

Palomar Observatory Airspace Safety Precautions

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The safety of the airspace above Palomar Observatory is assured by the use of a team of five human spotters, supplemented by three electronic sensors: A visible all-sky CCD camera, a boresighted infrared camera, and a boresighted radar. We continue to rely on human spotters as we develop and test the automated components of this system. We intend to submit a validation plan for the automated system the FAA during 2007, with the goal of eventually phasing out human spotters. A brief technical description of the safety interlock system and each sensor is presented below.

Laser Safety Shutter and Interlock System

Laser Safety Shutter

A high-speed laser safety shutter (Electro-Optical Products Corp. model SH-20-24) provides a fail-safe means to block the beam where it exits the laser optical bench, in the Coude lab of the Hale telescope dome. A relay holds power on a solenoid to hold the shutter open, and any loss of power results in the closure of the shutter. The actuation time of closure is 15 milliseconds. The shutter signal is connected, with several emergency stop buttons in series, to the main laser relay panel on the mezzanine level of the dome at which each of the following inputs must be satisfied for the shutter to remain open:

- Laser hazard area access interlocks.
- Beam transfer system final optical sensor and heartbeat.
- Telescope control system elevation and azimuth permission.
- Visible All-Sky Camera.
- Boresighted Infrared Camera.
- Boresighted radar.
- Control room key switch and emergency stop buttons (incl. human spotters).

Laser Hazard Area Interlocks

Regions of the dome and Coude room classified as laser hazard areas are protected by hardware interlocks at all possible access points to prevent access when the laser is energized with out immediate shuttering of the laser. These are hard wired lines in series with the shutter control relay.

Beam Transfer Optics Interlocks

An optical sensor (a high-speed photodiode) at the entrance of the laser launch telescope assures that the laser is aligned to the launch telescope at all times. When the laser shutter is opened via actuation of the key switch in the control room, a digital timer in the 'bto' computer begins counting down. If a positive signal is not received from the final photodiode of the Beam Transfer Optics (BTO) system within 10 milliseconds, then the

laser will be immediately shuttered. During laser projection, if the same photodiode does not detect light for any period longer than 10 milliseconds, the laser will also be shuttered. Finally, the 'bto' computer provides a heartbeat signal to the shutter relay, which must be active for the laser shutter to remain open. These measures insure that the laser beam always follows the designed path or is immediately shuttered.

Telescope Control System Interlocks

The telescope control system computer, 'tcs', provides an open/closed signal to the laser shutter relay depending on whether the Hale telescope (and attached laser launch telescope) pointing direction is consistent with azimuth and elevation limits. The minimum elevation limit has to date been set to 45 degrees above the horizon. With the filing of the attached form 7410-1, we request to reduce the minimum elevation limit to 30 degrees above the horizon between 120 and 240 degrees azimuth only.

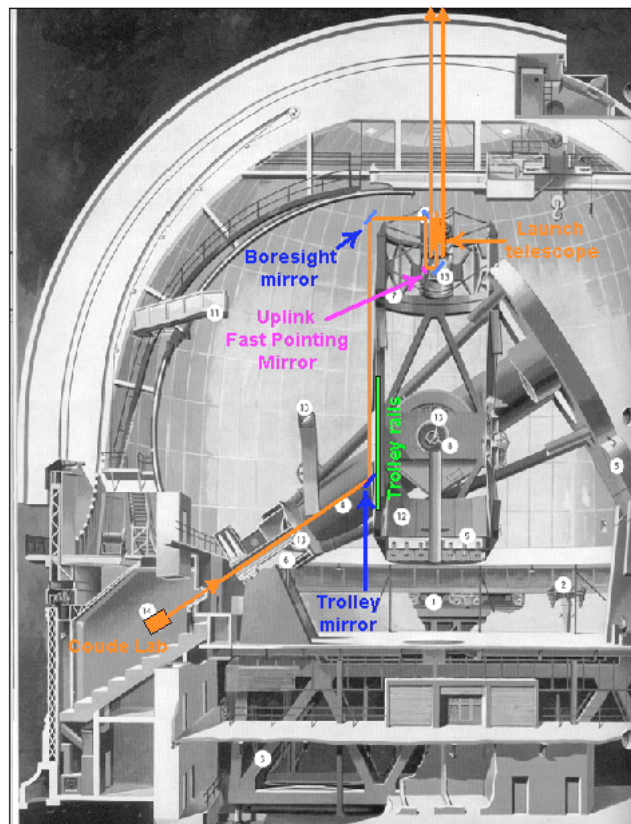


Figure 1: Palomar Hale Telescope, showing the laser launch system.

Visible All Sky Camera

The All Sky Camera (ASCAM) system is designed around a visible light, charge coupled sensor with a fish eye lens that affords a 360 degree, horizon to horizon field of view. The primary source of signal is the anti-collision strobe and wingtip navigation lights that the FAA requires for nighttime operations. The system is designed to detect aircraft out to the edge of space and to shutter the laser before the aircraft crosses the beam. The

response time of the ASCAM system is less than 9 seconds. This system is intended to identify all aircraft that a human spotter might identify.

