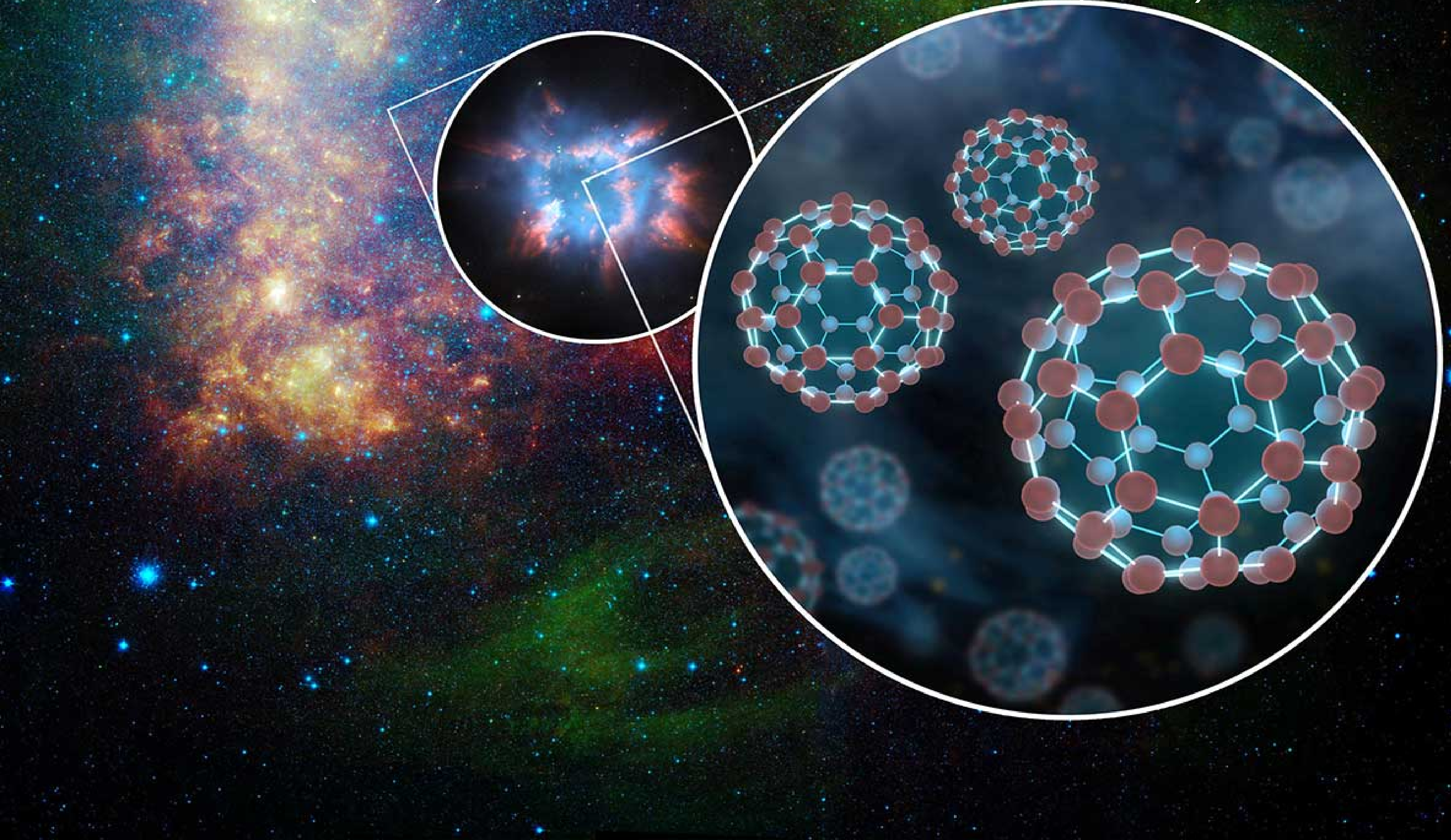
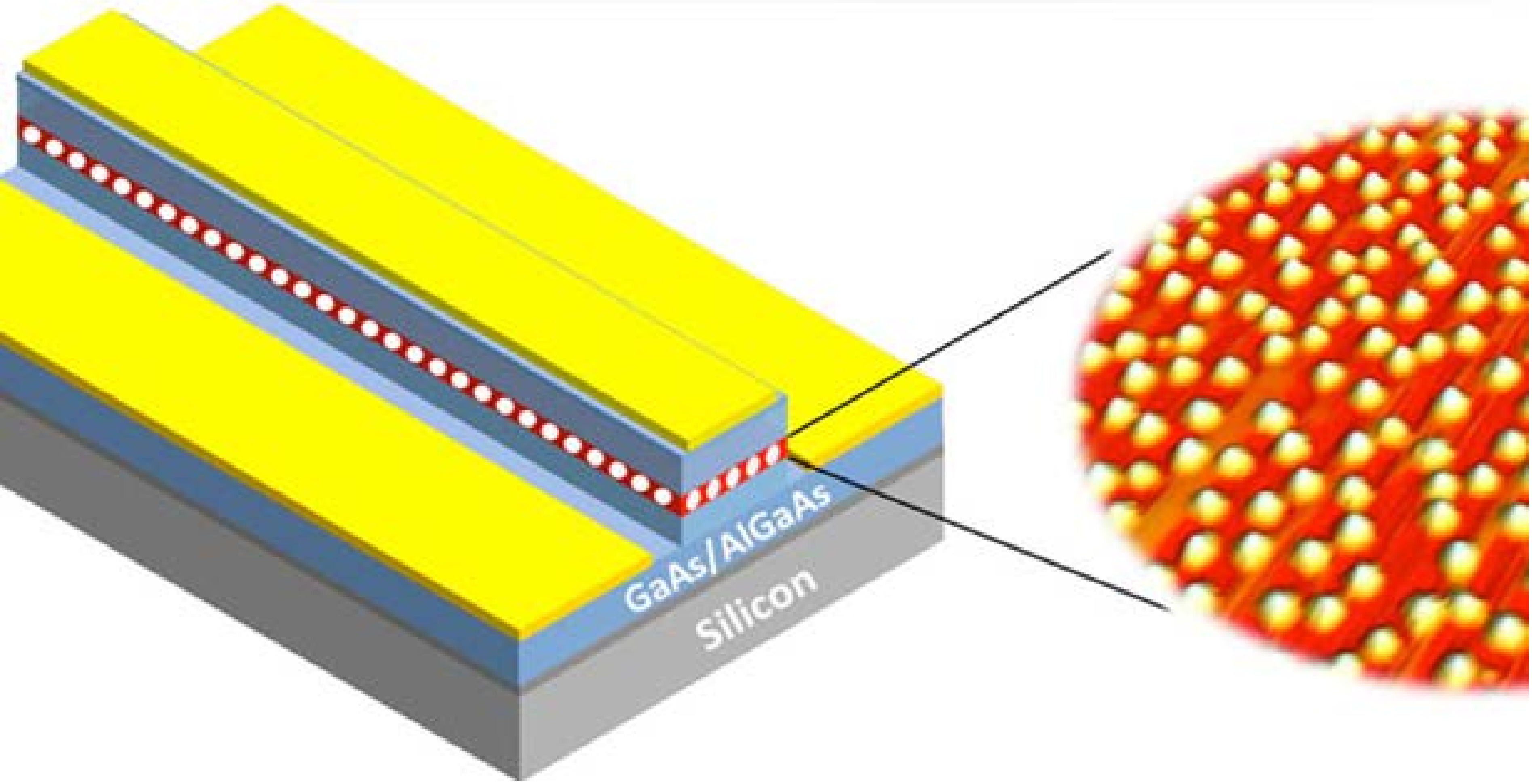
DARPA R&D: POWERS OF TEN

In its quest to develop technologies for national security, the Defense Advanced Research Projects Agency engages phenomena that range in scale from the atomic to the galactic. The following images from DARPA programs span this vast spatial spectrum, covering some 30 orders of magnitude—from tenths of nanometers (10^{-10} m) to tens of billions of billions of meters (10^{19} m).

