Current activities at the ESA/ESTEC Meteor Research Group

Detlef Koschny[1, 3], Thomas Albin[2,5], Esther Drolshagen[2], Gerhard Drolshagen[1], Sandra Drolshagen[2], Julius Koschny[1], Jana Kretschmer[2], Cornelis van der Luijt[1], Cosette Molijn[1], Theresa Ott[2], Bjoern Poppe[2], Hans Smit[1], Hakan Svedhem[1], Andrea Toni[1], Fritz de Wit[1] and Joe Zender[1]

[1] **European Space Agency, ESA/ESTEC, Keplerlaan 1, NL-22001 AZ Noordwijk, The Netherlands**

Detlef.Koschny@esa.int

[2] **Universitätssternwarte Oldenburg, Carl von Ossietzky University of Oldenburg, Ammerländer Heerstr. 114-118, D-26129 Oldenburg, Germany**

[3] **Chair of Astronautics, TU Munich, Boltzmannstr. 17, D-85748 Garching, Germany**

[4] **Isaak Newton Group of Telescopes, Apt. de correos 321, E-38700 Santa Cruz de La Palma, Canary Islands, Spain**

[5] **University of Stuttgart, Keplerstr. 7, D-70174 Stuttgart, Germany**

The Meteor Research Group of ESA/ESTEC has been active in the field of meteor research since the year 1998. Currently we are focusing on several activities: (a) Data analysis of the double-station data of our CILBO setup (Canary Island Long-Baseline Observatory): Determining the flux density of meteoroids, comparing it to other data sources, and determining whether the optical data can be used to constrain meteoroid models; testing the quality of the orbits computed from these cameras; producing a processing pipeline for the analysis of meteor spectra. (b) Expansion of the CILBO setup with wider-angle cameras that are better suited for the flux measurements. We modify existing cameras to be robust enough to survive the environmental conditions on the Canary Islands and install them in the existing CILBO hut. (c) We are supporting studies for lunar impact flash observations on the Moon, both ground-based and possibly space-based. (d) The meteor data archiving system at ESTEC is being upgraded to be conforming to modern network security standards. - This paper will give an overview of the activities and will put more detailed papers by other members of the group in context.

1 Introduction

The Meteor Research Group (MRG) of the European Space Agency has been working on the analysis of meteor observations, mainly using image-intensified video camera systems, since the year 1998. The group is located at ESA's center ESTEC in the Netherlands and regularly hosts summer students and post-doc students. We have started a close collaboration with the University of Oldenburg, in particular on the analysis of data from our double-station camera setup CILBO (Canary Island Long-Baseline Observatory). Detailed results of our work will be given in other papers in these proceedings; this paper focuses on an overview of the group's activities.

2 Our meteor cameras and the Canary Island Long-Baseline Observatory

We mainly use image-intensified video cameras for our work. The light of the meteor is focused onto the entry window of an image intensifier by a lens. The signal is amplified onto the output screen. This is filmed using a standard video camera using the PAL format. In some of our cameras we use image intensifiers that are fibre-coupled to the video camera sensor.

Currently two camera types are used – ICC7, ICC8, ICC9 (ICC stands for Intensified CCD Camera) with 22° x 28° field of view; and LIC1 and LIC4 (LIC = Large field-of-view Intensified Camera) having about 60° field of view.

Our main observing sites are the Canary Islands. We have one automated camera station on Tenerife, next to ESA's Optical Ground Station telescope, hosting ICC7 for high-precision astrometry, LIC1 having a large field of view, and ICC8 using an objective grating. An identical station on La Palma, close to the Automatic Transit Circle, hosts ICC9, aiming at the same volume in the atmosphere as ICC7. ICC7 and ICC9 work in double-station mode and allow the determination of good accuracy orbits. LIC4 is a camera similar to LIC1, operated in the Netherlands.

The camera data is acquired by the detection software MetRec (Molau, 1999) and sent via the ftp protocol to a central data server. The data is made available as part of the IMO video meteor data network. The complete setup is automated, for more details see Koschny et al. (2013).

In the time frame from December 2011 to May 2015, ICC7 and ICC9 have recorded 46911 and 52201 meteors in 7029 hours and 6751 hours, respectively. In the 'overlapping' time, i.e. the times when both cameras were on at the same time, the numbers were 28260 and 33881, respectively. Of these single station observations, 13772 meteors were observed simultaneously in 4212 hours of simultaneous observing time. Thus a bit less than 50 % of the individual meteors of each camera were seen simultaneously. This is consistent with the volume in the atmosphere covered by the cameras. A summary of the first months of operations and 'lessons learned' can be found in previous IMC proceedings (Koschny et al., 2014).

