Considering Gemini’s exquisite spatial resolution and infrared sensitivity, it’s no surprise that the study of exoplanets and low-mass objects has emerged as one of the most requested and productive applications demanded by our users. The result is a plethora of “firsts” and highly cited papers based on Gemini data. Furthermore, ongoing and future projects, like the Gemini NICI Planet-Finding Campaign and much-anticipated Gemini Planet Imager (GPI) instrument, portend an extremely bright future for Gemini in the area of exoplanet research.

Until very recently, most planet discoveries were made using radial velocity techniques (using high-resolution spectroscopy), which tend to favor the discovery of giant planets orbiting rather close to their host stars. Because key Gemini strengths lie in high-resolution adaptive optics (AO) in the near-infrared (and low- to medium-resolution spectroscopy), the direct imaging and spectroscopic studies of worlds orbiting farther away from their host stars is causing the emergence of a whole new class of exoplanets—and Gemini is leading the way in the search.

Gemini’s impact in the field of exoplanet research began ramping up in December 2007, with a paper in *The Astrophysical Journal* on the Gemini Deep Planet Survey (GDPS) led by René Doyon of the Université de Montreal.
Figure 2 (top): K-band (2.2 microns) AO image of the HR 8799 planetary system acquired on September 5, 2008 (north is up and east is left). The three planets are designated with red circles. The stellar flux has been subtracted using ADI (see page 19 for details) and the central saturated region is masked out. Multi-epoch observations have shown counterclockwise Keplerian orbital motion for all three planets.

(bottom), Gemini image of 1RXS J160929.1-210524 and its likely ~8 Jupiter-mass companion (at about the 11:00 position. This image is a composite of J-, H-, and K-band near-infrared images. All images obtained with the Gemini Altair adaptive optics system and the Near-Infrared Imager (NIRI) on the Gemini North telescope.
and David Lafrenière of the University of Toronto. This survey of 85 candidate stars used the Near-Infrared Imager and spectrometer (NIRI) with the Altair adaptive optics (AO) system on Gemini North and found no new planets by direct imaging. Given the selection criteria for the sample (see figure 3), a statistical analysis of these data indicate that the 95 percent credible upper limit—for the fraction of stars harboring at least one planet more massive than two Jupiter masses with a semi-major orbital axis in the range of 25-420 astronomical units (AU) or 50-295 AU—is 0.23 or 0.12, respectively. These upper limits, the most precise ever obtained, leave little room for the existence of a swarm of giant exoplanets orbiting their stars at distances greater than the size of our own solar system. The boundaries set by this study continue to be highly cited in the exoplanet research community.

In 2008, a team headed by David Lafrenière announced that their group discovered the first likely true planet by direct imaging using Gemini. The image and spectrum, made using the Altair AO system with NIRI on Gemini North, still required proper-motion studies to confirm the object’s association with the star 1RXS J160929.1-210524. However, the potential planet’s spectroscopic signature made it an extremely strong candidate. Located some 500 light-years away, the likely planet lies some 330 AU from its host star. The object’s spectrum also suggests a surface temperature around 1800 K and a low surface gravity, indicative of something that is very young and still hot. As this issue goes to press, Lafrenière is producing a paper presenting evidence that the star and planet share mutual proper motion. Once published, this paper is expected to verify the original tentative conclusion of a true direct-imaging exoplanet discovery.

Only a few months after the Lafrenière announcement, an international team led by Christian Marois of the National Research Council of Canada’s Herzberg Institute of Astrophysics, presented what could only be described as an exoplanet “hat trick.” This time, instead of finding only one world orbiting its host star, Marois et al. discovered three (see Figures 1 and 2, previous page). The Gemini Altair/NIRI data, augmented by archival data from the W.M. Keck Observatory, resulted in the quick realization that this planetary “first family” was indeed the first confirmed direct image of a planetary system orbiting a normal star outside of our own neighborhood. The star, called HR 8799, is about 130 light-years away and has a mass about 1.5 times that of our Sun. Its planets range from about 7 - 10 Jupiter masses, with distances spanning 25 - 70 AU from the host star. Team member Bruce Macintosh of the Lawrence Livermore National Laboratories said in the Gemini press release issued on November 13, 2008, "Until now, when astronomers discover new planets around a star, all we see are wiggly lines on a graph of the star's velocity or brightness. Now we have an actual picture showing the planets themselves, and that makes things very interesting."

Spectroscopy notwithstanding, and going beyond "wiggly lines on a graph," the combination of Gemini’s AO spatial resolution and infrared sensitivity are complemented in the search for exoplanets by the application of powerful
techniques like angular differential imaging (ADI). ADI’s power comes from the fact that, during a prolonged observation, the telescope’s field of view rotates, and any systemic optical aberrations (speckles) appear to drift relative to the astronomical target. The aberrations can then be isolated and subtracted out to reduce noise in the final data sets. While not unique to Gemini, ADI is fully integrated into our observational and data-reduction procedures, giving our user community an extremely powerful suite of tools for finding faint point sources very close to what are often bright primary stars.

More recently, the full integration of the Gemini Near-Infrared Coronagraphic Imager (NICI) at Gemini South adds a curvature-based AO system, with a coronagraphic occcluding mask to provide even better signal to noise and enhanced contrast between potential planets and their bright host stars. This combination of technologies and techniques power the Gemini NICI Planet-Finding Campaign led by Michael Liu of the University of Hawaiʻi. This systematic search of about 300 potential host stars is currently in its second epoch of observations and represents the single largest campaign science program ever performed at Gemini.

Looking toward the immediate future, the Gemini Planet Imager (GPI) is a next-generation instrument scheduled for delivery and integration at Gemini South in 2011-12. GPI brings integration of advanced AO correction, coronagraphic masks, spectroscopy, polarimetry, and diffraction-limited images between 0.9 to 2.4 microns into one cohesive package.

The current Gemini instruments for exoplanet research have already established a legacy that is propelling us into the next decade of science. The tools that allow our users to explore other worlds will undoubtedly continue to be in high demand for the foreseeable future, as will the next-generation of instruments. For the next 10 years, our users will be asking challenging questions about exoplanets at the same time they are pushing our technology to the limit. This combination will determine the impact of exoplanet observations on our research communities and on society at large.

References: