nightwatch

Newsletter of the Pomona Valley Amateur Astronomers

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President's Address

Star parties are probably the number one reason that I decided to join an astronomy club. An evening at a dark sky site, looking at the wonders of the Universe with other like minded folks is one of my favorite pastimes. And now that summer is here, the pleasant night time temperatures make spending a night under the stars all the more enjoyable.

Summer is the season of the Milky Way. Now, in the night sky, we can see the many nebulae and star clusters that reside near the center of our galaxy, in Sagittarius, Scorpius, and Ophiuchus. The richest part of galaxy is available for viewing in the evening sky.

At star parties we learn about objects that are new to us. Some of my favorite objects were first shown to me by someone else at a star party. We can compare views in various scopes and discuss what we see. We learn other's observing techniques.

PVAA has three star parties coming up this summer. The first is July 10 at Grandview Campground in the White Mountains, east of Bishop. I am not going to write a lot about it because I've written so much about White Mountain already. This is my personal favorite site, very little light pollution, 8600 feet high, terrific views of deep sky objects.

The second will be August 7th at the Girl Scout camp at Skyland Ranch near Idyllwild. Let us know if you are coming so they will know how much food to make.

The third will be September 4 at GMARS in Landers. As this is the Riverside Astronomical Society site there will be a big turnout with several dozen scopes.

I hope that many of you will be able to attend one or more of these star parties.

Finally, at our June meeting we will be accepting nominations for the club election to be held at our August meeting. See you there and happy stargazing.

Ron Hoekwater

Club Events Calendar

June 25, 2010, General Meeting –Tim Thompson

To quote Tim Thompson, he will speak to us "on Sofia, Herschel & Planck (mostly Herschel) and a thing or two in the news. If I talked about Herschel and Planck last June, that was right after the launched in May. Herschel is now releasing preliminary data so we have real science to look at. Planck has already mapped the sky, but is much slower to release any real data. And Sofia has seen first light at last"

July 10, Star Party – White Mountain
July 20, Star Party – Ontario Library, Main Branch 7–9 PM
July 22, Board Meeting
July 23, General Meeting - Bob Eklund and Al DeCanzio
Dialogue on the Galilean Imagination
August 7, Girl Scout Star Party - Skyland Ranch
August 19, Board Meeting
August 27, General Meeting - Dr. Rachael Akeson
on Finding Planets Through Transits
September 4, Star Party—GMARS in Landers
September 16, Board Meeting
September 24, General Meeting
October 9, Star Party
October 12, Star Party – Ontario Library, Main 7–9 PM
October 14, Board Meeting
October 22, General Meeting

The World's Largest Telescopes, Part 2: W.M. Keck Observatory

This is the second installment in a series on the largest single-aperture optical telescopes through history, starting at the present and working backward. Last time we looked at the Gran Telescopio Canarias (GTC), which with its 10.4-meter primary mirror just edged out the twin 10-meter Keck scopes for the title of “world's largest” at its first light in 2007. The GTC is a near-twin (triplet?) of the Keck scopes, with its vast computer-controlled 36-segment mirror, fast Ritchey-Chrétien optics, squat alt-azimuth mount, and compact, wind-tunnel-designed dome. If anything, it is perhaps surprising that it took so long for someone to build a bigger telescope.

It is hard now to appreciate just how groundbreaking the Keck telescopes were when the first one went online in 1993 on the summit of Mauna Kea in Hawaii. The great observatories of the world are now filled with 8-meter single-piece mirrors (four at the Very Large Telescope, two at the Large Binocular Telescope, one each in the Gemini telescopes, and one in the Subaru telescope, for a total of nine) and 9-meter multi-segment mirrors (one each in the Hobby-Eberly Telescope and the South African Large Telescope), but all of these 8- and 9-meter scopes were built after Keck II saw first light in 1996. At that time, the second- and third-largest telescopes in the world were the 6-meter Soviet BTA-6 from 1975 and the good old 200-inch (5-meter) Hale Telescope on Palomar Mountain, which was effectively the world's largest telescope from 1948 to 1993. (As we will see in a future installment, the BTA-6 was more of a publicity stunt than a functional instrument, and never rivaled, much less eclipsed, the Hale telescope scientifically.)

