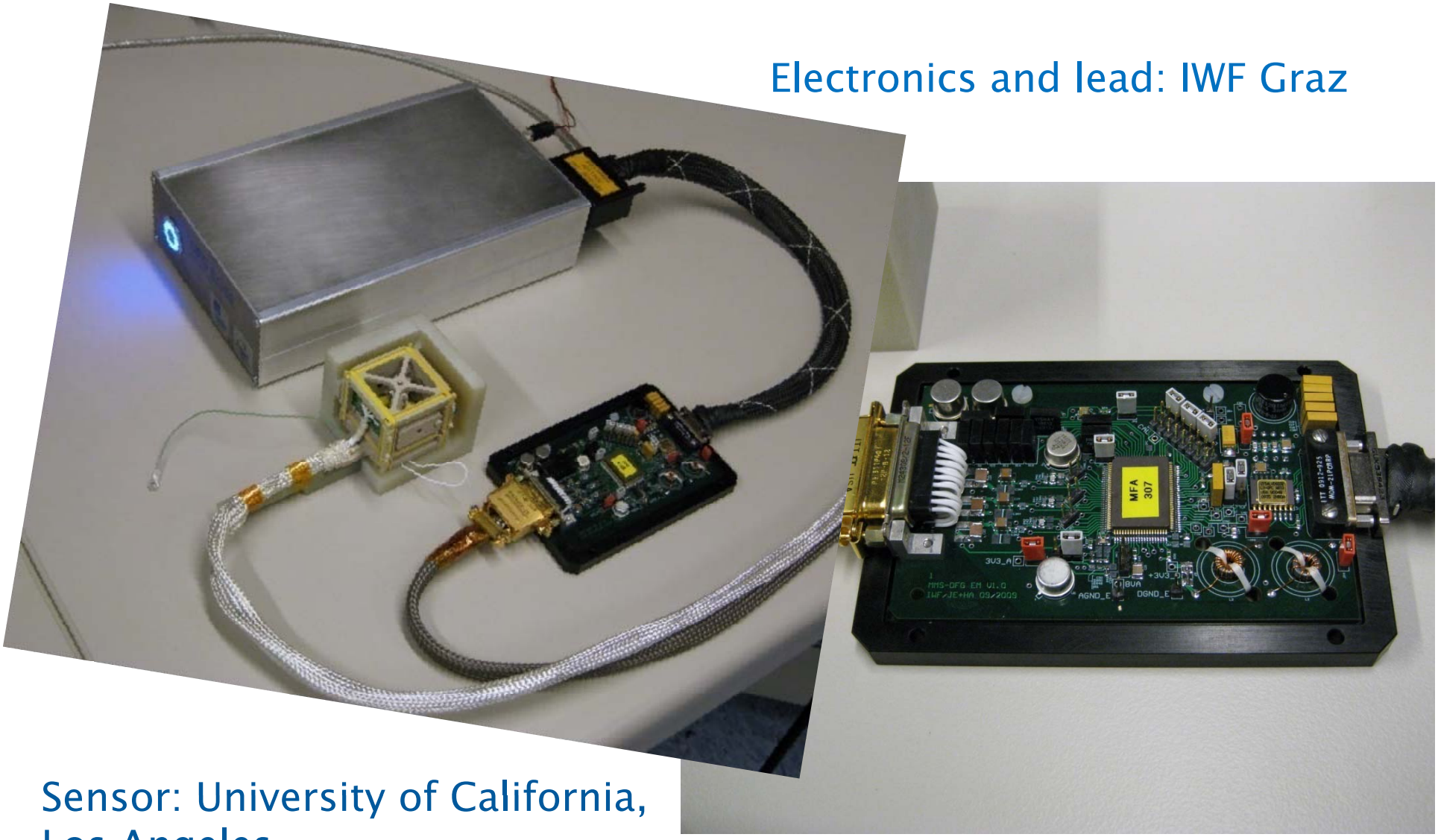
- Miniaturization (/4-5)
- TID radiation hardness (x4)
- Power reduction (/10)
- Offset stability (/2)

- Competitive performance!



MMS / DFG Engineering Model

Electronics and lead: IWF Graz



Sensor: University of California, Los Angeles

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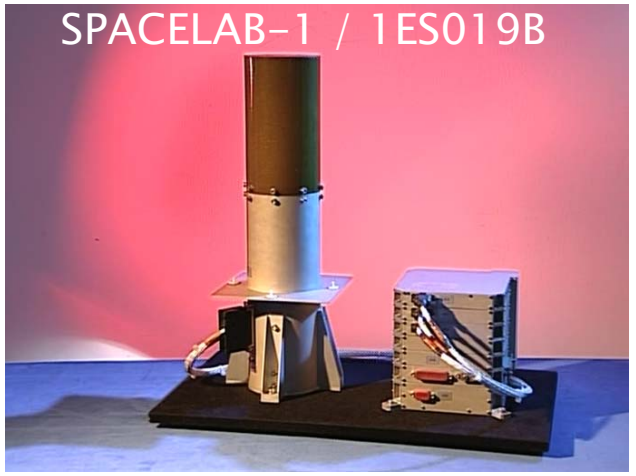
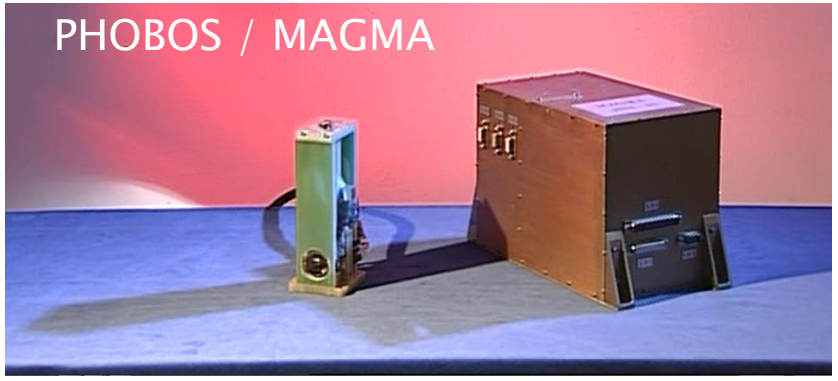
Eighties and Nineties

- VENERA-13/14 (Russia)
  - 1981/82: Venus
- SPACELAB-1(ESA)
  - 1983: Earth magnetic field
- VEGA-1/2 (Russia)
  - 1984-86: Venus and Comet Halley
- PHOBOS-1/2 (Russia)
  - 1988/89: Mars, Phobos
- Mars 96 (Russia)
  - 1996: Planned for Mars





Principal Investigator: Prof. Riedler; Management: Dr. Schmiedt, Dr. Schwingenschuh

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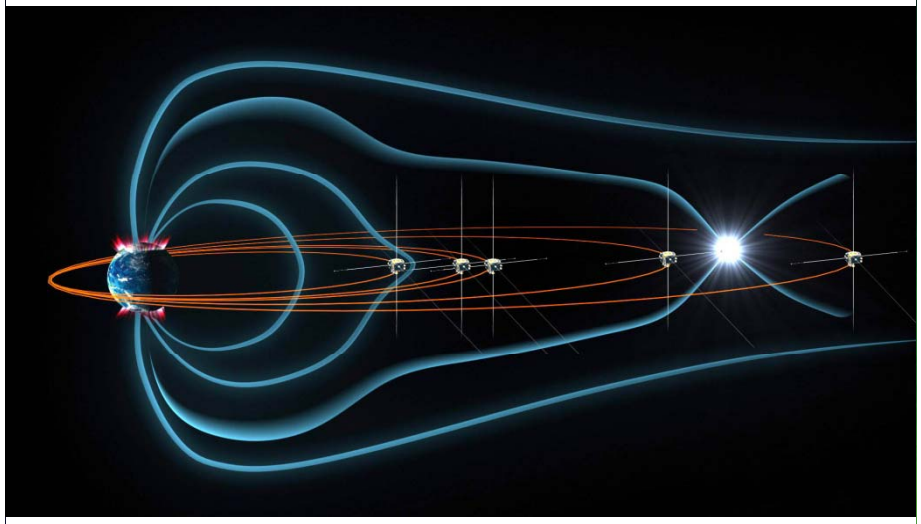
New Millennium

