Report of the 2015 LoNNe Intercomparison Campaign

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Campaign Participants

Local organizers: Andrea Giacomelli, Luciano Massetti
LoNNe IC coordinator: Salvador J. Ribas
Participants: Constantinos Bouroussis, Ramon Canal Domingo, Fabio Falchi, Andrea Giacomelli, Andreas Hänel, Zoltán Kolláth, Christopher Kyba, Henk Spoelstra, Kai Pong Tong, Günther Wuchterl

1) Introduction

The 2014 LoNNe (Loss of the Night Network) intercomparison campaign is the third of four campaigns planned during EU COST Action ES1204. The first campaign took place in 2013 in Lastovo, Croatia, the second in Madrid, Spain. This year's campaign continued the strategy started last year, of taking measurements at two sites, an urban location and a village. The main goals of the campaigns are to:

- Understand the systematic uncertainty of skyglow measurement instruments.
- Examine the differences and similarities between different types of measurements, and understand under what circumstances results can be converted or compared.
- Quantify the sky brightness at the selected sites.

This report provides a brief synopsis of the campaign and its preliminary outcomes. **Section 2** describes the measurement locations, the activities of the participants, the instruments used, and the environmental conditions. **Section 3** describes a public outreach event held during the campaign. **Section 4** provides some preliminary results, outlines the ongoing analyses, and presents research questions for the next campaign to address. **Section 5** provides recommendations for the final LoNNe intercomparison campaign in 2016. **Section 6** concludes the report.

The Municipality of Roccastrada officially endorsed the campaign, authorizing the shut-off of public lighting (Figure 1 below). The Municipality requested to receive a report about the campaign, representing an additional outreach opportunity.

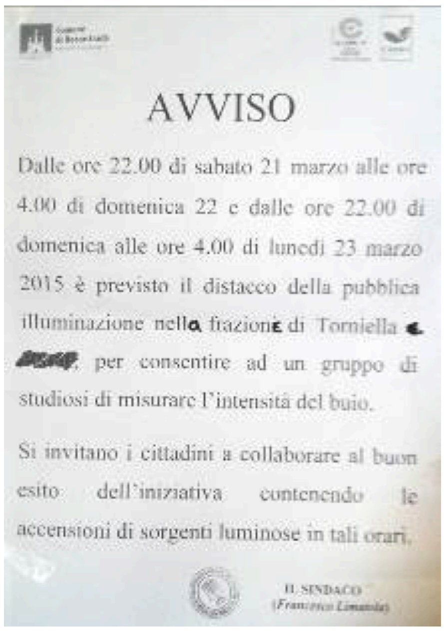

Figure 1: Photo of a local notice of the campaign and the planned switch-off of the lights in the village of Torniella.

2) Campaign details

Measurement locations

Torniella: (43.0736N, 11.1508E, 450m elevation)
Casa Nova (43.0755N, 11.2213E, 410m elevation)
Sesto Fiorentino (Florence): (43.8188N, 11.2019E, 43m elevation)

Figure 2: Location and satellite view of the measurement sites. Map source © OpenStreetMap contributors and aerial photos by Regione Toscana.

Measurement Instruments

- ASTMON all-sky camera
- AVT-GE CCD camera with SIGMA 4.5mm fisheye lens
- AVT-GC CCD camera with Fujinon panomorph lens
- Canon 6D cameras with 8mm Sigma fisheye lenses
- DigiLum
- Lightmeter mark 2.3L
- Loss of the Night app
- Sky Quality Meters (SQM) (see detailed list below in Table 1)
- Additional cameras for non-scientific work

- Detailed information about the instruments and their use in skyglow measurement is available in the following references:
- ASTMON (Aceituno et al. 2011)
- Canon all-sky (Kolláth 2010)
- Lightmeter (Müller et al. 2011)
- Loss of the Night app (http://lossofthenight.blogspot.com/2015/01/brief-introduction-to-loss-of-night-app.html)
- SQM (Cinzano 2005, den Outer et al. 2011, Kyba et al. 2015)

Table 1. List of SQMs used

Name	type	Ser. #	Housing	Rate	Dates
Falchi	SQM-LU-DL	2452	n	300s	21, 22
Giacomelli	SQM-LU-DL	2131	n	300s	22, 23
Tong	SQM-LE	1786	n	1s	21, 22, 23
	SQM-LE	2444	n	1s	21, 22, 23
Kyba	SQM-LU	1052	n	1s	21, 23
	SQM-LU-DL-V	2998	n		21, 22, 23
Spoelstra	Digilum		y	10s	21, 22, 23
	SQM-LE	980	y	10s	21,22,
	SQM-LE	1366	y	10s	21,22,
	SQM-LU-DL	2117	y	10s	21, 22, 23
Montsec	SQM-LU	2495	n	42s	23
	Astmon		n		21, 22, 23
Hänel	SQM-LU	2496	n	60s	22, 23
	SQM-LU-DL	2450	n	60s	22

Timeline of the campaign

Day of March 21

Participants arrived at airport and traveled to Torniella.

Night of March 21-22

Weather and environment:
The measurement area was prepared in the early evening (before sunset), but most instruments were not installed due to the chance of rain. We arrived in the evening at approximately 21:48 and began installing instruments. In the early evening the village of Torniella did not turn on lights near the football pitch where we took measurements. All public lighting in the village was turned off in steps at approximately 21:50 and 22:17. At approximately 23:18 the floodlight for the village church was turned off. At approximately 04:10 all of the public lighting in the village was turned back on.

Figure 3: Preparation of measurement site in Torniella (local football field).

At the start of the evening the sky had scattered clouds and clear patches. Near midnight the sky cleared up, and by 00:10 the sky was clear as far as the eye could see. These conditions lasted until around 00:45, when we packed up many of the instruments for the evening. ASTMON images (Figure 4) showed that the sky was not entirely clear, even when it appeared so by eye. Instruments tended to become covered with dew, ASTMON was cleared frequently. Clouds tended to make the sky brighter, and during the clear sky periods SQMs typically had values between 21.1 and 21.3 magnitudes per square arcsecond. Late in the night rain fell, and a noticeable amount of Sahara dust was deposited on the instruments. Figure 5 shows the image of the area obtained by the Day-Night Band (DNB) of the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite instrument.

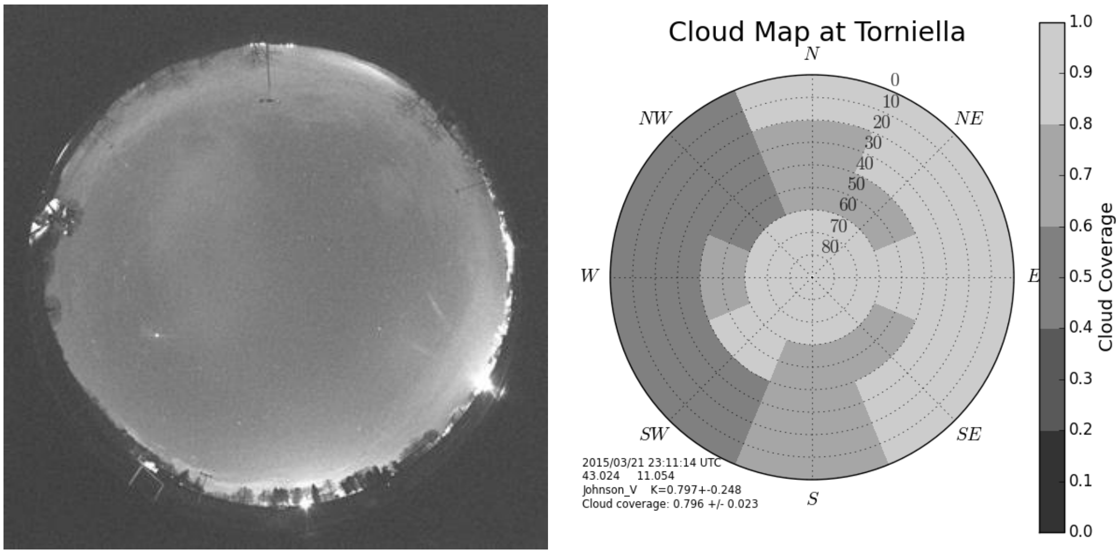

Figure 4: Left: Image obtained by ASTMON with some clouds in Torniella the 21st of March. Right: Processed cloud map of that moment obtained with pyASB software (Nievas 2012)

