by Nancy A. Levenson (with Rodrigo Carrasco)

Science Highlights

During the first half of 2012, Gemini users published a diverse collection of results. Here are several highlights:

A Comet or an Impact in the Main Asteroid Belt?

A handful of comets orbit with the main asteroid belt. One peculiar object, P/2010 A2 (LINEAR), discovered in 2010, has a cometary appearance (with a tail), and also an asteroid-like body. Is P/2010 (A2) LINEAR a genuine sublimating comet, or is another process responsible for the tail? Olivier Hainaut (European Southern Observatory) and colleagues used observations from Gemini North with the Gemini Multi-Object Spectrograph (GMOS), along with several other telescopes, to investigate this question.

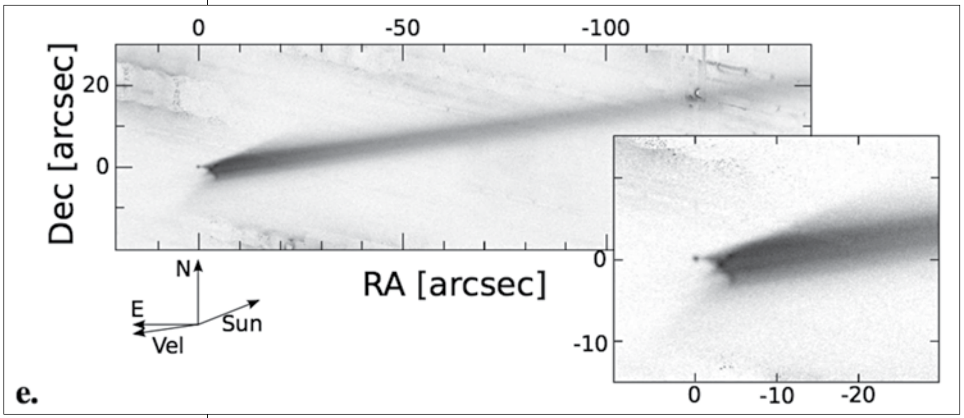


Figure 1.
The GMOS-North r′ image of P/2010 A2 (LINEAR) obtained on February 19, 2010, shows the small nucleus separated from the nearby dust tail.

The comet's appearance in early 2010 was striking (Figure 1). Dust does not immediately surround the small nucleus, and the much larger tail is detached. The tail is not uniform, but rather shows several crossing arcs close to the nucleus.

After first considering the survival of water ice and other volatiles at this location close to the Sun, the team concluded that water would not persist longer than a few times 10^6 years, even with a comet-like nuclear composition. Thus, cometary activity (sublimation) is not responsible for expelling dust from the surface to produce the observed tail. More detailed models of dust emission (Figure 2) include the effects of grain size and time since emission to describe the resulting extended tail. They determined that all cometary activity stopped at least several weeks before the observations, and propose a single burst of dust ejection about a year earlier

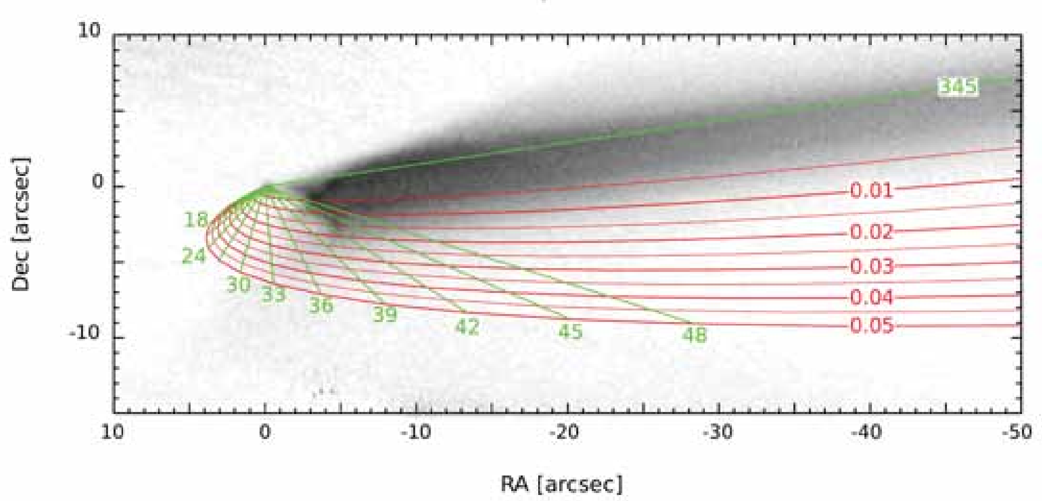


Figure 2. *Model contours overlaid on the GMOS image show the location of mixed dust at various times after ejection (green lines, marked in days since emission) and the location of dust of various sizes (red lines, defined in terms of the parameter β, which depends on the ratio of radiation to gravitational force). Most of the emission is consistent with a single epoch of ejection about a year before the observations.*

as the best model. Also, relatively large dust particles produced the X-shaped arcs.

