The Origin of the Moon: New Insights Accompany New Controversies

Richard J. Walker,
University of Maryland – College Park

Abstract: The origin of the Moon and how its formation relates to the accretionary history of the Earth remains a highly debated topic. Controversy continues to swirl around two major questions:

How did the Moon form? When did the Moon form?

The creation of the Moon as a result of a giant impact between the proto-Earth and a large body remains the current and favored paradigm. Yet the Earth and Moon appear to be genetically identical, evidenced by isotopic similarities in elements such as oxygen and tungsten. This is troubling for most giant impact models because they predict the Earth and Moon should be made of genetically distinct materials. The age of the Moon is similarly problematic. Most evidence points to its formation more than 50 million years into Solar System history. Recent, highly precise age determinations of the Moon’s crust, however, suggest either that the Moon may have formed much later, in conflict with dynamical models of the early Solar System, or question that the crust formed by plagioclase flotation in a magma ocean.
Reminder

After the meeting, everyone is invited to join us at Plato’s Diner in College Park. Plato’s is located at 7150 Baltimore Ave. (US Rt. 1 at Calvert Rd.), just south of the university’s campus. What if it’s clear and you want to stick around and observe? No problem -- just come over when you’re through. This is very informal, and we fully expect people to wander in and out.

Moon Formation Theories

Fission Theory

Fission was proposed by Astronomer George (son of Charles) Darwin in The Tides and Kindred Phenomena in the Solar System (1898 CE). The theory hypothesizes that the Moon was part of the Earth during the Solar System’s early days, but the young planet’s fast spin cast off some of its mantle (from what is currently the location of the Pacific Ocean) and hurled it into space, just not far enough to escape Earth’s gravitational field. Lunar rocks retrieved by astronauts and the physics of such a cleaving do not support Darwin’s theory.

Capture Theory

The Moon’s origin was from some other part of the Milky Way; but, it wandered past Earth and was captured by the gravitational field. Current prevailing views contradicting this theory, however, are that a Moon-sized object would have been torn apart by or broken free of Earth’s gravitational field. Also, the Earth & Moon isotope compositions do not support a different origin location.

Biographical Sketch:

Richard J. Walker is a professor and current Chair of the Department of Geology at the University of Maryland. He utilizes radiogenic isotopes and trace elements to conduct research in several areas of geo- and cosmochemistry, including the chemical evolution of Earth’s mantle, the formation and crystallization histories of early Solar System planetesimals, and the accretional & differentiation histories of Earth, Moon and Mars. The research his group conducts mainly utilizes concentration and high-precision isotopic measurements of siderophile (iron-loving) elements. These elements are of special interest in studies of planetary accretion because they are concentrated by planetary core formation.

Professor Walker received a B.S. in geology from the College of William and Mary. He received his M.S. and Ph.D. degrees in geology from the State University of New York at Stony Brook in 1981 and 1984, respectively. Dr. Walker also did postdoctoral work at the U.S. National Bureau of Standards, the Carnegie Institution of Washington’s Department of Terrestrial Magnetism, and the U. S. Geological Survey. He became a member of the faculty of the University of Maryland in 1990. In addition, Dr. Walker was the 1990 recipient of the Clarke Medal of the Geochemical Society and is currently a fellow of the American Geophysical Union, the European Association for Geochemistry and the Geochemical Society.

Moon Origin – continued from page 1

KREEP rocks are hypothesized to have formed during the Moon’s early, molten stage. The KREEP-rich lunar sample (above) retrieved by Apollo 12 is about 5 cm long and weighs 82 grams. “KREEP” rocks acquired their name because they are rich in potassium (atomic symbol = K), rare Earth elements (“REE”) and phosphorus (atomic symbol = P). During the investigation of the Giant Impact Theory, the Moon’s tungsten (atomic symbol = W) isotope composition was investigated. Therefore, KREEP rocks (from Apollo 16) were studied because of their high levels of tungsten.

Biographical Sketch:

Richard J. Walker is a professor and current Chair of the Department of Geology at the University of Maryland. He utilizes radiogenic isotopes and trace elements to conduct research in several areas of geo- and cosmochemistry, including the chemical evolution of Earth’s mantle, the formation and crystallization histories of early Solar System planetesimals, and the accretional & differentiation histories of Earth, Moon and Mars. The research his group conducts mainly utilizes concentration and high-precision isotopic measurements of siderophile (iron-loving) elements. These elements are of special interest in studies of planetary accretion because they are concentrated by planetary core formation.

