MACE TELESCOPE

Light of Night Sky at Hanle

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Performance of any astronomical experiment is directly or indirectly influenced by the observatory site of the experiment. A prospected site has to fulfill suitable environmental conditions like atmospheric transmission, cloud cover, wind pattern, snowfall, rainfall, light of night sky (LONS) etc. LONS play an important role in the performance of field instruments like MACE gamma ray telescope. Typically, a site possessing stable atmosphere and high atmospheric transparency, minimum cloud coverage, low occurrence of rainfall and snowfall, low level of night sky brightness is considered as a good astronomical site[1].

The site of MACE telescope at Hanle (32.8°N, 79.0°E, 4.3km above sea level), a less populated, cold and dry desert located in the Union Territory of Ladakh with its stable atmosphere throughout the year, provides excellent observational conditions for astronomical experiments.

Night Sky Background

The residual light present in the atmosphere at the night time is usually referred to as night sky background (NSB) or LONS. Hence even if the moonlight and man-made light is absent, night sky is not dark. The sources of brightness of night sky are zodiacal light, integrated starlight, air-glow, aurora, diffuse Galactic light and extragalactic background light[1]. In addition to this, artificial sources of light, like scattered street lights in the lower atmosphere also contribute significantly in the brightness of night sky. A brief description of these basic constituents of the night sky brightness is given below:

Zodiacal Light

The zodiacal light in the ultraviolet, visible and near-infrared part of the electromagnetic spectrum, is caused by scattering of sunlight by the dust particles orbiting around the Sun while the mid and far-infrared is due to the thermal emission of interplanetary dust particles[2,3]. The brightness of the zodiacal light depends on few factors like viewing direction, wavelength, distance to the Sun and position of the observer with respect to the orientation of the dust disk.

It also experiences seasonal variability due to heliocentric distance changes as the Earth orbits the Sun. In the northern hemisphere, it is most intense before dawn in the fall, and after sunset in the spring, the reason behind the most brightness is because the interplanetary dust plane lies in the same plane as the ecliptic.

Airglow

The emission of visible light due to photochemical luminescence from atoms and molecules present in the ionosphere is called Airglow. Since airglow is highly dependent on the constituents of the atmosphere above the observer's location, it is primarily a function of terrestrial coordinates[2]. In addition, temporal variability of airglow ranging from few minutes to few hours is also found. In the wavelength regime relevant for atmospheric Cherenkov telescopes like MACE, the sources of airglow are:

- Oxygen (O_2): 260-380 nm
- Nitrogen di-oxide: 500-650 nm
- Hydroxyl (OH): 380-4470 nm
- Atomic oxygen (O): Strong green line (557.7nm)
- Atomic oxygen (O): Deep red lines (630 and 636.4 nm)
- Atomic nitrogen (N): 519.8 and 520.1 nm
- Yellow sodium D lines at: 589 and 589.6 nm

Diffuse Galactic light

It is the diffuse component of the Galactic background radiation, produced by scattering of stellar photons by dust grains in the interstellar space. This light is most intense in the directions where the dust column density and the integrated stellar emissivity are both high and it covers most of the electromagnetic spectrum ranging from far-ultraviolet to the near-infrared. It contributes ~20-30% of the total integrated light from the Milky Way in the night sky brightness[2, 3].

Extragalactic Background Light

The contribution of extragalactic light in night sky background light is even smaller than the diffuse Galactic light. Most of the extragalactic photons are due to the redshifted starlight from the unresolved galaxies. In addition to this, hypothetically, the other possible contributors are scattered light from stars and dust present in intergalactic space. Unlike other contributors of the night sky background light, intergalactic light is isotropic in nature and covers ultraviolet, visible and near-infrared region of the electromagnetic spectrum[2, 3].

Aurora

The energetic charged particles (electrons and protons) from solar flares enter the Earth's atmosphere and do spiral motion along the Earth's magnetic field lines. These charged particles impart

▲ IMAGE of Night Sky above MACE Telescope in Ladakh.

their energy to the atoms (present in the atmosphere; e.g. N_2, O_2). After occupying energy, these atoms get excited and during de-excitation process an electromagnetic radiation called Aurora, is emitted. The energy of the emitted photons is in the visible range and depends upon the atoms which are involved in the excitation process and their energy level difference.

