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MÖSSBAUER SPECTROSCOPY
NEWSLETTER

May 2020

Advancing Miniatured Mössbauer Spectroscopy Technology Towards Deep Space Exploration

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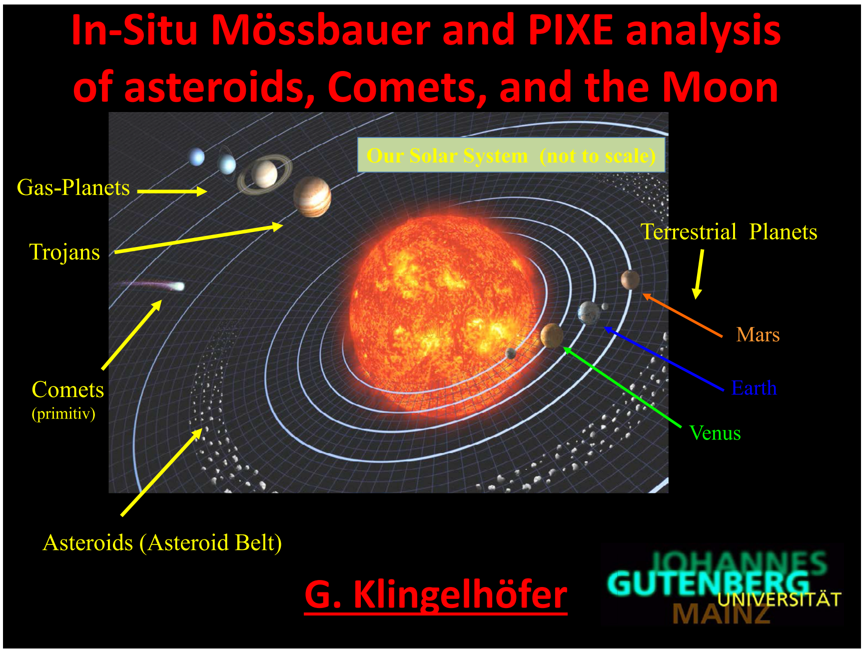
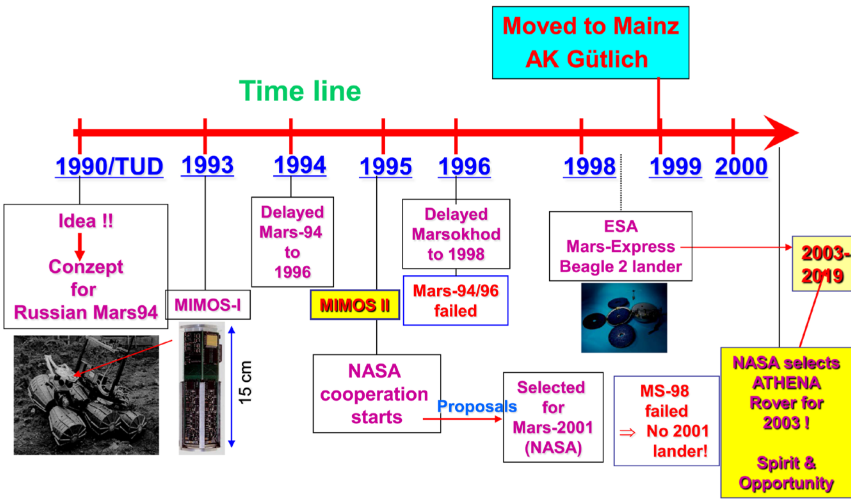
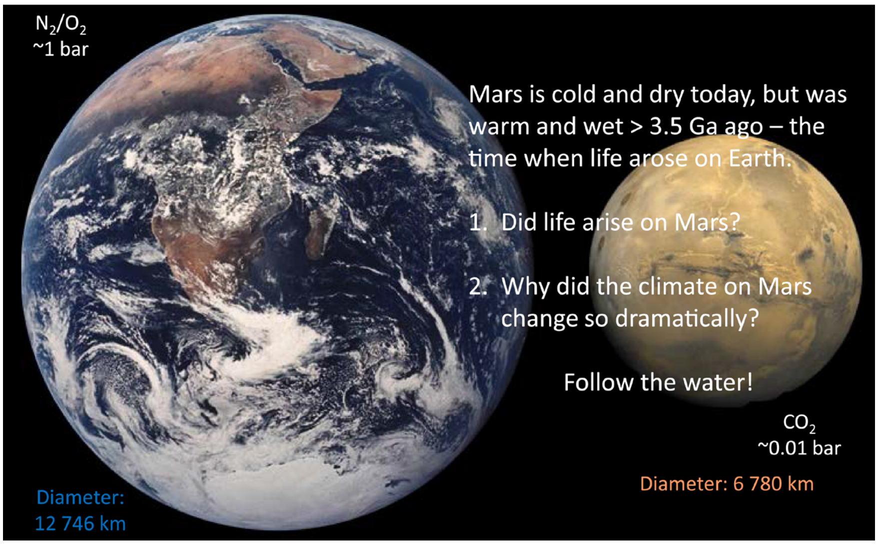
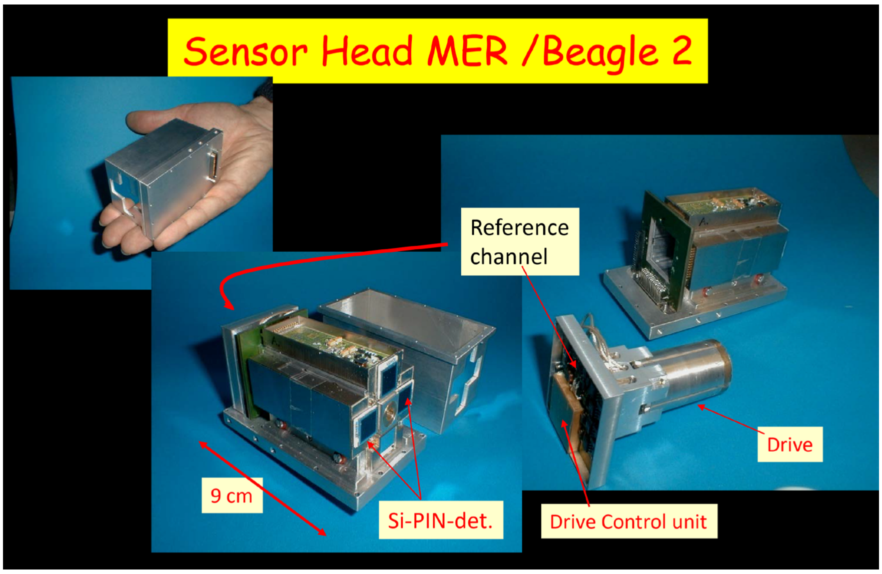




