Ongoing meteor work

Report from the ISSI team meeting "A Virtual Observatory for meteoroids"

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The content and format of the Virtual Meteor Observatory (VMO) was discussed in a one-week team meeting at the International Space Science Institute (ISSI) in Bern, Switzerland, in 2008 November. The current status of the VMO (in 'beta' version) was presented and discussed. The visual and camera sections are ready to be populated with data; a fireball section will be created. The radio/radar section is still open. In the discussion, several points were addressed: The relation to the Planetary Science Archive, treatment of shower catalogues, how to best perform astrometry, how to compute and store orbital data. The meeting ended by producing a list of future work, which is given at the end of the paper.

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1 History

Over the last 20 years, both intensified and un-intensified video cameras started to be used in the meteor community. Lately, more and more groups started setting up networks of cameras, which make it possible to determine meteoroid orbits from simultaneous meteor observations. Triggered by the question on how different orbit codes would compare, ESA/RSSD organized a EuroPlanet workshop called "Meteor Orbit Determination (MOD) Workshop" in collaboration with the IMO, just before the International Meteor Conference in Roden, the Netherlands, in 2006[a]. One of the conclusions of that workshop was that a common data format for storing orbit information would be very beneficial – and that it would be very important to also store the underlying single-station data in an easily accessible format. As a result of the MOD workshop, the Yahoo discussion group 'modwg' for MOD working group was formed at `http://groups.yahoo.com/groups/modwg`. Of course, within the International Meteor Organisation, data is already stored centrally. S. Molau maintains a database for video observations[b], Rainer Arlt one for visual observations[c]. G. Barentsen has supported R. Arlt in producing a web-based interface for the visual meteor observations[d]. In Roden, we decided that it would be good to merge all these efforts and offer a central repository to those who would be willing to contribute to one – and to produce an interface format definition to allow the 'interoperability' with those groups that would want to keep their local archives.

From this, the concept of a 'Virtual Meteor Observatory (VMO)' was born. It was initially called the 'Unified Meteor Database' (Barentsen, 2006). A prototype implementation was started by G. Barentsen during his time at ESA/RSSD's Meteor Research Group (Barentsen et al., 2007; Koschny et al., 2008). During an interface meeting between the authors in 2008 January the idea was born to propose a so-called ISSI Team in Bern, Switzerland (ISSI = International Space Science Institute). ISSI offers funding to host workshops for small scientific groups to discuss different scientific topics (see `http://www.issibern.ch`). They cover hotel costs and provide the meeting facilities. The travel costs have to be paid by the participants themselves. One has to write a proposal, a selection committee then decides on whether the workshop should be funded.

Rainer took the lead in writing a proposal and a few months later we received a positive reply. We finally met in Bern in the week 2008 November 23–28.

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[a]`http://europlanet.oeaw.ac.at/index.php?option=com_content&task=view&id=52&Itemid=41`
[b]`http://www.imo.net/video/data`
[c]`http://www.imo.net/data/visual`
[d]`http://www.imo.net/zhr`

Table 1 – Participants in the working group.

Name	Affiliation
Rainer Arlt	International Meteor Organization
Prakash Atreya	Armagh Observatory, UK
Geert Barentsen	Armagh Observatory, UK
Joachim Flohrer	DLR, Germany
Tadeusz Jopek	Adam Mickiewicz University, Poznan, Poland
André Knöfel	International Meteor Organization
Detlef Koschny	ESA/ESTEC, The Netherlands
Pavel Koten	Astronomical Institute of the Academy of Sciences, Czech Republic
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Jeremie Vaubaillon (*)	IMCCE, Paris, France
Robert Weryk	University of Western Ontario, Canada
Mariusz Wisniewski	Polish Fireball Network PKIM, Poland

2 Proposal and participants

This is the summary of the proposal as it was sent to ISSI:

"The investigation of the distribution and dynamics of dust in the Solar System is of statistical nature and depends critically on the amount and availability of observational data. The advent of virtual observatories in astrophysics is ideally timed with the observational advances in data recording in meteor science. We are seeking the installation of a virtual observatory for meteoroids and meteors. The team will deal with all types of requirements for such a project. Outcomes of the team meeting comprise data exchange interfaces, database models, data qualification procedures, and preview analysis tools. The team meeting consists of presentations of meteoroid data types at present and possible future types, discussions on the structure of the virtual observatory, and actual programming. The output will be considerable progress in creating a database of meteoroid information including interfaces for accessibility."

