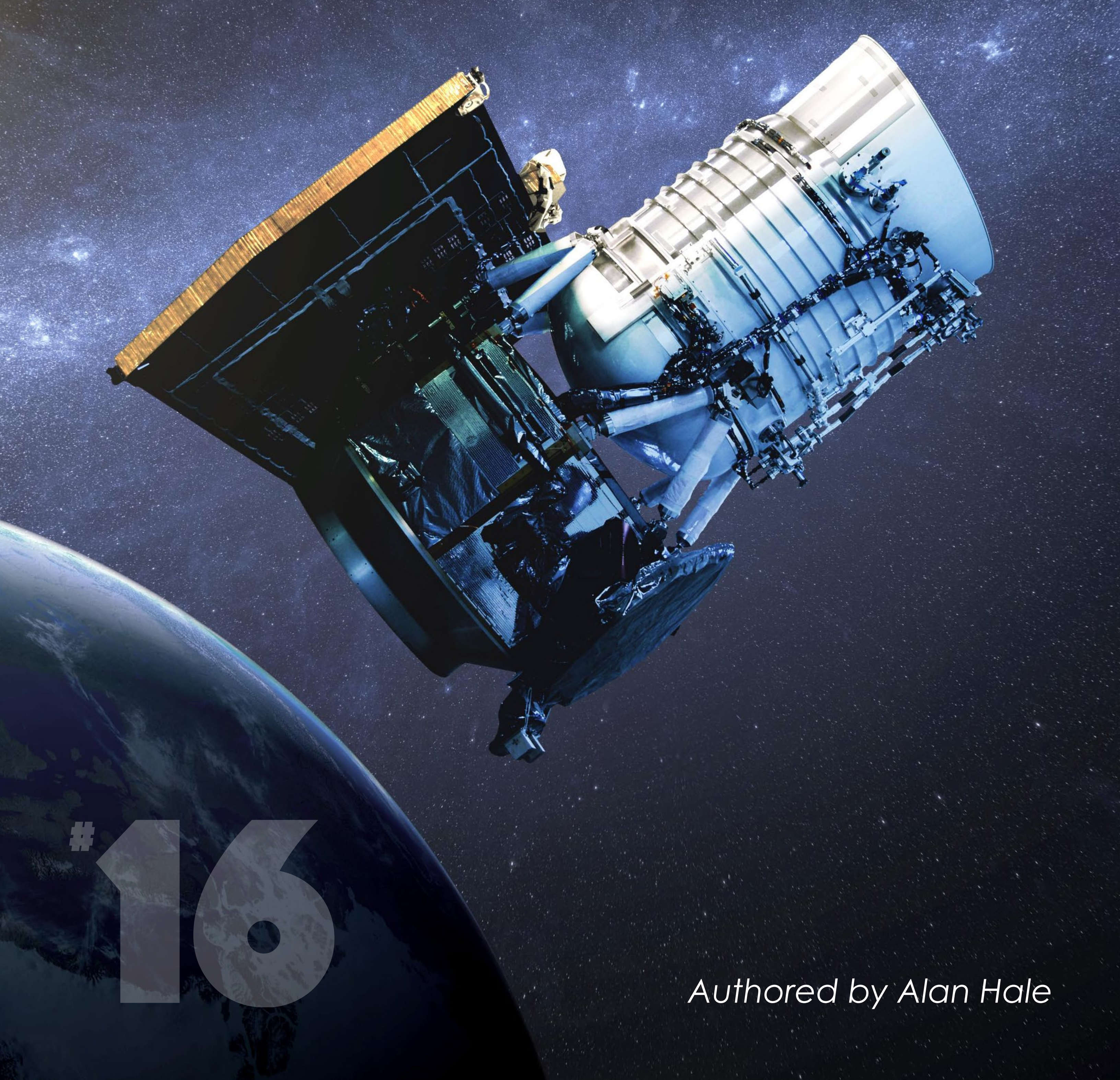
ICE & STONE 2020

WEEK 16: APRIL 12-18, 2020

Presented by The Earthrise Institute



#16

Authored by Alan Hale

THIS WEEK IN HISTORY

12 APRIL 13 14 15 16 17 18

APRIL 13, 2029: The near-Earth asteroid (99942) Apophis will pass just 0.00026 AU from Earth, slightly less than 5 Earth radii above the surface and within the orbital distance of geosynchronous satellites. At this time this is the closest predicted future approach of a near-Earth asteroid. The process of determining future close approaches like this one is the subject of this week's "Special Topics" presentation.