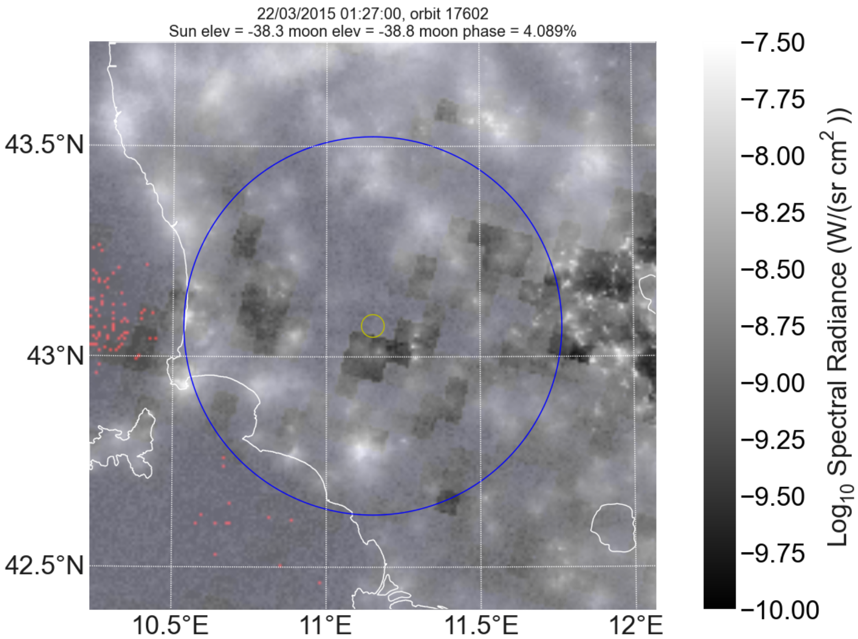

Figure 5: VIIRS DNB image from the first night of the campaign (March 22).

Instruments operated:
SQMs:
1 SQM-LU (Kyba)
4 SQM-LE (Tong x2, Spoelstra x2)
2 SQM-LU-DL (Falchi, Spoelstra)
1 SQM-LU-DL-V (Kyba)
several handheld SQMS, but not systematically studied.

Lightmeters:
2 Lightmeter mark 2.3L (Wuchterl, 10 Hz, and 1 Hz)

DigiLum (Spoelstra)

Cameras:
ASTMON all sky images (Ribas & Canal-Domingo)
1 6D Canon camera with 8mm fisheye (Kolláth)
AVT-GE CCD camera with fisheye (Bouroussis)
AVT-GC CCD camera with panomorph lens (Bouroussis)
Additional cameras not for scientific work

Apps:
Loss of the Night app

Day of March 22

Participants met at 10:00 for breakfast. Informal work and discussion continued until lunch at 1:00. Following lunch, we met to record the events from the last evening and prepare the plan for the coming evening.

Night of March 22-23

Weather and environment:

Astronomical twilight ended at 20:05, the moon set at 20:14 CET. The evening was almost clear until about 22:30 local time, cloud bank rolled in and then there was a mix of cloudy and clear skies until about 2:00 when it was overcast. All instruments that were not weatherproof were taken down by 2:10 (shortly after the pass of Suomi NPP, see Figure 6). Unfortunately, the sky was overcast during the overpass. There were no problems with dew on the second night.

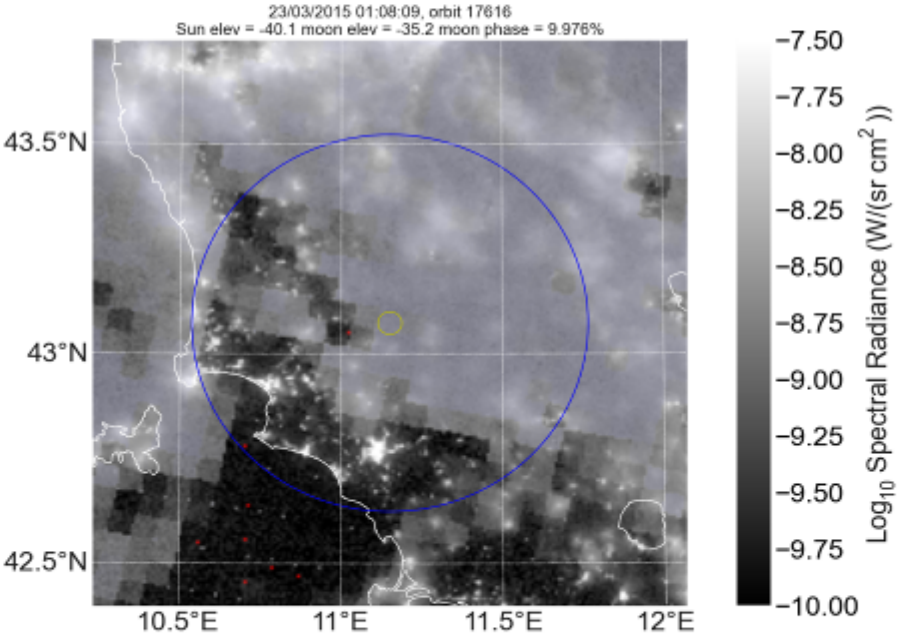

Figure 6: VIIRS DNB image from the second night of the campaign (March 23).

Streetlights near the field came on around 19:33, the nearest lights went out around 21:55, and another set went out at 22:15. Church clock turned off at 23:19. Kyba took a SQM-LU-DL-V observation at 23:12, when the sky had thin clouds and was slightly clearing.

Hänel, Kyba, Wuchterl, and Giacomelli drove out to a darker area (Casa Nuova, 43.0755N, 11.2213E). Hänel and Kyba performed SQM observations, and Hänel took some fisheye photographs. The overcast sky was extremely dark, at about 22.0-21.8 magnitudes per square arcsecond. On the way back at Casa Certo Piano (43.06530N, 11.17104E) it became clear, measurements were 21.4 mag/arcsec².

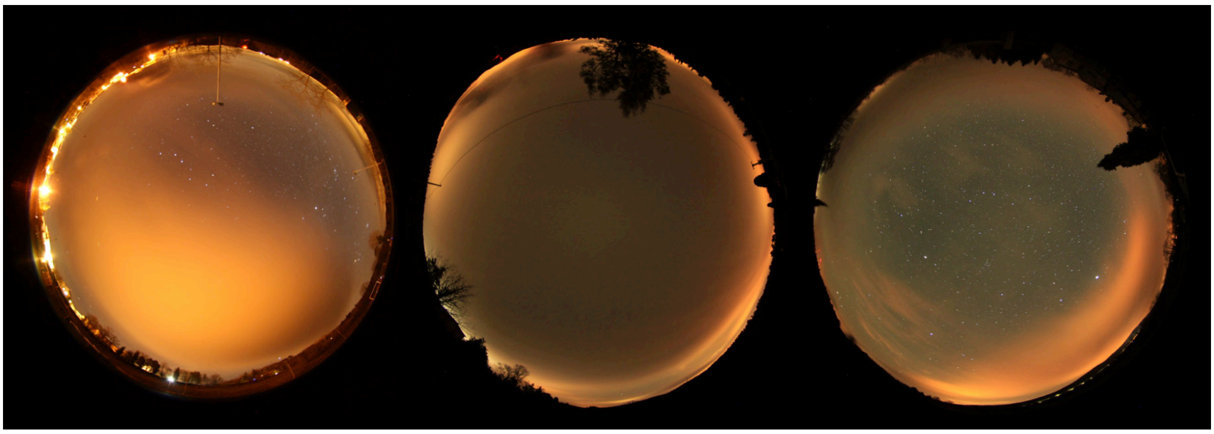

Figure 7: Canon 6D all-sky photos: left is the main measurement location in Torniella, about 21.0 mag/arcsec², middle: Casa Nuova Belagaio 22.0 mag/arcsec², right: Casa Certo Piano 21.4 mag/arcsec²

Instruments operated:
SQMs:
1 SQM-LU (Hänel)
4 SQM-LE (Tong x2, Spoelstra x2)
4 SQM-LU-DL (Falchi, Spoelstra, Giacomelli, Hänel)
1 SQM-LU-DL-V (Kyba)
Several handheld SQMS, but not systematically studied on this evening.

