THE GENESIS MISSION SOLAR WIND COLLECTION: SOLAR-WIND STATISTICS OVER THE PERIOD OF COLLECTION

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Introduction: The NASA Genesis spacecraft was launched August 8, 2001 on a mission to collect samples of solar wind for ≥ 2 years and return them to earth September 8, 2004. Detailed analyses of the solar wind ions implanted into high-purity collection substrates will be carried out using various mass spectrometry techniques. These analyses are expected to determine key isotopic ratios and elemental abundances in the solar wind, and by extension, in the solar photosphere. Further, the photospheric composition is thought to be representative of the solar nebula with a few exceptions, so that the Genesis mission will provide a baseline for the average solar nebula composition with which to compare present-day compositions of planets, meteorites, and asteroids. The implications of the solar oxygen isotopic composition have been discussed in [1]. A list of other isotopic and elemental measurement objectives, and some of the rationale behind them, is given in [2]. The collection of solar-wind samples is almost complete. Collection began for most substrates in early December, 2001, and is scheduled to be complete on April 2 of this year.

It is critical to understand the solar-wind conditions during the collection phase of the mission. For this reason, plasma ion and electron spectrometers are continuously monitoring the solar wind proton density, velocity, temperature, the alpha/proton ratio, and angular distribution of suprathermal electrons. Here we report on the solar-wind conditions as observed by these *in-situ* instruments during the first half of the collection phase of the mission, from December, 2001 to present.

Solar-Wind Regimes: The solar wind consists of three distinct types of plasma [e.g., 3]. All three types, or regimes, are elementally fractionated relative to the photosphere, but by different amounts and in different ways based on the characteristics of their acceleration out of the solar environment [e.g., 4]. Because of these different elemental compositions, a major effort was made for Genesis to collect separate samples of the different solar-wind regimes.

The interstream (IS), or slow (< 500 km/s), solar wind is the dominant regime encountered in the ecliptic. It is consistently fractionated based on first ionization potential (FIP), with elements having FIPs below 10 eV enhanced by a factor of about four relative to high-FIP elements. Coronal hole (CH) material is characterized by high velocity (500-800 km/s) and a relatively low FIP fractionation of around 2, with a consistent alpha/proton ratio of ~0.043. The Ulysses mission showed that CH is the dominant regime over the solar poles, particularly during the low-activity portion of the solar cycle [5]. Coronal mass ejections (CMEs) are characterized by strong and often uneven enrichments of heavy elements, including alpha/proton ratios often > 10%. A cold plasma temperature is nearly always an indicator of CME material. This material is also identified by containment within closed magnetic field lines which the Genesis spacecraft identifies by a double-peaked electron distribution with peaks 180 degrees apart, as the electrons stream both directions along the field lines.

Solar-Wind Collection To Date: Collectors in the capsule lid were exposed from 8/17/2001 to 9/15/2001 and then continuously since 11/26/01, for an estimated proton flux (to Jan-4-2004) of 1.94e16 cm^{-2}. Bulk collectors in the sample canister began collection November 30, 2001, and have been collecting continuously since then for a flux to date of 1.86e16 cm^{-2}. The regime-specific collectors began exposure on December 3, 2001, and have been in operation 99% of the time since then.

Figure 1 shows the trends in the fraction of time spent in each of the different regimes. The period just after solar maximum (which occurred around June, 2000) is typically characterized by more abundant CMEs. This characteristic was still observed after the Genesis spectrometers were turned on in late Summer, 2001, and into Spring of 2002. Starting in October, 2002, CH flows became much more abundant, a typical characteristic of the declining phase of the solar cycle. At the end of Genesis collection the CH fraction will probably be dropping off. The total fluence of protons on each of the regime-specific collectors is given in Fig. 2. The interstream array collected 46% of the total fluence, with the coronal hole and coronal mass ejection arrays each collecting 30 and 24% respectively. The amount of time spent in each regime is weighted slightly more towards the coronal hole regime, as the flux from this regime tends to be slightly lower.

