# The Gemini Planet Imager
# Integral Field Spectrograph Assembly Progress Update

Lauren Corlies,[1] and James Larkin[2]
[1]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19104
[2]Department of Physics and Astronomy, University of California – Los Angeles, Los Angeles, CA 90095

## ABSTRACT

The Gemini Planet Imager (GPI) is the first instrument designed specifically to directly image planets in the outer solar systems of other stars. It will allow us to search for types of planets that are inaccessible to current indirect methods of observation and test theories of planetary formation. Present timelines for the construction of GPI estimate the instrument being sent to the 8-m Gemini South telescope in Chile by late 2010 and first light occurring some time early in 2011. This paper summarizes aspects of the progress being made at UCLA, which is building the science instrument, an integral field spectrograph.

## 1. Introduction

The Gemini Planet Imager (GPI) is the instrument that will provide the next step in our search for extrasolar planets. Until this point, only indirect methods have been largely successful in locating extrasolar planets, limiting the type of planets that can reasonably be expected to be detected. Indeed, more extremely large and extremely close planets have been found than any other type which is believed to be an observed selection effect due to the indirect methods. Using a combination of adaptive optics, a coronagraph, an interferometer, and an integral field spectrograph, GPI will be able to directly image extrasolar planets and outer solar systems similar to our own in the near infrared (Macintosh et al. 2008). In fact, GPI is biased to find extrasolar planets that are further away from their parent star, where they will not be completely blocked by light from the star.

Other advantages to direct detection, include the fact that scientists would no longer be limited by planetary periods that are impossible to detect because they are longer than the time the planet has been observed. Furthermore, GPI is specifically intending to observe young solar systems where the planets are emitting their own light, instead of just reflecting light from the star. This way, planets can be detected more independently of their semi-major axis.

These improvements will help complement the selection effect present from the indirect methods and provide more statistical significance to the population of discovered extrasolar planets in order to test different theories of planetary formation.

A more detailed analysis of GPI's exoplanet parameter space can be found in Graham et al. 2008.

## 2. Integral Field Spectrograph

### 2.1 Basics of an Integral Field Spectrograph

A typical spectrograph uses long-slit spectroscopy so that one axis of the CCD detector represents a spatial position along the slit while the other axis represents the wavelength-dependent flux of the light. Thus, not only is one spatial dimension lost during observation but much of the field of view of the telescope goes unused as well. For this reason, long-slit spectroscopy is only efficient if the location of the object is already known.

Because GPI is intended to search for extrasolar planets, long-slit spectroscopy is inappropriate. Instead, the science instrument of GPI is an integral field spectrograph (IFS). The primary difference between the normal long-slit spectrograph and an IFS is that an IFS can preserve a moderately large field of view while still providing wavelength information for every point. The IFS does this using a lenslet array. Before the light reaches the prism, it passes through an array of lenslets that each focuses a part of the light beam. The light is then sent through the prism and a spectrum is attained for each lenslet in the array. Because each spectrum is associated with a particular lenslet, you can recreate the image of the field of view at each wavelength. Thus, with this instrument, both spatial components of the field of view are preserved as well as providing the wavelength component, creating what is called a datacube.

The main difficulty in designing an IFS is preventing the resulting spectra from overlapping on the detector. There are two main ways to prevent this. First, the lenslet array can be rotated relative to the detector to adjust the number of pixels perpendicularly between each spectrum. Then, the dispersion of the prism and filter bandpass can be chosen such that the spectra do not overlap in the horizontal direction.

In particular, GPI's lenslet array is rotated 26.6 degrees with respect to the dispersion axis of the prism, so that each spectrum is separated vertically by 4.5 pixels on the detector. The filters only allow about 20% of each filter's central wavelength through, resulting in spectra that are 18 pixels long.

In addition to the traditional spectral mode, the IFS can also provide a polarimetry mode by using a Wollaston prism in place of the traditional prism.

### 2.2 Explanation of Use in GPI

This datacube is a necessary complement to the adaptive optics system in identifying the planets. GPI contains an extreme adaptive optics system that achieves a Strehl ratio of 0.95. The light that does not make it into the central core appears as speckles throughout the field of view. These speckles are typically the same size and shape as potential planets and are sometimes even brighter. However, the speckles are a result of imperfections in the polishing and grinding of the mirrors and lenses and of the diffraction of light. Thus, the positions of the speckles depend on wavelength. By looking at the field of view at different wavelengths, that is by examining a datacube, it is possible to see the speckles shift position while the planets remain stationary. In this way, planets can then be distinguished from speckles.