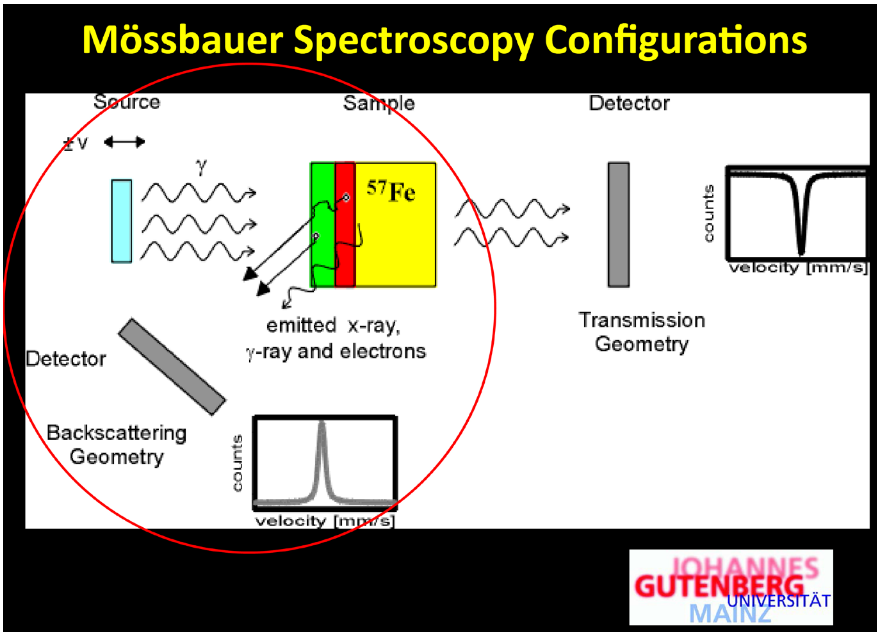
The roadmap of MIMOS development
Provided by Professor Franz Renz



N_2/O_2
~1 bar
Mars is cold and dry today, but was warm and wet > 3.5 Ga ago – the time when life arose on Earth.
1. Did life arise on Mars?
2. Why did the climate on Mars change so dramatically?
Follow the water!
CO_2
~0.01 bar
Diameter: 6 780 km
Diameter:
12 746 km



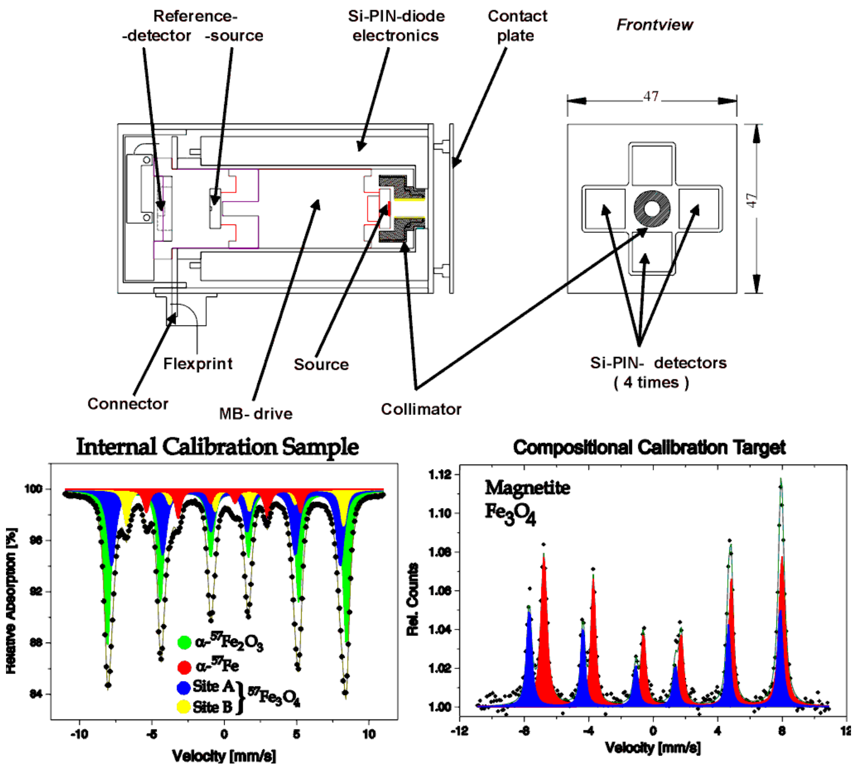
Sensor Head MER /Beagle 2
Reference channel
Drive
9 cm
Si-PIN-det.
Drive Control unit



Mössbauer Spectroscopy Configurations
Source
Sample
Detector
±v
γ
57Fe
counts
velocity [mm/s]
Transmission Geometry
emitted x-ray, γ-ray and electrons
Detector
Backscattering Geometry
counts
velocity [mm/s]
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

To enable the miniatured Mössbauer spectroscopy technology to have an important role in China's deep space exploration in the near future, and also to commemorate Dr. Göstar Klingelhöfer, for his great contribution to promoting international cooperation between China and Germany in this field, in this issue we have selected some pictures to look back on the MIMOS history, tell the MIMOS present, and look forward its bright future.

^{57}Fe Mössbauer spectroscopy proved to be very helpful in the study of lunar samples in 1969-72 and Mars rover expeditions in 2004, especially due to the presence of iron in practical all studied samples and producing a very strong signal. Mössbauer spectroscopy provides quantitative information about the distribution of Fe among its oxidation states, identification of Fe-bearing phases, and relative distribution of Fe among those phases.

