

# Monitoring Light Pollution on the Starlight Reserve of Montsec

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## Abstract

Montsec Mountains are a special protected place in Catalonia (NE of Iberian Peninsula). Since 2013 the site has been declared Starlight Reserve and Touristic Destination. In the last three years different projects took place in Montsec to evaluate the quality of night sky and the effects of Light Pollution of nearby (and not so nearby) municipalities.

Using SQM techniques in RoadRunner configuration (installed on a car) we have evaluated all the region (1 600 km<sup>2</sup>) and we determined the distribution of night sky brightness detecting some excellent areas with values around 21.5–22.0 mags. In addition we have evaluated the effects of the closest big city (Lleida with around 200 000 inhabitants) and we have estimated long distance effects of this city on the natural sky. The effect is detected on zenith up to 25 km away from the city. These data show the critical problem of the long-distance effects of LP on protected areas. To complete the monitoring of the region, a new SQM network is ongoing in cooperation with Parc Astronòmic Montsec and Catalan Service against Light Pollution. During 2014 six SQM permanent detectors are starting their measurements around the area of Montsec and major cities that affects this protected area. This data could be combined with meteorological data (clouds, humidity, etc) in some of the evaluation sites.

## 1 Introduction

Montsec is a calcareous mountain range more than 40 kilometers long, covering an area of 18 696 hectares divided between Aragon and Catalonia in the North-East of Iberian Peninsula.

The Catalan institutions since more than 10 years ago are working in the area to implement a regional development project, by taking advantage of its capabilities and potential helps to redirect and improve its socioeconomic situation. One of the most important capabilities is the dark sky and in this context Parc Astronòmic Montsec (PAM) became a reality. The PAM has two main parts: the Observatori Astronòmic del Montsec (OAdM) and the Centre d'Observació de l'Univers (COU). The OAdM is a professional observatory with an 80-cm catadioptric telescope (Joan Oró Telescope) and COU is a large multipurpose center which is intended to become an educational benchmark for teaching and communicate astronomy and other sciences in Catalonia.

Since the beginning of PAM project, Government of Catalonia starts to work in the protection of the dark sky of Montsec. Examples of this protection are the Catalanian Law (Law 6/2001), the first autonomic Law of Light Pollution in Spain, or its associate Measurement Plan (2000–2002) around Catalonia with special efforts in Montsec area. One of the topics of this Law is protect natural and astronomical sites, so the OAdM was defined as the reference point of Catalonia. Around 1600 km<sup>2</sup> in the surroundings were established as maximum protection area. In the last ten years, the Government of Catalonia has engaged many actions to improve Montsec night sky. The Measurement Plan of the Law generates the first standard measures of Montsec sky. This old measures were made using astronomical photometry with telescope and CCD camera. After some years without new measures, in 2012 we started a new Measurement Plan with the agreement of Catalan Service against Light Pollution and Parc Astronòmic Montsec. This new Measurements Plan is focused on monitoring the area using the newest techniques available and its first result was the certification of Montsec as Destination and Reserve Starlight.

## 2 Extensive Measurements

Since the beginning of this new measurements we have used two main techniques, using two of the most common instruments currently available. All the measurements have been made under strict conditions (during astronomical night, without Moon, without clouds or fog, skipping high humidity levels or any other perturbation).

### 2.1 SQM Photometry

We have used the most common instrument, Sky-Quality Meter (SQM) developed by Unihedron (<http://unihedron.com/>) that allows us to obtain the sky brightness in magnitudes per square arcsecond [2] of a region around 20 degrees in the zenith for the SQM-L devices. For extensive measurements we have used SQM-LU that sends the data to a PC using USB port. In the same PC there is a GPS plugged and RoadRunner Software developed by Sociedad Malagueña de Astronomía. This system allows us to collect data of the sky brightness and position at the same time. So we can install it on a car and made moving measurements using roads and paths of the study area. Many routes have been defined with the idea that could be repeated in the future. We have defined 11 routes around Montsec area, 4 routes in Pyrenees Valleys and 4 more in the surroundings of the city of Lleida (capital of the province).

