MINIATURE ESR SPECTROMETER FOR AGE DATING MARTIAN SURFACE MATERIALS. S.S. Kim[1], S.R. Carnes[1], N.R. Mysoor[1], C.T. Ulmer[2], and S.M. Clifford[3], [1]Jet Propulsion Laboratory (Mail Stop 183-401, 4800 Oak Grove Dr. Pasadena, CA 91109, Soonsam.Kim@jpl.nasa.gov), [2]Ulmer Systems, Inc., 380 S. Mentor Ave., Pasadena, CA 91106, [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058.

Introduction: The Martian surface exhibits abundant evidence of having undergone a complex geologic and climatic evolution -- involving eolian, fluvial, periglacial, impact and volcanic process that appear to have remained active through the present day. Thus establishing an accurate chronology is critical to addressing many of the outstanding questions regarding the evolution of the planet's surface and atmosphere. However, given the absence of returned samples, efforts to date the Martian surface have necessarily been limited to comparisons of relative crater densities -- with absolute values extrapolated from the Moon, based on poorly constrained assumptions about differences in flux and impact velocity. The result is that the uncertainty associated with the absolute date of some epoch boundaries on Mars is as much as 3.5 billion years. Particularly for timescales of ~ 1 M years, the large uncertainties and poor resolution associated with crater dating make it unsuited for everything but the crudest relative characterization of whether a surface is "young" or "old". Thus, there is a need for a miniature in-situ age dating instrument that can obtain preliminary data from the Martian surface materials.

For the quaternary dating purposes on Earth, Electron spin resonance (ESR, or electron paramagnetic resonance, EPR) has been utilized extensively with the applicable range of up to ~ 1 M years and as recent as 10 ~ 100 years before present (BP). For dating Martian surface materials, a miniature version of ESR spectrometer [1] (< 1 kg, 5W, 1000 cc) could be deployed on landers or rovers equipped with a manipulator arm or a drill (1-5 m) such as the Mars 2009 mission.

ESR Dating of Martian Surface Materials: Martian soil, rocks and ice caps have been receiving ionizing radiations from various sources, including the decay of naturally occurring isotopes and cosmic rays, and accumulating defect centers in the matrices, holes or trapped electrons at varying trap depths. The three dosimetric age dating techniques, thermoluminescence (TL), optically stimulated luminescence (OSL) and electron spin resonance (ESR), have different sensitivities depending on the type of traps. Thus, each technique should be used complementarily, to characterize the whole range of traps, and quantify them toward absolute age determinations. Some of the traps decay through radiationless pathway, and can not be detected by the luminescence technique, but detectable by the ESR technique. The ESR technique is the most noninvasive one, and can be used effectively for the dating of layers in the polar ice caps by the detection of trapped radical species, ice serving as a radiation sensitizer for the detection of organic impurities in the ice matrices. ESR can be applied for dating sedimentary volatile deposits such as age of crystallization of carbonates or sulfates. The ages of sedimentary deposits will have important implications for Martian water history. Through identification of radicals produced in the matrices, ESR can be used for the characterization of host materials.

Miniature Frequency Scan ESR Spectrometer: One can obtain ESR spectra either by scanning magnetic field by an electromagnet at a fixed microwave frequency (conventional laboratory instrument), or by scanning microwave frequency at a fixed magnetic field. For a compact, low power, low mass miniature spectrometer, we have taken the latter mode; the ESR microwave is scanned (VCO, 7.5 GHz ~ 8.5 GHz) with a permanent magnet (Halbach magnet assembly, @ 2.8 kGauss, 61 mm OD x 24.5 mm ID x 72 mm long, see Fig. 1).

To achieve the frequency scan ESR, we have fabricated a tunable dielectric resonator (see Fig. 2). The dielectric resonator consists of two disks of high dielectric constant placed concentrically inside a cylindrical brass shield. The frequency of the resonator is tuned by displacement of one disk relative the other with a total distance of travel, < 5 mm, by a small brushless motor. Sample is placed between the two disks through the center holes. With this scheme, we have achieved a resonator with high sensitivity, quality factor of Q_0 = 8000 ± 2000. The dielectric resonator is placed inside the Halbach magnet.

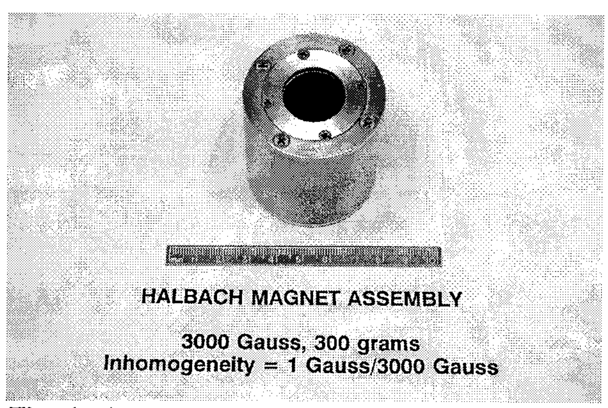

Fig. 1. A compact permanent magnet used for the miniature ESR spectrometer.

