The Earth's NUV Nightglow

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Abstract

In this paper we discuss the near ultra-violet (NUV) "nightglow" of the earth's atmosphere. This nightglow comes from a variety of sources and has been rarely measured over the past thirty years. We review old measurements, describe new measurements, and discuss the implications of these measurements for the NASA planned OWL/Airwatch mission.

1 Introduction:

Ultrahigh energy cosmic ray particles, with E $\geq 10^{20}$ eV are now the subject of intense interest, with recent observations by ground arrays (Afanasiev, 1993; Bird, 1994; Elbert and Sommers, 1995; Takeda, 1998). NASA is studying an orbiting instrument (the Orbiting Array of Wide-angle Light Collectors - OWL/Airwatch) for comprehensive studies of these extraordinary events. Related studies are in progress in Italy and Japan. In the atmosphere, these particles produce gigantic electromagnetic showers which excite the nitrogen and induce fluorescence. An interaction can be recognized as source of light, moving through the atmosphere at the speed of light, the intensity of which rises and falls as the electromagnetic shower peaks and then dies away. The nitrogen fluorescence occurs in bands around 337 nm, 357 nm and 391 nm. Other processes which produce emission in this same regime will contribute to the background against which the true signal must be seen. In this paper we discuss what some of these other processes are, review the data which exists, and provide our interpretation of what the implications are for the OWL/Airwatch mission.

2 Backgrounds and Existing Data:

2.1 Backgrounds: The sources of background for OWL/Airwatch, i.e. anything which can produce light between 300 - 400 nm, are numerous. They can be roughly divided into three broad categories: man-made, transient natural phenomena, and constant sources. Man-made sources consist of city lights, and lights from ships and planes. City lights produce emission at several orders of magnitude above the "natural" background. However, city lights can be avoided by restricting observations to unpopulated areas and oceans. (An equatorial orbit is ideal for meeting this criteria.) Lights on moving ships and planes cannot be avoided and will be very slow moving sources - compared to actual events. The absolute intensities are low and should make a negligible contribution to the background in any single pixel. Transient natural phenomena are mainly lightning and the aurora. The aurora produce extremely bright UV emissions, however they are confined to high northern and southern latitudes. They can be avoided by using an equatorial orbit. One should keep in mind however that light produced in the auroral region will still be scattered off the atmosphere and could contribute to a general increase in the background light level - even if the aurora are not in the direct field of view of the instrument. We should expect an increase in background intensity depending on the phase of the solar cycle. This effect has not yet been quantified. Lightning produces very intense NUV emission, travels at the speed of light, can extend over many tens of kilometers - it could mimic an actual UHE particle event. Fortunately, lightning strikes occur from cloud-to-cloud and cloud-to-ground and are extremely broadband. By monitoring cloud cover and not observing over cloudtops, and with ancillary sensors in other wavelengths it will be possible to avoid background contamination from lightning. However it should be noted that, globally averaged, the cloud cover over the equatorial region is about 60%, hence the optimum viewing aperture for an orbiting spacecraft is reduced by a sizable fraction.

The real background of concern for OWL/Airwatch is "constant" sources of NUV light, such as reflected starlight, reflected moonlight (except around the new moon), low energy cosmic-ray showers, and atmospherically produced light. It is these sources which we wish to measure, monitor, and understand. In particular, the atmospherically produced NUV light - from chemical reactions, which is comparable to the starlight component, is of primary concern.

Chemically produced atmospheric emission is referred to as *nightglow*. Nightglow is produced by atom-atom collisional excitations and ionic recombination. In the spectral region we are concerned with (300 - 400 nm), the major contribution is from the O_2 Herzberg I band, with weaker contributions from the Herzberg II and Chamberlain bands (relative ratios of 3:1:1). The Herzberg excitations are produced from three body collisions such as: O + O + M $\rightarrow$ O_2(A) + M. Due to its predominance in the atmosphere, M is usually nitrogen. The amount of light produced this way depends on the cube of the local oxygen density and is quite variable.

Low energy cosmic ray airshowers produce nitrogen fluorescence as well, although the individual showers are too weak to be seen from orbit. Because the cosmic ray spectrum is steep however, there are a million times more showers at 10^{15} eV. There will be on average 32 events (with E $\geq 10^{15}$ eV per second in the OWL field of view. As long as the focal plane integration time is short with respect to 10 msec, these showers will pose no problems for OWL.