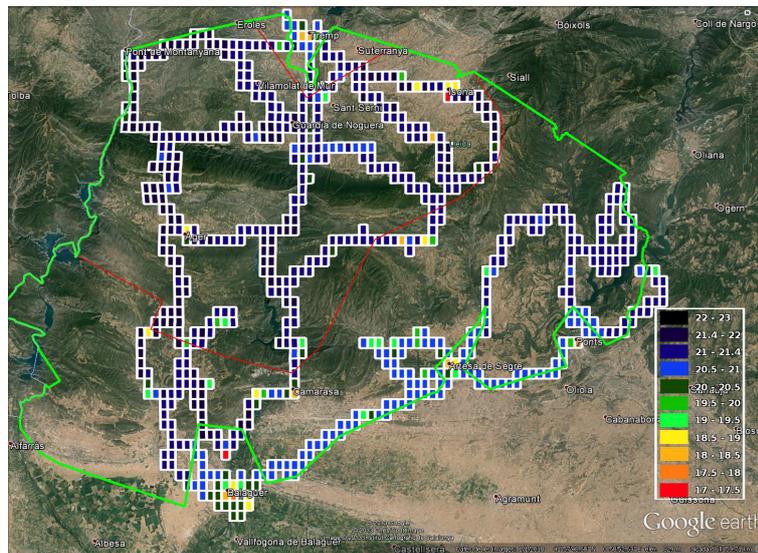


Figure 1: Map of Montsec area with the SQM processed data. The lines are the Starlight Reserve (red) and Touristic Destination (green).

The data obtained are processed using our own code to create boxes of 0.5 degrees in latitude and longitude with the mean of the measurements in every box. This code rejects measurements that are not consistent (e.g. trees or bridges in the route) and generate the map that could be loaded in Google Earth or any other GIS compatible with KML files. The results of Montsec and Lleida areas are plotted in Figs. 1 and 2.

The results in Montsec area (Fig. 1) confirms the sky of Montsec as one of the best skies in Southern Europe. Almost all the measurements outside villages are better than 21.0 mag in the zenith position. Some excellent areas are detected with values better than 21.40 mag (Starlight Reserve requirement). Just few municipalities inside the area create detectable light effects outside their urban areas (e.g. Balaguer, Tremp, Ponts or Artesa de Segre) and the rest of villages has no effect in their surroundings.

The study of Lleida city give us the idea of how important is the effect of light pollution in distance. To recover measurements of 21.0 mag or better in the zenith it is necessary to be around 25 km far from Lleida (see Fig.2). Travelling to south better than 21.0 mag are obtained at these distances and going to north the good numbers appears when approaching to Starlight area.

## 2.2 Astronomical Photometry with ASTMON

The second method is the classical method of astronomical photometry taking as reference the magnitude of standard stars and taking measurements in the different directions of the night sky [3]. Currently it is not necessary to use telescopes and CCD cameras, now it is possible to use systems with fisheye lens to provide easily an all-sky image. In our case we used ASTMON Lite. This is a portable version of ASTMON device [1] with a 4.5 mm

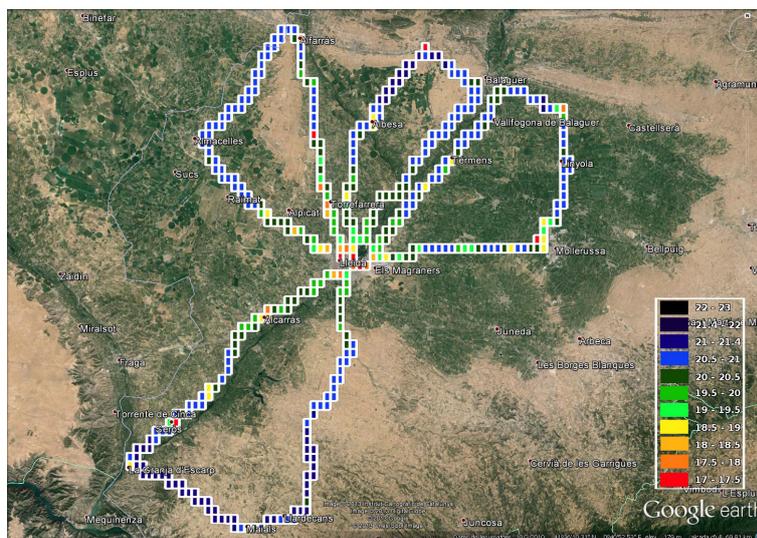


Figure 2: Map of the city of Lleida area with the SQM processed data.

fish-eye lens and an astronomical CCD camera with Johnson photometric filters. The system is operated by a specially designed software to get directly processed all-sky maps (e.g. Fig. 3). Alternatively it is possible to reprocess data with a more detailed code as the one developed by Nievas [4].

