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ISS nocturnal images as a scientific tool against Light Pollution

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LICA report, April 2011 Version 1.8 2011/05/04

Abstract

The potential of the night pictures taken from the International Space Station with a Nikon D3s digital camera to fight against light pollution is shown. A scientific analysis of ISS026-E-26493 RAW image of Madrid at night with techniques used by astronomers and cartographers is performed. We suggest an observational setup to obtain useful scientific information from the pictures including series of exposures and calibration frames.

1. Introduction

Light pollution (the introduction by humans, directly or indirectly, of artificial light into the environment) is a major issue worldwide, especially in urban areas. It increases the sky glow and prevents us from observing a dark starry sky. As 'Starlight, A Common Heritage', promoted by the International Astronomical Union (IAU) and the UNESCO, which is a international campaign in defense of the values associated with the night sky and the general right to observe the stars said: "An unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights, due to its impact on the development of all peoples and on the conservation of biodiversity." Starlight Declaration. La Palma, Spain 2008.

Astronauts aboard the International Space Station (ISS)[1] are publishing (Twitter for instance) pictures of the Earth taken from the space. These beautiful pictures are freely available and can be obtained from a repository maintained by NASA on Internet. A portion of the images is being taken at night and some of them show a network of light of the big cities. This illumination comes mainly from public lighting of the streets and buildings. The intensity in the picture is related to the light being sent to the space and bright light reveals an excess or bad use of lighting.

See the video "Cities at Night: an orbital tour around the world"
http://www.ngdc.noaa.gov/dmsp/movie/CitiesAtNightWorldTour720X480Edit7.wmv

[1] The International Space Station (ISS) is a co-operative program between space agencies: National Aeronautics and Space Agency (NASA) from United States, the Russian Federal Space Agency (Roscosmos), Canadian Space Agency (CSA), European Space Agency (ESA) and Japan Aerospace Exploration Agency (JAXA) for the joint development, operation and utilization of a permanently inhabited Space Station in low Earth orbit.

Among other scientific studies that could be performed with these images we are interested in those connected with light pollution and its effect on the night sky brightness and on the visibility of the stars (see for instance Cinzano and Elvidge 2004). Detecting light pollution is straightforward by visual inspection of the JPEG pictures. These images speak by themselves and are very useful to draw public attention of the problem. Unfortunately the JPEG is a lossy compression method, meaning that some original image information is lost and cannot be restored. To obtain useful scientific values from these pictures, the original RAW files are needed. Being the CMOS detector of the digital camera employed (Nikon D3s) a linear device, the intensities of each pixel are proportional to the emitted light and one can directly compare between different zones of the image. Besides, the color of the light sources can be obtained by comparing the value of the image in different channels or bands. From these colors the nature of the light bulb employed can be inferred.

This is why we have requested and obtained from NASA iss026e026493.nef, which is a RAW image (with a Bayer matrix) with the format of the digital images of Nikon. Information of this picture can be obtained at the Gateway to Astronaut Photography of Earth:

http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS026&roll=E&frame=26493

Exif data: Nikon D3S f=200mm f/4 1/15s 12800 ISO 4256x2832 pixels 2011:02:11 23:11:50

This is a preliminary report . The main aims of this study are, among others:

1) To obtain useful and scientific information of the light pollution at Madrid city area
2) To emphasize the importance of these ISS nocturnal images for science and public outreach.
3) To design a calibration sequence to be used by astronauts on board ISS for these kind of night pictures when they are taken for scientific studies.

Figure 1. Published JPEG image of Madrid in true color. This picture was taken by Scott Kelly.

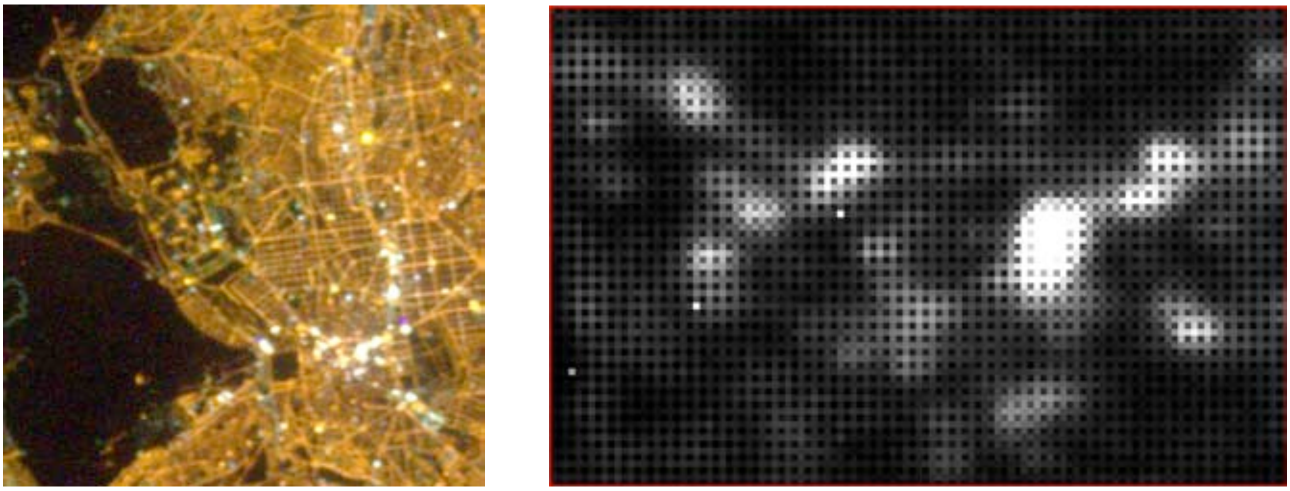


Figure 2. Detail of image ISS026e026493 in Madrid downtown. A deep zoom of the RAW image to show the Bayer matrix is also displayed.

Due to the light directly emitted to the space or reflected in the ground, the image shows clearly recognizable features of Madrid at night. These include streets, parks, airport, a soccer stadium, roads, etc.

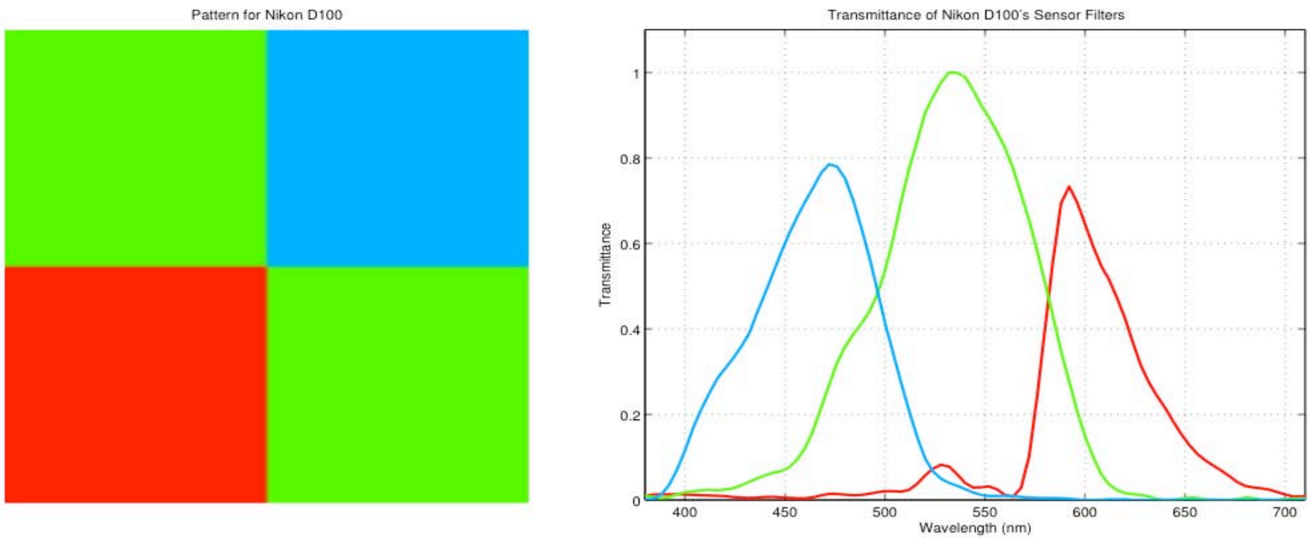


Figure 3. Bayer GBRG color filter array for Nikon D100. Note that the camera used was a Nikon D3s. Taken from “Resolution in Color Filter Array Images” by Jon Peterson and Cobus Heukelman (http://scien.stanford.edu/pages/labsite/2010/psych221/projects/2010/PetersonHeukelman/Website/index.html)

2. Image processing

The detector used a Bayer mosaic: a color filter array (CFA) which consists of one red, two green and one blue filter in a square 2x2 arrangement. The first step consists in separate or split the three channels (R, G & B) of the digital image in order to obtain useful scientific images. We used IRIS an astronomical image processing free software (http://www.astrosurf.com/buil/iris) developed by amateur astronomers.