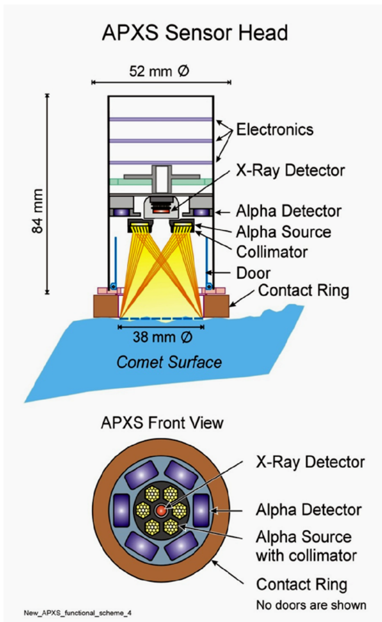


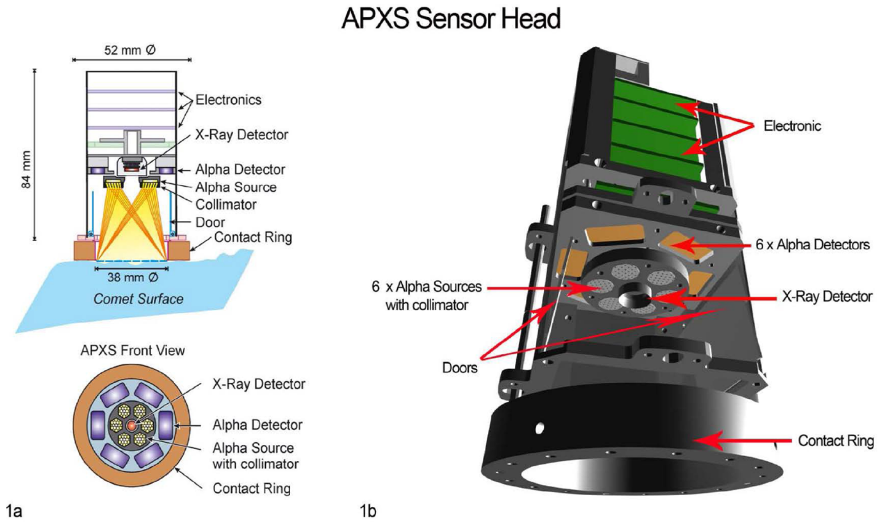
The APXS Instrument: basic principles

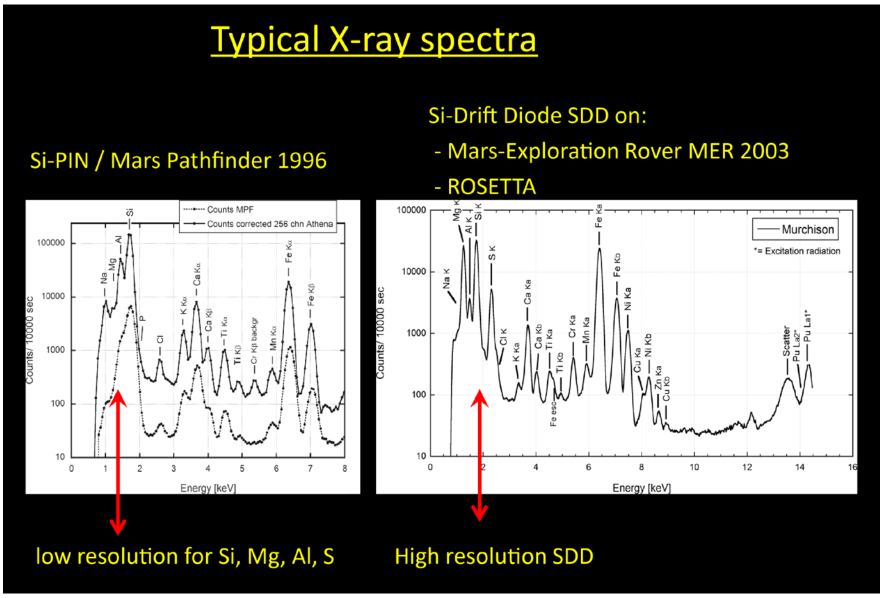
- irradiation of the sample with α-particles, γ- and X-rays, emitted by a Cm-244 radioactive source

- excitation of characteristic X-rays of all elements in the sample
- scattering of α-particles at the target nuclei.

- detection of X-rays by a high resolution Si-based X-ray detector
  ⟹ elements from Na, Mg, and above
- detection of backscattered α-particles by a Si-based α-detector
  detection of C, O, N and other
  ⟹ higher Z elements