All sky camera Hardware

The ASCAM is a Santa Barbara Instruments Group STL 1001.E, with a Nikon F/2.8 fisheye lens, providing a 2π steradian field of view on a 1k x 1k pixel detector. The camera is mounted in a Pelican waterproof case on top of the Hale telescope dome at Palomar Observatory (see Fig. 2). Its output is read continuously, providing a 3 second exposure every 7.4 seconds to the 'allsky' computer.



Figure 2: The All Sky Camera in its weather-proof case.

All sky camera data processing

The images from the ASCAM are read into a dedicated computer 'allsky' running Red Hat Linux, located in the dome attic. This computer runs custom software which identifies the existence of an aircraft by subtracting the most recent exposure from an median of several previous frames (see Fig. 3). If there is an aircraft moving through the field of view, it will appear as a light and a dark streak in the difference image. Any contiguous group of bright pixels in the difference image above a preset threshold will be considered a detection. The program is provided with the pointing coordinates of the laser projection telescope, and from the two data sets, predicts whether the detected aircraft is or is not within an exclusion zone around the laser beam. From the midpoint of an ASCAM exposure to the decision point at which a "shutter close" signal is sent is approximately 5.7 seconds.

An angular exclusion zone of 30 degrees around the laser beam provides an acceptable safety zone. A 777 flying at 562 knots travels 948 ft per sec. At 16000 ft MSL, a 30 degree (radius) exclusion zone provides a minimum of 6.3 seconds travel time from zone edge to the beam.

$$((16000 \text{ ft} - 5597 \text{ ft}) \times \tan(30)) / (948 \text{ ft/sec}) = 6.33 \text{ seconds}$$

At 30,000 ft MSL, the travel time is 14.8 seconds.

In our current mode of operation, the ASCAM system provides a signal to shutter the laser whenever a plane is detected in the exclusion zone, although currently the laser is already shuttered by human intervention. We intend to measure the sensitivity of the ASCAM by comparing automated detections against visual detections by human spotters during 2007.

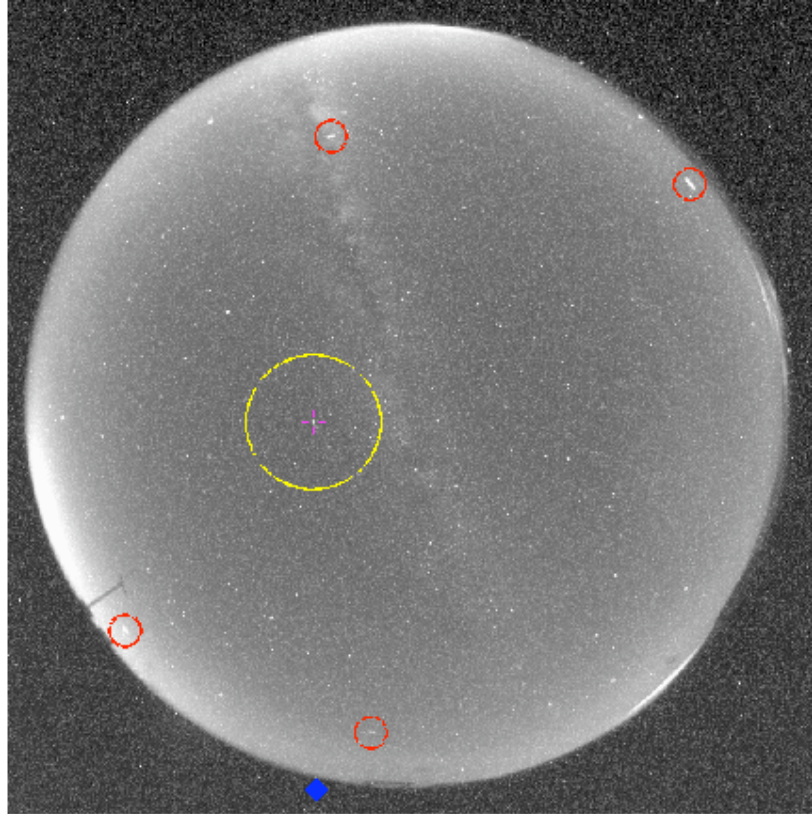


Figure 3: All sky camera image, with 4 aircraft highlighted by the automated detection software. The location of the laser projection point is marked with a pink cross (the laser was shuttered at the time). The exclusion zone is marked with a yellow circle.

Infrared Camera

All objects, whatever their temperature, emit infrared radiation. A thermal-IR detector array sees the target as a bright source against the cold sky, regardless of illumination conditions. The IR system also has the ability to observe an aircraft through moderate levels of clouds, dust and haze, conditions occasionally encountered at the Palomar Mountain site, through which Adaptive Optics systems are expected to continue to operate. In addition, such sensors can be read far more rapidly than visible CCD cameras, and thus the IR camera provides both more rapid response for the detection of low altitude or fast moving aircraft, and the ability to detect unilluminated aircraft. The IR camera thus serves as a second level of aircraft detection and laser shuttering.

