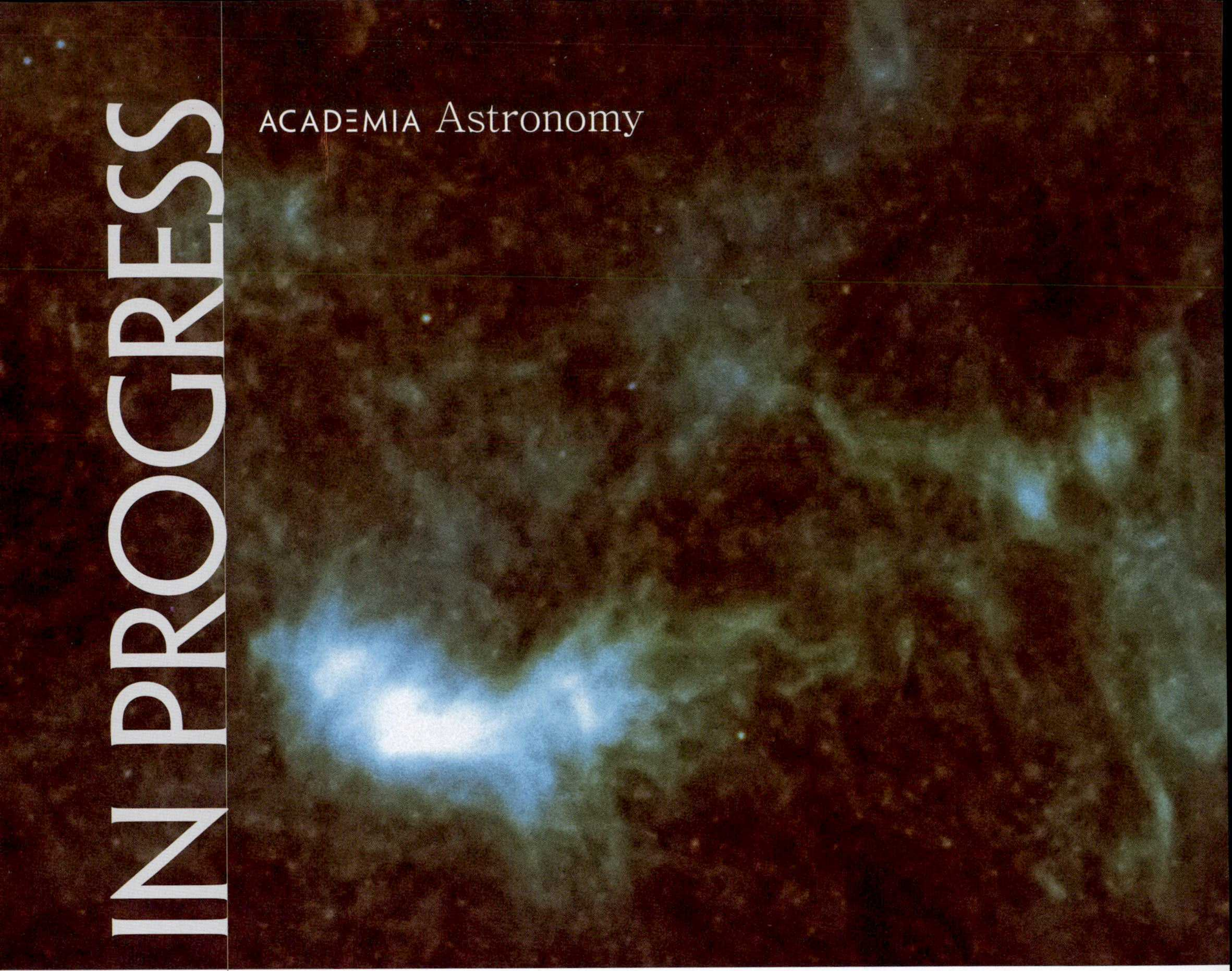

In the Beginning There Was Water

Water and fire are thought of as extreme opposites. So what does water have in common with the great fireballs known as stars? Data from the Herschel Space Observatory indicate that young stars are where water molecules are formed

