Gemini Gives the Galactic Center a Sharp Look

Robert Blum (CTIO)

An international team of astronomers led by François Rigaut (Gemini) has used adaptive optics imaging with the Gemini North 8-m telescope to obtain nearly diffraction-limited near-IR images of the central arcminute of the Galactic Center. These images were obtained as part of the early "Demonstration Science" project and have now been released by the Gemini Observatory for use by any interested astronomer.

A mosaic of four QUIRC images in the central few parsecs of the Galaxy (north is up, east is left). The concentration of bright stars to the lower right of the image is the nuclear cluster of the Galaxy. Many of the images obtained at K have 0.1 arcsec FWHM or better, some approaching the diffraction limit of 0.08 arcseconds.

The goal of the Galactic Center demonstration project was to provide a better understanding of the complex interplay between the stellar population and the extreme environment at the core of the Milky Way, which includes a two million solar mass black hole. Besides providing a view of the Galactic Center that is unprecedented in sharpness and field of view, the data provide an opportunity for Gemini partner country scientists to explore how to best obtain, reduce, and analyze near-infrared images using an adaptive optics (AO) system.

The Galactic Center Demonstration Science team completed successful runs in July and August 2000 using the University of Hawaii Hokupa'a adaptive optics system and the QUIRC near-infrared imager on the Gemini North 8-m telescope. This team, which included members from all the International Gemini Project partner countries, obtained H- (1.65 μm) and K-band (2.2 μm) images of eleven different fields around the Galactic Center (the FOV of QUIRC is 20 arcsec).

The Demonstration Science team also obtained a series of narrow band images in the 2.3 μm CO band-head (prominent in late-type stars) and several epochs of data on the central cluster and the massive star cluster

Highlights

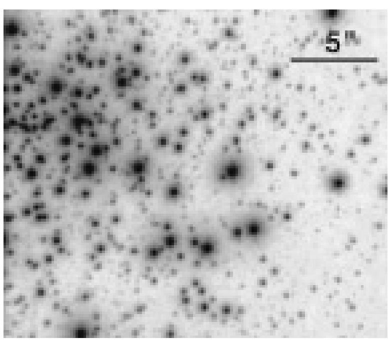
Gemini Galactic Center continued

"the Arches," located some 30 parsec in projection from the Galactic Center.

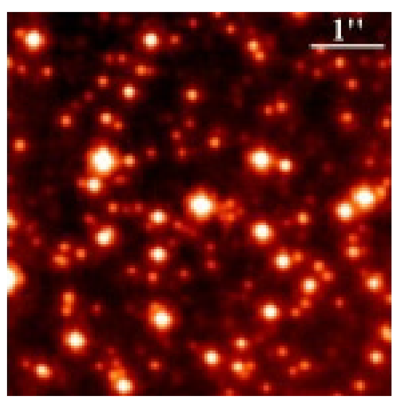
Science topics that will be addressed with the data set include star formation history in the Galactic Center, the distribution of late-type stars and dynamical evolution in the nuclear cluster, variability of the IR counterpart to the radio source SgrA* (commonly thought to be associated with the central black hole), and investigations of the stellar content of the SgrA* stellar cluster (for example, Ghez et al. 1998, *ApJ*, **509**, 678), to name just a few.

More details and information on how to obtain the data may be found on the Gemini Web pages (*http://www.gemini.edu/galactic.html*) and the USGP Web pages (*http://www.noao.edu/usgp*).

A close-up of the NW region shows a clear view of the bow shock created by a stellar object (IRS 8) as it slams into a streamer of gas, which is itself falling into the central parsec.



(Above) Using adaptive optics on the Gemini North telescope, the sharpness of star fields in the Galactic Center region come to resemble the visual appearance of commonly imaged fields of stars in the solar neighborhood. But with one critical difference: the density of stars in this detail of the Gemini Galactic Center mosaic is some 300,000 times the stellar density in our region of the Galaxy.



The Gemini Demonstration Science release of Galactic Center observations includes the sharpest image ever taken of the Arches Cluster, one of the largest clusters of stars in our galaxy, which is located about 100 light-years from the Galactic Center. This cluster is poorly understood because of the intervening 25,000 light-years of obscuring dust that completely blocks visible light. The lifetime of such a cluster must be very short, due to the intense tidal forces from the nucleus of our galaxy.

