Turning on to speckle imaging

Elliott Horch

Speckle imaging, an older technique for obtaining diffraction-limited resolution with large telescopes, is back in a big way thanks to electron-multiplying CCDs.

If you ask astronomers about the technique of speckle imaging, most would probably be able to say that it is an old and venerable way to obtain diffraction-limited images with large telescopes. But they might also ask if people still use it. After all, in the last 20 years, many large telescopes have been outfitted with adaptive optics systems that give high-resolution images directly on a CCD chip. In contrast, with speckle imaging, the individual speckle frames have to be carefully analyzed after the fact to build up a reconstructed image.

The fact is, that although the use of speckle imaging waned in the late 1990s and early 2000s, it is now seeing a resurgence for a couple of reasons. The main reason is the development of commercially available electron-multiplying CCD cameras (EMCCDs) from companies such as Andor and Princeton Instruments. These cameras allow the user to build up the charge associated with each detected photoelectron, prior to reading it out through the charge amplifier. If the charge is significantly higher than the read noise, the result is the ability to detect individual photons: it gives these cameras a photon-counting capability with the same high quantum efficiency than astronomical CCDs. An example of ‘turning on’ the electron-multiplying gain is shown in Figure 1. The second reason that EMCCDs have been a game changer for high-resolution imaging is that speckle imaging groups who use these cameras have shown that they can avoid an important problem encountered with earlier-generation photon-counting systems. In those devices, there is a dead-time effect in pixels that preferentially makes bright speckles look dimmer. This effect is a contributing factor in the loss of good photometry in speckle imaging with older systems. With EMCCDs, however, there is no issue because the amplification is done after detection.

In today’s speckle imaging, signal amplification and linear photometric response are combined. This allows much fainter targets to be reached and provides reconstructed images with much higher fidelity. Furthermore, unlike many adaptive optics systems that are optimized for science at IR wavelengths, speckle is easily conducted in the visible range. At the Gemini North 8.1m telescope, for example, a triple star with a visual magnitude of 16.9 has been successfully observed at the diffraction limit.

EMCCD-based speckle imaging is now being used at several telescopes, including the Southern Astrophysical Research and Gemini South telescopes (Chile), the Special Astrophysical Observatory 6m telescope (Russia), as well as the WIYN telescope, the Discovery Channel Telescope, and Gemini North (United States). The science being pursued spans a range of interesting projects. These include exoplanet follow-up, observations of solar system objects (e.g., main-belt asteroids and the Pluto-Charon system), obtaining resolved images of stellar disks in the blue region of the visible spectrum, and obtaining definitive orbits of binary stars for the purpose of deriving empirical stellar masses. A more detailed overview will be provided in an upcoming presentation.1

Observations of exoplanet host stars have been particularly productive. For these observations, the main goal is to discover and characterize any close stellar companions to the exoplanet’s host star. We have learned in recent years that stellar companions

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are relatively common in exoplanet systems. A handful of circumbinary planets (planets that orbit the center of mass of a close binary system) are known, but the second star frequently orbits the first at a distance significantly larger than the planets. In some studies it has been suggested that stellar companions are less common at distances more comparable to the planets.\(^2\)

We have shown, however, that at wider separations the number of stellar companions is not statistically different from the field population (i.e., between 40 and 50\%).\(^3\) This finding suggests that many planets have both a ‘day star’ and a ‘night star’ in the sky. The night star (i.e., the secondary star) would be at a typical distance of hundreds of astronomical units, and would take thousands of years to orbit the primary star once.

Looking toward the future, there are some possible opportunities to improve the performance of the speckle technique by using it in combination with elements of adaptive optics. For example, recent work by my graduate student János Lőbb has shown that incorporating wavefront sensor data in combination with traditional speckle imaging can improve the sensitivity of faint companion detection. With many more exoplanet hosts being detected from the K2 (i.e., Kepler’s ‘second light’ mission) and future satellite (e.g., NASA’s Transiting Exoplanet Survey Satellite) projects, this could be a very important way to extend the reach of speckle. Meanwhile, we are building two new speckle cameras that will be facility instruments for the WIYN and Gemini North telescopes,\(^4\) and will therefore be open to use by the entire astronomical community. These developments mean that the future of speckle imaging is brighter today than it has been for a while. It may be time to try speckle imaging on your favorite object!

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References