Lunar Meteoroid Impacts And How To Observe Them

Meteoroid experiments by five Lunar Orbiters have provided a direct measurement in the near-lunar environment of the rate of meteoroid penetration of 0.025-mm-thick beryllium-copper. Each experiment used 20 pressurized-cell detectors having a total effective exposed area of 0.186 m2. The spacecraft carrying the cells were in both equatorial and polar orbits; altituded ranged between 30 and 6200 km. Data collected continuously for 17 months indicate that the rate of penetration in the lunar environment is approximately half the rate in the near-earth environment as measured by detectors of the same type aboard Explorers XVI and XXIII.

The lunar surface is pockmarked with large and small craters mostly formed due to meteoroid impacts on the Moon. Most of the craters formed are not erased with time due to lack of "weathering" processes such as no atmosphere and little erosion. The main focus of this research is to develop ground-based observational techniques to search for ongoing hypervelocity meteoroid impacts on the lunar surface. Additionally, to design radar observational techniques to detect and map sub-surface structures that have been buried by the lunar regolith.It is hypothesized that the developing, optically-dense hot ejecta cloud associated with the hypervelocity meteoroid impacts produce an associated complex plasma component that rapidly evolves resulting in a highly-transient Electromagnetic pulse (EMP) in the VHF/UHF spectral region. An observational EMP search was conducted in May 2014 for about 5 hours using an overlapping-band (425-445 MHz) at the Arecibo (AO; Puerto Rico) and Haystack-(HO, Massachusetts, USA) observatories simultaneously to track the common visible lunar surface from two different locations on the Earth. Observations from two locations is helpful in eliminating the false impacts. Interleaved radar observations were used to calibrate the timing and synchronize both the AO and HO systems. As the AO/HO UHF EMP search was interference dominated, an alternative search mechanism using the Arecibo L-band ALFA Array that consists of seven beams arranged in the hexagonal manner was conducted in February 2016. During these observations, at any given time few of the receive-beams were on-Moon and few off-Moon thus allowing discrimination against local interference that might resemble the expected EMP signals. While still encountering local out-of-band radar interference, this observational paradigm did yield a few likely lunar impact EMPs.Additionally, to detect the sub-surface lunar structures, high power large aperture - Jicamarca Radio Observatory (JRO) 50 MHz radar located near Lima, Peru was used to map the lunar surface and subsurface features. This was accomplished by developing or refining various calibration and imaging procedures. This radar provides the ability to map the lunar sub-surface because the 6-meter wavelength radar signal penetrates the low-loss regolith and scatters from larger sub-surface structures allowing study of these structures. This analysis further depends on the (de)polarization of the return signals. Interpretation of lunar radar signal polarization is greatly complicated by the double traverse of the ionosphere at or near wavevector near to perpendicular to the geomagnetic field geometry as described. Preliminary radar observations were conducted in October 2015 by transmitting a circular polarized coded pulse during the lunar transit over JRO. The detected lunar echoes of the duration of 13 minutes were then processed to generate the lunar Range-Doppler maps and identify the (sub)surface features. Preliminary science results from the observations are given.Each of the three observational set-up's along with the signal processing paradigms such as Inverse Synthetic Aperture Radar (ISAR) mapping to form the lunar maps and the time-frequency technique to process the collected observational data are explained. Implications of the observed transient EMP events, processed lunar surface maps, characterization of the observed satellite radar echoes and the difficult radio-frequency interference environment (terrestrial-origin, Moon-bounce signals) surrounding these observations are discussed.

This excellent overview will appeal to all researchers who have an interest in Leonid showers. It contains over forty research papers that present some of the first observational results of the November 1999 Leonid meteor storm, the first storm observed by modern observing techniques.

In this volume, the geologic and planetary science communities explore impact events and how they affected the evolution of Earth and other planetary bodies. these papers are the outcome of a conference held every five years.

The degree to which the thin Martian atmosphere filters out meteoroids approaching the Martian surface was calculated by using a model of the meteoroid environment, a model of the Martian atmosphere, and equations of meteor physics. The secondary particle environment on the surface of Mars caused by the material ejected from meteoroid craters was modeled. The model consists of the mass distribution and the speed distribution of the secondary particles. Calculations were made of the penetration flux for aluminum structures on the Martian surface. The penetration hazard on the Martian surface was compared with the penetration hazard in space near Mars and on the lunar surface.