The command SPLIT_CFA (http://www.astrosurf.com/buil/iris/tutorial5/doc17_us.htm) splits the CFA

(Color Filter Array) structure into four distinct files (one for each of the colors/positions in the periodic Bayer matrix). The final FITS files (Flexible Transport Images System, a standard for astronomical use) correspond to images (2100 x 1400 pixels) with the intensities for the red, green and blue pixels. For the green pixels two files are created due to the structure of the Bayer matrix (see Figure 2).

Each pixel has 14 bits depth, i.e. 1E14 = 16384 quantization levels. When a pixel has received light in excess of this highest value, the pixel appears saturated and the only information that one could extract is that the intensity is higher than this value. Some pixels in the image are saturated. It is easy to prevent the image from saturation using a shorter exposure or by adjusting the sensitivity (lower ISO value) or reducing the aperture of the lens. The resulting image would be dimmer and the fainter regions poorly measured. It would be desirable to obtain a series of exposures to get all the regions properly registered. Read later on bracketing series of exposures.

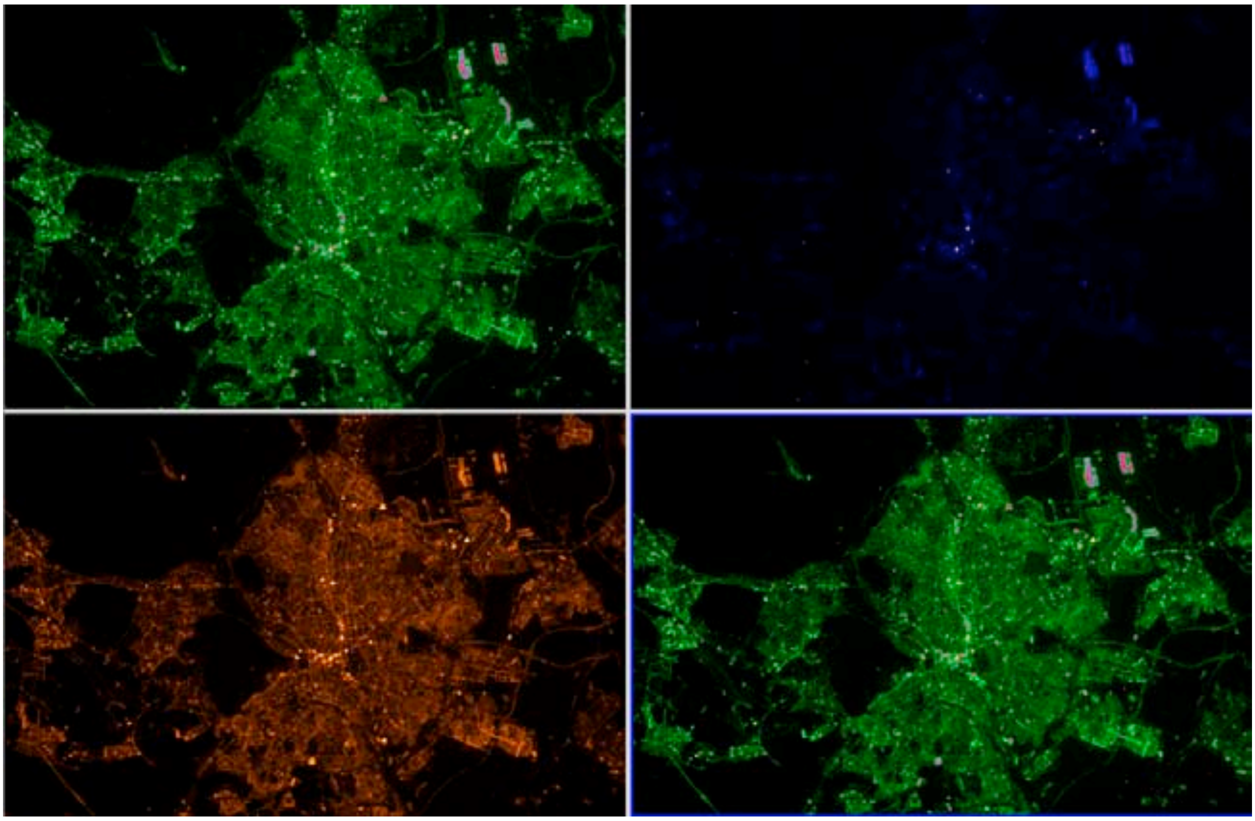


Figure 4. The four channels of the Color Filter Array structure of the RAW image of Madrid.

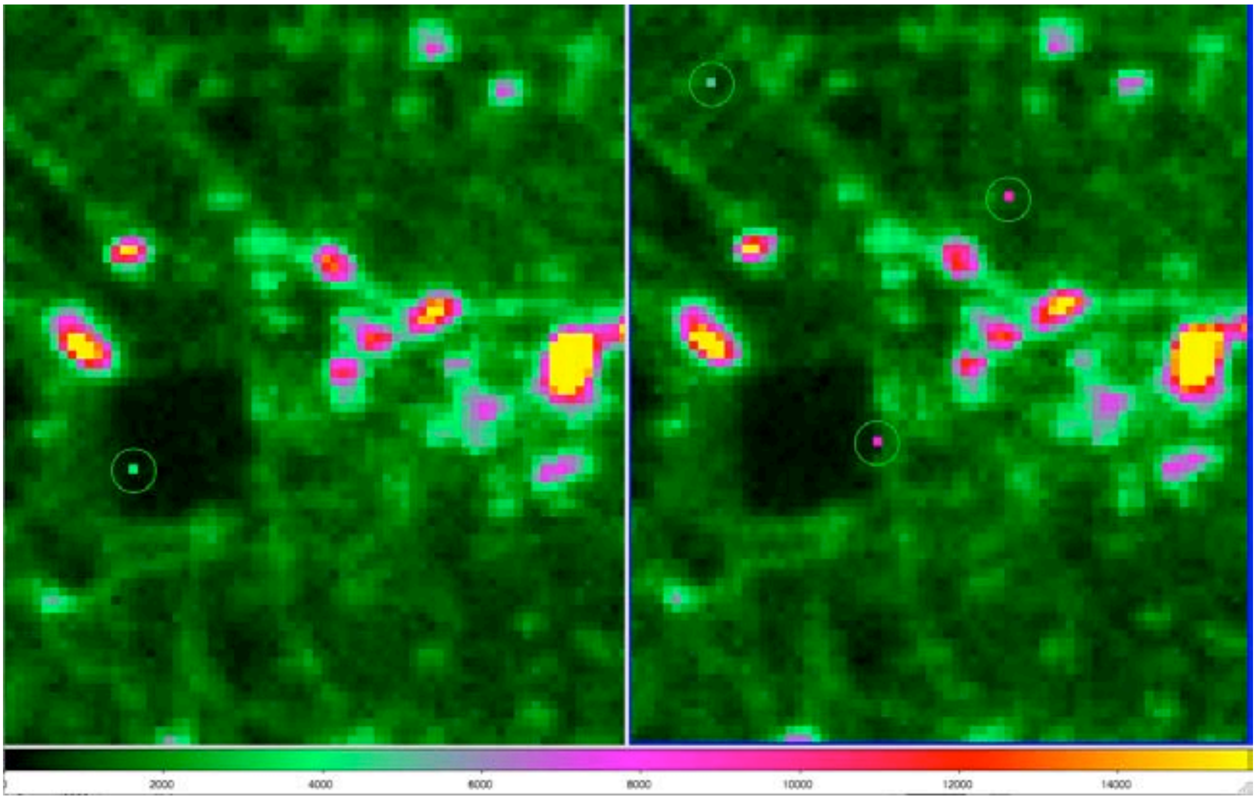


Figure 5. The same region of Madrid picture in both green channels. This is not a true color image. The intensity is color coded according to the color bar at the bottom being higher intensity pixels (and those saturated) in yellow color. Some bad pixels are marked in both images.

The green channels have been selected for this study because they yield more intensity data with better spatial resolution; the spectral range is also similar to the astronomical Johnson V band (read later on absolute calibration). A region of these green channel FITS files iss_G_1.fit and iss_G_2.fit is shown in figure 5. The images are rather similar, as expected, except for some bad pixels. These artifacts of the camera should be removed prior to any measure since they are not related to the lighting but to the camera detector. Bad pixels should appear in the same position on different frames for the same camera. Read later on dark calibration and masking of bad pixels. Fortunately we can search and clean these pixels comparing both images using the make up procedures of astronomy image processing packages. In this work we have used REDUCEME, an astronomical data reduction package to get rid of these cosmetic defects by careful visual inspection (http://www.ucm.es/info/Astrof/software/reduceme/reduceme.html).

SCIPY (www.scipy.org), a library of Python routines and C extensions developed as an open-source software for mathematics, science, and engineering, has been used to rebuilt the raw image with the pixels of each green channel in its original positions. The FITS files were read and written with PYFITS (http://www.stsci.edu/resources/software_hardware/pyfits), a development project of the Science Software Branch at the Space Telescope Science Institute. A zero value has been assigned to the pixels corresponding to the blue and red channels.