12 13 APRIL 14 15 16 17 18

APRIL 14, 2020: The near-Earth asteroid (52768) 1998 OR2, which will be passing close to Earth later this month, will occult the 7th-magnitude star HD 71008 in Cancer. The predicted path of the occultation crosses central Belarus, central Poland, northwestern Czech Republic, southern Germany, western Switzerland, southeastern France, central Algeria, far eastern Mali, and western Niger.

12 13 14 APRIL 15 16 17 18

APRIL 15, 2019: A team of scientists led by Larry Nittler (Carnegie Institution for Science) announces their discovery of an apparent cometary fragment encased within the meteorite LaPaz Icefield 02342 that had been found in Antarctica. This discovery provides information concerning the transport of primordial material within the early solar system.

COVER IMAGES CREDITS:

Front cover: This artist's concept shows the Wide-field Infrared Survey Explorer, or WISE spacecraft, in its orbit around Earth. From 2010 to 2011, the WISE mission scanned the sky twice in infrared light not just for asteroids and comets but also stars, galaxies and other objects. In 2013, engineers brought the spacecraft out of hibernation to hunt for more asteroids and comets in a project called NEOWISE. Courtesy NASA/JPL-Caltech.

Back cover: This graphic shows the orbits of all the known Potentially Hazardous Asteroids (PHAs), numbering over 1,400 as of early 2013. These are the asteroids considered hazardous because they are fairly large (at least 460 feet or 140 meters in size), and because they follow orbits that pass close to the Earth's orbit (within 4.7 million miles or 7.5 million kilometers). But being classified as a PHA does not mean that an asteroid will impact the Earth: None of these PHAs is a worrisome threat over the next hundred years. By continuing to observe and track these asteroids, their orbits can be refined and more precise predictions made of their future close approaches and impact probabilities. Courtesy NASA/JPL-Caltech.

12 13 14 15 16 **APRIL 17** 18

APRIL 17, 1968: Paul Wild at the University of Bern in Switzerland records, under the preliminary designation 1968 HD, the first images of the main-belt asteroid now known as (4151) Alanhale. For obvious reasons, I am using this asteroid as an example of how asteroids are designated, numbered, and named in next week's "Special Topics" presentation.

APRIL 17, 2004: Comet Bradfield C/2004 F4 passes through perihelion at a heliocentric distance of 0.168 AU. This comet, the 18th and last comet discovery by the champion Australian comet hunter William Bradfield, later became a somewhat-bright naked-eye object, and is a future "Comet of the Week."

APRIL 17, 2015: Following its launch as part of the SpaceX Cargo Resupply Mission 6 from Cape Canaveral, Florida, the proof-of-concept Planetary Resources Arkyd-3 Reflight CubeSat is attached to the International Space Station. Arkyd-3 Reflight would be deployed from the ISS three months later. Planetary Resources' initial efforts to establish asteroid mining operations are discussed in a previous "Special Topics" presentation.

12 13 14 15 16 17 **APRIL 18**

APRIL 18, 2018: NASA's Transiting Exoplanet Survey Satellite (TESS) mission is launched from Cape Canaveral, Florida. Although TESS' primary mission is – as its name indicates – the detection of exoplanets via the "photometric" or "transit" technique, it has observed some comets, and has detected transiting exocomets around the star Beta Pictoris; these are discussed in a previous "Special Topics" presentation.

APRIL 18, 2028: NASA's Lucy mission is scheduled to perform a flyby of the Jupiter Trojan asteroid (11351) Leucus, which is notable for having an unusually slow rotation (its rotation period being over 19 days). The Lucy mission was discussed in last week's "Special Topics" presentation, and Trojan asteroids are discussed in a future "Special Topics" presentation.

***THERE ARE NO ENTRIES FOR APRIL 12 AND 16.**

This is a conceptual image of the TESS mission. Courtesy of MIT.