Lightmeters:
2 Lightmeter mark 2.3L (Wuchterl, 10 Hz, and 1 Hz). The 1 Hz lightmeters lost a few hours during night due to power cut

DigiLum (Spoelstra)

Cameras:
ASTMON all sky images (Ribas & Canal-Domingo)
2 Canon 6D camera with 8mm fisheye (Kolláth, Kyba)
1 Canon 550D camera with 4.5mm Sigma fisheye (Hänel)
AVT-GE CCD camera with fisheye (Bouroussis)
Additional cameras not for scientific work

Day of March 23
Travel to Sesto Fiorentino (near Florence), setup on the CNR Campus rooftop. Measurements on all continuously recording instruments were started before the sunset, and participants then left to go for dinner.

Night of March 23-24

Weather and environment:

Evening started clear, at 22:00-22:10 some clouds passed over, shortly after midnight it became progressively more cloudy until the sky was completely overcast (see Figure 9). Sky was quite hazy, although individual stars were visible, and the haze was not uniformly distributed. There were no problems with dew on this evening. Tong had some interruptions of the data taking for the SQM-LEs and the SQM-LU.

Figure 8: Preparation of measurement site in Florence (CNR building).

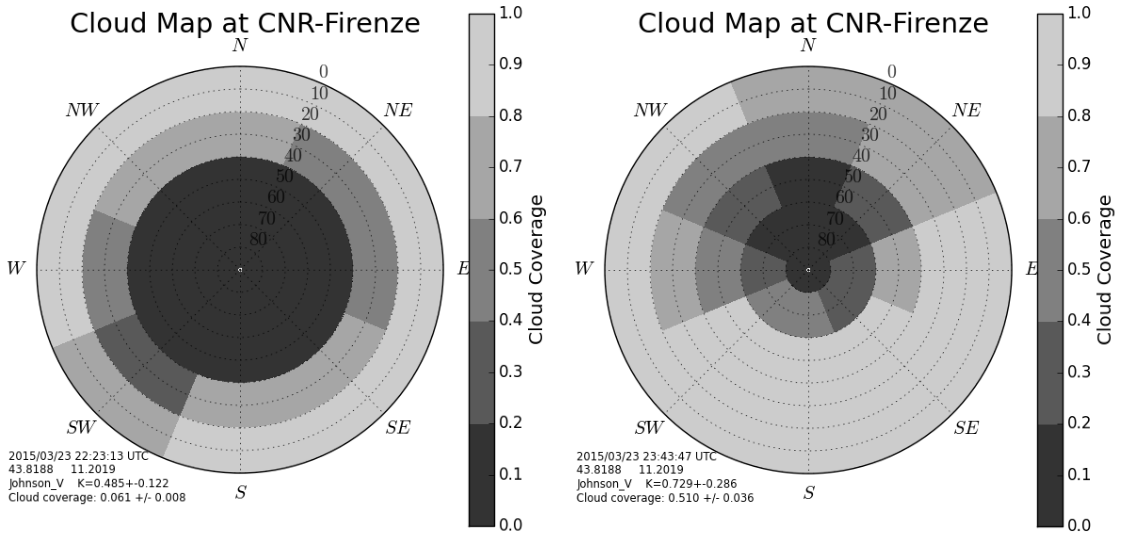

Figure 9: Two ASTMON clouds map obtained in CNR. The first one shows clear skies except in low altitudes were LP and fog masks the sky and the right one shows the arrival of clouds from south.

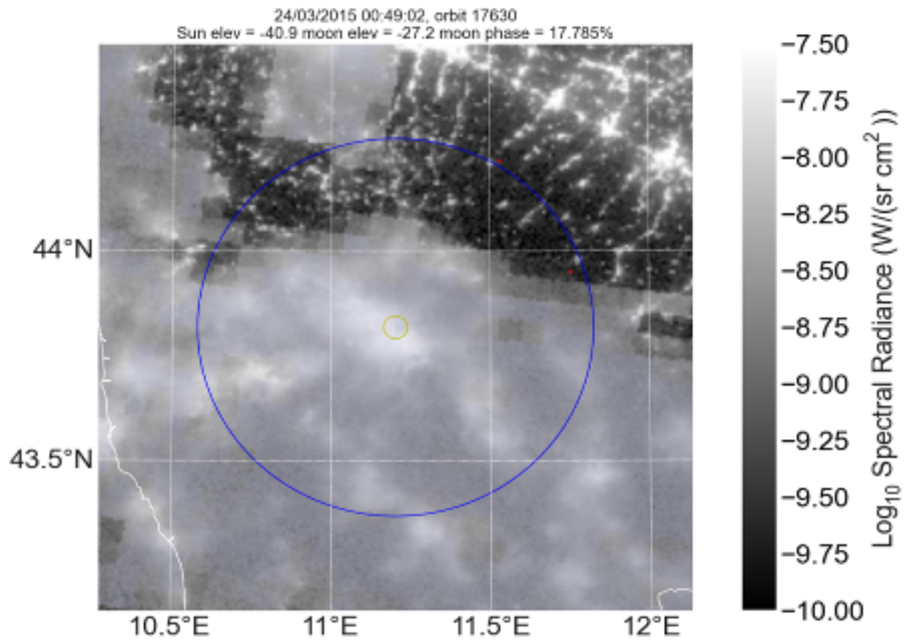

Figure 10: VIIRS DNB image from the third night of the campaign (March 24).

Hänel, Kyba, and Kolláth drove out to a lookout point on the nearby mountain to take additional all-sky images and photograph the town. Unfortunately, because the sky was overcast by the time they arrived all-sky photos were not taken.

Instruments operated:
SQMs:
3 SQM-LU (Hänel, Kyba, Ribas)
4 SQM-LE (Tong x2, Spoelstra x2)
2 SQM-LU-DL (Spoelstra, Giacomelli)
1 SQM-LU-DL-V (Kyba)
Several handheld SQMS, but not systematically studied.

Lightmeters:

2 Lightmeter mark 2.3L (Wuchterl, 10 Hz, and 1 Hz).

DigiLum (Spoelstra)

Cameras:
ASTMON all sky images (Ribas & Canal-Domingo)
2 Canon 6D camera with 8mm fisheye (Kolláth, Kyba)
1 Canon 550D camera with 4.5mm Sigma fisheye (Hänel)
AVT-GC CCD camera with panomorph lens (Bouroussis)
Additional cameras not for scientific work

Apps:
Loss of the Night (Kyba, Hänel)

Additionally, IBIMET will provide total solar radiation data to the group.

Day of March 24

Participants took all instruments off of the roof in advance of the arrival of weather that would prevent measurement (windy rainstorm). A meeting was held to transfer all data onto a common disk, discuss the campaign and preliminary analyses, and prepare recommendations for the next year.

Night of March 24-25

Measurements were cancelled because of the weather.

Day of March 25

Participants traveled home, or else to the LoNNe Working Group meetings in Florence.

3) Public event

During the preparation of the campaign, Attivarti.org proposed the possibility of arranging a brief public event in Torniella, as a form of dissemination related to LoNNe and the IC campaign. The proposal was accepted by the participants, and the presentation was held in the late afternoon on Sunday, March 22 on the premises of *Associazione Filarmonica Popolare Torniella*. The scope of the presentation was to allow the local community to gain some insight on the activities conducted by the LoNNe team and, more in general, to learn about some of the key issues related to light pollution.

The presentation was announced via a press release distributed by Attivarti.org in their network of media relations. Articles were published on all three local newspapers distributed in Southern Tuscany (*Il Tirreno*, *La Nazione*, and *Corriere di Maremma*, on March 19 and March 22) announcing the event, and was also re-advertised by several news web sites, so the outreach effect of the event was in fact extended.

Approximately 20 people attended the event (a good number for an event of this type in a rural location). The LoNNe participants briefly introduced themselves, explained their work, and provided anecdotes on artificial light at night. The event lasted from 17:30 to 19:00. After this event, a telescope (305 mm f4.5 newtonian) was set up in the measurement field to allow local people to observe the night sky. Unfortunately, there was only time to view three open star clusters before clouds rolled in, but the people who had a chance to observe were nevertheless enthusiastic about the view.