## 3. Progress Updates

Assembly of the IFS has begun at UCLA. Currently, the outer frame of the dewar, cold shield, and optics bench have all been machined and forms of the focus mechanism and prism slide mechanism have been assembled and cold-tested. Details of the testing process are presented below. For a more complete description of the instrument design itself, see the GPI IFS Sub-System Design Document.

### 3.1 Cool Down Testing

GPI operates over the near-infrared regime from 1-2.4μm, which is the same regime as thermal emission. In order to prevent environmental radiation from flooding the detector and blocking all scientific signals, the entire IFS is cooled to a temperature of 77K. This is done using two commercially available closed-cycle refrigerators (CCR) from the Sunpower company, which are compact Stirling cryocoolers. Each 3.1kg CCR is advertised to be able to maintain a temperature of 77K with a load of 15 W.

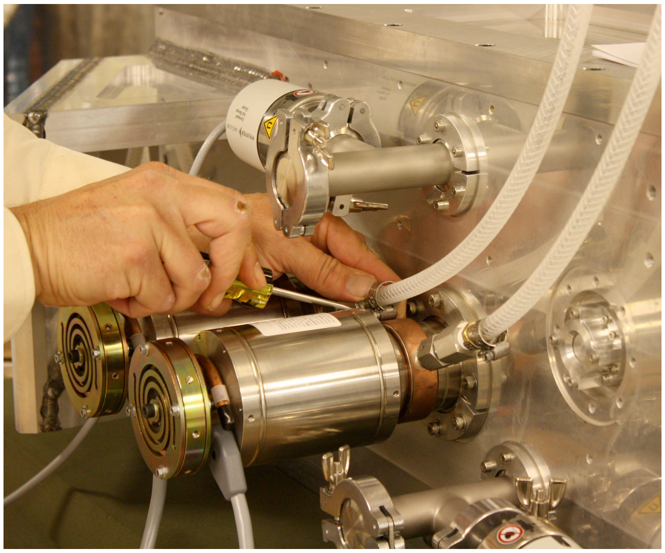

Fig 1.– A photograph of the two cryocoolers mounted to the outside of the dewar.

While in use, it is expected that approximately 20W of ambient power will fall on the dewar. To confirm that the CCR's will be able to sustain the operating temperature of 77K in these conditions, heaters were placed onto the heads of the CCR's and turned on while a cool-down of the dewar was in progress.

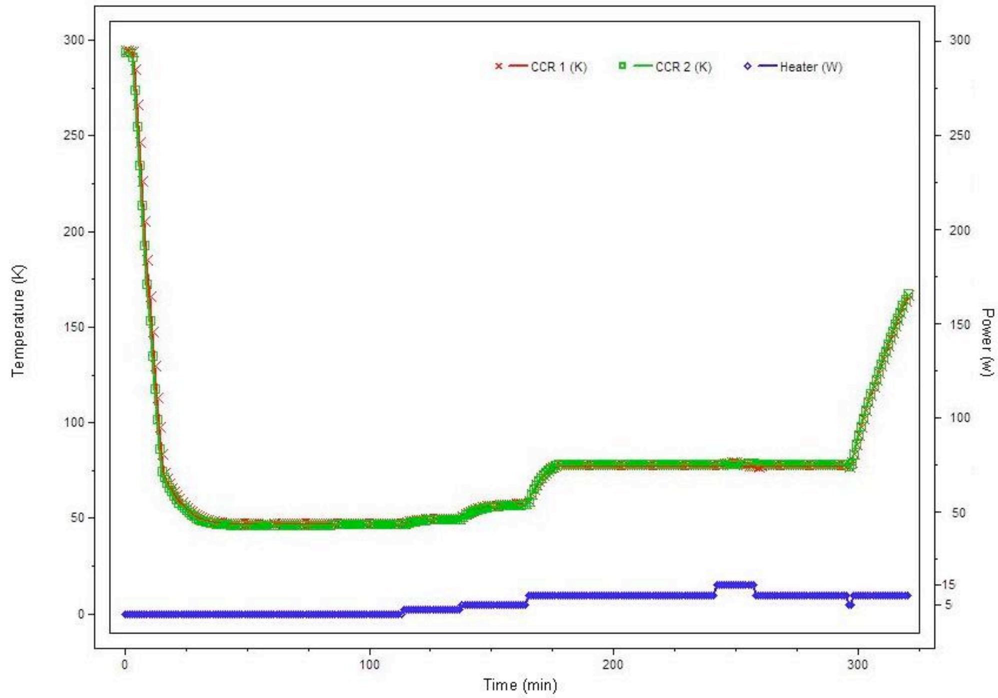


Fig 2.– The temperature of the CCR heads is plotted in Kelvin from the initial ambient temperature, throughout the heater testing and until approximately half-way through the warm up period. Also plotted is the power put onto each head in Watts.