- 7 Missions
- 20 Magnetometers
- Partners: IC London, TU Braunschweig, UC Los Angeles

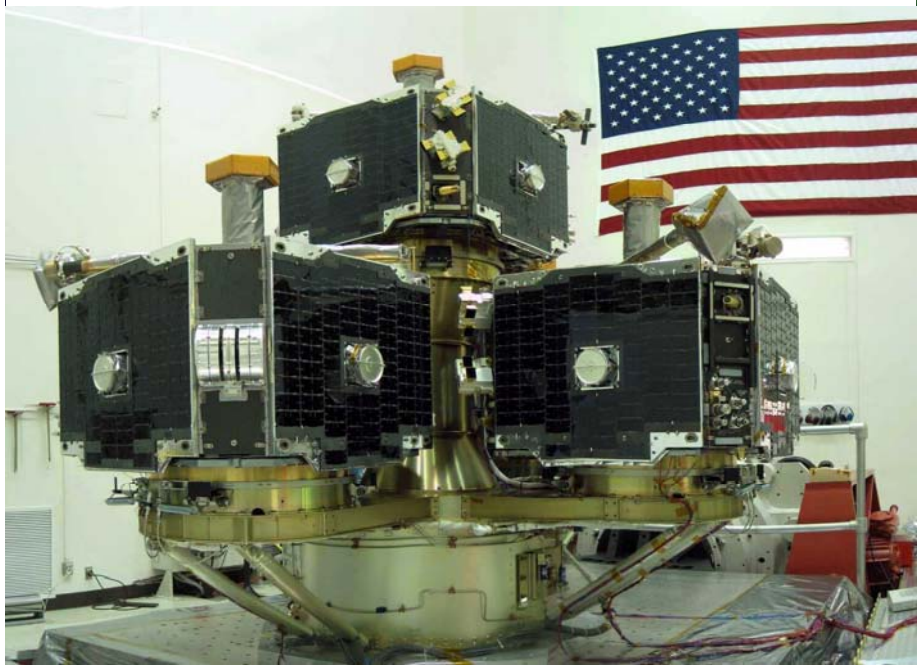
Satellite Mission	Agency	Goal	Launch	Experiment
Cluster	ESA	Earth's magnetosphere	2000	Potential control (ASPOC) Magnetometer (FGM)
Double Star	CNSA/ESA	Earth's magnetosphere	2003	Potential control (ASPOC) Magnetometer (DSP-MAG) Magnetometer (DSE-MAG)
Rosetta	ESA	Comet Churyumov-Gerasimenko	2004	Atomic force microscope (MIDAS) Dust mass spectrometer (COSIMA) Penetrator (MUPUS) Magnetometer (ROMAP, RPC-MAG)
Venus Express	ESA	Venus	2005	Magnetometer (MAG)
THEMIS	NASA	Earth's magnetosphere	2007	Magnetometer (FGM)
BepiColombo	ESA/JAXA	Mercury	2014	Magnetometer (MERMAG-M) Ion camera (PICAM) Magnetometer (MERMAG-P)
Magnetospheric MultiScale	NASA	Earth's magnetosphere	2014	Potential control (ASPOC) Magnetometer (FGM) Electron beam experiment (EDI)

Analyzing Auroral Phenomena

The five **THEMIS** satellites (Time History of Events and Macroscale Interactions during Substorms) and ground observatories study substorms in the Earth's magnetosphere and give the final answer to a 40 year old question



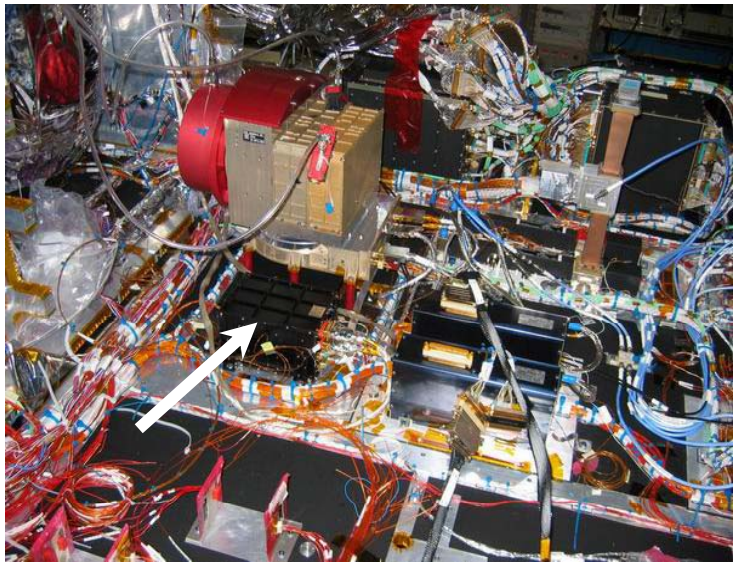
- Participation in designing and building the magnetometers
- Launch: 2007 (NASA)
- Observations partly together with Cluster and Double Star

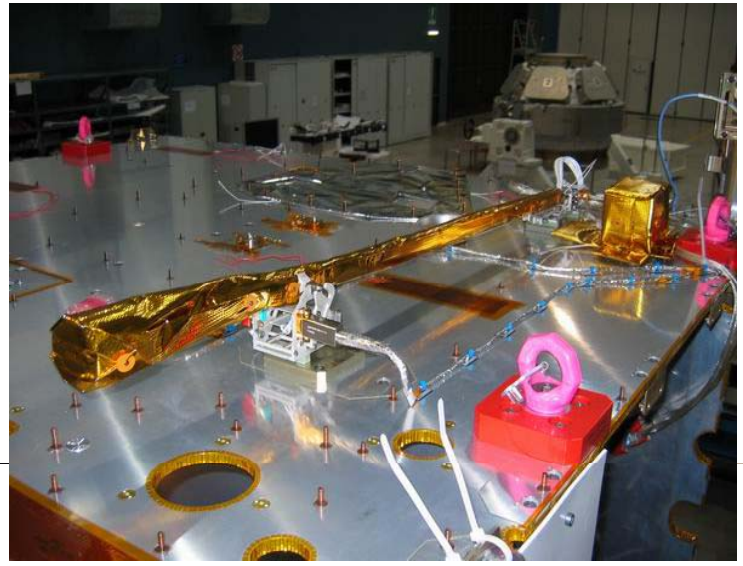


Flying to Venus

The Venus Express spacecraft and its instruments have been built in only three years

