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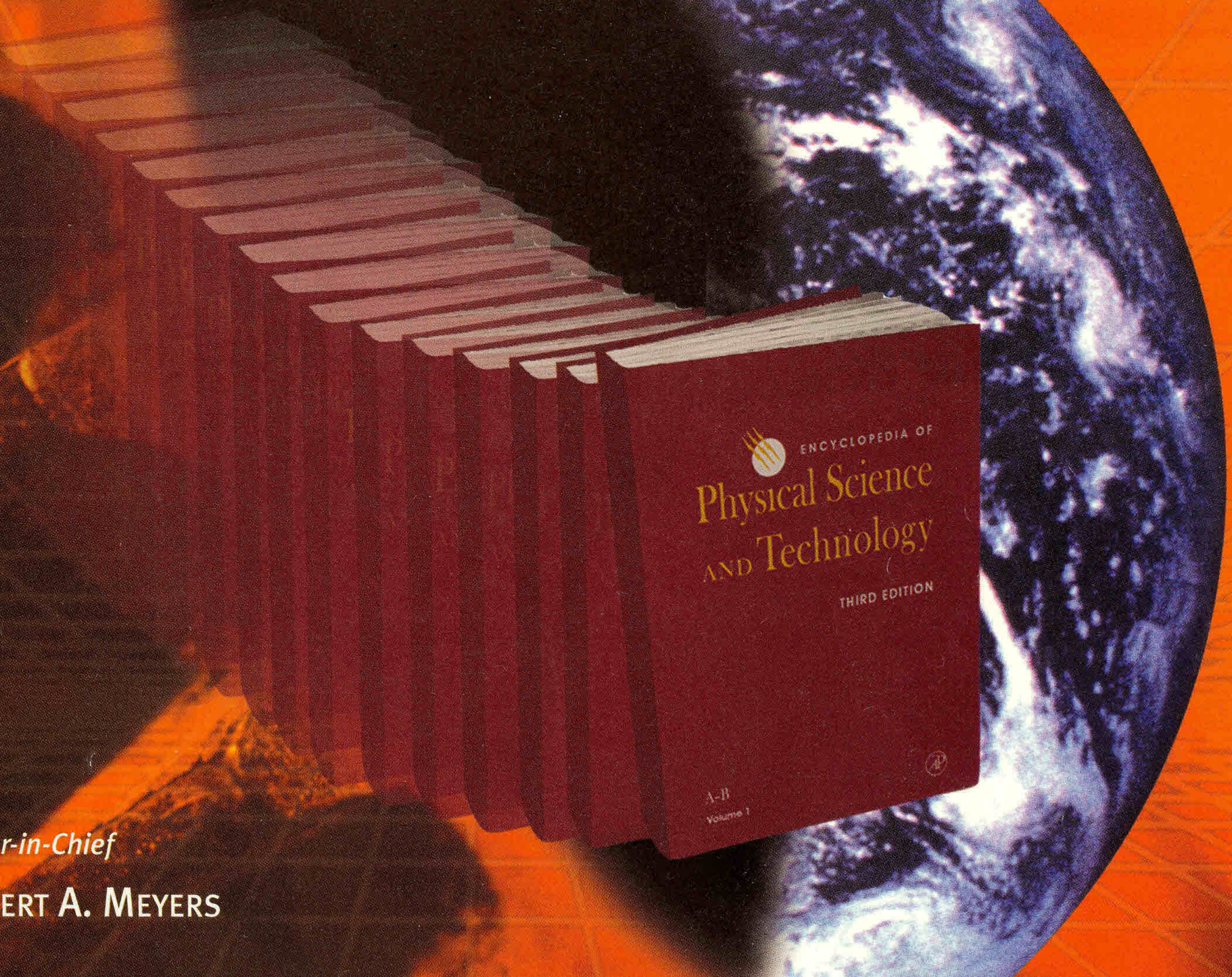

