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Dynamics of the urban lightscape

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ABSTRACT

The manifest importance of cities and the advent of novel data about them are stimulating interest in both basic and applied "urban science" (Bettencourt et al., 2007 [4]; Bettencourt, 2013 [3]). A central task in this emerging field is to document and understand the "pulse of the city" in its diverse manifestations (e.g., in mobility, energy use, communications, economics) both to define the normal state against which anomalies can be judged and to understand how macroscopic city observables emerge from the aggregate behavior of many individuals (Louail, 2013 [9]; Ferreira et al., 2013 [6]). Here we quantify the dynamics of an urban lightscape through the novel modality of persistent synoptic observations from an urban vantage point. Established astronomical techniques are applied to visible light images captured at 0.1 Hz to extract and analyze the light curves of 4147 sources in an urban scene over a period of 3 weeks. We find that both residential and commercial sources in our scene exhibit recurring aggregate patterns, while the individual sources decorrelate by an average of one hour after only one night. These highly granular, stand-off observations of aggregate human behavior – which do not require surveys, *in situ* monitors, or other intrusive methodologies – have a direct relationship to average and dynamic energy usage, lighting technology, and the impacts of light pollution. They may also be used indirectly to address questions in urban operations as well as behavioral and health science. Our methodology can be extended to other remote sensing modalities and, when combined with correlative data, can yield new insights into cities and their inhabitants.

1. Introduction

A nighttime image of the Manhattan skyline (see Fig. 1a) contains thousands of artificial light sources, including windows, buildings, streets, vehicles, and billboards. While virtually all of these sources are stationary in position, many are dynamic in time, changing in color and intensity throughout the night. The origins and timescales of variability are diverse, ranging from the 30 Hz flickers of a display screen to the few-Hz flickering induced by starting motors to discontinuities as shades are drawn or lights are turned on and off. Changing atmospheric conditions (for example the motions of clouds across the sky) also contribute variability. At low resolution, window lights in an urban night scene are analogous to variable stars on the night sky and so the techniques of observational astronomy

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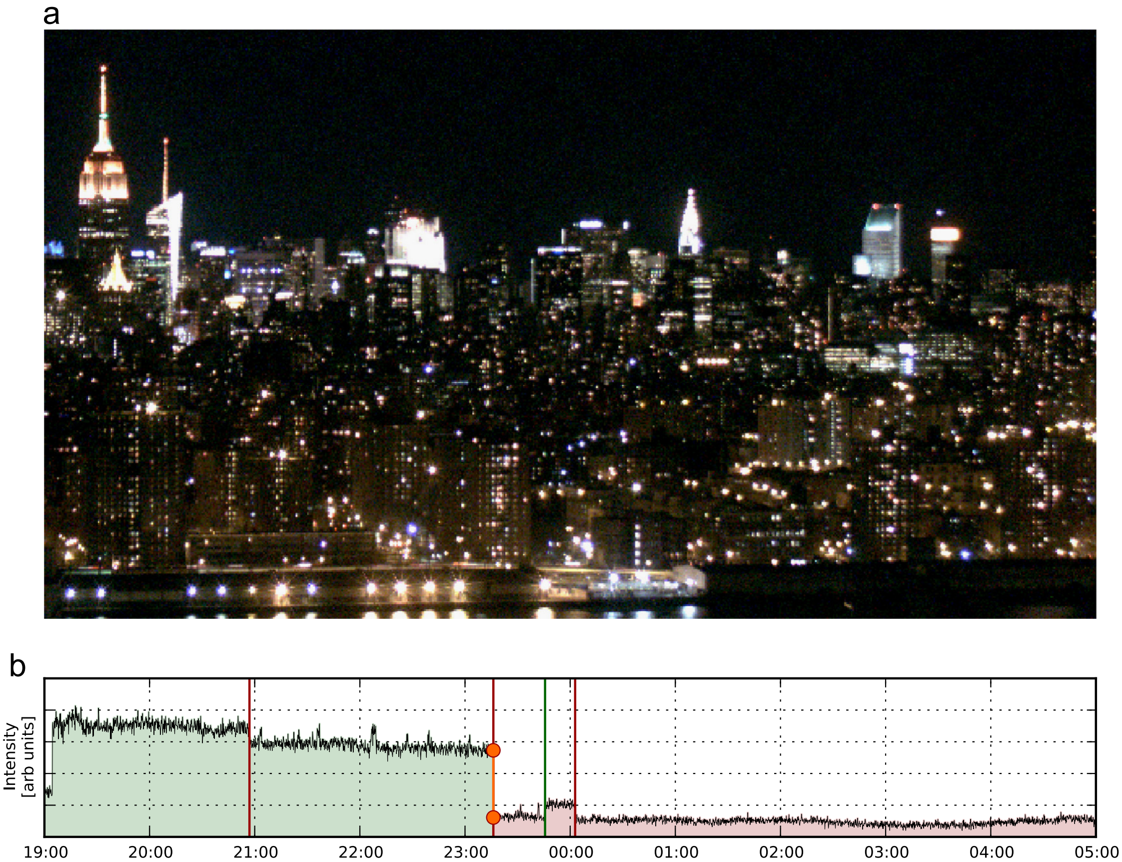

Fig. 1. The night scene viewed from the CUSP Urban Observatory. (a) This vantage point in downtown Brooklyn faces northward towards Manhattan. A time-lapse of the scene is available online at https://www.youtube.com/watch?v=D3UKcoh6gig. (b) A typical light curve for one of the sources in the scene. Vertical green (red) lines indicate on (off) transitions. The off transition corresponding to the largest change in average intensity, as measured before and after the transition (the t_{off} time), is shown in orange. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

can be applied to analyze the urban lightscape. In this paper, we demonstrate the utility of that approach in providing a new measure of urban activity and in revealing the dynamics of individual light sources.

While satellite observations of urban lights have been used to study city morphology, development, land use [12], energy consumption [14], and night lights [7], they are necessarily episodic and cannot probe dynamics on timescales shorter than a week. Observations from urban vantage points offer persistent coverage and an unchanging perspective, together with easy and low cost operations. Such images have been acquired for aesthetic purposes [13] but have not been analyzed for the scientific study of cities, with impacts from energy use and efficiency [8] to sleep patterns (which are a significant public health concern; see for example, [1,11]). *in situ* measurements with a comparable coverage, while perhaps more accurate, would be intrusive and would further entail the cost and operational difficulties of a large-scale sensor deployment.

In this work, visible light images were acquired from a rooftop in downtown Brooklyn, the first site of the Urban Observatory facility created by New York University's Center for Urban Science + Progress (CUSP). The northern view across the East River covers the east side of lower and midtown Manhattan and offers a diversity of features, including the tops of the Empire State Building (at a distance of 6.1 km) and the Chrysler Building, major and minor building lights, and street and river lights. There are roughly 20,000 residential and commercial windows in the scene, and we estimate that some 100,000 people reside in the 4.4 km^2 covered by our images.

In Section 2 we describe our data acquisition and analysis pipeline which draws heavily from astronomical image processing and time series procedures, while in Section 3 we identify patterns in the light variability and the implications for aggregate versus individual behavior. We conclude in Section 4.

2. Methods

The images analyzed in this paper were acquired with a Point Grey Flea 3 8.8 megapixel camera (equipped with a 25 mm lens) every 10 s between 19:00 and 05:00 h on each of the 22 nights between October 26 and November 16, 2013. Daylight Saving Time ended during this period on November 3rd. Upon acquisition, each image (~25 MB in three-color raw format) was timestamped, encrypted, and