The coronal hole material is probably the most desirable because its elemental composition is the most representative of the photosphere. The extent of *isotopic* fractionation among elements > 4 amu is poorly known [e.g., 6]. It is hoped that there is no isotopic fractionation between the photosphere and the solar wind. The best indication of this with Genesis data would come from identical isotopic ratios in material from all three solar-wind regimes. If isotopic fractionation does exist, its effect can be estimated based on intercomparisons of these regimes.

The solar-wind concentrator, which electrostatically concentrates oxygen and similar-mass ions on a small target, has been in operation 96% of the time. The concentrator's hydrogen rejection grid, which is designed to reject >90% of solar-wind protons while allowing the heavier ions through, has had its voltage limited to ~2000 V. This allows more hydrogen to reach the target during high-speed streams, so that the H rejection averaged over the mission will be about 75%, resulting in up to ~1.3 $x10^{17}$ protons/cm2 at the center of the target, which should still avoid damage to the target.

The solar-wind conditions and the algorithm's regime selections are being catalogued to allow analyses of the samples themselves to be placed in the proper context with regard to FIP fractionation and other solar-wind properties. These data will continue to be available at http://genesis.lanl.gov. The Genesis samples are due to be returned to Earth September 8, 2004.

References: [1] Wiens R.C. et al. (1999) *Meteoritics & Planet. Sci. 34*, 99-107. [2] Burnett D.S. et al. (2003) *Spa. Sci. Rev. 105*, 509-534. [3] Neugebauer M. (1991) *Science 252*, 404-409. [4] Bochsler P. (2000) *Rev. Geophys. 38*, 247-266. [5] McComas D.J. et al. (2002) *Geophys. Res. Lett. 29*, 1314-1317. [6] Kallenbach R. (2001) *Solar and Galactic Composition* (R. F. Wimmer-Schweingruber, ed), 113-119, Am. Inst. Of Physics.

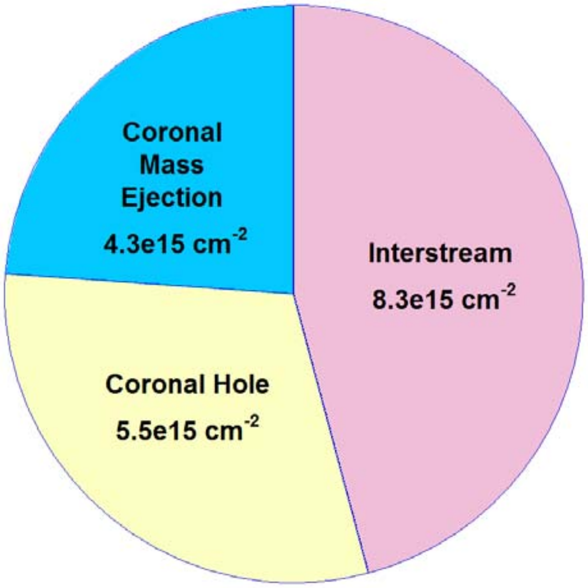

Fig. 2. Solar wind proton fluences for the various regimes during the collection period through Jan-4-2004, starting Dec-3-2001.