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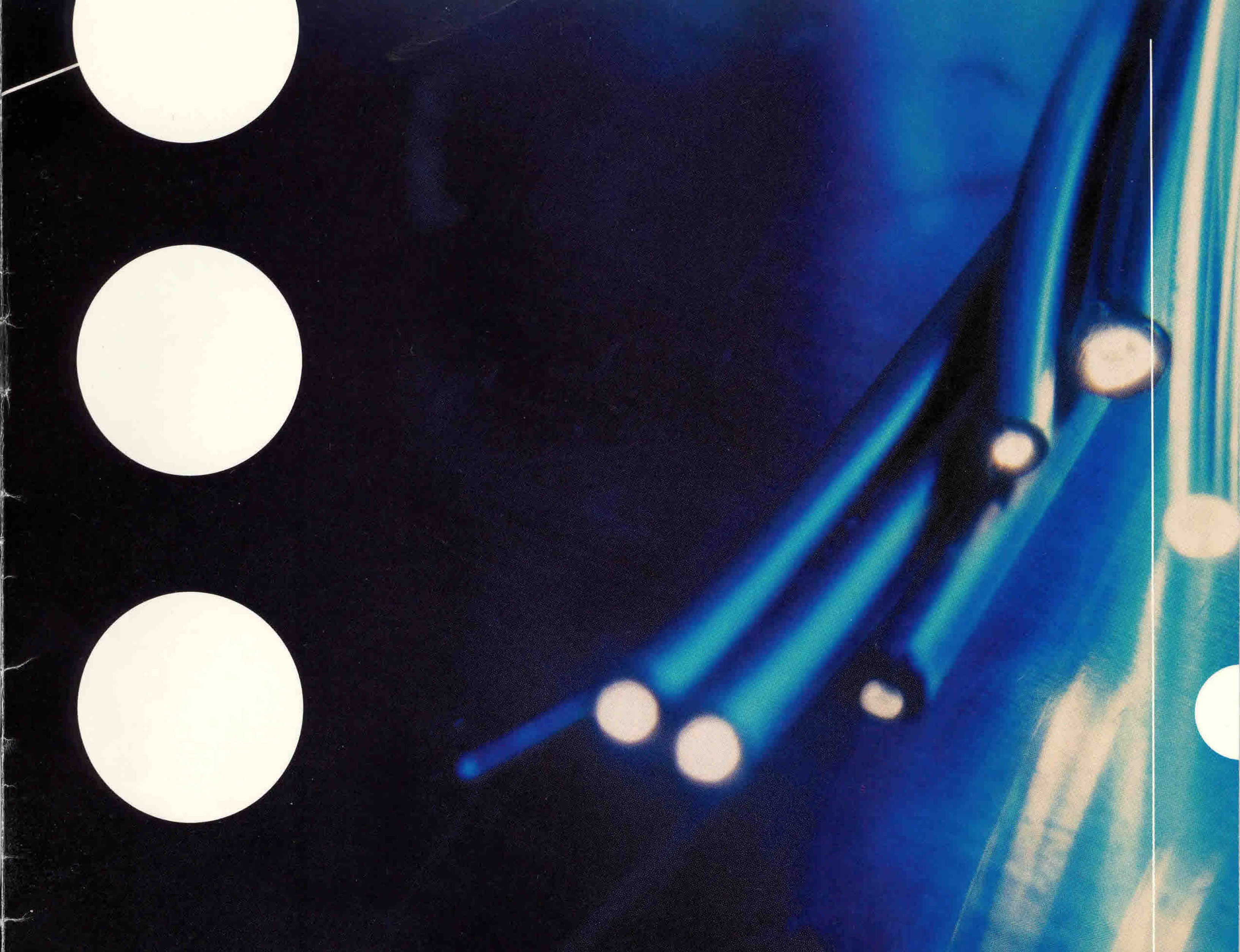

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1. *Multispectral imager* fitted with a charge-coupled device (CCD) imaging detector capable of photographing details on the asteroid as small as 3 m or 10 ft in diameter; it will determine the overall size, shape, and spin of Eros and map the surface morphology and mineralogy.
2. *X-ray/gamma-ray spectrometer,* which will measure and map abundances of several dozen important elements at and near the surface of the asteroid.
3. *Laser rangefinder,* which will determine the distance from the spacecraft to Eros and thus make possible the construction of a global shape model and a global topographic map with high resolution.
4. *Magnetometer* to measure the strength of Eros' magnetic field with implications about its thermal and geologic history.
5. *Radio science experiment* to determine the mass density and mass distribution of the asteroid.

The best procedure for addressing the impact on Earth of an asteroid or comet will depend on finding the answers to some of our questions.