In addition to dissemination to the local community, the intercomparison campaign generated interest also on a national scale: following the press release made by Attivarti.org prior to the campaign, on March 28 Andrea Giacomelli was interviewed by Radio 24 to talk about LoNNe and the IC experience.

Figure 11: Presentations in Torniella (left), official representatives on the football pitch where measurements took place (right).

4) Results and continuing analyses

Study of the data is ongoing, and includes the following projects:

1) The DigiLum and Lightmeter were compared under a basic assumption of the angular distribution of sky radiance and found to be in promising agreement. Further more detailed analysis is ongoing, including comparison to the fisheye camera and Astmon data.

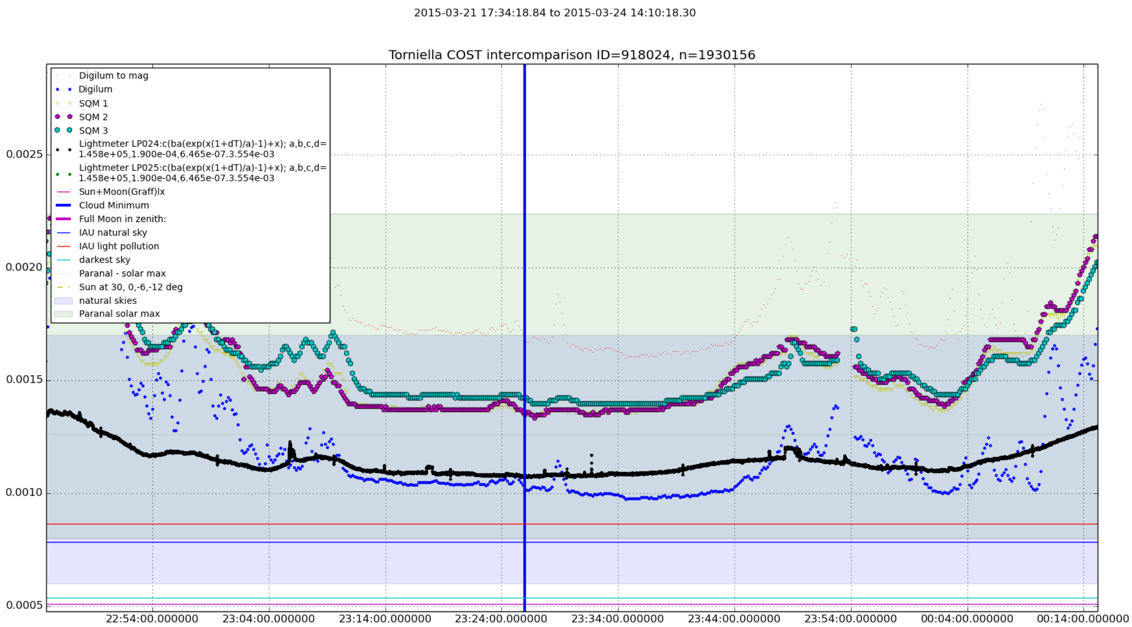

Figure 12: Comparison of Digilum (blue) with lightmeter (black) and three SQM (yellow, purple and green) obtained with data with cloudless conditions during first night in Torniella

2) Data from the lightmeter was used to compare the horizontal illuminance at our measurement site produced by the single floodlight from the nearby church to that produced by the village's public light system (Figure 23). The church lighting was found to produce approximately 6% as much light as the public lighting under skies with only few clouds, and 3.5% on the second night with clouds. Kolláth took a remarkable image of the shadow of the church on low-level clouds. The photo was likely so striking because the village had agreed to turn off the public street lighting.

3) Comparison of all-sky data from ASTMON, Canon with fisheye, and SQM-LU-DL-V. The goal is to understand the systematic uncertainty of the camera and SQM systems and provide advice for organizations that are interested in all-sky surveys. In addition, the noise profile of the two Canon 6Ds (one with ~50 exposures, one with tens of thousands of exposure) will be studied. These works are currently in progress.

4) Extinction and sky brightness can be calculated with ASTMON. Sky brightness at zenith data are displayed below in comparison with SQM in item 5) of this section.
The extinction coefficient has been evaluated by photometrical fit with well determined stars of every ASTMON image, because the nights were not stable the coefficient changes during the night (see Figure 13).

The extinction evolution shows clearly how the first night in Torniella had a big scatter due to the clouds and error bars are big (around 0.2). The second night of Torniella (middle panel on figure 13) shows a first part with acceptable values and relatively stable measurements, later the extinction became unstable due to clouds with just few windows of acceptable values. Finally the night in CNR shows stable values in the first part of the night with some points out of standard values due to clouds. The error bars in this case are bigger again due to fog and probably high LP. After midnight there are no data of extinction because it was not possible to compute it with the clouds (not enough stars).

5) Bouroussis exported the measurements and made some circular area measurements at zenith as well as at other points on the dome, in order to produce a time series of the variation of the sky luminance over time. The results are shown below in Figures 14-17.

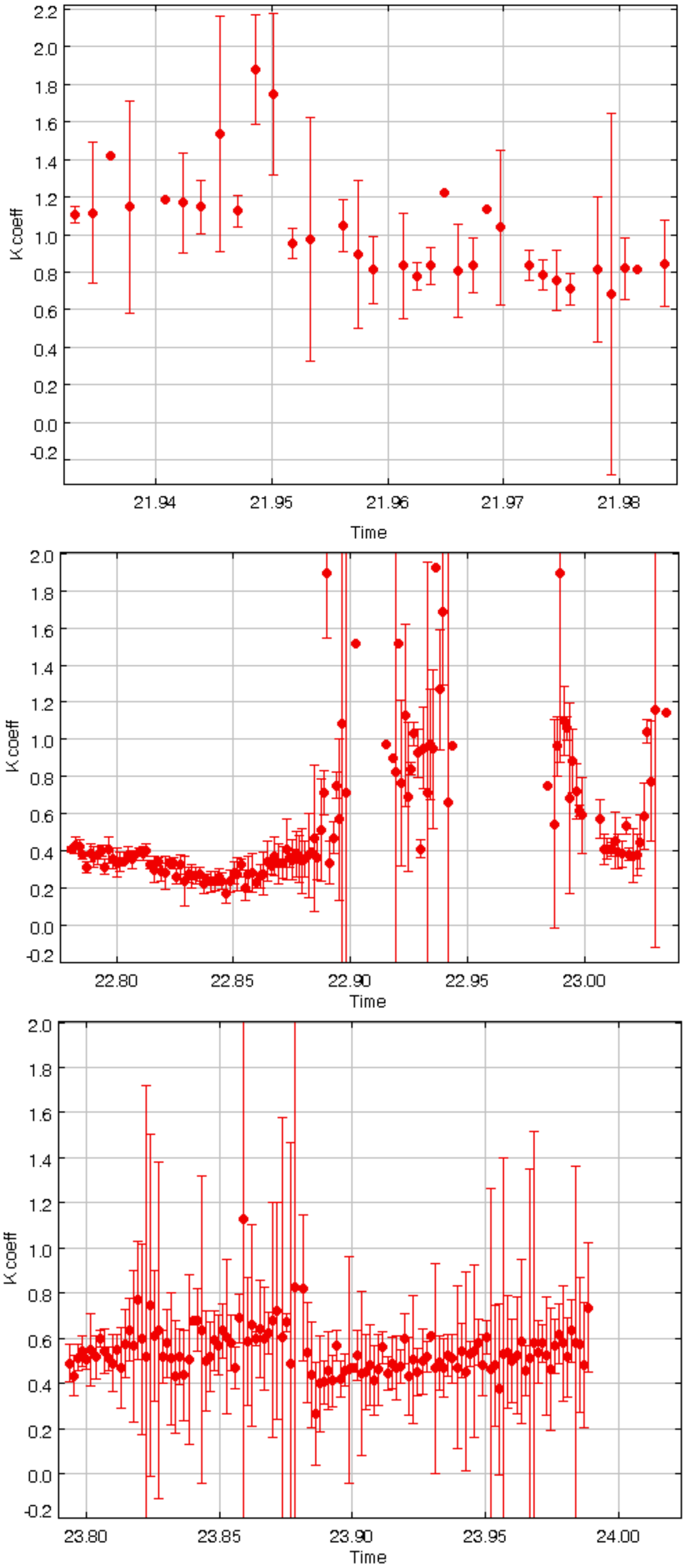

Figure 13: Extinction evolution of the three evaluated nights (21st and 22nd in Torniella and 23rd in CNR). Data obtained with ASTMON images and astronomical photometry evaluation.

