

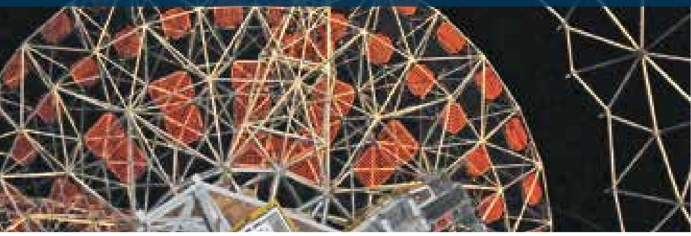
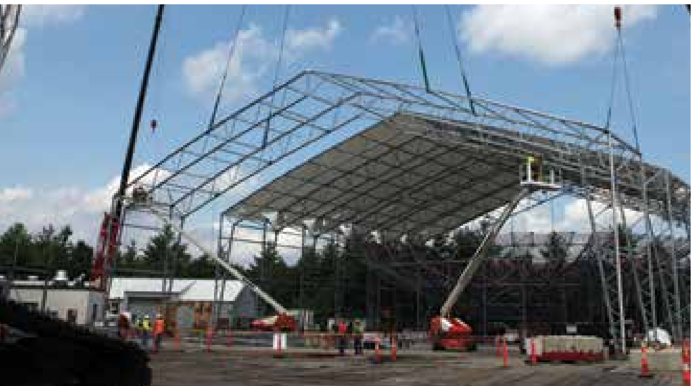

The Haystack Facility

Celebrating 50 Years of Research and Innovation

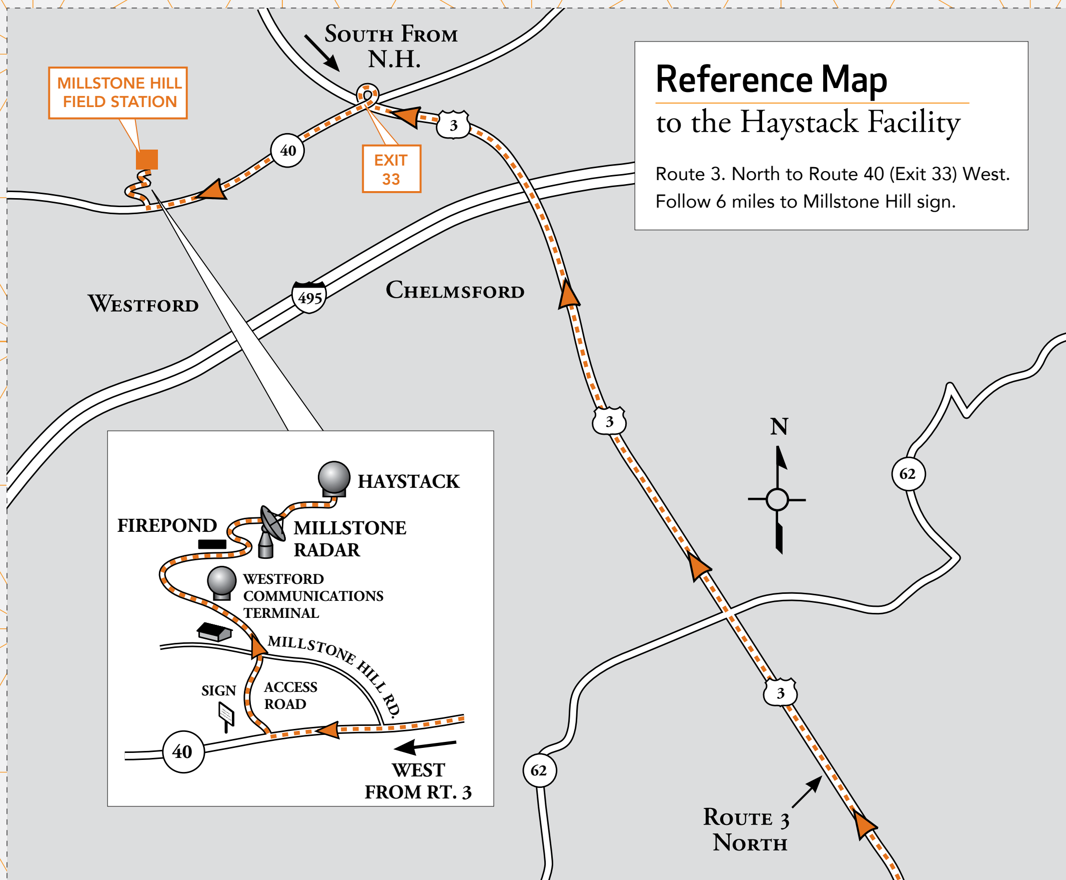
50TH

1964 2014



LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY



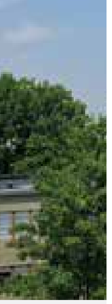
The Haystack Facility

Celebrating 50 Years of Research and Innovation

50TH

1964

2014



From the Director of Lincoln Laboratory

In 1964, the Haystack radar system began operations in Westford, Massachusetts. This high-performance microwave system was designed as an experimental facility for research on space communications, radar, and radio astronomy. It was soon enabling important contributions that advanced radar technology and astronomical science. Now 50 years later, the Haystack radar, recently upgraded through the dual-band Haystack Ultrawideband Satellite Imaging Radar (HUSIR) program, is the highest-resolution, space-object imaging radar in the world. Lincoln Laboratory has had a significant role in the development and use of this radar system, and we are pleased to be celebrating Haystack's five decades of service to the nation.

Throughout its history, Haystack has had an impact on both science and national security. Shortly after becoming operational, the radar was used for experiments in space communications, particularly Project West Ford, which demonstrated the feasibility of communications from orbiting dipole belts. At the conclusion of this project, Haystack was assigned to basic science experiments, serving primarily as a planetary astronomy radar.

In the 1960s, Haystack was used to map the lunar surface, and its antenna measurements contributed to scientists' production of the ambiguity-free radar maps of Venus, Mercury, and Mars. Between 1967 and 1971, Irwin Shapiro of Lincoln Laboratory and scientists from MIT conducted radar measurements for a "fourth" test of Einstein's general theory of relativity.

In 1974, Lincoln Laboratory proposed an upgrade of the Haystack system to provide a high-power, X-band capability for tracking and imaging objects in deep space. The Advanced Research Projects Agency sponsored the development of this capability, and this addition to Haystack, the Long-Range Imaging Radar (LRIR), was completed in 1978. With its ability to collect range-Doppler imagery at geostationary ranges, Haystack LRIR became a contributing sensor to the U.S. Space Surveillance Network (SSN).

In the 1980s, Haystack's scientific operations, which had been transferred to MIT in 1970 as the Haystack Observatory, enabled very-long-baseline interferometry that has detected tectonic plate motion and imaged activity in the black hole at the center of the Milky Way. In the late 1980s, Haystack began tracking space debris in support of NASA's manned space exploration program.

Haystack's role in the SSN has expanded with the addition of HUSIR's W-band capability to the X-band system. This major development and construction project that culminated with the new antenna achieving "first light" in 2012 took more than 10 years to complete. The enhanced image quality HUSIR achieves will contribute significantly to the situational awareness important to protecting U.S. assets in space. This project represents the dedicated efforts of many Lincoln Laboratory staff and the project sponsors, the Air Force and the Defense Advanced Research Projects Agency.

We invite you to read through this booklet to learn more about Haystack's impacts on astronomical science, the scope of the recent HUSIR project, which received a 2014 R&D 100 Award, and the facility's contributions to national security. We look forward to the future important milestones that Haystack will reach.

Eric D. Evans

Haystack has been vital to the Laboratory's space control mission.

From the Director of Haystack Observatory

The Haystack 37-meter telescope began life as a radar instrument. It was designed to operate at what was considered the extremely short wavelength of 3 centimeters, requiring a surface accuracy on the order of a millimeter. In 1964, creating a fully steerable parabolic reflecting surface of this size and precision was a major engineering accomplishment, and the Haystack dish was soon established as a world-class astronomy research tool in high demand by scientists from surrounding universities and around the world. By 1970, the telescope was the centerpiece of the newly established MIT Haystack Observatory and supported a burgeoning, diverse program of science projects, including radar tests of general relativity, pioneering experiments in very-long-baseline interferometry (VLBI), and initial forays into the field of astrochemistry.

Throughout the 1970s and 1980s, the Haystack telescope remained at the forefront of radio astronomical instrumentation with a suite of state-of-the-art receivers and data processing systems to leverage the precision and sensitivity of the dish. As one of the most productive telescopes of that era, Haystack was involved in a series of key discoveries, ranging from relativistic motions in distant quasars to the chemistry and physics of the birthplaces of stars.

A vibrant research community developed at Haystack Observatory, nucleated by the telescope and attracting a talented, scientifically diverse and technically oriented staff. From that fertile mix sprang a tradition of technical innovation in the service of science and, in particular, world leadership in VLBI. Close cooperation between Haystack Observatory and Lincoln Laboratory led to the efficient sharing of the telescope for astronomical science and national security missions.

The 1990s saw the gradual decline of Haystack as a frontier research tool, as sensitive instruments capable of operating at shorter wavelengths were built on mountaintops around the world. The surface accuracy of the Haystack dish was upgraded to permit astronomy operations at a wavelength of 3 millimeters, and a series of projects exploited this capability. However, by the mid-2000s, the competitiveness of the telescope had become limited, and its importance within the broad research portfolio of the Observatory had diminished.

