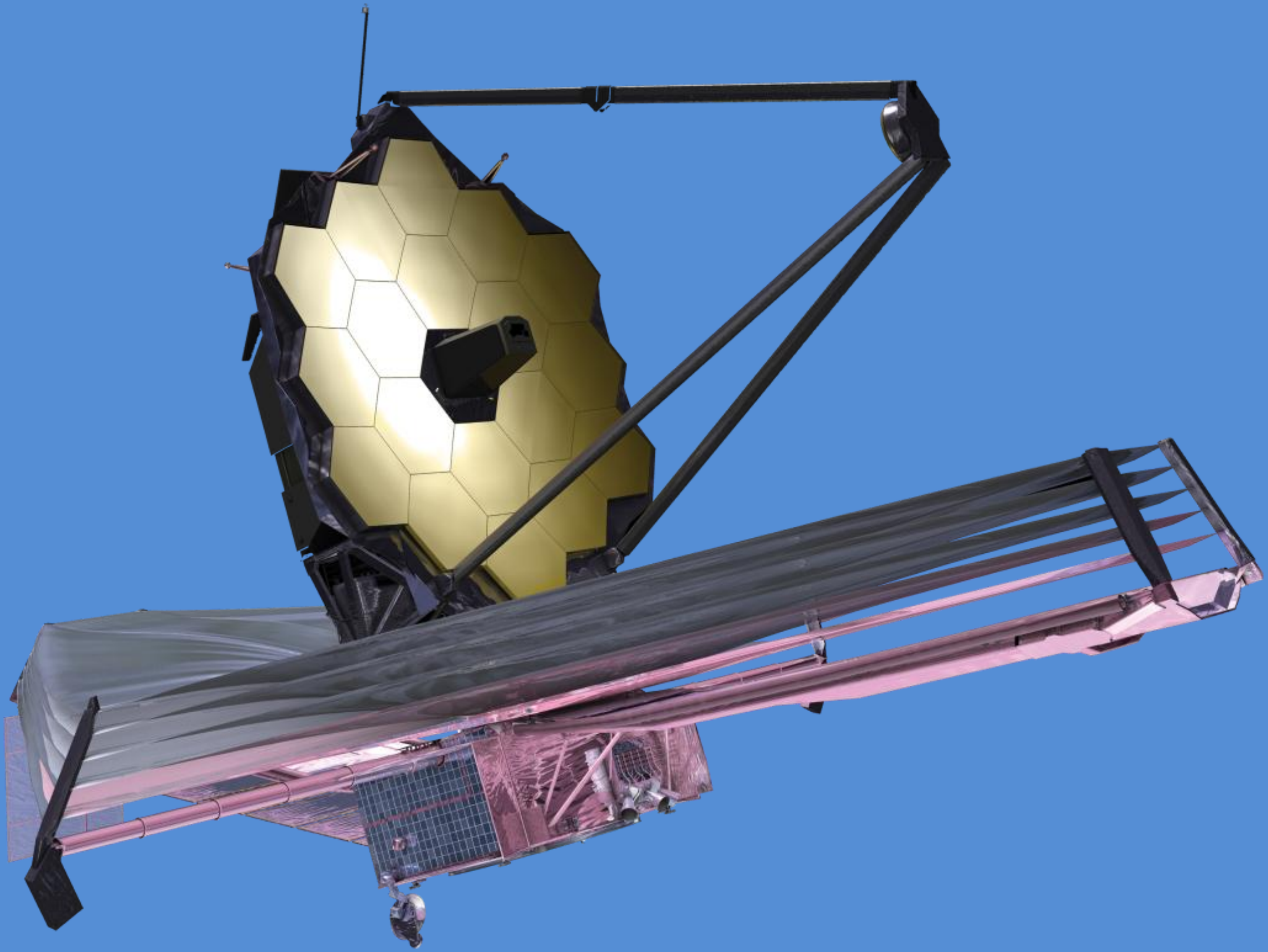
The new generation of great telescopes and what they reveal



Bob Dorsett
March 2026

The James Webb Space Telescope, NASA

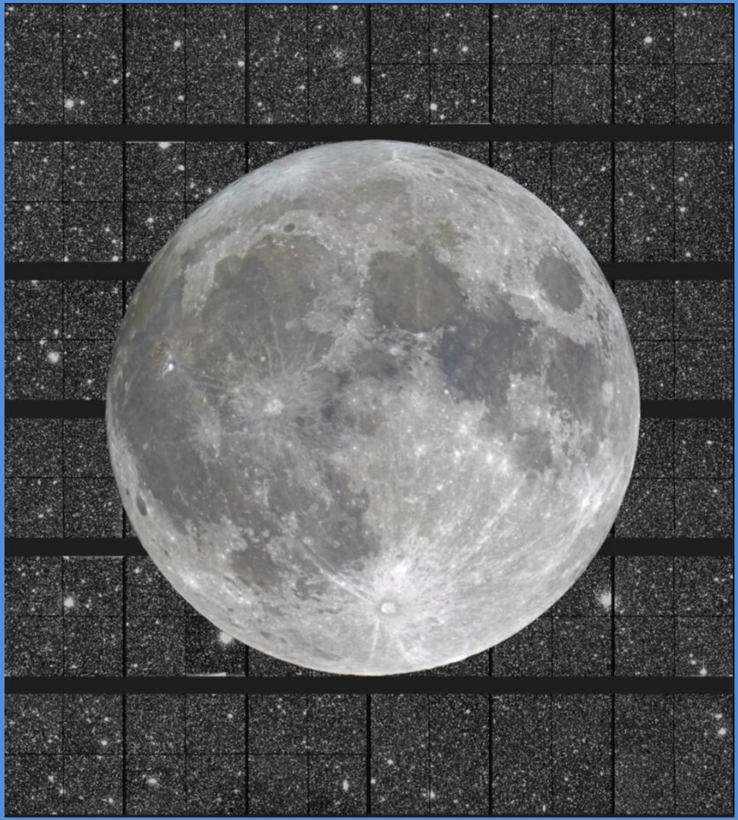
Introduction

A new generation of great telescopes has rewritten our understanding of the universe. The Hubble Space Telescope, now in its 36th year, led the way. New technologies and new detectors enable exploration beyond what even the Hubble scientists could imagine.

image: NASA

Hubble sees the universe through a narrow band of electromagnetic radiation, mostly in the visible spectrum. The new telescopes have expanded our view enormously. We now study the cosmos with improved infrared detectors, giant radio telescopes, particle detectors, and – a completely new window on the cosmos – gravitational wave detectors. Clever components allow some telescopes to study many thousands of objects simultaneously. New computer algorithms enable rapid analysis of enormous reams of observational data. We live in an era of exciting discovery.

Euclid captures one after another snapshots every 75 minutes of an area of sky greater than our moon's diameter and containing roughly 50,000 objects .



Our eyes collect information through the visible band, the rainbow of colors, in the electromagnetic spectrum. That's useful; most of the energy reaching earth from the sun comes in that band. Our eyes were the detectors for early telescopes, so those telescopes were optimized to collect visible light. Various objects in our universe, however, radiate vast amounts of energy in other bands of the electromagnetic spectrum. Highly energetic events such as supernovae radiate gamma rays and x-rays. Low temperature conditions, such as molecular clouds in star forming regions, radiate infrared. Galactic scale eruptions, as in the jets from accreting supermassive black holes, generate radio waves.