Torniella measurements

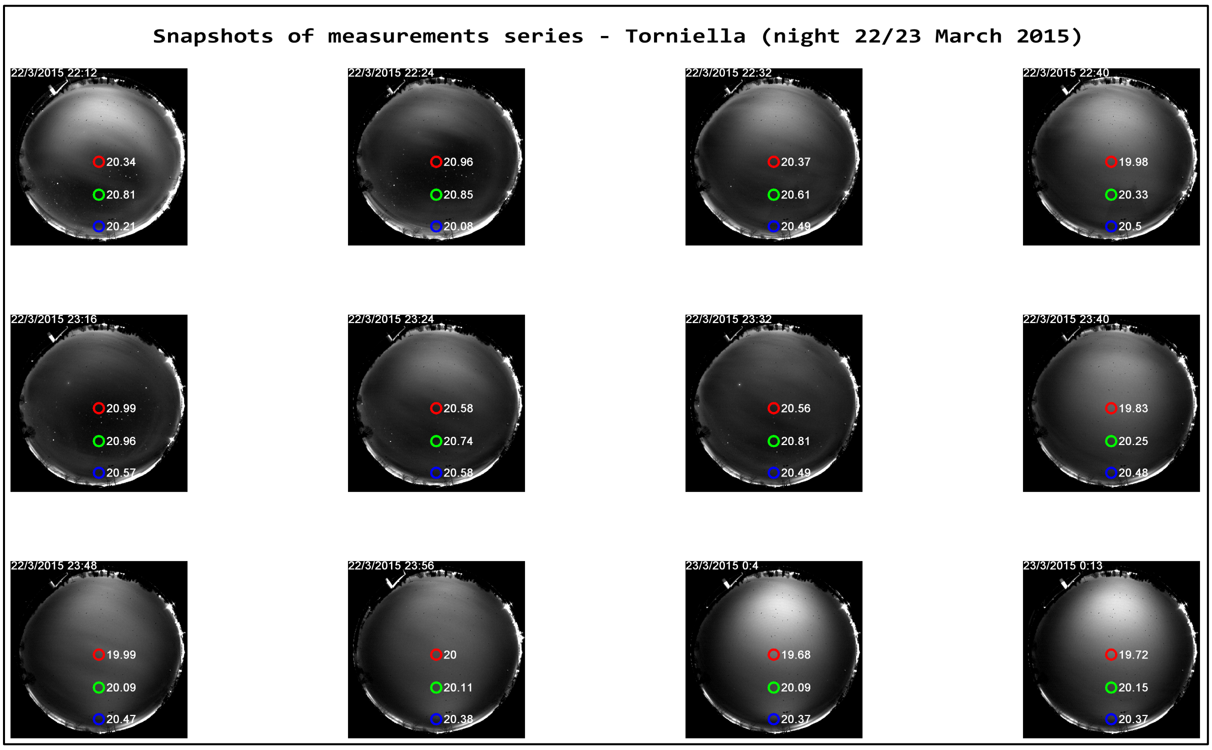

Figure 14: Selected snapshots of AVT-GE measurement series in Torniella (night 22/23 March)

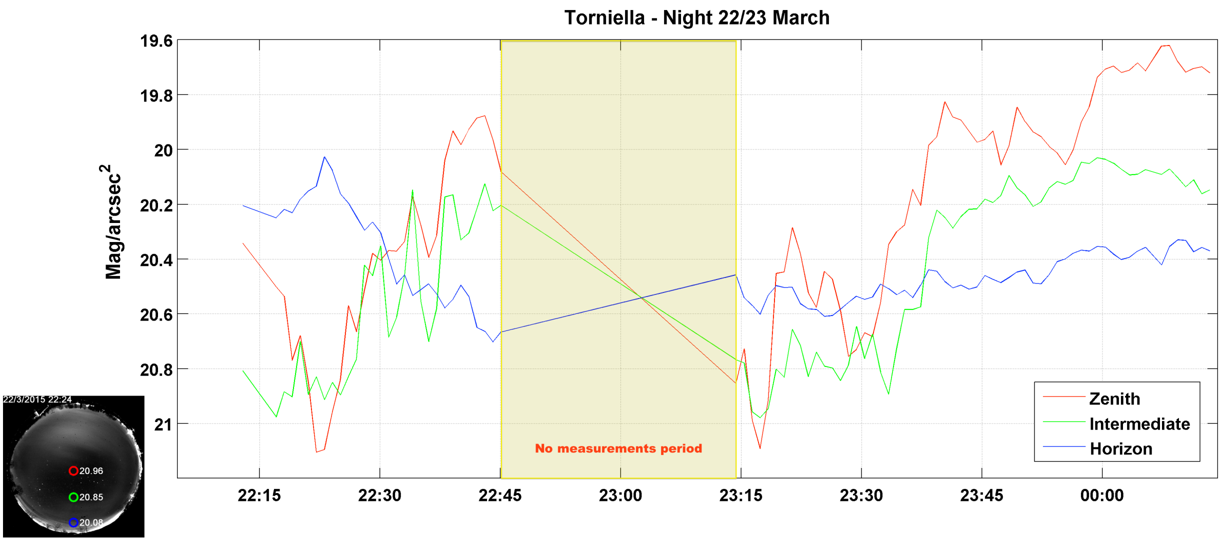

Figure 15: Time-series of AVT-GE measurement in Torniella (night 22/23 March) in three different dome areas

Florence measurements

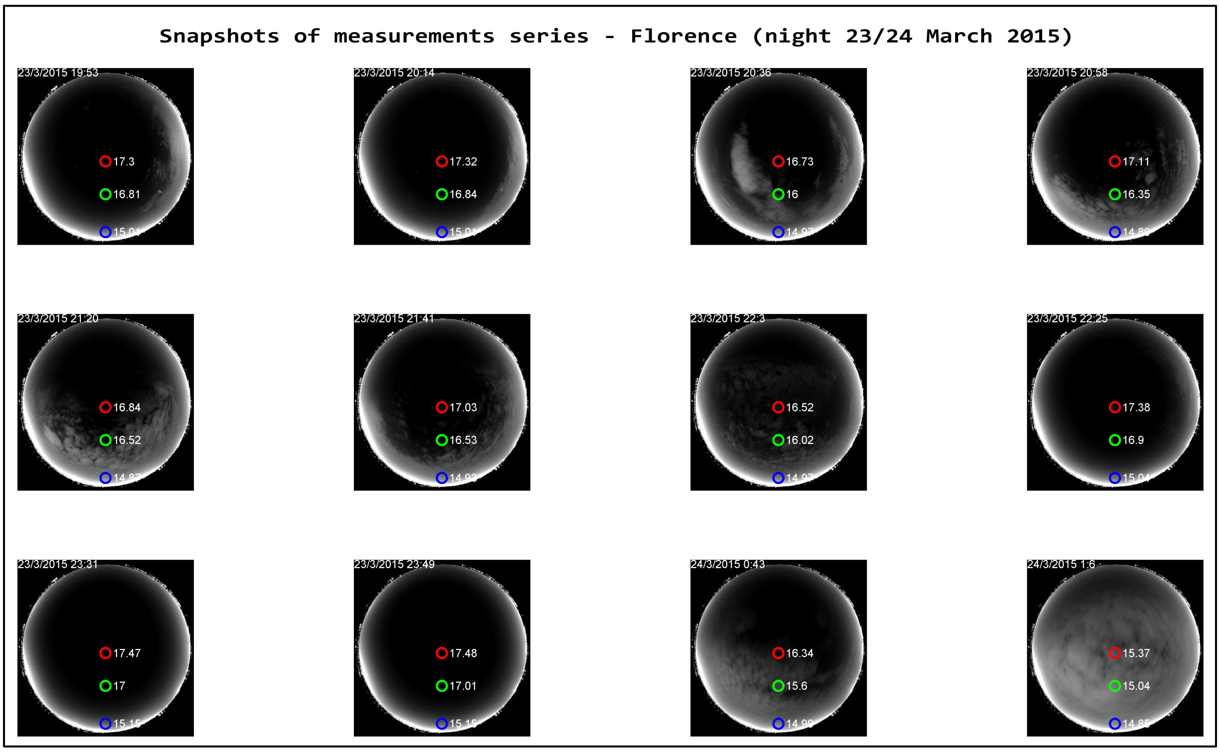

Figure 16: Selected snapshots of AVT-GE measurement series in Florence (night 23/24 March)

