Al-Khatim Observatory: The First Robotic Observatory in UAE

Mohammad Odeh[1]

1) International Astronomical Center (IAC), Abu Dhabi, P.O. Box 45015, UAE
modeh@AstronomyCenter.net, ORCID: 0000-0002-8986-6681

Abstract

Al-Khatam Astronomical Observatory (AKO), located in the Abu Dhabi desert, United Arab Emirates, is a robotic observatory operated by the International Astronomical Center (IAC). This paper demonstrates how a robotic observatory like AKO can be established on a modest budget with minimal personnel, offering a practical model for similar initiatives. The paper details the essential components required for setting up such an observatory and highlights some of AKO's significant contributions, particularly in photometric and astrometric observations. Notably, AKO has collaborated with international organizations to monitor newly discovered asteroids, contributing to planetary defense efforts within the space situational awareness (SSA) domain. The observatory places a special focus on photometric observations of gamma-ray burst (GRB) optical counterparts, particularly in the critical moments following their discovery by space-based observatories. Additionally, AKO's successful supernova search program led to the discovery of supernova SN 2023rve after nine months of continuous observation. Complementing AKO, the IAC has also constructed and operated the UAE Astronomical Cameras Network (UACN) since 2016. UACN comprises a series of advanced video cameras designed to automatically capture video footage upon detecting meteors, which may be part of a meteor shower, a meteorite fall, or even the reentry of satellite debris.

Keywords: Near earth asteroids, planetary defense, gamma-ray burst, supernovae.

1 Introduction

AKO is a fully remote and robotic observatory, which was established in January 2021 within the Abu Dhabi desert, situated approximately 50 kilometers away from the capital city of Abu Dhabi in the United Arab Emirates (UAE). It is registered with the Minor Planet Center (MPC) of the International Astronomical Union (IAU) and was assigned the code M44. It is noteworthy that the entire observatory, including both the building and the sliding roof, was entirely designed, and constructed by the members of the International Astronomical Center (IAC).

2 Site Conditions

Utilizing data from a nearby location, the observatory benefits from about 277 clear nights per year (Weather Spark 2024). With an estimated seeing value ranging between 1.0" to 1.25". The altitude of AKO is 90 meters above mean sea level. Initially it was located under moderately dark skies around Bortle class 5, the observatory's location has since experienced an increase in light pollution, now falling under Bortle class 6. For unfiltered 30-second exposure times, the limiting magnitude is approximately 18.5. Increasing the exposure time to 3 minutes raises the limiting magnitude to around 19.5. Additionally, by stacking several 3-minute exposure time images, the limiting magnitude can be further improved, reaching up to about 20.5.

3 Main Work and Objectives

The primary focus of our observatory revolves around photometric and astrometric observations. Photometric observations entail studying variable stars, asteroids, GRBs optical afterglow, and Kilonova. Astrometric observations, on the other hand, primarily target newly discovered asteroids and some spacecrafts from space missions. We also dedicate significant effort to lunar crescent observations, crucial for commencing the new lunar month in many Islamic countries. Additionally, we conduct solar observations utilizing a specialized Hydrogen Alpha telescope.

Our aim is to establish a remote-operated observatory for swift response during urgent observations and to develop a robotic observatory for streamlined, multi-observation sessions within the same night, without human intervention. Through these initiatives, we aim to create an efficient observatory that actively shares its findings and data with the global scientific community, contributing to international scientific endeavors.

4 Equipment and Software

In this section, we delve into the essential equipment and software necessary for establishing a robotic observatory, using the infrastructure of AKO as a prime example.