COMET OF THE WEEK: 153P/IKEYA-ZHANG P/2002 C1

Perihelion: 2002 March 18.98, q = 0.507 AU

Photograph I took of Comet Ikeya-Zhang on the evening of April 1, 2002, from south of Cloudcroft, New Mexico. The site overlooks the Tularosa Basin some 1500 meters lower.

One of the many successful Japanese comet hunters of the 1960s was Kaoru Ikeya who, coming from a family of modest means, built a homemade telescope for the equivalent of US$20 and began to hunt comets with it. He discovered his first comet in 1963 and would go on to discover four more over the next five years, one of these being the brilliant Kreutz sungrazer Comet Ikeya-Seki 1965f (a future "Comet of the Week"). After a hiatus of over 34 years Ikeya discovered his sixth comet on the evening of February 1, 2002, which an hour and a half later was independently discovered by a Chinese amateur astronomer, Daqing Zhang, who had been inspired by reading of Ikeya's earlier successes.

Comet Ikeya-Zhang was around 9th magnitude at the time of its discovery, but brightened rapidly, and had already reached 5th magnitude and naked-eye visibility by the end of February. By mid-March it had reached 4th magnitude, and during the latter part of March, shortly after perihelion passage, it was a 3rd magnitude in the evening sky with a bright naked-eye dust tail up to 5 degrees long. Shortly thereafter it went through inferior conjunction and entered the northern hemisphere's morning sky, and although receding from perihelion it was approaching Earth, with a minimum distance of 0.40 AU taking place on April 30. It faded slowly, still being around 4th magnitude during the second half of April and with a naked-eye tail for which I measured a maximum length of 8 degrees.

Following its closest approach to Earth the comet continued fading somewhat slowly, with the coma growing to a maximum size of around 18 arcminutes in mid-May. By the end of May it finally dropped below naked-eye brightness, and afterwards I continued to follow it visually until shortly before mid-

August. The final observations were obtained in early October.

Photograph I took of Comet Ikeya-Zhang on the morning of April 13, 2002. The constellation of Cassiopeia is to the comet's lower left.

Even as early as mid-February orbital calculations were beginning to show that Comet Ikeya-Zhang's orbit is distinctly elliptical, and before long the calculations indicated that it should have previously returned sometime in the early 1660s. It so happened that a fairly bright comet was observed throughout Europe in February and March 1661 including, particularly extensively, by the well-known Polish astronomer Johannes Hevelius who observed from the port city of Danzig (now Gdansk), and who first recorded the comet on February 3 of that year. A detailed study of Hevelius' observations of the 1661 comet by Dan Green (of the IAU's Central Bureau for Astronomical Telegrams) established that Hevelius' comet and Comet Ikeya-Zhang were indeed one and the same object, and it was then assigned the periodic comet designation 153P. With an orbital period of slightly over 360 years Comet 153P/Ikeya-Zhang becomes the longest-period comet that has been definitely seen on two different returns.

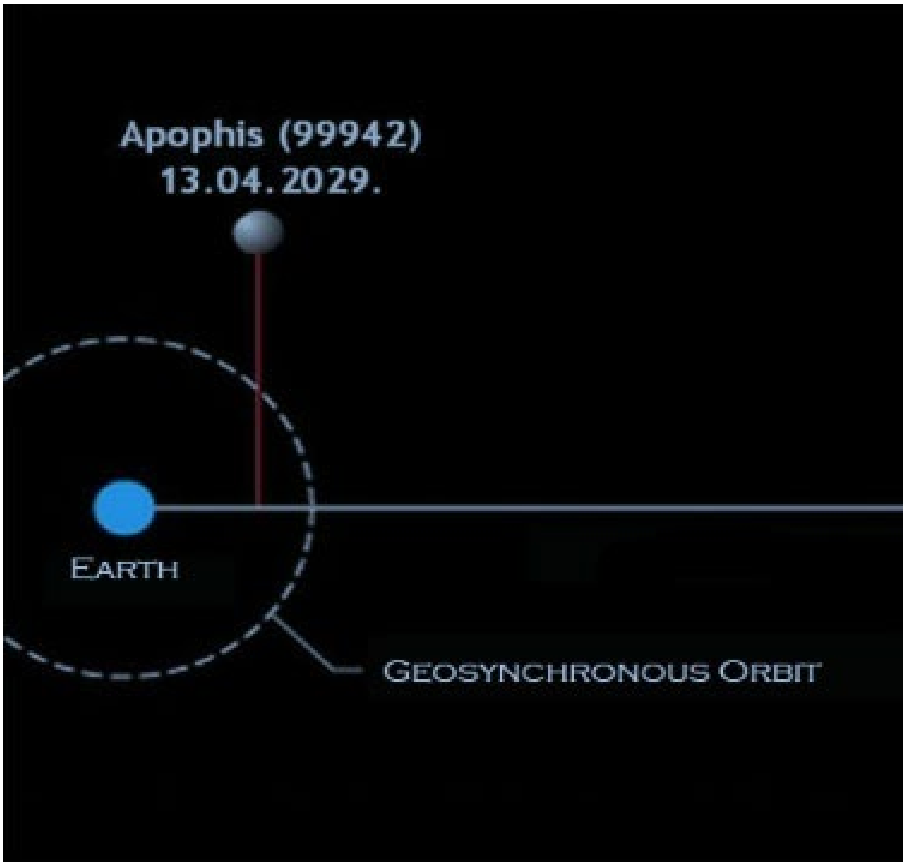
Diagram of the path of Comet Ikeya-Zhang during February and March 1661 as sketched by Johannes Hevelius from Danzig.