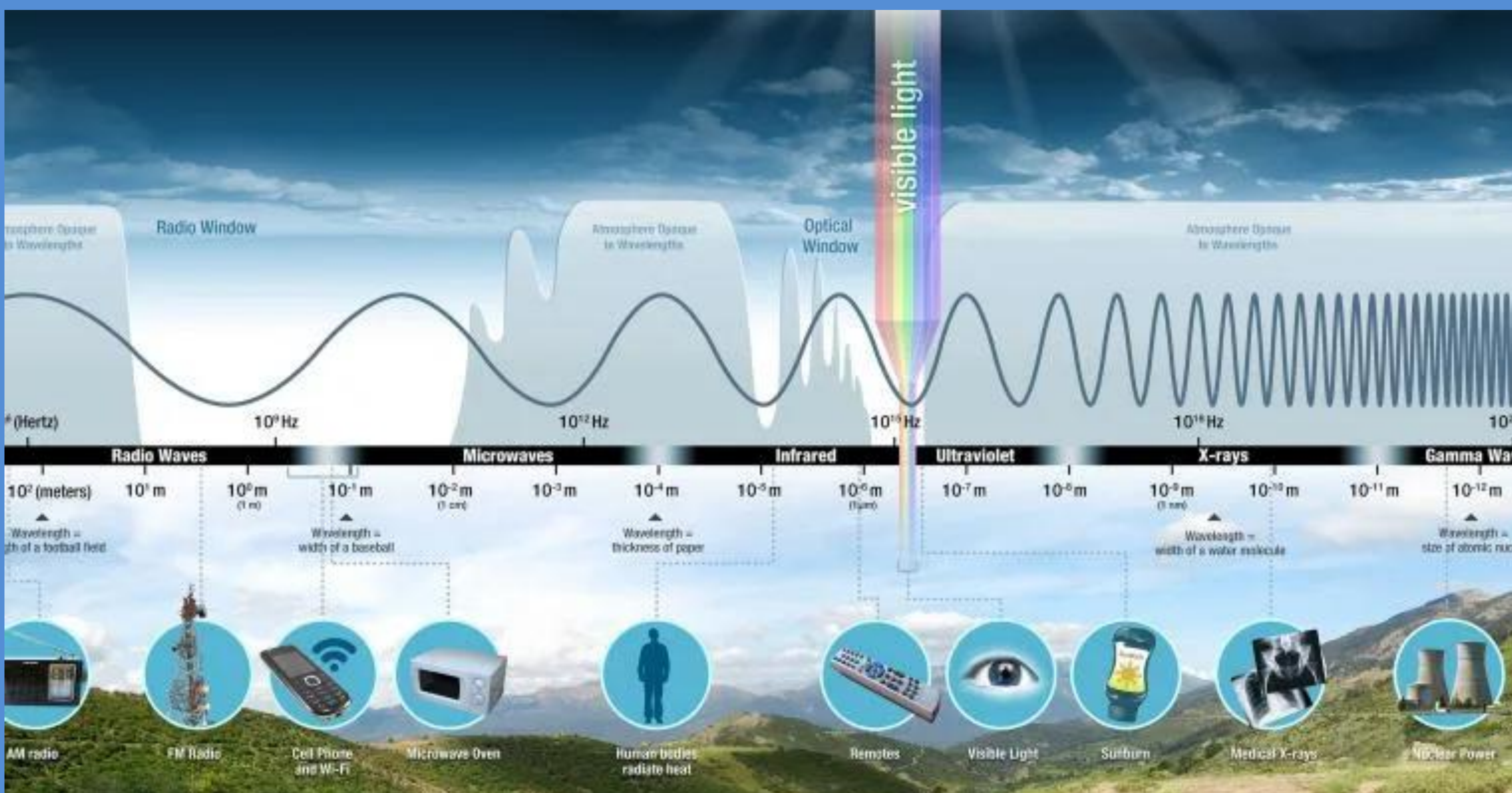
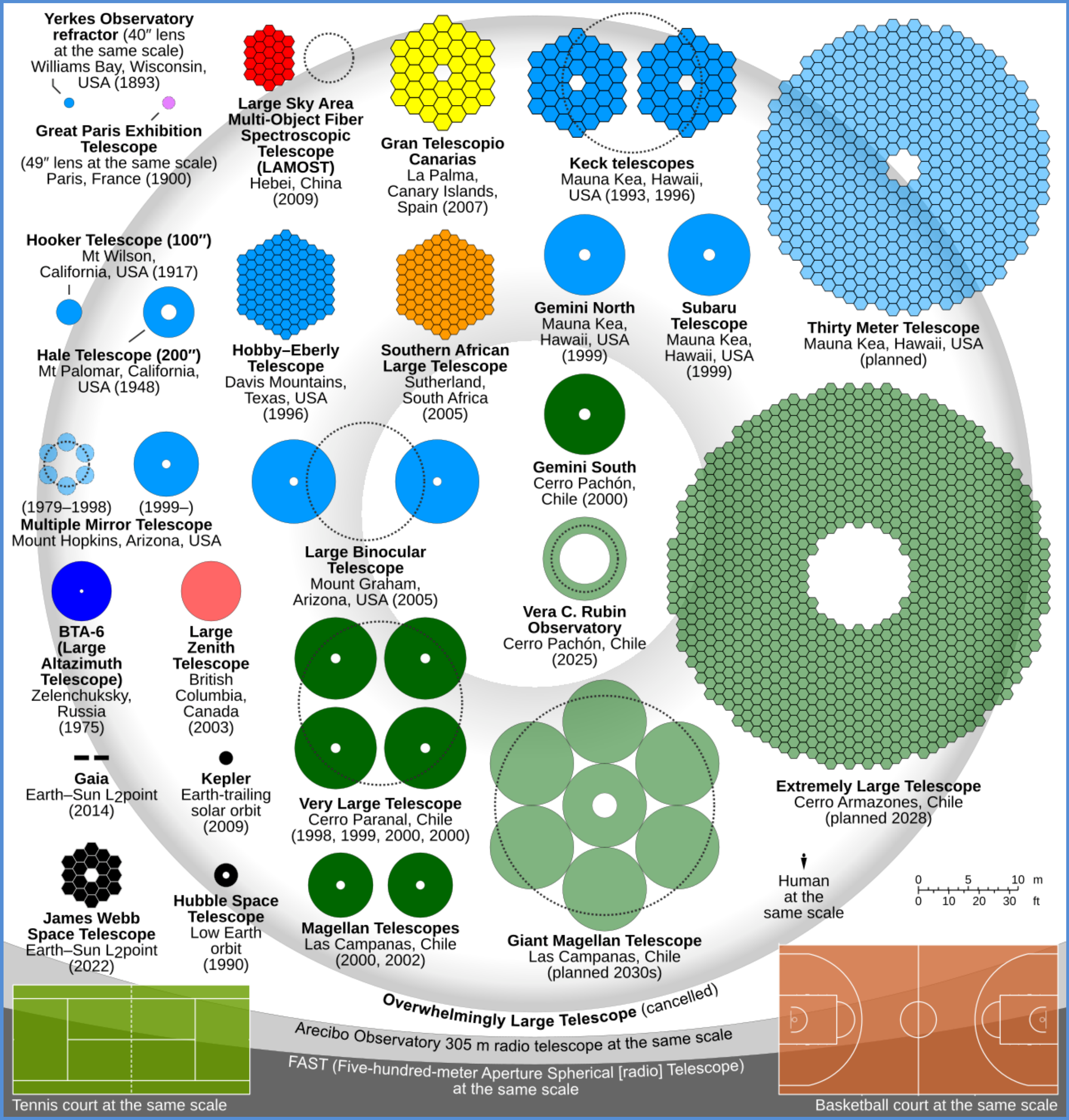


image: NASA

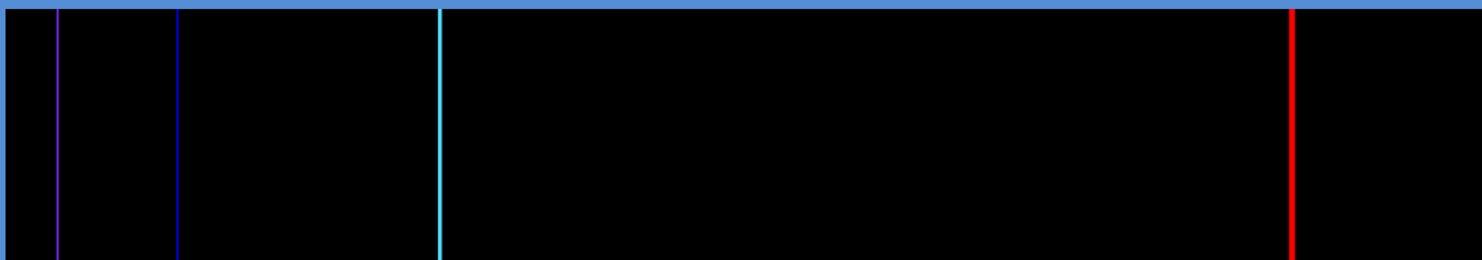


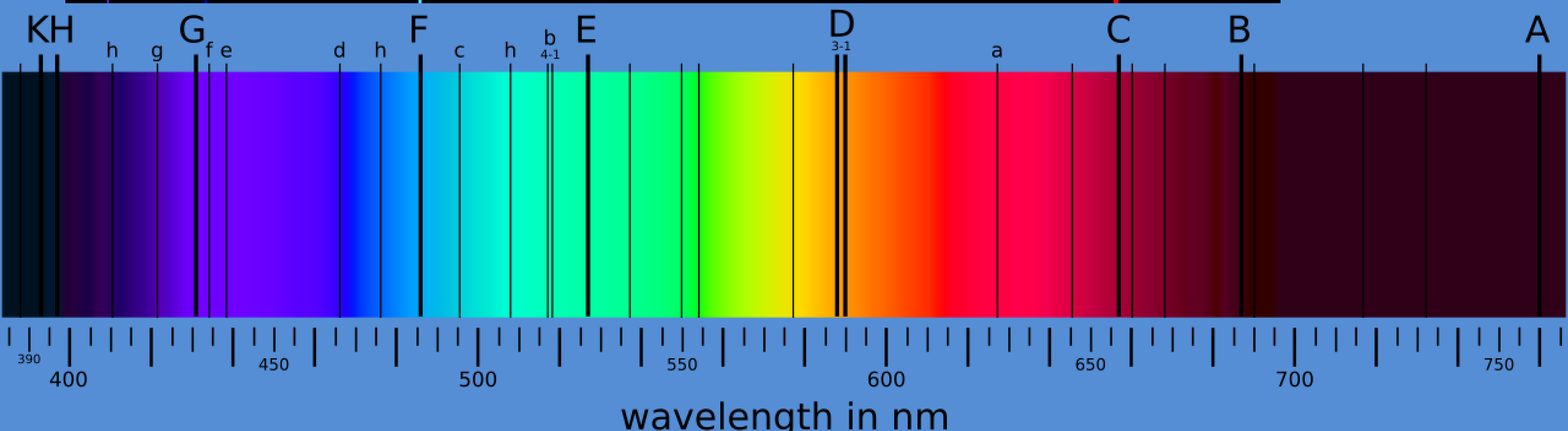
A sampling of the world's optical telescopes. Note latest segmented design with adaptive optics.

Image: Wikipedia

Electromagnetic radiation carries information about the elemental composition of distant objects, distance to those objects, and relative velocities.