When they were finally built in the early 1990s, the Keck telescopes represented a tremendous leap forward, in both aperture and telescope technology. But the road to Mauna Kea had started three decades earlier, with much more modest goals. Astronomers in the growing University of California system were competing for time on the UC's largest scope, the 3-meter Shane reflector at the Lick Observatory. But Lick Observatory overlooks San Jose and the scope's performance was already being degraded by Bay Area light pollution. By 1965, UC astronomers were looking for a darker site on which to build a second 3-meter telescope. Money proved to be the bigger challenge—in the words of astronomer J.B. Zirker, “Nobody wanted to fund just another medium-sized telescope.” So the UC astronomers took their cue from George Ellery Hale, who had built the “world's largest telescope” not once, but four times, with the 40-inch refractor at Yerkes, the 60- and 100-inch reflectors at Mt. Wilson, and the 200-inch reflector on Palomar Mountain. In each case, Hale had set out to build a telescope 50-100% larger in diameter than the last, and in each case he had been able to secure funding from wealthy philanthropists to achieve his ambitious goals. Funding, or lack thereof, can be a powerful motivator. In this case, it forced the UC astronomers to be as ambitious as Hale: they would build a 10-meter telescope, 66% larger than any previously conceived, because this unprecedented goal was more financially viable than the modest 3-meter scope they'd originally wanted!

The next problem was purely technological: no one knew how to build a 10-meter mirror. The Soviets had settled on a 6-meter mirror for the BTA because it was the largest monolithic mirror that would not deform under its own weight (a problem that plagues large amateur scopes even today, if the primary mirror is not adequately supported). Joseph Wampler at the Lick Observatory had the seemingly paradoxical idea of building a very thin mirror that would be easily deformable—and then supporting it with a system of actuators that would keep it from deforming. Today this solution is known as 'active optics' and it is employed on virtually all of the world's 8-, 9-, and 10-meter telescopes. But in the 1970s, active optics was an idea, not a technology, and someone would have to actually build it.

Berkeley astronomer Jerry Nelson had an even wilder idea: as long as one was using computerized actuators to control the shape of the mirror, why not break the reflective surface into dozens of small segments and leave it to the computers to align them into a functional mirror? Because each segment would be small, it could also be thin, lightweight, and relatively easy to control. An entire telescope built of such segments could be have double the aperture of the Hale telescope for little if any more weight.

Furthermore, a multi-segment mirror could have a shorter focal ratio than a single-piece mirror. With a focal ratios of f/1.75, the Keck telescopes are much faster than the BTA-6 (f/4) and Hale telescope (f/3.3). A smaller focal ratio means a shorter scope, a lighter mount, and a smaller dome. Today, computer-controlled grinding and polishing and active optics allow staggeringly fast single-piece mirrors, like the f/1.14 primaries of the Large Binocular Telescope, but at the time they were conceived, the Keck scopes were the fastest large observatory telescopes ever built. Nevertheless, by 1983 Nelson had conducted a technical demonstration with a single 1.8-meter mirror segment that satisfied all of the technical criteria necessary for the proposed 10-meter scope.

The last piece of the technological revolution underway in the 1970s and 80s was the advent of alt-azimuth mounts for observatory telescopes. Alt-azimuth mounts can be lighter and more compact than equatorial mounts, but they requires constant changes in both speed and direction on both axes to track the motion of celestial objects across the sky. Today you can buy an alt-az tracking mount for about $200, but four decades ago one was not available at any price, because computers could not control a mount's drive motors with the required precision. Alt-az mounts for observatory telescopes were first premiered by the BTA-6 in 1975 and the Multiple Mirror Telescope in 1979, and were used on several smaller “new technology” telescopes in the 1980s. The mounts for the Keck telescopes would be considerably larger and heavier than any previously constructed in the free world, and they would have to track with exceptional accuracy if the 10-meter mirrors were to deliver the 0.02-0.04 arcsecond resolution of which they were theoretically capable.