The data above demonstrate that even with each CCR head receiving 15W of power, they were quickly able to reestablish and maintain a temperature of approximately 77K. Thus, the team is convinced that the two CCR's should have no problem establishing the operating temperature and maintaining it once the temperature is reached.

### 3.2 Vibration Testing

Vibration of the dewar is an important concern for the GPI team as it mounts to both the adaptive optics system and the interferometer. The main source of vibration is the two CCR's, whose helium compression rate of 60Hz is easily seen in accelerometer measurements of the dewar.

To reduce the vibrations, dampers will be installed on the outside of the dewar. Currently, two different types of dampers are being tested. One is a passive balance unit for vibration reduction that came with the coolers. The second is a tuned mass damper set specifically for 60Hz. The main difference between the two is that the passive balance units dissipate the vibration energy as sound while the tuned mass dampers dissipate the vibration energy as heat.

We positioned the dampers in a variety of different orthogonal orientations. Thus far, only data for the passive balance units have been analyzed. The data presented in the figure below shows data for when the units were attached to the ends of the CCRs themselves. It shows considerable improvement in the y-direction, which was the direction of the helium compression. However, it also shows a slight increase in the vibration in the x direction.

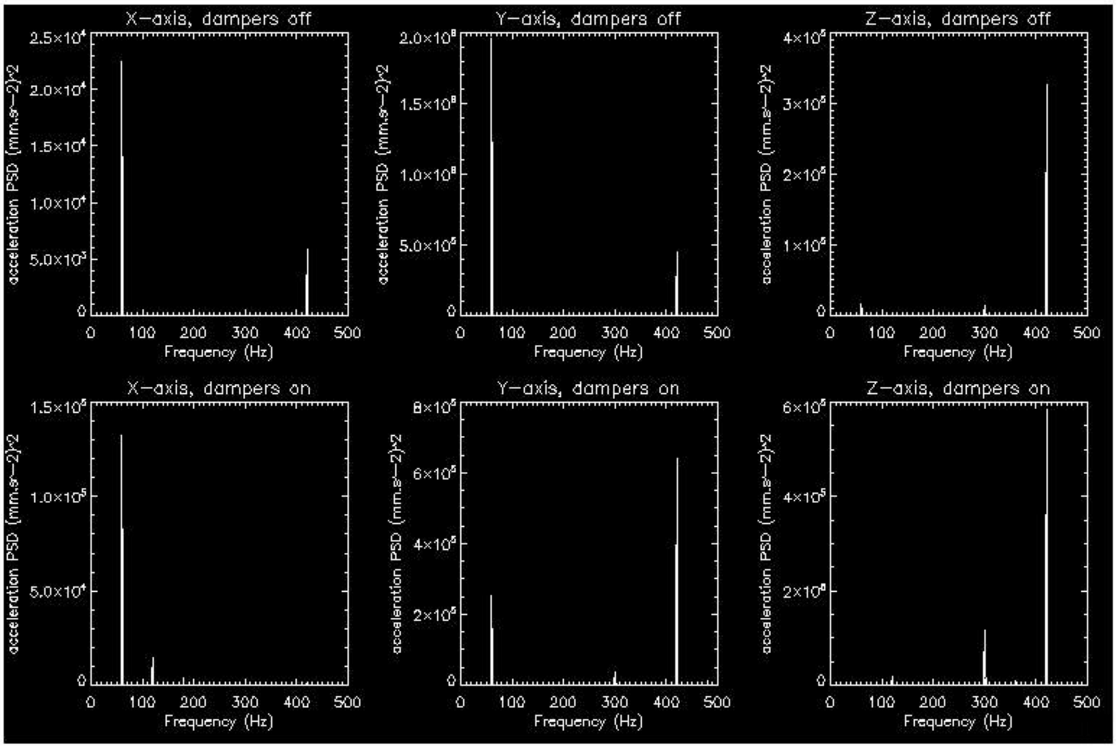


Fig 3.– This figure is plotting accelerometer data for all 3 axes. The above plots picture the acceleration without dampers and the below plots are the acceleration with the passive balance unit for vibration reduction.

