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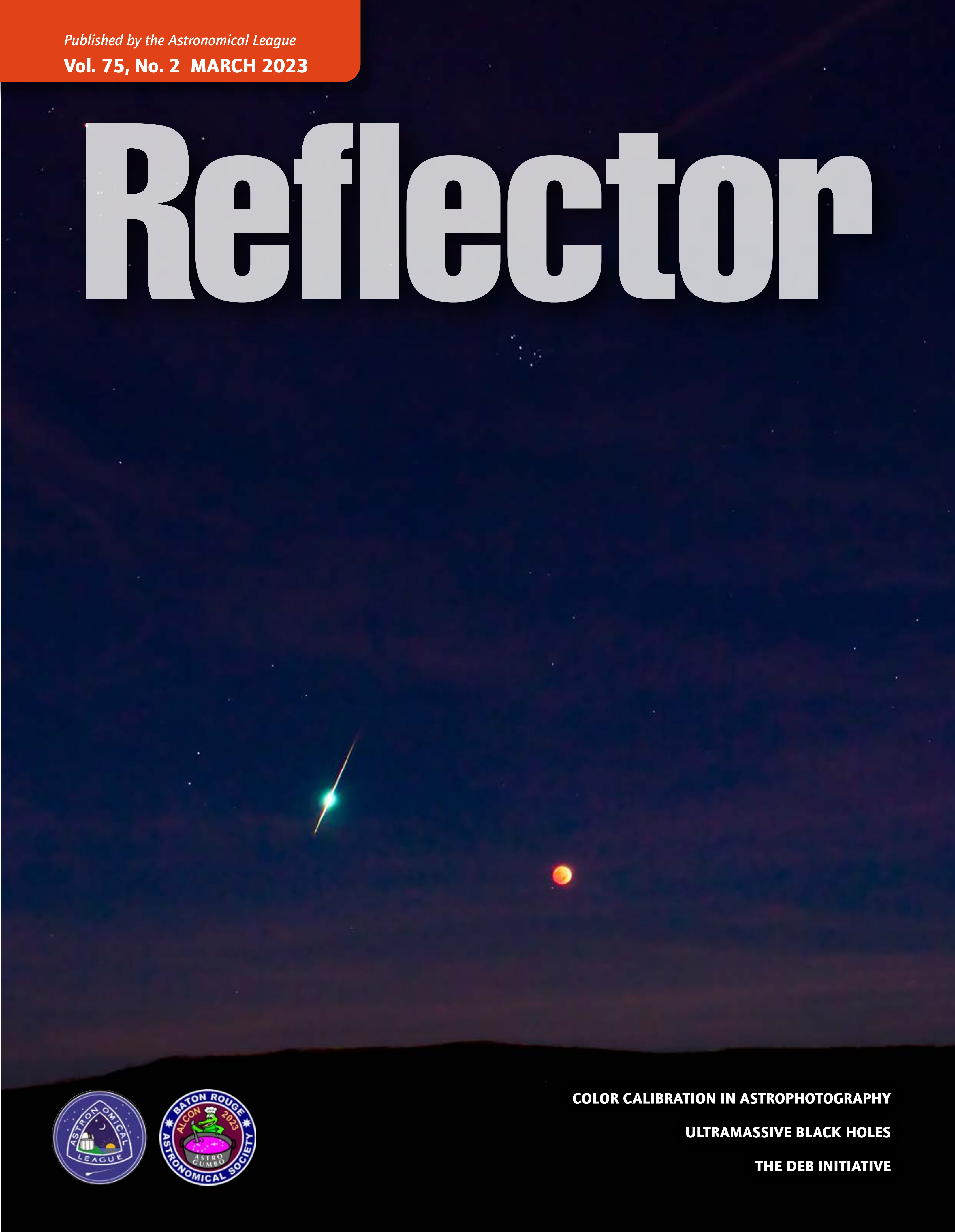
Reflector



COLOR CALIBRATION IN ASTROPHOTOGRAPHY

ULTRAMASSIVE BLACK HOLES

THE DEB INITIATIVE

Wanderers in the Neighborhood

IS THE SOLAR SYSTEM STABLE?

What if you looked up in the sky where Jupiter should be and found that it was halfway across the sky? We expect the planets and asteroids to move in an orderly fashion around the Sun, and they do. We are able to predict solar eclipses into the future and compare them to eclipse observations in the distant past. While the Solar System is stable in the short term (astronomically speaking), how stable is it over much longer periods?

As with much research in astronomy, the stability of the Solar System is studied using computer modeling. These models of the Solar System require high-precision information on the planets, Sun, and Moon. This includes their initial positions and velocities, as well as their masses and shapes. Models have become more accurate as observations have improved our knowledge of the Solar System.

