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A double-station meteor camera setup in the Canary Islands – CILBO

D. Koschny[1], F. Bettonvil[2], J. Licandro[3], C. v. d. Luijt[1], J. Mc Auliffe[4], H. Smit[1], H. Svedhem[1], F. de Wit[1], O. Witasse[1], and J. Zender[1]

[1]European Space Agency ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk ZH, the Netherlands
[2]Astronomical Institute Utrecht, Princetonplein 5, 3584 CC Utrecht, the Netherlands
[3]Observatorio del Roque de los Muchachos, Instituto de Astrofísica de Canarias, Apdo. Correos 50, C/Cuesta de San José s/n, San Antonio, 38712 – Breña Baja (La Palma), Spain
[4]European Space Agency ESA/ESAC, Camino bajo del Castillo, s/n, Urbanizacion Villafranca del Castillo, Villanueva de la Cañada, 28692 Madrid, Spain

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Correspondence to: D. Koschny (detlef.koschny@esa.int)

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Abstract

Meteors are caused by dust particles in the solar system which enter the Earth's atmosphere. Using double-station camera setups, the precise trajectory of these dust particles can be determined. The initial heliocentric orbits of the dust can be derived and valuable information about their distribution, velocities, and composition can be determined. This paper describes a double-station camera setup in the Canary Islands, called CILBO (Canary Island Long-Baseline Observatory). It makes use of automated roll-off roofs to house one camera on Tenerife, one on La Palma, monitoring the same volume of the atmosphere. From the obtained data, the meteoroid trajectory can be computed. A second camera on Tenerife is equipped with an objective grating. For bright meteors, a spectrum is recorded which allows to constrain the chemical composition of the meteor. The system is completely automated and sends the obtained data after every observing night to a central ftp server. It has been in operation for almost two years and the first scientific results are produced.

1 Introduction and scientific rationale

Dust is ubiquitous in the solar system. It is formed during impact events on solid solar system objects and by the gas-driven ejection of dust from cometary nuclei. It manifests itself in zodiacal light (e.g. Levasseur-Regourd et al., 2001) and thermal emission of the sky background (e.g. Pyo et al., 2009); in impact craters on natural and artificial surfaces in space (Grün et al., 1985; Krüger et al., 2007); and, when interacting with the Earth's atmosphere, in meteors.

The dust particles causing meteors are often referred to as meteoroids. When a meteoroid enters the Earth's atmosphere, it excites air molecules which generates light and an ionized path in the atmosphere. The light can be recorded with optical means; the ionized path reflects radio waves and allows the observation by radar systems.

Up until a few years ago, the global meteoroid complex was observed mainly by radar systems. Radars can observe the complete sky, and detect the ionisation trails of meteoroids down to an estimated size of micrometres. Due to the ready availability of low-light level video surveillance cameras, optical observations of meteors have seen a dramatic increase in popularity in the recent years. However, non-intensified video cameras are limited in sensitivity and typically only allow recording meteoroids larger than a few millimeters in diameter.

In order to contribute to the measurements of the global meteoroid dust distribution, we have set up a double-station system for meteor observations using intensified video cameras in the Canary Islands. The system is called CILBO, which stands for “Canary Island Long-Baseline Observatory”. CILBO also is a whistling language used by the indigenous population of the island for communication.

The two main scientific goals of the system are:

a. To study physical and chemical properties of meteoroids, and, taking into account the modifications of the meteoroid properties during their flight in the solar system, constrain the physical and chemical properties of their parent body.

b. To study the variability of the background dust flux in the Earth environment during a complete year.

The use of image intensifiers allows the system to record fainter meteors compared to non-intensified systems, bridging the gap to radar observations. It also results in very special operational constraints, as an image intensifier will be damaged when it is exposed to too much bright light (e.g. the Moon going through the field of view). This paper describes in detail the setup and explains in particular the special precautions needed to be taken when operating a light-sensitive image intensifier system in an autonomous way.

2 The observing stations

2.1 Overview

The location of the camera stations was supposed to fulfil the following requirements: they should be located under dark skies and about 100 to 150 km apart from each other. Infrastructure like power connections and internet must be available. We have selected the Canary Islands where two astronomical observatories provide not only technical infrastructure, but also personnel, which can be contacted in case of problems. One station (called CILBO-T) is located on Tenerife at the Izana Observatory, next to the ESA-operated Optical Ground Station (OGS) telescope. The control computer is located in the basement of the OGS. The other selected site is on La Palma, at the Observatorio del Roque de los Muchachos. There, our station (CILBO-L) is located next to the Automated Transit Circle, where the control computer is located.

We currently use one pair of cameras to monitor a volume in the sky about half way between the two islands in 100 km altitude, see Fig. 1. On Tenerife, a second camera with an objective grating is used to record meteor spectra. The camera is tilted such that the first order spectrum of the same meteor as that recorded in the "zero-order" camera is in the field of view. In the future we plan to add a second camera on La Palma to record meteors occurring at a higher altitude.

Table 1 gives the precise locations of the stations.