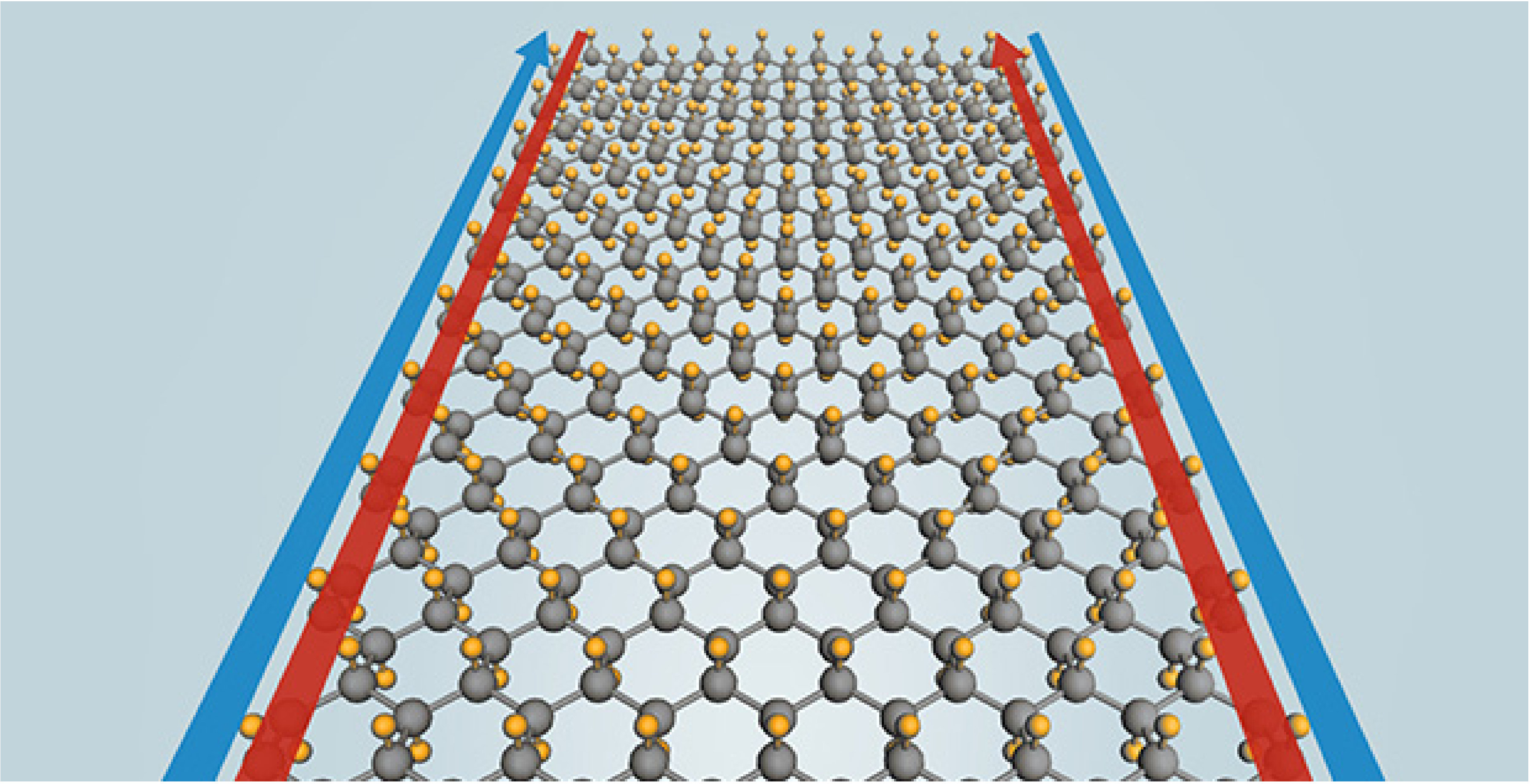


10^{-10} meters (tenths of nanometers)



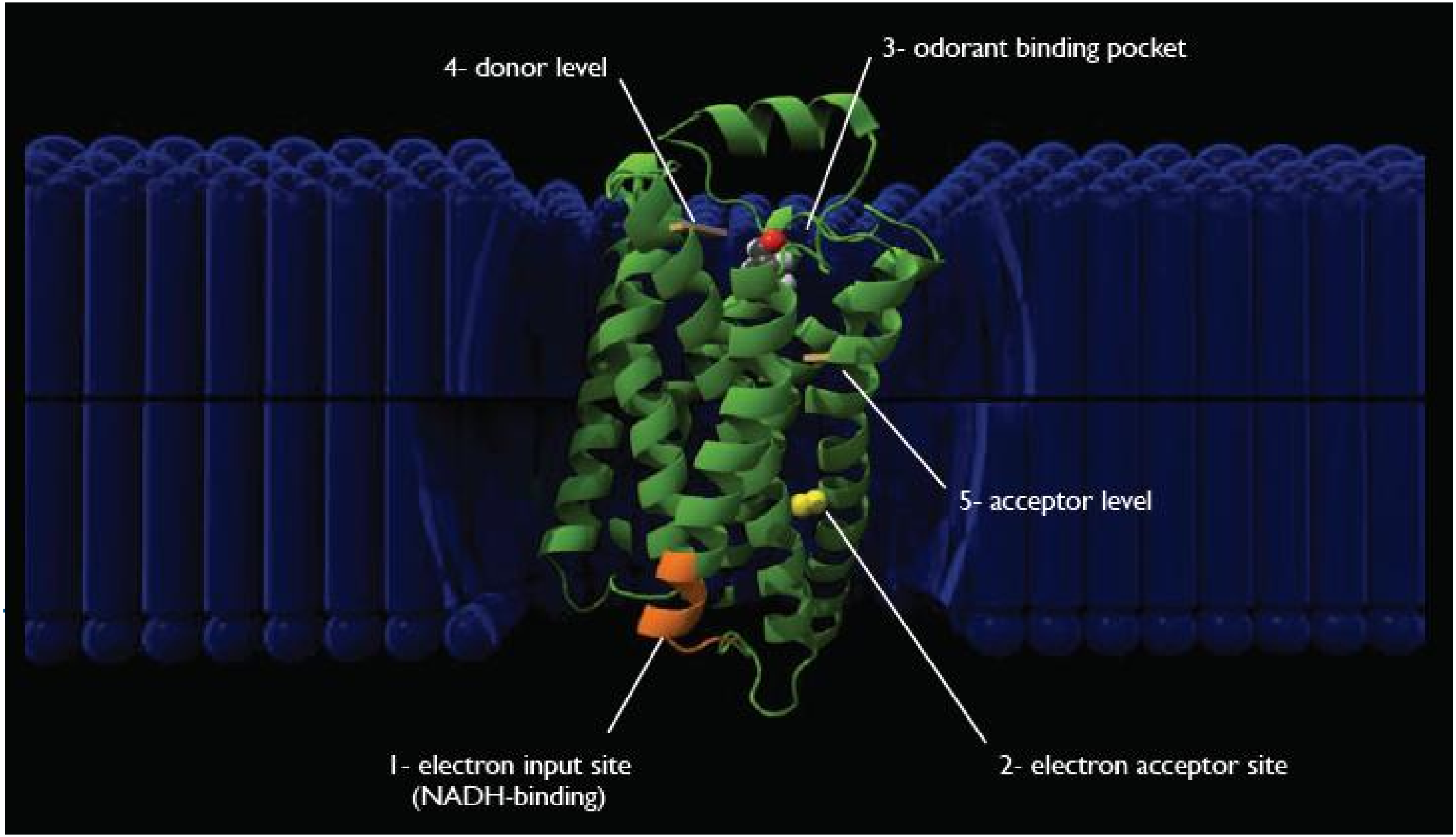
DARPA's **Electronic-Photonic Heterogeneous Integration (E-PHI)** program is all about combining different semiconductor materials into a new generation of chips that combine electronic, photonic and other functions. Shown is a diagram of just such a multi-material chip, along with an image—produced by a scanning tunneling microscope—of a layer that integrates billions of light-emitting, indium arsenide quantum dots, each one only a fraction of a nanometer in diameter. Such technology could lead to a new generation of miniature lasers for applications ranging from light-based computing to super-fast data transfer devices.