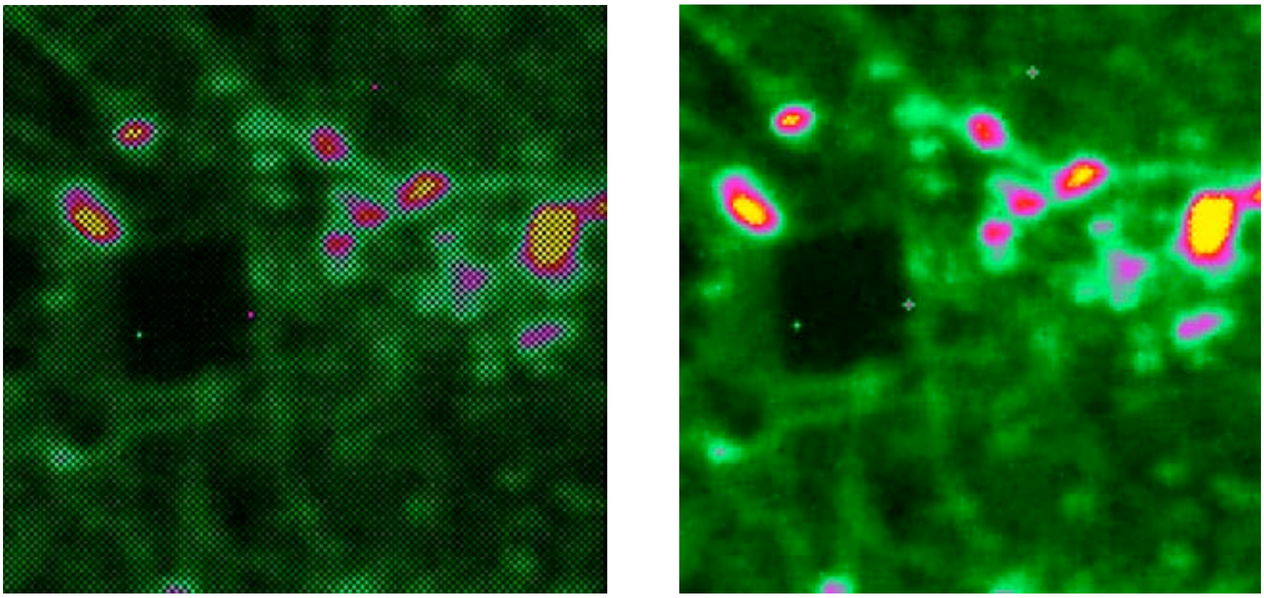


Figure 6. Intermediate image with pixels belonging to the two green channels and the final image in G channel with full resolution. (Note: not the final version. Bad pixels should be removed)

The empty pixels have been filled with a linear interpolation using the neighbor pixels. At the end of this process, an image with the same resolution as the original with information selected for the green channel is obtained.

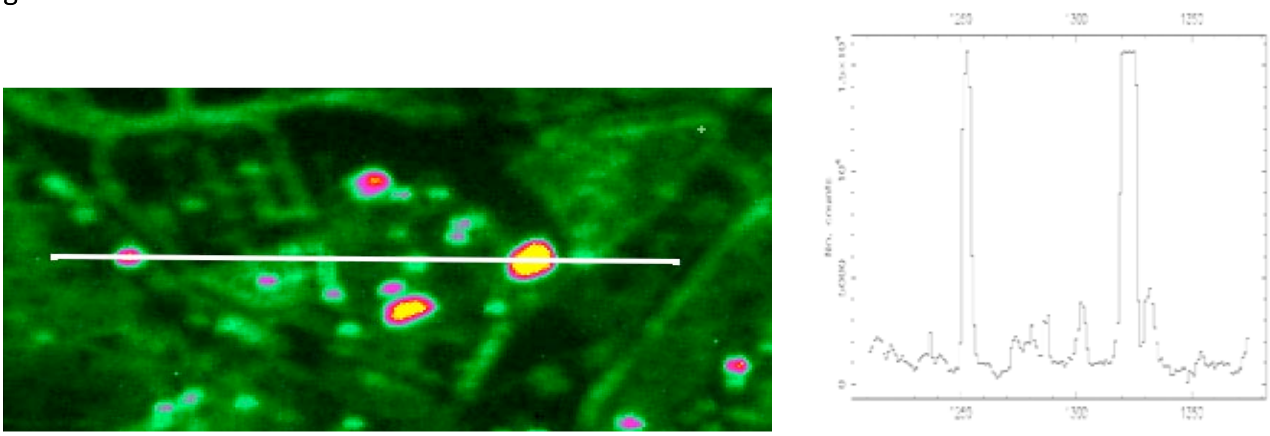


Figure 7. Zoom over the image and a graph with the pixels values along the line marked on the image. The values of the saturated pixels of the bright spot (yellow coded) are lost.

Bright spots (those with yellow color on the figures) present saturated pixels. No useful information can be derived from these values. For the example pictured in figure 7, maximum value can be estimated fitting a Gaussian to the unsaturated pixels at the wings of a single line cut. In this case the peak value is around 90,000 counts, although the method is uncertain. To obtain unsaturated pixels we need to reduce the exposure time by a factor of ~6 (~90,000/15,000), i.e. 1/100 s instead 1/15s (see below).

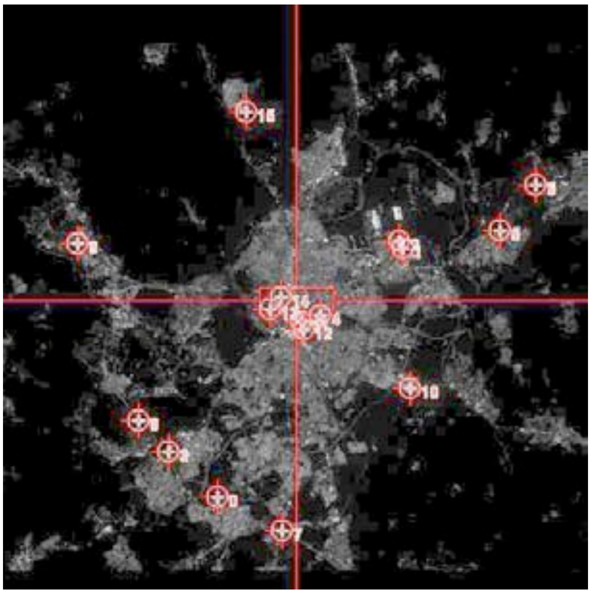
The plate scale for a 200mm focal lens is 17.19 arcmin/mm at the focal plane of the digital camera. This translates to 8.72 arcsec/pixel using the size of the pixels (8.45 microns/pixel). Assuming a distance of 350 km between ISS and Madrid, the final plate scale of the images is around 15 m/pixel. This is a 'back of the envelope' calculation that did not take into account the inclination and the final value after georeference (see bellow) is 16 m/pixel.

Plate scale should not be confused with resolution. This parameter can be derived analyzing the images of point sources. The Point Spread Function (PSF) of bright and unsaturated spots is around 5 pixels, i.e. the resolution is approximately 80 m. The PSF depends on tracking which is very good for this image since the point sources appear only slightly elongated in the East-West direction (ellipticity ≈ 0.7). During the exposure the satellite moves on the sky 1.12 deg/s x 1/15 s = 269 arcsec, i.e. around 500 m. Assuming an inclination of 43 degrees the angular scale of the ISS image is around 6.5 arcsec/pixel and thus the target moved around 42 pixels. So the image would be smeared or blurry and useless without the tracking system. Read more about the astronomical "barn-door tracker" built by astronaut Don Pettit at Cities at Night: The View from Space" (2008) (http://earthobservatory.nasa.gov/Features/CitiesAtNight/) by Cindy Evans & Will Stefanov.

3. Image georeference and spatial data analisys

Georeference is a previous necessary step before performing a correlation between the images and light sources from the field. The images have been georeferenced by using software GVSIG (http://www.gvsig.org). Orthophotos have been used as a cartographic base provided by the spanish PNOA project (National Orthophotographic Aerial Plan), and IGN (the Spanish *Instituto Geográfico Nacional*) base map, to help in identifying geographic references. We also have used GLOBALMAPPER (http://www.globalmapper.com) and UDIG (http://udig.refractions.net), to corroborate the results.

Georeference has been done using the reference system UTM30 EPSG 25830, to obtain the positions of the objects photographed in coordinates with meter scale. To transform into latitude and longitude positions in the system ETRS89 EPSG 2458, a coordinate transformation has been applied with an included utility in GVSIG. The result is a geotiff image for each band, giving correspondence pixel meter, with a spatial resolution of 16 meters per pixel. This procedure let us to obtain correlation between the position of the detected light source on the image and its counterpart in a geographic element, and hence its influence.



