



a multiverse of
EXPLORATION

THE FUTURE OF SCIENCE 2021



Institute for the Future
Technology Horizons
Fall 2011

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THE FUTURE OF SCIENCE 2021

Invisibility cloaks. Space hacking. Quantum consciousness. Open-source biology. Empowered with new tools, processes, and skills, scientists will gain new insight into the mysteries surrounding our brains, biology, and the strange matter that makes up our reality. We will develop powerful new instruments for gazing at the farthest reaches of space and descending into the deepest oceans, further illuminating our place in the universe.

Not only will our knowledge increase but the way science is done will change in profound ways. A new ecology of science will crystallize, one that shifts from the insular and closed structures of academic, industrial, and military research toward open models based on social connection, data commons, and democratized tools and technology. We will create unprecedented opportunities for collaboration and resource sharing between large organizations, communities, and individuals. This radical reimagining of science will supplant current approaches to R&D and inevitably translate into new technologies as well as new organizational structures.

The most transformational science is driven by curiosity, passion, and the promise of creating a better world. This map is a guide to finding your own path through the dynamic, turbulent, and startling multiverse of exploration.

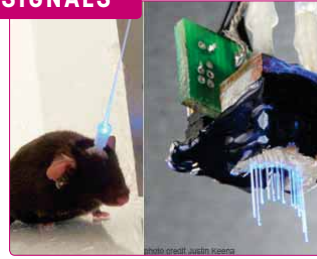
Decrypting the Brain

modeling the complex mind

At the intersection of neuroscience, molecular biology, and computer science, researchers are making slow but sure strides to reverse-engineer the human brain. New imaging technologies enable us to scan brains at unprecedented resolutions. Informed by that data, a combination of optical and genetic techniques will allow for precision control of specific neural circuits almost as easily as flipping on and off light switches. As we finally uncover the mysteries of how the brain works, the next step will be to build systems that mimic our own cognitive abilities. That will not only lead to profound shifts in the way we think about machines, but will also transform our own sense of self.

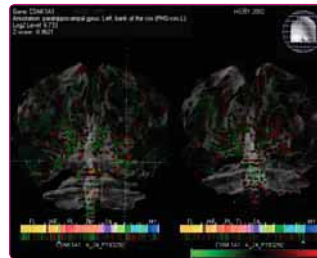
- Machine learning melds with cognitive science
- Quantum physics helps explain consciousness
- Gene jockeys build a brain atlas
- Brain scans record “mind movies”
- Optogenetics leads to a neural switchboard

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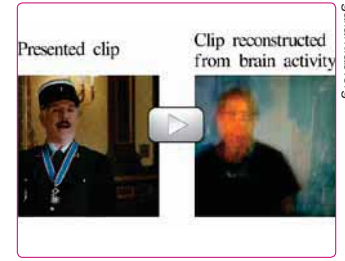
syntheticneurobiology.org

Synthetic Neurobiology: Method for controlling the brain with pulses of light



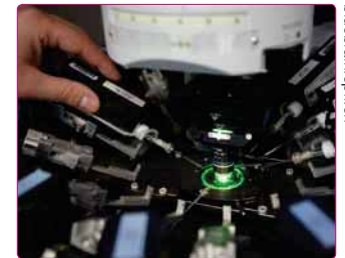
alleninstitute.org

Allen Human Brain Atlas: 3D map of gene expression in the brain



gallantlab.org

“Mind Movies”: Technique to record visual experiences from brain scans



bluebrain.epfl.ch

Bluebrain: Computer that simulates a rat's brain

Hacking Space

public and private access spurs a new space age

Even as NASA has been subjected to relentless budget cuts, and the Space Shuttle program has come to its long-delayed end, new means for engaging with the “final frontier” are emerging. The role of governmental organizations is changing from obligatory sponsors of orbital projects funded by taxpayers to secondary supporters and customers of entrepreneurial ventures around medicine, manufacturing, and surveillance funded by private industry. These commercial efforts will increasingly be complemented by an array of citizen science projects, informed by a do-it-yourself mindset, and harnessing the curiosity and passion of a public enchanted by the wonder of space and eager to help us understand our place in the cosmos.

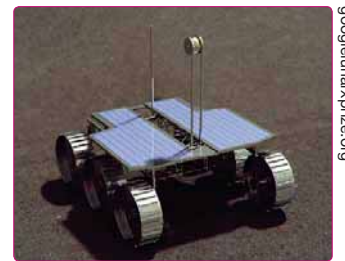
- Regulatory hurdles drive open standards and “coopetition”
- Discovery of extraterrestrial life
- Personal satellite for \$1000
- Zero-G biology accelerates drug discovery
- Orbital manufacturing becomes practical

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spacehack.org

Spacehack: Directory of ways for citizen scientists to participate in space exploration



googlularxprize.org

Google Lunar X Prize: Millions of dollars for the first privately funded teams to land a robot on the moon



virgin Galactic.com

Virgin Galactic: Commercial “spaceline” for tourism and private space science



makezine.com

MAKE's DIY Space Issue: How to put your own satellite in orbit, launch a stratosphere balloon probe, and analyze galaxies with a \$20 spectrograph