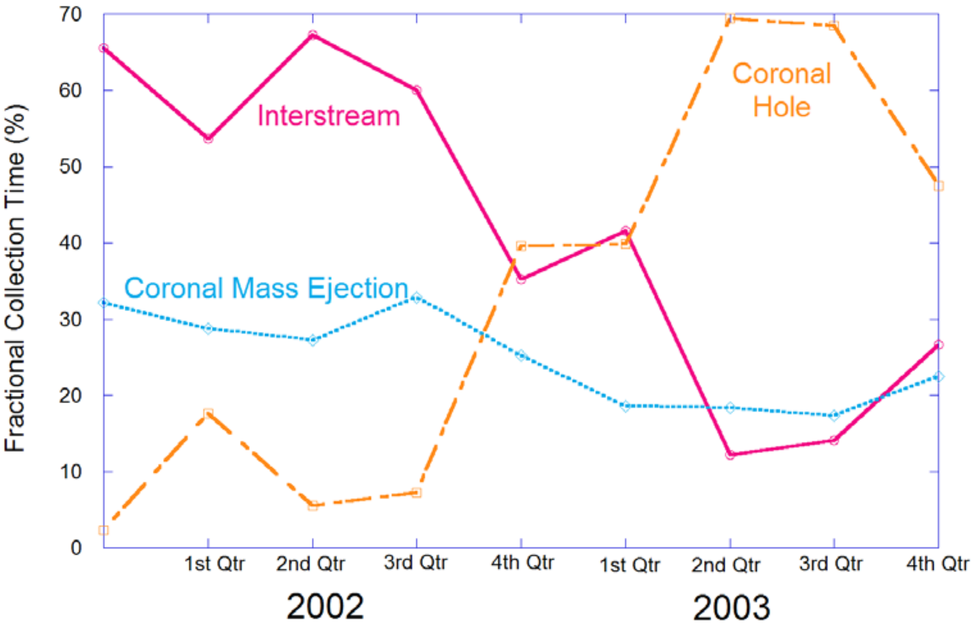

Fig. 1. Solar-wind regime trends during the collection phase of the Genesis mission.

EXPANSION IN GEOGRAPHIC INFORMATION SERVICES FOR PIGWAD.

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Introduction: GIS usually refers to Geographic Information Systems, although other common applications include Geographic Information Sciences and Geographic Information Services. This year the Planetary Interactive GIS on-the-Web Analyzable Database (PIGWAD) website focused on the latter. The PIGWAD task, funded by NASA's Planetary Cartography and Geologic Mapping Working Group, has been busy supporting the planetary community in working with GIS applications and dealing with the vast amount of planetary data now available.

Growth Rate: We have seen the use of GIS tools for planetary research steadily grow over the past few years, however this year, a noticeable increase in the growth rate was achieved. We anticipated this increase because more universities offer GIS training, more tools are available, many tools have matured, and the amount of digital planetary datasets has risen requiring a solution that can handle multiple and diverse datasets. The emergence of many standards has also helped this growth and the ability to share data across different applications. Some of these standards include:

1. Standard Interchange Formats
2. Open File Formats
3. Data Converters
4. Direct Read Application Programming Interfaces
5. Integration of Standard GIS Web Services

Services: Using planetary datasets in a GIS can be extremely challenging. Although some datasets are released from the Planetary Data System (PDS) in a map projected (level 2) format that can be readily ingested into a GIS (with a little help), most images are only released in a raw (level 0) format [1]. To help new and advanced GIS users, we have written many GIS tools and tutorials and we offer our time to answer questions on datasets, procedures or even feasibility. Although most of our experience is with Environmental Systems Research Institute (ESRI) software, we are familiar with other GIS, remote sensing and photogrammetry applications.

Because many planetary GIS users have similar questions, we started a Planetary GIS Discussion site. This site allows planetary researchers an outlet for their GIS-related questions on topics like GIS applications, planetary datasets, and working with ISIS [1]. This site has been extremely popular for planetary researchers, and we strive to answer the questions in a timely manner. Supporting this task has been time consuming but rewarding. We hope as more users become familiar with the technology, we can rely on the community to help answer more of the questions in the near future. At the beginning, many of the questions were posted by us based on previously received emails. There are now about thirty active planetary science users, but the discussion pages have been visited more than 15,000 times in the first 6 months of their posting.

On-Line Mapping Update: This year we have added Europa, Io and Ganymeade as newly available on-line mapping services [2]. Polar projections have also been added for these new services in addition to our other supported bodies, Venus, Mars, and the Moon. We will continue to use the on-line mapping solution called ArcIMS, by ESRI, however, we have also enabled all services to be compliant with the OpenGIS® Consortium (OGC) specification called WMS or Web Mapping Server [2]. This helps to open the mapping services to interact with many more web sites and stand-alone mapping clients. There have been several stand alone OGC clients made recently available. Some examples include:

1. MapLab's MapBrowser [3].
2. Chameleon [3].
3. Degree [4].
4. Geoserver [5].

PIGWAD's on-line mapping services are better utilized in stand-alone applications like these or other more robust GIS applications. However, for viewing the mapping services through a web browser, we have made available three levels of client software. This year we introduced a new beginner level called

ArcExplorer Web (figure 1). This software is written in JavaScript and is compatible with nearly all browsers and machine types. The ArcExplorer Web viewer allows you to view and query the datasets and has the benefit of loading multiple mapping services into a single interface. This would also include mapping services streamed from multiple locations.