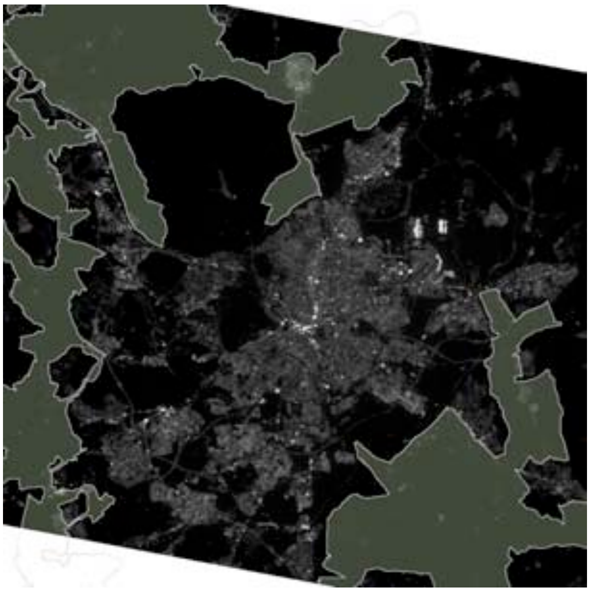


Figure 8. Calibration points (left) and resulting GeoTIFF image of channel G over PostGIS vectorial

layer with biodiversity information (right).

The geotiff image is now a new layer that can be used with GIS (Geographic Information Systems) tools. To perform spatial analysis IDEE (The spanish SDI, Spatial Data Infrastructure), has been used (www.idee.es). These data sources provide several layers where geographical elements, as buildings or cities, can be found. As an example, we show Natural Parks around Madrid on figure 8, to study possible light influence on protected areas.

Figure 9. WFS layer integration showing ISS image on top of a map of Madrid city (left) and with the main roads (right).

WMS (Web Map Service) and WFS (Web Feature Service) OGC (Open Geospatial Consortium) services have been used as data source protocol. These provide raster and vectorial data to perform the spatial analysis. Also a PostGIS database has been used to store no spatial data like population or electrical power consumption by cities. These data have a unique identifier that can be used to link them with spatial elements and they provide additional layers to the analysis. Spatial database has been used to perform SFSQL (Simple Feature Standard Query Language) analysis, like distance computations, delimit perimeter light sources or select them from a specific area. Sextante (www.sextante.org), a gvSIG extension, has been used to compute raster crops and interaction with vector layers.

Vectorial layers are used to crop selected regions from the image. In the example, a selection of municipal boundaries has been done to delimit urban nucleus. Automatic processing can be achieved using matplotlib python library (http://matplotlib.sourceforge.net). This library is also useful to get gradient maps distribution. To perform several studies, the following layers have been selected: (a) IDEE base map, (b) Catastro. Building information, and (c) Biodiversity, from Spanish *Ministerio de Medio Ambiente y Medio Rural y Marino*.

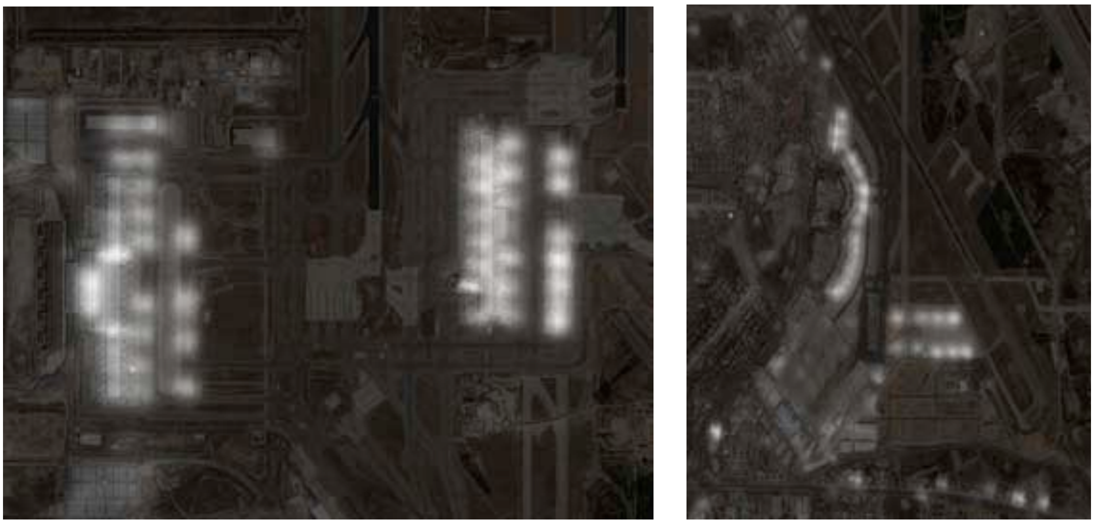


Figure 10. Integration of the ISS image on top of a geographical layer showing perfect match at the terminal buildings of Madrid Barajas international airport.

Once we have identified geographical coordinates from the image, correlation over the ground objects has been made. To do this, a buffer around each light source is defined and the resulting geometry is used to get geographic elements from each layer. The data provided by this method return information about type of element (building, natural zone, local road, highway, stadium…), type of use, owner, etc

We have developed an easy interactive web tool that allow us to identify bright ground sources. The geoTIFF image has been published using a Geoserver (www.geoserver.org) cartographic server. An OpenLayers (www.openlayers.org) based application is used to get latitude and longitude positions selected by the user using this interface. Then, Google Street View API (Application Programming Interface) is used to get a 360º view around those points. This tool can be reach at www.astroide.es/ucm/lightsources. These images provide the first look of the zone and, in most cases, an immediate identification of the luminaires.

NOAA DMSP satellites (Defense Meteorological Satellite Program) provide daily image during night periods from all around the earth. This information is accessible via WCS and WMS servers and it can be used with a gvSIG client. Although these images could be used to calibrate the ISS, their plate scales are 2.7 km/pixel, i.e. far from the resolution of the ISS images. The NOAA service provides 24 bits pixel information, and the WCS service served it on several raster formats.

Figure 11 NOAA DMSP image corresponding to April 1st 2011. (http://www.ngdc.noaa.gov/dmsp/)

One of the objectives of the study is, as was mentioned above, determining which are any sources of illumination and to produce quantitative maps of the illuminated zones. From the image we have generated a three-dimensional and dynamic field, where the heights represent different levels of illumination. First we determine isophotes in vector format from the georeferenced ISS026E026493 image (Fig. 12 shows a zoom of this image) and then generate a raster image pixels filling by a near neighbor interpolation, a Digital Elevation Model (MDE). d) Generation of a 3D image (Fig.13), and an overlay for the MDE, orthophotos from PNOA are used (Fig. 14).

