A Search for Monochromatic Light from the Andromeda Galaxy

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ABSTRACT: The Andromeda Galaxy was surveyed for monochromatic sources by using an objective prism optical telescope. The survey consisted of capturing 150 images of the entire galaxy using exposure times of only 10 to 20 sec, giving optical spectra of every point within the galaxy. The goal was to detect any sources, including transients lasting less than 10 s, that emit a narrow range of wavelengths (<3 nm) inconsistent with known astrophysical emission lines. Two different cameras were employed, having pixel sizes of 11 and 3.7 microns, the latter offering superior cosmic ray discrimination from monochromatic light. The 150 images revealed no monochromatic emission, neither short-lived (under 20 s) nor lasting the 30-minute duration of the sequence of exposures. Injection and recovery of synthetic monochromatic sources verified that lasers could be detected and yielded a detection threshold of 1 photon per second. At the Andromeda Galaxy, that detection threshold corresponds to a laser having a power of roughly 100 Terawatts for a benchmark 10-meter laser launcher that is diffraction-limited. Any lasers more powerful and directed toward Earth would have been detected. None were found.

KEYWORDS: Physics and Astronomy Extraterrestrial Intelligence; galaxies, Individual. Andromeda; techniques, spectroscopic.

Introduction

Many scientists, philosophers, and religious thinkers have noted that finding intelligent life elsewhere in the universe would be an important discovery, perhaps motivating humanity to abandon notions that we are special creatures and to reassess our Earthly purpose and cosmic future.[1-4] There can be little doubt that extraterrestrial intelligent life exists somewhere in the vast entirety of the expanding universe. It contains at least hundreds of billions of galaxies, each containing billions of star systems with Earth-size planets.[5] In the last few decades, astrophysicists have begun the challenging and systematic search for evidence of life elsewhere. While these searches have yielded no detections, there are still numerou

The search for intelligent life (SETI) is pursued with various approaches, most commonly a search for non-natural electromagnetic waves at various wavelengths, which is a fast and cheap way to send signals.[1-4] The signals may come from civilizations, space stations, interstellar or intergalactic vehicles, or even exotic powerhouses near binary neutron stars or black holes. The electromagnetic waves become fainter as the distance squared, greatly decreasing the intensity over hundreds, thousands, or millions of light years. The communication may be powered by nuclear energy, photovoltaics, or as-yet-undiscovered energy sources, offering gigawatts of power, and they may be sent by civilizations perhaps long extinct. In contrast, communication continues to travel at light speed.

Telescopes searching for extraterrestrial communication may collect optical, ultraviolet, infrared, or radio waves, taking advantage of the transparency of the Earth's atmosphere at many wavelengths. Most of these waves pass through the interstellar medium with only small extinction. Once a telescope detects such waves, further analysis, and new observations can be done to validate its existence and interpret any messages. Still to this day, despite hundreds of warm Earth-size planets discovered[5],evidence of life outside the Earth, including any that developed technology, has yet to be found.

SETI researchers have pursued the search for over 60 years with no success, motivating Philip Morrison and many others to explain "The Great Silence." In the 1980s Morrison noted that life on Earth is the consequence of a long, diverse sequence of chemical natural selection allowing specific chemical factors and environments to become reproductive systems we call "biology".[1] Any life that does emerge must make itself detectable over interstellar distances so that we can detect it, a challenge they may not be motivated to overcome.[1]

The leading SETI "Breakthrough Listen" program concentrates on detecting radio waves of technological origin[6], including from nearby stars and galaxies. Alternatively, one may search galaxies for laser beacons including from the nearby Andromeda Galaxy. Laser searches toward other galaxies would be sensitive only to powerful lasers used by civilizations that are interested in alerting us to their existence and sending high volumes of data.[7] Laser beams are particularly useful for intergalactic communication because their small divergence concentrates the message toward the intended recipient.[8] As optical lasers are rare in nature, if they exist at all, the detection of such beams would be extraordinary and worthy of follow-up study. ginger extract might support skin wound healing with strong antibacterial effects.

Searching for laser light from other galaxies represents an extreme domain of the plausible distributions of technological luminosity. Advanced civilizations are likely separated by millions of light years on average. The rare ones that flourish may be long-lived, allowing them to acquire the ability to send signals of high luminosity from their large energy availability. Accordingly, we describe here a search for laser beacons from the Andromeda Galaxy. Its structure, modest dust extinction, and tilted disk allow the entire disk and outer bulge to be observed for laser beacons originating within those regions.[9] Images of Andromeda have been obtained through different filters, from UV to IR[9,13], but a search for monochromatic sources has not been done.

