Mössbauer Effect Reference and Data Journal

October 2020 • Volume 43 • Number 8

Dr. Göstar Klingelhöfer & His Miniaturised Mössbauer Spectrometer MIMOS II

MÖSSBAUER SPECTROSCOPY
NEWSLETTER

October 2020

Dr. Göstar Klingelhöfer & His Miniaturised Mössbauer Spectrometer MIMOS II

Harald Gaber[a], Mathias Blumers[a], Franz Renz[b], Junhu Wang[c]

[a] Johannes Gutenberg-University Mainz, Saarstraße 21, 55128 Mainz, Germany, Email: mblumers@uni-mainz.de; harald.gaber@uni-mainz.de
[b] Leibniz University Hannover, Institute of Inorganic Chemistry, Callinstraße 9, 30167 Hannover, Germany, renz@acd.uni-hannover.de
[c] Mössbauer Effect Data Center, Dalian Institute of Chemical Physics, Chinese Academy of Sciences, 457 Zhongshan Road, Dalian 116023, China, wangjh@dicp.ac.cn

Authors' introduction

Dr. Harald Gaber got his Ph.D. degree of Albert–Ludwig-University in Freiburg (Germany) in 1993 with his Ph.D. thesis "Production and Deposition of Hydrocarbon-Clusters and Fullerenes". His research includes furthermore the LASER-induced fission of fullerenes, the analysis of diamond and other carbon films as well as ion–molecule–reactions with hydrogen and deuterium, but also LASER applications like IR-spectroscopy, Raman spectroscopy, and LASER ablation on metallic or polymeric surfaces.

After a short postdoctoral period at the Max Born-Institute in Berlin, Dr. Gaber went to the Johannes Gutenberg–University in Mainz and began his career as an university manager, initially in the science & technology department of the main administration, later in the real estate department. He also received a certification of medical physic of the Technical University in Kaiserslautern and a further diploma in business administration of the Open University in Hagen.

In 2005, Dr. Gaber began to cooperate with Dr. Göstar Klingelhöfer as a space science manager and assisted him preparing budget requests and project reports, particularly for the MER rovers "Spirit" and "Opportunity", and prepared documents for the ExoMars mission. Later he participated in the not successful Phobos Grunt mission and participated in the preparation of a ESA-led parabolic flight test of MIMOS II in 2010 for this mission.

After the death of Dr. Göstar Klingelhöfer he began to cooperate with Prof. Dr. Franz Renz and Prof. Dr. Junhu Wang and started with him the further development of the MIMOS II technology for space missions in the future.

Dr. Harald Gaber was a member of the ESA/CNSA-led International Lunar Research team, together with Prof. Dr. Renz and Prof. Dr. Wang. With these colleagues he is intensively working on the vision that an improved MIMOS IIC (like China) can be applied to Chinese spaceflight exploration in the near future, to the Moon, to Mars or elsewhere. Prior to this he wants to analyze Lunar samples from Chang'e 5 or 6 with Mössbauer spectroscopy together with his colleagues. To promote this, currently Lunar meteorites like NWA 12008 or Dar al Gani 400 area analyzed in Hannover.

Mathias Blumers obtained his Ph.D. degree from the Johannes-Gutenberg University in Mainz (Germany), on a thesis titled: “Thermoelectric properties of thin layers and superlattice structures of VI-VI and V-VI compound semiconductors”. This work was carried out within the framework of the BMBF project Nitherma (low-dimensional thermal materials for energy conversion), in cooperation with the industrial partners Siemens and Bosch. His research includes the calculation of the 2-dimensional charge and heat transport via Boltzmann theory, (and) the effect to the transport-coefficients electrical conductivity, Seebeck-voltage, and thermal conductivity. The theoretical prediction of the increase in the power factor was checked by measuring the transport sizes on different multi-quantum well structures and superlattices. Based on these results, a prototype of a miniaturized energy converter was designed and built.