10^{-9} meters (nanometers)



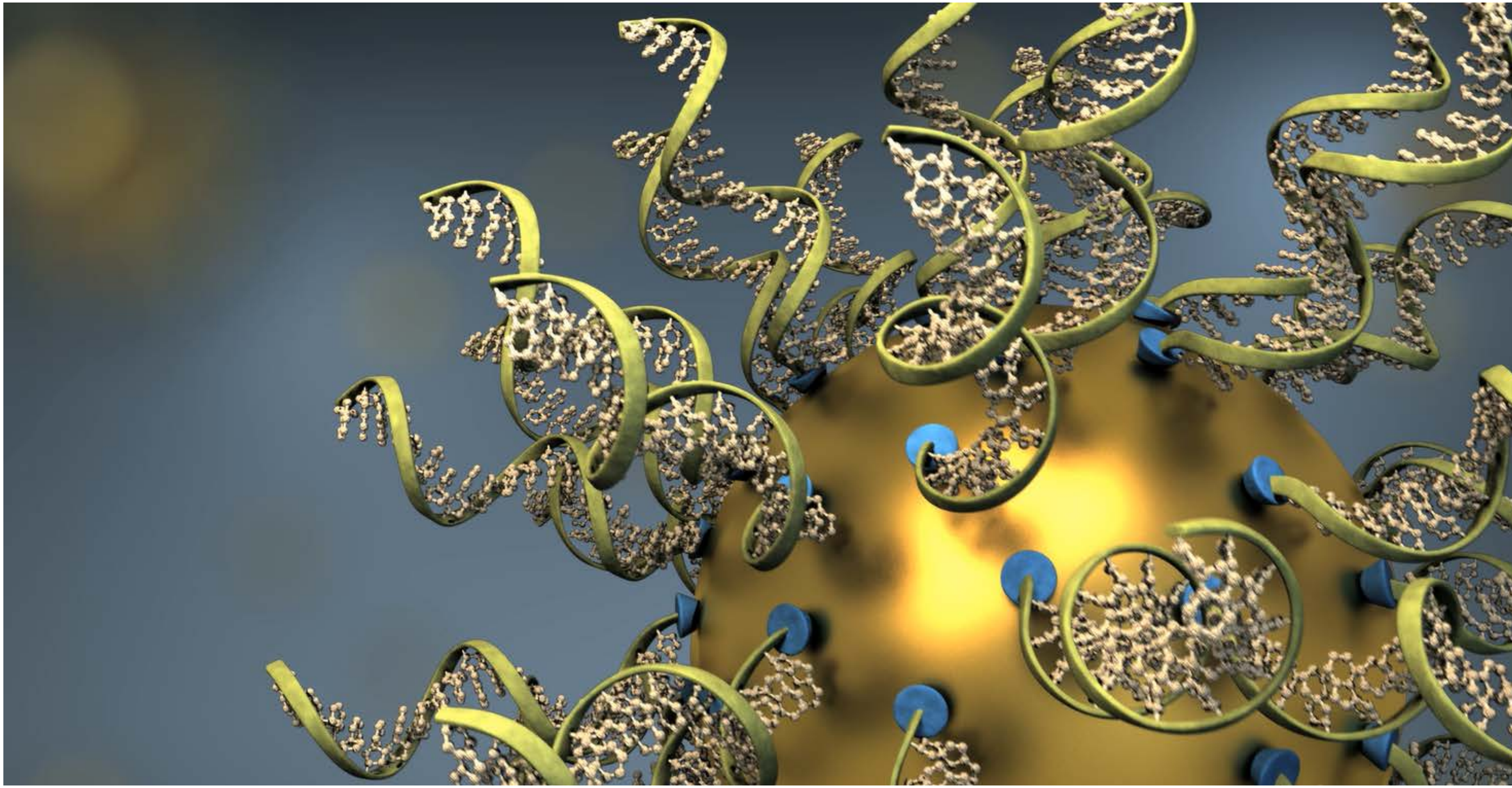
The **Mesodynamic Architectures (Meso)** program seeks to address future defense needs by exploiting unique characteristics of matter and energy that emerge specifically in structures precisely engineered at small spatial scales. Depicted here is a theoretical, atom-thick sheet of tin with unique planar electron conduction properties that three-dimensional versions of the same composition cannot have. Engineering with such 2D materials, including stacks of them, could lead to such breakthroughs as new supercapacitors for quick jolts of power to magneto-optical arrays for new types of displays.

10^{-9} meters (nanometers)



The **Quantum Effects in Biological Environments (QuBE)** program is laying the foundation for novel sensor designs by revealing that naturally occurring biological sensors leverage not only classical physics but quantum physical effects as well. Depicted is a cell membrane with a protein receptor that exploits quantum interactions to detect odor molecules. Research into natural chemical sensors like this cell-made one can open opportunities to build artificial materials and structures with life-like sensing capabilities.