Figure 1: All observations were made using a RASA Schmidt telescope with a prism over the front (at left). The wedge prism was custom-made and has a 7-degree angle (right image). The faces are polished flat to within 1 wavelength of visible light. The flint-type glass, with its large refractive index, spreads the incoming light into all optical wavelengths.[11]

Observational Methods:

We searched for laser light from Andromeda by using an objective prism telescope having an entrance diameter of 0.28 meters and a prism over the aperture having a 7-degree wedge angle, as shown in Figure 1. We were fortunate to use the telescope built and maintained by the team at the Center for Space Laser Awareness. We accessed their telescope remotely using Zoom to command operations. A full description of the telescope, its prism, camera, and the resulting wavelength dispersion are already described.[11] In brief, the 0.28-meter telescope (Celestron RASA-11) gathers light at each location in the sky within a 2 deg x 3 deg field of view. The prism over the front spreads the light into the full optical spectrum, from wavelengths 380 nm to 990 nm. The resolution in wavelength is typically about 3 nm and is better (smaller than 3 nm) at shorter wavelengths. Laser emission would be composed of a narrow range of wavelengths of light and thus spread over 3 nm on the sensor of the camera. In contrast, stars, planets, asteroids, planes, and satellites appear as a full spectrum of all wavelengths, easily distinguished from the single wavelength of laser light.

We collected images of the Andromeda Galaxy during two observing runs on 11 Feb 2021 and 21 Jan 2022, using two different cameras at the focus of the telescope. During the first observing run, we used the FingerLakes KL400 CMOS camera having 2000 x 2000 pixels, each of size 11x11 microns that subtend 3.5 arcseconds on the sky, with each having a quantum efficiency of 50% from 500 to 750 nm, spanning a total of 2 x 2 deg. During the second run, we used a QHY600 M CMOS camera that has 9400 x 6600 pixels each of size 3.7x3.7 microns that subtend 1.3 arcsec on the sky, with each having a quantum efficiency over 80% between 500 – 800 nm. This camera spans 2 x 3 deg in the sky. The QHY600M camera is superior because the point spread function of the telescope is 7 arcsec in width due to the optical imperfections in the prism. A point source, such as a distant laser, would be spread out into a circular image with an apparent angular diameter of 7 arcsec, corresponding to a full width at half the maximum of 5.5 pixels with the QHY600M camera. That 5.5-pixel width allowed secure discrimination of actual single-wavelength point sources from cosmic ray particles that hit the sensor on only a few pixels. Cosmic rays and laser light are easily distinguished due to the small pixels of the QHY600M camera.

During the first observing run in Feb 2021, the data acquisition involved 100 images, each 10 sec in duration. During the second observing run in 2022, the data acquisition involved 50 images, each 20 sec in duration. The entire Andromeda Galaxy and its two dwarf spheroidal satellite galaxies are captured in each image. The spectra of foreground stars located in our Milky Way Galaxy are also captured in each image, with the faintest being visual magnitude 14. A typical 20-sec exposure of the Andromeda Galaxy is shown in Figure 2. The central nucleus and bulge regions of the galaxy are white due to the grayscale employed here, and the disk of the Andromeda Galaxy is the diagonal faint smear of light extending from the lower left to the upper right. The two dwarf spheroidal galaxy companions to Andromeda are also visible as spectra slightly puffed in width. Also visible are hundreds of stellar spectra, the horizontal streaks from left to right due to the prism dispersing the wavelengths, 380 to 950 nm, with longer wavelengths to the left. These are spectra of stars in the foreground Milky Way Galaxy.

This objective prism telescope system is sensitive to sources of a narrow range of wavelengths of optical light, either pulses or continuously on, that would appear as "dots" the size of a point spread function in the image.[11] At the distance of Andromeda, 752 kiloparsecs, the plate scale (with the QHY600M) is 1.3 arcsec per pixel and a pixel spans a distance of 4.8 parsecs. Figure 3 shows the sum of the 50 images obtained with the KL400 camera, totaling an exposure time of 1000 sec. The three panels in Figure 3 display this summed image of Andromeda using three different grayscales. The different grayscales enable the identification of laser emission (dots) in regions that are faint outside the Andromeda Galaxy, medium-bright within the galactic disk, and very bright in the central region of Andromeda. These three grayscales permit the detection of laser point sources in the co-added image of all three domains of brightness. The co-added image reveals spectra of stars as faint as V magnitude 17.