In 2004, Dr. Blumers joined group of Dr. Göstar Klingelhöfer and was over 10 years responsible for the production, qualification, and further development of the miniaturized Mössbauer spectrometer MIMOS II. The use of the latest silicon drift detectors, in the advanced version MIMOS II, was created in close cooperation with the external cooperation partner of Hörner & Sulgar for the ESA ExoMars mission. For terrestrial applications, Dr. Blumers carried out all qualification tests and calibrations, as well as the maintenance and repair work. MIMOS II is used in science and research, especially, where non-destructive measurements are required. For possible use in space missions, the spectrometers were tested etc. during the ESA project study GIPF (Geochemical Instrument Package Facility) respectively in field missions, e.g. the ISRU (In Situ Resource Utilization) missions organized by NASA in 2010, and 2012 on Hawaii. He carried out the qualifications required for extra-terrestrial use, including low temperature measurements or accompanies them e.g. vibration and shock tests. The operational readiness of the MIMOS II under weightlessness was provided by him by use of a specially developed measurement setup, which was successfully tested in the ESA parabolic flight campaign in 2010. One of the tested spectrometers was later part of the scientific instrumentation of the Russian space mission Phobos-Grunt in 2012. As radiation protection officer, he was responsible for the use of the radioactive sources domestically and internationally. Besides to his main activities, Dr. Blumers developed and fabricated various modifications of detector systems for Mössbauer instrumentations.

In 2016, he changed from the scientific to the medical field, and was head of the Medical Physics department for nuclear medicine at the University Hospital in Bonn until 2020. During this time, he completed a distance learning course in the field of medicine and technology and qualified as medical physics expert.

After the death of Dr. Göstar Klingelhöfer in 2019, he began to cooperate with Prof. Dr. Franz Renz to ensure the existence and further development of MIMOS II.

Presently, Dr. Blumers is an employee in the radiation protection department at the University of Mainz.

Prof. Dr. Franz Renz is professor of Inorganic Chemistry at the Leibniz University Hannover, Germany since 2008. His research focuses on coordination chemistry, such as such as molecular switching in sequential and concerted stimuli-responsive mono- and multinuclear iron spin crossover materials as well as Mössbauer spectroscopy.

After mechanical engineering, he studied chemistry. In 1997, he finished his doctorate at the technical university in Vienna, which was honored with an Award of the Austrian Chemical Society.

• In 1997-1998 he was a JSPS fellow in Tokyo/Japan and from 1998-2000 a PostDoc as EC-TMR fellow, with Prof. Dr. Philipp Gütlich at the University of Mainz in Germany.

• In 2005 he finished his habilitation at the Johannes Gutenberg-University of Mainz.

• From 2010-2016 he was the representative chairman of the German Chemical Society (GDCh) in Hannover.

• Since 2015 he is a board member of the Graduate Academy of the Leibniz Universität Hannover. Since 2019 he is an elected german representative in the IBAME, the International Board of the Application of the Mössbauer Effect.

• He had several visiting professorships: in Japan at the National University of Yokohama 2000, the University of Tsukuba 2002 and 2017, at the CAS DICP in Dalian 2019, and currently at the University of Tokyo until 31.3.2021.

• Renz hold martial arts black belts in Aikido and Daitōryū-Aiki-Jūjutsu.

Franz Renz is known for his contributions to the discovery of the SF-LIESST, HAXITH and HAXIESST effects in molecular magnetism. His research group is on the so-called molecular switches. Compounds which can change their properties by an external stimulus and can thus be used as sensors or, in the future, data storage devices. Mössbauer spectroscopy has been established as a further research focus in the group for precise investigation of the above mentioned switchable compounds.

Since 2000, Renz became a member of the NASA MER mission in the team of the principal investigator Dr. Göstar Klingelhöfer, using the miniaturized Mössbauer spectrometer MIMOS II on the MER rovers Spirit and Opportunity during the Mars mission 2003-2019. They provided information about the water that once existed on Mars. Renz received the NASA Group Achievement Award for the Mars Exploration Rover (MER) Surface Operation Team.