Many asteroids and comets have the potential for either benefiting or destroying mankind. Impact and extinction are both natural and fundamental processes on our Earth, but the possibility of altering the direction of these processes remains.

Cross references lead to other topics of related interest

ALSO SEE THE FOLLOWING ARTICLES

Cometary Physics • Impact Cratering • Meteorites, Cosmic Ray Record • Planetary Geology • Primitive Solar System Objects: Asteroids and Comets

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Reference section provides guidance for further research on the topic

Subjects selected by the editors to provide coverage of the key issues in Physical Science and Technology

B

Biomass Utilization, Limits of

Articles written by prominent international authorities

David Pimentel
Cornell University

Every article begins with an outline of its contents

Glossary section defines key terms used in the article

GLOSSARY

Biodiversity All species of plants, animals, and microbes in one ecosystem or world.

Biogas A mixture of methane and carbon dioxide produced by the bacterial decomposition of organic wastes and used as a fuel.

Biomass Amount of living matter, including plants, animals, and microbes.

Energy Energy is the capacity to do work and includes heat, light, chemical, acoustical, mechanical, and electrical.

Erosion The slow breakdown of rock or the movement and transport of soil from one location to another. Soil erosion in crop and livestock production is considered serious worldwide.

Ethanol Also called ethyl alcohol. A colorless volatile flammable liquid with the chemical formula C_2H_5OH that is the intoxicating agent in liquors and is also used as a solvent.

Methanol Also called methyl alcohol. A light volatile flammable liquid with the chemical formula CH_3OH that is used especially as a solvent, antifreeze, or denaturant for ethyl alcohol and in the synth[...] other chemicals.

Pollution The introduction of foreign, us[...] made, products or waste into the environm[...]

Pyrolysis Chemical change brought about by [...] of heat.

Subsidy A grant or gift of money.

For quick reference, defining paragraph feature provides a capsule view of the issue to be discussed

THE interdependency of plants, animals, and microbes in natural ecosystems has survived well for billions of years even though they only captured 0.1% of the sun's energy. All the solar energy captured by vegetation and converted into plant biomass provides basic resources for all life, including humans. Approximately 50% of the world's biomass is used by humans for food plus lumber and pulp and medicines, as well as support for all other animals and microbes in the natural ecosystem. In addition some biomass is converted into fuel.

Serious shortages of biomass for human use and maintaining the biodiversity in natural ecosystems now exist throughout the world. Consider that more than 3 billion humans are now malnourished, short of food, and various

Encyclopedia of Physical Science and Technology, Third Edition, Volume 2

1

REVIEWS FROM THE FIRST EDITION:

"This encyclopedia will be a very useful and needed addition to the literature of the physical sciences and technology. The in-depth articles are written by experts and the topics selected represent the current view of the physical sciences in today's scientific world."

—AMERCAN REFERENCE BOOKS ANNUAL

Asteroid Impacts and Extinctions

9

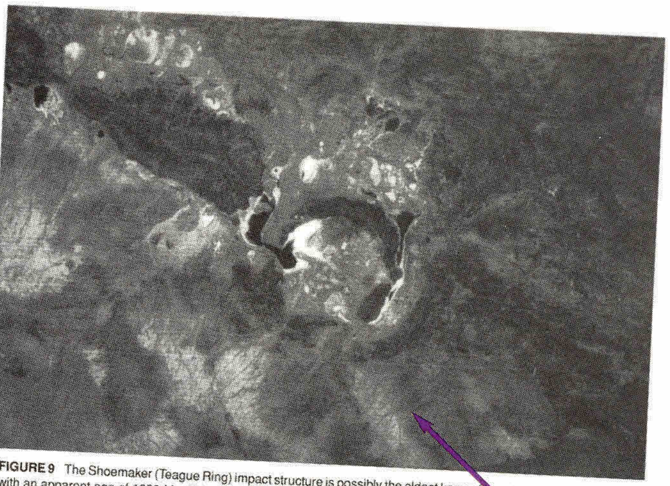

FIGURE 9 The Shoemaker (Teague Ring) impact structure is possibly the oldest known impact structure in Australia with an apparent age of 1630 Ma. This 30-km-diameter structure is prominent from orbit in Landsat images.

can be seen in the 30-km Shoemaker (Teague) structure of Proterozoic age in Australia, shown in Fig. 9.