3 Video camera characterization

Each measurement system introduces different biases into the measurements. For digital cameras, several effects play a role: (a) dark current; (b) readout noise; (c) flat field effects. The dark current is generated by thermal electrons and is normally present only when using longer exposure times or when operating at high temperatures. It will result in an apparent signal in the sensor even when the lens is covered (thus the term 'dark' current). Since we are using video cameras, the readout of the sensor will dominate the dark signal.

One of the obvious characteristics of a camera, in particular when using wide field of views, is that the light intensity of the sky background drops off towards the edges of the field of view. When analyzing image data, the standard calibration procedure would be to subtract a dark image (obtained with closed shutter) and divide by a flat field. Currently, MetRec allows to load a dark image. However, there is no division by a flat field; rather, MetRec subtracts a background noise image (also called flatfield). To better understand these effects, we plot the available camera data in different ways, see e.g. Albin et al. (2015).

Another example for our efforts to understand the properties of video cameras is illustrated in *Table 1*. One entry in the IMO video database is the 'In_FoV' code. It is set to '11' if the meteor starts and ends in the field of view; '01' denotes that it starts outside and ends inside, and '10' indicates a start in the field of view, end outside. From *Table 1*, it can be seen that most meteors have both start and end inside the field of view. However, there are large discrepancies between those that start outside and end outside the field of view. The table shows different behaviors for different cameras. We picked two of our cameras - there the types '10' and '01' have about the same numbers. Some other cameras, however, have very large differences. Pavela and Živanović (2015) have performed modeling activities that can be used to explain these numbers.

Table 1 – Number of meteors in the VMO database as a function of the position in the field of view for all meteors and for a few selected cameras. '11' = start and end in field of view; '10' = start in field of view, but not the end; '01' = end in field of view, but not the start.

In FoV	Total	ICC7	ICC9	MINCAM1	SRAKA
11	196672	17270	10403	10442	6528
10	19469	1725	988	1253	675
01	10700	1402	732	649	253

4 De-biasing double-station data

Context

Currently, our main interest lies in the determination of the flux density of meteoroids outside the Earth's atmosphere. This information can be used to constrain interplanetary meteoroid models such as presented by Soja et al. (2015).

Ryabova (2010) has pointed out that video meteor camera data has to be properly de-biased for doing exact data analyses. In addition to the camera effects described in the previous section, the following observational effects will play a role:

(a) the effect of the distance of the meteor to the camera; (b) the conversion of magnitude and speed to mass: (c) the size of the area seen by our cameras at 100 km height or alternatively the monitored volume; (d) the fact that the smaller the meteoroid, the higher its velocity has to be to generate enough light for the meteor to be visible.

Points (a), (b), and (c) have been addressed by Drolshagen et al. (2014) and Ott et al. (2014). Kretschmer et al. (2015) addresses (d). As a somewhat parallel project, Drolshagen et al. (2015) combines many different meteoroid flux density determination methods to obtain an average mass influx rate per day onto the Earth.

Meteoroid flux density at 100 km

Most of the de-biasing methods mentioned above give a relative de-biasing, but do not directly allow the assessment of absolute numbers. For that, we have performed the following exercise: We have determined the 3-D trajectory of all simultaneous meteors relative to the Earth's surface. In *Figure 1* we show the intersection point of the meteoroids trajectory with a plane at 100 km height, assuming the meteoroid's trajectory to be a straight line. The area at 100 km height covered by our double-station setup is the yellow hexagon visible behind the data points.

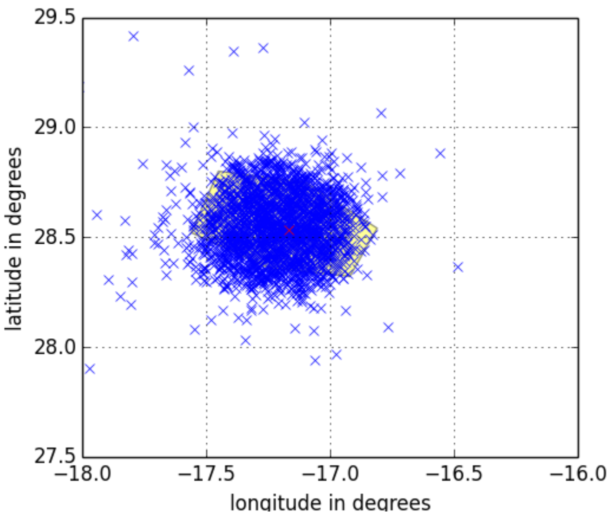


Figure 1 – The intersection of the simultaneously observed meteoroids with a plane at 100 km height. For a clearer display, only every 5th meteoroid was plotted.