Massively Multiplayer Data

human-data interaction emerges as a core discipline

Sensor networks, pervasive computing, and a host of other new technologies are translating our world into high-resolution data streams that can be analyzed, manipulated, and used to inform advanced simulations. Indeed, science has always been driven by data but now the sheer complexity and amount of information is demanding new practices and methods to translate the bits into knowledge. To that end, science will seek contributions from the networked public to tag raw data and make connections, seek patterns, and draw links between datasets. The speed of scientific discovery will be proportional to the availability of cross-disciplinary engagement with relevant data. Eventually, some discovery science will become automated as software analyzes experimental data to make new hypotheses and test them in simulations.

- Science is gameified
- Scientific papers are executable as code
- A Wikipedia of science models is created
- Data-intensive science spawns new disciplines
- Massively linked data becomes a public utility

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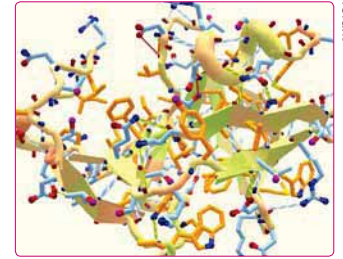
galaxyzoo.org

Galaxy Zoo: Public effort to process NASA Hubble Space Telescope data



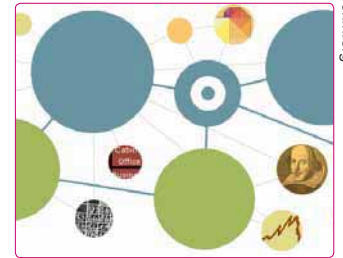
hibcc.ucsc.edu

Bolshoi: The most accurate computer simulation of the entire universe



fold.it

Foldit: Online gamers solve protein folding puzzles, like the structure of an AIDS-related enzyme



okfn.org

Open Data Commons: Provides legal frameworks for open database licensing

Sea the Future

oceans become the new frontier for energy, ecology, and engineering

The oceans, covering more than 70% of the Earth's surface, are our life-support system, supplying half the planet's oxygen and also harboring more than half the life on Earth. Over the next decade, deep-sea explorers will apply the tools of genomics in our oceans to learn about the millions of species living beneath the waves. Scientists will look to the sea as a renewable energy source while studying the complex interactions of the Earth, the ocean, and the atmosphere at the smallest scale. Of course, the oceans are also a leading indicator of climate change, regulating the climate by absorbing heat and carbon dioxide. As a result, the big blue will be a focal point for geoengineering efforts to counter the effects of global warming.

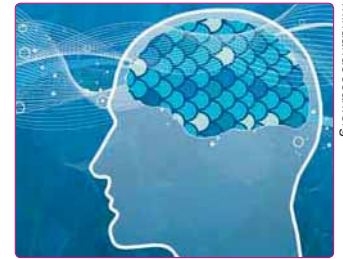
- Seawater fuels fusion
- Humans plumb ocean depths
- The ocean's top millimeter is mapped
- The majority of ocean species are inventoried

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oceanobservatories.org

Ocean Observatories Initiative: Global sensor network for studying the ocean and sea floor



mindandoccean.org

BlueMind: Conference that looks at the ocean through the neuro-science lens



cornell.org

Census of Marine Life: Ten-year international effort to inventory the oceans' life, from microbes to whales



dash.harvard.edu, flickr user ex-libris

Bright Water: Theory that pumping the sea with "microbubbles" will lower ocean temperatures

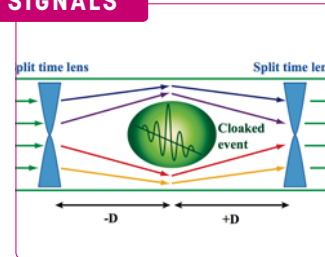
Strange Matter

unnatural materials reshape our world

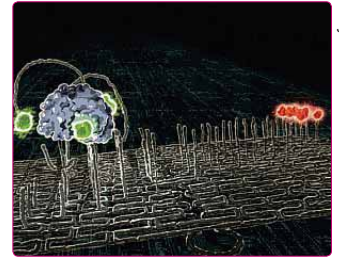
Arthur C. Clarke once said that “any sufficiently advanced technology is indistinguishable from magic.” He will most certainly be proven right by advances in materials science over the next decade, leading to such extraordinary possibilities as invisibility and even a space-time cloak that camouflages entire events. Meanwhile, the cross-disciplinary field of nanoscience will bear strange fruit in the form of useful microscopic machines made from DNA that folds itself up like origami, and metals whose properties can be altered with the push of a button. As we continue to learn more about the nature of matter at the smallest scales, and how to manipulate it, we will be on a better path to develop materials with less environmental impact at the macro level.