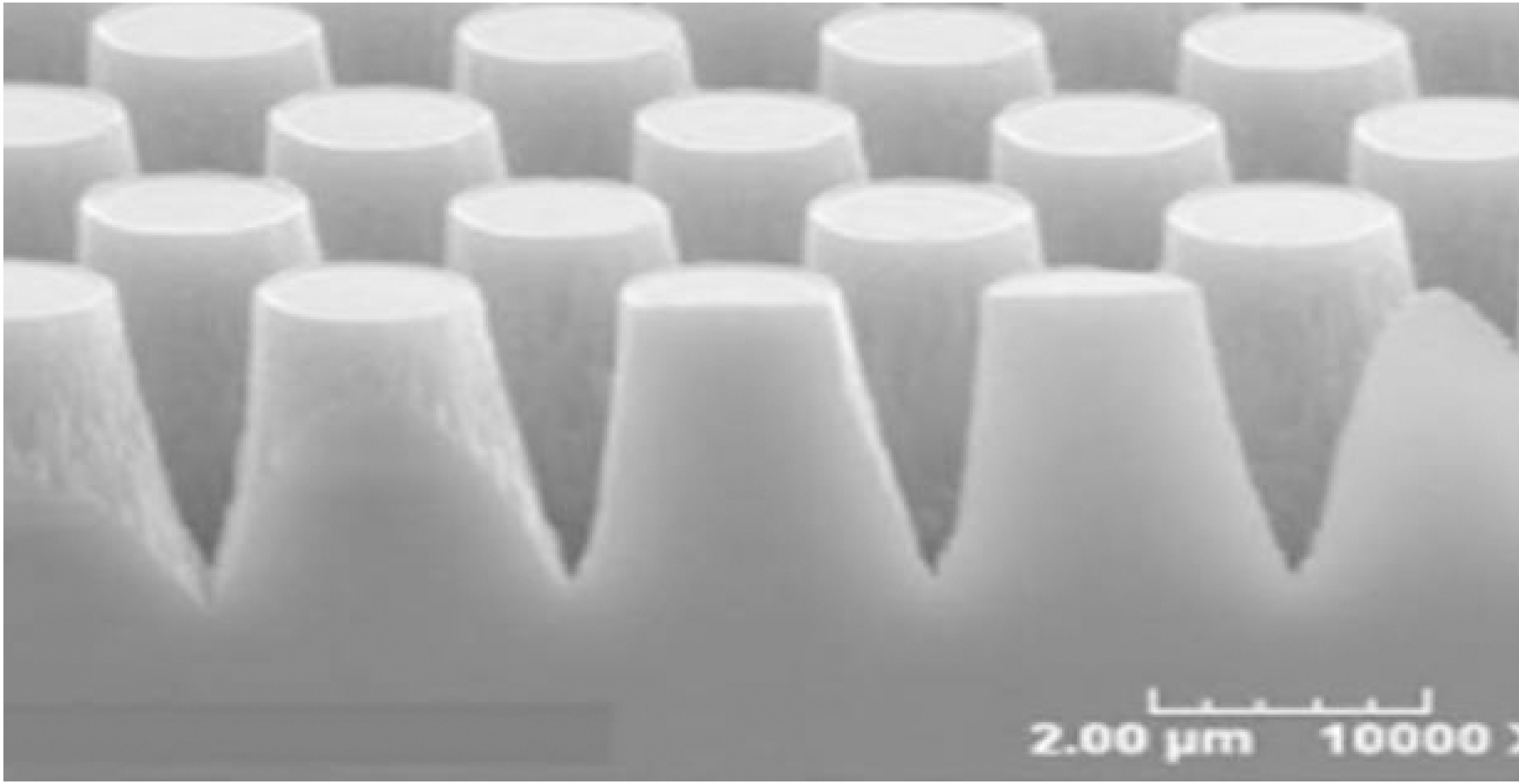
10^{-9} meters (nanometers)



DARPA's **Folded Non-Natural Polymers with Biological Function (Fold F(x))** program aims to emulate the powers of nature's own biological polymers, including DNA and proteins, using non-natural, sequence-dictated polymers built from lab-created chemical units known as monomers. Shown is an illustration of a cell-like factory churning out artificial protein-like polymers. Among the potential payoffs of such technology could be medicines that treat maladies, such as cancer and autoimmune disorders, without side effects.

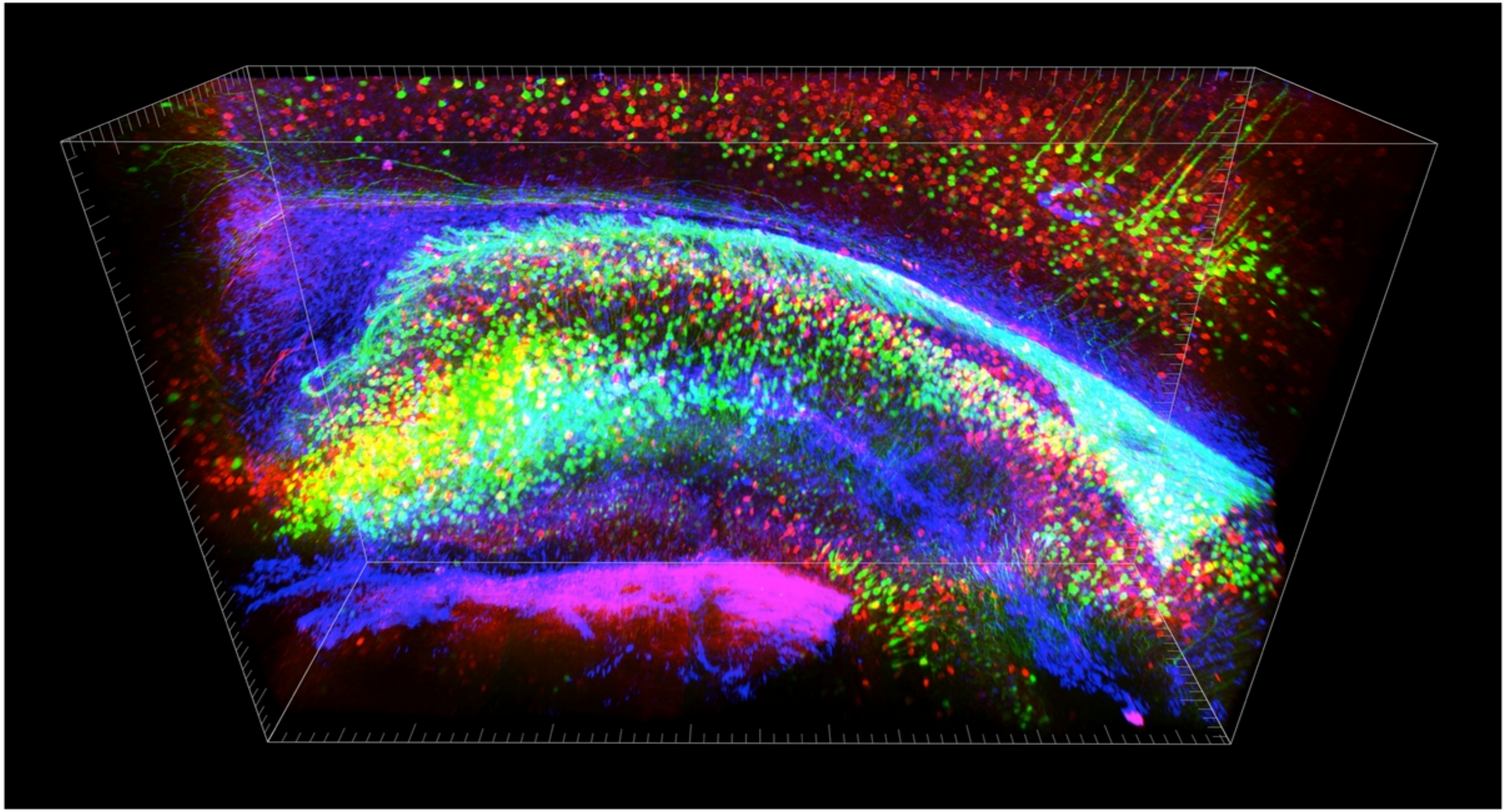
*Image courtesy of Northwestern University

10^{-6} meters (microns)