The next step is to further analyze data that was taken with both dampers, each in different orientations to see if the vibration reduction can be improved.

### 3.3 Jade-2 Cable Potting

The main detector cable for the IFS is a Jade-2 cable provided by Teledyne. Normally, cables enter the dewar wall through a connector panel with a twisting connector but Teledyne advised against using this method with the Jade-2 cable. Instead, they recommend potting the cable, which is a process where you put the cable directly through the dewar wall itself and create the vacuum seal with an epoxy.

The recommended epoxy is a material called Stycast that has been successful used in a similar setup at the University of Hawaii. Stycast is a commonly used epoxy for this type of cryogenic vacuum feedthrough because it creates a solid vacuum seal.

Typically, cables are potted permanently so a challenge was devising a way to create the vacuum seal while still being able to remove the cable from the dewar wall. The method that was successfully tested is a two-tiered bracketing system, shown below.

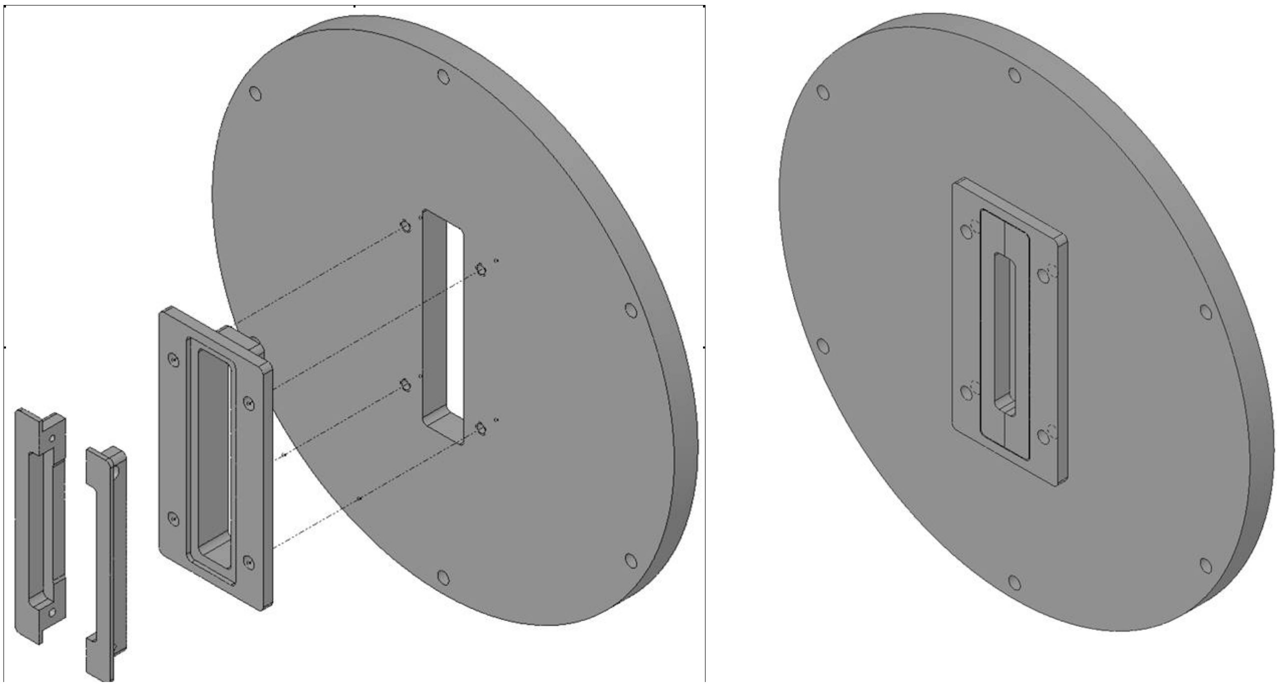

Fig 4.– Exploded and compact versions of the potting bracket assembly that is currently being tested. The initial bracket is featured first, followed by the second. The third round disk is designed specifically for a test dewar and will be replaced by the GPI dewar's connector panel in the final configuration.

An initial bracket is formed from two symmetric pieces that fit around the cable. Two pieces are needed because we want to leave only a small gap between the bracket wall and the cable, but the connectors at the top and bottom of the cable are much wider than the cable itself. By having two pieces, we can control the size of the gap. The gap is necessary to ensure that the Stycast can form a tight bond between the cable and the metal bracket for a strong vacuum seal. However, difficulties arise in keeping the Stycast from running down the cable during the potting process. Multiple tests in the lab have shown that generic, clear, packing tape provides a sufficient dam for the Stycast while still being easily removed and leaving behind a smooth surface once the epoxy has cured.

