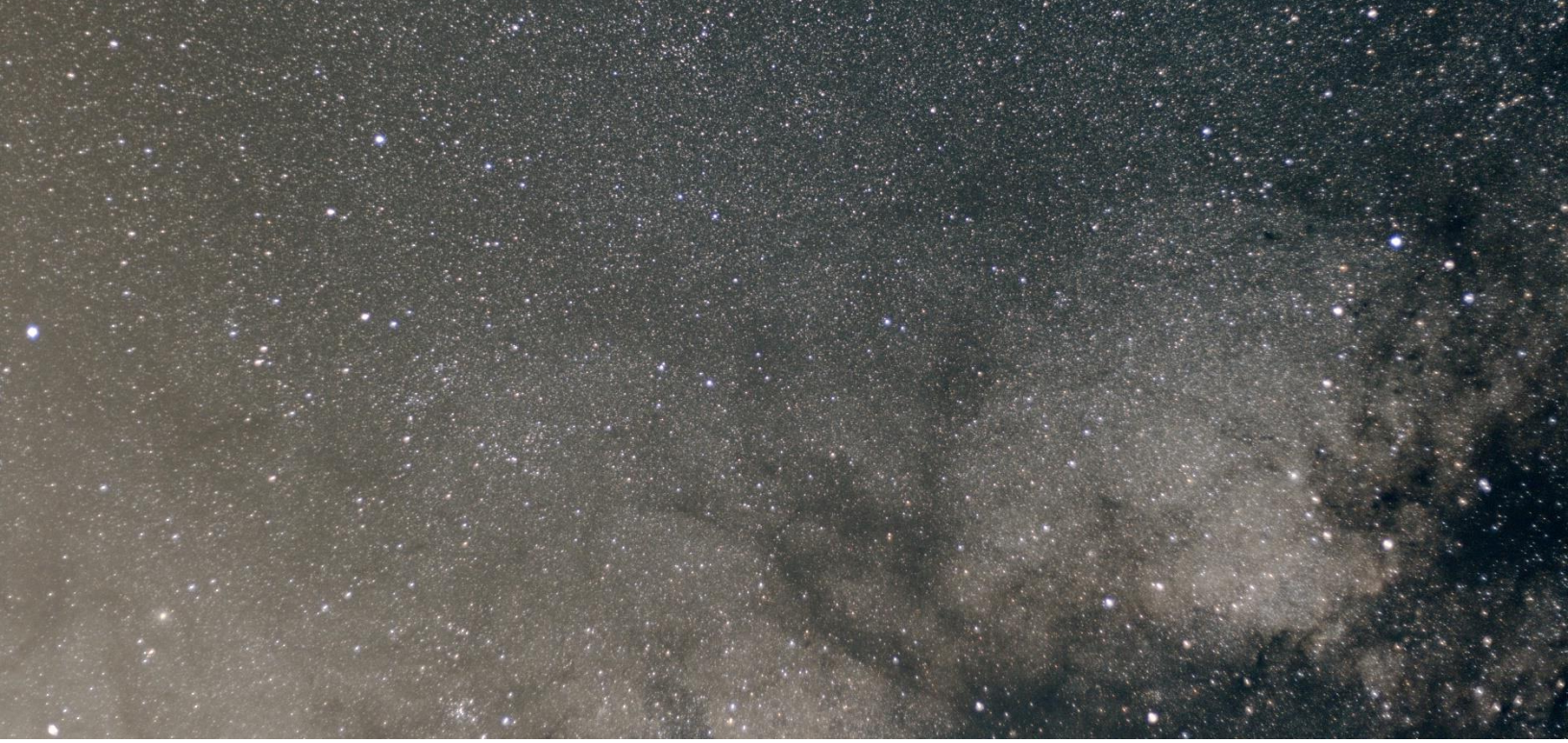
Summer 7-2019

Prospects of an Astrotourism Site in Namibia

Chris Stone
Olivet Nazarene University, cjstone@olivet.edu



Prospects of an Astrotourism Site in Namibia

Chris Stone

Dr. Stephen Case

July 2019

Olivet Nazarene University

Table of Contents

List of Figures iii
List of Tables vi
Acknowledgements vii
Abstract…. 1
Introduction 3
Background 4
Light Pollution 4
Seeing 5
Transparency 6
Criteria to Consider for an Astrotourism Site 6
Section I: Resources 8
Weather and Climate 9
Locations 11
Nearby Astronomical Observatories 13
Dark Sky Reserves 14
Southern Skies 15
Conclusion 15
Section II: Analysis of Existing Sites of Astrotourism 16
Namibia 17
Conclusion 18
Section III: Trends and Demographics 19
Section IV: Implementation 20
Binoculars 20
Telescopes 22
Astrophotography 24
Pricing 28

Conclusion 30
Conclusion 31
References 31
Appendix 35
Explanation 35
Section I: General Information on the Night Sky 36
Section II: Winter Sky Guide Sunset to Midnight (June to September) 39
Section III: Winter Sky Guide Midnight to Sunrise (June to September) 55
Section IV: Imaging 82

List of Figures

Figure 1: Image of Andromeda Galaxy 2
Figure 2: Map of World Light Pollution 5
Figure 3: Map of Weather in Namibia 8
Figure 4: Camp Locations 10
Figure 5: Map of Central Plateau Area with Light Pollution 13
Figure 6: Image of the Trifid and Lagoon Nebulas 23
Figure 7a: Image of Milky Way with Light Pollution 25
Figure 7b: Image of Milky Way as a Close-up 26
Figure 8: Southern Stars Diagram (Appendix) 36
Figure 9.1: Constellation Carina 39
Figure 9.2: Constellation Crux 40
Figure 9.3: Constellation Centaurus 41
Figure 9.4: Constellation Pavo 42
Figure 9.5: Constellation Canis Major 43
Figure 9.6: Constellation Cancer 43
Figure 9.7: Constellation Leo 44

Figure 9.8: Constellation Virgo 45
Figure 9.9: Constellation Boötes 46
Figure 9.10: Constellation Coma Berenices 46
Figure 9.11: Constellation Hercules 47
Figure 9.12: Constellation Scorpius 48
Figure 9.13: Constellation Sagittarius 49
Figure 9.14: Constellation Aquila 50
Figure 9.15: Constellation Lyra 50
Figure 9.16: Constellation Cygnus 51
Figure 9.17: Constellation Aquarius 52
Figure 9.18: Constellation Pegasus 53
Figure 9.19: Constellation Andromeda 54
Figure 9.20: Constellation Carina 55
Figure 9.21: Constellation Crux 56
Figure 9.22: Constellation Centaurus 57
Figure 9.23: Constellation Pavo 58
Figure 9.24: Constellation Grus 59
Figure 9.25: Constellation Phoenix 59
Figure 9.26: Constellation Hydrus 60
Figure 9.27: Constellation Eridanus 61
Figure 9.28: Constellation Canis Major 62
Figure 9.29: Constellation Cancer 62
Figure 9.30: Constellation Leo 63
Figure 9.31: Constellation Virgo 64
Figure 9.32: Constellation Ophiuchus 65
Figure 9.33: Constellation Scorpius 66
Figure 9.34: Constellation Sagittarius 67
Figure 9.35: Constellation Aquila 68

Figure 9.36: Constellation Lyra 69
Figure 9.37: Constellation Cygnus 70
Figure 9.38: Constellation Aquarius 71
Figure 9.39: Constellation Pegasus 71
Figure 9.40: Constellation Pisces 72
Figure 9.41: Constellation Cetus 73
Figure 9.42: Constellation Boötes 74
Figure 9.43: Constellation Coma Berenices 74
Figure 9.44: Constellation Hercules 75
Figure 9.45: Constellation Andromeda 76
Figure 9.46: Constellation Taurus 77
Figure 9.47: Constellation Orion 78
Figure 9.48: Constellation Perseus 79
Figure 9.49: Constellation Auriga 80
Figure 9.50: Constellation Gemini 81
Figure 10: Sensor Noise (Appendix) 83
Figure 11a: An Unprocessed Exposure of Andromeda (Appendix) 84
Figure 11b: A Final Image of Andromeda (Appendix) 85

List of Tables

Table 1a: Rainfall Data from Windhoek 9
Table 1b: Rainfall Data from Walvis Bay 10
Table 2: Jamy Traut Hunting Safari Location Data Compilation 11
Table 3: Equipment List 27
Table 4a: Price List (Hakos Guest Farm) 28
Table 4b: Price List (Tivoli Astrofarm) 29
Table 5: Final Price Estimates 29

Acknowledgements

I wish to thank several people for making this project a reality. I appreciate all the guidance and support I have received from Dr. Stephen Case from the beginning to the end of this project. He has been an incredible mentor in both work and school. His advice and critiques and have greatly improved this report. I also want to thank Steve Bell for sharing his expertise and equipment for astrophotography. I have learned so much from him, and he can be credited with providing the extra help I needed to capture the photos in this report. Finally, I want to thank the Pence-Boyce Research board for enabling me to engage in this 10-week summer research experience. I would have never been able to pursue this project without support from the board.

Abstract

Scope of Research

The purpose of this project is to identify the potential of an astrotourism site in Namibia. Astrotourism can be defined as a sector in the tourism industry that caters to travelers interested in viewing the night sky. Namibia is a sparsely populated country in Africa with exceptionally clear skies during the dry season. After determining potential for astrotourism in Namibia, the implementations of astrotourism are discussed, specifically considering a local business, the Jamy Traut Hunting Safari, and recommendations are offered regarding costs and equipment.

Methods

This report establishes and discusses a list of criteria to examine for an astrotourism start-up. Topics include resources, analysis of existing sites, trends, cost estimates, and implementation. Information in the report was compiled from sources including online weather databases, Namibian government reports, and various documents and journals pertaining to astrotourism. Additionally, some images of the night sky were collected to demonstrate the use of astrophotography as an additional component to an astrotourism start-up.

Results

Namibia has significant potential as an astrotourism destination. A handful of sites are already utilizing the region's clear, dark skies to draw tourists and establish a viable business model. These sites include the Gamsberg Observatory, NamibRand Nature Reserve, Sossusvlei Desert Lodge, Hakos Guest Farm, and Tivoli Astrofarm. The establishment of future professional astronomical research facilities on the Gamsberg Mountain Plateau will also likely add to the attraction of tourists interested in viewing Namibia's dark skies. The best months for

astronomical observing in Namibia are the dry winter months between June and September, which correspond to peak seasonal visits for hunting safaris. Each location of the Jamy Traut Hunting Safari exhibited excellent conditions for viewing. It would be very inexpensive for a service like the Jamy Traut Hunting Safari to implement Namibia's dark skies as an additional service or amenity offered to guests to both draw additional visitors to the sites or enhance their safari experience.

Figure 1 An image of Andromeda Galaxy. Deep sky objects like Andromeda Galaxy are more visible in Namibia than in many other locations in the world. The country has pristine skies due to low light pollution and low humidity. Image made from 44 stacked exposures (ISO1600; f/5.6; 122 seconds; 55-250mm telephoto lens).

Introduction

Astrotourism is a growing niche in the tourism industry that utilizes the night sky as a sustainable resource to offer to visitors. Dr. Eduardo Fayos-Solá defines astrotourism as "an activity of travelers wishing to use the natural resource of well-kept nightscapes for astronomy-related leisure and knowledge" (663). This is distinctive from traditional tourism as astrotourism draws people away from cities and commercial centers into the more sparse and remote areas of the world. A destination with adequate skies can further enhance guest experience by providing the instrumental means to view and the educational experience to enjoy the night sky. These means can be as simple as offering guided tours of the night sky and making some basic equipment like binoculars and telescopes available to guests.

Many sites specialize exclusively in astrotourism. In locations with exceptionally dark skies and clear seeing conditions, some sites offer their own astronomical observatories equipped with instruments adequate for both amateur and professional astronomy. Chile, for example, is a world leader in astrotourism with sites across the country utilizing dark skies as a resource. The quality skies of Chile have made it a major center for professional astronomical research, and the country is soon expected be home to 70% of the world's optical astronomy infrastructure (Blanc 85). Some of the world's top scientific observatories are atop the Andes mountains in northern Chile. These include sites like the Gemini South, ALMA, and Paranal Observatories. Light pollution in the valleys below these mountaintop observatories is limited due to government regulations and cooperation between local communities and observatories (Smith 5-8). Numerous sites in the Elqui Valley and Coquimbo region, for example, offer both tours to these scientific observatories and their own astronomy expertise and equipment to augment visitors' enjoyment of the dark skies.

Namibia is another country that offers ideal prospects for astrotourism. As one of the most sparsely populated countries on the planet, most of the country remains unaffected by light pollution. This report will identify key criteria for successful astrotourism sites and apply them to this region in order to discuss the potential of such sites in Namibia. In particular, the report will consider the Jamy Traut Hunting Safari business, a local service offering safari excursions to a variety of sites throughout the country. Services like the Jamy Traut Hunting Safari can be found across Namibia, but only a few exist that utilize the dark skies as a resource offered to guests. Businesses could utilize the resources of the night sky as a unique way to enhance guest experience or draw additional visitors.

Background

Light Pollution

For generations, the night sky has been source of inspiration and awe. An observer could look up and see the variety of color in the stars and observe comets, shooting stars, and the Milky Way spanning across the sky. With telescopes, deep sky objects like nebulas, galaxies, and star clusters could be seen in great detail. But the sky is changing. Light pollution has become a growing issue for both astronomers and casual observers around the world. Light pollution generally comes from the artificial lights in cities and towns and is officially defined as excessive or misdirected artificial lighting. This unwanted, ambient light decreases the contrast between the sky and stars and makes it more difficult to observe faint stars and deep sky objects (Rajkhowa, et al., 865).

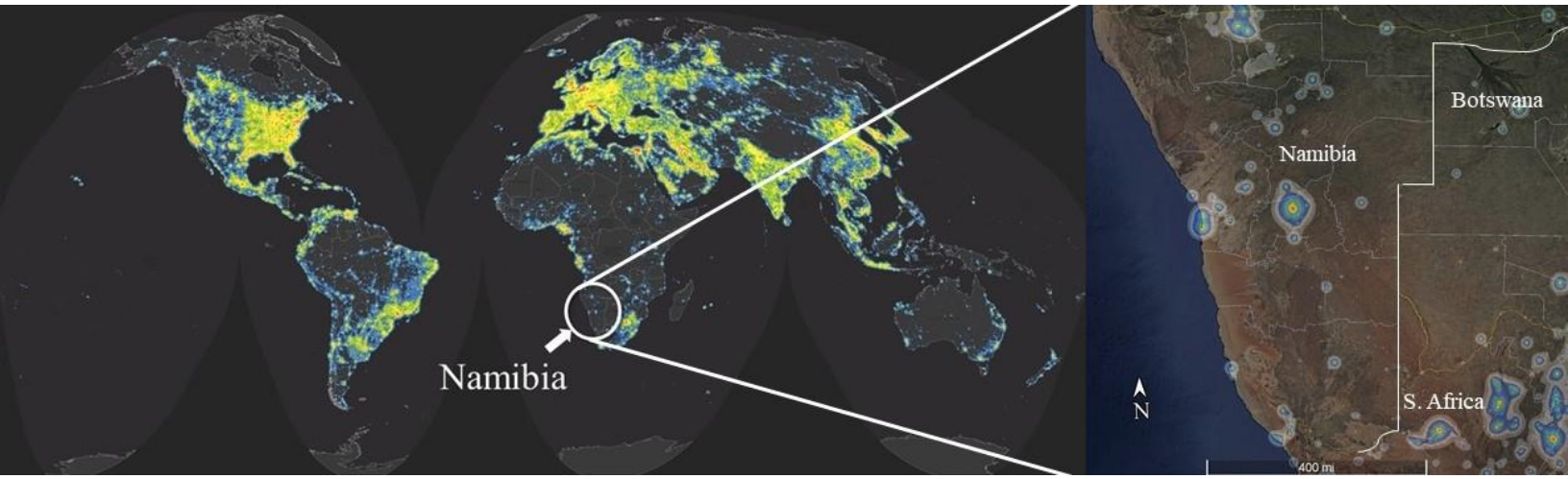


Figure 2 A map of the world's artificial light pollution in 2015. Namibia is shown to the right. Most light pollution in Namibia is in the centrally located capital, Windhoek. Adapted from Falchi, et al., "The New World Atlas of Artificial Night Sky Brightness." *ScienceAdvances*, 2016.

In the past, a rich view of the Milky Way and a pristine starry sky was available to anyone on a clear evening. However, in modern cities all but the brightest of objects such as the planets and Moon are obscured from view. A worldwide study of light pollution in 2000 found that an estimated one-fifth of the world's population could not see the Milky Way (Cinzano, et al., 701). This number has only increased over the years. As a 2017 study states, "Due to light pollution, the Milky Way is not visible to more than one-third of humanity, including 60% of Europeans and nearly 80% of North Americans" (Falchi, et al. 4). In other words, eight out of ten Americans simply can't see what has for most of human history been a powerful natural and cultural vista.

Seeing

Seeing is a characteristic of the sky that describes the effects of air flow on the viewing of celestial objects. On a night with poor seeing, stars twinkle and appear to change colors. Through a telescope, objects viewed in such conditions will lack sharpness and appear to jump around the

eyepiece. Seeing is physically dictated by the movement of air in the atmosphere along an observer's line of site between the ground and the stars. A site with good seeing is characterized by having a smooth, steady flow of air overhead. Additionally, convection between a warm surface and cool air can cause poor seeing (Peach; Petrovich 12-20). This convection is mostly localized near infrastructure like pavement or buildings. Observing a short distance away from these will reduce negative effects from convection. Geographically, sites with the best seeing are downwind of long expanses of smooth land like rolling hills, coastlines, or fields. In contrast, seeing at a site can be consistently poor if it is downwind of mountains, because mountains disrupt the smooth flow of air.

Transparency

Transparency is an atmospheric property that describes how clear the air is. Transparency does not describe cloud coverage. A sky might have zero cloud coverage, but transparency can still be poor enough to affect viewing. On a night with poor transparency, there will be less contrast between faint objects and the sky. This can create a loss of sharpness in objects viewed through a telescope. Transparency is controlled by the level of humidity, particles (such as pollutants, smog, dust, or mist), and the overall amount of air between an observer and the stars. Other things being equal, a dry area at high elevation will have better transparency than a humid site at sea level (Peach).

Criteria to Consider for an Astrotourism Site

Expanding a business to include astrotourism is only useful if these additional offerings benefit the business in some way. These benefits could include improving guest experience, increasing profit, or attracting more guests. A careful analysis of multiple factors should be

conducted to determine whether a particular site is viable for astrotourism before any investment is undertaken.

Firstly, all available resources should be identified. The key resource for astrotourism is of course a dark sky. However, the reliability of clear skies needs to be established as well. Climate, weather, and geography all play a role in impacting cloud coverage, seeing, and transparency. Sites should be shown to have good seeing and transparency. A site will obviously be unsuitable for astrotourism if it experiences consistently rainy or cloudy nights. Aside from the sky, other resources for astrotourism could include nearby professional astronomical facilities and the teaching capabilities of those on staff. For example, a site might offer tours to nearby research observatories or local educators could provide knowledge of local archeoastronomy or indigenous astronomical lore.

Secondly, nearby astrotourism sites should be identified and analyzed. A business like the Jamy Traut Hunting Safari should be aware of what local astrotourism sites offer to guests. For this section, three sites in particular are examined: the andBeyond Sossusvlei Desert Lodge, the Hakos Guest Farm, and the Tivoli Astrofarm. Each of these sites offer the equipment, expertise, and infrastructure necessary for guests to view the night sky. Information gathered from these sites will be useful, as any business expanding into astrotourism needs some knowledge of sites in the area that can compete for guests.

Thirdly, broad trends and demographics regarding regional tourism, travel, and future threats to dark skies should be understood. Developments in infrastructure continue to increase light pollution around the world, creating an increased demand for people to travel to dark skies but also endangering currently dark locations. With government regulation, a dark sky could be a

lasting sustainable resource for a business. If tourism in Namibia is shown to have increasing trends, this would be a good time to expand or start new tourism venues.

Finally, if a site proves to have positive potential for astrotourism, initial plans and cost estimates should be generated to understand how to best implement astrotourism into an existing business framework. For a venue like the Jamy Traut Hunting Safari, the cost and benefits of equipment must be taken into consideration. With the right planning, the night sky can be utilized at very little cost investment to a business. Different options in equipment and services will be discussed, and prices of any nearby sites offering similar services will be listed.

1 | Resources

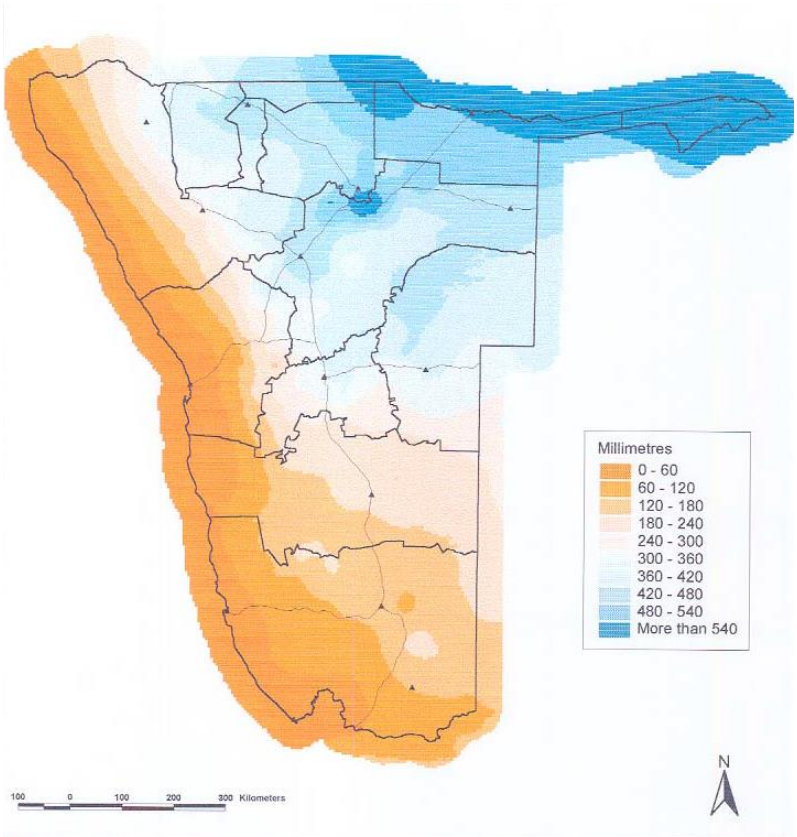


Figure 3 A map of Namibia showing differences in the of amount of rainfall across the country. "Rainfall Distribution in Namibia: Data Analysis and Mapping of Spatial, Temporal, and Southern Oscillation Index Aspects." *Ministry of Agriculture, Water, and Rural Development*

Weather and Climate

The 2003 *Atlas of Namibia* describes the country as generally dry, hot, and sunny (Mendelsohn, et al. 76-83). Although it is generally dry, there is a large variation in rainfall between the seasons of Namibia. In fact, Namibia is said to have the most variable seasonal weather in all of Africa. This has important implications for the seasonal viability of astrotourism there. Namibia experiences a "cool and dry winter" from May to September and a "hot and rainy summer" from October to April (Lu, et al. 67). This means that Namibia's climate allows for remarkably clear skies between the months of June and September but less reliable skies in the rainy season during the rest of the year.

Windhoek												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (mm)	91.3	87.0	69.5	32.3	6.2	1.2	0.4	0.8	3.8	11.4	25.7	33.2

Table 1a Notice the significant drop in rainfall between June and September. Data describes long-term conditions in Windhoek, the capital city of Namibia, located in the central plateau. Sourced from "Tabulation of Climate Statistics for Selected Stations in Namibia." *Ministry of Works & Transport,* 2012.

This cycle of dry and rainy seasons can be expected in the central plateau and northern regions of Namibia, but there are some exceptions. The Namib Desert, an extremely dry region, lies along the west coast of Namibia. Walvis Bay is situated near the center of the Namib Desert and is one of the driest locations in the country. Additionally, the Kalahari Desert along the eastern border of Namibia also receives markedly less rainfall than the rest of the country. These sites offer more consistent weather throughout the year, except for occasional fog along the west coast (Eckardt 16-17). Discussed in the next section, the Jamy Traut Hunting Safari site locations for the most part have similar weather patterns to Windhoek, except for the Kalahari Desert site and the Caprivi site.

Walvis Bay												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (mm)	0.9	1.4	4.4	0.4	0.9	1.0	0.0	0.2	0.1	0.2	0.4	0.1

Table 1b A table of Rainfall at Walvis Bay, an extremely dry area of Namibia. Sourced from "Tabulation of Climate Statistics for Selected Stations in Namibia." *Ministry of Works & Transport*, 2012.

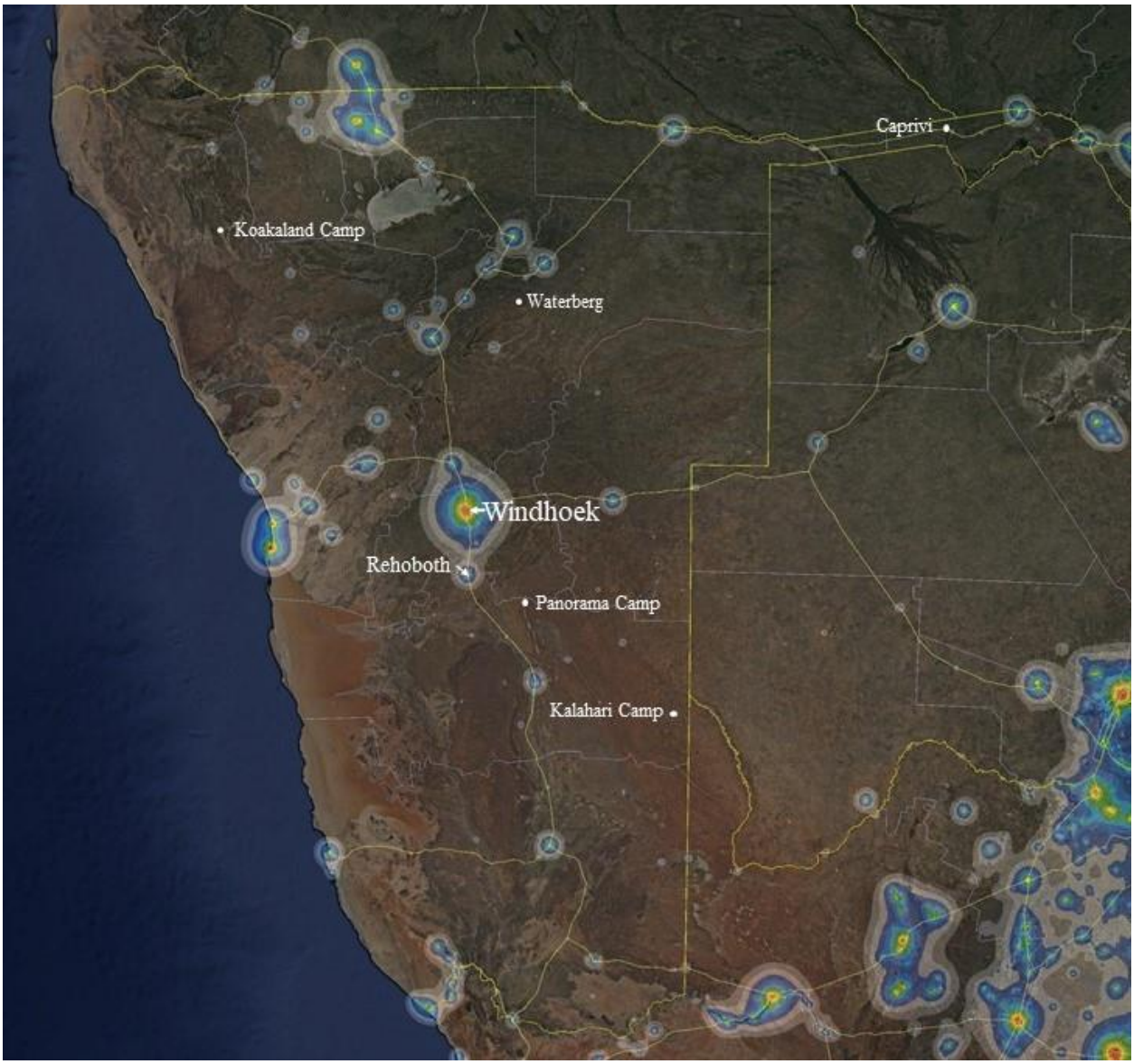


Figure 4 A map of Namibia showing the five locations of the Jamy Traut Hunting Safari: Panorama, Kalahari, Koakaland, Caprivi, and Waterberg.

Locations

The Jamy Traut Hunting Safari currently offers five established camp locations to guests. These are sites with amenities like food and housing included. The Panorama Camp is the main camp and is centrally located in Namibia. Each of these sites are far from sources of light pollution. The following table compiles some of the known characteristics of the Jamy Traut Hunting Safari sites. In the table, the column labeled Artificial Light Pollution uses a measurement of the magnitude of sky brightness per square meters. Values measured at the sites in Namibia indicate that the artificial light pollution is negligible. To offer some idea of the scale of artificial light pollution, in 2015 downtown New York capped at 110,000 μcd/m^2, small towns measured upwards of 1,800 μcd/m^2, and rural Midwest US areas measured at 80 μcd/m^2 (Stare; Falchi, et al.).

Table 2 A compilation of available information on light pollution levels, rainfall, and terrain at sites operated by the Jamy Traut Hunting Safari.

Location	Artificial Light Pollution [μcd/m^2]	Description	Geography
Waterberg	0.148	Waterberg is a newly established camp location. About 60% more rainfall occurs here yearly compared to that in Windhoek. **550mm average rainfall**. Winters are still very dry.	This area is on an elevated plateau varying from **1600m** to **1900m**. Wind tends come heading W, from very flat land.
Panorama	0	Site of the Jamy Traut Hunting Safari main camp. **359mm average rainfall**.	Elevation of **1400m**, with the tallest hills in the area reach **1700m**. Wind tends to come heading SW, from a mostly flat region with a collection of hills.
Kalahari	0	**220mm average rainfall**.	Average elevation around **1100m**. Wind generally heads W, from completely flat regions.

Caprivi	0.171	**600mm to 800mm average rainfall**.	Very flat terrain, elevation averaging around **1050m**.
Koakaland	0	**Average rainfall around 305mm.** Camp is situated just west of Etosha National Park.	Rough, hilly terrain. Elevations range from **1400m** to **1900m**. Wind heading generally SW

For the purposes of the Jamy Traut Hunting Safari, the most important factors to consider at each of these locations are the amount of rainfall per year, amount of light pollution, and expected seeing and transparency conditions. The Caprivi region receives the greatest amount of rainfall in Namibia. However, at all locations, the winter strictly remains a dry season. Clouds should be minimal between June and September. There should be very dark skies at each of these locations as light pollution levels are near minimum.