The intermediate level interface, called ArcIMS HTML, uses Java technology and allows the user to do advanced queries, selections, accurate measurements and linking [2].

The advanced interface, called Maplicity, allows the most customization. You can do all the above plus features generally only found in stand-alone GIS viewers [2]. We have also worked with Telemorphic, the creators of Maplicity, to supply our users with an accurate scale for planetary bodies (figure 2). Prior to this fix, the tool was hard-wired for Earth.

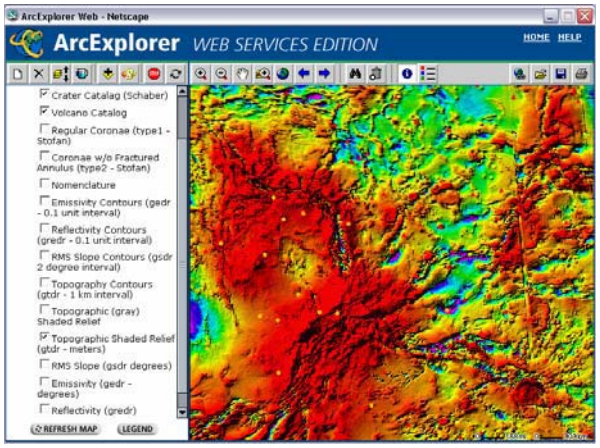
Future: We will continue to provide GIS services to the planetary community and provide upgrades to our servers and on-line services. This year we will also focus on converting paper-only published geologic maps. We will continue to strive to work with other facilities to incorporate web-streaming technologies such that all our services may be compatible. Lastly, we always encourage community input into how PIGWAD develops to meet the needs of planetary scientists.

[Any use of trade, product, or firm names is for descriptive purposes only and does not constitute endorsement by the U.S. Government.]

References: [1] Hare T., Tanaka K., Skinner J., GIS 101 for Planetary Research, ISPRS WG IV/9: Extraterrestrial Mapping Workshop, Advances in Planetary Technology, LPI, Houston, 2003. [2] Hare T. and Tanaka K. (2003) LPS XXXIV, Abstract #1974. [3] http://www.opengis.org
[4] http://www.maptools.org
[5] http://deegree.sourceforge.net
[6] http://geoserver.sourceforge.net

Additional Information: The PIGWAD website can be found at the following address: http://webgis.wr.usgs.gov. To learn more about using planetary datasets in various GIS applications please visit our Planetary GIS Discussion site:

http://webgis.wr.usgs.gov/pgis_discussion/



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☑ Volcano Catalog
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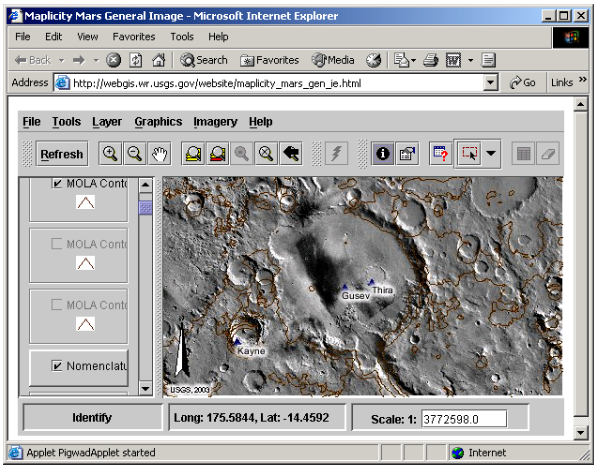
☐ Reflectivity Contours (gredr - 0.1 unit interval)
☐ RMS Slope Contours (gsdr 2 degree interval)
☐ Topography Contours (gtdr - 1 km interval)
☐ Topographic (gray) Shaded Relief
☑ Topographic Shaded Relief (gtdr - meters)
☐ RMS Slope (gsdr degrees)
☐ Emissivity (gedr - degrees)
☐ Reflectivity (gredr)

Figure 1. The beginner ArcExplorer Web interface showing the Venus general image service displaying a topographic color shaded relief and the crater and volcano catalogs.