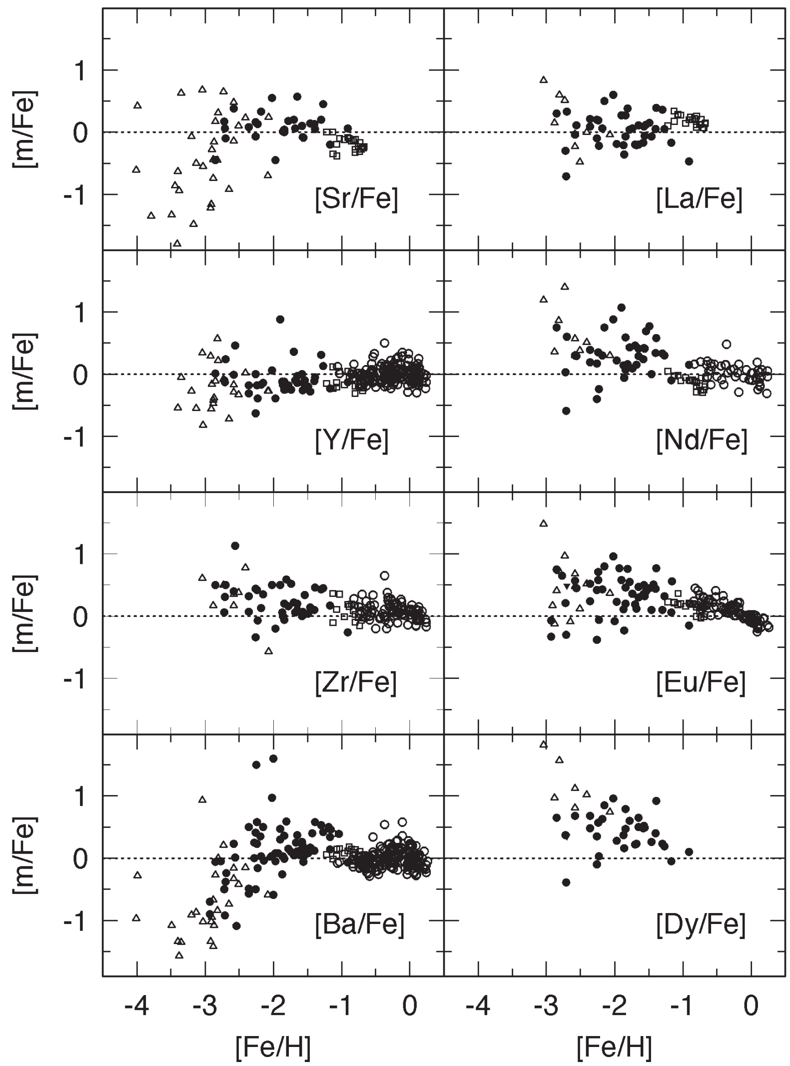
Heavy Metal and the Early Galaxy

Based on a Solicited Contribution from Caty Pilachowski (NOAO)

New abundances for neutron-capture elements in a large sample of metal-poor giants have been determined by Debra Burris (Oklahoma City Community College) in collaboration with Caty Pilachowski and Taft Armandroff (NOAO), John Cowan (Oklahoma), Chris Sneden (Texas), and Henry Roe (Berkeley). These new abundances, in combination with data from the literature, form a comprehensive picture of the production of elements in the early Galaxy, particularly of the role of supernovae with 1-3 $M_{\odot}$ progenitors in the precursors to the oldest stars we see today.

The spectra were acquired with the KPNO 4-m echelle and coudé feed spectrographs. Abundances of eight n-capture elements (Sr, Y, Zr, Ba, La, Nd, Eu, Dy) in 43 stars were derived from blue echelle spectra and red coudé spectra, and the abundance of Ba only was derived from the red spectra for an additional 27 stars.

The oldest metal-poor halo stars are Galactic fossils that provide clues to the conditions and populations of stars that existed early in the Galaxy's history. The chemical compositions of these halo stars are due to only a few, perhaps one, earlier generations of stars. Metal-poor stars provide an opportunity to observe neutron-capture elements (Z>30) produced in the unseen precursors to Population II, and through their abundances, to deduce characteristics of the first Galactic stellar population.