Seeing and transparency conditions can be difficult to predict without field observations. From topographical maps, it appears that every site except for the site in Koakaland is downwind of flat regions. These flat regions could mean minimal turbulence in the air, allowing for good seeing conditions. Transparency is dependent on humidity, altitude, and particles in the air. Transparency should be best in the winter, when humidity levels are lowest. Each site has an elevation of 1000 meters, and though there are no mountaintop sites, these elevations should generally allow for greater transparency than sites at sea level with the same conditions.

In other words, each location can be considered excellent for night sky viewing. Rainfall and cloud coverage are nearly zero in the winter months. Each site is far enough from towns to be totally free of light pollution. Finally, seeing and transparency are difficult to predict. Seeing should be excellent at each site, although the rough terrain in Koakaland may affect seeing conditions. Transparency should be good throughout the winter months, as humidity levels are low across Namibia.

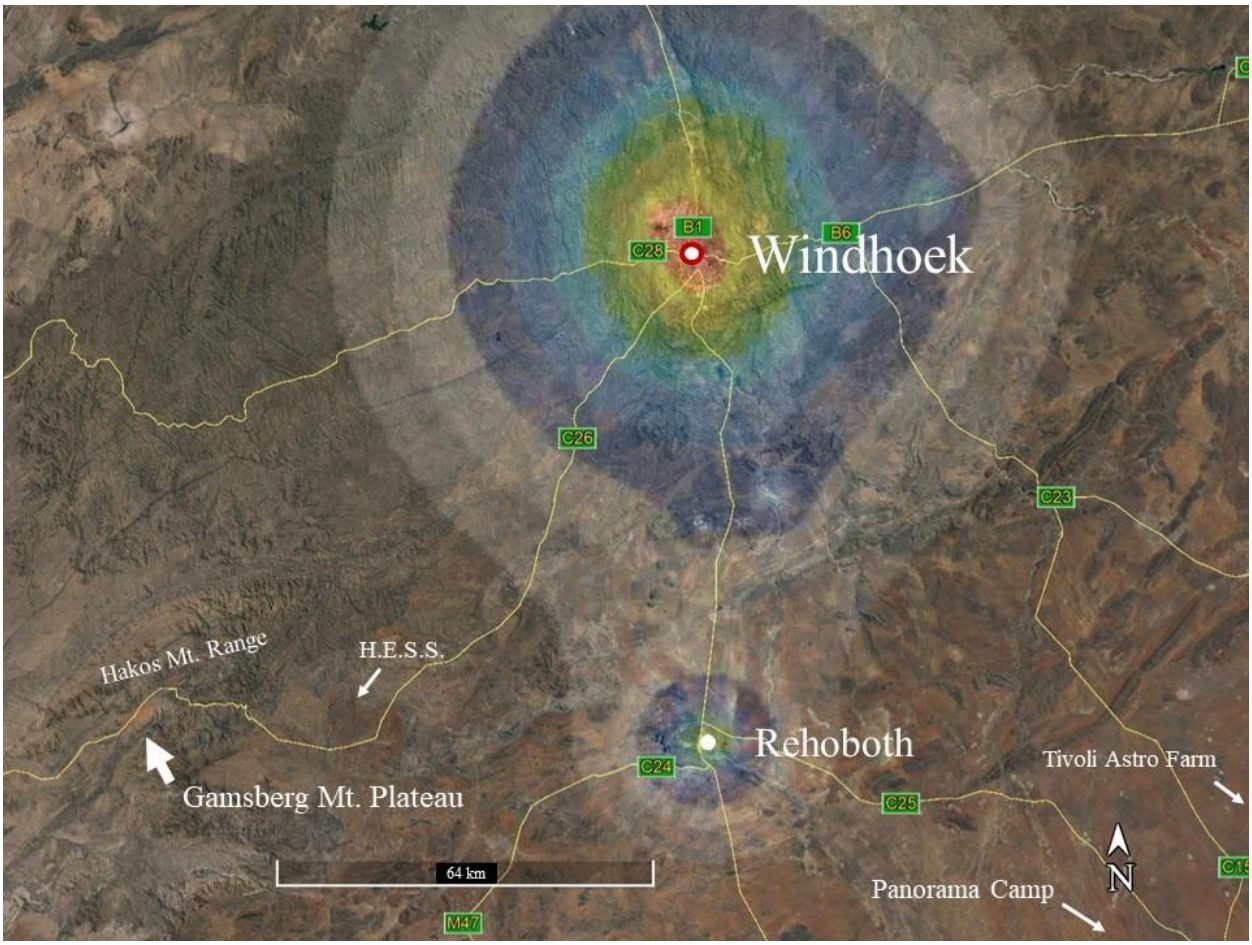


Figure 5 A map of the central plateau area. The proximity between the Gamsberg Mountain Plateau, HESS and Hakos Mountain Range indicate that this area in Namibia has exceptional astronomical viewing. Adapted from Google Earth Pro; Falchi, et al., "The New World Atlas of Artificial Night Sky Brightness." *ScienceAdvances, 2016.*

Nearby Astronomical Research Observatories

Most scientific observatories in Namibia today are in the vicinity of Gamsberg Mountain. This is a huge mountain plateau just west of Rehoboth and southwest of Windhoek. The mountains in this region of Namibia have some of the finest astronomical viewing conditions in the world due to a combination of altitude, dark skies, and climate. The area is owned by the Max Planck Society, an internationally renowned research association dedicated to academic studies in science. One of the most notable scientific facilities in Namibia is the High Energy

Stereoscopic System, or HESS, a group of five sensitive telescopes built to observe sources of high-energy gamma rays. On top of the Gamsberg Mountain Plateau is an observatory operated by the International Amateur Observatory Association (IAS), a non-profit science foundation. The largest telescope at this observatory, a 28" Newton reflector, is the second largest optical telescope in all of Namibia (Backes, et al., 2018, 3). As a dry, dark location at 2347 m elevation, the Gamsberg Mountain Plateau has the potential to be a big center for astronomical research in Africa. Specifically, Africa Millimetre Telescope (AMT) project is planned to be situated atop this plateau. This would be a huge radio telescope that would contribute to imaging active galactic nuclei (Backes, et al., 2019, 2)

HESS and the Gamsberg Observatory both draw tourists interested in Namibia's dark skies, and locals in the area are beginning to capitalize on this interest. The Hakos Guest Farm and Tivoli Astrofarm, for instance, already offer their own equipment and services to tourists and astronomers drawn to this growing center of astronomical research and experience. The proximity of these sites to the Jamy Traut Hunting Safari sites offers an incentive for hunting and safari businesses like this to augment their own services with astrotourism experiences.

Dark Sky Reserves

Dark skies are a critical resource of astrotourism sites. Light pollution grows with populations, and it can only be controlled with an increase in government and public awareness. Dark sky reserves are locations where the quality of the night sky is recognized as a resource that needs to be sustained and protected for the future. Lighting fixtures at these locations adhere to strict guidelines in order to minimize artificial light pollution.

The NamibRand Nature Reserve, about 300 km southwest of Panorama Camp, is an important location in Namibia that serves as an example of an increasing public awareness of light pollution. This site is currently the only dark sky reserve in Africa recognized by the International Dark Sky Association (IDA). The IDA is a non-profit association working to raise awareness of light pollution and recognize locations that are actively preserving dark skies. Of all the locations recognized by the IDA, NamibRand is ranked as one with the best quality dark skies. A recent audit conducted at the site affirms that actions are continuing to be taken to maintain the reserve's dark skies (Tindall 5-7).

Southern Skies

The southern skies are worth mentioning as a resource as they vary from the skies visible to many North Americans and Europeans. The night sky shifts as one changes latitude, and from Namibia's latitude of 23° S there are southern sky sights that overseas tourists may have never seen. If Namibia is viewed as an emerging astrotourist destination, the southern sky should be considered a key resource to draw in tourists from the northern hemisphere. Some of the unique southern sights include the Carina Nebula, the Magellanic Clouds, and the Southern Cross. Additionally, Namibia's latitude offers some of the greatest views of the Milky Way in the world. Here, the Milky Way's core passes directly overhead every winter, offering exceptional views of the galactic center.

Conclusion

The fact that Namibia is the only location with a dark sky reserve in all of Africa highlights the country's quality of night skies. The NamibRand Nature Reserve is recognized by the IDA as one of the finest dark sky locations in the entire world. Outside of the cities and

towns of Namibia, the skies are untouched by light pollution and will likely remain so for the foreseeable future. As has been shown though, besides clear and dark skies, astrotourism requires places with good seeing and high transparency. This means astrotourism in Namibia will likely follow seasonal cycles. In a report on the Tivoli Astrofarm, for instance, an astrophotographer emphasized the attraction of the dark, southern skies but mentioned that there was significant disturbance in the air between the warm ground and cool night air during the summer months (Rhemann 10). Ultimately, the winter months between June and September will likely offer the best time for seeing the night sky in Namibia. As will be discussed in a subsequent section, this conveniently corresponds to peak safari season in the country.

The NamibRand Nature Reserve and the area around the Gamsberg Mountain Plateau offer the most potential regions for astrotourism sites in Namibia. NamibRand has the benefit of being internationally renowned for its dark skies, and the Gamsberg Mountain Plateau has facilities such as the Hakos Guest Farm, IAS Observatory, and HESS. These sites offer potential resources to businesses in the area exploring options in astrotourism, as guests may be interested in using this nearby equipment for observations and astrophotography. All these sites are located near the Gamsberg Mountains, about 200 km west of Panorama Camp.

2 | Analysis of Existing Sites of Astrotourism

The goal of this section is to establish an understanding of how astrotourism sites might operate in Namibia. The locations, capabilities, and equipment of these sites will be investigated. This understanding will be useful when determining what new start-up in astrotourism should offer for their own business.

Namibia

The Sossusvlei Desert Lodge, located within the NamibRand Nature Reserve, is one of the most recognized locations for astrotourism in Namibia. The lodge is part of an international resort service called andBeyond. This resort is within the NamibRand Nature Reserve, so dark skies as a resource are guaranteed well into the future. Astrotourism is not the main focus of this lodge, but it is a major draw for visitors. The rooms at the lodge are designed to be open for night sky viewing. Stargazing with an in-house astronomer is also offered as an amenity to guests. The lodge has an observatory with a high-quality telescope, especially useful for digital imaging. Additionally, guests in suites are given high-end Swarovski Optik binoculars for the duration of their stay. The lodge puts a strong emphasis on the night sky, although it is geared toward the general public and amateur astronomers rather than professional astronomers. Other sites in Namibia can compete with the lodge by offering more equipment options at a lower price.

The Hakos Guest Farm is another astrotourism site in Namibia with a more exclusive focus on astronomy. It is located about 112 kilometers southwest of the capital Windhoek near the Hakos mountain range, right next to the Gamsberg Mountain Plateau and the IAS mountaintop observatory. This observatory, which is readily accessible from the Hakos Guest Farm, houses numerous scientific-grade telescopes and boasts some of the best viewing conditions in the southern hemisphere. The Hakos Guest Farm has two observatories of its own as well. Both are sheds with roll-off roofs and fixed telescope mounts. Equipment for both the general public and professional astronomers is available to guests. This includes (but is not limited to) camera adapters and motorized mounts, a 7” Meade refractor and an 11” Schmidt-Cassegrain telescope. This venue is an example of a site that augments its proximity to a professional site with a wide variety of instruments for both amateurs and professionals.

Finally, another astrotourism site in Namibia is the Tivoli Astrofarm, located about 177 kilometers southeast of Windhoek. This site focuses almost exclusively on astrotourism. Dozens of telescopes are offered for rent to guests, both for general and professional use. The Guest Farm hosts seven observatories with fixed mounts, some with capabilities for digital astronomy. The Tivoli Astrofarm is by far the closest site to Panorama Camp, roughly 60 kilometers north. It may be feasible for the Jamy Traut Hunting Safari to partner with the Tivoli Astrofarm or similar businesses. These are well established sites with a good base of knowledge and equipment that could be used by transporting guests to and from the sites.

Conclusion

Several sites specializing in astrotourism already exist in Namibia, including observatories at Hakos and Tivoli that are fit for casual observing, astrophotography, and professional astronomers. This creates a potential barrier to entry for any business looking to specialize *solely* in astrotourism. To truly compete, a combination of infrastructure and equipment would need to be established, requiring a significant amount of capital and expertise. Additionally, networks already exist between the Sossusvlei Desert Lodge and the NamibRand Nature Reserve and between the Hakos Guest Farm and Gamsberg Observatory. However, businesses do not need to specialize *only* in astrotourism in order to make astrotourism a viable part of their offering to guests. The Jamy Traut Hunting Safari, for example, is already established across Namibia and offers a reliable hunting and safari experience. A business like this has potential to utilize their dark skies to provide extra services or amenities to guests, as outlined below.

3 | Trends & Demographics

Most tourists come to Namibia from the neighboring countries Botswana, Angola, and South Africa. However, overseas tourists are coming to Namibia at an increasing rate. Between 2016 and 2017, Namibia saw an 11.1% increase in North American tourists, a 5.7% increase in European tourists, and a 16.6% increase in Chinese tourists ("Tourist" 9). The Namibian Ministry of Environment and Tourism recognizes the importance of overseas tourists to the economy:

> The overseas market has been growing steadily from the previous years and continues to grow progressively even in 2017 contributing about 27 percent of total tourist arrivals. Most of these overseas tourists (78.4 percent) come to Namibia with the purpose of leisure/holiday unlike tourists from African region who mostly come to visit friends/relatives (55.7 percent) thus they can be pivotal contributors to the foreign currency earnings ("Tourist" 7)

Overseas tourists are coming into Namibia at an increasing rate each year. These tourists will likely become greater contributors to the Namibian economy as they spend income on local goods and services. It should be noted that Europeans, largely from Germany, France and the UK make up the largest percent of overseas travelers to Namibia. North America ranks fourth for overseas travelers ("Tourist" 14). Businesses in the tourist industry might consider these demographics when reaching out to overseas tourists through advertising.

With light pollution increasing around the world, the number of people traveling to see the night sky will inevitably rise. Namibia is seeing a distinct and marked growth in its tourist industry, especially from overseas tourists. This trend is likely to continue. Additionally, with the

quality of Namibian skies, it is only a matter of time before new scientific facilities are established in the country, especially in areas around the Gamsberg Mountains. On top of Namibia's remarkably dark skies, these facilities will be a draw to tourists from around the world. Resourceful businesses in Namibia will likely have an opportunity to benefit in the future by branching out their services into astrotourism experiences.

4 | Implementation

A major benefit of offering astrotourism as a service is that start-up costs involved can be very minimal. The Jamy Traut Hunting Safari for example already has sites across Namibia offering full room and board. Because these sites are in areas with minimal or no light pollution and potentially exceptional seeing and transparency conditions, especially in the winter, there is excellent opportunity to offer star tours and/or astronomy related equipment for the use of guests as a means of augmenting their daytime experience with further evening activities unique to the skies of Namibia.

Binoculars

The skies can certainly be enjoyed without any equipment. The unaided eye may even be preferable for casually viewing the sky. One can easily view the constellations, the Milky Way, and astronomical events like eclipses or meteor showers without the aid of any instrumentation. However, it is advisable to at least have some pairs of binoculars on hand to assist guides in giving star tours. Binoculars give observers an opportunity to see the things in the sky that the unaided eye cannot see. For example, the Large and Small Magellanic Clouds, two dwarf satellite galaxies of the Milky Way, are interesting objects to spot with the naked eye. Without

any instrumentation, they look like big smudges broken off from the band of the Milky Way. However, binoculars can allow one to observe thousands of stars in these two dwarf galaxies. For some objects, like Andromeda Galaxy, star clusters, or large nebulas like the North American Nebula, binoculars are even preferable over telescopes because their lower level of magnification allows one to view the entire object at once.

Generally, regular binoculars used for hunting or wildlife observing would work just fine to observe the night sky. Binoculars of these types might be around *7x35* or *8x42*. In this specification, the first number indicates the amount of magnification (seven or eight times) and the second number the aperture, or diameter, of the binocular lenses (35mm or 42mm). There are also astronomical binoculars available specifically for observing the fainter objects of the night sky. The biggest difference between these and standard field binoculars is that astronomical binoculars tend to be heavier and have larger apertures for capturing more light. A pair of astronomical binoculars might be *10x50* or *12x75*. It is also important to note that when using binoculars for night sky observation, a tripod will likely be necessary. The higher magnification and heavier a pair of binoculars, the more it tends to shake in a user's hands and cause an unsteady view. A tripod will help to steady the binoculars and make viewing more comfortable, while also providing a means to lock them to a certain spot in the sky to easily share a view with others. When choosing binoculars, it's important to note that price usually directly reflects the quality of the optics. A 200 USD pair of binoculars will have a much better build quality than a 65 USD pair of binoculars. An expected price range for casual astronomical binoculars is around 100 USD to 150 USD, and tripods can be found for under 30 USD.

Telescopes

Many astrotourist destinations offer telescopes to guests for rent. The Hakos Guest Farm and Tivoli Astrofarm, both in Namibia, offer many of their scopes for use on stationary motorized mounts, usually in observatory sheds with roll-off roofs. These motor-controlled telescopes are excellent for use by guests of all types, whether professional, amateur, or casual. They allow for deep sky astrophotography with motorized mounts that can track the motion of the sky, and some also have motors that allow observers to automatically jump from object to object with a Go-To computer. All this equipment and infrastructure, however, represents a significant monetary investment. A motorized equatorial telescope mount, for example, can easily start at several thousand dollars USD. For a business like the Jamy Traut Hunting Safari that is looking to offer astrotourism as an extra amenity on the side, offering manually controlled reflector telescopes for use by guests is the most financially feasible option, especially since more advanced instrumentation is already offered at nearby venues and there is no need to directly replicate or compete with these types of amenities.

A more feasible option for a business like the Jamy Traut Hunting Safari is to invest in a few easily transportable telescopes that can be used to augment daytime hunting excursions with evening astrotourism. Telescopes vary quite a bit in size and design, but for this sort of application a reflector telescope is preferable because it offers the most light collection and magnification at the lowest price and least weight. These telescopes are designed specifically to see deep sky objects. In choosing a telescope size, however, it is important to consider that reflector telescopes above 8” in diameter start to become cumbersome due to size and weight. In addition, past the size of 10”, the price of commercial reflector telescopes rises significantly. Reflectors between 6” and 10” are the most advisable choice for a business like Jamy Traut

Hunting Safari, as they are affordable, practical for casual observing, and relatively easy to move.

Observing cannot be done with a reflector telescope tube alone. Accessories like eyepieces, view finders, and mounts are all required. The eyepiece is where an observer looks into a telescope. The size of an eyepiece (measured in millimeters) helps determine the magnification of the view in the telescope. A good rule of thumb is to use higher power eyepieces (below 17mm) to observe the planets and use lower power eyepieces (above 17mm) to view deep sky objects. It is advisable to have a good range of eyepieces available to allow observations of a wide range of objects. At the least, 4mm, 10mm, 17mm, 25mm, and 35mm should be available for use with the telescopes.

Figure 6 An image of the Trifid Nebula (Left) and Lagoon Nebula (right). These are two nebulas that pass directly overhead in Namibia throughout the winter months, offering ideal viewing conditions. A simple DSLR camera with

a telephoto lens and motorized tracking can take images like this. Image made from 26 stacked exposures (ISO 1600; f/5.6; 122 seconds; 55-250mm telephoto lens).

Astrophotography

Astrotourism sites often have equipment available to enable guests to take pictures of the night sky. Guests likely bring their own cameras to Namibia intent on bringing back pictures of the various wildlife and beautiful landscapes. Astrotourism and equipment that allows for astrophotography would let these guests add targets in the night sky to their list of captured sights. Being located well above the equator in the Northern Hemisphere, North American and European visitors to Namibia have a very different view of the night sky in their home countries. The brightest part of the Milky Way passes through zenith, the highest part of the sky, every year in Namibia. It is likely that most guests will have never seen this part of the Milky Way so high in the sky with such little light pollution. Additionally, there are objects in the southern Namibian skies that tourists from the northern hemisphere may have never seen, like the Large and Small Magellanic Clouds, the Coalsack Nebula, and the Southern Cross. Just as the savannahs and deserts of Namibia offer hosts of species that tourists will have never seen in the wild before, so the Namibian skies offer unique targets of a different kind.

Like telescopes, imaging equipment can become very expensive depending on what one wants to image. However, at a relatively low price, equipment exists that will enable guests to bring home gorgeous views of the sky with their own camera equipment. A sturdy tripod and camera are all that is necessary to capture star trail images. These are long exposure images that capture the motion of the sky throughout the night. More advanced astrophotography requires a motorized tripod. This is a tripod that can track the night sky, allowing for close-up long exposures of deep sky objects. Such a tripod is necessary for bright and clear Milky Way photos.

Astrophotography can be taken even further if desired by attaching cameras to telescopes which are themselves on motorized mounts. However, prices begin to rise significantly at this point, and sites like the Hakos Guest Farm and Tivoli Astrofarm already specialize in offering high-grade equipment like this to guests.

The following photos, as well as the other night sky photos in this paper, are meant to demonstrate the capabilities of a common, inexpensive camera and minimal equipment. Each photo was taken with a 300 USD motorized tripod, a Canon Rebel T1i camera, and several basic consumer lenses, from a 50-250mm telephoto to an 18-55mm stock lens.

Figure 7a A wide-angle image of the Milky Way. Light pollution from a small town three kilometers southwest can be seen in the bottom of the image. The center of the Milky Way is behind the tree line to the bottom left. Image made from two stacked exposures (ISO 800; f/3.5; 121 seconds; 18-55mm lens with wide-angle attachment).

Figure 7b A close-up image taken near the center of the Milky Way. Image made from 20 exposures stacked (ISO 800; f/1.8; 61 seconds; 50mm lens).

The use of astrophotography is not limited to guests. Photos of the night sky could be useful to catch a reader's attention in brochures and travel websites. If the Jamy Traut Hunting Safari were to begin offering any sort of equipment that enable guests to view the night sky, they may also consider capturing photos of their sites with the night sky included. A more in-depth section on the astrophotography is included in the appendix along with links to supplementary guides and information.

Table 3 is meant to give an overview of specific equipment that can be offered to guests in order to observe the night sky. Price is the primary factor in determining which equipment should be listed. Any item considered to be reasonably affordable for the use it provided was included in this table.

Table 3 A list of various equipment that could be provided to guests, with price estimates (shipping and tax not included)

Astronomical Binoculars		**Description**
Nikon 8248 Aculon A211 *10x50*	100 USD	Inexpensive binoculars for sky observation. Different magnifications are available from 7x to 16x.
Celestron SkyMaster Binoculars *15x70*	65 USD	Inexpensive binoculars that come with a tripod adapter. Due to the high *15x* magnification, a tripod is strongly advised.
Binocular Accessories		
BARSKA Binocular Tripod Adapter	9 USD	Standard 1/4" bolt. Necessary to attach most binoculars to a tripod.
Amazon Basics 60" Tripod	23.50 USD	Standard lower end, lightweight tripod.
Telescopes		
Orion 8945 SkyQuest XT8 Dobsonian	400 USD	An 8" reflector telescope. Comes with a single 25mm eyepiece.
Orion 8945 SkyQuest XT10 Dobsonian	630 USD	A 10" reflector telescope. Comes with a single 25mm eyepiece. More expensive and heavy than the 8" but gathers much more light.
Sky-Watcher 8" Collapsible Dobsonian	505 USD	An 8" reflector telescope, collapsible for easier transportation. Comes with a 25mm and a 10mm eyepiece.
Telescope Equipment		
Basic Eyepiece Set	45 USD – 120 USD	A good set of eyepieces is necessary for general telescope used. A set that offers these sizes is advised: 4mm, 10mm, 17mm, 25mm, and 35mm
Other		
Green Laser Pointer	10 USD – 30 USD	A useful tool for pointing out stars and constellations in the sky.

Astrophotography		
Intervalometer	15 USD – 30 USD	An intervalometer is a simple device that allows a user to remotely control their camera. Some night sky photos can require dozens of long exposures. This device expedites the imaging process.
Heavy-Duty Tripod	50 USD – 150 USD	Regular tripods are built to be easy to move and are usually very lightweight. Instead, a "surveyors" tripod is advised. These are generally cheaper than professional photography tripods, will not shake in the wind, and can hold the extra weight of a motorized sky tracker.
Sky-Watcher Star Adventurer Motorized Mount	300 USD	An example of an inexpensive motor that allows for sky tracking.

Pricing

Table 4a and **Table 4b** list services and equipment that are offered at the Hakos Guest Farm and Tivoli Astrofarm. These prices provide insight into what astrotourism sites in Namibia might charge guests for services. Start-ups should understand what existing sites charge for their services in order to offer their own services at competitive prices.

Table 4a A shortened list providing examples of prices at the Hakos Guest Farm in Namibia.

Service	N$	USD
Full Room & Board (p/p)	1240.00	86.0
Guided Star Tour (4p/hr.)	500.00	27.78
Observatory rental (per night)	~550.00	38.19
Celestron 11" EdgeHD (per night)	530.00	36.81
Skywatcher 16" GoTo Dobs. (per night)	530.00	36.81

8” Galaxy Dobsonian (per night)	215.00	14.91
Binoculars (20x90)	Free	Free
24” Dobs (per 3 nights)	4746.10	329.59

Table 4b: A shortened list providing examples of prices at the Tivoli Astro Farm in Namibia.

Service	**N$**	**USD**
Half Room & Board (p/p)	1775.66	123.31
Observatories (nightly, min 3 nights)	936.29 to 2260.08	65.02 to 156.95
Mount Rentals (nightly, min 3 nights)	355.10 to 565.06	24.66 to 39.24
Tripod Rentals (nightly)	80.78	5.61
14” Optics Meade “Advanced Ritchey Chretien”	435.89	30.27
11” Optics C11 Celestron carbon fiber tubes (per night)	290.59	20.18
10” Dobson (min 3 nights)	322.85	22.42
20” Dobson, 5 TeleVue eyepieces (min 3 nights)	1049.33	72.87
24” Bino Dobson “Pantherina” Argo Navis, GoTo, TeleVue eyepieces (min 3 nights)	1452.82	100.89

The following table is meant to give some conclusive estimates of prices that an astrotourism site in Namibia might charge to guests. Such information would be useful to start-up site that are ultimately looking to weigh in the potential costs and revenues by offering astrotourism services.

Table 5 This is a table of price estimates of different services and equipment that could be offered to guests, with prices of the Hakos Guest Farm and Tivoli Astrofarm considered.

Service	**Price**	**Description**
Guided Sky Tour	25 USD – 30 USD/hour	A guide brings a guest or group of guests outside and points out objects in the night

		sky, such as constellations, stars, and deep sky objects.
Binoculars	5 USD/night	Binoculars could be set for rent, but in any case it would be helpful to pass them around during a sky tour.
6” Dobsonian	10 USD/night	A lightweight telescope. Hassle-free and easy to move.
8” Dobsonian	12 to 15 USD/night	A medium sized telescope. Lightweight, relatively easy to move. Great for excursions to other locations.
10” Dobsonian	15 to 20 USD/night	A larger telescope. Can be heavy, would take up extra space in a vehicle. Good to have on hand at a camp.
Astrophotography Equipment	5 to 15 USD/night	A tripod, motorized tracker, and intervalometer. Could be offered for free, or the charge could be included to cover guidance on how to use the equipment.

Conclusion

Ultimately, the direction a business wants to take to begin offering astrotourism experiences to their current offerings in Namibia is entirely up to the site operators. The costs and benefits of each option should be weighed. Depending on what is already available to a site, the costs of expanding into astrotourism can be minimal. However, even this minimal investment would allow a business to position itself to capitalize on the growing stream of tourists who are coming to Namibia for its research facilities and to experience its clear, dark skies. For a business that already offers a solid field experience, such as safaris with the Jamy Traut Hunting Safari, astrotourism options would allow it to offer a wider variety of experiences or augment the evening hours with options that would make the overall package more appealing to potential guests.

Conclusion

There is a great potential for sites in Namibia to capitalize on the natural night-sky resources of their country with respect to astrotourism. Namibia has exceptionally dark skies. The dry winter months, which correspond to the months that draw the highest number of visitors and tourists for wildlife hunts and safaris, offer reliable skies for astronomical viewing. Namibia's position in the Southern Hemisphere means that tourists interested in astrotourism will be attracted to the skies not just because they are dark but also because they offer views of southern sky objects not visible to observers in the Northern Hemisphere. The NamibRand Nature Reserve, Africa's first official dark sky site, has established Namibia as a destination to view the night sky. As light pollution around the world increases, countries like Namibia have an opportunity to attract more tourists by bringing attention to their dark skies. Finally, if future science facilities are successfully established in Namibia, public interest to travel to Namibia for astronomy-related interests will increase. Tourists will be looking for places to stay, and sites that have branched into the astrotourism industry can expect to see future benefits.

References

Backes, M., et al. "Status of Astronomy in Namibia." *The African Review of Physics*, vol. 3, 4 Nov 2018. https://arxiv.org/abs/1811.01440. Accessed 4 June 2019.

Backes, M., et al. "Millimeter-Wave Monitoring of Active Galactic Nuclei with the Africa Millimetre Telescope." *Galaxies,* vol. 7, no. 66, 25 June 2019. https://www.mdpi.com/2075-4434/7/2/66. Accessed 15 July 2019.

Burnham, Robert Jr. *Burnham's Celestial Handbook.* 3 vols. Toronto, Ontario: General Publishing Company, 1978.

Cinzano, P. et al. "The First World Atlas of the Artificial Night Sky Brightness." *Monthly Notices of the Royal Astronomical Society,* vol. 328. 2000. https://academic.oup.com/mnras/article/328/3/689/1240556. Accessed 17 June 2019.

Damian, P. "The Atmosphere and Observing – A Guide to Astronomical Seeing." *DamianPeach,* 2002, www.ifa.hawaii.edu/~meech/a281/handouts/seeing.pdf. Accessed 28 May 2019.

Falchi, F., et al. "The New World Atlas of Artificial Night Sky Brightness" *ScienceAdvances,* vol. 2, no. 6, 10 June 2016, https://advances.sciencemag.org/content/2/6/e1600377.full. Accessed 16 June 2019.