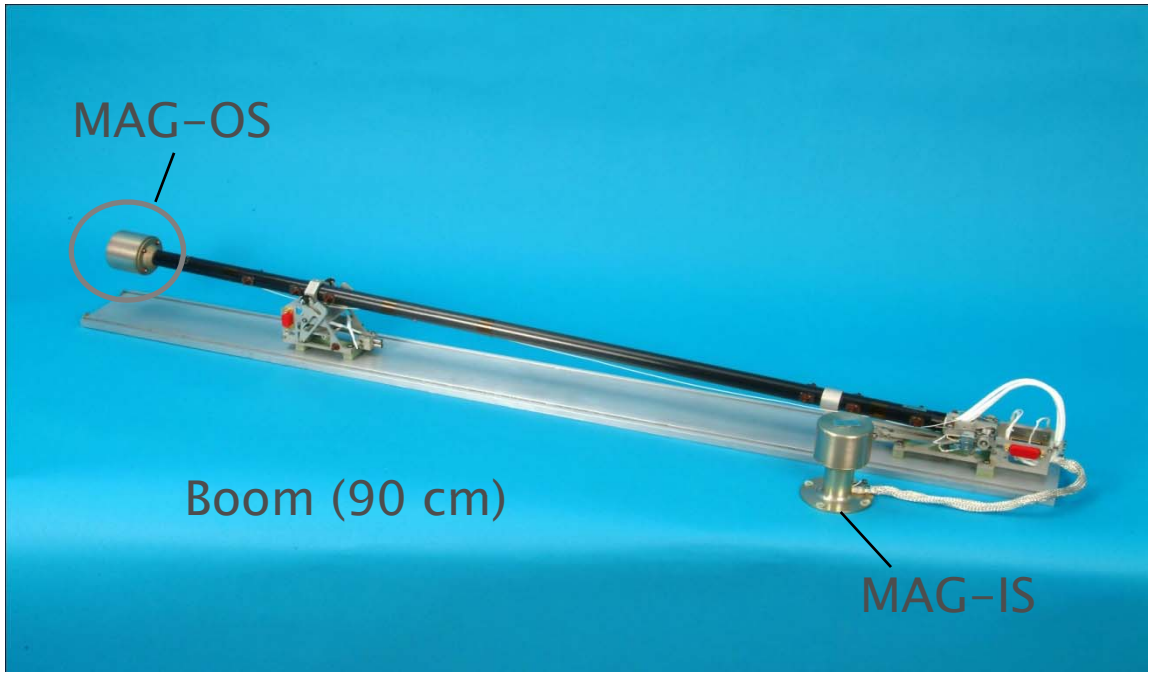
- Principal Investigator for magnetometer
- Challenge: magnetically dirty spacecraft, short boom
- CoI-ship for plasma detector
- Main objective: studying the loss of (ionized) Venusian atmosphere to the solar wind
- Launch: Nov. 2005 (ESA)
- In orbit around Venus since April 10, 2006





VEXMAG Units

- Magnetometer group had the lead position
- Extremely efficient international cooperation with TU Braunschweig and Imperial College London
- Short development time (< 2 years)
- Challenging thermal conditions around Venus (2 to 3 suns)
- Impressive science output

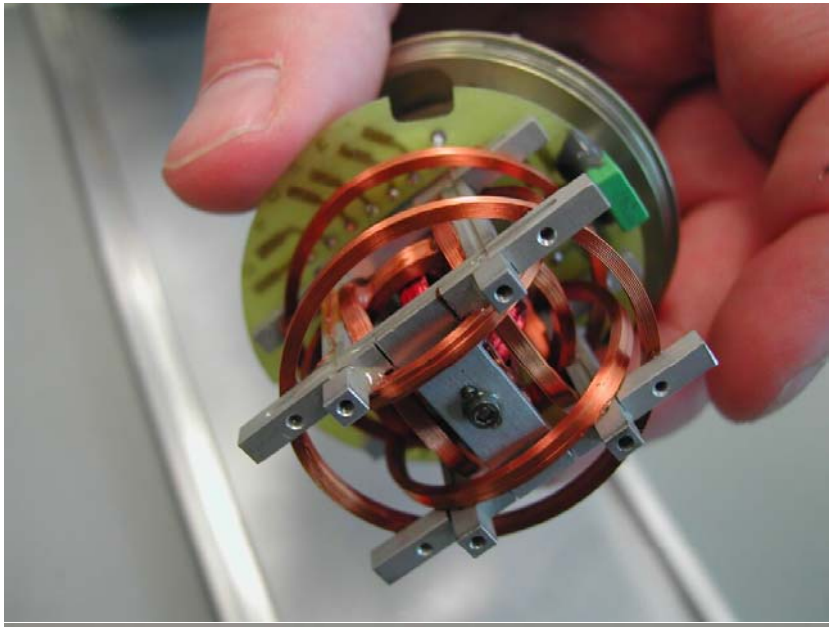


VEXMAG Team

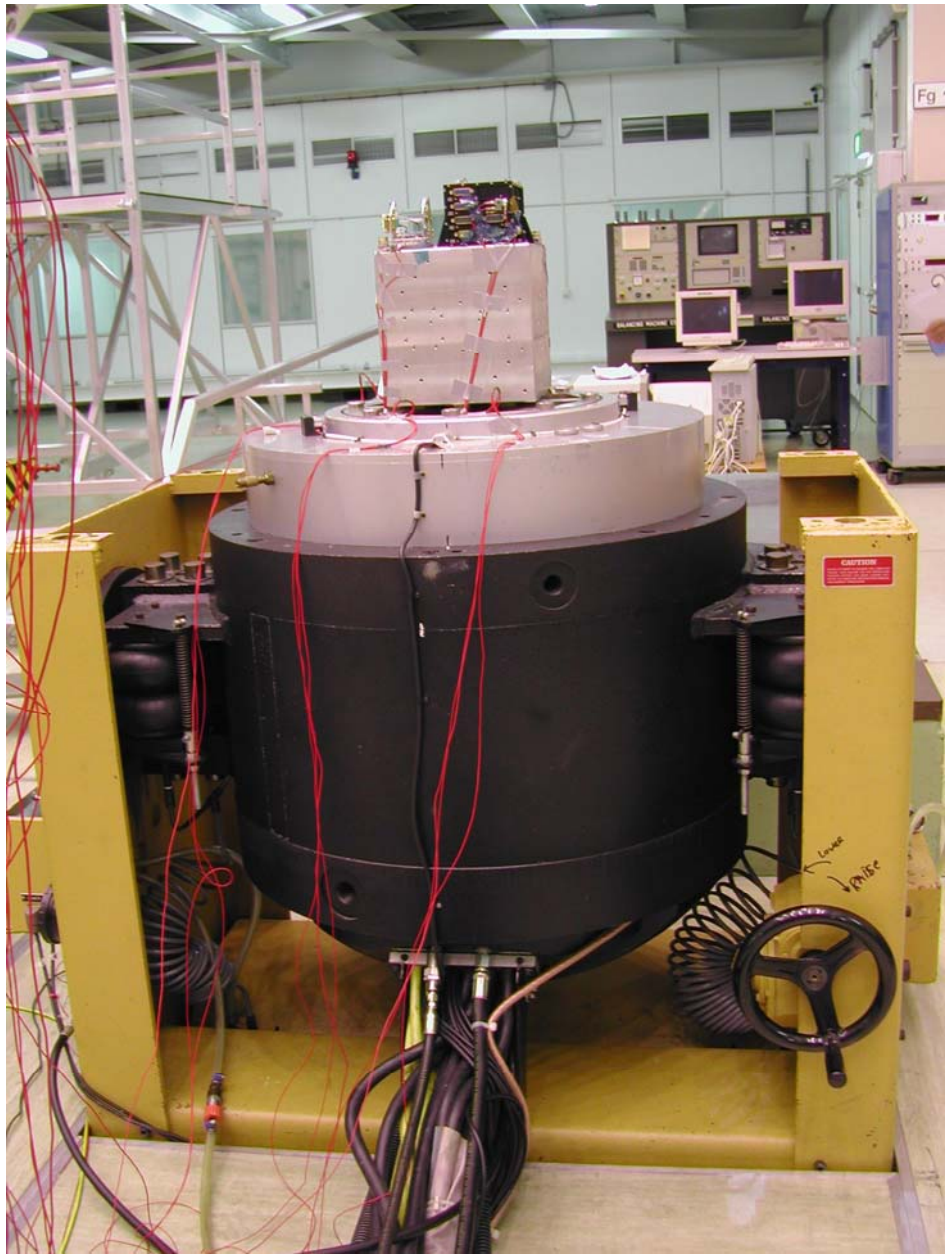

Christoph Kürbisch
Werner Magnes
Aris Valavanoglou
Franz Giner
Sonja Neukirchner
Gerhard Berghofer (TM)
Tielong Zhang (PI)
Irmgard Jernej
Werner Zambelli
Magda Delva
Karl Mocnik
Özer Aydogar