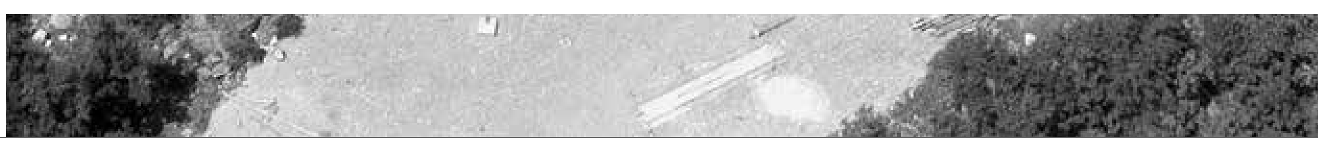
The recent project to upgrade to the Haystack Ultrawideband Satellite Imaging Radar, conducted by Lincoln Laboratory under Air Force and DARPA sponsorship, and supported by Observatory staff, represents a second truly major engineering accomplishment, no less impressive than the one that created the Haystack dish in 1964. With a surface precision of better than a tenth of a millimeter, the upgraded antenna is once again among the most accurate in the world and promises to enable an exciting new era of astronomy research and discovery.

We at Haystack Observatory look back with great pride at the many accomplishments of the last 50 years, and look forward with enthusiasm to the ongoing partnership with Lincoln Laboratory and to the pursuit of ground-breaking astronomical research in the coming decades.

Colin J. Lonsdale

The Haystack antenna has a long history of advancing scientific discoveries.

▶ Haystack Construction, 1961



Dedication to Herbert G. Weiss

Herb Weiss received the 2000 IEEE Pioneer Award for his work on the development of the Millstone Hill and Haystack Radars.

For someone pursuing a career in radar engineering, Herbert Weiss was in the right place at the right time: the Massachusetts Institute of Technology (MIT) during World War II. The Radiation Laboratory at MIT was developing radar systems to support the Allied war effort, and Herb joined the engineering team there in 1940 just after receiving his bachelor's degree from the Institute. At the Rad Lab, as it was known, Herb designed microwave receivers and automatic frequency control systems, and led a team that integrated the first microwave radar in an aircraft. He had assignments in both the Atlantic and Pacific theaters, helping the Allies operate the new radar systems.

After the war, Herb served as an instructor at MIT, but soon found his radar expertise was needed by a new enterprise, MIT Lincoln Laboratory. Established in 1951, Lincoln Laboratory was chartered by the Department of Defense (DoD) to develop a national air defense system. The motivating factors behind the birth of Lincoln Laboratory were reports in 1949 that the Soviet Union had tested its first atomic bomb and was developing long-range aircraft capable of carrying those bombs. As one of the first research staff of the Laboratory, Herb was placed in charge of the Distant Early Warning (DEW) Line project, which eventually deployed 35 radars above the Arctic Circle to provide a "fence" to detect incoming Soviet aircraft. In 1954, a new challenge presented Herb with the chance to pioneer techniques that would significantly improve long-range radar detection capabilities. Incoming intelligence indicated that the Soviets were experimenting with long-range rockets capable of delivering nuclear weapons across oceans and continents at distances of 3000 miles or more. At that time, the most powerful radars could track a large aircraft only within a 200-mile range. Because of the increased range and the lower radar cross section of the missile warhead, a sensitivity improvement factor of 1,000,000 was needed. Herb and his team developed the Millstone Hill radar, which had technology advances in the antenna, transmitter, and receiver components. When the Millstone system was close to completion, the first artificial satellite, *Sputnik I*, was launched. Millstone was hurriedly brought online in 1957 and successfully detected skin returns from *Sputnik*. Subsequently, Millstone radar technology was employed operationally in the Ballistic Missile Early Warning System (BMEWS).

At the completion of the Millstone demonstration and technology transfer, Herb and his colleagues were looking for another challenge. Recognizing that high-frequency microwaves had both civilian and defense applications in communications, radar, and radio astronomy, they developed an advanced microwave test bed, Haystack, enclosed in the largest radome of the time. In its first decade of operation beginning in 1964, Haystack was used for communications experiments, planet tracking, and very-long-baseline interferometry (VLBI) experiments. Since that time, Haystack has been upgraded to a long-range imaging radar and, most recently, a millimeter-wave radar.

Haystack exists primarily because of the foresight and audacity of Herb Weiss. He and his team were successful because they had the imagination and fortitude to see a difficult project through to completion. This 50th anniversary of Haystack's operation is dedicated to Herb Weiss and his remarkable vision.

Herb Weiss, seen here at the Millstone Hill site, envisioned the potential of microwaves for radar technology and radio astronomy; he thus energized the team that developed the Haystack test bed.

History of Haystack

Haystack, developed 50 years ago by MIT Lincoln Laboratory as an experimental research facility, has fostered advancements in radio astronomy and provided valuable radar images of objects in space. The capabilities of the facility expanded in 1978 to include long-range imaging of satellites at geostationary altitude. In the early 1990s, improvements to the reflector surface allowed operation of the antenna at 115 GHz for radio astronomy. A ten-year development program to add W-band capability to Haystack's X-band operations was completed in 2014 and has enabled very-high-resolution imaging of space objects.

Haystack was a remarkable instrument when it was built in 1964. It remains a vanguard microwave facility, continuing to support Lincoln Laboratory's space control mission and the Haystack Observatory's science and educational activities.

1960

Construction began on the Haystack facility with site preparation. A Lincoln Laboratory team, led by Herbert Weiss, developed Haystack as an experimental facility for research on space communications and radar. The advantages of high-frequency operation and the availability of high-power transmitter tubes led to the selection of an 8 GHz operating frequency.

1962

Construction continued. The radome was assembled, and the antenna dish and supporting systems were built inside the radome.

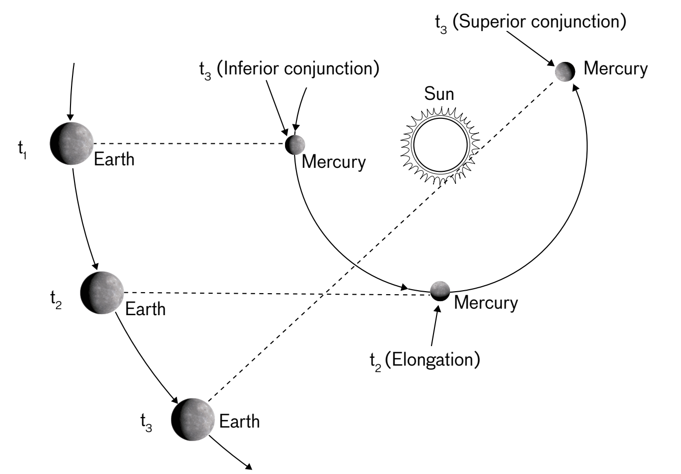
A surplus 150-foot radome was modified to allow the use of a 120-foot fully steerable parabolic Cassegrain antenna. Construction of a microwave antenna of this size was a significant challenge because of thermal gradients and gravitational loading, both of which would significantly distort the antenna surface. The solution, verified by extensive mechanical analysis, was a rigid, all-aluminum structure of circular rings attached by spokes with lightweight honeycomb panels as a surface. The radome protected the antenna from snow, ice, and wind loading and from direct solar radiation. Consequently, the antenna was lighter than an antenna exposed to weather, and precision pointing was not perturbed by the wind.

1960s

1960 1962

1963

After panel alignment, a root-mean-square (rms) error of 885 μm was achieved averaged over the entire quarter-acre surface. The Cassegrain design allows the use of interchangeable radio-frequency (RF) boxes, which enable the system to operate as a radar, communications receiver, or radio telescope. The versatile design of the Haystack system has sustained its long-term utility in a variety of applications.



Effects of general relativity on interplanetary time-delay measurements

1964

Haystack is completed.

1965–

Irwin Shapiro proposed a "fourth" test of general relativity—measuring the general-relativity prediction of "time dilation" or "excess delay" up to ~200 microseconds for radio waves that travel very near the Sun. He suggested that radar measurements of a planet near superior conjunction should double the one-way value; this value would be compared to the total round-trip time of up to ~1500 seconds. The first results from a radar-echo excess-delay experiment were obtained in 1967 using Mercury as a target.