This sequence is eroded away from most old structures and is entirely eroded away from the most ancient. The result is a shallower crater, which is broader by a factor of about 40% over the deeper original hole. This is the

a Columbia University paleonto ogist, was *Crypto-volcanic str* source must be a hidden volc until 1936 that the suggestion and C. C. Albritton that crypto- be the sites of ancient impacts.

Article text supported by photos, drawings, tables, and other visual material

TABLE I Largest Impact Craters on Earth

Crater name	Location	Age (10^6 years)	Diameter (km)
Vredefort	South Africa	2023	(300)
Sudbury	Canada	1850	250
Chicxulub	Mexico	64.98	(170)
Manicouagan	Canada	214	100
Popigai	Russia	(35)	100
Acraman	Australia	(590)	(90)
Chesapeake Bay	United States	35.5	90
Puchezh-Katunki	Russia	175	80
Morokweng	South Africa	145	70
Kara	Russia	73	65
Beaverhead	United States	(600)	60
Tookoonooka	Australia	128	55
Kara-Kul	Tajikistan	<25	52

Each entry provides comprehensive, in-depth treatment of an overview topic

Asteroid Impacts and Extinctions

7

III. CRATERING

Internal headings lead the reader to subtopics within the larger theme of the article

The abundant craters resulting from impact on all of the terrestrial planets as well as the moons of the gaseous giants have been revealed by a number of planetary spacecraft missions, manned and unmanned. Indeed, these missions have provided images of impact craters on asteroids.

The same lack of atmosphere as on the Moon pertains the terrestrial planets and their moons and has allowed to see a similar record of bombardment there. Planetary impact craters provide us with a record to do relative age dating of surfaces, which exhibit different crater densities for different ages. It is possible to know how old land surfaces are in years by learning the impact rate on a surface per year. Crater ages that can be measured on Earth can be extrapolated to the planets, if we know how the impact rate for comets and asteroids varies among the Earth, Moon, and planets. Coupled with radiometric dating of returned samples, craters allow us to estimate the flux of objects impacting over geologic time, especially on the Moon and the Earth.

A. Cratering Flux with Time

Satellites, built for the military in order to detect missile launches and nuclear explosions, have been able to detect frequent, high, fast explosions from small asteroids hitting the upper atmosphere of the Earth almost monthly. If a projectile is large enough, it can survive passage through tmosphere more or less intact and strike the high speed.

Article text meets the most rigorous standards of scientific accuracy, yet is written so as to be accessible to a general readership

e the possibility of impact, it is nec- y asteroids and comets of varying their orbits, to know the collision l to know how many craters have s and rates have been determined for sults of sky surveys; a study of impact ose neighbor, the Moon; and from a search study of craters found on Earth. While variations in this flux may be expected on theoretical grounds, there is an excellent agreement of the predicted cratering rate and the geologic record. Explosions the size of Tunguska may occur every few hundred years and cause local disasters or generate tidal waves, inundating low-lying coastal regions; impacts of 20 megatons energy, the size of Meteor Crater, Arizona, happen about every 50,000 years. Asteroid impact should create about three craters at least 10 km across on Earth's land surfaces every million years, and 3.5 craters greater than 20 km in diameter should be produced per million square kilometers per billion years. A 10- to 15-km impactor, such as the one making the Chicxulub crater, should strike every 100 million years or so. The frequency of impact occurrence has varied throughout geological time, from the early heavy bombardment to the late heavy bombardment, and the effects of impact on Earth evolution have varied also. These events occur on human time-scales and can be ignored today only to the peril of the human race.

B. Recognition of Craters

The only place where one can examine the cratering rate for early Earth history is in Australia, but one can look at a global distribution of craters by examining a large area of the Earth as shown in Fig. 7.

Many craters and structures have been recognized on the basis of shock-induced metamorphism and structural form. The initial result of impact is a crater, which disappears on Earth with time, tectonism, and erosion. The most common meteorites are stones, but they tend to break up in the atmosphere; the threshold size for their survival to Earth is about 150 m and those arriving as stony-irons tend to disappear from any crater as the environm its toll. Most of the very small craters on Earth by iron meteorites, which are the only small o enough to survive passage through the atmo make a crater. An iron asteroid about 40–50 m in survived passage about 50,000 years ago to form Me Crater, Arizona. It made a crater 1.2 km in diameter and 200 m deep. The Wabar Craters, one of which is portrayed in Fig. 8, are found in the Empty Quarter of Saudi Arabia and are unique for having been made entirely in high, shifting sand dunes with no bedrock exposed. Strong desert winds regularly cover and uncover them over the years. The record of impact over time mainly consists of craters or impact structures about 3 km in diameter or larger. 20 : 1 is a good ratio for estimating impactor size on our planet, because kinetic energy scales as the square of velocity. Thus, a stony body about 150 m across would form a 3-km-diameter crater.