4.1 The Telescope

Needless to say, one of the primary components of an observatory is the telescope, and contrary to common misconceptions, a small telescope can indeed facilitate serious scientific work. In AKO, our astronomical journey began with a 5” apochromatic refractor, through which we conducted photometric and astrometric observations, subsequently published in refereed journals. However, the advantages of a larger instrument are undeniable, providing observers with the capability to detect fainter objects and obtain more accurate results. The current main telescope at AKO is a 0.36m Schmidt-Cassegrain telescope, with a focal length of 2737mm and a focal ratio of 7.7. In addition to this primary instrument, we maintain the 5” apochromatic refractor telescope on the same mount, a 90mm Coronado solar telescope on a separate mount, and a dedicated small refractor telescope for lunar crescent observations, particularly during the daytime.

4.2 The Mount

It's not an exaggeration to emphasize the critical role of the mount within an observatory. A superior telescope paired with a subpar mount risks producing compromised data that could prove challenging to rectify later on. Therefore, our advice is to prioritize investing in a high-quality mount, as it's the most challenging component to upgrade afterward. We initially utilized a commercially available, budget-friendly German equatorial mount and gradually upgraded it. Presently, our observatory is equipped with a 10 Micron GM3000 HPS mount.

4.3 The Camera and Filters

We commenced our work with a color camera, which, although it imposed limitations on conducting serious scientific work, we managed to overcome at times. For instance, in photometric tasks, we extracted the green channel from the images and conducted subsequent analysis, closely resembling the utilization of a standard green photometric filter. Presently, our primary camera is the ZWO ASI2600MM Pro cooled mono camera, which provides decent results with very low noise and high-efficiency characteristics.

Regarding filters, we have LRGB filters, HSO narrowband filters, U, V, and Ic Johnson-Cousin photometric filters, and finally a clear filter. All filters have the same thickness to make sure they have the same focus point, and they are hosted in a large 11-position filter wheel. Using BIN1, our image scale is 0.28”/pixel and the field of view is 29.5’ by 19.7’.

4.4 The Guider

Most mounts require guiding to ensure precise tracking during long exposures. Two common guiding methods exist: the off-axis guider (OAG), which sends starlight to your guide camera using an internal pick-off prism that collects light running of the telescope axis, or to guide using a small telescope attached to the main telescope. Each method has its pros and cons. For long focal lengths, the OAG method is preferred due to its effectiveness in guiding. This is the method employed in AKO. However, for high-end mounts, guiding may not be necessary for short to medium exposures. This is the case in AKO since we upgraded our mount to the current one.

4.5 Dew Heater and Dew Shield

These items are strongly recommended. A dew heater is essential on nights when dew formation could otherwise hinder observations. While a dew heater alone may suffice in many cases, a dew shield offers additional protection. Initially, it delays dew formation and safeguards the telescope's mirror or plate from dust accumulation. Moreover, it shields the telescope from nearby lights, particularly beneficial if the observatory is situated in a light-polluted area.

4.6 Power & USB Hub and Focuser Motor

The telescope and its various components, including the camera, filter wheel, dew heater, and focuser, require power and/or USB connections for control. However, numerous cables can potentially affect the tracking accuracy of the mount, also some items might not work properly if connected to a long cable. To mitigate this issue, two solutions are commonly employed: installing a small PC at the telescope or using a power and USB hub.

Given the high temperatures in our desert location and since we use our lunar and solar telescope during the daytime, installing a PC at the telescope is not feasible, leaving us with the option of utilizing a power and USB hub. This setup involves running just one USB cable from the telescope to a PC located inside the control room, approximately 5 meters away.

It's crucial to note that the quality and length of cables play a significant role in the observatory's functionality. Poor-quality cables or those exceeding specified length limitations can lead to issues that require extensive troubleshooting. In a robotic observatory, the focuser motor is particularly important as it enables automatic focusing multiple times throughout the night, ensuring optimal image quality. Therefore, it's essential for the telescope's focuser to be equipped with such a motor for efficient operation.

4.7 Weather Station and Video Cameras

A weather station is an indispensable component of any robotic observatory, providing crucial information about environmental conditions such as cloud coverage, rain, temperature, pressure, humidity, and wind speed. This data is essential for ensuring the safety of operations, especially in remote sessions where observatories may be operated from another country. Before opening the observatory dome or roof, it's imperative to verify that conditions are safe. Furthermore, in a robotic observatory, all weather parameters are integrated into the automation software to determine whether to initiate or proceed with programmed observations.