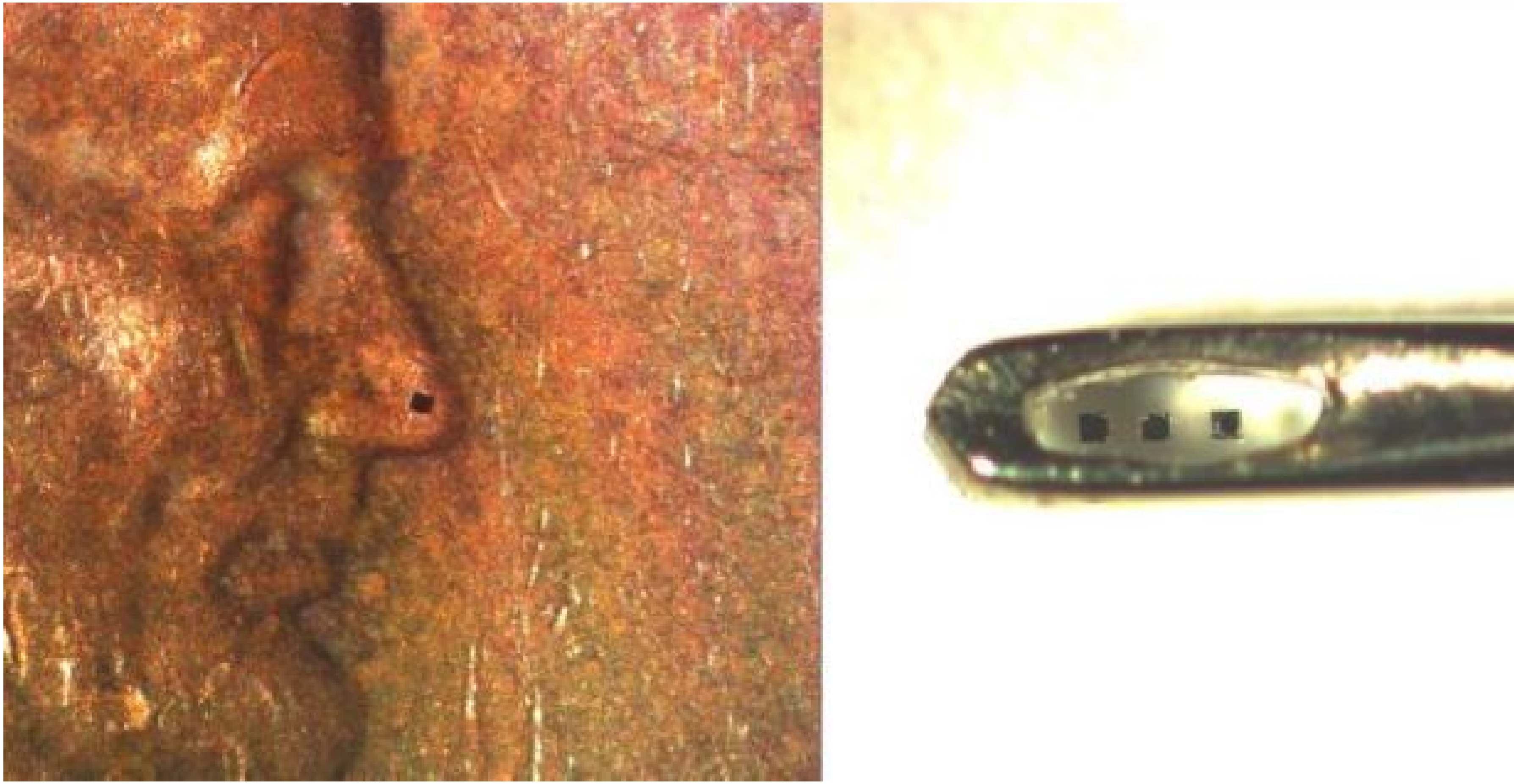
The **Advanced Wide FOV Architectures for Image Reconstruction and Exploitation (AWARE)** program could open new approaches to high-resolution and multi-band imagers sufficiently lightweight and compact to be fielded on a variety of ground and airborne platforms. Shown is an array of minuscule sensor elements, dozens of which could lay across a cut end of a human hair. Potential applications include sensors for search and discriminating targets in all weather day/night conditions.

10^{-6} meters to 10^{-3} (microns to millimeters)



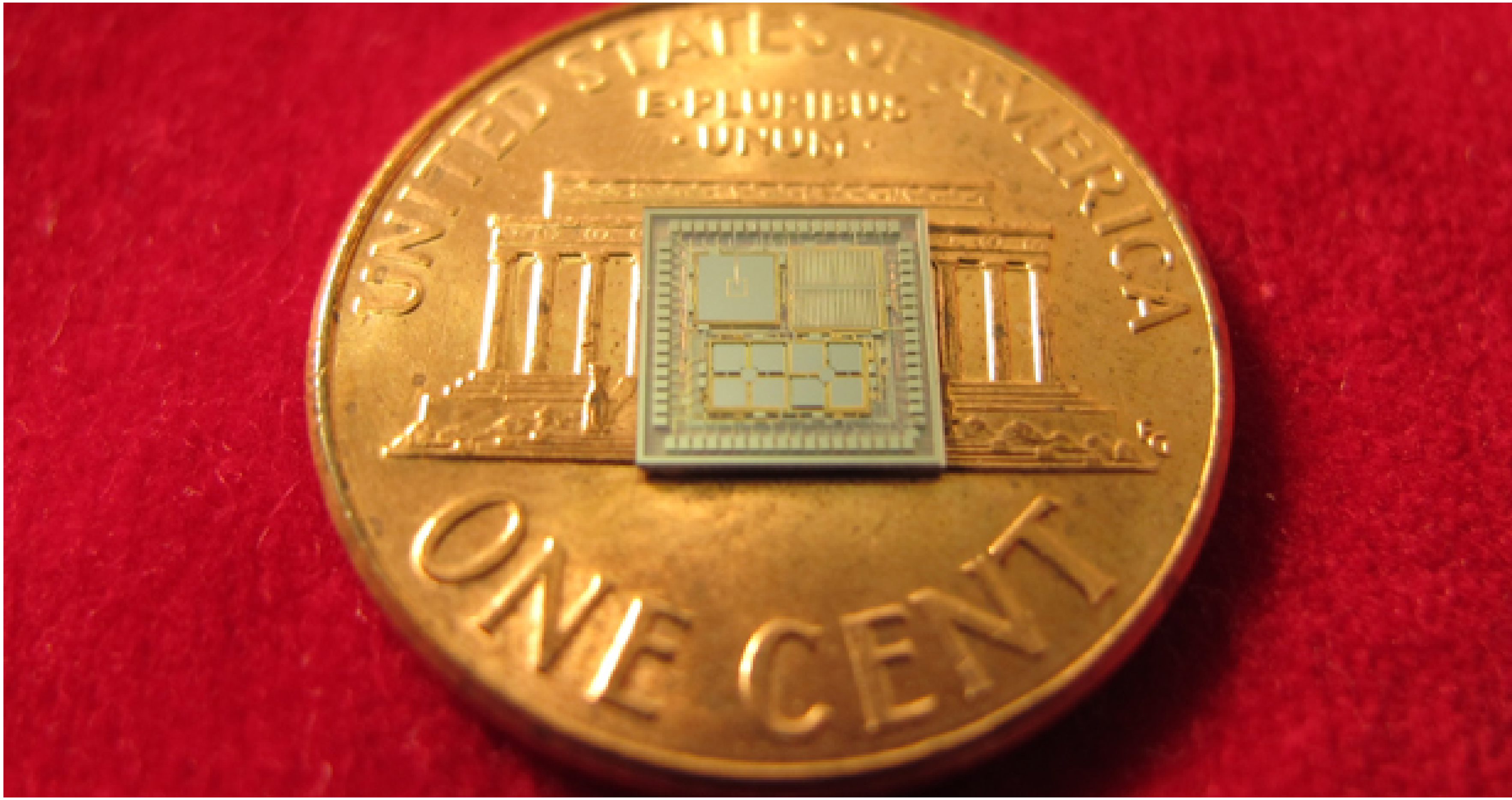
With support from the **Neuro Function, Activity, Structure, and Technology (Neuro-FAST)** program, Karl Deisseroth of Stanford University and colleagues developed a technique that renders brains transparent so that their microanatomies can be revealed with more CLARITY, which is what the researchers call the technique. Shown here is a block of mouse brain (the hippocampus) the size of a poppy seed, or about 1 cubic millimeter. By staining a clarified brain's different cells, such as excitatory neurons (green) and inhibitory neurons (red), with dyes that fluoresce in different colors, researchers can reveal, in unprecedented detail, how different cells and brain regions relate to one another.