Hydrogen spectrum

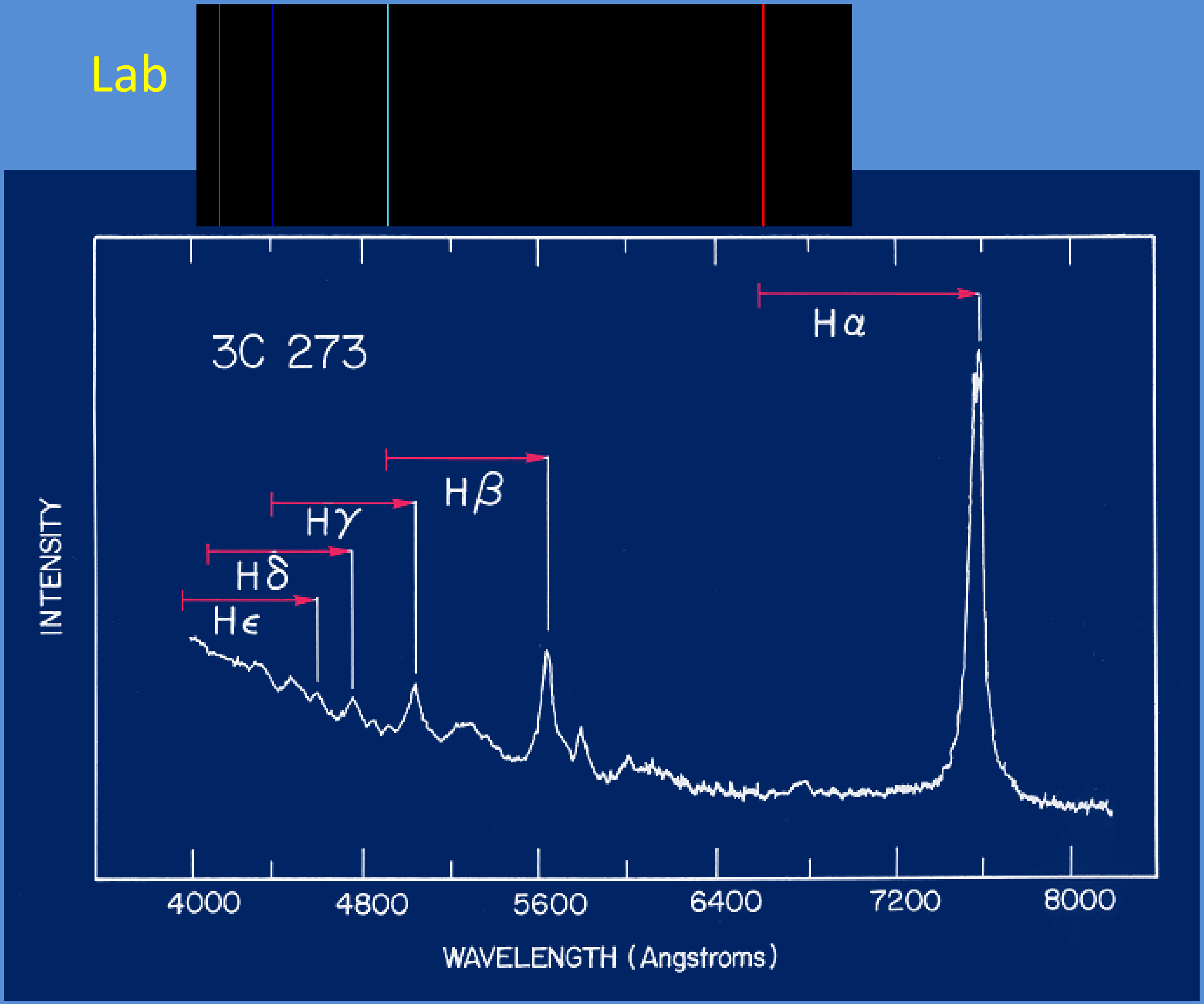




Solar spectrum

Hydrogen lab spectrum vs. 3C 273, a distant quasar. Red arrows indicate redshift of the 3C 273 spectrum.

Lab



Not only does the energy of an event affect what part of its spectrum we can see, but so do the dynamics of spacetime itself. We live in an expanding universe, and that expansion stretches the electromagnetic waves traveling through it. Spacetime expansion may stretch the x-ray from a distant supernova explosion into the infrared by the time it reaches us.

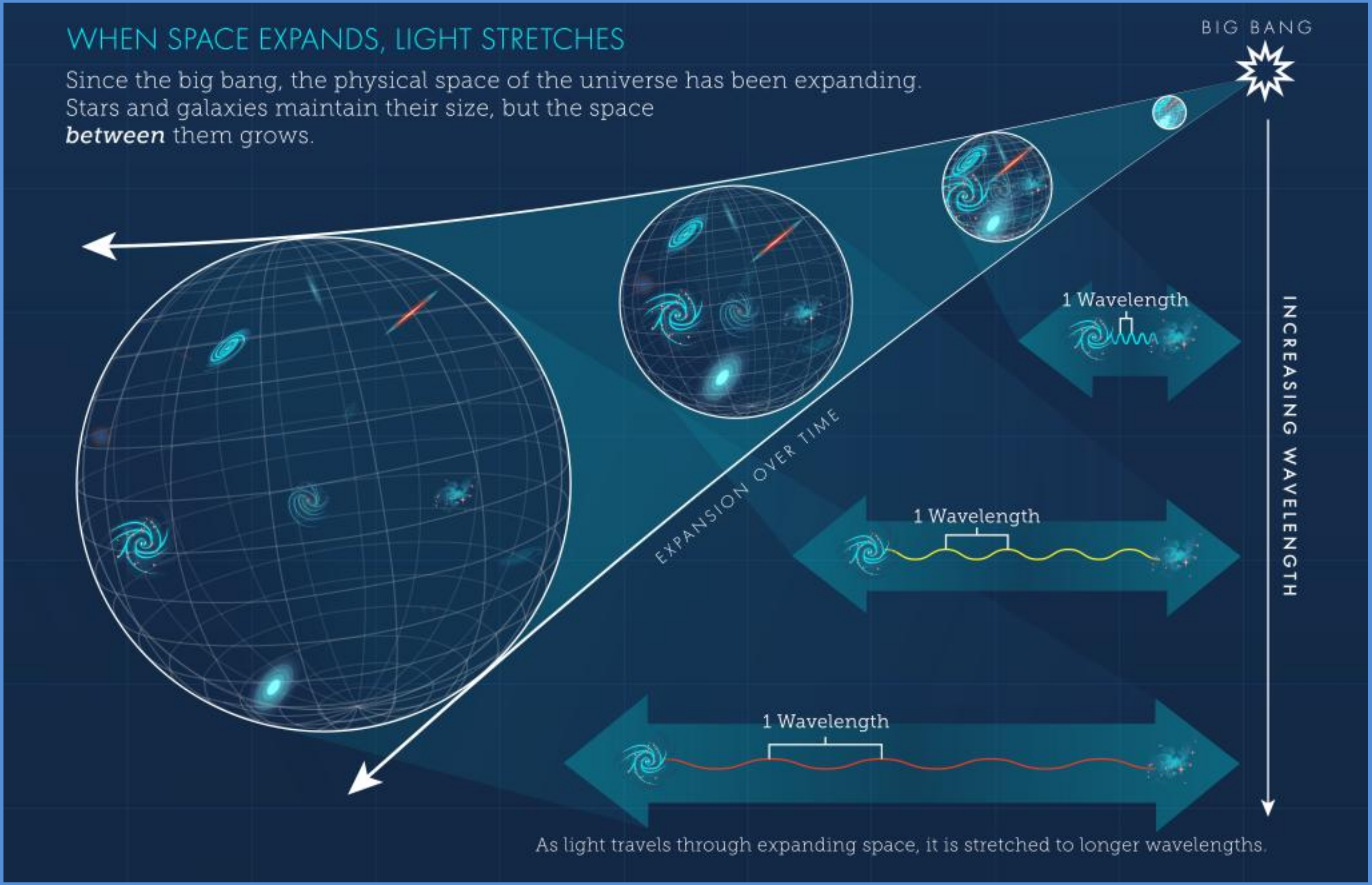
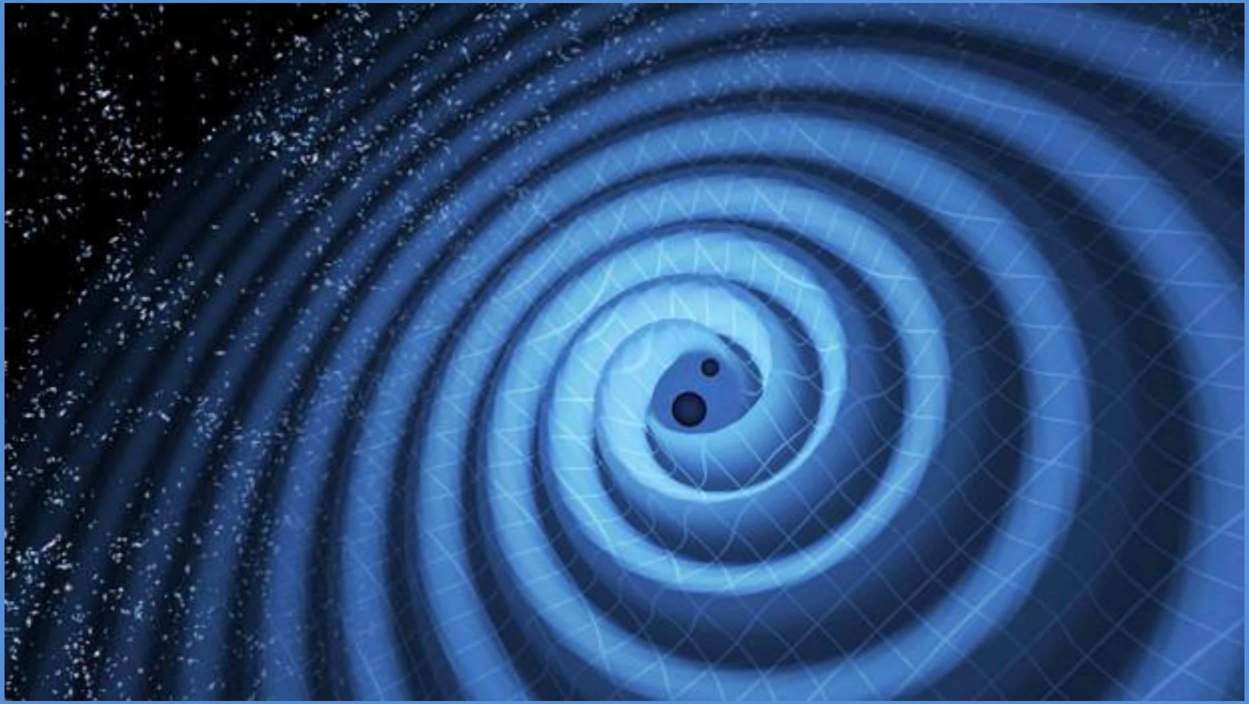