By the early 1980s, the UC astronomers had detailed plans for what would be not only the world's largest telescope by a wide margin, but also the most technologically advanced. But despite the promising technology demonstrations, major questions still hovered over the project. Would it actually work? The Hale telescope had represented a similar leap forward in aperture, but it was based on proven engineering from a generation of smaller reflectors. The BTA-6 and MMT had not

May General Meeting

Our May speaker was Dr. Eric Grosfils, a Pomona College professor who teaches planetary geology. With his students help he's worked on NASA-funded studies of the geological processes of Venus and Mars. At our meeting he asked, "How old is the surface of Venus?" Although Venus is similar in size to Earth, its surface has been dramatically altered by hot catastrophic means. Catastrophic geology was long ago rejected as a form of change on Earth. Sudden floods and such were thought to be too "biblical" and mythological. It was rejected in favor of a proven rule of a uniform and gradual geologic change. But Venus, with its extreme global warming, is an exception to many earthly rules.

Ever improving radar probes into its completely cloud shrouded surface show a modest number of impact craters that are evenly distributed and undamaged in appearance. In contrast, Mars, Mercury and our Moon have a lot of impact craters in various states of degradation. Impact craters on Earth have been mostly erased by water and plate tectonics, but Venus doesn't have these processes. Consequently Venus' craters are in a well-preserved condition. But why are there relatively few compared to other planets? The only geologic explanation for this is that Venus underwent a global resurfacing event about 500 million years ago. Without plate tectonics to dissipate heat from its mantle, Venus' mantle temperatures rise until they reach a critical level that fractures the crust. Then surface subduction occurs on a planetary scale, completely recycling the crust and renewing the surface. This has created a surface that is 80% smooth volcanic plains. Besides the undamaged craters, there are also volcanic features that have been flattened by a frying atmospheric pressure to look like pancakes. This melted looking topography is unusual compared to the solar system's other planets and moons with their rocky mountains and valleys.

The newest orbiter, the European Space Agency's Venus Express, is developing infrared maps of hot-spot volcanoes that seem be currently active. However, volcanic activity is difficult to spot because the entire planetary surface is extremely hot already.

So Venus, that appears to be our sister planet in size, is different from Earth in so many ways. Venus rotates in a clockwise manner, while Earth and other planets rotate counter-clockwise. Venus' very long day lasts 243 Earth days, more than a Venusian year. Venus' year takes 224.7 Earth days. While all the other planets (except little Mercury) have moons, Venus has no moon. A moon might have pulled away some of Venus' dense carbon dioxide and sulfur dioxide filled atmosphere making it cooler. As it is now, the atmosphere brings the ground temperature to an average 850° F. The surface has an atmospheric pressure 92 times that of Earth's, and is dimly lit.

Venus' clouds reflects 60% of the sunlight that falls on them. They concealed the planet's surface until the latter half of the 20th century. Then new spectroscopic, radar and ultraviolet observations revealed hidden surface features. The first successful spacecraft was America's Mariner 1 in 1962. It recorded many of Venus' oddities, including the mysterious fact that it has no magnetic field or radiation belt. In the competitive spirit of the 1960s, the Russians sent many Venera probes to analyze Venus. Several Venera craft landed on the surface, some of them returning pictures of a cooked looking landscape before being cooked themselves. The United States preferred surface mapping radar, as with its highly productive 1989 Magellan probe.

So we want to thank Dr. Grosfils for reminding us of the odd dissimilarity of Earth's sister planet, that "evening (or morning) star" that shines at a sensational brightness of - 4 magnitude.

We will visualize, not the goddess of love, but the ardor of hell.