2.2 The cameras

Most other camera networks we are aware of are using un-intensified low light-level surveillance cameras. These have a typical limiting stellar magnitude of 3–4 for the field of view which we are using (about 20 to 30°). The limiting magnitude for meteors depends on the apparent velocity of the meteor – the slower it is, the closer the limiting magnitude will be to that of the non-moving stars. The goal in our setup was to reach a limiting stellar magnitude of about 6.5 while at the same time reaching a positional accuracy of 1′ or better to allow good orbit determination. This can only be achieved using image intensifiers.

Figure 2 shows a photograph of one of our cameras. A technical overview drawing is shown in Fig. 3. All cameras are named ICCn where ICC is the abbreviation for "Intensified CCD Camera" and n is a number. We use low-distortion machine-vision lenses (Fujinon CF-25L) with 25 mm focal length and a maximum aperture of $f/0.85$. The lens images the sky onto the entrance aperture of a second-generation image intensifier (DEP XX-1700). The intensifier is fibre-coupled to a CCD which is read out via a camera Toshiba Teli CS8310Bi PAL video camera.

A dew remover (type Kendrick) is wrapped around the objective lens to avoid dewing.

The spectrum camera on Tenerife is identical to the zero-order camera. A Zeiss transmission grating with 611 grooves mm^{-1} is mounted in front of the objective lens. The holder is heated via four power resistors to avoid dewing.

2.3 The housing

The cameras must be protected against rain, wind, and also light. Even when the intensifier is not switched on, having the Moon and in particular the Sun in the field of view would lead to permanent damage of the intensifier. To allow additional camera systems to be added in the future, we have decided to use a roll-off roof from the company Pier-Tech to house the camera systems. Figure 4 shows the roll-off roof in its real-sky test environment in the Netherlands, before shipment to the Canaries. The roof comes with a control box, which was encapsulated together with additional control electronics in a weather-proof box. This box can be seen (with a transparent door) in the front of the roof.

Foundation, roll-off roof, and pier can be seen in the configuration drawing Fig. 5.

On the Canary Islands, the foundation and lower part of the wall was poured in concrete. A metal pier holds the camera via heavy-duty camera tripod heads.

On Tenerife, a second camera with an objective grating is mounted under an angle of 14° such that the first order spectrum of meteors recorded by the zero-order camera is visible centred in the field of view. The objective grating is blazed, and the orientation of the grating is chosen such that the maximum light is deflected into the field of view.

2.4 Electronic setup and software

The Pier-Tech roof is controlled by a dedicated controller provided by the company Pier-Tech. An ADLink NuDAM 6024 voltage controller is used to switch the cameras and image intensifiers on and off. It is controlled via an RS485 interface.

A block diagram showing the control process of hardware and software is shown in Fig. 6.

A control software interfaces with the different modules: a certain time after sunset, the weather conditions are checked. If they are ok, the roof opens and the cameras start detecting meteors. Detected events are stored to the hard disk. In the morning, the detection software is stopped, the cameras are switched off and the roof is closed. The collected data is packed in a zip file and sent to a central ftp server. An email notification system informs the operators of the system status.

The following paragraphs describe this process in more detail.

We have developed scheduling software using Python 2.7 and a number of Python scripts (see Table 2) called the “mrg software suite”. This software is running continuously on the control computer. It computes sunrise/-set times at given time intervals. Every evening when the Sun is a configurable number of degrees below the horizon it will start by reading out the weather sensor and checking the cloud cover, possible rain, ambient light and wind conditions. If all values are below fixed threshold values, it will command the PierTech controller to open the roof, the NuDAM controller to switch on cameras and image intensifier, and start up MetRec. On Tenerife, it will also start up a software called SpcRec which is reading out the camera with the objective grating.

The core of the software is the detection software MetRec (Molau, 1999). It is implemented in C and was initially developed for the DOS operating system. With the support of the MetRec developer, we have ported MetRec to run from the command line of Windows XP. MetRec is reading the real-time video data stream via a Matrox

Meteor II frame grabber card. It searches in real-time for possible meteors. The algorithm is actually searching for straight-line segments moving through the field of view. It is expected to detect more than 90 % of all meteors with a Signal-to-Noise ratio of 3 or higher. It will generate false detections when clouds move through the field of view. When the sky is bright (close to full moon), background noise fluctuations can also trigger false detections.

The cameras point in a fixed direction in azimuth and elevation. Using the tool “RefStars” from the MetRec software suite, we have determined the pointing position of the cameras to sub-pixel accuracy. With the pointing information and the time of a meteor event, MetRec will generate position measurements of each detected event in right ascension and declination. The given position is the photometric centre of the meteor image in a single frame.

MetRec will store, for each meteor, one sum image file of all frames in which the meteor was detected, a movie sequence of a sub-frame containing the meteor, and a text file giving a magnitude estimate and the position of the meteor in each frame. In addition, MetRec uses the visible stars in the field of view to determine an estimate of the limiting magnitude and possible cloud factor for every minute.

On Tenerife, a second camera with an objective grating is recording spectra of the detected meteors. Tests have shown that MetRec has difficulties to reliably detect meteor spectra. Therefore we have opted for the following solution: MetRec allows sending information to the RS232 serial port; in particular it will allow sending the information that a meteor was detected. We have physically connected one of the serial ports of the PC with another printer port. This printer port receives the information from MetRec. A dedicated software – called SpcRec (for “spectrum recorder”) is continuously grabbing frames from the spectrum camera into a ring buffer. It monitors the incoming serial port. When a “meteor detected” signal is received, it will store the relevant image frames.

