昆山杜克大学
DUKE KUNSHAN UNIVERSITY

ISIS 230K

CROSS-LISTED EOS 230K?

What Meteorites Tell Us about Our Origins

Fall 2016

Dates / contact hours:	300 contact minutes per week for seven weeks
Academic Credit:	one course
Areas of Knowledge:	recommended NS
Modes of Inquiry:	not coded for Modes of Inquiry
Course format:	integrated lecture, seminar, lab and field work with meteorites and computer simulations.

Critical perspectives on the history and progress of meteoritics, the science of meteorites. Hands-on study of a representative collection of meteorites from Mars, the Moon, and asteroids including Vesta. Petrographic microscope characterization of thin sections. Extensive use of written sources, film, the Web, imagery, and computer simulation of complex orbital dynamics and 3d models of meteorites and craters. A possible visit to the Purple Mountain Observatory, Nanjing, and planned hosting of a mini-conference on Chinese meteorites at DKU Friday, September 30th and exhibition of meteorites Saturday - Sunday, October 1st & 2nd. Our course will unite theory with practice at every opportunity.

Instructor's Information

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Prerequisite(s), if applicable

No prerequisites.

Course Description

(Information Science & Information Studies – 230, Earth and Ocean Sciences - 230,)

There is perhaps no larger-scale scientific and intellectual quest than that for knowledge of our own origins, the evolution of life, the solar system, and our universe. Meteorites fall to Earth as samples of worlds from light-minutes to light-years away and from the formation of our Sun and before. Our space missions lack this depth of time and space. Meteorites, "fossils" of 4.5 billion-year-old rocks, minerals, and organics, are our only direct and tangible evidence from those realms. From a scientific perspective, what can we learn about a universe so large from the macro scale of telescopes to the microscopic features of fallen rocks? From a cultural perspective, what can we learn about the evolution of ideas seeking to explain the meaning of rocks that fall from space? These are some of the questions we answer by a hands-on examination of a representative collection of meteorites (provided by the instructor), observing specimens by eye, by loupes and stereo microscopes, and by polished 30 micron thin sections analyzed in detail under polarizing petrographic microscopes.

Through the Internet, we will make extensive use of a wide range or resources and may make remote visits to a laboratory electron microprobe facility. We will also have the opportunity to investigate 3d X-Ray images of selected meteorites and construct 3d images of impact craters here on Earth. Meteorites and their parent asteroids, planetesimals, and planets also undergo complex perturbations to their orbits. Far from the circles and ellipses we imagine in an idealized cosmos, these bodies continually exert gravitational tugs on one another. Akin to the three-body-problem, for which there is no direct solution, only numerical simulations can reveal the sinuous trajectories of arcs and swings which fling chunks of Mercury up to Earth or chunks of Mars down to our planet, or to fall into the Sun or leave our solar system altogether. These circuitous journeys take tens of millions of years, but through computer modeling we can speed up the process and explore these new-ways-of-knowing through the science of complexity such as theories of "panspermia," positing the origin of Earthly life on Mars. These same dynamics are responsible for the rings of Saturn, the Kirkwood gaps in the asteroid belt, and Trojan asteroids which lead and follow the major planets by 60 degrees. We will experiment with some computer simulations of these processes.

In the history of ideas we revisit the accounts of eye-witnesses, dismissed as superstition by learned scholars in the early days of "meteorology," along with explanations from yesterday's great minds of science, who in retrospect believed in such absurdities as rocks congealing in the clouds. The once-in-a-lifetime fall of a 10,000 ton, 55-foot diameter rock travelling at 30,000 miles per hour, which landed in Russia on 14 February 2013, has provided us with the best film, sound, and cross-cultural suite of human reactions to a meteoroid shock wave impact to date, including its economic costs, opportunities and multicultural interpretations. That Russian fall at Chelyabinsk provides us with the "sound and fury" absent in earlier written accounts. Five hundred years ago the fall of the 125kg stone at Ensisheim, Alsace in 1492 was regarded as the voice of God, inspiring this political broadside,

> *"The German nation stands by you, oh King. God warns that you should arm yourself, lead out your army, curb the swollen pride of France."*

It was the rain of stones in L'Aigle, France in 1803 which finally swayed academic opinion in favor of meteorites' unearthly origins and vindicated Ernst Chladni, the "father of meteoritics," who authored his well-reasoned yet controversial theories in 1794. Meteorites fall everywhere with equal probability, mostly into the sea. We have 1,904 recorded meteorites from the United States, yet only 113 recorded from China. Interest is growing worldwide and especially here in China. Dr. Weibiao Xu, curator of meteorites at the Purple Mountain Observatory in Nanjing, has published a new book on meteorites. We are planning to visit his exhibition and to host a one day mini-conference and two-day exhibition on meteorites at the beginning of the National Holidays. We have already received support from several Chinese professionals and funding from the Meteoritical Society and others.