1967

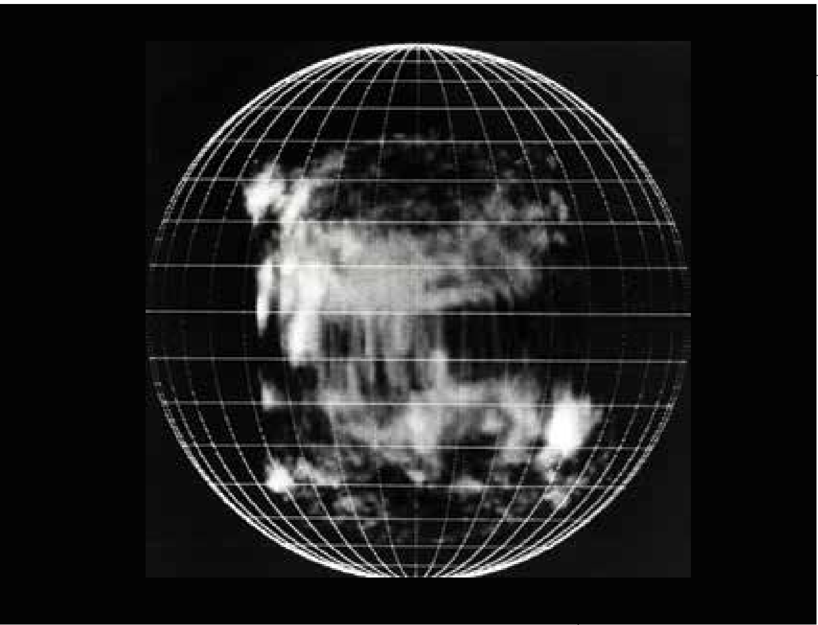
The first very-long-baseline interferometry (VLBI) experiment was conducted. In the early 1960s, new high-stability frequency standards for oscillators and large data recorders made it possible to use completely independent receivers in an array. With this hardware, receivers can be spaced anywhere on the surface of the Earth and, therefore, achieve high-resolution measurements even when using the relatively long radio wavelengths. This new technique was first demonstrated with some degree of success through a collaborative effort among three research teams in 1967. The American Academy of Arts and Sciences Rumford Prize was awarded in 1971 to members of groups from the National Radio Astronomy Observatory/Cornell University, MIT/Haystack, and Canada for this work in VLBI.

Haystack beam at 8 Gcps

1966

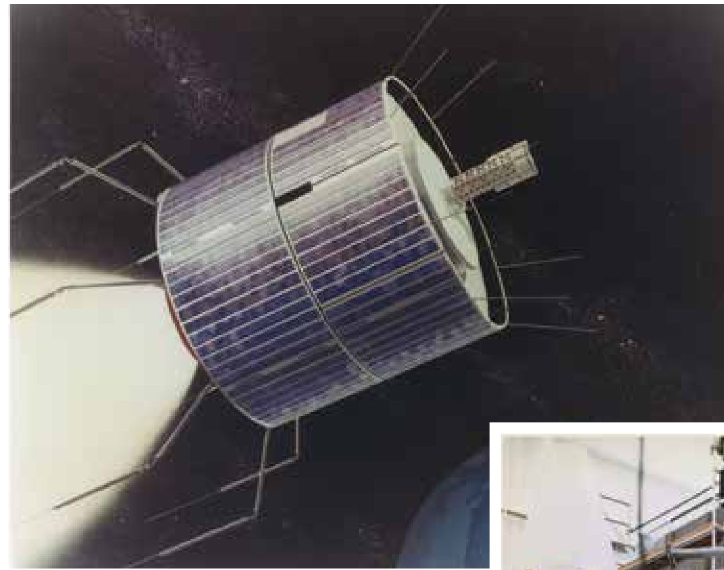
As early as the late 1950s, scientists at Lincoln Laboratory were using the Millstone radar to make range-Doppler measurements of the Moon. The completion of the Haystack radar brought these measurements to a new level. As a result of its antenna size and operating frequency, Haystack had a beam footprint that was only about an eighth of the diameter of the Moon, allowing high-resolution topographic lunar maps over most of its visible surface. Data from Haystack measurements helped NASA choose appropriate Apollo lunar landing sites.

1963 1964 1965 1966 1967



1971

Haystack was configured as a planetary radar with a 500 kW transmitter capable of tracking the Moon and nearby planets. Based on the general relativity prediction that an electromagnetic wave will be influenced by the gravitational potential along the path of transit, it was calculated that there would be an observable increase in transit time for radar signals that passed close to the sun. Observations of Mercury and Venus, built upon data such as the map of Venus at left made by Haystack in 1967, were used to test the prediction and confirm the additional time delay within 5% accuracy of the measurement.[1]

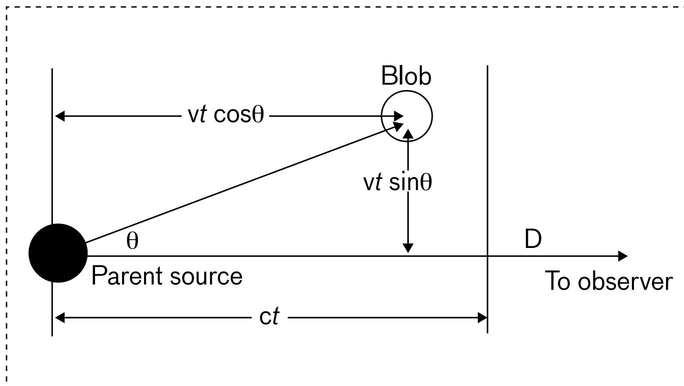


1974

Haystack tracked the Applications Technology Satellite program's ATS-3 geostationary satellite using a 50 kW transmitter and a 2 ms pulse width.[3] Although the single-pulse signal-to-noise ratio (SNR) was –6.7 dB on a 0 dBsm target, coherent integration of up to 1000 seconds improved the SNR by more than 41 dB. Haystack was used to demonstrate space surveillance techniques, including characterization of geostationary satellite spin period and wobble.

1970

Because of an amendment to the Military Authorization Act, which prohibited the use of Department of Defense funds for any research project not directly applicable to military needs, the Haystack Observatory was established as an entity of MIT operated under an agreement with the Northeast Radio Observatory Corporation (NEROC), a consortium of educational institutions. Thus, radio-astronomy research could continue at Haystack.



The geometry of this simple calculation shows how the illusion of faster-than-speed-of-light motion can be explained: $v_{apparent\text{-}transverse} = v \sin\theta / (1 - v/c \cdot \cos\theta)$

1971

Shortly after the first VLBI observations, the number of antennas equipped for the technique expanded. Haystack was paired with NASA's deep-space 210-foot dish to periodically monitor a dozen quasars, with the objective of studying the quasar variation with time at high spatial resolution. Quasar 3C 279 exhibited a feature that moved in the four-month interval between measurements. Using the change in angular separation of the feature and the distance to the quasar implied by the measured redshift, scientists determined the apparent velocity to be about 10 times the velocity of light. The 1971 publication of this observation in *Science* announced the first evidence of "superluminal motion."[2]

Many instances of superluminal motion have since been discovered in distant extragalactic clouds. The most likely explanation for this motion is that matter has been ejected at a velocity near the speed of light and at an angle close to the observer's line of sight. Given these conditions, the apparent velocity orthogonal to the line of sight can appear to exceed the velocity of light even though the actual velocity of the ejected mass is less than the velocity of light.

1970s

1970 1971 1971 1974

1975

Haystack Observatory began to offer radio astronomers a low-noise maser receiver at 1.3 cm wavelength and a 1024-channel digital correlator spectrometer. This receiver made it possible to make precision measurements of interstellar ammonia radiation lines, which were expected to be good probes of dense star-forming gas. Through systematic surveys, it was shown that low-mass star formation arises from self-gravitating condensations of about one solar mass extending about 0.1 parsec.[4]

1978

In the early 1970s, the Advanced Research Projects Agency (ARPA)–Lincoln C-band Observables Radar (ALCOR) demonstrated the value of imaging satellites in identifying satellite structure and distinguishable features. Information from radar-range-Doppler imagery was also useful in assessing mission purpose and satellite status.[5] These early images led to the Space Object Identification program. ALCOR was effective for low Earth-orbiting satellites, but was not sensitive enough to image satellites in deep space. Consequently, a long-range radar system for deep space was proposed at Haystack. ARPA sponsored the development of the long-range imaging radar (LRIR) that can detect, track, and image satellites at geostationary altitude. A new equipment box was developed for Haystack with a 10 GHz, 1024 MHz bandwidth transmitter. The existing reflector accommodated the 10 GHz center frequency. The system, which continues to operate today, provided range resolution of 0.25 meters.

1979

The Haystack LRIR became an operational sensor in the U.S. Space Surveillance Network.

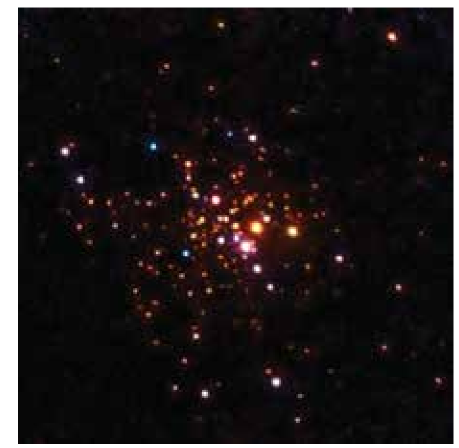
1980

Initial VLBI experiments were primarily aimed at making high-resolution maps of distant radio sources to place bounds on their angular size. But it was soon realized that VLBI was also a tool that could be used to make precision measurements of the Earth and its orientation in space relative to distant quasar radio sources. By combining the results of wavefront time-of-arrival measurements from antennas positioned over the globe, the relative positions of the antennas could be measured and tracked with a precision of a few millimeters. In 1980, the first regular observations began.

Throughout the 1980s, stations were added in Europe and Asia. Following years of data collection and analysis, the first global map of measured tectonic motion was created.