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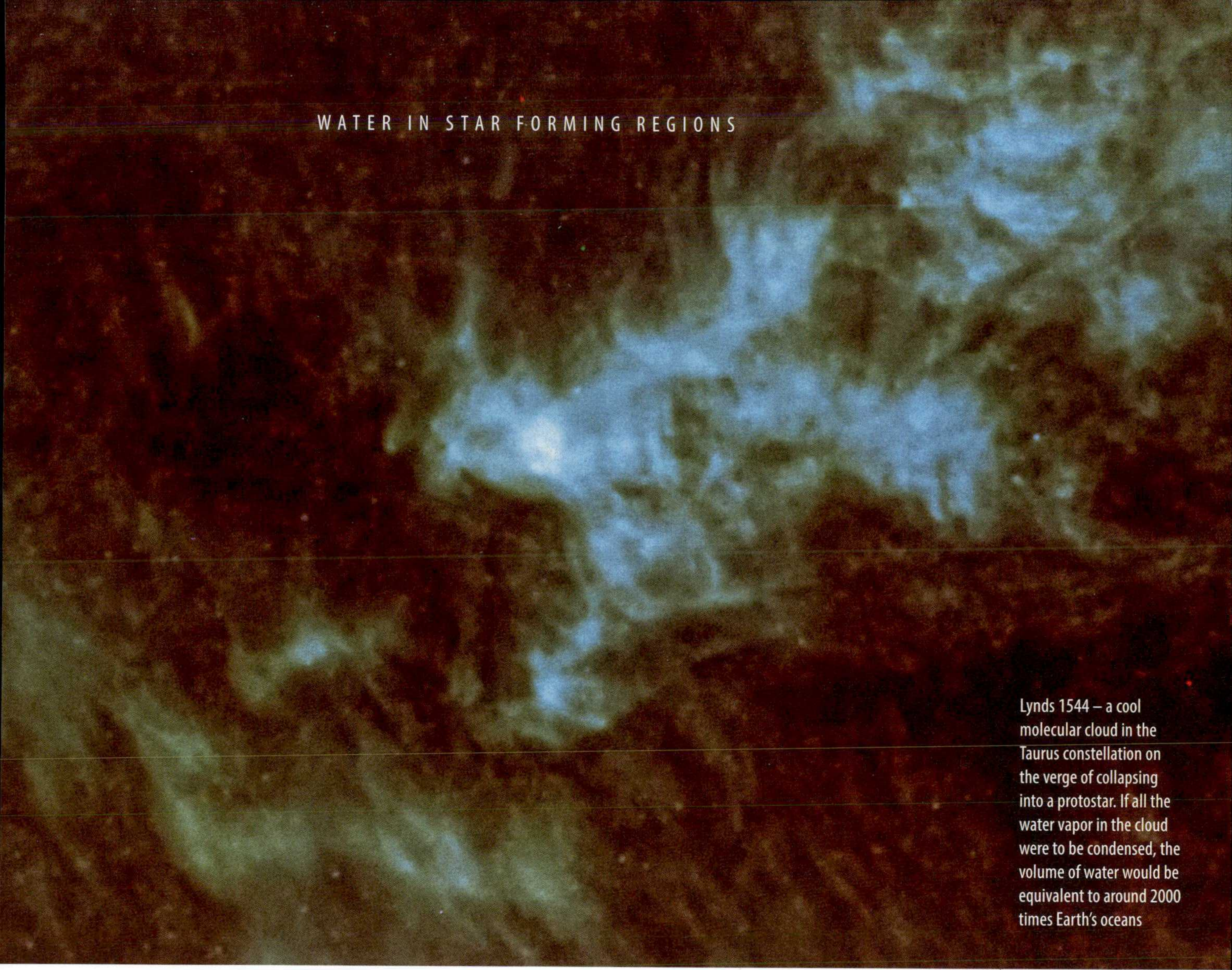
We have already catalogued over 1600 extra-solar planets, and yet we still know very little about how stars and their planetary systems are formed. The problem is largely to do with observation: protostars, objects which will someday start generating energy via thermonuclear synthesis and become "true stars", are formed in regions with a high dust and gas density, making them impermeable to visible light. Ob-