In addition to a weather station, employing multiple cameras to monitor the telescope's position and the dome or roof is highly recommended. This precaution becomes especially important when the telescope lacks encoders and the automation software may potentially lose track of the telescope's position. Without visual monitoring, there's a risk of damaging the telescope. Moreover, installing an all-sky camera is beneficial for assessing sky quality and cloud coverage, enhancing the overall effectiveness of observations.

4.8 Observatory Controller

This item serves at least dual purposes within the observatory. Firstly, it acts as the power controller for all observatory components, including the roof motor. Secondly, it is linked to various sensors throughout the observatory, such as the roof limit switches and telescope level sensor. Through integration with the automation software, this controller sends commands to different components to switch on or off. It also acts as a safety measure, preventing the roof shutter from closing if the telescope is not in the desired position.

Additionally, this controller can be utilized for other safety commands due to its connection to the weather station. For instance, it can park the telescope and close the roof shutter during risky weather conditions, although similar actions can also be programmed directly into the automation software.

4.9 Automation Software

The automation software acts as the observatory's brain, connecting to all previously mentioned components, it is also used to determine the objects to be observed during the night, including the exposure time, gain, filter, number of frames, …etc. Advanced scripting allows for detailed observation routines with specific constraints. Various software options are available, with some being free. The choice depends on the observatory's components and desired level of automation. Certain software can fully automate observatory operations efficiently.

5 Observations

This section demonstrates the scientific capabilities of a low-budget robotic observatory. It will be highlighted that such observatory can indeed participate in several important observations and share its results to others, where they can be used along with other’s data in publishing papers to find out certain parameters such as rotational period of asteroids, or orbital period of binary stars, or establishing accurate orbit for a newly discovered asteroid.

5.1 Asteroid Astrometry and Planetary Defense Program

One of AKO's initial observations involved astrometric observations of several asteroids, utilizing the small 5-inch refractor telescope. Subsequently, a paper was published showcasing the remarkable accuracy achievable with such a modest telescope size, demonstrating its efficacy in establishing asteroid orbits and calculating future coordinates with precision (Odeh & Al-Wardat 2023).

In 2022, AKO received a invitation from the Catalina Sky Survey, operated by the University of Arizona, to contribute to planetary defense efforts via the NEOfixer website (https://neofixer.arizona.edu/). This platform aids observers in optimizing their observing lists to maximize the utility of telescope time, with priorities automatically updated based on new observations posted by the Minor Planet Center.

Granted access to the NEOfixer website, AKO began observing critical and newly discovered asteroids of importance. Since then, AKO has confirmed the discovery of 35 new asteroids and comets as shown in Fig. 1 (Amrum 2024).