10^{-3} meters (millimeters)



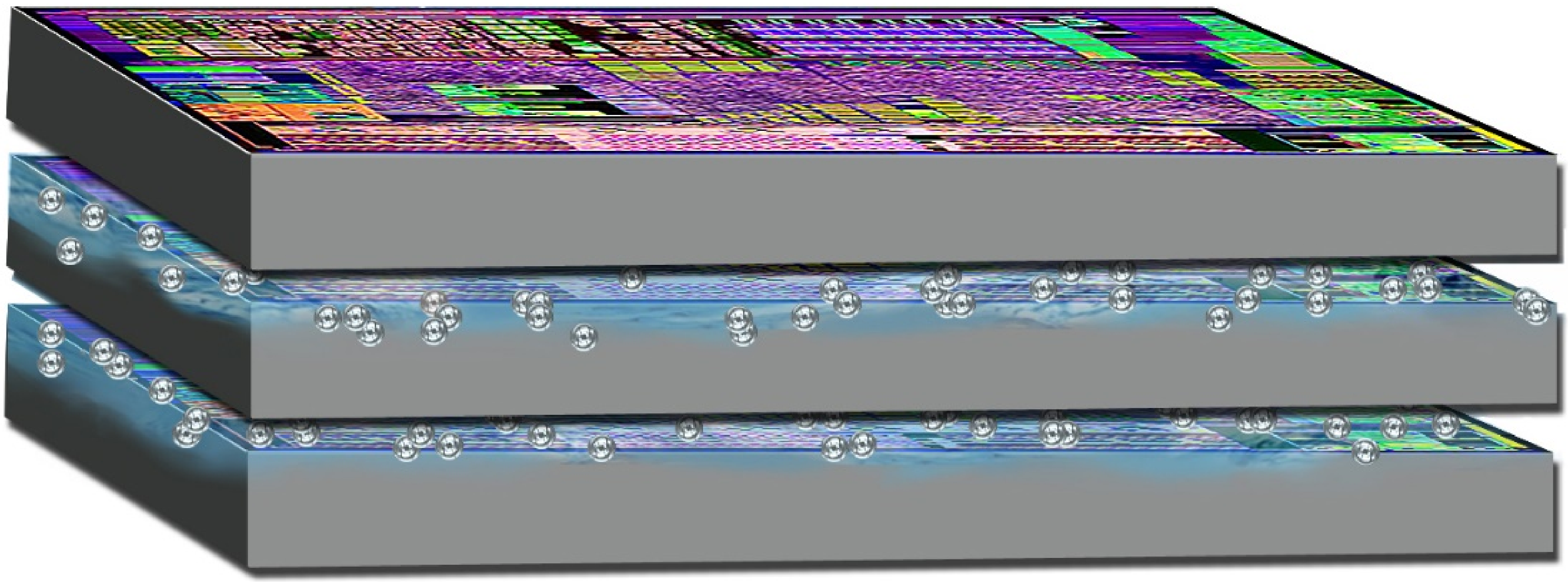
DARPA’s **Supply Chain Hardware Integrity of Electronics Defense (SHIELD)** program is taking on the growing threat of counterfeit, cloned or otherwise inauthentic chips becoming part of military systems, including fighter jets and missiles. Shown on the copper nose of this Lincoln penny and within the eye of a needle are preliminary versions of speck-sized chip-protecting dielets. Fully working dielets are expected to host up to 100,000 transistors and other devices. Among these will be tamper-detecting sensors, a two-way radio, and energy harvesters that cast away the need for a battery. Embedded in chips and other technologies, the dielets would detect counterfeit or adulterated circuitry in the civilian and military technology streams.

10^{-3} - 10^{-2} meters (millimeters to centimeter)



DARPA-supported researchers in the Agency's **Micro-Technology for Positioning, Navigation and Timing** (Micro-PNT) program developed a chip-scale timing and inertial measurement unit (TIMU) way smaller than a penny and is capable of kicking in for navigation if and when the Global Positioning System (GPS) becomes unavailable. The TIMU prototype shown contains three gyroscopes and three accelerometers, along with a highly accurate master clock. Embedded in on-ground systems, units like these could compensate if GPS signals from satellites suddenly went silent.

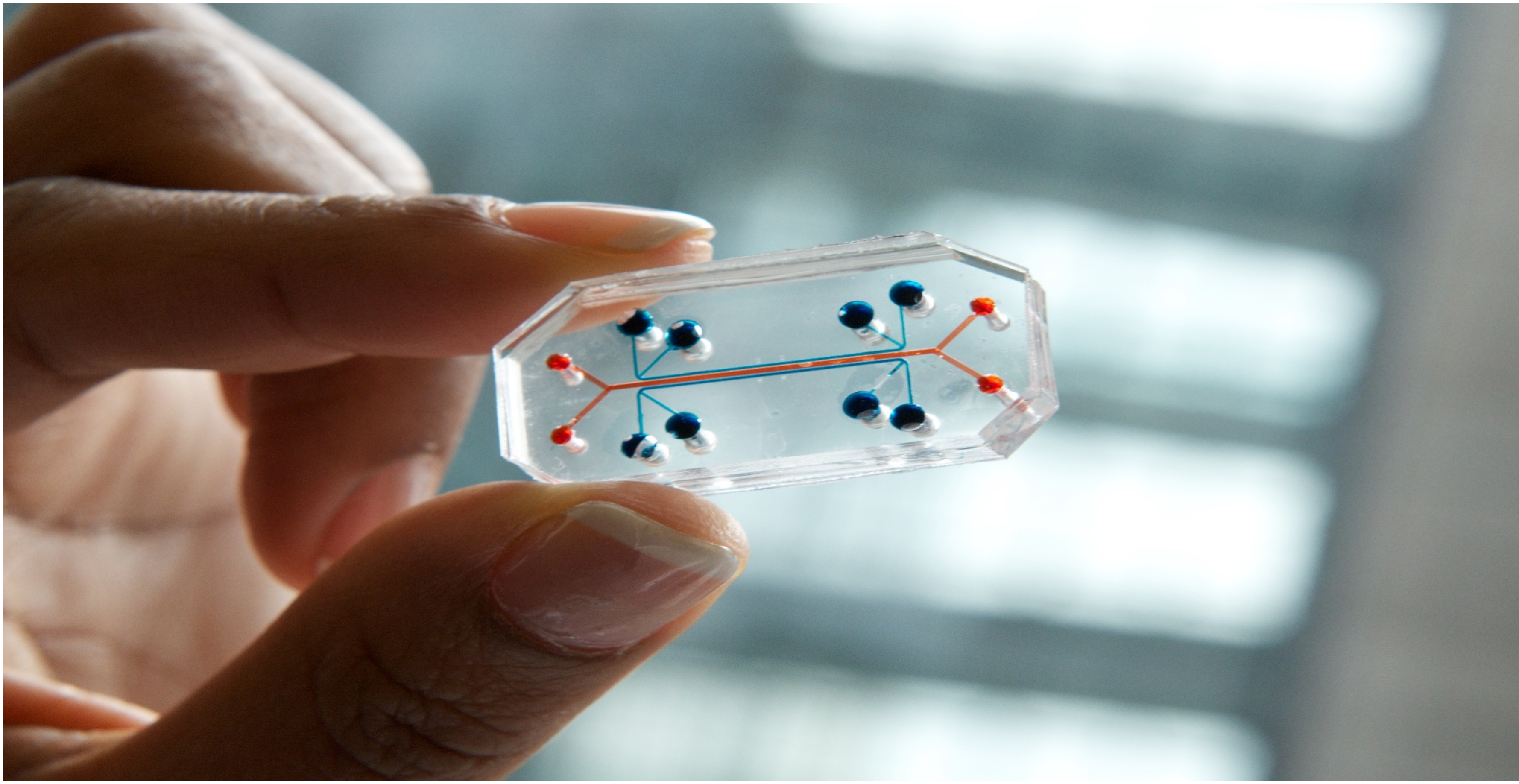
10^{-3} - 10^{-2} meters (millimeters to centimeter)