Time information for both MetRec and SpcRec is taken from the PC clock. The clock is synchronised every 2 min with a “network time protocol” server using the freeware software tool “TimeMemo”.

During the night, the environmental conditions are regularly checked every 2 s. The sensor – a Boltwood cloud sensor – comes with a driver software from the manufacturer which is used to read out values for the sky temperature in °C, the ambient temperature in °C, the light level (in arbitrary units), wind speed in $\mathrm{m\,s^{-1}}$, and the humidity in Reaumur. The difference between sky temperature and ambient temperature is an indication for the percentage of cloud coverage.

If any of the given thresholds are exceeded, the control software will properly close down MetRec, close the roof, and switch off cameras and image intensifiers. If the weather conditions get better again, the system may be switched back to operational status.

In the morning the control software will start shutting down the system when the Sun reaches a configurable elevation below the horizon. Then, the detection software MetRec is shut down, the cameras and image intensifiers are switched off, and the roof is closed.

In the next step, the data directories of all cameras for the night are packed into a zip file. This zip file is transferred via ftp to a server located at ESA/ESTEC in the Netherlands. An email notification with a summary of the night is generated. The email contains information on the time(s) the system was operating, the number of detections in these time intervals, the free disk space on the computer and the size and name of the transferred data files. A screenshot of graph showing the weather conditions, the roof open/closed status, and the cumulative number of meteor detections is also attached. Figure 7 shows an example of such a screenshot. It gives a very quick overview of the observing night and allows the trained user to judge whether everything went ok.

Several safety factors are built into the system:

a. The roof has mechanical limit switches. These are activated when the roof is open or closed. The Pier-Tech roof control will issue an error if the roof does not reach the commanded position within a preconfigured time. When this error is encountered, the scheduling software attempts to reset the Pier-Tech roof controller and sends another "open" or "close" command. If a total of three resets still don't result in a successful opening or closing, a power cycle for the roof is commanded via an USB-connected power distribution strip. If the first power-cycle does not succeed in re-establishing communication, a second and final attempt is made 30 s later. After a power cycle, an email is sent to a pre-defined email list with a notification message.

b. The NuDAM 6024 voltage controller also includes a watchdog timer. This timer is set to 30 s and will trigger a system shutdown in a controlled manner (camera off, intensifier off, close dome), if no "ping" communication is received from the control computer. Such an event may occur with mrg.exe program crashes, the control computer crashes, or due to a bad operation by system operator.

c. In normal operation, the software reads out the Boltwood cloud sensor every few seconds and triggers a dome closure if the weather conditions exceed predefined thresholds. An additional safety feature is built into the hardware using the Boltwood cloud sensor's "threshold exceeded" signal. This is used as redundancy in case of software logic failure. The "threshold exceeded" signal feeds into specially designed hardware, which will close the roof.

3 Data processing

After the cameras had been mounted, we have used the "RefStars" programme from the MetRec software suite to determine the precise pointing position of the camera. This allows the detection software to convert x/y positions in an image to celestial coordinates. For each detected meteor, the right ascension and declination of the photometric centre of the meteor will be measured and stored.

The system stores one directory per camera and per night. Each directory contains a number of files as defined in Table 3. The ftp server has one directory per camera. In each camera directory, the data from one observing night is contained in one zip file with the file name yyyymndd.zip.

The main scientific data is contained in the *.inf files which list, for each meteor, the right ascension and declination of the photometric centre of the meteor for each detected frame and its magnitude. If data of the same meteor is available from both stations, this information can be used to compute the trajectory w.r.t. the Earth and from that the heliocentric orbit of the meteor.

The *.flx files store information on the computed meteor flux for a given stream. This functionality is currently not (yet) exploited.

The actual sum image itself is also typically used for scientific analysis, e.g. to get a continuous light curve of the meteor. An example image and the corresponding *.inf file is shown in Fig. 8.

If the system is aligned well to the star background, the *.flx files can be used to estimate the flux in particles per $\mathrm{km}^3\,\mathrm{s}^{-1}$ as computed by the software MetRec.

After the data has been received at the central ftp server it is downloaded to a local processing machine. The software “PostProc” from the MetRec software suite is used to visually inspect all potential meteor events. False detections are deleted.

4 First scientific results

The station on Tenerife (CILBO-T) has been operational since July 2011; the La Palma station (CILBO-L) since December 2011. CILBO-L was not in operation due to technical issues from August 2012 to December 2012.

The double-station system has been fully operational with both stations for a total of about 12 months. Between 60 and 100 meteors are typically captured by each of the "zero-order" cameras in a clear night. About 10 nights per month are lost to the Moon or to bad weather, resulting in about 800 to 1000 meteors per month. About 70 % of these are double-station meteors, allowing trajectory and orbit computations.

The grating camera of CILBO-T records spectra only of the brightest meteors, typically these need to be brighter than 0 mag. About one to two meteors per night are bright enough, resulting in about 30–40 spectra per month.