- Space-time cloaks conceal macro-world events
- DNA origami constructs useful nanodevices
- Teleportation scales up from atoms to molecules
- Metamaterials make invisibility real

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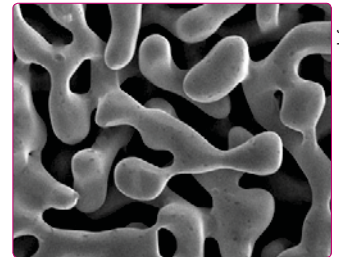
A Hole in Time: Events are masked by bending light around them



Molecular Robots: Nanobots traverse a DNA origami track



Metamaterial Solar Cells: Infrared is harnessed to boost efficiency



Switchable Metals: Materials that change from brittle to ductile and back

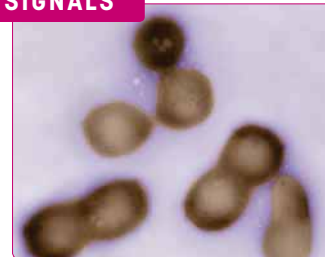
Engineered Evolution

manipulating biology from the bottom up

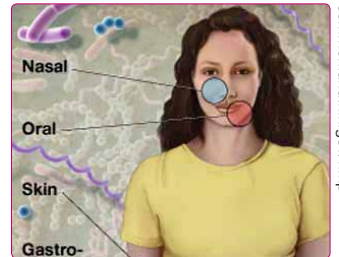
For 3.6 billion years, evolution has governed biology on this planet. But now, Mother Nature has a collaborator. Inexpensive tools to read and rewrite the genetic code of life will bootstrap our ability to manipulate biology from the bottom up. The more we learn about the physics of biological processes and the intricacies of the genome and the biome, the better we will be able to tweak our own biology. We will not only genetically reengineer existing life but actually create new lifeforms with purpose. Along the way, we will apply new techniques for rewinding and fast-forwarding evolution *in vitro* and *in silico* to understand how life came to be.

- The human microbiome is mapped
- Quantum biology reveals the physics of life
- Epigenetics informs real-time genome tweaking
- Organisms become programmable
- New lifeforms created from scratch

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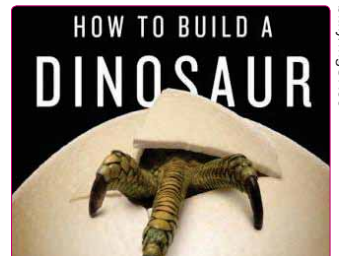
Toward *Mycoplasma* laboratory: Gene jockeys build the first self-replicating synthetic bacterial cell



Human Microbiome Project: Effort to characterize the microbe community living within our bodies



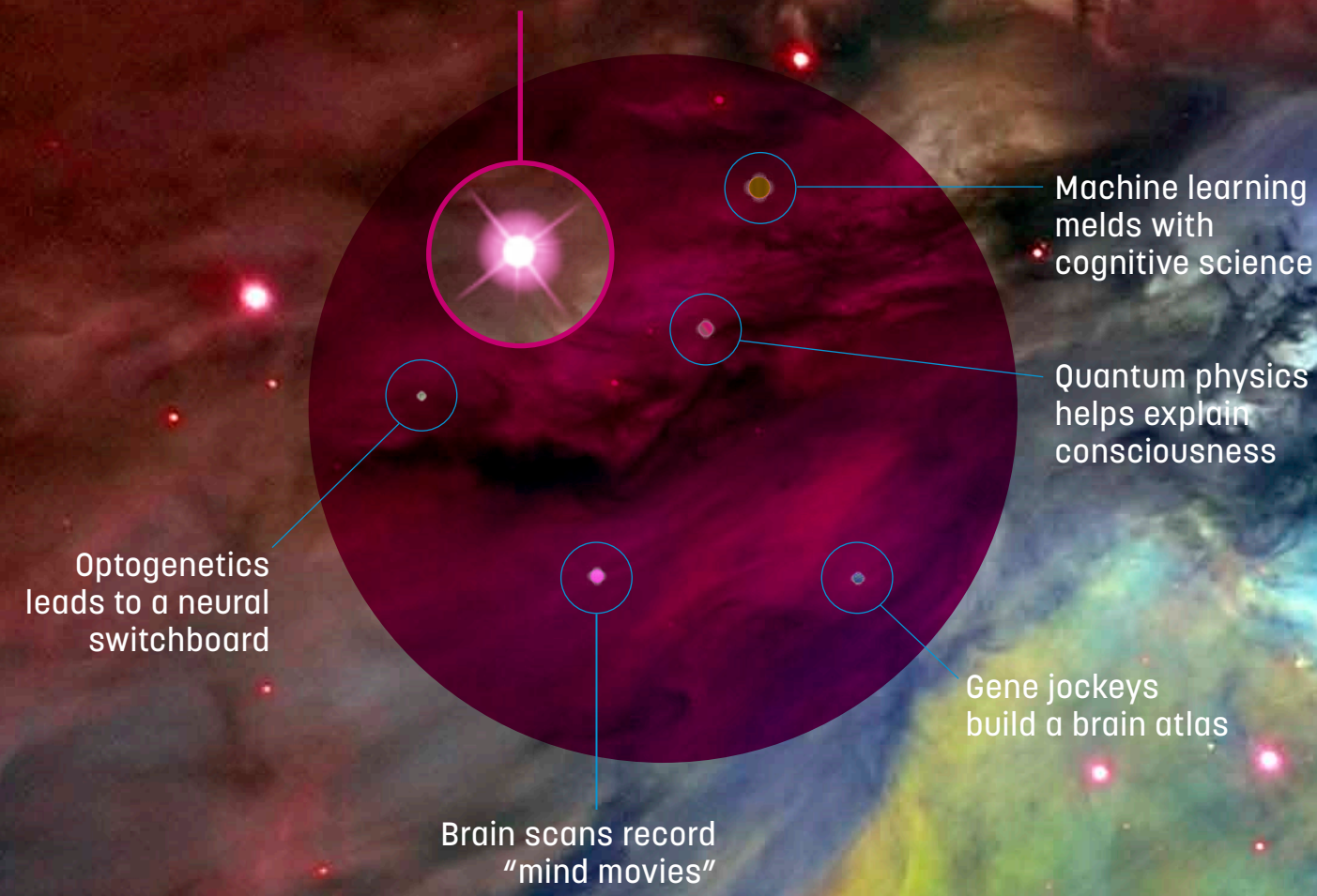
Synthetic Biology: Engineered microbes convert sugarcane into renewable fuels