Fayos-Solá, Eduardo, et al. "Astrotourism: No Requiem for Meaningful Travel." *Pasos Journal,* vol. 12, no. 4, 2014, pp. 663-671. https://www.researchgate.net/publication/318957095_Astrotourism_No_Requiem_for_Meaningful_Travel.

Hong Soo, L. "The Reality of Light Pollution: A Field Survey for the Determination of Lighting Environmental Management Zones in South Korea." *Sustainability*, vol. 10, no. 374, pp. 1. https://www.mdpi.com/2071-1050/10/2/374. Accessed 9 July 2019.

Lu, X., et al. "A Multi-Scale Analysis of Namibian Rainfall over the Recent Decade – Comparing TMPA Satellite Estimates and Ground Observations" *Journal of Hydrology: Regional Studies*, vol. 8, December 2016, http://www.*dx.doi.org/10.1016/j.ejrh.2016.07.003*. Accessed 4 June 2019.

Mendelsohn, J., et al. *Atlas of Namibia: A Portrait of the Land and its People.* Cape Town, David Philip Publishers, 2002.

"Rainfall Distribution in Namibia." *Ministry of Agriculture, Water and Rural Development,* April 1999. https://www.raison.com.na/sites/default/files/Rainfall%20Distribution%20In%20Namibia.pdf. Accessed 3 March 2019.

Rajkhowa, R. "Light Pollution and Impact of Light Pollution." *International Journal of Science and Research*, vol. 3, no. 10, Oct. 2014, https://www.ijsr.net/archive/v3i10/T0NUMTQyMTA=.pdf. Accessed 16 June 2019.

Rhemann, Gerald. "Astrophotography Under Namibia's Dark Sky." *Practical Astronomer,* November 2007. http://www.astrostudio.at/Publications/PDF/PracAstReport.pdf.

Ridpath, Ian. *Star Atlas*. Pearson Education, 2004.

Stare, Jurij. *Light Pollution Map*. 2019, www.lightpollutionmap.info. Accessed 3 March 2019.

"Tabulation of Climate Statistics for Selected Stations in Namibia." *Ministry of Works and Transport*, 2012, http://www.meteona.com/attachments/035_Namibia_Long-term_Climate_Statistics_for_Specified_Places%5b1%5d.pdf. Accessed 3 June 2019.

Tindall, M. "Annual Report and Light Audit 2018." *NamibRand Nature Reserve*, 2018. https://darksky.app.box.com/s/kbzx60edn86r998970klb9jbyba35hjl.

"Tourist Statistical Report 2017." *Ministry of Environment and Tourism.* 2017, http://www.met.gov.na/files/downloads/e9d_MET%20Tourist%20Statistical%20Report%202017.pdf. Accessed 19 June 2019.

Appendix

A guided night sky tour is one of the primary services offered by astrotourism destinations. Guests may not know what to look for when they view the night sky, especially from an unfamiliar location. What follows is by no means a full, stand-alone guide, but rather is meant to provide a site operator with an overview of what they might want to be familiar with in the Namibian sky and what objects of interest would be best suited for sharing during a sky tour.

The following observing guide is split into three sections:

Section I includes some basic information on how the sky might be observed and introduces some objects of interest that can be observed from Namibia.

Section II outlines from *sunset to midnight* some of the major constellations and deep sky objects that can be seen in the winter Namibian sky (June to September). These are objects that a guest could casually observe in the sky on any given night during the winter.

Section III outlines from *sunset to sunrise* some of the major constellations and deep sky objects that can be seen in the winter sky (June to September). These are objects that a guest would have to stay up and plan to observe during the winter and would be of use for those tourists who are particularly interested in astrotourism.

Apart from sky tours, imaging is another service that might interest both guests and site operators. Therefore, a fourth section **(Section IV)** introduces the process of astrophotography, from imaging to post-processing.

Section I | General Information on the Night Sky

1. **Determine Cardinal Directions with Southern Stars**
    a. Face south. Look for two things:
        i. *Crux*, "The Southern Cross"
        ii. *The Pointer Stars*, "Alpha Centauri" and "Beta Centauri"
    b. Use these to find the southern celestial pole.

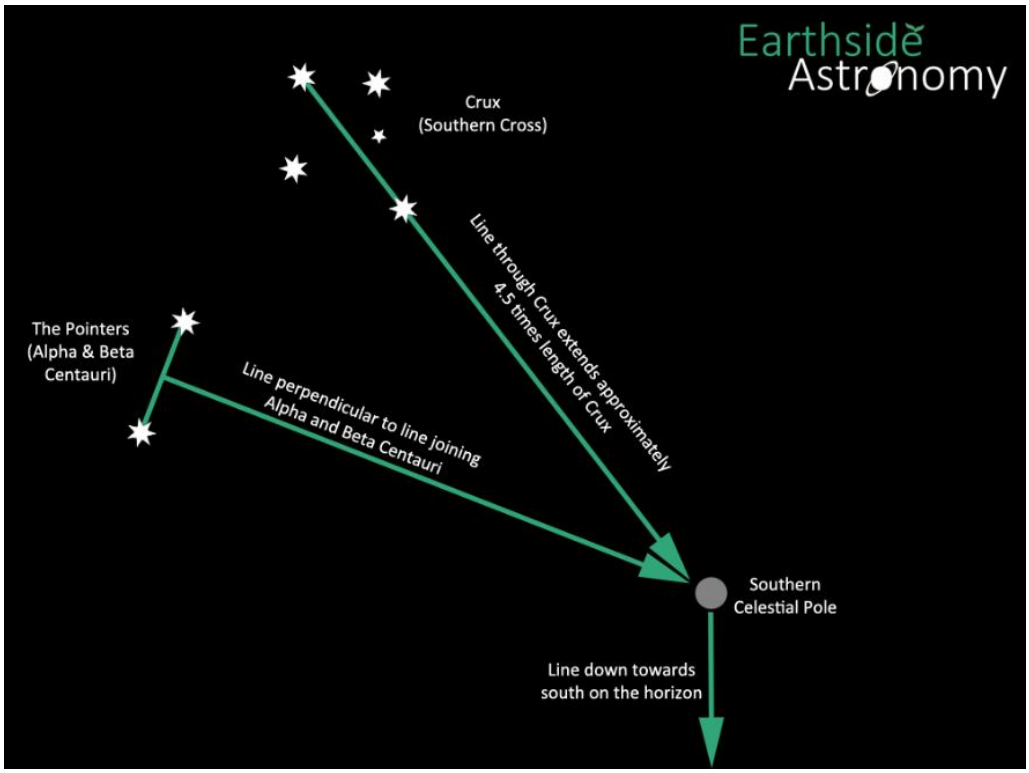


Figure 8 A diagram describing how to find the Southern Celestial Pole.

2. **Brightness**
    a. Stars and deep sky objects are assigned different *magnitudes*.
        i. Each step in magnitude (by 1) is a change in brightness by 2.512 times.
        ii. For example
            1. Sirius is the brightest star in the night sky (-1.45 magnitude)
            2. Alpha Centauri (otherwise known as Rigel Kentaurus) (+0.10 magnitude)
            3. Full Moon (-12.6 magnitude)
            4. Venus at brightest (-4.4 magnitude)
            5. Carina Nebula (+1 magnitude)
            6. Dimmest naked eye objects (+6 magnitude)
        iii. The lower the magnitude of an object, the brighter it is.
3. **Planets**

a. There are five planets that you can see with the naked eye: *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*. A telescope or binoculars are required to see *Uranus* and *Neptune*.
b. Where the planets are in the sky depends on where they are in their orbits compared to Earth's own orbit. The closer to the Sun a planet is, the more quickly it appears to move in the sky as time goes on. *Mercury*, for example, may be visible one week but not visible the next, while *Saturn* will be in about the same spot for the whole season.
c. All planets can be found near the *ecliptic*, the path that the sun follows across the sky each year. The *zodiac constellations* are the constellations found along the ecliptic. Therefore, planets are usually found in well-known zodiac constellations.
d. *Mercury* and *Venus* are usually seen near sunset or sunrise. A clear, open horizon increases the likelihood of seeing these planets.
e. The planets are always shifting in the skies. One of the best ways to keep track of where the planets are is to use planetarium software like *Stellarium* (for pc), or *Sky Safari* (for iOS or android). Links to these resources are linked below.

4. Deep Sky Objects

a. These are objects such as nebulas, star clusters, or galaxies. Often they are too small or faint to see with the naked eye, and a telescope or binoculars are required to view them.
b. Deep sky objects are usually designated by catalogue and number, although many are named. Some common catalogues include the Examples: *Messier 13 "The Hercules Cluster"* and *NGC 3372 "The Keyhole Nebula"*
c. Tourists from Europe and North America may be especially interested in some of the southern deep sky objects, as many of these can never be seen from higher latitudes. Some of the main southern sky objects to look for: *Large Magellanic Cloud, Small Magellanic Cloud, NGC 3532, C99 (Coalsack Nebula), NGC 3372 (Carina Nebula),* and *NGC5139 (Omega Centauri).*

5. **Lunar Cycle**

a. The Moon cycles about once every thirty days.
b. Light from the Moon can be enough to hinder views of the Milky Way and faint deep sky objects.
c. The best time for touring deep sky objects is near the *New Moon*
d. Near a *Full Moon*, one can still view the stars and constellations, and brighter deep sky objects. However, even with a telescope, views of faint objects are limited.
e. The best time for viewing the moon itself is between the *Full Moon* and *New Moon* phases. During these phases, shadows are cast across the uneven surfaces of the Moon. A telescope pointed at the moon during these times offers spectacular views of craters and ridges.
f. This website is a useful resource for determining the phase of the moon given month and year: https://stardate.org/nightsky/moon.

6. **Finding Resources**

a. For a computer, *Stellarium* is recommended. This a free software program that allows the user to interact with the night sky. https://stellarium.org/.

b. For a smartphone, there are low-priced or free applications that can bring up the night sky. Many applications allow you to aim your phone and match it to the stars and constellations using the app. *SkySafari* is a free app that allows you to interact with the sky, as well as track satellites and meteor showers.
c. Websites can provide information on when to view upcoming meteor showers, eclipses and any other astronomical events like comets, asteroids, or bright satellite passes. A free website that provides times and locations for these events: https://www.heavens-above.com/.
d. Star Maps
    i. A free digital resource for star maps is http://www.skymaps.com/downloads.html
    ii. Printed star maps are available but can be pricey. SkyAtlas 2000 and Uranometria 2000 are two print options.

Section II | Winter Star Tours (June to September): Sunset to Midnight

The following section attempts to establish a familiarity with the winter night sky. This guide includes some of the major constellations, stars, and deep sky objects visible in different months. Note that constellations are in **bold** and stars are in *italic*.

June

Sunset: approximately 6:15 PM

Sunrise: approximately 7:15 AM

Constellations

1. South

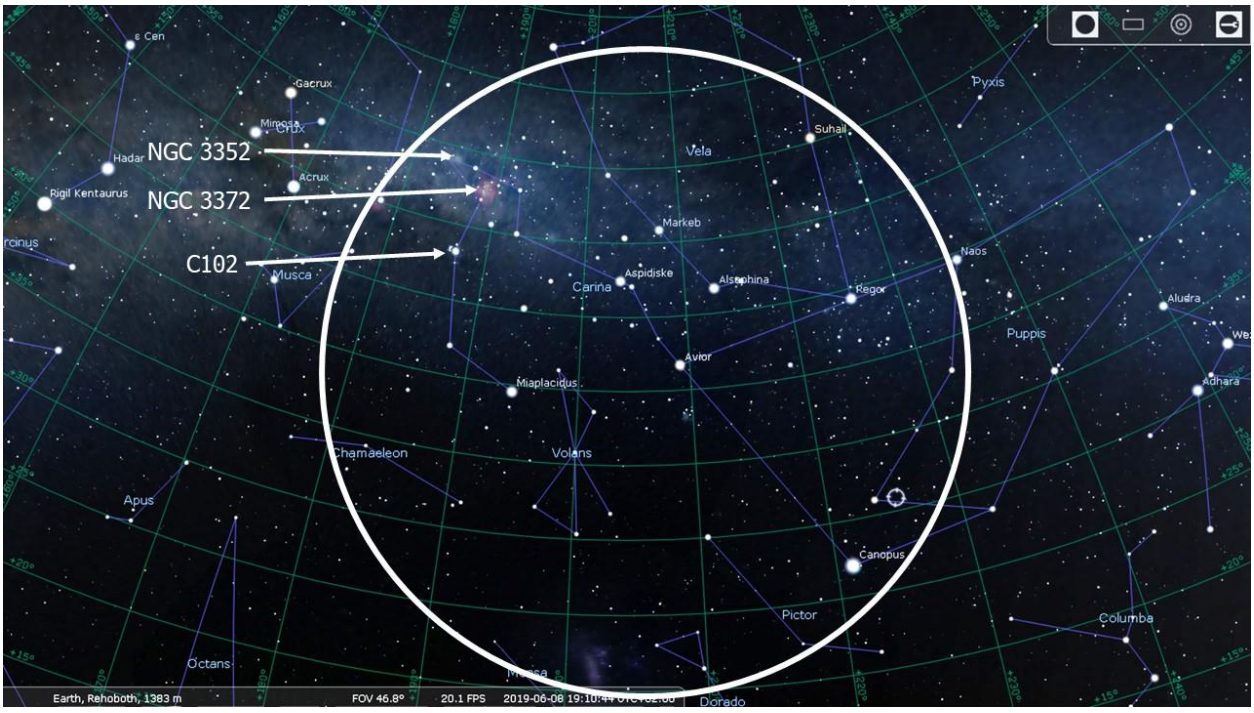


Figure 9.1 Constellation Carina. Mid-June, 7:00PM.

a. **Carina** "keel of the ship": Look for *Canopus*, "the Great Star of the South." This is the second brightest star in the night sky. After sunset, it is almost directly SW, near the horizon. It sets rather early, around 9:30PM.
    i. Deep sky objects:
        1. **NGC 3372 Carina Nebula:** Huge naked eye object, excellent target for binoculars or telescopes, as in the area are numerous open star clusters and other nebulas.

2. **NGC 3372 Keyhole Nebula:** An object within the Carina Nebula. Binocular or telescope required. Upwards of 1200 stars to see in the star cluster within, very distinct dust lanes.
3. **C102 Southern Pleiades:** An open star cluster visible with the naked eye.
4. **NGC 3532 Wishing Well Cluster:** One of the most brilliant and colorful open clusters in the sky.

Figure 9.2 Constellation Crux. Mid-June, 7:00PM.

b. **Crux** "southern cross": Look for the blueish-white star *Acrux*, 13th brightest star in the night sky. Also notable is the star *Gacrux*, a red giant, for its strong reddish orange color.
    i. Deep Sky Objects:
        1. **NGC 4755 Jewel Box:** Though not very populated, it is a bright and colorful open cluster visible to the naked eye. Around a hundred stars can be seen with binoculars or a telescope.
        2. **C99 Coalsack Nebula:** One of the most 'visible' nebulas in the night sky. Appears as a large dark splotch in the Milky Way, right next to Acrux.

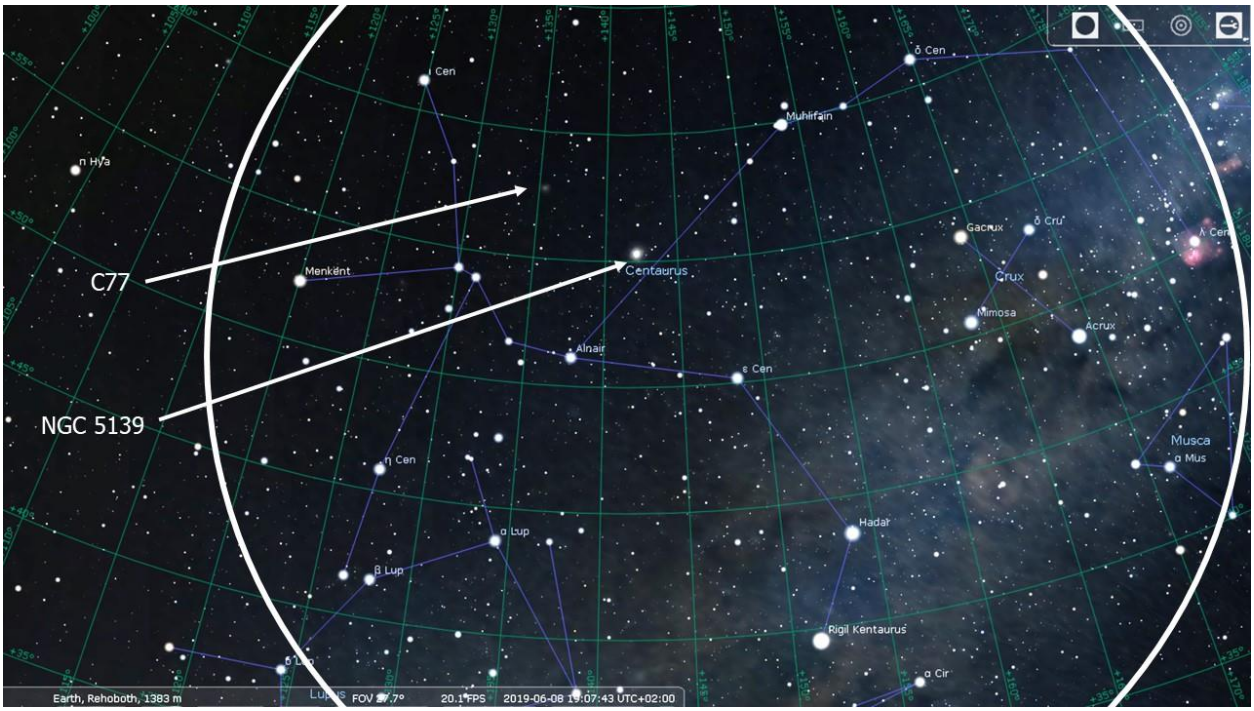


Figure 9.3 Constellation Centaurus. Mid-June, 7:00PM.

c. **Centaurus:** Brightest constellation in the southern sky. Look for *Alpha Centauri*, the third brightest star in the night sky. Noteworthy: this is the nearest star system to our own solar system. Also notable is the star *Beta Centauri*. *Alpha Centauri* and *Beta Centauri* are the "pointer stars" used to find the south pole.
   i. Deep Sky Objects:
      1. **C77 Centaurus A:** One of the brightest galaxies in the night sky. A telescope or binoculars are required. An interesting sight, as it is believed this is a galaxy formed by the merging of two galaxies.
      2. **NGC 5139 Omega Centauri:** Largest globular cluster in the Milky Way. The naked eye can just barely see it as a moon-sized speck in the sky, a telescope or binoculars would grant a much better view.

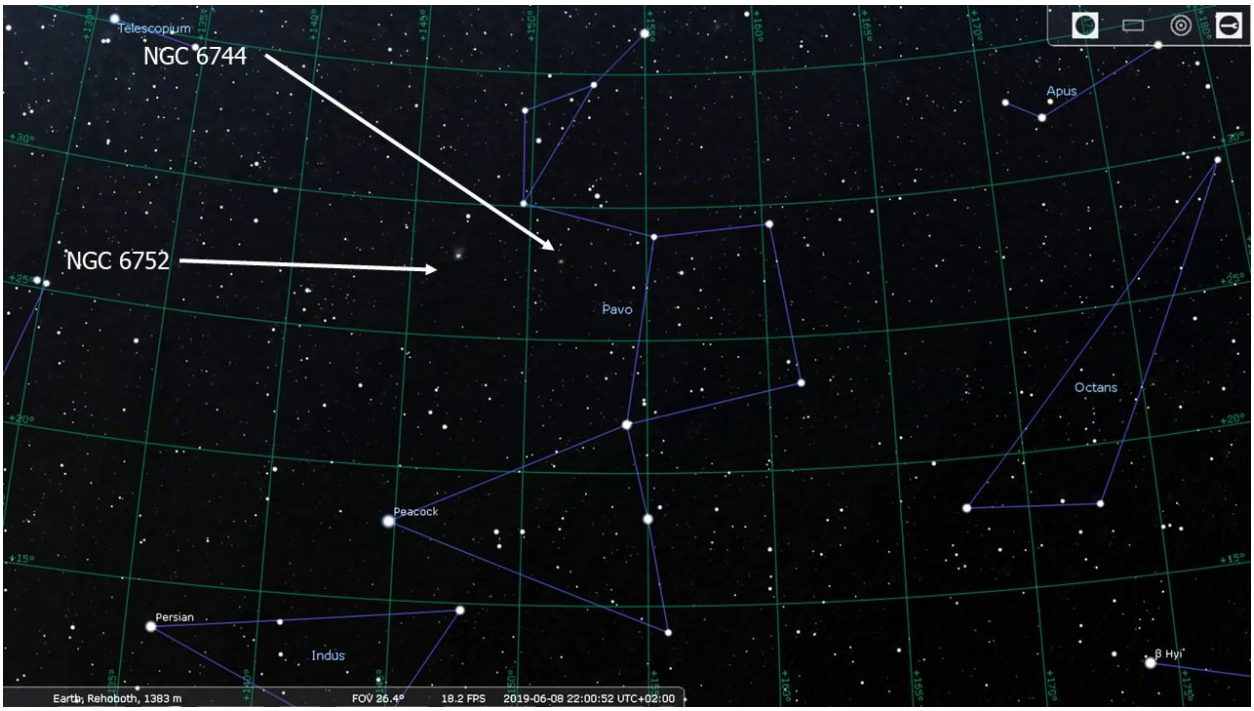


Figure 9.4 Constellation Pavo. Mid-June, 10:00PM.

d. **Pavo** "the peacock": Pavo is not a very bright constellation, but its stars are bright enough to find without too much difficulty. From Namibia, this is a circumpolar constellation (will always be in the sky), although in the summer months, much of it dips below the horizon. After sunset, Pavo has just risen in the SW sky.
    i. Deep Sky Objects:
        1. **NGC 6752:** The third brightest globular cluster in the night sky. Known for having a particularly dense core. An excellent target for binoculars or a telescope.
        2. **NGC 6744** A spiral galaxy within the Virgo Cluster. Although it is slightly larger, it is comparable to the Milky Way galaxy in structure. A telescope is required to bring up any details in the disc of the galaxy.

2. West

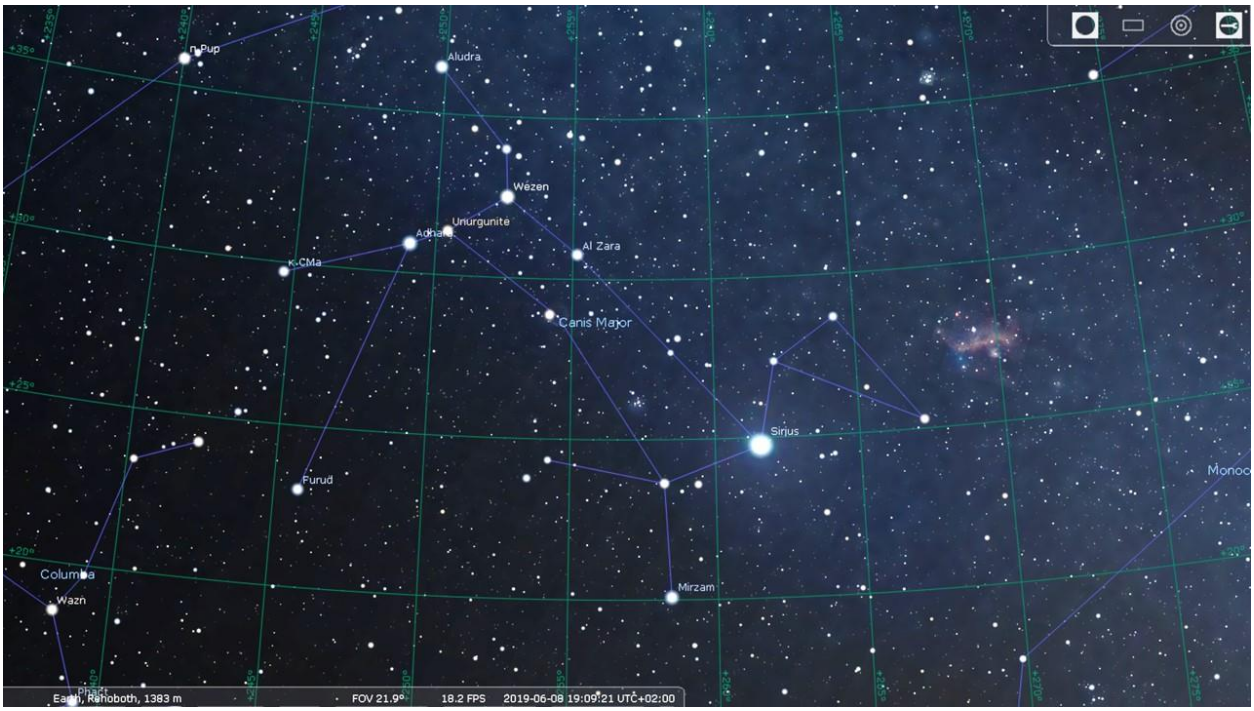


Figure 9.5 Constellation Canis Major, Mid-June, 7:00PM

e. **Canis Major** "greater dog": Look for *Sirius* the "dog star," brightest star in the night sky. Visible just after sunset, but not for long. By the end of June, it will be almost too low on the horizon to see.

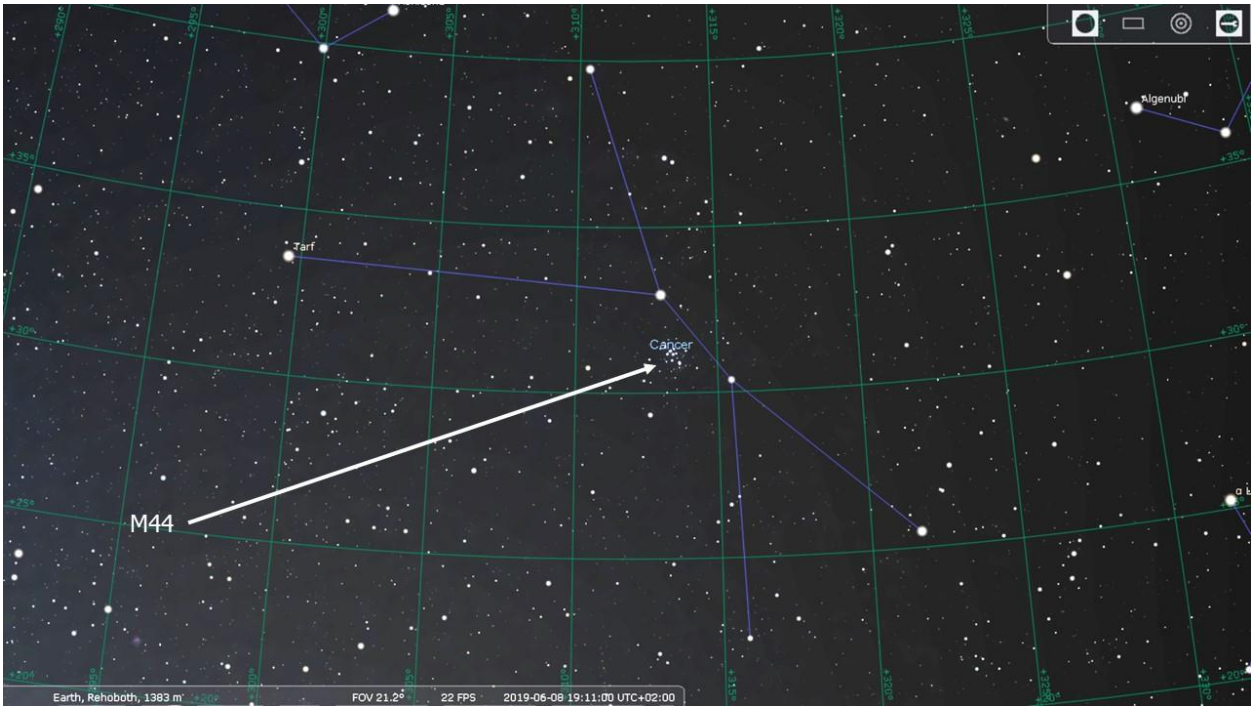


Figure 9.6 Constellation Cancer, Mid-June, 7:00PM

f. **Cancer** "the crab"**:** The constellation itself is quite dim, and near the low horizon. It will not be visible after June.
    i. Deep Sky Objects:
        1. **M44 Beehive Cluster:** One of the brightest open clusters in the night sky. A telescope or binoculars are required to make out the individual stars within. Good variety of color (reds and blues) between the stars within.