Course Goals / Objectives

- To empower participants with a hands-on understanding of the history, theory, methods, and practice of meteoritics as an example of scientific method and critical thinking.
- To enrich students' a practical knowledge of how to find meteorites, how to recognize them in the field, and how to balance their economic, cultural, and scientific values.
- To give students a familiarity with the study of meteorites today and its potential for the future.
- To instill in students a hands-on familiarity with the variety actual meteorite types from the microscopic scale of thin sections to the macroscopic scale of hand specimens.
- To provide students with interactive engagement with 3d scientific visualization and computer simulations of the complex dynamics of multi-bodied orbital systems, such as the Kirkwood gaps in the asteroid belt and ring structures and Trojans of Saturn and other planets.
- To enable students to work with actual Doppler radar data to track the fall of meteoroids.
- To introduce students to the collection at the Purple Mountain Observatory, Nanjing.
- To include students in a one-day conference and two-day exhibit interacting with researchers, curators, collectors, students, searchers and dealers.
- To acquaint students with actual field recovery techniques (if possible).

Required Text(s)/Resources (Likely excerpted on SAKAI)

<u>Required Access:</u>
My Duke web simulations and resources on meteoritics at: https://web.duke.edu/isis/gessler/

<u>Primary Texts (available in the Library, Bookstore and on Sakai):</u>

Grady, Monica, Giovanni Pratesi and Vanni Moggi Cecchi. ATLAS OF METEORITES. Cambridge University Press, Cambridge (2014).

Brandstatter, Franz, Ludovic Ferriere and Christian Koberl. METEORITEN / METEORITES: WITNESS OF THE ORIGIN OF THE SOLAR SYSTEM. Naturhistorisches Museum, Wien, Edition Lammerhuber, Baden (2013).

Smith, Caroline, Sara Russel and Gretchen Benedix. METEORITES. Firefly Books, Natural History Museum, London (2009).

Weibiao Xu, METEORITES: GIFTS FROM SPACE in Chinese (2016). http://www.sciencep.com/s_single.php?id=39106

Zanda, Brigitte and Monica Rotaru, editors. METEORITES – THEIR IMPACT ON SCIENCE AND HISTORY. Cambridge University Press, Cambridge (2001).

A Sampling of Other Readings (available in the Library and/or on Sakai):

Anonymous. MINERALS: WARD'S NATURAL SCIENCE ESTABLISHMENT. Ward's Natural Science Establishment, Rochester (1935).

Anonymous. THE MUNICH SHOW: THEME BOOK: METEORITES. Wachholttz Verlag, Neumunster/Hamburg (2014).

Anonymous. STORY OF A METEORITE (FALLEN IN ENSISHEIM ON NOVEMBER 7TH 1492. Saint George's Brotherhood of the Meteorite's Guardian, Mack, Meyenheim (19??).

Casper, Michael. METEORITES FOR SALE. Michael Casper Meteorites, Ithaca (1999).

Clayton, Robert, Naoki Onuma and Toshiko Mayeda. "A Classification of Meteorites Based on Oxygen Isotopes," in EARTH AND PLANETARY SCIENCS LETTERS, 30 (1976) 10-18.

Fei, Yu. "Deciphering the Secrets of Falling Stars." CHINA DAILY, August 15-16, 2015.

Fridman and Gorkavyi. PHYSICS OF PLANETARY RINGS, CELESTIAL MECHANICS OF PLANETARY MEDIA. Springer-Verlag (1999).

Haag, Robert. THE ROBERT HAAG COLLECTION: CATALOG OF METEORITES: SPECIAL EDITION (Volume 8 & Volume 6). Robert Haag Meteorites, Tucson (1986, 1988).