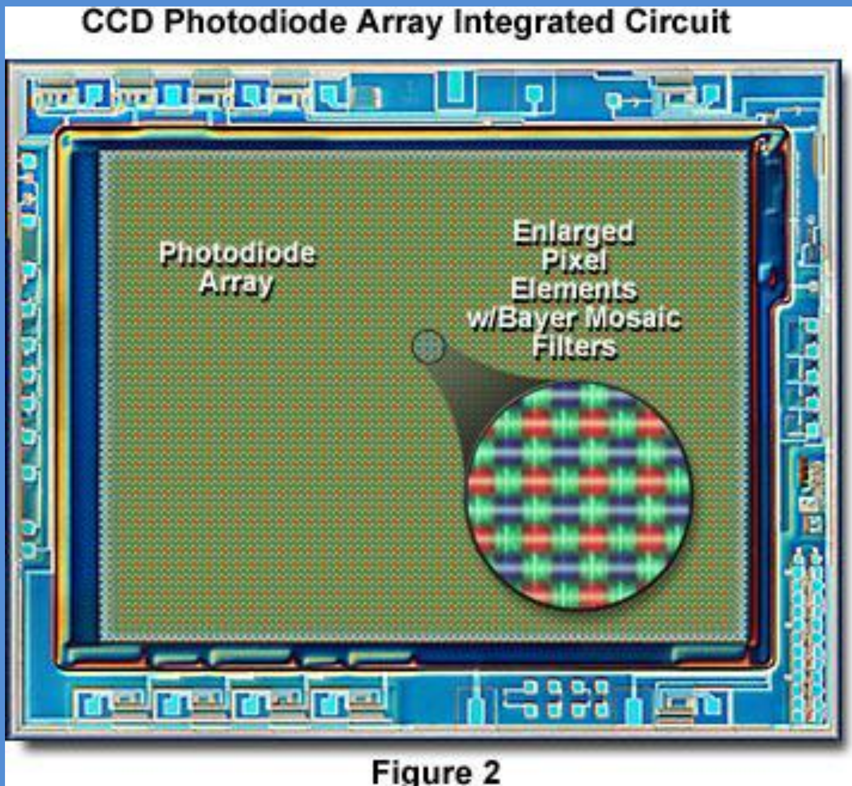
image: NASA

We can detect other messengers besides electromagnetic waves, however. Neutrinos carry information about conditions inside stars and supernovae. And gravitational waves – ripples in the very fabric of spacetime – carry information about colliding black holes and neutron stars and maybe even the origin of the universe. Astronomers have figured out how to detect those messengers and study those events with marvelous new observatories.

As of 2026, LIGO has detected gravity waves from nearly 300 spiraling black holes and their mergers.



New technologies enable rapid image acquisition and analysis of enormous data troves.



CCD. Hamamatsu Electronics.

Focal plane robots at DESI collect spectra from 5000 objects at once.

Part of the NVIDIA data collection system for the Vera C. Rubin Telescope. AI analyzes ten terabytes of data every night.

The new generation of observatories

The James Webb Space Telescope

Primary mission: identify the earliest structures in our universe and track their evolution over time.

Detectors: infrared detectors and spectrometers. Light from the most distant objects, formed within a few tens of millions of years after the Big Bang, has been stretched into the infrared due to cosmic expansion.

Major discoveries so far: Large galaxies and supermassive black holes formed a whole lot earlier than astronomers realized. And Webb has found objects that are real head-scratchers, including possible "dark matter stars."

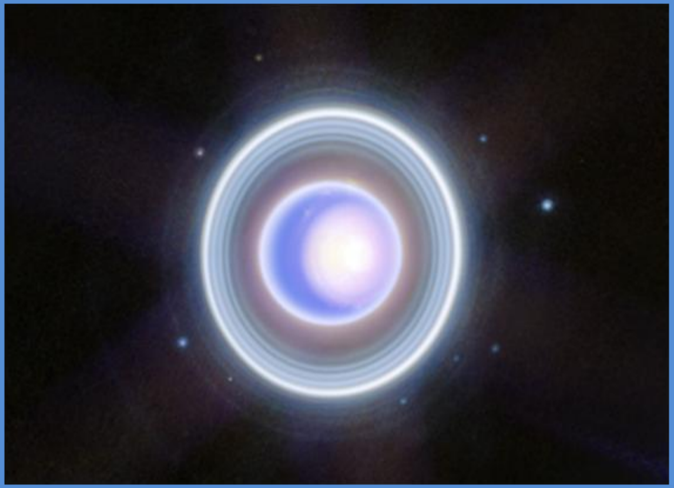
Science repository and image gallery:

https://science.nasa.gov/mission/webb/

https://webbtelescope.org/home

Deep field views, Hubble left, Webb right, same region of the sky. Faintest red dots in the Webb image are galaxies formed within the first 400 million years after the Big Bang.

A Webb sampler: Uranus, gravitational lensing, and interacting galaxies.



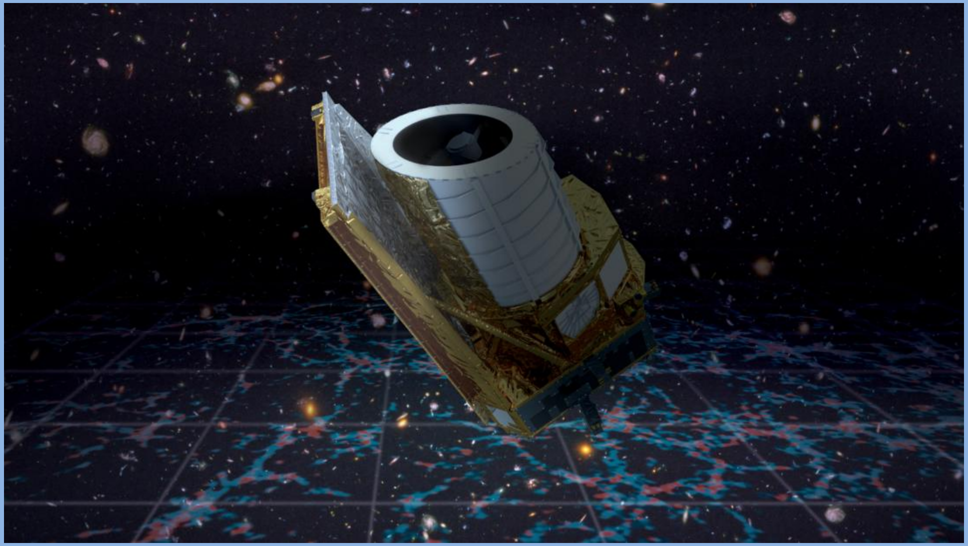
Euclid Space Telescope

Primary mission: map the distribution of galaxies throughout the universe and study the effect of dark energy on the rate of expansion

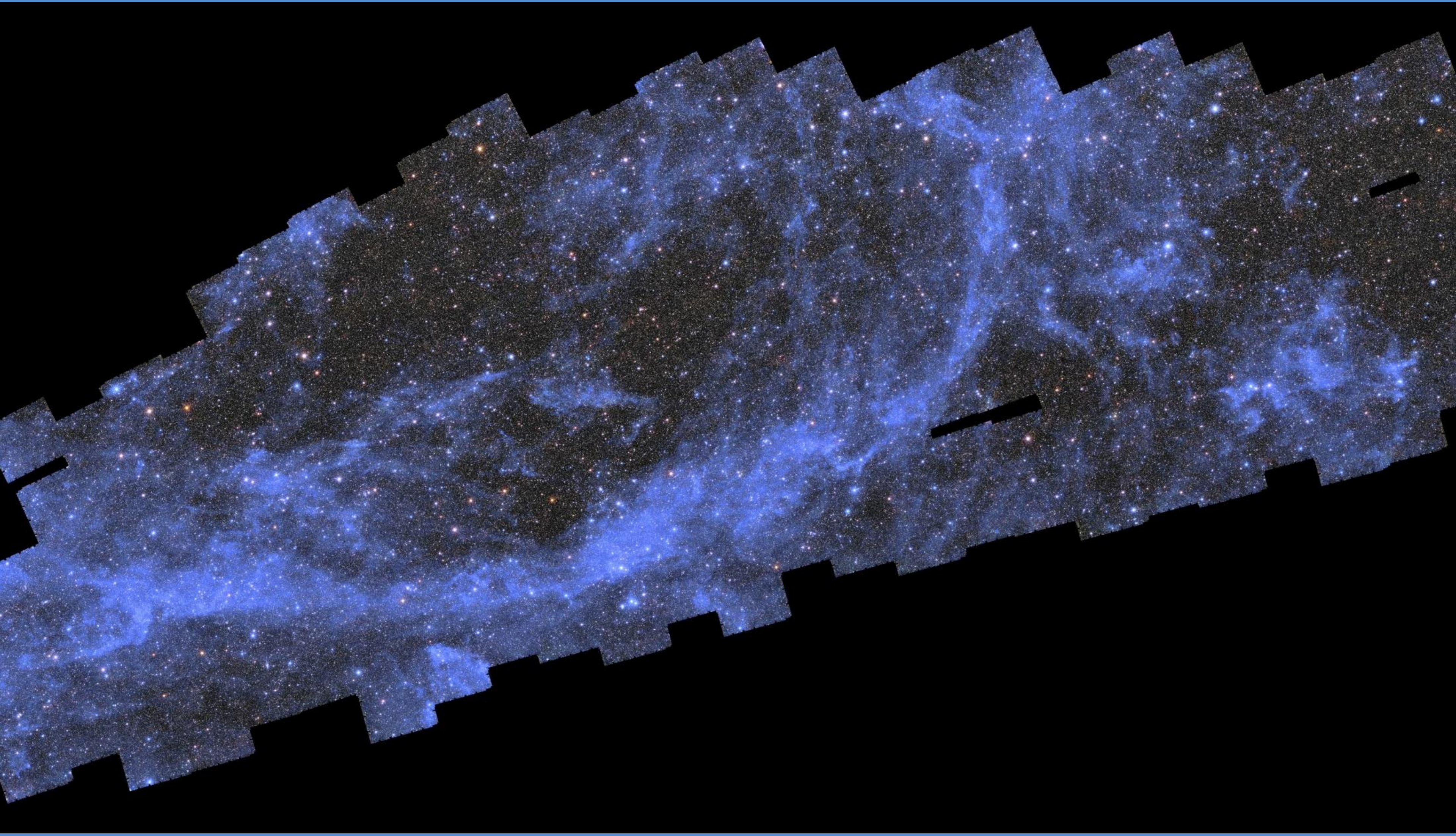
Detectors: visible wavelength and near-infrared detectors and spectrometers.

Major discoveries so far: The rate of expansion may vary over time. Dark energy, Einstein's "cosmological constant," might not be constant after all.