Lee Collins

<World's Largest Telescopes Continued>

been trouble-free—the former was plagued by fluctuating temperatures in both the mirror and the dome that made it almost impossible to form sharp images, and the latter had required seven years of hard work after first light to get all six mirrors to work together. The technical challenges for the 36-segment, 10-meter telescope were even greater. But the biggest unknown was funding: to turn the ambitious UC plan into a functional telescope would cost $100 million.

That's it for this time. Tune in next month to see how the 10-meter telescope was funded, named, built, provided with a earthbound twin and an orbital collaborator, and unleashed on targets from the nearest planets to the most distant galaxies.

Mathew Wedel

The quote from J.B. Zirker is from page 128 of his excellent book, An Acre of Glass: A History and Forecast of the Telescope, published in 2005 by Johns Hopkins University Press. For more information, see the Keck Observatory webpage (http://www.keckobservatory.org/) and the Keck Observatory Archive (http://nexsci.caltech.edu/archives/koa/). A nice fact sheet and model kit are available at http://spacecraftkits.com/KFacts.html.

Star Party - Mt. Baldy R.V Park

Shawn Griffin, Gary Gonnella and I were at the June 5th star party at Mt. Baldy R.V park. The night was warm and clear. Gary had his 8 inch Celestron SC scope, Shawn had his 16 inch Meade LightBridge and a few other scopes. I had my new 8 inch Celestron SC scope. We had a nice time looking at M5, M81, M82 and others that night. Hope to see more people at our next star party.

Jim Bridgewater

What's Up? Summer's Cosmic Line Ups

A cosmic line up of planets along the ecliptic line is visible in this summer's sunset sky. They're shining like airplanes coming in for a landing. Brilliant Venus is the lowest, then up past the star Regulus to reach a redder Mars. Highest, slowest and dimmest is Saturn in Virgo. As July comes to an end Mars and Venus will come closer to the slow moving Saturn to form a triangular grouping. This is a good time to observe this shiny line up of three planets (Mercury appears in July) along the ecliptic.

Another summer line up are the prominent nebulas and clusters along the Milky Way near the Galactic Center in Sagittarius. Start just above the two stinger (or "cat's eyes") stars in Scorpius. Here lie two bright open star clusters M7 and M6.

I'm amazed at how long ago astronomers made note these nebulous objects. In 130 AD naked-eye astronomer Ptolemy wrote of "a glowing nebula following Scorpius' sting." The bright M7 is now called Ptolemy's cluster. Edmond Halley wrote about it in 1678, almost a century before Charles Messier. Nearby is M6, called the Butterfly Cluster because of its shape. Giovanni Hodierna observed both clusters as early as 1654.

Of interest, Giovanni Hodierna (1597-1660) was a Sicilian catholic priest who became priest-astronomer to a local duke. Connections between religion and astronomy are typical of early observers. Hodierna was a follower of Galileo. He observed comets, planets, and published a pioneer catalog of 40 newly discovered deep space objects.

Moving north from M6 we pass the Galactic Center. It's brightness is obscured by dark clouds, but probing with X-ray, infrared, and radio wavelengths reveals a large black hole.

Still in Sagittarius we come to M8, the Lagoon Nebula. M8 is a gas emission nebula the size of the full moon (as is the Orion Nebula). I'm impressed by how large and far away these luminous nebula are. The lagoon is about 50 light years across and 5,700 ly. distant. It seems bright because it's complemented by an open star cluster, NGC 6530. Because of this extra brilliance it was first observed by Hodierna in 1654. It contains excellent examples of Bok globules. These are dark collapsing globes of protostellar material that can become new stars. The name Lagoon first appeared in the British Astronomical Catalog of 1890 and refers to a dark furrow that cuts into its island-like shape.

Following the Milky Way north we come Trifid Nebula. Messier first catalogued this object as M20 in 1764. William Herschel first noted its three-part appearance in 1786. His son John Herschel named it Trifid (three-lobed) and remarked on its flower-like appearance. The Trifid is a beautiful combination of an emission nebula, a reflection nebula, dark dust clouds, and young hot stars. At 9,000 light years the Trifid is the most distant nebula in this Milky Way line up.