Haag, Robert. THE ROBERT HAAG COLLECTION: ALL NEW FIELD GUIDE AND CATALOG OF METEORITES (Volume 10). Robert Haag Meteorites, Tucson (1989).

Haag, Robert. FIELD GUIDE OF METEORITES: 10TH ANNIVERSARY EDITION. Robert Haag Meteorites, Tucson (1991).

Haag, Robert. THE ROBERT HAAG COLLECTION OF METEORITES. Robert Haag Meteorites, Tucson (2003).

Hutchison, Robert. METEORITES, A PETROLOGIC, CHEMICAL AND ISOTOPIC SYNTHESIS. Cambridge University Press, Cambridge (2004).

Kenkmann, Deutsch et al. "Experimental Impact Cratering," a special issue in METEORITICS & PLANETARY SCIENCE, volume 48, number 1, January 2013.

Lauretta, Dante and Marvin Killgore. A COLOR ATLAS OF METEORITES IN THIN SECTION. Southwest Meteorite Press, Arizona (2005).

Lauretta, Dante and Harry McSween, editors. METEORITES AND THE EARLY SOLAR SYSTEM II. University of Arizona Press, Tucson (2006).

Kerridge, John and Mildred Matthews, editors. METEORITES AND THE EARLY SOLAR SYSTEM. University of Arizona Press, Tucson (1988).

Krinov, E.L. PRINCIPLES OF METEORITICS. Pergamon Press, Oxford (1960).

Krinov, E.L. GIANT METEORITES. Pergamon Press, Oxford (1966).

Marvin, Ursula. "Ernst Florens Friedrich Chladni (1756-1827) and the Origins of Modern Meteorite Research," in METEORITICS & PLANETARY SCIENCE, volume 42, Supplement, September 2007.

McCall, Bowden and Howarth. THE HISTORY OF METORITICS AND KEY METEORITE COLLECTIONS: FIREBALLS, FALLS AND FINDS. Geological Society, London (2006), Special Publication 256.

McSween, Harry. METEORITES AND THEIR PARENT PLANETS. Cambridge University Press, Cambridge (2000).

McSween, Harry and Gary Huss. COSMOCHEMISTRY. Cambridge University Press, Cambridge (2010).

Miner, Ellis, Randii Wessen et al. PLANETARY RING SYSTEMS. Springer-Verlag (2007).

Neese, William. INTRODUCTION TO OPTICAL MINERALOGY. Oxford University Press, Oxford (2013).

Norton, Richard and Lawrence Chitwood. FIELD GUIDE TO METEORS AND METEORITES. Springer-Verlag, London (2008).

Righter, Kevin, Catherine Corrigan, Timothy McCoy and Ralph Harvey (editors). 35 SEASONS OF U.S. ANTARCTIC METEORITES (1976-2010), Wiley, New Jersey (2-15).

Yanai, Keizo. PHOTOGRAPHIC CATALOG OF THE SELECTED ANTARCTIC METEORITES. National Institute of Polar Research, Tokyo (1981).

<u>Selected Screenings compiled from various sources, for example:</u>

Chelyabinsk / Chebarkul meteor security, dash-cam and hand-held video.

Sims, Karl. PANSPERMIA, computer simulation on Thinking Machines CM2.

Farmer, Michael and Robert Haag. INTERVIEWS.

Recommended Text(s)/Resources

See Selected Required and Recommended Readings above…

Additional Materials (optional)

Two USB memory sticks.
12 each: writable CD/DVD, CD/DVD sleeves, 8 ½ x 11 sheet protectors.
Students should each have a laptop computer available (preferably a PC).

Course Requirements / Key Evidences

Participants are expected to explore one or more facets of meteoritics at a depth beyond that presented in class. Students are expected to critically engage in discussions, analysis, and hands-on activities with the analytical equipment. Students are expected to conduct interactive "what if?" experiments with the computer simulation tools provided. Grading is by demonstrated engagement in the material presented, measured by attendance, discussions, presentations, analysis, and any outdoor trips and field research.

Technology Considerations, if applicable

The meteorite collection, meteorite recovery and preparation equipment, petrographic microscopes and software will be provided by the instructor, but assistance will be requested from DKU for safe shipping and return.
Access to a well-equipped media classroom (with VHS, DVD, projector and PCs for each student).
Quick FTP access to my established Duke website is a must.
Access to a one-student-per-PC computer station is needed.
A Teaching Assistant would greatly improve the effectiveness of this course.