Science repository and image gallery: https://www.esa.int/Science_Exploration/Space_Science/Euclid



Euclid’s preliminary map of the southern sky



Event Horizon Telescope (EHT)

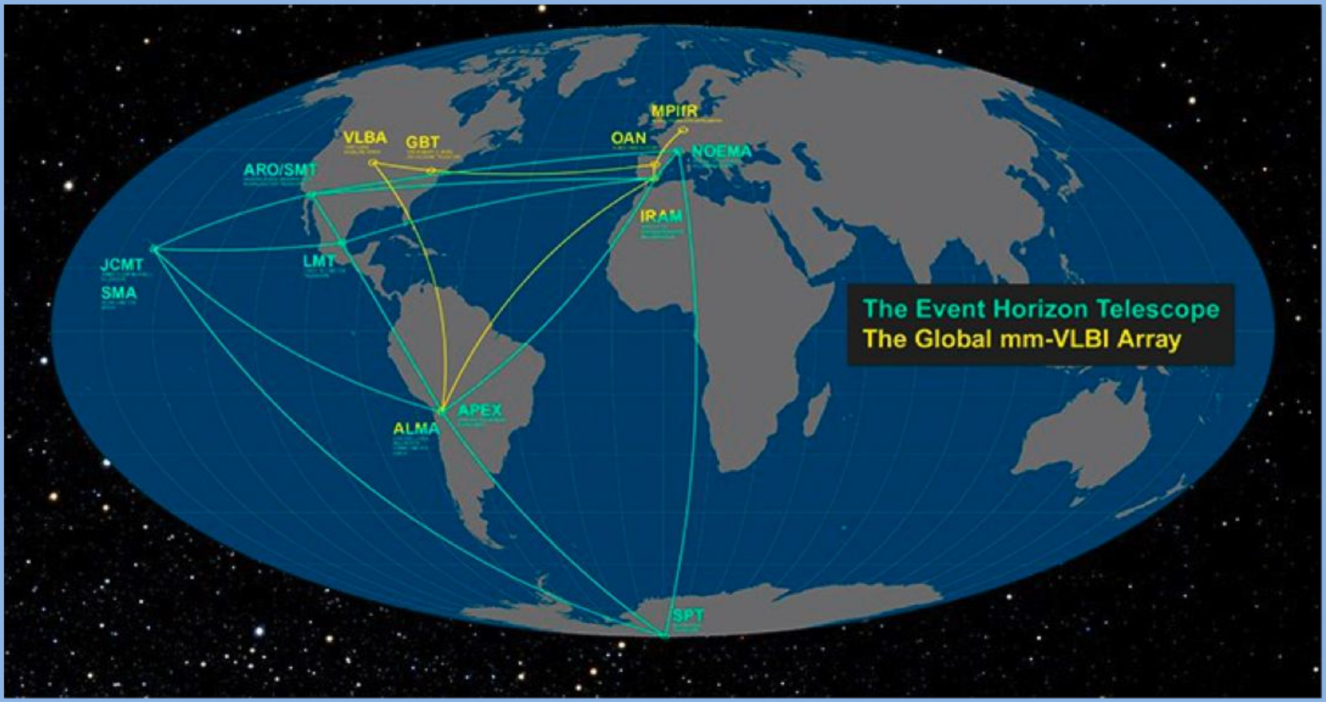
Primary mission: image supermassive black holes and study their dynamics

Detectors: a global network of radio telescopes calibrated by atomic clocks, data analyzed by supercomputers. See map below. ETH effectively turns earth into a giant telescope!

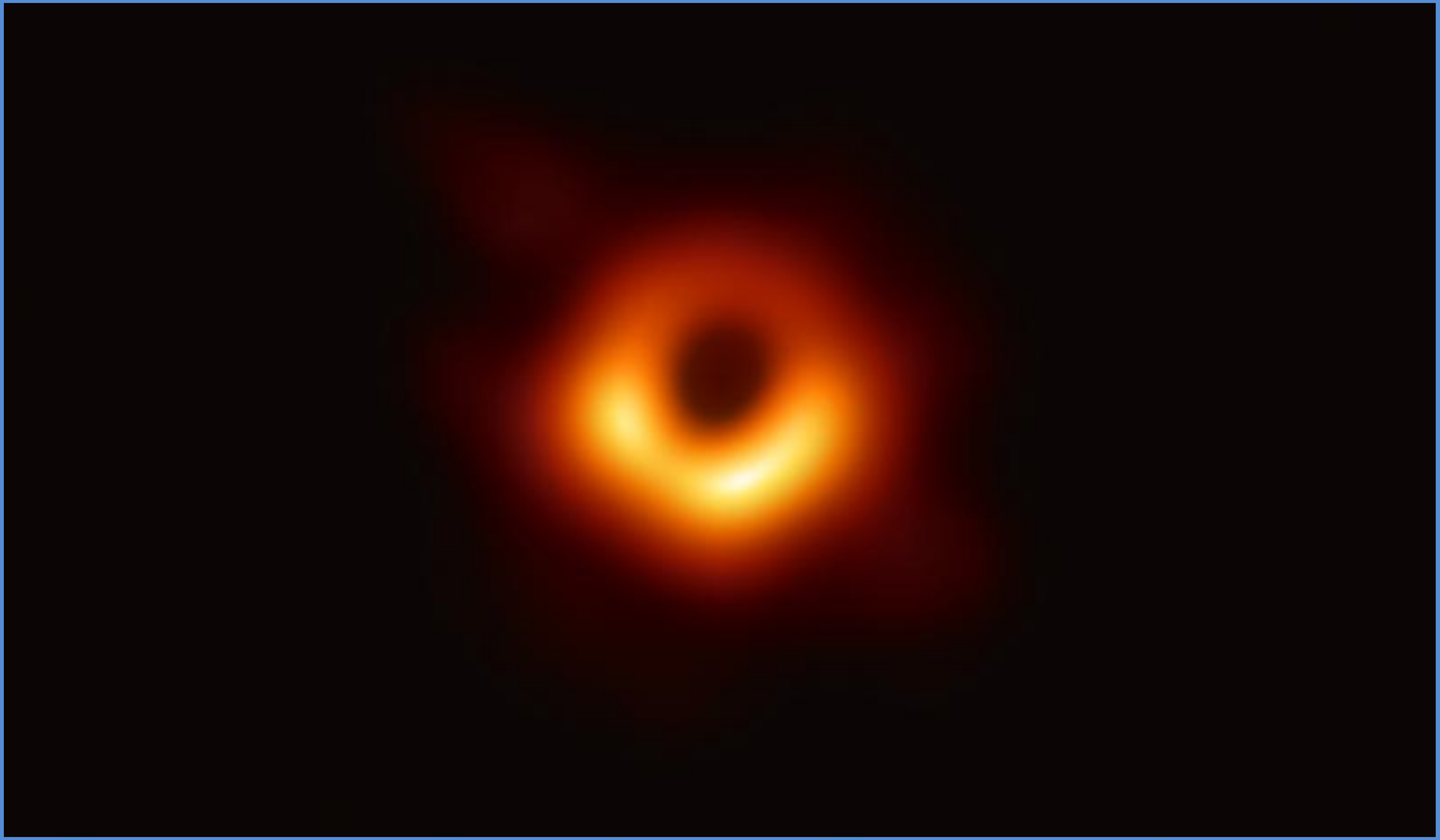
Major discoveries so far: time sequence images of the supermassive black holes in M87* and SgrA*

Science repository and image gallery:

https://eventhorizontelescope.org/



The supermassive black hole at the center of the galaxy M87. Dark center is the shadow of the black hole. Glowing donut is an accretion disk of hot gases spiraling into the black hole.



LIGO (Laser Interferometer Gravitational-wave Observatory)

Primary mission: detect gravitational waves generated by objects with masses tens of times the mass of our sun

Detectors: long baseline laser interferometers. See image below.

Major discoveries so far: around three hundred detections of in-spiraling and colliding black holes, as well as neutron star mergers and NS-black hole mergers.

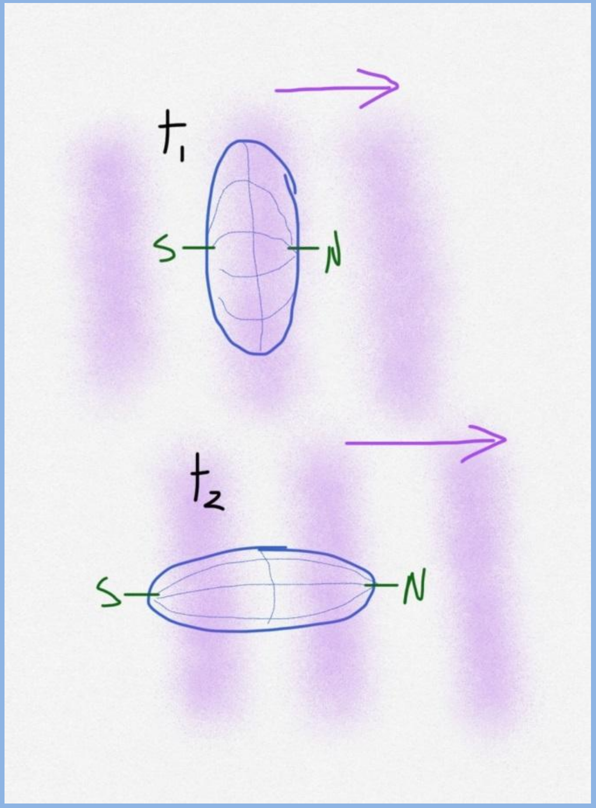
Science repository and image gallery: https://www.ligo.caltech.edu/

LIGO observatory in Hanford, WA. The perpendicular beam arms are 4 km in length.