Table 1 gives a list of the team members which proposed and their affiliation. Not the complete proposal group managed to be there, the people absent are marked with an asterisk (*).

3 Workshop overview

The workshop was scheduled for one week, from Monday through Friday. Most of us arrived on Sunday evening in the hotel Arabelle, organized by ISSI. We started on Monday, $09^{h}30^{m}$, with introductions by the team members to their observational setups. Some of us are directly involved in double-station video meteor work and we saw presentations of the Polish Fireball Network, the intensified all-sky video camera of the Czech observing group, the meteor observing activities of the DLR Berlin, and the camera and radar systems of the University of Western Ontario. D. Koschny gave a flash-back to the Meteor Orbit Determination (MOD) workshop in Roden 2006. There, the participants produced some recommendations for data storage which we realized are mainly fulfilled—the recommendation was to start the development of the Virtual Meteor Observatory, in particular to start the definition of a data structure, and to ensure proper archiving and backing up of the data. During the MOD workshop, we identified a number of points which should be tested to better understand the quality of the data. There, the progress was very small—out of a long list (see Koschny & Mc Auliffe, 2008, p. 85) only one point had been addressed, namely that the timing accuracy of video cameras is good to about 1 ms (see e.g. `http://www.dangl.at` or `http://tko.koschny.de/Time_measurements/index.html`). The statistical power of visual flux measurements and format issues of the Visual Meteor Database (VMDB) which need to be addressed in a VMO were presented by R. Arlt on Tuesday afternoon. The next day was dedicated to existing databases and data formats. We learned about the database fields of the Fireball Data Center (FIDAC), the output format of the meteor detection software MetRec, and the output format of the Sposh (Smart Panoramic Optical Sensor Head) camera of ESA and DLR. On Wednesday G. Barentsen introduced the existing prototype for the Virtual Meteor Observatory, located at `http://vmo.imo.net`. The interface format of the VMO will be based on the XML (Extended Markup Language) standard, which we were introduced to. We discussed the top-level architecture of the VMO, see the next Section for more details. Wednesday afternoon and Thursday was dedicated to going through all fields of the VMO and ensuring that we all agree and have a common understanding of the data which will be supported. On Friday we agreed on the future activities—the main agreement was that we need to involve more people outside this group, and that we want to meet again in June 2009, hopefully again at ISSI.

4 Overview of the current VMO

A detailed description of the current architectural design of the VMO is given in Koschny et al. (2008). The main idea is to define a standard for storing all kind of meteor data, and to offer a central repository for all meteor data—it is not required to store the data centrally; but we'll provide an interface definition which will allow groups that want to store their data locally that data

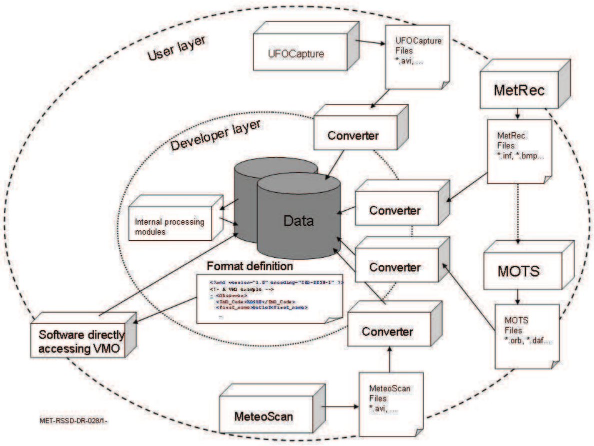

Figure 1 – Architectural design of the VMO. For an explanation, see the text.

```
<?xml version="1.0" encoding="utf-8"?>
<vmo xmlns="http://www.imo.net">
    <fireball>
        <time>2008-11-23T15:24:13</time>
        <brightness>as the full moon</brightness>
        <observer>Heidi Klum</observer>
        <location_latitude>
          35.24351
        </location latitude>
        <location_longitude>
          -89.62907
        </location longitude>
        <country code>US</country code>
        ...
    </fireball>
</vmo>
```

Figure 2 – Example XML fragment.