The highest number of points is in the center of the overlap area. Towards the edges of the overlap, the number of meteoroids reduces. The fact that some intersection points are outside the overlap area can easily be explained with meteoroids that fly under a shallow angle 'above' or 'below' the overlap area.

The fact that the number drops toward the edges is an observational effect - two cameras located say 50 km towards the East would show the same effect with a maximum number of intersections shifted by 50 km. Thus, we assume that total number of meteoroids per area is the one at the center of the overlap area.

Figure 2 shows a cut through the plane in the East-West direction. The peak number corresponds to 1.2 meteoroids per 1000 km^2 and hour. This is the flux density of all observed meteoroids by ICC7/ICC9 during a total of 4212 hours of observing time.

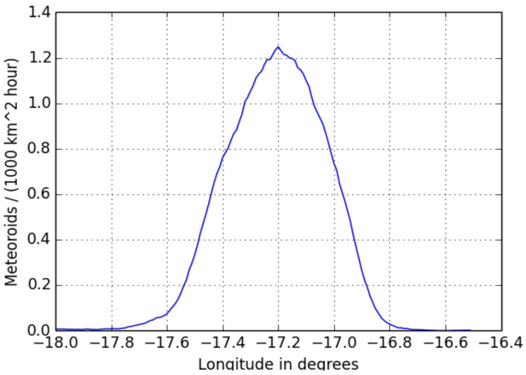


Figure 2 – East-West cut through the area of overlap, giving the number of meteoroids per 1000 km^2 and hour which were observed.

Figure 1 shows an asymmetry of meteoroid intersections; there are more points towards the North and West of the overlap area. This can be explained with the apex meteoroids. Most of the observed volume is above the 100 km plane. We have shown elsewhere that our observations are dominated by apex meteors, which come from the (South-) East. As more of these are detected above the 100-km plane, more intersections will be towards the North and the East.

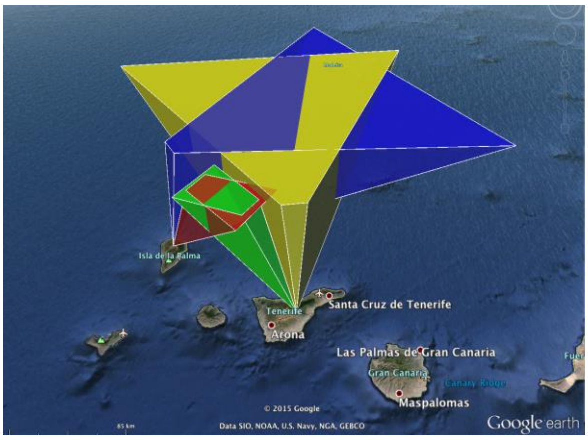


Figure 3 – The extended CILBO setup with two more wide angle cameras added. Small field of view, bright: ICC7, dark: ICC9. Large field of view, bright: LIC1, dark: not yet installed.

5 Upgrading CILBO

The characteristics of ICC7 and ICC9 were selected such that they can provide astrometric measurements with an accuracy higher than most other existing camera systems. The resulting field of views of the camera are rather small, reducing the number of detectable meteors. To allow even better meteoroid flux density determinations, we are in the processing of adding cameras with a wider field of view. One camera (LIC1) has started operations on Tenerife in August 2015. A second similar camera will be installed on La Palma. These cameras have a circular field of view of about 60°. An additional benefit of the larger field of view is that the cameras will capture more bright meteors, thus extending the observed mass range to larger masses.

Figure 3 shows a view of the setup with the two new cameras.

6 Software

ESA's Meteor Research Group hosts the Virtual Meteor Observatory[1], which complements other existing databases by providing the raw data of all IMO video network observations until August 2014 (Koschny et al., 2007). A web-based frontend allows accessing the raw data in an easy way. The current implementation, however, does not fulfill standard web security requirements anymore. We are currently testing whether it is possible to update the database to be part of the existing 'cosmos' web environment of ESA's Scientific Support Office[2].

The VMO contains orbit computation software (Koschny and Diaz, 2002); we have extracted the on-line code to stand-alone Python scripts, which can be run in batch mode over large datasets.

