NASA facts

# Space Technology

## Game Changing Development

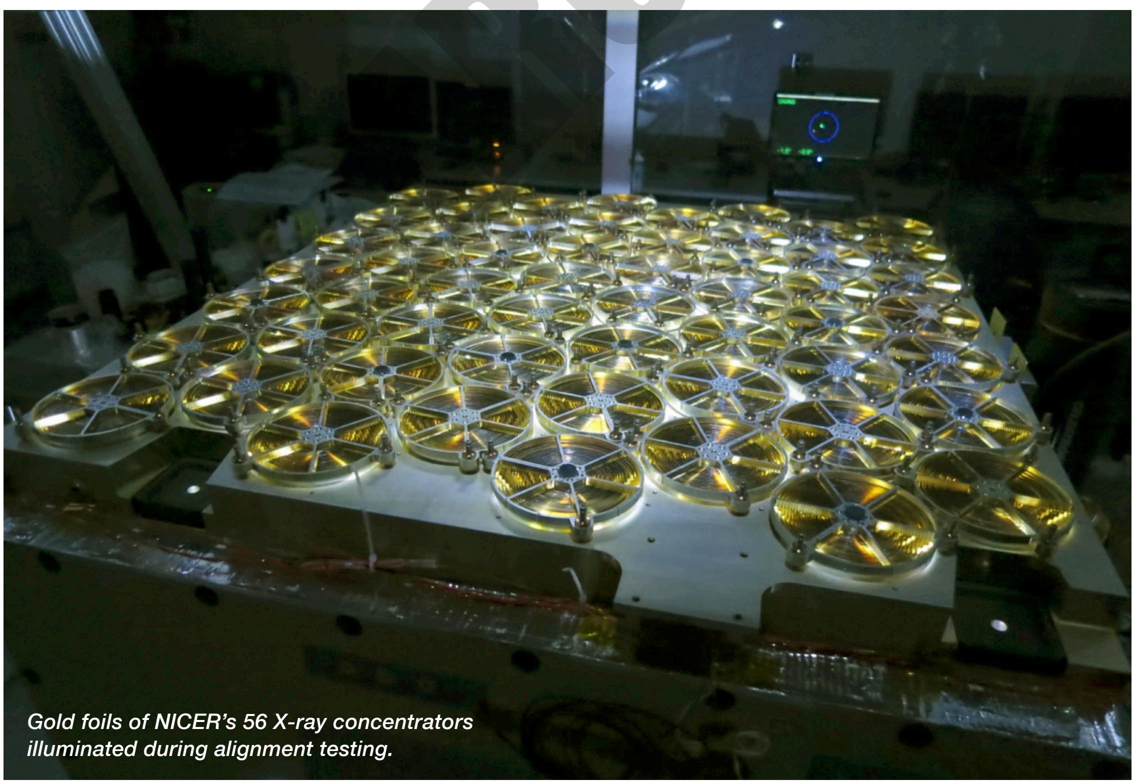
## NICER/SEXTANT: The Latest Incarnation of Celestial-Based Navigation



As history has shown, there really is nothing new under the Sun. Since the beginning of recorded history, if not before, humans have used the stars to find their way. In 2017, a team led by two NASA astrophysicists plans to demonstrate a potentially game-changing technology that would use millisecond pulsars to help space travelers and scientific spacecraft navigate the far reaches of the solar system and beyond.

The latest incarnation of celestial-based navigation is an experiment called the Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT). Selected as a NASA Explorer Mission of Opportunity in April 2013, the payload will use one of nature's most accurate clocks, pulsars, as navigational beacons when it begins operations from its berth on the International Space Station in 2017.

These extraordinary objects, which are a subgroup of neutron stars, rotate rapidly, emitting powerful beams of light, much like a lighthouse, from their magnetic poles that sweep around as the star spins. At Earth, these beams are seen as flashes of light, blinking on and off at intervals from seconds to, in the fastest-spinning cases, milliseconds.