Before the advent of electronic computers, calculating the positions of the planets was done by hand, using formulae that were created in the 1890s. The resulting ephemerides (lists of the positions of an object at certain times) were published each year in almanacs. *The Astronomical Almanac* comes from a long line of almanacs starting back when they were crucial for naval navigation, long before the advent of GPS.

These nautical almanacs provided positions of the Sun, Moon, and planets to facilitate computing a ship's position based on sightings (altitude and azimuth) of celestial objects. Combined with the accurate time, the ship's latitude and longitude could be determined and would allow the captain to keep the ship on course. *The Astronomical Ephemeris and Nautical Almanac* has been published by the United States Naval Observatory (USNO) since 1852. In 1981, the USNO joined with Her Majesty's Nautical Almanac Office (HMNO) in the U.K. to coproduce the book, which was renamed *The Astronomical Almanac.*

These books included information about the planets, their moons (especially our Moon), and minor planets. These were all hand computed until electronic computers started to become available in the 1940s. With this additional computing power, the formulae used to produce the ephemerides were updated to include Einstein's relativistic corrections to the orbits.

The Jet Propulsion Laboratory (JPL) started producing its Developmental Ephemeris (DE) in the 1960s to guide its spacecraft and distributed the ephemeris on magnetic tape. The motions of the Sun, Moon, and planets were integrated on UNIVAC mainframes in the 1970s. The resulting tables were transformed into Chebyshev polynomial coefficients that were fit to 32-day intervals. They could be used to compute positions quickly without a large computer. The DE is available from JPL over the Internet (*ssd.jpl.nasa.gov/horizons*).

Versions of the Developmental Ephemeris are differentiated by a number. For example, DE69 was released in 1969. As observations have improved our knowledge of the Solar System, JPL has released new ephemerides. The latest version, DE441, was released in June 2020.

In building Solar System models, the initial conditions are crucial to matching the results with observations. Very small errors can accumulate over time to produce inaccurate results. To compound the problem, weak gravitational effects between the planets can also corrupt the final result. To minimize this effect, as many Solar System objects must be included in the model as possible. This means including the larger minor planets and moons in the model, but there is a limit imposed by the time it takes to calculate each step in the model. The more objects in the model, the more time it takes to calculate the gravitational effects between each pairing of the objects. To model the Sun, planets, 205 moons, 9 dwarf planets, and 35 minor planets larger than 160 miles across would require calculating 33,153 interactions for each step.

Modeling has revealed some scenarios that could destabilize our Solar System. For example, a resonance exists between periodic changes in the closest approaches of Mercury and Jupiter to the Sun (technically speaking, in the precession of their perihelia). As a result, Jupiter's gravity could pull Mercury out of its orbit in three to four billion years, sending it into the Sun, Venus, Earth, or Mars or ejecting it from the Solar System. Another potential instability is the possibility that Earth's polar axis could start to shift due to tidal interactions with the Moon (1.5 billion or more years from now).

Resonances between Neptune and Pluto (3:2 orbits) could make Pluto's location in its orbit unpredictable in a few hundred million years, even though the orbit itself will be stable. The Jovian moons have resonances as well, with Io and Europa (2:1) and Europa and Ganymede (2:1) interacting in unpredictable ways. Tidal stresses from the Io-Europa interaction produce volcanic activity on Io.

Finally, if a massive object from outside the Solar System were to pass by, its gravity could destabilize the Solar System. It would certainly alter the orbits of objects in the Oort Cloud. At least a dozen stars could approach us in the next few million years, however, an approach close enough to affect the major planets is unlikely to occur for a hundred billion years.

To study the stability of the Solar System on a shorter time scale, Angel Zhivkov and Ivaylo Tounchev of Sofia University in Bulgaria produced a model with simplifying assumptions that allowed them to run the program on a workstation in a reasonable amount of time. The run covers the next 100,000 years. During that time, the major planets' average distances from the Sun and the eccentricities of their orbits vary by less than one percent. This indicates that our Solar System will be stable over that time period.

Zhivkov and Tounchev believe that with a more powerful computer they can extend the model run to a million years. The algorithm could be modified to include relativistic effects, the fact that the planets are not point masses, and smaller bodies in our Solar System. Their work shows that, at least in the short run, the planets in our Solar System will continue their stately motion around the Sun, barring the arrival of an interloper from outside our system. You can read a technical preprint of their methodology at *arxiv.org/abs/2206.13467.*

—Berton Stephens

Deep-Sky Objects

COMPACTING GALAXIES

In 1982 Paul Hickson (1950–), an American-born astronomer with the University of British Columbia, published a catalog of 100 compact galaxy groups. A compact galaxy group is a tight collection of galaxies visible in our sky. Not only does each span a very small region of the celestial sphere, but they are also extremely close to each other in three-dimensional space. In many cases they are gravitationally interacting with each other. The most famous Hickson compact group is HCG 92, otherwise known as Stephan's Quintet. All Hickson Compact Groups contain four to seven galaxies. The galaxies are typically much fainter than can be seen in an 8-inch telescope. However, the group covered here, Hickson 44, is bright enough to see with an 8-inch scope and is easy to find due to its position in the constellation Leo.