Leading specialists in various disciplines were first invited to a multidisciplinary workshop funded by ICSU on the topic to gain a better appreciation and perspective on the subject of comet/asteroid impacts as viewed by different disciplines. This volume provides a necessary link between various disciplines and comet/asteroid impacts.

The only work to date to collect data gathered during the American and Soviet missions in an accessible and complete reference of current scientific and technical information about the Moon.

Meteor Showers and their Parent Comets is a unique handbook for astronomers interested in observing meteor storms and outbursts. Spectacular displays of 'shooting stars' are created when the Earth's orbit crosses a meteoroid stream, as each meteoroid causes a bright light when it enters our atmosphere at high speed. Jenniskens, an active meteor storm chaser, explains how meteoroid streams originate from the decay of meteoroids, comets and asteroids, and how they cause meteor showers on Earth. He includes the findings of recent space missions to comets and asteroids, the risk of meteor impacts on Earth, and how meteor showers may have seeded the Earth with ingredients that made

life possible. All known meteor showers are identified, accompanied by fascinating details on the most important showers and their parent comets. The book predicts when exceptional meteor showers will occur over the next fifty years, making it a valuable resource for both amateur and professional astronomers.

"This volume contains a sizable suite of contributions dealing with regional impact records (Australia, Sweden), impact craters and impactites, early Archean impacts and geophysical characteristics of impact structures, shock metamorphic investigations, post-impact hydrothermalism, and structural geology and morphometry of impact structures - on Earth and Mars"--

This textbook details basic principles of planetary science that help to unify the study of the solar system. It is organized in a hierarchical manner so that every chapter builds upon preceding ones. Starting with historical perspectives on space exploration and the development of the scientific method, the book leads the reader through the solar system. Coverage explains that the origin and subsequent evolution of planets and their satellites can be explained by applications of certain basic principles of physics, chemistry, and celestial mechanics and that surface features of the solid bodies can be interpreted by principles of geology.

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Although about 70 percent of known terrestrial meteorite impacts involve sedimentary rocks, the response of such rock to hyper- velocity impact is not well understand. Evans (Missouri State U., Springfield) introduces a dozen papers from a session on impact geology at the 2004 Geological Society of America Annual Meeting. Arranged by rocks' stratigraphic order (oldest to youngest) in proximal and distal settings, papers study topics including: characterization of impact sediments; a model for impact cratering processes; development of breccias (rock composed of sharp fragments embedded in a fine- grained matrix) in the Chesapeake Bay impact structure; and the method of impact stratigraphy applied to aging of the K-T boundary associated with mass extinction. The well-illustrated volume is not indexed.

The Earth-Moon neighborhood is the scene of a large variety of applications that concern asteroids, lunar exploration and space debris in Earth orbit. In particular, recent efforts by the scientific community have focused on the possibility of extending the human operations beyond the radiation belts; of exploiting in-situ resources, either on the lunar surface or on asteroids retrieved to the vicinity of the Earth; and of mitigating the space debris concern by taking advantage of the lunar perturbation. The characteristic dynamics in the cislunar space represents an opportunity for the mission designer, but also a challenge in terms of theoretical understanding and operational control. This Research Topic covers the Earth-Moon dynamics in its complexity and allure, considering the most relevant aspects for both natural and artificial objects, in order to get a new comprehension of the dynamics at stake along with the operational procedures that can handle it.

Over 150 crater-producing events have been identified, and this book describes all 139 sites worldwide at which evidence of the impacts can be seen. They range in age from recent craters formed this century to highly eroded billion-year-old craters. Some are spectacular to visit, such as the Barringer Crater in Arizona, the ring-shaped mountains of Gosses Bluff, Australia, and the huge crater at Ries in Germany. The author has visited many of the sites and his photographs enrich this thorough survey. For each site there is a summary table giving location, size, age and present condition. Maps are included where necessary. Meteorite craters are fascinating to visit, so the descriptions include guidance about access and suggested itineraries for the large structures.

The genesis of modern searches for observable meteoritic phenomena on the Moon is the paper by Lincoln La Paz in Popular Astronomy magazine in 1938. In it he argued that the absence of observed fashes of meteoritic impacts on the Moon might be interpreted to mean that these bodies are destroyed as luminous meteors in an extremely rarefed lunar atmosphere. The paper suggested the possibility of systematic searches for such possible lunar meteors. With these concepts in mind, I was surprised to note a transient moving bright speck on the Moon on July 10, 1941. It appeared to behave very much as a lunar meteor would – except that the poorly estimated duration would lead to a strongly hyperbolic heliocentric velocity. Thus, the idea of systematic searches for both p- sible lunar meteors and meteoritic impact fashes was born. It was appreciated that much time might need to be expended to achieve any positive results. Systematic searches were carried out by others and myself chiefy in the years 1945–1965 and became a regular program at the newly founded Association of Lunar and Planetary Observers, or ALPO.