Professor Walker received a B.S. in geology from the College of William and Mary. He received his M.S. and Ph.D. degrees in geology from the State University of New York at Stony Brook in 1981 and 1984, respectively. Dr. Walker also did postdoctoral work at the U.S. National Bureau of Standards, the Carnegie Institution of Washington’s Department of Terrestrial Magnetism, and the U. S. Geological Survey. He became a member of the faculty of the University of Maryland in 1990. In addition, Dr. Walker was the 1990 recipient of the Clarke Medal of the Geochemical Society and is currently a fellow of the American Geophysical Union, the European Association for Geochemistry and the Geochemical Society.

KREEP rocks are hypothesized to have formed during the Moon’s early, molten stage. The KREEP-rich lunar sample (above) retrieved by Apollo 12 is about 5 cm long and weighs 82 grams. “KREEP” rocks acquired their name because they are rich in potassium (atomic symbol = K), rare Earth elements (“REE”) and phosphorus (atomic symbol = P). During the investigation of the Giant Impact Theory, the Moon’s tungsten (atomic symbol = W) isotope composition was investigated. Therefore, KREEP rocks (from Apollo 16) were studied because of their high levels of tungsten.
Moon Formation – continued from page 2

Condensation (Co-accretion) Theory
In this theory, the Moon and Earth were created simultaneously via the nebula from which the Solar System formed. However, as evidenced by the Moon’s lighter density, it does not have an iron core like Earth does (and one would expect this similarity if the 2 bodies were created at the same time and in the same space).

Giant Impact (Ejected Ring) Theory
The currently accepted theory hypothesizes that a nearby planetesimal (small Mars-size planet) collided with Earth 4.5 billion years ago, ejecting super-heated rock debris from the surface of both bodies into Earth’s orbit, which eventually formed the Moon. According to scientists at NASA’s Astrophysics Science Division, the impact of the 2 bodies released energy that was 100 million times greater than the energy released by the impact thought to have wiped out the dinosaurs; so, the planetesimal (which some refer to as Theia) was utterly destroyed. This theory could also explain the Moon’s super-heated rock composition as compared to Earth’s.

Sky Watchers

Spring Schedule

April

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1:00 am</td>
<td>Planets, N. Hemisphere. Jupiter 2° north of Moon.</td>
</tr>
<tr>
<td>22</td>
<td>Overnight</td>
<td>Meteors, N. Hemisphere. Lyrids.</td>
</tr>
<tr>
<td>29-30</td>
<td>Evening</td>
<td>Globe at Night, Global. Features: Constellations Leo (N. Hemisphere) and Crux (S. Hemisphere).</td>
</tr>
</tbody>
</table>

Times EDT

May

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>Evening</td>
<td>Globe at Night, Global. Features: Constellations Leo (N. Hemisphere) and Crux (S. Hemisphere).</td>
</tr>
<tr>
<td>7</td>
<td>9:00 pm</td>
<td>Exploring the Sky, Features: Mars, Saturn, Antares &amp; the Big Dipper.</td>
</tr>
<tr>
<td>8</td>
<td>7 am</td>
<td>Planets, N. Hemisphere. Venus 5° north of Moon.</td>
</tr>
</tbody>
</table>

Times EDT

Exploring the Sky

“Exploring the Sky” is an informal program that, for over 60 years, has offered monthly opportunities for anyone in the Washington area to see the stars and planets through telescopes from a location within the District of Columbia. Presented by the National Park Service and National Capital Astronomers, sessions are held in Rock Creek Park once each month on a Saturday night from April through November. Beginners (including children) and experienced stargazers are all welcome—and it’s free!

2016 Observation Dates for Spring and Summer

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 May</td>
<td>9:00 pm</td>
<td>Mars, Saturn, Antares &amp; the Big Dipper</td>
</tr>
<tr>
<td>4 June</td>
<td>9:00 pm</td>
<td>Vega &amp; 3 planets</td>
</tr>
<tr>
<td>9 July</td>
<td>9:00 pm</td>
<td>Summer Triangle, Moon &amp; Jupiter</td>
</tr>
<tr>
<td>6 August</td>
<td>8:30 pm</td>
<td>Andromeda &amp; Mercury</td>
</tr>
</tbody>
</table>

Hosted by: National Capital Astronomers, Inc and Rock Creek Park

The Great North American Eclipse

Aug 21st 2017

www.greatamericaneclipse.com/
CubeSats

CubeSats are playing an increasingly larger role in exploration, technology demonstrations, scientific research and educational investigations at NASA. They are a class of research spacecraft called nanosatellites. The cube-shaped satellites measure about four inches on each side, have a volume of about one quart and weigh less than three pounds each. These miniature satellites provide a low-cost platform for NASA missions, including planetary space exploration; Earth observation; fundamental Earth and space science; and technology demonstrations such as cutting-edge laser communications, energy storage, in-space propulsion and autonomous movement capabilities. They also allow educators an inexpensive means to engage students in all phases of satellite development, operation and exploitation through real-world, hands-on research and development experience on NASA-funded, ride-share launch opportunities.