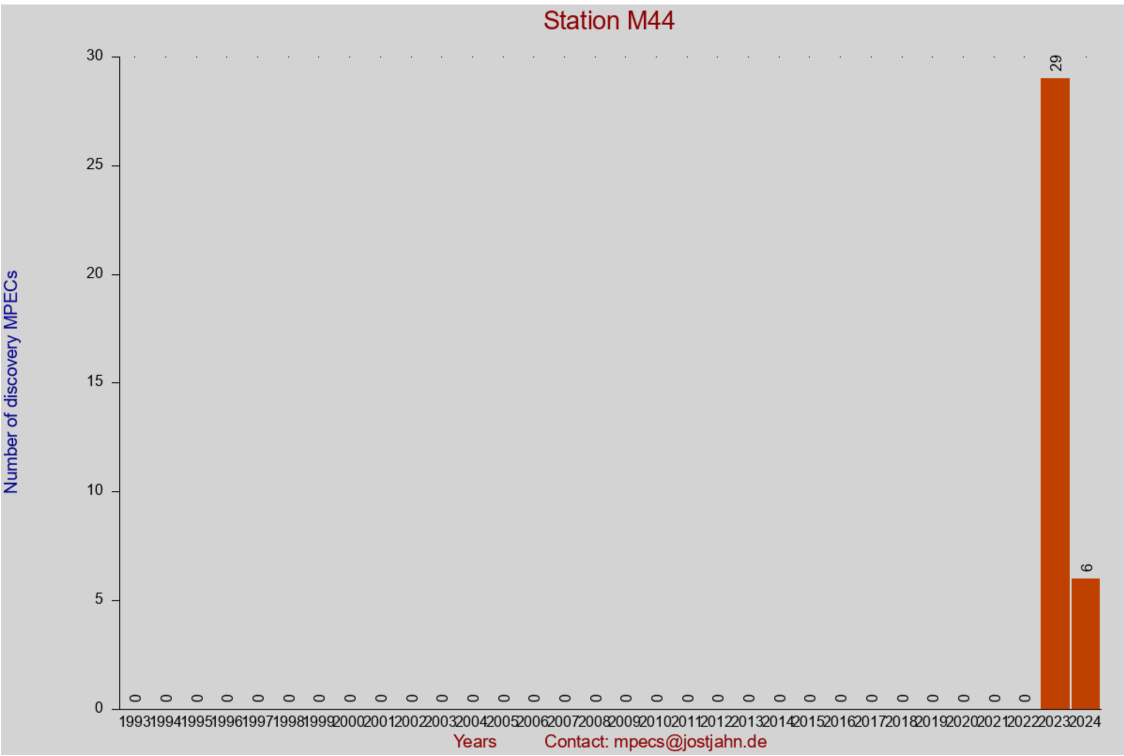

Fig. 1: Number of asteroids/comets which M44 participated in confirmation per year.

5.2 Spectroscopic Observations

While spectroscopic observations are not among AKO's primary objectives, the observatory has conducted basic spectroscopic studies using cost-effective tools. These observations hold significant educational value for public outreach initiatives and university students, providing practical demonstrations of astrophysical principles through live observations.

Using a high-efficiency diffraction grating, AKO obtained spectra from various astronomical objects. Notably, the Balmer series was clearly visible when observing an "A" type star, while TiO absorption lines were distinguishable in observations of an "M" type star. Methane absorption lines were observed in Uranus and Neptune, while HI and HeI emission lines were detected in a blue hypergiant. Additionally, C2 Swan band absorption lines were identified in observations of a red giant carbon star. Further details regarding these spectroscopic observations were published in a paper by AKO (Odeh 2021).

5.3 Public Outreach

AKO places a strong emphasis on public outreach, occasionally observing intriguing phenomena and sharing the results, along with images and simple descriptions, through its social media channels. One such example is the phenomenon of gravitational lensing, where AKO observed the twin quasar PGC 2518326. This quasar, the first identified gravitationally lensed object, appears as two distinct images due to gravitational lensing caused by the galaxy YGKOW G1 situated between Earth and the quasar.

Another observation is the relativistic jet of the galaxy M87 in the Virgo constellation. This galaxy's central black hole ejects a relativistic jet, or plasma jet, outward at velocities close to the speed of light. Both of these events were clearly captured in images taken by the observatory's main telescope, showcasing captivating astronomical phenomena to the public.

5.4 Astrometric and Photometric Observations for Space Missions

AKO diligently monitors new space missions and aims to observe them, especially immediately after launch. At this stage, astrometric and photometric data are crucial for some researchers. For instance, AKO observed the James Webb Space Telescope (JWST) during its journey to its final orbit, conducting photometric and astrometric observations on 06 January 2022. These observations revealed fluctuations in JWST's magnitude, changing by approximately 1.5 magnitude within half an hour.

Similarly, AKO observed the Orion spacecraft from the Artemis1 mission as it returned to Earth on 07 December 2022. Astrometric data provided by AKO along with others were utilized by researchers to construct the spacecraft's trajectory. Additionally, AKO observed the Jupiter Icy Moons Explorer (JUICE) shortly after its launch on 14 April 2023, contributing to trajectory calculations alongside data from other observers.

