Richard Roberts
ATO, Western Service Center
System Support Group, AJO2-W2
Federal Aviation Administration

Subject: Laser Guide Star for Astronomical Observations; Letter of Non-Objection

Dear Mr. Roberts,

We have reevaluated our elevation angle requirements, and found that we can significantly reduce the affected airspace by raising the minimum elevation in the north, as follows:

Azimuth range	Min. Elev.	Max. Elev.
0°-120° and 240°-360°	45°	90°
120° - 240°	30°	90°

While this restricts the length of time we can track astronomical objects, it still will allow us to access high-priority targets in the far south, such as the region around the center of our galaxy. I have attached an updated copy of form 7140-1, and a figure illustrating the footprint at 45,000 MSL. I hope this restriction in the north addresses your concerns.

Please also find attached a more detailed description of the automated airspace safety monitoring system at Palomar Observatory. We will over the next several months be continuing development work on this system, and during this time we will run it "live" (allowing detections to automatically shutter the laser), while using a team of 5 human aircraft spotters on every night. We intend to submit a more detailed validation plan for a fully automated system later this spring.

Sincerely,

Dr. Antonin Bouchez

Caltech Optical Observatories
ph: 626-395-8915
fax: 626-568-1517
e-mail: abouchez@astro.caltech.edu

Please find form 7140-1 and two attachments below.

Please Type or Print on This Form — Form Approved OMB No. 2120-0662

Failure To Provide All Requested Information May Delay Processing of Your Notice

FOR FAA USE ONLY

U.S. Department of Transportation
Federal Aviation Administration

NOTICE OF PROPOSED OUTDOOR LASER OPERATION(S)

1. GENERAL INFORMATION

(a) To: *(FAA Regional Office)*	(b) From: *(Proponent)*
Western Pacific Region AWP-520	California Institute of Technology
(c) Event or Facility Palomar Observatory Laser Guide Star Facility	(d) Report Date: February 15, 2007
(e) Customer California Institute of Technology	(f) Site address Palomar Observatory 35899 Canfield Road Palomar Mountain, CA 92060

2. DATE(S) AND TIME(S) OF LASER OPERATION

(a) Testing and alignment	(b) Operation
N/A	Approximately 5 nights per month.

3. BRIEF DESCRIPTION OF OPERATION

This is an updated filing for the Palomar Observatory Hale Telescope 12 Watt pulsed sum frequency laser, operating at 0.59 microns and launched into space with a 25cm 1/e diameter parallel beam.

4. ON-SITE OPERATION INFORMATION

(a) Operator(s) Robert P. Thicksten, Antonin H. Bouchez, Jennifer Roberts

(b) On-site phone #1 (706) 742-2134	(c) On-site phone #2 (760) 742-2106

5. FDS CDRH LASER LIGHT SHOW VARIANCE (if applicable)

(a) Variance # N/A	(b) Accession # N/A	(c) Expiration date N/A

6. BRIEF DESCRIPTION OF CONTROL MEASURES

Five safety spotters with direct communication to the laser operator, augmented by an automated aircaft detection system described in the attached note.

7. ATTACHMENTS

(a) Number of laser configurations [fill out one copy of page 2 of this notice ("Laser Configurations Worksheet") for each configuration] 1

(b) List Additional attachments *(including maps, diagrams, and details of control measures)*

Attachment A: Planned laser projection schedule.
Attachment B: Diagram of laser projector and maps of the location of Palomar observatory.

8. DESIGNATED CONTACT PERSON *(if further information is needed)*

(a) Name Dr. Antonin Bouchez		(b) Position Adaptive Optics Group Lead
(c) Phone (626) 395-8915	(d) Fax (626) 568-1517	(e) E-mail abouchez@astro.caltech.edu

9. STATEMENT OF ACCURACY

To the best of my knowledge, the information provided in this Notice and attached worksheet(s) is accurate and correct.

(a) Name *(if different from contact person)*	(b) Position
(c) Signature	(d) Date February 15, 2007

Please Type or Print on This Form Form Approved OMB No. 2120-0662

U.S. Department of Transportation
Federal Aviation Administration

Failure To Provide All Requested Information May Delay Processing of Your Notice

FOR FAA USE ONLY

LASER CONFIGURATION WORKSHEET

1. CONFIGURATION INFORMATION	(b) Name of event/facility	(c) Report date:
(a) Configuration number 1 of 1	Palomar Observatory	February 15, 2007

(d) Brief Description of Configuration
12 Watt pulsed sum frequency laser operated at 0.59 microns, projected into space with a 25 cm 1/e diameter diameter parallel beam. We will restrict the elevation range of laser projection to 45-90 deg. over azimuth ranges 0-120 deg. and 240-360 deg., and 30-90 deg. over azimuth range 120-240 deg.

