Rise of the robot astronomers

Long nights spent peering into the cosmos are over, for humans at least. Artificial intelligence will take charge of the planet's greatest telescopes

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IN October 1923, after nights of meticulous observations with the 100-inch telescope on Mount Wilson near Pasadena, California, Edwin Hubble noticed three new specks of light in one photograph of the Andromeda nebula that he marked with N for nova.

Hubble's specks were the first step towards his discovery that the universe was expanding. When he compared his Andromeda photograph with earlier images, he crossed out one N and wrote VAR! next to it. It was not a nova but a variable star, whose brightness fluctuates in a manner that allowed him to measure how fast it was receding from Earth.

Such a romantic tale of a lone astronomer unlocking the secrets of the universe is unlikely to be repeated. Robot astronomers are increasingly scouring the skies in place of humans, cataloguing stars and galaxies as well as making the observations that could help solve the puzzle of dark energy, the stuff we think is accelerating the expansion of the universe.

Social networking for telescopes

To automate astronomy you need a network of robotic telescopes, all talking to each other. The Las Cumbres Observatory Global Telescope Network, when complete, will link up robotic telescopes in Hawaii, Chile, Australia, South Africa, Texas and the Canary Islands. This will ensure that the sky will always be dark over at least one of the telescopes in the network, and observations can be passed automatically from one telescope to another.

Similarly, the Heterogeneous Telescope Network (HTN) consortium has developed a common software language for telescopes . It's being used by the eSTAR project, an intelligent robotic telescope network. For instance, the system links NASA's SWIFT satellite and the 3.8-metre United Kingdom Infrared Telescope (UKIRT) on Mauna Kea, Hawaii. If SWIFT spots a gamma-ray burst an alert is relayed instantly to UKIRT, which can perform follow-up observations. Observatories can choose to join the network as and when they please. It's a planet-spanning chatroom for telescopes.

Remote-controlled robotic telescopes are also ideal for regions that are hostile to astronomers but brilliant for astronomy. Telescopes are now being built on Dome C, 3260 metres up on the Antarctic Plateau and at the 4517-metre-high Hanle Observatory in the Indian Himalayas. The instrument at Hanle is part of an international collaboration called COSMOGRAIL (for Cosmological Monitoring of Gravitational Lenses), which uses a network of small telescopes to continually monitor the bending of light from quasars due to the gravity of a galaxy or cluster of galaxies in the line of sight.

At the Mount Palomar Observatory, about 150 kilometres south-east of Hubble's workplace, the Palomar Transient Factory (PTF) has artificial intelligence to help it find "transients" – variable stars and short-lived celestial objects such as supernovae.

Computers analyse images, identifying interesting transients so that the robot telescopes can follow them before they disappear from the night sky. "Our grand goal is to remove astronomers from the real-time loop of looking at images and doing discovery of astronomical transients," says team member Joshua Bloom of the University of California, Berkeley. This will allow humans to focus on the theoretical ramifications of what the automatons find.

Why is such a change necessary? Telescopes can dwarf large office buildings in size and they are getting bigger, drowning astronomers in a deluge of data. Consider the Large Synoptic Survey Telescope (LSST), an 8.4-metre telescope being built atop Cerro Pachón in Chile. Every night, its 3200-megapixel camera is expected to find 100,000 transients. "There are not enough graduate students in the world to follow up all these things," says astronomer Kirk Borne of George Mason University in Fairfax, Virginia.

Astronomers hope AI and automation will come to the rescue. The neural network, software that mimics networks of neurons in the brain, was one of the first AI techniques employed in astronomy. Neural networks have been trained to analyse astronomical images and distinguish the point sources of light that are stars from the more diffuse light of galaxies.

Now more sophisticated AI techniques are being added to the mix. The astrometry.net project, for example, uses machine-learning algorithms to help astronomers tag any image of the sky with precise coordinates. The software is trained by analysing existing star catalogues and creating sets of four stars, each of which serves as a three-dimensional reference for some part of the sky. Given a new snapshot of the sky, the algorithms look for sets of four stars in the image and try and match them to those extracted from the star catalogues.

The trouble is, camera angles and scales can change from image to image. So the algorithms use a technique called geometric hashing to describe the geometry of any set of four stars in a way that does not depend on their relative positions or the camera angle. "In other words, no matter where you see those four stars,

"Robotic telescopes are making observations that could solve the puzzle of dark energy"

you'll still be able to recognise that shape," says team member Dustin Lang of Princeton University. "It's a little bit like our ability to recognise the constellations."

Machine-learning algorithms can also unearth outliers, odd objects such as quasars. In any given image of the sky, the majority of the point sources of light are stars. Maybe 1 in a 1000 is a quasar, an extremely distant but powerful galaxy. It is quasars that interest Borne. He starts with a set of parameters that define the pinpricks of light in an image – such as colour and brightness, among hundreds of other

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Who will analyse the images?

properties. The parameters of each object are compared with those of every other object in the image. Stars will have similar properties, but occasionally the object will be a quasar and its matrix will stand out brightly.

The system isn't foolproof, and sometimes the outlier is simply noise. To avoid such mistakes and to figure out whether something interesting really is lurking in that part of the sky, Borne's software taps into the Virtual Observatory – a massive collection of astronomical data sets spread around the world. Maybe, for example, another telescope identified the region as a radio source. The additional data allows the software to weed out spurious signals, and will help refine its predictions. The goal is to identify a source in the sky worth following up.

Examining images, and directing telescopes to follow up on objects of interest in real time, rather than weeks after as Borne's system does, is a much trickier prospect.

Over the past six months, the Palomar Transient Factory has automated this entire process. It starts with images collected by a 48-inch Schmidt telescope on Mount Palomar. Each night, computers pore over the images for transients. First, they take a reference image for a given part of the sky, which has been built up by combining multiple earlier images. This is aligned with and subtracted from the latest image to reveal any new objects in the sky. If the position of a new source has changed appreciably over days, for instance, it's likely to be an asteroid, not a variable star or a supernova, and is weeded out.

The system then searches other astronomical databases on the internet for additional information about that location in the sky, looking for a nearby X-ray source or data taken by different telescopes in other wavelengths.

"The Palomar Transient Factory looks for short-lived objects and can spot a supernova in real time"

This information helps firm up the prediction of the nature of the mysterious object.

Supernovae need to be studied immediately, before they fade. So if the classifier is confident it has found one, two robotic telescopes will swing into action – the Peters Automated Infrared Imaging Telescope in Arizona and a 60-inch optical telescope on Mount Palomar. "Some of the slam-dunk things that we are already doing is finding and identifying type Ia supernovae weeks before their maximum light," says Bloom.

Every night, PTF is turning up 100 variable stars and five supernovae that have yet to reach their maximum brightness, all without the need for human astronomers. Catching supernovae before their peak brightness allows astronomers to tell their distances from Earth. They can then be used as "standard candles", to help understand how the expansion of the universe has changed with time, which in turn will tell us about the nature of dark energy.

And Hubble's legacy might yet play a role in solving the mystery of dark energy. The famous Hubble Space Telescope is also robotic, and is routinely used to make follow-up observations of supernovae. ■