After the initial bracket is potted, a second bracket is fitted over the first and potted on the opposite side to make sure that the gaps between the two initial pieces are sealed.

The third larger disk in the drawing is a test piece for an existing dewar in the UCLA lab that has been used in a successful vacuum test with a test potted cable. In the final design, the second bracket will fit into the dewar's connector panel. This way, the potted bracketed piece containing the cable can easily be removed from the dewar if necessary and a vacuum seal can still be achieved.

### 3.4 Focus Mechanism Testing

The focus mechanism is a mechanism attached to the science detector at the end of the optical path. The basic design consists of a bar that sits on a ramp that is attached to the top of a flexure block. The detector is then attached to the back of the flexure block. A gear spins the bar so it begins to move up the ramp; however, the bar must remain parallel at all times. Thus, as it moves up the ramp, the flexure block moves to ensure that the bar remains parallel. The flexing is minute and accurate, so the detector can be precisely moved into focus.

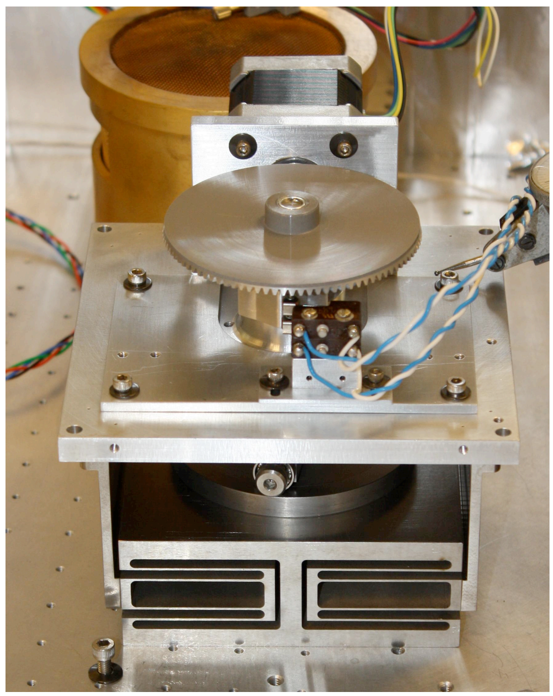

Fig 5.– Photograph of the assembled focus mechanism.

A mechanism like this is necessary because GPI will operate at a temperature of 77K. Although the optics can be aligned when warm, the optical components shift because of thermal compression once the instrument is cooled. Thus, this mechanism can be used to shift the detector along the beam axis to re-find the focus. It should only be necessary during alignment and will not normally operate while the IFS is in use.

One such mechanism has been assembled at UCLA and both warm and cold-tested. The main gear has a total of 800 steps and there are two ramps around. Each ramp has a gentle increase on one side and a rapid descent down the other. During the first cold-test, the bearings that move the bar up the ramp seized. They have been cleaned and the mechanism reassembled for more testing.

While warm, measurements have been taken to begin characterizing the motion of the bar up the ramps and the backlash of the gears. Using rough measurements, it appears that about three quarters of the gear is available for realigning the detector while for the other fourth, the bar never compresses the flexure and thus can not move the detector as shown in the figure below.