Address http://webgis.wr.usgs.gov/website/maplicity_mars_gen_ie.html

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Figure 2. The advanced Maplicity inferface showing the Mars general image service displaying the MDIM 2.1, MOLA contours and nomenclature and zoomed into the MER A landing site, Gusev Crater.

www.thepigsite.com

THE 2009 MARS TELECOMMUNICATIONS ORBITER.

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Introduction

The first spacecraft with a primary function of providing communication links while orbiting a foreign planet has begun development for a launch in 2009. NASA's Mars Telecommunications Orbiter would use three radio bands to magnify the benefits of other future Mars missions and enable some types of missions otherwise impractical. It would serve as the Mars hub for a growing interplanetary Internet. And it would pioneer the use of planet-to-planet laser communications to demonstrate the possibility for even greater networking capabilities in the future.

With Mars Telecommunications Orbiter overhead in the martian sky, the Mars Science Laboratory rover scheduled to follow the orbiter to Mars by about a month could send to Earth more than 100 times as much data per day as it could otherwise send. The orbiter will be designed for the capability of relaying up to 15 gigabits per day from the rover, equivalent to more than three full compact discs each day. The same benefits would accrue to other future major Mars missions from any nation.

Relay service by the orbiter would also relieve designers of smaller future Mars landers, and perhaps aircraft, from needing to equip those missions with the ability to communicate directly with Earth. That would reduce launch weight and free up payload capacity for more science equipment.

During its nearly 10-year mission in orbit, Mars Telecommunications Orbiter would aid navigation of arriving spacecraft to their martian landing sites and monitor critical events during landings and orbit insertions. In addition, it would enable data-transmission volumes great enough to bring a virtual Mars presence to the public through a range of Internet and video features.

Mission Overview

This communications mission has been designed to orbit Mars about 20 times farther from the planet's surface than current spacecraft designed primarily for science, such as Mars Global Surveyor, Mars Odyssey and Mars Reconnaissance Orbiter. To make radio contact with a surface mission, an orbiter must be above Mars' horizon. From its altitude of nearly 5,000 kilometers (3,000 miles) Mars Telecommunications Orbiter would remain above the horizon from the perspective of a landed spacecraft for several hours every day, allowing much greater data-relay capability than lower-altitude orbiters.

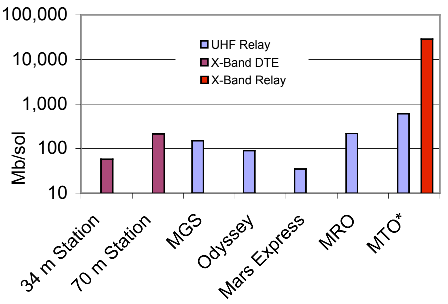

Figure 1. Data volumes (Mbit/Sol) from the surface of Mars for various communications strategies.

Approximately 10 months after launch from central Florida's Cape Canaveral Air Force Station, Mars Telecommunications Orbiter would fire its main engine three times to brake into a nearly circular orbit when it arrives at the planet in August 2010. Standard chemical propulsion will be used for braking because getting into the final high-altitude orbit limits the usefulness of aerobraking -- a fuel-saving technique employed by recent Mars orbiters to shape their orbits by repeatedly dipping into Mars' upper atmosphere.

The spacecraft is being designed for a prime mission of 6 years after it reaches Mars, with the capability to serve for an additional 4 years if its mission is extended. Over that period, it could support an assortment of spacecraft studying Mars from orbit, as well as at or near the surface, including landers, rovers, aircraft or dispersed ground stations.

Spacecraft

The spacecraft design concept is currently being studied. At launch, the spacecraft is expected to weigh about 2 tons, most of which would be propellant to be expended getting into Mars orbit. On orbit, the spacecraft would span more than 7 meters (23 feet) across. Its most prominent feature, besides the large solar arrays required to power it, would be a large dish antenna with a diameter in the range of 2 to 3 meters (7 to10 feet). From Mars orbit, that narrow-beam antenna would communicate with Earth-based antennas in NASA's Deep Space Network in both the X-band and the Ka-band of radio frequencies.

