Figure 1. Gemini North's laser propagating up into the sky above Mauna Kea in Hawaii. The blue-and-white boxes mounted behind the primary mirror in the lower half of this image contain the instruments that make use of the artificial star created by the laser to compensate for the blurring effect of the Earth's atmosphere. Image courtesy of Gemini Observatory/AURA.

Supernova Safari

BY STUART RYDER

Astronomers are now using "laser vision-corrected" telescopes to hunt for supernovae that would otherwise have gone undetected.

Stars that are born with at least eight times the mass of our Sun are destined to end their lives in brilliant supernova explosions, when the supply of nuclear fuel in their cores is exhausted and energy generation can no longer balance the force of gravity. The most massive stars live fast and die young, often within a few million years of their birth. At its peak, a supernova explosion can briefly outshine the light of all the other stars in its host galaxy.

By counting the number of supernovae that occur in galaxies, astronomers can work out the rate at which these galaxies have recently been forming stars. However, these star formation rates are well short of those derived by other means, so where are all the missing supernovae? Like the tree that falls unheard in the forest, could there be entire supernova events that occur in the nearby universe without anyone noticing?

For a long time supernova discoveries were the serendipitous by-product of case studies of individual galaxies, when astronomers happened to notice a new star that was not apparent in earlier pictures of the same galaxy. Amateur astronomers have made a valuable contribution, exemplified by Australian Bob Evans who has found more than 40 supernovae using nothing more than a modest backyard telescope, his own eyesight, and a prodigious memory for the location and appearance of hundreds of galaxies.

Today amateurs face stiff competition from robotic telescope surveys, such as the Lick Observatory's Katzman Automatic Imaging Telescope. But all these searches are necessarily restricted to surveying the nearest galaxies at optical wavelengths, when we know that much of our own Milky Way galaxy and similar spiral galaxies elsewhere are obscured from view by dust clouds.

Upping the Odds

Just as big game hunters would like to increase their chances of a kill by being allowed to hunt inside a wildlife reserve, professional astronomers would like to boost the odds of discovering supernovae by being able to peer inside the types of galaxies undergoing a "starburst" episode, in which the massive stars that give rise to supernovae are being born at the highest rates. The class of starburst galaxies known as Luminous Infrared Galaxies (LIRG) ought to be the ideal hunting grounds for supernovae, hosting at least one supernova each per year. Yet barely a handful of the more than 4500 catalogued supernova discoveries were found in LIRGs. Why is this?

There are two main reasons. First, LIRGs are incredibly dusty. Indeed, it is the action of all that dust absorbing nearly all of the optical and ultraviolet radiation emitted by the young massive stars, and re-radiating it at the longer infrared wavelengths, that gives rise to their prodigious infrared luminosities. Second, both this dust and the tendency of stars to form in compact clusters around their nuclei make LIRGs appear extremely clumpy.

Theoretically, by observing LIRGs at infrared wavelengths longer than 2 μm, the obscuration by dust is reduced a million times compared with visual wavelengths, while at the same time improving the resolution of our telescopes by a factor of four. In practice the Earth's atmosphere acts as a "gamekeeper" and claws back some of these gains by absorbing some infrared wavelengths and blurring out the sharper images to some degree.

With no guaranteed access to the venerable Hubble Space Telescope, how can astronomers in Australia hope to make any headway in this important area?