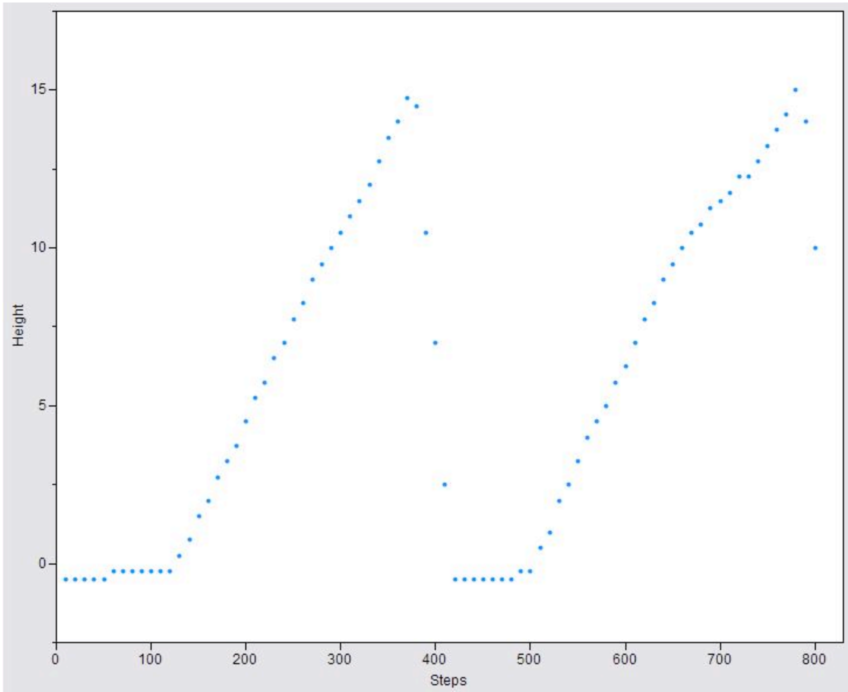


Fig 6.– Graph representing the move up the ramp with the gears turning counterclockwise. The x-axis is the number of gear steps while the y-axis the amount of flexure that occurred, measured in 0.001". Where the height remains constant corresponds to the unusable part of each ramp.

With preliminary measurements taken, it appears that the backlash of the gears is minimal and that both ramps are fairly uniform. Work remains to more accurately characterize the flexure in order to precisely move the detector into focus once the entire IFS is assembled and cooled.

### 3.5 Prism Stage Testing

GPI has two data-taking modes – a typical spectral mode as well as a polarimetry mode. Both modes require the use of separate prisms. In order to change between modes while operating, a prism stage has been designed and the prototype tested. It is comprised of a slide that holds the two prisms and can move them in and out of the optical path. The slide has three switches along its path to relay the location of the prisms and magnets located at each end to lock the prisms in place while they are used.

In both warm and cold conditions, the motor was strong enough to overcome the magnetic force and move smoothly back and forth. The plans for the final version have been submitted for machining.

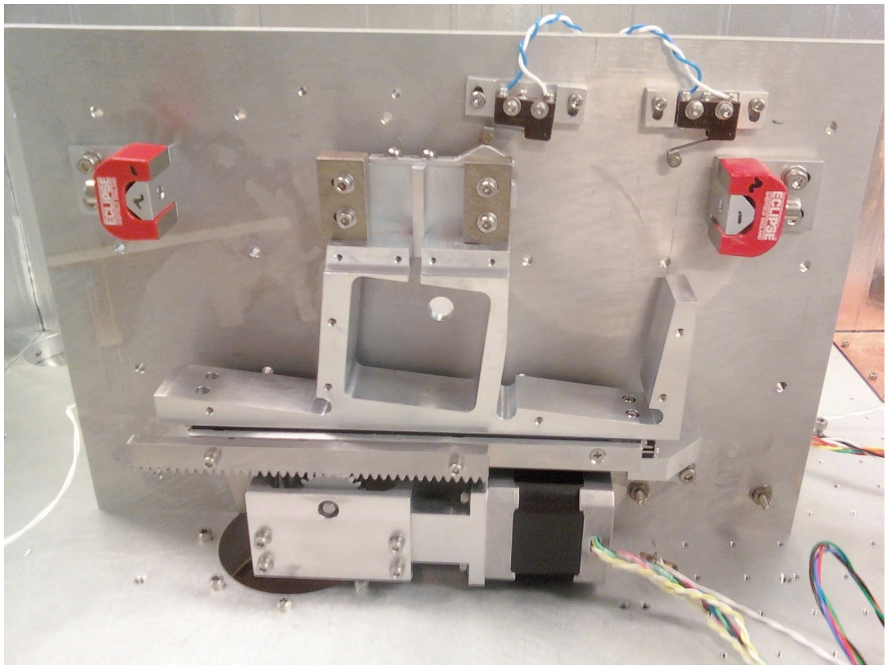

Fig 6.– Photograph of the assembled prism stage prototype.

## 4. The Future of the IFS and GPI

Assembly of the IFS is currently scheduled to be finished by spring of 2010. The IFS will then be shipped to UC Santa Cruz with the other parts of GPI for a full instrument assembly. Integration testing will be done and is scheduled to be completed by the winter of 2010. The Gemini Planet Imager will then be sent to the Gemini South Telescope where first light is expected to occur in early 2011.

## 5. Acknowledgements

I would like to thank James Larkin for his continuous help and support throughout the summer, along with Jeff Chilcote and the rest of the UCLA Infrared Astronomy Lab. I would also like to thank Francoise Queval and UCLA for organizing and hosting this program. Finally, I would like to thank the NSF, whose generous grant made this research experience possible.

## 6. References

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