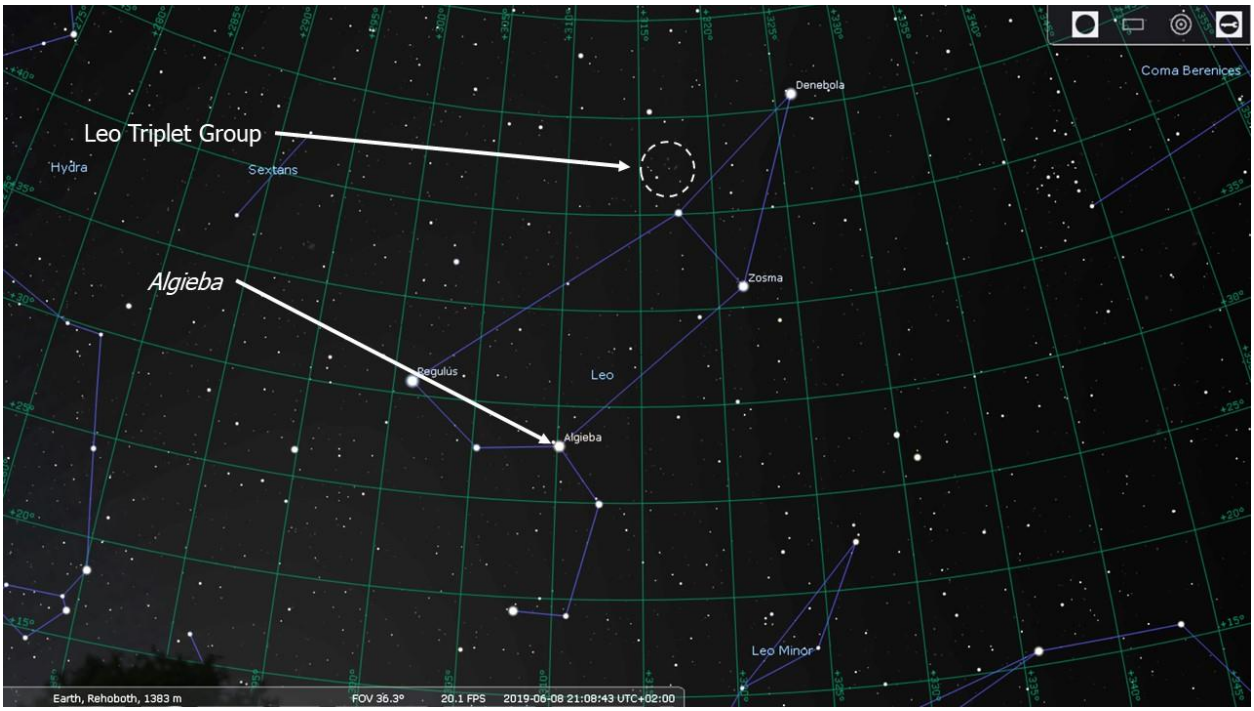


Figure 9.7 Constellation Leo, Mid-June, 9:00PM

g. **Leo** "the lion": Look for a collection of bright stars called the "sickle." In June, Leo sets at 10:00PM.
    i. Deep Sky Objects:
        1. *Algieba*: A bright, double star, positioned toward the middle of the "sickle." A telescope is ideal to visually split the two stars. However, it could be done with strong enough binoculars (x60 magnification) and a good eye.
        2. **Leo Triplet Group**: With a telescope, numerous galaxies can be seen in Leo. Perhaps the best known are the three galaxies in the Leo Triplet Group: **M65, M66,** and **NGC 3628.**

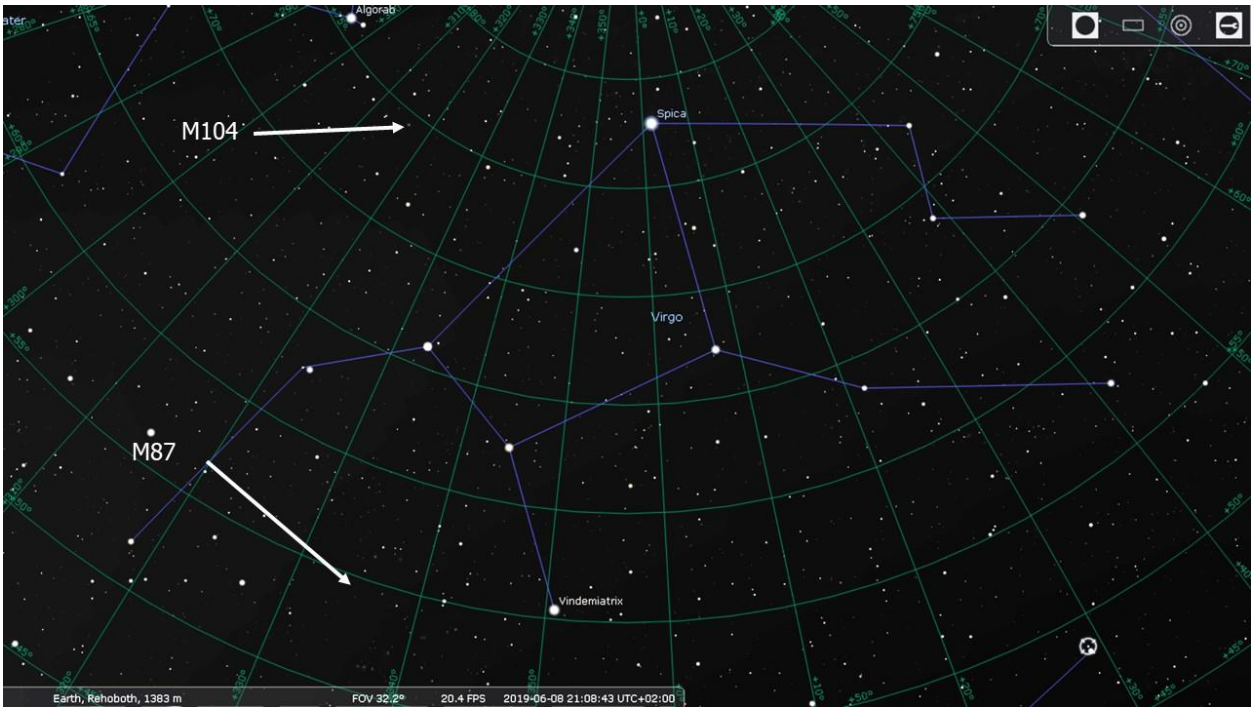


Figure 9.8 Constellation Virgo, Mid-June, 9:00PM

h. **Virgo** "the virgin": Look for *Spica*, a bluish-white colored star. Virgo is not an especially bright constellation, but most notable is the Virgo Cluster. A reflector telescope can bring out well over a hundred galaxies from this cluster, although most are small and too faint to make out much detail.
    i. Deep Sky Objects:
        1. **M87 Virgo A**: A massive elliptical galaxy toward the center with a bright core. Visible with a small telescope or binoculars.
        2. **M104 Sombrero Galaxy:** An interesting object, as it's a galaxy seen from the side rather than from above or below. Easily visible in binoculars. With a sizeable telescope (10"+) one can easily see the bulge in the center of the galaxy and might be able to see the dust lanes.

3. North

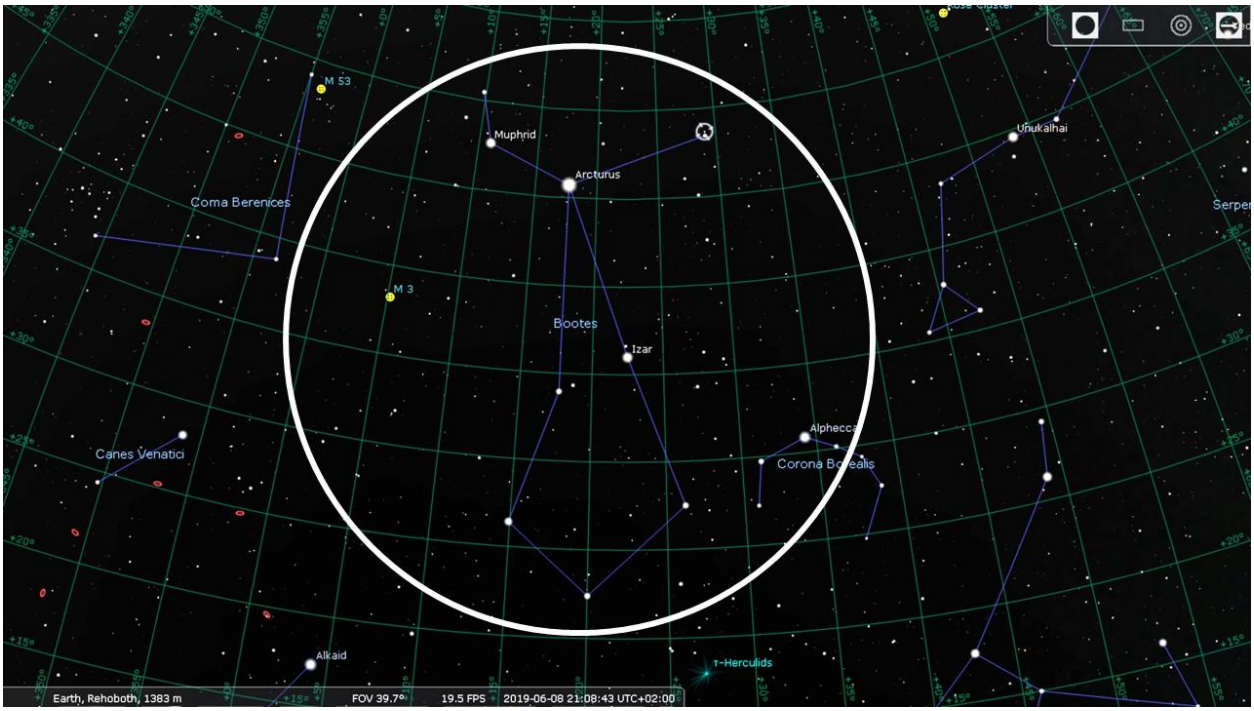


Figure 9.9 Constellation Boötes, Mid-June, 9:00PM

i. **Boötes** "the herdsman": Look for the red giant *Arcturus,* fourth brightest star in the night sky. Boötes can be identified by first finding Arcturus and looking for the "kite," a diamond shape in the sky.

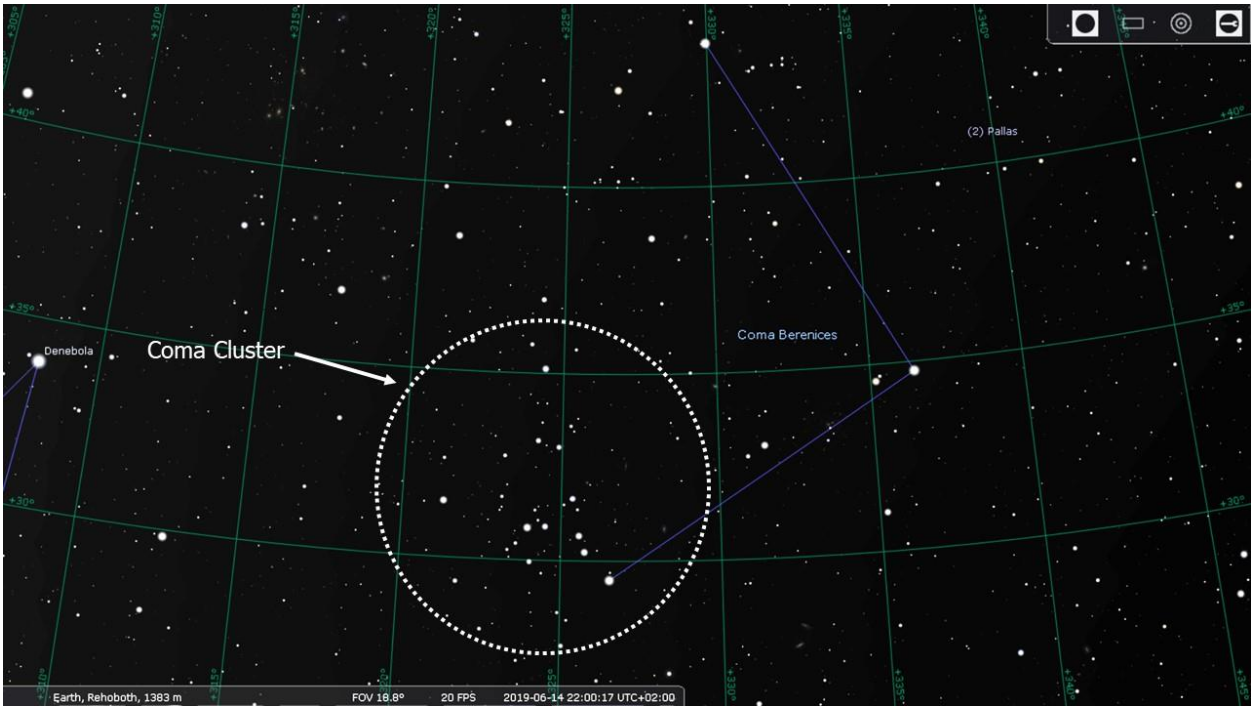


Figure 9.10 Constellation Coma Berenices. Mid-June, 10:00PM.

j. **Coma Berenices:** This is a very faint northern constellation, but notable as an excellent target for binoculars.
    i. Deep Sky Object:
        1. **Coma Star Cluster:** A very loose, but bright open star cluster. Visible with the naked eye. Covers a wide portion of the constellation.

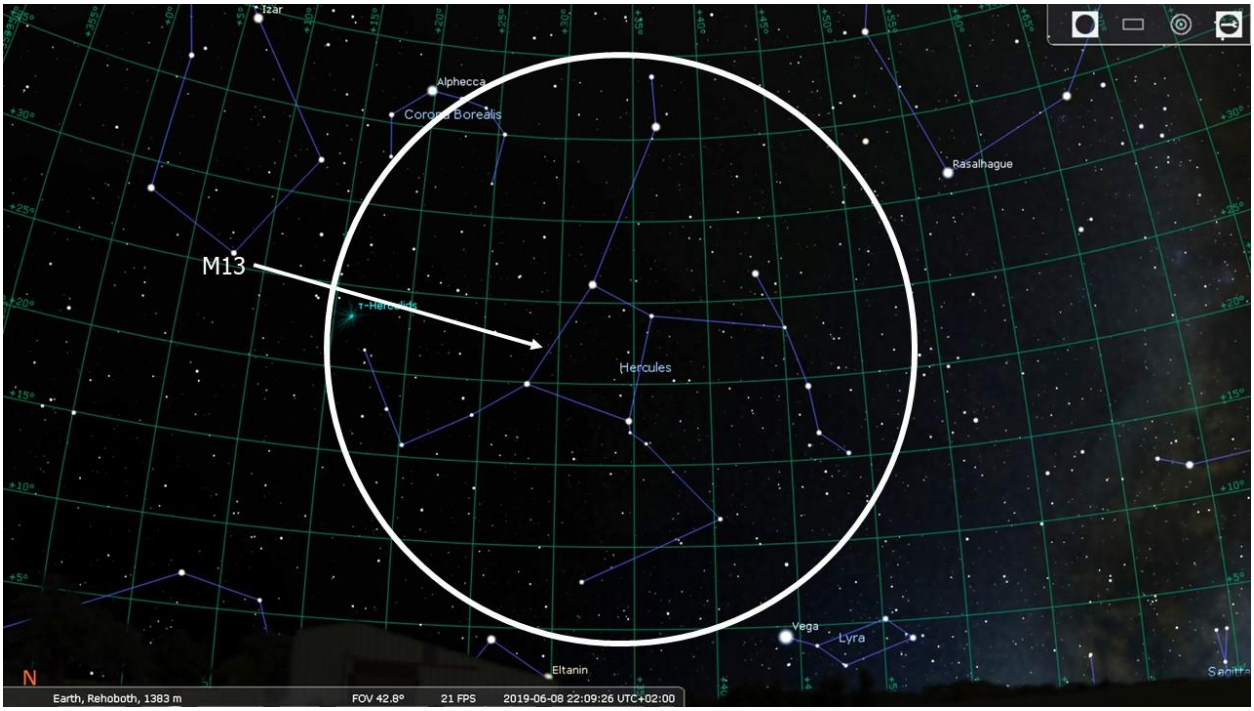


Figure 9.11 Constellation Hercules. Mid-June, 10:00PM.

k. **Hercules:** Does not contain any particularly bright stars, but the shape of this constellation is well defined. It will be low on the horizon throughout the winter.
    i. Deep Sky Objects:
        2. **M13:** One of the brightest globular clusters. Visible as a fuzzy ball with binoculars. Very dense and excellent target for a reflector telescope.

4. East

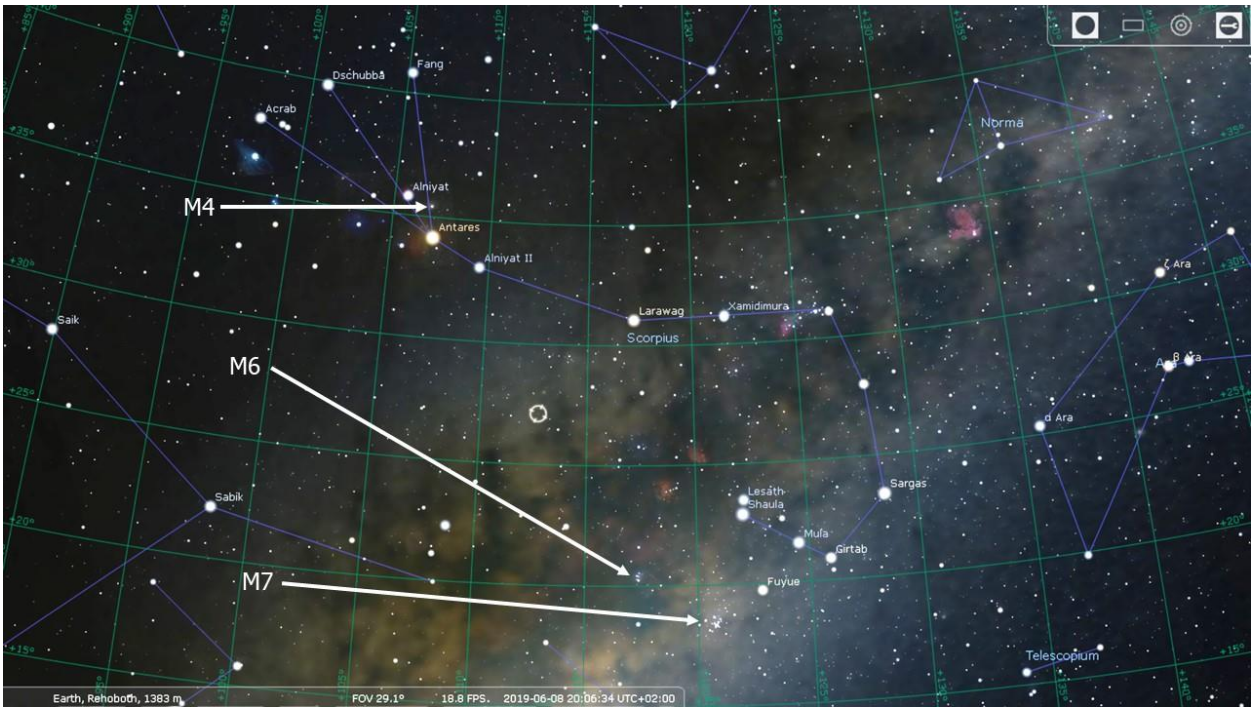


Figure 9.12 Constellation Scorpius. Mid-June, 8:00PM.

l. **Scorpius**: Look for *Antares*, a star with a strong reddish color. Scorpius is one of the brighter constellations and can be found easily by looking for the distinctive 'hook' shape of the tail. Scorpius is near the eastern horizon, right above Sagittarius.
    i. Deep Sky Objects:
        1. **M4 Crab Globular Cluster:** A bright globular cluster. It is one of the nearest globular clusters to our own solar system. As a result, it covers an area about the size of the full moon and is easy to find with binoculars.
        2. **M6 Butterfly Cluster:** A bright open cluster, easily visible with binoculars.
        3. **M7 Ptolemy Cluster:** A very bright open cluster, visible with the naked eye.

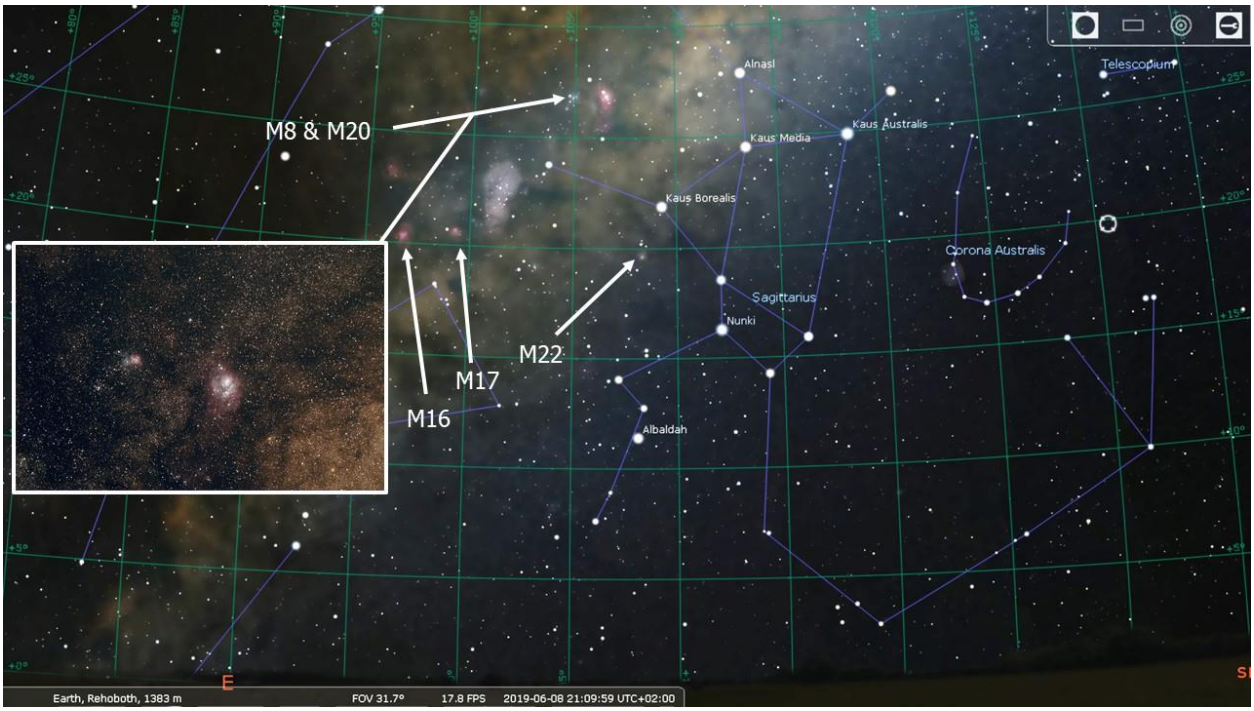


Figure 9.13 Constellation Sagittarius. Mid-June, 9:00PM.

m. **Sagittarius:** Most notable for its "teapot" shape, and its proximity to the center of the Milky Way galaxy. As the Sun sets, Sagittarius will just be rising above the horizon. Binoculars in this area of the sky will offer views of countless stars, and several bright and large nebulas and star clusters.
    i. Deep Sky Objects:
        1. **M22 Great Sagittarius Cluster:** One of the brightest globular clusters in the sky. Easily visible in binoculars, telescope required to view individual stars.
        2. **M8 Lagoon Nebula:** A rather large and bright nebula, visible with the naked eye. Binoculars or a telescope are necessary to bring out any detail in the nebula.
        3. **M20 Trifid Nebula:** Located next to M8, an excellent target for a small telescope. The features in this nebula are well defined and relatively easy to see.
        4. **M17 Omega Nebula:** A small telescope or binoculars are required to see adequately.
        5. **M16 Eagle Nebula:** A nebula paired with a star cluster. Rather large, best viewed through binoculars.

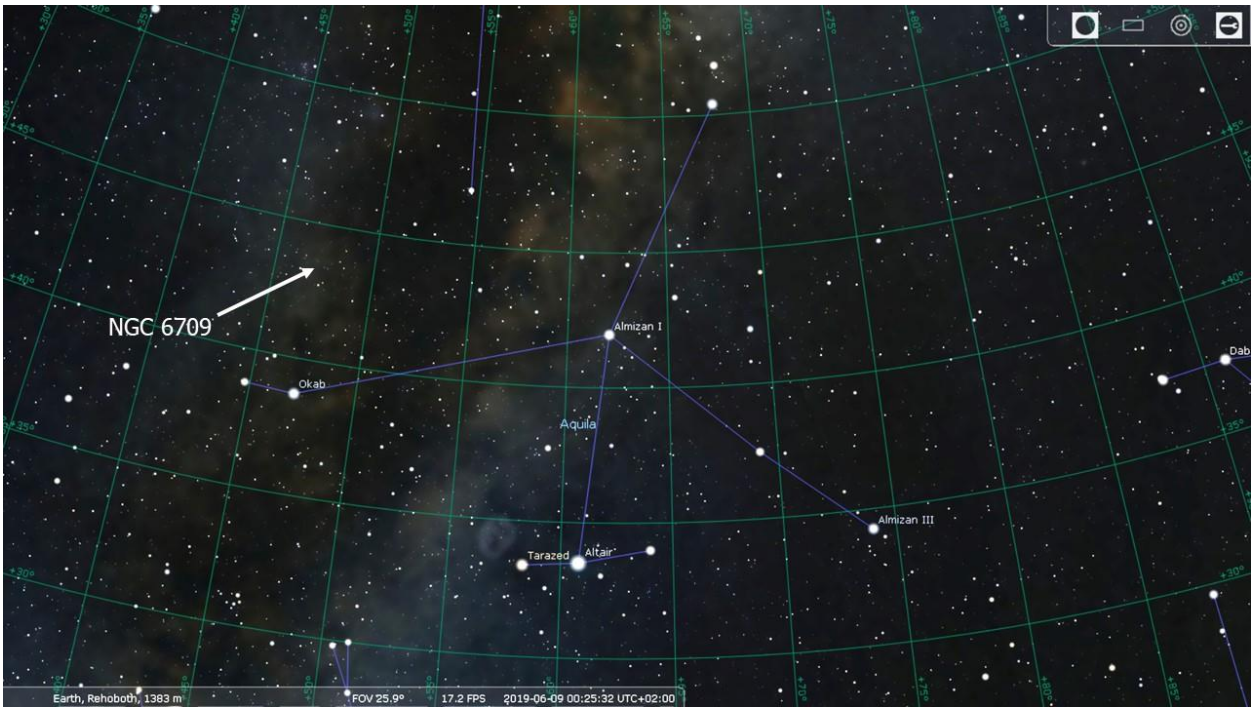


Figure 9.14 Constellation Aquila. Mid-June, 12:00AM.

n. **Aquila** "the eagle": This constellation rises around 9:00PM. Look for *Altair*, the brightest star in Aquila, 12th brightest in the night sky.
    i. Deep Sky Objects:
        1. **NGC 6709:** A loose open cluster, with only around 40 stars. Good target for binoculars.

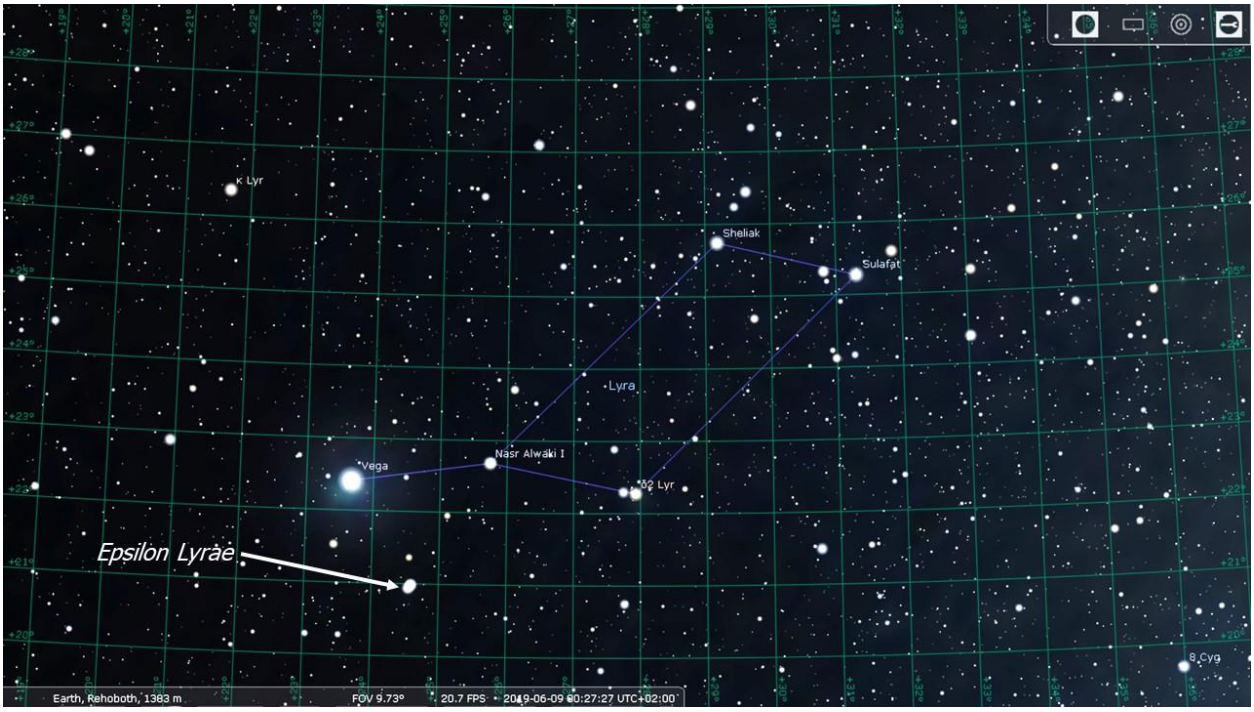


Figure 9.15 Constellation Lyra. Mid-June, 12:00AM.

o. **Lyra** "the lyre": Look for the star *Vega,* fifth brightest star in the night sky. Lyra starts to rise around 9:00PM and will stay in the northern portion of the sky throughout the night.
   i. Deep Sky Objects:
      1. **M57 Ring Nebula:** An easily observed and well-defined planetary nebula. It is quite small, so you can see it with binoculars; a telescope is necessary to see detail.
      2. *Epsilon Lyra "double-double"*: A unique sight in the night sky. Visible to the naked eye, but telescopes are required to split the stars. With the right seeing conditions and a strong enough telescope, one can see two pairs of double stars in the eyepiece.

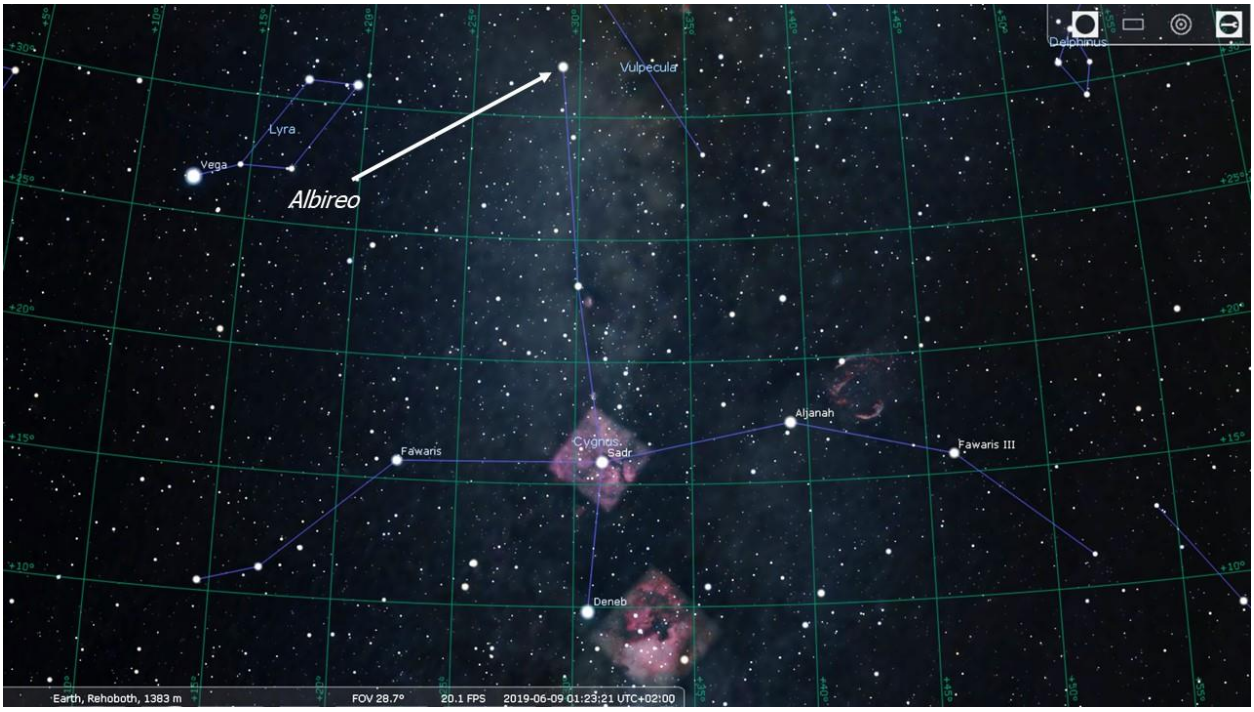


Figure 9.16 Constellation Cygnus. Mid-June, 1:30AM.

p. **Cygnus** "the swan": Look for the star *Deneb,* 19th brightest in the night sky. Cygnus will have risen by midnight.
   i. Deep Sky Objects:
      1. *Albireo***:** A double star, visible as a single star with the naked eye. A small telescope will resolve two stars, quite different in color and brightness. The brighter star is reddish or orange, and the other is blue.