As an example, light from oxygen atoms may be either red (wavelength of 630 nm) or green (wavelength of 558 nm). These lights are generally located between latitudes of 60°-70° north and south of the equator-because the interaction of magnetic field and energetic charged particles coming from solar flare is greatest near the Earth's magnetic poles. Aurora near the North Pole are called Northern lights or Aurora Borealis and near the South Pole are called Southern lights or Aurora Australis [2, 3, 4].

Integrated starlight

Lights from unresolved stars in the ultraviolet to mid-infrared region, hot stars, white dwarfs at the shorter wavelengths, main sequence stars in the visible region, red-giants in the infrared region of the electromagnetic spectrum as a combined light contribute to night sky brightness.

LIGHTS from unresolved stars in the ultraviolet to mid-infrared region, hot stars, white dwarfs at the shorter wavelengths, main sequence stars in the visible region, red-giants in the infrared region of the electromagnetic spectrum as a combined light contribute to the brightness of night sky.

http://www.putmanmountainobservatory.com/zodiacal-light/

▲ ZODIACAL light observed near Putman Mountain Observatory.

▼ AURORA above the Southern Indian Ocean as captured by the International Space Station.

https://spaceplace.nasa.gov/aurora/en/aurora2.en.jpg

Atmospheric Extinction of LONS

Any ground based astronomical photometric measurement involves the study of atmospheric extinction of light. The term 'atmospheric extinction' means dimming of light which passes through the atmosphere. It is wavelength dependent and caused mainly by scattering and absorption of light. The three main sources of extinction in the Earth's atmosphere are (i) Aerosol scattering, (ii) Rayleigh scattering by air molecules, (iii) molecular absorption (dominated by ozone). Each of these three sources has its own dependence on characteristic wavelength, varying altitude and time.

Starlight just overhead in the zenith suffers the least absorption from the atmosphere, at positions away from the zenith, the absorption or extinction is greater as the path length through the atmosphere is longer. The normalized path length is called the airmass, which can be approximated by sec (Z) where Z is the zenith angle. The airmass is 1 at $Z=0^{\circ}$ and 2 at $Z=60^{\circ}$. For the visible part of the electromagnetic spectrum, extinction is a combination of continuous absorption from Rayleigh scattering of gas molecules and mainly neutral absorption from dust and aerosols. Rayleigh scattering varies with λ^{-4}, where λ is the wavelength and therefore scattering is high in the ultraviolet and blue part of the spectrum. In addition to this, there is some absorption at specific wavelengths mainly due to oxygen, carbon dioxide and water molecules. Ozone is responsible for the atmospheric cutoff in the ultraviolet and water severely affects the transmission in the infrared. The continuous absorption is proportional to airmass, whereas the specific molecular absorption is non-linear with airmass and can vary with time as well as airmass in case of water molecule. The wavelength dependent extinction is quite steady throughout the night and even from month to month so it is usually possible to adopt mean extinction values and simply solve for the neutral component that can and does change nightly. Rayleigh scattering by air molecules at an altitude h is given by

$$A_{ray.}(\lambda, h) = 9.4977 \times 10^{-3} (1/\lambda)^4 C^2 \times \exp\left(\frac{-h}{7.996}\right) \quad (1)$$

with

$$C = 0.23465 + \frac{1.076 \times 10^2}{146-(\frac{1}{\lambda})^2} + \frac{0.93161}{41-(\frac{1}{\lambda})^2}$$

In this equation, atmospheric pressure is assumed as 760 torr at height h = 0 and for the lower troposphere the density scale height is 7.996 km. Here wavelength (λ) is in microns and altitude (h) is in km[5]. The aerosol scattering is due to particulates, including mineral dust, salt particles, water droplets and man-made pollutants; hence extinction due to this is highly variable and is expressed as