The CubeSat Launch Initiative (CSLI) enables the launch of CubeSat projects designed, built and operated by students, teachers and faculty. CSLI provides access to space for CubeSats developed by the NASA centers and programs, educational institutions and nonprofit organizations, enabling all these CubeSat developers access to a low-cost pathway to conduct research in the areas of science, exploration, technology development, education or operations. ELaNa Missions, managed by the Launch Services Program at NASA’s Kennedy Space in Florida, provide a deployment opportunity or ride-share launch to space for the CubeSats selected through CSLI. ELaNa Mission managers and their teams reach students at schools and colleges across the United States, providing spaceflight education through the preparation of payloads – licensing, integration and testing – that are flown in space. Since its inception in 2010, the initiative has selected more than 100 CubeSats and launched 43 CubeSats from primarily educational and government institutions around the United States. These miniature satellites were chosen from a prioritized queue established through a short-listing process from responses to public announcements on NASA’s CubeSat Launch Initiative.

continued on page 6
Occultation Notes

- D following the time denotes a disappearance, while R indicates that the event is a reappearance.
- When a power (x; actually, zoom factor) is given in the notes, the event can probably be recorded directly with a camcorder of that power with no telescope needed.
- The times are for Greenbelt, MD, and will be good to within +/- 1 min. for other locations in the Washington-Baltimore metropolitan areas unless the cusp angle (CA) is less than 30 deg., in which case, it might be indicated with “mg3” or “m3”. Double is sometime abbreviated “dbl”.
- Sometimes the Watts angle (WA) is given; it is aligned with the Moon’s rotation axis and can be used to estimate where a star will reappear relative to lunar features. The selenographic latitude is WA -270. For example, WA 305 - 310 is near Mare Crisium.
- Some stars in Flamsteed’s catalog are in the wrong constellation, according to the official IAU constellation boundaries that were established well after Flamsteed’s catalog was published. In these cases, Flamsteed’s constellation is in parentheses ( ), and sometimes its PA from the primary.
- Double stars is often given. “Close double” followed by its separation in arc seconds is nearly equal components with a separation less than 50 and is gibbous if it is more than 50.
- Cusp Angle is described more fully at the main IOTA Web site.
- Sp. is the star’s spectral type (color), O,B,blue; A,F,white; G,yellow; K,orange; M,N,S,C red.
- Also in the notes, information about double stars is often given. “Close double” with no other information usually means nearly equal components with a separation less than 0.2”. “mg2” or “m2” means the magnitude of the secondary component, followed by its separation in arc seconds (“), and sometimes its PA from the primary. If there is a 3rd component (for a triple star), it might be indicated with “mg3” or “m3”. Double is sometime abbreviated “dbl”.

Mid-Atlantic Occultations

David Dunham

Asteroidal and Planetary Occultations

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>EDT</th>
<th>Star</th>
<th>Mag</th>
<th>Asteroid</th>
<th>dmag</th>
<th>s</th>
<th>Location, Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 30 Sat 20:45</td>
<td>SAO 116537</td>
<td>8.9</td>
<td>Alauda</td>
<td>4.13</td>
<td>3</td>
<td>eSc,Snc,Sun -9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lunar Grazing Occultations

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>EDT</th>
<th>Star</th>
<th>Mag</th>
<th>Location &amp; Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 10 Sun 19:22</td>
<td>Aldebaran</td>
<td>0.9 16+</td>
<td>29 -IN</td>
<td>Good Enough BigPond,Labrador</td>
<td></td>
</tr>
<tr>
<td>Apr 14 Thu 20:51</td>
<td>SAO 97835</td>
<td>8.5 59+</td>
<td>64</td>
<td>4N Woodbine,ElicoCC,Sarbutus,MD</td>
<td></td>
</tr>
<tr>
<td>May 12 Thu 21:45</td>
<td>SAO 98343*</td>
<td>7.4 43+</td>
<td>43</td>
<td>4N Hyattstown,Ofney,Saurel,Md</td>
<td></td>
</tr>
</tbody>
</table>