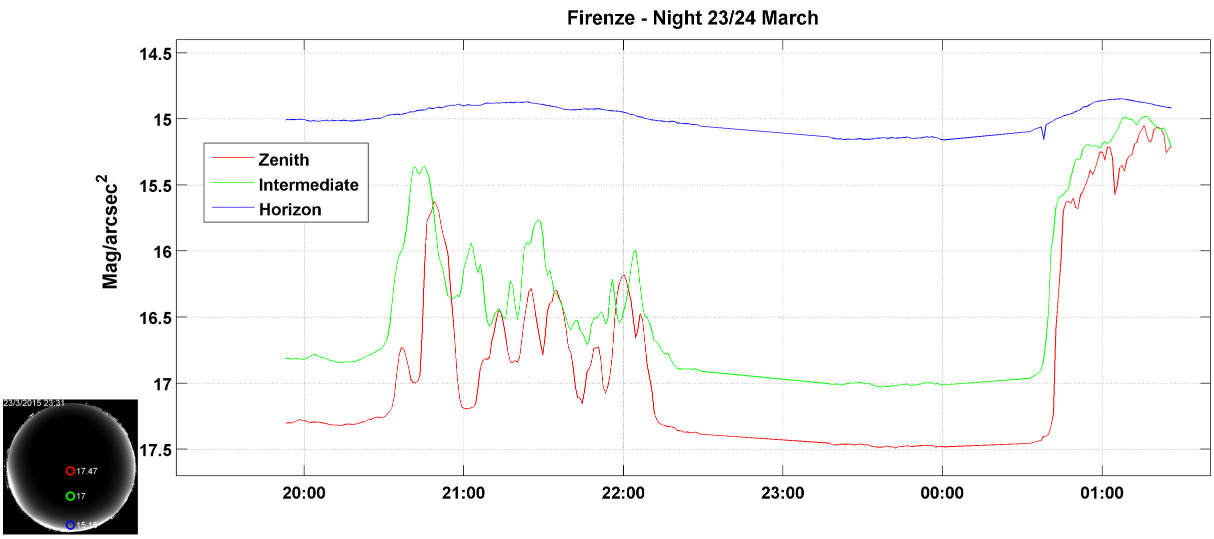

Figure 17: Time-series of AVT-GE measurement in Florence (night 23/24 March) in three different dome areas

6) The self-agreement of SQMs will be examined, for example their linearity and offsets. Preliminary analysis of the SQM measurements from the night of March 22-23 in Torniella and March 23-24 in Sesto follow in Figures 18-22. In all plots below, the SQM data of Spoelstra has been corrected by -0.11 mag/arcsec² for the transmission of the housing window. In the CNR night, SQM-LEs #980 and #1399 gave no data.

For comparison Bouroussis‘ zenith data (AVT, photometric calibrated, estimated 18° diameter) and preliminary ASTMON data (astronomical photometry calibrated) are included.

ASTMON measurements during the clear part in the beginning were disturbed by reflection of football field lights.

Astronomical twilight ended at 19:05, the moon set at 20:14 UT, time in the graph is UT.