There have been suggestions made that a comet observed from the Orient in 1273, and another one observed from the Orient and from Europe in A.D. 877, might be even earlier returns of Ikeya-Zhang, but the positional data for those two comets is too sparse to allow positive identifications to be made. Meanwhile, Japanese astronomer Syuichi Nakano has calculated that it should return again in the year 2362; if his calculated perihelion date of September 1 is close to correct, the viewing geometry then would be quite poor, with the comet's being on the opposite side of the sun from Earth around the time of perihelion passage and remaining at a fairly small elongation for several months on either side of that.

The appearance of Comet Ikeya-Zhang is rather poignant for me, for three days after its perihelion passage my father, Nile Hale, passed away at the age of 83. Among other things, he was the person who initially got me interested in studying astronomy, and although he wasn't any kind of astronomer himself, he did show a bit of interest in the subject, and he took one of the photographs of Comet West 1975n that I display in that object's "Comet of the Week" presentation. Although in all honesty I don't subscribe to any such beliefs, a part of me likes to think that Comet Ikeya-Zhang is escorting my father's essence with it as it departs Earth for places unknown, and will bring it back when it returns around 2362 to check up on us and see how we're doing. I wonder what kind of world our descendants might have to show him then.

SPECIAL TOPIC:
PREDICTION OF FUTURE APPROACHES

During the third week of July 1994 the various fragments of Comet Shoemaker-Levy 9 1993e impacted Jupiter, liberating enormous amounts of energy in the process and creating large planet-sized "scars" in Jupiter's atmosphere that lingered for some time afterwards. (Comet Shoemaker-Levy 9 and these events are discussed in a future "Comet of the Week" presentation.) The events provided a vivid demonstration of the destructive power contained within such impacts, and with the thought that "it could be us next time," people on Earth started to give serious thoughts as to how to prevent such things from happening here. The U.S. Congress chartered a special commission, headed by renowned planetary geologist and Comet Shoemaker-Levy 9 co-discoverer Eugene Shoemaker, to investigate this issue and report on the best ways to address it, particularly focusing on the identification of threatening objects.