No expedition from DC area planned

Total Lunar Occultations

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>EDT</th>
<th>Star</th>
<th>Mag</th>
<th>% alt</th>
<th>CA</th>
<th>Sp.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 27 Wed 3:03</td>
<td>4U427055675</td>
<td>13.0</td>
<td>Dufour</td>
<td>2.8</td>
<td>4</td>
<td>10</td>
<td>NJ,PA,NH;MD</td>
<td></td>
</tr>
<tr>
<td>Apr 29 Fri 1:06</td>
<td>4U474050012</td>
<td>12.7</td>
<td>Nethrus</td>
<td>2.1</td>
<td>6</td>
<td>10</td>
<td>neNC,VA,Wi,OH</td>
<td></td>
</tr>
</tbody>
</table>

Further explanations & more information is at http://iota.jhuapl.edu/exped.htm, david.dunham@starpower.net
SAO 98343

David Dunham

A good grazing occultation of 7.4-magnitude SAO 98343 will be visible on the evening of May 12th from the zone between the two dark gray lines on the map of central Maryland (below). A short total occultation will be visible from locations south of the zone, while the star will not be occulted for locations north of it. Video recordings of the event will be valuable to check for stellar duplicity since the star is in the Kepler 2 exoplanet search program.
Calendar of Events

- **NCA Mirror- or Telescope-making Classes**: Tuesdays and Fridays, from 6:30 to 9:45 pm at the Chevy Chase Community Center (intersection of McKinley Street and Connecticut Avenue, N.W.) Contact instructor Guy Brandenburg at 202-635-1860 or email him at gfbrandenburg@yahoo.com.

- **Open house talks and observing at the University of Maryland Observatory**: in College Park on the 5th and 20th of every month at 8:00 pm (Nov.-Apr.) or 9:00 pm (May-Oct.). Details: www.astro.umd.edu/openhouse

- **Mid-Atlantic Senior Physicists Group**: "Earth’s Changing Sea Ice Coverage and Its Connections with Broader Climate Change and Geo-engineering" with Claire Parkinson (GSFC) Wed. Apr. 20, at 1 pm at the American Center for Physics (1st floor conference room). www.aps.org/units/maspg

- **Owens Science Center Planetarium (Planetarium Patty’s Plaza)**: "Searching for Signs of Life" with Jane Ulrich, Fri. May 6, 7:30 pm; $5/adult; $3/students/senior/teachers/military. www1.pgcps.org/howardbowens

- **Owens Science Center Planetarium (Family Night)**: “Astin’s Sky Adventure,” Fri. May 13, 7:30 pm; $5/adult; $3/students/senior/teachers/military; children under 3 free. www1.pgcps.org/howardbowens

- **Upcoming NCA Meetings** at the University of Maryland Observatory:
  - **14 May**: Chyssa Kouveliotou (GWU), “Magnetars.”
  - **11 June**: Science Fair Winners’ presentations, Elections, Astro-Photos!

**Clear Skies!**

**National Capital Astronomers Membership Form**

Name: ____________________________________________ Date: ___/___/___

Address: ______________________________________________________ ZIP Code: _____

Home Phone: _____-____-____ E-mail: ___________________________ Print / E-mail Star Dust (circle one)

Membership (circle one): Student….. $ 5; Individual / Family…..$10; Optional Contribution…..$__

Please indicate which activities interest you:

- Attending monthly scientific lectures on some aspect of astronomy
- Making scientific astronomical observations
- Observing astronomical objects for personal pleasure at relatively dark sites
- Attending large regional star parties
- Doing outreach events to educate the public, such as Exploring the Sky
- Building or modifying telescopes
- Participating in travel/expeditions to view eclipses or occultations
- Combating light pollution

Do you have any special skills, such as videography, graphic arts, science education, electronics, machining, etc.?

Are you interested in volunteering for: Telescope making, Exploring the Sky, Star Dust, NCA Officer, etc.?

Please mail this form with check payable to National Capital Astronomers to:

Henry Bofinger, NCA Treasurer; 727 Massachusetts Ave. NE, Washington, DC 20002-6007

Star Dust © 2016. Star Dust may be reproduced with credit to National Capital Astronomers, Inc.
Next NCA Meeting:
2016 April 9th
7:30 pm
@ UMD Observatory

Richard J. Walker

Inside This Issue
Preview of Apr 2016 Talk...............1
Sky Watchers..........................3
CubeSats................................4
Occultations............................5
SAO 98343...............................6
Calendar..................................7