This book includes a selection of 30 reviewed and enhanced manuscripts published during the 15th SpaceOps Conference held in May 2018 in Marseille, France. The selection was driven by their quality and relevance to the space operations community. The papers represent a cross-section of three main subject areas: Mission Management – management tasks for designing, preparing and operating a particular mission Spacecraft Operations – preparation and implementation of all activities to operate a space vehicle (crewed and uncrewed) under all conditions Ground Operations – preparation, qualification, and operations of a mission dedicated ground segment and appropriate infrastructure including antennas, control centers, and communication means and interfaces This book promotes the SpaceOps Committee’s mission to foster the technical interchange on all aspects of space mission operations and ground data systems while promoting and maintaining an international community of space operations experts.

The US Antarctic meteorite collection exists due to a cooperative program involving the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Smithsonian Institution. Since 1976, meteorites have been collected by a NSF-funded field team, shipped for curation, characterization, distribution, and storage at NASA, and classified and stored for long term at the Smithsonian. It is the largest collection in the world with many significant samples including lunar, martian, many interesting chondrites and achondrites, and even several unusual one-of-a-kind meteorites from as yet unidentified parent bodies. Many Antarctic meteorites have helped to define new meteorite groups. No previous formal publication has covered the entire collection, and an overall summary of its impact and significant samples has been lacking. In addition, available statistics for the collection are out of date and need to be updated for the use of the community. 35 seasons of U.S. Antarctic Meteorites (1976-2011): A Pictorial Guide to the Collection is the first comprehensive volume that portrays the most updated key significant meteoritic samples from Antarctica. 35 seasons of U.S. Antarctic Meteorites presents a broad overview of the program and collection nearly four decades after its beginnings. The collection has been a consistent and reliable source of astromaterials for a large, diverse, and active scientific community. Volume highlights include: Overview of the history, field practices, curation approaches Special focus on specific meteorite types and the impact of the collection on understanding these groups (primitive chondrites, differentiated meteorites, lunar and martian meteorites) Role of Antarctic meteorites in influencing the determination of space and terrestrial exposure ages for meteorites Statistical summary of the collection by year, region, meteorite type, as

well as a comparison to modern falls and hot desert finds The central portion of the book features 80 color plates each of which highlights more influential and interesting samples from the collection. 35 seasons of U.S. Antarctic Meteorites would be of special interest to a multidisciplinary audience in meteoritics, including advanced graduate students and geoscientists specializing in mineralogy, petrology, geochemistry, astronomy, near-earth object science, astrophysics, and astrobiology.

The Lunar Surface Layer: Materials and Characteristics focuses on the characteristics, nature, and materials located in the lunar surface layer, including lunar soil mechanics, water vapor adsorption, and soil behavior. The selection first elaborates on soil mechanics considerations in the testing of lunar soil models, an experimental study in lunar soil mechanics, and gravity effects on soil behavior. Discussions focus on cohesion in lunar soils, gravity effect on dynamic shear strength of soils, porosity, soil bearing strength, lunar effects, soil cohesion in the lunar environment, gradation, structure and contact characteristics, and statics and dynamics. The book then examines the investigation of soil adhesion under high vacuum; water vapor adsorption behavior of kaolinite after high-vacuum storage; and sonic velocity and shear strength of possible lunar surface materials. Concerns cover shear strength, sonic velocity, experimental apparatus, and calibration. The manuscript takes a look at the consideration of properties of simulated lunar soil with possible stabilization techniques; feasibility of remote compositional mapping of the lunar surface; thermal emission characteristics of mineral dusts; and thermal properties of postulated lunar surface materials. The selection is highly recommended for researchers wanting to study the lunar surface layer.

"The third volume of the series “Large Meteorite Impacts” provides an updated and comprehensive overview of modern impact crater research. In 26 chapters, more than 90 authors from Europe, the United States, Russia, Canada, and South Africa give a balanced, firsthand account of the multidisciplinary field of cratering science, with reports on field studies, geophysical analyses, and experimental and numerical simulations. Nine chapters focus on structure, geophysics, and cratering motions of terrestrial craters. Recent advances in impact ejecta studies and shock metamorphism are assembled, each with seven chapters, and three chapters extend the scope from a terrestrial to a planetary perspective."--pub. desc.