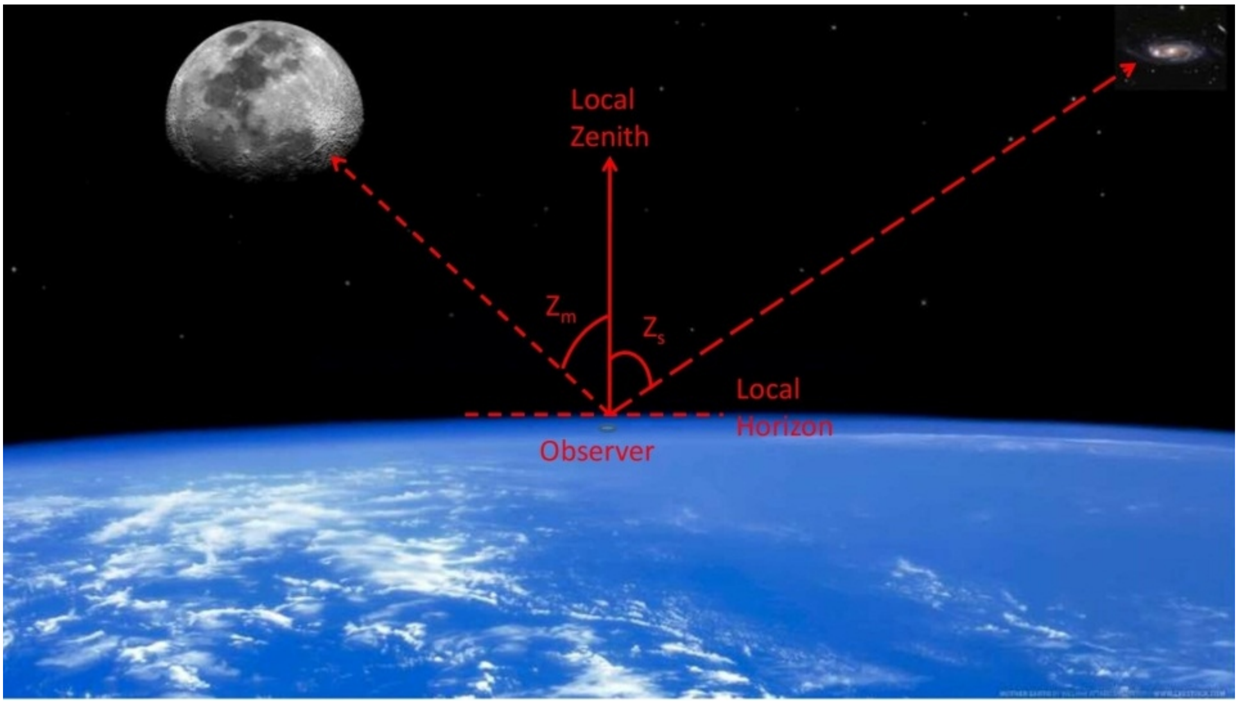
$$A_{aero.}(\lambda, h) = A_o \lambda^{-\alpha} \exp\left(\frac{-h}{H}\right) \quad (2)$$

Where H=1.5 km is the density scale height for aerosols and A_o is the total optical thickness for atmospheric aerosols which is 0.087 for λ = 1μm. The optical thickness depends on the total content of particles and their efficiency for scattering and absorption. α is a parameter which depends on the size of the aerosol grains. Molecular absorption is mainly caused by ozone, which is concentrated at altitudes between 10 and 35 km. So, ozone absorption does not depend on the altitude of the observatory. The only variable for ozone absorption is wavelength and experimentally it is observed for wavelength band 330nm-575nm[5]. The extinction due to water vapor is difficult to estimate because the amount of water vapor above a site is variable and centered only around a few wavelength bands. Therefore, in a broad wavelength band, the contribution to extinction can be neglected. The extinction due to ozone is estimated as

$$A_{oz} = 0.2775 C_{oz}(\lambda) \quad (3)$$

where C_{oz} is the ozone absorption coefficient and is given as [5]

$$C_{oz} = 3025_{exp}(-131(\lambda-0.26)) + 0.1375_{exp}(-188(\lambda-0.50)^2) \quad (4)$$



▲ REPRESENTATIVE diagram showing the relative position of Earth, Moon and gamma-ray source.