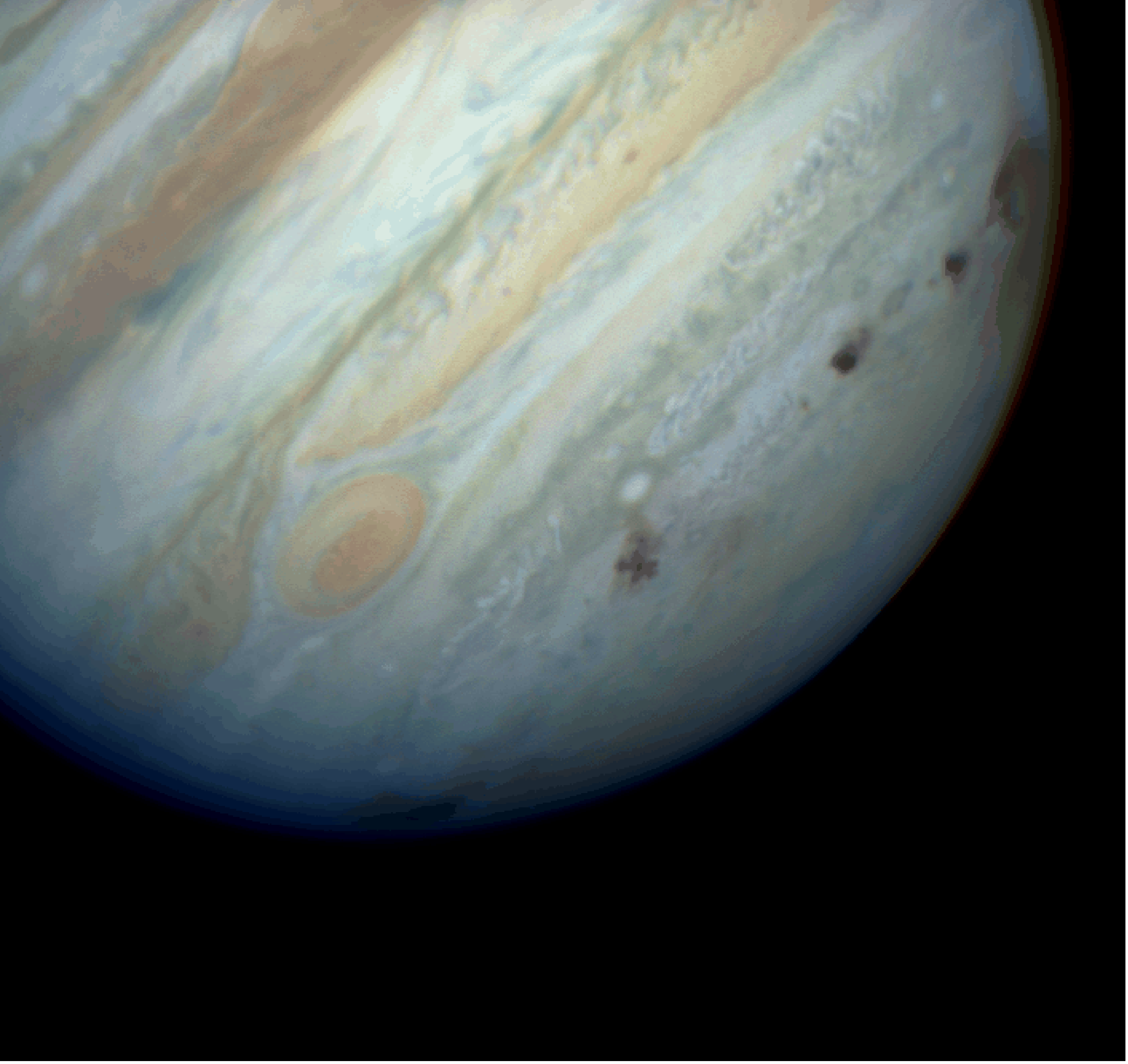


A graphical representation of the approach distance of (99942) Apophis during its passage by Earth on April 13, 2029.

The Shoemaker Commission delivered its report to Congress, and to NASA, in June 1995. The bulk of the report describes ways to implement comprehensive survey programs, given that the state of imaging technology had by that time reached the point where such programs were possible. With programs as they described, it would be possible to identify 90% of all threatening objects 1 km or larger in diameter within the next ten years. The survey programs that began coming on-line within the next few years, and which are described in a future "Special Topics" presentation, came about in no small part due to the recommendations of the Shoemaker Commission.

The primary rationale, certainly, is to identify any threatening objects before they might have an opportunity to threaten us. If a potentially threatening object could be identified two or three decades in advance, it should then be possible to do something about it; while destruction may not be feasible (or necessarily even advisable), a small change in its orbital motion 30 years in advance could make a significant difference in its location at the time of its closest approach, and if such a change could be made when an object is near aphelion and thus is exhibiting its slowest orbital motion, this would in turn require the lowest amount of energy. Specific deflection strategies that could be employed are the subject of a future "Special Topics" presentation.