7 Lunar impact flashes

Meteoroids or asteroids hitting the Moon will generate an impact flash which can be observed from the Earth. With video cameras and typical amateur telescopes (say 10" to 14" aperture) one can detect flashes of objects as small as 30 cm. NASA's Meteoroid Environment Office is leading the current effort of observing lunar impact flashes. ESA has started a contract with the University of Athens to set up a European counterpart to this program. To get the currently active community together, the Meteor Research Group had organized a workshop in June 2015.[3] In this workshop, 15 people from 8 different places came together to discuss the topic. Observing lunar impact flashes nicely extends the size/mass range of meteoroids to larger values compared to meteor observations. They are therefore a very complementary means of determining e.g. the flux density of meteoroids (see e.g. Drolshagen et al., 2015).

[1] http://vmo.imo.net
[2] http://cosmos.esa.int
[3] http://cosmos.esa.int/lunar-impact-workshop

8 Meteor spectra

We operate one camera with an objective grating (ICC8). The camera is tilted such that it records the 1st order spectrum of a meteor going through the center of ICC7. The needed data processing steps are described in Zender et al. (2014). One of these, to convert the position of a meteor recorded in ICC7 to a pixel position in ICC8 as a function of wavelength, was implemented recently by Molijn (2015). *Figure 4* illustrates this. The pipeline software reads the celestial coordinates of the meteor from the *.inf file of the observation by ICC7, as generated by MetRec. With this information, the pixel position of selected wavelengths in the 1st-order spectrum is computed, simplifying the process of line association.

Figure 4 – Illustration of the spectral data processing pipeline. The meteor position is read from the *.inf file produced by MetRec via camera ICC7 and tick marks are generated for different selected wavelengths.

9 Summary

In this paper, we give a short overview of the current main activities of the Meteor Research Group of ESA's Scientific Support Office and refer to papers where more details of the ongoing work are given. The activities are focussed on the data analysis from meteor observations performed with intensified video cameras. There, we focus on determining a value for the flux density of meteoroids, i.e. the number of particles per area and time (or volume) as a function of mass.

One of results to be highlighted here is that we have determined the total number of meteoroids observed by our CILBO double-station camera setup to be on average 1.2 meteoroids per 1000 km^2 an hour.

Acknowledgment

The faculty of ESA's Scientific Support Office of ESA provided travel funding and funding for our CILBO hardware. Thanks also to our IT support group.

References

Albin T., Koschny D., Drolshagen G., Soja R., Srama R. and Poppe B. (2015). “Influence of the pointing direction and detector sensitivity variations on the detection rate of a double station meteor camera”. In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Mistelbach, Austria, 27-30 August 2015. IMO, pages 225–231.

Drolshagen S., Kretschmer J., Koschny D., Drolshagen G. and Poppe B. (2015). “Mass accumulation of Earth from interplanetary dust, meteoroids, asteroids and comets”. In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Mistelbach, Austria, 27-30 August 2015. IMO, pages 219–224.

Koschny D. and Diaz del Rio J. (2002). “Meteor Orbit and Trajectory Software (MOTS) - Determining the position of a meteor w.r.t the Earth using data collected with the software MetRec”. *WGN, The Journal of the IMO*, **30**, 87–101.

Koschny D., Mc Auliffe J. and Barentsen G. (2007). “The IMO Virutal Meteor Observatory (VMO): Architectural design”. *Earth, Moon, and Planets*, **102**, 1–4, pages 247ff.

Koschny D., Bettonvil F., Licandro J., v. d. Luijt C., Mc Auliffe J., Smit H., Svedhem H., de Wit F., Witasse O. and Zender J. (2013). “A double-station meteor camera setup in the Canary Islands – CILBO”. *Geosci. Instrum. Method. Data Syst.*, **2**, 339–348.

Koschny D., Mc Auliffe J., Drolshagen E., Bettonvil F., Licandro J., v.d.Luijt C., Ott T., Smit H., Svedhem H., Witasse O. and Zender J. (2014). “CILBO - Lessons learned from a double-station meteor camera setup in the Canary Islands”. In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Giron, France, 18-21 September 2014. IMO, pages 10–15.

Kretschmer J., Drolshagen S., Koschny D., Drolshagen G. and Poppe B. (2015). “De-biasing CILBO meteor observational data to mass fluxes”. In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Mistelbach, Austria, 27-30 August 2015. IMO, pages 209–213.

Molau S. (1999). “The Meteor Detection Software MetRec”. In Arlt R., Knöfel A., editors, *Proceedings of the International Meteor Conference*, Stara Lesna, Slovakia, 20-23 August 1998. IMO, pages 9–16.