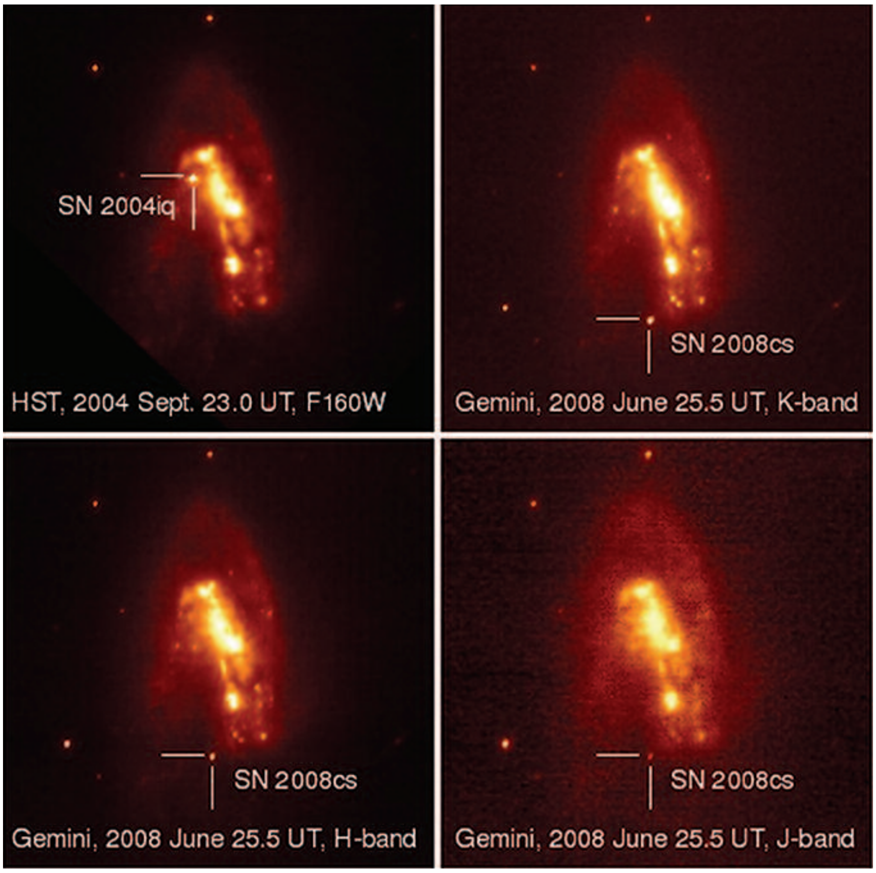

Figure 2. Infrared images of the LIRG IRAS 17138-1017 obtained with the Hubble Space Telescope in September 2004 at a wavelength of 1.6 μm (top left); and with the Gemini laser guide star system in June 2008 at wavelengths of 2.2 μm (top right), 1.65 μm (bottom left) and 1.25 μm (bottom right). Notice how supernova 2008cs is much fainter at the shorter wavelengths due to the reddening effects of dust, and that the Gemini images are easily as good as those obtained by the Hubble Space Telescope.

Image courtesy of Erkki Kankare and Seppo Mattila, Tuorla Observatory of the University of Turku, Finland.

Adaptive Optics to the Rescue

Australia has a 6.2% share in the international Gemini Observatory partnership, which built and now operates two telescopes with 8.1-metre diameter mirrors, one on the 4200-metre high summit of Mauna Kea in Hawaii and the other on Cerro Pachon in Chile. Among the world's largest telescopes, Gemini prides itself on being the best at infrared astronomy on account of the telescopes' lightweight design, high and dry locations, and state-of-the-art instrumentation.

In the past 5 years, both telescopes have been outfitted with an "adaptive optics" system that all but undoes the blurring effects of the Earth's atmosphere at infrared wavelengths. It does this by monitoring the smeared appearance of a stellar point source at or near the object of interest; figuring out the distortions introduced to the originally-flat wavefront by the atmosphere; applying the inverse distortion to the incoming waves by mechanically deforming a mirror in the beam; and repeating this process 1000 times every second. The end result is typically five times sharper than without the use of adaptive optics, and at least as sharp as the Hubble Space Telescope can deliver.

While this technique of adaptive optics has revolutionised our ability to study the Universe in more detail, not every LIRG we might wish to look at just happens to have a natural guide star that is close enough and bright enough. Not to be deterred, astronomers and engineers have found a way to create our own artificial guide star wherever we need to by using a laser.