2. GEOGRAPHIC LOCATION		(d) Latitude 33 ° *(deg.)* 21 ' *(min.)* 22.3 " *(sec.)*
(a) Site Elevation (ft. above Mean Sea Level)	5496 ft	(e) Longitude 116 ° *(deg.)* 51 ' *(min.)* 52.7 " *(sec.)*
(b) Laser Height Above Site Elevation (ft.)	103 ft	(f) Determined by: ☒ GPS ☐ Map *(Quad)* ☐ Other ______
(c) Overall Laser Elevation (a + b)	5599 ft	(g) Horizontal Datum: ☐ NAD 27 ☒ NAD 88 (h) Vertical Datum: ☐ NGVD 29 ☒ NAVD 88

3. BEAM CHARACTERISTICS AND CALCULATIONS ***(check one Mode of Operation only, and fill in only that column)***

Mode of Operation	☐ SINGLE PULSE	☐ CONTINUOUS WAVE	☒ REPETIVELY PULSED
Laser Type *(lasing medium)*	*(not applicable)*		Sum Frequency
Power *Watts (W)*		*maximum power*	*average power* 12 W (max)
Pulse Energy *Joules (J)*		*(not applicable)*	24 mJ/pulse
Pulse Width *Seconds (s)*	*(not applicable)*	*(not applicable)*	200 microseconds
Pulse Repetition Frequency *Hertz (Hz)*		*(not applicable)*	500 Hz.
Beam Diameter @ 1/e points *Centimeters (cm)*			25 cm
Beam Divergency 1/e @ full *Angle Milliradians (mrad)*			0.005 mrad
Wavelength(s) *Nanometers (nm)*			589 nm, 1 GHz bandwidth
(a) MAXIMUM PERMISSIBLE EXPOSURE (MPE) CALCULATIONS ***(will be used to calculate NOHD)***			
MPE *W/cm²*	*(not applicable)*		0.00045 W/cm^2
MPE per pulse J/cm²		*(not applicable)*	
(b) VISUAL EFFECT CALCULATIONS ***(will be used only for visible lasers [400-700 nm] to calculate SZED, CZED, and LFED)***			
Pre-Corrected Power *(PCP)* Watts *(W)*	*Pulse Energy (J) x 4*	*Maximum Power (from above)*	*Pulse Energy (J) x PRF (Hz) OR Average Power* 12 W
Visual Correction Factor *(VCF)* **(Enter "1.0" or use Table 5)**			1.0
Visually corrected Power *PCP x VCF*			12 W

4. BEAM DIRECTION(S)		*Magnetic variation (degrees)*
Maximum elevation angle *(degrees)*	90 deg.	*Azimuth* ☒ *True* ☐ *Magnetic*
Minimum elevation angle *(degrees, where horizontal = 0º)*	30-45 deg.	*(degrees)* 0-360 deg. (see note above)

