iLocater Mechanical Design

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ABSTRACT

The infrared Large Binocular Telescope Exoplanet Recovery, iLocater, spectrometer is an instrument that will be built for use at the Large Binocular Telescope (LBT) Observatory to discover exoplanets around local M dwarf stars. The mechanical design for iLocater is based primarily off of the designs of the Palomar High Angular Resolution Observer (PHARO) and Project 1640 (P1640). iLocater is a fiber fed instrument and will be made almost entirely of aluminum alloy 6061-T6. It will be operating in the near infrared which forces the detector to be cooled to cryogenic temperatures and housed in a vacuum. Pictures and dimension for each part are included. Smaller aspects of the design need to be reviewed, and frequency and thermal simulations need to be run to test the instrument design.

*Key words*: Radial velocity, M dwarf, Spectrograph, Y-band, SOLIDWORKS

1. INTRODUCTION

The Doppler Effect, which enables the detection of planets through the shift of the emission spectrum of the host star, allows scientists to determine the orbital period and mass of these exoplanets (Mayor & Queloz 1995). *Kepler* has found many planets using the transit technique, and its findings provide the surprising conclusion that there is a larger occurrence of small planets around low mass stars, particularly M dwarfs (Howard et al. 2012, Muirhead et al. 2012). Furthermore, multiple planet systems are found more commonly around M dwarfs than any other type of star (Muirhead et al. 2012). M dwarf stars are the most common type of stars in the universe and are fortunately located close to the galactic plane and relatively nearby to the earth, making them easier to observe (Howard et al. 2012, Swift et al. 2012).
With the expansive list of planets found by Kepler, follow up ground based observations are now needed to determine if any of these planets are actually hospitable (Charbonneau et al. 2009). Because the population of planets is greater around M dwarfs, the possibility of finding a habitable planet orbiting this type of star is very likely. Extremely sensitive ground based spectroscopic observations of the radial velocity of the star is the best way to determine the characteristics of a planet and see if it is located in the habitable zone (Charbonneau et al. 2009).

The infrared Large Binocular Telescope Exoplanet Recovery, iLocater, spectrometer is a fiber fed instrument that will be built for use at the Large Binocular Telescope (LBT) Observatory. Due to the “extreme” adaptive optics system of the LBT, the radial velocity measurements of iLocater will be diffraction limited. iLocater will be operating at near infrared (NIR) wavelengths in the Y-band (.95 – 1.13 μm), which is free of telluric absorption (Reiners et al. 2010), to observe M dwarf stars. Because of the 110.8 m² of collecting area of the LBT and its ability to use one dish to monitor radial velocity shifts, iLocater will be able to make precision measurements of the host star’s radial velocity to find planets in the habitable zone.

2. MECHANICAL DESIGN

iLocater will use the HAWAII-2RG (H2RG) detector supplied by Teledyne (Figure 9). It has a 2048 x 2048 pixel array with an 18 x 18 μm² pixel area (Beletic et al. 2008, Hawaii-2RG Technical Manual). When operating at 77K, its median dark current is ≤ .05 e-/s, and its median readout noise at 100 KHz readout rate is ≤ 18 e- (H2RG Product Sheet). Because this detector is operating in the IR, it must be cooled down by liquid nitrogen (LN₂) to 77K to prevent it from being saturated by thermal excitation. Lovis and Fischer (2011) also point out that variations in the index of refraction of air and thermal and mechanical effects of the instrument need to be corrected for to achieve high-precision radial velocity measurements.
The Infrared and Electro-optical Systems Handbook provides solutions to these problems. To combat changes in the ambient temperature and pressure, the spectrograph and optics will be placed in a vacuum chamber. Because the detector is so sensitive to movement, it needs to be isolated from vibrations; the instrument will be placed on a vibration isolation table which has pneumatic isolators in each leg (Erin et al. 1998). As an added measure, the instrument will be placed on pneumatic mounts to elevate it from the table. The addition of multilayer insulation (MLI) within the vacuum chamber, surrounding the detector and optics, will also reduce thermal radiation. MLI acts as a low emittance radiation shield that reduces temperature fluctuations (Lyle et al. 1973). Thermal radiation is minimized by reflective surfaces in the MLI, and thermal conduction is minimized by a spacer material (Gilmore 2002).

Most materials do not operate well at cryogenic temperatures. Marquardt et al. (2001) instructs that metals with lower thermal conductivity coefficients, higher specific heat, and small thermal expansion coefficients will work optimally in low temperature environments. Aluminum alloy 6061-T6 and stainless steel 304 are some of the best metals to use at cryogenic temperatures as seen in Figure 1. These metals also have some of the lowest outgassing rates (Danielson 2003). Outgassing is the process of releasing gas that is trapped or adsorbed in a material. This effect will decrease the vacuum and could lead to convection within the chamber (Danielson 2003). These materials are the two most commonly chosen for any instrument that operates at cryogenic temperatures. iLocater will be made almost entirely of aluminum alloy 6061-T6.

The designs of PHARO and P1640 gave a basis for iLocater’s design. The details of these designs can be found in Hayward et al. (2001), Hinkley et al. (2010), and Hinkley et al. (2011). Figure 2 shows the design of P1640 and what is encompassed by the vacuum. For iLocater, the
3D Computer Aided Design software SOLIDWORKS was used to design the instrument. The optical design of the spectrograph is a double pass shown in Figure 3.