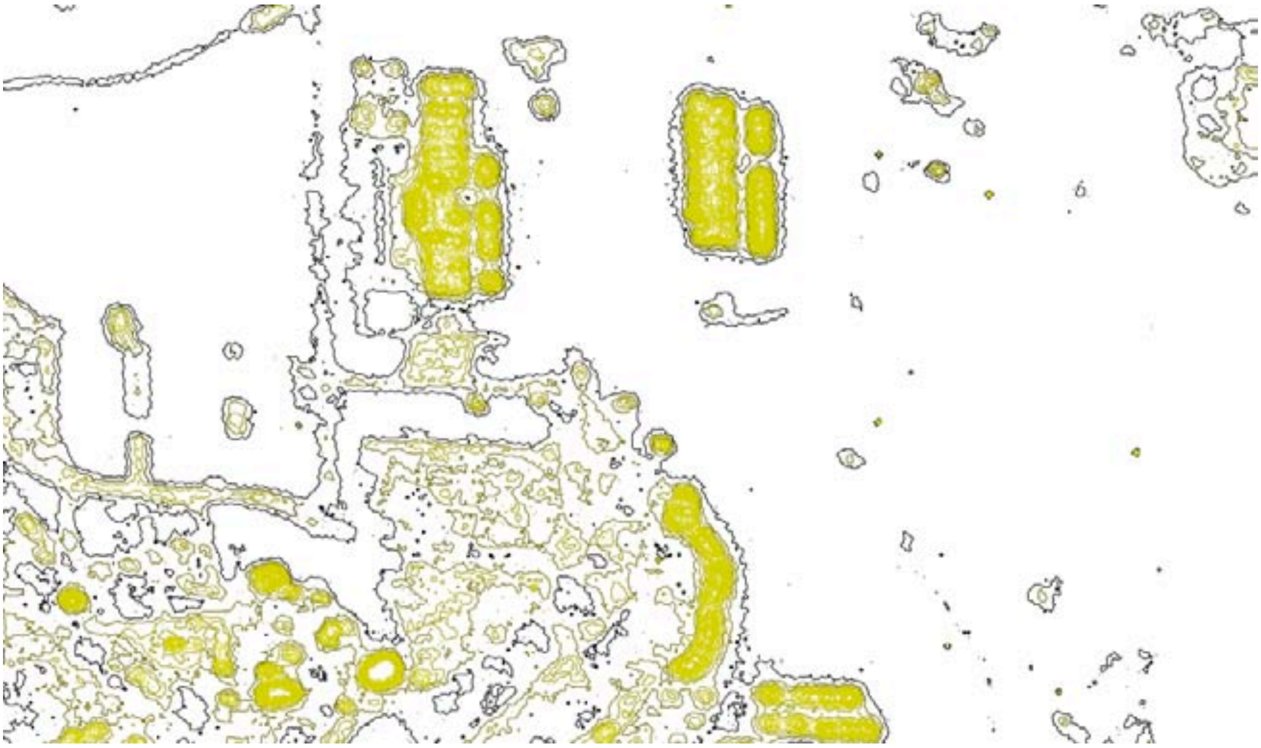


Figure 12 Isophotes of the processed image at Barajas International Airport zone

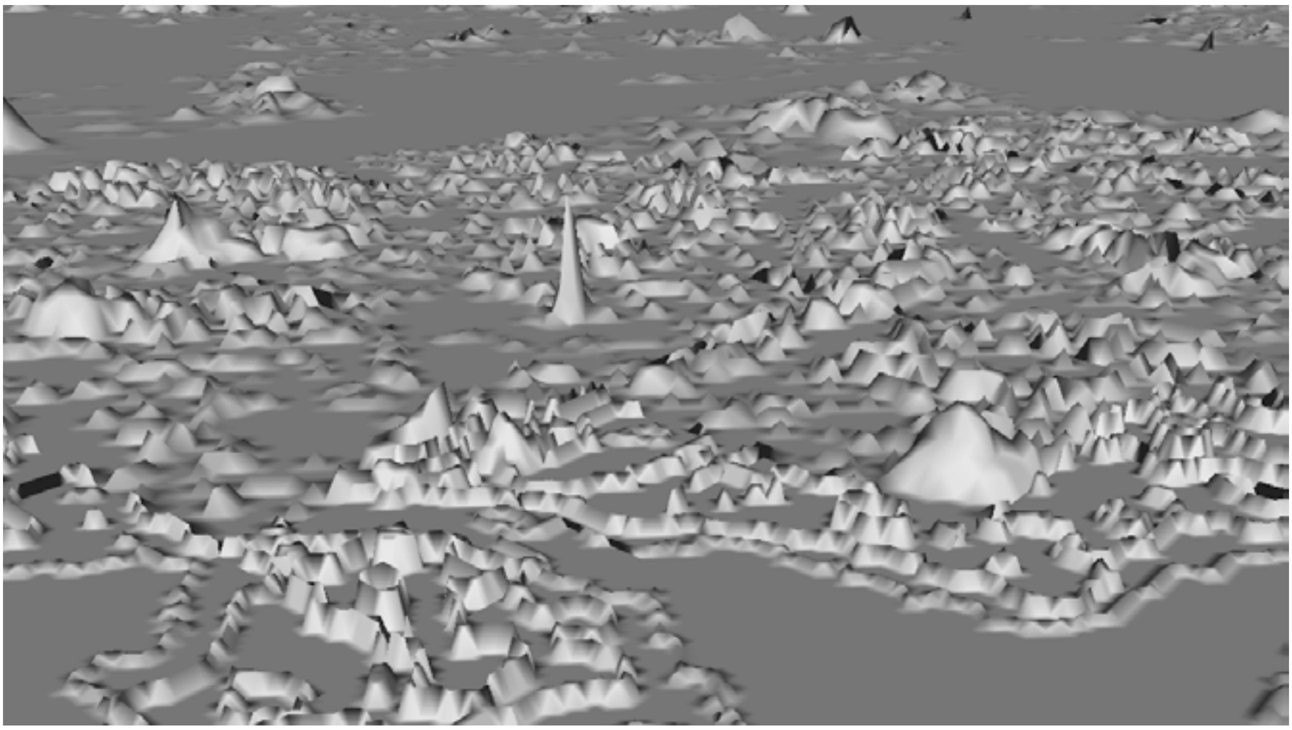


Figure 13 Digital Elevation Model using values from georeferenced image (Fuenlabrada)

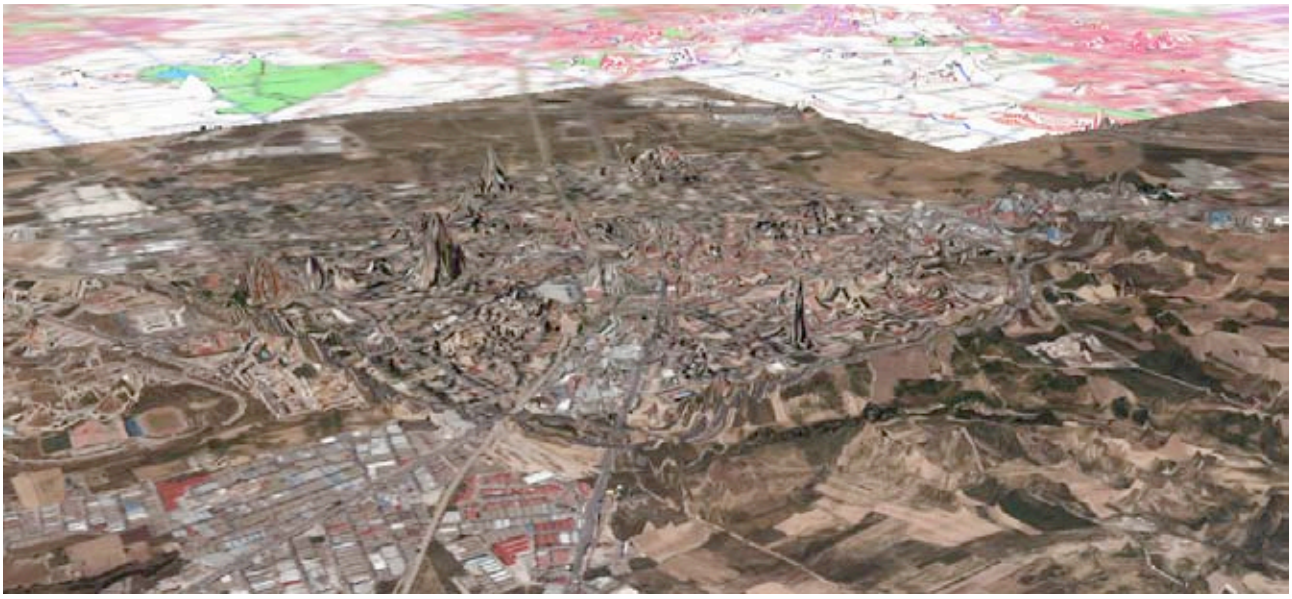


Figure. 14 Ortophotographic interactive image overlay on Digital Elevation Model. (Fuenlabrada)

As a result we have obtained a 3D ortophotographic image that keeps the georeferencing (X, Y). Elevation information (Z) has replaced by the value of the illumination counts from the original image. This digital model represents more attention to the areas that produce higher lighting. The model allows us some interactive navigation though the resulting image. So we can pan, change the perspective or zoom to identify each item. Fuenlabrada, a city at south of Madrid, has been selected for this test.

4. Cross calibration with ground data

A useful and immediate yield of this study consists in obtaining the list of the worst sources of light pollution that is useful to draw the attention of the technicians in lighting or better to the people in charge of political decisions. To show the solutions and not only the problem, it would be interesting to obtain a relationship between public lighting and impact on satellite images. Detecting places where the values are higher than expected would allow us to show the use of bad equipment or the existence of poorly designed installations.

This part of the work is being made collecting information and data on earth. Digital photometers (also known as lux meters) to measure the light brightness of the street illumination are being employed. Detailed data on selected places are taken on a grid of positions on the street and using a photographic tripod. To speed the gathering of data, the photometer is placed on top of a car and linked to a laptop computer. The positional data capture is performed with a GPS at the same time. The speed during the courses never exceeds 50 km/h on downtown streets (<90 km/h on ring roads of the beltway) and data is collected at a pace of one per second. More information can be found in the reports of the trainee projects of undergrad students Cepero (2009), Rodríguez (2010), and Ruiz (2010) under the supervision of prof. Zamorano.

To obtain recent ground data to compare to the ISS image, we made a course at the beginning of the night corresponding to 2011/03/22. The total path (41.358 km long) was georreferenced using a gps track log during luxometer measurements (see Fig. 15). We have used the geometry of this path to get the values of each point from the ISS georreferenced image (See Fig. 16).