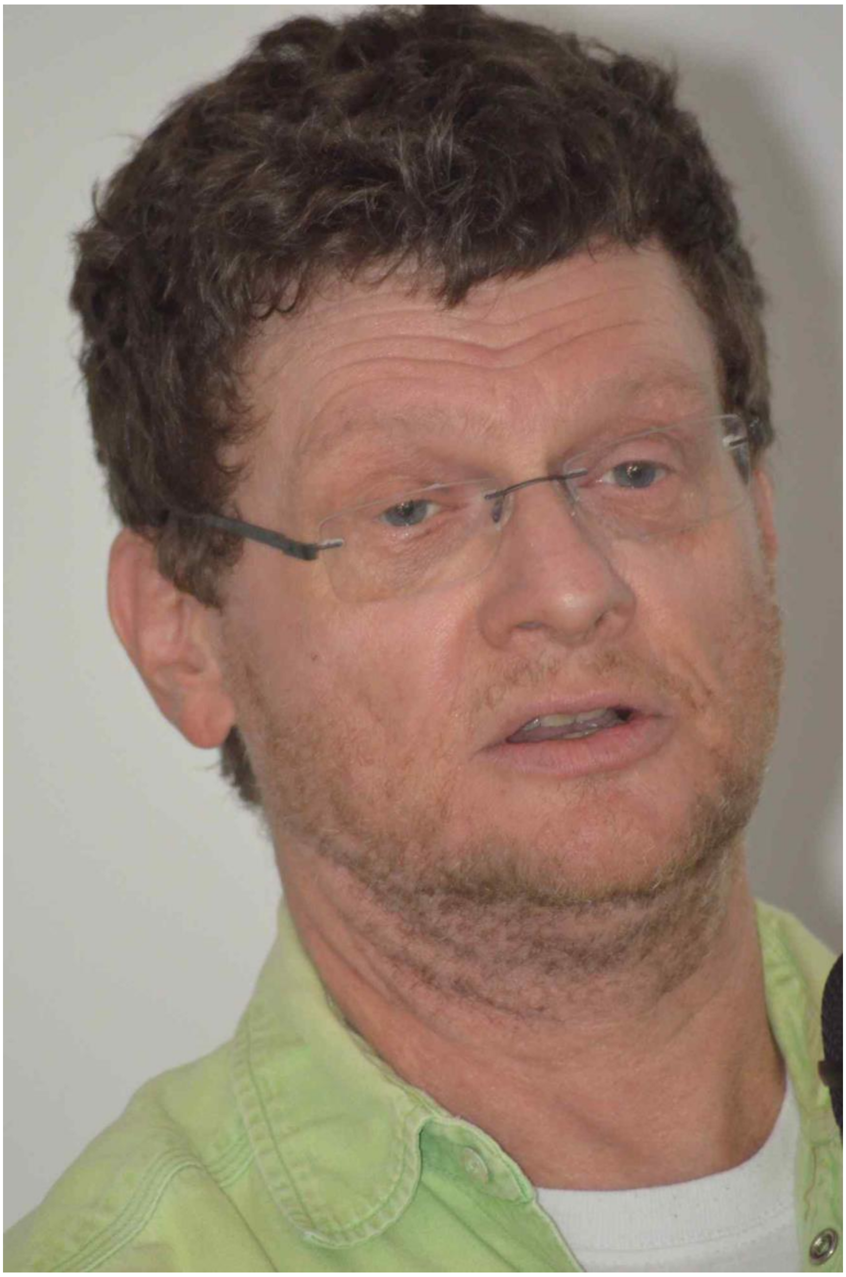
Molijn C. (2015). “An automatic pipeline for the calibration of meteor spectra”. Bachelor's Thesis, Univ. Utrecht.

Ott T., Drolshagen E., Koschny D., Drolshagen G. and Poppe B. (2015). "Meteoroid flux determination using image intensified video camera data from the CILBO double station". In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Giron, France, 18-21 September 2014. IMO, pages 23–29.

Pavela D. and Živanović M. (2015). "The effective number of shower meteors in a reduced field of view". In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, Mistelbach, Austria, 27-30 August 2015. IMO, pages 33–36.

Ryabova G. (2006). "On the possible use of meteoroid orbital data". In Mc Auliffe J. and Koschny D., editors, *Proceedings of the first EuroPlaNet workshop on Meteor Orbit Determination*, 11-13 September 2006, Roden, The Netherlands. IMO, pages 7–13.

Zender J., Koschny D. and Ravensberg K. (2014). "Calibration of spectral video observations in the visual". In Gyssens M., Roggemans P. and Zoladek P., editors, *Proceedings of the International Meteor Conference*, Poznan, Poland, 22-25 August 2015. IMO, pages 126–129.



The author, *Detlef Koschny*, during his lecture (Photo by *Axel Haas*).