Chickenosaurus: Reversing a chicken's evolution to build a dinosaur

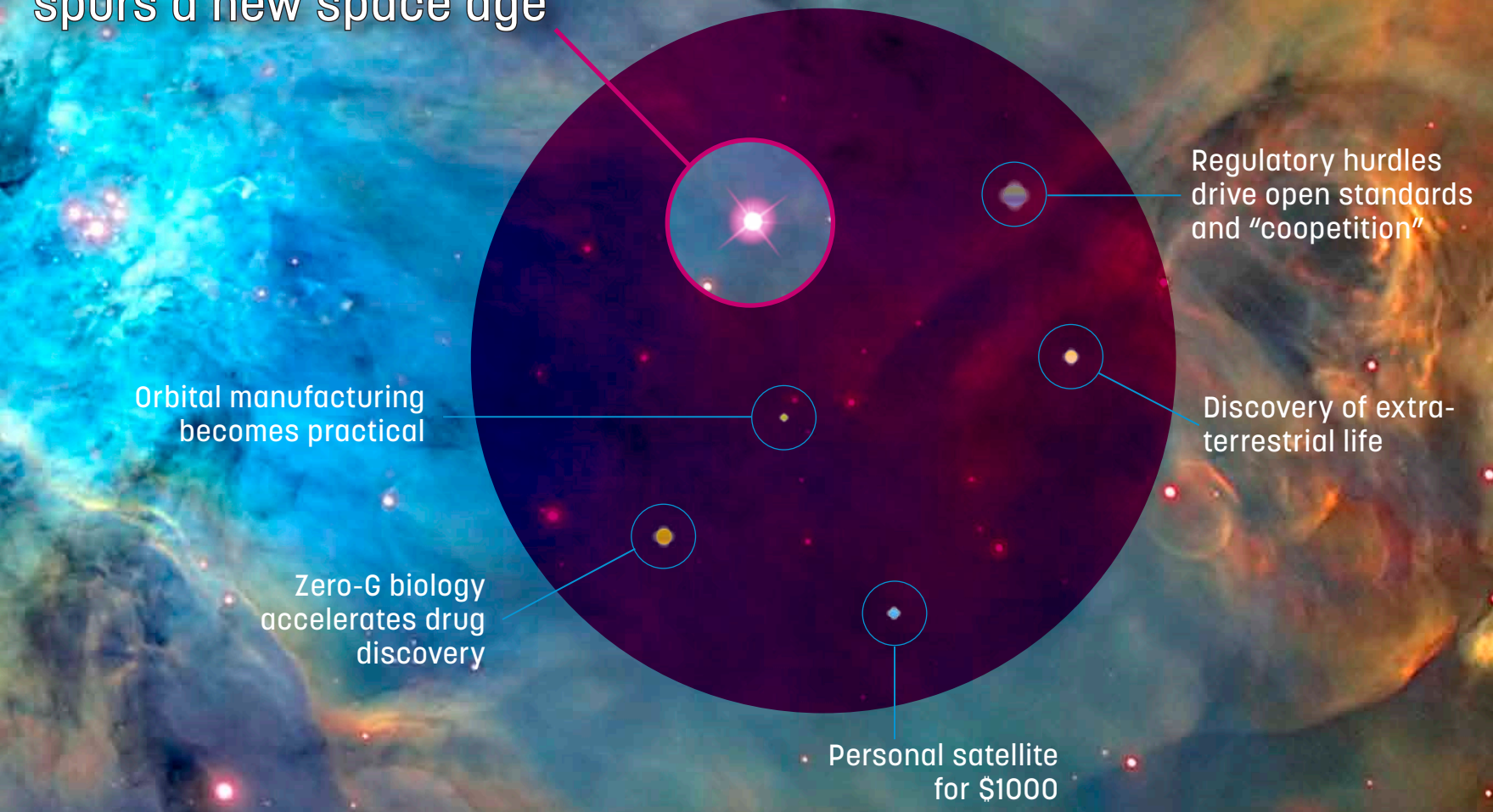