To give a first impression of the science this setup is capable to produce, we have analysed double-station data from the Geminid meteor stream on 13–15 December 2011. We uploaded the data into the Virtual Meteor Observatory (http://vmo.estec.esa.int, Barentsen et al., 2010) and used its built-in orbit computation tool MOTS (Meteor Orbit and Trajectory Software, Koschny and Diaz, 2002).

Using the double-station data of all meteors marked as Geminids by the detection software, we obtain Fig. 9. The 3-D view of the inner solar system shows the position of the Earth, Mars, and the orbits of the detected meteors. The dotted orbit embedded in the meteor orbits denotes the orbit of (3200) Phaeton.

Plotting the light curve of all those meteors allows us to determine the so-called *F* factor, i.e. the position of the brightness peak relative to the length of the meteor. An *F* factor of 0 corresponds to a peak at the beginning of the meteor, an *F* factor of 1 at the end of the meteor (Fleming, 1993). It is commonly assumed that this value allows to constrain the strength of the material. A late-peaked light curve (high *F* values) would correspond to high-strength material; an early-peaked light curve indicates a very fragile particle. If Phaeton were an asteroid (assumed to be made of high strength material compared to cometary material), more late-peaked meteors would be expected.

In Fig. 10 we plot the *F* factor for all meteors observed during the three nights of 13–15 December 2011. It can be seen that the *F* factor of the Geminids shows as much scatter as any of the other stream meteors. We conclude that (3200) Phaeton may be cometary after all.

5 Summary and lessons learned

This paper describes the technical aspects of a double-station meteor camera setup in the Canary Islands. It has been operational for over a year now and first scientific results were presented. The following lessons learnt are worth mentioning:

a. The setup is working well, even though reliability could still be improved. There are times where the opening and/or closing of the roof does not happen within the expected time, leading to errors. We suspect issues with the end switches. It seems to be difficult to build up a robust autonomous system with commercial elements. Still, the setup has survived the extreme weather of the Canary Islands in >2000 m altitude – extended frost and ice periods in winter and storms with wind speeds above $120\,\mathrm{km\,h^{-1}}$.

b. The cameras seem to be sagging continuously, possibly because of the weight of the cables at the back end of the camera. This requires regular use of the "Ref-Stars" programme to re-establish the pointing direction of the camera. A strain relieve for the cables could solve this issue. The slight shift in the field of view can be corrected by using the capability of the "PostProc" software of the MetRec suite to recompute the precise position of the camera. This will result in the highest precision astrometry of the measured meteors. However, the produced flux information on meteor streams will be lost due to the way MetRec determines the limiting magnitude needed for this computation.

c. Using a roll-off roof for housing just one camera may be an overkill. Possibly a compact camera housing with a mechanical protection shutter in front of the lens may have been enough. The roof, however, gives us the flexibility to add more camera systems with little additional effort.

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Table 1. Geographical positions of the two observing stations and the aim point.

Island	Station code	Longitude	Latitude	Elevation
Tenerife (ICC7/ICC8)	CILBO-T	28°18′04″ N 28.3011° N	16°30′43″ W −16.5119°	2395 m
La Palma (ICC9)	CILBO-L	28°45′36″ N 28.7600° N	17°52′57″ W −17.8824°	2327 m
Aim point		28°32′00″ N 28.5333° N	17°10′00″ W −17.1667°	100 000 m

Table 2. C++ and Python scripts developed as part of the "mrg" application.

Name	Description
mrg.exe	The main controller which calls all the other routines. Can be used with different options to test the elements of the system: – dome: allows opening/closing/resetting the roof controller – nudam: setting the power switch via the Nudam controller (on/off/gain control for intensifiers) – meteo: reads out the Boltwood II cloud sensor
watchdog.exe	Installs a program as a service, and regularly checks that it is still running. If not, the program is restarted.
fov.py	Field of View calculator module. This Python program makes use of the pyephem library to determine the ephemeris of the Moon and the Sun. These calculations are then used to determine the GTI (good time interval) that are the opening and closing times of the dome.
archive.py	Takes care of sending the data of one night to the central ftp server, collects statistics from the data, which are then sent as an email notification to the user(s) of the system.
metrec.exe	The meteor detection software developed by Sirko Molau.
pm.exe	Commercial software from the company GEMBIRD. A USB-driven 220 V power bar controller. This program is used to power cycle the system in case of communication problems.
timememo.exe	Open Source software from Patrick Chevalley. Synchronizes the PC time at regular intervals.

Table 3. The data which the system generates automatically every night.