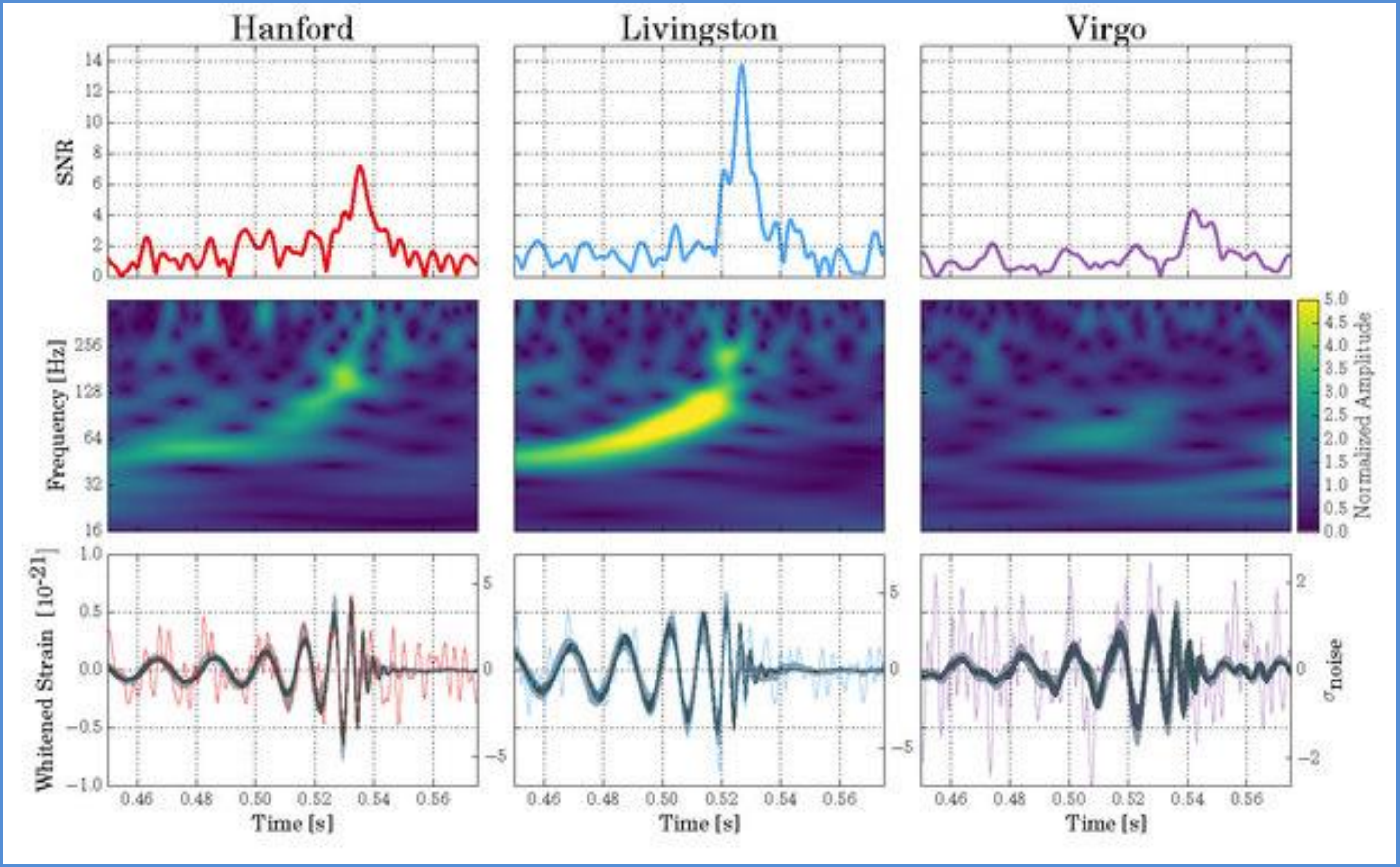
How does LIGO work?

Imagine a gravitational wave generated somewhere above earth's south pole. As the "crest" of the wave passes, it compresses the earth along its axis. At the same time it stretches the equator. When the wave trough arrives it stretches earth as if tugging on the poles and squeezes like a belt around the equator. Earth oscillates in this "quadrupole" manner until the wave dissipates. So do the arms of LIGO.

See the LIGO resource at https://www.ligo.caltech.edu/video/ligo20160211v6 for further information and an animation how passing gravitational waves affect the LIGO detectors.



Gravitational waves from merging black holes detected simultaneously by the three functioning gravitational wave detectors in 2017.



The LIGO detectors are engineering marvels, the most sensitive measuring devices ever made. They can detect gravity waves that displace the system mirrors less than one-ten-thousandth the diameter of a proton!

NANOGrav Pulsar Timing Array (PTA)

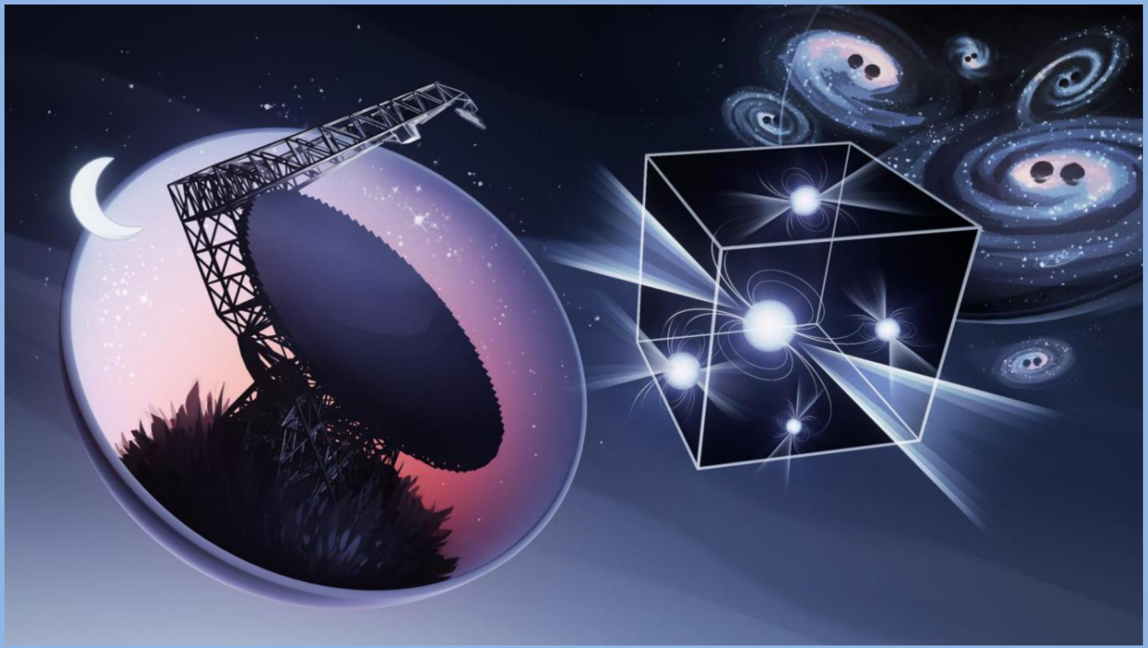
Primary mission: detect long wavelength gravitational waves generated by objects with masses millions of times the mass of our sun

Detectors: pulsars distributed around the celestial sphere

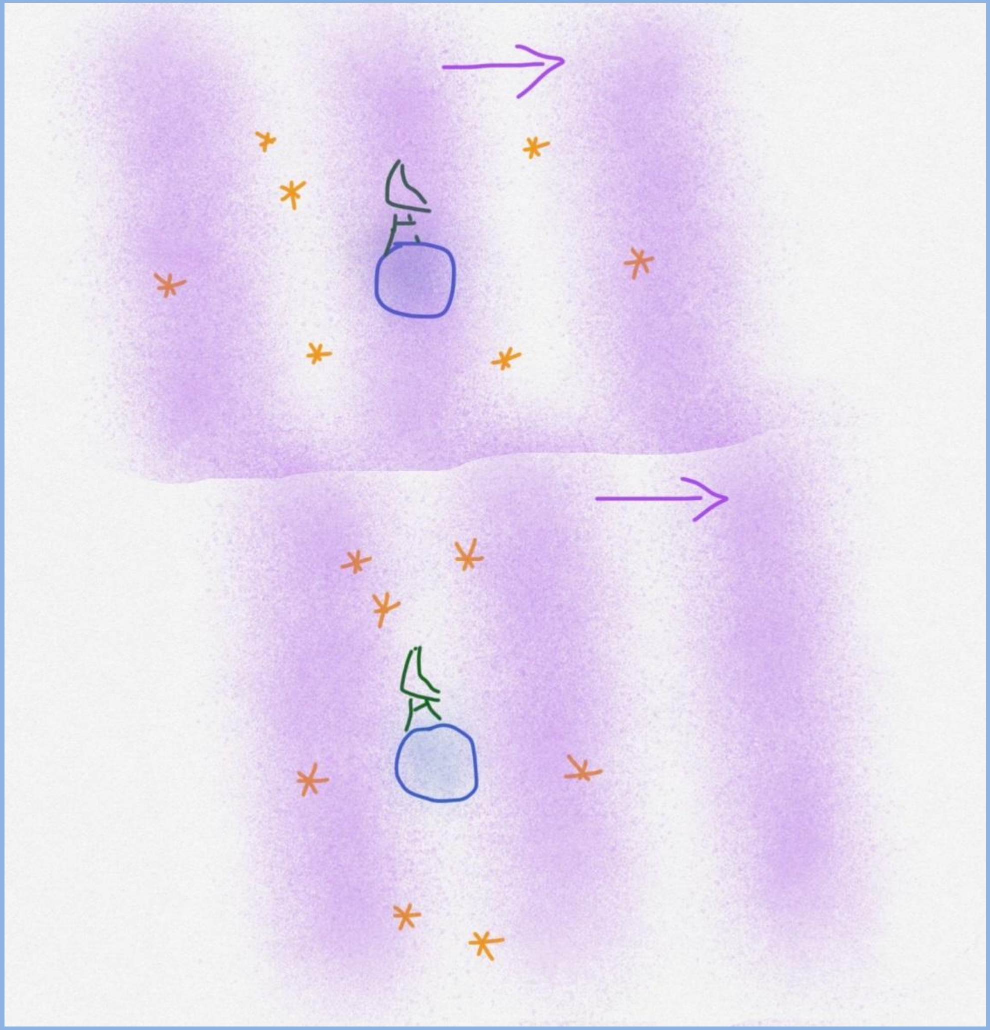
Major discoveries so far: evidence for a continuous background of gravitational waves sloshing around the universe. Distribution and amplitudes are consistent with supermassive black hole mergers and / or gravitational ripples remnant from the big bang.

Science repository and image gallery:
https://nanograv.org/

Radio telescopes monitor pulsars. Passing gravity waves change the arrival time of the pulsar signals.