Impact on a main belt asteroid best explains the appearance of P/2010 A2 (LINEAR), not an origin as a true sublimating comet. In addition to the short duration of dust emission, the velocity distribution of the particles and the amount of mass ejected are consistent with this interpretation. An oblique impact is more likely than a head-on collision, since the latter would have destroyed the whole body, which had an extent of 80-90 meters.

Although this object does not add to the known population of true main belt comets, this study not only reveals the ongoing processes of the dynamic Solar System, but that these main belt comets are potentially important as a significant source of the water and volatile materials found on Earth today. The complete work is published in *Astronomy and Astrophysics*, **537:** A69, 2012.

Is the Globular Cluster M71 Hiding Something?

The dense environments of globular clusters may be the homes of intermediate-mass black holes, those with masses of around several 100 to 10^4 M_{Sun}. These values are intermediate between the stellar-mass remnants of supernovae and the supermassive variety at millions to billions of solar masses in the centers of galaxies. The globular cluster M71 (also NGC 6838), at a distance of about 4 kiloparsecs (13,000 light-years), offers an opportunity to measure member stars' motions in search of evidence for a central black hole.

Raminder S. Samra (University of British Columbia, Canada) and colleagues have used the Near-Infrared Imager and Spectrograph (NIRI) with the Altair adaptive optics system on Gemini North for observations in the H and K bands to measure these proper motions. They made the original observations in 2005, with a subsequent set in 2007 and 2009 (Figure 3). Over the longer time baseline, they found the proper motion dispersion of the central stars to be 179 ± 17 microarcseconds per year.

The search for evidence of a black hole begins with the measurement of proper motion dispersion as a function of distance from the cluster's center. In the presence of a black hole, the dispersion would increase toward the center. Grouping the data into radial bins, the team finds that the proper motion dispersion is instead constant, despite the small central bin, which is less than 5 arcsec-

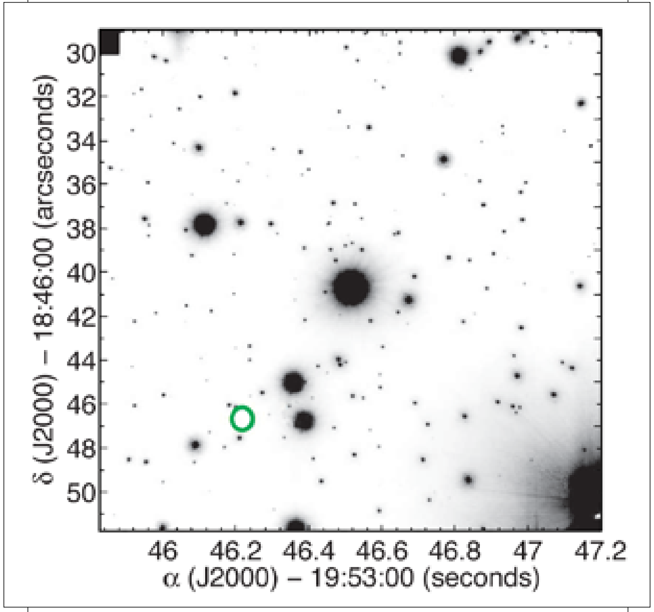


Figure 3. *Core of the globular cluster M71 in the H band, observed with NIRI/Altair on Gemini North. The cluster center is marked with a green circle.*

onds in radius. Alternatively, comparing the observations with a model system that includes a black hole and stars results in an upper limit on black hole mass of 150 M_{Sun}. Thus, although M71 presents the opportunity for high-resolution measurements, it does not appear to hold an intermediate-mass black hole in its core.