Filename	Generated by	Description
yyyymndd.log	MetRec	Log file repeating the MetRec configuration parameters, a timed list of all meteors, and a summary.
yyyymndd.cfg	mrg	The configuration file for MetRec. The mrg.exe application generates this file from a standard template and updates all date entries in this file to the current date.
yyyymndd.mag	MetRec	The effective stellar limiting magnitude for every minute.
yyyymndd.ref	MetRec	"Reference star file" – correlates the actually observed position of stars with the expected position of the stars.
mndddata.dbf	MetRec	Data file in the meteor position data format PosDat (Koschny, 1992).
mnddhead.dbf	MetRec	Header file in the meteor position data format PosDat (Koschny, 1992).
hhmmss.bmp	MetRec	An image file showing the complete meteor event.
hhmmss.inf	MetRec	An ASCII file listing position and brightness of meteor for each detected frame.
hhmmss.bnd	MetRec	An animation of the meteor in a proprietary format.
mndd_SSS.flx	MetRec	A file containing the calibrated flux of meteors for a meteor stream "SSS" (e.g. GEM for Geminids, PER for Perseids).
mrg.log	mrg	A log file created by the control software mrg.exe.
timememo.txt	TimeMemo	Log file created by the time synchronisation programme TimeMemo.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◂◂ | ▸▸
◂ | ▸
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

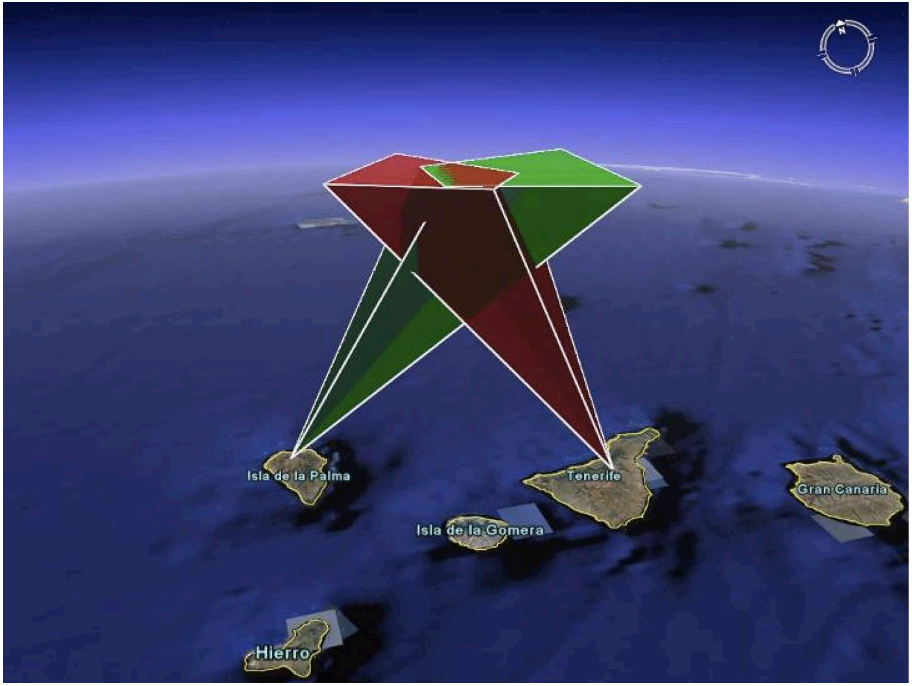


Fig. 1. Principle sketch of the CILBO camera setup. Image: Google Earth.

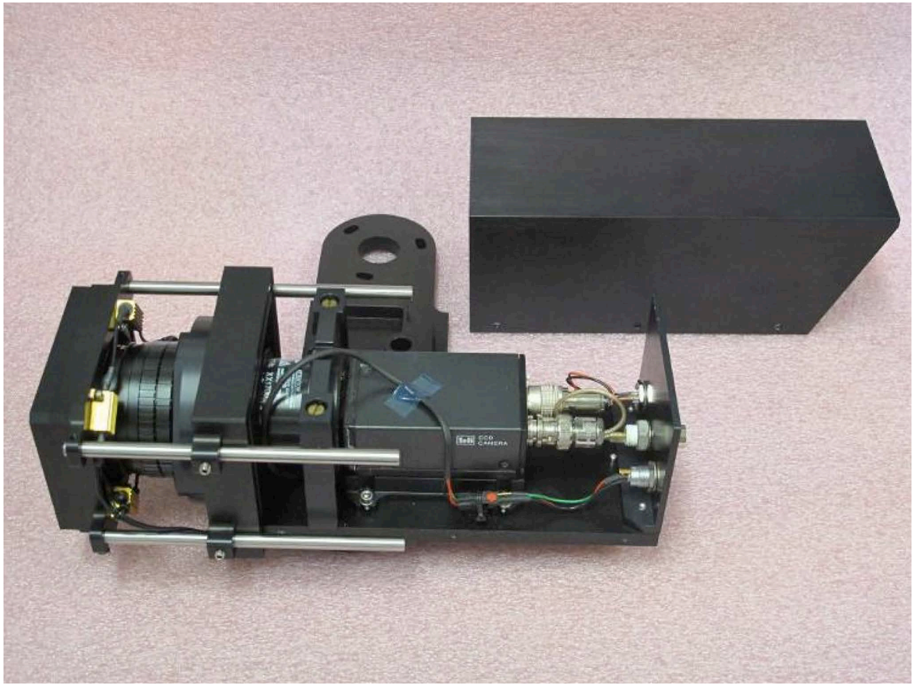


Fig. 2. Photograph of one of the intensified video cameras. The protective cover is removed and visible in the back. The camera is shown with the optional grating holder on the left side. Power resistors to heat the grating can be seen on the left.

