

EULE - European Urban Light Explorer

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Abstract

The presentation will detail the proposed EULE mission - European Urban Light Explorer. It was originally proposed as Earth Explorer 12 to ESA (European Space Agency). At any moment, one half of the Earth's surface is experiencing daytime, and the other half nighttime. Most Earth surface observation missions focus on the first half. The EULE mission focuses on Earth's night. The scientific goal of EULE is to improve the understanding and quantitative description of artificial light during Earth's night. In achieving this goal, it provides a unique data stream for scientific questions related to anthropogenic and atmospheric light emissions. Artificial lighting of the night environment has brought enormous benefits to humankind, and has shaped societies in dramatic ways by enabling activities to take place despite a lack of natural light. The connection between human activity and light emissions means that artificial light is closely linked to social factors (e.g. wealth) as well as to environmental disruption (e.g. via light pollution). Recently 41 pressing scientific questions in seven thematic fields were identified that would benefit from improved nighttime visible band imagery. Research based on artificial nighttime light has increased rapidly in recent years, due to the introduction of improved instruments from the US and China. However, this research remains limited by the overall lack of current sensors, as well as issues related to their insufficient spatial resolution, spectral information, radiometric sensitivity, and revisits. Further issues are an overall lack of reliability, and overpass times which are not matched to peak evening emissions and with no detection of changes between evening and night activities. Compared to sunlight, artificial light sources are characterized by their spatial heterogeneity, as well as extreme variability in spectra, angular emission characteristics, and temporal properties. These factors interact to make interpretation of nighttime light series challenging. Consider, for example, that different sources are observed for the same area on Earth's surface, depending on whether the satellite view is from the East or West. This gives rise to considerable variability in observations from night to night, which causes problematic dispersion in the radiance values reported in monthly and annual composite images. Furthermore, the changing phase of the moon means that with a revisit cycle of 14 days or longer, geometric revisits often alternate between moon-lit and moon-free conditions. Changes in lighting technology have proved especially problematic for existing time series, as transitions from high pressure sodium to LED streetlights that preserve photometric illuminance can cause dramatic decreases in the radiance observed in a panchromatic band. The EULE mission would considerably advance the state of the art for most of the existing limitations of night lights data as a standalone satellite, and the overpass time limitation in synergy with other missions. It provides reliable radiometric observations in multiple spectral bands. This allows nighttime radiance to be re-expressed in terms of sensitivity curves, such as those for human or other animal vision systems, as well as the identification of lighting technologies. It has unprecedented sensitivity, making the detection of even individual spatially isolated artificial lights possible, and allows direct observation of the flux of artificial

light in the atmosphere above and surrounding selected cities. An innovative variable mode of acquisition allows the instrument to switch focus during moon-lit periods, when it produces continental-scale maps. The mission is designed to answer key research questions centred around two application areas, using the following synergistic products: Energy: The energy used to produce artificial light, and the total energy transfer (power) through the atmosphere are both unknown parameters related to sustainability science. Prior experimental and theoretical techniques have yielded conflicting results on the basic question of whether and at what rate cities are brightening. EULE makes it possible for the first time to identify lighting types and track their changes on the global scale. In unlit areas near to large lighting sources (e.g. urban areas), the sky is brightened by the scatter of artificial light in the atmosphere. In addition to being a form of global environmental change with social and ecological impacts, this scattered light contains information about the horizontal transfer of light (from e.g. illuminated advertisements) that are difficult to directly observe from space. EULE is the first satellite instrument specifically designed to measure this skyglow on large scales. Electricity: Many areas of the world lack access to a stable electrical supply. Lack of access to stable electricity has dramatic consequences for development, for example, due to the inability to study or work at night, or to ensure the storage of cooled goods such as medicine and food. Tracking electricity access is therefore critical for academic researchers, governments and NGOs that study or support human development. Unfortunately, national statistics of electricity access often do not match the reality on the ground, especially in LMICs (Low- and Middle-Income Countries) and particularly in informal settlements. Furthermore, some areas that are technically electrified nevertheless experience an unreliable supply, with frequent power outages. This means that global statistics from bodies such as the World Bank or the UN overestimate the true access to reliable power. EULE identifies electricity access at a resolution matching small clusters of buildings, based on the presence of outdoor light emissions, and further examines electricity reliability based on their radiometric stability. Major advancement over the state of the art are achieved from the combination of greatly improved spatial resolution and radiometric accuracy. The EULE mission core objective is to improve our understanding of Earth's night environment, lighting practices, and human access to electricity worldwide, via measurement and identification of spectral-spatial-temporal variations in nighttime artificial lighting. This requires characterisation of how much artificial outdoor light or radiation is emitted (intensity), in what form (spectral wavelength, source light type), where (spatial directions, light distribution), and when (time, light use). The acquisition of this information requires global, frequent, high-resolution, multi-spectral optical remote sensing nighttime low-light (NTL) data at similar observation geometries and times, providing a unique view of the activities of humans on Earth's surface. The products established in order to answer these questions will also have wide applicability for numerous further research fields, including but not limited to human health and well-being, ecology (animals and plants), urbanization and socio-economy, identification and monitoring of disasters and conflicts, natural properties of the Earth atmosphere and surface, and cross-calibration. The EULE mission would therefore acquire imagery for selected, geographically distributed, typically populated areas at a frequency of approx. 6x/month (not necessarily cloud-free), and for all populated land surfaces at a frequency of approx. 1x/month at night to achieve the objectives. These areas are observed for at least four years (to consider long-term changes between nights of different seasons). This could be achieved, for example, in a 2-day repeat orbit (to ensure consistent observation geometries) with one satellite at a local (solar) time of 21:30 (to observe peak evening human activities) with a coverage of 150 km x 150 km per acquisition. If it would be achievable, additional satellites operate in the same orbit at a local (solar) time of 01:30 (to consider evening and night changes and mitigate effects of polar days) or to allow for revisits of one day (to consider intra-night changes at highest

frequency). In the visible and near infrared (VIS/NIR), one panchromatic band at 10 m (to detect single street lamps having a common distance of ≥ 25 m) and four multi-spectral bands (to consider the artificial and natural lighting characteristics) at 20 m are achieved at nadir view, along with two spectral bands at 150 m in the longwave infrared (LWIR) (to estimate temperatures and atmosphere). Because of low-light conditions (e.g. for PAN a radiometric range 5×10^{-7} (detection limit) to 7.5×10^{-4} (saturation) $\text{Wm}^{-2}\text{sr}^{-1}\text{nm}^{-1}$ is required), step and stare is applied resulting with state-of-the-art optics in a Signal-to-Noise Ratio ≥ 10 at reference radiance 1×10^{-6} $\text{Wm}^{-2}\text{sr}^{-1}\text{nm}^{-1}$. This requires a highly stable platform with precise yaw steering. The strong heritage from existing systems leads here to a mature system. Finally, view and access to the products at various processing levels would be provided through the official Copernicus digital platform services to fulfil user demands for modelling and mapping. To obtain required Bottom-of-Atmosphere (BOA) observations based on Top-of-Atmosphere (TOA) measurements, implies an accurate consideration of the nocturnal atmosphere, which is a supported research topic on its own. The sustained and quality-controlled observations of the EULE mission would revolutionise understanding of artificial nighttime lighting and its human and environmental impacts. The review of the proposal by ESA highlights the important novel aspects. They represent long-standing observational gaps and address some urgent scientific and societal questions of the Living Planet Challenges. Adaptions of the originally proposed EULE mission will focus on more specific research questions allowing to pare down the EULE mission.