Since 2019, after the unexpected passing of Dr. Göstar Klingelhöfer, the Renz group is continuing the research and development of the MIMOS technology, at the Leibniz University Hannover, with support of the german air and space agency (DLR), for further terrestrial and extraterrestrial applications. Renz is a member of the international lunar research team (=ILRT) with the aim of an international lunar research station (=ILRS).

Prof. Junhu Wang graduated from Lanzhou University (1991), majoring in radiochemistry, received his Ph.D. in inorganic and radiochemistry from Toho University, Japan (2002). He was a research fellow at the National Institute for Materials Science (NIMS) and National Institute of Advanced Industrial Science and Technology (AIST), Japan (2002-2004). After that, he was appointed as an associate researcher at Chukyo University and senior advisor at NonamiScience, Japan for three years.

Since 2007, Prof. Junhu Wang was invited back to China from Japan, now he is a full professor and doctoral supervisor at Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences (CAS). Since 2010, he has been Secretary General, Mössbauer Effect Data Center (MEDC) and Execute Chief Editor of Mössbauer Effect Reference and Data Journal (MERDJ, ISSN 0163-9587). Since 2016, he has been Director, Center for Advanced Mössbauer Spectroscopy (DNL2005), DICP, CAS.

Prof. Junhu Wang is a member of the Chinese Chemical Society and the American Chemical Society, a member of the Board on the Chinese Mössbauer Community, a advisor member of the International Board on the Applications of the Mössbauer Effect (IBAME), a senior technical consultant of WissEl Mössbauer Instrument (Germany) and Sunday Produce (Japan), and a visiting professor of Tokyo Metropolitan University of Japan.

Prof. Junhu Wang has been engaged in Mössbauer spectroscopy and its applications in chemistry and catalysis for a long time. 5 book chapters have been published by Nova and Wiley, about 200 papers have been published in the peer-reviewed international journals, such as Nat. Commun., Sci. Adv., J. Am. Chem. Soc., Angew. Chem. Int. Ed., ACS Nano, Adv. Catal., Appl. Catal. B, Nanoscale, Chem. Mater., Chem. Commun., etc and a dozen patents have been authorized.

Prof. Junhu Wang has successively engaged in many researches, including in the structural chemistry of lanthanide and actinide compounds, photocatalytic splitting of water for hydrogen production by semiconductor composite oxides, degradation and mineralization organic pollutants by hydroxyapatite/titanium oxide nanocomposite photocatalyst, high-temperature anti-sintering high-efficiency nano gold catalysts by designing the novel strong support-metal interaction (SMSI), heterogeneous composite and cation/anion doped new titanium oxide photocatalytic materials, controllable synthesis of precious metals and composite oxide electrocatalytic materials, Prussian blue/ hydroxyapatite and spinel oxide reactive adsorption materials development, advanced oxidation process (photocatalysis, Fenton-like reaction including hydrogen peroxide and persulfate activation), developments of in-situ/operando thermal/electro/photo-catalytic Mössbauer instruments, Mössbauer technique towards deep space exploration, and further development of the MEDC database, etc.

Memorial article to Dr. Göstar Klingelhöfer

On January 8, 2019, our colleague, friend and mentor Dr. Göstar Klingelhöfer died unexpectedly in the bosom of his family.

1) Göstar and his lifework

Göstar was an experienced physicist in the chemistry department of the Johannes Gutenberg-university in Mainz (Germany), and he was on outstanding expert in Mössbauer spectroscopy. His greatest success was the development of the Miniaturised Moessbauer Spectrometer MIMOS and the landing of the more advanced version MIMOS II on Mars in January 2004. In addition, Göstar was also coworker of the Alpha particle X-ray Spectrometer APXS which was developed from the Max Planck Institute for Chemistry in Mainz, and which was used to determine the elemental composition of Martian minerals. Göstar and MIMOS II were also team members of the not successful European Mars mission Beagle 2 in 2003 and the also not successful Russian Phobos Grunt mission in 2011, but he never gave up and found new ways to participate in new ambitious space projects.