Artist's Concept

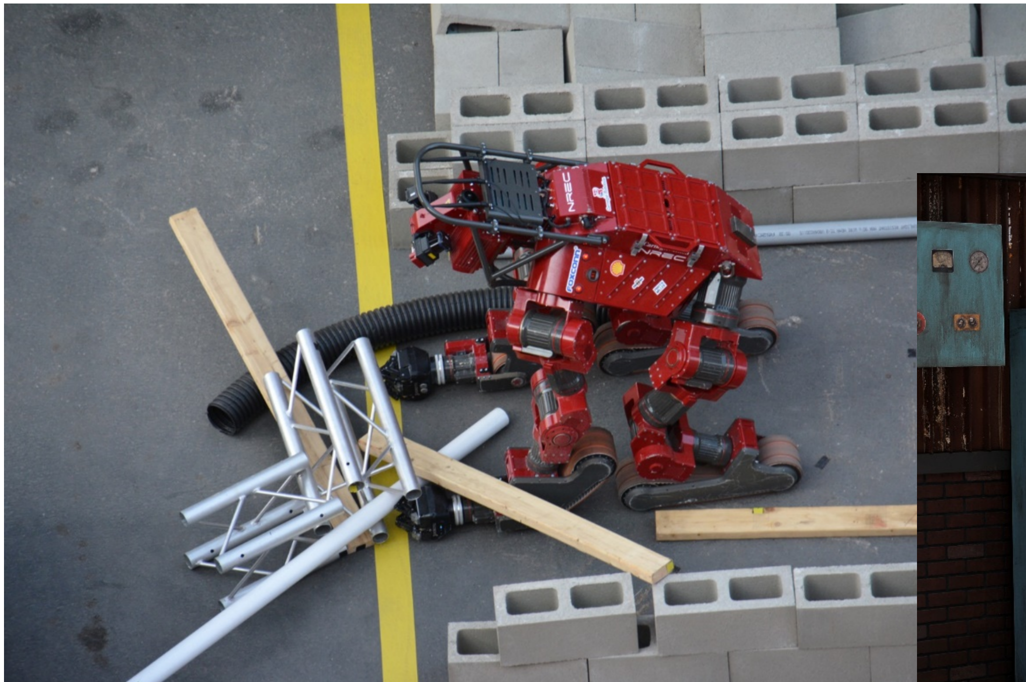
The **Intrachip/Interchip Enhanced Cooling (ICECool)** program is all about innovating ways of rapidly shunting heat away from microelectronic chips, which pack ever more heat-generating transistors and devices into ever tinier areas. The cooler one can keep a chip, the more the chip can handle higher-power operation and/or more working devices. Depicted is a microfluidic approach to this challenge in which coolant flows inside the chip via structures that directly underlie the active microelectronic layer (top). Success with ICECool may further the cause of many high-performance electronic systems, such as computers, high-power radar systems and solid-state lasers.

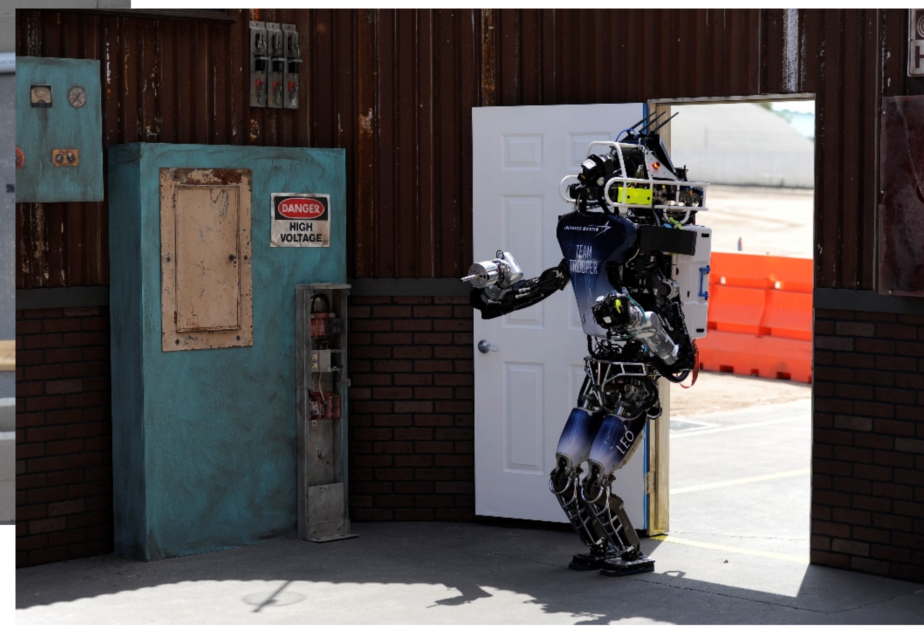
10^{-2} meters (centimeters)