1983

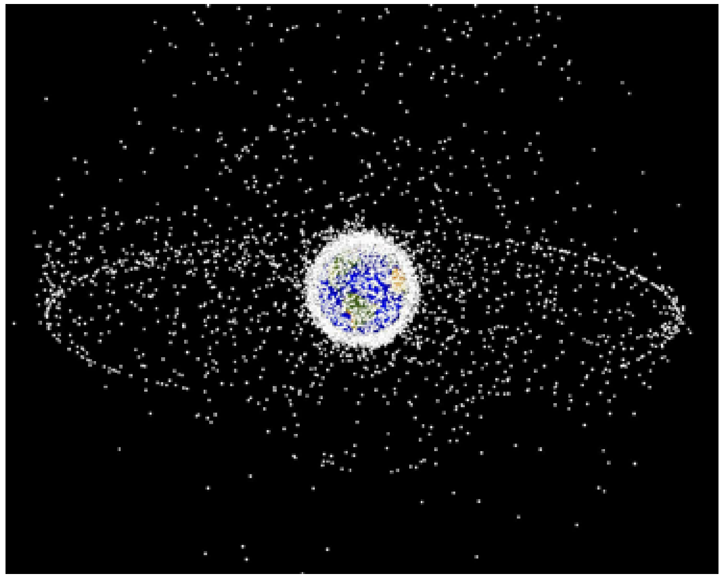
Systematic surveys and follow-up studies conducted with the Haystack Observatory allowed researchers to develop a picture of the initial conditions of low-mass star formation, as arising from self-gravitating condensations of about one solar mass extending about 0.1 parsec, supported mainly by their internal thermal motions at a temperature of about 10 K. The role of dense cores in forming stars was confirmed by observations with the Infrared Astronomical Satellite (IRAS).[4]



1986

Many of the dense cores found with the Haystack surveys proved to harbor previously unknown IRAS protostars. The core properties identified also matched theoretical models of gravitational collapse and star formation.[6]

1975 1978 1979 **1980s** 1980 1983 1986

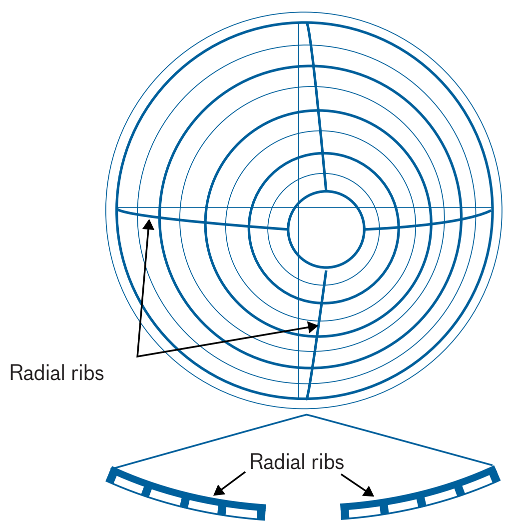


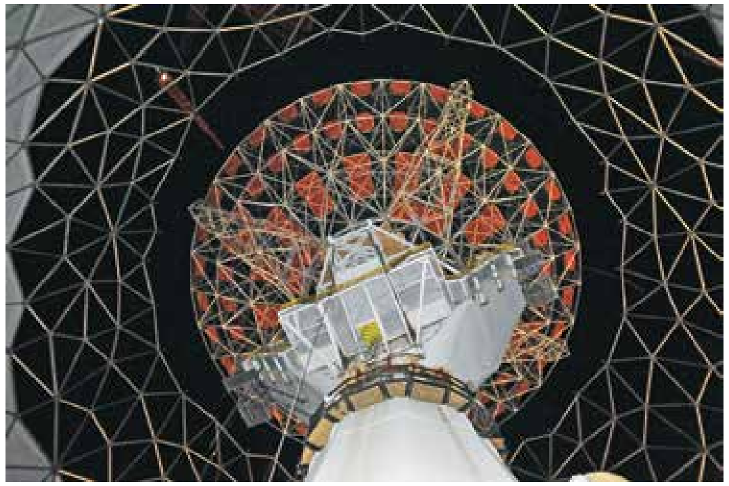
1989

Orbital debris fragments as small as 1 cm in diameter and moving at ~10 km/s can cause permanent damage to spacecraft. Because these small objects are not tracked and maintained in the space catalog, in 1989, through a U.S. Space Command agreement with NASA, a space debris measurement program was initiated. The Haystack radar has been used to help calibrate NASA debris models for this program by detecting debris that fly through its beam. Data regarding the density and altitude of orbital debris are used to help quantify the risk of collision.

1992

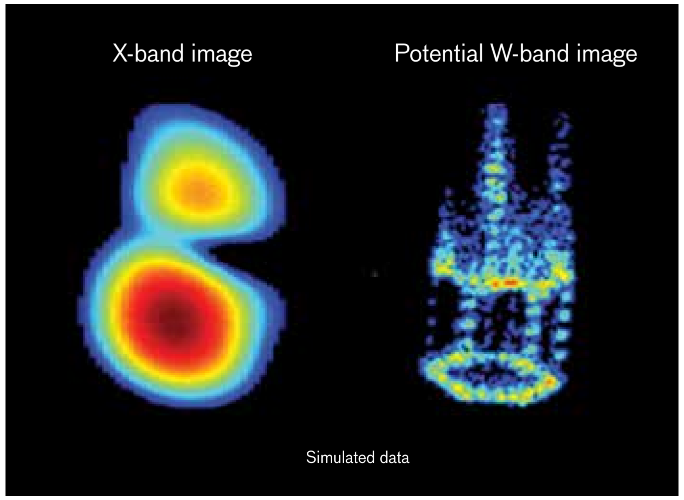
Several modifications were made to improve the quality of the reflector surface.[7] A deformable subreflector with active actuator control corrected for gravity distortion of the truss structure and surface panel deflections. Active thermal control was used to correct for thermal lag effects in large truss members. The resulting surface improved to a 210 µm rms error and allowed operation of the antenna up to 115 GHz for radio astronomy.





2004

A joint U.S. Air Force and DARPA program was initiated to develop the Haystack Ultrawideband Satellite Imaging Radar (HUSIR). The Air Force was designated as the lead agency for the project and funded the development of the new antenna and the low-power driver transmitter. DARPA funded the development of the high-power transmitter and advanced imaging techniques. The real-time signal processing effort was split equally between the two agencies. MIT transferred the ownership of the Haystack antenna and radome to the U.S. government.



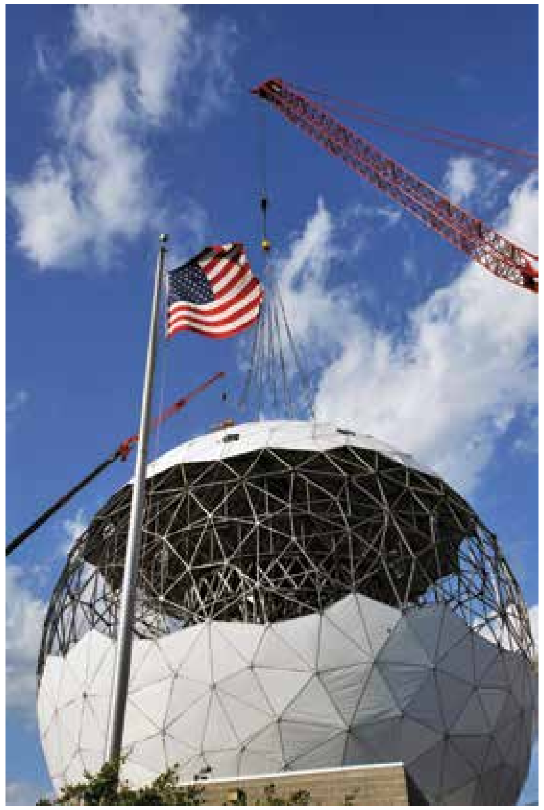
1996

After the 1993 Haystack antenna upgrade to 115 GHz, line observations at 3 mm wavelength were used to study the motions in and around dense cores. These measurements indicated that the surrounding gas has inward motion at about half the speed of sound.[8]

2002

Motivated by the increasing numbers and capabilities of small satellites in both low Earth and geostationary orbits, the U.S. Space Command, Air Force, and Defense Advanced Research Projects (DARPA) showed interest in improving the resolution achieved by radar imaging.[9]

1989 **1990s** 1992 1996 **2000s** 2002 2004



2008

Because of its experience in VLBI, Haystack Observatory has led the formation of the Event Horizon Telescope (EHT), an international collaborative effort to use submillimeter telescopes as VLBI stations for observing supermassive black holes. Observations of the black hole at the center of the Milky Way, Sagittarius A*, show a compact emission less than the size of the event horizon of the presumed black hole.[10] These observations suggest that the black hole has been resolved by the EHT and the emission is radiation from mass accretion flow. The image below is a theoretical model of a black hole.

2010

The installation of the HUSIR antenna required multiple critical lifts and precision assembly. The installation was completed safely and without mishap.

2012

The Haystack azimuth bearing refurbishment was completed.

2013

The X-band Long-Range Imaging Radar returned to operations. Initial W-band images on targets of opportunity were collected and provided to the National Air and Space Intelligence Center for evaluation.

2014

The Air Force certified that HUSIR meets system requirements.

On 13 January, HUSIR successfully completed the operational trial period and was accepted as a U.S. Space Surveillance Network contributing sensor.

2008 2010s 2010 2012 2013 2014

Footnotes

[1] Irwin I. Shapiro et al., "Fourth Test of General Relativity: New Radar Result," *Physical Review Letters*, vol. 26, no. 18, 1971, pp. 1132–1135.