■ Analysis

We inspected, by eye, each of the 150 images of the Andromeda Galaxy in search of laser light that would appear as a "dot" on the image having the same size as the point spread function. Visual analysis was preferred over an algorithm due to the mere 150 images, a small enough sample that visual inspection is possible, and offers the value of human pattern recognition and identification of unexpected noise in the images. With the KL400 camera and its 11-micron pixels, the full width at half maximum of the image shape of an unresolved laser source, i.e., the point spread function, is 2.5 pixels in the spatial direction and perhaps slightly wider in the wavelength direction. To examine the images, we found that the grayscale made a significant difference in the ability to filter out the stars and background galaxy light that constitute background noise. We adjusted the grayscale to provide a modest brightness of the background light from stars and the galaxy, allowing any laser light to be visible above that background.

Co-adding the images taken in Feb 2021 with the KL400 camera required technical help from the Space Laser Awareness team. We had positioned the telescope at the correct coordinates of the Andromeda Galaxy, RA= 0h 42m 44s and Dec = +41° 16 09 (equinox 2000), centering the fully visible galactic disk of Andromeda in the 2 x 2 deg field of view. But during the acquisition of 100 exposures, no guiding was done, allowing the telescope to drift by 30 arcseconds. The co-addition was done by the Space Laser Awareness, using a simple cross-correlation to reposition the images to be coincident before adding the 100 images together. The final grand image of those 100 exposures is shown in Figure 2. The images, including the sum, using all three grayscales were examined.

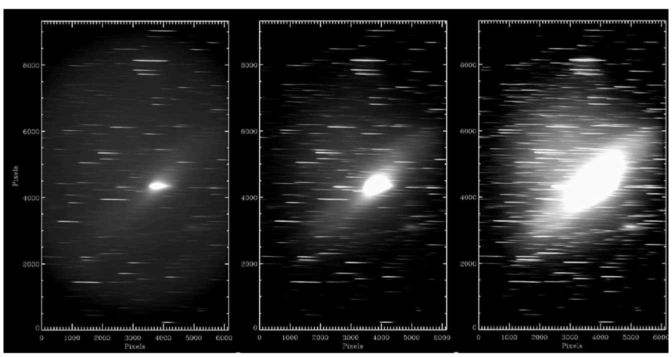

Figure 2: The three different grayscales are utilized to suppress the background of stars, allowing any dots of single-wavelength light to stand out. We examined the images displayed with different gray scales to search for any dots of monochromatic light.

A visual inspection of each of the 100 images of Andromeda obtained with the KL400 camera and of the co-added image was conducted to search for "dots" that could be single-wavelength laser emission. The coadded image contained much less noise, as the fluctuations of photons arriving were averaged out. The photos were identified by the specific exposure number. We expect a laser "dot" to have a width of roughly 2.5 pixels due to the point spread function and perhaps occupy 3x3 pixels due to the resolution of the telescope. Among the 100 images obtained with the KL400 camera, neither the individual images nor the co-added image showed evidence of a "dot," i.e., no candidate laser light was found.

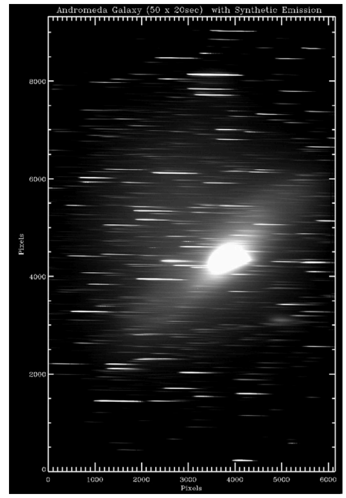

Figure 3: The sum of 50 exposures, each 20 sec of the Andromeda galaxy obtained with QHY600M camera. Wavelengths 380 – 950 nm, with longer wavelengths to the left. The faintest stars visible have V magnitude 14 mag. All objects are dispersed along a spectrum, including the nucleus, light from the galactic disk, the dwarf spheroidal companion galaxies, and the foreground stars. Any monochromatic light would appear as a single dot in the shape of the point spread function having an FWHM of 5.5 pixels (7 arcsec).

For the 50 exposures of Andromeda taken with the QHY600M camera in Jan 2022, shown in Figure 3, the full width at half maximum of an unresolved laser should be 5.5 pixels wide, i.e., that of the point spread function of the telescope with the smaller pixels. We searched for any region in the Andromeda Galaxy that contained a dot standing above the background light of the galaxy and having that 5.5-pixel width. This visual approach allowed me to distinguish unresolved, monochromatic emissions from the dominant light sources that are primarily stars in the foreground Milky Way and smeared starlight across the Andromeda galaxy itself. Again, any laser light would appear as a "dot" roughly 5.5 pixels across containing wavelengths confined to within the spectral resolution of 3 nm in wavelength. The analysis involved examining both the 50 individual images and also the sum of those 50 images.