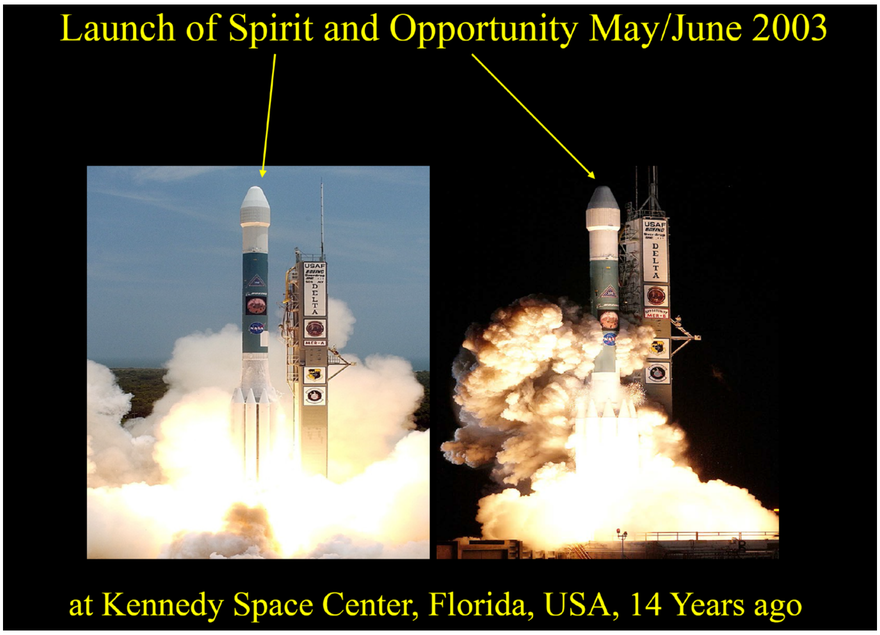


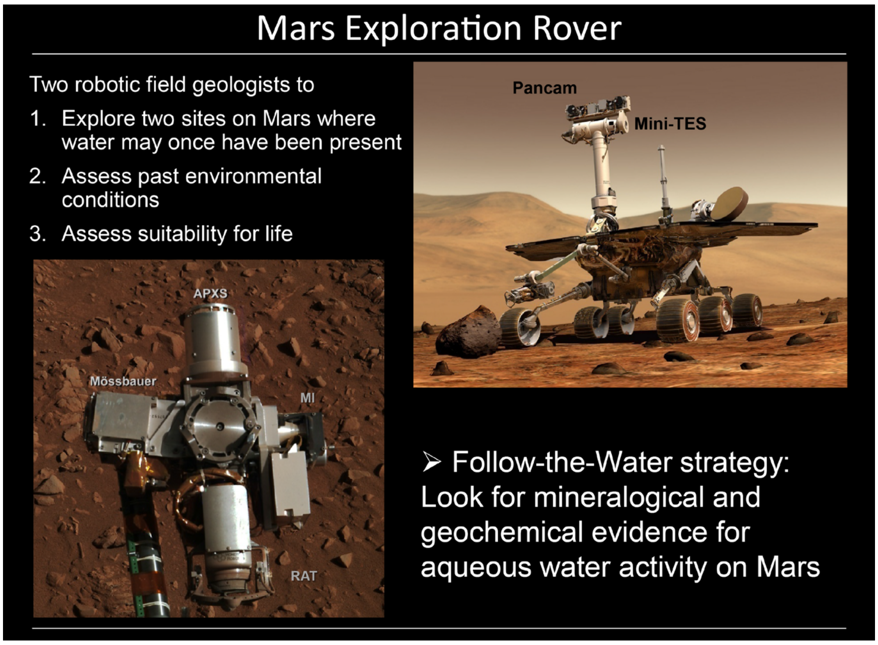
Quite successful application of in situ Mössbauer studies was performed by Spirit and Opportunity Mars Rovers. Both of them were equipped with compact Mössbauer spectrometer MIMOS (from **MI**niaturized **Mö**ssbauer **S**pectrometer) II, and started the exploration on the surface of Mars in 2004 after they had been operated almost ten years correspondingly performing together more than 700 measurements.

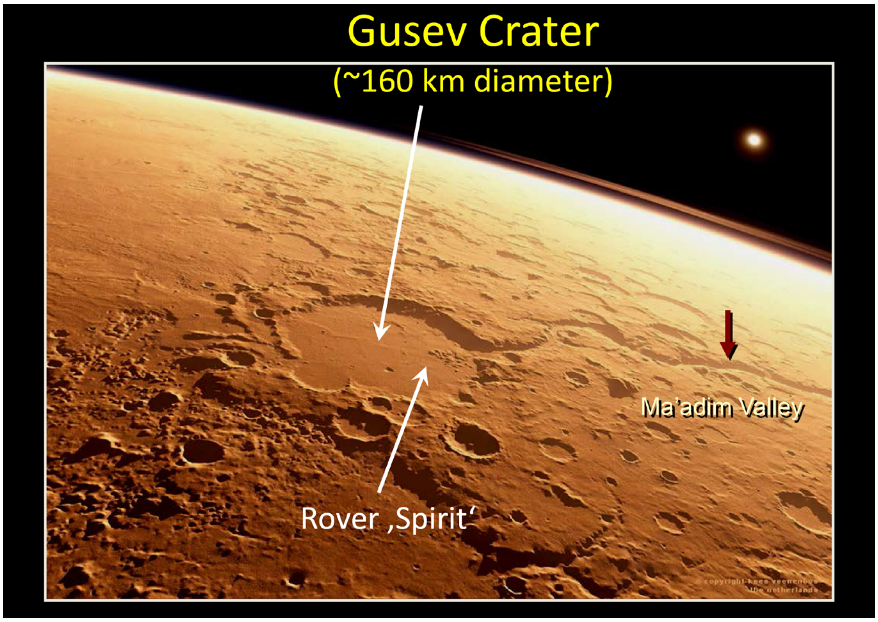
The Mössbauer instrument on board Spirit detected the iron mineral goethite in the Columbia Hills, which was clear mineralogical evidence for the presence of water at the time of formation. It also detected olivine in the soils at Gusev Crater, which in general is of basaltic composition, indicating the very small degree of chemical weathering in the plains of Gusev Crater. The Mössbauer instrument mounted on Opportunity detected the Fe-sulfate jarosite, which formed under very acidic conditions in the presence of water, and was therefore a direct mineralogical evidence for the presence of large amounts of water in the past at the Opportunity landing site.

The MIMOS II backscattering Mössbauer spectrometers on board the Mars Exploration Rovers were developed for space exploration by the Mars Mössbauer Group at Universität Mainz, headed by Dr. Göstar Klingelhöfer. For comparison, a dozen jarosite samples collected in different locations around the world were also measured by Mössbauer spectroscopy in many laboratories.

MIMOS II consists of a sensor head and an electronics board. The sensor head can be mounted on a robotic arm and needs to be brought in physical contact to the sample for the measurement. There is no additional sample preparation necessary. The sensor head carries

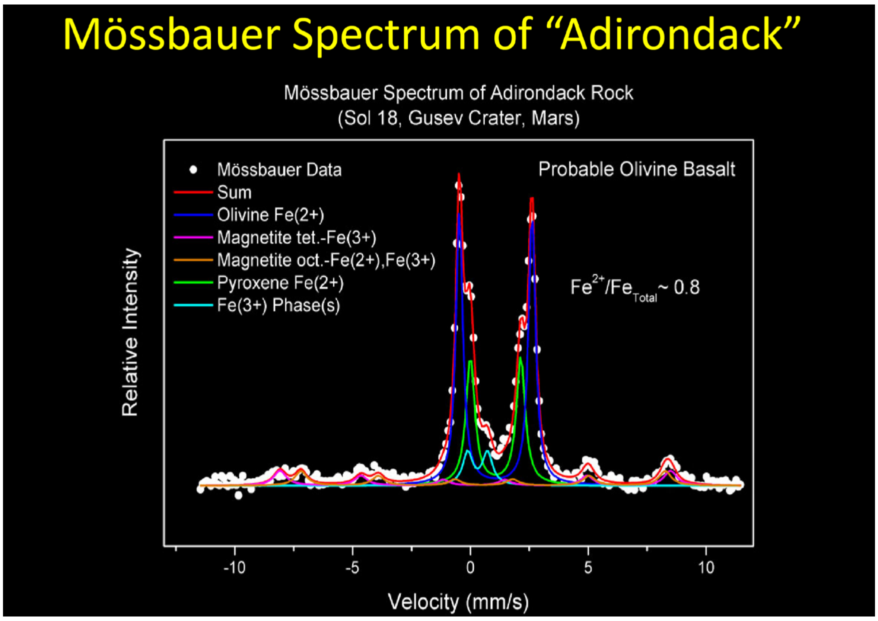

Launch of Spirit and Opportunity May/June 2003
at Kennedy Space Center, Florida, USA, 14 Years ago