[2] A.R. Whitney et al., "Quasars Revisited: Rapid Time Variations Observed via Very-Long-Baseline Interferometry," *Science*, vol. 173, no. 3993, 1971, pp. 225–230.

[3] L.B. Spence and G.P. Banner, "Observations of Synchronous Satellite ATS-3 with Three Coherent Radars," *Lincoln Laboratory Technical Note 1975–36*, June 1975.

[4] P.C. Myers and P.J. Benson, "Dense Cores in Dark Clouds. II. NH_3 Observations and Star Formation," *The Astrophysical Journal*, vol. 266, 1983, pp. 309–320.

[5] W.W. Camp et al., "Wideband Radar for Ballistic Missile Defense and Range-Doppler Imaging of Satellites," *Lincoln Laboratory Journal*, vol. 12, no. 2, 2000, pp. 267–280.

[6] C.A. Beichman, P.C. Myers, J.P. Emerson, S. Harris, R. Mathieu, P.J. Benson, and R.E. Jennings, "Candidate Solar-Type Protostars in Nearby Molecular Cloud Cores," *The Astrophysical Journal*, vol. 307, 1986, pp. 337–349.

[7] R.P. Ingalls et al., "Upgrading the Haystack Radio Telescope for Operation at 115 GHz," *Proceedings of the IEEE*, vol. 82, no. 5, 1994, pp. 742–755.

[8] C.W. Lee, P.C. Myers, and M. Tafalla, "A Survey of Infall Motions Toward Starless Cores. I. CS (2-1) and N_2H+ (1-0) Observations," *The Astrophysical Journal*, vol. 526, 1999, pp. 788–805.

[9] DARPATECH 2002 Symposium, Tim Grayson, archive.darpa.mil/DARPATech2002/presentation.html

[10] S.S. Doeleman et al., "Event-Horizon-Scale Structure in the Supermassive Black Hole Candidate at the Galactic Centre," *Nature*, vol. 455, 2008, pp. 78–90.

Building the Haystack Ultrawideband Satellite Imaging Radar Antenna

In February 2014, the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) joined the U.S. Space Surveillance Network as the highest-resolution space-object-imaging radar in the world.

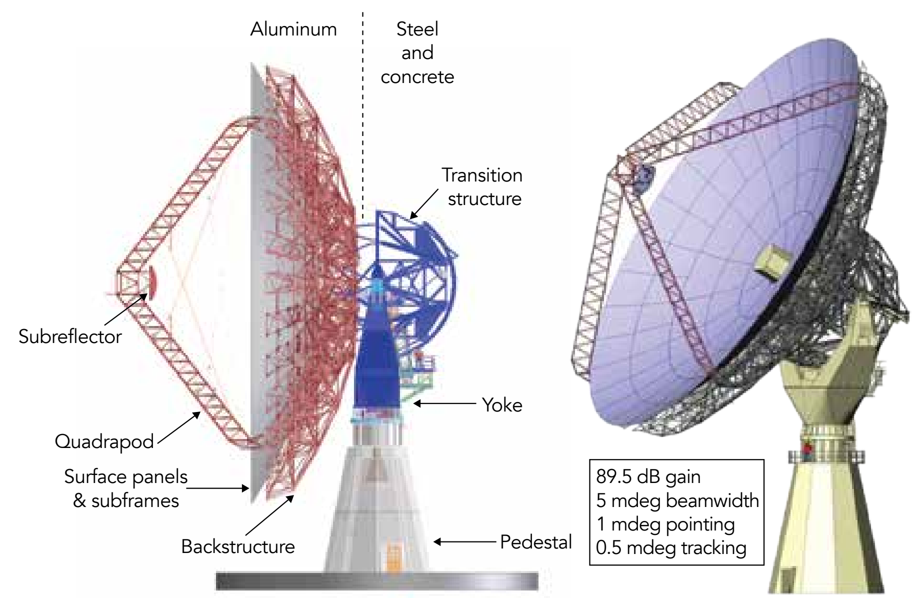
The entry of HUSIR into this worldwide network marked the culmination of a 12-year effort that began in 2002 with the planning for a wideband radar capable of imaging at W band, the next major technological step for imaging radars. At that time, one of the first considerations was whether to build an entirely new system or transform the existing Haystack radar. The project team decided to pursue the latter option, working with a number of subcontractors to create a design that would leverage much of the existing Haystack facility (radome, infrastructure, site, hydrostatic azimuth bearing, and yoke) and that would replace or supplement those components not compatible with the new high-frequency capabilities (e.g., primary and secondary reflectors, waveguide pathway, and radio-frequency [RF] box). This decision not only led to major advancements in antenna design, high-power electronics, and signal processing electronics, but also to the HUSIR antenna construction project chronicled in this set of photographs.

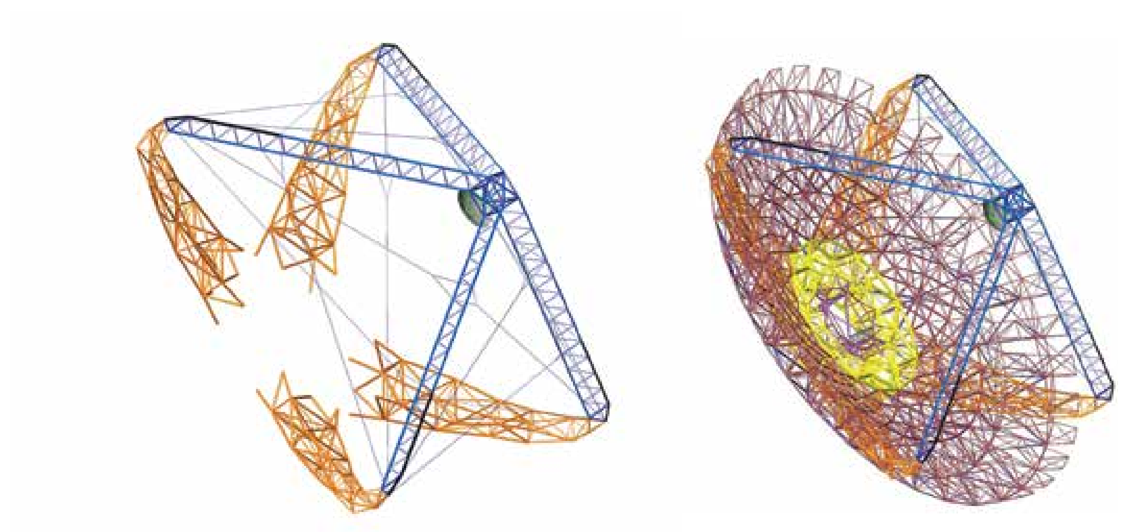
The photos to follow show the story of how the old Haystack antenna was replaced with a new Cassegrain antenna, all the while maintaining the integrity of the 150-foot-diameter radome. As the steps of the HUSIR antenna upgrade are revealed, it is important to keep in mind the behind-the-scenes technological and engineering challenges that had to be overcome to allow dual-band operation in both X and W bands:

- Achieving a 100 µm root-mean-square (rms) surface accuracy over the 120-foot-diameter antenna under all environmental conditions
- Designing and controlling the antenna to track a satellite with 0.5-millidegree accuracy
- Upgrading the hydrostatic azimuth bearing assembly to support the 675,000 lb weight of the new antenna
- Producing a W-band transmitter with an 8 GHz instantaneous bandwidth and the power to track and image satellites in low Earth orbit
- Developing new signal processing techniques to compensate for the effects of W-band electromagnetic wave propagation through the troposphere

ANATOMY OF THE ANTENNA

Key Antenna Parameters	
Diameter	120 ft (36.6 m)
Weight	675,000 lbs
Number of surface panels	432
Surface tolerance (rms)	<100 µm
Beamwidth (100 GHz)	0.005°
Azimuth slew rate	5°/s
Elevation slew rate	2°/s





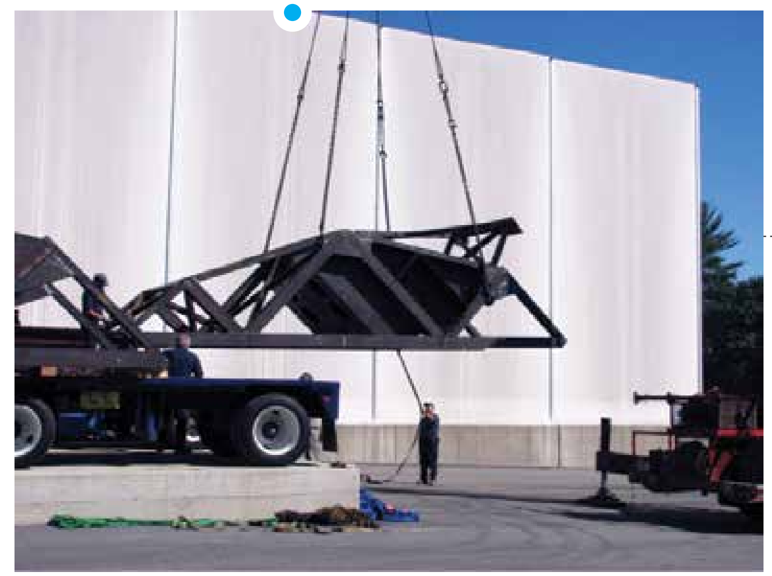
The antenna has a Cassegrain feed. Energy is reflected from the surface to a subreflector suspended from a quadrapod assembly (left) that is entirely supported by the backstructure (right). The quadrapod avoids contact with the surface to minimize surface distortion.