[Sr/Fe], [Y/Fe], [Zr/Fe], [Ba/Fe], [La/Fe], [Nd/Fe], [Eu/Fe] and [Dy/Fe] as a function of metallicity. Filled circles are from the research described here; triangles represent upper limits for Eu and Dy. Other symbols represent abundances taken from the literature.

continued

The Early Galaxy continued

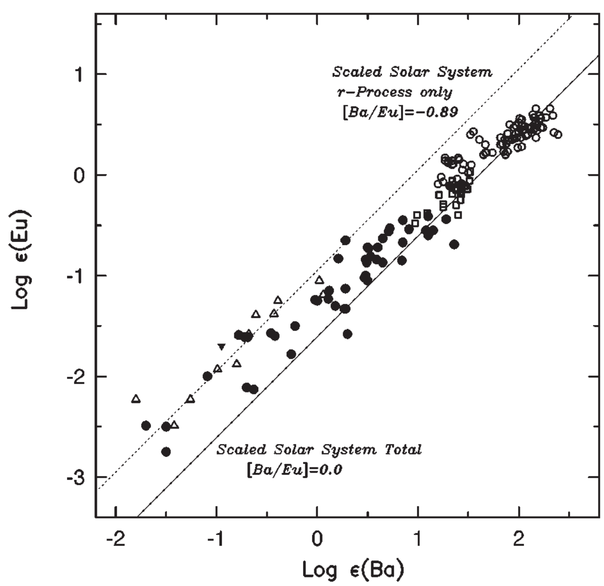
The neutron-capture elements are produced through both slow (s-) and rapid (r-) neutron-capture processes that are believed to occur at different sites. The r-process requires a high neutron flux level (with many neutron captures over a timescale of a fraction of a second) thought to occur in supernova explosions, while the s-process, which requires a lower neutron flux (with a typical neutron-capture taking many years), is generally thought to occur during the double-shell burning phase of low- (1–3 $M_{\odot}$) and intermediate-mass (4–7 $M_{\odot}$) asymptotic giant branch (AGB) stars. However, for the most metal-poor stars, many observational and theoretical studies have demonstrated that the observed abundances of neutron-capture elements in metal-poor stars are consistent with production via the r-process only, without contributions from the main s-process.

Overall, the abundances of the neutron-capture elements in metal-poor stars show clear evidence for a large star-to-star dispersion in the heavy element-to-iron ratios. This condition must have arisen from individual nucleosynthetic events in rapidly evolving halo progenitors that injected newly manufactured neutron-capture elements into an inhomogeneous early Galactic halo interstellar medium. The new data also confirm that at metallicities [Fe/H] < -2.4, the abundance pattern of the heavy (Z ≥ 56) neutron-capture elements in most giants is well matched to a scaled Solar System r-process nucleosynthesis pattern.

The onset of the main r-process can be seen at [Fe/H] ~ -2.9; this onset is consistent with the suggestion that low-mass Type II supernovae are responsible for the r-process. Contributions from the s-process can first be seen in some stars with metallicities as low as [Fe/H] ~ -2.75, and are present in most stars with metallicities [Fe/H] > -2.3. The appearance of s-process contributions as metallicity increases presumably reflects the longer stellar evolutionary timescale of the (low-mass) s-process nucleosynthesis sites.

The lighter neutron-capture elements (Sr-Y-Zr) are enhanced relative to the heavier r-process element abundances. Their production cannot be attributed solely to any combination of the Solar System r- and main s-processes, but requires a mixture of material from the r-process and from an additional neutron-capture process that can operate at early Galactic time. This additional process could be the weak s-process in massive (~25 $M_{\odot}$) stars, or perhaps a second r-process site, i.e., different from the site that produces the heavier (Z ≥ 56) neutron-capture elements.

Finally, the excess of heavy elements at intermediate metallicities confirms the delay in Fe production by Type Ia supernovae relative to the production of neutron-capture elements in Type II supernovae. Type Ia's are thought to arise from stars of lower mass than the Type II's, and this delay reflects the evolutionary timescales involved.