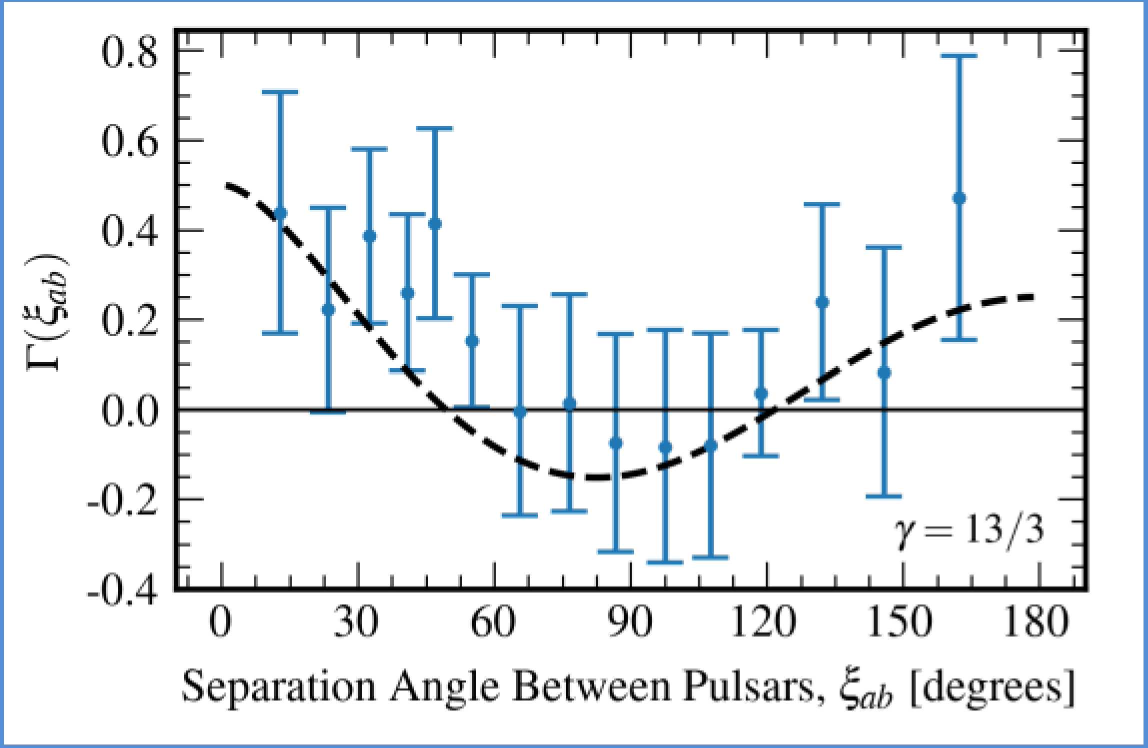


How it works: Pulsars are rapidly ticking clocks. Gravitational waves change the distribution of those clocks. PTA compares clocks in the array to “see” the passing waves.



Top: apparent distribution of pulsars (orange stars) at the crest of a passing gravitational wave (purple bars).
Bottom: distribution of pulsars at the trough of a passing wave.

First results from the NANOGrav collaboration. Graph shows correlation between change in pulse arrival times (ticks on a clock) and relative positions of pulsars (the clocks). Ticks from pulsars close together and pulsars 180 degrees apart oscillate together. Interval between pulses match. Ticks from pulsars separated 90 degrees in the sky arrive out of phase: ticks from one pulsar arrive earlier than expected while ticks from the other arrive later.



Agazie et al. 2023. The NANOGrav 15-year data set: evidence for a gravitational-wave background. The study timed 67 pulsars for fifteen years.

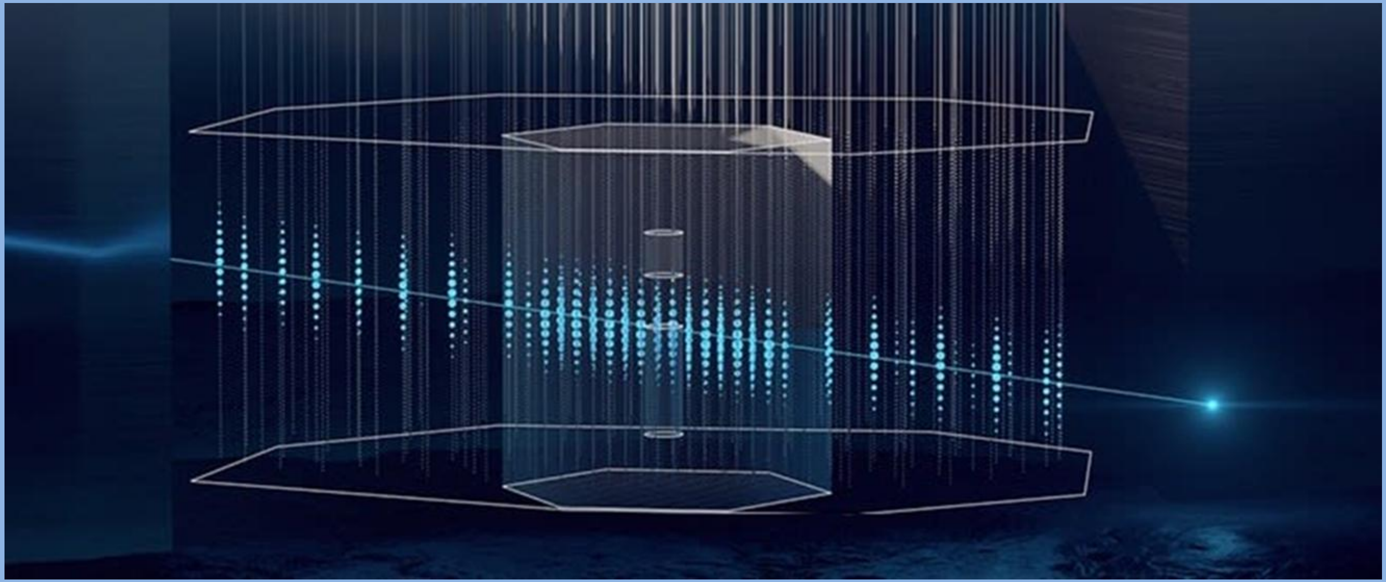
IceCube Neutrino Observatory

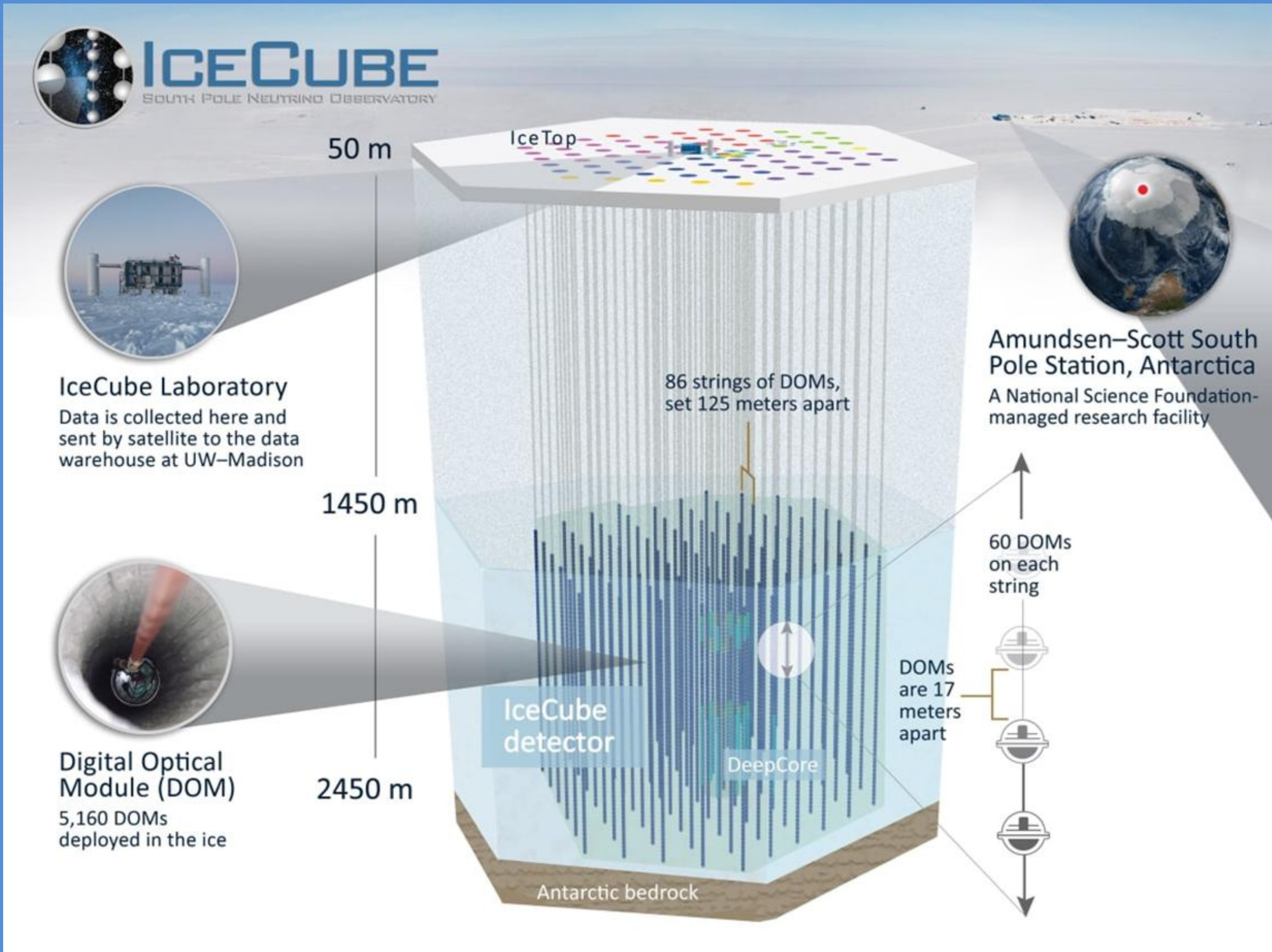
Primary mission: detect astrophysical neutrinos and trace them back to their sources

Detectors: photomultiplier tubes suspended in deep bore holes in the Antarctic ice sheet at the South Pole.

Major discoveries so far: improved understanding of supernova events, unexpected neutrino sources, and the physics of the neutrinos themselves.