Lynds 1544 – a cool molecular cloud in the Taurus constellation on the verge of collapsing into a protostar. If all the water vapor in the cloud were to be condensed, the volume of water would be equivalent to around 2000 times Earth's oceans

ESA/HERSCHEL/SPIRE

servations need to be conducted using long wavelength electromagnetic waves, ideally in the far infrared part of the spectrum. That's where the dust luminosity is at its highest, as are key molecular transitions which can be used for measuring gas temperature and density in the immediate surroundings of the protostar. Unfortunately, the Earth's atmosphere is completely impenetrable in most infrared bands, and until recently observations could only be conducted by experimental balloons or small satellites with very limited function.

The Herschel Space Observatory, launched in 2009, provided breakthrough imaging and spectroscopy in the infrared. One of the main scientific aims of the mission was studying water in regions where stars are formed. The pivotal program "Water in Star Forming Regions with Herschel" (WISH) brought together over 80 scientists from 35 research institutes around the globe wishing to study water vapor around protostars of different ages and masses. The objective was to trace water content in the matter around stars from their birth up as far as planet formation.

The researchers were surprised to discover that the observatory was only able to easily detect water around the youngest protostars, no older than 500,000 years. This naturally raised the questions: where does all this water come from? What physical processes are responsible for its formation and emission? And where does it disappear to?

Origins of water

In chemical terms, water can be formed in space in one of three ways: through collisions of molecules in gas, either ions and neutral particles, or two neutral particles, or on the surface of dust particles. Interstellar space is largely devoid of matter, so the likelihood of such events is extremely low.

However, in star forming regions conditions are very different: a single cubic centimeter can contain as many as a million molecules of hydrogen – the most abundant element in the Universe. When such a region is heated to a few hundred Kelvins (making it around a hundred times hotter than a typical cloud of interstellar matter), collisions between neutral molecules become extremely effective. In a short time, the abundance of water vapor can increase by several orders of magnitude. The high water abundance observed in regions of star formation reveals

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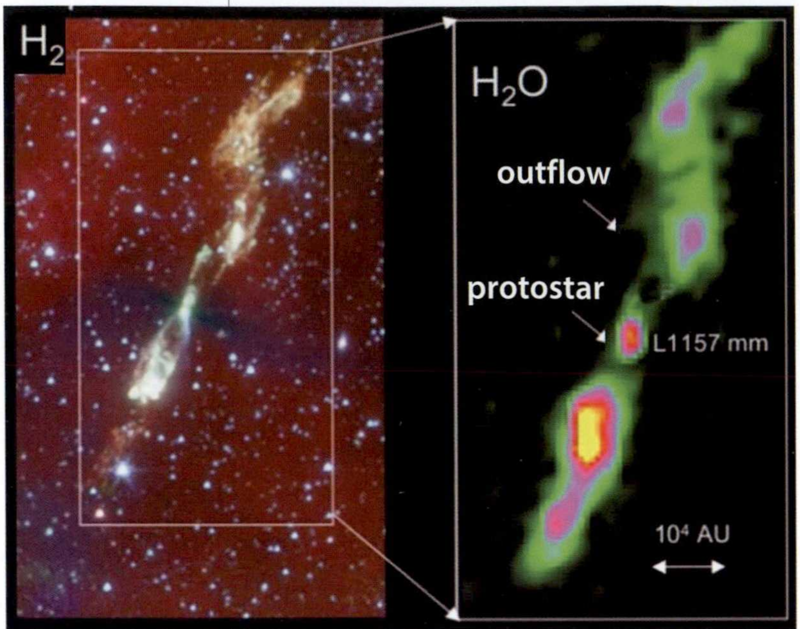

Images of a star being formed taken by the Spitzer Space Telescope (left) and the Herschel Space Observatory (right). Most of the molecular emissions originate from the bipolar molecular outflows.