The abundance of Ba vs. Eu, where ε is the number of atoms on a logarithmic scale where the abundance of H is 12. The dotted line indicates the Solar System r-process abundance ratio and the solid line indicates the total Solar System abundance ratio of Ba/Eu. For metal-poor stars, the Ba/Eu abundance ratio matches the observed solar system r-process-only ratio, while for more metal-rich stars that contain the nucleosynthesis products of double-shell burning, the ratio shifts to match the solar system total ratio. (The symbols are as in the first figure.)

Extrasolar Planets Are Not Out of Line

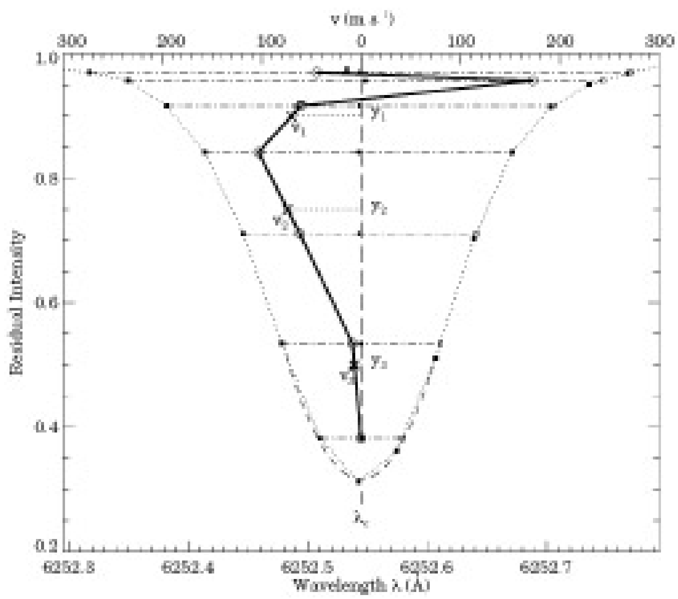
Mark Giampapa (NSO)

Former NSO REU student Matthew Povich (Harvard) has published an analysis of high-resolution synoptic spectra of ten F- and G-type stars, seven of which exhibit periodic radial velocity variations due to the presence of one or more extrasolar planets. Povich and his advisors and collaborators—Mark Giampapa (NSO), Jeff Valenti (STScI), Trudy Tilleman (NSO), Sam Barden (NOAO), Drake Deming (NASA/GSFC), Bill Livingston (NSO), and Caty Pilachowski (NOAO)—searched for subtle periodic variations in photospheric line asymmetry as characterized by line bisectors.

In principle, periodic variations in line asymmetry observed at lower spectral resolutions could mimic the radial velocity signature of a low-mass companion (see figure). No significant evidence of such behavior was found in the data. No correlation was seen between bisector velocity displacement and the known orbital phase of planets around the program stars. Simulations of a periodic signal with noise levels that mimic the measurement errors suggest that bisector variations with amplitudes greater than about 20 m s^{-1} can be excluded. These results support the conclusion that extrasolar planets best explain the observed periodic variations in radial velocity.

The observations were obtained from 1998 March to 1999 February using the NSO 1.52-m McMath-Pierce solar telescope facility on Kitt Peak and the solar-stellar spectrograph, to achieve a resolving power of 1.2×10^5. The synoptic data were obtained by Trudy Tilleman with support from a grant to the NSO/NOAO from the NASA Origins of Solar Systems Program.

The paper, "Limits on Line Bisector Variability for Stars with Extrasolar Planets," has been accepted for publication in the *Astronomical Journal*. In the meantime, Matt Povich, following his graduation from Harvard, has joined the Peace Corps for a two-year assignment in Tanzania as a secondary education physics teacher. Matt hopes, in his words, "to help some African students discover the joys and wonder of the pursuit of science." We all wish Matt the best of success in this very worthwhile endeavor!



Subtle periodic line profile asymmetry, which is revealed by the spectral line bisector technique, was not found to be correlated with the known orbital motion of planets around ten F- and G-type stars. These results support the conclusion that periodic variations in radial velocity in these stars are due to extrasolar planets. The bisector points (filled circles) are the midpoints of the line segments drawn parallel to the wavelength scale of the spectrum. The equivalent velocity scale is magnified at top to reveal the relatively small amplitude of the periodic variation in photospheric line asymmetry (solid, dark line with open circles).