Moving north again we pass five Messier star clusters, M18, M21, M23, M25, and the huge M24 (the Star Cloud). The Star Cloud is not a cluster but a view through a window in dark obscuring clouds into the star rich central regions of the Galaxy nearly 30,000 light years away.

Next we come to M17, a emission nebula with several popular names: Omega, Swan, Horseshoe, and Lobster. Containing unusually massive stars it glows as a solid form with a horseshoe shaped projection. It was first written about by Philippe De Cheseaux in 1745.

Of note, De Cheseaux (1718-1751) was a wealthy Swiss landowner who was able to build his own observatory with a refractor and a reflector. He published a catalog of 21 nebulous objects. Famous for his observations of the six-tailed comet of 1743, he sadly died at age 33.

It was in 1833, that British astronomer John Herschel noted that M17 was shaped like the Greek letter Omega. Later astronomers saw it all as shaped like a swan or even a "rubber ducky." It's 6,000 light years away and its central form is 15 light years across.

Farther north along the Milky Way is M16, the Eagle Nebula, in Serpens Cauda (Serpent's Tail). An eagle-shaped emission nebula that also contains an open star cluster. It was first noted by de Cheseaux in 1746. Hubble Space Telescope images made in 1995 made the Eagle famous as the home of the "Pillars of Creation." This highly enlarged section shows elongated clouds filled with active star formation. The many picturesque "columns" of the Eagle have also been photographed (as have all these nebulae) with the Spitzer Space Telescope and the Chandra X-ray observatory. The Eagle Nebula is 7,000 light years away, 70 ly. in length.

The line up along the Milky Way doesn't stop here, it continues as far as you have viewing time. Other notable open star cluster further north include M26 and M11, the Wild Duck. It looks like a V-shaped flock of wild ducks flying through the heavens.

So follow the cosmic line ups this summer, first Venus, Mars and Saturn. Then fly along the Milky Way past the Galactic Center to observe the summer sky's splendid line up of clusters and nebulae.

Lee Collins

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Observing Report from Mount Wilson

On Saturday, June 12, about a dozen of us from the PVAA met at Mount Wilson to spend the night observing with the 60-inch telescope. Spending a night with the 60-inch scope is a real trip back in time. The telescope saw first light in 1908 and was the world's largest working telescope from its inception until 1917, when it was eclipsed by the 100-inch Hooker telescope, also at Mount Wilson. I had gone with the PVAA group last fall so this was my second time. There was a wide range of experience in the group--at least a couple of people were there for the first time, whereas this was the 11th or 12th visit for others.

Because of the geometry of the dome, the telescope can't be used to observe objects less than about 30 degrees above the horizon. Our first target probably would have been Saturn anyway, but we especially wanted to catch the ringed planet before it either got out of the telescope's grasp or descended too far into the roiling miasma over LA. Saturn looks good under almost any circumstances, and the views that night were indeed good--but not great. At 286x there was about as much detail visible as one can see in a 10-inch scope at the same magnification, so the atmosphere was definitely holding us back a bit. We would confirm this on some double stars later in the evening.

Next we went to M51, the Whirlpool galaxy, and its companion, NGC 5195. Here the sky let us down again--the two galaxies just weren't standing out very strongly from the surrounding sky glow. The cores of both galaxies were easily visible, but instead of well-defined spiral arms and a bridge of glowing gas, all we could see around them was a haze of nebulosity. Not long after someone poked their head outside the dome and reported that the marine layer over LA, which had been fairly solid when we came through the gate at 7:30, was considerably broken up.