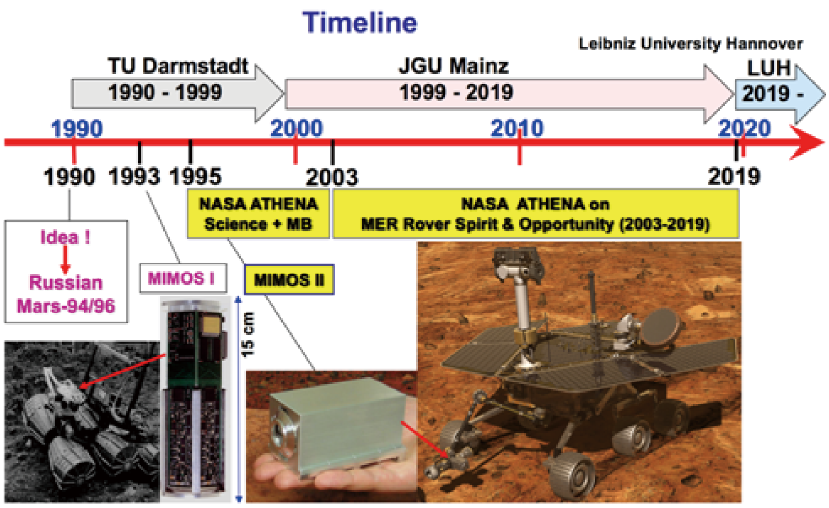

Figure 1: It shows the timeline of the development of MIMOS I (1993), start of MIMOS II (1995), and the selection for the NASA Athena science payload applied at the MER Spirit and Opportunity. After the launch 2003, landing in 2004 the Mission lasted until 2019. The Beagle 2 (2003) and Phobos Grunt (2011) missions failed and are not shown. The project started at the TU Darmstadt (1990-1999), continued at the Johannes Gutenberg University (JGU) Mainz (1999-2019), and runs now at the Leibniz University Hannover (LUH).

In the 1980s, several ideas about a possible space application of the Mössbauer effect were discussed but remained a dream. In 1990, a historical meeting took place in Darmstadt/Germany. Egbert Kankeleit, Göstar Klingelhöfer, and Peter Held from the Institute of Nuclear Physics, TU Darmstadt discussed with Oleg Prilutski, Boris Zubkov, and Evgeny Evlanov from the Space Research Institute (IKI) in Moscow the development of an In-Situ Mössbauer spectrometer. Figure 1 shows the timeline of the MIMOS development. In 1993 the MIMOS I was ready for the Russian Mars-94 mission. Mars-94 was delayed to Mars-96 and finally failed. In 1995 the cooperation with NASA started when MIMOS II was selected as Athena science payload and later applied to the NASA Mars Exploration Rover (MER) Mission Spirit and Opportunity.

Figure 2: It shows the official NASA Mars Exploration Rover (MER) Spirit and Opportunity members as part of the surface operation team (SOT) for the Mössbauer spectrometer (MB) payload (PDL/PUL) at NASA-JPL in January 2004. In the front from right: Tom Wdowiak, Albert Yen, Daniel Rodionov, Ralf Gellert. In the back from right: Christian Schröder, Paolo de Souza, Bodo Bernhardt, Richard V. Morris, Franz Renz, and Göstar Klingelhöfer.

MIMOS II has been developed and built at the Technical University Darmstadt, from 1999 until 2019 at the Johannes Gutenberg-University (JGU) Mainz and since 2019 at the Leibniz University Hannover (LUH) (see Figure 1). The MER MIMOS II version has a mass of ca. 400 g and an electrical energy consumption of only 4 W. The main goal was the investigation of the mineralogical composition of the Martian surface during the NASA-led mission of the both rovers Spirit and Opportunity. During this missions, MIMOS II