can easily be exchanged. The following considerations are written as if there were only a single repository, but the plan is to allow for a distributed database in the future. Figure 1 shows a sketch of the architecture, based on a first discussion at the Meteor Orbit Determination workshop in Roden in 2006 (see Koschny et al., 2007 for a summary of that workshop). The VMO is a relational database implemented in PostgreSQL. The actual data formats are defined via files in the XML (Extended Markup Language) format. It is physically hosted on a dedicated computer at ESA/RSSD's computing department and can be reached via the url `http://vmo.imo.net`. Figure 1 shows the different layers of the system. The central layer is called the 'developer layer'. In it, the VMO gives direct access to the database elements. This requires that user software base their data files on the XML definitions of the VMO. An example XML fragment is given in Figure 2.

Alternatively, in the 'user layer', the software outputs their own data formats (as is the case for some of the existing meteor detection software such as MetRec (Molau, 1999), MeteorScan (Gural, 1997), or UFOCapture). A converter will then convert the output data to the VMO format. Currently, a converter is available only for the MetRec data files, but more will be produced in the upcoming months. The data in the VMO is organised into different sections:

- VIS – Visual meteor observations;
- CAM – Video and still camera data;
- RAD – Forward or backward scatter radio observations;
- FIR – Fireball observations;
- ORB – Orbit data

The data of each section is stored in a separate database. Certain metadata is stored separately and linked to from the actual data sections. These are:

- Observers
- Locations
- Shower codes
- Radiant catalogs

In addition, the database allows keeping a plain file repository. Meteor data ingestion is done by using ftp to transfer data files to an incoming directory. Via a web interface, one can 'validate' the data files—different consistency checks will be executed and error messages or warnings will be displayed in case of problems. After fixing all issues, the data will be converted to the VMO-internal format and ingested into the database. Different search and browse tools are available; also, a SQL-interface is available which allows to user to write his/her own queries. The data is grouped in so-called 'sessions' which contain a logical block of observations, typically one observing night. Each session can be broken down in 'periods'. While the observer, observing equipment, and location would be constant for on session, items like the limiting magnitude or the cloud factor change, thus requiring the periods. We discuss the usefulness of this concept. Would an observer who observes with the same equipment in exactly the same setup for one year only have one session? The answer is no, the session could be seen as the dataset which is delivered at one delivery, and a daily (nightly) delivery would be acceptable. In the end we agree that the concept of sessions and periods is good, the session is a logical duration of an observation and does not necessarily imply anything scientific. The periods shall be useful entities for the determination of meteoroid flux for a given source. Thus, significant changes in limiting magnitude or cloud cover should result in a new period to be started. Note that the combined availability of visual and video data will allow for very detailed analyses of the particle flux of meteoroid streams. The VMO also provides routines to search and identify potential simultaneously observed meteors, and allows the computation of orbits using an updated version of the Meteor orbit and trajectory software called MOTS (Koschny & Diaz del Rio, 2002). Alternatively, complete orbit data sets can be ingested (e.g., the IAU orbit database (Kornos & Toth, 2006)).

5 Discussion points

Organisational aspects

One of our discussion points was addressing 'political' aspects. While we try to involve as many data providers as possible in our discussions, some of us may not want to store all their data centrally, or they may not able to do it for proprietary reasons. We agree that the idea of the VMO is not to *require* central data storage; rather, the VMO will *offer* the possibility to centrally store the data. However, all meteor data providers shall be encouraged to follow the recommendations laid down by the VMO working group to ensure easy data exchange. Besides storing data, the VMO also aims at providing data mining possibilities and provide 'services' to do data analysis, e.g., the already implemented possibility of computing orbits of ingested data.

Relation to the Planetary Science Archive (PSA)

At the MOD workshop in 2006, the two external reviewers of the recommendations which were decided recommended to get the support of official entities like ESA and NASA, and look into the possibility of using support of official planetary archives like the European Planetary Science Archive (PSA), which stores all the data of the European planetary space missions and some related ground-based data. The first part has been successful—the prototype implementation of the VMO has been done with support from ESA. We confirm that we want to draw on the expertise available in the PSA. We see the VMO as an 'active archive' which can be used for daily data ingestion, quick-look, and data mining. We recommend to consider the PSA as a long-term archive. This would require a conversion of the data in the VMO to the PSA format (which is following the Planetary Data System (PDS) standard). The PSA-responsible at ESA is supporting this idea and suggested to request funding from the European Union for getting support to prepare the data. The team believes that this is a good idea, however, no immediate action will be taken. This will be kept in mind for possible future implementation.