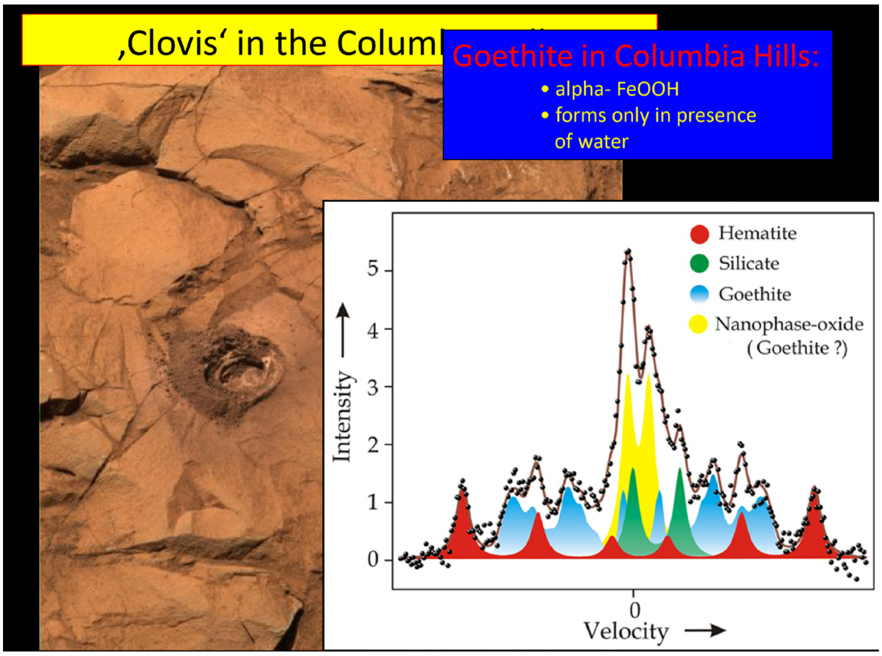

Mars Exploration Rover
Two robotic field geologists to
1. Explore two sites on Mars where water may once have been present
2. Assess past environmental conditions
3. Assess suitability for life
Pancam
Mini-TES
APXS
Mössbauer
MI
RAT
➢ Follow-the-Water strategy: Look for mineralogical and geochemical evidence for aqueous water activity on Mars

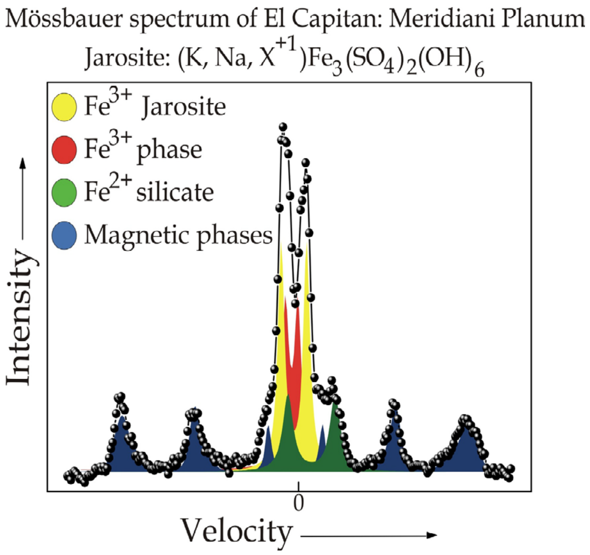

Gusev Crater
(~160 km diameter)
Ma'adim Valley
Rover ‚Spirit'

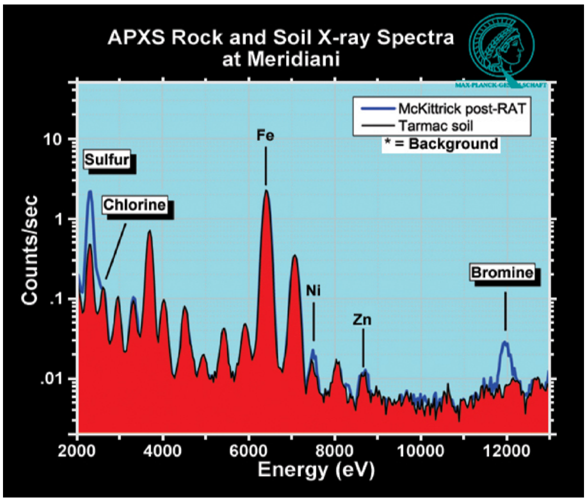
the radiation source (^{57}Co with a half-life of 272 days) and detector system, and has a volume of only 50×50×90 mm³. The whole system including connecting cables weighs less than 500 g. Beside the NASA's Mars Exploration Rover (MER) mission, the MIMOS II was also on – board the UK – led Beagle 2 and the Russian Phobos – Grunt missions.

The MIMOS II has made highly exciting results. They had been published in numerous articles in Science. Our Mössbauer Effect Reference and Data Journal (MERDJ) also reported these above highly exciting results by a review paper titled as "Two Working Mössbauer Spectrometers on the Surface of Mars" in Volume 27, Issue 2 of 2004.