Assessment Information / Grading Procedures

All challenges stress "the four Es" of creative critique: explore, experiment, enhance, and enjoy.
Grading will be based on demonstrated engagement with course material.
Inexperienced and experienced participants have equal prospects for success.
25% Weekly take-home, written essay challenges.
25% Weekly in-class hands-on analytical and identification challenges.
25% Several mid-course exams based upon key course definitions & concepts.
25% One course research paper (participants' choice after instructor's approval).

Diversity and Intercultural Learning (see Principles of DKU Liberal Arts Education)

Expressing one's theories, hypotheses, and ideas across the boundaries of the sciences, humanities, and philosophy is an internationally recognized means of objectifying often diverse subjective cultural impressions and perceptions. It does so by forcing the ambiguity of single and multiple natural languages into a coherent and objective model of reality, thus effectively converting diverse languages and cultural understandings into a universal language of description and analysis.
Integration of Chinese and American perspectives on meteoritics.

Course Policies and Guidelines

- Academic integrity: Collaborative work is invited as long as there is "value added" (a multiplier effect) and each member's contributions are clearly indicated.
- Attendance: The initial sessions are critical as they lay the foundation for subsequent challenges. Absentees should consult other participants and/or the instructor to keep up to date.
- Attention to assignment deadlines: Late work is accepted if it is a substantial improvement upon the level of engagement expected for work submitted on time.
- Make-up work: Late work is accepted if it is a substantial improvement upon the level of engagement expected for work submitted on time.

- Appropriate or inappropriate use of cell phone, laptop, or other technology during class: Students are responsible for not disrupting the class environment. Use of laptops and PCs encouraged. Use of cell phones only in emergencies.

Tentative Course Outline or Schedule

EXPECT VARIATION IN THE WEEKLY TOPICS SINCE NONE ARE "NATURAL" SCIENTIFIC CATEGORIES.

WEEK 1: Experiencing the awe and fury of a fireball, an introduction to rocks from space.

Hand-held, dash-cam and security video of the February 15, 2013 event at Chebarkul and Chelyabinsk. Its effect on people, their property, the land and animals. Meteors and meteoroid breakup tracked by Doppler radar, evidenced in seismograms and triangulated by shadows moving across the Earth. Bright and dark meteoroid flight. Reductions of velocity and mass due to ablation and breakup. Frequency of falls by season and time of day. Pre-fall orbits. The strewn field of meteorites, an ellipse of finds on the surface of the Earth.

A brief overview of expectations and course topics. Participant introductions and discussion of your interests from which we may stress or de-stress particular facets of the course. A quick review of the origin of the elements, the hot solar nebula and its condensation to form our Sun, minerals, planets and asteroids. A quick review of terminology: meteoroid, meteor, meteorite, orientation, fusion crust, traditional vs. genetic classification, chondrules and chondrites, achondrites and primitive achondrites, stony irons, mesosiderites and irons, equilibration, differentiation, chemical and petrographic type, shock and weathering.

Readings: Monica Grady, ATLAS OF METEORITES, Chapter 1.

WEEK 2: Impact! Disruption of a planet's crust and ecology, craters and new rock types.

Physical dynamics of meteorite cratering. A survey of craters on solid planets with comparisons to craters on the Earth and their correlation with major changes in the evolution of flora and fauna. Characteristics of impacted rocks, tektites and fused glasses including Libyan Desert Glass evidencing a collision with hundreds of times the energy of the Trinity nuclear test. Laboratory experiments with high velocity impactors on various rocks and soils.

Dynamics of planetary rock swaps: Simulating the probability of meteorites arriving from Mercury, Venus, Mars, the moons of Jupiter and Saturn and from the Earth itself. The unusual and surprising ring-structures resulting from Lagrangian dynamics, the interaction of orbiting bodies with multiple gravitational influences on one another.

Readings: Brett Gladman, "Exchange of Ejecta Between Terrestrial Planets" and "Destination Earth – Martian Meteorite Delivery."

WEEK 3: Intellectual and cultural history of the development of the science of meteoritics.

Early views of meteors as the products of the gaseous atmosphere and weather, hence Meteorology. Chladni's contribution as the "father" of the field. The separation of Meteorites from terrestrial weather phenomena and the birth of Meteoritics. The intellectual battles and debates and their connections with then current theories.