Furthermore, AKO observed the asteroid Dimorphos minutes before the impact of the DART mission on 26 September 2022. Despite foggy conditions preventing observation of the impact itself, AKO conducted subsequent observations and detected three tails for the asteroid.

5.5 Nova and Supernova Photometry

Photometric observations of novae and supernovae hold high priority in our observatory. To ensure our results are accessible to interested researchers, we regularly submit our data to the American Association of Variable Star Observers (AAVSO) website at https://www.aavso.org/.

Noteworthy observations include those of the nova U Scorpii on 06 June 2022. Our data from this observation were utilized for detailed analysis in a paper titled "Optical and soft X-ray light-curve analysis during the 2022 eruption of U Scorpii: structural changes in the accretion disk." This paper is currently in the process of being published in the journal of the

Astronomical Society of Japan. Additionally, we conducted photometry for several supernovae, such as SN 2022hrs, SN 2023rve and SN 2023wrk.

5.6 Photometry for Asteroids and Binary Stars

Several photometric observations were conducted for asteroids to determine their rotational period, as well as for eclipsing binary stars to ascertain their orbital period. The detailed results of these observations were published in a dedicated paper (Odeh & Al-Wardat 2023).

5.7 GRB Optical Afterglow and Kilonova Observations

Since October 2022, AKO has started photometric observations for GRB optical afterglows, with results being sent to Gamma-ray Coordinates Network (GCN). Among the notable GRBs observed was GRB 221009A, considered the strongest GRB in history. AKO was among the first observatories to follow up on this event. For instance, on 09 October 2023 at 19:30 local time, its magnitude was 14.0, which subsequently dropped to magnitude 14.6 after 45 minutes.

Additionally, AKO is participating in the Kilonova Catcher Program, supported by GRANDMA and the University of Paris. Members of this program contribute to the optical follow-up of gravitational wave (GW) events detected by the worldwide network of GW detectors. These follow-up campaigns aim to detect kilonova emissions arising from the coalescence of two compact objects.

5.8 Supernova Search Program

AKO launched its supernova search program on 26 November 2022, systematically observing around 90 galaxies daily. The following day, thorough analysis of the collected data was conducted to identify any potential new supernovae in the images. After nine months of consistent effort, on the evening of 08 September 2023, a bright new star with a magnitude of 14 was observed within the galaxy NGC 1097.

Promptly, the team reported this discovery to the International Astronomical Union (IAU). The IAU officially documented the discovery and designated it as "SN 2023rve." (Odeh 2023).

6 The UAE Astronomical Cameras Network (UACN)

The UAE Astronomical Cameras Network (UACN) is a collaborative initiative between the International Astronomical Center (IAC) and the SETI Institute. This network comprises a series of advanced, sky-oriented cameras strategically positioned across various locations in the United Arab Emirates. These cameras are designed to automatically record video footage upon detecting a meteor. The detected meteor could be part of a meteor shower, a meteorite fall, or even the reentry of satellite debris. When a meteor is captured from multiple sites, its trajectory can be precisely calculated, allowing researchers to identify its meteor shower of origin and, in the case of a meteorite fall, to pinpoint potential impact sites within the UAE.

The network consists of three stations, named UACN1, UACN2, and UACN3, which have been operational and contributing valuable data since the following dates: UACN1 on 28 January 2016, UACN2 on 31 August 2016, and UACN3 on 01 October 2016. Each station is equipped with 17 specialized cameras. Sixteen of these cameras are configured as a "fly's eye" system, collectively covering the sky above 30 degrees altitude. These 16 cameras are part of the Cameras for Allsky Meteor Surveillance (CAMS) project, a NASA/SETI Institute initiative that automates video surveillance of the night sky to detect meteor showers and validate the IAU's working list of meteor showers. The 17th camera at each station is fitted with a wide-angle lens to capture the entire sky above 20 degrees altitude in a single image.