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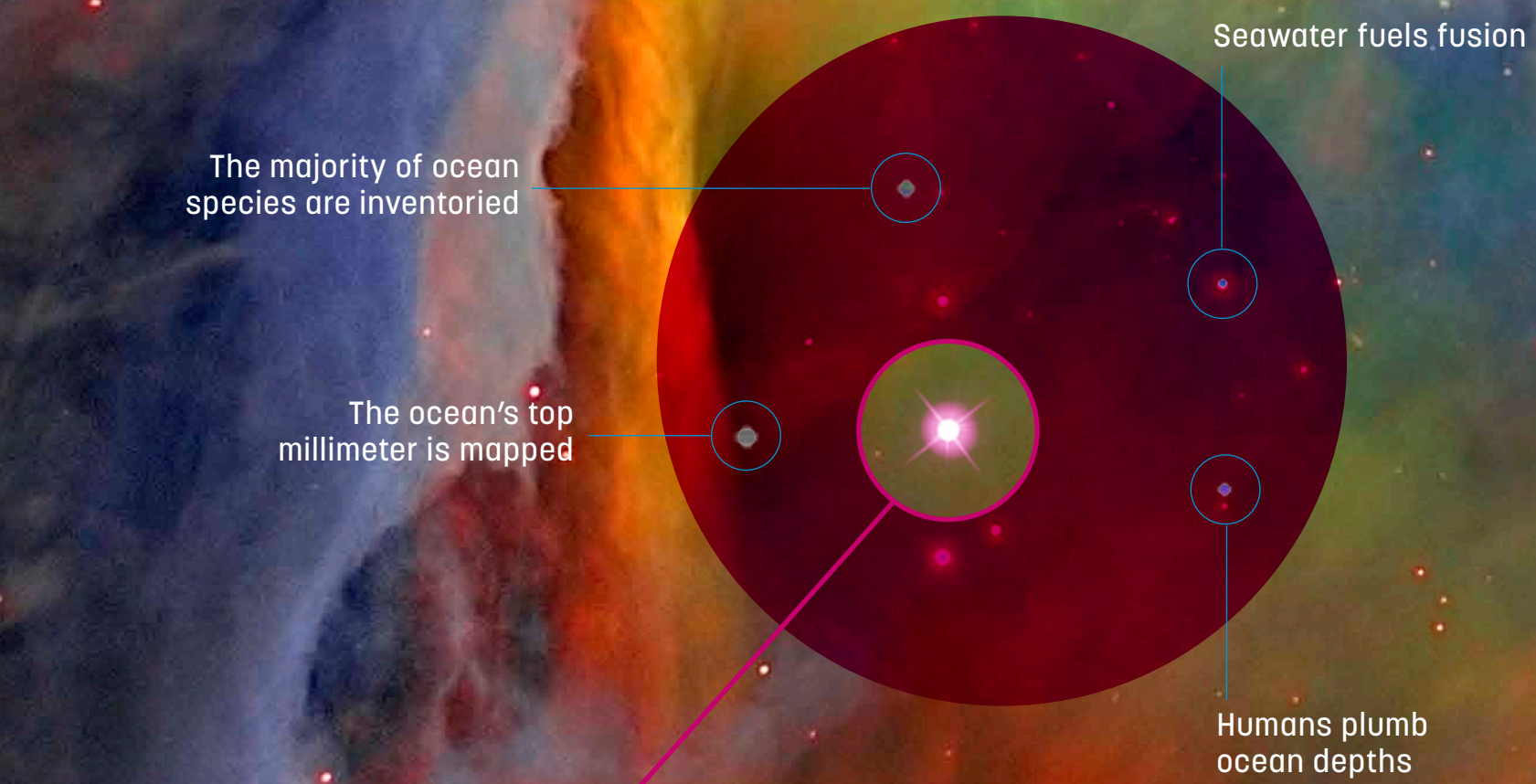