Other antennas with broader beams will be mounted on an independently pointable platform. These antennas will cover the ultra-high-frequency band and the X-band of radio frequencies. They are designed for the other leg of the relay job, communicating with other craft on or near Mars' surface.

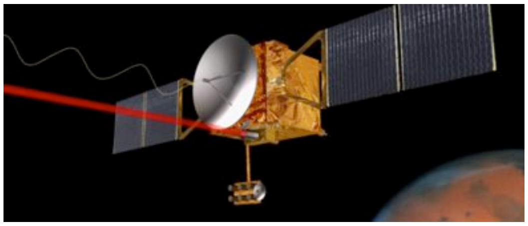

Figure 2. Artist concept for the Mars Telecommunications Orbiter at Mars. (Note: Radio and Optical beams simulated.)

As part of a technology demonstration project, Mars Telecommunications Orbiter would carry an optical communications terminal with a 30-centimeter-diameter (12-inch) telescope to communicate with a terminal on Earth using a highly focused laser beam. The Earth terminal will use a telescope with an effective aperture of about 5 meters (16 feet). This Mars Laser Communication Demonstration Project will demonstrate a capacity of 10 megabits per second, with a goal of 30 megabits per second, making it the first high-rate, deep space optical communications experiment. The high data-rate potential of optical communications makes the technology appealing for extensive use in future planetary missions. This demonstration project is intended to build experience for weighing the speed advantage of optical communications against the susceptibility of having the communications channel blocked by clouds.

Mars Telecommunications Orbiter would also demonstrate a key technology for orbital rendezvous by taking to Mars a sphere about the size of a soccer ball. It would release the sphere, then track its location from separation distances of up to about 6,000 kilometers (3,600 miles). This task would be a test run of technology that could be needed to support a possible future Mars sample-return mission to collect rocks from Mars and bring them back to Earth. Such a mission would likely launch a sealed sample-return capsule from Mars' surface for retrieval by a spacecraft temporarily orbiting Mars but capable of returning to Earth. Precise knowledge of the capsule's location would be needed for the retrieval to succeed. The sphere to be tracked by Mars Telecommunications Orbiter would mimic the physical properties of a sample-return capsule, providing a demonstration of systems for locating it from a great distance.

Project/Program Management

NASA's Jet Propulsion Laboratory, a division of the California Institute of Technology, Pasadena, manages the Mars Telecommunications Orbiter project for the NASA Office of Space Science, Washington, D.C.

The Mars Laser Communications Demonstration Project is being provided by NASA's Goddard Space Flight Center, Greenbelt, Md. The Massachusetts Institute of Technology's Lincoln Laboratories, Lexington, Mass., is providing the flight terminal for the demonstration. JPL is developing the ground station.

The spacecraft will be constructed by an industry contractor. NASA plans to issue an industry wide request for proposals for that contract in late 2004. Conceptual studies for the spacecraft design have already been completed by four aerospace companies: Ball Aerospace, Boulder, Colo.; Lockheed Martin Space Systems, Denver, Colo.; Northrop Grumman Space Technology, Redondo Beach, Calif.; and Spectrum Astro, Gilbert, Ariz.

For Mars Telecommunications Orbiter, Dr. Ramon DePaula at NASA Headquarters is program executive and Tom Komarek at JPL is project manager. For the Laser Communication Demonstration, Richard Fitzgerald at Goddard is project manager and Dr. Steve Townes at JPL is acting principal investigator.

NOVEL SAMPLE-HANDLING APPROACH FOR XRD ANALYSIS WITH MINIMAL SAMPLE PREPARATION.

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Introduction: Sample preparation and sample handling are among the most critical operations associated with X-ray diffraction (XRD) analysis. These operations require attention in a laboratory environment, but they become a major constraint in the deployment of XRD instruments for robotic planetary exploration. We are developing a novel sample handling system that dramatically relaxes the constraints on sample preparation by allowing characterization of coarse-grained material that would normally be impossible to analyze with conventional powder-XRD techniques.