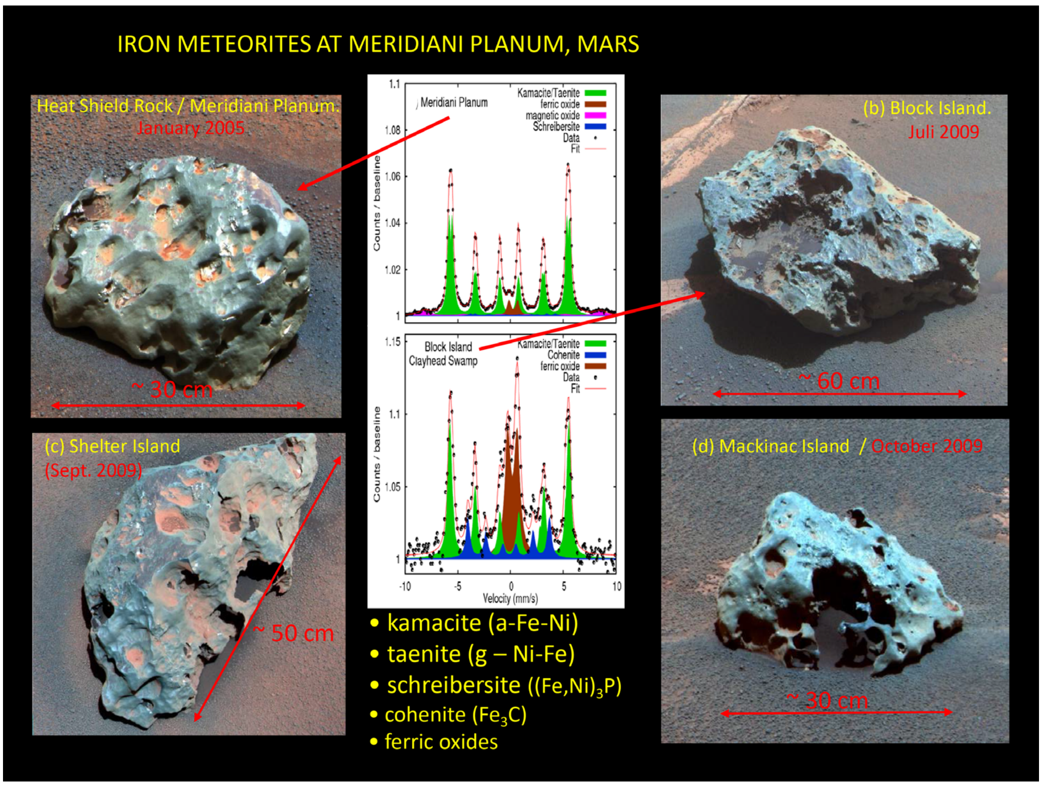




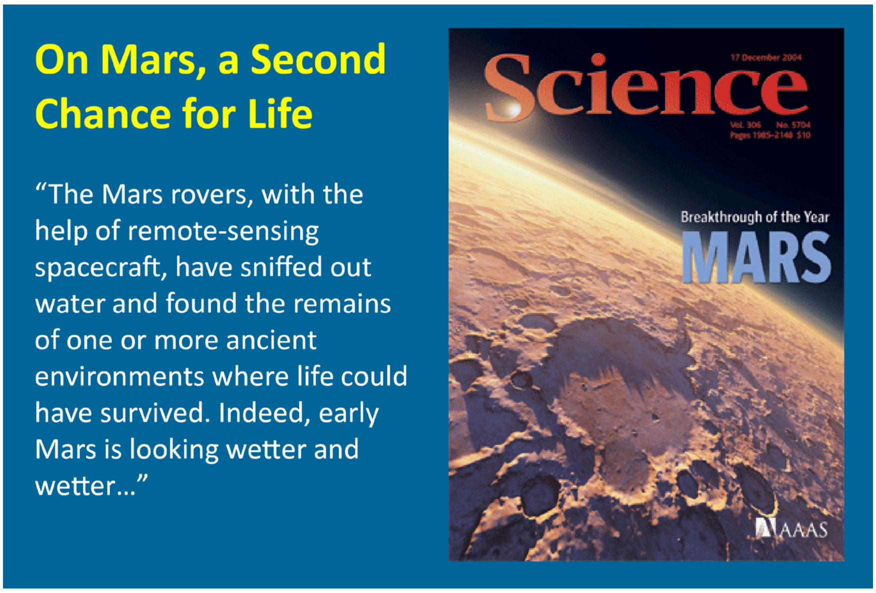
MIMOS II has proven to be the key instrument in identification of the mineral composition of rocks and soil in different spots along the path of their journey.

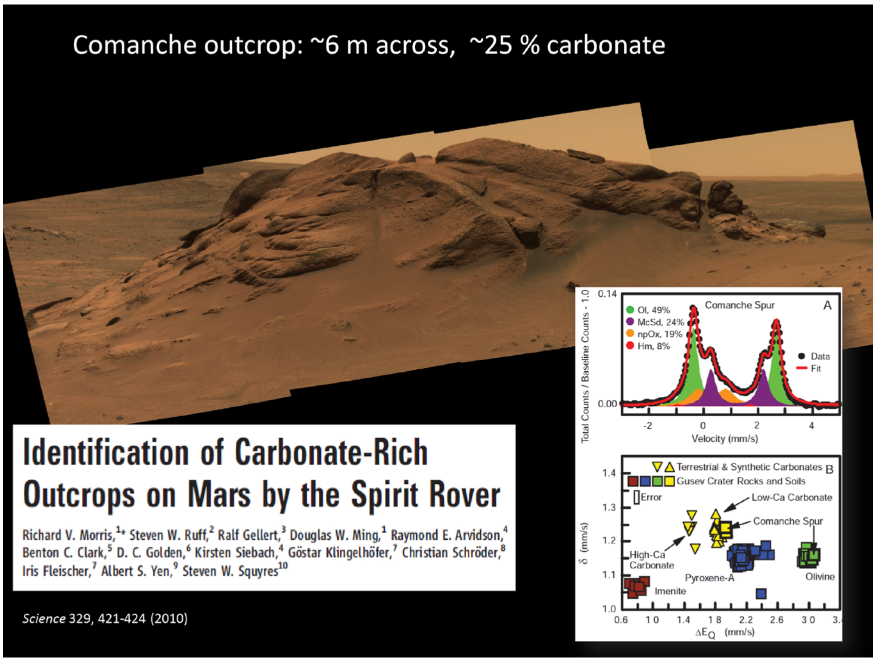
In 2006 Dr. Göstar Klingelhöfer became the recipient of the first IBAME (International Board on the Applications of the Mössbauer Effect) Science Award due to his exceptional contribution to Mössbauer Spectroscopy, especially for the design and construction of miniaturised instrumentation. Congratulations to Dr. Göstar Kingelhöfer, Prof. Philipp Gütlich (Institut für Anorganische Chemie und Analytische Chemie, Johannes Gutenberg-Universität Mainz) also contributed a special paper titled as “Brief Biography and Scientific Achievements of Göstar Klingelhöfer” in 2905 issue of MERDJ.