The total atmospheric extinction at any given wavelength λ is given by

$$A_{\lambda} = A_{ray.}(\lambda,h) + A_{aero.}(\lambda,h) + A_{oz}(\lambda) \quad (5)$$

At Hanle site, the mean extinction coefficients for U, B, V, and R filters at their central wavelengths are observed as 0.36± 0.07, 021± 0.04, 0.12 ± 0.04 and 0.09± 0.04, respectively[1].

Additional LONS on Account of Moonlight

With all the components of the light of night sky, moonlight has a significant contribution. The huge variation in the flux of night sky is mainly because of the different phases of the moon. Moonlight is a function of the Moon's phase, zenith distances of the Moon, zenith distances of the source under observation, and the angular separation of the Moon and sky position. At a particular wavelength, the night sky brightness due to moon can be modeled theoretically by considering these important parameters such as lunar phase, properties of the Earth's atmosphere, zenith distance of the Moon, zenith distance of the source and the angular separation of Moon and the source under observation [6]. For IACTs like MACE, regular operation under dark conditions (absence of moonlight or twilight), severely limits their duty cycle. If these telescopes would be operated under the presence of moonlight, there will be significant enhancement in the total number of observation hours. A feasibility study for operating MACE under partial moonlight condition has been performed[7]. In this study, operating parameters, like PMT anode current, Discrimination Threshold and Energy Threshold are studied for their appropriate desirable performance under moonlight condition. This study suggests that, with 30μA of individual PMT anode current, up to ~100 mV of discrimination threshold and increased energy threshold up to ~100 GeV, MACE telescope can be safely operated to observe the gamma-ray sources under partial moonlight conditions [7].

LONS Measurements at Hanle

Long term measurement of moonless night sky brightness and its atmospheric extinction in the UBVR pass bands has been studied by the IAO (Indian Astronomical Observatory) Hanle during the period 2003-2008. This was basically the period of minimum solar activity[1]. The brightness data obtained along with the atmospheric extinction values is given in the Table presented below.

LONS flux measured in UBVR pass bands at the Hanle site

Filter	λ_{center} (nm)	Mean extinction	Flux ($ph\ m^{-2}\ s^{-1}\ sr^{-1}\ nm^{-1}$)
U	365	0.36 ± 0.07	(4.552 ± 1.342) x 10^{9}
B	440	0.21 ± 0.04	(6.416 ± 1.77) x 10^{9}
V	550	0.12 ± 0.04	(1.316 ± 2.42) x 10^{10}
R	630	0.09 ± 0.04	(1.787 ± 6.09) x 10^{10}

The Brightness values are translated from mag-arcsec^2 to corresponding flux (ph cm^{-2} s^{-1} nm^{-1}sr^{-1}) values (f) using the relation:

$$\log_{10} f = -0.4(m_{sky} - m_o - 26.573)$$

Where m_o is zero magnitude brightness and m_{sky} is the measured sky brightness at zenith in mag-arcsec^2 units.

During the period from January-August 2021, moonless night sky brightness is also measured at the Hanle using Unihedron make SQM (Sky Quality Meter). After analyzing the SQM data, it is found that the seasonal variation of mean night sky brightness is very less.

Relevance for MACE

The gamma-ray telescopes like MACE detect faint Cherenkov light pulse from air showers over the bright LONS. The spectral range of Cherenkov light is in the wavelength range 300nm-700 nm and it dominates in the blue region whereas LONS flux dominates at longer wavelengths (>700 nm)[7]. This is due to the intensive emission lines of OH and H_2O bands in the upper atmosphere. The spectral distributions of Cherenkov light and LONS have been obtained. In the MACE like telescopes, generally PMTs of Bialkali photocathodes and UV/quartz window glass are chosen, because it offers highest yield of photo electrons in the detection of Cherenkov light (maximum emission in 300nm-450nm band). This is also the region, where the background light from the night sky is near minimum. As we do not have any control over natural sources of night sky, by selecting a site away from the man-made lights and choosing the observation period with no sunlight, moonlight and lightning etc., LONS can be minimized significantly.

