PROTECTION OF HAWAII'S OBSERVATORIES FROM LIGHT POLLUTION

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Hawaii is home to two major observatories – Mauna Kea Observatory on the island of Hawaii, and Haleakala Observatory on Maui. A lighting ordinance has been in place for many years to protect the night sky above Mauna Kea; a new lighting ordinance has just been enacted to protect Haleakala. As the population of these islands grows, further efforts are required to protect the dark night skies over the observatories.

Introduction

Mauna Kea Observatory — the world's largest collection of telescopes — has been protected for many years by a strong lighting ordinance on the island of Hawaii. Mauna Kea has an extremely dark sky — arguably the darkest of any major observatory site. Specific factors that contribute to the extremely dark sky are:

- Its high altitude of 4,200 meters, which reduces the amount of air above it from which light can scatter. The atmospheric pressure at the observatory is approximately 60% of the sea level pressure.
- The low aerosol content of the air. Hawaii is located in the middle of the Pacific Ocean, distant from dust from deserts and pollution sources. Particles from the ongoing eruption of the Kilauea volcano are trapped at lower altitudes by the temperature inversion.
- Its distant location from Earth's magnetic poles, which reduces the sky brightness contribution from auroral emission lines.
- Common low-altitude cloud cover over the eastern side of the island that naturally blankets artificial lights.
- The strong lighting ordinance.

The Hawaii county lighting ordinance has provided good protection. It was one of the earliest lighting ordinances to be introduced anywhere, and was last modified in 1989. Since then, new, larger telescopes have begun operating, and detectors and instruments have become much more sensitive. These changes have meant that it is now time to revisit some of the provisions of the lighting ordinance. The Keck telescopes are already detecting faint artificial emission lines, and as the population of the Island of Hawaii grows, there is an increasing need for more vigorous light control.

The island of Hawaii currently has a population of approximately 150,000. The island of Oahu, where Honolulu is located, is approximately 300 km from Mauna Kea and has a population of approximately 900,000. Nearby light sources on the island of Hawaii are the dominant sources of artificial sky brightness for Mauna Kea. More distant Honolulu

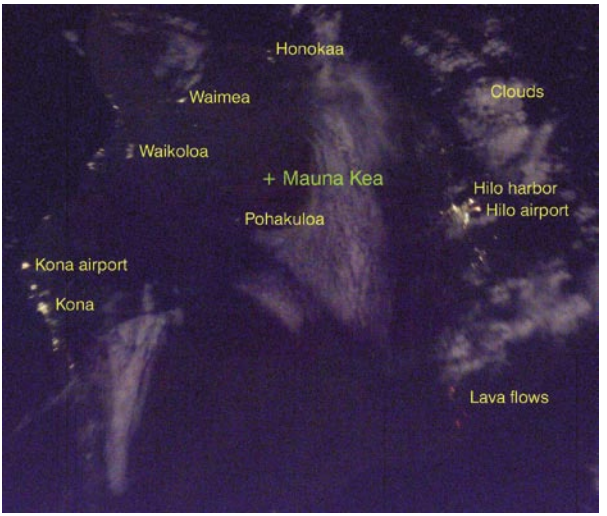

Figure 1. The Island of Hawaii photographed at night from the International Space Station. Important sources of light are labeled in yellow. The location of Mauna Kea Observatory relative to the light sources is shown. For scale, the distance between the Hilo and Kona airports is 105 km. (Photo by Ed Lu/NASA)

and other towns on Oahu make a small contribution that is of growing concern, and preliminary discussions are underway for a lighting ordinance for the City and County of Honolulu.

Haleakala Observatory, on the island of Maui, has for many years been mostly a solar observatory. In recent years, however, several new optical telescopes have begun operation, and the Pan-STARRS 1 telescope will start surveying the sky from Haleakala in 2008. This has produced a new and urgent need for a lighting ordinance in Maui County, and a new ordinance was enacted in early 2007. Haleakala presently has a moderate problem with light pollution that will be ameliorated over the next 10 years as the new ordinance takes effect. Honolulu is only 175 km from Haleakala, so is a more serious source of light pollution for Haleakala than it is for Mauna Kea.

Both Mauna Kea and Haleakala do not lie in commonly traveled air routes. Aircraft flying between Hawaii and the continental United States fly to the north of the Hawaiian islands, and aircraft flying between the United States and Asia fly far to the north. Unlike the observatories in Chile, Hawaii's observatories seldom have problems with lights from aircraft or from vapor trails coming from aircraft engines.