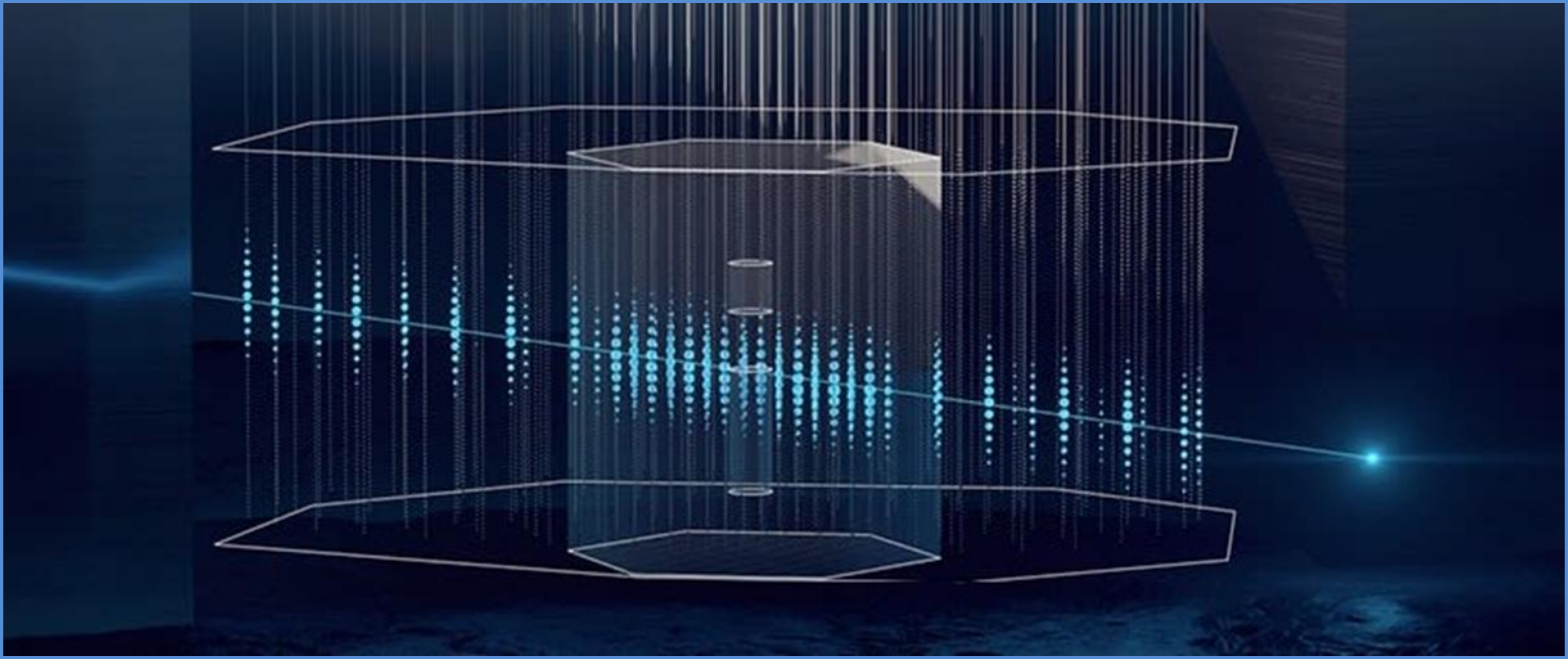
Science repository and image gallery: https://icecube.wisc.edu/





ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Antarctic bedrock

<u>How it works</u>. A neutrino traveling through the IceCube array interacts with atoms in the ice. That interaction generates flashes of light (Cerenkov radiation). Photodetectors in the array detect those flashes. By recording the sequence of light flashes IceCube can reconstruct the path of the neutrino and calculate from whence it came.



Vera C. Rubin Observatory

Primary mission: map the Southern Sky repeatedly over the next ten years to create a motion picture of its evolution. Main interest will be the distribution of dark matter and the evolution of dark energy over cosmic time.

Detectors: world's largest digital camera, recording a spectrum from near-UV to near-IR reflected off its 8.4 meter mirror

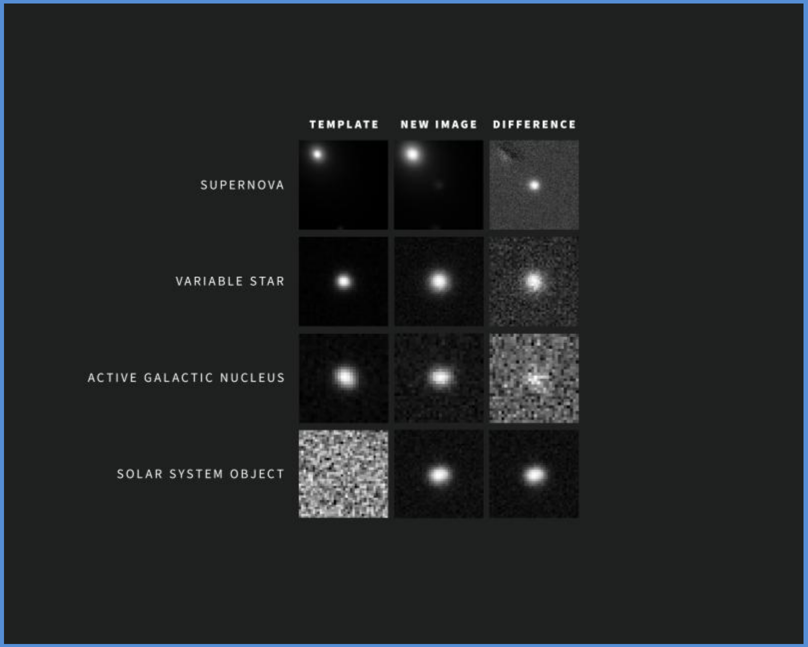
Major discoveries so far: Rubin identified ~2000 new asteroids in its first 10 hours and ~800,000 new objects in the first night of active alerts.

https://rubinobservatory.org/

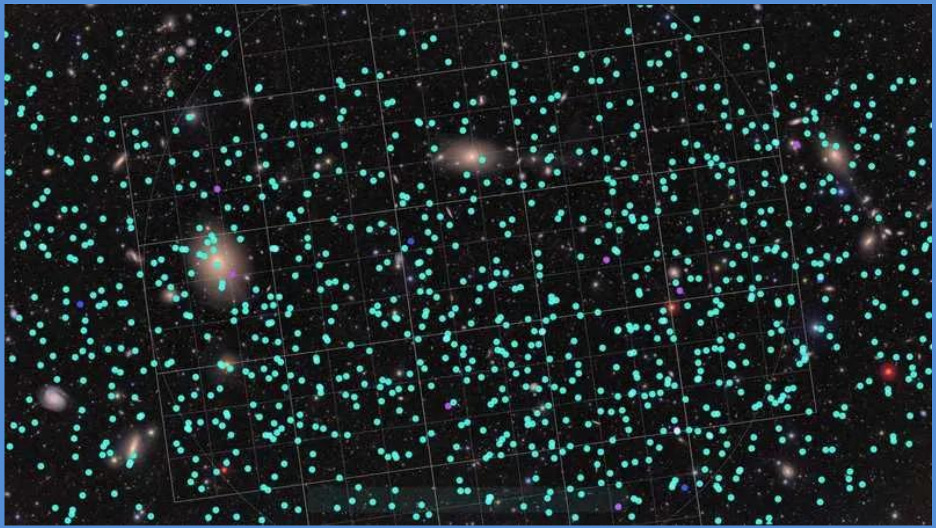
https://rubinobservatory.org/gallery/collections/first-look-gallery

Rubin first images, Virgo Cluster

Sparks

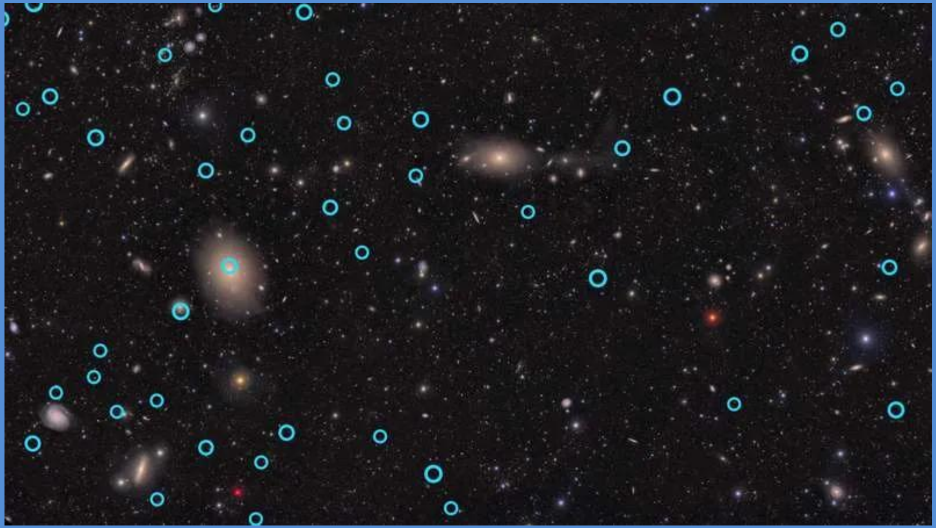


New asteroids

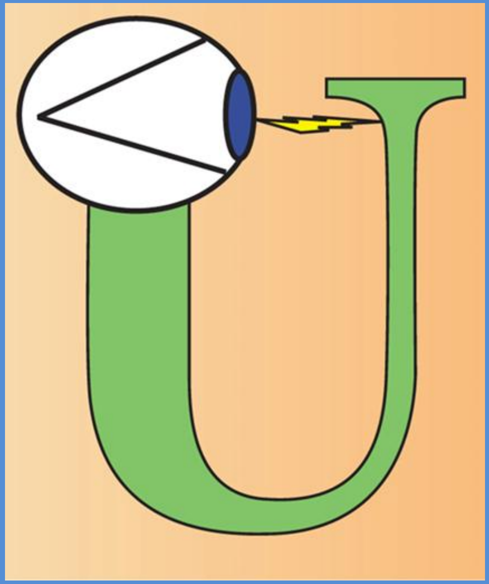


Rubin will send out about 7 million alerts each night. The first alerts were posted on 2/24/2026.

RR Lyrae variables



These great observatories promise to answer fundamental questions about the structure and the evolution of our universe. They undoubtedly will see (already have seen!) unexpected phenomena that raise new questions. It is an exciting new age of discovery. All of these observatories offer educational programs, and some invite public participation in their research. You can join the exploration!



Misner, Thorne, Zurek. 2006. Wheeler's Participatory Universe. *Physics Today*.

Thank you!