July

Sunset: approximately 6:25 PM

Sunrise: approximately 7:30 AM

1. South
    a. Constellations have shifted slightly clockwise.
    b. **Carina** approaches the horizon at sunset.
2. West
    a. Constellations are slightly lower after sunset than in June.
    b. **Canis Major** and **Cancer** are no longer visible.
    c. **Leo** approaches the horizon at sunset and will be too low to see at the end of July.
3. North
    a. Constellations have shifted slightly counterclockwise.
4. East
    a. Constellations are slightly higher after sunset than in June.

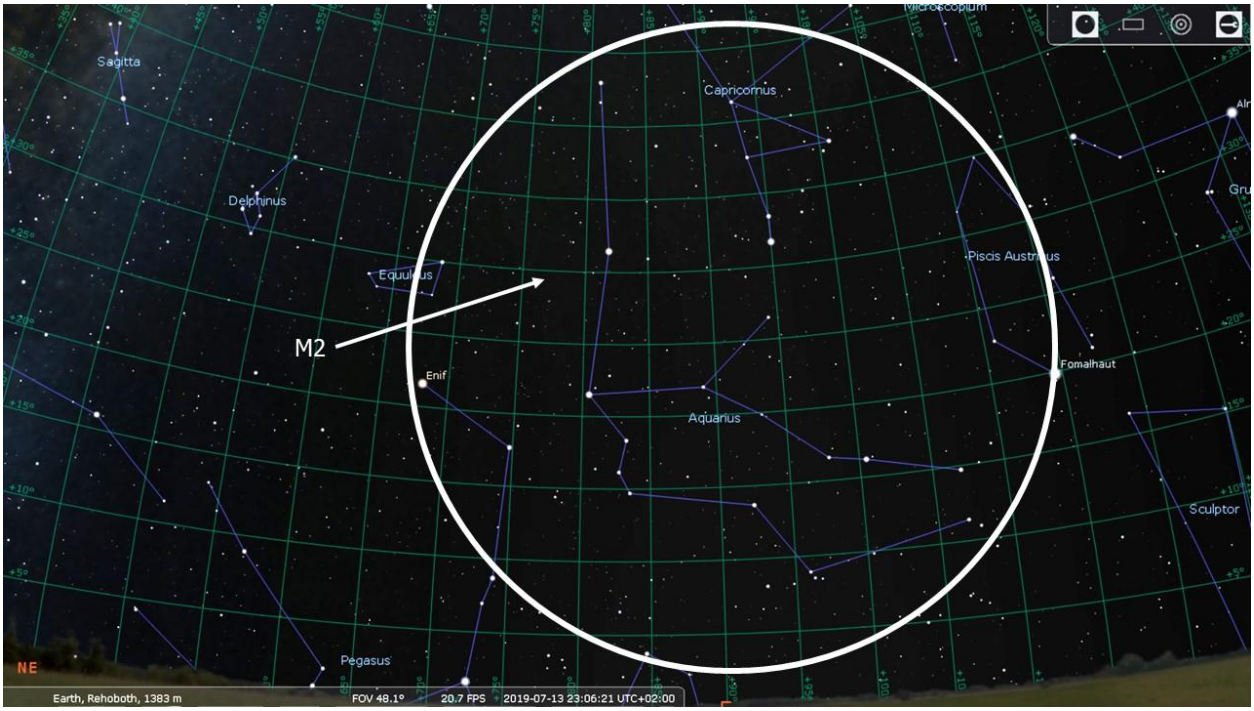


Figure 9.17 Constellation Aquarius. Mid-July, 11:00 PM.

    q. **Aquarius** "water bearer": A relatively dim, but large constellation. Aquarius has risen from the east by 11:00PM.
        i. Deep Sky Objects:
            1. **M2**: One of the largest known globular clusters in the sky. Just bright enough to be visible with the naked eye.

August

Sunset: approximately 6:35 PM

Sunrise: approximately 7:15 AM

1. South
    a. Constellations have shifted slightly clockwise.
    b. **Carina** sets below the horizon by 10:00PM.
2. West

   a. Constellations are slightly lower after sunset than in June.
   b. **Leo** is no longer visible after sunset.
3. North
   a. Constellations have shifted slightly counterclockwise.
4. East
   a. Constellations are slightly higher after sunset than in June.

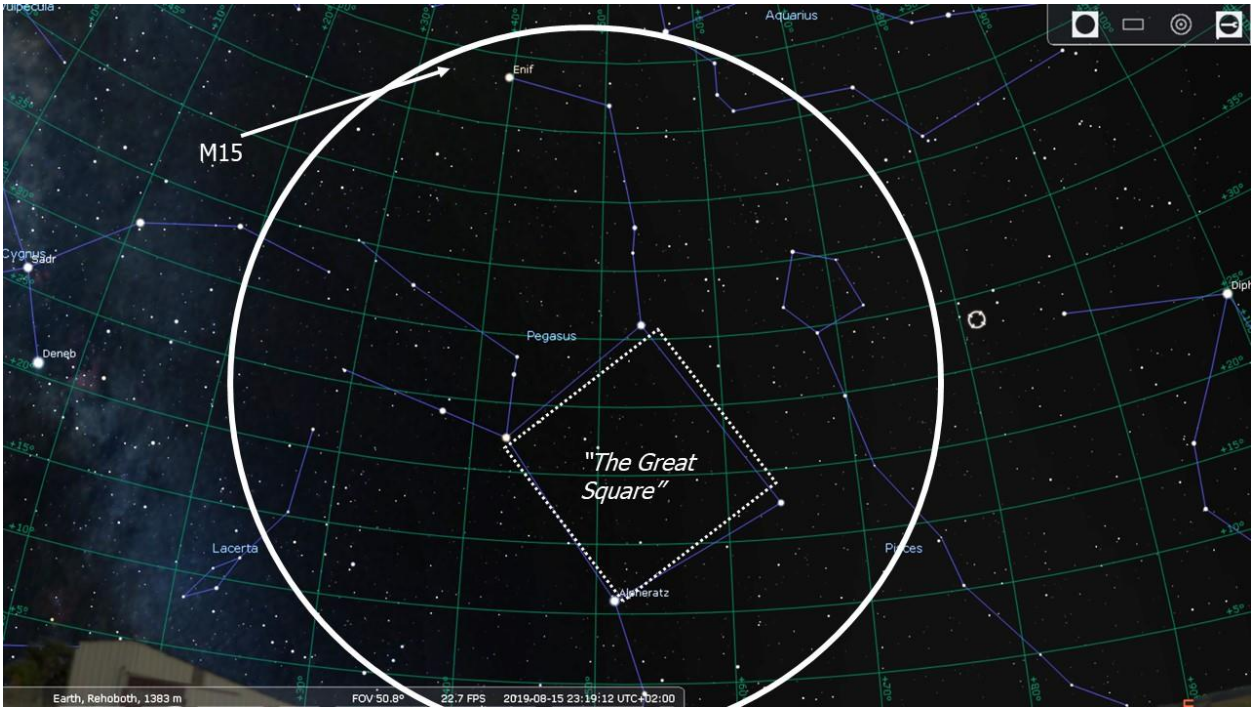


Figure 9.18 Constellation Pegasus. Mid-August, 11:00PM.

   r. **Pegasus** "winged horse": Pegasus has risen above the eastern horizon by midnight. Look for the "great square," made of up four of the brighter stars in Pegasus.
      i. Deep Sky Objects:
         1. **M15**: One of the densest globulars in the Milky Way, just barely visible with the naked eye.

September

Sunset: approximately 6:45 PM

Sunrise: approximately 6:45 AM

1. South
   a. Constellations have shifted slightly clockwise
   b. **Carina** is no longer visible.
2. West
   a. **Virgo** approaches the horizon at sunset and will not be visible by the end of September.
   b. **Scorpius** has shifted from east to west.
3. North

a. Constellations have shifted slightly counterclockwise.
b. **Lyra** is now more northern than eastern.

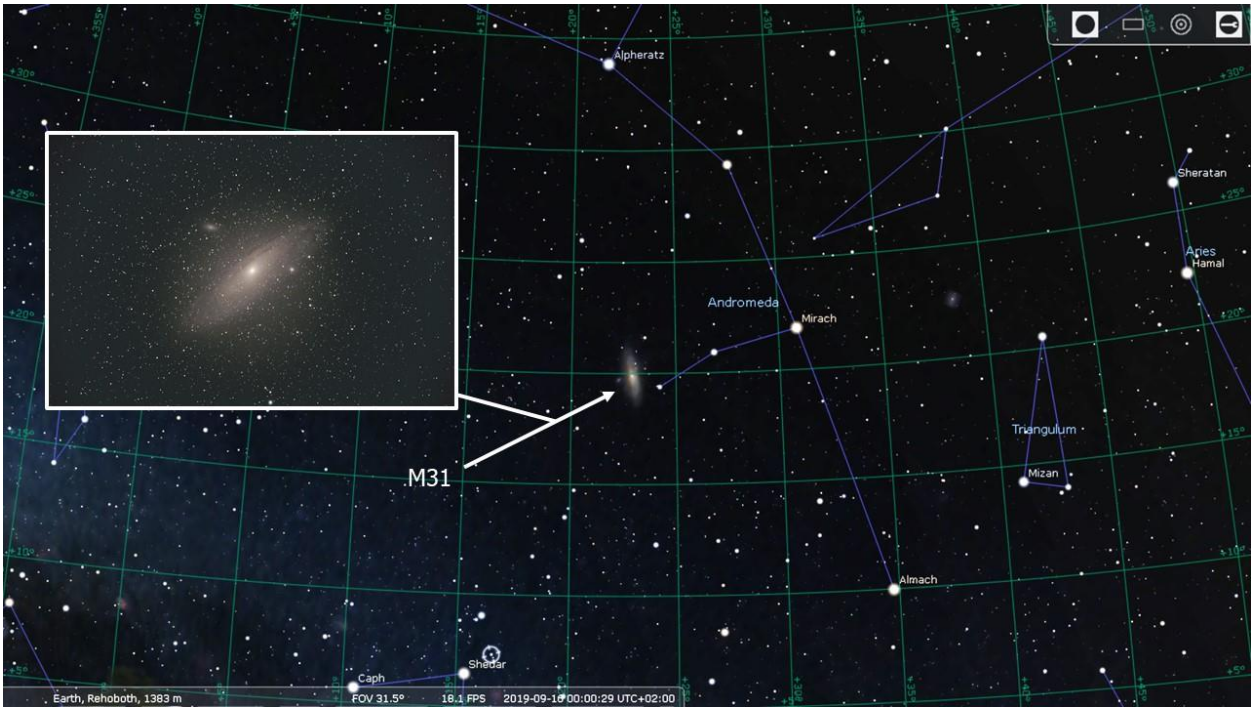


Figure 9.19 Constellation Andromeda. Mid-September, 12:00AM.

s. **Andromeda:** A relatively dim constellation that branches out from Pegasus. Visible above the horizon by 10:00PM.
    i. Deep Sky Objects
        1. **M31 Andromeda Galaxy:** One of the brightest and largest galaxies of the night sky. Takes up an area several times larger than the full moon. Visible with the naked eye, but a telescope or binoculars can resolve more detail in the disc of the galaxy.

t. East
a. Constellations are slightly higher after sunset than in June.

Section III | Winter Star Tours (June to September): Sunset to Sunrise

The following section outlines some major constellations and deep sky objects that can be seen all throughout the winter night. The section could be useful to guests specifically interested in staying up and observing the night sky past midnight. In the month sections after June, only new information (constellations that are now visible or no longer visible) will be outlined.

June

Sunset: approximately 6:15 PM

Sunrise: approximately 7:15 AM

Constellations

1. South

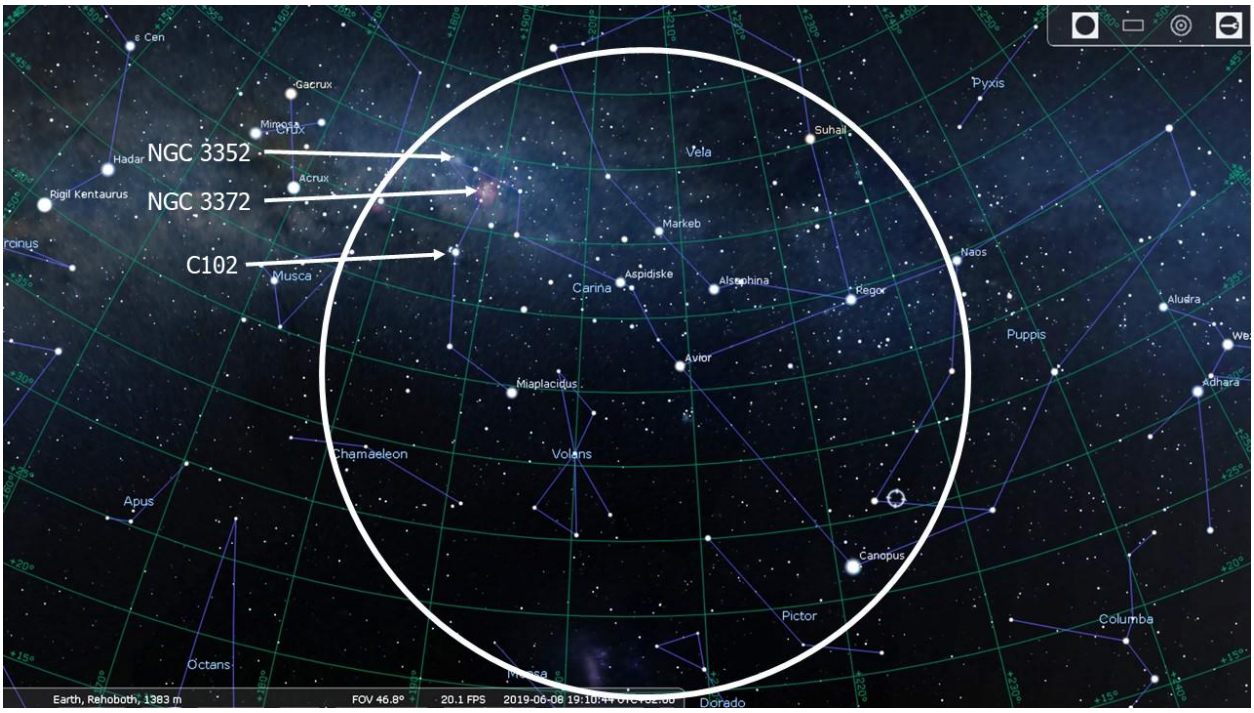


Figure 9.20 Constellation Carina. Mid-June, 7:00PM.

a. **Carina** "keel of the ship": Look for *Canopus*, "the Great Star of the South." This is the second brightest star in the night sky. After sunset, it is almost directly SW, near the horizon. It sets rather early, around 9:30PM. Carina sets by 4:00AM.
    i. Deep sky objects:
        1. **NGC 3372 Carina Nebula:** Huge naked eye object, excellent target for binoculars or telescopes, as in the area are numerous open star clusters and other nebulas.

2. **NGC 3372 Keyhole Nebula:** An object within the Carina Nebula. Binocular or telescope required. Upwards of 1200 stars to see in the star cluster within, very distinct dust lanes.
3. **C102 Southern Pleiades:** An open star cluster visible with the naked eye.
4. **NGC 3532 Wishing Well Cluster:** One of the most brilliant and colorful open clusters in the sky.

Figure 9.21 Constellation Crux. Mid-June, 7:00PM.

b. **Crux** "southern cross": Look for the blueish-white star *Acrux*, 13th brightest star in the night sky. Also notable is the star *Gacrux*, a red giant, for its strong reddish orange color. Crux sets around 5:00AM.
    i. Deep Sky Objects:
        1. **NGC 4755 Jewel Box:** Though not very populated, it is a bright and colorful open cluster visible to the naked eye. Around a hundred stars can be seen with binoculars or a telescope.
        2. **C99 Coalsack Nebula:** One of the most 'visible' nebulas in the night sky. Appears as a large dark splotch in the Milky Way, right next to Acrux.

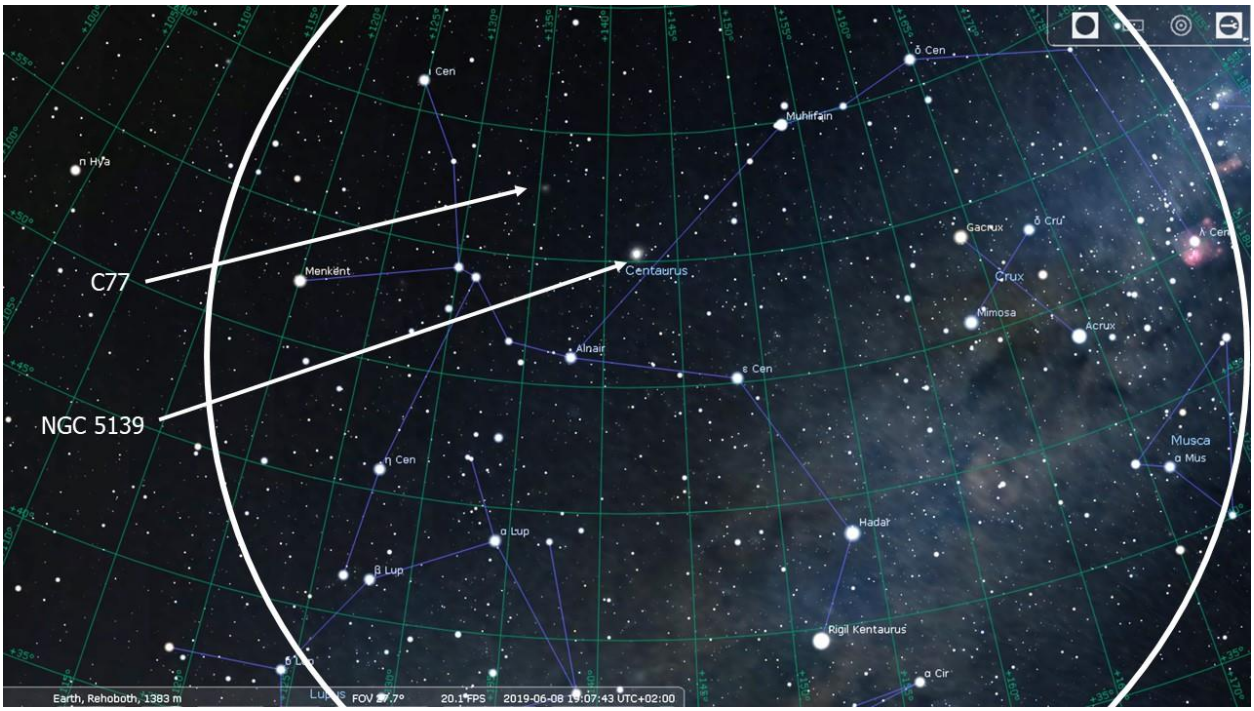


Figure 9.22 Constellation Centaurus. Mid-June, 7:00PM.

c. **Centaurus:** Brightest constellation in the southern sky. Look for *Alpha Centauri*, the third brightest star in the night sky. Noteworthy: this is the nearest star system to our own solar system. Also notable is the star *Beta Centauri*. *Alpha Centauri* and *Beta Centauri* are the "pointer stars" useful for finding the south pole. *Alpha Centauri* sets at 7:00AM, just as the sun is rising.
    i. Deep Sky Objects:
        1. **C77 Centaurus A:** One of the brightest galaxies in the night sky. A telescope or binoculars are required. An interesting sight, as it is believed this is a galaxy formed by the merging of two galaxies.
        2. **NGC 5139 Omega Centauri:** Largest globular cluster in the Milky Way. The naked eye can just barely see it as a moon-sized speck in the sky, a telescope or binoculars would grant a much better view.

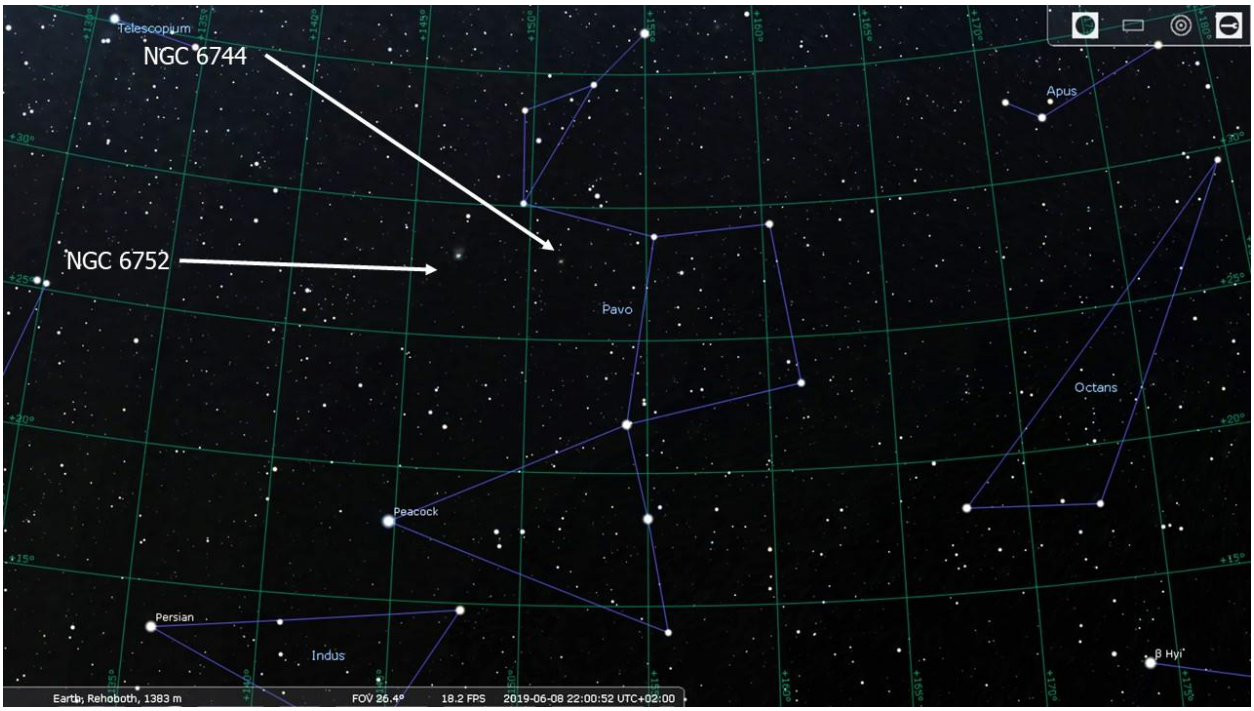


Figure 9.23 Constellation Pavo. Mid-June, 10:00PM.

d. **Pavo** "the peacock": Pavo is not a very bright constellation, but its stars are bright enough to find without too much difficulty. From Namibia, this is a circumpolar star (will always be in the sky), although in the summer months, much of it dips below the horizon. After sunset, Pavo has just risen in the SW sky. Pavo does not set at night during June.
    i. Deep Sky Objects:
        1. **NGC 6752:** The third brightest globular cluster in the night sky. Known for having a particularly dense core. An excellent target for binoculars or a telescope.
        2. **NGC 6744** A spiral galaxy within the Virgo Cluster. Although it is slightly larger, it is comparable to the Milky Way galaxy in structure. A telescope is required to bring up any details in the disc of the galaxy.

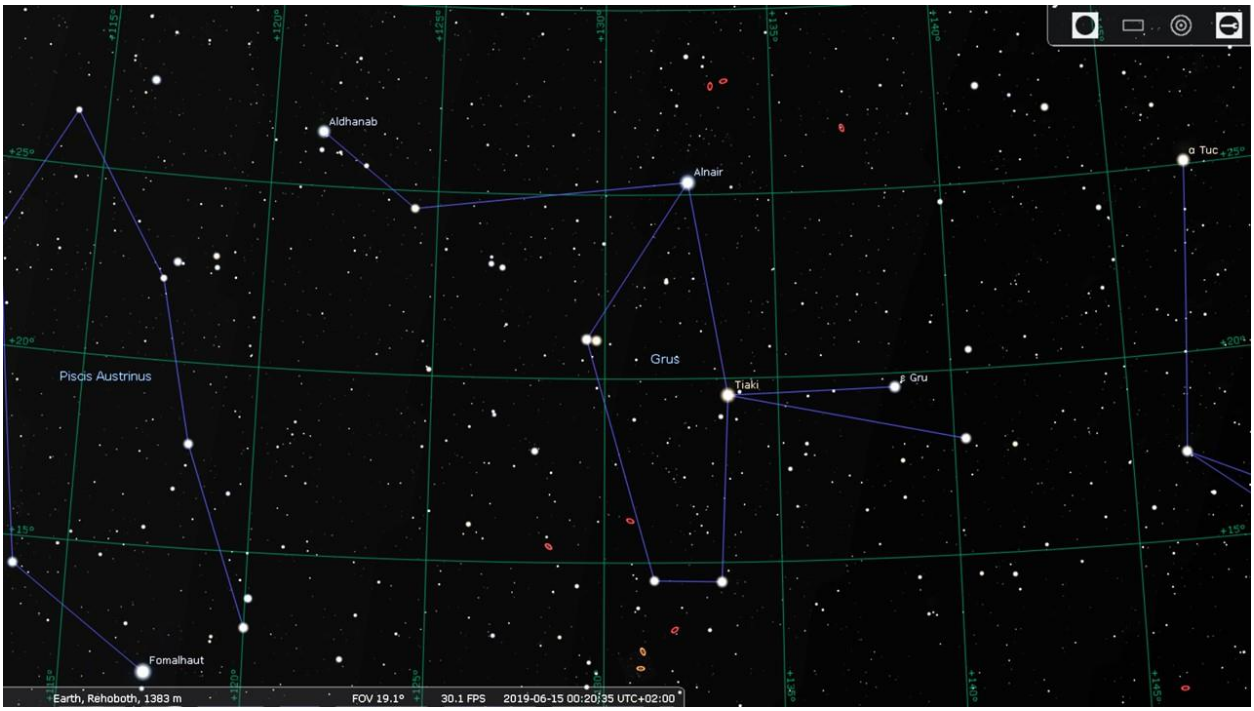


Figure 9.24 Constellation Grus. Mid-June, Midnight.

e. **Grus** "the crane": Grus is a moderately bright but small constellation. It will have risen in the south by Midnight and will not set at night during June.

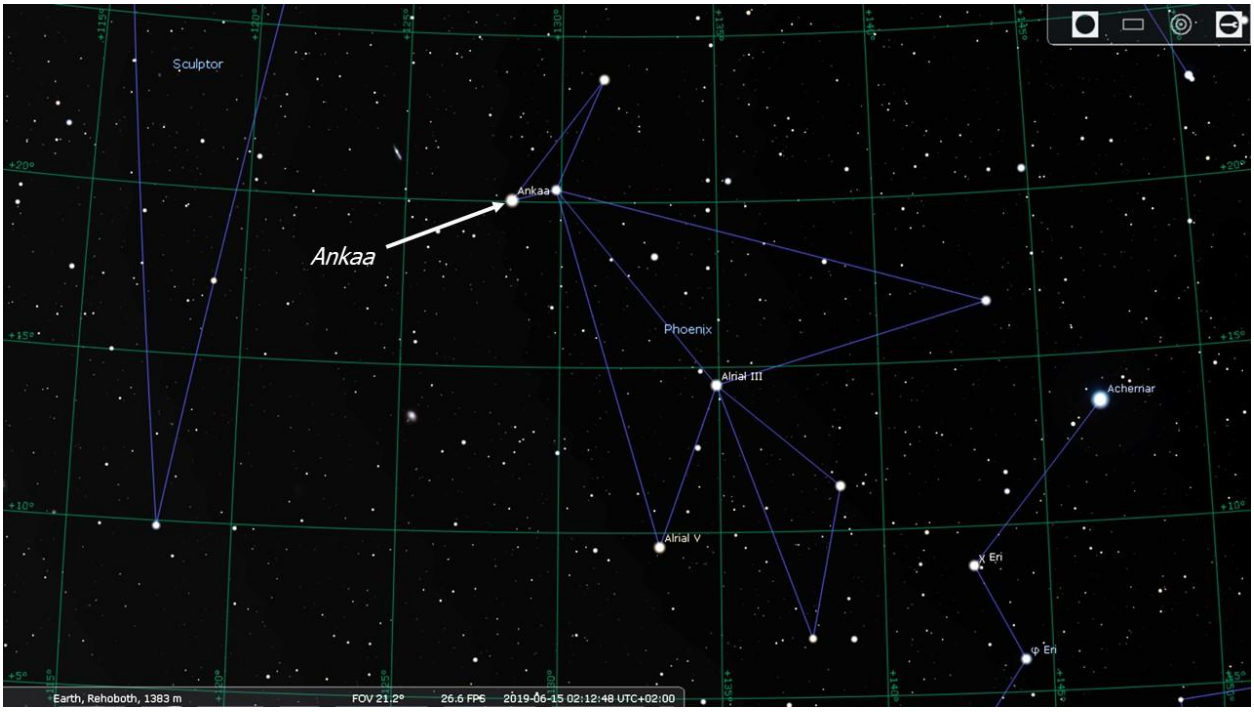


Figure 9.25 Constellation Phoenix. Mid-June, 2:00AM.

f. **Phoenix** "the phoenix": Phoenix is another moderately bright constellation. Look for its brightest star, *Ankaa,* notable for its orangish tint. Phoenix will have risen in the south by 1:30AM.