Requirements for Sample Preparation: Performing an XRD analysis consists of measuring the direction and intensities at which crystalline matter diffracts X-rays. Placing an individual crystal in a fixed orientation in a monochromatic X-ray beam can at the best lead to a single diffracted beam, which does not allow identification of the crystal structure. In order to identify the structure, one must present the crystal to the X-ray beam under all orientations to record all possible diffracted beams within the angular range covered. With a single crystal, this can be accomplished by rotating the sample about several axes. The most common technique for XRD is called powder-diffraction because it uses powdered materials - or solid polycrystalline materials - to create a sample that offers all possible crystalline orientations for each mineral. In laboratory powder-XRD instruments, the very high number of crystallites in the analytical volume is obtained by grinding the sample to a very fine-grained size of less than 10 μm [1], or using fine-grained polycrystalline solids. With miniature XRD instruments such as would be deployed for planetary exploration, the grain-size constraint is much more stringent because the analytical volume must be dramatically reduced to preserve an acceptable resolution. In such case, an ideal sample would have a submicron grain size practically impossible to achieve.

Interest has been shown in planetary XRD instruments that would directly characterize geological samples (soil, rock) with no sample preparation. Although this approach is appealing for its apparent mechanical simplicity, it is fundamentally limited to the characterization of very fine-grained materials such as fine soils and aphanitic rocks. Phaneritic rocks such as gabbro and granite have grain sizes on the order of 100's of μm to centimeters, much larger than the analytical volume of the instrument. Attempts to directly characterize such materials would fail unless complex single-crystal diffraction techniques are applied. Any technical solution for achieving this would be far more complicated than a sample preparation and handling system for quality powder-XRD.

Sample handling principle: When non-ideal fine-grained powders are being characterized in a powder-XRD instrument, one must find a means of increasing the number of crystallite orientations explored during analysis. One approach is to translate the sample in the beam to analyze a larger amount of material. Another solution, commonly used in laboratories, is to rotate or rock the sample to present each crystallite in a range of orientations in the beam. Both solutions require complex mechanisms.

The approach we are developing is to generate random motions within powdered samples to increase the *effective* number of grains being analyzed as well as randomly rotate the grains to expose them to the X-ray beam in many different orientations. Random motions are induced by sonic or ultrasonic vibrations applied to the sample holder to fluidize the powder. Depending on the design of the sample-holder, one can obtain an overall flow of material through the system or generate internal motions by granular convection. This provides greatly improved orientation statistics when samples are too coarse to be analyzed in a conventional manner. Additionally, the technique allows easy insertion and removal of the sample into the instrument and offers possibilities of thickness adjustment for optimizing the output of diffracted X-rays in transmission geometry instruments.

Experimental: Vibrating sample-holders were built and tested with a laboratory instrument and a breadboard prototype of the CheMin XRD/XRF instrument. These sample-holders were composed of a vessel with two parallel X-ray-transparent windows having an adjustable gap (100-400 μm) and a mechanically amplified piezoelectric actuator with a power supply that allows control of the amplitude and frequency of vibration. The sample holders were loaded by simply pouring a small amount of powder into a funnel machined on the top of the assembly and applying sonic vibrations. The vessels contained about 10mg of powder. During XRD analysis, sonic vibrations were applied to generate granular convection (Figure 1). Unloading the samples was easily done by flipping the assembly upside-down and applying vibrations. Cleaning procedures involving ultrasonic vibrations generated by the same actuator were shown to be effective in preventing cross-contamination.

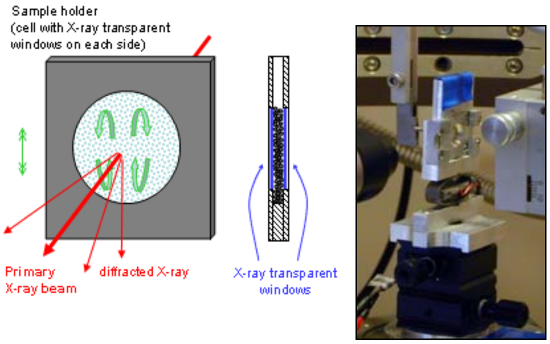

Figure 1: Sample holder allowing granular convection; Left: schematic diagrams; Right: prototype with piezo-actuator installed in an INEL XRD instrument.