18 September 2006

Construction of HUSIR's backstructure—a 70,000 lb all-welded aluminum, stiffness-optimized primary reflector made up of 2896 aluminum tubes joining at 632 nodes and ranging in diameter from 2–11 inches—entailed the fabrication of 16 radial rib sections, one of which is pictured below.

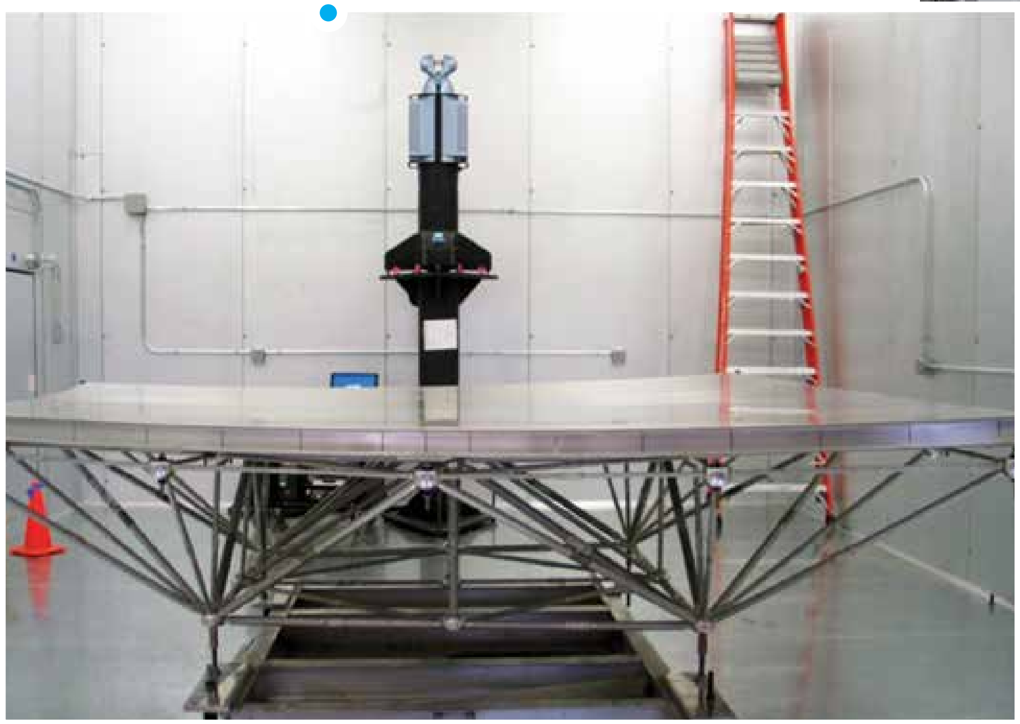
7 March 2007

The first two of 16 radial rib sections were installed on their assembly stands inside the temporary building that permitted work on the backstructure to proceed year-round. Each rib was positioned by using three adjustors (x, y, and z), and rib position was verified with laser metrology performed from a central tower. Next, the ribs were welded together and the positions were reverified.



12 June 2008

The transition structure components arrived at Haystack for final assembly.

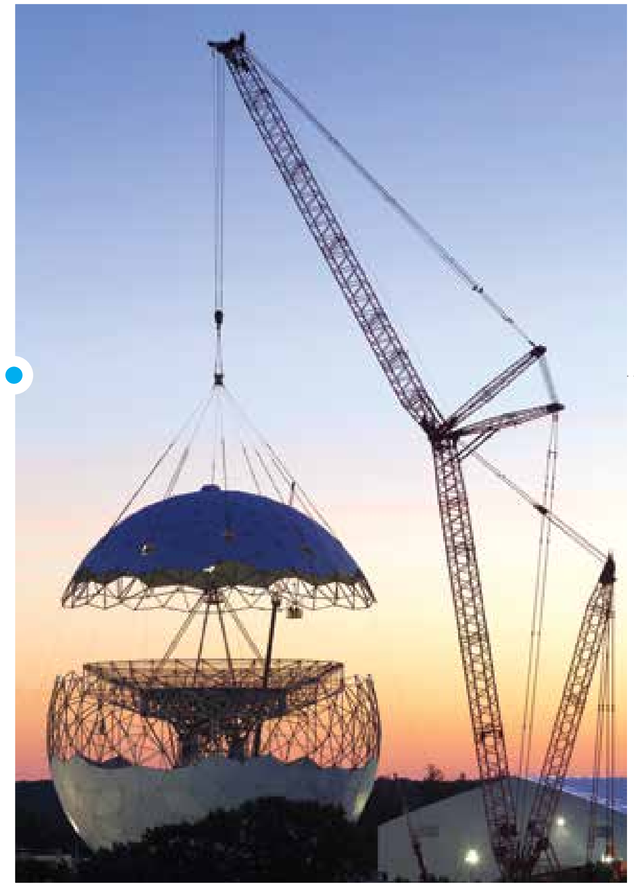


9 March 2009
Panels were mounted to aluminum subframes, each of which holds four or five panels.

26 October 2009
An onsite temporary building enabled aluminum welding to continue uninterrupted throughout the winter and in windy conditions that would have otherwise interfered with the creation of high-quality welds.

9 December 2009
The final assembly of the transition structure was completed onsite at Haystack.

20 May 2010
The Haystack site was prepared for removal of the old antenna and installation of the new antenna. The assembly of the heavy-lift crane took place along a 400 ft roadbed built into the treeline while the radome panels around the equator were removed in preparation for the separation of the radome cap. The temporary landing zone for the cap is the ring of steel piers in the lower right corner.



28 May 2010
The upper third of the 141 ft diameter, 115,000 lb radome structure was removed, or uncapped, to enable the crane to access the facility for removal and installation of the major subassemblies.

28 May 2010
The Haystack team involved in the uncapping of the radome structure consisted of engineers, technicians, and ironworkers.

21 June 2010

Once the old antenna's backstructure was removed, the antenna yoke tips were modified to support the antenna's elevation axis bearings.

8 July 2010

The quadrapod—the support structure for the secondary reflector, or subreflector—was assembled onsite.

4 June 2010

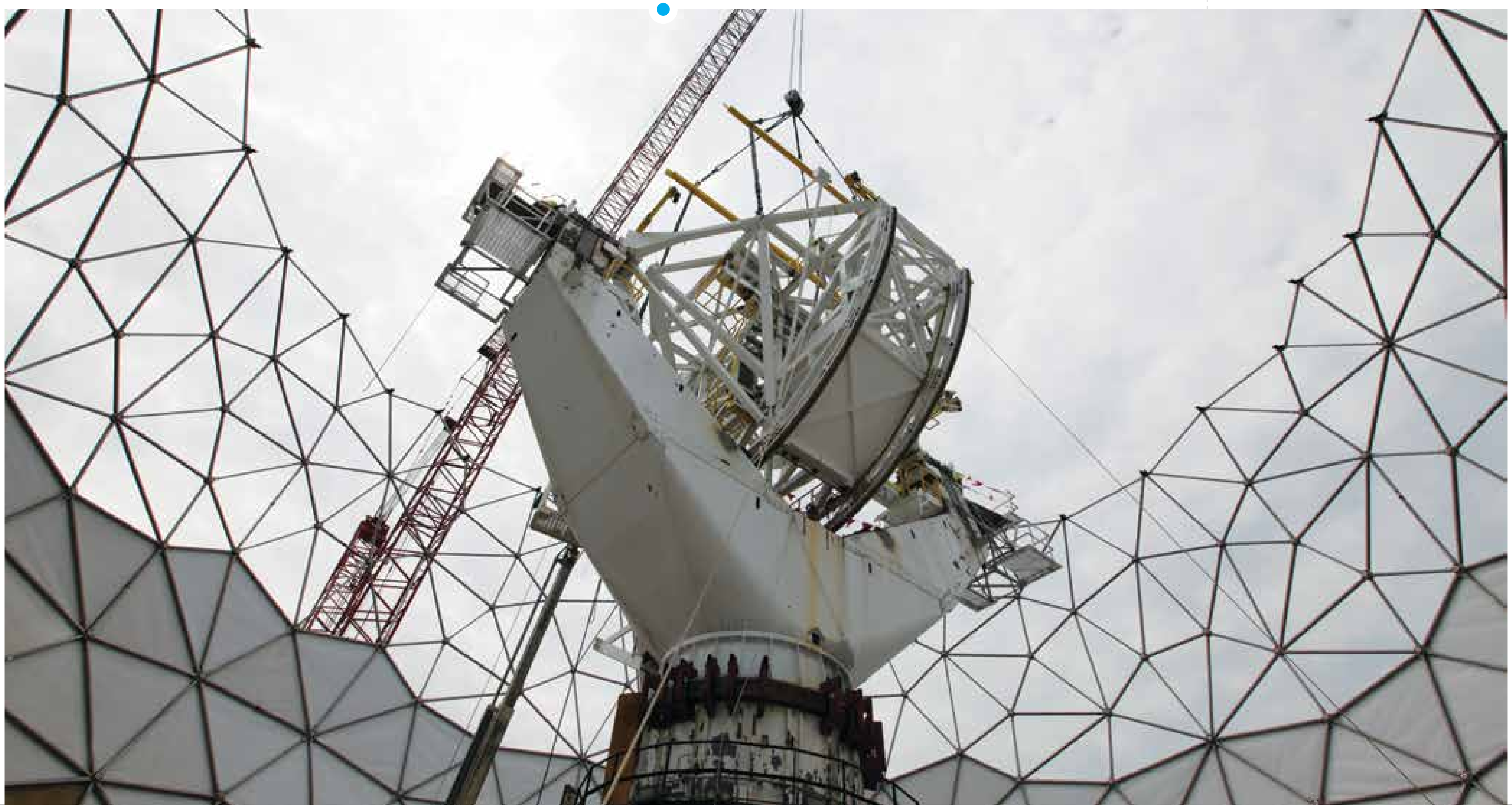
The 43-ton old backstructure was lifted over the edge of the radome and set down behind the temporary building to await demolition.