Not just any laser mind you; the laser on the Gemini North telescope (Fig. 1) has a mere 10 Watts of power, but this is still 10,000 times more powerful than the most powerful laser pointers you are now permitted to legally own or import. And instead of being deep red or bright green in colour, the Gemini laser has an orange colour similar to that of sodium street lamps.

There's a very good reason for this: by tuning the laser to only emit light at a wavelength of 589 nm, the laser is able to excite sodium atoms located 90 km up in the Earth's atmosphere and make them glow, producing a perfectly acceptable artificial star-like point right where it's needed.

What are sodium atoms doing 90 km high? They are debris from the disintegration of meteors as they enter the Earth's atmosphere. The continual rain of meteors of all sizes is enough to provide the trace amounts of sodium required to make laser guide star adaptive optics a reality.

Bagging a Trophy

Since the start of 2008, Dr Seppo Mattila and I have led a team of astronomers from Australia, Finland, Spain and South Africa in a program to find new supernovae in a sample of nine LIRGs. Every 3 months or so, the Gemini North telescope in Hawaii turns its "laser vision" on each of the LIRGs in turn and collects an image in the infrared. Thanks to Gemini's queue mode of operation, it is not necessary for us to travel to the telescope several times a year; the data are taken for us by experienced Gemini staff, and made available to us within hours over the internet from a data archive in Canada. Careful matching and subtraction of an earlier image of the same LIRG helps us to spot any new supernovae.

We hit the jackpot with just our third observation. The LIRG named IRAS 17138–1017 – which is named after the coordinates on the sky where the IRAS satellite found a bright infrared source in the early 1980s – had in fact previously been observed with an infrared camera on board the Hubble Space Telescope in September 2004. A simple comparison by eye of our 2008 Gemini observation with the Hubble image from 2004 showed not just one new source in our 2008 image, but also that one of the sources visible in 2004 has now disappeared (Fig. 2).

The Hubble images had been taken for a completely different purpose and, with nothing to compare it to, no one had noticed this transient source. We reported these results to the International Astronomical Union's Central Bureau for Astronomical Telegrams which, once determining that both sources were genuine and not likely to be asteroids or variable stars in our galaxy, conferred on them the designations Supernova 2004iq and Supernova 2008cs.

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Although Supernova 2004iq is now long gone, we have been able to follow the rise and fall of Supernova 2008cs in subsequent months, confirming that it behaves just like a supernova should. We have found that Supernova 2008cs is much redder than supernovae found elsewhere, which we attribute to the effects of intervening dust within the LIRG, much as the Sun appears deep red when observed through smoke from a bushfire.

Our calculations indicate that fewer than one in every 10 million optical photons emitted by Supernova 2008cs are able to escape the LIRG's dust and reach the Earth. To put this in context, if Supernova 1987A in the Large Magellanic Cloud – the only supernova in the past four centuries bright enough to be seen with the naked eye – had been hidden behind this much dust then it would in all likelihood have gone completely unnoticed by astronomers on Earth, at least until it could be detected at radio and X-ray wavelengths.

Despite these early successes, we have yet to find any more supernovae in LIRGs. Our modelling indicates that many events will still be lost behind even more dust, or lost in the glare of the bright LIRG nuclei, but we ought to be finding more in coming months. If not, then the fundamental assumption that LIRGs are powered by the formation of stars may be called into question.

Perhaps the contribution from an active galactic nucleus, in which gas is spiralling in towards a super-massive black hole at their centre, is greater than we thought? Or perhaps LIRGs are even dustier than previously imagined?

Either way, the results of our search will have profound implications for our understanding of the supernova phenomenon, as well as the nature of the LIRGs themselves.

Towards the end of this year, the Gemini South telescope in Chile will be fitted with a laser guide star system five times more powerful than the one on Gemini North, and it will feed corrected images to a special infrared camera built by the Australian National University's Research School of Astronomy and Astrophysics at Mt Stromlo. This, coupled with Australia's involvement in the Giant Magellan Telescope due for completion in 2016, with seven times the collecting area of each Gemini telescope, should help us ensure that supernovae have no place left to hide.

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