The key, then, is not only to discover potentially threatening objects, but to determine their orbits with sufficient accuracy so that not only are we able to identify those that might threaten us someday, but also allow us to send spacecraft missions to them if that becomes necessary. Doing this requires weeks and months of follow-up observations, which may not be as glamorous as discovery but which is almost every bit as important. If the orbit can become well enough known so that the object in question can be recovered during a subsequent visit to near-Earth space, or identified in older images taken during a previous visit, this helps greatly in refining the orbit still further.



Hubble Space Telescope image of Jupiter, showing multiple "scars" in the atmosphere from the impacts by fragments of Comet Shoemaker-Levy 9 in July 1994. Courtesy NASA.

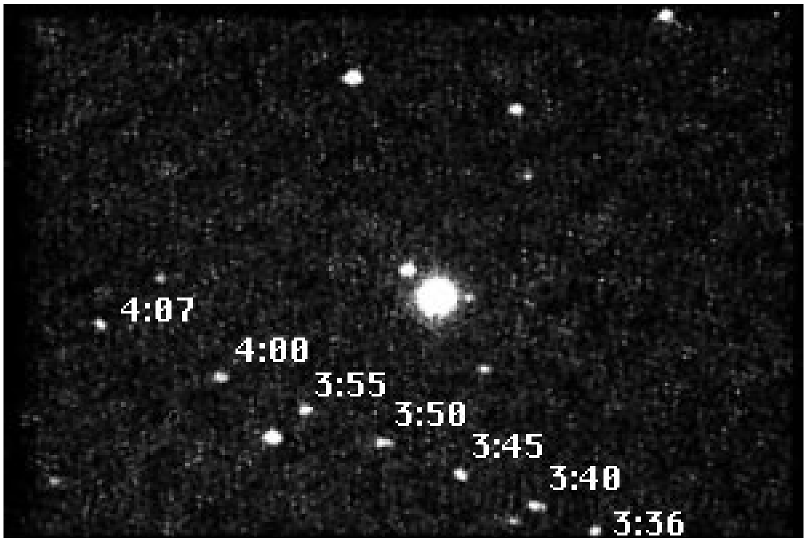
The practice of determining positions of objects such that orbits can be calculated is called "astrometry," and since these are measured against the positions of background stars, good catalogs of stars' positions are necessary. (Fortunately, with spacecraft-measured stellar positions being determined by ESA's Hipparcos mission in the early 1990s and the present ESA Gaia mission, such catalogs are now available.) In general, the more observations – and, in particular, the longer the orbital arc covered by those observations – the better when it comes to determining accurate and precise orbits.

If the sun and the orbiting object were the only objects around, the calculation of its orbit and the determination of its location at future times would be a simple and straightforward matter. However, there are other objects, like Earth and other planets (especially Jupiter for objects out that far), and each of these gravitationally influences the objects' orbits. Mathematically, while the "two-body problem" is relatively easy to solve, it turns out that there is no analytical solution possible for the "three-body problem" or the general "n-body problem," and the best that can be achieved is a numerical solution that approximates the true orbit. Fortunately, with modern computer technology high-accuracy numerical solutions are achievable without too much difficulty.

Additional effects can come into play for certain types of objects. Small asteroids, particularly those which can best be described as loose piles of dust, can be subject to effects produced by solar radiation such as the Poynting-Robertson effect which causes a slow decrease in an object's angular momentum. Comet nuclei can experience the effects of erupting jets off their surfaces, a phenomenon described as "non-gravitational forces" and described in a previous "Special Topics" presentation. Objects that pass near the sun during the course of their orbits can experience the effects of General Relativity.

When all of these considerations are allowed for, the process of calculating orbits, and predicting future approaches to Earth, commences . . .

On March 11, 1988 the IAU's Central Bureau for Astronomical Telegrams created a stir when it issued IAU Circular 6837, about the asteroid 1997 XF11 (now permanently designated as (35396)). This object had been discovered the previous December by Jim Scotti with the Spacewatch survey based in Arizona, and orbital calculations based upon a three-month arc indicated that, on October 26, 2028, 1997 XF11 would be passing just 0.00031 AU from Earth – just barely over six Earth radii above the surface, close enough to be of significant concern given the uncertainties still involved. Within a day images of 1997 XF11 from photographs taken in 1990 were identified, and the now eight-year-long arc moved the "miss distance" in 2028 to a much more comfortable 0.0062 AU. The accurate determination of its orbit was helped still further when it passed 0.064 AU from Earth in October 2002 and was extensively observed, including by me.