24 July 2010

To minimize risk to the newly built backstructure, the removal of the temporary building involved setting the building on rollers and rolling it into the parking lot for disassembly.

6 August 2010

The quadrapod was welded to the backstructure.



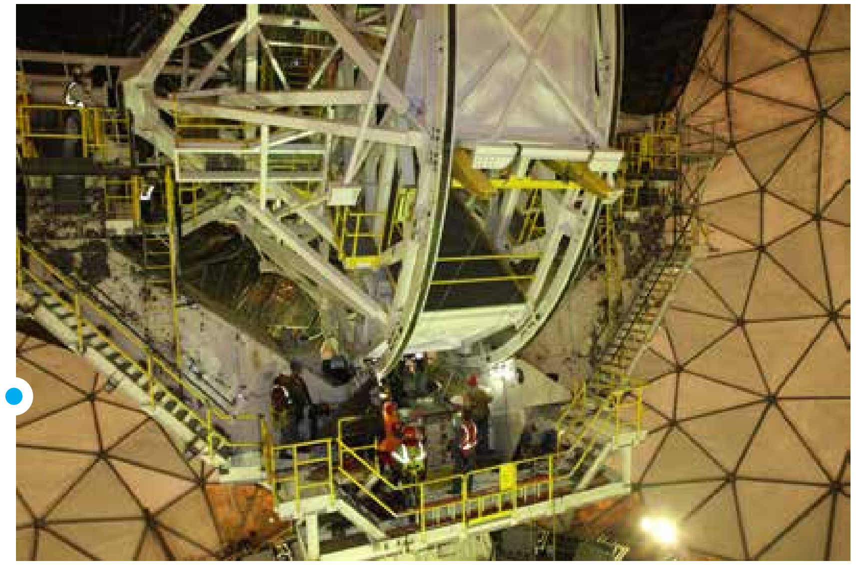
3 August 2010

The transition structure was lifted to prepare for installation on the modified yoke structure.

2 September 2010
The backstructure was carefully lowered into position on top of the waiting transition structure.

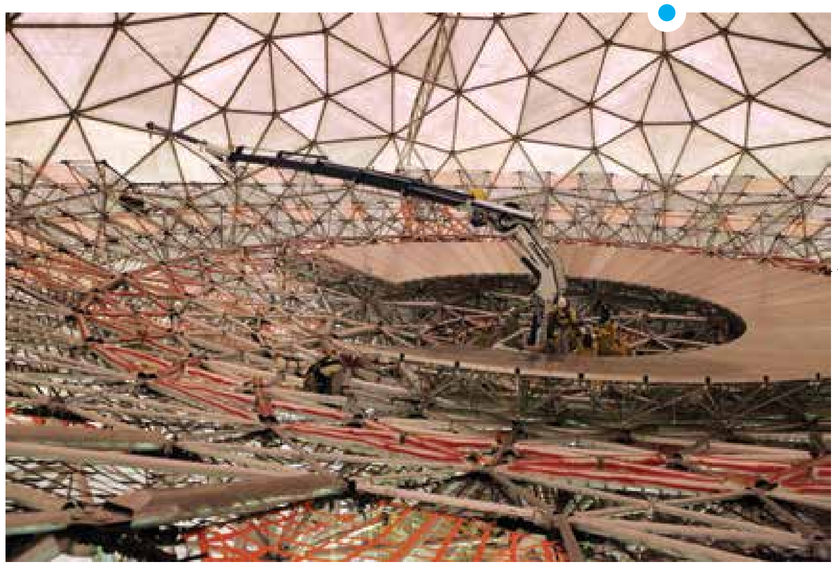
16 September 2010

The radome cap and remaining radome panels were replaced.



19 January 2011

With the antenna's primary surface fully installed, the new HUSIR antenna was ready for its first rotation about the elevation axis.

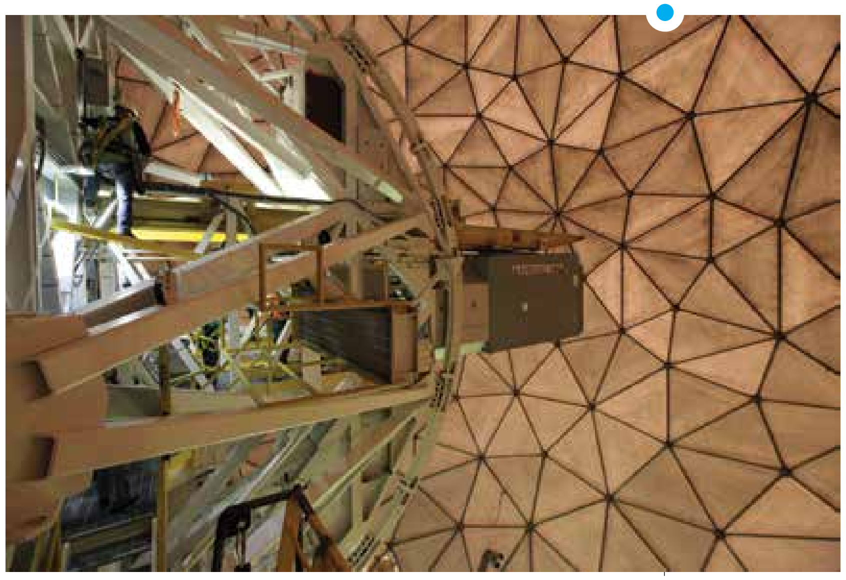


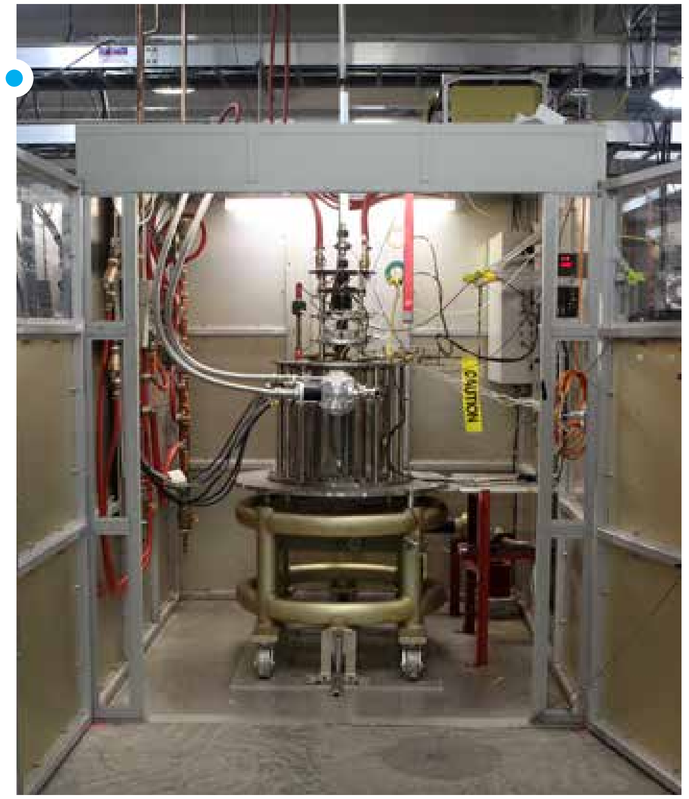
25 October 2010

Panels and subframes were installed.

26 January 2012

The addition of the Octagon onto the front of the RF box enables the once separate functions of radar and radio astronomy to be merged into a common RF box for nearly instantaneous switchover between the two modes.