*Gold foils of NICER's 56 X-ray concentrators illuminated during alignment testing.*

Because of their predictable pulsations, pulsars are highly reliable celestial clocks that can provide high-precision timing similar to the atomic clock signals supplied through the 26-satellite, military-operated Global Positioning Satellite System (GPS)—a space-age navigational capability now as ubiquitous as the stars in the sky.

To demonstrate this technique, NICER/SEXTANT will use its 56 X-ray telescopes, detectors, and other advanced technologies to detect X-ray photons from these powerful, flashing beams of light, estimating their arrival times at the spacecraft. Specially developed algorithms will then use these measurements to stitch together an onboard navigation solution.

Long before the advent of GPS and now NICER/SEXTANT, humans relied on the sky and increasingly more sophisticated technology to find their way.

### Early Navigational Tools

The Phoenicians and Greeks were among the first to observe the Sun and stars to navigate far from land and to sail at night. The Sun moving across the Mediterranean sky provided direction by following the sunrise, now known as the East, and the sunset, now known as the West. At night, they steered by the stars. At any time of the year and at any point on the globe, the Sun and stars appeared above the horizon at fixed heights, or "altitudes"—a distance that navigators could measure with their fingers laid horizontally atop one another and held at arm's length.

Navigators also determined direction with the magnetic compass. Although the Chinese apparently knew about the powers of magnetism as early as the third millennium B.C.E., early sojourners did not use the device until the 12th century. Before then, they estimated their courses by the direction of prevailing winds or ocean swells.

Though these techniques kept early navigators to a general course, the development of specific navigational tools, combined with observations of celestial objects, improved precision, particularly in determining latitude.

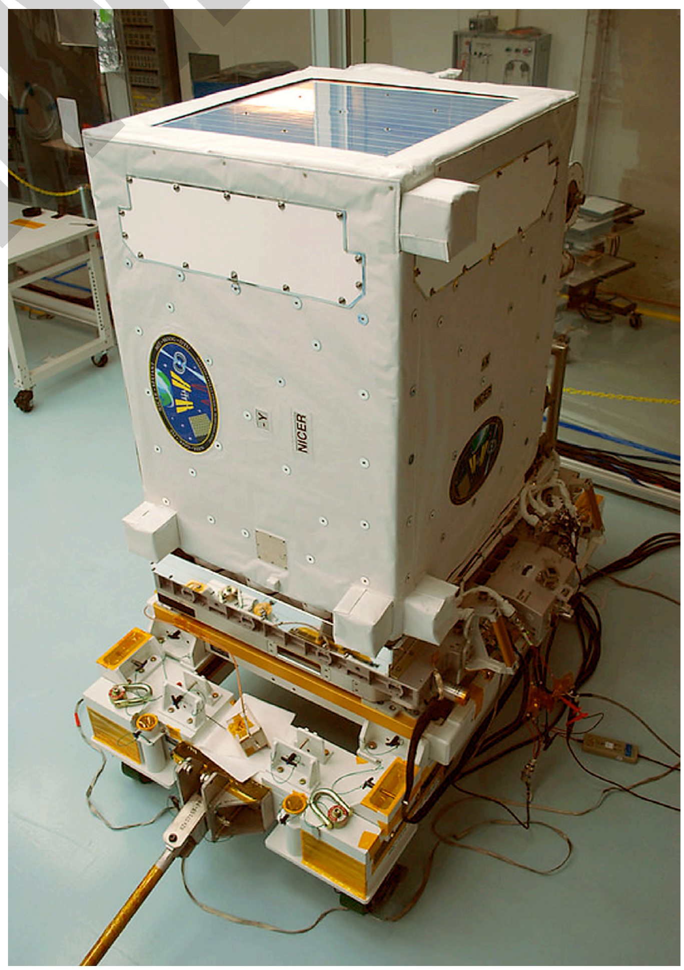
### Determining Latitude

In particular, navigators used and improved upon the early astrolabe and cross-staff, two devices created in ancient times to measure the altitudes of celestial bodies. These devices enabled sailors to travel in an East-West direction away from the sight of land.