The final summed image of the Andromeda galaxy, observed with the QHY600 camera, was separated into 54 sub-images, allowing a magnified view of the sub-images to search for laser "dots." Figure 4 shows the sum of those 50 images, and the dashed lines show the 54 sub-images. A search concentrated on finding “dots” having a shape similar to the known point spread function of the optical system. We verified the point spread function by noting the widths in the spatial direction of the stellar spectra. The widths remained between 5 and 6 pixels; thus, the full width at half maximum of the point spread function was 5 to 6 pixels, corresponding to an angle of 6.5 to 7.8 arcsec on the sky. Careful examination of the 54 sub-images revealed no evidence of monochromatic emission.

To test the experimental search technique and to determine detection thresholds, the Space Laser Awareness team generated synthetic single-wavelength emission "dots" and added them to the co-added image shown in Figure 4. This constituted a blind test, as I was not told where the synthetic

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laser "dots" were placed nor how many. Figure 4 contains three such injected synthetic laser sources. The sub-image containing the synthetic laser "dot" is shown in Figure 5. Laser emission "dots" representing 10 photons/sec and 1 photon/sec are easily visible and detectable in Figure 5. We would have easily detected such laser emission. This represents the detection threshold

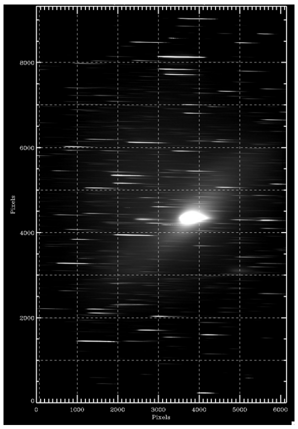

Figure 4: A coadded image of the Andromeda galaxy, 1000 sec total, with the QHY600M camera, displayed with a grayscale that reveals the medium bright regions in the bulge and inner disk of Andromeda. The hundreds of horizontal streaks are optical spectra of foreground stars in the Milky Way. Three synthetic sources of laser emission were placed along row 3750 at columns 3200, 3300, and 3400 having photon rates of 10 ph/s, 1 ph/s, and 0.1 ph/s. The sources have the shape of the point spread function with full width at half a maximum of 5.5 pixels. The first synthetic laser "dot" is barely visible here. The dashed grid shows the sub-image regions that were examined separately and in detail by eye (see Figure 5).

The synthetic point sources of single-wavelength emission injected into the images shown in Figures 2, 3, and 4 are two-dimensional Gaussian profiles with a full width at half the maximum of 5.5 pixels, i.e., the point spread function expected for lasers. The detection threshold of 1 photon/sec in a single-wavelength dot represents the limit of detection of laser emission in this project. Laser sources in the Andromeda galaxy that deliver more than 1 photon/sec to this 0.27-meter telescope would be detected.

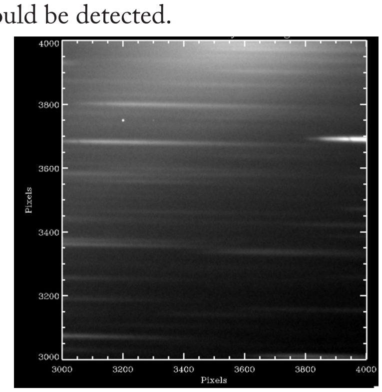

Figure 5: One sub-image within the coadded image of Andromeda galaxy (shown in Figure 4). This sub-image shows the region between columns 3000 and 4000 and rows 3000 to 4000 containing the galactic disk between 3 and 7 kiloparsecs from the nucleus of Andromeda. Three synthetic point sources of monochromatic emission are placed in the image in row 3750 at columns 3200, 3300, and 3400 having injected 10 photons/sec, 1 photon/sec, and 0.1 photons/sec, respectively. The first two synthetic laser emission "dots" are visible. The detection threshold is apparently 1 photon/sec. All 54 sub-images of the co-added image of Andromeda (1000 sec total) were searched for such monochromatic emission. None was found.

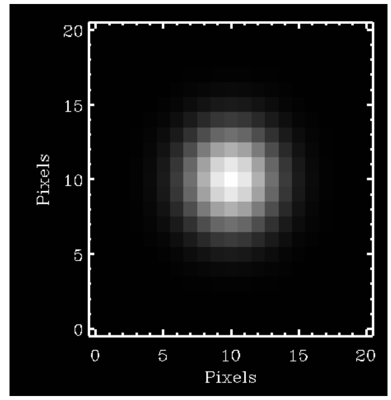

Figure 6: A magnified view of a synthetic laser emission (see Figure 5) in observations with the Objective Prism telescope and the QHY600M camera. Notice that the laser puts light in a few pixels in the point spread function, with only a little light hitting outside the width of 5.5 pixels for the QHY600M camera with its 3.76-micron pixels.