Famous meteors, meteorites, falls, finds, and persons. The Tunguska and Sikhote-Alin events, the Allende and Murchison falls, Meteor Crater, the Willamette and Hoba irons, hunt for Muonionalusta irons, the recent Tissint, Morocco Martian fireball and meteorite pioneers such as Harvey Nininger and hunters like Bob Haag, Michael Casper and Mike Farmer. A history of Chinese meteoritics and an inventory of falls and finds. New research on the Armanty iron family from Xinjiang.

Readings: Ursula Marvin, "The Meteoritical Society 1933-1993" & "Origins of Modern Meteorite Research."

Week 4: Undifferentiated Meteorites, the Chondrites.

Chondrites as mineral and rock "fossils" of the early condensing Solar Nebula. Carbonaceous, ordinary and enstitite chondrites. They are from unmelted bodies and thus retain the structural elements from which they were originally formed. Chondrules, droplets of fiery rain, nickel-iron flecks, pre-solar grains, interplanetary dust, calcium-aluminum inclusions and other constituents. An introduction to thin sections and cross-polarizing microscopy.

Readings: Monica Grady, ATLAS OF METEORITES, Chapters 2-5.

WEEK 5: Differentiated meteorites, the achondrites.

Meteorites from melted parent planets. Primitive achondrites, howardites, eucrites, diogenites and aubrites, their appearances, characteristics and origins. The stony-irons and mesosiderites and the beautiful transparent golden-yellow olivine-studded iron meteorites called pallasites. Their origins at the core/mantle boundary of melted planets. Irons, the metallic cores of melted planets which no longer exist and iron melted as a result of violent impacts. The Widmanstatten lines etched with acid which show the crystalline boundaries between nickel-iron alloys.

Meteorites from Mars, the Moon and Vesta. The evidence for meteorites from Mars and an iron meteorite found on Mars. Lunar meteorites and the lunar samples brought back by astronauts. The asteroid Vesta, its globe rendered from a digital elevation model, the birthplace of the HED family of meteorites.

Readings: Monica Grady, ATLAS OF METEORITES, Chapters 6-17.

WEEK 6: Meteorite recovery and allocation.

Recognizing meteorites in the field: meteor-rights and meteor-wrongs. Fusion crusts, flow lines, orientation, petal formation, rivulets and regmaglypts in fresh meteorites. Attraction to a magnet of various meteorite types. Difficulties in identifying weathered meteorites. Inspection of hand specimens. Techniques of predicting the strewn fields of witnessed fireballs and bolides. All-sky cameras and Doppler radar. Search methods by eye and metal-detector. The market in space rocks ranging from 10-cents to $5,000 per gram. The Tucson, Munich and Ensisheim/Sainte Marie rock, mineral and meteorite shows, eBay and other auctions. Effects of publicity from the TV series "Meteorite Men," the recent Sutter's Mill and Russian fireballs and meteorites. Conserving the resource for science, the public and collectors and the roles of hunters and dealers in the distribution of meteorites. Who owns meteorites? The successes and failures of legislation.

Readings: Michael Blood, "Meteorite Market Trends", Ward, Haag and Casper catalogs.

WEEK 7: Advanced analytical techniques.

Petrographic Polarized Microscopic Analysis of Meteorite Thin Sections. Cutting the samples, polishing and identifying meteorite types, shock and weathering from sections so thin they are transparent to light. Microprobe and isotopic analysis. Theory and methods and a possible visit to a microprobe lab if we find one available. Calculating formation, flight and time-on-earth ages of rocks from space. Theory and methodology of dating techniques based on the rates of production and decay of radioactive isotopes.

Readings: Yuri Amelin, "Dating the Oldest Rocks and Minerals in the Solar System."

Bibliography (optional)

See required and recommended texts and resources above.

Poetry (optional)

"Modified," (i.e. corrected) from Joanna Newsom's album, "Emily" (2006):

Though all I knew of the rote universe were those Pleiades loosed in December
I promised you I'd set them to verse so I'd always remember

That the meteoroid is a source of the light
And the meteor's just what we see
And the meteorite is a stone that's devoid of the fire that propelled it to thee

And the meteoroid's just what causes the light
And the meteor's how it's perceived
And the meteorite's a bone thrown from the void that lies quiet in offering to thee