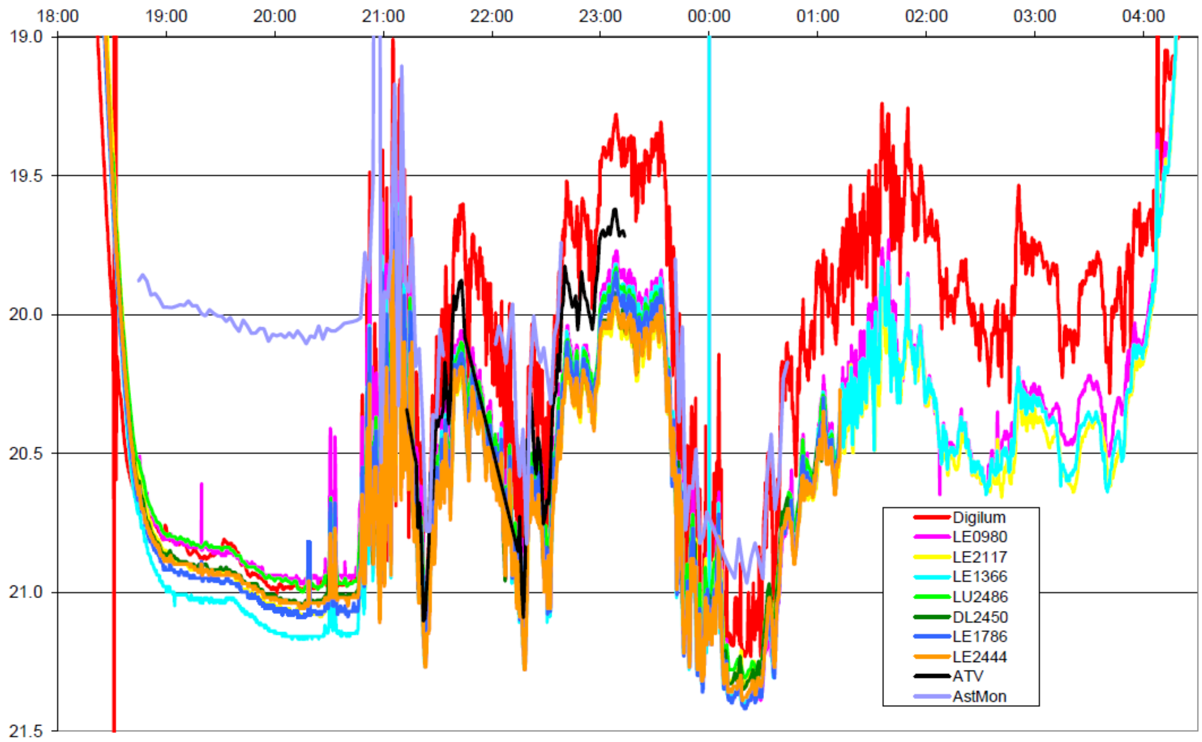

Figure 18: SQM measurements from stationary devices on the night of March 22-23

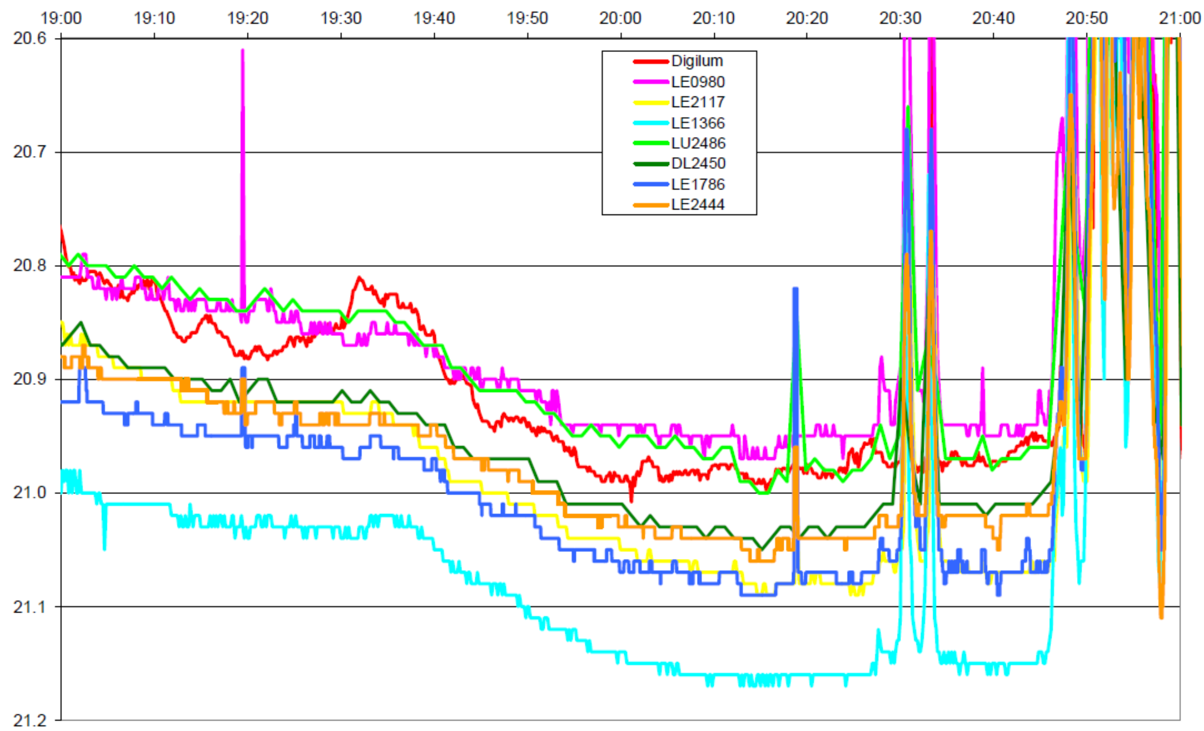

Figure 19: enlargement of the beginning of the night

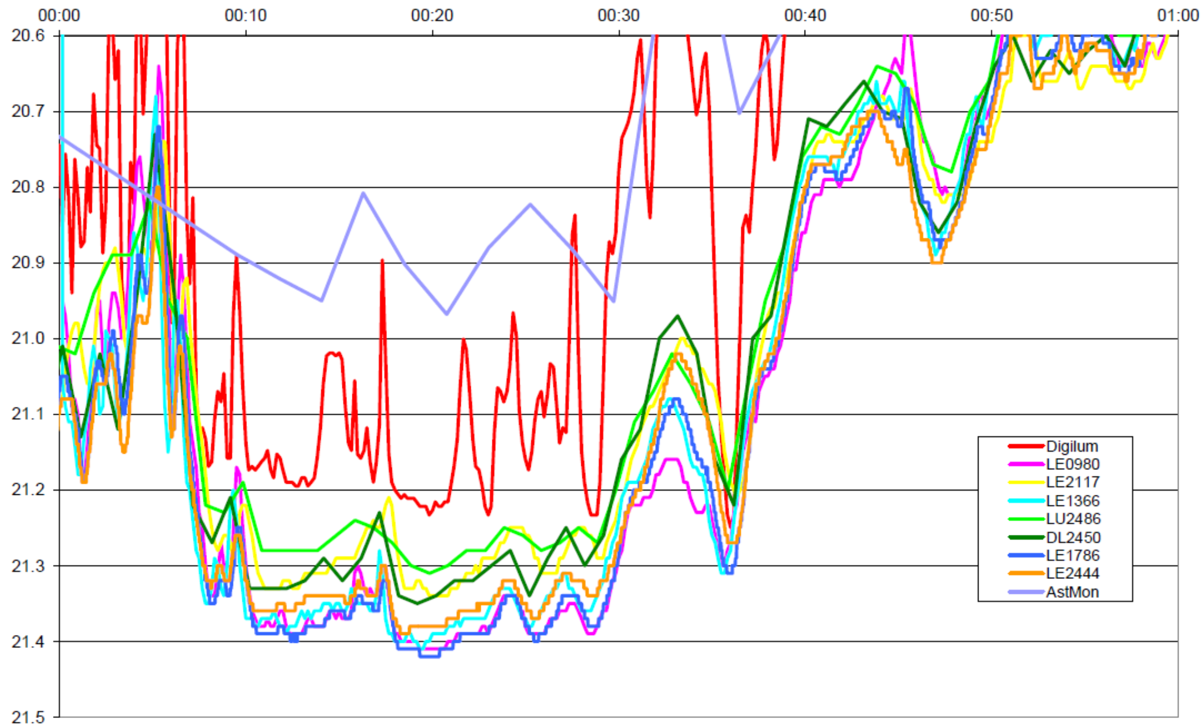

Figure 20: Enlargement of the partially clear section after midnight (UT)

Astronomical data for the March 23-24 in CNR are: end of astronomical twilight 19:08 UT, moon sets 21:25 UT