With those two slightly sour notes behind us, the evening picked up considerably. Our next stop was M3, the first of several globular clusters we visited. The 60-inch telescope is a cluster buster par excellence, and M3 was well-resolved and the illusion of depth, even with just one eye, was profound. Cor Caroli was our first double star of the evening, and its slightly fainter yellow and brighter blue-white components were well split and very pretty. The Cat's Eye Nebula, NGC 6543, was our first planetary nebula, and one of the highlights of the entire session. At the eyepiece it was a striking green S-shape surrounding a prominent central star, like a green nebulous version of the Screen Gems logo (Google it if that comparison makes no sense). Our next target was Epsilon Lyrae, the famous Double Double star, which was nicely split. The high magnification and narrow field of view imposed by the scope's very long focal length (24380 mm at the bent Cassegrain focus used for visual observing) meant that two pairs of stars were almost on opposite sides of the eyepiece field of view!

We finished with Epsilon Lyrae at around midnight. We were three hours into the observing run, we'd been to half a dozen objects, and it really felt like we were settling into a productive groove--a happy circumstance that lasted for the rest of the night. We started off our very early Sunday morning with M57, the Ring Nebula. The striking crispness that the Ring shows in a small scope at low power evaporates with more aperture and magnification. The edges of the nebula get fuzzy as more nebulosity comes into view. This effect is obvious even in a 16-inch scope under dark skies; in the 60-inch scope, the Ring is a whole new object. The central star tended to flit in and out of visibility but most people found it a pretty easy catch. The central "lagoon" or "donut hole" was filled with nebulosity and much closer in brightness to the outer ring than to the background sky.

Our next stop was M13, the Great Globular Cluster in Hercules. The seeing wasn't perfect, but it wasn't too distracting, either, manifesting as waves that swept steadily across the field of view rather than the roiling and bubbling that sometimes bedevil our summer evening observations. I had only recently gotten around to seriously comparing M13 and M5 in my 10-inch scope, and much to my surprise I had found that I preferred M5 as the slightly prettier of the two. At my request, we went to M5 next, and it did not disappoint. M5 is slightly smaller than M13, with a brighter, more compact core, and its outer stars form loops and shells rather than radiating chains as in M13. I still like M5 better, but I don't think anyone stepped away from the eyepiece without being impressed by both objects.

After a pair of back to back clusters, we returned to planetary nebulae with NGC 6826, the so-called Blinking Planetary. It doesn't blink in a 60-inch scope--the bright central star punctuated a slightly oval cotton ball of nebulosity. After that it was Albireo, and then another planetary nebula, NGC 6572, the Blue Racquetball. That was our twelfth object, at about 2:00 AM, and the evening was starting to feel like an endless buffet of galactic goodies. Our next object, M92, was stunning--a useful reminder that it's a nice glob in it's own right, and only suffers by comparison to its brighter neighbor, M13. At Jeff Felton's suggestion we had a look at Eta Coronae Borealis, a tough double with a separation of about 0.7 arcseconds. As we'd half-suspected, the seeing was not good enough for even the 60-inch to split the pair. A few people reported seeing elongation, but I don't know if there was any consensus about what direction the elongation was in!

Our next object was, for me at least, the most exotic of the night. PK 64+1.5 is a small planetary nebula surrounding Campbell's Hydrogen Star. The star is a Wolf-Rayet type, a very hot, massive star that is rapidly losing mass through its very

<Observing Report Continued>

strong stellar wind. At the eyepiece the star was surrounded by a pink glow that stubbornly refused to come into focus. Unlike the central stars of the other planetary nebulae we observed that evening, Campbell's Hydrogen Star will not get to enjoy a long slide into senescence as a white dwarf. Instead, it's high mass dooms it to a fast and fiery death as a Type Ib or Ic supernova.

The last two DSOs of the evening were also planetary nebulae: NGC 7009, the Saturn Nebula, and M27, the Dumbbell. As with the Ring, nicknames coined by small-scope drivers don't hold up when you're using a 1.5-meter instrument. The "Saturn" in the Saturn Nebula was plain enough, but so was the almost perfectly circular sphere of gas in which it is embedded. I've heard big-Dob drivers talk about how the Dumbbell looks more like an apple core with enough aperture. In the 60-inch scope the "apple core" was obvious, and it cut across a much wider "football" of nebulosity that I have seen in some long-exposure photos but never before visually.