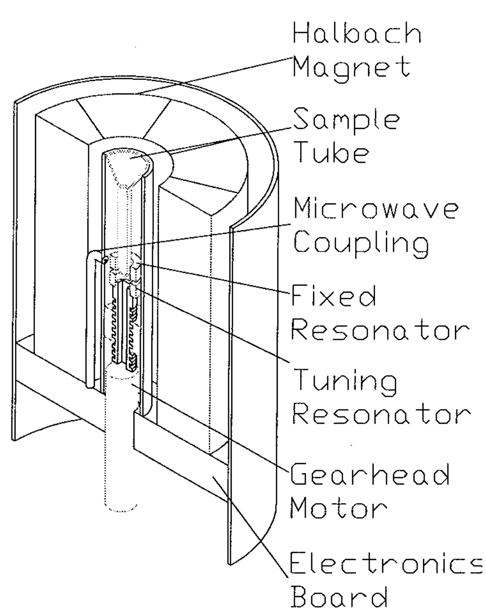

Fig. 2. Dielectric resonator assembly for the frequency scan ESR. The resonator is tuned by displacement of one disk relative to the other by a motor.

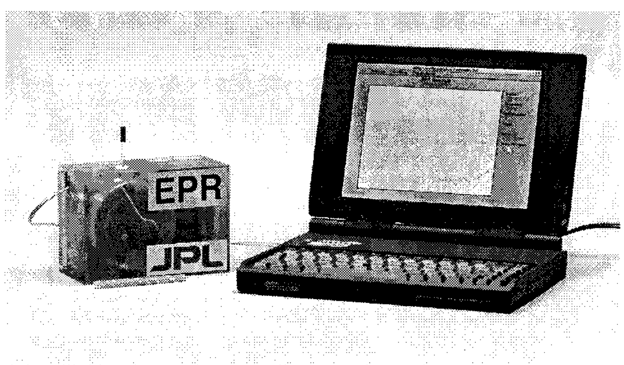

Fig. 3 A frequency scan ESR spectrometer operated by a lap-top PC.

A prototype miniature ESR spectrometer operated by a lap-top PC is shown in Fig. 3.

Age Dating Examples with a Laboratory ESR Spectrometer: As a preliminary test for dating, samples of carbonate, sulfate and chemically doped ice were irradiated with γ-ray from a ^{60}Co source (@ 1.9 Gy/min). With the CO_2^- radical signal observed from the carbonate sample {dolomite $[CaMg(CO_3)_2]$}, the ESR signal intensity was plotted as a function of dose, and a linear response was observed up to 1000 Gy (Fig.4). Compared with other defects, the ESR signal is very robust, and will be a good candidate for dating purpose as well as detection of carbonates. The CO_2^- radical signal was observed from room temperature down to 77°K.

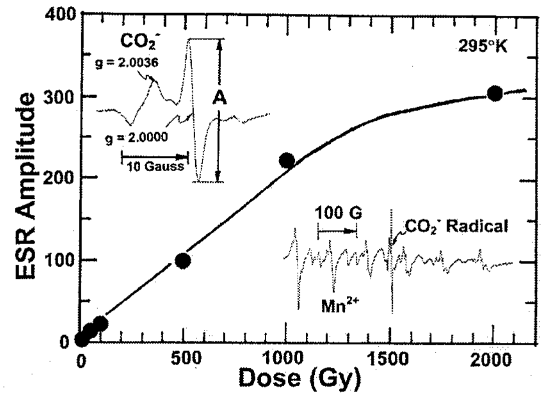

Fig. 4 A plot of dose dependence of CO_2^- radical from dolomite sample. The response is linear up to 1000 Gy. The inset shows 6 large peaks from Mn^{2+} impurities present in the dolomite.

Radicals or defect centers created in the polar ice caps by high energy irradiation can be characterized with high sensitivity by ESR and used as probes to obtain chemical information of the ice caps. By interaction with host ice (H_2O) matrices, the high energy radiation first creates •OH radicals which have enough mobility in the temperature ranges of 100 ~ 150°K, and diffuse through the matrix. Even though the majority of •OH radicals decay by recombination processes, a minor fraction will interact with the impurity molecules and initiate a secondary reaction by transfer of unpaired electrons. Through the sensitizing effect of water molecules, trace amounts of impurity molecules are effectively transformed to stable radicals and become detectable by ESR with high sensitivity (Fig. 5). Through characterization of such radicals, one can deduce the original molecular structures and their concentrations in the ice matrices.

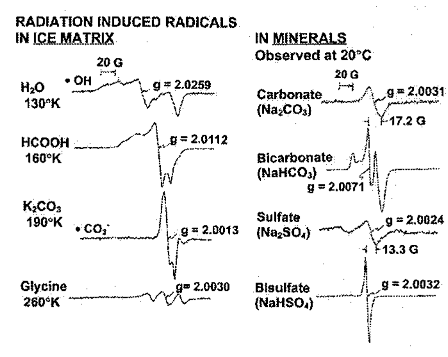

Fig. 5 ESR spectra of radiation-induced radicals in ice matrices and in minerals that can be used as signatures for material characterization. For the radicals in ice matrices, the highest stable temperatures are indicated.

References: [1] S.S. Kim, N.R. Mysoor, S.R. Carnes, C.T. Ulmer and K. Halbach, "Miniature Magnetic Resonance Spectrometers," in "Proceedings of 16th Digital Avionics Systems Conference (DASC)," pp.2.2-14 ~ 2.2-23, 1997.