Figure 4 shows the full instrument, and Figure 5 shows a cutaway view of the instrument. The dimensions are .777m x .477m x .347m, and the weight without LN2 is 264.47 lbs. The

![Figure 1](image)

**Figure 1.** A listing of metals suitable for use at specific temperatures (Hurlich 1968). Aluminum alloy 6061-T6 and stainless steel 304 are some of the best metals for use at cryogenic temperatures.

optics sit on a breadboard that is .62m x .32m x .0254m with holes for optical mounts spaced 1in apart and .75in in from the sides (see Figure 6). There are only four points where the optical components are in contact with the outer shell (blue) and hence the ambient room temperature. Four G-10 fiberglass tabs, Figure 7, connect the breadboard to the outer shell. This material is a super insulator and will therefore suppress any temperature change to the optics and detector through thermal contact. Their dimensions are .0381m x .00556m x .000508m. The tabs become thinner in the middle where their thickness is .00278m.
Figure 2. This sketch of the inside of P1640 shows what is encompassed by the vacuum (Hinkley et al. 2010).

Figure 3. iLocater has a double pass optical design that was created using the ray tracing program Zemax.

Figure 4. This is the outside view of iLocater. The dimensions are .777m x .477m x .347m, and it weighs 264.47 lbs.

Figure 5. The inside of iLocater is seen in this cutaway view.

Figure 6. This is the breadboard the optics will be mounted on. It is .62m x .32m x .0254m with holes for optical mounts spaced 1in apart and .75in in from the sides.

Figure 7. The super insulating G-10 fiberglass tabs will be the only points of contact between the optics and casing.
The purple LN$_2$ can in Figure 5 is .62m x .32m x .1127m with wall thickness .0127m. The tube for filling the can extends .1016m from the bottom and has an outer radius of .025m and inner radius of .02m. The volume that the can will hold is 15.34 L of LN$_2$. The can will be bolted to the bottom of the breadboard so the optics and detector will be cooled through thermal contact. The brown radiation shield in Figure 5 is made of MLI and surrounds the optics and detector. It is .6m x .3m x .1281m with wall thickness .00635m. In Figure 8 the detector (purple) and its housing are shown. This is not the final design, but was put in to help aid in understanding where the detector is located within the setup of the optics.

The length and width of the outer casing are .726m x .426m, but each section has a different height. The bottom is .1397m high, and the top is .2073m high, for a total instrument height of .347m. The walls are 1in thick and have a flange that is also 1in thick. Including the flange, the length and width are .777m x .477m. The black lining is an O-ring that is .5in thick that helps seal the casing and prevent air leaks in the vacuum. The screw holes on the flange are .1087m apart lengthwise and .115m apart widthwise. The bottom shell has two ports that extend

![Figure 8](image1.png)  
**Figure 8.** This is the sample detector and housing used to understand where the detector will be placed within the optics.

![Figure 9](image2.png)  
**Figure 9.** iLocater will use the HAWAI-2RG detector from Teledyne to make observations.
.0508m from the side with an outer radius of .03m and inner radius of .25m that will be used for the vacuum pump and vacuum gauge. A sample gauge is shown in Figure 10. The port extending .0508m from the bottom of the shell has an outer radius of .04m and inner radius of .03m. This port lines up with the port on the LN\textsubscript{2} can. The top casing has only one port of radius .025m which will be closed with the hermetically sealed feedthrough in Figure 11. The fiber optic cable will enter the chamber through the feedthrough, and the electrical information from the detector will come out. The smaller radius of the feedthrough is .025m, and the larger radius is .035m. The feedthrough is .03175m high. The two ports extend .005m off of the front and back and have an outer radius of .03175m and inner radius of .0015875m. The screw holes are placed .025m apart from each other.

Figure 12 shows a sample vibration table with pneumatic mounts elevating the instrument 5.5in above the table top. The table is modeled after the Newport M-RPR-36-8 vibrational isolation table that is .9m x 1.8m x 203mm. There is limited space where iLocater will be housed at the LBT, so a model of the room, Figure 13, was created make sure it would fit. The model person is 6ft tall, and the room space is 160in across and 140in back, though this length is shortened to 100in due to piping extending from the wall.

![Figure 10. A sample vacuum gauge that measures the pressure inside the vacuum chamber.](image1)

![Figure 11. The hermetically sealed feedthrough will feed the fiber optic cable to the optics inside the chamber.](image2)
3. CONCLUSION

The basic design of iLocater has been created, but there are still many smaller items that need to be decided upon like the types of screws that will be used to close the casing, sensors inside the chamber to monitor temperature and pressure, and a filter to only pass the Y-band wavelengths to the optics. There are also many considerations given by Teledyne to ensure the detector will perform at maximum efficiency, such as what type of metal the detector should be mounted on, which is covered in their Handling Manual. We also need to test how the materials act at cryogenic temperatures and to what extent the enclosure will be affected by vibrations. SOLIDWORKS has the capability to test the instrument through simulations in these areas, which will help determine if the design needs to be changed. The vibration simulation will be the most important; the space where iLocater will be housed is located by an elevator shaft, so it is crucial that it is isolated from those vibrations.

REFERENCES