Nighttime International Space Station Imaging of Hawaii

Because the large telescopes on Mauna Kea had started to detect (albeit faint) artificial emission lines commonly associated with urban light sources (such as mercury), we requested that nighttime photographs of Hawaii be obtained from the International Space Station (ISS). Astronaut Ed Lu obtained two photographs in October 2003. *Figure 1* shows the image of the Island of Hawaii, which was taken in the light of a gibbous moon in mostly cloud-free conditions.

The photograph shows the island of Hawaii essentially as it would appear to the human eye, in orbit approximately 320 km above Earth. It is a powerful diagnostic tool for locating sources of light pollution, and shows several major sources. Selected sources are listed in *Table 1*. State government installations (airports, harbors) are indicated by green in the table, federal government installations are indicated by brown, natural sources (lava flows) are shown using beige; the remaining light sources, which fall under the jurisdiction of the county, are shown with a white background. The third column of

Table 1 lists the impact of each source on the observatory, calculated by scaling the brightness by $d^{-2.5}$ (Walker's law, 1977) where d is the distance from the summit of Mauna Kea.

Most of the lighting under the county jurisdiction uses low-pressure sodium (LPS) lamps. This is the least damaging light source for astronomy because the light is nearly monochromatic, and therefore can be filtered out in some cases. Additionally, Rayleigh scattering in the atmosphere is much less for red light than for blue light. The LPS lamps emit yellow-orange light at 589 nm.

Table 1

Location	Brightness	Scaled Brightness
Hilo Airport	19,000	1.5
Hilo Harbor	19,000	1.5
Kona Airport	30,000	1.6
Hilo Town Center	34,000	3.0
Hilo Mall Area	27,000	2.2
Kona Town	59,000	2.7
Waikoloa Village	22,000	3.0
Waimea	17,000	3.2
Quarry	1,100	0.3
Lava flows	5,000	0.2
Pohakuloa	2,300	7.2

The State lighting at the airports is mostly high-pressure sodium. The ISS image shows that the airports are a significant source of light pollution to Mauna Kea. The army training facility at Pohakuloa is located 10 km from the summit of Mauna Kea, and is the single largest source of light pollution for the observatory. Natural light sources — lava flows from the eruption of Kilauea volcano — have a negligible impact on the observatory.

Efforts to reduce light pollution on the Island of Hawaii

Using the ISS data as a starting point, we have focused our efforts to reduce light pollution in four major areas:

1. Pohakuloa Training Area: Additional lights were installed at the Pohakuloa army training area in 2002 following the terrorist attacks on the United States. Many of these lights are poorly shielded and use high-pressure sodium lamps. The problems that these lights cause to the observatories have been discussed with the army. Ironically, these same lights are causing problems with army training using night-vision equipment. Many of the lights are being replaced by fully shielded LPS lamps.
2. State airports, harbors and highways: Much of the lighting at the airports is not properly shielded. Most of the lamps in use are high-pressure sodium because of color rendition requirements. Because of the damaging effects these State facilities were having on the observatories — in particular the airports — new legislation was passed in 2007 to require all new lighting at state airports, harbors and on state highways to comply with county lighting ordinances. During the coming years, we will try to get new legislation passed to fund the retrofitting of existing poor lighting at the airports and harbors. Retrofitting the airport ramp lights with fully shielded fixtures will produce a reduction by a factor of approximately 2 in light pollution from the airports.
3. Streetlights: When viewing the island of Hawaii from the summit of Mauna Kea (see *Figure 2*), it is clear that streetlights are the dominant source of artificial light. Even though these are monochromatic, they are still damaging to astronomy. Both the Subaru and Canada-France-Hawaii telescopes spend much of their time doing wide-area imaging surveys. Almost half of this surveying work is done using the *r*, *R*,

Figure 2. The view from Mauna Kea at night looking to the northwest. The yellow-orange glow over the towns comes from the low-pressure sodium streetlights. The photograph clearly shows that local light sources, located on the island of Hawaii, dominate over more distant lights from Maui and Honolulu. A blanket of cloud is seen covering the eastern half of the island. (Photo by Richard Wainscoat).

or *V* filters, each of which transmits the yellow-orange light of LPS lamps. In 1989, when the present version of the island of Hawaii lighting ordinance was passed, there were few fully shielded streetlight fixtures available. The lighting ordinance therefore required only partial shielding of streetlights. Fully shielded streetlight fixtures now available offer better performance than the partially shielded lights presently in use. We are therefore working with the county to replace all streetlights on the Island of Hawaii with fully shielded ones. A pilot project will replace the streetlights in the town of Waimea with fully shielded fixtures. This should be completed late in 2007. Apart from decreasing the impact on the observatories, these changes will result in better road safety by reducing glare. It is expected that changing all streetlights to fully shielded fixtures will result in a decrease by a factor of approximately 2 in the amount of light pollution at the observatories from streetlights.