2.2 Existing Data: The earliest measurements of the nightglow come from a Russian COSMOS flight in 1965 (Lebedinsky, 1965) and a 4 minute Aerobee sounding rocket flight by Hennes (Hennes, 1966). The COSMOS spacecraft was in a 200 km altitude orbit. In the Hennes flight, the data were recorded by a spectrograph which was kept pointed toward the horizon during the flight which reached a maximum altitude of 184 km. The pointing accurcacy was $\pm 2^\circ$.

Hennes' data are shown in Figure 1, in which the vertical scale is Rayleighs per Angstrom. (1 Rayleigh = $(4\pi)^{-1} \times 10^6 photons/(cm^2$ s sr)) The total integrated flux between 325 and 387 nm from the Hennes data is 278 R. This is $\approx$ 22 photons /($cm^2 \mu$sec sr). The total flux between 300 - 400 nm is 396 R. (The spectrograph had a resolution of 12 Angstroms.) The data were corrected to produce an equivalent zenith emission rate (and to remove instrumental effects). The COSMOS level was comparable in magnitude, varying from 20-60 photons per ($cm^2 \mu$sec sr), but over a larger spectral band, extending down to 260 nm from 400 nm. The intensity in the COSMOS data were correlated with cloud cover, the lowest values being recorded over cloudless regions. They observed that the uv brightness was $\approx$ one tenth the visual (400 - 600 nm).

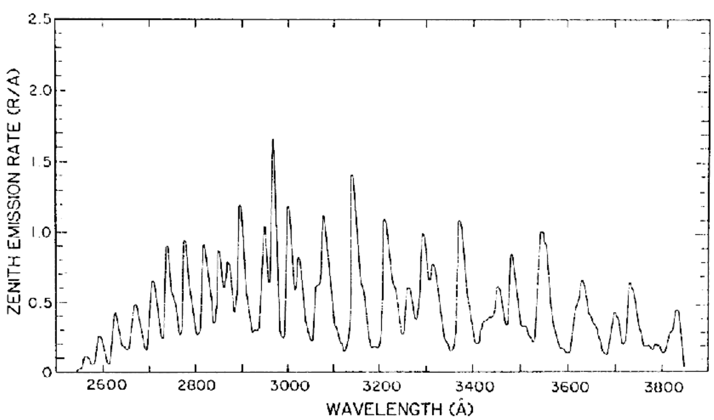

Figure 1: Data from the Hennes rocket flight. The integrated flux from 330 to 400 nm is 396 R.

The only other direct measurement from space published thus far was from a series of rocket flights carried

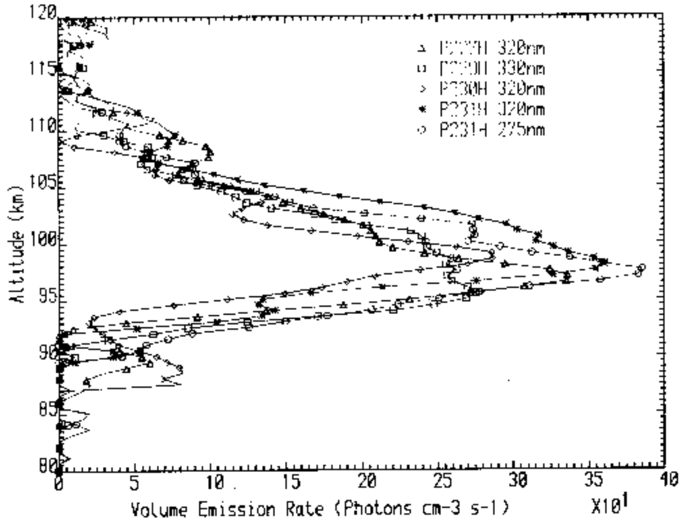

Figure 2: Altitude dependence of the atmospheric uv emission. The bulk of the emissioncomes from above 90 km.

out by Greer (Greer, 1986; Murtagh, 1986). Greer and collaborators made 7 Petrel rocket flights in March 1982. Three of these made observations in the wavelength range of interest to us, i.e. around 320 nm and 370 nm. As with Hennes, the spectrometer was pointed toward the horizon and "extraterrestrial background" was removed and the data corrected to a vertical emission rate.

The Greer data, shown in Figure 2, clearly demonstrate that the bulk of the nightglow emission comes from a region between 90 and 110 km in altitude. This source of background will be directly viewed by OWL/Airwatch instrument independent of cloud cover, ozone concentration, aerosol layers, surface properties, etc.