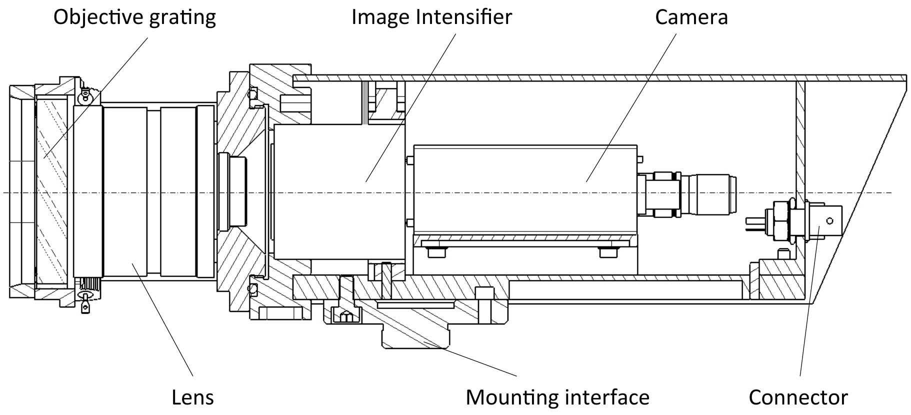


Fig. 3. Technical drawing of the camera showing the main elements.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Fig. 4. Roll-off roof in real-sky test environment.

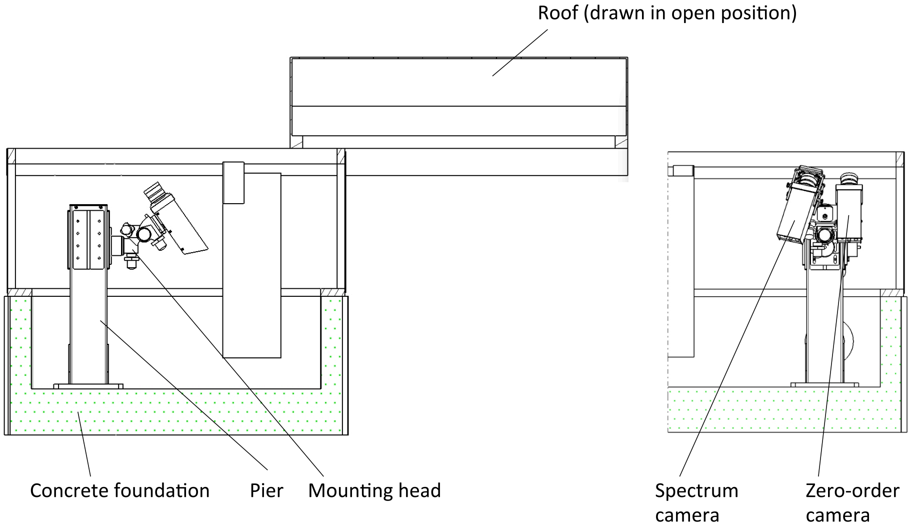
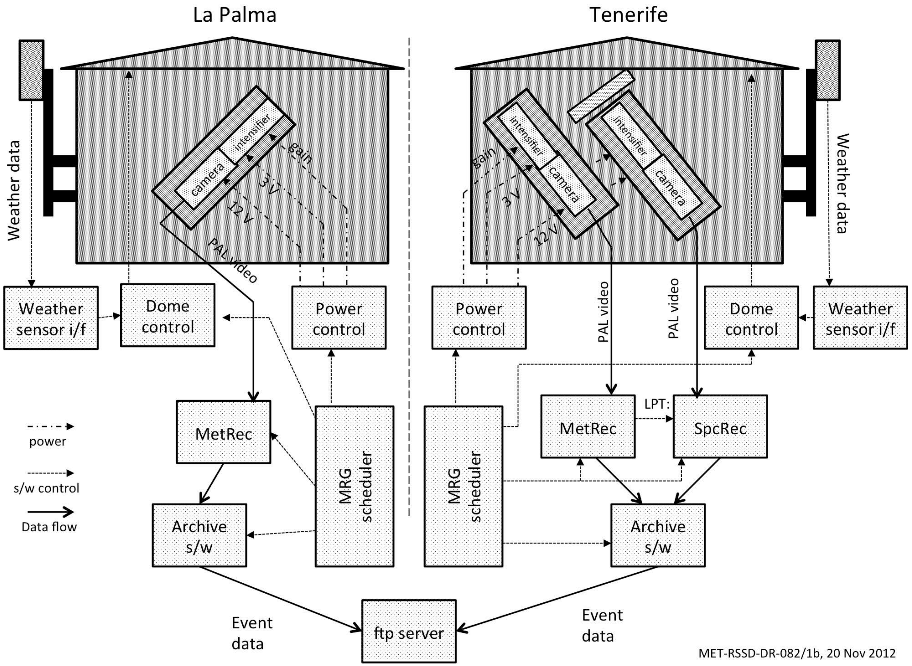


Fig. 5. Cut side view and back view of the complete housing with pier.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion



MET-RSSD-DR-082/1b, 20 Nov 2012

Fig. 6. CILBO block diagramme.