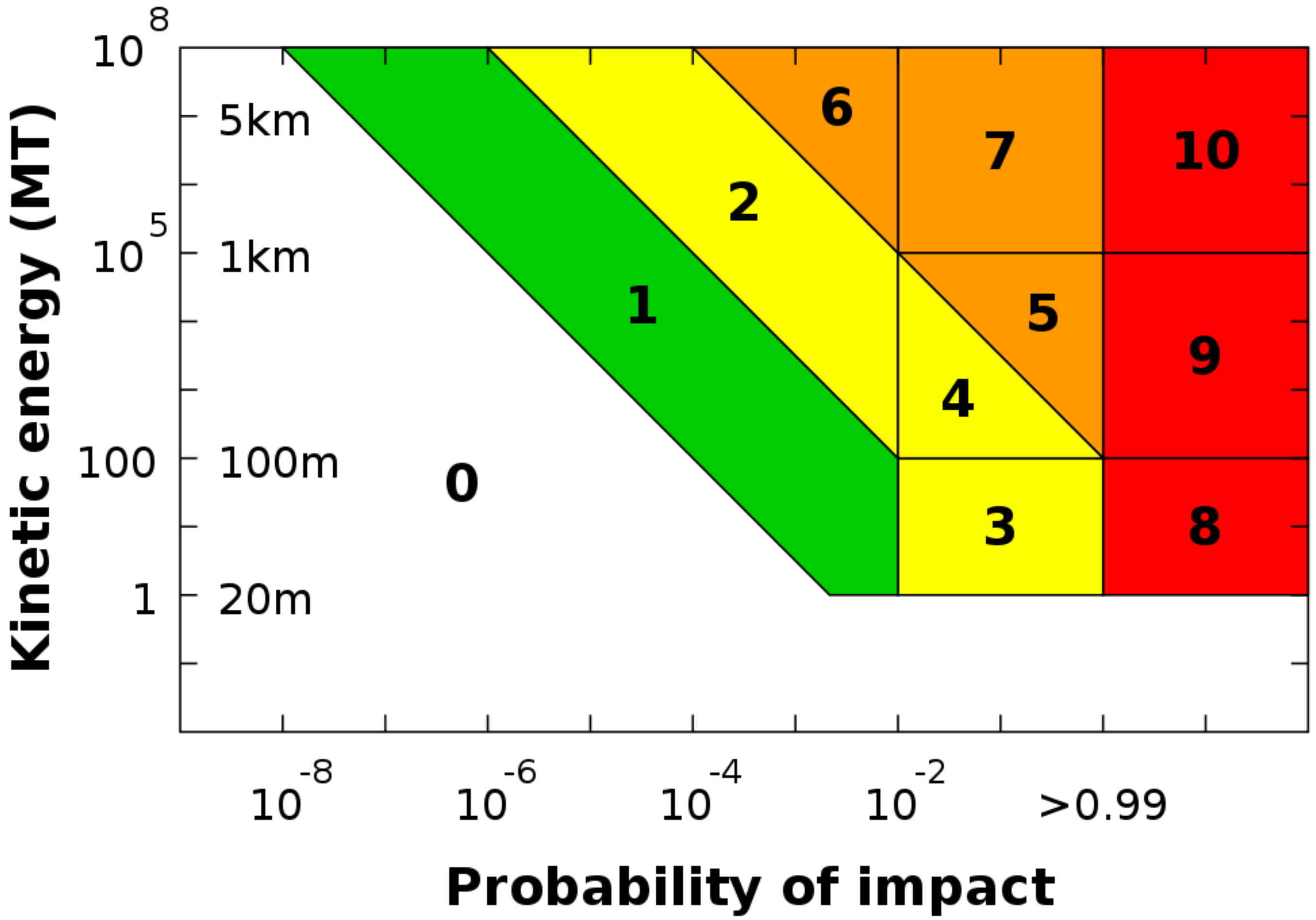


A series of images I took of (35396) 1997 XF11 on November 5, 2002, a few days after its closest approach to Earth. The asteroid's images are time-tagged in Universal Time.