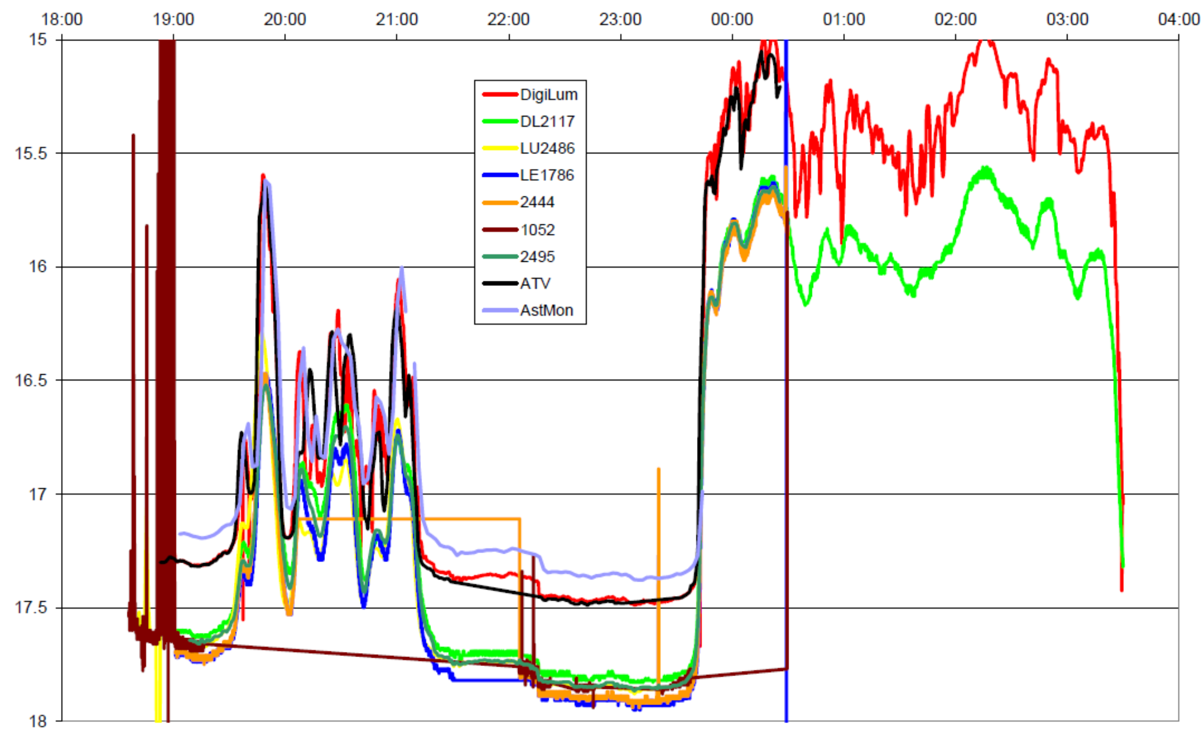

Figure 21: SQM measurements from stationary devices on the night of March 23-24

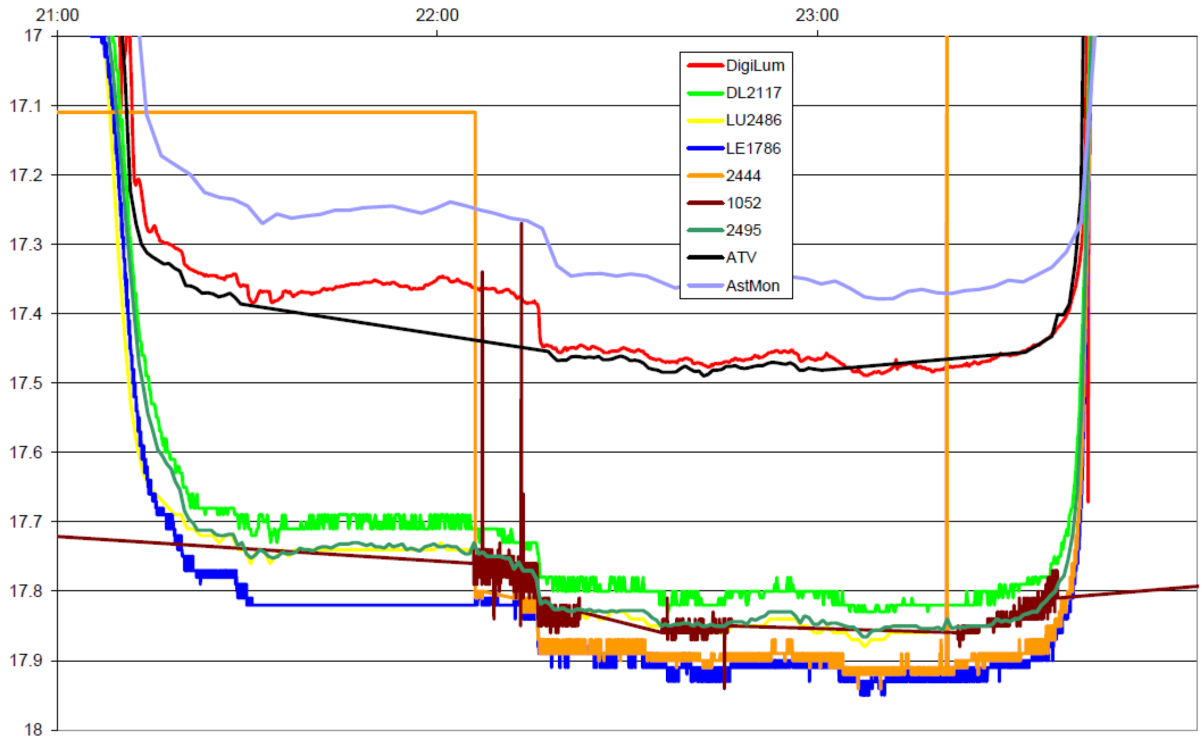

Figure 22: SQM measurements during the clear hours of the night of March 23-24

Some preliminary conclusions:

- During the clear time in the beginning of the night of March 22-23 and during the clear phase between 0:00 and 0:30 UT, the differences between the different instruments was small (up to 0.2 mag/arcsec²)
- Under brighter conditions (clouds and Sesto) the difference especially against the Digilum/AVT/AstMon is much larger (about 0.5 mag/arcsec²). This might be due to the different measurement angles of the devices and/or different calibration methods.
- Photometric (Digilum and AVT) and astronomical (AstMon) calibrations seem to be not systematically different.
- It is an open question as to whether the differences observed between the SQMs occur only under the brighter conditions.
- Differences between the SQMs might be partially due to different sampling rates (1–60 sec) and that not all measurements were at the exact same time (differences in cloud brightness).
- The handheld SQM-LU measurements at the clear phases correspond well to the registered data.

7) During the campaign some measurements with handheld SQMs were obtained, albeit not with a systematic procedure defined in advance. An example of measurements obtained with one of this device is shown in Table 2.

Table 2. Handheld SQM-L measurements (# 2536)

Date	UT	Place	Long.	lat.	SQM-L	conditions
2015-03-22	23:21	Casa Nouva, Belagaio	11.22104	43.07553	22.00	covered DSLR
2015-03-22	23:48	Casa Certo Piano (Andrea)	11.17104	43.06530	21.40	part. clear DSLR
2015-03-23	0:12	Torniella football place	11.15090	43.07356	21.40	part. clear DSLR
2015-03-23	18:45	Sesto, CNR E-platform	11.20195	43.81882	17.70	Moon
2015-03-23	22:28	Sesto, CNR W-platform	11.20034	43.81781	17.90	DSLR

Future research questions

- What is a "characteristic value" of skyglow for a site, and how can it be derived
    - What is the influence of extinction on skyglow for an individual site
- Which quantity (and which instruments) should be observed for specific given research question?
    - For example, for the hunting behavior of animals, how useful is it to measure e.g. illuminance vs zenith radiance
- Relatedly, what accuracy is necessary for given research questions.
    - For example, as discussed in the LoNNe Intercomparison report from 2014, the SQM can be very useful for comparing sites along a strong skyglow gradient, but individual observations with different SQMs at different unpolluted sites provide little comparative value.

Figure 23: Shadow of the church tower illuminated by a single upward directed floodlight. Photo by Zoltan Kollath. More images are available at http://lossofthenight.blogspot.de/2015/03/effect-of-single-floodlamp-in-natural.html.

5) Recommendations for the final campaign

- The movement between different sites is extremely strenuous, and combined with the late nights results in people being quite tired. It also greatly reduces the time that is available for meeting and analyzing the data. We recommend that regardless of whether a single site or multiple sites are used, there should be a single "base camp" where the participants sleep and have their luggage based, to reduce the time needed to move.
- One possibility is that a suite of permanently installed weather-proof instruments could be left at a single secure site, while more portable instruments (e.g. cameras) can be used in a set of locations. This will also make short-distance movement based on local weather more feasible. The permanent site would provide comparative information as well.
- The permanent site should be secure, so that instruments and computers can be left with no one left to guard them.
- For the SQMs, the host should prepare a way to record data from multiple SQMs to minimize the number of laptops that must be out in the field.
- Stable clear nights are essential, because comparison of the instruments is made simpler. Similarly, computer and device clocks should be correctly synchronized at the start of each night
- Future sites should have no direct light shining on the measurement location. Due to some private lighting, we cast shadows upon the field.
- As next year will be the final intercomparison campaign, it will be more critical than ever that the research questions, most necessary instruments, and most essential participants be defined far in advance. Furthermore, a Skype call should be arranged about a month or two before the meeting in order to help finalize the planned timeline of the event (weather depending, of course).
- One of the difficulties in comparing the data from this year's campaign was the lack of spectral information of the sky radiance. The addition of a zenith-oriented spectrometer to the campaign would greatly help in understanding the differences between the devices.
- Twilight has been overlooked, and next year's campaign should place a much higher focus on obtaining a sequence of data taken during the twilight. The measurements needs to be really simultaneous (PC clocks sync) due to rapid changes of brightness.
- Based on the research questions identified, and the inhomogeneity, and controllability issue associated with bright sites, we recommend that next year's campaign take place in a dark site. The possibility of moving to a bright site is not discarded, but we note that the twilight makes the site brighter.
- It would be appreciated if next year's site has:
    - Professional extinction measurements (by telescope or other device)
    - Total radiation monitor during the day
    - Some information about aerosols
- One major goal for the next year should be to obtain an intercalibration between the different instruments (i.e. an approximate conversion factor to scale between different instruments)
- Instruments intended for next year:
    - DSLR all-sky cameras (to provide directional information and integrals over the sky brightness)
    - Astmon

    - DigiLum
    - Extinction measurements (e.g. astronomical photometry on astronomical observatory)
    - Lux meter
    - Lightmeter
    - Spectrometer (if possible, e.g. with a telescope or portable spectrometer from Martin Aubé)
    - SQMs
    - US National Park Service camera system
- Highest priority participants for next year
    - Someone from the National Park Service in US to operate their system
        - Alternate if they are not available Fernando Patat (based on his work on photometry)
        - If neither can attend, possibly Martin Aubé to bring his portable spectrometer
    - Salvador Ribas
    - Wim Schmidt (to discuss how he works with extinction)
    - Henk Spoelstra
    - Gunther Wuchterl
    - Costas Bouroussis
    - Andreas Hänel
- On the basis of each of these recommendations, we suggest that Montsec be the site of the next campaign. Based on weather and other considerations, the campaign should be held partially over a weekend in May.

6) Conclusion

The campaign was a success. A great deal of data was collected under four different conditions (clear sky and cloudy skies in both a light and dark location). The data is still being analyzed, and there are likely to be future papers or reports published based on the data collected. The recommendations from section 5 for the final LoNNe Intercomparison Campaign were presented to the LoNNe Management Committee shortly after the Intercomparison Campaign ended. The Management Committee accepted the proposed location (Montsec, Spain) and agreed with the plan to invite an external expert from North America.

Campaign participants 2015. Top row from left: Günther Wuchterl, Luciano Massetti, Andreas Hänel, Fabio Falchi, Henk Spoelstra, Christopher Kyba, Zolthan Kolláth, Kai Pong Tong, Salvador Ribas. Bottom row from left: Andrea Giacomelli, Costas Bouroussis, Ramon Canal Domingo

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