VEXMAG Models

- Laboratory Model
  - Processor board
  - Sensor electronics end sensor
- Engineering Model
  - Full instrument
- Structural Model
  - Full instrument
- Qualification Model
  - Full instrument
- Flight Model
  - Full instrument
- Spare Model
  - Processor board
  - Sensor electronics end sensor
  - Boom



VEXMAG Qualification Tests



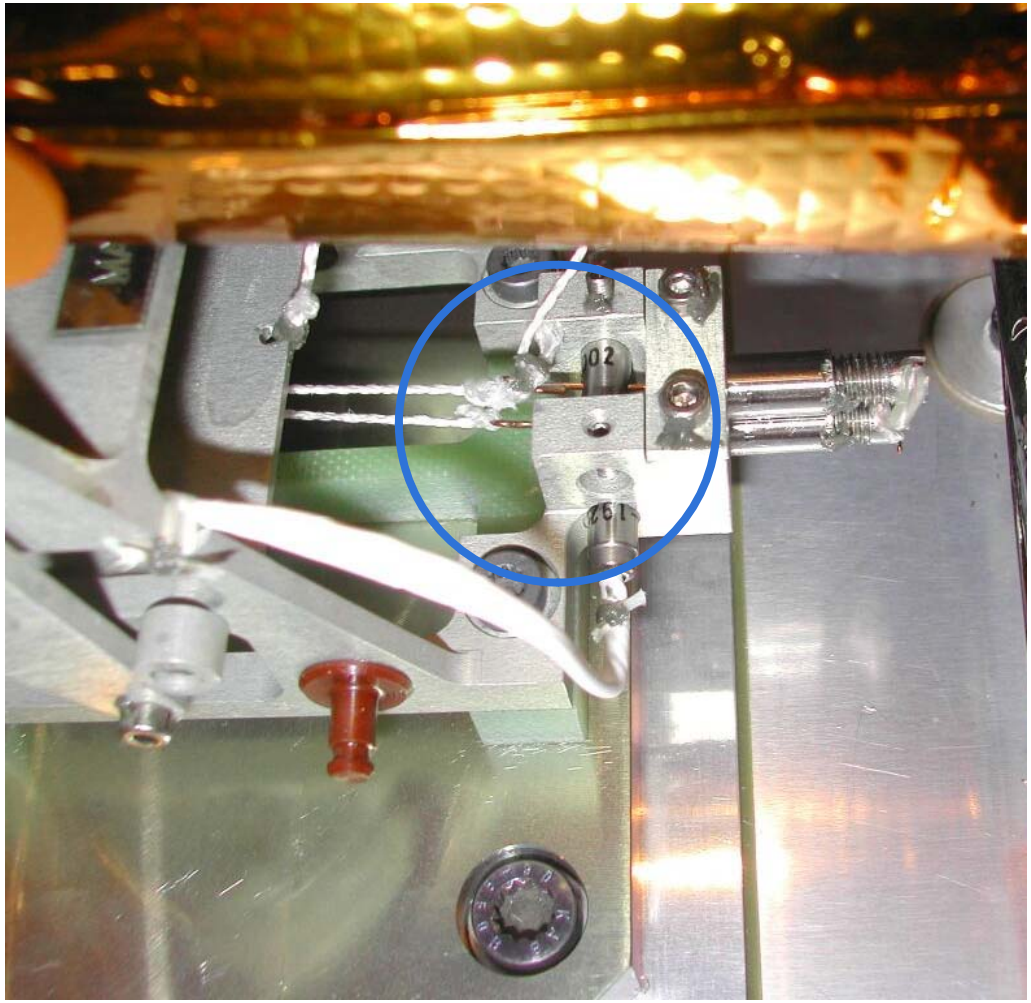
Vibration test

with electronics box

and launch lock

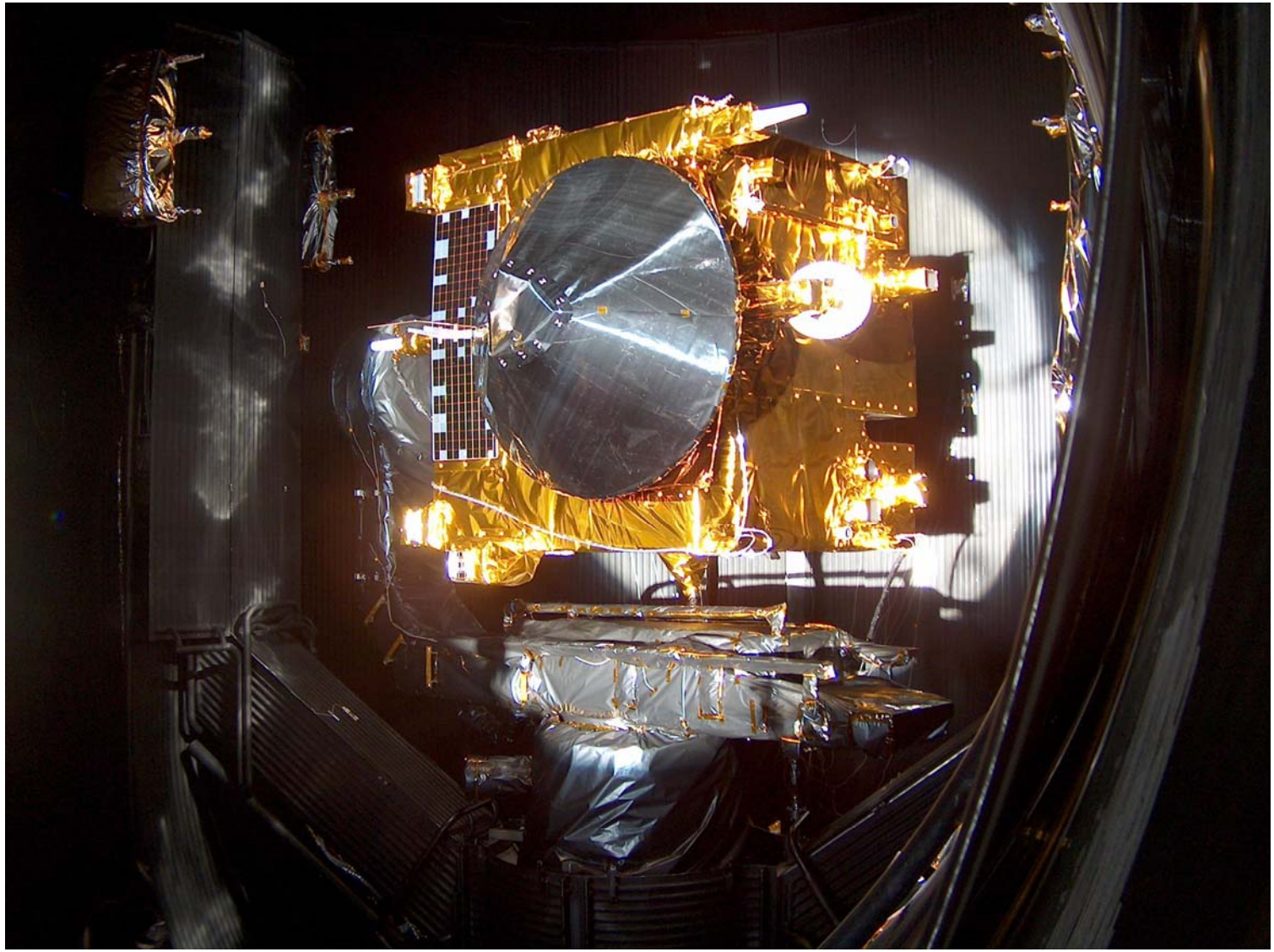
VEXMAG Special Task