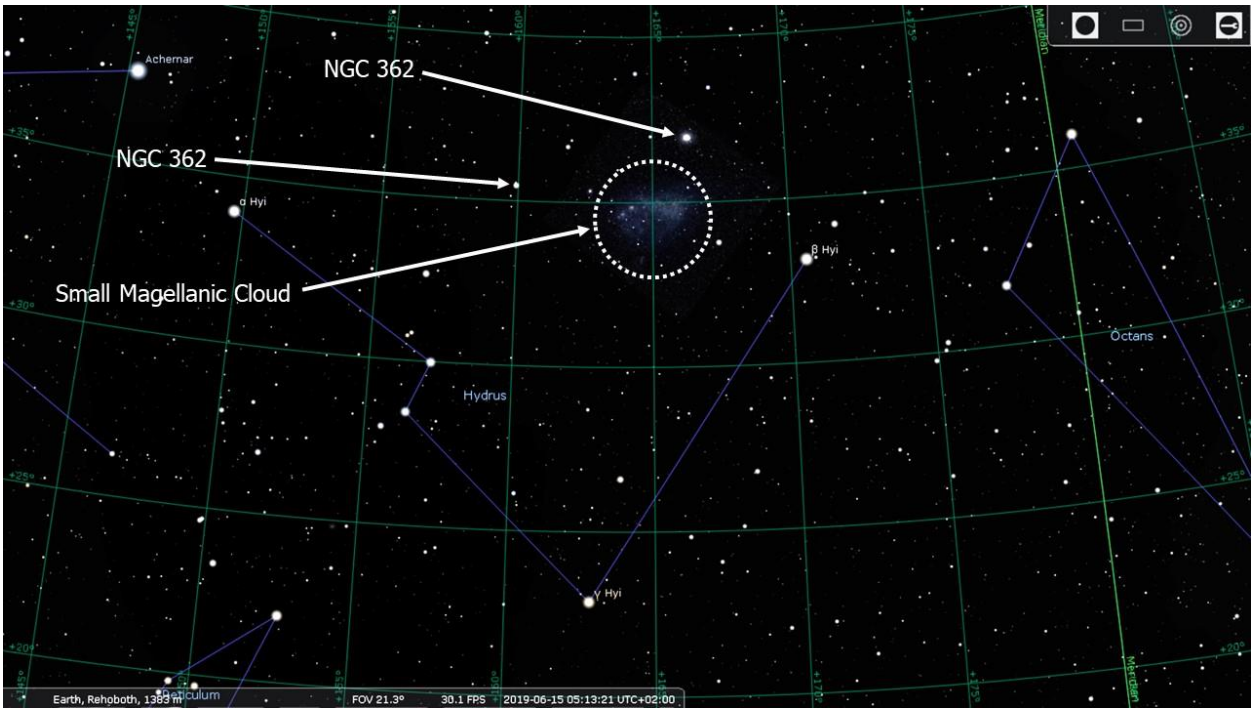


Figure 9.26 Constellation Hydrus. Mid-June 5:00AM.

g. **Hydrus** "the water snake": Hydrus is a very small and dim constellation, but it is home to several very noteworthy deep sky objects. This is a circumpolar constellation, meaning it never sets in the sky. However, it is best viewed when well above the horizon. In June, it can offer adequate views by around 2:00AM.
    i. Deep Sky Objects:
        1. **Small Magellanic Cloud:** A famous southern sky object. The Small Magellanic Cloud is a dwarf galaxy interacting with the Milky Way galaxy. Telescopes and binoculars both offer dense views of stars.
        2. **NGC 362:** A brilliant naked eye globular cluster, offering excellent views to telescope observers.
        3. **47 Tuc:** The second brightest globular cluster in the night sky, visible with the naked eye.

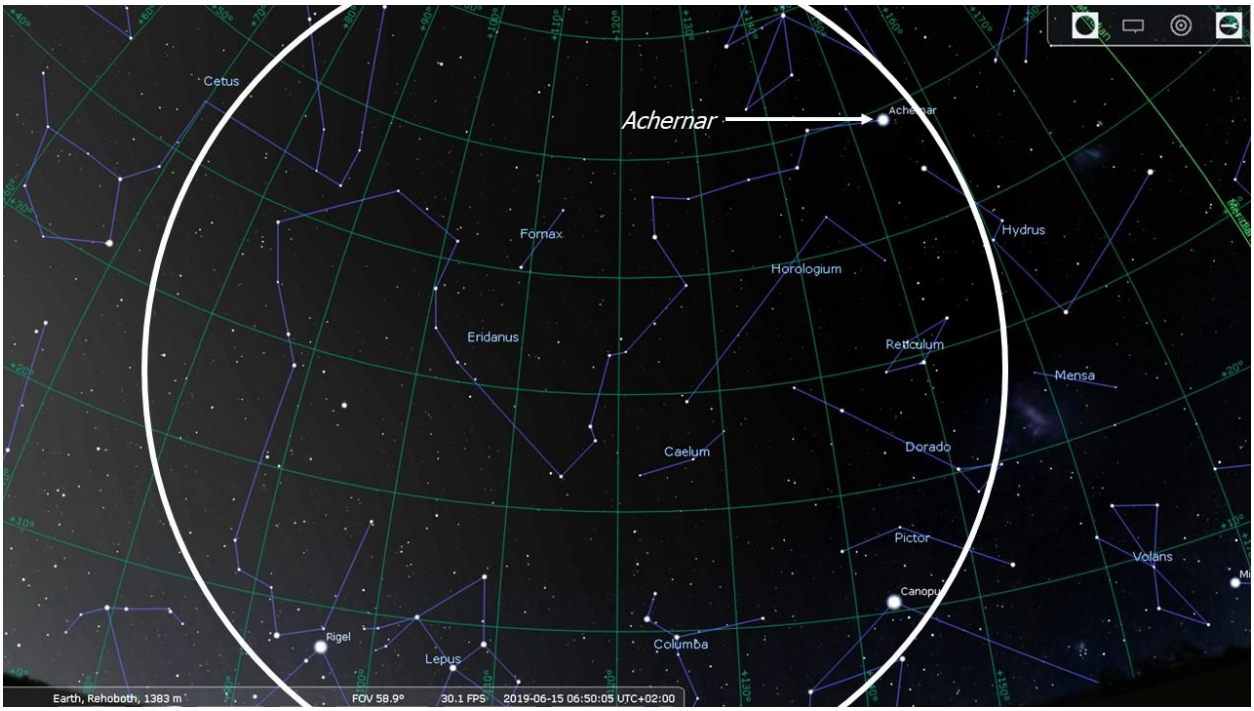


Figure 9.27 Constellation Eridanus. Mid-June, 7:00AM.

h. **Eridanus** "the river": Eridanus is the sixth largest constellation in the night sky, although it is not particularly bright. Most notable in Eridanus is its brightest star, *Achernar*. Through a telescope, *Achernar* is visibly flattened, or oval-shaped. *Achernar* rises above the southern horizon just after midnight. Eridanus will not have fully risen in the sky until the sun has nearly risen, at 7:00AM.

2. West to East

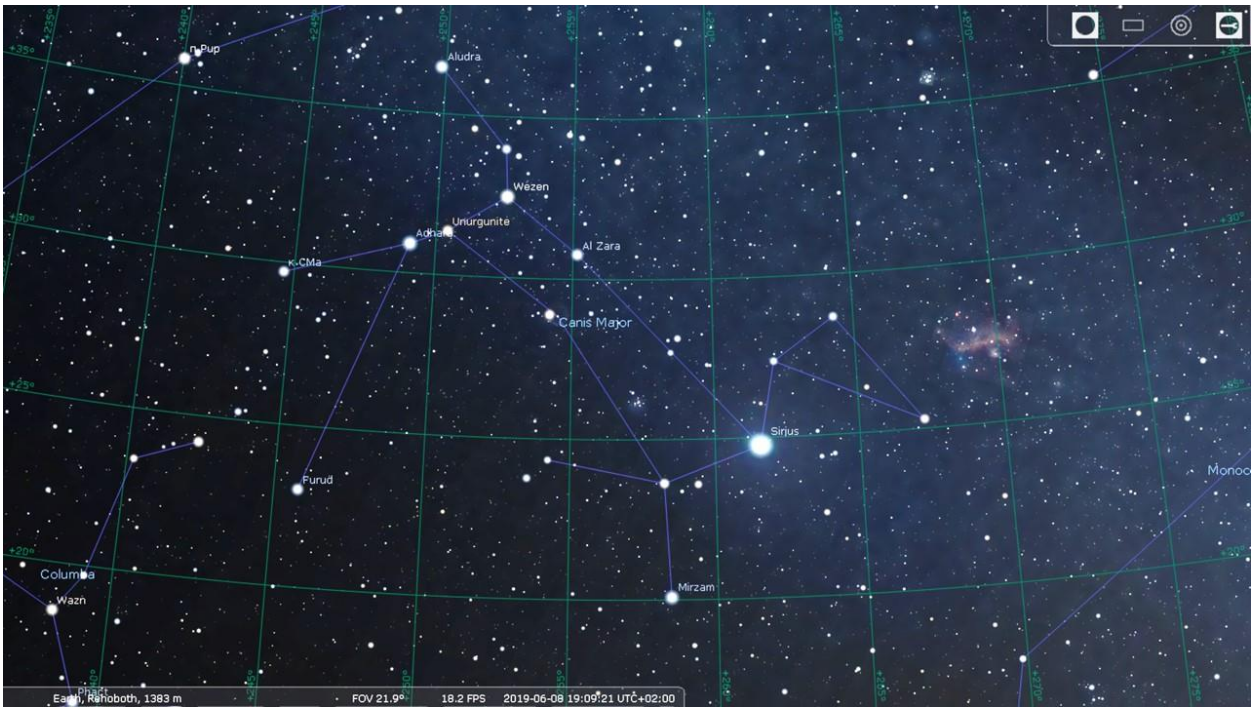


Figure 9.28 Constellation Canis Major, Mid-June, 7:00PM

i. **Canis Major** "greater dog": Look for *Sirius* the "dog star," brightest star in the night sky. Visible in the west just after sunset, but not for long. By the end of June, it will be almost too low on the horizon to see.

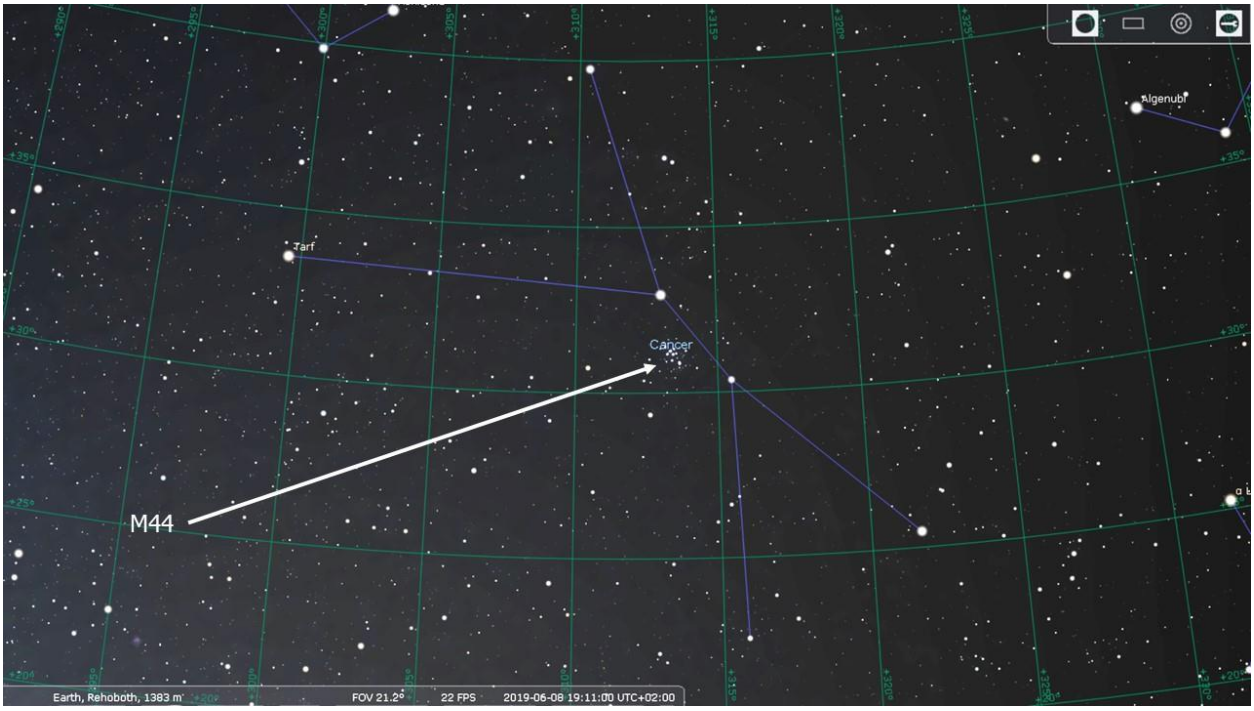


Figure 9.29 Constellation Cancer, Mid-June, 7:00PM

j. **Cancer** "the crab"**:** The constellation itself is quite dim, and near the western horizon. It will not be visible after June.
    i. Deep Sky Objects:
        1. **M44 Beehive Cluster:** One of the brightest open clusters in the night sky. A telescope or binoculars are required to make out the individual stars within. Good variety of color (reds and blues) among the stars within.

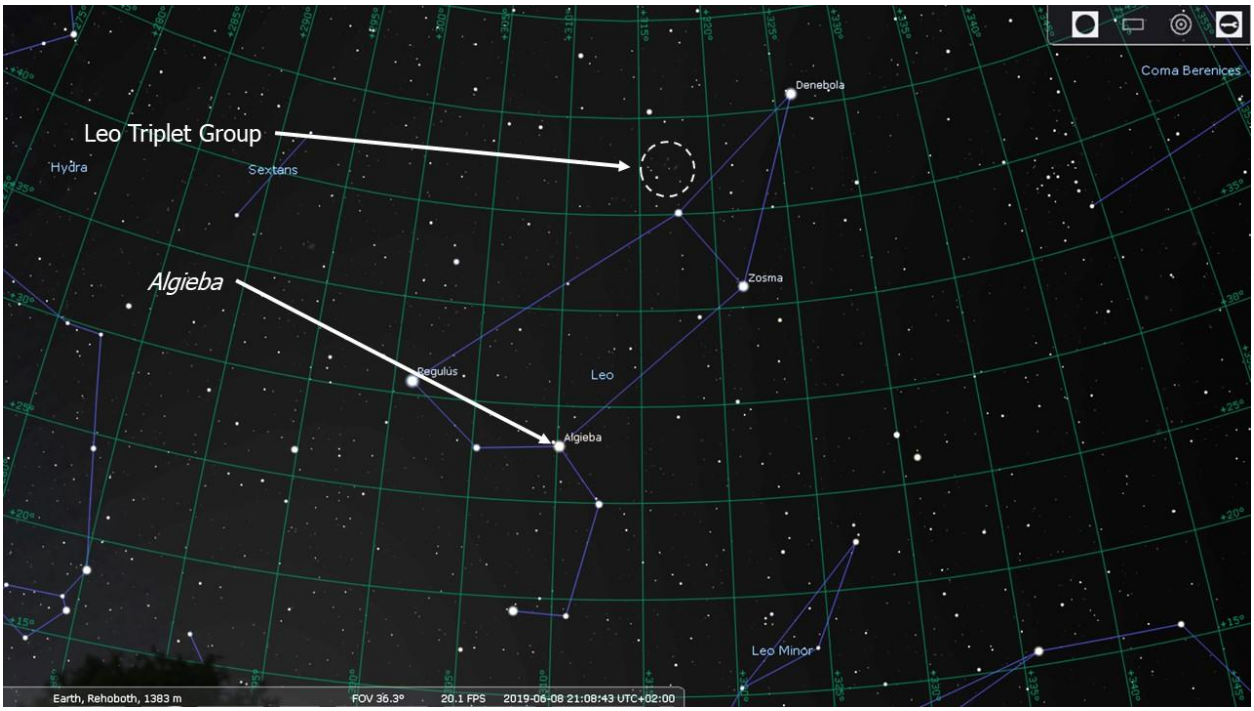


Figure 9.30 Constellation Leo, Mid-June, 9:00PM

k. **Leo** "the lion": Look in the west for a collection of bright stars called the "sickle." In June, Leo sets at 10:00PM.
    i. Deep Sky Objects:
        1. *Algieba*: A bright, double star, positioned toward the middle of the "sickle." A telescope is ideal to visually split the two stars. However, it could be done with strong enough binoculars (x60 magnification) and a good eye.
        2. **Leo Triplet Group**: With a telescope, numerous galaxies can be seen in Leo. Perhaps the best known are the three galaxies in the Leo Triplet Group: **M65, M66,** and **NGC 3628.**

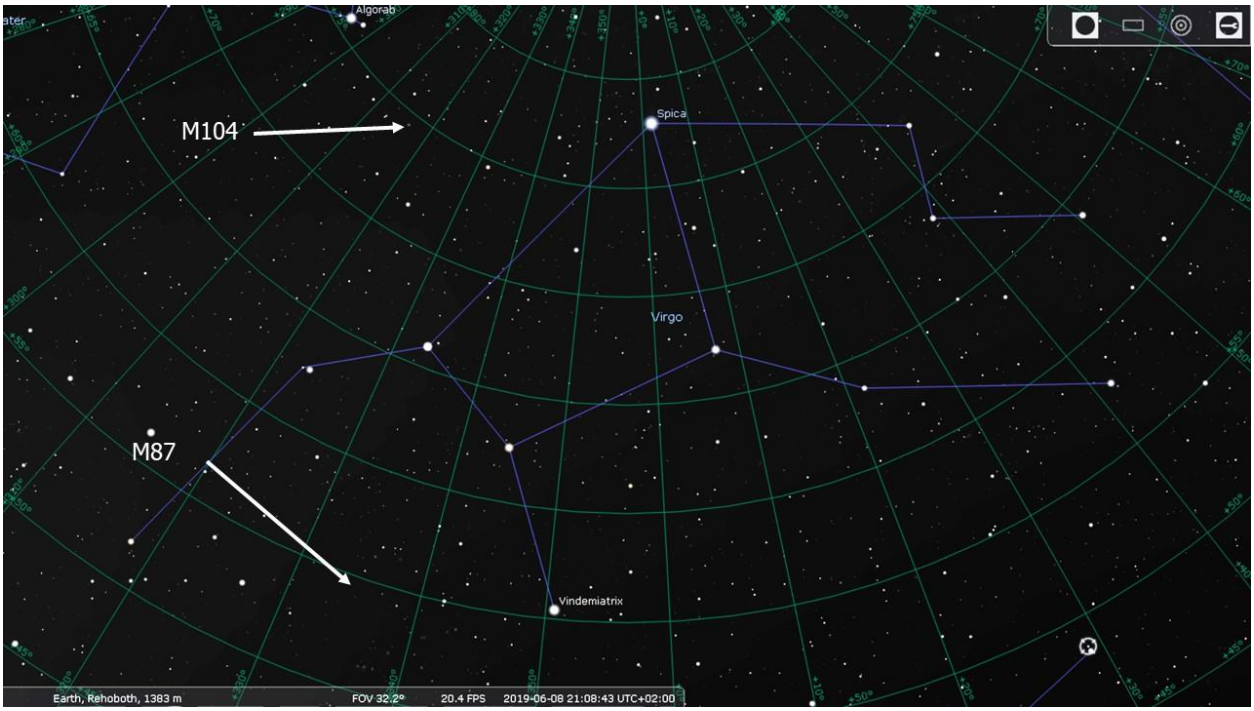


Figure 9.31 Constellation Virgo, Mid-June, 9:00PM

l. **Virgo** "the virgin": Look in the west for *Spica*, a bluish-white colored star. Virgo is not an especially bright constellation, but most notable is the Virgo Cluster. A reflector telescope can bring out well over a hundred galaxies from this cluster, although most are small and too faint to make out much detail. Virgo sets around 3:00AM.
    i. Deep Sky Objects:
        1. **M87 Virgo A**: A massive elliptical galaxy toward the center with a bright core. Visible with a small telescope or binoculars.
        2. **M104 Sombrero Galaxy:** An interesting object, as it's a galaxy seen from the side rather than from above or below. Easily visible in binoculars. With a sizeable telescope (10"+) one can easily see the bulge in the center of the galaxy and might be able to see the dust lanes.

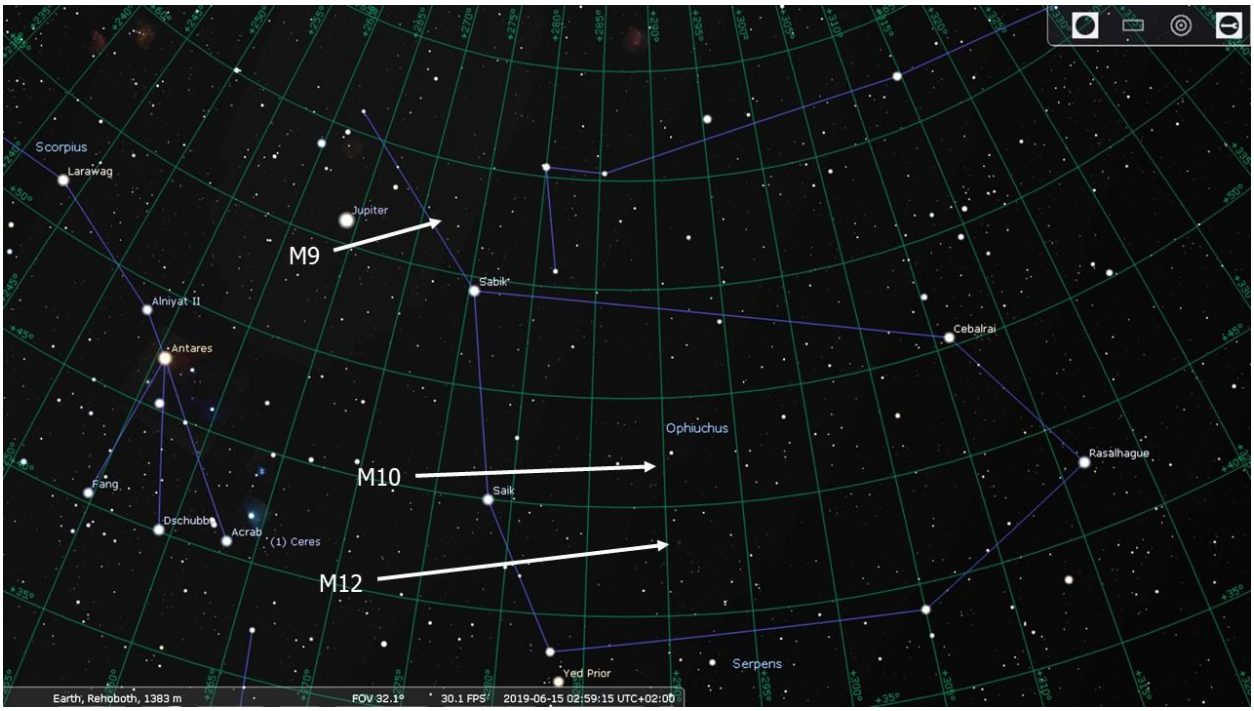


Figure 9.32 Constellation Ophiuchus. Mid-June, 3:00AM.

m. **Ophiuchus** "the serpent bearer": A fairly large but dim constellation. It fully is visible just above the eastern horizon right after sunset. Ophiuchus sets around 6:00AM.
    i. Deep Sky Objects:
        1. **M9:** A dim globular cluster near the center of the Milky Way galaxy. Visible with binoculars, stars can be resolved with an 8" telescope.
        2. **M10:** A dim globular cluster visible with binoculars. Stars can be resolved with a 6" telescope.
        3. **M12:** A dim globular cluster visible with binoculars. Stars can be resolved with an 8" telescope.
        4. **C349 Summer Beehive Cluster:** An open star cluster, just visible with the naked eye. Excellent target for binoculars.

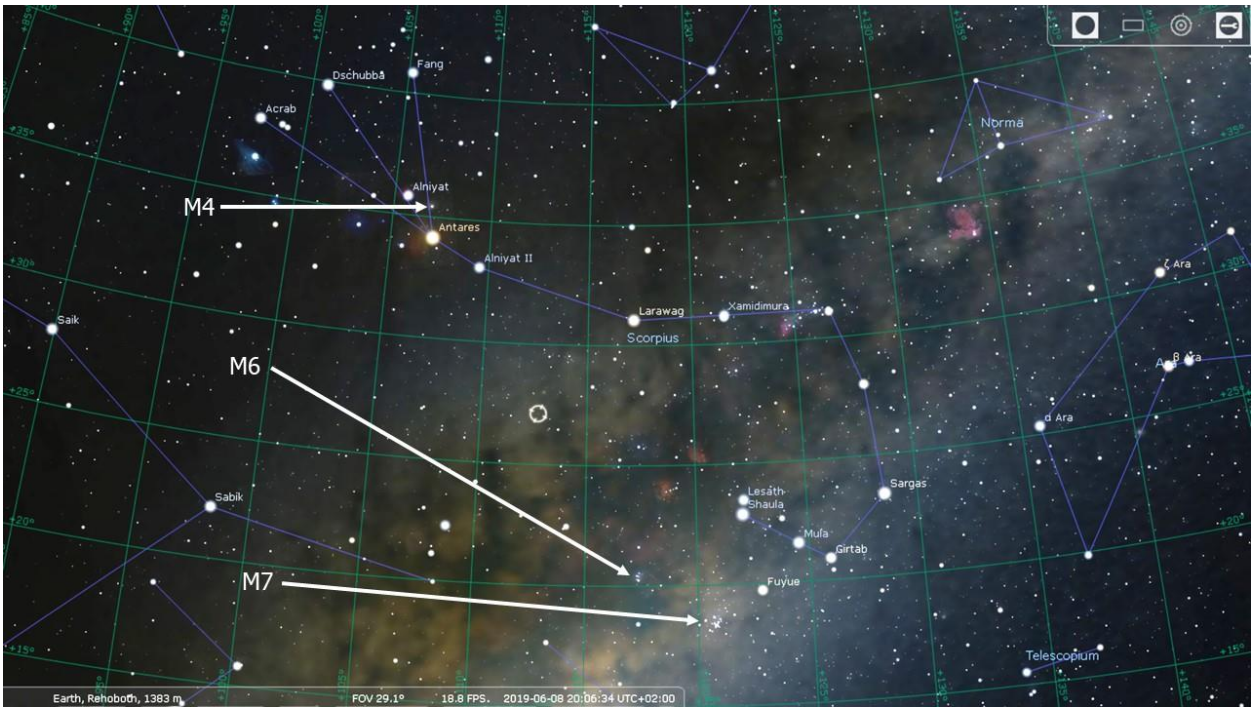


Figure 9.33 Constellation Scorpius. Mid-June, 8:00PM.

n. **Scorpius**: Look for *Antares*, a star with a strong reddish color. Scorpius is one of the brighter constellations and can be found easily by looking for the distinctive 'hook' shape of the tail. At sunset, Scorpius is near the eastern horizon, right above Sagittarius. Scorpius sets just as the sun rises, around 7:00AM.
    i. Deep Sky Objects:
        1. **M4 Crab Globular Cluster:** A bright globular cluster. It is one of the nearest globular clusters to our own solar system. As a result, it covers an area about the size of the full moon and is easy to find with binoculars.
        2. **M6 Butterfly Cluster:** A bright open cluster, easily visible with binoculars.
        3. **M7 Ptolemy Cluster:** A very bright open cluster, visible with the naked eye.

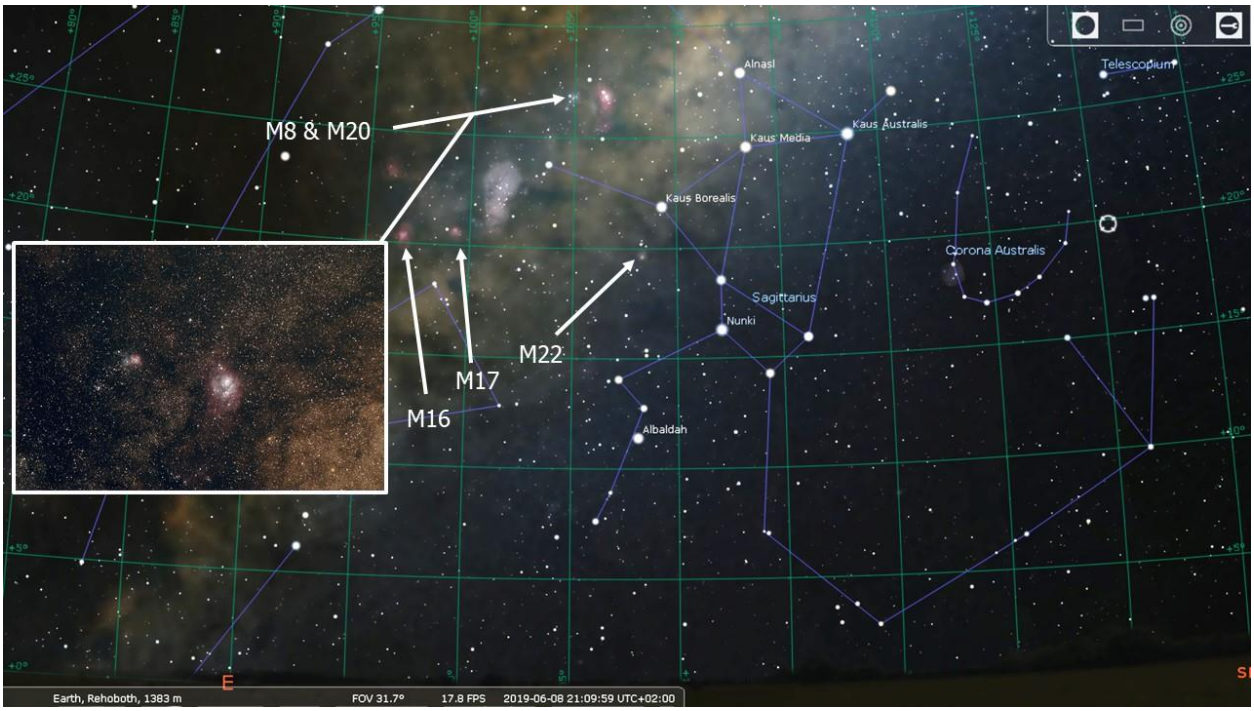


Figure 9.34 Constellation Sagittarius. Mid-June, 9:00PM.

o. **Sagittarius:** Most notable for its "teapot" shape, and its proximity to the center of the Milky Way galaxy. As the Sun sets, Sagittarius will just be rising above the eastern horizon. Sagittarius is visible near the western horizon as the sun rises. Binoculars in this area of the sky will offer views of countless stars, and several bright and large nebulas and star clusters.
    i. Deep Sky Objects:
        1. **M22 Great Sagittarius Cluster:** One of the brightest globular clusters in the sky. Easily visible in binoculars, a telescope is required to view individual stars.
        2. **M8 Lagoon Nebula:** A rather large and bright nebula, visible with the naked eye. Binoculars or a telescope are necessary to bring out any detail in the nebula.
        3. **M20 Trifid Nebula:** Located next to M8, an excellent target for a small telescope. The features in this nebula are well defined and relatively easy to see.
        4. **M17 Omega Nebula:** A small telescope or binoculars are required to see adequately.
        5. **M16 Eagle Nebula:** A nebula paired with a star cluster. Rather large, best viewed through binoculars.