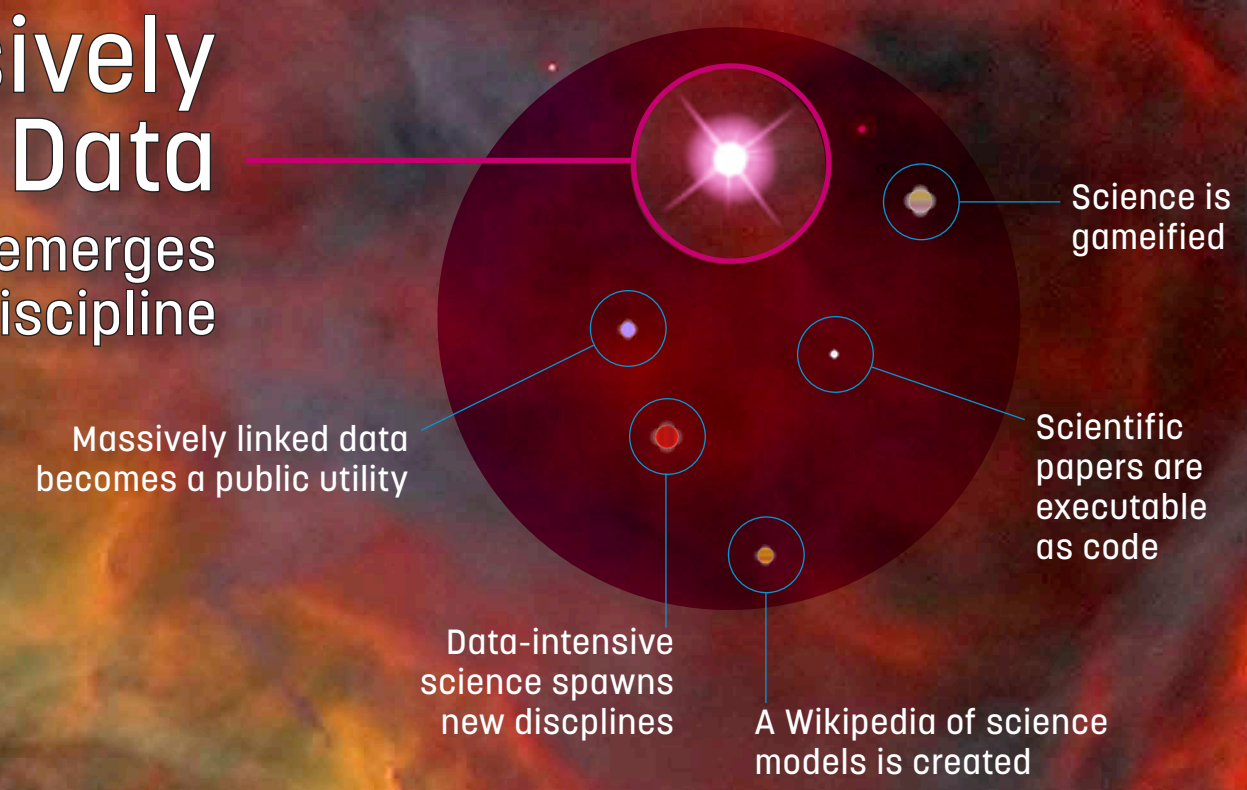
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