This entire episode involving (35396) 1997 XF11 has helped in refining how forthcoming close approaches are treated – and in how they are presented to the general public. What has happened on several occasions is that a recently-discovered object will be described as having a "1 in X" chance of impacting Earth at some future date; what is really happening is that, at that future date, the uncertainties in the object's orbit will create a volume of space that it could theoretically occupy at that time, called its "error ellipsoid," and if Earth happens to be within that "error ellipsoid" the probability of any impact is simply the volume of Earth divided by the volume of that ellipsoid. As additional observations come in and the object's orbit gets better defined, the odds of an impact may actually increase, but this is entirely due to the fact that the "error ellipsoid" shrinks in volume, while Earth's volume, of course, remains the same. Eventually, the "error ellipsoid" will shrink to the point that Earth is no longer inside it, and the probability of impact drops to zero.

The most dramatic example of this process involves the asteroid now known as (99942) Apophis. This object was discovered in June 2004 but only observed for two nights, until accidentally re-discovered that following December. Calculations soon began to show the possibility of an impact on April 13, 2029, and as per the usual occurrences the odds of an impact kept increasing; however, instead of suddenly dropping to zero, the odds kept increasing until they were as high as 1 in 40 before the possibility of an impact vanished. The "miss distance" in 2029 is now firmly established as being 0.00026 AU, or 31,000 km (five Earth radii) above the surface – within the orbital distance of geosynchronous satellites. Apophis is roughly 400 meters in diameter and should be a naked-eye object of 3rd magnitude when it flies by Earth; this event will be best seen from the eastern hemisphere. This remains the closest predicted future approach of any known asteroid. (For what it's worth, the encounter date – April 13 – is a Friday.)

Even though an Earth impact by Apophis in 2029 has been completely ruled out, for a while it seemed possible that Apophis could impact Earth seven years later, on April 13, 2036. The 2029 approach is close enough that gravitational perturbations by Earth – which would be strongly dependent on the actual distance between the two objects – could place Apophis on an intercept trajectory if it were to pass through a certain window, or "keyhole," 800 meters wide during that approach. This possibility has now been ruled out, and the 2036 "miss distance" is a relatively large 0.14 AU, on April 4. At this time there



The Torino Scale for evaluating the threats posed by near-Earth objects.

is still a very tiny chance (odds 1 in 150,000) of an impact in April 2068.

There are several organizations around the world dedicated to keeping track of any potentially threatening objects. The IAU's Minor Planet Center is charged with announcing discoveries of asteroids and comets, collecting observations, and publishing orbits. The Center for Near Earth Object Studies is run by NASA to maintain information about potentially threatening objects, and the Near Earth Objects – Dynamic Site performs a similar function for ESA. The Spaceguard Foundation is a private organization based in Italy that acts as somewhat of a clearinghouse for near-Earth object observation efforts and information, and in fact the entire collection of worldwide observatories engaged in this effort is sometimes referred to as "Spaceguard," a name taken from Arthur C. Clarke's 1973 novel "Rendezvous with Rama" as an homage. Another private organization, the B612 Foundation based in California, is primarily devoted to developing deflection techniques but is also involved in searching for threatening objects.

Although its usage is not strictly formal, many scientists in the near-Earth object community utilize the Torino Scale, developed by MIT astronomer Richard Binzel, as a means of numerically quantifying the risks of potentially threatening objects. The Torino Scale uses integers from 0 to 10, with 0 meaning no chance of an impact and 10 meaning a definite impact of global catastrophe, with allowances being made for both the calculated odds of an impact and the size of the potentially impacting object (and thus the kinetic energy an impact would release). Since its introduction a handful of newly-discovered objects have briefly rated a "1" on the Torino Scale before being dropped to "0;" the only object to receive a higher rating was Apophis, which reached the level of "4" during the brief period when calculations were indicating a close to 3% possibility of an impact in 2029. At this time no objects are listed as being higher than "0."

The color codes on the Torino Scale are:

- White (level "0"): no hazard
- Green (level "1"): normal [no cause for public concern]
- Yellow (levels "2," "3," and "4"): meriting attention by astronomers
- Orange (levels "5," "6," and "7"): threatening
- Red (levels "8," "9," and "10"): certain collisions

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