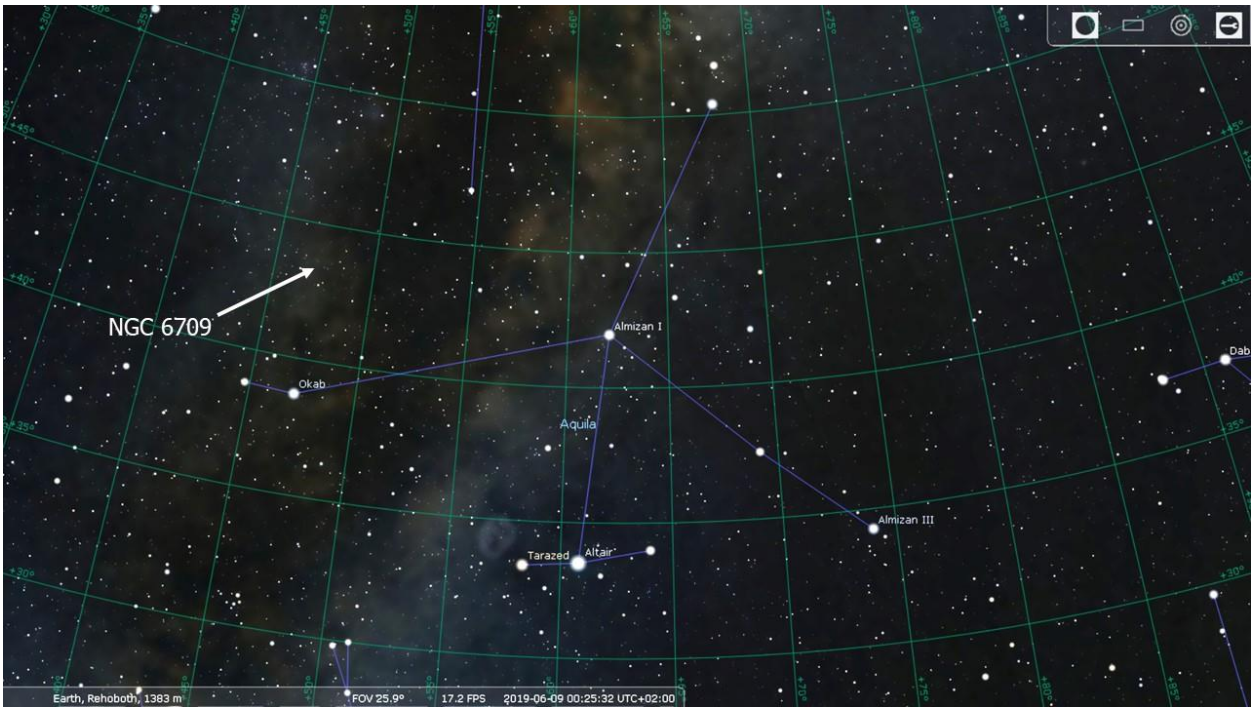


Figure 9.35 Constellation Aquila. Mid-June, 12:00AM.

p. **Aquila** "the eagle": This constellation rises around 9:00PM. Look for *Altair*, the brightest star in Aquila, 12th brightest in the night sky. Aquila is near the NW horizon as the sun rises.
    i. Deep Sky Objects:
        1. **NGC 6709:** A loose open cluster, with only around 40 stars. Good target for binoculars.

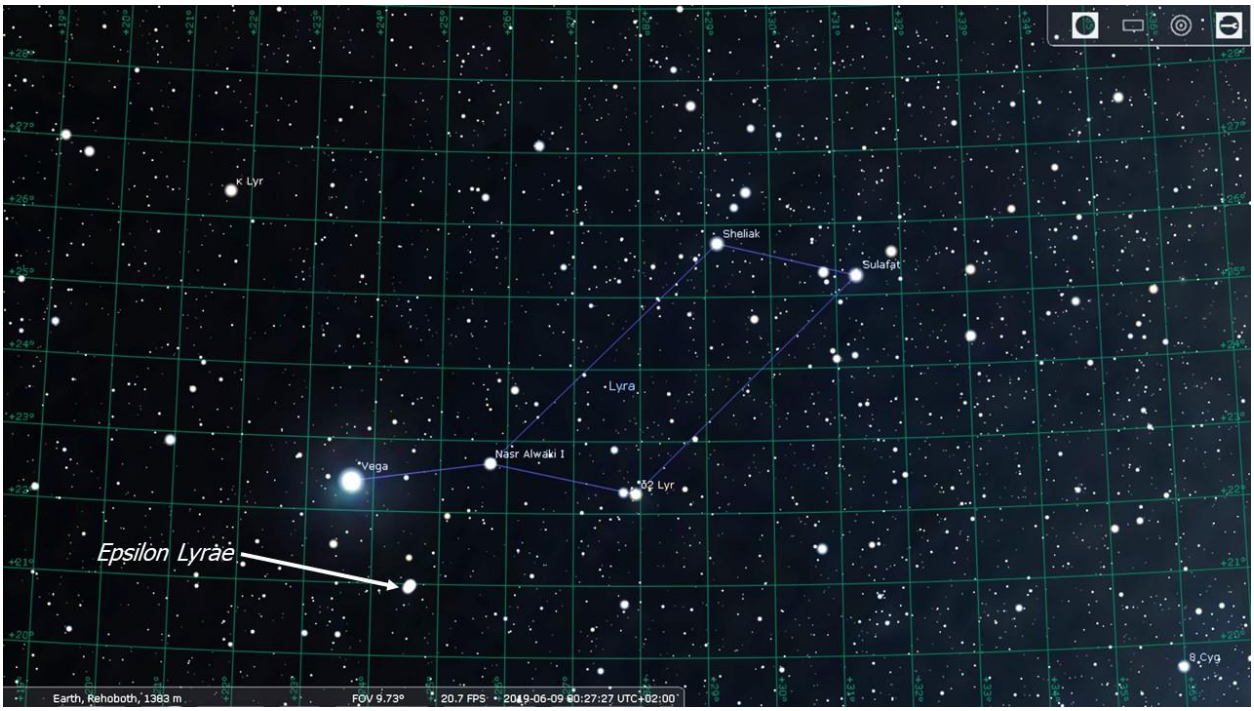


Figure 9.36 Constellation Lyra. Mid-June, 12:00AM.

q. **Lyra** "the lyre": Look for the star *Vega,* fifth brightest star in the night sky. Lyra starts to rise around 9:00PM and will stay in the northern portion of the sky throughout the night. Lyra sets just before sunrise, at around 6:30AM.
    i. Deep Sky Objects:
        1. **M57 Ring Nebula:** An easily observed and well-defined planetary nebula. It is quite small, so you can see it with binoculars; a telescope is necessary to see detail.
        2. *Epsilon Lyra "double-double"*: A unique sight in the night sky. Visible to the naked eye, but telescopes are required to split the stars. With the right seeing conditions and a strong enough telescope, one can see two pairs of double stars in the eyepiece.

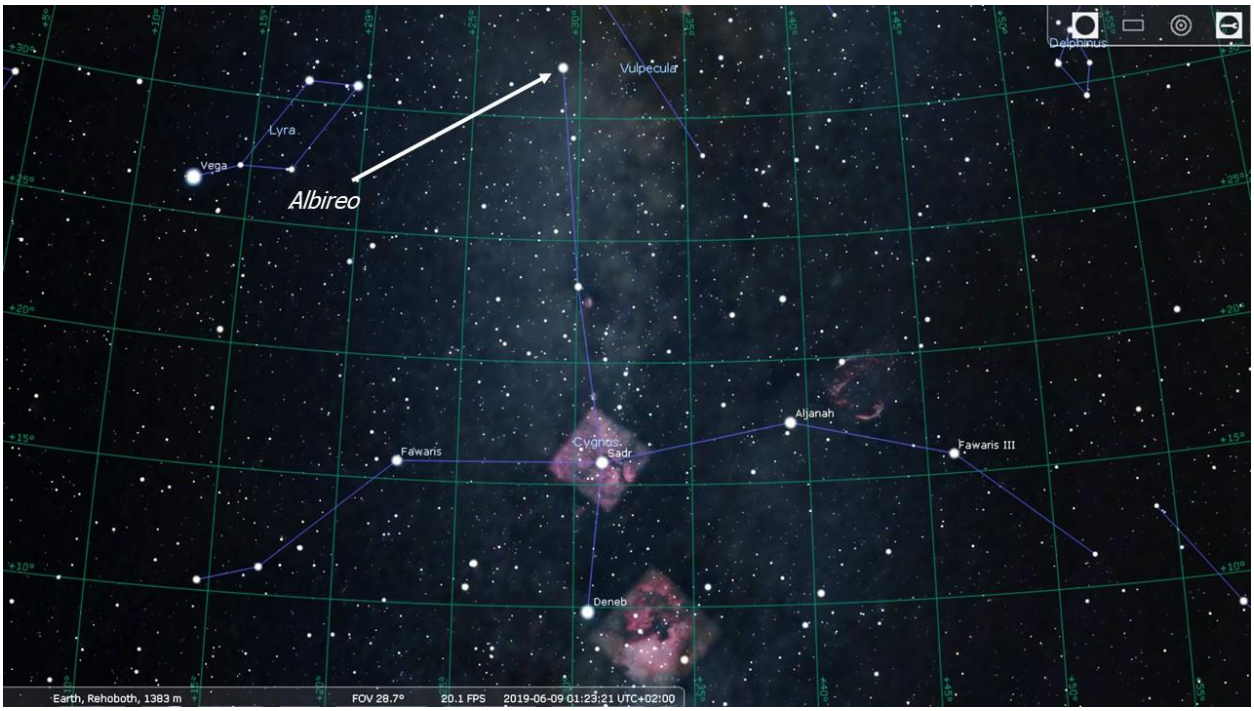


Figure 9.37 Constellation Cygnus. Mid-June, 1:30AM.

r. **Cygnus** "the swan": Look for the star *Deneb*, 19th brightest in the night sky. Cygnus will have risen by midnight. Cygnus sets in the NW as the sun rises, at around 7:00AM.
    i. Deep Sky Objects:
        1. *Albireo***:** A double star, visible as a single star with the naked eye. A small telescope will resolve two stars, quite different in color and brightness. The brighter star is reddish or orange, and the other is blue.

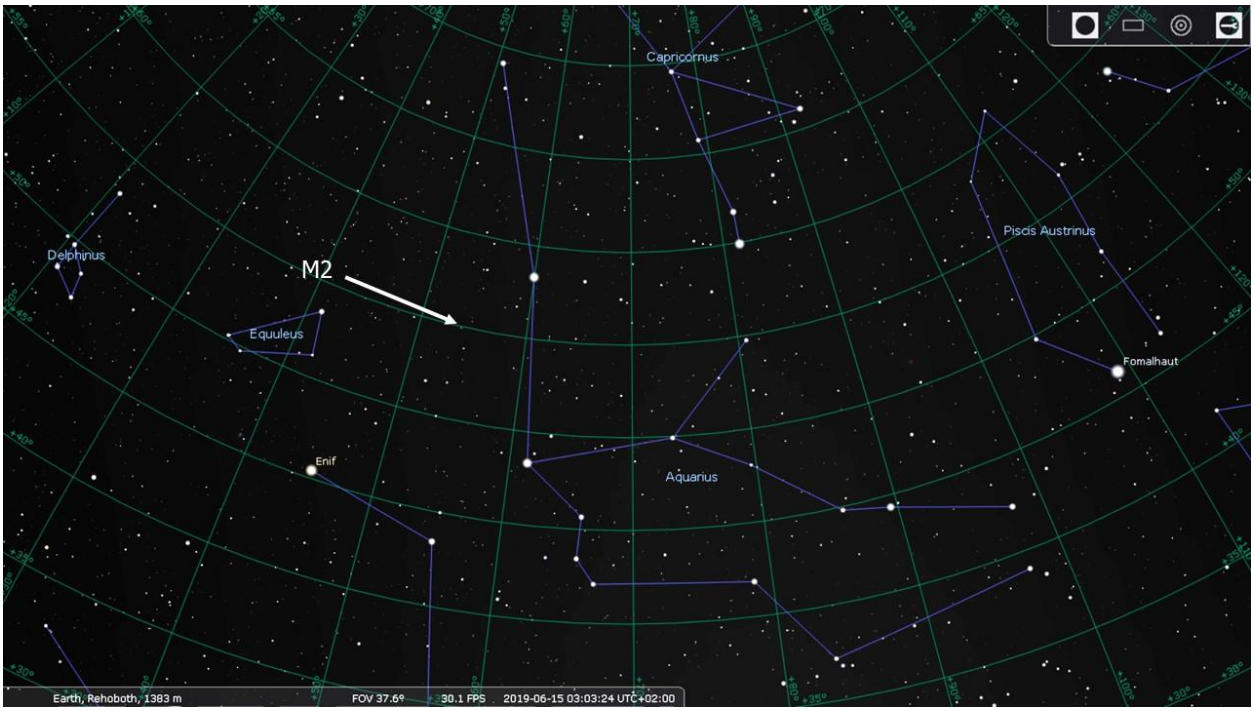


Figure 9.38 Constellation Aquarius. Mid-June, 3:00AM.

s. **Aquarius** "water bearer": A relatively dim, but large constellation. Aquarius has risen from the east by 1:00AM.
    i. Deep Sky Objects:
        1. **M2**: One of the largest known globular clusters in the sky. Just bright enough to be visible with the naked eye.

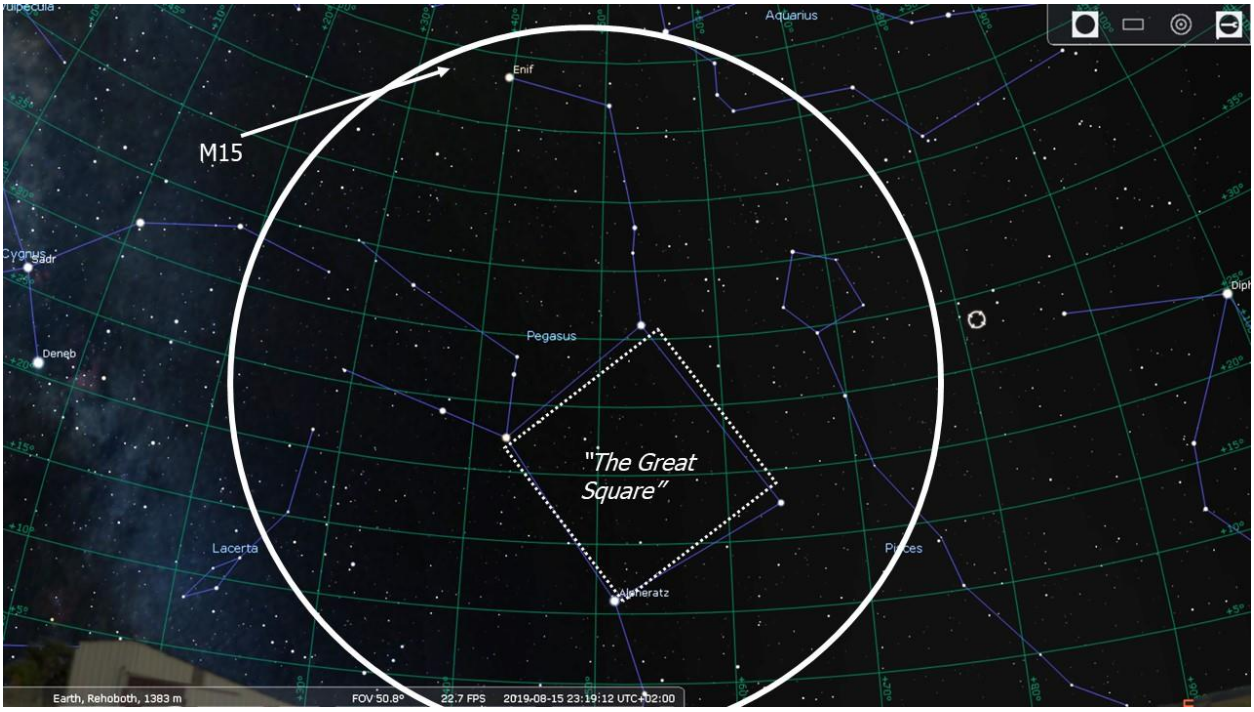


Figure 9.39 Constellation Pegasus. Mid-August, 11:00PM.

t. **Pegasus** "winged horse": Pegasus has risen above the eastern horizon by midnight. Look for the "great square," made of up four of the brighter stars in Pegasus. Pegasus has risen in the NE by 3:00AM and remains up throughout the night.
    i. Deep Sky Objects:
        1. **M15**: One of the densest globulars in the Milky Way, just barely visible with the naked eye.

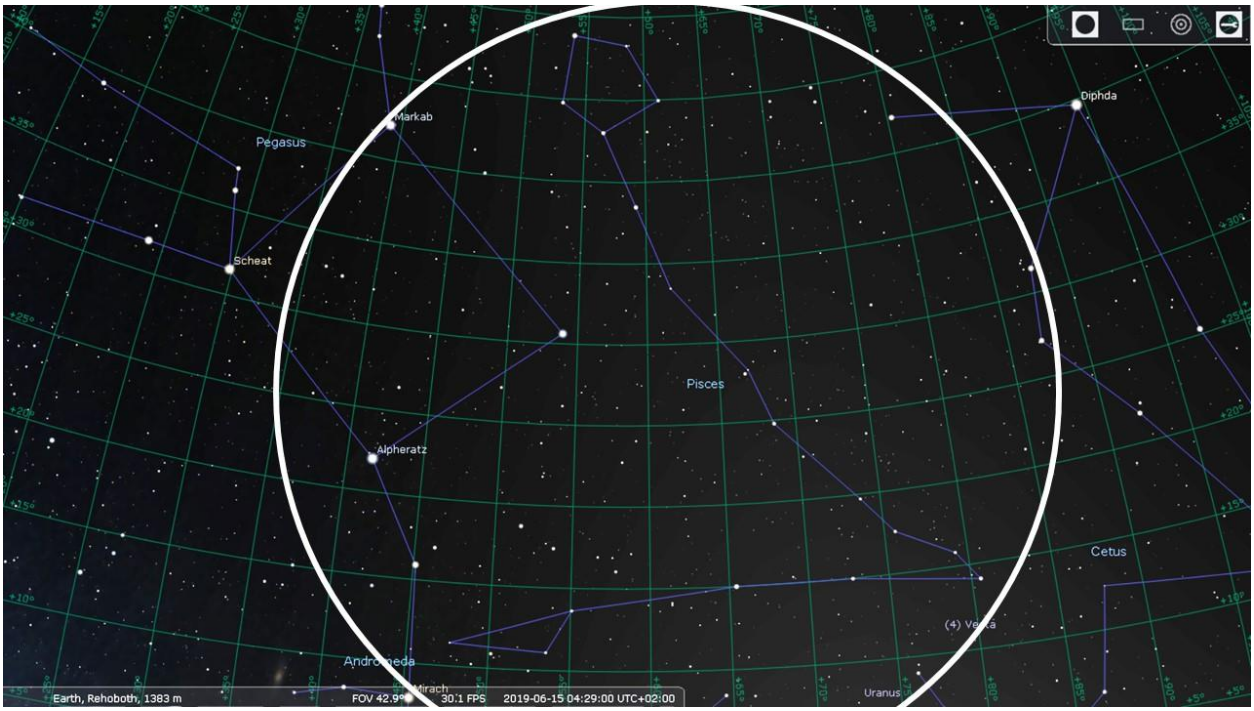


Figure 9.40 Constellation Pisces. Mid-June, 4:30AM.

u. **Pisces** "the fish": A well-known but rather dim constellation. Pisces will have risen by 4:00AM and remains up throughout the night.

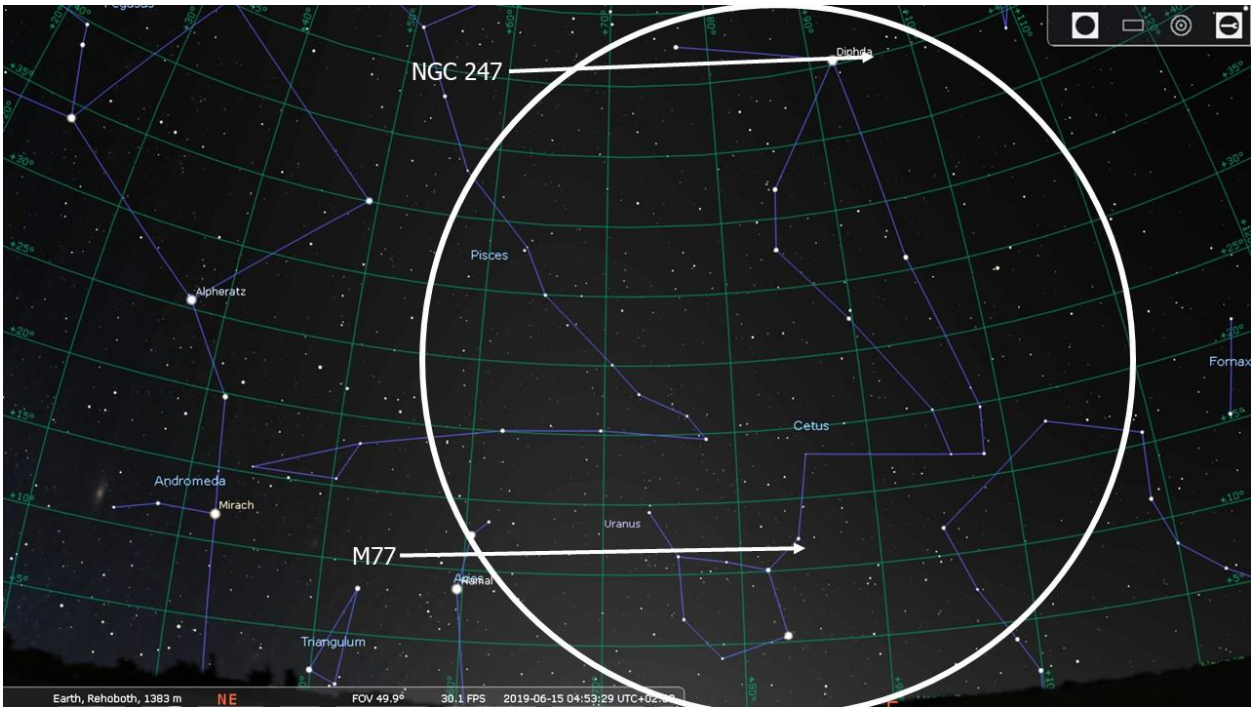


Figure 9.41 Constellation Cetus. Mid-June, 5:00AM.

v. **Cetus** "the whale": Cetus is the fourth largest constellation in the night sky. Cetus will have risen by about 4:30AM and remains up throughout the night.
    i. Deep Sky Objects:
        1. **M77:** A barred spiral galaxy. A telescope is required to view this object.
        2. **NGC 247:** A dim, but fairly large dwarf spiral galaxy, relatively near the Milky Way galaxy. Binoculars or telescopes are required to view this object.

3. North

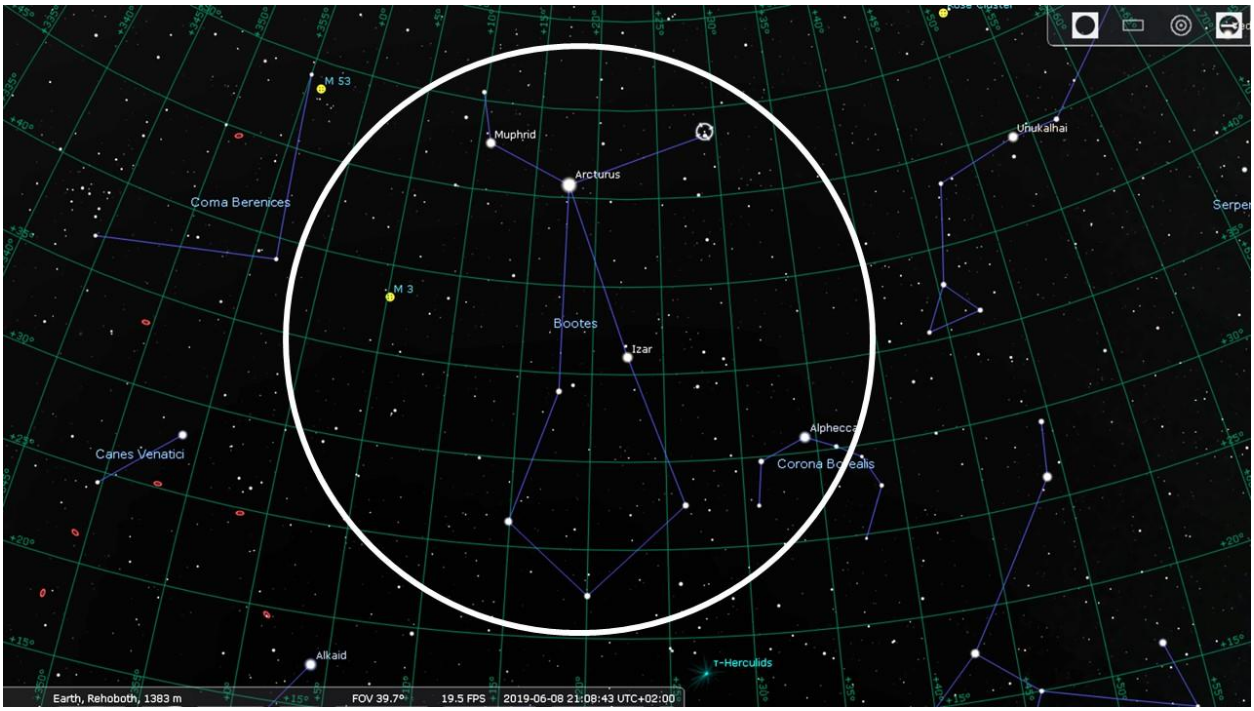


Figure 9.42 Constellation Boötes, Mid-June, 9:00PM

w. **Boötes** "the herdsman": Look for the red giant *Arcturus,* fourth brightest star in the night sky. Boötes can be identified by first finding Arcturus and looking for the "kite," a diamond shape in the sky. Sets in the NW by around 3:00AM.

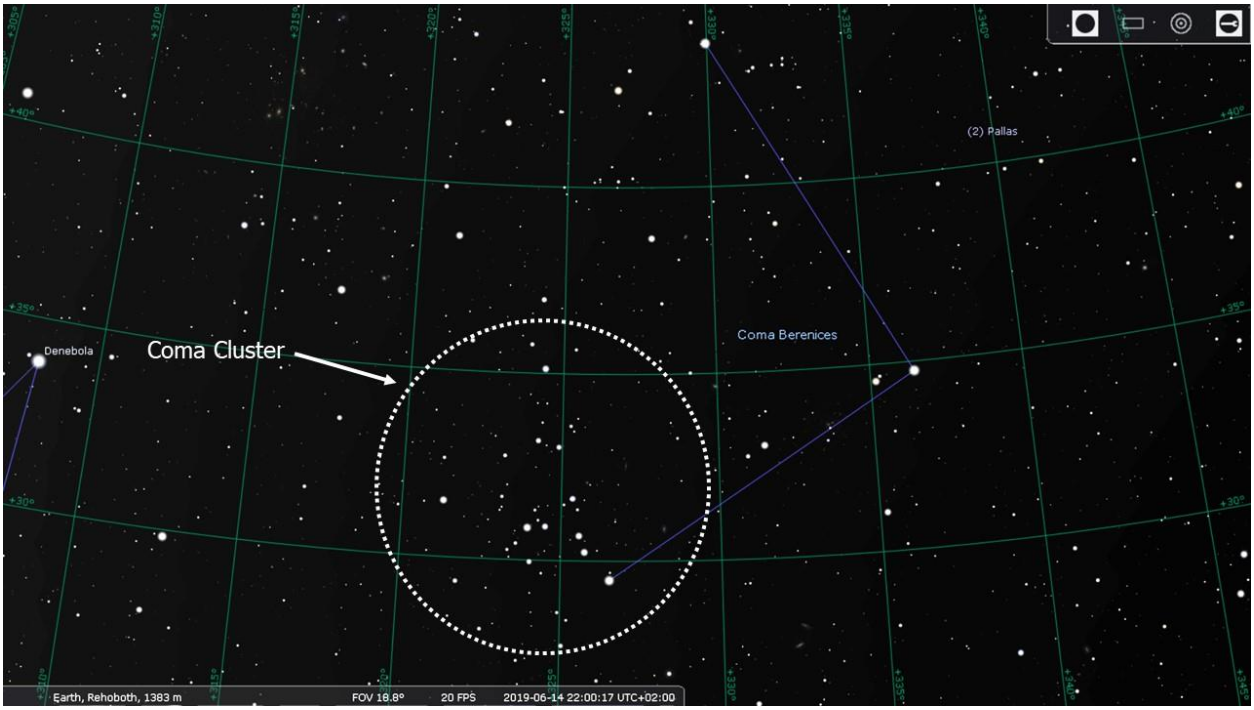


Figure 9.43 Constellation Coma Berenices. Mid-June, 10:00PM.

x. **Coma Berenices:** This is a very faint northern constellation, but notable as an excellent target for binoculars. Coma Berenices sets in the NW by 1:30AM.
    i. Deep Sky Object:
        1. **Coma Star Cluster:** A very loose, but bright open star cluster. Visible with the naked eye. Covers a wide portion of the constellation.