Bringing together some of the most recognized and influential researchers and scientists in various space-related disciplines, Lunar Settlements addresses the many issues that surround the permanent human return to the Moon. Numerous international contributors offer their insights into how certain technological, physiological, and psychological challenges must be met to make permanent lunar settlements possible. The book first looks to the past, covering the Apollo and Saturn legacies. In addition, former astronaut and U.S. Senator Harrison H. Schmitt discusses how to maintain deep space exploration and settlement. The book then discusses economic aspects, such as funding for lunar commerce, managing human resources, and commercial transportation logistics. After examining how cultural elements will fit into habitat design, the text explores the physiological, psychological, and ethical impact of living on a lunar settlement. It also describes the planning/technical requirements of lunar habitation, the design of both manned and modular lunar bases, and the protection of lunar habitats against meteoroids. Focusing on lunar soil mechanics, the book concludes with discussions on lunar concrete, terraforming, and using greenhouses for agricultural purposes. Drawing from the lunar experiences of the six Apollo landing missions to the many American and Soviet robotic missions to current space activities and research, this volume summarizes the problems, prospects, and practicality of enduring lunar settlements. It reflects the key disciplines, including engineering, physics, architecture, psychology, biology, and anthropology, that will play significant roles in establishing these settlements.

When in 1981 Louis and Walter Alvarez, the father and son team, unearthed a tell-tale Iridium-rich sedimentary horizon at the 65 million years-old Cretaceous-Tertiary boundary at Gubbio, Italy, their find heralded a paradigm shift in the study of terrestrial evolution. Since the 1980s the discovery and study of asteroid impact ejecta in the oldest well-preserved terrains of Western Australia and South Africa, by Don Lowe, Gary Byerly, Bruce Simonson, Scott Hassler, the author and others, and the documentation of new exposed and buried impact structures in several continents, have led to a resurgence of the idea of the catastrophism theory of Cuvier, previously largely supplanted by the uniformitarian theory of Hutton and Lyell. Several mass extinction of species events are known to have occurred in temporal proximity to large asteroid impacts, global volcanic eruptions and continental splitting. Likely links are observed between asteroid clusters and the 580 Ma acritarch radiation, end-Devonian extinction, end-Triassic extinction and end-Jurassic extinction. New discoveries of ~3.5 – 3.2 Ga-old impact fallout units in South Africa have led Don Lowe and Gary Byerly to propose a protracted prolongation of the Late Heavy Bombardment (~3.95-3.85 Ga) in the Earth-Moon system. Given the difficulty in identifying asteroid impact ejecta units and buried impact structures, it is likely new discoveries of impact signatures are in store, which would further profoundly alter models of terrestrial evolution. .

This volume contains five articles describing the mission and its instruments. The first paper, by the project scientist Richard C. Elphic and his colleagues, describes the mission objectives, the launch vehicle, spacecraft and the mission itself. This is followed by a description of LADEE’s Neutral Mass Spectrometer by Paul Mahaffy and company. This paper describes the investigation that directly targets the lunar exosphere, which can also be explored optically in the ultraviolet. In the following article Anthony Colaprete describes LADEE’s Ultraviolet and Visible Spectrometer that operated from 230 nm to 810 nm scanning the atmosphere just above the surface. Not only is there atmosphere but there is also dust that putatively can be levitated above the surface, possibly by electric fields on the Moon’s surface. Mihaly Horanyi leads this investigation, called the Lunar Dust Experiment, aimed at understanding the purported observations of levitated dust. This experiment was also very successful, but in this case their discovery was not the electrostatic levitation of dust, but that the dust was raised by meteoroid impacts. This is not what had been expected but clearly is the explanation that best fits the data. Originally published in Space Science Reviews, Volume 185, Issue 1-4, 2014.

Proceedings of the Fourth International Conference on Large Meteorite Impacts and Planetary Evolution held at the Vredefort Dome, South Africa, in Aug. 2008.

Comprises 28 papers which grew out of the International Conference on Large Meteorite Impacts and Planetary Evolution, August/September, 1992 in Sudbury, Ontario. The interdisciplinary papers, encompassing diverse studies from trace element geochemistry to planetary exploration, are arranged into f