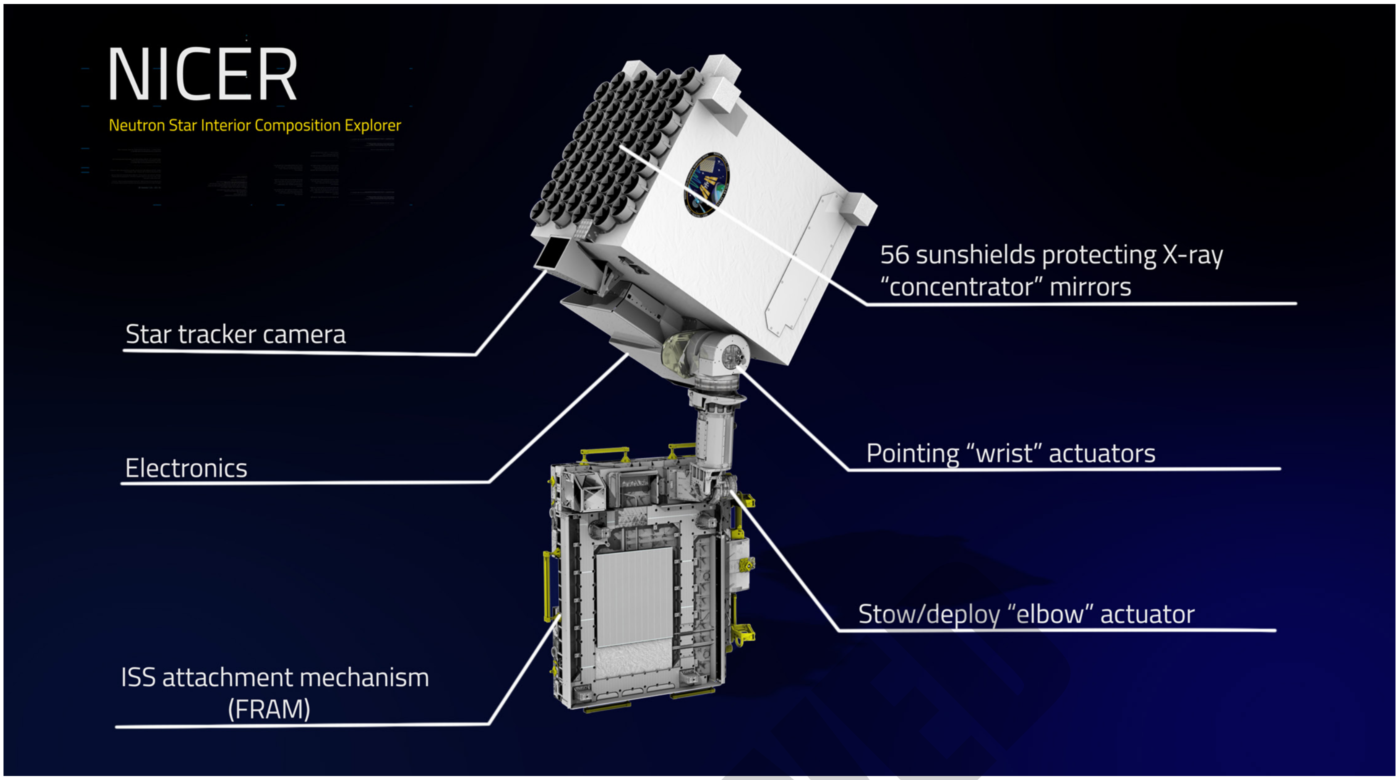
The astrolabe was a simple sphere made of brass, measuring about 6 inches in diameter. With the device, navigators determined the latitude of a ship at sea by measuring the noon altitude of the Sun or the meridian altitude of a star of known declination. To do this, the navigator would sight on the celestial object with the astrolabe's movable arm, called the alidade, and measure the angle of height of the object above the horizon, thereby determining the ship's position.