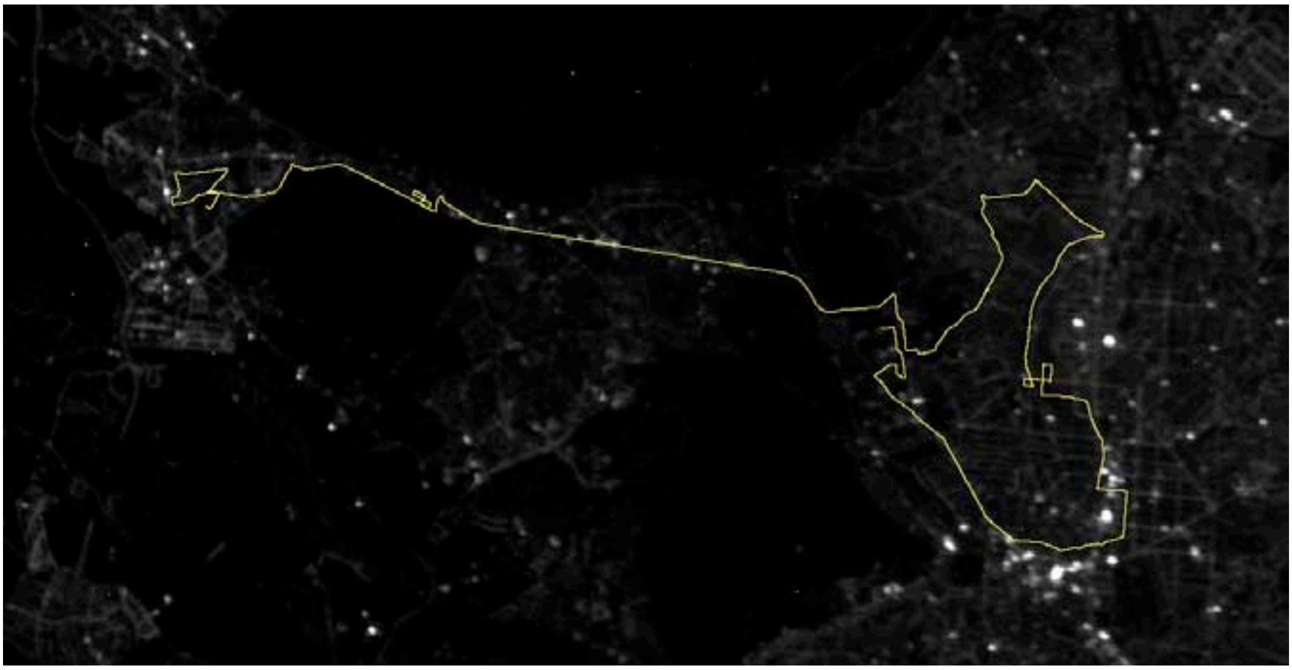


Figure 15. Whole course of 22nd march 2011 where light intensity measures were taken with a photometer on top of the car. The path is displayed over the ISS026E026493 image. Besides Madrid downtown, a main road and part of Majadahonda (a city near Madrid) were surveyed.

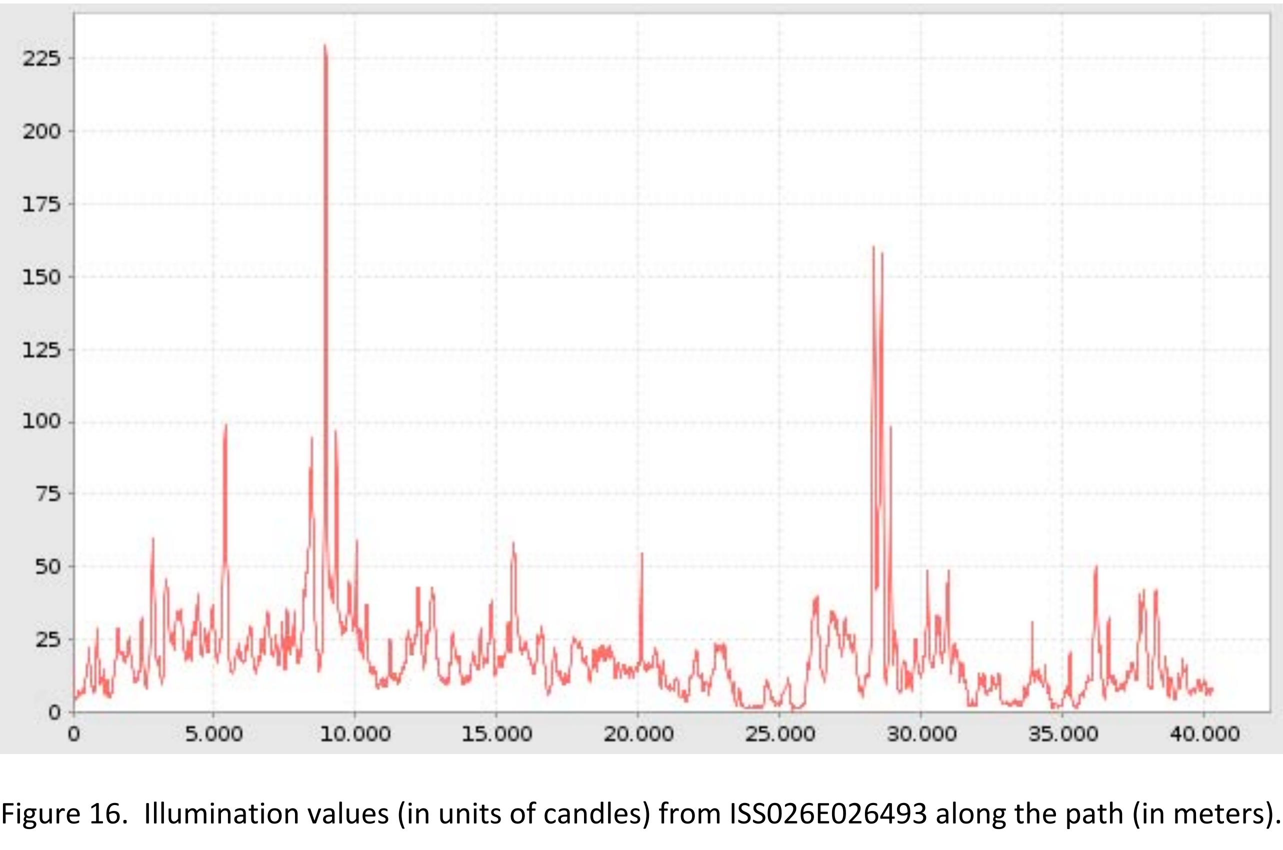


Figure 16. Illumination values (in units of candles) from ISS026E026493 along the path (in meters).

It is not straightforward to use this data because some caveats were found. The ideal scenario would be that where the ground and satellite data were taken at the same time (or at least the same night or a close night at the same hour).

In the meantime between the date were the ISS image was taken and the ground data was collected some changes took place in public lighting. For us it is obvious that the main street of Universidad Complutense campus at Ciudad Universitaria was switch off (see the blue linear track in the middle of Figure 17) and we made a remark in our logbook.

Changes at streets not so familiar for us could be unnoticed. Thus one should be cautious when comparing space and ground data. Conversely the Picasso tower, one of the brightest sources, was switch off during the ISS pass. See below some comments on street geometry as another source of error.

Figure 17. First part of the course of 22nd march 2011 corresponding to Universidad Complutense of Madrid campus (Ciudad Universitaria). The track is coded with a color scale where bright yellow corresponds to brightest measures.

To tackle this problem we could compare the whole set of data in a blindfold or unbiased way and discard data not adjusting to the expected relationship, which introduces a bias. Our referred method is to use only data of selected places according to the notes in our logbook. We have discarded data corresponding to streets where a fraction or the total number of luminaires was switched off. This part of the study is under way at the time of writing the report.

We are also trying to link the night sky brightness measured at places outside Madrid city area with the number and intensities of the light pollution sources around. This study is out of the scope of this report. Interested readers could browse the trainee project of Pila Díez (2010).

5. Other interesting issues

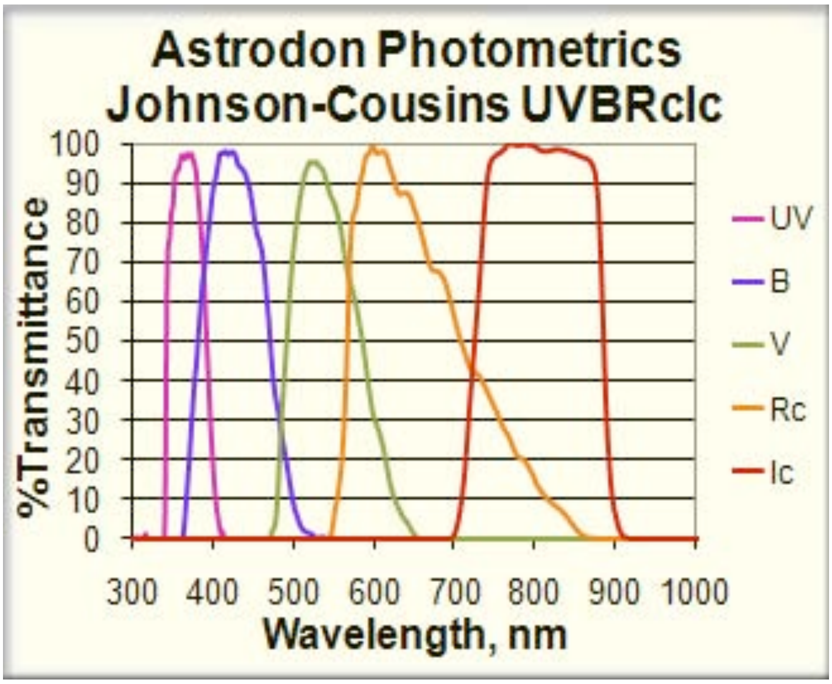
1) Image projection.
It should be taken into account that the image was not taken from the perpendicular to the ground (i.e. the ISS was not at the zenith of Madrid). According to the Gateway to astronaut Photography of the Earth the camera tilt (look angle away from a straight nadir, i.e. straight down below the spacecraft) was 43 degrees. To obtain a map projection to an appropriate coordinate system the image should be corrected for this inclination or georeferenced as we have shown.