SOURCES: LOONEY ET AL. (2003: APJ, 670, L131) AND NISINI ET AL. (2010: A&A, 518, L120) [MORE PRECISELY HTTP://EU-TOPIAS.ORG/EN/THE-WATER-TRAIL-FROM-THE-CRADLE-OF-A-YOUNG-SUN-TO-EARTH-LIKE-PLANETS/]

the presence of violent phenomena which dramatically increase the temperature around the star.

One of the first results reported by the WISH project was mapping the emission of water around the protostar L1157 – a prototype region of formation of a star similar to our Sun. Most of the water is seen as bullet-like structures formed as a result of matter being ejected from the protostar's surroundings, known as molecular outflows. A minor part of the emissions is linked with the immediate surroundings of the central object.

This means that most of the water is found at points where outflows and stellar winds act on the protostar's surroundings. Maps showing many transitions of water molecules and other particles (such as carbon monoxide molecules and the hydroxyl group -OH allow us to describe conditions found at molecular outflows with a good degree of precision, in particular the temperature and gas density. By comparing the relative luminosity of individual molecular lines against models, we have learned that the dominant process in the outflows involves shock waves. This means that they are regions where temperature and gas density increase rapidly, creating ideal conditions for the formation of water molecules.

How much water is there?

A precise analysis of observations conducted by the Herschel Space Observatory has raised doubts over a certain important aspect of commonly used shock wave models: the amount of water they produce. Comparison of observations and models for around twenty young protostars from the Perseus constellation reveals that current models overestimate the number of water molecules.

The problem can be solved by taking into consideration the illumination of shock waves by ultraviolet light. The source of this radiation is not the protostar itself, but rather matter falling from the disc onto the star and creating an extremely hot, luminous region.

This type of radiation leads to the photodissociation of water molecules – their breakdown into oxygen and hydrogen. Additionally, it changes the structure of the shock wave, resulting in an even greater compression of the gas. New models are starting to take these processes into consideration, and comparisons against observations of protostars are very promising.

Although most of these water molecules do not remain in the protostar's surroundings, being able to better describe these processes is significant for predicting the star's eventual mass and the chemical composition of the matter which will form planets.

Observations conducted by Herschel have provided us with a new perspective on processes occurring at protostars, although we are yet to discover the origins of water on Earth. Next year, the Atacama Large Millimeter Array (ALMA) in Chile will start observations of selected water bands with a higher spatial resolution than Herschel. The James Webb Space Telescope is scheduled to launch in late 2018, conducting observations of high-energy transitions of water molecules and ice in the vicinity of young stars. In the meantime, astronomers are analyzing data from the extensive archives generated by Herschel, which are bound to hold many more secrets.

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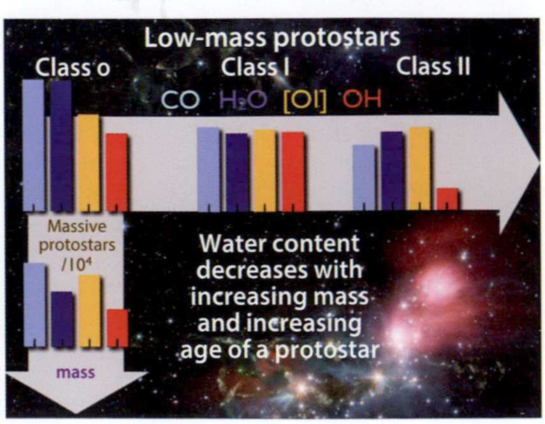

Further reading:

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