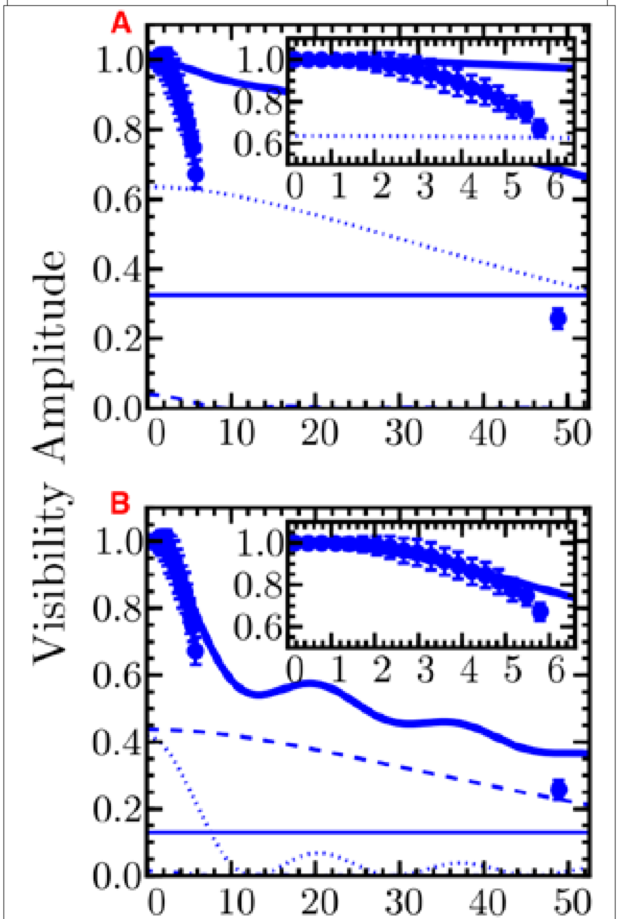


Figure 4 . *Visibility amplitude as a function of baseline for observations at 8.74 microns. The thick solid line shows the model prediction, for the basic model (A, top) and including the additional hot, optically thick component attributed to a companion (B, bottom). The thin solid line represents the contribution of the central star, the dotted line shows the optically thin disk, and the dashed line represents the optically thick disk emission. The insets show the Gemini data and corresponding model.*

A Self-Luminous Companion to TW Hydrae

Variable star TW Hydrae exhibits an important and nearby example of a transitional disk, the state between a pre-main sequence star, which is embedded in its natal cocoon, and an evolved planetary system. Now, Timothy Arnold (Steward Observatory, University of Arizona) and colleagues have used novel mid-infrared observations with the Thermal Region Camera and Spectrograph (T-ReCS) on Gemini South to find tentative evidence for a planetary companion within the disk of TW Hya.

This result builds on previous analyses, which had already suggested that the disk has a gap (based on the spectral energy distribution; SED), and which measure the extent of the disk at millimeter wavelengths to approximately 100 astronomical units (AU). The model presented here begins with an optically thin disk and optically thick emission located at 3.9 AU (which could be the illuminated face of a flared optically thick disk) in addition to the central star. While these components sufficiently account for the current SED, which includes new observations at 8.74, 11.7, and 18.3 microns (μm), they cannot account for the very well-resolved emission in the shortest bandpass (Figure 4). The required addition is an optically thick component inside the thick disk that is hotter than equilibrium temperature at that distance from the star.

Physically, the team interprets this component as a self-luminous companion. Modeled as a single object, it would be located 3.5 AU from the star. Given the age of the system of about 10 million years, the companion's modeled luminosity implies a mass of 8-10 $M_{Jupiter}$. A single object would mean an asymmetric emission distribution. Further analysis shows that the observations are consistent with asymmetry, with the largest expected at 8.74 μm, but the asymmetry is not a significant requirement.

These conclusions are based on the novel approach of speckle imaging with T-ReCS. The exposure times of individual recorded frames are extremely very short (around 170 milliseconds) to achieve diffraction-limited images, avoiding the atmospheric blurring that arises on longer timescales. With this approach, Fourier techniques are employed to analyze the data fully (T. Arnold *et al.*, *The Astrophysical Journal*, **750:** 119, 2012).

This work offers significant possible evidence for the presence of a planet in a transitional disk system. Planet formation may generally contribute to the evolution and dissipation of such disks, in the transition from an embedded pre-main sequence star to a mature planetary system.