An additional source of "space-based" data comes from the BABY balloon instrument, built and flown by the Italian OWL/Airwatch collaborators (Catalano, 1998). BABY made its first flight in July 1998, with five hours of data. The preliminary data is shown in Figure 3, and yields a value of ≈40 photons/($cm^2\,\mu$sec sr). Bright emission from cities is clearly visible when the instrument was over land.

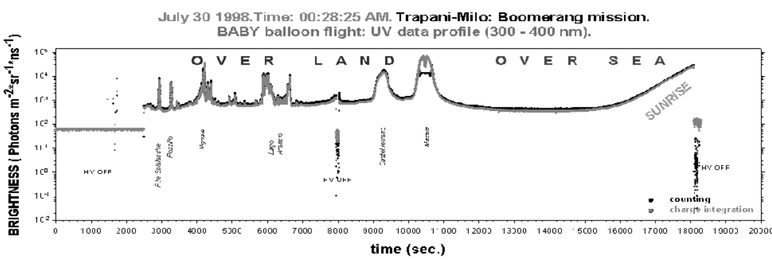

Figure 3: Balloon flight data showing nightglow levels over land and water.

In addition to these balloon or rocket data, there have been observations of nightglow from the ground, most notably Broadfoot and his collaborators in Arizona (Broadfoot, 1968; Johnston, 1993). The ground data show the magnitude of the variability of the nightglow, which is at least a factor of three over several months time. The ground data however are subject to the strong effects of ozone absorption (the ozone layer being at roughly a 30 km altitude).

3 Implications for OWL/Airwatch:

The signal expected for the baseline OWL/Airwatch instrument for an incident particle at 10^{20} eV has been calculated by Krizmanic and Streitmatter (Krizmanic, 1997; Streitmatter, 1998). They determine that the number of photons per pixel at shower max would be ≈ 78, collected in ≈ 1 μsec. The noise from all sources of background should be substantially less than this number for a significant detection of an event. With the current measurements of background as given above, this condition is met. The number of background photons per microsecond at the detector being around five.

The effects of clouds and ozone absorption both play a role in the actual signal to noise ratio which can be achieved on orbit. The showers reach their maximum (in number of particles and light output) within a few kilometers of the surface. Clouds are typically found at altitudes from 10 - 15 km and ozone is concentrated around 30 - 35 km.

The result of this is that the actual signal one wishes to observe can be obscured by clouds (if any) and reduced by ozone absorption while the atmospherically produced background light is not absorbed or obscured. This ozone absorption is strong, as shown by a MODTRAN calculation in Figure 4. The lower curve shows the transmittance from the ground to the s/c orbit. At 330 nm, for example, only 25 - 30 % of the light gets through.

While the background levels are low, it is important to recognize that many components of the background are variable - in time and space. The variability of the background however is not expected to be a serious problem for OWL/Airwatch because the baseline instrument is signal limited, not background limited. This means that the threshold will not be changing even though the background light level may vary. The only exception to this may be if OWL/Airwatch attempts to extend its observing time beyond the new moon nights. Then the reflected moonlight could become a limitation.

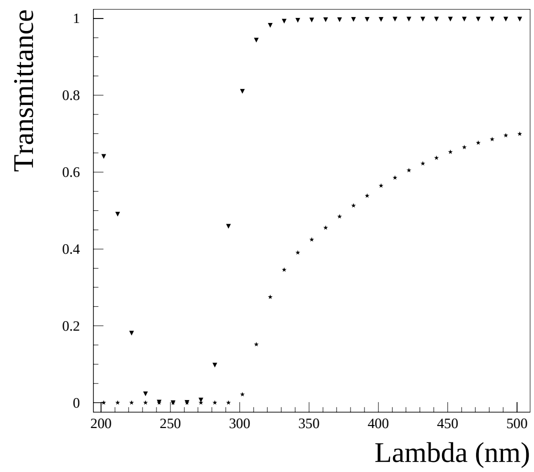

Figure 4: Atmospheric transmittance with and without ozone absorption. The lowercurve includes the ozone layer at approximately 30 km.

4 Future Work:

Future work will concentrate on measurements above the ozone layer with a second BABY balloon flight, a potential orbiting satellite measurement, and a long duration, around the world, mid-latitude balloon flight of a new instrument, NIGHTGLOW. NIGHTGLOW will make measurements over the ocean and will measure the atmospherically produced background light as well as the reflected light components. Because it is a long duration flight, NIGHTGLOW will also study the background light level as a function of the phase of the moon and hence help determine the largest possible aperature for OWL/Airwatch.

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