To the Moon and Beyond:

The Transformation of Our Understanding of the Solar System in the Decades Since Apollo 11

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From Telescope to Human Footprints
Apollo 17 astronaut Harrison Schmitt standing next to boulder at Taurus-Littrow
Craters on the Earth

Meteor Crater, Arizona
*Rim diameter:* 1.2 kilometers
*Age:* 49,000 ± 3000 years

Image courtesy of the Lunar and Planetary Science Institute
Prior to Apollo, many astronomers, and the first planetary scientists, recognized the importance of impact craters on the Moon and the Earth.
Erased on the Earth

Manicouagan, Canada

Original rim diameter: ~100 kilometers
Age: 214 ± 1 million years

Image courtesy of the Lunar and Planetary Science Institute
Since Apollo, impacts have been shown to have played a major role in the history of our planet. The idea that an impact ended the age of the dinosaurs was first proposed in 1980. The crater has since been found.
Giant Impact

Proposed by two planetary research groups in the mid-1970’s, the idea our Moon resulted from Mars size (or larger) body impacting the Earth 4.5 billion years ago.

The giant impact hypothesis explains many of the unique features of the Earth-Moon system.

http://www.astrobio.nau.edu/~koerner/ast180/lectures/lec12.html
Return to the Moon

Just days prior to the 40th anniversary of Apollo 11, Lunar Reconnaissance Orbiter imaged the landing site of this historic mission.
Our First Steps Beyond the Earth

The International Space Station orbits at only about 1/1000th of the Earth-Moon distance of 384,000 km.
Pioneer Venus

Earth’s “Twin” Revealed

Image Credit: NASA/USGS
Magellan vs. Pioneer

Image Credit: NASA/JPL
The Strange Volcanoes of Venus

Image Credits: NASA/JPL/USGS
Addams Crater

Magellan radar image of Addams crater, Venus. The radar bright outflow associated with the 90 km crater stretches over 600 km to the east.

Image Credit: NASA/JPL/USGS
Crater Aurelia

As seen by Magellan

31.9 km (20 miles) in diameter

Image Credit: NASA/JPL/USGS
Venus and Catastrophic Resurfacing

• Wide-spread volcanic plains surrounding older, heavily faulted and folded highlands.

• Well preserved impacts - few modified by volcanism or tectonics dating the volcanic plains to between about 500 million years of age (±/− a few 100 million years).

• No visible signs of active volcanism
Earth’s Future Fate?

In one billion years: our Sun will be 10% brighter. This will cause, at first, a moist greenhouse effect on Earth, driving away most of the water into the atmosphere, and then possibly a runaway greenhouse.

In 3.5 billion years, the Sun will be 40% brighter.

In 6 billion years, the Sun will be more than twice as bright as today.
Earth and Mars to Scale in Size
The Two Faces of Mars Geography

Global Mars topography from the Mars Orbiter Laser Altimeter as shown in Smith et al., 1999.
Craters on Mars

Image from the LPI slide set *The Red Planet: A Survey of Mars*
Volcanoes on Mars

Image from the LPI slide set The Red Planet: A Survey of Mars
Images from the LPI slide set *The Red Planet: A Survey of Mars*
Mars Paleoclimates

(MOC -0002100)

Image Credits NASA/JPL/MSSS/UofA/Texas A&M
Ancient Mars

Orbital spectrometers reveal composition of the most ancient crust of Mars.

Phyllosilicates (clay minerals) are found in early Mars sedimentary/altered layers (before the end of late heavy bombardment.)

Early Mars had - at least periodic - rain fall.
A desert with abundant ground water

Sulfates (sulfur-rich salts) and opal-like deposits have been found in concentrations in more isolated locations.

Altered minerals in bedrock have been found at both Mars Exploration Rover landing sites.

Image credits NASA/JPL
A Frozen World

Anhydrous iron oxide formation and abundant olivine. Largely unaltered basaltic rock (like crust of Earth’s oceans) or sedimentary materials derived from basaltic rock cover most of Mars. These are found globally and represent the current planet.
An Mars avalanche is caught in action in January 2010. The cliff, approximately 700 meters (2000 feet) high, is made up of layers of water ice with varying dust content, roughly similar to the polar ice caps on Earth.
Jupiter

Image credit: NASA (Voyager)
Impact at Jupiter!

Comet Shoemaker-Levy 9 Impact Photos
Photo CD Images - 14" Schmidt Cassegrain
Texas A&M Observatory

July 20, 1994 1:29UT
Impacts G/D and L

July 20, 1994 2:25UT
Impacts H
G/D and L

July 27, 1994 1:25UT
Impacts G/D/S/R
L and K/W

G Impact Site
Green

Methane

18 July 1994
Scaled to the Earth

Jupiter’s Moon Io

The most volcanically active body in the Solar System.
Active Lava Flows

Io — Tvashtar Catena

I25 (26 Nov 1999)
+ C21 low-resolution color

I27 (22 Feb 2000)
visible wavelength data
+ IR data of active lava flow

Image Credit: NASA/JPL
Europa: An Ocean Moon?

This color-stretched image from NASA’s Galileo spacecraft covers an area approximately 70 by 30 kilometers (44 by 19 miles).

An impact 86 km across.
The Four Galilean Satellites of Jupiter

Image Credit: NASA/JPL/DLR
Mimas

A small satellite just on the edge of “roundness”, but very interesting to see, this small (392 km in diameter) satellite looks much like the Death Star from Star Wars.

Image credit: NASA
Saturn’s Enceladus -
500 km in diameter
A tiny world...

Image credit: NASA/JPL
Watery Plume from a Tiny World

Enceladus is the origin of Saturn’s faint E-ring.

Image Credits: NASA/JPL/ESA/Space Science Institute
Titan

“Earth of the Outer Solar System”

Image credit: NASA/JPL
Anti-Greenhouse Effect

The hazy nitrogen atmosphere scatters blue and ultraviolet light, but allows thermal infrared to pass through, effectively doing the opposite of the greenhouse effect, despite the presence of methane.

Image Credit: NASA/JPL/Space Science Institute
Titan Huygens Probe 2005
Approximation of Landing Site Mosaics

Credit to ESA, NASA, UofA and all the Amateur community
levin@spacescience.ca
Titan with Earth and the Moon

Image produced from NASA images by Kelvin Case (a teacher).
On Titan, with a surface temperature of -178 °C (-288 °F) water ice is a mineral and methane rains from the sky, carving rivers and filling lakes.
Pluto and Charon

http://imgsrc.hubblesite.org/hu/db/1990/14/images/a/formats/large_web.jpg
The first Kuiper Belt Object (KBO) was discovered in 1992
Diameter: 200 km

A 1992 discovery image of 1992 QB1 (indicated by the arrow) captured by Jewitt and Luu using the University of Hawaii’s 2.2 m telescope on Mauna Kea, from http://science.nasa.gov/headlines/y2001/ast13sep_1.htm
Meet Eris: the largest known dwarf planet and Kuiper Belt object.
A growing family

Two more officially designated dwarf planets have joined the ranks of Ceres, Pluto, and Eris. Many more await official designation by the IAU.

All but Ceres are also now known as “Plutiods”
More than 440 planets, from gas giants to “super-Earths”, have been discovered orbiting distant stars.

Kepler, launched in March 2009, hold the promise of finding true Earth-like planets beyond our Solar System.
Taken by Voyager 1 in 1990, at a distance of more than 6 billion km (almost 4 billion miles) from Earth, this picture was dubbed 'Pale Blue Dot'.

In this image, our home planet is nearly lost in a ray of light from the Sun.