THE MINIATURIZED MÖSSBAUER SPECTROMETER MIMOS II FOR THE ASTEROID REDIRECT MISSION (ARM): QUANTATIVE IRON MINERALOGY AND OXIDATION STATES.

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Introduction: The miniaturized Mössbauer spectrometer MIMOS II [1] is an off-the-shelf instrument with proven flight heritage. It has been successfully deployed during NASA's Mars Exploration Rover (MER) mission [2-4] and was on-board the UK-led Beagle 2 Mars lander [5] and the Russian Phobos-Grunt sample return mission [6]. A Mössbauer spectrometer has been suggested for ASTEX, a DLR Near-Earth Asteroid (NEA) mission study [7], and the potential payload to be hosted by the Asteroid Redirect Mission (ARM) [8]. Here we make the case for in situ asteroid characterization with Mössbauer spectroscopy on the ARM employing one of three available fully-qualified flight-spare Mössbauer instruments.

Instrument Description: MIMOS II [1] consists of a sensor head (Fig. 1) and an electronics board. The sensor head can be mounted on e.g. a robotic arm (see Fig. 2 for a MER instrument) and needs to be brought in physical contact with the sample to be analyzed. No sample preparation is necessary. The sensor head carries the radiation source (^{57}Co, halflife 270 d) and detector system, and has a volume of 50×50×90mm³. The electronics board holds data acquisition and instrument control units (CPU + FPGA), voltage converters, and electrical and data interfaces to the spacecraft. It is 100×160×25mm³. The whole system including connecting cables weighs <500 g, power consumption is 4W during data acquisition, and data product size per analysis is 512 kBytes (4 Mbit).

Asteroid Redirect Mission: ARM consists of the Asteroid Redirect Robotic Mission (ARRM) to be followed by the Asteroid Redirect Crewed Mission (ARCM). ARRM will visit a larger than ~100 m diameter NEA and collect a meter-sized boulder and regolith from its surface. The boulder will be used for a gravity tractor asteroid deflection demonstration before it will be transported to a stable orbit around the Moon where astronauts can explore it and return samples to Earth during the ARCM [8]. Asteroid 2008 EV_5 has been used to support mission design studies but the final target asteroid has yet to be selected. Asteroid 2008 EV_5 is probably a CR-type carbonaceous chondrite.

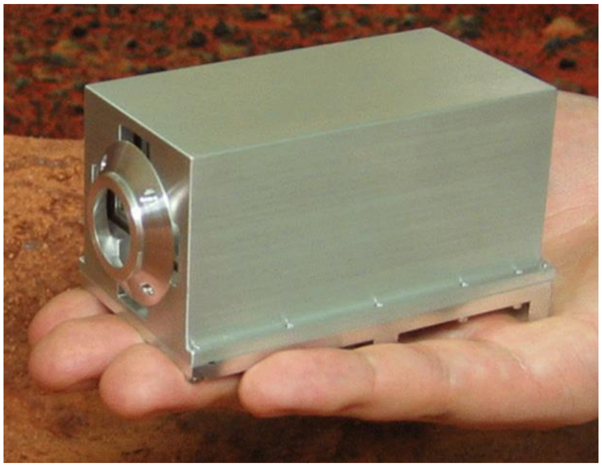

Fig. 1. The MIMOS II sensorhead. Credit: University of Mainz.

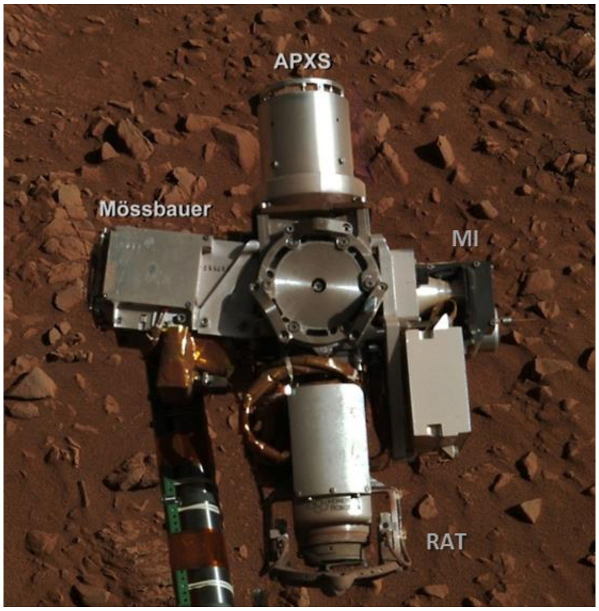

Fig. 2. A MIMOS II sensorhead (Mössbauer) mounted on Mars Exploration Rover Spirit's robotic arm, together with the Alpha Particle X-ray Spectrometer (APXS), the Microscopic Imager (MI), and the Rock Abrasion Tool (RAT). Credit: NASA/JPL/Cornell.