Soldering of copper-beryllium-wire for the Launch Lock



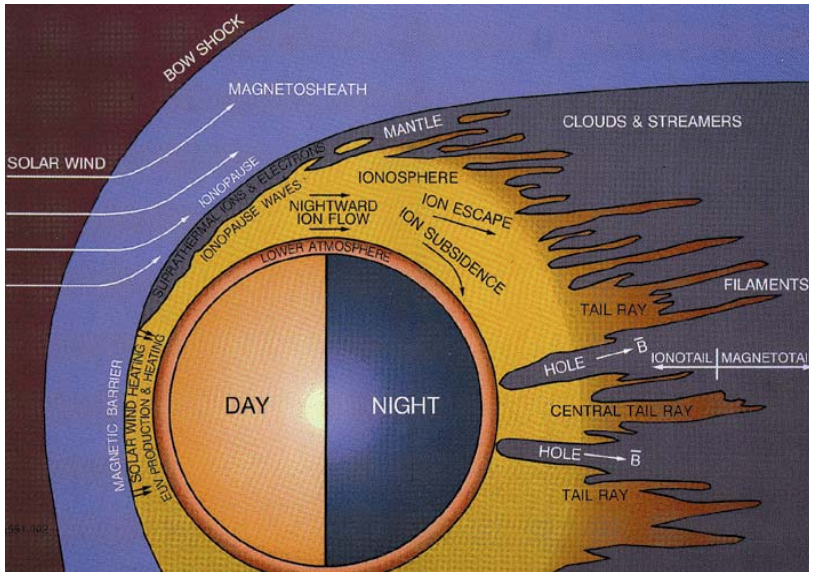
VEX Thermal Balance Test

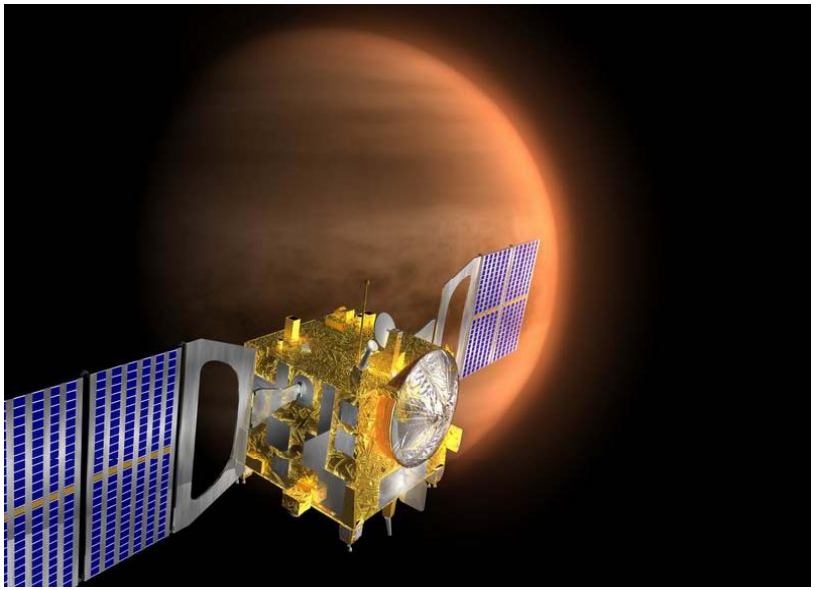
Thermal test with artificial Sun



VEXMAG Science Output

- Foreshock and upstream waves
- Bow shock
- Ionopause and magnetic barrier
- Terminator region
- Near-Venus Wake
- Lightning
- Ion Pickup
- Contribution to space weather study
- Intrinsic field



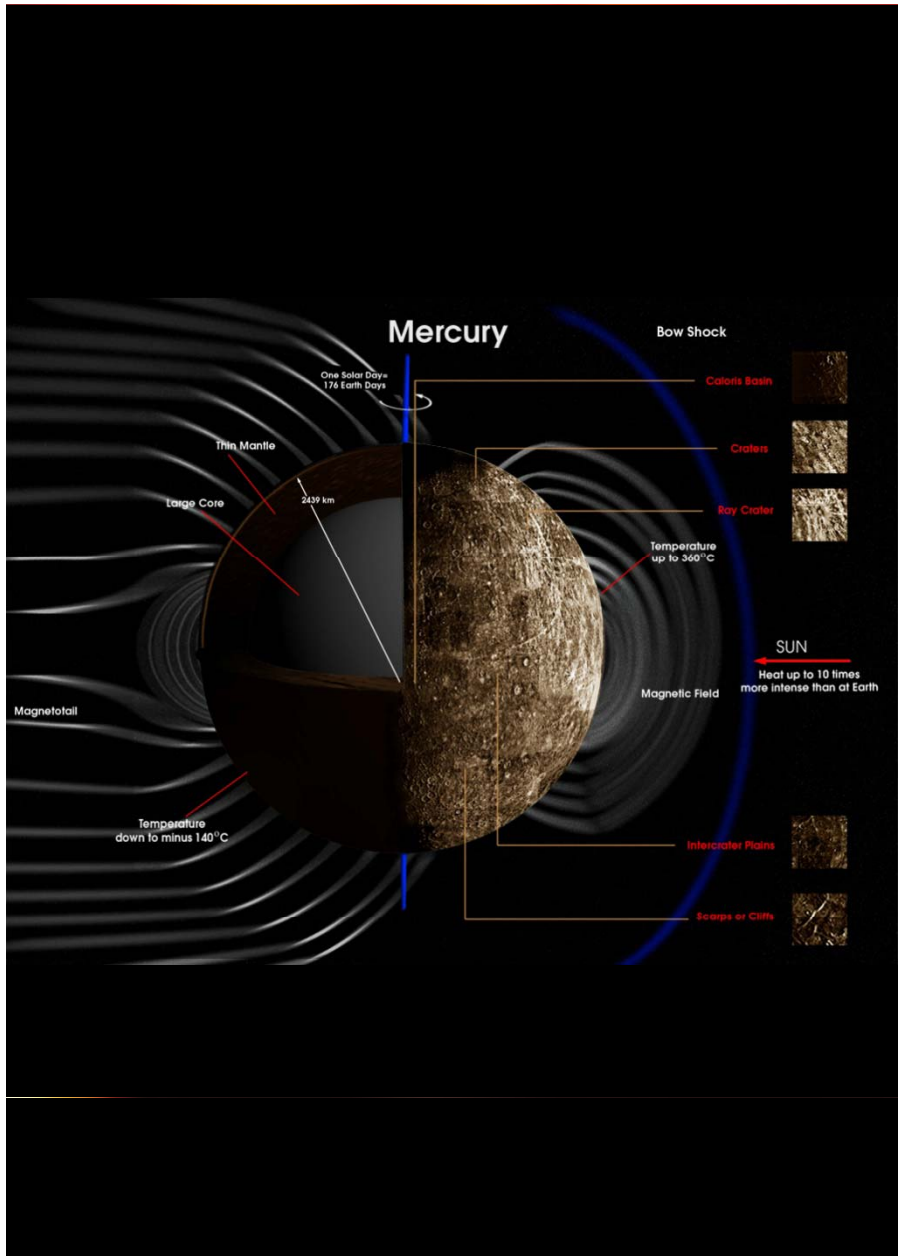


- More than 50 first author papers published so far
- 2 papers published in Nature