Treatment of shower catalogues

The VMO adopts the shower codes and names as designated by the IAU (Jenniskens, 2007) but allows multiple shower catalogues to be archived and used. In particular it is important to keep the designation of old showers, as showers may be disappearing or newly forming over the years. Even if a shower turns out to be spurious, the designation should be reserved for all times for database consistency. For every meteor shower determination, the VMO stores a link to the used shower catalogue.

Astrometry

While not directly related to the data base structure, we spent some time discussing the positional accuracy of meteor data. ESA/RSSD's intensified and non-intensified video cameras yield a mean stellar deviation of typically 0.5 pixel, corresponding to 1′, when using about 30–40 reference stars for the astrometric solution. The Polish Fireball Network uses an advanced technique of stacking many images to obtain a reference star image for performing the astrometric solution, which effectively results in many hundred stars used for performing an astrometric fit. M. Wisniewski states that their cameras yield about 1/4 pixel accuracy, about 3–5′ at their typical field of view of 60–80°. On the other hand, the Sposh camera used at ESA yields about 1/8 to 1/10 pixel accuracy (40–50″ at 120° field of view). P. Koten presents a comparison between an astrometric solution as obtained automatically by MetRec and manual measurements of the same images. He shows the resulting orbit data for four different meteors and in some cases the orbit obtained via the automatic measurement deviates very much from the manual measurements. He concludes that it may not be possible at all to obtain good orbits using automatic measurements. His presentation is much disputed though—D. Koschny mentions that comparisons done at ESA/RSSD between MetRec measurements and manual measurements do not differ significantly (Piberne, 2004). In conclusion we realize that the astrometric quality of the existing systems should be better tested and compared—confirming a conclusion from the MOD workshop in 2006.

A separate section for fireball data?

On Tuesday, A. Knöfel presented the current content fields of the IMO Fireball Data Center (FIDAC). On the IMO web site, there is a fireball report form available; however, searching for fireballs is only possible for the years 1993 to 1997, as this form has not been given high priority recently. We compare different fireball report forms, e.g. from the Czech group[e] and the American Meteor Society[f]. The general usefulness of an additional report form for fireballs in addition to 'normal' meteor data was discussed. The group concluded that it is important to collect information for bright fireball events from the general public to support e.g. the identification of potential meteorite-dropping fireballs, and also as an outreach activity. A. Knöfel prepares an updated proposal for data to be stored in the fireball database during the meeting which is agreed by the group on Friday as an excellent starting point. In particular, we want to add references to possible 'accidental' photographic or video observations. We also discuss some aspects of the user interface, where e.g. the direction of begin and end positions of the fireball could be determined via a link to the Google Maps application. We recognise that fireball data from the general public is best collected by local astronomy groups; also a number of report forms are already available on different web pages and we should not try to 'take something away' from them. However, not for all local pages a search capability is available—this would be a useful add-on service of the VMO. We thus agree on the following:

[e] `http://www.asu.cas.cz/~meteor/report.htm`
[f] `http://www.amsmeteors.org/fireball/report.html`

a. We will have a separate fireball section in the VMO;

b. We will produce source code for a sample form which can be regenerated in different languages by local astronomy groups. The data from the form sheet can be ingested into a local database, directly into the central database, or in both. In the central database it shall be possible to search for fireballs provided by one particular local group only.

c. An interface definition will be made available so that external groups can ingest fireball data into the VMO.

d. A. Knöfel will take the lead in implementing the fireball section.