Articles provide a balanced, scholarly view of the topic, based on current research

The mechanics for a large crater start out the same: An object hits the Earth at interstellar speeds (20 km/sec for an asteroid, 30 km/sec for a comet), forming two shock waves, one in front and one behind, one that goes into the target rock and one that goes into the impactor. The first travels down through the host rock, pushing it down and out; the second interacts with the first to melt, vaporize, and eject the rocky material and impact glass from the crater. In very large, complex craters caused by large impactors releasing more energy, the walls of the crater are pushed up and out to form a transient cavity. A crater larger than 3 km in soft, sedimentary rocks or larger than about 4 km in hard crystalline rocks will collapse immediately. As the walls slump in, shallow-shaped faults called *listric faults* and diagnostic of impact develop where the layers Au:

"...I found several of the articles not only informative and interesting, but done on a scholarly level that served as an outstanding introduction to the field."

—DANIEL BERG, PRESIDENT,
RENSSELAER POLYTECHNIC INSTITUTE

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Analog Electrical Filters
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Acoustics, Linear
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Natural Antioxidants in Foods
Nucleic Acid Synthesis
Pharmaceuticals, Controlled Release of
Pharmacokinetics
Protein Folding
Protein Structure
Protein Synthesis
Ribozymes
Separation and Purification of Biochemicals
Spectroscopy in Forensic Science
Tissue Engineering
Toxicology in Forensic Science
Translation of RNA to Protein
Vitamins and Coenzymes

CHEMICAL ENGINEERING

Absorption (Chemical Engineering)
Adsorption (Chemical Engineering)
Aerosols
Batch Processing
Catalysis, Industrial
Catalyst Characterization
Chemical Process Design, Simulation, Optimization, and Control
Cryogenic Process Engineering

The **Thematic Index** lists all the articles according to the general discipline they fall under; for example, all the articles that deal with Aeronautics or Astronomy or Materials Science. This allows the reader to obtain a complete overview of the **Encyclopedia's** entire coverage of a given discipline of physical science and technology.

Thematic Index

AERONAUTICS

Aircraft Aerodynamic Boundary Layers
Aircraft Avionics
Aircraft Instruments
Aircraft Performance and Design
Aircraft Speed and Altitude
Airplanes, Light
Computational Aerodynamics
Flight (Aerodynamics)
Helicopters
Ramjets and Scramjets
Structural Analysis, Aerospace
V/STOL Airplanes

ANALYTICAL CHEMISTRY

Analytical Chemistry, Overview
Atomic Spectrometry
Auger Electron Spectroscopy
Capillary Zone Electrophoresis
Electrochemistry
Electron Spin Resonance
Electrophoresis
Elemental Analysis, Organic Compounds
Fiber-Optic Chemical Sensors
Gas Chromatography
Infrared Spectroscopy
Liquid Chromatography
Magnetic Resonance in Medicine
Mass Spectrometry
Microscopy (Chemistry)
Microwave Molecular Spectroscopy
Nuclear Magnetic Resonance (NMR)
Organic Chemistry, Compound Detection
Photoacoustic Spectroscopy
Photoelectron Spectroscopy
Raman Spectroscopy
Scanning Probe Microscopy
Sonoluminescence and Sonochemistry
Thermal Analysis
Tomography
X-Ray Analysis
X-Ray Photoelectron Spectroscopy

ASTRONOMY

Astrochemistry
Binary Stars
Celestial Mechanics
Cometary Physics
Cosmic Inflation
Cosmic Radiation
Cosmology
Dark Matter in the Universe
Galactic Structure and Evolution
Gamma-Ray Astronomy
Gravitational Wave Astronomy
Gravitational Wave Detectors
Image Restoration, Maximum Entropy Methods
Impact Cratering

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