Orbiting around Mercury

The two **BepiColombo** spacecraft (MMO & MPO) will study the surface, interior and magnetosphere of Mercury

- Principal Investigator for magnetometer on Japanese MMO
- Principal Investigator for ion spectrometer on European MPO
- Participation in designing and building MPO magnetometer
- Launch: 2014 (ESA/JAXA)



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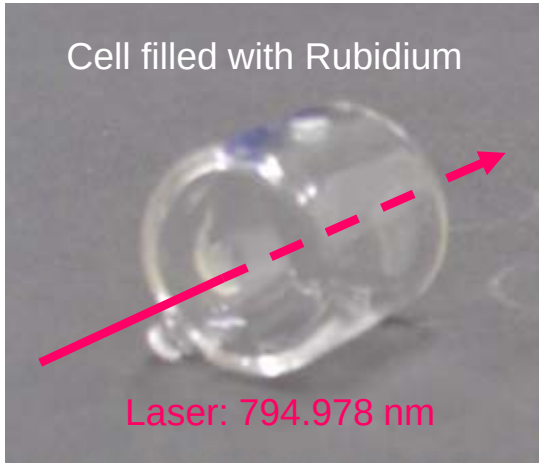
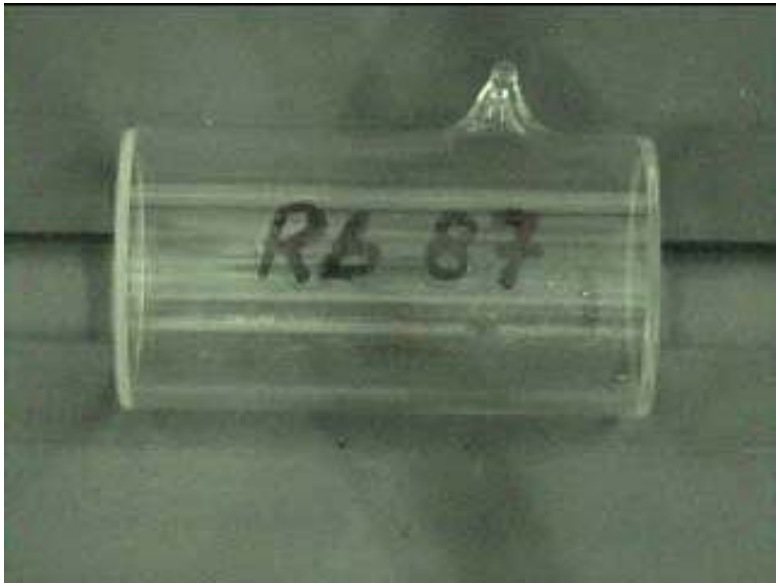
Dark State Magnetometer

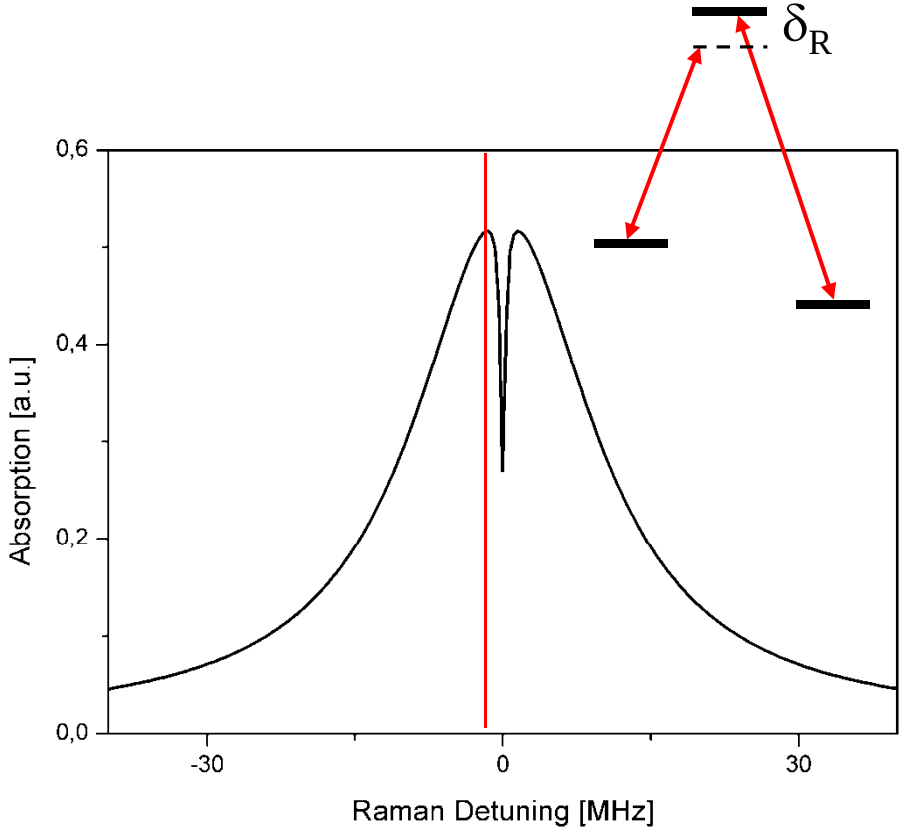
- New generation of scalar magnetometer
- Cooperation between Institute of Experimental Physics, TUG and IWF
- Patent by Dr. Roland Lammegger
  - Lammegger, R., WO 2008/151344 A3, *Method and Device for Measuring Magnetic Fields*, 2008
- Advantages
  - Light weight
  - Low power consumption
  - Large dynamic range
  - Passive vector mode



Observations of Dark Resonances

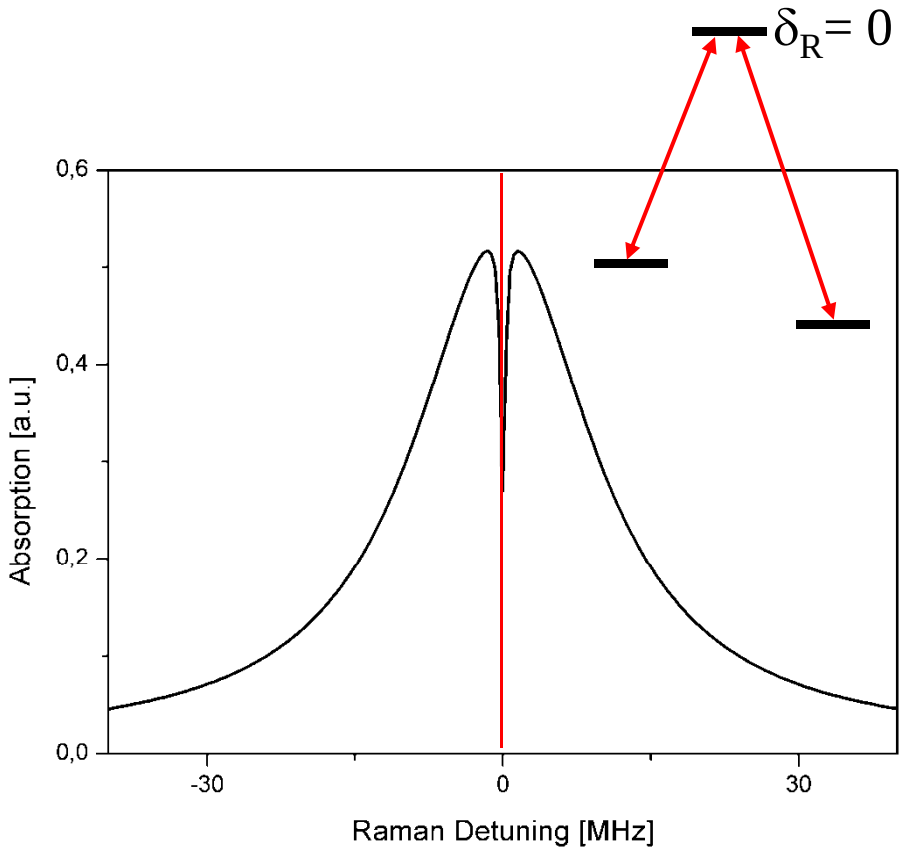
Rubidium-87 vapour cell without buffer gas