The cross-staff was a simple device made principally of wood that determined the vessel's latitude by measuring the angle of the Sun or Polaris (the North Star) above the horizon. It consisted of a long staff with a perpendicular vane that slid back and forth. By moving the sighting vanes along the staff, navigators could determine angular measurements between the horizon and a celestial body—measurements that could be read off the scale on the staff. Over time, these devices became more elaborate and by the mid-1600s, they had multiple vanes or transoms of varying lengths.

By the 1700s, the most popular instrument was the Davis quadrant or backstaff. It was a major conceptual leap in seagoing celestial navigation because it provided a quantitative measurement in degrees of the altitude of Polaris or the Sun and related this position to a geographic




*NICER at Kennedy undergoing International Space Station interface testing.*




*Components of the NICER payload.*



position. It could measure up to 90 degrees, or a quarter of a circle, determining the altitude of the Sun by observing its own shadow while sighting the horizon.

By the end of the 1600s and into the 1700s, the more inventive instrument makers were shifting focus to optical systems, basing their designs on mirrors and prisms that could be used to observe the nighttime celestial bodies.

**Introduction of the Sextant**

Introduction of the sextant was a critical development made independently and almost simultaneously in about 1731 by John Hadley in England and by Thomas Godfrey, a Philadelphia glazier. The fundamental idea was to use two mirrors to make a doubly reflecting instrument. Often referred to as an octant, the instrument was truly a "point and shoot" device and is similar to the sextant in common use today.

When developed, the sextant consisted of a triangular frame, the bottom of which was a graduated arc of 60 degrees. A telescope was attached horizontally to the plane of the frame. A small index mirror was mounted perpendicular to the frame at the top of a movable index arm or bar, which swung along the arc. A horizon glass, half transparent and half mirror, sat in front of the telescope. The image of the Sun or other body reflected from the index mirror onto the mirror half of the horizon glass, and then into the telescope. If the user adjusted the index (or image) arm so that the horizon was seen through the transparent half of the horizon glass, the reflected image of the Sun lined up with the arm and the Sun's altitude could be read from the position of the index arm on the arc.

**Fixing Longitude**

Throughout the history of navigation, latitude could be determined by measuring the altitude of the Sun at noon or the altitude of any tabulated star when it crossed the local meridian. Instruments, such as the astrolabe, quadrant and sextant, helped with those measurements. But determining the longitude remained a serious challenge. Navigators could only determine longitude by comparing the time-of-day difference between the mariner's starting location and his new location. In the early days, navigators kept time with sand-filled hourglasses that had to be watched and turned hourly. Even some of the best clocks of the early 18th century could lose as many as 10 minutes per day, which translated into a computation error of 150 miles or more.

In 1764, British clockmaker John Harrison invented the seafaring chronometer, which was the most important advance in marine navigation in the 3,000 years that mariners had taken to the sea. Over the next 40 years, he improved on the technology, making his chronometers more and more accurate. Although expensive at the time, Captain James Cook used Harrison's chronometer to circumnavigate the globe. When he returned, his calculations of longitude proved correct within 8 miles, enabling him to develop detailed charts of the world—a development that changed the nature of navigation forever, transforming seafaring from a dangerous activity into profitable enterprise.