In addition to this, at hardware level, by selecting photo detectors sensitive in the blue region and using Winston cone or compound parabolic concentrators ahead of the detectors can also maximize the signal to noise ratio of these telescopes.

Conclusion

Using the data of the night sky brightness measured by IAO, the integral photon flux due to LONS at the Hanle site is ~4.2x 10^{10} *ph* $m^{-2}s^{-1}sr^{-1}$. In Bortle Dark Sky Scale, which quantifies the observability of the celestial objects and interference caused by the light pollution, it can be categorized as the excellent dark astronomical site with Bortle colour key ‘Black’. The site characterization study for MACE telescope site at Hanle suggests an annual average of about 260 uniformly distributed spectroscopic nights for gamma-ray observations. However, due to increased light pollution caused by the man-made activities, there is a huge scope of present night sky brightness study at the experimental site.

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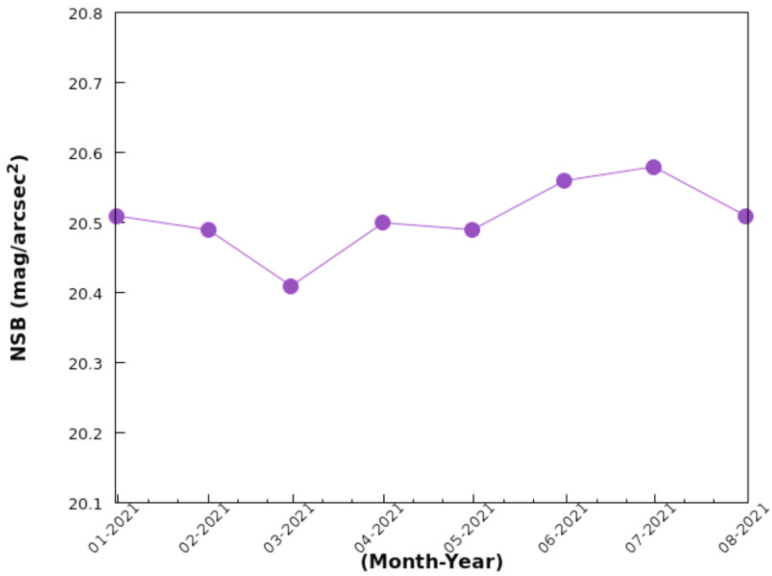
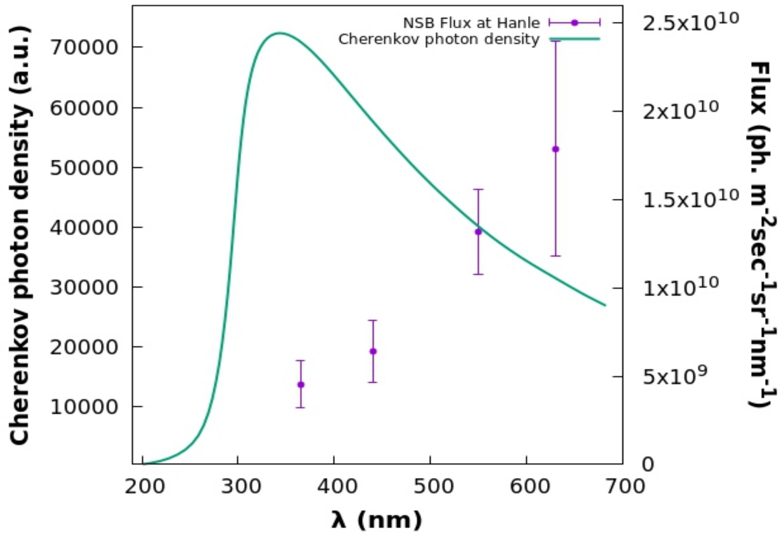


▲ LONS measurement at Hanle during January–August 2021.



▲ SPECTRAL distribution of Cherenkov light & LONS flux at Hanle.

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