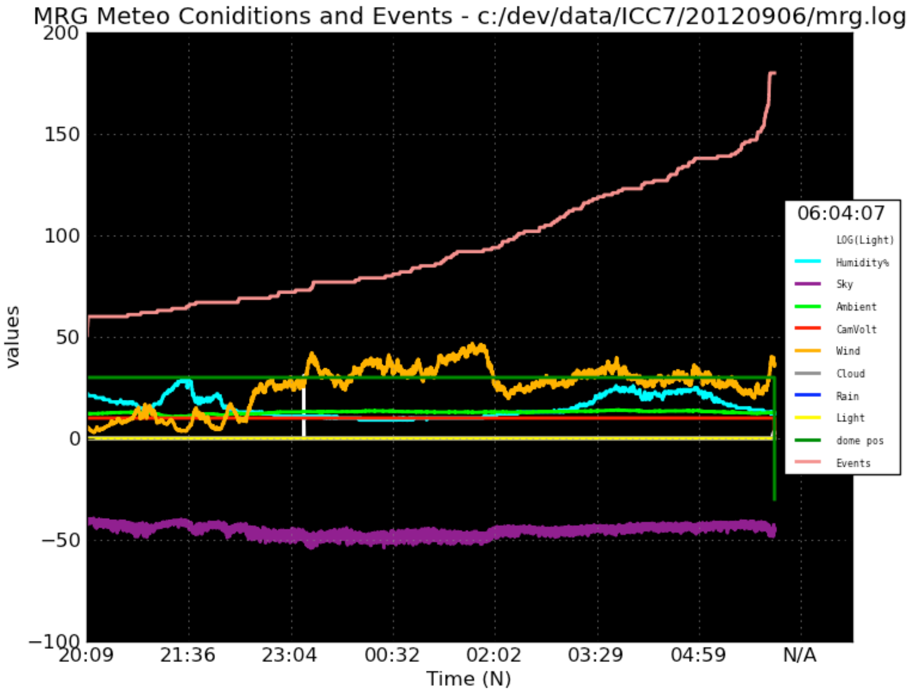
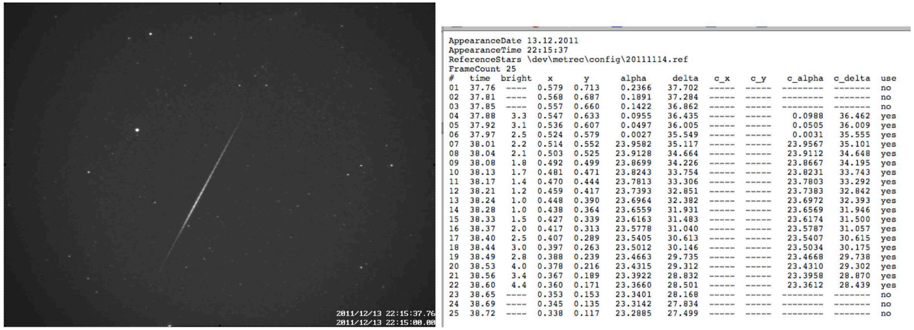


Fig. 7. Screenshot of weather conditions, roof status, and number of detections as sent from CILBO via email at the end of an observing night.



```
AppearanceDate 13.12.2011
AppearanceTime 22:15:37
ReferenceStars \dev\metrec\config\20111114.ref
FrameCount 25
#   time  bright   x      y       alpha     delta   c_x    c_y    c_alpha  c_delta  use
01  37.76  ----  0.579  0.713    0.2366    37.702  -----  -----  --------  -------  no
02  37.81  ----  0.568  0.687    0.1891    37.284  -----  -----  --------  -------  no
03  37.85  ----  0.557  0.660    0.1422    36.862  -----  -----  --------  -------  no
04  37.88   3.3  0.547  0.633    0.0955    36.435  -----  -----    0.0988   36.462  yes
05  37.92   3.1  0.536  0.607    0.0497    36.005  -----  -----    0.0505   36.009  yes
06  37.97   2.5  0.524  0.579    0.0027    35.549  -----  -----    0.0031   35.555  yes
07  38.01   2.2  0.514  0.552   23.9582    35.117  -----  -----   23.9567   35.101  yes
08  38.04   2.1  0.503  0.525   23.9128    34.664  -----  -----   23.9112   34.648  yes
09  38.08   1.8  0.492  0.499   23.8699    34.226  -----  -----   23.8667   34.195  yes
10  38.13   1.7  0.481  0.471   23.8243    33.754  -----  -----   23.8231   33.743  yes
11  38.17   1.4  0.470  0.444   23.7813    33.306  -----  -----   23.7803   33.292  yes
12  38.21   1.2  0.459  0.417   23.7393    32.851  -----  -----   23.7383   32.842  yes
13  38.24   1.0  0.448  0.390   23.6964    32.382  -----  -----   23.6972   32.393  yes
14  38.28   1.0  0.438  0.364   23.6559    31.931  -----  -----   23.6569   31.946  yes
15  38.33   1.5  0.427  0.339   23.6163    31.483  -----  -----   23.6174   31.500  yes
16  38.37   2.0  0.417  0.313   23.5778    31.040  -----  -----   23.5787   31.057  yes
17  38.40   2.5  0.407  0.289   23.5405    30.613  -----  -----   23.5407   30.615  yes
18  38.44   3.0  0.397  0.263   23.5012    30.146  -----  -----   23.5034   30.175  yes
19  38.49   2.8  0.388  0.239   23.4663    29.735  -----  -----   23.4668   29.738  yes
20  38.53   4.0  0.378  0.216   23.4315    29.312  -----  -----   23.4310   29.302  yes
21  38.56   3.4  0.367  0.189   23.3922    28.832  -----  -----   23.3958   28.870  yes
22  38.60   4.4  0.360  0.171   23.3660    28.501  -----  -----   23.3612   28.439  yes
23  38.65  ----  0.353  0.153   23.3401    28.168  -----  -----  --------  -------  no
24  38.69  ----  0.345  0.135   23.3142    27.834  -----  -----  --------  -------  no
25  38.72  ----  0.338  0.117   23.2885    27.499  -----  -----  --------  -------  no
```