10 August 2012

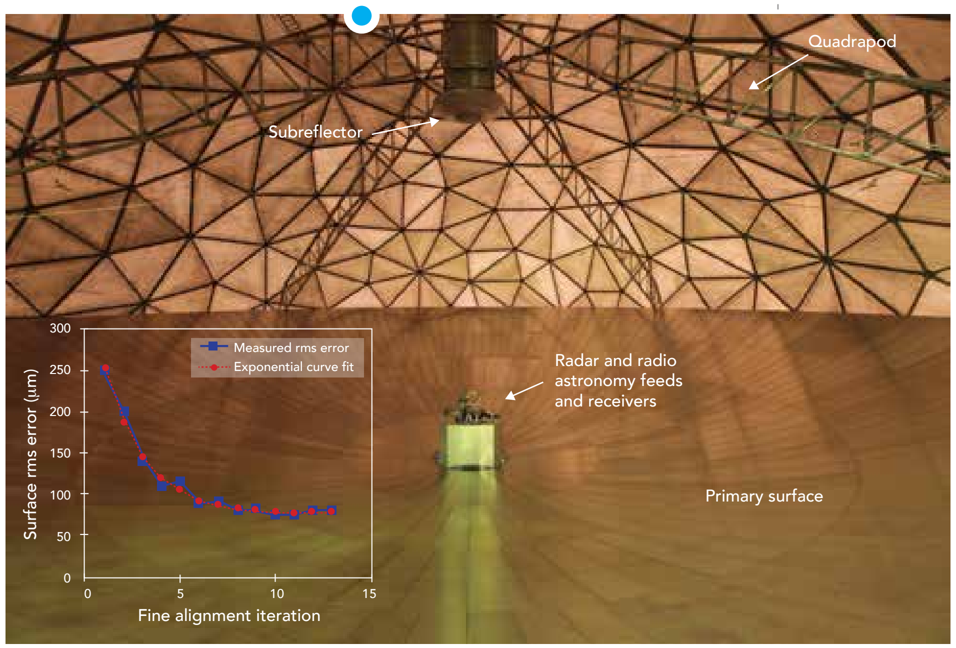
The gyrotron traveling-wave tube (gyro-TWT) was installed in its high-voltage enclosure. The gyrotron is immersed in a strong magnetic field produced by a cryogenically cooled superconducting magnet that is isolated to prevent distortion of the magnetic field. The gyro-TWT has a peak output power of 1 kW and operates from 92–100 GHz.

19 April 2013

Inside the HUSIR control room, a series of computer screens displayed radar and mission status information, as a single operator controlled the radar.

6 March 2013

Following panel alignment, the 120 ft diameter primary reflector surface achieved its final precision alignment goal, allowing final dual-band (X and W) integration and testing to proceed in preparation for transitioning HUSIR to operational use in the U.S. Space Surveillance Network.



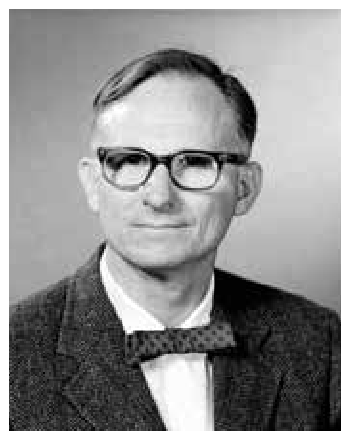
11 February 2014

(Left to right) Lt Gen Ellen Pawlikowski, Gen William Shelton, and Dr. Eric Evans performed the honors at the HUSIR ribbon-cutting ceremony.

Haystack Facility Leadership, 1959–2014

Beginning in 1959, Herbert G. Weiss, then the leader of the Special Radars Group at Lincoln Laboratory, directed the development of the Haystack Facility. By 1964, the Haystack radar was completed, Weiss was an associate division head in the Radar Division, and the Laboratory assumed operation of the facility. In 1970, in response to an amendment to the Military Authorization Act (see page 9), the facility was transferred to MIT ownership as the MIT Haystack Observatory, and operations were conducted under an agreement with the Northeast Radio Observatory Corporation. Since 1959, the following individuals have led the research and science missions at the facility.

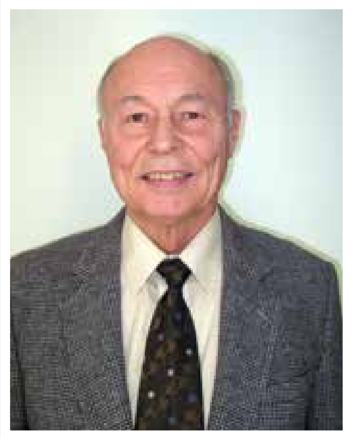
Herbert G. Weiss
Project Leader
Haystack Facility
1959–1964



Paul B. Sebring
Site Supervisor
Haystack Facility, 1964–1970
Director
MIT Haystack Observatory,
1970–1980

John V. Evans
Director
MIT Haystack Observatory
1980–1983

Joseph E. Salah
Director
MIT Haystack Observatory
1983–2006



Alan R. Whitney
Interim Director
MIT Haystack Observatory
2006–2008

Colin J. Lonsdale
Director
MIT Haystack Observatory
2008–Present

Microwave spectrum bands referenced in this booklet

Band	Frequency range	Wavelength range
C	4–8 GHz	7.5–3.75 cm
X	8–12 GHz	3.75–2.5 cm
W	75–110 GHz	4.0–2.73 mm

Production Credits

This commemorative booklet was created by the Communications and Community Outreach Office of MIT Lincoln Laboratory: David Granchelli, manager; Tammy Ko, designer; Dorothy Ryan, editor; Ariana Tantillo, editor.

The following people contributed their knowledge and guidance to this publication: William Brown, Colleen Cooney, Mark Czerwinski, Eric Evans, Colin Lonsdale, Mary Reynolds, Grant Stokes, and Nora Zaldivar.

Image Credits

Images not listed below were provided by Lincoln Laboratory and the Haystack Observatory.

Page 10
ATS satellite images courtesy of NASA.

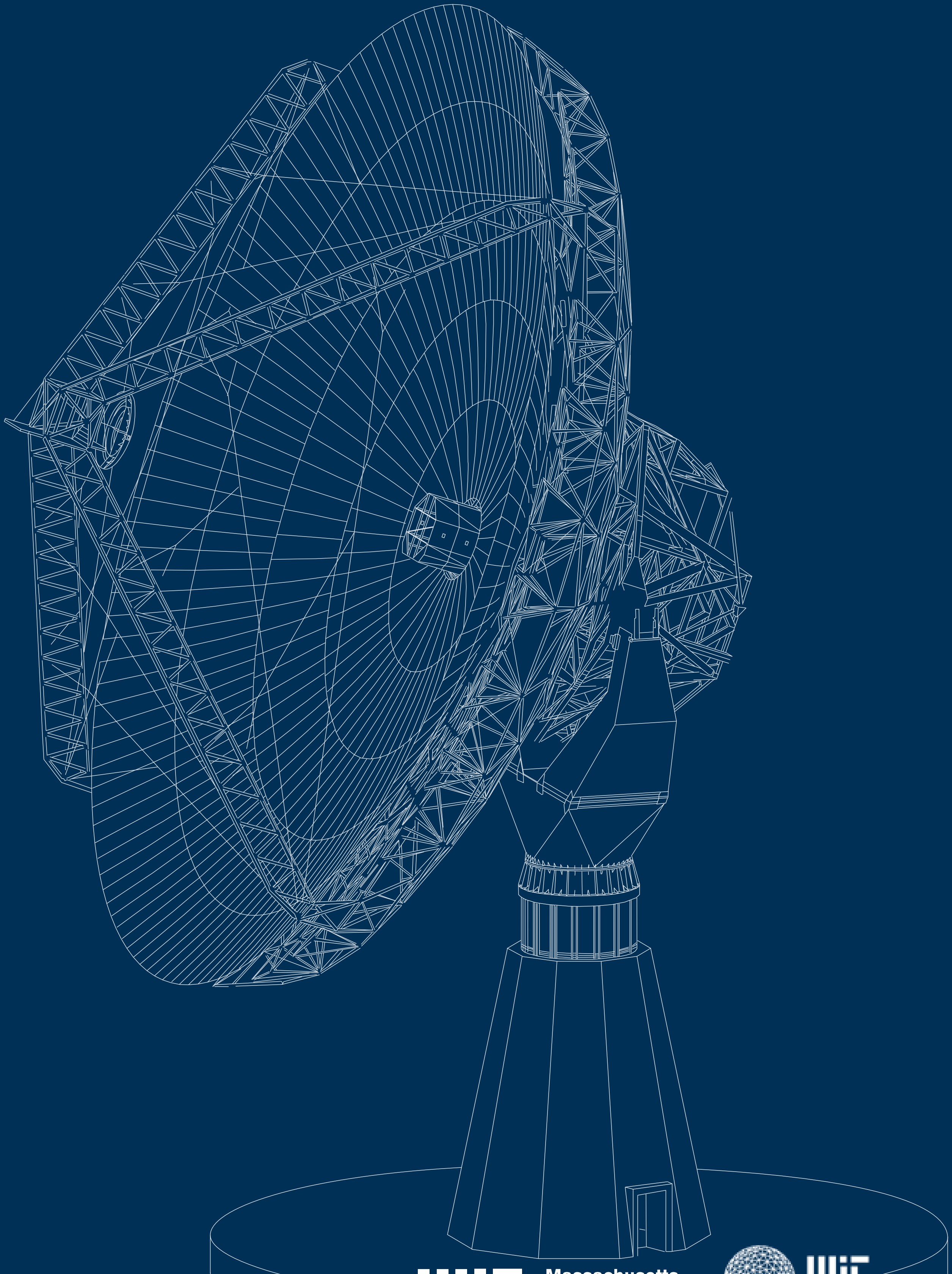
Page 11
Dense star cluster image courtesy of NASA.

Page 12
IRAS rendering and dense core image courtesy of NASA.

Page 13
Orbital debris image courtesy of NASA.

MIT Lincoln Laboratory: www.ll.mit.edu
MIT Haystack Observatory: www.haystack.mit.edu

Approved for public release; distribution is unlimited. This work is sponsored by the Department of the Air Force under Air Force contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.



LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
244 Wood Street, Lexington, MA 02420-9108

Massachusetts
Institute of
Technology

HAYSTACK
OBSERVATORY