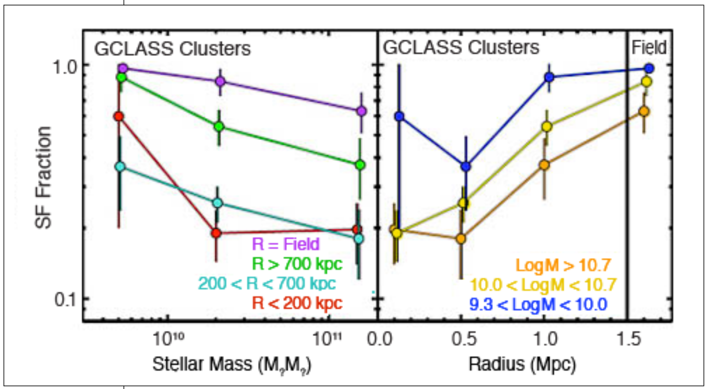


Figure 5.
Left panel: The fraction of star-forming galaxies as a function of galaxy stellar mass for galaxies in different environments. Right panel: The fraction of star forming-galaxies as a function of environment for galaxies with different stellar masses. Both stellar mass and environment determine the likelihood of finding star-forming galaxies.

Environment and Galaxy Mass Quench Star Formation at *z* ~1

What determines the history of star formation in galaxies? Locally, both intrinsic characteristics of galaxies, namely mass and the environment, are correlated with properties such as star formation rate and galaxy color. Adam Muzzin (Yale University and Leiden Observatory, The Netherlands) and collaborators pursued this question in the earlier universe with observations of 10 massive clusters at $z \sim 1$, as part of the Gemini Cluster Astrophysics Spectroscopic Survey (GCLASS). They conclude that in the early universe, both mass and environment play roles to determine a galaxy's star formation, but the effects are separable.

According to Muzzin, "While both stellar mass and environment determine whether a galaxy is 'on' (*i.e.*, forming stars), once it is 'on,' the rate at which it consumes gas and forms stars is completely self-regulated by its mass."

Environment still has a strong effect on quenching star formation, suppressing it in the denser regions at the cluster centers. The team argues that this environmental effect occurs rapidly, so no signature exists to link environment to certain properties such as specific star formation rate (Figure 5).

The GCLASS sample is selected based on observations at 3.6 microns, which corresponds to the H-band in the rest frame of these galaxies and is thus a good indicator of stellar mass. The clusters offer the advantage of a range of environments and galaxy masses, so either the mass or the environment can be fixed to isolate the effects of the other. The team obtained the new observations with the Gemini Multi-Object Spectrograph instruments on Gemini North and Gemini South. Complete results appear in A. Muzzin *et al.* (*The Astrophysical Journal*, **746:** 188, 2012).

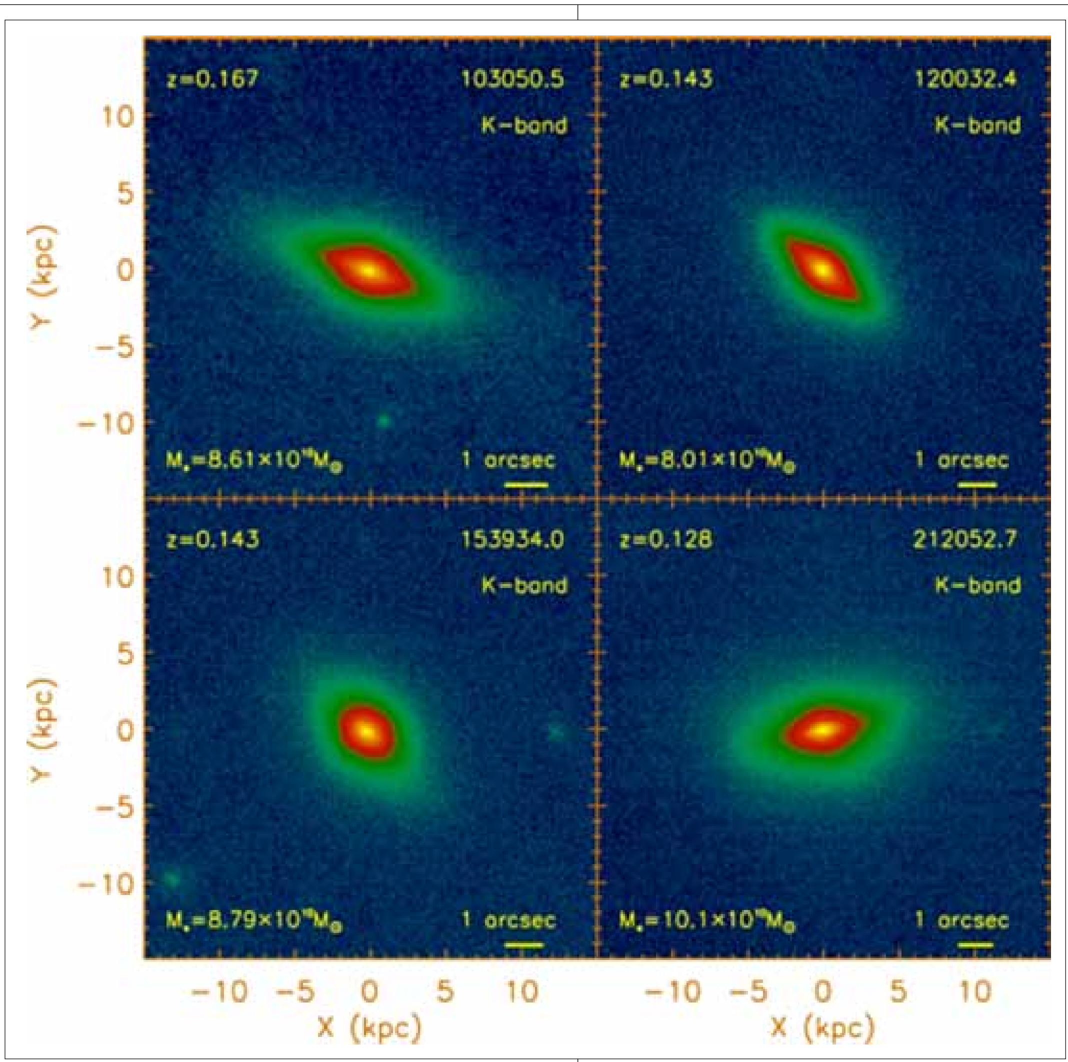
Exploring the Early Stages of Massive Galaxy Formation in the Local Universe