Items concerning the orbit data

One of the important points discussed at the MOD workshop in 2006 was that we need to have traceability — i.e. for any given orbit it should be possible to find out how many observations were used to compute the orbit and which method was used. It should also be possible to go back to the underlying single station data and check its quality. In the current implementation of the VMO this is possible via links (none of the data is stored in more than one place). We discuss different possibilities of computing the orbits. One could use heliocentric orbits or solar system barycentric orbits. We recommend using the same method as used in the Minor Planet Center, which is using heliocentric orbits (Spahr, pers. comm.) to make comparison of orbits easier. It was suggested that for each orbit it should be made quite clear how the orbit was computed, i.e. which method was used. In the optimum case, the orbit computation code would be available via the VMO; in the minimum case a reference should be given. If no detailed description is available on how an orbit was computed, it should be written, thus requiring some work on the side of the programmers. To assess the quality of an astrometric measurement, a 'distortion plot' can be helpful. This is a plot of the coordinate grid of celestial coordinates in the field of view. The software MetRec, for example, will display this grid when using the program RefStars, but it does not allow to store this image. It is recommended to the data producers that it will be made possible to store such images. We discuss the best way of presenting the distortion, e.g. in terms of how many pixels the grid is distorted. In the end we agree that we should not require any specific representation, as long as it is clear how to interpret the distortion map. The main discussion concerning orbit data addresses the question of which orbit we really want to store. After the double-station analysis of a meteor one can derive a state vector relative to the Earth which describes the x/y/z position in geocentric coordinates and the velocity components in an Earth-centered coordinate system for a given time. From this one can backward-propagate the orbit of the meteor to the edge of the sphere of influence of the Earth, or one can determine the radiant as use the formula for the zenithal attraction to correct for the influence of the Earth. Note that we found that different values are in use for the sphere of influence – this needs to be further discussed and a value needs to be agreed to achieve consistent datasets. Both methods should result in very similar heliocentric radiants for the meteor (i.e. the direction where the meteor comes from when outside the sphere of influence). Also, it was not clear in the beginning whether the orbit outside the sphere of influence (or after applying the Zenithal attraction) should be given at all, as it is not the directly observed direction where the meteor comes from, but a derived value. In the end, we agree after some discussion that we should give the orbit of the meteor which it would have without the influence of the Earth's gravitation, at a given time (also called Epoch). Thus, if a meteor is seen at 17:30:00, one could give the orbit at the time when it entered the sphere of influence of the Earth, say at 15:30:00, in solar system barycentric coordinates. Or, one could give the orbit at the epoch (i.e. the time) of observation, but without the influence of the Earths mass. Thus ones orbital code would need to integrate the orbit backwards to the edge of the sphere of influence, then integrate forward to the time of the meteors occurrence but without the Earths mass, and give the orbital elements at that time. The group agrees to allow the orbital elements to be given at any epoch, as long as the epoch is specified. We should clarify here that the orbit given in the VMO is only one representation of the motion of the observed meteoroid, chosen by the contributor of the data. It should come along with a reference to the orbit determination method used. The team found it unsuitable to enforce a certain orbital representation which may easily become outdated once better methods are developed in the future.

6 Conclusions and future work

The major decisions were:

a. The concept of sessions and periods within the VMO is approved.

b. The VMO shall offer a central repository for data, but not require it.

c. The VMO shall specify its interface standard, so that all data producers can provide their data in a similar way, allowing 'interoperability' of possible decentralized databases and tools.

d. The general structure of the VMO data definition as presented by Barentsen was approved.

e. D. Koschny, R. Arlt, and J. Tóth will take the lead in producing a set of documentation which describes the implementation of the VMO in detail, with technical input coming from G. Barentsen. This documentation shall be made available via the IMO.

f. We will have a dedicated section for fireballs, with the detailed statements as given in Section 3, 'A separate section for fireball data?' A. Knöfel will lead this effort.

g. Concerning orbit data, the group recommends to use the heliocentric coordinates rather than solar system barycentric coordinates.

h. A reference shall be given for which orbit code was used to produce any given orbit.

i. It is recommended that the software which is used to determine the astrometric solution (e.g. MetRec, UFOCapture) allows to store 'distortion maps' which will allow to assess the quality of an astrometric fit.

j. It is not clear whether the accuracy of automated orbit computations based on data from cheap video cameras is sufficient for scientific analysis. More work has to be done to verify this.

k. A broader audience shall be involved in the process of defining the VMO, both by addressing relevant people directly and by involving the MOD working group via the Yahoo discussion group.

l. We will request a follow-up ISSI Team meeting to focus on teaching data providers how to interface with the VMO. The target date for this workshop is 2009 June 08–12.

m. An ESTEC workshop will be requested in addition by D. Koschny.

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Figure 3 – The ISSI Team "Virtual Observatory for meteoroids".