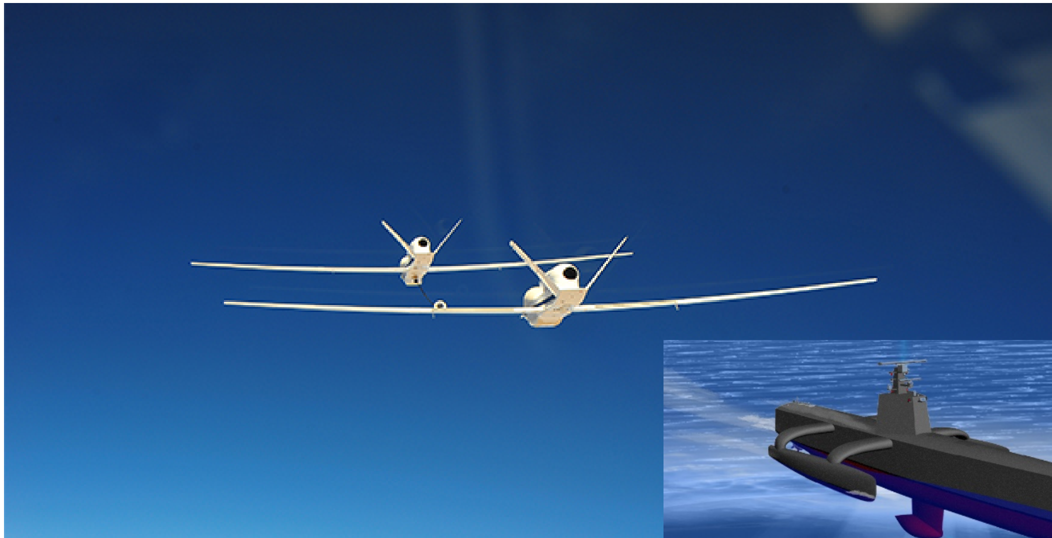
The point of DARPA's **Microphysiological Systems (MPS)** program is to accelerate the development of safe and effective countermeasures to protect warfighters from existing or emerging diseases, pandemics and bioterrorism. One approach in MPS is to develop chip- and cartridge-sized platforms, such as the "organ-on-a-chip" device shown here, that use engineered human cells and tissue to mimic physiological systems. The interactions that candidate drugs and vaccines have with these mimics could become helpful in predicting the efficacy and safety in humans of potential medical countermeasures.

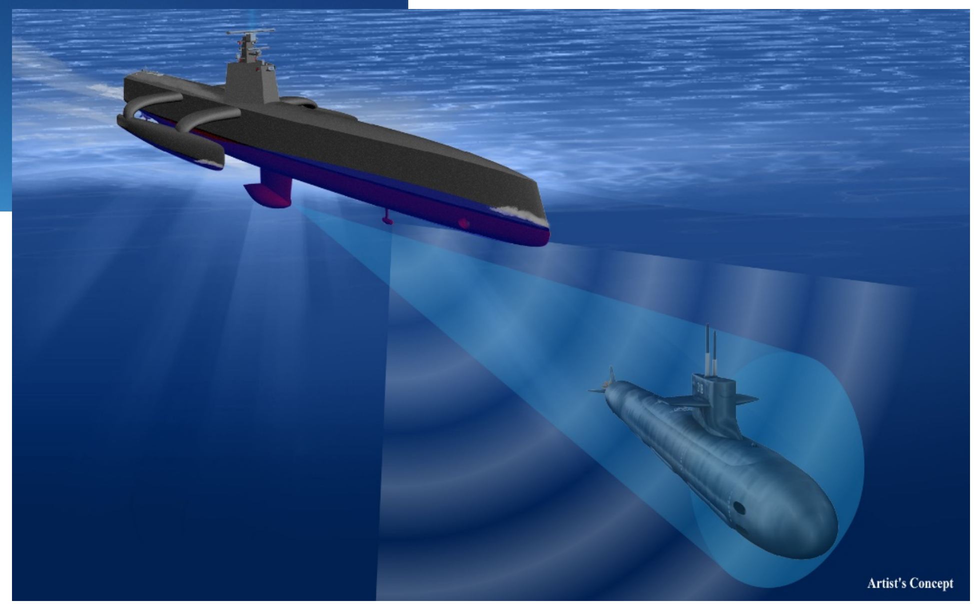
10^0 meters (meters)





In June 2015, more than 20 leading-edge robotics teams from around the world convened in Pomona, CA, for the **DARPA Robotics Challenge Finals.** Each team took on the task of building a robot system capable of executing seven basic tasks, such as driving a vehicle and turning a valve, which would likely apply in an industrial accident, earthquake, or other natural or human-wrought disaster. The robots shown here, CHIMP (left) and LEO, were fielded by teams from Carnegie Mellon University and Lockheed Martin.





Both the new **Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV)** program and the older **High-Altitude Refueling** program share the aim of pushing autonomous capabilities in military assets. The latter program demonstrated even in 2007 that one unmanned air vehicle (UAV) could refuel another one, while ACTUV's ultimate deliverables could be unmanned vessels optimized to robustly track quiet diesel electric submarines across oceans. The core platform and autonomy technologies of both programs are broadly extendable to underpin a wide range of missions and configurations for future unmanned vehicles.

10^3 meters (kilometers)

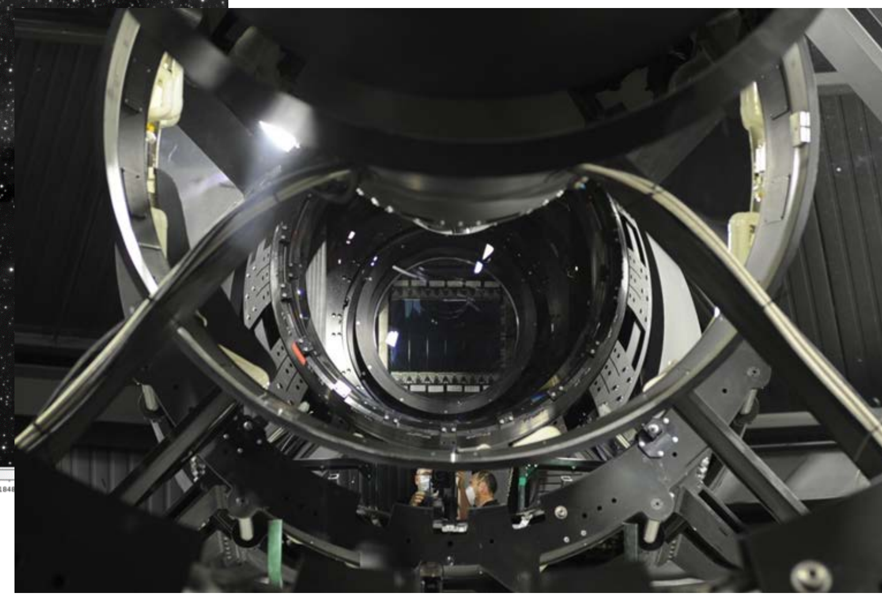
The DARPA **Nimbus** program was a fundamental science program focused on uncovering more about the still only partially understood lightning processes, including their associated emissions (such as x-rays) and their radio-relevant ionospheric components at the upper edges of the atmosphere. Shown is a bolt of lightning artificially induced by shooting conductors into highly charged clouds overhead. Among the potential payoffs of such research are insights into high-voltage, high-current electromagnetic phenomena, which could be applied to better protect troops, ordnance, and other military assets.

DARPA

10^3 to 10^6 meters (kilometers to thousands of kilometers)

Named for the imaginary, mischievous imps that became the good luck charms of many British pilots during World War II, DARPA's **Gremlins** program seeks to show the feasibility of conducting safe, reliable operations involving multiple air-launched, air-recoverable unmanned systems. To be successful, the program will likely employ intelligence, surveillance and reconnaissance (ISR) and other modular payloads, such as those depicted here.

10^5 to 10^{19} meters (planetary to galactic)



The **Space Surveillance Telescope (SST)** program aims to enable ground-based, broad-area search, detection, and tracking of faint objects in deep space for purposes such as protecting space-based assets and asteroid monitoring. Shown here is the SST’s Wide Field Camera and the telescope’s image of the Eagle Nebula, a Milky Way structure about 7000 light years away. The SST is designed to improve orbital determinations of newly discovered objects and to provide rapid observations of events, such as a supernova, which may only occur over a short period of time. In time, the telescope will serve as a dedicated sensor in the U.S. Space Surveillance Network, which tracks thousands of potentially dangerous pieces of large and small space debris.