IR camera hardware

The IRCAM is an uncooled Indigo Merlin InSb MWIR camera with a 320 x 256 pixel microbolometer array detector. It is mounted inside the prime focus cage of the Hale telescope alongside the laser launch telescope. A warm shutter and internal calibration software allow self-calibration of the camera, performed at the start of each night. The camera has a 15x20 degree field of view and is boresighted with the laser launch telescope so it sees a cone of sky of at least +/- 7.5 degrees around the laser beam. The camera detector is read out continuously at 60 Hz frame rate.

IR camera data processing

The video stream from the IRCAM is fed into a frame grabber in the 'lwir' computer, located in the telescope west arm, and analyzed for the detection of a hot target. The analysis software is identical to that used for the ASCAM, with each new frame subtracted from a median of several recent images to detect only the changes due to a passing aircraft. Any contiguous group of pixels in the difference image above a preset threshold will be considered a detection and will immediately shutter the laser. The frame grabber runs at 4 frames/sec. From the midpoint of an IRCAM exposure to the decision point at which a "shutter close" signal is sent is 0.34 seconds.

A low altitude aircraft flying at 200 knots travels 338 ft in one second, or 118 feet in the length of time it takes to shutter the laser. Such an aircraft passing 1000 ft above the observatory (6600 ft MSL), would cross the 7.5 degree minimum radius of the IRCAM field in 0.39s.

$$(1000 \text{ ft} \times \tan(7.5)) / (338 \text{ ft/sec}) = 0.390 \text{ s}$$

The current system thus only effectively protects aircraft above 1000 ft above ground level. We are investigating ways to reduce the response time of the IRCAM to address this deficiency.

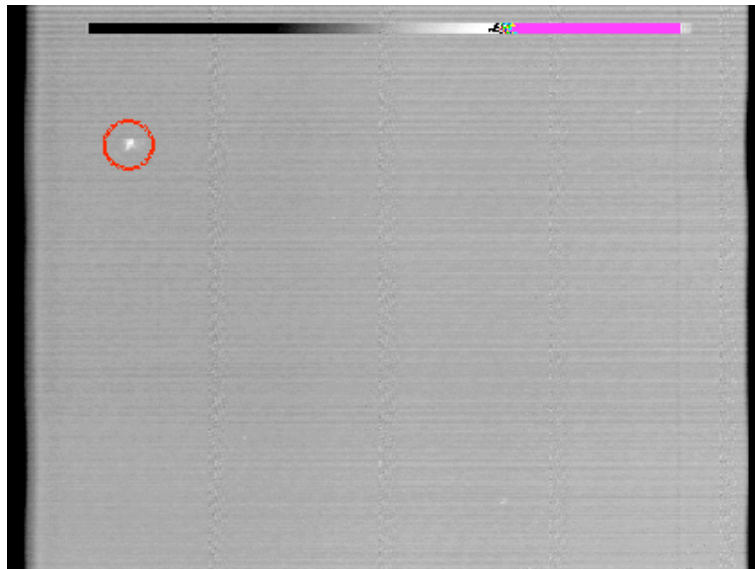


Figure 4: Infrared Camera image, with an aircraft highlighted by the automated detection software.

Boresight Radar

The final tier of the automated airspace safety system consists of a modified Honeywell Primus 400 weather radar, mounted on the top ring of the Hale telescope and aligned with the laser. Any aircraft which enters the radar conical field of view of 7.9 degrees in diameter will trigger the closure of the laser shutter with a latency of under 45 ms, including radar transmission, detection, interlock relay actuation, and the closure time of the laser safety shutter. This is sufficient to protect aircraft traveling at 200 knots down to an altitude of only 250 feet above the dome from inadvertent illumination.

$$(250 \text{ ft} \times \tan(3.95)) / (338 \text{ ft/sec}) = 0.058 \text{ s}$$

The boresight radar thus provides a final tier of protection to all low-flying aircraft to which the longer latency IRCAM and ASCAM are insensitive.

Control room key switch and human spotters

The final inputs to the laser safety shutter relay are the control room switches, consisting of a key switch to open the laser shutter, and two red mushroom-style emergency shutoff switches which result in the immediate shuttering of the laser. A team of two aircraft spotters are in direct radio contact with the laser operator in the control room, while a second team of two is indoors, with one substitute on standby. Prior to opening the laser shutter, an all-clear is required from the outdoor spotter team. During laser projection, they report the locations of all visible aircraft, and warn of aircraft which might approach a 30 degree zone of avoidance around the beam. If an aircraft enters the zone of avoidance, their word to the operator results in the immediate shuttering of the laser. It cannot be opened again until the aircraft spotters give the all clear signal and all other interlocks are again satisfied.

The use of human spotters alongside the three-tiered automated detection system allows us to test the automated sensors in a fail-safe mode, including on nights when the laser is not in use. We will continue to do so until we can secure FAA approval of a fully-automated airspace safety system.