Fig. 8. A typical meteor image and the corresponding *.inf file.

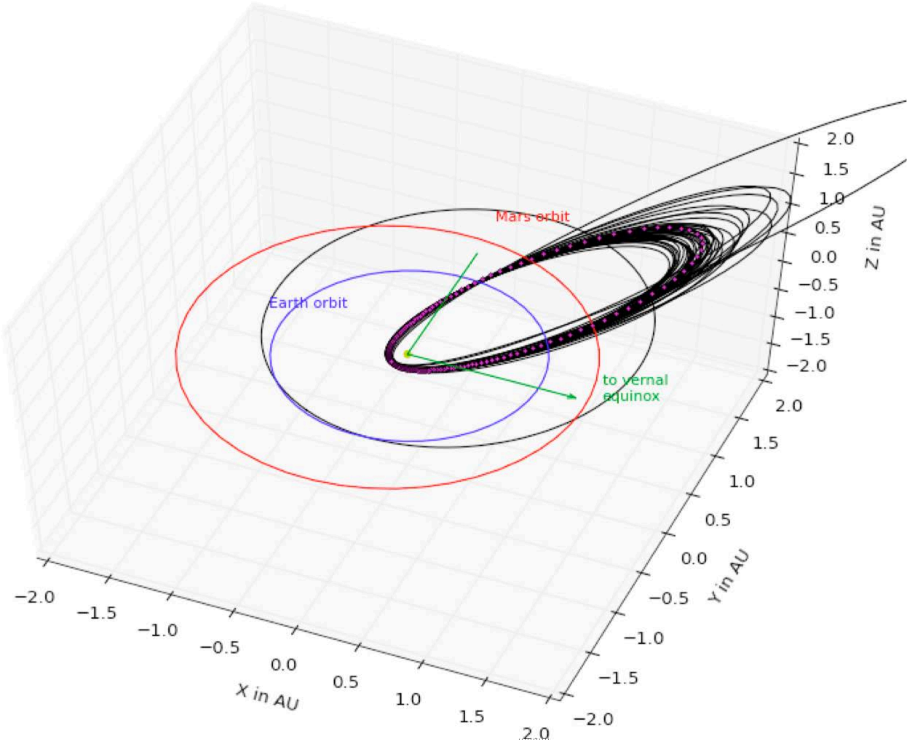


Fig. 9. 3-D view of the orbits of meteors associated with the Geminid meteor stream by MetRec in the nights 13–15 December 2011.

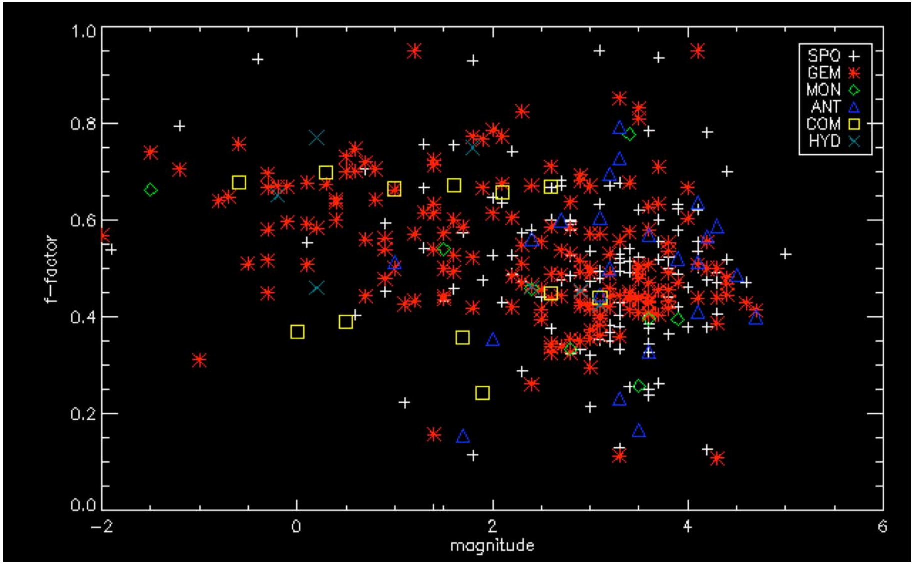


Fig. 10. *F* factor of all meteors observed in the nights from 13–15 December 2012. The different meteor streams are marked with different symbols: SPO = sporadic meteors, GEM = Geminids, MON = Monocerides, ANT = Antihelion source, COM = Coma Berenicids, HYD = Hydrids.