Mössbauer Investigations Related to ARM and NASA Goals: Mössbauer spectroscopy identifies Fe-bearing mineral phases (e.g., silicates, oxides, and sulfides) and Fe oxidation states, and determines the quantitative distribution of Fe between mineral phases and oxidation states. It also yields insights into magnetic properties. This information is vital to support ARM and NASA goals regarding science, planetary defense, asteroidal resources and ISRU, as demonstrated by the examples given below.

Science. Asteroid 2008 EV5 is likely a CR carbonaceous chondrite on the basis of its reflectance spectrum and albedo but could also be a CI, CM, or CK chondrite. Such uncertainty is the case for most asteroids. This uncertainty in composition can be removed by establishing a firm link to a single group of meteorites through knowledge of the geochemical and mineralogical composition. Importantly, the MB instrument can "see through" more than a millimetre of basaltic dust and obtain information on the solid substrate beneath. Modal mineralogy or the distribution of Fe^{2+} in the silicate olivine and Fe^0 in metal phases can be used to differentiate between meteorite groups [9,10], which works particularly well when complemented by chemical composition and/or magnetic susceptibility measurements. For example, using Mars Exploration Rover Opportunity's Alpha Particle X-ray Spectrometer (APXS) and Mössbauer spectrometer on Bounce Rock, a boulder float at Meridiani Planum, we identified the first rock on Mars similar in composition to the shergottite group of meteorites who originated on Mars [11]. We also identified and grouped both iron and stony meteorites on Mars [12,13], and could establish that fragments of the latter encountered by Opportunity were most likely paired [13].

Carbonaceous chondrites and their parent asteroids are particularly interesting targets because they display a history of aqueous alteration. The abundance of the mixed-valent Fe-oxide magnetite can be used as a tracer for the extent of aqueous alteration. Fe-bearing minerals and Fe oxidation states can also be used to trace the thermal and shock history of meteorites or asteroids. Magnetite and metal phases influence the electromagnetic properties of an asteroid.

Space weathering can alter the optical spectrum and albedo of an asteroid and may thus lead to uncertainty when comparing to known groups of meteorites. These effects may not be apparent through geochemical changes but changes in Fe oxidation states only. The Fe^0 content of surface fines, for example, is a measure of exposure time [14], which may be used to constrain the flux of micrometeoroids. At the opposite end, we have used the oxidation of metallic Fe in stony meteorites on Mars to demonstrate extremely slow chemical weathering rates under the current extremely arid conditions [15].

Planetary defense. The knowledge of physical or geotechnical properties such as density, porosity, shear strength, compressive strength or tensile strength is essential for planetary defense purposes. By ascertaining the link between asteroid and correct group of meteorites, many of these properties can be obtained from the meteorites in collections. A good knowledge of mineralogy and Fe oxidation states further enables estimating coefficients of thermal expansion or electromagnetic properties. Asteroids may have been weakened through thermal and shock events.

Asteroidal resources and ISRU. Asteroids may be used in several ways for in situ resource utilization during human exploration. Knowledge of the mineralogical compositions helps to assess the radiation protective properties of asteroidal materials, as well as the potential to yield precious water or oxygen. In experiments with lunar regolith, the yield of oxygen that can be extracted is directly proportional to FeO content [16]. Several oxygen extraction hardware concepts were evaluated during two field tests on Mauna Kea, Hawaii, in 2008 [17,18] and 2010 [19,20]. MIMOS II worked successfully as both a process monitor and a prospecting tool. Feedstock would be selected for high FeO content and mineral content: Ilmenite is reduced at 900°C, olivine at 1000°C and all other FeO-bearing phases at 1100°C.

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