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The *Astro2020* road map lays the foundation for finding habitable planets.

US ASTRONOMY'S 10-YEAR PLAN IS SUPER-AMBITIOUS

'Decadal survey' pitches big new space observatories and funding for large telescopes.

By Alexandra Witze

A long-anticipated road map for the next ten years of US astronomy is here – and it's nothing if not ambitious.

It recommends that NASA coordinate, build and launch three flagship space observatories; suggests that the US National Science Foundation (NSF) fund two enormous ground-based telescopes, in Chile and possibly Hawaii; and, for the first time, it issues recommendations for how federal agencies should fight systemic racism, sexism and other structural issues that drive people out of astronomy.

"There are tremendous scientific opportunities before us – twenty-first-century astrophysics is incredibly rich," says Fiona Harrison, an astrophysicist at the California Institute of Technology in Pasadena and co-chair of the steering committee that wrote the report, known as *Astro2020*. The plan, released on 4 November, attempts to capitalize on those opportunities while also being realistic about budget and schedule constraints, she says.

US astronomy has sometimes taken a haphazard approach to building research facilities. *Astro2020* is "imposing order on the field in a way that probably hasn't been done before", says Matt Mountain, president of the Association of Universities for Research in Astronomy in Washington DC. For instance, *Astro2020* describes how the NSF could consider withdrawing its support from either of the large ground-based telescopes if they fail to reach certain milestones. It also sets out the deliberate steps NASA should take to develop technology for its ambitious space missions.

NASA, the NSF, the US Department of Energy (DOE) and the US Air Force commissioned the US National Academies of Sciences, Engineering, and Medicine to research and produce *Astro2020*. It is the latest in a series of 'decadal surveys' that aim to guide the direction of US astronomy, by gathering input from thousands of astronomers every ten years. "They're influential because they really do let the whole community speak their voice," says Aki Roberge, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Funding agencies generally follow the decadal survey's recommendations, which means that billions of dollars are at stake.

Many astronomers welcome the vision laid out in the report. "They really set the whole framework for how we can go about doing this ambitious science," says Scott Gaudi, an astronomer at the Ohio State University in Columbus. "It's a very balanced view," adds Priyamvada Natarajan, an astrophysicist at Yale University in New Haven, Connecticut. "I like that they really acknowledge that it takes time for the science and technology for missions to mature."

A forced partnership

Astronomers have been worried about the United States falling behind Europe, which is building the Extremely Large Telescope in Chile. Slated to come online in 2028, that facility is larger, and its construction is further advanced, than either of the extremely large US telescope projects under way. The 24.5-metre-wide Giant Magellan Telescope (GMT) is under construction in Chile, and the Thirty Meter Telescope (TMT) is planned for the Hawaiian mountain of Maunakea; *Astro2020* recommends that the NSF buy into both of them.

Under this arrangement, the GMT and the TMT, once bitter rivals, would partner to cover skies in both the Northern and Southern hemispheres, which the European telescope cannot do. They could make new types of astronomical discovery in galaxy evolution, exoplanet studies and other fields. "The only way to have astronomy in the United States be competitive at this scale is with this kind of capability," says John O'Meara, chief scientist at the W. M. Keck Observatory in Kamuela, Hawaii.

The decadal survey's recommendation would deliver a much-needed boost in funding: the GMT is estimated to cost at least US$2 billion and the TMT $2.6 billion, but neither has all the money it needs. Buy-in from the US federal government would give all US astronomers a chance to compete for a portion of observing time on both telescopes.

But it's not clear whether the NSF could afford to support both facilities. So *Astro2020* lays out a process for deciding whether to jettison one of the telescopes if need be.

It remains to be seen how the TMT might move forwards, however. Maunakea is one of the best sites in the world for stargazing, but construction there has been halted since 2015 owing to protests from Native Hawaiians, to whom the mountain is sacred.

In addition to suggestions for ground-based astronomy, the report provides guidance on the future of space-based missions, typically the most expensive and highest-profile astronomical observatories. Recommendations from previous decadal surveys have led to iconic spacecraft such as the Hubble Space Telescope. This time around, the top recommendation is to launch not one, but three flagship observatories.

First out of the gate in the next set of missions would be a space telescope similar to Hubble, but with a mirror more than twice the width. It would detect light in ultraviolet, visible and near-infrared wavelengths, and be able to discover objects of astrophysical interest ranging from habitable planets to violent black holes. It would cost around $11 billion and launch in the early 2040s.

Second and third would be missions detecting X-rays, a sector of the electromagnetic spectrum in which some of the most powerful astrophysical phenomena can be observed, and far-infrared radiation, which can penetrate the shrouds of dust around newborn stars. These missions would cost $3 billion to $5 billion each, and a decision on whether to build them would be made five years after the start of the first Hubble-like mission.

Lurking behind these ambitious spacecraft is the spectre of previous space missions whose budgets have blown out of control. For instance, the James Webb Space Telescope, the leading recommendation in the 2000 survey, is set to launch on 18 December, years later than intended, at a cost of nearly $10 billion – well above its original budget.