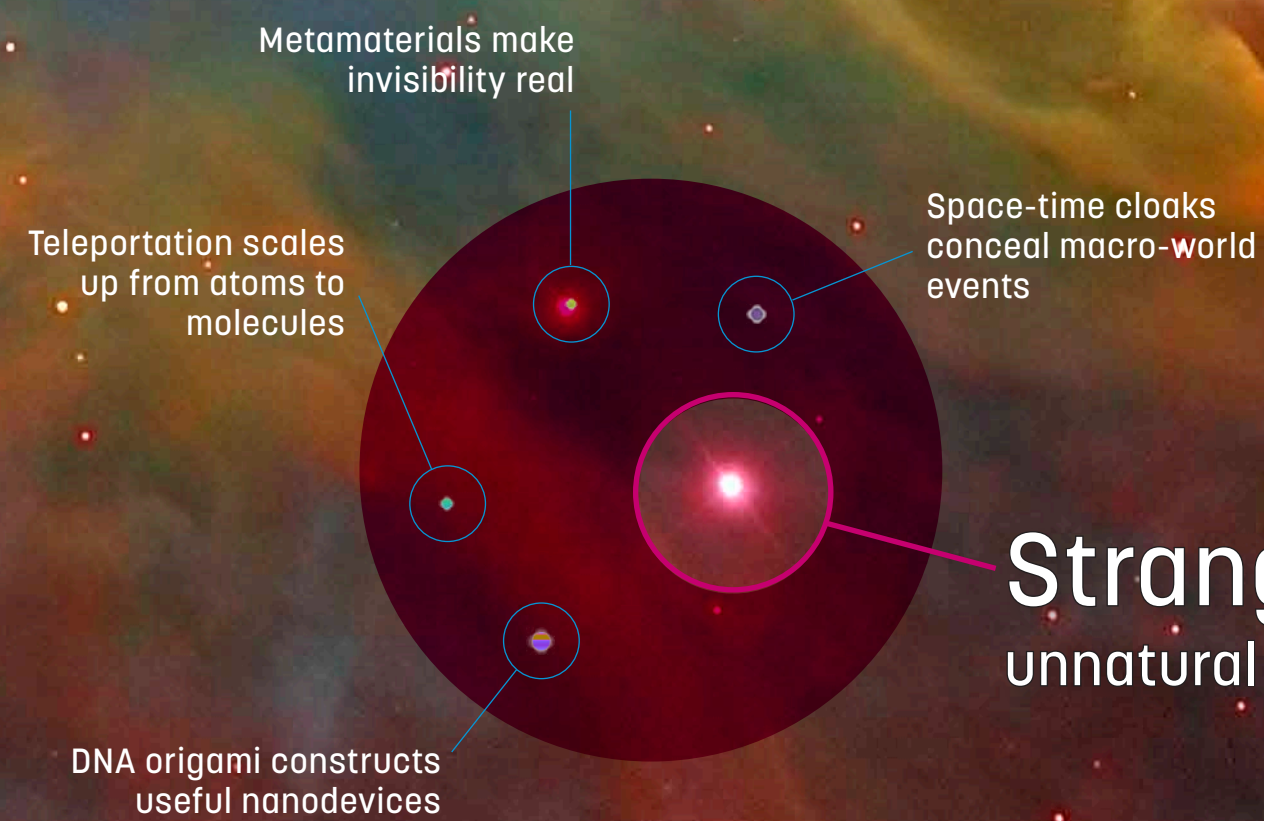
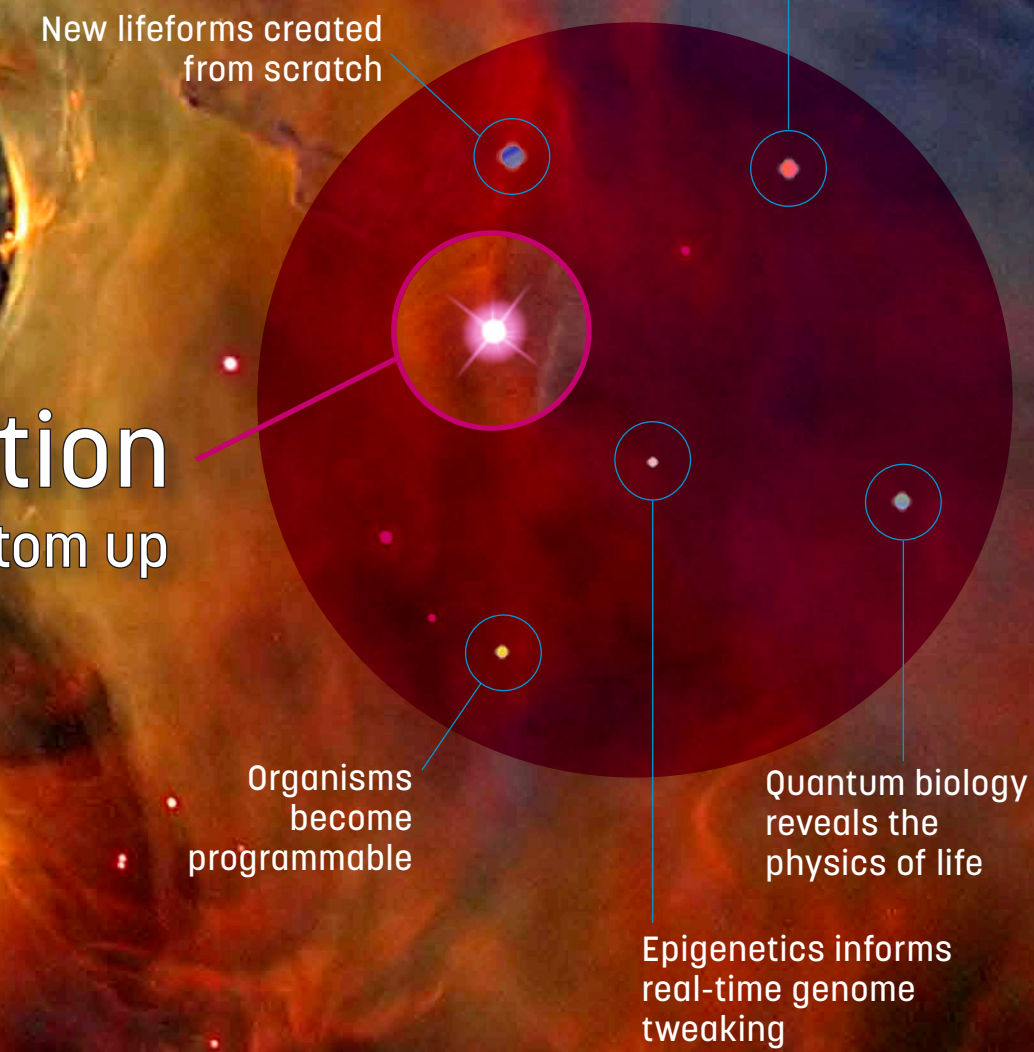