Since its establishment, the UACN has achieved several significant scientific milestones. Notably, it has contributed to the discovery of new meteor showers in collaboration with other stations. Among these discoveries are the “29 Piscids” in 2019 (Jenniskens 2020), the “September Upsilon Taurids” in 2020 (Jenniskens & Cooper 2020), and the “August Delta Capricornids” in 2022 (Jenniskens 2022).

In 2023, the UACN published a comprehensive paper detailing the analysis of all meteors detected by the network since its inception. This analysis led to the discovery and subsequent registration of 12 new meteor showers by the International Astronomical Union (Odeh et al., 2023).

Members of the UACN have actively contributed to several scientific papers published in refereed journals, often collaborating with researchers from other stations. Notable publications include: “A Survey of Southern Hemisphere Meteor Showers” (Jenniskens et al., 2018), “2019 Outburst of 15-Bootids (IAU#923, FBO) and Search Strategy to Find the Potentially Hazardous Comet” (Jenniskens et al., 2020), “Meteor Showers from Known Long-Period Comets” (Jenniskens et al., 2021), “New Showers Identified Among Meteors Observed in the UAE” (Odeh et al., 2023), and “Lifetime of cm-Sized Zodiacal Dust from the Physical and Dynamical Evolution of Meteoroid Streams” (Jenniskens et al., 2024).

The UACN has also successfully detected several satellite reentries, including the notable reentry of the PROGRESS MS-07 SL-4 R/B on 16 October 2017 at 19:30 (UT+4). This event was witnessed across the UAE, Oman, Qatar, Bahrain, Kuwait, and the eastern regions of Saudi Arabia. The satellite in question was the second stage of a Russian Soyuz-2.1a rocket. UACN1 and UACN3 captured this reentry at 19:29:34 (UT+4), as illustrated in Fig. 2.