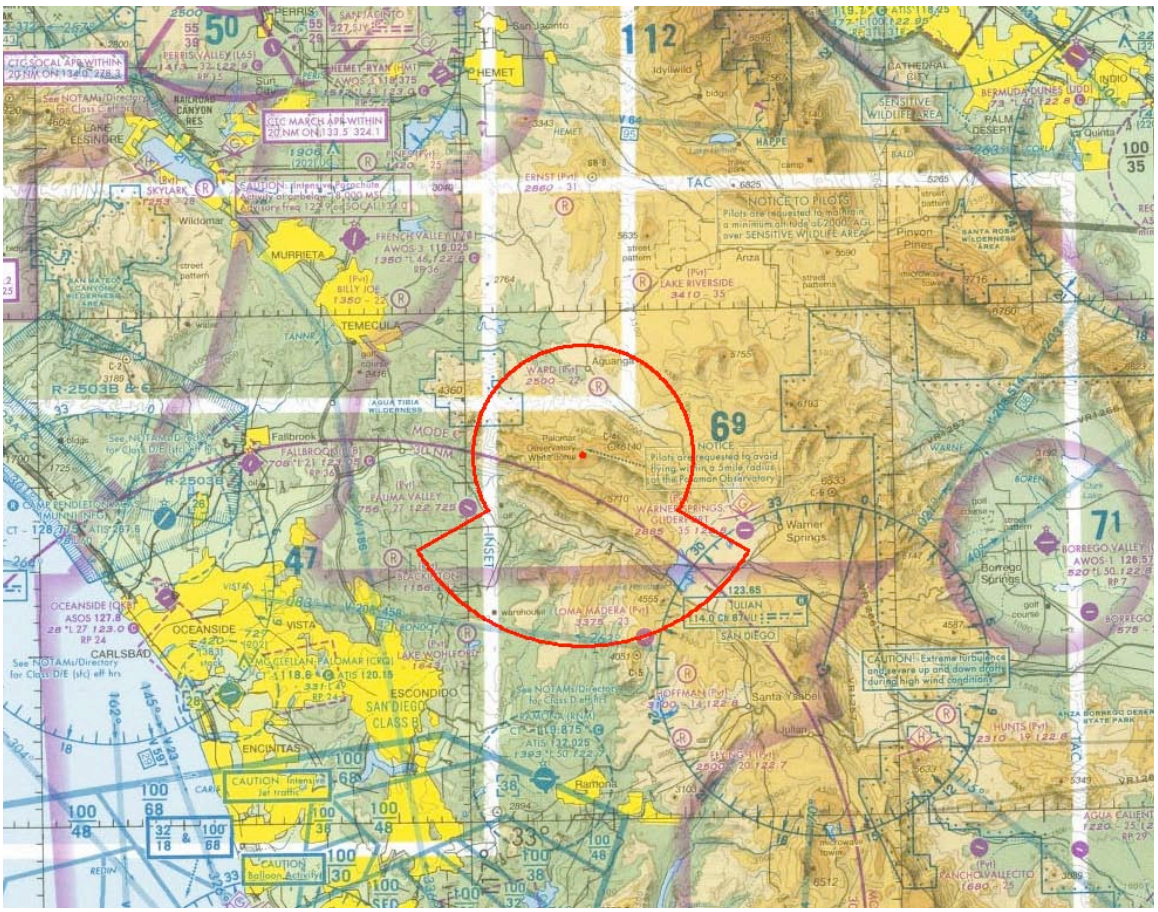
5. CALCULATED DISTANCES *(fill in all three columns)*	**SLANT RANGE** *(ft.)*	**HORIZONTAL DISTANCE** *(ft.)*	**VERTICAL DISTANCE** *(ft.)*
NOHD (based on MPE)	1,190,000 ft	1,190,000 ft	1,190,000 ft
***SZED** *(for 100 µ W/cm² level)*	> NOHD	> NOHD	> NOHD
***CZED** *(for 5 µ W/cm² level)*	> NOHD	> NOHD	> NOHD
***LFED** *(for 50 n W/cm² level)*	> NOHD	> NOHD	> NOHD

*If the laser has no wavelengths in the visible range (400-700 nm), enter "N/A (non-visible laser)" in all blocks.
For visible lasers, if the calculated SZED, CZED, and/or LFED is less than the NOHD, enter "less than NOHD." than "NOHD."

6. CALCULATION METHOD ☒ Commercial software *(print product name)* Easy Haz Professional v3.1, Laser-Professionals Inc.

☐ Other [*describe method (spreadsheet, calculator, etc.)*]

Attachment A: Projected footprint of the Palomar laser



VFR map of the Palomar region. The location of Palomar Observatory is marked with a red dot. The red region marks the footprint at 45,000 ft MSL corresponding to the elevation and azimuth ranges specified in the attached form 7140-1.

Attachment B: Palomar Airspace Safety Precautions

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.

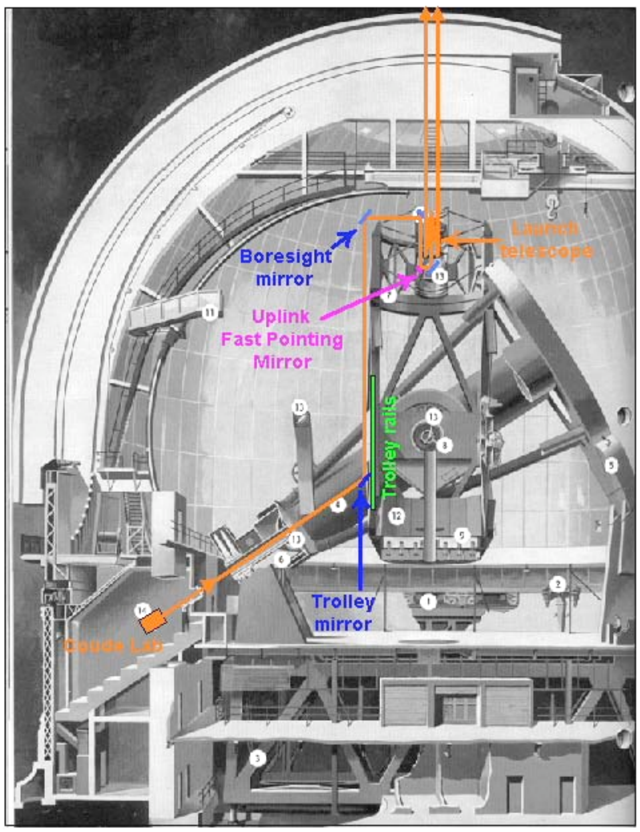


Figure 1: Palomar Hale Telescope, showing the laser launch system.