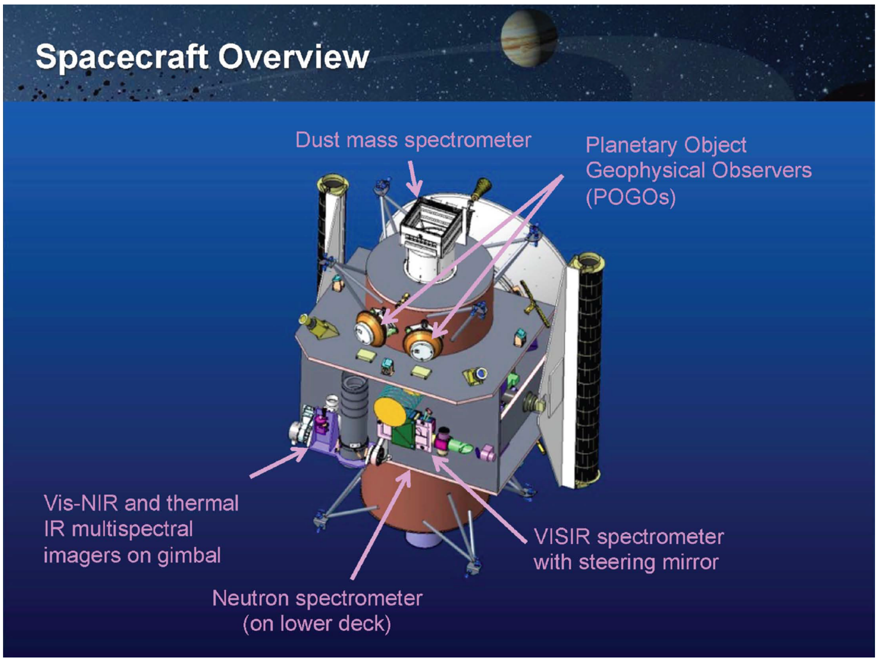
In 2017, the Dr. Göstar Klingelhöfer’s team in Johannes Gutenberg University Mainz and the Prof. Franz Renz’s team in Leibniz University Hannover reached a formal cooperation agreement with Prof. Junhu Wang’s team in Center for Advanced Mössbauer Spectroscopy, Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences (CAS) on the cooperative research of the application of the Miniaturized Mössbauer Spectroscopic technology in China’s deep space exploration.




6. August 2004
Reprint Series
Science
Vol. 305 No. 5685
Pages 737–900 $10
“Mineralogy at Gusev Crater from the Mössbauer Spectrometer on the Spirit Rover”
Spirit
at Gusev Crater
AAAS
3. December 2004
Reprint Series
Science
Vol. 306 No. 5702
Pages 1633–1844 $10
“Jarosite and Hematite at Meridiani Planum from Opportunity’s Mössbauer Spectrometer”
Opportunity
at Meridiani Planum
AAAS

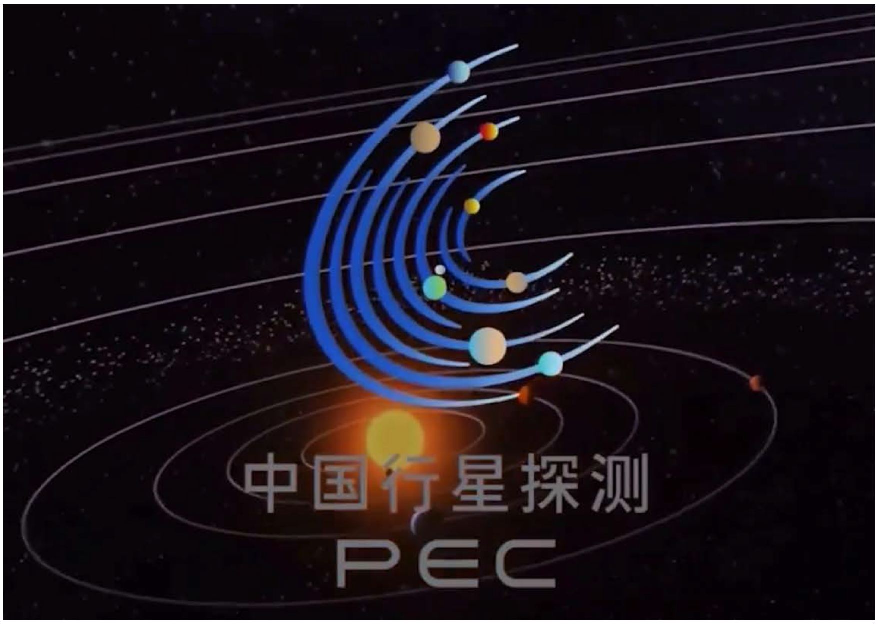

On Mars, a Second Chance for Life
“The Mars rovers, with the help of remote-sensing spacecraft, have sniffed out water and found the remains of one or more ancient environments where life could have survived. Indeed, early Mars is looking wetter and wetter…”
Science
17 December 2004
Vol. 306 No. 5704
Pages 1985–2148 $10
Breakthrough of the Year
MARS
AAAS