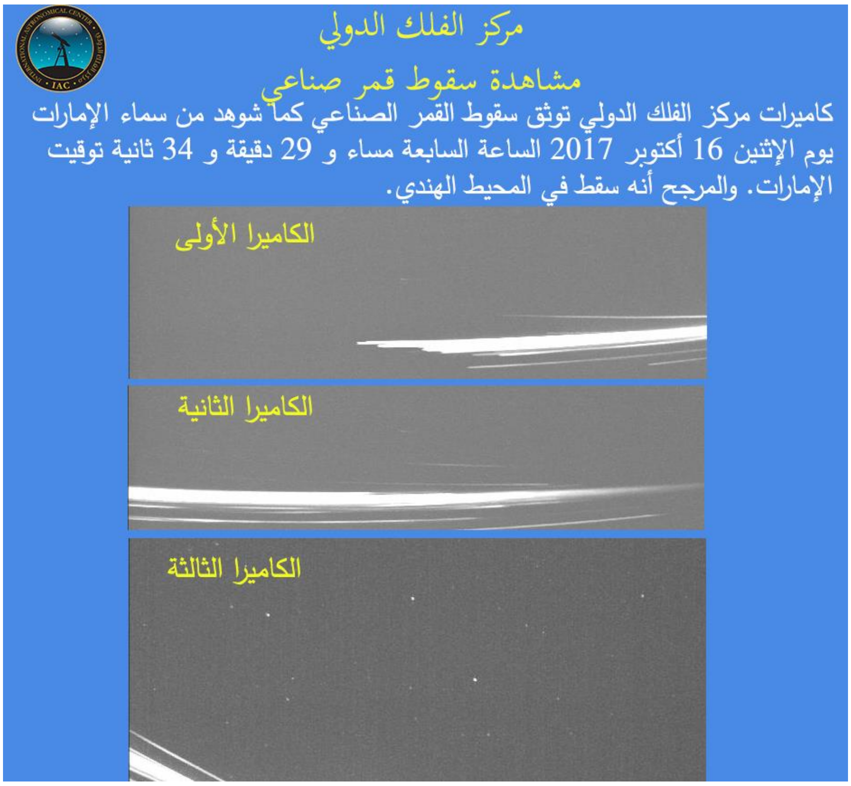

Fig. 2: Satellite re-entry as captured by UACN1 and UACN3 on 16 October 2017

The UACN's data is crucial in determining the location of falling meteorites when a fireball is captured by more than one station. For instance, on 05 March 2019, a bright fireball was detected at 19:40:11 local time, and it was recorded by cameras at both UACN1 and UACN3. Calculations based on these recordings indicated that a possible meteorite might have reached the ground near the Arabian Nights Village Resort. In response, the International Astronomical Center (IAC) organized a team to search the area on 12 March 2019. During this search, the team discovered a magnetic stony-iron fragment. Subsequent analysis in specialized labs both within and outside the UAE confirmed that the fragment was indeed an old meteorite, as depicted in Fig. 3.