The analysis of all-sky maps shows the effect of the major cities in the limits of the area as Balaguer (red area in the bottom-center of Montsec map in Fig. 3) or Tremp (green colors in the top left of the same map). The major problem is produced by the big cities a long distances, this is the case of Lleida (50 km) or Barcelona (more than 100 km) clearly visible from the top of the mountains (OAdM site).

### 3 The immediate future: permanent stations

To continue monitoring this protected area and the effects of the cities that are generating light pollution in this area, it is possible to use another approach with permanent stations. A new cooperation project between Parc Astronòmic Montsec and Government of Catalonia, called XCL, is starting with the installation of the first six permanent devices during 2014. These devices are SQM instruments working with a weatherproof housing and transferring the data through ethernet (SQM-LE version) to our servers. The basic data processing and operation of the device is done using PySQM software developed by Universidad Complutense de Madrid (<http://guaix.fis.ucm.es/PySQM>).

These first stations have been installed in OAdM site and COU site in the Starlight Reserve area, Balaguer city and village of Seró in the border of Starlight Touristic Destination, and in Lleida and Barcelona cities because these are the main polluters of the protected area. This continued monitoring (e.g. see Fig. 4) will allow us to start with cross-correlated studies

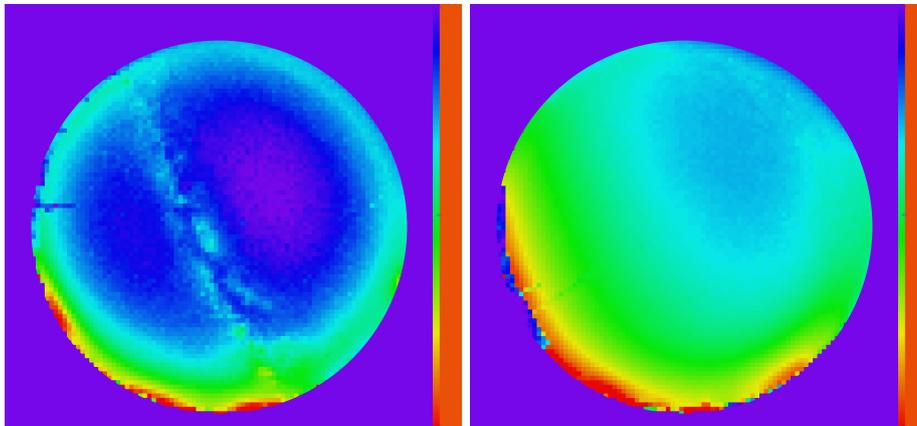


Figure 3: *Left*: All-sky map obtained from the OAdM site. The three red spots are from left to right: Barcelona, Balaguer and Lleida. *Right*: All-sky map obtained in the surroundings of Balaguer. The city is clearly dominating the emission but in the bottom right side the lights from Lleida are still detectable.

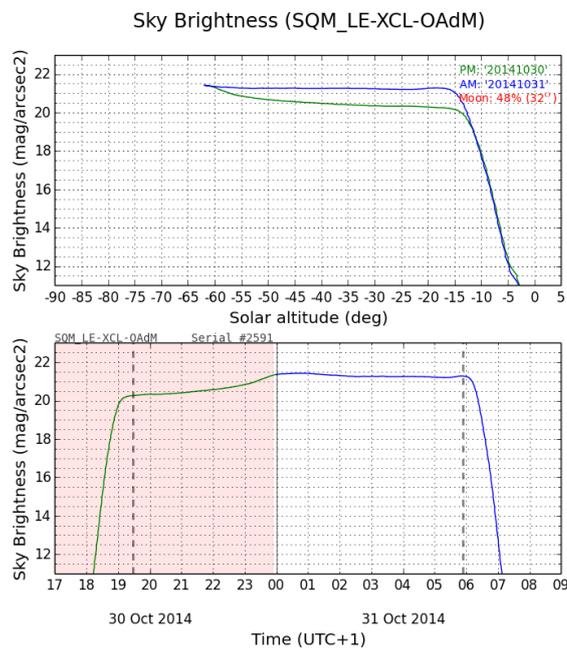


Figure 4: Example of night evolution of OAdM site using SQM with PySQM code. The section colored in pink shows when the Moon is above the horizon. In a pristine area is clearly visible the natural effect of the Moon.

of night sky brightness with environmental parameters using for example weather stations data or ceilometer [5] to evaluate aerosol or clouds effects.

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