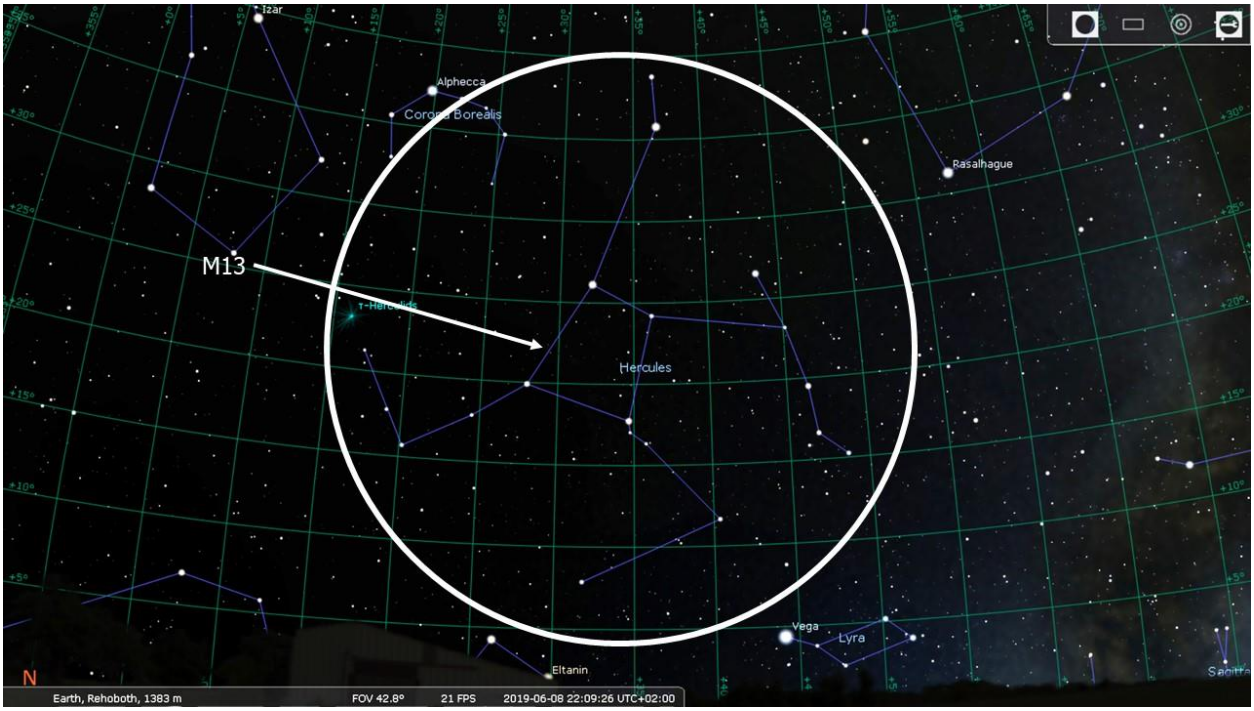


Figure 9.44 Constellation Hercules. Mid-June, 10:00PM.

y. **Hercules:** Does not contain any particularly bright stars, but the shape of this constellation is well defined. It will be low on the horizon throughout the winter. Hercules sets at around 5:00AM.
    i. Deep Sky Objects:
        1. **M13:** One of the brightest globular clusters. Visible as a fuzzy ball with binoculars. Very dense and excellent target for a reflector telescope.

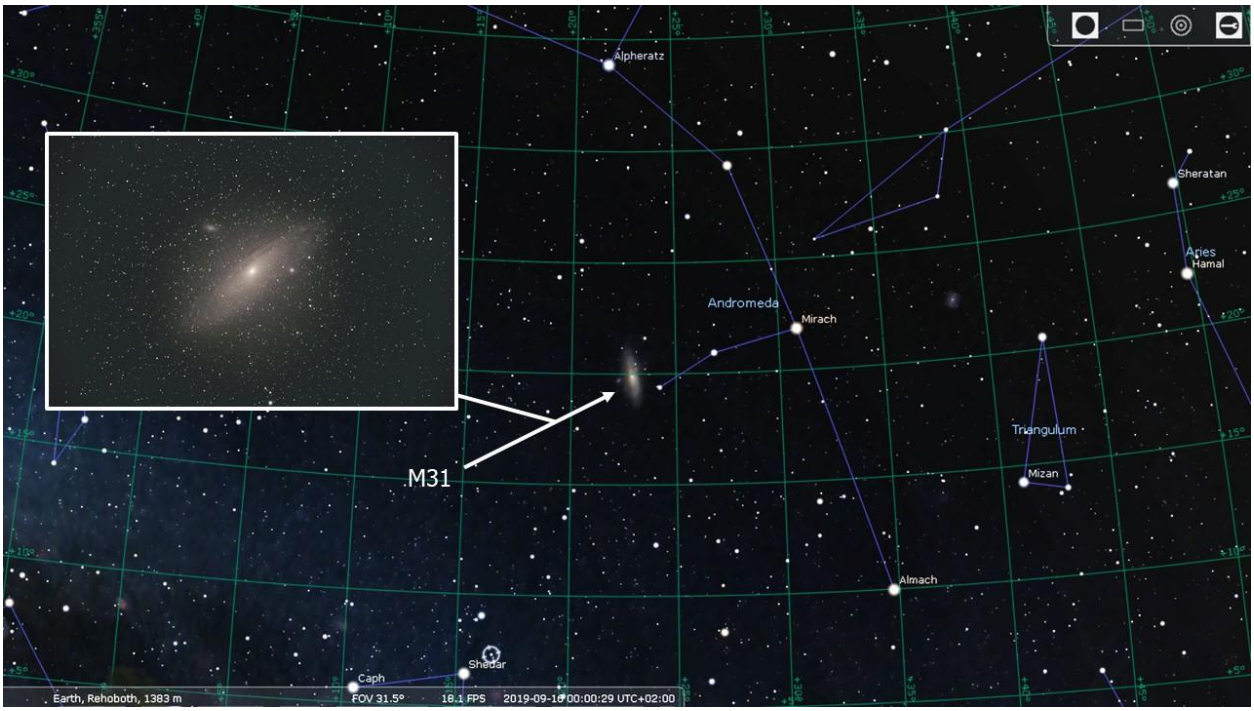


Figure 9.45 Constellation Andromeda. Mid-September, 12:00AM.

z. **Andromeda:** A relatively dim constellation that branches out from Pegasus. Andromeda will have risen by 5:00AM and is up for the remainder of the night.
    i. Deep Sky Objects:
        1. **M31 Andromeda Galaxy:** One of the brightest and largest galaxies of the night sky. Takes up an area several times larger than the full moon. Visible with the naked eye, but a telescope or binoculars can resolve more detail in the disc of the galaxy.

July

Sunset: approximately 6:25 PM

Sunrise: approximately 7:30 AM

1. South
    a. Constellations have shifted slightly clockwise.
    b. **Carina** approaches the horizon at sunset.
2. West
    a. Constellations are slightly lower after sunset than in June.
    b. **Canis Major** and **Cancer** are no longer visible.
    c. **Leo** approaches the horizon at sunset and will be too low to see at the end of July.
3. North
    a. Constellations have shifted slightly counterclockwise.
4. East
    a. Constellations are slightly higher after sunset than in June.

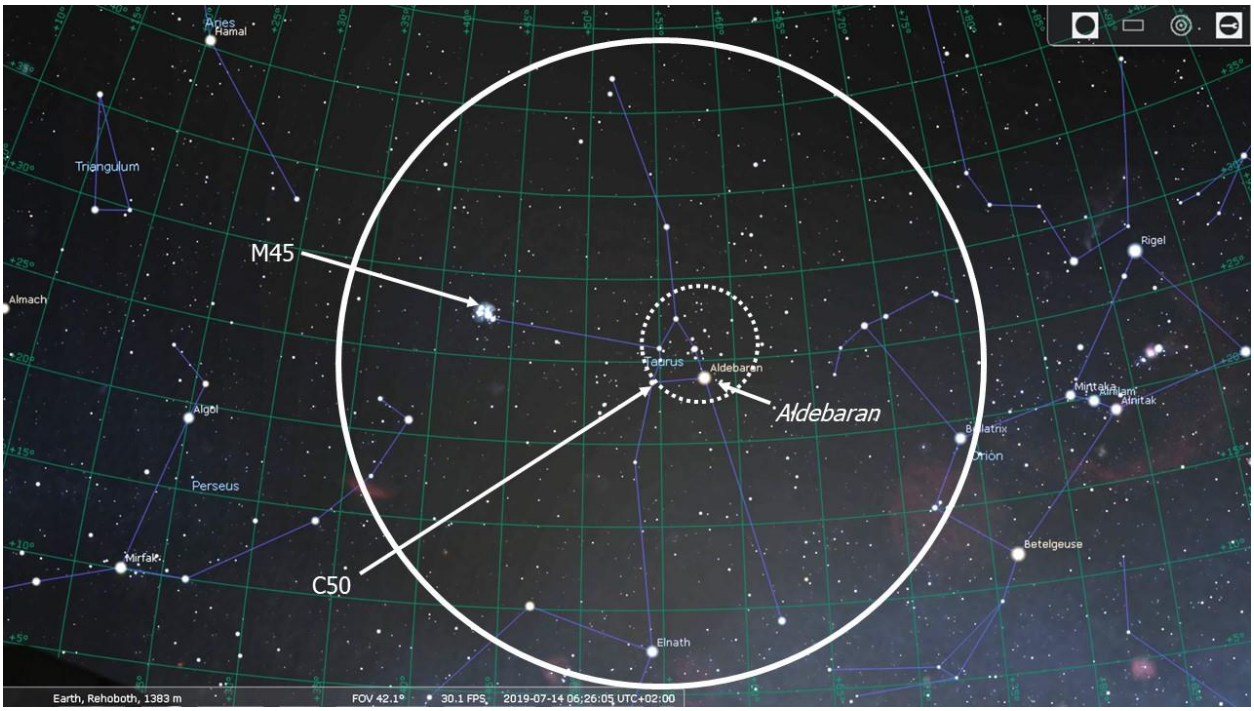


Figure 9.46 Constellation Taurus. Mid-July, 6:30AM.

aa. **Taurus** "the bull": Look for *Aldebaran*, "eye of the bull." By mid-July, Taurus can be seen every morning before sunrise by 6:00AM.

i. Deep Sky Objects:

1. **M45 The Pleiades**: This is a very well-known star cluster, often nicknamed "the seven sisters." An excellent object to view with the naked eye. Binoculars or telescopes can resolve dozens of stars in this cluster as well as reveal some nebulosity.
2. **C50 The Hyades**: A very loosely collected open star cluster scattered near *Aldebaran.* Given its large size, it is best viewed with the naked eye or binoculars.

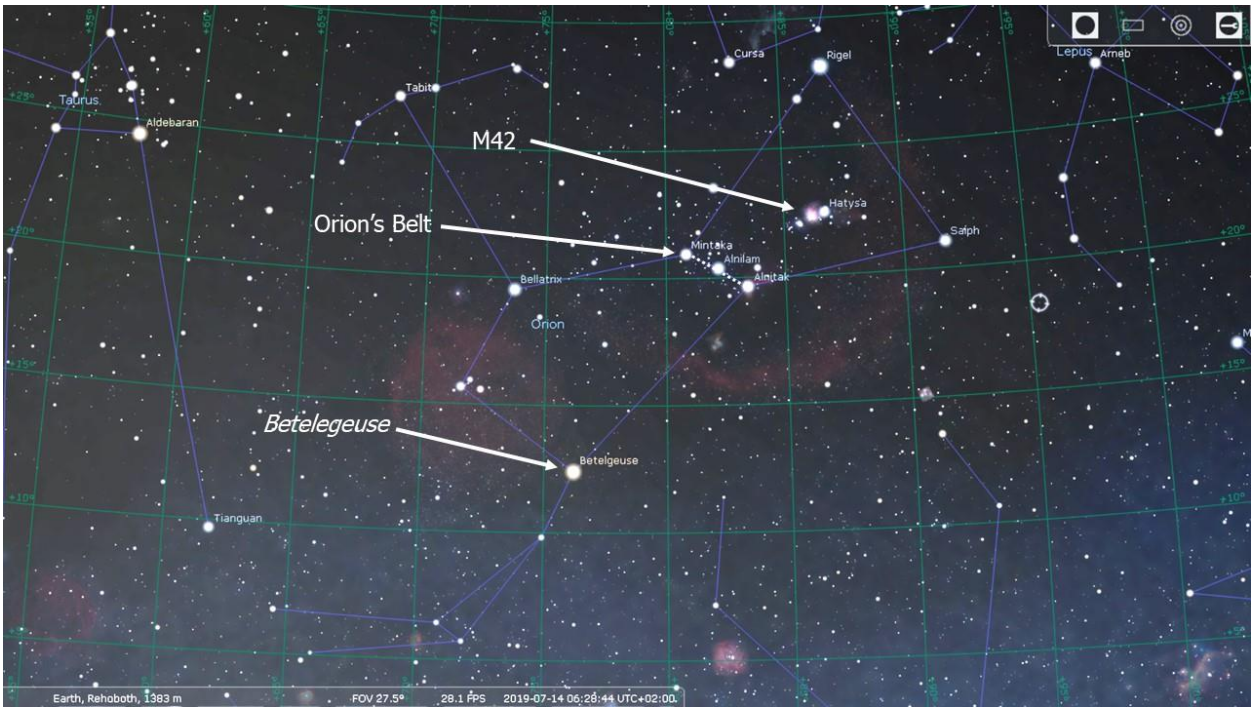


Figure 9.47 Constellation Orion. Mid-July, 6:30AM.

bb. **Orion** "the hunter." Orion is one of the brightest and most recognizable constellations in the night sky. Look for Orion's belt, made up of three bright stars lined up in the middle of the constellation. Additionally, look for the bright red/orange star *Betelgeuse*.

i. Deep Sky Objects:

1. **M42 The Great Orion Nebula:** One of the brightest nebulas in the night sky. Visible with the naked eye. A telescope or binoculars will yield excellent views.

August

Sunset: approximately 6:35 PM

Sunrise: approximately 7:15 AM

1. South
   a. Constellations have shifted slightly clockwise.
   b. **Carina** sets below the horizon by 10:00PM.
2. West
   a. Constellations are slightly lower after sunset than in June.
   b. **Leo** is no longer visible after sunset.
3. North
   a. Constellations have shifted slightly counterclockwise.
4. East
   a. Constellations are slightly higher after sunset than in June.
   b. **Canis Major** is again visible in the sky, rising just before dawn.

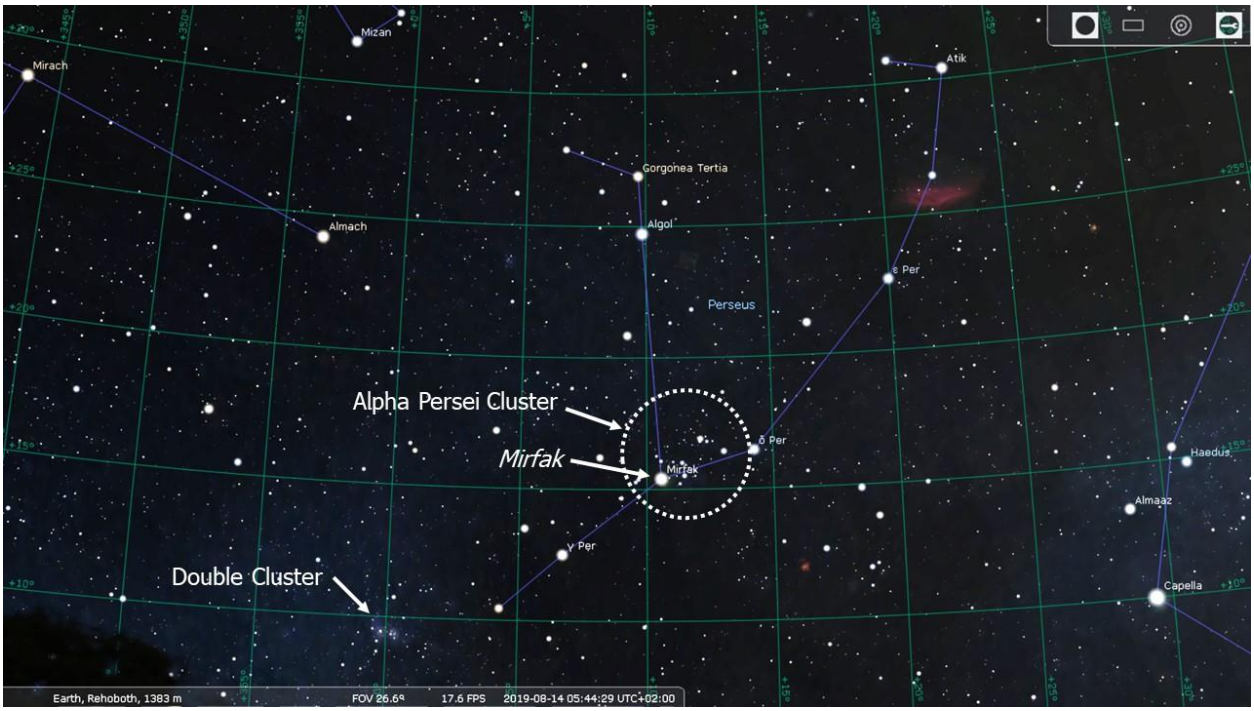


Figure 9.48 Constellation Perseus. Mid-August 5:30AM.

cc. **Perseus** "the hero": A small, but easily recognizable constellation. Perseus is visible in the eastern sky by around 3:30AM.

i. Deep Sky Objects:

1. **Alpha Persei Cluster**: A very loose cluster of stars centered around the brighter star *Mirfak*. Excellent naked eye or binocular target.
2. **Double Cluster**: A famous collection of two open star clusters, visible to the naked eye. Both are quite bright and make for very good telescope views.

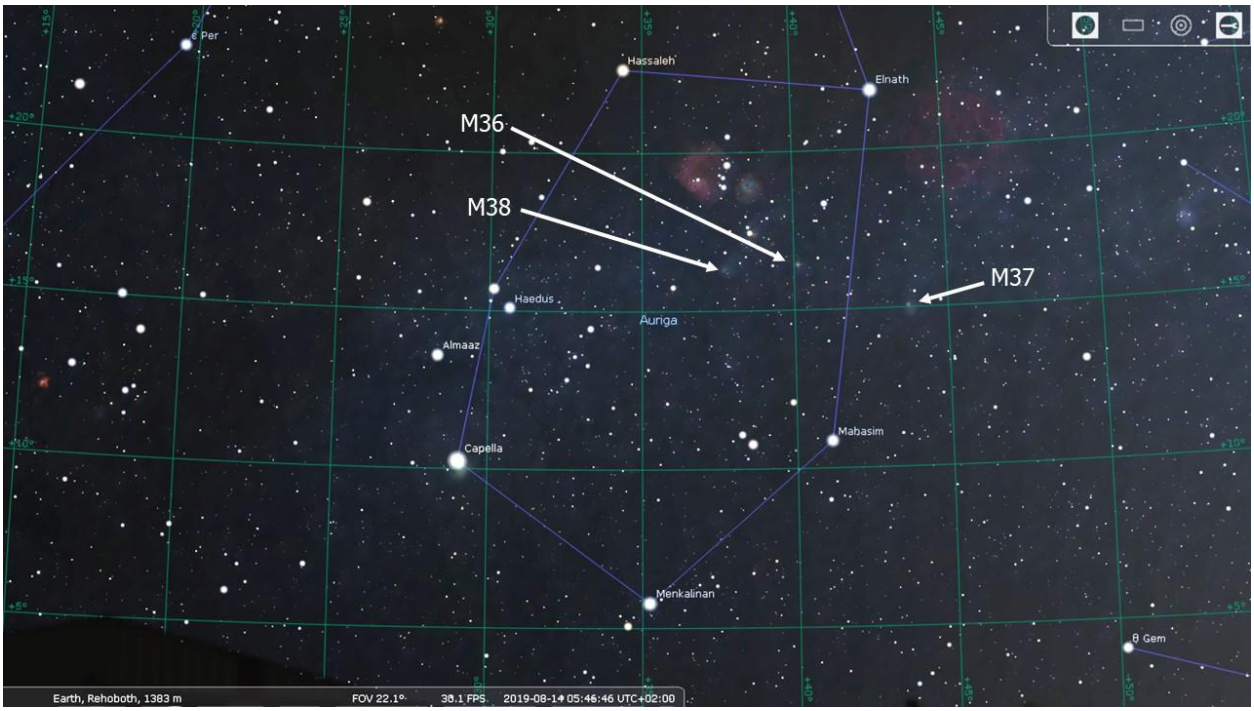


Figure 9.49 Constellation Auriga. Mid-August 6:00AM.

dd. **Auriga** "the charioteer.": Auriga is a small but bright constellation. Look for its brightest star, *Capella*, sixth brightest star in the night sky. The constellation is a good telescope target as it is densely packed with open star clusters. Auriga will have risen by 5:30AM.

i. Deep Sky Objects:

1. **M36 Pinwheel Cluster:** A fairly small open cluster. A telescope can resolve around ten stars.
2. **M37:** An open cluster. Binoculars or telescopes will resolve dozens of stars, with a contrast between red and yellowish colored stars.
3. **M38 Starfish Cluster:** An open cluster comparable to M36, with a notable yellow giant star easily visible to telescopes.

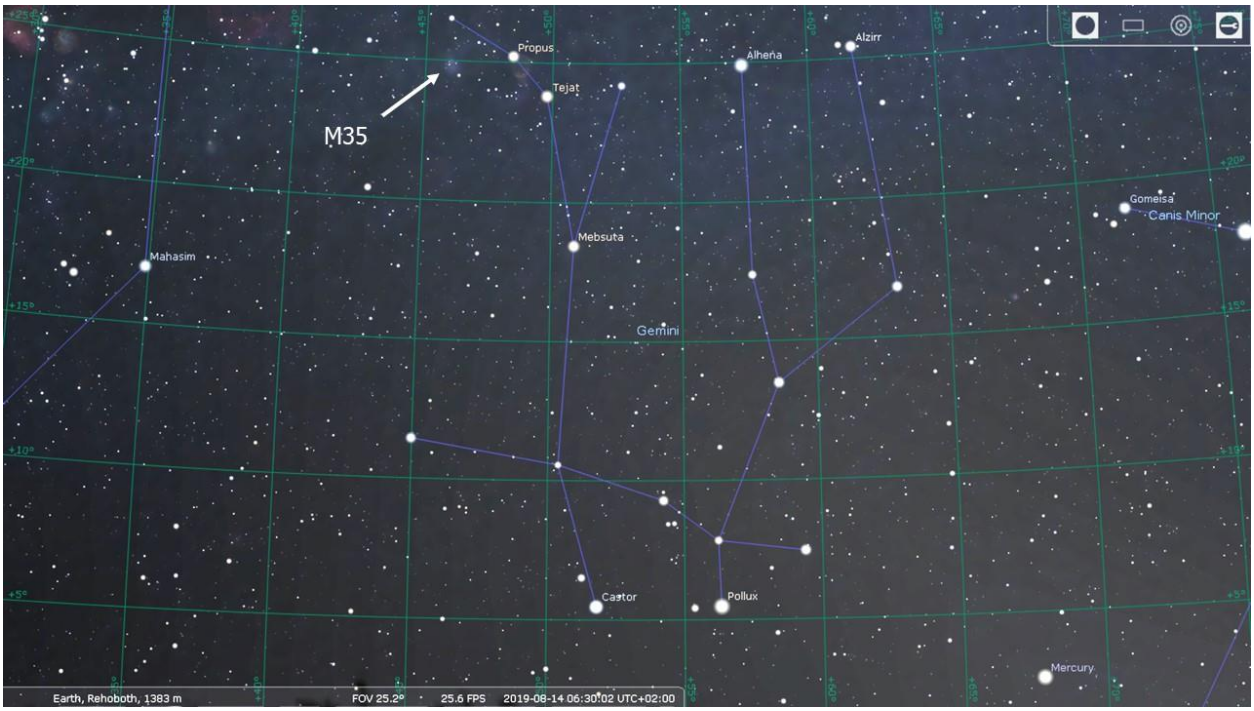


Figure 9.50 Constellation Gemini. Mid-August 6:30AM.

ee. **Gemini** "the twins.": A well-known winter constellation. Look for the "twin" stars, *Castor* (left) and *Pollux* (right). Gemini will have risen by 6:00AM.

i. Deep Sky Objects:

1. **M35**: A large and dense open star cluster. An excellent target for telescopes, offering views of over a hundred closely packed stars.

September

Sunset: approximately 6:45 PM

Sunrise: approximately 6:45 AM

1. South
   a. Constellations have shifted slightly clockwise
   b. **Carina** is no longer visible.
2. West
   a. **Virgo** approaches the horizon at sunset and will not be visible by the end of September.
   b. **Scorpius** has shifted from east to west.
3. North
   a. Constellations have shifted slightly counterclockwise.
   b. **Lyra** is now more northern than eastern.
4. East
   a. Constellations are slightly higher after sunset than in June.
   b. **Cancer** is again visible, rising just before sunrise in the east.

Section IV | Imaging

Equipment used to capture the images

- DSLR Camera: Canon Rebel T1i
- Intervalometer
- 50mm f/1.8 lens
- 55-250mm f/4-5.6 lens
- 18-55 f/3.5-5.6 lens (with a wide-angle attachment)
- Sky-Watcher Star Adventurer Motorized Mount
- Surveyor Tripod

Software used in post-processing (all available for free)

- Deep Sky Stacker
- XnConvert
- Gimp 2.10.10

Noise Reduction

Astrophotography is not quite as simple as going outside and taking pictures of the night sky. Post processing is a necessary step that can often take more time than taking the original images. Reducing noise in night sky images is one of the primary challenges in astrophotography. Cameras generally work by exposing very sensitive sensors to light and collecting the data as electrical signals. **Noise** is generated when these sensors encounter electrical interference, often through heat energy. The longer an exposure, the more noise is generated in the image. This is especially apparent in low-light photos, as they require longer exposures. An important technique called **stacking** is used to reduce noise and resolve other defects in the image (hot pixels, atmospheric distortion, satellite streaks).

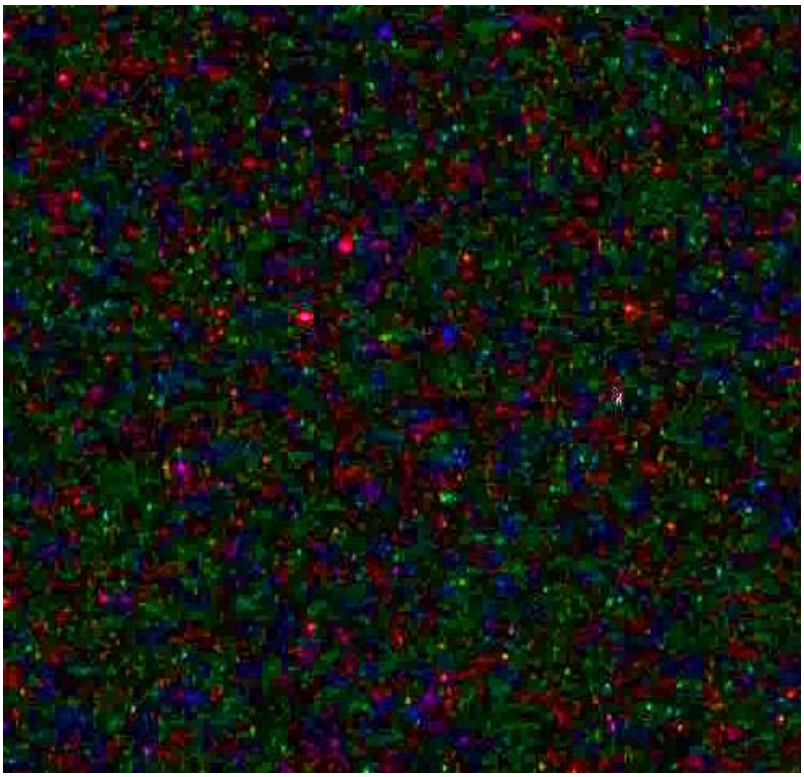


Figure 10 Example of sensor noise. The image is from a long exposure with the lens cap *on*, meaning the speckles of color here are generated from within the camera itself. The image was magnified, and brightness and saturation increased in order to make the noise more visible.

Astrophotography Process

An image of the Andromeda Galaxy from its original imaging up to the final steps to produce a photo will be used as an example to briefly outline the astrophotography process. This is not a full guide, but rather meant to be used to give an idea of what is often involved in producing night sky photos.

1. Imaging
    a. Deep sky photography requires a tripod with a motorized tracker. This is critical because in exposures longer than a few seconds, stars cease being points and start to trail due to the motion of the night sky.
    b. **Night sky photos should be shot as RAW files**. Most cameras have a setting that allows the user to switch from JPG to RAW format.
        i. The JPG file format compresses information, saving data but losing information, which limits what a user can do in post-processing.
        ii. RAW files are larger. They store much more data on light and color values. This allows users to eventually bring out more detail in their night sky photos.
    c. Sometimes a single exposure with minimal processing is fine, but the clearest images require multiple exposures stacked together.

d. A good target for adequate total exposure time to aim for is two to three hours per image. The more time the better, but for a basic photo two is more than enough.

Figure 11a A single, unedited exposure of Andromeda Galaxy. 50-250mm telephoto lens, 122 seconds, 1600 ISO, f/5.6 aperture.

2. Stacking
    a. After multiple exposures of a deep sky object are taken, they are inputted into a photo stacking program. In this case, Deep Sky Stacker was used.
        i. Deep Sky Stacker is the free software used in the production of each of the night sky photos discussed here. A user inputs several types of images:
            1. L**ights** (exposures of the night sky)
            2. **Darks** (images consisting only of noise, taken with the lens cap on; 10-15 of these would be fine)
            3. **Flats** (images taken to even out the inequal amount of light on an image due to the lens optics and dust on the sensor; 10-15 of these would be fine)
        ii. The software outputs a single image with reduced noise and higher detail.
3. Editing
    a. The stacked image is edited in a post-processing program such as Gimp or Photoshop.

   i. Gimp was used in this case, as it is free and works as well as Photoshop.
b. The end goal of editing is to maintain the original accuracy and integrity while maximizing the level of detail visible in deep sky objects.
c. Light levels in the photo are manipulated to bring out faint details (such as the dust lanes of a galaxy)

Figure 11b A finished photo of Andromeda Galaxy. Consists of 44 exposures (see **Figure 11a**) stacked in Deep Sky Stacker. Stacked image processed in Gimp.

4. Conversion
   a. Finished photos can be very large in size, especially those in the .µcd file format that Gimp usually outputs (upwards of 1 GB).
   b. Photos should be converted to a different file format to save space. Free software like XnConvert is useful for file conversion.
      i. RAW is the largest but allows for future editing.
      ii. JPG can be compressed significantly without a loss in too much quality. Photos can no longer be edited. This format should only be used when a photo has gone through all post-processing and is ready to be stored or shared.

Summary

The purpose of this section was to introduce the reader to astrophotography. With a little equipment and practice, excellent photos can be taken of the night sky. Astrophotography can be utilized as a tool to visually showcase a location's dark skies. This could be especially useful for businesses wanting to include photos in online brochures and websites. Additionally, with some equipment and guidance, guests could be enabled to capture their own images of the night sky.