Compact galaxy groups represent physically related galaxies that are in the process of merging. Astronomers hypothesize that when galaxies merge, whether they are spiral galaxies or elliptical galaxies, a single larger elliptical galaxy is created. These compact groups are relatively short-lived compared to the age of the universe. Mergers are thought to occur within a billion years.

The Milky Way Galaxy, M31, and M33 are not a compact group. But as these three galaxies, and possibly others in the Local Group, get closer together, they may someday be considered a compact galaxy group.

Hickson 44 contains four galaxies: NGC 3185, 3187, 3190, and 3193. Hickson 44 resides on the back of the Lion's neck. To find it, look for the stars Algeiba (Gamma Leonis) and Adhafera (Zeta Leonis). These two stars are on the east side of the curved region of the Sickle of Leo asterism (the backwards question mark in the sky). Hickson 44 lies on a line connecting these two stars, just north of the midpoint.

I captured an image of Hickson 44 (shown here) using a 10-inch f/6 Newtonian with a Paracorr 2 coma corrector yielding f/6.9. The total exposure was 260 minutes using 10-minute subframes with an SBIG ST-2000XCM CCD camera. In the image north is up and east to the left.

What appears to be two bright stars at the upper left of the image is actually a star and an elliptical galaxy. The star is a magnitude 9.5 G5 (Sun-like) star 72 light-years away. The elliptical galaxy is NGC 3193. It has an integrated magnitude of 11.05 and it is 79 million light-years away. The galaxy is around 2.2 arcminutes in diameter. Which of the two looks bigger and brighter in your telescope?

Just above the center of the image is the nearly edge-on spiral galaxy NGC 3190. This galaxy is magnitude 10.9 and measures 3.6 by 1.2 arcminutes. The galaxy has a huge central bulge and a prominent, distorted dust lane. Of course, all of the galaxies in Hickson 44 are about the same distance from Earth.

To the upper right of NGC 3190 is NGC 3187. This is a barred spiral galaxy that looks as if two spiral arms have been unwound. The galaxy is magnitude 13.3 and, not counting the unwound arms, measures 2.2 by 0.7 arcminutes. The unconventional spiral structure of NGC 3187 and the warped spiral disk of NGC 3190 result from a close interaction between these two galaxies and perhaps another in the compact group.

The final galaxy in the group, located on the lower right side of the image, is NGC 3185, a magnitude 12.1 spiral galaxy measuring 2.1 by 1.2 arcminutes in size. It's a little farther away from the other three galaxies and shows no sign of a close interaction with the others. All of the other galaxies in the image are background objects and are too faint to be seen in most amateur telescopes.

Hickson 44 is also known as Arp 316. It was the 316th of 388 entries in the *Atlas of Peculiar Galaxies* published in 1966 by Halton Arp (1927–2013). Arp was an American astronomer who spent the last 30 years of his life with the Max Planck Institute for Astrophysics in Munich, Germany.

If NGC 3190 looks familiar, it may be because it was the desktop image on MacOS 10.8, Mountain Lion, when it was released in 2012. If you haven't seen it, hop over to it this spring while hunting galaxies in Leo. You'll capture four galaxies for the effort of one.

—Dr. James Dire

IMAGING THE NEWEST OF MOONS

By Anas Sawallha

I'm 35 years old, live in Jordan, and work as an endodontist/dentist. Since my childhood, I've had a strong passion for science, especially astronomy and history.

When I was a kid, I used to spend hours at home looking at the sky wondering about the names of stars or where constellations were located. At that time, the only constellation I could recognize was Orion. I was also obsessed with seeing any meteor, to the degree that I still remember them clearly even now. I can't count the hours I spent just to see one meteor. Finally, my patience was rewarded when the 1999 Leonid storm came, and it was a sensation. I could not believe my eyes.

Many years went by without owning a telescope until 2017 when I was working in Saudi Arabia. I got my first scope on my birthday. It was a small 70 mm refractor which I pointed at Saturn, the first celestial object I ever saw through a telescope. What a birthday present!

Then I bought a 5-inch Celestron telescope with a manual mount, which taught me a lot. I started learning the sky and in 2019 I completed observing the Messier catalogue along with