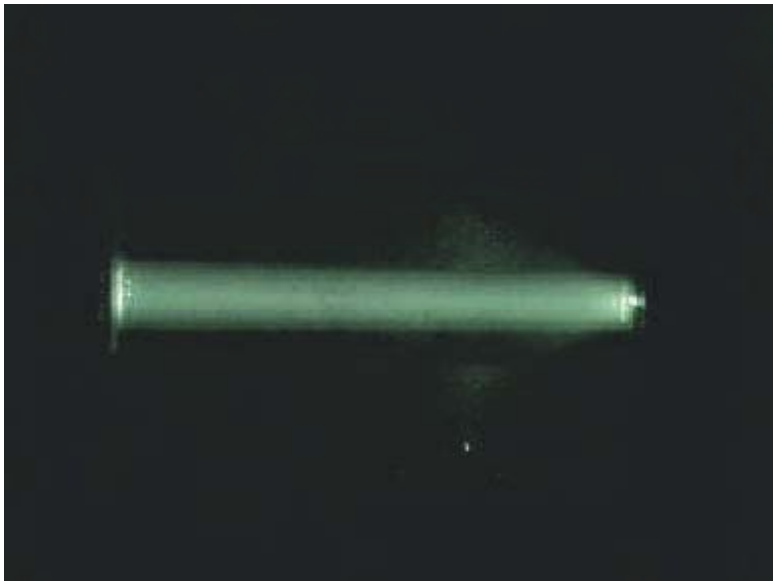
Observations of Dark Resonances

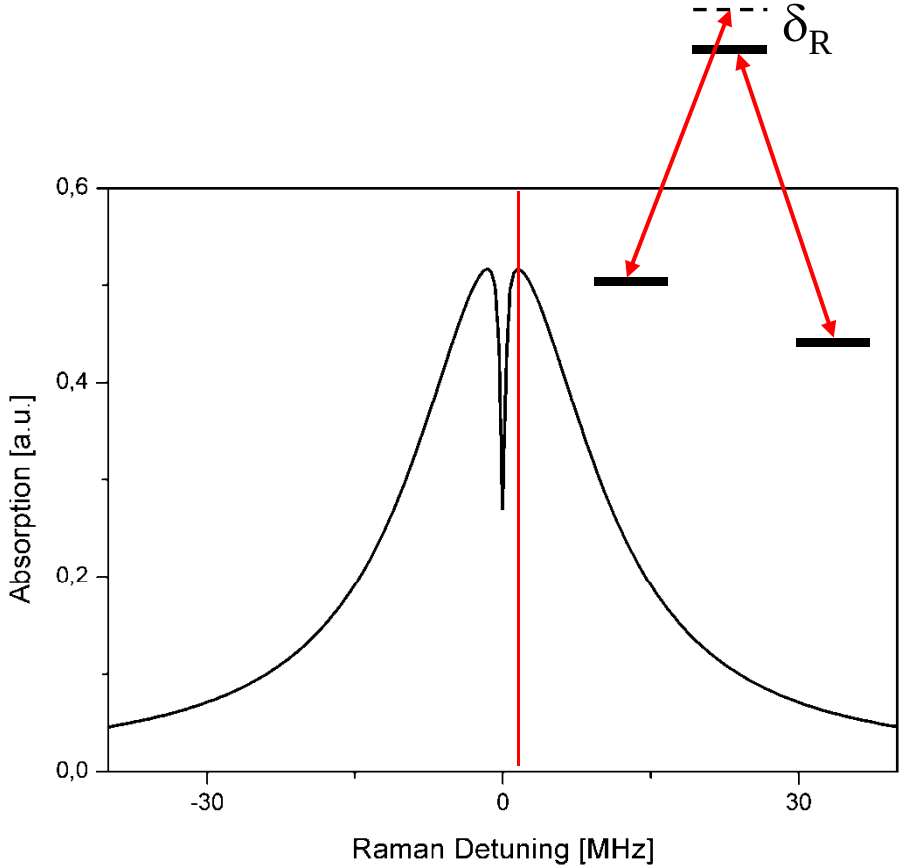
Rubidium-87 vapour cell without buffer gas