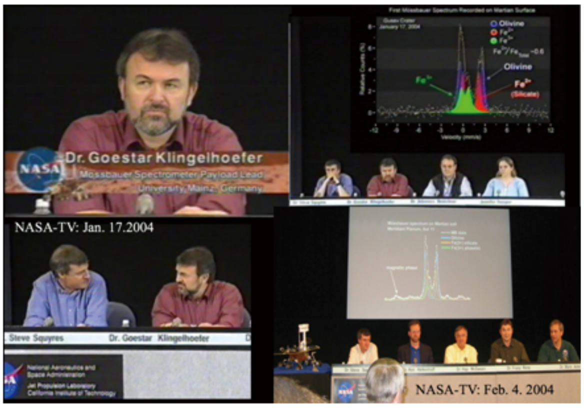

Figure 3: Göstar Klingelhöfer is presenting the first Mössbauer spectra on Mars taken by MB on MER Spirit in the NASA-TV press conference on Jan. 17. 2004 (WWW.NASA.GOV). While at the NASA-TV press conference on Feb. 4. 2004 the first Mössbauer spectra of MB on MER Opportunity is presented by F. Renz.

and APXS were a good tandem. Figure 2 shows some official NASA MER MB members at the NASA Jet Propulsion Laboratory (JPL) next to the mission control center shortly after landing on the Mars. Figure 3 shows Göstar in the NASA-TV. Figure 4 shows his goup at JGU Mainz in 2007.

Göstar was honored with many scientific distinctions, particularly he awarded the Eugen Sänger medal of the German space agency DLR in 2005 and the Helmholtz price for precision measurements in 2007. Figure 5 shows the Göstar Klingelhöfer Memorial placed in his hometown.

Figure 4: MIMOS-team, 2007 at the Johannes Gutenberg-University (JGU) Mainz.

Figure 5: The Göstar Klingelhöfer Memorial is located in his hometown Eckartsborn in Ortenberg.

2) Terrestrial implementation of MIMOS II

MIMOS II was investigated for extra-terrestrial missions where sample preparation is not possible. Therefore the spectra are measured in backscattering geometry. As both the source and the detectors are placed on the same side of the sample, a preparation of the sample is not necessary. MIMOS II can directly be placed on the sample, performing a destruction free analysis of all kind of iron bearing subjects.

One of the striking advantages of MIMOS II is the simultaneous detection of 14 keV and 6 keV, due to their different penetration depth of the gamma radiation. This enables a depth selected Mössbauer spectroscopy, which can show differences between surface and bulk, e.g. in weathering effects.

Because of its mobility-handy dimensions, robust chassis, low weight and very low energy consumption-MIMOS II is ideal for the use outdoors but also in laboratory, especially when non-destructive analysis is necessary. These tasks include the detection of air pollution and the analysis of antique archaeological artefacts.

MIMOS II uses the Mössbauer effect of iron and can therefore applied in many fields of applied science and technology:

- Material science and-control
- Corrosion research
- Quality assurance of industrial fabrication (e.g. steal manufacturing)
- Optimization of industrial processes (e.g. ore smelting)
- Archaeology and artwork (e.g. cave painting, modern art, …)
- Geology and mineralogy
- Environmental research (e.g. air or soil pollution)

Today, in a cooperation between China (Chinese Academy of Science, CAS; Dalian Institute of Chemical Physics, DICP; Chinese National Space Agency, CNSA) and Germany (Leibniz University Hannover, LUH), further extra-terrestrial, e.g. to the moon with Change 7, and terrestrial application are in progress, e.g. the investigation of the moon meteorites.

Figure 6: Application of MIMOS II on Klimt´s Putto masterpiece and an old man artefact.

3) MIMOS II on Mars

Mars is a popular subject of modern research in order to learn more about possible development scenarios of an Earth-like planet. In order to investigate two landing sites in detail, NASA launched in 2003 the Mars Exploration Rovers MER. The two rovers "Spirit" and "Opportunity" are the second generation of robotic Mars explorers after "Viking" and "Mars Pathfinder". The main objective of the mission was to search for evidence of water activity in the past at the two landing sites "Gusev Crater" and "Meridiani Planum" and to assess past climate conditions and their suitably for life.

The task of MIMOS II was the detection of iron bearing minerals. Some of these minerals is connected to the presence of water during their formation or H_2O components are even an integral part of their composition. The mineral characterization of the landing sites will give additional information about the formation and weathering of Martian rocks.