To summarize the analysis, the goal was to identify close clusters of pixels, and dots, that are approximately 3 pixels across for the KL400 camera and 5.5 pixels across for the QHY600M camera. Any laser "dot" must have some photons above the background consistent with the point spread function of the telescope. No such evidence of laser light was found, neither in individual images nor the co-added images, with a detection threshold of 1 photon/sec.

Results and Discussion

We obtained and examined 100 images of 10 sec each and 50 images of 20 sec each of the Andromeda Galaxy. No evidence of monochromatic emission was found, with a detection threshold of 1 photon per sec. No evidence of optical lasers was found. Laser emission would have appeared as a patch of pixels the size of the point spread function, having a peak of 1 photon per sec. None were found. By simple visual inspection and analysis of the objective prism images of the Andromeda Galaxy, we would have detected optical laser beams. For a benchmark laser transmitter of 10-meter size, similar in size to the largest telescope on Earth, a laser power of at least a terawatt would be required (see below) to enable minimal detection.

The purpose was to detect laser beams sent by technological life or their machines. The results showed that in two 30-minute time intervals, one in Feb 2021 and one in Jan 2022, the telescope did not pick up a laser beam. It remains possible that laser light does come from the Andromeda Galaxy that is either fainter than our detection threshold or was beaming while we were not observing.

With the KL400 camera, some dots did appear, but they were smaller than 2 pixels across. Those dots consisting of roughly 2x1 pixels were almost certainly caused by cosmic rays that hit the sensor of the camera. Cosmic rays are muons, protons, neutrons, electrons, or gamma rays that came from astrophysical sources, such as the Sun or supernova explosions. By bad luck, some of them hit our camera while we were observing that night. Their energy liberates electrons in the pixel, as if a photon hit it, appearing as a tiny dot smaller than the point spread function of a point of light seen through the telescope.

The intensity of any laser beam from the Andromeda galaxy is greatly weakened by its great distance, 2.5 million light years.

Lasers with a power of a megawatt are detectable from stars located 100 light years away.[11,12] Thus, lasers in Andromeda must have a power of at least 100 terawatts (1014 W) to be detectable, as intensity decreases as the square of the distance. This power threshold is comparable to that of the future radio telescope searches for radio signals.[4] This required power is also due to the relatively small 0.28-meter RASA telescope we used. Another limitation is that we captured only 150 exposures, taken within a total of 1 hour. This is a good sample for a first attempt.

The extinction of light due to dust has been measured carefully between the Earth and different regions of Andromeda.[13] From half of its disk, more than 50% of the light arrives at Earth. From the other half, light extinction varies between 50% and 95% and is most severe for stars (or lasers) buried within dense molecular clouds. Thus, in the regions of dense dust, the laser light would have to be 2x to 20x stronger to permit detection.

A next attempt would involve taking more exposures, at least 1000, spanning a few hours. Also, it would be better to search for laser beams at a wide variety of times spread over a month or a year. We don't know how often lasers in the Andromeda galaxy might be shining in our direction. If intelligent life occasionally cast a laser beam toward earth, we would have no way to know the exact time, or cadence, of their beaming. If any laser beam were detected, the next step would involve follow-up observations by other telescopes and by our telescope to verify the extraordinary discovery. Surely 150 exposures are not enough. Therefore, a larger sample size at different times is warranted. Another limitation is the position of the earth in its orbit around the Sun. The exposures were captured on one night in 2021 and one night in 2022. The Andromeda Galaxy is visible through the months June-February setting a time window when we could capture more exposures.

Conclusion

No evidence of laser emission was found toward the Andromeda Galaxy in 150 exposures totaling 2000 s. The individual exposures of 10 or 20 s duration showed no laser emission. The sum of exposures totaling 2000 s also showed no evidence of laser emission, with the detection threshold of 1 photon per sec at the peak of the laser dot on the detector. Adopting a benchmark 10-meter aperture of a hypothetical laser launcher, the laser must have a power of roughly 100 terawatts (10^{14} W) to be detectable. More observations of Andromeda are warranted to detect non-astrophysical narrowband emission, using both higher spatial resolution and other wavelengths, notably x-ray, UV, IR, and radio. Other galaxies can be observed for narrowband emission using this technique, as the high end of the luminosity function of extraterrestrial technology remains unknown.

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