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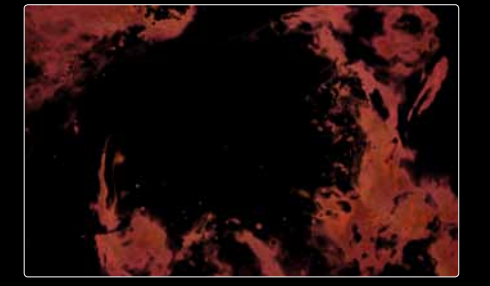


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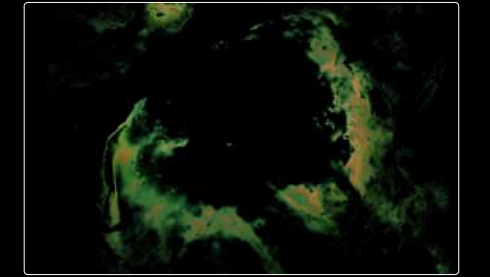
interstellar clouds of creation

amplified collaboration



Unprecedented endeavors demand new skills and communities-of-practice.

peer review and peer pressure



New social and crowdsourced systems emerge for knowledge-sharing and evaluation.

recycle, reuse, research



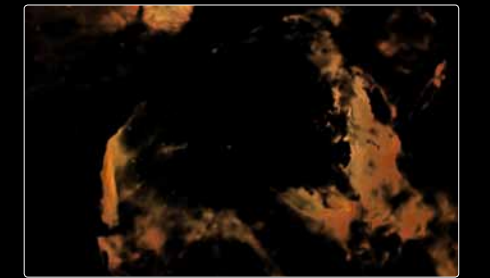
Obsolete tools are hacked, modded, and shared for new purposes.

reshuffling the global deck



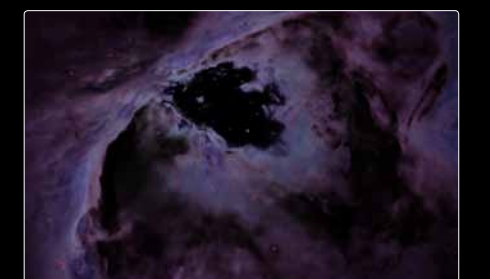
Innovation increasingly comes from beyond the Americas and Europe.

public patronage



Community funding and microgrants support scientific efforts.

citizens of science



The public is awakened as active contributors to scientific endeavors.



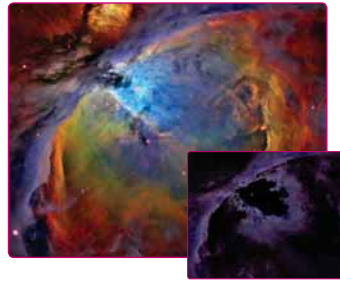
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"Imagination is more important than knowledge." —Albert Einstein

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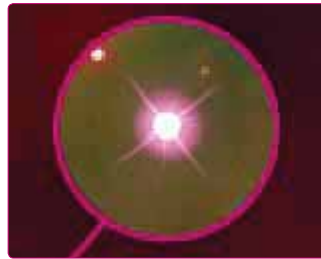
HOW TO USE THIS MAP

Consider the Technology Horizons *Future of Science* map to be a star chart of possibility, pointing the way toward opportunities for wonder, knowledge, and insight. Use this map to raise questions about how your life and work may change in light of the startling transformations that science may bring about during the next ten years. Indeed, every forecast could be rephrased as a “what if” question. What if you could record your dreams? What if you could design a lifeform? What if you could launch a company in orbit? Your answers to those questions can help inform decisions in the present. Inside this map you’ll find plenty of space to think.



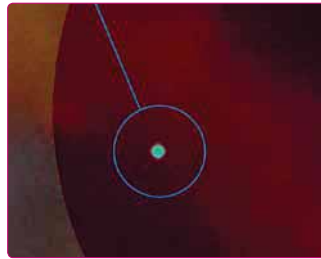
Nebula

In the vastness of space, nebulae are interstellar clouds of dust and gas where stars often form. On our map, the gases in the nebula, differentiated by their color, represent the “interstellar clouds of creation” or foundation that will support and stimulate tomorrow’s scientific transformations.



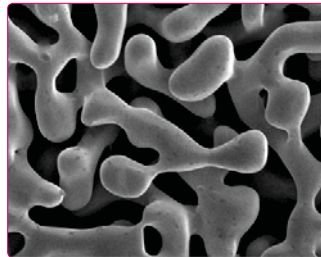
Stars

We’ve focused on six stars formed out of the nebulae. These stars are the six big stories of science that will play out over the next decade.



Planets

Orbiting the stars are planets that represent the forecasts embodied by the six big stories.



Signals

The back of the map shows some of the many moons in our metaphorical solar systems. These are the signals, early indicators pointing the way toward future research and breakthroughs, that inform our stories and forecasts.

Credits

Authors: David Pescovitz, Marina Gorbis, Ariel Waldman

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Producer & Creative Director: Jean Hagan

Design & Production: Karin Lubeck & Ariel Waldman

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