Laboratory instrument: An INEL CPS120 (Curved Position Sensitive detector, 120°) diffractometer at Los Alamos National Laboratory was configured in transmission geometry and fitted with a vibrating sample holder. A range of minerals was prepared by crushing and wet sieving to obtain different size fractions: <45 µm, 45-75 µm, and 75-150 µm. XRD measurements were made with and without granular convection. Figure 2 shows the results obtained with a coarse-grained fraction of a crushed quartz crystal loaded in a sample holder with a 175 µm gap between windows.

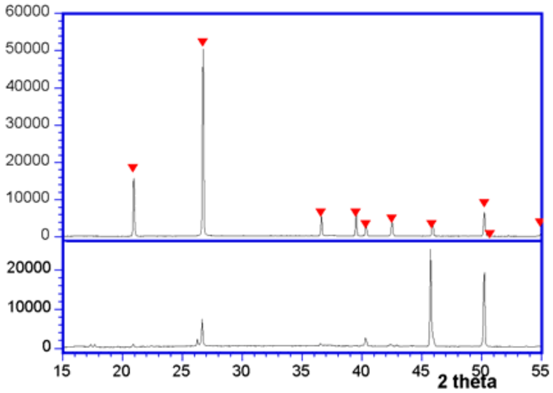

Figure 2: Diffraction pattern of the 75-150 µm fraction of a crushed quartz crystal; Upper: with vibrations (PDF reference in red); Lower: without vibrations; Cu Kα radiation; analytical volume 3x0.3x0.175 mm.

Although the pattern collected with a fixed sample is not interpretable, that collected when vibrating shows all peaks with relative intensities matching reference data from the Powder Diffraction File. Similar results were obtained with other minerals.

Miniature XRD: A 3rd generation CheMin instrument as described in Blake et al. [2] was fitted with a vibrating sample holder. The analytical volume dimensions were approximately 50 x 50 x 200 µm. Figure 3 shows a 2-D diffraction pattern recorded with a sandstone crushed and sieved to <150 µm. It displays perfectly smooth rings that could normally only be obtained with extremely fine powders (<1 µm). Integration of the intensity of the rings allows construction of a 1-D diffraction pattern that can be analyzed with conventional powder-XRD analysis methods. This sample handling technique was used for characterizing a range of minerals as reported in Bish et al. [3] and was successfully tested with a sample prepared with the miniature rock crusher developed at JPL.

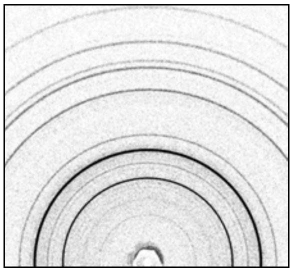

Figure 3: diffraction pattern of a <150 µm size fraction of a crushed sandstone recorded with CheMin III using a vibrating sample-holder. (Co Kα)

Conclusion: This new approach for handling powder during XRD analysis shows a dramatic improvement in data quality for coarse-grained samples. Powders with grain sizes as large as 150 µm can be accurately analyzed in either laboratory or miniature instruments. This grain size range can be directly obtained from crushing systems with no need for further grinding. Insertion and removal of the sample is very simple and does not require movement other than vibrations and valve actuation. Future versions under development will provide automatic sample delivery, sample removal and cleaning of the sample holder, and will allow characterization of a stream of powder when large quantities of material are available. The resulting assembly will be very compact and robust. Fitted to the CheMin XRD/XRF instrument, it would enable characterization of powders produced by the rock crusher planned for the Mars Science Laboratory. A NASA patent application has been filed for this technique.

References: [1] Bish D. L. and Post J. E., *Modern Powder Diffraction*, Reviews in Mineralogy, 20, publisher: Mineralogical Society of America.[2] Blake D. et al., (2004) LPSC XXXV [3] Bish D. L. et al. (2004) LPSC XXXV.