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.

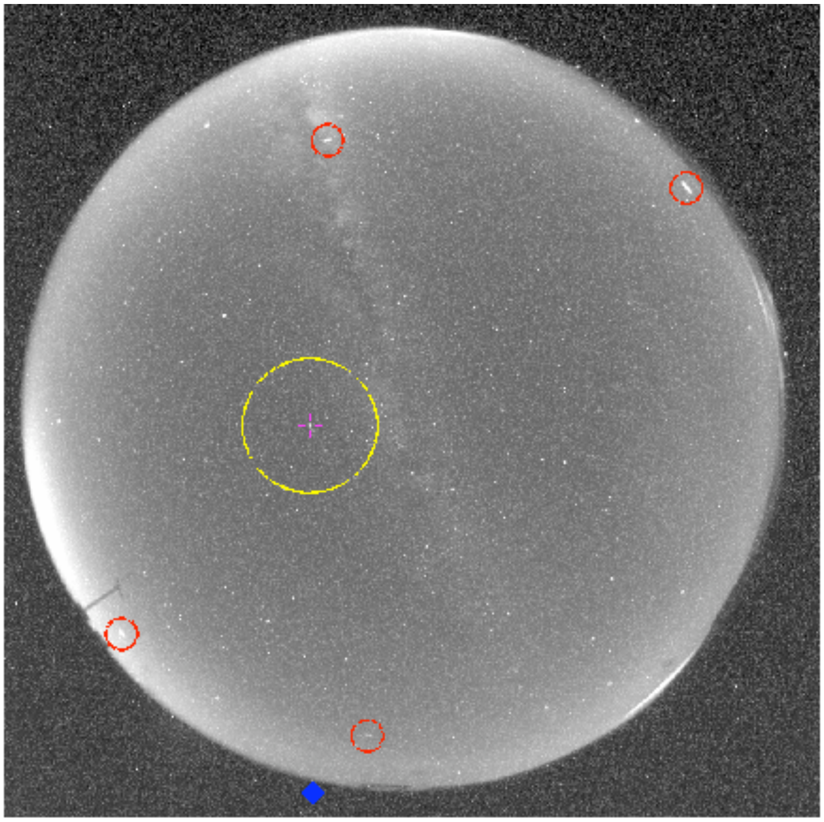


Figure 3: All sky camera image, with 4 aircraft highlighted by the automated detection software. The location of the laser projection point is marked with a pink cross (the laser was shuttered at the time). The exclusion zone is marked with a yellow circle.

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. We also intend to verify the sensitivity of the IRCAM by hiring a private pilot to repeatedly fly across the field of the IRCAM at a known range during 2007.

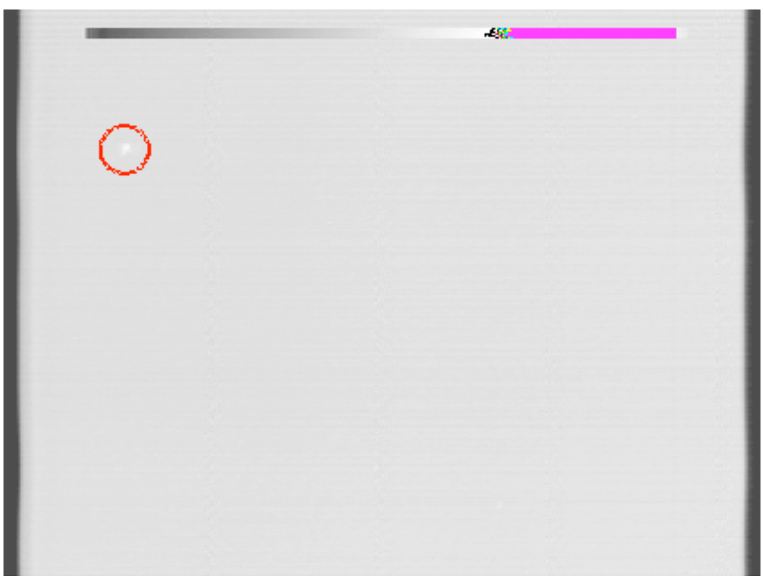


Figure 4: Infrared Camera image, with an aircraft highlighted by the automated detection software.

Boresight Radar

The boresight radar is a modified Honeywell Primus 400 weather radar, mounted on the top ring of the Hale telescope. Any aircraft which enters the radar conical field of view of 7.5 degrees will trigger the closure of the laser shutter within 0.5 seconds. This sensor therefore provides redundancy to the ASCAM and IRCAM, with a response time similar to the IRCAM. As with the IRCAM, we are investigating ways to reduce the response time of the radar, to improve the ability to detect low altitude aircraft. We plan to measure the sensitivity of the radar concurrently with the IRCAM sensitivity test described above.

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.