"We've learned a lot in the course of the last 10–20 years about how to do large missions," says Gaudi. "For me, it's almost inconceivable that we couldn't do better the next time, because we've learned from our past mistakes."

A human endeavour

Astro2020 also attempts to grapple with the importance of equity and inclusion to the health of US astronomy. "Astrophysics is done by humans," says Jane Rigby, an astrophysicist at the Goddard centre. "How these humans treat each other, how they are led, how they hold each other accountable, what the policies and the systems are that they're working in – this makes so much of a difference to the quality of the science that gets done."

US astronomy has found itself at the forefront of many social issues, including the ethics of doing science on Maunakea and other lands seized from Indigenous groups.

The report lays out some recommendations for reducing the systemic barriers that block many people from entering and staying in science. They include increasing federal funding for student and early-career researchers, making diversity a criterion in awarding grants, and gathering data to better track the lack of equity in funding.

"Racial/ethnic diversity among astronomy faculty remains, in a word, abysmal," the report says.

Attention will now turn to how the survey's recommendations might become reality. Pandemic-related delays in the report's release mean that the NSF, NASA and the DOE have already missed their chance to incorporate the findings into the budgets they are drawing up for the 2023 fiscal year. As a result, *Astro2020* priorities will not start receiving funding until 2024 at the earliest.

SPONGE CELLS HINT AT ORIGINS OF NERVOUS SYSTEM

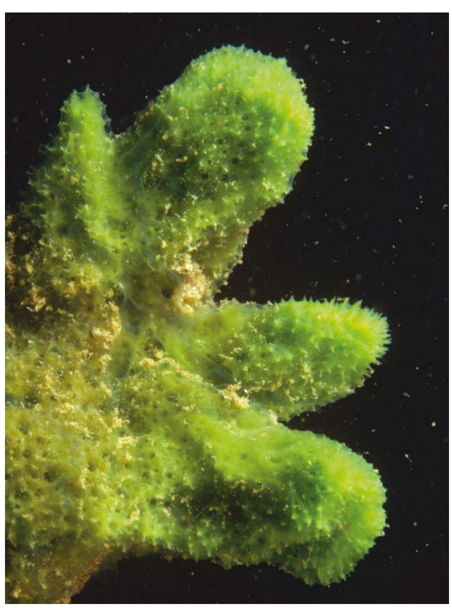
Synapse genes help cells to communicate in the digestive chambers of sponges.

By Max Kozlov

Sponges are simple creatures, yet they are expert filter feeders, straining tens of thousands of litres of water through their bodies every day. Their mastery of this process is all the more remarkable because they have no brain or neurons.

A study published on 4 November in *Science* now reveals that sponges use an intricate cell communication system to regulate their feeding and potentially to weed out invading bacteria (J. M. Musser *et al. Science* https://doi.org/g4xt; 2021). The findings could help researchers to understand how animals' nervous systems evolved, says Casey Dunn, an evolutionary biologist at Yale University in New Haven, Connecticut. "This is a really exciting study that allows us to see sponges in a new light," he says.

Cells frequently communicate with one another, and neurons do so by passing signals through connections called synapses. Previous research has found that sponges possess genes encoding proteins that typically help synapses to function, despite the animals' lack of neurons (M. Srivastava *et al. Nature* **466**, 720–726; 2010).



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Freshwater sponges might hold clues about the evolution of the nervous system.

To discover which cells were expressing these genes, Detlev Arendt, an evolutionary biologist at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, and colleagues sequenced the RNA in various individual cells from a freshwater sponge (*Spongilla lacustris*). They found that the sponge has 18 distinct cell types. Synaptic genes were active in a few of these types, which were clustered around the sponge's digestive chambers. This suggests that some form of cellular communication might coordinate the animal's filter-feeding behaviour.

The researchers then used X-ray imaging and electron microscopy to study one of these cell types, which they called secretory neuroid cells. The scans revealed that neuroids send out long arms to reach choanocytes, cells with hair-like protrusions that drive sponges' water-flow systems and capture most of their food.

On the basis of the proximity of the two cell types and the expression of genes that might allow for the secretion of chemicals, the researchers think that these arms enable neuroids to communicate with choanocytes, so that they can pause the water-flow system and clear out any debris or foreign microbes. However, these neuroid cells are not nerves, and there is no sign of synapses. Instead, this cell type might represent an evolutionary precursor to a true nervous system, says Jacob Musser, an evolutionary biologist at EMBL, who co-authored the study. "We're at an intermediate point, where you've gone from having all these independent pieces to bringing them together more broadly, but you haven't gotten all the interconnectivity needed to create a fast synapse," he says.

Some scientists say that calling these cells a precursor to a nervous system is a stretch. "It's tantalizing, but it's hardly definitive," says Linda Holland, an evolutionary developmental biologist at the University of California, San Diego. She says it will be difficult to prove whether nervous systems evolved from this cellular communication system or arose earlier or even multiple times, as some groups have proposed.

April Hill, a developmental geneticist at Bates College in Lewiston, Maine, hopes that scientists will use this study and its methods as a "launchpad" for further investigation of this ubiquitous sponge.