We finished with Jupiter, fittingly. At 4:00 AM the King of Planets had just lumbered into range of the Big Gun, and we knew it would be our last stop so we took our time. By 4:45 the eastern sky was getting bright enough to light the inside of the dome, and that was effectively the end of the run. It was a solid night--18 objects in 8 hours of observing, and everyone got as much time as they wanted at the eyepiece. I had a blast, and I intend to go back at every available opportunity. I urge you to do likewise, whether you've been there, or especially if you haven't.

Mathew Wedel

read more on Mat's blog
http://10minuteastronomy.wordpress.com/2010/06/14/mt-wilson-even-better-the-second-time-around/

How Does It Work?

At least one visitor asked about Kepler's Laws and why it is important. For that answer, we have to go back into history to about 1605. Wikipedia gives a detailed discussion and states the laws as:

1. The orbit of every planet is an ellipse with the Sun at a focus.
2. A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

Kepler was trying to understand what Tycho Brahe had observed. Brahe had been studying the planets and trying to determine their orbits. Until then the common knowledge was that the orbits were circles.

Kepler's first law was simply a result of Brahe's observations and a postulate that the orbits were ellipses instead of circles. In the second law, the area of the orbit and the time to travel around the segment can be observed. The third law may also come from observation. It is thought that Kepler proved these using a geometrical proof at that time. Feynman, however, was unable to duplicate the proof in its entirety.

It was about a century after Kepler when Newton began to put this all together. Newton added the concept of universal gravity and applied Kepler's laws. Newton also is credited by some as developing the first form of calculus which made it much easier to verify the laws.

The equation which Newton established says that the gravitational force on a body is proportional to the product of masses and inversely proportional to the square of the distance. This must be equal to the centrifugal force on the body which is proportional to the mass times the distance times the square of the rate of change of angle. When we divide by the mass and distance on both sides we see the distance cubed in the denominator on one side and the mass of the orbiting body cancels out. When an orbit is complete, the right side of the equation is inversely proportional to the period. Thus we have Kepler's third law.

Why is this important? If the solar system only had one planet and no moons, Kepler's laws would be adequate to describe the motion. In fact, the laws do come very close. But the planets affect each other. So any variation from Kepler's laws tells us to look at the position of the other planets. Most of the orbital changes can be explained this way.

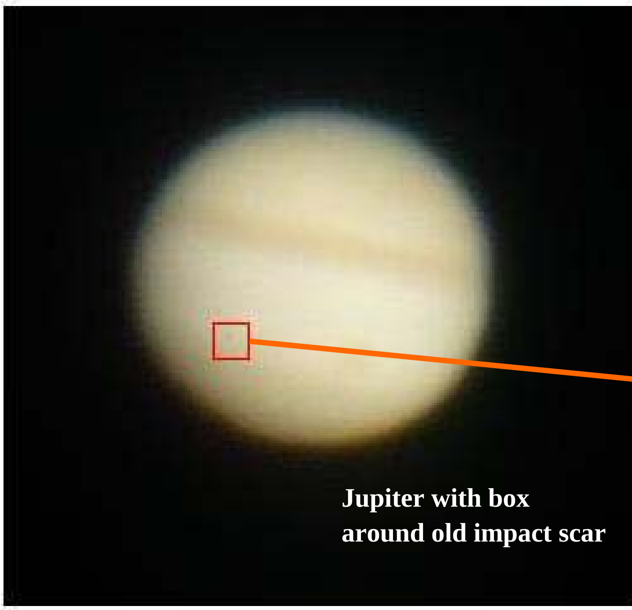
The only major exception was Mercury. Its orbit didn't follow Kepler and Newton's laws as it came closest to the Sun. The explanation waited for Einstein to postulate the General Theory of Relativity. When that was applied, the orbit was as it should be. This was one of the first tests of the General Theory.

Ken Crowder

Ron shares his snaps from Mt. Wilson

Photos by Gary Thompson at Mt. Wilson

Saturn



Jupiter with box around old impact scar

Cor Caroli in Canes Venatic