Among the most important discoveries in extragalactic astronomy during the past few years is that massive, spheroidal-like galaxies ($M_* > 10^{11}\ M_{Sun}$) at redshift $z > 1$ are significantly more compact (by a factor of 4) than their local equivalent counterparts.

Recent theoretical models show that some of these massive, high-redshift compact galaxies could have possibly survived untouched since their formation epoch at $z > 3$. If these models are correct, the existence of a population of nearby, old, compact massive galaxies presents the possibility of detailed studies of galaxy formation mechanisms in the early universe using a sample of local galaxies.

Ignacio Trujillo (Instituto de Astrofísica de Canarias, Spain) and collaborators performed the first systematic search of these galaxies using the *New York University Value-Added Galaxy Catalog* from Sloan Digital Sky Survey Data Release 6 (*The Astrophysical Journal*, **692:** 118, 2009). They find that the fraction of local massive compact galaxies, similar to those found at high redshift (*i.e.* with a $r_e < 1.5$ kiloparsec (5,000 light-years) and $M_* > 10^{11}\ M_{Sun}$), represent only 0.03 percent of the massive galaxies in the nearby universe ($z < 0.2$). Moreover, these galaxies are relatively young and metal-rich.

Figure 6.
K-band high-resolution images of the four nearby (z ~ 0.15) massive compact galaxies observed with NIRI and ALTAIR/LGS.



Detailed analysis of the morphological properties of these nearby massive compact galaxies, in particular their inner regions, is the key ingredient in answering several relevant questions, such as: What is the morphological nature of the massive galaxies? Is the compactness only an artifact of missing light in the outer regions?

To answer these questions, Rodrigo Carrasco (Gemini Observatory), Trujillo, and Anna Ferré-Mateu (Instituto de Astrofísica de Canarias, Spain) obtained ultra-deep, high-spatial-resolution images of four nearby super-dense massive galaxies with the Near-infrared Imager and Spectrometer (NIRI) using the adaptive optics system Altair (in laser guide star mode) on the Gemini North telescope.

Contrary to previous studies, where the morphological properties of these galaxies have been seriously limited by the seeing, the observations provided by Gemini North with adaptive optics allowed (for the first time) an in-depth analysis of their inner and outer regions to unprecedented resolution. These galaxies are genuinely very massive and compact, with elongated shapes resembling the structures of S0 galaxies (Figure 6), with no evidence of an extended faint component altering their size estimate. Furthermore, the stellar mass density profiles are significantly denser in the inner regions than any galaxy with similar stellar mass and normal size in the local universe. Moreover, these galaxies are almost exact copies of the high-redshift ($z > 1$), massive compact galaxies. The complete results are presented in *The Astrophysical Journal* (Trujillo, I., Carrasco, E. R., and Ferré-Mateu, A., **751:** 45, 2012).