Spirit landed on January 4, 2004 on the plains of Gusev Crater. Mössbauer spectra near the landing site show the signature of basaltic, slightly weathered rocks (olivine, pyroxene, nanophase oxide). More strongly weathered rocks were found in the Columbia Hills 3km away where the mineral goethite, i.e. the iron(III) oxy hydroxyl compound alpha FeOOH, was detected. On Earth, this mineral is known to form only in the presence of water. The detection of goethite is therefore clear mineralogical evidence that there were once great amounts of water in the Columbia Hills. The fact, that the older Columbia hills reach out of the younger plains indicate that the Gusev crater have been flooded with Lava afterwards. On earth similar old-hill-on-young-plain processes can be seen, e.g. on Hawaii.

Opportunity landed on January 24, 2004 inside the crater “Eagle” with a layered outcrop at Meridiani Planum. The outcrop turned out to be sulfate-rich sedimentary rock, as indicated by APXS. Mössbauer spectra obtained on the outcrop show the mineral jarosite with an intensity of about 30%. Jarosite, an iron(III) hydroxy sulfate, can only form in wet environment, e.g. a pH range of 2–4 of a sulfuric acidic aqueous solution. While a pH below two yields iron sulfates and a pH above four forms iron oxy hydroxy compounds. The presence of the hydroxy group in the Jarosite structure excludes a high temperature solvent-free molten synthesis pathway and includes the formation out of aqueous solution. Beside Eagle crater Jarosite was detected on many more sites during the ongoing MER opportunity mission. The detection of Jarosite is a clear mineralogical evidence for the presence of water in Meridiani Planum in the past.

In connection with the outcrop rock, little spherules called “blueberries” were found covering the whole plain. Mössbauer spectra show them to be composed mainly of hematite. Scientists were also attracted by a rock, whose appearance was quite different from all other rocks. According to Mössbauer data, this metallic-shimmering rock is made of the mineral kamacite, an iron-nickel alloy. This rock is the first iron meteorite ever found on a foreign planet.

On March 2015, after more than 11 years, Opportunity finished the first marathon (42.195km) on the surface of a foreign planet.

4) Dr. Göstar Klingelhöfer in China

In 2012, based on many discussions on the collaborative studies with Dr. Göstar Klingelhöfer and his MIMOS II team, taking the opportunity to host the International Symposium on the Industrial Applications of the Mössbauer Effect (ISIAME 2012), Prof. Junhu Wang invited Dr. Göstar Klingelhöfer to visit China and give a special lecture on the project of MIMOS II in Mars Exploration Rover in ISIAME 2012.

In 2017, the Dr. Göstar Klingelhöfer’s team in Johannes Gutenberg University Mainz and the Professor Franz Renz’s team in Leibniz University Hannover reached a formal cooperation agreement with Prof. Junhu Wang’s team in DICP-CAS on the cooperative research of the application of the Miniaturized Mössbauer Spectroscopic technology in China’s deep space exploration.

Figure 7: Dr. Göstar Klingelhöfer deliveried a lecture titled as “The Miniaturized Mössbauer Spectrometers MIMOS II & MIMOS IIA: Instrument Development and Applications” in ISIAME 2012 which was held in Dalian, China.

In 2018, a formal international cooperation project lasting three years was started 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 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 DICP-CAS.

In December 2018, officially invited by the Dalian Association for Science and Technology (DAST) Dr. Göstar attended the Overseas Expert Forum of DAST as well as the Culture Forum of Dalian Institute of Chemical Physics (DICP). Bases on the purpose of popularization of space exploration science, he delivered two special lectures of “Roving the Red Planet: Spirit, Opportunity and the Exploration of Mars” in DICP and in the University of Chinese Academy of Science (UCAS). He was also invited to visit the Laboratory of Catalysts & New Materials for Aerospace in DICP and National Space Science Center in CAS for a consulting discussion of the well-known MIMOS II technology with Prof. Aibing Zhang and his team staff.

