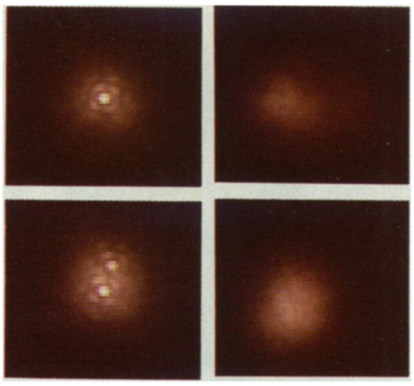
A Window on Turbulence

Taking the twinkle out of infrared images of stars

By IVARS PETERSON



Courtesy Christou/NOAO

Correcting for telescope motion and tracking errors can produce surprisingly sharp images (left) of single stars and closely spaced binary stars observed at wavelengths of 2.2 microns. Long exposures normally produce much fuzzier images (right).

The atmospheric turbulence that adds a twinkle to a star's appearance also blurs the stellar images produced by ground-based astronomical telescopes. The resulting fuzziness limits a telescope's resolving power – its ability to produce separate images of closely spaced objects.

A fresh, albeit controversial look at how light propagates through the atmosphere and how atmospheric turbulence affects images formed by large, ground-based telescopes now suggests that, at infrared wavelengths at least, atmospheric turbulence actually has a much smaller effect than conventional theory predicts.

"The notion that ground-based telescopes are forever limited and that you must go above the atmosphere for good viewing is just not true," says T. Stewart McKechnie, chief scientist at the Lentec Corp. in Albuquerque, N.M. "My theory says that if you observe at certain wavelengths, you can get extremely high resolution – much better than astronomers have traditionally expected."

McKechnie contends that building better instruments and taking greater care with observations should enable astronomers to achieve significant improvements in resolution when observing at infrared wavelengths ranging from 1 to 4 microns. Earlier this month, at a meeting of the Optical Society of America in Boston, he described recent astronomical observations apparently supporting his theory.

The crux of McKechnie's argument rests on estimates of the typical size of the vortices that disturb the atmosphere. Conventional theory assumes that such eddies occur on relatively large scales and over a wide range of sizes, from a few meters to several kilometers across. The resulting model of atmospheric turbulence predicts that using longer wavelengths would produce only marginal improvement in clarity.

On the other hand, McKechnie's model of atmospheric turbulence suggests that most of that turbulent energy actually concentrates in significantly smaller vortices – typically just 20 centimeters wide. His calculations show that such small-scale eddies don't completely wipe out the information carried by infrared signals. In other words, atmospheric turbulence interferes much less with observations at infrared wavelengths than astronomers have come to believe.

Because they assumed that atmospheric turbulence would be a limiting factor, astronomers rarely built high-precision telescopes. "Most telescopes have poor optics because people in the past were interested only in total light-gathering power when they built large [telescopes]," says Kenneth J. Johnston of the Naval Research Laboratory in Washington, D.C. "They were pretty well convinced that the atmosphere would just wipe out any efforts to improve resolution."

The blurring usually attributed to turbulence in the atmosphere is more often the result of telescope oscillations, tracking errors and flawed mirrors, McKechnie contends. He argues that by using higher-quality mirrors and compensating for the oscillations that regularly shake a telescope, astronomers could build large telescopes – for example, those with a 5-meter aperture – that routinely achieve a resolution of 0.05 arc-second at an infrared wavelength of 2 microns.

That's comparable to the resolution needed to distinguish a car's right headlight from its left at a distance of about 3,000 kilometers. Larger apertures would produce even better resolutions. Conventional theory, in contrast, puts a limit of approximately 0.5 arc-second on the resolution a ground-based telescope can achieve.

If McKechnie's predictions prove correct, they could have a significant impact on the construction of large telescopes in the future. Imaging techniques such as speckle interferometry – which essentially "freezes" the motion in the atmosphere from moment to moment by taking a succession of quick snapshots – are already pushing telescope technology to greater precision.

Several astronomers have recently reported unusually high resolutions even though the telescopes they used are flawed in some way. For example, an experiment at the Steward Observatory's Multiple-Mirror Telescope attained 0.1-arc-second resolution at 3.4 microns, and Julian C. Christou of the National Optical Astronomy Observatories in Tucson, Ariz., can produce images at the Kitt Peak 4-meter telescope with a resolution of 0.1 arc-second at a wavelength of 2.2 microns.

"They're confirming what I'm claiming," McKechnie says. "They're getting remarkable results even when their telescopes are less than perfect."

Christou isn't sure yet whether the residual blurring seen in his images is caused by the atmosphere or by imperfections in the telescope's mirror and the effects of telescope vibrations. "We are seeing some low-level aberration, which could well be due to our primary mirror," he says. "We're investigating this further."

He adds, "If McKechnie's theory is right, then it has a lot of implications for the way we build large telescopes – to what degree of precision we figure the mirror."

That could affect plans for new telescopes. "With telescopes such as the 8-meter currently in the planning stages, now is the time to investigate the matter," Christou says.

"The results . . . can be applied to both large ground-based astronomical telescopes and telescopes used for tracking and surveillance of objects in space," McKechnie writes in a paper scheduled for the December JOURNAL OF THE OPTICAL SOCIETY OF AMERICA. "The results are also relevant to the focusing of ground-based lasers on targets in space."

Researchers at Sandia National Laboratories in Albuquerque, N.M., have taken an interest in McKechnie's work. While no one has tested the direct relevance of his ideas to surveillance and targeting applications, Sandia scientists say those ideas are intriguing enough to merit further investigation. □