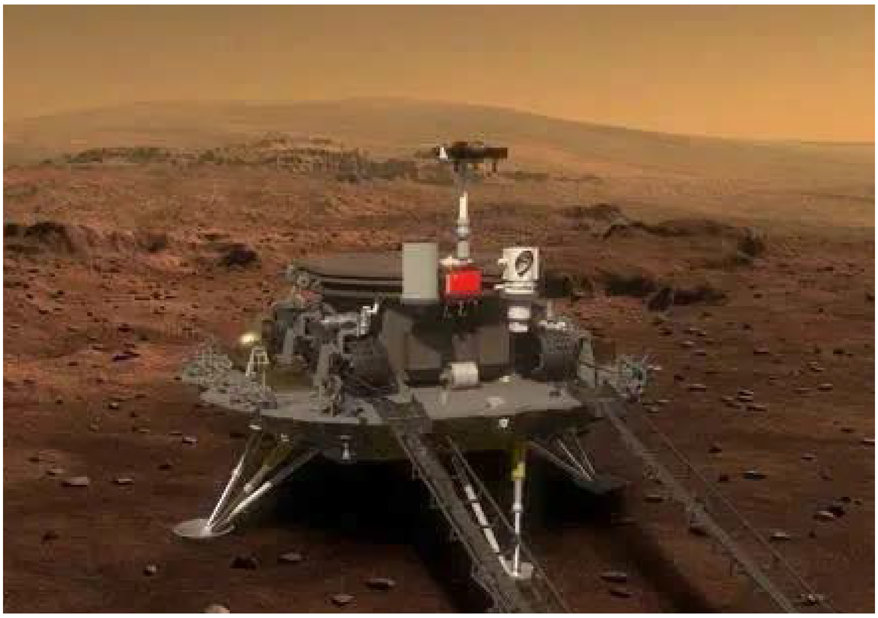

Comanche outcrop: ~6 m across, ~25 % carbonate
Identification of Carbonate-Rich Outcrops on Mars by the Spirit Rover
Richard V. Morris,1* Steven W. Ruff,2 Ralf Gellert,3 Douglas W. Ming,1 Raymond E. Arvidson,4 Benton C. Clark,5 D. C. Golden,6 Kirsten Siebach,4 Göstar Klingelhöfer,7 Christian Schröder,8 Iris Fleischer,7 Albert S. Yen,9 Steven W. Squyres10
Science 329, 421-424 (2010)
Comanche Spur
A
Ol, 49%
McSd, 24%
npOx, 19%
Hm, 8%
Data
Fit
Total Counts / Baseline Counts - 1.0
Velocity (mm/s)
Terrestrial & Synthetic Carbonates
B
Gusev Crater Rocks and Soils
Error
Low-Ca Carbonate
Comanche Spur
High-Ca Carbonate
Pyroxene-A
Olivine
Imenite
δ (mm/s)
ΔEQ (mm/s)



In 2018, a formal international cooperation project lasting three years was initiated by the funding support for the International Partnership Program of CAS. The Dr. Göstar Klingelhöfer's team, the Professor Franz Renz's team and the Hungarian Academy of Sciences Professor Denes Nagy's team, together with the Prof. Junhu Wang's team, started to develop the Miniaturized Mössbauer Spectrometer MIMOS IIC towards China's deep space exploration. Furthermore the feasibility as payload on the Chang'E series exploration rovers was explored, with the aid of the German's Miniaturized Mössbauer spectroscopy technology, the Hungarian high-quality & uniform Mössbauer radioactive source production technology and the Mössbauer Effect database resources of Mössbauer Effect Data Center (MEDC), DICP, CAS.

In 2018 Dr. Göstar Klingelhöfer visited China again with the support of overseas expert funds of Dalian Association of Science and Technology continuing to promote the smooth progress of the cooperation project, and gave a popular science lecture of Mars exploration by the Miniaturized Mössbauer Spectroscopic technology. Accompanied by Prof. Junhu Wang, Dr. Göstar Klingelhöfer visited the National Space Science Research Center of CAS, the





University of CAS and the headquarter of CAS under the arrangement of Prof. Tao Zhang, currently Vice President of CAS as well as director of MEDC, and Professor Chi Wang, current director of the National Space Science Center of CAS.

China's deep space exploration activities started with lunar exploration. From October 2007 to nowadays, China's lunar exploration successfully launched Chang'E 1 to Chang'E 4. In December 2018, Chang'E 4 was successfully launched with the aim to achieve the first major breakthrough in the lunar backside soft landing. Lunar surface patrol detection, lunar night survival, and other major exploration activities such as investigation of the lunar surface topography and geological structure, mineral composition and chemical composition, lunar interior structure, lunar space and lunar surface environment were also targeted.

In 2019, Dr. Göstar Klingelhöfer was awarded as a visiting professor with the support of the CAS President's International Fellowship (PIFI), unfortunately, Dr. Göstar Klingelhöfer passed away suddenly and unexpected on January 8, 2019, coming just back from the travel to China. He was full of plans for the new projects.

In 2019, Prof. Franz Renz and another one leading member of the MIMOS II team in Germany, Dr. Christian Schröder from University of Stirling, UK participated in the 35th International Conference on the Applications of the Mössbauer Effect

Future of MIMOS II (1)

CNSA Sample Return: Chang'E 5 (2020) **and Chang'E 6**

(Collaboration: CAS Tao Zhang & Junhu Wang)

The MIMOS II team intends to participate in the Chinese „Virtual Laboratory"

Chemical, mineralogical und geologic composition of:

- Rock
- Soil
- Meteorits
- Samples from polar regions which are chemically altered by volatiles like water (in particular from dark lunar craters)

A sample of some 100 mg (@ 5% iron) is needed (nondestructive)

Franz Renz,

Future of MIMOS II (2)

CNSA Rover Mission: Chang'E 7 (2023)

(Collaboration: CAS Tao Zhang & Junhu Wang)

Motivation:

- Origin of the Moon
- Development of its crust
- Formation of the basins, maria and lunar highlands
- Evolution of lunar vulcanism

International Lunar Research Team (ILRT) (ESA & CNSA),
International Lunar Research Station (ILRS):

Extraction of chemical elements is necessary!
Good knowledge of the local geology is essential → deposits

⇨ **Rover Mission**

Franz Renz

Future of MIMOS II (3)

In Situ Ressource Utilisation (ISRU)

ESA: **ISRU Demonstration Mission** (not later than 2025):

- A minimum of 100 g contained water or 90g oxygen shall be produced
- An image for the public shall be generated of any water that is produced

The MIMOS II team is engaged in the phase A study.

CAS: **ISRU Laboratory Experiments** (O_2, Fe, Ti from ilmenite …)

- Preparation to produce materials on the Moon
- All processes must be thought from a Lunar perspective

Franz Renz, Junhu Wang,

(ICAME2019), Dalian, China and organized a Dr. Göstar Klingelhöfer Memorial Session, two keynote lectures were delivered and titled as 1) In-situ Mössbauer Spectroscopy on Mars – in Memoriam and Tribute to Göstar Klingelhöfer; 2) Göstar Klingelhöfer Memorial Talk – My Way and Future of MIMOS.

In 2019, an International Lunar Research Team (ILRT) has been established between European Space Agency (ESA) and Chinese National Space Agency (CNSA) in the context of shared sustainable lunar exploration. The ILRT is tasked with defining scientific priorities and objectives for an international lunar research station (ILRS), identifying scientific and technological requirements for the station, and considering coordination with planned missions in the 2020s.

In 2020, China will launch Chang'E 5 to implement the first lunar sampling back to Earth. Also in 2020, China is carrying out its first Mars exploration mission. So, the ILRT's task also should include identifying how ESA and CNSA missions in the 2020s can be used to prepare scientifically for science at the Lunar Research Station and preparing recommendations for implementation of a "Joint Laboratory" for returned lunar samples. The Prof. Franz Renz's team and Prof. Junhu Wang's team want to cooperate and participate in the Joint Laboratory, in other lunar research projects [for instance ISRU (In Situ Resources utilization)] and primarily in lunar missions of CNSA and ESA. The current focus is on Chang'E 5 (lunar sample return in the Mons Rümker area in 2020) and Chang'E 6 & later ones.