Figure 8: Dr. Göstar Klingelhöfer in Prof. Junhu Wang's office met with the MEDC's staff and his graduated students in Dalian in December 18, 2018.

Vice President of CAS, Prof. Tao Zhang met Dr. Göstar in the headquarters of CAS in Beijing, and made a deep discussion on the further cooperation in the development of an advanced MIMOS IIC system towards Chinese space exploration projects.

Figure 9: Prof. Tao Zhang, Prof. Junhu Wang, Prof. Jianfeng Li and Dr. Göstar Klingelhöfer had dinner in the canteen of the headquarter of Chinese Academy of Sciences in Beijing in December 20, 2018 and discussed further strengthening cooperation in the development of MIMOS IIC technology. (From left to right: Prof. Jianfeng Li, Dr. Göstar Klingelhöfer, Prof. Tao Zhang and Prof. Junhu Wang)

During his 2018's China visit, Dr. Göstar Klingelhöfer was also informed to be awarded as a visiting professor with the support of the CAS President's International Fellowship (PIFI), sadly, this was the last international journey of Dr. Göstar Klingelhöfer before he began his very last journey only a few weeks later. We, his colleagues and friends, feel very committed to continue his lifework and lead MIMOS II to new space destinations, and the next destination can be the Moon.

5) A MIMOS IIC on the Moon

The Leibniz University Hannover and CAS want to jointly participate in Chinese Lunar missions. First,we want to analyze lunar samples from the Chang'e 5 and Chang'e 6 lunar sample return missions through performing Mössbauer spectroscopy of a notable number of samples. Chang'e 5 is currently targeted to start in December 2020 and land in the Mons Rümker area in the Oceanus Procellarum basin. Apollo 12 had also landed on Oceanus Procellarum, but south of Mons Rümker. A comparison of the Mössbauer spectra of the younger lava flows near Mons Rümker with the older Maria regolith of the Apollo 12 landing site promises deeper insights in the lunar volcanic history. Chang'e 6 is intended to land near the lunar South Pole, but no precise landing site has been selected yet.

Currently, the Lunar meteorite NWA 12008 is analyzed together with the "Joint Virtual Laboratory" of the Chinese-European "International Lunar Research Team", as well as other meteorites like DAR AL GANI 400. The Mössbauer spectra predominantly show volcanic minerals like olivine and pyroxene, but also titan-rich minerals like ilmenite (TiFeO3) and other iron-containing minerals. Furthermore, the MIMOS II team aims to get some Apollo samples from NASA for comparison with the Chang'e landing sites.

It is also aspired to provide a Mössbauer instrument (MIMOS IIC) on a robotic arm of a Lunar rover (Chang'e 7). This mission is scheduled to land on the lunar Antarctic around 2024 and to carry out environmental and resource exploration in the polar region, to examine lunar mineralogy and chemistry along the rover's traverse, similar to the Mars Exploration rovers Spirit and Opportunity.

In Situ Ressource Utilisation (ISRU) is of immense importance for supplying a manned lunar research station. ISRU examines various different methods to ensure the production of essential materials (e.g. oxygen). A few processes are known that can extract Oxygen from lunar regolith. In some way the yield is proportional to the ferrous iron or iron oxide content. However, Oxygen is only one potential resource from ISRU on the Moon. Another is the extraction/production of metals or metal alloys from metal bearing oxides (e.g. ilmenite) on the lunar surface. The fundamental idea for experimental realization is to obtain metals or alloys from lunar analogue materials, treat them for utilization in a 3D-printer and print simple components which are needed on the Moon.

Therefore Mössbauer spectroscopy - MIMOS II - is indispensable for a sample return mission and as an out-standing monitoring tool on a lunar rover the predestined scientific instrument.

During future missions, ISRU with MIMOS II the Mössbauer spectroscopy can be tested and performed on the Moon and support the sustainable living on the Lunar surface.

Figure 10: Dr. Harald Gaber, Prof. Aibing Zhang, Prof. Franz Renz and Prof. Junhu Wang (from left to right) met in the 4th international conference on lunar and deep space exploration which was held in Zhuihai, China on July 22-24, 2019.