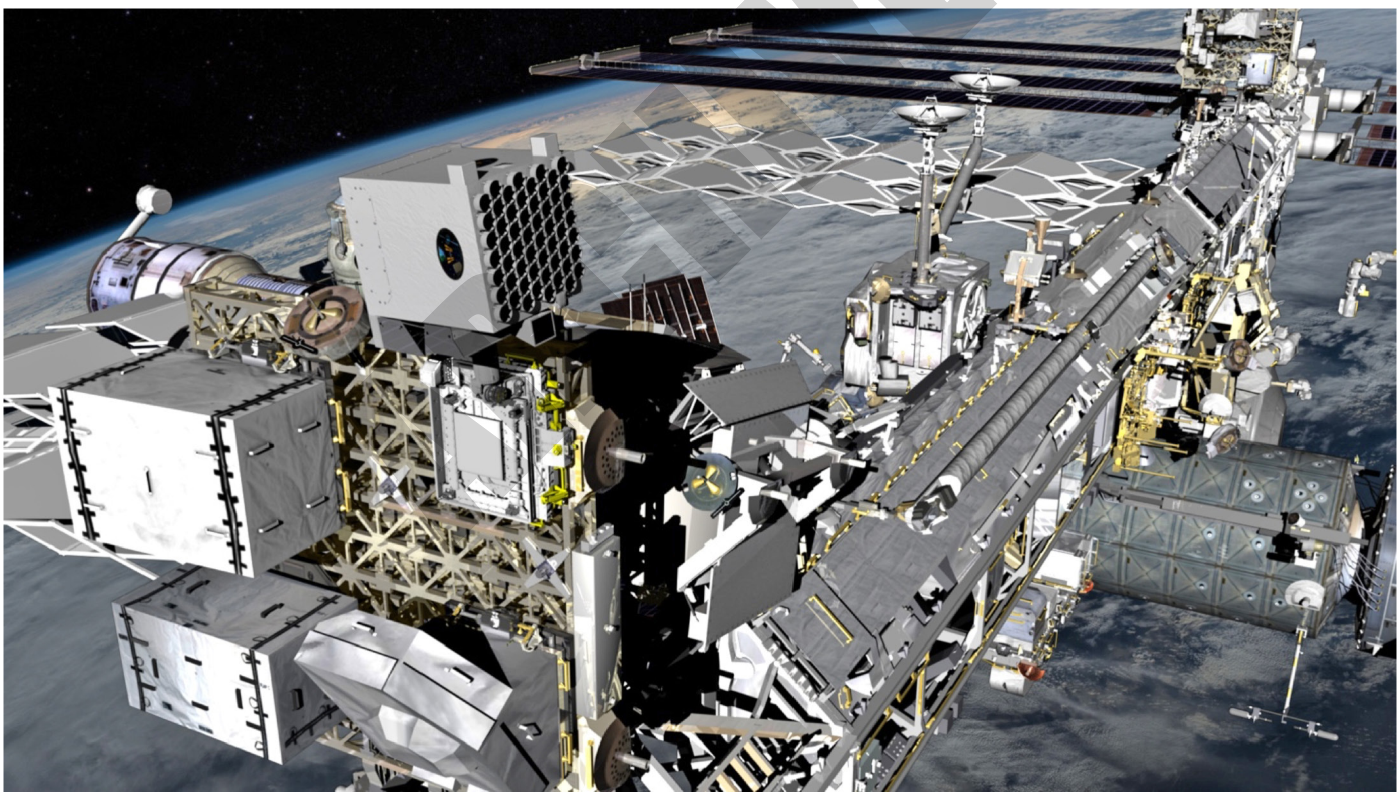
**Modern Times**

Today, navigators use radar and loran to find their way. The former, developed in 1935, is used to locate objects beyond the range of vision by projecting radio waves against them. This remains a useful method for locating other ships when visibility is reduced. By 1940, the U.S. developed the Long Range Navigation (Loran) system that used pulsed radio transmissions to determine a ship's position. And in 1978, the U.S. Air Force deployed its GPS. It has provided continuous worldwide coverage adequate for determining latitude and longitude to within about 30 feet and, in many places, altitude, with the same accuracy.

And now, NASA scientists are developing NICER/SEXTANT, the latest incarnation of celestial navigation. This technique could extend humankind's ability to navigate to the farthest reaches of the solar system and potentially beyond using pulsars as a timepiece. In a sense, the development follows a grand tradition that began thousands of years ago when the first travelers looked to the skies to venture beyond the horizon.

The Game Changing Development (GCD) Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and subsystem testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Mission Directorate.

For more information about GCD, please visit
http://gameon.nasa.gov/



*Artist's conception of NICER payload on the International Space Station.*

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