distant exoplanets in deep space[2].

Insights from many disciplines are needed to discover which ingredients, mechanisms and environmental pathways create and sustain life. Molecular biologists need to explain how proto-life might operate. Evolutionary biologists and ecologists need to probe life's interplay with alien environments. Geophysicists, geochemists and planetary scientists need to describe how planets evolve over billions of years. And astronomers have to detect more remote biospheres, while astrobiologists help to tie the pieces together.

Exoplanetary exploration should be central to this quest. Although exoplanets pique public attention, some astronomers see this field as niche and immature — they prefer to leave the review and funding of interdisciplinary projects in exoplanetary science to other fields. But if astronomers aren't included in such efforts, scientific quality suffers. Exoplanet science requires large and expensive teams, telescopes, satellites and computing facilities. But allied fields such as planetary and Earth science are established, vibrant and have their own wish lists of discipline-specific projects that are more ready for action than those in exoplanet research.

Competition over resources and intellectual turf is fierce among all these fields. For example, astronomers may favour building space-based observatories to gather more statistical data on exoplanets[3]. Meanwhile, planetary scientists might argue for detailed studies of a few planets. Both approaches are ultimately compatible, but that tension erodes the clarity of goals and can make funders nervous.

Crucial opportunities for scientists to learn from one another are falling between the cracks. For example, most Solar-System research is barely influenced by exoplanetary studies, and vice versa. Yet exoplanet data must be calibrated with knowledge about the Solar System, from the nature of runaway greenhouse-gas effects on Venus-like planets to how the orbits of young planetary systems are reconfigured.

INTERACTION, NOT ISOLATION

There has to be a radical shift. Now that answers about life's universality are finally within reach, funding agencies and scientists must step up. In our view, the field needs a systems-science approach[4] focused on interactions — between galactic environments, planet formation, orbital dynamics, heliophysics, atmospheres, hydrospheres, cryospheres, geospheres, biospheres and magnetospheres — rather than on components in isolation. This would extend Earth-systems science to encompass other types of planet and ecosystem.

Here we highlight three key questions that illustrate how exoplanet systems science can draw disciplines together.

Studying organisms from Yellowstone National Park's hot springs can uncover conditions needed for life.

SMITH COLLECTION/GADO/GETTY

What dictates planets' variety and properties? For example, why are the atmospheres and climates of Venus, Earth, Mars and Titan so different? To find out, we must bridge the gaps between Solar-System, exoplanet and astrophysical science. Observational data must be tied to models that simulate the evolution of the atmospheres, interiors and surfaces of planets over billions of years[5]. Tools from data science must be adapted to tackle increasingly large and complex data sets.

The Solar System should serve as one calibration point while its statistical significance is assessed. For example, structures in Jupiter's atmosphere and magnetic field revealed by NASA's Juno spacecraft are changing views of the planet's core and of how gas giants form. Studies of vortices and reflective particles in Neptune's atmosphere have shown how chemistry affects the spectra of ice giants. And the New Horizons mission to the dwarf planet Pluto and the Dawn mission to the minor planets Vesta and Ceres helped to trace how condensed volatile compounds are distributed in the Solar System.

Exoplanetary data challenge established ideas and put our understanding of the Solar System into a wider context. For example, we now know that planets can form around binary stars, extremely close to stars and in dense packs. Gas giants have a wider range of chemical compositions than was previously thought. Planetary orbits can be highly elongated or inclined. Astronomy facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile are revealing details of the agglomeration of dust and solids, and chemical zones in nascent planetary systems unlike ours.

Wider insights from astronomy are also needed. A major question is how stars influence the planets around them. Stars spin and oscillate according to their age, internal structure and activity. Young and low-mass stars can emit intense X-rays and γ-rays or eject charged particles. These may erode the atmospheres of planets and modify their composition, affecting their surface temperature and ability to hold water[6]. A planet's magnetosphere can mitigate this, but needs to be better understood.

The elements in stars influence planet formation, but it is unclear how. Elements can accumulate in different areas of the disks that ring young stars. The build-up of material might be affected by the rates at which stars and disks spin. The bulk properties of stars and their births across the Milky Way need to be investigated in more depth to establish how planets have formed from the Big Bang to today.

How can we identify worlds that are capable of harbouring life? The study of exoplanets opens up a wider range of planetary characteristics than we can observe in the Solar System alone, such as mass, composition and orbital configuration. Knowledge of Earth's deep environmental history, climate and chemical state is essential for calibrating models that explore the likelihood of life forming on other worlds, perhaps under different conditions. But a broader approach to planets would also help to interpret Earth: from the puzzles of ancient atmospheric oxygenation and chemical and climatic change, to the influence of human activity.

Geoscientists and astronomers need to develop better criteria for categorizing