2) Absolute calibration.
The image of Madrid was taken from ISS that was at an altitude of around 350 km from the ground. The space between Madrid and ISS was not empty and part of the light is lost in its travel

through the atmosphere. This atmospheric extinction depends on wavelength (higher for blue, lower for red photons) and it varies from night to night (and even during the night). Astronomers observe standard stars along the night and, using the method of absolute photometry, determine atmospheric extinction.

Some tests should be performed to obtain an absolute calibration of the images taken with the camera on board ISS (see bellow our recommendation on calibration tests) and besides the extinction coefficient (and the inclination angle) in each channel at the moment of the shot must be know.

The astronomical observatory of Universidad Complutense de Madrid (Observatorio UCM) has an all-sky camera (AstMon-UCM) to map the night sky brightness (which is related to light pollution) and monitor the extinction in the astronomical photometric bands Johnson B, V and R. Unfortunately, AstMon-UCM was on maintenance during the night of 11th February of 2011. The mean extinction in Johnson V band for 8 nights of February was 0.32 (precision 0.18).



The green channel is close to this V band (compare transmission curves in figure 3 and figure 18), thus we can estimate (taken into account the light path on the atmosphere, which depends on inclination) that around 30% of the light was lost.

Figure 18. Transmission curves of the Astrodon Johnson filter set (http://www.astrodon.com/) of AstMon-UCM. Green line corresponds to V band and it is similar to G filter of Nikon cameras (see Figure 3).

3) Color of the light sources

Street lighting uses lamps of different types. Some of them are high pressure sodium (HPS) whose spectrum is plenty of emission lines and the resulting color is white. The preferred type for astronomers is Low Pressure Sodium (LPS) lamps which is monochromatic (orange) and easily filtered. Other lamps are made with mercury as the metal halide lamps. The spectrum of the night sky at a polluted site as Madrid is a combination of the spectrum of the lamps and mercury (Hg I) and sodium (Na I) emission lines are present. The strongest lines are Hg I 436 nm and Na I 589 nm doublet.

To complete the work outlined in this report, we should study light pollution using the 3 channels or bands provided by the RAW image. The color of the light sources could provide information about the nature of the lamps employed in lighting since mercury lamps are bluer than the yellow sodium vapor lamps. We intend to obtain in the near future a spectrum of Madrid night sky similar to that of figure 14 and compare it with the color, intensity and number of light sources detected in the satellite images.

Related with this topic, we have studied the change in intensity and color of the sky over Madrid during the Earth Hour (http://www.earthhour.org/) of 26 March 2011. ISS images of Madrid during the hour when some buildings switched off their lights are not available. Programmed ISS pictures of big cities during the next years Earth Hours would be desirable to measure the real impact on the intensity of light emitted to the sky. A simple approach to this calculation could be made by comparing the total intensity of the ISS nocturnal image obtained any night (adding up all the pixels) and the intensity obtained after discarding those corresponding to areas which were switched off. Unfortunately the available image is saturated and only a hint of the intensity of the brightest spots could be obtained. This is another argument for the series of exposures proposed (see bellow).

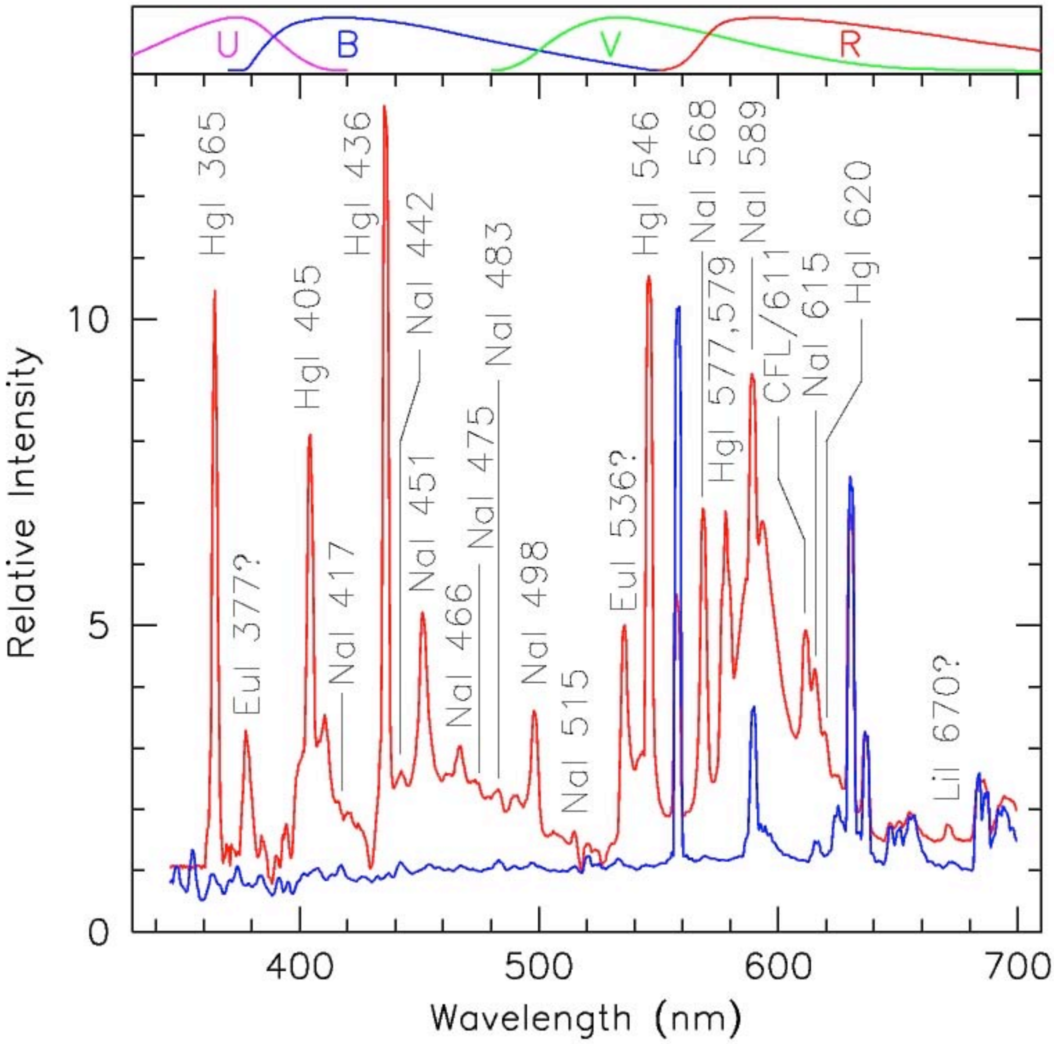
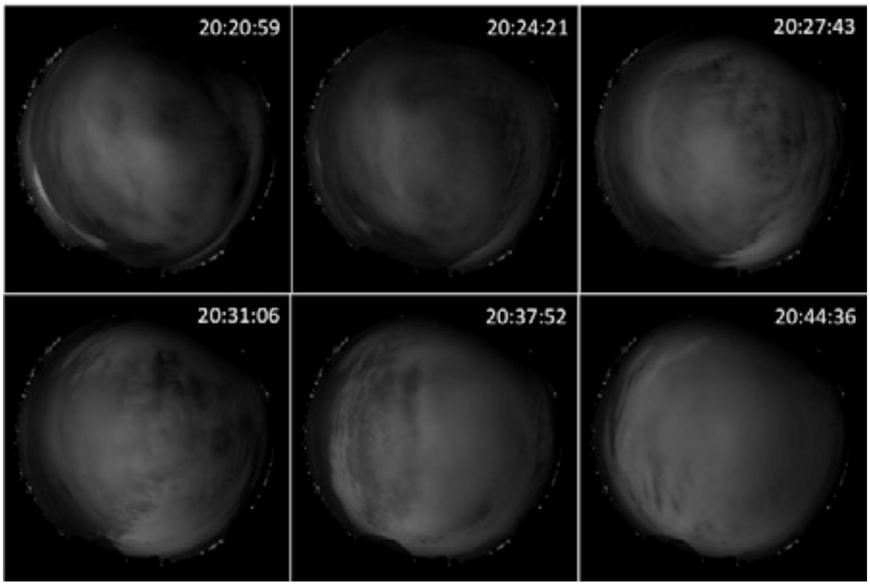


Figure 19. Tracings of night sky spectra at a polluted (red) and at a dark site (blue). Main line identifications for artificial features are marked. The colored curves on the top of the figure are the transmission functions of UBVR standard astronomical photometric bands. Although the light pollution appears to be more important in the V band, the strong Na I 589 nm doublet is the main feature of the red filter. Figure 3 of “The effects of improper lighting on professional astronomical observations”, Ferdinando Patat, (astro-ph1011.6175, 2010) European Southern Observatory.