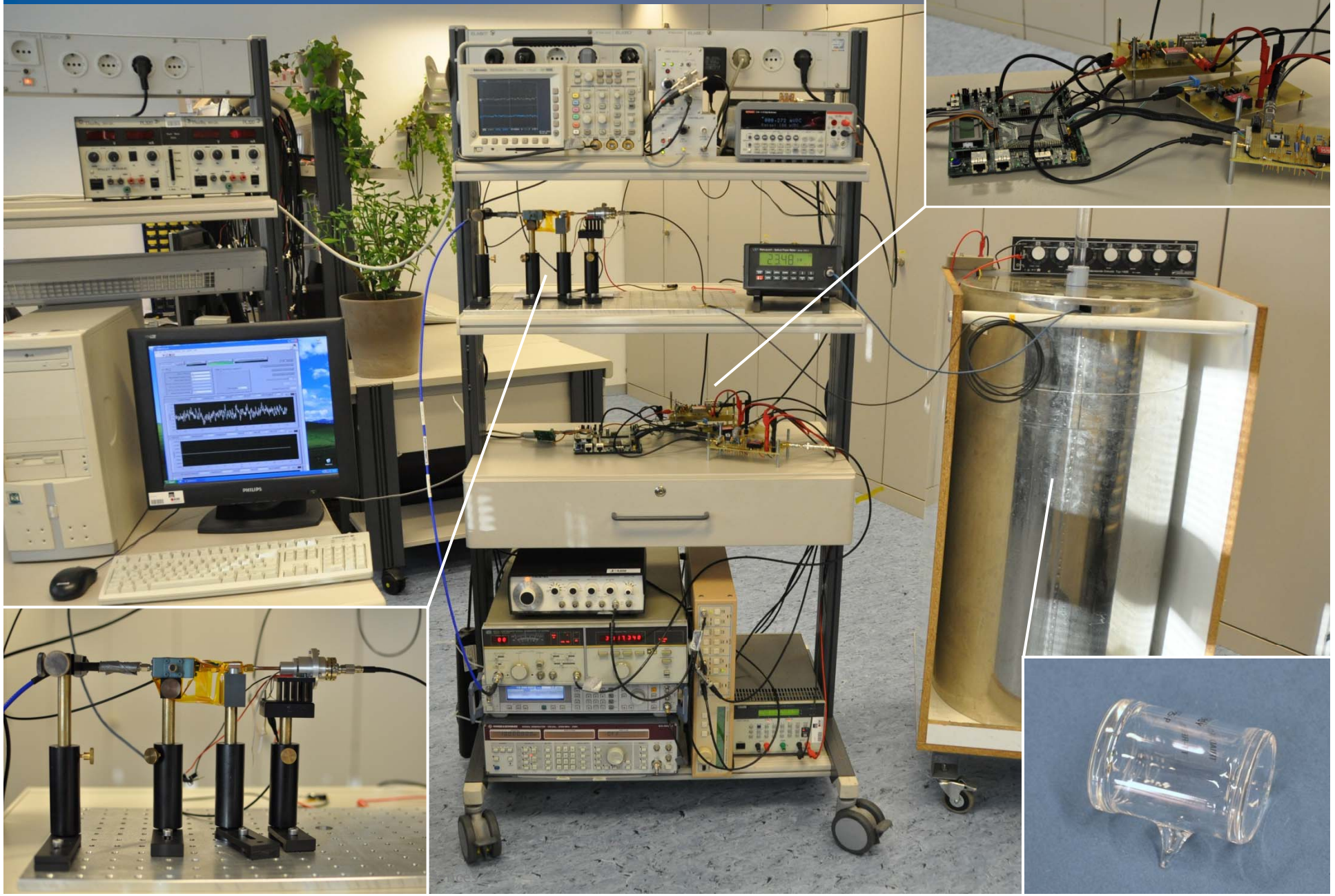
Observations of Dark Resonances

Rubidium-87 vapour cell without buffer gas





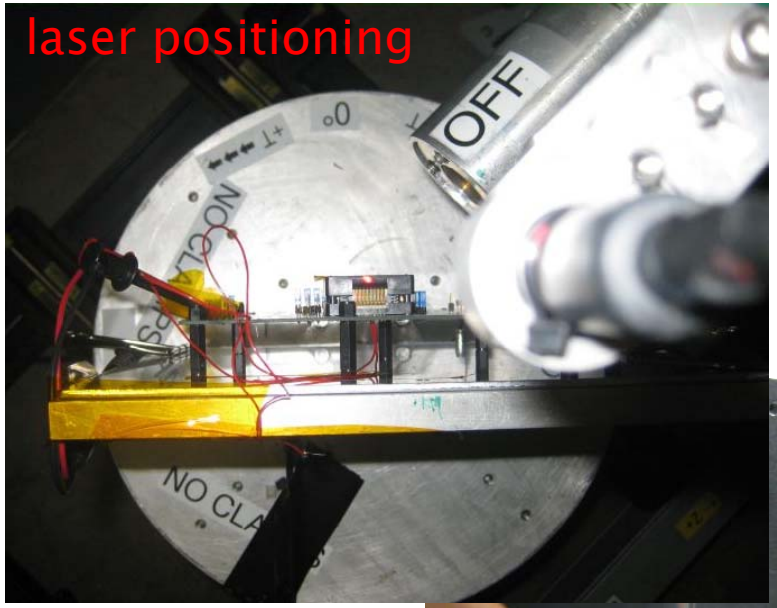
Current CDSM Test Setup



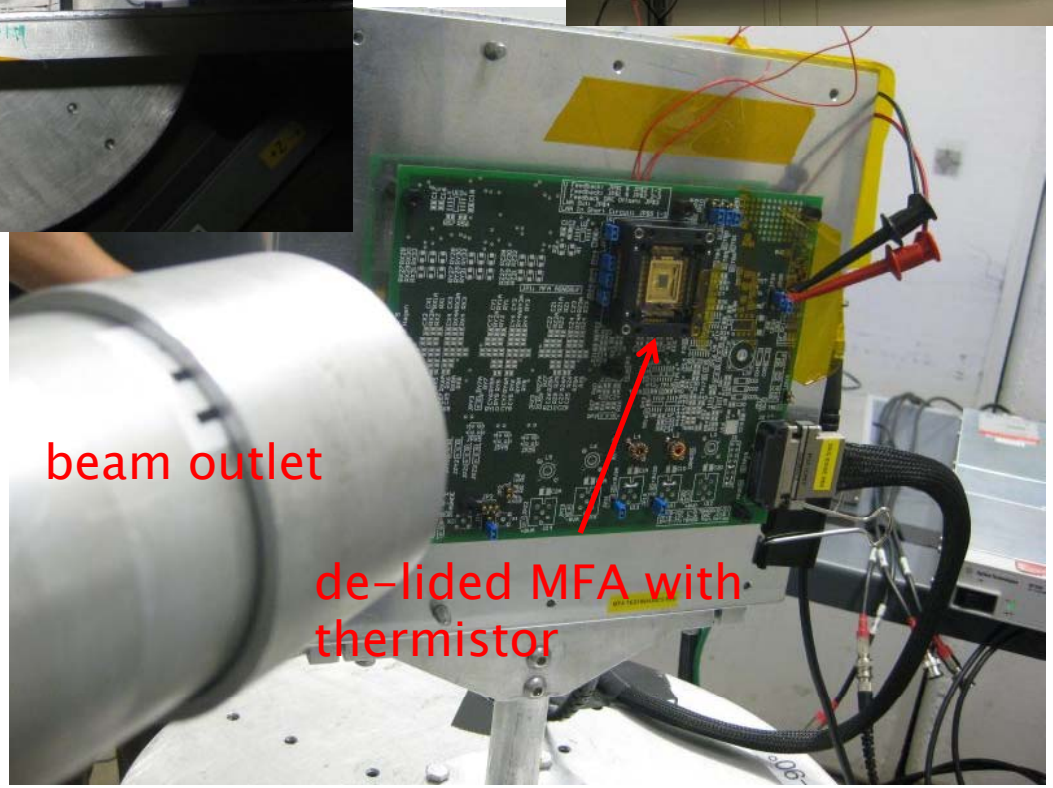
Single Event Effects (SEE) Test

‚cave‘

laser positioning



control room



Outline

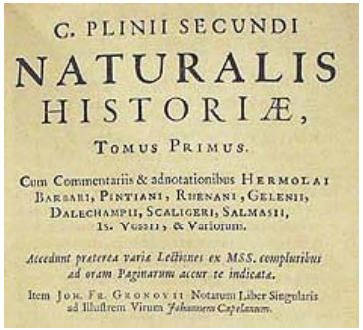
- Magnetic Field – Magnetometer
- Fluxgate Magnetometer
- IWF – Eighties and Nineties
  - Russian Missions, Spacelab …
- IWF – New Millennium
  - Cluster, Rosetta, Themis, VENUS EXPRESS …
- Future Directions
  - Laser/Atomic Magnetometer
- Calibration and Test
- Magnes and Magnetic Field

Magnes and Magnetic Field

The Roman *Pliny the Elder* (23–79 AD) wrote in the 36th book of his **Historiae Natoralis** about the person who detected the mysterious attraction between iron metals and a Magnetit stone:

> *"MAGNES appellatus est ab inventore in Ida. … invenisse autem fertur clavis crepidarum baculi cuspide haerentibus, cum armenta pasceret."*

It received its name MAGNES from the person who was the first to discover it, upon Ida. MAGNES, it is said, made this discovery, when, upon taking his herds to pasture, he found that the nails of his shoes and the iron tip of his staff adhered to the ground.


C. PLINII SECUNDI
NATURALIS
HISTORIÆ,
TOMUS PRIMUS.
Cum Commentariis & adnotationibus HERMOLAI BARBARI, PINTIANI, RHENANI, GELENII, DALECHAMPII, SCALIGERI, SALMASII, Is. VOSSII, & Variorum.
Accedunt praterea varia Lectiones ex MSS. complurib⁹ ad oram Paginarum accurate indicata.
Item JOH. FR. GRONOVII Notarum Liber Singularis ad Illustrem Virum Johannem Capelanum.