4. Enforcement of the lighting ordinance: Compliance with the island of Hawaii lighting ordinance has become a growing problem. While there is general compliance, a drive through any of the urban areas at night reveals many noncompliant light sources — typically poorly shielded broad-spectrum lights. At the core of the compliance problem is the fact that the building inspectors responsible for ensuring compliance work only in the daytime, when the lights are turned off. Lights on buildings are only inspected when they are new, so any change to lighting made later is typically not inspected for compliance. We are working with the county to encourage more enforcement activities.

With the efforts described above, the contribution from artificial light to the sky brightness over Mauna Kea can be approximately halved. These efforts are very important to preserve the dark night sky because the population of the island of Hawaii is continuing to grow.

Protecting Haleakala — Maui's new lighting ordinance

After many years of discussion, which traversed several elections, a new lighting ordinance was passed in January 2007 for the County of Maui, where Haleakala Observatory is located. Maui, with a population of 120,000, is a much smaller island than the island of Hawaii, so its population lives closer to the observatory. Until recently, Maui county did not have a lighting ordinance. Artificial light sources have grown to make a significant contribution to the night sky brightness, increasing the sky brightness by as much as 30% above its natural level in the northwest direction where much of the population is located. The southeastern half of the sky seen from Haleakala remains very dark.

The main provision of the new lighting ordinance is a requirement that nearly all lights are fully shielded. This will eliminate direct upward lighting of the sky, and should deliver a factor of 2 reduction in artificial lighting of the night sky over Haleakala. All lights in Maui county must comply with the new shielding requirements within the next 10 years.

The most controversial aspect of the ordinance was the request from the University of Hawaii for widespread use of LPS lighting. Aside from its benefits to astronomy, Maui has several endangered species, including turtles and birds, each of which would benefit

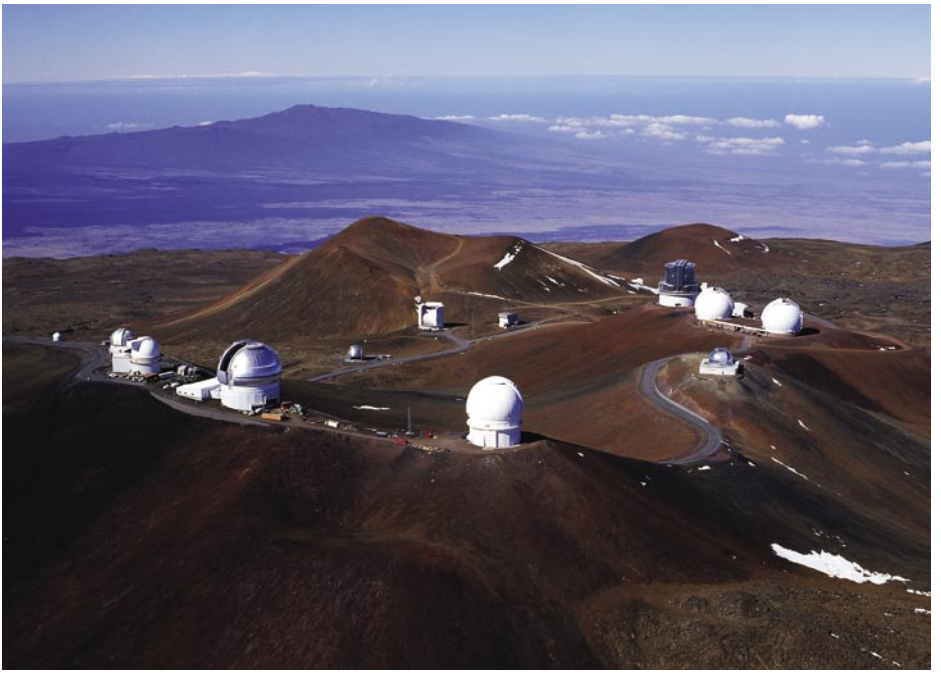

Figure 3. Mauna Kea Observatory, located on the Island of Hawaii (Big Island).

from use of monochromatic LPS lighting. However, Maui's economy is dominated by tourism, and hotel and resort operators argued that the use of LPS lamps at night would drive tourists away. The failure to introduce widespread use of LPS lamps will make it difficult to restore the night sky over Haleakala to the pristine level of darkness currently enjoyed by Mauna Kea.

Summary

Mauna Kea is one of the darkest observatory sites in the world. It has been protected for many years by a strong lighting ordinance. Continued efforts, which span all levels of government, are required to preserve the dark sky over Mauna Kea. Haleakala Observatory presently has a moderate light pollution problem in the northwestern part of the sky. A new lighting ordinance in Maui county will significantly decrease the light pollution on Haleakala.

Notes and References

1. WALKER, M.F. 1977, PASP, 89, 405