The AstMon-UCM of *Observatorio UCM* was programmed to obtain a series of images in B, V and R Johnson photometric bands during 26 March 2011. The night sky brightness at zenith derived from these images were compared with those of previous and following Saturdays to show up differences in lighting evolution at the time around that of the Earth Hour (local 8:30-9:30 pm). Our preliminary analysis shows that, for typical clear nights, the value of the night sky brightness at zenith is very constant in the three bands and it is very difficult to detect variation even at the time when some buildings are routinely switched off along the night. For instance, the median values for 19 March (the previous Saturday, between 20:55 and 22:03) are SB(B)=17.98+-0.02, SB(V)=17.22+-0.03 and SB(R)=16.61+-0.04 in astronomical units of mag/arcsec2.

The night of 26 March 2011 was cloudy at Madrid. The clouds prevented us from measure the night sky brightness. However, the data obtained from AstMon-UCM could contain very useful information since the cloud cover acted as a screen to reflect the escaping light. Using the values of this false sky brightness (cloud brightness should be said), we noticed a variation that could be real if the albedo and total reflectivity of the clouds do not change during these hours.



AstMon-UCM is a camera that delivers images and, as expected due to the high variation registered, the cloud cover did vary during this time as figure 20 shows clearly. Thus the measured change is mainly due to this unwanted effect.

Figure 20. Cloud evolution for part of the night of 26 March 2011 as recorded with AstMon-UCM for the Johnson R band.

4) Street geometry, ground albedo and weather station.

The impact of public lighting on light pollution depends strongly on several parameters. The first one is the type of street lamp, being the oldest ones very inefficient since they lost a no negligible part of the light directly to the space. For similar street lamps, the observed effect on satellite images depends also on properties of the street as its width or the height of the surrounding buildings or even the ground albedo. Images taken in different weather station of the year should differ due to the tree canopy (leaves that cover or shelter light) and the presence of snow (with high albedo) on the ground.

5) Comparison with NOAA DMS data

Our group has gained a valuable experience on analysis of NOAA images (Sánchez 2007; Sánchez & Zamorano et al. 2008, 2010). Using DMPS satellite night images taken in 2000 we have estimated the saturated surface in many European countries. The objective of this study was to compare the illumination conditions and its effects in light pollution. With images in the interval 1992-2007, we derived the real power consumption in public lighting in Spain and its evolution.

6. Recommended observational setup and calibration

We intend in this section to define an observational setup and procedure to obtain more useful scientific data from digital pictures taken from ISS. It is worth noting that the actual setup of the Nikon D3s camera includes some of our recommendations: to record RAW data images and to use 14 bits instead of 12 bits data.

To measure spatial variation of intensities along a frame it is necessary to correct of lens vignetting. This effect is noticeable in most wide field lenses whose images show a decrease in illumination near the edges of the field of view. The Nikon D3s on board ISS is using a lens with focal length of 200mm and the effect should be negligible. The recommended laboratory test consists in picturing a white card whose surface is homogeneously illuminated. To obtain this illumination image or FlatField inside ISS we propose to picture a flat illumination theme. The target should be determined according to available items as, for instance, a gray wall panel.

Bad pixels, which develop during the detector aging, should be mapped and discarded. These pixels also appear when a Dark frame, i.e. a picture without incoming light, is taken. Dark frames with different exposure times are routinely obtained as calibration files when long exposures observations are performed to correct from thermal signal. Since the exposure times proposed to this study are short enough, there is no need of such frames.

Linearity tests should be made to obtain the response curve. Differences from linearity are expected near saturation level due to the anti-blooming system of some cameras (Nikon D3s has anti-blooming?). Several pictures of the same subject with same settings except the exposure time will allow us to build the response curve assuming that the intensities of the pixels in the image do not vary during the series of exposures.

There is not a single optimum exposure time or setting of the digital camera which records with good signal to noise the large range of values of a nocturnal image of a big city as Madrid. The image analyzed has some bright spot with saturated pixels even using 14 bits per pixel. The easy and safe solution to saturation would be to reduce the exposure time (keeping untouched the rest of parameters). Unfortunately, since signal is directly proportional to exposure time, this method would result in a dimmer image.

To get enough signal at the darkest regions and useful unsaturated values at bright spot a series of exposures should be taken. The data from these images can be combined to build a High Dynamic Range (HDR) image or used separately to measure regions of different brightness. This procedure is easily programmed with the Nikon D3s digital camera using the bracketing exposure system. The analysis of the images would allow to determine the response curve of the camera and to detect the range of the detector linearity.

Absolute calibration of the ISS images would be a great bonus. We could read pixel values in physics units instead of counts and determine the sensitivity of the digital camera. A standard source is needed to perform a photometric calibration. Calibrated photodiodes are used at laboratory tests. Assuming that the digital camera is onboard ISS, it is necessary to use a calibrator of known intensity outside the satellite. Although many people would think on earth based light sources the best choice is to use astronomical sources. A series of short exposures of a bright star (Sirius,Vega, Capella, etc, not the Sun), with the same set up for the nocturnal images of the earth, will be enough. Since the satellite is at high altitude, there is no atmospheric extinction. The inclination of the digital camera when shooting to the star is not relevant in this case since the light path along the atmosphere is null when pointing far from earth.

Table 1. Recommended frames for calibration

Set Up	Nikon D3S f=200mm f/4 RAW 14 bits			
Dark	10x	1/60s Bracketing +-3	12800 ISO	Lens cover on
Calibration	10x	1/60s Bracketing +-3	12800 ISO	Select a known bright star
Flat Field	10x	Auto Bracketing +-1	400 ISO	Flat illuminated surface (1)

(1) Gray or white wall panel for instance. The camera should be rotated between shots to remove differences in illumination.

Table 2. Recommended scientific frames

Set Up	Nikon D3S f=200mm f/4 RAW 14 bits		
Frames	1/60s Bracketing +-3	12800 ISO	Keep the camera steady

Note: Bracketing in 1 EV steps.

7. Conclusions

Observation of the earth at night, showing the artificial lights caused by humans is of extraordinary interest for many purposes, including scientific fields. One of them is the location and measure (and study of the evolution in time) of their brightness as a tool for fighting against light pollution. While waiting for a satellite system for global and continuous observation and fully dedicated to this task as Nightsat (http://www.ngdc.noaa.gov/dmsp/nightsat.html, Elvidge et al. 2007), ISS images taken with a digital camera provide very useful scientific data.

The spatial resolution of the ISS pictures, with a plate scale of around 16 m/pixel, is better than that of NOAA (2.7 km/pixel). A resolution of around 80 m is enough for our purposes, although aerial photography from an airplane or a balloon would be a great complement for finer detail data.

We have presented in this report an ongoing analysis of a nocturnal image of Madrid taken by astronauts aboard the International Space Station. The preliminary results have shown the potential of these images as source data for scientific studies. Although we focused in light pollution, there are more interesting topics. The importance of these images for public outreach is beyond any doubt.

The raw image has been processed using freeware software to split their color channels, to get rid of bad pixels, to build a green channel frame with full resolution. This channel is similar to the photometric Johnson V band used in astronomy and easily calibrated with standard stars observations. Georeference of the images is a first and necessary step in order to unambiguously locate the bright spots and to compare with ground based measurements.

A calibration sequence to be used by the photographer-astronauts on board ISS for this kind of night pictures has been designed. Only one calibration sequence should be enough provided the bright star image is not saturated. The procedure of photo series with bracketing should be performed for images taken for scientific studies. We are aware that the schedule of astronauts aboard ISS is very tight, but the procedure is not time consuming: one shot will produce 7 pictures (bracketing +-3, 1EV steps).

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Acknowledgements

We wish to thank to the NASA JSC Imaging Lab and more specifically to the Head of the Crew Earth Observation, Ms Sue Runco, who has been so kind to provide us with the RAW image. We also acknowledge the time spend by astronauts aboard ISS to take the beautiful pictures and made them available to the public during these years. In particular we are grateful to Soichi Noguchi (JAXA) and Col. Douglas Wheelock and by Scott Kelly (NASA) who appear as authors of night shots of Spain.

We thank useful comments from Nicolás Cardiel and Jesús Gallego. "*Laboratorio de Investigación Científica Avanzada*" (LICA) is a facility of Universidad Complutense de Madrid and it has been funded by the Spanish MICINN AYA2009-06330-E and AstroMadrid Program CAM S2009/ESP-

1496: “Astrofísica y Desarrollos Tecnológicos en la Comunidad de Madrid'' (Comunidad de Madrid and the European Union). We acknowledge support from the Spanish Programa Nacional de Astronomía y Astrofísica under grant AYA2009-10368. Partially funded by the Spanish MICINN under Consolider-Ingenio 2010 Program grant CSD2006-00070: ''First Science with the GTC''.