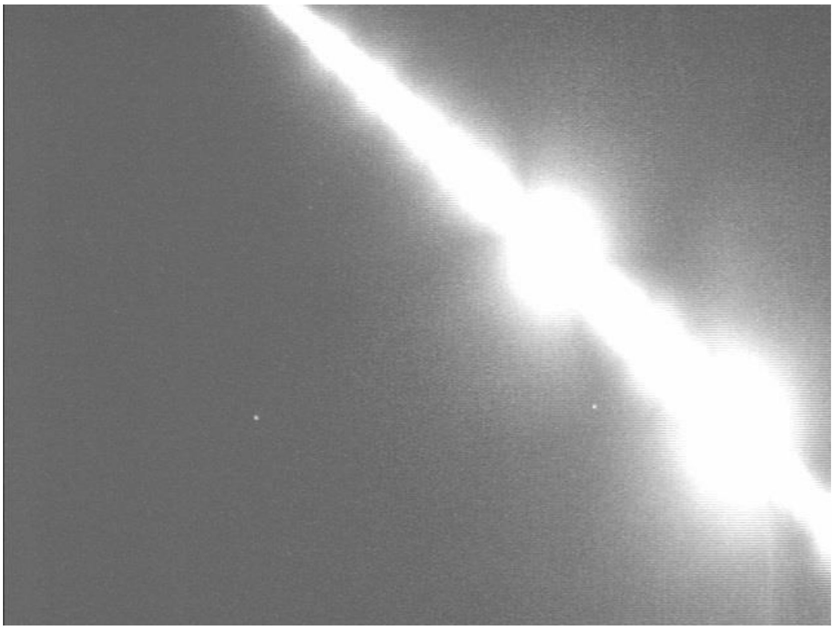

Fig. 3a: The fireball as detected by UACN3 narrow-field camera

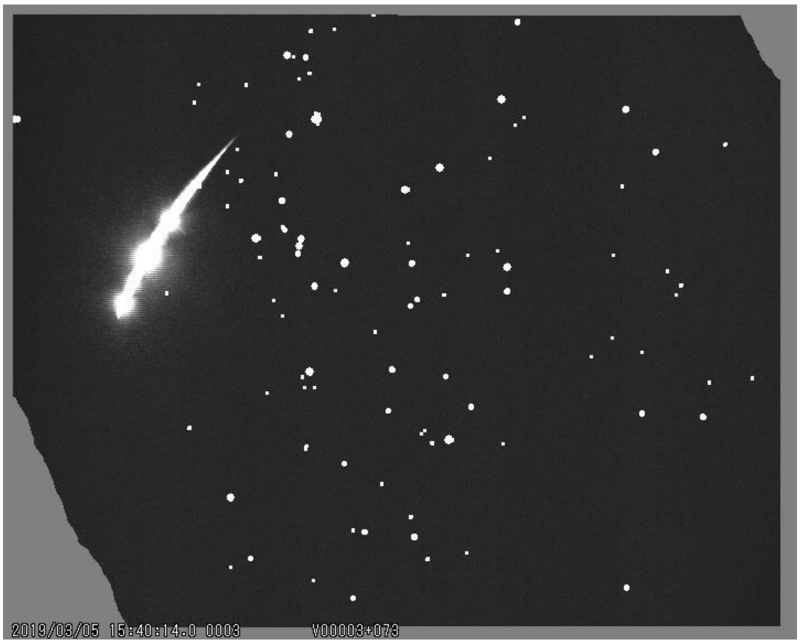

Fig. 3b: The fireball as detected by UACN1 wide-field camera

Fig. 3c: The found meteorite

7 Conclusion

A fully robotic observatory can indeed be built by enthusiastic astronomers or amateurs with limited budgets. It's not necessary to have all the required components from the beginning. For instance, AKO started with a basic equatorial mount and a 5-inch telescope without any filters, and gradually upgraded its equipment over time.

Even smaller and moderate-sized telescopes can contribute significantly to serious scientific work. Observers must carefully select objects suitable for their available equipment. Sharing results with others by submitting them to dedicated websites or groups is crucial. This ensures that the efforts put into the observatory yield the maximum benefit to the scientific community.

Acknowledgement

I extend my heartfelt gratitude to the exceptional team of AKO for their invaluable contributions to the construction and ongoing dedication to observation and maintenance tasks at the observatory. Special thanks to Khalfan Al-Noimy, Anas Mohammad, Osama Ghannam, Sameh Al-Ashi, and Mohammad Mudallal for their unwavering commitment and hard work.

References

Cedar Lake Ventures, Weather Spark, The Typical Weather Anywhere on Earth, https://weatherspark.com, 2024.

Amrum, J., 2024, MPEC statistics, https://mpec.jostjahn.de/M44-stat.html

Jenniskens, P., Baggaley, J., Crumpton, I., et al., “A survey of southern hemisphere meteor showers”, Planetary and Space Science, vol. 154, pp. 21–29, 2018.

Jenniskens, P., Lyytinen, E., Johannink, C., Odeh, M., Moskovitz, N., and Abbott, T. M. C., “2019 outburst of 15-Bootids (IAU#923, FBO) and search strategy to find the potentially hazardous comet”, Planetary and Space Science, vol. 181, 2020.

Jenniskens, P., 29 Piscid Meteor Shower in 2019, 2020. CBET 4882 (October 29, 2020), D. W. E. Green (ed.), Central Bureau for Astronomical Telegrams, Cambridge, MA.

Jenniskens, P., Cooper, T., September Upsilon Taurid Meteor Shower, 2020. CBET 4862 (September 28, 2020), D. W. E. Green (ed.), Central Bureau for Astronomical Telegrams, Cambridge, MA.

Jenniskens, P., Lauretta, D., Towner, C., Heathcote, S., Jehin, E., Hanke, T., Cooper, T., et al., “Meteor showers from known long-period comets”, Icarus, vol. 365, 2021.

Jenniskens, P., August Delta Capricornids Meteor Shower 2022, 2022. CBET 5161 (August 26, 2022), D. W. E. Green (ed.), Central Bureau for Astronomical Telegrams, Cambridge, MA.

Jenniskens, P., Pilorz, S., Gural, P., et al., “Lifetime of cm-sized zodiacal dust from the physical and dynamical evolution of meteoroid streams”, Icarus, vol. 415, 2024.

Odeh, M., 2023, Transient Name Serv Discov Rep, 2023–2217, 1

Odeh, M., Al-Wardat, M., 2023, Emir J Space Astron Sci, 1, 4

Odeh, M., 2021, J Instrum, 16, T12009

Odeh, M., Al-Wardat, M., 2023, J Astron Space Sci, 40, 19

Odeh, M., Al-Wardat, M., and Jenniskens, P., "New showers identified among meteors observed in the UAE", Experimental Astronomy, vol. 56, no. 2–3, Springer, pp. 793–819, 2023.